Impacts of climate change on the UK's coastal and marine waterbirds

N.H.K. Burton[1], G.E. Austin[1], T.M. Frost[1] and J.W. Pearce-Higgins[1]

[1] *British Trust for Ornithology, The Nunnery, Thetford, Norfolk, IP24 2PU, UK*

EXECUTIVE SUMMARY

- UK coastal habitats support internationally important numbers of waterbird species during the non-breeding seasons (autumn and spring passage, winter), from populations which breed across the UK and continental Europe to the subarctic and Arctic, and which may winter further south in Europe and Africa. Climate change may affect processes operating during the non-breeding seasons and also while species are on their breeding grounds, which in combination may alter their distributions, abundance and timing of occurrence in the UK.

- In response to climate change, the distribution of wintering waterbirds across Europe has shifted north-eastwards. This evidence has continued to build since the previous assessment, with a particular increase in published studies documenting changes in wildfowl distributions over recent decades.

- Winter warming has been associated with changes in the timing of spring departure of species to their breeding grounds.

- Past changes in the abundance and distributions of the UK's non-breeding waterbirds have been correlated with changes predicted from climatic models, indicative of widespread population-level climate change impacts. There is some evidence, for a limited number of species, that the observed changes have been the result of movements of individuals, although improved demographic monitoring is needed to better understand the underlying processes.

- Increases in the abundance of many of the UK's non-breeding waterbirds (e.g. 23% by 2050, 58% by 2080 under high-emissions scenarios) are projected. Six non-breeding waterbird species are regarded as being at high risk of range loss in the UK from climate change, a further 14 species at moderate risk, whilst 20 species are projected to benefit through range expansion.

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- Projected changes in sea level are likely to impact the extent and quality of coastal habitats, but this has yet to be properly included within species' climate change vulnerability assessments.

- There is some limited evidence that climate change may be impacting the breeding success of some species, affecting their non-breeding abundance in the UK. The future extent of the Arctic and subarctic breeding areas of the majority of waterbird species are predicted to decline by 2080, although reductions may be less severe in the Eurasian and Canadian Arctic from where the majority of UK non-breeding waterbirds originate. Climate change impacts may additionally affect waterbirds that also breed in the UK, with northern/upland breeding species projected to be greatest risk of decline. Potentially positive population-level impacts of milder winter weather on survival rates may be more than compensated for by projected negative climate change impacts on reproductive success.

1. INTRODUCTION

The UK's coast and marine waters support internationally important numbers of waterbird species during the non-breeding seasons (autumn and spring passage, winter). Some of these birds originate from local breeding populations within the UK or continental Europe, but a great many travel here along the East Atlantic Flyway, a migratory pathway that connects breeding grounds in Scandinavia and Russia, Iceland, Greenland and Canada (Wernham *et al*., 2002) with wintering grounds in Europe and farther south. As such, these species' populations may be subject to multi-scale environmental effects, including climate change, through processes operating in different geographical locations at different periods of their annual life cycle – on their breeding grounds, staging sites and wintering grounds (Piersma and Lindström, 2004; Maclean *et al*., 2007). Whilst weather conditions are an important driver of both the breeding success (Meltofte *et al*., 2007) and annual survival (Clark, 2004) of waterbirds through direct impacts on ambient conditions, climate change may also affect these population processes indirectly (Lindström and Agrell, 1999), for example, through changes to predator populations (Kausrud *et al*., 2008; Gilg *et al*., 2009; Schmidt *et al*., 2012) prey abundance (Pearce-Higgins *et al*., 2010) and habitat quality on the breeding grounds (Wauchope *et al*., 2017), or through impacts on prey distributions or habitat loss on non-breeding grounds (Iwamura *et al*., 2013; Murray *et al*., 2019). Constraints operating at one part of the annual cycle can significantly impact abundance at other stages of that cycle, and in other locations. For example, resulting changes in abundance and distribution on the breeding grounds will have consequences for the numbers occurring in non-breeding areas, whilst impacts in one non-breeding area may also affect numbers from the same population at another (Iwamura *et al.*, 2013).

In a previous assessment of the impacts of climate change on these populations, Pearce-Higgins and Holt (2013) presented evidence, particularly from studies of waders, for north-easterly shifts in species' overwinter distributions consistent with anticipated impacts of a warming climate, associated with a medium level of confidence. However, at that time, there was little existing evidence that those species that migrate to winter in the UK from the Arctic and subarctic were being impacted by climate change on their breeding grounds. Here, we summarise more recent evidence for impacts of climate change on the waterbirds that spend the non-breeding seasons in the UK (and across Europe) assessing first, changes in species' numbers, distributions and phenology that have been observed in non-breeding areas and, second, the potential environmental drivers and processes behind these changes, including those that may be operating on the species' breeding grounds, and elsewhere along the East Atlantic flyway. It is worth noting that some of these species also associate with freshwater or terrestrial habitats to a variable extent, and therefore in order to present as complete a picture as possible, some of the supporting literature for this assessment may come from non-coastal or marine habitats.

Non-breeding waterbirds in the UK are monitored by the Wetland Bird Survey (WeBS: https://www.bto.org/webs), with around 3000 volunteer counters participating in synchronised monthly counts at both inland and coastal wetlands. Data are used to assess the numbers of non-breeding waterbirds at a country-level, trends in their numbers and distribution, and the importance of individual sites for waterbirds, in line with the requirements of multilateral environmental agreements (Frost *et al.*, 2019; Woodward *et al.*, 2019). WeBS covers both inland waterbodies and coastal sites, most especially estuaries, but provides less complete coverage of the open coast. For this reason, periodic surveys of non-breeding waterbirds on this habitat are also undertaken through the Non-Estuarine Waterbird Survey (NEWS; e.g. Austin *et al.*, 2017), counts from which feed into WeBS reporting.

2. WHAT IS ALREADY HAPPENING?

Changes in wintering numbers and distributions and phenology

Much of the focus of research on the impacts of climate change on waterbirds has been on changes in species' wintering distributions. The processes behind these changes are likely to be complex, but may include absolute changes in the sizes of populations, the direct movements of individuals, or differential changes in overwinter survival rates or juvenile settlement patterns across species' wintering ranges. The relative importance of these processes is related to variation in the site-fidelity of different species (Pearce-Higgins and

Holt, 2013). Using data from WeBS and sister schemes across Europe that also feed into the International Waterbird Census (IWC: https://www.wetlands.org/iwc), the evidence for changes in wintering waterbird distributions has continued to build through a large volume of peer-reviewed publications from across Europe. In particular, published studies document changes in wildfowl distributions over this period, which were lacking at the time of the previous assessment (Pearce-Higgins and Holt 2013). Considering IWC data from 1990–2013 from across western, central and northern Europe, Pavón-Jordán *et al.* (2018) examined changes in the wintering distributional abundance of 25 wildfowl species, and described how they varied between species associated with different habitats. 'Deep-water' species showed long-term north-eastwards shifts in distributional abundance through this period, reflecting the breeding origins of the majority of species considered and climatic gradients; distributions of both deep- and 'shallow-water' species were linked to inter-annual variation in winter weather, as shown by the winter North Atlantic Oscillation (NAO) index, but there were no significant changes in 'farmland' species' distributions. These results are in line with the previously documented north-easterly shifts in the wintering distributions of coastal waders that have been associated with warmer temperatures (Austin and Rehfisch, 2005; Maclean *et al.*, 2008), and suggests that diving duck species dependent upon ice-free deep water are exhibiting the same response.

This response appears largely driven by warming winter temperatures in Scandinavia reducing ice-cover, leading to widespread increases in the numbers of a range of wintering waterbirds in both Sweden (Nilsson, 2014; Nilsson and Haas, 2016) and Finland (Fraixedas *et al.*, 2015). Trends in the proportion of individuals overwintering in Finland have increased for four of six wildfowl and one of three gull species, with early winter temperature (daily mean temperature in November–December) positively associated with this proportion for six of these species overall (Meller *et al.*, 2016). Numbers of 13 of 18 waterbirds staging in south Sweden increased from 1973–2013 (Nilsson, 2014), although there have been recent declines in the numbers of some species (Nilsson and Haas, 2016). Specifically, there have been north-easterly shifts in the distribution of tufted duck *Aythya fuligula*, goldeneye *Bucephala clangula*, smew *Mergellus albellus* and goosander *Mergus merganser* (Lehikoinen *et al.*, 2013; Pavón-Jordán *et al.*, 2015), all of which are diving ducks (species defined as associated with deep-water by Pavón-Jordán *et al.*, 2018) which require ice-free water. In contrast, declines of pochard *Aythya ferina* in western Europe appear unrelated to shifts in distribution towards species' breeding grounds (Folliot *et al.*, 2018). Many wetland sites are designated as protected sites, for example, in the European Union as Special Protection Areas (SPAs), due to their importance for waterbird species. Pavón-Jordán *et al.* (2015) highlighted the added importance of this network for species whose distributions are changing, such as smew, even though this species itself is only a feature of a relatively small number of sites.

Changes in the wintering distributions of dabbling ducks (species defined as associated with shallow-water habitats by Pavón-Jordán *et al.*, 2018) are more mixed and appear less closely correlated with temperature (Dalby *et al.*, 2013). Numbers of wigeon *Anas penelope* have declined in Spain and Ireland, remained broadly stable in the UK and increased in Scandinavia (Fox *et al.*, 2016). There has been a similar change in the distribution of Mallard *Anas platyrhynchos* (Gunnarsson *et al.*, 2012). More broadly across Europe, the distribution of the migratory north-west / south-west Europe greylag goose *Anser anser* population (defined as associated with farmland habitats by Pavón-Jordán *et al.*, 2018) has also shifted north-eastwards, a combination of reduced migration distance by individuals, and an increasing population (Ramo *et al.*, 2015; Podhrázský *et al.*, 2017). These trends are not apparent everywhere and may be modified by changes in habitat condition at specific sites. Evidence from the Camargue in south-west France shows that both teal *Anas crecca* and mallard are now overwintering there for longer than in previous years, which in combination with improved body condition and increased sedentariness suggest that local improvements in habitat quality for these species may be over-riding north-easterly shifts in distributions (Guillemain *et al.*, 2015a, b).

The latest wintering waterbird indicator for the UK, produced using WeBS data as part of wider Biodiversity Indicators (Defra, 2018), shows that while indices for all waterbirds, waders and wildfowl were higher in 2015/16 than at the start of the time series in 1975/76, there had been declines over the most recent 2009/10–2014/15 period. These declines are consistent with the evidence described above for wildfowl and previous evidence for waders (Austin and Rehfisch, 2005; Maclean *et al.*, 2008) of north-easterly shifts in distributions, but also suggest wider overall declines in abundance.

Comparative trends, based on January counts from 2005/06–14/15, in the numbers of 10 ‘deep-water’ and seven ‘shallow-water’ associated species (as defined by Pavón-Jordán *et al.*, 2018) wintering in the UK and south Sweden are shown in Figure 1a (UK and Swedish data are drawn from WeBS and Nilsson and Haas, 2016, respectively). For three diving duck or ‘deep-water’ species with predominantly eastern subarctic or Arctic breeding distributions, scaup *Aythya marila*, goldeneye and smew, there have been recent increases in wintering numbers in Sweden, while numbers wintering in the UK have declined (Figure 1b–d). Trends for other deep-water species with wider European distributions and shallow-water species do not appear correlated between Sweden and UK.

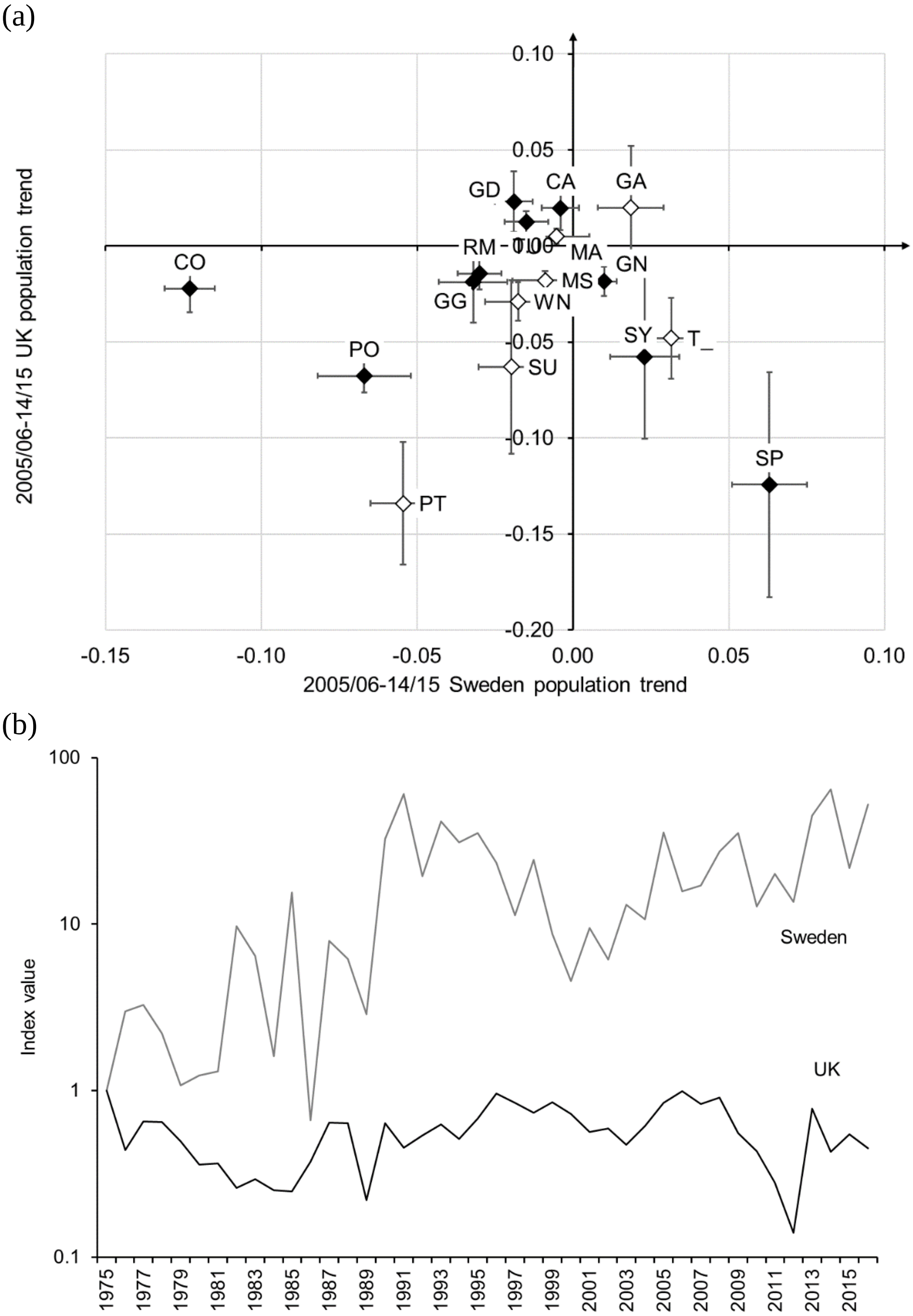


Figure 1: (a) Comparative trends (± 1 standard error) in the numbers of waterbirds wintering in the UK and Sweden between 2005/06 and 2014/15: closed symbols – 'deep-water' species; open symbols – shallow-water species. Based on January indices from the UK Wetland Bird Survey (WeBS: see https://www.bto.org/volunteer-surveys/webs/publications/webs-alerts/methods/data-analysis for indexing methods) and Nilsson and Haas (2016) respectively (see Nilsson and Haas, 2016, for trend analysis methods). Deep-water species: PO = pochard, TU = tufted duck, SP = scaup; GN = goldeneye, SY = smew, GD = goosander, RM = red-breasted merganser Mergus serrator*, GG = great crested grebe* Podiceps cristatus*, CA = cormorant* Phalacrocorax carbo*, CO = coot* Fulicra atra*; shallow-water species: MS = mute swan* Cygnus olor*, SU = shelduck* Tadorna tadorna*, GA = gadwall* Anas strepera*, WN = wigeon, MA = mallard, PT = pintail, T_ = teal. (b) January indices for scaup for the UK (black lines) and Sweden (grey lines) show divergent trends (note logarithmic scale).*

Figure 1 – contd. January indices for (c) goldeneye and (d) smew for the UK (black lines) and Sweden (grey lines) show divergent trends (note logarithmic scale).

Whilst much of the new literature is focussed on wildfowl, there has been less additional evidence about the impacts of climate change on the numbers and distributions of wintering waders. From 1977 to 2009 changes in the wader assemblage across Wetlands in France, as shown by the community temperature index, shows that species associated with warmer climates in winter have tended to increase in abundance relative to those associated with cooler climates (Godet *et al.*, 2011). This same process has probably contributed to a significant increase in the functional diversity and species-richness of the wader communities on British estuaries over the same period (Mendez *et al.*, 2012). Functional diversity in wintering wader communities on British estuaries increased to the greatest extent on east coast estuaries between 1980/81 and 2006/07, reflecting a decreased advantage in wintering in the milder west following recent increases in winter temperatures across the country (Austin and Rehfisch, 2005). Previously less widely distributed species, such as black-tailed godwit *Limosa limosa*, avocet *Recurvirostra avosetta* and greenshank *Tringa nebularia* have become more extensively distributed; changes in the overall non-breeding numbers of more common species in the UK have predominantly resulted in changes in local abundance rather than changes in site occupancy (Mendez *et al.*, 2018). On the UK's non-estuarine coast, declines between 1984/85 and 2015/16 in the numbers of purple sandpiper *Calidris maritima*, redshank *Tringa totanus* and turnstone *Arenaria interpres* and changes in their distributions within the country are consistent with shifts towards species' breeding origins resulting from a warming climate (Austin *et al.*, 2017).

Another key signal of climate change has been that of altered timing of bird migration or breeding. Across the globe, there has been a general advancement in first arrival dates of both wildfowl and waders to their breeding grounds (Pearce-Higgins and Green, 2014). Of 24 waterbird species (two divers, 11 waterfowl and 11 waders) that winter in the Republic of Ireland, three show evidence of departing later from the East coast in the spring (pintail *Anas acuta*, purple sandpiper and dunlin), and one earlier (greenshank). Annual variation in the trends of six species (red-throated diver *Gavia stellata*, whooper swan *Cygnus cygnus*, pintail, scaup, goldeneye and grey plover *Pluvialis squatarola*) were significantly correlated either with temperature or the North Atlantic Oscillation Index (NAOI). For three species (red-throated diver, pintail and grey plover), correlations with temperature were negative, implying earlier departure in warmer years, whilst for whooper swan, the correlation was positive. Both scaup and goldeneye showed positive correlations between NAO and departure date (Donnelly *et al.*, 2015). Greenland white-fronted geese *Anser albifrons flavirostris* have advanced their departure from Ireland by 15 days from 1969 to 2012 in response to warmer temperatures and changing cropping patterns (Fox *et al.*, 2014). Across Europe, there is evidence for a significantly earlier departure of pochard from the wintering locations (Folliot *et al.*, 2018). Indeed, changes in the distribution of species and earlier migration phenology are probably linked in many species, as shown for greylag geese across Europe, where individual decisions of movements in response to temperature enable those individuals to remain closer to the breeding grounds during milder winters, so allowing those birds to return to their breeding territories earlier (Podhrázský *et al.*, 2017). Updated estimates of the timing of prenuptial (spring) migration for Great Britain and Ireland are presented for 25 wildfowl and 16 waders in Massimino and Gillings (2018), although most of the changes from previous assessments are probably due to improved data quality rather than climate change.

Environmental drivers and processes

For both waders and wildfowl, observed changes in species' winter abundance across the UK have been shown to be strongly correlated with expected changes based on climate models linking site-level abundance to precipitation and temperature variables (Johnston *et al.*, 2013). Those relationships also show that the abundance of wintering waterbirds across Western Europe is negatively correlated with summer temperature at the wintering sites, but strongly positively associated with winter temperature. These relationships result from a combination of spatial associations between abundance and climate and the impact of weather upon populations. Across species, wildfowl (Anatidae) tend to show positive relationships between breeding season temperature and measures of abundance or productivity (Pearce-Higgins and Green 2014), probably because warmer weather is associated with improved invertebrate abundance and reduced energetic demands for the free-ranging chicks. Conversely, waders tend to show positive associations between winter temperature and measures of abundance or survival (Pearce-Higgins and Green, 2014), which probably results from the negative consequence that severe winter weather has on restricting access to food and increasing energy requirements. Specific studies from the UK have related changes in lapwing *Vanellus vanellus* populations to fluctuations in the frequency of severe winters, with cold winter weather associated with high levels of mortality (Robinson *et al.*, 2014). High levels of winter rainfall can similarly affect some estuarine wader species, such as dunlin *Calidris alpina* (Ryan *et al.*, 2016).

The populations of many wader species (Stroud *et al.*, 2008) and some wildfowl, such as long-tailed duck *Clangula hyemalis* and velvet scoter *Melanitta fusca* (Kilpi *et al.*, 2014), are in long-term decline across Europe, including in the UK (Eaton *et al.*, 2015). However, for many species, more work is required to specifically identify the extent to which climate change is simply redistributing species, as opposed to causing large-scale population changes, as well to better understand the demographic processes behind these changes. A key component to population trends may also be the impacts of climate change on the breeding grounds, where there is growing evidence. Increased growing season length associated with warmer spring and summer weather has contributed to larger goose populations (Descamps *et al.*, 2017), with the potential to impact other waterbird species, such as waders (Flemming *et al.*, 2019), Climate-related disruption of lemming cycles may also be impacting predation rates of Arctic-breeding waterfowl and waders. Whilst this appears to have caused recent declines in dark-bellied brent geese that winter in the Netherlands (Nolet *et al.*, 2013), a similar pattern is apparent in the English time–series (Frost *et al.*, 2019), which may therefore also be responding to the same drivers. There is growing evidence of a general reduction in the breeding success of waders across the globe, which is most apparent from northern temperate and Arctic regions, where most UK non-breeding waterbirds come from (Kubelka *et al.*, 2018). Although the proximate driver of this reduction is increasing predation rates, Kubelka *et al.* (2018) suggest that this could be a consequence of warming, although this is disputed by Bulla *et al.* (2019) who reanalysed the data and found no evidence for a latitudinal gradient in trends in predation rates.

The importance of nest losses and predation as a driver of wader declines is in line with the results of both pan-Europe (Roodbergen *et al.*, 2012), and UK-specific (Roos *et al.*, 2018). Recent studies of curlew *Numenius arquata*, which has recently been red-listed across Europe, and is globally near-threatened, have found strong associations between changes in the population breeding in the UK, and increasing predator populations, as well as associations with land-use (Douglas *et al.*, 2014; Franks *et al.*, 2017). In addition, breeding population declines have been greatest in areas where warming had been greatest, and with low levels of summer rainfall (Franks *et al.*, 2017). Although correlative only, and lacking mechanistic underpinning, this would be consistent with studies of other breeding waders, such as golden plover *Pluvialis apricaria* and dunlin in the UK, which link breeding success and population changes to summer temperature and water levels, mediated through impacts upon soil invertebrates (Pearce-Higgins *et al.*, 2010; Carroll *et al.*, 2015).

Aside from climate change, predation and changing land-use, waterbirds face a number of other threats that may translate into observed changes in abundance and distribution through impacts on the fitness (breeding productivity, survival) of individuals (Stillman *et al.*, 2015). A range of anthropogenic threats have been identified as impacting wader populations (specifically curlews and godwits, but these are likely to also apply to many other species) across the East Atlantic Flyway, which may therefore affect numbers wintering in the UK, either directly or directly. The most important threats, as assessed from expert knowledge, include agricultural change, aquaculture, renewable development, transport infrastructure, fisheries, disturbance and artificial drainage of wetland habitats (Pearce-Higgins *et al.*, 2017a). The current UK Article 12 report is not yet available but found no evidence of coastal habitat loss for the UK, instead highlighting multiple managed retreat and coastal wetland recreation projects that is likely to have led to a net coastal habitat gain (D. Stroud, pers. comm.).

Socio-economic impacts

Biodiversity provides many benefits to humans, including cultural ecosystem services. Coastal sites, many of which are protected for their importance for waterbird species, may be a particular focus for ecotourism, while they may also be important for other human activities, for example, wildfowling and shellfishing. Fisher *et al.* (2011) evaluated the trade-offs between different services, including production, conservation or cultural services, which may be affected by changes in waterbird populations resulting from climate change. Considering case studies of two managed realignment sites, constructed as mitigation for climate change-induced sea-level rise, Luisetti *et al.* (2013) assessed people's willingness to pay for measures including bird species richness and the presence of key bird species, highlighting the importance of an ecosystem services approach to management decisions. More-recent unpublished work under the NERC 'Biodiversity and Ecosystem Services' programme (https://synergy.st-andrews.ac.uk/cbess/) has also highlighted the importance of a multi-dimensional concepts of biodiversity in ecosystem management, and the need to consider heterogeneous public preferences for biodiversity when planning conservation actions, including responses to climate change.

2. WHAT COULD HAPPEN IN THE FUTURE?

Evidence on potential future impacts of climate change on the UK's coastal and marine waterbirds are available from studies on both non-breeding and breeding distributions and abundances. A large-scale modelling project considering the projected impacts of climate change on 45 species of wintering waterbirds projected there to be 23% more individual birds by 2050 under a high A1F1 (Fossil Intensive) emissions scenario, and 58% by 2080, although with a geometric population change of –11% and –33% respectively. Some species were projected to increase significantly to increasingly dominate waterbird communities, whilst a total of 11 species were projected to suffer declines of more than 50% by 2050 and 19 by 2080 (Johnston *et al.*, 2013). Projections were summarised for SPAs to assess the extent that the current network in the UK would continue to protect internationally important assemblages and populations of wintering waterbirds in the future. As a result of these projected changes, a high degree of turnover was projected at individual SPAs, consistent with current patterns (Mendez *et al.*, 2012, 2018). Only 10 of 57 SPAs were projected to lose all qualifying species by 2050, and 11 by 2080, whilst increases in abundance were projected to result in six and seven new sites respectively supporting internationally important numbers. Importantly, this study showed that, as coastal sites within EU SPA network are often designated for their importance for multiple non-breeding waterbird species, most are likely to continue to meet legal designation criteria as species abundances change in response to climate change (Johnston *et al.*, 2013).

Based on a combination of observed and projected changes in abundance (the latter from the Johnston *et al.*, 2013 study), in conjunction with additional ecological information, Pearce-Higgins *et al.* (2013) applied a published framework for assessing climate change vulnerability (Thomas *et al.*, 2011) to non-breeding waterbird species around the UK. This framework has already been demonstrated to have some power in predicting changes in breeding birds in the UK (Wheatley *et al.*, 2017). Specifically, under a medium (A1B) emissions scenario, six non-breeding wildfowl species were regarded at high risk from climate change and a further 14 species at moderate risk; 21 species were projected to benefit (Table 1). It is worth noting that these assessments generally had a high uncertainty at the species level, with only three associated with a moderate or high degree of confidence (avocet, sanderling *Calidris alba* and little egret *Egretta garzetta*).

Table 1: Summary of climate change risk assessments for waterbird species in Great Britain or the United Kingdom, listing the classification of each species in different assessments. The assessments summarised consider non-breeding numbers (from Pearce-Higgins et al., 2013), breeding distributions (from Pearce-Higgins et al., 2017b) and breeding abundances (from Massimino et al., 2017). Note, in particular, that climate change is projected to have contrasting impacts on the breeding and non-breeding numbers and distributions of several waterbird species. Species are summarised using BTO five-letter codes.

	High decline	**Moderate decline**	**Mixed / low risk**	**Moderate benefit**	**High benefit**
Non-breeding numbers (UK)	CANGO, GREGO, MALLA, POCHA, EIDER, LOTDU	GRCGR, LITGR, BEWSW, WHOSW, PIFGO, WIGEO, GADWA, TUFDU, VELSC, GOOSA, OYSTE, LAPWI, PURSA, BATGO	PINTA, GOLDE, KNOT, REDSH, WHIMB	SCAUP, REBME, RINPL, DUNLI, TURNS	RETDI, SLAGR, BREGO, SHELD, TEAL, SHOVE, COMSC, AVOCE, GOLPL, GREPL, SANDE, SNIPE, BLTGO, CURLE, GRESH, LITEG
Breeding distribution (GB)	WIGEO, GOOSA, GOLPL, DUNLI, SNIPE, CURLE	TEAL, REBME	GRCGR, CANGO, PINTA, EIDER, LAPWI, REDSH	LITGR, MUTSW, MALLA, TUFDU, GOLDE, OYSTE, RUFF.	GREGO, SHELD, GADWA, GARGA, SHOVE, POCHA, AVOCE, RINPL, BLTGO
Breeding abundance (GB)	SNIPE, CURLE	CANGO, TUFDU, OYSTE, LAPWI	LITGR, MUTSW, GREGO, SHELD, REDSH, LITEG	GRCGR	MALLA

AVOCE, avocet; BATGO, bar-tailed godwit *Limosa lapponica;* BEWSW, Bewick's Swan *Cygnus columbianus;* BLTGO, black-tailed godwit; BREGO, brent goose *Branta bernicla;* CANGO, Canada goose *Branta Canadensis;* COMSC, common scoter *Melanitta nigra;* CURLE, curlew; DUNLI, dunlin; EIDER, eider; GADWA, gadwall; GARGA, garganey *Spatula querquedula;* GRCGR, great-crested grebe; GREGO, greylag goose; GRESH, greenshank; GOLDE, goldeneye; GOLDPL, golden plover; GOOSA, goosander; GREPL, grey plover; KNOT, knot *Calidris canutus;* LAPWI, lapwing; LITEG, little egret; LITGR, little grebe *Tachybaptus ruficollis;* LOTDU, long-tailed duck; MALLA, Mallard; MUTSW, mute swan; OYSTE, oystercatcher *Haematopus ostralegus;* PIFGO, pink-footed goose *Anser brachyrhynchus;* PINTAI, pintail; POCHA, pochard; PURSA, purple sandpiper; REBME, red-breasted merganser; REDSH, redshank; RETDI, red-throated diver; RINPL, ringed plover *Charadrius hiaticula;* RUFF., ruff *Calidris pugnax;* SANDE, sanderling; SCAUP, scaup; SHELD, shelduck; SHOVE, shoveler *Spatula clypeata;* SLAGR, Slavonian Grebe *Podiceps auritus;* SNIPE, snipe *Gallinago gallinago;* TEAL, teal; TUFDU, tufted duck; TURNS, turnstone; VELSC, velvet scoter; WHIMB, whimbrel *Numenius phaeopus;* WHOSW, whooper Swan; WIGEO, wigeon.

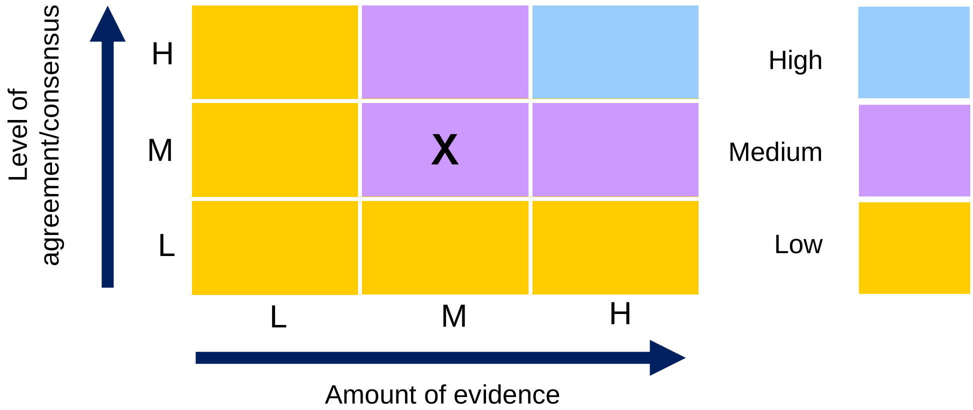
In addition to the effects of changes in weather patterns, climate change is projected to have impacts on sea levels and therefore to threaten coastal ecosystems and the biodiversity that they support worldwide. UK sea level, relative to a 1981–2000 baseline is projected to rise by 0.29–0.66m under a low (RCP2.6) scenario to 0.56–1.12m under a high (RCP 8.5) scenario (Lowe *et al.*, 2018). The impact this will have on natural coastal habitats will depend upon the extent to which human responses to sea-level rise impose a hard barrier to the sea, or involve managed retreat, but potential reductions in the extent of intertidal habitats, saltmarsh and adjacent freshwater habitats may impact both non-breeding and breeding waterbirds (Ausden *et al.*, 2011; Franks *et al.*, 2016; Murray *et al.*, 2019). Resulting changes in the morphology and dynamics of estuarine systems may also affect sediment patterns, invertebrate food resources and the potential number of birds those estuaries can support, but potentially in ways that are difficult to predict (Austin and Rehfisch, 2003). Through a modelling-based approach for waders on the East Asian–Australasian Flyway, Iwamura *et al.* (2013) highlighted that migratory waterbirds may be at magnified risk to this habitat loss, with risk greatest for those taxa whose migration routes contain bottlenecks – sites through which a large fraction of the population travels.

Clearly an important component of the future trends of non-breeding waterbirds in the UK is determined by what happens on their breeding grounds. The Arctic is warming twice as fast as the rest of the planet and is both the site and source of some of the world's greatest environmental changes (House of Commons Environmental Audit Committee, 2018). For those waterbirds breeding in the Arctic, there is a considerable likelihood that areas climatically suitable for breeding will change and decline in size by 2080, with 66–83% of species losing the majority of suitable area across the Arctic, although reductions are predicted to be less severe in the Eurasian and Canadian Arctic from where the majority of UK non-breeding waterbirds originate (Wauchope *et al.*, 2017). For other species that breed closer to the UK, there are relevant results from a risk assessment undertaken within the UK (Table 1). This suggests that, of 11 wader species, four which breed in the uplands are at high risk of negative climate change impacts in the UK (dunlin, snipe, curlew and golden plover), whilst there is either a moderate or high benefit for five others (oystercatcher, ruff, ringed plover, black-tailed godwit, avocet). Of the ducks breeding in the UK, which make only a small contribution to non-breeding numbers, only two, wigeon and goosander, were projected to be at high risk of negative climate-change impacts, whilst 10 were projected to benefit from climate change (Pearce-Higgins *et al.*, 2017b). It is worth noting that these assessments were also associated with a high degree of uncertainty. Analysis of UK and French Breeding Bird Survey data suggests that the size of the breeding populations of great-crested grebe and mallard may increase in the future, but that Canada goose, tufted duck, oystercatcher, lapwing, snipe and curlew populations may decline (Massimino *et al.*, 2017).

Looking across these studies, there is a high degree of uncertainty, and a low level of consistency in the impacts that climate change is projected to have on the breeding and non-breeding numbers and distributions of waterbirds, which may well reflect biological reality in terms of anticipated impacts. The net consequence of these results is that whilst the non-breeding numbers and distributions of a range of species may increase in response to warmer conditions, for many, climate change is expected to result in reductions in the UK, probably associated with increased short-stopping associated with milder temperatures. Species which breed in Arctic, subarctic and upland habitats are also likely to be vulnerable to future climate-change impacts, which may account for already declining population trends of species in those habitats (Lehikoinen *et al.*, 2019). Through time, it may well be the impacts of climate change on the breeding grounds which become the greatest limiting factor on the non-breeding numbers of these species in UK coastal and marine habitats.

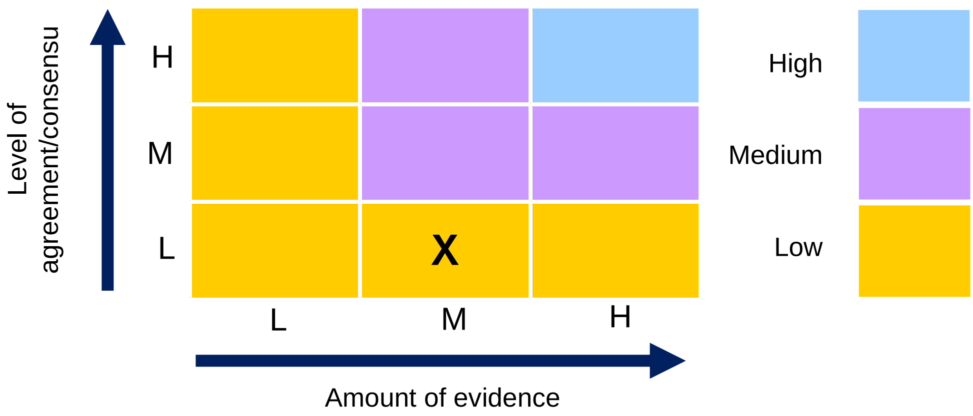
3. CONFIDENCE ASSESSMENT

What is already happening



Since the last MCCIP Report Card, there has been an increase in the number of papers describing changes in the wintering distributions of some species of wildfowl, which are consistent with anticipated impacts of a warming climate, and with the changes in non-breeding numbers and distributions of waders summarised in the previous assessment. Changes in migration phenology have also been reported. Although there is some evidence that climate change may be affecting the reproductive success of species over-wintering in the UK, this is limited and with low consensus, particularly in relation to climate change on the Arctic and subarctic breeding grounds, reflecting a lack of ecological, abundance and demographic monitoring data. As such, the overall assessment is unchanged.

What could happen in the future?



Recent modelling work of changes in the distributions of waterbirds on both their non-breeding and breeding grounds has confirmed the conclusions of a previous large-scale review of climate impacts on migratory bird populations submitted to CMS (UNEP/CMS/Conf. 8.22) that identified Arctic-breeding waterbirds as amongst the most vulnerable to climate change (Robinson *et al.*, 2009). A number of new climate change impact projections have been published for both breeding and non-breeding distributions in recent years, particularly for the UK. Although these identify a number of species for which anticipated negative impacts of climate change on the breeding grounds are likely to over-ride potentially positive impacts on over-winter survival on the UK non-breeding habitats, the high degree of uncertainty associated with specific projections for individual species, and these variable projections across breeding and non-breeding distributions for the same species, mean that we regard the level of consensus as remaining low.

4. KEY CHALLENGES AND EMERGING ISSUES

Previous MCCIP Report Cards have identified three main knowledge gaps that need to be addressed and which are updated below:

(a) The need for monitoring of populations that breed in the Arctic and subarctic (that winter in the UK).

(b) The need to integrate data from wider and improved monitoring of waterbird abundance and demography (breeding productivity, survival) in population models and to combine this with wider environmental monitoring to identify the causes of population and distributional change.

(c) The need to continue to quantify potential impacts associated with other anthropogenic pressures and their likely interactions with future climate change.

These knowledge gaps remain relevant and challenging to address. There is little direct monitoring of Arctic and subarctic breeding waterbirds, due to logistic and other challenges. However, there is significant potential to monitor Arctic and subarctic breeding populations of both waders and wildfowl through expansion of existing volunteer-based monitoring of abundance, productivity and survival on temperate non-breeding grounds (Robinson *et al.*, 2005; Guillemain *et al.*, 2013).

Consistent with the Arctic Biodiversity Assessment (CAFF, 2013) that recommended "improved monitoring and research to survey, map, monitor and understand Arctic biodiversity", collation of abundance and demographic data and their use in models to identify the processes underpinning population and distributional changes of Arctic and subarctic breeding waterbirds should be addressed as a high priority (House of Commons Environmental Audit Committee, 2018).

Associated with these knowledge gaps, the following emerging issues have also recently been highlighted:

(a) Coincident with the difficulties of monitoring waterbirds on their Arctic and subarctic breeding birds, Fox *et al.* (2018) have recently highlighted the increasing challenge of monitoring these species during the non-breeding seasons as climate change leads to shifts in distributions to the north and east of areas currently well-covered by volunteer-based schemes in Europe.

(b) High rates of predation have long-been regarded as a key driver of ground-nesting waterbird populations, particularly waders. Climate-mediated disruptions in Arctic predator-prey dynamics, such as lemming cycles, have the potential to reduce breeding success in many species that winter in the UK. Although there is some isolated evidence for this (Nolet *et al.*, 2013), there is debate over the extent to which this is a large-scale phenomenon (Kubelka *et al.*, 2018; Bulla *et al.*, 2019). More-detailed research on the mechanisms underpinning the potential climate-change vulnerability of species breeding in Arctic and subarctic regions, where the greatest negative climate change impacts are anticipated, is required.

(c) With a building evidence base for climate change impacts on both breeding and wintering grounds, there is an urgent need to understand the potential for climate change adaptation to moderate those impacts, or to increase the resilience of these populations to climate change. Whilst there is now consistent evidence that protected areas, such as SPAs, will remain important for the conservation of protected species in a changing climate (e.g. Johnston *et al.*, 2013; Pavón-Jordán *et al.*, 2013), the potential for the active management of sites, whether on the breeding (e.g. Pearce-Higgins, 2011) or non-breeding grounds, remains uncertain. The potential for managed realignment at UK coastal sites to effectively compensate for any loses of inter-tidal habitats associated with sea-level rise should be quantified. Given that these are migratory species, any policies to promote their protection in the context of climate change should require international solutions across Range States. Although existing international instruments have the potential to be used to promote policies that support adaptation, the extent to which legally binding measures may be required and promoted through international agreement remains uncertain.

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