Beatrice Offshore Wind Farm

Pre-Construction Aerial Survey Report

February 2016

Beatrice Offshore Windfarm Ltd

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Executive Summary

The Beatrice Offshore Wind Farm is located in the Moray Firth, at its closest 13.5 km from the Caithness Coast. Potential impacts on seabirds due to the construction and operation of the Wind Farm were assessed prior to consent being granted. The consent includes conditions which require monitoring of seabirds in order to validate the conclusions in the Environmental Statement (ES) and Supplementary Environmental Information Statement (SEIS) and to improve understanding of seabird interactions with offshore wind farms.

A digital aerial survey was designed to allow collection of data for answering key questions raised during the Wind Farm ES and SEIS assessments, relating to potential impacts on breeding populations of great black-backed gull, herring gull and puffin (primary species) and also guillemot, razorbill, kittiwake and gannet (secondary species). With the exception of gannet all of these species breed within the East Caithness Cliffs Special Protection Area.

During the 2015 seabird breeding season (May to July) six pre-construction surveys were conducted. As well as updating the seabird distribution and abundance data, these provided a baseline dataset for later comparison with post-construction surveys. This report details the results of these surveys, provides a comparison with the equivalent data collected in 2010 and 2011 using boat surveys (conducted for site characterisation) and presents methods developed to permit the Wind Farm effects to be assessed.

All surveys were successfully completed, although due to several periods of unsuitable weather (predominantly low cloud) the final survey took place in the first week of August (following agreement for an extension beyond July from the Ornithology subgroup of the Moray Firth Regional Advisory Group). Data include bird locations and behavioural observations which included (where possible) flight height and flight direction.

Overall, seabird abundance and distributions in the Wind Farm were similar to those seen previously, with guillemot the most numerous species in the Wind Farm (peak Wind Farm abundance > 7,000) followed by kittiwake (peak >1,500), puffin (peak >900), gannet (peak > 400), razorbill (peak > 200), herring gull (peak >100) and great black-backed gull (peak > 25).

Prior to surveys commencing a power analysis was conducted to guide survey intensity with the aim of detecting puffin displacement from the Wind Farm. This was updated using the survey results, which confirmed the prediction that displacement of puffins is expected to be detected if it occurs. In addition, fine scale analysis was conducted of auk (guillemot, razorbill and puffin) locations in relation to planned turbine positions. This included simulation of expected locations if birds enter the Wind Farm but avoid approaching the turbines themselves. On the basis of the 2015 data this method is designed to identify avoidance of turbines by as little as 200m.

Evidence for connectivity between the Wind Farm and the East Caithness Cliffs SPA for the large gull species (great black-backed gull and herring gull) was very limited due to the low numbers of individuals observed overall and especially within the Wind Farm. Flight heights

were obtained for these species as well as kittiwake and gannet. The method used currently generates estimates with poor precision, limiting the conclusions which can be drawn, although the height distributions obtained were broadly comparable with previous estimates.

On the basis of the results of the pre-construction surveys completed during May – August 2015, and the comparison with the 2010 and 2011 boat based survey results, it is concluded that a single year of pre-construction aerial monitoring will provide sufficient data to enable robust comparisons with post-construction data.

Contents

1 Introduction

The Beatrice Offshore Wind Farm is located in the Moray Firth, at its closest 13.5km from the Caithness coast (Fig. 1). Construction of offshore elements will commence in spring 2017. The potential ornithological impacts which were considered of greatest concern during the application process were collision risk to large gulls (great black-backed gull and herring gull) and displacement of foraging auks (guillemots, razorbills and puffins). All these species breed at colonies which comprise the East Caithness Cliffs SPA and some of the birds at the Wind Farm are likely to be from those SPA populations. Through discussion with the Moray Firth Regional Advisory Group Ornithology Subgroup (MFRAG-OS), the potential for the above impacts to affect these breeding populations has been identified as the focus of ornithological monitoring for the Wind Farm.

During the 2015 breeding season six digital aerial surveys of the Wind Farm and a wider area were conducted by HiDef on behalf of BOWL. The survey area covered an approximately rectangular shape aligned parallel to the coast, extending from the Caithness coast to 4km beyond the seaward edge of the Wind Farm site boundary and measuring approximately 40km from north-east to south-west (Fig. 1).

Data were provided for all seabirds recorded during the surveys, however the targets for this monitoring identified by the MFRAG-OS (referred to as focal species) were great black-backed gull, herring gull, puffin, common guillemot, razorbill, kittiwake and gannet. Therefore this report is focussed on these species.

The primary aims of the pre-construction aerial surveys were:

- To collect seabird distribution data during the breeding season to enable comparisons of seabird abundance distributions before and after construction and estimate the magnitude (if any) of displacement resulting from avoidance of the Wind Farm (with a particular emphasis on puffin);
- Estimate the extent of connectivity between the Wind Farm and the East Caithness Cliffs SPA through analysis of flight directions; and
- Investigate the robustness of flight heights calculated from digital aerial data.

In addition, the results obtained during the current study have been compared with those obtained during the same months as part of the pre-application boat-based surveys (conducted between October 2010 and September 2011; RPS 2012).

The report has the following structure:

- Methods
- Results
- Discussion
- Conclusions

2 Methods

2.1 Survey Methods

The area of interest for surveying was identified as a region extending from the East Caithness coast to beyond the eastern Wind Farm boundary and extending to the north-east and south-west beyond the limits of the Wind Farm (Fig. 1). Following discussions with MFRAG-OS the finalised design of the aerial surveys was submitted to Marine Scotland on 29th May 2015 (Doc Ref: LF000005-SOW-051).

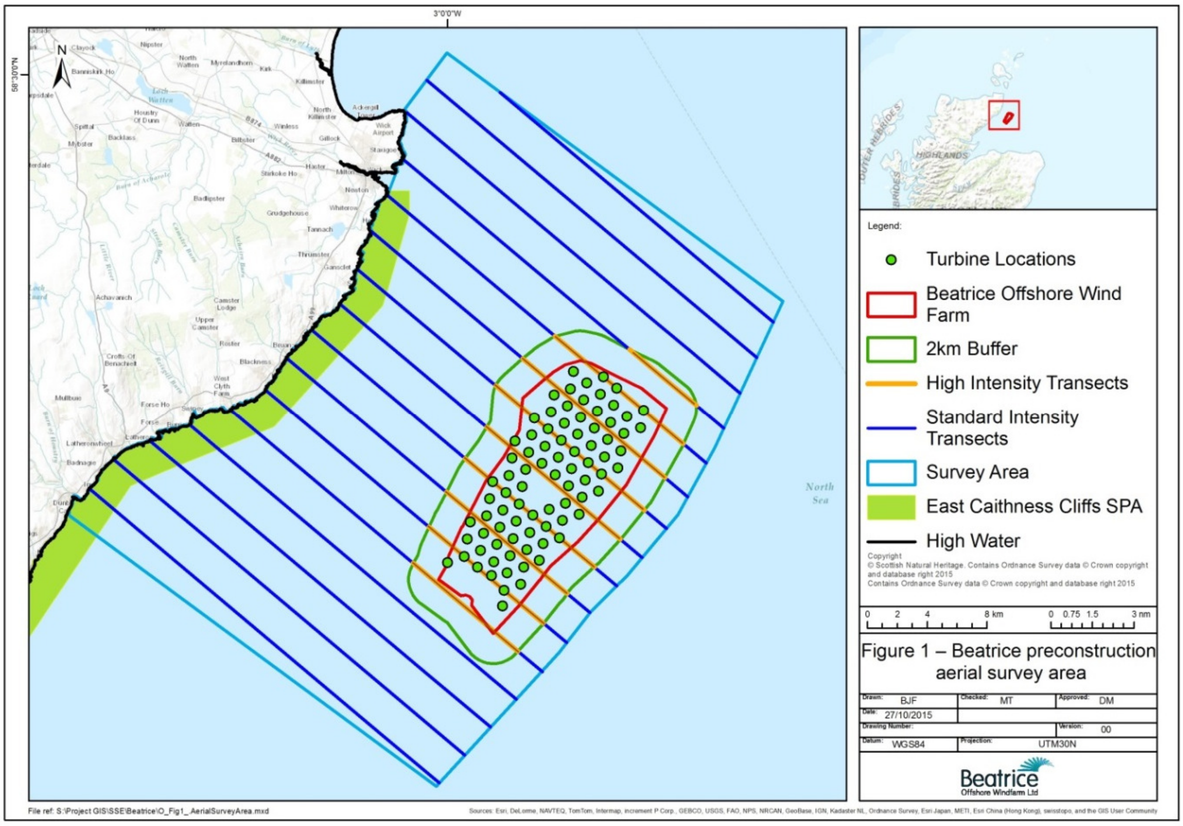

Figure 1. Survey area (light blue boundary) for aerial survey coverage of the Beatrice Offshore Wind Farm and the region of sea between the Wind Farm and the Caithness coast. Transects shown in dark blue, Wind Farm boundary (red), 2km buffer (green) and turbine locations (green circles) shown.

A rectangular survey area was defined (Figure 1), measuring approximately 40km south-west to north-east and 26km to 30km north-west to south-east. The seaward boundary followed a 4km buffer from the Wind Farm boundary to match the site characterisation boat survey buffer. The area was divided into 16 transects oriented along the turbine rows and perpendicular to the coastline. Transects were separated by 2.5km, and were between 24.2 and 31.7km in length, giving a total transect length of 456km. Approximately 60km of this crossed the Wind Farm area (i.e. the area within the red line boundary shown in Figures 1 and 2) (calculated as 8 transects x average Wind Farm width of 7.5km).

Surveys were conducted by HiDef using high definition video cameras which record data continuously, generating strip transect data with the entire area surveyed within a single day on each occasion.

Two different transect widths were employed, achieved by varying the number of cameras used for data capture (up to four, each with an individual strip width of 125m). Within a 2km buffer of the Wind Farm boundary all four cameras were used, giving a width of 500m (hereafter ‘high intensity’ survey). Survey coverage in the high intensity area was 20%. Outside this 2km buffer only the central two cameras were used, giving a strip width of 250m (hereafter ‘standard intensity’ survey). Survey coverage in the standard intensity area was 10%. The high intensity transects were positioned so that alternate ones crossed rows of planned turbine locations (Figure 2). The total area surveyed was approximately 1,142km^2, within which the wind farm area plus buffer covers an area of 383km^2 and the wind farm covers an area of 131km^2.

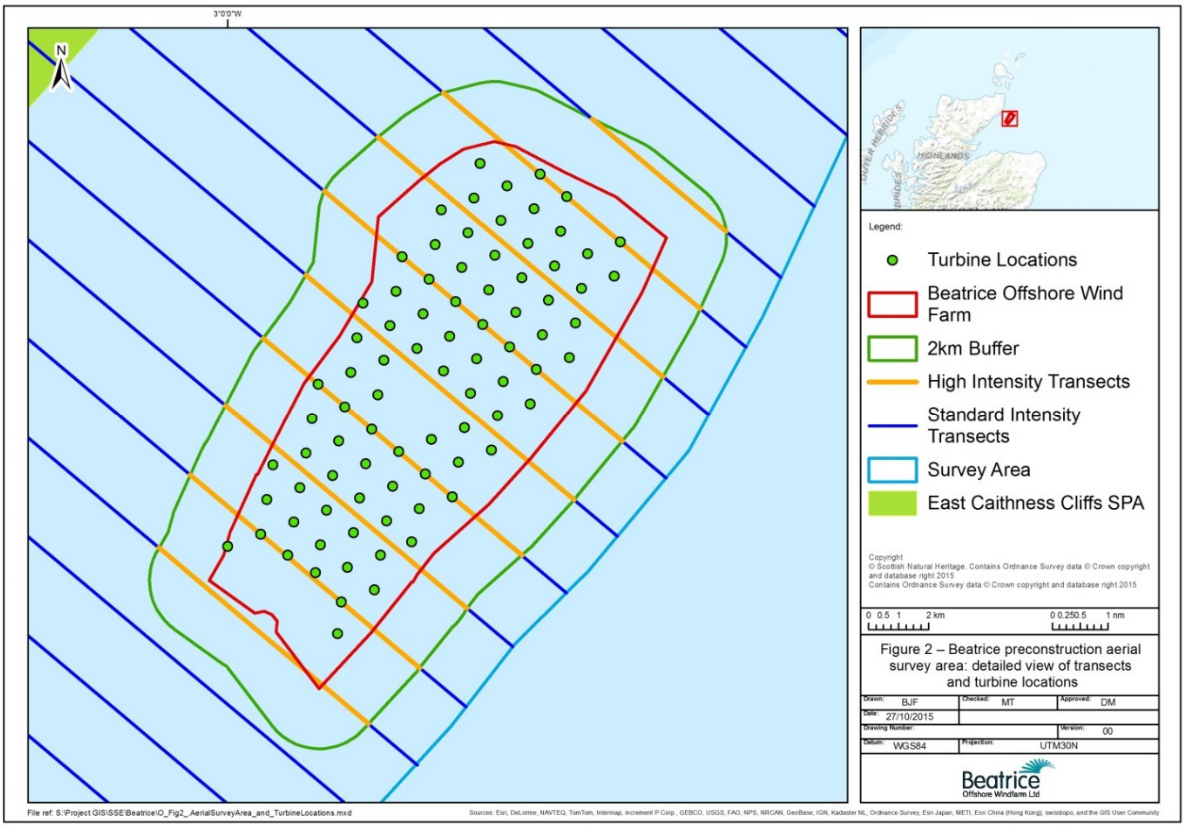

Figure 2. Detail of transects for aerial surveys over the Beatrice Wind Farm showing transect alignment in relation to turbine rows.

Data collected during each survey were supplied to BOWL as spreadsheets and GIS shapefiles following image processing and transcription by HiDef. Each bird observed was identified using a hierarchical classification, down to species level wherever possible, with an associated confidence level. The following data were supplied to BOWL following the surveys (and as set out in the scope submitted to Marine Scotland on 29th May 2015):

1. Bird locations for all species;
2. Flight directions for selected species (great black-backed gull, herring gull, puffin, guillemot, razorbill, gannet and kittiwake); and,
3. Flight heights for selected species (great black-backed gull, herring gull, gannet and kittiwake).

Additional data which were collected include behaviour (e.g. flying, sitting, etc.), age and sex (if possible).

It was agreed that BOWL should complete six surveys across the months of May, June and July.

2.2 Data Analysis Methods

For different aspects of the analysis the survey data were divided into the following areas:

- Total survey area – this was the entire survey region within the survey boundary (i.e. 1,142km^2) making use of the standard intensity survey data;
- Wind Farm and 2km buffer – this was the area within the 2km buffer of the Wind Farm and used the high intensity survey data;
- Wind Farm and 500m buffer – this was a subset of the Wind Farm and 2km (high intensity) data.
- Wind Farm – this was the area within the Wind Farm site boundary only.

Data analysis was split into the following components:

1. Assessment of the distribution and abundance of great black-backed gull, herring gull, puffin, common guillemot, razorbill, kittiwake and gannet across the entire surveyed area using the standard intensity data. Birds on the water and in flight were analysed separately; spatial models were used for birds on the water (if seen in sufficient numbers), permitting the use of explanatory variables to improve model precision; birds seen in lower numbers (on the water) and birds recorded in flight were analysed using design based methods (further details are provided below). Spatial modelling outputs were used to generate density surface maps for the total survey area and estimates of the population abundance in the total survey area and the Wind Farm area;

2. Analysis of auk distributions within the Wind Farm and 500m buffer in relation to planned turbine locations. A method to assess within Wind Farm avoidance of turbines was developed using these data and the results of this approach are included (note that this aspect was focussed on the potential to detect displacement of foraging birds from areas of

sea near turbine bases rather than estimation of avoidance rates as used in collision modelling);

3. Analysis of flight height data for collision risk species (great black-backed gull, herring gull, kittiwake and gannet), including assessment of the relationship between height and distance offshore;

4. Analysis of flight direction data using the high intensity data collected within the Wind Farm and 2km buffer to explore connectivity with the East Caithness Cliffs SPA colonies; and,

5. Power analysis using observed puffin distributions to provide a guide to the potential magnitude of detectable displacement from the Wind Farm (this will update the results of earlier power analysis discussed in the MFRAG-OS).

2.2.1 Spatial modelling and design based analysis of birds on the water

The distributions of the focal species across the survey area were analysed using the MRSea Package for R, developed by Scott-Hayward et al. (2013). This package was developed under contract to Marine Scotland for analysis of data collected for marine renewable developments and is therefore directly applicable for the current study. It represents the most sophisticated and robust methods currently available.

The spatial modelling permits potential explanatory variables to be included in the analysis in order to identify significant relationships between the variables and the recorded distributions. Any significant covariates identified can then be used in a predictive manner to estimate distributions in areas not surveyed, either between transects or to areas beyond the surveyed area (in the current analysis only the former was undertaken). Thus, the observations made along transects can be used to estimate the density between transects.

The candidate covariates used in the analysis were coordinate (a combined x-y position), sea depth and distance to coast. To conduct this analysis the data were assigned to 500m long segments along each transect. Segment width for analysis of the total survey area was 250m, and for the data collected on the Wind Farm and 2km buffer was 500m. Covariate values for use in the modelling (e.g. distance to coast and depth) were obtained for the midpoint of each segment (i.e. on the transect line). The depth value was the average value for the 90x90m cell in which the segment midpoint was located. This analysis was conducted using only birds recorded on the sea surface for two reasons. Firstly this matches the approach adopted for the pre-application surveys (conducted using boat based methods between October 2009 and September 2011, see RPS 2012 for details), and therefore the results are consistent with these earlier ones. Secondly, the explanatory covariates used were selected on the basis of expected relationships with foraging locations. These would not be expected to show strong correlations with the distribution of flying birds since these records include bird movements over areas of presumably lower importance. Analysis of the density and abundance of flying birds was conducted separately (see Section 3.2).

Spatial model fitting followed the methods set out in Scott-Hayward et al. (2013). All models included an x-y spatial term, with depth and minimum distance to coast included as smoothed additive terms (with no interactions). Following estimation of the relationship between the covariates and each species' distributions, predictions across the entire survey area were generated using a prediction grid of cells spaced evenly at 500m for which the average depth and mid-point distance to coast were calculated. For each grid cell a predicted abundance was calculated using the model relationships and the covariate values. The abundance of each species in the total survey area was calculated by summing the value for each grid cell, while smaller areas were calculated using just the cells located within them (e.g. for the Wind Farm just those cells located inside the Wind Farm Boundary).

Density surface maps were generated using the model predictions for each key species for each survey (for which the modelling was successful). The actual bird observations were overlaid on the maps to aid interpretation. If modelling was unsuccessful for a particular species on a survey, maps of the observed bird locations are provided without an underlying density surface. This was the case for great black-backed gull and herring gull on each survey and for gannet and razorbill on surveys five and six.

In addition to estimating density and abundance from the model predictions, the density of birds on each transect was calculated (as the number seen divided by the transect area) from which the average density across transects was calculated (i.e. a design based approach). The abundance for the total survey area and the Wind Farm area were calculated by multiplying the average density estimates by the relevant areas. For the Wind Farm area this analysis made use of the high intensity data collected by all four cameras while that for the total survey area used the standard intensity data collected using the central two cameras (note density was estimated across the Wind Farm and 2km buffer area with Wind Farm abundance calculated as the density multiplied by the Wind Farm area. The same method was used for analysis of the boat-based site characterisation data reported in the ES and SEIS).

Although design-based estimates are less robust than model-based ones, for species observed in smaller numbers it was not possible to successfully fit models and therefore design based methods were required.

For those species for which availability bias may lead to underestimation of absolute abundance (e.g. diving species such as auks), abundance estimates can be multiplied by correction factors to obtain the estimated total abundance allowing for birds which were underwater when the images were obtained. This is useful for comparisons with previous estimates, assuming those have also been corrected for potential bias. However, as the correction factor is a constant rate for each species, there is no benefit in terms of comparing distributions between surveys. Correction factors for guillemot, razorbill and puffin were taken from Thaxter et al. (2010) and Burton et al. (2013). The values used were: guillemot, 1.237; razorbill, 1.174; puffin, 1.202.

2.2.2 Abundance of birds in flight

The abundance of birds in flight was estimated using design-based methods, with the density of birds in each transect calculated as the number observed divided by the area surveyed. To estimate abundance across the total survey area the standard intensity data were used, while for the estimated abundance in the Wind Farm area the high intensity data were used, thereby maximising use of the data. The average density across transects was multiplied by the relevant area to obtain estimates of the abundance of birds in flight.

2.2.3 Auk distributions in relation to turbine locations

The high intensity data were used to develop a methodology to undertake comparisons between pre-construction and post-construction within Wind Farm seabird distributions. The intention is that this method will provide an understanding of turbine avoidance behaviour which will complement estimates of overall wind farm avoidance.

The analysis considered the distribution of each auk species within 500m of turbines as this approximates to half the turbine separation distance. Consequently only data collected within a 500m buffer of the Wind Farm boundary were used in the analysis. In order to maximise sample sizes, data for each species were combined across the 6 surveys. The minimum distance between each bird and the nearest turbine location was calculated from which the density of birds within sequential 100m radius circles (100, 200, 300 and 400) around all turbines was calculated. To test if the observed density within each radius differed from a random distribution a two-dimensional bootstrap procedure was developed.

For each bootstrap simulation the grid of actual turbine locations was offset using a uniformly distributed random offset value generated independently for both x and y coordinates within a range of +/-500m. The location of the turbines relative to each other was maintained (i.e. all turbines were offset by the same amount). Following re-location of the turbines the minimum turbine distance for each bird was re-calculated and stored. The bootstrap procedure was repeated 1,000 times with new random coordinates each time.

The simulated data were presented as histograms of the density of birds within each 100m radius circle (i.e. <100m, <200m, <300m, <400m). The density in these circles obtained using the actual turbine locations was overlaid to indicate if the observed densities fall within the simulated range. In the absence of turbines the expectation was that the density in relation to the actual turbine locations would lie in the middle of the simulated densities.

To indicate how this analysis could be used to investigate turbine avoidance behaviour following turbine installation the bootstrap routine was re-run following removal of birds located within each 100m circle (from actual turbine locations). Removal of birds within 100m of turbines replicates 100% avoidance of turbines by this distance. The expectation was that while the observed density in the manipulated circle would decrease (in this example to 0), the bootstrap derived distribution of densities would be unaffected. Comparison of the two would therefore indicate the presence of turbine avoidance behaviour.

A permutation test was used to provide a measure of the probability of obtaining the density estimated around the actual turbine locations compared with the range of density estimates for the re-sampled turbine locations.

2.2.4 Flight heights

Flight heights were estimated using a parallax method developed by HiDef, comparing the position of the birds to features on the sea surface across several image frames. This method generates wide confidence intervals, and the magnitude of uncertainty increases with decreasing altitude. The reliability of the height estimates obtained is undergoing scrutiny within the wind farm industry (e.g. a Natural England project is due to report before then end of 2015) and is not yet fully established. Consequently the results of the analysis of these data need to be treated with caution. It is worth noting, for example, that 15% of the average flight height estimates were recorded below sea level. These data were retained in the analysis to avoid introducing bias.

Flight heights were supplied for great black-backed gull, herring gull, kittiwake and gannet. Each bird for which height was estimated had a mean height value and upper and lower 95% confidence intervals.

Height data were pooled across surveys to increase the sample size (as there was no biological reason to expect differences in heights between surveys) and plotted in relation to turbine rotor height (32.7 – 186.7m). The proportion of flights at rotor height was calculated for the overlap with each observation's mean height and also for each observation's upper and lower confidence interval.

Linear models were fitted to log transformed mean flight height data using distance from coast as an explanatory variable. The data were plotted and the best fit linear trend (if one was obtained) added. In addition, locally smoothed regression lines (lowess) were fitted to check for non-linear trends. To avoid biasing the results due to the presence of height estimates ≤0m, prior to modelling the minimum observed height (i.e. the most negative value) was added to all observations. The results were then back transformed by taking away the minimum flight height.

2.2.5 Flight directions

Birds in flight for which a consistent flight direction could be determined were given a flight direction supplied as one of eight compass directions (N, NE, E, SE, S, SW, W or NW). These data were used to investigate the potential connectivity between the Wind Farm and the East Caithness Cliffs SPA breeding colonies. The individual flight directions of each focal species recorded in the high intensity data (in the Wind Farm and 2km buffer) were extracted and the relative proportions in each direction calculated for plotting on rose diagrams. The expectation was that connectivity to the Wind Farm would be observed in higher proportions in the NW-SE axis as this represents the shortest straight line distance to the breeding colonies which make up the East Caithness Cliffs SPA.

2.2.6 Power analysis – puffin displacement

Prior to commencement of the 2015 aerial surveys a power analysis was conducted to investigate the likelihood of detecting a 50% displacement rate of puffin from the Wind Farm following construction. This preliminary analysis (included in Appendix 1) used a survey design similar to that used for the subsequent aerial surveys reported here. However, the simulated puffin abundance and distribution data were derived from interpretation of surveys covering either much smaller areas (e.g. of the Wind Farm and 4km buffer from the pre-application surveys) or much larger ones (e.g. the entire Moray Firth, Mudge and Crooke 1986). Furthermore, the latter surveys were conducted 30 years ago.

Following the analysis of puffin data reported here, the power analysis was rerun using the updated puffin abundance estimates across the total survey area. The original outputs and description of the methods are included in Appendix 1.

3 Results

3.1 Surveys

Six surveys were conducted between 30th May and 5th August 2015, spaced at approximately equal intervals through the period (as weather permitted). Each survey was conducted within a single day in good visibility and at different times of day (Table 2).

Table 2. Survey dates, start and end times and weather conditions.

Survey no.	**Date (all 2015)**	**Start time**	**End time**	**Weather conditions**	
				Wind speed (knots)	Cloud base (feet)
1	30/05	17:43	20:12	15	5,000
2	10/06	09:40	12:09	11	6,000
3	29/06	13:18	15:48	10	4,000
4	15/07	10:28	13:19	5	2,000
5	22/07	08:10	11:25	10	NIL
6	05/08	09:31	11:58	14	>10,000

It was agreed with MFRAG-OS prior to survey commencement that the surveys would be completed by the end of July to ensure the data obtained reflected distributions during the breeding season rather than post-breeding dispersal. However, due to the challenging weather conditions experienced in the region during the 2015 breeding season (e.g. extended periods of low cloud which reduce visibility to unsuitable levels for surveying) the MFRAG-OS agreed (at a meeting on the 3rd July 2015) that an extension to include the first week of August (with a cut-off date of 7th August) was appropriate in order to ensure all six surveys could be completed.

3.2 Spatial modelling and design based analysis of birds on the water

The best-fit spatial models of seabird distribution, selected on the basis of significant explanatory variables, for each species and each survey are presented in Table 3. Explanatory variables were only retained in the model if they achieved a significance level (p) of 0.05 or less. Abundance estimates generated as predictions from the best-fit spatial models from each survey are presented across the total survey area for gannet, guillemot, kittiwake, puffin and razorbill are presented in Figures 3 to 8 and in Table 4. If it was not possible to obtain a fit of the model to the data (e.g. due to too few records) for any particular survey, the raw observations are presented without the underlying density surface.

In all surveys there were too few records of great black-backed gull and herring gull to permit modelling, therefore raw observations for these species are presented in Figures 9 and 10.

The abundance calculated using the average density in the surveyed transects (i.e. design-based estimates) are presented in Table 5.

Table 3. Significant terms in spatial models for each species and survey. Depth is mean sea depth in each observed grid cell (90m x 90m), cdist is the minimum distance to coast for grid cell centres and xy is the spatial coordinate term. For depth and cdist, if a smoothed (nonlinear) term was identified as the bestfit (rather than a linear term) then the number of knots is indicated in parentheses.

Species	Survey	Significant covariates (no. of knots in smooth term)	P-value
Gannet	1	xy	0.013206
	2	xy	0.000478
	3	xy	0.001235
	4	xy	<0.0001
Guillemot	1	depth(2)	0.001292
		cdist	0.005808
		xy	<0.0001
	2	depth(2)	<0.0001
		cdist(3)	<0.0001
		xy	<0.0001
	3	cdist(3)	0.000724
		xy	<0.0001
	4	xy	<0.0001
	5	cdist(3)	<0.0001
		xy	<0.0001
	6	cdist(2)	0.000241
		xy	<0.0001
Kittiwake	1	xy	<0.0001
	2	xy	<0.0001
	3	xy	<0.0001
	4	xy	<0.0001
	5	xy	<0.0001
	6	xy	<0.0001
Puffin	1	cdist(3)	<0.0001
		xy	<0.0001
	2	depth	0.000123
		cdist	0.000554
		xy	<0.0001
	3	depth(2)	0.000372
		xy	0.000834
	4	xy	<0.0001
	5	cdist(3)	<0.0001

Species	Survey	Significant covariates (no. of knots in smooth term)	P-value
		xy	<0.0001
	6	cdist(2)	<0.0001
		xy	<0.0001
Razorbill	1	xy	<0.0001
	2	cdist(3)	<0.0001
		xy	<0.0001
	3	xy	<0.0001
	4	xy	<0.0001

Table 4. Model derived population abundance estimates in the total survey area and within the Wind Farm boundary for each species in each survey. Estimates were generated as predictions from the best-fit models identified in Table 3 using appropriate covariate values for the total survey area and within the Wind Farm boundary respectively. Entries marked with '-' indicate instances when small sample sizes prevented model fitting.

Species	Area	Population abundance on each survey					
		1	2	3	4	5	6
Gannet	Total survey area	198.3	520.6	816.6	206.1	-	-
	Wind Farm	21.9	207.9	458.5	4.1	-	-
Guillemot	Total survey area	48494.2	50252.9	20176.8	61625.6	8457.8	4501.4
	Wind Farm	5410.1	2720.5	6056.7	7630.5	680.5	803.1
Kittiwake	Total survey area	1689.6	3708.1	3415.1	3801.5	1683.2	377.9
	Wind Farm	13.3	196.6	62.0	1616.6	86.2	101.3
Puffin	Total survey area	1738.2	1315.5	566.5	930.9	261.6	3413.7
	Wind Farm	209.7	60.6	50.3	33.9	5.5	938.2
Razorbill	Total survey area	798.6	1686.7	3692.1	1750.2	-	-
	Wind Farm	68.3	122.5	177.0	229.4	-	-

Table 5. Design-based population abundance estimates in the total survey area and within the Wind Farm boundary for each species in each survey. Abundance across the total survey area was estimated using the standard intensity data, Wind Farm abundance was estimated using the high intensity data.

Species	Area	Population abundance on each survey					
		1	2	3	4	5	6
Gannet	Total survey area	294.3	620.9	897.2	233.7	32.7	10.2
	Wind Farm	48.4	133.1	344.6	18.9	12.9	0.0
Guillemot	Total survey area	59340.6	61011.6	21136.7	67176.6	16186.3	5068.3
	Wind Farm	6158.5	2545.7	3122.5	5233.9	3415.9	685.6
Kittiwake	Total survey area	1693.2	4189.1	3498.3	4055.3	4164.0	458.4
	Wind Farm	75.9	754.2	391.8	1571.2	849.9	67.8
Puffin	Total survey area	2359.8	1982.1	627.7	1063.6	335.7	3691.1
	Wind Farm	186.0	104.1	39.8	16.6	24.0	1014.8
Razorbill	Total survey area	945.8	2454.7	3939.4	1906.0	77.3	10.9
	Wind Farm	51.6	82.8	198.4	64.1	32.3	4.8
Great black-backed gull	Total survey area	22.6	33.7	32.4	52.7	33.5	10.9
	Wind Farm	0.0	11.5	2.8	27.5	6.3	0.0
Herring gull	Total survey area	76.6	74.6	9.7	430.6	125.1	22.3
	Wind Farm	0.0	5.7	0.0	125.6	3.1	0.0

The most abundant species recorded was guillemot, with about 67,000 individuals estimated within the total survey area in late July and a peak of over 6,000 on the Wind Farm in late May. Including a correction factor of 1.237 (derived from Thaxter et al. 2010) to account for birds underwater at the time of the survey, the maximum number across the total survey area rises to just over 83,000 individuals.

Kittiwake numbers peaked at around 4,000 in the total survey area in June and July and 1,500 in the Wind Farm in July.

Puffin abundance peaked in August at 3,700 in the total survey area and 1,000 in the Wind Farm (numbers which increase to 4,500 and 1,200 respectively when individuals underwater are accounted for; correction factor 1.202 Burton et al. 2013). The large number estimated for the August survey is considered to represent post-breeding dispersal of birds from breeding colonies.

Razorbill was present in highest numbers in early July with a peak abundance of nearly 4,000 in the total survey area and around 200 in the Wind Farm (4,700 and 235 respectively when individuals underwater are accounted for, correction factor 1.174, Thaxter 2010).

The peak gannet estimate was 900 in the total survey area in early July, of which over 450 were estimated to be present within the Wind Farm, although very few were observed later in July and in August.

Herring gull was mostly present in low but variable numbers, although there was an estimated abundance of up to 430 in July in the total survey area, when the highest number in the Wind Farm (125) was also estimated. No herring gulls were recorded in the Wind Farm on three of the surveys.

The peak estimate of 53 great black-backed gulls across the total survey area occurred in July, numbers otherwise ranging between 10 and 30. On the Wind Farm a peak abundance of 27 was estimated. No great black-backed gulls were recorded in the Wind Farm on two of the surveys.

Scrutiny of the high intensity data used to calculate the Wind Farm design-based density estimates for herring gull and great black-backed gull revealed that the majority of the individuals observed on the 22nd July survey (when the peak estimates were obtained) were sat on structures associated with the Jacky oil platform (57 of 62 herring gulls and 33 of 40 great black-backed gulls; although these structures are located just outside the south-western Wind Farm boundary, the data were collected as part of the high intensity survey covering the Wind Farm and 2km buffer and included in the analysis in order to maximise sample sizes when estimating the density for these scarce species). Thus, the peak abundances estimated on this survey did not represent an influx of individuals foraging within the Wind Farm but rather birds recorded in association with the artificial structures in the area.

The estimated abundance of those species for which both model (Table 4) and design-based estimates (Table 5) were calculated (gannet, kittiwake, puffin, guillemot and razorbill) followed the same patterns across the two methods. However, the design-based estimates were consistently higher than the model-based ones. Comparing estimates across the total survey area, the design-based estimates averaged 1.25 times the model-based ones, while for the Wind Farm the design based estimates were on average 2.1 times higher (although there was greater variation and less consistency in the Wind Farm comparisons).

These differences are a reflection of the greater flexibility that the model-based approach allows in terms of spatial variations, compared with the relatively simplistic design based method. This effect tends to be more pronounced for subsets of the total area, leading to the greater magnitude of differences obtained within the Wind Farm. When species are distributed evenly, the two methods will generate similar results. But as a distribution becomes increasingly uneven (e.g. with large, localised aggregations), the magnitude of difference between the two methods will increase. For species such as seabirds, which exhibit large variations in density, model based methods are therefore preferable.

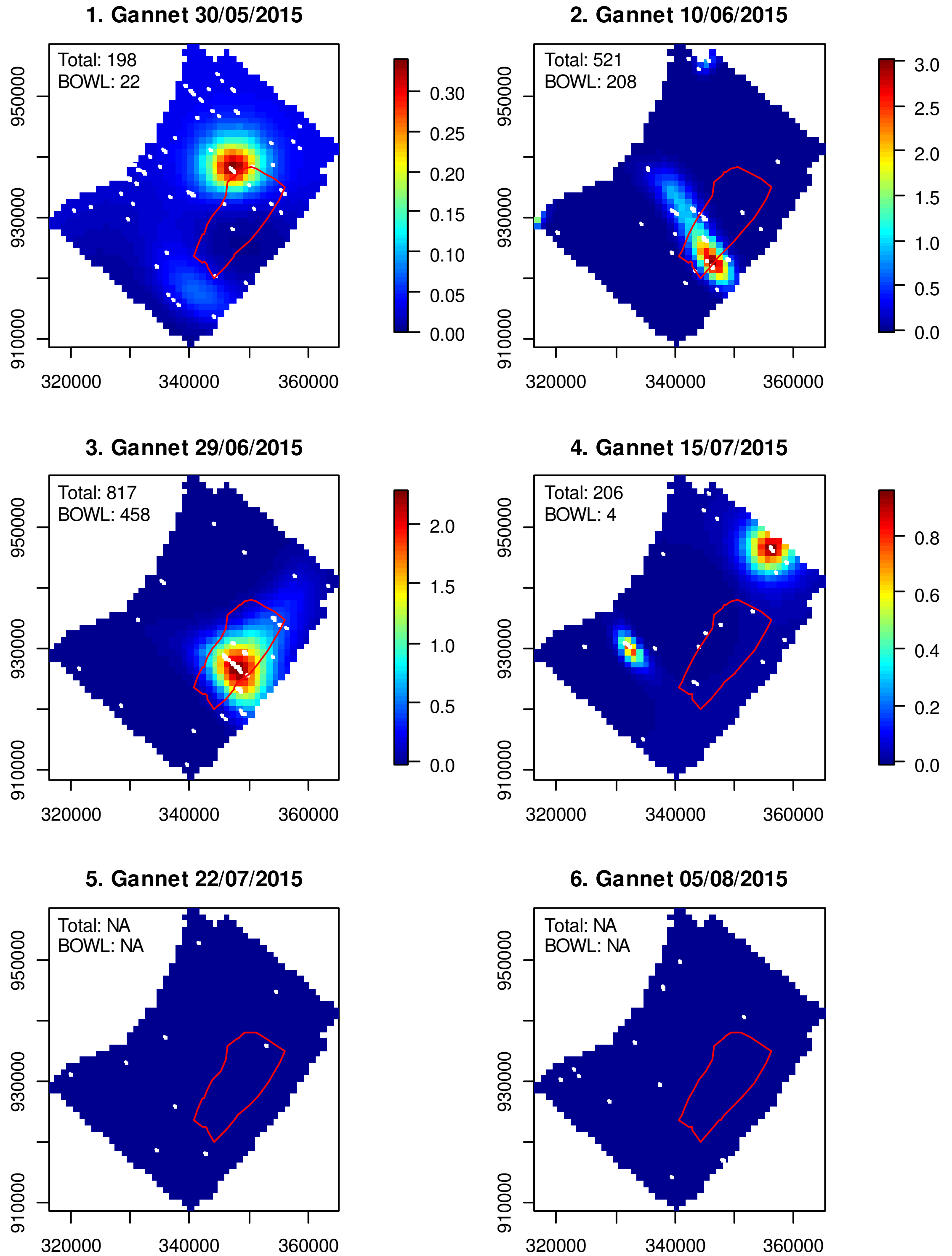

Figure 3. Gannet distributions (scale bars indicate birds/km^2). Density surfaces generated using the best fit spatial model for each survey (note the scale differs for each survey). White dots are birds recorded on the water (standard intensity data only). The abundance in the total survey area ('Total') and Wind Farm ('BOWL') are included on each plot. Note, too few birds were recorded to permit model fitting on surveys 5 (22/7/2015) and 6 (05/08/2015).

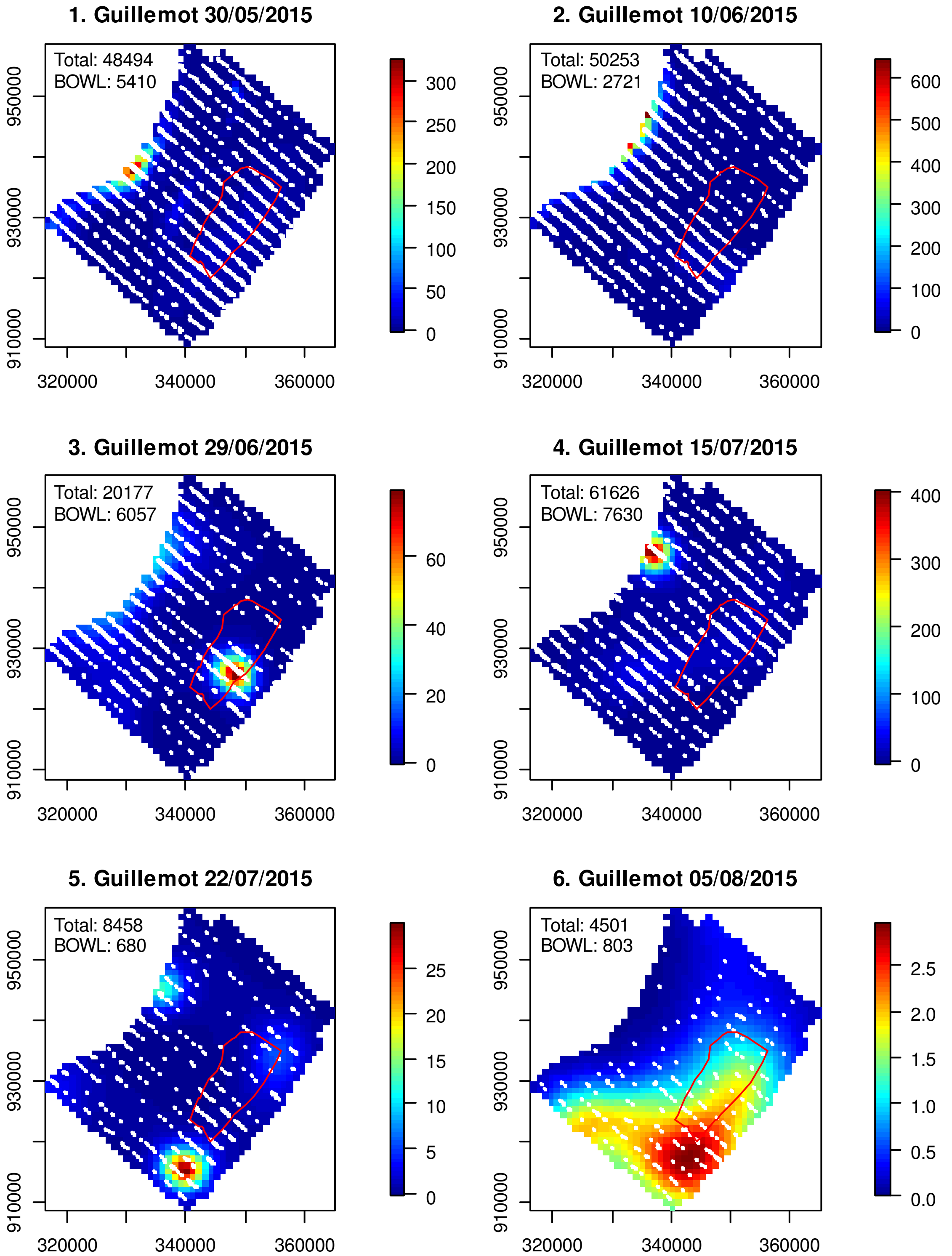

Figure 4. Guillemot distributions (scale bars indicate birds/km^2). Density surfaces generated using the best fit spatial model for each survey (note the scale differs for each survey). White dots are birds recorded on the water (standard intensity data only). The abundance in the total survey area ('Total') and Wind Farm ('BOWL') are included on each plot.

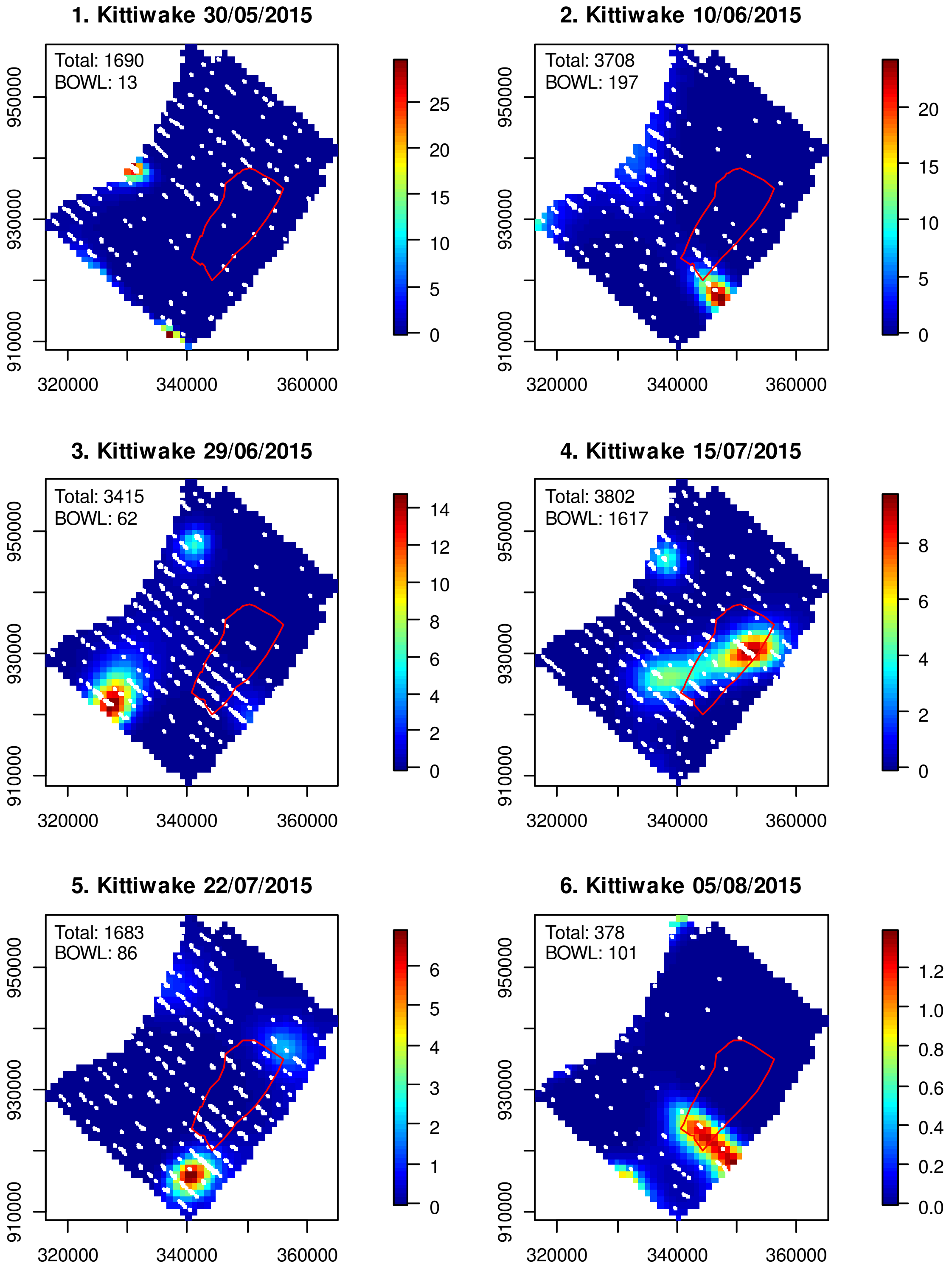

Figure 5. Kittiwake distributions (scale bars indicate birds/km^2). Density surfaces generated using the best fit spatial model for each survey (note the scale differs for each survey). White dots are birds recorded on the water (standard intensity data only). The abundance in the total survey area ('Total') and Wind Farm ('BOWL') are included on each plot.

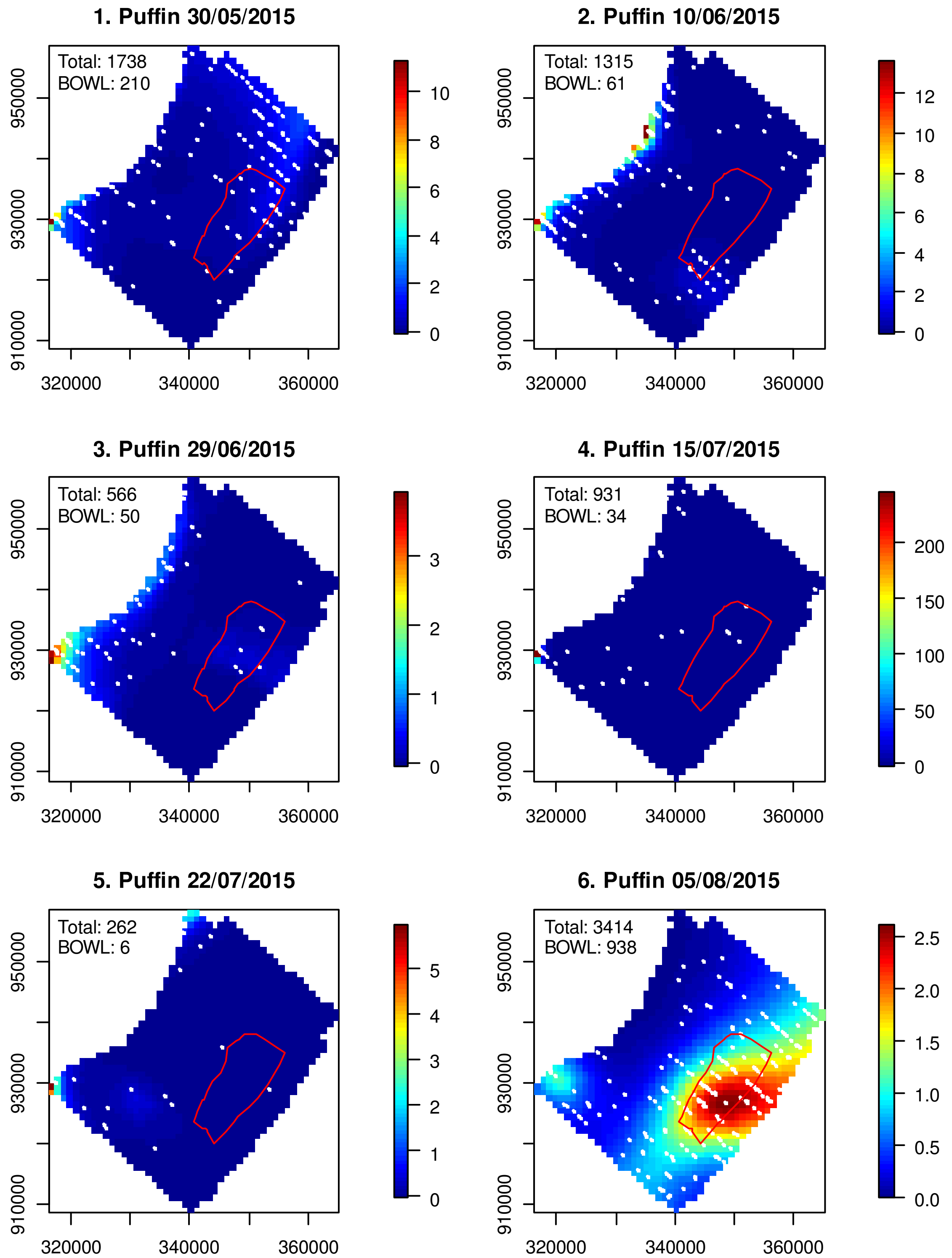

Figure 6. Puffin distributions (scale bars indicate birds/km^2). Density surfaces generated using the best fit spatial model for each survey (note the scale differs for each survey). White dots are birds recorded on the water (standard intensity data only). The abundance in the total survey area ('Total') and Wind Farm ('BOWL') are included on each plot.

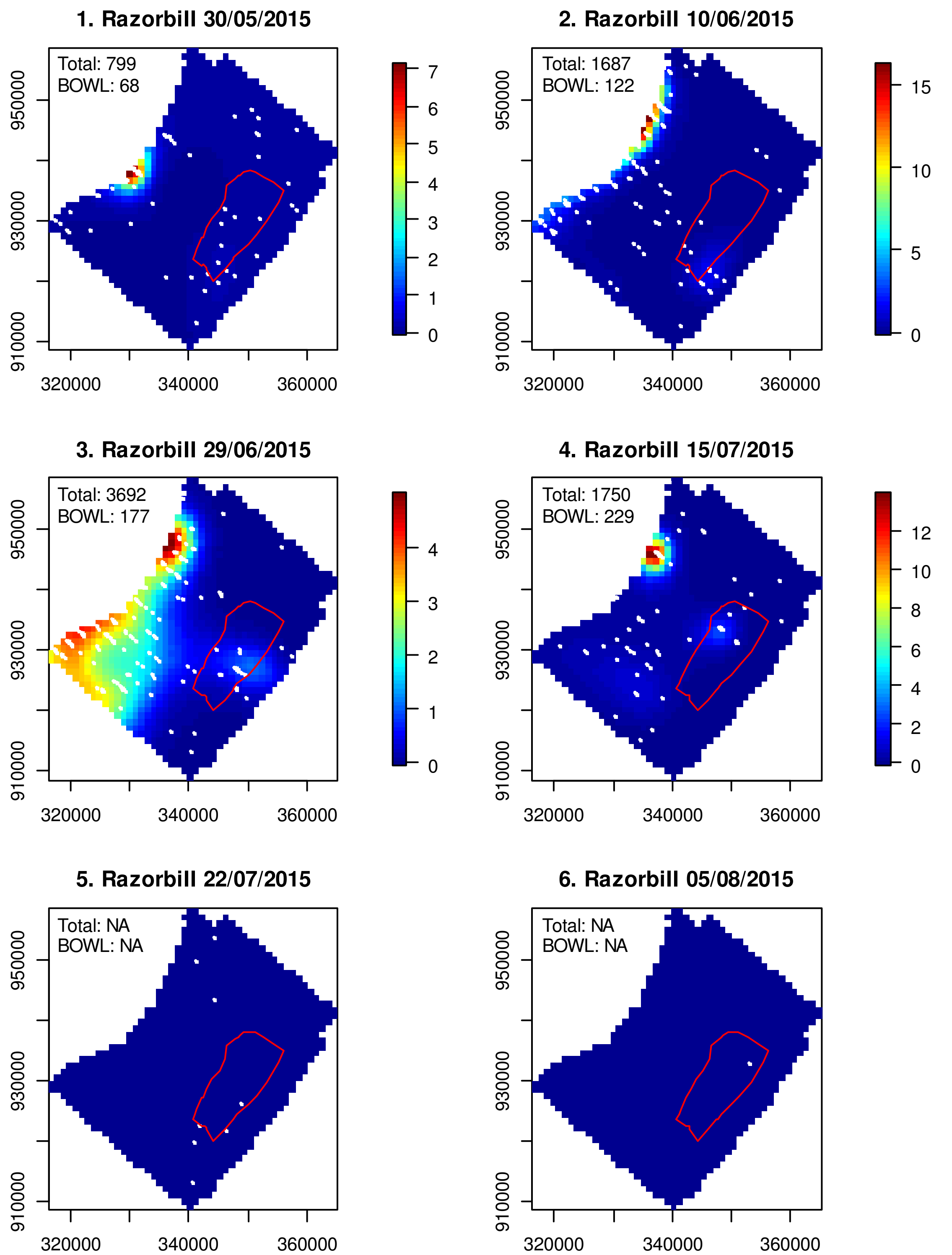

Figure 7. Razorbill distributions (scale bars indicate birds/km^2). Density surfaces generated using the best fit spatial model for each survey (note the scale differs for each survey). White dots are birds recorded on the water (standard intensity data only). The abundance in the total survey area ('Total') and Wind Farm ('BOWL') are included on each plot. Note too few birds were observed for model fitting on surveys 5 (22/07/2015) and 6 (05/08/2015).

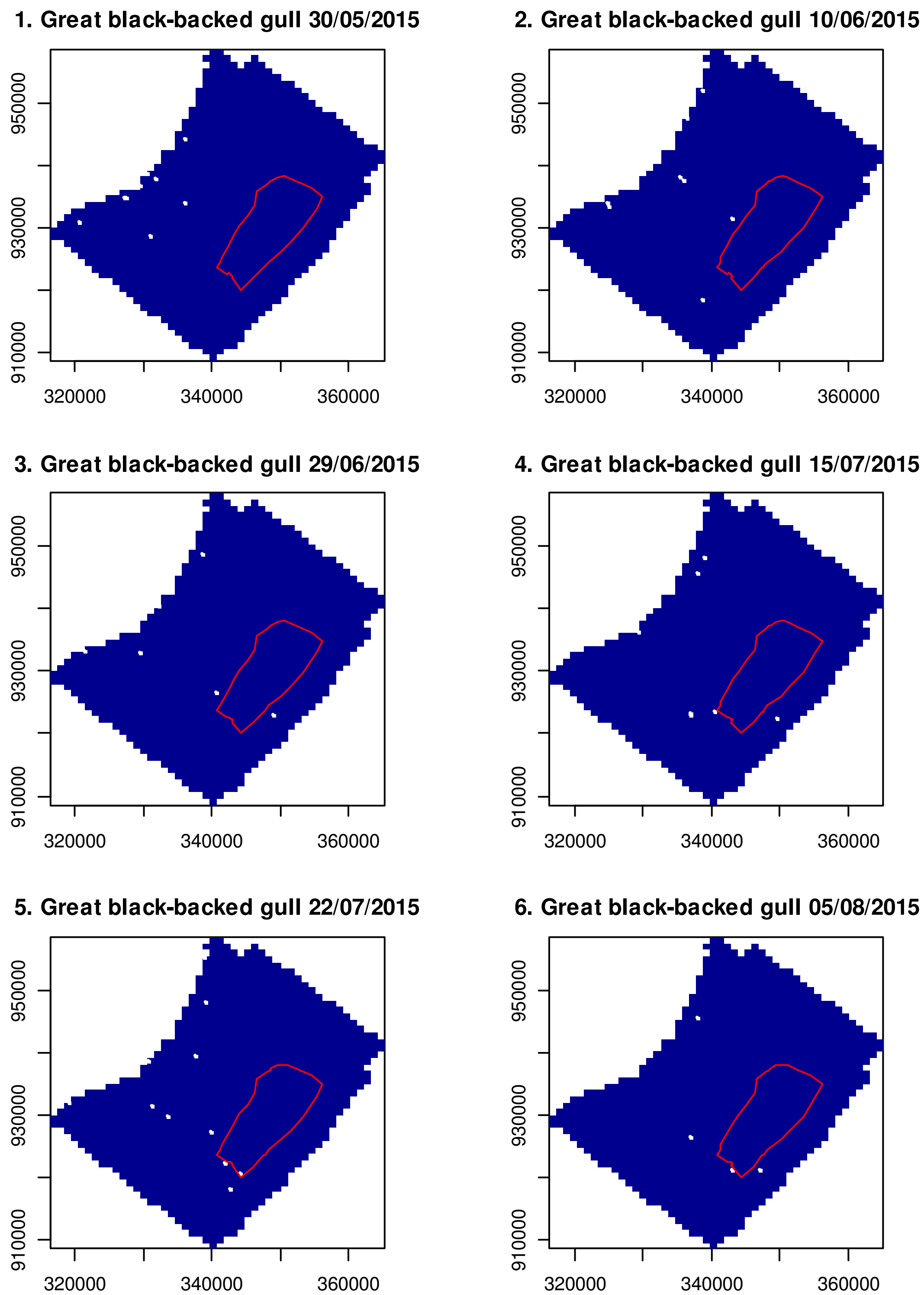

Figure 9. Great black-backed gull distributions. White dots are birds recorded on the water during transects (standard intensity data). Too few birds were recorded to permit spatial modelling.

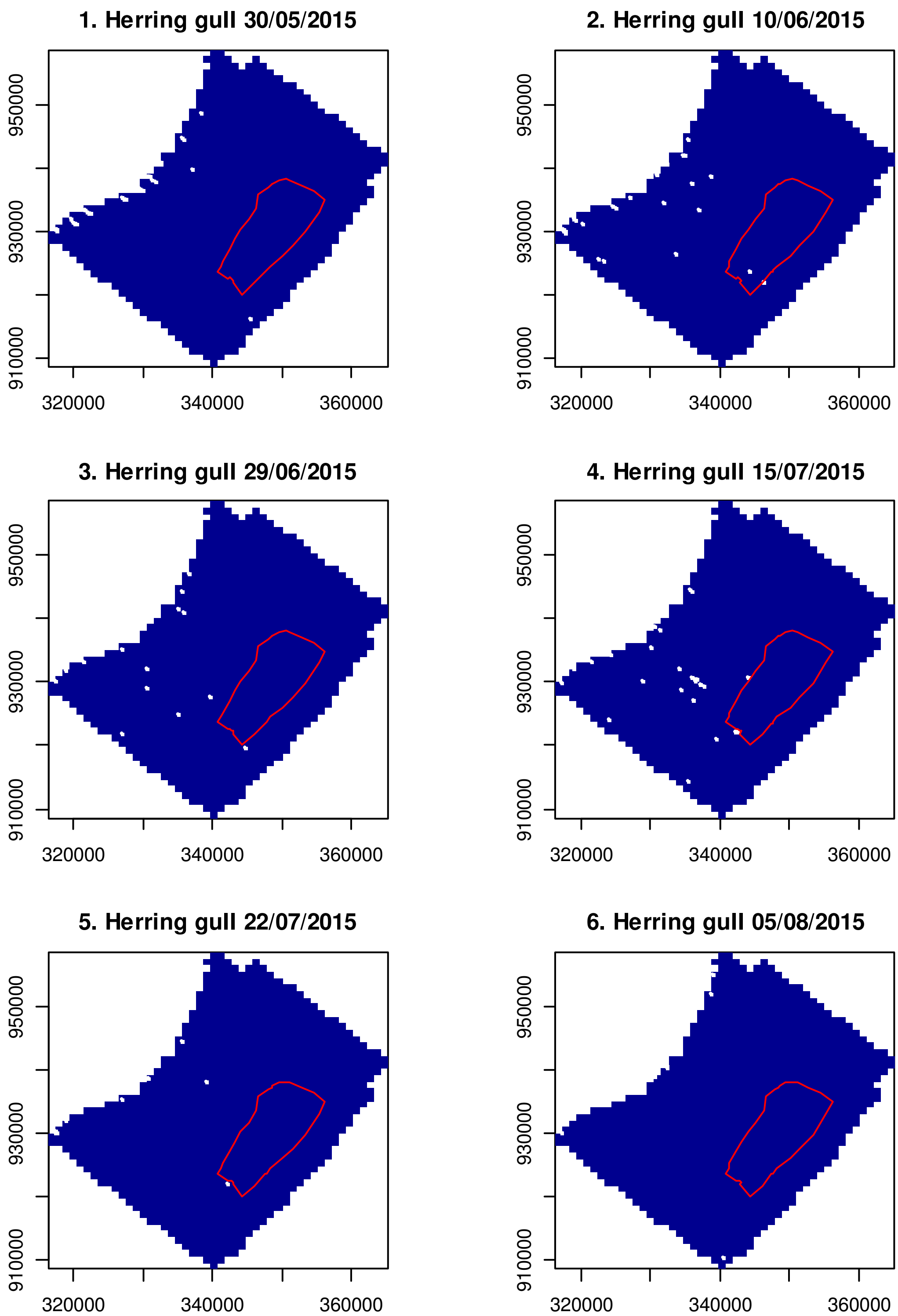

Figure 10. Herring gull distribution plots. White dots are birds recorded on the water during transects (standard intensity data). Too few birds were recorded to permit spatial modelling.

3.3 Abundance of birds in flight

The abundance of birds recorded in flight across the total survey area and within the Wind Farm are presented in Table 6.

Table 6. Design-based population abundance estimates of birds in flight in the total survey area and within the Wind Farm boundary for each species in each survey. Abundance across the total survey area was estimated using the standard intensity data, Wind Farm abundance was estimated using the high intensity data.

Species	**Area**	**Population abundance on each survey**					
		1	**2**	**3**	**4**	**5**	**6**
Gannet	Total survey area	815.2	166.9	183.2	130.7	86.1	149.5
	Wind Farm	56.6	24.5	45.0	9.9	10.8	0.0
Guillemot	Total survey area	5236.1	6595.0	4115.9	2639.4	1030.8	22.8
	Wind Farm	312.2	776.6	368.7	319.0	236.6	2.8
Kittiwake	Total survey area	4108.1	5679.9	5664.2	5446.0	6774.6	849.4
	Wind Farm	188.5	677.8	985.9	924.1	999.6	44.6
Puffin	Total survey area	0.0	209.8	114.3	30.2	34.0	0.0
	Wind Farm	0.0	2.9	18.5	0.0	0.0	0.0
Razorbill	Total survey area	78.0	255.4	348.8	44.0	22.7	0.0
	Wind Farm	5.2	39.9	21.6	0.0	2.6	0.0
Great black-backed gull	Total survey area	86.0	76.1	53.1	22.6	89.4	64.9
	Wind Farm	0.0	5.5	2.9	95.6	0.0	68.4
Herring gull	Total survey area	496.4	292.9	326.9	513.9	129.7	108.9
	Wind Farm	0.0	2.9	8.8	66.7	0.0	0.0

Comparison of the design based estimates for birds on the water (Table 5) and birds in flight (Table 6) reveals a split between gannet the gull species (kittiwake, herring gull and great black-backed gull) and the auks. When looked at across all the surveys, the former species were recorded more often in flight (in flight: gannet 52%, kittiwake 62%, great black-backed gull 66% and herring gull 75%), while the auks were recorded much more often on the water (in flight: guillemot 7%, puffin 6% and razorbill 8%). This presumably reflects differences in the species' foraging ecology, with gannets and gulls foraging on the wing, whereas auks forage from the sea surface and only fly between foraging locations and the colony. Thus, gulls are equally likely to be recorded in flight as on the sea leading to a high degree of correlation, whereas auks are much more likely to be recorded on the sea surface than in flight and with no particular reason for the two estimates to be correlated.

3.4 Auk distributions in relation to turbine locations

The density of birds within circles radiating from planned turbine locations (with radii of 100m, 200m, 300m and 400m) for each auk species is plotted in Figures 11 to 13, together with the range of densities obtained for 1,000 randomly relocated turbine layouts. The recorded density of birds in these circles mostly fell within the middle of the bootstrapped distributions, which is to be expected in the absence of turbines. Departures from the expected distribution (e.g. observed densities offset from the middle of the simulated distribution) may be a reflection of the sampling design, or perhaps indicate genuine preferences for particular areas within the Wind Farm (e.g. foraging hotspots). However, there were no systematic differences (i.e. the recorded density was not consistently higher or lower in all of the four circle radii), suggesting the differences may simply be due to chance.

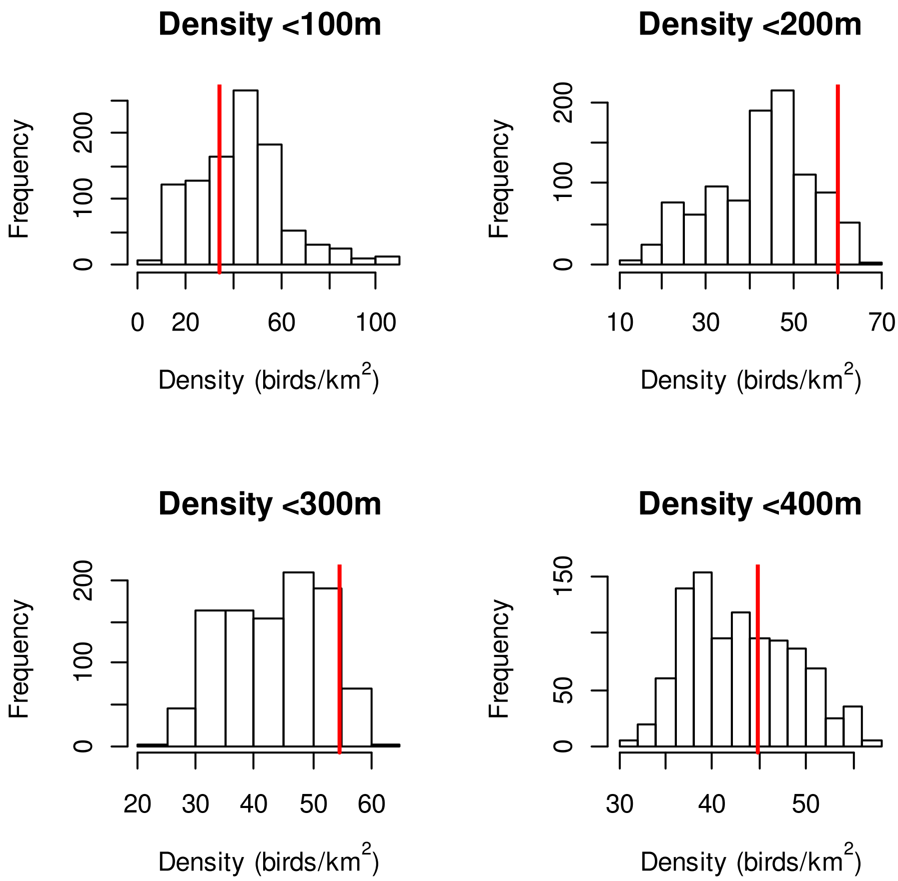

Figure 11. Guillemot densities within 100/200/300/400m of turbine locations (red lines) and distribution of densities estimated for 1,000 simulations with randomly re-positioned turbines (relative turbine positions maintained).

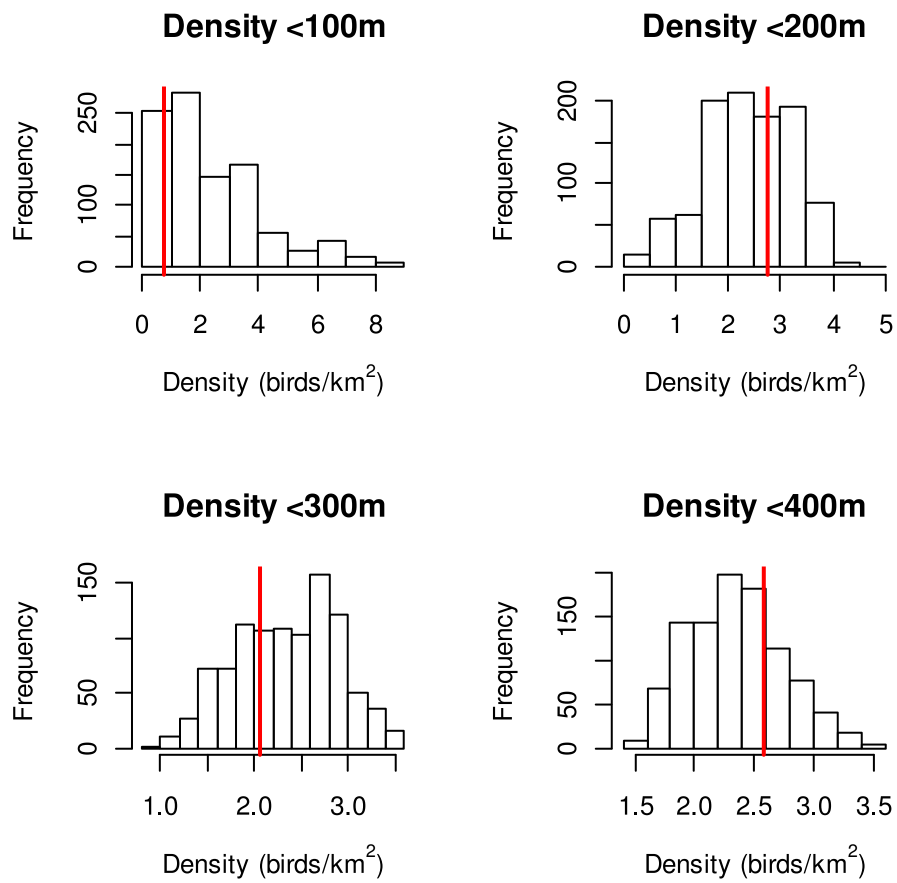

Figure 12. Puffin densities within 100/200/300/400m of turbine locations (red lines) and distribution of densities estimated for 1,000 simulations with randomly re-positioned turbines (relative turbine positions maintained).

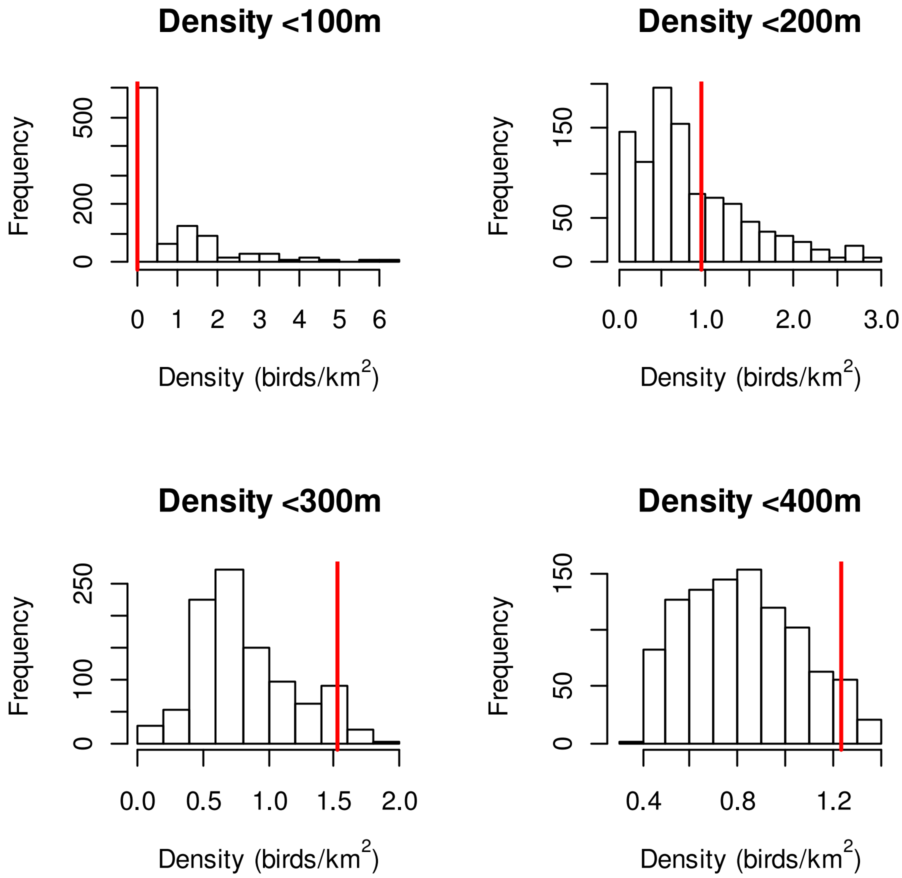

Figure 13. Razorbill densities within 100/200/300/400m of turbine locations (red lines) and distribution of densities estimated for 1,000 simulations with randomly re-positioned turbines (relative turbine positions maintained).

When birds within one of the circles (i.e. 0-100, 0-200, 0-300 or 0-400m) were removed from the dataset prior to running the bootstrap routine (i.e. simulating avoidance of turbines to that distance) a very clear difference between the (manipulated) recorded densities and the simulated ones was apparent (example plots for puffin are provided in Figures 14 to 17). For example, in Figure 14, with all birds within 100m of planned turbine locations removed, the recorded density is zero (Figure 14, top-left panel), and this is clearly different from the simulated density range. However, what is more revealing is that the recorded density within each of the larger radius circles is also reduced, with a consistent shift of the red lines to the left of the plots. Thus, displacement from inner bands was also detectable in reduced overall densities at greater distances, and as the avoidance distance increased the effect becomes more marked.

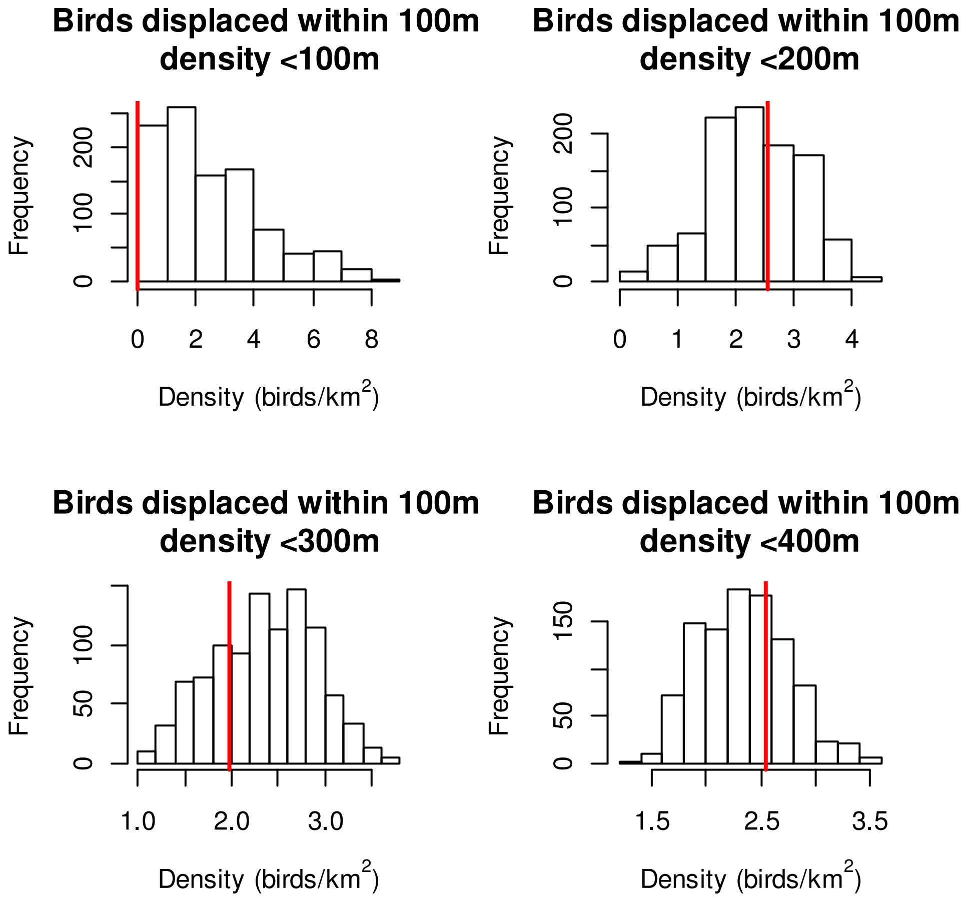

Figure 14. Simulated puffin densities within 100/200/300/400m of randomly re-positioned turbine locations with removal of birds within 100m of planned turbine locations (relative turbine positions maintained).Red lines indicate actual densities within radial distances of turbine positions.

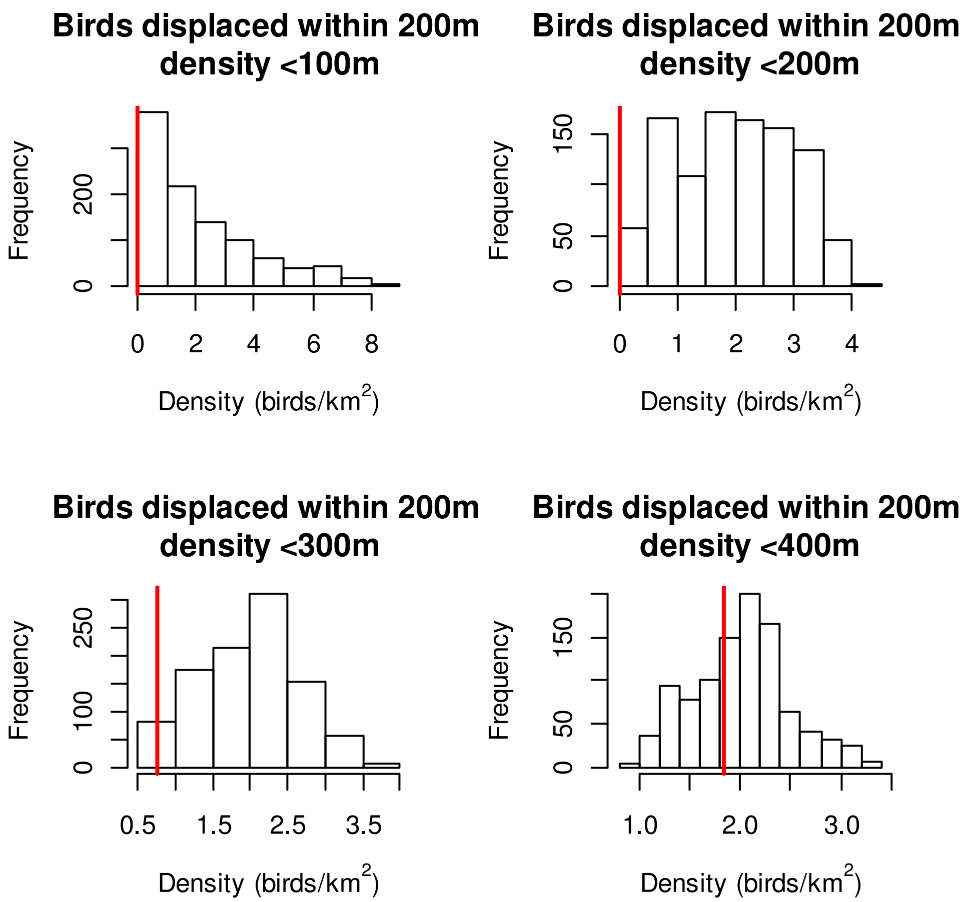

Figure 15. Simulated puffin densities within 100/200/300/400m of randomly re-positioned turbine locations with removal of birds within 200m of planned turbine locations (relative turbine positions maintained).Red lines indicate actual densities within radial distances of turbine positions.

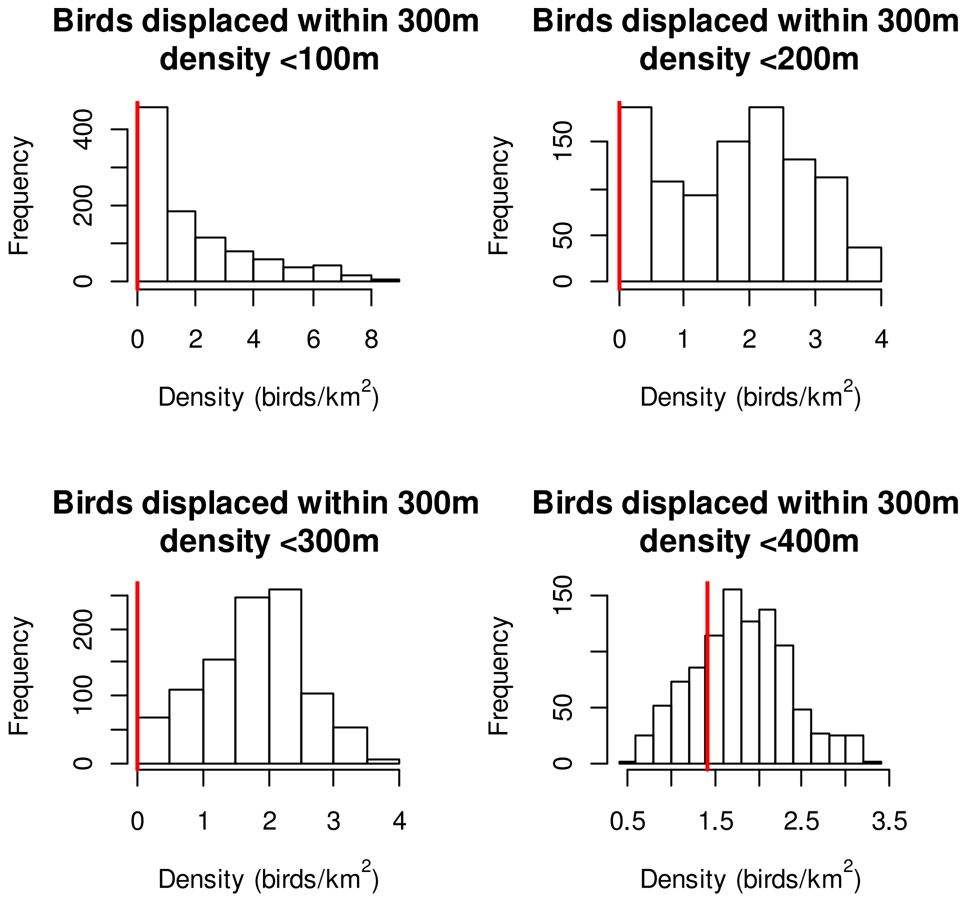

Figure 16. Simulated puffin densities within 100/200/300/400m of randomly re-positioned turbine locations with removal of birds within 300m of planned turbine locations (relative turbine positions maintained).Red lines indicate actual densities within radial distances of turbine positions.

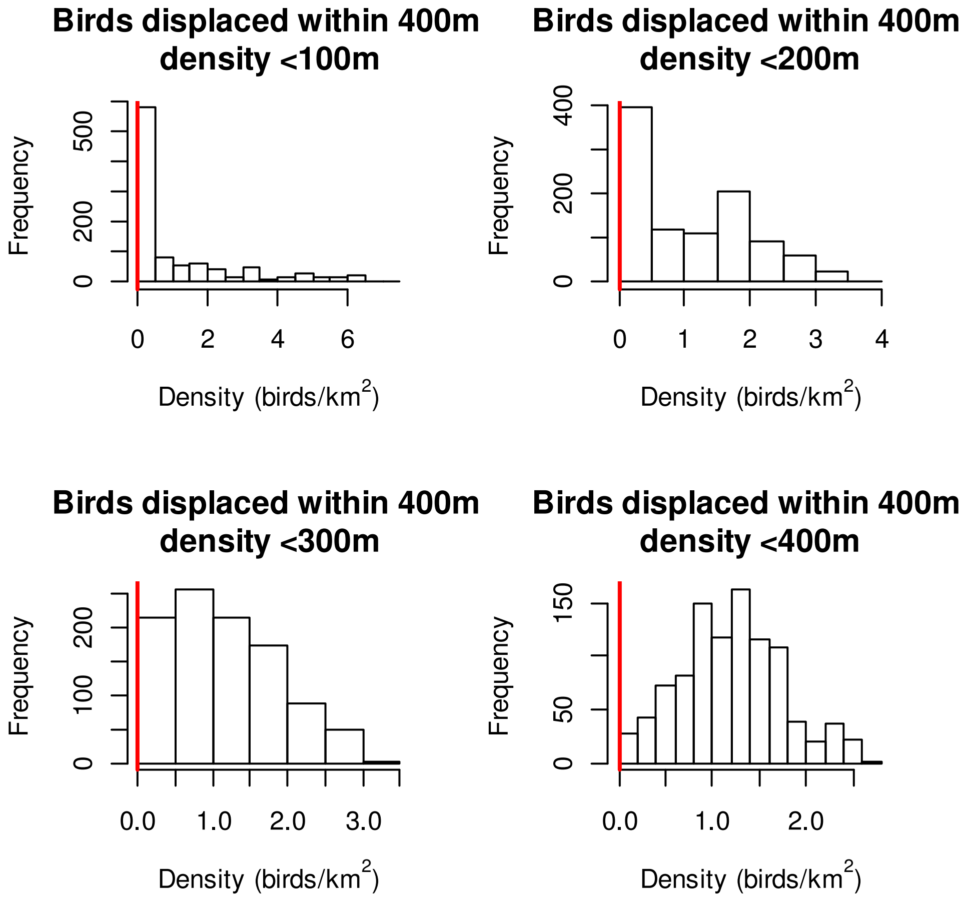

Figure 17. Simulated puffin densities within 100/200/300/400m of randomly re-positioned turbine locations with removal of birds within 400m of planned turbine locations (relative turbine positions maintained).Red lines indicate actual densities within radial distances of turbine positions.

A permutation test was used to calculate how likely it was that the above shift in the 'true' density relative to the simulated turbine locations would be obtained by chance. This probability of a chance effect was calculated as the proportion of random samples which had density estimates as small, or smaller, than the observed estimates (Table 7).

The results of the permutation tests indicate that if birds avoid turbines by 200m or more, the bootstrap simulation method is expected to identify the correct displacement distance (this can be seen by the presence of the lowest probabilities in the shaded cells of Table 7). For example, if birds are displaced by 200m around actual turbine locations (Table 7 column 2), in only 1 simulated turbine layout out of 1,000 was a lower density obtained (although there was a small risk that this would be mistaken as avoidance by 300m, p = 0.038). If birds are only displaced by 100m (Table 7 column 1) the result was not quite significant (p = 0.063).

Therefore on the basis of this test (and birds being present at the density observed for puffin in these surveys) it may not be possible to reliably detect avoidance of only 100m, however this would represent a loss of less than 3% of the available area within the Wind Farm.

Table 7. Results of permutation tests of probability that the difference between density estimates around actual turbine locations and around randomly relocated turbine positions would be observed by chance rather than due to displacement. Shaded cells indicate the probabilities of detecting the 'correct' displacement magnitudes (i.e. that turbine avoidance up to *x* m is correctly identified and not ascribed to a different avoidance distance). Probability values are considered significant (i.e. unlikely to be due to chance) if less than 0.05.

Probability that lower density around actual turbine locations (within *y* m) is due to chance rather than displacement	**Distance (m)**	**Birds displaced within *x* m**			
		100	**200**	**300**	**400**
	100	0.063	0.143	0.282	0.499
	200	0.621	0.001	0.086	0.233
	300	0.282	0.038	0.004	0.074
	400	0.697	0.340	0.242	0.001

3.5 Flight heights

Across all the surveys and only considering birds recorded in flight, heights were obtained for 42% of gannets (n=71), 57% of great black-backed gulls (n=25), 54% of herring gulls (n=95) and 38% of kittiwakes (n=1,294; Table 8). The height estimation method used by HiDef requires several images for each bird to be captured across sequential video frames. Thus, height cannot be estimated for birds observed across a small number of frames, which gave rise to the comparatively small sample sizes for analysis.

The percentage of birds flying at rotor height (defined as 32.7 – 186.7m asl) on the basis of the individual mean height estimates was: gannet, 33.8%; great black-backed gull, 44.0%; herring gull, 54.7% and kittiwake, 3.9% (Table 8). A breakdown of flight data for each survey is provided in Table A2.1 (Appendix 2). The distribution of flight heights for each species is presented in Figures 18 to 21.

With the exception of kittiwake, none of the height sample sizes attained the recommended minimum number of records for generating robust estimates of height (n=100, Natural England 2013). This is reflected in the wide confidence intervals around the mean flight height estimates for gannet (-7.5 to 102m), herring gull (-5 to 103m) and great black-backed gull (4 to 130m). In addition, the presence of flights estimated below sea level also indicates the overall poor precision of the height estimates obtained.

Table 8. Summary of all flight height estimates (pooled across surveys).

Species	**No. birds recorded**		**Flight height estimates (m asl)**		**Proportion at rotor height using individual estimates of:**	
	In flight	**With height estimate**	**Mean**	**95% percentiles**	**Mean**	**Lower and upper 95% confidence intervals**
Gannet	167	71	27.63	-7.5 – 102.0	0.338	0.169 - 0.662
Great black-backed gull	44	25	43.80	4.0 – 130.0	0.440	0.280 - 0.840
Herring gull	176	95	39.76	-5.0 – 103.0	0.547	0.316 - 0.779
Kittiwake	3435	1294	11.00	-6.7 – 35.0	0.039	0.005 - 0.379

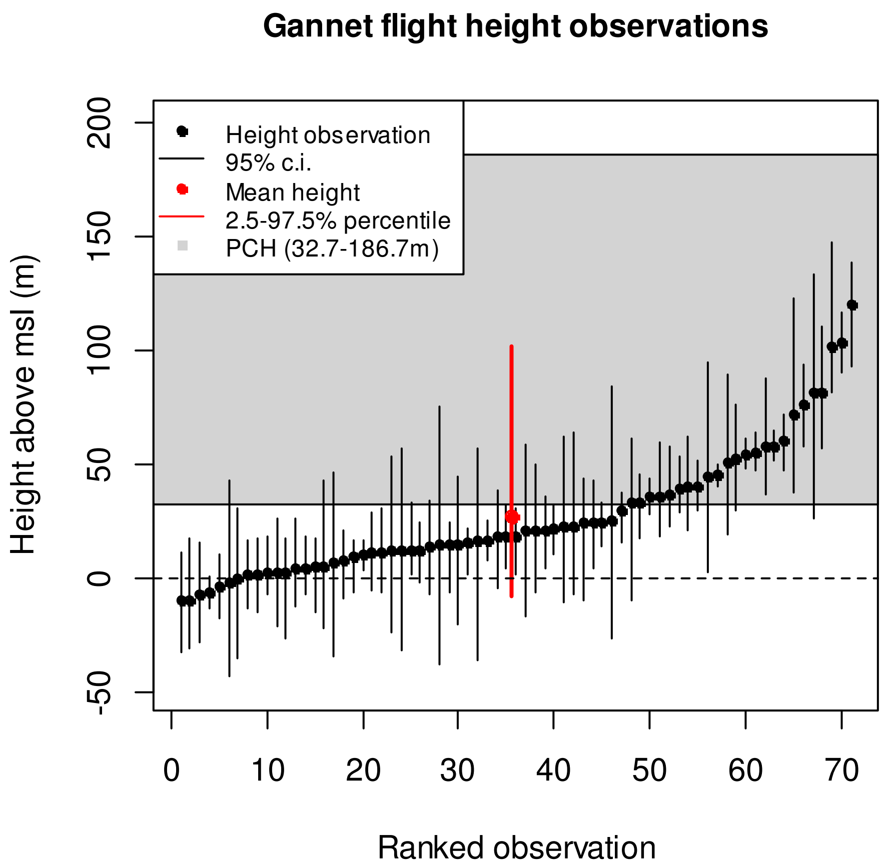

Figure 18. Gannet flight height estimates pooled across all surveys. Each individual mean and 95% confidence range is indicated (black dot and lines), the mean height (mean of individual means) and 95% percentile (red dot and line), potential collision height (PCH; grey shading) and sea level (dashed line).

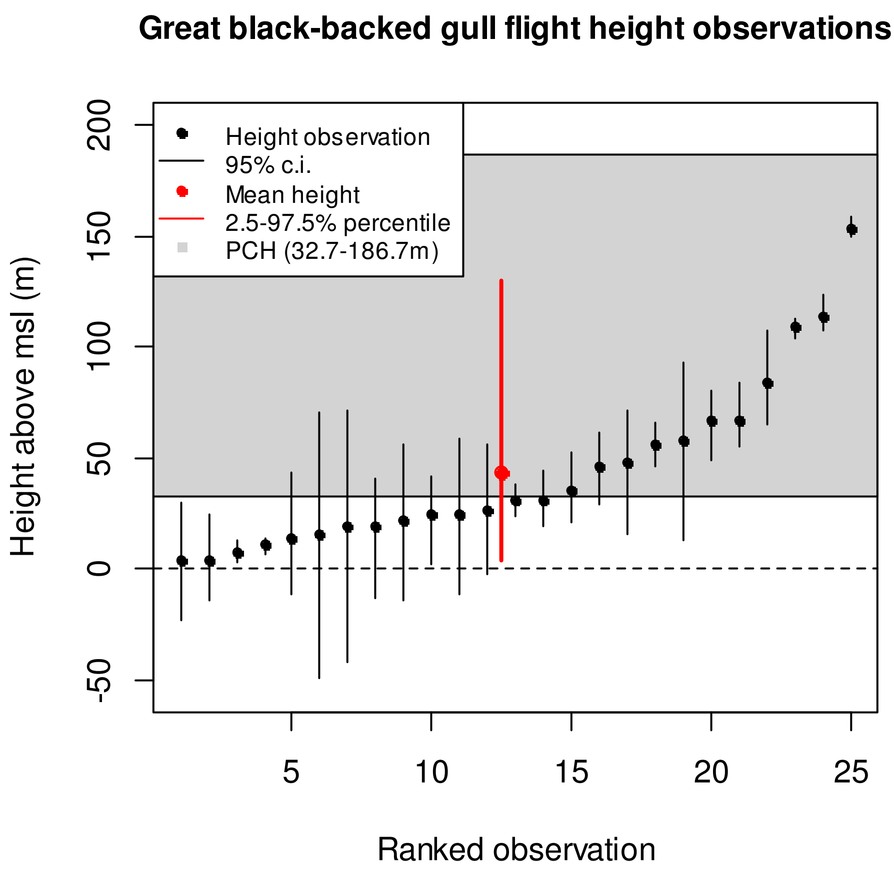

Figure 19. Great black-backed gull flight height estimates pooled across all surveys. Each individual mean and 95% confidence range is indicated (black dot and lines), the mean height (mean of individual means) and 95% percentile (red dot and line), potential collision height (PCH; grey shading) and sea level (dashed line).

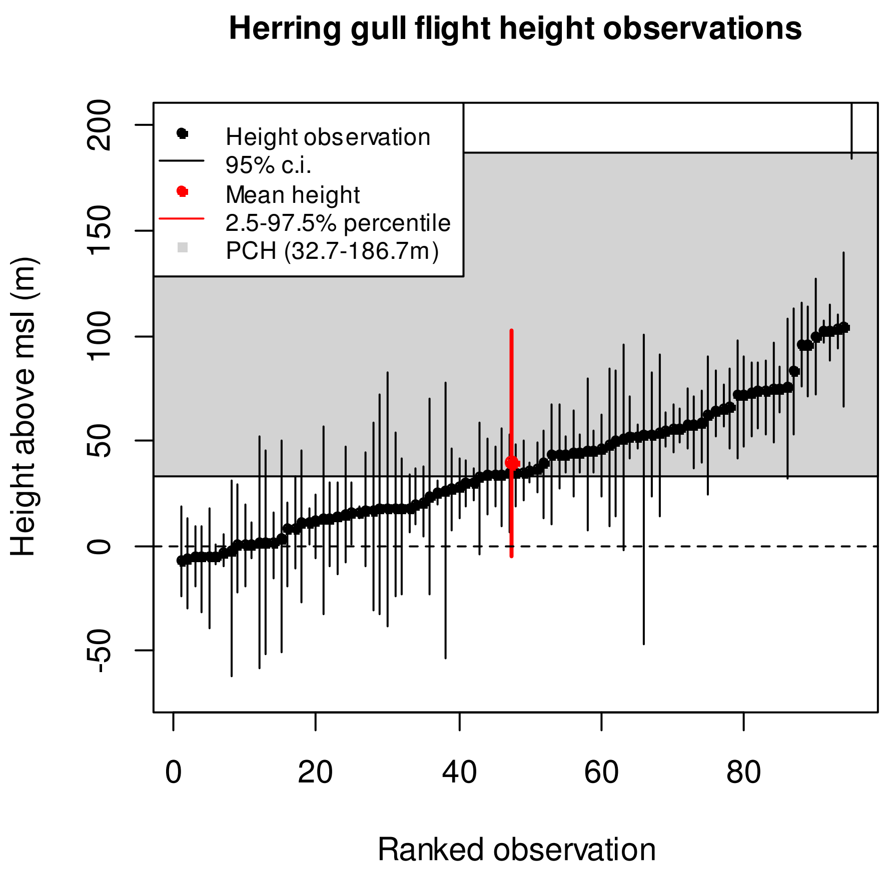

Figure 20. Herring gull flight height estimates pooled across all surveys. Each individual mean and 95% confidence range is indicated (black dot and lines), the mean height (mean of individual means) and 95% percentile (red dot and line), potential collision height (PCH; grey shading) and sea level (dashed line). Note one individual was estimated to be flying at 217m (95% c.i. 184 - 255m), but to keep the y-axis consistent with the other species only the lower edge of this observation is visible.

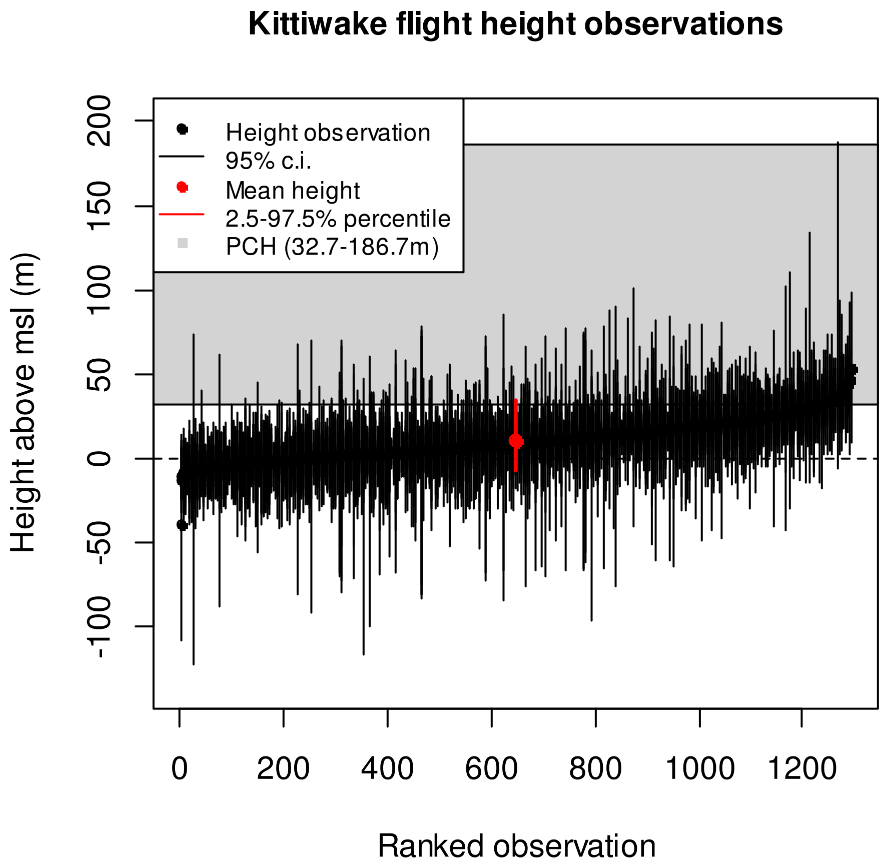

Figure 21. Kittiwake flight height estimates pooled across all surveys. Each individual mean and 95% confidence range is indicated (black dot and lines), the mean height (mean of individual means) and 95% percentile (red dot and line), potential collision height (PCH; grey shading) and sea level (dashed line).

The relationship between flight height and distance to coast for each species is presented in Figures 22 to 25. Only kittiwake showed a significant negative relationship between flight height and distance from coast (linear model, $t=-4.1$, $p < 0.001$; Figure 25). The modelled flight height decreased from 11.6m at 0km to 7.9m at 30km. Although the linear model and the locally smoothed (lowess) line show close correspondence, the local regression gives a slight indication of a step in the height distribution at around 17km from the coast (Figure 25).

For the two large gull species, the distribution of observations was skewed towards coastal areas (particularly for herring gull) which limited the ability to model the relationship with distance to coast, as can be seen from the extremely non-linear shape of the lowess model fits (Figures 23 and 24). Gannet showed an even distribution of heights at all distances to coast (Figure 22).

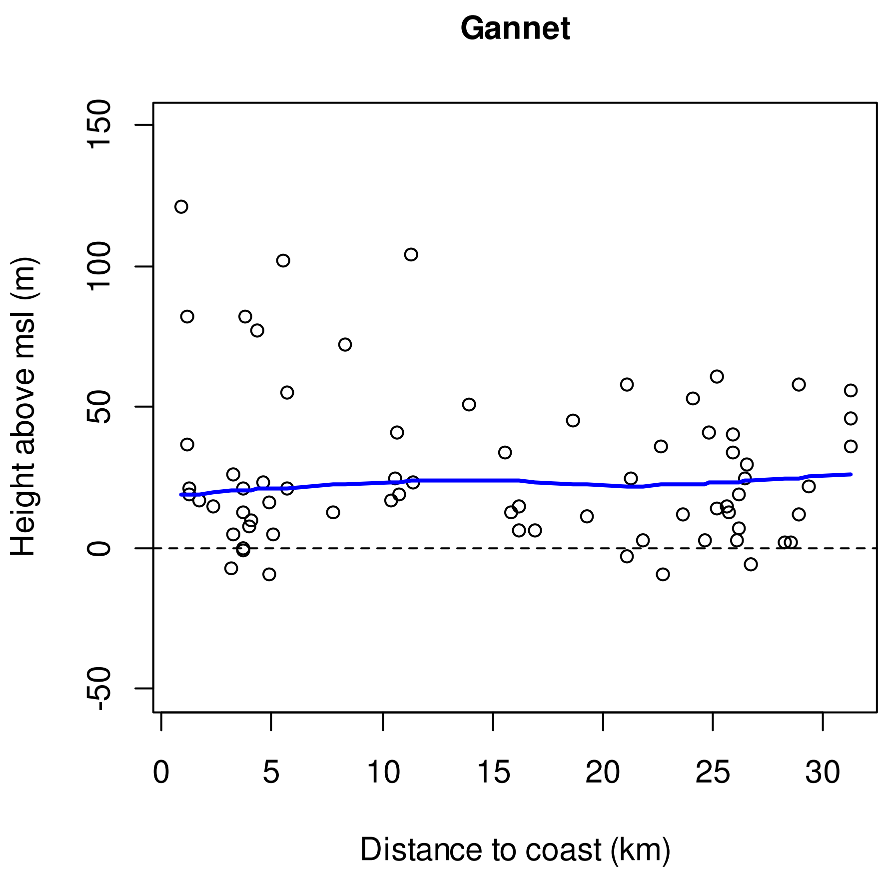

Figure 22. Relationship between gannet mean flight height and distance from coast. Dots represent individual observations, the blue line is a locally smoothed regression (lowess) and the dashed line indicates sea level. No significant trend was evident.

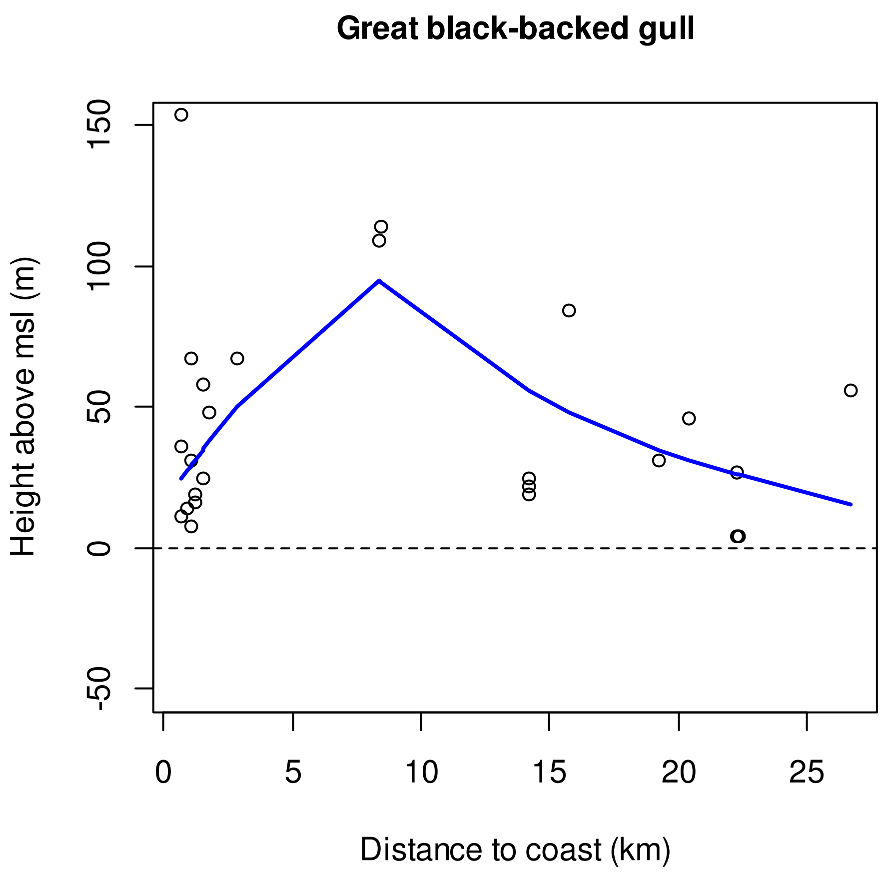

Figure 23. Relationship between great black-backed gull mean flight height and distance from coast. Dots represent individual observations, the blue line is a locally smoothed regression (lowess) and the dashed line indicates sea level. No significant trend was evident.

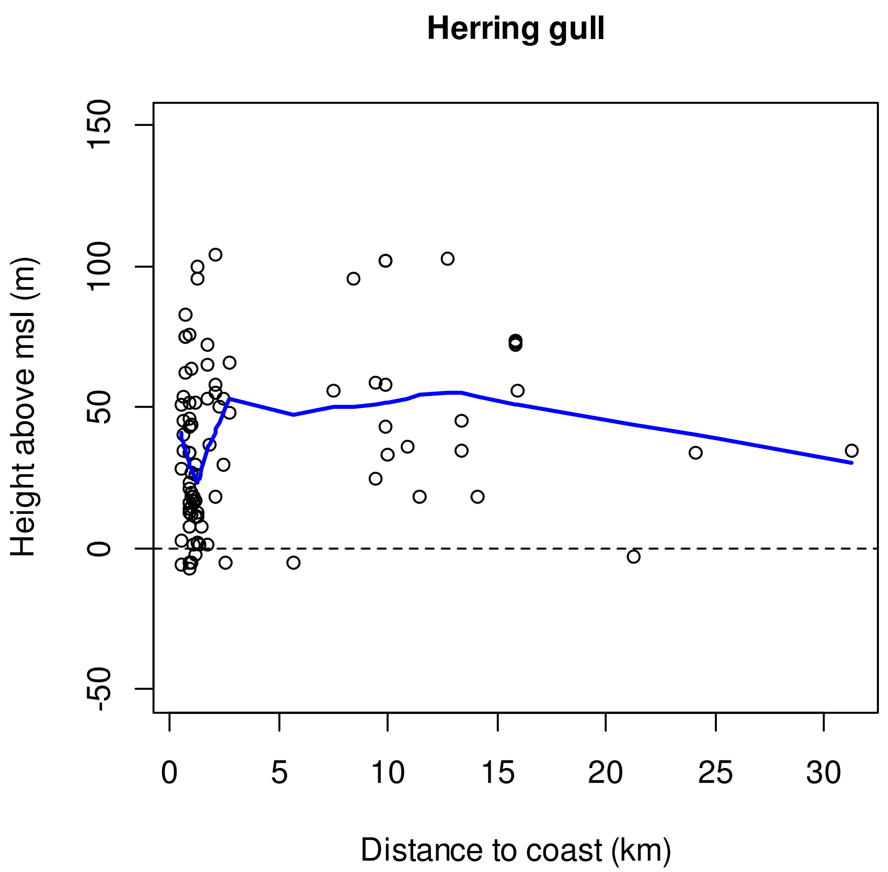

Figure 24. Relationship between herring gull mean flight height and distance from coast. Dots represent individual observations, the blue line is a locally smoothed regression (lowess) and the dashed line indicates sea level. No significant trend was evident.

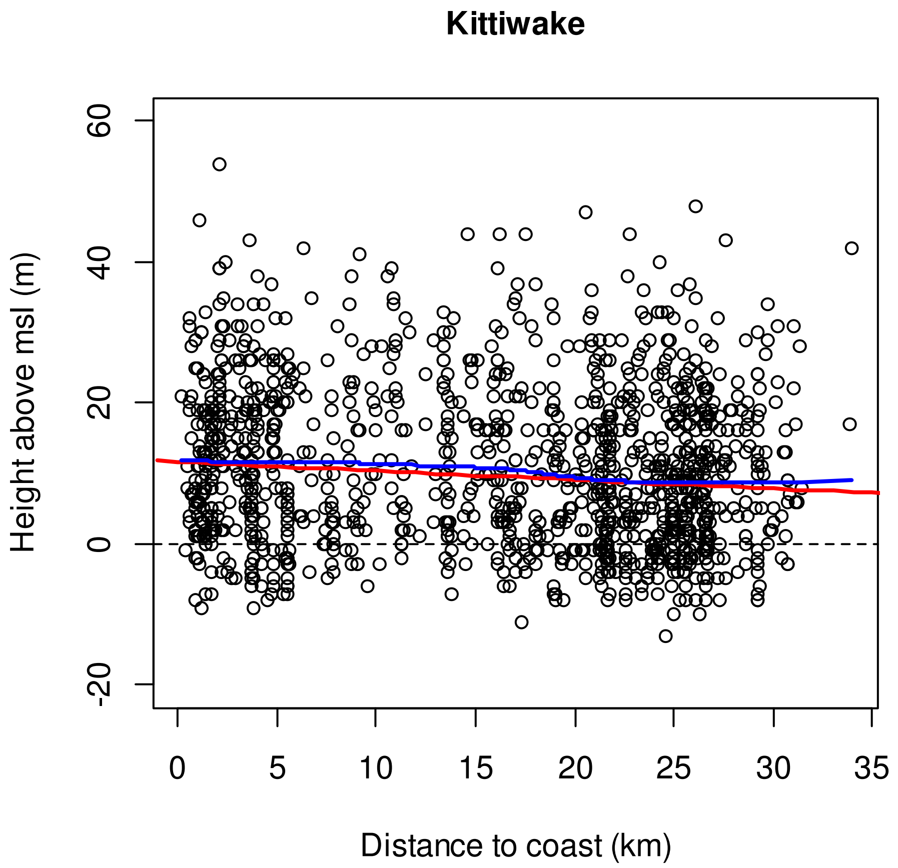

Figure 25. Relationship between kittiwake mean flight height and distance from coast. Dots represent individual observations, the red line is the best fit linear regression, the blue line a locally smoothed regression (lowess) and the dashed line indicates sea level.

3.6 Flight directions

The proportions of birds recorded flying in each 8 point compass direction are provided in Figure 26. Few great black-backed gull and herring gull were observed in flight within the Wind Farm and 2km buffer with only 11 and 10 records across all surveys respectively (Figure 26a and 26b), although it is of note that there were no unassigned flights (i.e. 'flying, direction unknown'). However, given the low numbers of these species observed there is little that can be concluded with respect to flight directions and potential connectivity to the SPA colonies.

All flying gannets were assigned a flight direction, however relatively few were recorded (57, Figure 26c) and there was no obvious flight direction preference present.

Kittiwakes had the largest number of flights with an assigned direction (1,012, Figure 26d), although a further 345 (25% of the total in flight records) were not assigned to a direction. There was a clear south and south-easterly focus to the records, with very few flights heading the opposite way. While this potentially indicates some connectivity to the SPA, in terms of birds heading away from the colonies, it is not clear why there are few apparent return flights. Nonetheless, there does appear to be some indication for connectivity to the SPA in these data.

Guillemots demonstrated the clearest evidence for connectivity to the SPA colonies, with flights predominantly in the NW-SE axis (Figure 26e), derived from a large sample size (746) with only a further 4 birds for which no direction was assigned.

There was a suggestion of a similar pattern for razorbills (Figure 26f), however the sample size was small (25) and hence less certainty can be given to this conclusion.

The same applied to puffins (Figure 26g), for which even fewer direction flights (8) were recorded. This was too few to permit any inference on Wind Farm connectivity to be made.

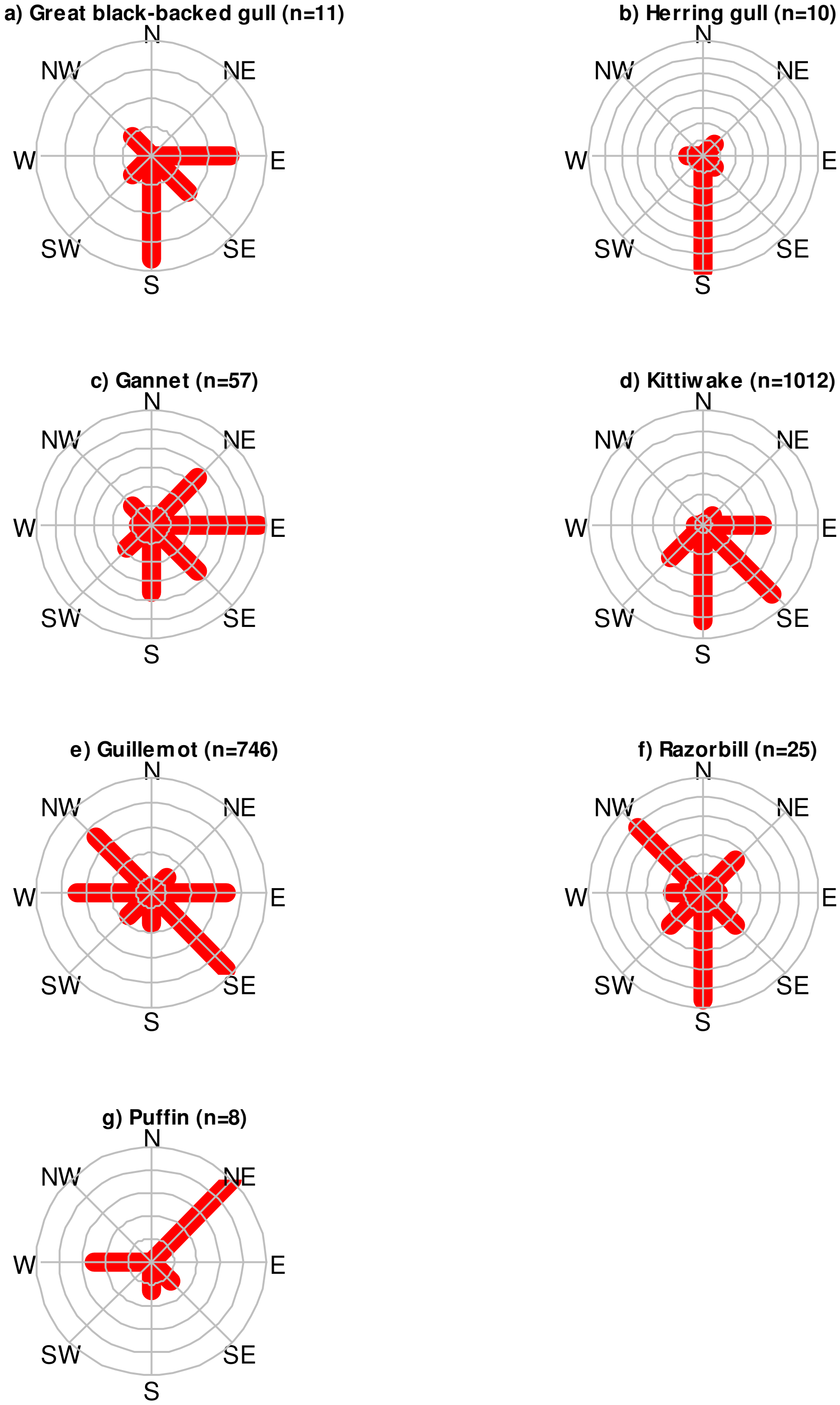

Figure 26. Proportions of flight directions recorded in the Wind Farm (high intensity data). The sample size is provided in brackets for each species. The length of the bars indicates the relative proportions of flights recorded in each direction for that species.

3.7 Power analysis – puffin displacement

The average puffin density (birds/km^2) in each month across the total survey area, calculated using the values in Tables 4 and 5, is presented in Table 9. Although the final survey was conducted in August, during discussions with the MFRAG-OS it was agreed that August did not fall within the period of primary concern as birds begin their post-breeding dispersal during this month (the August survey was only necessary due to an absence of suitable weather in the second half of July). This being the case, the power analysis was set up to replicate the intended aerial survey period of May to July, comprising six surveys. This covers the breeding season period when displacement of breeding adults is of greatest concern. Two densities were defined in each month, derived from the observed abundances across the total survey area (Table 9). Upper and lower values were obtained from the model and design based analyses respectively, giving two smoothed trends in density of 1.5 to 0.25 (by 0.25 increments) and 2.0 to 0.75 (by 0.25 increments) across the 6 surveys.

Table 9. Puffin abundance and density estimates from survey data and values derived from these for use in the power analysis. Note that only one May survey was conducted, thus density estimates were interpolated for the second May value for the power analysis. The total survey area (1,142km^2) was used to calculate densities.

Data source and values used in power analysis	**Survey**						**Statistical power (percentage of simulations when effect detected in power analysis)**
	May 1	**May 2**	**June 1**	**June 2**	**July 1**	**July 2**	
Model based abundance (Table 4)	1738		1315	566	931	261	NA
Design based abundance (Table 5)	2359		1982	628	1064	336	
Model based density (km^2)	1.52		1.15	0.50	0.82	0.23	
Design based density(km^2)	2.07		1.74	0.55	0.93	0.29	
Density (km^2) used in power analysis	**1.5**	**1.25**	**1**	**0.75**	**0.5**	**0.25**	**73**
	2.0	**1.75**	**1.5**	**1.25**	**1.0**	**0.75**	**83**

The density values in Table 9 update those used in the preliminary power analysis, when the abundance in each survey was set at a constant value of either 2,000 or 3,000. The preliminary analysis included simulations with temporally skewed distributions. These simulated a shift in the focus of the bird's distributions from coastal waters at the beginning of the season to an offshore focus at the end. This pattern was intended to replicate movements incorporating post-breeding dispersal. However, as discussed above, the focus of puffin monitoring is on the potential effects on breeding adults prior to dispersal, therefore this shift in distribution offshore was not included in the updated power analysis. Furthermore, there was no evidence for an increasing offshore distribution of puffins during the period from May to July (Figure 6). Thus bird locations within the simulated survey area were generated at random using uniform distributions for both x and y coordinates.

Of 100 simulations run using the lower (design-based) density values in Table 9 (1.5 to 0.25 birds/km^2), comparing a single season of pre-construction (before) and a single season of post-construction (after), a simulated 50% displacement from the Wind Farm site was detected in 73% which is slightly lower than the recommended target for power analysis of 80%.

However, using the higher (model-based) density values in Table 9 (2.0 to 0.75 birds/km^2), the displacement effect was detected in 83% of simulations. It is worth noting that although at the lower densities the power to detect an effect did not quite attain the desired 80% threshold, these results are expected to be conservative as the spatial modelling did not include covariates which improve the precision of estimates obtained and thus increase the likelihood of detecting differences. The spatial analysis of puffin distributions identified either distance to coast or depth (or both) as significant explanatory variables in all but one of the six surveys (Table 3).

Thus, on the basis of the current power analysis and survey design, a comparison based on one year of pre-construction data and one year of post-construction data would be expected to reliably detect a displacement effect of 50%.

4 Discussion

4.1 Population abundances and distributions

The 2015 breeding season aerial surveys revealed seabird densities in the Wind Farm similar to those reported in the Beatrice Environmental Statement for the same period in 2010 and 2011.

The most abundant species recorded (combining the estimates of birds on the water and in flight) has remained guillemot, with more than 80,000 individuals estimated to be present in the total survey area and over 7,500 in the Wind Farm site (when availability bias is accounted for). Kittiwake, puffin and razorbill were the next most numerous, each with peaks of over 4,000 individuals in the total survey area and Wind Farm peaks of 1,500, 1,200 and 230 respectively (after accounting for availability bias in the auks). Gannet numbers varied quite widely, reflecting their wide ranging habits, reaching a total survey area peak of 900 individuals and a Wind Farm peak of around 400. The two large gull species were observed in insufficient numbers to permit reliable modelling. On the basis of the average densities observed in transects great black-backed gull peaked in the total survey area at around 50 individuals and 30 in the Wind Farm and 2km buffer. Herring gull was present in higher numbers, with a peak of 430 in the total survey area and 125 in the Wind Farm and 2km buffer. However, as can be seen from the flight height analysis (Figures 23 and 24), great black-backed and herring gulls were primarily recorded in coastal areas, corresponding with the patterns seen in recent tagging studies (Bogdanova 2015).

Within the Wind Farm itself there were occasional congregations of certain species which presumably indicated concentrations of prey at the time of the survey. An example can be seen for gannet and guillemot on survey 3 (Figures 3 and 4) which indicate both species were feeding in the Wind Farm site.

The spatial modelling identified significant covariate relationships for the species present in larger numbers (e.g. guillemot) more frequently than for the less abundant ones (e.g. gannet). It is interesting to note that that while distance to coast and sea depth were generally informative for auk distributions, these variables had no predictive power for kittiwake and gannet. In the case of gannet this may reflect the different prey species being targeted and also the wider ranging behaviour of this species, while for kittiwake, which feed at the surface, the link between sea depth and foraging location would perhaps be expected to be weaker. Thus, while auks show greater predictability in their distributions, which can be linked to physical variables, species such as gannet which exhibit greater foraging flexibility, are much harder to predict, with distributions more related to dynamic (e.g. fronts) rather than static features. The smaller number of gannets recorded may also have affected the ability to model relationships.

Species which typically forage on the wing (gannet, kittiwake, herring gull, great black-backed gull) were recorded in flight in numbers similar to, or higher than, the numbers recorded on the water. The reverse was the case for the auks which dive from the surface and were recorded in flight at much lower numbers than on the sea. Furthermore, the distribution of birds recorded in flight (although not plotted here) matched the distributions of birds on water.

4.2 Comparison with pre-application surveys of the Wind Farm

Pre-application site characterisation surveys were conducted across the Wind Farm site and 4km buffer using boat based methods between October 2009 and September 2011. The density estimates from the May, June and July site characterisation surveys and the design-based Wind Farm and 2km buffer pre-construction aerial surveys are plotted together on Figure 27 to aid comparison (note to ensure comparability design-based estimates were used without adjustment for availability bias). Overall, although different survey methods were employed and seabird distributions typically vary across years, the densities obtained are broadly comparable across the three years with no indication of systematic bias introduced due to the different survey platforms. This is in line with the findings of previous studies which have compared the results from these two seabird survey methods (e.g. Henkel et al. 2007).

Gannet showed the largest difference in density between the site characterisation and pre-construction surveys in 2015. In the earlier surveys the density in the Wind Farm site peaked at around 0.4 birds/km^2, compared with a peak in 2015 of 2.6/km^2. While this may simply reflect the natural variability in seabird distributions, for gannet it also probably reflects the increasing population, both in British waters as a whole and also within the Moray Firth. The estimated number of pairs at the nearest breeding colony (Troup Head) increased from around 2,800 in 2010 to 6,500 in 2014 (Murray et al. 2015; note, at this rate of increase there may have been over 8,000 pairs in 2015).

Guillemot density in the Wind Farm in 2010 peaked at around 39/km^2 (May) and in 2011 at around 9.5/km^2 (May), compared with a 2015 peak estimate of 47/km^2 (May). However, the pattern of densities across the breeding season in 2015 is quite similar to that seen in 2010 (Figure 27).

Kittiwake densities in the Wind Farm in the 2010 and 2011 breeding seasons were generally low, with a peak 2010 estimate of 3.8/km^2 (May) and a 2011 peak of 1.2/km^2 (July), compared with a higher peak of 12/km^2 in July 2015. However, the estimates in the other 2015 surveys were closer to those seen in 2010 and 2011. It is thus likely that the higher peak in 2015 was simply chance rather than representative of a change in use of the Wind Farm. Furthermore, it is informative to compare the 2015 peak abundance (approx. 1,500) with the potential number of birds present in the Moray Firth. The most recent East Caithness Coast SPA population estimate is 40,140 pairs (Seabird 2000), which indicates there are potentially 150,000 individuals in the region (assuming 53% of the population are adults, Furness 2015). Thus, compared with the number of kittiwake potentially present in the region, the differences observed across the three years are relatively small and within the natural range which could be expected.

Between May and July puffin densities in the Wind Farm were low in 2010 (1 to 2 birds/km^2) and 2011 (0.4 to 0.7 birds/km^2) which was similar to the pattern seen in 2015 (0.3 to 1.4

birds/km^2). In all years increases were observed during August (not shown on Figure 27) consistent with post-breeding dispersal, and in 2010 there is an indication that this increase in density may have begun by late July.

Razorbill densities in the Wind Farm in 2015 (0.4 to 1.5 birds/km^2) were generally lower than those reported in 2010 (2.1 to 2.4 birds/km^2) and 2011 (1.6 to 2.2 birds/km^2).

The density of great black-backed gulls and herring gulls in the Wind Farm in 2010 peaked at 0.3 and 0.15 birds/km^2 respectively, while in 2011 the equivalent peaks were 0.05 and 0. Great black-backed gulls were recorded at similar densities in 2015, peaking at 0.2 birds/km^2. However, herring gull showed a peak in density in July 2015, when 0.96 birds/km^2 were estimated to be present within the Wind Farm. However, closer scrutiny of the data revealed that this apparent influx of herring gulls was actually due to around 50 individuals being recorded on structures associated with the Jacky oil platform, which were overflown on this survey. Although these are located outside the Wind Farm boundary, they are within the 2km buffer area, and all these data were used in the density estimation. The boat surveys also passed through this area, but would not have recorded similar concentrations of gulls as the structures were not within the transect strip and therefore equivalent observations were not made. This anomalous peak aside, the aerial survey derived density estimates were very similar to the boat based ones and do not indicate a change in site usage by either of these species.

Overall the 2015 pre-construction surveys recorded very similar densities for the species of interest. Given this, there is little justification for a second year of pre-construction surveys since these would be unlikely to alter the current understanding of seabird densities and distributions on the Wind Farm within the breeding season.

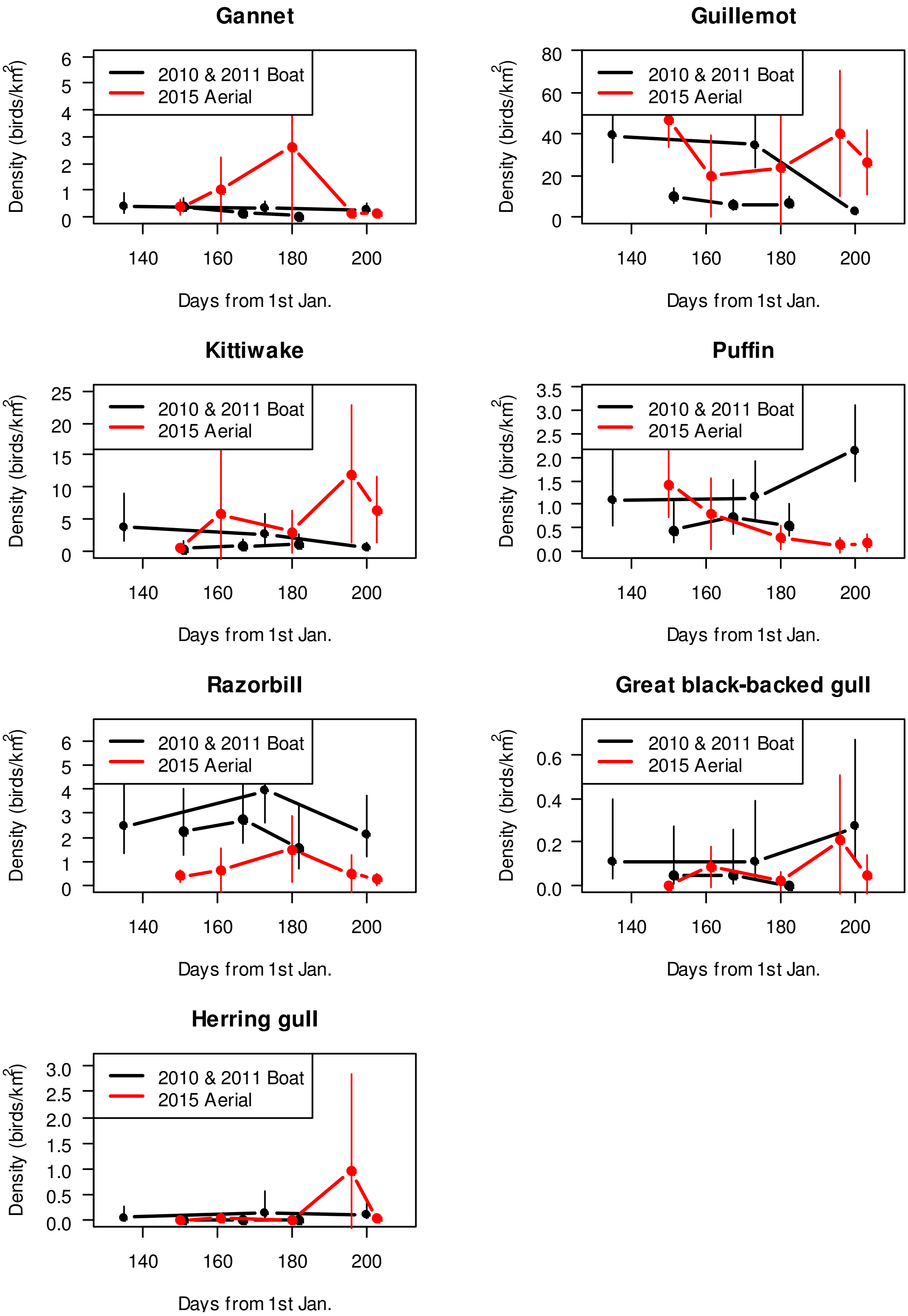

Figure 27. Comparison of Wind Farm density estimates (design-based, inc. 95% confidence intervals) in May, June and July from boat surveys in 2010 and 2011 (black lines) and aerial surveys in the same months in 2015 (red line).

4.3 Auk distributions within the Wind Farm

The analysis of auk locations in relation to planned turbine locations was developed to provide a means by which the fine scale avoidance of turbines within the Wind Farm boundary can be estimated, once turbines have been installed. By repeatedly applying a random relocation of approximately half the turbine separation distance (i.e. +/-500m) to all the turbines it is possible to check if the observed bird distributions fall within the expected range for alternative Wind Farm layouts or lie outside that range (which would indicate a distribution influenced by the turbines). As there were no turbines for the birds to respond to during the current surveys, the prediction was that the observed densities would lie in the middle of the simulated data range. This was generally the result obtained, although there was more variation than might otherwise have been expected. However, as the differences were not all in the same directions these are considered most likely to be due to chance.

Manipulation of the data to remove birds located within particular distances of turbines revealed that if complete displacement occurs in this manner following turbine installation the current survey design and analysis methods will allow it to be identified, even if it only occurs within quite short (c. 200m) distances of turbines.

4.4 Flight heights

Estimating flight heights from digital video, as used here, is a relatively new technique and the accuracy of the data has not yet been fully validated. It is also worth stating that the decision to use digital aerial survey methods for the monitoring survey was based on this method's suitability for collecting bird distributions, not flight heights and that the inclusion of these data in the current report followed specific requests from the members of the MFRAG ornithology subgroup. It is clear from the large uncertainty attached to each height estimate, the presence of a significant number of <0m heights and the relatively small sample sizes obtained, that the results obtained need to be treated with considerable caution (this is particularly true of great black-backed gull, for which only 25 estimates were obtained).

The average flight heights obtained from the current survey data are higher than those reported in wind farm guidance for gannet, great black-backed gull and herring gull. However, previous flight height estimates reported for use in collision risk modelling (e.g. Johnston et al. 2014, corrigendum) have been obtained from data collected throughout the year, which will include for example, periods of migration, when seabirds often fly at lower altitudes (e.g. Cleasby et al. 2015).

This may account for the different proportions at rotor height in the current analysis from reported values. For example, the proportion of gannets at collision height (34%) is higher than that estimated by Cook et al. (2012) or Johnston et al. (2014, corrigendum) which were 9.6% and 12.6% respectively. Since the latter estimates were derived across a large number of sites using data collected throughout the year, these lower values will represent an estimate of the annual proportion at risk height, while the current study was focussed on three months during the middle of the breeding season when foraging activity will be at its most intense.

Gannet is the only one of the four species for which flight height data were collected which does not breed at East Caithness Cliffs. Therefore all birds observed can be assumed to have been either foraging or commuting from foraging areas to a breeding colony elsewhere (the nearest being at Troup Head). The mean height estimate from this study (27.6m) is close to that of 26.5m recently estimated for foraging adults during the breeding season obtained using altimeter tags (Cleasby et al. 2015). Cleasby et al. (2015) found that gannet flight height followed a bimodal distribution, with lower heights whilst travelling (e.g. to/from foraging areas) and higher ones whilst engaged in foraging behaviour.

The herring gull and great black-backed gull height estimates, are both higher than the composite ones used in collision modelling (Cook et al. 2012, Johnston et al. 2014, corrigendum). For these species the reported proportions at collision height are; herring gull 28.4% and 31.9%; great black-backed gull 33.1% and 32.5%. The current survey generated estimates of 55% and 44%, however, for these two species most of the observations made in the current study were for birds located within 3km of the coast, whereas most data used for estimating generic flight heights has been collected farther offshore. The current high values may therefore reflect a more coastal distribution, although the small sample sizes, combined with the uncertainty in the estimation methods used, limits the conclusions which can be drawn from these data.

Kittiwakes fly lower than the other two gull species, although the proportion at rotor height (4%) is lower than the annual values of 15.7% (Cook et al. 2012) and 15.0% reported by Johnston et al. (2014, corrigendum). Kittiwake was the only species for which there was evidence for a significant decrease in flight height with distance offshore. This may be a reflection of the larger dataset available, although the distributions of large gull heights in relation to offshore distance indicates that they utilise a wide range of heights and thus such a relationship might be expected to be absent.

4.5 Flight directions

A crucial aspect for determining potential impacts on the SPA breeding colonies is the establishment of connectivity with the Wind Farm. The flight direction analysis only identified strong evidence of connectivity for guillemot, with flights predominantly oriented along a NW-SE axis. However, the small sample sizes for some species, especially the large gulls, puffin and razorbill, means that connectivity cannot be excluded on the basis of these data. However, considering the small flight direction sample sizes and the results of the spatial models together indicates that the Wind Farm site, while utilised by many of the seabirds which breed at the SPA, probably does not represent a key foraging destination but is instead used to a similar extent to the surrounding areas. An alternative explanation which could account for the lack of apparent directionality is that birds observed within the wind farm site were predominantly undertaking short range flights between bouts of foraging rather than traveling to or from the colony. However, if this was the case it seems likely that higher concentrations of birds would have been recorded on the wind farm site in more of the surveys than was found to be the case.

4.6 Power analysis – puffin displacement

The original power analysis explored the effects of several parameters on the ability to detect puffin displacement from the Wind Farm. This indicated that a minimum of four surveys between May and July would be expected to generate a sufficient dataset to permit displacement to be detected in a comparison of one year of pre-construction with one year of post-construction data (Appendix 1).

The updated analysis was run on the basis that the survey design used in 2015 would be used for subsequent surveys. Therefore, it was assumed that 6 surveys would be conducted between May and July and utilising transects of the same width (250m) and spacing (2.5km).

There was little evidence from the 2015 surveys to suggest that during the breeding season when adults are foraging they show a skewed distribution (i.e. a decline in density with increasing distance offshore). Therefore a uniform distribution was used in the simulations.

The monthly density estimates showed a declining trend between May and July, and this was used in the simulations. The updated analysis reported here supports the results obtained from the preliminary analysis (which suggested that a 50% displacement could be detected using these methods). With an estimate that a displacement effect would be detected 73%-83% of the time from a comparison of one year of pre-construction and one year of post-construction data, even without the inclusion of covariates which have been found to provide significant explanatory power (Table 3), this suggests that a second year of pre-construction surveys should not be required to assess displacement effects pre- and post- construction.

Furthermore, consideration of this result together with those from the turbine avoidance analysis indicates that the current survey design and analytical methods provide a good basis with which to investigate puffin displacement in relation to the Wind Farm, operating at both a fine scale (100s of metres) and large scale (kms).

5 Conclusions

- The primary aim of the pre-construction aerial surveys conducted between May and August 2015 was to obtain seabird distribution data to provide a robust baseline dataset for comparisons with post-construction data. This aim was achieved, with six surveys successfully undertaken.
- The 2015 surveys found similar seabird densities on the Wind Farm to those obtained from the site characterisation surveys conducted between 2009 and 2011. Since other studies have found that boat and aerial methods generate similar results, this provides a clear indication that bird activity on the Wind Farm has remained consistent. Therefore, with three years of seabird density and distribution data to draw on, BOWL considers there to be no requirement for a second year of pre-construction aerial surveys.
- The key effect of concern to be investigated using these data is puffin displacement. This aspect was explored using a power analysis prior to survey commencement (which informed the survey design). The power analysis was updated using the results obtained from the current surveys. The results confirm the earlier predictions (from the preliminary analysis) that a 50% displacement of breeding adult puffins from the Wind Farm will be reliably detected on the basis of a comparison of data collected during a single year of pre-construction surveys and a single year of post-construction surveys.
- To further consider displacement effects, additional (high intensity) data were collected within the Wind Farm and 2km buffer. A method for investigating finer scale distributional responses to turbines was developed using these data which will enable detailed examination of changes in the distribution of birds within the Wind Farm.
- By combining the results from the wide scale (total survey area) distribution analysis and the turbine avoidance analysis there is a high probability that displacement effects following Wind Farm construction can be detected if present.
- Although it is likely that birds recorded on the Wind Farm originate from the East Caithness Cliffs SPA as this is the closest breeding colony, connectivity on the basis of flight directions could only be established for one species (guillemot). However, this is more likely to reflect the small sample sizes for most of the other species rather than an absence of connectivity.
- Estimating bird flight heights is an ongoing challenge for the offshore wind industry. The methods to estimate height from digital aerial data which have been developed offer theoretical advantages over previous ones (e.g. boat based surveyor judgement), not least in that a permanent data record exists. However, consideration of the data obtained from the current surveys indicates that at present these methods require to be refined in terms of precision (wide confidence intervals) and accuracy (e.g. heights estimated below sea level). Consequently flight heights reported here should to be treated with caution.

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7 Appendix 1 – Preliminary Power Analysis

(originally submitted to MFRAG-OS (29th May 2015, doc. ref: LF000005-SOW-051)

7.1 Note on use of power analysis to inform number of surveys

Following discussions with the MFRAG-OS, power analysis was conducted prior to appointment of the aerial surveyor. This analysis was undertaken to provide a guide for the power of the proposed survey design to detect a redistribution of 50% of the puffins from the Wind Farm. This analysis considered the number of surveys conducted in May, June and July. The puffin distributions simulated for each of these months differed in the coastal-offshore (i.e. west-east) skew, with a moderate inshore preference in May, a weaker inshore preference in June and a moderate offshore preference in July. In all cases the simulations were conducted assuming a puffin population of 3,000 individuals and the same survey coverage and design was used (as per the above survey design description). Table A1.1 provides the results of these analyses.

Increasing the number of surveys from 3 to 6 increased the power to detect a redistribution effect. There was not much difference in power between 4 or 5 surveys and both exceeded the target of 80%, although with 3 surveys this target was not reached. With 2 surveys per month (6 in total) the effect was detected in almost all simulations.

Table A1.1. Power to detect puffin redistribution from the Beatrice Wind Farm. Circles in the month columns indicate which months were simulated.

<table>
<tr><th rowspan="2">Total no. of surveys</th><th colspan="6">Survey timing</th><th rowspan="2">No. simulations</th><th rowspan="2">No. simulations detecting effect</th><th rowspan="2">Proportion simulations detecting effect</th></tr>
<tr><th colspan="2">May</th><th colspan="2">June</th><th colspan="2">July</th></tr>
<tr><td>3</td><td colspan="2">O</td><td colspan="2">O</td><td colspan="2">O</td><td>88</td><td>61</td><td>0.693</td></tr>
<tr><td>4</td><td colspan="2">O</td><td>O</td><td>O</td><td colspan="2">O</td><td>92</td><td>78</td><td>0.848</td></tr>
<tr><td>5</td><td colspan="2">O</td><td>O</td><td>O</td><td>O</td><td>O</td><td>93</td><td>80</td><td>0.860</td></tr>
<tr><td>6</td><td>O</td><td>O</td><td>O</td><td>O</td><td>O</td><td>O</td><td>95</td><td>90</td><td>0.947</td></tr>
</table>

The survey has been designed to reflect the requirement (or preference) to conduct 6 surveys as advised by Marine Scotland Science, SNH, JNCC and RSPB.

The data collected during the 2015 pre-construction surveys will be used to re-run the power analysis with the data permitting refinement of the simulated bird abundance and distributions. This will provide greater confidence in the predictions of, for example, the magnitude of change which may be detectable (e.g. displacement percentage) for a given number of surveys. In discussion with MFRAG-OS the results will be used to determine the appropriate level (e.g. number of surveys) required for post-construction monitoring.

The power analysis was repeated using the results from the current aerial surveys (2015) to inform the distribution of puffins and the survey design. Illustrations of the simulated survey area and bird distribution are provided in Figure A1.1. Note the simulated bird distribution in Figure A1.1 was right-skewed. For the updated analysis reported here a uniform (i.e. even) distribution was assumed.

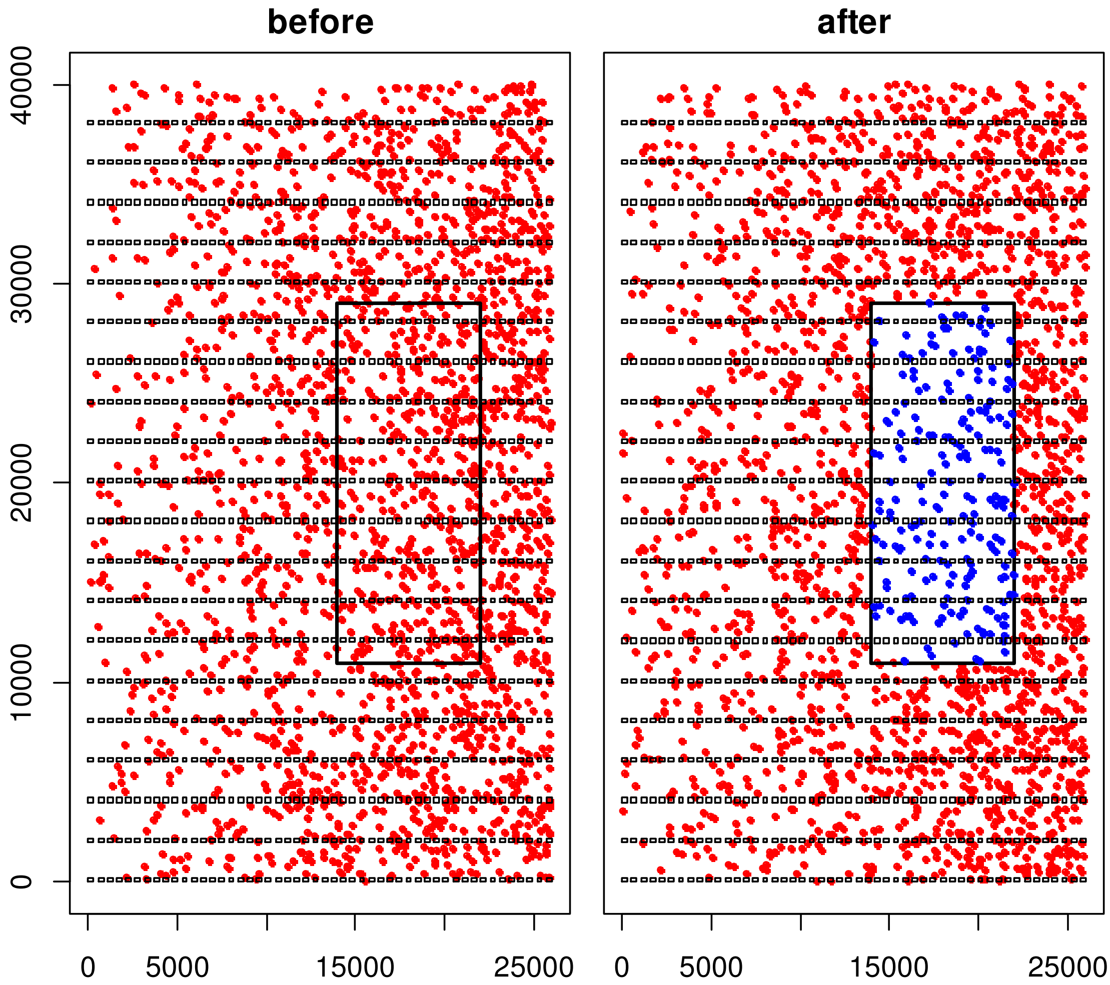

Figure A1.1. Illustration of before/after puffin distributions, with 50% displacement effect from Wind Farm. The Wind Farm is indicated by the rectangle, the aerial survey transects by the horizontal rows of cells and the birds by dots. Only birds located within the survey cells are recorded and used in the analysis. The coast layout of the Wind Farm and coast has been rotated anti-clockwise to simplify the analysis, but the survey area and Wind Farm area are both close to the actual sizes.

7.2 Power analysis methods

A simulation tool was developed which is designed to replicate offshore Wind Farms and bird data collected by aerial surveys. This simulation tool works as follows:

1. A survey region is defined and one or more Wind Farm polygons located within it (see Figure A1.1 for a simplified representation);

2. For each month to be surveyed, random bird locations (x/y) are generated using uniform distributions (Note that the uniform values for either coordinate can be modified to generate skewed distributions, with gradients in abundance, thereby replicating changes which may occur with distance offshore, etc.). The total number of birds for which points are generated is calculated using a predefined value for the bird density in each month multiplied by the total area of the survey region;

3. Each bird location is identified as being within or outside the Wind Farm polygon(s);

4. In the baseline period (i.e. pre-construction) no modification to locations is performed;

5. In the impact period (i.e. post-construction) a pre-determined percentage (e.g. 50%) of birds within the Wind Farms are given new random locations outside the Wind Farm(s) (i.e. simulating displacement, but ensuring birds remained within the overall survey region);

6. A digital aerial survey is simulated by overlaying a grid of cells across the survey region. Birds located within the cells are retained for analysis and identified as either within or outside the Wind Farms (see Figure A1.1 for illustration). The survey design can replicate either continuous sampling (e.g. video) or discontinuous (e.g. still);

7. Sampling regimes can be set to match actual or planned surveys, e.g. the number of surveys per month, the number of months and the number of years can all be set. For each survey a new randomised bird distribution is generated;

9. The before and after Wind Farm construction simulated survey data are then analysed using spatially modelling methods: CReSS (Complex Region Spatial Smoother) with Spatially Adaptive Local Smoothing Algorithms (SALSA; Mackenzie et al. 2013). These tools have been developed by the Centre for Research into Ecological and Environmental Modelling (CREEM) at St. Andrews University;

10. The results provide an indication of whether a proposed survey design can correctly detect if a redistribution of individuals given the input parameters selected. The results can also identify overall reductions in abundance;

11. Repeating the above process gives an indication of how often the true effect can be detected. The aim is to detect the effect (if present) in 80% of simulations.

8 Appendix 2 - Flight height data for key species for each survey

Table A2.1. Summary of flight height estimates for each survey.

Species	Survey no.	n	Flight height using individual mean estimates (m asl)			Proportion at rotor height		
			Mean height	Lower 95% c.i. height	Upper 95% c.i. height	Individual mean values	Individual lower 95% c.i. values	Individual upper 95% c.i. values
Gannet	1	39	28.95	-1.40	104.85	0.359	0.154	0.744
	2	8	8.88	-6.83	32.50	0.125	0.000	0.250
	3	8	17.88	-7.08	42.38	0.125	0.000	0.625
	4	5	37.40	2.30	99.00	0.400	0.400	0.600
	5	6	42.33	0.50	79.00	0.667	0.333	0.833
	6	5	35.60	8.40	75.10	0.400	0.400	0.600
Great black-backed gull	1	4	61.25	26.73	109.80	0.750	0.250	1.000
	2	6	21.33	4.00	62.50	0.167	0.167	0.500
	3	3	15.33	11.25	18.85	0.000	0.000	0.667
	4	4	71.75	32.13	146.65	0.750	0.500	1.000
	5	4	74.00	38.33	107.13	1.000	0.750	1.000
	6	4	23.25	19.23	26.85	0.000	0.000	1.000
Herring gull	1	25	38.36	-1.40	99.20	0.560	0.240	0.840
	2	16	38.00	-3.88	100.38	0.438	0.313	0.625
	3	18	33.78	-6.15	146.88	0.333	0.111	0.667
	4	22	52.23	-4.43	102.00	0.818	0.591	0.909
	5	9	32.78	-1.00	64.00	0.444	0.333	0.889
	6	5	31.60	2.10	71.00	0.600	0.200	0.600
Kittiwake	1	140	16.74	-7.00	39.53	0.129	0.000	0.607
	2	256	9.32	-5.63	29.00	0.000	0.000	0.352
	3	315	8.87	-5.00	28.15	0.006	0.000	0.352
	4	234	12.58	-6.18	33.18	0.034	0.000	0.325
	5	325	10.60	-8.00	39.90	0.065	0.018	0.357
	6	24	13.33	-7.43	35.13	0.083	0.000	0.542