CLIMATE CHANGE AND BRITAIN'S BIRDLIFE:

WHAT MIGHT WE EXPECT?

Could the Short-toed Eagle start colonising Britain's lowland heaths? Emanuele Biggi/FLPA

Malcolm Ausden, Richard Bradbury, Andy Brown, Mark Eaton, Leigh Lock and James Pearce-Higgins

The authors discuss how Britain's birdlife might change in the next few decades, concentrating on which birds we might gain, or risk losing, as regular breeding species. They then use this, together with other information on the predicted impacts of climate change on birds and their habitats, to explore the implications of changes in climate for our approach to bird conservation in Britain.

For the sake of this article, we shall assume that our overall aim for bird conservation is: 'to ensure that Britain is able to support self-sustaining, non-threatened populations of the fullest range of naturally occurring bird species for which it is climatically suitable now and in the next few decades'. Within this overarching aim, we also need to place a particular priority on birds for which Britain is especially important in a global context: mainly wintering waterbirds, breeding seabirds, and several other species such as Curlew *Numenius arquata* and Scottish Crossbill *Loxia scotica*.

Achievement of our aim requires that we reduce non-climate-related pressures on birds, including those in areas where they are considered to be at risk of climate-driven decline or extinction. This is with the purpose of slowing their rate of decline, or stabilising their population and, importantly, enabling them to produce sufficient offspring to colonise new areas. It also requires that we facilitate the range expansion of species which are otherwise likely to be severely limited by lack of suitable habitat or other constraints. Taking account of the predicted impacts of climate change in this way is commonly referred to as 'climate-change adaptation'.

Potential impacts of climate change and implications for conservation

Current projections (UK Climate Projections: UKCP09) are for Britain's climate to become warmer all year round, with slightly higher rainfall in winter and slightly lower rainfall in summer. Increases in temperature and summer drying are expected to be greatest in south-east England. An increase in the frequency and magnitude of intense rainfall events throughout the year is also expected. There has already been an increase in the frequency of extreme temperature and rainfall events in the Northern Hemisphere since the early 1980s (Hansen *et al*. 2012). In addition, sea levels are expected to continue to rise, and at a faster rate than in the last century.

Box 1 Methods used to assess which birds we might lose and gain as regular breeding species in Britain

Our assessments are based mainly on the results of climate-envelope modelling by Huntley *et al*. (2007), which assume a 3˚C rise in global temperatures above those of pre-industrial times, together with information on observed changes in species' populations/distributions since the early 1990s. During this period, birds in Europe have, in general, shown population trends consistent with the levels of warming that have already taken place (see main text). Our approach follows that outlined by Thomas *et al*. (2011). Current projections suggest that, with current emission trajectories, we should probably expect a 3˚C rise in global temperatures to take place at some time during this century.

Climate-envelope modelling

This involves building a mathematical model which relates a species' current/recent distribution to climate variables. This model is then used to describe the species' potential future distribution given the ways in which climate is predicted to change, assuming that the relationship between its current/recent distribution and climate remains the same. It is important to note that, although the range of many species is well described by climate, the range of some species is poorly predicted if they are absent from areas which are climatically suitable for them because of, for example, human land-use or persecution. The extent to which a species is likely to occupy fully its potential future distribution will vary with dispersal ability and the availability of suitable habitat. An additional uncertainty for migratory species is that the modelling referred to in this article does not take account of changes that might take place in species' wintering areas and on migration.

Species whose British breeding populations are at risk of extinction

Our list comprised all birds for which Huntley *et al*. (2007) show five or fewer *ca* 50 × 50km squares in Britain as having a suitable climate under the future 3˚C-rise scenario. We considered a species to be at high risk of extinction if Britain's future climate is expected to become very unsuitable for it and it has declined in Britain since 1990. It is important to note that the mere fact that a species has been declining during this period does not necessarily mean that this has been due to changes in climate. For completeness, we have also included two species for which Britain's climate is projected to remain very suitable by Huntley *et al*. (2007), but which have been declining very rapidly in Britain: Turtle Dove *Streptopelia turtur* (88% decline between 1995 and 2012) and Willow Tit *Poecile montanus* (83% decline between 1995 and 2012) (Harris *et al*. 2014).

Species which have the potential to establish (or re-establish) regular breeding populations in Britain

Our list comprised all birds:

- For which the results of climate-envelope modelling by Huntley *et al.* (2007) predict that Britain will have a suitable climate under the 3˚C-rise scenario.
- Whose breeding population has been increasing elsewhere in north-west Europe since the early 1990s, irrespective of the results of climate-envelope modelling.

We have assessed the likelihood of each species colonising Britain based on: its population change in its nearest breeding areas to Britain since the early 1990s; the predicted climatic suitability of Britain for the species; the distance of Britain from the species' nearest significant breeding populations; and whether colonisation of Britain might be limited by poor dispersal ability. We considered species to have a high likelihood of colonising Britain if their breeding population has been rapidly increasing on the near-Continent, irrespective of the results of climate-envelope modelling. For many of the species listed, it is important to note that recent increases have not necessarily been driven by changes in climate.

Breeding populations of Dotterel are assessed as being at high risk of extinction in Britain. Michael Callan/FLPA

On a European scale, the results of climate-envelope modelling (Box 1) suggest that, by the end of the 21st century, changes in climate are likely to result in the potential breeding distributions of birds shifting by an average of several hundred kilometres in a north-north-westerly to north-easterly direction (Huntley *et al*. 2008). Since the early 1990s, breeding birds in Europe have already, in general, shown population trends consistent with a warming climate (e.g. Green *et al*. 2008; Gregory *et al*. 2009). In north-west Europe, the winter distributions of a number of waterbirds have also exhibited north-eastward shifts associated with a trend towards milder winters (MacLean *et al*. 2008; Lehikoinen *et al*. 2013).

We next explore the likely impacts of changes in climate on the bird fauna of different habitats in Britain, and the implications of these. The methods

used to assess which bird species we might gain, or lose, as regular breeders in Britain are described in Box 1, together with the limitations of these methods. The results of these assessments are shown in Tables 1 (page 164) and 2 (page 166).

Upland habitats

The current birdlife of Britain's upland heaths, blanket bogs, high mountain tops and other upland habitats is dominated by species at the southern edge of their global breeding range. It is, therefore, unsurprising that breeding populations of several of these species are assessed as being at high risk of climate-related extinction in Britain (Table 1). The majority of other birds characteristic of Britain's uplands are considered also to be at high risk of climate-related decline (Pearce-Higgins *et al*. 2013). For some of these, we can identify mechanisms by which these impacts might occur. Most notably, a number of species, such as Golden Plover *Pluvialis apricaria*, appear sensitive to summer warming reducing the abundance of their main prey, crane-flies (Pearce-Higgins *et al*. 2010; Pearce-Higgins 2011a, 2011b). We do, however, need to be especially cautious in assessing how changes in climate may affect the uplands. This is because of great uncertainty over how changes in climate may affect snowfall and exposure, and how changes in these may influence conditions for wildlife (e.g. Scott 2009). It is also difficult to predict how changes in climate would affect grazing by wild and domestic animals, and other land management.

There is also a suite of bird species characteristic of mountains in southern Europe, but the results of climate-envelope modelling by Huntley *et al*. (2007) predict that the uplands of Britain are unlikely to become climatically suitable for any of these species during the next few decades. The climate in parts of lowland Britain, on the other hand, is predicted to become suitable for several birds that currently nest in caves and on crags in mountainous areas of southern Europe (Table 2). In the case of several other montane birds currently found in southern Europe (Alpine Accentor *Prunella collaris*, Wallcreeper *Tichodroma muraria*, Alpine Chough *Pyrrhocorax graculus* and Snowfinch *Montifringilla nivalis*), colonisation of Britain's uplands is unlikely owing to these species' poor capacity for long-distance dispersal.

As the climate continues to warm, several birds that already breed regularly in Britain might extend their breeding range to higher altitudes. Black Redstarts *Phoenicurus ochruros* could start to breed in areas of scree and on other rocky slopes, as they currently do in mountainous areas farther south in Europe. Dartford Warblers *Sylvia undata* might also expand their range northwards and upwards on heather-dominated moorlands, a trend which has already been taking place following the colonisation of these habitats by Stonechats *Saxicola torquata* (Bradbury *et al*. 2011; Henderson *et al*. 2014).

In Britain, breeding populations of many birds which are towards the southern limits of their global breeding range, such as Slavonian Grebe (below left) and Whimbrel (below right), might become extinct in the next few decades as the climate continues to warm. Richard Revels/Bill Coster/FLPA

Table 1 Assessment of birds whose British breeding populations might be at risk of extinction in the next few decades (see Box 1 for methods).

Climate projections = number of *ca* 50 × 50km squares simulated to be suitable for the species in Britain
– – – = none projected to be presently suitable.
– – = none projected to be suitable with a 3˚C rise in global temperatures.
– = only 1 to 5 projected to be suitable with a 3˚C rise in global temperatures.

Population trends in Britain since 1990 are derived from data from the Rare Breeding Birds Panel (RBBP: www.rbbp.org.uk) or from other monitoring programmes and periodic surveys as summarised in Hayhow *et al.* (2014); start dates vary slightly. Trends (from RBBP data) are between five-year means for 1988–92 and 2008–12. Trends are categorised: ~ = <10% increase or decline, + = 10–40% increase, + + = 40–70% increase, + + + = >70% increase, – = 10–40% decline, – – = 40–70% decline, – – – = >70% decline.

Species	Likelihood of extinction	Climate projections	Population trend in Britain since 1990
Upland habitats			
Purple Sandpiper *Calidris maritima*	High	– – –	– –
Whimbrel *Numenius phaeopus*	High	– –	– –
Snow Bunting *Plectrophenax nivalis*	High?	– –	?
Dotterel *Charadrius morinellus*	High	–	– –
Golden Eagle *Aquila chrysaetos*	Low	–	~
Ptarmigan *Lagopus muta*	Low?	–	?
Greenshank *Tringa nebularia*	Low?	–	?
Freshwater and coastal wetlands			
Common Scoter *Melanitta nigra*	High	– – –	– –
Slavonian Grebe *Podiceps auritus*	High	– –	– –
Ruff *Philomachus pugnax*	High	– –	–
Pintail *Anas acuta*	High	– –	–
Marsh Warbler *Acrocephalus palustris*	High	–	– –
Goldeneye *Bucephala clangula*	Medium	– –	+
Red-throated Diver *Gavia stellata*	Medium	– –	+
Whooper Swan *Cygnus cygnus*	Low	– – –	+ + +
Crane *Grus grus*	Low	– – –	+ + +
Green Sandpiper *Tringa ochropus* [a]	Low	– – –	+ + +
Wood Sandpiper *Tringa glareola*	Low	– – –	+ + +
Black-necked Grebe *Podiceps nigricollis* [b]	Low?	– – –	~
Red-necked Phalarope *Phalaropus lobatus*	Low	– –	+ +
Osprey *Pandion haliaetus*	Low	– –	+ + +
Bittern *Botaurus stellaris* [b]	Low	–	+ + +
Black-throated Diver *Gavia arctica*	Low	–	+
Wigeon *Anas penelope*	Low?	–	?
Lowland farmland, lowland heathland and other open, dry habitats			
Turtle Dove *Streptopelia turtur*	High		– – –
Woodland			
Fieldfare *Turdus pilaris*	High	– – –	– – –
Brambling *Fringilla montifringilla*	High	– – –	–
Parrot Crossbill *Loxia pytyopsittacus*	High?	– – –	?
Scottish Crossbill *Loxia scotica*	High?	– –	?
Capercaillie *Tetrao urogallus*	High	–	– –
Redwing *Turdus iliacus*	High	–	– –
Willow Tit *Poecile montanus*	High		– – –
Seabirds			
Arctic Skua *Stercorarius parasiticus*	High	– –	– – –
Leach's Storm-petrel *Oceanodroma leucorhoa*	High?	– –	?
Great Skua *Stercorarius skua*	Low	– –	+ +

Notes:
a Thought to have (re) commenced regular breeding in Britain in 1999, but may have regularly bred during the 1930s to 1950s.
b Current distribution in western Europe is very fragmented owing to lack of suitable habitat, meaning that the species' potential future distribution in this region is probably poorly simulated.

As the climate continues to warm, a key measure expected to benefit a range of upland birds is the re-wetting of degraded upland peatlands, as shown here at Dove Stone RSPB Reserve, in the Peak District. Re-wetting of peatlands also reduces the rate of loss of important soil carbon stocks and reduces discoloration of drinking water. Jon Bird

Nightjars *Caprimulgus europaeus* might also breed at higher elevations on Britain's uplands in a warmer climate, both on heather-dominated moorlands with scattered trees and in the early stages of regrowth in clear-felled areas of upland conifer plantations. A warmer climate may also increase the altitude at which trees are able to grow in Britain, although, in practice, in most areas of Britain the height to which trees grow is limited by grazing and burning, rather than by climate *per se*.

Given these expected changes, the best strategy if we are to achieve our overarching aim for bird conservation is to continue to reduce non-climate-related pressures on upland birds considered to be at risk of decline or extinction in Britain. Examples of measures expected to achieve this include restoration of degraded peatlands by blocking artificial drainage, revegetating areas of bare peat, and cessation of burning (Pearce-Higgins *et al*. 2010; Carroll *et al*. 2011; Pearce-Higgins 2011a); felling of conifer plantations planted on, or adjacent to, blanket bog (e.g. Wilson *et al*. 2014); and the prevention of illegal killing of birds of prey (Whitfield *et al*. 2008; Fielding *et al*. 2011). Notably, the first of these sets of measures also provides other important benefits, namely a reduction in loss of important soil carbon stocks and in the discoloration of drinking water (e.g. Wilson *et al*. 2011; Brown *et al*. 2014). As the climate continues to warm, we expect the ranges of many upland birds in Britain to become increasingly confined to areas of sympathetically managed habitat.

Freshwater and coastal wetlands

In contrast to Britain's upland birds, a large number of wetland birds were assessed as having the potential to establish (or re-establish) regular breeding populations in Britain in the next few decades (Table 2). It is important to note that the recent range expansion of many of these species has undoubtedly been due as much to recovery from past human-induced declines as to changes in climate (Ausden *et al*. 2014).

On the other hand, for a wide range of wetland birds Britain's climate is expected to become far less suitable in the next few decades. Many of these species, however, have been 'bucking the climate trend', and have actually increased in Britain since the early 1990s (Table 1). Increases of many of these species (Whooper Swan *Cygnus cygnus*, Goldeneye *Bucephala clangula*, Bittern *Botaurus stellaris*, Osprey *Pandion haliaetus* and Crane *Grus grus*) have been due largely to increased protection and/or other conservation measures. This suggests that, for at least some bird species, there is likely to be much that we can do to counteract the expected negative impacts of climate change.

Britain is expected to remain climatically capable of supporting large wintering populations of waterbirds for at least the next few decades, although the species composition at individual sites is expected to change significantly (Johnston *et al*. 2013). The total populations of many species breeding in the Arctic and Subarctic are likely to decline in the future, though, because of changes

Table 2 Assessment of birds which have the potential to establish (or re-establish) regular breeding populations in Britain in the next few decades (see Box 1 for methods).

(R) = known to have formerly bred in Britain. We have not included Spoonbill because this species is considered to have re-established regular breeding in Britain since 2010.

Climate projections = number of *ca* 50 × 50km squares predicted by Huntley *et al.* (2007) to be suitable for breeding with a 3°C rise in global temperatures above those of pre-industrial times. + = 1–5; ++ = 6–25; +++ = >25.

Information on population trends since 1990 in nearest breeding areas to Britain are mainly from www.sovon.nl/nl/content/vogelinfo; vigienature.mnhn.fr/page/resultants. Abbreviations used for population trends are as shown in Table 1.

Species	Likelihood of colonisation/ recolonisation	Climate projections	Population trend since 1990 in nearest breeding areas to Britain	Significant breeding populations in north half of France or the Netherlands?	Colonisation likely to be prevented/ limited by poor dispersal ability?
Freshwater and coastal wetlands					
Black Kite *Milvus migrans*	High	+ + +	+ + +	✓	
White-spotted Bluethroat *Luscinia svecica*	High	+ +	+ + +	✓	
Zitting Cisticola *Cisticola juncidis*	High	+ +	+ + +	✓ [a]	
Night-heron *Nycticorax nycticorax*	High	+ +	+ + +	✓	
Little Bittern *Ixobrychus minutus*	High	+ +	+ +?	✓	
Purple Heron *Ardea purpurea*	High	+	+ + +	✓	
Cattle Egret *Bubulcus ibis*	High		+ + +	✓	
Great Egret *Ardea alba*	High		+ + +	✓	
White Stork *Ciconia ciconia*	High		+ + +	✓	
Glossy Ibis *Plegadis falcinellus*	High		+ + +		
Black-winged Stilt *Himantopus himantopus*	High	+	+	✓	
Whiskered Tern *Chlidonias hybridus*	Medium	+	+ + +	✓	
Baillon's Crake *Porzana pusilla* (R)	Medium [b]	?	?	✓	
Great Reed Warbler *Acrocephalus arundinaceus*	Low	+ +	– –	✓	
Kentish Plover *Charadrius alexandrinus* (R)	Low	+ +	– –	✓	
Black Tern *Chlidonias niger* (R)	Low	+	~	✓	
Squacco Heron *Ardeola ralloides*	Low		+ + +		
Lowland farmland, lowland heathland and other open, dry habitats					
Short-toed Eagle *Circaetus gallicus* [c]	High	+ + +	+ + +		
Red-backed Shrike *Lanius collurio* (R)	High	+ + +	+ + +	✓	
Hoopoe *Upupa epops*	Medium	+ + +	~	✓	
Woodchat Shrike *Lanius senator*	Medium?	+ +	?		
Scops Owl *Otus scops*	Medium?	+ +	?		
Bee-eater *Merops apiaster*	Medium	+	~	✓	
Crested Lark *Galerida cristata*	Low	+ + +	– – –	✓	
Serin *Serinus serinus*	Low	+ + +	– – –	✓	
Little Bustard *Tetrax tetrax*	Low	+ +	– – –	✓	
Tawny Pipit *Anthus campestris*	Low	+ +	– – –		
Ortolan Bunting *Emberiza hortulana*	Low	+ +	– – –		
Rock Sparrow *Petronia petronia*	Low?	+ +	?		✓?
Great Grey Shrike *Lanius excubitor*	Low	+	– – –	✓	
Black-eared Wheatear *Oenanthe hispanica*	Low	+	?		
Rock Bunting *Emberiza cia*	Low?	+	?		✓?
Woodland and scrub					
Melodious Warbler *Hippolais polyglotta*	High	+ + +	+ + +	✓	
Short-toed Treecreeper *Certhia brachydactyla*	High	+ + +	+ (NL) / + + + (F)	✓	
Golden Oriole *Oriolus oriolus* (R)	Medium	+ + +	~	✓	

Western Bonelli's Warbler *Phylloscopus bonelli*	Medium [d]	+ + +	–	✓	
Subalpine Warbler *Sylvia cantillans*	Medium	+	+ + +		
Middle Spotted Woodpecker *Dendrocopos medius*	Low / medium	+ + +	+ + +	✓	✓
Wryneck *Jynx torquilla* **(R)**	Low / medium?	+ + +	?	✓	
Western Orphean Warbler *Sylvia hortensis*	Low	+	+ + +		
Sardinian Warbler *Sylvia melanocephala*	Low	+	+		
Black Woodpecker *Dryocopus martius*	Low	+ +	– (NL) / + + + (F)	✓	✓
Grey-headed Woodpecker *Picus canus*	Low?	+ +	?	✓	✓
Great Spotted Cuckoo *Clamator glandarius*	Low?	+	?		
Upland and lowland areas with cliffs					
Alpine Swift *Tachymarptis melba* [e]	Medium?	+ +	?		
Eagle Owl *Bubo bubo*	Low [f]	+	+ + +	✓	✓
Egyptian Vulture *Neophron percnopterus*	Low	+	–		
Crag Martin *Ptyonoprogne rupestris*	Low?	+	?		
Blue Rock Thrush *Monticola solitarius*	Low?	+	?		
Miscellaneous open habitats					
Red-rumped Swallow *Cecropis daurica*	Low [g]		?		

Notes:
a Although has recently been lost from many northern areas of its range following hard winters.
b Included as medium potential because influxes of Baillon's Crakes in NW Europe may occur more frequently in the future with more frequent drying-out of wetlands in Spain (Ausden *et al.* 2013).
c Found in open, dry habitats throughout much of its range, but also in wetlands towards its northern range limits in mainland Europe.
d Included as medium potential because, despite an overall decline in France between 1989 and 2012, there has been a 42% increase there between 2001 and 2012.
e Will nest also on buildings as well as on cliffs.
f Considered to have a low potential for natural colonisation, because of reluctance to disperse across the sea. There is currently, however, a small breeding population in Britain which is thought to be derived from escaped birds (Melling *et al.* 2008).
g Included because of a large increase in numbers recorded in Britain since the early 1990s (White & Kehoe 2014).

in climate on their breeding grounds. The recent population decline of Dark-bellied Brent Geese *Branta bernicla bernicla* has been associated with faltering lemming cycles in the Arctic, itself associated with reduced snow cover. Dark-bellied Brent Geese typically have high breeding productivity in years when lemming numbers are high, and in these years predators such as Arctic Foxes *Vulpes lagopus* feed mainly on lemmings instead of on eggs and chicks (Nolet *et al.* 2013).

The changes that we have so far described are based on the results of climate-envelope modelling but, importantly, do not take into account other significant climate-driven changes in the extent and quality of wetland habitat. Climate-driven rises in sea levels, and a possible increase in the frequency and severity of storms, are expected to reduce the extent of intertidal habitat through coastal squeeze. These changes are expected also to increase the risk of coastal flooding and eventual loss of many freshwater and non-tidal brackish wetlands (e.g. Ramsbottom *et al.* 2012). It is projected that, in the south-east of England, wetlands will dry out more quickly in summer owing to higher temperatures and reduced rainfall, which may be exacerbated by increased human demand for water in this region (e.g. Rance *et al.* 2012).

There is probably very little suitable habitat in Britain for many of the potential colonists and recolonising species shown in Table 2. In particular, we have very few large wetlands capable of supporting significant breeding colonies of herons, egrets and Glossy Ibises *Plegadis falcinellus*, few large areas of early successional freshwater wetlands suitable for breeding Black-winged Stilts *Himantopus himantopus* and Baillon's Crakes *Porzana pusilla*, and few complexes of shallow saline lagoons suitable for breeding Black-winged Stilts and feeding Spoonbills *Platalea leucorodia*. Measures aimed at providing suitable habitat for potential wetland bird colonists (and recolonisers) are described by Ausden *et al.* (2014). It is notable that most of the recent colonisations, or known or suspected one-off breeding events, by wetland birds in Britain (Great Egret *Ardea alba*, Little Bittern *Ixobrychus minutus*, Purple Heron *Ardea purpurea*,

Many of the wetland birds that appear likely to establish regular breeding populations in Britain in the next few decades are colonial-breeding herons, such as this Purple Heron, and their allies. We probably have insufficient habitat in Britain to support many significant-sized breeding colonies of most of these species, though. Do van Dijk, NiS/Minden Pictures/FLPA

Glossy Ibis, Baillon's Crake and Black-winged Stilt) have been at recently created wetlands.

Therefore, in order to achieve our overall aim for bird conservation in Britain, we need not only to continue looking after our existing wetlands but also to re-create more and larger areas of wetland habitat. This includes continuing to re-create freshwater and brackish wetlands to help to offset losses of these habitats due to increased coastal flooding, and re-creating intertidal habitat through managed realignment and regulated tidal exchange.

There is also the potential to adapt the management of wetlands to take account of climate-driven changes in water availability. The hydrology of most bird-rich lowland wetlands in Britain is already heavily modified by human activity. An important consideration is the extent to which this management focuses on *resisting* climate-driven changes in hydrology (for example, by reducing the impact of increased climate-related drying in summer by supplementing a site's water supply in spring and summer), or on *accommodating* (i.e. accepting) these climate-driven changes in hydrology (for example, by designing wetland habitat so that it provides suitable conditions for birds and other wildlife despite this increased rate of drying-out in summer). In south-east England, one of the potential solutions to projected reductions in water availability in summer, but increased rainfall in winter, is to store more winter water in newly constructed reservoirs. These could be used to irrigate farmland in summer and, if designed suitably, could provide valuable habitat for waterbirds. Our ability to manage many wetlands for birds in the future is, in many cases, already being hampered by more extreme periods of drought, and by the increasing frequency and severity of extreme rainfall events causing summer flooding of wetlands.

Lowland farmland, lowland heathland and other open, dry habitats

Changes in climate during the next few decades are expected to have a relatively small direct effect on most birds currently found on farmland in Britain (Pearce-Higgins *et al*. 2013), as there are very few farmland species for which Britain is towards the edge of their current climatic range. In recent decades, agricultural intensification has been far more important in explaining population trends of farmland birds than have changes in climate (Eglington & Pearce-Higgins 2012), and the management of farmland is likely to continue to be the driving force for many years to come. Specifically, changes in crop type and farming practice in response to changes in climate, food demand and economics are likely to be more important in affecting habitat suitability for farmland birds than are changes in climate *per se*. The only farmland bird assessed as being at risk of extinction in Britain is the Turtle Dove *Streptopelia turtur*, but its decline appears to be largely unrelated to changes in climate (Eglington & Pearce-Higgins 2012).

There is a large number of birds associated with farmland and other open, dry habitats for which Britain's climate is predicted to become suitable in the next few decades (Table 2). A striking difference compared with wetlands, however, is that many of these species have been declining towards their northern range limits in western Europe since the early 1990s, i.e. during the period when the climate in these areas is expected to have become

more suitable for them. These declining species are generally associated with High Nature Value Farmland (especially Little Bustard *Tetrax tetrax*, Tawny Pipit *Anthus campestris* and Ortolan Bunting *Emberiza hortulana*). It is notable that only one bird associated with farmland and other largely open, dry habitats, namely the Collared Dove *Streptopelia decaocto*, has successfully colonised Britain in modern times (and its range expansion has undoubtedly been fuelled largely by untidy grain stores and garden bird-feeding). Serins *Serinus serinus* started to breed occasionally in Britain in the late 1960s, but the numbers of this species recorded in Britain have subsequently fallen (White & Kehoe 2014), mirroring large declines in its breeding population on the near Continent.

To maintain reasonable populations and a reasonably wide geographical distribution of farmland birds in Britain will require a major expansion of targeted agri-environment-scheme measures. Even the small number of more southerly-distributed farmland species which, in Britain, are currently towards the edge of their breeding range (Stone-curlew *Burhinus oedicnemus*, Montagu's Harrier *Circus pygargus* and Cirl Bunting *Emberiza cirlus*) are still likely to remain dependent on bespoke conservation measures for the foreseeable future. Promotion of High Nature Value farming, and of suitable uncropped habitats within farmland, may help to provide suitable habitat for a variety of potential colonists, but the prospects for range expansion of most of these appear to be limited.

Britain's climate is expected to become more suitable for most birds characteristic of lowland heathlands in Britain (Nightjar, Dartford Warbler and Woodlark *Lullula arborea*: Pearce-Higgins *et al*. 2013). Short-toed Eagle *Circaetus gallicus* appears the most likely bird species to colonise Britain's lowland heaths. Numbers of Short-toed Eagles recorded in the Netherlands (which is just to the north of their current breeding range in western Europe) have increased markedly since the early 2000s, some individuals now remaining there for long periods in summer, and in 2014 a Short-toed Eagle was recorded summering in Britain for the first time. A warming climate might also increase the likelihood of recolonisation of Britain by Red-backed Shrikes *Lanius collurio*. Northward range expansion of the Nightjar, Dartford Warbler and Woodlark in Britain is likely to be severely limited by the lack of lowland heathland, although, as described earlier, the first two of these might expand their range into upland areas as the climate continues to warm. The most practical way to increase the area of lowland heathland farther north in Britain is to remove conifer plantations from afforested heathland (e.g. Ausden *et al*. 2010). Nightjars and Woodlarks should also benefit from sympathetic management of rides and other open areas within conifer plantations. Reducing the impact of grazing and burning on lower areas of upland heath should increase their structural diversity, and is therefore expected to make these areas more suitable for lowland-heathland birds.

In western Europe, many birds associated with farmland and other open, dry habitats, such as Little Bustard (shown here in courtship display), have declined towards their northern range margins, during a period when the climate in these areas is expected to have become more suitable for them. Sylvain Cordier/Biosphoto/FLPA

Despite this apparently rosy picture regarding the bird fauna of lowland heathland, there remain some important issues concerning the conservation of lowland heathland and its associated birdlife. First, the levels of human disturbance that occur on many areas of lowland heathland are sufficient to reduce the breeding success of most of the characteristic bird species of this habitat (Liley & Clarke 2003; Mallord *et al*. 2007; Murison *et al*. 2007; Langston

et al. 2007). Thus, managing public access on heathland, and reducing the recreational pressures from surrounding development, will continue to be necessary for maintaining existing populations of these species and, importantly, enabling them to produce sufficient offspring to colonise new areas. Secondly, in south-east England, it is predicted that higher temperatures and reduced rainfall will increase the risk of large, catastrophic wildfires. This increased risk could be mitigated by the creation and maintenance of more and wider firebreaks, which would also provide valuable habitat for a range of invertebrates, scarce plants and reptiles. Finally, the impacts of atmospheric-nitrogen deposition, which tends to encourage grasses at the expense of Heather *Calluna vulgaris*, might, in some situations, be exacerbated by changes in climate (e.g. Bjorsne *et al*. 2014). Removal of nutrients from lowland heathland by turf-stripping is likely to remain important (and perhaps become more so) in a warmer climate.

Woodland and scrub

Populations of several woodland birds with a more northerly breeding distribution in Britain, particularly those associated with native pinewood, are predicted to be at high risk of climate-driven extinction in Britain (Table 1). Again, we do need to be cautious about the predictions of climate-envelope modelling. For example, Scottish Crossbills feed on the cones of native Scots Pine *Pinus sylvestris* and a variety of widely planted non-native conifers (e.g. Summers *et al*. 2002). We do not know what limits the breeding range of Scottish Crossbills, and there may well continue to be suitable tree species present for them in Scotland for a long time.

In addition, the suite of migrant species characteristic of Western Atlantic oakwoods (Redstart *Phoenicurus phoenicurus*, Wood Warbler *Phylloscopus sibilatrix*, Pied Flycatcher *Ficedula hypoleuca* and Tree Pipit *Anthus trivialis*) is thought to be at high risk of climate-driven decline in Britain (Pearce-Higgins *et al*. 2013). As with other migrants, conditions on migration and in these species' wintering areas might be important in driving their current and future population trends. For some woodland birds, potential climate-driven mismatch between the timing of invertebrate-prey availability and peak food requirements might also provide a mechanism by which changes in population take place (Both *et al*. 2010), although the evidence for this remains equivocal (Pearce-Higgins & Green 2014).

In contrast, climatic conditions might become more suitable for several declining species of current high conservation priority in Britain (Lesser Spotted Woodpecker *Picoides minor*, Nightingale *Luscinia megarhynchos* and Golden Oriole *Oriolus oriolus*) (Pearce-Higgins *et al*. 2013). Climatic benefits for many woodland species might, however, be offset by further declines in the quality of many woodlands for birds caused by reductions in structural diversity resulting from, for example, high deer numbers. There is also a wide range of birds found in woodland and scrub which have the potential to establish regular breeding populations in Britain (Table 2). Of these, the woodpeckers and Short-toed Treecreeper *Certhia brachydactyla* are characteristic of more mature, closed-canopy woodland, while the remaining species are found in more open woodland and scrub. None of the woodpeckers listed in Table 2 (other than Wryneck *Jynx torquilla*) has been recorded in Britain, despite the fact that all breed close to the coast of northern France. This suggests that colonisation of Britain by these woodpeckers may be prevented by their apparent reluctance to cross the sea.

Adapting the management of woodlands to a changing climate is difficult because of the long timescales over which many changes in woodland-

Middle Spotted Woodpeckers are increasing in France and the Netherlands, and the climate in Britain is expected to become more suitable for them. But will the sea prove a barrier to their colonising Britain, and do enough of our woodlands contain sufficient dead wood to support this species?
Franz Christoph Robi/Imagebroker/FLPA

tree species composition and structure take place. In particular, trees will reach maturity in a quite different climate from that in which they established themselves. To maximise commercial timber production, especially, it would be best to plant trees with a provenance well suited to both the current climate and that expected to occur once the tree is mature (Broadmeadow *et al.* 2005). Probably the best strategy is to provide greater structural diversity within woodlands as a whole, helping to produce suitable conditions for a wide range of bird species under uncertain future climates (Fuller *et al.* 2007). A more diverse woodland structure and composition is likely to reduce the potential for mismatch between the timing of breeding and peaks in invertebrate-food abundance (Pearce-Higgins & Green 2014). A key way to encourage more diverse woodland species composition and structure is by managing deer populations to allow trees to regenerate, and to restore the understorey. In woodlands in south-east and eastern England, the blocking of artificial drainage should help to reduce the impacts of expected increased summer drying. It is also prudent to take measures to reduce the spread of tree diseases.

Seabirds

Many seabird populations in Britain are at great risk from changes in climate, but we have less confidence in projections of how their distribution and abundance might change. The climate-envelope models on which our assessments are based use only air temperature and precipitation. Even though these models have good predictive ability in describing recent population trends (Johnston *et al.* 2013), we still have only a limited understanding of how variation in sea surface temperatures and stratification affect seabirds' foraging and population size. We also have little knowledge of how other factors which are known to be highly significant in driving seabird populations (exploitation, persecution and pollution) interact with climate.

The majority of northerly-breeding seabirds in Britain, including those in Table 1 and other species which feed predominantly on Lesser Sandeels *Ammodytes marinus* (Arctic Skua *Stercorarius parasiticus*, Kittiwake *Rissa tridactyla*, Arctic Tern *Sterna paradisaea* and Puffin *Fratercula arctica*), are likely to be at high risk of climate-related decline in Britain (Pearce-Higgins *et al.* 2013).

Breeding populations of many of our seabirds, such as these Kittiwakes, are thought to be at great risk of decline in Britain due to climate change. Richard Revels

These projections are supported by a good understanding of the mechanisms that link warming to a cascade of impacts through the food chain, which in turn reduces sandeel abundance and quality and thereby ultimately affects seabird breeding success and survival (Frederiksen *et al.* 2006).

The results of climate-envelope modelling suggest that Britain's climate will become increasingly suitable for a range of more southerly-distributed seabirds – Little Tern *Sternula albifrons*, Sandwich Tern *Thalasseus sandvicensis*, Roseate Tern *Sterna dougallii*, Manx Shearwater *Puffinus puffinus* and European Storm-petrel *Hydrobates pelagicus* (Pearce-Higgins *et al.* 2013). There are also several seabirds that breed farther south in Europe which could conceivably breed in Britain in the future, such as Cory's Shearwater *Calonectris diomedea* (which has recently been found summering at a Manx Shearwater colony in Ireland) and maybe even Audouin's Gull *Larus audouinii*. The range expansion of all of these species is likely to be severely limited by lack of ground-predator-free nesting habitat.

Key measures expected to reduce non-climate-related pressures on seabirds are: action to minimalise the impacts of current sandeel fisheries on sandeel-eating seabird species (e.g. Frederiksen *et al.* 2004); eradication of rats from islands which are otherwise suitable for nesting storm-petrels, Manx Shearwaters, Puffins and terns; prevention of invasion by rats of currently important nesting islands for these species through biosecurity; and regulating of recreational disturbance and controlling of generalist predators in areas important for ground-nesting species, including

all of the terns. Some current nesting sites for terns are likely to become unsuitable owing to higher sea levels and increased coastal erosion; low-lying islands are particularly vulnerable to being lost. Key measures to provide additional, or replacement, nesting habitat for terns are the creation of islands as part of managed realignment schemes, and the use of dredgings to provide suitable nesting areas and help to maintain existing nesting islands.

Conclusions

Our assessment shows that, while consideration of the predicted impacts of climate change does not fundamentally change bird-conservation priorities, it does upgrade the priority afforded to some species and to certain types of conservation activity. It also introduces the need to protect and provide suitable habitat to the north of species' current breeding ranges in order to facilitate species' range expansion where suitable habitat is otherwise lacking.

It is important to note that the impacts of climate change on birds in Britain are expected to be far less severe than those on many other groups of wildlife, or in many other regions of the world. Britain's geographical location means that (other than for seabirds and possibly upland birds) a warmer climate may enable it to support a wider variety of bird species than at present, since avian species-richness is generally greater in warmer areas immediately to the south of Britain. Britain also supports very few restricted-range bird species, which are expected to be particularly vulnerable to climate-driven extinction. Importantly, birds are far better at dispersing than most other groups, and therefore more able to track changes in the area which is climatically suitable for them. Many less mobile species, such as some habitat-specialist butterflies and reptiles, have not increased their range in Britain (and in some cases have declined) in recent decades during which Britain's climate is thought to have become more suitable for them (e.g. Warren *et al*. 2001; Hickling *et al*. 2006).

While climate-envelope modelling provides valuable insights into how species' distributions might change in relation to climate, in practice we are likely also to see more complex changes in some species' distributions and migration routes. An intriguing possible illustration of this involves Yellow-browed Warblers *Phylloscopus inornatus*

Will birds such as the Yellow-browed Warbler overwinter more frequently in the UK?
Harri Taavetti/FLPA

and Pallas's Warblers *P. proregulus*. Both breed in Siberia, most individuals wintering in southern Asia, but the numbers of both species recorded in Britain have recently increased (although there is no suggestion that this has been due to changes in climate), and some now winter in Britain (Gilroy & Lees 2003; White & Kehoe 2014). It is possible that milder winters may allow a higher proportion of 'pioneering' individuals of these and other species to winter in Britain, thereby resulting in the establishment of new migration routes and wintering areas, as has occurred with Blackcaps *Sylvia atricapilla*.

Despite the uncertainties involved with predicting the future, there remains one simple truth, whether trying to prevent decline/extinction or to facilitate range expansion. The best way to help wildlife to adapt to climate change is to provide large areas of good-quality habitat, especially by creating an effective network of nature reserves and statutorily protected areas, while also making the intervening landscape more nature-friendly (Dodd *et al*. 2010; Lawton *et al*. 2010; Thomas *et al*. 2012; Hiley *et al*. 2013; Johnston *et al*. 2013). This will mean that species' populations are larger, and therefore less vulnerable to extinction through random events; there are more individuals to disperse to new areas and colonise these; and there is more suitable habitat for individuals to colonise. It is also important that we pay particular attention to birds for which Britain has a particular international responsibility.

Making sure our conservation action remains effective at a time when our climate is changing

References and further reading

Ausden, M., Allison, M., Bradley, P., Coates, M., Kemp, M., & Phillips, N. 2010. Increasing the resilience of our lowland dry heaths and acid grasslands. *British Wildlife* 22: 101–109.

Ausden, M., Hirons, G., Lock, L., & White, G. 2014. Managing and re-creating wetlands in Britain for potential colonists. *British Birds* 107: 726–755.

Ausden, M., White, G., & Eaton, M. 2013. Breeding Baillon's Crakes in Britain. *British Birds* 106: 7–16.

Bjorsne, A. K., Rutting, T., & Ambus, P. 2014. Combined climate factors alleviate changes in gross soil nitrogen dynamics in heathlands. *Biogeochemistry* 120: 191–201.

Both, C., Van Turnhout, C. A. M., Bijlsma, R. G., Siepel, H., Van Strien, A. J., & Foppen, R. P. B. 2010. Avian population consequences of climate change are most severe for long-distance migrants in seasonal habitats. *Proceedings of the Royal Society, Series B* 277: 1259–1266.

Bradbury, R. B., Pearce-Higgins, J. W., Wotton, S. R., Conway, G. J., & Grice, P. V. 2011. The influence of climate and topography in patterns of territory establishment in a range expanding bird. *Ibis* 153: 336–344.

Broadmeadow, M. S. J., Ray, D., & Samuel, C. J. A. 2005. Climate change and the future for broadleaved tree species in Britain. *Forestry* 78(2): 145–161.

Brown, L. E., Holden, J., & Palmer, S. M. 2014. *Effects of moorland burning on the ecohydrology of river basins. Key findings from the EMBER project*. University of Leeds.

Carroll, M. J., Dennis, P., Pearce-Higgins, J. W., & Thomas, C. D. 2011. Maintaining northern peatland ecosystems in a changing climate: effects of soil moisture, drainage and drain blocking on craneflies. *Global Change Biology* 17: 2991–3001.

Dodd, A., Hardiman, A., Jennings, K., & Williams, G. 2010. Protected areas and climate change: Reflections from a practitioner's perspective. *Utrecht Law Review* 6: 141–148.

Eglington, S. M., & Pearce-Higgins, J. W. 2012. Disentangling the relative importance of change in climate and land-use intensity in driving recent bird population trends. *PLoS ONE* 7(3): e30407. doi:10.1371/journal.pone.0030407

Fielding, A., Haworth, P., Whitfield, P., McLeod, D., & Riley, H. 2011. *A Conservation Framework for Hen Harriers in the United Kingdom*. JNCC Report No: 441. JNCC, Peterborough.

Frederiksen, M., Wanless, S., Harris, M. P., Rothery, P., & Wilson, L. J. 2004. The role of industrial fisheries and oceanographic change in the decline of North Sea black-legged kittiwakes. *Journal of Applied Ecology* 41: 1129–1139.

Frederiksen, M., Edwards, M., Richardson, A. J., Mann, A. D., & Wanless, S. 2006. From plankton to top predators: bottom-up control of a marine food web across four trophic levels. *Journal of Animal Ecology* 75: 1259–1268.

Fuller, R. J., Smith, K. W., Grice, P. V., Currie, F. A., & Quine, C. P. 2007. Habitat change and woodland birds in Britain: implications for management and future research. *Ibis* 149 (Suppl. 2): 261–268.

Gilroy, J. J., & Lees, A. C. 2003. Vagrancy theories: are autumn vagrants really reverse migrants? *British Birds* 96: 427–438.

Green, R. E., Collingham, Y. C., Willis, S. G., Gregory, R. D., Smith, K. W., & Huntley, B. 2008. Performance of climate envelope models in retrodicting recent changes in bird population size from observed climatic change. *Biology Letters* 4: 99–602.

Gregory, R. D., Willis, S. G., Jiguet, F., Vořišek, P., Klvaňová, A., van Strien, A., Huntley, B., Collingham, Y. C., Couvet, D., & Green, R. E. 2009. An Indicator of the Impact of Climate Change on European Bird Populations. *PLoS ONE* 4(3): e4678. doi:10.1371/journal.pone.0004678

Hansen, J., Sato, M., & Ruedy, R. 2012. Perception of climate change. *Proceedings of the National Academy of Sciences of the United States of America* 109: E2415-E2423. DOI: 10.1073/pnas.1205276109

Harris, S. J., Risely, K., Massimino, D., Newson, S. E., Eaton, M. A., Musgrove, A. J., Noble, D. G., Procter, D., & Baillie, S. R. 2014. *The Breeding Bird Survey 2013*. BTO Research Report 658. British Trust for Ornithology, Thetford.

Hayhow, D. B., Conway, G., Eaton, M. A., Grice, P. V., Hall, C., Holt, C. A., Kuepfer, A., Noble, D. G., Oppel, S., Risely, K., Stringer, C., Stroud, D. A., Wilkinson, N., & Wotton, S. 2014. *The state of the UK's birds 2014*. RSPB, BTO, WWT, JNCC, NE, NIEA, NRW & SNH, Sandy, Bedfordshire.

Henderson, I., Calladine, J., Massimino, D., Taylor, J. A., & Gillings, S. 2014. Evidence for contrasting causes of population change in two closely related, sympatric breeding species the Whinchat *Saxicola rubetra* and Stonechat *Saxicola torquata* in Britain. *Bird Study* 61: 553–565.

Hickling, R., Roy, D. B., Hill, J. K., Fox, R., & Thomas, C. D. 2006. The distributions of a wide range of taxonomic groups are expanding polewards. *Global Change Biology* 12: 450–455.

Hiley, J. R., Bradbury, R. B., Holling, M., & Thomas, C. D. 2013. Protected Areas act as establishment centres for species colonising the United Kingdom. *Proceedings of the Royal Society of London Series B–Biological Sciences* 280 (1760):20122310. DOI: 10.1098/rspb.2012.2310

Huntley, B., Green, R. E., Collingham, Y. C., & Willis, S. G. 2007. *A Climatic Atlas of European Breeding Birds*. Durham University, RSPB and Lynx Edicions, Barcelona.

Huntley, B., Collingham, Y. C., Willis, S. G., & Green, R. E. 2008. Potential impacts of climatic change on European breeding birds. *PLoS ONE* 3(1):e1439. doi:10.1371/journal.pone.0001439

Johnston, A., Ausden, M., Dodd, A. M., Bradbury, R. B., Chamberlain, D. E., Jiguet, F., Thomas, C. D., Cook, A. S. C. P., Newson, S. E., Ockendon, N., Rehfisch, M. M., Roos, S., Thaxter, C. B., Brown, A., Crick, H. Q. P., Douse, A., McCall, R. A., Pontier, H., Stroud, D. A., Cadiou, B., Crowe, O., Deceuninck, B., Hornman, M., & Pearce-Higgins, J. W. 2013. Observed and predicted effects of climate change on species abundance in protected areas. *Nature Climate Change*. DOI: 10.1038/NCLIMATE2035

Langston, R. H. W., Liley, D., Murison, G., Woodfield, E., & Clarke, R. T. 2007. What effects do walkers and dogs have on the distribution and productivity of breeding European Nightjar *Caprimulgus europaeus*? *Ibis* 149 (Suppl. 1): 27–36.

Lawton, J. H., Brotherton, P. N. B., Brown, V. K., Elphick, C., Fitter, A. H., Forshaw, J., Haddow, R. W., Hilborne, S., Leafe, R. N., Mace, G. M., Southgate, M. P., Sutherland, W. A., Tew, T. E., Varley, J., & Wynne, G. R. 2010. *Making Space for Nature: a review of England's wildlife sites and ecological network*. Report to Defra.

Lehikoinen, A., Jaatinen, K., Vahatalo, A. V., Clausen, P., Crowe, O., Decueninck, B., Hearn, R., Holt, C. A., Hornman, M., Keller, V., Nilsson, L., Landendoen, T., Tomankova, I., Wahl, J., & Fox, A. D. 2013. Rapid climate driven shifts in wintering distributions of three common waterbird species. *Global Change Biology*. doi:10.1111/gcb.12200

Liley, D., & Clarke, R. J. 2003. The impact of urban development and human disturbance on the numbers of nightjar *Caprimulgus europaeus* on heathlands in Dorset, England. *Biological Conservation* 114: 219–230.

MacLean, I. M. D., Austin, G. E., Rehfisch, M. M., 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 site abundance of waterbirds. *Global Change Biology* 14: 2489–2500.

Mallord, J. W., Dolman, P. M., Brown, A. F., & Sutherland, W. J. 2007. Linking recreational disturbance to population size in a ground-nesting passerine. *Journal of Applied Ecology* 44: 185–195.

Melling, T., Dudley, S., & Doherty, P. 2008. The Eagle Owl in Britain. *British Birds* 101: 478–490.

Murison, G., Bullock, J. M., Underhill-Day, J., Langston, R., Brown, A. F., & Sutherland, W. J. 2007. Habitat type determines the effects of disturbance on the breeding productivity of the Dartford Warbler *Sylvia undata*. *Ibis* 149 (Suppl. 1): 16–26.

Nolet, B. A., Bauer, S., Feige, N., Kokorev, Y. I., Popov, I. Y., & Ebbinge, B. S. 2013. Faltering lemming cycles reduce productivity and population size of a migratory Arctic goose species. *Journal of Animal Ecology* 82: 804–813.

Pearce-Higgins, J. W. 2011a Modelling conservation management options for a southern range-margin population of Golden Plover

Pluvialis apricaria vulnerable to climate change. *Ibis* 153: 345–356.
Pearce-Higgins, J. W. 2011b Using diet to assess the sensitivity of northern and upland birds to climate change. *Climate Research* 45: 119–130.
Pearce-Higgins, J. W., & Green, R. E. 2014. *Birds and Climate Change. Impacts and Conservation Responses*. Cambridge University Press, Cambridge, UK.
Pearce-Higgins, J. W., Dennis, P., Whittingham, M. J., & Yalden, D. W. 2010. Impacts of climate on prey abundance account for fluctuations in a population of a northern wader at the southern edge of its range. *Global Change Biology* 16: 12–23.
Pearce-Higgins, J. W., Ausden, M. A., Beale, C. M., Oliver, T. H. & Crick, H. Q. P. (eds) 2013. *Research on the assessment of risks & opportunities for species in England as a result of climate change*. NECR175, Natural England, York.
Ramsbottom, D., Sayers, P., & Panzeri, M. 2012. *Climate change risk assessment for the floods and coastal erosion sector*. UK 2012 Climate Change Risk Assessment. Defra, London.
Rance, J., Wade, S. D., Hurford, A. P., Bottius, E., & Reynard, N. S. 2012. *Climate change risk assessment for the water sector*. UK 2012 Climate Change Risk Assessment. Defra, London.
Scott, M. 2009. Climate change and the high Cairngorms: reality and hyperbole. *British Wildlife* 20: 389–397.
Summers, R. W., Jardine, D. C., Marquiss, M., & Rae, R. 2002. The distribution and habitats of crossbills *Loxia* spp. in Britain, with special reference to the Scottish Crossbill *Loxia scotica*. *Ibis* 144: 393–410.
Thomas, C. D., Hill, J. K., Anderson, B. J., Bailey, S., Beake, C. M., Bradbury, R. B., Bulman, C. R., Crick, H. Q. P., Eigenbrod, F., Griffiths, H. M., Kunin, W. E., Oliver, T. H., Walmsley, C. A., Watts, K., Worsfold, N. T., & Yardley, T. 2011. A framework for assessing threats and benefits to species responding to climate change. *Methods in Ecology & Evolution* 2: 125–142.
Thomas, C. D., Gillingham, P. K., Bradbury, R. B., Anderson, B. J., Baxter, J. M., Bourn, N. A. D., Crick, H. Q. P., Findon, R., Fox, R., Hodgson, J. A., Holt, A. R., Morecroft, M. D., O'Hanlon, N. J., Oliver, T. H., Pearce-Higgins, J. W., Procter, D., Roy, D. B., Thomas, J. A., Walker, K. J., Walmsley, C. A., Wilson, R. J., & Hill, J. K. 2012. Protected areas facilitate species' range expansions. *PNAS* 109: 14063–14068.
Warren, M. S., Hill, J. K., Thomas, J. A., Asher, J., Fox, R., Huntley, B., Roy, D. B., Telfer, M. G., Jeffcoate, S., Harding, P., Jeffcoate, G., Willis, S. G., Greatorex-Davies, J. N., Moss, D., & Thomas, C. D. 2001. Rapid responses of British butterflies to opposing forces of climate and habitat change. *Nature* 414: 65–69.
White, S., & Kehoe, C. 2014. Report on scarce migrant birds in Britain in 2008–10. Part 2: passerines. *British Birds* 107: 251–281.
Whitfield, D. P., Fielding, A. H., McLeod, D. R. A., & Haworth, P. F. 2008. *A conservation framework for golden eagles: implications for their conservation and management in Scotland*. Scottish Natural Heritage Commissioned Report No. 193 (ROAME No. F05AC306).
Wilson, J. D., Anderson, R., Bailey, S., Chetcuti, J., Cowie, N. R., Hancock, M. H., Quine, C. P., Russell, N., Stephen, L., & Thompson, D. B. A. 2014. Modelling edge effects of mature forest plantations on peatland waders informs landscape-scale conservation. *Journal of Applied Ecology* 51: 204–213.
Wilson, L., Wilson, J., Holden, J., Johnstone, I., Armstrong, A., & Morris, M. 2011. Ditch blocking, water chemistry and organic carbon flux: Evidence that blanket bog restoration reduces erosion and fluvial carbon loss. *Science of the Total Environment* 409: 2010–2018.

Scottish Crossbill feeding on Scots Pine. Paul Hobson/FLPA

will demand both our full attention and additional resources, and must be given priority by those who determine the political agenda. These are required in order not only to continue to carry out 'business as usual' conservation but also to reduce further the other pressures on species at risk of climate-driven decline, to replace habitat lost through coastal change, and to provide additional good-quality habitat to facilitate climate-driven shifts in species' distributions.

Acknowledgements

Much of the literature review on the predicted impacts of climate change on birds was carried out as part of the Defra-funded project 'Climate Change Impacts on Avian Interests of Protected Area Networks' (CHAINSPAN) (Defra Ref: WC0750/CR0440) and the Natural England-funded project 'Research on the assessment of risks & opportunities for species in England as a result of climate change' (Natural England Contract Ref: 24800). We should like to thank Steven Ewing, Pat Thompson, Gwyn Williams and Jeremy Wilson for commenting on an earlier draft.

Malcolm Ausden is Principal Ecologist at the RSPB. Richard Bradbury is Head of Environmental Research at the RSPB Centre for Conservation Science. Andy Brown is Principal Specialist in Species Conservation at Natural England. Mark Eaton is Principal Conservation Scientist for Species Monitoring & Research at the RSPB Centre for Conservation Science. Leigh Lock is Senior Species Recovery Officer at the RSPB. James Pearce-Higgins is Director of Science at the BTO. Email address for correspondence: malcolm.ausden@rspb.org.uk.