Hornsea Project Four

MRSea Baseline Sensitivity Report (Gannet)

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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.
Design-based Abundance Estimates	An estimated total abundance of identified targets (in the case of this report gannets) within a given area ("design- based" because the approach relies on the survey design providing representative sampling and assuming transects can be considered independent samples from a uniform distribution) based on the raw observations recorded within a survey.
"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 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).
P-value	A p-value is a measure of the probability that an observed difference could have occurred just by random chance.
Raw Observations	The georeferenced locations of identified targets (in the case of this report gannets) that were recorded within the flown transects for the site specific digital aerial surveys.
Runs Test	A statistical procedure that examines whether a string of data is occurring randomly from a specific distribution.
Zero-inflated data	Count data with excess of zeros.

Acronyms

Term	Definition
1D	One-dimensional
2D	Two-dimensional
ACF	Auto-correlation Function
AFL	Agreement for Lease
ANOVA	Analysis of Variance
CREEM	Centre for Research into Ecological and Environmental Modelling
CReSS	Complex Region Spatial Smoother
CI	Confidence Interval
CRM	Collison Risk Model
CV	Coefficient of Variation
DAA	Developable Area Approach
DCO	Development Consent Order
EIA	Environmental Impact Assessment
EP	Evidence Plan
ES	Environmental Statement
ETG	Expert Topic Group
FFC	Flamborough and Filey Coast
GAM	Generalised Additive Model
GEE	Generalised Estimating Equation
GLM	Generalised Linear Model
GVIFS	Generalised Variance Inflation Factors
KDE	Kernal Density Estimation
MRSea	Marine Renewables Strategic environmental assessment
PEIR	Preliminary Environmental Information Report
RSPB	Royal Society for the Protection of Birds
SALSA	Spatially Adaptive Local Smoothing Algorithm
SD	Standard Deviation
SNCB	Statutory Nature Conservation Bodie
SPA	Special Protection Area
WTG	Wind Turbine Generators

1 Introduction to Hornsea Four's MRSea modelling for Offshore Ornithology

1.1.1.1 Through the Developable Area Process for Hornsea Four the project area being considered for development reduced from 846 km^2 at Scoping to 468 km^2 for the DCO Application. As the original aerial digital survey data set for offshore ornithology relied on 24 transects across the entire Agreement for Lease (AfL) area plus a 4 km buffer, whilst the final data set relied on 15 across the final array area plus 4 km buffer as submitted in the DCO Application. The Applicant worked with Natural England and the RSPB to consider methods of modelling these data to optimise the baseline characterisation. The use of MRSea for Hornsea Four was proposed and agreed for a limited number of species in consultation with both Natural England and the Royal Society for the Protection of Birds (RSPB), following Natural England's advocation to consider MRSea modelling in their Section 42 responses to the Preliminary Environmental Report. Therefore, the Applicant ran MRSea modelling to characterise the baseline for offshore ornithology for a limited number of species agreed as being appropriate to model (fulmar, gannet, kittiwake, great black-backed gull, guillemot, razorbill and puffin).

1.1.1.2 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. 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.

1.1.1.3 The Applicant followed the guidance written by CREEM (Scott-Hayward et al. 2017) to undertake the MRSea modelling, though it is recognised that for such a complex model that requires considerable user expertise and multiple testing for it to perform the guidance and advice within it would benefit from updates to allow for consistency in modelling preparation and approaches. The results of the MRSea modelling were then shared with Natural England and the RSPB and agreement reached that the outputs from the modelling were fit for the purpose of defining the baseline and for use in assessing the potential impacts from Hornsea Four on seabirds (ETG#13). The outputs from the MRSea modelling were used to define the final baseline for these species, supplemented with additional data from design-based abundance estimates from apportioned unidentified birds (and corrected for availability bias for auk species). These data were then subsequently used to underpin the impact assessments within **A2.5 Environmental Statement Volume A2 Chapter 5 Offshore and Intertidal Ornithology (APP-017)** and **B2.2: Report to Inform Appropriate Assessment (APP-167** to **APP-178)**.

1.1.1.4 This document is split into three separate parts presenting the following details:

- **Part 1** - Applicant's response to Natural England and CREEM comments and advice on the Applicant's MRSea approach and methodology. This report provides an account of the Relevant Representations received on MRSea modelling from Natural England (**RR-029**) and CREEM's additional advice note, the consultation process undertaken by the Applicant to resolve any issues and agreed actions and approach to re-run the MRsea model for a single species (gannet). It also provides the initial revised MSRea model outputs from the initial stages of the re-building and testing process (see Appendix A); Part 1 of the MRSea Baseline Sensitivity Report was submitted at Deadline 2 (**REP2-046**);

- **Part 2** - Presents the results of the revised MRSea modelling for a single species (gannet), with the modelling approach, inputs and outputs (where available and / or appropriate) inserted to satisfy Natural England with regards to their Relevant Representations on MRsea (**RR-029**). The results of the revised MRSea modelling, including visual representation of the spatial distribution in comparison to the raw observation data and DCO MRSea data are presented in Part 2; and
- **Part 3** – Provides a full comparison between the DCO MRSea results used to define the Hornsea Four baseline that underpins the impact assessments with the revised MRSea results and the design-based abundance estimates. This section sets out the implications, if any, of the changes to the baseline characterisation and impact assessments for Hornsea Four for a single species (gannet).

2 Natural England's Relevant Representations (RR-029) – MRSea Query

2.1.1.1 Following the Hornsea Four DCO Application, Natural England submitted their Relevant Representations (**RR-029**). Comments received related to the preparation and approach used in running the MRSea model for Hornsea Four to define the baseline, which informs the impact assessments undertaken. Further to **RR-029**, Natural England provided the Applicant with an additional review (Scott-Hayward, 2021, not submitted with **RR-029** and presented in **Table 2**). The review was undertaken by the MRSea model developers (Centre for Research into Ecological & Environmental Modelling (CREEM), University of St Andrew's), including retrospective requests for additional screenshots and downloads from the initial model preparation stages of the approach to model building, coding, testing and running stages that are not routinely saved or downloaded due to the scale of such a task. The review requested confirmation of a number of MRSea modelling inputs and outputs that had not been submitted by the Applicant within **A5.5.6 ES Volume A5 Annex 5.6 Offshore Ornithology MRSea Report (APP-079)**.

2.1.1.2 The Applicant is unaware of the specific requests from Natural England to CREEM, which would clarify the basis of the requested review, or why it was felt that this should be concluded post-application and not within the pre-application phase of project development in which to facilitate detailed and timely consideration of the rationale for the review and the subsequent content. At the request of the Applicant Natural England provided supplementary comments specific to MRSea (see **Table 1**).

2.1.1.3 As a consequence of the post-application review of the MRSea model, reports and associated outputs, Natural England have reversed their original position of agreement on the outputs from the MRSea modelling (as concluded from consultation at ETG#13) being used to define the baseline and have not provided opinion on the potential impact levels from Hornsea Four on seabirds as a result, as stated within Natural England's relevant representation (**RR-029**). Natural England's main comments are summarised within the following statements within their Relevant Representations (**RR-029**) on the use of MRSea modelling for Hornsea Four below;

- *'In principle, NE welcome the use of modelling-based approaches to density and abundance estimation, and for the examination of trends in spatial distributions, however these values underpin much of the EIA and RIAA and it is therefore important that there is confidence in the modelling approach.'*; and
- *'Whilst NE remains supportive of using MRSea to produce estimates, the current description and justification for the approach provided here and in Volume A5, Annex 5.6 do not allow appraisal of the relative merits or risks associated with the MRSea approach. We therefore cannot currently have confidence in the density and abundance estimates produced by this method.'*.

3 The Applicant's Response to Natural England's Relevant Representations

3.1.1.1 In response to Natural England's Relevant Representations (**RR-029**) and CREEM review the Applicant agreed to produce a Baseline Sensitivity Report that incorporates all responses and additional information to inform Natural England and the Examining Authority of the progress made on the MRSea modelling queries. Due to the ongoing technical clarifications between CREEM and APEM (one meeting and two telephone conversations and numerous email requests between Feb and March 2022), the Baseline Sensitivity Report is to be submitted in three parts into the examination, as a complete model re-build is proving to be time-consuming and an iterative process requiring clarifications from the model developer. The three parts will provide the following;

- Part 1 - Applicant's response to Natural England and CREEM comments and advice on MRSea approach and methodology. This report provides an account of the Relevant Representations received on MRSea modelling, the consultation process undertaken by the Applicant to resolve any issues and agreed actions and approach to re-run the MRsea model for a single species (gannet). It will also provide initial revised MSRea model outputs from the initial stages of the re-building and testing process (see **Appendix A**);
- Part 2 - Results of the revised MRSea modelling for a single species (gannet) to be presented, with modelling approach, inputs and outputs (where available and / or appropriate) to be inserted to satisfy Natural England with regards to their Relevant Representations on MRsea (**RR-029**); and
- Part 3 - A full comparison between the current MRSea results used to define the Hornsea Four baseline that underpins the impact assessments with the revised MRSea results. This report will set out the implications, if any, of the changes to the baseline characterisation and impact assessments for Hornsea Four for a single species (gannet), with recommendations on how to close out the issues for other species.

3.1.1.2 It is anticipated that Parts 2 and 3 will be ready shortly after Deadline 2 and will then be submitted to Natural England for review. The updated Baseline Sensitivity Report, including Parts 2 and 3 will then be submitted into Examination at Deadline 3, addressing as many of

Natural England's comments as is reasonably possible in the short time between Deadline 2 and 3.

4 Baseline Sensitivity Report – Part 1 (Consultation and Agreed Actions)

4.1.1.1 For Part 1 of the Baseline Sensitivity Report the Applicant facilitated a meeting with the MRSea model developers at CREEM, on 20th January 2022, to understand and specific technical aspects of the Natural England review. Following that meeting the Applicant consulted with Natural England to determine, beyond doubt, which aspects of the methodology, preparation and approach used to run MRSea modelling their concerns related to during a meeting on 17th February 2022 and agreed on an approach to resolve the remaining issues. The Applicant agreed with Natural England during this meeting to rerun the MRSea model using a methodology that addressed Natural England's comments for a single species (gannet) in the first instance.

4.1.1.2 Gannet was selected and agreed with Natural England as the most suitable species to undertake initial revised MRSea modelling for, as this species does not require apportionment of unidentified species groups from the raw data and therefore represents the best option to investigate. Should any changes between the current MRSea modelling and revised results be at a level that is judged to be insignificant then additional modelling of other species would not be undertaken following agreement with Natural England.

4.1.1.3 In addition to agreeing to rerun the MRSea model for gannet the Applicant also agreed to provide a further set of clarifications to update Natural England and the Examining Authority on the progress to date on the revised MRSea modelling for a single species (gannet). At the request of Natural England the Applicant also agreed to provide detailed responses to the comments from Natural England in their Relevant Representations (**RR-029**), which are provided in **Table 1**. The Applicant also agreed to provide detailed responses to comments and advice received by the developer of the MRSea model, CREEM, in order to ensure all questions regarding the MRSea modelling process are responded to, which are provided in **Table 2**.

Table 1: Natural England's Relevant Representations comments on MRSea modelling (REP1-029) and Applicant's responses.

ID	Natural England's Comment	Applicant's Initial Response	Agreed Actions and Further Applicant Response
NE1	Natural England note that it is implied in Volume A5.1 Offshore and Intertidal Ornithology Baseline Characterisation Report that design-based estimates have been estimated for all species and that additional modelling was undertaken where possible as a supplementary approach. However, MRSea estimates have been used in preference to the design-based methods where sufficient data has allowed models to be fitted (fulmar, gannet, kittiwake, great black-backed gull, guillemot, razorbill and puffin). NE have significant concerns about the suitability of the methods used to analyse the baseline characterisation data to produce the modelled density and abundance estimates in preference to design-based estimates. These are summarised below:	The Applicant and Natural England agreed through the Expert Technical Panel (TPs) that MRSea would be relied upon for all species run through the model and any unidentified birds and correction factors applied to those data. Therefore, in order not to cause confusion the design-based estimates for the key species were not included in the final baseline. For clarity, design-based data were run for all species.	The Applicant agreed with Natural England to rerun the MRSea model using a methodology that addresses Natural England's comments for a single species (gannet) in the first instance. Gannet was selected and agreed with Natural England as the most suitable species to undertake initial revised MRSea modelling for, as this species does not require apportionment of unidentified species groups from the raw data and therefore represents the best option to investigate. For clarity the predicted abundance for the full 24 months of design-based abundance estimates are presented in **Appendix B**. Should any changes between the current MRSea and revised results be at a level that is judged to be insignificant then additional modelling of other species would not be undertaken following agreement with Natural England.
NE2	Natural England note that, despite the scale of the estimates changing, the modelled spatial distributions for each species remain fundamentally the same across all surveys and/or seasons. This appears to be due to the production of a single model for each species and a lack of any temporal flexibility in the spatial parameterisation of the models (e.g. interaction between survey number, latitude and longitude or other selected parameters).	The DAA process ahead of the Hornsea Four DCO Application submission provided for a proactive review of seabird data to reduce the array area and remove WTGs from areas of higher seabird density. When viewing the MRSea outputs for the entire AfL area plus a 4 km buffer it is clearer to see patterns of bird densities both spatially and temporally, which are perhaps less obvious in the reduced size of the final array area assessed and presented in **A2.5 Environmental Statement Volume A2 Chapter 5 Offshore and Intertidal Ornithology (APP-017)**. With regards to the modelling approach and the inclusion of any temporal flexibility in the spatial	Revised MRSea modelling will include the interaction term that allows distributions to vary between months/bio-seasons. The monthly spatial distributions for the revised MRSea modelling are presented in **Section 6.2**.

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		parameterisation these were considered, though they were not included in the final model runs as they caused issues with the model fit and ability to run MRSea.	
NE3	The rationale for using the model-based approach over design-based estimates has not been addressed and there has been no consideration of model performance and the precision (coefficients of variation CVs) of estimates produced. Despite requests by NE, there has been no comparison between the raw data (i.e. counts and maps showing observations) or design-based estimates with the MRSea modelled estimates (including CVs). Moreover, the estimated relationships with selected covariates are not described and limited model diagnostics are presented.	The Applicant held a meeting with Natural England (ETG#13) to discuss the draft MRSea report and the suitability of the model concluded with agreement from all parties that these data were fit for the purpose of characterising the baseline for Hornsea Four and use in impact assessments. The assumption was therefore taken that any previous requests for additional information were superseded as all queries were discussed and agreed. As agreement was reached that MRSea abundance and density estimates were appropriate for use and no further requests were made ahead of the Application to provide any comparison between the raw data (i.e. counts and maps showing observations) or design-based estimates with the MRSea modelled estimates (including CIs) to use than design-based abundances this was not provided. With regards to the latter point, it was explained during ETG#13 that certain model diagnostics were not downloaded or screenshots taken though explanations as to the decision-making were described and agreed as appropriate. The modelled coefficients for each selected environmental variable in each model were included in the appendix to **A5.5.6 ES Volume A5 Annex 5.6 Offshore Ornithology MRSea Report (APP-079)**, however, further discussion of these relationships could be included in a revised version.	An updated Baseline Sensitivity Report providing design-based abundances estimates and basic dot-density maps with the current MRSea analysis and the revised MRSea analysis for one species (gannet) was submitted at Deadline 2. This comparison included consideration of model performance and output precision for the revised MRSea analysis. Additional information on estimated relationships and model diagnostics is presented for the revised MRSea analysis. Details of the running of the model are presented in **Appendix A** of this document.
NE4	It also remains unclear how model-based estimates (all bird behaviours) have been treated to derive estimates for specific behaviours (sitting or flying birds) and how subsequent data corrections (apportioning of unidentified birds and adjustment for availability bias)	The Applicant provided CIs for all data within the Baseline Technical Report for modelled and design-based abundance and density estimates. However, CIs were not calculated for the post-apportioned and corrected datasets. There are some issues with applying	The Applicant's position remains as that provided in their initial response.

ID	Natural England's Comment	Applicant's Initial Response	Agreed Actions and Further Applicant Response
	have been applied and Confidence Intervals (CIs) calculated or adjusted. It also appears the Applicant has not reported CIs associated with density estimates, though they appear to be used in the collision risk modelling.	or producing CIs retrospectively to modelled or design-based datasets meaning that the accuracy of such CIs may not be as reliable. With regards to the CRM seabird densities, the method to calculate the variation around the mean was agreed with Natural England through the ETGs and relies on the estimation of Standard Deviations (SDs) around the central estimates of the two survey years monthly data.	
NE5	Natural England advises that there are several options available to resolve these concerns: A. Provide a robust defence of the adopted modelling approach (see below), including a clear comparison with design-based estimates; B. Revise the modelling approach to address specific issues (in line with CREEM advice), or C. Revert to design-based estimates and use other spatial mapping techniques (e.g. KDE) to illustrate temporal variations in spatial distributions.	The Applicant defends their use of MRSea as agreed in consultation with both Natural England and the Royal Society for the Protection of Birds (RSPB) through the Ornithology Technical Panel meetings (note agreement reached on MRSea use in ETG#13). The Applicant considers Option C to be contrary to all agreements and progress made on matters pertaining to ornithology over the past four years in consultation with Natural England and maintains that the MRSea as presented for baseline characterisation to be robust, using the best evidence available and aligned with agreements from the Statutory Nature Conservation Bodies (SNCBs).	Revised MRSea modelling for gannet has been conducted to both address the specific issues highlighted in the CREEM advice and also serve to validate the results of the current MRSea results.
NE6	6. If Ørsted elect to defend the results of the models used in their assessment, we recommend the following approach is required: • Please provide a more detailed methodology and rationale for the modelling approach ultimately adopted. This should include further clarification on model specification and selection. Selected models should also be described in more detail (illustrating estimated relationships with included covariates) and model diagnostics (e.g.	In consideration of the comments received from Natural England and CREEM the Applicant is currently drafting a new Baseline Sensitivity Report in order to provide as much clarity as possible on all points, as described above. The Applicant is also re-running the MRSea model for a single species (gannet) to check on how any slight changes in the model preparation may alter the final outcome of the dataset. The output from the MRSea model is the predicted number of birds within each cell of a user-supplied	Revised MRSea modelling for gannet has been conducted to both address the specific issues highlighted in the CREEM advice and also serve to validate the results of the current MRSea results. The Baseline Sensitivity Report presents the revised modelling methodology (see Appendix A) and results are presented in Part 2 and 3 (Section 6 and 7) submitted at Deadline 3 in a manner that clarifies any outstanding concerns raised.

ID	Natural England's Comment	Applicant's Initial Response	Agreed Actions and Further Applicant Response
	observed vs fitted and cumulative residual plots) presented. • Please provide a full justification for the use of the model-based method over the design-based method. This should include comparisons of modelled spatial distributions with raw data or KDE derived surfaces. It is also requested that the full spatial extent of the modelled surfaces should be presented on maps. Density and population estimates, and associated CIs, should be compared between model- and design-based methods and there should be discussion in relation to the precision of each of the methods based on CVs. • Please also clearly define how population and density estimates were derived (apparently using different approaches) from the modelled surfaces. Confirm whether densities scaled to the relevant area would produce the same populations and associated CIs. Describe how data from cells intersected by the wind farm perimeter or relevant buffer (i.e. part cells of < 1 km^2) have been treated during population and density estimation. • Please provide a description of how populations and densities were apportioned to different behaviours; and • Please clearly describe how Standard Deviations (SDs), CIs and CVs (SD/mean or SE/mean) were estimated using model-based approaches for total populations, densities, apportioned behaviours and corrected apportioned behaviours. Based on discussion with statisticians at CREEM, NE suggests consideration of the following approach for deriving mean abundance and density estimates, and their associated SDs and CIs when bootstrapping is used	prediction grid. The area of each cell of the prediction grid is included and forms part of the prediction. The density of birds per grid cell is then calculated by dividing the predicted number of birds in each cell by the area of the grid cell. When using the modelled output to assess abundances and densities of smaller areas within the prediction grid, it is assumed that density is constant within each grid cell, and therefore the abundance within a specified area can be readily calculated as the product of the density per grid cell and the area of each grid cell within the specified area. With regards to behaviours, the raw count data (for flying and sitting) were used to split modelled data, which was run with all birds (flying and sitting). See note above regarding why. The process for adjusting data to account for unidentified birds and to account for availability bias are fully described in **A5.5.1 ES Volume A5 Annex 5.1 Offshore and Intertidal Ornithology Baseline Characterisation Report (APP-074)** and follow standard industry methods. CIs were provided for all data presented within the **A5.5.1 ES Volume A5 Annex 5.1 Offshore and Intertidal Ornithology Baseline Characterisation Report (APP-074)** for modelled and design-based abundance and density estimates (prior to any apportionment). However, CIs were not calculated for the post-apportioned and corrected datasets as the approach undertaken for apportionment does not allow robust CIs to be readily calculated. It is not straight forward to run design-based or model-based abundances to include CIs with CVs around apportioned and corrected data. With regards to the Collision Risk Model (CRM) seabird	

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	(applicable to model- or design-based estimates). Apportioning (unidentified birds or behaviours) and application of correction factors (e.g. availability corrections) should be applied to model- or design-based bootstrap sample estimates for each survey. The resultant overall abundance distributions from the samples should be used to derive the means, SDs and CIs. If a mean, SD and CIs are required based on two or more surveys (e.g. from two peak abundance estimates within a season or two densities of birds in flight in a calendar month), the relevant corrected bootstrap samples should be pooled to provide a single sample from which to draw the estimates.	densities, the method to calculate the variation around the mean was agreed with Natural England through the ETGs and relies on the estimation of SDs around the central estimates of the two survey years monthly data.	
NE7	In essence, a more detailed methodology is required that fully describes the different aspects of the modelling and associated diagnostics in relation to performance. More fundamentally, in order for Natural England to re-appraise our position on the modelling presented, we require a comparison of the model-based estimates with the design-based estimates and modelled spatial distributions against the raw observation data for each survey/month.	As noted above it is not possible to provide all elements of CREEM's requests due to certain aspects not being exported from R during the modelling process. However, the Applicant intends on running a single species (gannet) again following the advice from Natural England and CREEM to present as much additional data as possible and to download or take screenshots of the modelling process, where applicable. This will then be reviewed and issued in a Baseline Sensitivity Report to Natural England. With regards to the latter point, the use of MRSea was agreed through consultation with Natural England (at ETG#13) as being the preferred method to determine the baseline for this project. The change in position post-application is contrary to the agreements in place during the pre-application phase.	Revised MRSea modelling for gannet has been conducted to both address the specific issues highlighted in the CREEM advice and also serve to validate the results of the current MRSea results. The revised modelling and results are presented in the updated Baseline Sensitivity Report at Deadline 3 in a manner that clarifies any outstanding concerns raised.
NE8	With respect to the CREEM report, as stated in our meeting of 08 December 2021 it was the tone/opinions that did not reflect Natural England's position rather than the technical content. As CREEM are the experts	The Applicant has provided responses to the CREEM report (see **Table 2**).	The Applicant has provided responses to the CREEM report (see **Table 2**).

ID	Natural England's Comment	Applicant's Initial Response	Agreed Actions and Further Applicant Response
	on the MRSea modelling technique, we consider their concerns relating to methodology to be entirely justified and suggest Ørsted should address and/or provide a response to each point raised.		

Table 2: CREEM's comments on MRSea modelling and Applicant's responses.

ID	CREEM's Comment	Applicant's Initial Response	Agreed Actions and Further Applicant Response
CREEM1	In general, the overall methods description is poor with some key errors. This suggests that author is not clear on how the methods work or how to adapt them to suit their needs. This is further indicated by including function names rather than the actual methods (for example cv.gamMRSea instead of k-fold cross-validation).	The method section has been reviewed following a conversation between Lindsay Scott-Hayward from CREEM and Tim Kasoar & Sean Sweeney from APEM to understand which description they felt needed clarification. It is the Applicant's opinion is that by including function names in the methods sections it ensures maximum clarity for the reader and enables easy and precise replication. However, the Applicant recognises that statisticians may benefit from being able to see both function names and generic statistical terminology, which will be provided to explain the methods in a manner that allows a clearer understanding for readers with different levels of modelling/statistical expertise.	The Applicant's Baseline Sensitivity Report (Part 2 and 3; Section 6 and 7), submitted at Deadline 3, accounts for the advice received by CREEM to provide a clearer understanding for readers with different levels of modelling/statistical expertise. Please see Appendix A for the outcomes of the application of the advice from CREEM in relation to cross-validation.
CREEM2	There is no description of the sightings data or visual representation of the sightings or transect data for any species which makes it very difficult to pass judgement on model fit and suitability of the analysis.	A review of model fit was undertaken against the raw distribution of species to ensure model fit and suitability of analysis. However, the Applicant recognise that some of these details are not contained within the methods section of the A5.5.6 ES Volume A5 Annex 5.6 Offshore Ornithology MRSea Report (APP-079) as the inclusion of such would unnecessarily have increased the volume of the document. These data are available and could be provided as evidence to support the use and suitability of MRSea modelling to define the baseline for Hornsea Four.	The Applicant's Baseline Sensitivity Report (Part 2 and 3; Section 6 and 7), submitted at Deadline 3, allows for comparisons between design-based abundances estimates and basic dot-density maps, the previous iteration of MRSea analysis, and the revised MRSea analysis, all for one species (gannet). This comparison includes consideration of model performance and output precision for the revised MRSea analysis.
CREEM3	In paragraph 2.2.1.4. the authors state that the "CReSS" method incorporates auto-correlation. This is not strictly true, "CReSS" is the name given to the spatial smooth. The R package MRSea has the ability to allow for residual correlation but the user must specify its use via a panel variable.	The Applicant recognise and understand that the "CReSS" method is the name given to the spatial smoother within the MRSea model. Residual autocorrelation within the data was accounted for by specifying a unique transect number as the panel variable. The Applicant recognise that statisticians may benefit from being able to see both function names and	The Applicant's Baseline Sensitivity Report (Part 2 and 3; Section 6 and 7), submitted at Deadline 3, accounts for the advice received by CREEM to provide a clearer understanding for readers with different levels of modelling/statistical expertise.

ID	CREEM's Comment	Applicant's Initial Response	Agreed Actions and Further Applicant Response
		generic statistical terminology, which will be provided to explain the methods in a manner that allows a clearer understanding for readers with different levels of modelling/statistical expertise.	
CREEM4	In paragraph 2.3.1.3. it is stated that "autocorrelation within the data.". Data correlation is not a problem but residual correlation violates a major assumption of a GLM/GAM. How was residual correlation tested? ACF plot/ Runs Test? Additionally, it seems odd to include month/season in the blocking structure when survey date is already included.	The Applicant can confirm that residual correlation was examined using both ACF plots and Runs Test. For ACF plots residual correlation in the model was examined by ensuring that autocorrelation decays close to zero in a short lag period. For Runs Test residual correlation in the model was examined by interpreting the P value produced to ensure a non-significant value. When running the Runs Test, a significant P value of less than 0.05 was found. This indicated that there was presence of residual correlation within the model, however by specifying an appropriate blocking structure, residual correlation should be corrected for within the model to ensure model p-values and error margins were robust. The appropriateness of the blocking structure was tested using an ACF plot. The absence of the documentation of these tests was brought up during the EP Process with Natural England. The Applicant explained that in relation to the tests referred to above, the outputs were not saved after interrogation. This was due to not having prior knowledge of which outputs would be required at the time of running the model, and these outputs are not provided as automatic outputs or available after models have been run. Due to the stochastic nature of the model fitting process, if the Applicant were to rerun the models this would have produced slightly different outputs, so they could not be provided. Natural England were content with this explanation and the matter was agreed and closed.	A complete re-run of MRSea modelling for gannet has been carried out. The runs test and ACF plot generated as part of the process are presented in **Appendix A**. In the revised MRSea model, only survey ID is used within the blocking structure.

ID	CREEM's Comment	Applicant's Initial Response	Agreed Actions and Further Applicant Response
		Month/season is included as a factor to recognise species' migratory patterns and noting that the surveys cover a two-year period, which is therefore distinct from the temporal autocorrelation that results from surveys being close in time.	
CREEM5	It is earlier stated that the blocking structure is included in modelling to account for autocorrelation, why then in paragraph 2.3.1.4 are models re-fitted as GEEs? If a blocking structure was given to MRSea, all standard errors and p-values from the model will be adjusted for the presence of residual correlation. Assuming the GEE has been fitted using an independent working correlation matrix (as opposed to AR(1) for example) and robust standard errors calculated (the default in this scenario) then this part is entirely redundant.	It is not possible for the Applicant to provide all elements of CREEM's requests due to certain aspects not being exported from R during the modelling process. However, the Applicant intends on running a single species (gannet) again following the advice from Natural England and CREEM to present as much additional data as possible and to download or take screenshots of the modelling process, where applicable.	A complete re-run of MRSea modelling for gannet has been carried out as presented in **Appendix A**. Models are no longer refitted as GEES.
CREEM6	This paragraph also states that "The best model can have inaccurate p-values if auto-correlation still exists despite the blocking structure". This is not true if the blocking structure has been specified correctly (and can be checked with a block based ACF plot). Further, MRSea uses a block structure and robust standard errors to account for residual correlation. It does not remove residual correlation as the methods for accounting for it operate solely on the standard errors (not the residuals themselves). In this case any residual correlation will still be present (even after the inclusion of a blocking structure) and an ACF plot would therefore still show the correlation.	It is not possible for the Applicant to provide all elements of CREEM's requests due to certain aspects not being exported from R during the modelling process. However, the Applicant intends on running a single species (gannet) again following the advice from Natural England and CREEM to present as much additional data as possible and to download or take screenshots of the modelling process, where applicable.	A complete re-run of MRSea modelling for gannet has been carried out as presented in **Appendix A**, with robust p-values generated.
CREEM7	The inclusion of a sentence about co-linearity in a paragraph predominantly about residual correlation is confusing. VIFs can be checked up front (prior to any	The Applicant ensured to check VIFs upfront, before proceeding further with modelling. However, in accordance with best practice, variables showing co-	A complete re-run of MRSea modelling for gannet has been carried out as presented in **Appendix A**. As per the original MRSea modelling the VIFs are checked upfront, but any co-linearity identified is not

ID	CREEM's Comment	Applicant's Initial Response	Agreed Actions and Further Applicant Response
	modelling) so collinearity as an issue can be dealt with early on.	linearity were not removed at that stage and were instead re-assessed after fitting the spatial smooth. As stated above, the Applicant's Baseline Sensitivity Report will provide as much clarity as possible these matters.	dealt with upfront as it is addressed through the model selection process.
CREEM8	Paragraph 2.3.1.4. states the use of cross validation but only the function name is given and no mention of the type of CV; k-fold. Was it 10-fold cross-validation and did it select folds whilst maintaining the block structure? There is also no mention of how the best model including s(x,y) was chosen and at the end of the paragraph it is then stated that p-values are used for model selection. A look at the results, where there are non-significant p-values would suggest that these have not been used for selection. It would be better to stick to a process and either use k-fold CV for everything (smoothness selection and variable inclusion) or k-fold CV for smoothness and p-values for variable inclusion, whichever you prefer.	It is not possible for the Applicant to provide all elements of CREEM's requests due to certain aspects not being exported from R during the modelling process. However, the Applicant intends on running a single species (gannet) again following the advice from Natural England and CREEM to present as much additional data as possible and to download or take screenshots of the modelling process, where applicable.	A complete re-run of MRSea modelling for gannet has been carried out as presented in **Appendix A**. 10-fold cross validation was used for both smoothness selection and variable inclusion.
CREEM9	In the methods section, the general models trialled are not specified at all. I would expect a generic equation/paragraph in the methods section stating what is being fitted and to include things like a. Poisson GAM with (over)dispersion and log link b. Discrete covariates (survey or season) c. Quadratic (?) B-splines for the 1D covariates (also allowed as linear?) d. Gaussian (?) radial basis function for the two dimensional smooth of coordinates e. How much flexibility has the user allowed for the B-splines and the spatial smooth – these are user defined.	The Applicant will review the methods sections and provide greater input in relation to the points specified above (a to e) to ensure the rationale taken forward for modelling is evidenced. In summary: The initial GLM was a quasipoisson (allowing for oversdispersion) with a log link; survey month or survey season (depending on species) was included as a discrete covariable; b-splines were quadratic (degree = 2); the radial basis function was not specified and therefore the default was used; the maximum number of knots was set to 5 for both 1D and 2D smooths.	A complete re-run of MRSea modelling for gannet has been carried out as presented in **Appendix A**.

ID	CREEM's Comment	Applicant's Initial Response	Agreed Actions and Further Applicant Response
	f. Were the discrete variables trialled as interaction terms with the spatial term? Given the 1D variables are all static over time, the only option in the model for a change in distribution over time would be to allow an interaction term of survey or season with s(x,y). Your model selection process would then be used to assess if the inclusion of this term was warranted. Alternatively, if there are computational issues with this, you could fit separate models to each survey. The possibility of a change in spatial distribution over time should, at the very least, be discussed.	With regards to point (f) it is not possible for the Applicant to provide all elements of CREEM's requests due to certain aspects not being exported from R during the modelling process. However, the Applicant intends on running a single species (gannet) again following the advice from Natural England and CREEM to present as much additional data as possible and to download or take screenshots of the modelling process, where applicable.	
CREEM10	Paragraph 2.2.1.4 briefly comments on the use of bootstraps to generate confidence intervals. Presumably this was done using the functionality in MRSea and so is a parametric bootstrap (each bootstrap replicate is based on sampling the model parameters from a multivariate normal). How many bootstraps were used? 500, 1000? Additionally, the glossary definition of "Bootstrapping" in the context of MRSea is incorrect.	The Applicant confirmed 500 bootstraps were used and were carried out using the built-in functionality and accordingly it was a parametric bootstrap. The glossary definition will be updated.	A complete re-run of MRSea modelling for gannet has been carried out as presented in **Appendix A**. This uses 1,000 parametric bootstraps to generate CIs (**Figure 40** and **Figure 41**).
CREEM11	Paragraph 2.3.1.6 describes the calculation of abundance and density estimates. It is not clear how the confidence intervals were calculated and why they were not also presented for the density. The bootstraps can be used to get a set of abundances for each time frame and then as for the cell-based estimates, take the quantiles to get your intervals.	The Applicant agreed that any updated reporting will be modified for clarity. Confidence intervals were generated using the bootstrapping approach as acknowledged in the previous comment. Confidence intervals were not presented for density in order to keep the results concise, though these can be readily calculated from the abundance upper and lower confidence limits if required.	A complete re-run of MRSea modelling for gannet has been carried out as presented in **Appendix A**. This uses 1,000 parametric bootstraps to generate CIs (**Figure 40** and **Figure 41**).
CREEM12	In the results sections, the final model specifications are not given correctly as each one omits the spatial term (which appears to have been selected for in most models) and there is no reason given for why some variables are not in the final model (model selection, collinearity, model fitting issues etc). As mentioned	It is not possible for the Applicant to provide all elements of CREEM's requests due to certain aspects not being exported from R during the modelling process. However, the Applicant intends on running a single species (gannet) again following the advice from Natural England and CREEM to present as much additional data	A complete re-run of MRSea for gannet has been carried out, with the detailed approach and final model specifications presented in **Appendix A**.

ID	CREEM's Comment	Applicant's Initial Response	Agreed Actions and Further Applicant Response
	earlier, I would not give R commands as a result in a report. You could try a table with each of the potential variables and give estimated degrees of freedom (or reason for exclusion), and an image of the estimated 1D relationships etc. There is no discussion of the 1D variable relationships and some seem to have excessive flexibility (7df) which is often not warranted in these sorts of settings. Additionally, having fitted two types of model (survey or season) some information about which is the better fitting model would be useful (using say CV scores). If the survey model was best then, being the finer temporal resolution, the season estimates can be post processed from the predictions/bootstraps.	as possible and to download or take screenshots of the modelling process, where applicable.	
CREEM13	Model diagnostics (observed vs fitted and cumulative residuals) were mentioned in paragraph 2.3.1.4 but are not shown/described for any species so the reader has little idea of whether the models are any good. In addition to the diagnostics mentioned, the mean-variance relationship and spatial residuals could/should also be assessed.	The Applicant will provide further detail in the Baseline Sensitivity Report with model diagnostics provided when revising the MRSea modelling for a single species (gannet). However, the Applicant are unable to provide the output diagnostics for the model due to them not being automatically outputted from the current MRSea model when it was run. The Applicant understands that the absence of such diagnostics does not allow for external interpretation of the model. However, the Applicant confirmed that the statisticians did review the diagnostics from the model and were confident with the results produced. It was also recognised that not providing the diagnostics would not lead to the results changing.	A complete re-run of MRSea for gannet has been carried out as presented in **Appendix A**. Additional model diagnostics for this initial re-run have been provided (**Figure 44** to **Figure 46**).
CREEM14	There is no presentation of the spatial uncertainty. It could be shown in the form of plots of coefficient of variation or percentile-based confidence intervals. The bootstraps have been done so it would be easy to calculate either of these for each grid cell.	The Applicant will provide the confidence intervals as requested when revising the MRSea modelling and present this in the Baseline Sensitivity Report.	A complete re-run of MRSea for gannet has been carried out as presented in **Appendix A**. This includes presentation of spatial uncertainty (**Figure 43**).

5 Baseline Sensitivity Report – Part 1 (Methodology for Revised MRSea Modelling)

5.1.1 Data processing & Modelling Approach

5.1.1.1 In line with the approach agreed with Natural England, during the consultation meeting on the 17th February 2022, MRSea analysis was performed *de novo* for gannet following the best practice guidance in Scott-Hayward et al. (2017). The initial stages of the re-building and testing process for the revised MRSea modelling also accounts for the comments provided in the CREEM Statistical Review of Hornsea Project Four: Environmental Statement for Natural England (Scott-Hayward, 2021, comments related to the review presented in **Table 2**).

5.1.1.2 Aerial digital video surveys were conducted by HiDef over 24 months from April 2016 to March 2018 across the Hornsea Four AfL area plus 4 km buffer. The full Hornsea Four AfL plus 4 km buffer data were used to extract locations and counts of gannets recorded, the use of the full survey data ensured the models were as accurate as possible, as utilisation of the maximum amount of data available across the largest area available ensured that any relationships between environmental variables and gannet density had the greatest opportunity to be recognised and integrated as possible. Shapefiles of observations and transect lines from each survey were supplied by HiDef. The footprint of each survey was estimated from the transect line shapefile by assuming a 125m image half-width, as specified by HiDef, and generated using the MMQGIS Create Buffer tool within QGIS (QGIS Version 3.10.5; MMQGIS version 2020.1.16). Observation and transect shapefiles were clipped to the Hornsea Four Agreement for Lease (AfL) area plus 4 km buffer.

5.1.1.3 A regular grid of 1x1km squares covering the Hornsea Four AfL plus 4 km buffer was generated using the "Create grid" tool within QGIS. The transect footprints were intersected with this grid to produce a shapefile of transect segments for each survey.

5.1.1.4 The three environmental variables considered for modelling were; distance to coast, distance to Flamborough and Filey Coast Special Protection Area (FFC SPA) and depth. These environmental variables were selected on the basis of having a biologically plausible relationship with gannet distribution and agreed as suitable in ETG#13. For each transect segment, distance to coast, distance to FFC SPA, and depth were calculated within R (R Core Team, 2020) as follows. The distance to coast was measured in kilometres from the centroid of each transect segment to the nearest point on the coast based on a publicly available shapefile of coastlines[1] and using the st_nearest_points function in the sf package (Pebesma, 2018). The distance to FFC SPA was measured in kilometres from the centroid of each transect segment to the centroid of FFC SPA, based on the SPA shapefile available from JNCC (2021). The depth of each transect segment was calculated as the area-weighted mean depth in metres within each transect segment using the OceanWise Bathymetry

[1] https://www.naturalearthdata.com/downloads/10m-physical-vectors/10m-coastline/

raster. The coordinates of the centroid of each transect segment in UTM zone 31N (EPSG:32631) were added as variables named "x.pos" and "y.pos".

5.1.1.5 The same approach was taken to assign a distance to coast, distance to FFC SPA, depth, x.pos and y.pos to each grid cell of the 1x1km grid, to be used as the prediction grid.

5.1.1.6 Observations of birds were assigned to each transect segment using a spatial join with the join term set to "nearest". This accommodates minor discrepancies between the observation shapefile and the transect footprints. The number of gannets per transect segment was then extracted and added to the transect shapefile. The survey month was extracted from the date field present within the transect line shapefile, and a field for gannet bio-seasons was created based on the survey month and the definitions of bio-seasons presented in **A2.5 Environmental Statement Volume A2 Chapter 5 Offshore and Intertidal Ornithology (APP-017)**. The transect shapefile was then converted into a data frame for use as input to the subsequent modelling.

5.1.1.7 All subsequent modelling was carried out in R (R Core Team, 2020) using MRSea version 1.3.

5.1.1.8 Details of the modelling undertaken are presented in **Appendix A**. This includes full details of the final best model, along with other candidate models considered and justification for the model choice.

6 Part 2 - Revised MRSea Results

6.1 Gannet MRSea Results

6.1.1.1 The results of the revised MRSea modelling (hereafter referred to as MRSea_v2) following the agreed methodology as detailed in **Section 5**. The model code has been shared with CREEM and it has been agreed that approach undertaken appears to be the most suitable approach given the data (Scott-Hayward, *pers. comms.*). The results are presented as monthly abundances in **Table 3** and as bio-season mean peak abundances in **Table 4** below for the revised array area, array area plus 2 km buffer and array area plus 4 km buffer. In order to use the MRSea modelling approach in the most appropriate and statistically robust manner, it has been used to predict abundances per calendar month, based on data from all 24 aerial digital surveys. As such, the results presented are for each calendar month and not for individual surveys and should, therefore, be considered to represent the average abundances and distributions within each calendar month (i.e. results presented for "January" will be informed by survey data from both January 2017 and January 2018). The upper and lower confidence limits presented in **Table 3** and **Table 4** incorporate inter-annual variation in addition to model uncertainty. Further statistical details on why this approach has been adopted are presented in **Appendix A**. The bio-seasons presented in **Table 4** are based on those described in Furness (2015) for gannet, for which the component months and subsequent colour-coding for each bio-season are as follows:

- Return migration (Green): December to March;
- Migration-free breeding (Purple): April to August; and
- Post-breeding migration (Red): September to November.

Table 3: Gannet MRSea_v2 monthly abundance estimate results for the Hornsea Four array area, array, array area plus 2 km buffer and array area plus 4 km buffer.

Hornsea Four Array Area									
Month	All behaviours			Flying			Sitting		
	Abundance	Lower CI	Upper CI	Abundance	Lower CI	Upper CI	Abundance	Lower CI	Upper CI
January	15.3	4.3	105.8	0.0	0.0	0.0	15.3	4.3	105.8
February	17.6	4.9	77.9	17.6	4.9	77.9	0.0	0.0	0.0
March	159.1	70.0	366.2	73.9	32.5	170.0	85.2	37.5	196.2
April	26.6	10.3	74.0	15.9	6.2	44.4	10.6	4.1	29.6
May	107.9	23.8	752.3	27.0	6.0	188.1	80.9	17.9	564.2
June	555.1	306.8	1,029.4	370.1	204.5	686.3	185.0	102.3	343.1
July	333.7	176.6	630.7	226.9	120.1	428.9	106.8	56.5	201.8
August	246.9	137.0	473.7	203.7	113.0	390.8	43.2	24.0	82.9
September	153.0	87.4	274.9	85.0	48.6	152.7	68.0	38.9	122.2
October	327.3	174.0	631.5	122.7	65.2	236.8	204.6	108.7	394.7
November	449.3	247.1	836.0	240.1	132.1	446.8	209.1	115.0	389.2
December	179.9	60.3	580.7	8.6	2.9	27.7	171.3	57.4	553.0
Total	5,143.0	2,604.9	11,666.2	2,785.2	1,429.0	6,051.6	2,357.8	1,175.9	5,614.6
Hornsea Four Array Area plus 2 km buffer									
Month	All behaviours			Flying			Sitting		
	Abundance	Lower CI	Upper CI	Abundance	Lower CI	Upper CI	Abundance	Lower CI	Upper CI
January	36.7	10.4	251.8	0.0	0.0	0.0	36.7	10.4	251.8
February	27.7	8.0	124.7	27.7	8.0	124.7	0.0	0.0	0.0
March	218.1	91.8	536.4	102.2	43.0	251.4	115.9	48.8	285.0
April	44.9	17.1	128.6	25.7	9.8	73.5	19.2	7.3	55.1
May	174.6	37.8	1,350.3	38.8	8.4	300.1	135.8	29.4	1,050.3
June	742.7	401.8	1,418.9	594.2	321.5	1,135.1	148.5	80.4	283.8
July	497.8	252.9	990.4	339.4	172.4	675.3	158.4	80.5	315.1
August	373.0	203.3	730.0	265.6	144.7	519.7	107.5	58.6	210.3
September	240.4	135.6	437.2	138.7	78.2	252.2	101.7	57.4	185.0
October	488.6	252.3	973.7	148.7	76.8	296.3	339.9	175.5	677.3

November	667.4	359.8	1,265.2	343.0	184.9	650.2	324.4	174.9	615.0
December	270.6	92.3	899.9	32.2	11.0	107.1	238.4	81.3	792.7
Total	7,565.1	3,726.1	18,214.3	4,034.2	2,021.9	9,217.3	3,531.0	1,704.2	8,997.0
Hornsea Four Array Area plus 4 km buffer									
Month	**All behaviours**			**Flying**			**Sitting**		
	Abundance	**Lower CI**	**Upper CI**	**Abundance**	**Lower CI**	**Upper CI**	**Abundance**	**Lower CI**	**Upper CI**
January	70.8	19.0	527.6	0.0	0.0	0.0	70.8	19.0	527.6
February	41.0	11.9	187.0	32.8	9.6	149.6	8.2	2.4	37.4
March	277.8	111.7	738.0	106.8	43.0	283.9	170.9	68.7	454.2
April	77.0	28.4	232.3	38.5	14.2	116.1	38.5	14.2	116.1
May	262.4	56.3	2,208.9	37.5	8.0	315.6	224.9	48.2	1,893.4
June	927.0	493.9	1,815.0	695.2	370.4	1,361.2	231.7	123.5	453.7
July	683.4	334.6	1,425.7	512.6	250.9	1,069.3	170.9	83.6	356.4
August	520.6	279.5	1,036.0	378.0	202.9	752.1	142.6	76.6	283.8
September	350.4	193.2	651.8	195.8	108.0	364.2	154.6	85.2	287.5
October	685.9	341.9	1,436.7	221.9	110.6	464.8	464.0	231.3	971.9
November	946.9	498.8	1,841.0	492.4	259.4	957.3	454.5	239.4	883.7
December	366.2	129.3	1,224.7	45.8	16.2	153.1	320.5	113.1	1,071.6
Total	10,418.5	4,996.7	26,649.3	5,501.2	2,691.6	13,179.5	4,917.3	2,305.1	13,469.8

Table 4: Gannet MRSea_v2 bio-season results for the Hornsea Four array area, array, array area plus 2 km buffer and array area plus 4 km buffer.

Hornsea Four Array Area									
Season	All behaviours			Flying			Sitting		
	Abundance	Lower CI	Upper CI	Abundance	Lower CI	Upper CI	Abundance	Lower CI	Upper CI
Return Migration	179.9	70.0	580.7	73.9	32.5	170.0	171.3	57.4	553.0
Migration-free breeding	555.1	306.8	1,029.4	370.1	204.5	686.3	185.0	102.3	564.2
Post-breeding migration	449.3	247.1	836.0	240.1	132.1	446.8	209.1	115.0	394.7
Annual	1,184.2	623.9	2,446.1	684.0	369.1	1,303.1	565.5	274.7	1,512.0
Hornsea Four Array Area plus 2 km buffer									
Month	All behaviours			Flying			Sitting		
	Abundance	Lower CI	Upper CI	Abundance	Lower CI	Upper CI	Abundance	Lower CI	Upper CI
Return Migration	270.6	92.3	899.9	102.2	43.0	251.4	238.4	81.3	792.7
Migration-free breeding	742.7	401.8	1,418.9	594.2	321.5	1,135.1	158.4	80.5	1,050.3
Post-breeding migration	667.4	359.8	1,265.2	343.0	184.9	650.2	339.9	175.5	677.3
Annual	1,680.7	853.9	3,584.0	1,039.4	549.4	2,036.8	736.6	337.3	2,520.3
Hornsea Four Array Area plus 4 km buffer									
Month	All behaviours			Flying			Sitting		
	Abundance	Lower CI	Upper CI	Abundance	Lower CI	Upper CI	Abundance	Lower CI	Upper CI
Return Migration	366.2	129.3	1,224.7	106.8	43.0	283.9	320.5	113.1	1,071.6
Migration-free breeding	927.0	493.9	2,208.9	695.2	370.4	1,361.2	231.7	123.5	1,893.4
Post-breeding migration	946.9	498.8	1,841.0	492.4	259.4	957.3	464.0	239.4	971.9
Annual	2,240.1	1,121.9	5,274.6	1,294.4	672.7	2,602.4	1,016.2	476.0	3,936.9

6.2 Spatial Distribution Results and Comparison

6.2.1.1 As detailed in **Table 1** (NE2, NE6 and NE7), Natural England requested that the spatial distribution of the MRSea_v2 results be considered in comparison to the raw observational data, in order to review the spatial fit of the model (NE3). Distributional comparisons have been produced as presented in **Figure 1** to **Figure 24** on a monthly basis comparing the following:

- A comparison between the spatial distribution of the AfL plus 4 km buffer raw observation point data for all gannets behaviours (flying and sitting combined) recorded across the two years of site specific aerial digital surveys combined (including a heatmap base layer to aid visualisation of areas with assumed higher abundance) and AfL plus 4 km buffer MRSea_v2 predicted density, as presented in **Figure 1**, **Figure 3**, **Figure 5**, **Figure 7**, **Figure 9**, **Figure 11**, **Figure 13**, **Figure 15**, **Figure 17**, **Figure 19**, **Figure 21** and **Figure 23** on a month by month basis; and
- A comparison between the spatial distribution of the Hornsea Four array area plus 4 km buffer raw observation point data for all gannets behaviours (flying and sitting combined) recorded across the two years of site specific aerial digital surveys presented separately (including a heatmap base layer to aid visualisation of areas with assumed higher abundance), MRSea_v2 array area plus 4 km buffer predicted density and the DCO MRSea (hereafter referred to as DCO MRSea_v1) array area plus 4 km buffer presented separately for each survey year predicted density, as presented in **Figure 2**, **Figure 4**, **Figure 6**, **Figure 8**, **Figure 10**, **Figure 12**, **Figure 14**, **Figure 16**, **Figure 18**, **Figure 20**, **Figure 22** and **Figure 24** on a month by month basis.

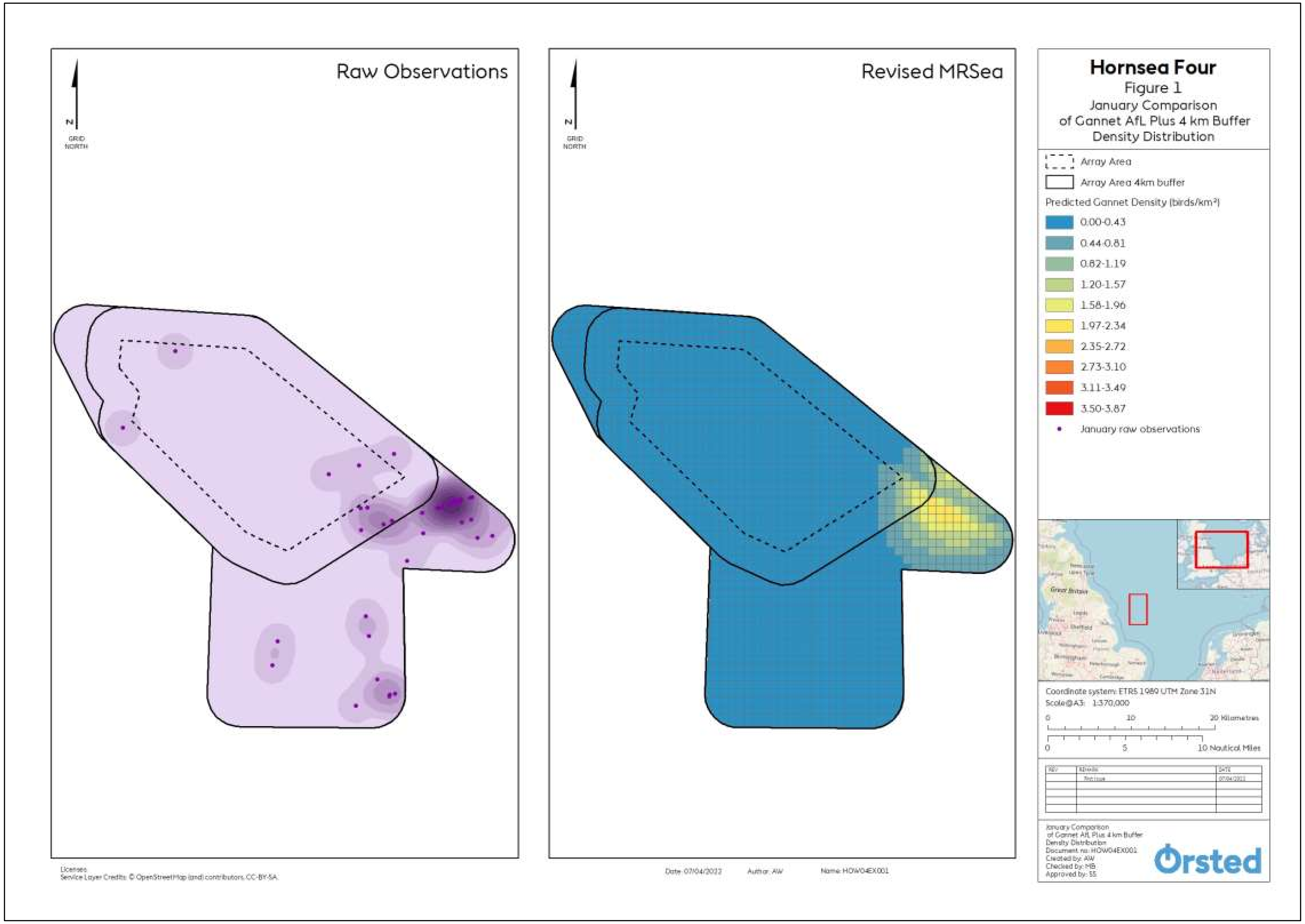

Figure 1: January comparison of gannet AfL plus 4 km buffer density distribution.

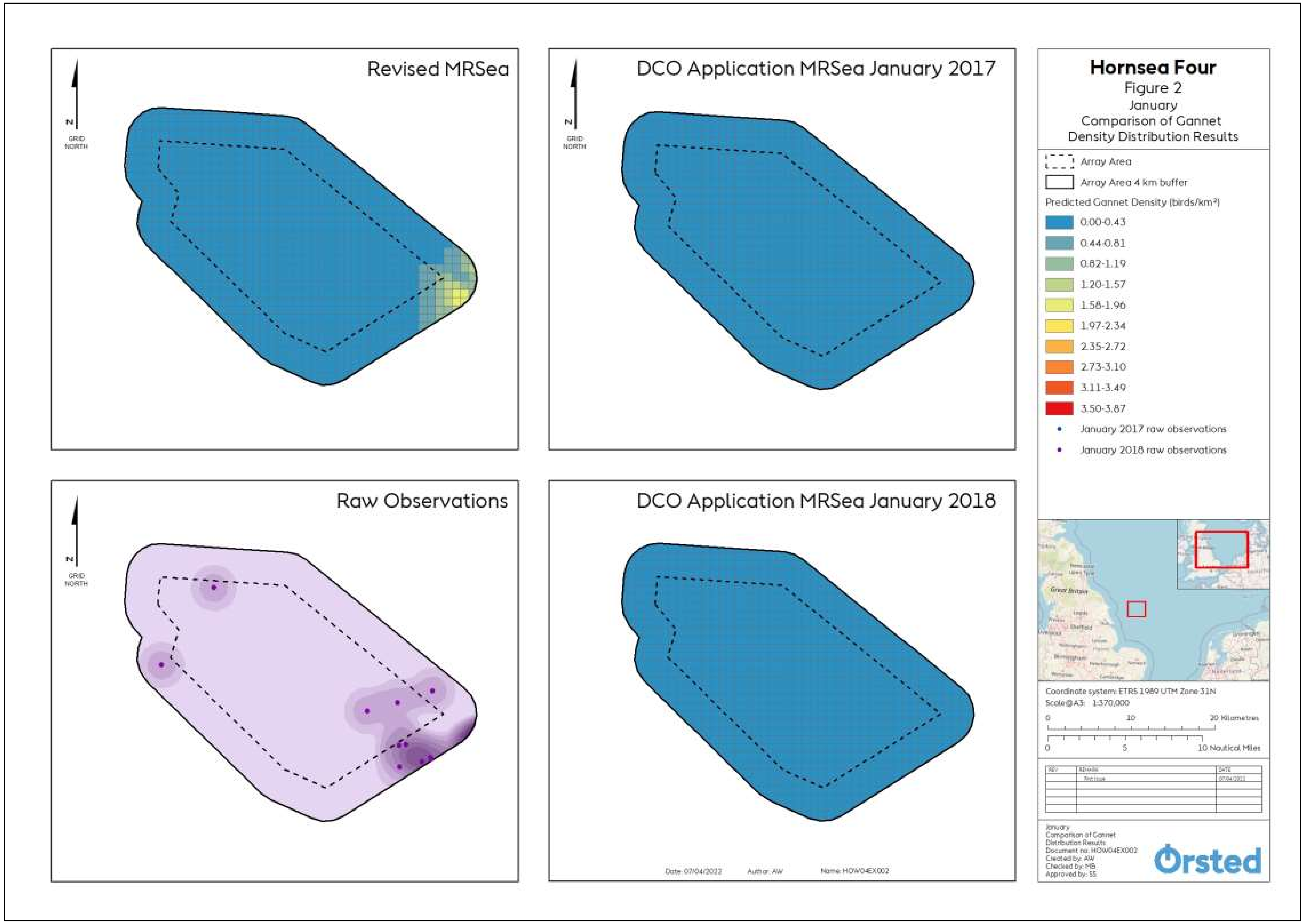

Figure 2: January comparison of gannet density distribution results

6.2.2 January Spatial Distribution Results and Comparison

6.2.2.1 As presented in **Figure 1**, across the two years of raw observation data for January very low numbers of gannets were recorded in the AfL plus 4 km buffer, with the exception of a distinct hotspot located in the southeast corner outside of the array area plus 4 km buffer. The very low abundance of gannets recorded for the majority of the AfL plus 4 km buffer is mirrored in the MRSea_v2 predicted density distribution, with a similar exception in the southeast corner where a distinct localised area of high density is observed. It is clear that the spatial density distribution for January of the MRSea_v2 data matches the distribution of the raw data, which suggests the modelling is a good fit spatially.

6.2.2.2 As presented in **Figure 2**, the raw count for both January surveys combined is a total of three lone gannets within the array area, a further six lone gannets within the array area plus 4 km buffer and a small cluster on the southern edge of the array area plus 4 km buffer. Overall, the abundance within the array area and 4 km buffer can be considered very low. It should be noted, as detailed in **Appendix B**, that the abundance for the January 2017 survey is zero. For the two January values from the DCO MRSea_v1 the density across the array area and 4 km buffer is the lowest density bracket across the entire area. For the MRSea_v2, again for nearly all the array area and 4 km buffer the density is of the lowest bracket, with the exception of the southeast corner where a small hotspot occurs similar to that observed for the raw observations. In summary, it can be considered that for all MRSea data (v1 & v2) the density distribution matches that of the distribution of the raw data and therefore, all can be considered a good fit spatially.

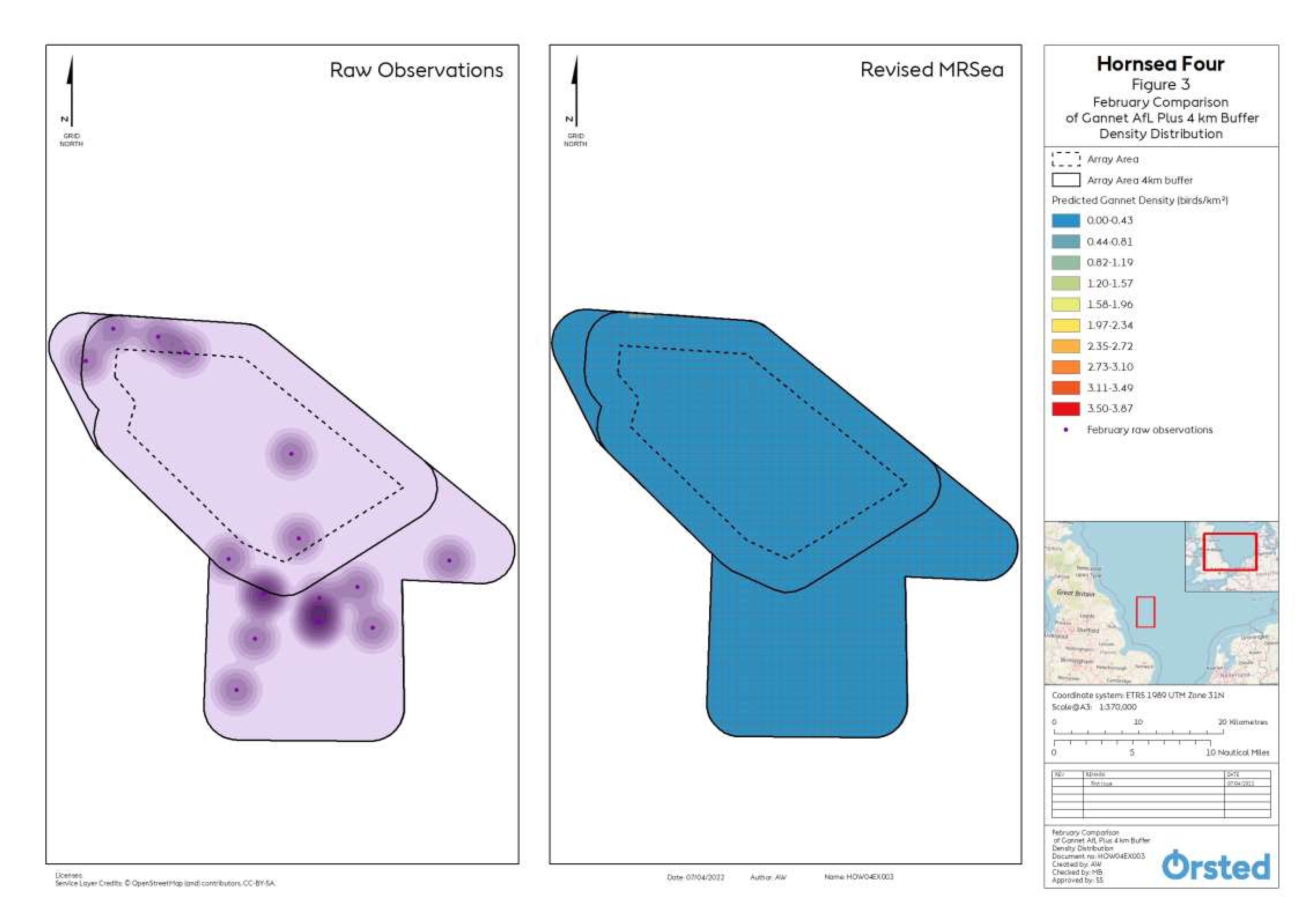

Figure 3: February comparison of gannet AfL plus 4 km buffer density distribution.

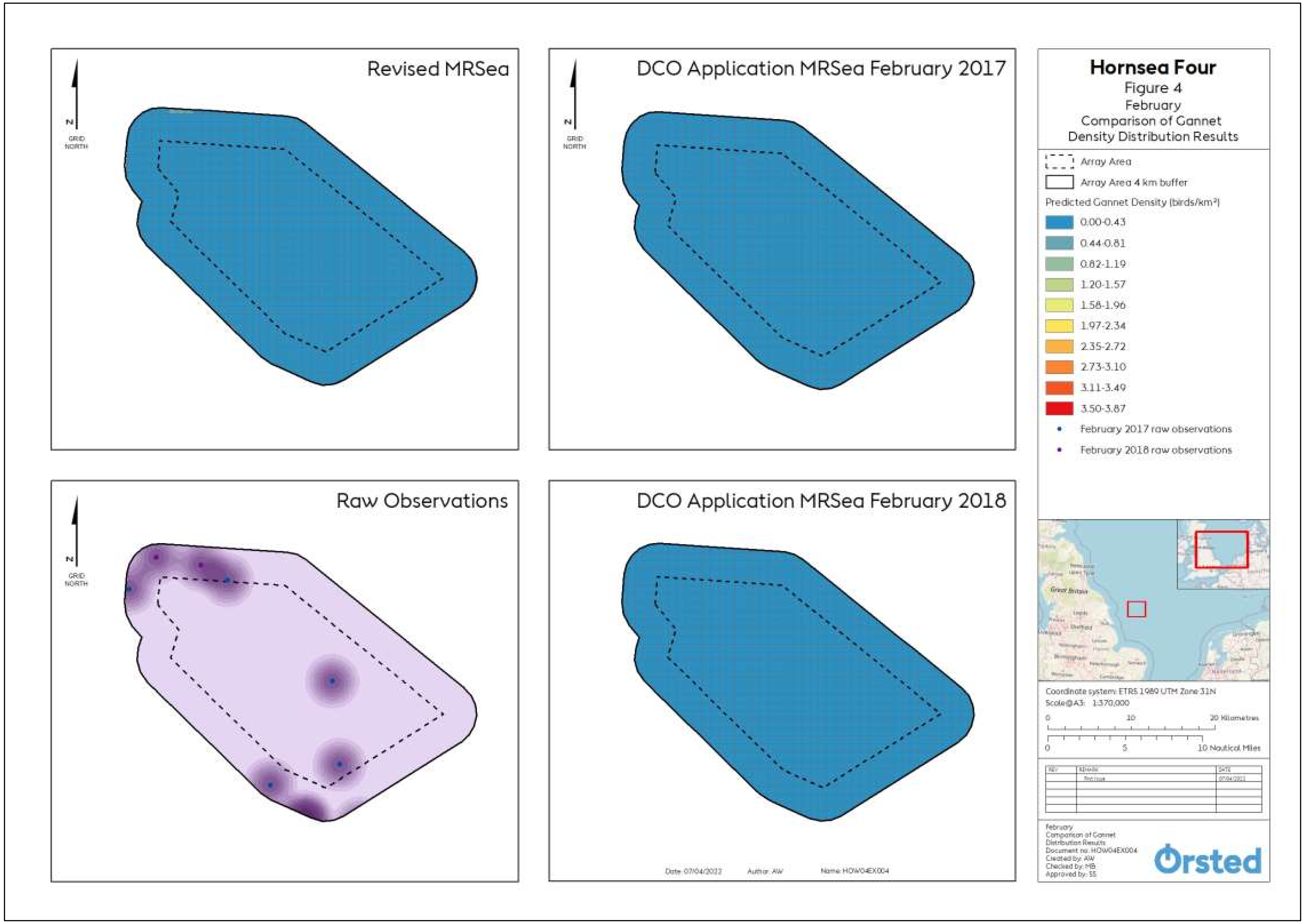

Figure 4: February comparison of gannet density distribution results

6.2.3 February Spatial Distribution Results and Comparison

6.2.3.1 As presented in **Figure 3**, across the two years of raw observation data for February very low numbers of gannets were recorded in the AfL plus 4 km buffer, with primarily lone gannets recorded to the north and south of the Hornsea Four array area. For the MRSea data density is of the lowest racket for nearly the entire AfL plus 4 km buffer, with only a small area of increase in density along the northern edge of the AfL 4 km buffer. For both datasets the abundance / density is very low across the entire area. It is clear that the spatial density distribution for February of the MRSea_v2 data matches the distribution of the raw data and is, therefore, a good fit spatially.

6.2.3.2 As presented in **Figure 4**, the February 2017 raw observations were very low with a total of five individual gannets recorded within the array area plus 4 km buffer located in either the north or southwest of the array area plus 4 km buffer. A raw count of two single individuals were recorded in the February 2018 raw observations both located in the north of the array area 4 km buffer. The density distribution for the two DCO MRSea_v1 areas were of the lower density bracket across the entire array area plus 4 km buffer coinciding with the very low number of raw counts observed in either year. The MRSea_v2 density distribution is also of the lowest density bracket for the vast majority of the array area plus 4 km buffer, except for a slight increase in density along a portion of the northeast 4km buffer boundary. Overall, it can be considered that for all MRSea data (v1 & v2) the density distribution matches that of the distribution of the raw data, and therefore all can be considered a good fit spatially.

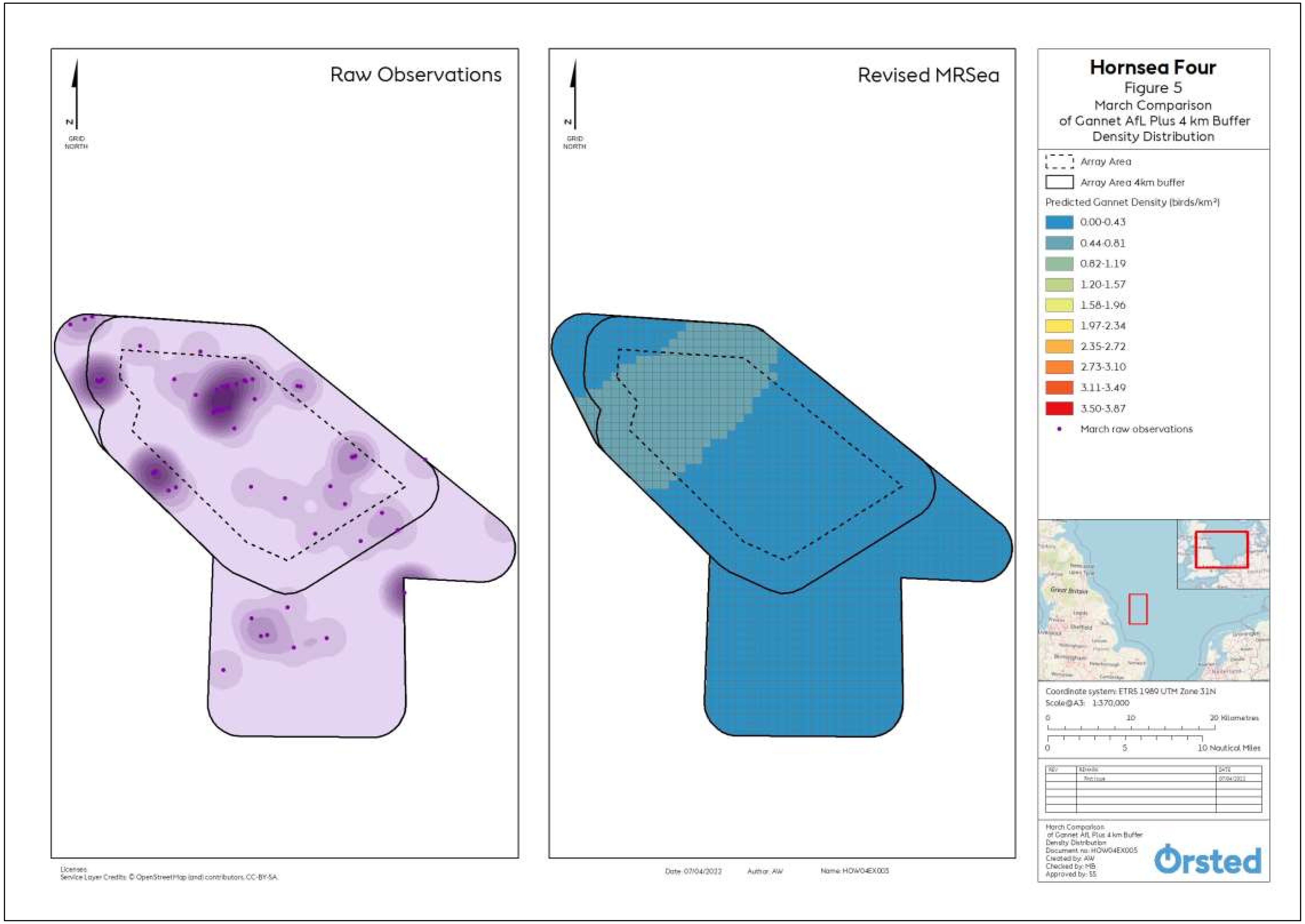

Figure 5: March comparison of gannet AfL plus 4 km buffer density distribution.

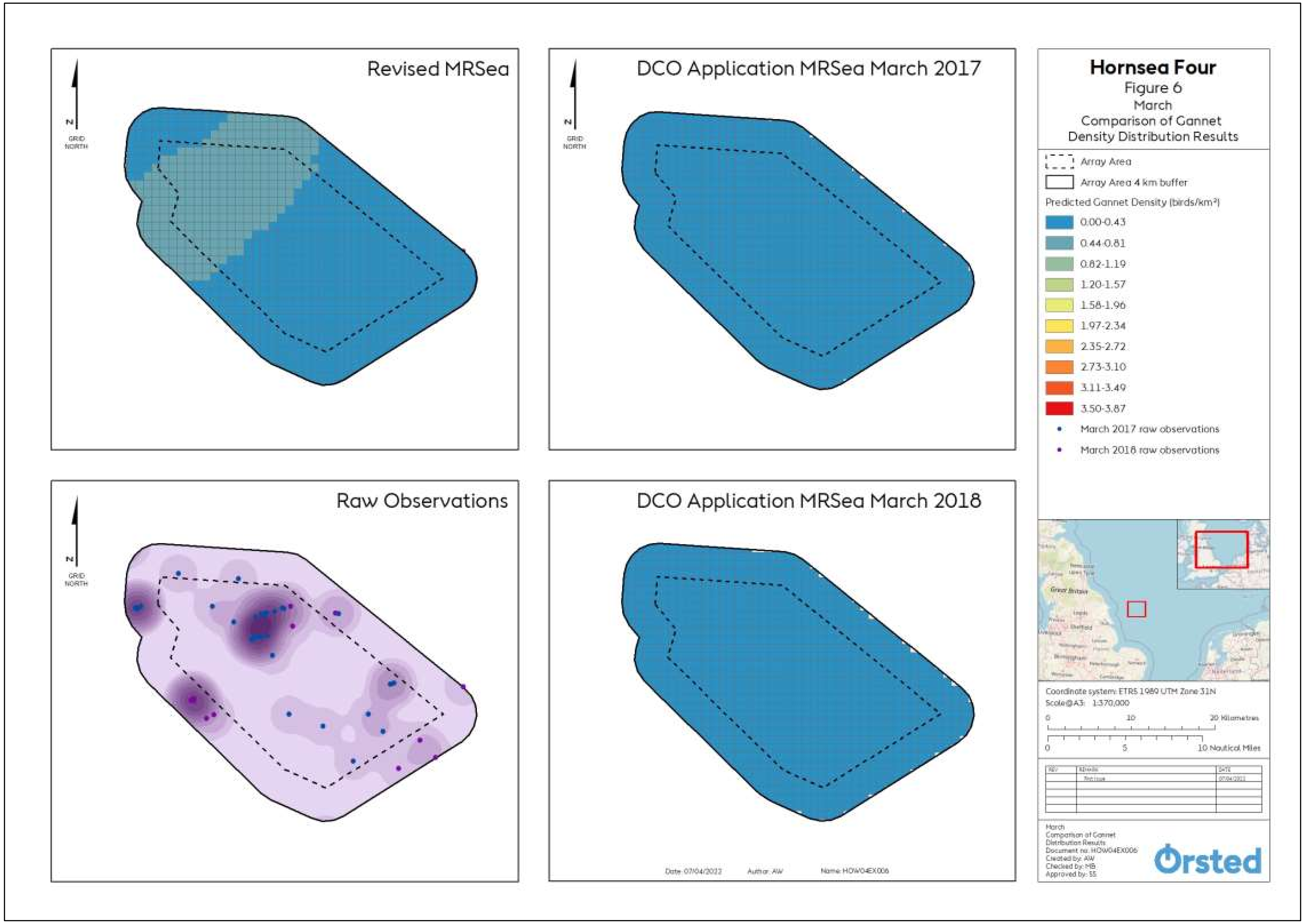

Figure 6: March comparison of gannet density distribution results

6.2.4 March Spatial Distribution Results and Comparison

6.2.4.1 As presented in **Figure 5**, across the two years of raw observation data for March low numbers of gannets were recorded widely distributed in the AfL plus 4 km buffer. One larger and two smaller clusters of gannets were recorded in the north of the array area and 4 km buffer. For the MRSea_v2 the density within the AfL plus 4km buffer is of the lowest density range signifying low density for the majority of the area, an increase in density is observed in a band across the north of the array area plus 4 km buffer encompassing the three clusters of gannets recorded in the raw observations. Both models show low abundance for the majority of the AfL plus 4 km buffer except for a northern section of the array area plus 4 km buffer, where an increase of abundance is visible for models in the same areas. Therefore, the MRSea_v2 can be considered a good fit spatially.

6.2.4.2 As presented in **Figure 6**, the March 2017 raw observations were widely distributed throughout the array area plus 4 km buffer with a cluster of observations with the east of the 4 km buffer. The March 2018 raw observations were focused in the east of the 4 km buffer and north of the array area. The density distribution for the two DCO MRSea_v1 areas were of the lower density bracket across the entire array area plus 4 km buffer. The MRSea_v2 density distribution is also of the lowest density bracket for the southern part of the array area and 4 km buffer, with an increase in density in the north of the array area and 4 km buffer encompassing the cluster of raw observations. As neither 2017 and 2018 DCO MRSea_v1 density distribution accounts for the cluster of gannets in the north of the array area plus 4 km buffer, they can be considered a weaker fit in comparison to the MRSea_v2 spatial fit.

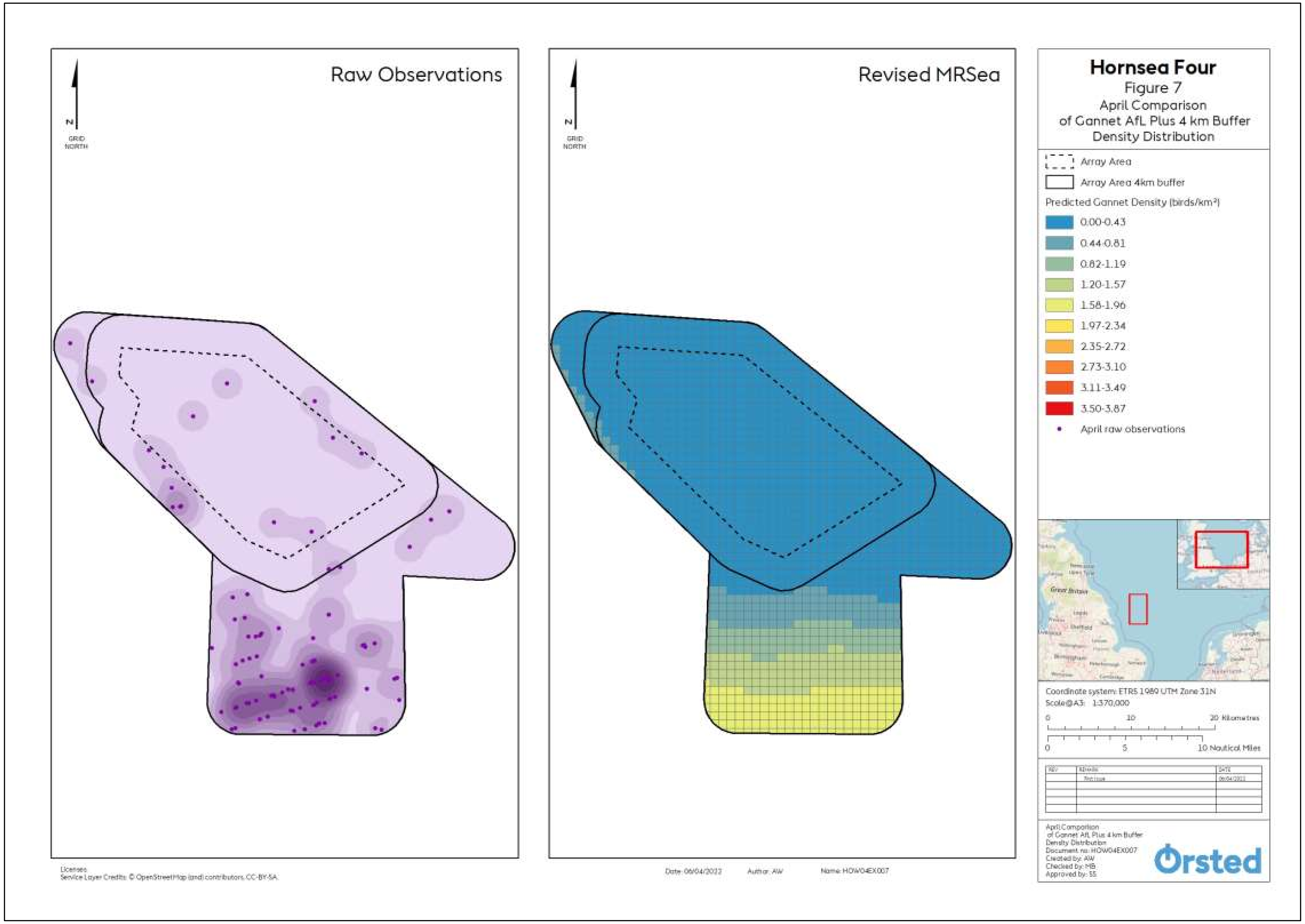

Figure 7: April comparison of gannet AfL plus 4 km buffer density distribution.

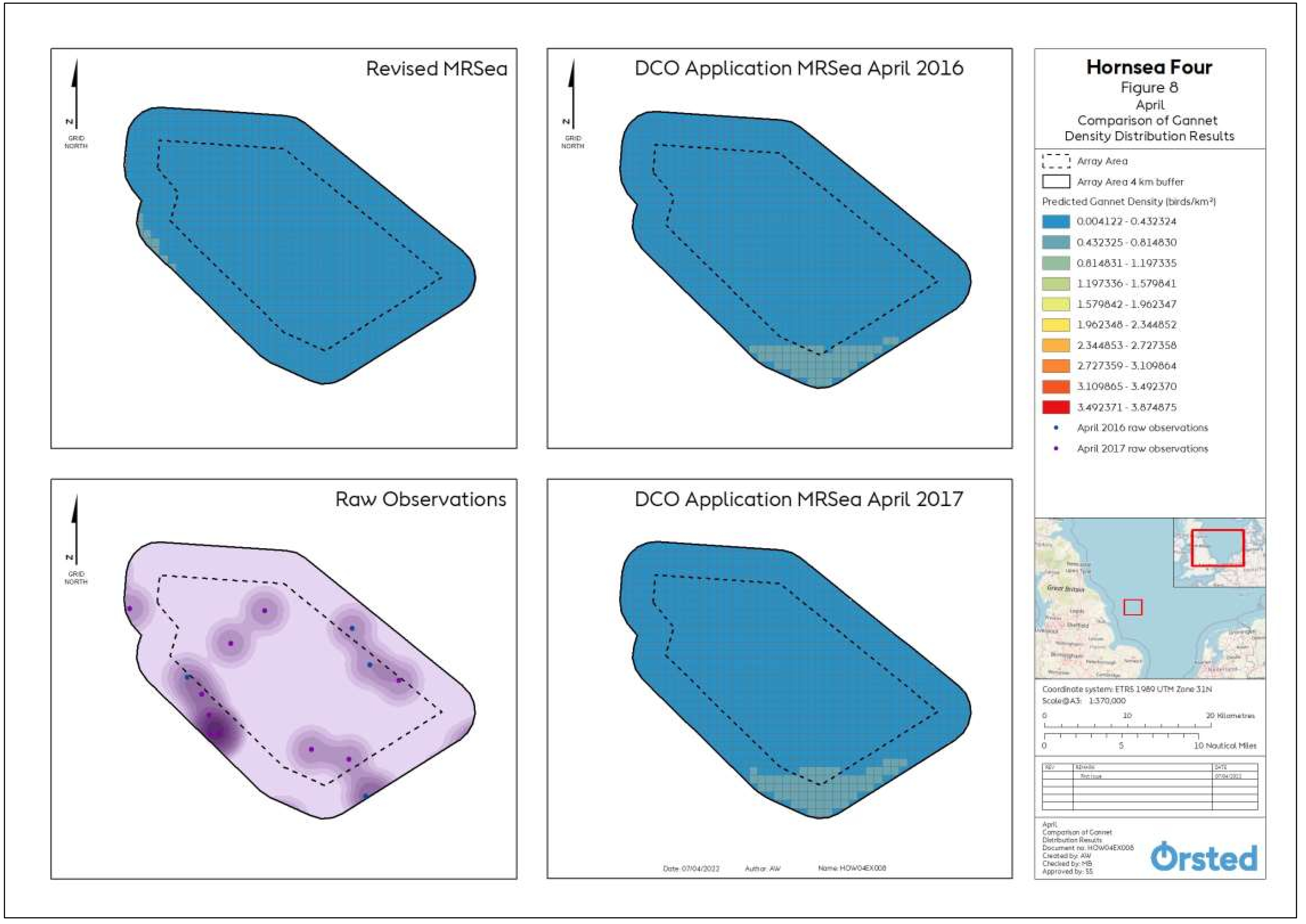

Figure 8: April comparison of gannet density distribution results

6.2.5 April Spatial Distribution Results and Comparison

6.2.5.1 As presented in **Figure 7**, raw observations in April were mainly distributed within the south of the AfL plus 4 km buffer. In a similar manner to the raw observations, a gradient of increased density is apparent within the south of the AfL plus 4 km buffer for the MRSea_v2 data, with the remainder of the AfL plus 4 km buffer being of low density. A clear pattern of higher density is apparent in the south of the AfL plus 4 km buffer for both datasets comparatively to the rest of the AfL plus 4 km buffer, therefore the MRSea_v2 can be considered a good fit spatially.

6.2.5.2 As presented in **Figure 8**, the April 2016 raw observations were very low in abundance and widely distributed throughout the array area plus 4 km buffer. The April 2017 raw observations were similarly in low abundance within the array area plus 4 km buffer and widely distributed. The density distribution for the two DCO MRSea_v1 areas both have an increase in density in the southern corner of the array area 4 km buffer. Based on the raw observations in **Figure 7** this is likely due to the high abundance of birds in the south of the AfL plus 4km buffer. The MRSea_v2 density distribution is primarily of the lowest abundance bracket with the exception of a minor area within the 4 km buffer western boundary, where a marginal increase in density is observed. Overall considering that the primary location of the raw abundance was outside of the array area plus 4 km buffer (**Figure 7**), all MRSea (v1 & v2) spatial distributions can be considered a suitable fit.

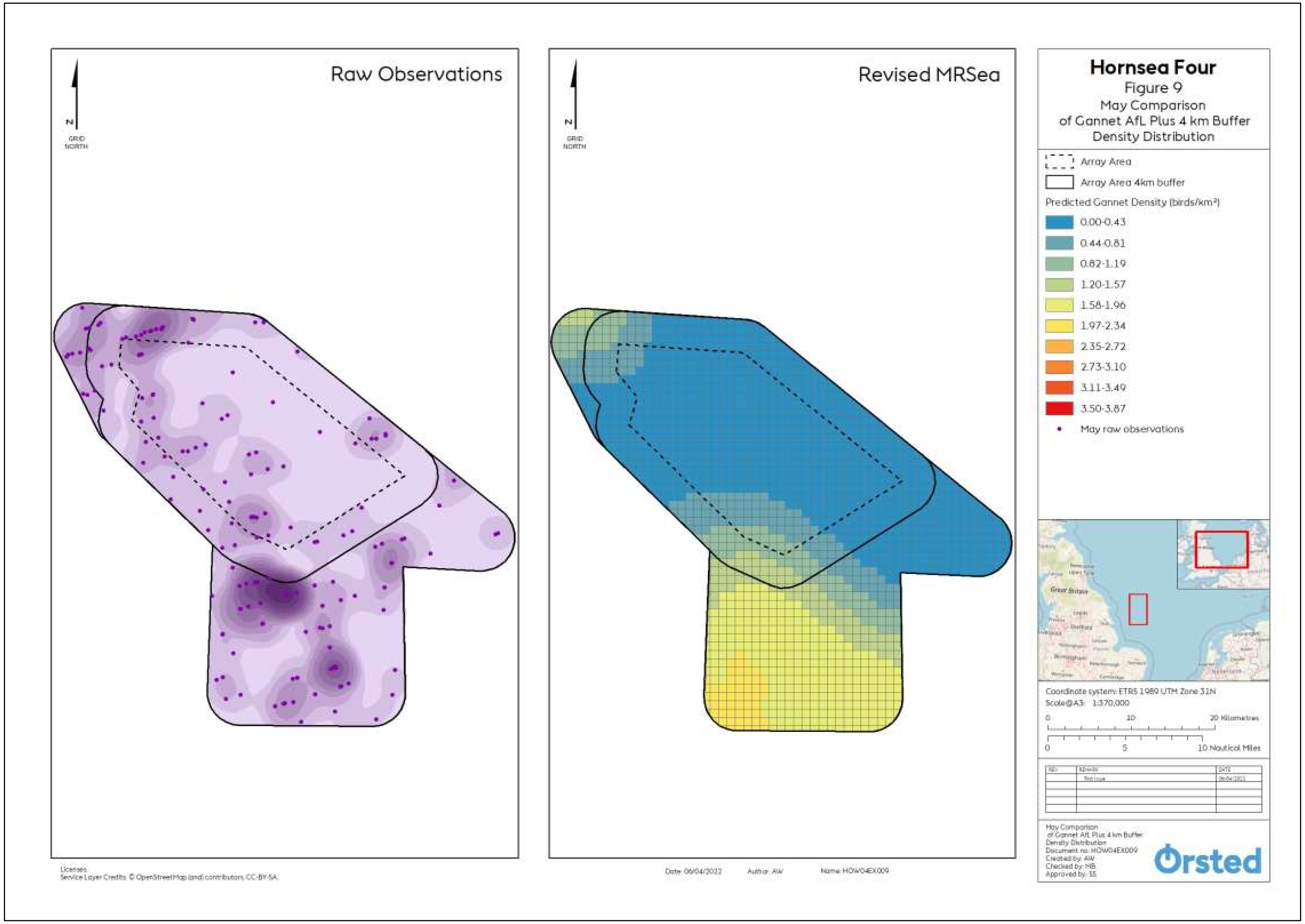

Figure 9: May comparison of gannet AfL plus 4 km buffer density distribution.

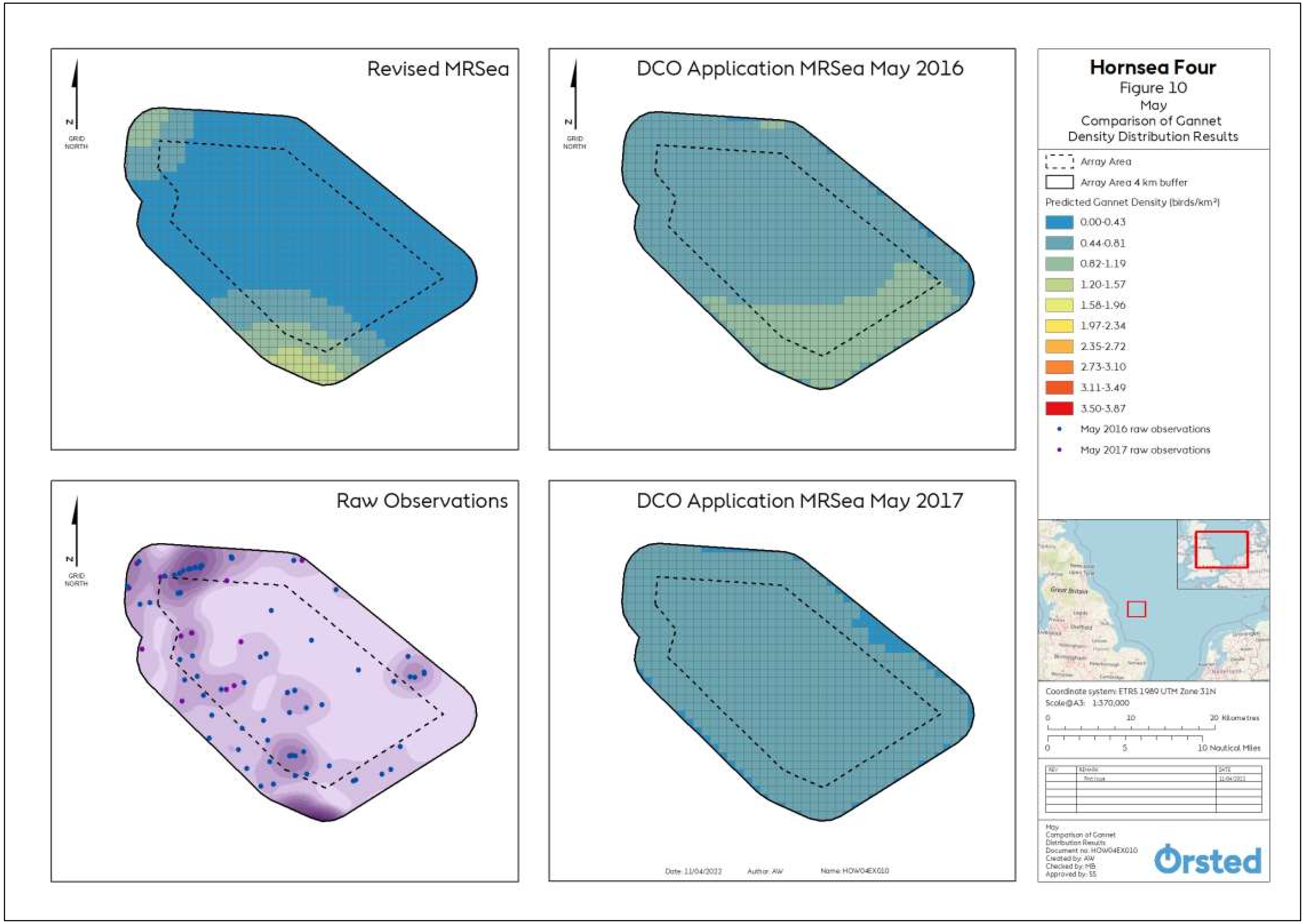

Figure 10: May comparison of gannet density distribution results

6.2.6 May Spatial Distribution Results and Comparison

6.2.6.1 As presented in **Figure 9**, raw observations in April were widely distributed throughout the AfL plus 4 km buffer, with the highest densities apparent in the northwest and southwest of the AfL plus 4 km buffer. Matching the raw observations, a gradient of increased density is seen within the southwest and northwest of the AfL plus 4 km buffer for the MRSea_v2 data, with the rest of the AfL plus 4 km buffer being of low density. A clear pattern of higher density is apparent in the southwest and northwest of the AfL plus 4 km buffer for both datasets comparatively to the rest of the AfL plus 4 km buffer, therefore the MRSea_v2 can be considered a good fit spatially.

6.2.6.2 As presented in **Figure 10**, May 2016 had the greater number of raw observations comparatively to the 2017 dataset, with points distributed throughout the whole of the array area plus 4 km buffer and a hotspot in the north of the array area 4 km buffer. For May 2016 raw observations were primarily located in the northern half of the array area and 4 km buffer. A hotspot is present in the southwest corner of the array area 4 km buffer due to the number of raw observations in the wider dataset (**Figure 9)**, although no raw observations were within the array area and 4 km buffer. The DCO MRSea_v1 data for May 2016 overall has limited areas of the lowest density bracket with higher densities in the southwest of the array area and 4 km buffer, this is likely due to the higher number of raw observations in the southwest of the wider dataset (**Figure 9**), with no increase in density is observed in the north of the array area 4 km buffer where a cluster of raw observations were recorded. The May 2017 DCO MRSea_v1 density distribution shows limited areas of the lowest density bracket and no data hotspots. The limited areas of the lowest density bracket does not match the limited raw observations recorded in the May 2017 data, especially in the south of the array area and 4 km buffer. The MRSea_v2 May data has two distinct areas of higher density to the north and southwest of the array area plus 4 km buffer, correlating with the areas of higher recorded observations in the raw data. The rest of the array area plus 4 km buffer is of the lowest density bracket, matching the limited number of raw observations in the remainder of the array area plus 4 km buffer. In comparison to the raw observations, the MRSea_v2 dataset presents a better spatial fit in comparison to the DCO MRSea_v1 datasets. The 2016 DCO MRSea_v1 dataset does partially correlate with the raw observations, due to the observed increase in density in the southwest corner but does not show an increase in the north of the array area 4 km buffer. With the exception of the north and southwest of the array area plus 4 km buffer, both 2016 and 2017 DCO MRSea_v1 datasets show a higher than expected density value comparatively to the raw observations.

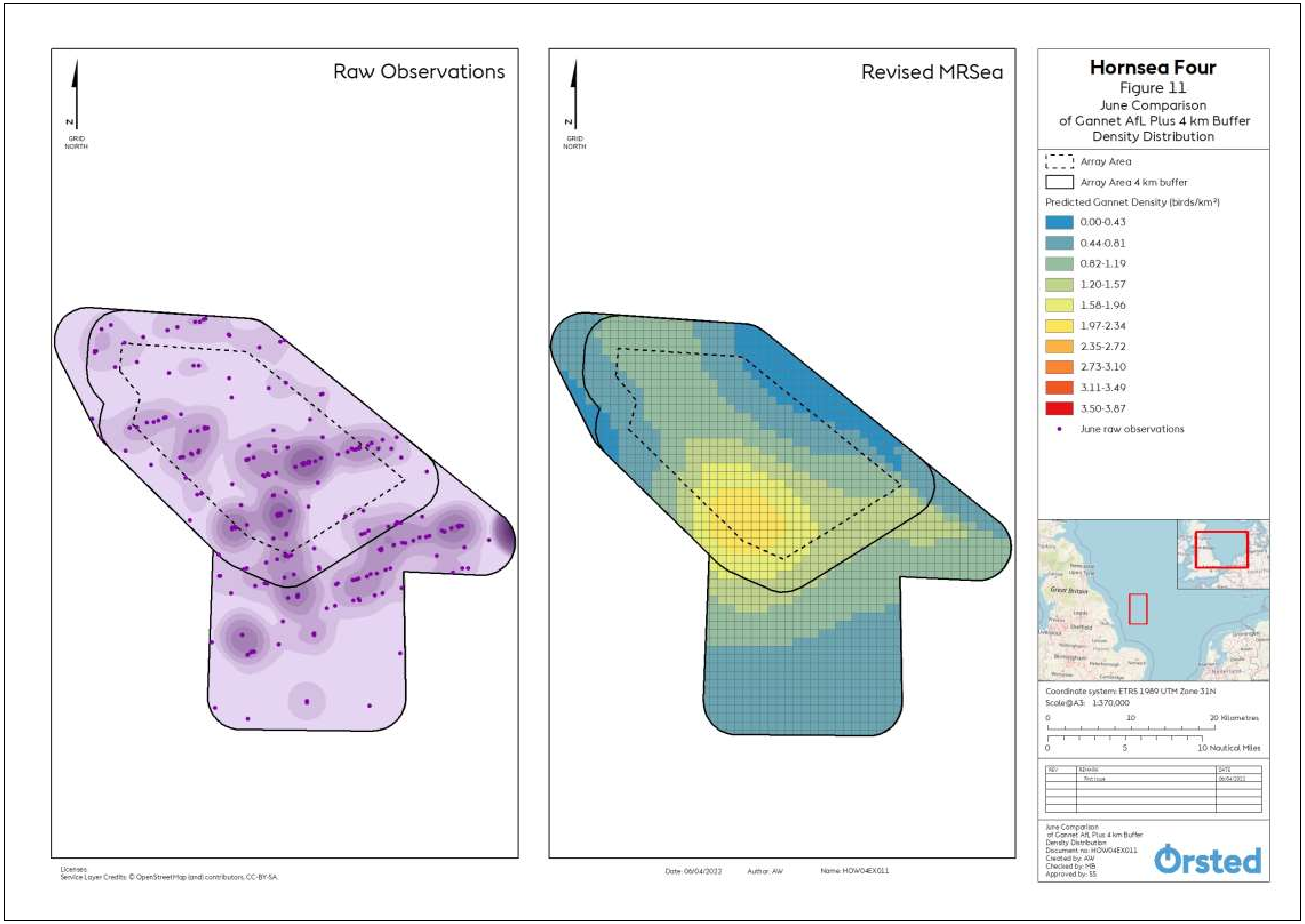

Figure 11: June comparison of gannet AfL plus 4 km buffer density distribution.

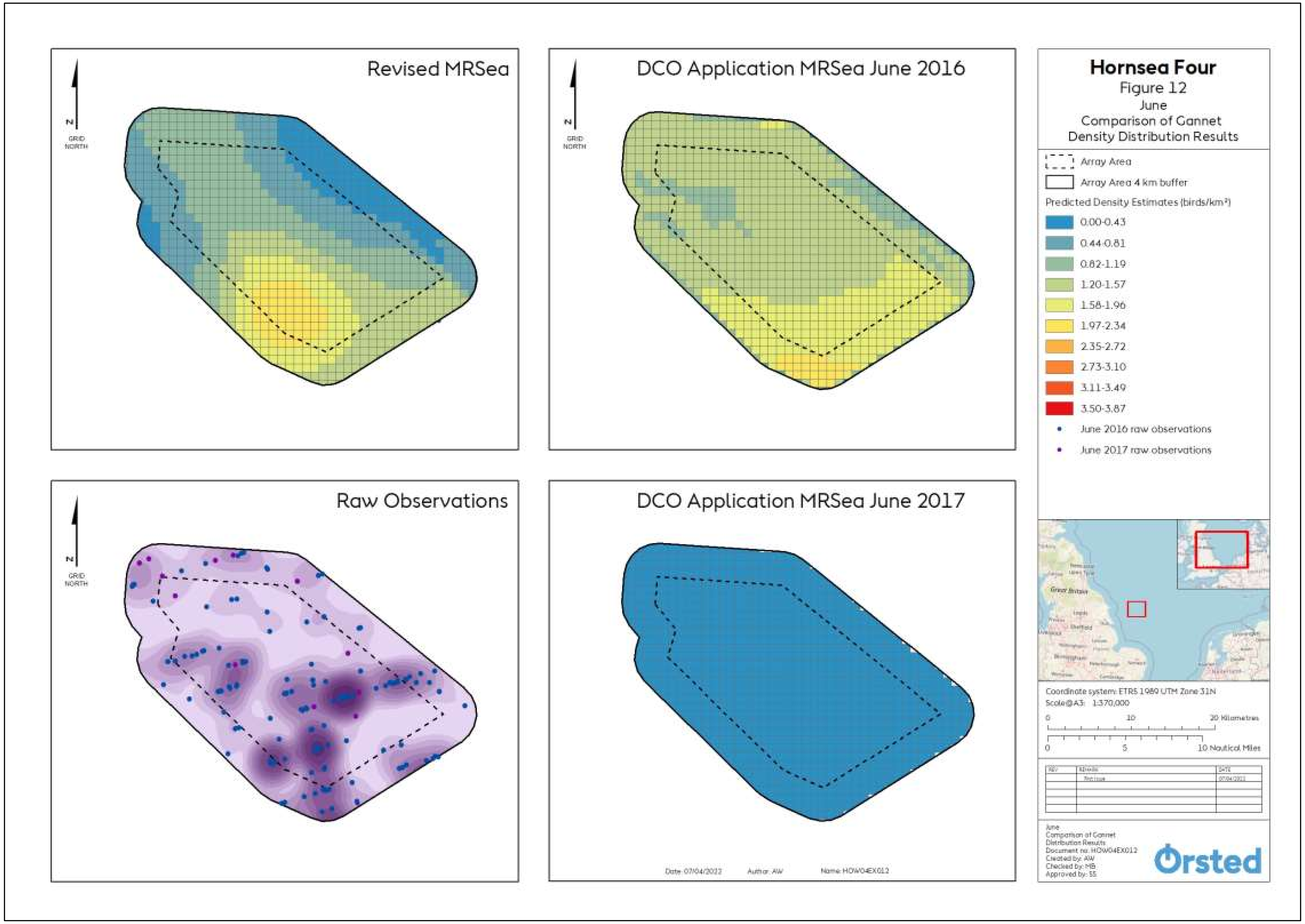

Figure 12: June comparison of gannet density distribution results

6.2.7 June Spatial Distribution Results and Comparison

6.2.7.1 As presented in **Figure 11**, raw observations in June show a distinct hotspot within the south of the array area and out to the southeast of the AfL plus 4 km buffer. This similar pattern is present within the MRSea_v2 density distribution with a clear density hotspot within the south of the array area and 4 km buffer and out to the southeast of the AfL plus 4 km buffer. Density decreases in the MRSea_v2 to the northeast and northwest of the AfL plus 4 km buffer, which correlates with areas of limited abundance in the raw observations. The density in the south of the AfL plus 4 km buffer is higher than expected considering the low number of raw observations. Overall, the spatial pattern for MRSea_v2 is similar to that of the raw observations and can, therefore, be considered a good spatial fit.

6.2.7.2 As presented in **Figure 12**, there were significantly greater observations in the June 2016 raw observations comparatively to June 2017, with the greatest abundance observed in the south and southeast of the array area. Lowest abundances were recorded in the northeast and east of the array area and 4 km buffer for June 2016. Raw observations for June 2017 were widely distributed with low numbers of gannets recorded overall. The DCO MRSea_v1 data for 2016 showed a clear pattern of increasing density towards the southeast corner or the array area 4 km buffer, which coincides with the areas of higher abundance for the 2016 raw observations. The DCO MRSea_v1 data for 2017 was of the lowest density bracket for the entire array area and 4 km buffer, which matches the low number of raw observations for June 2017. The MRSea_v2 data shows a clear increasing density gradient towards the southeast of the array area and 4 km buffer correlating with the area of highest abundance in the raw observations datasets, similar to the distribution observed in the DCO MRSea_v1 for June 2016, albeit more refined in terms of correlations with areas of low and higher abundance in the raw observations. Overall, the spatial distribution for both the MRSea_v2 and DCO MRSea_v1 datasets follow a similar spatial distribution to that of the raw observations, though both have subtle differences.

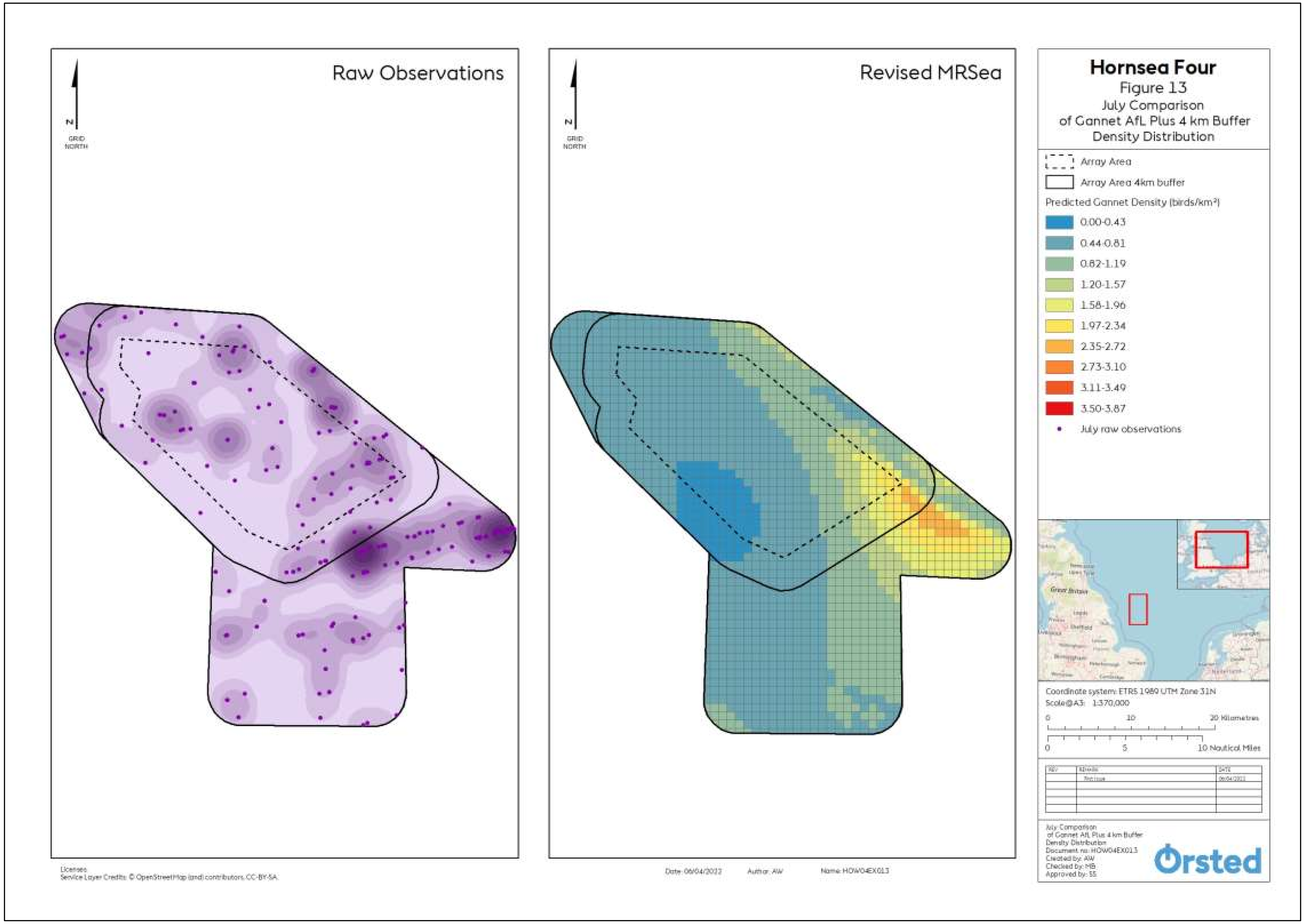

Figure 13: July comparison of gannet AfL plus 4 km buffer density distribution.

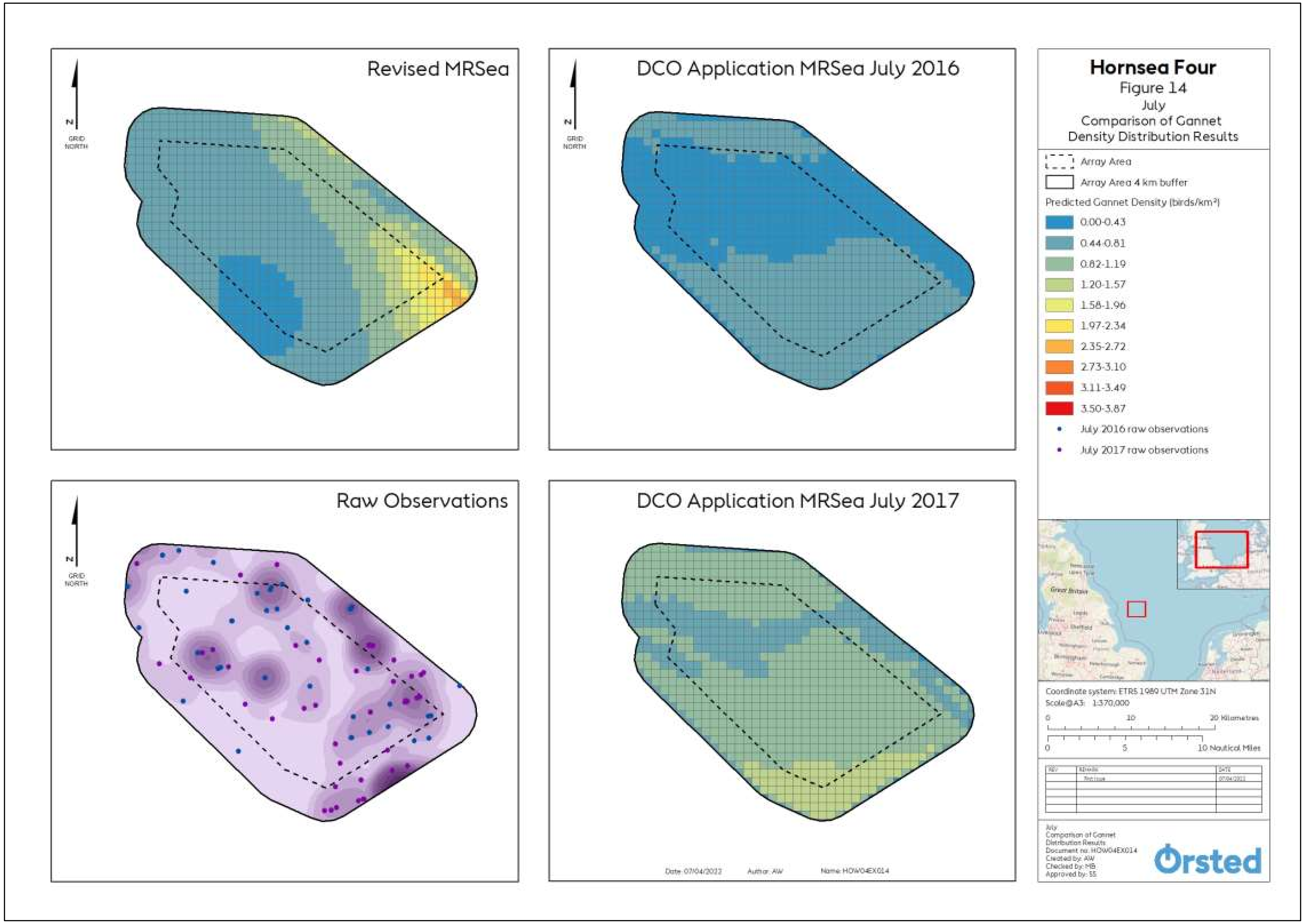

Figure 14: July comparison of gannet density distribution results

6.2.8 July Spatial Distribution Results and Comparison

6.2.8.1 As presented in **Figure 13**, raw observations in July were widely distributed across the entire AfL plus 4 km buffer, with two clear adjoining hotspots in the southwest of the AfL plus 4 km buffer. The MRSea_v2 density distribution also shows a clear pattern of higher density in the southwest corner of the AfL plus 4 km buffer, overlapping with the area adjoining the two density hotspots in the raw observation data. A reduction in density is observed to the east and southeast of the AfL, which correlates with the areas of lower abundance within the raw observations. The MRSea_v2 density distribution follows closely that of the raw observation data, therefore, the model can be considered a good fit spatially.

6.2.8.2 As presented in **Figure 14**, both years of raw observations show a similar pattern in distribution and number of raw observations. Both datasets show hotspot clusters primarily along the east to south of the array area and 4 km buffer. A large area of low abundance is observed in the southwest of the array area and 4 km buffer comparatively to the rest of the array area and 4 km buffer. The 2016 July DCO MRSea_v1 dataset shows relatively low densities across the entire array area plus 4 km buffer with slight increases in the northeast and south to southwest of the array area plus 4 km buffer. The July 2017 DCO MRSea_v1 data shows a similar pattern to that for 2016 with the areas of higher density in the northeast and southwest of the array area plus 4 km buffer. When compared to the raw observations both DCO MRSea_v1 density distributions do not fully align with the raw observations, in both years the west to southwest of the array area and 4 km buffer show increased density compared to the rest of the area, which does not fit as well with the raw observations. The MRSea_v2 density distribution has a better spatial fit with a clear area of higher density in the southeast and east of the array area plus 4 km buffer and an area of lowest abundance in the southwest of the array area plus 4 km buffer, matching the raw observations better.

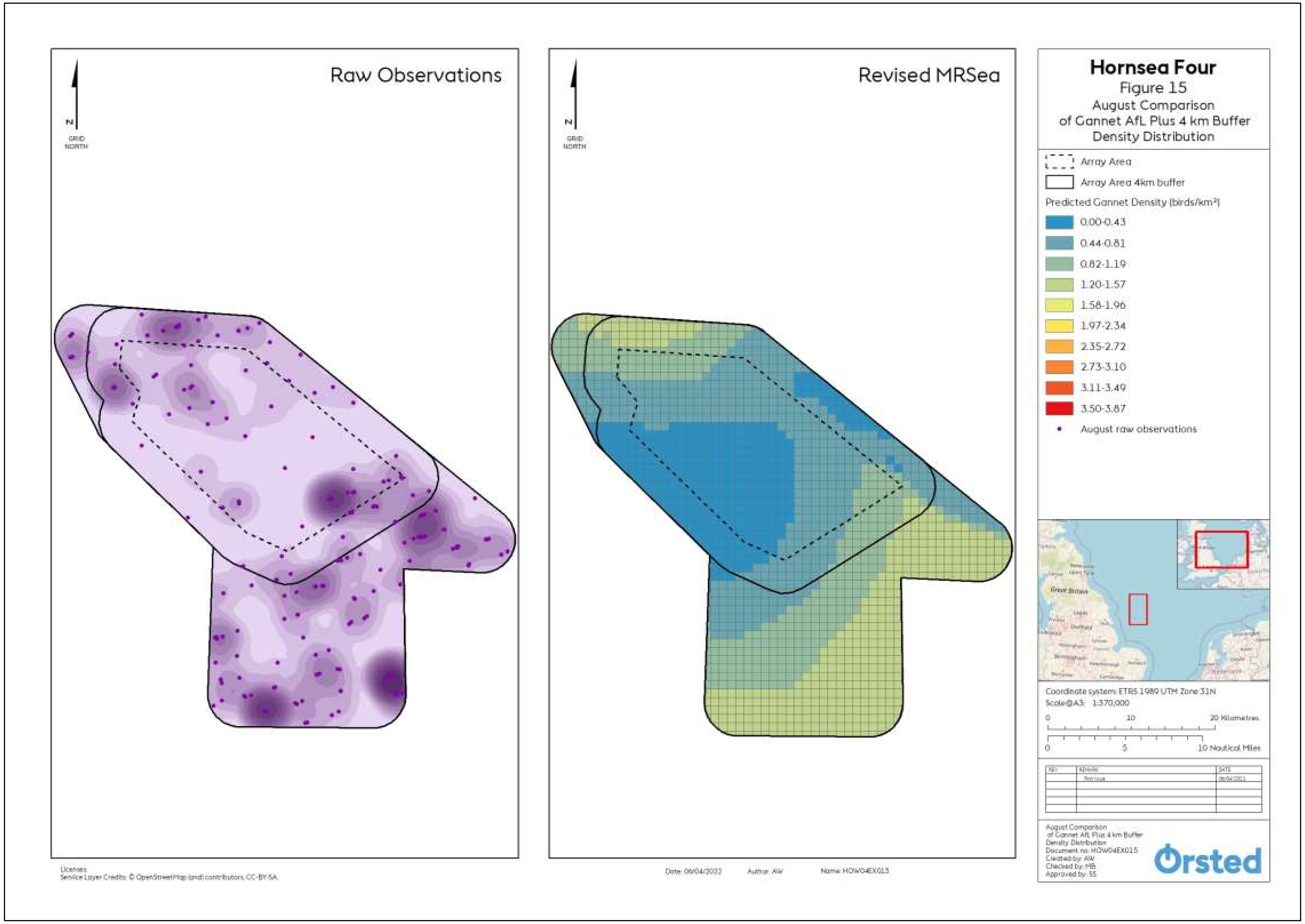

Figure 15: August comparison of gannet AfL plus 4 km buffer density distribution.

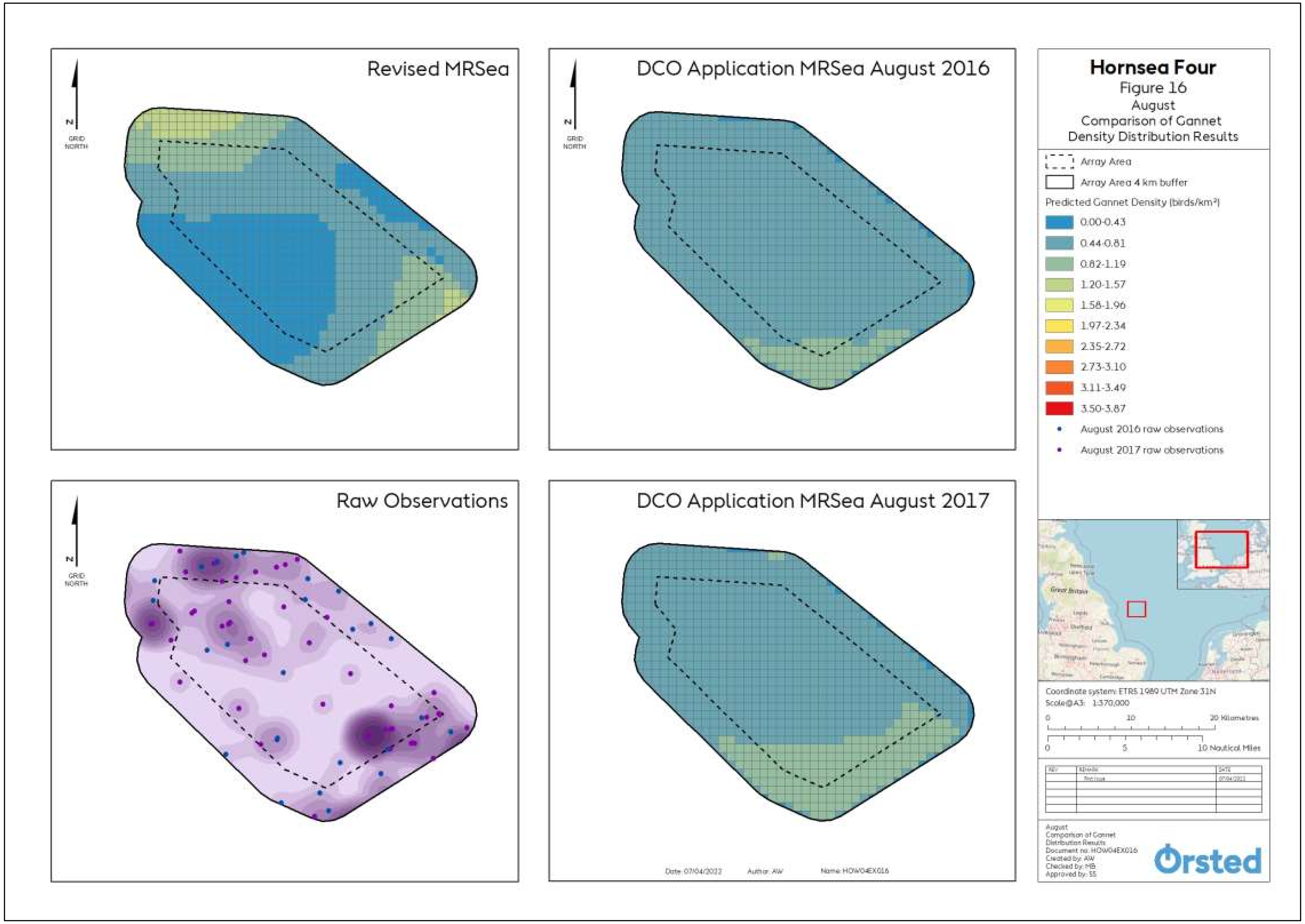

Figure 16: August comparison of gannet density distribution results

6.2.9 August Spatial Distribution Results and Comparison

6.2.9.1 As presented in **Figure 15**, raw observations in August were focused to the north, south and east of the AfL plus 4 km buffer and a distinct band of low observations running through the centre of the AfL plus 4 km buffer. The MRSea_v2 density distribution shows a similar pattern to that of the raw observations with the highest densities predicted in the north, south and east of the AfL plus 4 km buffer and lowest densities in the centre of the AfL plus 4 km buffer. As both datasets show the same spatial pattern the MRSea_v2 can be considered a good fit spatially.

6.2.9.2 As presented in **Figure 16**, the August 2016 and 2017 raw observations both have a similar distribution of observations primarily in the north and south of the array area plus 4 km buffer, with the 2017 raw observations having a greater number of observations. Both DCO MRSea_v1 datasets show the same pattern of uniform distribution, except from the southwest corner of the array area plus 4 km buffer. When compared to the raw observations, both the DCO MRSea_v1 density distributions do not fully align with the raw observations as there is no clear differentiation in density accounting for the lower number of recorded observations in the centre of the array area plus 4 km buffer in either year. The MRSea_v2 has a better spatial fit comparatively to the DCO MRSea_v1 density distributions, showing clear increases in density to the north and southeast of the array area plus 4 km buffer with a band of lower density within the centre of the array area plus 4 km buffer, which aligns with the raw observations. Based on the density distribution presented within the individual MRSea results, the MRSea_v2 can be concluded as having a better spatial fit in comparison to the 2016 and 2017 DCO MRSea_v1.

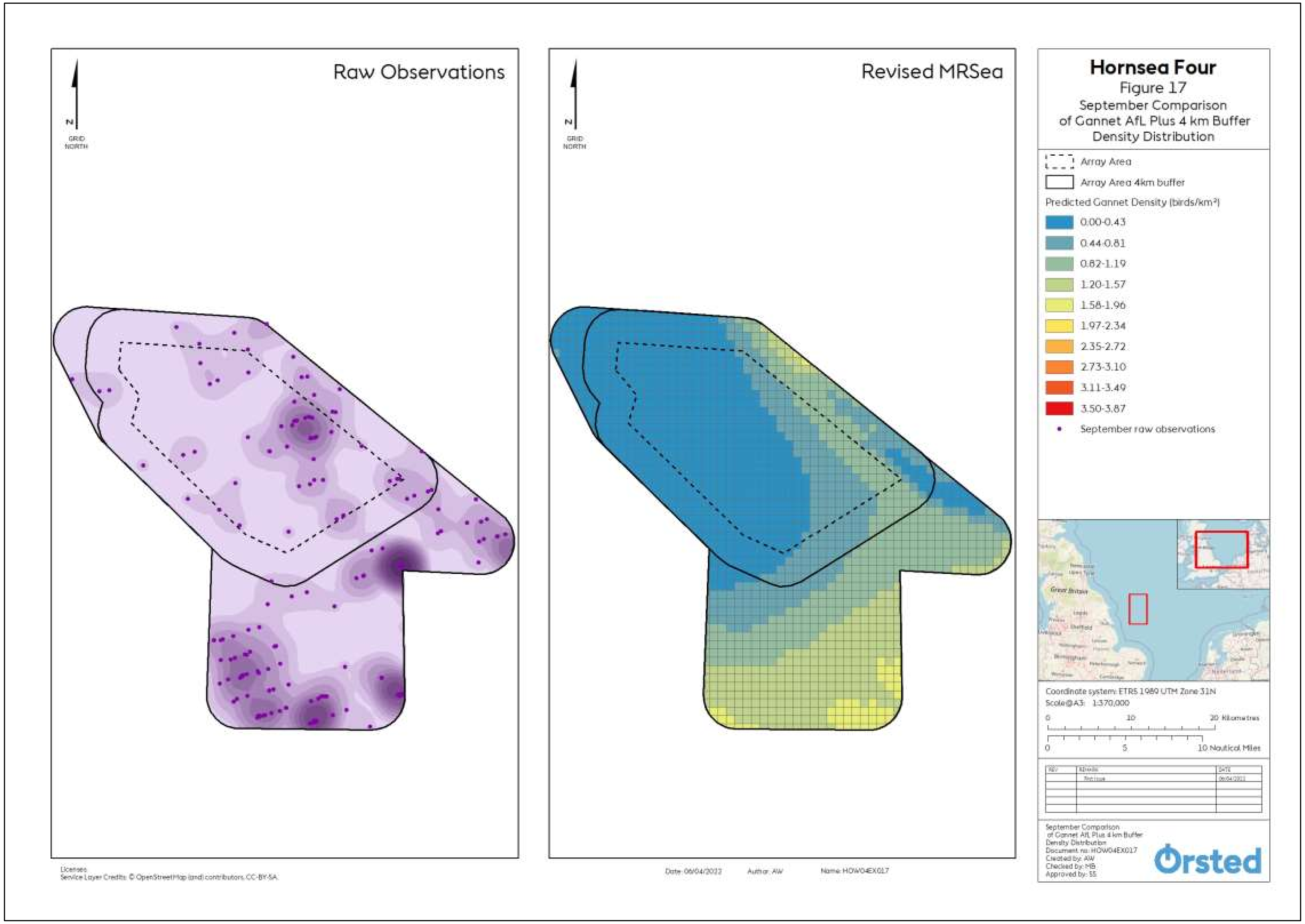

Figure 17: September comparison of gannet AfL plus 4 km buffer density distribution.

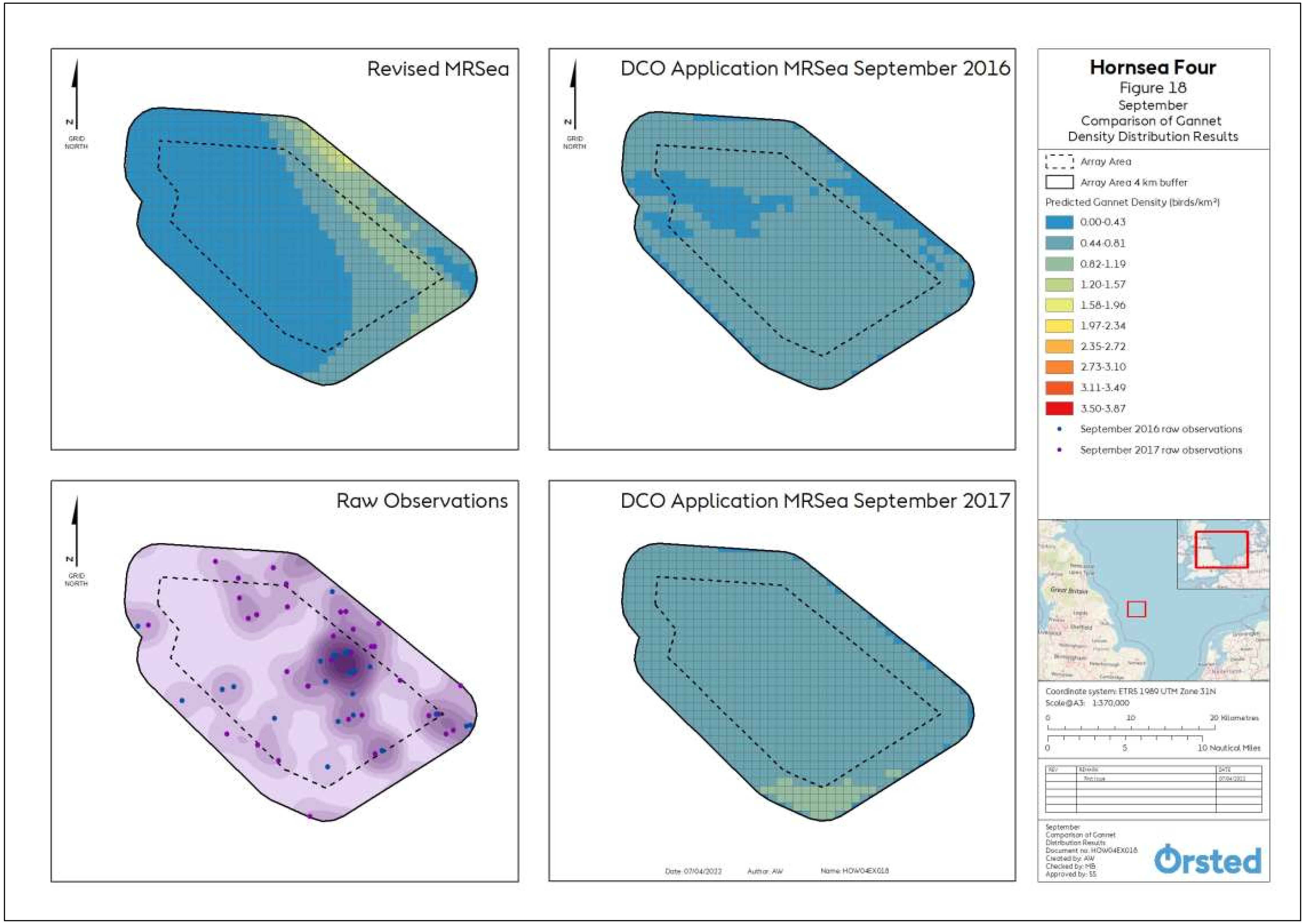

Figure 18: September comparison of gannet density distribution results

6.2.10 September Spatial Distribution Results and Comparison

6.2.10.1 As presented in **Figure 17**, raw observations in September showed a clear pattern of increased observations in the south, southeast and east side of the AfL plus 4 km buffer, with lower numbers of observations recorded in the west and northern areas of the AfL plus 4 km buffer. The MRSea_v2 density distribution shows a clear gradient of increased density in the south of the AfL plus 4 km buffer with the peak areas of density matching the location of hotspots in the south of the AfL plus 4 km buffer. Higher densities are also recorded along the eastern side of the AfL plus 4 km buffer correlating with the band of records seen in the raw observations. The remainder of the AfL plus 4km buffer (west and northern areas) are of the lowest density bracket, which matches the low number of observations in the raw data. The MRSea_v2 and raw observations both clearly show the same spatial distribution for the AfL plus 4 km buffer and can, therefore, be considered a good fit spatially.

6.2.10.2 As presented in **Figure 18**, the September 2016 raw observations were primarily within the eastern half of the array area plus 4 km buffer with a wider hotspot in the east of the array area. The September 2017 raw observations were more widely distributed throughout the array area plus 4 km buffer, although a clear increase in observations in the eastern half of the array area plus 4 km buffer is apparent. The DCO MRSea_v1 for September 2016 has relatively low density throughout the array area plus 4 km buffer with no clear hotspots in density. The September 2017 DCO MRSea_v1 also has relatively low density throughout the whole of the array area plus 4 km buffer, with a small increase in density in the southern corner of the array area 4 km buffer. Neither of the DCO MRSea_v1 density distributions show differentiation between the areas of higher observations and areas with low to no records within the array area plus 4 km buffer. The MRSea_v2 density distribution presents a better fit comparatively to the DCO MRSea_v1 datasets, showing an increase in density to the east of the array area plus 4 km buffer and the remainder of the array area plus 4 km buffer being of the lower density bracket, matching areas of low to no records in the raw observations. Based on the density distribution presented within the results, the MRSea_v2 can be concluded as having a better spatial fit in comparison to the both 2016 and 2017 DCO MRSea_v1 density distributions.

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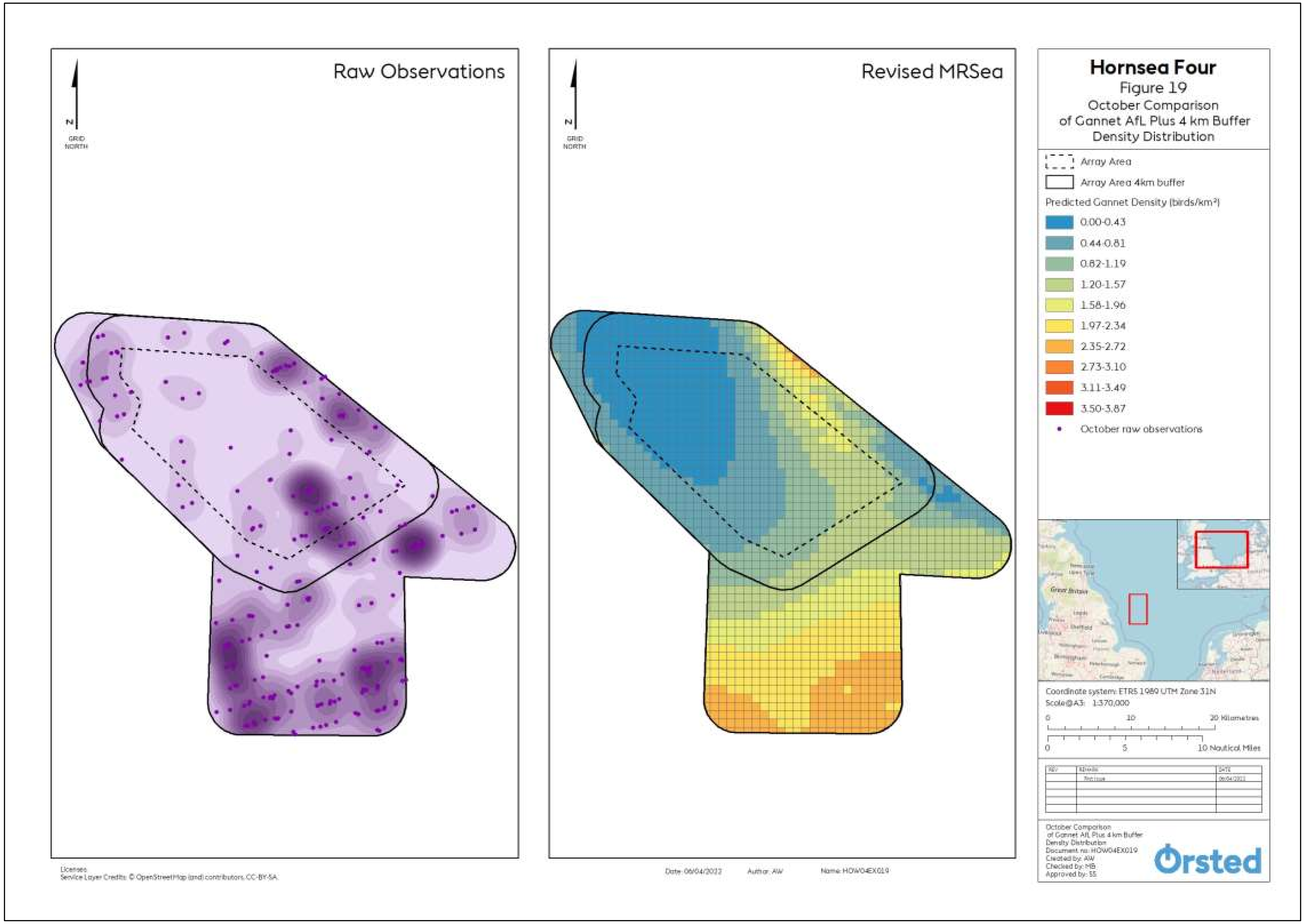

Figure 19: October comparison of gannet AfL plus 4 km buffer density distribution.

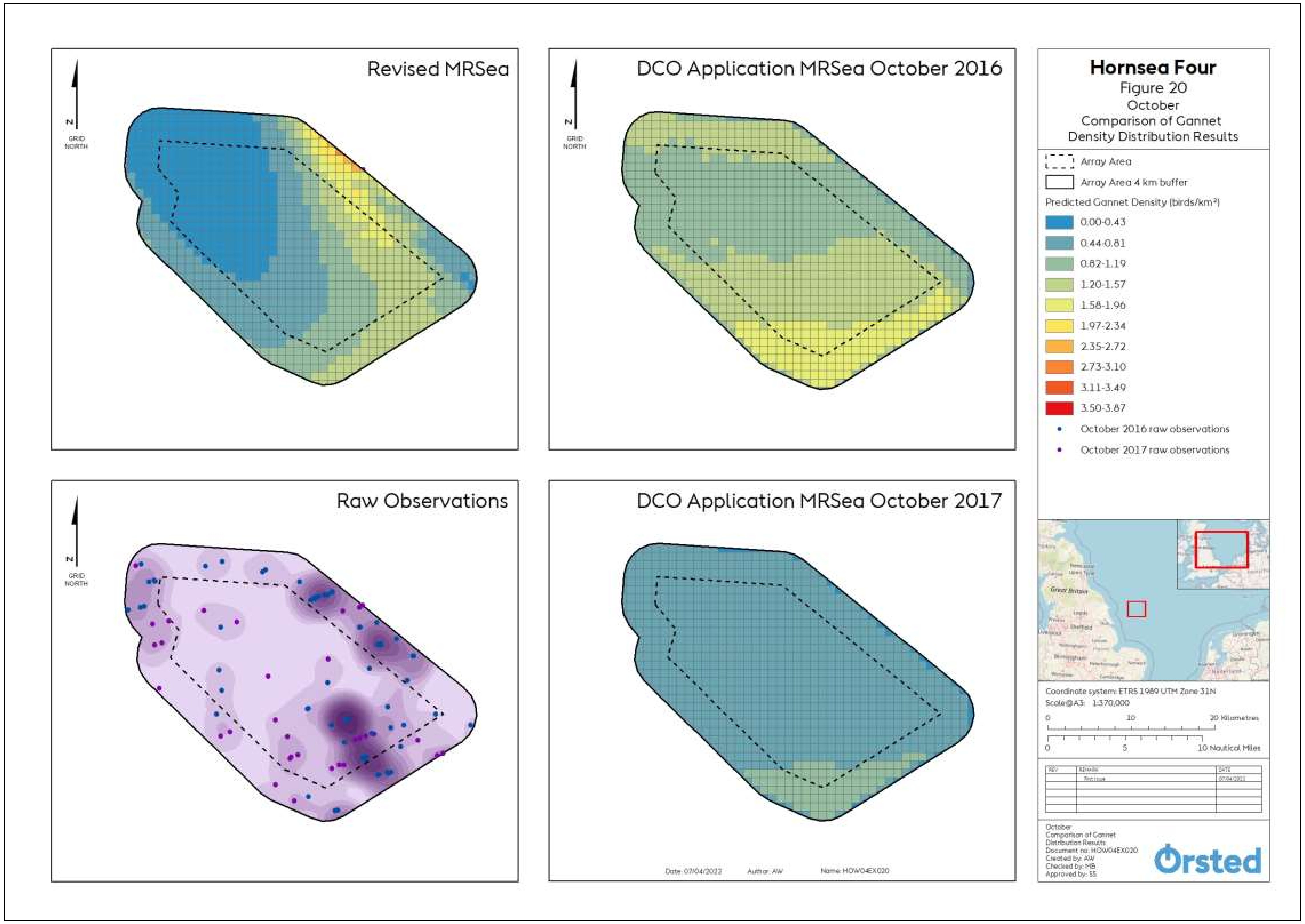

Figure 20: October comparison of gannet density distribution results

6.2.11 October Spatial Distribution Results and Comparison

6.2.11.1 As presented in **Figure 19**, raw observations in October shows a clear band of observational hotspots in the south, east and some to the northeast of the array area plus 4 km buffer. These hotspots are also mirrored in the MRSea_v2 data density distribution. An area of low observations/ density is apparent in the northern half of the AfL plus 4 km buffer in both datasets. The MRSea and raw observations both clearly show the same spatial distribution for the AfL plus 4 km buffer and can, therefore, be considered a good fit spatially.

6.2.11.2 As presented in **Figure 20**, the October 2016 raw observations showed hotspots in the south and east of the array area plus 4 km buffer, with low number of observations in the northern half of the array area. The 2017 October raw observations were more widely distributed than the 2016 data with no distinct hotspots. The 2016 DCO MRSea_v1 shows the highest density to be the southwest corner of the array area plus 4 km buffer, this is mirrored in the 2017 DCO MRSea_v1 data, albeit at a lower overall density. The 2016 DCO MRSea_v1 areas of highest density do not correlate with the hotspots recorded in the raw observation data. The MRSea_v2 areas of higher density does align with the hotspots seen in the 2016 raw observations and also the northern half of the array area, which had low records of the lowest density bracket unlike the DCO MRSea_v1 datasets. Based on the density distributions, the MRSea_v2 can be concluded as having a better spatial fit in comparison to both the 2016 and 2017 DCO MRSea_v1 model outputs.

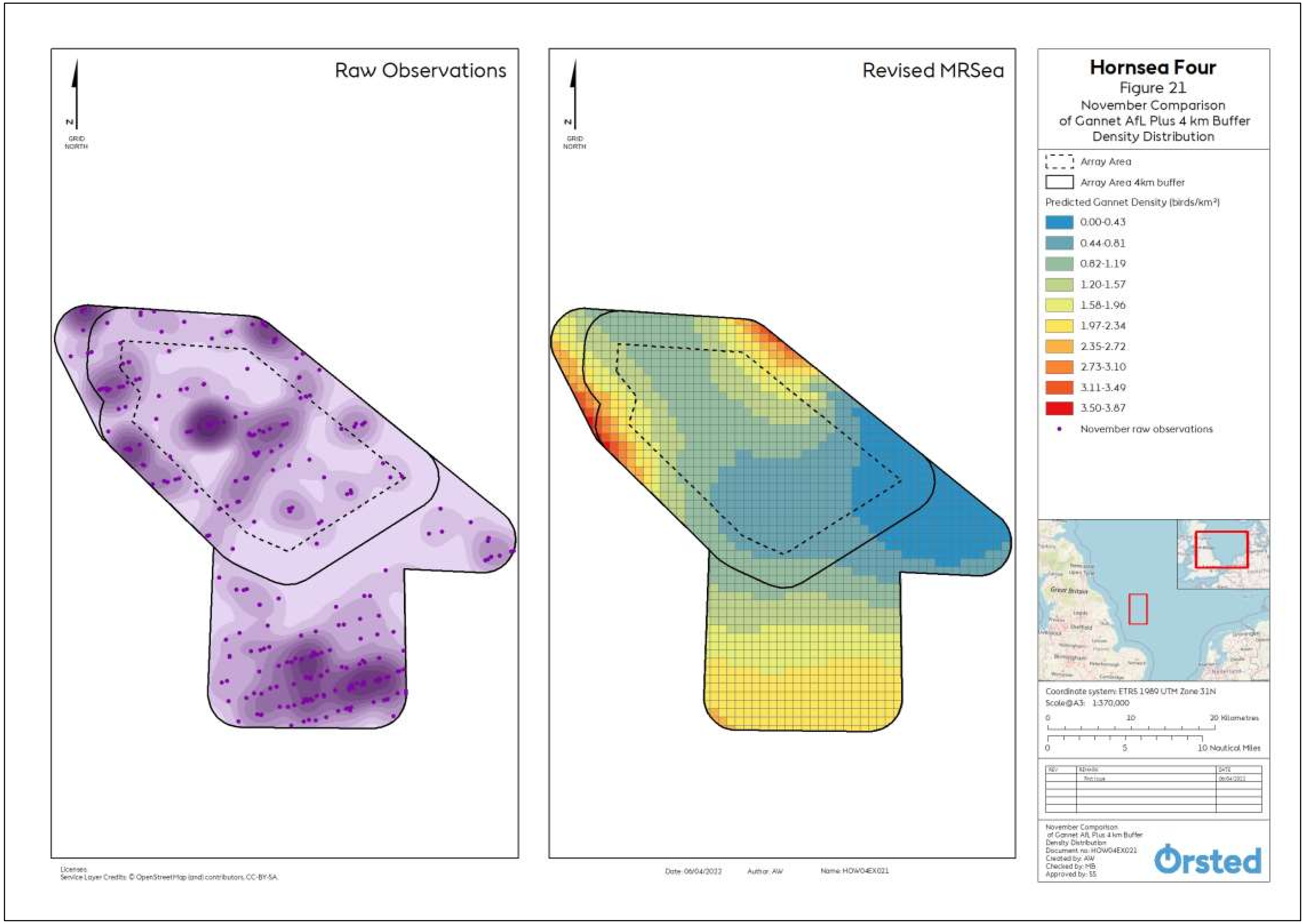

Figure 21: November comparison of gannet AfL plus 4 km buffer density distribution.

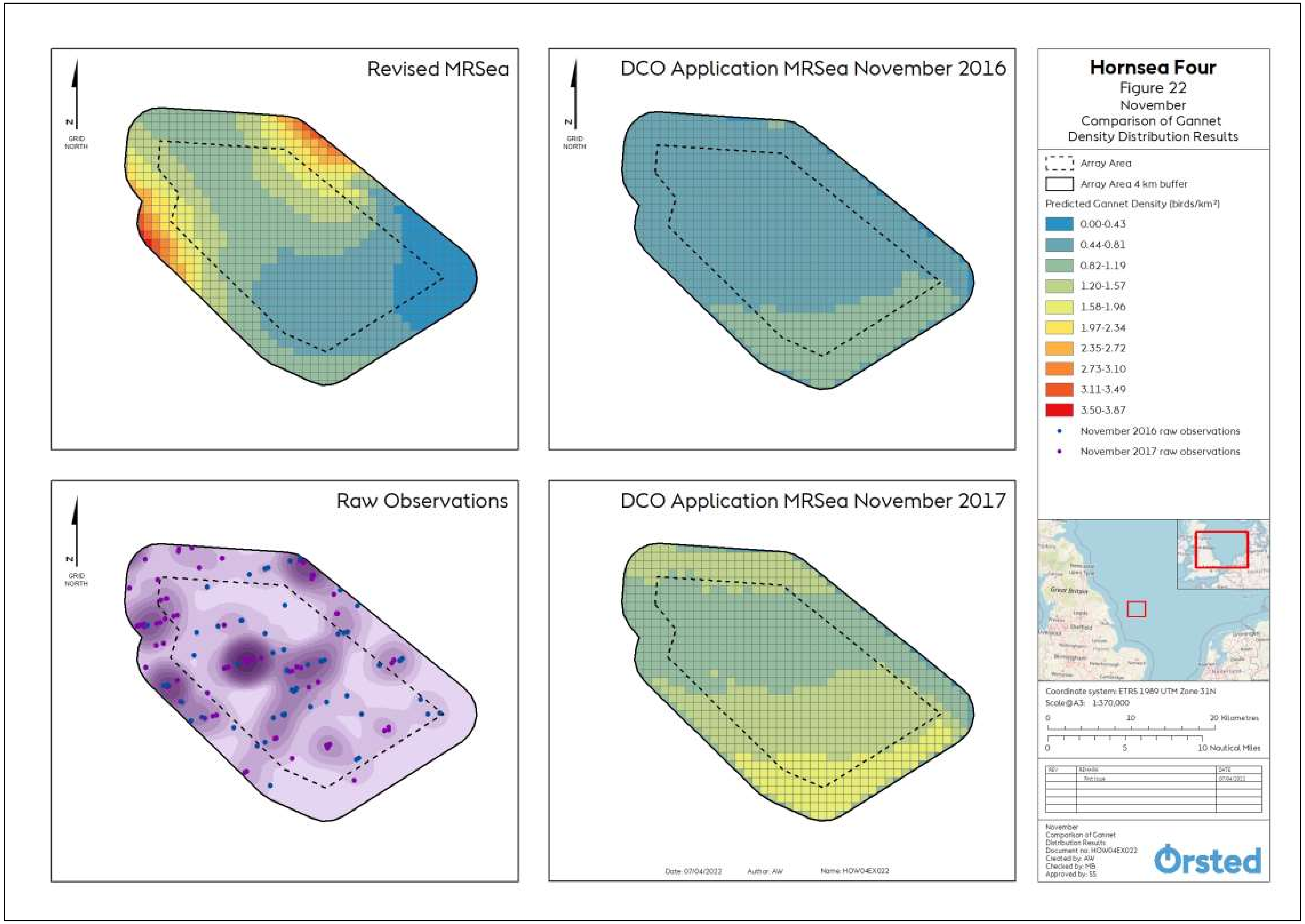

Figure 22: November comparison of gannet density distribution results

6.2.12 November Spatial Distribution Results and Comparison

6.2.12.1 As presented in **Figure 21**, raw observations in November were primarily recorded in the south as a clear hotspot and the north with several smaller hotspots within the AfL plus 4 km buffer. An area of lower abundance is apparent in the southeast comparatively to the rest of the AfL plus 4 km buffer. The MRSea_v2 areas of highest density are to the south and north of the AfL plus 4 km buffer, which generally aligns with the raw observation data noting the northern hotspot in the raw data is smoothed out. There is also a distinct reduction in density in the southeast of the AfL plus 4 km buffer, which again correlates with the area of low records in the raw observation data. The areas of both high and low density align for both the MRSea_v2 data and raw observations across the AfL plus 4 km buffer, therefore the MRSea_v2 can be considered in general to be a good fit spatially.

6.2.12.2 As presented in **Figure 22**, for both years the raw observations in November were predominantly higher in the northern half of the array area plus 4 km buffer. Within the 2016 raw observations a distinct hotspot is observed in the northwest of the array area 4 km buffer, whilst in the 2017 data hotspots are present in the northeast and northwest of the array area 4 km buffer and north of the array area. The DCO MRSea_v1 datasets both show the area of highest density to be in the south of the array area plus 4 km buffer, which is contradictory to the raw observations. There are also no apparent density hotspots within either DCO MRSea_v1 datasets, which does not align with the raw observations. The MRSea_v2 has a clear increase in density in the northern parts of the array area plus 4 km buffer comparatively to the south. There are also two distinct hotspots to the northeast and northwest, which overlap with some of the hotspots observed in the raw observation datasets. Based on the density distributions, the MRSea_v2 can be concluded as having a better spatial fit in comparison to the both 2016 and 2017 DCO MRSea_v1 datasets.

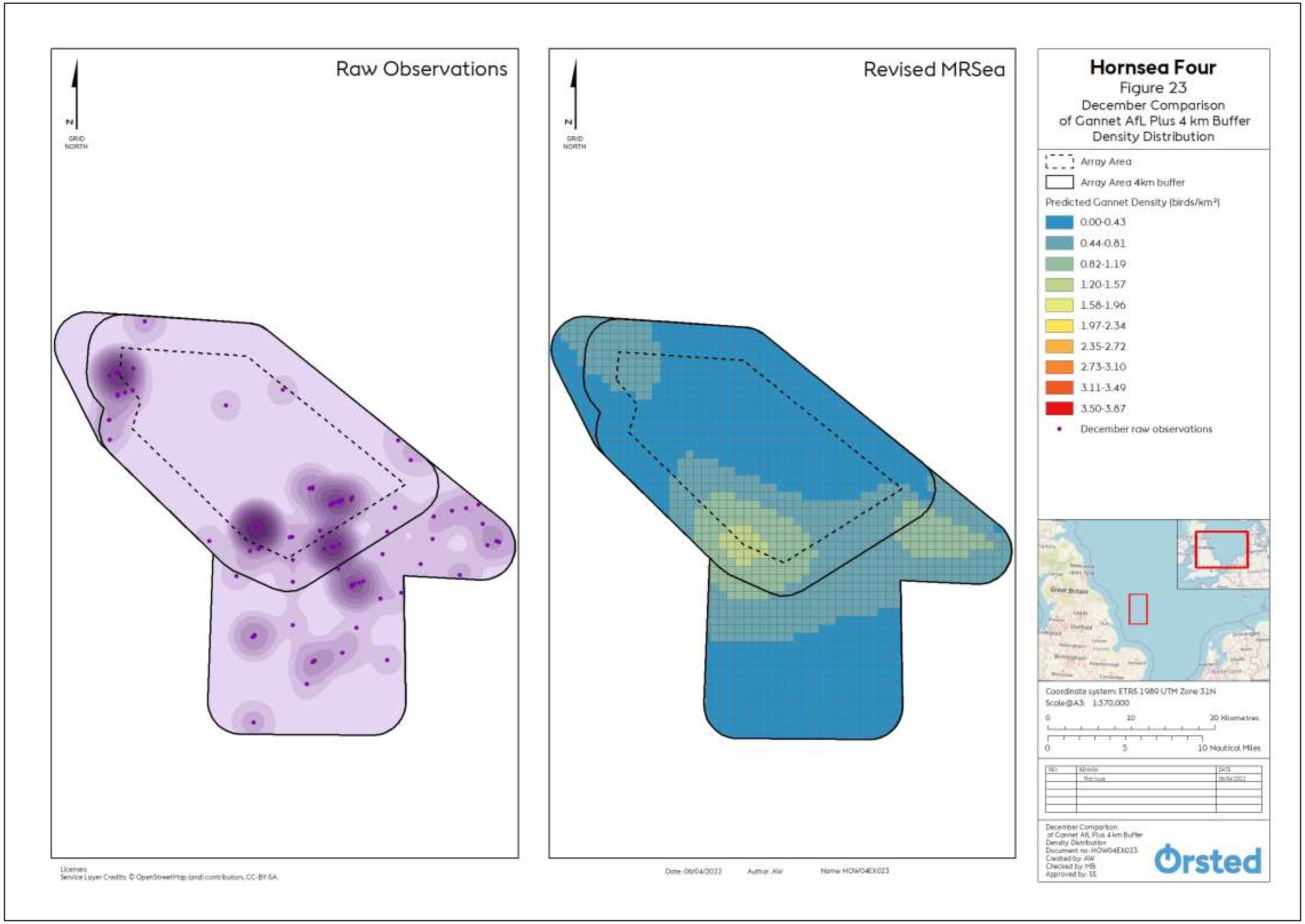

Figure 23: December comparison of gannet AfL plus 4 km buffer density distribution.

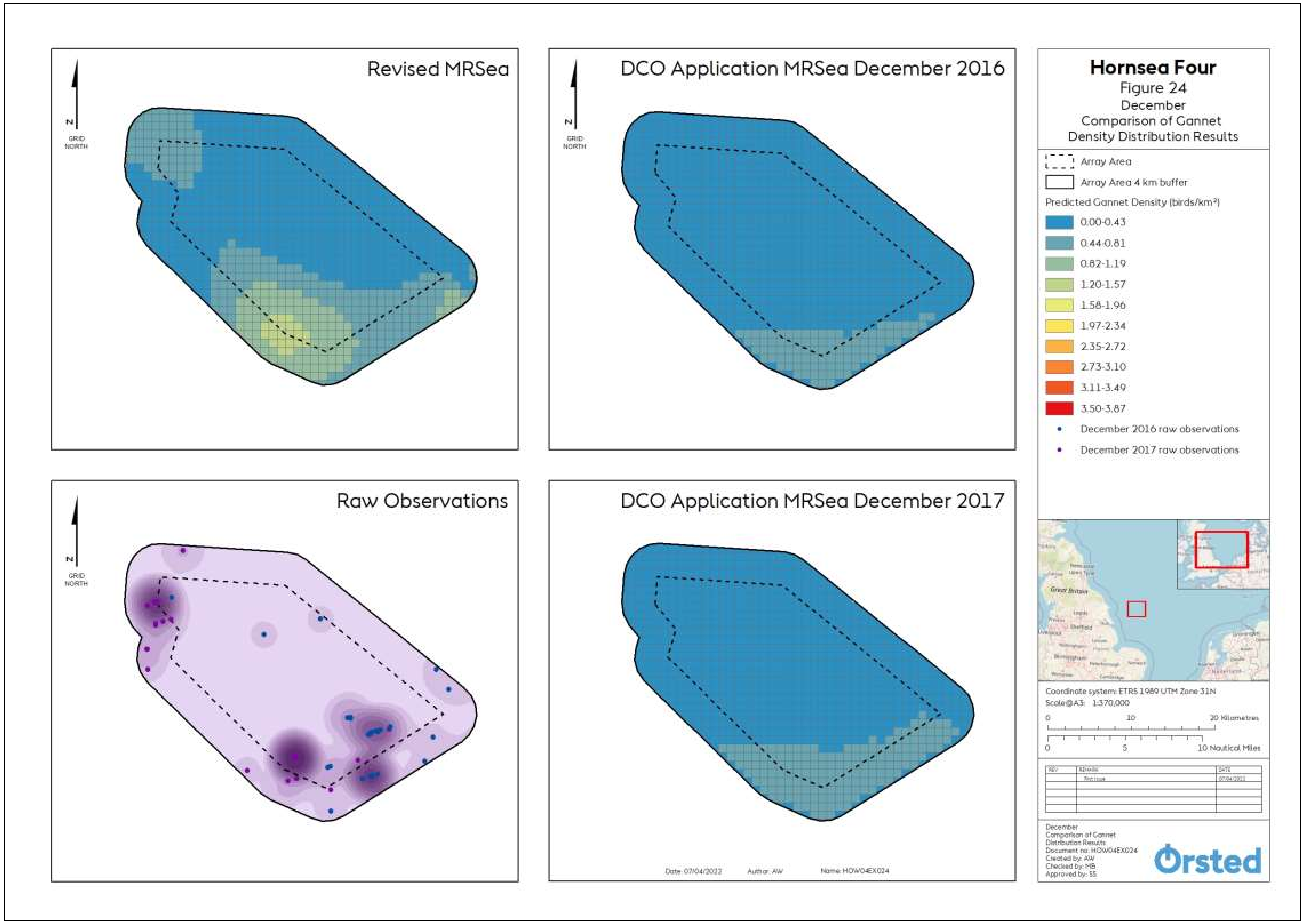

Figure 24: December comparison of gannet density distribution results.

6.2.13 December Spatial Distribution Results and Comparison

6.2.13.1 As presented in **Figure 23**, the raw observations in December showed a large hotspot of observations in the south of the array area plus 4 km buffer and a smaller hotpsot in the north of the array area 4 km buffer. For the remainder of the AfL plus 4 km buffer records were low, especially in the northern half of the AfL plus 4 km buffer. The MRSea_v2 density distribution shows a clear hotspot in the south of the array area plus 4 km buffer encompassing the large hotspot of records observed in the raw data. There is also a slight increase in the northwest of the AfL plus 4 km buffer, which correlates with other areas of higher density comparatively to the rest of the AfL plus 4 km buffer. The areas of both high and low density align for both the MRSea_v2 data and raw observations across the AfL plus 4 km buffer, therefore, the MRSea_v2 can be considered a good fit spatially.

6.2.13.2 As presented in **Figure 24**, the raw observations in December 2016 were primarily recorded in the south of the array area plus 4 km buffer only, with a clear hotspot present. The 2017 raw observations were only recorded in two clusters only, located in the north and southwest of the array area plus 4 km buffer. For both raw observation datasets the majority of the array area plus 4 km buffer had very low to no records in December. The 2016 DCO MRSea_v1 density distribution shows the majority of the array area plus 4 km buffer to be of the lowest of density bracket which aligns with the raw observations. There is a slight increase in density in the southwest corner of the array area plus 4 km buffer, but not quite aligning with the hotspot present in the raw observations. Similarly, the 2017 density distribution is of the lowest density bracket with the exception of the southwest of the array area plus 4 km buffer, which does overlap with one of the hotspots observed in the 2017 raw observations. However, there is no increase in density in the north of the array area plus 4 km buffer where another hotspot is present in the 2017 raw observations. For the MRSea_v2 the density distribution within the array area plus 4 km buffer is primarily of the lowest density bracket, except for increases in the north and south of the array area plus 4 km buffer overlapping with the hotspots in both years of raw observation data. Based on the density distribution, the MRSea_v2 can be concluded as having a better spatial fit in comparison to the 2016 and 2017 DCO MRSea_v1 datasets.

6.3 Summary of the Spatial Distribution Results

6.3.1.1 The density distribution results for the AfL plus 4 km buffer MRSea_v2 results in **Section 6.2** for all of the 12 months show clear similarities in the density distributional patterns observed in the raw observation datasets and the MRSea_v2. Due to the clear similarities between both datasets, the MRSea_v2 for all 12 months was concluded as having a good fit spatially.

6.3.1.2 When the MRSea_v2 results are compared with the DCO MRSea_v1 density distributions, it is clear for all 12 months that the remodeling has improved the spatial fit of these data, especially in months with distinct raw observation hotspots (**Figure 11** & **Figure 21**), which appear to not affect the overall spatial distribution in the DCO MRSea_v1 datasets.

6.3.1.3 In summary it can be concluded, based on the comparisons above for all of the 12 months provided from the MRSea_v2, that the model is a good spatial fit with clear monthly spatial variation matching the raw observational datasets.

7 Part 3 - Comparison of DCO Application and MRSea_v2 Results

7.1.1.1 The design-based and DCO application MRSea abundance estimate results for the full 24 months of site specific surveys are presented in **Appendix B** as both monthly and seasonal estimates for the array area, array area plus 2 km buffer and array area plus 4 km buffer. Due to the MRSea_v2 results being presented as results for each calendar month instead of each survey, the simplest method for comparison is to consider both the total abundance and seasonal abundance for each of the different datasets. The total and seasonal abundances therefore are presented in **Table 5** comparing the design-based and MRSea_v2 abundance estimates and **Table 6** comparing the DCO and MRSea_v2 abundance estimates. However, it should be noted that it is not a valid approach to directly compare design-based estimates with modelled outputs, as they are fundamentally different approaches and the purpose of this exercise was to review the MRSea model fit, whilst providing design-based estimates should the modelled outputs remain an unsatisfactory outcome with Natural England.

7.1.1.2 When considering the two MRSea total abundance estimates and bio-season abundances it is apparent that where abundances are higher there is less variation between the two datasets, whilst there is greater variation where abundances are estimated to be lower. However, there is limited variation in the total values when considering all bio-seasons combined (6%; **Table 6**) for gannets within the array area and 2 km buffer. It is also noted that the overall outcome from the MRSea_v2 modelling approach is that the central estimates MRSea_v2 are typically slightly lower in value, whilst they have wider confidence limits in general, which is a reflection of two years of data providing inter-annual variation as well as other uncertainties being considered and included in the model. However, this is not specifically a limitation as the comparisons presented above suggest the data from the MRSea_v2 spatially fit better than those presented in the DCO MRSea_v1 results and also provide greater confidence in the spatial distribution and associated abundance estimates in comparison to the more simplistic design-based estimates.

Table 5: Comparison between the design-based and MRSea_v2 predicted abundance estimates.

Hornsea Four Array Area

Season	Estimate	Design-based Abundance			MRSea_v2			Difference (%)		
		All behaviours	Flying	Sitting	All behaviours	Flying	Sitting	All behaviours	Flying	Sitting
Return Migration	**Central**	**244.5**	**95.0**	**175.0**	**179.9**	**73.9**	**171.3**	**64.6 (26%)**	**21.1 (22%)**	**3.7 (2%)**
	Lower CI	41.5	24.5	5.0	70.0	32.5	57.4	-28.5 (-69%)	-8 (-33%)	-52.4 (-1048%)
	Upper CI	519.5	199.0	422.5	580.7	170.0	553.0	-61.2 (-12%)	29 (15%)	-130.5 (-31%)
Migration-free breeding	**Central**	**708.5**	**364.0**	**349.5**	**555.1**	**370.1**	**185.0**	**153.4 (22%)**	**-6.1 (-2%)**	**164.5 (47%)**
	Lower CI	293.5	150.0	112.0	306.8	204.5	102.3	-13.3 (-5%)	-54.5 (-36%)	9.7 (9%)
	Upper CI	1,033.5	525.0	528.5	1,029.4	686.3	564.2	4.1 (0%)	-161.3 (-31%)	-35.7 (-7%)
Post-breeding migration	**Central**	**529.5**	**280.0**	**330.0**	**449.3**	**240.1**	**209.1**	**80.2 (15%)**	**39.9 (14%)**	**120.9 (37%)**
	Lower CI	232.0	107.5	64.5	247.1	132.1	115.0	-15.1 (-7%)	-24.6 (-23%)	-50.5 (-78%)
	Upper CI	1,115.5	612.5	615.5	836.0	446.8	394.7	279.5 (25%)	165.7 (27%)	220.8 (36%)
Annual	**Central**	**1,482.5**	**739.0**	**854.5**	**1,184.2**	**684.0**	**565.5**	**298.3 (20%)**	**55 (7%)**	**289 (34%)**
	Lower CI	567.0	282.0	181.5	623.9	369.1	274.7	-56.9 (-10%)	-87.1 (-31%)	-93.2 (-51%)
	Upper CI	2,668.5	1,336.5	1,566.5	2,446.1	1,303.1	1,512.0	222.4 (8%)	33.4 (2%)	54.5 (3%)
Total*	**Central**	**5,547.0**	**2,760.0**	**2,791.0**	**5,143.0**	**2,785.2**	**2,357.8**	**404 (7%)**	**-25.2 (-1%)**	**433.2 (16%)**
	Lower CI	1,996.0	941.0	592.0	2,604.9	1,429.0	1,175.9	-608.9 (-31%)	-488 (-52%)	-583.9 (-99%)
	Upper CI	9,907.0	5,336.0	5,342.0	11,666.2	6,051.6	5,614.6	-1,759.2 (-18%)	-715.6 (-13%)	-272.6 (-5%)

Hornsea Four Array Area plus 2 km buffer

Season	Estimate	Design-based Abundance			MRSea_v2			Difference (%)		
		All behaviours	Flying	Sitting	All behaviours	Flying	Sitting	All behaviours	Flying	Sitting
Return Migration	**Central**	**395.0**	**174.5**	**270.5**	**270.6**	**102.2**	**238.4**	**124.4 (31%)**	**72.3 (41%)**	**32.1 (12%)**
	Lower CI	88.0	48.0	19.5	92.3	43.0	81.3	-4.3 (-5%)	5 (10%)	-61.8 (-317%)
	Upper CI	1,097.0	516.0	589.5	899.9	251.4	792.7	197.1 (18%)	264.6 (51%)	-203.2 (-34%)
Migration-free breeding	**Central**	**1,011.0**	**490.5**	**520.5**	**742.7**	**594.2**	**158.4**	**268.3 (27%)**	**-103.7 (-21%)**	**362.1 (70%)**
	Lower CI	551.0	276.5	182.0	401.8	321.5	80.5	149.2 (27%)	-45 (-16%)	101.5 (56%)
	Upper CI	1,492.0	704.5	906.0	1,418.9	1,135.1	1,050.3	73.1 (5%)	-430.6 (-61%)	-144.3 (-16%)
Post-breeding migration	**Central**	**790.0**	**340.0**	**525.0**	**667.4**	**343.0**	**339.9**	**122.6 (16%)**	**-3 (-1%)**	**185.1 (35%)**
	Lower CI	433.0	155.5	259.5	359.8	184.9	175.5	73.2 (17%)	-29.4 (-19%)	84 (32%)
	Upper CI	1,242.0	531.5	804.0	1,265.2	650.2	677.3	-23.2 (-2%)	-118.7 (-22%)	126.7 (16%)
Annual	**Central**	**2,196.0**	**1,005.0**	**1,316.0**	**1,680.7**	**1,039.4**	**736.6**	**515.3 (23%)**	**-34.4 (-3%)**	**579.4 (44%)**
	Lower CI	1,072.0	480.0	461.0	853.9	549.4	337.3	218.1 (20%)	-69.4 (-14%)	123.7 (27%)
	Upper CI	3,831.0	1,752.0	2,299.5	3,584.0	2,036.8	2,520.3	247 (6%)	-284.8 (-16%)	-220.8 (-10%)
Total*	**Central**	**8,191.0**	**3,940.0**	**4,252.0**	**7,565.1**	**4,034.2**	**3,531.0**	**625.9 (8%)**	**-94.2 (-2%)**	**721 (17%)**
	Lower CI	3,808.0	1,771.0	1,326.0	3,726.1	2,021.9	1,704.2	81.9 (2%)	-250.9 (-14%)	-378.2 (-29%)
	Upper CI	14,337.0	7,092.0	8,181.0	18,214.3	9,217.3	8,997.0	-3,877.3 (-27%)	-2,125.3 (-30%)	-816 (-10%)

Hornsea Four Array Area plus 4 km buffer

Season	Estimate	Design-based Abundance			MRSea_v2			Difference (%)		
		All behaviours	Flying	Sitting	All behaviours	Flying	Sitting	All behaviours	Flying	Sitting
Return Migration	**Central**	**449.5**	**223.5**	**329.5**	**366.2**	**106.8**	**320.5**	**83.3 (19%)**	**116.7 (52%)**	**9 (3%)**
	Lower CI	126.5	67.0	47.0	129.3	43.0	113.1	-2.8 (-2%)	24 (36%)	-66.1 (-141%)
	Upper CI	929.5	486.5	674.5	1,224.7	283.9	1,071.6	-295.2 (-32%)	202.6 (42%)	-397.1 (-59%)
Migration-free breeding	**Central**	**1,219.0**	**619.5**	**599.5**	**927.0**	**695.2**	**231.7**	**292 (24%)**	**-75.7 (-12%)**	**367.8 (61%)**
	Lower CI	732.0	389.5	237.0	493.9	370.4	123.5	238.1 (33%)	19.1 (5%)	113.5 (48%)
	Upper CI	1,760.5	998.0	982.5	2,208.9	1,361.2	1,893.4	-448.4 (-25%)	-363.2 (-36%)	-910.9 (-93%)
Post-breeding migration	**Central**	**1,200.5**	**514.0**	**751.5**	**946.9**	**492.4**	**464.0**	**253.6 (21%)**	**21.6 (4%)**	**287.5 (38%)**
	Lower CI	645.5	235.0	371.5	498.8	259.4	239.4	146.7 (23%)	-24.4 (-10%)	132.1 (36%)
	Upper CI	1,811.5	791.5	1,114.5	1,841.0	957.3	971.9	-29.5 (-2%)	-165.8 (-21%)	142.6 (13%)

Annual	**Central**	**2,869.0**	**1,357.0**	**1,680.5**	**2,240.1**	**1,294.4**	**1,016.2**	**628.9 (22%)**	**62.6 (5%)**	**664.3 (40%)**
	Lower CI	1,504.0	691.5	655.5	1,121.9	672.7	476.0	382.1 (25%)	18.8 (3%)	179.5 (27%)
	Upper CI	4,501.5	2,276.0	2,771.5	5,274.6	2,602.4	3,936.9	-773.1 (-17%)	-326.4 (-14%)	-1,165.4 (-42%)
Total*	**Central**	**10,893.0**	**5,359.0**	**5,533.0**	**10,418.5**	**5,501.2**	**4,917.3**	**474.5 (4%)**	**-142.2 (-3%)**	**615.7 (11%)**
	Lower CI	5,402.0	2,615.0	1,961.0	4,996.7	2,691.6	2,305.1	405.3 (8%)	-76.6 (-3%)	-344.1 (-18%)
	Upper CI	17,610.0	9,378.0	9,496.0	26,649.3	13,179.5	13,469.8	-9,039.3 (-51%)	-3,801.5 (-41%)	-3,973.8 (-42%)

Table Note: *Total equates to the sum of all the monthly abundance estimates, which are presented in Table 8 for the design-based abundance estimates and Table 3 for the MRSea_v2 abundance estimates (MRSea_v2 total value multiplied by two due to being only 12 months of data vs 24 months for the design-based) .

Table 6: Comparison between the DCO MRSea_v1 and MRSea_v2 predicted abundance estimates.

Hornsea Four Array Area										
Season	**Estimate**	**DCO MRSea_v1**			**MRSea_v2**			**Difference (%)**		
		All behaviours	**Flying**	**Sitting**	**All behaviours**	**Flying**	**Sitting**	**All behaviours**	**Flying**	**Sitting**
Return Migration	**Central**	**163.3**	**119.5**	**108.6**	**179.9**	**73.9**	**171.3**	**-16.6 (-10%)**	**45.6 (38%)**	**-62.7 (-58%)**
	Lower CI	75.9	55.0	48.4	70.0	32.5	57.4	5.9 (8%)	22.5 (41%)	-9 (-19%)
	Upper CI	321.6	256.6	243.5	580.7	170.0	553.0	-259.1 (-81%)	86.6 (34%)	-309.5 (-127%)
Migration-free breeding	**Central**	**548.7**	**278.0**	**298.4**	**555.1**	**370.1**	**185.0**	**-6.4 (-1%)**	**-92.1 (-33%)**	**113.4 (38%)**
	Lower CI	346.7	179.8	184.6	306.8	204.5	102.3	39.9 (12%)	-24.7 (-14%)	82.3 (45%)
	Upper CI	860.5	452.5	537.2	1,029.4	686.3	564.2	-168.9 (-20%)	-233.8 (-52%)	-27 (-5%)
Post-breeding migration	**Central**	**592.9**	**249.1**	**378.9**	**449.3**	**240.1**	**209.1**	**143.6 (24%)**	**9 (4%)**	**169.8 (45%)**
	Lower CI	385.1	155.4	253.4	247.1	132.1	115.0	138 (36%)	23.3 (15%)	138.4 (55%)
	Upper CI	897.5	406.4	554.5	836.0	446.8	394.7	61.5 (7%)	-40.4 (-10%)	159.8 (29%)
Annual	**Central**	**1,304.9**	**646.5**	**785.9**	**1,184.2**	**684.0**	**565.5**	**120.7 (9%)**	**-37.5 (-6%)**	**220.4 (28%)**
	Lower CI	807.7	390.2	486.3	623.9	369.1	274.7	183.8 (23%)	21.1 (5%)	211.6 (44%)
	Upper CI	2,079.6	1,115.5	1,335.2	2,446.1	1,303.1	1,512.0	-366.5 (-18%)	-187.6 (-17%)	-176.8 (-13%)
Total	**Central**	**5,884.4**	**3,059.4**	**2,825.0**	**5,143.0**	**2,785.2**	**2,357.8**	**741.3 (13%)**	**274.1 (9%)**	**467.2 (17%)**
	Lower CI	3,596.3	1,839.1	4,187.2	2,604.9	1,429.0	1,175.9	991.4 (28%)	410.1 (22%)	3,011.4 (72%)
	Upper CI	10,100.7	5,330.7	5,528.7	11,666.2	6,051.6	5,614.6	-1,565.5 (-15%)	-721 (-14%)	-85.9 (-2%)
Hornsea Four Array Area plus 2 km buffer										
Season	**Estimate**	**DCO MRSea_v1**			**MRSea_v2**			**Difference (%)**		
		All behaviours	**Flying**	**Sitting**	**All behaviours**	**Flying**	**Sitting**	**All behaviours**	**Flying**	**Sitting**
Return Migration	**Central**	**235.3**	**171.6**	**147.6**	**270.6**	**102.2**	**238.4**	**-35.3 (-15%)**	**69.4 (40%)**	**-90.8 (-62%)**
	Lower CI	111.4	79.3	67.0	92.3	43.0	81.3	19.1 (17%)	36.3 (46%)	-14.3 (-21%)
	Upper CI	463.4	372.6	332.7	899.9	251.4	792.7	-436.5 (-94%)	121.2 (33%)	-460 (-138%)
Migration-free breeding	**Central**	**790.8**	**400.9**	**435.4**	**742.7**	**594.2**	**158.4**	**48.1 (6%)**	**-193.3 (-48%)**	**277 (64%)**
	Lower CI	498.4	246.9	269.5	401.8	321.5	80.5	96.6 (19%)	-74.6 (-30%)	189 (70%)
	Upper CI	1,248.2	689.4	784.2	1,418.9	1,135.1	1,050.3	-170.7 (-14%)	-445.7 (-65%)	-266.1 (-34%)
Post-breeding migration	**Central**	**854.4**	**354.6**	**555.5**	**667.4**	**343.0**	**339.9**	**187 (22%)**	**11.6 (3%)**	**215.6 (39%)**
	Lower CI	556.5	222.4	371.8	359.8	184.9	175.5	196.7 (35%)	37.5 (17%)	196.3 (53%)
	Upper CI	1,294.0	578.1	816.0	1,265.2	650.2	677.3	28.8 (2%)	-72.1 (-12%)	138.7 (17%)
Annual	**Central**	**1,880.6**	**927.0**	**1,138.5**	**1,680.7**	**1,039.4**	**736.6**	**199.9 (11%)**	**-112.4 (-12%)**	**401.9 (35%)**
	Lower CI	1,166.3	548.5	708.2	853.9	549.4	337.3	312.4 (27%)	-0.9 (0%)	370.9 (52%)
	Upper CI	3,005.6	1,640.0	1,932.8	3,584.0	2,036.8	2,520.3	-578.4 (-19%)	-396.8 (-24%)	-587.5 (-30%)
Total	**Central**	**8,480.0**	**4,292.8**	**1,757.2**	**7,565.1**	**4,034.2**	**3,531.0**	**914.9 (11%)**	**258.6 (6%)**	**-1,773.8 (-101%)**
	Lower CI	5,187.6	2,584.0	2,603.6	3,726.1	2,021.9	1,704.2	1461.5 (28%)	562.1 (22%)	899.4 (35%)
	Upper CI	14,623.4	7,536.9	3,417.1	18,214.3	9,217.3	8,997.0	-3,590.9 (-25%)	-1,680.4 (-22%)	-5,579.9 (-163%)
Hornsea Four Array Area plus 4 km buffer										
Season	**Estimate**	**DCO MRSea_v1**			**MRSea_v2**			**Difference (%)**		

		All behaviours	Flying	Sitting	All behaviours	Flying	Sitting	All behaviours	Flying	Sitting
Return Migration	**Central**	**312.4**	**231.3**	**203.5**	**366.2**	**106.8**	**320.5**	**-53.8 (-17%)**	**124.5 (54%)**	**-117 (-57%)**
	Lower CI	149.6	107.1	93.9	129.3	43.0	113.1	20.3 (14%)	64.1 (60%)	-19.2 (-20%)
	Upper CI	616.8	506.2	463.1	1,224.7	283.9	1,071.6	-607.9 (-99%)	222.3 (44%)	-608.5 (-131%)
Migration-free breeding	**Central**	**1,049.8**	**575.6**	**582.9**	**927.0**	**695.2**	**231.7**	**122.8 (12%)**	**-119.6 (-21%)**	**351.2 (60%)**
	Lower CI	658.3	351.4	357.3	493.9	370.4	123.5	164.4 (25%)	-19 (-5%)	233.8 (65%)
	Upper CI	1,673.6	962.4	1,069.2	2,208.9	1,361.2	1,893.4	-535.3 (-32%)	-398.8 (-41%)	-824.2 (-77%)
Post-breeding migration	**Central**	**1,134.3**	**469.4**	**717.2**	**946.9**	**492.4**	**464.0**	**187.4 (17%)**	**-23 (-5%)**	**253.2 (35%)**
	Lower CI	737.0	293.1	478.1	498.8	259.4	239.4	238.2 (32%)	33.7 (11%)	238.7 (50%)
	Upper CI	1,728.2	771.0	1,062.4	1,841.0	957.3	971.9	-112.8 (-7%)	-186.3 (-24%)	90.5 (9%)
Annual	**Central**	**2,496.5**	**1,276.3**	**1,503.5**	**2,240.1**	**1,294.4**	**1,016.2**	**256.4 (10%)**	**-18.1 (-1%)**	**487.3 (32%)**
	Lower CI	1,544.8	751.6	929.4	1,121.9	672.7	476.0	422.9 (27%)	78.9 (10%)	453.4 (49%)
	Upper CI	4,018.6	2,239.5	2,594.7	5,274.6	2,602.4	3,936.9	-1,256 (-31%)	-362.9 (-16%)	-1,342.2 (-52%)
Total	**Central**	**11,257.5**	**5,728.8**	**4,770.0**	**10,418.5**	**5,501.2**	**4,917.3**	**839 (7%)**	**227.6 (4%)**	**-147.3 (-3%)**
	Lower CI	6,866.4	3,449.4	7,086.5	4,996.7	2,691.6	2,305.1	1,869.7 (27%)	757.8 (22%)	4,781.3 (67%)
	Upper CI	19,556.1	10,070.5	9,485.6	26,649.3	13,179.5	13,469.8	-7,093.2 (-36%)	-3,109 (-31%)	-3,984.3 (-42%)

Table Note: *Total equates to the sum of all the monthly abundance estimates, which are presented in **Table 9** for the DCO MRSea_v1 abundance estimates and **Table 3** for the MRSea_v2 abundance estimates (MRSea_v2 total value multiplied by two due to being only 12 months of data vs 24 months for the DCO MRSea_v1) .

8 References

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Appendix A Details of initial MRSea_v2 re-run for gannet

8.1.1 Introduction

8.1.1.1 An initial re-run of MRSea has been carried out for gannet. The aim of this re-run is to demonstrate the process and present model details and diagnostics, in order to seek agreement that the approach is acceptable and the details presented are appropriate. Full details are provided for the final chosen model; the same process was carried out for other model iterations as detailed in **Table 7**.

8.1.1.2 The approach taken is based on the MRSea guidance (Scott-Hayward et al., 2017), the advice given (see **Table 2**) on the previous approach to MRSea modelling (Scott-Hayward, 2021) and also further direct communications with Lindsay Scott-Hayward by email and video call, on multiple dates between January and April 2022. A notable contrast to the previous approach is that while "surveyID" has been included in the blocking structure, it has not been included as an explanatory variable. Instead "month" or "bio-season" have been used as explanatory variables. This aligns with the approach set out in the MRSea guidance (Scott-Hayward et al., 2017) of using MRSea as a predictive model to understand the impact of biologically relevant explanatory variables. Furthermore, it enables more robust and reliable model fitting given that several surveys had very low raw counts of gannets and also the relatively small number of independent transects per survey (Scott-Hayward, *pers. comms.*).

8.1.2 Initial Set-up

8.1.2.1 To assess co-linearity of explanatory variables, Generalised Variance Inflation Factors (GVIFs) are checked at the start of the process (**Figure 25**) in line with comment CREEM7.

```
> vif(initial_gannet_model_month_only)
                       GVIF Df GVIF^(1/(2*Df))
mean_depth         4.076740  1        2.019094
as.factor(month)   1.000254 11        1.000012
x.pos              1.356699  1        1.164774
y.pos              4.737407  1        2.176559
```

Figure 25: Code snippet showing testing for co-linearity

8.1.2.2 In this case, the adjusted GVIFs for mean_depth and *y*.pos are both approximately 2 (i.e. the confidence intervals are twice as wide as they would be in the absence of any co-linearity). There is therefore some co-linearity, but as it is relatively small and as *y*.pos will not be modelled in a linear manner, no further action is taken.

8.1.2.3 In order to fit the model, there needs to be non-zero counts for all levels of categorical variables (in this case month; **Figure 26**). This is the case and so no action needs to be taken.

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

Figure 26: Code snippet showing check of non-zero counts for all factor levels.

8.1.3 Generalised Linear Model

8.1.3.1 A basic Generalised Linear Model (GLM) is run as an initial model (**Figure 27**).

```
> summary(initial_gannet_model_month_only)

Call:
glm(formula = response ~ mean_depth + as.factor(month) + x.pos +
    y.pos + offset(log(area)), family = "quasipoisson", data = gannet_model_data)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.3446  -0.5503  -0.3312  -0.1479  15.1951

Coefficients:
                      Estimate Std. Error t value Pr(>|t|)
(Intercept)          2.593e+01  3.849e+01   0.674 0.500411
mean_depth           1.738e-02  7.483e-03   2.322 0.020228 *
as.factor(month)Aug  7.038e-01  2.119e-01   3.321 0.000899 ***
as.factor(month)Dec  8.037e-02  2.408e-01   0.334 0.738606
as.factor(month)Feb -1.970e+00  4.973e-01  -3.963 7.43e-05 ***
as.factor(month)Jan -8.908e-01  3.223e-01  -2.764 0.005718 **
as.factor(month)Jul  7.595e-01  2.101e-01   3.616 0.000300 ***
as.factor(month)Jun  8.574e-01  1.964e-01   4.367 1.27e-05 ***
as.factor(month)Mar -5.833e-01  2.904e-01  -2.008 0.044610 *
as.factor(month)May  5.436e-01  2.553e-01   2.129 0.033281 *
as.factor(month)Nov  1.114e+00  2.000e-01   5.572 2.55e-08 ***
as.factor(month)Oct  1.073e+00  2.007e-01   5.346 9.07e-08 ***
as.factor(month)Sep  5.283e-01  2.184e-01   2.419 0.015582 *
x.pos                5.384e-06  4.103e-06   1.312 0.189432
y.pos               -4.706e-06  6.342e-06  -0.742 0.458060
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for quasipoisson family taken to be 3.693347)

    Null deviance: 14215  on 22396  degrees of freedom
Residual deviance: 13127  on 22382  degrees of freedom
AIC: NA

Number of Fisher Scoring iterations: 7
```

Figure 27: Code snippet showing summary of initial GLM

8.1.3.2 A runs test is carried out on the initial model (**Figure 28**). From the highly significant p-value, it is evident that there is significant residual correlation within the initial model.

```
> runs.test(residuals(initial_gannet_model_month_only, type = "pearson"), alternative = c("two.sided"))

        Runs Test - Two sided

data:  residuals(initial_gannet_model_month_only, type = "pearson")
Standardized Runs Statistic = -15.162, p-value < 2.2e-16
```

Figure 28: Code snippet showing runs test

8.1.3.3 This is further evidenced by non-randomness in the runs profiles (**Figure 29**).

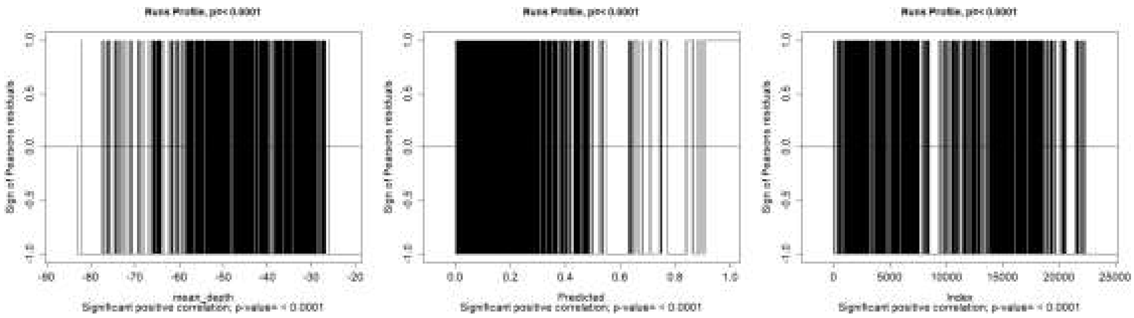

Figure 29: Runs profile plots for the initial GLM. The lines are sequences of positive and negative residuals. In the absence of correlated residuals, the lines would be randomly distributed. Significance of the correlation is also printed beneath each plot.

8.1.3.4 Therefore, a blocking structure is necessary. Survey ID concatenated with Transect ID was specified as the blocking structure – i.e. the model should treat data from within each transect of each survey as correlated, but independent between different transects and surveys. An Auto-Correlation Function (ACF) plot is used to assess the appropriateness of this blocking structure (**Figure 30**). The mean correlation in residuals (indicated by the red line) and the correlation in residuals within each block (grey lines) both drop to approximately zero, suggesting that the blocking structure specified is appropriate.

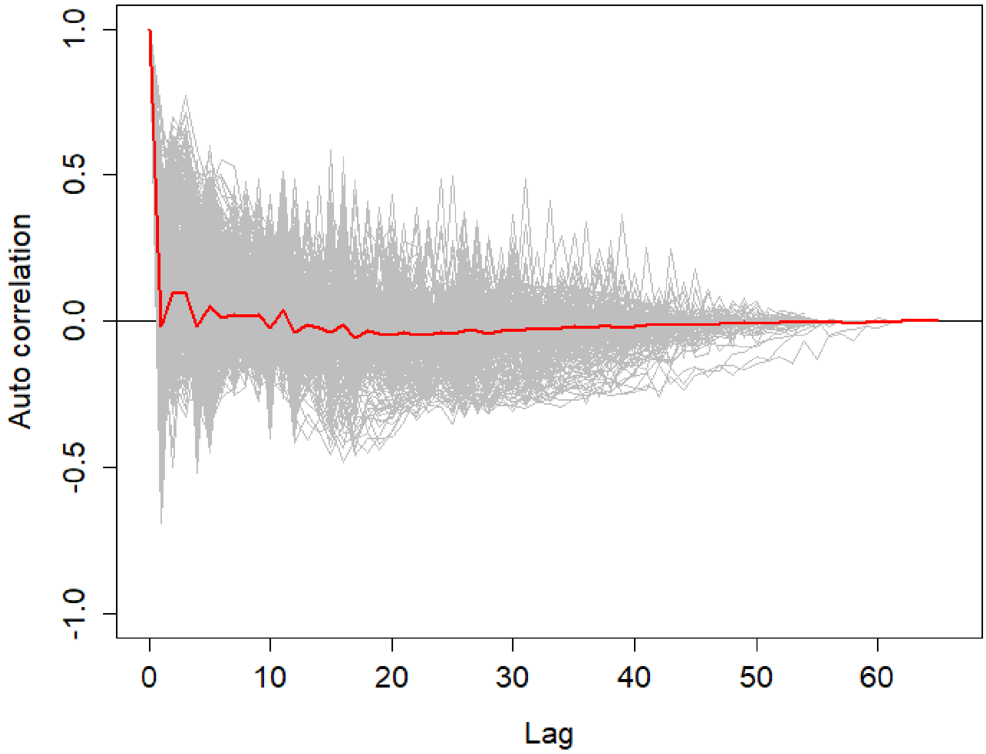

Figure 30: Auto-correlation Function (ACF) plot for the initial GLM. Grey lines are correlation in residuals within each block. Red line is the mean correlation in residual.

8.1.3.5 Cumulative residuals are calculated (**Figure 31**). The black line shows the modelled cumulative residuals, while the grey line shows what we would expect if the model was correctly fitted. It is evident that there is some systematic over- and under-prediction, especially at shallow water depths. This confirms the need for a more complex model.

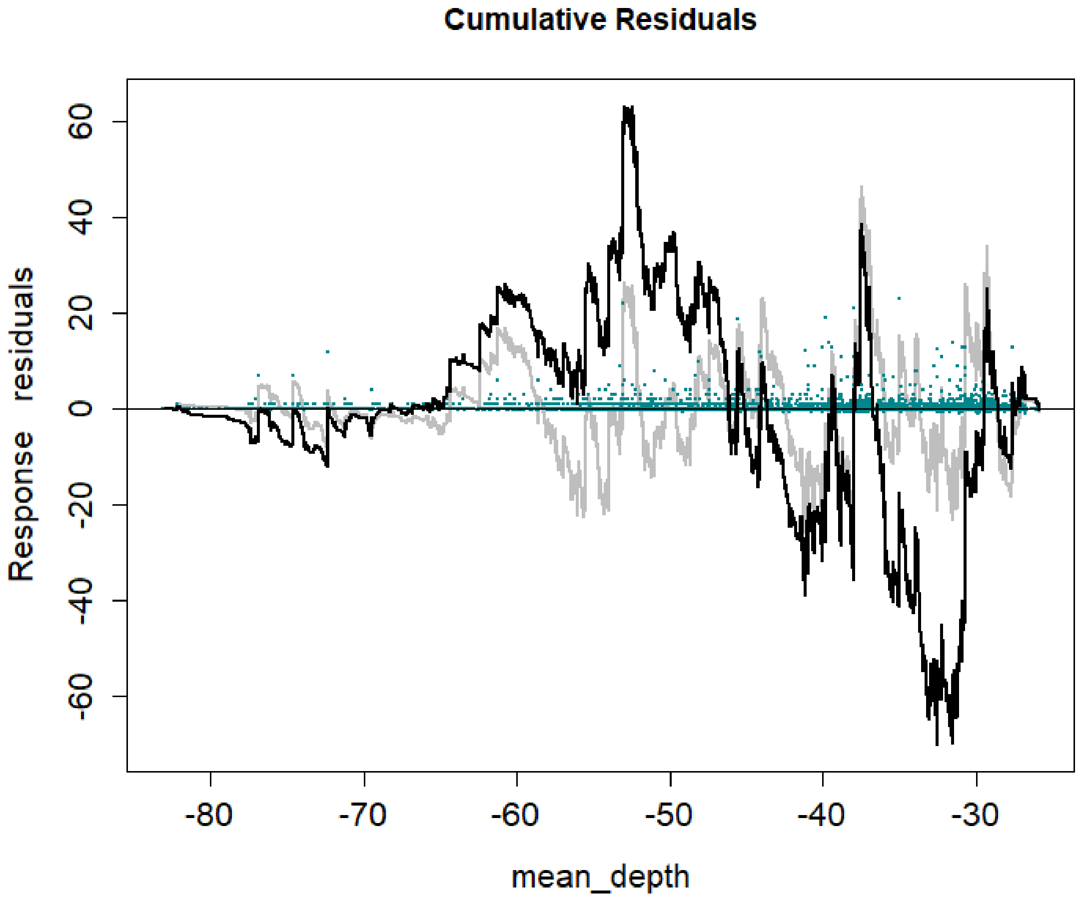

Figure 31: Cumulative residuals for the initial GLM ordered by depth.

8.1.4 Smoothed Model (1D SALSA)

8.1.4.1 Therefore, with an appropriate blocking structure identified and a clear need for a non-linear model, 1D SALSA is carried out using the parameters specified below (**Figure 32**). The spline parameters were generated using the built-in function (makesplineParams) and defaults to a degree of two. As the "removal" term was not specified in the runSALSA1D function, all variables were considered with smooth splines (not allowed to be linear or removed). Note that the 1D SALSA routine does not allow for an interaction term to be fitted; an interaction term is considered as part of the 2D SALSA routine in line with comments NE2 and CREEM9.

```
initial_gannet_model_month <- glm(response ~  as.factor(month) + offset(log(area)),
                                  family = "quasipoisson", data = gannet_model_data

varlist <- c('mean_depth')

salsa1dlist <-list(fitnessMeasure = "cv.gamMRSea",
                   minKnots_1d = c(1),
                   maxKnots_1d = c(3),
                   startKnots_1d = c(1),
                   degree=c(2),
                   maxIterations = 10,
                   gaps = c(1),
                   cv.opts = list(cv.gamMRSea.seed = 1, K=10))

salsa1dOutput_month <- runSALSA1D(initialModel=initial_gannet_model_month,
                                  salsa1dlist=salsa1dlist,
                                  varlist=varlist,
                                  factorlist=c("month"),
                                  datain = gannet_model_data,
                                  panelid = gannet_model_data$blockID,
                                  predictionData = predict_grid_df_mo)
```

Figure 32: Code snippet showing setting up of 1D SALSA.

8.1.4.2 The 1D SALSA function produces many different models and compares them using the specified fitness measure, in this case 10-fold cross validation. The model with the best fit (lowest cross-validation error) is returned as the "best model". A summary of the best model is shown in Figure 33.

```
> summary(salsa1dOutput_month_only$bestModel)

Call:
gamMRSea(formula = response ~ as.factor(month) + bs(mean_depth,
    knots = splineParams[[2]]$knots, degree = splineParams[[2]]$degree,
    Boundary.knots = splineParams[[2]]$bd) + offset(log(area)),
    family = quasipoisson(link = log), data = gannet_model_data,
    splineParams = splineParams)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.4516  -0.5549  -0.3310  -0.1496  15.2944

Coefficients:
                    Estimate Std. Error Robust S.E. t value Pr(>|t|)
(Intercept)         -1.35964    0.43381     0.65581  -2.073  0.03816 *
as.factor(month)Aug  0.70362    0.21279     0.04754  14.801  < 2e-16 ***
as.factor(month)Dec  0.08018    0.24181     0.02507   3.199  0.00138 **
as.factor(month)Feb -1.97074    0.49924     0.46694  -4.221 2.45e-05 ***
as.factor(month)Jan -0.89081    0.32361     0.66571  -1.338  0.18086
as.factor(month)Jul  0.75932    0.21089     0.25308   3.000  0.00270 **
as.factor(month)Jun  0.85698    0.19714     0.39382   2.176  0.02956 *
as.factor(month)Mar -0.58341    0.29157     0.19183  -3.041  0.00236 **
as.factor(month)May  0.54343    0.25636     0.01247  43.596  < 2e-16 ***
as.factor(month)Nov  1.11423    0.20075     0.20917   5.327 1.01e-07 ***
as.factor(month)Oct  1.06951    0.20154     0.24393   4.384 1.17e-05 ***
as.factor(month)Sep  0.52781    0.21927     0.07488   7.049 1.85e-12 ***
s(mean_depth)1      -0.05313    0.53826     1.01505  -0.052  0.95825
s(mean_depth)2       0.54697    0.37811     0.54395   1.006  0.31464
s(mean_depth)3       1.08409    0.45211     0.89027   1.218  0.22334
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for quasipoisson family taken to be 3.722853)

    Null deviance: 14215  on 22396  degrees of freedom
Residual deviance: 13126  on 22382  degrees of freedom
AIC:  NA

Max Panel Size = 958; Number of panels = 24
Number of Fisher Scoring iterations: 7
```

Figure 33: Summary of model identified as the best fitting model through the 1D SALSA algorithm.

8.1.4.3 Ten-fold cross-validation is used to compare the 1D model to the GLM (Figure 34). Although the estimates are similar, the estimated error for the 1D model is lower and therefore that model is a better fit than the GLM.

```
> # 1D model
> cv.gamMRSea(data=gannet_model_data, modelobject = salsa1dOutput_month_only$bestModel, K=10)$delta[2]
[1] 0.4925561
> # intitial model
> cv.gamMRSea(data=gannet_model_data, modelobject = initial_gannet_model_month_only, K=10)$delta[2]
[1] 0.4926745
```

Figure 34: Code snippets showing cross-validation error estimates for GLM and the best fitting 1D smoothed model

8.1.5 2D Smoothed model (SALSA 2D)

8.1.5.1 Next, the 2D SALSA function was run, using the best model from the 1D SALSA as the initial model. An interaction between Month and the smoothed parameters (x.pos, y.pos and depth) was specified in the model to enable spatial flexibility between months, as requested by NE2 and CREEM7.

```
salsa2dlist <-list(fitnessMeasure = "cv.gamMRSea",
                   cv.opts = list(cv.gamMRSea.seed = 1, K=10),
                   knotgrid = knot_grid,
                   startKnots = 6,    # ~~~
                   minKnots = 4,
                   maxKnots = 20,
                   gap = 0,
                   interactionTerm = "as.factor(month)")

salsa2dOutput_month <-runSALSA2D(salsa1dOutput_month$bestModel,
                                 salsa2dlist,
                                 distMats$dataDist,
                                 distMats$knotDist,
                                 panels = gannet_model_data$blockID)
```

Figure 35: Code snippet showing setting up of 2D SALSA

8.1.5.2 The summary of the best-fitting 2D SALSA model is shown in Figure 36, Figure 37 and Figure 38. This summary provides additional information about the model fit that addresses comment NE3.

```
> summary(best_model_month)

Call:
gamMRSea(formula = response ~ as.factor(month) + bs(mean_depth,
    knots = splineParams[[2]]$knots, degree = splineParams[[2]]$degree,
    Boundary.knots = splineParams[[2]]$bd) + LRF.g(radiusIndices,
    dists, radii, aR) + as.factor(month):LRF.g(radiusIndices,
    dists, radii, aR) + offset(log(area)), family = quasipoisson(link = log),
    data = gannet_model_data, splineParams = splineParams)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.5337  -0.5167  -0.2575  -0.1023  14.0417
```

Figure 36: Code snippet showing summary of best fitting model from SALSA 2D (first section).

```
Coefficients:
                                       Estimate Std. Error Robust S.E. t value Pr(>|t|)
(Intercept)                            -3.37116    0.72642     0.57925  -5.820 5.97e-09 ***
as.factor(month)Aug                     2.49496    0.67168     0.43329   5.758 8.62e-09 ***
as.factor(month)Dec                     1.84698    0.72005     0.54471   3.391 0.000698 ***
as.factor(month)Feb                    -0.92829    1.40104     0.67823  -1.369 0.171111
as.factor(month)Jan                     2.72832    0.71573     0.93626   2.914 0.003571 **
as.factor(month)Jul                     3.17501    0.65423     0.62286   5.097 3.47e-07 ***
as.factor(month)Jun                     2.27991    0.65702     0.52132   4.373 1.23e-05 ***
as.factor(month)Mar                     0.39537    0.86644     0.76408   0.517 0.604851
as.factor(month)May                     0.77035    0.87971     0.78780   0.978 0.328155
as.factor(month)Nov                     1.64541    0.68330     0.52649   3.125 0.001779 **
as.factor(month)Oct                     2.87644    0.65745     0.44288   6.495 8.49e-11 ***
as.factor(month)Sep                     2.31486    0.68234     0.54147   4.275 1.92e-05 ***
s(mean_depth)1                          0.96496    0.64022     0.77762   1.241 0.214651
s(mean_depth)2                          1.24538    0.37452     0.47166   2.640 0.008286 **
s(mean_depth)3                          1.17961    0.52448     0.64467   1.830 0.067293 .
s(x.pos, y.pos)b1                      -0.62729    1.50406     0.89905  -0.698 0.485353
s(x.pos, y.pos)b2                       3.34716    0.76768     0.56404   5.934 3.00e-09 ***
s(x.pos, y.pos)b3                       1.54314    2.67614     1.53219   1.007 0.313874
s(x.pos, y.pos)b4                      -2.74834    3.71457     1.75677  -1.564 0.117730
as.factor(month)Aug:s(x.pos, y.pos)b1  -0.65917    1.65892     1.17165  -0.563 0.573713
as.factor(month)Dec:s(x.pos, y.pos)b2   3.83270    1.72311     1.52099   2.520 0.011747 *
as.factor(month)Feb:s(x.pos, y.pos)b3   4.47066    3.19814     2.02019   2.213 0.026909 *
as.factor(month)Jan:s(x.pos, y.pos)b4  -4.10025    3.02070     1.74804  -2.346 0.019004 *
as.factor(month)Jul:s(x.pos, y.pos)b1  -1.62707    1.61551     1.19601  -1.360 0.173712
as.factor(month)Jun:s(x.pos, y.pos)b2   2.46926    1.55705     1.12292   2.199 0.027890 *
as.factor(month)Mar:s(x.pos, y.pos)b3  -0.20604    1.85628     1.07585  -0.192 0.848123
as.factor(month)May:s(x.pos, y.pos)b4   3.36925    2.03613     2.45995   1.370 0.170812
as.factor(month)Nov:s(x.pos, y.pos)b1  -0.37278    1.59347     1.12859  -0.330 0.741175
as.factor(month)Oct:s(x.pos, y.pos)b2  -0.93953    1.59393     1.33264  -0.705 0.480811
as.factor(month)Sep:s(x.pos, y.pos)b3  -2.34874    1.69726     1.01370  -2.317 0.020513 *
as.factor(month)Aug:s(x.pos, y.pos)b4  -3.40099    0.84639     0.72462  -4.694 2.70e-06 ***
as.factor(month)Dec:s(x.pos, y.pos)b1  -5.28923    1.11071     0.91078  -5.807 6.43e-09 ***
as.factor(month)Feb:s(x.pos, y.pos)b2  -3.10181    2.10008     1.14523  -2.708 0.006765 **
as.factor(month)Jan:s(x.pos, y.pos)b3  -6.78476    1.29025     1.74871  -3.880 0.000105 ***
as.factor(month)Jul:s(x.pos, y.pos)b4  -5.24309    0.87766     0.86470  -6.063 1.35e-09 ***
as.factor(month)Jun:s(x.pos, y.pos)b1  -4.54111    0.86191     0.83710  -5.425 5.86e-08 ***
as.factor(month)Mar:s(x.pos, y.pos)b2  -4.61864    1.59187     1.33172  -3.468 0.000525 ***
as.factor(month)May:s(x.pos, y.pos)b3  -0.84308    1.07162     0.95928  -0.879 0.379483
as.factor(month)Nov:s(x.pos, y.pos)b4  -1.59114    0.83487     0.78951  -2.015 0.043880 *
as.factor(month)Oct:s(x.pos, y.pos)b1  -3.21914    0.80461     0.63974  -5.032 4.89e-07 ***
as.factor(month)Sep:s(x.pos, y.pos)b2  -2.89134    0.85073     0.79073  -3.657 0.000256 ***
as.factor(month)Aug:s(x.pos, y.pos)b3  -2.38013    2.88628     1.73251  -1.374 0.169517
as.factor(month)Dec:s(x.pos, y.pos)b4 -10.46078    3.41975     2.66168  -3.930 8.52e-05 ***
as.factor(month)Feb:s(x.pos, y.pos)b1 -12.57553    7.55792     5.28054  -2.381 0.017251 *
as.factor(month)Jan:s(x.pos, y.pos)b2  -4.60452    6.00705     3.38477  -1.360 0.173728
as.factor(month)Jul:s(x.pos, y.pos)b3  -0.13258    2.81935     2.03903  -0.065 0.948156
as.factor(month)Jun:s(x.pos, y.pos)b4  -4.91652    2.77873     1.96789  -2.498 0.012484 *
as.factor(month)Mar:s(x.pos, y.pos)b1   1.27864    3.02606     1.83399   0.697 0.485693
as.factor(month)May:s(x.pos, y.pos)b2  -8.13665    4.01471     6.56181  -1.240 0.214988
as.factor(month)Nov:s(x.pos, y.pos)b3   1.79347    2.75357     1.71122   1.048 0.294620
as.factor(month)Oct:s(x.pos, y.pos)b4  -0.08562    2.81569     2.29101  -0.037 0.970190
as.factor(month)Sep:s(x.pos, y.pos)b1   2.34602    2.93266     1.83390   1.279 0.200822
as.factor(month)Aug:s(x.pos, y.pos)b2   3.66205    3.88817     2.00369   1.828 0.067615 .
as.factor(month)Dec:s(x.pos, y.pos)b3  10.21854    4.20987     2.63980   3.871 0.000109 ***
as.factor(month)Feb:s(x.pos, y.pos)b4  13.64329    7.25228     4.67467   2.919 0.003520 **
as.factor(month)Jan:s(x.pos, y.pos)b1   0.45839    6.92634     4.00506   0.114 0.908881
as.factor(month)Jul:s(x.pos, y.pos)b2  -0.33270    3.88690     2.23175  -0.149 0.881494
as.factor(month)Jun:s(x.pos, y.pos)b3   5.78109    3.80918     2.27327   2.543 0.010995 *
as.factor(month)Mar:s(x.pos, y.pos)b4   1.45732    4.03222     1.88194   0.774 0.438719
as.factor(month)May:s(x.pos, y.pos)b1   9.55796    4.72309     5.28479   1.809 0.070530 .
as.factor(month)Nov:s(x.pos, y.pos)b2   0.55062    3.80994     1.94781   0.283 0.777420
as.factor(month)Oct:s(x.pos, y.pos)b3  -0.84980    3.92926     2.70712  -0.314 0.753591
as.factor(month)Sep:s(x.pos, y.pos)b4  -4.05359    4.20034     2.48367  -1.632 0.102673
```

Figure 37: Code snippet showing summary of best fitting model from SALSA 2D (second section).

```
(Dispersion parameter for quasipoisson family taken to be 2.785872)

    Null deviance: 14215  on 22396  degrees of freedom
Residual deviance: 12187  on 22334  degrees of freedom
AIC:   NA

Max Panel Size = 66; Number of panels = 572
Number of Fisher Scoring iterations: 8
```

Figure 38: Code snippet showing summary of best fitting model from SALSA 2D (third section).

8.1.5.3 Ten-fold cross-validation is used to compare the 2D model (Error! Reference source not found.) to the 1D model and GLM (**Figure 34**). Although the estimates are similar, the estimated error for the 2D model is lower and therefore that model is a better fit than the 1D model.

```
> cv_2d_mo
[1] 0.491806
```

Figure 39: Code snippet showing cross-validation error estimates for the 2D model.

8.1.5.4 This full modelling process is carried out for a number of candidate models, using combinations of mean depth, distance to FFC SPA and distance to coast as continuous explanatory variables, and either month or bio-season as categorical explanatory variables. All are tested using 10-fold cross validation using the built-in cross-validation function (i.e. blocking structure is retained) and the random seed set to 1 to ensure repeatability. The list of candidate models and the cross-validation error for the GLM, 1D SALSA and 2D SALSA model fits are presented in **Table 7**, presented in an order based on their 2D SALSA values, with the smaller the error indicating the better the model fit. Note that due to very high co-linearity, no candidate model included both distance to FFC SPA and distance to coast.

Table 7: Results of 10-fold cross-validation on candidate models trailed.

	Cross-validation error		
Candidate model	GLM	1D SALSA	2D SALSA
Mean depth + month	0.4926745	0.4925561	0.491806
Bioseason-year + distance to FFC + mean depth	0.492822	0.4927874	0.4919532
Mean depth + bio-season	0.4929538	0.4929384	0.4920409
Mean depth + distance to coast + month	0.4927862	0.4927880	0.4942655
Distance to coast + month	0.4939167	0.4940053	0.4945566
Distance to FFC SPA + month	0.4936127	0.4924820	0.4946928
Bioseason-year + month + distance to FFC + mean depth	TBC	TBC	TBC
Bioseason-year + survey + distance to FFC + mean depth	TBC	TBC	TBC

8.1.5.5 Central estimates of predicted abundances for the entire AfL plus 4km buffer are generated directly from the model results for each grid cell of the prediction grid. Although the prediction grid is largely a 1x1km grid, as the prediction grid is cropped to the Hornsea Four AfL plus 4 km buffer, the modelled response (counts of gannets per cell) is converted to a density by dividing by the area of each grid cell (Figure 40). In order to aid evaluation of model fit, raw observation data is overlaid (NE3 and CREEM2).

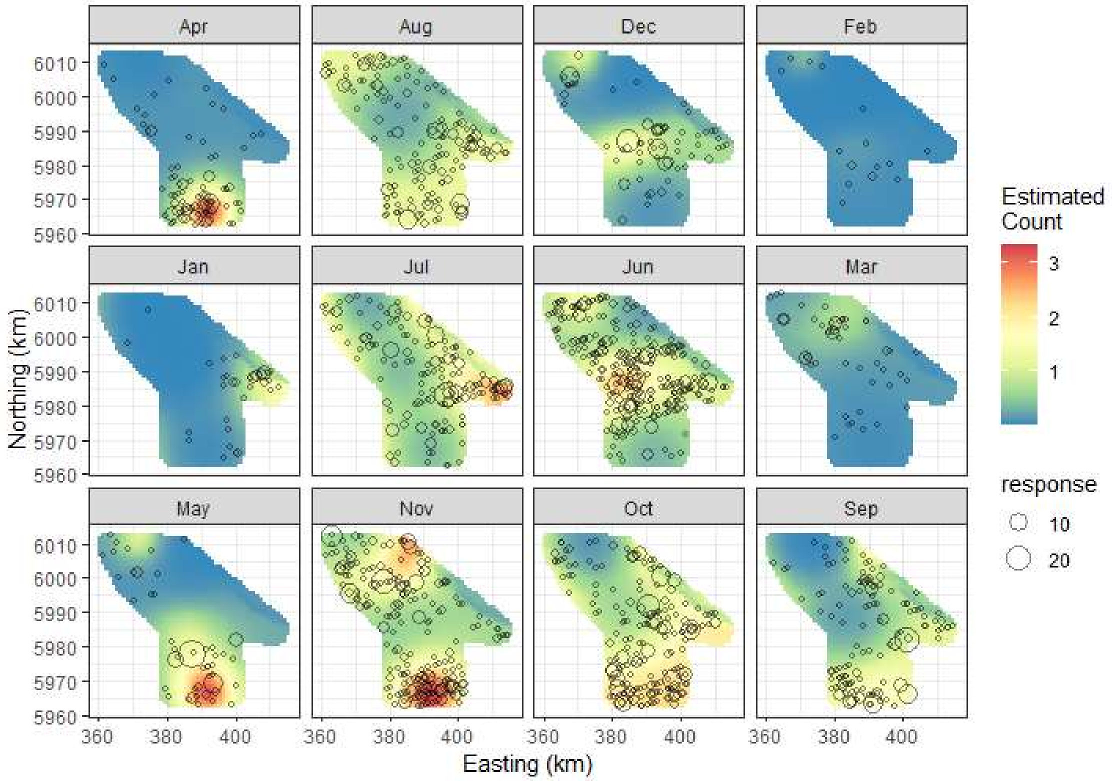

Figure 40: Predicted gannet density per month also showing raw observations

8.1.5.6 Upper and lower 95% confidence intervals (CIs) were generated using the bootstrapping tool supplied with the MRSea package; this is a parametric bootstrap that generates predictions by resampling coefficients from a multivariate normal distribution defined by the maximum likelihood estimation and coefficient of variation from the best fitting model. The bootstrap was run with 1,000 runs. The 95% CIs are presented in **Figure 41** and **Figure 42**. This addresses comment CREEM11. Note that the colour scale differs between the mean, lower CI, and upper CI figures.

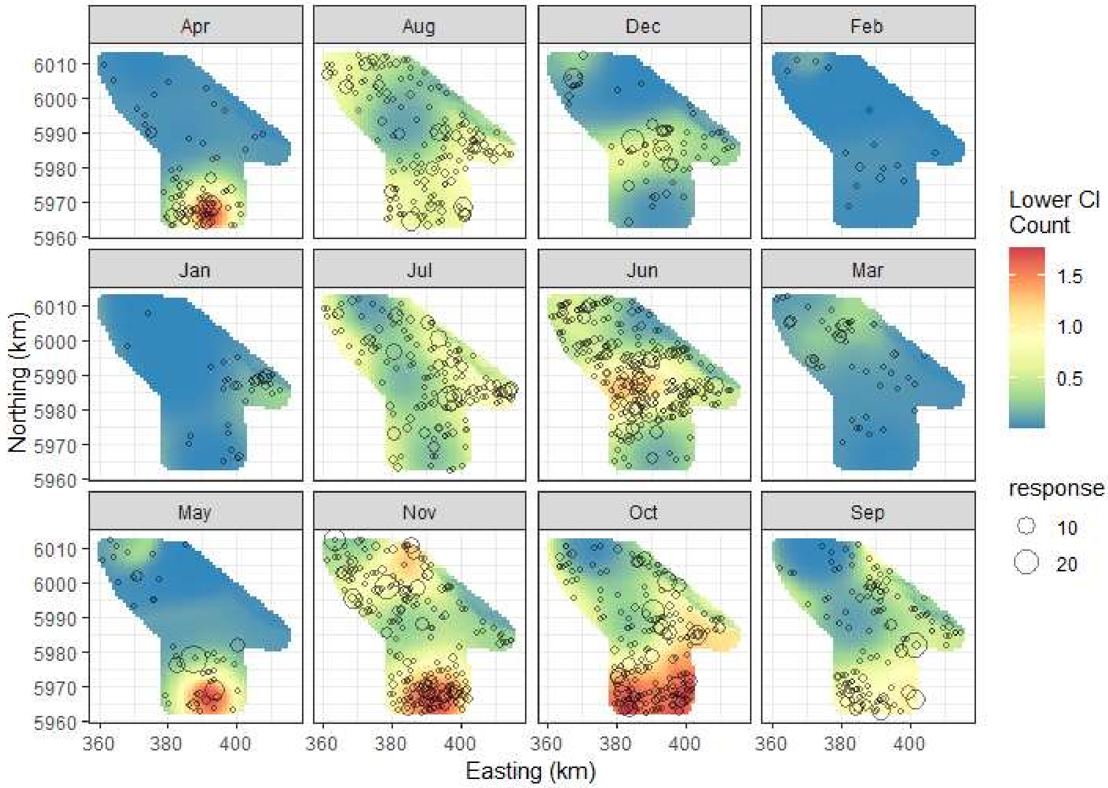

Figure 41: Lower density estimate from 95% Confidence Intervals also showing raw observations

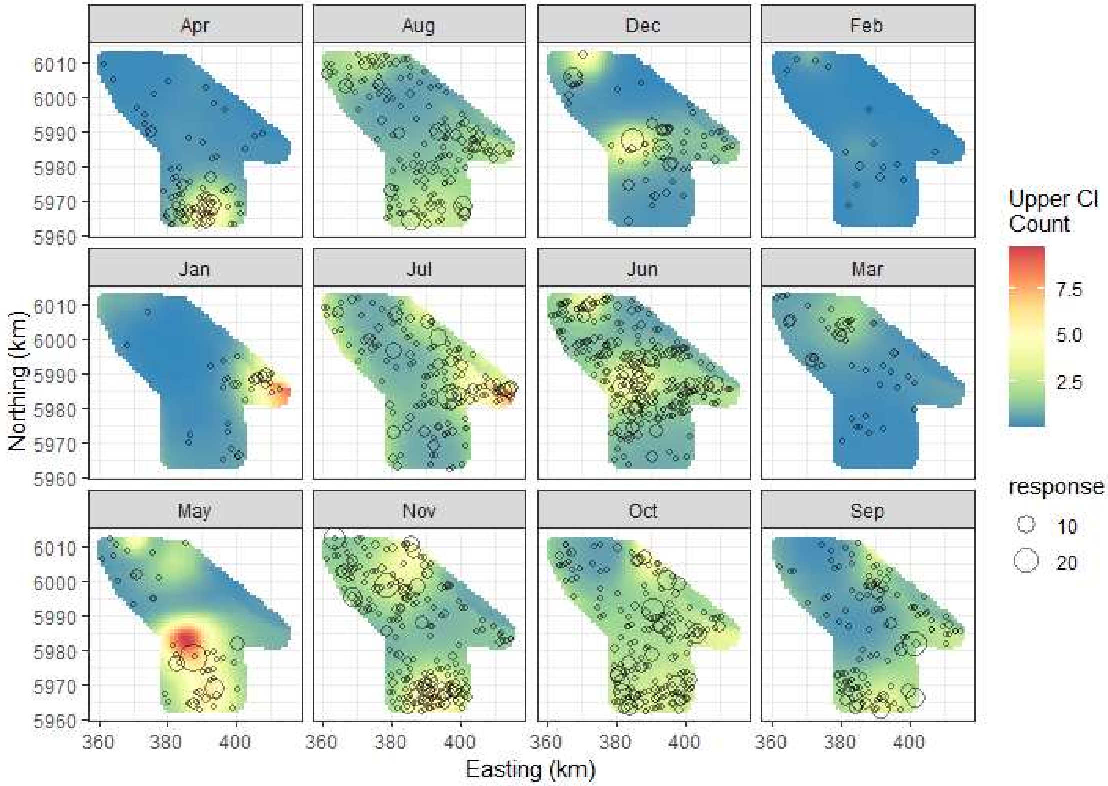

Figure 42: Upper density estimate from 95% Confidence Intervals also showing raw observations

8.1.5.7 The spatial uncertainty can be visualised as the range of the 95% CI limits (i.e. upper CI minus lower CI; Figure 43). This addresses comment CREEM14.

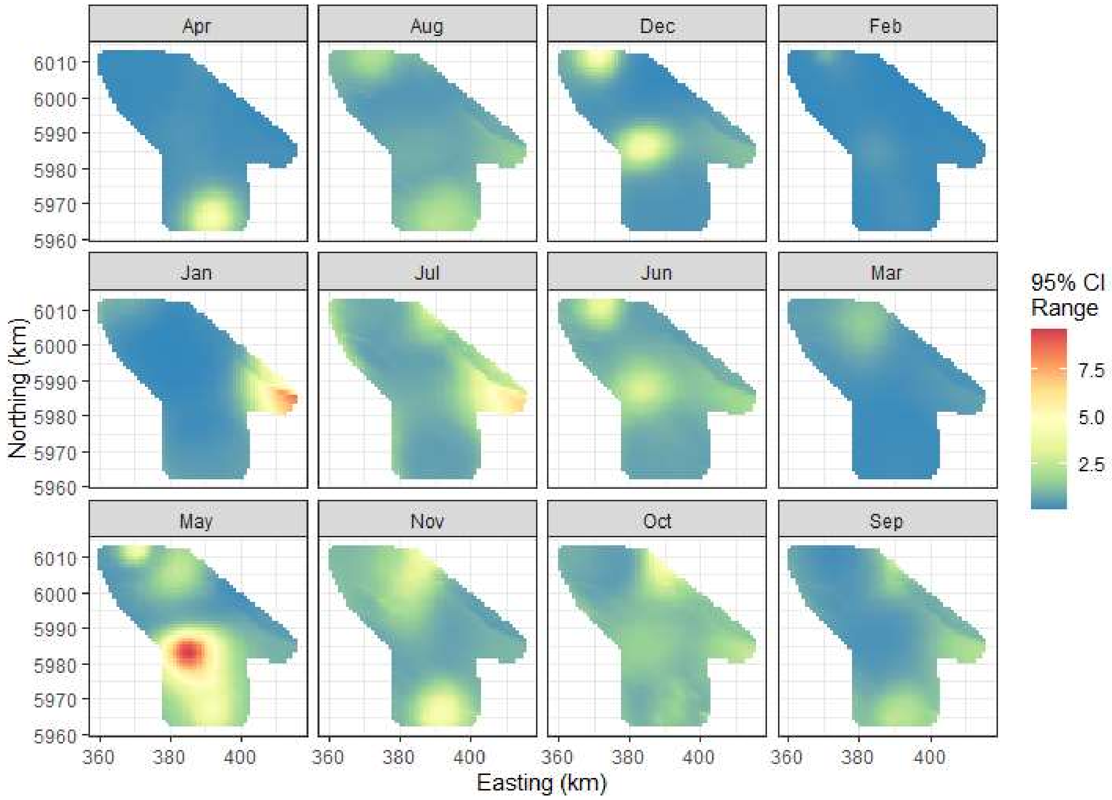

Figure 43: Spatial uncertainty in model predictions shown as width of 95% CIs for each grid cell.

8.1.6 Model Diagnostics

8.1.6.1 Additional model diagnostics for the best fitting SALSA 2D model are given in Figure 44 to Figure 46 in order to address comment CREEM13.

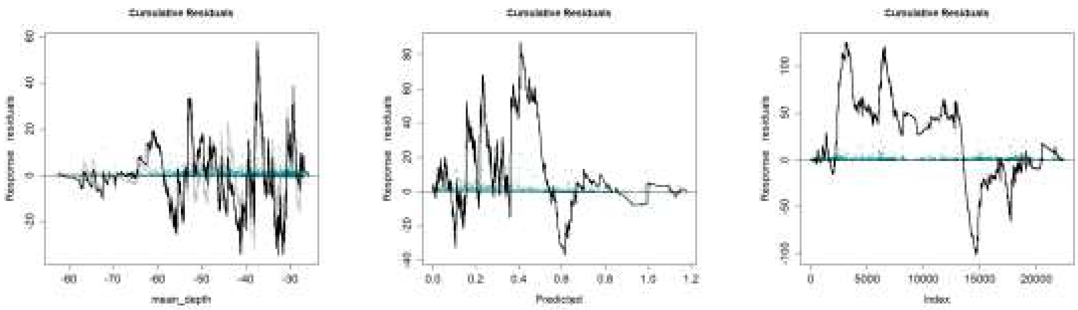

Figure 44: Cumulative residuals of best fitting 2D smoothed model by predicted value, depth, and index (data order).

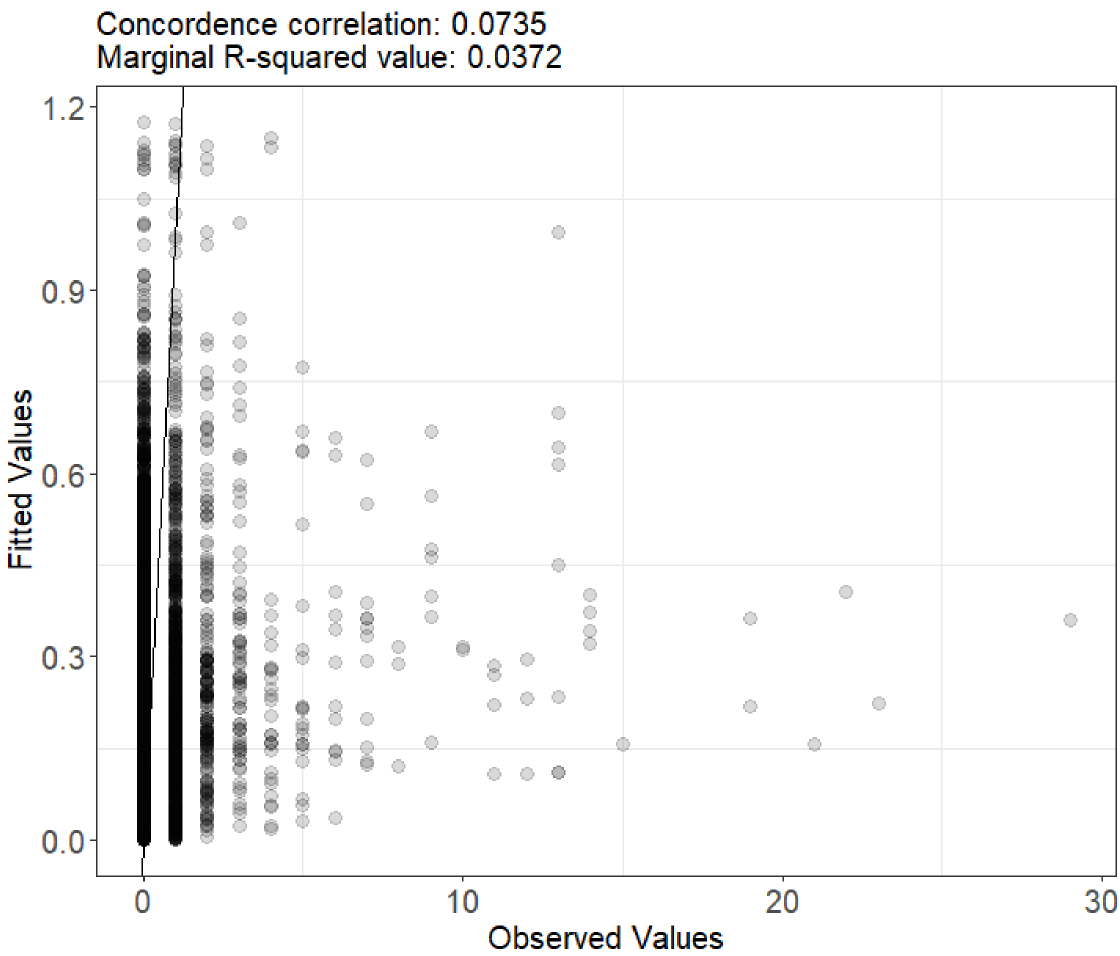

Figure 45: Observed versus fitted values from best fitting 2D smoothed model.

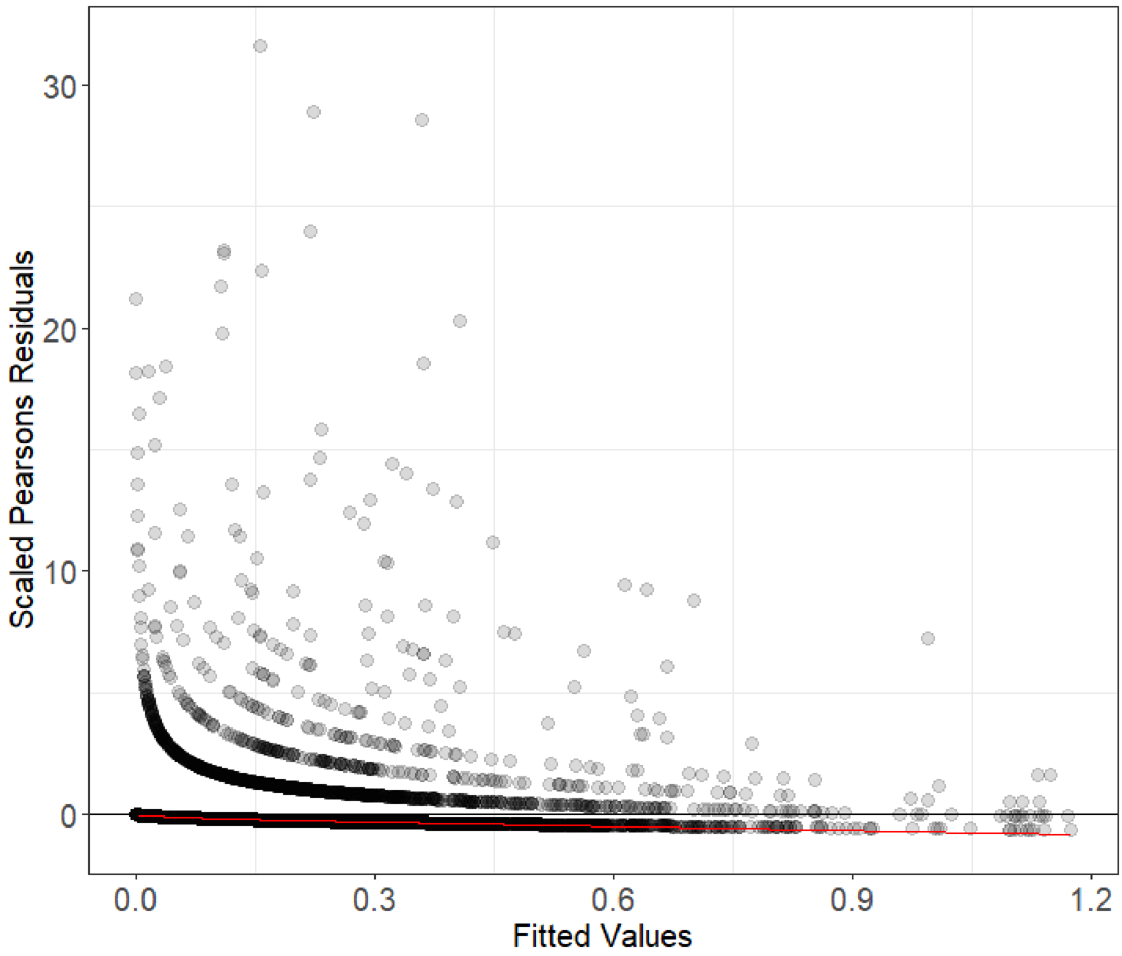

Figure 46: Scaled Pearson Residuals by fitted value for best fitting 2D smoothed model.

Appendix B Hornsea Four Design-based and DCO Application MRSea monthly and Bio-season abundance estimate results

Table 8: Gannet design-based monthly abundance estimate results for the Hornsea Four array area, array, array area plus 2 km buffer and array area plus 4 km buffer.

Hornsea Four Array Area									
Month	All behaviours			Flying			Sitting		
	Abundance	Lower CI	Upper CI	Abundance	Lower CI	Upper CI	Abundance	Lower CI	Upper CI
Apr-16	10.0	0.0	28.0	10.0	0.0	27.0	0.0	0.0	0.0
May-16	309.0	161.0	505.0	130.0	47.0	188.0	180.0	63.0	405.0
Jun-16	1,018.0	459.0	1,402.0	399.0	167.0	552.0	619.0	214.0	890.0
Jul-16	392.0	214.0	560.0	271.0	134.0	399.0	121.0	20.0	275.0
Aug-16	90.0	21.0	167.0	70.0	10.0	125.0	20.0	0.0	67.0
Sep-16	261.0	62.0	477.0	100.0	36.0	151.0	161.0	26.0	330.0
Oct-16	480.0	78.0	996.0	90.0	10.0	245.0	390.0	71.0	781.0
Nov-16	450.0	226.0	600.0	250.0	100.0	339.0	200.0	75.0	301.0
Dec-16	210.0	47.0	416.0	160.0	47.0	310.0	50.0	0.0	123.0
Jan-17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Feb-17	20.0	0.0	59.0	20.0	0.0	60.0	0.0	0.0	0.0
Mar-17	279.0	83.0	492.0	130.0	49.0	179.0	150.0	10.0	339.0
Apr-17	50.0	14.0	91.0	30.0	1.0	71.0	20.0	0.0	39.0
May-17	80.0	15.0	478.0	20.0	0.0	455.0	60.0	0.0	149.0
Jun-17	60.0	20.0	114.0	40.0	8.0	95.0	20.0	0.0	56.0
Jul-17	251.0	95.0	391.0	171.0	56.0	253.0	80.0	10.0	167.0
Aug-17	399.0	128.0	665.0	329.0	133.0	498.0	70.0	0.0	159.0
Sep-17	179.0	85.0	231.0	100.0	28.0	138.0	80.0	24.0	120.0
Oct-17	160.0	50.0	300.0	60.0	0.0	182.0	100.0	25.0	185.0
Nov-17	579.0	238.0	1,235.0	310.0	115.0	886.0	270.0	54.0	450.0
Dec-17	210.0	0.0	547.0	10.0	0.0	27.0	200.0	0.0	506.0
Jan-18	30.0	0.0	83.0	30.0	0.0	88.0	0.0	0.0	0.0
Feb-18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Mar-18	30.0	0.0	70.0	30.0	0.0	68.0	0.0	0.0	0.0
Total	5,547.0	1,996.0	9,907.0	2,760.0	941.0	5,336.0	2,791.0	592.0	5,342.0

Hornsea Four Array Area plus 2 km buffer

Month	All behaviours			Flying			Sitting		
	Abundance	Lower CI	Upper CI	Abundance	Lower CI	Upper CI	Abundance	Lower CI	Upper CI
Apr-16	30.0	0.0	61.0	30.0	0.0	68.0	0.0	0.0	0.0
May-16	580.0	337.0	1,393.0	220.0	130.0	332.0	360.0	146.0	1,103.0
Jun-16	1,431.0	819.0	2,091.0	560.0	337.0	797.0	871.0	338.0	1,435.0
Jul-16	440.0	215.0	628.0	300.0	122.0	430.0	140.0	21.0	326.0
Aug-16	200.0	104.0	607.0	170.0	78.0	581.0	30.0	3.0	103.0
Sep-16	260.0	62.0	431.0	100.0	29.0	151.0	160.0	20.0	284.0
Oct-16	860.0	494.0	1,277.0	160.0	86.0	325.0	700.0	378.0	1,031.0
Nov-16	539.0	265.0	709.0	310.0	146.0	401.0	230.0	91.0	328.0
Dec-16	369.0	75.0	1,291.0	279.0	59.0	903.0	90.0	0.0	325.0
Jan-17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Feb-17	30.0	0.0	66.0	30.0	0.0	64.0	0.0	0.0	0.0
Mar-17	320.0	121.0	544.0	150.0	82.0	220.0	170.0	18.0	343.0
Apr-17	70.0	30.0	93.0	40.0	10.0	70.0	30.0	0.0	53.0
May-17	90.0	25.0	191.0	20.0	0.0	86.0	70.0	0.0	153.0
Jun-17	100.0	57.0	185.0	80.0	47.0	176.0	20.0	0.0	57.0
Jul-17	440.0	209.0	625.0	300.0	153.0	432.0	140.0	26.0	235.0
Aug-17	591.0	283.0	893.0	421.0	216.0	612.0	170.0	17.0	377.0
Sep-17	260.0	148.0	323.0	150.0	64.0	216.0	110.0	38.0	156.0
Oct-17	230.0	104.0	361.0	70.0	13.0	150.0	160.0	68.0	257.0
Nov-17	720.0	372.0	1,207.0	370.0	165.0	662.0	350.0	141.0	577.0
Dec-17	421.0	55.0	903.0	50.0	10.0	126.0	371.0	21.0	836.0
Jan-18	70.0	12.0	135.0	70.0	14.0	129.0	0.0	0.0	0.0
Feb-18	10.0	0.0	77.0	10.0	0.0	77.0	0.0	0.0	0.0
Mar-18	130.0	21.0	246.0	50.0	10.0	84.0	80.0	0.0	202.0
Total	8,191.0	3,808.0	14,337.0	3,940.0	1,771.0	7,092.0	4,252.0	1,326.0	8,181.0

Hornsea Four Array Area plus 4 km buffer									
Month	All behaviours			Flying			Sitting		
	Abundance	Lower CI	Upper CI	Abundance	Lower CI	Upper CI	Abundance	Lower CI	Upper CI
Apr-16	40.0	0.0	135.0	40.0	0.0	131.0	0.0	0.0	0.0
May-16	769.0	436.0	1,358.0	319.0	185.0	504.0	449.0	201.0	850.0
Jun-16	1,708.0	988.0	2,371.0	709.0	448.0	975.0	999.0	429.0	1,591.0
Jul-16	648.0	372.0	904.0	399.0	221.0	612.0	249.0	50.0	481.0
Aug-16	319.0	169.0	671.0	259.0	126.0	596.0	60.0	22.0	101.0
Sep-16	309.0	62.0	501.0	130.0	41.0	186.0	180.0	23.0	334.0
Oct-16	1,153.0	687.0	1,547.0	248.0	110.0	484.0	904.0	499.0	1,246.0
Nov-16	678.0	294.0	852.0	379.0	148.0	507.0	299.0	119.0	402.0
Dec-16	419.0	118.0	931.0	327.0	113.0	708.0	92.0	0.0	226.0
Jan-17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Feb-17	50.0	8.0	101.0	40.0	0.0	83.0	10.0	0.0	48.0
Mar-17	389.0	127.0	612.0	150.0	67.0	201.0	239.0	20.0	466.0
Apr-17	120.0	39.0	198.0	60.0	20.0	87.0	60.0	0.0	117.0
May-17	140.0	52.0	265.0	20.0	0.0	59.0	120.0	32.0	255.0
Jun-17	160.0	100.0	427.0	120.0	69.0	363.0	40.0	0.0	118.0
Jul-17	559.0	295.0	1,150.0	419.0	240.0	1,021.0	140.0	22.0	233.0
Aug-17	730.0	476.0	1,072.0	530.0	331.0	786.0	200.0	45.0	374.0
Sep-17	339.0	200.0	397.0	189.0	86.0	251.0	150.0	61.0	234.0
Oct-17	315.0	184.0	431.0	102.0	34.0	163.0	213.0	120.0	297.0
Nov-17	1,248.0	604.0	2,076.0	649.0	322.0	1,076.0	599.0	244.0	983.0
Dec-17	480.0	126.0	928.0	60.0	13.0	108.0	420.0	74.0	883.0
Jan-18	120.0	23.0	262.0	120.0	21.0	265.0	0.0	0.0	0.0
Feb-18	20.0	0.0	105.0	20.0	0.0	103.0	0.0	0.0	0.0
Mar-18	180.0	42.0	316.0	70.0	20.0	109.0	110.0	0.0	257.0
Total	10,893.0	5,402.0	17,610.0	5,359.0	2,615.0	9,378.0	5,533.0	1,961.0	9,496.0

Table 9: Gannet DCO MRSea_v1 abundance estimate results for the Hornsea Four array area, array, array area plus 2 km buffer and array area plus 4 km buffer.

Hornsea Four Array Area									
Month	All behaviours			Flying			Sitting		
	Abundance	Lower CI	Upper CI	Abundance	Lower CI	Upper CI	Abundance	Lower CI	Upper CI
Apr-16	150.8	76.3	338.0	150.8	76.3	338.0	0.0	0.0	0.0
May-16	334.1	214.0	541.9	140.1	89.7	227.3	194.0	124.3	314.7
Jun-16	661.3	443.2	956.1	259.3	173.8	375.0	401.9	269.4	581.2
Jul-16	212.8	136.0	329.8	147.3	94.2	228.3	65.5	41.9	101.5
Aug-16	289.6	177.9	494.9	225.2	138.4	384.9	64.4	39.5	110.0
Sep-16	235.5	154.3	376.3	90.6	59.3	144.7	144.9	94.9	231.6
Oct-16	593.2	427.1	788.0	111.2	80.1	147.8	481.9	347.0	640.3
Nov-16	326.7	229.6	494.2	181.5	127.5	274.5	145.2	102.0	219.6
Dec-16	158.3	78.8	274.8	120.6	60.1	209.3	37.7	18.8	65.4
Jan-17	4.9	1.4	18.2	1.7	0.0	0.0	3.3	1.4	18.2
Feb-17	34.6	20.9	59.8	34.6	20.9	59.8	0.0	0.0	0.0
Mar-17	106.4	50.8	254.2	49.4	23.6	118.0	57.0	27.2	136.2
Apr-17	153.3	61.7	339.7	92.0	37.0	203.8	61.3	24.7	135.9
May-17	259.7	133.0	657.6	64.9	33.2	164.4	194.8	99.7	493.2
Jun-17	76.8	46.3	125.5	51.2	30.9	83.7	25.6	15.4	41.8
Jul-17	436.2	250.2	764.9	296.6	170.1	520.1	139.6	80.1	244.8
Aug-17	324.1	225.1	509.5	267.4	185.7	420.3	56.7	39.4	89.2
Sep-17	281.9	175.6	457.3	156.6	97.6	254.1	125.3	78.1	203.2
Oct-17	295.7	194.6	484.7	110.9	73.0	181.7	184.8	121.6	302.9
Nov-17	592.6	343.1	1,006.9	316.8	183.4	538.2	275.9	159.7	468.7
Dec-17	168.3	73.0	368.4	8.0	3.5	17.5	160.3	69.6	350.9
Jan-18	118.3	49.9	303.9	118.3	49.9	303.9	0.0	0.0	0.0
Feb-18	7.4	2.5	20.8	2.5	0.0	0.0	4.9	2.5	20.8
Mar-18	61.8	30.9	135.2	61.8	30.9	135.2	0.0	0.0	0.0
Total	5,884.4	3,596.3	10,100.7	3,059.4	1,839.1	5,330.7	2,825.0	1,757.2	4,770.0

Hornsea Four Array Area plus 2 km buffer

Month	All behaviours			Flying			Sitting		
	Abundance	Lower CI	Upper CI	Abundance	Lower CI	Upper CI	Abundance	Lower CI	Upper CI
Apr-16	217.3	110.7	489.4	217.3	110.7	489.4	0.0	0.0	0.0
May-16	481.5	306.8	790.5	182.6	116.4	299.8	298.9	190.4	490.7
Jun-16	953.0	640.7	1,372.1	373.2	250.9	537.3	579.8	389.8	834.8
Jul-16	306.7	195.9	477.2	209.1	133.5	325.3	97.6	62.3	151.8
Aug-16	417.3	255.6	720.2	354.7	217.2	612.2	62.6	38.3	108.0
Sep-16	339.4	223.8	541.3	130.5	86.1	208.2	208.8	137.7	333.1
Oct-16	854.8	617.6	1,140.6	159.0	114.9	212.2	695.8	502.7	928.4
Nov-16	470.7	331.1	718.3	270.2	190.1	412.4	200.5	141.0	305.9
Dec-16	228.2	115.6	394.7	172.7	87.5	298.7	55.5	28.1	96.0
Jan-17	7.1	2.0	26.0	2.4	0.0	0.0	4.7	2.0	26.0
Feb-17	49.8	30.1	85.8	49.8	30.1	85.8	0.0	0.0	0.0
Mar-17	153.4	74.5	369.9	71.9	34.9	173.4	81.5	39.6	196.5
Apr-17	221.0	89.0	498.5	126.3	50.9	284.8	94.7	38.1	213.6
May-17	374.3	191.8	943.1	83.2	42.6	209.6	291.1	149.1	733.6
Jun-17	110.6	66.3	181.0	88.5	53.0	144.8	22.1	13.3	36.2
Jul-17	628.6	356.1	1,124.3	428.6	242.8	766.6	200.0	113.3	357.7
Aug-17	467.1	326.9	731.4	332.5	232.7	520.6	134.6	94.2	210.7
Sep-17	406.3	251.7	663.6	234.4	145.2	382.8	171.9	106.5	280.8
Oct-17	426.1	279.3	704.1	129.7	85.0	214.3	296.4	194.3	489.8
Nov-17	854.0	495.5	1,447.4	438.9	254.6	743.8	415.2	240.8	703.6
Dec-17	242.5	107.2	532.2	28.9	12.8	63.4	213.6	94.4	468.8
Jan-18	170.4	71.1	446.4	170.4	71.1	446.4	0.0	0.0	0.0
Feb-18	10.7	3.7	29.8	3.6	3.7	29.8	7.1	0.0	0.0
Mar-18	89.1	44.6	195.5	34.3	17.2	75.2	54.8	27.5	120.3
Total	8,480.0	5,187.6	14,623.4	4,292.8	2,584.0	7,536.9	4,187.2	2,603.6	7,086.5

Hornsea Four Array Area plus 4 km buffer									
Month	All behaviours			Flying			Sitting		
	Abundance	Lower CI	Upper CI	Abundance	Lower CI	Upper CI	Abundance	Lower CI	Upper CI
Apr-16	288.4	147.3	652.8	288.4	147.3	652.8	0.0	0.0	0.0
May-16	639.2	404.4	1,061.3	265.7	168.1	441.0	373.6	236.3	620.2
Jun-16	1,265.1	850.4	1,826.7	525.3	353.1	758.4	739.8	497.3	1,068.2
Jul-16	407.2	258.8	637.8	250.6	159.3	392.5	156.6	99.5	245.3
Aug-16	554.0	336.4	965.3	450.1	273.3	784.3	103.9	63.1	181.0
Sep-16	450.5	298.0	718.4	188.9	125.0	301.3	261.6	173.0	417.2
Oct-16	1,134.8	817.0	1,530.0	244.6	176.1	329.7	890.2	641.0	1,200.2
Nov-16	624.9	437.7	966.7	349.2	244.6	540.2	275.7	193.1	426.5
Dec-16	302.9	155.0	523.8	236.4	121.0	408.8	66.5	34.0	115.0
Jan-17	9.5	2.6	34.4	3.2	0.0	0.0	6.3	2.6	34.4
Feb-17	66.1	39.9	114.1	52.9	31.9	91.3	13.2	8.0	22.8
Mar-17	203.6	100.2	496.0	78.3	38.5	190.8	125.3	61.7	305.2
Apr-17	293.4	117.9	674.4	146.7	59.0	337.2	146.7	59.0	337.2
May-17	496.9	253.6	1,248.5	71.0	36.2	178.4	425.9	217.4	1,070.1
Jun-17	146.9	87.3	241.7	110.1	65.4	181.3	36.7	21.8	60.4
Jul-17	834.5	466.2	1,520.6	625.9	349.6	1,140.4	208.6	116.5	380.1
Aug-17	620.1	434.2	971.1	450.2	315.3	705.0	169.9	119.0	266.0
Sep-17	539.4	332.0	889.8	301.4	185.5	497.3	238.0	146.5	392.6
Oct-17	565.7	369.2	942.9	183.0	119.4	305.1	382.7	249.7	637.8
Nov-17	1,133.8	656.9	1,926.4	589.6	341.6	1,001.7	544.2	315.3	924.7
Dec-17	321.9	144.2	709.7	40.2	18.0	88.7	281.7	126.2	621.0
Jan-18	226.3	93.3	603.5	226.3	93.3	603.5	0.0	0.0	0.0
Feb-18	14.2	5.0	39.3	4.8	5.0	39.3	9.4	0.0	0.0
Mar-18	118.3	59.1	261.1	46.0	23.0	101.5	72.3	36.1	159.5
Total	11,257.5	6,866.4	19,556.1	5,728.8	3,449.4	10,070.5	5,528.7	3,417.1	9,485.6