No evidence of long-term displacement of key wildlife species from wave and tidal energy testing

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***Abstract*— There is a regulatory need to understand the potential for marine renewable energy developments to significantly impact the marine environment and a site's integrity. To increase certainty, it is necessary to identify whether marine renewable energy devices have any impact on the abundance and distribution on wildlife in the vicinity. The European Marine Energy Centre (EMEC), in Orkney, Scotland, has completed an extensive wildlife observation programme to collect surface-visible wildlife observation data since the site's inception. Following the observation programme, an in-depth analysis has been undertaken to understand species displacement relative to the operational status of devices. The analysis has been completed on observational data from both EMEC's wave and tidal test sites. The data analysis utilised statistical package MRSea to quantify any spatially-explicit change attributable to marine renewable energy devices. The results from the analysis demonstrated a change in distribution and, in some cases, abundance with installation works, but typically the density recovered during the operational phase of the development. The study found little evidence to suggest that there are any long-term effects on seabirds or marine mammals associated with the installation and operation of marine renewable energy devices and it is anticipated that they will continue to use the waters around such devices when operational.**

***Keywords*— Environmental monitoring, displacement, environmental impact, wildlife.**

I. INTRODUCTION

Throughout the world commercial interest in harnessing the power of the ocean is increasing rapidly. Understanding the potential for impacts (positive or negative) on the marine environment that may arise from the siting and operation of marine renewable energy developments is crucial to the success of the wave and tidal energy industry.

There are several key unknowns facing the industry, one of which is the displacement of key wildlife species from their normal range of habitats. In the UK and elsewhere, there is a regulatory need to determine whether the deployment of marine energy devices is likely to have any significant effect on the abundance or distribution of wildlife species [1]. In Europe the Habitats Directive requires Member States

Off the north coast of the UK is the Orkney Islands, an archipelago positioned between the Atlantic Ocean and North Sea and home to the European Marine Energy Centre (EMEC). Established in 2003, EMEC is the world's leading centre for testing wave and tidal stream energy devices.

Throughout EMEC's operation, a wildlife observation programme has been undertaken to record surface-visible wildlife, for instance birds and marine mammals, that utilise and transit through the gird-connected wave and tidal test sites. The programme, funded by Marine Scotland, Scottish Natural Heritage and Highlands and Islands Enterprise, has run for five-year period at the wave test site, Billia Croo, whist at the tidal test site, Fall of Warnnes, the dataset exends to nearly ten years. Wildlife observers have been undertaking observation surveys for 20 hours per week, accumulating a dataset of ~18,000 hours of observation records. Crucially, the data are being analysed with respect to the overall status of each test site taking account of the operational status of the different devices, the latter information being sought from developers through the licensing authority.

To improve understanding, EMEC led a detailed analysis of the data, investigating how species distribution and density varied across the test sites, relative to varying device presence and operational activity. Using the expertise from the University of St Andrews, statistical analysis was conducted using the R software package 'MRSea' to quantify any spatially-explicit change attributable to device testing. The predictive model was refined utilising spatially-adaptive smoothing methods (e.g. CReSS/SALSA), which account for residual auto-correlation (via Generalised Estimating Equations [6]). Environmental (e.g. seasonality and interannual variability) and grid-specific covariates were included in the selection process. In certain cases, natural variation evident under baseline conditions and the lack of control site made it difficult to determine changes associated with varying device operational status and the level of natural variation occurring in the population. For each operational status, predictive surfaces were produced identifying any differences in site-wide species abundance or distribution alongside redistribution within the sites.

Geo-referenced confidence intervals were acquired for each model surface to account for the uncertainty inherent in the parameters and any detection functions employed. Outputs from the modelling process were geo-referenced predictions accompanied by 95% confidence intervals. The modelling work for each species was followed by a power analysis to ensure that natural features of the system were accounted for and power calculation results were realistic.

Statistical significance was attributed to some of the density changes in the model. The models for the tidal test site indicated a change in density and redistribution of some bird species, including the great northern diver, black and common guillemot, cormorants and shags, when construction work commenced. However, in nearly all cases, numbers returned to around previous levels once the tidal energy converters were installed and operational. Observations of seals, whales and dolphins revealed similar findings.

The change in density associated with the installation of support structures was not confined to the immediate area where the devices are located, but often extended beyond. This finding suggests that it may not be the physical presence of the device or support structure that influenced the change in density, but rather the increase in vessel movements associated with installation. Vessel movements are expected to reduce when devices become operational and subsequently be limited to maintenance activities.

At the wave test site, Billia Croo, no significant changes in distribution or density of birds or mammals around the site were detected. No correlation was apparent between changes in species density and the location of test devices at the site, and similar species densities were recorded for all device operational states.

In conclusion, it is believed that the increase in boat activity associated with the installation of wave and tidal devices might cause temporary disturbance and displacement of some species, but numbers recover once this busy phase of activity is complete and the devices are operational.

The study found little evidence to suggest that there are any long-term effects on seabirds or marine mammals associated with the installation and operation of wave and tidal energy converters; it is anticipated that they will continue to use the waters around such devices when operational. However, further research is required to understand the true impact pathways during the installation phase and to consider whether any temporary negative effects during this short period are due only to increased vessel movements and their associated noise.

II. DATA COLLECTION METHODOLOGY

By employing the observation data collected during the Wildlife Observation Programme at EMEC, the study undertook a site-wide analysis of the land-based wildlife observations against the device operational data from marine renewable energy developers that have undergone testing at EMEC's grid-connected test sites.

A. *Survey sites*

For the purposes of this study, only EMEC's two grid-connected test sites were assessed. The tidal test site, Fall of Warness (59° 08.710'N 002° 48.914'W) is located within a tidal passage off the southwest coast of Eday, one of Orkney's North Isles. The site is approximately 9km^2 and provides eight grid-connected test berths. Whereas, EMEC's wave test site, Billia Croo (58° 58.543'N, 003° 23.425'W), is located off the exposed west coast of Orkney's Mainland. There are five grid-connected berths and two inshore berths at the wave test site. The site is a similar size to the Fall of Warness, 9km^2.

Observations commenced at the Fall of Warness in July 2005 and were completed in December 2015. During this period, it is estimated that 2500 shore-based surveys (each of four hours in duration) were completed. The observation programme at Billia Croo commenced in March 2009, and run for just under six years, completing in December 2015. During this time period 1700 shore-based surveys (again, each of four hours' long), were undertaken.

The Wildlife Observation Programme at EMEC was funded by Scottish Government through Marine Scotland, Scottish Natural Heritage and Highland and Islands Enterprise.

B. *Survey methodology*

The method employed for conducting the shore-based observation surveys differed between the two test sites, due to dimensions of the observation area to survey and the local geomorphology. Typically, four watches (each of approximately one hour in duration) were completed each survey.

At the tidal test site, Fall of Warness, the observations were carried out from a single shore-based vantage-point, Ward Hill, on the island of the Eday. The vantage point is located approximately 50 above sea level. From the vantage point, the entire test sites can be viewed. An Opticron GS 815 telescope at 20x magnification was used and, when necessary, the telescope could be switched to 60x magnification for species identification purposes. To be able to identify the location of observations, an observation grid system was employed, see Figure 1.

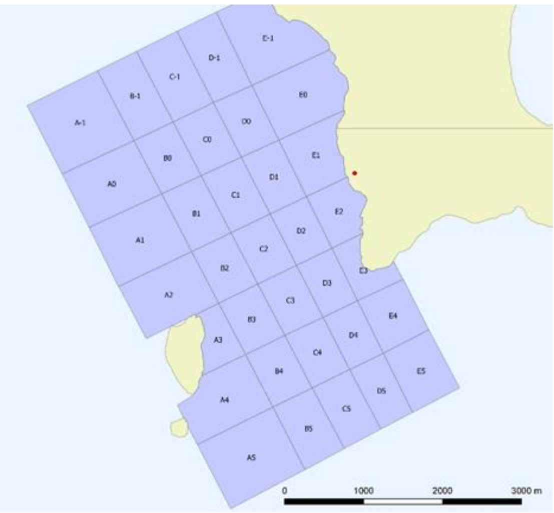

Fig. 1 Observation gird employed at the European Marine Energy Centre's tidal test site, Fall of Warness. The red mark indicates the position of the vantage point at Ward Hill.

The grid comprises 35 zones that vary in areas (due to geomorphology of the land) from 0.304 km^2 to 0.979 km^2. Certain environmental conditions are also recorded at the end of each watch period, these key parameters may include, sea state, wind strength, visibility, glare extent and precipitation. As there were a team of observers (four observers) completing the programme each observer adopted observer-specific observation patterns for each watch, these needed to be mapped and taken into consideration during the analysis. In general, each observer tended to cover the site four times during an hour-long watch. The observer-specific observation pattern alongside the grid area can provide a proxy from observer effort.

The observation method employed at the wave test site, Billia Croo, varied from the Fall of Warness. The vantage point overlooking the test site, is positioned 110m above sea level at Black Craig.

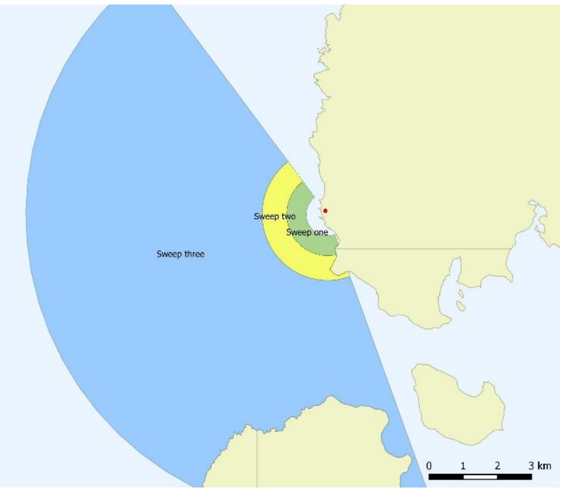

Fig. 2 Observation area covering EMEC's wave test site, Billia Croo, and beyond. Each colour represents different sweep areas: green = sweep one, yellow = sweep two, blue = sweep three. Red dot marks the location of Black Craig vantage point.

Observations were completed using a 25x100 Monk Leviathan Binoculars, known as 'Big Eyes' and sighting locations quantified using the horizontal and declination angles exhibited on the binoculars' angle board and inclinometer. The method for calculating the geographical angle is outlined is a report produced by SMRU Ltd [8]. Throughout the observation programme at Billia Croo, the two observers have been constant. To ensure consistency in the methodology employed by the two observers, dual watches were conducted regularly during the initial years. Due the size of the site and the lack of geographic reference points, the observation area was subdivided into separate areas, which replicates the area covered during a sweep. As shown in Figure 2, the sweeps vary in duration but generally between three and six sweeps were covered in a four-hour period. Unlike the Fall of Warness, the environmental conditions were recorded at the start and end of each sweep. Similar parameters as those collected at the Fall of Warness were recorded.

In order to gain a proxy for observer effort, it was necessary to superimpose a radial grid onto the sweep areas. (see Figure 3) This allowed the observer-specific sweep area to be calculated as this varied between the two observers. By combining the area and sweep duration, it was possible to calculate an area/time variable. This was calculated for sweep at the site and was utilised as a proxy for observer effort.

Only surface-visible species were recorded during the observation programme, therefore limited to seabird, marine mammals, basking shark and European otter. It was possible for the majority of sighting to be recorded at species level; however there were certain families were observers experienced problems discriminating between species, for example pinnipeds, *Phalacrocoracidae* and *Laridae*. Where possible, any information regarding the species behaviour were recorded.

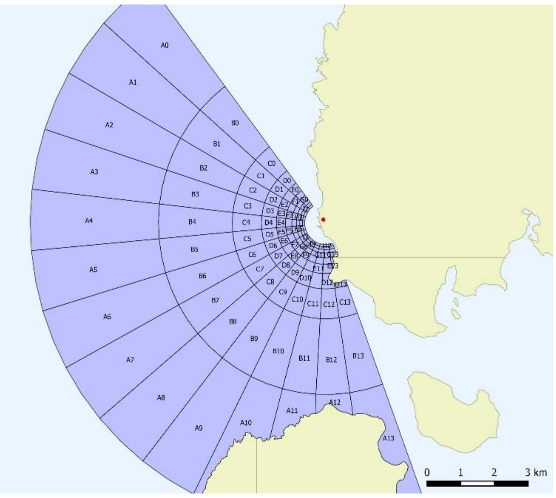

Fig. 3 Radial grid superimposed onto the observation area from Black Craig vantage point, positioned above EMEC's wave test site, Billia Croo

C. Device operational data

To understand any potential for species displacement from marine renewable energy device operation, it was necessary to collect operational data from the device developers testing and operating at EMEC's test sites. In collaboration with the regulator, Marine Scotland, EMEC collected the data from the developers and anonymised. As the coorperation of the developers, was paramount to the success of this study, it was essential the commercial confidentiality could be maintained throughout the study and therefore, no output from the analysis can be attributed to a singe device or developer.

The data collected were categorised under the following operational statuses:

0) Baseline conditions – Offsite;
1) Device associated infrastructure only e.g. moorings, foundations;
2) Device onsite; and
3) Device onsite and operational.

Information on scientific instrument deployments, location, date/time and any buoyage were also recorded but not utilised in the analysis. As EMEC's test sites operate with multiple devices being tested at once, the sites are not always in a single development phase/operational status at any one time. Therefore, it was necessary to employ site-wide impact levels for each observation. This meant that the maximum site impact level occurring at the time was recorded. The assessment assumed the impact level 3 was the worst-case scenario and always adopted the highest impact level regardless of the number of devices or number of different impact levels recorded. Despite a site-wide impact level being adopted, when analysing the predictions, it was useful to identify those grid cells which contains test berths.

D. Detection functions

For vantage point observations, it is recommended to employ detection function to account for reducing detectability from the vantage point [9][10] however, in this circumstance, any detection function may have been confounded for the distribution of the animals relative to land.

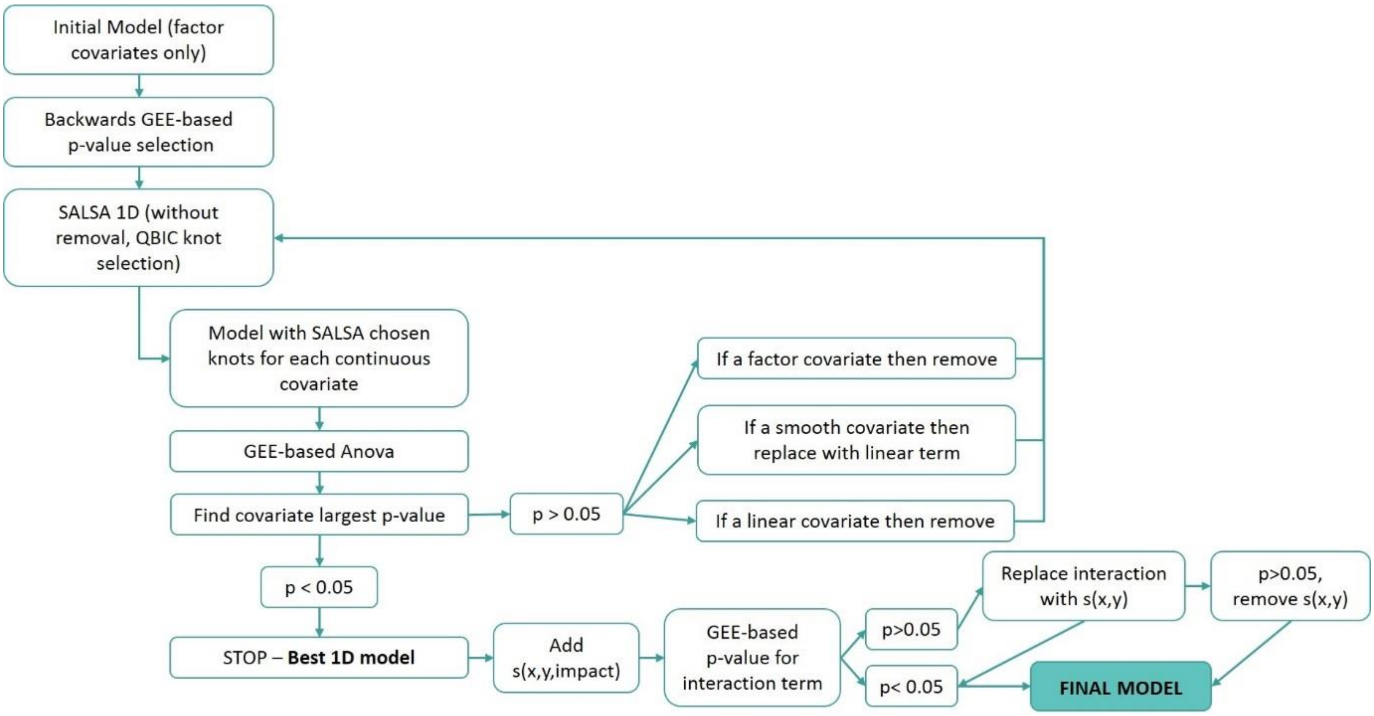

Fig. 4 Model selection process.

Unfortunately, for this analysis a detection function was not applied and therefore the observed counts were not corrected for imperfect detection with distance and all density estimates are relative (rather than absolute).

E. *Zero-inflation*

Due to recording method employed, the observation data only contained species sightings and did not account for species absence. It was therefore necessary to zero-inflate the data, to ensure periods of time when no species were sighted were accounted for in the density estimates. This was conducted by creating 35 empty gird cells for each hour of surveying at the Fall of Warness. The relevant sighting data was then merged. For the Billia Croo, gridded data for each sweep was creating and then merged with the observation data.

III. STATISTICAL ANALYSIS METHODOLOGY

The modelling was restricted to ten species or species groups for each test site, species were selected depending on the species abundance and potential sensitivity to marine renewable energy [11].

By utilising the expertise of the Centre for Ecological and Environmental Modelling (CREEM), at the University of St Andrews, Scotland, the statistical analysis was completed utilising the MRSea package [2][3][7] to quantify any spatially-explicit change that is attributable to marine renewable energy devices testing on key seabird and marine mammal species at the test sites.

During the analysis, environmental, operational and grid-specific covariates were utilised to enable development of more accurate predictions. The potential impact parameter was based on the operational status of the test devices at EMEC sites, was dependent on where test devices were on their development lifespan. For each operational status, evidence for a change in abundance or distribution was investigated. This included redistribution within the test site.

Initially, exploratory data analysis was carried out on each species' data in order to identify any clearly erroneous data and to provide summary characteristics for that species.

A. *Model specification*

Following the zero-inflation, the data were over dispersed and the data were species counts per cell and include large numbers of zeros. This led to Response data (species abundance) to be significantly variable under certain model types. This variability had to be allowed under the selected model and so the response data were modelled using a quasipoisson distribution, with a log link function.

In addition, due to proximity of observations both spatially and temporally, it was likely that observations would be correlated rather than distant and independent. As correlation exists in the model residuals, a crucial assumption of Generalised Linear Models and Generalised Additive Models is violated [12]. However, as correlation is permitted in Generalised Estimating Equations (GEEs) as well as over dispersion, the species abundance was modelled using a GAM-GEE framework to allow non-linear covariate relationships and autocorrelation in residuals. The GEE was constructed with an independent working correlation matrix and robust standard errors were used for uncertainty estimation.

Smooth terms were fitted using B-splines (degree = 2) for one-dimensional (1D) covariates and a CReSS smooth (Complex Region Spatial Smoother) [4] for two-dimensional (2D) spatial coordinates (e.g. x position and y position). The Spatially Adaptive Local Smoothing Algorithm (SALSA) and SALSA2D [5]; [13] were used to select the number and location of knots for the two types of smooth term. These methods allowed for spatially-adaptive smooth terms, rather than uniform smoothness, permitting some parts of the smooth to be more undulating than others. The CReSS method for the spatial component allowed the accommodation of potentially patchy numbers of animals across the survey areas.

An interaction term between the two-dimensional spatial smooth and the site-wide impact level was also considered. This allowed the spatial distribution of animals to vary between impact levels and provided an opportunity to identify spatially-explicit changes, should they be present.

B. *Model selection*

An overview of the model selection process is provided in Figure 4. In this two-stage process, the one-dimensional (1D) predictor covariates (i.e. depth, month, etc.) were considered first to produce a best-fit model. Thereafter, the spatial component with the interaction term was added to the model. At each stage, covariate selection was undertaken using backwards GEE-based p-value selection, whilst the flexibility of each of the smooth terms (1D and 2D) was undertaken using a quasi-likelihood based information criterion, with penalty log(n) for each additional parameter (QBIC)[15]. Covariates were retained in the model if the GEE-based p-value was <0.05.

Models were fitted using R 3.2.0 [17] and packages MRSea [13] and geepack [18].

C. *Model assessment / diagnostics*

Assessment of the model included checking of assumptions and model fit. Partial residual plots on the scale of the link function (log(animal counts)) were used to assess the strength and shape of the relationship of each covariate with species abundance. The mean-variance relationship ($\lambda = \mu = \mathrm{Var}(\mu)$) was assessed using plots of fitted values vs scaled Pearsons residuals [14]. If the relationship was modelled appropriately, then there should not be any pattern observed in the output plot. If extra dispersion in the model was ignored, then this could have led to inappropriate CIs and *p*-values.

D. *Prediction and inference*

Once the most suitable model was selected, predicted density estimates could be created. To be able to produce the prediction surfaces, it was necessary to set the environmental and temporal covariates in the fitted model to fixed conditions. The environmental covariates excluded from this were those that were cell-specific (e.g. depth, distance to land). If not otherwise stated, all the predictions discussed in the results have been made when environmental and temporal covariates were set at conditions when the greatest number of sightings was made for that species/group.

It was crucial to understand whether any change in abundance or distribution was real or if it was ‘noise’ within the system and, if real, whether any of these changes could be classified as significant. Uncertainty was estimated by a parametric bootstrap, with 1000 realisations, using a multivariate normal with parameters, on the estimated model coefficients and their associated GEE-based standard errors. Coefficient of Variation (CV) was calculated for each prediction providing the relative variability in the animal densities allowing comparisons across species and sites[16].

To demonstrate spatially-explicit changes across the site, the difference between model predictions for each site impact level was calculated for each bootstrap iteration and a median density difference was plotted for each cell within the prediction grid. Model predictions for each site impact level and the associated changes between impact levels were calculated for each bootstrap iteration. The 95% confidence intervals were calculated using the percentile method, which allowed the significance of the difference to be determined.

Density difference projections were also used to understand how species’ density changes with distance from a potential impact location. The spatially-explicit changes were collapsed into one dimension to examine changes in density with increasing distance from potential impact locations. Similarly, bootstrap-based 95% Cis were used to show uncertainty in predictions.

E. *Power analysis*

There were two key stages performed when carrying out the simulation-based power analysis: 1) generation of simulated data; and 2) model fitting and assessment of detection of changes. Three power analysis scenarios have been tested on the fitted data for the Fall of Warness test site, to understand the power behind the models. The three scenarios test were:

1) A site-wide decline in abundance of 50%
2) A redistribution in abundance defined as a 50% decline in cells with test berths and an increase in cells without test berths
3) A 50% site-wide decrease in abundance, with an additional 50% reduction in survey effort.

The first stage of the power analysis (simulated data generation) was attempted for the Billia Croo data; however, this was not successful doe to the inclusion of survey effort.

IV. RESULTS AND FINDINGS

Fitted models have been produced for ten species or species groups for both the Fall of Warness and Billia Croo test sites. For the purposes on this paper, only certain species results have been outlined below, however, all findings are discussed in detail in the Scottish Natural Commissioned Report 947: Analysis of the possible displacement of bird and marine mammal species related to the installation and operation of marine energy conversion systems.

A. *Fall of Warness – Black guillemots*

Black guillemots are observed regularly at the Fall of Warness test site, with similarly levels of abundance estimated at ebb and flood tides compared to dramatic decrease in abundance during slack tide.

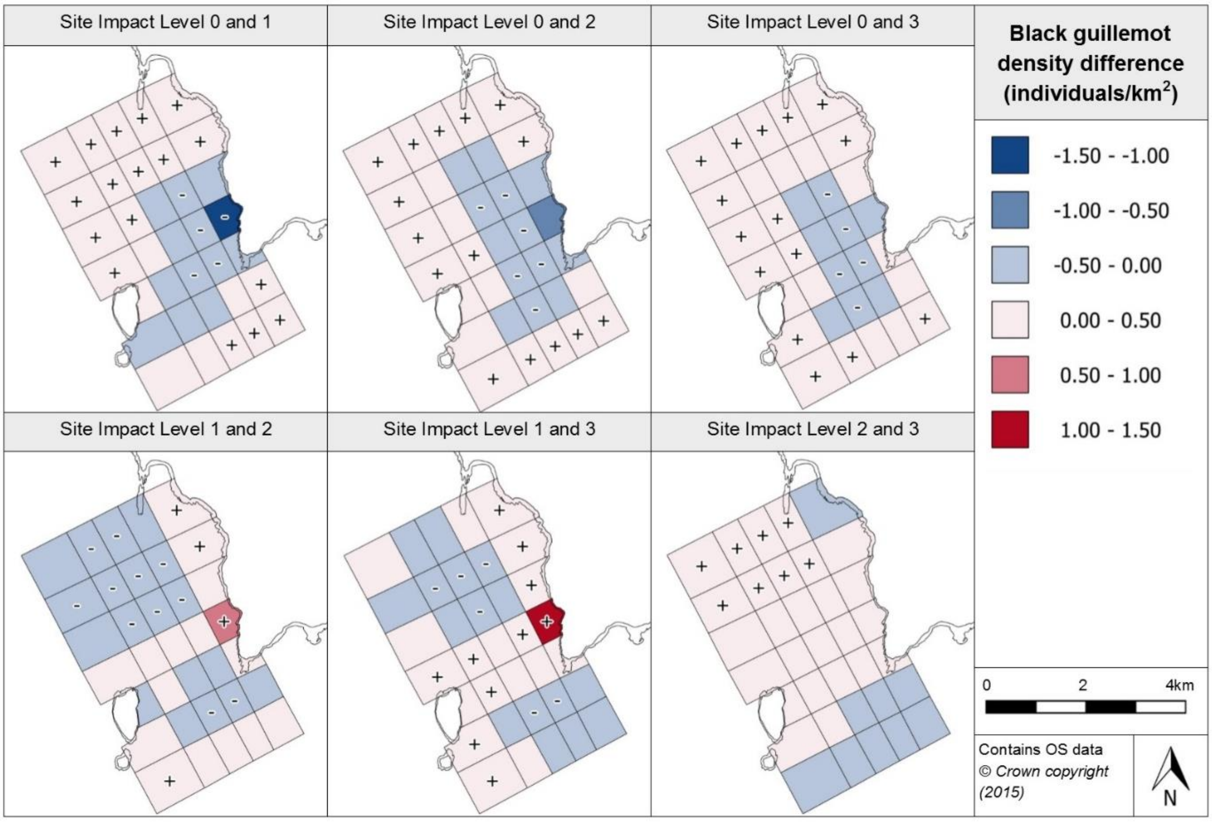

Fig. 5 Estimated density difference between various site impact levels for black guillemot at the Fall of Warness. A plus symbol (+) marks cells where a significant increase in density is modelled whereas a minus symbol (-) marks cells where a significant decrease in density is modelled.

The fitted spatial surface for the black guillemot model was relatively smooth, with eight knots fitted. The relationship between the interaction terms (site impact/spatial surface) and the response term (species abundance) was also found to e statistically significant. The black guillemot model suggests that they are most abundant close to the cliffs of Eday and on the eastern side of Muckle Green Holm (an uninhabited island to the west of the of the test site); this distribution pattern is evident at all four site impact levels. Black guillemots were one of the most common species at the Fall of Warness and, therefore, the density estimates gained from the fitted model for the species have greater certainty compared to other models. However, there is much less certainty in the estimates produced for the southernmost row of the prediction grid.

As shown in Figure 5, the largest estimated density change from baseline conditions occurs with the emplacement of infrastructure; although density falls in the areas of highest occurrence, it returns to baseline conditions as devices are installed and become operational. When infrastructure is installed at test berths, areas where a low density of black guillemots is predicted at baseline conditions, are expected to experience a decrease in density; this effect is limited in distance from the impact location and shows recovery when the device becomes operational. This may reflect a reduction in site disturbance by vessels when devices are operating.

B. Fall of Warness – Auks

For this analysis, a group has been created named Auks which includes all the species from the auk family that have been observed at the Fall of Warness over the duration of the observations programme, this included: black guillemot; common guillemot; little auk; Atlantic puffin; and, razorbill.

Ten terms were found to be highly statistically significant and therefore kept within the final fitted model. The model anticipated a strong seasonal distribution of auk species as presented in Figure 6.

The model shows a large reduction in auk density from baseline conditions when infrastructure is installed. The estimated decrease in density is maintained until approximately 1.5km away from the potential impact location.

A reduction, particularly in the central cells, exists between baseline conditions and when devices are installed and become operational. As many of the decreases are expected to be significant this would suggest that there is greater certainty behind the predictions. Numbers only recover slightly when devices are installed and become operational.

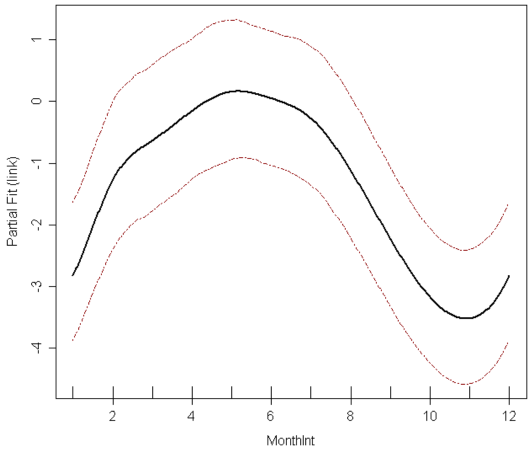

Fig. 6 Estimated partial relationship of month against log(density) for auk at the Fall of Warness. The red lines represent 95% confidence intervals about the estimated relationship and the tick marks show where the data lie in the covariate range.

The pattern of the change may suggest that it is vessel movements associated with the installation activities that impact on auk densities, rather than stationary objects. The change in auk density when infrastructure is installed is the strongest indicator of change amongst all the species and groups studied at the Fall of Warness.

The density difference between various site impact levels relative to increasing distance from a cell containing a test berth has been mapped in Figure 7. It appears auk density decreases with the installation of infrastructure onsite when compared to baseline conditions. The decrease is maintained up to 4km from the potential impact location. The decrease is deemed to be significant up to 1.5km from the test berth. The same pattern in density change with increasing distance from an impact location is apparent when comparing baseline conditions to when devices are installed and operational. When the change in auk density between the other site impact levels is considered, there appears negligible changes in density with increasing distance from a potential impact location.

C. Fall of Warness – Seals

Both harbour and grey seals are regular visitors to the Fall of Warness. Sometimes the observers at the Fall of Warness site were unable to distinguish between the grey and harbour seal species and the observations are recorded as ‘unidentified seal’ i.e. unclassified seal. Harbour seals are of particular interest to the regulator in Scotland due to the well-documented decline of the species in the north of Scotland including the Orkney Islands. The final model selected for the two species contained ten terms, three of which were found to be significant and seven highly significant. Over the duration of the observations programme, there appears to have been a reduction in seal abundance which has been modelled to be reducing at a steady rate from the programme’s inception in 2005. This decline correlates with the population-wide decline of harbour seals observed across the north coast of Scotland. A spatial surface was able to be fitted to the model and four knots were used during the fitting.

The seal model (both grey and harbour seals) shows a clear peak in density around Muckle Green Holm, a known haul-out site, at all site impact levels, together with smaller peaks adjacent to the War Ness headland (towards the south of the site) and Seal Skerry (located in the north of the site). There is high certainty in estimates produced from the fitted seal model. Due to the fewer raw observations collected for baseline conditions, the certainty behind estimates under these conditions is significantly lower compared to the other site impact levels. Changes in seal density are apparent with each change in site impact levels. When infrastructure is installed, there is a density decrease between War Ness and Muckle Green Holm, and a corresponding increase to the north and south. These changes are repeated with the installation of devices but, when devices become operational, seal numbers return to previous levels. The greatest change from baseline conditions occurs with the installation of infrastructure, but the extent of this change is reduced with the installation of devices and their operation. As with other species, this again suggests that perhaps it is the movement of vessels that is influencing seal abundances rather than devices in the water. There also appears to be a decrease in density predicted immediately adjacent to a potential impact location (test berth) which is sustained to approximately 600m away.

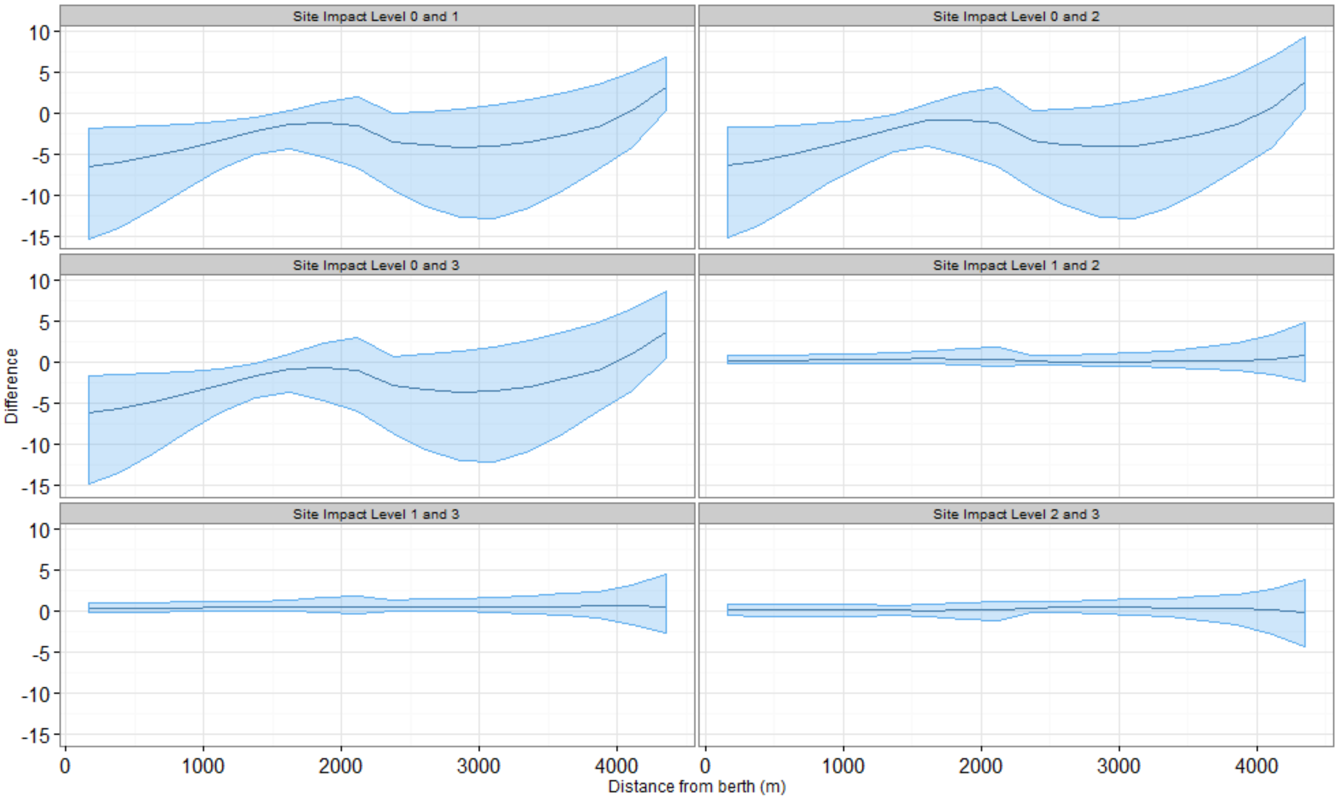

Fig. 7 Density change between site impact levels with increasing distance from a potential impact location, with associated confidence intervals, for auks at the Fall of Warness modelled.

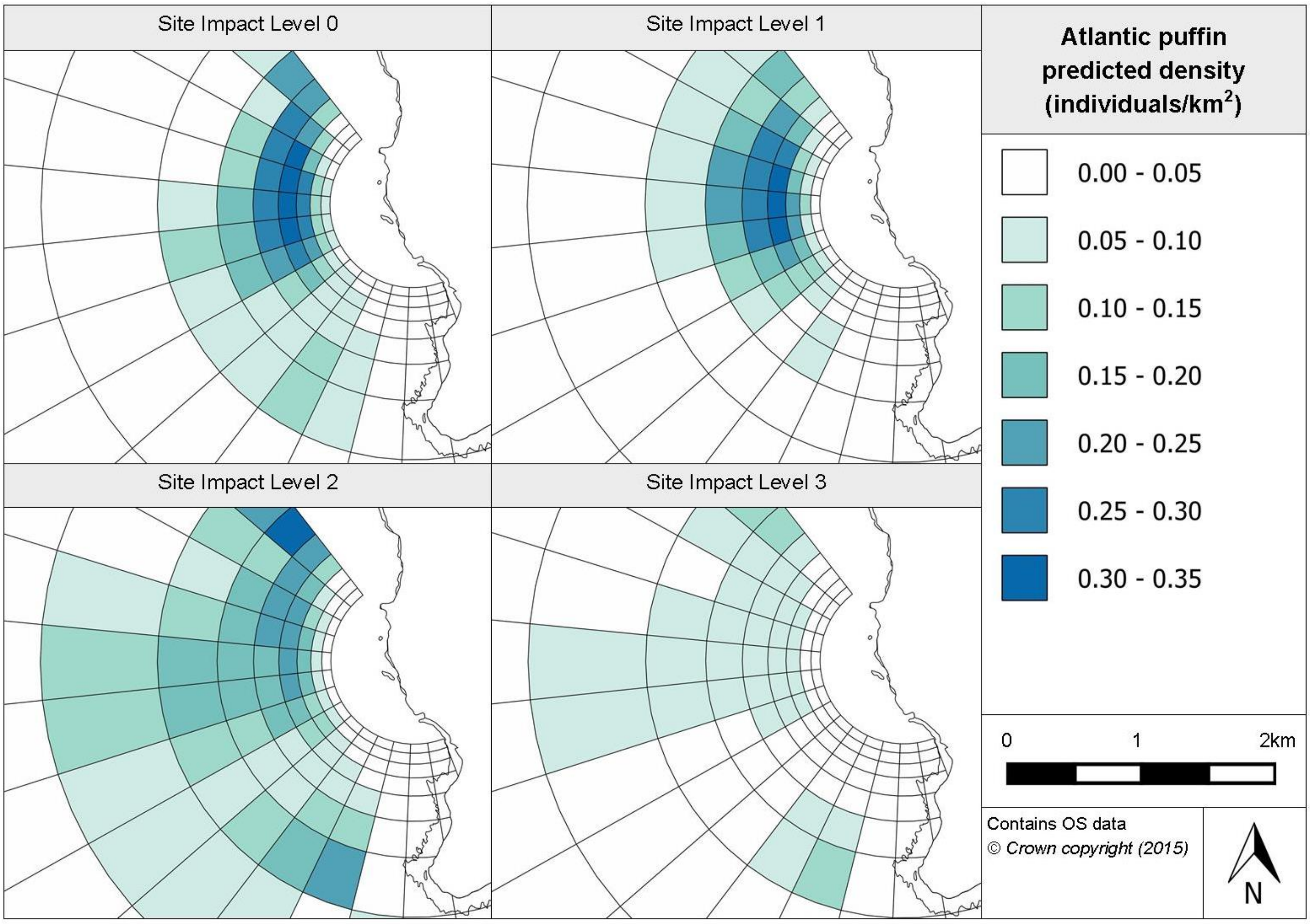

Fig. 8 Inner prediction surfaces for Atlantic puffin density at Billia Croo for each site impact level as devices become operational

D. Billia Croo – Atlantic puffin

The Atlantic puffin are regularly sighted at Billia Croo and tend to be seasonal species.

The Atlantic puffin model shows clusters of higher densities with varying increases and decreases in density between infrastructure installation, device installation and device operation but an apparent overall density reduction, as shown in Figure 8. As with the other Billia Croo species models, there is a lack of certainty in predictions in the outer grid cells. There is greater certainty in the inner grid cells; however, this varies across the site impact levels.

Despite an observable relationship between estimated puffin density and varying site impact level and the location of a grid cell containing a test berth, this was not estimated for all the grid cells containing test berths and hence it is not possible to state that there is a clear correlation between changes in density for each of the site impact levels and the location of test berths.

E. Billia Croo – Northern gannet

The largest member of the gannet family and the largest seabird in the North Atlantic, the northern gannet is frequently spotted in small groups at Billia Croo. Five terms remained to be highly significant and one term significant in the fitted Northern gannet model for Billia Croo.

There is generally a good degree of certainty across the prediction surface, particularly when compared to the other Billia Croo species models. An overview of the predicted changes in density with changing site impact level are provided in Figure 9. Between baseline conditions and infrastructure being onsite, there appears to be a general increase in density in the grid cells in the inner grid bands of the survey area. There is a decrease from baseline conditions in the southern part of the grid, most noticeably in the outer band. When devices are in place but not operational, the majority of grid cells show an increase in density, with the majority being deemed significant. As devices become operational, the majority of the site, continue to have a significant density increase predicted.

Despite these site-wide estimated changes, there does not appear to be any direct correlation between changing density and the location of test berths within the site. Between baseline conditions and infrastructure installation, device installation and device operation, there is a clear increase in density directly at the impact location which tends to extend to at least 1.8km away from the potential impact location. This suggests that the activity surrounding test berths may be causing an increase in northern gannet numbers.

F. Billia Croo – Harbour porpoise

The harbour porpoise is the most common cetacean species observed at Billia Croo where they are seen with much greater frequency than at the Fall of Warness. The final fitted harbour porpoise model contans five terms, one of which is highly statistically significant and three significant. As the fnial fitted harbour porpise model contained a spatial term, unlike the other marine mammal models for Billia Croo, it was possible to produce density prediction surfaces.

Generally, the harbour porpoise model shows that highest densities are located closer to land and reduce with increasing distance. However, as a detection function was not applied to the raw observations this prediction may be a result of the influence of declining detection with increasing distance from observation point. Clusters of high harbour porpoise densities are present which are consistent across the various site impact levels. The estimated density differences between baseline conditions and when infrastructure is installed, devices are installed and devices operational are all very similar. There does not appear to be any correlation between density increases/decreases and the disposition of test berths.

V. CONCLUSIONS

In terms of whether there is any evidence to suggest the presence and/or operation of the marine renewable energy devices, or device-associated infrastructure, altered the abundance or distribution of the birds and mammals observed, many of the analyses completed evidence the greatest changes in density, occurred when infrastructure is installed. However, as the scale of this change often reduced when the site impact level progresses to device operation, it is possible that it is not the physical presence of the infrastructure and the device that has altered the distribution and abundance of the species. It is suggested that vessel movements associated with installation activities may be instigating these changes in density, as it may be expected that vessel movements will be limited when devices are operating; at this latter stage, the scale of such activities may be closer to that occurring under baseline conditions.

With regards to identifying the nature and scale of the changes in density, if they exist, and whether is can be demonstrated that such changes are distinct from natural variation, the analyses concluded that, in many instances, the estimated density differences noted when infrastructure and devices are installed, are statistically significant. However, even though the impact term has been included in the final fitted models for all of the species, its inclusion in the models does not mean that links can be made between devices and their direct effect on species abundance. The impact term could be a proxy for something that was not measured, for instance, changes in the wider population. Note, due to the limited period of baseline conditions compared to the total duration of the observations programme, the results obtained

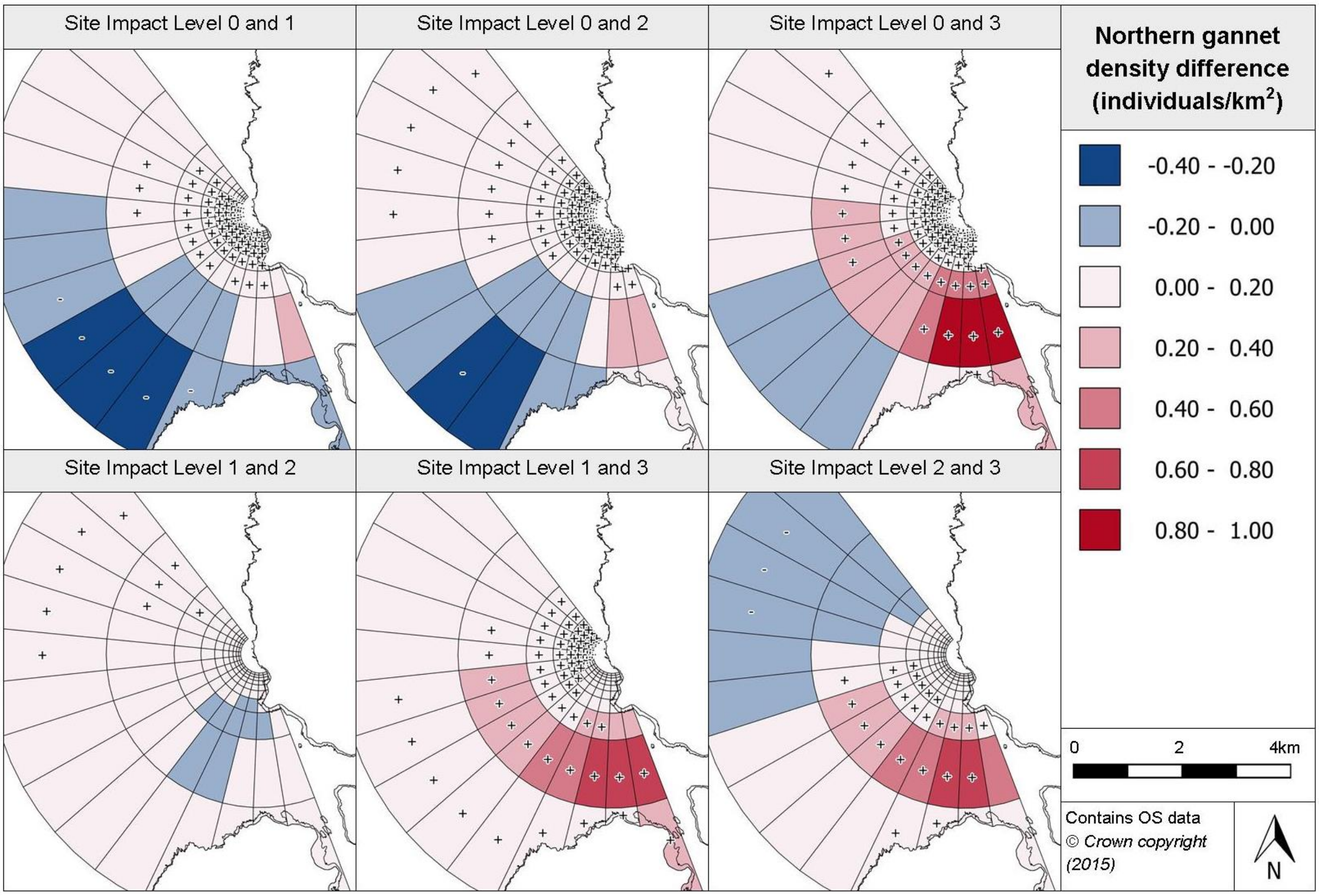

Fig. 9 Estimated density difference between various site impact levels for northern gannet during 2014 (year with least variation) at Billia Croo

may to be undermined, resulting in false relationships observed between the baseline conditions and the other site impact levels.

Throughout this analysis, all of the outputs produced have accounted for natural variation through the covariates included in the model (e.g. the environmental and temporal terms). The variation that cannot be modelled remains in the residuals and, therefore, is reflected in the size of the confidence intervals pertaining to the predictions.

Also considered as part of the analysis was if any of the observed changes in species abundance and/or distribution associated with the deployment of devices were significant when compared with changes in species abundance and/or distribution consequent upon other external factors (and therefore not attributable to device operational status levels). While the observation programme did not include a control site to provide information to allow this question to be addressed more fully, the modelling of many of the species undertaken in the course of this study indicates seasonality and interannual changes in abundance. As an example of a temporal factor, the common guillemot at the Fall of Warness shows dramatic reductions in abundances for certain years (2010 and 2013) as well as strong seasonality, with abundances in autumn and winter only 1-2% of those seen in spring and summer. In terms of environmental factors that appear to be associated with changes in abundance, the modelling of seals indicates that sea state has a strong impact on the number of seal observations. Similarly, razorbill abundances seem to increase with increasing cloud cover, with highest abundances occurring when cloud cover is recorded as 7 or 8 oktas.

The fitted models produced during the analysis have been useful in understanding that the temporary phases of the site development, such as installation, may cause the greatest changes in terms of species displacement however, further research is required to understand the effect of long-term operation on populations and barrier-effects.

The study has highlighted the challenges of analysing long-term datasets, and the importance of establishing the methods for analysing the data whilst developing the data collection methodology. It is anticipated that the results of the study will be used by marine renewable energy developers, environmental consultees, and the regulator to establish the potential impact of the site development on the environment and site's integrity.

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