Chapter 12
Climate Change Impacts on Bird Species

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Abstract Climate change has been shown to be an increasingly important driver of changes in the distribution, abundance and life history of bird species, causing changes of biodiversity and community compositions, e.g., measured by climate change indicators. Especially changes in the distributional ranges of species have been demonstrated in many cases, with some species being driven towards their altitudinal or latitudinal limits leading to shrinking populations. But also changes of phenology, genetics, and population sizes have been proposed to be caused by climate change. Although there is recent evidence only for regional climate-driven extinction events for birds, climate change can be considered among the major risk factors that might lead to the complete extinction of bird species. Together with (and sometimes contradicting) land-use change and demographic effects, climate change is shown to be a risk factor especially for cold-dwelling, restricted-range, and slowly adapting species. However, indirectly, by means of climate change mitigation measures modifying land-use patterns, also widespread generalist species are becoming increasingly threatened. Despite demonstrated niche conservatism in several cases, also adaptation of species to climate change is taking place, changing their multidimensional niche spaces. Birds are not sufficiently tracking climate change, nor do northern and southern range limits shift at the same pace. Thus, altered migration phenology and distance have been proven, often proposed to result from phenotypic adaptation. In a few cases, however, genetic predisposition and/or microevolution appear to shape the impact climate change has on bird species. There is broad consensus that climate change will lead to a reshuffling of communities and altered selection pressures both within and among species. The extent of the projected changes largely differs among studies owing, e.g., to the uncertainty inherent in climate change predictions. Nevertheless, niche space is expected to undergo future changes for many species, which, in turn, can have beneficial or detrimental effects on the survival of the respective species or communities and may

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also lead to changes in the effectiveness of bird protection which in turn should be adjusted to climate change impacts.

Keywords Climate change · Climatic niche · Climate change indicator · Distribution · Phenology · Adaptation · Microevolution · Species richness · Leading/trailing range margins · Demographic changes · Warm-dwelling/cold-dwelling species · Niche conservatism · Stepping-stones

12.1 Introduction

Past climatic changes have regularly triggered large-scale alterations of plant and animal communities. Single large-scale extinction events occurred at least five times in Earth's history, the sixth mass extinction being suspected to be under way (Barnosky et al. 2011).

Non-analogue climatic regimes and communities stimulated both the extinction of existing and the evolution of new species. For birds, such stimuli comprise the Cretaceous-Paleogene mass extinction (Longrich et al. 2011) but also ice ages and the creation of new weather systems like the monsoon in Southeast Asia (Weir and Schluter 2004; Koch and Barnosky 2006; Päckert et al. 2012).

Since the twentieth century, life on Earth has been faced with an anthropogenic increase in Earth surface temperature of 0.74 °C, with mean temperature increases exceeding over two degrees in certain areas of the temperate and arctic climate zones (Pacifici et al. 2015; Houghton et al. 2001). Future climatic projections predict a continued rise in Earth surface temperature by 0.3–4.8 °C (relative to 1986–2005 conditions) until the end of the twenty-first century (IPCC 2013).

Ongoing climatic change markedly differs from preceding changes, because the latter supposedly did not occur at such small temporal scales and were not accompanied by changes in land use which act—at least partly—independently of them.

Accepting climate change as a scientific fact, this inevitably leads us to the question of how those unprecedented changes might influence the future of bird species.

12.2 Birds and Climate Change: Is There an Impact?

When focusing on climate change impacts, it becomes apparent that a vast amount of knowledge already exists showing various types and magnitudes of impacts on bird species.

We especially find phenologic, genetic, population level and biogeographic changes.

Regarding **phenology**, changes in the arrival (and partly also departure) timing of migratory species, in some cases diminishing migratory activity, alteration of migratory distances, and changes in breeding behavior related to earlier arrival and timing of breeding as well as increased length of the breeding season and numbers of broods have been found, but no strong effects on clutch sizes could be demonstrated (Doswald et al. 2009; Visser et al. 2009; Both and Visser 2001; Smallegange et al. 2010; Both et al. 2004; Møller et al. 2010; Parmesan and Yohe 2003; Winkler et al. 2002).

For most of those effects, it remains unclear whether phenotypical plasticity or rather **genetic changes** cause them (e.g., Gienapp et al. 2007). In some cases, it has been hypothesized that climate change might have led to altered selection pressures, e.g., resulting in changed coloration (Karell et al. 2011), smaller body sizes (Salewski et al. 2010), and the change of migration routes or migratory activity within few generations (Bradshaw and Holzapfel 2006; Plummer et al. 2015). Especially, selection for dispersal and reproductive traits is thought to increase toward range edges (Oliver and Morecroft 2014).

Population changes reveal themselves as a result of altered biotic and abiotic conditions and can be more or less pronounced, depending on the adaptability of species. Changes of species abundance have been increasingly related to climate change effects (Jiguet et al. 2010; Renwick et al. 2012; Tayleur et al. 2015; Huang et al. 2017).

Biogeographic changes are caused by the aforementioned factors, first in the form of spatial abundance shifts, local extinction, and colonization events and then, ultimately, as areal shifts, resulting in either gain or loss (in Europe at the northern and southern range margins, respectively) of species' ranges (e.g., Thomas and Lennon 1999; Hitch and Leberg 2007). In Europe, predominantly range extensions could be demonstrated, whereas range loss is much less commonly reported. Yet, climate change-driven global or continental extinction events for bird species remain to be unambiguously proven, although together with weather extremes it already seems to be a primary or secondary threat of extinction for around 10% of bird taxa (Szabo et al. 2012) and local extinctions have already been demonstrated in both northern temperate and tropical parts of the Americas (Wiens 2016).

Within the last two decades, range shifts have increasingly been debated as a proof of measurable climate change impact on bird species and communities.

In northern temperate regions, mostly, shifts at the northern or leading range margins toward the northeast or northwest have been reported (e.g., Lehikoinen and Virkkala 2016) and seem to be constricted by winter temperatures (Parmesan 2006), whereas evidence for corresponding shifts of the southern or trailing range margins remains scarcer (e.g., Gillings et al. 2015; Tayleur et al. 2016). Furthermore, range shifts in the tropics (Walther et al. 2002; Şekercioğlu et al. 2012) or southern temperate areas (Hughes 2003) have less frequently been reported.

But even for proven shifts, not in all cases the directions of the shifts fit with the expectations (e.g., western or eastern range shifts, shifts downslope or toward tropical latitudes, (Bateman et al. 2016; Huang et al. 2017; Lenoir and Svenning 2014; Gibson-Reinemer and Rahel 2015), and sometimes alleged shifts are disproven (Taheri et al. 2016). Also, altitudinal shifts caused by climate change are not unambiguously supported by the current literature (Tingley et al. 2012).

In the light of such inconsistent results, sometimes it has even been disputed, whether apparent range shifts are actually attributable to climate change or rather to land-use or demographic changes (Beale et al. 2008, 2009; Peterson et al. 2009; Bateman et al. 2016).

Thus, although climate change and its impacts are widely accepted as scientific facts, it should neither be considered as an isolated driver of changes in bird populations or communities nor can its effects always be distinguished from other drivers such as land use.

12.2.1 Climate Change Indicators

Despite all those blurred views, however, we still find a generalizable effect of climate change on a large spatial and temporal scale, especially at the community level (Araújo et al. 2009). Therefore, climate change indicators have been invented in order to measure effects that might be masked by the large spectrum of reactions of single species or populations.

As some species are more, others less dependent on climate, this individual relationship has to be captured in one common framework in order to reveal generalizable effects. Several attempts have been made to do so.

One of them is to examine changes of species richness as a measure of the overall climatic influence on birds (e.g., H-Acevedo and Currie 2003; Lemoine et al. 2007).

More frequently, the climatic associations of single species were estimated using species distribution modeling (see Chap. 9) and then aggregated to community level, e.g., resulting in the **climate impact indicator** (Gregory et al. 2009). This approach was recently modified to allow for different reactions of the same species to climate change, depending on the region in which the species occurs (Stephens et al. 2016). Changes in the local climatic suitability for bird species can be calculated using regression models of occurrence/abundance of species in a given area at a time and the climatic circumstances in the same area and time period. Those trends in climatic suitability can then be linked to the climatic changes in the same time period and area.

Apart from changes of suitability, a simpler measure of the climatic dependence or niche of a species can be used by calculating the average temperature throughout the range of their occurrence. This value can be used to distinguish warm-dwelling and cold-dwelling species. Furthermore, weighing the abundance (relative to other species) of a species in a given year by its temperature value and averaging over the whole community of species, a **community temperature index** (DeVictor et al. 2008, cf. Fig. 12.1) can be calculated, representing the “fever curve” of the bird community. This indicator is not just sensitive to changes in the distribution of species but also to changes in abundance and thus unveils the changes happening within ranges rather than focusing only on range margins.

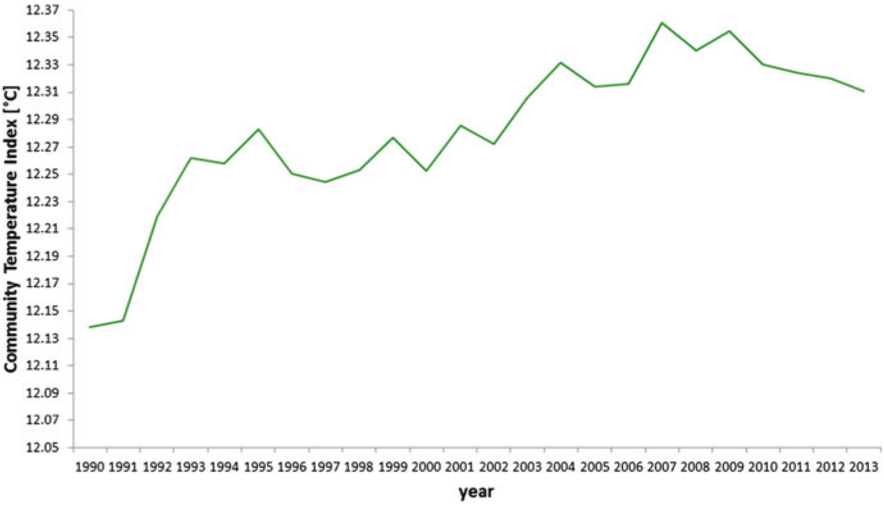

Fig. 12.1 The community temperature index in Germany is the "fever curve" of the bird community. It contains 88 common bird species and shows the relative changes in the proportion of warm-vs. cold-dwelling species by averaging the population trend indices, weighed by the temperature niche of the single species within their European distributional range. Changes do not seem to be tremendous between 1990 and 2013 but reflect very well the changes in mean April–July temperatures in Germany with increases at the beginning of the 1990s and 2000s and a decrease since 2009

All those approaches have added tremendously to our perception of climate change effects on birds. Thereby, it became known that bird species richness is changing, especially due to the immigration and increase of new species but regionally also due to the decline and/or loss of species. Additionally, proposed range shifts reflected very well changes among potential "winners" and "losers" of climate change on continental levels or even across continents (Gregory et al. 2009; Stephens et al. 2016). But also, smaller-scale changes in the climatic impact could be tracked, and the reshuffling of communities was demonstrated (DeVictor et al. 2008; Princé and Zuckerberg 2015).

Nevertheless, still some doubts remained about whether community-based indicators can disentangle climate and land-use change effects. Some effects that seem to be caused by climate may in fact be due to land-use changes acting only on one part of a community that has distinct properties of its climatic niche like, e.g., changes in temperate forest birds, which tend to be rather cold-dwelling (Clavero et al. 2011). On the other hand, differential effects (e.g., regarding sensitivity to land-use change) on subsets of communities might even cover climate change effects (Reif et al. 2010).

Thus, more recent community-based indicators aim to correct for effects of habitat specialization of communities to rule out such effects (Kampichler et al. 2012).

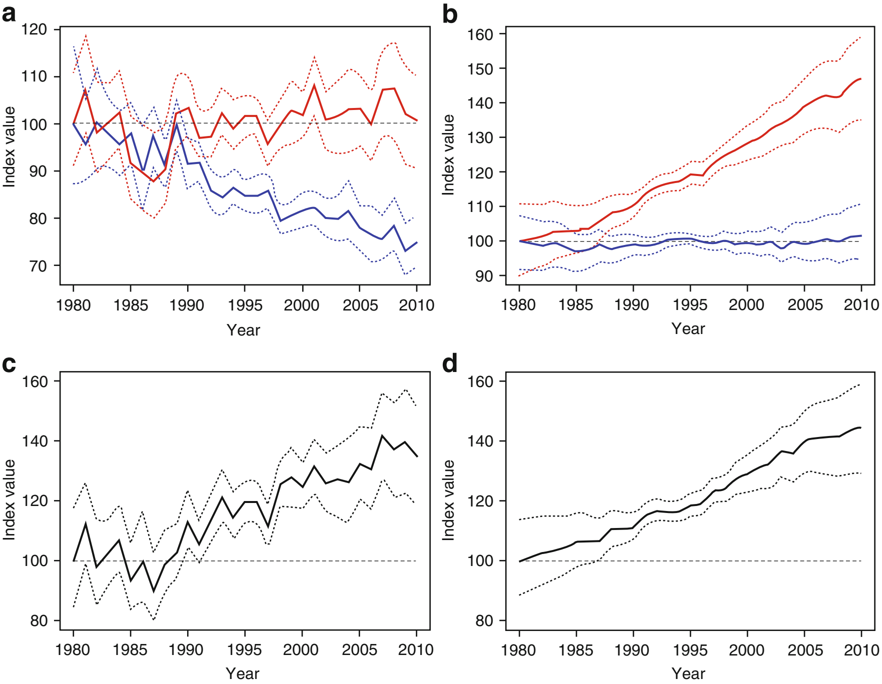

Fig. 12.2 The climate impact indicator (CII) connects changes in the climatic suitability for bird species in defined areas with their population changes among 1980 and 2010. For Europe, in (**a**) the average population changes are shown for species for whom climatic suitability increased (CST+) in red and for species for whom climatic suitability decreased (CST−) in blue (red and blue dashed lines depict 90% confidence intervals; the dashed horizontal line depicts the expectation if climatic suitability played no role). In (**b**), the same is shown for the USA. Annual values of the ratio of the CST+ index to the CST− index form the climate impact indicator (CII), which is shown for Europe in (**c**) and for the USA in (**d**). On both continents, since 1980, a consistently increasing climatic impact for bird populations can be demonstrated. Figure taken from Stephens et al. (2016)

Ultimately, results of species- or community-based indicator systems can provide insights into the climate change impacts which can yield either positive or negative consequences for birds (Fig. 12.2).

12.3 What Are the Consequences of Climate Change for Birds?

Climate change-induced alterations of bird phenology and distribution have been identified as important threats for single bird species. Less prominently, species might also profit from climatic change. Thus, a number of species in the climate impact indicator have been labeled as potential “winners” and others as “losers” of climate change. However, in the new edition of the CII (Stephens et al. 2016), both are somewhat intermingled, as the same species might in one part of its range be subject to positive yet in another part to negative climatic impacts. And in a number of species, no unambiguous climate change associations are apparent at all (e.g., Huang et al. 2017).

Positive aspects of climate change comprise increasing abundance and/or ranges for sedentary, general, and warm-dwelling species (Kampichler et al. 2012; Davey et al. 2012; Devictor et al. 2008). Also, changed competition structures might favor some species over others (Ahola et al. 2007; Wittwer et al. 2015). And especially, wintering conditions have already improving for a number of species (Princé and Zuckerberg 2015; Tellería et al. 2016).

Nevertheless, in most publications, negative impacts are expected to prevail for the majority of species.

Phenological mismatches have been hypothesized and regionally been proven (e.g., Both et al. 2010). Also, unequal climate change in breeding, passage and wintering areas and less flexibility to adapt to changes (especially for long-distance migrants, compare Gomez et al. 2016; Potvin et al. 2016) lead to a higher threat potential for migrants (Hüppop and Winkel 2006; Jones and Cresswell 2010). Changes of wintering or passage conditions also have additional detrimental effects on bird populations (Hüppop and Winkel 2006; Lehikoinen et al. 2013). And during the breeding season, enhanced extreme weather events are causing negative effects for bird species (Van de Pol et al. 2010).

However, at the community level, threats from climate change seem to arise especially from the changes in wintering and breeding distributions of species and the accompanying reshuffling of bird communities (La Sorte and Thompson 2007). Especially, asynchronous changes lead to altered competition and facilitation structures and make communities more susceptible to other detrimental (often anthropogenic) effects.

Ranges can expand or shrink due to climate change, depending on the adaptability of species to new conditions (Massimino et al. 2015). For generalist species or species which are able to shift their habitat preferences quickly, new habitats become available through climatic change, whereas other species might lose ranges, if habitat quality deteriorates due to climate change (Davey et al. 2012).

Although land-use change can be more important for habitat specialists (e.g., Virkkala et al. 2005), climate change might locally even have overtaken land use as the most important threat factor (compare Lemoine et al. 2007). However, the highest threat potential does probably not arise from climatic or land-use changes per se but rather from their interaction (Oliver and Morecroft 2014).

Not only is climate change known to drive changes in land-use patterns by changing environmental conditions for agriculture or forestry.

Also, climate change mitigation measures have the potential to reduce the impact of climatic change by up to 20% for birds (Warren et al. 2013) and in some cases are already promising regarding positive impacts on bird communities (Lindbladh et al. 2014). However, several mitigation measures show adverse effects on bird populations and diversity (Danielsen et al. 2009; Immerzeel et al. 2014).

So, it is estimated that one of the largest negative effects for birds at community level in Germany can currently be observed for the cultivation of energy crops. Especially, the increased cultivation of rapeseed for biofuel (E10) and winter wheat, rye, and especially corn for biogas production has led to higher agricultural intensification. Large-scale monocultures and the simultaneous loss of both extensive grassland and fallow land have probably led to a "biodiversity disaster" and might continuously add to an accelerated loss of farmland bird abundance and diversity (Flade 2012; Sauerbrei et al. 2014). Such negative effects could be minimized, if monocultures were avoided and habitats were enriched when cultivating bioenergy crops or grassland (Casado et al. 2014).

12.4 Projections of Potential Climate Change Impacts: What Else Is Waiting for Us?

Regarding future projections of climate change impacts, very often mismatches and uncertainty occur.

Interestingly, perceived climate change impacts and future projections very often differ markedly. While currently no climate-driven global extinctions of bird species can be proven, vast species losses are predicted for the future.

Dramatic distribution shifts of on average up to 550 km northward in Europe have been hypothesized (Huntley et al. 2008). Including land use into such projections leads to less pronounced shift projections of 335 km, at least under the expectation of *niche conservatism* (Barbet-Massin et al. 2012). Nevertheless, on a global perspective, vast land-use change acting jointly with climate change might very well lead to an even higher threat for biodiversity (Jetz et al. 2007; Mantyka-Pringle et al. 2015).

In the USA, 53% of species are projected to lose more than half of their current range (Langham et al. 2015). Especially, rare species with restricted ranges might be affected by such changes (Ohlemüller et al. 2008).

Furthermore, climate change impacts are proposed to be more severe for cold-dwelling species, restricted-range species, and species using seasonal habitats (Both et al. 2010). In contrast, warm-dwelling, generalist, and adaptable species are expected to profit from forecast climatic changes (Davey et al. 2012).

Additionally, although projections do not show associations to conservation prioritization (Langham et al. 2015), it has been proposed that protected areas might be able to at least partly buffer climate change impacts due to offering habitat niches and allowing for range shifts by providing refuges or stepping-stones for bird populations and communities (Hole et al. 2009).

Another mismatch occurs in the relationship between effects of climate and land-use change.

There are hypotheses stating that climate change might become an even more important threat factor than land-use change (Boit et al. 2016). However, there still exists considerable debate over this issue and especially for the tropics, but also for temperate regions, rather land-use change is expected to remain more important than climate change, whereas in arctic, boreal, and alpine environments, a larger effect of climate change is expected (Jetz et al. 2007; Sala et al. 2000).

Despite the unresolved question of which factor might be more important, future change projections of bird distributions often do not consider both climate and land-use change and their interactions which leads to an even higher uncertainty. Also, ecological features of species which influence dispersal, adaptability, resilience, and persistence of species are often ignored (Jiguet et al. 2007; Møller et al. 2008). Studies that incorporate those factors mostly reveal tremendously different or even contrasting possible outcomes in comparison to pure climate-based projections (e.g., Urban et al. 2012).

Even when incorporating interaction effects and biological mechanisms into future projections, there still remains considerable uncertainty regarding the extent to which single species, geographical areas, and ecosystems might be influenced by climate change. Future projections remain very vague for several reasons. They especially depend on many assumptions, e.g., about the fundamental and realized niches of species but also about the equilibrium of species distributions and climate. They sometimes even have to extrapolate to non-analogue conditions. And, overall, not only is the future extent of climate change on a global level unknown, but also its potential effects on regional and local scales are yet poorly understood. But for all that uncertainty about which effects climate change and other factors might have on biodiversity, the footprint of climate change is already apparent, e.g., illustrated by current bird population trends mirroring forecast climatic changes (Jiguet et al. 2013). This scientific fact clearly calls us into action.

12.5 Do Niches and Interactions with Abiotic and Biotic Environment "Evolve"?

As outlined before, future projections of climatic impacts on bird species or communities still remain vague. Despite the uncertainties of climate change, land-use change, their interactions, species traits, and species distribution models, major causes for this are assumptions of niche conservatism and stability. Those can in many cases be questioned and thus represent an additional source of uncertainty. Although for many species a clear relation to climate has been found, projections in time and space are hampered by several factors.

Species have been shown to react to climate change, e.g., by adapting their migratory behavior (Schaefer et al. 2008). Several species have shifted their arrival dates, changed wintering and stopover areas, or their migratory routes (Lehikoinen et al. 2004, 2013; Maclean et al. 2008).

But even without such changes, species might react to climatic changes in unexpected ways, especially when they are faced with non-analogue conditions (i.e., abiotic or biotic conditions they have not yet faced with within their former range). They can, e.g., occur in new environments which through climate change might offer more food resources in winter or during the breeding season. And they obviously react to climate change in different ways according to regionally different environmental conditions or altered community structures and competition. Thus, no straightforward predictions can be made for the "evolution" of non-analogue communities, i.e., communities which bird species have not encountered before (Urban et al. 2012).

It can however be expected that some species will react to such new challenges using ecological innovations. Especially changes in relative abundances within communities will necessarily force species under pressure to adapt to new conditions. The more generalist or innovative (e.g., niche-switching) species might fill niches that become available during the competition with species that are incapable of quick and efficient adaptation to new conditions.

Not only the competition among species but also subspecies distributions and furthermore genetic diversity might alter due to climate change (Peterson and Holt 2003; Pearman et al. 2010; McQuillan and Rice 2015).

But also external drivers like pathogens might influence species' capacities for climate change adaptation through impacts on the population structures of species. One example of induced pathogens that might have an impact on birds in the face of climate change is represented by the Usutu virus. This virus has been introduced into Europe by single events and caused mass mortality events in Common Blackbirds *Turdus merula* in 2001 in Austria and 2011 in Germany (Weissenböck et al. 2003; Becker et al. 2012). Such events lead to the selection of immune birds and might also regionally change relative abundance structures within bird communities as the blackbird is among the most abundant bird species in Central Europe. It remains yet to be examined to which extent other bird species are affected by this virus and whether other species that are immune to it might profit from changed competition structures within the bird community.

Also, at medium or long temporal scales, such pathogens by means of selection might shape the population genetic structure of species affected by them which in the case of Usutu cannot yet be demonstrated.

It can be expected that on larger timescales, such effects will become more prominent. Large-scale subliminal effects might already be existent but become apparent only in some decades.

Climate change is held responsible for the creation, differentiation, and extinction of species on evolutionary timescales. Availability of new niche space, altered selection pressure, and the loss of established niches are hypothesized to have driven evolution over millions of years. However, it seems difficult to predict how those processes act on small timescales of decades or centuries. Thus, current climatic changes and subsequent reactions of species have to be observed carefully in order to disentangle phenotypic adaptation from microevolutionary processes which might lead to altered conditions for species and communities.

One approach to do so includes a comparison of cues for past niche evolution to population trends. By this means, Lavergne et al. (2013) showed that niche conservatism correlates with population declines.

Nevertheless, not only the question of whether species adapt to climate change will be a matter of survival but also how quickly this can happen. If birds are not able to keep pace with climate change (DeVictor et al. 2008) or evolve new niches (Quintero and Wiens 2013), they will be subject to population declines and might ultimately be threatened with extinction.

The inherent uncertainties of those dangers and of climate change lead us to the question of how to combat climate change impacts.

12.6 Conservation Implications

Climate change has been shown to be an increasingly important threat factor for both bird species and communities. As it acts on large spatial and comparatively short temporal scales, it is a factor that (if only regionally) has the potential to quickly outperform land-use change as the current major threat factor for biodiversity (Eglington and Pearce-Higgins 2012). Major problems posed for conservation are that in contrast to land-use change, climate change is hard to revert on a short timescale but also difficult to detect as it is often intermingled with the first. And, even more dangerous appears the current lack of proof for negative impact of climate change on bird species. This may sound paradox, but despite a large body of research on the topic and numerous projections of future biodiversity loss, ultimately for no bird species, anthropogenic climate change has been unambiguously proven as the major driver of its extinction. Instead, the new appearances of many species outside of their previous ranges seem to overstress the positive effects of climate change. Also, the high uncertainty of future projections complicates climate change adaptation (see, e.g., Bagchi et al. 2013). Such projections are not only weakened by the inherent uncertainties of climate and land-use change predictions but also by the unpredictable responses of species.

In different parts of their ranges, species can react differently to changes, as shown by Stephens et al. (2016). Species can additionally be in disequilibrium with their climatic niche (DeVictor et al. 2008), or they might have a considerably broader fundamental niche than expected by their current realized climatic niche and not react to changes at all. Also, it remains unknown to which extent species will be able to adapt to non-analogue conditions (of climate, land use, community structure). Most of those issues are subject to both spatial and temporal scale effects.

Thus, conservation policy might be hampered by disequilibrium among the proposed long-term and the observed short-term impacts of climate change.

How can conservation policy react to this, and which measures have to be taken in order to help species and biodiversity adapt to climate change?

Importantly, uncertainty has to be communicated. Although this is quite unpopular with stakeholders and policy-makers, there is no one-solution-for-all situation.

Whereas politics currently still focuses on climate change mitigation, this should not counteract conservation and the necessary adaptation measures that have to be taken. Climate change is a fact and cannot be stopped immediately. However, it is currently happening and already showing impacts which have to be dealt with.

The inherent uncertainty and regional and temporal disparity of climate change has to be included into management concepts. Not only concepts for single species or on small spatial scales have to be developed, but rather concerted action plans are needed. It has already been shown that, not only in protected areas, adaptive landscape management can mitigate climate change effects (Princé et al. 2015).

Furthermore, conservation policy has to focus on international scales. Not only national breeding grounds but also breeding grounds in Europe, stopover sites, and also wintering areas have to be considered, especially for long-distance migrants (Sanderson et al. 2015).

In all regards, management necessarily has to be flexible so that it can be adapted to changed conditions. It should be combined with a comprehensive network of protected areas that can be used as habitat corridors in order to warranty connectivity of bird populations (Trautmann et al. 2013). Nevertheless, connectivity is only valuable, if it does not come at the cost of losing high-quality areas (Hodgson et al. 2009). Furthermore, it has been shown that habitat mosaics and diversity have positive effects on the resilience of communities to climatic change (Jarzyna et al. 2015).

One of the major threats is related to the mismatch among today's protected areas and the future ranges of species for which they were designed. Protected areas are designated and managed for species and might become less effective, if species shift ranges due to climate change (Coetzee et al. 2009). But how can adaptive management work in a changing world? And how can the success of a protected area network like Natura 2000 in Europe be assessed when species which triggered the designation of a protected area disappear due to climate rather than land-use change?

Those questions are currently pending an answer. However, protected areas seem to mitigate climate change impacts both at species and community level (Gaüzere et al. 2016).

Managing areas proactively might be one solution, at least if the new occurrence of a species of high conservation concern and/or climatic risk can be predicted with high certainty. Helping colonizing species to find new habitats can be a task for which existing protected areas could be used (Thomas et al. 2012). Also, as projections show that new refugia outside the protected area network might arise (Coetzee et al. 2009), new areas could be managed for prospective species, and protected area networks could be expanded.

This can also take place in current protected areas but then has to be well-balanced with attempts to maintain populations of diminishing species.

For some species, both approaches might be valuable in different parts throughout their ranges and might thus give them enough time and space to adapt to climate change. For this task, protected area networks give us a well-suited toolset yet remain to be extended and often still lack sufficient management planning (or at least information about it, as shown for individual countries, but also indicated by Gamero et al. 2017 for Europe). Also, it seems clear that protected areas cannot act as the only tool for climate change adaptation but have to be embedded in an enriched landscape matrix which has to provide stepping-stones for whole communities rather than only for single species.

References

Ahola MP, Laaksonen T, Eeva T, Lehikoinen E (2007) Climate change can alter competitive relationships between resident and migratory birds. J Anim Ecol 76:1045–1052

Araújo MB, Thuiller W, Yoccoz NG (2009) Reopening the climate envelope reveals macroscale associations with climate in European birds. Proc Natl Acad Sci USA 106:E45–E46

Bagchi R, Crosby M, Huntley B, Hole DG, Butchart SH, Collingham Y, Kalra M, Rajkumar J, Rahmani A, Pandey M, Gurung H, Trai LT, Van Quang N, Willis SG (2013) Evaluating the effectiveness of conservation site networks under climate change: accounting for uncertainty. Glob Chang Biol 19:1236–1248

Barbet-Massin M, Walther BA, Thuiller W, Rahbek C, Jiguet F (2009) Potential impacts of climate change on the winter distribution of Afro-Palaearctic migrant passerines. Biol Lett 5 (2):248–251. https://doi.org/10.1098/rsbl.2008.0715

Barbet-Massin M, Thuiller W, Jiguet F (2012) The fate of European breeding birds under climate, land-use and dispersal scenarios. Glob Chang Biol 18:881–890

Barnosky AD, Matzke N, Tomiya S, Wogan GO, Swartz B, Quental TB, Marshall C, McGuire JL, Lindsey EL, Maguire KC, Mersey B, Ferrer EA (2011) Has the Earth's sixth mass extinction already arrived? Nature 471:51–57

Bateman BL, Pidgeon AM, Radeloff VC, Van Der Wal J, Thogmartin WE, Vavrus SJ, Heglund PJ (2016) The pace of past climate change vs. potential bird distributions and land use in the United States. Glob Chang Biol 22:1130–1144

Beale CM, Lennon JJ, Gimona A (2008) Opening the climate envelope reveals no macroscale associations with climate in European birds. Proc Natl Acad Sci USA 105:14908–14912

Beale CM, Lennon JJ, Gimona A (2009) European bird distributions still show few climate associations. Proc Natl Acad Sci USA 106:E41–E43

Becker N, Jöst H, Ziegler U, Eiden M, Höper D, Emmerich P, Fichet-Calvet E, Ehichioya DU, Czajka C, Gabriel M, Hoffmann B, Beer M, Tenner-Racz K, Racz P, Günther S, Wink M, Bosch S, Konrad A, Pfeffer M, Groschup MH, Schmidt-Chanasit J (2012) Epizootic emergence of Usutu virus in wild and captive birds in Germany. PLoS One 7:e32604

Boit A, Sakschewski B, Boysen L, Cano-Crespo A, Clement J, Garcia-Alaniz N, Kok K, Kolb M, Langerwisch F, Rammig A, Sachse R, van Eupen M, von Bloh W, Zemp DC, Thonicke K (2016) Large-scale impact of climate change vs. land-use change on future biome shifts in Latin America. Glob Chang Biol 22:3689–3701

Both C, Visser ME (2001) Adjustment to climate change is constrained by arrival date in a long-distance migrant bird. Nature 411:296–298

Both C, Artemyev AV, Blaauw B, Cowie RJ, Dekhuijzen AJ, Eeva T, Enemar A, Gustafsson L, Ivankina EV, Järvinen A, Metcalfe NB, Nyholm NEI, Potti J, Ravussin P-A, Sanz JJ, Silverin B, Slater FM, Sokolov LV, Török J, Winkel W, Wright J, Zang H, Visser ME (2004) Large-scale geographical variation confirms that climate change causes birds to lay earlier. Proc R Soc Lond B 271:1657–1662

Both C, Van Turnhout CAM, Bijlsma RG, Siepel H, Van Strien AJ, Foppen RPB (2010) Avian population consequences of climate change are most severe for long-distance migrants in seasonal habitats. Proc R Soc Lond B 277(1685):1259–1266. https://doi.org/10.1098/rspb.2009.1525

Bradshaw WE, Holzapfel CM (2006) Evolutionary response to rapid climate change. Science 312:1477–1478

Casado MR, Mead A, Burgess PJ, Howard DC, Butler SJ (2014) Predicting the impacts of bioenergy production on farmland birds. Sci Total Environ 476:7–19

Clavero M, Villero D, Brotons L (2011) Climate change or land use dynamics: do we know what climate change indicators indicate? PLoS One 6:e18581. https://doi.org/10.1371/journal.pone.0018581

Coetzee BW, Robertson MP, Erasmus BF, Van Rensburg BJ, Thuiller W (2009) Ensemble models predict important bird areas in southern Africa will become less effective for conserving endemic birds under climate change. Glob Ecol Biogeogr 18:701–710

Danielsen F, Beukema H, Burgess ND, Parish F, Brühl CA, Donald PF, Murdiyarso D, Phalan B, Reijnders L, Struebig M, Fitzherbert EB (2009) Biofuel plantations on forested lands: double jeopardy for biodiversity and climate. Conserv Biol 23:348–358. https://doi.org/10.1111/j.1523-1739.2008.01096.x

Davey CM, Chamberlain DE, Newson SE, Noble DG, Johnston A (2012) Rise of the generalists: evidence for climate driven homogenization in avian communities. Glob Ecol Biogeogr 21:568–578

Devictor V, Julliard R, Couvet D, Jiguet F (2008) Birds are tracking climate warming, but not fast enough. Proc R Soc Lond B 275:2743–2748

Doswald N, Willis SG, Collingham YC, Pain DJ, Green RE, Huntley B (2009) Potential impacts of climatic change on the breeding and non-breeding ranges and migration distance of European *Sylvia* warblers. J Biogeogr 36:1194–1208

Eglington S, Pearce-Higgins JW (2012) Disentangling the relative importance of changes in climate and land use intensity in driving recent bird population trends. PLoS One 7:e30407

Flade M (2012) Von der Energiewende zum Biodiversitäts-Desaster–zur Lage des Vogelschutzes in Deutschland. Vogelwelt 133:149–158

Gamero A, Brotons L, Brunner A, Foppen R, Fornasari L, Gregory RD, Herrando S, Horak D, Jiguet F, Kmecl P, Lehikoinen A, Lindström A, Paquet J-Y, Reif J, Sirkiä PM, Skorpilova J, van Strien A, Szep T, Telensky T, Teufelbauer N, Trautmann S, van Turnhout CAM, Vermouzek Z, Vikström T, Vorisek P (2017) Tracking progress toward EU biodiversity strategy targets: EU policy effects in preserving its common farmland birds. Conserv Lett 10:395–402

Gaüzere P, Jiguet F, Devictor V (2016) Can protected areas mitigate the impacts of climate change on bird's species and communities? Divers Distrib 22:625–637

Gibson-Reinemer DK, Rahel FJ (2015) Inconsistent range shifts within species highlight idiosyncratic responses to climate warming. PLoS One 10:e0132103

Gienapp P, Leimu R, Merilä J (2007) Responses to climate change in avian migration time—microevolution versus phenotypic plasticity. Clim Res 35:25–35

Gillings S, Balmer DE, Fuller RJ (2015) Directionality of recent bird distribution shifts and climate change in Great Britain. Glob Chang Biol 21:2155–2168

Gomez C, Tenorio EA, Montoya P, Cadena CD (2016) Niche-tracking migrants and niche-switching residents: evolution of climatic niches in New World warblers (Parulidae). Proc R Soc Lond B 283:20152458

Gregory RD, Willis SG, Jiguet F, Vorisek P, Klvanova A, van Strien A, Huntley B, Collingham YC, Couvet D, Green RE (2009) An indicator of the impact of climatic change on European bird populations. PLoS One 4:e4678. https://doi.org/10.1371/journal.pone.0004678

H-Acevedo D, Currie DJ (2003) Does climate determine broad-scale patterns of species richness? A test of the causal link by natural experiment. Glob Ecol Biogeogr 12:461–473

Hitch AT, Leberg PL (2007) Breeding distributions of North American bird species moving north as a result of climate change. Conserv Biol 21:534–539

Hodgson JA, Thomas CD, Wintle BA, Moilanen A (2009) Climate change, connectivity and conservation decision making: back to basics. J Appl Ecol 46:964–969

Hole DG, Willis SG, Pain DJ, Fishpool LD, Butchart SMH, Collingham YC, Rahbek C, Huntley B (2009) Projected impacts of climate change on a continent wide protected area network. Ecol Lett 12:1–12

Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson CA (eds) (2001) Climate change 2001: the scientific basis. Cambridge University Press, Cambridge

Huang Q, Sauer JR, Dubayah RO (2017) Multidirectional abundance shifts among North American birds and the relative influence of multifaceted climate factors. Glob Chang Biol 23:3610–3622

Hughes L (2003) Climate change and Australia: trends, projections and impacts. Austral Ecology 28:423–443. https://doi.org/10.1046/j.1442-9993.2003.01300.x

Huntley B, Green RE, Collingham YC, Willis SG (2007) A climatic atlas of European breeding birds. Lynx Edicions, Barcelona

Huntley B, Collingham YC, Willis SG, Green RE (2008) Potential impacts of climatic change on European breeding birds. PLoS One 3:e1439

Hüppop O, Winkel W (2006) Climate change and timing of spring migration in the long-distance migrant *Ficedula hypoleuca* in central Europe: the role of spatially different temperature changes along migration routes. J Ornithol 147:344–353

Immerzeel DJ, Verweij PITA, Hilst FLOOR, Faaij AP (2014) Biodiversity impacts of bioenergy crop production: a state-of-the-art review. Glob Change Biol Bioenergy 6:183–209

IPCC (2013) Summary for policymakers. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) Climate change 2013: the physical science basis—contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge

Jarzyna MA, Porter WF, Maurer BA, Zuckerberg B, Finley AO (2015) Landscape fragmentation affects responses of avian communities to climate change. Glob Chang Biol 21(8):2942–2953. https://doi.org/10.1111/gcb.12885

Jetz W, Wilcove DS, Dobson AP (2007) Projected impacts of climate and land use change on the global diversity of birds. PLoS Biol 5:e157

Jiguet F, Gadot AS, Julliard R, Newson SE, Couvet D (2007) Climate envelope, life history traits and the resilience of birds facing global change. Glob Chang Biol 13:1672–1684

Jiguet F, Devictor V, Ottvall R, Van Turnhout C, Van der Jeugd H, Lindström A (2010) Bird population trends are linearly affected by climate change along species thermal ranges. Proc R Soc Lond B 277:3601–3608

Jiguet F, Barbet-Massin M, Devictor V, Jonzé N, Lindström A (2013) Current population trends mirror forecasted changes in climatic suitability for Swedish breeding birds. Bird Study 60:60–66

Jones T, Cresswell W (2010) The phenology mismatch hypothesis: are declines of migrant birds linked to uneven global climate change? J Anim Ecol 79:98–108

Kampichler C, van Turnhout CAM, Devictor V, van der Jeugd HP (2012) Large-scale changes in community composition: determining land use and climate change signals. PLoS One 7:e35272. https://doi.org/10.1371/journal.pone.0035272

Karell P, Ahola K, Karstinen T, Valkama J, Brommer JE (2011) Climate change drives microevolution in a wild bird. Nat Commun 2:208

Koch PL, Barnosky AD (2006) Late quaternary extinctions: state of the debate. Annu Rev Ecol Evol Syst 37:215–250

La Sorte FA, Thompson FR III (2007) Poleward shifts in winter ranges of North American birds. Ecology 88:1803–1812

Langham GM, Schuetz JG, Distler T, Soykan CU, Wilsey C (2015) Conservation status of North American birds in the face of future climate change. PLoS One 10:e0135350. https://doi.org/10.1371/journal.pone.0135350

Lavergne S, Evans MEK, Burfield IJ, Jiguet F, Thuiller W (2013) Are species' responses to global change predicted by past niche evolution? Philos Trans R Soc B 368:20120091

Lehikoinen A, Virkkala R (2016) North by north-west: climate change and directions of density shifts in birds. Glob Chang Biol 22:1121–1129

Lehikoinen E, Sparks TH, Zalakevicius M (2004) Arrival and departure dates. Birds and climate change. In: Møller AP, Fiedler W, Berthold P (eds) Advances in ecological research, vol 35. Elsevier Academic, London, pp 1–32

Lehikoinen A, Jaatinen K, Vähätalo AV, Clausen P, Crowe O, Deceuninck B, Hearn R, Holt CA, Hornman M, Keller V, Nilsson L, Tomankova I, Wahl J, Fox AD (2013) Rapid climate driven shifts in wintering distributions of three common waterbird species. Glob Chang Biol 19:2071–2081

Lemoine N, Schaefer H-C, Böhning-Gaese K (2007) Species richness of migratory birds is influenced by global climate change. Glob Ecol Biogeogr 16:55–64

Lenoir J, Svenning J-C (2014) Climate-related range shifts – a global multidimensional synthesis and new research directions. Ecography 37:1–14

Lindbladh M, Hedwall P-O, Wallin I, Felton AM, Böhlenius H,Felton A (2014) Short-rotation bioenergy stands as an alternative to spruce plantations: implications for bird biodiversity. Silva Fennica 48:1135. p. 18

Longrich NR, Tokaryk T, Field DJ (2011) Mass extinction of birds at the Cretaceous–Paleogene (K–Pg) boundary. Proc Natl Acad Sci USA 108:15253–15257

Maclean IMD, Austin GE, Rehfisch MM, Blew J, Crowe O, Delany S, Devos K, Deceuninck B, Günther K, Laursen K, van Roomen M, Wahl J (2008) Climate change causes rapid changes in the distribution and abundance of birds in winter. Glob Chang Biol 14:2489–2500

Mantyka-Pringle CS, Visconti P, Di Marco M, Martin TG, Rondinini C, Rhodes JR (2015) Climate change modifies risk of global biodiversity loss due to land-cover change. Biol Conserv 187:103–111

Massimino D, Johnston A, Pearce-Higgins JW (2015) The geographical range of British birds expands during 15 years of warming. Bird Study 62:523–534

McQuillan MA, Rice AM (2015) Differential effects of climate and species interactions on range limits at a hybrid zone: potential direct and indirect impacts of climate change. Ecol Evol 5:5120–5137

Møller AP, Rubolini D, Lehikoinen E (2008) Populations of migratory bird species that did not show a phenological response to climate change are declining. Proc Natl Acad Sci USA 105:16195–16200

Møller AP, Flensted-Jensen E, Klarborg K, Mardal W, Nielsen JT (2010) Climate change affects the duration of the reproductive season in birds. J Anim Ecol 79:777–784

Ohlemüller R, Anderson BJ, Araújo MB, Butchart SH, Kudrna O, Ridgely RS, Thomas CD (2008) The coincidence of climatic and species rarity: high risk to small-range species from climate change. Biol Lett 4:568–572

Oliver TH, Morecroft MD (2014) Interactions between climate change and land use change on biodiversity: attribution problems, risks, and opportunities. Wiley Interdiscip Rev Clim Chang 5:317–335

Pacifici M, Foden WB, Visconti P, Watson JEM, Butchart SHM, Kovacs KM, Scheffers BR, Hole DG, Martin TG, Akçakaya HR, Corlett RT, Huntley B, Bickford D, Carr JA, Hoffmann AA, Midgley GF, Pearce-Kelly P, Pearson RG, Williams SE, Willis SG, Young B, Rondinini C (2015) Assessing species vulnerability to climate change. Nat Clim Chang 5:215–224. https://doi.org/10.1038/NCLIMATE2448

Päckert M, Martens J, Sun Y-H, Severinghaus LL, Nazarenko AA, Ting J, Töpfer T, Tietze DT (2012) Horizontal and elevational phylogeographic patterns of Himalayan and Southeast Asian forest passerines (Aves: Passeriformes). J Biogeogr 39:556–573

Parmesan C (2006) Ecological and evolutionary responses to recent climate change. Annu Rev Ecol Evol Syst 37:637–669

Parmesan C, Yohe G (2003) A coherent fingerprint of climate change impacts across natural systems. Nature 421:37–42

Pearman PB, D'Amen M, Graham CH, Thuiller W, Zimmermann NE (2010) Within-taxon niche structure: niche conservatism, divergence and predicted effects of climate change. Ecography 33:990–1003

Peterson AT, Holt RD (2003) Niche differentiation in Mexican birds: using point occurrences to detect ecological innovation. Ecol Lett 6:774–782

Peterson AT, Barve N, Bini LM, Diniz-Filho JA, Jiménez-Valverde A, Lira-Noriega A, Lobo J, Maher S, de Marco P Jr, Martínez-Meyer E, Nakazawa Y, Soberón J (2009) The climate envelope may not be empty. Proc Natl Acad Sci USA 106:E47

Plummer KE, Siriwardena GM, Conway GJ, Risely K, Toms MP (2015) Is supplementary feeding in gardens a driver of evolutionary change in a migratory bird species? Glob Chang Biol 21 (12):4353–4363. https://doi.org/10.1111/gcb.13070

Potvin DA, Välimäki K, Lehikoinen A (2016) Differences in shifts of wintering and breeding ranges lead to changing migration distances in European birds. J Avian Biol 47:1–10

Princé K, Zuckerberg B (2015) Climate change in our backyards: the reshuffling of North America's winter bird communities. Glob Chang Biol 21:572–585

Princé K, Lorrillière R, Barbet-Massin M, Léger F, Jiguet F (2015) Forecasting the effects of land use scenarios on farmland birds reveal a potential mitigation of climate change impacts. PLoS One 10:e0117850. https://doi.org/10.1371/journal.pone.0117850

Quintero I, Wiens JJ (2013) Rates of projected climate change dramatically exceed past rates of climatic niche evolution among vertebrate species. Ecol Lett 16:1095–1103

Reif J, Šťastný K, Bejček V (2010) Contrasting effects of climatic and habitat changes on birds with northern range limits in central Europe as revealed by an analysis of breeding bird distribution in the Czech Republic. Acta Ornithoica 45:83–90

Renwick AR, Massimino D, Newson SE, Chamberlain DE, Pearce-Higgins JW, Johnston A (2012) Modelling changes in species' abundance in response to projected climate change. Divers Distrib 18:121–132

Sala OE, Chapin FS, Armesto JJ, Berlow E, Bloomfield J, Dirzo R, Huber-Sanwald E, Huenneke LF, Jackson RB, Kinzig A, Leemans R, Lodge DM, Mooney HA, Oesterheld M, Poff NL, Sykes MT, Walker BH, Walker M, Wall DH (2000) Global biodiversity scenarios for the year 2100. Science 287:1770–1774

Salewski V, Hochachka WM, Fiedler W (2010) Global warming and Bergmann's rule: do central European passerines adjust their body size to rising temperatures? Oecologia 162:247–260

Sanderson FJ, Pople RG, Ieronymidou C, Burfield IJ, Gregory RD, Willis SG, Howard C, Stephens PA, Beresford AE, Donald PF (2015) Assessing the performance of EU nature legislation in protecting target bird species in an era of climate change. Conserv Lett 9:172–180

Sauerbrei R, Ekschmitt K, Wolters V, Gottschalk TK (2014) Increased energy maize production reduces farmland bird diversity. Glob Change Biol Bioenergy 6:265–274

Schaefer HC, Jetz W, Böhning-Gaese K (2008) Impact of climate change on migratory birds: community reassembly versus adaptation. Glob Ecol Biogeogr 17:38–49

Şekercioğlu ÇH, Primack RB, Wormworth J (2012) The effects of climate change on tropical birds. Biol Conserv 148:1–18

Smallegange IM, Fiedler W, Köppen U, Geiter O, Bairlein F (2010) Tits on the move: exploring the impact of environmental change on blue tit and great tit migration distance. J Anim Ecol 79:350–357

Stephens PA, Mason LR, Green RE, Gregory RD, Sauer JR, Alison J, Aunins A, Brotons L, Butchart SHM, Campedelli T, Chodkiewicz T, Chylarecki P, Crowe O, Elts J, Escandell V, Foppen RPB, Heldbjerg H, Herrando S, Husby M, Jiguet F, Lehikoinen A, Lindstrom A, Noble DG, Paquet J, Reif J, Sattler T, Szep T, Teufelbauer N, Trautmann S, van Strien AJ, van Turnhout CAM, Vorisek P, Willis SG (2016) Consistent response of bird populations to climate change on two continents. Science 352:84–87

Szabo JK, Khwaja N, Garnett ST, Butchart SHM (2012) Global patterns and drivers of avian extinctions at the species and subspecies level. PLoS One 7:e47080

Taheri S, Naimi B, Araújo MB (2016) Did British breeding birds move north in the late 20th century? Clim Chang Res 3:5

Tayleur C, Caplat P, Massimino D, Johnston A, Jonzén N, Smith HG, Lindström A (2015) Swedish birds are tracking temperature but not rainfall: evidence from a decade of abundance changes. Glob Ecol Biogeogr 24:859–872

Tayleur CM, Devictor V, Gaüzere P, Jonzen N, Smith HG, Lindström A (2016) Regional variation in climate change winners and losers highlights the rapid loss of cold-dwelling species. Divers Distrib 22:468–480

Tellería JL, Fernández-López J, Fandos G (2016) Effect of climate change on Mediterranean winter ranges of two migratory passerines. PLoS One 11:e0146958

Thomas CD, Lennon JJ (1999) Birds extend their ranges northwards. Nature 399:213

Thomas CD, Gillingham PK, Bradbury RB, Roy DB, Anderson BJ, Baxter JM, Bourn NAD, Crick HQP, Findon RA, Fox R, Hodgson JA, Holt AR, Morecroft MD, O'Hanlon NJ, Oliver TH, Pearce-Higgins JW, Procter DA, Thomas JA, Walker KJ, Walmsley CA, Wilson RJ, Hill JK (2012) Protected areas facilitate species' range expansions. Proc Natl Acad Sci USA 109:14063–14068

Tingley MW, Koo MS, Moritz C, Rush AC, Beissinger SR (2012) The push and pull of climate change causes heterogeneous shifts in avian elevational ranges. Glob Chang Biol 18:3279–3290

Trautmann S, Laube I, Schwager M, Böhning-Gaese K (2013) Sind Vögel vom Klimawandel gefährdet? Modellierung des Einflusses des Klimawandels auf Vögel. In: Vohland K, Badeck F, Böhning-Gaese K, Ellwanger G, Hanspach J, Ibisch PL, Klotz S, Kreft S, Kühn I, Schröder E, Trautmann S, Cramer W (Hrsg) Schutzgebiete Deutschlands im Klimawandel – Risiken und Handlungsoptionen. Naturschutz und Biologische Vielfalt 127, pp 25–31

Urban MC, Tewksbury JJ, Sheldon KS (2012) On a collision course: competition and dispersal differences create no-analogue communities and cause extinctions during climate change. Proc R Soc Lond B 279:2072–2080

Van De Pol M, Ens BJ, Heg D, Brouwer L, Krol J, Maier M, Exo K-M, Oosterbeek K, Lok T, Eising CM, Koffijberg K (2010) Do changes in the frequency, magnitude and timing of extreme climatic events threaten the population viability of coastal birds? J Appl Ecol 47:720–730

Virkkala R, Luoto M, Heikkinen RK, Leikola N (2005) Distribution patterns of boreal marshland birds: modelling the relationships to land cover and climate. J Biogeogr 32:1957–1970

Visser ME, Perdeck AC, Balen V, Johan H, Both C (2009) Climate change leads to decreasing bird migration distances. Glob Chang Biol 15:1859–1865

Walther G-R, Post E, Convey P, Menzel A, Parmesan C, Beebee TJC, Fromentin J-M, Hoegh-Guldberg O, Bairlein F (2002) Ecological responses to recent climate change. Nature 416:389–395

Warren R, VanDerWal J, Price J, Welbergen JA, Atkinson I, Ramirez-Villegas J, Osborne TJ, Jarvis A, Shoo LP, Williams SE, Lowe J (2013) Quantifying the benefit of early climate change mitigation in avoiding biodiversity loss. Nat Clim Chang 3:678–682

Weir JT, Schluter D (2004) Ice sheets promote speciation in boreal birds. Proc R Soc Lond B 271:1881–1887

Weissenböck H, Kolodziejek J, Fragner K, Kuhn R, Pfeffer M, Nowotny N (2003) Usutu virus activity in Austria, 2001–2002. Microbes Infect 5:1132–1136

Wiens JJ (2016) Climate-related local extinctions are already widespread among plant and animal species. PLoS Biol 14:e2001104

Winkler DW, Dunn PO, McCulloch CE (2002) Predicting the effects of climate change on avian life-history traits. Proc Natl Acad Sci USA 99:13595–13599

Wittwer T, O'Hara RB, Caplat P, Hickler T, Smith HG (2015) Long-term population dynamics of a migrant bird suggests interaction of climate change and competition with resident species. Oikos 124:1151–1159