
# Hornsea Project Four: Environmental Statement (ES)

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# Volume A5, Annex 5.6: Offshore Ornithology MRSea Annex


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# Glossary

| Term | Definition |
| --- | --- |
| Auto-correlation | Data containing systemic variation; for example, spatial variation and is seen by sites close to each other having more similar values. |
| Bootstrapping | Tests that use random sampling with replacement to assign measures of accuracy to sample estimates. |
| Bio-season | Bird behaviour and abundance is recognised to differ across a calendar year, with particular months recognised as being part of different seasons. The biologically defined minimum population scales (BDMPS) bio-seasons used in this report are based on those in Furness (2015), hereafter referred to as bio-seasons. |
| Confidence intervals | Range of values that with a specified certainty contains the true mean of the population that a sample was taken from. For example, 95% confidence intervals states a range of values with a 95% certainty those values contain the population mean. |
| "Generalised Additive Model" framework | Statistical models to predict relationships between individual predictors and dependent variable following smooth patterns that can be linear or nonlinear. |
| Hornsea Four array area | The proposed area for Hornsea Four within which the Wind Turbine Generators (WTGs) would be installed. |
| Hornsea Project Four Offshore Wind Farm | The term covers all elements of the project (i.e. both the offshore and onshore). Hornsea Four infrastructure will include offshore generating stations (wind turbines), electrical export cables to landfall, and connection to the electricity transmission network. Hereafter referred to as Hornsea Four. |
| MRSea | Statistical package to model spatial count data and predict spatial abundances; developed by the Centre for Research into Ecological and Environmental Modelling (CREEM) specifically for dealing with data collected for offshore wind farm projects. |
| Orsted Hornsea Project Four Ltd | The Applicant for the proposed Hornsea Project Four Offshore Wind Farm Development Consent Order (DCO). |
| Special Protection Area (SPA) | Protected areas for birds in the UK classified in accordance with European Council Directive 2009/147/EC on the conservation of wild birds, known as the Birds Directive. |
| Zero-inflated data | Count data with excess of zeros. |

# Acronyms

| Acronym | Definition |
|---|---|
| 2D | Two-dimensional |
| ACF | Auto-correlation function |
| AfL | Agreement for Lease |
| BDMPS | Biologically Defined Minimum Population Scales |
| CREEM | Centre for Research into Ecological and Environmental Modelling |
| CReSS-SALSA | "Complex Region Spatial Smoother" with a "Spatially Adaptive Local Smoothing Algorithm" |
| DCO | Development Consent Order |
| EIA | Environmental Impact Assessment |
| ES | Environmental Statement |
| FFC | Flamborough and Filey Coast |
| GAM | Generalised Additive Model |
| GEE | Generalised Estimating Equation |
| GLM | Generalised Linear Model |
| LCI | Lower Confidence Intervals |
| MRSea | Marine Renewables Strategic Environmental Assessment |
| PEIR | Preliminary Environmental Information Report |
| QGIS | Quantum Geographic Information System |
| SALSA1D | Spatially Adaptive Local Smoothing Algorithm including one dimensional variables |
| SALSA2D | Spatially Adaptive Local Smoothing Algorithm incorporates spatial variables |
| SPA | Special Protection Area |
| UCI | Upper Confidence Intervals |

# Units

| Unit | Definition |
|---|---|
| km | Kilometre (distance) |
| $km^2$ | Kilometre squared (area) |
| m | Metres (distance) |
| % | Percentage (proportion) |

# 1 Introduction

## 1.1 Project Background

1.1.1.1 Orsted Hornsea Project Four Ltd. (hereafter the 'Applicant') is proposing to develop the Hornsea Project Four Offshore Wind Farm (hereafter 'Hornsea Four'). Hornsea Four will be located approximately 69 km offshore from the coastline of the East Riding of Yorkshire in the Southern North Sea, with the array area covering an area of approximately 468 km$^2$ and will be the fourth project to be developed in the former Hornsea Zone. Hornsea Four will include both offshore and onshore infrastructure including an offshore generating station (wind farm), export cables to landfall, and connection to the electricity transmission network.

1.1.1.2 The Hornsea Four Agreement for Lease (AfL) area was 846 km$^2$ at the Scoping phase of project development. In the spirit of keeping with Hornsea Four's approach to Proportionate Environmental Impact Assessment (EIA), the project gave due consideration to the size and location (within the existing AfL area) of the final project that is being taken forward to Development Consent Order (DCO) Application. This consideration is captured internally as the "Developable Area Process", which includes Physical, Biological and Human constraints in refining the developable area, balancing consenting, and commercial considerations with technical feasibility for construction.

1.1.1.3 The combination of Hornsea Four's Proportionality in EIA and Developable Area Process resulted in a marked reduction in the array area taken forward at the point of application. Hornsea Four adopted a major site reduction from the array area presented at Scoping (846 km$^2$) to the Preliminary Environmental Information Report (PEIR) boundary (600 km$^2$), with a further reduction adopted for the Environmental Statement (ES) and DCO application (468 km$^2$) due to the results of the PEIR, technical considerations and stakeholder feedback. The evolution of the Hornsea Four Order Limits is detailed in **Volume A1, Chapter 3: Site Selection and Consideration of Alternatives** and **Volume A4, Annex 3.2: Selection and Refinement of the Offshore Infrastructure**.

1.1.1.4 APEM Ltd (hereafter APEM) was commissioned by the Applicant to undertake a modelling exercise using the statistical package, MRSea (Marine Renewables Strategic Environmental Assessment), to analyse the spatial density distribution of bird species across the revised Hornsea Four array area and a 4 km buffer. This latest analysis was undertaken following the recent revisions to the Hornsea Four array area, which reduced by approximately 110 km$^2$. Spatial density distribution was modelled for each of the 24 months of baseline (pre-construction) aerial digital video survey data as well as for species-specific bio-seasons for those bird species for which sufficient data had been recorded. Following a review of the data available, seven species were identified as having a sufficient sample size to allow the modelling, these being fulmar (*Fulmarus glacialis*), gannet (*Morus bassanus*), kittiwake (*Rissa Tridactyla*), great black-backed gull (*Larus marinus*), guillemot (*Uria aalge*), razorbill (*Alca torda*) and puffin (*Fratercula arctica*). For the purpose of defining the baseline for these seven species, the modelling outputs (monthly abundance and density estimates) from the MRSea replace the design-based abundance and density estimates and form the basis of the impact assessments for offshore ornithology for Hornsea Four. A full account of how these data are integrated into the baseline characterisation is provided in **Annex 5.1: Offshore and Intertidal Ornithology Baseline Characterisation Report.** This technical annex has been produced to support the Environmental Statement (ES) for **Volume A2, Chapter 5: Offshore and Intertidal Ornithology**.

1.1.1.5 This report contains the methodology for the statistical package, MRSea, used by APEM to model the spatial density distribution of the bird species in the Hornsea Four array area plus 4 km buffer, which will form the baseline for offshore ornithological EIA in **Volume A2, Chapter 5: Offshore and Intertidal Ornithology** of the DCO application. In addition, the methods used for data processing prior to MRSea analysis are also included along with the methods used to handle the outputs of the MRSea analysis.

1.1.1.6 The results included in this report are represented as maps showing the spatial distribution of each species for each of the 24 individual months as well species data combined into standard bio-seasons, defined according to Furness (2015). In addition, all monthly and bio-season abundance and density estimates are tabulated for each species modelled.

### 1.2 What is MRSea analysis?

1.2.1.1 The MRSea statistical package was developed specifically for analysing offshore ornithological distribution and abundance data collected for offshore wind farm projects, allowing spatially auto-correlated and zero-inflated data to be modelled in a robust method.

1.2.1.2 The package was designed by the Centre for Research into Ecological and Environmental Modelling (CREEM) and uses complex smoothing techniques to model spatial data in a "Generalised Additive Model" (GAM) framework (Scott-Hayward et al. 2014). This allows spatial differences in the density of a species to be understood, as well as allowing the use of environmental variables to predict density.

1.2.1.3 This MRSea method has allowed APEM to use the baseline survey data and additional environmental variables described in **Section 2.1** to predict bird densities and abundances across the Hornsea Four array area plus 4 km buffer. In addition, this method will enable the detection of statistically significant differences in bird abundance between different temporal periods, for example allowing the comparison of data collected from before and after the construction of Hornsea Four (once those data are available) (APEM 2016).

## 2 Methods

### 2.1 Data processing

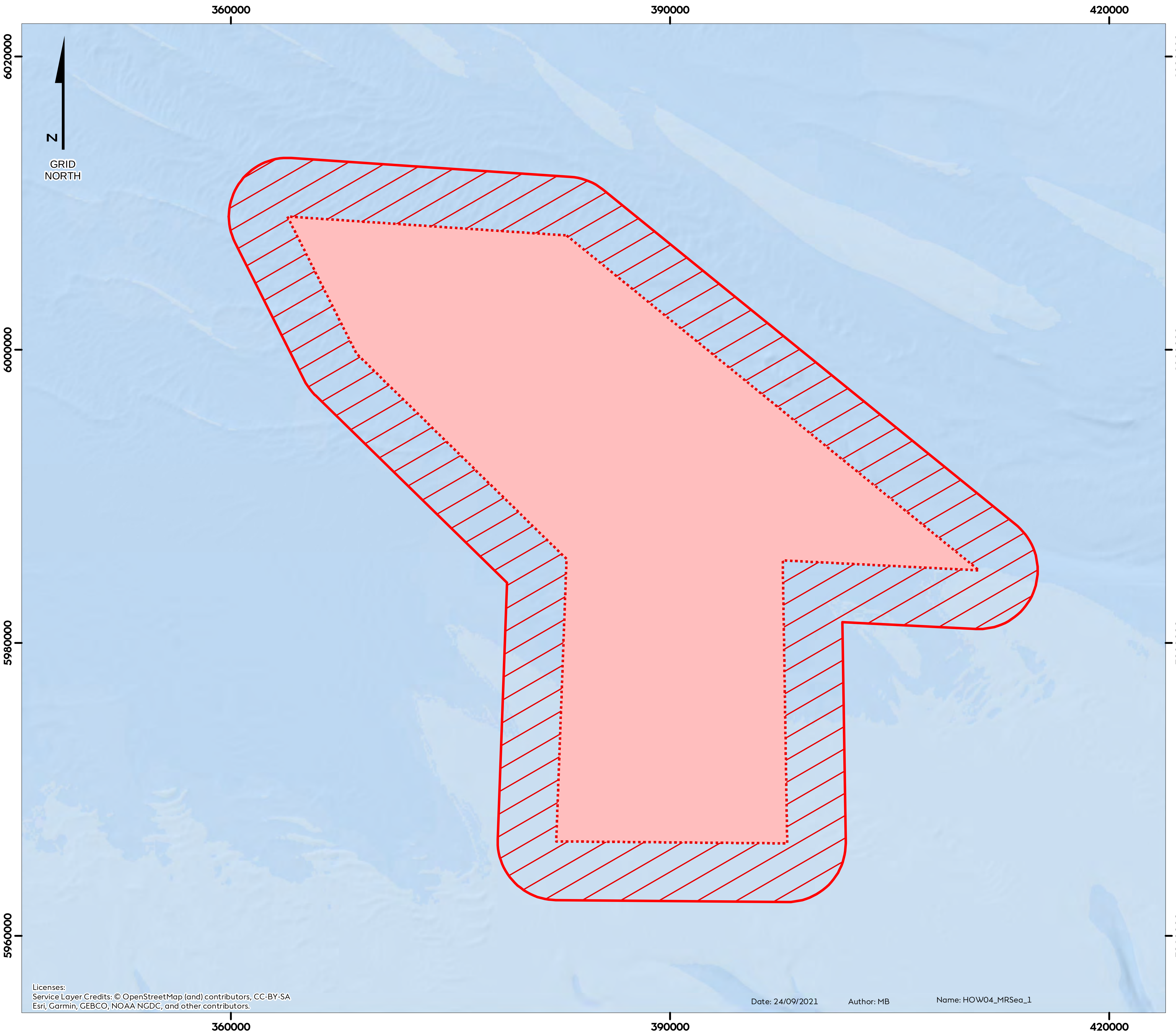
2.1.1.1 Spatial density distributions were predicted for seven seabird species: fulmar, gannet, kittiwake, great black-backed gull, guillemot, razorbill, and puffin. These are considered to be the key species for the baseline and impact assessments for Hornsea Four, which constitute the main focus of the offshore ornithology section of **Annex 5.1: Offshore and Intertidal Ornithology Baseline Characterisation Report** and have a large enough sample size in the baseline aerial digital video survey data to be included in the MRSea analysis.

2.1.1.2 Data collected from HiDef's aerial digital video transects over 24 surveys from April 2016 to March 2018 across the Hornsea Four AfL area plus 4 km buffer (**Figure 1**) were used to extract locations and counts for the seven bird species across this wider area. It is noted that the survey methodology and data coverage has been agreed through the Offshore and Intertidal Ornithology Evidence Plan Technical Panel (OFF-ORN-1.7, OFF-ORN-1.8 and OFF-ORN-1.19). The use of the full survey data ensured the models were as accurate as possible, as utilisation of the maximum amount of data available on bird abundance across the largest area available ensured that any relationships between environmental variables and bird density had the greatest opportunity to be recognised and integrated as possible. It should be noted that the use of the full survey data can produce results that appear inconsistent with design-based abundance estimates. For example it is possible that in months with no birds from one species recorded as present in the Hornsea Four array area (from the survey data used for the design-based abundance estimates), there may be individuals from that species within the wider AfL, which may lead to the results of MRSea analysis showing some birds are predicted to be within the Hornsea Four array area as the distribution is influenced by the relationship between the bird density and the environmental variables. As MRSea analysis provides predicted spatial density distributions and uses environmental variables to help predictions, consequently it is considered to be more informative than design-based analysis.

2.1.1.3 The environmental variables included bathymetry (depth of water from the sea surface to the seabed) data (**Figure 2**) and distance to nearby Special Protection Area (SPA), in this case, specifically, the Flamborough and Filey Coast (FFC) SPA. The distance to the nearest point of the FFC SPA (which includes Flamborough Head and Bempton Cliffs) was directly calculated in Quantum Geographic Information System (QGIS).

2.1.1.4 For the MRSea analysis, a complete grid of abutting 1 km x 1 km cells was constructed over the entire AfL area plus a 4 km buffer. Therefore, the full data available were used as the input data for the MRSea analysis. Environmental variables, including bathymetry data and distance to the FFC SPA, were attached to each grid square. The transect lines from the aerial digital video surveys were used to create polygons to show the exact surveyed area. Georeferenced locations of individual birds (from the aerial digital video survey data) were spatially joined to the grid squares to create bird data that was characterised by spatial and environmental covariates. The survey effort (area covered per grid cell in each transect) was included in the MRSea analysis. MRSea analysis was then undertaken to predict the density of birds within each grid cell.

2.1.1.5 The predictions from the MRSea analysis are at a 1 km x 1 km resolution and a prediction grid was created by clipping the 1 $km^2$ grid to the shapefile of the Hornsea Four array area plus a 4 km buffer, which was then used to help determine the baseline for the offshore ornithological EIA that will form **Volume A2, Chapter 5: Offshore and Intertidal Ornithology** of the DCO application. Each grid cell was associated with the environmental variables described above and the outputs from the MRSea analysis were predicted over all the grids based on relationships between the seabird data, environmental variables, and spatial locations within the model.




# Hornsea Four

Figure 1

Extent of the AfL

Array Area Plus 4 km Buffer

AfL

AfL Plus 4 km Buffer


Coordinate system: ETRS 1989 UTM Zone 31N

Scale@A3: 1:250,000

0 5 10 Kilometres

0 2 4 Nautical Miles

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Extent Of The AfL

Array Area Plus 4 km Buffer

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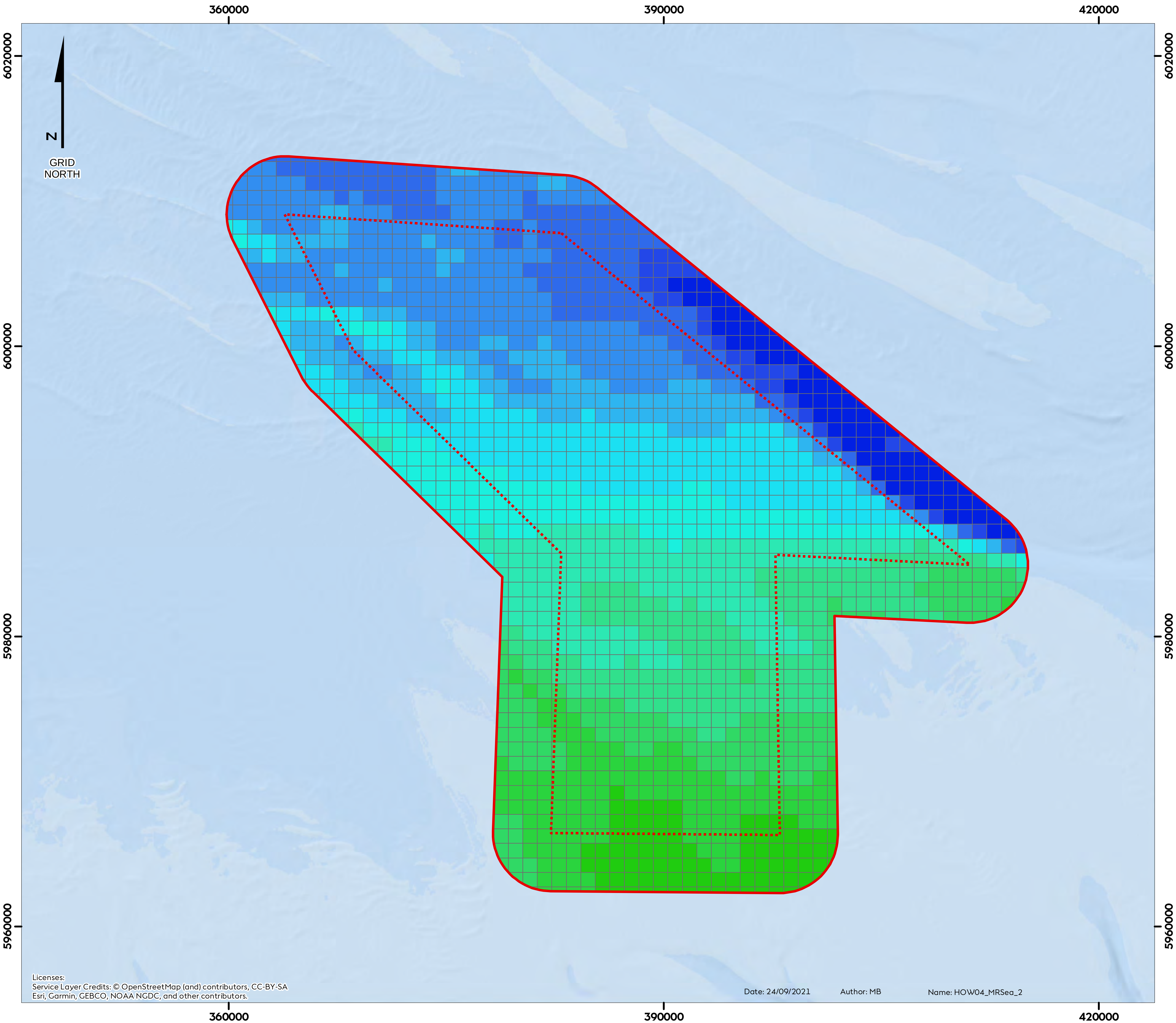
# Hornsea Four

## Figure 2

Bathymetry Data For the
AfL Array Area Plus 4 km Buffer




AfL
AfL Plus 4 km Buffer

Ocean Depth Relative to Sea Level (m)

- -29.79 - -26.16
- -32.45 - -29.80
- -35.09 - -32.46
- -37.69 - -35.10
- -40.55 - -37.70
- -44.23 - -40.56
- -48.35 - -44.24
- -51.95 - -48.36
- -55.51 - -51.96
- -61.57 - -55.52
- -69.66 - -61.58
- -79.55 - -69.67


Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:250,000
0 5 10 Kilometres
0 2 4 Nautical Miles

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Bathymetry Data For the
AfL Array Area Plus 4 km Buffer
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## 2.2 Modelling approach

2.2.1.1 The following methodology describes the steps used to undertake MRSea analysis. The method is similar to that described in APEM (2016), however there are a number of differences in the steps because of changes to the statistical package (Scott-Hayward pers. comm.) that have been developed since that time and in response to the specific questions the analysis is addressing, i.e. not investigating differences between temporal periods.

2.2.1.2 The bird survey data was analysed using the statistical package MRSea in R (R, being an open-source software for statistical computing). MRSea uses "Complex Region Spatial Smoother" spatial modelling techniques with a "Spatially Adaptive Local Smoothing Algorithm" (CReSS-SALSA; Mackenzie et al. (2014)) to estimate bird distributions in a GAM framework (Scott-Hayward et al. 2014).

2.2.1.3 This modelling method was developed specifically for dealing with offshore ornithological data collected for offshore wind farm projects, allowing spatially auto-correlated and zero-inflated data to be modelled in a robust method. Auto-Correlation Function (ACF) plots allow detection of spatial auto-correlation and an appropriate blocking structure, based on study design, was specified within the model to account for any auto-correlation detected. Confidence intervals, generated using CReSS, incorporate the uncertainty in the spatial model fitting process (Mackenzie et al. 2014). In addition, using the CReSS modelling method enables any spatial auto-correlation within the data to be incorporated providing more robust confidence intervals.

2.2.1.4 Following model selection and the creation of predictions, bootstrapping was used to generate 95% confidence intervals for each grid cell to allow for an assessment of uncertainty. The bootstrapping procedure incorporated any auto-correlation specified within the prediction model following the CReSS method.

## 2.3 Model details

2.3.1.1 For each species, the total number of individuals from the 24 months of surveys was used as the input data and the analysis was run twice for each species to cover different temporal periods: 1) spatial distribution for each of the 24 monthly surveys and; 2) average spatial distribution across bio-seasons as described by Furness (2015) and presented in **Table 1**, which are also in line with those described in **Annex 5.1: Offshore and Intertidal Ornithology Baseline Characterisation Report**. The monthly models were used to characterise the baseline environment; the seasonal models were created to visually represent the spatial distribution of seabirds within Hornsea Four and a 4 km buffer across the standard bio-seasons and can be found in **Annex 5.1: Offshore and Intertidal Ornithology Baseline Characterisation Report.**

**Table 1: Months included in each bio-season for each species.**

| Species | Migration Free Breeding | Post-Breeding Migration | Migration Free Winter | Return Migration |
|---|---|---|---|---|
| Fulmar | April - August | September - October | November | December - March |
| Gannet | April - August | September - November | - | December - March |
| Kittiwake | May - July | August - December | - | January - April |
| Great black-backed gull | May - July | August - November | December | January - April |
| Guillemot | March – June | July - October | November | December - February |
| Razorbill | April – July | August – October | November – December | January – March |
| Puffin | May - June | July - August | September – February | March - April |

2.3.1.2 The bird data from the aerial digital video surveys of the AfL plus a 4 km buffer was used for the analysis to create the most robust predictive model (OFF-ORN-1.21). The environmental covariates used to predict the species' distribution were bathymetry, X and Y coordinates, and distance to FFC SPA. Other environmental variables were not used due to data availability in the timescales of the project and the difficulty of accessing data of the same spatial and temporal scale as the survey data (OFF-ORN-1.22).

2.3.1.3 Auto-correlation within the data was first tested and if it was positive a blocking structure created from transect ID, survey date and month/season was included in the model. An initial Generalised Linear Model (GLM) was created to include the month/season (set as a factor term) and an offset term of area surveyed (survey effort). This was included in the Spatially Adaptive Local Smoothing Algorithm including one-dimensional variables (SALSA1D) analysis with the continuous variables, bathymetry, and distance to FFC SPA, to create a GAM to account for potential non-linear relationships (Walker et al. 2011).

2.3.1.4 Model selection in SALSA1D used the cv.gamMRSea fitness measure (unique MRSea measure to select the best model).The best model selected by the SALSA1D analysis, which may or may not include all the original variables, provided the base model for the two-dimensional (2D) spatial smoother model. This is run through the Spatially Adaptive Local Smoothing Algorithm including two-dimensional variables (SALSA2D) analysis which also incorporates the X and Y coordinates, a knot grid which provides the possible 300 knot locations across the study area and a distance matrix (distance between data and knots and distances between knots to knots, which is calculated from the input variables (OFF-ORN-1.23). SALSA2D analysis finds the appropriate number and location of knots for the 2D smooth term of X and Y coordinates (OFF-ORN-1.23). The best model from the SALSA2D analysis was checked for best fit by using plots of observed values versus fitted values and cumulative residual plots (OFF-ORN-1.20). The best model can have inaccurate p-values if auto-correlation still exists despite the blocking structure. Therefore, the variables were tested for auto-correlation and collinearity. If variables were collinear, they were removed from the initial model and the analysis run again. The Variance Inflation Factors, to show collinearity between covariates in each final model, are presented in **Appendix A** (OFF-ORN-1.20). If auto-correlation was still present, assessed with autocorrelation plots (OFF-ORN-1.20), a Generalised Estimating Equation (GEE) was created to incorporate the auto-correlation and provide realistic model-based estimates. The p-values from the GEE were used to assess the variables within the final model. The p-values for each covariate in the final models are presented in **Appendix A** (OFF-ORN-1.20).

2.3.1.5 The final model was used to calculate predictions of bird counts across the prediction grid (Hornsea Four array area plus a 4 km buffer) along with 95% Confidence Intervals. The predicted counts were clipped to show the predicted counts in the Hornsea Four array area plus a 4 km buffer, array area plus a 2 km buffer and array area only.

2.3.1.6 Density information for each species were obtained from the predicted counts of birds from the final model. Results are presented as: total predicted number of birds in each species group for each month/season, with the total confidence intervals (lower confidence interval (LCI) and upper confidence interval (UCI) and the average density per 1 km grid square (birds per km$^2$).

# 3 Results

## 3.1 Fulmar

### 3.1.1 Model Specifications

3.1.1.1 The MRSea analysis was run twice to predict fulmar abundance, (1) to predict abundance for each survey across 24 months and (2) to predict average abundance for each bio-season.

3.1.1.2 The final model specification equations were:

(1) fulmar = geeglm (as.factor (survey.number) + s (distance_SPA), family = quasipoisson (link=log))

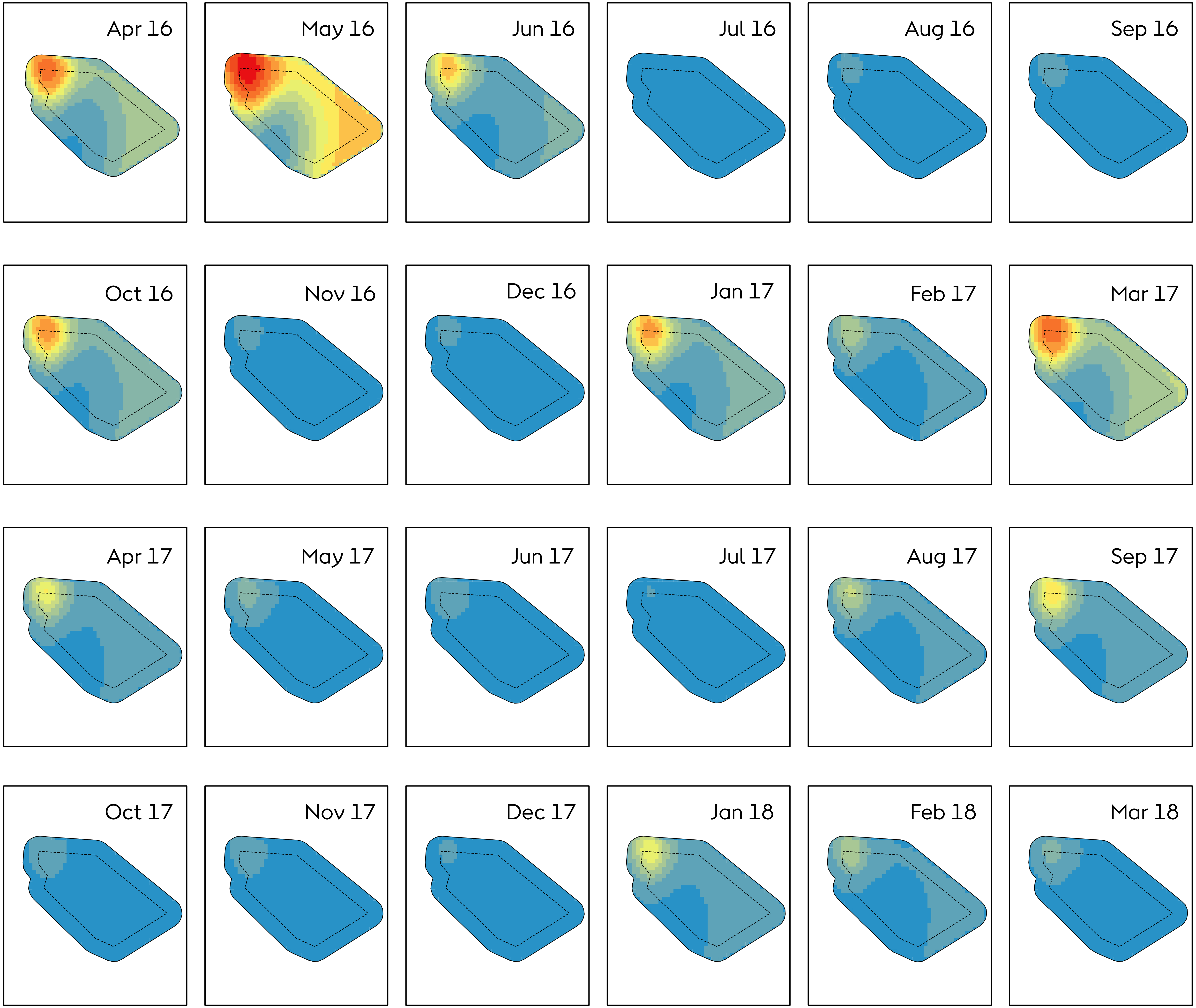
(2) fulmar = geeglm (as.factor (bioseason) + s (distance_SPA) family = quasipoisson (link=log))

3.1.1.3 Following the testing of each of the environmental input data by the SALSA1D analysis, as described in **Section 2.3.1.4**, bathymetry was not included as an influencing variable in either of the final models for fulmar.

3.1.1.4 The final model was used to predict abundance of fulmars in each 1 km$^2$ grid square across the AfL area plus a 4 km buffer. The area was then clipped to the Hornsea Four array area plus a 4 km buffer.

### 3.1.2 Spatial Density Distribution

3.1.2.1 The predicted abundances in each 1 km$^2$ grid square were used to create maps showing the variation in fulmar density across the array area plus the 4 km buffer. Predicted density across the Hornsea Four array area plus a 4 km buffer for each survey (**Figure 3**) and each of the bio-seasons (**Figure 4**) are presented here.




# Hornsea Four

Figure 3
Monthly Spatial Density Distribution of Fulmar Within Hornsea Four Plus 4 km Buffer

Array Area

Array Area plus 4 km Buffer

Predicted Fulmar Density (birds / km²)

- 0.00 - 0.15
- 0.16 - 0.30
- 0.31 - 0.40
- 0.41 - 0.50
- 0.51 - 0.59
- 0.60 - 0.67
- 0.68 - 0.75
- 0.76 - 0.88
- 0.89 - 1.09
- 1.10 - 1.37
- 1.38 - 1.75
- 1.76 - 2.14

N
GRID NORTH


Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:1,000,000
0 20 40 Kilometres
0 10 20 Nautical Miles

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Monthly Spatial Density
Distribution of Fulmar Within
Hornsea Four Plus 4 km Buffer
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Checked by: SS
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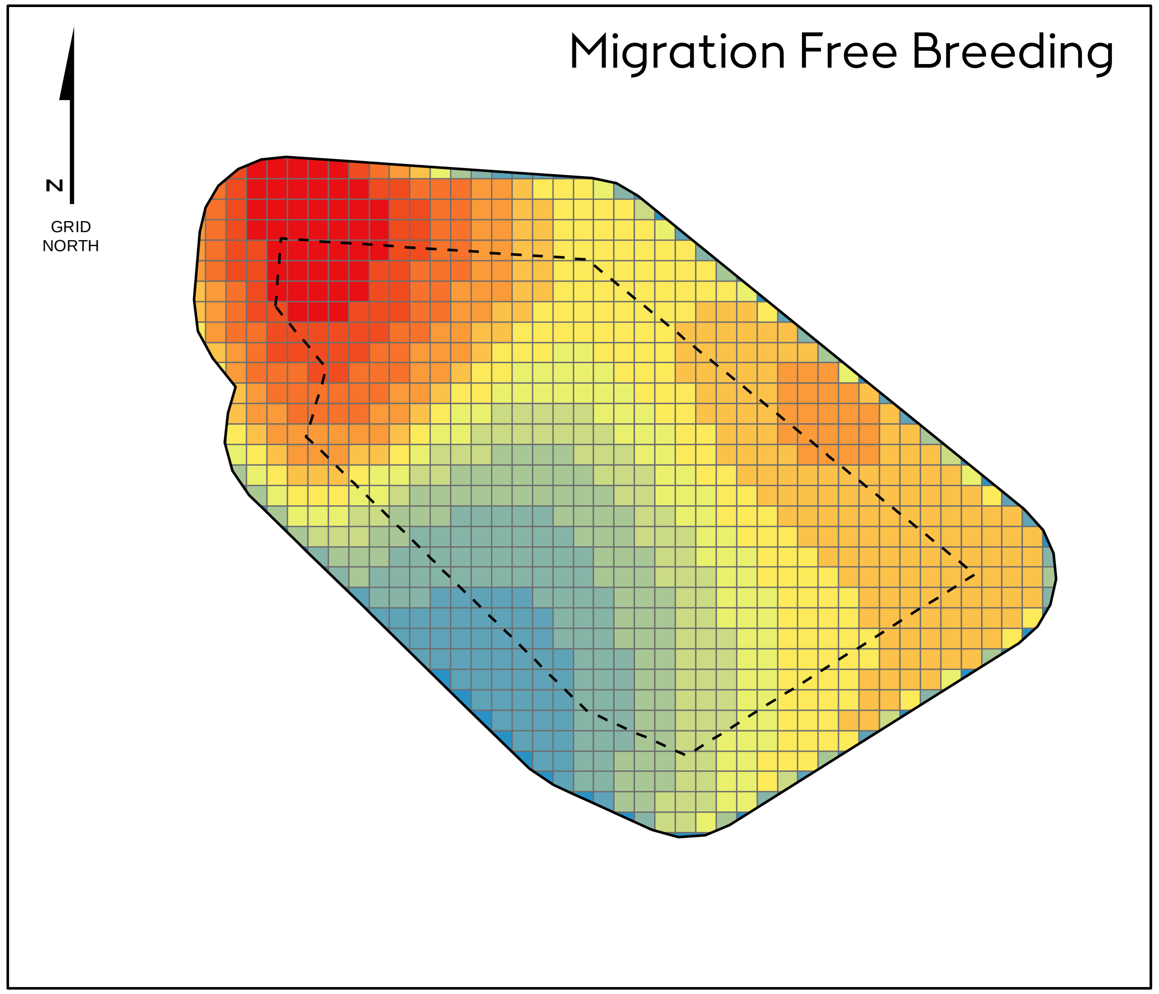
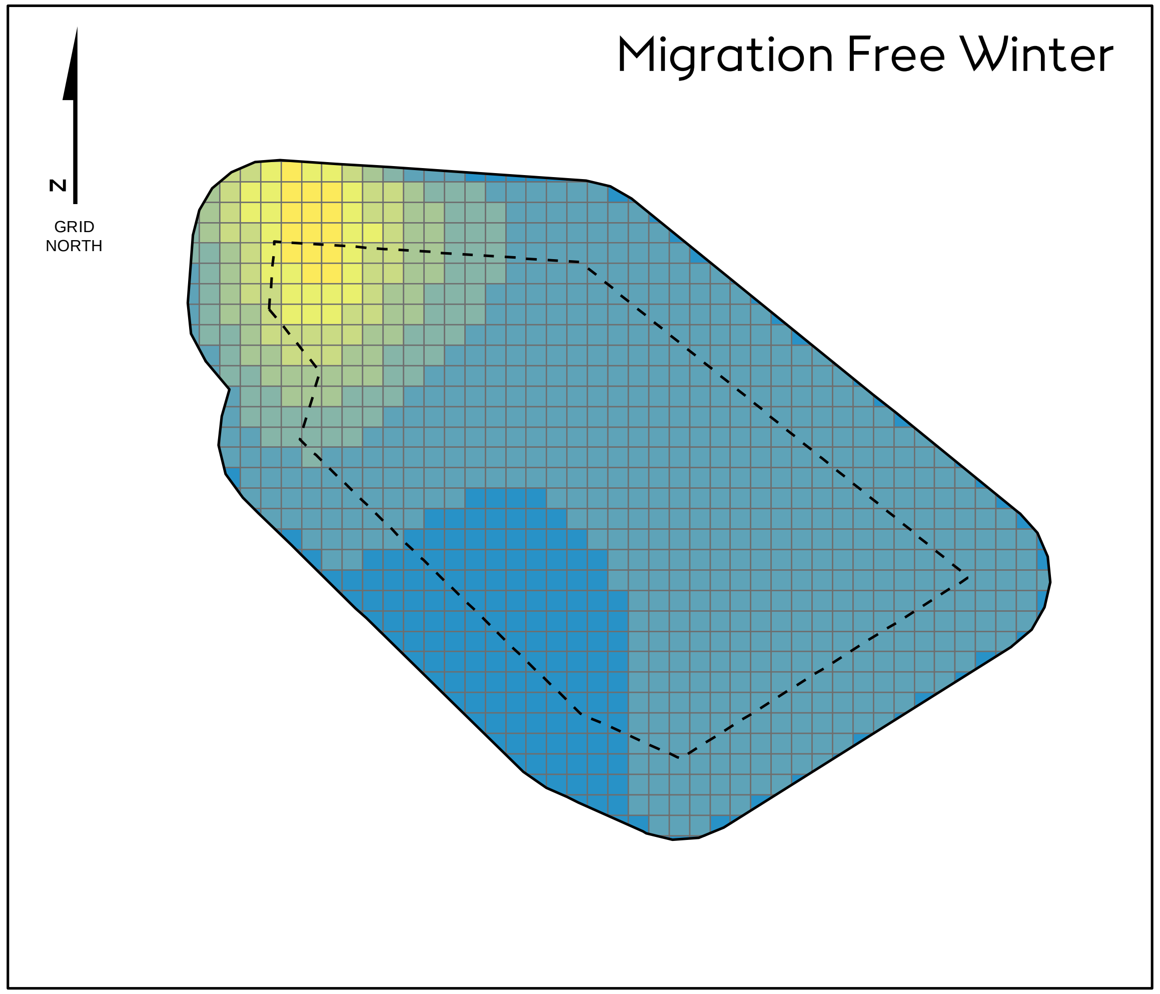
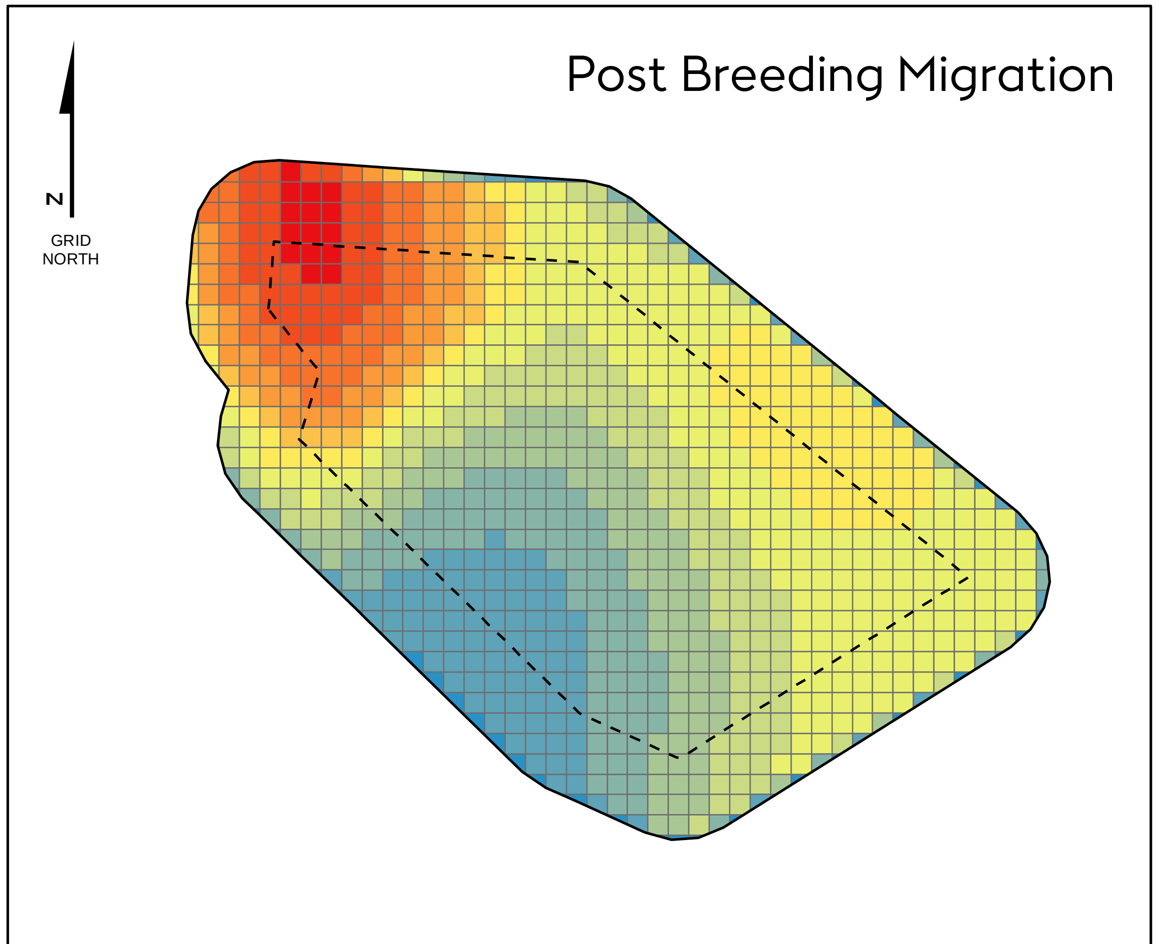
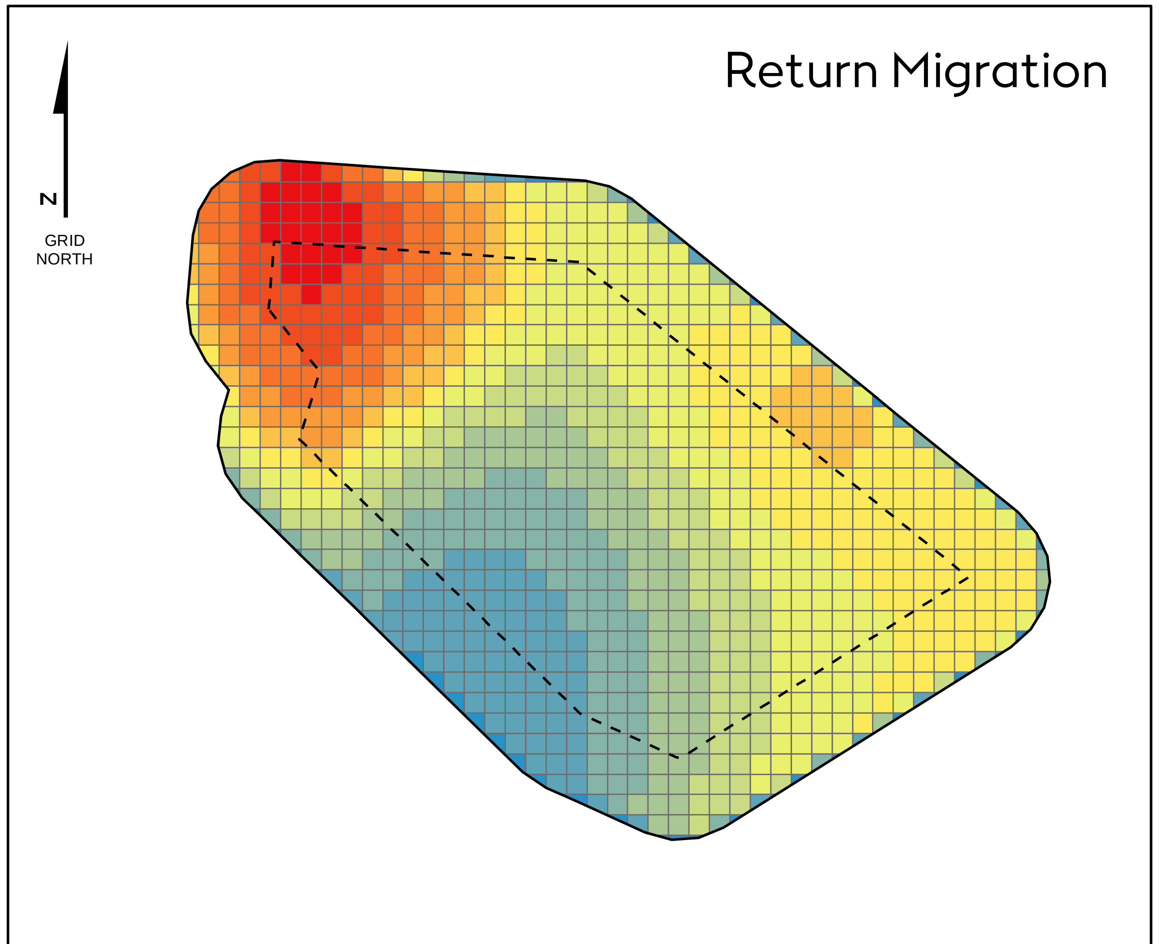
Date: 08/06/2021 Author: MB Name: HOW04_MRSea_3




# Hornsea Four

Figure 4

Bio-season Spatial Density Distribution of Fulmar Within Hornsea Four Plus 4 km Buffer

Array Area

Array Area 4 km buffer

Predicted fulmar density (birds / km$^2$)

- 0.00 - 0.05
- 0.05 - 0.09
- 0.09 - 0.12
- 0.12 - 0.15
- 0.15 - 0.18
- 0.18 - 0.20
- 0.20 - 0.22
- 0.22 - 0.25
- 0.25 - 0.30
- 0.30 - 0.39
- 0.39 - 0.49
- 0.49 - 0.61


Coordinate system: ETRS 1989 UTM Zone 31N

Scale@A3: 1:370,000

0 10 20 Kilometres

0 5 10 Nautical Miles

| REV | REMARK | DATE |
|---|---|---|
| | First Issue | 08/06/2021 |

Bio-season Spatial Density Distribution of Fulmar Within Hornsea Four Plus 4 km Buffer
Document no: HOW04_MRSea_4
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Approved by: SS

Ørsted



Date: 08/06/2021 Author: MB Name: HOW04_MRSea_4_10.6

### 3.1.3 Summary of Fulmar Abundance

3.1.3.1 Density of all fulmars in the Hornsea Four array area plus a 4 km buffer was extracted from the predicted abundance. The modelled abundance and average density (birds per km$^2$) for each survey (**Table 2**) and for each bio-season (**Table 3**) are presented here.

**Table 2: Modelled fulmar abundance for each survey, Lower and Upper 95% Confidence Intervals (LCI and UCI) and density of fulmars for all behaviours in the Hornsea Four array area plus a 4 km buffer.**

| Survey | Total abundance estimate | LCI | UCI | Density (birds per km$^2$) |
|---|---|---|---|---|
| Apr-2016 | 385.62 | 245.74 | 613.61 | 0.43 |
| Jun-2016 (01) | 659.28 | 391.63 | 1065.01 | 0.74 |
| Jun-2016 (02) | 255.65 | 99.60 | 532.71 | 0.29 |
| Jul-2016 | 41.54 | 17.84 | 86.39 | 0.05 |
| Aug-2016 | 59.38 | 29.30 | 123.81 | 0.07 |
| Sep-2016 | 65.45 | 35.10 | 131.78 | 0.07 |
| Oct-2016 | 307.67 | 167.01 | 537.28 | 0.35 |
| Nov-2016 | 65.29 | 32.99 | 142.82 | 0.07 |
| Dec-2016 | 59.19 | 31.05 | 110.44 | 0.07 |
| Jan-2017 | 296.19 | 172.91 | 509.90 | 0.33 |
| Feb-2017 | 154.12 | 89.13 | 266.71 | 0.17 |
| Mar-2017 | 397.64 | 144.21 | 1278.10 | 0.45 |
| Apr-2017 | 207.48 | 72.77 | 516.09 | 0.23 |
| May-2017 | 112.76 | 63.74 | 200.22 | 0.13 |
| Jun-2017 | 83.14 | 40.82 | 171.21 | 0.09 |
| Jul-2017 | 47.46 | 20.72 | 119.93 | 0.05 |
| Aug-2017 | 160.38 | 102.06 | 272.42 | 0.18 |
| Sep-2017 | 231.18 | 137.24 | 410.12 | 0.26 |
| Oct-2017 | 81.64 | 25.17 | 373.58 | 0.09 |
| Nov-2017 | 77.40 | 38.98 | 176.07 | 0.09 |
| Dec-2017 | 53.43 | 23.43 | 118.66 | 0.06 |
| Jan-2018 | 206.15 | 122.69 | 343.13 | 0.23 |
| Feb-2018 | 148.19 | 84.80 | 259.30 | 0.17 |
| Mar-2018 | 106.83 | 60.91 | 200.88 | 0.12 |

**Table 3: Modelled fulmar abundance for each bio-season, Lower and Upper 95% Confidence Intervals (LCI and UCI) and density of fulmars for all behaviours in the Hornsea Four array area plus a 4 km buffer.**

| Bio-season | Average abundance estimate | LCI | UCI | Density (birds per km$^2$) |
|---|---|---|---|---|
| Migration Free Breeding | 433.38 | 246.85 | 790.55 | 0.49 |
| Post-Breeding Migration | 269.42 | 152.13 | 473.70 | 0.30 |
| Migration Free Winter | 71.35 | 35.98 | 159.70 | 0.08 |
| Return Migration | 301.89 | 147.80 | 810.61 | 0.34 |

## 3.2 Gannet

### 3.2.1 Model Specifications

3.2.1.1 The MRSea analysis was run twice to predict gannet abundance, (1) to predict abundance for each survey across 24 months and (2) to predict average abundance for each bio-season.

3.2.1.2 The final model specification equations were:

(1) gannet = geeglm (as.factor (survey.number) + depth, family = quasipoisson (link = log))

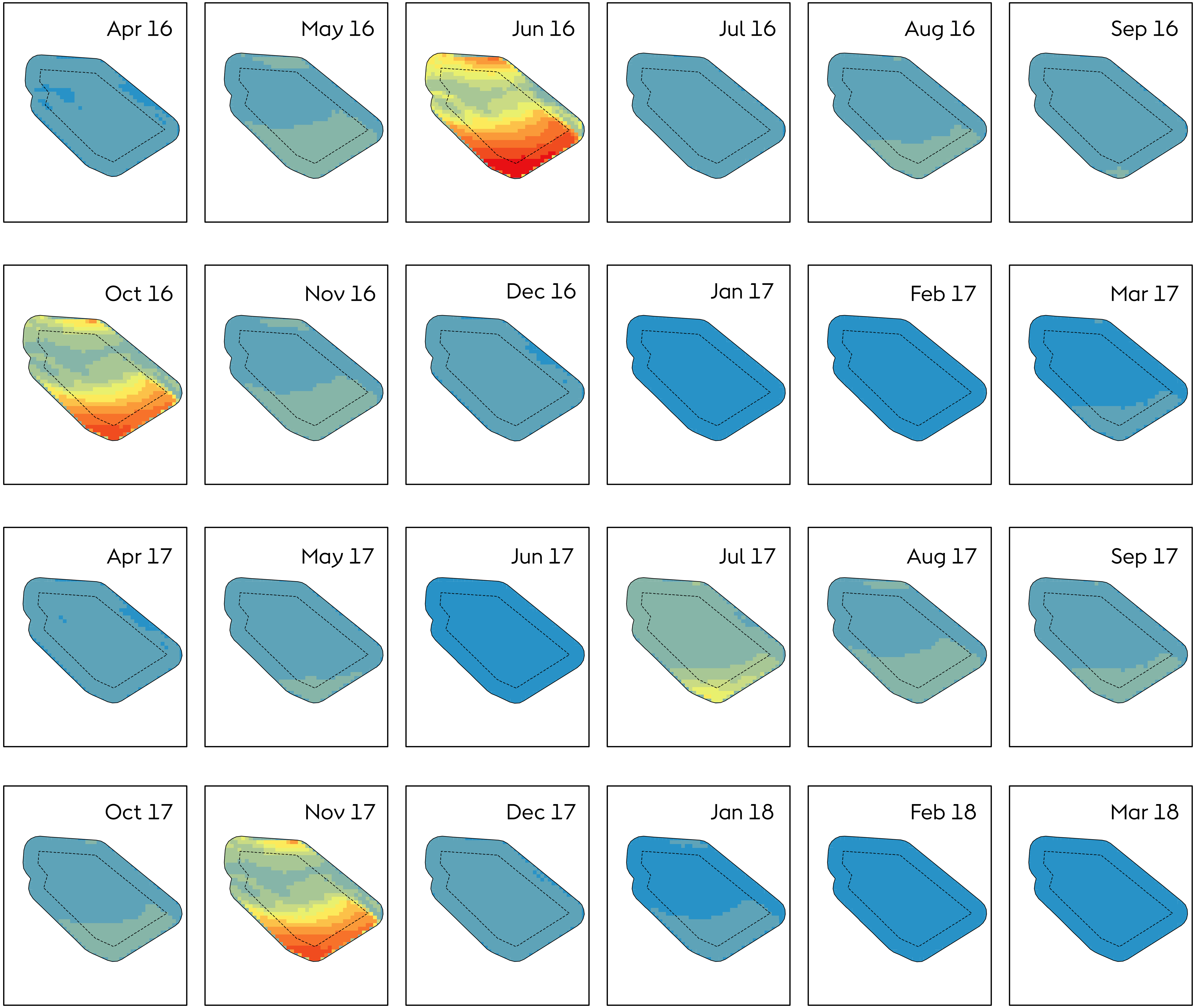
(2) gannet = geeglm (as.factor (bioseason) + s (depth), family = quasipoisson (link = log))

3.2.1.3 Following the testing of each of the environmental input data by the SALSA1D analysis, as described in **Section 2.3.1.4**, distance to SPA was not included as an influencing variable in either of the final models for gannet.

3.2.1.4 The final model was used to predict density of gannets in each 1 $km^2$ grid square across the AfL area plus a 4 km buffer. The area was then clipped to the Hornsea Four array area plus a 4 km buffer.

### 3.2.2 Spatial Density Distribution

3.2.2.1 The predicted abundances in each 1 $km^2$ grid square were used to create maps showing the variation in gannet density across the array area plus the 4 km buffer. Predicted density across the Hornsea Four array area plus a 4 km buffer for each survey (**Figure 5**) and each of the bio-seasons (**Figure 6**) are presented here.




# Hornsea Four

Figure 5
Monthly Spatial Density Distribution of Gannet Within Hornsea Four Plus 4 km Buffer

Array Area

Array Area plus 4 km Buffer

Predicted Gannet Density (birds / km²)

0.00 - 0.27
0.28 - 0.71
0.72 - 1.10
1.11 - 1.22
1.23 - 1.28
1.29 - 1.35
1.36 - 1.42
1.43 - 1.50
1.51 - 1.60
1.61 - 1.73
1.74 - 1.87
1.88 - 2.06

N
GRID NORTH


Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:1,000,000
0 20 40 Kilometres
0 10 20 Nautical Miles

| REV | REMARK | DATE |
|---|---|---|
| | First Issue | 08/06/2021 |

Monthly Spatial Density
Distribution of Gannet Within
Hornsea Four Plus 4 km Buffer
Document no: HOW04_MRSea_5
Created by: MB
Checked by: SS
Approved by: SS

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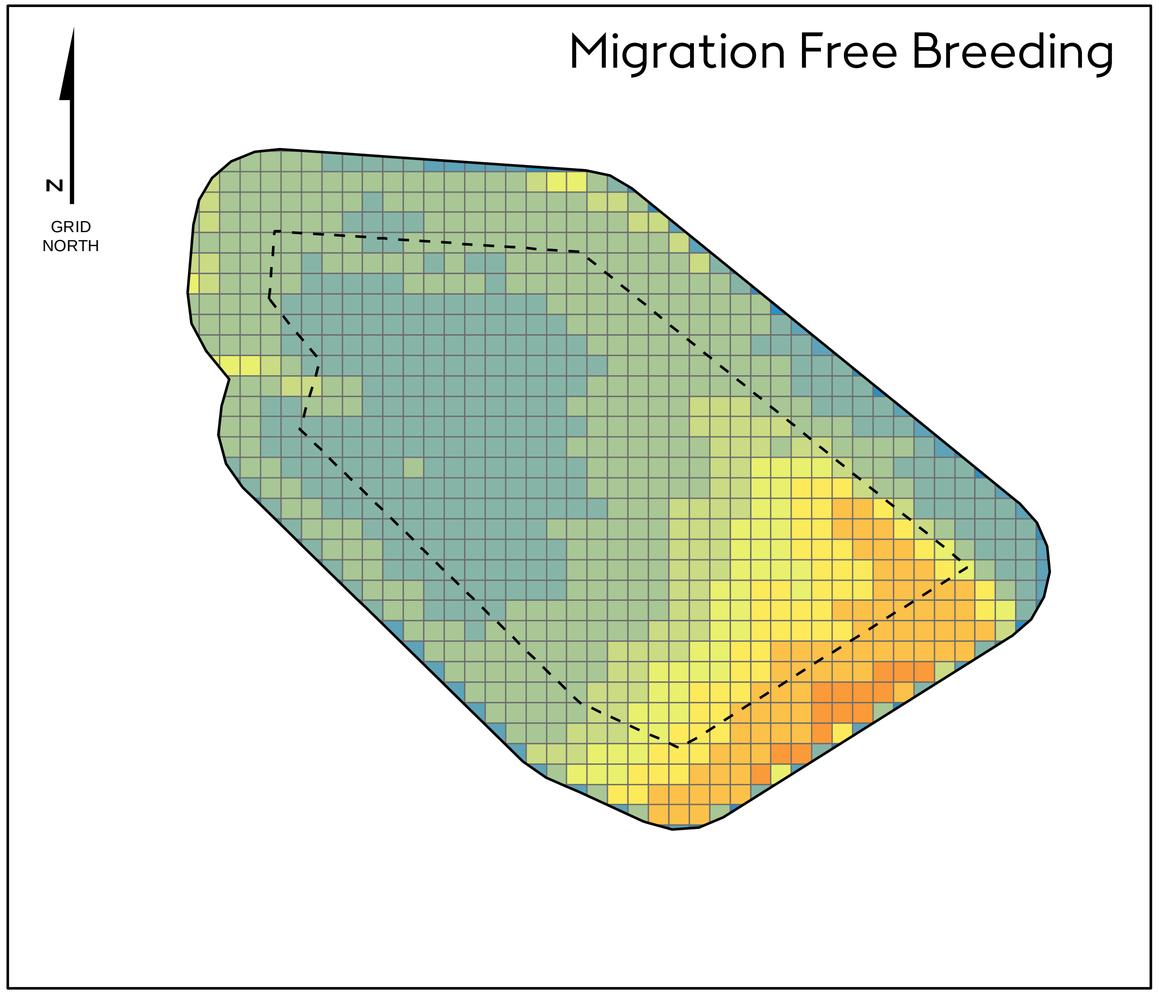
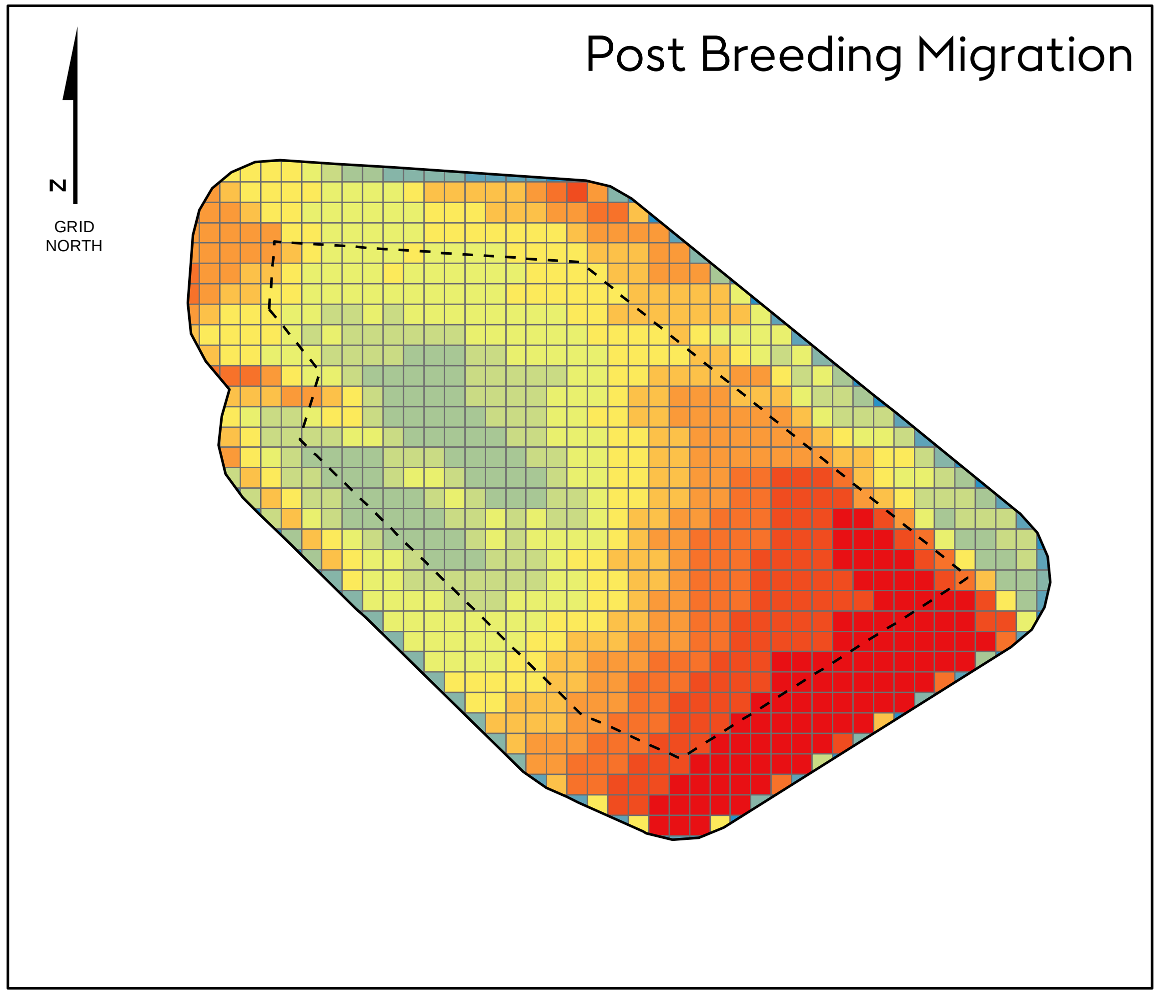
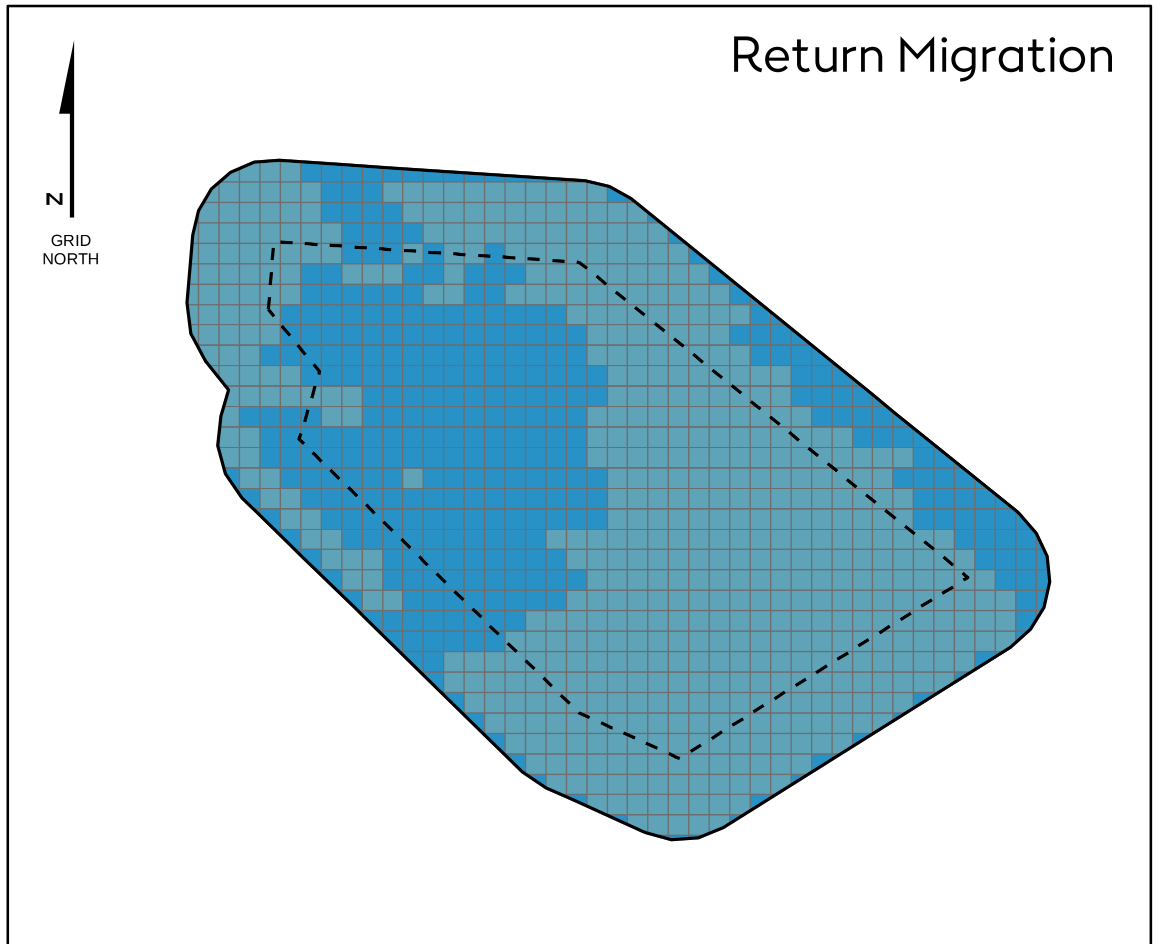
Date: 08/06/2021 Author: MB Name: HOW04_MRSea_5






# Hornsea Four

## Figure 6

Bio-season Spatial Density Distribution of Gannet Within Hornsea Four Plus 4 km Buffer

- Array Area
- Array Area 4 km buffer

Predicted gannet density (birds / km²)

- 0.00 - 0.16
- 0.16 - 0.37
- 0.37 - 0.55
- 0.55 - 0.66
- 0.66 - 0.71
- 0.71- 0.76
- 0.76 - 0.80
- 0.80 - 0.86
- 0.86 - 0.92
- 0.92- 0.99
- 0.99 - 1.07
- 1.07 - 1.18


Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:370,000

0 10 20 Kilometres
0 5 10 Nautical Miles

| REV | REMARK | DATE |
|---|---|---|
| | First Issue | 08/06/2021 |
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Bio-season Spatial Density Distribution of Gannet Within Hornsea Four Plus 4 km Buffer
Document no: HOW04_MRSea_6
Created by: MB
Checked by: SS
Approved by: SS

Ørsted

Date: 08/06/2021 Author: MB Name: HOW04_MRSea_6_10.6

### 3.2.3 Summary of Gannet Abundance

3.2.3.1 Density of all gannets in the Hornsea Four array area plus a 4 km buffer was extracted from the predicted abundance. The modelled abundance and average density (birds per km$^2$) for each survey (Table 4) and for each bio-season (Table 5) are presented here.

**Table 4: Modelled gannet abundance for each survey, Lower and Upper 95% Confidence Intervals (LCI and UCI) and density of gannets for all behaviours in the Hornsea Four array area plus a 4 km buffer.**

| Survey | Total abundance estimate | LCI | UCI | Density (birds per km$^2$) |
|---|---|---|---|---|
| Apr-2016 | 288.42 | 147.31 | 652.78 | 0.32 |
| Jun-2016 (01) | 639.23 | 404.42 | 1061.26 | 0.72 |
| Jun-2016 (02) | 1265.07 | 850.43 | 1826.65 | 1.42 |
| Jul-2016 | 407.18 | 258.81 | 637.77 | 0.46 |
| Aug-2016 | 553.99 | 336.38 | 965.30 | 0.62 |
| Sep-2016 | 450.51 | 297.98 | 718.43 | 0.51 |
| Oct-2016 | 1134.77 | 817.05 | 1529.97 | 1.28 |
| Nov-2016 | 624.92 | 437.66 | 966.75 | 0.70 |
| Dec-2016 | 302.92 | 154.97 | 523.78 | 0.34 |
| Jan-2017 | 9.46 | 2.59 | 34.39 | 0.01 |
| Feb-2017 | 66.13 | 39.86 | 114.10 | 0.07 |
| Mar-2017 | 203.60 | 100.19 | 495.96 | 0.23 |
| Apr-2017 | 293.37 | 117.95 | 674.45 | 0.33 |
| May-2017 | 496.88 | 253.60 | 1248.47 | 0.56 |
| Jun-2017 | 146.86 | 87.26 | 241.68 | 0.17 |
| Jul-2017 | 834.53 | 466.16 | 1520.58 | 0.94 |
| Aug-2017 | 620.12 | 434.24 | 971.05 | 0.70 |
| Sep-2017 | 539.36 | 331.97 | 889.82 | 0.61 |
| Oct-2017 | 565.72 | 369.17 | 942.89 | 0.64 |
| Nov-2017 | 1133.78 | 656.87 | 1926.38 | 1.28 |
| Dec-2017 | 321.92 | 144.22 | 709.74 | 0.36 |
| Jan-2018 | 226.27 | 93.29 | 603.49 | 0.25 |
| Feb-2018 | 14.20 | 4.96 | 39.33 | 0.02 |
| Mar-2018 | 118.29 | 59.12 | 261.06 | 0.13 |

**Table 5: Modelled gannet abundance for each bio-season, Lower and Upper 95% Confidence Intervals (LCI and UCI) and density of gannets for all behaviours in the Hornsea Four array area plus a 4 km buffer.**

| Bio-season | Average abundance estimate | LCI | UCI | Density (birds per km$^2$) |
|---|---|---|---|---|
| Migration Free Breeding | 1049.80 | 658.29 | 1673.62 | 1.18 |
| Post-Breeding Migration | 1134.27 | 736.96 | 1728.18 | 1.28 |
| Return Migration | 312.42 | 149.60 | 616.76 | 0.35 |

## 3.3 Kittiwake

### 3.3.1 Model Specifications

3.3.1.1 The MRSea analysis was run twice to predict kittiwake abundance, (1) to predict abundance for each survey across 24 months and (2) to predict average abundance for each bio-season.

3.3.1.2 The final model specification equations were:

(1) kittiwake = geeglm (as.factor (survey.number) + s (depth) + s (distance_SPA), family = quasipossion (link = log))

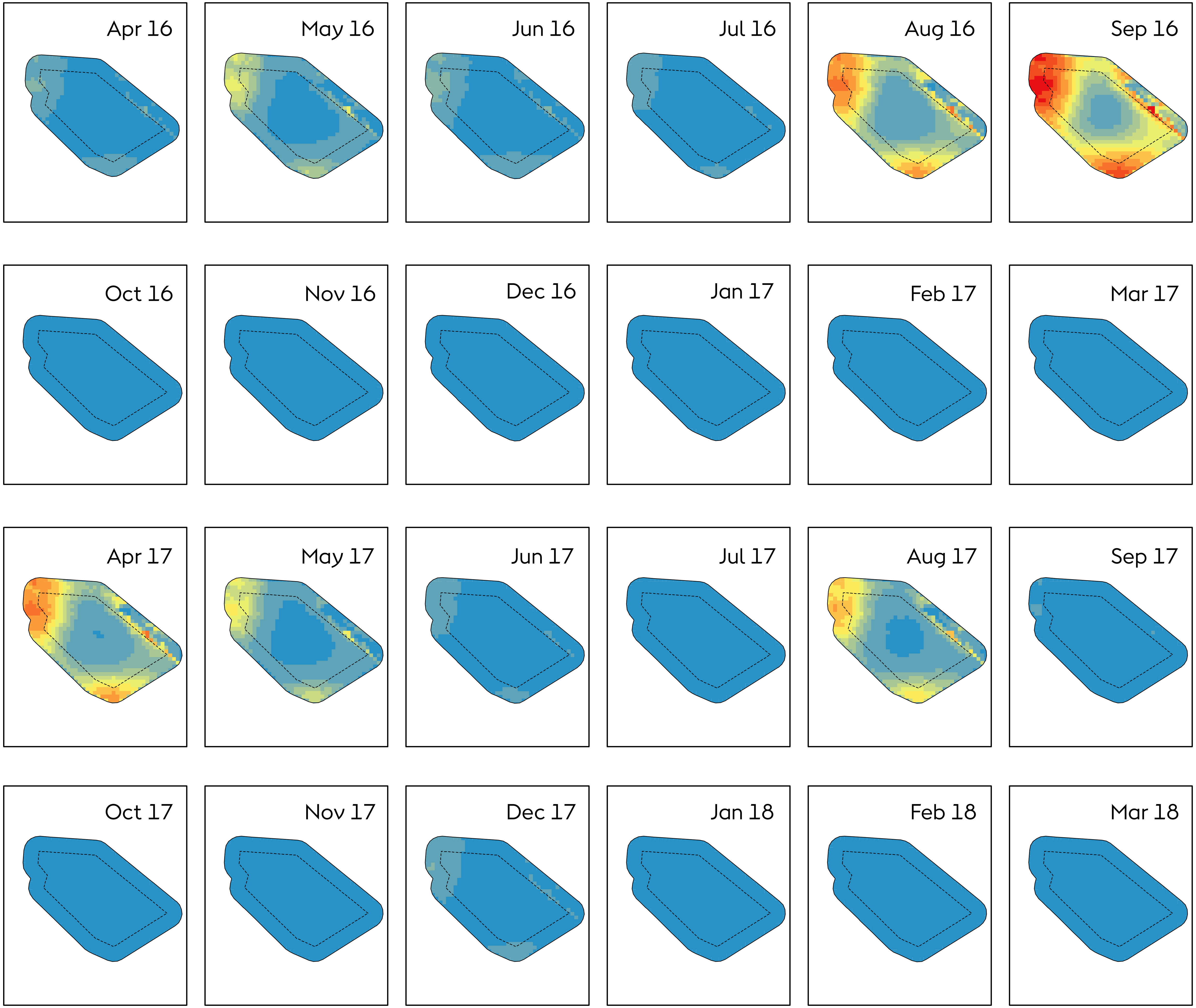
(2) kittiwake = geeglm (as.factor (bioseason) + s (depth), family = quasipossion (link = log))

3.3.1.3 Following the testing of each of the environmental input data by the SALSA1D analysis, as described in **Section 2.3.1.4**, distance to SPA was not included as an influencing variable in either of the final models for kittiwake.

3.3.1.4 The final model was used to predict abundances of kittiwakes in each 1 $km^2$ grid square across the AfL area plus a 4 km buffer. The area was then clipped to the Hornsea Four array area plus a 4 km buffer.

### 3.3.2 Spatial Density Distribution

3.3.2.1 The predicted abundances in each 1 $km^2$ grid square were used to create maps showing the variation in kittiwake density across the array area plus the 4 km buffer. Predicted density across the Hornsea Four array area plus a 4 km buffer for each survey (**Figure 7**) and each of the bio-seasons (**Figure 8**) are presented here.




# Hornsea Four

Figure 7

Monthly Spatial Density Distribution of Kittiwake Within Hornsea Four Plus 4 km Buffer

Array Area

Array Area plus 4 km Buffer

Predicted Kittiwake Density (birds / km²)

- 0.00 - 2.10
- 2.11 - 4.24
- 4.25 - 5.52
- 5.53 - 6.78
- 6.79 - 8.03
- 8.04 - 9.47
- 9.48 - 11.44
- 11.45 - 14.24
- 14.25 - 17.97
- 17.98 - 22.04
- 22.05 - 26.05
- 26.06 - 31.84

N
GRID NORTH


Coordinate system: ETRS 1989 UTM Zone 31N

Scale@A3: 1:1,000,000

0 20 40 Kilometres

0 10 20 Nautical Miles

| REV | REMARK | DATE |
|---|---|---|
| | First Issue | 08/06/2021 |

Monthly Spatial Density Distribution of Kittiwake Within Hornsea Four Plus 4 km Buffer
Document no: HOW04_MRSea_7
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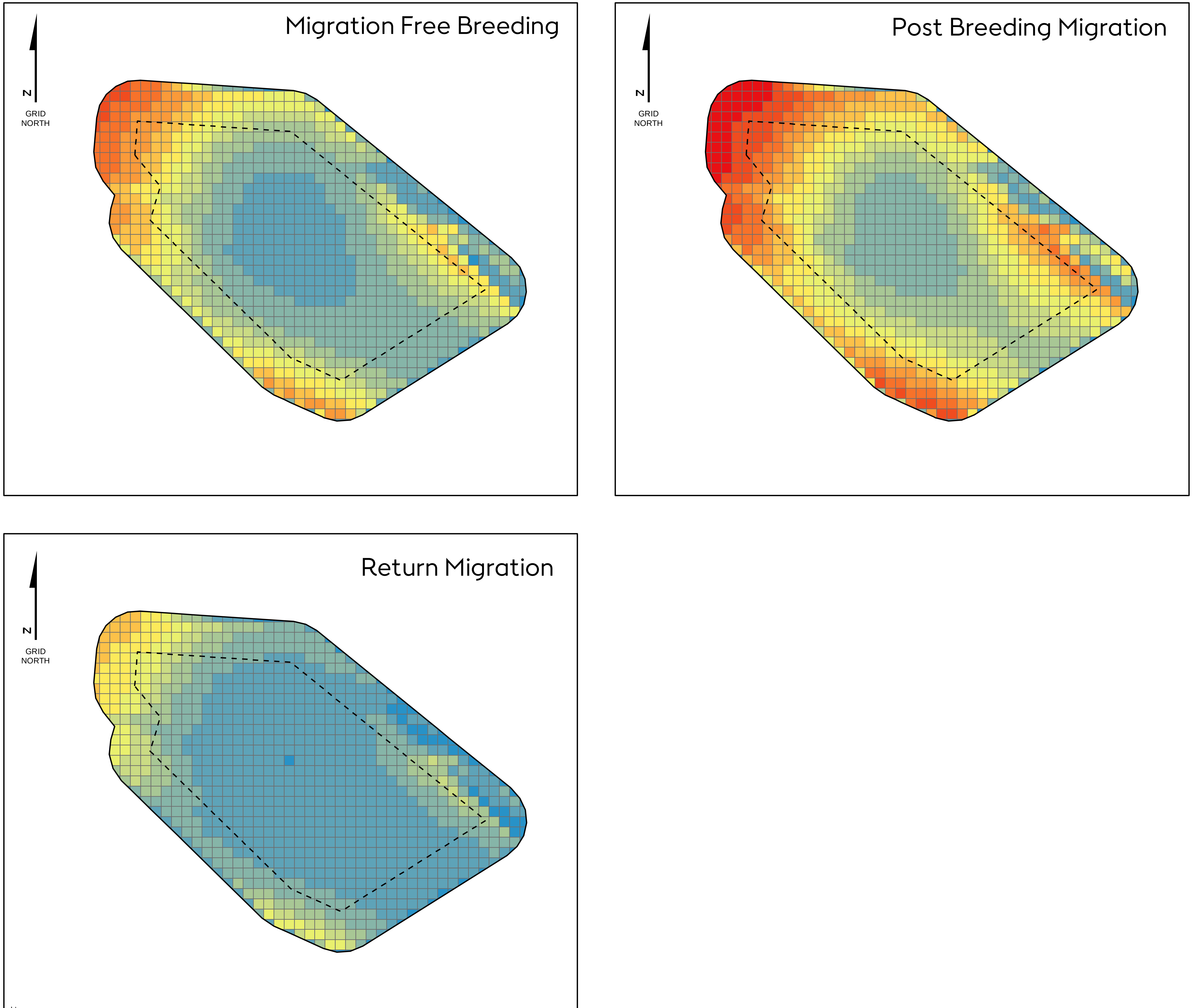
Date: 08/06/2021 Author: MB Name: HOW04_MRSea_7




# Hornsea Four

## Figure 8

Bio-season Spatial Density Distribution of Kittiwake Within Hornsea Four Plus 4 km Buffer

Array Area

Array Area 4 km buffer

Predicted kittiwake density (birds / km²)

- 0.00 - 0.57
- 0.57 - 1.14
- 1.14 - 1.50
- 1.50 - 1.77
- 1.77 - 2.04
- 2.04 - 2.35
- 2.35 - 2.73
- 2.73 - 3.17
- 3.17 - 3.69
- 3.69 - 4.31
- 4.31 - 5.05
- 5.05 - 6.33


Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:370,000

0 10 20 Kilometres

0 5 10 Nautical Miles

| REV | REMARK | DATE |
|---|---|---|
| | First Issue | 08/06/2021 |

Bio-season Spatial Density Distribution of Kittiwake Within Hornsea Four Plus 4 km Buffer
Document no: HOW04_MRSea_8
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Approved by: SS

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Date: 08/06/2021 Author: MB Name: HOW04_MRSea_8_10.6

### 3.3.3 Summary of Kittiwake Abundance

3.3.3.1 Density of all kittiwakes in the Hornsea Four array area plus a 4 km buffer was extracted from the predicted abundance. The modelled abundance and average density (birds per km$^2$) for each survey (Table 6) and for each bio-season (Table 7) are presented here.

**Table 6: Modelled kittiwake abundance for each survey, Lower and Upper 95% Confidence Intervals (LCI and UCI) and density of kittiwakes for all behaviours in the Hornsea Four array area plus a 4 km buffer.**

| Survey | Total abundance estimate | LCI | UCI | Density (birds per km$^2$) |
|---|---|---|---|---|
| Apr-2016 | 1497.95 | 846.98 | 2943.84 | 1.69 |
| Jun-2016 (01) | 2796.02 | 1479.29 | 5074.00 | 3.15 |
| Jun-2016 (02) | 1701.53 | 966.87 | 3024.47 | 1.92 |
| Jul-2016 | 1082.97 | 581.97 | 1972.34 | 1.22 |
| Aug-2016 | 6464.37 | 3587.91 | 11566.33 | 7.28 |
| Sep-2016 | 9843.29 | 5372.02 | 20341.68 | 11.08 |
| Oct-2016 | 103.73 | 33.01 | 308.04 | 0.12 |
| Nov-2016 | 62.30 | 29.55 | 139.65 | 0.07 |
| Dec-2016 | 181.37 | 91.68 | 352.53 | 0.20 |
| Jan-2017 | 344.35 | 174.87 | 740.13 | 0.39 |
| Feb-2017 | 29.70 | 12.93 | 72.45 | 0.03 |
| Mar-2017 | 337.91 | 153.75 | 817.99 | 0.38 |
| Apr-2017 | 6214.04 | 2818.43 | 13273.91 | 6.99 |
| May-2017 | 3158.59 | 1762.19 | 5863.56 | 3.56 |
| Jun-2017 | 1102.01 | 509.54 | 2266.34 | 1.24 |
| Jul-2017 | 556.69 | 291.52 | 1106.11 | 0.63 |
| Aug-2017 | 4492.47 | 1920.55 | 12232.33 | 5.06 |
| Sep-2017 | 710.84 | 180.53 | 3102.95 | 0.80 |
| Oct-2017 | 78.70 | 34.87 | 194.24 | 0.09 |
| Nov-2017 | 326.69 | 158.39 | 724.82 | 0.37 |
| Dec-2017 | 1345.29 | 587.05 | 3041.25 | 1.51 |
| Jan-2018 | 150.50 | 82.62 | 266.84 | 0.17 |
| Feb-2018 | 347.31 | 176.16 | 664.45 | 0.39 |
| Mar-2018 | 180.91 | 92.42 | 389.21 | 0.20 |

**Table 7: Modelled kittiwake abundance for each bio-season, Lower and Upper 95% Confidence Intervals (LCI and UCI) and density of kittiwakes in the Hornsea Four array area plus a 4 km buffer.**

| Bio-season | Average abundance estimate | LCI | UCI | Density (birds per km$^2$) |
|---|---|---|---|---|
| Migration Free Breeding | 2977.31 | 1620.74 | 5468.78 | 3.35 |
| Post-Breeding Migration | 7167.88 | 3646.29 | 16287.00 | 8.07 |
| Return Migration | 3069.98 | 1504.13 | 6387.20 | 3.46 |

## 3.4 Great black-backed gull

### 3.4.1 Model Specifications

3.4.1.1 The MRSea analysis was run twice to predict great black-backed gull abundance, (1) to predict abundance for each survey across 24 months and (2) to predict average abundance for each bio-season.

3.4.1.2 The final model specification equations were:

(1) great black-backed gull = geeglm (as.factor (survey.number) + depth, family = quasipoisson (link = log))

(2) great black-backed gull = geeglm (as.factor (bioseason) + s (depth), family = quasipoisson (link = log))

3.4.1.3 Following the testing of each of the environmental input data by the SALSA1D analysis, as described in **Section 2.3.1.4**, distance to SPA was not included as an influencing variable in either of the final models for great black-backed gull.

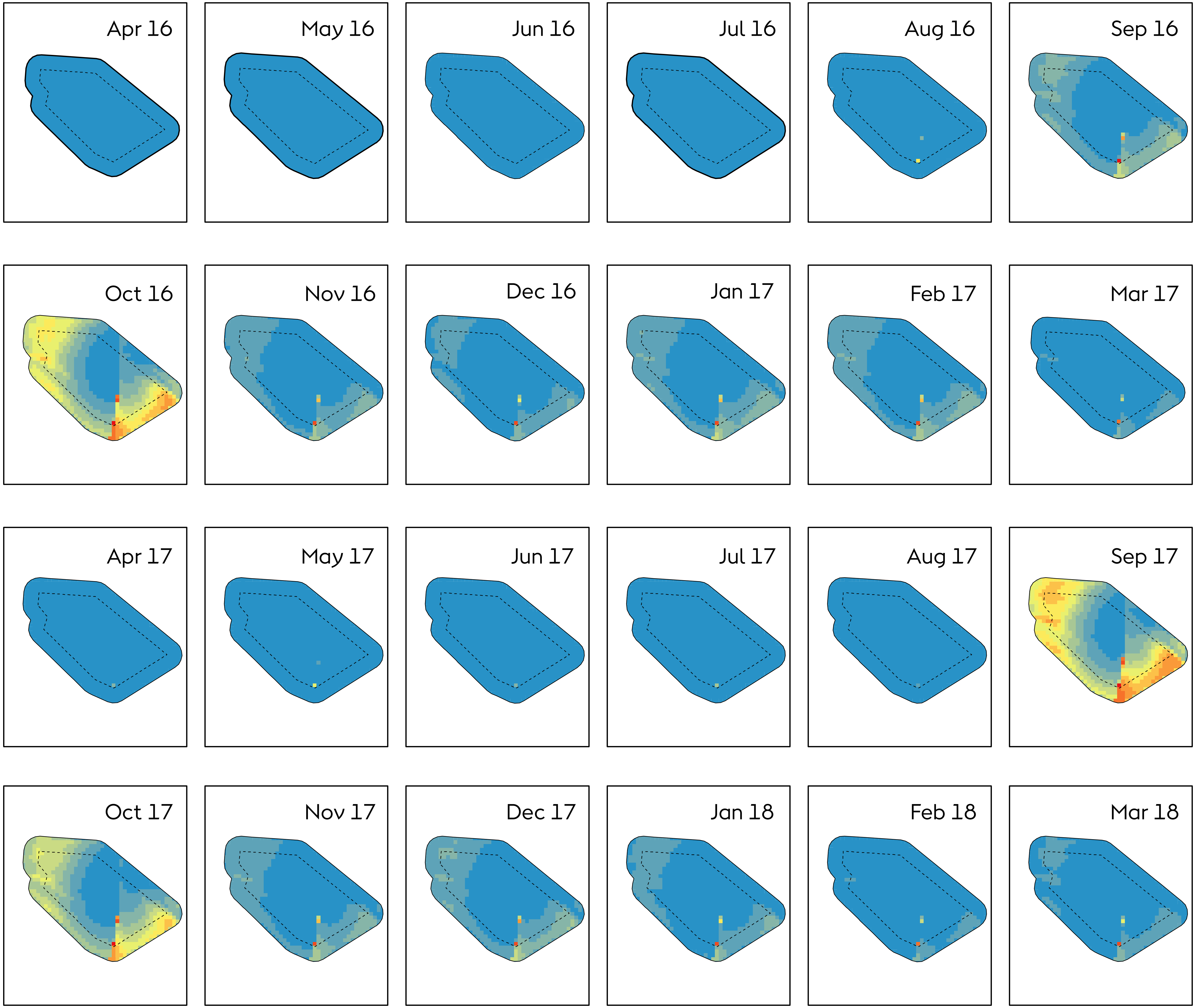
3.4.1.4 The final model was used to predict the abundance of great black-backed gull in each 1 $km^2$ grid square across the AfL area plus a 4 km buffer. The area was then clipped to the Hornsea Four array area plus a 4 km buffer.

### 3.4.2 Spatial Density Distribution

3.4.2.1 The predicted abundances in each 1 $km^2$ grid square were used to create maps showing the variation in great black-backed gull density across the array area plus the 4 km buffer. Predicted density across the Hornsea Four array area plus a 4 km buffer for each survey (**Figure 9**) and each of the bio-seasons (**Figure 10**) are presented here. In **Figure 9**, there are a small number of abundance hotspots in the south of the array area, which have resulted from instances of clumping of this species recorded within the AfL area. The clumping will have likely resulted from a fishing vessel, food resource or may be an artefact of clumping of birds at specific values of the environmental variables (distance to SPA and bathymetry).

# Hornsea Four

Figure 9
Monthly Spatial Density Distribution of Great Black-backed Gull Within Hornsea Four Plus 4 km Buffer




Array Area

Array Area plus 4 km Buffer

Predicted Great Black-backed Gull Density (birds / km²)

- 0.00 - 0.13
- 0.14 - 0.25
- 0.26 - 0.39
- 0.40 - 0.54
- 0.55 - 0.69
- 0.70 - 0.85
- 0.86 - 1.03
- 1.04 - 1.30
- 1.31 - 1.75
- 1.76 - 2.65
- 2.66 - 5.56
- 5.57 - 21.43

N
GRID NORTH


Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:1,000,000

0 20 40 Kilometres

0 10 20 Nautical Miles

| REV | REMARK | DATE |
|---|---|---|
| | First Issue | 08/06/2021 |

Monthly Spatial Density Distribution of Great Black-backed Gull Within Hornsea Four Plus 4 km Buffer
Document no: HOW04_MRSea_9
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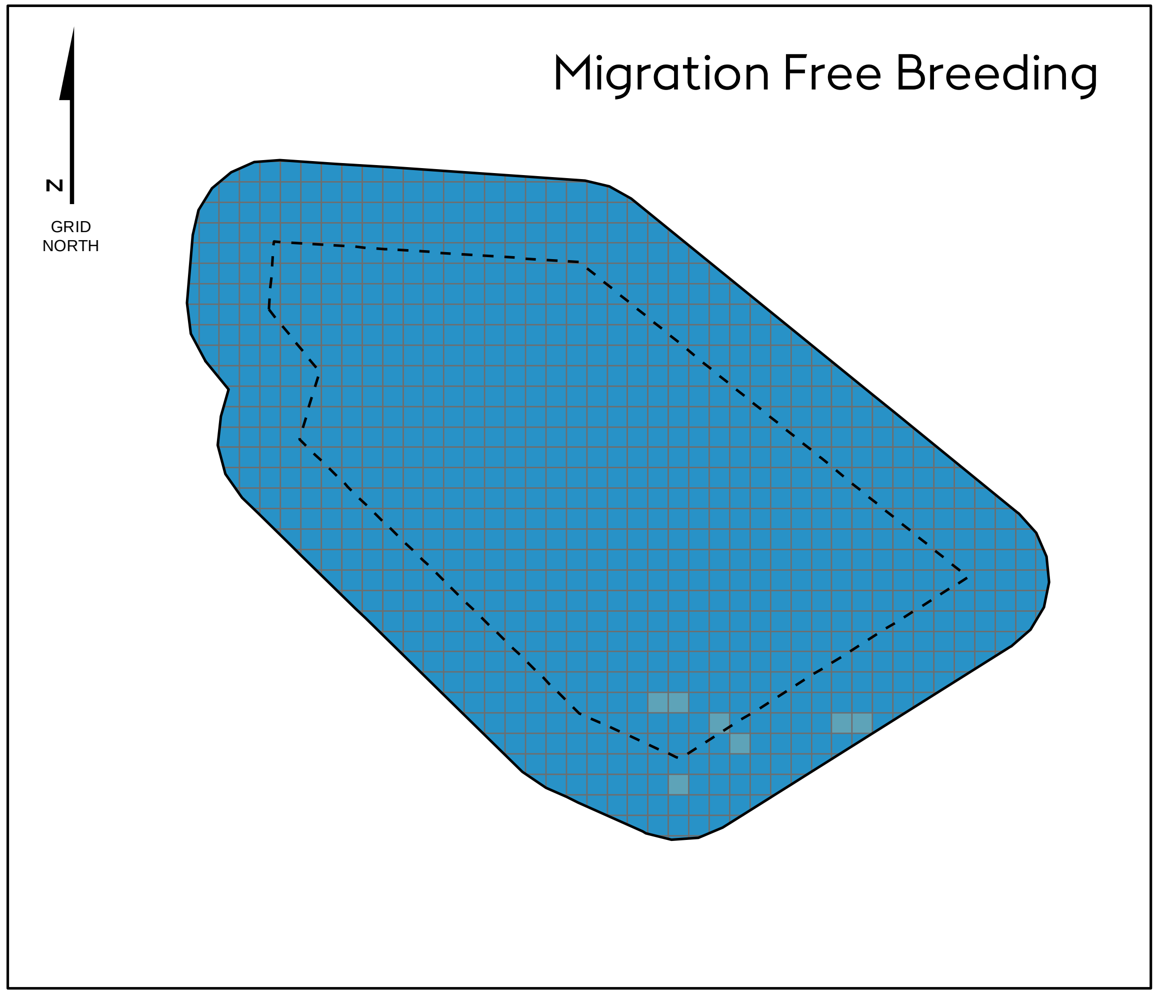
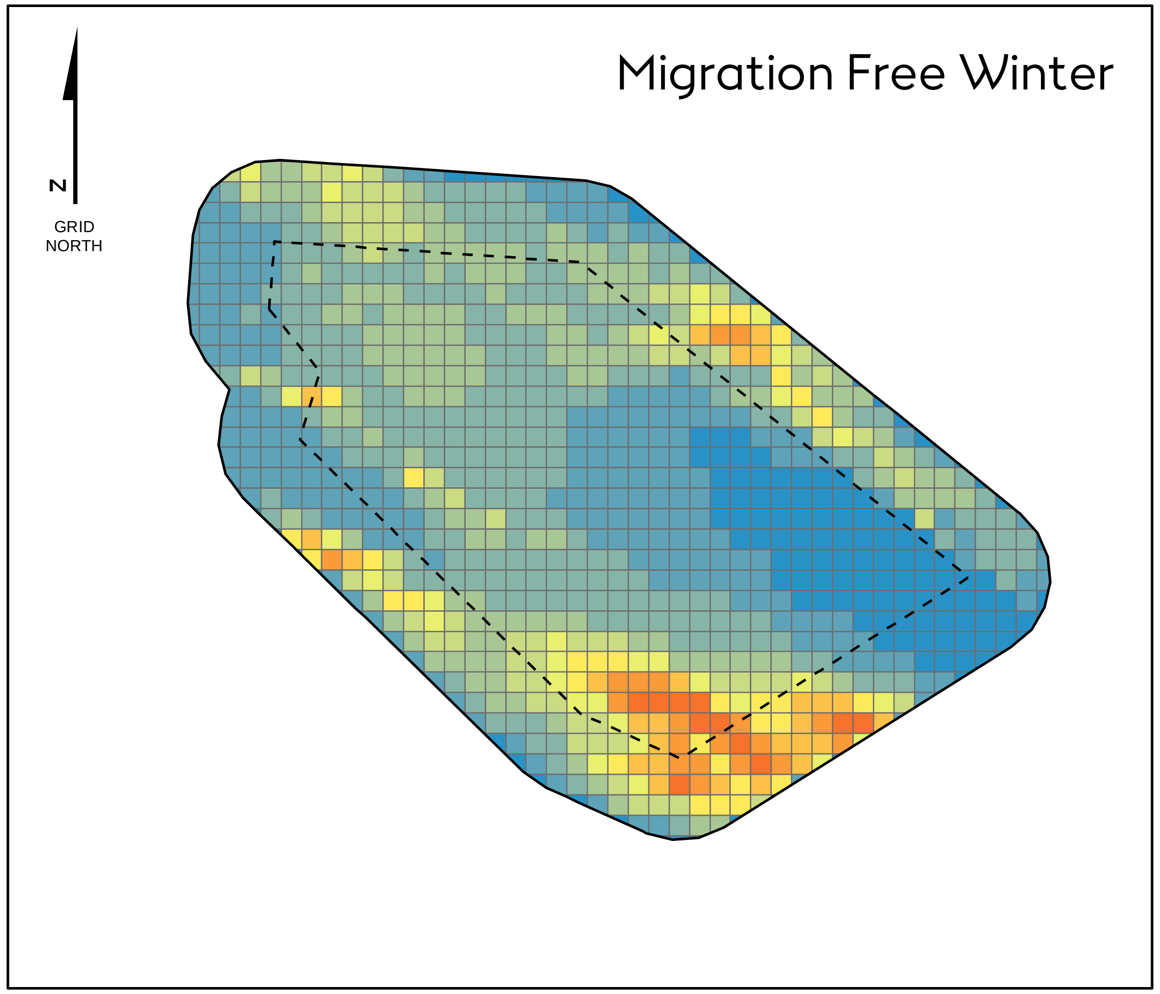
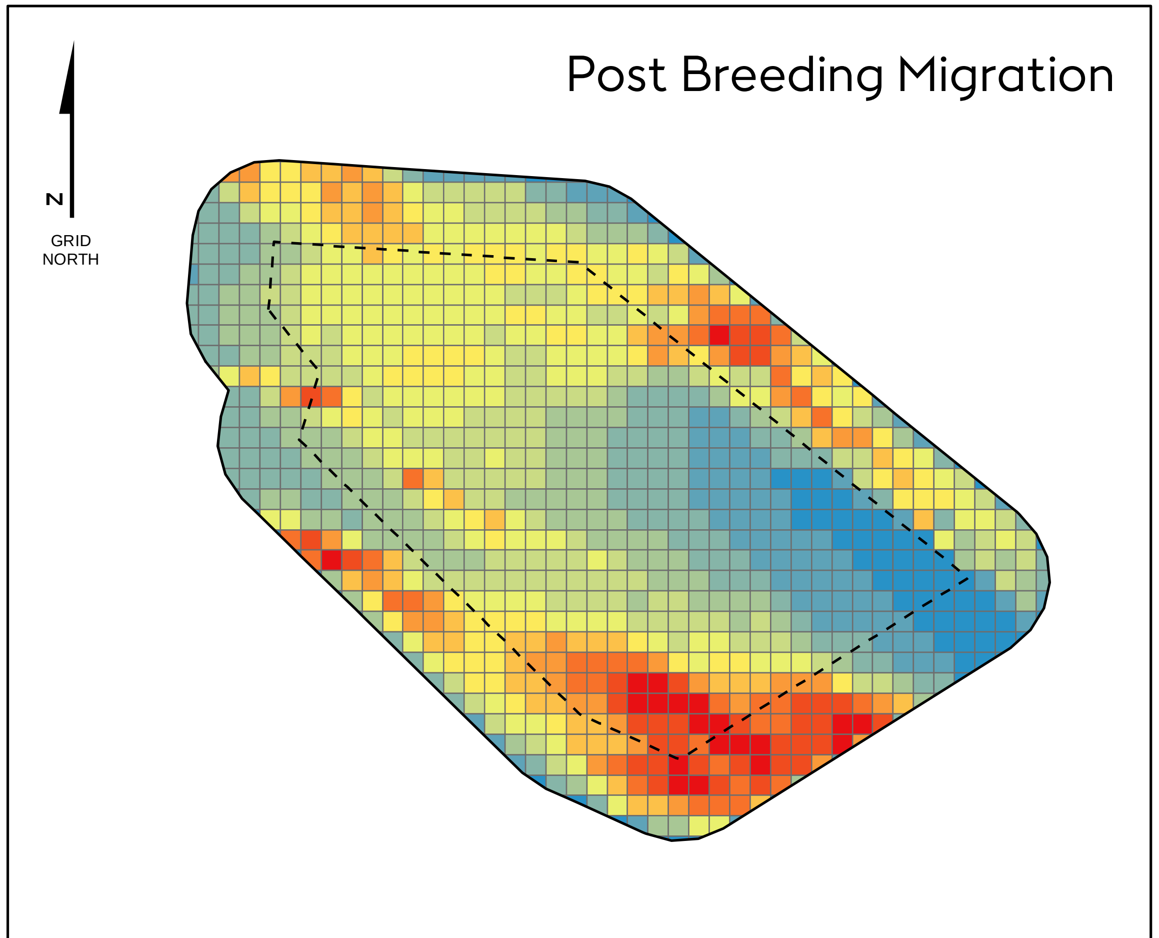
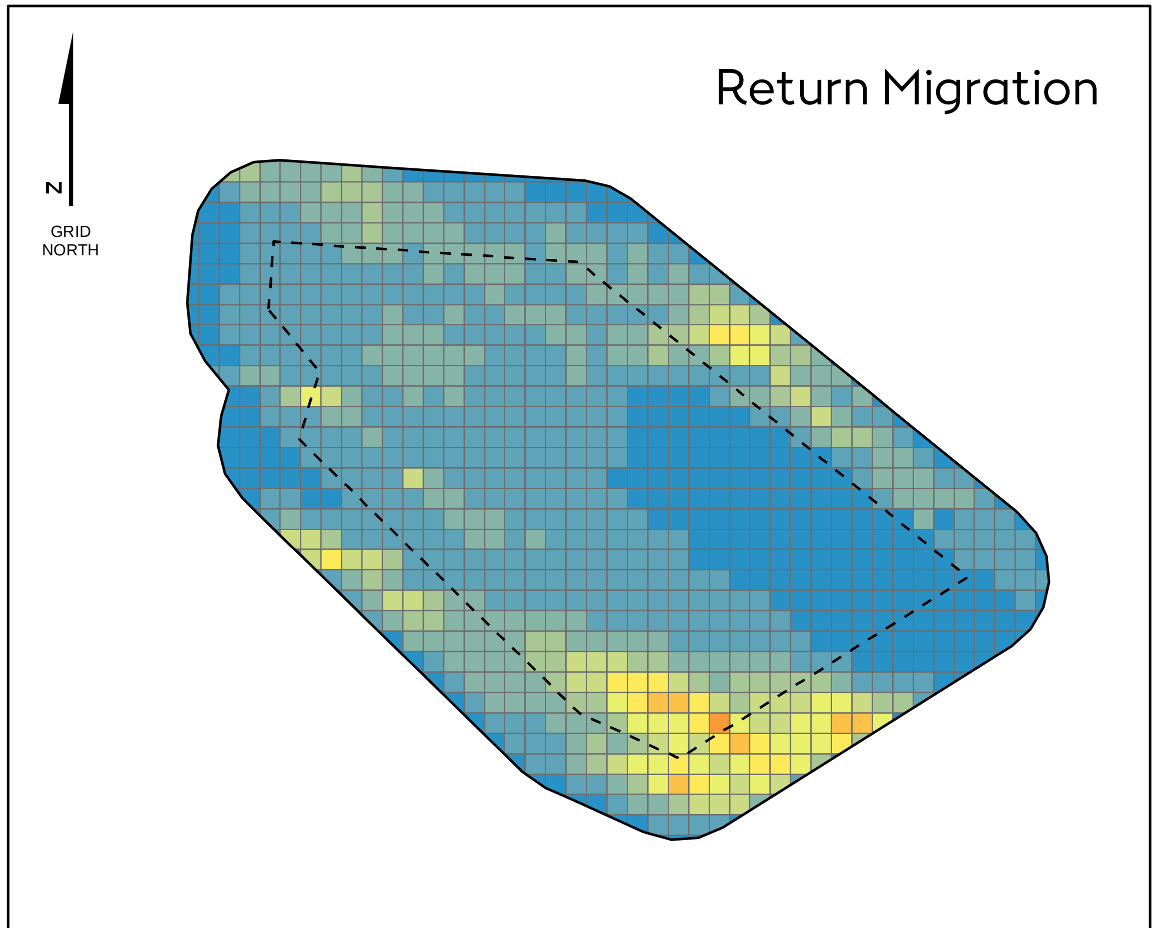
Date: 08/06/2021 Author: MB Name: HOW04_MRSea_9




Licenses:


Date: 08/06/2021 Author: MB Name: HOW04_MRSea_10_10.6

# Hornsea Four

## Figure 10

Bio-season Spatial Density Distribution of Great Black-backed Gull Within Hornsea Four Plus 4 km Buffer

Array Area

Array Area 4 km buffer

Predicted great black-backed gull density (birds / km²)

- 0.00 - 0.04
- 0.04 - 0.08
- 0.08 - 0.13
- 0.13 - 0.17
- 0.17 - 0.23
- 0.23 - 0.28
- 0.28 - 0.34
- 0.34 - 0.42
- 0.42 - 0.51
- 0.51 - 0.70
- 0.70 - 0.91
- 0.91 - 1.38


Coordinate system: ETRS 1989 UTM Zone 31N

Scale@A3: 1:370,000

0 10 20 Kilometres

0 5 10 Nautical Miles

| REV | REMARK | DATE |
|---|---|---|
| | First Issue | 08/06/2021 |
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Bio-season Spatial Density Distribution of Great Black-backed Gull Within Hornsea Four Plus 4 km Buffer
Document no: HOW04_MRSea_10
Created by: MB
Checked by: SS
Approved by: SS

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### 3.4.3 Summary of Great Black-backed Gull Abundance

3.4.3.1 Density of great black-backed gulls in the Hornsea Four array area plus a 4 km buffer was extracted from the predicted abundance. The modelled abundance and average density (birds per km$^2$) for each survey (Table 8) and for each bio-season (Table 9) are presented here.

**Table 8: Modelled great black-backed gull counts for each survey, Lower and Upper 95% Confidence Intervals (LCI and UCI) and density of great black-backed gulls in the Hornsea Four array area plus a 4 km buffer.**

| Survey | Total abundance estimate | LCI | UCI | Density (birds per km$^2$) |
|---|---|---|---|---|
| Apr-2016 | - | - | - | - |
| Jun-2016 (01) | - | - | - | - |
| Jun-2016 (02) | 2.71 | 0.41 | 28.30 | 0.00 |
| Jul-2016 | - | - | - | - |
| Aug-2016 | 24.77 | 5.37 | 119.30 | 0.03 |
| Sep-2016 | 140.91 | 50.26 | 464.43 | 0.16 |
| Oct-2016 | 441.33 | 125.41 | 1720.09 | 0.50 |
| Nov-2016 | 103.29 | 42.54 | 300.54 | 0.12 |
| Dec-2016 | 81.82 | 32.31 | 305.79 | 0.09 |
| Jan-2017 | 120.16 | 38.76 | 416.36 | 0.14 |
| Feb-2017 | 112.60 | 40.63 | 409.36 | 0.13 |
| Mar-2017 | 57.53 | 15.65 | 225.32 | 0.06 |
| Apr-2017 | 7.84 | 1.85 | 33.91 | 0.01 |
| May-2017 | 18.60 | 6.15 | 72.70 | 0.02 |
| Jun-2017 | 7.98 | 1.82 | 55.98 | 0.01 |
| Jul-2017 | 10.75 | 1.57 | 65.56 | 0.01 |
| Aug-2017 | 5.25 | 0.89 | 46.31 | 0.01 |
| Sep-2017 | 540.87 | 150.21 | 3772.84 | 0.61 |
| Oct-2017 | 335.41 | 106.59 | 1184.23 | 0.38 |
| Nov-2017 | 112.54 | 38.33 | 435.27 | 0.13 |
| Dec-2017 | 127.99 | 42.30 | 482.68 | 0.14 |
| Jan-2018 | 90.69 | 33.37 | 297.27 | 0.10 |
| Feb-2018 | 56.12 | 20.26 | 191.66 | 0.06 |
| Mar-2018 | 73.20 | 23.90 | 253.51 | 0.08 |

**Table 9: Modelled great black-backed gull abundance for each bio-season, Lower and Upper 95% Confidence Intervals (LCI and UCI) and density of great black-backed gulls in the Hornsea Four array area plus a 4 km buffer.**

| Bio-season | Average abundance estimate | LCI | UCI | Density (birds per km$^2$) |
|---|---|---|---|---|
| Migration Free Breeding | 10.65 | 3.28 | 50.50 | 0.01 |
| Post-Breeding Migration | 491.10 | 137.81 | 2746.46 | 0.55 |
| Migration Free Winter | 104.90 | 37.30 | 394.24 | 0.12 |
| Return Migration | 70.28 | 24.66 | 237.88 | 0.08 |

## 3.5 Guillemot

### 3.5.1 Model Specifications

3.5.1.1 The MRSea analysis was run twice to predict guillemot abundance, (1) to predict abundance for each survey across 24 months and (2) to predict average abundance for each bio-season.

3.5.1.2 The final model specification equations were:

(1) guillemot = geeglm(as.factor (survey.number) + s (depth), family = quasipoisson (link = log))

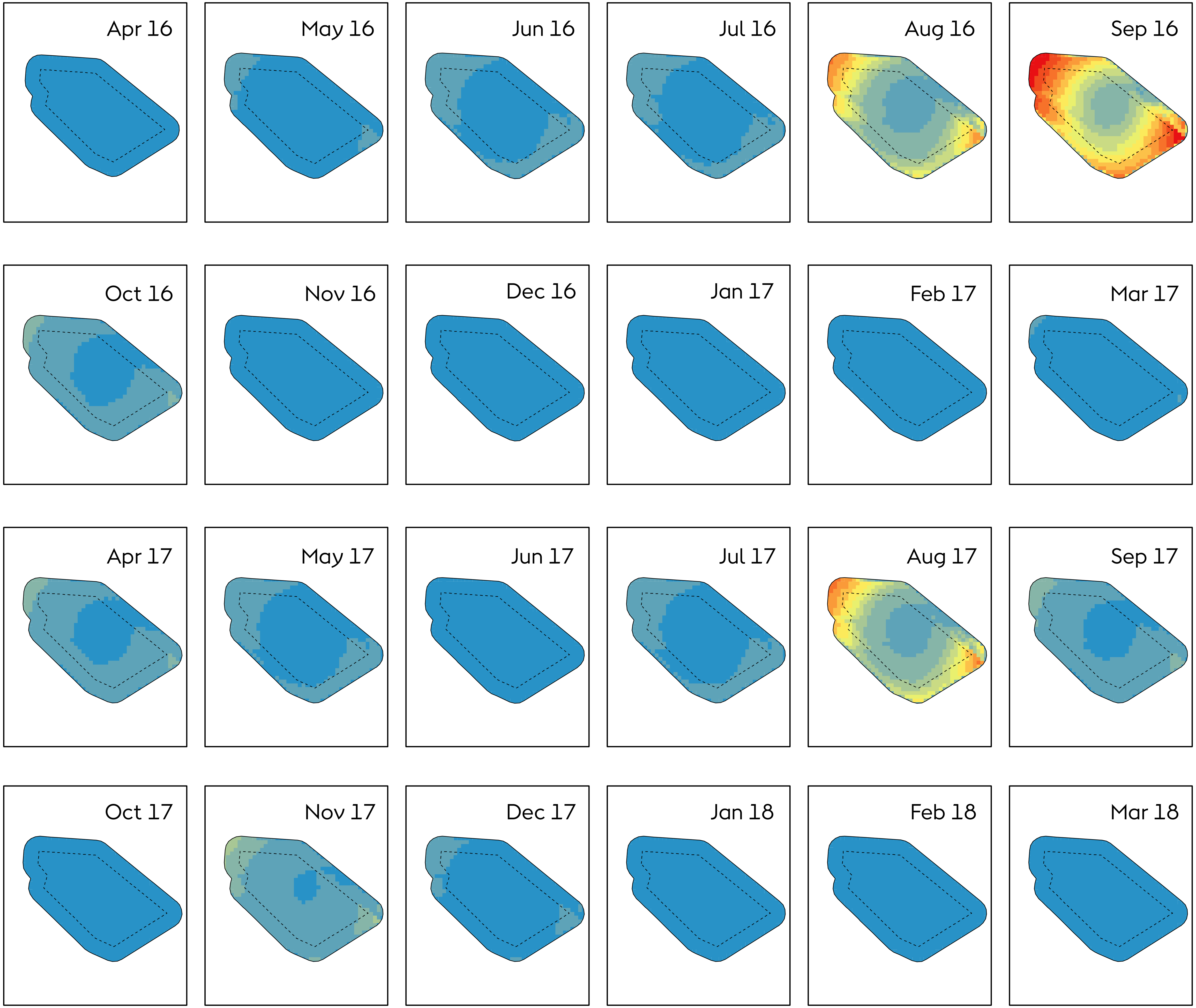
(2) guillemot = geeglm(as.factor (bioseason) + s(depth) + s (distance_SPA), family = quasipoisson (link = log))

3.5.1.3 Following the testing of each of the environmental input data by the SALSA1D analysis, as described in **Section 2.3.1.4**, all were determined to be influencing variables and included in the final models for guillemot.

3.5.1.4 The final model was used to predict abundance of guillemots in each 1 $km^2$ grid square across the AfL area plus a 4 km buffer. The area was then clipped to the Hornsea Four array area plus a 4 km buffer.

### 3.5.2 Spatial Density Distribution

3.5.2.1 The predicted abundances in each 1 $km^2$ grid square were used to create maps showing the variation in guillemot density across the array area plus the 4 km buffer. Predicted density across the Hornsea Four array area plus a 4 km buffer for each survey (**Figure 11**) and each of the bio-seasons (**Figure 12**) are presented here.




# Hornsea Four

## Figure 11

Monthly Spatial Density Distribution of Guillemot Within Hornsea Four Plus 4 km Buffer

Array Area

Array Area plus 4 km Buffer

Predicted Guillemot Density (birds / km²)

- 0.00 - 9.30
- 9.31 - 20.93
- 20.94 - 28.86
- 28.87 - 32.89
- 32.90 - 37.10
- 37.11 - 41.48
- 41.49 - 46.73
- 46.74 - 52.82
- 52.83 - 59.83
- 59.84 - 68.57
- 68.58 - 79.28
- 79.29 - 95.15

N

GRID NORTH


Coordinate system: ETRS 1989 UTM Zone 31N

Scale@A3: 1:1,000,000

0 20 40 Kilometres

0 10 20 Nautical Miles

| REV | REMARK | DATE |
| --- | --- | --- |
| | First Issue | 08/06/2021 |
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Monthly Spatial Density Distribution of Guillemot Within Hornsea Four Plus 4 km Buffer
Document no: HOW04_MRSea_11
Created by: MB
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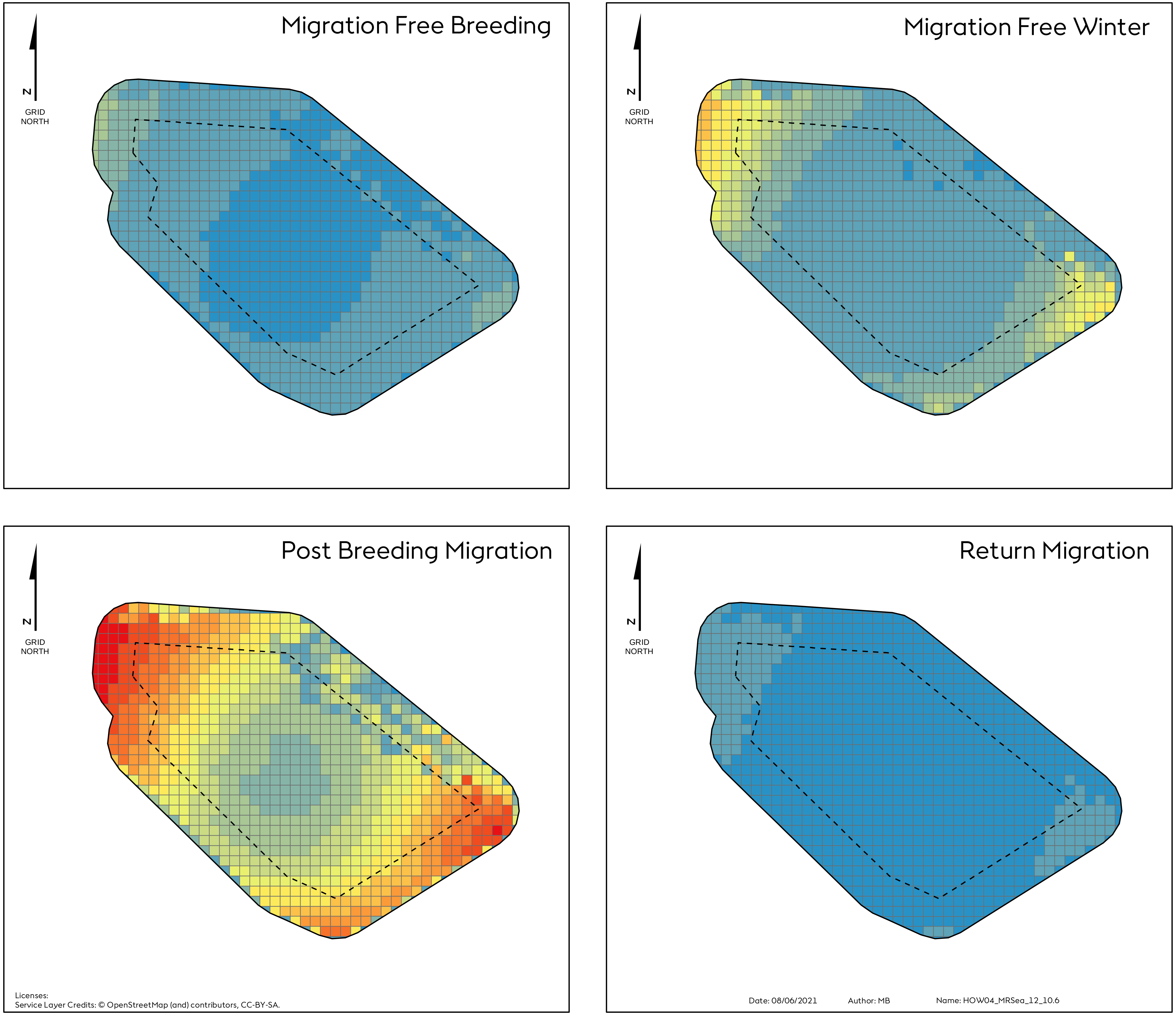


# Hornsea Four

## Figure 12

Bio-season Spatial Density Distribution of Guillemot Within Hornsea Four Plus 4 km Buffer

Array Area

Array Area 4 km buffer

Predicted guillemot density (birds / km²)

- 0.00 - 4.71
- 4.71- 9.92
- 9.92 - 12.29
- 12.29 - 13.79
- 13.79 - 15.46
- 15.46 - 17.46
- 17.46 - 19.83
- 19.83 - 22.61
- 22.61 - 25.96
- 25.96 - 30.07
- 30.07 - 35.06
- 35.06 - 42.50


Coordinate system: ETRS 1989 UTM Zone 31N

Scale@A3: 1:370,000

0 10 20 Kilometres

0 5 10 Nautical Miles

| REV | REMARK | DATE |
|---|---|---|
| | First Issue | 08/06/2021 |

Bio-season Spatial Density Distribution of Guillemot Within Hornsea Four Plus 4 km Buffer
Document no: HOW04_MRSea_12
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Checked by: SS
Approved by: SS

Ørsted

Date: 08/06/2021 Author: MB Name: HOW04_MRSea_12_10.6

### 3.5.3 Summary of Guillemot Abundance

3.5.3.1 Density of all guillemots in the Hornsea Four array area plus a 4 km buffer was extracted from the predicted abundance. The modelled abundance and average density (birds per km$^2$) for each survey (Table 10) and for each bio-season (Table 11) are presented here.

**Table 10: Modelled guillemot abundance for each survey, Lower and Upper 95% Confidence Intervals (LCI and UCI) and density of guillemots for all behaviours in the Hornsea Four array area plus a 4 km buffer.**

| Survey | Total abundance estimate | LCI | UCI | Density (birds per km$^2$) |
|---|---|---|---|---|
| Apr-2016 | 2737.10 | 1600.76 | 5309.06 | 3.08 |
| Jun-2016 (01) | 5564.45 | 3581.99 | 8607.29 | 6.26 |
| Jun-2016 (02) | 7984.09 | 5638.22 | 11282.96 | 8.99 |
| Jul-2016 | 7742.99 | 5505.99 | 10869.06 | 8.72 |
| Aug-2016 | 25978.45 | 18689.35 | 37800.30 | 29.24 |
| Sep-2016 | 39482.42 | 29091.89 | 54685.03 | 44.44 |
| Oct-2016 | 10564.46 | 7397.68 | 14874.50 | 11.89 |
| Nov-2016 | 3562.91 | 2619.31 | 5091.09 | 4.01 |
| Dec-2016 | 1515.76 | 927.79 | 2286.43 | 1.71 |
| Jan-2017 | 2455.05 | 1751.96 | 3451.43 | 2.76 |
| Feb-2017 | 3000.98 | 2047.86 | 4438.54 | 3.38 |
| Mar-2017 | 4281.24 | 2603.22 | 8306.01 | 4.82 |
| Apr-2017 | 10879.52 | 4483.46 | 25905.57 | 12.25 |
| May-2017 | 8021.42 | 5741.50 | 11186.66 | 9.03 |
| Jun-2017 | 1901.02 | 1145.35 | 3276.32 | 2.14 |
| Jul-2017 | 8107.97 | 5459.81 | 12830.35 | 9.13 |
| Aug-2017 | 26837.77 | 16344.01 | 49081.24 | 30.21 |
| Sep-2017 | 11431.78 | 5370.70 | 31599.82 | 12.87 |
| Oct-2017 | 1314.59 | 886.22 | 1992.49 | 1.48 |
| Nov-2017 | 13509.88 | 8547.53 | 23468.53 | 15.21 |
| Dec-2017 | 5956.38 | 4295.08 | 8383.11 | 6.70 |
| Jan-2018 | 2821.88 | 1442.08 | 5447.78 | 3.18 |
| Feb-2018 | 2735.81 | 1967.81 | 3809.98 | 3.08 |
| Mar-2018 | 1206.92 | 879.43 | 1758.50 | 1.36 |

**Table 11: Modelled guillemot counts for each bio-season, Lower and Upper 95% Confidence Intervals (LCI and UCI) and density of guillemots for all behaviours in the Hornsea Four array area plus a 4 km buffer.**

| Bio-season | Average abundance estimate | LCI | UCI | Density (birds per km$^2$) |
|---|---|---|---|---|
| Migration Free Breeding | 9431.81 | 5689.86 | 18594.27 | 10.62 |
| Post-Breeding Migration | 33160.10 | 22717.95 | 51883.13 | 37.32 |
| Migration Free Winter | 8536.40 | 5583.42 | 14279.81 | 9.61 |
| Return Migration | 4478.68 | 3171.47 | 6410.82 | 5.04 |

## 3.6 Razorbill

### 3.6.1 Model Specifications

3.6.1.1 The MRSea analysis was run twice to predict razorbill abundance, (1) to predict abundance for each survey across 24 months and (2) to predict average abundance for each bio-season.

3.6.1.2 The final model specification equations were:

(1) razorbill = geeglm (as.factor (survey.number) + s (depth), family = quasipoisson (link = log))

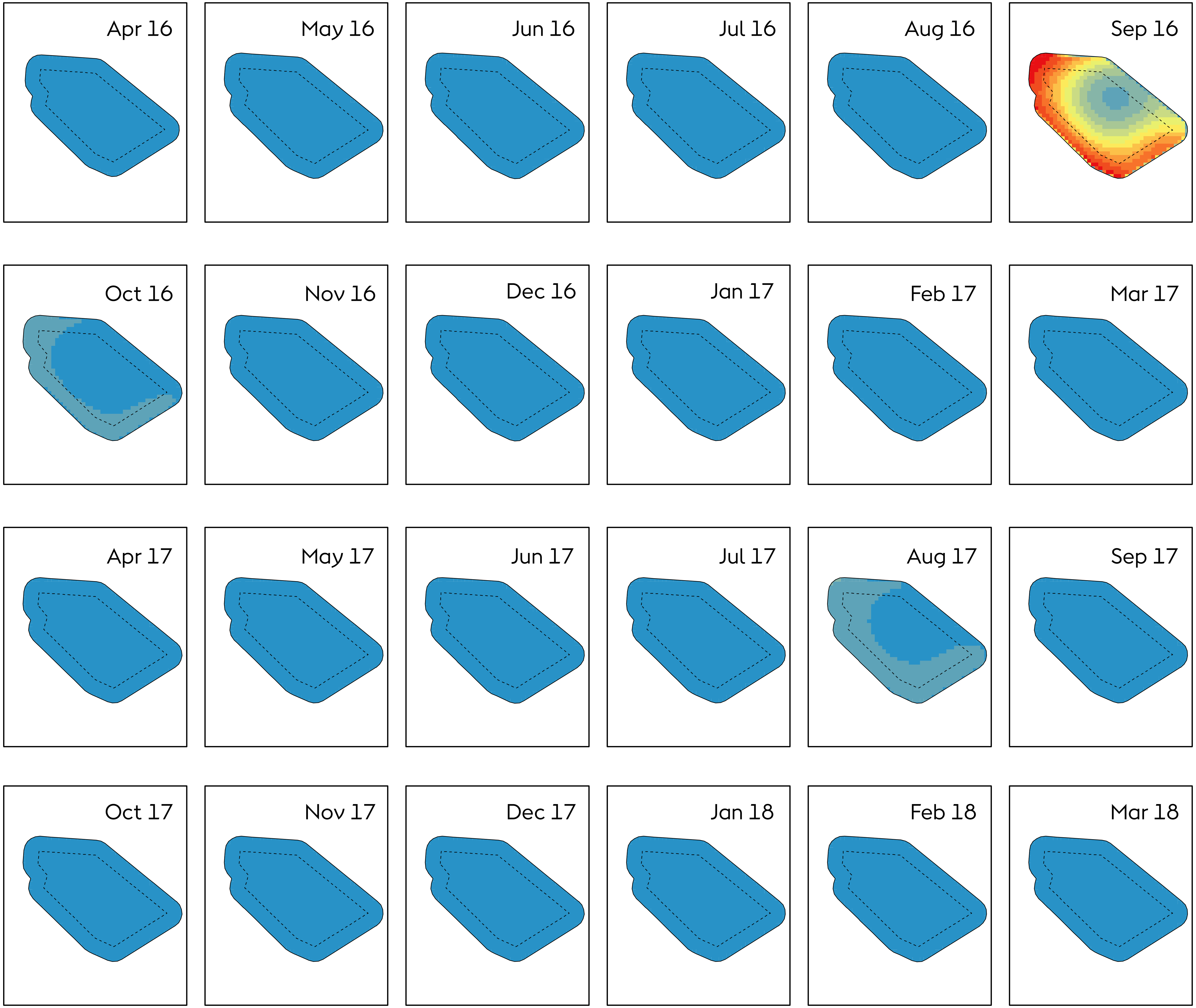
(2) razorbill = geegelm (as.factor (bioseason) + s (depth), family = quasipoisson (link = log))

3.6.1.3 Following the testing of each of the environmental input data by the SALSA1D analysis, as described in **Section 2.3.1.4**, distance to SPA was not included as an influencing variable in either of the final models for razorbill.

3.6.1.4 The final model was used to predict abundance of razorbills in each 1 $km^2$ grid square across the AfL area plus a 4 km buffer. The area was then clipped to the Hornsea Four array area plus a 4 km buffer.

### 3.6.2 Spatial Density Distribution

3.6.2.1 The predicted abundances in each 1 $km^2$ grid square were used to create maps showing the variation in razorbill density across the array area plus the 4 km buffer. Predicted density across the Hornsea Four array area plus a 4 km buffer for each survey (**Figure 13**) and each of the bio-seasons (**Figure 14**) are presented here.




# Hornsea Four

## Figure 13

Monthly Spatial Density Distribution of Razorbill Within Hornsea Four Plus 4 km Buffer

Array Area

Array Area plus 4 km Buffer

Predicted Razorbill Density (birds / km²)

- 0.00 - 2.02
- 2.03 - 3.90
- 3.91 - 4.53
- 4.54 - 5.16
- 5.17 - 5.79
- 5.80 - 6.45
- 6.46 - 7.09
- 7.10 - 7.74
- 7.75 - 8.45
- 8.46 - 9.24
- 9.25 - 10.20
- 10.21 - 11.93

N GRID NORTH


Coordinate system: ETRS 1989 UTM Zone 31N

Scale@A3: 1:1,000,000

0 20 40 Kilometres

0 10 20 Nautical Miles

| REV | REMARK | DATE |
|---|---|---|
| | First Issue | 08/06/2021 |

Monthly Spatial Density Distribution of Razorbill Within Hornsea Four Plus 4 km Buffer
Document no: HOW04_MRSea_13
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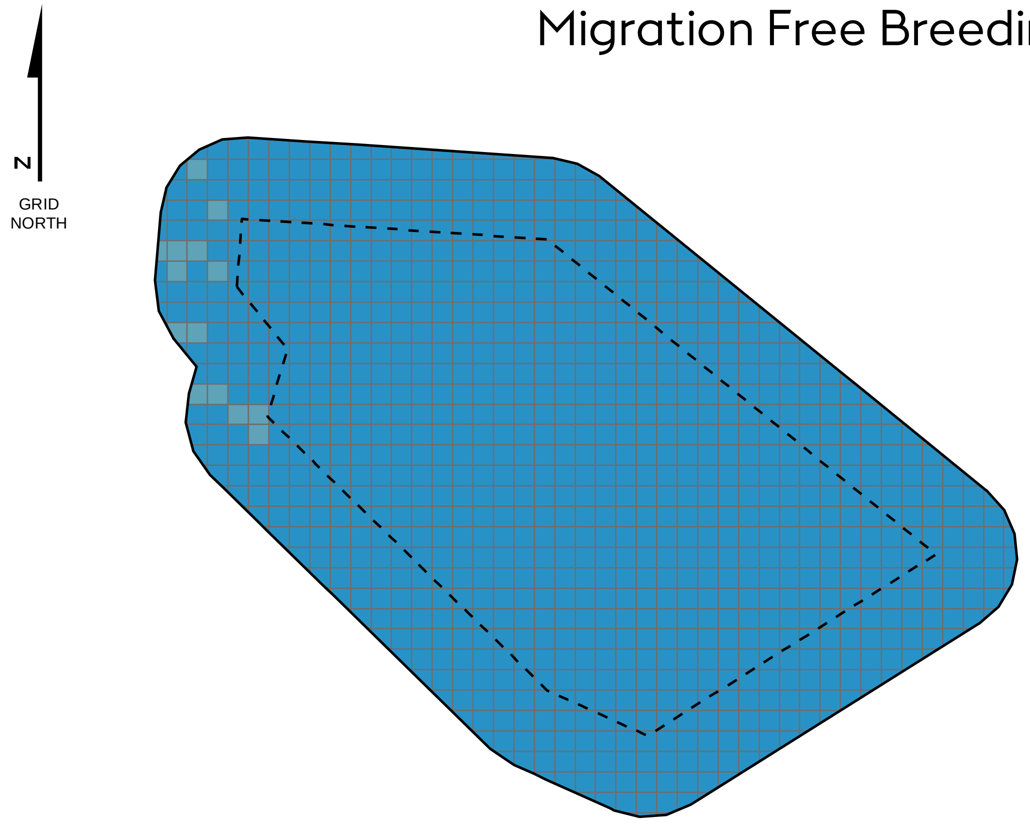
Date: 08/06/2021 Author: MB Name: HOW04_MRSea_13

# Hornsea Four

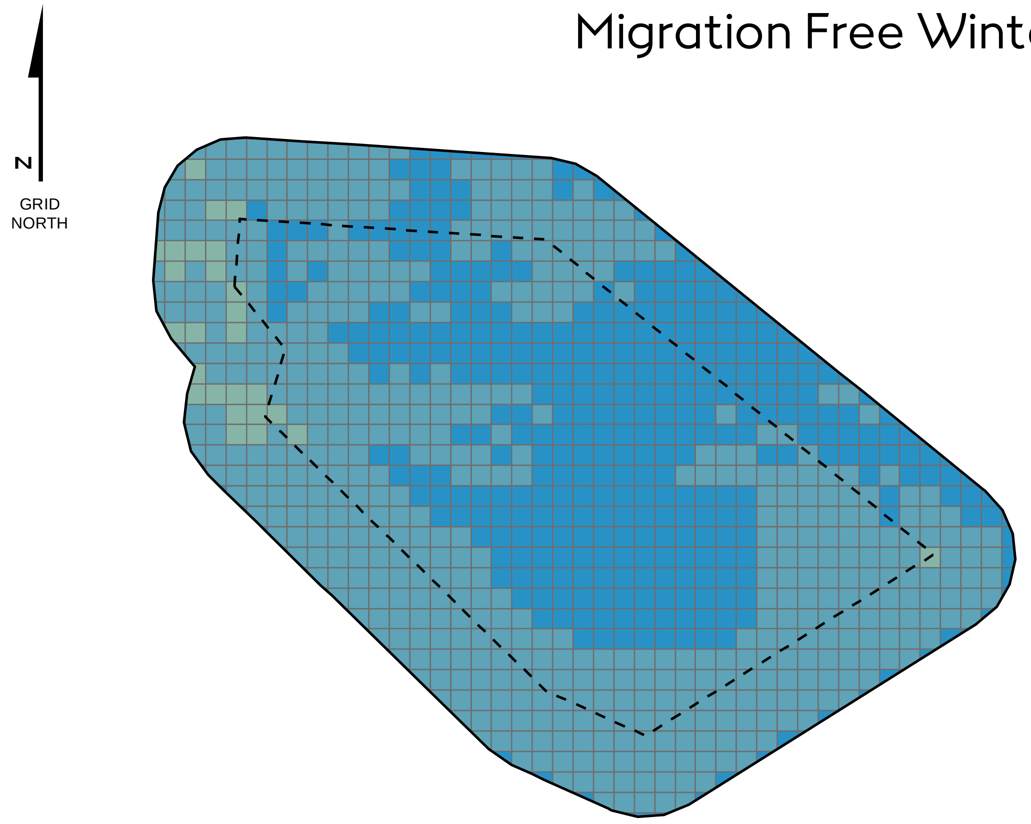
Figure 14

Bio-season Spatial Density Distribution of Razorbill Within Hornsea Four Plus 4 km Buffer

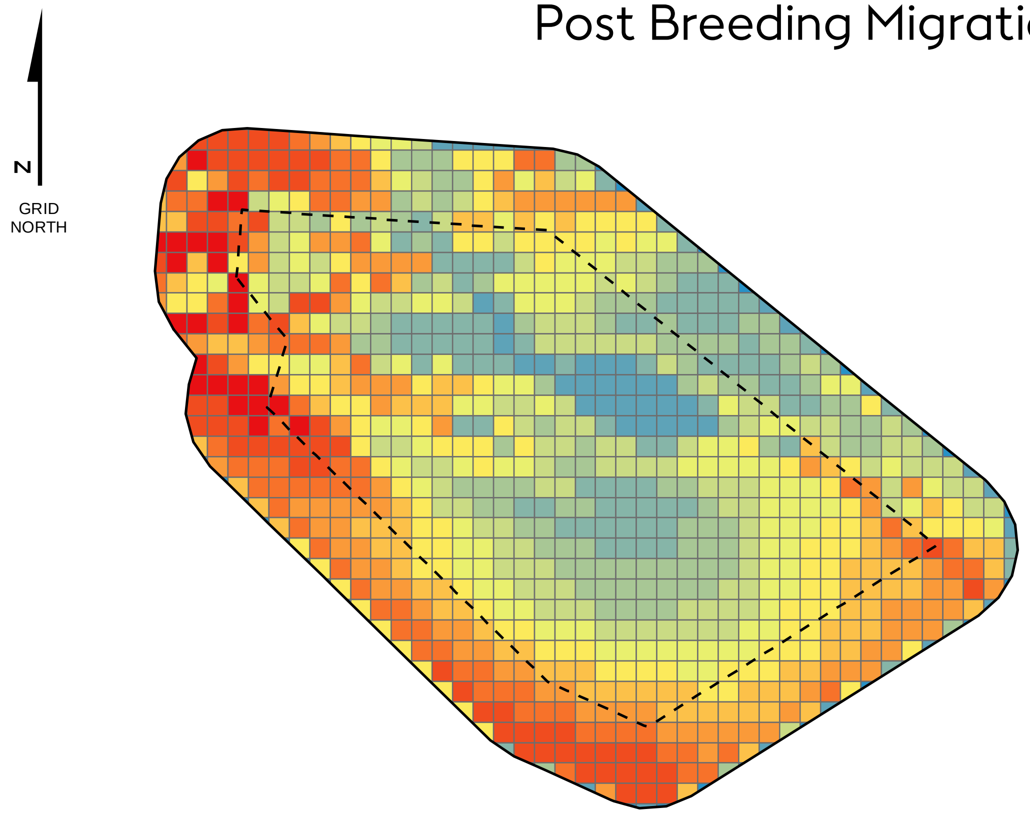
## Migration Free Breeding



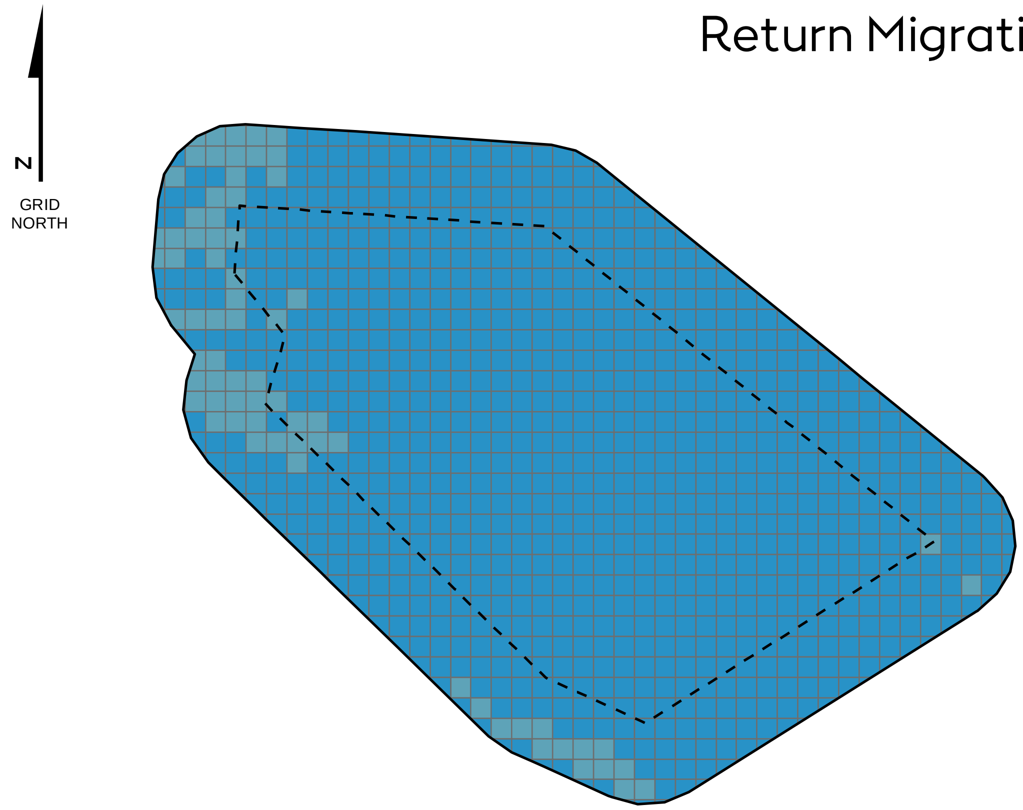

## Migration Free Winter




## Post Breeding Migration




## Return Migration




Array Area

Array Area 4 km buffer

Predicted razorbill density (birds / km²)

- 0.00 - 0.43
- 0.43 - 0.95
- 0.95 - 1.28
- 1.28- 1.49
- 1.49- 1.70
- 1.70- 1.92
- 1.92 - 2.16
- 2.16 - 2.41
- 2.41- 2.73
- 2.73 - 3.18
- 3.18 - 3.84
- 3.84 - 4.91


Coordinate system: ETRS 1989 UTM Zone 31N

Scale@A3: 1:370,000

0 10 20 Kilometres

0 5 10 Nautical Miles

| REV | REMARK | DATE |
|---|---|---|
| | First Issue | 08/06/2021 |

Bio-season Spatial Density Distribution of Razorbill Within Hornsea Four Plus 4 km Buffer

Document no: HOW04_MRSea_14

Created by: MB

Checked by: SS

Approved by: SS

Ørsted



Date: 08/06/2021 Author: MB Name: HOW04_MRSea_14_10.6

### 3.6.3 Summary of Razorbill Abundance

3.6.3.1 Density of all razorbills in the Hornsea Four array area plus a 4 km buffer was extracted from the predicted abundance. The modelled abundances and average density (birds per km$^2$) for each survey (Table 12) and for each bio-season (Table 13) are presented here.

**Table 12: Modelled razorbill abundance for each survey, Lower and Upper 95% Confidence Intervals (LCI and UCI) and density of razorbills for all behaviours in the Hornsea Four array area plus a 4 km buffer.**

| Survey | Total abundance estimate | LCI | UCI | Density (birds per km$^2$) |
|---|---|---|---|---|
| Apr-2016 | 111.00 | 63.78 | 225.61 | 0.12 |
| Jun-2016 (01) | 28.49 | 10.07 | 75.21 | 0.03 |
| Jun-2016 (02) | 179.60 | 101.03 | 297.86 | 0.20 |
| Jul-2016 | 51.32 | 19.95 | 111.88 | 0.06 |
| Aug-2016 | 758.37 | 481.15 | 1175.21 | 0.85 |
| Sep-2016 | 5939.84 | 4049.46 | 9038.76 | 6.69 |
| Oct-2016 | 1632.91 | 864.40 | 2910.43 | 1.84 |
| Nov-2016 | 426.65 | 251.92 | 730.44 | 0.48 |
| Dec-2016 | 5.70 | 0.80 | 31.23 | 0.01 |
| Jan-2017 | 460.70 | 253.43 | 852.64 | 0.52 |
| Feb-2017 | 87.93 | 47.78 | 162.32 | 0.10 |
| Mar-2017 | 247.35 | 112.23 | 649.92 | 0.28 |
| Apr-2017 | 406.71 | 190.61 | 836.46 | 0.46 |
| May-2017 | 565.87 | 340.88 | 995.13 | 0.64 |
| Jun-2017 | 54.20 | 18.49 | 164.48 | 0.06 |
| Jul-2017 | 117.33 | 50.16 | 295.42 | 0.13 |
| Aug-2017 | 1999.62 | 1101.15 | 4212.44 | 2.25 |
| Sep-2017 | 748.23 | 409.71 | 1553.87 | 0.84 |
| Oct-2017 | 59.24 | 14.56 | 337.56 | 0.07 |
| Nov-2017 | 674.24 | 379.81 | 1313.03 | 0.76 |
| Dec-2017 | 720.69 | 441.30 | 1162.36 | 0.81 |
| Jan-2018 | 51.21 | 26.15 | 107.48 | 0.06 |
| Feb-2018 | 470.26 | 241.86 | 908.64 | 0.53 |
| Mar-2018 | 122.36 | 58.08 | 282.79 | 0.14 |

**Table 13: Modelled razorbill abundance for each bio-season, Lower and Upper 95% Confidence Intervals (LCI and UCI) and density of razorbills for all behaviours in the Hornsea Four array area plus a 4 km buffer.**

| Bio-season | Average abundance estimate | LCI | UCI | Density (birds per km$^2$) |
|---|---|---|---|---|
| Migration Free Breeding | 372.74 | 220.96 | 646.50 | 0.42 |
| Post-Breeding Migration | 3969.73 | 2575.30 | 6625.60 | 4.47 |
| Migration Free Winter | 573.67 | 346.61 | 1021.73 | 0.65 |
| Return Migration | 465.48 | 247.65 | 880.64 | 0.52 |

## 3.7 Puffin

### 3.7.1 Model Specifications

3.7.1.1 The MRSea analysis was run twice to predict puffin abundance, (1) to predict abundance for each survey across 24 months and (2) to predict average abundance for each bio-season.

3.7.1.2 The final model specification equations were:

(1) puffin = geeglm (as.factor (survey.number) + s (depth), family = quasipoisson (link = log))

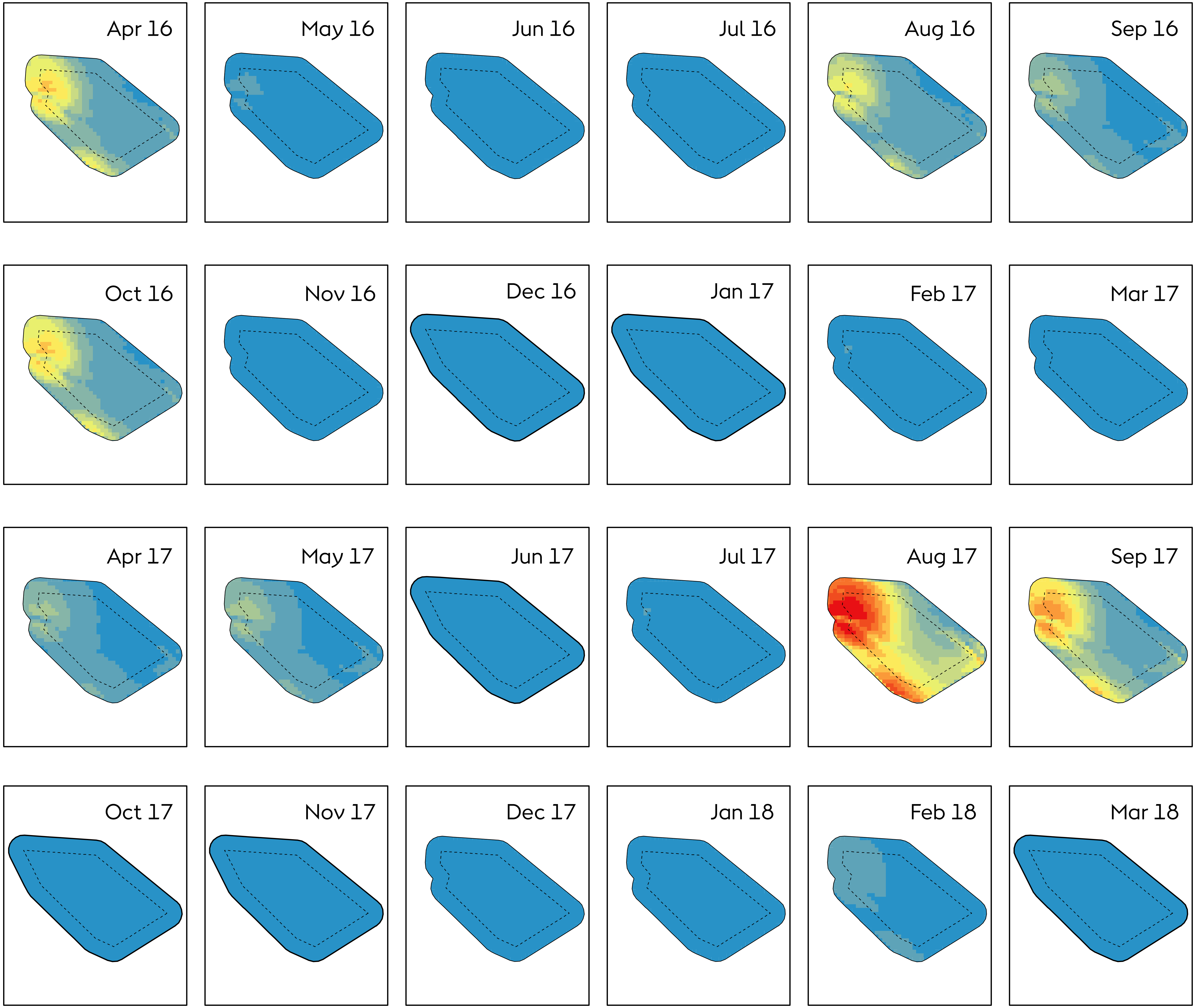
(2) puffin = geegelm (as.factor (bioseason) + s (depth), family = quasipoisson (link = log))

3.7.1.3 Following the testing of each of the environmental input data by the SALSA1D analysis, as described in **Section 2.3.1.4**, distance to SPA was not included as an influencing variable in either of the final models for puffin.

3.7.1.4 The final model was used to predict abundance of puffin in each 1 km$^2$ grid square across the AfL area plus a 4 km buffer. The area was then clipped to the Hornsea Four array area plus a 4 km buffer.

### 3.7.2 Spatial Density Distribution

3.7.2.1 The predicted abundances in each 1 km$^2$ grid square were used to create maps showing the variation in puffin density across the array area plus the 4 km buffer. Predicted density across the Hornsea Four array area plus a 4 km buffer for each survey (**Figure 15**) and each of the bio-seasons (**Figure 16**) are presented here.




# Hornsea Four

Figure 15

Monthly Spatial Density Distribution of Puffin Within Hornsea Four Plus 4 km Buffer

Array Area

Array Area plus 4 km Buffer

Predicted Puffin Density (birds / km²)

0.00 - 0.08
0.09 - 0.21
0.22 - 0.29
0.30 - 0.34
0.35 - 0.41
0.42 - 0.49
0.50 - 0.59
0.60 - 0.71
0.72 - 0.85
0.86 - 1.02
1.03 - 1.21
1.22 - 1.45

N
GRID NORTH


Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:1,000,000

0 20 40 Kilometres

0 10 20 Nautical Miles

| REV | REMARK | DATE |
|---|---|---|
| | First Issue | 08/06/2021 |
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Monthly Spatial Density
Distribution of Puffin Within
Hornsea Four Plus 4 km Buffer
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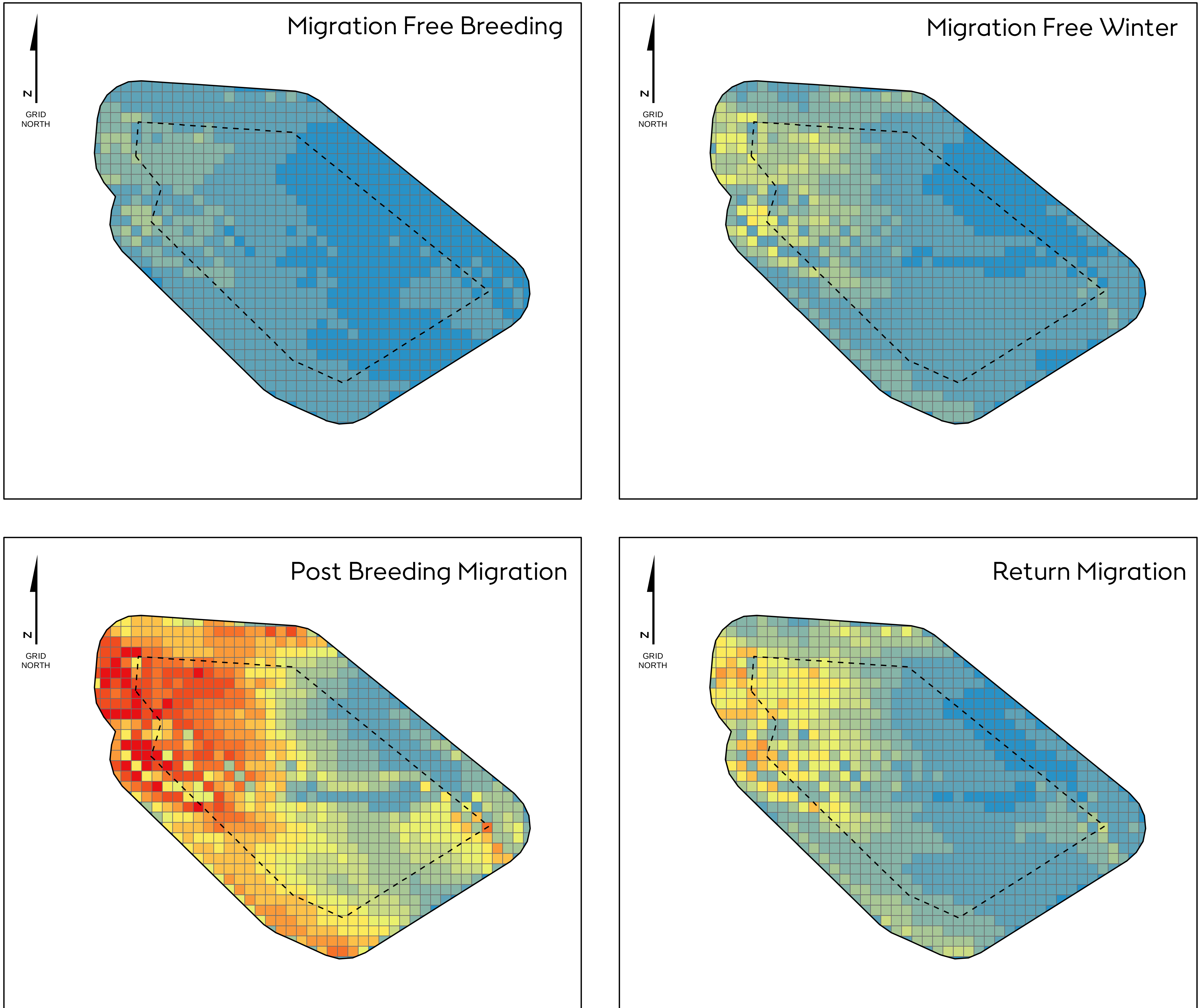
Created by: MB
Checked by: SS
Approved by: SS



Date: 08/06/2021 Author: MB Name: HOW04_MRSea_15






Date: 08/06/2021 Author: MB Name: HOW04_MRSea_16_10.6

# Hornsea Four

## Figure 16

Bio-season Spatial Density Distribution of Puffin Within Hornsea Four Plus 4 km Buffer

Array Area

Array Area 4 km buffer

Predicted puffin density (birds / km$^2$)

- 0.00 - 0.04
- 0.04 - 0.08
- 0.08 - 0.11
- 0.11 - 0.14
- 0.14 - 0.16
- 0.16- 0.19
- 0.19 - 0.22
- 0.22 - 0.26
- 0.26 - 0.31
- 0.31 - 0.38
- 0.38 - 0.46
- 0.46 - 0.57


Coordinate system: ETRS 1989 UTM Zone 31N

Scale@A3: 1:370,000

0 10 20 Kilometres

0 5 10 Nautical Miles

| REV | REMARK | DATE |
|---|---|---|
| | First Issue | 08/06/2021 |
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Bio-season Spatial Density
Distribution of Puffin Within
Hornsea Four Plus 4 km Buffer
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Checked by: SS
Approved by: SS

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### 3.7.3 Summary of Puffin Abundance

3.7.3.1 Density of all puffins in the Hornsea Four array area plus a 4 km buffer was extracted from the predicted abundance. The modelled abundance and average density (birds per km$^2$) for each survey (Table 14) and for each bio-season (Table 15) are presented here.

**Table 14: Modelled puffin abundance for each survey, Lower and Upper 95% Confidence Intervals (LCI and UCI) and density of puffins for all behaviours in the Hornsea Four array area plus a 4 km buffer.**

| Survey | Total abundance estimate | LCI | UCI | Density (birds per km$^2$) |
|---|---|---|---|---|
| Apr-2016 | 228.97 | 146.30 | 376.16 | 0.26 |
| Jun-2016 (01) | 37.41 | 14.66 | 97.01 | 0.04 |
| Jun-2016 (02) | 14.03 | 5.19 | 33.11 | 0.02 |
| Jul-2016 | 9.35 | 1.43 | 46.71 | 0.01 |
| Aug-2016 | 182.40 | 91.28 | 363.02 | 0.21 |
| Sep-2016 | 121.75 | 71.92 | 222.60 | 0.14 |
| Oct-2016 | 228.73 | 138.40 | 361.81 | 0.26 |
| Nov-2016 | 9.35 | 2.56 | 36.31 | 0.01 |
| Dec-2016 | - | - | - | - |
| Jan-2017 | - | - | - | - |
| Feb-2017 | 32.66 | 10.26 | 88.52 | 0.04 |
| Mar-2017 | 9.35 | 2.20 | 40.70 | 0.01 |
| Apr-2017 | 116.81 | 74.43 | 202.67 | 0.13 |
| May-2017 | 121.43 | 70.58 | 231.30 | 0.14 |
| Jun-2017 | - | - | - | - |
| Jul-2017 | 32.74 | 13.98 | 75.65 | 0.04 |
| Aug-2017 | 528.99 | 327.62 | 845.08 | 0.60 |
| Sep-2017 | 289.69 | 158.59 | 511.28 | 0.33 |
| Oct-2017 | - | - | - | - |
| Nov-2017 | - | - | - | - |
| Dec-2017 | 4.68 | 0.77 | 32.95 | 0.01 |
| Jan-2018 | 4.64 | 1.08 | 40.82 | 0.01 |
| Feb-2018 | 70.10 | 35.89 | 134.49 | 0.08 |
| Mar-2018 | - | - | - | - |

**Table 15: Modelled puffin abundance for each bio-season, Lower and Upper 95% Confidence Intervals (LCI and UCI) and density of puffins for all behaviours in the Hornsea Four array area plus a 4 km buffer.**

| Bio-season | Average abundance estimate | LCI | UCI | Density (birds per km$^2$) |
|---|---|---|---|---|
| Migration Free Breeding | 79.42 | 42.62 | 164.15 | 0.09 |
| Post-Breeding Migration | 355.70 | 209.45 | 604.05 | 0.40 |
| Migration Free Winter | 259.21 | 148.49 | 436.54 | 0.29 |
| Return Migration | 172.89 | 110.37 | 289.42 | 0.19 |

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## Appendix A: Model Information and diagnostics

### Fulmar

#### Monthly Spatial Abundance Model Information

Variance Inflation Factors

| Variable | GVIF | Df | GVIF (1/2 Df) |
|---|---|---|---|
| Survey.number | 1.00 | 23 | 1.00 |
| Distance_SPA | 110.50 | 4 | 1.80 |
| X and Y Coordinates | 110.52 | 4 | 1.80 |

Model variables, coefficients, and p-values (displaying Wald statistic (X2) and degrees of freedom (Df))

| Variable | X2 | Df | p-value |
|---|---|---|---|
| Survey.number | 205.16 | 23 | <0.01 |
| Distance_SPA | 10.62 | 4 | 0.03 |
| X and Y Coordinates | 11.23 | 4 | 0.02 |

#### Seasonal Spatial Abundance Model Information

Variance Inflation Factors

| Variable | GVIF | Df | GVIF (1/2 Df) |
|---|---|---|---|
| Survey.number | 1.00 | 3 | 1.00 |
| Distance_SPA | 79.71 | 4 | 1.73 |
| X and Y Coordinates | 79.71 | 4 | 1.73 |

Model variables, coefficients, and p-values (displaying Wald statistic (X2) and degrees of freedom (Df))

| Variable | X2 | Df | p-value |
|---|---|---|---|
| Survey.number | 17.30 | 3 | <0.01 |
| Distance_SPA | 14.52 | 4 | <0.01 |
| X and Y Coordinates | 9.25 | 4 | 0.055 |

## Gannet

### Monthly Spatial Abundance Model Information

Variance Inflation Factors

| Variable | GVIF | Df | GVIF (1/2 Df) |
|---|---|---|---|
| Survey.number | 1.00 | 23 | 1.00 |
| Depth | 3.37 | 1 | 1.84 |
| X and Y Coordinates | 3.37 | 5 | 1.13 |

Model variables, coefficients, and p-values (displaying Wald statistic (X2) and degrees of freedom (Df))

| Variable | X2 | Df | p-value |
|---|---|---|---|
| Survey.number | 292.39 | 23 | <0.01 |
| Depth | 2.53 | 1 | 0.11 |
| X and Y Coordinates | 5.01 | 5 | 0.41 |

### Seasonal Spatial Abundance Model Information

Variance Inflation Factors

| Variable | GVIF | Df | GVIF (1/2 Df) |
|---|---|---|---|
| Survey.number | 1.00 | 2 | 1.00 |
| Distance_SPA | 43.90 | 3 | 1.88 |
| X and Y Coordinates | 43.90 | 5 | 1.46 |

Model variables, coefficients, and p-values (displaying Wald statistic (X2) and degrees of freedom (Df))

| Variable | X2 | Df | p-value |
|---|---|---|---|
| Survey.number | 61.09 | 2 | <0.01 |
| Distance_SPA | 4.86 | 4 | 0.18 |
| X and Y Coordinates | 5.40 | 5 | 0.37 |

## Kittiwake

### Monthly Spatial Abundance Model Information

Variance Inflation Factors

| Variable | GVIF | Df | GVIF (1/2 Df) |
|---|---|---|---|
| Survey.number | 1.00 | 23 | 1.00 |
| Depth | 49.79 | 5 | 1.48 |
| Distance.SPA | 389.76 | 5 | 1.82 |
| X and Y Coordinates | 2254.92 | 5 | 2.16 |

Model variables, coefficients, and p-values (displaying Wald statistic (X2) and degrees of freedom (Df))

| Variable | X2 | Df | p-value |
|---|---|---|---|
| Survey.number | 721.57 | 23 | <0.01 |
| Depth | 18.98 | 5 | <0.01 |
| Distance.SPA | 10.87 | 5 | 0.05 |
| X and Y Coordinates | 28.41 | 5 | <0.01 |

### Seasonal Spatial Abundance Model Information

Variance Inflation Factors

| Variable | GVIF | Df | GVIF (1/2 Df) |
|---|---|---|---|
| Survey.number | 1.00 | 2 | 1.00 |
| Depth | 40.24 | 4 | 1.59 |
| X and Y Coordinates | 40.25 | 6 | 1.36 |

Model variables, coefficients, and p-values (displaying Wald statistic (X2) and degrees of freedom (Df))

| Variable | X2 | Df | p-value |
|---|---|---|---|
| Survey.number | 4.10 | 2 | 0.13 |
| Depth | 11.69 | 4 | 0.02 |
| X and Y Coordinates | 29.28 | 6 | <0.01 |

## Great black-backed gull

### Monthly Spatial Abundance Model Information

Variance Inflation Factors

| Variable | GVIF | Df | GVIF (1/2 Df) |
|---|---|---|---|
| Survey.number | 1.02 | 20 | 1.00 |
| Depth | 4.01 | 1 | 2.00 |
| Distance.SPA | 413.59 | 6 | 1.65 |
| X and Y Coordinates | 954.39 | 4 | 2.36 |

Model variables, coefficients, and p-values (displaying Wald statistic (X2) and degrees of freedom (Df))

| Variable | X2 | Df | p-value |
|---|---|---|---|
| Survey.number | 102.84 | 20 | <0.01 |
| Depth | 1.56 | 1 | 0.21 |
| Distance.SPA | 70.41 | 6 | <0.01 |
| X and Y Coordinates | 7.72 | 4 | 0.10 |

### Seasonal Spatial Abundance Model Information

Variance Inflation Factors

| Variable | GVIF | Df | GVIF (1/2 Df) |
|---|---|---|---|
| Survey.number | 1.00 | 3 | 1.00 |
| Depth | 141.46 | 4 | 1.86 |
| X and Y Coordinates | 141.57 | 7 | 1.42 |

Model variables, coefficients, and p-values (displaying Wald statistic (X2) and degrees of freedom (Df))

| Variable | X2 | Df | p-value |
|---|---|---|---|
| Survey.number | 51.69 | 3 | <0.01 |
| Depth | 22.01 | 4 | <0.01 |
| X and Y Coordinates | 45.64 | 7 | <0.01 |

## Guillemot

### Monthly Spatial Abundance Model Information

Variance Inflation Factors

| Variable | GVIF | Df | GVIF (1/2 Df) |
|---|---|---|---|
| Survey.number | 1.00 | 23 | 1.00 |
| Depth | 11.18 | 3 | 1.50 |
| X and Y Coordinates | 11.18 | 5 | 1.27 |

Model variables, coefficients, and p-values (displaying Wald statistic (X2) and degrees of freedom (Df))

| Variable | X2 | Df | p-value |
|---|---|---|---|
| Survey.number | 1037.38 | 23 | <0.01 |
| Depth | 7.35 | 3 | 0.06 |
| X and Y Coordinates | 62.63 | 5 | <0.01 |

### Seasonal Spatial Abundance Model Information

Variance Inflation Factors

| Variable | GVIF | Df | GVIF (1/2 Df) |
|---|---|---|---|
| Survey.number | 1.00 | 3 | 1.00 |
| Depth | 69.00 | 7 | 1.35 |
| Distance.SPA | 44.04 | 3 | 1.88 |
| X and Y Coordinates | 487.10 | 4 | 2.17 |

Model variables, coefficients, and p-values (displaying Wald statistic (X2) and degrees of freedom (Df))

| Variable | X2 | Df | p-value |
|---|---|---|---|
| Survey.number | 158.69 | 3 | <0.01 |
| Depth | 20.35 | 7 | 0.004 |
| Distance.SPA | 31.72 | 3 | <0.01 |
| X and Y Coordinates | 41.32 | 4 | <0.01 |

## Razorbill

### Monthly Spatial Abundance Model Information

Variance Inflation Factors

| Variable | GVIF | Df | GVIF (1/2 Df) |
|---|---|---|---|
| Survey.number | 1.00 | 23 | 1.00 |
| Depth | 113.71 | 4 | 1.81 |
| X and Y Coordinates | 113.71 | 6 | 1.48 |

Model variables, coefficients, and p-values (displaying Wald statistic (X2) and degrees of freedom (Df))

| Variable | X2 | Df | p-value |
|---|---|---|---|
| Survey.number | 586.59 | 23 | <0.01 |
| Depth | 5.22 | 4 | 0.27 |
| X and Y Coordinates | 31.26 | 6 | <0.01 |

### Seasonal Spatial Abundance Model Information

Variance Inflation Factors

| Variable | GVIF | Df | GVIF (1/2 Df) |
|---|---|---|---|
| Survey.number | 1.00 | 23 | 1.00 |
| Depth | 113.71 | 4 | 1.81 |
| X and Y Coordinates | 113.71 | 6 | 1.48 |

Model variables, coefficients, and p-values (displaying Wald statistic (X2) and degrees of freedom (Df))

| Variable | X2 | Df | p-value |
|---|---|---|---|
| Survey.number | 586.59 | 23 | <0.01 |
| Depth | 5.22 | 4 | 0.27 |
| X and Y Coordinates | 31.26 | 6 | <0.01 |

## Puffin

### Monthly Spatial Abundance Model Information

Variance Inflation Factors

| Variable | GVIF | Df | GVIF (1/2 Df) |
|---|---|---|---|
| Survey.number | 1.00 | 17 | 1.00 |
| Depth | 51.84 | 3 | 1.93 |
| X and Y Coordinates | 51.84 | 5 | 1.48 |

Model variables, coefficients, and p-values (displaying Wald statistic (X2) and degrees of freedom (Df))

| Variable | X2 | Df | p-value |
|---|---|---|---|
| Survey.number | 208.82 | 17 | <0.01 |
| Depth | 5.69 | 3 | 0.13 |
| X and Y Coordinates | 32.41 | 5 | <0.01 |

### Seasonal Spatial Abundance Model Information

Variance Inflation Factors

| Variable | GVIF | Df | GVIF (1/2 Df) |
|---|---|---|---|
| Survey.number | 1.00 | 3 | 1.00 |
| Depth | 104.76 | 6 | 1.47 |
| X and Y Coordinates | 104.75 | 5 | 1.59 |

Model variables, coefficients, and p-values (displaying Wald statistic (X2) and degrees of freedom (Df))

| Variable | X2 | Df | p-value |
|---|---|---|---|
| Survey.number | 33.14 | 3 | <0.01 |
| Depth | 15.60 | 6 | 0.02 |
| X and Y Coordinates | 25.02 | 5 | <0.01 |