



BTO Research Report 369

**The effect of climate change
on bird species in the UK**

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EXECUTIVE SUMMARY

1. Mean annual global temperatures have increased by 0.6°C since 1900, making the 1990s the warmest decade in the millennium. The Intergovernmental Panel on Climate Change (IPCC), in its 3rd Assessment report (2002), stated that "most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations" and went on to say that there was "new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities."
2. Temperature and precipitation levels can influence survival rates and productivity and the movement of individuals into and out of a population either directly, for example through their actions on the energetic costs of thermoregulation, or indirectly, for example by determining the availability or accessibility of food supplies.
3. Changes in survival rates, productivity and immigration/emigration rates may lead to changes in species abundance in some cases. However, density-dependent processes, such as competition for resources, may act to maintain numbers, such that they fluctuate about a certain level. For example, as the size of a population is reduced, the remaining individuals may benefit from the increased availability of food or nesting places, resulting in higher survival rates and/or greater productivity.
4. Responses of birds to climate change in the UK during the previous century have been well documented.
 - Changes in sea temperatures have affected food availability for some seabird species, including Common Guillemot (*Uria aalge*) and Kittiwake (*Rissa tridactyla*), resulting in reduced breeding success.
 - An increasing number of short-distance (intra-European) migrants from continental breeding populations, including many Blackcap (*Sylvia atricapilla*), are now wintering in the UK rather than moving to their more traditional wintering grounds in the Mediterranean Basin. An easterly and northerly shift in the distribution of waders such as Ringed Plover (*Charadrius hiaticula*) and Dunlin (*Calidris alpina*) wintering in Britain has also been demonstrated.
 - Laying dates of a wide range of UK breeding species have advanced seasonally since the 1970s.
 - Summer migrants have advanced their arrival time and, at least for short-distance migrants, may also have delayed their departure to the wintering grounds.
 - Changes in the distribution of some European species, for example Black Redstart (*Phoenicurus ochruros*) and Cetti's Warbler (*Cettia cetti*), may have resulted in their colonisation of the UK. Breeding ranges of UK avifauna have, on average, moved northwards since the 1970s.
5. Climatic models for the next 75 years predict that winters in the UK will become warmer and wetter, whilst summers will become warmer and drier, leading to a reduction in the moisture content of the soil. The frequency of extreme events such as storms, droughts and floods, is also predicted to increase. Sea level is predicted to continue to rise.

6. Climatic warming may increase over-winter survival by reducing thermoregulatory costs and increasing food availability for many terrestrial species. However, increased winter rainfall may reduce the survival rates of wader species, particularly first-year birds, and of terrestrial species such as Treecreeper (*Certhia familiaris*) that are particularly susceptible to wetting.
7. Warmer, drier summers may also increase productivity, particularly for insectivorous species and aerial predators that may benefit from the increasing abundance and/or activity of their prey species. However, the reduction in soil moisture content in summer may reduce food availability, and therefore productivity, for wader (e.g. Snipe (*Gallinago gallinago*), Curlew (*Numenius arquata*)) and passerine (e.g. Blackbird (*Turdus merula*), Song Thrush (*Turdus philomelos*)) species feeding on soil invertebrates.
8. Shifts in the North Atlantic Oscillation (NAO) are likely to influence oceanic currents and sea surface temperatures. These in turn will affect the abundance of prey species available to breeding seabirds in the UK.
9. Increasing spring temperatures are likely to result in the continued seasonal advancement of leaf, and therefore caterpillar, emergence dates. Further advancement of laying dates is therefore predicted. However, there is increasing evidence to suggest that constraints preventing sufficient advancement of laying dates may lead to increasing asynchrony between peak offspring demand and peak food availability for some species, significantly reducing productivity for species such as Great Tit (*Parus major*). Long-distance summer migrants such as Common Redstart (*Phoenicurus phoenicurus*) and Pied Flycatcher (*Ficedula hypoleuca*) may be particularly susceptible to such asynchrony if environmental cues used to initiate departure from the wintering grounds do not advance at the same rate as the phenology of the resources on the breeding grounds.
10. Northward and westward shifts in species distribution may lead to the colonisation of the UK by novel species from the continent, but may also lead to the loss of species restricted to breeding either at high altitudes (e.g. Ptarmigan (*Lagopus mutus*), Snow Bunting (*Plectrophenax nivalis*)) or in northern Scotland (e.g. Whooper Swan (*Cygnus cygnus*), Arctic Skua (*Stercorarius parasiticus*), Greenshank (*Tringa nebularia*)). Reductions in internationally important non-breeding wader populations resulting from an eastwards shift in the preferred wintering grounds might also be predicted for species such as Sanderling (*Calidris alba*) and Purple Sandpiper (*Calidris maritima*). Even under conservative scenarios, populations are predicted to decrease by up to 60%. Indeed, declines in populations of eight out of 14 common wader species have already been recorded. These distributional shifts may have important impacts on the effectiveness of current conservation policy in the UK.
11. Inter-tidal environments, such as mudflats and salt marshes, would naturally respond to increases in sea level by retreating inland. However, the presence of coastal defences and human habitation may prevent retreat in many areas, resulting in inundation and habitat loss. Other coastal habitats, such as reedbeds, may also be affected by increasing salinity. The consequences of these changes could be severe for breeding species such as Bittern (*Botaurus stellaris*) and wintering species such as Twite (*Carduelis flavirostris*). The creation of new habitat through managed retreat

schemes may potentially increase the area of some inter-tidal habitats and therefore the size of the bird populations that they are able to support. This may be particularly beneficial in terms of global conservation, as internationally important numbers of waders and wildfowl utilise these habitats during the winter months.

12. Climate change outside the UK could have severe repercussions for migrant species. Reduced rainfall, particularly on the margins of the Sahara, and an increase in the incidence of extreme weather events may reduce food availability and therefore population sizes of long-distance migrants wintering in Africa such as Swallow (*Hirundo rustica*), Common Whitethroat (*Sylvia communis*) and Sedge Warbler (*Acrocephalus schoenobaenus*). Northward movement of temperate habitats in the high Arctic is likely to greatly reduce the availability of breeding habitat for many wader and geese species that winter in the UK, including Knot (*Calidris canuta*) and Bean Goose (*Anser fabalis*), in the latter case by as much as 93%. However, warmer wintering conditions may permit more short-distance migrants to remain on, or close to, their breeding grounds (e.g. Chiffchaff (*Phylloscopus collybita*), Woodlark (*Lullula arborea*)), which may be beneficial for their survival rates.
13. Although most evidence for the influence of climate change on ecosystems is predominantly correlational, the complexity of the relationships reported and their consistency across regions and taxa suggest that the interactions observed are not the result of confounding factors such as habitat destruction.
14. There is increasing evidence to suggest that climatic change has already impacted significantly on the population dynamics and distribution of a wide range of taxa, with between 17% and 35% of species globally predicted to become extinct by 2050, dependent on levels of greenhouse gas emissions over the next 50 years. Bird populations in the UK are no exception. Although birds are a highly mobile group and are therefore theoretically able to move to areas in which conditions were more favourable, the rapidity of changes in climatic condition coupled with the effects of habitat destruction and other direct impacts of human activity may leave many unable to do so. While generalist species may be able to cope with rapidly changing conditions, species unable to adapt quickly are likely to decline in abundance or, in severe cases, to become extinct, leading to a loss in avian biodiversity.

1. INTRODUCTION

Infrared radiation emitted from the sun is absorbed and then reradiated by trace gases in the atmosphere, including carbon dioxide, water vapour, nitrous oxide, chlorofluorocarbons and methane, resulting in a net warming of the Earth's surface termed the 'greenhouse effect'. Without the influence of the greenhouse effect the mean annual temperature of the Earth's surface averaged over all latitudes would be 33°C lower than it is at present (Houghton *et al.*, 2001).

Human activity has increased the level of greenhouse gases in the Earth's atmosphere by more than 50% over the last 200 years (Houghton *et al.*, 2001), resulting in an atmospheric concentration of CO₂ that is currently higher than at any point in the last 420,000 years (King, 2004). Mean global temperatures have increased by 0.6°C since 1900 and the rate of warming since 1976 has been greater than at any other time in the last 1,000 years (Houghton *et al.*, 2001). Indeed, historical data suggest that the 1990s were the warmest decade in the millennium, with 1998 the warmest year (Houghton *et al.*, 2001), at least in the Northern Hemisphere. The Intergovernmental Panel on Climate Change (IPCC), in its 3rd Assessment report (Houghton *et al.*, 2001), stated that "most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations" and went on to say that there was "new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities."

Patterns of atmospheric and oceanic circulation may also be affected by global warming, thus influencing weather systems. Since 1900, annual precipitation totals have increased in mid- and high latitudes but have decreased in the tropical and subtropical regions (Houghton *et al.*, 1996). In the UK, the frequency of heavy precipitation events has increased in the winter months, whilst decreasing in the summer months during the 20th century (Osborn *et al.*, 2000). The frequency and distribution of extreme events such as hurricanes, tornadoes and floods may also be affected by shifts in global climate (Dai *et al.*, 1998; Easterling *et al.*, 2000; King, 2004). In addition, sea level has risen by 20 cm over the last century (King, 2004), as predicted if the water in the Earth's oceans is expanding as temperatures rise and if polar ice caps and glaciers are melting at increased rates (Rignot *et al.*, 2003; Parizek & Alley, 2004; Miller & Douglas, 2004).

Concurrent trends in species ecology and climatic conditions over recent decades are well documented in the scientific literature (Hughes, 2000; McCarty, 2001; Walther *et al.*, 2002). The abundance, distribution and phenology of a broad range of plant and animal species exhibit correlations with changing patterns of atmospheric temperature, precipitation and other weather variables over recent decades.

2. CLIMATE AND POPULATION DYNAMICS

The size of a population is a function of the number of breeding attempts made, the relative success of those breeding attempts, the survival rate of individuals and the movement of those individuals into and out of the population. Weather conditions, may influence the survival, productivity and immigration/emigration rates of bird species, either directly, for example by affecting the costs of thermoregulation, or indirectly, for example by limiting habitat or food availability, and can therefore play an important role in determining abundance.

2.1 Influence of climate on survival rates

Adverse weather conditions can influence the survival rates of bird species directly. The rate of heat loss from the body increases as temperatures decrease and wetting of the feathers by rain reduces the effectiveness of the plumage as insulation. In cold, wet conditions birds therefore have to invest more energy in maintaining their body temperature, and individuals failing to meet these increased costs may die. The survival rates of both adult and first-year Lapwing (*Vanellus vanellus*) (Peach *et al.* 1994) in the UK have been shown to decrease with decreasing winter temperatures. A similar relationship has also been identified for Song Thrush (*Turdus philomelos*) (Thomson *et al.*, 1997) and Wren (*Troglodytes troglodytes*) (Robinson *et al.*, in prep.). A study in Nottinghamshire found that Treecreeper (*Certhia familiaris*) mortality increased as winter rainfall increased (Peach *et al.* 1995). Treecreepers may be particularly susceptible to plumage wetting as the breast feathers are in constant contact with the trunks of trees while feeding. A recent analysis of British Trust for Ornithology (BTO) Ringing Scheme data also show that cold, wet weather is associated with declines in Blue Tit (*Parus caeruleus*) survival rates (Robinson *et al.*, in prep.). An analysis of Redshank (*Tringa totanus*) data on the Moray Firth by Insley *et al.* (1997) found that the survival rates of first-year Redshank were lower in cold winters and in very wet winters, possibly due to increasing thermoregulatory costs in this relatively exposed environment.

The majority of bird species are limited in the amount of energy they are able to store as fat reserves because the excess weight increases the energetic cost of flight (Alerstam, 1990) and decreases manoeuvrability, potentially increasing the likelihood of predation (Gosler *et al.*, 1995). Brief periods of extreme weather conditions can therefore result in large-scale mortality events over very short periods of time. Clark (2004) found that the number of dead, ringed individuals of several wader species, including Redshank, Grey Plover (*Pluvialis squatarola*) and Dunlin (*Calidris alpina*), reported to the BTO Ringing Unit increased during severe winters. Severe spring snowstorms in the 1980s greatly reduced the survival rates of migrant Common Sandpiper (*Actitis hypoleucos*) on their return to the UK (Hollands & Yalden, 1991) and extreme cold spells in Scandinavia have been shown to result in reductions in Lapwing populations of up to 90% (Marcström & Masscher, 1979). Rainstorms can also lead to widespread mortality, particularly of groups such as wildfowl (Smith & Webster, 1955) that tend to weather storms rather than seek shelter, and ice storms in Europe have been recorded as causing similar damage to avian populations. After one such storm, Lens & Dhondt (1992) reported the death of 62% of their study population of Crested Tit (*Parus cristatus*) in Belgium. The effect of tornadoes and hurricanes may be similarly devastating (Askins & Ewert, 1991; Wauer & Wunderle, 1992).

Weather conditions can also influence the accessibility and the availability of food items, particularly over the winter period. Extended periods of frost or snow cover may prevent ground-feeding birds from foraging, leading to increased rates of mortality. Greenwood & Baillie (1991) reported reduced population sizes for a variety of UK bird species as the number of snowy days during the previous winter increased. Both Song Thrush abundance during the breeding season and over-winter survival rates have also been shown to decline as the number of frost days during the previous winter increases (Baillie, 1990; Robinson *et al.*, 2004) and Peach *et al.* (1995) found that Wren survival rates were lower during winters with longer periods of snow cover. Waterbirds, such as Grey Heron (*Ardea cinerea*), are particularly susceptible to decreases in food availability during spells of cold winter weather when areas of open water freeze over (Besbeas *et al.*, 2002) and the freezing of mudflats is likely to hinder the foraging of wader species such as Redshank (Insley *et al.*, 1997). High winter rainfall has also been observed to reduce the food intake rate of Redshank (Goss-Custard, 1970) and Grey Plover (Pienkowski, 1983), possibly because the number of invertebrate prey near the surface of the mud are depressed (Goss-Custard, 1970). Insley *et al.* (1997) reported that survival rates of first-year Redshank on the Moray Firth were lower during four of the five the wettest winters over the study period.

For summer migrants breeding in the UK, weather conditions on their African wintering grounds can also be an important factor in determining population sizes. In particular, droughts during the winter months can lead to a serious reduction in the extent of the insect-rich wetland habitats in which many migrants, such as Sedge Warbler (*Acrocephalus schoenobaenus*), forage (Peach *et al.*, 1991; Marchant, 1992), which in turn may lead to increased mortality rates. Periods of low rainfall may also result in poor berry crops on shrubs in the Sahel such as *Salvadora persica*, an important component of the diet of Blackcap (*Sylvia atricapilla*) and Common Whitethroat (*Sylvia communis*) when building up fat reserves for migration back to the UK (Stoate & Moreby, 1995). Marchant (1992) reported that population sizes of a number of migrant passerines in the UK were larger after wetter winters in sub-Saharan Africa, and Peach *et al.* (1991) identified a similar relationship between rainfall and abundance for Sedge Warbler. The survival rates of adult Sedge Warbler (Peach *et al.*, 1991), Swallow and Common Whitethroat (Baillie & Peach, 1992) have all been demonstrated to increase with the amount of precipitation falling on their wintering grounds.

2.2 Influence of climate on productivity

Cold, wet weather conditions during the breeding season may affect the survival of chicks in the nest, as well as adults. Indeed, young birds may be particularly vulnerable to increased energetic demands due to their smaller size, and therefore larger surface area:volume ratio, and relatively undeveloped plumage (Newton, 1998). Climatic conditions can also influence the amount of food that parents are able to collect for their offspring.

The proportion of juveniles in the post-breeding population of a variety of passerine species has been demonstrated to increase with temperature (Sokolov, 1999). Several studies of Pied Flycatchers (*Ficedula hypoleuca*) in Europe have identified a positive relationship between fledging success and temperature (Jarvinen, 1989a, Eeva *et al.*, 2002) and a recent analysis of BTO Nest Record Scheme (NRS) data has shown that the success rates of Pied Flycatcher, Common Redstart (*Phoenicurus phoenicurus*) and Chaffinch (*Fringilla coelebs*) nestlings in the UK are higher in warmer breeding seasons (Leech & Crick, in prep.). Warm, sunny

weather in June is also associated with increased survival rates of Spotted Flycatcher (*Muscicapa striata*) offspring (O'Connor & Morgan, 1982). Wet weather in summer has been linked to increased chick mortality for species such as Capercaillie (*Tetrao urogallus*) (Moss *et al.*, 2001; Summers *et al.*, 2004), Black Grouse (*Tetrao tetrix*) (Summers *et al.*, 2004), Grey Partridge (*Perdix perdix*) (Panek, 1992) and Corncrake (*Crex crex*) (Tyler & Green, 2004), possibly because their chicks leave the nest soon after hatching and are particularly susceptible to wetting when foraging in damp vegetation.

Low temperatures may reduce the activity levels of invertebrates (Davies & Green, 1976; Avery & Krebs, 1984), as might periods of rainfall (Foster, 1974; Morse, 1989), limiting the amount of food that insectivorous species are able to collect for their offspring. Both Pied Flycatcher (Siikmaki, 1996; Eeva *et al.*, 2002) and Willow Warbler (*Phylloscopus trochilus*) (Leech & Crick, in prep) failure rates at the nestling stage have been found to increase during wetter breeding seasons. The body condition of Yellowhammer (*Emberiza citrinella*), Chaffinch and Skylark (*Alauda arvensis*) nestlings, which are fed primarily on invertebrate prey, was observed by Bradbury *et al.* (2003) to decline as rainfall increased and as minimum temperatures fell, but the same was not true of Linnet (*Carduelis cannabina*) nestlings which are fed almost exclusively with seeds. Rainfall also has a detrimental effect on the growth rate of Cirl Bunting (*Emberiza cirlus*) nestlings (Evans *et al.*, 1997)

Wet summers are associated with poor breeding success for raptors such as Peregrine (*Falco peregrinus*) (Norriss, 1995; Leech & Crick, in prep) and Merlin (*Falco columbarius*) (Leech & Crick, in prep) that hunt other bird species on the wing. Heavy rain may both reduce the activity levels of their avian prey species and reduce visibility (Ratcliffe, 1980). However, the influence of rainfall on the survival rates of nestlings is not necessarily always negative. Schmidt *et al.* (1992) found that the fledging success of Nuthatch (*Sitta europea*) chicks increased with rainfall in March and April, suggesting that wet springs may actually result in increased food availability later in the year when the chicks have hatched.

The relationship between climate and breeding success has been well documented for seabirds. Many studies have identified significant relationships between sea surface temperatures, which determine the abundance of plankton and therefore of fish species, and the reproductive success of seabird species across the world's oceans (Kitaysky & Golubova, 2000; Durant *et al.*, 2003; Jenouvrier *et al.*, 2003; Smithers *et al.*, 2003), and similar trends can be observed for some seabird species in the UK. Aebischer *et al.* (1990) observed that Kittiwake (*Rissa tridactyla*) fledging success in the North Sea is related to the abundance of phytoplankton, zooplankton and marine fish, which in turn is related to the predominance of westerly weather systems during the breeding season. While these relationships are essentially correlative, they do suggest that that influence of climate can move upwards along the marine food chain. The phase of the North Atlantic Oscillation (NAO), the weather system responsible for influencing patterns of temperature and precipitation in the Northern Hemisphere, has also been reported to influence the breeding success of Fulmar (*Fulmaris glacialis*) in a Scottish population (Thompson & Ollason, 2001).

Many of the wader species that winter in internationally important numbers in the UK breed north of the Arctic Circle. Climatic conditions not only influence the abundance of insects, and therefore the availability of food with which to provision the offspring, but also affect the size of the lemming (*Lemmus* spp. and *Dicrostonyx* spp.) populations (Soloviev &

Tomkovich, 2003). In years when lemmings are scarce, avian and mammalian predators such as skuas (*Stercorarius* spp.) and Arctic Fox (*Alopex lagopus*) turn their attention to the contents of nests, reducing the breeding success of the ground-nesting wader species.

Weather conditions may also influence adult condition at the start of the breeding season. Even if individuals are able to survive harsh winter conditions, they may be left with depleted energy reserves that are insufficient to allow successful breeding during the following season. Reductions in the number of individuals attempting to breed may also have a negative influence on the size of the population. Ambient temperatures during the laying period have been found to positively influence the clutch size of a number of passerine species, including Pied Flycatcher (Jarvinen, 1989b; Winkel & Hudde, 1997) and Common Redstart (Leech & Crick, in prep.). In addition, Nager & Zandt (1994) and Stevenson & Bryant (2000) both observed that Great Tit (*Parus major*) laid smaller eggs in colder temperatures. There is some evidence to suggest that smaller eggs may suffer reduced hatching success (Jarvinen & Vaisanen, 1983) and produce lighter chicks (O'Connor, 1984; Perrins, 1996) that are less likely to survive to breed (Both *et al.*, 1999).

2.3 Influence of survival rates and productivity on population size

Several population modelling studies of UK bird species have identified relationships between changes in survival rates and population trends. The annual survival rate of first-year song thrushes (*Turdus philomelas*) in the UK decreased from 0.484 to 0.405 between 1975 and 1993, a fall of sufficient magnitude to account for the 65% decline in the population size over the same period (Thomson *et al.*, 1997). Investigating a 54% decline in Reed Bunting (*Emberiza schoeniclus*) population size between 1975 and 1995, Peach *et al.* (1999) identified concurrent reductions in survival rates, particularly of first-year birds, that were large enough to be the sole causal factor of the species' decline. Similar relationships between survival rates and population size were found for Goldfinches (*Carduelis carduelis*), House Sparrows (*Passer domesticus*) and Starlings (*Sturnus vulgaris*) in the UK (Siriwardena *et al.* 1998, 1999; Freeman & Crick, 2002; Freeman *et al.*, 2002).

There is also strong evidence to suggest that decreased breeding success is responsible for the declines of some UK bird species. Siriwardena *et al.* (2000) reported that the national decrease in the abundance of Linnet (*Carduelis cannabina*) since the mid 1960s could be explained solely by a decrease in reproductive success, which may have been caused by an increased incidence of nest failure at the egg stage. Increased chick mortality due to starvation was identified as the primary cause of the population decline of Grey Partridge over the same period (Potts, 1986) and reduced fledging success is likely to be responsible, at least in part, for Lapwing (*Vanellus vanellus*) declines during the late 20th century (Peach *et al.*, 1994). A reduction in the number of breeding attempts, rather than the productivity of individual attempts, has been identified as a contributing factor in the decline of the UK Skylark (*Alauda arvensis*) population (Wilson *et al.*, 1997; Chamberlain *et al.*, 1999).

However, the relationship between population processes and population size may not be as intuitive as at first it may seem. Decreased survival rates may be compensated for by increased productivity, as the intensity of competition for resources amongst the remaining breeding individuals may be reduced. Indeed, several studies of UK bird species, including Corn Bunting (*Miliaria calandra*), Tree Sparrow (*Passer montanus*), Song Thrush, Goldfinch, Turtle Dove (*Streptopelia turtur*) and Reed Bunting, have identified trends

towards increased productivity during periods of population decline (Siriwardena *et al.*, 2000; Peach *et al.*, 1999). Alternatively, increased productivity may be compensated for by a decrease in survival rates as more individuals compete for resources.

2.4 Influence of immigration and emigration on population size

While decreasing survival rates and reduced breeding success can lead to a decrease in the absolute size of the population, shifting patterns of distribution can also lead to an apparent drop in numbers if individuals move out of the surveyed area. Using data from the BTO Ringing Scheme, Baillie *et al.* (1986) demonstrated that several waterbird species, including Teal (*Anas crecca*), Wigeon (*Anas penelope*), Curlew (*Numenius arquata*) and Snipe (*Gallinago gallinago*), exhibited an increased tendency to move southwards during exceptionally cold winters, travelling either to southern Britain or into continental Europe. The extent of Teal movement to the continent increased with the incidence of freezing conditions during the winter period, leading to a reduction in the size of the population wintering in the UK.

3. THE IMPACT OF CLIMATE CHANGE ON BIRD POPULATIONS IN THE UK.

Responses of a wide range of taxa to increasing atmospheric temperatures have been widely studied (Walther *et al.*, 2002; Parmesan & Yohe, 2003; Root *et al.*, 2003). Elevated temperatures and levels of atmospheric CO₂ have increased the photosynthetic activity of plant species, extending the length of the growing season in many regions (Myneni *et al.*, 1997; Menzel & Fabian, 1999). Warmer springs have also influenced the timing of spring events such as leaf emergence, which in Europe has advanced by an average of six days between 1959 and 1963 (Menzel & Estrella, 2001). Changes in the seasonal timing, or phenology, of reproductive events have not been limited to plants – the emergence dates of some butterfly species (Roy & Sparks, 2000) and the spawning dates of some amphibians (Beebee, 1995) have also been affected. Climatic changes have also been identified as the primary force driving shifts in the distribution of many plant (Kullman 2001; Grabherr *et al.*, 1994), butterfly (Parmesan *et al.*, 1999) and fish species (Southward *et al.*, 1995) throughout the terrestrial and marine environments of Europe.

A growing body of evidence suggests that the direct and indirect effects of global climate change may also influence the size, distribution and phenology of bird populations in the UK.

3.1 The impact of climate change on patterns of distribution and population processes

Climatic changes may lead to shifts in regional or global patterns of species distribution as conditions in some areas become increasingly favourable and those in other areas become less so. Such shifts are likely to result from changes in the settlement patterns of juveniles (Townshend, 1985; Austin and Rehfish, in press) or local extinctions rather than from the progressive movement of individuals between breeding seasons.

In the UK, Thomas and Lennon (1999) reported that, over the period 1972-1991, bird species had extended their breeding ranges northwards by an average of 18.9 km, a shift which they suggested was linked to increasing mean annual temperatures at the northern extent of the species' distribution. Increasing temperatures in the Eastern Atlantic are thought to have played a role in the range expansion of the Fulmar population since the 18th Century (Brown, 1970), and climatic amelioration in the UK could help to explain the colonisation of the UK by novel breeding species from the continent, such as Black Redstart (*Phoenicurus ochruros*), Cetti's Warbler (*Cettia cetti*), Golden Oriole (*Oriolus oriolus*), during the 20th century (Burton, 1995; Moss, 1995), and possibly, more recently, Little Egret (*Egretta garzetta*) (Musgrove, 2002). However, it should be noted that definitively ascribing shifts in distribution to climatic changes is very difficult due to the potential influence of many other confounding factors, such as changes in land use, predator distribution, hunting pressures, etc. Thus, while the observations referenced above are indeed suggestive, further research will be necessary to provide more conclusive evidence of the link between climate change and the range expansions of these species.

Several warbler species, most notably Blackcap, that breed in the UK but traditionally winter in Iberia or Africa have become increasingly frequent winter visitors over the past decade. There is good evidence to suggest that these are continental birds taking advantage of the increasingly warm winter conditions in the UK (Berthold & Helbig, 1992). Not only do these individuals have to travel a shorter distance to their wintering grounds, increasing the

probability of survival during this hazardous phase of the life cycle, but they also have the potential to arrive back on the breeding grounds before those birds that winter further south, which might confer a competitive advantage in terms of territory acquisition. A similar shift in wintering location has been observed for many wader species in the UK (Austin *et al.*, 2000; Rehfisch & Crick, 2003; Rehfisch *et al.*, in press; Austin and Rehfisch, in press; Rehfisch & Austin, in prep.). A higher proportion of these species used to winter in the Southwest of Britain where climatic conditions during the winter were relatively mild due to the influence of the Gulf Stream. However, as mean winter temperatures have increased since 1960, such climatic constraints have eased and an increasingly large proportion of the wader population has wintered on the east coast where the quality of the feeding grounds is higher and the birds are nearer to their northern breeding grounds. This distributional shift is most pronounced for smaller waders, such as Dunlin, Sanderling (*Calidris alba*) and Ringed Plover (*Charadrius hiaticula*) (see Figure 1), which experience greater rates of heat loss due to their relatively high surface area:volume ratio than larger species and therefore potentially incur greater thermodynamic costs in cold weather.

While many studies have related survival rates and productivity to weather conditions in the UK, fewer have investigated trends in these population processes relative to past trends in climatic variables. As mean temperatures in the Northern Hemisphere have risen, so increasing temperatures in North Sea waters have led to seasonal shifts in peak sand eel abundance, resulting in reduced breeding success for a number of seabird species, including Common Guillemot (*Uria aalge*), Shag (*Phalacrocorax aristotelisi*) and Kittiwake (Rinderf *et al.*, 2000). Changes in weather conditions may also lead to shifts in the rate of reproduction of pathogens, or in the distribution of vectors carrying these pathogens. Epstein (2001) suggested that warm winters and spring droughts might have contributed to the spread of West Nile Virus through avian populations in Europe and North America. The distribution and incidence of other avian diseases, such as malaria, may also be dependent on climatic variables although little information is currently collected on diseases in wild bird populations and there are insufficient historical data to allow the assessment of trends in infection over time.

3.2 The impact of climate change on timing of breeding

Advancement in leaf emergence is likely to result in advancement of caterpillar emergence, as insect herbivores must maintain synchronicity with their food source if their productivity is to be maximised. Buse *et al.* (1999) demonstrated that a 3°C rise in ambient temperature advanced leaf budding of Pedunculate Oak (*Quercus robur*) by 12 days and advanced hatching of Oak Winter Moth (*Operophtera brumata*) by 10 days. Birds provisioning their offspring on invertebrate larvae will likewise benefit by ensuring that the period of peak offspring demand and peak prey species abundance overlap temporally. Natural selection would therefore favour the advancement of laying dates as temperatures become warmer.

Using data collated by the BTO Nest Record Scheme from across the UK, Crick *et al.* (1997) investigated trends in the laying dates of 65 bird species over the previous 25 years. The study found that the laying dates of 20 of these species had advanced significantly, and that the average advancement was 8.8 days (Figure 2). Species displaying a trend towards earlier laying were not limited to one taxonomic group, but rather included resident and migrant insectivores, seed-eaters, corvids and waterbirds. Detailed analysis of the data over a longer, 57-year period indicated that laying dates were significantly related to either spring

temperatures or to spring rainfall for 31 of the 36 species studied (Crick & Sparks, 1999). Furthermore, it was possible to demonstrate that the recent advancement of laying dates for seven of these species could be explained solely by climatic trends. The evidence for this relationship is particularly compelling as many species displayed a trend towards later laying as spring temperatures decreased up to the 1970s, only advancing their laying dates when this temperature trend was reversed during the following decades. Laying date advancements since the 1970s have also been reported from long-term studies of UK Great Tit (McCleery & Perrins, 1998) and Pied Flycatcher (Slater, 1999) populations.

As thermoregulation and egg production are both energetically expensive, there may be a trade-off between the two processes. As temperatures increase, so the cost of thermoregulation decreases and more energy can be invested in egg production. Costs of thermoregulation are relatively greater for smaller birds, due to their higher surface area: volume ratio and therefore increased rates of heat loss, suggesting that species with a lower body mass may be more sensitive to temperature changes. A study by Stevenson & Bryant (2000) lends support to this hypothesis by demonstrating that laying date advancements of smaller species in response to climatic change have been relatively greater than those of larger species.

3.3 The impact of climate change on timing of migration

The results of several studies investigating the spring arrival times of migrant species in temperate latitudes suggest that birds are reaching their breeding grounds progressively earlier in the season as the climate becomes warmer. This adjustment of arrival dates is vital if birds are to compensate for the advancements in the timing of peak prey availability that have also been driven by climatic change.

The positive phase of the NAO is associated with areas of high pressure over Western Europe, resulting in increased temperatures and therefore possibly in more favourable conditions for flight and foraging along the migration route (Forchhammer *et al.*, 2002). A number of studies have shown that mean arrival dates of species breeding in Europe are advanced when the NAO is in a more positive phase during winter and spring. Such a relationship has been reported from Finland (Vahatalo *et al.*, 2004), where the arrival dates of 79% of bird species was related to the phase of the NAO, and Helgoland (Huppopp & Huppopp, 2003), where 23 out of 24 species arrived earlier if the NAO was in a positive phase. Some researchers have found similar patterns in both short-distance and long-distance (sub-Saharan) migrants (Forchhammer *et al.*, 2002), whilst others have identified the relationship only for short-distance migrants (Hubalek, 2003).

Analysis of arrival date information for migrants in the UK suggests that many species are indeed arriving earlier on the breeding grounds. Using data from bird observatories, Loxton & Sparks (1997) identified a trend towards earlier arrival in seven of the 27 species studied, including Wheatear (*Oenanthe oenanthe*), Willow Warbler, Chiffchaff (*Phylloscopus collybita*), Blackcap and Pied Flycatcher, over the last 40 years. Data collated by county recorders in Leicester & Rutland and Sussex show that arrival dates of 20 of the 56 species included in the analysis have advanced significantly since 1966 (Sparks, 1999), and records from Essex for the period 1950-1988 show a similar relationship for 23 of the 32 species studied (Sparks & Mason, 2001). Furthermore, the arrival dates for two species, Willow Warbler and Blackcap, in the first study, 19 species in the second and 10 species in the third

indicated that individuals reach the breeding grounds earlier, on average, during warmer years. There is also some evidence to suggest winter migrants that travel relatively short distances within the UK, such as Merlin and Hen Harrier (*Circus cyaneus*), may also have advanced their arrival dates on the wintering grounds (Sparks & Mason, in press), but this trend is less consistent across species with many others displaying no advancement.

Sparks & Mason (2001) also observed that nine species displayed trends towards progressively later departures for the wintering grounds since the 1950s, whereas only one species was leaving the UK at a significantly earlier date than before. An analysis of data concerning the autumn passage of Willow Warblers at Dungeness Bird Observatory in Kent (Marchant & Wernham, 2003) revealed that departure dates were on average 5-10 days later over the period 1994-2000 than they had been between 1962 and 1968. Such delays may be beneficial as adults potentially have more time available to recoup the costs of producing and rearing offspring before they embark on an energetically expensive migratory journey, and juveniles may also have more time to build up their energy reserves and flight muscles. However, data collected in the Swiss-French Alps between 1958 and 1999 (Jenni & Kery, 2003) suggest that the influence of climate change on departure dates may be more complex, at least for some European populations. Analysis of data for short-distance migrants wintering in the Iberian and Mediterranean regions revealed a significant trend for delayed departure dates, whereas departure dates of long-distance migrants tended to advance progressively. It was suggested that the increasingly early departure of these species might be related to the advancement of the start of the dry season in the Sahel region of Africa, through which they would have to pass on their southerly migration. Interestingly, species that produce a variable number of broods per season also tended to delay their departure in recent years, possibly because climatic change has facilitated the production of repeat broods.

4. THE OUTLOOK FOR THE FUTURE

4.1 What changes are predicted for the UK climate?

The UK Climate Impacts Programme (UKCIP) was set up by DEFRA in 1997 to co-ordinate research into the repercussions of climate change at a national level. The UKCIP02 report (Hulme *et al.*, 2002) presents a series of potential climate change scenarios over a series of time scales (2020, 2050 and 2080), based on the level of emissions of greenhouse gases over this period (defined as Low, Medium-Low, Medium-High and High).

The UKCIP02 report predicts that temperatures in the UK will rise by an average of 2.0-3.5°C by 2080, with temperatures in summer and autumn likely to increase by more than those in winter and spring. The greatest increases are predicted in the southeast, where temperatures may rise by as much as 5.0°C. This increase in temperature could theoretically be countered if climatic changes cause the Gulf Stream, a warm water current passing through the Atlantic and along the coast of northwest Europe, to shut down. However, climatic models suggest that the Gulf Stream will remain intact, although it may weaken during the 21st century (Hulme *et al.*, 2002). Very hot spells in summer are likely to become more frequent and very cold winters less so. Seasonal timing is also likely to have changed markedly by 2050, with the onset of typical spring temperatures advancing by between one and three weeks and a similar delay experienced in the onset of typical winter temperatures.

Mean annual rainfall is predicted to decrease by up to 15% by 2080, although there may be large regional differences, with the southeast becoming generally drier than the northwest. Rainfall is likely to decrease during the summer months, but increase during the winter, with intense periods of winter rain becoming more frequent. Under a High Emissions scenario, rainfall in the southeast is predicted to fall by up to 50% in the summer, but increase by up to 30% in the winter. Winter snowfall will become a rare event, possibly decreasing by up to 90% by 2080.

The combination of increasing temperatures and decreasing precipitation during the summer months is predicted to cause a significant reduction in soil moisture content. Soil moisture may be reduced by up to 30% over large parts of the UK by 2050 and by up to 40% by 2080.

4.2 How will sea-level change?

UKCIP02 predictions of sea-level changes again vary according to the emissions scenario. Global sea level is predicted to rise by 7-36 cm by 2050 and by 9-69 cm by 2080, primarily due to the expansion of seawater as temperatures rise. In addition, the south of the UK is sinking as the north rebounds from the weight of the ice sheet that covered it during the last glacial period, a process known as isostatic change. The combined influence of these two processes is predicted to result in a sea level change of between -2 cm and 58 cm in western Scotland and an increase of between 26 cm and 86 cm in southeast England by 2080. Extreme high sea levels are also likely to be experienced more frequently in coastal areas.

4.3 How might these changes impact on the UK's avifauna?

4.3.1 Over-winter survival rates

The relationships between weather conditions and both avian survival and productivity outlined in Section 2 of this report suggest that increasing annual temperatures could be beneficial for many species in the UK. Warmer winters may lead to decreased energetic costs of thermoregulation, particularly for smaller birds such as Wren, Long-tailed Tit (*Aegithalos caudatus*) and Goldcrest (*Regulus regulus*). Indeed, population trends produced by the BTO's Common Bird Census (CBC) indicate that populations of all three of these species have increased in size by more than 50% since the mid 1960s (Crick *et al.*, 2004). The abundance of Wren has been chosen as one of the UK government's indicators of climate change (Crick, 1999). A reduction in snow cover is also likely to increase food availability for many species, including ground feeders such as thrushes and waders. In addition, birds reliant on small bodies of open water, such as dabbling ducks, Grey Heron and Kingfisher (*Alcedo atthis*), may benefit from higher temperatures as their feeding grounds are less likely to freeze over. Over-winter survival rates of a wide range of species might therefore be expected to increase, although the predicted increase in precipitation during the winter could counter the effect of warmer conditions for some species, including Treecreeper. Increasing winter rainfall may also inhibit the feeding behaviour of wintering wader species (Goss-Custard, 1970), particularly first-year birds which may possess inadequate fat reserves (Swann & Etheridge, 1989) or be forced to forage in poorer habitats (Groves, 1978), thus leading to reduced rates of survival and possibly to reductions in population size (Insley *et al.*, 1997).

One group that may not be predicted to benefit from the amelioration of the winter climate are the raptor and corvid species in remote upland areas such as Golden Eagle (*Aquila chrysaetos*) and Raven (*Corvus corax*), which rely heavily on carrion during this period but, unlike lowland scavengers, are unable to utilise road casualties as a food source. In addition, the colonisation of the UK by continental species could lead to increased competition for resources and therefore to lower survival rates for a range of species, dependent on the ecological niche of the colonists.

4.3.2 Breeding success

Predicted climate changes for the UK could also lead to increases in productivity. If the energetic demands of the winter period are reduced, individuals may be in better condition at the start of the breeding season and may therefore be able to invest a greater amount of energy in reproduction, for example by producing larger clutches or by increasing provisioning rates to chicks. Warmer temperatures during the breeding season may also increase productivity by reducing the thermoregulatory costs of both adults and nestlings. Aerial insectivores, including flycatchers, martins, Swallow and Swift (*Apus apus*), may benefit from warmer, drier conditions during the breeding season, as flight activity of their insect prey may increase (Davies & Green, 1976; Morse, 1989). Periods of heavy summer rain can wash invertebrates from vegetation, and thus species that glean insects from leaves, such as Willow Warbler and Chiffchaff, may also benefit from drier summers. Again, as mentioned in Section 4.3.1, competition with novel species that have colonised the UK as a result of climate change may have a negative impact on the productivity of some of the species that are already present.

Increasing rainfall in late winter and early spring could have a positive impact on the growth of vegetation, leading to a general increase in the abundance of herbivorous insects and therefore in food availability for many passerine species. However, the predicted reduction in soil moisture content during the summer months may have severe impacts on the productivity of species that rely primarily on soil invertebrates to provision their young, including Rook (*Corvus frugilegus*), Blackbird (*Turdus merula*) and Song Thrush, as earthworms and soil insects will tend to move deeper as the topsoil starts to dry out (Gerard, 1967; Peach *et al.*, 2004). Hardening of the ground may also cause problems for non-coastal wader species such as Snipe, Woodcock (*Scolopax rusticola*), Redshank and Curlew, which probe for food (Elkins, 2004).

Breeding seabirds could also experience a reduction in food availability leading to reduced levels of productivity. Montevecchi and Myers (1997) observed that slight variations in oceanic currents due to climatic warming may have major consequences for fish population sizes, and therefore for the abundance and distribution of Gannet (*Sula bassana*) foraging off the Newfoundland Shelf. UK seabird populations might experience similar food shortages if ocean currents in the North Atlantic and/or the North Sea are altered by changes in the relative temperature of different regions of the marine environment. This is one of the possible explanations for the catastrophic breeding failure of seabirds in Shetland in 2004 (Hay, 2004).

4.3.3 Advancement of laying dates

Further increases in temperature are likely to result in the continued advancement of laying dates for a wide range of species. Crick & Sparks (1999) calculated that, while 53% of species included in their study had advanced their laying dates significantly by 1995, by 2080 this figure could have risen to 75%. This general trend towards advancement of the breeding season could be construed as potentially advantageous for many species. Advanced breeding may allow adults and offspring more time to replenish their energy reserves prior to the energetically demanding winter period (Crick *et al.*, 1997). In addition, as the breeding season becomes extended so the time available to raise repeat broods increases, although, Crick & Sparks (in press) have shown that the majority of UK species studies have not altered the length of their breeding season but merely shifted the timing.

However, should individuals be unable to maintain synchrony between offspring production and food availability, the consequences in terms of reduced productivity may be severe. Both & Visser's (2001) observation that Great Tit eggs laid relatively earlier in the season were more likely to fledge young suggests that individuals would benefit from advancing their laying dates still further but appear to be constrained from doing so. Visser *et al.* (1998) demonstrated that there was an increasing tendency for young from early broods to be recruited into the breeding population in the following year relative to young from later broods. Freeman *et al.* (in prep) found that productivity of 14 of the 26 species they studied decreased as temperatures during the post-laying period increased, possibly due to increasing asynchrony with food supplies.

One possible constraint on the advancement of egg laying relates to the costs of egg production. Eggs are energetically expensive to produce, yet food availability over the preceding (winter) period is relatively low and the costs of thermoregulation are relatively high. Females therefore may require a sufficient period of more clement weather prior to

laying over which to recoup their energy reserves, preventing laying dates from advancing indefinitely. Variation in the response of different tree species to climatic change may reduce food availability during the pre-laying period for some birds. Visser *et al.* (1998) observed that, whilst Great Tits collect food for their offspring from oak (*Quercus* spp.) trees, females feed on birch (*Betula* spp.) and larch (*Larix* spp.) prior to laying. Whilst the emergence date of oak leaves has advanced seasonally, the budding date of birch trees has not. This food source is therefore available to the female for a relatively shorter period prior to laying.

Additionally, cues traditionally used to provide birds with information about optimum laying dates may be becoming less reliable. Van Balen (1973) observed that Great Tit laying dates in Holland were earlier when the mean temperature during the first two weeks of March was higher. However, temperatures over this period have remained constant during the period 1973-1995 whilst temperatures over the following 30 days, which determine caterpillar emergence, have increased (Visser *et al.*, 1998).

Migrant species may experience even greater constraints on laying date advancement. The relative timing of cues used to initiate migration and periods of peak food availability during breeding may vary, causing mistimed arrival (Berthold, 1990). Indeed, it may not even be possible for individuals to advance migration dates further. Although Pied Flycatcher laying dates on the continent have advanced by 10 days over the last 20 years, arrival dates have remained constant (Both & Visser, 2001) or have advanced to a lesser degree (Coppack & Both, 2002). The time available to recoup energy reserves for reproduction following the energetically expensive migration period is therefore becoming increasingly shortened, which may potentially lead to declines in survival or in productivity. Sanz (2003) noted that Pied Flycatcher laying dates were positively related to clutch sizes, with early-laying birds producing smaller clutches. If the laying advancement of migrants, particularly late-arriving species such as Spotted Flycatcher and Garden Warbler (*Sylvia borin*), is constrained to a greater degree than that of resident species, the latter may have an increased competitive advantage when securing territories and nesting sites (Berthold, 1993).

Asynchrony between offspring production and prey availability may be unavoidable for both resident and migrant species if the length of the development period of the prey species is reduced at higher ambient temperatures but the development period of chicks cannot be. Whilst an increase of 3°C above ambient temperature allows the Oak Winter Moth caterpillars to shorten their development period from 49 days to 36 days, the rate of development of Great Tit fledglings remains unchanged (Buse *et al.*, 1999).

4.3.4 Shifts in breeding and wintering ranges

One method of investigating distributional changes is to analyse current distributions in terms of climate and other factors and use the results to produce models that can predict population distributions under future climate scenarios. This approach was trialled for a range of species in the UK by Berry *et al.* (2001). While some species, such as Turtle Dove (*Streptopelia turtur*) and Yellow Wagtail (*Montacilla flava*) displayed little change in distribution, others showed substantial population expansions (Nuthatch, Reed Warbler (*Acrocephalus scirpaceus*)), contractions (Willow Tit, *Parus montanus*) or redistributions (Oystercatcher).

As the climate in the UK becomes warmer and drier, so the breeding ranges of species that are currently restricted to southern England, such as Cirl Bunting (*Emberiza cirlus*), Cetti's

Warbler, Dartford Warbler (*Sylvia undata*), Firecrest (*Regulus ignicapillus*) and Nightingale (*Luscinia megarhynchos*), are likely to extend northwards, potentially leading to an increase in their abundance nationally (Moss, 1998; Wilson *et al.*, 2002). Likewise, many species found throughout England, including Green Woodpecker (*Picus viridis*), Reed Warbler and Nuthatch, are predicted to extend their breeding ranges in Scotland.

If the northward range expansion of European species such as Black Kite (*Milvus migrans*), Cattle Egret (*Bubulcus ibis*) and Great Reed Warbler (*Acrocephalus arundinaceus*) continues, there is a strong possibility that they will colonise the UK during the present century (Moss, 1998). Moss (1995) calculated that a 1°C rise in mean temperatures would bring Kent and Sussex within the breeding range of Zitting Cisticola (*Cisticola juncidis*). Some eastern European vagrants, such as Penduline Tit (*Remiz pendulinus*), Thrush Nightingale (*Lucinia lucinia*) and Greenish Warbler (*Phylloscopus trochiloides*) are also extending their range westwards and could soon become breeding species in the UK (Moss, 1998). In addition, an increased number of short-distance migrants from the continent might be predicted to winter in the UK rather than moving south to the Mediterranean Basin, including Chiffchaff and possibly Woodlark (*Lullula arborea*).

However, while some species may colonise the UK as a result of climatic warming, others are more likely to be lost. The species likely to be at greatest risk of extinction in the UK are those that breed in the lichen-dominated arctic-alpine habitat found in the Cairngorms and a few other high-altitude areas in northern Scotland. As temperatures increase, so plant species from lower altitudes will begin to move upslope and encroach on this already scarce habitat. As there is no higher altitude to move to, the total area of arctic-alpine habitat in the UK will start to decrease and by 2050 it may have disappeared altogether (Briggs & Hossell, 1995). Under High Emissions scenarios, the models of Berry *et al.* (2001) indicated that Highland species such as Capercaillie (*Tetrao urogallus*) and Snow Bunting (*Plectrophenax nivalis*) would lose nearly all suitable climate space, suggesting that they might become extinct in the UK. It is highly likely that Ptarmigan (*Lagopus mutus*) and Dotterel (*Charadrius morinellus*) would suffer a similar fate.

Species that breed only in the far north of Scotland are also likely to be at risk. The UK is at the southern edge of the breeding range for a number of non-passerine species, including Whooper Swan (*Cygnus cygnus*), Red-necked Phalarope (*Phalaropus lobatus*), Arctic Skua (*Stercorarius parasiticus*) and Greenshank (*Tringa nebularia*). As the ranges of these species move northwards, tracking changes in habitat, the numbers of breeding individuals of these species is likely to fall and they may well eventually cease to breed in the UK (Cadbury, 1995; Sparks *et al.*, 2002).

Wintering species may also be lost from the UK as a result of climate change. The number of wintering ducks and geese might be predicted to fall, as these species will have to move shorter distances south to avoid the harsh winter conditions of the highest latitudes. In addition, if the northerly and easterly shifts in the distribution of wader species during the winter identified by Austin & Rehfisch (in press) continue, increasing numbers of birds may stay on the continent. Declines in abundance have already been identified for eight of the 14 common wader species inhabiting both estuarine and non-estuarine coasts (Rehfisch *et al.*, 2003a, 2003b), suggesting that such a trend has already begun. Even under relatively conservative scenarios, numbers of Sanderling, Purple Sandpiper (*Calidris maritima*) and Turnstone (*Arenaria interpres*) are predicted to decrease by between 35% and 60% in their

strongholds of the Western Isles, Orkney and Shetland (Rehfishch *et al.*, in press, see Figure 3). Furthermore, under the same scenarios the Curlew population in Shetland and Orkney would be predicted to decline by at least 40% and Ringed Plover numbers in the Western Isles, which held 41% of the British population in 1997/98 (Rehfishch *et al.*, 2003b), would be predicted to fall by up to 36%. Not all wader species would fare so badly, however. If the area of suitable habitat remained constant, Oystercatcher (*Haematopus ostralegus*) and Redshank declines would be relatively minor, whilst Lapwing and Dunlin might be expected to increase in abundance. As populations of wildfowl and waders wintering in the UK are of international importance, the movement of these species out of the country has major implications for the conservation of these species and for conservation policy in the UK.

Movements of breeding or wintering ranges within the UK could cause a number of practical problems for conservationists. Firstly, additional work is urgently needed to discover whether observed declines are due to shifts in distribution or to actual reductions in the number of individuals that may be reversible if appropriate conservation initiatives are implemented (Rehfishch *et al.*, in press). Secondly, many areas of particular importance to breeding or wintering birds are currently protected under both UK and European law (e.g. National Nature Reserves, Special Protection Areas, Ramsar sites, Environmentally Sensitive Areas). If the locations of breeding or wintering sites move outside the boundaries of these protected areas, not only are the species involved put at greater risk but government agencies and NGOs may spend valuable resources on protecting areas that are no longer of significant conservation interest (Hossell *et al.*, 2000; Rehfishch, 2000; Boere & Taylor, in press; Austin & Rehfishch, in press).

4.3.5 Impact of rising sea levels

Rising sea levels are predicted to have a huge impact on lowland coastal habitats in the UK. Under natural conditions, increases in sea levels would cause inter-tidal habitats, such as mudflats and salt marshes, to retreat inland. As habitat is lost by inundation on the seaward edge, so new habitat will develop at the landward edge, with the total area remaining relatively constant. However, such a retreat is prevented in many areas of the UK by the presence of sea defences or human habitation (Pethick & Crooks, 2000; Crooks, in press). If retreat is not possible, submergence of the seaward edge of these habitats will reduce their total area, a process known as ‘coastal squeeze’ (Lee, 2001). Increases in sea level could result in the permanent inundation of mudflats (Pethick & Crooks, 2000), with severe implications for both wintering and breeding wildfowl and wader species. Salt marshes are likely to be under threat as well (Pethick & Crooks, 2000), with implications both for breeding species, like Redshank, and species that winter in these areas, including Twite (*Carduelis flavirostris*). Southern England’s salt marshes face an additional threat in the form of elevated rates of erosion that have resulted from increases in the strength and frequency of winds and storm events. In some areas where these important habitats would theoretically be able to move in land as sea levels become higher, the land is being developed by conservationists to facilitate this process, creating areas of managed retreat through “coastal realignment” (Atkinson *et al.*, in press; Crick, in press).

Estuarine mudflats represent important feeding sites for wintering waders. If artificial barriers do not prevent retreat, as sea levels rise, so the shape of these estuaries may change (Austin & Rehfishch, 2003), influencing sediment composition and therefore altering the species composition and density of the invertebrate populations on which the waders feed. If

the sea were allowed to encroach unhindered, the densities of waders that prefer muddy estuaries, such as Redshank and Dunlin, would be predicted to fall (Austin & Rehfish, 2003) as substrates become sandier. However, an increase in the area of sediment may actually permit an increase in the total number of individuals that can be supported. Species that prefer sandy estuaries, such as Oystercatcher, would be predicted to increase in both density and number.

However, even with the creation of managed retreat, some habitats are still likely to be under threat as sea levels rise. The depth of water and the salinity in coastal reed beds is likely to increase, destroying the breeding habitat of a range of species including rare breeders such as Bittern (*Botaurus stellaris*) (Moss, 1998). Coastal spits and bars, home to many gull and tern colonies, could also be destroyed by a combination of inundation and increased erosion rates. Furthermore, new areas of habitat such as salt marsh may take some time to develop (Crick, in press). If sea level rise is rapid, even retreating habitats may therefore decline in area initially.

4.3.6 Incidence of disease

Climatic change may affect the distribution of pathogens as well as that of bird species themselves. The spread of West Nile Virus in Europe identified by Epstein (2001) is likely to continue if a general amelioration of the climate occurs. Novel pathogens may have negative impacts on avian populations, particularly if they spread rapidly, as it may take some time for the necessary resistance to build up in a population. Furthermore, if increasing global temperatures lead to reduced rainfall and a higher incidence of drought, individuals may concentrate around limited resources, such as water sources, increasing potential rates of pathogen transmission. This affect may be exacerbated by the patchy distribution of suitable habitats for some species resulting from habitat destruction due to human activity. Rising temperatures may therefore result in an increase in the incidence of disease and a subsequent decrease in survival rates of some species. However, this is an area of great uncertainty due to the current lack of research.

4.3.7 Climatic change outside the UK

Climate change outside the UK may influence the population size of migrant species breeding or wintering in the UK. Temperatures in Africa are predicted to increase by 0.2°C and 0.5°C per decade, with the greatest increases in central southern Africa (Hulme *et al.*, 2001). Trends in precipitation are less clear-cut but, with the possible exception of eastern Africa, rainfall totals are generally predicted to decrease over the next 75 years, which would decrease the productivity of plants during the growing season and therefore on food availability during the winter months for species such as Swallow, Sedge Warbler and Whitethroat. The incidence of extreme events such as floods and droughts in Africa is predicted to increase over the next 75 years, which may also have significant effects on survival rates.

The trend towards increasing global temperatures is likely to have severe effects for birds that breed in the Arctic tundra, including many wader and goose species that winter in the UK. Species from lower latitudes will begin to extend their ranges northwards but there will be no scope for a compensatory shift of tundra habitats to higher latitudes because of the limits imposed by the Arctic Ocean. The total area of tundra habitat is therefore likely to decrease

progressively and change in character as the limits of permafrost recede northwards. Lindström & Agrell (1999) reported that Cramer (1997) predicted a 65% decline in the area of tundra habitat in the Arctic. Zockler and Lysenko (2000) predict that the northward advance of boreal forests into tundra regions would lead to a reduction in the breeding range of Arctic species of between 5% (Sanderling) and 93% (Bean Goose, *Anser fabalis*), dependent on the species. The extent to which high Arctic species would adapt to such changes is currently unknown.

Migration routes and timing may also be influenced directly by climate change, both via changes in the strength and direction of air streams and prevailing winds and by the location and quality of stop-over sites, which are likely to be affected by changes in global temperature regimes (Lindström and Agrell, 1999).

4.4 How confident can we be in these predictions?

Weather systems are extremely complex and it is therefore necessary to take into account a very large number of factors when trying to predict patterns of future climatic change. However, the number of models producing similar predictions continues to increase, validating the methodology and providing increased support for the conclusions drawn. In addition, the predictions made by many such models also agree with recent observations made in the field (Easterling *et al.*, 2000), suggesting that our ability to forecast climatic changes continues to improve.

Modelling the future incidence and distribution of extreme weather conditions such as floods, droughts, tornadoes and hurricanes, is particularly problematic as, by their very definition, these events occur both erratically and infrequently, greatly reducing the opportunity for climatologists to collect sufficient data. As more information is collected, so the predictions generated by these models of climate change will become progressively more accurate. Climate modellers currently suggest that it is likely that extreme events will increase in frequency, but that the scale of this change is uncertain (Hulme *et al.*, 2002).

Understanding the processes underlying the functioning of ecosystems is an equally complex task, again necessitating the collection of large amounts of data concerning a wide range of potentially important factors. Where species range expansion or contraction occurs in response to climate change, changes in the level of competition and predation may occur (Davis *et al.* 1998a, b; Harrington *et al.* 1999). The potential for invasive and alien species to have detrimental impacts is another important factor that needs to be considered: some species that are currently benign or inhibited from colonising certain areas may change their attributes under future environmental conditions.

Predicting the outcome of interactions between weather conditions and bird populations is therefore difficult due to the large number of potential mechanisms by which climatic changes may influence the population dynamics of bird species, as illustrated in Figure 4. Making such predictions is further complicated by the influence of density dependence. Stenseth *et al.* (2002) point out that climate variability can affect populations in a density-independent manner, but may also affect the strength of density dependence regulating a population. In the absence of such changes, population declines, will tend to reduce levels of competition between individuals, potentially increasing survival rates and productivity and

acting so as to regulate populations about a certain level. If the strength of density dependence changes, then populations will shift to a different level of abundance. The influence of climate changes on population processes is a largely unexplored area at present.

One criticism often levelled at studies of the interactions between weather and population processes is that relationships are predominantly correlational as it is almost impossible to simulate large-scale climatic changes to study these interactions experimentally except by using small-scale and simple model ecosystems involving plants and invertebrates (e.g. Davis *et al.*, 1998a, 1998b). It is therefore possible that observed relationships between climatic variables such as temperature and population processes are in fact caused by confounding factors, including habitat destruction, disease, shifts in predation, etc. However, a number of recent meta-analyses (Parmesan & Yohe, 2003; Root *et al.*, 2003) have shown that many of the relationships observed hold true across a broad range of taxa, habitats and regions. In addition, in some studies changes in the direction of the ecological trends are closely matched by changes in direction of the climatic trends (e.g. Crick & Sparks, 1999). As the patterns of variation become more complex, so the probability of both population processes and climatic variables displaying simultaneous fluctuations by chance is reduced, and thus the probability that climatic changes are responsible for the ecological trends observed increases.

5. CONCLUSION - IS GLOBAL WARMING A CONSERVATION ISSUE?

There is an increasing body of evidence to suggest that the global climate is changing rapidly in response to the increased output over greenhouse gases as a result of human activity over the last 200 years. These climatic changes have already impacted on the population dynamics and distribution of a huge range of taxa across a broad range of geographical locations and habitats (Walther *et al.*, 2002; Parmesan & Yohe, 2003; Root *et al.*, 2003) and are likely to have even more severe consequences over the coming century. Thomas *et al.* (2004) predicted global extinction rates across taxa of between 17% and 35% by 2050 depending on future levels of greenhouse gas emissions.

A growing number of studies have demonstrated the influence of changing climatic conditions on the abundance, distribution and phenology of a wide variety of bird species in the UK. Current climatic models predict that winters in the UK will become progressively warmer and wetter over the next 75 years, while summers will become warmer and drier. Although bird species inherently possess the ability to adapt to changes in their environment and are theoretically able to move to areas where conditions are more favourable, the rapid pace of the predicted changes (Root & Schneider, 1993) coupled with the impact of human activity (Pitelka *et al.*, 1997), in terms of habitat manipulation and destruction, may leave many unable to do so. While generalist species may be able to cope with rapid environmental change, it is likely that species with more specialised ecological niches will be less able to do so. Thus, avian biodiversity in the UK is likely to decline.

Climate change is also predicted to have a marked impact on socio-economic factors (King, 2004). Human responses to changes in climatic variables, in terms of land use and the distribution of the population, will in turn feed back to natural systems, interacting with the more direct effects of global warming to increase the pressure on existing ecosystems still further.

Species unable to adapt sufficiently are likely to experience reductions in productivity and or/survival rates, and are therefore likely to decline in abundance, or in severe cases, to become extinct in the UK. Continued monitoring and research is needed to develop techniques for limiting future climatic changes and mitigating for their consequences.

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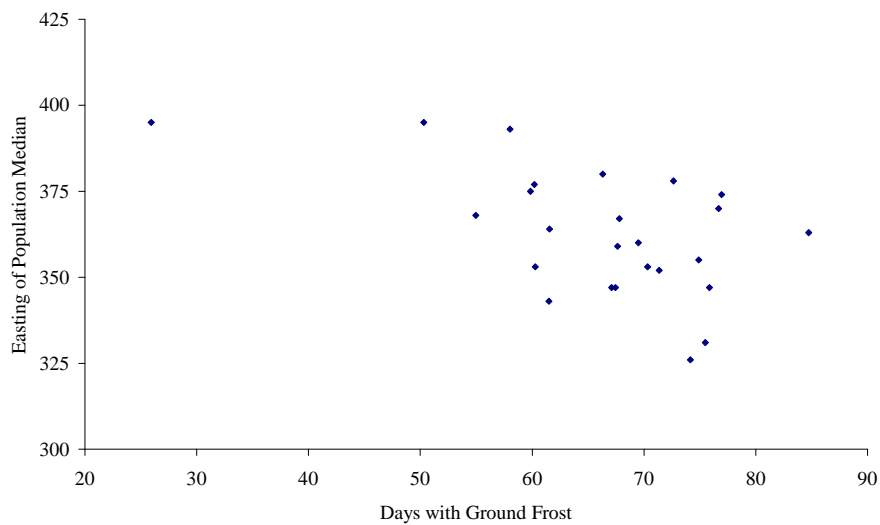


Figure 1 Relationship between the median longitude of the Ringed Plover distribution in Britain and the average number of days with ground frost recorded across 39 British weather stations (Rehfish & Austin, 1999).

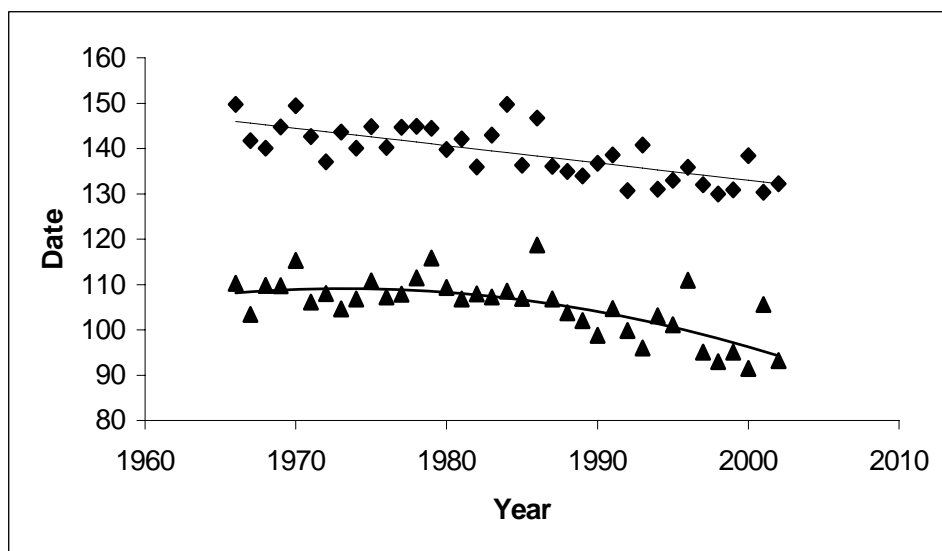


Figure 2 Trends of change in the laying dates of the first eggs in the nests of Long-tailed Tit (triangles) and Greenfinch (*Carduelis chloris*) (diamonds). (Each point represents the annual mean laying date and the lines represent the best fit linear or quadratic (curved) regression lines through the data points.) Data from the British Trust for Ornithology UK Nest Record Scheme.

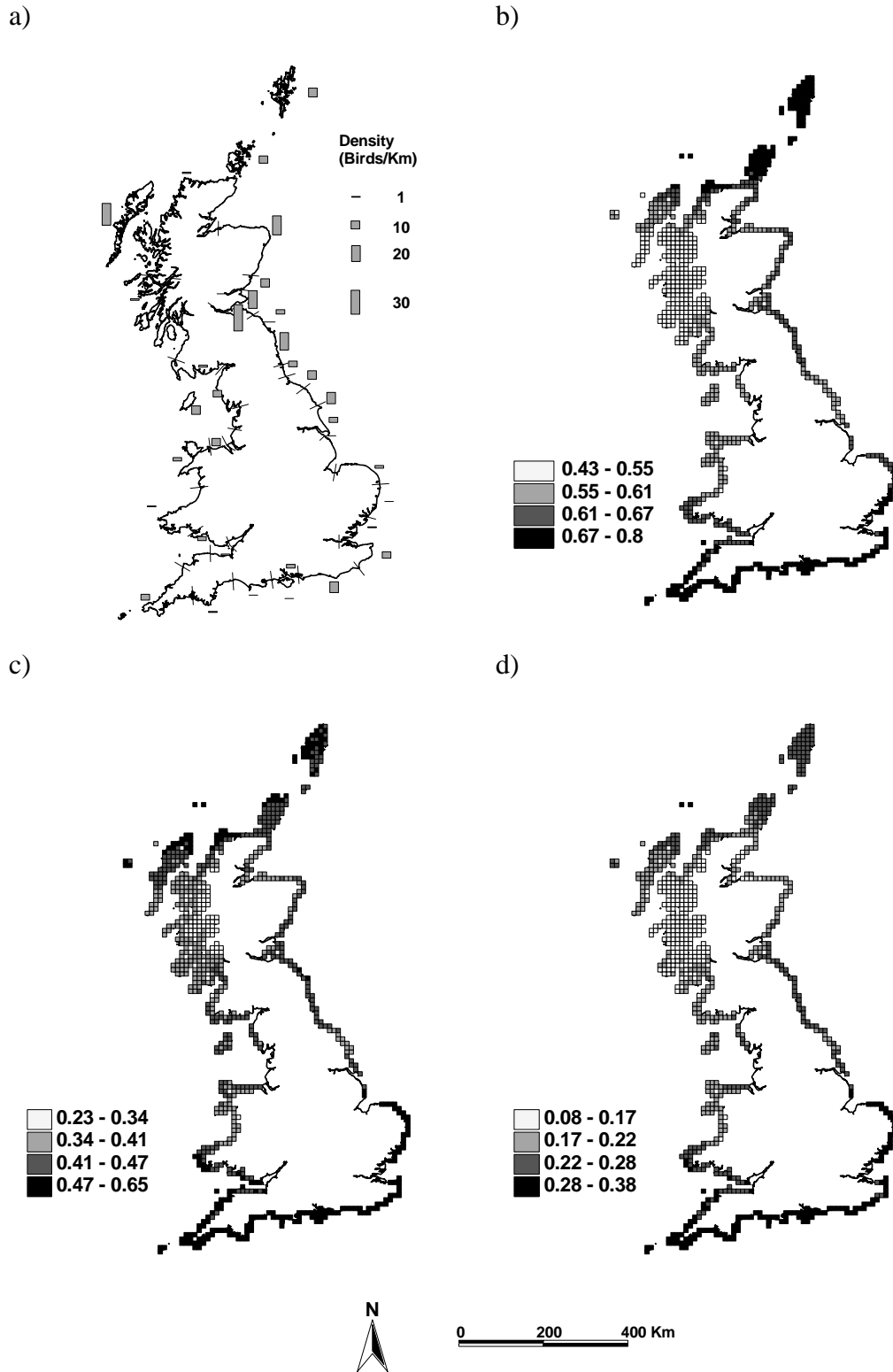


Figure 3 a) Turnstone densities on the non-estuarine coast of each of Great Britain's counties during the winter of 1984-85, and predicted relative change in their numbers at a scale of 10-km square under various UKCIP climate change scenarios: b) 2020 medium-low vs 1961-1990 baseline; c) 2080 medium-low vs 1961-1990 baseline; d) 2080 high vs 1961-1990 baseline. 1 = no change, <1 = decrease, > 1 = increase (Rehfishch *et al.* in press). All changes in (b) to (d) are <1, thus indicating declines.

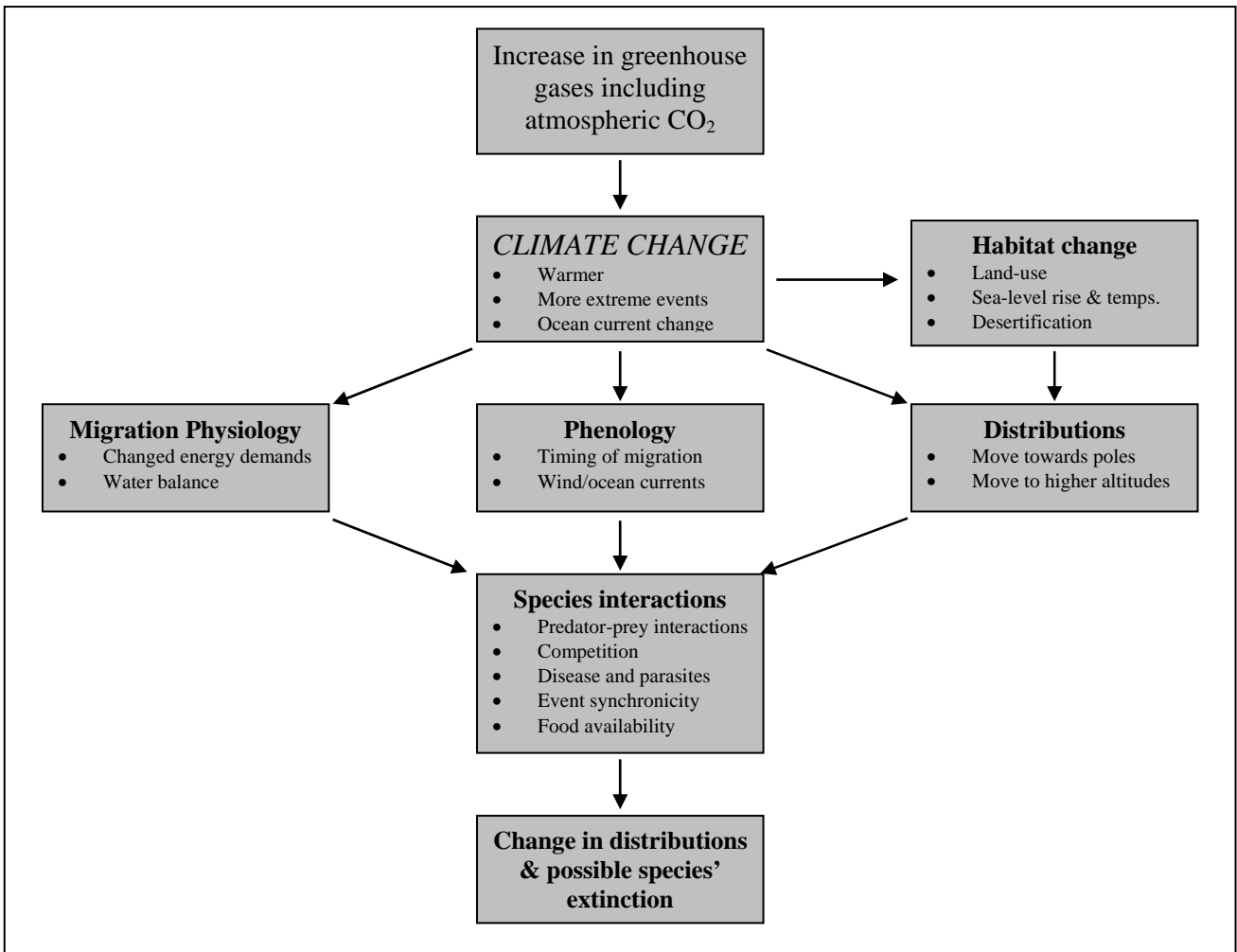


Figure 4 A simplified schema demonstrating the range of mechanisms by which climatic change can influence the population dynamics of bird species in the UK and therefore, ultimately, the size of avian populations.

