Bird communities and climate change.

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CHAPTER 18

Bird communities and climate change

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18.1 General context

Climate is a key factor behind the structure and composition of plant and animal communities. Variability in climate drives many aspects of species ecology directly or indirectly through changes in habitat type and structure (Berthold, 1998; Pimm, 2008) so that long-term climatic variability is thought to be the key determinant of communities at large spatial scales (Forsman and Mönkkönen, 2003). Sudden changes in climatic conditions are suggested to have been the main causes of species extinctions and large-scale community changes and reorganization in the past (Mayhew *et al.*, 2008). Since current rates of change in climatic conditions are faster than those previously reported (Chapter 2), species extinction rates and community structure changes at present may be stronger and may occur faster (Pimm, 2009).

Disruptions of current climatic regimes may cause loss of a large fraction of the planet's biodiversity, even if the only acting mechanism was the move of species ranges latitudinally and altitudinally as temperatures rise (Thomas *et al.*, 2004; Pimm, 2009). However, climate change is a much more complex environmental process and the move of species ranges latitudinally and altitudinally is not the only likely factor affecting ecological communities. First, climate change is likely to be complex and differ regionally in intensity and directionality, leading to idiosyncratic impacts on species ecology. Second, climate will differentially change the distribution of resources at different sites, creating mismatches in resource use and availability in different species (Pimm, 2009; Chapter 11). Such mismatches lead to cascade effects and asynchronies between the responses of different trophic groups, enhancing the negative cumulative impacts of climate change on ecological communities (Brown *et al.*, 1997). In mobile species located high in the trophic chain such as birds, the impacts of such effects will probably be strong, but very difficult to anticipate, given the complexity of the mechanisms involved in these responses. How will these additive effects—across species, space, and time—affect present and future bird communities?

The community approach can be an integrative view of the summed effects of different factors of change on different species, trophic levels, and spatial scales. Recent essays have argued that the distributions of species within a region reveal more about the processes that generate diversity patterns than does the co-occurrence of species at any given point (Ricklefs, 2008). Therefore, measures of community composition and structure at a site may offer a way to analyse how communities are structured at a local level. Besides, analyses of distribution patterns across species at regional scales will be an adequate approach to deal with the processes that lead to current and future diversity patterns and community structures.

In this review, we use both perspectives to analyse the effects of climate change on bird communities. First, we summarize the predictions of potential impacts of climate change on bird communities by analysing responses of individual species and predictions from models based on current distributions of species and community descriptors (section 18.2).

We discuss potential and reported impacts of climate change at upper levels of biological complexity of birds by focusing on understanding consistent changes and shifts in species richness and functional roles. We then proceed to test available predictions by reviewing recorded changes at the community level (section 18.3) in terms of local species composition and community structure—the latter seen as the result of interactions between populations over a continuum of spatial and temporal scales within regions.

Much interest on climate change impacts has concentrated on increases in global temperatures or in the occurrence of extreme events and their direct effect on species and habitats. Here, we will explicitly enlarge the review to indirect effects mediated via interactions with other global change components (section 18.4). Such interactions between climate changes and other large-scale environmental changes have recently been proposed as the key mechanisms determining future species loss and critical changes in community structure (Brook *et al.*, 2008; Pimm, 2008). These other large-scale environmental changes include the pervasive expansion of invasive species, land use changes involving habitat loss and habitat fragmentation (Opdam and Wascher, 2004), or changes in dominant regimes of perturbation like fires, storms, and heat waves.

At present and probably due to climate change science being very recent, reported impacts of this environmental driver at the community level are still scarce. Furthermore, the cumulative effects at different ecological levels are virtually unknown beyond the claim that they will probably be large and have considerable spatial variability. Recent evidence suggests that the impacts of climate change on bird communities are already visible at a continental scale (Gregory *et al.*, 2009) with marked regional variability (Jetz *et al.*, 2007; Barbet-Massin *et al.*, 2009). Here, we build from previous reviews of this recent research field (Møller *et al.*, 2004) and assess the present state of the art in order to identify key points mining our capability to anticipate impacts of climate change on bird communities. Finally, we propose a general conceptual framework to guide our capability of understanding models and anticipate the likely and complex impacts of climate change on bird communities in a context of general and global environmental change (section 18.5).

18.2 The impacts of climate change on bird communities: which are the current predictions?

Assessing the accumulative impacts of global change on bird communities is not an easy task. Climate affects a great number of basic ecological mechanisms and therefore the number of impacted species at different complexity levels is large (Walther, 2007). Furthermore, the impacts under similar climate change scenarios may differ among species and trophic levels and lead to resource mismatch (Chapter 11) and cascade effects affecting community composition and structure. In order to scrutinize our current knowledge about the impacts of climate change on bird communities, we have chosen to separate current predictions from observed data on reported impacts of climate change at the community level.

Predictions of what we may expect from climate change impacting bird communities come from two main sources of information: (1) reported impacts at the species level that may produce hypotheses on how communities may respond if the response is sufficiently general or consistent among species, and (2) predictions originating from modelling exercises aiming at incorporating specific processes affected by climate using a dynamic perspective. This second approach is having enormous influence in shaping recent advances in global change science and therefore deserves particular attention.

18.2.1 Predictions at the community level derived from single-species studies

Current climate change rates are high, and a large number of studies on birds dealing with specific impacts of such environmental changes on specific species flood the literature. There is mounting evidence that global climate change has extended growing seasons, changed distribution patterns, and altered phenology of flowering, leading to impacts on breeding biology or migration patterns of different species (Parmesan and Yohe, 2003; this volume).

Many reported impacts of climate change at the specific level may be interpreted at more general levels of complexity and be used to elaborate predictions at the community level. Particular responses linked to specific functional traits or species characteristics may have strong effects at the community level if they are general or predominant.

Direct impacts of climate on breeding performance and behaviour are expected to be common (Chapter 10) and have major influences on bird populations (Chapter 14). In seasonal environments, the main selection pressure on timing of reproduction is synchrony between offspring requirements and food availability (Altwegg and Anderson, 2009). Recent rapid climate change is associated with dramatic changes in phenology of plants and animals. This may lead to potential mismatches between food abundance and offspring needs in cases where changes in the environment of decision making do not match those in the environment where these biological traits have been selected (Sanz *et al.*, 2003). The cases in which species pay the costs of reduced reproductive rates in the new conditions may accumulate and lead to generalized decreases in species richness. However, some will show potential for phenotypic plasticity, allowing better coping with expected changes. In this case, one may expect ecological plasticity to play a key role in enabling more generalist species to benefit from a wider range of resource conditions. Hence, such species are expected to increase their abundance in communities. Furthermore, the effects of climate change on breeding biology vary among species within a community. As an example, Jiguet *et al.* (2006) found that during a spring and summer heat wave in France the reproductive performance of some species benefited from temperature increases while that of others did not. If such differences occur repeatedly through time, species interactions within communities will certainly be affected, and hence also community structure and composition.

Changes in direct mortality are another direct effect of climate change that may impact the structure of bird communities. Only a very small proportion of juvenile birds succeed in recruiting into the breeding population, suggesting that recruitment is under strong selection at different stages of the annual cycle (Brotons and Broggi, 2003; Frederiksen *et al.*, 2008). Climate is a key factor in determining individual survival, and significant changes in non-breeding environmental conditions driven by weather are likely to exert critical effects on species (Barbraud *et al.*, 1999; Blais *et al.*, 2001; Ballerini *et al.*, 2009). Close matching between particular weather conditions and survival is common in birds (Pearce-Higgins *et al.*, 2009) and suggests that many bird communities are likely to experience changes in composition driven by changes in survival. These effects are species and region dependent (Balbontín *et al.*, 2009) and therefore difficult to anticipate. Bird communities relying on resources tightly linked to current climatic patterns, such as those in Arctic and semi-desert regions, are predicted to suffer strong declines in species richness and large-scale disruptions in population dynamics.

In a context of rapid changes in climate, and in contrast to other less mobile taxa, movement patterns, including migration, are expected to mediate a great proportion of changes in bird communities (Studds *et al.*, 2008). Individuals of species with more structured seasonal migratory patterns have evolved to profit from more stable differences in climatic conditions between regions. For migratory birds, timing of arrival on breeding territories and over-wintering grounds are key determinants of reproductive success, survivorship, and fitness. Asynchrony in changes between these regions may disrupt the benefits that migratory species obtain from migratory movements. Therefore, migratory species have been suggested to be more sensitive to changes in resource synchrony between breeding and wintering areas (Møller *et al.*, 2008). The disjunction between phenology at low and high altitudes or between breeding and wintering quarters may also create problems for species that migrate, leading to changes in arrival and departure times (Inouye *et al.*, 2000; Sillett *et al.*, 2000; Gordo *et al.*, 2004). Evidence is thus accumulating at the species level, prompting the prediction of progressive loss of the migratory component of bird communities in temperate assemblages with some unexpected impacts on local species arrangements (Schaefer *et al.*, 2008). The number of migratory species at the community level is predicted to decrease due to a decrease in the proportion of migratory populations in partially migratory species (settling process) and to population declines in migratory species. This may further disrupt bird communities through the alteration of population processes such as dispersal and heterospecific attraction, especially in temperate and boreal systems (Mönkkönen and Forsman, 2002). Finally, because comparative studies have shown that resident bird species disperse less than migrants (Paradis *et al.*, 1998), have a smaller degree of population synchrony (Paradis *et al.*, 1999; Inouye *et al.*, 2000), and have a greater degree of population differentiation (Belliure *et al.*, 2000), we predict that these two groups of species will differ in impacts of climate change, leading to increased differences in migratory components of communities.

There is plenty of evidence reporting that species ranges and range boundaries are correlated and to a large extent determined by climatic factors (Brown and Lomolino, 1998). Thus, we expect species range boundaries to change as a direct response to climatic change in order to adjust to new environmental conditions. Northwards and upwards changes in distributions have been recorded for some species (Pounds *et al.*, 1999; Thomas and Lennon, 1999), and, if predominant, are expected to constitute a major impact of climate change on communities because this would lead to major shifts in co-occurrence patterns of species. This may be especially relevant in communities located at high altitudes or on the extremes of climatic gradients where climate change will lead to extinctions and therefore to declines in overall species richness (Chapter 17). Species-specific differences in responses to climate change can become particularly important when interacting species are shifting their distributions. Global climate change impacts have been considered largely in terms of simple distributional shifts, but studies available indicate that shifts can also increase biotic costs when species move into habitat types for which they are poorly adapted or that create new biotic interactions (Martin, 2001). The complex and indirect effects of climate change on species interactions need to be seriously taken into account if we are to accurately forecast the long-term effects of global warming (Poloczanska *et al.*, 2008; Schweiger *et al.*, 2008).

Finally, intra-specific latitudinal clines in body size of terrestrial vertebrates—including birds, where members of the same species are larger at higher latitudes—are widely interpreted as evidence for natural selection and adaptation to local climate. Such clines are predicted to shift in response to climate change. Recent studies on museum specimens from Australia, England, and Israel (Yom-Tov, 2001; Gardner *et al.*, 2009) have reported significant changes in body size of passerine birds over the last 100 years. In the Australian case, southern high-latitude populations now display the body sizes typical of more northern populations pre-1950 fitting predictions derived from climate warming. On the other hand, a recent study of changes in morphology of birds captured in southern Germany showed no evidence of consistent change in body size (Salewski *et al.*, 2009). These declines may lead to changes in basic community parameters, including competition relationships among bird species and survival of small passerines. Larger species have also generally larger natal or breeding dispersal capacities, so that large bird species are expected to more easily and more accurately track their geographically moving climatic niche under climate change. As an example, the natal dispersal of small passerines is on average only a few kilometres (Paradis *et al.*, 1999) while the natal dispersal of Alpine eagle owls *Bubo bubo* is close to 50 km (Aebischer *et al.*, 2010). Hence, the effects of climate change on community composition according to body size might differ markedly along latitudinal or altitudinal gradients, with stronger shifts for large species.

18.2.2 Predictions at the community level derived from modelling approaches and projections under expected future climatic conditions

Present bird community patterns and species distributions show clear relationships with environmental variability, including climate. If such relationships can be adequately established, they may help develop hypotheses of changes in community structure and species ranges in a context of climate change. In the context of this review, modelling approaches can be divided into two broad categories. The first regroups modelling exercises aimed at identifying associations between community-scale descriptors such as species richness or the proportion of different functional species groups with climate variables. The second regroups modelling exercises focusing on a species-based estimation of climate determinants to later combine species and derive community responses. Other modelling exercises may include more mechanistic-based processes such as physiological responses to climate change impacts, but these will not be treated here.

Modelling of species distribution changes in response to climate change has revolutionized our ability to derive inferences on the potential impacts of climate change on bird community structure and dynamics (Erasmus *et al.*, 2002; Thomas *et al.*, 2004). The application of such methodologies to multiple species has allowed mapping of areas where community changes are most likely (species gains or losses) (Stralberg *et al.*, 2009) and, therefore, generate explicit predictions of climate change impacts on bird communities. Here we describe the main predictions and discuss limitations of null hypotheses in setting references for assessing the complex effects expected from climate change (Jetz *et al.*, 2007; Schaefer *et al.*, 2008; Barbet-Massin *et al.*, 2009).

18.2.2.1 Projected changes in species richness

Species distribution models, combining current species occurrence data and climatic variables, have been widely used to predict the future distribution of species under climate change scenarios. The principle is simple: current distribution and climatic data are used to model the climatic niche of a species or to infer the suitability of any part of the climatic space for a species (Chapter 8). Under the assumption that a given species will conserve its climatic preferences in the future, the geographical projection of the modelled climatic niche, using data layers on future climatic conditions (scenarios provided by the International Panel on Climate Change, IPCC), allows to predict the potential future distribution. Dispersal ability of a species will determine its capacity to colonize eventual new areas so that the future-predicted range is considered to fall somewhere between the global-predicted future range (full dispersal ability), and the only overlap between the modelled current range and the predicted future range (no dispersal). Most modelling techniques provide probabilities of niche suitability, and further application of a threshold is necessary to make a dichotomous separation between predicted presence and absences. From such distribution models, the combination of predicted presence–absence distributions for multiple species provides the opportunity to study geographical variation in predicted changes in species richness, again under various scenarios of species dispersal ability.

Two major steps in these developments for birds have been the publication of *A climatic atlas of European breeding birds* (Huntley *et al.*, 2007), followed by an assessment on global bird diversity (Jetz *et al.*, 2007). Both studies compiled maps of species richness and potential climate-induced changes in species richness for the 21st century. Assessing the potential ability of species to disperse from current to predicted future range is crucial, and assumptions of total or null dispersion can lead to opposite regional trends in species richness, as shown by Barbet-Massin *et al.* (2009) when studying wintering ranges of Afro-Palaearctic migrant passerines (Figure 18.1). In the case of null dispersal, local species richness is at best stable. However, birds are highly mobile (Paradis *et al.*, 1998), and considering range shifts of a few hundred kilometres during a century does not seem unreasonable for breeding ranges. Larger shifts for non-breeding range will depend on the stop-over system available for a migratory species to reach newly suitable wintering areas.

Predictions on changes in species richness derived from species distribution models are only one of the methods used to predict the impact of climate change on this basic community descriptor. As productive energy such as vegetation productivity is often associated with species richness (Honkanen *et al.*, 2009), climate change may result in increased species richness due to increasing amount of productive and solar energy in systems limited by temperature or decreased species richness in systems limited by water. Further investigation is needed on agreement in species richness predictions between different modelling approaches and how they match real patterns of community change.

18.2.2.2 Projected changes in species assemblages

Despite limitations, species distribution models allow projection of current species–climate

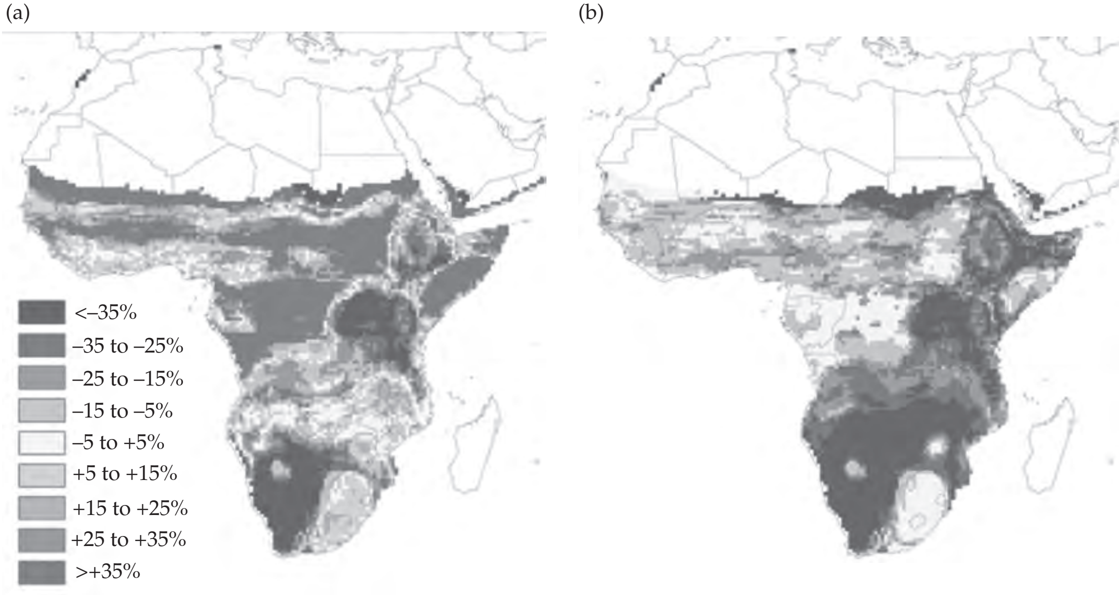

Figure 18.1 Predicted changes in species richness of migrant passerines in Africa under future climatic scenarios (by 2100). (a) Future-predicted variations in species' richness under the hypothesis of full dispersal ability between predicted present and future ranges and (b) future-predicted variations in species richness under the hypothesis of null dispersal ability. Based on Barbet-Massin *et al.* (2009). See Plates 8a and b.

relationships to future climate scenarios. Many studies have projected future changes in species distributions and patterns of diversity (species richness, turnover, and extinction rates), with an emphasis on range contractions and potential for species extinctions. To synthesize multi-species impacts of climate disruption, however, we must take a next step in considering changes in patterns of species co-occurrence. Very few studies have done this on birds by quantifying expected rates of species turnover as an indication of change in community composition (Lawler *et al.*, 2009). Although high rates of projected species turnover have been identified for many geographic regions, this does not directly consider the degree to which novel or 'no-analogue' communities may be anticipated. Such turnover patterns would also intuitively be highly scale dependant, making the topic particularly difficult to study. Entirely unique combinations of species and new interactions that occur among species may lead to even greater rates of local extirpation if species cannot adapt sufficiently quickly. Indeed, climate disruption is predicted to induce independent shifts of species distributions, resulting in rapid development of novel species assemblages that could challenge the capacity of species to co-exist and adapt. Stralberg *et al.* (2009) focused on 60 bird species to estimate potential changes in California breeding bird communities, based on the combination of current and future-predicted species-specific distributions under climate and land use change scenarios. They used a multivariate approach borrowed from paleo-ecology to define future no-analogue communities, i.e. future communities that have no analogy with currently observed species assemblages. Their results indicate that by 2070 over half of California could be occupied by novel bird assemblages, with potential dramatic changes in species interactions.

18.2.2.3 Projected changes in multiple-species climatic suitability

When combining species distribution models to obtain information on species assemblages, another option is to combine raw data of predicted suitability probability, instead of combining threshold-dependent presence–absence model outputs. Marini *et al.* (2009) stated that climate-driven changes will alter bird species composition in reserves of the Cerrado region of Brazil. Their study was based on the combination of species distribution models obtained for 38 endemic or rare bird species. Comparing current and future (2046–2060) distributions with the current Brazilian reserve system highlighted large gaps in their protection and the need for new conservation planning. The cumulative climatic suitability of all 38 species under future climate scenarios (Figure 18.2) was proposed as a useful tool to implement new reserves, especially in the southeastern part of the Cerrado region and in the mountains of eastern Brazil. This approach differs from the more classical mapping of species richness, which requires a fixed threshold value for each species-specific modelled suitability distribution, in order to obtain a binary presence vs. absence mapping of each species to be further combined into a species richness map.

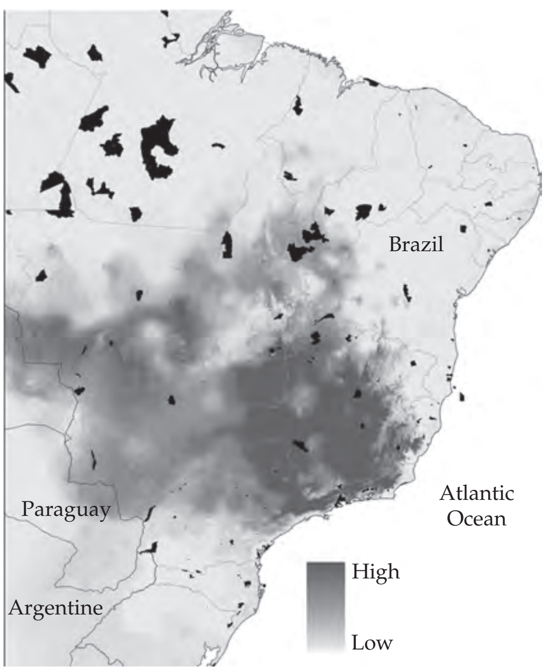

Figure 18.2 Predicted cumulative probabilities of occurrence for the 38 Cerrado birds in Brazil for the future (2046–2060), as obtained with an ensemble-forecasting approach. The colours in the maps represent the cumulative probability of occurrence (climatic suitability) within a pixel, ranging from 0 to 1 (pale to dark green). Large (>30,000 ha) reserves are represented by black polygons. Based on Marini *et al.* (2009). See Plate 9.

18.2.2.4 Projected changes on the relative composition of functional groups in bird communities

While species distribution modelling has been widely used in assessment of potential impacts of climate change on bird communities, a range of other modelling tools have been employed to disentangle effects of this driver on different community descriptors. For avian communities, we would expect warmer winters to lead to declines in numbers of long-distance migrants if resident birds benefit from warmer winters and impose increasing competitive pressure on migrants. To study the potential influence of global climate change on long-distance migrants, Lemoine and Böhning-Gaese (2003) correlated the number of all species of land birds and the number and proportion of long-distance migrants, short-distance migrants, and residents in 595 grid cells across Europe. The number and proportion of long-distance migrants decreased with increasing winter temperature, decreasing spring temperature, and increasing spring precipitation. Then they used the estimated spatial relationship between bird community structure and climate in Europe and predicted that increasingly warmer winters may pose a more severe threat to long-distance migrants than to other groups.

Species can respond to global climate change by range shifts or phenotypic adaptation. At the community level, range shifts lead to a turnover of species, i.e. community reassembly. In contrast, phenotypic adaptation allows species to persist in situ, conserving community composition. So far, community reassembly and adaptation have mostly been studied separately. In nature, however, both processes would occur simultaneously. In migratory birds, climate change has been shown to result in both species turnover and adaptation of migratory behaviour. Schaefer *et al.* (2008) developed a model aimed to predict the impact of global climate change on migratory bird communities to assess the extent to which reassembly and adaptation may contribute to changes. They analysed the relationship between current climate and the proportion of migratory species across bird assemblages in Europe. The magnitude of community reassembly was measured using spatial variation in the proportion of potentially migratory species. These spatial relationships were used to make temporal predictions about changes in migratory species under global climate change. According to their models, increasing winter temperature is expected to lead to declines in the proportion of migratory species, whereas increasing spring temperature and decreasing spring precipitation may lead to increases. Changes in winter and spring temperature are expected to mainly cause adaptation in migratory activity, while changes in spring precipitation may result in both changes in the proportion of potentially migratory species and adaptation of migratory activity. They concluded that under current climate change forecasts, changes in the proportion of migratory species will be modest, and communities of migratory birds in Europe are projected to change through adaptation of migratory activity rather than species turnover.

Seed dispersal by frugivorous birds plays a major role at the ecosystem level (Sekercioglu, 2006). Such bird species profiting from seeds and fruits are known to spatially track food resources according to the species requirements imposed by weather conditions (Rey, 1995). In this context, changes in climate may alter the need for frugivorous species to search for new food sources heavily impacting on the ecological network and structure of communities (Rivalan *et al.*, 2007), potentially causing cascade effects at other trophic levels. Most frugivorous birds belong to particular orders such as perching birds (Passeriformes), woodpeckers (Piciformes), parrots (Psittaciformes), and pigeons (Columbiformes), and current climate explains more variance in species richness in this functional group than in any other. Actual evapotranspiration is the best single climatic predictor of avian frugivory (Kissling *et al.*, 2009). This analysis allows prediction of asymmetric impacts of future climatic change on bird communities that will disproportionately affect frugivorous species.

Most predictions developed for different functional groups use the ‘space-for-time’ substitution approach, allowing forecasting of temporal trends from spatial climatic gradients. However, this approach has been adopted often with little empirical support. La Sorte *et al.* (2009) examined changes during 1975–2001 in three community attributes (species richness, body mass, and occupancy) for 404 assemblages of terrestrial winter avifaunas in North America. They examined the accuracy of space-for-time substitution and assessed causal associations between community attributes and observed changes in annual temperature using a longitudinal study design. La Sorte *et al.* (2009) concluded that, in the face of rapid climate change, applying space-for-time substitution as a predictive tool could be problematic with communities developing temporal patterns not reflected by spatial ecological associations. In this context, it should be noticed that temporal data are associated with intrinsic temporal autocorrelation that has been rarely taken into account in the analyses, and that this can potentially lead to misinterpretations of the mechanisms producing changes in biological and community characteristics (Chapter 6).

18.3 Observed community changes: what are the observed responses so far?

Evidence is now plentiful concerning the potential effect of climate change on bird communities. A plethora of studies has shown through a variety of mechanisms that bird species respond to changes in climatic conditions with potential but unknown impacts at the community level (Table 18.1). Furthermore, expected impacts of climate change may not be gradual but induce drastic changes and shifts in ecological communities (Brown *et al.*, 1997), leading to large-scale extinctions especially in areas of previous long-term climatic stability (Pounds *et al.*, 1999). This level of uncertainty has forced researchers to elaborate hypotheses on expected future changes in bird communities based on modelling exercises generally relying on current fitted relationships between species distribution patterns and current or past climatic variability.

Despite the information gathered, only some evidence suggests that global climate change has led to systematic changes in structure of ecological communities. This step towards identification of dominant mechanisms by which climate change acts on bird species is of crucial importance for determining mechanisms of adaptation or conservation measures. In this section, we review the literature that describe evidence that bird communities are

Table 18.1 Examples of the main predictions of climate change impacts on bird communities derived from species-specific and modelling-based studies.

Species traits	Finding	Community-derived impact	Type of study	Study
Breeding	Advancement in breeding phenology	Increases in generalist species	Species based	Winkler *et al.* (2002)
Breeding	Increases in asynchrony between trophic levels	Decreases in species richness and community turnover	Species based	Sanz *et al.* (2003)
Winter survival	Increases in winter survival in temperate climates and decrease in tropical climates	Regional variation in species richness	Species based	Barbraud *et al.* (1999)
Migration	Changes the proportion of migratory individuals in migratory species	Increases in species richness due to increased residency	Species based	Visser *et al.* (2009)
Migration	Altered migration regimes in long-distance migrants	Decreases in species richness due to decreases in populations of long-distance migrants	Species based	Cotton (2003)
Body size	Increasing body size with temperature	Changes in competition between species leading to species turnover	Species based	Yom-Tov (2001); Gardner *et al.* (2009)
Species distribution	Species richness related to ecosystem productivity	Increases in species richness in temperature-limited systems and decreases in precipitation-limited systems	Modelling	Jetz *et al.* (2007)
Species distribution	Species distribution matching changes in climatic conditions	Northern shifts of winter range	Species based	La Sorte and Thompson (2007), Chapter 17
Species distribution	Species distribution matching changes in climatic conditions	Changes in species richness patterns at different locations	Modelling	Huntley *et al.* (2007); Jetz *et al.* (2007)
Species distribution	Species distribution matching changes in climatic conditions	Species turnover due to idio-syncratic responses to climate	Modelling	Lawler *et al.* (2009); Stralberg *et al.* (2009)
Migratory component	Association between climatic gradients and proportion of migrants in the community	Decreases of abundance of long-distance migrants with increased winter temperatures	Modelling	Lemoine and Böhning-Gaese (2003)
Thermal composition	Community thermal index increased locally	Community shifts to more species which like it hot	Modelling	Devictor *et al.* (2008)

Main finding, type of prediction (derived from single species study or modelling), and community-derived impact (prediction) are shown for different studies.

already systematically responding to climate change and to which degree observed changes fit predictions (McRae *et al.*, 2008).

18.3.1 Large-scale changes in distributions matching climate change

Global warming predicts that species should shift their range polewards, everything else being equal (Thomas and Lennon, 1999; La Sorte and Thompson, 2007) and that failure to do so could be detrimental. Evidence is accumulating of shifts in species distributions during recent climate warming. Hickling *et al.* (2006) showed that a wide variety of vertebrates, including birds, and invertebrates have moved northwards and uphill in Britain over approximately 25 years. At a larger scale, evidence exists supporting the view that species distributions may be changing in line with climate change predictions. Modelling predictions issued from the climatic bird atlas (Huntley *et al.*, 2007) were used by Gregory *et al.* (2009) to generate an explicit hypothesis of large-scale patterns of population changes for common breeding bird species in Europe. Data from long-term monitoring schemes point in the same direction as predictions of climate-driven changes in future range size: increasing current population trends for species predicted to expand their range and decreasing current trends for species predicted to shrink their distributions. Despite data suggesting that currently reported changes are in line with predictions derived from climate change, some scientists have argued that responses are highly idiosyncratic and depend on habitat selection, feeding ecology, or migration ecology (Brommer, 2008). Recent studies suggest that processes causing shift in bird range margins may not necessarily be involved in recent changes in bird abundance. Indeed, Brommer (2008) asked for caution in interpretation of observed changes and more explicit reporting of potential non-exclusive causes behind observed community impacts.

In some cases, climate change will not impact bird communities through progressive warming but through changes in precipitation regime. Pounds *et al.* (1999) reported changes in tropical vertebrate communities altering demography of communities of birds, reptiles, and amphibians linked to recent warming. The changes were all associated with patterns of dry-season mist frequency, which is negatively correlated with sea surface temperature in the equatorial Pacific and that has declined dramatically since the mid-1970s. In general, data suggest that the shift in species ranges is likely to be a dominant factor leading to changes in bird communities. However, observed and predicted changes do not show close agreement when analysed across species. This illustrates that although acknowledging distribution changes, asynchronies in the ability of species to track environmental changes and unanticipated interactions with environmental changes are major factors potentially shaping future bird communities.

Furthermore, these uncertain accumulated effects of climate change at the community scale also result in the lack of clarity in relation to predictions of its impact on community descriptors such as a sharp decrease in species richness. At present, a decrease in species richness unambiguously attributed to climate change is related to global warming of mountain tops, leading to sharp decreases in alpine and mountain species (Pounds *et al.*, 1999). At a wider scale, data seem to give more support to the impacts of climate change on bird communities for the turnover hypothesis, leading to sharp changes in species composition according to idiosyncratic species responses including both positive and negative effects (Green *et al.*, 2008).

18.3.2 Community shifts, thermal ranges, and specialization

Under the influence of global warming, the geographical location of the climatic niche of a species is expected to shift to the north and in altitude. Such species-specific changes affect the overall species assemblage, i.e. community composition, but this has rarely been investigated. Some scientists have attempted to measure this phenomenon by assessing changes in community composition, using space-for-time substitution to assess causal associations between community attributes and observed changes in annual temperature. Devictor *et al.* (2008) studied breeding bird communities, and La Sorte *et al.* (2009) winter bird assemblages. In the first study, the thermal index of a species was defined as the average spring–summer temperatures of atlas grid cells where a species was breeding in Europe, and the community thermal index was the mean of species thermal indices of all individual birds detected at a location. For each site and year, average temperature of species assemblages was estimated. Between 1989 and 2006, the average temperature of communities increased steadily each year by about 0.1 units (Figure 18.3). This change reflects restructuring of local assemblages of species favouring species occurring in the warmest parts at the expense of those occurring in the coldest. This change was calibrated by comparison to the north–south gradient of temperature indices in bird communities in France. The change of 0.1 units for the bird community index is equivalent to a northward shift of 90 km. In other words, at a given point in France today, the composition of bird communities in terms of warm and cold loving species is what we observed 90 km further south 18 years ago. Over the same period, the temperature in spring rose approximately 1 °C, and while the north–south temperature gradient in France is about 0.4 °C/100 km, the climate shifted northwards by 270 km. In this case, change in community composition was insufficient to keep up with temperature increase: Birds are lagging approximately 180 km behind climate warming. Thus, bird communities shift northwards, but not as fast as temperatures do.

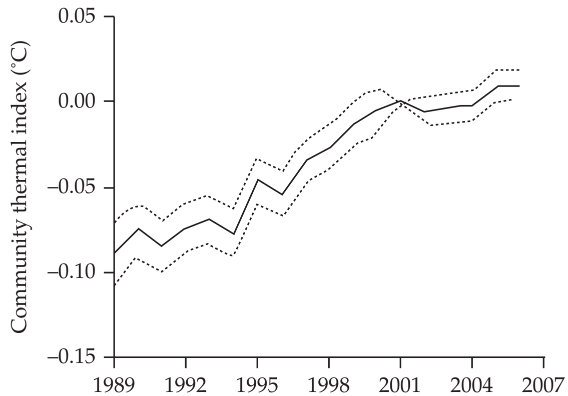

Figure 18.3 Trend in the community thermal index of local bird communities in France for the period 1989–2006. The index increased by an average 0.1°C, which means that locally, the bird community are more and more composed of species that 'like it hot'.

18.3.3 Functional turnover vs. species turnover: which are the impacts of turnover rates for different bird groups?

Effects at the community level regarding the relative contribution of different species groups could also be derived from particular studies showing idiosyncratic responses to climate change by particular functional groups such as pollinators, predators, or frugivores. Insectivorous birds, which are often long-distance migrants under temperate climates, seem to be more prone to decline (Sanderson *et al.*, 2006; Møller *et al.*, 2008) and their population declines change local community composition (Lemoine *et al.*, 2007b), potentially affecting biological control of invertebrates. Functional traits of species and associated diversity of bird communities have to be defined and studied in a variety of ways, not only based on diet or nesting habits, but potentially combining morphometry, habitats and habits, breeding biology, and diet.

Through asymmetric impact on different species, climate change is likely to impact more heavily or introduce larger changes for particular groups of birds. The degree of mismatch may differ among species and be particularly large for migratory species, eventually leading to declining populations and local extinctions. Long-term effects on species richness and composition of ecological communities have been predicted using modelling approaches, but so far have hardly been demonstrated in the field. Lemoine *et al.* (2007b) tested whether changes in the composition of bird communities was influenced by recent climate change in Europe. They analysed the proportion of migratory and resident birds and used spatial relationships between climatic factors and bird communities in Europe to predict changes in 21 European bird communities under recent climate change. Observed changes corresponded significantly with predicted changes and could not be explained by effects of spatial autocorrelation. Alternative factors such as changes in land use were tested in a first approximation, but no significant effects were found, suggesting that global climate change has already influenced the species richness and composition of European bird communities in terms of their migratory component. In a previous study, Lemoine and Böhning-Gaese (2003) reported changes in bird communities fitting predictions from spatial relationships between bird community structure and climate in Europe. In the Lake Constance region in Central Europe, winter temperature increased significantly between two censuses, whereas spring temperature and precipitation did not. As predicted from the models, the proportion of long-distance migrants decreased and the number and proportion of short-distance migrants and residents increased between two census periods (1980–1981 and 1990–1992). The significant declines of long-distance migrants in the Lake Constance region are of a magnitude that can be explained by observed climate change, suggesting that increasingly warmer winters pose a more severe threat to long-distance migrants than to other bird groups.

This higher sensitivity of migratory birds was also demonstrated by Møller *et al.* (2008), who related changes in spring migration of 100 European bird species to their population trends. Species that declined during 1990–2000 did not advance their spring migration, whereas those with stable or increasing populations advanced their migration considerably. The association between 1990–2000 population trends and phenological migration changes was not confounded by other classical predictors of population trends in birds. Their findings imply that ecological factors affecting population trends can change over time and suggest that ongoing climate change will increasingly threaten vulnerable migratory bird species, augmenting their extinction risk. If an increasing number of species become residents, this may have consequences for resource use, predator–prey interactions, and host–parasite interactions (Lemoine and Böhning-Gaese, 2003; Lemoine *et al.*, 2007b). Finally, how climate change could affect the development, persistence, and spread of diseases such as avian influenza is certainly of great interest, with potentially challenging impacts on more mobile species groups such as waterbird communities.

18.4 Indirect climate change effects on bird communities: the complexity of interacting global change components

Climate change is not likely to impact bird communities in isolation but will interact with a range of other global change impacts. If habitat destruction or population over-exploitation is severe, species loss can occur directly and abruptly. Yet the final descent to extinction is often driven by synergistic processes that can be disconnected from the original cause of decline. Brook *et al.* (2008) have shown that owing to interacting and self-reinforcing processes, estimates of extinction risk for most species are more severe than previously recognized (Gil-Tena *et al.*, 2009). Therefore, conservation actions that only target single-threat drivers are inadequate due to cascading effects caused by unmanaged synergies. Indeed, future works should focus on how climate change interacts with and exacerbate ongoing threats to biodiversity.

These mechanisms have already been described and usually lead to major impacts on community change. Understanding such indirect impacts is of major importance because they may have critical consequences for bird communities and could help interpret current mismatches or lags between predicted impacts of climate change and observed community responses. For example, shifting ranges are inhibited but not blocked in landscape zones in which the degree of habitat fragmentation allows persistence. In areas where the spatial cohesion of the habitat is below the critical level of meta-population persistence, expansion of ranges will be blocked (Opdam and Wascher, 2004). Here we briefly review a number of potential indirect effects of climate change on bird communities and identify this front line as a major challenge for future research.

18.4.1 Interactions between climate change and other components of global change

18.4.1.1 Invasive species

Recent research suggests that the climate-mediated increase in the impact of invasive species affecting ecological systems worldwide is one of the largest threats to biodiversity (Walther *et al.*, 2009). In the same way that climate change affects the ecology of native species, it might also directly influence the likelihood of alien species becoming invasive. It can also increase the probability of impacting new systems to different degrees from simple space occupancy to complete transformation, where alien species dominate function or richness, leading to reduced diversity of native species. In such climate-mediated invasive processes, the occurrence of an alien species depends on a change in site conditions that shift the systems to a different environmental space (Jackson, 2007).

Some invasive species, such as the ring-necked parakeet *Psittacula krameri* and the lovebird *Agapornis* sp., may be favoured by warming climates in recent years (Jiguet, 2009), leading to an increasing influence of such invasive species on native communities. In other cases, bird communities may be heavily impacted by invasive species of other taxonomic groups being favoured by climatic change too. For example, avian malaria plays an important role in limiting the distribution and population sizes of many Hawaiian birds, and projected climate change is likely to eliminate most disease-free habitat in Hawaii in the next century (Benning *et al.*, 2002). Kilpatrick (2006) used a modelling approach to examine alternative management scenarios for conservation of native Hawaiian birds. The analyses suggested that differences in life history cause some species to be more susceptible to local extinctions from transmission of malaria, but that climate change generally will result in stronger negative impacts on the native Hawaiian bird community.

Climate change such as increases in precipitation promotes a wider distribution of Argentine ants and increases colonization rate to new areas (Heller *et al.*, 2008). Recent evidence suggests that reproduction of canopy-foraging foliage-gleaning bird species that mostly rely on caterpillars for feeding their young could be compromised by Argentine ant invasion. This alien ant species could be promoting bottom-up effects in the trophic web through its effects on availability of arthropod prey (Estany-Tigerström *et al.*, 2010).

Effects of climate change meditating indirect effects of invasive species are expected to be strongly associated with the invasive species impacting a given community. However, information available suggests that invasives have the potential to lead to generalized impact at the community level (Clavero *et al.*, 2009) by affecting different groups of birds through different mechanisms involving a plethora of ecological processes such as competition (Walther *et al.*, 2009).

18.4.1.2 Land use changes in the context of climate change

Although changes in land use and climate have an impact on ecological communities, it is unclear which of these factors is currently most important. Some studies have sought to determine the influence of land use and climate alteration on changes in abundance. Lemoine *et al.* (2007a) analysed Central European bird communities to examine impact of these factors by contrasting changes in abundance of birds of different breeding habitat, latitudinal distribution, and migratory behaviour. Changes in regional abundance of 159 coexisting bird species from 1980–1981 to 2000–2002 were influenced by all three factors. Farmland birds, species with northerly ranges, and long-distance migrants declined, and wetland birds and species with southerly ranges increased in abundance. A separate analysis of the two decades between 1980–1981 and 1990–1992 and between 1990–1992 and 2000–2002 showed that the impact of climate change increased significantly over time, as shown by Møller *et al.* (2008). Latitudinal distribution was not significant in the first decade and became the most significant predictor of changes in abundance in the second. Although the spatial scale and temporal resolution of their study were limited, Lemoine *et al.* (2007a) argued that their study was one of the few acknowledging concomitant effects of climate and land use changes on bird communities, with the relative effects of the different components changing over time.

However, when the hypothesis of climate and land use changes has been confronted, land use changes often over-ride observed community changes. In Mediterranean forests, northern species have recently increased in abundance and distribution due to widespread effects of forest maturation, thus acting opposite to the predicted impacts of climate change (Gil-Tena *et al.*, 2009). Furthermore, Hockey and Midgley (2009) documented the chronology and habitat use of 18 regionally indigenous bird species that colonized the extreme southwestern corner of Africa after the late 1940s. This incorporates a period of almost four decades of observed regional warming in the Western Cape, South Africa. Observations of these colonization events concur with a ‘climate change’ explanation, assuming extrapolation of Northern Hemisphere results and simplistic application of theory. However, when closely scrutinized, all but one may be more parsimoniously explained by direct anthropogenic changes to the landscape than by indirect effects of climate change. Indeed, no a priori predictions relating to climate change, such as colonizers being small and/or originating in nearby arid shrub, were upheld. This suggests that observed climate change has not yet been sufficient to trigger extensive shifts in ranges of indigenous birds or that a priori assumptions are incorrect. Either way, this study highlights the danger of naive attribution of range changes to climate change, even if range changes are in accordance with predictions of climate change models.

There is an urgent need to develop effective integrative, community-based approaches to track impacts of climate change on biodiversity. However, different components of global change can have interacting effects on biodiversity, influencing our ability to detect consequences of climate change, through the use of compound biodiversity indicators. Clavero and Brotons (2010) analysed variation of a climate change community-based indicator (community temperature index) at different altitudinal bands (i.e. different thermal environments) along three land use landscape gradients (farmland to forest, wildfire to forest, and urban to forest). They assessed whether land use derived changes in the indicator overlapped changes related to climatic gradients (i.e. altitude). The climatic indicator varied as much along landscape gradients as it did along the entire altitudinal range. The forest extremes of all gradients had bird communities with a higher proportion of cold-temperature species, independent of altitude. As measured from the use of compound climatic indicators, the effects of transformation of a forest to agricultural land, urbanization, or burning by wildfire would be equivalent to a decrease in altitude of up to 575 m, a decrease in latitude of some 500 km, or over a century of bird community responses to global warming. In the light of these results, Clavero and Brotons (2010) emphasized the need for explicit incorporation of interactions between climate change and land use dynamics and their possible effects on commonly used biodiversity indicators of climate change.

18.4.2 Changes in disturbance regimes

Sudden changes in community composition related to climate change may not be the results of direct climate impacts, but the results of mediated changes in disturbance regimes (Herrando *et al.*, 2002). Global climate change is expected to affect temperature and precipitation, oceanic and atmospheric circulation, rate of rising sea level, and frequency, intensity, timing, and distribution of hurricanes and tropical storms and wildfires (Chapter 2). The magnitude of these projected physical changes and their subsequent impacts on different communities will vary regionally. Coastal wetlands in southeastern USA have naturally evolved under a regime of rising sea level and specific patterns of hurricane frequency, intensity, and timing. Michener *et al.* (1997) reviewed ecological effects of tropical storms and hurricanes and indicated that storm timing, frequency, and intensity can alter coastal wetland hydrology, geomorphology, biotic structure, energetics, and nutrient cycling. Research conducted to examine impacts of Hurricane Hugo on colonial waterbirds highlighted the importance of long-term studies for identifying complex interactions that may otherwise be dismissed as stochastic processes. Rising sea level and even modest changes in frequency, intensity, timing, and distribution of tropical storms and hurricanes are expected to have substantial impacts on coastal wetland patterns and processes. Persistence of coastal wetlands will be determined by interactions of climate and anthropogenic effects, especially how humans respond to rising sea level and how further human encroachment on coastal wetlands affects resource exploitation, pollution, and water use. Long-term changes in frequency, intensity, timing, and distribution of hurricanes and tropical storms will probably affect biotic functions (e.g. community structure, natural selection, extinction rates, and biodiversity) and underlying processes such as nutrient cycling and primary and secondary productivity.

Fire is a widespread natural disturbance agent in many systems. In light of climate change and effects of fire exclusion, single and repeated high-severity (stand-replacement) fires have become prominent land management issues. Fire regime significantly impacts bird communities and therefore is a major factor determining community shifts in the context of climate change. Animal succession and restoration of community structure after fire are related to vegetation regeneration, which is influenced by climate. Species richness and community composition are strongly impacted by fire and later by site-specific successional processes (Herrando *et al.*, 2002; Fontaine *et al.*, 2009). In areas with an increasing fire frequency, bird communities may shift their relative composition towards early successional stages. In many regions, such as the Mediterranean, these community shifts are generally predicted from climate warming, with more temperate species being more common in more mature forest habitats. In this context, the two processes may interact, but at the community level impacts of climate change on bird communities are very high.

Understanding such processes is critical to be able to forecast expected impacts of climate change on bird communities. Because land cover changes result from a variety of processes, it is unclear how effectively species distribution models capture responses to these changes, including those derived from climate (Vallecillo *et al.*, 2009).

18.5 Bird community and climate changes: perspectives and the way forward

An important challenge for ecologists is to identify climatic factors that drive temporal variation in demographic parameters and, ultimately, the dynamics of natural populations. Bird communities are expected to radically change their structure and composition, but we know much more about the relative role of the plethora of potential changes and how such changes interact and contribute to observed changes at the community level. The number of possible changes at the community level is so complex that further investigation is warranted.

Careful reporting of current community changes and careful confronting of model projections with hard data on community dynamics are two ways to better identify likely impacts of climate change on bird communities and should guide future research. At present, there is an agreement about the role of climate warming on changes in species distributions, including community shifts fitting predictions. However, once the complexity of direct and indirect effects of climate change is recognized, assessments and predictions of impacts at the community level should move forward and explicitly recognize the major role of cascade effects, lags in responses to current change between species, and interactions between climate and other global change components.

Most community-based predictions of climate change impacts have been based on single-species studies and projections from simple distribution models based on simple impacts of climate change (warming) (Figure 18.4). There are very few examples of specific community impacts or specific modelling projections including the complexity of expected cascades or mismatching impacts accumulated across species. Despite different studies showing that bird communities are rapidly changing, the lack of adjustment between the complexity of expected impacts and our current modelling capabilities leads to a discrepancy between the observations and the available predictions (Chapter 17; La Sorte *et al.*, 2009).

For instance, most predictions have been based on niche-based models. The reliability of bioclimatic niche models to predict species response to future climatic conditions has been based on model validation procedures that rely on spatial data from a unique time window. However, when these models are used in a temporal perspective, we are indeed not interested in how well the climatic niches of species will be spatially represented and thus fit contemporary species data, but to what extent changes in climate conditions will be associated with distributional species shifts. The appropriate validation of this process requires adequate temporal data on species

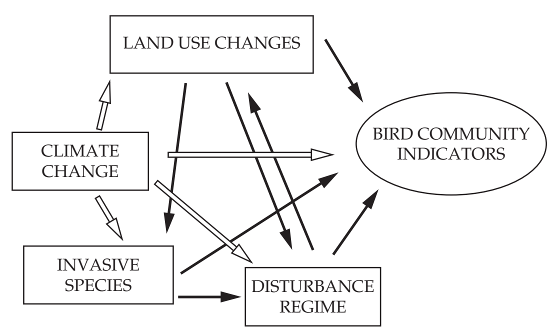

Figure 18.4 Conceptual framework for assessment of the potential effects of climate change at the community level measured by means of bird community-based indicators. Black arrows denote potential indirect effects of climate change (i.e. interactions) on bird community indicator influences, while white arrows stand for direct effects of climate change on both bird communities and other components of global change. Future assessments through the use of compound community indicators should explicitly integrate the impacts of concurrent global change on communities.

changes to justify this link. Only when bioclimatic niche models can be validated for the temporal process they aim for, is the use of these powerful methodologies fully justified. Unfortunately, the majority of exercises that assess future projections for species based on bioclimatic models are only validated with data from one time window, and the temporal projections are no more than educated guesses of distribution change. Past use of modelling projections in a predictive context has produced little progress in our knowledge of the effects of climate change on community structure.

Similarly, climatic science has generated different scenarios for future climate change based on explicit climate mechanisms and forcings, and ecologists should aim at developing more explicit projections of community change based on different and explicit assumptions on how ecological mechanisms structure communities. Such exercises should be viewed not in a predictive framework, but explicitly as a null hypothesis of community change to be confronted with real data on observed community changes (Gregory *et al.*, 2009).

Developing a comprehensive understanding of the ecological ramifications of global change will necessitate close coordination among scientists from multiple disciplines and a balanced mixture of approaches. Michener *et al.* (1997) proposed that insights may be gained through careful design and implementation of broad-scale comparative studies that incorporate salient patterns and processes, including anthropogenic influences. Well-designed, broad-scale comparative studies could serve as the scientific framework for developing relevant and focused long-term ecological research, monitoring programmes, experiments, and modelling studies.

Confidence in projections of future distributions of species requires demonstration that recently observed changes could be predicted adequately (Green *et al.*, 2008). An essential step forward in our ability to generate predictions about impacts of climate change on bird communities will come from the development of species distribution models towards more mechanistic dynamic species distribution models. These models should specifically and explicitly integrate species interactions and ecological constraints such as dispersal, allowing future scenarios of species distribution changes to be ecologically sound. Some examples of these new approaches have recently appeared in the literature. Willis *et al.* (2009) used a dynamic model framework combining a colonization model superimposed on a high-resolution map of habitat availability to demonstrate that recently observed changes in expanding northern boundaries of three British butterfly species could be predicted with high accuracy. McRae *et al.* (2008) illustrated how models of land use, climate change, and other dynamic factors can be integrated into a coherent framework for predicting wildlife population trends. Their framework starts with land use and climate change models developed at a regional scale. Vegetation changes through time are predicted under alternative future scenarios using an individual-based plant community model. These predictions were combined with spatially explicit animal habitat models to map changes in the distribution and quality of wildlife habitat as expected under the various scenarios. Animal population responses to habitat changes and other factors are then projected using a flexible, individual-based animal population model. Using climate and land use predictions and incorporating effects of landscape history and limited dispersal, their framework predicted population changes that typically exceeded those expected based on changes in mean habitat suitability alone. Although land use had greater impacts on habitat quality than climate change in their simulations, small changes in vital rates resulting from climate change or other stressors can have large consequences for population trajectories. The ability to integrate bottom-up demographic processes like these with top-down constraints imposed by climate and land use in a dynamic modelling environment is a key advantage of the resulting framework. In the future, modelling approaches that combine climate suitability and spatially explicit population models, incorporating demographic variables, and habitat availability, are likely to be valuable tools in projecting responses of species to climatic change and hence for anticipating management to facilitate dispersal and persistence of species.

The investigation of impacts of climate change at the community level is affected by the complexity of the process ahead. We lack clear references, good information on bird community changes, and explicit integration of climate change interactions with other global change components. These are currently the greatest challenges for assessing community scale impacts of climate change on birds (Table 18.2). As a final message, we propose a conceptual framework for advancement and some lines of development in this formidable quest ahead:

1) Integration of studies on responses of single species through meta-analysis. These kinds of approaches have been successfully applied to the observed effects of climate change on bird phenology and could be extended to other aspects of bird ecology such as breeding or changes in species interactions. The results of such meta-analyses should allow more general hypotheses of observed and potential future effects of climate change to be used as a basis for further work. Furthermore, a more general view of the life cycle of birds should be used in which the different phases through the year are taken explicitly into account.
2) Developing hypotheses based on dynamic modelling of future projections that explicitly incorporate expected interactions and ecological constraints: trophic levels (such as forest, conifers, and crossbills), competition and commensalism (forest, trees, woodpeckers, and hole nesting owls), and host–parasite interactions (cuckoos and hosts). These future scenarios of community change could be viewed only as a range of null hypotheses indicative of potential future responses of communities to the complexity of mechanisms involved in the predictions.
3) Explicit integration of complexity and interactive nature of climate change impacts with other components of global change such as invasive species and land use changes, including alterations in perturbation regimes.
4) Recording of community responses at the landscape and regional levels to allow validation of predictions using hard data on community descriptors. Comparison of observed community changes with the range of changes predicted by different null hypotheses of change will allow identification of prevailing factors influencing community dynamics in specific situations. Only by building on such a structured and hypothesis-based framework will we be able to advance in our ability to understand and anticipate the certainly complex effects of climate change on bird communities.

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Table 18.2 Future priorities for research in order to adequately assess and quantify the impacts of climate change on bird communities.

Priority	Methodology	Objective
Integration of currently detected responses at the species level to climate change	Meta-analyses/reviews	Development of background information on potential impacts of climate change at the species level
Integration of trophic levels beyond birds	Dynamic niche-based modelling	Understanding potential cascade effects along trophic chains
Integration of species interactions	Community dynamics models	Changes in competition, predation, and parasitism (increase, release, etc.)
Integration of natal and breeding dispersal in distributions models	Dynamic niche-based modelling	Obtain more realistic future-predicted distribution range hence community richness
Integration of interactions between global change components	Continent-scale monitoring data	Understanding potential cascade effects within global changes
Developments of community dynamics models integrating distribution modelling and population dynamics	Integration of all previously cited methods	More comprehensive modelling of community changes

For each priority the proposed methodology and its main objective are described.

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