

Climate change affects populations of northern birds in boreal protected areas

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Human land-use effects on species populations are minimized in protected areas and population changes can thus be more directly linked with changes in climate. In this study, bird population changes in 96 protected areas in Finland were compared using quantitative bird census data, between two time slices, 1981–1999 and 2000–2009, with the mean time span being 14 years. Bird species were categorized by distribution pattern and migratory strategy. Our results showed that northern bird species had declined by 21 per cent and southern species increased by 29 per cent in boreal protected areas during the study period, alongside a clear rise (0.7–0.8°C) in mean temperatures. Distribution pattern was the main factor, with migratory strategy interacting in explaining population changes in boreal birds. Migration strategy interacted with distribution pattern so that, among northern birds, densities of both migratory and resident species declined, whereas among southern birds they both increased. The observed decline of northern species and increase in southern species are in line with the predictions of range shifts of these species groups under a warming climate, and suggest that the population dynamics of birds are already changing in natural boreal habitats in association with changing climate.

Keywords: birds; boreal; climate change; decrease; protected areas

1. INTRODUCTION

Species ranges are expected to move latitudinally polewards because of climate change towards higher temperatures [1]. Consequently, communities and species in northern boreal and arctic regions may face particular risk from climate change [2]. In a comprehensive climate envelope modelling study, the mean range centroid of 431 bird species was predicted to move 258–882 km northwards by 2070–2099 in Europe [3]. The protected area (PA) network is a basic means of adaptation to climate change, because many species are already threatened by intensive human land use, causing habitat loss. However,

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changes in local species populations may be inevitable also in PAs, on account of the severity of the projected climate change, though little is yet known of these trends.

This paper examines bird population changes in a boreal PA network in northern Europe. We compare population densities in PAs as assessed through large-scale quantitative censuses in Finland in 1981–1999 and in 2000–2009. We investigate whether population changes of possibly receding northern and extending southern species are already observable in PAs, which provide the benefit that the environment has changed less than in unprotected areas elsewhere. Migratory strategy may be an important life-history characteristic for adaptation to climate change [4]. To assess whether such differences are visible in northern birds, we also studied population changes of different migratory groups.

2. MATERIAL AND METHODS

(a) Protected areas

The total area of PAs ($n = 96$) in Finland (60–70° N, 21–31° E) in which bird counts were carried out was 22 493 km², with the PAs studied ranging in size from 3 to 2524 km² (mean = 234.3 km², median = 51.6 km²). Six areas were smaller than 10 km² and six larger than 1000 km². Twenty-four PAs were studied in the southern half of Finland (total size: 910 km²) and 72 in the northern half (total size: 21 583 km²). Most of the protected land area is in northern Finland [5]. Forests cover 56 per cent of the land area in the reserves studied, the rest being open mires and mountain areas. Two-thirds of protected forest stands are over 100 years old.

(b) Bird censuses

Land birds in PAs were counted by using the Finnish line transect census method, which is suitable for counting birds over large areas [5,6]. The line transect method is a one-visit census in which birds are counted during the breeding season (June) along a transect with an average length of 5–6 km (see electronic supplementary material).

The total length of line transect censuses in the PAs was 6587 km in 1981–1999 and 5087 km in 2000–2009. Birds were counted in 96 areas, in which the total length of transects was at least 10 km in both periods. The median number of census years/PA was three in 1981–1999 and two in 2000–2009. Exactly, the same transects were not repeated but censuses in each PA included the same proportion of habitats in both periods. The median census year was 1992 in the first and 2006 in the second period, so the average time span in the study was 14 years.

(c) Analyses

Bird species were categorized by distribution and migratory patterns. Distribution pattern (southern or northern) was classified in terms of distribution and regional density variation in Finland ([6]; see electronic supplementary material). Species without any northward or southward pattern in their regional density were deemed a separate class ('whole country'). Migratory pattern was classified according to Väisänen *et al.* [6]: residents and partial migrants, short-distance migrants and long-distance migrants (see electronic supplementary material). Short-distance migrants include species wintering in central and southern Europe and in the Mediterranean region. Long-distance migrants include species wintering in Africa south of the Sahara or in southern Asia. We took into account in the analysis all species observed in at least two-thirds of PAs in both periods (in 64 out of 96 areas, 37 species). This was essential because parametric statistical analyses were adopted, and the other, less common species were non-normally distributed in PAs owing to a high proportion of zero classes. However, bird pairs in the studied species consisted of vast majority of the bird communities, 88 per cent of all bird pairs in PAs.

Densities of species groups between the two time periods were first compared according to distribution pattern by paired *t*-tests. Next, in a combined analysis, distribution pattern and migratory strategy were compared by repeated-measures analysis of variance (ANOVA). Time (periods) represents here a quantitative, repeated factor, the effects of which can be examined by within-subject

Table 1. Results of within-subject contrasts of repeated measures analysis of variance (ANOVA). Factor levels (within-subject): density in 1981–1999 and 2000–2009; between-subjects factors: distribution pattern, migratory strategy; covariates: species, protected areas. m.s. = mean square, d.f. = degrees of freedom and * = denotes interaction between factor levels and different between-subjects factors.

source	d.f.	m.s.	<i>F</i>	<i>p</i>
factor	1	0.002	0.000	0.984
factor * species	1	32.523	7.138	0.008
factor * protected areas	1	20.926	4.593	0.032
factor * distribution	2	141.581	31.072	<0.001
factor * migratory strategy	2	5.841	1.282	0.278
factor * distribution * migratory strategy	3	45.147	9.908	<0.001
error (factor)	3542	4.556		

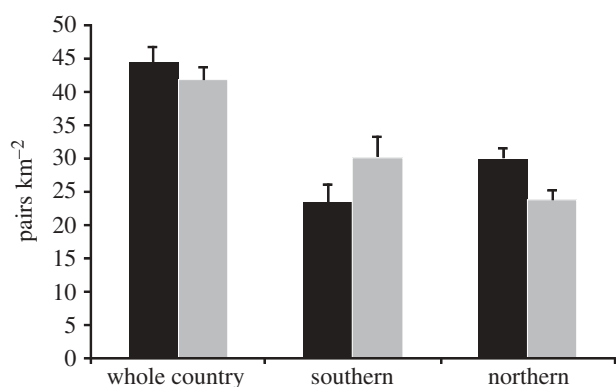


Figure 1. Mean densities (pairs km⁻²) with s.e. in the different bird species groups according to distribution patterns in 1981–1999 (black columns) and in 2000–2009 (grey columns) in the PAs.

contrasts (e.g. [7]). Distribution pattern and migratory strategy were regarded as between-subjects factors and individual species and PAs as covariates in the analysis.

(d) *Climate change*

The mean temperatures of the coldest month (February) and April–June essential for the breeding of bird species [2,8] were compared from Finnish Meteorological Institute data. The mean temperature of the coldest month rose by 0.8°C (1981–1999: -9.46°C; 2000–2009: -8.66°C) and that for April–June by 0.7°C in Finland (1981–1999: 6.71°C; 2000–2009: 7.43°C).

3. RESULTS

The periods showed no statistically significant differences in the densities of species distributed over the whole country ($t = 1.413$, $p = 0.161$, d.f. = 95; figure 1). However, the density of southern species had increased significantly by 29 per cent ($t = 5.205$, $p < 0.001$) and that of northern species decreased by 21 per cent ($t = 5.939$, $p < 0.001$). In the repeated-measures ANOVA, there was a significant difference in the densities of different distribution pattern groups between the time periods but not in the densities of different migratory groups (table 1). However, the interaction between these two factors was significant, showing that density changes in migratory groups vary in relation to distribution patterns (table 1 and figure 2). Among northern species, birds in all the three migratory strategy classes declined, whereas among southern species both short-distance migrants

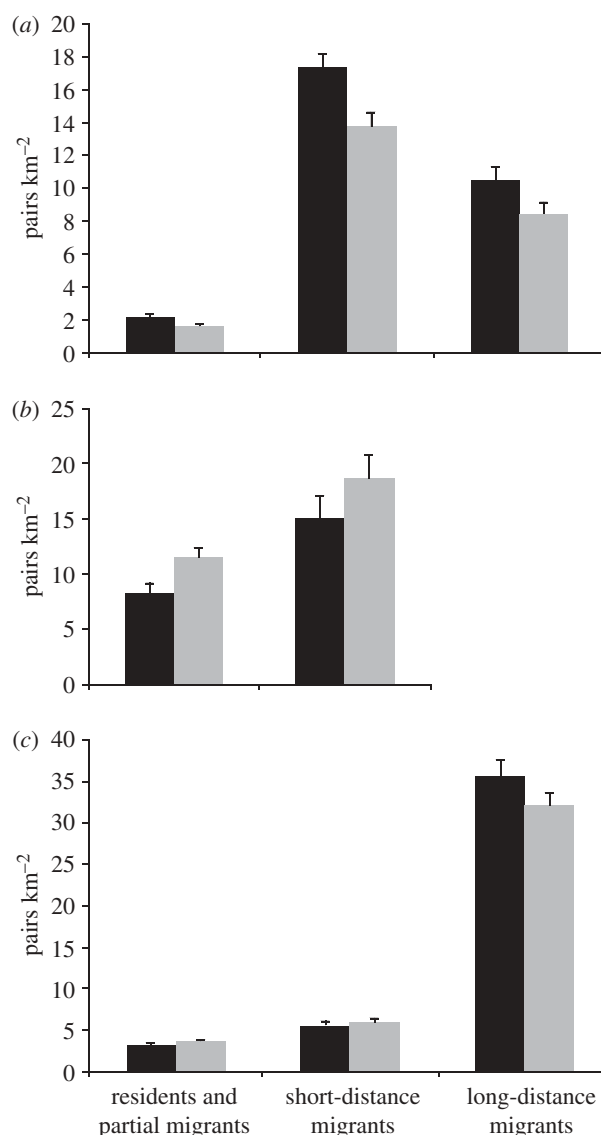


Figure 2. Mean densities with s.e. of the different migratory groups in each distribution pattern class in 1981–1999 (black columns) and in 2000–2009 (grey columns) in the PAs. (a) Northern species, (b) southern species and (c) species distributed in the whole country.

and residents increased (no species of southern long-distance migrant in the analysis, figure 2). Among species distributed in the whole country, long-distance migrants decreased, residents slightly increased whereas

the density of short-distance migrants did not change from 1981–1999 to 2000–2009.

4. DISCUSSION

Population changes of birds can be explained by direct habitat- or climate-induced changes in breeding or wintering grounds. We compared bird populations in PAs, which had remained largely the same in habitat structure during the study. Most PAs in our study were also fairly large and, therefore, not highly susceptible to the effects of the surrounding managed areas. This means that human-caused direct habitat changes (clear-cutting and other logging procedures, drainage of mires, etc.) on the breeding grounds cannot explain the changes observed in the populations of the bird species studied. For example, Virkkala [9] observed earlier that bird species that increased and those that decreased in northern Finland owing to habitat alteration, such as logging and increased forest fragmentation, showed no such trends in large protected virgin forests, either from the 1940–1950s to the 1980s or during the 1980s.

Väisänen [10] studied population changes of the 86 most common land-bird species in Finland in 1983–2005 using yearly repeated censuses mostly in unprotected areas. Thirty-six species included in the present work were studied also by Väisänen [10]. Eighteen species of these show similar population changes (increase, decrease or no change) in protected and in unprotected areas, but in 18 species, population changes differ between the two studies. It seems that patterns of population changes differ for many species in protected versus unprotected areas, most probably owing to habitat changes in unprotected areas. However, more detailed species-specific analyses with proper time series are needed to separate the different factors affecting population trends.

Northern species declined clearly in PAs between 1981–1999 and 2000–2009, with an average annual decline in density of about 1.8 per cent. In an earlier study, Virkkala *et al.* [2] showed, based on atlas data, that northern bird species may be expected to lose 74–84% of their present-day range up to 2051–2080 in Finland and in adjoining areas. Our results are in line with these predictions; i.e. this study shows that the population decline of northern species owing to climate change is already evident. Furthermore, Gregory *et al.* [11] showed that there is a relationship between observed bird population trends and predicted species range extent in Europe in the 21st century, such that species predicted to lose range had declined already in 1980–2005.

Jiguet *et al.* [12,13] have noticed that those species with the lowest thermal maxima (the mean spring and summer temperature of the hottest part of the distribution in Europe) showed the sharpest decline both on the scale of France in 1989–2005 and on that of Europe in 1980–2005. Jiguet *et al.* [13] estimated a yearly decrease of 0.5–0.7% in annual population growth rate for each 1°C decrease in the upper limit of the climate niche. Their study thus shows that species occurring in the coolest climate have declined the most.

In general, long-distance migrants have declined, which can partly also be explained by events in wintering areas in Africa and Asia and in migration stop-over sites (e.g. [14]). On the other hand, residents and partial migrants benefit from the warming climate because their winter mortality decreases in the cold boreal climate [15,16]. However, according to our study, distribution pattern is the main factor with migratory strategy interacting in explaining population changes in boreal birds in PAs. Overall, the decline in northern bird species calls for further attention for conservation and management.

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