Climate Change and the UK's Birds

BTO
Inspired by birds, informed by science

EXECUTIVE SUMMARY

In this report we show how **climate change is already impacting the UK's birds**.

Our internationally important **breeding seabird populations** and unique assemblage of **upland breeding birds are already negatively affected and appear most vulnerable to future change**.

Many **southern species and widespread resident species are increasing** in response to warmer temperatures.

Overall, **a quarter of our breeding species appear to be negatively affected** and **a quarter may be responding positively**; the remaining breeding species that have been studied appear relatively unaffected by climate change.

There are significant gaps in our knowledge for other species, notably our wintering bird populations.

BACKGROUND

An increasing body of research demonstrates the impacts of climate change on bird species across the globe, revealing a suite of responses. The timing of bird breeding and of migration have both become earlier. These shifts in timing have averaged one to three days per decade.

Climate change is driving a consistent poleward shift in the distribution of bird species, the rate of change exceeding 11 km per decade.

Globally, bird population declines have been greatest where warming has been most rapid.

Climate change is driving large-scale shifts in bird communities across the globe, and we are seeing a consistent simplification of bird communities as they become more similar to each other.

Migratory bird populations are declining widely aroound the world and migratory birds may be particularly exposed to the impacts of climate change.

Scientific evidence is required for robust decision making to maximise win–win solutions for climate change mitigation, adaptation and nature. Long-term monitoring is needed to ensure such interventions are successful.

WHAT WE DID

We assess the impact that climate change has already had on UK bird populations by relating their long-term trends to separately published species' responses to climate change, temperature and rainfall.

We summarise the results of different climate change vulnerability assessments to provide the most comprehensive synthesis of the likely future impacts of climate change on UK birds to date.

We highlight examples where large-scale climate mitigation has the potential to transform landscapes with significant impacts on birds and where conservation action may also help species adapt to climate change.

WHAT WE FOUND

Within the UK, breeding seabirds and upland breeding birds are the two groups most vulnerable to climate change. Fourteen seabird species are regarded as being at risk of negative climate change impacts. These include Puffin, for which a population decline across Britain and Ireland of 89% is projected by 2050.

Conversely, climate change appears to be contributing to population increases and expansion in breeding waterbirds, including species colonising from continental Europe. Southerly-distributed waterbirds, coastal species and heathland species* are those most likely to benefit from climate change.

Tendencies for upland birds and seabirds to decline may be related to their more negative responses to warming temperature, whilst positive impacts of temperature change may contribute to increases in wetland and non-native species.

Climate change has been one of the two most important drivers of breeding population changes since the 1970s.

Populations of one third of common and widespread breeding bird species fluctuate with temperature and rainfall*. Warmer spring temperatures can increase breeding success whilst a reduction in winter severity has boosted annual survival of many resident species.

Populations of long-distance migrants vary with conditions in Africa where they winter, and generally benefit from wet rainy seasons there. Warming in the UK, contrasted with mixed rainfall trends in Africa, has contributed to divergent breeding population trends between resident and migratory bird species.

We lack information about the extent to which climate change might be driving population trends for 132 (55%) of our breeding bird species and for most of our wintering birds. It is essential that we address these important knowledge gaps.

* SEE SUPPLEMENTARY MATERIAL ONLINE AT WWW.BTO.ORG

REDSTART : EDMUND FELLOWES; REED WARBLER : GRAHAM CATLEY; SPOONBILL : EDMUND FELLOWES; GARGANEY : CHRIS KNIGHTS; CANADA GOOSE : SARAH KELMAN; BARN OWL : LIZ CUTTING



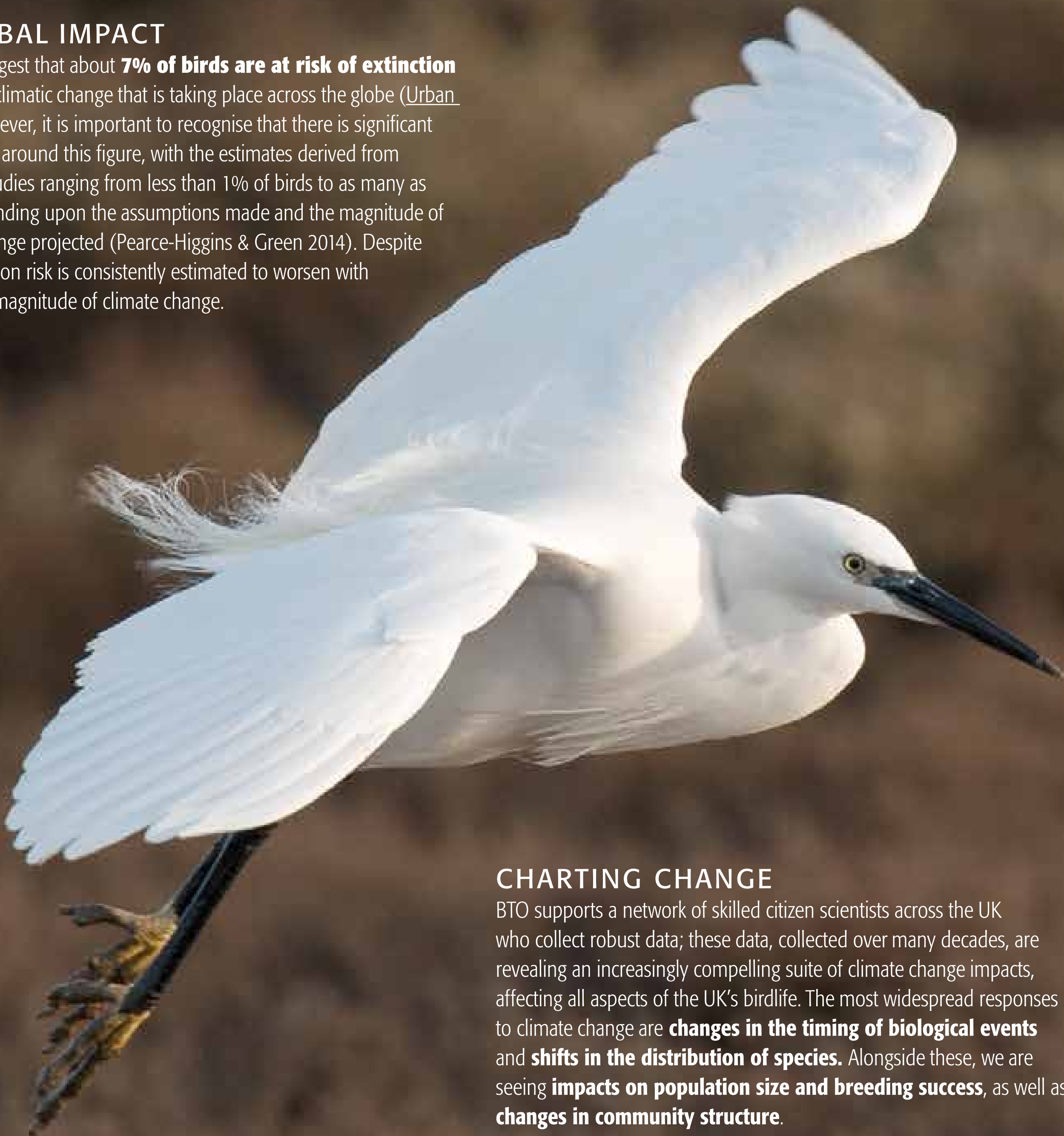



INTRODUCTION

Climate change is having an impact on all biological levels, from genes to species' populations, and on to the structure of communities and the functioning of ecosystems (Scheffers *et al.* 2016). It is already driving long-term changes in UK biodiversity (Morecroft & Speakman 2015), and its effects are evident in the data collected through BTO's core monitoring schemes for birds.

A GLOBAL IMPACT

Studies suggest that about **7% of birds are at risk of extinction** due to the climatic change that is taking place across the globe (Urban 2015). However, it is important to recognise that there is significant uncertainty around this figure, with the estimates derived from different studies ranging from less than 1% of birds to as many as 30%, depending upon the assumptions made and the magnitude of climate change projected (Pearce-Higgins & Green 2014). Despite this, extinction risk is consistently estimated to worsen with increasing magnitude of climate change.



CHARTING CHANGE

BTO supports a network of skilled citizen scientists across the UK who collect robust data; these data, collected over many decades, are revealing an increasingly compelling suite of climate change impacts, affecting all aspects of the UK's birdlife. The most widespread responses to climate change are **changes in the timing of biological events** and **shifts in the distribution of species.** Alongside these, we are seeing **impacts on population size and breeding success**, as well as **changes in community structure**.

In this report we show how **climate change is already impacting the UK's birds.** We also present an assessment of the **vulnerability of UK bird species to climate change** and highlight the **potential impacts of mitigation measures**, such as tree-planting and marine renewables, on bird populations. This is the first time that this information has been brought together for the UK's birds.

CONTENTS

MAP ON PAGE 6: REPRODUCED FROM *BIRD ATLAS 2007–11*, WHICH WAS A JOINT PROJECT BETWEEN BTO, BIRDWATCH IRELAND AND THE SCOTTISH ORNITHOLOGISTS' CLUB

LITTLE EGRET : SARAH KELMAN / BTO

HOW CLIMATE CHANGE IMPACTS BIRDS

Climate change may affect species and individuals in different ways; sometimes the effects are negative and sometimes they may be beneficial. A growing body of research has revealed the underlying mechanisms by which climate change effects birds, helping us to predict future impacts.

CHANGES IN THE TIMING OF BIOLOGICAL EVENTS

In response to climatic warming, **the timing of bird breeding and of migration have both become earlier**, a pattern that has been particularly evident across medium and high latitudes; here, these **shifts in timing have averaged one to three days per decade** (Pearce-Higgins & Green 2014, Ambrosini *et al.* 2019, Dunn 2019).

Advancement in breeding seasons was **first detected in BTO's Nest Record Scheme data** (Crick *et al.* 1997), and the pattern reflects a more general advance in the timing of biological events, particularly in spring, affecting both plants and animals, and marine, freshwater and terrestrial environments (Thackeray *et al.* 2010, Cohen *et al.* 2018). Such shifts in the timing of biological events are known as 'phenological changes.'

The **rates of phenological change vary between taxa**, with more rapid advances evident in the timing of key events in plants, such as bud burst, compared to insects, and of insects compared to their vertebrate predators, including birds (Thackeray *et al.* 2010, 2016, Cohen *et al.* 2018). This has led to the suggestion that linked events in different taxa will become misaligned (e.g. a peak in leaf-eating caterpillar emergence and availability will no longer align with the peak demand for caterpillar prey for breeding songbirds).

Different rates of phenological change could lead to a mismatch that will disrupt ecological networks and food-webs. Despite this topic being studied in well over 100 taxa, with some good examples, there is no strong evidence that climate-mediated asynchrony in the timings of predator and prey events is currently causing widespread problems across the globe (Samplonius *et al.* 2021).

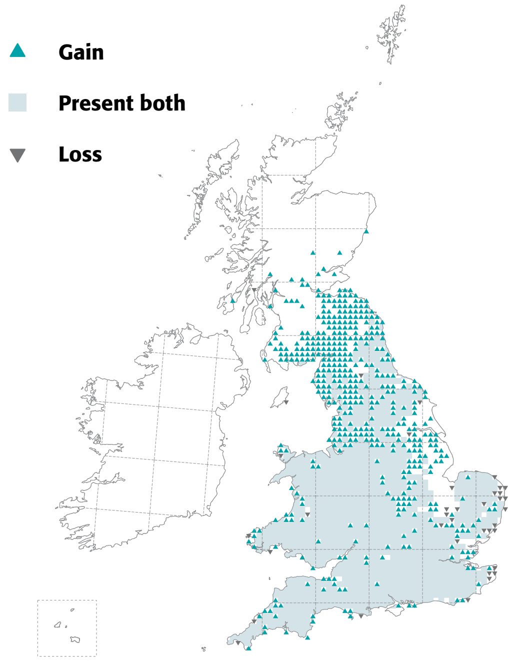
DISTRIBUTION CHANGES

Climate change is driving a consistent poleward shift in the distribution of species by an average of 17 km per decade (Chen *et al.* 2011). In birds, **the rate of change exceeds 11 km per decade** (Pearce-Higgins & Green 2014).

At medium and high latitudes these responses are largely driven by warming (Chen *et al* 2011). In the tropics, shifts may be multi-directional due to more complex responses to changes in rainfall (VanDerWal *et al.* 2013).

There is less evidence for altitudinal shifts in birds in response to climate change (Pearce-Higgins & Green 2014). Across taxa, rates of upward altitudinal shift average 11 m per decade, and although correlated with warming trends, are at much slower rates than expected (Chen *et al.* 2011).

NUTHATCH
WINTER DISTRIBUTION CHANGE ***1981–84 to 2007–11***



POPULATION CHANGES

Bird populations across both Europe and North America are responding to climate change (Stephens *et al.* 2016, Mason *et al.* 2019). Globally, **bird population declines have been greatest where warming has been most rapid** (Spooner *et al.* 2018). Population responses to temperature are greatest at intermediate and high-latitudes, whilst in the tropics, populations are influenced more by changes in precipitation (Pearce-Higgins *et al.* 2015).

The main mechanisms underpinning these changes appear to be changes in species interactions, such as reductions in prey abundance, rather than direct responses to warming (Cahill *et al.* 2013, Ockendon *et al.* 2014).

COMMUNITY CHANGES

The net result of these changes is that **climate change is driving large-scale shifts in bird communities across the globe**. For example, species associated with warmer temperatures are tending to increase in abundance at individual locations relative to more northern or upland species associated with colder temperatures (Devictor *et al.* 2012, Lehikoinen *et al.* 2021). A **consistent simplification of bird communities** as they become more similar to each other (Le Voil *et al.* 2012) may also be at least partially driven by warming (Davey *et al.* 2012, Pearce-Higgins *et al.* 2015).

BRENT GEESE: DAVID TIPLING / BIRDPHOTO.CO.UK

FLYWAYS

By virtue of their global journeys, **migratory birds may be particularly exposed to climate change**. Impacts at different stages of their migratory journey, from breeding grounds, stopover locations and wintering destinations, may disrupt dependencies between them. **Migratory bird populations are declining widely across the globe** (Bairlein 2016). Is climate change contributing to this decline?

Differential responses of populations to climate change across breeding and wintering grounds mean that the **climatic drivers of migratory bird populations may be more complex than those of resident species** (Pearce-Higgins & Green 2014, Pearce-Higgins *et al.* 2015). In response to milder winters, the UK's internationally important waterbird populations are increasingly wintering further north and east in Europe (Maclean *et al.* 2008). There is also potential for impacts at one stage in a species global cycle to carry-over to alter processes at another (e.g. Finch *et al.* 2014), although such **carry-over effects are often less-important than the more direct effects of climate** (Ockendon *et al.* 2013).

As already noted, climate change is altering the timing of migration (Pearce-Higgins & Green 2014, Ambrosini *et al.* 2019), potentially affecting the duration of residency at different stages of the annual cycle. Whilst the ability of migratory birds to respond to advances in the timing of spring on their breeding grounds may be particularly constrained (Moller *et al.* 2008), **phenological asynchrony does not yet appear to be a major cause of population decline in most migratory birds** (Franks *et al.* 2018, Samplonius *et al.* 2021).

The impacts of climate change upon species' distributions can lead to significant changes in the migratory patterns. Warming may reduce the need for some migratory birds to migrate to avoid severe winter weather, leading to significant reductions in migratory tendency and reducing the distance individuals need to travel (Visser *et al.* 2009, Lehikoinen *et al.* 2013). **Migrants may therefore have the potential to show greater adaptive capacity to climate change than less mobile resident species** (Pearce-Higgins & Green 2014).

OUR APPROACH

This report brings together our knowledge of climate change impacts on UK birds to deliver an assessment of the vulnerability of species, and species groups. It also examines the potential impacts of society's responses to a changing climate, from increased use of renewables to carbon-capture through woodland planting.

ASSESSING CLIMATE CHANGE IMPACT

By collating responses to climate change, temperature and rainfall described in published papers, many of which have BTO authors, and comparing those responses to long-term trends in bird populations, **we are able to assess the role of climate change in driving population changes in UK birds over the last 25 years**.

We summarise the results of different climate change vulnerability assessments to provide the most comprehensive synthesis of the likely future impacts of climate change on UK birds to date. This allows us to identify those species and functional species groups that are most vulnerable to climate change, revealing those that are already being impacted, as well as highlighting those for which climate change is likely to improve conditions in the UK.

Our responses to climate change, specifically those centred on climate change mitigation and adaptation, may also have an impact on the UK's birds. For this reason **we also highlight the possible impacts of these response on birds in the UK**, illustrating these through examples drawn from current and ongoing BTO work. These include the potential impacts of marine renewables, large-scale tree planting in the UK uplands, and the adaptation of nature conservation policies to climate change.

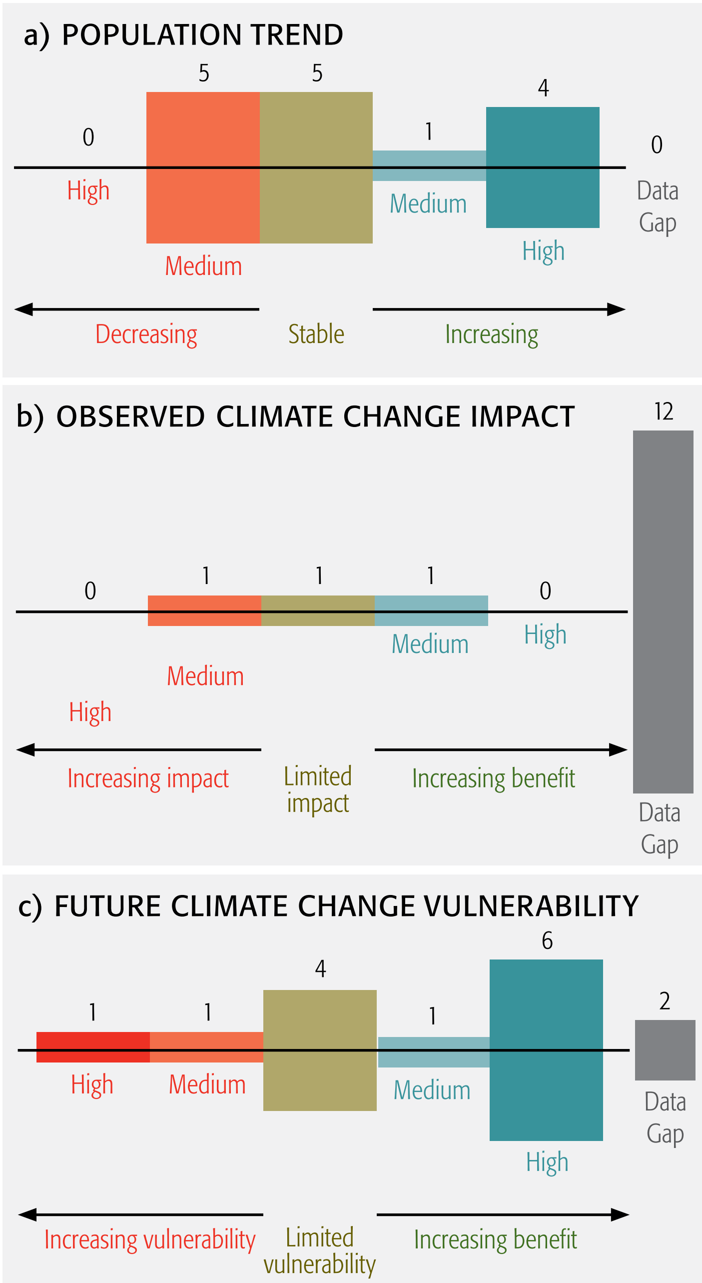
The importance of evidence to inform decision-making is a theme throughout the document, with all statements referenced. Robust long-term monitoring, supported by BTO's network of skilled citizen scientists, provides much of the data on population trends, and on which assessments of climate change impacts and future vulnerabilities are based. **The value of this voluntary contribution is estimated to be equivalent to £15 million annually if provided professionally, a significant return on the government investment to support these schemes that also delivers wider health and well-being benefits** (Pearce-Higgins & Robinson 2019).

These data and the associated results are summarised for particular species-groups, with the individual species responses provided at the end of the report.

For each functional group (see example of **COASTAL BIRDS**, below), we show the number of species in each category of a) decreasing / increasing population trend, and b) / c) increasing impact / increasing benefit. Also shown is the number of species in the group for which data are lacking (termed 'Data Gap').

These graphics provided an 'at a glance' overview of the changing population status of a group, its vulnerability to climate change and its sensitivity to mitigation measures, such as renewables or large-scale tree planting.

COASTAL BIRDS (SEE PAGE 16)



BREEDING BIRD SURVEY VOLUNTEER: DAVID TIPLING / BTO

IMPACTS ON BREEDING POPULATIONS

The best evidence for negative impacts of climate change causing declines in UK breeding birds are for seabirds and upland birds. Conversely, climate change appears to be contributing to population increases and expansion in breeding waterbirds, including species colonising from continental Europe.

The UK all-species Wild Bird Index, which represents population change across 130 species, shows a 10% decline since 1970 (Defra 2020). Given that it is the most common bird species which have tended to decline, this represents **a significant loss of bird abundance and biomass**, a pattern also seen more widely across Europe (Inger *et al.* 2015). After the impact of agricultural intensification, responsible for the widespread declines in farmland birds (Eglington & Pearce-Higgins 2012), **climate change is regarded as the second-most important driver of breeding population changes since the 1970s** (Burns *et al.* 2016).

When looking at the species level, both *Bird Atlas 2007–11* (Balmer *et al.* 2013) and the results of the annual BTO/JNCC/RSPB Breeding Bird Survey (BBS) and Waterways Breeding Bird Survey (WBBS, Harris *et al.* 2020) show that **similar numbers of breeding species have increased in their range extent or abundance, as have declined**. However, **there are important differences in the patterns of increase or decrease between different species groups**, and it is also worth noting that not all of our breeding species are covered by the annual breeding season surveys – notably some of our breeding seabirds.

Understanding the extent to which climate change may be associated with the population changes evident through these core surveys has been the subject of wider work. The population responses to climate change of 105 breeding species (45% of the 234 species considered) have been covered by peer-reviewed studies. Studies of 71 species have been largely correlative, and have generally involved multi-species studies that link variation in populations over time to changes in climatic variables.

Some 34 species have been the subject of more detailed mechanistic studies, for example also analysing information on breeding success, survival or wider aspects of environmental change to more closely link impacts to climate change. We can have greater confidence in the impacts of climate change detected by these studies which are by their very nature, more intensive; but it is worth noting that species showing likely responses to climate change may be more likely to be studied than not, at least by mechanistic studies. These studies show that, of the 34 species covered, 17 are negatively impacted by climate change, 11 appear unaffected, and six show a positive response.

It is also important to note that **we lack information about the extent to which climate change might be driving population trends for 132 (55%) of our breeding bird species**. It is essential that we address this important knowledge gap.

BLUE TIT : DAVID TIPLING / BIRDPHOTO.CO.UK

IMPACTS ON WINTERING POPULATIONS

We have a relatively poor understanding of the impacts that climate change is having on wintering populations in the UK. This reflects the fact that there is much less monitoring of birds in winter than during the breeding season, leaving a knowledge gap that we urgently need to address.

Many of the UK's bird populations are swelled by large numbers of individuals that arrive from elsewhere in the autumn to spend the winter here. These arrivals include wintering waterbirds and waders, together with thrushes and finches, and are drawn from across a wide area that extends from Canada in the west to Russia in the east.

Although most wintering birds showed evidence of increased range extent from the *1981–84 Winter Atlas* to *Bird Atlas 2007–11*, the pattern of change in wintering range cannot be disentangled from the greater levels of coverage achieved in 2007–11 compared to 1981–84 (Balmer *et al.* 2013).

There is much less monitoring of birds in winter than during the breeding season. The only systematic annual monitoring of wintering species in the UK is of internationally important wintering waterbirds, with 46 species population trends routinely reported through BTO/RSPB/JNCC Wetland Bird Survey (WeBS); 25-year trends of more uncertain representativeness are calculated for a further 49 species.

Despite recent evidence from across Europe and North America, that **the impacts of climate change are more apparent on wintering than breeding populations** (Lehikoinen *et al.* 2021), wintering populations have been the subject of studies of the impacts of climate change for only 28 species, the bulk of which are waterbirds; these have been correlative rather than mechanistic in nature.

This means that **we have a relatively poor understanding of the impacts that climate change is having on wintering populations in the UK.** Whilst we can infer the likely responses of many other common and widespread terrestrial resident species to climate change from studies of breeding populations, we cannot track these impacts directly at present. This is another important gap in our current understanding.

BLUE TIT : DAVID TIPLING / BIRDPHOTO.CO.UK

RESPONSE TO TEMPERATURE & RAINFALL

Long-term population trends of both breeding and wintering birds in the UK are strongly associated with their individual responses to temperature. Winter temperature affects breeding populations the following year, and also shapes the numbers of waterbirds wintering in the UK.

Reviewing the climatic responses apparent in the published studies which underpin these assessments, it is evident that **far more breeding population responses to temperature were positive than negative in nature** – 31% of studies versus 18% of studies. **Two-thirds of the studies examining the responses of wintering populations showed negative responses to temperature.** All of these involved waterbirds. **One in four of the studies examining the effects of precipitation on breeding populations were positive, and 12% negative**, whilst there were relatively few studies of the effects of precipitation on wintering populations, again the majority of which involved waterbirds.

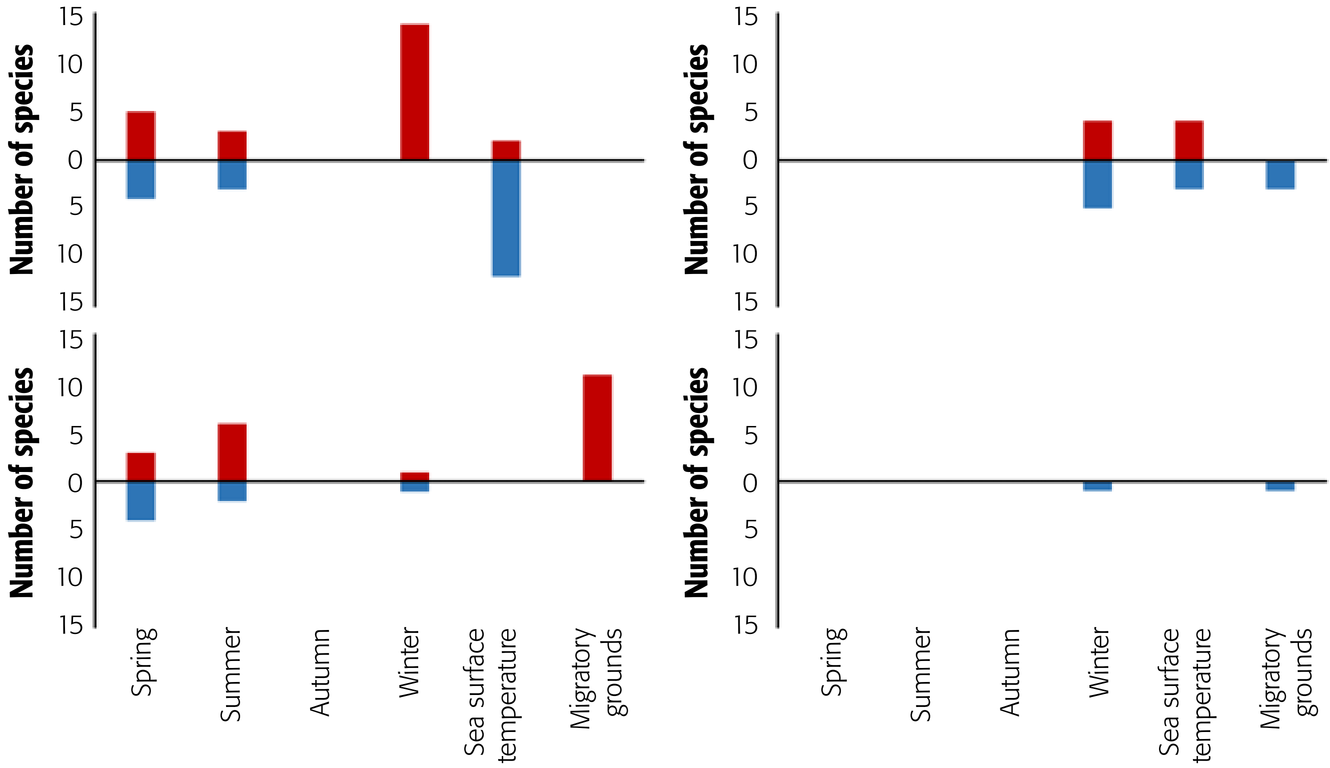
There are statistically significant differences in mean population trend and mean responses to temperature between different bird species groups, largely split by habitat. **Upland species are tending to decline, whilst coastal and wetland species tend to be increasing in abundance**. **Marine and upland species tend to show strong negative responses to temperature, whilst the responses of wetland and non-native species tend to be positive.** There is an association between mean temperature responses and these trends, suggesting that tendencies for upland birds and seabirds to decline may be related to their more negative responses to temperature, whilst positive impacts of temperature may contribute to increases in wetland and non-native species .

Positive responses for breeding populations tend to be particularly strong for winter temperature, the winter conditions shaping the population size the following breeding season. **Effects of warming during the spring and summer tended to be mixed**. Many of the negative responses were of seabirds responding negatively to higher sea-surface temperatures (SST – Figure 1a, 1b).

Effects of precipitation on breeding populations tended to be positive, particularly during the summer, whilst 11 Afro-Palaearctic migrants responded positively to wet conditions in Africa (Figure 1c, 1d).

In summary, **for terrestrial breeding birds, positive effects of warming are particularly apparent during the winter when cold temperatures limit populations, and more mixed during the breeding season, whilst effects of rainfall tend to be most positive when moisture is limiting, such as in the summer in the UK, and on the African wintering grounds for long-distance migrants.** This reflects latitudinal gradients in the importance of temperature and rainfall for driving species' populations, with rainfall more important in the tropics and temperature more important at the higher latitudes (Pearce-Higgins *et al.* 2015).

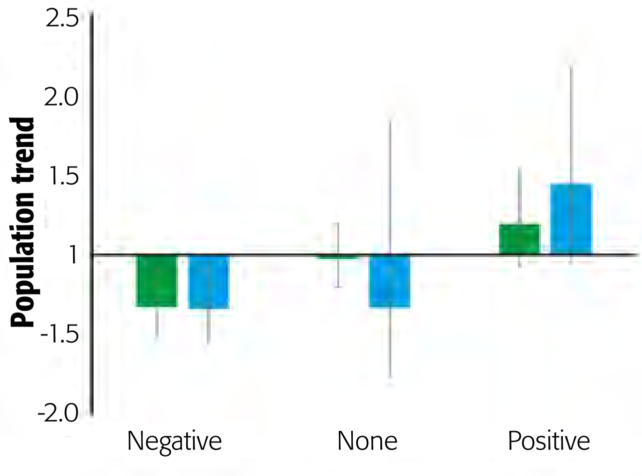
Figure 1. Bar charts indicating the number of bird species with evidence of positive (red) or negative (blue) associations between populations and temperature (top) and precipitation (bottom) for breeding populations (left) and wintering populations (right).



The responses of many UK species to changing temperatures highlight a statistically significant impact on long-term population trends. **Species that exhibit negative responses to temperature tend to have declined by the equivalent of 33% in 25 years, whilst those with positive responses to temperature tend to have increased by an average of 19% over the same period (Figure 2).** Those species exhibiting a mixed response, or showing no response, to temperature have been largely stable.

The equivalent analysis for wintering populations also shows the same statistically significant contrast, although with populations more likely to decline in the absence of a temperature effect. **Wintering populations negatively associated with temperature declined on average by 34%, whilst those associated with positive temperature responses tended to increase by 44%**, although with greater variation than for the breeding population's.

Figure 2. Mean population trend (± 95% CI) standardised to 25-years for breeding (green) and wintering (blue) populations varies in relation to the effect that climate change has had on populations as assessed by climate change studies.



ROBIN: DAVID TIPLING / BIRDPHOTO.CO.UK

IMPACTS ON DISTRIBUTION & RANGE

Data collected through bird atlas projects and the Breeding Bird Survey can be used to examine changes in the distribution and range of species through time, changes that may be rooted in climate change.

Significant changes in species' distributions have occurred in response to warming. Analyses using data collected for national bird atlas projects, shows the northern range margins of 77 southerly-distributed species, which include birds such as Nuthatch, Great Spotted Woodpecker and Garden Warbler, have shifted northwards by an average of 13.5 km between BTO's 1988–91 and 2007–11 atlases. Alongside this, there is no evidence of a consistent range retraction of northerly-distributed species like Golden Plover and Red-throated Diver (Gillings *et al.* 2015).

Similar analysis of Breeding Bird Survey data for a subset of commoner species found **mean rates of northern range shift in excess of 3 km per year**, equivalent to a rate of shift of about 10 m per day. This work has also revealed that the **range shift has been more rapid at the leading edge of the range than at its trailing edge, leading to an expansion in range size**. During the 15 years of warming from 1994 to 2009, species' ranges expanded in extent by approximately 1 km per year (Massimino *et al.* 2015). In-line with the positive effect of temperature upon the abundance of common and widespread generalists, **many southerly-distributed species have therefore expanded their distributions in the UK in response to recent warming**.

Across Europe, the projected impacts of climate change are regarded as likely to result in north and north-easterly range shifts in species that fall within the order of 3.6–6.6 km per year (Huntley *et al.* 2008).

GOLDEN PLOVER: PHILIP CROFT / BTO

Although our report is focussed on birds that already occur in the UK, **a number of additional colonists are also anticipated from continental Europe, as species continue to shift their distributions northwards in response to warming**. Colonisations are most likely to occur if species' populations are increasing on the continent and there are significant breeding populations near to the southern shores of England (Ausden *et al.* 2015).

Eleven waterbirds, two lowland terrestrial species and two woodland species were identified by Ausden *et al.* (2015) as likely to colonise the UK. Of these, we have included Night Heron, Little Bittern, Cattle Egret and Great White Egret as breeding species that have already colonised (RBBP).

Combined modelling of UK and French Breeding Bird Survey data also identified eight species that do not currently breed in the UK, for which changes in climatic conditions should make the UK suitable for breeding; these include Black Kite, Short-toed Treecreeper and Bonelli's Warbler (Massimino *et al.* 2017).

Table 1. Annual rates of poleward (northern) range shift from BTO Atlases over 20 years (Gillings *et al.* 2015) and BBS over 15 years (Massimino *et al.* 2015).

	Atlas range changes 1988–91 to 2007–11	BBS range changes 1994–2009
Northern range margin of southern species	**0.7 ± 0.4 km** 77 species	**3.3 ± 0.9 km** 17 species
Southern range margin of northern species	**0.2 ± 0.4 km** 48 species	**0.5 ± 0.9 km** 7 species

IMPACTS ON BIRD COMMUNITIES

Climate change is driving large-scale shifts in the structure of communities across the globe. A consistent simplification of bird communities, as they become more similar to each other, may also be at least partially driven by warming.

The impacts of climate change on individual species drive large-scale changes in bird communties across the UK. Over the last two decades, southerly-distributed warm-associated species, such as Cetti's Warbler and Nuthatch, have tended to do better than cold-associated species, such as Curlew and Willow Warbler, resulting in gradual increases in the Community Temperature Index (CTI) of bird communities. This index reflects the climate that species at a particular location are typically associated with, and has been used to track the impacts of climate change across Europe and North America, in both breeding seasons and the winter (Devictor *et al.* 2012, Lehikoinen *et al.* 2021). **Here in the UK, observed increases in CTI appear to be driven by the more rapid population declines evident in cold-associated species than are seen in other species** (Oliver *et al.* 2017).

Warming has also contributed to contrasting population trends of habitat specialists, such as Starling (now largely restricted to the urban environment) and Meadow Pipit, which have declined in abundance relative to habitat generalists like Woodpigeon and Goldfinch, whose populations can be found across a wide range of habitats (Sullivan *et al.* 2016). Again, the patterns seen here in the UK are also apparent more widely across Europe (Le Voil *et al.* 2012).

Such changes in community structure are correlated with temperature, suggesting that warming has contributed to the large-scale changes in bird communities apparent across the UK (Davey *et al.* 2012, Pearce-Higgins *et al.* 2015).

Warming has also been associated with an increase in species' richness and diversity in breeding bird populations in the UK (Davey *et al.* 2012). This is probably linked to the latitudinal gradient in species richness (Eglington *et al.* 2015), which means that rising temperatures and poleward range-shifts are likely to result in a greater proportion of species that will respond positively to climate change, than negatively. **An increase in functional diversity of wintering waders on estuaries in the UK may also be related to warming** (Mendez *et al.* 2011).

MEADOW PIPIT: PHILIP CROFT / BTO

SEABIRDS AND COASTAL SPECIES

Twenty UK species are associated with the marine environment as their primary foraging habitat. There is published evidence that 11 of these species are negatively impacted by climate change. Of the 20 seabirds, 14 are regarded as being at high or medium risk of negative climate change impacts.

Conversely, only one species appears positively affected by climate change, and one regarded as likely to benefit from climate change.

One third of the UK's breeding seabird species have suffered population declines of at least 20–30% since the 1990s. Alongside these declines we have witnessed increasing rates of large-scale breeding failures, affecting seabirds at colonies around our coasts (Mitchell *et al.* 2018a, 2018b). **Climate change has been identified as one of three key threats to UK seabirds and a key cause of recent declines,** along with invasive alien species and by-catch in fisheries (Dias *et al.* 2019, Mitchell *et al.* 2020).

Seabirds are potentially impacted by a range of negative climate change mechanisms (Johnston *et al.* 2021). **Increasing sea temperatures are disrupting marine food webs**, impacting plankton communities, and affecting the size, abundance and availability of the fish species taken as prey. Many seabirds rely on sandeels to feed their chicks during the breeding season, particularly at North Sea colonies, and **documented declines in sandeel populations have led to reduced breeding success in seabirds,** and at least partially underpin long-term population declines (Johnston *et al.* 2021).

Whilst the results of the current seabird census (Seabirds Count) will provide an important stock-take of these trends, there is already good evidence that Kittiwake, Arctic Tern, Arctic Skua, Puffin and Fulmar are being affected by these processes (Frederiksen *et al.* 2004, Burthe *et al.* 2014, Cook *et al.* 2014, Perkins *et al.* 2018).

In addition to the disruption of the food chains on which they depend, **seabirds may also suffer from the direct negative impacts of high temperatures when breeding** (Oswald *et al.* 2008), and of **storms that lead to adult mortality** (Burthe *et al.* 2012) and the reduced breeding success of low-lying colonies due to their exposure to flooding risks (Johnston *et al.* 2021).

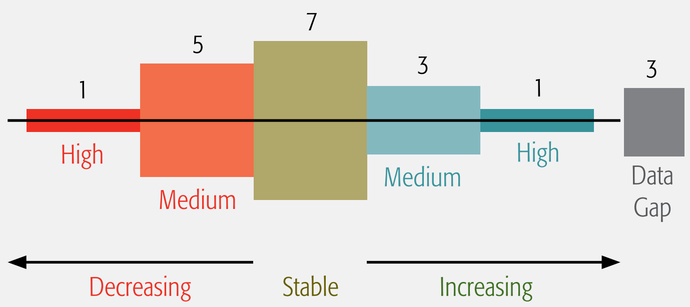
Other published studies support our conclusion that **seabirds are highly vulnerable to future climate change**. Declines of more than 50% in the number of internationally important breeding seabirds around the UK are projected under a high climate change scenario by 2080, with **40% of species projected to be Red-listed solely as a result of climate change** (Johnston *et al.* 2013). Separately, 11 of 19 seabird species are regarded as having a high vulnerability to climate change, and a further four a moderate vulnerability around Britain and Ireland (Davies *et al.* 2021).

At a European scale, two thirds of 23 seabird species are projected to decline in range extent in response to climate change (Russell *et al.* 2015), whilst models linking a wider range of marine species (including breeding seabirds and marine waterbirds) to variation in sea-surface temperature in the North Sea, suggest that 44% of 45 species have a very high or high vulnerability to climate change (Burthe *et al.* 2014).

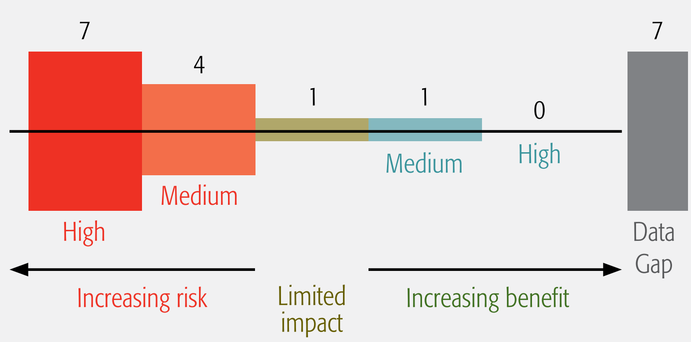
In addition to the 20 seabirds associated with marine habitats, a further five seabirds (all gulls), five waders and five other species are associated with coastal habitats. With roughly balanced population trends for a range of reasons, only three of these species have been the subject of any study of the impacts of climate change, with mixed results. Unlike the marine seabirds, seven (47%) of the species are regarded as likely to benefit from climate change. The summary for these 15 'coastal' species is shown in the methods section on page 9.

SEABIRDS

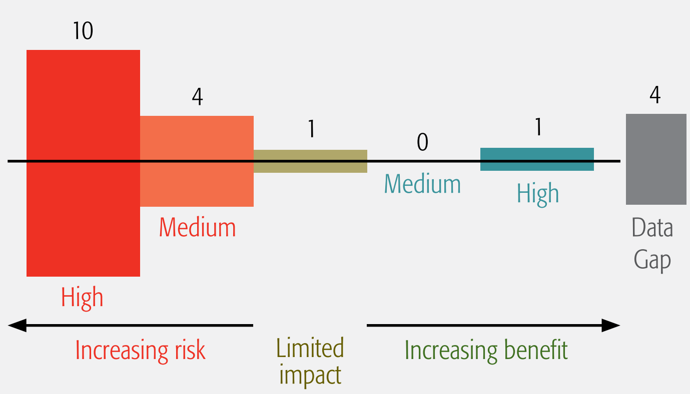
POPULATION TREND



OBSERVED CLIMATE CHANGE IMPACT

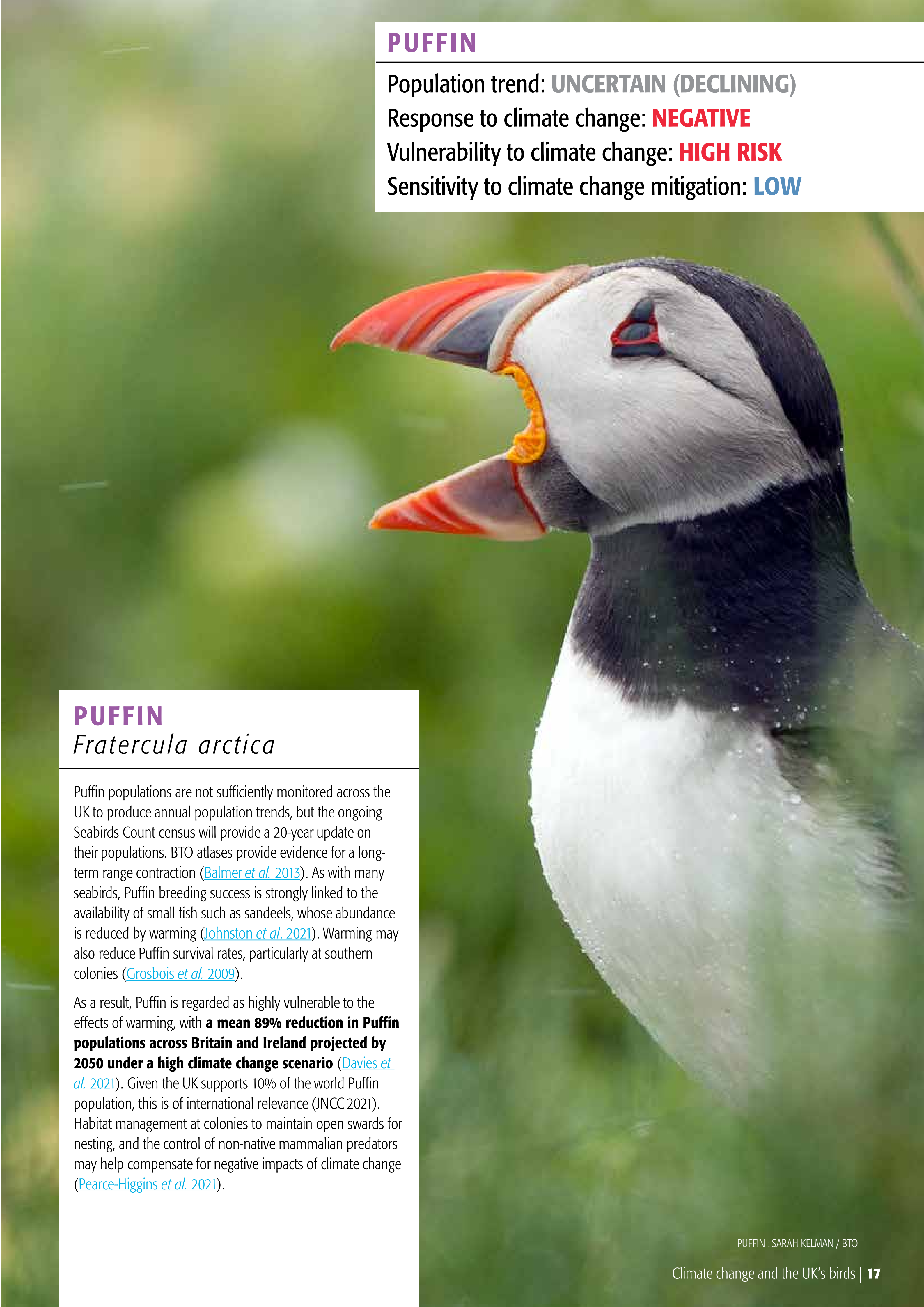


FUTURE CLIMATE CHANGE VULNERABILITY



PUFFIN

Population trend: **UNCERTAIN (DECLINING)**
Response to climate change: **NEGATIVE**
Vulnerability to climate change: **HIGH RISK**
Sensitivity to climate change mitigation: **LOW**



PUFFIN
Fratercula arctica

Puffin populations are not sufficiently monitored across the UK to produce annual population trends, but the ongoing Seabirds Count census will provide a 20-year update on their populations. BTO atlases provide evidence for a long-term range contraction (Balmer *et al.* 2013). As with many seabirds, Puffin breeding success is strongly linked to the availability of small fish such as sandeels, whose abundance is reduced by warming (Johnston *et al.* 2021). Warming may also reduce Puffin survival rates, particularly at southern colonies (Grosbois *et al.* 2009).

As a result, Puffin is regarded as highly vulnerable to the effects of warming, with **a mean 89% reduction in Puffin populations across Britain and Ireland projected by 2050 under a high climate change scenario** (Davies *et al.* 2021). Given the UK supports 10% of the world Puffin population, this is of international relevance (JNCC 2021). Habitat management at colonies to maintain open swards for nesting, and the control of non-native mammalian predators may help compensate for negative impacts of climate change (Pearce-Higgins *et al.* 2021).

PUFFIN : SARAH KELMAN / BTO

UPLAND BIRDS

Thirteen of 28 upland species are in decline, and six species show evidence of negative responses to climate change, and only one showing positive responses to warming.

As a result, the overall assessment of upland bird climate change vulnerability is that 19 species are vulnerable and 16 are at high risk of climate-related declines, and none thought likely to increase in response to climate change.

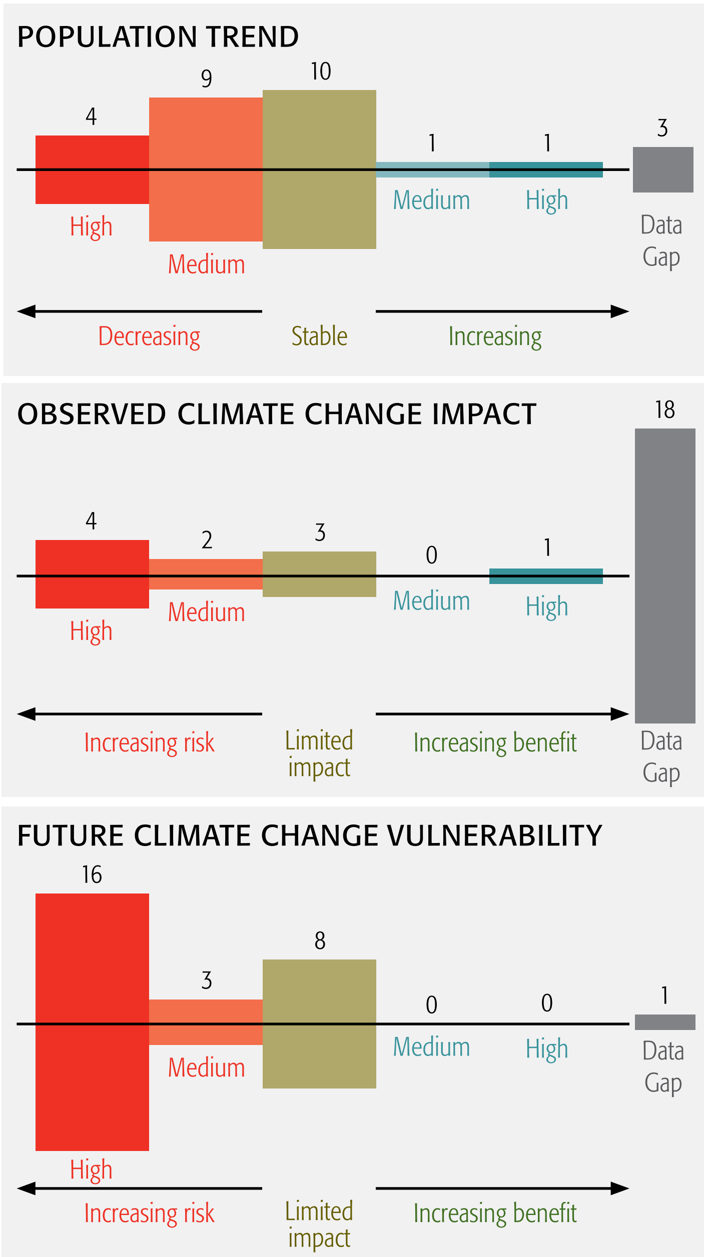
Many upland bird species are declining in the UK (Lehikoinen *et al.* 2019) something that has been linked to a combination of factors, including land-use change and increases in generalist predator populations, (Pearce-Higgins & Grant 2009, Roos *et al.* 2018); however, **climate change is also making an increasing contribution to these trends**.

Changes in the abundance of breeding waders, including Golden Plover, Dunlin and Curlew, and other upland birds, such as Ring Ouzel and Red Grouse, have been linked to variation in temperature or moisture availability. **Hot, dry summers reduce the availability or abundance of soil-dwelling invertebrates, such as earthworms and craneflies, impacting food availability for upland breeding birds** (Beale *et al.* 2006, Pearce-Higgins *et al.* 2010, Pearce-Higgins 2010, Fletcher *et al.* 2013, Carroll *et al.* 2015, Franks *et al.* 2017). These effects potentially mask **short-term positive effects of temperature on the breeding success of ground-nesting waders**, such as in the case of Golden Plover (Pearce-Higgins & Yalden 2002) and Common Sandpiper (Pearce-Higgins & Grant 2009).

Some upland species, such as grouse, are also **sensitive to increases in the intensity of spring rainfall**, which can result in significant chick mortality and rapidly reduce breeding populations (Summers *et al.* 2004, Pearce-Higgins *et al.* 2019).

In the longer-term, **a wider range of climate change mechanisms may also negatively affect upland bird populations**, from the impacts of parasites and disease, often associated with warmer temperatures (Pearce-Higgins & Green 2014, Douglas *et al.* 2019) to longer-term habitat change (Pearce-Higgins & Green 2014).


RED GROUSE : EDMUND FELLOWES / BTO



GOLDEN PLOVER

Population trend: **STABLE**
Response to climate change: **NEGATIVE**
Vulnerability to climate change: **HIGH RISK**
Sensitivity to climate change mitigation: **HIGH**

GOLDEN PLOVER : LIZ CUTTING / BTO

GOLDEN PLOVER
Pluvialis apricaria

Golden Plover populations are largely stable across the UK (Harris *et al.* 2020), although it has suffered a 13% range contraction from 1988–91 to 2007–11 (Balmer *et al.* 2013). **Population fluctuations in the Peak District are negatively related to warm summer temperatures which are associated with the drying out of the peat**, reducing the abundance of their cranefly prey the following spring (Pearce-Higgins *et al.* 2010). Unchecked, this has the potential to drive the Peak District population to extinction by the end of this century (Pearce-Higgins *et al.* 2010), but proactive management to control predation rates and block drainage ditches on peatlands to increase cranefly abundance should increase the resilience of population to 2°C of warming (Pearce-Higgins 2011).

Like many upland breeding waders, **Golden Plovers show strong avoidance of woodland, making them highly vulnerable to large-scale tree-planting in the uplands for climate change mitigation** (Pearce-Higgins &Grant 2009). They also show significant avoidance of wind turbines (Pearce-Higgins *et al.* 2009), with **population declines within wind farm areas following construction** (Pearce-Higgins *et al.* 2012, Samson *et al.* 2016).

AFRO-PALAEARCTIC MIGRANTS

Forty-four species are identified as long-distance migrants that winter in Africa, excluding a number of seabirds and waders that winter primarily on the coast.

Almost half (20 species) are in decline, reflecting general concerns over the declines of long-distance migrants (Vickery *et al.* 2014), particularly in southern Britain (Ockendon *et al.* 2012).

Whilst climate change has been suggested to have only contributed to population changes of fewer than 10% of these, many populations are highly sensitive to changes in rainfall patterns in Africa; changes in rainfall are less clearly attributed to climate change than warming.

Vulnerability assessments based on the breeding grounds suggest that climate change may benefit breeding ground conditions for 19 species, particularly those with a southerly distribution such as Garganey, Red-backed Shrike and Reed Warbler, whilst 11 are at risk from climate change, including Cuckoo, Dotterel and Ring Ouzel, all of which are concentrated in northern and upland Britain. These assessments do not consider potential impacts of climate change on migration or the wintering grounds, and are likely to under-estimate future changes.

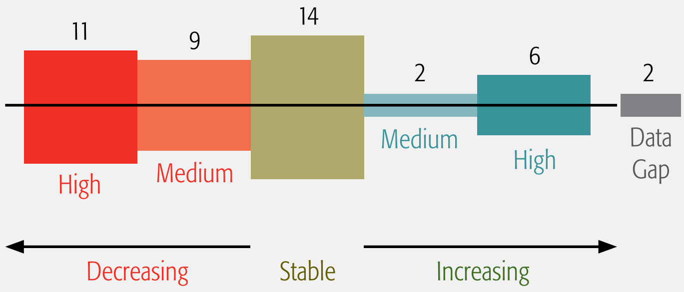
Populations of long-distance migratory birds, such as Swallow, Whitethroat and Redstart, vary with conditions in Africa where they winter. In particular, **wetter rainy seasons in Africa are associated with increased overwinter survival** (Robinson *et al.* 2007, Johnston *et al.* 2014) and **more positive changes in breeding populations back on the breeding grounds the following year** (Ockendon *et al.* 2014b).

Since the 1960s, populations of migrant species that use the Sahel, which include Sand Martin and Sedge Warbler, have fluctuated in response to changes in rainfall in this West African region. **Breeding populations of some of these species declined dramatically during the Sahelian droughts of the 1970s and 80s**, though they have partially recovered since (Pearce-Higgins & Green 2014).

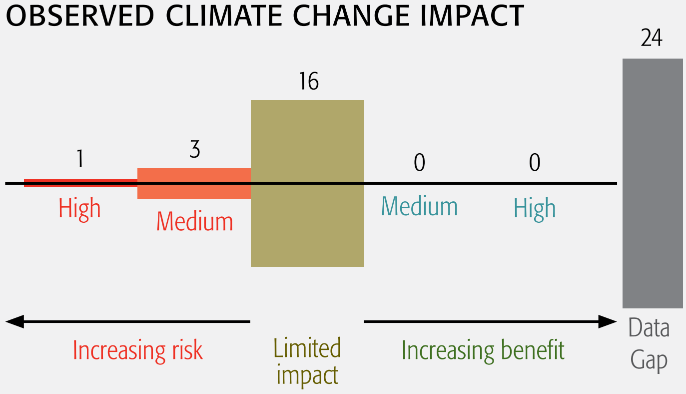
More recently, **it is migrants that winter further south, within the Humid Zone of West Africa, like Spotted Flycatcher and Cuckoo, which have declined the most** (Thaxter *et al.* 2010). The net result of warming trends in the UK and more mixed rainfall trends on the African wintering grounds, is that **climate change has contributed to divergent population trends between resident and migratory bird species** (Pearce-Higgins *et al.* 2015, Howard *et al.* 2020).

Long-distance migrants are regarded as being more sensitive to the negative effects of temperature on the breeding grounds, driving a mismatch in the timing of invertebrate food and breeding season, with those species failing to advance their timing of arrival to the UK most likely to decline (Newson *et al.* 2016). However, **the evidence that this is down to reductions in breeding success is weak** (Franks *et al.* 2018, Samplonius *et al.* 2021). Instead, **late summer warming may have a more negative effect on long-distance migrant populations** (Pearce-Higgins *et al.* 2015), although the mechanism underlying this remains unclear.

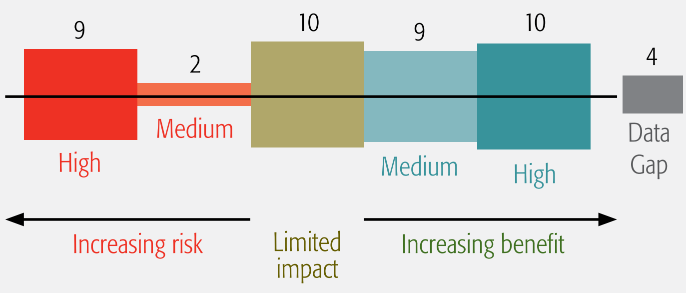
POPULATION TREND



OBSERVED CLIMATE CHANGE IMPACT



FUTURE CLIMATE CHANGE VULNERABILITY



CUCKOO

Population trend: **MEDIUM DECLINE**
Response to climate change: **NEGATIVE**
Vulnerability to climate change: **HIGH RISK**
Sensitivity to climate change mitigation: **LOW**

CUCKOO
Cuculus canorus

Cuckoo populations have declined by 38% across the UK since 1995. Like many long-distance migrants, **population declines have been most notable in the south and east, whilst populations have increased in the north** (Hewson *et al.* 2016), as might be expected if linked to climate change. Cuckoos breeding in lowland England **appear to suffer increased mortality on their post-breeding south-western migration route**, compared to those from the northern uplands that migrant through central Europe (Hewson *et al.* 2016). This **may be linked to periods of drought in the Mediterranean but could also be related to individuals in declining populations being in poorer condition at the end of the breeding season**.

It is possible that large-scale reductions in moth populations in southern Britain may have contributed to these declines (Denerley *et al.* 2018), which could be partially climate-change related (Martay *et al.* 2017). Cuckoo population changes in the UK are negatively related to spring temperature (Pearce-Higgins & Crick 2019). As a result of these patterns, **Cuckoos are regarded as vulnerable to future climate change** (Pearce-Higgins *et al.* 2017).

CUCKOO : EDMUND FELLOWES / BTO

WETLAND BIRDS

Fifty-two species are listed as associated with wetland habitats, of which 24 (46%) are increasing in abundance whilst only six (12%) are declining.

There is evidence for five species that climate change may be enhancing their abundance, whilst negative impacts of climate change have been identified for only two. The majority remain unstudied.

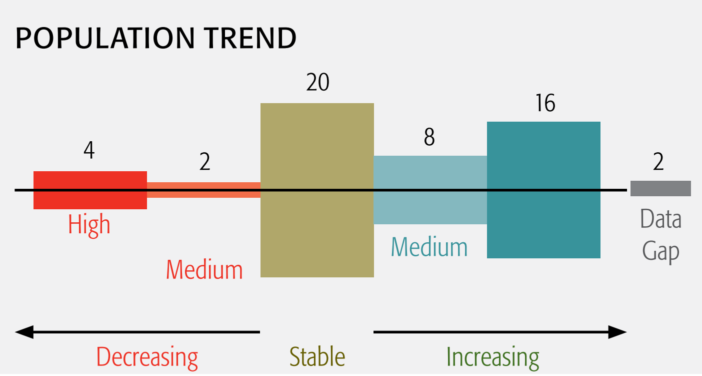
Over half of the species assessed (23 species) are thought likely to benefit from climate change, with only four at risk of decline.

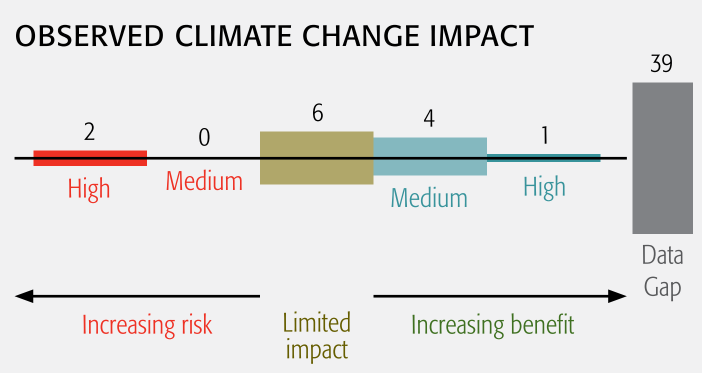
A large number of **breeding waterbird populations are increasing in the UK as a direct result of climate change**. The colonisation of the UK by Little Egret, Cattle Egret, Great White Egret and Spoonbill in response to climate change (Ausden *et al.* 2015) has added to our avifauna.

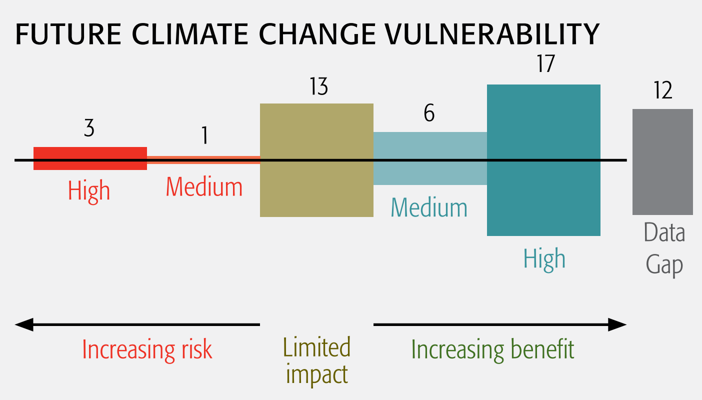
Resident waterbird species previously limited by severe cold winters, such as Grey Heron, Moorhen, Coot, and Cetti's Warbler, have also become more common through time (Robinson *et al.* 2007, Pearce-Higgins 2018, Pearce-Higgins & Crick 2019).

Climate change also appears to be contributing to the increases seen in certain non-native waterbird species, such as Canada Goose, covered below. **Excessive flooding can have negative impacts on ground nesting species**, caused either by summer rainfall (as in the case of Black-tailed Godwits; Ratcliffe *et al.* 2005), or coastal storm-surges leading to saline inundation of freshwater wetlands, as in the case of Bittern (Gilbert *et al.* 2010).

BITTERN : GRAHAM CATLEY / BTO







CETTI'S WARBLER

Population trend: **LARGE INCREASE**
Response to climate change: **POSITIVE**
Vulnerability to climate change: **HIGH BENEFIT**
Sensitivity to climate change mitigation: **LOW**

CETTI'S WARBLER : DAVID TIPLING / BIRDPHOTO.CO.UK

CETTI'S WARBLER
Cettia cetti

Since colonising England with the first breeding records from Kent in the 1970s, Cetti's Warbler's have expanded northwards across England and Wales, a 6,783% range expansion from 1968–72 to 2007–11 (Balmer *et al.* 2013) and 417% breeding population increase from 1995 (Harris *et al.* 2020). **These colonisation and population increases are driven by warmer winter temperatures** as, in common with many resident insectivores, cold weather can increase mortality (Robinson *et al.* 2007).

Cetti's Warblers are regarded as having a high benefit from climate change (Pearce-Higgins *et al.* 2017), as this expansion is expected to increase with **ongoing warming. The population is projected to 32-fold by 2080 under a medium emissions scenario** (Massimino *et al.* 2017).

This is one of the range-expanding species which **has benefited from a protected area network of wetland habitats** for it to colonise and then expand from (Hiley *et al.* 2013).

WINTERING WATERBIRDS

We focus on 85 waterbird species that winter in the UK, including the 46 core species reported through the Wetland Bird Survey. The data for the additional species also come from the survey but, particularly for marine species, are less reliable as they monitor only the part of the population that is close inshore.

Across all waterbirds there is a balance of population increases and decreases, although with evidence of negative impacts of climate change on 17, compared to positive impacts on six species. One quarter of species are regarded as vulnerable to climate change, including ducks such as Mallard and Tufted Duck (Gunnarson *et al.* 2012, Lehikoinen *et al.* 2013), and waders like Purple Sandpiper, showing evidence of reduced recruitment from continental Europe (Summers *et al.* 2012), whilst one fifth may benefit, including those whose populations are sensitive to cold winter weather such as Lapwing (Robinson *et al.* 2014) or with southerly distributions such as Avocet.

Many of the **UK's bird populations are swelled by large numbers of individuals that arrive from elsewhere in the autumn to spend the winter here.** The only systematic annual monitoring of wintering species in the UK is of wintering waterbirds, 24 species of which are increasing compared to 28 species declining.

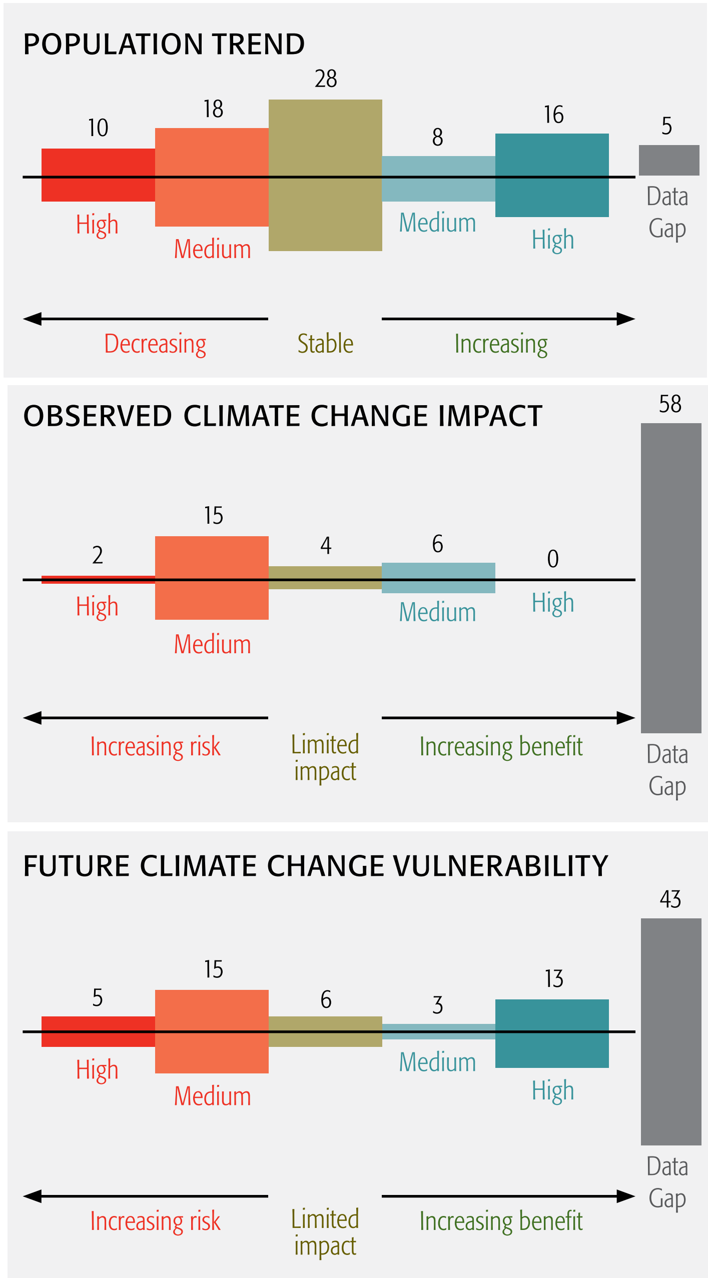
Despite recent evidence from across Europe and North America, which shows that the impacts of climate change are more apparent on wintering than breeding populations (Lehikoinen *et al.* 2021), the wintering populations of only 28 species have been the subject of studies of the impacts of climate change, the bulk of which have been correlative rather than mechanistic in nature).

GOLDENEYE : EDMUND FELLOWES / BTO

Wintering waterbirds have responded to a combination of warmer temperatures improving overwinter survival for many species (Pearce-Higgins & Green 2014), and north- and eastwards shifts in distribution across Europe, as species migrate less far in response to warmer temperatures.

Coastal waders (Austin & Rehfisch 2005, Maclean *et al.* 2008) and waterfowl are both changing their patterns of abundance. These changes in abundance are **most apparent in deep-water species like Tufted Duck and Goldeneye**, both of which are sensitive to winter ice reducing access to their underwater food (Lehikoinen *et al.* 2013, Pavón-Jordán *et al.* 2015, 2018). **These wintering waterbird distribution shifts across Europe are probably contributing to recent declines in the numbers of wintering waterbirds in the UK** (Burton *et al.* 2020).

Species which breed in the High Arctic may also be vulnerable to the effects of warming on the breeding grounds, which in the long-term may pose an additional threat to their populations (Nagy *et al.* 2021).



BAR-TAILED GODWIT

Population trend: **STABLE (DECLINING)**
Response to climate change: **NEGATIVE**
Vulnerability to climate change: **MEDIUM RISK**
Sensitivity to climate change mitigation: **MEDIUM**

BAR-TAILED GODWIT
Limosa lapponica

Bar-tailed Godwits are long-distance migrants that breed in the High Arctic but winter in the UK in internationally important numbers. Monitoring through WeBS has picked up 21% population declines from 1994–2019 (Frost *et al.* 2021). **This decline is associated with warmer winter temperatures reducing the number of individuals arriving in the UK** as they are able to survive the winter further east (Maclean *et al.* 2008).

Although warmer winter temperatures may boost adult survival and increase populations (Johnston *et al.* 2013), given high rates of warming in the Arctic, **Bar-tailed Godwit is one of the High Arctic breeding waders regarded as vulnerable to future impacts of climate change through impacts on breeding success** (Nagy *et al.* 2021).

Like many migrants, their future conservation is likely to depend upon international cooperation and the maintenance of an extensive network of large, protected sites which they rely on during migration and overwinter (Johnston *et al.* 2013). As with other waders, **their populations may also be vulnerable to large-scale wind farm development** (Pearce-Higgins *et al.* 2017).

BAR-TAILED GODWIT : LIZ CUTTING / BTO

MITIGATION

It is essential that we not only understand the potential future impacts of a changing climate on the populations of UK birds, but that we also identify any possible impacts that might arise from the mitigation measures, such as increasing renewable energy generation or planting trees to support net zero targets, that we adopt to counter or adapt to climate change.

Managing the impacts of mitigation measures on birds

A number of different approaches are being adopted to deal with the impacts of climate change, including adaptation and mitigation. Such measures might have their own impacts on the UK's birds, and we need to develop a good understanding of these so that we can identify the potentially vulnerable species.

We need extensive data on the distribution and abundance of species in order to identify where conflicts are most likely to occur, so they can be avoided, and we also need long-term monitoring in order to track those impacts into the future.

These principles are exemplified in relation to two areas of research where BTO is actively working. The first of these is that of tree planting to support net zero targets, and the second is the development of renewables, notably wind energy.

The principles can also be applied to other areas, such as changing farming practices to mitigate climate change, where BTO data and modelling are already informing potential policy responses (Lamb *et al.* 2019, Thomas *et al.* 2021), but here more fieldwork is required to quantify the bird responses to different potential land management options to inform future modelling predictions.

TURBINES : DAVID TIPLING / BIRDPHOTO.CO.UK

TREE PLANTING TO SUPPORT NET ZERO

Tree planting is strongly promoted for reasons of climate change mitigation. While it can provide considerable conservation benefits (Fuller & Robles 2017, Calladine *et al.* 2019), tree planting in the wrong place can come with significant costs, threatening naturally open ecosystems and the species using them (Graham *et al.* 2017).

In a UK context, there are ambitious annual tree planting targets of 5,000 hectares per year in Wales, 7,000 hectares in England and 12,000 hectares in Scotland, and a 9,000 hectares target by 2030 in Northern Ireland. **If not planned properly, these could be damaging to open country birds of conservation concern.** However, if planned well, they could make a positive and important contribution to supporting the conservation of woodland biodiversity, which in the case of woodland birds, has been in long-term decline (Defra 2020).

Previous large-scale tree planting during the 20th century targeted marginal upland habitats, where a suite of bird species of conservation concern are vulnerable to the negative impacts of afforestation (Bunce *et al.* 2010). **Of the 17 upland bird species for which associations between populations and woodland habitat have been studied, 11 show some form of avoidance or exclusion from mature woodland** (Pearce-Higgins *et al.* 2009).

Afforestation is regarded as one of the major threats to declining wader populations across the East Atlantic Flyway, which includes the UK (Pearce-Higgins *et al.* 2017). Large-scale maturation of **commercial plantations made a significant contribution to the 50% decline in breeding Curlew populations across the UK since 1994 (**Franks *et al.* 2017**) and the 70% decline in Black Grouse populations in Perthshire from 1990 to 2002** (Pearce-Higgins *et al.* 2007); both of which species are on the UK's Birds of Conservation Concern Red List. While some naturally forested landscapes, which include open and semi-open habitats, can support such species, **for many open country species, negative effects of commercial tree planting extend at least 1 km from the woodland edge** (Wilson *et al.* 2014).

Large-scale data collected by skilled volunteers, such as from the *Bird Atlas 2007–11*, **enable hotspots of vulnerable open-country species to be identified.** BTO is working with Forestry Commission England, Cairngorm National Park, Scottish Forestry and others to develop a wader sensitivity map for the UK, which will help regulators and the forestry industry to avoid tree-planting in areas where this could cause serious negative impacts for waders. This approach could be extended to identify the areas where tree planting has the greatest potential to benefit woodland bird conservation, as well as providing guidance about the most appropriate tree species and management regimes. **This combination of citizen science and professional research is a highly effective way of generating evidence that can be used by society to minimise conflicts between nature conservation and climate change mitigation**.

UPLAND PLANTING: JOHN CALLADINE / BTO

DUNLIN : EDMUND FELLOWES / BTO

DUNLIN

Population trend: **UNCERTAIN (DECLINING)**
Response to climate change: **NEGATIVE**
Vulnerability to climate change: **HIGH RISK**
Sensitivity to climate change mitigation: **HIGH**

DUNLIN
Calidris alpina

Although upland coverage of the Breeding Bird Survey is not quite sufficient to report on Dunlin populations, there has been a 20% range contraction from 1988–91 to 2007–11 (Balmer *et al.* 2013). Dunlin populations are highly vulnerable to future climate change (Pearce-Higgins *et al.* 2017).

Population declines in the Peak District have been linked to hydrology, with those occupying sites with a high water-table and high cranefly abundance the most stable (Carroll *et al.* 2015). The species is associated with pool systems, and large-scale peatland restoration, using the blocking of drainage ditches to raise water levels, is likely to benefit their populations by boosting cranefly and other insect populations (Carroll *et al.* 2011). Such measures are likely to increase the resilience of this species to future warming, whilst also delivering wider benefits for climate change mitigation and adaptation.

Dunlin are negatively affected by the fragmentation of open habitats by large-scale tree planting (Wilson *et al.* 2014).

MARINE RENEWABLES

The UK has plans for the delivery of 40 GW of offshore wind capacity by 2030. These must be balanced against obligations to protect internationally important seabird populations, which may be impacted directly as a result of mortality from collision, or indirectly through displacement and barrier effects and their consequences.

BTO research, which has been ongoing for more than a decade, is improving our understanding of the risks that seabirds face from offshore wind farms. Given high profile examples from coastal and onshore wind farms, collision is seen as a particular concern. Whilst many seabirds, such as auks and shearwaters, fly close to the sea surface and have a low risk of collision, others, such as Gannet and the gulls, fly higher and are at greater risk (Johnston *et al.* 2014, Ross-Smith *et al.* 2016). This work has identified that **not only is Kittiwake particularly vulnerable to climate change, but it also flies high enough to be at risk of collision with turbines**.

BTO work has highlighted the potential for raising turbine hub height as a mitigation measure to reduce collision risk within a wind farm (Johnston *et al.* 2014), an approach which has been widely adopted. This work demonstrates that offshore wind farms, which will be vital for effective climate change mitigation, can be delivered without adding to the pressures our seabirds already face, including from climate change.

Another aspect of this work is to establish how the distribution and behaviour of birds may influence their exposure to the impacts of collision, displacement and barrier effects. **This approach is supported through the collection of GPS data to better understand how flight heights and speeds influence the risk of collision or displacement.** Such information can be taken into account as projects are planned, helping developers to avoid particularly sensitive areas.

Whilst the focus has been offshore wind farms around the UK, migratory species may face similar threats elsewhere over the course of their annual cycles. Through the use of remote tracking technologies we have been able to track individuals from migratory populations of Lesser Black-backed Gulls, **highlighting their potential vulnerability to onshore wind farms** in Iberia, in addition to offshore wind farms in the UK (Thaxter *et al.* 2019).

BTO is playing a critical role, working with stakeholders from industry, NGOs and government, and providing robust scientific evidence to support and improve decision-making processes (Cook & Robinson 2017, Cook *et al.* 2018). As the industry continues to develop we will need in-depth monitoring of the impacts on seabird populations. Analyses by BTO have demonstrated that current monitoring is insufficient to detect the predicted impacts of offshore wind farms on key seabird populations (Cook et al. 2019), **highlighting the importance of supporting and developing national schemes, such as the Seabird Monitoring Programme**.

The offshore renewables industry is undergoing rapid global expansion, and many of the same issues apply, not least the lack of evidence to underpin decision-making processes. BTO's expertise in this area has been acknowledged internationally, as we have been asked to offer advice in relation to projects in Japan, Australia and the USA. BTO has led an assessment of the likely vulnerability to wind farms of bird and bat species around the world, **identifying the risks posed to birds of prey and at migratory hotspots** (Thaxter *et al.* 2017).

TURBINE : DAVID TIPLING / BIRDPHOTO.CO.UK

KITTIWAKE

Population trend: **MEDIUM DECLINE**
Response to climate change: **NEGATIVE**
Vulnerability to climate change: **HIGH RISK**
Sensitivity to climate change mitigation: **HIGH RISK**

KITTIWAKE
Rissa tridactyla

Kittiwake populations have declined by 29% since 2000 (JNCC 2021), linked to periods of poor productivity due to reductions in sandeel prey driven by increases in sea-surface temperature (reviewed by Johnston *et al.* 2021). Given their northern distribution in the UK, this makes them **highly vulnerable to future climate change**, with recent modelling **projecting a 54% decline in abundance across Great Britain and Ireland by 2050 under a high (RCP 8.5) climate change scenario** (Davies *et al.* 2021).

They are also highly sensitive to industrial sandeel fisheries, the closure of which may help populations cope with about 2°C of warming (Frederiksen *et al.* 2004).

Given the height at which they fly, **Kittiwakes may also be vulnerable to collision with offshore wind farms** (Cook *et al.* 2014) which due to their habitat preferences may overlap with areas suitable for offshore wind farm development (Thaxter *et al.* 2015). Increasing turbine size may reduce the risk of collision whilst increasing energy production (Cook *et al.* 2014).

KITTIWAKE : LIZ CUTTING / BTO

PROTECTED AREAS

The distributions of many species are changing in response to climate change. Whilst this led some to question the value of fixed protected sites in a changing climate, research, much of which uses BTO's large-scale and long-term data, has actually shown the reverse.

A functioning protected area network will play a critical role in enabling species to adapt to climate change. **Range-expanding bird species like Bittern and Dartford Warbler are three-times more likely to colonise protected areas than non-protected sites** (Thomas *et al.* 2012).

The protection of rare natural and semi-natural habitats within nature reserves appears to provide suitable areas for habitat specialists to colonise (Pearce-Higgins & Green 2014). For example, wetland nature reserves provide particularly important landing-sites for many colonising waterbirds (Hiley *et al.* 2013). In addition, **protected areas also enable species to persist in trailing-edge range-margins, where the climate is most marginal** (Gillingham *et al.* 2015); this may be because they offer better habitat and resource conditions, or because of the specific management practices often adopted at such sites.

The maintenance of an extensive network of large sites that protect important natural and semi-natural habitats, such as the Special Protection Areas established under the EU Birds Directive, will therefore play an important continent-wide role in the conservation of birds in a changing climate (Johnston *et al.* 2013).

Some 10.6% of the UK is covered by protected areas (27.8% including landscape-scale AONBs, NSAs and National Parks), although this figure is lowest in England at 6.5% (JNCC 2021). This means that the management of the wider countryside outside of protected sites will also be critical for climate change adaptation.

Within this wider landscape **there are clear conservation benefits to be gained from increasing the extent of natural habitats, improving their condition and connectivity with one another**, following the 'Lawton principles' (Lawton *et al.* 2010), which will also help species adapt to climate change. We already know that woodland bird populations at sites in a well-wooded landscape are more likely to recover quickly from cold-winter events than those occupying more isolated patches; this suggests that greater connectivity facilitates more rapid immigration and colonisation of such sites in species like Nuthatch (Newson *et al.* 2014).

Changes in the structure of butterfly and bird communities in response to warming are related to the extent of semi-natural habitat in the wider landscape (Oliver *et al.* 2017).

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LAND MANAGEMENT

The ways in which we manage our wider landscapes have benefited some species but impacted others. We have an opportunity to use the evidence from long-term monitoring and more intensive research studies to better shape future approaches to land management, as these shift in response to a changing climate.

This report has highlighted the vulnerability of northerly distributed upland bird species to climate change. Whilst this might paint a bleak picture for these species, there is growing evidence that **appropriate conservation management can reduce the vulnerability of these species to climate change**. For example, the current poor condition of many of the UK's upland peatlands exacerbates their vulnerability to hotter, drier summers, which reduces the availability of soil-dwelling invertebrates, such as craneflies, to the detriment of many upland bird species (Pearce-Higgins 2010, Pearce-Higgins *et al.* 2010).

In response to the damage caused by decades of artificial drainage that lowers water levels, conservation organisations and private land managers have been blocking drainage ditches to restore habitats. Ecologically, this can successfully raise water tables, increase the abundance of key invertebrate groups (Carroll *et al.* 2011), and benefit peatland breeding birds, such as Golden Plover (Pearce-Higgins *et al.* 2010, Pearce-Higgins 2011, Carroll *et al.* 2015). More than that, such habitat restoration can also improve the supply of drinking water, reduce vulnerability to wildfire and help protect soil carbon, delivering important nature-based solutions to climate change with multiple benefits (Smith & Chausson 2021).

With appropriate research and evidence, nature-based solutions to climate change adaptation can be developed that align the needs of biodiversity conservation and ecosystem services that benefit people and communities.

A second example of management to reduce negative climate change impacts is the recovery of Black Grouse in Wales. Populations like this, located at their southern edge of their range, are particularly vulnerable to climate change. This species is particularly sensitive to high levels of June rainfall, which can bring about large reductions in breeding success.

Analysis of data collected during the Welsh Black Grouse Recovery Project demonstrated that a combination of predator control and appropriate habitat management drove an increase in the national population (Lindley *et al*. 2003). **This management transformed the populations from being highly sensitive to June rainfall, when good breeding seasons only occurred during dry conditions, to being driven by positive responses to habitat management.** This suggests that **proactive management for vulnerable species can help them cope with even unfavourable weather conditions, increasing the resilience of their populations** to future detrimental impacts of climate change.

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THE METHODS WE USED

We use data from long-term monitoring schemes operated by BTO to examine the impacts of climate change on the UK's birds, and assess the vulnerability of individual species to both climate change and those measures that are being used to mitigate its effects.

MONITORING

Long-term monitoring is essential to documenting and understanding the impacts of climate change. In the UK, this is achieved primarily through citizen science monitoring projects that use a large number of skilled individuals to regularly count birds.

The **BTO/JNCC/RSPB Breeding Bird Survey** (BBS) monitors the population changes of 117 breeding bird species across the UK thanks to the dedication of almost 3,000 volunteers who survey the same randomly selected 1-km square(s) each spring.

Rarer species are either surveyed periodically through bespoke surveys, potentially involving a mix of professional and volunteer effort, or monitored annually through the collection of records from birdwatchers or specific study groups and reported through the **Rare Breeding Birds Panel**, also supported by JNCC.

Seabirds are covered by the **Seabird Monitoring Programme**, coordinated by JNCC, which aims to present annual monitoring of 25 species, although coverage is only sufficient to monitor 16 species at the moment. A seabird census takes place once every 20 years and provides a comprehensive stock-take across all species – Seabirds Count is currently underway, but the results are not yet available.

The **BTO/JNCC/RSPB Wetland Bird Survey** monitors internationally important non-breeding waterbird (waders, wildfowl and other waterbirds such as herons) populations in the UK, and also provides data for a small number of breeding species or migratory species with peak numbers during spring or autumn migratory passage. This covers a total of 94 species, with 14 separate populations of some waterfowl also reported where those have discrete distributions.

BBS VOLUNTEER : DAVID TIPLING / BTO

In addition to these annual data, comprehensive stock-takes of the country's bird life are achieved through periodic Atlases. **Bird Atlas 2007–11** was the most recent. Through the efforts of some 50,000 volunteers, this mapped birds in both winter and the breeding seasons from across Britain and Ireland. We use the 20-year index of distribution change from the previous Atlas (1998–91) to 2007–11 as an index of breeding population change for 24 species where population monitoring data are lacking, a metric which accounts for potential changes in recording bias.

From these different sources, we provide some form of population trend for 213 of 234 potentially breeding bird species in the UK, and from WeBS for 94 of the 177 wintering species, including 9 non-native wintering population trends.

BARNACLE GEESE : EDMUND FELLOWES / BTO

CLIMATE CHANGE STUDIES

A number of different approaches have been used to study the impacts of climate change on bird populations. **Detailed long-term studies of individual populations are able to collect demographic data on the survival and breeding success of species, and relate those to environmental changes, including ecological responses to climate change.** Such studies often provide an understanding of the processes and mechanisms that link population responses to climate change, particularly if they also collect additional environmental data, but are intensive and require considerable effort (e.g. Pearce-Higgins *et al.* 2010). **We term these mechanistic studies.** BTO's Nest Record Sc heme tracks long-term changes in the timing of breeding, whilst the Ringing Scheme also provides data on survival rates and breeding success (www.bto.org/birdtrends). Long-term analyses of such data enable us to better understand the impacts of climate change (Robinson *et al.* 2007, Eglington *et al.* 2015).

Alternatively, large-scale and long-term monitoring data, such as those gathered through the citizen science schemes outlined above, can be used to document large-scale responses to climate change across multiple species. Some studies relate spatial variation in distribution or abundance changes to the climate (e.g. Franks *et al.* 2017). **Others look at changes in the abundance of populations through time as a function of changes in climatic variables that in the short-term describe response to the weather but through time can describe some impacts of climate change** (Ockendon *et al.* 2014a, Pearce-Higgins & Crick 2019). **These are correlative studies**.

Attributing ecological responses to climate change is difficult (Parmesan *et al.* 2013). **The species whose population changes can be most confidently linked to climate change are those which show large-scale responses that are consistent with the results of well-evidenced mechanistic studies** (e.g. Kittiwake, Frederiksen *et al.* 2004; Golden Plover, Pearce-Higgins *et al.* 2010; Arctic skua, Perkins *et al.* 2018), whilst the results from correlative studies (e.g. Pearce-Higgins & Crick 2019) will have a greater level of uncertainty associated with them.

FUTURE PROJECTIONS

Assessments of species' vulnerability to climate change depend upon adequately describing the link between a species' distribution and/or abundance and climate, and then using climatologists' projections of future climate to indicate how species are likely to respond. These projections vary with uncertainty in modelling the climate system, the amount of greenhouse gas emissions modelled in the atmosphere and the time-scale over which projections are made. The latest (sixth) IPCC report states that it is 'unequivocal that human influence has warmed the atmosphere, ocean and land.' (IPCC 2021), and that 'Global surface temperature will continue to increase until at least the mid-century under all emissions scenarios considered'. The magnitude of climate change is dependent upon the rate of ongoing greenhouse gas emissions, which will in turn affect the precise impact of warming upon the UK climate (UKCP18). The latest projection for the UK are the UKCP18 projections available from the Met Office (https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/index)

A number of different approaches to assessing species' vulnerability to climate change exist (Foden & Young 2016, Foden 2019). **In this report, we use a number of related assessments that combine projected species' responses to climate change with additional ecological information to assess climate change vulnerability.** The Thomas *et al.* (2010) framework uses models linking spatial variation in bird occurrence and climate to make projections into the future. In its basic application, projected future trends are combined with observed trends to assess vulnerability, whilst in the full application, extra information on the ecology of the species and the existence of additional non-climatic constraints that may have limited species' responses, moderate those vulnerability assessments (see Pearce-Higgins *et al.* 2017 for more detail).

For a subset of species, models of abundance, rather than occurrence are available based upon the models of Johnston *et al.* (2013), reported in Pearce-Higgins *et al.* (2015), or using more bespoke modelling for seabirds that also incorporates oceanographic variables (Davies *et al.* 2021). These abundance models are used in preference to the occurrence models of Pearce-Higgins et al. 2017). Finally, for a small number of species, unpublished models using the same Thomas *et al.* (2010) framework and models as Pearce-Higgins *et al.* (2017) were used (Ausden *et al.* unpubl.). All approaches use projections from UKCP09 based on a medium climate change scenario (A1B) to 2080, roughly analogous to a 3°C global warming scenario, with the exception of Davies *et al.* (2021) which used a higher emissions pathway RCP8.5, but to 2050, and so is approximately equivalent in terms of warming (Rogelj *et al.* 2012).

MODELLING

Having assessed the impacts of temperature and precipitation from climate change studies, we link these to species' long-term trends, standardised to an annual rate of change to account for differences in the duration of monitoring between species. **We test the extent to which breeding and wintering population trends vary between species with positive, negative or no / mixed responses to temperature and rainfall using a linear model.** We also test the extent to which standardised long-term trends, and species' responses to temperature (coded into -1 for negative, 0 for mixed or no-effect and 1 for positive) also differ between species-groups, classified by primarily habitat association. **Habitat classifications are based on the allocation of birds to wild bird indicators and empirical data on habitat associations from BTO's BirdFacts pages.**

Appendix 2. Table showing the categorisation and assessment data for individual species used in the analyses summarised in this report. Detail on the categories and assessment information appears as a footnote to this table.

Species	Breeding habitat	Breeding pop trend	Data source	Winter pop trend	Data source	Climate change breeding	Climate change wintering	TempB	RainB	TempW	RainW	Breeding population vulnerability	Winter population vulnerability
Arctic Skua	Marine		SMP			-ve (M)		-ve				HIGH RISK	
Arctic Tern	Marine		SMP			-ve (M)		-ve				HIGH RISK	
Avocet	Coastal		RBBP		WeBS							HIGH BENEFIT	HIGH BENEFIT
Bar-headed Goose	Non-native				WeBS								
Barn Owl	Farmland		BBS			+ve (M)		+ve				HIGH BENEFIT	
Barnacle Goose	Non-native		WeBS		WeBS								
Bar-tailed Godwit					WeBS		-ve (C)			-ve			MEDIUM RISK
Bean Goose					WeBS								
Bearded Tit	Wetland		RBBP									HIGH BENEFIT	
Bewick's Swan					WeBS		-ve (M)			-ve			MEDIUM RISK
Bittern	Wetland		RBBP		WeBS	-ve (M)			-ve			LIMITED IMPACT	
Black Grouse	Upland		PAPER			-ve (M)			-ve			MEDIUM RISK	
Black Guillemot	Marine		ATLAS									HIGH RISK	
Black Redstart	Urban		RBBP									HIGH BENEFIT	
Black Swan	Non-native				WeBS								
Blackbird	Woodland		BBS			No/Mix		No/Mix	+ve			LIMITED IMPACT	
Blackcap	Woodland		BBS			No/Mix	+ve (M)	No/Mix	+ve	+ve		MEDIUM BENEFIT	
Black-headed Gull	Coastal		SMP		WeBS	+ve (C)		+ve				HIGH BENEFIT	
Black-necked Grebe	Wetland		RBBP		WeBS								
Black-tailed Godwit	Wetland		RBBP		WeBS	-ve (M)			-ve			HIGH BENEFIT	
Black-throated Diver	Wetland		PAPER		WeBS							HIGH BENEFIT	
Black-winged Stilt	Coastal		RBBP										
Blue Tit	Woodland		BBS			No/Mix		No/Mix	No/Mix			MEDIUM BENEFIT	
Brambling	Woodland												
Brent Goose					WeBS		-ve (M)			-ve			HIGH BENEFIT
Bullfinch	Woodland		BBS			No/Mix		No/Mix	No/Mix			LIMITED IMPACT	
Buzzard	Woodland		BBS									LIMITED IMPACT	
Canada Goose	Non-native		BBS		WeBS	+ve (C)		+ve				MEDIUM RISK	
Capercaillie	Woodland		PAPER			-ve (M)		No/Mix	-ve			HIGH RISK	

Species	Breeding habitat	Breeding pop trend	Data source	Winter pop trend	Data source	Climate change breeding	Climate change wintering	TempB	RainB	TempW	RainW	Breeding population vulnerability	Winter population vulnerability
Carrion Crow	Urban		BBS			No/Mix		No/Mix	No/Mix			MEDIUM BENEFIT	
Caspian Gull													
Cattle Egret	Wetland		RBBP		WeBS								
Cetti's Warbler	Wetland		BBS			+ve (M)		+ve				HIGH BENEFIT	
Chaffinch	Woodland		BBS			No/Mix		No/Mix	No/Mix			LIMITED IMPACT	
Chiffchaff	Woodland		BBS			No/Mix		No/Mix	No/Mix			MEDIUM BENEFIT	
Chough	Farmland		PAPER										
Cirl Bunting	Farmland		PAPER									HIGH BENEFIT	
Coal Tit	Woodland		BBS			No/Mix		No/Mix	No/Mix			RISK & BENEFIT	
Collared Dove	Urban		BBS									LIMITED IMPACT	
Common Guillemot	Marine		SMP			-ve (M)		-ve				MEDIUM RISK	
Common Gull	Coastal		ATLAS		WeBS							MEDIUM BENEFIT	
Common Redpoll	Woodland					No/Mix		No/Mix	No/Mix				
Common Sandpiper	Upland		BBS			+ve (M)		+ve				RISK & BENEFIT	
Common Scoter	Wetland		RBBP		WeBS		+ve (C)			+ve		RISK & BENEFIT	HIGH BENEFIT
Common Tern	Marine		SMP			-ve (C)		-ve				HIGH BENEFIT	
Coot	Wetland		BBS		WeBS	+ve (C)		+ve	No/Mix			LIMITED IMPACT	MEDIUM RISK
Cormorant	Marine		SMP		WeBS	-ve (C)	+ve (C)	-ve		+ve		HIGH RISK	
Corn Bunting	Farmland		BBS			+ve (C)		No/Mix	No/Mix			LIMITED IMPACT	
Corncrake	Farmland		PAPER									MEDIUM BENEFIT	
Crane	Wetland		RBBP		WeBS								
Crested Tit	Woodland		ATLAS									RISK & BENEFIT	
Crossbill	Woodland		BBS									MEDIUM RISK	
Cuckoo	Woodland		BBS			-ve (C)		-ve	+ve			HIGH RISK	
Curlew	Upland		BBS		WeBS	-ve (C)	No/Mix	-ve	+ve	No/Mix		HIGH RISK	HIGH BENEFIT
Curlew Sandpiper													
Dartford Warbler	Heathland		PAPER			+ve (C)						HIGH BENEFIT	
Dipper	Upland		BBS									HIGH RISK	
Dotterel	Upland		PAPER			No/Mix		No/Mix	+ve			HIGH RISK	
Dunlin	Upland		ATLAS		WeBS	-ve (M)			+ve			HIGH RISK	
Dunnock	Woodland		BBS			+ve (C)		+ve	No/Mix			LIMITED IMPACT	
Egyptian Goose	Non-native		BBS		WeBS	No/Mix		No/Mix					

Species	Breeding habitat	Breeding pop trend	Data source	Winter pop trend	Data source	Climate change breeding	Climate change wintering	TempB	RainB	TempW	RainW	Breeding population vulnerability	Winter population vulnerability
Eider	Coastal		ATLAS		WeBS		+ve (C)			+ve		RISK & BENEFIT	HIGH RISK
Fieldfare	Woodland		ATLAS									RISK & BENEFIT	
Firecrest	Woodland		ATLAS			+ve (C)		+ve				HIGH BENEFIT	
Fulmar	Marine		SMP			-ve (M)		-ve				HIGH RISK	
Gadwall	Wetland		BBS		WeBS							HIGH BENEFIT	MEDIUM RISK
Gannet	Marine		SMP			+ve (C)		+ve				LIMITED IMPACT	
Garden Warbler	Woodland		BBS			No/Mix		No/Mix	No/Mix			HIGH RISK	
Garganey	Wetland		RBBP									HIGH BENEFIT	
Glaucous Gull													
Glossy Ibis	Wetland		RBBP										
Goldcrest	Woodland		BBS			+ve (C)		+ve	No/Mix			RISK & BENEFIT	
Golden Eagle	Upland		PAPER									HIGH RISK	
Golden Oriole	Woodland		RBBP									HIGH BENEFIT	
Golden Pheasant	Non-native		ATLAS										
Golden Plover	Upland		BBS		WeBS	-ve (M)		No/Mix	+ve			HIGH RISK	HIGH BENEFIT
Goldeneye	Wetland		ATLAS		WeBS		-ve (C)			-ve		MEDIUM BENEFIT	RISK & BENEFIT
Goldfinch	Farmland		BBS			+ve (C)		+ve	No/Mix			MEDIUM BENEFIT	
Goosander	Wetland		BBS		WeBS		-ve (C)			-ve		HIGH RISK	MEDIUM RISK
Goshawk	Woodland		RBBP									MEDIUM BENEFIT	
Grasshopper Warbler	Wetland		BBS									HIGH BENEFIT	
Great Black-backed Gull	Marine		SMP		WeBS	-ve (C)		-ve				HIGH RISK	
Great Bustard	Heathland												
Great Crested Grebe	Wetland		BBS		WeBS		-ve (C)			-ve		LIMITED IMPACT	MEDIUM RISK
Great Grey Shrike													
Great Northern Diver					WeBS								
Great Skua	Marine		ATLAS										
Great Spotted Woodpecker	Woodland		BBS			No/Mix		No/Mix	No/Mix			LIMITED IMPACT	
Great Tit	Woodland		BBS			No/Mix		-ve	No/Mix			MEDIUM BENEFIT	
Great White Egret	Wetland		RBBP		WeBS							HIGH BENEFIT	
Green Sandpiper	Woodland		RBBP		WeBS							HIGH RISK	LIMITED IMPACT
Green Woodpecker	Woodland		BBS			No/Mix		No/Mix	No/Mix			LIMITED IMPACT	
Greenfinch	Farmland		BBS			+ve (C)		No/Mix	No/Mix			MEDIUM BENEFIT	

Species	Breeding habitat	Breeding pop trend	Data source	Winter pop trend	Data source	Climate change breeding	Climate change wintering	TempB	RainB	TempW	RainW	Breeding population vulnerability	Winter population vulnerability
Greenshank	Upland		ATLAS		WeBS							HIGH RISK	HIGH BENEFIT
Grey Heron	Wetland		HERON		WeBS	+ve (C)		+ve				MEDIUM BENEFIT	
Grey Partridge	Farmland		BBS			+ve (C)		+ve	No/Mix			HIGH RISK	
Grey Phalarope													
Grey Plover					WeBS		-ve (C)			-ve			HIGH BENEFIT
Grey Wagtail	Upland		BBS									RISK & BENEFIT	
Greylag Goose	Non-native		BBS		WeBS	+ve (C)		+ve					HIGH RISK
Hawfinch	Woodland		ATLAS									HIGH BENEFIT	
Hen Harrier	Upland		PAPER			No/Mix						HIGH RISK	
Herring Gull	Coastal		ATLAS		WeBS	-ve (C)		-ve				HIGH RISK	
Hobby	Heathland		BBS									RISK & BENEFIT	
Honey-buzzard	Woodland		RBBP										
Hooded Crow	Farmland		BBS										
House Martin	Urban		BBS			No/Mix		No/Mix	+ve			LIMITED IMPACT	
House Sparrow	Urban		BBS									LIMITED IMPACT	
Iceland Gull													
Indian Peafowl	Non-native		BBS										
Jack Snipe					WeBS								
Jackdaw	Farmland		BBS			No/Mix		+ve	+ve			LIMITED IMPACT	
Jay	Woodland		BBS			No/Mix		No/Mix	No/Mix			MEDIUM BENEFIT	
Kestrel	Farmland		BBS			No/Mix		No/Mix	No/Mix			LIMITED IMPACT	
Kingfisher	Wetland		WBBS		WeBS	+ve (C)		+ve				RISK & BENEFIT	
Kittiwake	Marine		SMP		WeBS	-ve (M)		-ve				HIGH RISK	
Knot					WeBS		-ve (C)			-ve			LIMITED IMPACT
Lady Amherst's Pheasant	Non-native												
Lapland Bunting													
Lapwing	Farmland		BBS		WeBS	+ve (M)		+ve	No/Mix			HIGH RISK	MEDIUM RISK
Leach's Petrel	Marine												
Lesser Black-backed Gull	Coastal		ATLAS		WeBS	No/Mix		No/Mix				HIGH BENEFIT	
Lesser Redpoll	Woodland		BBS									HIGH RISK	
Lesser Spotted Woodpecker	Woodland		CBC			-ve (M)		-ve				HIGH BENEFIT	
Lesser White-fronted Goose													

Species	Breeding habitat	Breeding pop trend	Data source	Winter pop trend	Data source	Climate change breeding	Climate change wintering	TempB	RainB	TempW	RainW	Breeding population vulnerability	Winter population vulnerability
Lesser Whitethroat	Woodland		BBS									RISK & BENEFIT	
Linnet	Farmland		BBS			+ve (C)		+ve	No/Mix			LIMITED IMPACT	
Little Bittern	Wetland		RBBP										
Little Egret	Wetland		BBS		WeBS							HIGH BENEFIT	
Little Grebe	Wetland		BBS		WeBS							LIMITED IMPACT	MEDIUM RISK
Little Gull					WeBS								
Little Owl	Non-native		BBS			-ve (C)		No/Mix	No/Mix			MEDIUM BENEFIT	
Little Ringed Plover	Wetland		PAPER									HIGH BENEFIT	
Little Stint													
Little Tern	Marine		SMP			-ve (C)		-ve				HIGH RISK	
Long-eared Owl	Woodland											MEDIUM RISK	
Long-tailed Duck					WeBS		+ve (C)			+ve			HIGH RISK
Long-tailed Skua													
Long-tailed Tit	Woodland		BBS			+ve (C)		+ve	No/Mix			MEDIUM BENEFIT	
Magpie	Urban		BBS			No/Mix		No/Mix	No/Mix			MEDIUM BENEFIT	
Mallard	Wetland		BBS		WeBS	No/Mix	-ve (C)	+ve		-ve		LIMITED IMPACT	HIGH RISK
Mandarin Duck	Non-native		BBS		WeBS							MEDIUM RISK	
Manx Shearwater	Marine												
Marsh Harrier	Wetland		RBBP									HIGH BENEFIT	
Marsh Tit	Woodland		BBS									HIGH RISK	
Marsh Warbler	Wetland		RBBP										
Meadow Pipit	Upland		BBS			No/Mix		No/Mix	No/Mix			RISK & BENEFIT	
Mediterranean Gull	Coastal		SMP		WeBS								
Merlin	Upland		PAPER									MEDIUM RISK	
Mistle Thrush	Woodland		BBS			No/Mix		No/Mix	No/Mix			MEDIUM BENEFIT	
Montagu's Harrier	Farmland		RBBP									HIGH BENEFIT	
Moorhen	Wetland		BBS		WeBS	+ve (C)		+ve	No/Mix			RISK & BENEFIT	
Muscovy Duck	Non-native				WeBS								
Mute Swan	Wetland		BBS		WeBS	No/Mix		No/Mix				LOW RISK	
Night-heron	Wetland		RBBP									LIMITED IMPACT	
Nightingale	Woodland		BBS									MEDIUM BENEFIT	
Nightjar	Heathland		PAPER									HIGH BENEFIT	

Species	Breeding habitat	Breeding pop trend	Data source	Winter pop trend	Data source	Climate change breeding	Climate change wintering	TempB	RainB	TempW	RainW	Breeding population vulnerability	Winter population vulnerability
Nuthatch	Woodland		BBS			No/Mix		No/Mix	No/Mix			LIMITED IMPACT	
Osprey	Wetland		RBBP									RISK & BENEFIT	
Oystercatcher	Coastal		BBS		WeBS		+ve (C)			+ve		LIMITED IMPACT	MEDIUM RISK
Pallid Harrier													
Parrot Crossbill	Woodland												
Peregrine	Upland		BBS									HIGH RISK	
Pheasant	Non-native		BBS			+ve (C)		+ve	No/Mix			MEDIUM BENEFIT	
Pied Flycatcher	Woodland		BBS			-ve (C)		-ve				HIGH RISK	
Pied Wagtail	Urban		BBS			+ve (C)		+ve	No/Mix			MEDIUM BENEFIT	
Pink-footed Goose					WeBS								MEDIUM RISK
Pintail	Wetland		RBBP		WeBS							RISK & BENEFIT	LOW RISK
Pochard	Wetland		RBBP		WeBS		No/Mix						HIGH RISK
Pomarine Skua													
Ptarmigan	Upland		ATLAS									RISK & BENEFIT	
Puffin	Marine		ATLAS			-ve (M)		-ve				HIGH RISK	
Purple Heron	Wetland											MEDIUM BENEFIT	
Purple Sandpiper	Upland		RBBP		WeBS		-ve (C)			-ve		HIGH RISK	MEDIUM RISK
Quail	Farmland		RBBP									MEDIUM BENEFIT	
Raven	Upland		BBS									RISK & BENEFIT	
Razorbill	Marine		SMP									MEDIUM RISK	
Red Grouse	Upland		BBS			-ve (M)		+ve	-ve			HIGH RISK	
Red Kite	Woodland		BBS									HIGH RISK	
Red-backed Shrike	Heathland		RBBP			No/Mix		No/Mix				HIGH BENEFIT	
Red-breasted Merganser	Coastal		ATLAS		WeBS		-ve (C)			-ve		MEDIUM RISK	MEDIUM BENEFIT
Red-crested Pochard	Non-native		ATLAS		WeBS								
Red-legged Partridge	Non-native		BBS			+ve (C)		+ve	No/Mix			RISK & BENEFIT	
Red-necked Grebe	Wetland				WeBS								
Red-necked Phalarope	Wetland		RBBP									RISK & BENEFIT	
Redshank	Coastal		BBS		WeBS		-ve (C)			+ve	-ve	LIMITED IMPACT	LIMITED IMPACT
Redstart	Woodland		BBS			No/Mix		No/Mix	+ve			HIGH RISK	
Red-throated Diver	Wetland		PAPER		WeBS							HIGH BENEFIT	
Redwing	Woodland		RBBP									HIGH RISK	

Species	Breeding habitat	Breeding pop trend	Data source	Winter pop trend	Data source	Climate change breeding	Climate change wintering	TempB	RainB	TempW	RainW	Breeding population vulnerability	Winter population vulnerability
Reed Bunting	Farmland		BBS			No/Mix		+ve	No/Mix			LIMITED IMPACT	
Reed Warbler	Wetland		BBS			No/Mix		No/Mix	+ve			HIGH BENEFIT	
Ring Ouzel	Upland		PAPER			-ve (C)		-ve	+ve			HIGH RISK	
Ringed Plover	Coastal		PAPER		WeBS							HIGH BENEFIT	MEDIUM BENEFIT
Ring-necked Parakeet	Non-native		BBS			No/Mix		No/Mix				HIGH BENEFIT	
Robin	Woodland		BBS			No/Mix		No/Mix	No/Mix			LIMITED IMPACT	
Rock Dove / Feral Pigeon	Urban		BBS									LIMITED IMPACT	
Rock Pipit	Coastal		ATLAS									HIGH BENEFIT	
Rook	Farmland		BBS									LIMITED IMPACT	
Roseate Tern	Marine		SMP										
Ruddy Duck	Non-native		ATLAS		WeBS								
Ruff	Wetland		RBBP		WeBS							MEDIUM BENEFIT	
Sabine's Gull													
Sand Martin	Wetland		BBS			No/Mix		No/Mix	+ve			MEDIUM BENEFIT	
Sanderling					WeBS		-ve (C)			-ve			HIGH BENEFIT
Sandwich Tern	Marine		SMP			No/Mix		No/Mix				MEDIUM RISK	
Savi's Warbler	Wetland		RBBP									HIGH BENEFIT	
Scaup					WeBS		-ve (C)			-ve			MEDIUM BENEFIT
Scottish Crossbill	Woodland												
Sedge Warbler	Wetland		BBS			No/Mix		No/Mix	+ve			RISK & BENEFIT	
Shag	Marine		SMP		WeBS	-ve (M)	No/Mix	-ve	-ve			MEDIUM RISK	
Shelduck	Coastal		BBS		WeBS							HIGH BENEFIT	HIGH BENEFIT
Shore Lark													
Short-eared Owl	Upland											HIGH RISK	
Short-toed Treecreeper													
Shoveler	Wetland		ATLAS		WeBS							HIGH BENEFIT	HIGH BENEFIT
Siskin	Woodland		BBS									RISK & BENEFIT	
Skylark	Farmland		BBS			No/Mix		+ve	No/Mix			LIMITED IMPACT	
Slavonian Grebe	Wetland		RBBP		WeBS	No/Mix		+ve	-ve				HIGH BENEFIT
Smew					WeBS		-ve (C)			-ve			
Snipe	Wetland		BBS		WeBS							HIGH RISK	HIGH BENEFIT
Snow Bunting	Upland											RISK & BENEFIT	

Species	Breeding habitat	Breeding pop trend	Data source	Winter pop trend	Data source	Climate change breeding	Climate change wintering	TempB	RainB	TempW	RainW	Breeding population vulnerability	Winter population vulnerability
Snow Goose	Non-native				WeBS								
Snowy Owl	Upland												
Song Thrush	Woodland		BBS			+ve (M)		+ve	+ve			LIMITED IMPACT	
Sparrowhawk	Woodland		BBS									RISK & BENEFIT	
Spoonbill	Wetland		RBBP		WeBS								
Spotted Crake	Wetland		RBBP									HIGH BENEFIT	
Spotted Flycatcher	Woodland		BBS			No/Mix		No/Mix	No/Mix			MEDIUM RISK	
Spotted Redshank					WeBS								
Starling	Urban		BBS			No/Mix		No/Mix	No/Mix			LIMITED IMPACT	
Stock Dove	Farmland		BBS			No/Mix		No/Mix	No/Mix			LIMITED IMPACT	
Stonechat	Heathland		BBS									LIMITED IMPACT	
Stone-curlew	Heathland		RBBP									HIGH BENEFIT	
Storm Petrel	Marine											HIGH RISK	
Swallow	Farmland		BBS			No/Mix		No/Mix	+ve			MEDIUM BENEFIT	
Swift	Urban		BBS									MEDIUM BENEFIT	
Tawny Owl	Woodland		BBS			No/Mix		+ve	No/Mix			RISK & BENEFIT	
Teal	Wetland		BBS		WeBS							MEDIUM RISK	HIGH BENEFIT
Temminck's Stint	Upland		RBBP									RISK & BENEFIT	
Tree Pipit	Woodland		BBS			No/Mix		No/Mix	+ve			HIGH RISK	
Tree Sparrow	Farmland		BBS			No/Mix		No/Mix	No/Mix			LIMITED IMPACT	
Treecreeper	Woodland		BBS			No/Mix		No/Mix	-ve			MEDIUM RISK	
Tufted Duck	Wetland		BBS		WeBS		-ve (C)			-ve		MEDIUM BENEFIT	MEDIUM RISK
Turnstone					WeBS								
Turtle Dove	Farmland		BBS			No/Mix		No/Mix	No/Mix			LIMITED IMPACT	
Twite	Upland		PAPER									HIGH RISK	
Velvet Scoter					WeBS		No/Mix						MEDIUM RISK
Water Pipit													
Water Rail	Wetland		ATLAS		WeBS							HIGH BENEFIT	
Waxwing													
Wheatear	Upland		BBS					-ve	+ve			MEDIUM RISK	
Whimbrel	Upland		ATLAS		WeBS							HIGH RISK	LIMITED IMPACT
Whinchat	Upland		BBS									HIGH RISK	

Species	Breeding habitat	Breeding pop trend	Data source	Winter pop trend	Data source	Climate change breeding	Climate change wintering	TempB	RainB	TempW	RainW	Breeding population vulnerability	Winter population vulnerability
White Stork	Farmland												
White-billed Diver													
White-fronted Goose					WeBS		-ve (C)			-ve	-ve		
White-tailed Eagle	Coastal		RBBP									LIMITED IMPACT	
Whitethroat	Farmland		BBS			No/Mix		No/Mix	+ve			LIMITED IMPACT	
Whooper Swan	Wetland		RBBP		WeBS		+ve (C)			+ve			MEDIUM RISK
Wigeon	Wetland		ATLAS		WeBS							HIGH RISK	MEDIUM RISK
Willow Tit	Woodland		BBS									HIGH RISK	
Willow Warbler	Woodland		BBS			-ve (M)		No/Mix	No/Mix			RISK & BENEFIT	
Wood Sandpiper	Upland		RBBP									RISK & BENEFIT	
Wood Warbler	Woodland		BBS									HIGH RISK	
Woodcock	Woodland		PAPER		WeBS							HIGH RISK	
Woodlark	Heathland		PAPER			No/Mix						HIGH BENEFIT	
Woodpigeon	Farmland		BBS			No/Mix		No/Mix	No/Mix			MEDIUM BENEFIT	
Wren	Woodland		BBS			+ve (M)		+ve	No/Mix			LIMITED IMPACT	
Yellow Wagtail	Farmland		BBS			No/Mix		No/Mix	-ve			LIMITED IMPACT	
Yellowhammer	Farmland		BBS			No/Mix		No/Mix	No/Mix			MEDIUM RISK	
Yellow-legged Gull					WeBS								

FOOTNOTE: Breeding habitat is derived from a combination of Breeding Bird Survey habitat associations, the current habitat breakdown of the indicator suite, and other published sources.

Breeding population trend and **Winter population trend** are scored using the same criteria as for the species groups (large decline <50%, medium decline < 25%, stable or small decline/increase, medium increase >33%, large increase >100%).

Data sources for the breeding and winter trends are: **ATLAS**=Atlas data, **BBS**=Breeding Bird Survey, **CBC**=Common Birds Census, **HERON**=Heronries Census, **PAPER**=Peer-reviewed paper, **RBBP**=Rare Breeding Birds Panel, **SMP**=Seabird Monitoring Programme, **WBBS**=Waterways Breeding Bird Survey, **WeBS**=Wetland Bird Survey.

Climate change breeding and **Climate change winter** highlight evidence of impacts on breeding and wintering populations respectively, presented in peer-reviewed studies where: -ve denotes a negative impact and +ve a positive impact. The studies are categorised as (C)orrelative or (M)echanistic and greater emphasis is given on mechanistic studies.

The effects of Temperature on breeding populations (**TempB**) and winter populations (**TempW**), and of rainfall on breeding populations (**RainB**) and winter populations (**RainW**) are shown where significant positive (+ve) and negative (-ve) relationships have been found in the peer-reviewed studies. Note that this means, for example, that effects on breeding populations in the winter are listed in the breeding column.

Breeding population vulnerability and **Winter population vulnerability** show the vulnerability score derived from various sources (see methods)..

In 2019, an independent review panel concluded that BTO has had a remarkable impact on policy and practice given its size and resources.

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BTO
Inspired by birds, informed by science

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