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The range margins of northern birds shift polewards

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The changes in range margins of birds breeding in Finland was analysed from published atlas data for a 12-year period (1974–1979 to 1986–1989). The change in range margin was statistically corrected for changes in species' distribution using linear regression. For species predominantly occurring in southern Finland (n = 116), the expected range margin shift, if their distribution would not have changed, was 18.8 km northwards. Northerly species (n = 34) showed no such significant range margin shift. A similar result was found earlier for UK birds. Recent range margin shifts in birds therefore seem to be a general phenomenon, which may be related to climate change.

Introduction

Plants and animals show ecological responses consistent with an effect of climate change (Walther *et al*. 2002, Parmesan & Yohe 2003). Such 'fingerprints' of climate change include advancement in a species' phenology (e.g. Beebee 1995, Crick *et al*. 1997, Roy & Sparks 2000, Fitter & Fitter 2002) and poleward shifts of range margins (Parmesan *et al*. 1999, Thomas & Lennon 1999). Clearly, proving a causal link between climate change and, for example, changes in a species' geographical distribution is not straightforward (Parmesan & Yohe 2003, but *see* Thomas *et al*. 2001).

One approach to strengthen conclusions on the consequences of climate change for the ecology of species is to quasi-replicate (i.e. use the same methods to study a phenomenon, Palmer 2000). Ideally, studies across different environments and in different time periods are conducted. In this paper, I follow the same approach that Thomas and Lennon (1999) used to document a polewards shift in the range margins of southerly birds in Great Britain. I compare the changes in range margins of breeding birds for a 12-year period covered by two Finnish bird atlases.

Material and methods

Material

I quantified the change in distribution and the shift of range margins in Finnish birds from two atlases of breeding birds (1974–1979, Hyytiä *et al*. (1983); 1986–1989, Väisänen *et al*. (1998)). These atlases use a grid based on 3813 10×10-km^2 grid cells. For most species, it is noted for each grid cell whether that species bred in the cell or not. Surveys are based on intensive mapping of volunteer ornithologists (*see* Väisänen *et al*. 1998 for more details on the methods).

The latitude of grid cells with breeding birds is mapped in these atlases using the Finnish uniform grid which gives the latitude in kilometres north from the equator. I considered species that breed inland and for which the breeding was recorded in 10 × 10-km^2 grid cells with a minimum occurrence of at least twenty grid cells in both atlases. Species were categorised as southerly (weighted centre grid cell (WCG) as given in Hyytiä *et al*. (1983) below 7000) or northerly (WCG ≥ 7200). These restrictions avoid including species that occur over the entire country and for which a range shift therefore cannot be detected at the scale of Finland. In addition, six species (*Calidris alpine, Calidris temminckii, Charadrius hiaticula, Clangula hyemalis, Melanitta fusca* and *Tringa totanus*) had a disjunct distribution (breeding both in Lapland and along the south coast, but not in central Finland) and were discarded from the analyses, because their distribution does not allow the detection of range margin shifts.

Analysis

I followed the same approach as Thomas and Lennon (1999). I calculated the latitude of the species' range margin as the median of the location of the ten most marginal 10 × 10-km^2 grid cells (i.e. northern-most cells for southerly species and vice versa for northerly species). The change in range margin was calculated as the difference between the range margin in 1986–1989 and the range margin in 1974–1979. Hence, positive values indicate a shift to the north and negative values a shift to the south (in kilometres). In order to analyse the significance of a shift in a species' range margin, one has to correct for changes in distribution because an expanding species will tend to colonise more marginal grid cells, away from its distributional core. Vice versa, the range margins of species whose distribution is shrinking will contract towards the distributional core. Distribution changes were calculated as the $\log_{10}$ of the proportion of the number of 10 × 10-km^2 grid cells of 1986–1989 over the number of grid cells occupied in 1974–1979. Hence, no change in distribution has value 0 (proportional change = 1), positive values indicate an expansion and negative values a distributional contraction. For both periods, the distributions were taken from Väisänen *et al*. (1998) as there were some small errors in the distributions given in Hyytiä *et al*. (1983) (R. A. Väisänen pers. comm.). The change in the number of occupied 10 × 10-km^2 grid cells correlated with changes in species' abundance as based on line-transect counts (Väisänen *et al*. 1998). The overall expected change in range margin if there would be no change in distribution was calculated as the intercept of a regression of the changes in the species' range margins on the changes in their distributions (Thomas & Lennon 1999). Northerly and southerly species were analysed separately. Because the monitoring intensity of especially raptors and threatened species was increased during the 12-year study period (Väisänen 1998), I analysed the data also without these species.

Results

There were 116 southerly species and 34 northerly species that corresponded to the above criteria (Appendix). The changes in range margins varied markedly in the 12-year period studied. Range margin changes varied from 205 km southwards to 250 km northwards in southerly bird species and 225 km southwards and 135 km northwards in northerly species (Fig. 1 and Appendix). The expected change in range margins if there would be no change in overall distribution, was 18.8 km polewards for southerly species (Fig 1a; intercept: 18.8 ± 6.1, $t = 3.1$, $P = 0.002$; change in distribution: 29.8 ± 4.3, $t = 7.0$, $P < 0.001$). Correcting for changes in the overall distribution, northerly species did not experience a significant shift in their range margins (Fig. 1b; intercept: –16.9 ± 14.8 km, $t = –1.1$, $P = 0.26$; change in distribution: –26.3 ± 9.7, $t = – 2.7$, $P = 0.01$). These results qualitatively did not change when raptors and threatened species (*see* Appendix) were omitted from the analyses (northerly species ($n = 97$): intercept 27.0 ± 6.6, $t = 4.1$, $P < 0.001$; southerly species ($n = 30$): intercept –13.8 ± 15.8, $t = –0.9$, $P = 0.4$).

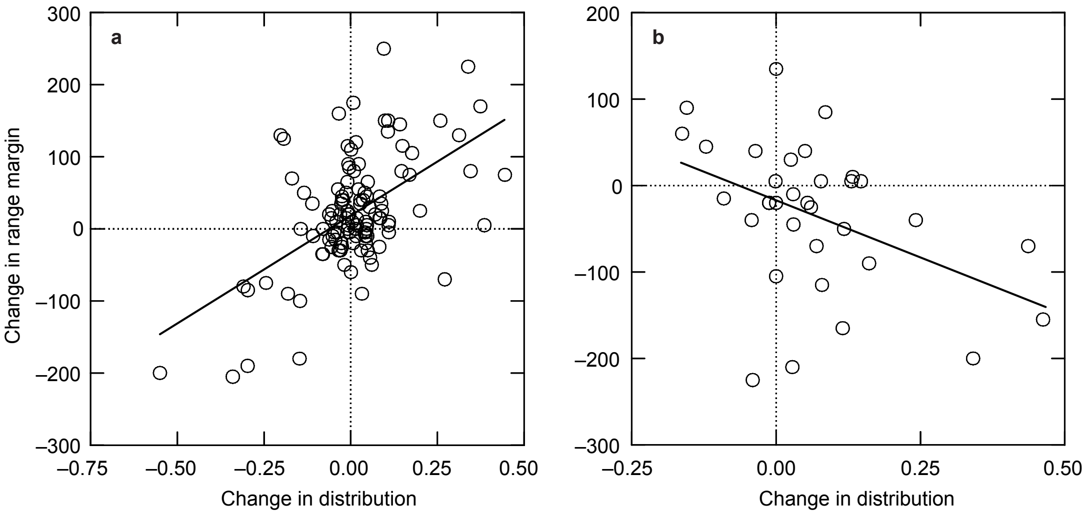

Fig. 1. The change in the latitude of range margins (in km) plotted against the change in distributions for (**a**) 116 southerly species (regression $F_{1, 114} = 48.9$, $P < 0.001$, $R^2 = 29.4\%$) and (**b**) 34 northerly species (regression $F_{1,32} = 7.4$, $P = 0.01$, $R^2 = 16.3\%$). The expected change in range margin if a species would not change in overall distribution is given by the intercept of the regression line. *See* text for the coefficients of the drawn regression lines and their significance.

Discussion

Thomas and Lennon (1999) used atlas data to show that southerly UK bird species shifted their range margins polewards. Their approach takes into account that range margins will change if a species' overall distribution changes. Thomas and Lennon (1999) showed an expected range margin shift (i.e. the expected change in range margin if there would be no change in distribution) of 18.9 km to the north in a twenty-year period (1968–1972 to 1988–1991). I here show that also the range margins of southerly Finnish birds, after correcting for changes in distribution, shift polewards about the same distance (18.8 km) in about half the time (twelve years). Northerly species had no shifts in their range margins after correcting for changes in distribution, neither in the United Kingdom (Thomas & Lennon 1999) nor in this study. In general, for northern hemisphere species, southerly range margins of species are less responsive to climate change than the northerly margins (Parmesan 1996, Parmesan *et al*. 1999).

The results presented here are consistent with the putative effects of climate change. The period studied here coincides with the period of the earth's most rapid climate warming in the last 10 000 years which started in 1976 (McCarthy *et al*. 2001). Climate warming induces a poleward shift of isotherms (in Europe ca. 120 km in the last century) and organisms are expected to follow this change (Parmesan *et al*. 1999, McCarthy *et al*. 2001). In birds, an advance in the timing of breeding (Crick *et al*. 1997) and migration (Both & Visser 2001, Hüppop & Hüppop 2003) and a reduction in breeding success (Visser *et al*. 1998) are all associated with recent climate change. The Fennoscandian rate of climate change (in terms of temperature and precipitation) is not more severe than the climate change in the United Kingdom (McCarthy *et al*. 2001). Nevertheless, the almost double rate in the expected range margin shift of Finnish birds compared to UK birds may indicate that northern, high-latitude species are more sensitive to changes in temperature than central European species, but additional evidence is needed to verify this finding.

Although the polewards shift of the range margins described here are consistent with climate warming, they may be due to other factors. For example, recent change in landscape use is known to have affected the distribution of species within the assemblage of Finnish bird species studied here (analysed in Väisänen *et al*. 1998). In principle, such changes in the landscape could also have an effect on range margins, even after correcting for changes in the distribution as was done here. However, factors such as landscape change will have species-specific effects, whereas climate change predicts a general shift polewards across all species. Because different species assemblages are found in different regions, it becomes increasingly unlikely that range margins would shift in different regions in the same direction due to other causes than climate warming (Parmesan & Yohe 2003). The assemblage of southerly bird species used in this study differs somewhat from southerly UK species considered by Thomas and Lennon (1999). For example, *Mergus merganser* is considered a northerly species by Thomas and Lennon (1999), but is a southerly species in Finland. Data sets used to study the potential ecological effects of climate change are typically very heterogenous in methodology and spatial and temporal scale (e.g. Walther *et al*. 2002, Parmesan & Yohe 2003). Hence, quasi-replication (Palmer 2000) of studies based on nationwide atlas data across different environments and time periods has a large potential for addressing the ecological consequences of global warming in a standardised way.

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Appendix. List, classification, IUCN threat status in Finland, change in the latitude of range margins and change in distribution of the species used. The Latin name of species is given and the names of raptors are underlined. Species are classified as either northerly (n) or southerly (s) species, as based on the coordinate of the weighted centre 10 × 10-km^2 grid cell (in Hyytiä *et al.* 1983). Status is the IUCN status in Finland (S = in need of monitoring, V = vulnerable, E = endangered, from Väisänen *et al.* 1998). The change in range margin is the difference in the median latitude of the 10 most marginal grid cells between the two study periods (1974–1979 to 1986–1989). Change in distribution is the $\log_{10}$ of the proportional change in the number of occupied 10 × 10-km^2 grid cells between the two study periods as given in Väisänen *et al.* (1998).

Species	Classification	Status	Change in	
			range margin	distribution
<u>*Accipiter gentilis*</u>	s		–40	0.06
<u>*Accipiter nisus*</u>	s		5	0.11
Acrocephalus arundinaceus	s		85	0.00
Acrocephalus dumetorum	s		105	0.18
Acrocephalus palustris	s		130	0.31
Acrocephalus schoenobaenus	s		0	0.01
Acrocephalus scirpaceus	s		45	0.05
Aegithalos caudatus	s	S	–190	–0.30
Aegolius funereus	s		150	0.11
Alauda arvensis	s		–10	–0.11
Anas clypeata	s		–5	0.04
Anas platyrhynchos	s		–5	0.00
Anas querquedula	s		15	–0.06
Anas strepera	s		170	0.37
Anser fabalis	n		5	0.00
Anthus cervinus	n		90	–0.15
Apus apus	s		–5	–0.05
Ardea cinerea	s		115	0.15
Asio otus	s		–50	0.06
Aythya ferina	s		10	–0.04
Bombycilla garrulus	n		–90	0.16
Bonasa bonasia	s		20	–0.06
Botaurus stellaris	s		125	–0.19
Bubo bubo	s		–70	0.27
<u>*Buteo buteo*</u>	s		20	–0.01
<u>*Buteo lagopus*</u>	n		–165	0.12
Calcarius lapponicus	n		135	0.00
Caprimulgus europaeus	s	S	–180	–0.15
Carduelis cannabina	s		–90	–0.18
Carduelis carduelis	s		–80	–0.31
Carduelis chloris	s		250	0.10
Carduelis flammea	n		–20	–0.01
Carduelis spinus	s		40	0.03
Carpodacus erythrinus	s		–30	0.03
Certhia familiaris	s		45	–0.03
Charadrius dubius	s		115	–0.01
Charadrius morinellus	n		10	0.13
Chlidonias niger	s		–200	–0.55
Cinclus cinclus	n	S	–50	0.12
<u>*Circus aeruginosus*</u>	s		25	0.09
Coccothraustes coccothraustes	s		225	0.34
Columba livia	s		10	0.00
Columba oenas	s		35	–0.03
Columba palumbus	s		175	0.01
Corvus frugilegus	s		5	0.39

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Appendix. Continued.

Species	Classification	Status	Change in	
			range margin	distribution
Corvus monedula	s		50	–0.01
Crex crex	s	V	20	0.07
Cygnus cygnus	n		–200	0.34
Dendrocopos leucotos	s	E	–75	–0.24
Dendrocopos major	s		65	0.05
Dendrocopos minor	s	S	–30	–0.04
Dryocopus martius	s		–10	0.05
Emberiza citrinella	s		0	–0.01
Emberiza hortulana	s		–35	–0.08
Emberiza pusilla	n		–155	0.46
Erithacus rubecula	s		90	–0.01
<u>*Falco columbarius*</u>	n	S	5	0.08
<u>*Falco subbuteo*</u>	s	S	35	0.03
<u>*Falco tinnunculus*</u>	s	S	–15	–0.04
Ficedula parva	s	S	50	0.04
Fringilla coelebs	s		15	–0.01
Fringilla montifringilla	n		–20	–0.01
Fulica atra	s		35	–0.11
Gallinula chloropus	s		–85	–0.30
Garrulus glandarius	s		80	0.01
Glaucidium passerinum	s		–90	0.03
Hippolais icterina	s		75	0.17
Hirundo rustica	s		25	–0.01
Jynx torquilla	s		–25	–0.03
Lagopus lagopus	n		45	–0.12
Lagopus mutus	n		5	0.13
Lanius collurio	s		20	–0.03
Larus argentatus	s		–25	0.08
Larus canus	s		5	0.05
Larus fuscus	s	S	–30	–0.03
Larus minutus	s		150	0.26
Larus ridibundus	s		5	–0.01
Limicola falcinellus	n		60	–0.16
Locustella fluviatilis	s		25	0.20
Locustella naevia	s		80	0.15
Loxia curvirostra	s		10	0.04
Loxia leucopterus	n		–70	0.44
Lullula arborea	s	V	–205	–0.34
Luscinia luscinia	s		15	0.08
Luscinia svecica	n		85	0.09
Lymnocryptes minimus	n		–225	–0.04
Melanitta nigra	n	S	–70	0.07
Mergus merganser	s		10	0.11
Mergus serrator	s		–10	0.04
Milvus migrans	s		–25	–0.06
Nucifraga caryocatactes	s		80	0.35
Numenius arquata	s		20	0.00
Numenius phaeopus	n		30	0.03
Oriolus oriolus	s		–10	–0.05
<u>*Pandion haliaetus*</u>	s	S	–5	0.04
Parus ater	s		0	0.02
Parus caeruleus	s		145	0.14

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Appendix. Continued.

Species	Classification	Status	Change in	
			range margin	distribution
Parus cinctus	n		–115	0.08
Parus cristatus	s		–50	–0.02
Parus major	s		5	0.02
Parus montanus	s		15	0.02
Passer domesticus	s		65	–0.01
Passer montanus	s		75	0.44
Perdix perdix	s	S	50	–0.14
Perisoreus infaustus	n		–10	0.03
Pernis apivorus	s		–30	0.05
Phalaropus lobatus	n		–40	–0.04
Phasianus colchicus	s		150	0.10
Philomachus pugnax	n		–15	–0.09
Phylloscopus borealis	n		5	0.15
Phylloscopus collybita	s		160	–0.03
Phylloscopus sibilatrix	s		135	0.11
Phylloscopus trochiloides	s		0	–0.14
Pica pica	s		–10	0.02
Picus canus	s	S	40	0.04
Pinicola enucleator	n		40	–0.04
Plectrophenax nivalis	n		–45	0.03
Pluvialis apricaria	n		–20	0.05
Podiceps auritus	s		–20	–0.03
Podiceps cristatus	s		90	0.02
Podiceps grisegena	s		–20	0.04
Porzana porzana	s		15	0.08
Prunella modularis	s		0	0.05
Pyrrhula pyrrhula	s		120	0.02
Rallus aquaticus	s		130	–0.20
Regulus regulus	s		25	–0.05
Saxicola rubetra	s		40	–0.02
Scolopax rusticola	s		55	0.02
Stercorarius longicaudus	n		40	0.05
Sterna hirundo	s		110	0.00
Streptopelia decaocto	s		–5	–0.04
Streptopelia turtur	s		70	–0.17
Strix aluco	s		–35	–0.08
Strix nebulosa	n		–25	0.06
Strix uralensis	s		–5	0.11
Sturnus vulgaris	s		–100	–0.15
Surnia ulula	n		–40	0.24
Sylvia atricapilla	s		45	0.08
Sylvia borin	s		–20	0.01
Sylvia communis	s		–60	0.00
Sylvia curruca	s		40	–0.03
Sylvia nisoria	s		–30	–0.03
Tringa erythropus	n		–210	0.03
Tringa nebularia	n		–20	0.00
Tringa ochropus	s		30	0.05
Troglodytes troglodytes	s		55	–0.04
Turdus merula	s		0	–0.08
Turdus torquatus	n		–105	0.00
Turdus viscivorus	s		35	0.09
Vanellus vanellus	s		–15	–0.06