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Using kernel density estimation to explore habitat use by seabirds at a marine renewable wave energy test facility

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Key words: wet renewables, seabird distributions, spatial overlap, wave energy converter, environmental impacts

Abstract

If Scottish Government targets are met, the equivalent of 100 % of Scotland’s electricity demand will be generated from renewable sources by 2020. There are several possible risks posed to seabirds from marine renewable energy installations (MREIs) and many knowledge gaps still exist around the extent to which seabird habitats can overlap with MREIs. In this study, underlying seasonal and interannual variation in seabird distributions was investigated using kernel density estimation (KDE) to identify areas of core habitat use. This allowed the potential interactions between seabirds and a wave energy converter (WEC) to be assessed. The distributions of four seabird species were compared between seasons, years, and in the presence and absence of WECs. Although substantial interannual variation existed in baseline years prior to WEC deployment, the KDEs for all four species analysed were closer to the mooring points in the presence of a WEC in at least one season. The KDEs for all four species also increased in area in at least one season in the presence of a WEC. The KDEs of the northern fulmar and great skua overlapped the mooring points during spring in the presence of a device. The density of observations close to the mooring points increased for great skua, northern gannet, and northern fulmar during summer in the presence of a device. These results suggest that none of the four species analysed have shown avoidance or an extreme change in distribution as a result of the presence of a WEC. The continued monitoring of seabirds during WEC deployments is necessary to provide further data on how distributions may change in response to the presence of WECs.

Key words: wet renewables; seabird distributions; spatial overlap; wave energy converter; environmental impacts

1. Introduction

The Scottish Government is committed to generating the equivalent of 100 % of Scotland’s electricity demand from renewable resources by 2020 [1] and offshore renewable energy has been given full consideration within Scotland’s National Marine Plan [2]. Twelve sites in the Pentland Firth and Orkney waters have been leased for the development of commercial-scale wave or tidal renewable energy arrays. However, many knowledge gaps still exist concerning the possible ecological interactions of wave and tidal devices with marine organisms including seabirds [3–6].

Several possible risks to seabirds from marine renewable energy have been identified: collision [7] or entanglement mortality [8–10], barrier effects [11–13], displacement [14,15], and disturbance [16,17]. The relative infancy of the wave and tidal energy industry means that most marine renewable energy devices (MREDs) are still in the development phase, with limited opportunities to study environmental interactions in the field. Consequently, there are currently no empirical, quantitative accounts published in the peer-reviewed literature of how these risks are associated with wave energy converters (WECs) and tidal energy converters (TECs). In addition, there is considerable variety in the designs of WECs and TECs [18,19] and no standardised approach for the Environmental Impact Assessment (EIA) of MREDs, as the risks posed will most likely be location and species-specific [18,20,21]. The Pelamis Wave Power Ltd ‘P2’ [22] is an example of a semi-submerged attenuator WEC, and the risk of collision mortality associated with WECs of this type is likely to be relatively low for the majority of species [18,21]. The main potential negative impact is loss of foraging habitats, either through exclusion due to the physical presence of the WEC or through underlying changes in the quality of the foraging habitat [4].

Much uncertainty also exists around how best to monitor and assess the biological effects of marine renewable energy arrays [23,24]. Further consideration still needs to be given to identifying the drivers of habitat selection by foraging seabirds over multiple spatial and temporal scales. Establishing the degree of spatial overlap between seabird distributions and development sites will be important in addressing the uncertainty surrounding the potential risks [25].

A long-term dataset of land-based, spatially-explicit seabird observations were analysed using kernel density estimation (KDE) [26] to describe the distributions of the most commonly observed seabird species at a wave energy test facility where Pelamis P2 WECs were being tested. The aims were to assess the impact of the presence of a WEC on seabird distributions within the test site and to compare these changes with underlying seasonal or annual variation: are potential changes in seabird distributions in the presence of a P2 WEC identifiable using KDE and if so, how do these changes compare to intra- and interannual variation observed prior to WEC deployment?

2. Methods

2.1. Study site

The European Marine Energy Centre (EMEC), Billia Croo site (58.9775°N 03.3959°W) in Orkney, Scotland (Fig. 1) is the only accredited full scale wave test site in the world (area approximately 5.50 km^2), allowing for the simultaneous testing of multiple WECs in five grid-connected berths. All berths are capable of exporting electricity to the national grid [27] and testing of the P2 began in late 2010. The test site has a significant wave height of 2-3 metres, and the highest recorded wave has been 17 metres [28].

Figure 1 approximately here- single column width

2.2. Data collection

Seabird distribution data were collected between March 2009 and February 2013 by two observers employed by EMEC as part of a Scottish Government funded wildlife monitoring programme [29]. The survey area extended approximately 5 km in all seaward directions from the observation point, forming a semi-circular arc that encompassed the full test site which was approximately 2 km from shore (Fig. 1) [29]. Surveys were undertaken 5 days out of every 7 between 04:00hrs and 20:00hrs, sampling evenly throughout the day and across the tidal cycle as conditions allowed. A survey period lasted 4 hours and was conducted from a coastal observation point approximately 110m above sea level (Fig. 1). Surveying was not undertaken in sea conditions above sea state 4 of the Beaufort scale, and was suspended in reduced visibility during thick fog or heavy rain. For each observation the date, time, species and number present, and the appropriate behaviour, were recorded. The angle of declination from the observation point to the point of interest, and the associated compass bearing, were also recorded and used to calculate the geographical location of each observation [29]. Only birds that were in contact with, or close to the sea surface were recorded. The data were stored in an Access database, and are freely available online [30].

Coordinates for each data point used in the analysis were transformed using ESRI ArcMap 10.0 to Universal Transverse Mercator (UTM) Zone 30, using WGS 1984 datum. Observations that overlapped land were removed and only data within 3 km of the elevated observation point were included; this was deemed a suitable distance range for describing habitat use within the test site and retained confidence in the detectability and identification of sightings. Pre-deployment baseline data were collected between 11th March 2009 and 28th February 2011, however during this time two short device deployments of 3 and 4 days occurred in October and December 2010 respectively. Due to the short timeframe of these deployments it is unlikely that they would have a noticeable prolonged effect on seabird distributions. During 2012-2013 there were a maximum of two P2 WECs regularly deployed; for this period observational data were split into two groups: those recorded in the presence of a P2 WEC and those recorded when the P2 WECs were absent. No distinction was made between whether one or two P2 WECs were present.

Data gathered from a linear feature, such as a coast, are not uniformly distributed at all distances from the observation point. This non-uniformity would have generated biased results had conventional distance sampling been used [31] therefore data were not corrected for distance prior to analysis and the results presented here are only indicative of habitat use.

2.3. Statistical Analyses

Distribution patterns were explored by identifying changes in the location and size of the 50 % KDE contour; this area is the probability contour that accounts for 50 % of the observations and was considered to represent core habitat use. KDEs were calculated for the first two years of baseline data (2009-11), weighting observations by the number of individuals recorded. A minimum of *n* > 15 [32] was used to calculate KDEs, where *n* is the number of geographical locations where one or more individuals were observed. KDEs were calculated in Geospatial Modelling Environment (GME) Version 0.7.2.0, [33] using the bivariate normal kernel and the 'SCV' plugin (*ks* library, [34]) to estimate the smoothing parameter *h*.

2.4. Assessing the change in habitat utilisation

The P2 WEC is approximately 180 m in length and can rotate on its moorings in response to wave direction, with approximately 390 metres between the 2 mooring points. The distances from the midpoint between the moorings of the P2 WECs to the centroid of each of the 50 % KDE contours were measured; this distance is hereinafter referred to as 'point distance'. The percentage change in point distance was then calculated between the baseline years, between seasons, and between the absence and presence of a P2 WEC. The centroid of a 50 % KDE contour that consisted of multiple parts was calculated by weighting each part by the size of its area using ESRI ArcMap 10.0 (i.e. if one area was proportionally larger than the rest, the centroid would be calculated closer to that part of the polygon). This approach was preferred over a direct comparison of KDE overlap as the majority of sample sizes were unbalanced and indices of KDE overlap could have produced biased results [35]. KDEs that overlapped land were clipped in ESRI ArcMap 10.0 prior to calculating the centroid and the area. The change in density between years and between the absence and presence of a WEC was also investigated. By subtracting the density surfaces calculated for 2009 from those calculated for 2010, the areas showing the greatest increase and decrease in density were identified. Similarly the density surface calculated in the absence of a device was subtracted from the density surface calculated in the presence of a WEC.

3. Results

The results for 4 species, each with differing foraging ecologies, are presented here in detail: Atlantic puffin *Fratercula arctica* (pursuit diver), great skua *Stercorarius skua* (generalist omnivore), northern fulmar *Fulmarus glacialis* (surface seizing and scavenging) and northern gannet *Morus bassanus* (plunge diver). Changes in point distance are presented in Fig. 2a and changes in the size of the 50% KDE area are presented in Fig. 2b. For results of all species see supplementary material.

Figure 2 approximately here – double column width

3.1.Change in point distance

3.1.1. Atlantic Puffin

The point distance decreased by 2.94 % between spring 2009 (1191.23 m, *n* = 76) and 2010 (1156.26 m, *n* = 98) and by 9.24 % between summer 2009 (1428.61 m, *n* = 158) and 2010 (1296.62 m, *n* = 129). There was a seasonal increase between spring and summer in both baseline years (19.93 %, 2009 and 12.14 %, 2010). In spring in the presence of a P2 WEC (1170.62 m, *n* = 46) the point distance decreased by 13.08 % compared to when it was absent (1346.72 m, *n* = 52); there were insufficient data to compare presence and absence KDEs in summer.

3.1.2. Great skua

The point distance decreased by 63.59 % between spring 2009 (2161.72 m, *n* = 24) and 2010 (787.15 m, *n* = 79) and increased by 4.00 % between summer 2009 (2844.19 m, *n* = 147) and 2010 (2958.04 m, *n* = 165). There was a 31.57 % increase between spring and summer in 2009 and a 275.79 % increase between spring and summer 2010. In spring the point distance decreased in the presence (1376.53 m, *n* = 26) of a device of a P2 WEC compared to when it was absent (1684.70 m, *n* = 19) by 18.29 %. In summer the point distance decreased in the presence of a P2 WEC by 27.96% (absence, 2482.88 m, *n* = 67, presence, 1788.57 m, *n* = 122).

3.1.3. Northern fulmar

Point distance increased by 13.24 % between spring 2009 (1246.04 m, *n* = 609) and 2010 (1411.08 m, *n* = 1008) and by 46.11 % between summer 2009 (1019.77 m, *n* = 994) and 2010 (1489.95 m, *n* = 1049). Point distance decreased by 18.16 % between spring and summer 2009 and increased by 5.59 % between spring and summer 2010. During spring in the presence (1389.10 m, *n* = 334) of a P2 WEC the point distance increased by 1.19 % compared to when it was absent (1372.70 m, *n* = 359) and decreased in summer by 8.37 % (absence, 1410.51 m, *n* = 300, presence, 1292.52 m, *n* = 452).

3.1.4. Northern gannet

Point distance decreased by 49.94 % between spring 2009 (1978.88 m, *n* = 40) and 2010 (990.62 m, *n* = 124) and increased by 9.71 % in summer 2010 (3220.33 m, *n* = 301) compared to 2009 (2935.27 m, *n* = 256). There was a seasonal increase between spring and summer in both 2009 and 2010, of 48.33 % and 225.08 % respectively. In spring the point distance increased by 6.78 % in the presence (1215.46 m, *n* = 87) of a P2 WEC compared to when it was absent (1138.33 m, *n* = 22) In the presence of a P2 WEC the point distance reduced in summer by 54.16 % (absence, 3056.55 m, *n* = 195, presence, 1401.22 m, *n* = 181).

Figure 3 approximately here - single column width

3.2.Change in KDE area

3.2.1. Atlantic Puffin

The baseline 50 % KDE contour area decreased by 21.04 % between spring 2009 (1.39 km^2) and 2010 (1.10 km^2) and increased by 86.13 % between summer 2009 (0.62 km^2) and 2010 (1.15 km^2). The area of the 50% KDE decreased by 55.50 % between spring and summer in 2009 and increased by 4.90 % in 2010. In the presence (1.55 km^2) of a P2 WEC the 50 % KDE area increased by 7.87 % compared to when it was absent (1.44 km^2) Fig.3a & 3b.

3.2.2. Great skua

The 50 % KDE contour decreased in area by 14.97 % between spring 2009 (1.91 km^2) and 2010 (1.62 km^2) and increased by 26.49 % between summer 2009 (1.44 km^2) and 2010 (1.82 km^2). The area decreased by 24.72 % between spring and summer in 2009 and increased between spring and summer in 2010 by 11.97 %. In spring in the presence of a P2 WEC the area decreased by 21.06 % compared to when the WEC was absent (absence 3.16 km^2, presence

2.50 km^2, Fig.4a & 4b). In the presence of a WEC the 50 % KDE contour overlaps with the mooring points (Fig. 4b) There was also overlap between the great skua and northern gannet absence and presence KDEs (Fig. 4). In the presence of a P2 WEC in summer the KDE area increased by 30.16 % (absence, 1.94 km^2, presence, 2.52 km^2).

Figure 4 approximately here – single column width

3.2.3. Northern fulmar

The area of the 50 % KDE contour decreased between spring 2009 (0.87km^2) and 2010 (0.77 km^2) by 11.57 % and increased between summer 2009 (0.87 km^2) and 2010 (1.06 km^2) by 22.04 %. There was a seasonal increase of 0.33 % between spring and summer 2009 and an increase of 38.46 % between spring and summer 2010. In the presence of a P2 WEC (Fig. 3d) the area increased by 61.19 % in spring (0.92 km^2) compared to when it was absent (0.57 km^2) (Fig. 3c) and increased in summer by 0.83 % (absence, 1.28 km^2, presence, 1.29 km^2). There was a small area of the spring presence 50 % contour that is immediately adjacent to a WEC mooring point (Fig. 3d).

3.2.4. Northern gannet

The interannual change in the baseline area of the 50 % KDE contour was largest in spring, a 15.56 % increase in 2010 (1.81 km^2) compared to 2009 (1.56 km^2); in summer there was a 19.33 % decrease in 2010 (1.01 km^2) compared to 2009 (1.26 km^2). Between spring and summer in 2009 the area decreased by 19.71 % and by 43.96 % in 2010. In spring in the presence of a P2 WEC the area increased by 40.11 % compared to when the WEC was absent (absence 1.97 km^2, presence 2.77 km^2) (Fig. 4c & 4d). The spring presence contour also overlaps the mooring points (Fig. 4d). In the presence of a WEC the area of the 50 % KDE contour increased in summer by 22.36 % (absence, 1.34 km^2, presence, 1.64 km^2).

3.3.Changes in density

3.3.1. Atlantic Puffin

There was an observable increase in the density close to the mooring points between spring 2009 and 2010 (Fig. 5a). In the presence of a P2 WEC there was a decrease in density in the centre of the overlapping absence and presence 50 % contours (Fig. 5b) and a relative increase in density located in the northern half of the presence contour.

Figure 5 approximately here- single column width

3.3.2. Great skua

The summer 2009 and 2010 50 % KDE contours overlap, and an area of reduced density is visible within the 50% KDE contour indicating that the density of observations decreased in this area in 2010 (Fig. 6a). There is partial overlap between the absence and presence 50 % contour and visibly darker areas close to shore where there was a higher density of observations further from the mooring points in the absence of a WEC. There is also a lighter area near to the moorings points where the density of observations increased in the presence of a WEC, and the 50% KDE contour is closer to the mooring points in the presence of the device (Fig 6b).

3.3.3. Northern fulmar

The 50 % KDE contour comprised multiple parts in summer 2009 and 2010, with some overlap of the largest parts, with lighter areas indicating higher density in 2010 (Fig. 5c). Although there is overlap between the absence and presence contours, there is an area of higher density within the presence 50 % KDE contour closer to the mooring points (Fig. 5d).

3.3.4. Northern gannet

The summer 2009 and 2010 50 % KDE contours overlap, with an area of higher density closer to the coast in 2010 (Fig. 6c). In the presence of a P2 WEC there was an increase in density closer to the mooring points within the presence 50 % KDE contour and a decrease in density that can be observed close to shore within the absence 50 % KDE contour (Fig 6d).

Figure 6 approximately here – single column width

4. Discussion

4.1. Baseline KDE

It is thought that marine renewable energy devices may impact seabirds, and lead to changes in distributions; however, identifying a change in response to anthropogenic pressures can often be extremely challenging [36]. This is because seabird life-histories and distributions [37–39] inherently vary in response to changes in resource availability [40], or meteorological [41,42] and ocean conditions [43,44].

A large amount of seasonal variation was observed during 2009 and 2010, both in the size of the 50% KDE area and the point distance. The magnitude of the observed change also varied, making the interpretation of the presence/absence KDE difficult as few consistent patterns in the distributions were apparent prior to device deployment. The baseline seasonal changes in 50 % KDE area were more variable and difficult to interpret than those observed for point distance; the majority of 50 % KDE areas decreased between spring and summer 2009, but increased in 2010.

4.2. Presence/absence KDE

Overall there was little observable change in point distance from the midpoint of the moorings in the presence of a P2 WEC compared to when it was absent. All 4 species showed a decrease in point distance in at least one season in the presence of a device. However, when changes between presence and absence 50 % KDEs were compared to the seasonal changes observed in baseline years many were smaller or similar in magnitude; this is possibly suggestive of a change within the limits of natural variability. The 50 % KDE contours all increased in area in the presence of a P2 WEC, except for great skua spring KDE; however, again the magnitude of the changes varied among seasons and species. Great skua 50 % KDE contour area decreased in the presence of a device in spring, but increased by a similar amount in summer. Therefore, although there appears to be some consistency within the trends there is still a large amount of variation in the resulting measurements.

4.3. Species-specific impacts

Accounting for species-specific ecologies is important for correctly assessing the associated risk posed by marine renewables. A large foraging range might ‘buffer’ a species against the increased energetic costs resulting from displacement or barrier effects, compared to perhaps a red-throated diver (*Gavia stellata*) where productivity may vary depending on the distance of nesting locations from the coast [45]. Unfortunately there were insufficient data to consider the distributions of ‘moderately’ vulnerable diver species [21] and the 4 species analysed here were identified as having either ‘low’ or ‘very low’ vulnerability to the potential impacts of WECs. Assessing the impacts on less common and potentially vulnerable species can be challenging as the ability to assess impacts at ‘test stage’ is ultimately limited by whether they occur in sufficient numbers, or at all, within the test site. Separating observations into absence and presence groups for this study severely limited sample sizes for many species as the detectability issues associated with shore-based surveys restricted the data available for analysis in this study to within 3km of the observation point. Limiting the observations to this range meant that the observations no longer completely covered the entire test site, although the mooring points were still within this range. A possible alternative to these shore-based methods that would potentially improve detectability would be vessel based surveys using European Seabird At Sea methodology [46,47]. However, the logistics of vessel surveys with an active test site may be challenging. In some cases more targeted intensive surveying or tagging studies are appropriate and high-resolution data generated from data logger studies can be useful in identifying areas important to seabirds [48–51]. Further consideration is still needed to identify the drivers of habitat selection by foraging seabirds over multiple spatial and temporal scales [4,52]; this is particularly prudent in situations where direct observations fail to capture the underlying spatial variability [53].

4.4. P2 WEC presence and absence

Other WECs were present at times during 2012-13 and possibly during 2009-10. WEC deployment timetables are regarded as ‘commercially sensitive’ and were not made available by other developers. Consequently it was not possible to assess the contribution that these WECs may have made to the overall disturbance within the test site. Nonetheless, in this study we were specifically addressing the device-specific changes induced by the presence of the Pelamis WEC. Although it is possible that distributions of seabirds may have been modified due to the presence of other WECs, it is unlikely that this would mask any strong redistribution associated with the Pelamis device.

4.5. Detectability and seasonality

The P2 is in test phase and deployments are scheduled for fair weather when birds are easier to detect, and could be coinciding with larger numbers of birds in summer and early autumn; in winter when there are fewer birds on site, which are potentially more difficult to detect due to adverse weather conditions and rougher seas, there are also fewer deployments. Detection rates also vary with distance and the WECs are moored close to shore where observations of many species were clustered. This combination of seasonality, and varying detection rates in differing sea conditions and distances from shore could lead to spurious relationships between WEC presence and bird abundance. 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. There is a possibility that birds are more easily observed on the sea surface close to the device as it provides a reference point in an otherwise featureless search area; any possible apparent attractant effect could be attributed to this detectability issue [54]. An alternative method that would avoid this effect could be digital aerial surveys.

4.6. Measurement of distance

The centroids for 50 % KDE contours with multiple parts were calculated based on the weighted area of each part. Weighting the calculation of the centroid imposes additional meaning on the data; many of the larger numbers of individuals (i.e. greater than 50) may have a disproportionately large effect on the KDE generated, despite being unrelated to the presence or absence of a P2 WEC (possibly the result of attraction by a fishing boat). Weighting the calculation limited the potential for biased interpretation, but it may have underestimated a change in point distance compared to those modelled as one continuous area. There is no environmental information associated with the images presented and therefore it is impossible to infer what may be driving the distribution of the observations used to generate the KDEs. By only measuring point distance from the centroid of the 50 % KDE contour, any change in the shape of the distribution is unaccounted for. A possible measurement to account for the change in shape of the KDE would be to measure from the mooring point to the nearest edge of the 50 % KDE. However, this approach also has the potential to overestimate a change and lead to biased interpretation of multiple contour KDEs; the contour closest to the mooring may not be the most biologically important (see Appendix A: S5 & S6).

5. Conclusion

Anthropogenic pressures on the marine environment are increasing, and our ability to accurately quantify and manage the associated risks to seabirds needs to keep pace. These results suggest that the effect of the presence of a WEC on seabird distributions at the EMEC wave energy test site was relatively small. The centroids of all 4 species distributions moved closer to the mooring points in the presence of a WEC. This may indicate that a small attractant effect exists for some species, but the available data are not sufficient to demonstrate this authoritatively; these observed changes may still be due to underlying spatio-temporal variability within the marine environment or detectability issues. Changes in the area of the 50 % KDE were harder to interpret, but, bearing in mind a number of associated caveats, this analysis shows that there is little evidence that any of the 4 species analysed exhibit avoidance, displacement, or extreme changes in distribution as a result of the presence of a WEC. The species considered here are of low vulnerability to WECs and therefore a possible overlap with WEC, as demonstrated by this study, should not cause undue concern. The continued monitoring of seabirds at wave energy sites with operational WECs is necessary to achieve an adequate sample size, across all seasons, to investigate the changes in habitat distributions for more vulnerable species and those that are less abundant. However, full consideration needs to be given to how best to supplement data on potentially vulnerable species that are not adequately detected using shore-based observations.

Appendix A: Supplementary material

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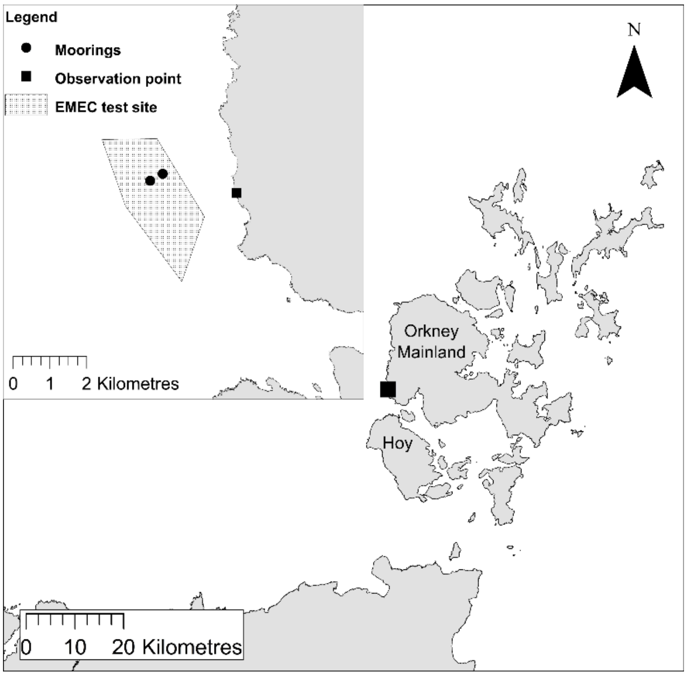

Figure 1. Main image: A map of the north east corner of mainland Scotland and south west corner of Orkney Mainland. Insert: Map of the EMEC wave test site, detailing the location of the mooring points.

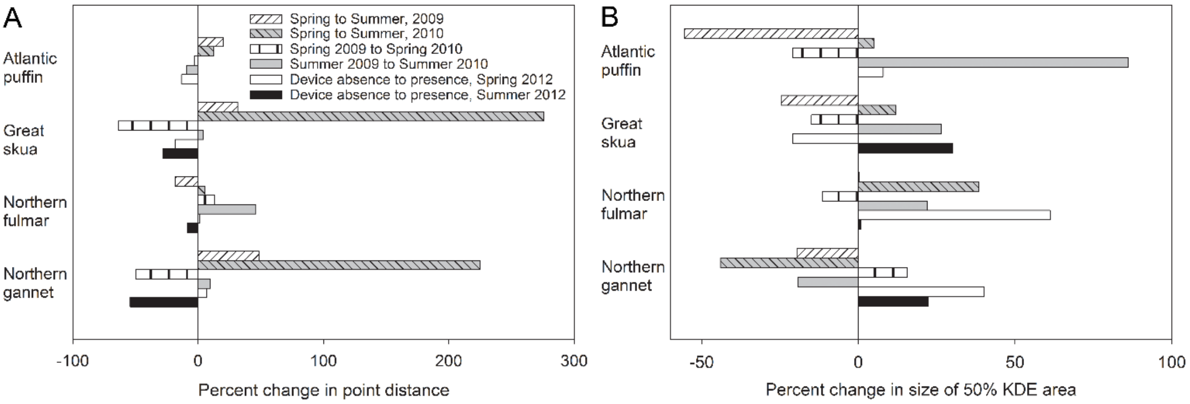

Figure 2. a) Percentage change in the point distance of the 50% KDE contour, b) percentage change in the area of the 50% KDE contour, for legend see Fig. 2a.

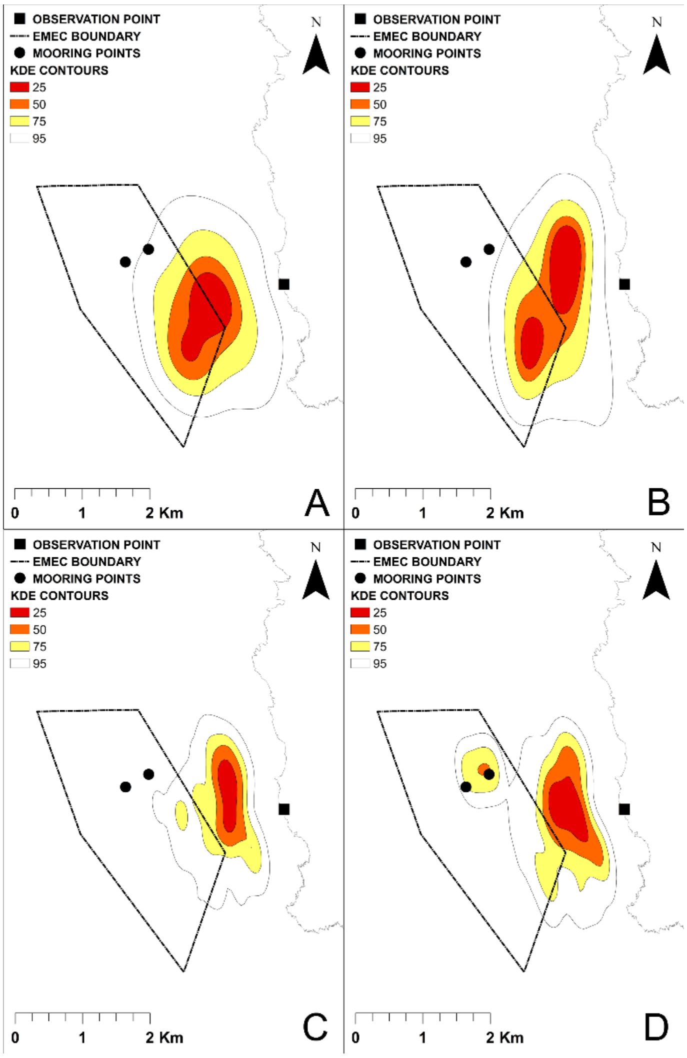

Figure 3. Spring KDEs calculated for Atlantic puffin: a) WEC absence 2012, b) WEC presence 2012, and for northern fulmar c) WEC absence 2012, d) WEC presence 2012

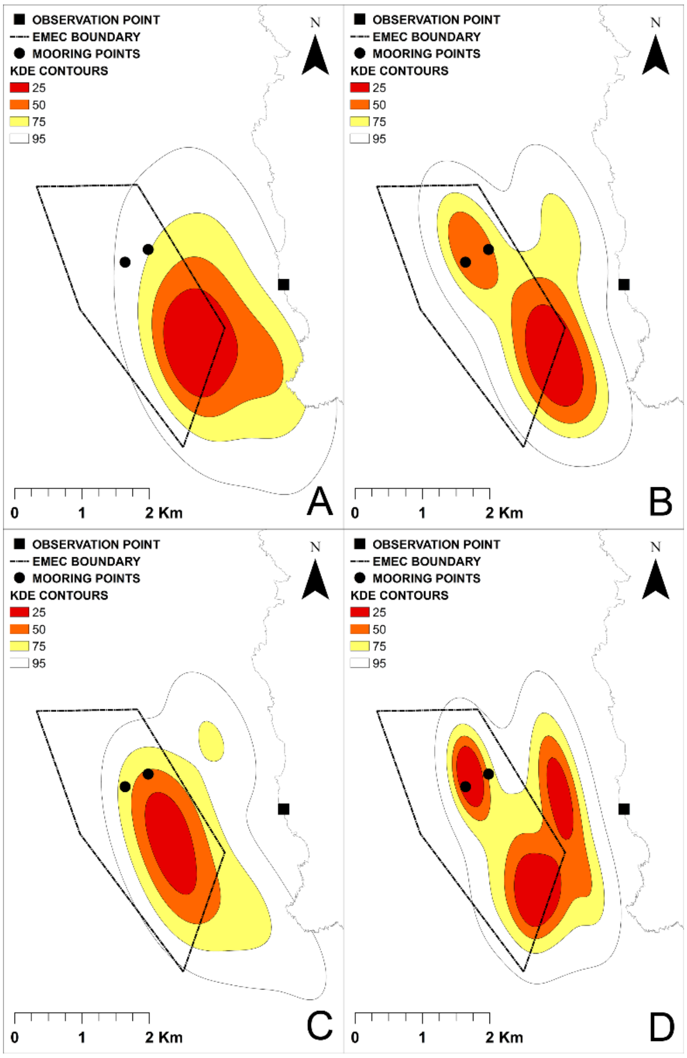

Figure 4. Spring KDEs calculated for great skua: a) WEC absence 2012, b) WEC presence 2012, and for northern gannet c) WEC absence 2012, d) WEC presence 2012.

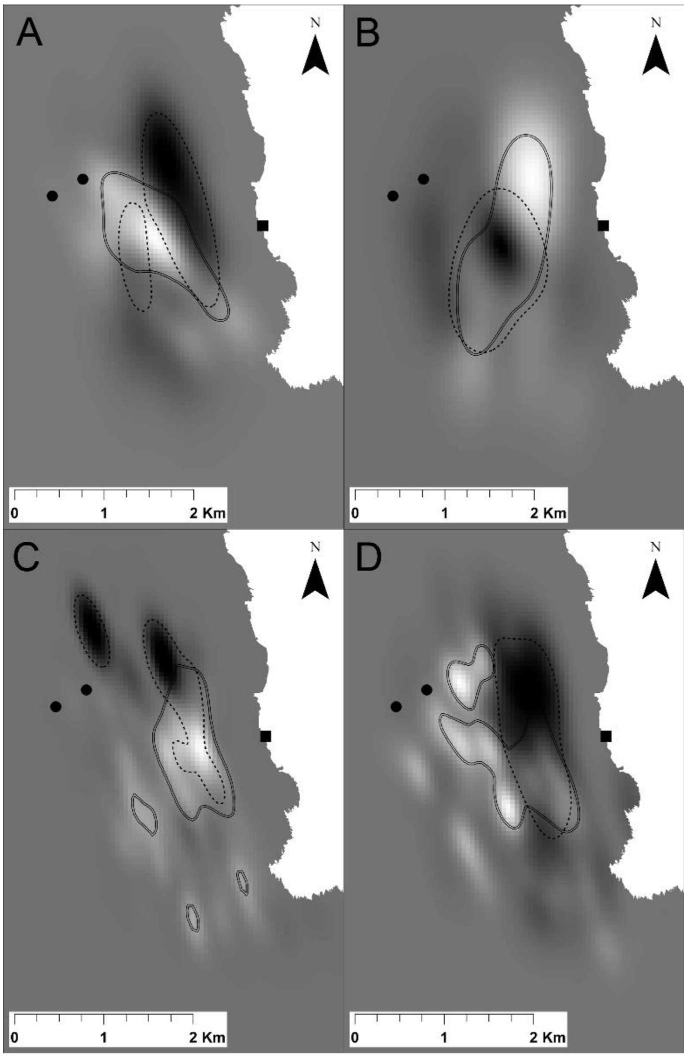

Figure 5. Changes in the density surface of distributions. For each individual plot the white and black areas show the greatest relative increase and decrease in density, respectively. a) Atlantic puffin Spring 2009 (dashed line) to Spring 2010 (solid double line), b) Atlantic puffin WEC absence Spring 2012 (dashed line) and WEC presence Spring 2012 (solid double line), c) northern fulmar Summer 2009 (dashed line) to Summer 2010 (solid double line), d) northern fulmar WEC absence Summer 2012 (dashed line) and WEC presence Summer 2012 (solid double line).

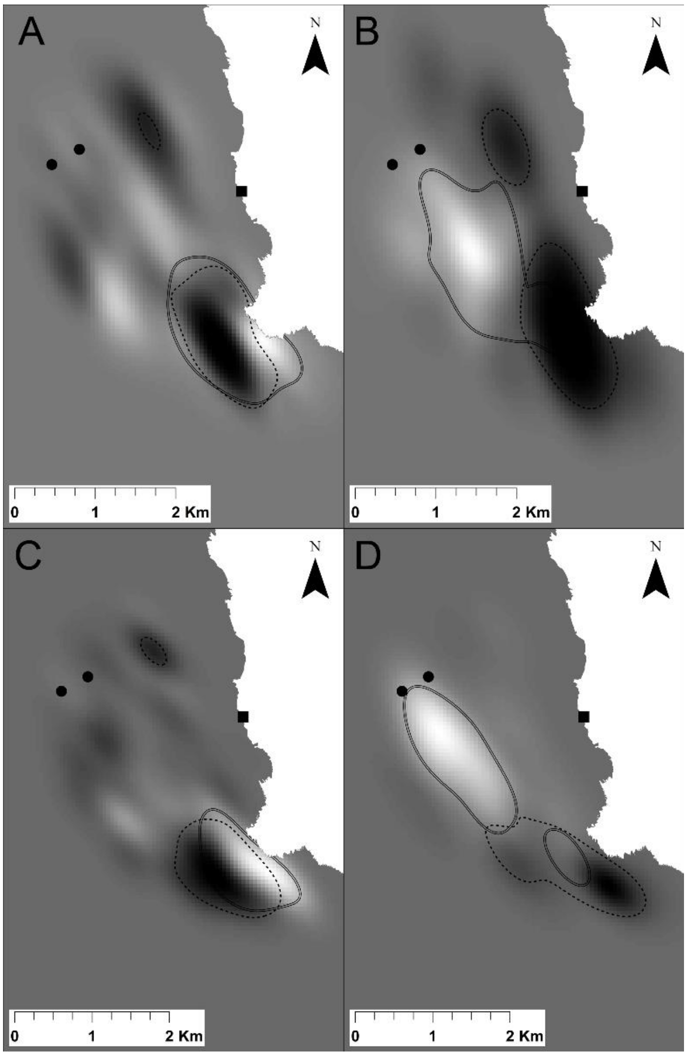

Figure 6. Changes in the density surface of distributions. For each individual plot the white and black areas show the greatest relative increase and decrease in density, respectively. a) great skua Summer 2009 (dashed line) to Summer 2010 (solid double line), b) great skua WEC absence Summer 2012 (dashed line) and WEC presence Summer 2012 (solid double line), c) northern gannet Summer 2009 (dashed line) to Summer 2010 (solid double line), d) northern gannet WEC absence Summer 2012 (dashed line) and WEC presence Summer 2012 (solid double line).