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HEBRIDEAN MARINE ENERGY FUTURES. WORK PACKAGE 4: SEABIRDS

INVESTIGATING THE POTENTIAL EFFECTS OF WAVE RENEWABLE ENERGY DEVICES ON SEABIRDS

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ABSTRACT

The Pentland Firth and Orkney waters is the first region to contain commercial-scale marine renewable energy sites in the UK, with a potential capacity to generate up to 1,600 MW. Breeding seabirds are central-place foragers and Scotland has many internationally important colonies. Wave and tidal technology is still in its infancy and with few opportunities to directly observe interactions between seabirds and devices in the field, the number of peer-reviewed papers assessing their impacts remains small. The Hebridean Marine Energy Futures project has provided a unique opportunity to monitor seabird interactions with the Pelamis wave energy converter (WEC) at the EMEC test facility off the West coast of Orkney. By combining spatially-explicit observational data with information on the marine environment and the location of devices at the EMEC test facility we explored the potential consequences of WECs for seabirds at both the individual and population level.

INTRODUCTION

The effects of anthropogenic pressures on seabird colonies have been well studied, but despite increasing attention, the ecological consequences of wave and tidal energy generation remain unclear[1–5]. To understand how wide-ranging seabirds may respond to potentially disparate anthropogenic pressures, and how best to protect them, requires an understanding of how seabirds interact with the marine environment over multiple spatial and temporal scales (e.g. Louzao et al., 2010).

In order to begin to understand how seabirds use the EMEC test site we used kernel density estimation (KDE) and generalised additive mixed models (GAMMs) to analyse a long-term spatially-explicit dataset of seabird observations, environmental variables and fine-scale, ~1 km high-resolution oceanographic covariates. The potential population level consequences for red-throated divers (one of three diver species identified as moderately vulnerable to WECs[5]) was investigated using population matrices. Additional direct observations across the EMEC test site were also conducted to investigate possible behavioural interactions with the Pelamis WEC and other test site marine structures (i.e. cardinal buoys); for brevity these are not presented in this summary paper.

METHODOLOGY

The collection of the spatially-explicit land-based seabird observations used in these analyses began in March 2009 and will continue through 2014. The observation point at Black Craig, is approximately 5 km north of Stromness on the west coast of Orkney, 110m above sea level. For full details of the methods used in collecting these land-based observations see[6].

Kernel Density Estimation

KDEs were calculated for 9 of the most common seabird species observed at the EMEC test site using the first two years of baseline data (2009-11) and in the presence/absence of the Pelamis device where sample size allowed (2012-13), using both presence-only observations and observations weighted by the number of individuals. KDEs were calculated using Geospatial Modelling Environment (GME) Version 0.7.2.0[7] and bandwidth was estimated using the SCV plugin available through the *ks* library in R.

The two measures used to compare position of KDEs were 'nearest distance' and 'point distance'. 'Nearest distance' was defined as the shortest distance between the edge of the 50% KDE and the closest Pelamis mooring point. 'Point distance' was defined as the distance from the moorings to the centroid of the 50% KDE polygon and calculated as the mean of the distance to each of the mooring points.

Generalised Additive Mixed Models

Previous generalised mixed models used the number of seabirds observed at the EMEC test site as the response variable and incorporated a number of physical covariates such as wind strength and direction, tide state and time from low tide[8]. By integrating additional oceanographic variables into models we investigated remaining patterns within the residuals and explored further the variation in distribution of seabirds in relation to the EMEC test facility. For the years 2012-2013 presence/absence of a device was also included in the model as a factor.

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Population Projection Model

Local census data and species-specific demographic parameters (Equation 1) from published data were used to construct a series of Leslie matrices [9,10], a form of Population Projection Matrix (PPMs) that can model the growth of a population and the resulting projected age distribution of the population. It assumes the population is closed and that growth is unlimited. Each matrix (Equation 2) reflected four plausible hypothetical scenarios based on the potential effects of wave energy devices on red-throated divers.

All models were parameterised according to a post-breeding census and included only females. Fecundity (f) was calculated as:

Equation 1: $\boldsymbol{f = mp_x s_x}$ where:

$m =$ number of female offspring per female (sex ratio of offspring 1: 1)
$x =$ age class breeding
$p_x =$ proportion of females
$s_x =$ survival rate

Hypothetical scenarios:

1. High productivity due to a positive change in foraging habitat.
2. Reduced productivity due to a negative change in foraging habitat.
3. Reduced survival due to direct mortality of breeding adults.
4. Naïve 1st summer non-breeders return to natal area and suffer reduced survival.

Models were based on a 5 age-class population projection matrix (Equation 2) using the parameters defined in Equation 1.

Equation 2:

$$\begin{pmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \\ n_5 \\ n_6 \end{pmatrix}(t+1) = \begin{pmatrix} f_1 & f_2 & f_3 & f_4 & f_5 \\ s_1 & 0 & 0 & 0 & 0 \\ 0 & s_2 & 0 & 0 & 0 \\ 0 & 0 & s_3 & 0 & 0 \\ 0 & 0 & 0 & s_4 & 0 \\ 0 & 0 & 0 & 0 & s_5 \end{pmatrix} \begin{pmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \\ n_5 \\ n_6 \end{pmatrix}(t)$$

Where:
n = the initial number of individuals in each age class
t = time
s = survival (the probability of an individual transitioning to the next age class)
f = fecundity

Perturbation analysis of all four scenarios was completed and the sensitivity and elasticity of the growth rate (λ) to changes to elements within each these projection matrices was calculated. This perturbation analysis allowed us to investigate how changes in one particular matrix element, such as adult survival, might affect the population dynamics when other model parameters are held constant and what the magnitude of the effect would be.

RESULTS

Kernel Density Estimation

The greatest decrease in 'point distance' in the presence of a device, compared to when no devices were present, was for great skua (summer 2012, 48.08%, Figure 1), the largest increase was for gannets (autumn 2012, 15.01%) and the smallest overall change was a decrease in distance for shags (winter 2012-13, 0.32%).

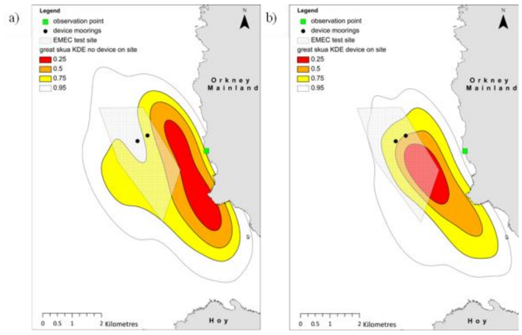

Figure 1 Great skua KDE summer 2012 in the absence (a) and presence (b) of a Pelamis wave device, calculated using presence-only observations.

The largest increase and decrease in 'nearest distance' were both for gannets, a 155.65% increase (spring 2012) and an 89.31% decrease (summer 2012). The smallest overall change was a decrease of 0.15% for guillemots (winter 2012-13). The smallest change in overall KDE area in the presence of a device was a 2.52% increase (guillemot, winter 2012-13). The largest increase was 269.16% (shags, autumn 2012) and the largest decrease was 62.63% (shags, spring 2012).

Generalised Additive Mixed Models

Most of the extra covariates used in the models were non-significant or failed to improve the fit of the original models[8]. One possible reason for this is that they were not of a high enough resolution either temporally or spatially. Sea surface temperature, chlorophyll-α and turbidity were binned monthly and while this leads to fewer missing values it may blur the definition of finer scale temporal relationships and habitat associations.

Device as a factor in the model was significant for several species. The presence of a wave energy device significantly increased the number of black guillemot ($p < 0.05$), kittiwake ($p < 0.05$) and eider ($p < 0.01$). The presence of a device in the chosen guillemot model predicted a significant decrease in the numbers of birds in the presence of the device.

Population Projection Model

Adult survival was the model parameter with the highest sensitivity and elasticity values and therefore the one that most affected the population growth rate. A 0.15 probability of adult mortality was enough to cause a substantial decline in the population even if the remaining years were above average. The population based on the parameters used in the model appeared resilient to fluctuations in productivity as long as adult survival remained high, however a prolonged period of increased risk of juvenile mortality could cause a notable decline in the growth rate and reduce the overall population size.

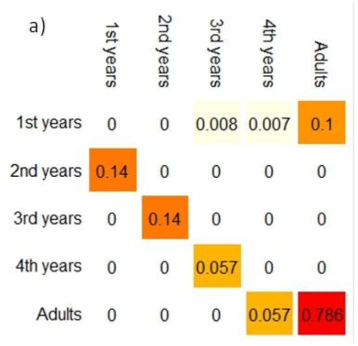

Figure 2: Sensitivity analysis matrix. The sensitivity of the growth rate (λ) to changes in age-class survival and fertility for Scenario 3.The colour of the grid plots are graded white to red where red indicates the matrix element that λ is most sensitive to changes in and therefore has the highest value

CONCLUSIONS

Differences were observed in KDE area and distance from the mooring points, however it is currently impossible to say if these differences are due to the presence of a device or to other patterns of habitat use, as a large amount of intraannual and interannual variation occurred in the size of 50% KDE areas within the two years of baseline data. There were also some similarities between the location, size and shape of some baseline KDEs and 50% kernel areas modelled using observations recorded during device deployments.

A combination of seasonality in device deployments, and varying detection rates in differing sea conditions and distances from shore could lead to spurious relationships between device presence and bird abundance and could explain the significance of device presence in the GAMM analysis. These issues cannot be meaningfully resolved until device deployments increase in length and cover periods in all seasons, including winter when there are fewer birds near the coast. It is also possible that there is a genuine effect correctly selected for by the model. A camera was mounted on the Pelamis WEC as part of this project and black guillemots and kittiwakes were both identified in photos from this camera which could provide data to support model predictions. It is possible that the device does have a small attractant effect for these species; it could also be that birds interacting with the device are more detectable than a lone bird in an expanse of water and therefore more are encountered during device deployments.

There are many possible ways in which changes in the marine environment could impact red-throated diver populations (mortality of different age classes due to collision or entanglement, non-fatal impacts such as disturbance or displacement, changes in prey distribution or availability) and the magnitude of these impacts on populations is not always clear. A direct mortality event may be less likely than a possible change in the prey distribution or repeated disturbance events, however if the risk of this is prolonged there could be a large impact on the population growth rate.

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