# Impacts of oceanographic change on UK kittiwake productivity

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## Summary

Declines in black-legged kittiwake (*Rissa tridactyla*) populations in the UK have been linked to changing oceanographic conditions, with reduced food availability under higher temperatures leading to reduced productivity and survival. However, analyses have typically focused on relatively few intensively-studied colonies and have primarily considered sea surface temperature (SST), meaning that important drivers may have been overlooked. Here, we use data from tracking studies to produce colony-specific estimated foraging areas for eleven kittiwake colonies throughout the UK and Ireland, and examine the impacts of physical (SST, stratification strength, stratification onset) and biological (larval fish and copepod abundance) on kittiwake productivity. Higher productivity was associated with lower SSTs, and weaker, later stratification. Climate change projections indicated that rising SSTs could drive further productivity declines by the late 21$^{st}$ Century. Finally, higher kittiwake productivity associated with higher larval sandeel and *Calanus finmarchicus* abundance.

## Introduction

In the UK, black-legged kittiwake (*Rissa tridactyla*) populations have declined by around 60% since the mid-1980s and productivity has declined by around 30% (JNCC, 2013). Declines have been linked to rising sea surface temperatures (SSTs), with reduced availability of lesser sandeels (*Ammodtyes marinus*) a possible underlying mechanism (Frederiksen *et al.*, 2004). However, to better understand drivers of declines, several issues must be addressed. First, there may be variation between colonies and regions in the strength and significance of SST relationships, meaning that analyses should not focus solely on intensively-studied colonies (Lauria *et al.*, 2013). Second, observed variation in habitat use amongst seabird colonies (e.g., Wakefield *et al.*, 2013) has not been accounted for. Finally, variables other than SST may be important, particularly those relating to ocean stratification conditions (Scott *et al.*, 2006). These issues must therefore be addressed to better understand the drivers of kittiwake declines and the longer-term threats posed by climate change.

## Materials and Methods

Analyses considered physical and biological predictor variables. Gridded physical oceanographic data were acquired for individual years from 1967-2004 (Holt *et al.*, 2012), and for climatic baseline (1961-1990) and future (2070-2099) periods (Lowe *et al.*, 2009). SST was extracted directly from temperature data; potential energy anomaly (PEA; a metric of stratification strength) and stratification onset date were calculated as in Holt *et al*. (2010). One stratification onset value was calculated for each year; PEA and SST means were calculated separately for winter and spring. Data on abundance of fish larvae and calanoid copepods were acquired from the Continuous Plankton Recorder survey (Richardson *et al.*, 2006); separate means were calculated for February-March and April-May.

For extraction of oceanographic variable values, estimated foraging areas were defined using data from kittiwake tracking carried out in the 2010-2012 breeding seasons using high-resolution GPS tags. Data were filtered to identify points likely to be associated with foraging, and kernel density estimates were calculated using retained locations. Oceanographic predictor variables falling within these foraging areas were extracted, and means calculated for each colony and year.

Breeding success data were acquired from the Seabird Monitoring Programme (http://www.jncc.defra.gov.uk/smp). Eleven colonies had both tracking data and productivity data; of these, nine had plankton abundance data. Productivity was modelled using generalised linear mixed models, first considering single oceanographic predictor variables, then considering multiple predictor variables simultaneously. Climate change projections were driven by data from baseline and future climatic periods, using all physical candidate models in a randomisation procedure.

## Results and Discussion

The best model with a single physical predictor variable was that with winter PEA (-0.641 ± 0.201, ΔAIC = -11.502 (calculated relative to AIC of null model fitted with intercept only)), followed by that with spring SST (-0.700 ± 0.264, ΔAIC = -5.242). The best model with multiple physical predictor variables contained both winter PEA (-0.602 ± 0.190; $P$ = 0.002) and spring SST (-0.539 ± 0.244; $P$ = 0.027). Therefore, higher kittiwake productivity was associated with lower SST, but stronger stratification early in the year also had a strong negative impact.

Climate change projections indicated that kittiwake productivity could decline by 32.6% by 2070-2099. Changes were likely to be brought about by significant rises in SST, with winter PEA not showing a significant increase between the two periods. Therefore, although ocean stratification appeared to show a greater impact on kittiwake productivity over recent years, longer-term impacts of climate change are likely to be driven by rising sea temperatures.

Finally, relationships key food web components were examined. Higher kittiwake productivity was associated with higher larval sandeel abundance in April-May of the preceding year (1.041 ± 0.492, ΔAIC = -2.266) and weakly associated with higher abundance of *Calanus finmarchicus* in April-May of the current year (0.397 ± 0.237, ΔAIC = -0.625), supporting previous conclusions about the importance of sandeels and *Calanus finmarchicus* to North Sea food webs.

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