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Seabirds

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KEY HEADLINES

- The seabird declines that commenced at the end of the last century have continued in the last decade.
- Climate change is considered to be one of the main causes of the declines. The principal mechanism is the effect of climate warming on their food supply.
- There is growing evidence that short-term weather conditions are having an important effect, including extreme weather events. Climate models are predicting further warming and increased severity and frequency of extreme weather events.
- Seabirds face an uncertain future and may decline further in the coming decades.

1. INTRODUCTION

The UK holds internationally important populations of seabirds (Mitchell *et al.*, 2004). After expanding for much of the last century, UK seabirds have shown substantial declines in the last two decades (Grandgeorge *et al.*, 2008; JNCC 2016). Three seabird species have recently been upgraded from Amber to Red in the Birds of Conservation Concern list (European shag, Atlantic puffin and black-legged kittiwake; Eaton *et al.*, 2015). Of the 25 species breeding in the UK, six (24%) are Red listed (the above three species plus Arctic skua, roseate tern and herring gull) and 18 (72%) are Amber listed. Investigating these declines is important because the UK is legally obliged to safeguard seabird populations, and they play an important role in UK recreation and culture. Furthermore, they have the potential to be cost-effective indicators of marine environmental change (Parsons *et al.*, 2008). To develop effective conservation strategies and fulfil the potential of seabirds as indicators requires the mechanisms underpinning population change to be quantified.

Climate change is considered to be one of the primary causes of these declines and for the increase in the number of red-listed species (Daunt and Mitchell, 2013; McDonald *et al.*, 2015; Eaton *et al.*, 2015). Climate may affect seabird populations via two main processes: indirect effects via changes in food supply, and direct effects such as mortality from extreme weather (Oro 2014; Sydeman *et al.*, 2015; McDonald *et al.*, 2015). These mechanisms are of critical importance to the future prospects of UK seabird populations since climate models predict both an increase in mean temperature and in the frequency and severity of extreme weather events in the region (IPCC, 2014). Furthermore, the extent to which climate will interact with current and emerging anthropogenic drivers such as fisheries, plastics and other pollutants, marine renewables and disease may also be of profound importance (Burthe *et al.*, 2014; Oro, 2014). Accordingly, the current evidence suggests that UK seabirds face an uncertain future because of predicted further climate change and potential interactions with other drivers.

2. TOPIC UPDATE

Some important studies have been undertaken since the last review in 2013 that provide further evidence of the negative relationships between seabird population dynamics and ocean temperatures. Burthe *et al.* (2014) showed that the productivity of black-legged kittiwakes, fulmars, Atlantic puffins and common, arctic and little terns all showed a negative relationship with temperature. The annual survival rates of black-legged kittiwakes and European shags were also negatively related to temperature. Using tracking data to define colony-specific foraging ranges from which to extract relevant environmental data, Carroll *et al.* (2015) also showed that breeding success of kittiwakes was negatively related to temperature. Reed *et al.* (2015) demonstrated that average frequency of skipped breeding in common guillemots was greater in years where sea surface temperature was higher. Russell *et al.* (2015a) assessed species' vulnerability to changes in climate using 'climate envelope' models and found that those species, notably Arctic skuas, whose distributions matched climate suitability in the 1980s most closely had shown the greatest declines in the last three decades.

Whilst climate-related research has traditionally focussed on effects of temperature, a new research effort is emerging on the effects of short-term weather conditions. Newell *et al.* (2015) showed profound effects of a summer storm on breeding performance of four UK seabird species, with particularly strong effects on razorbills. Recent research has also shown that flight (in flapping flight species) and diving may both be more costly at higher wind speeds, which may have demographic consequences under future predicted changes in storminess (Lewis *et al.,* 2015; Kogure *et al.,* 2016).

Whilst studies have traditionally focussed on retrospective analyses of historical data, an important development since the last review is that more studies are projecting future population change under climate change scenarios. Carroll *et al.* (2015) showed that kittiwake breeding success is predicted to decline by 21-43% between 1961–90 and 2070–99. Frederiksen *et al.* (2013) predicted that habitat suitability for seabirds will shift northward over the next century, and concluded that northern distributional shifts of seabirds are likely over this period. Russell *et al.* (2015b) used climate envelope models together with climate scenarios to predict that 65% of species that breed in the British Isles would show a decline in their European range, some by as much as 80%. The study estimated that, under a best case scenario of unlimited dispersal, Leach's storm petrel, great skua and Arctic skua will come close to or reach extinction in the UK by 2100, while the ranges of black-legged kittiwake, Arctic tern and auks are predicted to decline significantly. The study considered two climate scenarios, neither of them extreme, which generated very different predicted changes in range. These studies support the climate envelope modelling of Huntley *et al.* (2007) that predicted that, by the end of the 21st century, the range of some seabird species breeding in the UK would shift northwards and other species may become extinct within the UK.

The level of confidence on what is currently happening remains at moderate, as in previous report cards. There is broad consensus on the current effects of climate change on UK seabird populations, but there is a lack of precise, mechanistic understanding of how climate affects seabirds and the interplay between climate and other factors. Furthermore, confidence remains low on what will happen in the future. Predictive studies are becoming more common but results show high uncertainty and are dependent on the choice of climate scenario. Furthermore, there are no available model projections on frequency of extreme storm events, impairing our ability to predict future changes in seabird populations affected by weather.

3. HOW OUR UNDERSTANDING HAS DEVELOPED OVER THE LAST DECADE

Research on the effects of climate change continues to find strong indirect effects of climate, whereby the warming of waters around the UK over the last three decades is linked to declines in seabird population size and demographic rates, mediated via changes in the abundance, distribution and energetic value of lower trophic level species (reviewed in Daunt and Mitchell 2013; McDonald *et al.,* 2015). However, important regional differences are apparent, with these effects appearing stronger in the North Sea than the Irish Sea, the Celtic Sea and the English Channel (Cook *et al.,* 2011; 2013; Lauria *et al.,* 2013; Carroll *et al.,* 2015). Research has increased over the course of the decade on the direct effects of climate on seabirds, showing that increased wind speeds and storminess may have an impact both on over-winter survival rates and breeding success (Frederiksen *et al.,* 2008; Newell *et al.*, 2015), and this is likely to be an important research focus in the coming years.

Considerable research focus has been placed on understanding the mechanistic link between climate, food availability and foraging dynamics. Technological advances coupled with reduced cost have led to a huge expansion of studies using bird-borne data loggers such as GPS and accelerometers (Wakefield *et al.,* 2013, 2015; Carroll *et al.,* 2015; Kogure *et al.,* 2016). These advances in empirical data collection have been supported by the development of analytical approaches to quantify foraging dynamics (Wakefield *et al*., 2009; Fauchald *et al*., 2011; Dean *et al*., 2013). This work has greatly improved our understanding of the links between climate, oceanography, distribution of lower trophic levels and seabird foraging ecology. These relationships are scale dependent. For example, foraging dynamics of gannets is determined by both contemporaneous and seasonally persistent frontal zones (Scales *et al.,* 2014). This field has benefitted considerably from closer integration between seabird ecologists and researchers from other disciplines, in particular climate scientists, oceanographers, mathematicians and computer programmers (Frederiksen and Haug 2015).

Overall, the studies on the effects of warming on population dynamics, and the underpinning mechanisms, have supported the studies that took place in the decade prior to this. A good example of this is the 2004 study which showed that over-winter survival of adult black-legged kittiwakes breeding in eastern Scotland was lower following winters with higher SST, and breeding success one year later was reduced (Frederiksen *et al.,* 2004). A recent update of this analysis that included another ten years' data demonstrated that these relationships still hold (Frederiksen, 2014). Although the precise mechanisms are unknown (including whether survival and productivity are independently affected by temperature or whether there are seasonal carry-over effects), the two analyses suggest that temperature has shown a consistent effect on the demography of kittiwakes over a sustained period. In addition to effects of warming, the last decade has seen a growing realisation of the importance of extreme weather events, which may have a profound impact on seabird populations by reducing both breeding performance and survival rates of immature and adult birds (Frederiksen *et al.,* 2008; Newell *et al.,* 2015). Furthermore, studies are, for the first time, projecting future population change and are predicting substantial changes in the range and population sizes of seabirds in the UK, including some species for which the UK holds internationally important numbers such as great skua and Arctic skua (Huntley *et al.,* 2007; Frederiksen *et al.,* 2013; Carroll *et al.,* 2015; Russell *et al.,* 2015b). This shift in emphasis towards future forecasting is of fundamental importance to developing effective conservation strategies for these species, in keeping with the drive to take a spatio-temporally dynamic approach to species conservation and habitat protection. However, there remain considerable knowledge gaps that are not easy to fill (see next section).

4. KNOWLEDGE GAPS AND KEY CHALLENGES

Previous report cards have identified three main knowledge gaps, (a) the effects of climate on the small shoaling fish (notably sandeels) that are the principal prey of seabirds; (b) the interaction between climate and other anthropogenic drivers such as fisheries, pollutants, disease and marine renewables; (c) the role of phenotypic plasticity and micro-evolution in enabling seabird populations to adapt to climate change.

These knowledge gaps are as relevant now as they were a decade ago because they are very challenging to address. The approach of most studies is still to link climate or plankton to seabirds, because of the limited data available on mid-trophic level fish such as sandeels or sprat. However, a growing body of work is emerging on the links between climate and these important fish species (notably sandeels) and their prey (in particular *Calanus* copepods), which is proving of great benefit to seabird ecologists (van Deurs *et al.,* 2009; 2014; Engelhard *et al*., 2014; McDonald *et al*., 2015; Rindorf *et al.,* 2016). The interaction between climate and other drivers remains unknown and should be a focus for future research (Burthe *et al.,* 2014; Oro, 2014). Research is emerging on phenotypic plasticity of traits in relation to environmental variation in seabirds (Grémillet and Charmentier, 2010; Sydeman *et al.,* 2015). The next steps involve testing the relationship between plasticity and demographic rates, and the heritability of these traits. Comparatively few study systems have the potential to do this, but this should not discourage researchers to focus on this important question. Central to this research area is the need to better understand the mechanisms underpinning the effects of environmental conditions on demography, in particular the energetic trade-offs shaped by variation in food availability (Crossin *et al*., 2014) and the diet of seabirds throughout the annual cycle (Harris *et al*., 2015).

5. EMERGING ISSUES (CURRENT AND FUTURE)

Many seabirds are at the limit of their breeding range in the UK, and models of habitat suitability under scenarios of climate warming suggest there will be a retraction to more northern parts of the UK and overall changes in population size (Huntley *et al.,* 2007). Northward shifts of the principal prey of seabirds, sandeels, are also expected due to movements of critical thermal boundaries (Frederiksen *et al.,* 2013). Trophic mismatch may also increase, with the potential for negative consequences on seabirds if they become desynchronised with their prey (Burthe *et al.,* 2002). Emerging prey species may also be of crucial importance since they will need to be of sufficient abundance and energetic quality for seabirds to feed on them profitably, which was not the case with the snake pipefish which increased dramatically in UK waters in the mid 2000s before the population crashed (Harris *et al.,* 2007). Furthermore, an increasing consequence of rising levels of CO_2 in the atmosphere is ocean acidification, the effects of which may be felt throughout the food chain to higher trophic levels including seabirds. Such effects may be exacerbated outside the breeding season, when seabirds feed more extensively on prey at lower trophic levels (Harris *et al*., 2015). Although the evidence has yet to emerge in UK waters, a recent study showed a link between survival of kittiwakes breeding in Norway and the abundance of pteropods, which are threatened by ocean acidification, at their wintering grounds off Newfoundland (Reiertsen *et al*., 2014). In addition, recent increases in certain species such as jellyfish may be important since they may compete with sandeels and other seabird prey for food (Brotz *et al*., 2012). Any increase in the frequency or severity of extreme weather is likely to have a profound effect on seabirds that is likely to operate independently from the processes outlined above (Frederiksen *et al*., 2008; Moreno and Muller, 2011). Finally, there will be some species, particularly those that breed in low lying coastal locations that will potentially be affected by sea-level rise.

Seabirds may also face additional threats that may interact with climate change (Burthe *et al*. 2014; Oro, 2014). There is growing concern with the increase in plastics in the marine environment, which seabirds are known to ingest, but the ramifications are unclear (Wilcox *et al*., 2015). Other pollutants and emerging diseases may also be important (Lafferty, 2009). Predation by invasive native and non-native mammals at colonies can restrict the availability of safe nesting sites (Mitchell and Ratcliffe, 2007). Finally, a potential driver of future relevance is the impact of marine renewables on seabirds. A large expansion of renewable developments is planned in UK waters to meet ambitious clean energy targets. Seabirds may be affected by these developments, notably through collision and displacement from foraging habitats (Furness *et al*., 2012; 2013).

Furthermore, positive management measures designed to allow commercial fish stocks to recover may have adverse impacts on seabird populations (Bicknell *et al*., 2013). The current implementation of EC Landing Obligations will lead to an eventual halt to discarding fish from vessels and remove an important food source for some species (ICES, 2016). In addition, Reilly *et al.* (2014) suggested that haddock and whiting could outcompete kittiwakes for sandeels in the North Sea and, if management succeeds in recovering stocks of these two fish species, the resulting competition could have an important effect on the availability of sandeels to kittiwakes that could potentially exceed the effect the industrial sandeel fishery had in the past (Frederiksen *et al.*, 2004).

It will be critically important to consider these multiple drivers simultaneously, not in isolation, because the complex way in which they interact with climate may play a key role in determining the long term well-being of UK's seabirds.

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