NORTH FALLS

Offshore Wind Farm

Report to Inform Appropriate Assessment

Appendix 4.1 Modelling the abundance of red-throated divers in the area of overlap between North Falls digital aerial surveys (12km buffer) and the Outer Thames Estuary Special Protection Area

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Modelling the overlap of red-throated divers from North Falls digital aerial surveys with the Outer Thames SPA

Authorisations

Responsibility	Name	Signature	Date
Prepared by	[redacted]	[redacted]	[redacted]
Checked by	[redacted]	[redacted]	[redacted]
	[redacted]	[redacted]	[redacted]
Approved by	[redacted]	[redacted]	[redacted]

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Executive Summary

In February 2019, Innogy, now RWE, commissioned HiDef Aerial Surveying Limited (HiDef) to undertake a programme of high-resolution digital video aerial surveys of marine megafauna, ornithological and human activity in support of the development proposals for the proposed North Falls Offshore Wind Farm (NFOW). Previously to this, two surveys were performed for Natural England in the Outer Thames SPA in February 2018 to quantify the abundance and distribution of red-throated divers: the focal species for the below study (Irwin *et al.*, 2019). In August 2022, RWE further commissioned HiDef to analyse these data in the context of a density surface model to assess potential displacement of red-throated divers (RTD) within the Outer Thames Estuary (OTE) SPA.

NFOW is an extension to the existing Greater Gabbard Wind Farm, which is located approximately 23km east of the Suffolk coast in the southern North Sea. The NFOW also lies approximately 4.5km northeast of the Outer Thames Estuary SPA.

Monthly surveys in the NFOW were flown from March 2019 to February 2021. This equated to 24 surveys in total, comprising a complete two-year programme. HiDef designed a survey that placed transects at 2.5km separation across the 772km^2 survey area including a 4km buffer around the proposed extension (the survey area), and a 12km buffer during surveys in January and February 2021.

Surveys were undertaken using an aircraft equipped with four HiDef Gen II cameras with sensors set to a resolution of 2cm Ground Sample Distance (GSD). Each camera sampled a strip of 125m width, separated from the next camera by ~25m, which provides a combined sampled width of 500m within a 575m overall strip. To ensure that sufficient footage is available to allow either a design-based or model-based analysis, footage from three cameras was analysed to give a site coverage of 15%.

Data analysis followed a two-stage process in which video footage is reviewed (with a 20% random sample used for audit) then the detected objects are identified to species or species group level (again with 20% selected at random for audit). The audit of both stages requires 90% agreement to be achieved.

Density surface models were generated for February 2018 (in the Outer Thames Estuary SPA), and January and February 2021 (in the NFOW survey area); all surveys had sufficient observations to generate spatial density models. Examining the effect of several environmental covariates demonstrated that all predictors only contributed marginally to the model with only the spatial covariate contributing information to the predictions.

Inlabru predictions of red-throated diver density within the 12 km buffer of North Falls overlap with the OTE SPA show that birds were mostly distributed through the western and northern regions of the study area (i.e., the eastern side of the SPA) in the 2021 surveys. The same patterns of high densities in the western-most buffers were also noted in the 2018 models suggesting that the distribution of red-throated divers is not significantly different between both survey years.

1 Introduction

1 The Greater Gabbard Offshore Wind Farm is a joint venture between RWE and SSE Renewables (SSER), operated by SSER. The wind farm is located 23km off the Suffolk coast, close to its sister project, Galloper Wind Farm, and is comprised of 140 operational wind turbines.

2 In February 2019, RWE commissioned HiDef Aerial Surveying Limited (HiDef) to undertake a programme of high-resolution digital video aerial surveys of marine megafauna, ornithological and human activity in support of the development proposals for a proposed extension to Greater Gabbard, North Falls Offshore Wind Farm (NFOW). Furthermore in 2018, two digital aerial surveys were flown for Natural England in February in the Outer Thames SPA by HiDef.

3 HiDef designed the survey methodology to provide information suitable to support the RWE/SSER joint venture proposal to extend Greater Gabbard for which an accurate assessment of abundance and distribution of seabirds and marine mammals is required to enable environmental assessment to take place. Surveys were conducted across both the proposed NFOW array and a surrounding 4km (or 12km) buffer (the survey area).

4 Several important bird sites classified as Special Protection Areas (SPA) under the European Council (EC) Directive 2009/147/EC on the Conservation of Wild Birds (the Birds Directive) are in the vicinity of the survey area. The Outer Thames Estuary SPA approximately 4.5km west of NFOW is designated for non-breeding red-throated diver (*Gavia stellata*) and breeding common tern (*Sterna hirundo*) and little tern (*Sternula albifrons*) in summer.

5 Digital aerial surveys flown by HiDef overlapped the southern section of the Outer Thames SPA in January and February 2021, thus allowing for an examination of the potential displacement effects into the SPA. Although the Outer Thames SPA is made up of a southern and northern region, for the purposes of this work, reference to the Outer Thames SPA is only to the southern region.

6 Red-throated divers are waterbirds known to be sensitive to displacement effects from wind turbines and frequent the Outer Thames estuary in the non-breeding season. With the increase in the number of offshore wind developments in the region, it is therefore imperative to understand the impact these wind farms have on this species. This report provides estimates from density surface modelling of red-throated diver in the area where the 12km buffer of NFOW overlaps with the Outer Thames Estuary SPA. These estimates are from the 2 NFOW baseline surveys with sufficient sample size, undertaken in January and February 2021, and from a survey of the SPA undertaken in February 2018 (Irwin *et al*., 2019).

2 Methods

2.1 Survey flights

7 A series of strip transects were flown in February 2018 and January and February 2021, following the methodology agreed in February 2017 (in the Outer Thames SPA for 2018; document reference: HP00088-702, Irwin *et al.* (2019)) and 2019 (in the NFOW region for 2021; document reference: HP00100-001).

8 For the Outer Thames SPA, HiDef designed a survey that placed transects at 3.3km apart across the survey area (i.e., the boundary of the SPA), making up 22 transect lines in total (Figure 1). Transect lines ran north to south. In the NFOW region, HiDef designed a survey that placed transects at 2.5km apart across the 772km^2 survey area, including a 12km buffer around the proposed NFOW site (Figure 2). the distribution of the survey design consisted of 19 strip transects extending roughly north-west to south-east, perpendicular to the depth contours along the coast.

9 The transect-based non-stratified survey design helps to ensure that each transect samples a similar range of habitats (primarily relating to water depth) to reduce the variation in bird and mammal abundance estimates between transects.

10 Surveys were undertaken using an aircraft equipped with four HiDef Gen II cameras with sensors set to a resolution of 2cm Ground Sample Distance (GSD). Each camera sampled a strip of 125m width, separated from the next camera by ~25m, thus providing a combined sampled width of 500m within a 575m overall strip.

11 Approximately 15% site coverage was achieved for the Outer Thames SPA and NFOW surveys.

12 The surveys were flown along the transect pattern shown in Figure 2 at a height of approximately 550m above sea level (ASL) (~1800’). Flying at this height ensures that there is no risk of flushing those species which have been proven to be easily disturbed by aircraft noise (Thaxter *et al.* (2016) recommends a minimum flight altitude of 500m ASL).

13 Position data for the aircraft was captured from a Garmin GPSMap 296 receiver with differential GPS enabled to give 1m accuracy for the positions and recording updates in location at one second intervals for later matching to bird and marine mammal observations.

Figure 1 Survey design showing stratified survey transects for the Outer Thames Estuary SPA with (inset) 'Foulness SPA extension' for February 2018. For modelling purposes in this work, only the southern SPA region is focused on.

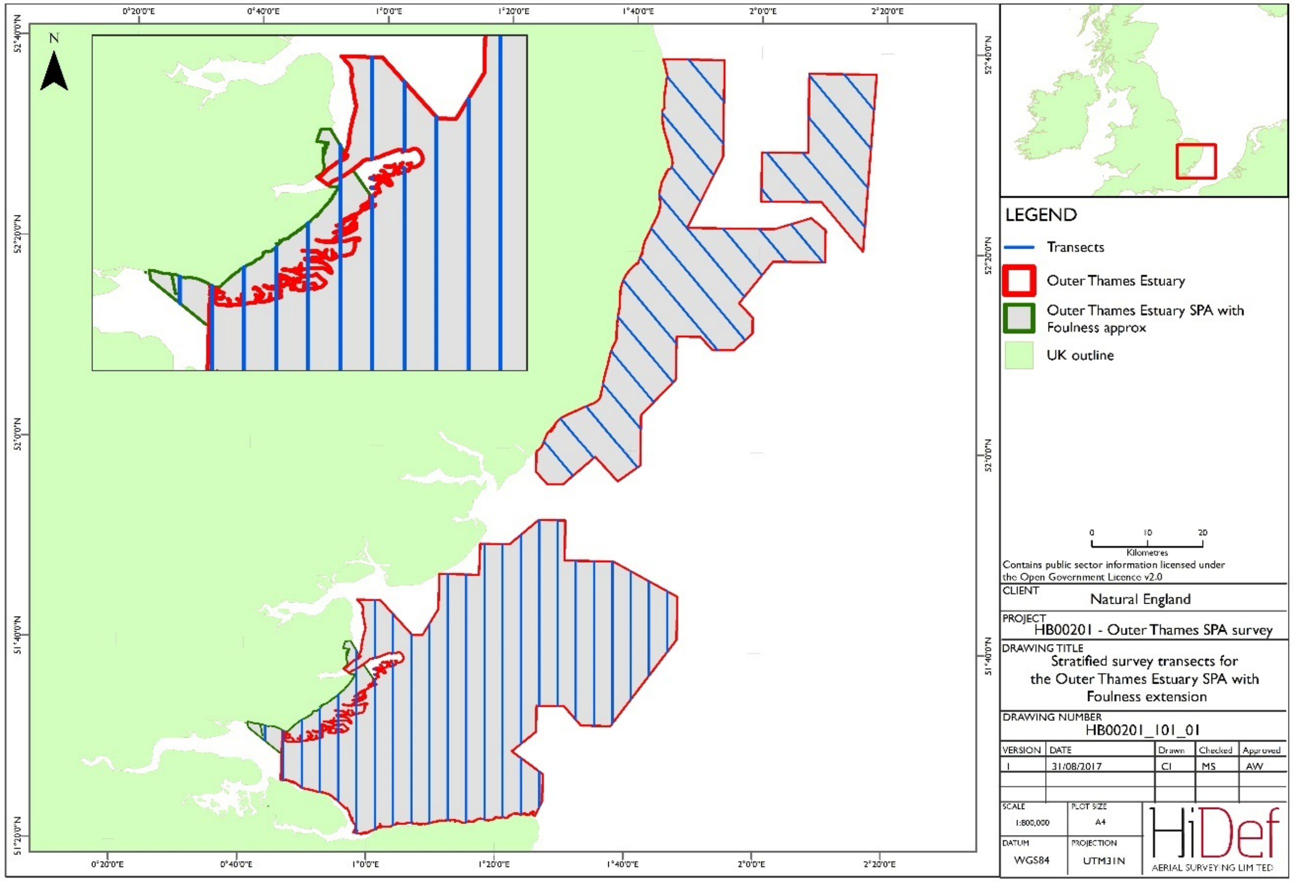
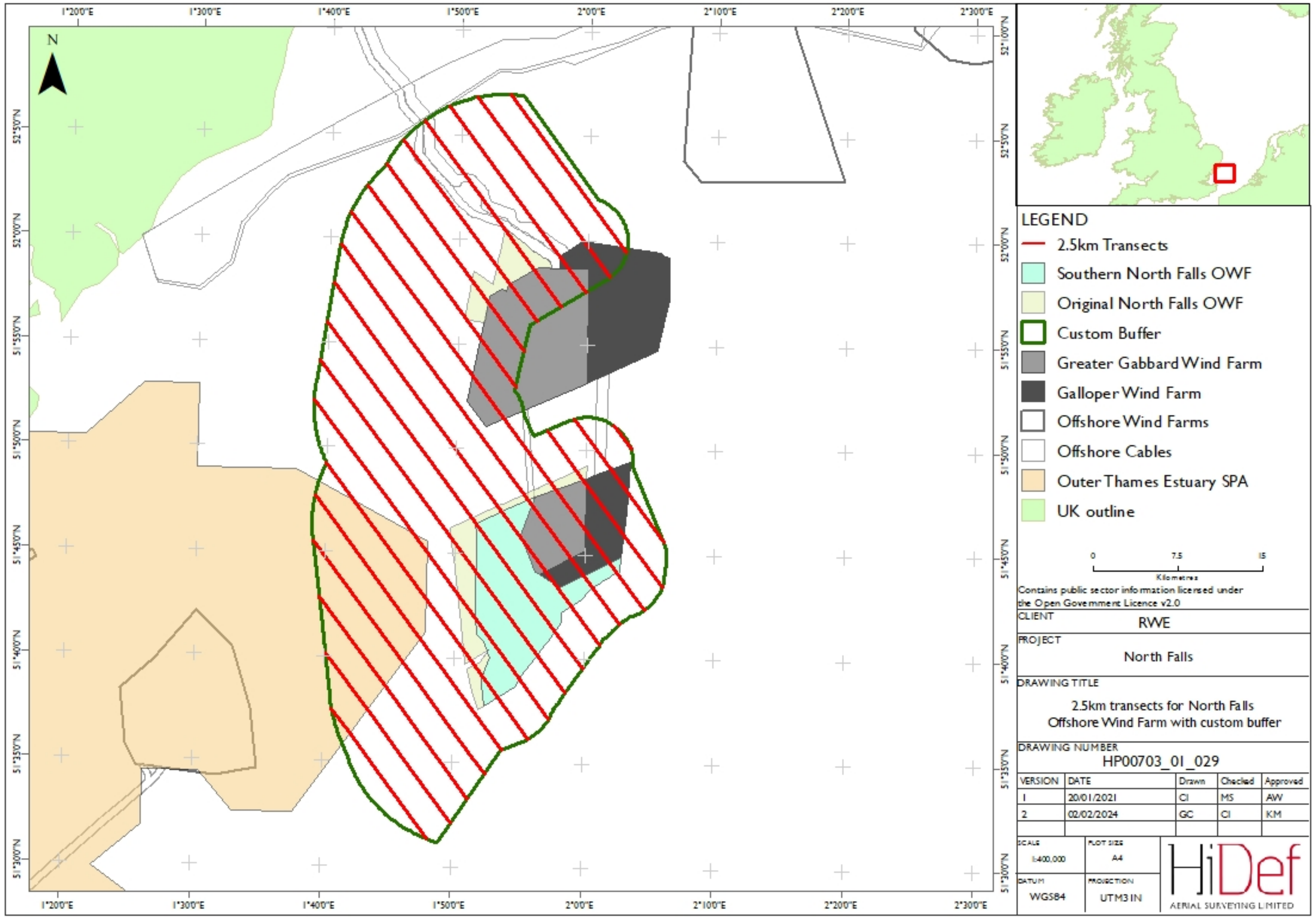


Figure 2 **Survey design showing the NFOW survey area with 12km buffer and 2.5km spaced transects**



2.2 Data Review and Object Detection

14 Data were viewed by trained reviewers who marked any objects in the footage as requiring further analysis, as well as determining which are birds, marine megafauna (defined within this report as cetaceans, pinnipeds or other large, non-avian marine fauna) or anthropogenic objects such as ships or buoys.

15 As part of HiDef's quality assurance (QA) process, an additional 'blind' review of 20% of the raw data was carried out and the results compared with those of the original review. If 90% agreement is not attained during the QA process, then corrective action is initiated: the remaining data set is reviewed and where appropriate, the failed reviewer's data discarded and all the data re-reviewed. In addition, additional training is then given to the reviewer to improve performance. No re-reviews were required for the data set.

16 An object is only recorded where it crosses a reference line (known as 'the red line') which defines the true transect width of 125m for each camera. This red line is visible on the data during the analysis stage to ensure objects cross it. By excluding objects that do not cross the red line, biases to abundance estimates caused by flux (movement of objects in the video footage relative to the aircraft, such as 'wing wobble') are eliminated.

2.3 Object Identification

17 Images marked as requiring further analysis were reviewed by specialist ornithologists[1] and marine mammal specialists[2] for identification (ID) to the lowest taxonomic level possible and for assessment of the approximate age and the sex of each animal, as well as any behaviour traits visible from the imagery.

18 At least 20% of all objects were selected at random and subjected to a separate 'blind' QA process. If less than 90% agreement was attained for any individual camera then corrective action is initiated: if appropriate, the failed identifier's data were discarded, and the data re-identified. Any disputed identifications were passed to a third-party expert ornithologist for a final decision[1]. The level of agreement within the QA process is calculated as the final number of agreements as a percentage of all identifications subjected for QA for the entire survey.

19 All objects are assigned to a species group and where possible, each of these then further identified to species level. The species identifications are given a confidence rating of 'possible', 'probable' or 'definite'[3]. It is important to note that this is not a standardised assessment. The likelihood of achieving a definite or probable identification is not consistent for all component members of a species group. For example, someone undertaking ID of a large auk species will find it easier to be confident of guillemot identification than razorbill. If these confidence scores are used to filter or weight the probability of large auk being one species or another in any analysis, then this will lead to biased results, particularly if

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[1] HiDef currently employs three (3) of the ten (10) current members of the British Birds Rarities Committee (BBRC) as expert ornithologists

[2] Our staff have long-standing experience in marine mammal identification, regularly undertaking boat surveys as part of ESAS (European Seabirds At Sea Partnership). We process thousands of cetacean images, hold regular internal training sessions and have access to marine specialists within our wider company BioConsult SH.

[3] Definite: as certain as reasonably possible. Probable: very likely to be this species or species group. Possible: more likely to be this species or species group than anything else.

the identification rate is low. It is better to use the assessment of the person who is looking at the images rather than making assumptions based on biased data with high confidence identifications.

20 Any animals that could not be identified to species level were assigned to a category 'No ID'. If, on occasion, the unidentified bird is suspected of belonging to two different possible genera, then a broader group category may be used. For example, a bird would usually be assigned to the group category 'Shearwater species' if identified as a Manx shearwater (*Puffinus puffinus*), or to 'Auk species' if identified as a guillemot. However, if the bird has the potential to be either, then it would be assigned to the group category 'Shearwater / Auk species' and the species level recorded as No ID.

21 Another species group on this site which is problematic is the 'commic' terns comprising of common and Arctic terns. Depending on angle to camera, weather conditions and bird behaviour, identification can be challenging. The identification team take species identification to the highest level possible, but at times it is deemed safer to retain the either-or-status.

22 In the case of birds, additional information was recorded on behaviour (whether the bird was sitting, loafing on land or other objects, or flying). More detail was recorded where possible on foraging behaviour, approximate age and sex and any other details of interest. Aging of birds was based on moults and is thus mostly conducted on flying individuals and species which show seasonal variation in plumage.

23 Anthropogenic activity was recorded as either 'man-made object', 'fishing boat' or 'other boat'. Further details were noted in the comments, including further specifying the type of object (e.g., 'fishing buoy', 'marker buoy', 'wind turbine') or noting any names and numbers that can be seen.

2.4 Data quality check

24 HiDef's method is designed to ensure low rejection of data on grounds of quality, such as low cloud, sun glare or other issues. Care is taken to avoid survey in low cloud or poor visibility by careful selection of survey days with the correct survey conditions. In the unlikely event that low cloud occurs during a survey, the pilot is instructed to either avoid areas affected and return to those at the end of the survey, return to a nearby base and wait for cloud to clear or abandon the survey. Sun glare is avoided by design of the survey rig which uses angled cameras on a rotating plinth. This means that the cameras are always angled away from any sun glare, with the camera rig rotated in between transects to ensure that this angle is maintained.

25 All data undergoes a full check on return to the office consisting of a review of every camera and every transect. Any issues that may affect usability of the data are flagged at this stage and may result in a re-fly of the survey.

26 Glare data are recorded on all cameras throughout the survey. For each individual survey, on one of the cameras (known as the 'weather camera') the following weather conditions are also recorded – sea state and turbidity. Operators carrying out bird and mammal identification carry out environmental checks of the data and score sun glare and turbidity on a scale from 1 - 4 in which score 4 is a high degree of sun glare or turbidity in which the data should not be used because it would affect detection rates. Sea state is scored based on the WMO Sea State code, in which score 6 or more is a high degree of sea state in which the data should not be used as it would affect detection rates.

27 Tables are provided below to show how glare, sea state and turbidity are scored.

Table 1 **Scoring criteria for recording glare and turbidity**

Score	Criteria
0	Can't tell / Not Recorded / Over land
1	None present
2	Slight
3	Moderate
4	Strong

Table 2 **Scoring criteria for recording sea state as outlined by the WMO Sea State code**

WMO Sea State Code	Wave height (m)	Characteristics
0	0	Calm (glassy)
1	0 to 0.1	Calm (rippled)
2	0.1 to 0.5	Smooth (wavelets)
3	0.5 to 1.25	Slight (first whitecaps)
4	1.25 to 2.5	Moderate (many whitecaps)
5	2.5 to 4	Rough (some spray)
6	4 to 6	Very rough (large waves, many whitecaps, much spray)
7	6 to 9	High (streaks of wind-blown foam)
8	9 to 14	Very high
9	Over 14	Phenomenal

2.5 Final processing

28 All data were geo-referenced, considering the offset from the transect line of the cameras, and compiled into a single output; Geographical Information System (GIS) files for the Observation and Track data are issued in ArcGIS shapefile format, using UTM31N projection, WGS84 datum.

2.6 Data analysis

2.6.1 Data treatment

29 No apportioning of 'partially identified' birds to species level was undertaken and they were not included in the analysis. All confidence levels of species identifications were used in the analysis. Surveys from 2018 and 2021 with identification categories of diver species and large auk/diver species were identified as red-throated divers in 97.6% and 94.6% of instances, respectively. Diver species category records were not identified as anything other than red-throated divers or given a No ID status. No ID accounted for three out of 3,676 records of diver species in February 2018 and zero of 248 records in January and February 2021. Large auk/diver species category records were identified as red-throated divers, guillemots, razorbills or given a No ID status. No ID and auks accounted for 69 and ten out of 88 records of large auk/diver species in February 2018, respectively, against six and three out of 19 records in January and February 2021, respectively.

30 The total number of records found during the strip transect surveys was calculated.

2.6.2 Density surface modelling

31 Because digital aerial surveys did not sample 100% of the study area, the data needed to be extrapolated between transects. These sorts of modelling exercises are done by associating covariates to observations, and then predicting (extrapolating) into areas where we have information on the covariates, but not on observations. This work was done using a point pattern process in a Bayesian framework.

32 A point pattern records the occurrence of events in a study region where the locations of these observations depend on an underlying spatial process (e.g., bathymetry or sea surface temperature, which can vary in space). This spatial process can be characterised using the Cox process, which is a Poisson process with intensity $\lambda(s)$ that varies in space. This intensity function measures the average number of events per unit of space, and it can be modelled to depend on covariates and other effects (Diggle *et al*., 2014; Baddeley *et al*., 2015).

33 Under the log-Cox point process model assumption, log intensity of the Cox process is modelled with a Gaussian linear predictor. In this case, the log-Cox process is known as a log-Gaussian Cox process (LGCP, Møller *et al*., 1998), and inference can be made using the Integrated Nested Laplace Approximation approach (INLA; Illlian *et al*. 2012), which was developed as a computationally efficient alternative to Markov Chain Monte Carlo (MCMC) methods (Robert and Casella 2010; Brooks, 2011). The log-Gaussian part of the LGCP name comes from modelling $\log(\lambda(s))$ as a latent Gaussian parameter (conditional on a set of hyper-parameters), in the typical GLM/GAM framework.

34 To fit these models in INLA we used the stochastic partial differential equation (SPDE) approach (Simpson *et al*., 2016). The SPDE approach consists of representing a continuous spatial process, e.g., a latent stationary Gaussian Field (GF) with the Matèrn covariance function as a discretely indexed spatial random process (e.g., a Gaussian Markov Random Field (GMRF); Rue and Held, 2005). This approach is faster and uses less computing power, while accounting for spatio-temporal interdependence and autocorrelation in the data and it considers a direct approximation of the logCox point process model likelihood, where observations are modelled considering its exact location instead of binning them into cells. This approach is flexible in handling non-rectangular areas such as coastlines.

35 Model fitting was carried out given a model of the point density and a set of priors for all model parameters (Williamson, et al., 2022). The use of priors is particularly useful for clustered data as they allow for the incorporation of prior information and the quantification of uncertainty at different levels of the model hierarchy (Williamson, et al., 2022). The data sets for each survey are also large enough to avoid issues with outliers or zero-inflation.

36 Separate models were fitted to the individual data sets for each survey to generate density estimates and abundance predictions for each month. These models were fitted with the same priors for each of the surveys. The priors were set for the range, ρ, as follows:

$$P(\rho < 10) = 0.01$$

This implies that the probability of the range being less than 10km is 0.01. We can interpret this as 10km being the minimum distance across which points are likely to be correlated (Laxton, et al., 2023). This is chosen based on previous knowledge of the spatial distribution of red-throated divers and by looking at the patterns of the current observations.

The priors for standard deviation, σ, were set as follows:

$$P(\sigma > 1) = 0.01$$

This can be interpreted as the probability that the actual standard deviation from the model is greater than 1 (Laxton, et al., 2023). Since the probability is low, the actual standard deviation is likely to be between 0 and 1.

37 To account for environmental processes that potentially underpin the density and distribution of red-throated diver, several covariates were incorporated into a Bayesian negative binomial count model which was fitted to a pooled data set containing observations from all surveys (Table 3). Environmental covariates were spatially overlain against observation records binned into approximately 500m long units along the transect line. This extracted the pertinent environmental information for each observation into the data frame for analysis.

Table 3 **List of environmental covariates included in the Bayesian density surface model**

Covariate	Source/Description
Bathymetry	www.gebco.net (Gebco_2022)
Bathymetric slope	Calculated as % change between pixels in bathymetry
Sea surface temperature	Podaac.jpl.nasa.gov (GHRSST v4.1)
Sea surface temperature gradient	Calculated as % change between pixels in SST layer
Sea surface temperature standard deviation	Standard deviation of SST across the survey month
Distance to shipping lanes	Derived from centre lines of main shipping lanes through the Outer Thames region
Distance to active wind farms	Euclidean distance to boundaries of active wind farms

38 In the NFOW only January and February 2021 surveys were modelled for this study as they were the only two which utilised a 12km buffer from the NFOW and >10 observations of red-throated diver. The 12km buffer was needed to assess the impact of the development on displacement, as the effects of wind farms on this species can be >9km (Webb *et al*., 2016; SNCBs, 2022).

39 In the Outer Thames Estuary SPA, the two surveys in February 2018 were modelled and used to compare against outputs from the 2021 models.

40 To assess the potential displacement effect of the NFOW into the Outer Thames Estuary SPA, 1km wide buffers were generated that radiated away from the existing NFOW (**Figure 3**). Buffers that overlapped with the Outer Thames Estuary SPA were clipped to the boundary of the SPA. The mean density was computed by the density surface models, as well as the mean upper and lower confidence limits, which were calculated for each of the buffer regions that overlapped the SPA.

Figure 3 Reference identification of 1km buffers in the overlap region between the survey area and the Outer Thames SPA.

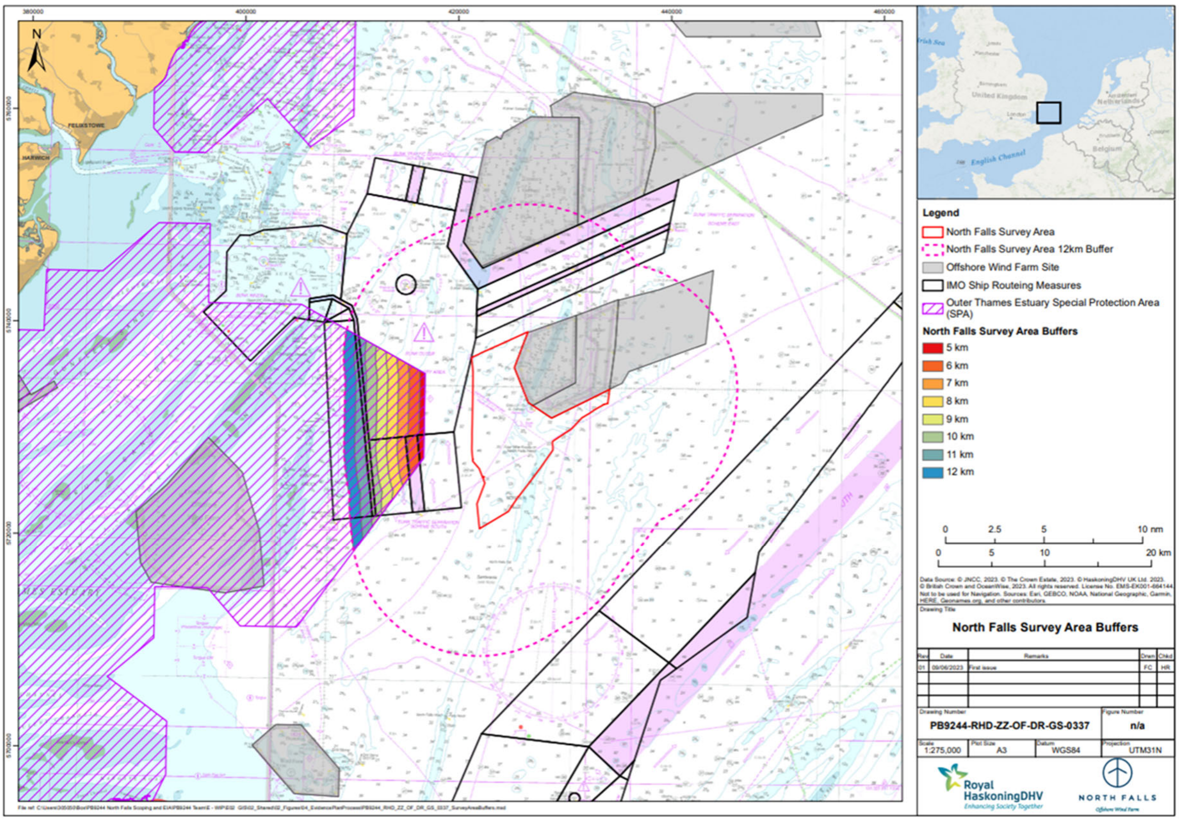


Table 4 Terms used in population density estimates

Term	Definition
Density estimate *(birds/km^2)*	The mean number of birds (or animals) per square km surveyed over the whole area (NFOW array plus 12km buffer)
Population estimate *(number)*	The mean number of birds (or animals) estimated to exist across the whole area (NFOW array plus 12km buffer)
95% confidence intervals or 'limits' of population *(CI)*	A measure of uncertainty in the mean value. If the analysis was repeated, 95% of the time the mean population estimate would fall within this upper and lower boundary. The smaller the relative CI range, the more confident we can be that the mean estimate is an accurate reflection of the true population size.
Standard deviation *(SD)* of population estimate (Also known as standard error)	The amount of variation or dispersion of a set of values. A low SD indicates that the values in the posterior distribution tend to be close to the mean.
CV *(%)*	The coefficient of variation is a standard measure that describes the dispersion of data points around the mean. The lower the CV the more precise the estimate. It is calculated as the SD / mean.

Relative abundance	In the case of diving birds and mammals, this is the estimated population size based on animals recorded on or above the sea surface and does not account for any that may be diving and thus submerged at the time of the survey.
Absolute abundance	The most accurate estimate of population size. In the case of diving birds and mammals, this includes an estimate for the number that are believed to be submerged at the time of survey.

3 Results

3.1 Survey effort

41 The date, number of transects and survey effort (expressed by length of transects) undertaken in 2018 and 2021 are presented in Table 5. The number of transects and the total length of transects are those used in subsequent analysis.

Table 5 Survey effort across the NFOW survey area between January and February 2021 inclusive

Survey date	Survey number	Number of transects analysed	Total length of transects analysed (km)	Area covered (km²)	% coverage
04 February 2018	1	22	661.13	330.56	14.99
17 February 2018	2	22	664.41	332.20	15.07
22 January 2021	23	16	307.38	~115	15.00
13 February 2021	24	16	308.46	115.67	14.98

3.2 Red-throated diver

42 In the southern component of the Outer Thames Estuary SPA, the inlabru population estimate of red-throated divers was highest in the second February 2018 survey with an estimate of 17,429 birds (95% CI 16,693 – 18,174). This is nearly double the estimate of 9,072 (95% CI 8,438 – 9,733) birds in the first February 2018 survey. Birds were seemingly distributed randomly throughout the Outer Thames SPA.

43 In the NFOW area, inlabru modelling showed that the highest estimate of red-throated divers was in February 2021, which gave an estimated population size of 307 birds (95% CI 240 – 389) in the 12km buffered survey area. This compared to the January 2021 estimate of 48 birds (95% CI 24 – 76). In January and February 2021, birds were mostly restricted to the north and west of the survey area, with fewer birds present around the proposed NFOW array (Table 6).

44 Red-throated divers were recorded in both years during the winter months, with birds potentially linked to the nearby Outer Thames Estuary SPA. Birds were mostly distributed in the outer buffer areas to the north and west, away from the turbine proposal area, although some cross-over into the NFOW proposed site was recorded (Figure 4 to Figure 7). However, displacement effects on red-throated divers can be far-reaching outside of wind farms: Webb *et al.* (2016) reported up to 9km displacement at Lincs OWF, Heinänen *et al.* (2020) reports a 10-15km effect, Mendel *et al.* (2019) reports 20km and Petersen *et al.* (2014) reports 13km.

3.3 Bayesian model outputs

45 In the Outer Thames SPA, predicted model outputs show an area of lower densities of red-throated divers associated with the London Array offshore wind farm in the southeast. The highest densities were predicted to the southwest and northeast of this area of low densities. In both surveys, densities of red throated diver in the overlap region with the NFOW 12km buffer were lower than those areas to the west of the overlap region (Figure 4 and Figure 5).

46 In the NFOW survey area, predicted model outputs demonstrate lower densities of red-throated divers in the southern and eastern parts of the survey region. The highest densities of red-throated divers were predicted in the northern and western areas for both the January and February surveys (Figure 6 and Figure 7).

47 Mean densities within 1km bands that overlap the Outer Thames SPA in January 2021 increased steadily from 0.12 birds/km^2 in buffer 1 to a peak of 0.68 birds/km^2 in buffer 8 (Table 6). In February 2021, the lowest mean density was in buffer 1 (1.62 birds/km^2) and peaked at buffer 6 (3.12 birds/km^2; Table 6, Figure 8 and Figure 9). These patterns were very similar to those in the February 2018 surveys where densities were lowest in the most eastern buffers (Table 6, Figure 10 and Figure 11).

48 In all models there was good overlap between observations and predicted distributions when subjectively considering the variability in the data, which suggests that the model fits were appropriate (Figure 12).

Table 6 **Mean, and upper/lower confidence limits (UCL/LCL) within 1km buffer bands inside the Outer Thames SPA.**

Buffer	Distance to NFOW (km)	Mean density (LCL, UCL) 04 February 2018	Mean density (LCL, UCL) 17 February 2018	Mean density (LCL, UCL) 22 January 2021	Mean density (LCL, UCL) 13 February 2021	Area (km^2)
1	5	1.17 (0.31 - 3.91)	0.28 (0.02 - 1.17)	0.12 (0.04 - 0.26)	1.62 (0.94 - 2.57)	4.2
2	6	1.15 (0.39 - 2.91)	0.28 (0.02 - 1.10)	0.14 (0.05 - 0.32)	1.86 (1.14 - 2.86)	9.7
3	7	1.1 (0.38 - 2.52)	0.34 (0.04 - 1.26)	0.19 (0.08 - 0.41)	2.26 (1.40 - 3.55)	11.4
4	8	1.12 (0.35 - 2.86)	0.43 (0.04 - 1.78)	0.24 (0.10 - 0.47)	2.63 (1.71 - 4.02)	13.1
5	9	1.02 (0.38 - 2.42)	0.50 (0.08 - 1.84)	0.33 (0.13 - 0.66)	3.03 (1.91 - 4.58)	15.0
6	10	1.05 (0.39 - 2.27)	0.61 (0.14 - 2.00)	0.42 (0.18 - 0.82)	3.12 (1.98 - 4.50)	16.7
7	11	1.34 (0.57 - 2.68)	0.82 (0.19 - 2.23)	0.58 (0.25 - 1.23)	3.11 (1.99 - 4.74)	18.4
8	12	1.92 (0.94 - 3.66)	0.96 (0.31 - 2.34)	0.68 (0.31 - 1.35)	3.08 (1.91 - 4.60)	20.2
Whole area	NA	1.31 (0.54 - 2.80)	0.59 (0.12 - 1.80)	0.40 (0.18 – 0.80)	2.81 (1.71 - 4.45)	108.67

Figure 4 **Predicted densities of red-throated divers using the *inlabru* R package in the Outer Thames SPA survey region in 04 February 2018**

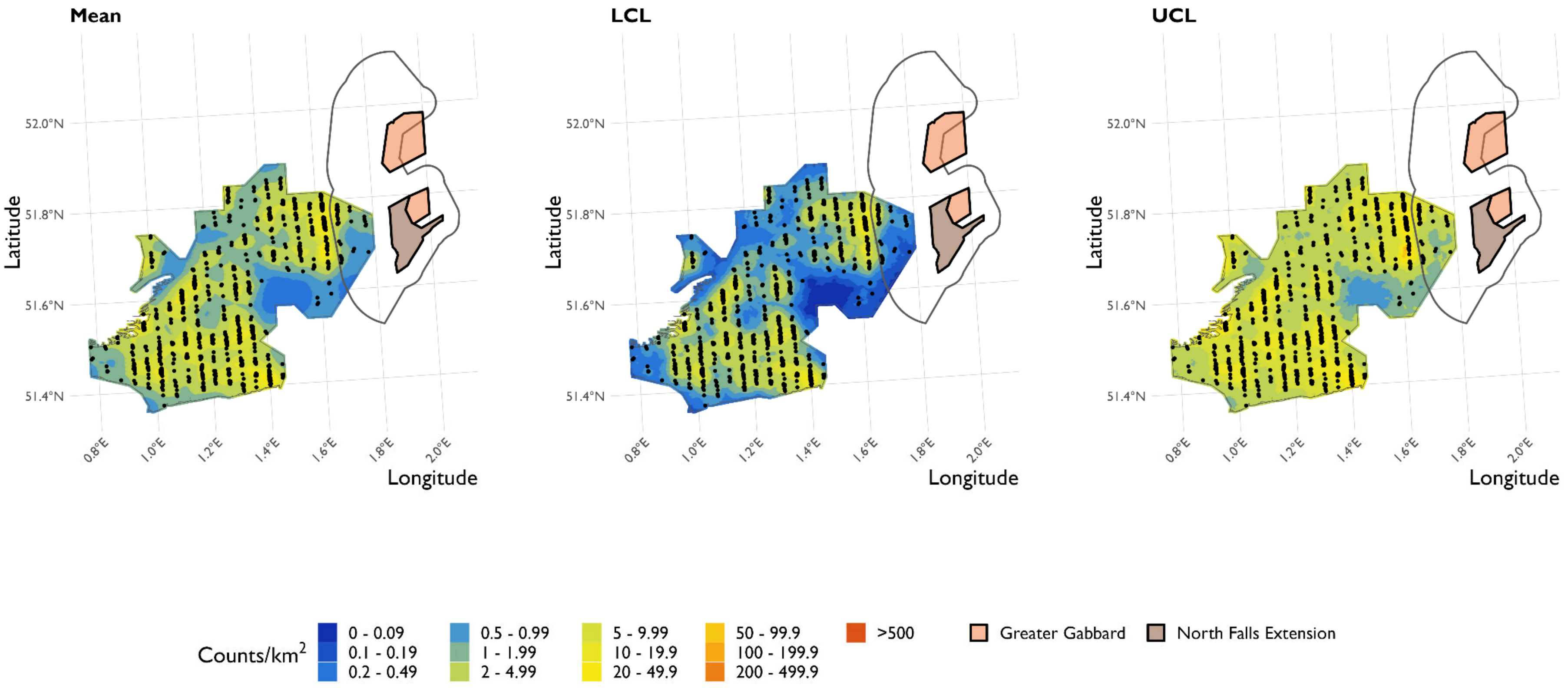


Figure 5 Predicted densities of red-throated divers using the *inlabru* R package in the Outer Thames SPA survey region in 17 February 2018

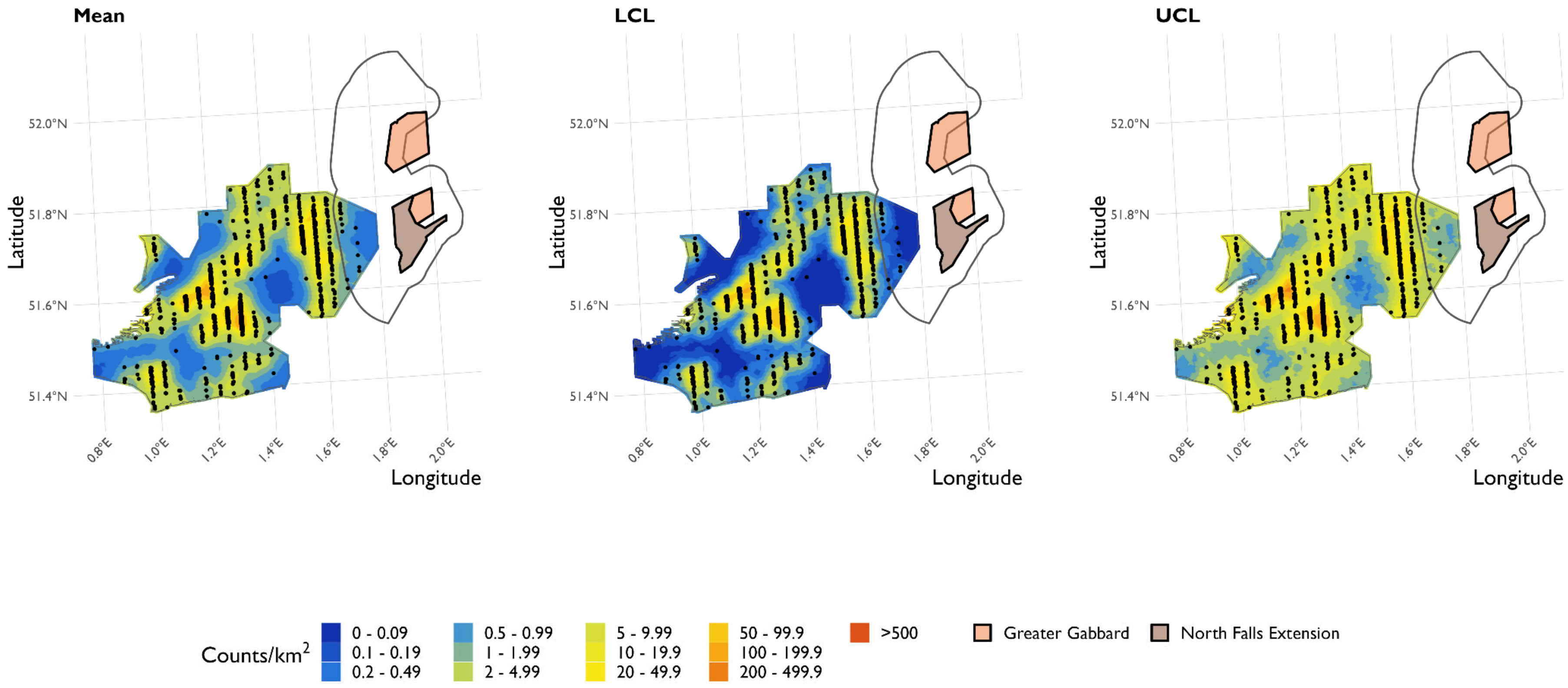


Figure 6 **Predicted densities of red-throated divers using the *inlabru* R package in the NFOW survey region in 22 January 2021**

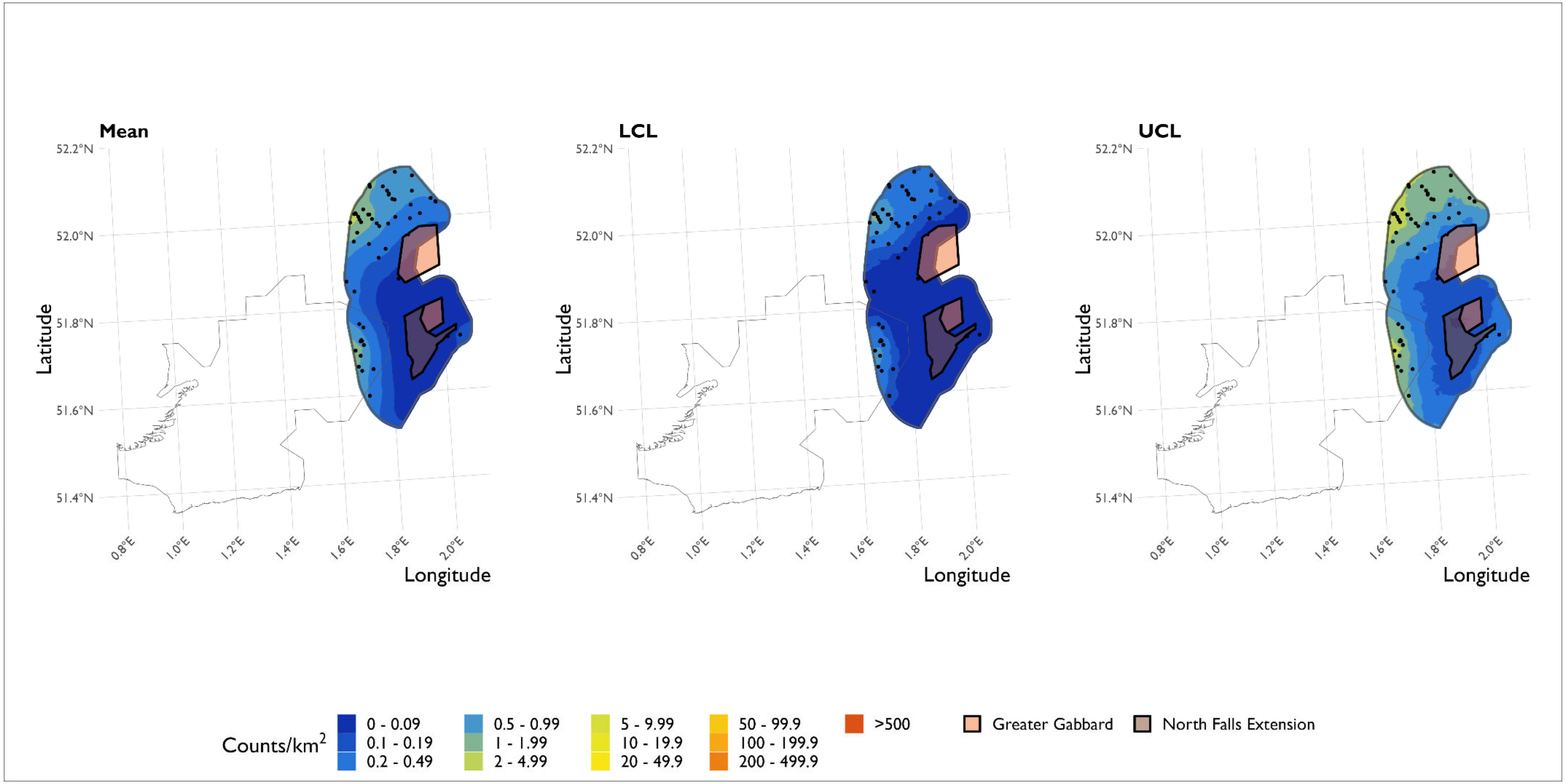


Figure 7 **Predicted densities of red-throated divers using the *inlabru* R package in the NFOW survey region in 13 February 2021**

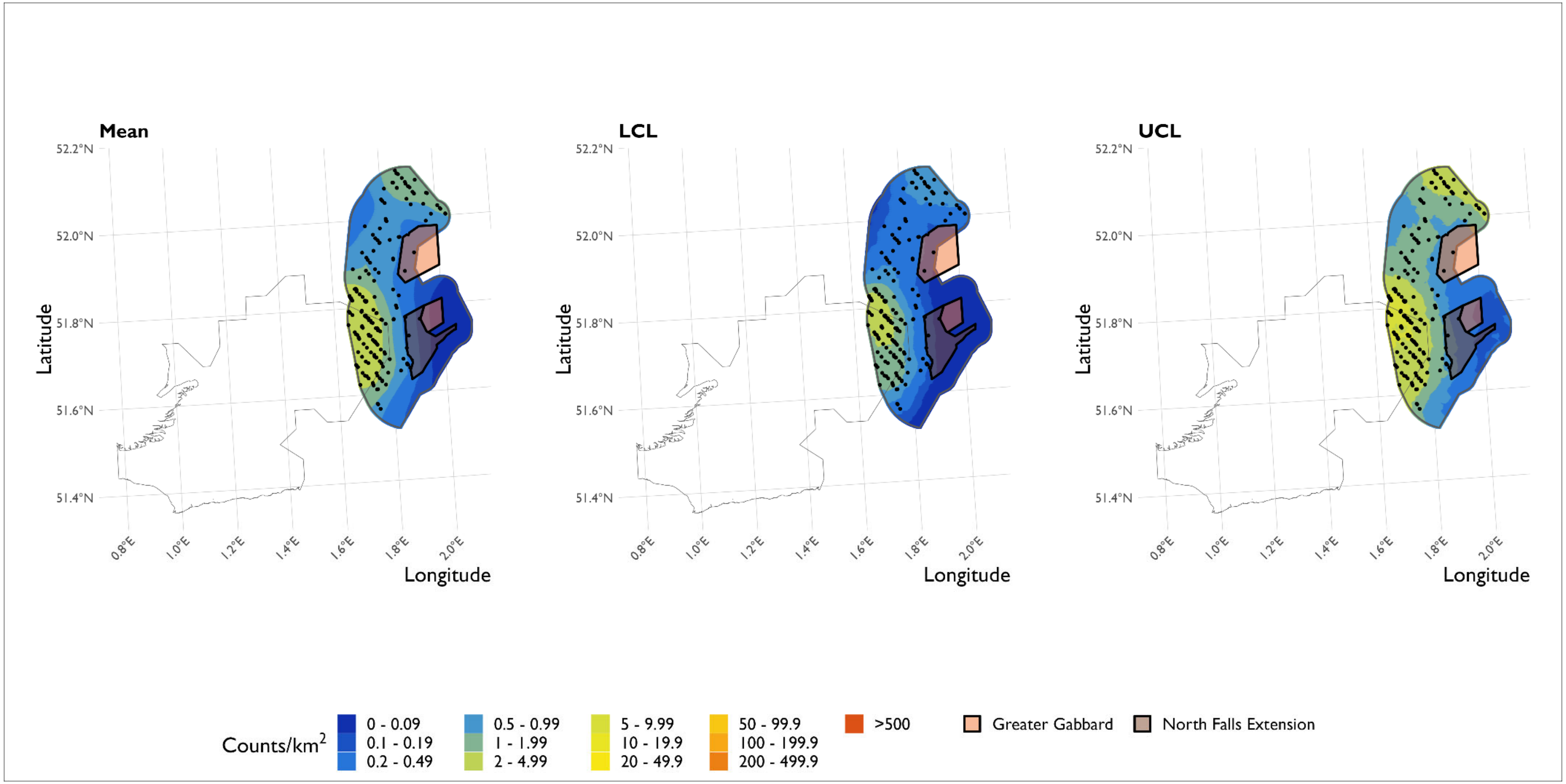


Figure 8 **Mean, lower and upper confidence limits of predicted red-throated diver distribution in 1km width bands in the Outer Thames estuary on 04 February 2018**

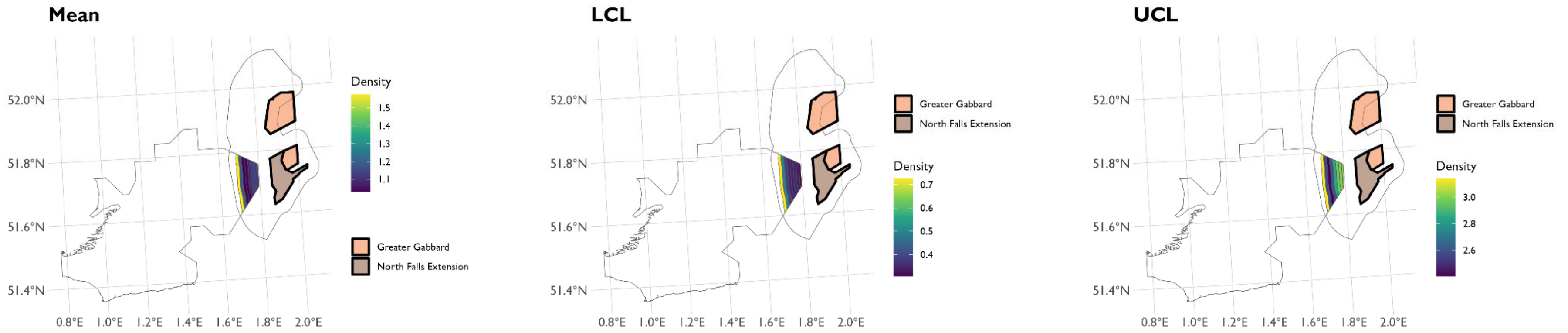


Figure 9 **Mean, lower and upper confidence limits of predicted red-throated diver distribution in 1km width bands in the Outer Thames estuary on 17 February 2018**

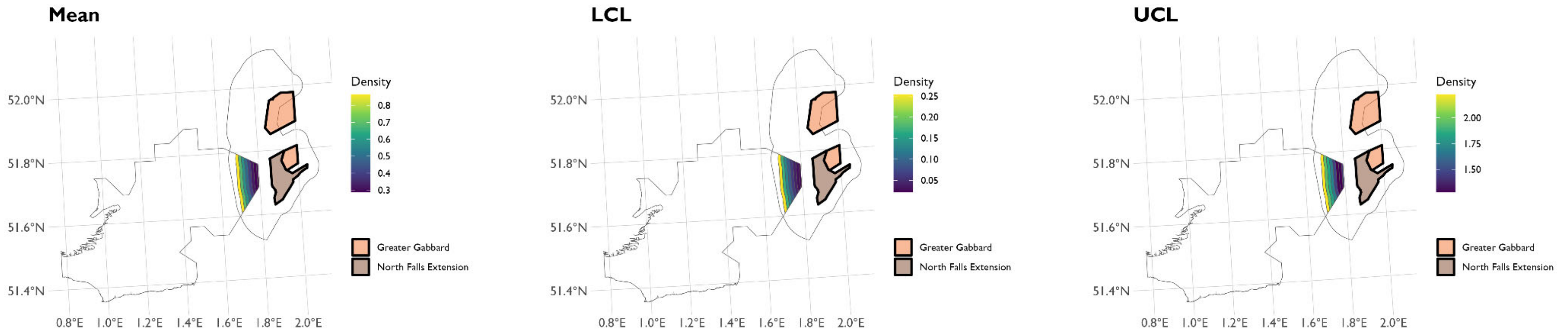
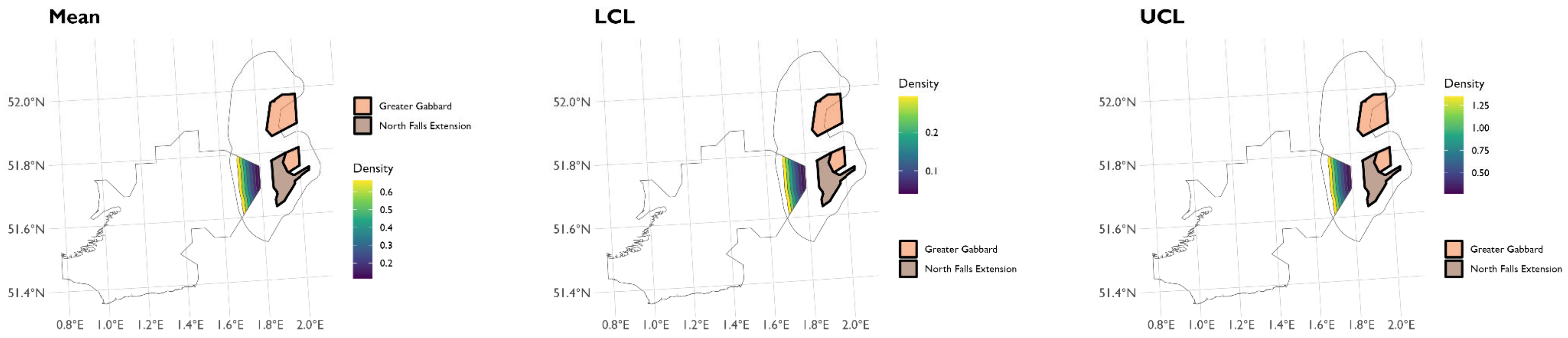


Figure 10 **Mean, lower and upper confidence limits of predicted red-throated diver distribution in 1km width bands in the Outer Thames estuary on 22 January 2021**

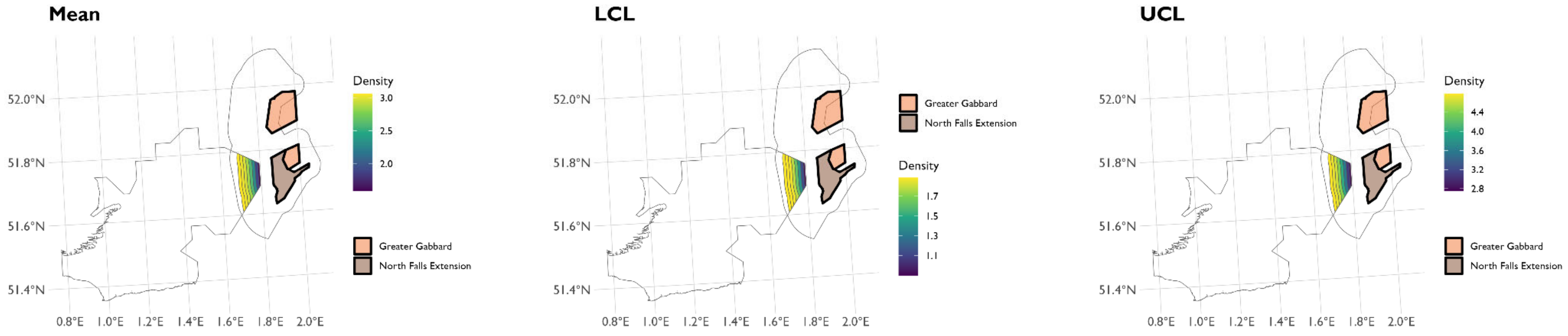


Mean

LCL

UCL

Figure 11 **Mean, lower and upper confidence limits of predicted red-throated diver distribution in 1km width bands in the Outer Thames estuary on 13 February 2021**



Mean

LCL

UCL

3.4 Environmental covariates

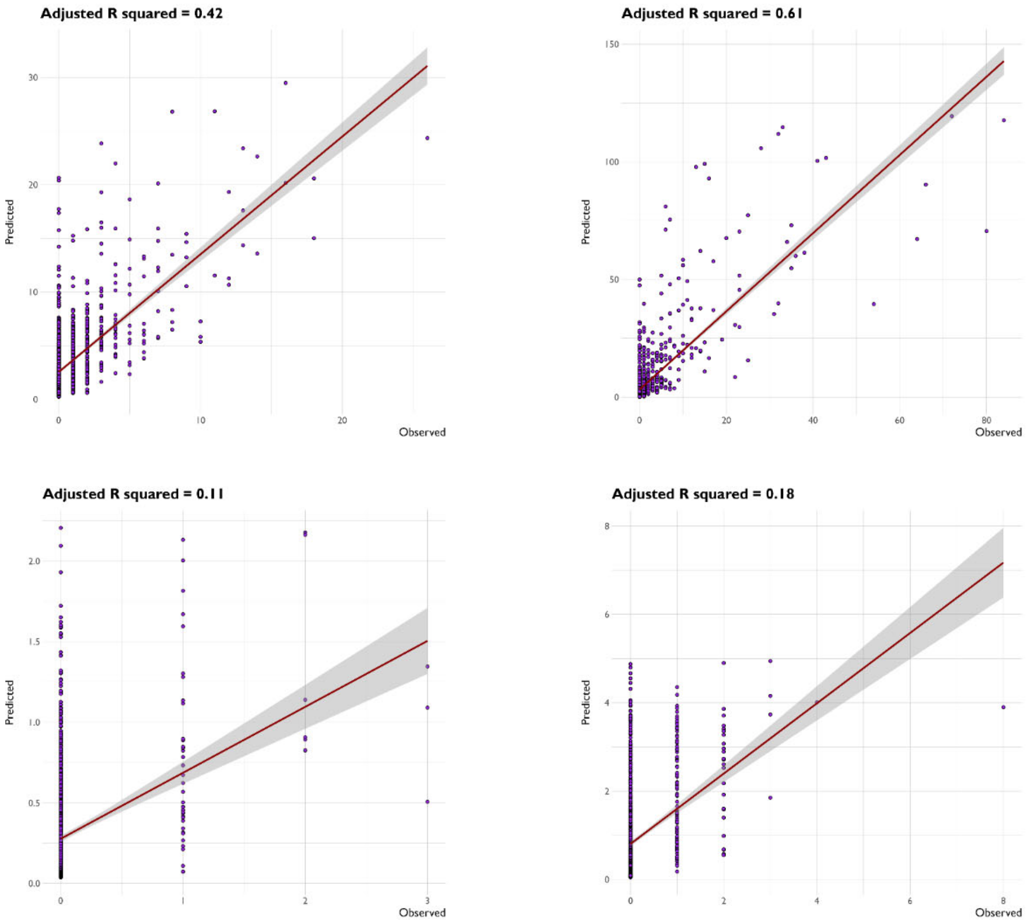
49 In a model that pooled all the data from four surveys, the effect of the environmental covariates was very small with standard deviation of the monthly sea surface temperature having the largest effect aside from the spatial element. The spatial smoother (i.e., the SPDE model) was the primary element of the model that explained the predicted distribution (Table 7).

Table 7 Effect size of environmental covariates in the INLA model using a negative binomial model where data from all surveys were pooled.

Covariate	Mean	SD
Mean sea surface temperature	-0.002	0.001
STD sea surface temperature	-0.226	0.033
Gradient sea surface temperature	-0.051	2.230
Bathymetry	0.010	0.001
Bathymetric slope	-0.112	0.018
Distance to shipping lanes	0.000	0.001
Distance to wind farms	0.000	0.001
Spatial smoother (SPDE)	14.98	0.022

50 Adjusted R squared values for inlabru models of red-throated diver in the NFOW survey area were 0.11 and 0.18 for January and February 2021 surveys respectively, while in the Outer Thames SPA, R squared values were 0.42 and 0.61 for the first and second surveys in February 2018 respectively. The low R squared values are somewhat expected due to the dispersion (i.e., the variability in the raw observations, particularly when there are fewer observations) of these kinds of count data (Figure 12).

Figure 12 **Predicted versus observed densities of red-throated diver showing adjusted R-squared values for February 2018 (4th) (upper left panel), February 2018 (17th) (upper right panel), January 2021 (lower left panel) and February 2021 (lower right panel)**



4 Conclusions

51 Red-throated divers occur in internationally important numbers in the Outer Thames estuary through the winter months. With the increase in the number of offshore wind developments in the region, it is imperative to understand the impact these wind farms have on red-throated diver, particularly in the Outer Thames Estuary special protection area (SPA).

52 A density surface model was generated by combining observations from digital aerial surveys and environmental covariates using '*inlabru'* in the R programming language, for two surveys of red-throated divers in the Outer Thames Estuary SPA in February 2018 (Irwin etal. 2019), and two surveys of the NFOW and a 12km buffer in January and February 2021 (four surveys in total). Model predictions closely matched observations due to the use of the Log Gaussian Cox Process model, which optimizes outputs based on the spatial distribution of the observations.

53 A series of 1km buffers radiating outwards from the NFOW array area was generated, and then clipped to the Outer Thames SPA boundary. Mean densities as well as lower and upper confidence limits from the inlabru models were computed within the 1km buffers that overlapped the Outer Thames SPA.

54 For January and February 2021, the peak mean predicted density was highest in February 2021 (3.12 birds/km^2), in buffer 8, which is 10km away from the western boundary of the southern NFOW extension zone. In January 2021, the densities increased progressively with increasing distance to the existing wind farms. Similar patterns were found in the February 2018 models where the highest densities in the overlap region were in the western buffers.

55 The findings suggest that some displacement effects from the existing operational wind farms might be apparent on the eastern edge of the Outer Thames SPA, however, looking into the proximity of observations of red-throated diver near the northern array of the Greater Gabbard wind farm, the effect is not replicated.

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