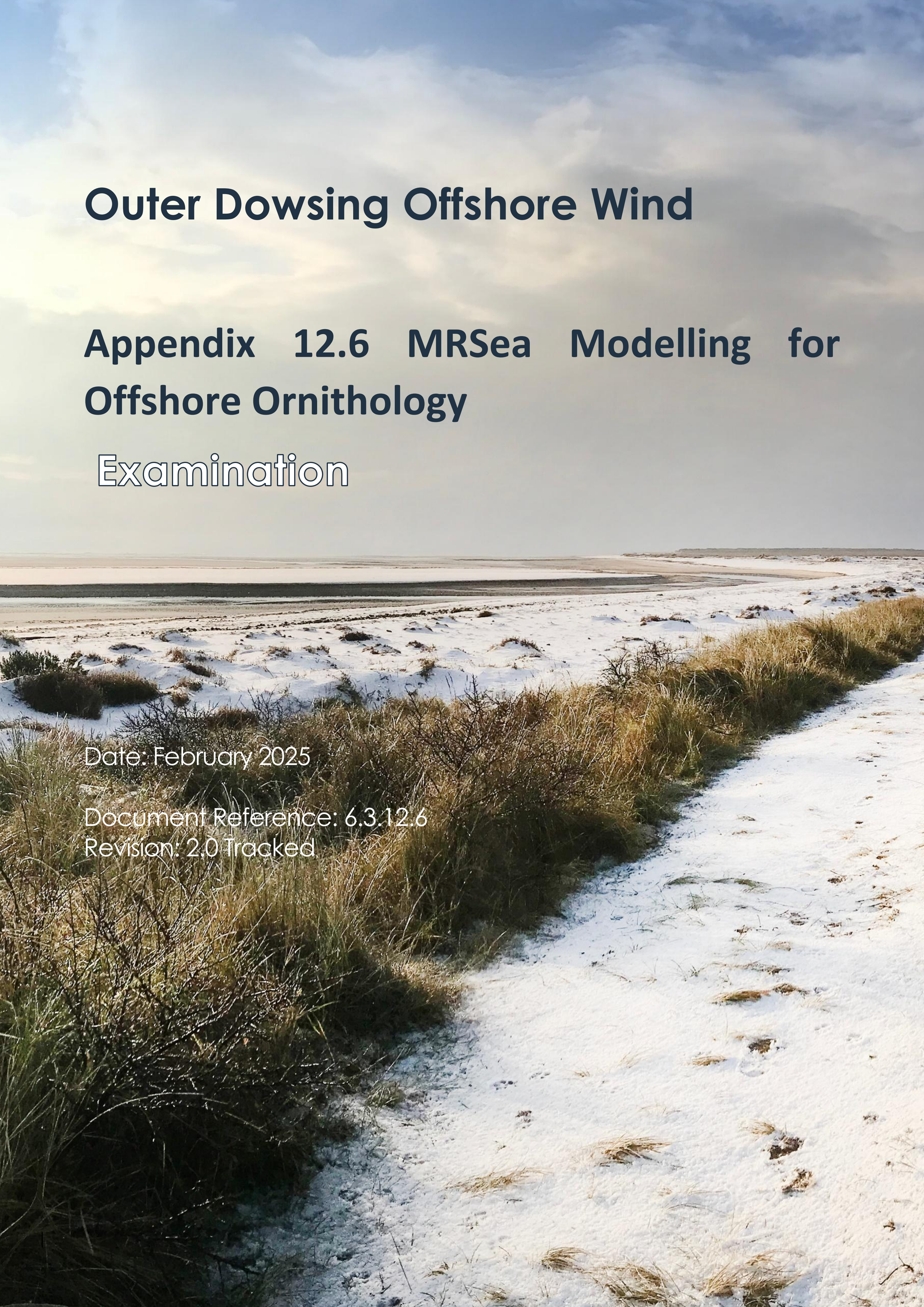

Outer Dowsing Offshore Wind

Appendix 12.6 MRSea Modelling for Offshore Ornithology

Examination

Date: February 2025

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1.0	September 2024	Procedural Deadline 19 September	GoBe	GoBe	Shepherd & Wedderburn	Outer Dowsing
2.0	February 2025	Deadline 4	GoBe	GoBe	Shepherd & Wedderburn	Outer Dowsing

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Acronyms & Definitions

Abbreviations / Acronyms

Abbreviation / Acronym	Description
AoI	Area of Interest
AONs	Apparently Occupied Nests
ACF	Autocorrelation function
ANOVA	Analysis of variance
CI	Confidence interval
CL	Confidence limits
CREEM	Centre for Research into Ecological and Environmental Modelling
CReSS	Complex Region Spatial Smoother
DAS	Digital Aerial Surveys
ECC	Export Cable Corridor
FFC	Flamborough and Filey Coast
GAM	Generalised Additive Model
GIS	Geographical Information System
GLM	General Linear Model
GSD	Ground Sample Distance
GVIF	Generalised variance inflation factors
LAT	Lowest astronomical tide
MCZ	Marine Conservation Zone
MRSea	Marine Renewables Strategic Environmental Assessment
ODOW	Outer Dowsing Offshore Wind (The Project)
OWF	Offshore Wind Farm
QA	Quality assurance
QBIC	Quasi-likelihood analogue of the Bayesian Information Criterion
SAC	Special Area of Conservation
SALSA	Spatially Adaptive Local Smoothing Algorithm
SNCBs	Statutory nature conservation bodies
SPA	Special Protection Area

Terminology

Term	Definition
Array Area	The area offshore within the Order Limits within which the generating stations will be situated (including wind turbine generators (WTG), offshore platforms and Inter-array cables), offshore accommodation platforms, offshore transformer substations and associated cabling are positioned.
Bootstrapping	A statistical procedure that resamples a single data set to create many simulated samples.

Term	Definition
Effect	Term used to express the consequence of an impact. The significance of an effect is determined by correlating the magnitude of an impact with the sensitivity of a receptor, in accordance with defined significance criteria.
Outer Dowsing Offshore Wind (ODOW)	The Project
Study area	Area(s) within which environmental impact may occur –to be defined on a receptor-by-receptor basis by the relevant technical specialist.
The Project	Outer Dowsing Offshore Wind including proposed onshore and offshore infrastructure

1 Introduction

1.1 Project Background

1. GT R4 Limited (trading as Outer Dowsing Offshore Wind) hereafter referred to as the 'Applicant', is proposing to develop the Project. The Applicant submitted an application for a DCO ('the Application') for the Project to the Planning Inspectorate in March 2024, which was accepted for Examination in April 2024.
2. The Project array will be located approximately 54km from the Lincolnshire coastline in the southern North Sea. The Project will include both offshore and onshore infrastructure including an offshore generating station (windfarm), export cables to landfall, Offshore Reactive Compensation Platforms (ORCPs), onshore cables, connection to the electricity transmission network, ancillary and associated development and areas for the delivery of up to two Artificial Nesting Structures (ANS) and the creation of a biogenic reef (if these compensation measures are deemed to be required by the Secretary of State) (see Volume 1, Chapter 3: Project Description [APP-058] for full details).
3. The consideration of offshore and intertidal ornithology for the Project has been discussed with consultees (Natural England and the Royal Society for the Protection of Birds (RSPB)) through the Project Evidence Plan Process (EPP) (summarised in Volume 1, Chapter 12: Offshore and Intertidal Ornithology [AS1-040]. The latest Natural England and Statutory Nature Conservation Bodies (SNCB) advice has been followed (Parker et al., 2022c; MIG-Birds, 2022).

1.2 Overview

4. This document is part of a suite of documents which introduces two changes which have been made by the Applicant to the proposed Outer Dowsing Offshore Wind (the Project):
    - the introduction of an Offshore Restricted Build Area (ORBA) over the northern section of the Project array area; and
    - the removal of the northern section of the offshore Export Cable Corridor (ECC).
5. As a result of continuing engagement with stakeholders, and enabled by progress on engineering design, the area within which the Wind Turbine Generators (WTGs) and Offshore Platforms (OPs) will be positioned has been refined. The proposed ORBA has been introduced to reduce the impact from the presence of the WTGs on auk species (specifically common guillemot), informed by a consideration of geophysical and geotechnical data.
6. The proposed ORBA covers the northern section of the array area and would restrict the installation of WTGs and OPs. For the avoidance of doubt, this area may still be used for cable installation and ancillary operations during construction (and decommissioning) and operations and maintenance. Additionally, Project parameters including number of structures, foundation types, and cable parameters will remain unchanged. As such, no change is being proposed to the extent of the array area, as defined within the draft Development Consent Order (DCO).

7. Further engineering design and procurement work, informed by additional geophysical, geotechnical and environmental survey work, undertaken post-consent (if granted), will confirm the final layout of infrastructure. Final details will be set out in a design plan to be submitted to and approved by the MMO, following consultation with Trinity House, the MCA and UKHO prior to commencement of the licensed works, in line deemed Marine Licence condition 13 (see condition 13(1)(a), Part 2, Schedule 10 of the dDCO [document 3.1].
8. The location and size of the ORBA was decided using various factors. MRSea based analysis was used to generate estimates of distribution and abundance, underpinned by observations of guillemot recorded in the DAS imagery (Scott -Hayward et al., 2014). This produced month by month density distribution mapping for the period March 2021 to August 2023 that identified hotspots within the EA Array area plus 2 km buffer.
9. There were some commonality in the hotspots between the 2021 and 2022 surveys with denser concentrations of guillemots recorded in the north and east of the area of interest (Figures 3.1 – 3.4) particularly within the months of April and August both in 2021 and 2022.
10. The MRSea data (document 15.9G) strongly agreed with the design based density estimates, which also show a general pattern of higher densities of guillemot and razorbill to the north of the array area (see Figures 12.33 - 12.35 and 12.39 - 12.41 of the Offshore Restricted Build Area and Revision to the Offshore Export Cable Corridor Ornithology Baseline Summary (document reference 15.9D)).
11. The introduction and size of the ORBA has been made possible through continued engagement with the relevant oil and gas operators who have interests which overlap with the Project, i.e. due to the presence of oil and gas platforms within or adjacent to the array area. Since the Application, the Applicant has been able to agree the principles for co-existence between the Project and access arrangements to the Malory platform with Perenco, specifically for helicopter transfers to and from this platform. Confidence in the likely final protective provisions for this operator within the DCO for the Project has therefore allowed further engineering work to be undertaken to support additional mitigation of the impact to auk species through a reduction in the area within which WTGs and OPs may be placed.
12. The introduction of the ORBA has resulted in a reduction in the summed mean seasonal peak abundance of guillemot from 27,653.3 birds in the array area plus 2 km buffer (Appendix 12.1 Offshore and Intertidal Ornithology Technical Baseline AS1-064) to a summed mean seasonal peak abundance of 23,586 guillemot in the array area minus the ORBA plus 2km buffer (Appendix 15.9D).

13. The offshore ECC presented within the Environmental Statement (ES) that supported the DCO Application included two routeing options within the inshore area of the cable route, a northern and a southern route. The northern route was included as it is situated north of the Inner Dowsing sandbank and thus avoided impacts to this designated feature. The southern route was also included as the northern route passes through aggregates Area 1805 which has an option and exploration area agreement with The Crown Estate, although this was due to expire on 31st August 2024. In the event that the option agreement was not taken up by the holder, this seabed area would have become available, thus allowing the Project to avoid crossing the Inner Dowsing sandbank.
14. It has now been confirmed that the option on this area has been extended by TCE until 2025 (pers. comms. Hansons via email 1st May 2024), with a Marine Licence Application (MLA/2024/00227) having been made by the agreement holder on 25th April 2024 to permit aggregates extraction within the site. As such, it is clear that the agreement holder intends to take up the option over this area of the seabed for aggregate extraction, and therefore it is no longer a viable option for the Project to pursue. Consequently, the Project has excluded the northern route from the offshore ECC.

1.3 Document Purpose

15. This technical appendix provides GoBe's analysis of pre-construction Digital Aerial Survey (DAS) for Outer Dowsing Offshore Wind Farm (ODOW) Ltd (hereafter referred to as the Project) to provide MRSea modelled density and abundance estimates to complement the "design based" density estimates used to inform the ES [AS1-040, ref F14], specifically for guillemot as a key species of interest for the Project due to their relatively high abundance in the array area relative to other species. The Offshore Restricted Build Area and Revision to the Offshore Export Cable Corridor Ornithology Baseline Summary (document reference 15.9D) provides the findings from offshore and intertidal ornithology surveys to determine the receptors that characterise the baseline and are of relevance to the assessment of potential impacts from the Project. Surveys were conducted for two years, on 24 consecutive months, between March 2021 and August 2023 (inclusive). This survey programme consisted of 37 surveys, with additional effort being carried out in months expected to show increased densities of seabirds within the Area of Interest (AoI).
16. This report presents model-based abundance and density estimates using the MRSea (Marine Renewables Strategic Environmental Assessment) modelling framework, developed specifically for offshore wind development (Scott-Hayward et al., 2014). A single model run was completed to determine receptor distribution across all surveys.

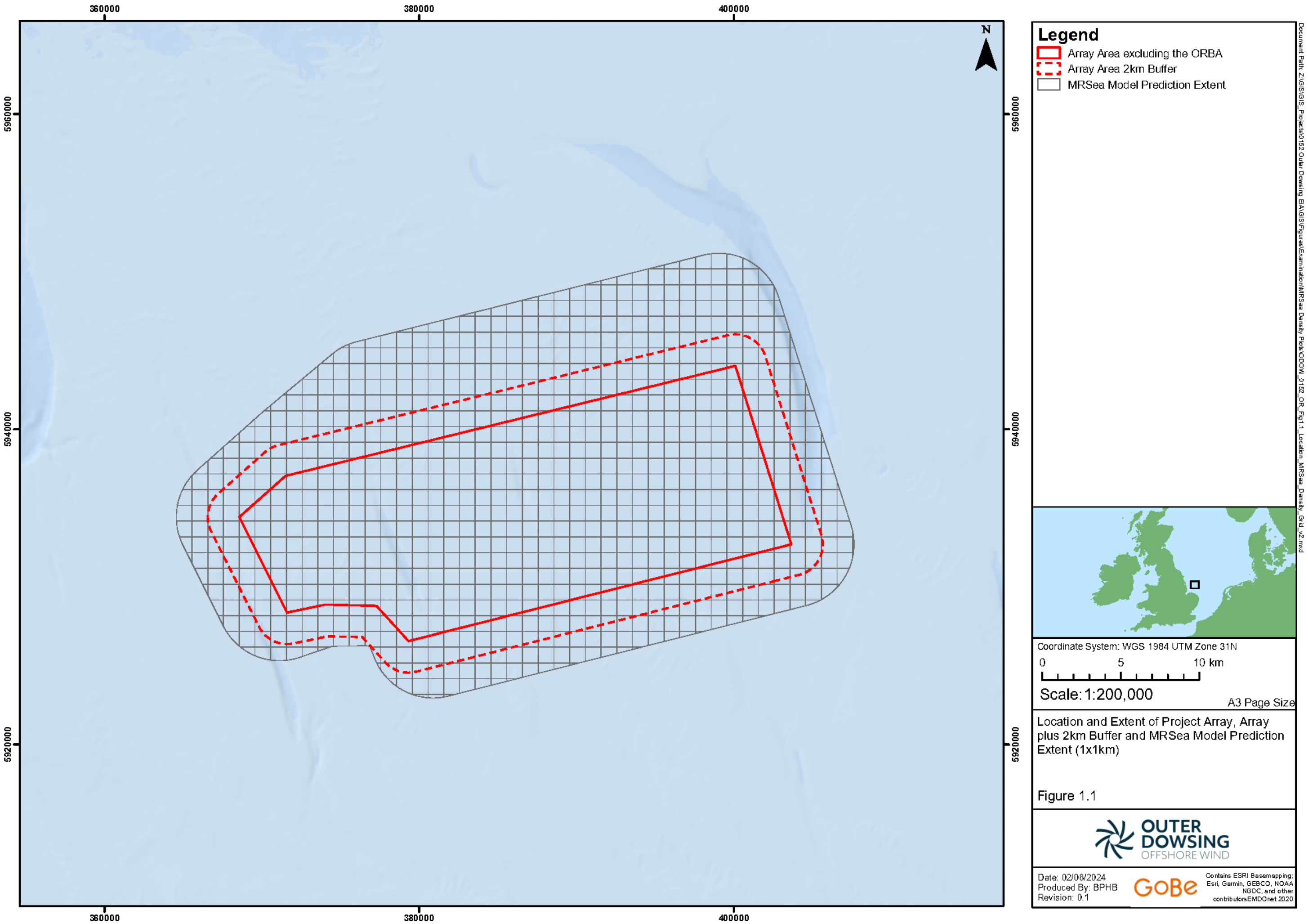

Figure 1-1. Location and extent of Project array, array plus 2km buffer and MRSea model prediction extent (1x1km).

2 Survey Methods

2.1 Survey Design – Digital Aerial Surveys

17. The survey programme commenced in March 2021, running for two complete years plus an additional 6 months to cover a third breeding season (March – August) up to August 2023 inclusive (Table 2-1). Several months were identified as potentially biologically important, with additional surveys carried out in these months. As a result, in 2022, six months were surveyed more than once (March, April, May, June, July, August, September).
18. The survey design comprised 22 transect lines spaced 0.5 km apart at a consistent altitude to capture abutting digital still imagery at 2 cm Ground Sampling Distance (GSD) (Figure 2-1). The imagery captured represents 16.7% coverage of the AoI.
19. Full details of the survey methodology are available within the Offshore Restricted Build Area and Revision to the Offshore Export Cable Corridor Ornithology Baseline Summary (Document Reference 15.9D) and not repeated here for brevity.

Table 2-1. Surveys included in the MRSea modelling approach for guillemot.

2021		2022		2023	
Survey No.	Survey Month 2021	Survey No.	Survey Month 2022	Survey No.	Survey Month 2023
01	March	11	January	30	January
02	April	12	February	31	February
03	May	13	March (I)	32	March
04	June	14	March (II)	33	April
05	July	15	April (I)	34	May
06	August	16	April (II)	35	June
07	September	17	May (I)	36	July
08	October	18	May (II)	37	August
09	November	19	June (I)		
10	December	20	June (II)		
		21	July (I)		
		22	July (II)		
		23	August (I)		
		24	August (II)		
		25	September (I)		
		26	September (II)		
		27	October		
		28	November		
		29	December		

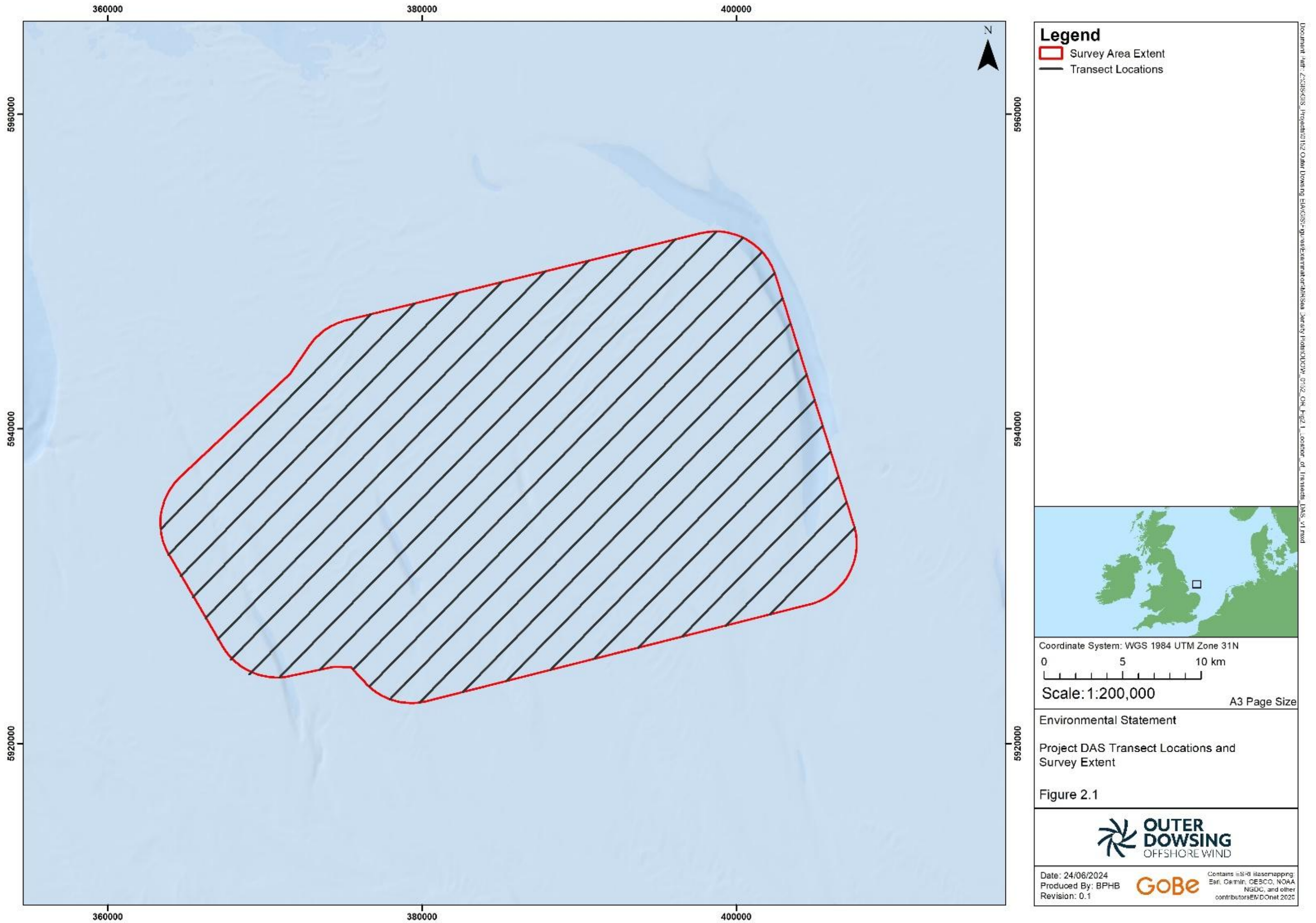

Figure 2-1. Project DAS transect locations and survey extent.

2.2 Data Analysis: Model-based Abundance Estimates

20. To provide more detail for common guillemot, *Uria aalge* (referred to as guillemot for the remainder of this report) within the Project site, model-based approaches were used to determine statistically robust, spatially distributed population estimates. Using model-based techniques means that environmental variables can be included within the analysis to help predict more accurate abundance and density distributions within the AoI. MRSea based analysis was used to generate estimates of distribution and abundance, underpinned by observations of guillemot recorded in the DAS imagery (Scott-Hayward et al., 2014).
21. MRSea is a statistical analysis R software (R, 2022) package specifically designed by the Centre for Research into Ecological and Environmental Modelling (CREEM) for both baseline analysis (site characterisation) and, where data are available, pre- and post-construction analysis. The latter can be used for investigating potential changes in distributions of birds following an OWFs development. The model uses a “Complex Region Spatial Smoother” (CReSS) spatial modelling technique with a “Spatially Adaptive Local Smoothing Algorithm” (SALSA) to estimate bird distributions in a Generalised Additive Model (GAM) framework. This modelling method was developed to analyse spatial abundance data following an environmental change, such as the construction of a wind farm, and allows spatially auto-correlated and zero-inflated data to be modelled in a robust way (Scott-Hayward et al., 2021).

2.2.1 Modelling Approach Details

22. The steps used to fit the models are described below in general terms.
23. The model was based on a spatially adaptive GAM to permit nonlinear relationships on the link scale for each candidate covariate (depth and distance to coast). This model was used to test for collinearity between variables using generalised variance inflation factors (GVIF) using the Car package (Fox & Weisberg, 2019). Variables were assessed using both the GVIF value and by inspecting correlation plots to determine whether the variables correlate with each other. Excessive levels of collinearity (above five) can cause issues with model fit; however, none of the GVIF values were high enough to be of concern. Behaviour was also included as a factor term for the model outputs to be split according to behaviour. An interaction term between survey and behaviour was included, allowing the proportions of birds exhibiting each behaviour to alter between surveys. Model selection was carried out using QBIC scores (the quasi-likelihood analogue of the Bayesian Information Criterion), allowing both removal of terms and comparison of both linear and smoothed terms.
24. The X and Y coordinates were included as a two-dimensional spatial smoother. Survey was included as a factor variable within the model which also included an interaction term between the survey variable and the smoothed spatial term (X and Y coordinates). This allowed for the knot coefficients (but not the position of the knots) to vary between surveys, if appropriate.

2.2.2 Model Specifications

25. Due to the nature of seabird count data, such data generally displays properties of an over-dispersed Poisson distribution. Models were assessed visually to determine the most appropriate error terms. Data collected along transects and repeated surveys may lead to temporal correlation. This was assessed as part of the model process with runs tests and autocorrelation function plots.
26. A CreSS basis was used to fit the spatial density surface. Model flexibility is determined by both the number of 'knots' used (i.e. anchor points) for the model and the effective range (r) of the basis associated with each knot. SALSA2D was used to determine the number/location of knots and the r parameters with QBIC as the selection criterion.

2.2.3 Spatially Explicit Inference

27. The data used within the modelling process were collected from DAS programme of the Project, conducted from March 2021 to August 2023 (inclusive). Similar geo-referenced locations are deemed more likely to return similar counts, with points close together often showing greater similarity than points distant in time and space. If the environmental variables that describe patterns of high and low numbers in a specific geographic location were missing from the model specification, a pattern in the model residuals often remains. This pattern in the model residuals violates the critical assumption for most statistical analysis (such as GAMs) which requires independence of errors. This can invalidate all model-based estimates of precision and may mean estimates are poor. If residual correlation was detected, then robust standard errors were used as these allow for the autocorrelation present to provide realistic model-based estimates of uncertainty. As part of this process, a blocking structure must be chosen such that the residuals are permitted to be correlated within blocks but are deemed independent between blocks. Survey ID (month as a numeric variable), concatenated with Transect ID, was specified as the blocking structure to ensure that the model should treat data from within each transect of each survey as correlated, but independent between different transects and surveys. These independence assumptions were validated by visual assessment of autocorrelation function (ACF) and mean variance plots (Annex A – Overall Model).

2.2.4 Model Selection

28. In the initial one-dimensional SALSA model, a knot is placed at the median of the variables. During the optimisation process, additional knots can be chosen based on areas within the covariate range in greatest need of extra flexibility. For the two-dimensional SALSA model, initial knot locations on the spatial surface were chosen to maximise the coverage across the spatial area, with these permitted to move according to the SALSA model selection. QBIC ~~was be~~was used to determine the flexibility for the spatial models or to have knots added or removed depending on the areas in need of flexibility across the spatial term.

29. Model fits were assessed via review of levels of residual autocorrelation using autocorrelation functions and run tests. Additionally, model selection was completed using an analysis of variance (ANOVA), enabling p-values for each term to be scrutinised. The two-dimensional relationship was plotted and checked for sensibility and an F-test was used for cumulative residual plots to check if covariates were modelled appropriately.

30. The complete model selection methodology, validation and outputs can be found in Annex A – Overall Model. A description and results of the model validation can be found in Annex A – Overall model. The final model used for analysis is summarised in Table 2-2. The model selection process for the complete dataset determined the best model to include covariates of survey, smoothed X and Y coordinates (spatial term), the interaction term between survey and the smoothed spatial term, and an area offset. Depth and distance to coast were dropped in the model. ().

Table 2-2. Covariates included in the final model for guillemot

Model	Model Covariates
All survey data	Survey + LRF.g(radiusIndices, dists, radii, aR) + Survey:LRF.g(radiusIndices, dists, radii, aR) + offset(log(area))

2.2.5 Prediction Grid

31. The prediction grid was constructed by clipping a grid of 1 km² grid cells to the survey area of the Project (QGIS; Figure 1-1). The survey area represented the array area minus the ORBA plus 4km buffer. Outputs are presented for the array area minus the ORBA plus a 2km buffer, as shown in Table 3-2. Each grid cell was then associated with depth (bathymetry) and distance to shore, which were obtained from the location information derived from the survey observations.

32. This analysis was used to model the abundance and distribution of guillemots. Bootstrapping (n=1,000) was used to estimate the uncertainty of parameter estimation and the resulting parametric confidence intervals were plotted for each month.

2.2.6 Modelling Distribution

33. To model the distribution of guillemots, the output of the model-based abundances for each species were clipped to the AoI. A population estimate, the density per km^2, and lower and upper confidence intervals (CIs) were calculated. The 95% CIs were generated from the 1,000 replicates of a parametric bootstrap created during the modelling process. Population estimate values were used to visually present the density of guillemots in the AoI within Guillemot results. Apportioned estimates are presented alongside those corrected for availability bias.

2.2.7 Apportioning

34. Apportioning of 'unidentified' birds to species level was also undertaken for the purposes of calculating population estimates within the array area minus the ORBA plus 2 km buffer. The number of unidentified birds in each species group were assigned to species where appropriate, based on their respective abundance ratios. For example, if identified guillemots and razorbills occurred in a 4:1 ratio in a survey, then 80% of unidentified birds would be assigned to guillemot and 20% assigned to razorbill.

2.2.8 Availability Bias

35. Using Barlow's method, the proportion of time that an animal is available at the surface was calculated (Pr (visible)) for guillemot and razorbill. Absolute density, corrected for availability, was then obtained by dividing the density of birds observed by Pr(visible).
36. For guillemots and razorbills, data obtained during the breeding season using data loggers were used to estimate availability bias. Thaxter et al. (2010) gives mean times for these species engaged in flying, feeding and underwater per trip during the chick-rearing period.
37. Thus, the proportion of time that guillemots are available at the surface (Pr(visible)) was estimated at 0.7595.

3 Guillemot results

3.1 Guillemot Population Estimates and Distribution

3.1.1 Overall Analysis

38. Guillemots were recorded in all surveys. The peak count for guillemots was recorded in August 2022 (14,578 individuals), with raw counts for each month presented in Table 3-1. Throughout the survey period, a slight trend of higher relative densities to the west of the AoI was observed. January 2022 returned the lowest raw counts of 82 individuals. All months remained above the threshold required for use in statistical modelling approaches when considering the full ~~analysis~~ survey area (Table 6-1). Model outputs for the project array area minus the ORBA were also considered (Table 7-1).

39. Model-based population estimates (unapportioned, apportioned and apportioned with availability bias) within the array area minus the ORBA plus 2 km buffer are presented in Table 3-2. Peak abundance (apportioned & availability bias) was estimated in April 2022, with 29,720 guillemots - equating to a density of 54.17 birds/km^2. Results from the model-based abundance estimates show that in August 2021, the highest density of guillemots were estimated in the east of the AoI (Figure 3-1). Similar densities were predicted in 2022 for April, July and August, but the density hotspots were located to the southern, eastern and northern edges of the AoI respectively (Figure 3-2Figure 3-3). Within 2023, smaller hotspots were observed in the north and eastern edges of the AoI, particularly within the months of May and August (Figure 3-4). The MRSea data strongly agreed with the design based density estimates, which also show a general pattern of higher densities of guillemot and razorbill to the north of the ~~array~~ survey area (see Figures 12.33 - 12.35 and 12.39 - 12.41 of the Offshore Restricted Build Area and Revision to the Offshore Export Cable Corridor Ornithology Baseline Summary (document 15.9D)). ~~This information~~The model distribution within the full survey area has been used to inform the ORBA location alongside continued engagement with the relevant oil and gas operators who have interests which overlap with the Project, i.e. due to the presence of oil and gas platforms within or adjacent to the array area.

40. Cross-examination between the months with two surveys generally showed low variability in occurrence between surveys, but overall densities were different. Denser concentrations of guillemots were recorded in the north and east of the AoI during months of peak abundances (Figure 3-1, Figure 3-2, Figure 3-3 & Figure 3-4).

Table 3-1. Numbers of individuals of guillemots recorded within the Project site on a per-survey basis for the March 2021 to August 2023 survey period.

Survey Month	Year	Month	Count
01	2021	March	1,084
02	2021	April	3,599
03	2021	May	772

Survey Month	Year	Month	Count
04	2021	June	181
05	2021	July	1,291
06	2021	August (I)	3,644
07	2021	September	4,088
08	2021	October	978
09	2021	November	1,028
10	2021	December	466
11	2022	January	82
12	2022	February	648
13	2022	March (I)	2,078
14	2022	March (II)	2,293
15	2022	April (I)	9,006
16	2022	April (II)	4,133
17	2022	May (I)	4,305
18	2022	May (II)	1,484
19	2022	June (I)	488
20	2022	June (II)	1,584
21	2022	July (I)	1,115
22	2022	July (II)	4,415
23	2022	August (I)	13,269
24	2022	August (II)	1,309
25	2022	September (I)	1,584
26	2022	September (II)	256
27	2022	October	447
28	2022	November	322
29	2022	December	646
30	2023	January	289
31	2023	February	724
32	2023	March	1,040
33	2023	April	1,646
34	2023	May	662
35	2023	June	350
36	2023	July	451
37	2023	August	1,887

Table 3-2. Model-based population estimates and densities of guillemots, with lower and upper confidence limits for the array area minus the ORBA plus a 2 km buffer.

Survey No.	Survey Month	Population Estimate	Lower Cl	Upper Cl	Density (birds/km^2)	Population Estimate	Lower CI	Upper CI	Density	Population Estimate	Lower CI	Upper CI	Density
		Unapportioned				Apportioned				Apportioned & Availability Bias			
01	March	4,047	3,043	5,460	7.38	4,428	3,330	5,974	8.07	5,830	4,384	7,866	10.63
02	April	11,360	7,946	16,326	20.71	11,924	8,341	17,137	21.74	15,700	10,982	22,563	28.62
03	May	2,813	1,933	4,407	5.13	2,956	2,032	4,631	5.39	3,892	2,675	6,098	7.09
04	June	662	454	986	1.21	732	502	1,090	1.33	964	660	1,435	1.76
05	July	4,440	3,390	5,850	8.09	4,558	3,481	6,005	8.31	6,001	4,583	7,907	10.94
06	August	12,922	8,020	21,429	23.55	13,641	8,466	22,622	24.87	17,961	11,147	29,785	32.74
07	September	12,211	8,706	17,342	22.26	12,745	9,087	18,100	23.23	16,781	11,964	23,832	30.59
08	October	3,637	3,037	4,359	6.63	4,007	3,347	4,803	7.30	5,275	4,406	6,324	9.62
09	November	2,859	2,384	3,452	5.21	3,058	2,550	3,692	5.57	4,026	3,358	4,861	7.34
10	December	1,681	1,338	2,110	3.06	1,854	1,476	2,327	3.38	2,441	1,943	3,064	4.45
11	January	247	153	448	0.45	296	184	537	0.54	389	242	707	0.71
12	February	2,532	1,823	3,605	4.62	2,677	1,927	3,811	4.88	3,525	2,538	5,018	6.43
13	March (I)	4,295	2,861	6,765	7.83	4,527	3,015	7,131	8.25	5,960	3,970	9,389	10.86
14	March (II)	4,407	3,531	5,563	8.03	4,968	3,981	6,271	9.06	6,541	5,241	8,256	11.92
15	April (I)	14,758	11,699	18,761	26.90	15,048	11,929	19,129	27.43	19,813	15,707	25,187	36.12
16	April (II)	7,344	5,356	10,132	13.39	7,524	5,487	10,380	13.71	9,906	7,225	13,667	18.06
17	May (I)	8,667	6,817	11,186	15.80	8,929	7,023	11,524	16.28	11,756	9,247	15,173	21.43
18	May (II)	2,575	1,697	4,194	4.69	2,696	1,777	4,391	4.91	3,549	2,339	5,781	6.47
19	June (I)	1,401	744	2,764	2.55	1,455	773	2,871	2.65	1,916	1,018	3,780	3.49
20	June (II)	2,175	1,614	2,938	3.97	2,201	1,634	2,973	4.01	2,898	2,151	3,914	5.28
21	July (I)	1,301	952	1,762	2.37	1,322	967	1,791	2.41	1,741	1,274	2,358	3.17
22	July (II)	4,339	2,646	7,466	7.91	4,560	2,781	7,846	8.31	6,004	3,661	10,331	10.95
23	August (I)	5,078	2,540	13,743	9.26	5,285	2,643	14,303	9.63	6,958	3,481	18,832	12.68
24	August (II)	2,059	1,334	3,280	3.75	2,077	1,346	3,309	3.79	2,735	1,772	4,356	4.98
25	September (I)	4,486	2,908	7,407	8.18	4,730	3,066	7,810	8.62	6,227	4,036	10,283	11.35
26	September (II)	845	662	1,105	1.54	882	690	1,153	1.61	1,161	909	1,519	2.12
27	October	1,475	1,198	1,846	2.69	1,648	1,339	2,063	3.00	2,169	1,763	2,716	3.95

Survey No.	Survey Month	Population Estimate	Lower Cl	Upper Cl	Density (birds/km^2)	Population Estimate	Lower CI	Upper CI	Density	Population Estimate	Lower CI	Upper CI	Density
		Unapportioned				Apportioned				Apportioned & Availability Bias			
28	November	1,017	727	1,450	1.85	1,144	818	1,631	2.09	1,506	1,077	2,147	2.75
29	December	2,274	1,828	2,860	4.14	2,493	2,004	3,135	4.54	3,282	2,639	4,128	5.98
30	January	983	518	1,810	1.79	1,119	590	2,061	2.04	1,473	777	2,713	2.69
31	February	1,720	1,061	2,844	3.14	1,781	1,098	2,945	3.25	2,345	1,446	3,877	4.27
32	March	1,757	1,239	2,528	3.20	1,879	1,325	2,703	3.42	2,474	1,744	3,559	4.51
33	April	2,565	1,893	3,503	4.67	2,684	1,981	3,666	4.89	3,533	2,608	4,827	6.44
34	May	1,019	422	3,155	1.86	1,076	445	3,331	1.96	1,417	586	4,386	2.58
35	June	530	338	838	0.97	557	355	881	1.02	734	468	1,159	1.34
36	July	620	474	814	1.13	679	519	891	1.24	894	684	1,174	1.63
37	August	3,204	2,217	4,854	5.84	3,335	2,308	5,053	6.08	4,391	3,039	6,653	8.00

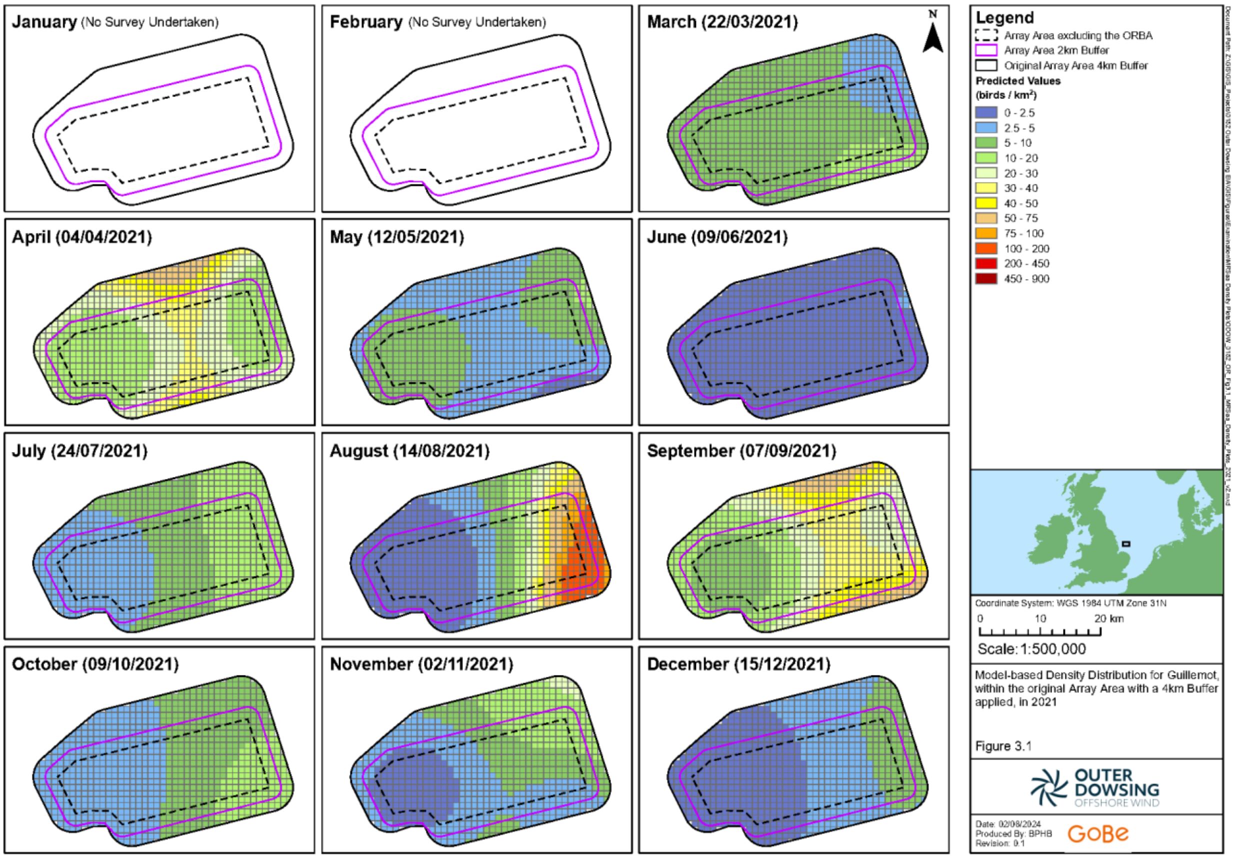

Figure 3-1. Model-based Density Distribution for Guillemot, within the ES Array Area with a 4km Buffer applied, in 2021. The array area minus the ORBA is shown with a dashed line. The ORBA is not shown in this figure.

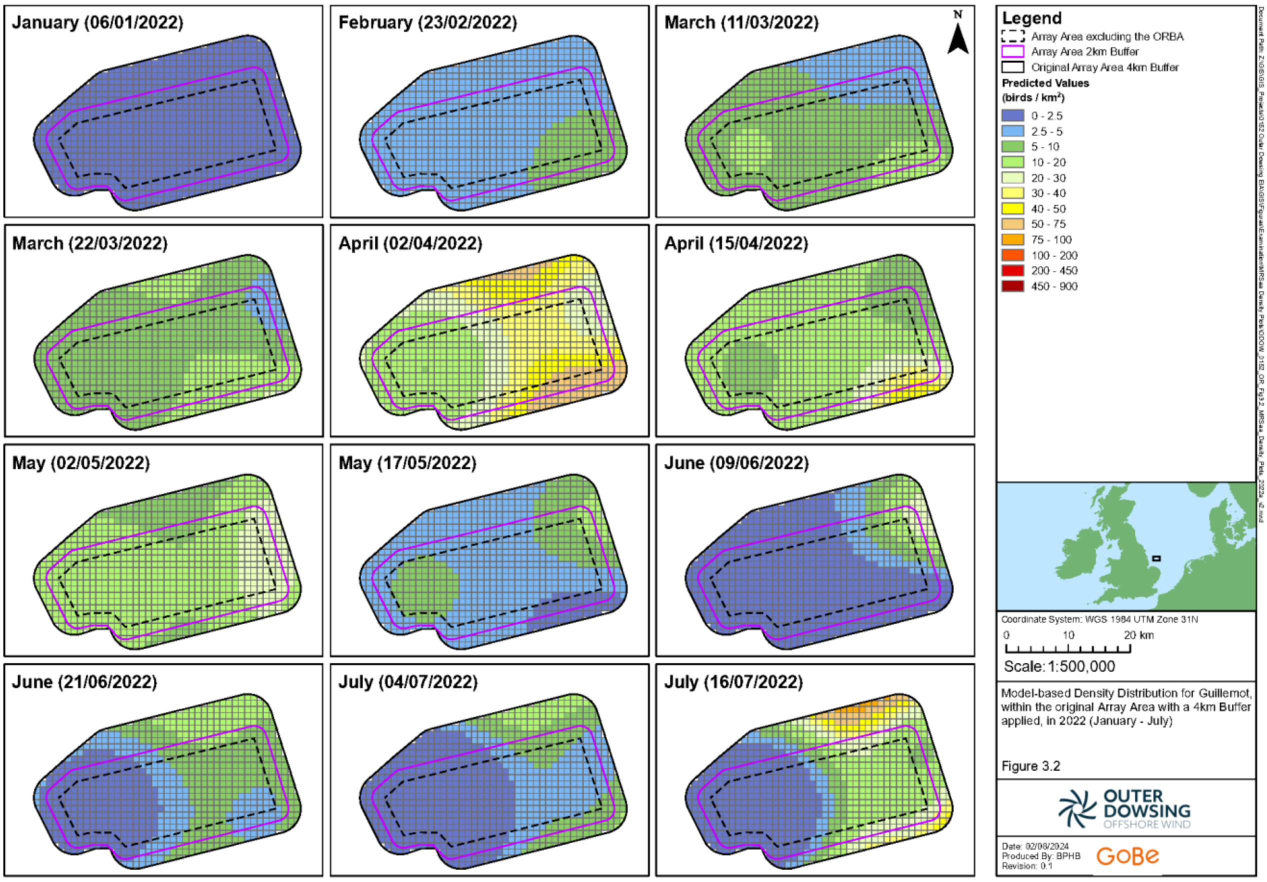

Figure 3-2. Model-based Density Distribution for Guillemot, within the ES Array Area with a 4km Buffer applied, in 2022 (January – July). The array area minus the ORBA is shown with a dashed line. The ORBA is not shown in this figure .

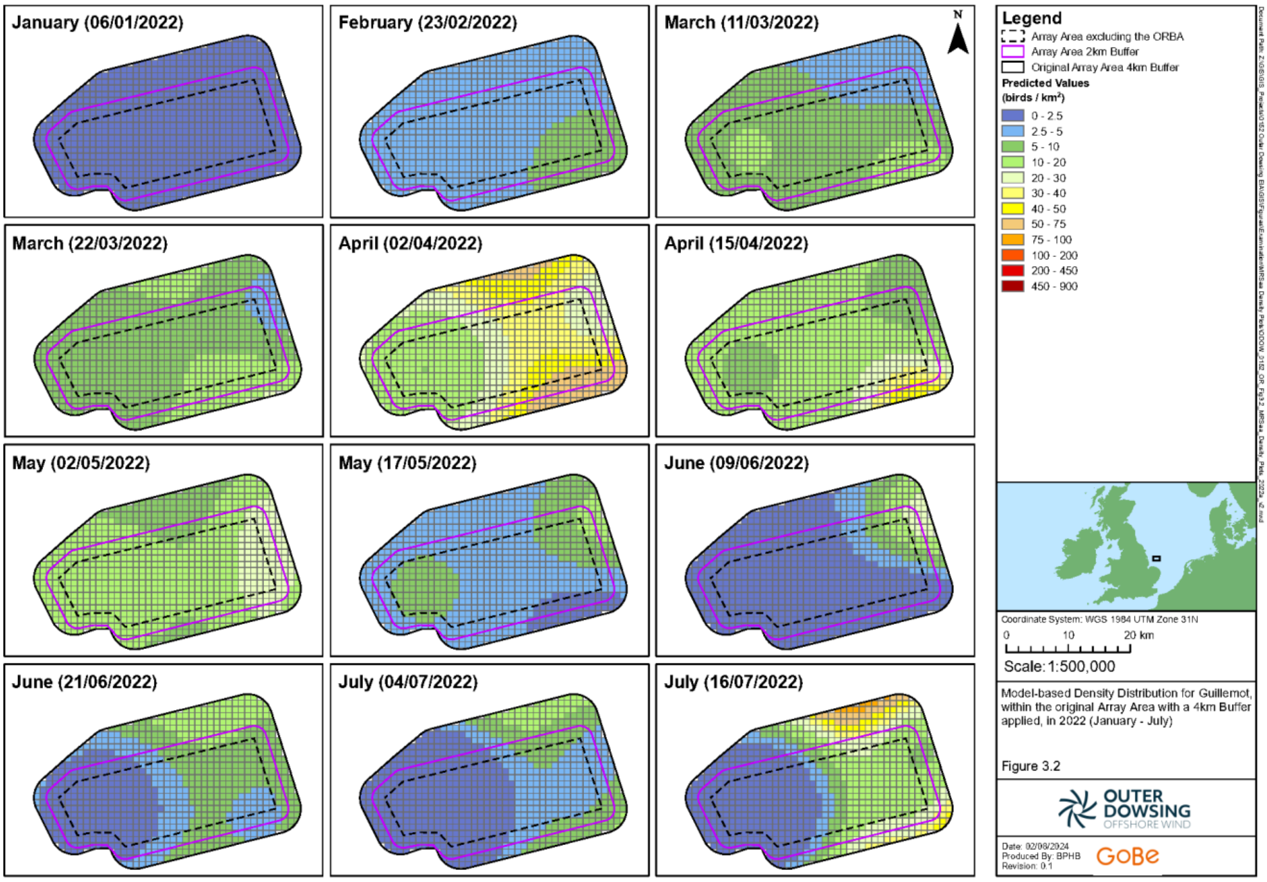

Figure 3-3. Model-based Density Distribution for Guillemot, within the ES Array Area with a 4km Buffer applied, in 2022 (August – December). The array area minus the ORBA is shown with a dashed line. The ORBA is not shown in this figure.

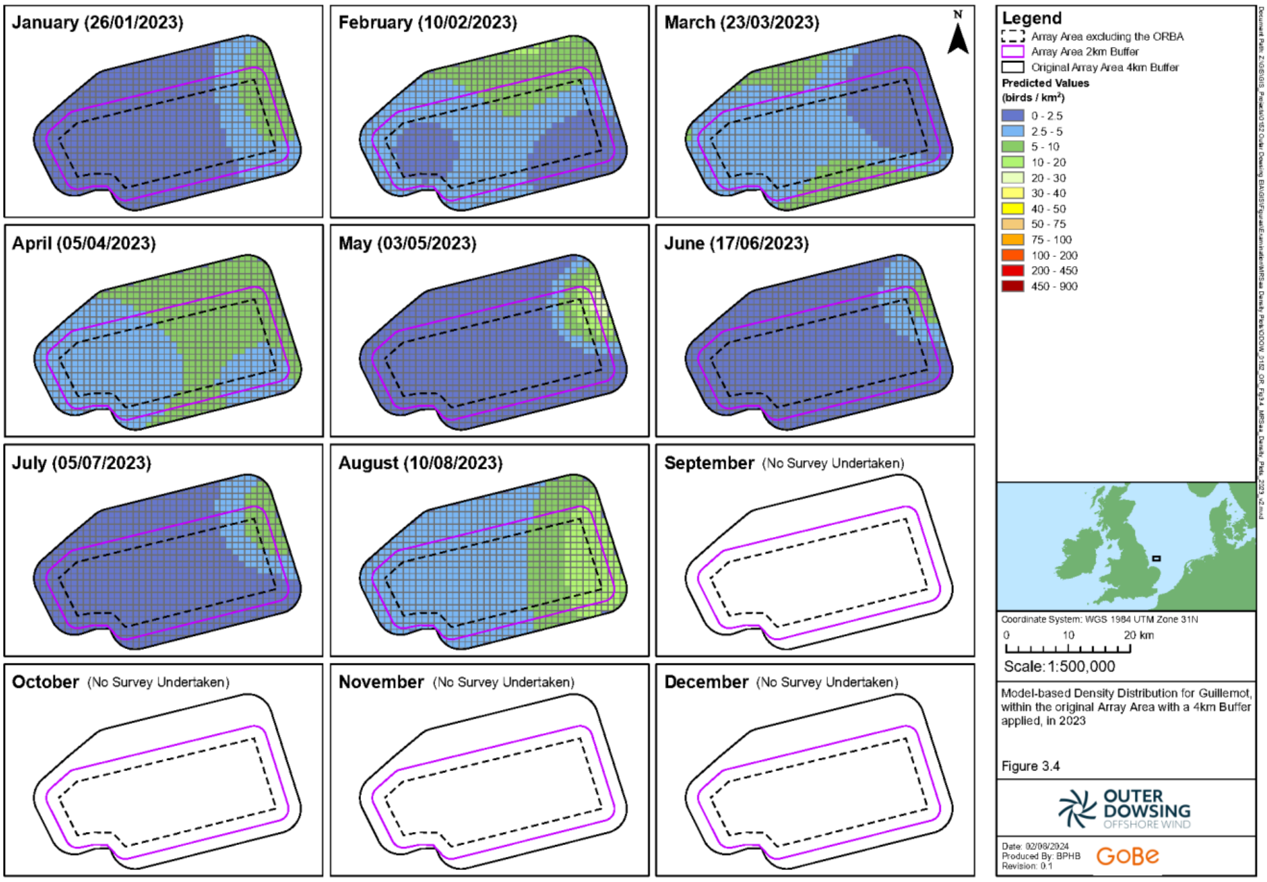

Figure 3-4. Model-based Density Distribution for Guillemot, within the ES Array Area with a 4km Buffer applied, in 2023. The array area minus the ORBA is shown with a dashed line. The ORBA is not shown in this figure.

4 Discussion

4.1 Density and Distribution

4.1.1 Density and Distribution of Guillemots

41. The peak raw count of guillemots (n = 14,578) was recorded in August 2022, equating to a model-based population estimate of 9,692 and a density of 17.67 guillemots/km^2 within the array area minus the ORBA plus 2 km buffer. Guillemot distributions varied little between months, but hotspots were identified in the north and east of the AoI, particularly within August 2021 and August 2022 (Figure 3-1 and Figure 3-3). The MRSea data strongly agreed with the design based density estimates, which also show a general pattern of higher densities of guillemot and razorbill to the north of the array area (see Figures 12.33 - 12.35 and 12.39 - 12.41 of the Offshore Restricted Build Area and Revision to the Offshore Export Cable Corridor Ornithology Baseline Summary (document 15.9D)).

42. The introduction and size of the ORBA has been made possible through continued engagement with the relevant oil and gas operators who have interests which overlap with the Project, i.e. due to the presence of oil and gas platforms within or adjacent to the array area. Since the Application, the Applicant has been able to agree the principles for co-existence between the Project and access arrangements to the Malory platform with Perenco, specifically for helicopter transfers to and from this platform. Confidence in the likely final protective provisions for this operator within the DCO for the Project has therefore allowed further engineering work to be undertaken to support additional mitigation of the impact to auk species through a reduction in the area within which WTGs and OPs may be placed.

43. The introduction of the ORBA has resulted in a reduction in the summed mean seasonal peak abundance of guillemot from 27,653.3 birds in the array area plus 2 km buffer (Appendix 12.1 Offshore and Intertidal Ornithology Technical Baseline (AS1-064)) to a summed mean seasonal peak abundance of 23,586 guillemot in the array area minus the ORBA plus 2km buffer (Appendix 15.9D).

44. The largest protected sites closest to the Project are the Greater Wash SPA (c. 70 km) and the Flamborough and Filey Coast (FFC) Special Protection Area (SPA) (c. 117 km), with guillemots listed as a qualifying feature for the latter (JNCC, 2018). As a qualifying feature, guillemots at FFC SPA were reported at an estimated 45,504 Apparently Occupied Nests (AONs) in 2017 (Lloyd et al., 2019), whilst more recent figures have shown a slight decrease to 44,574 AONs in 2022 (Clarkson et al., 2022). In the UK, the guillemot return migration period covers January-April, with migration-free breeding occurring May-July, and migration away from UK colonies occurring in August-December (Furness, 2015).

45. The peak numbers recorded in August 2022, and comparatively higher numbers through the rest of the summer, likely reflect high usage of both breeding and non-breeding adults as well as post-fledging groupings. In April and March, breeding adult guillemots would be expected to be encountered more frequently and, therefore, constitute a greater number of observations. In June, immature birds arriving later to colonies would be expected to increase guillemot encounter rate in the Project. Subsequently, the peak raw count recorded in August 2022, may reflect the mixture of post-fledging adult-chick groupings as well as immatures/non-breeders.

5 References

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6 Annex A – Overall Model

~~6.1 Model Selection~~

~~**Final model**~~

~~Call:~~

~~gamMRSea(formula = response ~ Survey + LRF.g(radiusIndices, dists,~~

~~radii, aR) + Survey:LRF.g(radiusIndices, dists, radii, aR) +~~

~~offset(log(area)), family = "quasipoisson", data = model_data,~~

~~splineParams = splineParams)~~

~~Deviance Residuals:~~

~~Min 1Q Median 3Q Max~~

~~-13.440 -1.179 -0.672 -0.235 61.682~~

~~(Dispersion parameter for quasipoisson family taken to be 8.822032)~~

~~Null deviance: 206966 on 42775 degrees of freedom~~

~~Residual deviance: 131286 on 42628 degrees of freedom~~

~~AIC: NA~~

~~Max Panel Size = 74; Number of panels = 832~~

~~Number of Fisher Scoring iterations: 7~~

~~6.2~~6.1 Model Outputs

Table 6-1. Model-based population estimates and densities of guillemots, with lower and upper confidence limits, for the entire MRSea analysis area.

Survey No.	Survey Month	Population Estimate	Lower CI	Upper CI	Density (birds/km^2)
01	March	6,755	4,986	9,348	8.02
02	April	22,839	15,517	33,837	27.11
03	May	4,578	3,025	7,655	5.43
04	June	1,097	735	1,663	1.30
05	July	7,848	5,912	10,474	9.31
06	August	23,038	13,583	40,700	27.34
07	September	24,661	17,015	35,997	29.27

Survey No.	Survey Month	Population Estimate	Lower CI	Upper CI	Density (birds/km^2)
08	October	6,128	5,044	7,465	7.27
09	November	5,994	4,991	7,242	7.11
10	December	2,943	2,282	3,800	3.49
11	January	490	301	900	0.58
12	February	4,127	2,917	6,003	4.90
13	March (I)	6,659	4,310	10,870	7.90
14	March (II)	7,906	6,233	10,157	9.38
15	April (I)	28,194	21,896	36,549	33.46
16	April (II)	12,620	9,061	17,747	14.98
17	May (I)	13,355	10,218	17,820	15.85
18	May (II)	4,285	2,699	7,450	5.09
19	June (I)	2,952	1,475	6,238	3.50
20	June (II)	4,889	3,652	6,612	5.80
21	July (I)	3,341	2,277	4,864	3.97
22	July (II)	12,571	6,564	25,761	14.92
23	August (I)	38,629	13,610	137,852	45.85
24	August (II)	4,017	2,557	6,583	4.77
25	September (I)	7,776	5,043	12,714	9.23
26	September (II)	1,485	1,146	1,968	1.76
27	October	2,572	2,082	3,221	3.05
28	November	1,906	1,316	2,800	2.26
29	December	3,862	3,054	4,927	4.58
30	January	1,795	889	3,547	2.13
31	February	3,605	2,212	5,985	4.28
32	March	3,184	2,200	4,692	3.78
33	April	4,552	3,298	6,316	5.40
34	May	1,872	686	6,825	2.22
35	June	1,006	604	1,703	1.19
36	July	1,247	927	1,695	1.48
37	August	5,295	3,549	8,344	6.28

6.2 Model Selection and Validation

6.2.1 Model Setup

46. Co-linearity of explanatory variables was initially examined by observing Generalised Variance Inflation Factors (GVIFs) (Figure 6-1). Where strong collinearity was detected (a value of over 20) covariates would be removed. All adjusted GVIF values were below this threshold, and as a non-linear approach was used, no explanatory variables were removed at this point.

```
            GVIF Df GVIF^(1/(2*Df))
Survey      1.000013 36        1.000000
depth       1.386459  1        1.177480
dist_coast 23.427181  1        4.840163
x.pos      10.204969  1        3.194522
y.pos      12.344182  1        3.513429
```

Figure 6-1 Code snippet detailing testing for co-linearity.

47. To fit the model, there was a requirement for all levels of any categorical variables to contain non-zero counts. The only categorical variable “Survey” (a proxy for month) was checked and required no further action (Figure 6-2).

```
> checkfactorlevelcounts(factorlist=c("Survey"),
+                        model_data,
+                        model_data$response)
[1] "Survey will be fitted as a factor variable; there are non-zero counts for all levels"
```

Figure 6-2 Code snippet verifying non-zero counts for all factor levels.

6.2.2 Generalised Linear Model

48. Before creation of more complex models, a simple Generalised Linear Model (GLM) was created and run as an initial model (Figure 6-3).

```
Call:
glm(formula = response ~ Survey + depth + dist_coast + x.pos +
    y.pos + offset(log(area)), family = "quasipoisson", data = model_data)

Coefficients:
                        Estimate     Std. Error t value              Pr(>|t|)
(Intercept)       -444.808268226  65.740534925  -6.766    0.0000000001339847 ***
Survey2021_04_04     1.197704875   0.152465464   7.856    0.0000000000000407 ***
Survey2021_05_12    -0.369007124   0.209025602  -1.765              0.077509 .
Survey2021_06_09    -1.807462610   0.355703577  -5.081    0.0000037629184038 ***
Survey2021_07_24     0.148852095   0.182222703   0.817              0.414008
Survey2021_08_14     1.204760674   0.152347235   7.908    0.0000000000000268 ***
Survey2021_09_07     1.265356519   0.151287461   8.364  < 0.0000000000000002 ***
Survey2021_10_09    -0.098355374   0.193768192  -0.508              0.611741
Survey2021_11_02    -0.130434261   0.195505904  -0.667              0.504672
Survey2021_12_15    -0.830628763   0.242598824  -3.424              0.000618 ***
Survey2022_01_06    -2.629946420   0.515773975  -5.099    0.0000003428533722 ***
Survey2022_02_23    -0.485017427   0.216504768  -2.240              0.025082 *
Survey2022_03_11    -0.001095222   0.189062427  -0.006              0.995378
Survey2022_03_22     0.145375465   0.182505711   0.797              0.425715
Survey2022_04_02     1.406117248   0.149138147   9.428  < 0.0000000000000002 ***
Survey2022_04_15     0.616331969   0.165872050   3.716              0.000203 ***
Survey2022_05_02     0.702143832   0.163429967   4.296    0.0000174057399771 ***
Survey2022_05_17    -0.436550644   0.213256458  -2.047              0.040657 *
Survey2022_06_09    -0.830904044   0.242598813  -3.425              0.000615 ***
Survey2022_06_21    -0.354072940   0.208082251  -1.702              0.088837 .
Survey2022_07_04    -0.770594987   0.237577302  -3.244              0.001181 **
Survey2022_07_16     0.528731287   0.168503097   3.138              0.001703 **
Survey2022_08_08     1.531416769   0.147392791  10.390  < 0.0000000000000002 ***
Survey2022_08_23    -0.550694424   0.220977806  -2.492              0.012703 *
Survey2022_09_13     0.149786372   0.182293133   0.822              0.411264
Survey2022_09_25    -1.519963653   0.315405153  -4.819    0.0000014471371208 ***
Survey2022_10_10    -0.969057396   0.254853327  -3.802              0.000143 ***
Survey2022_11_07    -1.293228500   0.287668773  -4.496    0.0000069573421812 ***
Survey2022_12_13    -0.555444584   0.221096166  -2.512              0.012001 *
Survey2023_01_26    -1.332165405   0.292194311  -4.559    0.0000051496852681 ***
Survey2023_02_10    -0.635680162   0.227065262  -2.800              0.005120 **
Survey2023_03_23    -0.766382307   0.190334915  -4.026    0.0000567124261534 ***
Survey2023_04_05    -0.391419923   0.174673509  -2.241              0.025040 *
Survey2023_05_03    -1.276464274   0.219242309  -5.822    0.0000000058505651 ***
Survey2023_06_17    -1.902433643   0.273992058  -6.943    0.0000000000038825 ***
Survey2023_07_05    -1.698109808   0.252080664  -6.736    0.0000000000164440 ***
Survey2023_08_10    -0.237253684   0.168683203  -1.407              0.159582
depth                0.000102636   0.001086667   0.094              0.924752
dist_coast          -0.046567741   0.011996661  -3.882              0.000104 ***
x.pos                0.000056925   0.000006296   9.042  < 0.0000000000000002 ***
y.pos                0.000072058   0.000010827   6.655    0.0000000000286264 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for quasipoisson family taken to be 18.36378)

    Null deviance: 206966  on 42775  degrees of freedom
Residual deviance: 156318  on 42735  degrees of freedom
AIC: NA

Number of Fisher Scoring iterations: 8

>
```

Figure 6-3 Code snippet summarising the initial GLM.

49. A runs test was carried out on the initial model (Figure 6-4). This indicated that significant residual correlation was present due to the highly significant p-value.

```
> runsTest(residuals(test_model, type = "pearson"),
+          alternative = c("two.sided"))

        Runs Test - Two sided

data:  residuals(test_model, type = "pearson")
Standardized Runs Statistic = -93.588, p-value < 0.00000000000000022
```

Figure 6-4 Code snippet highlighting the runs test results.

50. This is further backed up by non-randomness in the runs profiles (Figure 6-5).

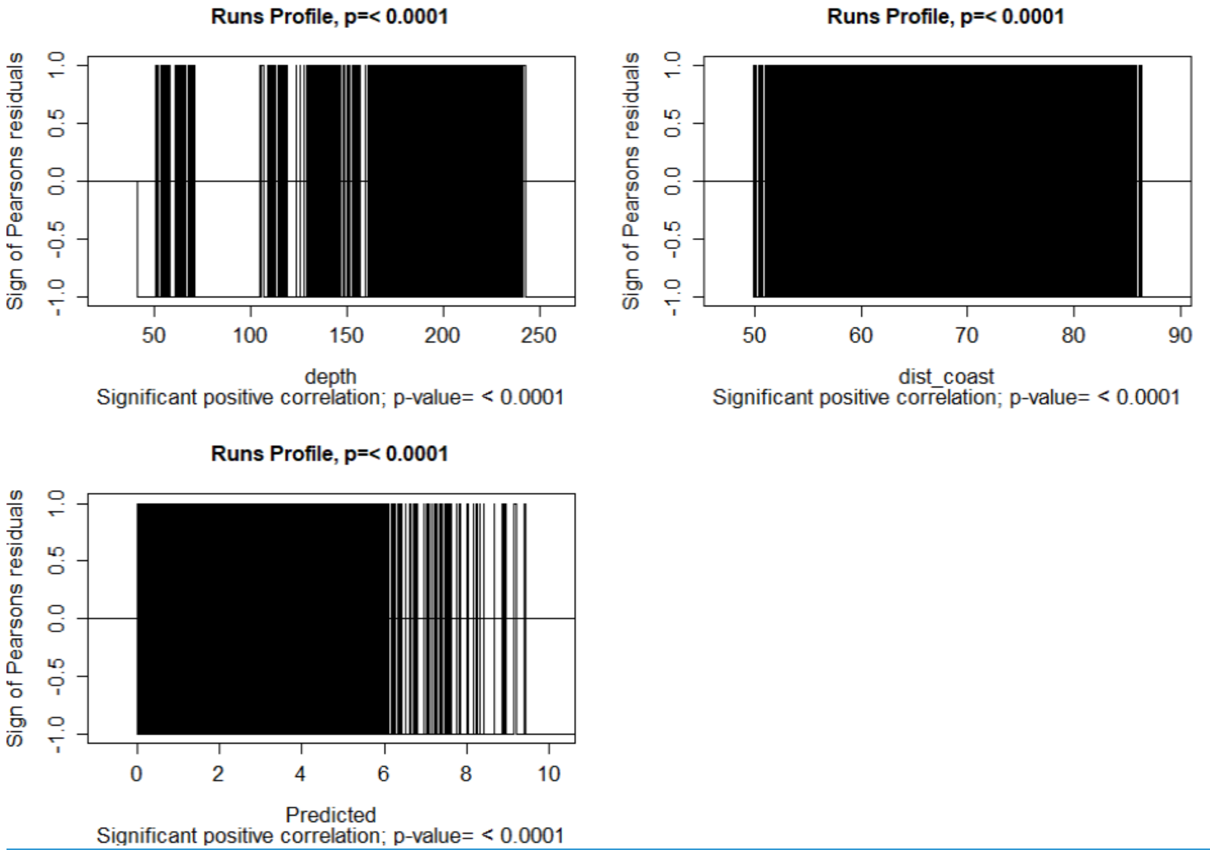


Figure 6-5 Runs profile for the initial GLM. Black lines display the sequence of positive and negative residuals. It is expected to see random distribution of lines in the absence of correlated residuals. Significance of correlation within each variable is displayed.

51. As correlation is present it was deemed appropriate to incorporate a blocking structure moving forward. The blocking structure was based on the combination of Survey ID and Transect ID. This approach enabled the model to treat data from each transect within a survey as correlated, while assuming independence between different transects and surveys. An Auto-Correlation Function (ACF) plot was used to assess the effectiveness of the blocking structure (Figure 6-6). Both the mean correlation in residuals (red line) and correlation in residuals within each block (grey lines) quickly moved to zero, indicating that the blocking structure was fit for purpose.

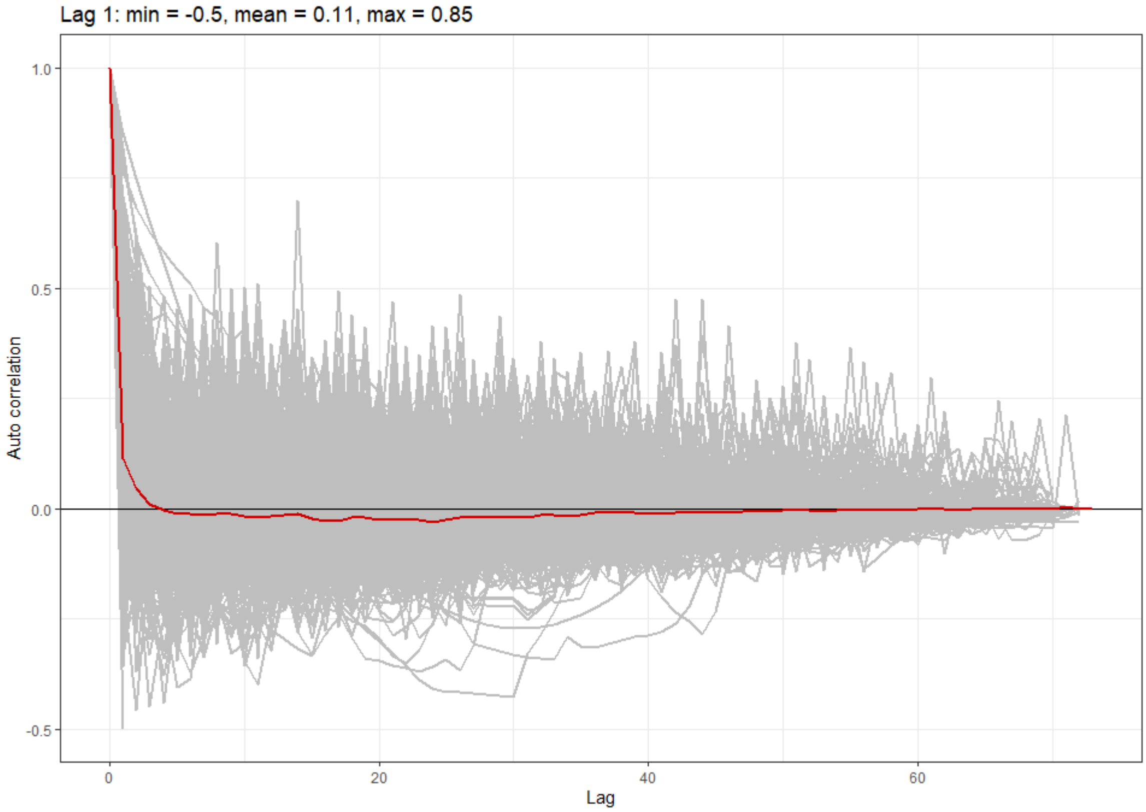


Figure 6-6 Auto-Correlation Function (ACF) plot used for the initial GLM. The grey lines represent the correlation of residuals within each block, while the red line indicates the average correlation of the residuals.

52. Cumulative residuals were plotted for explanatory variables (Figure 6-7 & Figure 6-8). The black line shows the modelled cumulative residuals, while the grey line highlights the expected model fit. It was evident that systematic over- and under- prediction is present for both depth and distance to coast, resulting in the requirement for a more complex, non-linear, model to be used.

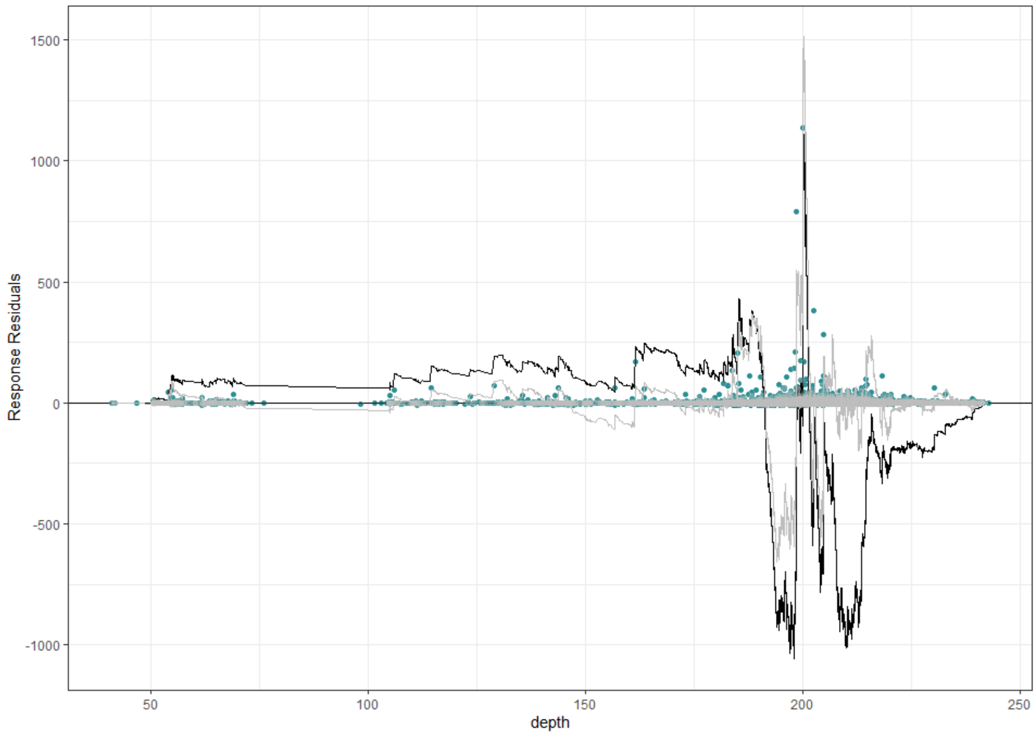


Figure 6-7 Cumulative residuals for initial GLM structured by depth.

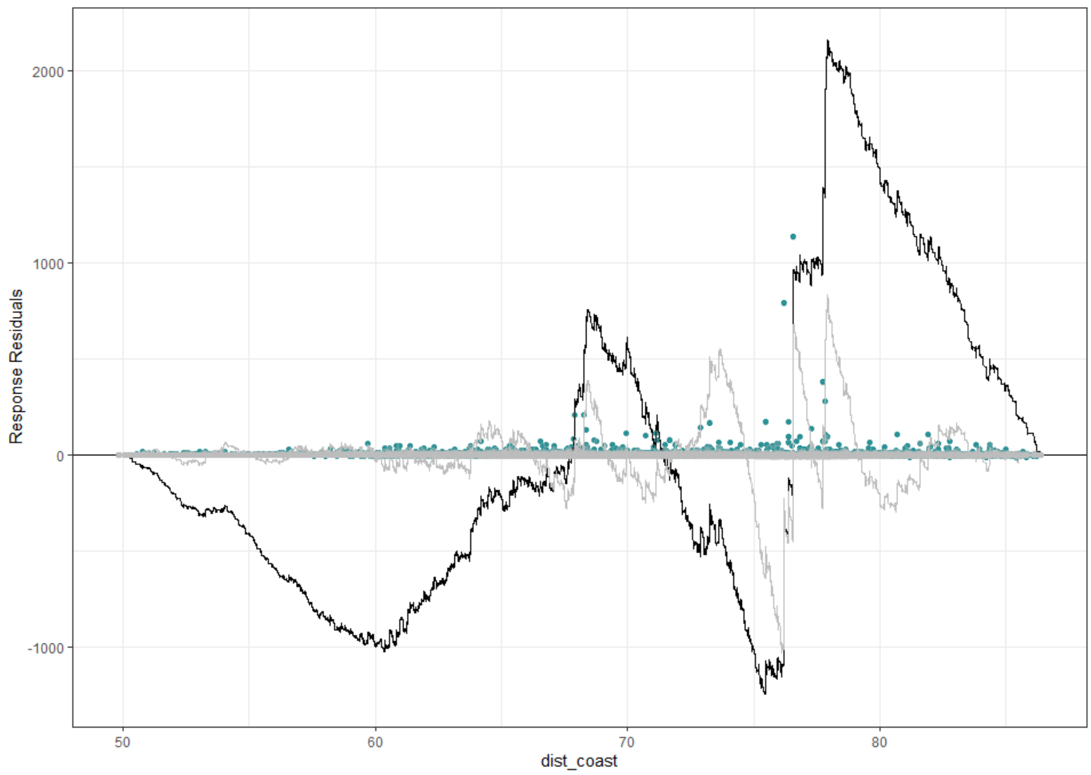


Figure 6-8 Cumulative residuals for initial GLM structured by distance to coast.

6.2.3 Smoothed Model (1D SALSA)

53. Having applied an effective blocking structure and demonstrated a clear requirement for a non-linear modelling approach, 1D SALSA was carried out using the parameters specified below (Figure 6-9). Spline parameters were generated using the built-in makesplineParams function with a default degree of two. Since no "removal" term was specified in the runSALSA1D function, all variables were fitted with smooth splines, without linear terms or removals. Interaction terms are only supported in the 2D SALSA routine.

```
initial_model <- glm(response ~ Survey + offset(log(area)),
                     family = "quasipoisson", data = model_data)
summary(initial_model)
anova(initial_model, test = "F")

varlist <- c("depth","dist_coast")
factorlist <- c("Survey")

if(length(varlist) == 2) {
  salsa1dlist <-list(fitnessMeasure = "QBIC",
                     minKnots_1d = c(1,1),
                     maxKnots_1d = c(6,6),
                     startKnots_1d = c(4,4),
                     degree=c(2,2),
                     maxIterations = 10,
                     gaps = c(1, 1))
} else {
  salsa1dlist <-list(fitnessMeasure = "QBIC",
                     minKnots_1d = c(1),
                     maxKnots_1d = c(6),
                     startKnots_1d = c(4),
                     degree=c(2),
                     maxIterations = 10,
                     gaps = c(1))
}

set.seed(604)
salsa1doutput <- runSALSA1D(initialModel=initial_model,
                            salsa1dlist=salsa1dlist,
                            varlist=varlist,
                            factorlist= factorlist,
                            datain = model_data,
                            panelid = model_data$blockID,
                            removal = FALSE,
                            predictionData = pred_grid)
```

Figure 6-9 Code snippet showing the setup process used for 1D SALSA model.

54. The SALSA 1D function produces multiple distinct models and compares them using a user-specified fitness measure, Quasi-Baysian Information Criterion (QBIC) in this instance. This process will return the model with the best fit, hereafter “best model”, which is selected based on having the lowest QBIC value indicating the best trade-off between model fit and complexity. See below for a summary of the best model (Figure 6-10).

```
Call:
gamMRSea(formula = round(response) ~ Survey + bs(depth, knots = splineParams[[2]]$knots,
    degree = splineParams[[2]]$degree, Boundary.knots = splineParams[[2]]$bd) +
    bs(dist_coast, knots = splineParams[[3]]$knots, degree = splineParams[[3]]$degree,
        Boundary.knots = splineParams[[3]]$bd) + offset(log(area)),
    family = quasipoisson(link = log), data = model_data, splineParams = splineParams)

Deviance Residuals:
   Min      1Q  Median      3Q     Max
-5.380  -1.264  -0.802  -0.268  92.329

Coefficients:
                  Estimate Std. Error Robust S.E. t value             Pr(>|t|)
(Intercept)       0.488114   0.303823    0.418987   1.165             0.244031
Survey2021_04_04  1.198648   0.136782    0.169442   7.074  0.0000000000152727 ***
Survey2021_05_12 -0.368502   0.187524    0.174786  -2.108             0.035011 *
Survey2021_06_09 -1.806594   0.319114    0.168796 -10.703 < 0.0000000000000002 ***
Survey2021_07_24  0.151247   0.163479    0.172422   0.877             0.380388
Survey2021_08_14  1.205591   0.136676    0.270988   4.449  0.0000086541135313 ***
Survey2021_09_07  1.264086   0.135725    0.162331   7.787  0.0000000000000701 ***
Survey2021_10_09 -0.098199   0.173836    0.141995  -0.692             0.489212
Survey2021_11_02 -0.130326   0.175395    0.140093  -0.930             0.352233
Survey2021_12_15 -0.828465   0.217644    0.132454  -6.255  0.0000000004019948 ***
Survey2022_01_06 -2.629421   0.462719    0.206381 -12.741 < 0.0000000000000002 ***
Survey2022_02_23 -0.484785   0.194234    0.161071  -3.010             0.002616 **
Survey2022_03_11  0.001075   0.169614    0.192987   0.006             0.995556
Survey2022_03_22  0.147546   0.163732    0.141541   1.042             0.297222
Survey2022_04_02  1.405234   0.133797    0.136162  10.320 < 0.0000000000000002 ***
Survey2022_04_15  0.617169   0.148810    0.172205   3.584             0.000339 ***
Survey2022_05_02  0.702629   0.146619    0.154428   4.550  0.0000053827719491 ***
Survey2022_05_17 -0.435431   0.191320    0.182638  -2.384             0.017124 *
Survey2022_06_09 -0.830649   0.217644    0.275869  -3.011             0.002605 **
Survey2022_06_21 -0.353208   0.186678    0.142347  -2.481             0.013094 *
Survey2022_07_04 -0.769712   0.213139    0.186080  -4.136  0.0000353388955611 ***
Survey2022_07_16  0.528075   0.151170    0.234575   2.251             0.024378 *
Survey2022_08_08  1.532497   0.132232    0.458276   3.344             0.000826 ***
Survey2022_08_23 -0.550386   0.198247    0.197677  -2.784             0.005367 **
Survey2022_09_13  0.150020   0.163541    0.212705   0.705             0.480631
Survey2022_09_25 -1.519036   0.282961    0.158829  -9.564 < 0.0000000000000002 ***
Survey2022_10_10 -0.968621   0.228638    0.147395  -6.572  0.0000000000503526 ***
Survey2022_11_07 -1.294683   0.258078    0.209352  -6.184  0.0000000006296074 ***
Survey2022_12_13 -0.554497   0.198353    0.137889  -4.021  0.0000579715427996 ***
Survey2023_01_26 -1.331532   0.262138    0.355873  -3.742             0.000183 ***
Survey2023_02_10 -0.634721   0.203708    0.208963  -3.037             0.002387 **
Survey2023_03_23 -0.761944   0.170758    0.154772  -4.923  0.0000008553389485 ***
Survey2023_04_05 -0.389207   0.156706    0.175046  -2.223             0.026190 *
Survey2023_05_03 -1.272349   0.196691    0.492595  -2.583             0.009799 **
Survey2023_06_17 -1.898539   0.245809    0.192154  -9.880 < 0.0000000000000002 ***
Survey2023_07_05 -1.693683   0.226151    0.189924  -8.918 < 0.0000000000000002 ***
Survey2023_08_10 -0.232774   0.151333    0.167824  -1.387             0.165445
s(depth)1         0.117529   0.405689    0.841948   0.140             0.888983
s(depth)2        -0.169460   0.215222    0.303142  -0.559             0.576155
s(depth)3        -0.587736   0.229819    0.345319  -1.702             0.088761 .
s(depth)4        -0.395880   0.271417    0.335457  -1.180             0.237959
s(depth)5        -0.092518   0.354023    0.414615  -0.223             0.823426
s(dist_coast)1    2.218515   0.251455    0.394438   5.624  0.0000000187212458 ***
s(dist_coast)2    1.989215   0.146889    0.169385  11.744 < 0.0000000000000002 ***
s(dist_coast)3    3.008740   0.182633    0.316316   9.512 < 0.0000000000000002 ***
s(dist_coast)4    1.325692   0.209445    0.614170   2.159             0.030894 *
s(dist_coast)5    2.560534   0.239264    0.308634   8.296 < 0.0000000000000002 ***
s(dist_coast)6    0.504283   0.591482    0.679427   0.742             0.457959
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for quasipoisson family taken to be 14.78009)

    Null deviance: 206966  on 42775  degrees of freedom
Residual deviance: 154307  on 42728  degrees of freedom
AIC:  NA

Max Panel Size = 74; Number of panels = 832
Number of Fisher Scoring iterations: 8
```

Figure 6-10 Code snippet detailing the summary of the best fitting model through 1D SALSA.

55. A ten-fold cross-validation compared the 1D model to the initial GLM (Figure 6-11). Despite similar estimates, the 1D model showed lower error indicating a better fit.

```
> cv_1d # 1D SALSA
[1] 69.19652
> cv_0d # Initial GLM
[1] 69.54846
```

Figure 6-11 Code snippet displaying cross-validation error estimates for the initial GLM and the best-fitting 1D smoothed model.

6.2.4 2D Smoothed Model (SALSA 2D)

56. In the final stage, the SALSA 2D function was employed to fit a Complex Region Spatial Smoother (CReSS) model to the existing best fit 1D model. Bird count served as the response variable, with x.pos and y.pos as spatial coordinates, and log(area) included as an offset. The model used a quasi-Poisson error distribution with a log link and incorporated Transect ID as a panel identifier (Figure 6-12).

```
salsa2dlist <-list(fitnessMeasure = "QBIC",
                   knotgrid = knot_grid,
                   startKnots = 5,    # ~~~
                   minKnots = 2,
                   maxKnots = 100,
                   gap = 1, interactionTerm = c("Survey"))

salsa2dOutput <-runSALSA2D(model = initial_model,
                           salsa2dlist = salsa2dlist,
                           panels = model_data$blockID,
                           d2k = distMats$dataDist,
                           k2k = distMats$knotDist)
```

Figure 6-12 Code snippet demonstrating the 2D SALSA model setup.

57. SALSA 2D tested multiple models, selecting the one with the lowest QBIC validation score as the "best fitting 2D model". A summary of the best fit 2D SALSA model is shown below (Figure 6-13, Figure 6-14, Figure 6-15, Figure 6-16, Figure 6-17 & Figure 6-18).

```
Call:
gamMRSea(formula = response ~ Survey + LRF.g(radiusIndices, dists,
    radii, aR) + Survey:LRF.g(radiusIndices, dists, radii, aR) +
    offset(log(area)), family = "quasipoisson", data = model_data,
    splineParams = splineParams)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-13.440   -1.179   -0.672   -0.235   61.682
```

Figure 6-13 Code snippet summarising the best fitting model from SALSA 2D (1/6).

```
Coefficients:
                                    Estimate Std. Error Robust S.E. t value
(Intercept)                         2.048150   0.460040    0.328937   6.227
Survey2021_04_04                    3.026995   0.508811    0.561945   5.387
Survey2021_05_12                   -1.128396   0.713279    0.725295  -1.556
Survey2021_06_09                   -2.395138   1.224160    0.590149  -4.059
Survey2021_07_24                    0.185468   0.622942    0.451556   0.411
Survey2021_08_14                    0.163501   0.591127    0.810793   0.202
Survey2021_09_07                    2.986840   0.509572    0.610422   4.893
Survey2021_10_09                   -0.402270   0.673763    0.428322  -0.939
Survey2021_11_02                    1.127032   0.626532    0.377780   2.983
Survey2021_12_15                   -0.804593   0.819626    0.461955  -1.742
Survey2022_01_06                   -1.289917   1.511864    0.639155  -2.018
Survey2022_02_23                   -0.906223   0.748251    0.503713  -1.799
Survey2022_03_11                   -1.006223   0.674823    0.853185  -1.179
Survey2022_03_22                    0.914595   0.612752    0.451044   2.028
Survey2022_04_02                    2.663120   0.505721    0.497299   5.355
Survey2022_04_15                    0.688337   0.574598    0.504344   1.365
Survey2022_05_02                   -0.816435   0.579576    0.482662  -1.692
Survey2022_05_17                   -1.153022   0.723019    0.715042  -1.613
Survey2022_06_09                   -1.434200   0.843012    1.111655  -1.290
Survey2022_06_21                    1.847370   0.653157    0.455170   4.059
Survey2022_07_04                    2.434120   0.766693    0.652120   3.733
Survey2022_07_16                    4.510917   0.563459    1.006367   4.482
Survey2022_08_08                    8.571683   0.501261    2.041542   4.199
Survey2022_08_23                    0.604763   0.758206    0.548619   1.102
Survey2022_09_13                   -2.215270   0.715339    0.590647  -3.751
Survey2022_09_25                   -1.458643   1.080088    0.463745  -3.145
Survey2022_10_10                   -1.027874   0.879721    0.425433  -2.416
Survey2022_11_07                   -0.813284   1.051859    0.603235  -1.348
Survey2022_12_13                   -0.577263   0.744073    0.423893  -1.362
Survey2023_01_26                   -1.703247   1.081705    0.980147  -1.738
Survey2023_02_10                    0.845342   0.693886    0.680374   1.242
Survey2023_03_23                    0.407204   0.650681    0.523965   0.777
Survey2023_04_05                    0.113854   0.579963    0.417618   0.273
Survey2023_05_03                   -4.626934   0.916136    2.104617  -2.198
Survey2023_06_17                   -2.237905   0.937962    0.989585  -2.261
Survey2023_07_05                   -1.677672   0.895281    0.519489  -3.229
Survey2023_08_10                   -1.084836   0.593140    0.526972  -2.059
LRF.g(radiusIndices, dists, radii, aR)b1  1.055895   0.457617    0.385501   2.739
LRF.g(radiusIndices, dists, radii, aR)b2 -1.134032   0.683202    0.680948  -1.665
LRF.g(radiusIndices, dists, radii, aR)b3 -0.061945   0.623237    0.432181  -0.143
```

Figure 6-14 Code snippet summarising the best fitting model from SALSA 2D (2/6).

```
Survey2021_04_04:LRF.g(radiusIndices, dists, radii, aR)b1        0.000124 ***
Survey2021_05_12:LRF.g(radiusIndices, dists, radii, aR)b1        0.008145 **
Survey2021_06_09:LRF.g(radiusIndices, dists, radii, aR)b1        0.288656
Survey2021_07_24:LRF.g(radiusIndices, dists, radii, aR)b1        0.136247
Survey2021_08_14:LRF.g(radiusIndices, dists, radii, aR)b1        0.061297 .
Survey2021_09_07:LRF.g(radiusIndices, dists, radii, aR)b1        0.008178 **
Survey2021_10_09:LRF.g(radiusIndices, dists, radii, aR)b1        0.996121
Survey2021_11_02:LRF.g(radiusIndices, dists, radii, aR)b1 0.0000000000496 ***
Survey2021_12_15:LRF.g(radiusIndices, dists, radii, aR)b1        0.120216
Survey2022_01_06:LRF.g(radiusIndices, dists, radii, aR)b1        0.019246 *
Survey2022_02_23:LRF.g(radiusIndices, dists, radii, aR)b1        0.828557
Survey2022_03_11:LRF.g(radiusIndices, dists, radii, aR)b1        0.476456
Survey2022_03_22:LRF.g(radiusIndices, dists, radii, aR)b1        0.206452
Survey2022_04_02:LRF.g(radiusIndices, dists, radii, aR)b1        0.042322 *
Survey2022_04_15:LRF.g(radiusIndices, dists, radii, aR)b1        0.519169
Survey2022_05_02:LRF.g(radiusIndices, dists, radii, aR)b1        0.629563
Survey2022_05_17:LRF.g(radiusIndices, dists, radii, aR)b1        0.000565 ***
Survey2022_06_09:LRF.g(radiusIndices, dists, radii, aR)b1 0.0000355103909 ***
Survey2022_06_21:LRF.g(radiusIndices, dists, radii, aR)b1 0.0000000032219 ***
Survey2022_07_04:LRF.g(radiusIndices, dists, radii, aR)b1 0.0000099420266 ***
Survey2022_07_16:LRF.g(radiusIndices, dists, radii, aR)b1        0.001749 **
Survey2022_08_08:LRF.g(radiusIndices, dists, radii, aR)b1 0.0000000044465 ***
Survey2022_08_23:LRF.g(radiusIndices, dists, radii, aR)b1        0.276977
Survey2022_09_13:LRF.g(radiusIndices, dists, radii, aR)b1        0.804547
Survey2022_09_25:LRF.g(radiusIndices, dists, radii, aR)b1        0.350254
Survey2022_10_10:LRF.g(radiusIndices, dists, radii, aR)b1        0.375527
Survey2022_11_07:LRF.g(radiusIndices, dists, radii, aR)b1        0.622818
Survey2022_12_13:LRF.g(radiusIndices, dists, radii, aR)b1        0.141144
Survey2023_01_26:LRF.g(radiusIndices, dists, radii, aR)b1        0.522038
Survey2023_02_10:LRF.g(radiusIndices, dists, radii, aR)b1 0.0000000006669 ***
Survey2023_03_23:LRF.g(radiusIndices, dists, radii, aR)b1        0.192776
Survey2023_04_05:LRF.g(radiusIndices, dists, radii, aR)b1        0.003895 **
Survey2023_05_03:LRF.g(radiusIndices, dists, radii, aR)b1        0.353707
Survey2023_06_17:LRF.g(radiusIndices, dists, radii, aR)b1        0.008516 **
Survey2023_07_05:LRF.g(radiusIndices, dists, radii, aR)b1        0.000826 ***
Survey2023_08_10:LRF.g(radiusIndices, dists, radii, aR)b1        0.942355
Survey2021_04_04:LRF.g(radiusIndices, dists, radii, aR)b2        0.195645
Survey2021_05_12:LRF.g(radiusIndices, dists, radii, aR)b2        0.065415 .
Survey2021_06_09:LRF.g(radiusIndices, dists, radii, aR)b2        0.013859 *
Survey2021_07_24:LRF.g(radiusIndices, dists, radii, aR)b2        0.016015 *
Survey2021_08_14:LRF.g(radiusIndices, dists, radii, aR)b2        0.002051 **
Survey2021_09_07:LRF.g(radiusIndices, dists, radii, aR)b2        0.463196
Survey2021_10_09:LRF.g(radiusIndices, dists, radii, aR)b2        0.028353 *
Survey2021_11_02:LRF.g(radiusIndices, dists, radii, aR)b2        0.141984
Survey2021_12_15:LRF.g(radiusIndices, dists, radii, aR)b2        0.019963 *
Survey2022_01_06:LRF.g(radiusIndices, dists, radii, aR)b2        0.986796
Survey2022_02_23:LRF.g(radiusIndices, dists, radii, aR)b2        0.101827
Survey2022_03_11:LRF.g(radiusIndices, dists, radii, aR)b2        0.300956
Survey2022_03_22:LRF.g(radiusIndices, dists, radii, aR)b2        0.578616
Survey2022_04_02:LRF.g(radiusIndices, dists, radii, aR)b2        0.629844
Survey2022_04_15:LRF.g(radiusIndices, dists, radii, aR)b2        0.876001
Survey2022_05_02:LRF.g(radiusIndices, dists, radii, aR)b2        0.000680 ***
Survey2022_05_17:LRF.g(radiusIndices, dists, radii, aR)b2        0.044422 *
```

Figure 6-15 Code snippet summarising the best fitting model from SALSA 2D (3/6).

```
Survey2022_06_09:LRF.g(radiusIndices, dists, radii, aR)b2        0.016631 *
Survey2022_06_21:LRF.g(radiusIndices, dists, radii, aR)b2        0.576825
Survey2022_07_04:LRF.g(radiusIndices, dists, radii, aR)b2        0.077066 .
Survey2022_07_16:LRF.g(radiusIndices, dists, radii, aR)b2        0.039861 *
Survey2022_08_08:LRF.g(radiusIndices, dists, radii, aR)b2        0.029762 *
Survey2022_08_23:LRF.g(radiusIndices, dists, radii, aR)b2        0.603947
Survey2022_09_13:LRF.g(radiusIndices, dists, radii, aR)b2 0.0000000000756 ***
Survey2022_09_25:LRF.g(radiusIndices, dists, radii, aR)b2        0.041003 *
Survey2022_10_10:LRF.g(radiusIndices, dists, radii, aR)b2        0.014404 *
Survey2022_11_07:LRF.g(radiusIndices, dists, radii, aR)b2        0.090622 .
Survey2022_12_13:LRF.g(radiusIndices, dists, radii, aR)b2        0.081566 .
Survey2023_01_26:LRF.g(radiusIndices, dists, radii, aR)b2        0.006181 **
Survey2023_02_10:LRF.g(radiusIndices, dists, radii, aR)b2        0.850173
Survey2023_03_23:LRF.g(radiusIndices, dists, radii, aR)b2        0.003620 **
Survey2023_04_05:LRF.g(radiusIndices, dists, radii, aR)b2        0.314894
Survey2023_05_03:LRF.g(radiusIndices, dists, radii, aR)b2        0.017057 *
Survey2023_06_17:LRF.g(radiusIndices, dists, radii, aR)b2        0.014692 *
Survey2023_07_05:LRF.g(radiusIndices, dists, radii, aR)b2        0.000251 ***
Survey2023_08_10:LRF.g(radiusIndices, dists, radii, aR)b2        0.006415 **
Survey2021_04_04:LRF.g(radiusIndices, dists, radii, aR)b3        0.000132 ***
Survey2021_05_12:LRF.g(radiusIndices, dists, radii, aR)b3        0.297722
Survey2021_06_09:LRF.g(radiusIndices, dists, radii, aR)b3        0.597778
Survey2021_07_24:LRF.g(radiusIndices, dists, radii, aR)b3        0.153534
Survey2021_08_14:LRF.g(radiusIndices, dists, radii, aR)b3        0.094871 .
Survey2021_09_07:LRF.g(radiusIndices, dists, radii, aR)b3        0.000615 ***
Survey2021_10_09:LRF.g(radiusIndices, dists, radii, aR)b3        0.790147
Survey2021_11_02:LRF.g(radiusIndices, dists, radii, aR)b3 0.0000005510138 ***
Survey2021_12_15:LRF.g(radiusIndices, dists, radii, aR)b3        0.250281
Survey2022_01_06:LRF.g(radiusIndices, dists, radii, aR)b3        0.038256 *
Survey2022_02_23:LRF.g(radiusIndices, dists, radii, aR)b3        0.512788
Survey2022_03_11:LRF.g(radiusIndices, dists, radii, aR)b3        0.203044
Survey2022_03_22:LRF.g(radiusIndices, dists, radii, aR)b3        0.046547 *
Survey2022_04_02:LRF.g(radiusIndices, dists, radii, aR)b3        0.000892 ***
Survey2022_04_15:LRF.g(radiusIndices, dists, radii, aR)b3        0.549713
Survey2022_05_02:LRF.g(radiusIndices, dists, radii, aR)b3        0.002440 **
Survey2022_05_17:LRF.g(radiusIndices, dists, radii, aR)b3        0.353091
Survey2022_06_09:LRF.g(radiusIndices, dists, radii, aR)b3        0.608521
Survey2022_06_21:LRF.g(radiusIndices, dists, radii, aR)b3 0.0000000003286 ***
Survey2022_07_04:LRF.g(radiusIndices, dists, radii, aR)b3 0.0000000005903 ***
Survey2022_07_16:LRF.g(radiusIndices, dists, radii, aR)b3 0.0000007183645 ***
Survey2022_08_08:LRF.g(radiusIndices, dists, radii, aR)b3        0.000358 ***
Survey2022_08_23:LRF.g(radiusIndices, dists, radii, aR)b3        0.000203 ***
Survey2022_09_13:LRF.g(radiusIndices, dists, radii, aR)b3        0.093432 .
Survey2022_09_25:LRF.g(radiusIndices, dists, radii, aR)b3        0.154129
Survey2022_10_10:LRF.g(radiusIndices, dists, radii, aR)b3        0.251595
Survey2022_11_07:LRF.g(radiusIndices, dists, radii, aR)b3        0.009653 **
Survey2022_12_13:LRF.g(radiusIndices, dists, radii, aR)b3        0.657906
Survey2023_01_26:LRF.g(radiusIndices, dists, radii, aR)b3        0.190709
```

Figure 6-16 Code snippet summarising the best fitting model from SALSA 2D (4/6).

```
survey2023_02_10:LRF.g(radiusIndices, dists, radii, aR)b3          0.046639 *
survey2023_03_23:LRF.g(radiusIndices, dists, radii, aR)b3          0.068046 .
survey2023_04_05:LRF.g(radiusIndices, dists, radii, aR)b3          0.117255
survey2023_05_03:LRF.g(radiusIndices, dists, radii, aR)b3          0.242950
survey2023_06_17:LRF.g(radiusIndices, dists, radii, aR)b3          0.554836
survey2023_07_05:LRF.g(radiusIndices, dists, radii, aR)b3          0.002730 **
survey2023_08_10:LRF.g(radiusIndices, dists, radii, aR)b3          0.507863
```

Figure 6-17 Code snippet summarising the best fitting model from SALSA 2D (5/6).

```
(Dispersion parameter for quasipoisson family taken to be 8.822032)

    Null deviance: 206966  on 42775  degrees of freedom
Residual deviance: 131286  on 42628  degrees of freedom
AIC:  NA

Max Panel Size = 74; Number of panels = 832
Number of Fisher Scoring iterations: 7
```

Figure 6-18 Code snippet summarising the best fitting model from SALSA 2D (6/6).

58. A ten-fold cross-validation was used to compare the final 2D model to a 1D and GLM model. The 2D model CV value was lower, than the 1D model, indicating that it was a better fit, and that smoothing parameters were appropriate for use (Figure 6-19).

```
> cv_2d # 2D SALSA
[1] 67.92155
> cv_1d # 1D SALSA
[1] 69.19652
```

Figure 6-19 Code snippet presenting cross-validation error estimates comparing the 2D model to the 1D model.

6.2.5 SALSA 2D Model Diagnostics

59. Additional model diagnostics for the best fitting SALSA 2D model are displayed below (Figure 6-20, Figure 6-21 & Figure 6-22).

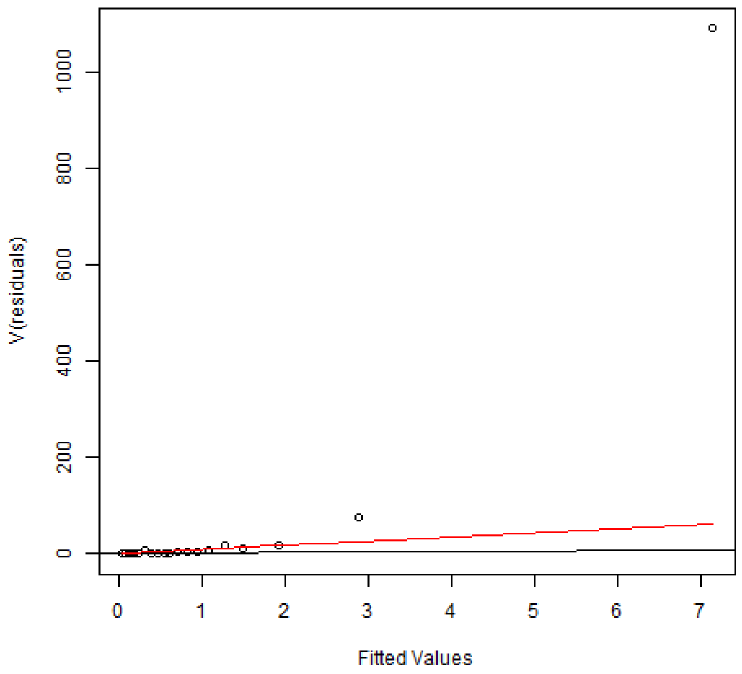


Figure 6-20 Mean-Variance relationship for best fitting 2D smoothed model.

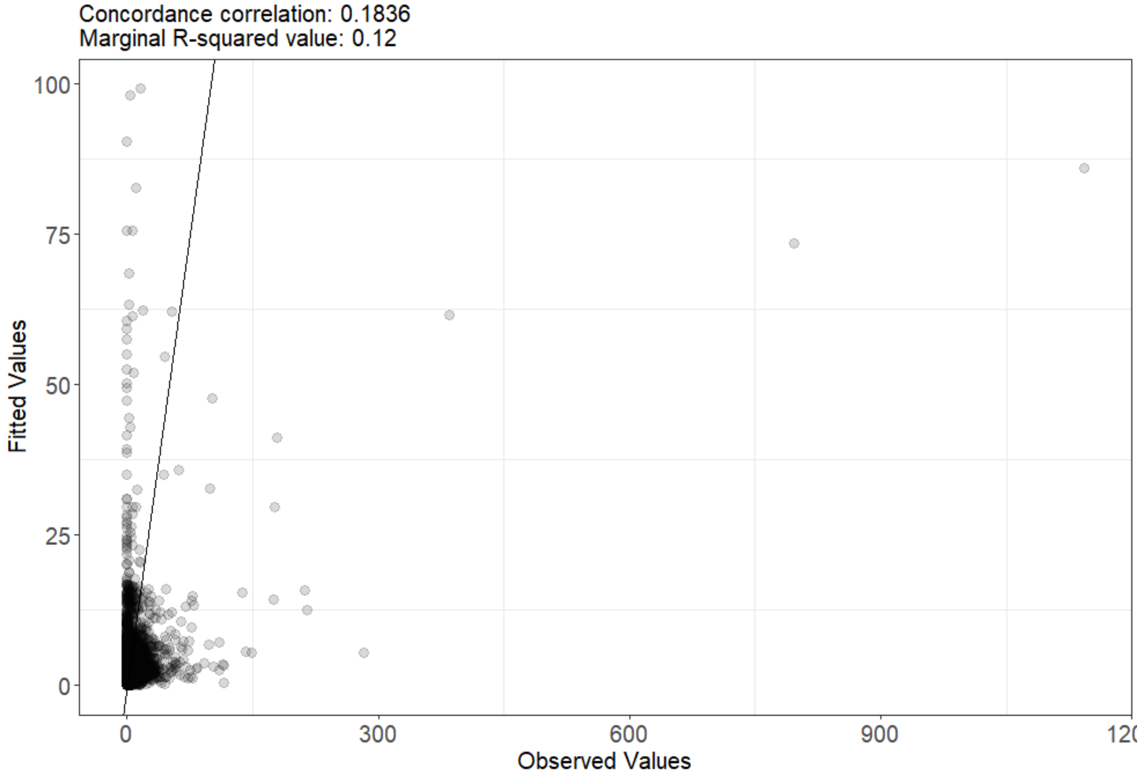


Figure 6-21 Observed versus predicted values for the best fitting 2D smoothed model.

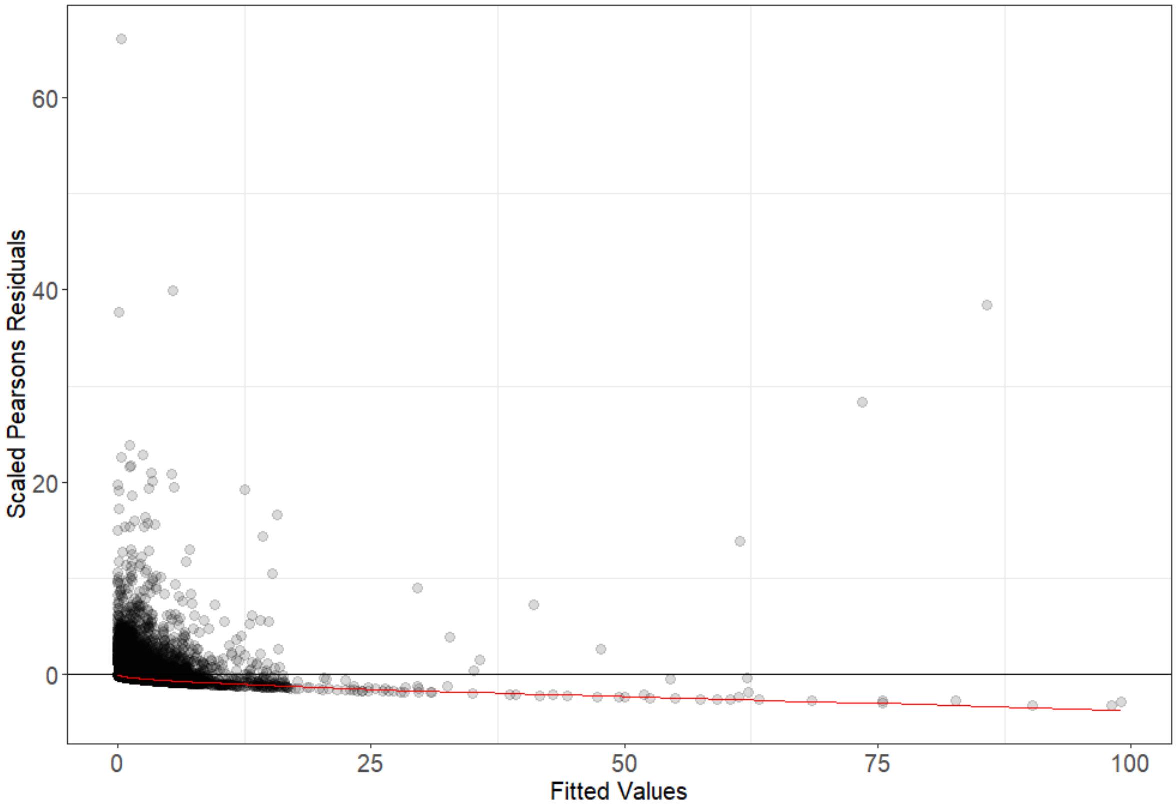


Figure 6-22 Scaled Pearson Residuals by fitted value for the best fitting 2D smoothed model.

6.3 Model Diagnostic Plots

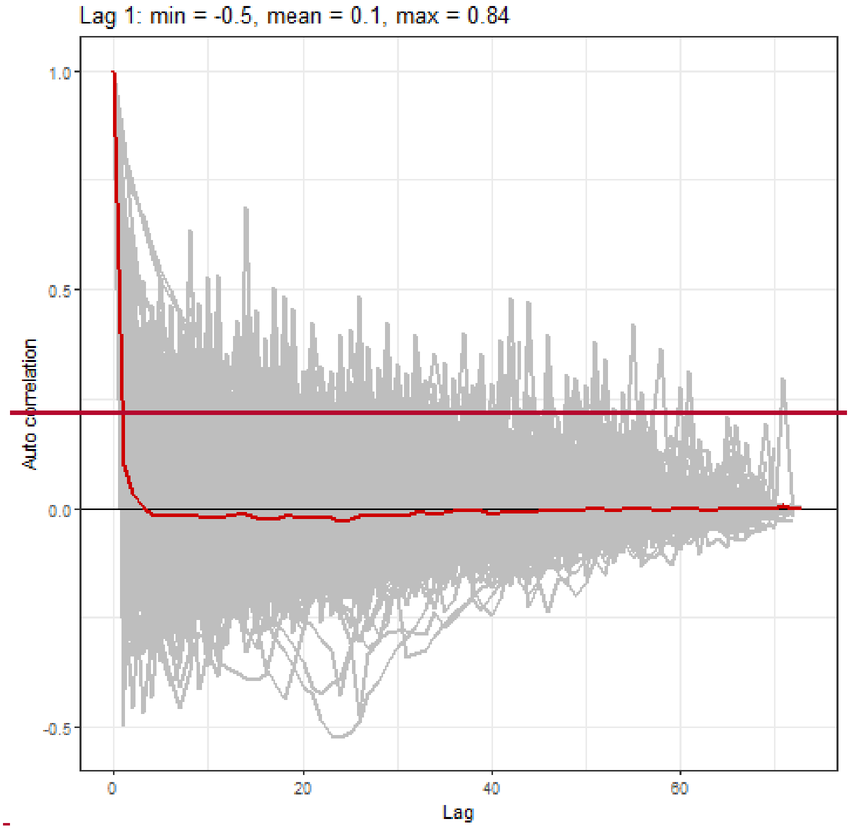
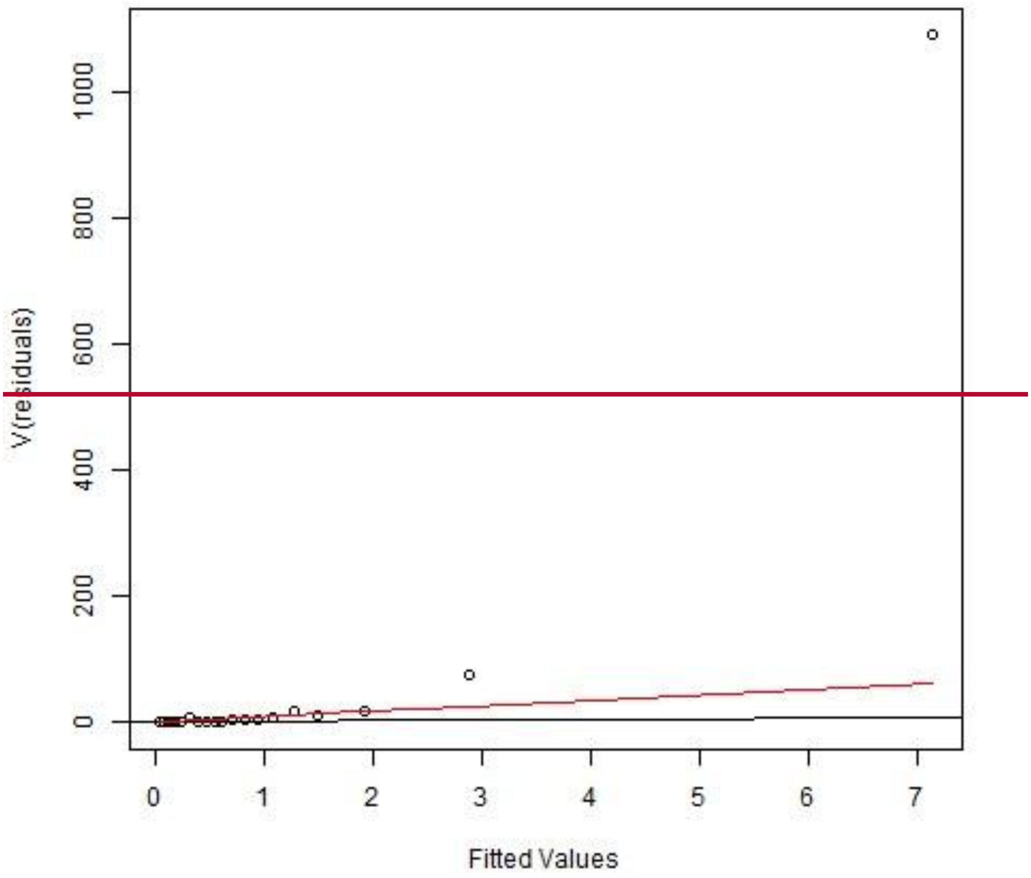


Figure 6.1. ACF for the final MRSea full data model.



~~Figure 6.2. Mean variance plot for final MRSea full data model.~~

7 Annex B – Array Area Minus the ORBA Guillemot Population and Density Estimates

7.1 Model Outputs

Table 7-1 Model-based population estimates and densities of guillemots.

Survey No.	Survey Month	Population Estimate	Lower CI	Upper CI	Density (birds/km^2)
01	March	2,654	2,031	3,494	7.28
02	April	7,409	5,261	10,462	20.33
03	May	1,866	1,315	2,772	5.12
04	June	433	302	632	1.19
05	July	2,831	2,189	3,681	7.77
06	August	7,176	4,709	11,267	19.69
07	September	7,800	5,664	10,875	21.41
08	October	2,343	1,975	2,783	6.43
09	November	1,795	1,508	2,150	4.93
10	December	1,082	873	1,338	2.97
11	January	161	100	283	0.44
12	February	1,670	1,222	2,336	4.58
13	March (I)	2,857	1,927	4,414	7.84
14	March (II)	2,859	2,323	3,550	7.85
15	April (I)	9,454	7,555	11,944	25.94
16	April (II)	4,707	3,468	6,433	12.92
17	May (I)	5,740	4,597	7,239	15.75
18	May (II)	1,691	1,152	2,583	4.64
19	June (I)	777	449	1,378	2.13
20	June (II)	1,382	1,047	1,822	3.79
21	July (I)	793	592	1,054	2.18
22	July (II)	2,594	1,694	4,112	7.12
23	August (I)	2,866	1,423	7,672	7.87
24	August (II)	1,269	858	1,912	3.48
25	September (I)	2,602	1,711	4,203	7.14
26	September (II)	539	429	692	1.48
27	October	940	766	1,175	2.58
28	November	614	448	861	1.68
29	December	1,491	1,212	1,852	4.09
30	January	590	317	1,066	1.62
31	February	1,103	688	1,809	3.03
32	March	1,132	805	1,610	3.11
33	April	1,688	1,265	2,266	4.63
34	May	562	261	1,408	1.54
35	June	321	212	487	0.88

Survey No.	Survey Month	Population Estimate	Lower Cl	Upper Cl	Density (birds/km^2)
36	July	359	282	458	0.99
37	August	2,053	1,477	2,950	5.63