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Impacts of climate change on seabirds

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EXECUTIVE SUMMARY

What is already happening?

Seabird breeding populations in the UK increased in size over much of the last century, but since 1999 these populations have declined by an average of 7.5%. Breeding success has also declined over the same period. Some of the greatest reductions have occurred in the northern North Sea and Scottish Continental Shelf.

Climate change is considered to be one of the main drivers of these declines. Warmer winter sea temperatures have resulted in major changes in abundance and species composition of plankton in the North Sea that have contributed to the reduction in abundance and quality of seabird prey species such as sandeels, with knock-on effects for seabirds. Furthermore, there is growing evidence that breeding phenology is changing, with seabirds becoming increasingly de-synchronised from their prey. However, regional variations in the impacts of climate change are apparent, with weaker effects on seabird demography in the Irish Sea, Celtic Sea and English Channel.

What could happen?

Models predict that, by 2100, the UK climate will no longer be suitable for great skua and Arctic skua. The same models predict that the geographic range of black guillemot, common gull and Arctic tern will shrink so that only Shetland, Orkney and the most northerly tips of mainland Scotland will hold breeding colonies.

Further changes in prey abundance, species composition, energetic quality or synchronisation may have profound effects on seabirds. In addition, an increase in the frequency of extreme weather events could affect breeding habitat and create unfavourable foraging conditions, which may lead to increased mortality of adults and chicks.

Other drivers of seabird populations may interact with climate change. There is concern that climate change may increase the effects of disease and pollutants. Furthermore, impacts of collision and displacement from marine renewables may be exacerbated by reductions in prey quantity and quality as a result of climate change.

1. WHAT IS ALREADY HAPPENING?

Seabird breeding populations in the UK increased throughout much of the last century, with numbers expanding by ca. 55% between the late 1960s when coordinated monitoring began to the late 1990s when the last complete census was conducted (Mitchell *et al.*, 2004). However, numbers had peaked for some species, with declines apparent in the last decade of the century. Furthermore, these declines have continued by an average of 7.5% between 1999 and 2010 (UKMMAS, 2010). Changes in breeding numbers have varied greatly amongst species over the last decade, with abundance decreasing by more than 10% in ten species, increasing by more than 10% in three species and changing by less than 10% in three species (JNCC, 2012; Table 1). Of the ten species showing the greatest declines over this period, there are now substantially fewer European shag, Arctic skua, herring gull, great black-backed gull and black-legged kittiwake than in the late 1960s. Arctic skua, herring gull and roseate tern are red-listed, due to severe declines in their UK breeding population of more than 50% during the last 25 years, although the latter has experienced an increase over the last decade.

There has been considerable variation in trends in seabird numbers across constituent countries of the UK over the last decade (Table 1). In Scotland, all species with sufficient data with the exception of black guillemot have declined at a faster rate than the UK trend. In Wales, some species have fared better, notably great cormorant, great black-backed gull, black-legged kittiwake, common guillemot and razorbill, whilst European shags have declined more rapidly than elsewhere. Species have experienced fluctuating fortunes in England, although overall declines have been less marked than in the UK as a whole with, for example, Arctic tern showing substantial increases. In Northern Ireland, herring gull has shown an increase that bucked the national trend, but numbers are recovering after a huge decline from almost 18,000 pairs in the mid 1980s to just 700 in the late 1990s.

Climate change is believed to be one of the primary causes of these declines (Wanless and Harris, 2012). Most of the waters around the UK have been warming since the 1980s, and recent studies have demonstrated links between breeding success or adult survival and climate (Thompson and Ollason, 2001; Frederiksen *et al.*, 2004b; Grosbois and Thompson, 2005; Votier *et al.*, 2005, 2008; Harris *et al.*, 2005a; Grosbois *et al.*, 2009; Lewis *et al.*, 2009). In the North Sea, average winter sea-surface temperature (SST) has increased by approximately 1°C since the early 1980s. The over-winter survival of adult black-legged kittiwakes breeding in eastern Scotland is lower following winters with higher SST, and breeding success one year later is reduced (Frederiksen, 2004b, 2007b). Sea temperature rise has led to a change in species composition and biomass of the North Sea plankton community (Beaugrand *et al.*, 2003), and warmer sea temperatures are associated with a reduction in the recruitment of the lesser sandeel *Ammodytes marinus* (Arnott and Ruxton, 2002), the principal prey of most seabird species in the region. In accordance with this, several studies have shown that the link between climate and seabird performance is mediated via changes in prey availability (so-called bottom-up effects; Rindorf *et al.*, 2000; Oro and Furness, 2002; Frederiksen *et al.*, 2006; Parsons *et al.*, 2008; Daunt *et al.*, 2008). However, as evidenced by the contrasting demographic trends across the UK (Table 1; Cook *et al.*, 2011), regional variation in the effects of climate change on seabirds is apparent. In particular, there is growing evidence that the climate impacts recorded in the North Sea are not replicated elsewhere. The effect of winter SST on black-legged kittiwake breeding success outlined above is not apparent throughout the UK (Frederiksen *et al.*, 2007a) and analyses of the Irish Sea, the Celtic Sea and the English Channel have found only weak climate effects on seabird demography (Lauria *et al.*, 2012, 2013).

The mechanisms underlying this regional variation are poorly understood. Sandeel distribution in UK waters is patchy, with distinct spawning aggregations resulting from the availability of sandy sediments and the sedentary behaviour of adult sandeels (Proctor *et al.*, 1998; Pedersen *et al.*, 1999; Wright *et al.*, 2000). The varying fortunes of these distinct sandeel stocks may have led to the observed geographical variation in seabird breeding success (Frederiksen *et al.*, 2005). However, the effects of climate on clupeids and gadoids may also be important since they form an important component of seabird diet in many parts of the region (Bull *et al.*, 2004; Swann *et al.*, 2008). Moreover, a recent analysis of common guillemot diet has shown that sandeels are increasingly being replaced by clupeids (principally sprat *Sprattus sprattus*) along the east coast of the UK (Anderson *et al.*, 2013), in line with recent increases in sprat abundance (Alvarez-Fernandez *et al.*, 2012; Heath *et al.*, 2012a). Exploring the effects of multiple prey species on seabird performance is therefore important in understanding regional variation in climate impacts. A recent study developed a multi-species functional response of common guillemots on the Isle of May National Nature Reserve (NNR), south-east Scotland, and showed that they were more sensitive to changes in the abundance of sprat than sandeels (Smout *et al.*, 2013). However, such analyses require high quality diet data which are only available from a small number of species and locations (Anderson *et al.*, 2013).

Table 1: Change in breeding numbers of seabird species at colonies in the UK during 1999-2011. Red = declines of >10%, Green = increases of >10%; Yellow = change of 10% or less; grey indicates no robust analysis was possible due to inadequate data; nb = not breeding. Data source: JNCC (2012).

	% change in abundance 1999-2011				
Species	UK	Scotland	England	Wales	Northern Ireland
Northern Fulmar	-39%	-41%		-12%	
Manx Shearwater					
European Storm-petrel					
Leach's Storm-petrel			nb	nb	nb
Northern Gannet					nb
Great Cormorant	-14%		-10%	27%	
European Shag	-15%	-18%	-4%	-26%	
Great Skua			nb	nb	nb
Arctic Skua	-62%	-62%	nb	nb	nb
Black-legged Kittiwake	-47%	-58%	-29%	-10%	
Mew Gull		-38%			
Black-headed Gull	53%		79%		
Lesser black-backed Gull	-30%			-20%	
Herring Gull	-31%	-50%			29%
Great black-backed Gull	-43%	-57%		36%	
Sandwich tern	7%	-37%	-22%		
Roseate Tern	61%				
Common Tern	-14%	-46%	6%	-6%	
Arctic Tern	-14%	-81%	53%		
Little tern	-5%		-8%		nb
Common Guillemot	11%	-36%		69%	
Razorbill	7%	-22%		63%	
Black Guillemot		13%			
Atlantic Puffin					

One important mechanism whereby climate change may drive bottom-up effects on seabirds is temporal mismatching between peak energy demands in the breeding season and availability of prey. There is growing evidence that seabird breeding phenology is changing, with laying dates getting later in several species, though a trend for earlier breeding has also been recorded (Frederiksen *et al*., 2004a; Wanless *et al*., 2008, 2009; Votier *et al*., 2009; Burthe *et al*., 2012). Phenological changes can disrupt ecosystem functioning by de-synchronising species' interactions, known as trophic mismatch. In the North Sea, significant changes in the timing of key life history events have resulted in changes in the length, and therefore energy value, of sandeels (Wanless *et al*., 2004; Frederiksen *et al*., 2011). The birds have not kept pace with these changes and as a result, are now relying on prey of lower calorific value during the chick rearing period when energy demands are highest (Burthe *et al*., 2012). Continued warming may further alter the phenology of seabirds and their prey, resulting in more pronounced trophic mismatch.

Seabirds may also be affected by climate directly, in particular during extreme weather (Jenouvrier, 2013). An analysis of European shags on the Isle of May NNR has revealed that very poor adult survival occurs during sustained periods of strong onshore winds and high rainfall in late winter (Frederiksen *et al*., 2008a). Extreme weather events may also be important during the breeding season when high winds and rainfall can result in widespread breeding failure (Aebischer, 1993; Mallory *et al*., 2009). Vulnerability to extreme weather is an understudied but potentially important mechanism whereby climate can affect seabirds, since many climate models are predicting an increase in frequency of such events (Solomon, 2007, Rahmstorf and Coumou, 2011).

Climate change impacts may interact with other drivers of seabird populations. For, instance, in the Northern North Sea off south-east Scotland a sandeel fishery that operated in the 1990s significantly depressed sandeel populations (Greenstreet *et al*., 2006; Heath *et al*., 2012b), with associated changes in adult survival and breeding success of black-legged kittiwakes at adjacent colonies compared with years prior to the fishery opening and after it closed (Frederiksen *et al*., 2004b, 2008b; Daunt *et al*., 2008). Since 2000 there has been a ban on sandeel fishing off eastern Scotland and north-east England. If fishing is resumed to levels that significantly reduce local sandeel stock size, it could exacerbate reductions in breeding success and survival caused by increases in sea surface temperature as a result of climate change (Frederiksen *et al*., 2004b, 2007b).

For many years, some seabird species have benefited from fisheries through food provided at sea by discharging offal and discarding undersize fish. The abundance of scavenging species (e.g. great skua, northern fulmar) may have been elevated above levels that naturally occurring food sources could sustain (Tasker and Furness, 1996). The introduction of measures to conserve fish stocks has consequently reduced the amount of discards, as has the decline of some commercial fisheries. It is conceivable that the reduction in food provided by the fishing industry may have contributed to a population downturn of fulmars and other offshore surface-feeders since the mid-1990s (Reeves and Furness, 2002; JNCC, 2009). Another consequence of fewer discards is that great skuas have had to rely increasingly on other food sources, including the predation of other seabirds (Votier *et al*., 2004). Future changes to the Common Fisheries Policy in European waters which will lead to further reductions or elimination of discards is likely to put more pressure on scavenging species (Bicknell *et al*., 2013). It remains uncertain whether natural food sources are sufficient to enable scavenging species to meet their energetic needs in future (Votier *et al*., 2010, 2013).

Charting Progress 2 (UKMMAS, 2010) identified the following additional pressures on UK Seabird populations:

- **Introduction of non-indigenous species**: introductions of non-native mammals to islands have had major negative impacts on the resident colonies of ground-nesting seabirds (Craik, 1997, 1998; Mitchell and Ratcliffe, 2007; Ratcliffe *et al.* 2008). Mammals such as brown rat (*Rattus norvegicus*) and American mink (*Mustela vison*) predate on seabird eggs, chicks and in some cases, adult birds. Predation by mammals has caused the extinction of some colonies of ground-nesting seabirds such as terns, gulls, storm-petrels, Manx shearwater and Atlantic puffin. Other colonies have been substantially depleted, with seabirds confined to breeding in places that are inaccessible to predators.

- **Visual disturbance**: activities associated with the construction and operation of offshore renewable energy developments and with leisure and recreation can create visual disturbance to seabirds that may lead to the loss of habitat available for foraging or breeding. These impacts are currently localised and considered to be low across the UK as a whole. However, offshore renewable energy is expanding rapidly and these effects may become more important in future.

- **Removal of non-target species**: species such as northern fulmars and auks are caught by long-line and other fisheries in UK waters (Dunn and Steel, 2001). Quantitative data on seabird bycatch are currently lacking for most areas of the NE Atlantic (ICES, 2008, 2011). The European Commission have recently published a European-wide National Plan of Action that will encourage Member States and Regional Fisheries Management Organisations to reduce incidental catches of seabirds in fishing gears (COM, 2012).

- **Contamination by non-hazardous substances**: large numbers of seabirds from UK colonies have been killed by contamination from oil spills from ships in recent decades, with detectable effects on winter survival in some cases (Votier *et al*., 2005).

- **Marine litter**: marine litter is ingested by northern fulmars and other surface feeding seabirds (van Franeker *et al*., 2005). As a consequence, non degradable plastics accumulate in large quantities in their stomachs. However, it is unclear what effect this ingested litter has on the birds' health and long-term survival.

Continued research on seabird ecology is needed to understand the impacts of climate change and other drivers on populations. There has been a significant expansion in research into at-sea distributions of UK seabirds using GPS tracking of breeding birds in summer (Guilford *et al*., 2008; Hamer *et al*., 2009; Harris *et al*., 2012; RSPB, 2013) and GLS tracking of seabirds in winter (Guilford *et al.,* 2009; Harris *et al*., 2010; Fort *et al*., 2012). Furthermore, there is a growing recognition of the importance of seasonal interactions, whereby events or processes that affect an individual in one season also affect its performance in subsequent seasons (Bogdanova *et al*., 2011). Development of analytical approaches to quantify habitat association and preference are also a source of active research (Wakefield *et al*., 2009; Guilford *et al*., 2009; Fauchald *et al*., 2011; Embling *et al*., 2012; Tancell *et al*., 2013; Dean *et al*., 2013). These advancements in empirical data collection and analysis will improve our understanding of the mechanisms underpinning effects of climate change on seabird productivity and survival. However, some key knowledge gaps remain that are not easily filled, notably the diet of seabirds throughout the year and functional responses to variation in the abundance of multiple prey species.

2. WHAT COULD HAPPEN?

Most seabird species in the UK are at the southern limit of their range. As a result, we may see changes in species' ranges due to climate change, with associated changes in overall population size. By the end of the 21st century, great skua and Arctic skua may no longer breed in the UK and the range of black guillemot, common gull and Arctic tern shrink to such an extent that only Shetland and the most northerly tips of mainland Scotland will hold breeding colonies. Many other species may shift their distribution north, no longer breeding in south-eastern England. These predictions are based on modelling by Huntley *et al.* (2007) who described the 'climate envelope' that each species currently occupies in Europe and predicted how the shape of this envelope, and hence the breeding range of the birds, would change by the last 30 years of the 21st century. The climate envelope was a composite of measures of a) winter cold, b) overall warmth or growing season, and c) available moisture. These predictions seem plausible given that these species, particularly the skuas, are confined to colder parts of the northern hemisphere (Furness 1988). The predicted extinction of great skuas is of particular concern since the UK holds 60% of the world breeding population (Furness and Ratcliffe, 2004). Huntley *et al.* (2007) also predicted that Leach's storm-petrel would no longer be breeding in the UK by the end of the 21st century. This is unlikely to result from direct effects of a warmer climate, since they breed in warmer climes than currently experienced in the UK. The current distribution in the Scottish Continental Shelf is positively correlated with the proximity to deep oceanic water where they feed on plankton concentrated by upwellings and ocean currents (Mitchell, 2004). Thus, future changes in the number and distribution of Leach's storm-petrel breeding in the UK are likely to result from indirect, bottom-up effects of climate on their planktonic food resources.

Warming of waters in the North Sea has led to substantial changes in species composition and abundance at lower trophic levels (Beaugrand *et al.,* 2008; Kirby and Beaugrand, 2009; Luczak *et al*., 2012; Frederiksen *et al*., 2013), with detrimental effects on sandeels (van Deurs *et al*., 2009). These changes are linked to northward shifts of favoured copepod prey of sandeels, associated with critical thermal boundaries, altering habitat suitability for seabirds (Beaugrand *et al*., 2008; Reyondeau and Beaugrand, 2011; Frederiksen *et al*., 2013). Effects of climate on these bottom-up processes are set to intensify as warming continues. Trophic mismatch may also increase, with the potential for detrimental impacts on seabirds (Burthe *et al*., 2012). Any repetition of the very low energy values recorded in North Sea sandeels and sprat preyed on by seabirds in 2004 (Wanless *et al*., 2005) could also have dramatic consequences. However, it is not clear whether warming will have a similar impact in other regions around the UK where climate effects are weaker, such as in the Irish Sea, Celtic Sea and English Channel (Lauria *et al*., 2012, 2013). Emerging prey species may be critical to the future wellbeing of seabirds, but to be an effective alternative to current prey such as sandeels and sprats, they will have to fulfil important criteria of abundance, availability and quality. This was not the case for the snake pipefish *Entelurus aequoreus* which increased dramatically in UK waters in the mid 2000s, before the population crashed (Kirby *et al*., 2006; Harris *et al*., 2007, 2008). Furthermore, an outcome of climate change that is of increasing concern is ocean acidification, whose consequences may be felt right up the food chain to forage fish and associated top predators (Heath *et al*., 2012a). Finally, recent increases in jellyfish, which have been linked to overfishing and climate change, have been observed around the world including in UK waters (Purcell *et al*., 2007; Brotz *et al*., 2012). They may impact on seabirds since they are in direct competition with lesser sandeels and other forage fish for planktonic food such as copepods, while also being predators of fish larvae. In summary, if sea temperatures continue to rise as predicted, it is likely that seabirds such as black-legged kittiwakes that feed on small shoaling fish will experience poor breeding seasons and lower survival with increasing frequency in some parts of the UK (Frederiksen *et al*., 2004b).

Future climate change is also likely to have direct impacts on breeding seabirds through sea-level rise, particularly in the southern North Sea where ground-nesting seabirds such as terns, and in particular the little tern, tend to nest just above the high water mark. Habitat loss to sea-level rise may be mitigated by nesting habitat creation further up the shore. Extreme weather events may also become more important since most climate models predict an increase in their frequency in the future (Solomon, 2007; Rahmstorf and Coumou, 2011).

Other drivers of seabird populations are also expected to interact with climate change in complex ways. The previously demonstrated additive effect of fisheries and sea temperatures (Frederiksen *et al*., 2004b, 2007b) is unlikely to be maintained at higher sea-surface temperatures, where climate effects are predicted to override fishery effects. Evidence is emerging of the importance of parasites on seabirds (Duneau *et al*., 2008; Reed *et al*., 2008, 2012; Burthe *et al*., 2013). There is widespread concern that climate change may interact with disease, since increasing temperatures can alter host susceptibility, pathogen survival and disease transmission rates (Lafferty, 2009). Furthermore, the effects of pollutants, which can have a deleterious impact on seabirds (Thompson and Hamer, 2000), may be exacerbated by climate change and disease. Finally, a potential driver of immediate and future relevance is the impact of marine renewables on seabirds. A huge expansion in marine renewable developments is planned in the coming years to meet ambitious renewable energy targets. Seabirds may be affected by these developments through a range of mechanisms, notably collision and displacement (Grecian *et al*., 2010). These effects may be additive to climate change, or may interact with climate if, for example, the latter results in seabird range shifts, changing the spatial overlap with fixed developments. Breeding birds may be particularly vulnerable because, as central place foragers, they are constrained to obtain food within a certain distance from the breeding colony (Masden *et al.,* 2010b; Langton *et al*., 2011), and developments are proposed in areas that lie within breeding seabird foraging ranges (Harris *et al*., 2012). Cumulative and in-combination effects must also be considered when quantifying interactions between marine renewables and climate (Masden *et al*., 2010a).

Efforts to forecast change under future climate scenarios (e.g. Huntley *et al*., 2007; Frederiksen *et al*., 2013), together with research into species' adaptation potential through processes such as phenotypic plasticity (Reed *et al*., 2009; Grémillet and Charmantier, 2010; Lewis *et al*., 2012), will be particularly useful in determining likely impacts. However, the current evidence suggests that many UK seabirds face an uncertain future because predicted changes in climate, and potential interactions with other drivers, indicate that conditions will become more challenging.

3. KNOWLEDGE GAPS

a. **Indirect effects of climate**: In the short-term, we need to better understand the nature of the interactions between climate, plankton and seabird prey species, in order to predict the likely magnitude of future impacts on seabirds. A particular priority is information on lesser sandeel population dynamics that provide the link between many UK seabird species and lower trophic levels. It is unclear why sandeel recruitment is negatively correlated with SST. We therefore need a better understanding of the nature of the relationship between sandeel populations and food availability, predation, fisheries and density dependent factors. However, research should also focus on other important seabird prey, notably clupeids and gadoids. Furthermore, it is becoming increasingly apparent that top predators such as seabirds not only require prey of sufficient abundance and quality, but that it is available at the right time to coincide with their peak energy demands. An understanding of the importance of climate-mediated trophic mismatch is an important priority for future research.

b. **Scale dependence in climate effects**: Many UK seabird species winter in the seas around the UK, but others migrate to distant foraging grounds across a vast area from the North Atlantic to the Southern Ocean. Most mortality of breeding adults takes place at this time, and survival rate of adults is the principal determinant of seabird population size. Thus, it is important to incorporate an understanding of the spatio-temporal scale of climate effects that may include factors occurring at global scales at different times of the year, and carry over effects between seasons.

c. **Interactions between climate effects and other human impacts**: if we are to continue to exploit our seas whilst maintaining them as 'Healthy and biologically diverse' (cf. The UK Marine Strategy's vision of our seas), we need to better understand how potential drivers such as marine renewables, pollutants and disease impact on seabirds and the rest of the marine ecosystem in a changing climate. Such evidence is vital if we are to successfully implement the EC Marine Strategy Framework Directive and achieve its goal of Good Environmental Status in Europe's seas by 2020 (see Cefas, 2011).

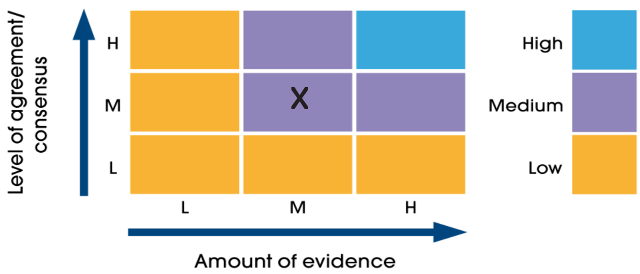
There is strong consensus that these represent important knowledge gaps (Lewison *et al*., 2012).

4. SOCIO-ECONOMIC IMPACTS

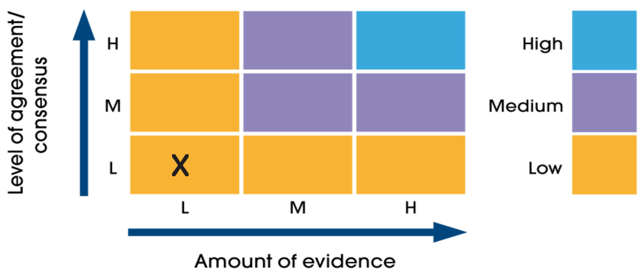
Seabirds provide an important source of income for some local economies, because seabirds have a wide appeal to people. Spectacular 'seabird cities' and enigmatic species like the Atlantic puffin draw large numbers of visitors to UK seabird colonies.

5. CONFIDENCE ASSESSMENT

What is already happening?



What could happen?



The level of confidence hasn't changed since the 2010 card (Mitchell and Daunt, 2010). The evidence for what is currently happening is moderate since aspects of the ecology of seabirds are comparatively well understood. Consensus on the key drivers of seabirds is also moderate. In contrast, there is little firm evidence about what will happen in the future, because of the uncertainty surrounding climate change projections and of impacts on seabirds. It is unclear how climate will interact with current and emerging drivers such as fisheries, pollutants, marine renewables and disease. As a result, consensus on future change is low.

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