BERWICK BANK WIND FARM **OFFSHORE ENVIRONMENTAL IMPACT ASSESSMENT**

APPENDIX 11.1, ANNEX L: MODEL-BASED ANALYSIS USING MRSEA: ABUNDANCE ESTIMATES AND DENSITY SURFACES

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CONTENTS

FIGURES

TABLES

1. DENSITY SURFACE MODELLING WITH MRSEA

1.1. INTRODUCTION

1. Density surface modelling was undertaken using the Marine Renewables Strategic Environmental Assessment (MRSea Windows Package package) in R (Scott-Hayward *et al.,* 2013).

2. HiDef adapted and customised some of the MRSea code so that the modelling approach could cope with the specific nuances of the Berwick Bank data (code can be made available on request). This work was undertaken through consultation with the package author (Scott-Hayward) and was reported to Consultees during the Road Map consultation process.

3. Design-based estimates are used within the Collision Risk Modelling (Appendix 11.2: Ornithology collision risk modelling technical report) and displacement (Appendix 11.3: Ornithology displacement technical report) analyses.

4. The MRSea outputs presented here are only for additional context.

1.2. METHODS

5. Observation and effort data from digital video aerial surveys conducted by HiDef between March 2019-April 2021 were used for spatial modelling of species monthly distribution and abundance. Data for five species were processed:

- kittiwake;
- guillemot;
- razorbill;
- puffin; and
- gannet.

6. Monthly data for "all birds" (flying and sitting) were used in the analysis from the Berwick Bank Array area and 16km buffer (Offshore Ornithology Study Area). Only detections identified to species were used; categories of species groups (e.g., large auks) have not been apportioned to species for use in the analysis.

7. We used the Complex Regional Spatial Smoother (CReSS) spatial modelling method with Spatially Adaptive Local Smoothing Algorithm ("SALSA") based model selection to model survey-specific bird distribution (Scott-Hayward *et al.,* 2013). The models essentially fit the relationship between the observations (count response variable) and the environment (covariates) at each location which can then be used to estimate and predict the density of animals throughout the area of interest.

8. To prepare the input data for the species-specific model, for each survey the transects were grouped into segments of ~0.5km and counts of animals of each species assigned to the mid-point of the appropriate segment. Values of covariates (see Selection of model covariates below) were also assigned to the midpoint of each segment. The resulting data frame therefore contained survey-specific species counts and covariate values for each transect segment.

1.2.2. MODEL INFERENCE

9. The count data are collected during the HiDef surveys along transects and consecutive measurements on these transects are closely linked in space and time. Additionally, due to environmental/prey conditions the abundance of animals at any particular location is likely to be more similar for points close together in time compared with points distant in time. Models fitted to the (relative) abundance data attempt to explain animal abundance at any location but the information (covariate data) that describes why animals are found in high/low numbers at particular locations is often missing from the model and this leaves pattern in the noise component of the model (model residuals). Further, these patterns are likely to be similar along the track lines. This (positive) correlation in model residuals along the track lines violates a critical assumption for standard statistical models (such as Generalised Linear Models (GLMs) / Generalised Additive Models (GAMs)) which require an independent set of residuals. Further, ignoring this violation can invalidate all model-based estimates of precision (e.g., standard errors, CI and p-values) resulting in overly complicated models which suggest that unrelated environmental covariates are statistically significant.

10. Transect data can often subject to such spatio-temporal autocorrelation, which violates a fundamental assumption of GLMs/GAMs. To control for this in the model, transect ID was included as a blocking factor in the analysis. This informs the model that correlation within a transect is permitted, and independence between transects is assumed.

11. To examine the statistical significance of covariates in the predictive model, a one-way Analysis of Variance (ANOVA) was run. Covariates with significant relationships with the observations in the model were further explored by way of partial dependence plots. Further model inference could be made by examining the cumulative residual plots output from the models.

1.2.3. SELECTION OF MODEL COVARIATES

12. Covariates were agreed with Consultees during the Ornithology Road Map process.

13. A model with terms (Table 1) for each survey (as a factor); sea surface temperature (SST) on the day of the survey and SST gradient; bathymetry, bathymetric slope and bathymetric aspect; probability of sandeel presence and sandeel predicted density; distance to coast, and seabed sediment type was first fitted for each species without a smooth term for the spatial component to allow the relationships between covariates and species counts to initially be unhindered by spatial information. We used the Variance inflation Factor to remove terms form the initial model fitting process which were colinear with other terms. A threshold of 2 was used to determine which parameters to remove.

14. Flexibility of the smoother-related term for each term was chosen first, followed by model selection for the two-dimensional smoother term for the spatial component. As each segment may have comprised slightly different dimensions due to the way the transects were split, segment area was included in the model as an offset term.

15. Each model was permitted to contain the covariates (Table 1) as a linear or smooth term (or omitted altogether). Smooth function fitting for each covariate was carried out using SALSA (Walker *et al.,* 2011).

16. For both the covariates and spatially based smoothers, model selection was governed using an objective fit measure akin to a Bayesian Information Criterion (BIC) for quasi-likelihood (QL) models. Models permitting over-dispersion for Poisson-style counts are QL based and thus require QL-based fit scores.

1.2.4. KNOT PLACEMENT AND BASIS FUNCTION DETAILS

17. Model flexibility for the spatial surfaces in this setting was determined by both the number of 'knots' used (i.e., anchor points, but also referred to as coefficients in the results) for the model and the effective range of each knot (the spatial extent to which each knot influences the fitted surface). Since the optimal choices for both features are always unknown, a range of models were considered for the candidate models which vary in both the number of knots specified and the effective range (r-value) of each knot.

18. For a given knot number, the initial knot locations on the spatial surface were chosen to maximise the coverage across the spatial area (via a space filling algorithm; John *et al.,* 1995) and these locations were permitted to move according to the SALSA (Walker *et al.,* 2011) model selection method. The local exponential basis function ((exp(-d/r²)) with d=Euclidean distance) was implemented and permitted to have variable r-values across the surface. A variable number of knot numbers were used for the candidate

models (2-40 depending on data sparsity; the number is denoted by the degrees of freedom in the model) and an objective fit criterion used to choose the best model(s). In effect, the location of the knot placement and to a lesser extent the number of knots reflects the relationship between the complexity in the spatial relationship between the bird abundance and the covariates used in the analysis.

19. To account for variation in survey effort and bird distributions between surveys, knot locations were identified separately for each survey.

Table 1 Covariates included in the MRSea analyses. The * denotes parameters which were retained for modelling; other terms were removed due to collinearity.

Model covariate	Definition	Source
Survey ID (factor)*	Unique ID for each survey	HiDef Aerial Surveying
Seabed sediment type (factor)*	Marine habitat classification of seabed substrate for Britain and Ireland	JNCC UK SeaMap 2018 Version 2 (https://hub.jncc.gov.uk/assets/202874e5-0446-4ba7-8323-24462077561e)
Bathymetry*	Depth below sea surface (m)	GEBCO Gridded Bathymetry Data 2019
Bathymetric slope	Change in bathymetry between pixels	GEBCO Gridded Bathymetry Data 2019
Bathymetric aspect	Direction bathymetric slope faces	GEBCO Gridded Bathymetry Data 2019
SST	Interpolated sea surface temperature on hourly 0.01 degree grid	PODAAC (https://podaac.jpl.nasa.gov/dataset/MUR-JPL-L4-GLOB-v4.1)
SST gradient*	Change in SST between pixels/ slope of SST	PODAAC (https://podaac.jpl.nasa.gov/dataset/MUR-JPL-L4-GLOB-v4.1)
Sandeel predicted density*	Probability of presence of buried sandeel in the North Sea study region.	Marine Scotland (https://spatialdata.gov.scot/geonetwork/srv/eng/catalog.search#/metadata/Marine_Scotland_FishDAC_12377)
Sandeel probability of presence	Predicted density of buried sandeel in the North Sea study region (number per m^2)	Marine Scotland (https://spatialdata.gov.scot/geonetwork/srv/eng/catalog.search#/metadata/Marine_Scotland_FishDAC_12377)
Distance to coast*	Distance to coast (m)	NA
Segment area*	Area of each segment within a transect (m^2)	HiDef Aerial Surveying
Spatial component*	Latitude and Longitude coordinates	GIS (WGS84)

1.2.5. GEO-REFERENCED RESULTS

20. The species-specific fitted surfaces were generated by making predictions to a grid using the final model at a 1km x 1km resolution. These grids were projected as the Universal Transverse Mercator (Zone 30) projection.

21. The CV for each model is also expressed spatially (and for abundance estimates). The CV represents the ratio of the standard error of the estimate to the estimate for that grid cell. To ensure the CV surfaces are not dominated by very small predictions (an artefact of such a measure for low predictions), surface uncertainty was also expressed using lower and upper 95% CI. These confidence limits are based on combining uncertainty from all parameters from the model using a parametric bootstrap (with 500 replicates).

1.2.6. ABUNDANCE ESTIMATES FROM MRSEA DENSITY SURFACES

22. Monthly abundance estimates were made by summing the grid cells across the prediction surface for each month. To get abundance estimates within the survey area, we summed up grid cells that fell entirely within the boundary. Upper and lower confidence limits were calculated by determining the 95% confidence limits of the sums of the 500 bootstraps. That is, for every bootstrapped density surface, the overall population within the wind farm and buffer area is calculated; those sums (n = 500) are then used to calculate the 95% CIs and the means and standard deviations are used to calculate the CV by: standard deviation / mean.

23. MRSea outputs were modelled using detections that had been apportioned for unidentified birds (Appendix 11.1: Baseline Ornithology Technical Report). Density and abundance estimates for auks have not been corrected for availability bias.

1.3. RESULTS

24. Mean density surfaces for each survey from MRSea outputs mapped to the Offshore Ornithology Study Area are provided in Figure 1 - Figure 5, Figure 24 - Figure 28, Figure 47 - Figure 51, Figure 70- Figure 74, Figure 93 - Figure 97.

1.3.2. KITTIWAKE

25. The highest densities calculated using MRSea were recorded in April 2021 and October 2019 in the Development Array and Offshore Ornithology Study Area, reaching peaks of 22.86 birds/km^2 (95CI 13.91 – 37.13) and 24.79 birds/km^2 (95CI 1.82 – 181.14), respectively (Table 2 and Table 3). This equated to peak population estimates of 23,093 birds (95CI 14,049 – 37,512) and 98,549 birds (95CI 7,220 – 720,005).

26. Distribution maps created using model-based analyses (MRSea) (Figure 1 to Figure 5) suggest that kittiwake are generally widely dispersed across the Offshore Ornithology Study area throughout the breeding season. In the non-breeding period, distribution varied, with higher densities generally observed to the south, west or north of the Development array (e.g. October to December 2019, October 2020 and December 2020. The highest densities of Kittiwake were observed to the north of the Development Array in October 2019 and February 2021.

27. Broadly, model fit was quite poor for kittiwake with a marginal R squared value of 0.064 and root mean squared error of 21.14. Furthermore, the cumulative residuals in the model showed that there was overall a poor relationship between predicted and observed values across most of the range of predicted values (Figure 22).

Table 2 Monthly density and population estimates of kittiwakes in the Development Array derived from MRSea

Survey	Density Estimate (n/km²)	SD of Density	Lower 95% CL of Density	Upper 95% CL of Density	Population Estimate (number)	SD of Population	Lower 95% CL of Population	Upper 95% CL of Population	CV (%)
Mar-19	18.32	2.85	13.61	24.85	18503	2881	13753	25101	15.57%
May-19	3.84	0.49	3.03	4.84	3878	494	3066	4886	12.74%
Jun-19	2.53	0.29	2.03	3.15	2553	297	2053	3185	11.63%
Jul-19	6.03	0.59	4.93	7.24	6087	601	4982	7318	9.87%
Aug-19	8.64	0.64	7.5	9.96	8728	644	7574	10058	7.38%
Sep-19	1.67	0.3	1.16	2.34	1683	301	1168	2359	17.88%
Oct-19	1.77	1.49	0.65	6.24	1784	1505	656	6299	84.36%
Nov-19	0.33	0.05	0.24	0.44	329	54	240	449	16.41%
Dec-19	0.34	0.1	0.2	0.58	345	99	201	587	28.7%
Jan-20	2.38	0.44	1.69	3.31	2403	444	1704	3346	18.48%
Feb-20	2.27	0.57	1.41	3.62	2296	575	1420	3655	25.04%
Mar-20	8.29	1.2	6.24	10.86	8371	1216	6301	10974	14.53%
May S01 20	4.9	1.22	3	7.62	4949	1235	3029	7702	24.95%
May S02 20	9	1.01	7.24	11.07	9096	1024	7318	11183	11.26%
Jun-20	8.22	0.62	7.16	9.49	8308	628	7234	9587	7.56%
Jul-20	9.01	1.03	7.13	11.05	9105	1040	7205	11167	11.42%
Aug-20	12.44	1.58	9.79	15.84	12563	1600	9888	15998	12.74%
Sep-20	16.54	1.94	13.42	21.19	16711	1962	13558	21411	11.74%
Oct-20	1.09	0.29	0.64	1.78	1104	293	646	1794	26.54%
Nov-20	5.68	0.84	4.18	7.55	5742	852	4220	7623	14.84%
Dec-20	1	0.22	0.67	1.51	1012	222	675	1530	21.94%
Jan-21	3.34	0.78	2.25	5.14	3377	787	2276	5193	23.3%
Feb-21	3.34	1.69	1.37	7.58	3378	1704	1384	7653	50.44%
Apr S01 21	8.03	1.12	5.98	10.4	8111	1131	6042	10505	13.94%
Apr S02 21	22.86	6.26	13.91	37.13	23093	6328	14049	37512	27.4%

Table 3 Monthly density and population estimates of kittiwakes in the Offshore Ornithology Study Area derived from MRSea

Survey	Density Estimate (n/km²)	SD of Density	Lower 95% CL of Density	Upper 95% CL of Density	Population Estimate (number)	SD of Population	Lower 95% CL of Population	Upper 95% CL of Population	CV (%)
Mar-19	13.72	2.14	10.34	18.33	54545	8489	41108	72864	15.56%
May-19	2.77	0.23	2.37	3.21	10999	897	9421	12740	8.16%
Jun-19	2.2	0.15	1.94	2.52	8734	602	7697	10023	6.89%
Jul-19	3.68	0.34	3.13	4.41	14634	1348	12436	17514	9.21%
Aug-19	8.44	0.58	7.44	9.63	33547	2309	29553	38294	6.88%
Sep-19	2.01	0.25	1.63	2.55	7997	1000	6460	10148	12.5%
Oct-19	24.79	55.31	1.82	181.14	98549	219835	7220	720005	223.07%
Nov-19	0.45	0.08	0.33	0.64	1784	320	1331	2542	17.94%
Dec-19	0.56	0.12	0.39	0.85	2209	486	1536	3390	22%
Jan-20	2.12	0.26	1.7	2.76	8446	1049	6768	10961	12.42%
Feb-20	1.62	0.25	1.23	2.18	6458	984	4878	8682	15.24%
Mar-20	5.83	0.92	4.42	8.01	23169	3676	17561	31846	15.87%
May S01 20	3.87	0.64	2.75	5.31	15379	2559	10911	21097	16.64%
May S02 20	5.64	0.45	4.8	6.52	22427	1788	19092	25917	7.97%
Jun-20	5.01	0.26	4.54	5.53	19918	1015	18059	21965	5.1%
Jul-20	6.31	0.59	5.15	7.55	25093	2365	20459	30029	9.42%
Aug-20	10.06	0.71	8.76	11.44	39986	2830	34803	45463	7.08%
Sep-20	15.02	1.06	13.13	17.04	59690	4224	52201	67721	7.08%
Oct-20	2.29	0.27	1.82	2.9	9086	1067	7232	11524	11.74%
Nov-20	3.82	0.35	3.2	4.55	15186	1394	12702	18077	9.18%
Dec-20	2.79	0.8	1.82	4.69	11108	3191	7231	18657	28.73%
Jan-21	4.98	1.32	3.28	8.31	19799	5245	13024	33018	26.49%
Feb-21	6.98	64.3	0.75	7.05	27742	255564	2990	28038	921.22%
Apr S01 21	6.8	0.69	5.55	8.14	27031	2728	22062	32375	10.09%
Apr S02 21	9.43	2.11	6.5	13.97	37463	8387	25846	55522	22.39%

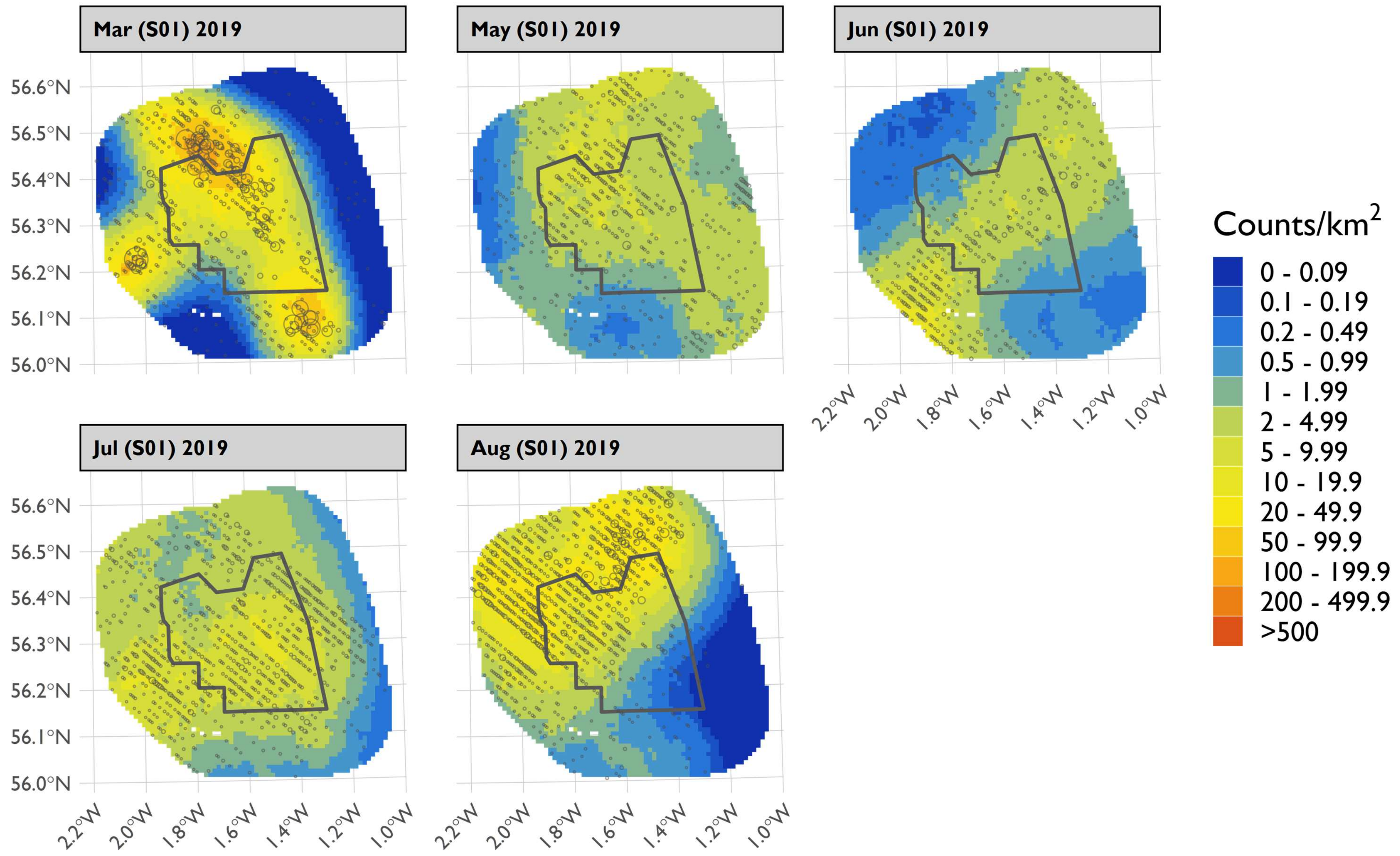

Figure 1 **Mean density of kittiwakes across the Offshore Ornithology Study Area between March and August 2019, modelled using MRSea**

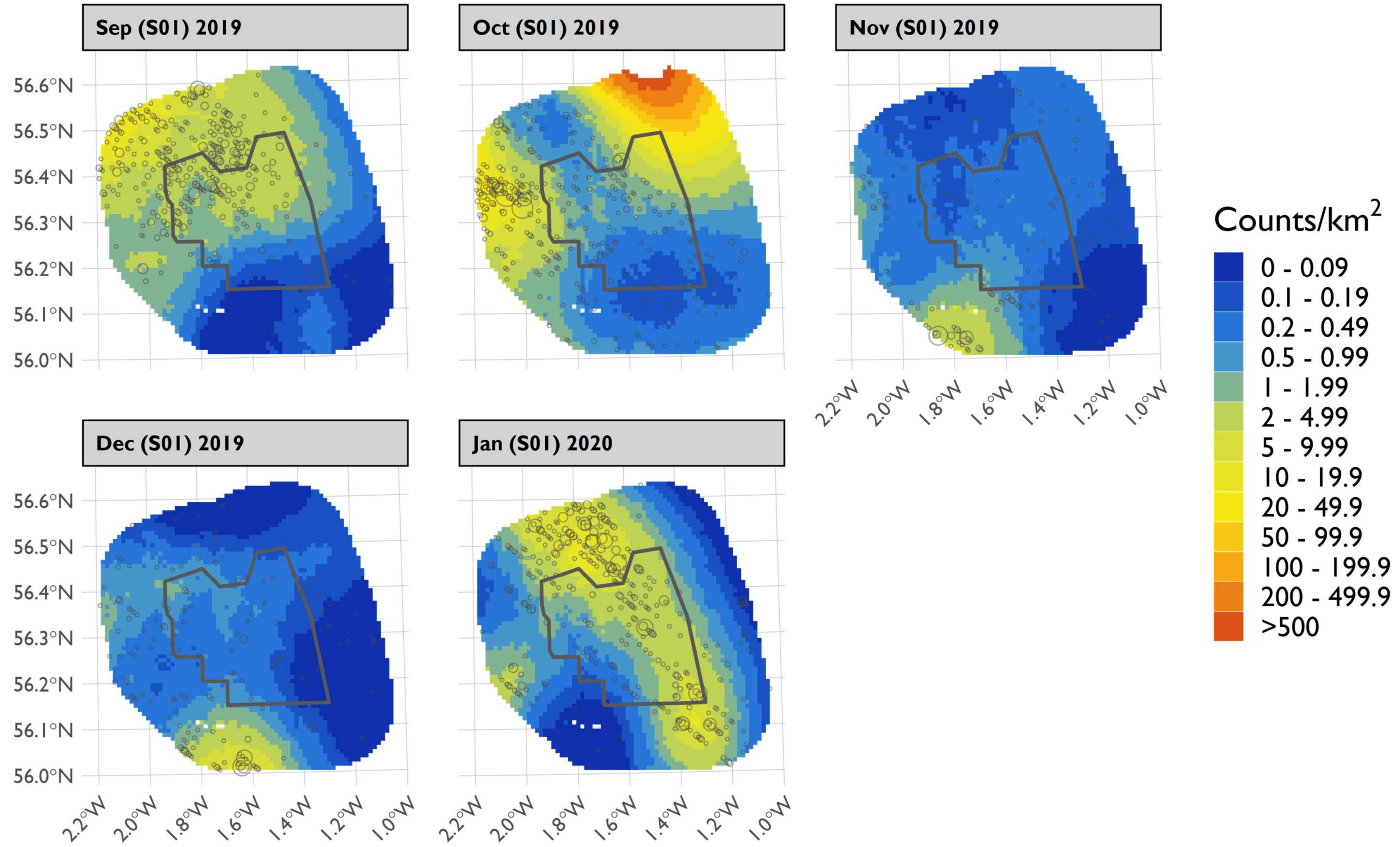

Figure 2 **Mean density of kittiwakes across the Offshore Ornithology Study Area between September 2019 and January 2020, modelled using MRSea**

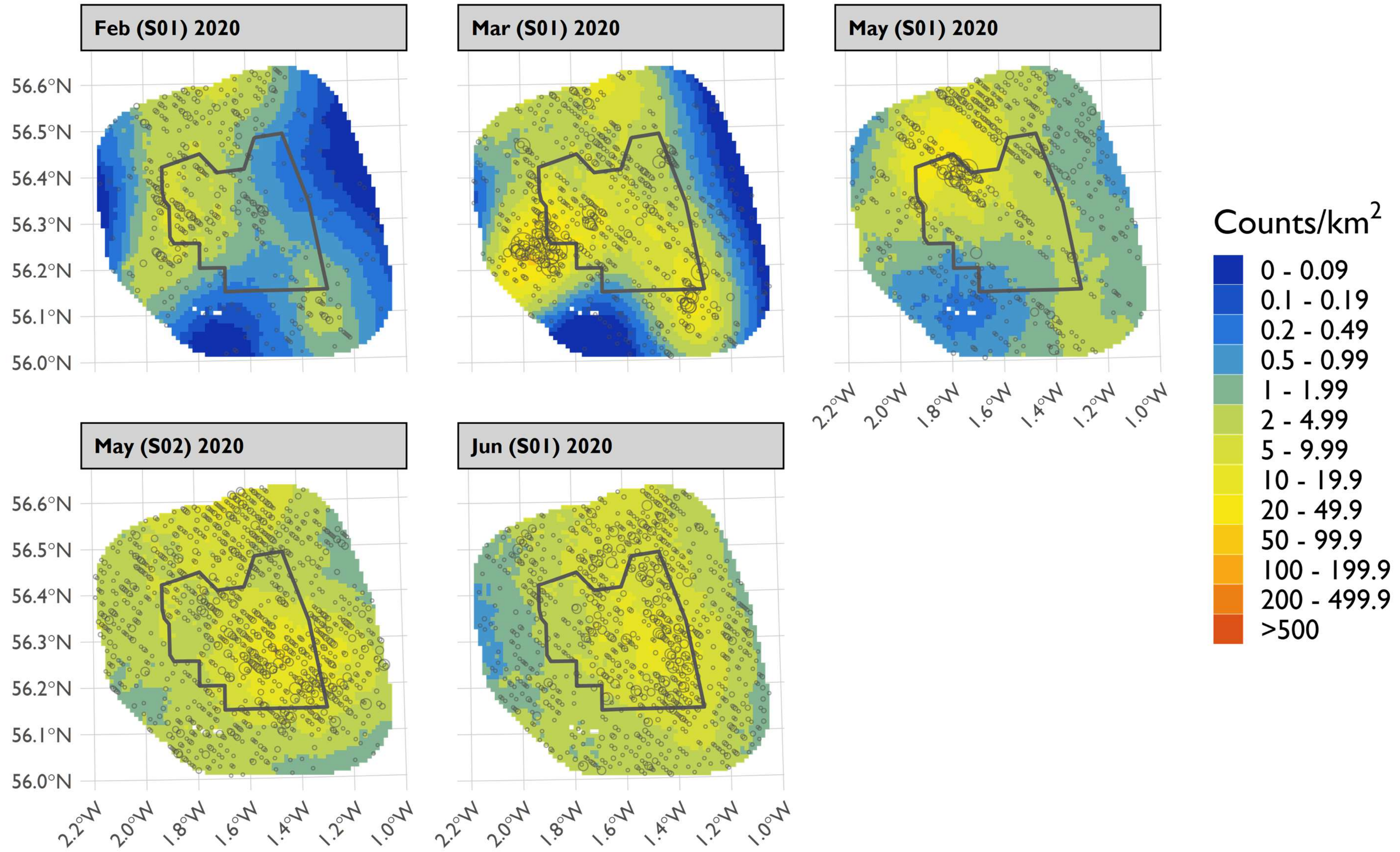

Figure 3 **Mean density of kittiwakes across the survey area Offshore Ornithology Study Area between February and June 2020, modelled using MRSea**

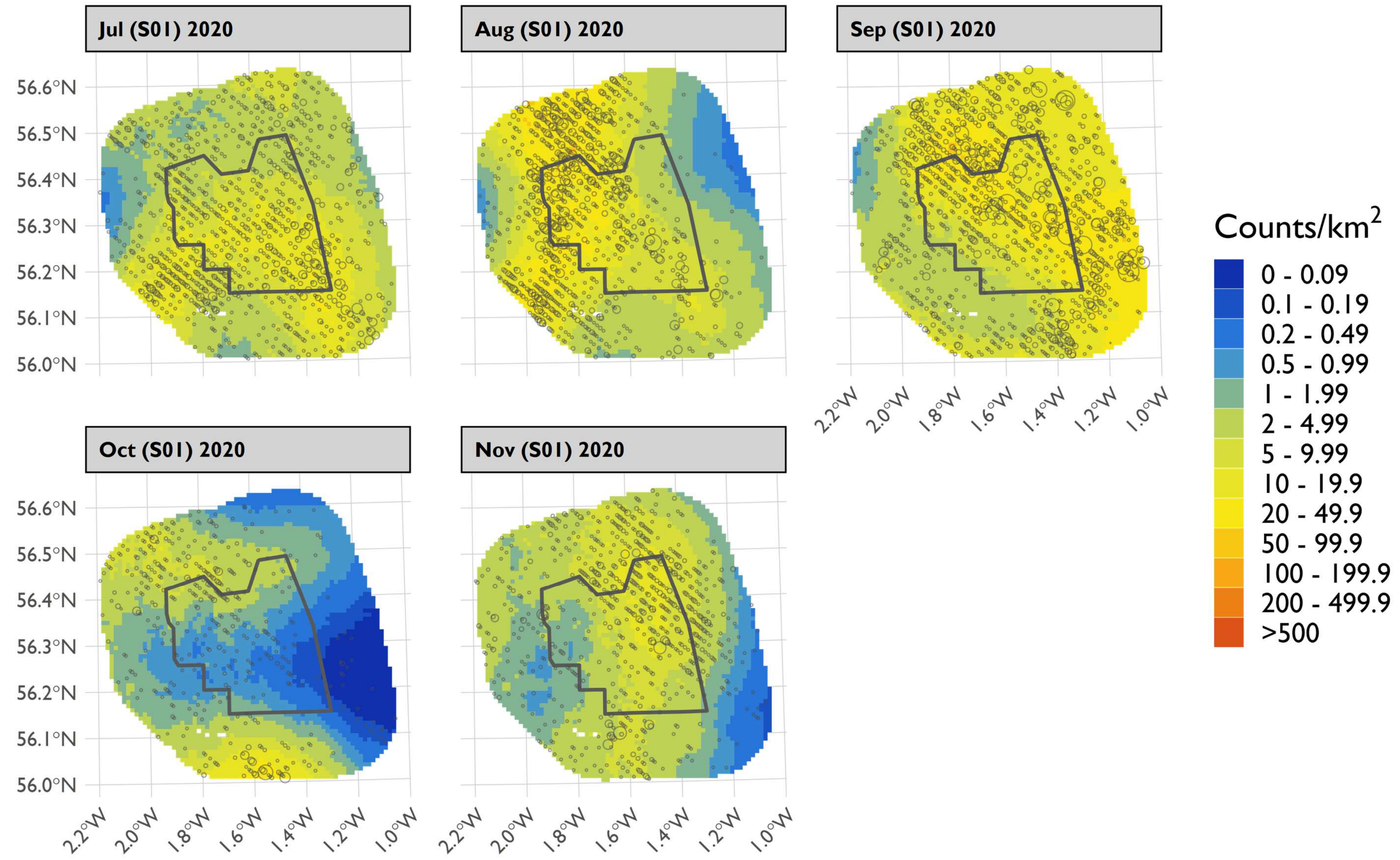

Figure 4 **Mean density of kittiwakes across the Offshore Ornithology Study Area between July and November 2020, modelled using MRSea**

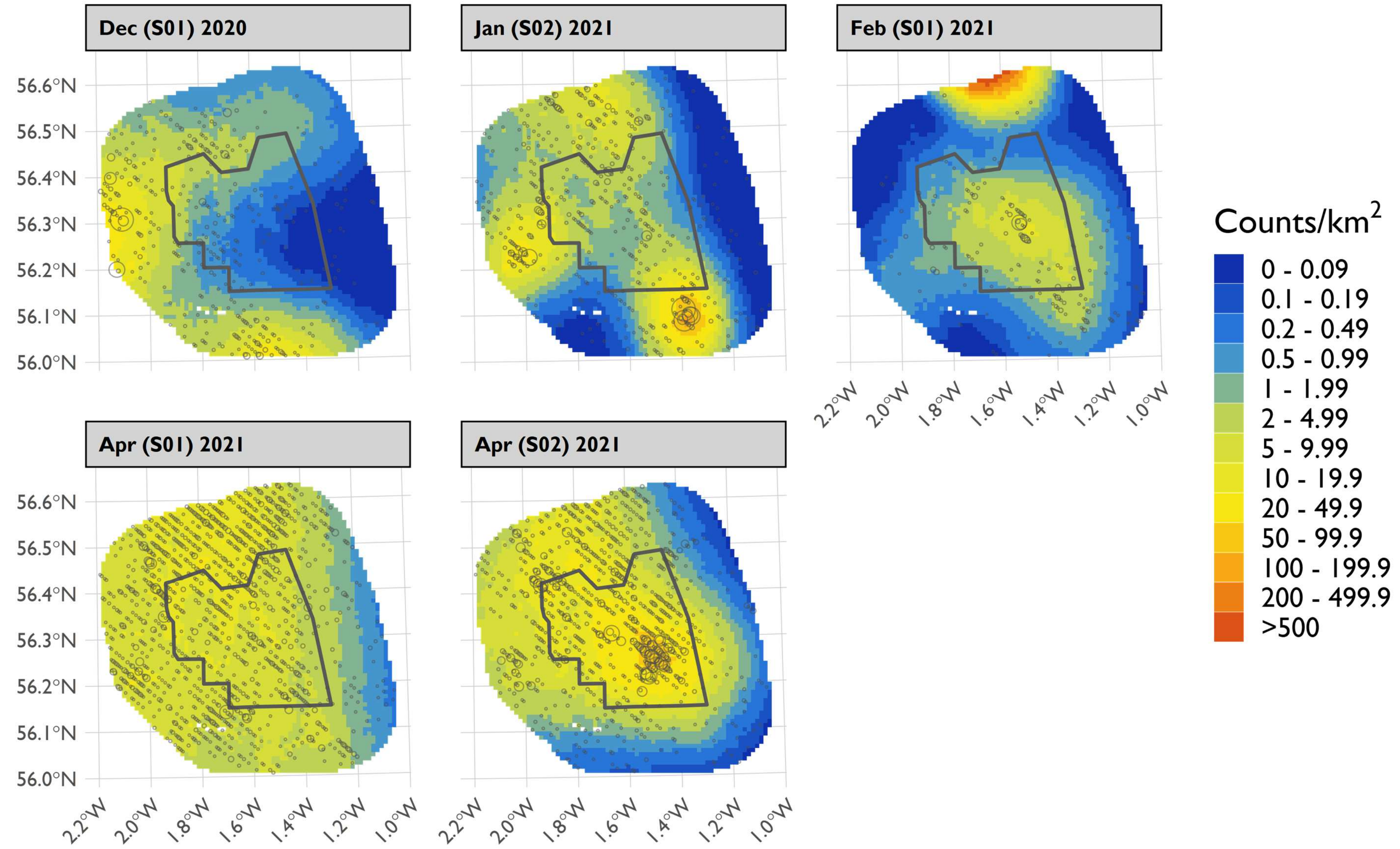

Figure 5 **Mean density of kittiwakes across the Offshore Ornithology Study Area between December 2020 and April S02 2021, modelled using MRSea**

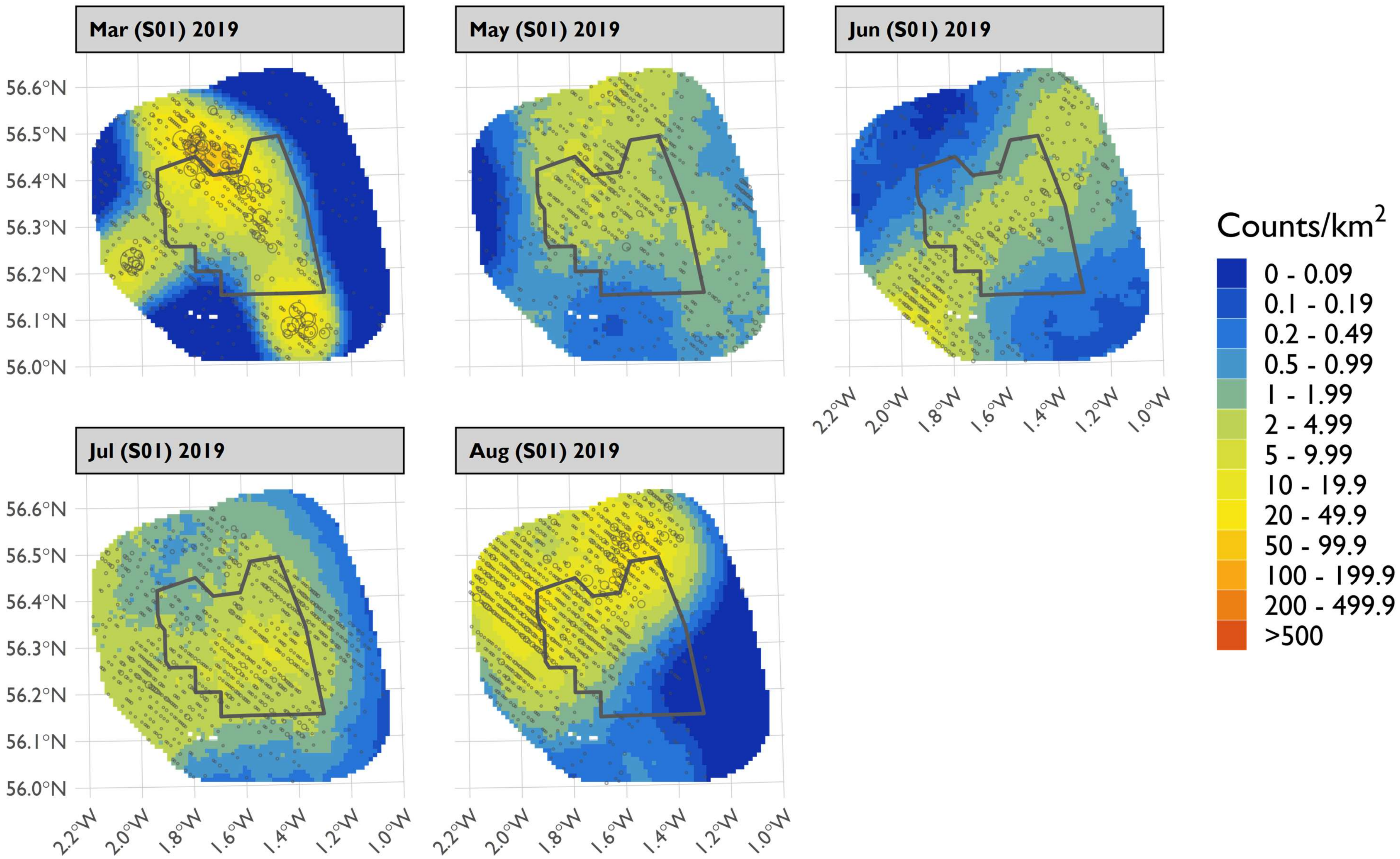

Figure 6 Lower confidence limit of density of kittiwakes across the Offshore Ornithology Study Area between March and August 2019, modelled using MRSea

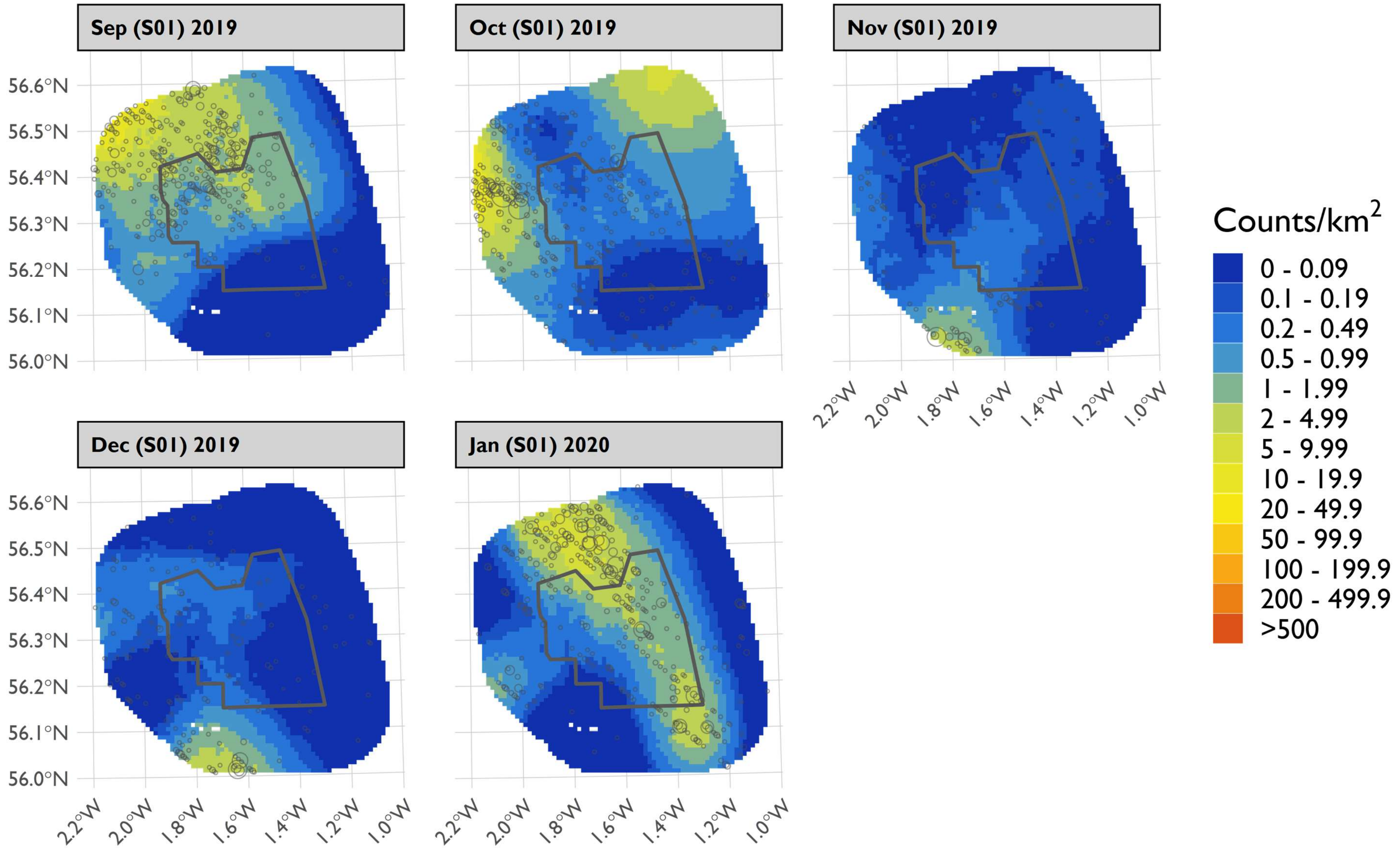

Figure 7 Lower confidence limit of density of kittiwakes across the Offshore Ornithology Study Area between September 2019 and January 2020, modelled using MRSea

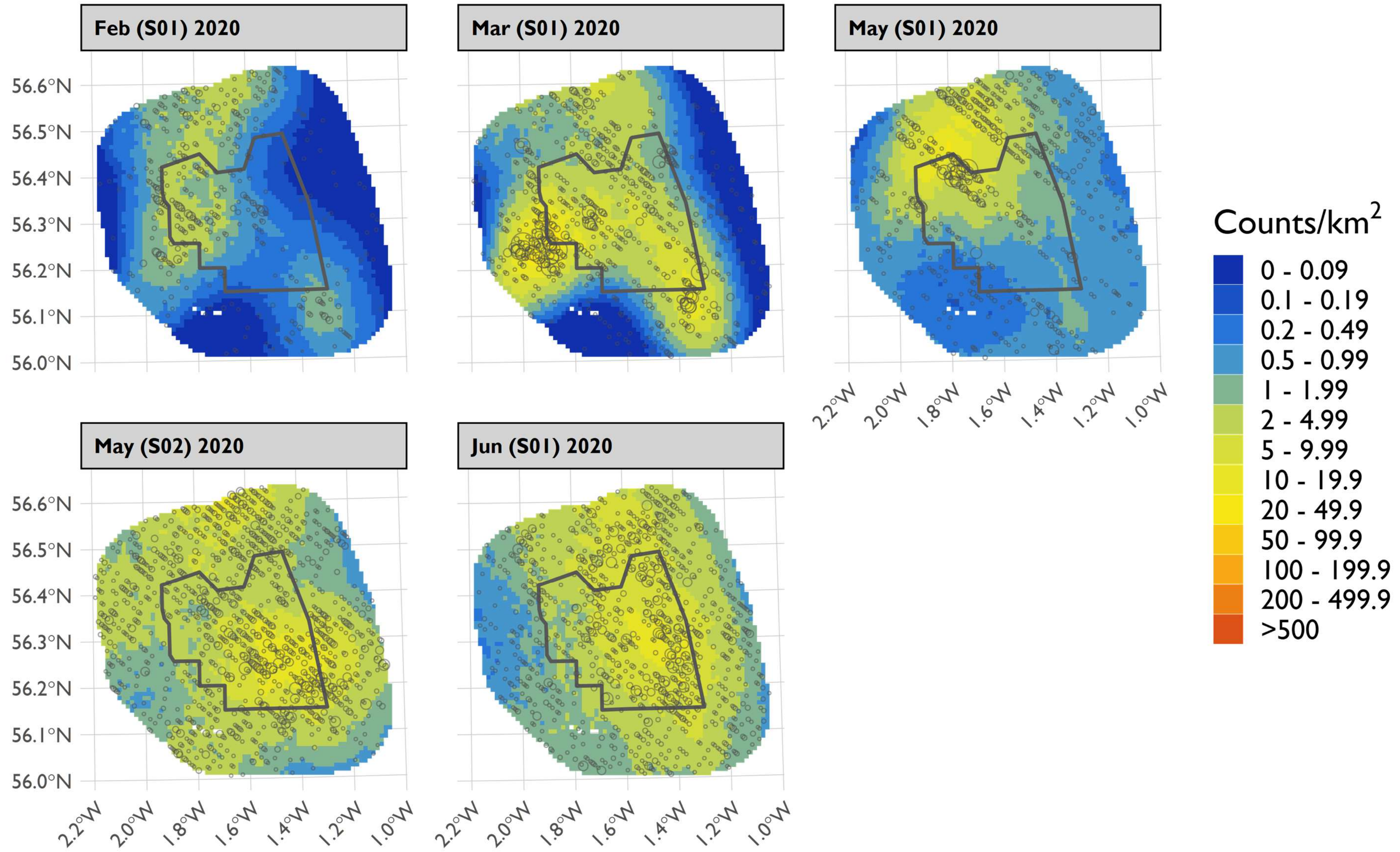

Figure 8 **Lower confidence limit of density of kittiwakes across the Offshore Ornithology Study Area between February and June 2020, modelled using MRSea**

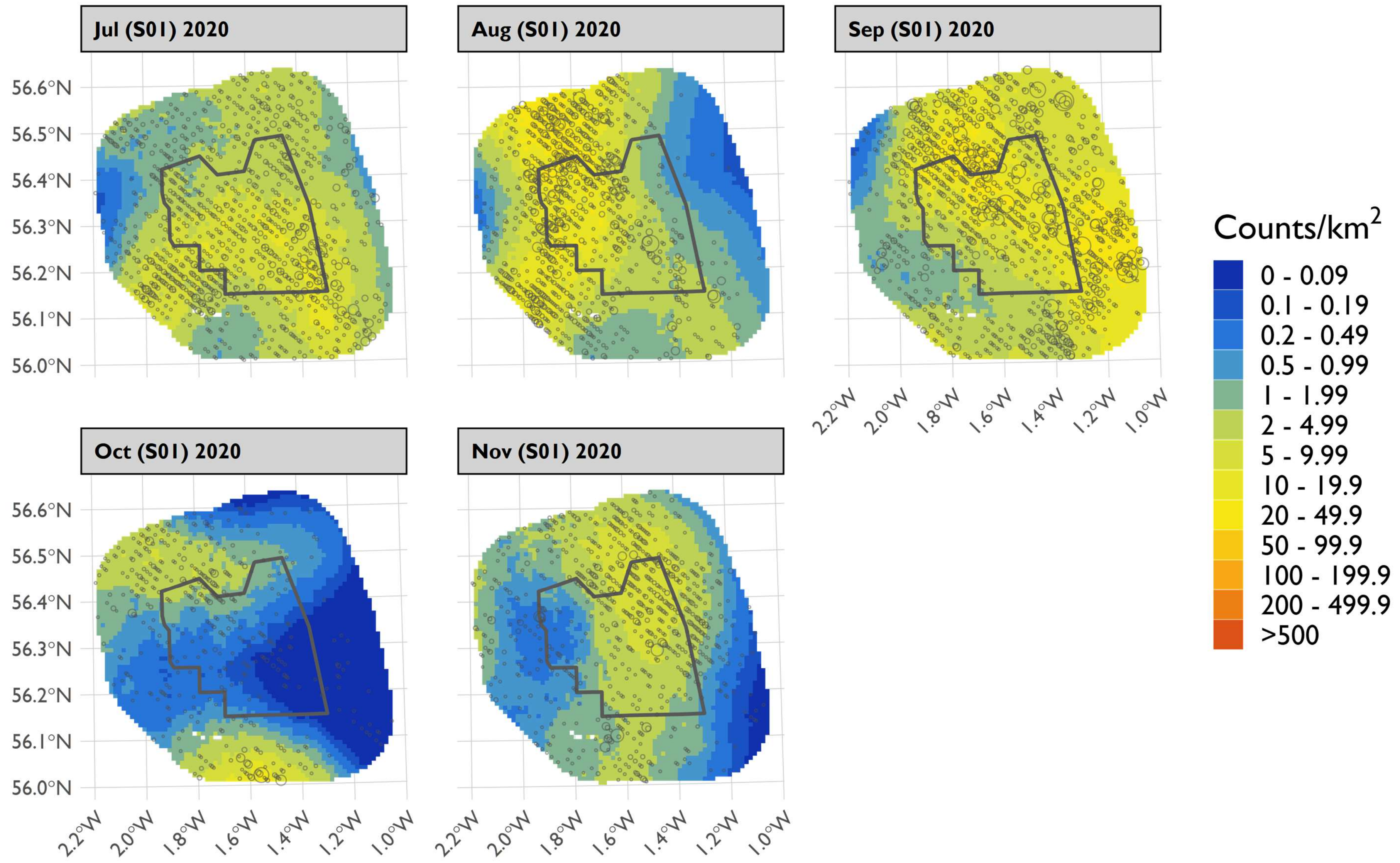

Figure 9 **Lower confidence limit of density of kittiwakes across the Offshore Ornithology Study Area between July and November 2020, modelled using MRSea**

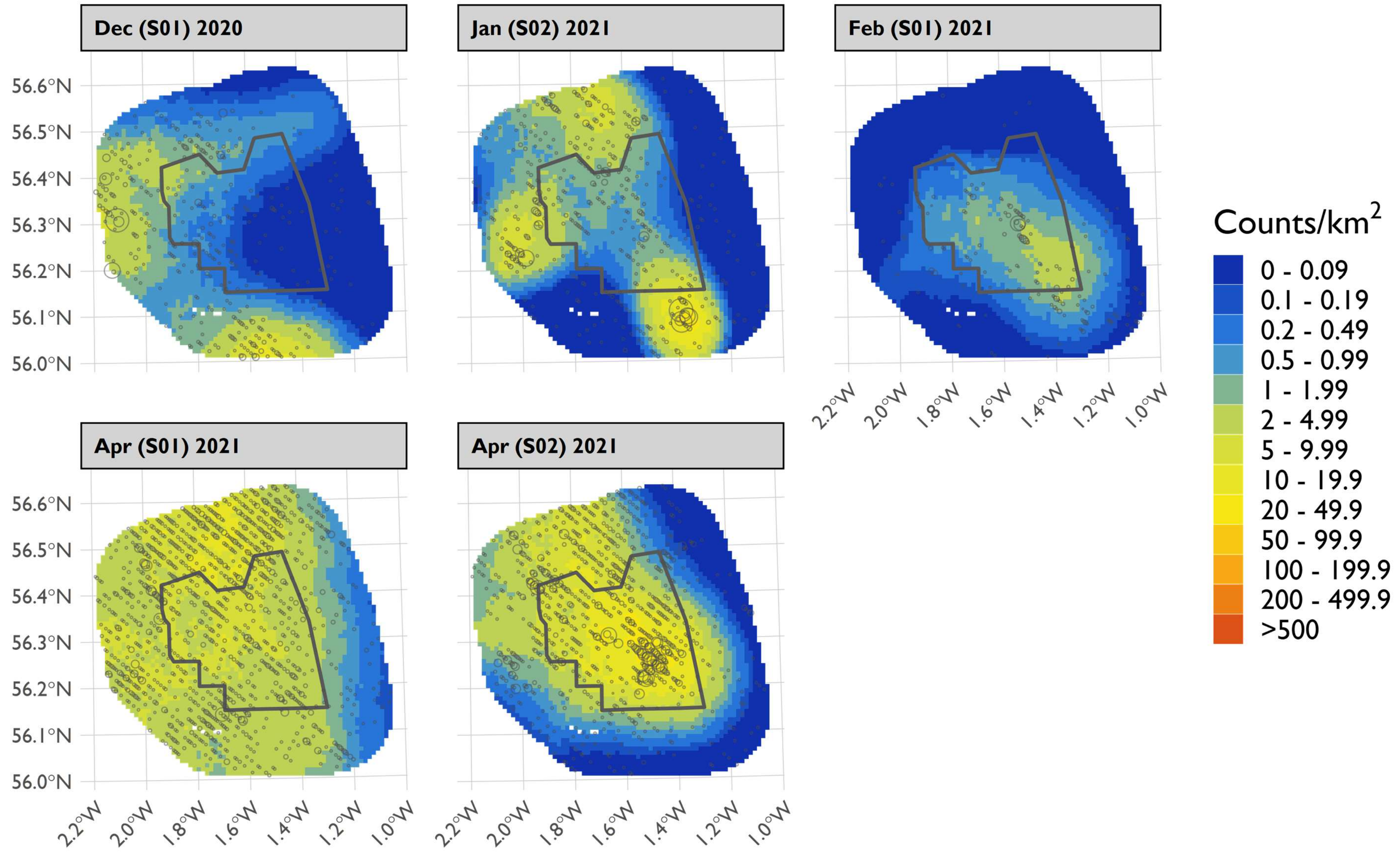

Figure 10 Lower confidence limit of density of kittiwakes across the Offshore Ornithology Study Area between December 2020 and April S02 2021, modelled using MRSea

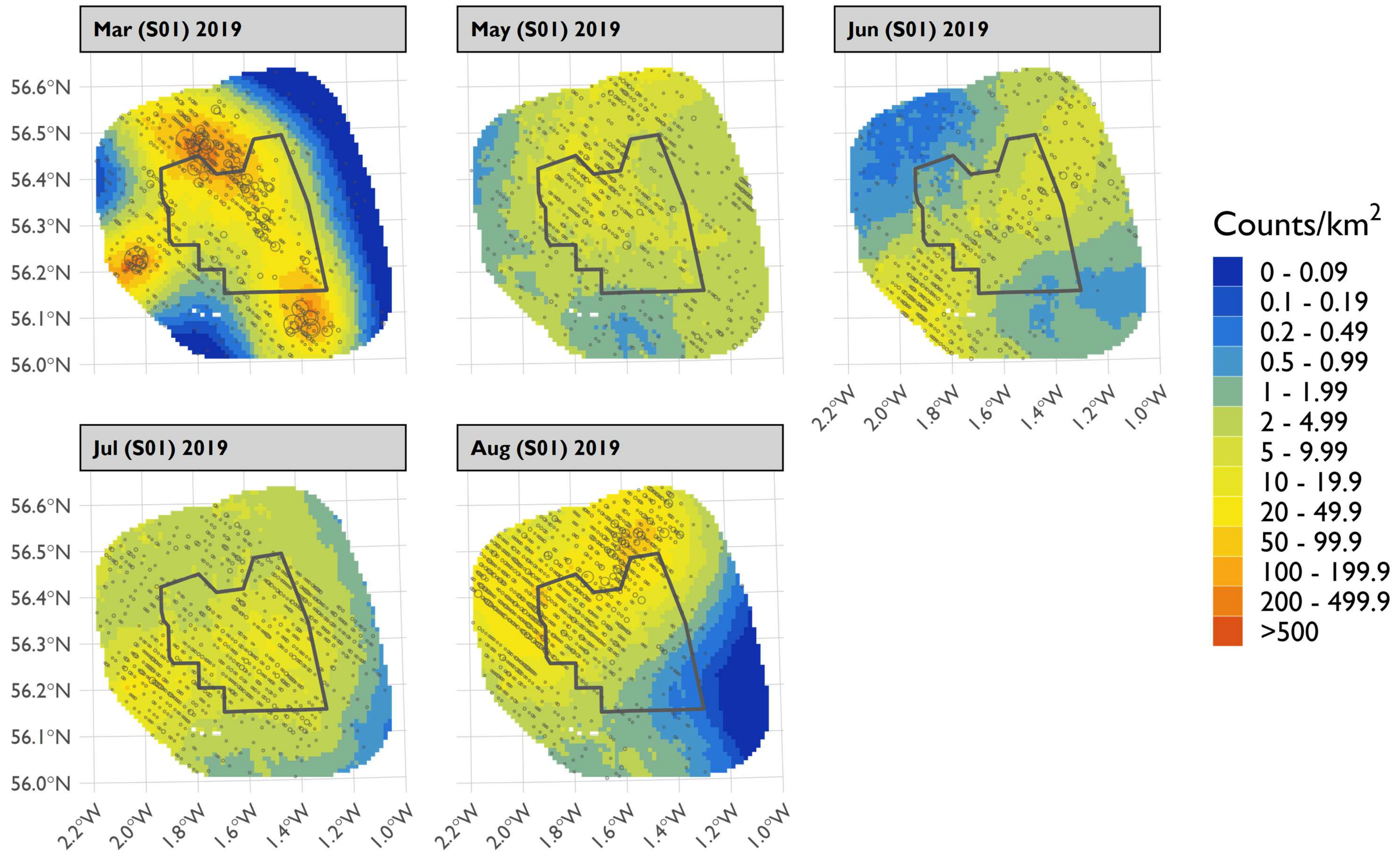

Figure 11 **Upper confidence limit of density of kittiwakes across the Offshore Ornithology Study Area between March and August 2019, modelled using MRSea**

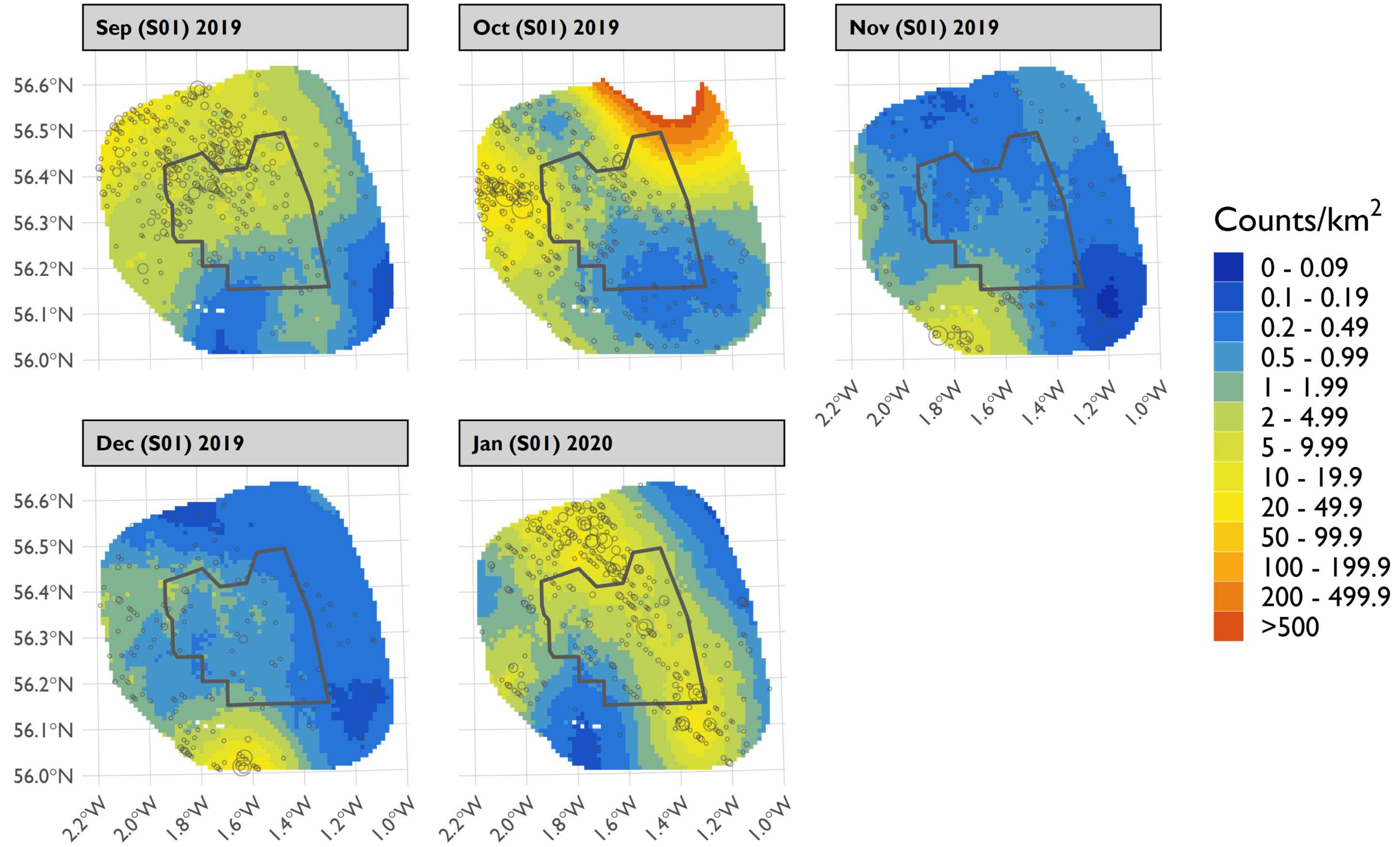

Figure 12 Upper confidence limit of density of kittiwakes across the Offshore Ornithology Study Area between September 2019 and January 2020, modelled using MRSea

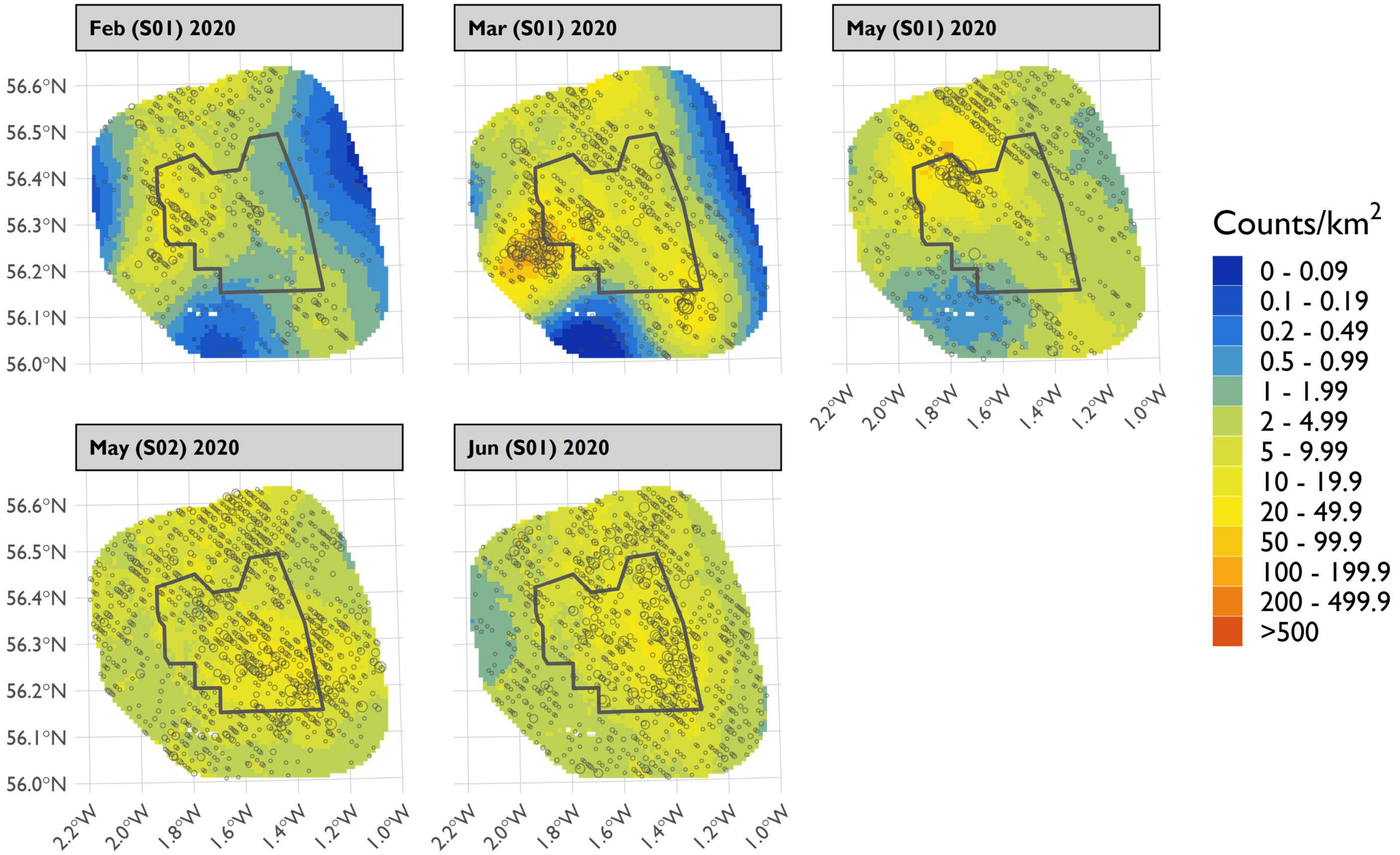

Figure 13 **Upper confidence limit of density of kittiwakes across the Offshore Ornithology Study Area between February and June 2020, modelled using MRSea**

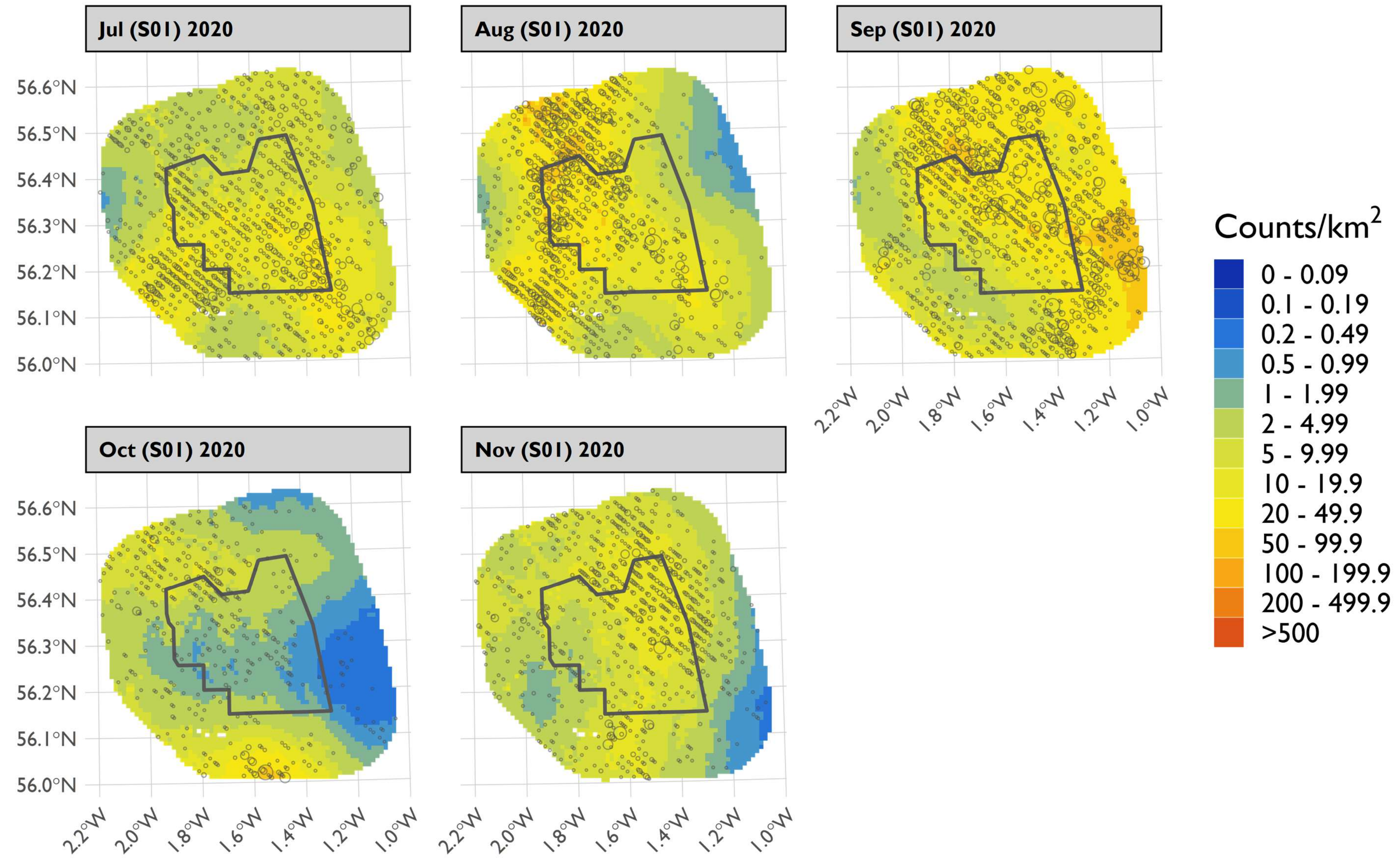

Figure 14 **Upper confidence limit of density of kittiwakes across the Offshore Ornithology Study Area between July and November 2020, modelled using MRSea**

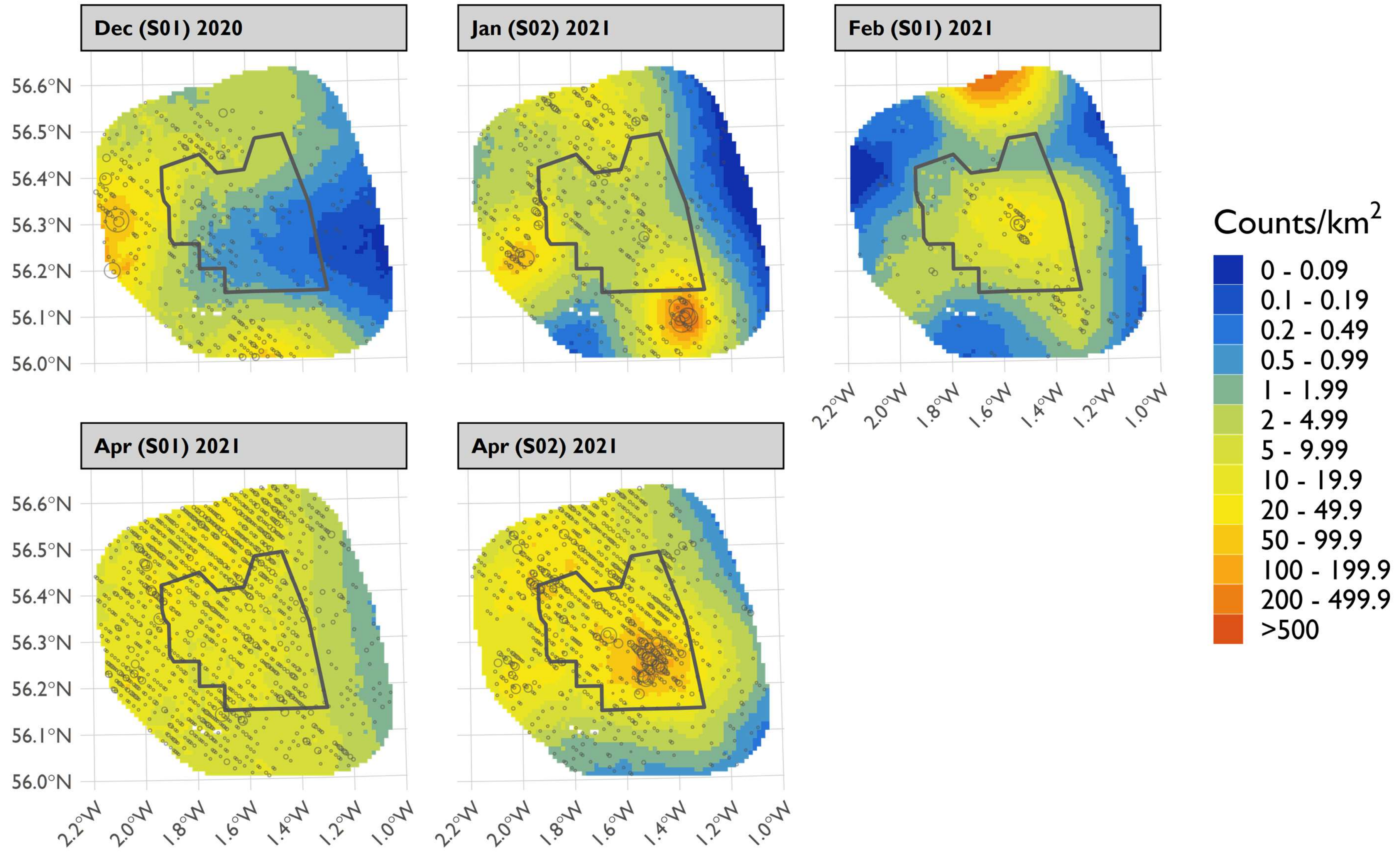

Figure 15 Upper confidence limit of density of kittiwakes across the Offshore Ornithology Study Area between December 2020 and April S02 2021, modelled using MRSea

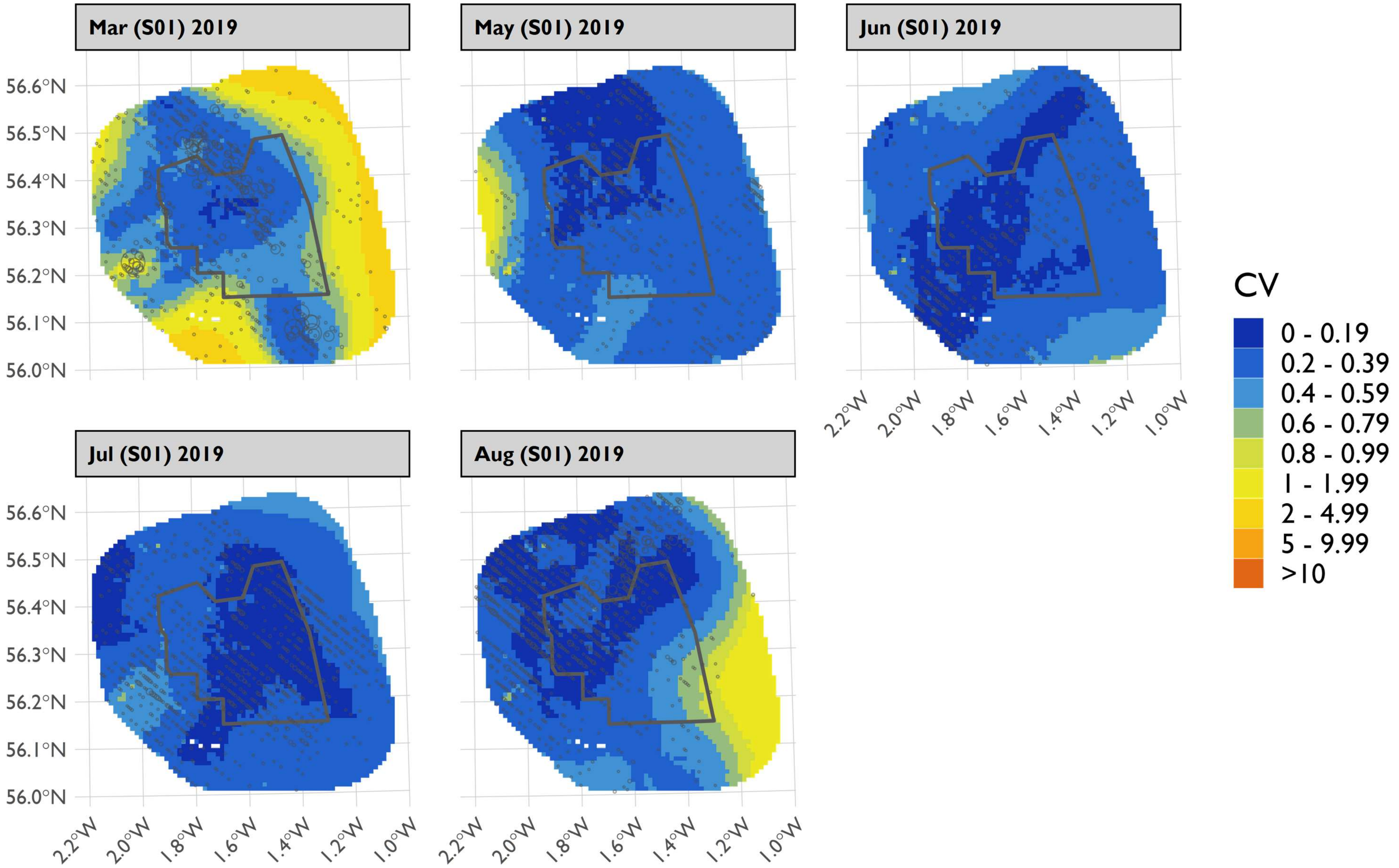

Figure 16 Spatial coefficient of variation of predicted kittiwake densities from MRSea across the Offshore Ornithology Study Area between March and August 2019

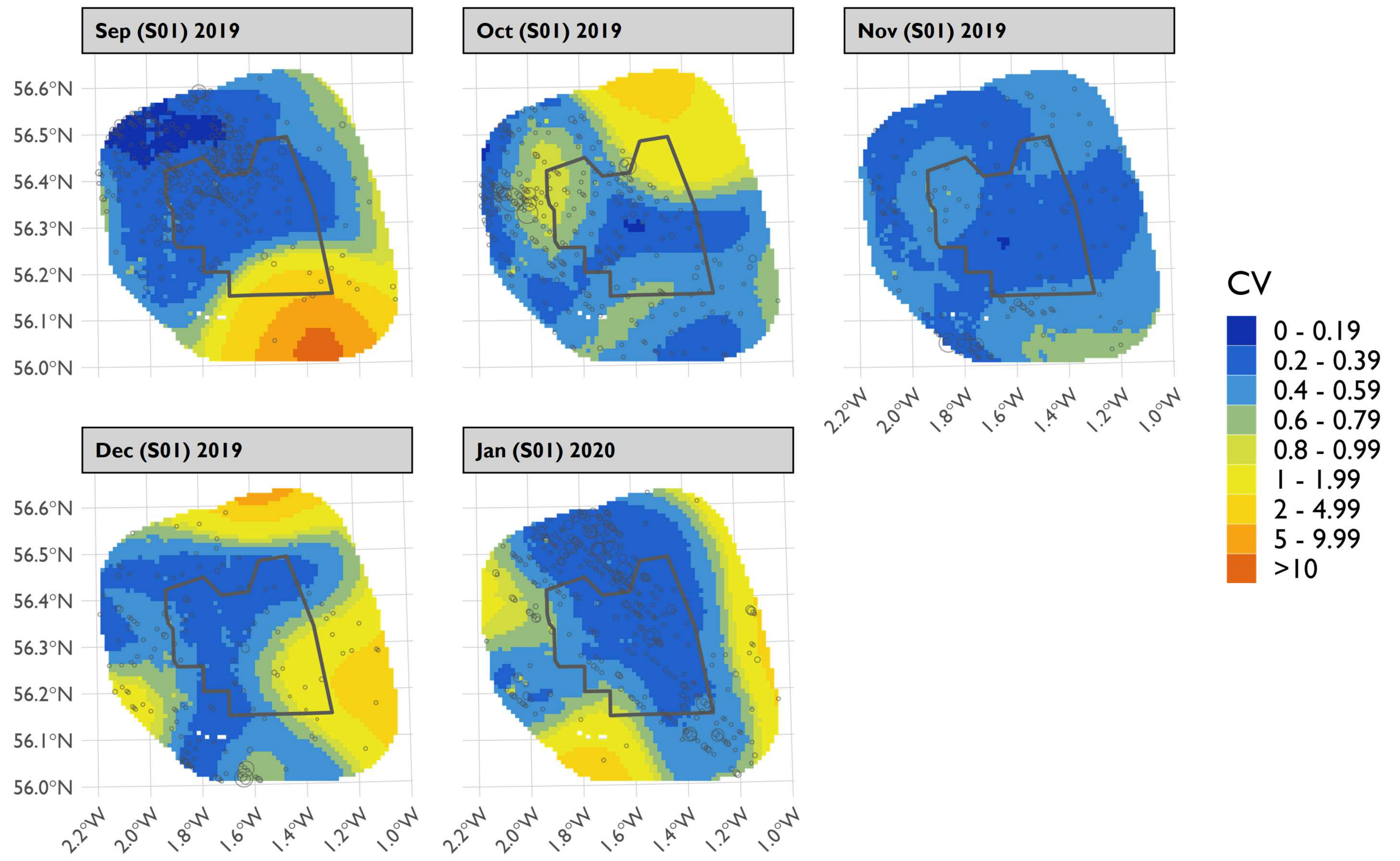

Figure 17 Spatial coefficient of variation of predicted kittiwake densities from MRSea across the Offshore Ornithology Study Area between September 2019 and January 2020

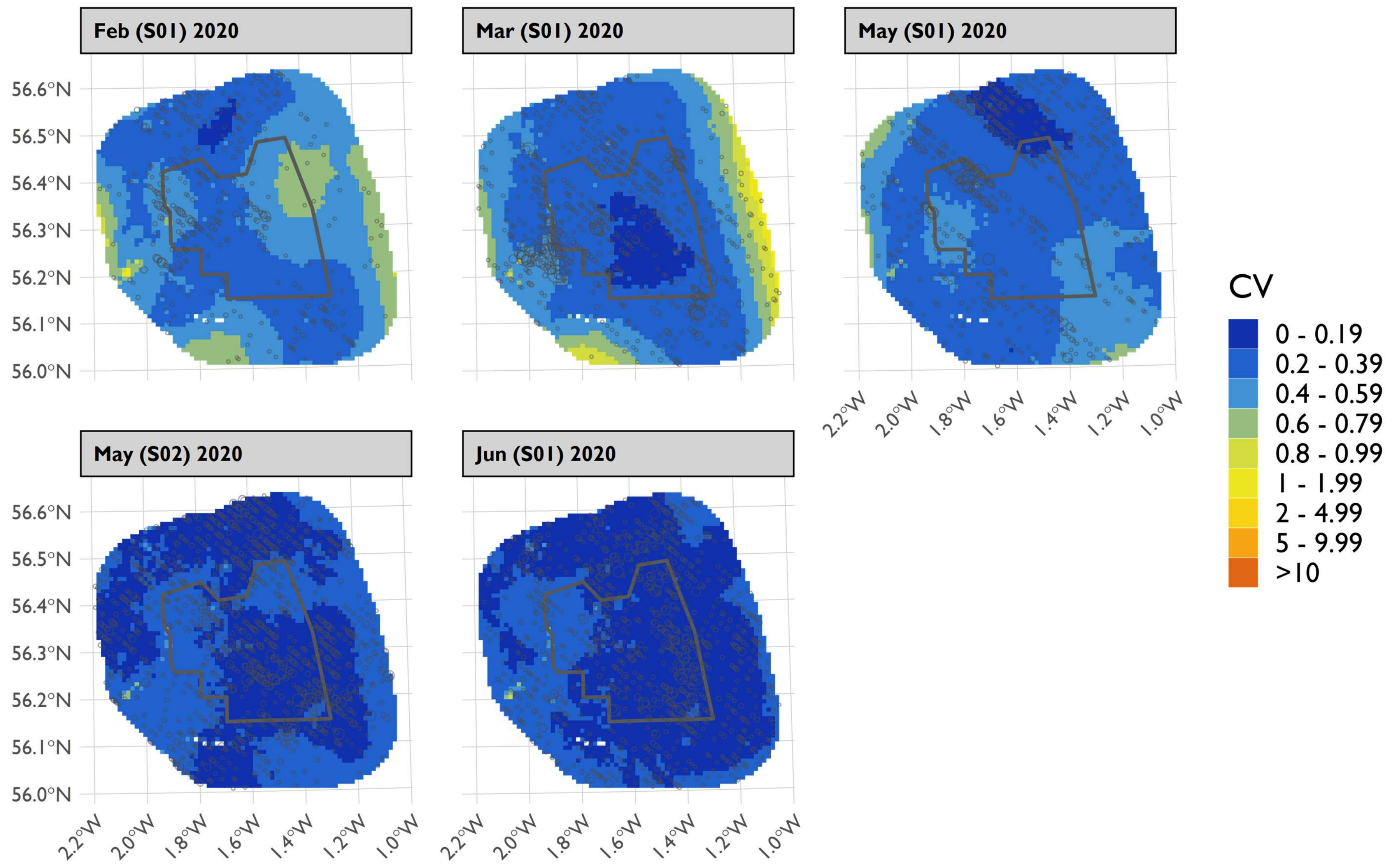

Figure 18 **Spatial coefficient of variation of predicted kittiwake densities from MRSea across the Offshore Ornithology Study Area between February and June 2020**

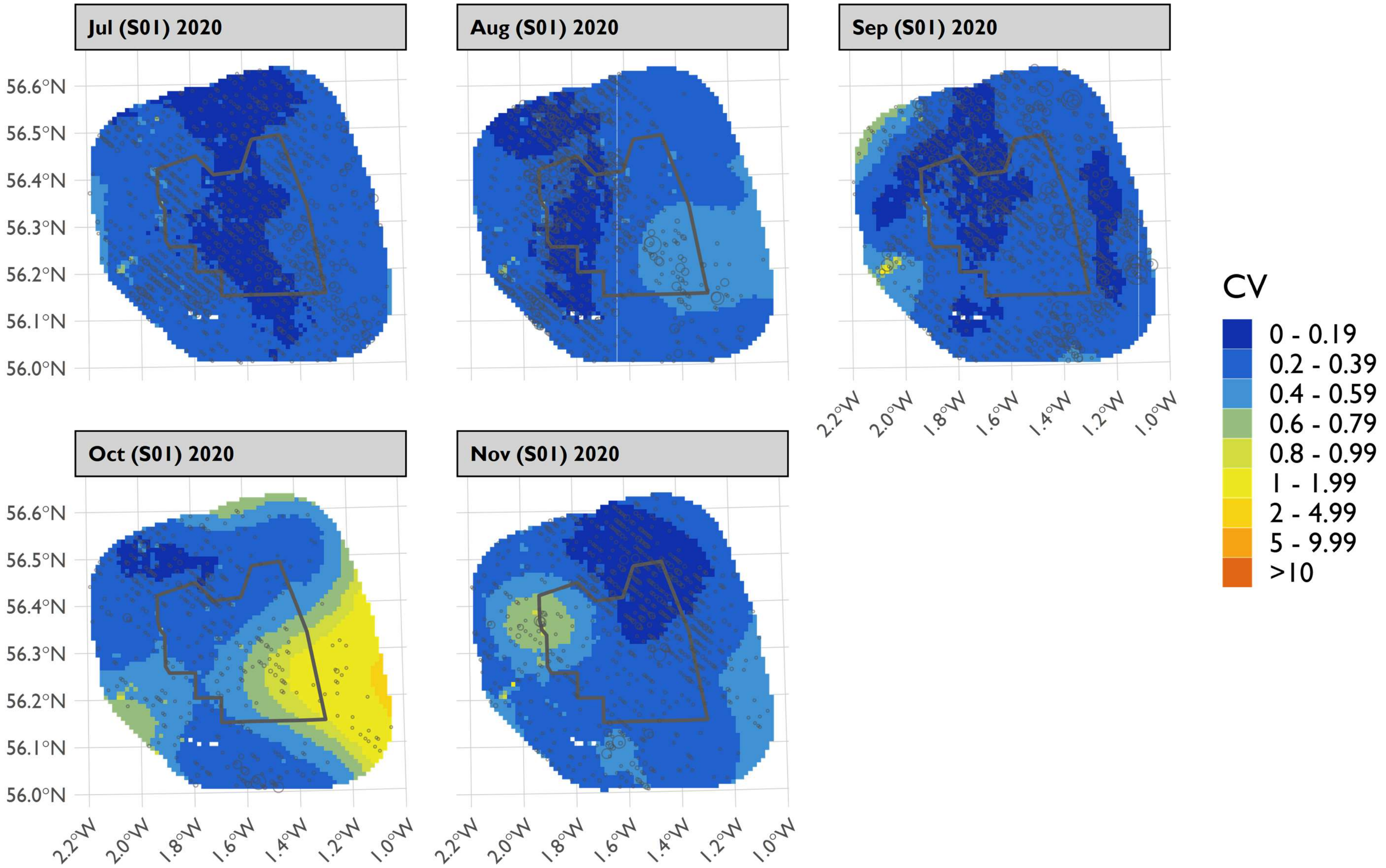

Figure 19 **Spatial coefficient of variation of predicted kittiwake densities from MRSea across the Offshore Ornithology Study Area between July and November 2020**

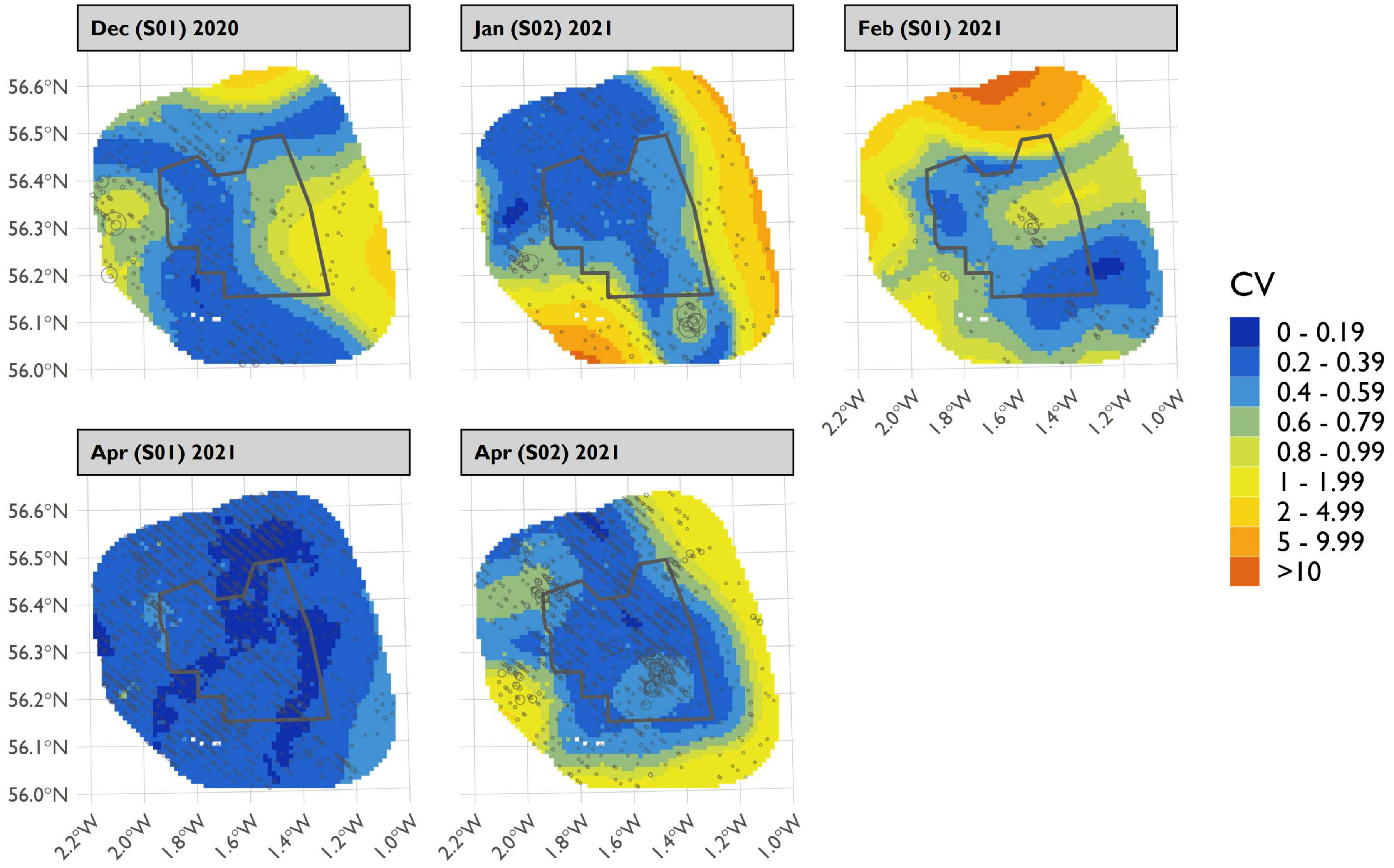

Figure 20 **Spatial coefficient of variation of predicted kittiwake densities from MRSea across the Offshore Ornithology Study Area between December 2020 and April S02 2021**

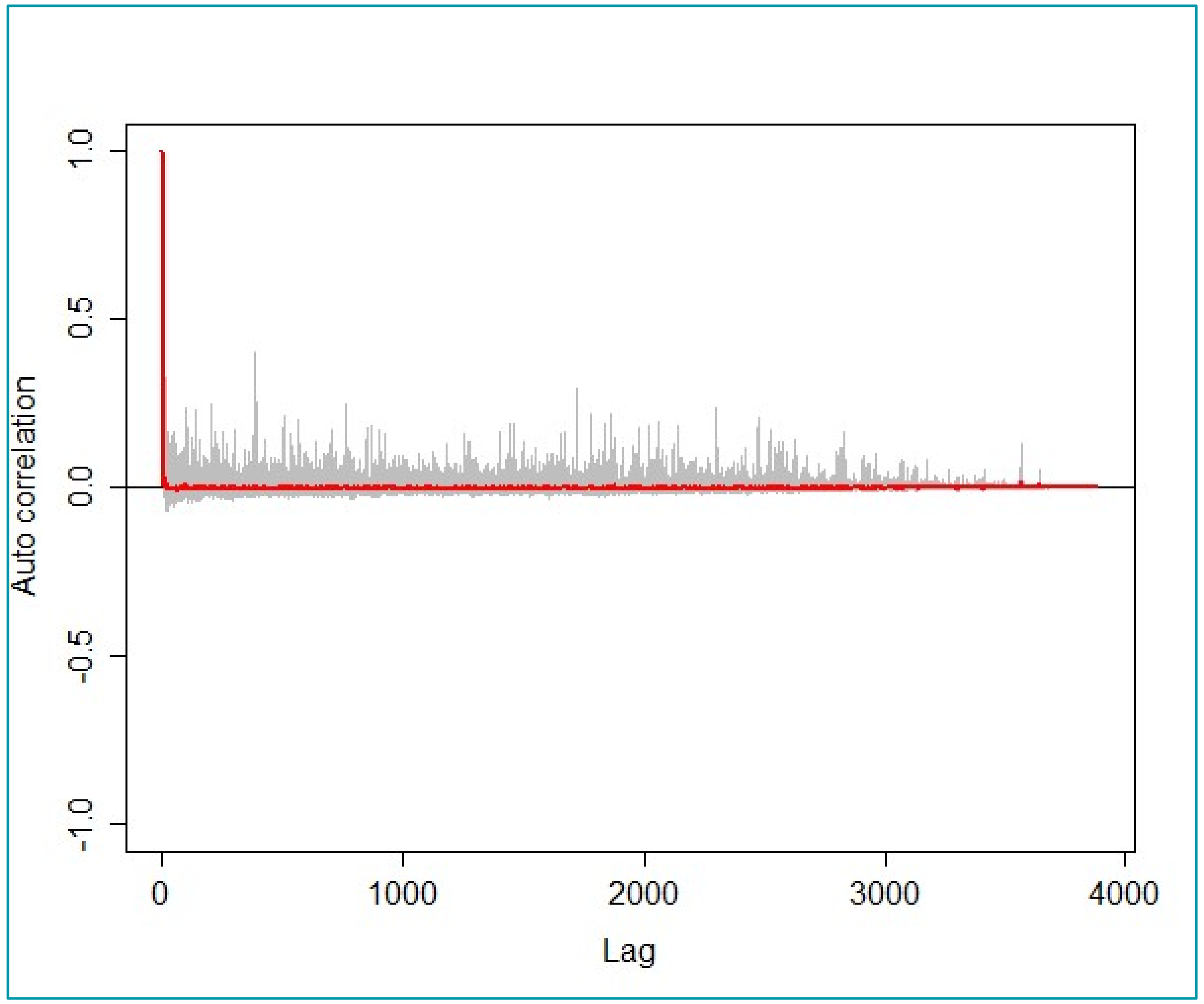

Figure 21 Autocorrelation test for Kittiwake density surface models when using transect as a blocking feature in MRSea showing no significant correlation. A Runs test on the data prior to using transect as a blocking feature gave a p-value of << 0.0001 (i.e., that the data were significantly autocorrelated when not using a blocking feature)

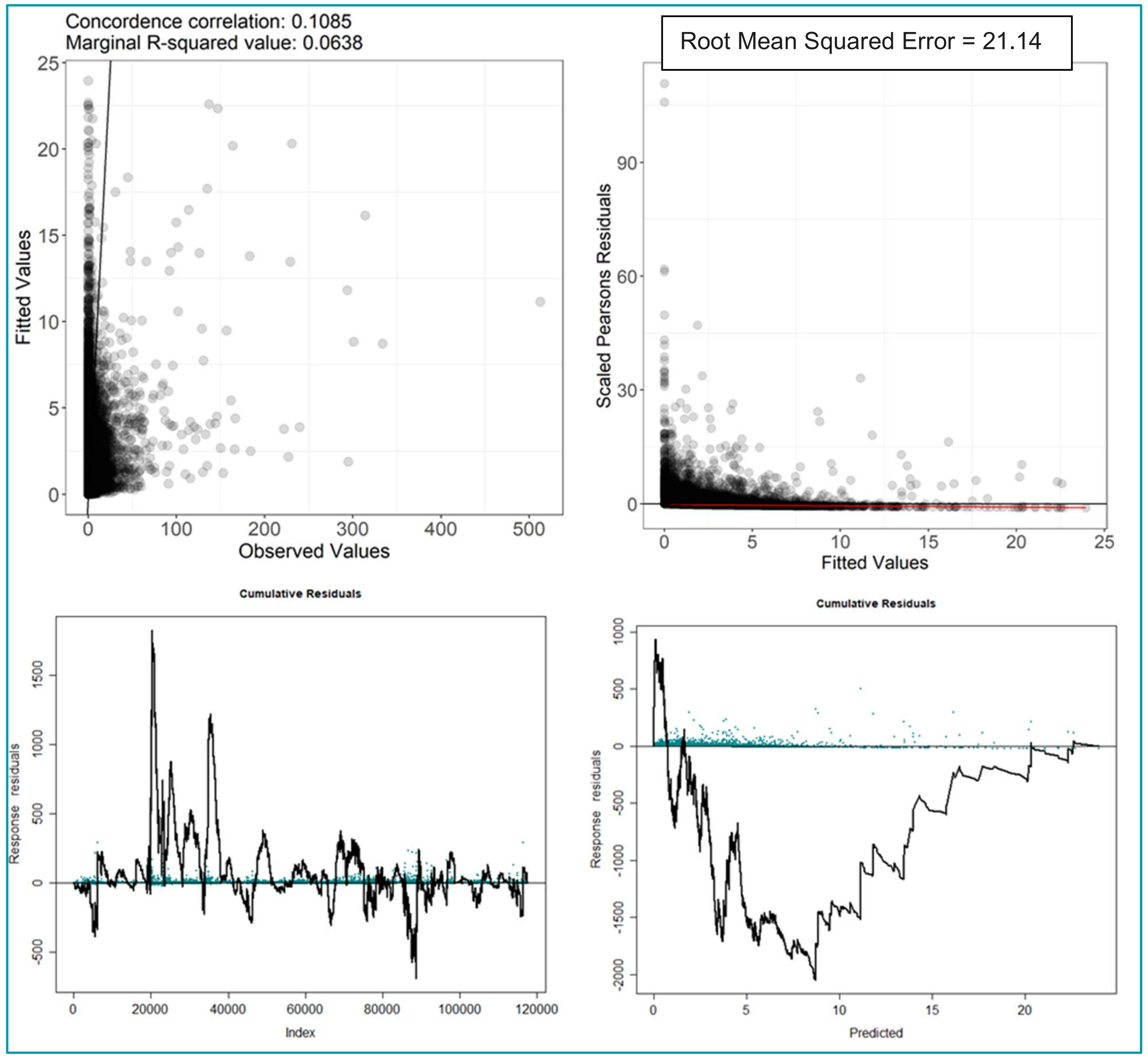

Figure 22 Fitted (MRSea predictions) versus observed counts of Kittiwake (top left), and residual plots from MRSea

Table 4 ANOVA results from the best MRSea model for Kittiwake as selected by cross-validation

Variable	Degrees of Freedom	Chi-square	P value
Sediment type	3	2.9	0.41
Bathymetry	3	33.67	<< 0.001
SST gradient	1	16.07	<< 0.001
Sandeel density	3	5.03	0.17
Distance to coast	3	38.65	<< 0.001
X/Y (location)	4	-	<< 0.001

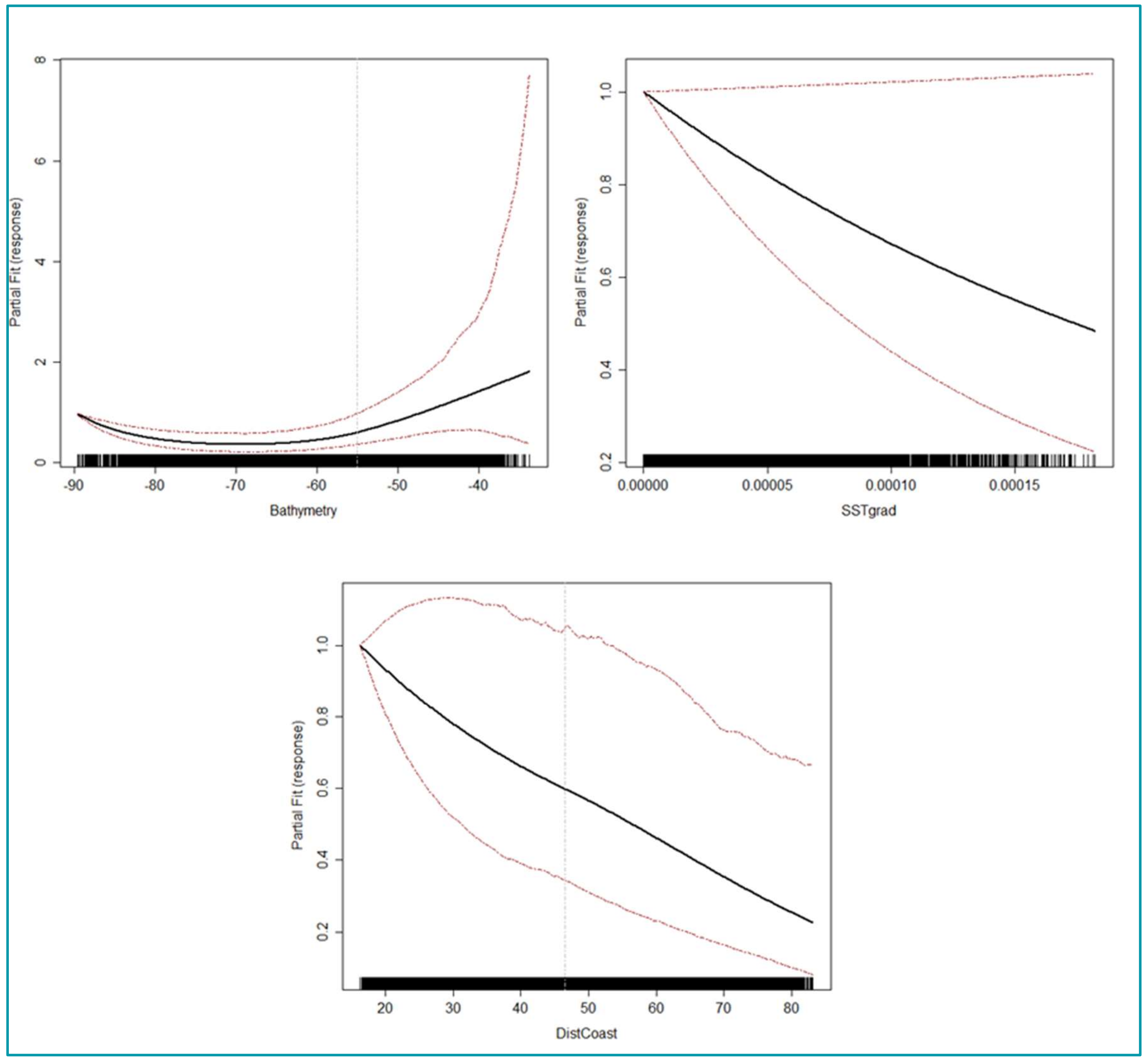

Figure 23 Partial dependence plots for significant variables for Kittiwake from MRSea models

1.3.3. GUILLEMOT

28. The highest densities calculated using MRSea were recorded in October 2019, reaching peaks of 443.76 birds/km^2 (95CI 5.63 – 3,557.51) and 3.87E+12 birds/km^2 (95CI 9.30E+6 – 2.00E+13) in the Development Array and Offshore Ornithology Study Area, respectively (Table 5 and Table 6). This equated to peak population estimates of 448,304 birds (95CI 5,692 – 3,593,901) and 1.54E+16 birds (95CI 3.70E+10 – 7.96E+16).

29. Mapped mean densities of guillemots created using model-based analyses throughout the Offshore Ornithology Study Area indicate the species is prolific throughout the region, occurring in high densities in most months (Figure 24 - Figure 28).

30. Elevated densities within the breeding season were observed in both years. In the non-breeding period (e.g. October to December in 2019 and October to November 2020), higher densities were observed south and west of the Development Array. This could be indicative of guillemots remaining closer to colonies during this time.

31. Broadly, model fit was better for Guillemot than other species, with a marginal R squared value of 0.2005 and root mean squared error of 35.36. The cumulative residuals in the model showed that there was overall a poor relationship between predicted and observed values across most of the range of predicted values, but typically bounded around 0 across the whole (Figure 45).

Table 5 Monthly density and population estimates of guillemots in the Development Array derived from MRSea

Survey	Density Estimate (n/km²)	SD of Density	Lower 95% CL of Density	Upper 95% CL of Density	Population Estimate (number)	SD of Population	Lower 95% CL of Population	Upper 95% CL of Population	CV (%)
Mar-19	10.66	1.24	8.5	13.55	10768	1254	8582	13692	11.65%
May-19	22.55	2.85	17.84	29.14	22783	2875	18019	29442	12.62%
Jun-19	5.94	1.14	4.08	8.57	5999	1153	4117	8662	19.22%
Jul-19	23.36	2.55	19.15	28.84	23595	2577	19347	29137	10.92%
Aug-19	32.44	3.91	24.99	40.71	32769	3949	25244	41123	12.05%
Sep-19	4.53	0.37	3.8	5.3	4580	375	3843	5357	8.19%
Oct-19	443.76	1420.41	5.63	3557.51	448304	1434943	5692	3593901	320.08%
Nov-19	0.68	0.14	0.46	1	691	144	469	1013	20.84%
Dec-19	1.66	0.14	1.41	1.97	1681	137	1420	1992	8.15%
Jan-20	13.28	1.8	10.45	17.75	13411	1819	10552	17932	13.56%
Feb-20	8.36	0.57	7.35	9.4	8448	572	7430	9501	6.77%
Mar-20	30.36	4.48	23.21	39.89	30667	4527	23452	40293	14.76%
May S01 20	20.49	4.01	14.1	29.6	20701	4051	14247	29900	19.57%
May S02 20	14.32	2.44	10	19.12	14463	2461	10105	19312	17.02%
Jun-20	33.73	3.53	27.33	41.29	34073	3571	27606	41708	10.48%
Jul-20	8.86	1	6.97	10.84	8951	1006	7037	10954	11.24%
Aug-20	23.76	1.28	21.52	26.45	24006	1293	21742	26722	5.39%
Sep-20	27.65	2.23	23.46	32.05	27928	2254	23704	32376	8.07%
Oct-20	4.06	1.05	2.54	6.54	4103	1064	2564	6605	25.93%
Nov-20	2.88	0.52	2.09	4.04	2914	522	2109	4079	17.91%
Dec-20	11.78	2.07	8.31	16.64	11900	2096	8395	16815	17.61%
Jan-21	9.44	0.92	7.87	11.48	9536	926	7951	11600	9.71%
Feb-21	5.22	0.93	3.65	7.27	5277	939	3691	7345	17.79%
Apr S01 21	22.33	2.08	18.77	26.42	22555	2101	18964	26693	9.32%
Apr S02 21	51.46	5.76	41.6	63.94	51987	5822	42022	64597	11.2%

Table 6 Monthly density and population estimates of guillemots in the Offshore Ornithology Study Area derived from MRSea (16k buffer region)

Survey	Density Estimate (n/km²)	SD of Density	Lower 95% CL of Density	Upper 95% CL of Density	Population Estimate (number)	SD of Population	Lower 95% CL of Population	Upper 95% CL of Population	CV (%)
Mar-19	6.6	0.55	5.63	7.85	26245	2194	22389	31220	8.36%
May-19	19.91	1.12	18.02	22.28	79130	4445	71615	88566	5.62%
Jun-19	4.89	0.55	3.96	6.12	19447	2186	15723	24333	11.24%
Jul-19	26.53	4.43	20.81	37.4	105468	17595	82715	148673	16.68%
Aug-19	31.68	3.4	25.74	38.96	125924	13530	102324	154874	10.74%
Sep-19	4.54	0.31	3.99	5.15	18040	1215	15846	20470	6.74%
Oct-19	3.87054E+12	3.79173E+13	9304898.88	2.00297E+13	1.53848E+16	1.50715E+17	36985527496	7.96149E+16	979.64%
Nov-19	1.65	0.24	1.26	2.2	6571	949	5021	8751	14.44%
Dec-19	2.53	0.13	2.27	2.79	10046	509	9014	11071	5.07%
Jan-20	10.03	0.96	8.48	12.22	39878	3797	33709	48580	9.52%
Feb-20	5.34	0.31	4.74	5.93	21216	1248	18850	23582	5.88%
Mar-20	18.12	1.89	14.84	22.19	72044	7524	58979	88201	10.44%
May S01 20	24.98	3.04	20.21	31.5	99300	12078	80323	125227	12.16%
May S02 20	18.4	1.63	15.34	22.09	73133	6481	60958	87794	8.86%
Jun-20	21.48	1.32	19.16	24.14	85361	5238	76177	95954	6.14%
Jul-20	8.09	0.75	6.75	9.59	32150	3001	26839	38136	9.33%
Aug-20	25.58	1.28	23.43	28.15	101658	5075	93114	111902	4.99%
Sep-20	36.24	1.51	33.5	39.46	144040	6009	133152	156849	4.17%
Oct-20	8.41	1.02	6.61	10.5	33428	4073	26256	41723	12.18%
Nov-20	6.07	0.54	5.16	7.26	24124	2137	20516	28863	8.86%
Dec-20	14.61	0.94	12.86	16.55	58068	3741	51131	65798	6.44%
Jan-21	8.27	0.49	7.38	9.18	32891	1931	29342	36472	5.87%
Feb-21	3.75	0.31	3.2	4.39	14915	1250	12716	17455	8.38%
Apr S01 21	19.58	1.54	17.01	22.79	77813	6139	67598	90577	7.89%
Apr S02 21	46.8	3.86	39.91	54.56	186014	15329	158630	216854	8.24%

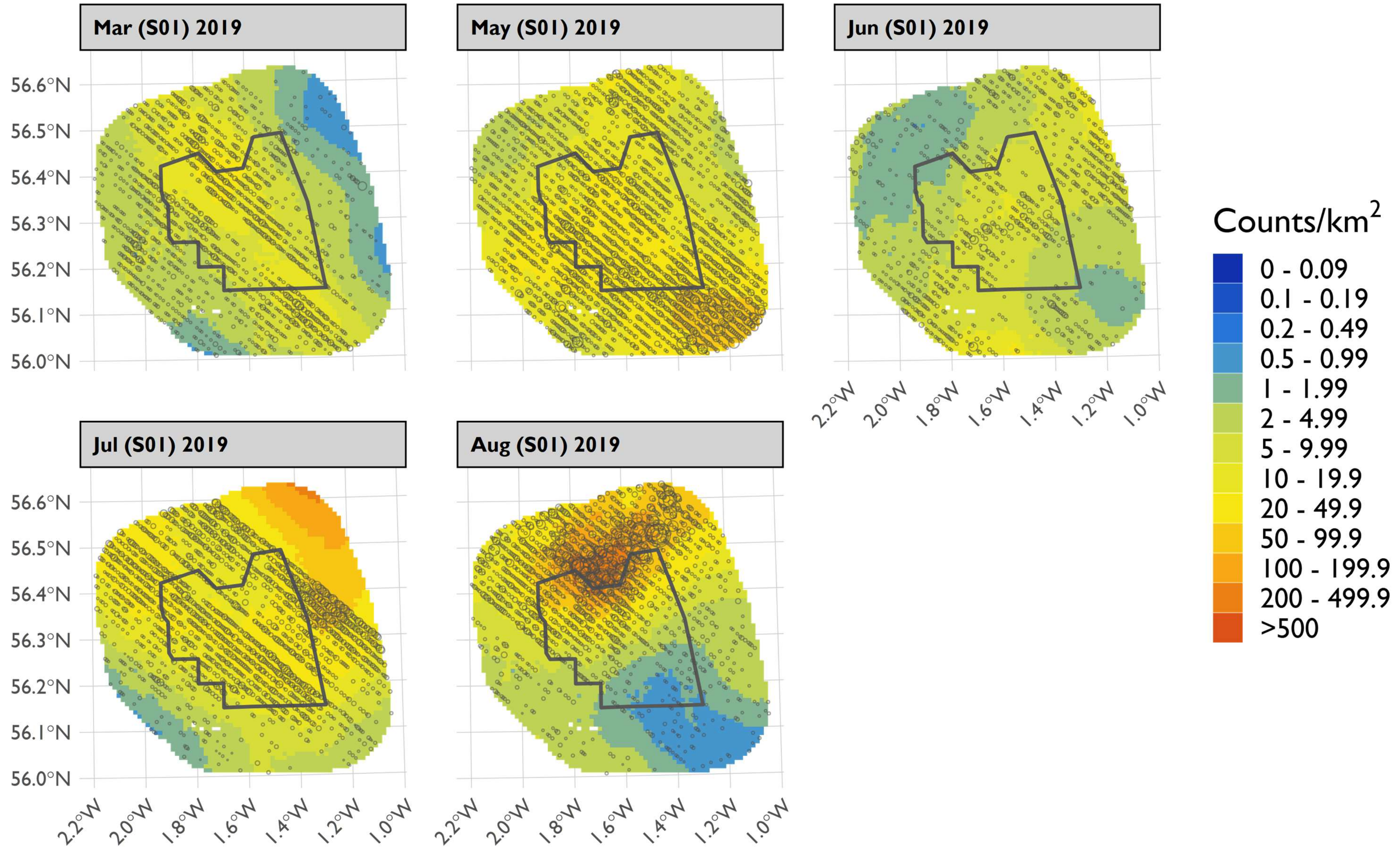

Figure 24 Mean density of guillemots across the Offshore Ornithology Study Area between March and August 2019, modelled using MRSea

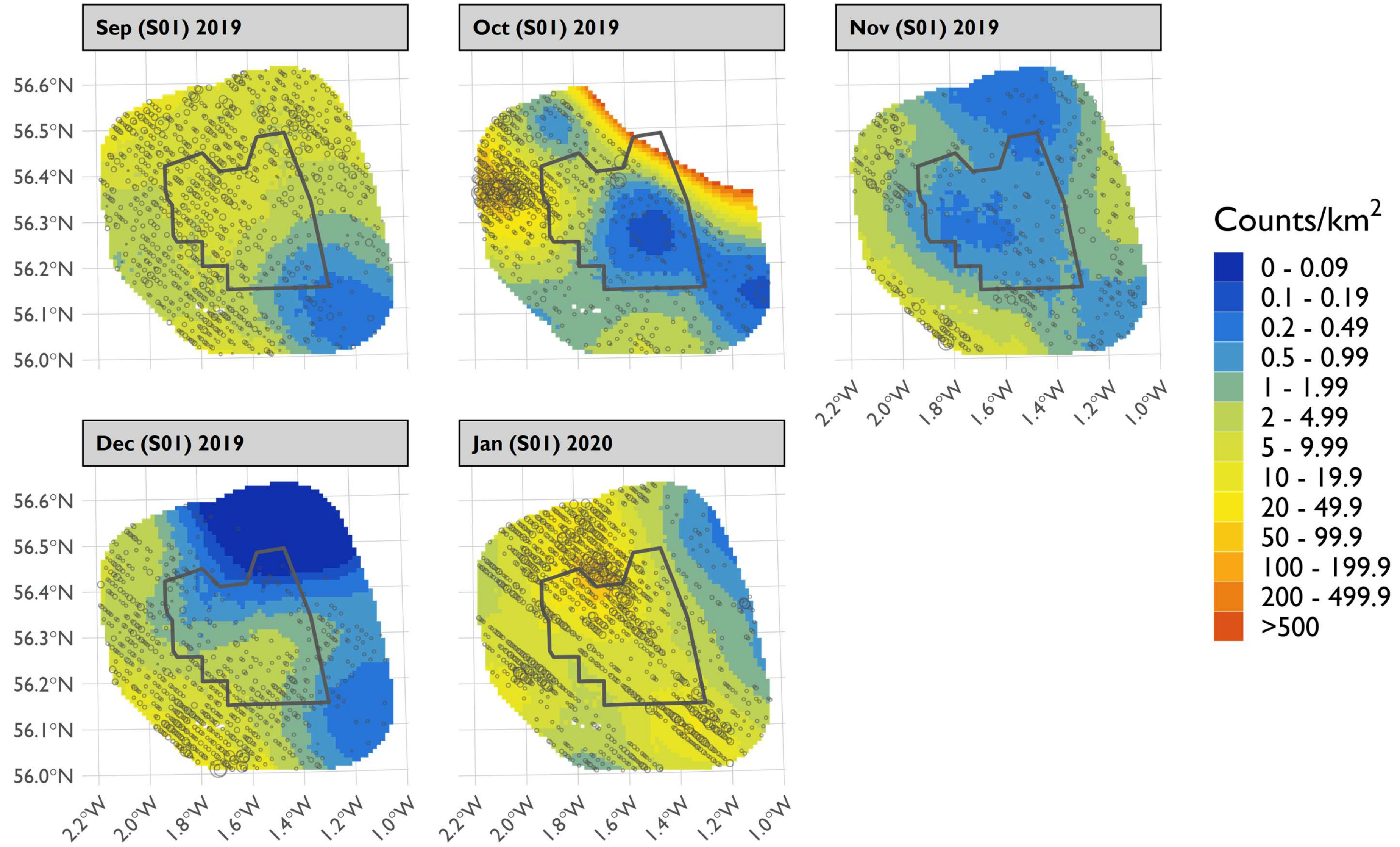

Figure 25 Mean density of guillemots across Offshore Ornithology Study Area between September 2019 and January 2020, modelled using MRSea

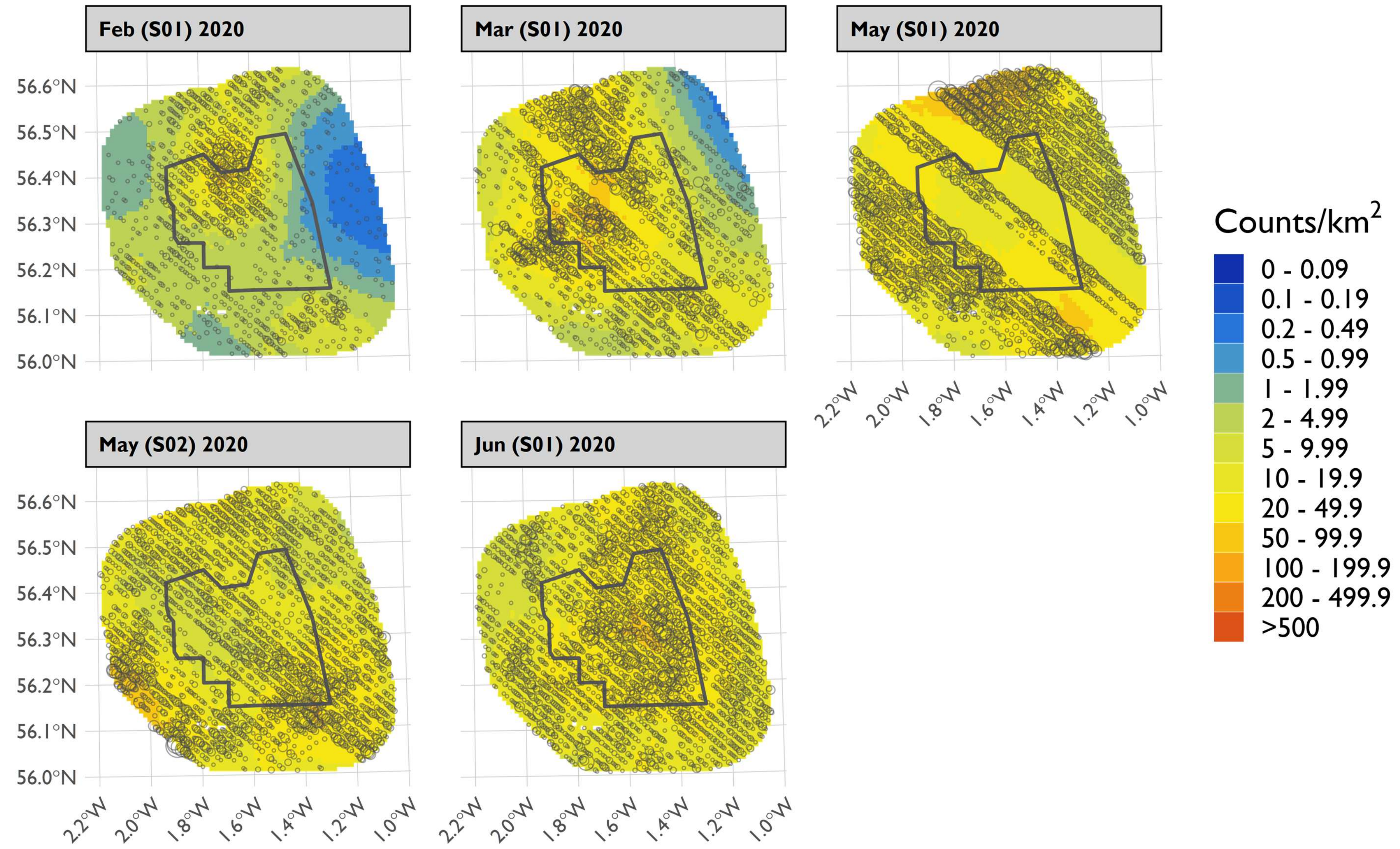

Figure 26 **Mean density of guillemots across the survey area Offshore Ornithology Study Area between February and June 2020, modelled using MRSea**

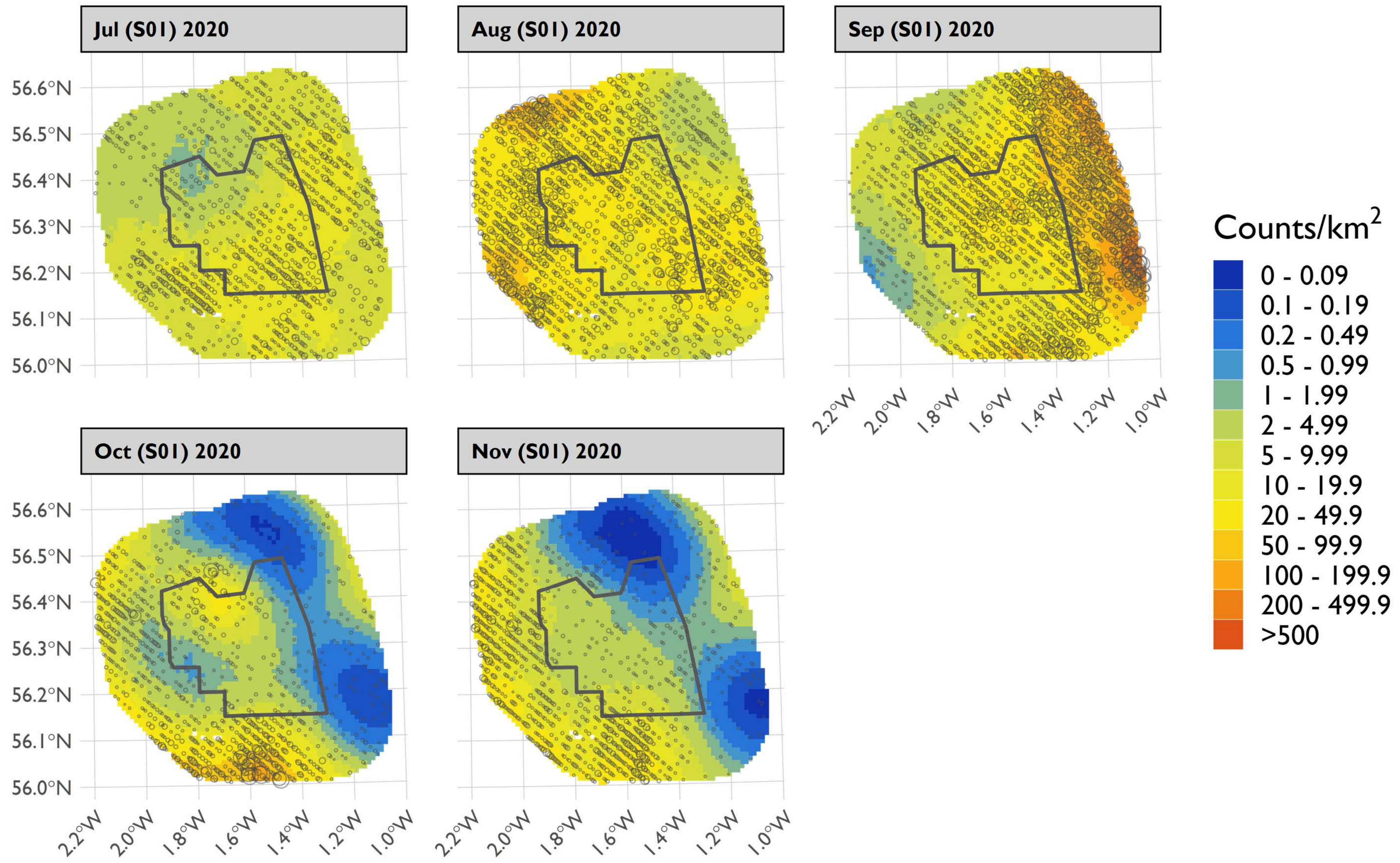

Figure 27 Mean density of guillemots across the Offshore Ornithology Study Area between July and November 2020, modelled using MRSea

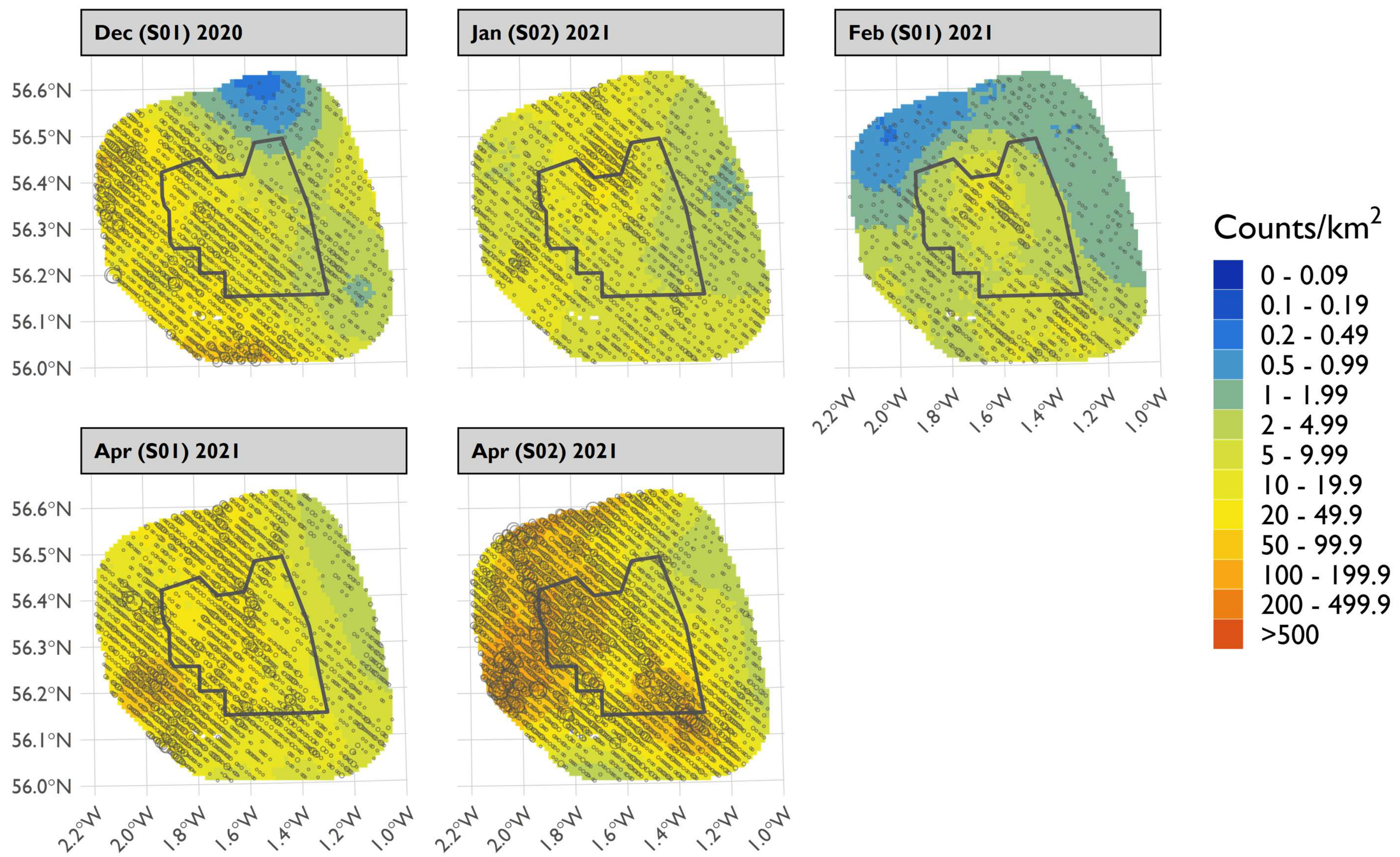

Figure 28 **Mean density of guillemots across the Offshore Ornithology Study Area between December 2020 and April S02 2021, modelled using MRSea**

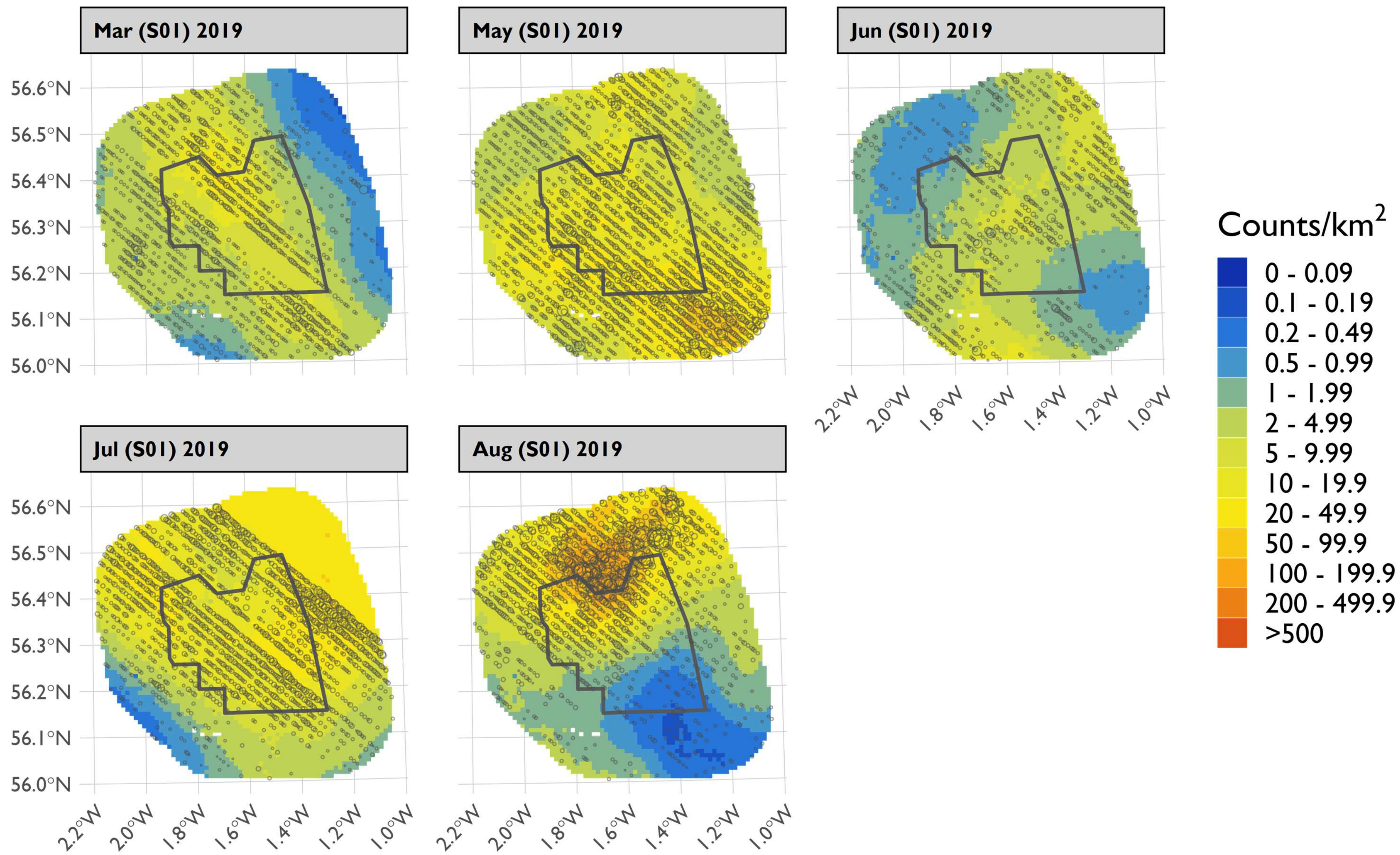

Figure 29 **Lower confidence limit of density of guillemots across the Offshore Ornithology Study Area between March and August 2019, modelled using MRSea**

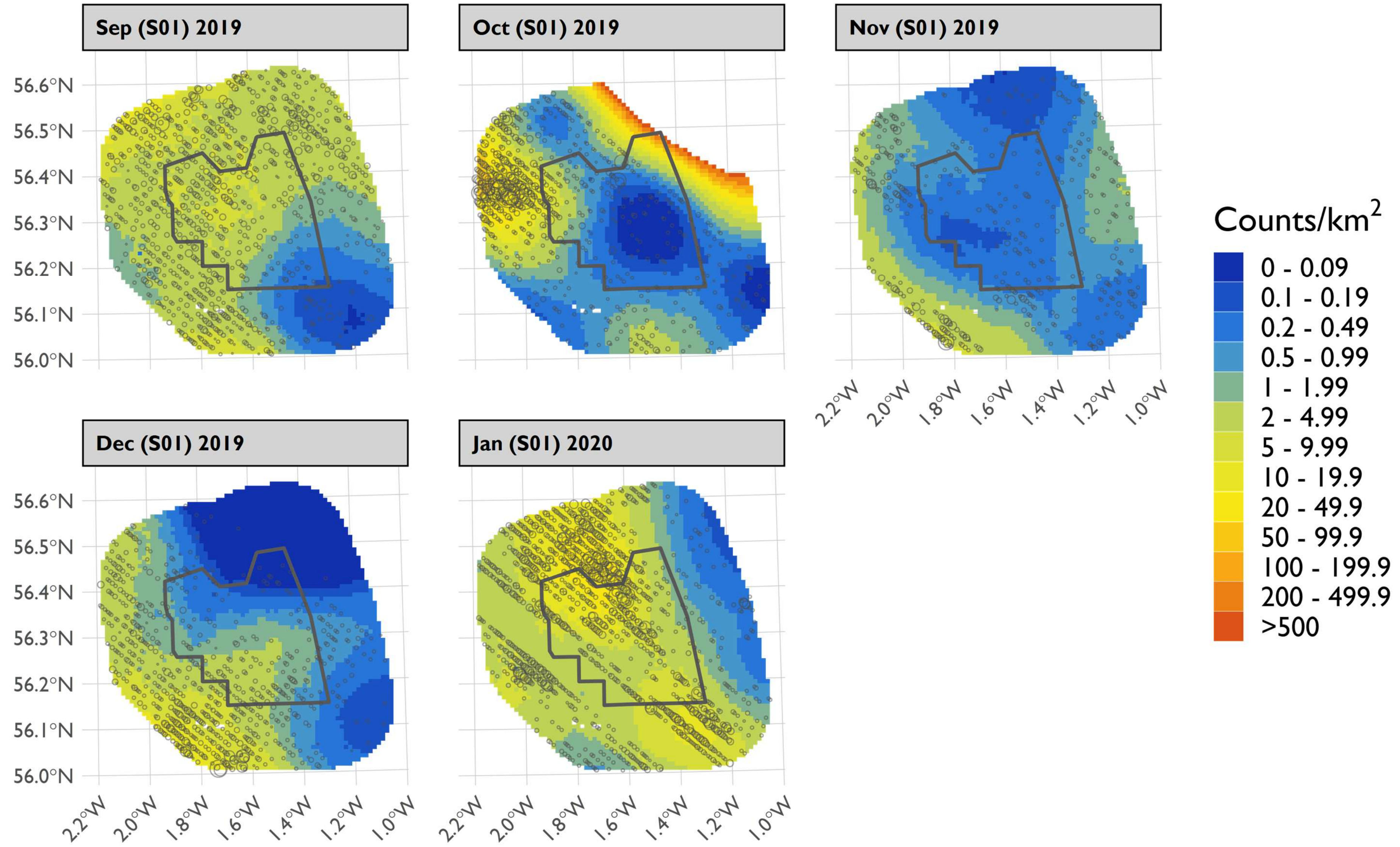

Figure 30 Lower confidence limit of density of guillemots across the Offshore Ornithology Study Area between September 2019 and January 2020, modelled using MRSea

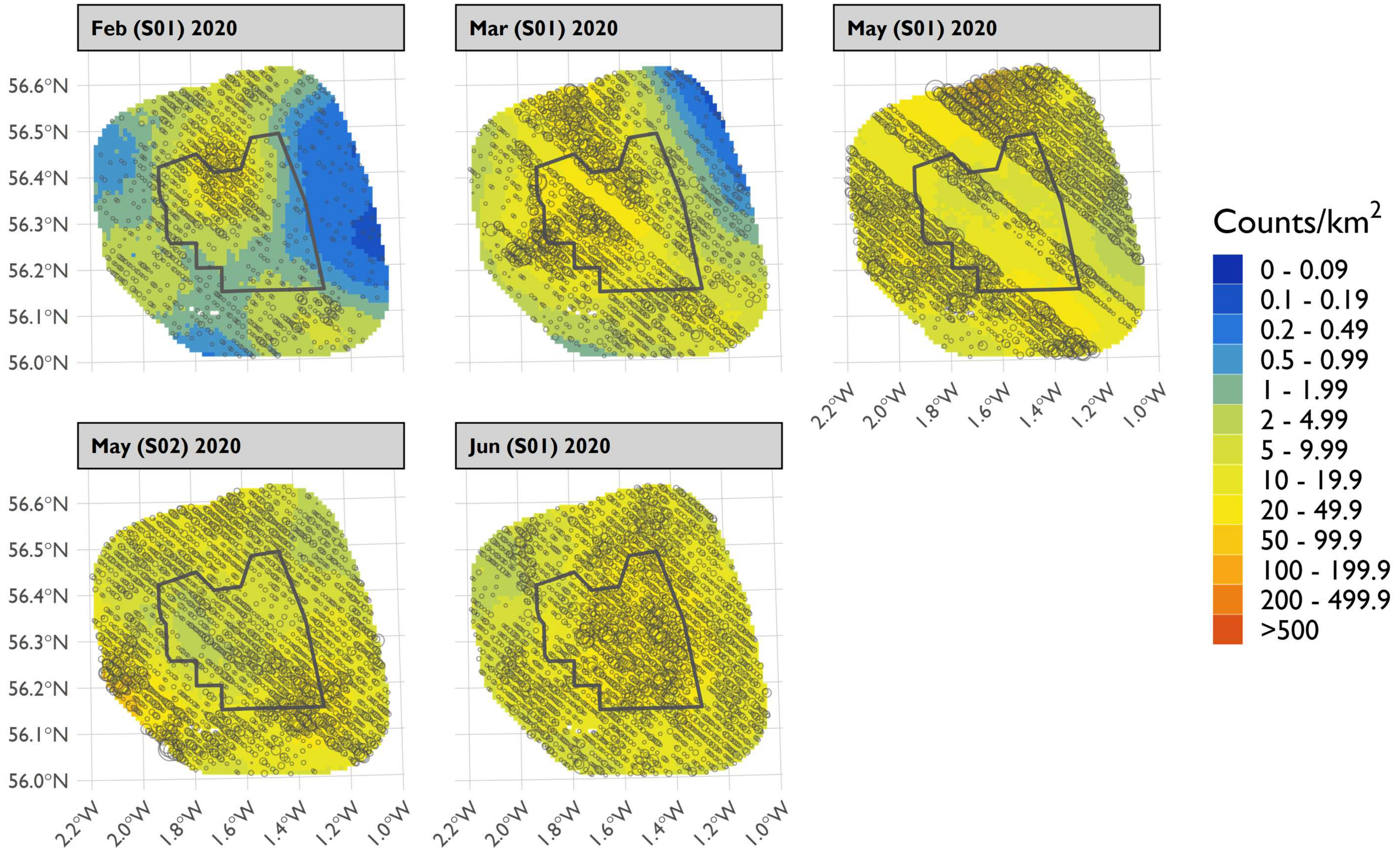

Figure 31 Lower confidence limit of density of guillemots across the Offshore Ornithology Study Area between February and June 2020, modelled using MRSea

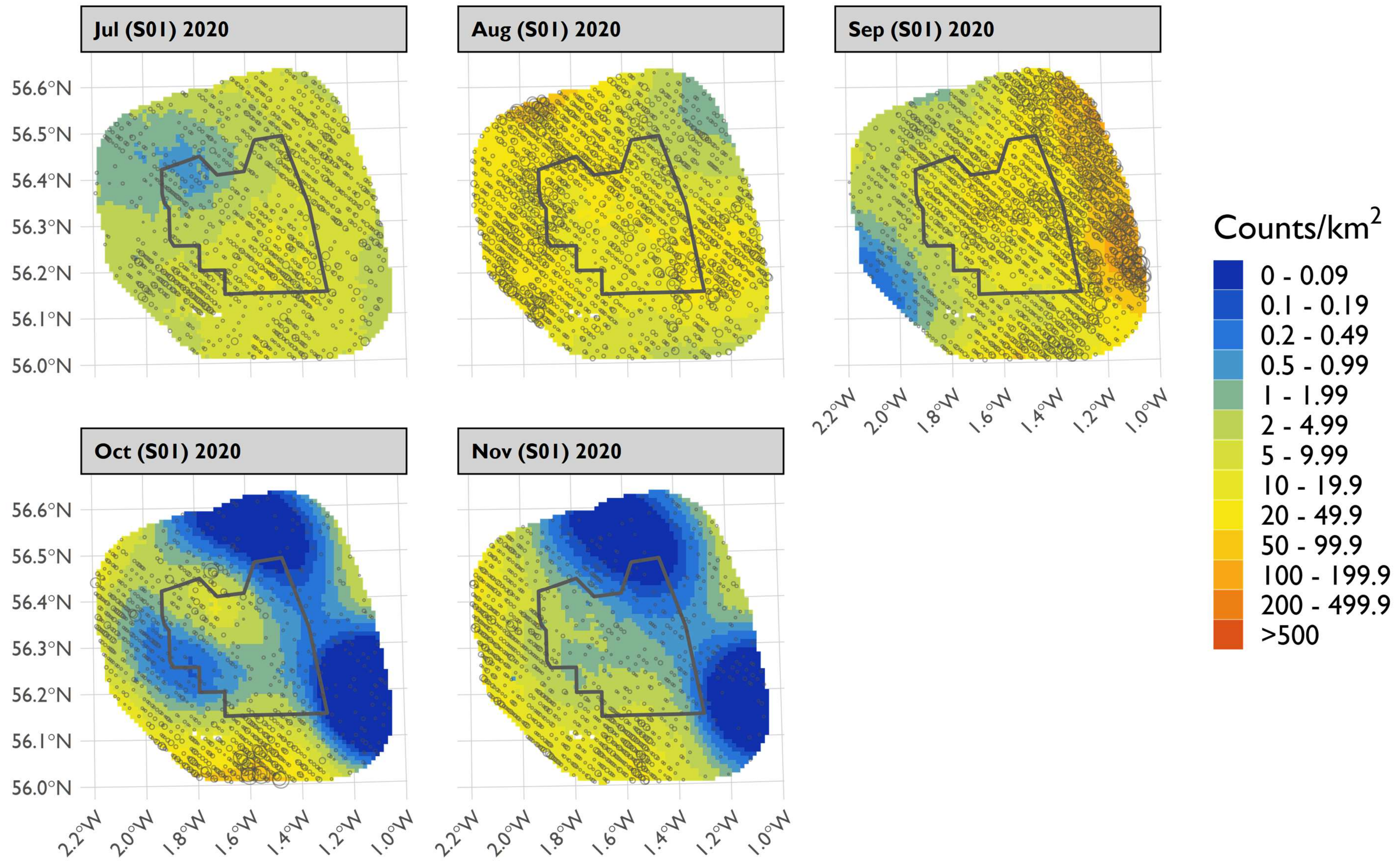

Figure 32 **Lower confidence limit of density of guillemots across the Offshore Ornithology Study Area between July and November 2020, modelled using MRSea**

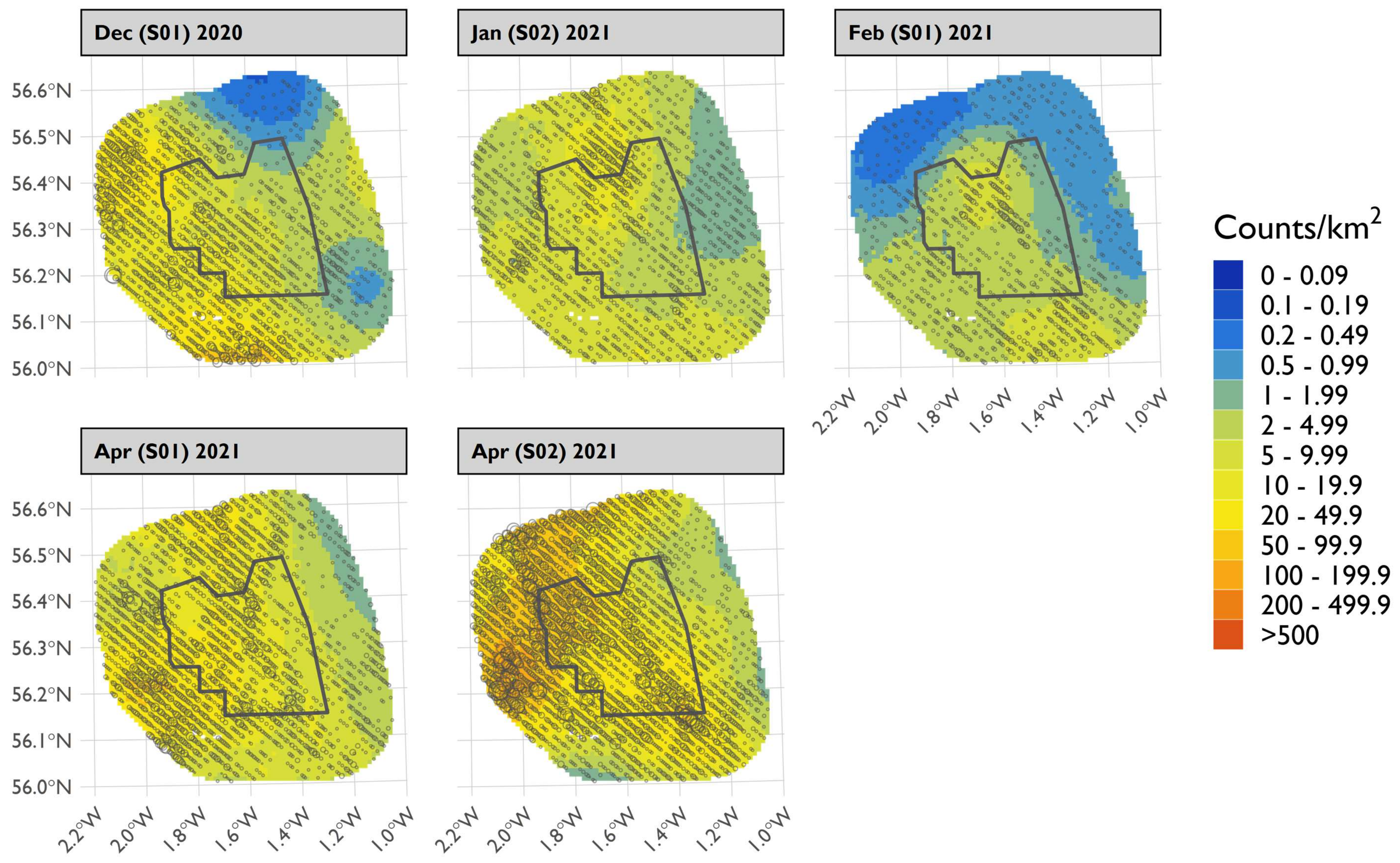

Figure 33 Lower confidence limit of density of guillemots across the Offshore Ornithology Study Area between December 2020 and April S02 2021, modelled using MRSea

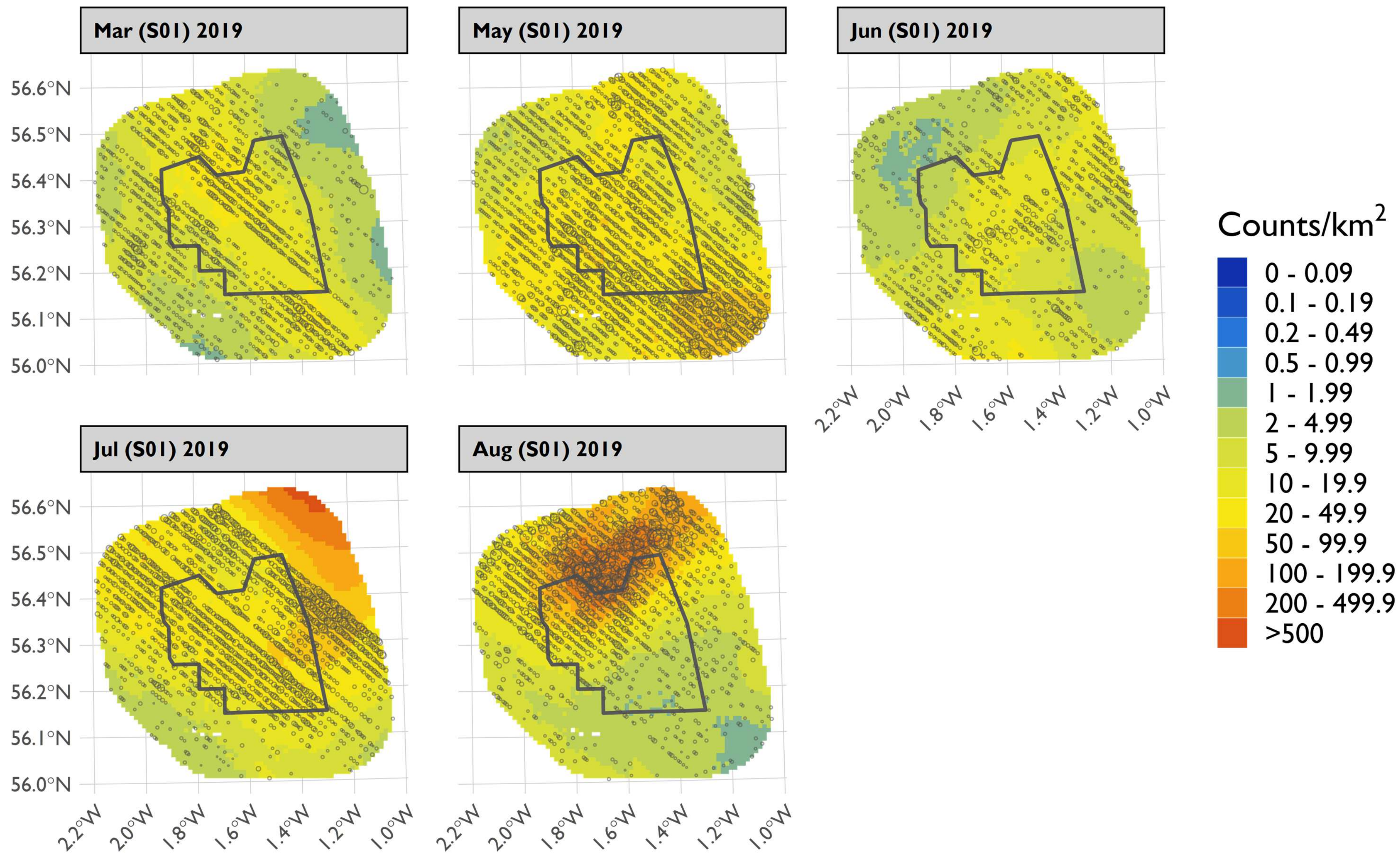

Figure 34 **Upper confidence limit of density of guillemots across the Offshore Ornithology Study Area between March and August 2019, modelled using MRSea**

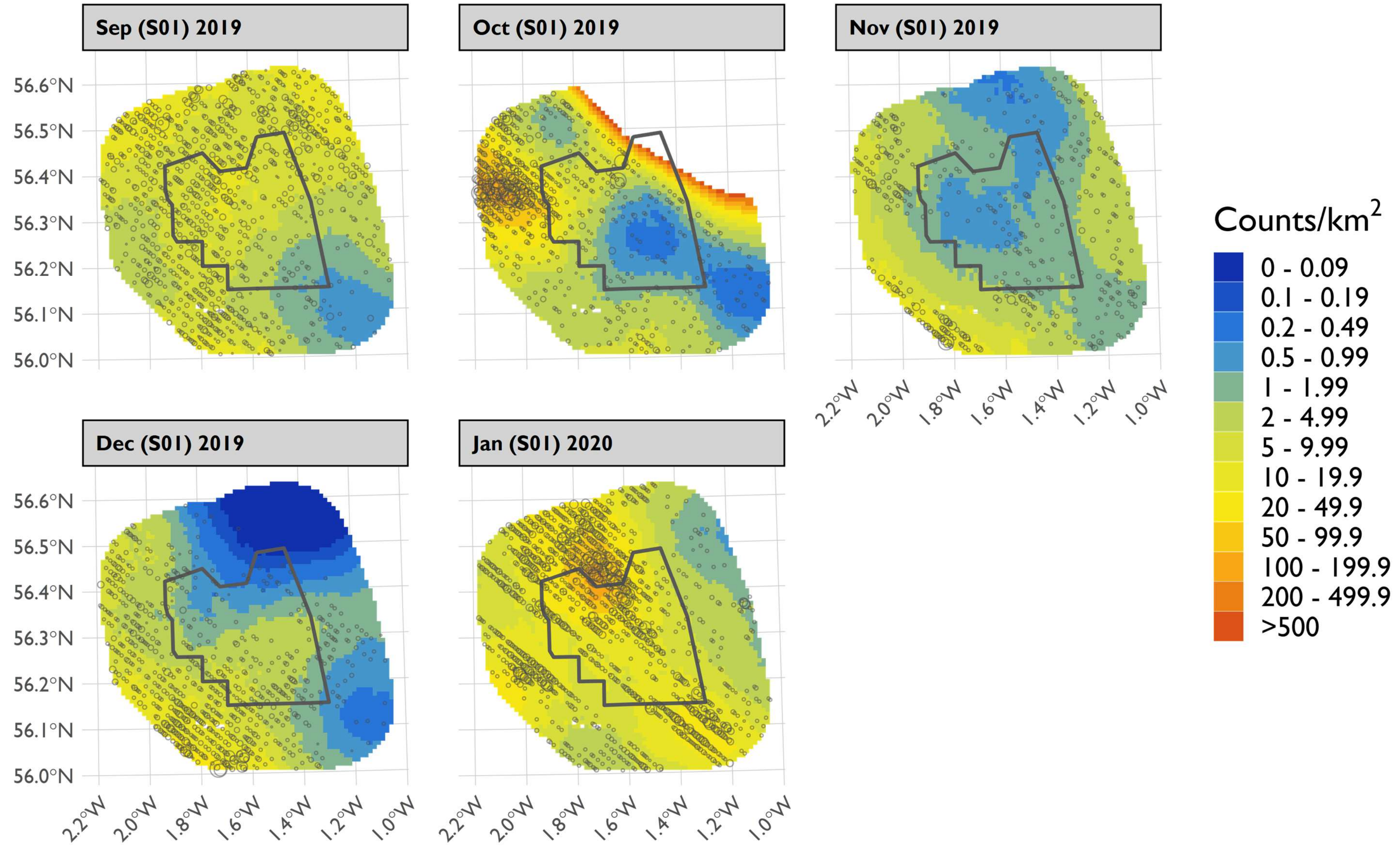

Figure 35 **Upper confidence limit of density of guillemots across the Offshore Ornithology Study Area between September 2019 and January 2020, modelled using MRSea**

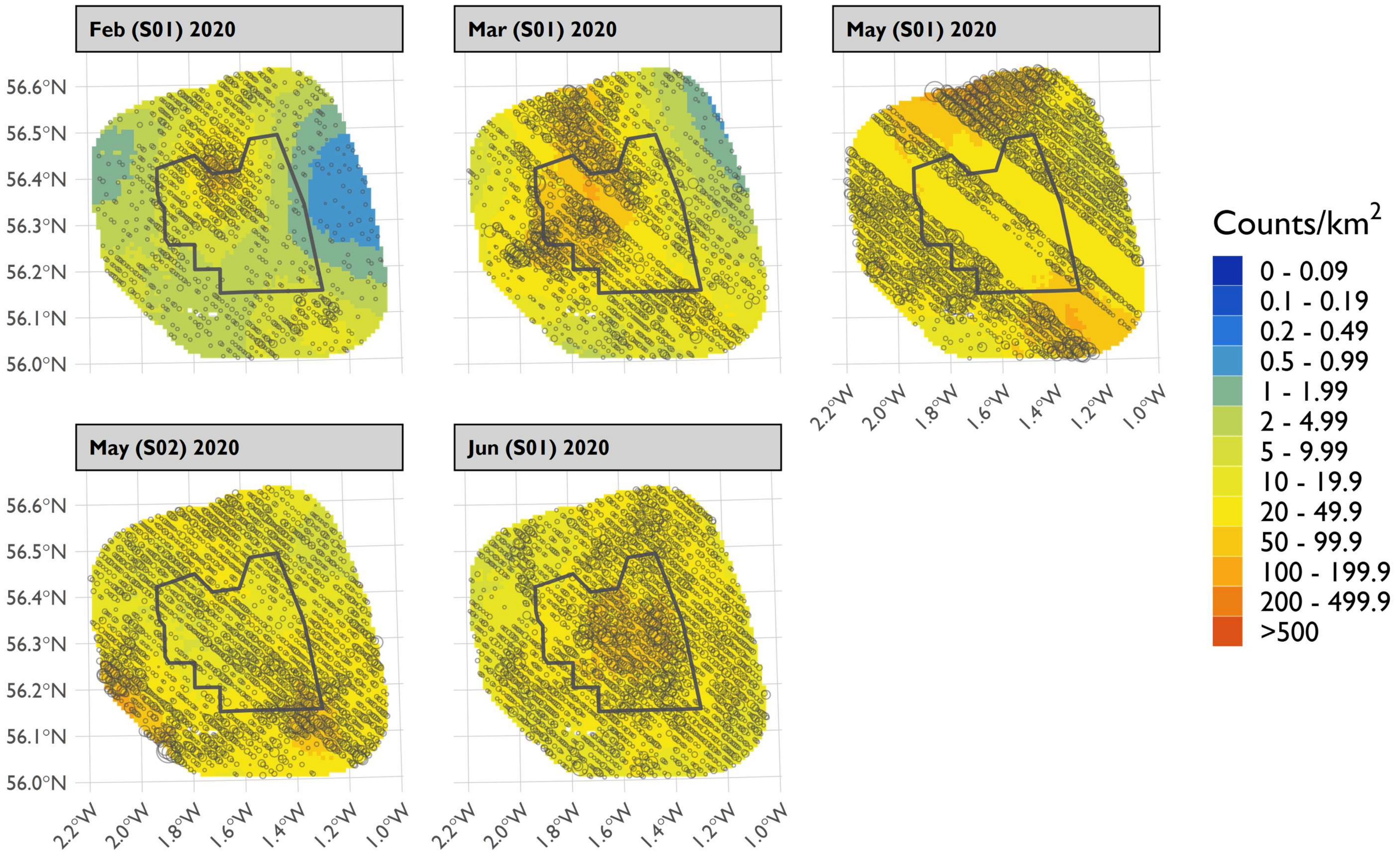

Figure 36 **Upper confidence limit of density of guillemots across the Offshore Ornithology Study Area between February and June 2020, modelled using MRSea**

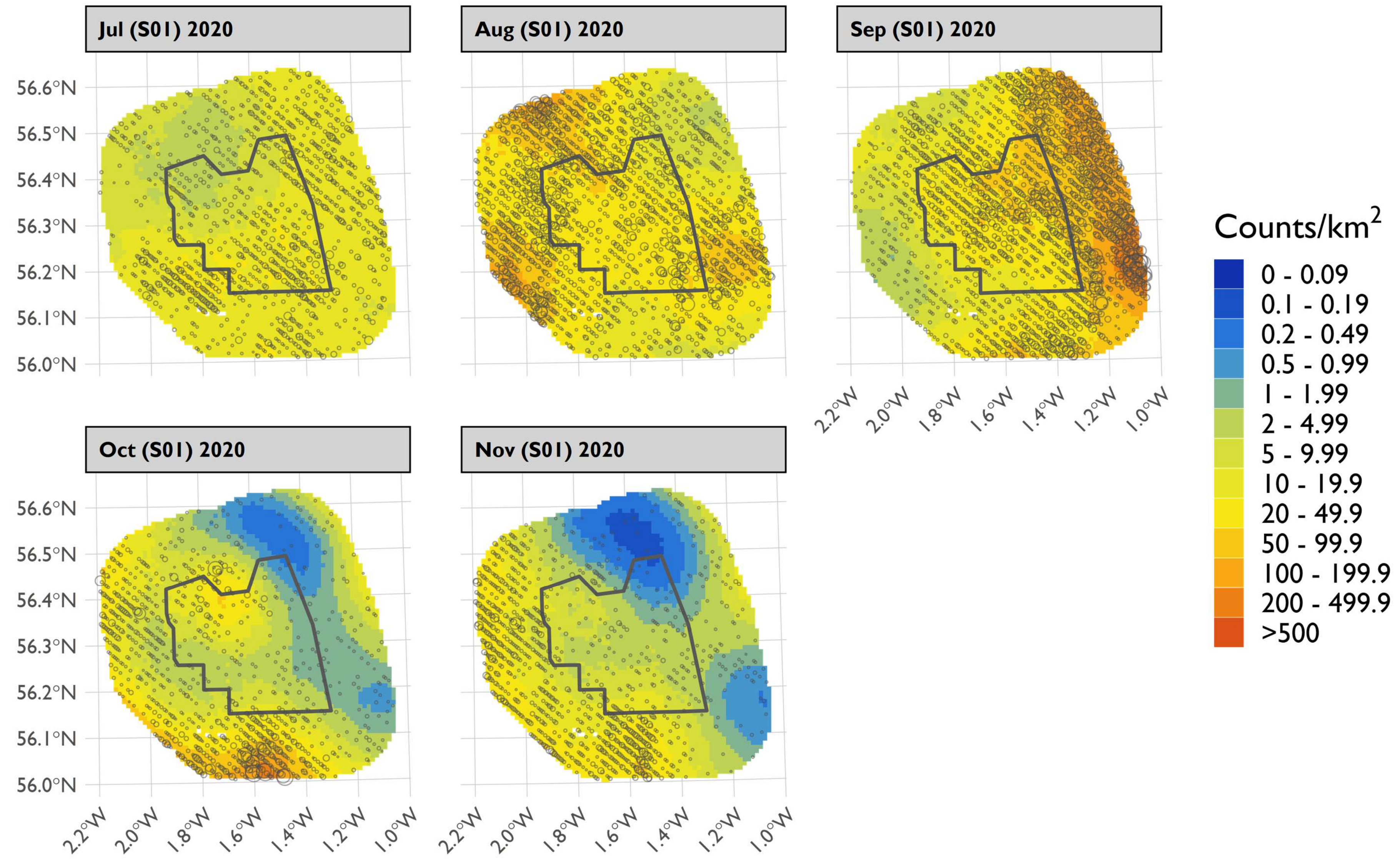

Figure 37 Upper confidence limit of density of guillemots across the survey area Offshore Ornithology Study Area between July and November 2020, modelled using MRSea

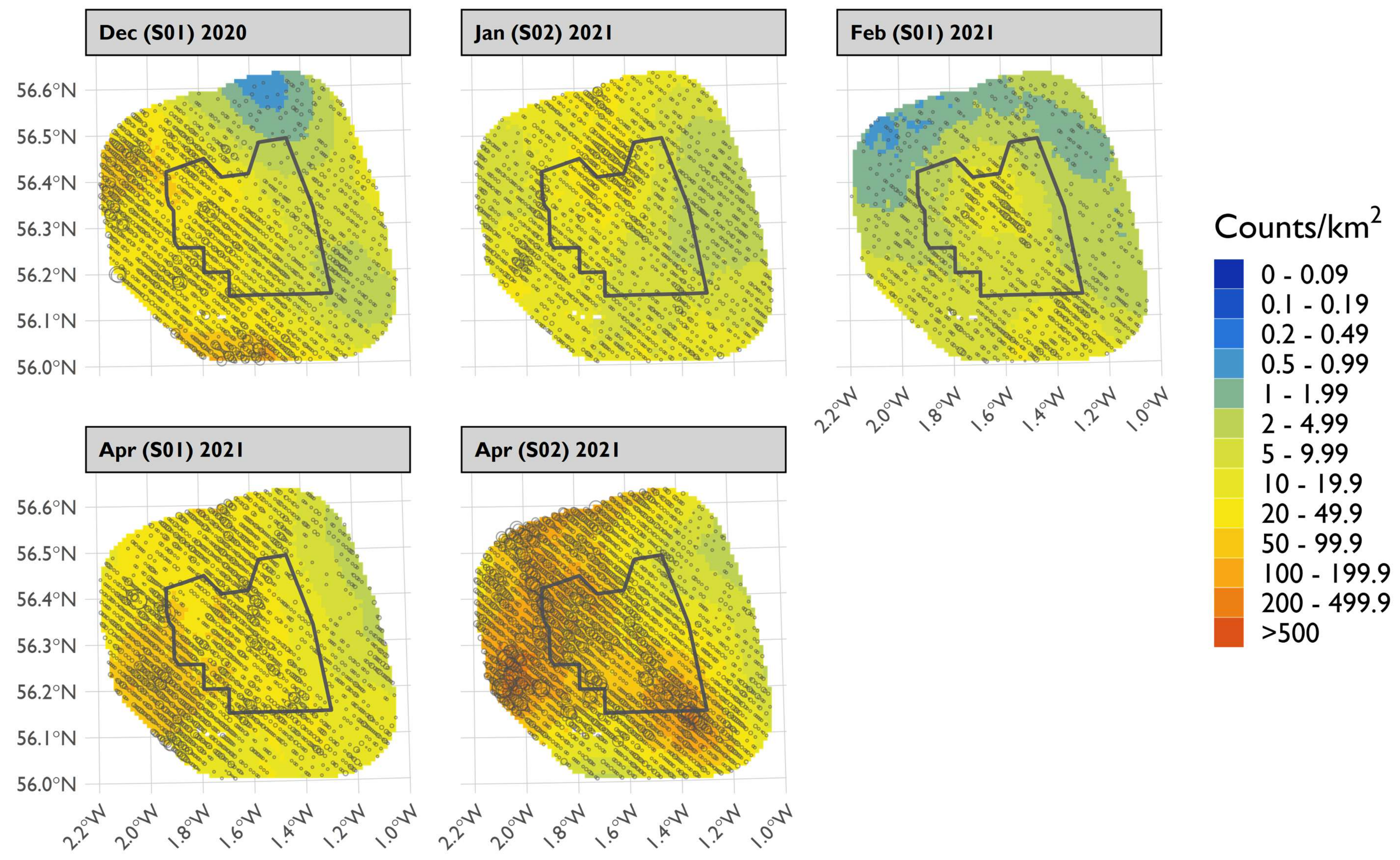

Figure 38 **Upper confidence limit of density of guillemots across the Offshore Ornithology Study Area between December 2020 and April S02 2021, modelled using MRSea**

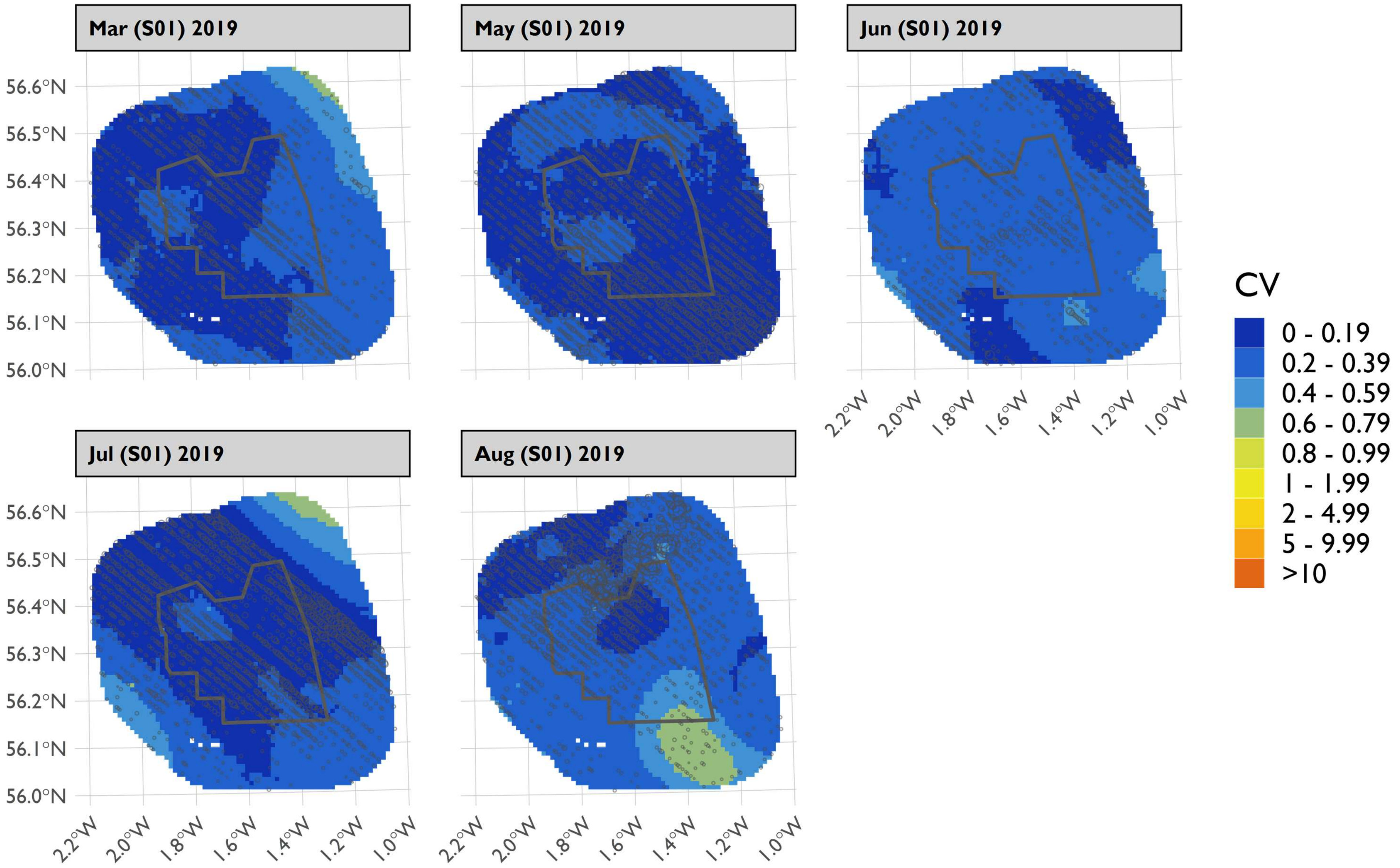

Figure 39 Spatial coefficient of variation of predicted guillemot densities from MRSea across the Offshore Ornithology Study Area between March and August 2019

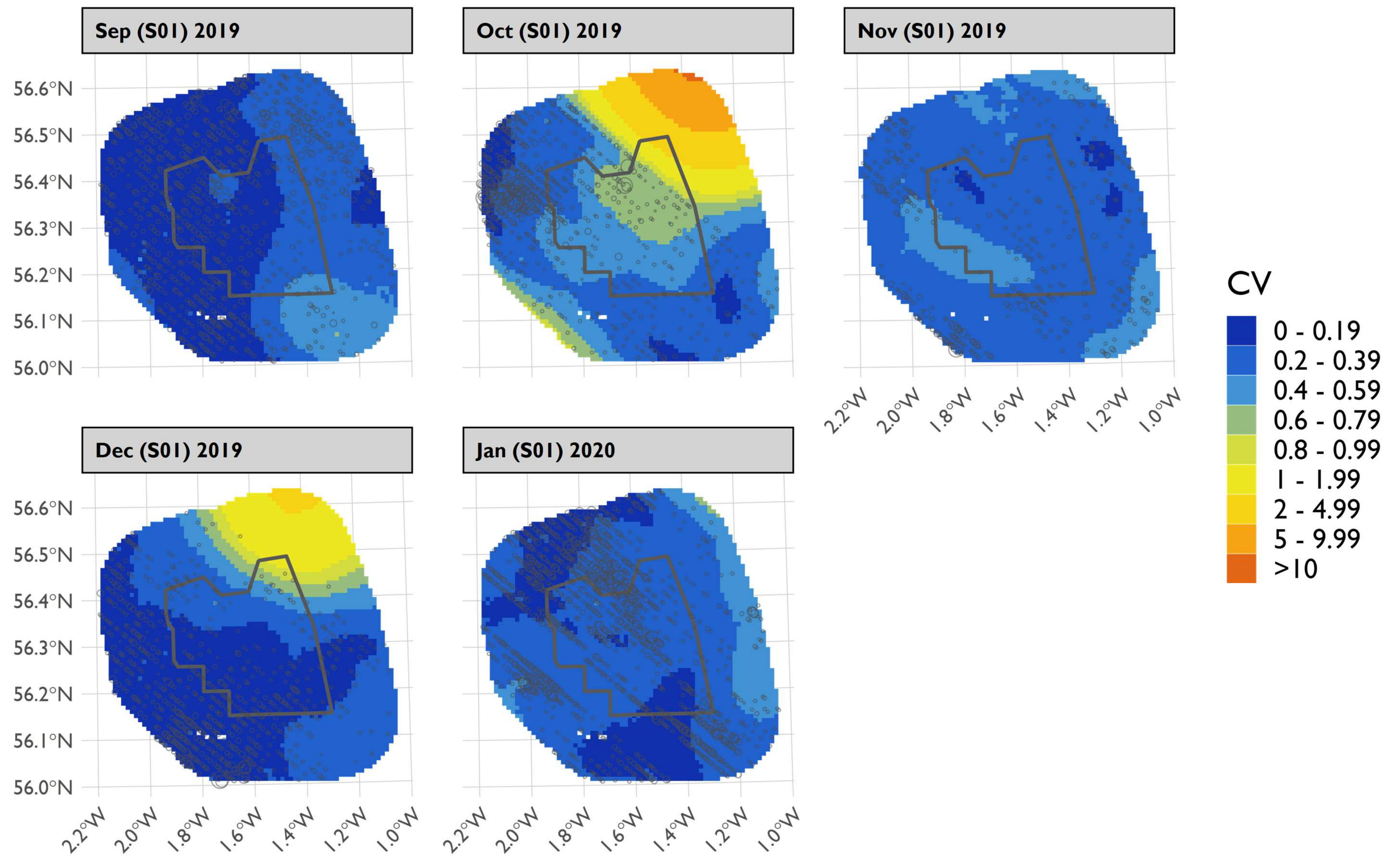

Figure 40 Spatial coefficient of variation of predicted guillemot densities from MRSea across the Offshore Ornithology Study Area between September 2019 and January 2020

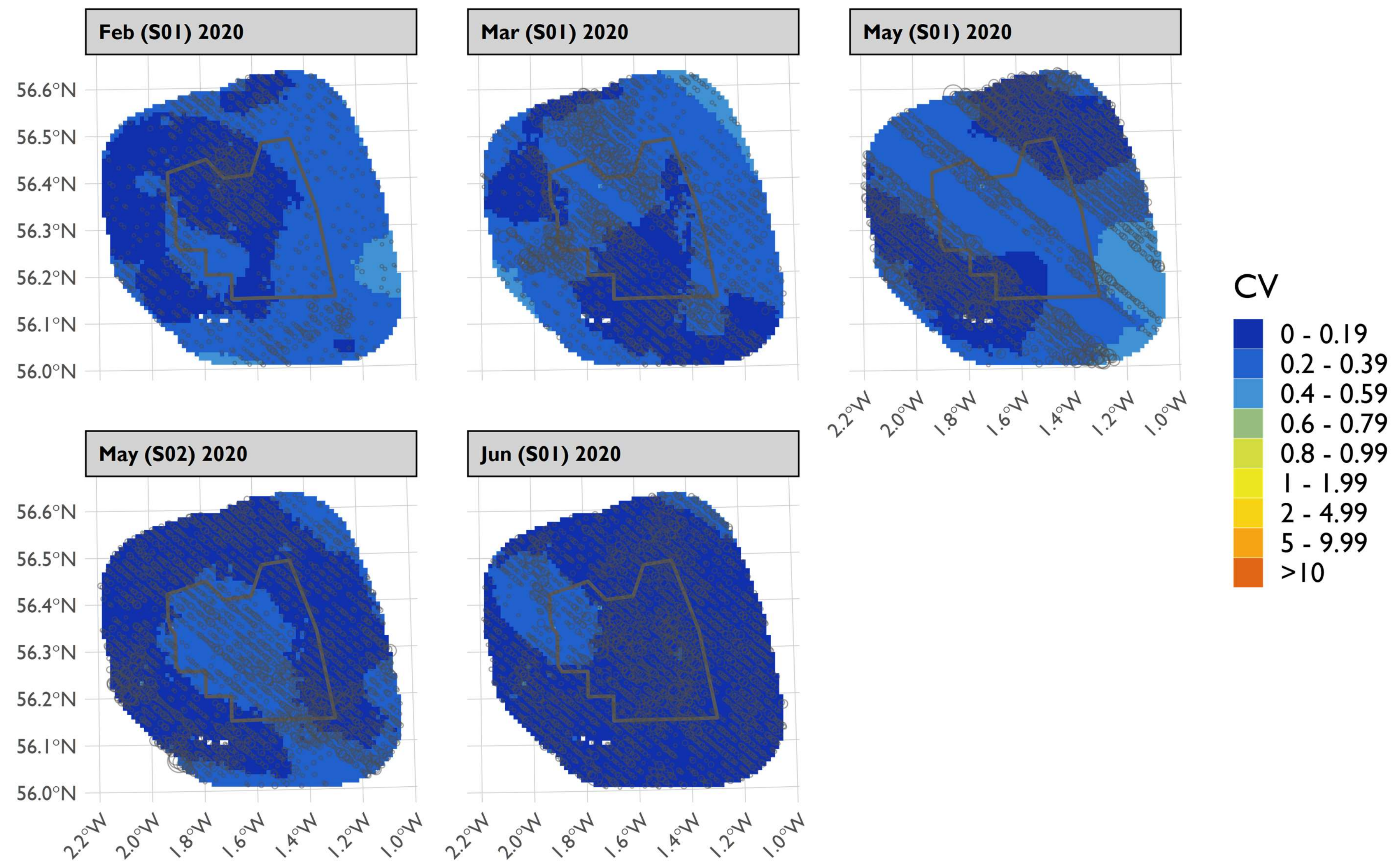

Figure 41 **Spatial coefficient of variation of predicted guillemot densities from MRSea across the Offshore Ornithology Study Area between February and June 2020**

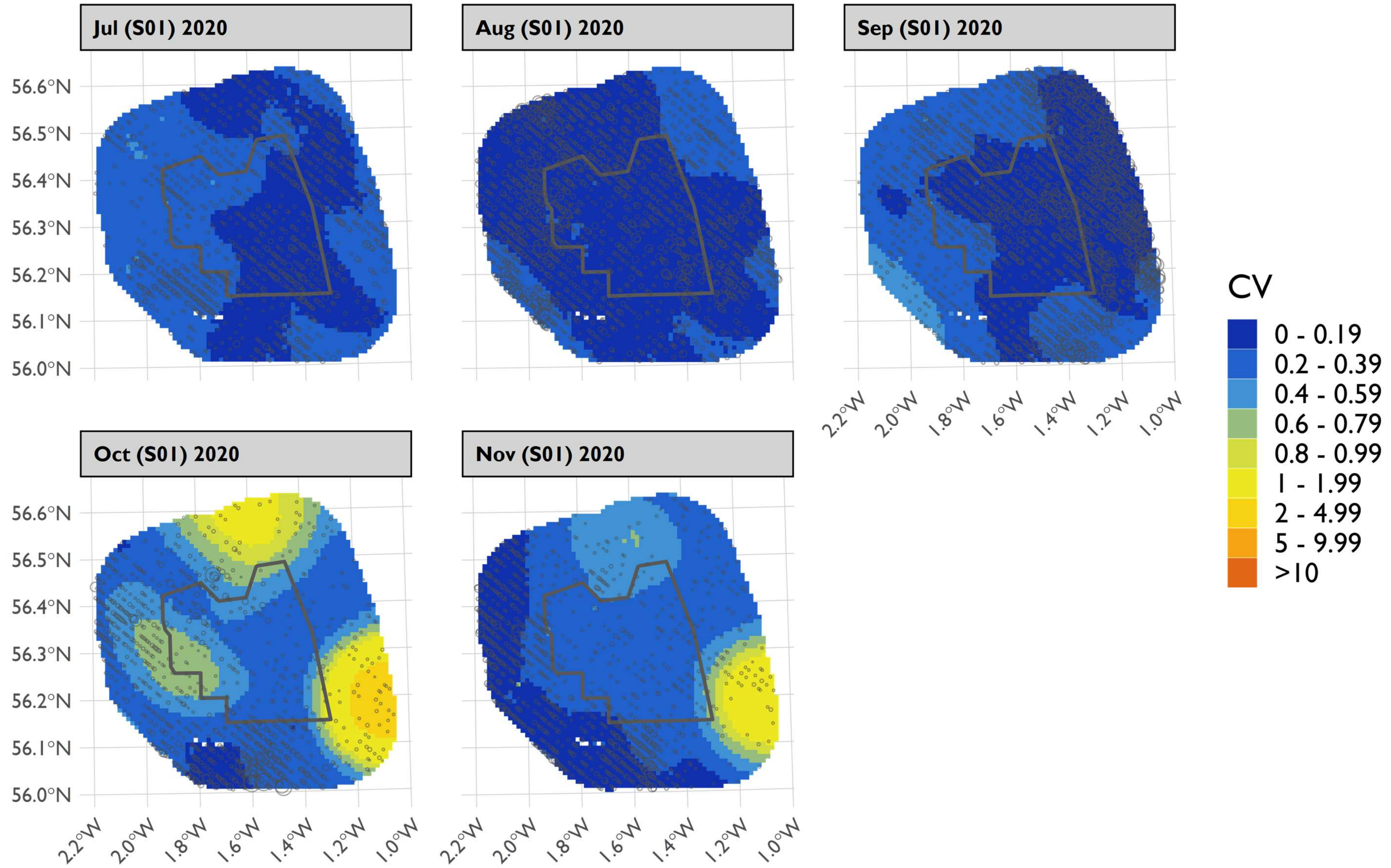

Figure 42 Spatial coefficient of variation of predicted guillemot densities from MRSea across the Offshore Ornithology Study Area between July and November 2020

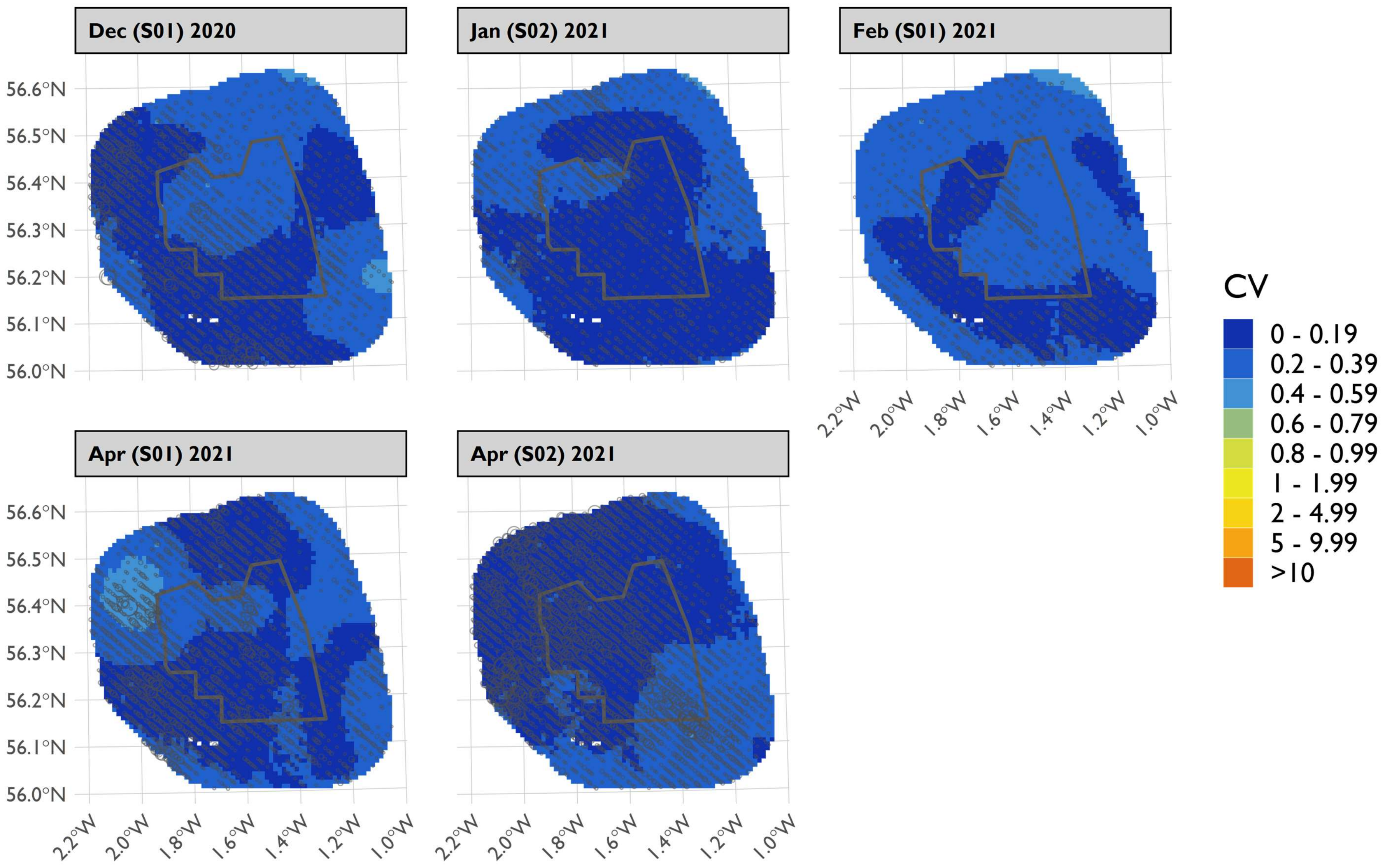

Figure 43 **Spatial coefficient of variation of predicted guillemot densities from MRSea across the Offshore Ornithology Study Area between December 2020 and April S02 2021**

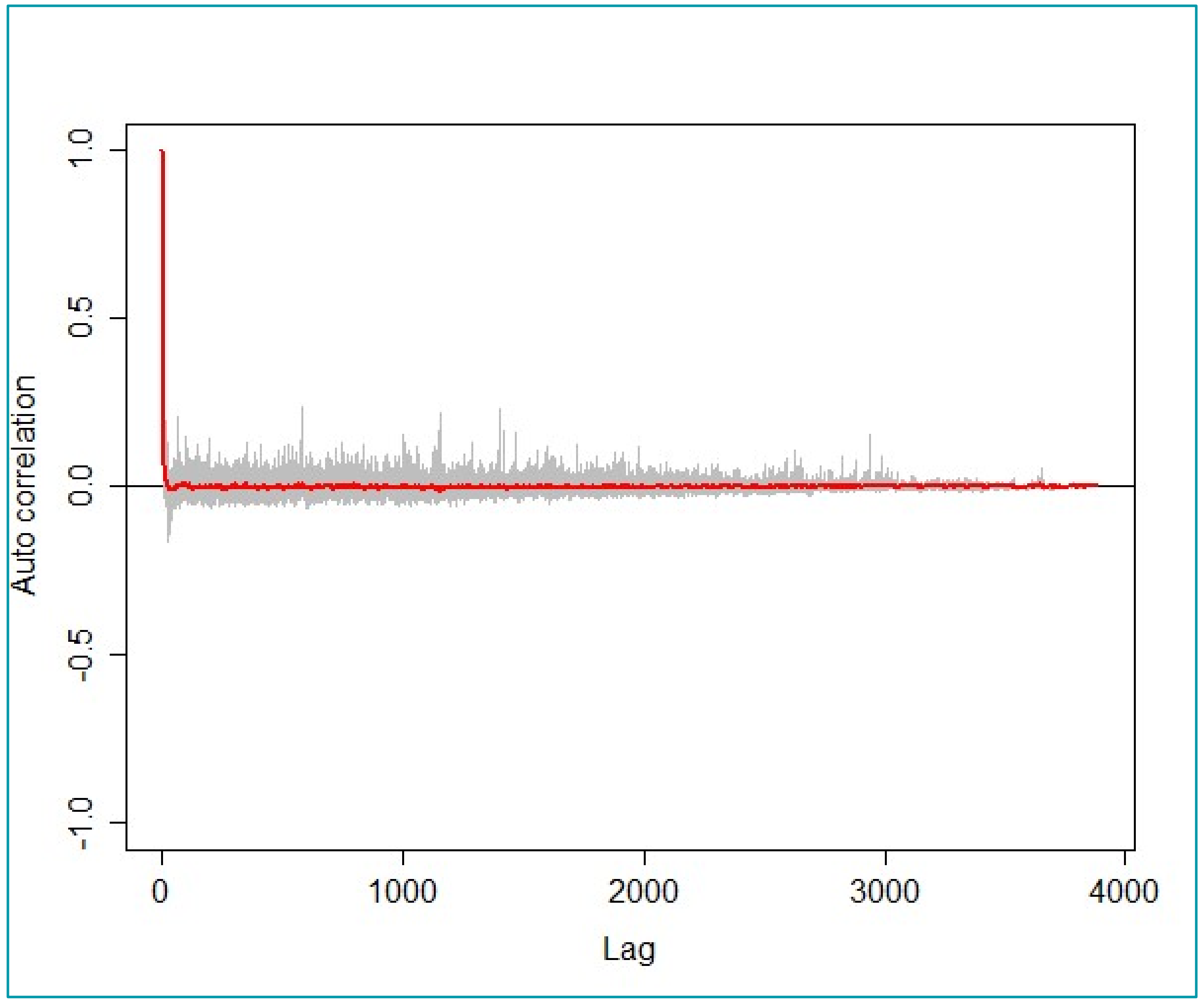

Figure 44 **Autocorrelation test for guillemot density surface models when using transect as a blocking feature in MRSea showing no significant correlation. A Runs test on the data prior to using transect as a blocking feature gave a p-value of << 0.0001 (i.e., that the data were significantly autocorrelated when not using a blocking feature)**

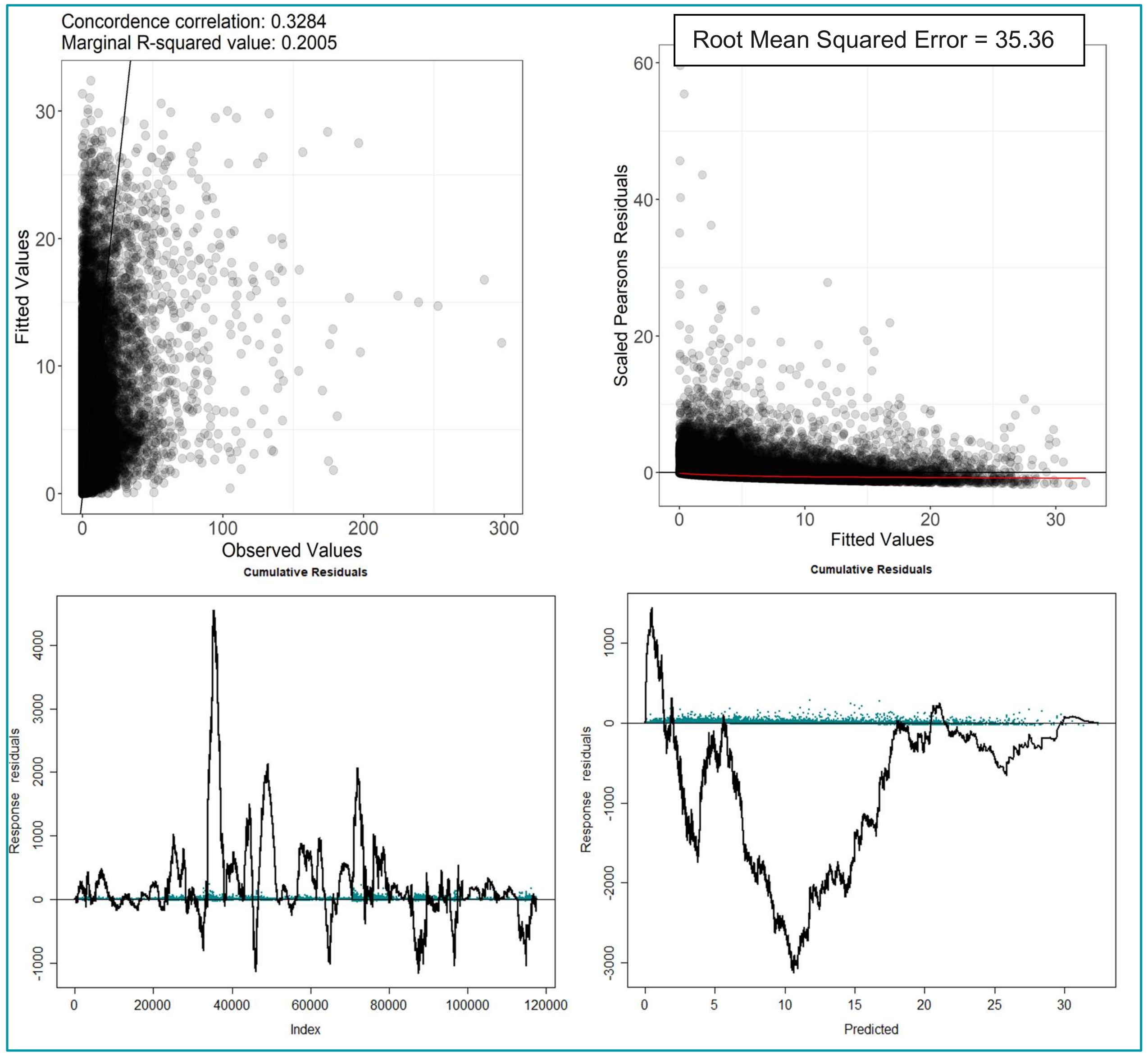

Figure 45 **Fitted (MRSea predictions) versus observed counts of guillemot (top left), and residual plots from MRSea**

Table 7 **ANOVA results from the best MRSea model for guillemot as selected by cross-validation**

Variable	Degrees of Freedom	Chi-square	P value
Sediment type	3	2.1	0.56
Bathymetry	5	31.7	<< 0.001
SST gradient	5	121.6	<< 0.001
Sandeel density	5	15.8	<< 0.01
Distance to coast	3	2.3	0.52
X/Y (location)	4	-	<< 0.001

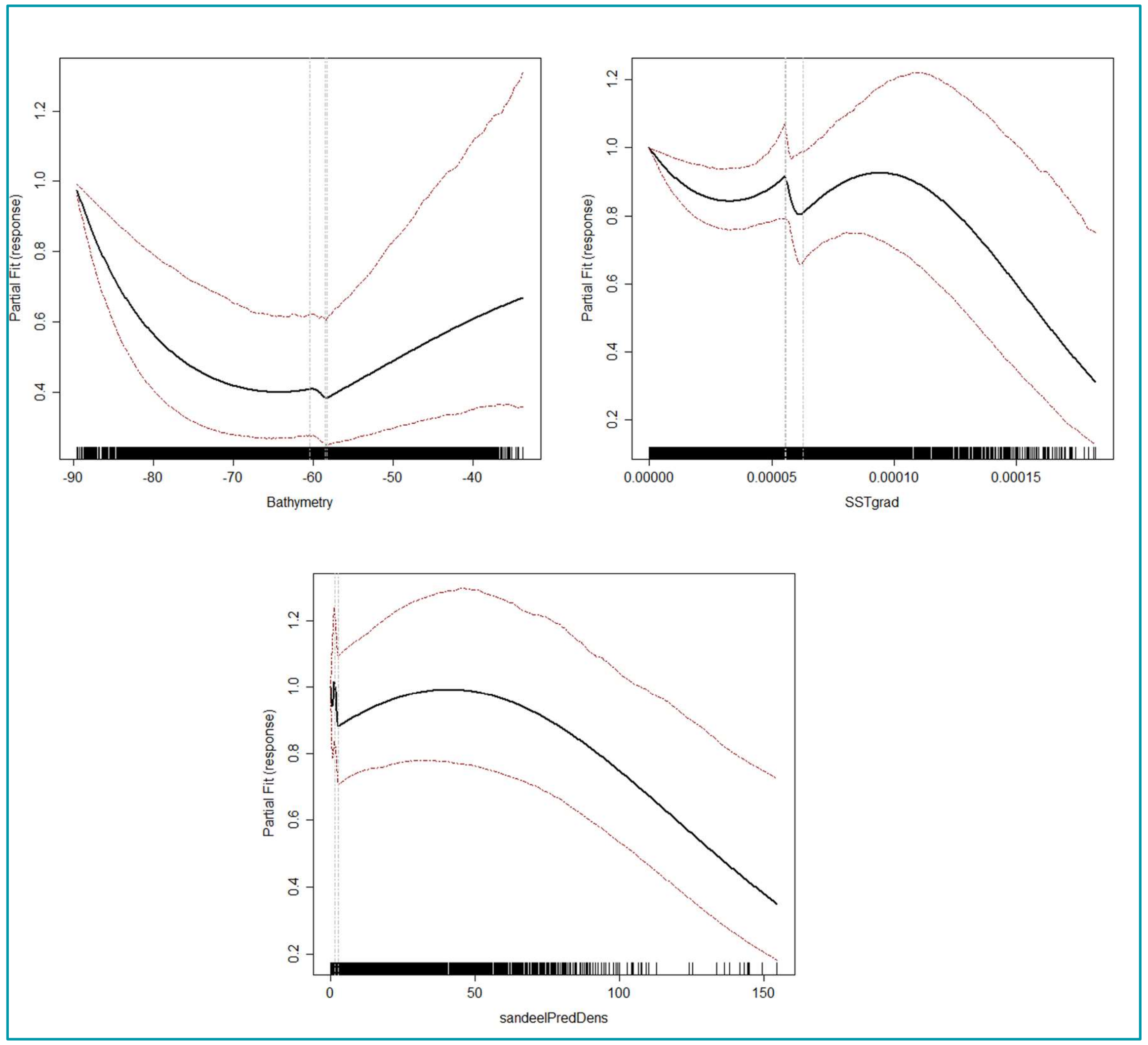

Figure 46 **Partial dependence plots for significant variables for guillemot from MRSea models**

1.3.4. RAZORBILL

32. The highest densities calculated using MRSea were recorded in September 2019 reaching peaks of 9.3 birds/km^2 (95CI 6.24 – 13.31) and 11.76 birds/km^2 (95CI 8.11 – 16.48) in the Development Array and Offshore Ornithology Study Area, respectively (Table 8 and Table 9).This equated to peak population estimates of 9,397 birds (95CI 6299.03 – 13,449.90) and 46,725 birds (95CI 32,254.74 – 65,503.52).

33. The highest density of razorbills was generally observed around the north of the Development Area, such as in January and February 2020 and 2021 Figure 47 to Figure 51). Immediately either side of the breeding season, such as in March and September, razorbill were widely distributed across the survey area. In October and December, during the non-breeding period, razorbill were distributed to the west of the Offshore Ornithology Study Area, with lower densities observed across the Development Array particularly in November.

34. Broadly, model fit was moderate compared to other species for Razorbill with a marginal R squared value of 0.1521 and root mean squared error of 2.13. The cumulative residuals in the model showed that there was overall a moderate relationship between predicted and observed values across most of the range of predicted values, but all bounding around 0 (Figure 68).

Table 8 Monthly density and population estimates of razorbill in the Development Array derived from MRSea

Survey	Density Estimate (n/km²)	SD of Density	Lower 95% CL of Density	Upper 95% CL of Density	Population Estimate (number)	SD of Population	Lower 95% CL of Population	Upper 95% CL of Population	CV (%)
Mar-19	1.63	0.23	1.01	2.51	1649	229	1020	2540	13.91%
May-19	1.08	0.17	0.66	1.76	1093	169	662	1782	15.48%
Jun-19	0.22	0.08	0.06	0.56	219	84	62	570	38.32%
Jul-19	2.02	0.37	1.12	3.49	2040	369	1129	3530	18.11%
Aug-19	1.51	0.25	0.86	2.49	1529	254	870	2515	16.58%
Sep-19	1.37	0.2	0.86	2.14	1384	197	867	2165	14.26%
Oct-19	0.89	0.22	0.41	1.77	902	218	414	1788	24.16%
Nov-19	0.07	0.04	0.02	0.22	74	35	17	227	47.91%
Dec-19	0.38	0.09	0.18	0.74	388	87	180	749	22.38%
Jan-20	1.89	0.31	1.06	3.12	1909	314	1068	3150	16.48%
Feb-20	1.23	0.17	0.78	1.89	1240	171	783	1906	13.76%
Mar-20	6.44	0.93	3.87	10.05	6503	944	3914	10151	14.52%
May S01 20	0.84	0.18	0.4	1.59	850	183	400	1605	21.55%
May S02 20	0.58	0.16	0.24	1.23	590	160	237	1246	27.05%
Jun-20	0.81	0.12	0.47	1.29	817	126	479	1306	15.43%
Jul-20	1.45	0.27	0.79	2.52	1465	274	797	2543	18.73%
Aug-20	3.13	0.44	1.96	4.86	3163	441	1978	4906	13.95%
Sep-20	9.3	1.07	6.24	13.31	9397	1083	6299	13450	11.52%
Oct-20	0.88	0.24	0.36	1.87	889	240	359	1890	27%
Nov-20	0.33	0.07	0.16	0.6	331	67	164	603	20.29%
Dec-20	1.5	0.18	1	2.19	1512	185	1008	2212	12.23%
Jan-21	3.72	0.43	2.51	5.35	3761	434	2538	5400	11.55%
Feb-21	1.41	0.22	0.82	2.25	1421	221	829	2276	15.53%
Apr S01 21	3.32	0.46	2.04	5.08	3354	468	2057	5130	13.95%
Apr S02 21	1.36	0.15	0.93	1.95	1376	154	944	1967	11.2%

Table 9 **Monthly density and population estimates of razorbill in the Offshore Ornithology Study Area derived from MRSea**

Survey	Density Estimate (n/km²)	SD of Density	Lower 95% CL of Density	Upper 95% CL of Density	Population Estimate (number)	SD of Population	Lower 95% CL of Population	Upper 95% CL of Population	CV (%)
Mar-19	1.14	0.16	0.7	1.78	4542	653	2791	7071	14.38%
May-19	1.14	0.17	0.71	1.8	4529	662	2803	7161	14.62%
Jun-19	0.32	0.07	0.16	0.62	1279	287	625	2460	22.44%
Jul-19	8.89	3.57	2.38	24.09	35326	14172	9468	95739	40.12%
Aug-19	2.2	0.75	1.16	3.9	8761	2979	4609	15509	34%
Sep-19	1.33	0.19	0.83	2.07	5300	754	3300	8245	14.22%
Oct-19	3.02	0.76	1.76	5.81	12023	3034	6984	23112	25.24%
Nov-19	0.35	0.09	0.15	0.73	1392	376	612	2891	26.97%
Dec-19	0.82	0.16	0.44	1.45	3248	653	1751	5775	20.12%
Jan-20	1.37	0.27	0.7	2.47	5434	1082	2797	9798	19.9%
Feb-20	0.67	0.11	0.39	1.12	2672	444	1558	4454	16.63%
Mar-20	3.58	0.53	2.15	5.62	14229	2111	8529	22357	14.83%
May S01 20	1.08	0.17	0.63	1.77	4294	689	2488	7020	16.05%
May S02 20	0.77	0.18	0.35	1.5	3056	721	1410	5967	23.58%
Jun-20	0.67	0.12	0.37	1.12	2670	462	1482	4466	17.29%
Jul-20	1.64	0.28	0.92	2.75	6510	1114	3668	10922	17.12%
Aug-20	2.68	0.39	1.64	4.22	10649	1561	6522	16776	14.66%
Sep-20	11.76	1.27	8.11	16.48	46725	5061	32255	65504	10.83%
Oct-20	1.41	0.29	0.72	2.58	5604	1162	2851	10246	20.73%
Nov-20	0.42	0.09	0.21	0.76	1652	340	832	3007	20.56%
Dec-20	1.4	0.18	0.9	2.1	5548	728	3575	8328	13.12%
Jan-21	2.46	0.3	1.63	3.6	9788	1189	6468	14297	12.15%
Feb-21	0.85	0.13	0.5	1.36	3383	521	1994	5414	15.4%
Apr S01 21	2.95	0.41	1.82	4.55	11720	1646	7233	18070	14.04%
Apr S02 21	1.33	0.15	0.91	1.9	5291	594	3633	7571	11.23%

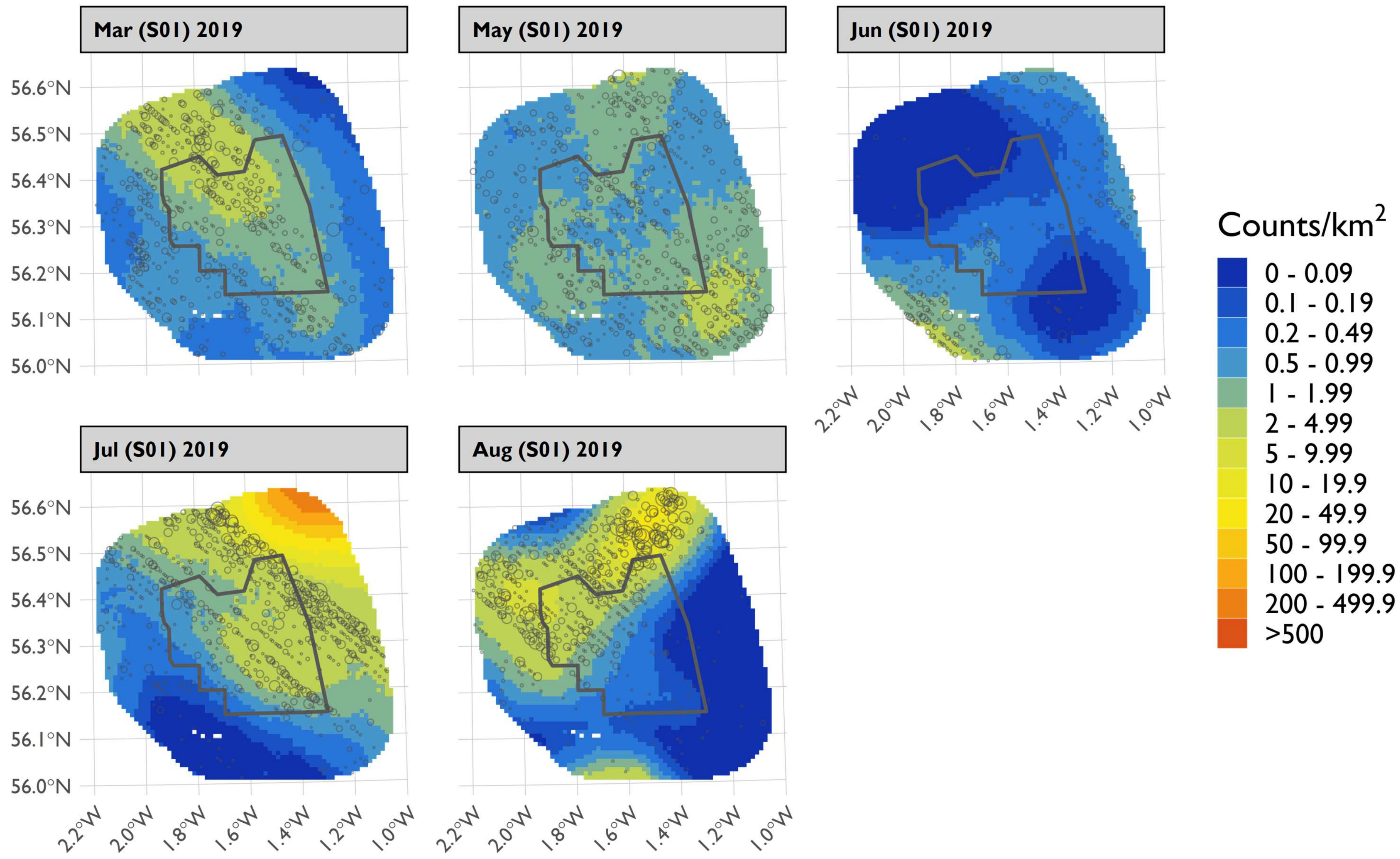

Figure 47 **Mean density of razorbills across the Offshore Ornithology Study Area between March and August 2019, modelled using MRSea**

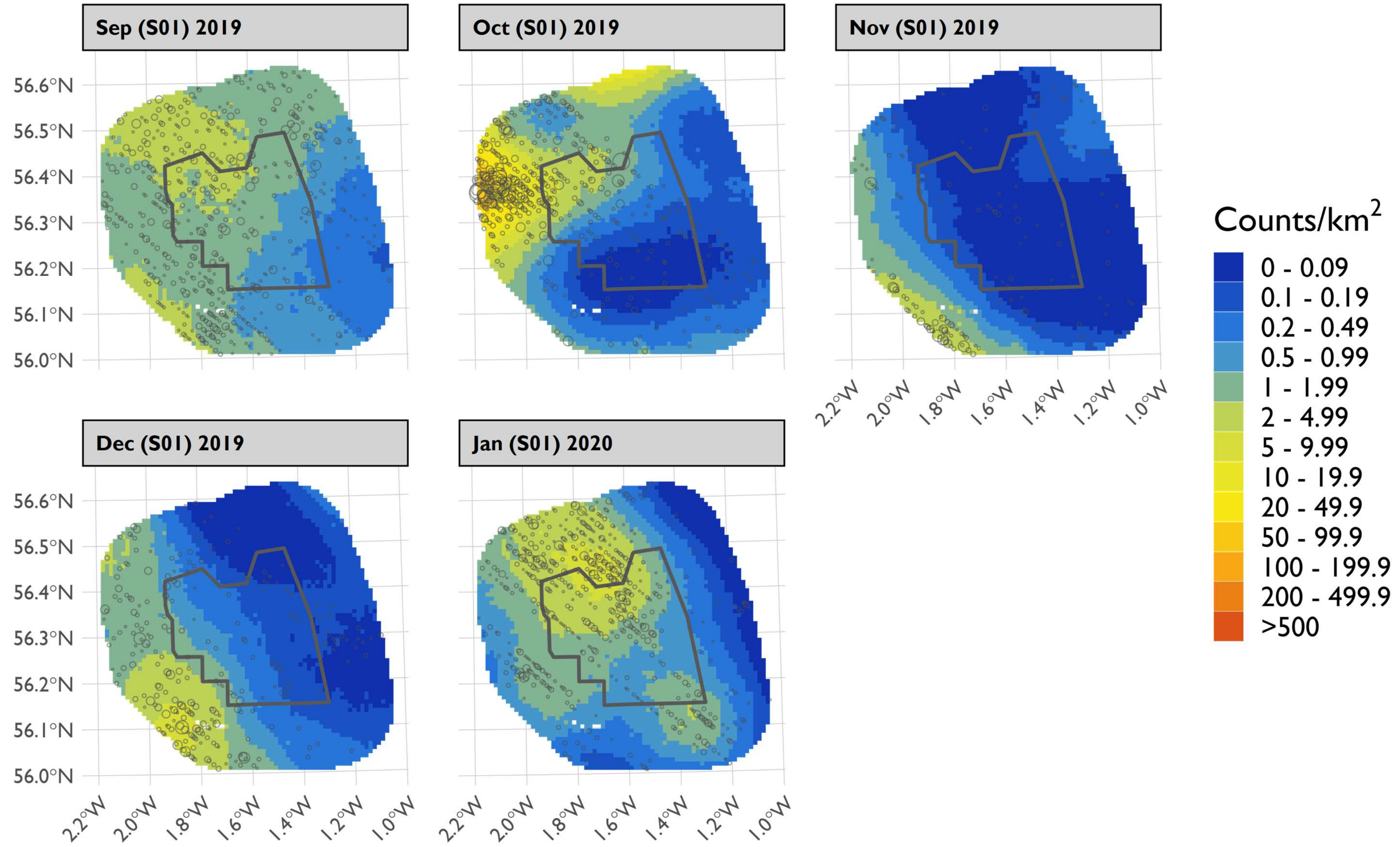

Figure 48 **Mean density of razorbills across the Offshore Ornithology Study Area between September 2019 and January 2020, modelled using MRSea**

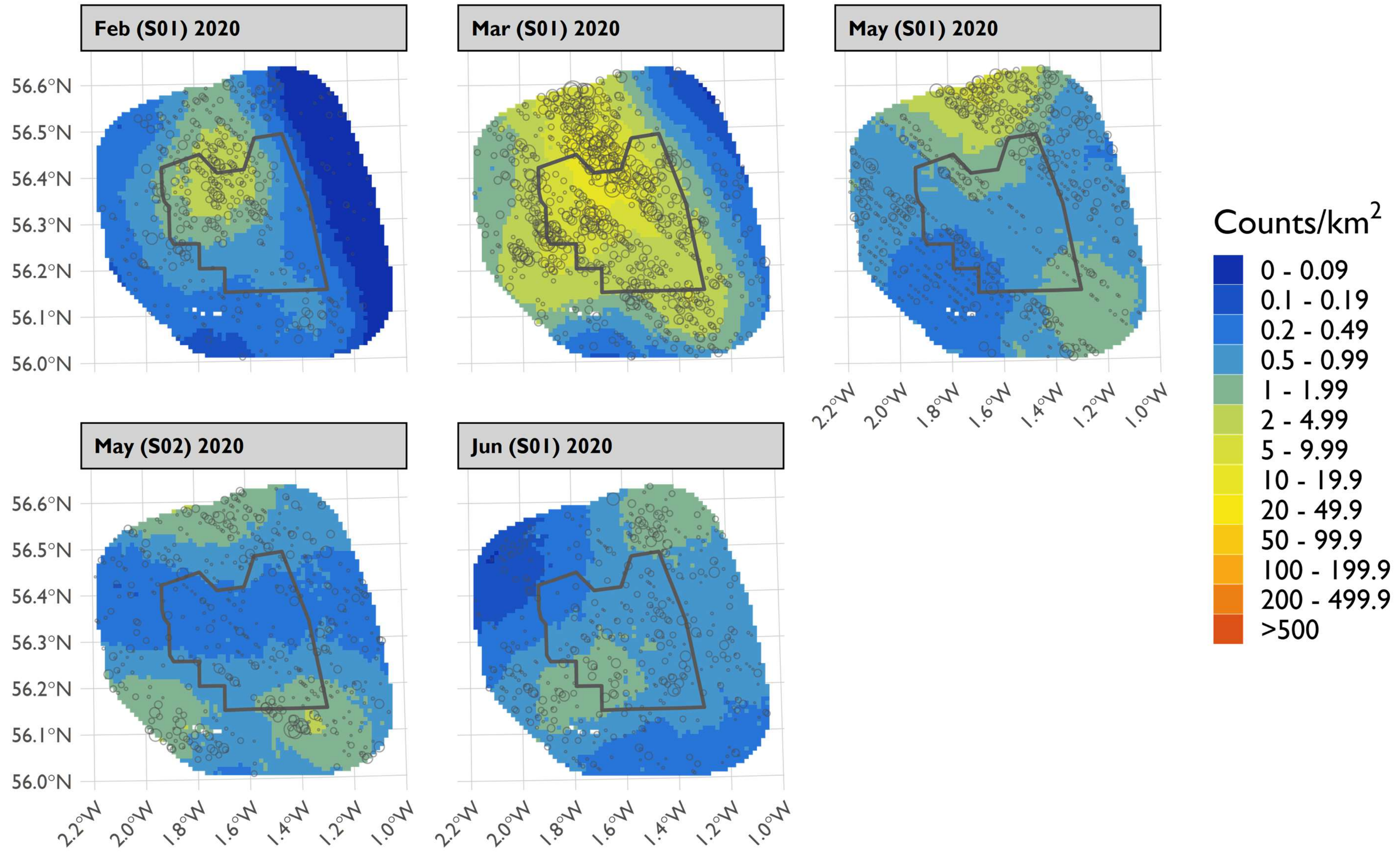

Figure 49 Mean density of razorbills across the Offshore Ornithology Study Area between February and June 2020, modelled using MRSea

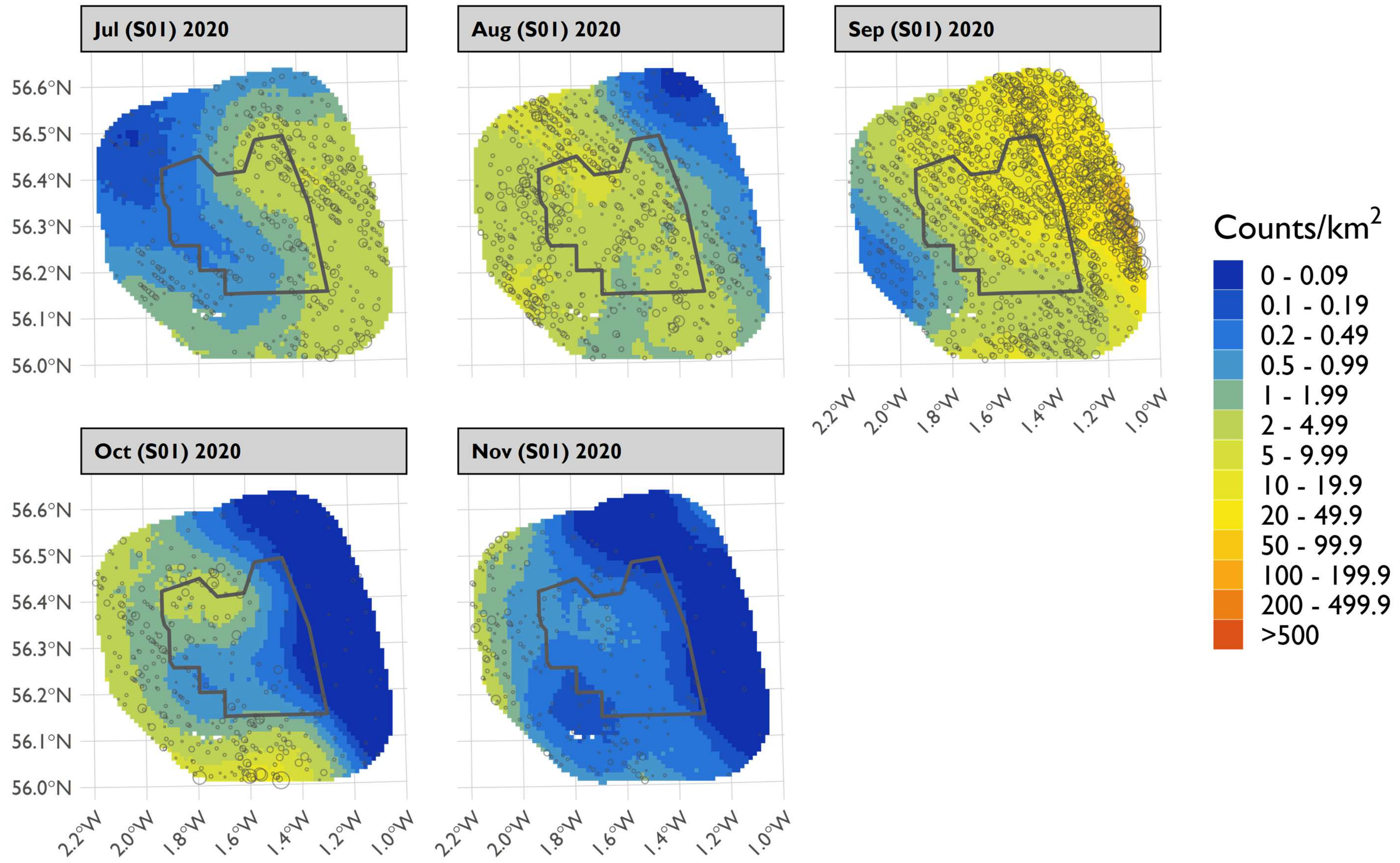

Figure 50 Mean density of razorbills across the Offshore Ornithology Study Area between July and November 2020, modelled using MRSea

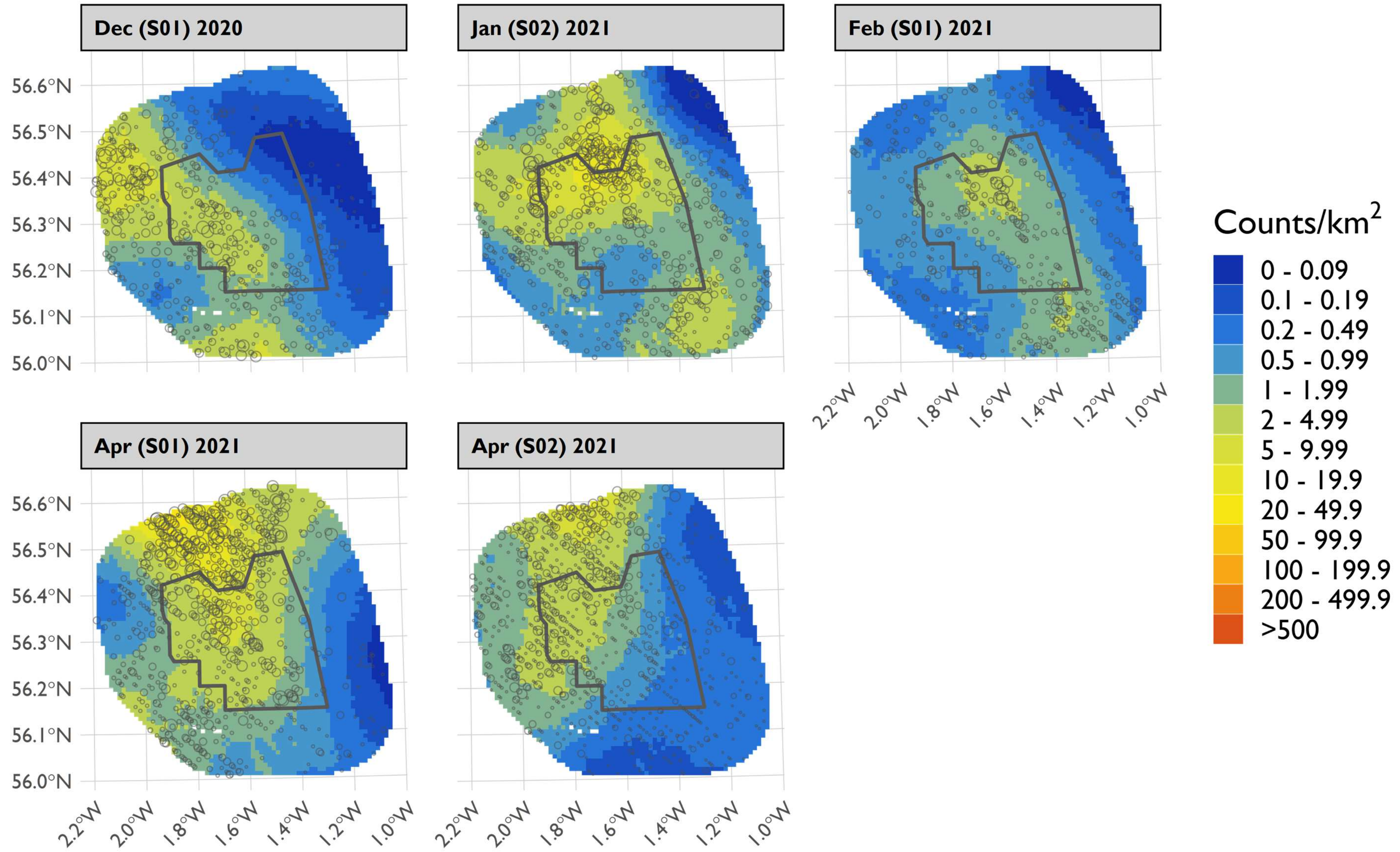

Figure 51 Mean density of razorbills across the Offshore Ornithology Study Area between December 2020 and April S02 2021, modelled using MRSea

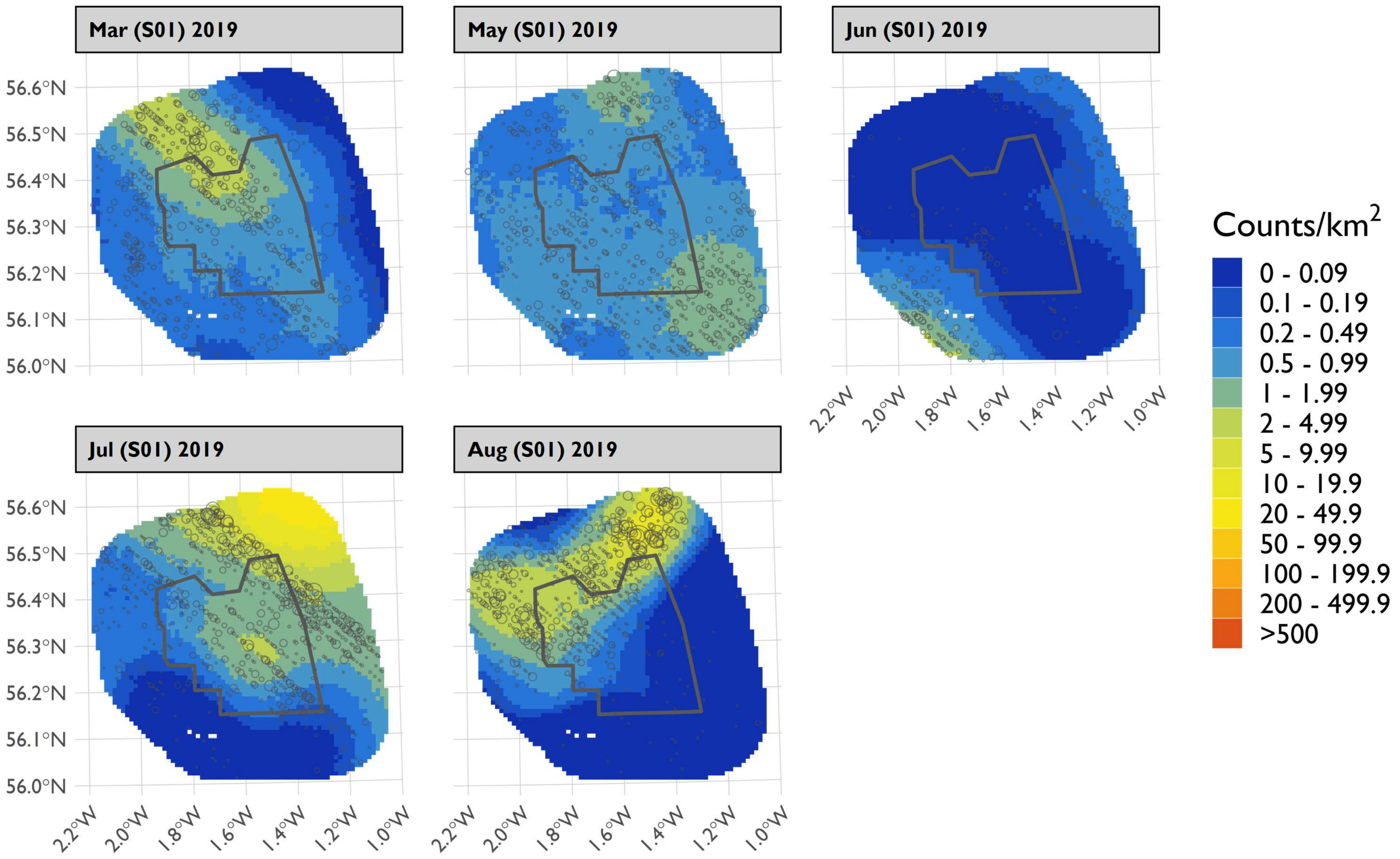

Figure 52 Lower confidence limit of density of razorbills across the Offshore Ornithology Study Area between March and August 2019, modelled using MRSea

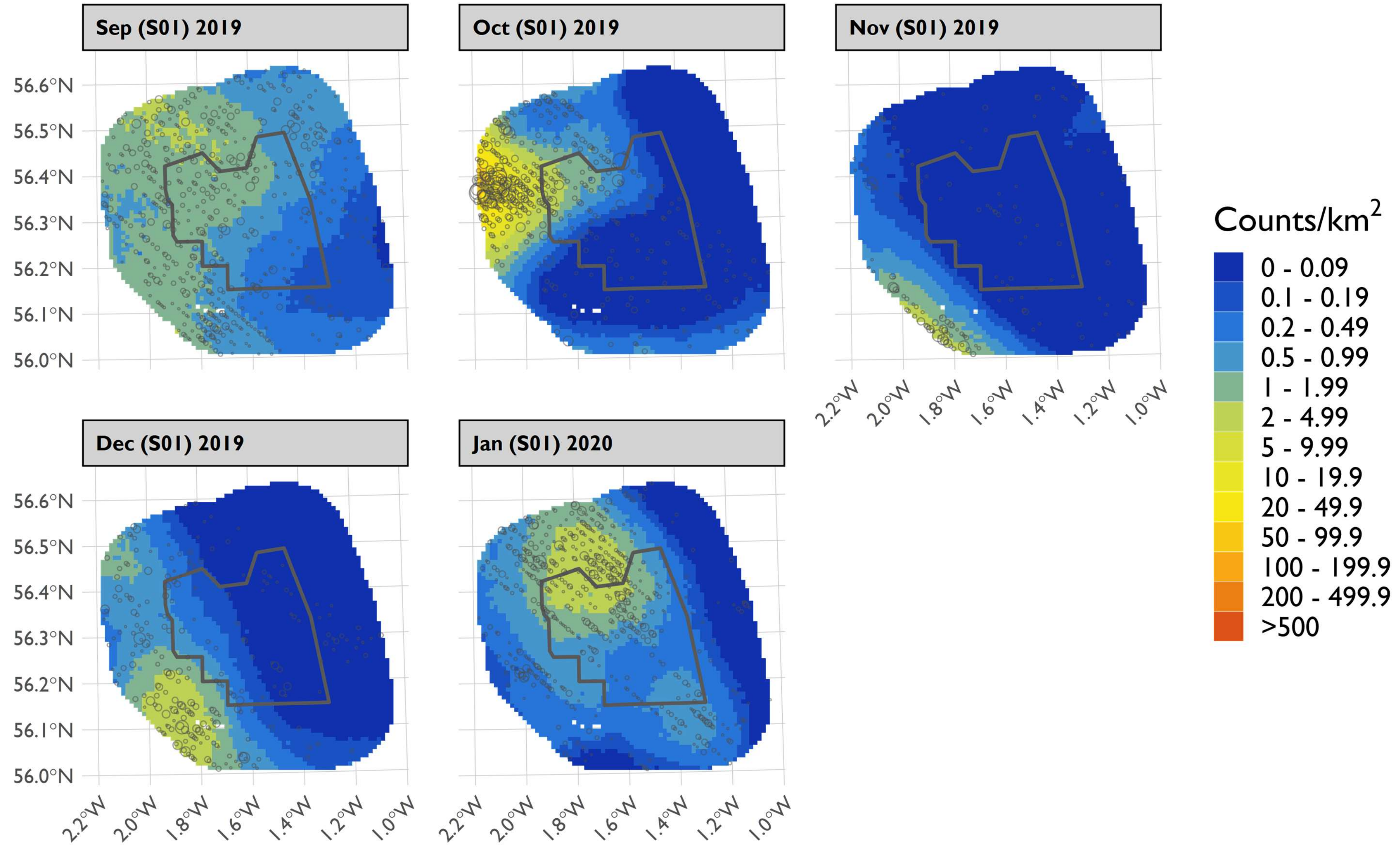

Figure 53 **Lower confidence limit of density of razorbills across Offshore Ornithology Study Area between September 2019 and January 2020, modelled using MRSea**

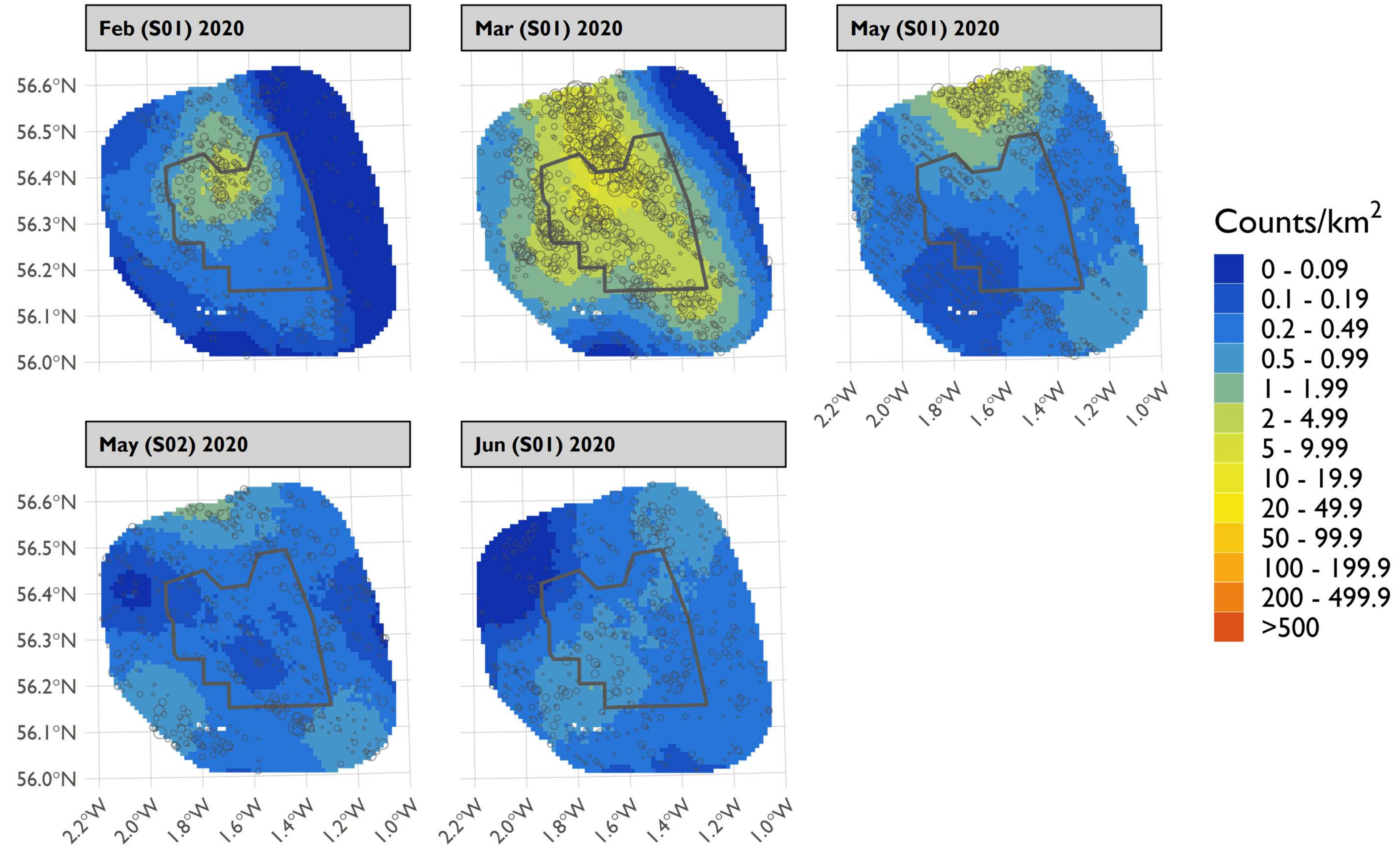

Figure 54 Lower confidence limit of density of razorbills across Offshore Ornithology Study Area between February and June 2020, modelled using MRSea

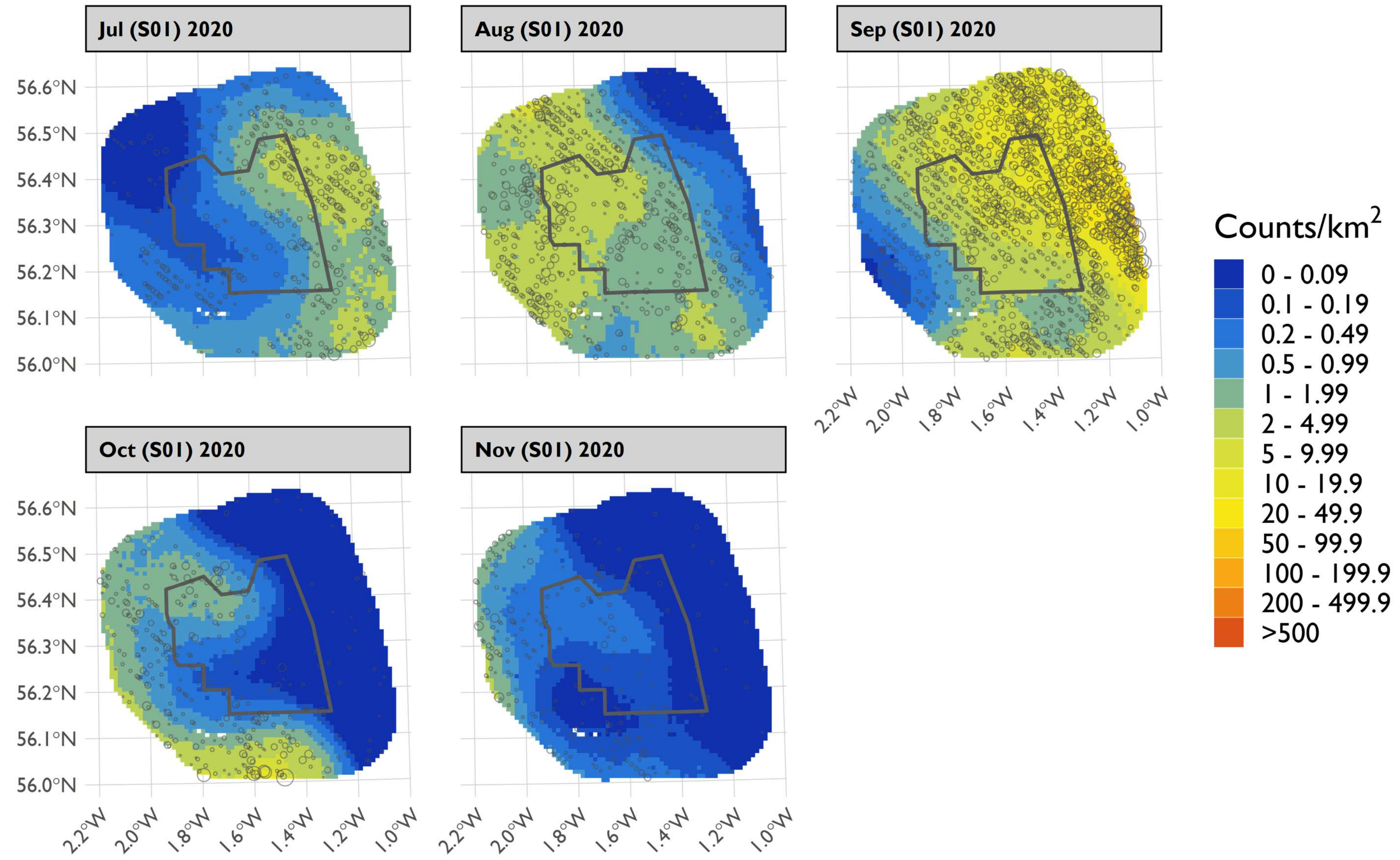

Figure 55 **Lower confidence limit of density of razorbills across the Offshore Ornithology Study Area between July and November 2020, modelled using MRSea**

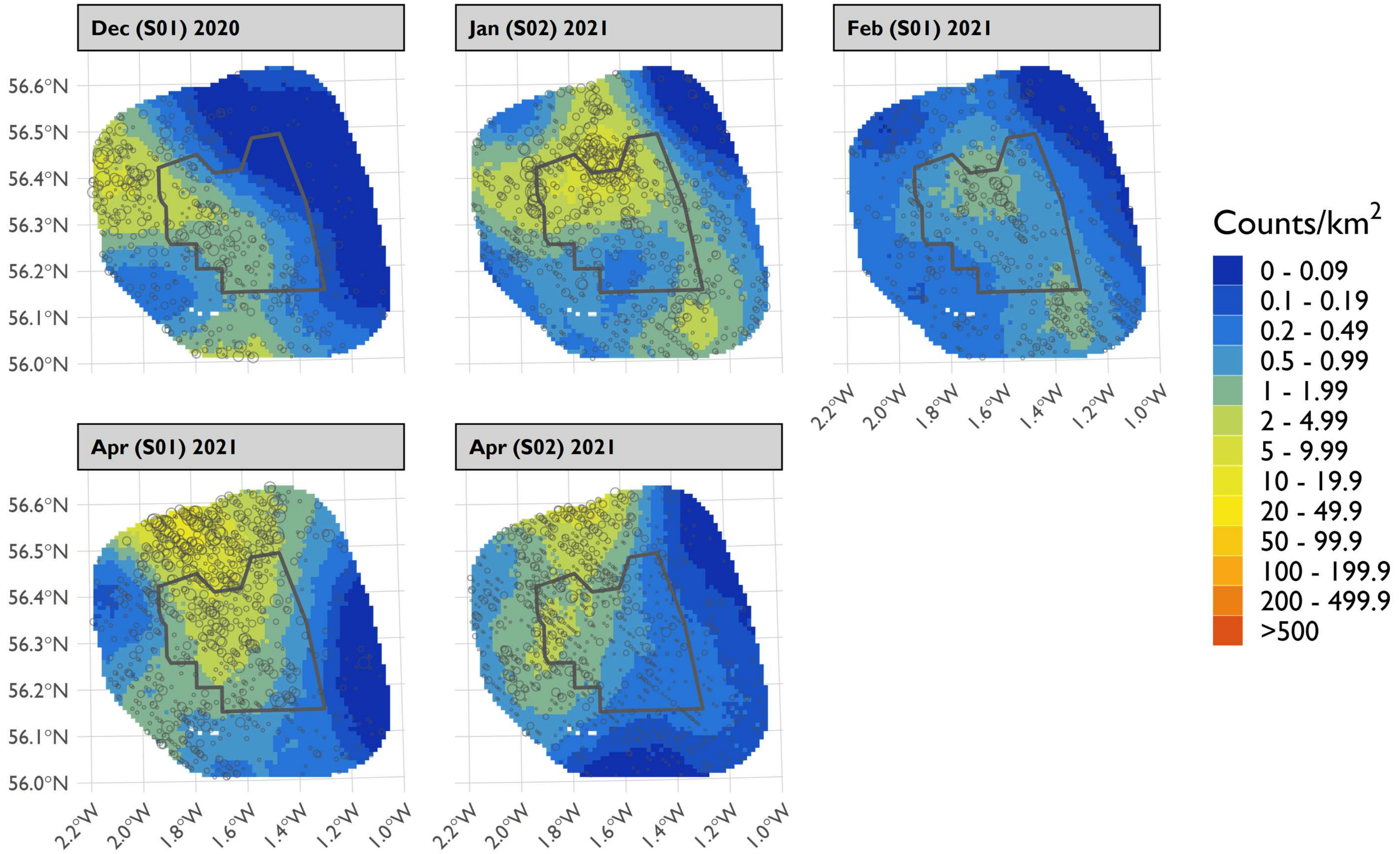

Figure 56 Lower confidence limit of density of razorbills across the Offshore Ornithology Study Area between December 2020 and April S02 2021, modelled using MRSea

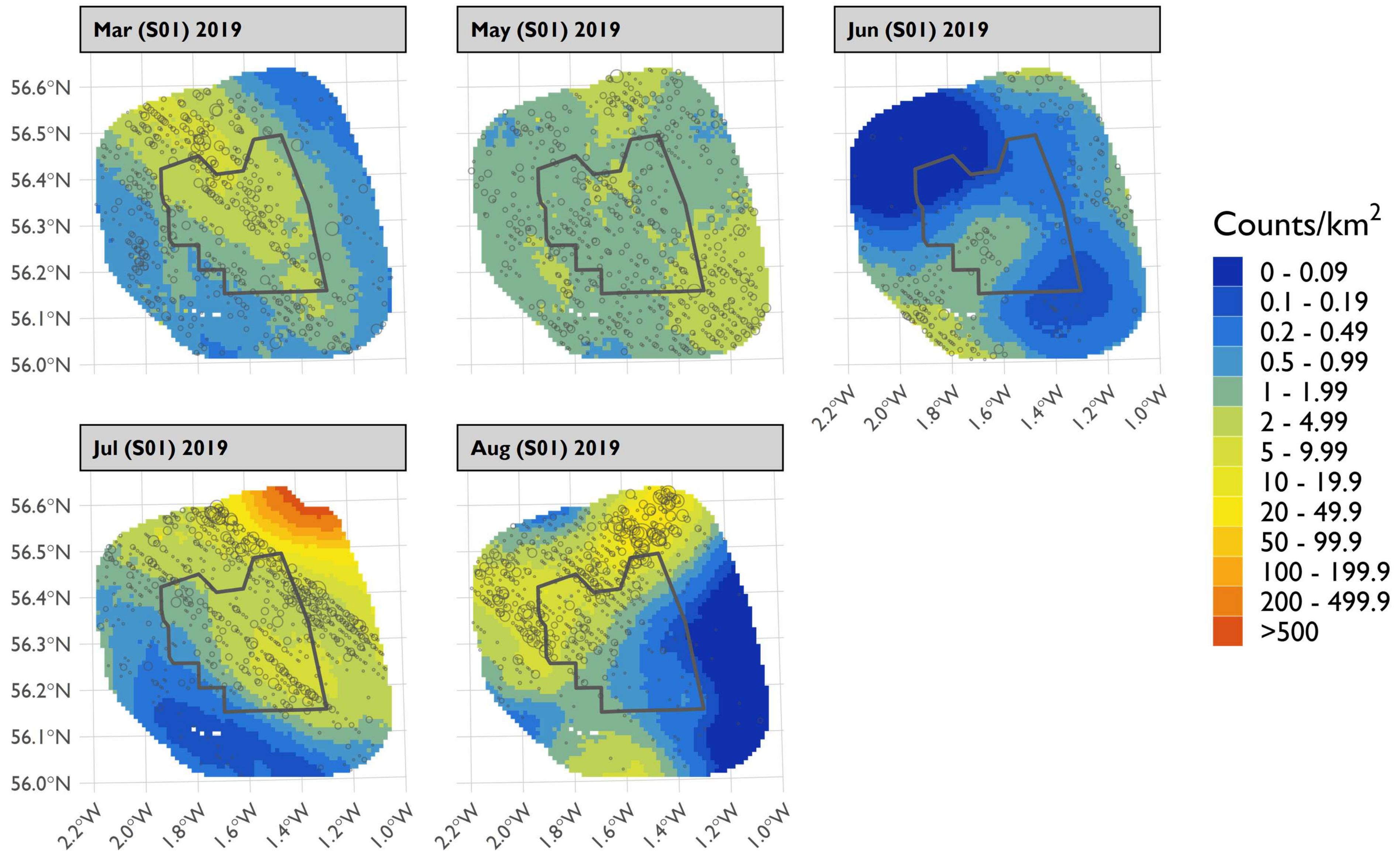

Figure 57 Upper confidence limit of density of razorbills across the Offshore Ornithology Study Area between March and August 2019, modelled using MRSea

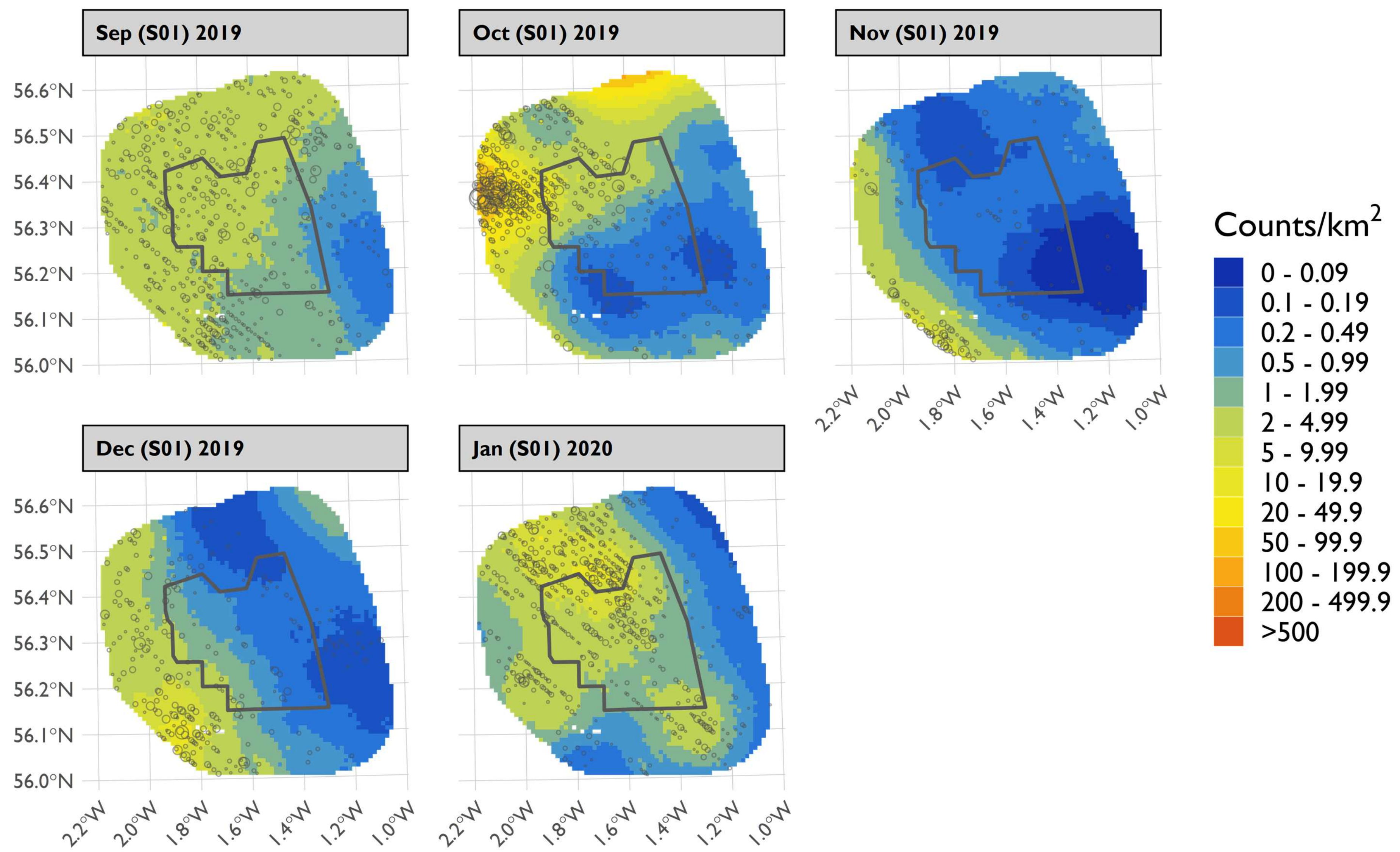

Figure 58 Upper confidence limit of density of razorbills across the Offshore Ornithology Study Area between September 2019 and January 2020, modelled using MRSea

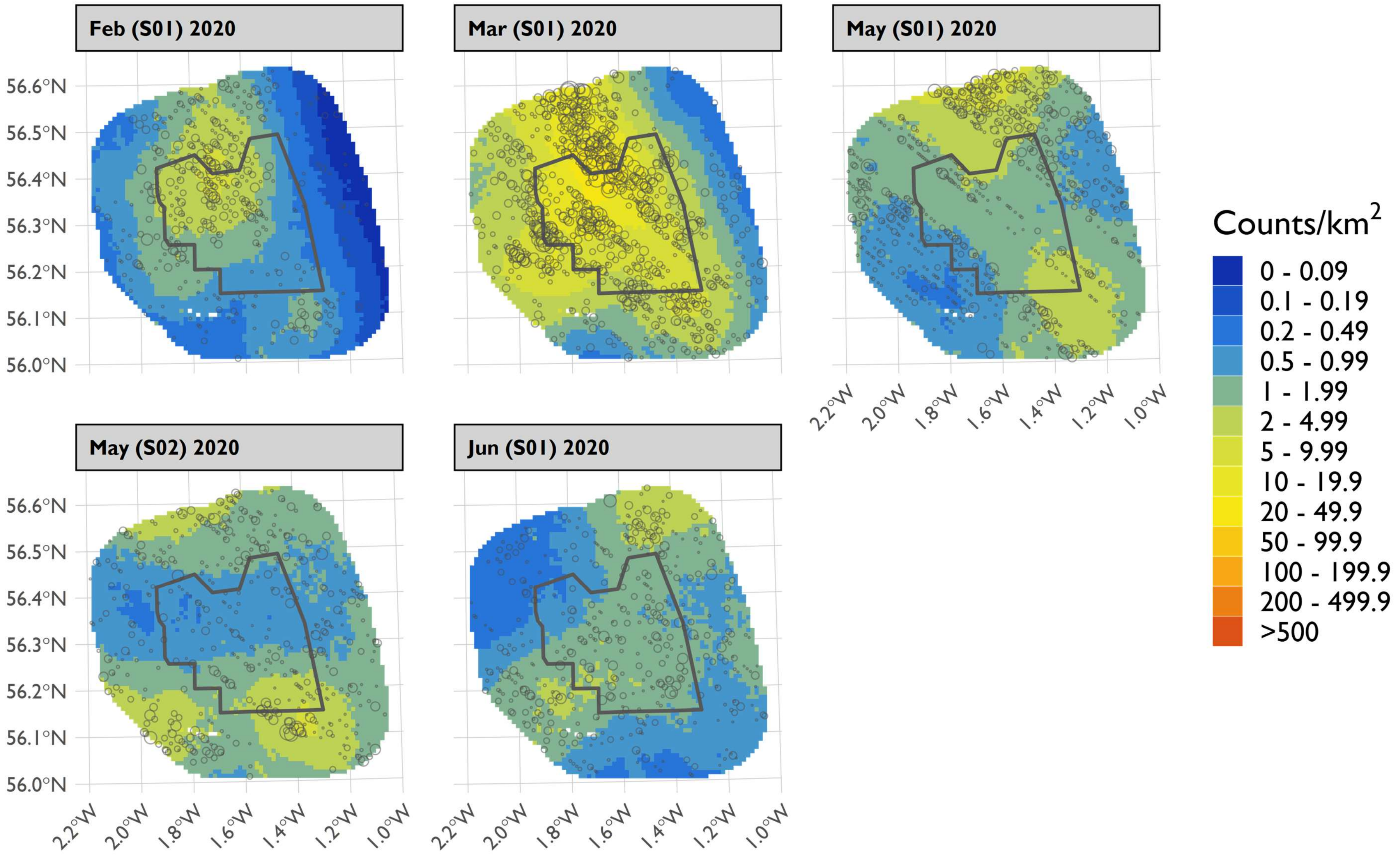

Figure 59 **Upper confidence limit of density of razorbills across the Offshore Ornithology Study Area between February and June 2020, modelled using MRSea**

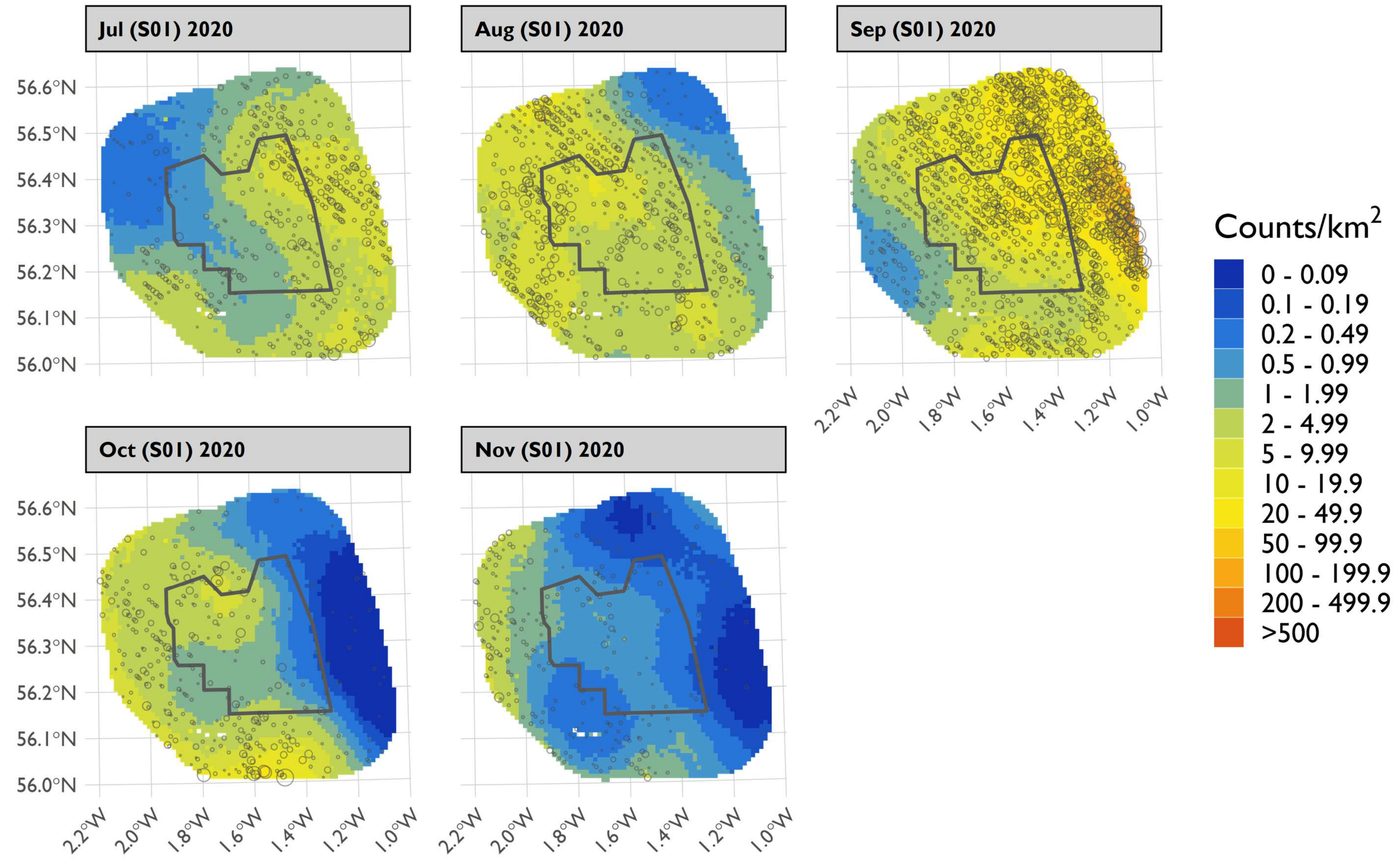

Figure 60 Upper confidence limit of density of razorbills across the Offshore Ornithology Study Area between July and November 2020, modelled using MRSea

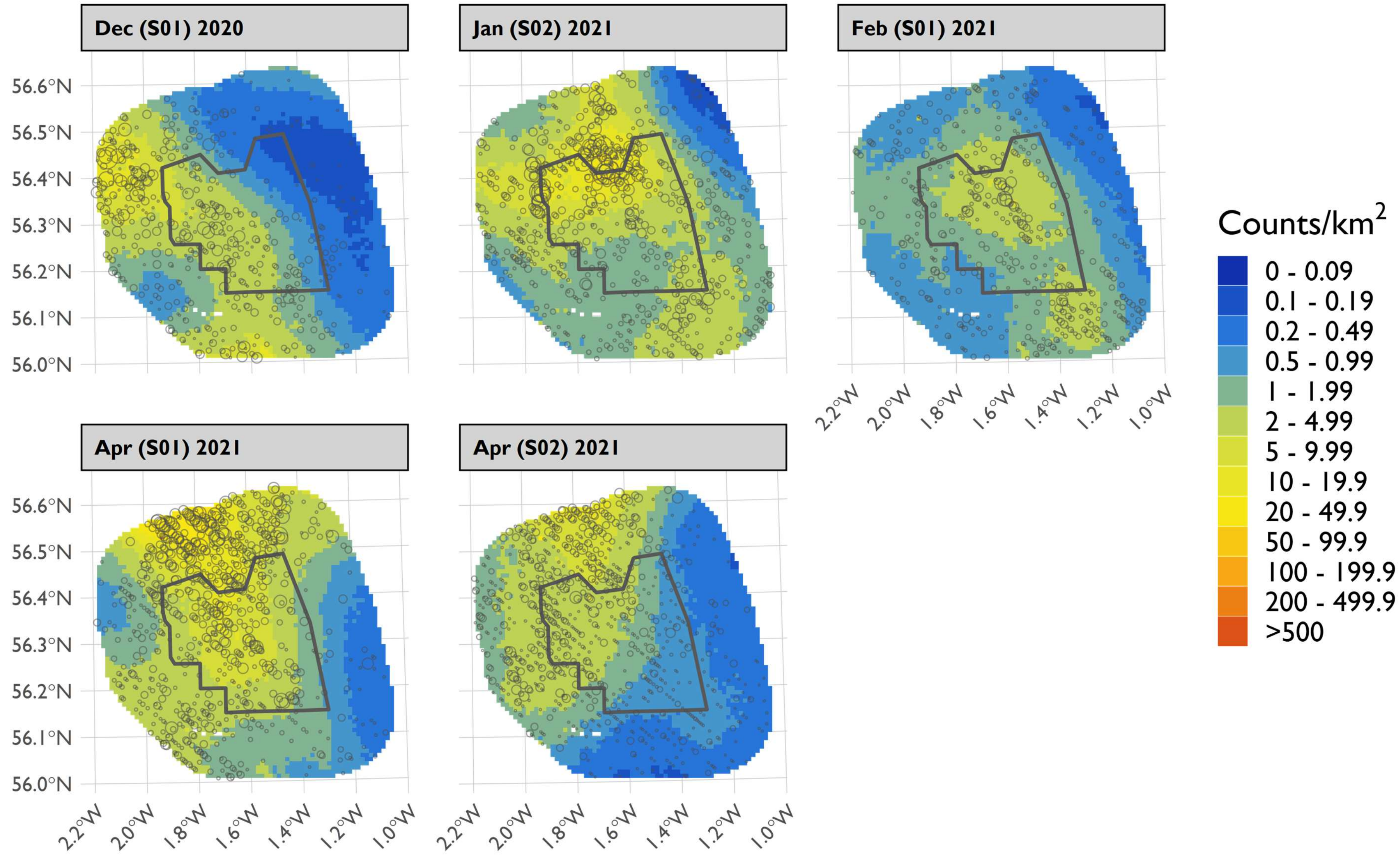

Figure 61 Upper confidence limit of density of razorbills across the Offshore Ornithology Study Area between December 2020 and April S02 2021, modelled using MRSea

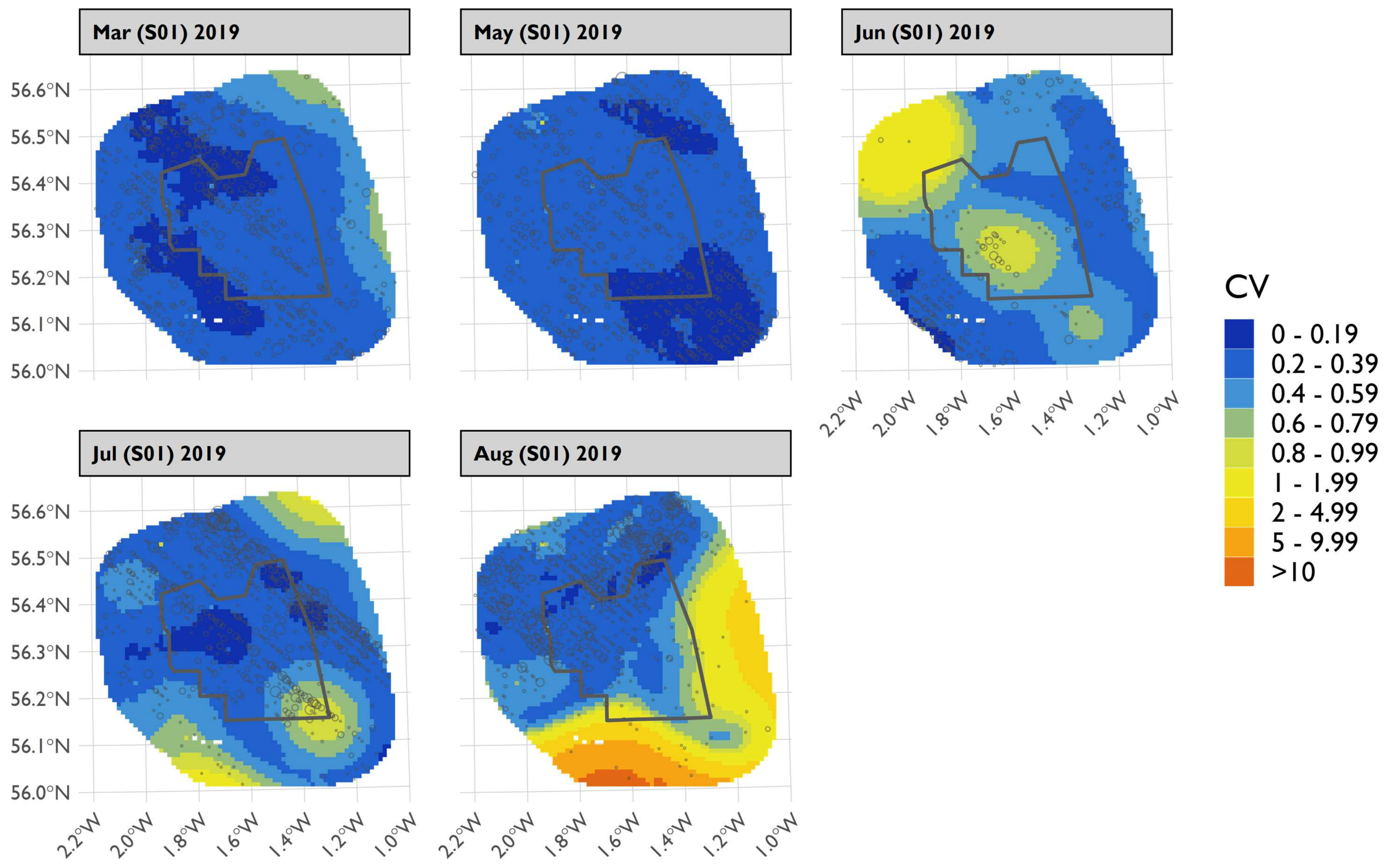

Figure 62 Spatial coefficient of variation of predicted razorbill densities from MRSea across the Offshore Ornithology Study Area between March and August 2019

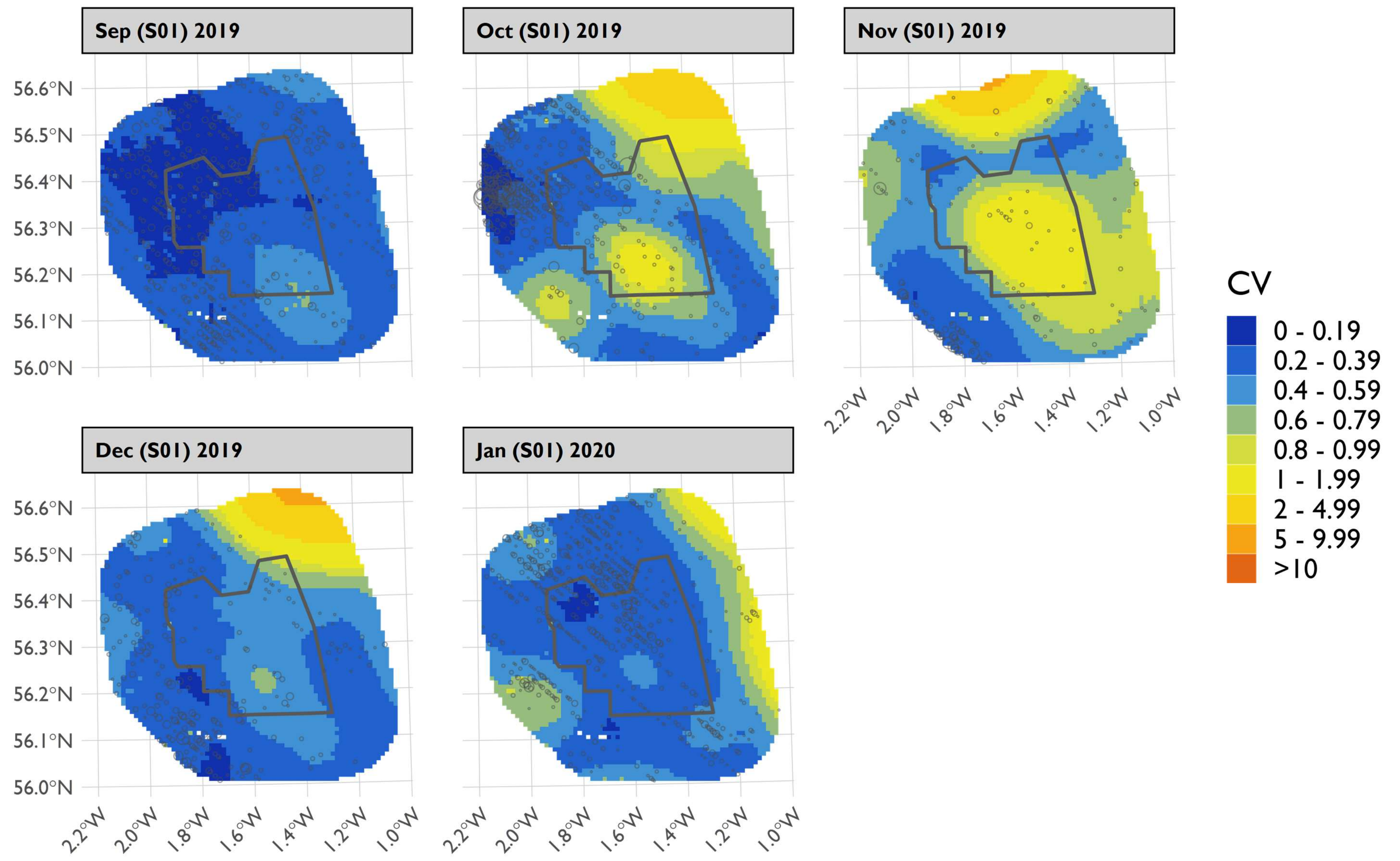

Figure 63 **Spatial coefficient of variation of predicted razorbill densities from MRSea across the Offshore Ornithology Study Area between September 2019 and January 2020**

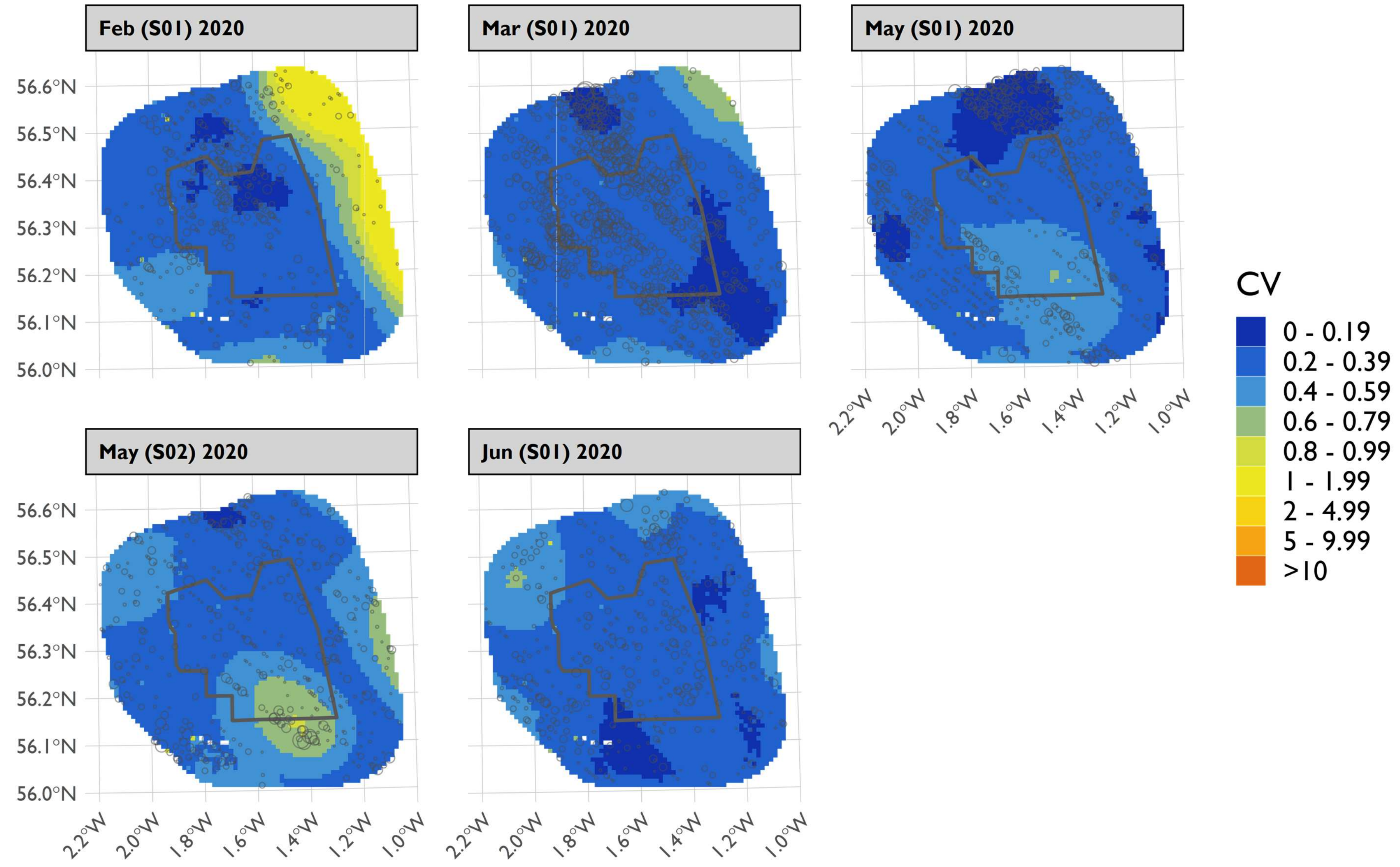

Figure 64 Spatial coefficient of variation of predicted razorbill densities from MRSea across the Offshore Ornithology Study Area between February and June 2020

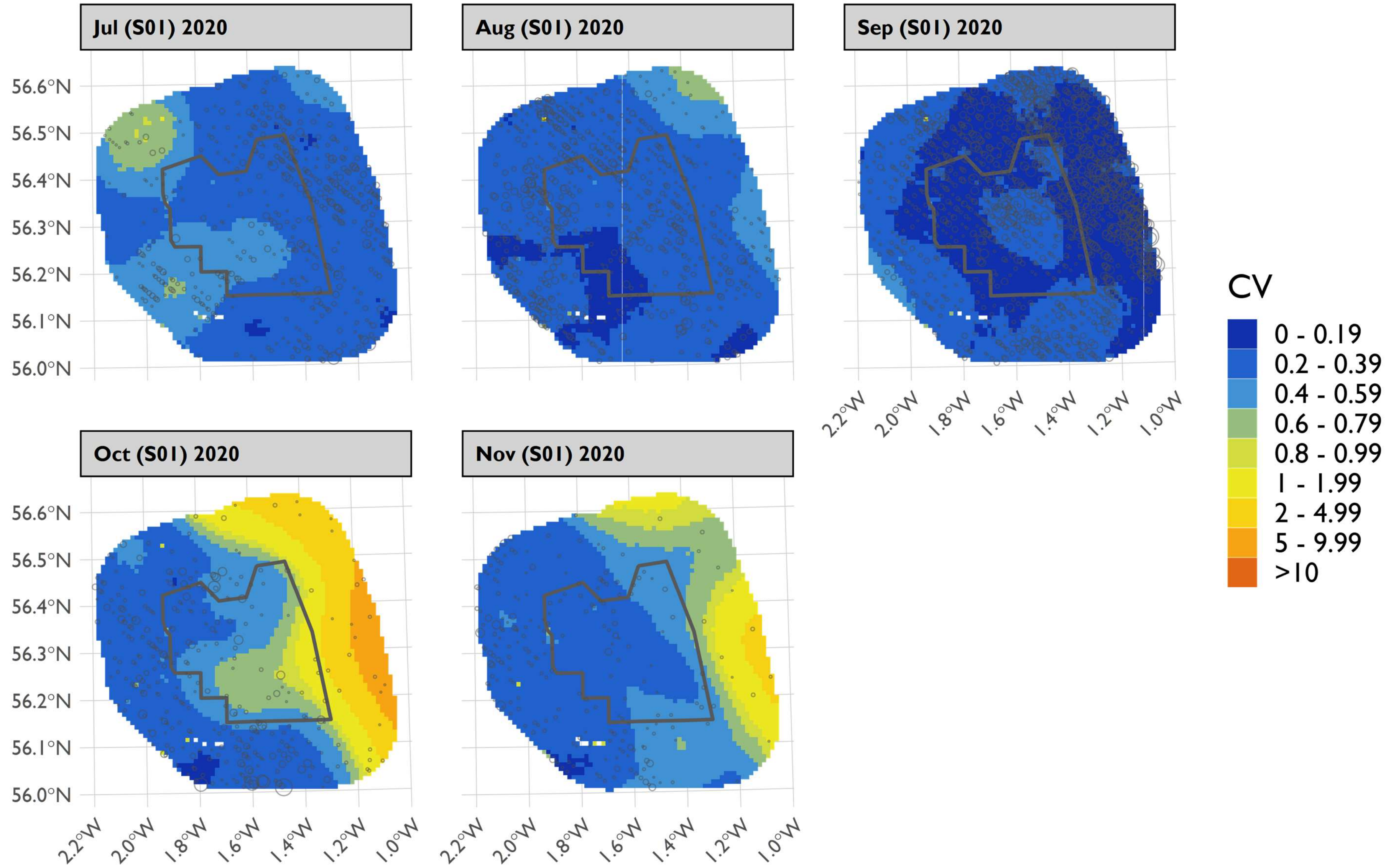

Figure 65 **Spatial coefficient of variation of predicted razorbill densities from MRSea across the Offshore Ornithology Study Area between July and November 2020**

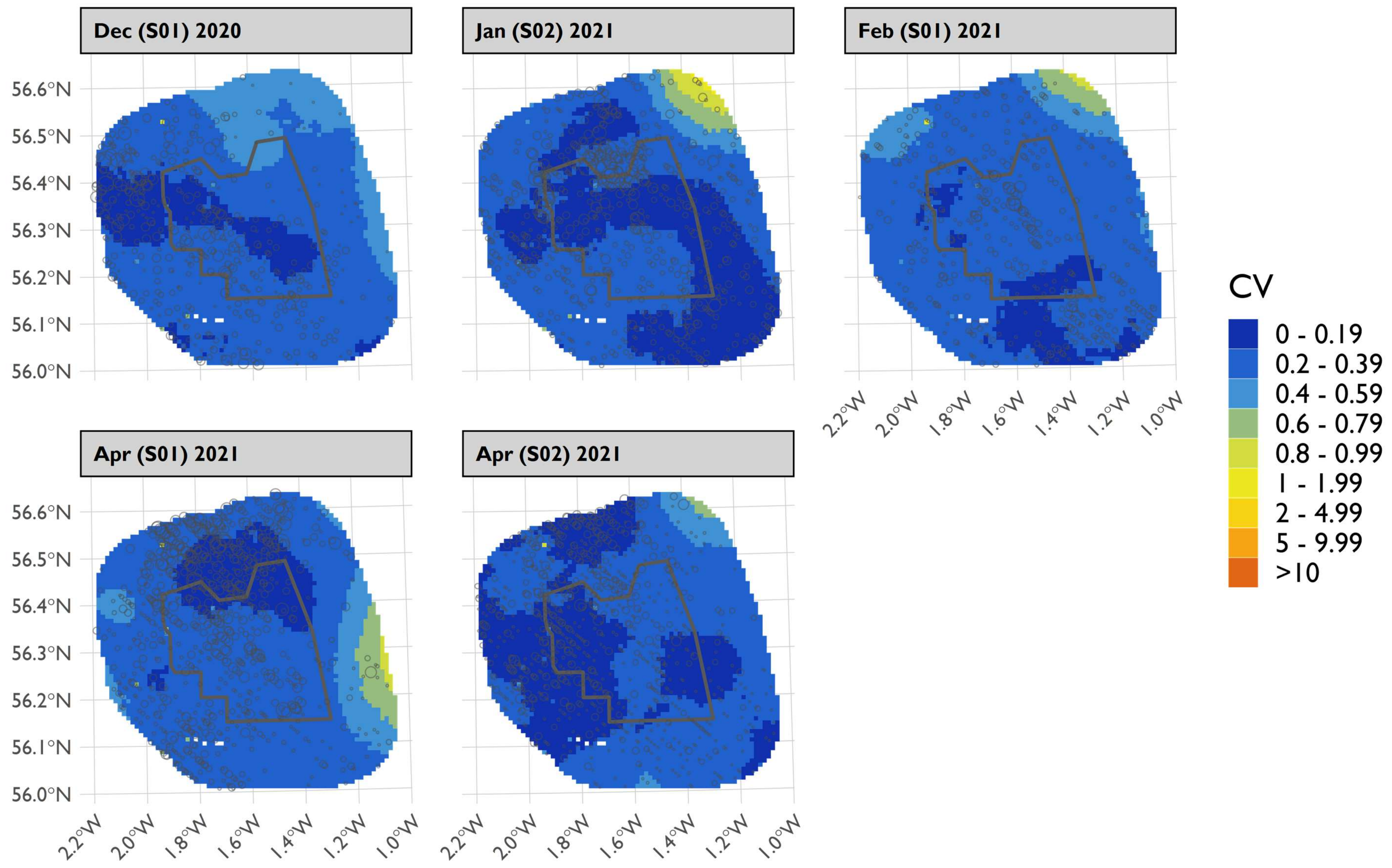

Figure 66 Spatial coefficient of variation of predicted razorbill densities from MRSea across the Offshore Ornithology Study Area between December 2020 and April S02 2021

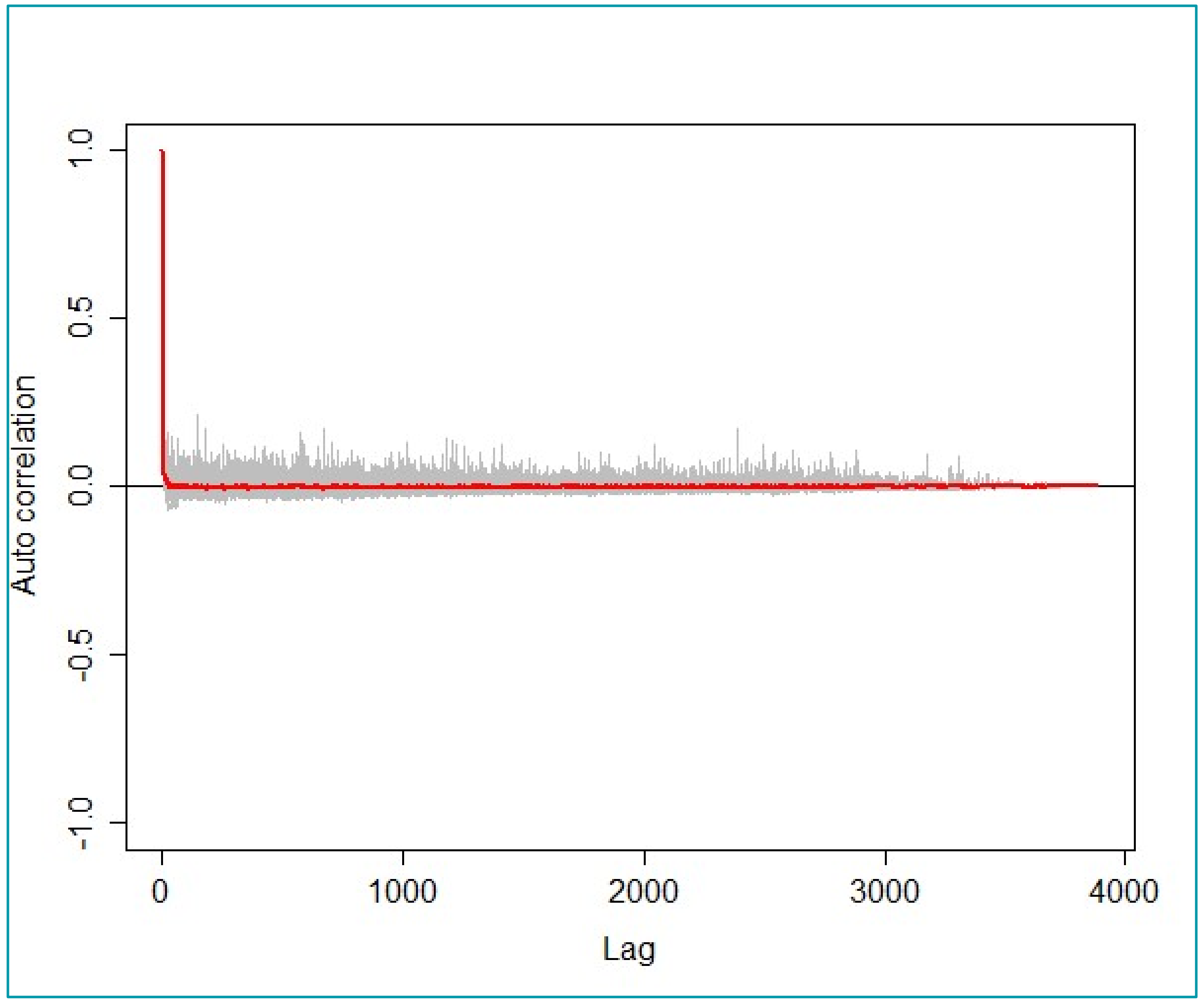

Figure 67 Autocorrelation test for razorbill density surface models when using transect as a blocking feature in MRSea showing no significant correlation. A Runs test on the data prior to using transect as a blocking feature gave a p-value of << 0.0001 (i.e., that the data were significantly autocorrelated when not using a blocking feature)

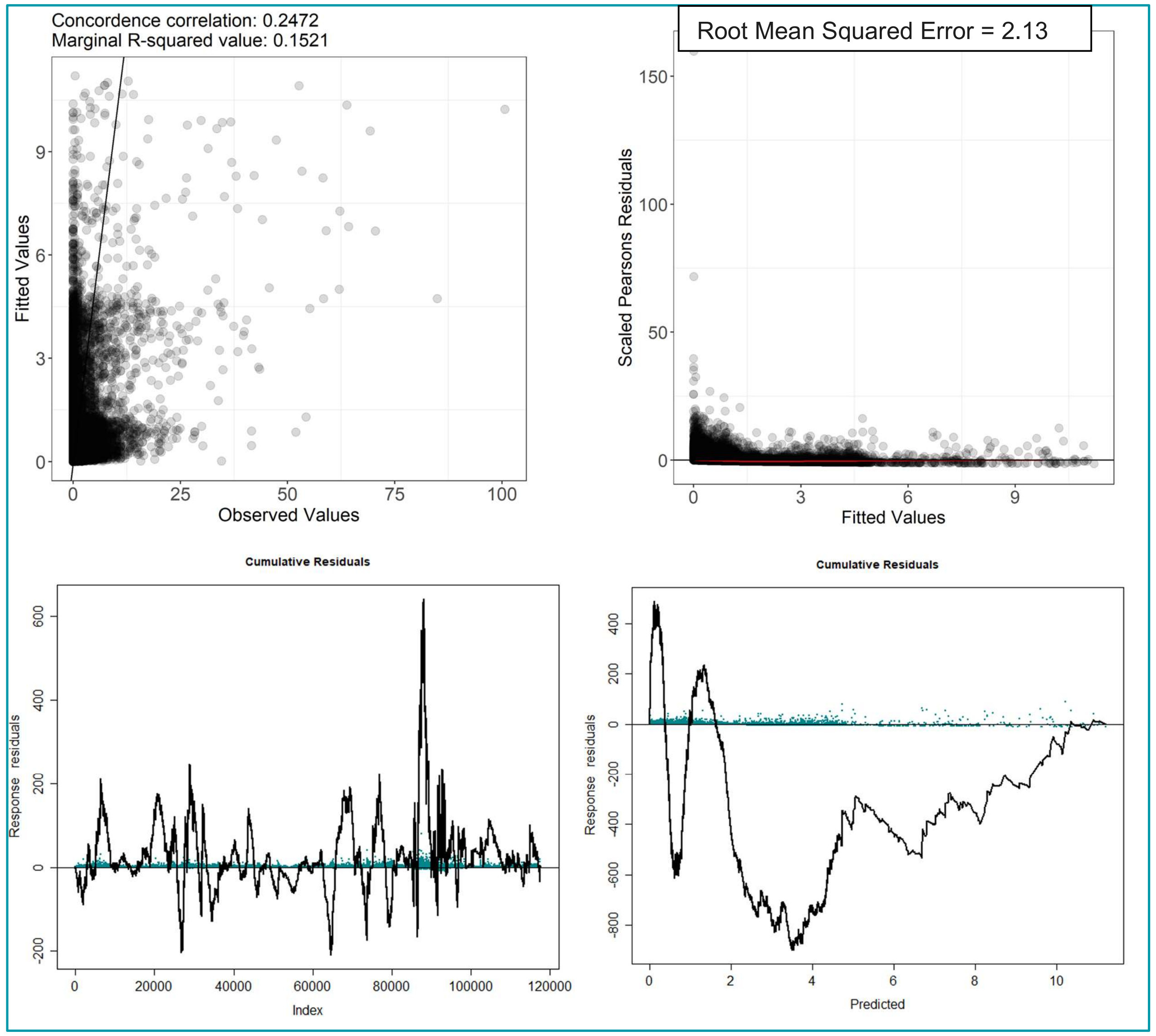

Figure 68 Fitted (MRSea predictions) versus observed counts of razorbill (top left), and residual plots from MRSea

Table 10 ANOVA results from the best MRSea model for razorbill as selected by cross-validation

Variable	Degrees of Freedom	Chi-square	P value
Sediment type	3	11.26	<< 0.1
Bathymetry	3	37.99	<< 0.001
SST gradient	3	77.81	<< 0.001
Sandeel density	5	10.81	0.06
Distance to coast	3	14.94	<<0.01
X/Y (location)	4	-	<< 0.001

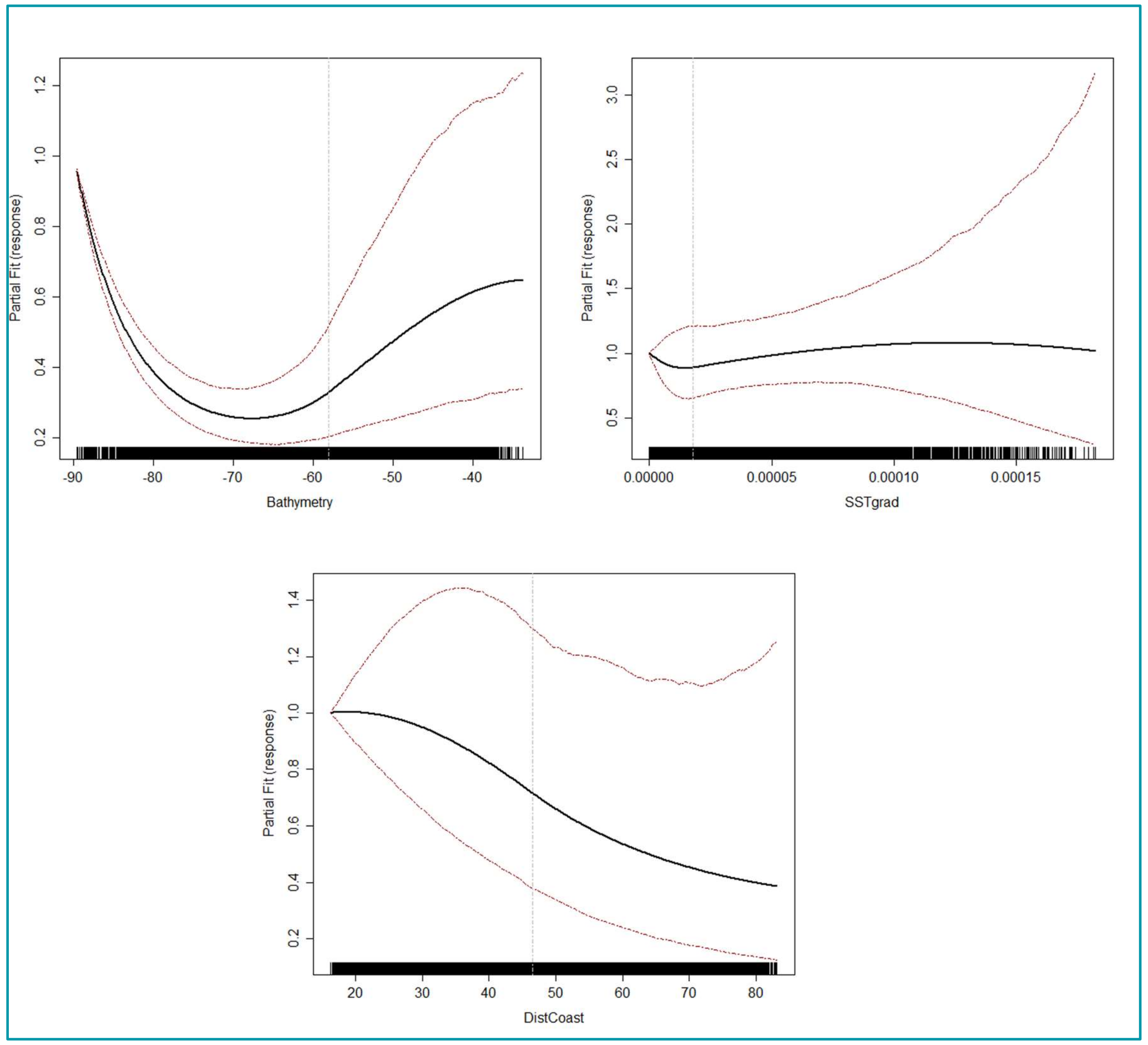

Figure 69 Partial dependence plots for significant variables for razorbill from MRSea models

1.3.5. PUFFIN

35. The highest densities calculated using MRSea were recorded in September 2020 reaching peaks of 12.63 birds/km^2 (95CI 7.44 – 19.44) and 7.81 birds/km^2 (95CI 4.86 – 11.69) in the Development Array and Offshore Ornithology Study Area respectively (Table 11 and Table 12). This equated to peak population estimates of 12,764 birds (95CI 7,514 – 19,642) and 31,050 birds (95CI 19,335 – 46,469).

36. Maps produced using MRSea indicate varied use of the survey area, the eastern half of the survey area tended to have lower densities during the breeding season (Figure 70 to Figure 74). Higher densities in the west of the study area in months such as June and July 2019, July 2020 and April 2021, suggest many birds select areas closer to colonies and chicks during this time. More widespread dispersal towards the end of the chick-rearing period, such as in September 2020, suggests movement of birds offshore, with elevated densities also observed to the east of the survey area in September 2019.

37. Broadly, model fit was moderate for Puffin when compared to other species with a marginal R squared value of 0.1583 and root mean squared error of 0.50. The cumulative residuals in the model showed that there was overall a poor relationship between predicted and observed values particularly when predicted counts were between 0.75 – 1.75 birds (Figure 91).

38. The highest densities calculated using MRSea were recorded in September 2020 reaching peaks of 12.63 birds/km^2 (95CI 7.44 – 19.44) and 7.81 birds/km^2 (95CI 4.86 – 11.69) in the Development Array and Offshore Ornithology Study Area respectively.

Table 11 Monthly density and population estimates of puffin in the Development Array derived from MRSea

Survey	Density Estimate (n/km^2)	SD of Density	Lower 95% CL of Density	Upper 95% CL of Density	Population Estimate (number)	SD of Population	Lower 95% CL of Population	Upper 95% CL of Population	CV (%)
Mar-19	1.09	0.31	0.6	1.85	1102	313	605	1870	28.4%
May-19	2.17	0.54	1.27	3.39	2197	543	1282	3425	24.72%
Jun-19	0.56	0.17	0.3	0.99	568	174	306	996	30.63%
Jul-19	3.31	0.88	1.97	5.31	3341	892	1991	5364	26.7%
Aug-19	4.28	1.24	2.23	6.96	4323	1250	2252	7030	28.92%
Sep-19	1.35	0.37	0.8	2.27	1362	378	811	2298	27.75%
Oct-19	0.29	0.09	0.15	0.49	289	91	149	496	31.49%
Nov-19	0.03	0.01	0.01	0.05	28	10	14	51	35.71%
Dec-19	0.05	0.02	0.02	0.09	49	20	20	95	40.82%
Jan-20	0.18	0.06	0.09	0.31	180	60	87	314	33.33%
Feb-20	0.78	0.24	0.4	1.36	791	242	407	1370	30.59%
Mar-20	1.6	0.46	0.9	2.61	1617	467	907	2639	28.88%
May S01 20	0.48	0.14	0.26	0.79	485	139	264	802	28.66%
May S02 20	0.72	0.22	0.39	1.18	729	220	397	1191	30.18%
Jun-20	1.09	0.34	0.58	1.89	1098	342	583	1905	31.15%
Jul-20	1.75	0.47	1.01	2.83	1763	474	1020	2860	26.89%
Aug-20	12.63	3.22	7.44	19.44	12764	3251	7514	19642	25.47%
Sep-20	0.15	0.05	0.08	0.26	156	46	83	259	29.49%
Oct-20	0.11	0.04	0.06	0.2	113	38	59	202	33.63%
Nov-20	0.03	0.01	0.01	0.06	29	13	12	59	44.83%
Dec-20	0.03	0.01	0.01	0.06	29	13	12	58	44.83%
Jan-21	0.39	0.12	0.21	0.7	398	124	209	705	31.16%
Feb-21	0.81	0.22	0.48	1.28	821	219	480	1292	26.67%
Apr S01 21	3.73	1.04	2.15	5.92	3769	1046	2169	5982	27.75%
Apr S02 21	1.09	0.31	0.6	1.85	1102	313	605	1870	28.4%

Table 12 **Monthly density and population estimates of puffin in the Offshore Ornithology Study Area derived from MRSea**

Survey	Density Estimate (n/km²)	SD of Density	Lower 95% CL of Density	Upper 95% CL of Density	Population Estimate (number)	SD of Population	Lower 95% CL of Population	Upper 95% CL of Population	CV (%)
Mar-19	1.19	0.3	0.68	1.86	4724	1192	2707	7410	25.23%
May-19	1.95	0.46	1.17	2.96	7749	1816	4661	11757	23.44%
Jun-19	1.28	0.35	0.73	2.14	5080	1407	2885	8508	27.7%
Jul-19	4.18	1.1	2.55	6.53	16612	4360	10130	25944	26.25%
Aug-19	2.99	0.84	1.6	4.9	11878	3319	6358	19457	27.94%
Sep-19	1.4	0.33	0.89	2.16	5560	1331	3519	8587	23.94%
Oct-19	0.57	0.17	0.32	0.93	2262	676	1272	3684	29.89%
Nov-19	0.05	0.02	0.03	0.09	207	65	114	358	31.4%
Dec-19	0.04	0.01	0.02	0.08	173	55	90	300	31.79%
Jan-20	0.19	0.05	0.11	0.3	744	179	452	1188	24.06%
Feb-20	0.69	0.2	0.37	1.17	2759	789	1475	4648	28.6%
Mar-20	1.61	0.43	0.92	2.55	6415	1728	3652	10133	26.94%
May S01 20	0.65	0.17	0.37	1.04	2571	669	1483	4139	26.02%
May S02 20	0.8	0.23	0.45	1.29	3193	903	1788	5141	28.28%
Jun-20	1.28	0.4	0.7	2.32	5072	1585	2775	9221	31.25%
Jul-20	2.06	0.51	1.21	3.15	8188	2027	4807	12536	24.76%
Aug-20	7.81	1.76	4.86	11.69	31050	7012	19335	46469	22.58%
Sep-20	0.21	0.06	0.12	0.33	834	220	460	1321	26.38%
Oct-20	0.17	0.05	0.09	0.3	694	214	368	1203	30.84%
Nov-20	0.03	0.01	0.02	0.06	133	40	72	226	30.08%
Dec-20	0.03	0.01	0.02	0.05	124	38	71	211	30.65%
Jan-21	0.33	0.1	0.19	0.59	1321	397	739	2364	30.05%
Feb-21	1.41	0.36	0.87	2.24	5601	1439	3447	8898	25.69%
Apr S01 21	3.89	1.07	2.27	6.34	15449	4245	9042	25196	27.48%
Apr S02 21	1.19	0.3	0.68	1.86	4724	1192	2707	7410	25.23%

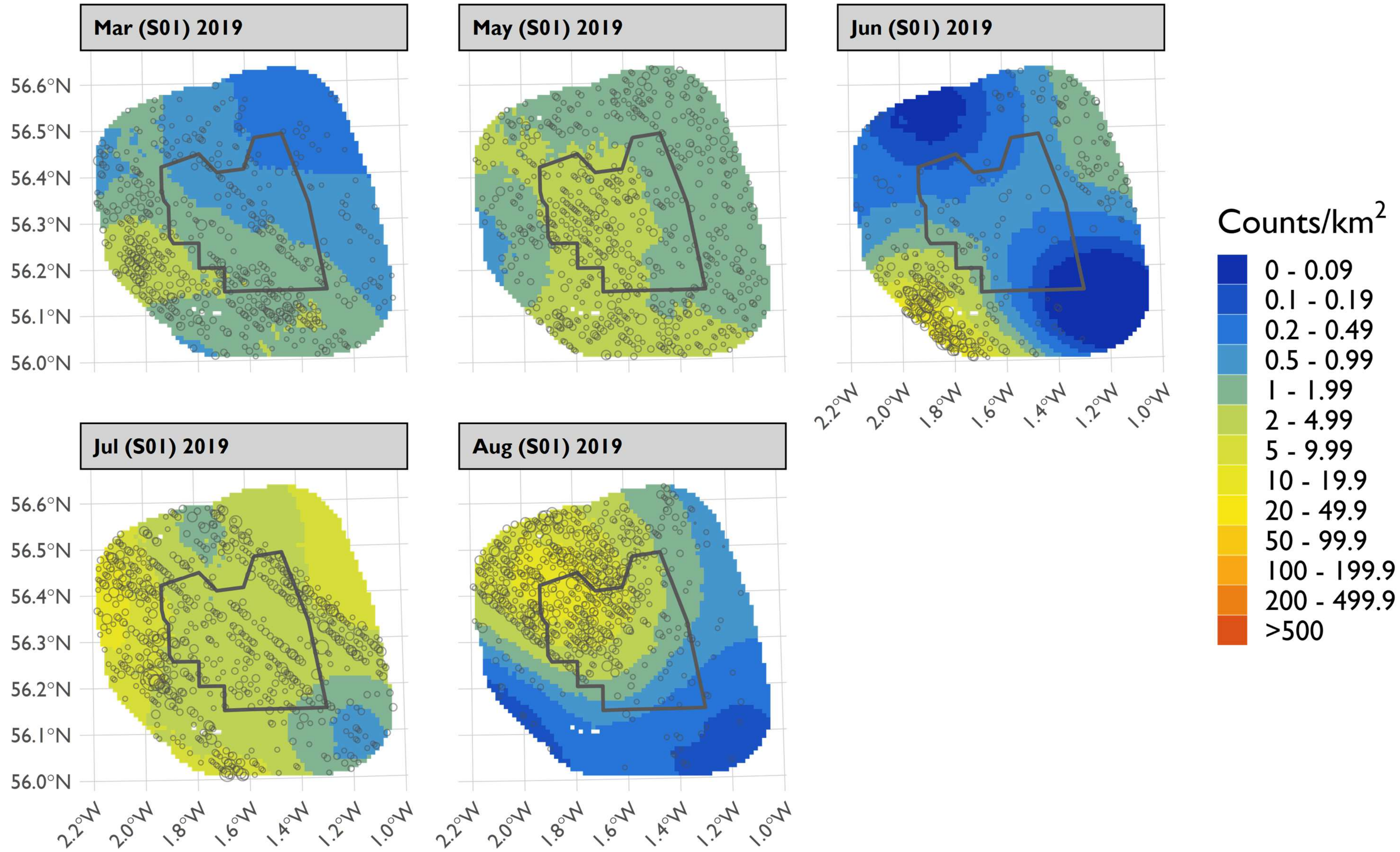

Figure 70 Mean density of puffins across the Offshore Ornithology Study Area between March and August 2019, modelled using MRSea

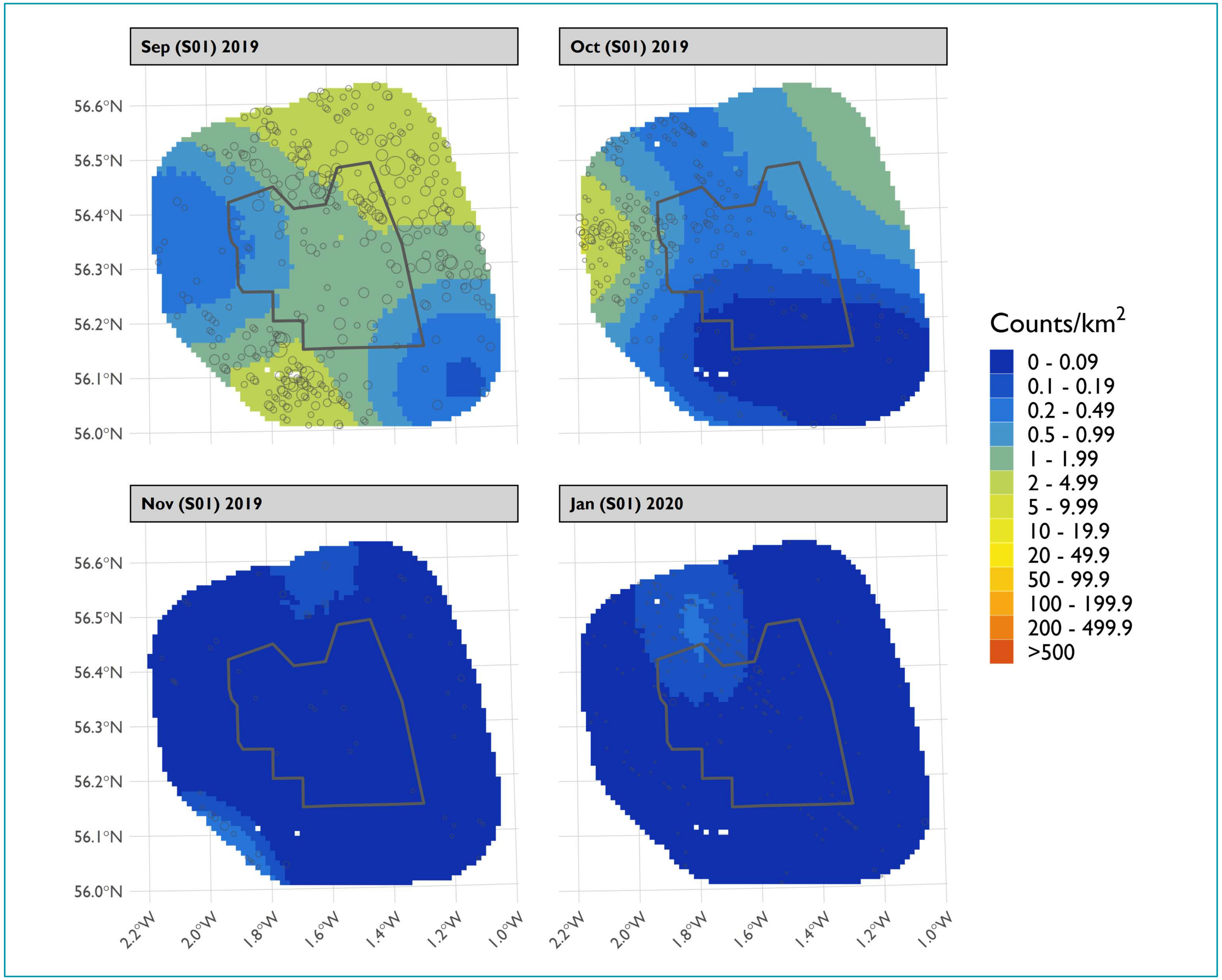

Figure 71 **Mean density of puffins across the Offshore Ornithology Study Area between September 2019 and January 2020, modelled using MRSea**

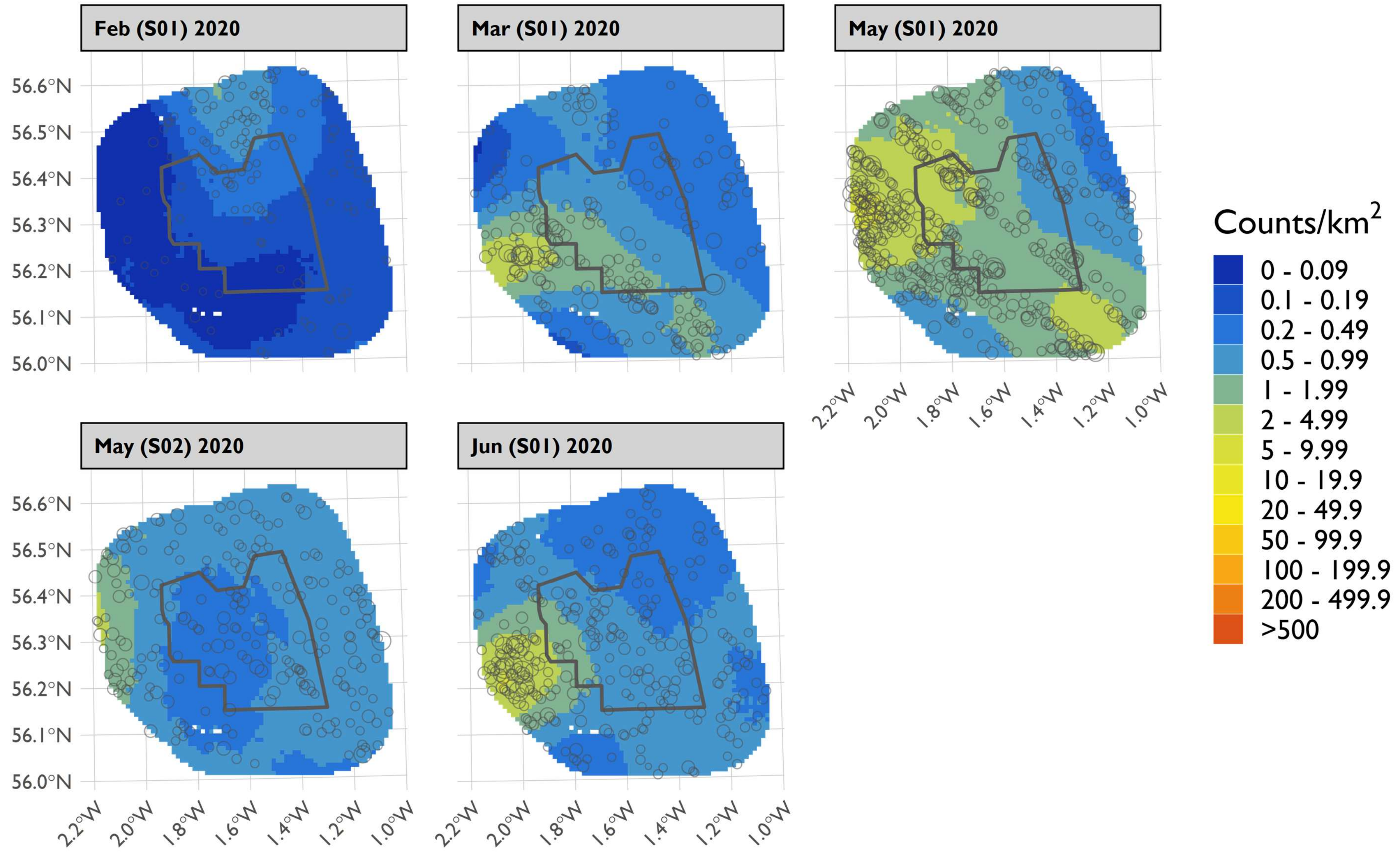

Figure 72 Mean density of puffins across the Offshore Ornithology Study Area between February and June 2020, modelled using MRSea

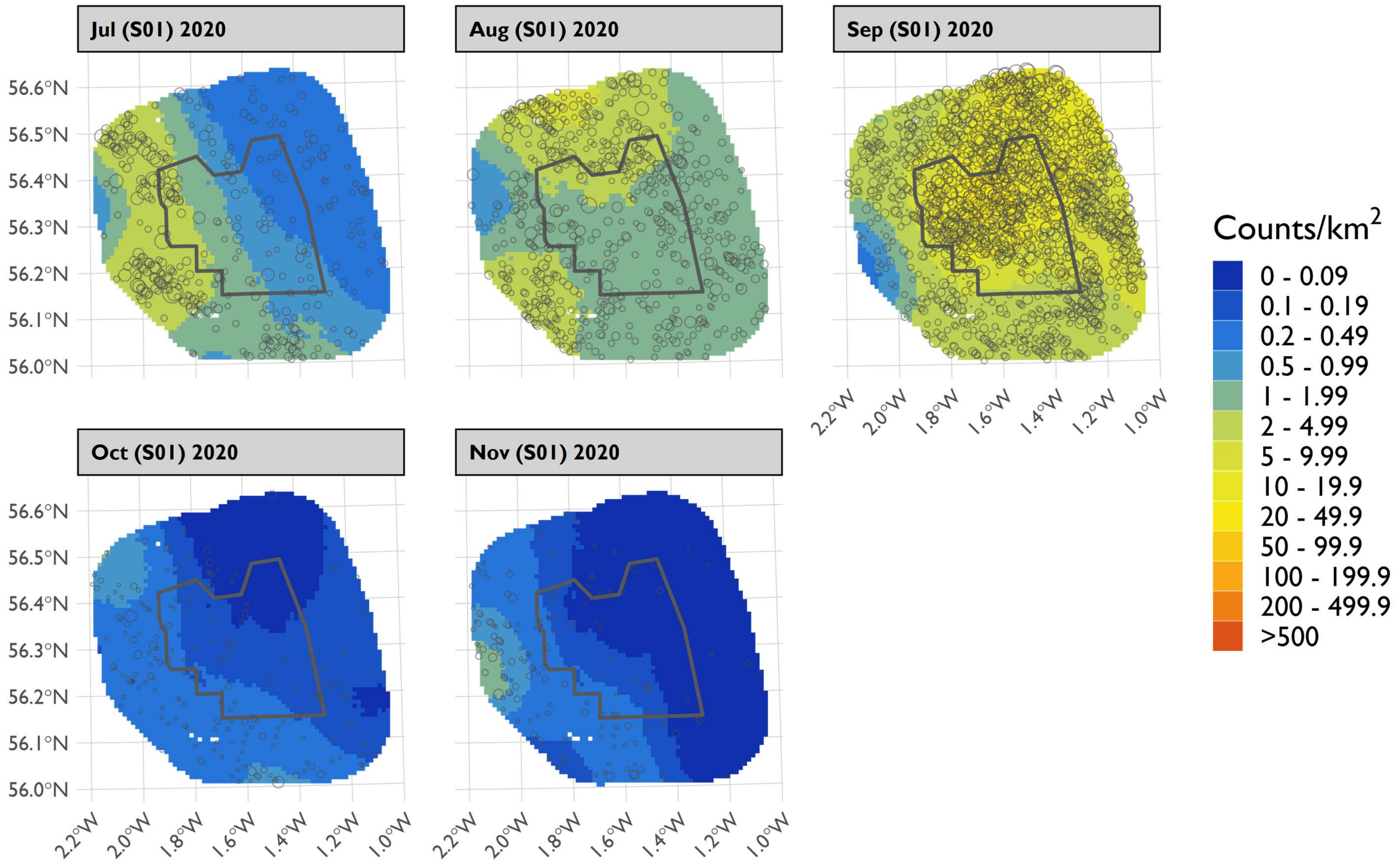

Figure 73 **Mean density of puffins across the Offshore Ornithology Study Area between July and November 2020, modelled using MRSea**

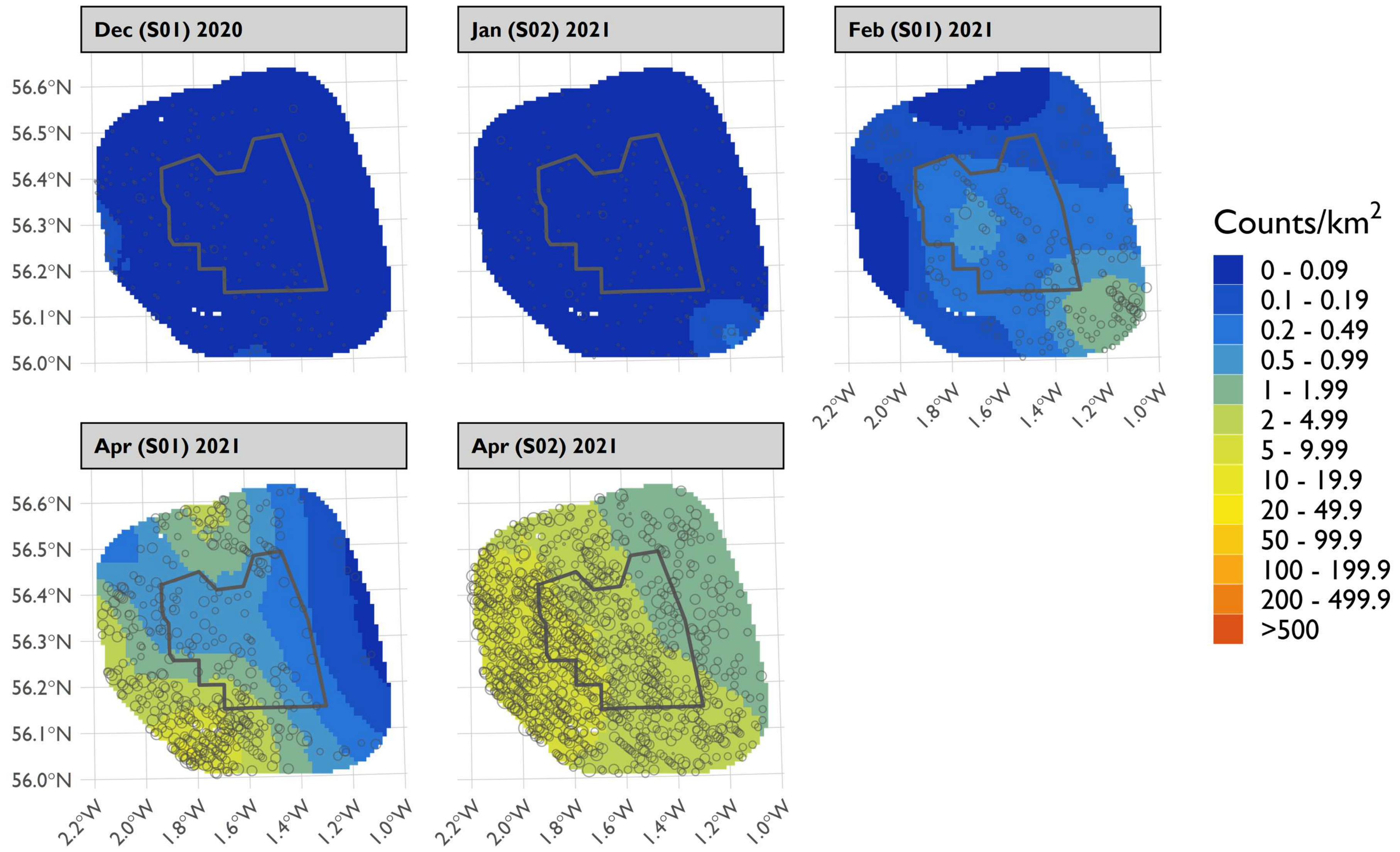

Figure 74 Mean density of puffins across the Offshore Ornithology Study Area between December 2020 and April S02 2021, modelled using MRSea

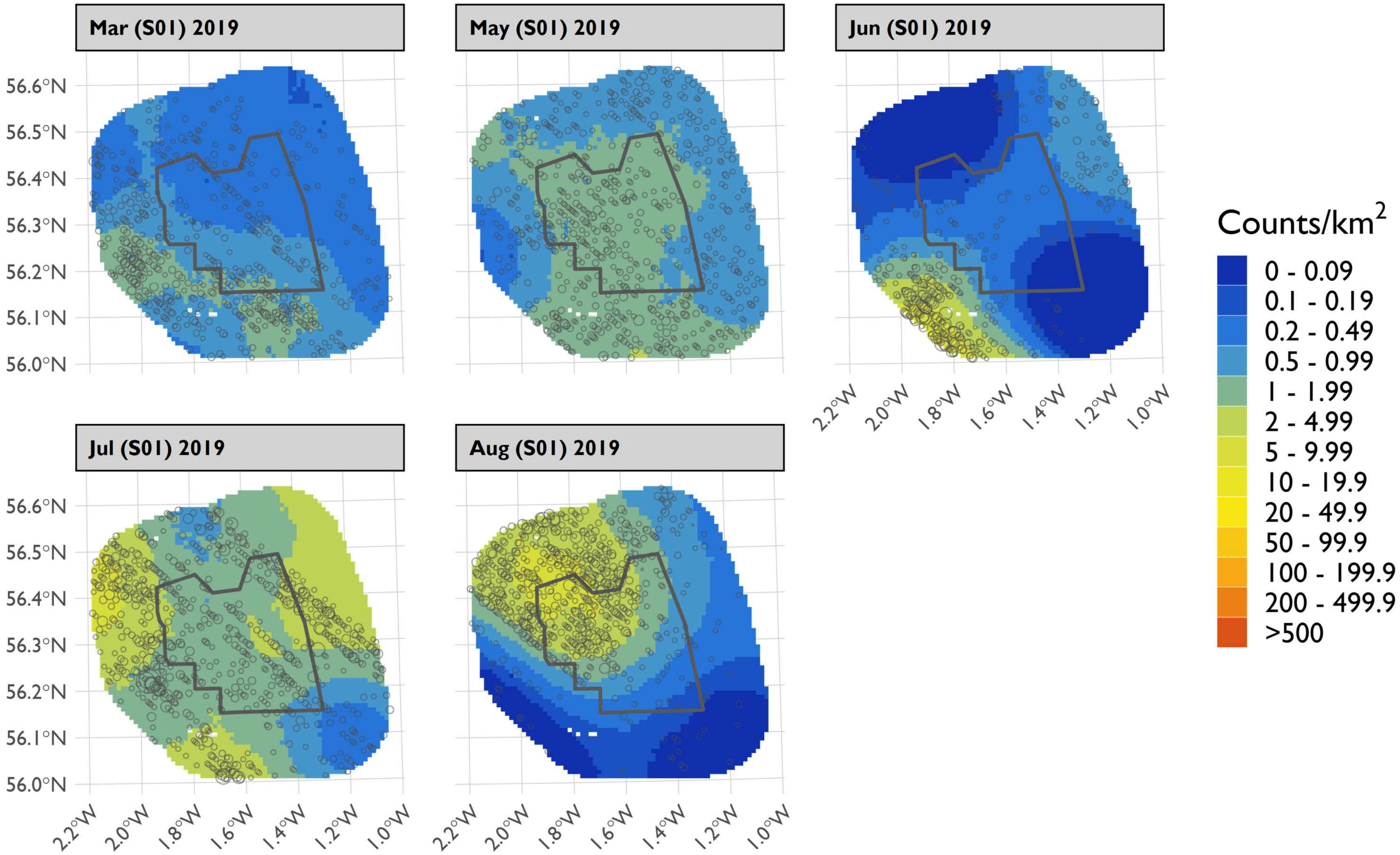

Figure 75 Lower confidence limit of density of puffins across the Offshore Ornithology Study Area between March and August 2019, modelled using MRSea

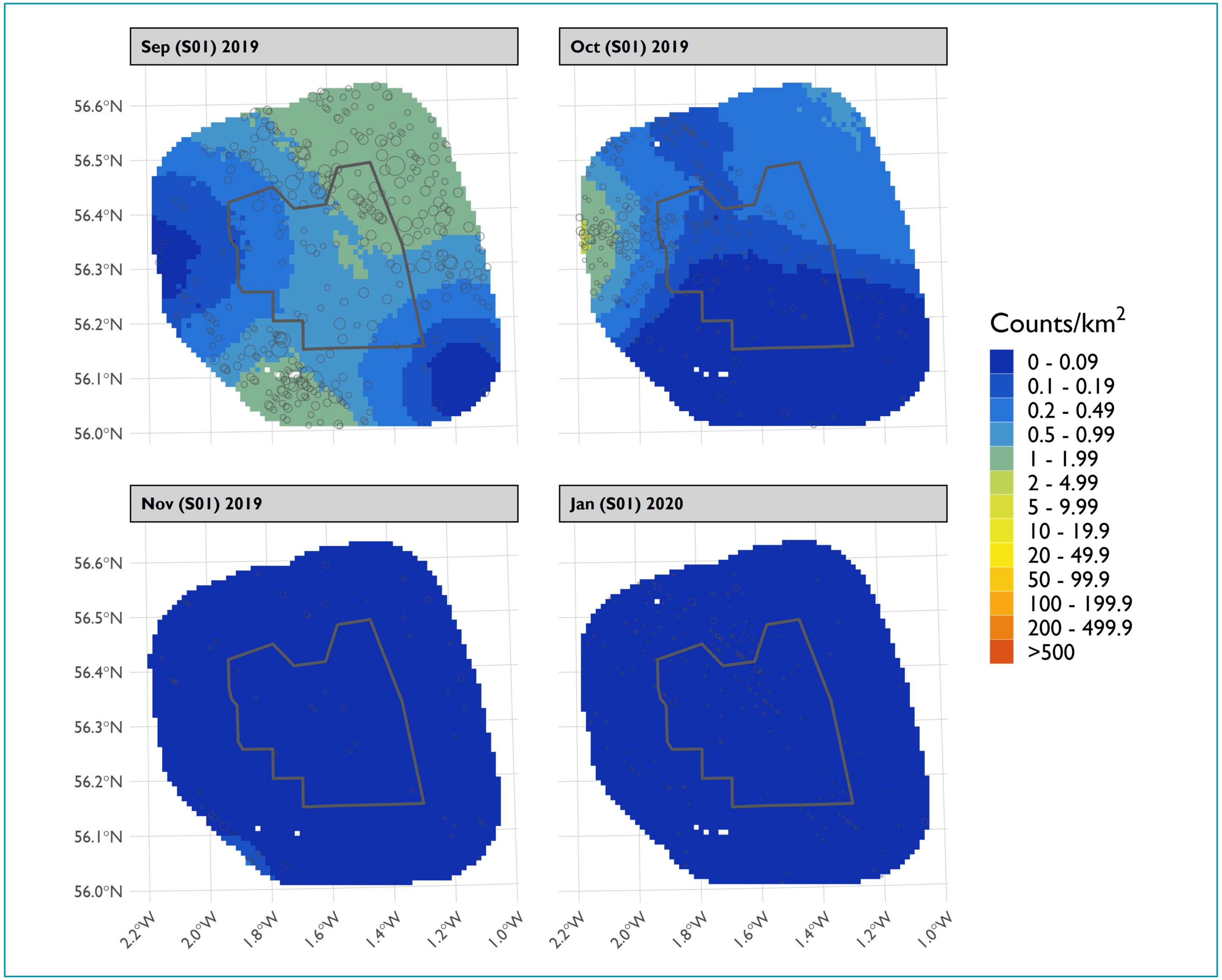

Figure 76 Lower confidence limit of density of puffins across the Offshore Ornithology Study Area between September 2019 and January 2020, modelled using MRSea

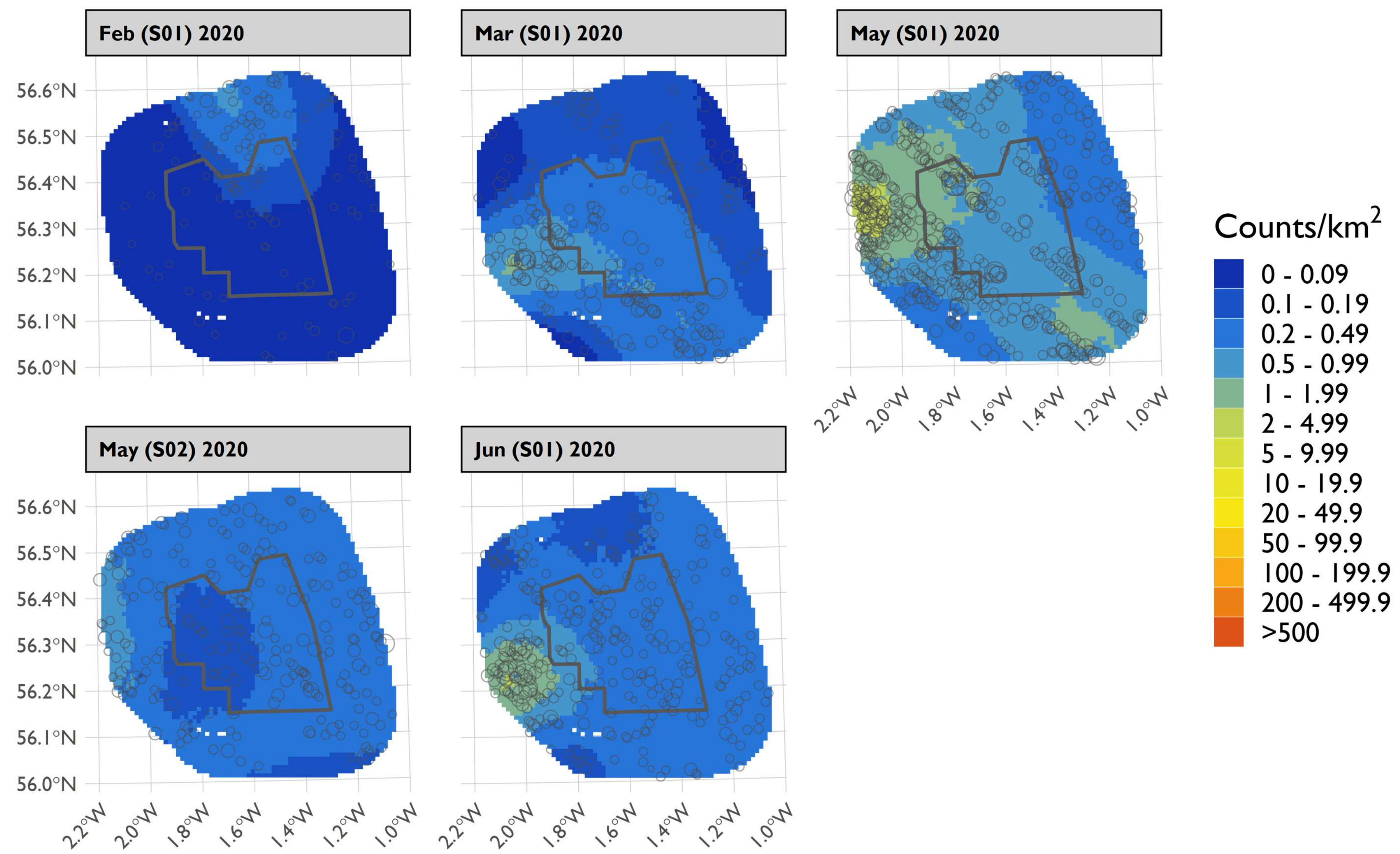

Figure 77 **Lower confidence limit of density of puffins across the Offshore Ornithology Study Area between February and June 2020, modelled using MRSea**

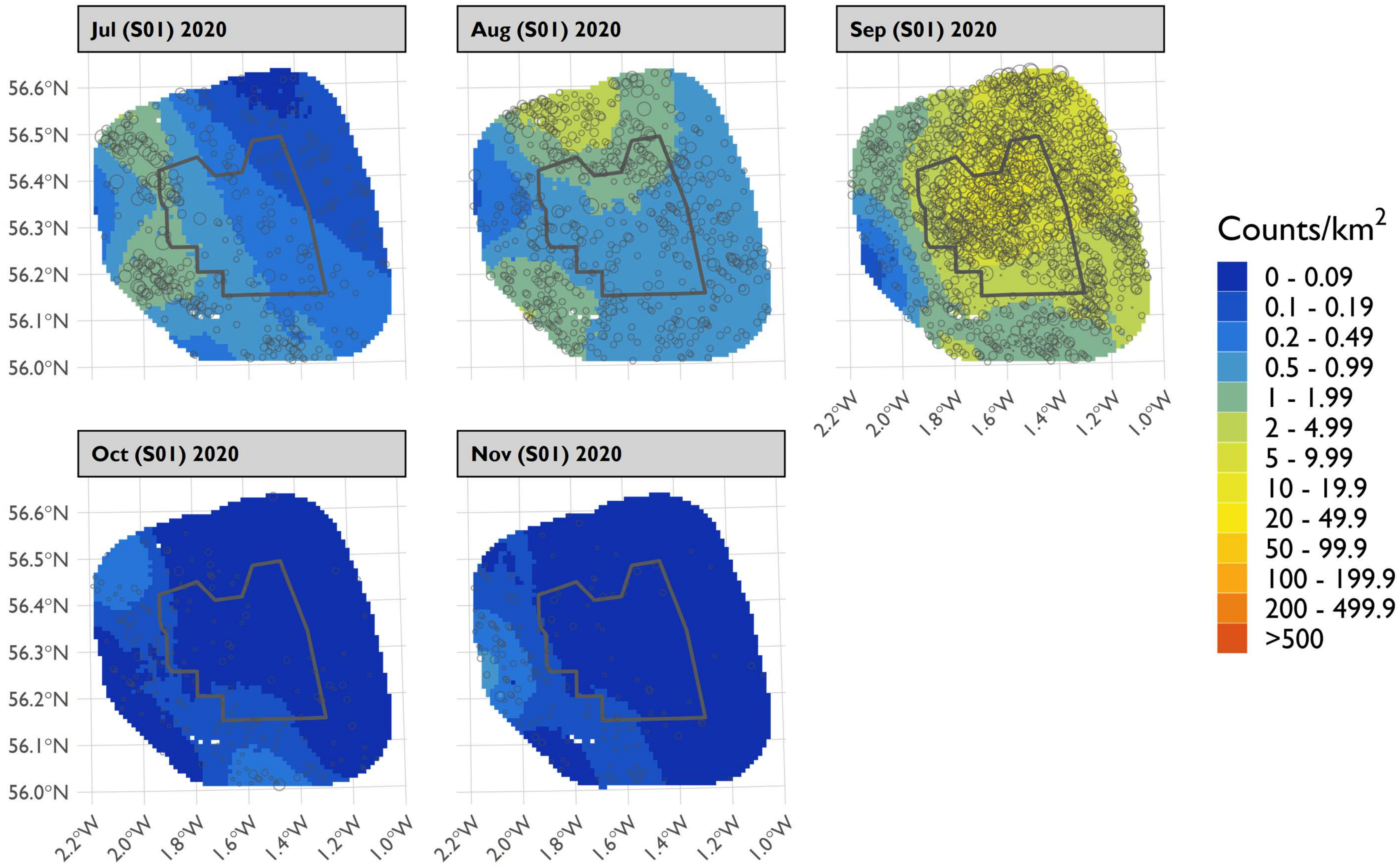

Figure 78 **Lower confidence limit of density of puffins across the Offshore Ornithology Study Area between July and November 2020, modelled using MRSea**

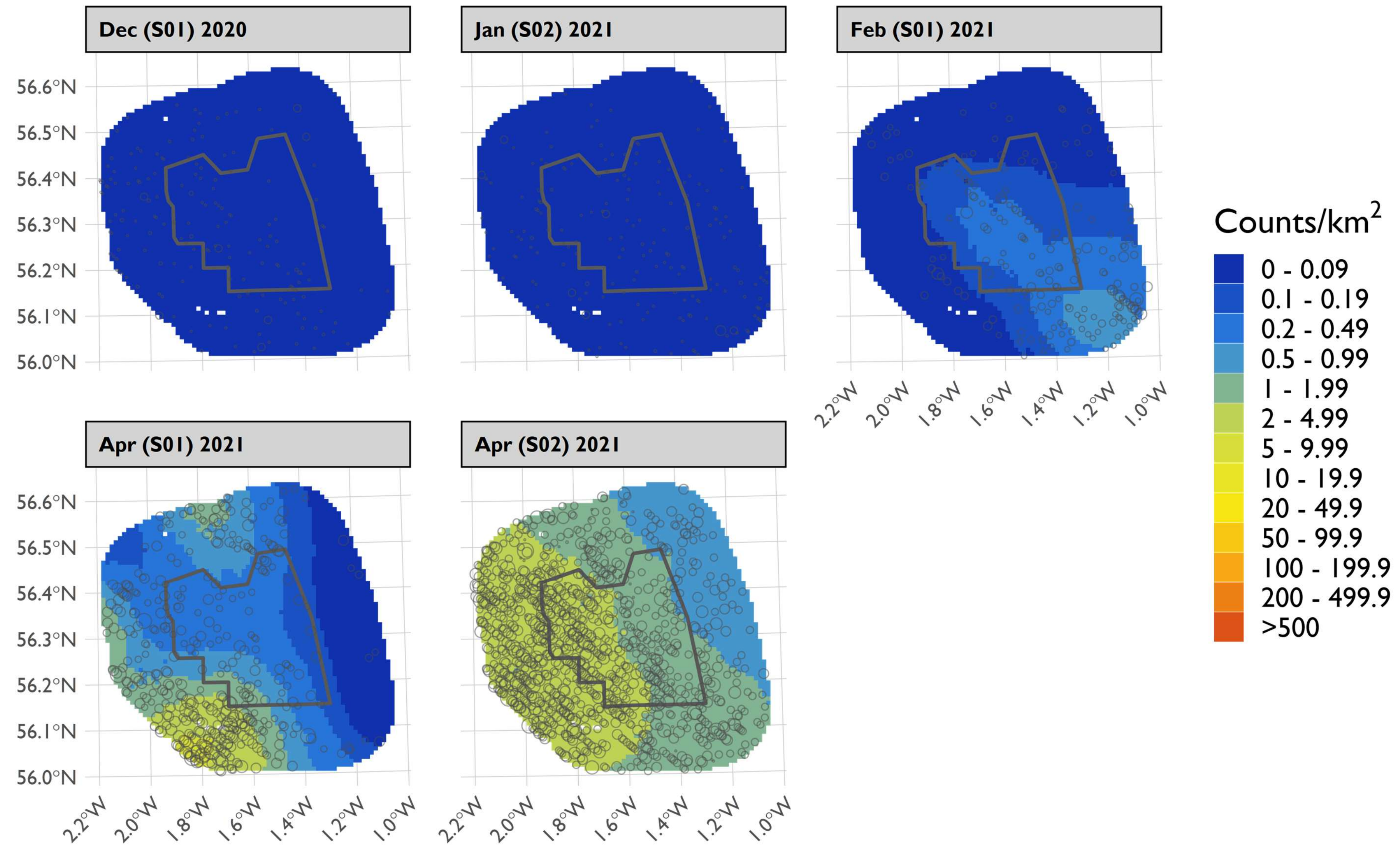

Figure 79 **Lower confidence limit of density of puffins across the Offshore Ornithology Study Area between December 2020 and April S02 2021, modelled using MRSea**

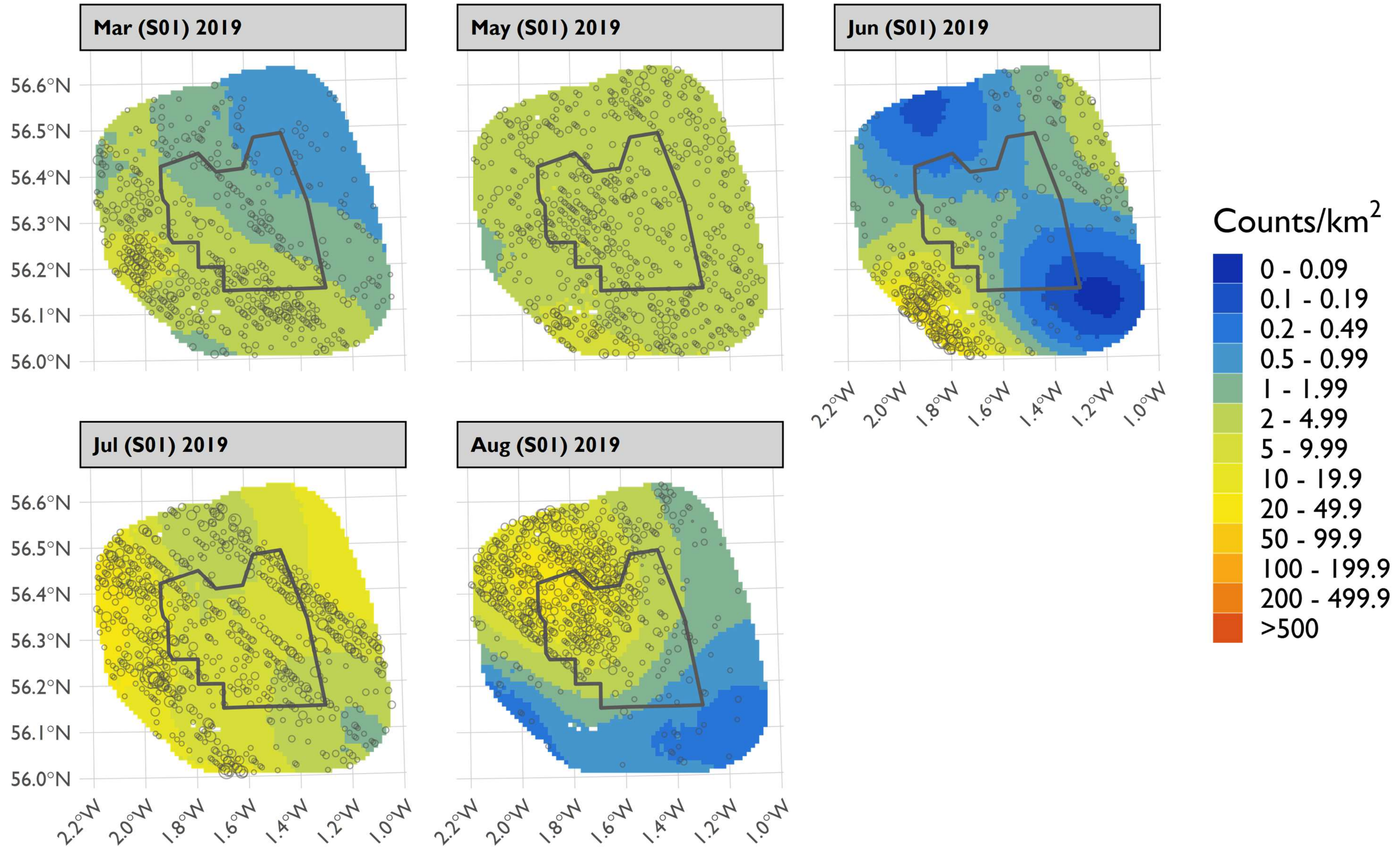

Figure 80 Upper confidence limit of density of puffins across the Offshore Ornithology Study Area between March and August 2019, modelled using MRSea

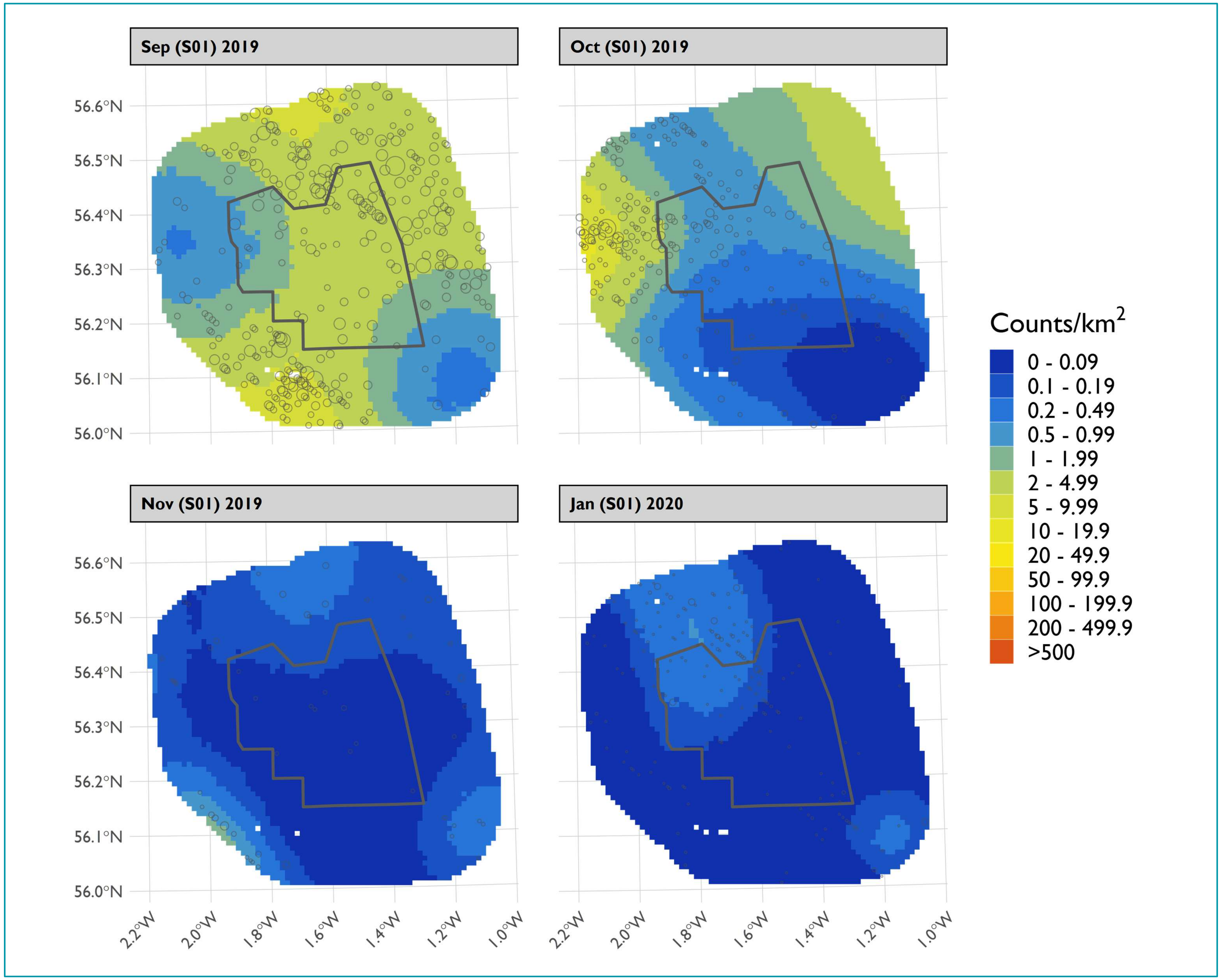

Figure 81 Upper confidence limit of density of puffins across the Offshore Ornithology Study Area between September 2019 and January 2020, modelled using MRSea

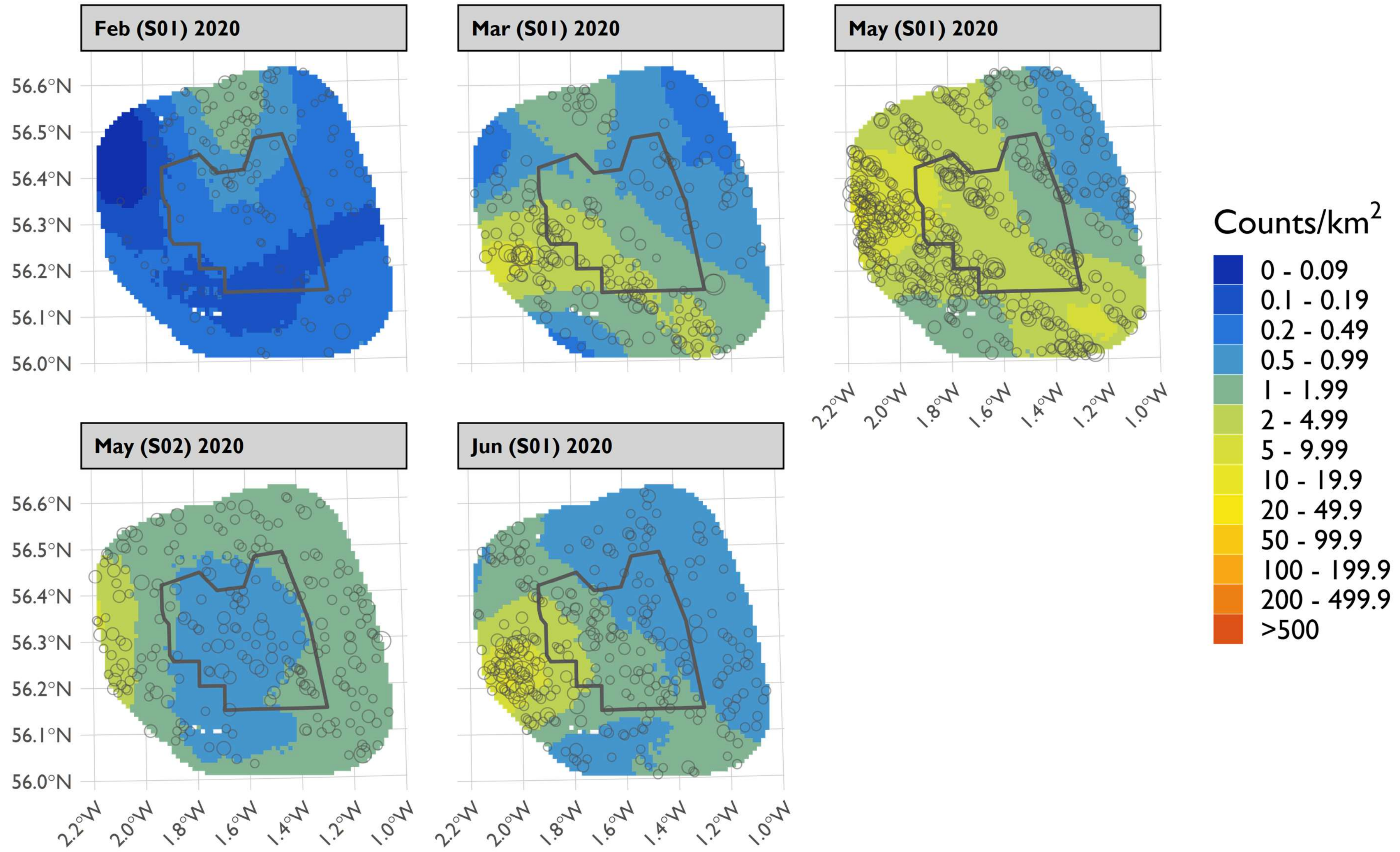

Figure 82 Upper confidence limit of density of puffins across the Offshore Ornithology Study Area between February and June 2020, modelled using MRSea

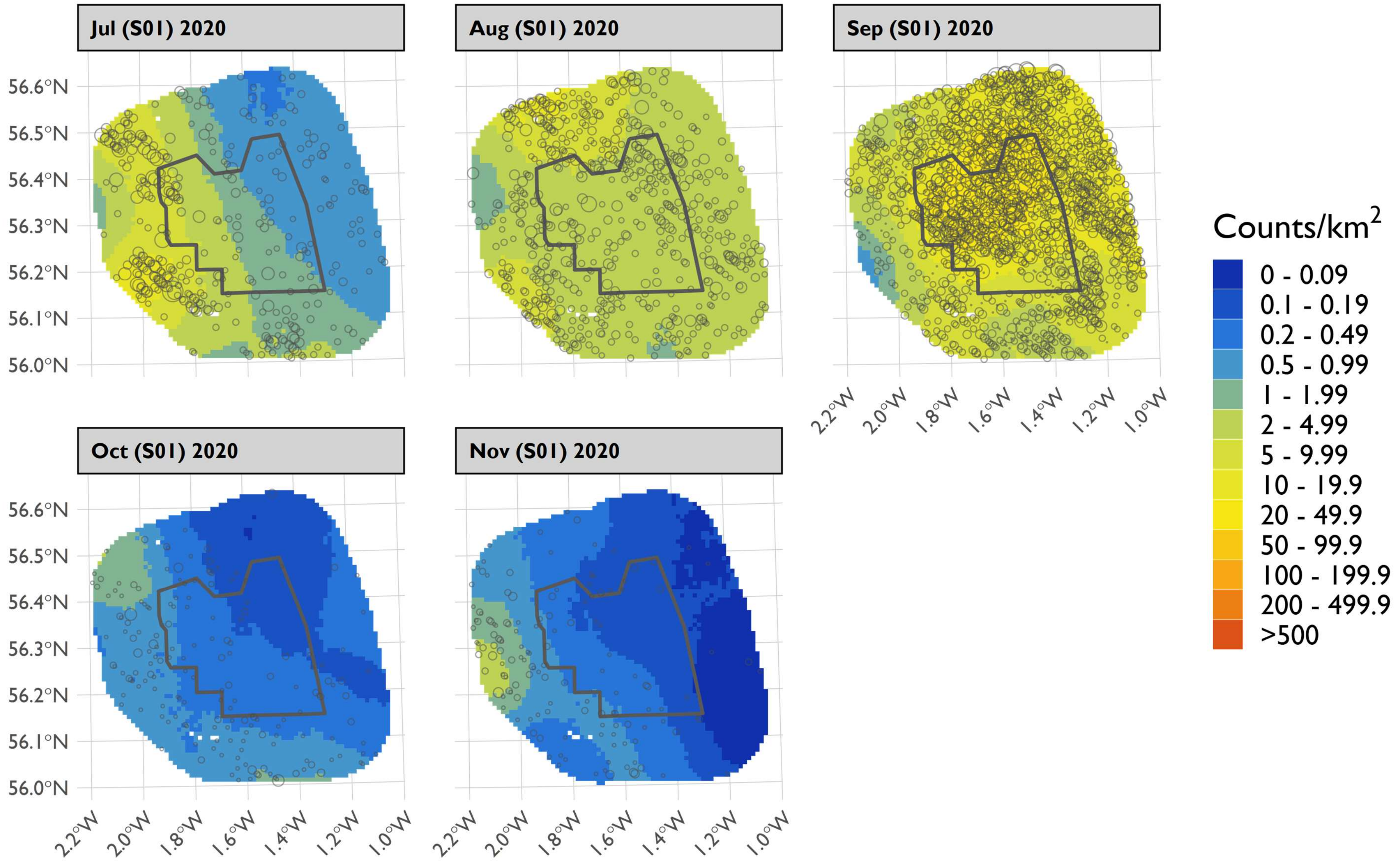

Figure 83 **Upper confidence limit of density of puffins across the Offshore Ornithology Study Area between July and November 2020, modelled using MRSea**

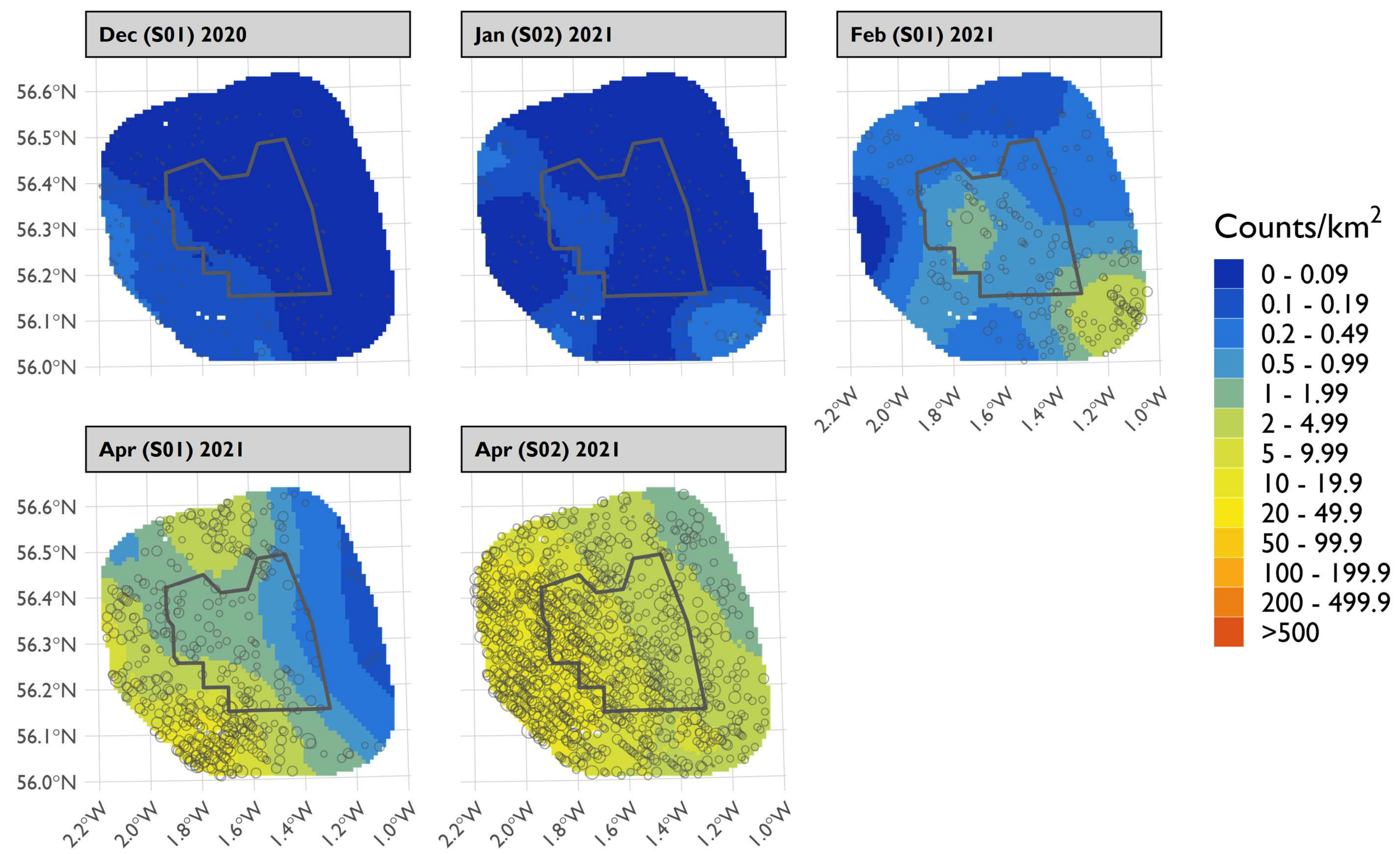

Figure 84 Upper confidence limit of density of puffins across the Offshore Ornithology Study Area between December 2020 and April S02 2021, modelled using MRSea

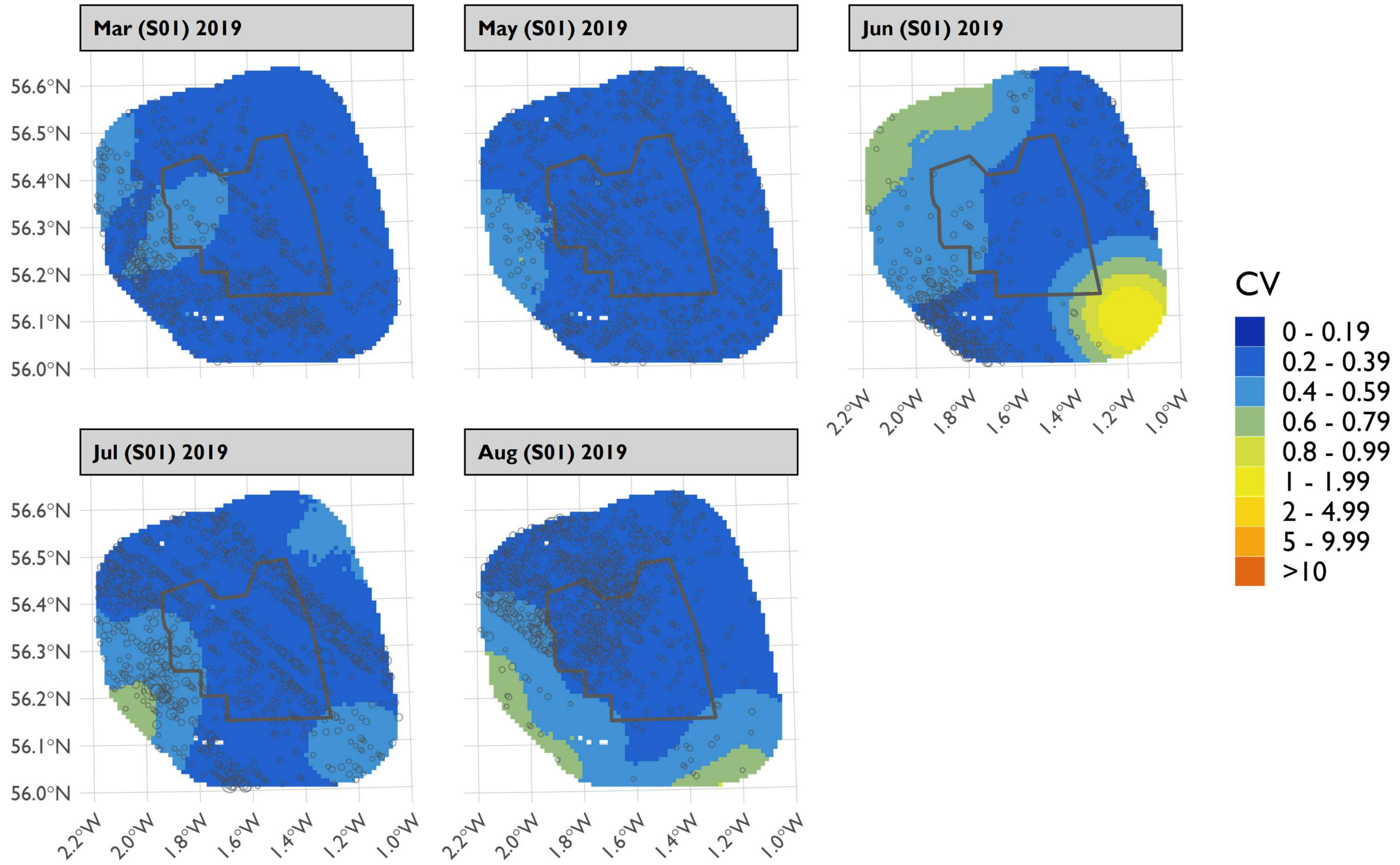

Figure 85 **Spatial coefficient of variation of predicted puffin densities from MRSea across the Offshore Ornithology Study Area between March and August 2019**

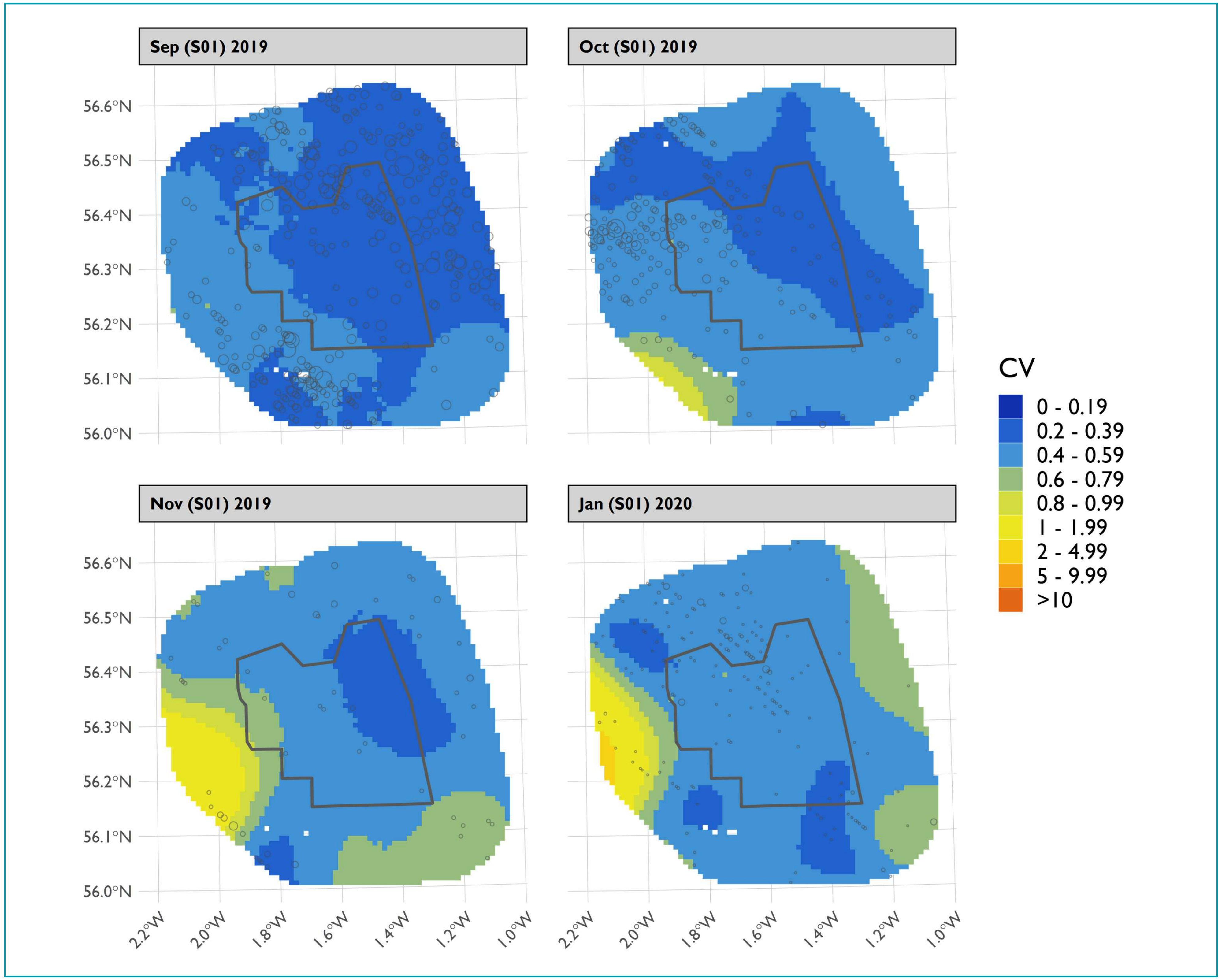

Figure 86 **Spatial coefficient of variation of predicted puffin densities from MRSea across the Offshore Ornithology Study Area between September 2019 and January 2020**

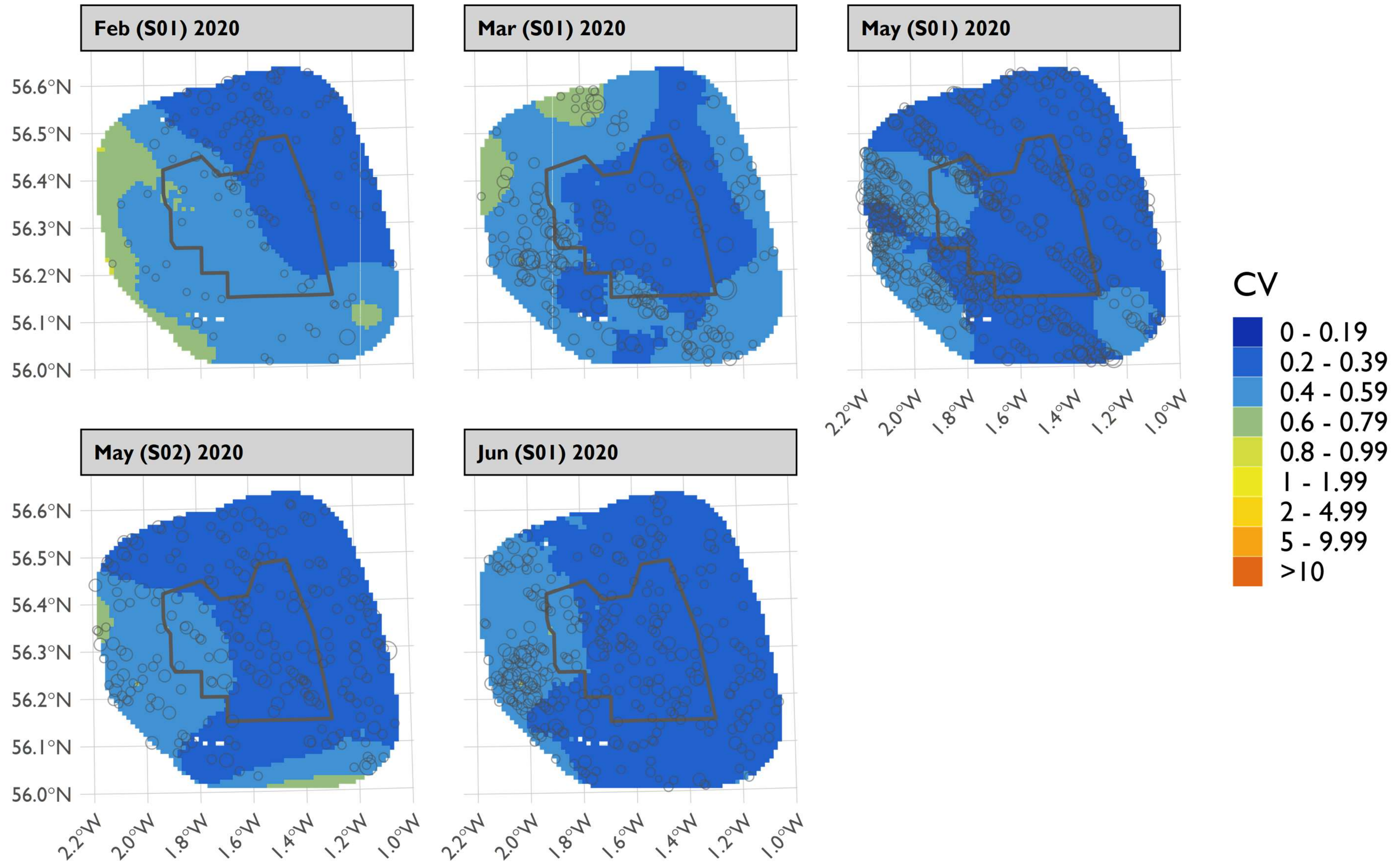

Figure 87 **Spatial coefficient of variation of predicted puffin densities from MRSea across the Offshore Ornithology Study Area between February and June 2020**

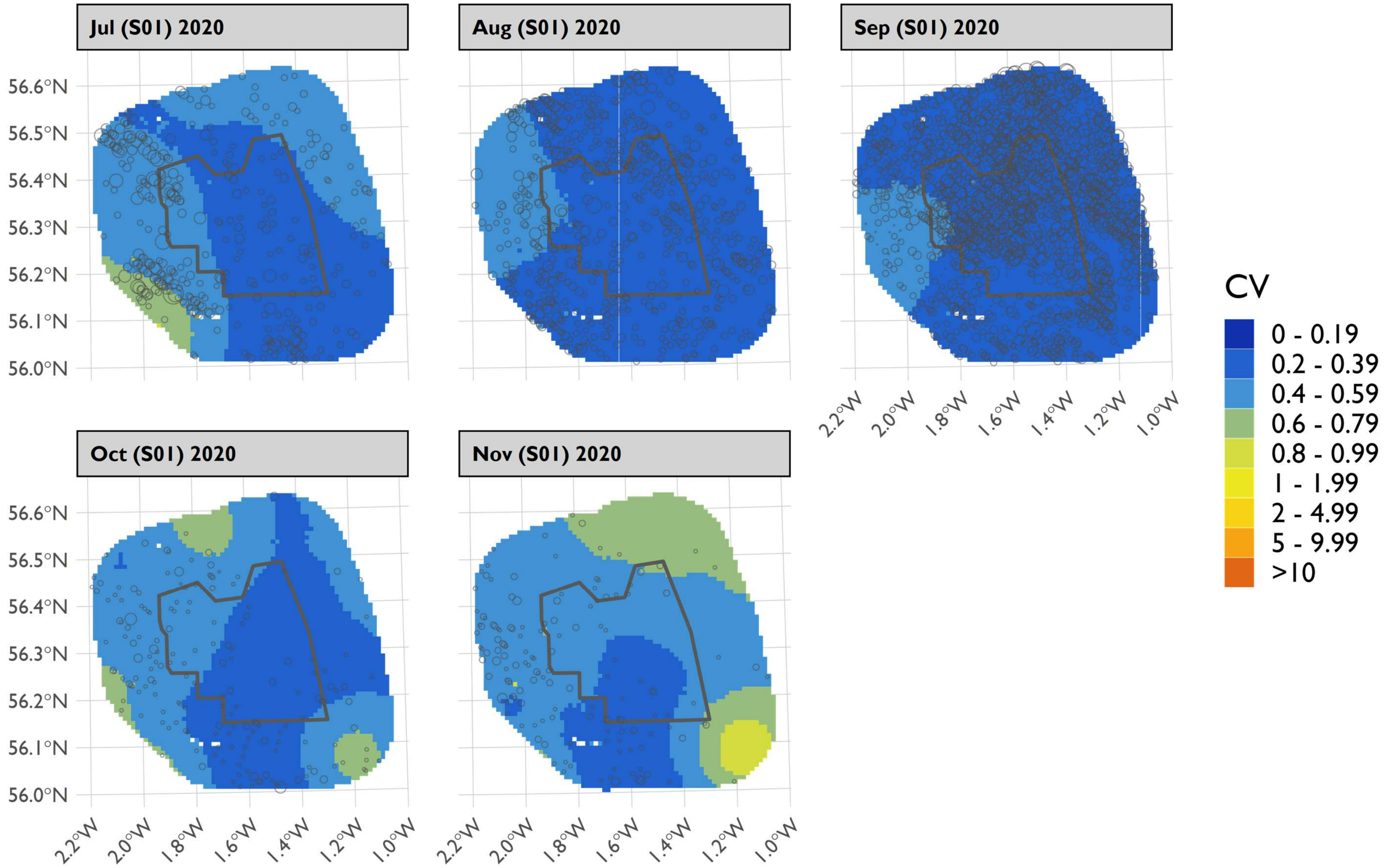

Figure 88 **Spatial coefficient of variation of predicted puffin densities from MRSea across the Offshore Ornithology Study Area between July and November 2020**

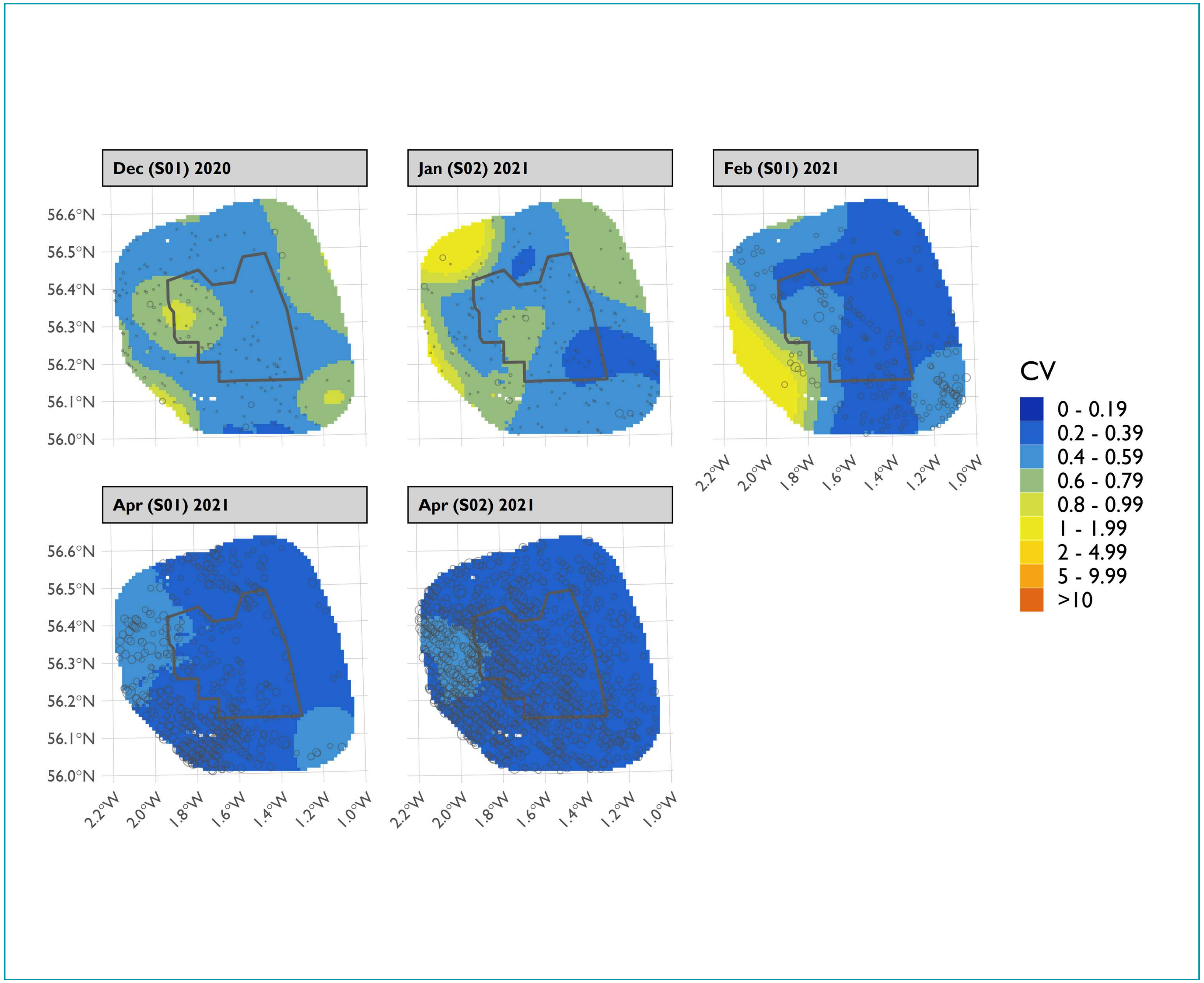

Figure 89 **Spatial coefficient of variation of predicted puffin densities from MRSea across the the Offshore Ornithology Study Area between December 2020 and August S02 2021**

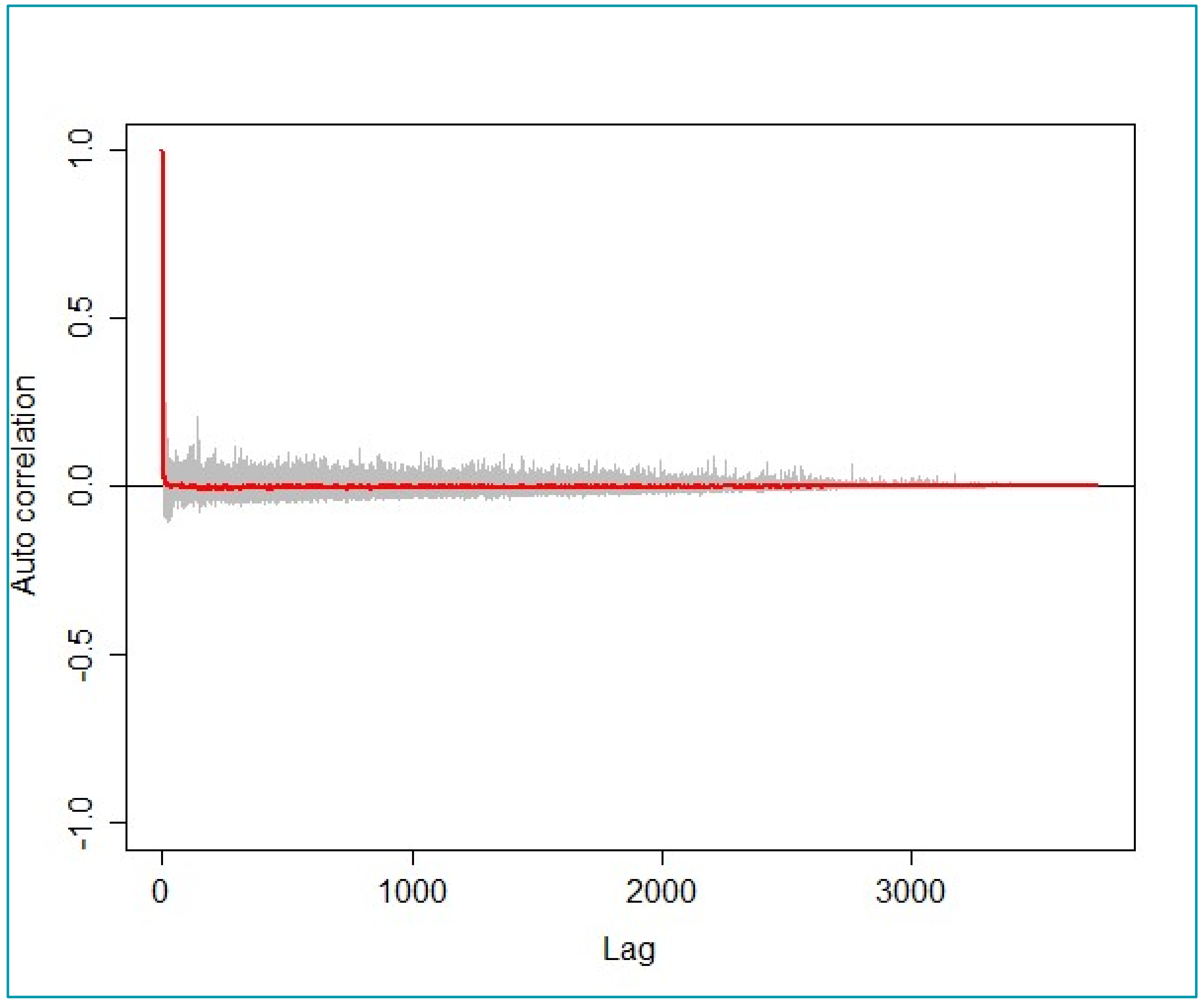

Figure 90 Autocorrelation test for puffin density surface models when using transect as a blocking feature in MRSea showing no significant correlation. A Runs test on the data prior to using transect as a blocking feature gave a p-value of << 0.0001 (i.e., that the data were significantly autocorrelated when not using a blocking feature)

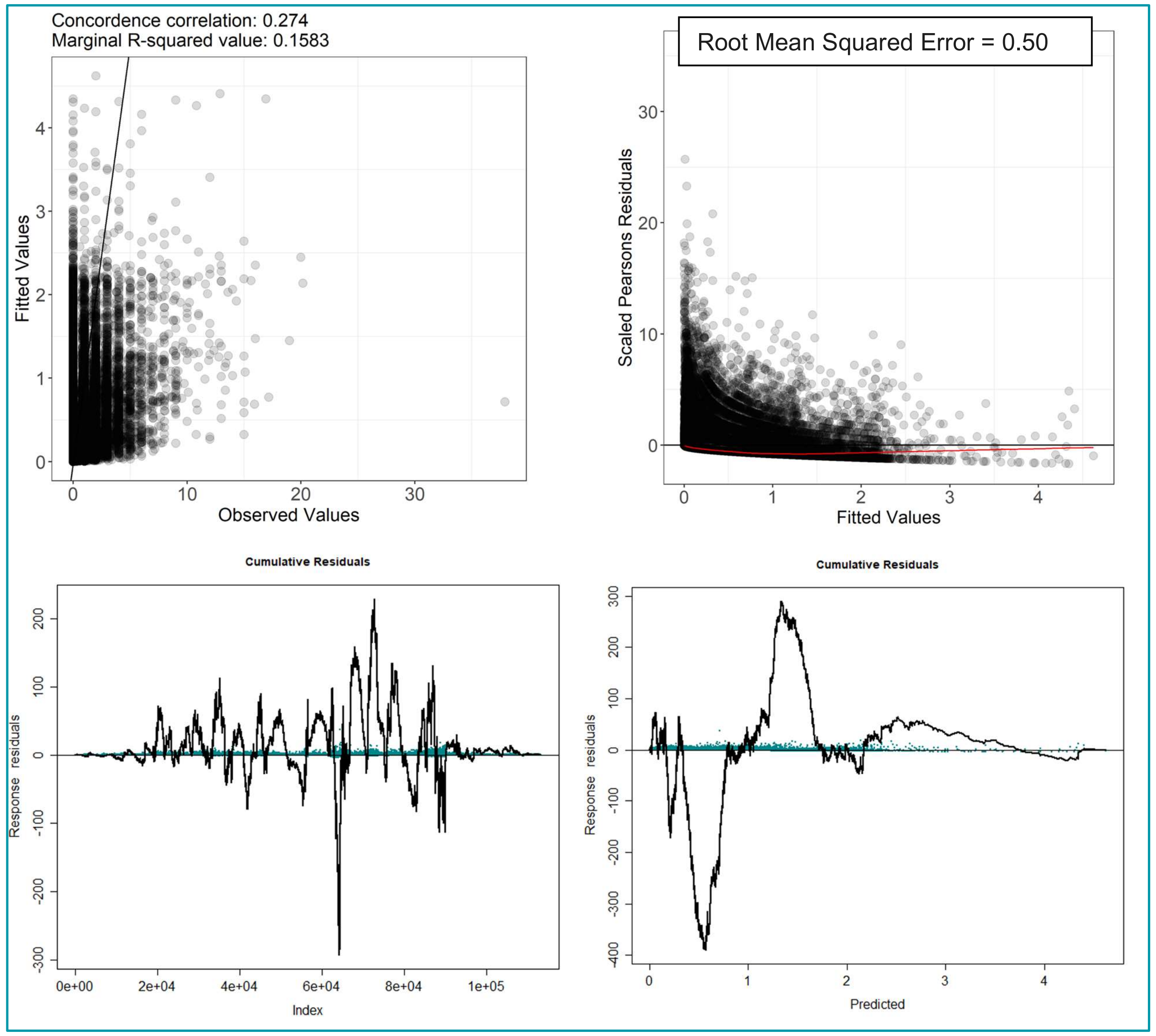

Figure 91 Fitted (MRSea predictions) versus observed counts of puffin (top left), and residual plots from MRSea

Table 13 ANOVA results from the best MRSea model for puffin as selected by cross-validation

Variable	Degrees of Freedom	Chi-square	P value
Sediment type	2	0.8	<< 0.001
Bathymetry	3	95.4	<< 0.001
SST gradient	1	37.5	<< 0.001
Sandeel density	3	15.2	0.002
X/Y (location)	4	-	<< 0.001

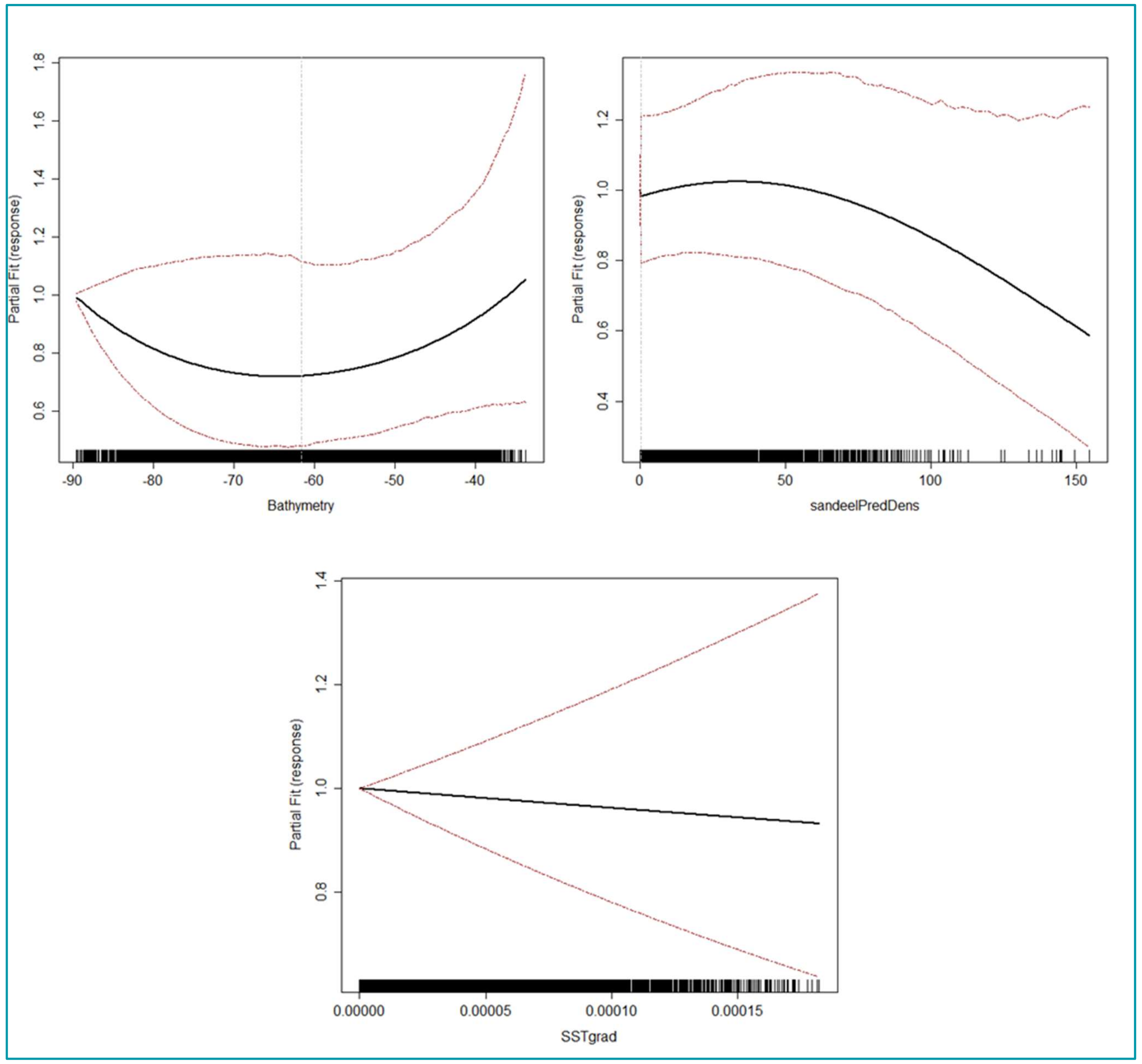

Figure 92 **Partial dependence plots for significant variables for puffin from MRSea models**

1.3.6. GANNET

39. The highest densities calculated using MRSea for the Development Array and Offshore Ornithology Study Area were recorded in December 2019 reaching peaks of 2.75E+49 birds/km² (95CI 0.00 – 6.51E+20) 5.48E+55 birds/km² (95CI 0.01 – 5.06E+28) respectively (Table 14 and Table 15). This equated to peak population estimates of 2.78E+52 birds (95CI 1 – 6.58E+23) and 2.18E+59 birds (95CI 41 – 2.01E+32). It should be noted however that these results are driven by MRSea predictions that tend towards infinity in areas that were poorly covered by aerial surveys. Ignoring these clearly spurious results gives peak densities in July 2019 and July 2020 with estimates of 3.61 (95CI 3.11 – 4.22) and 3.53 (95CI 3.03 – 4.12) birds/km² respectively.

40. Distribution maps created using model-based analyses (MRSea) indicate higher densities for the species within the survey area during the breeding season (Figure 93 to Figure 97). Distribution varied between months, with gannets selecting the north and west of the survey area during the breeding season (e.g., between August and September in both years). Generally, in both Year 1 and Year 2, it appeared that high densities of gannets were more widespread throughout the survey area during the breeding season compared to the post-breeding and return migration periods, such as in November 2019 and March 2020 specifically.

41. Broadly, model fit was quite poor for Gannet with a marginal R squared value of 0.0595 and root mean squared error of 1.03. Furthermore, the cumulative residuals in the model showed that there was overall a poor relationship between predicted and observed values between predicted values of ~1.75 to 3.75 birds/km² (Figure 114).

Table 14 Monthly density and population estimates of gannet in the Development Array derived from MRSea

Survey	Density Estimate (n/km²)	SD of Density	Lower 95% CL of Density	Upper 95% CL of Density	Population Estimate (number)	SD of Population	Lower 95% CL of Population	Upper 95% CL of Population	CV (%)
Mar-19	0.25	0.06	0.16	0.38	254	56	157	381	22.05%
May-19	0.65	0.1	0.47	0.88	655	105	479	886	16.03%
Jun-19	1.31	0.16	1.03	1.61	1321	160	1038	1625	12.11%
Jul-19	3.61	0.28	3.11	4.22	3650	280	3138	4259	7.67%
Aug-19	3.23	0.27	2.73	3.78	3264	277	2759	3814	8.49%
Sep-19	3.01	0.22	2.63	3.49	3040	223	2657	3528	7.34%
Oct-19	0.67	0.12	0.47	0.93	672	126	475	936	18.75%
Nov-19	0.15	0.03	0.1	0.23	150	33	97	229	22%
Dec-19	2.74773E+49	6.1441E+50	0	6.50861E+20	2.77583E+52	6.20695E+53	1	6.57519E+23	2236.07%
Jan-20	0.02	0.09	0	0.06	20	91	4	62	455%
Feb-20	1.00676E+18	1.66695E+19	0	17223.64	1.01706E+21	1.684E+22	4	17399814	1655.76%
Mar-20	0.21	0.05	0.14	0.33	217	52	141	330	23.96%
May S01 20	0.56	0.09	0.4	0.75	561	93	401	757	16.58%
May S02 20	1.17	0.18	0.88	1.6	1187	184	889	1613	15.5%
Jun-20	1.2	0.17	0.93	1.57	1214	167	942	1587	13.76%
Jul-20	3.53	0.28	3.03	4.12	3565	283	3058	4161	7.94%
Aug-20	1.51	0.21	1.15	1.96	1522	217	1165	1979	14.26%
Sep-20	1.79	0.2	1.43	2.22	1806	204	1444	2241	11.3%
Oct-20	0.6	0.08	0.47	0.76	608	79	473	771	12.99%
Nov-20	1.32	0.26	0.9	1.91	1333	258	908	1926	19.35%
Dec-20	0.13	0.06	0.05	0.27	136	60	54	271	44.12%
Jan-21	0.12	0.04	0.07	0.21	119	38	66	210	31.93%
Feb-21	0.11	0.07	0.03	0.29	110	75	31	297	68.18%
Apr S01 21	0.56	0.06	0.45	0.71	563	65	454	713	11.55%
Apr S02 21	1.61	0.56	0.83	2.94	1628	566	841	2974	34.77%

Table 15 **Monthly density and population estimates of gannet in the Offshore Ornithology Study Area derived from MRSea**

Survey	Density Estimate (n/km²)	SD of Density	Lower 95% CL of Density	Upper 95% CL of Density	Population Estimate (number)	SD of Population	Lower 95% CL of Population	Upper 95% CL of Population	CV (%)
Mar-19	0.23	0.04	0.17	0.31	896	145	662	1221	16.18%
May-19	0.74	0.07	0.61	0.89	2940	295	2415	3548	10.03%
Jun-19	1.36	0.12	1.15	1.62	5390	491	4557	6436	9.11%
Jul-19	3.12	0.13	2.87	3.38	12411	530	11395	13434	4.27%
Aug-19	4.1	0.31	3.54	4.77	16313	1243	14090	18976	7.62%
Sep-19	2.35	0.15	2.07	2.63	9323	579	8210	10456	6.21%
Oct-19	1.32	0.19	1.01	1.69	5264	742	4002	6736	14.1%
Nov-19	0.25	0.06	0.17	0.39	1000	225	674	1561	22.5%
Dec-19	5.48378E+55	1.22621E+57	0.01	5.05774E+28	2.17972E+59	4.874E+60	41	2.01037E+32	2236.07%
Jan-20	0.02	0.09	0	0.05	83	363	18	186	437.35%
Feb-20	2.89263E+37	6.46458E+38	0	5.15639E+11	1.14978E+41	2.56957E+42	7	2.04959E+15	2234.84%
Mar-20	0.21	0.04	0.16	0.29	853	140	637	1144	16.41%
May S01 20	0.61	0.07	0.49	0.75	2420	264	1953	2981	10.91%
May S02 20	1.09	0.12	0.89	1.38	4336	481	3544	5482	11.09%
Jun-20	1.29	0.16	1.05	1.67	5133	641	4172	6626	12.49%
Jul-20	3.15	0.16	2.84	3.49	12531	643	11282	13870	5.13%
Aug-20	1.91	0.16	1.62	2.24	7597	648	6439	8909	8.53%
Sep-20	1.8	0.16	1.5	2.13	7137	630	5977	8478	8.83%
Oct-20	0.99	0.1	0.82	1.2	3944	378	3259	4756	9.58%
Nov-20	1.2	0.14	0.96	1.51	4789	552	3796	5985	11.53%
Dec-20	0.37	0.07	0.25	0.55	1488	294	1010	2173	19.76%
Jan-21	0.1	0.02	0.06	0.16	403	97	256	652	24.07%
Feb-21	0.07	0.03	0.03	0.14	277	113	139	551	40.79%
Apr S01 21	0.53	0.05	0.45	0.63	2098	182	1792	2485	8.67%
Apr S02 21	1.41	0.41	0.81	2.37	5585	1640	3208	9405	29.36%

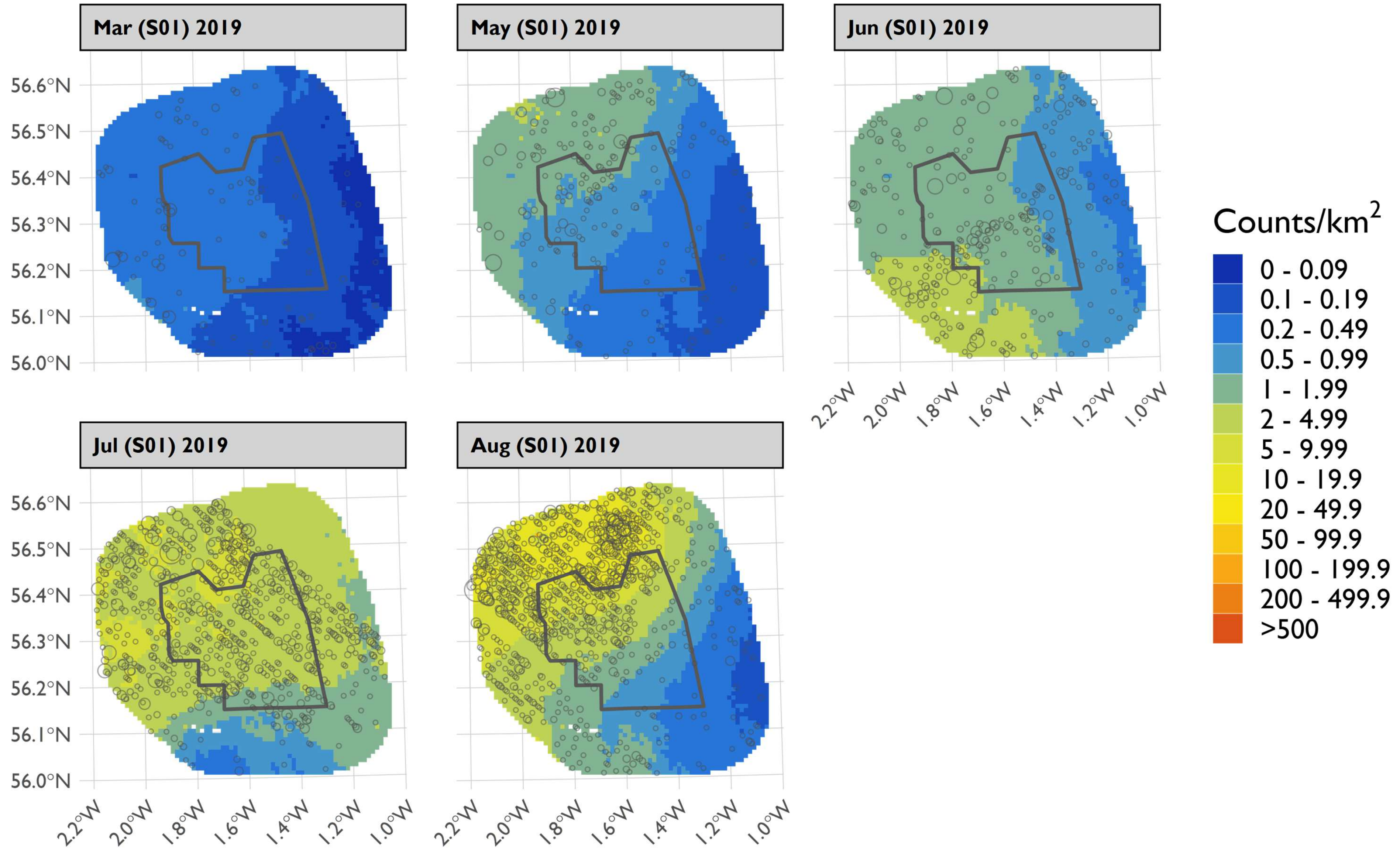

Figure 93 Mean density of gannets across the Offshore Ornithology Study Area between March and August 2019, modelled using MRSea

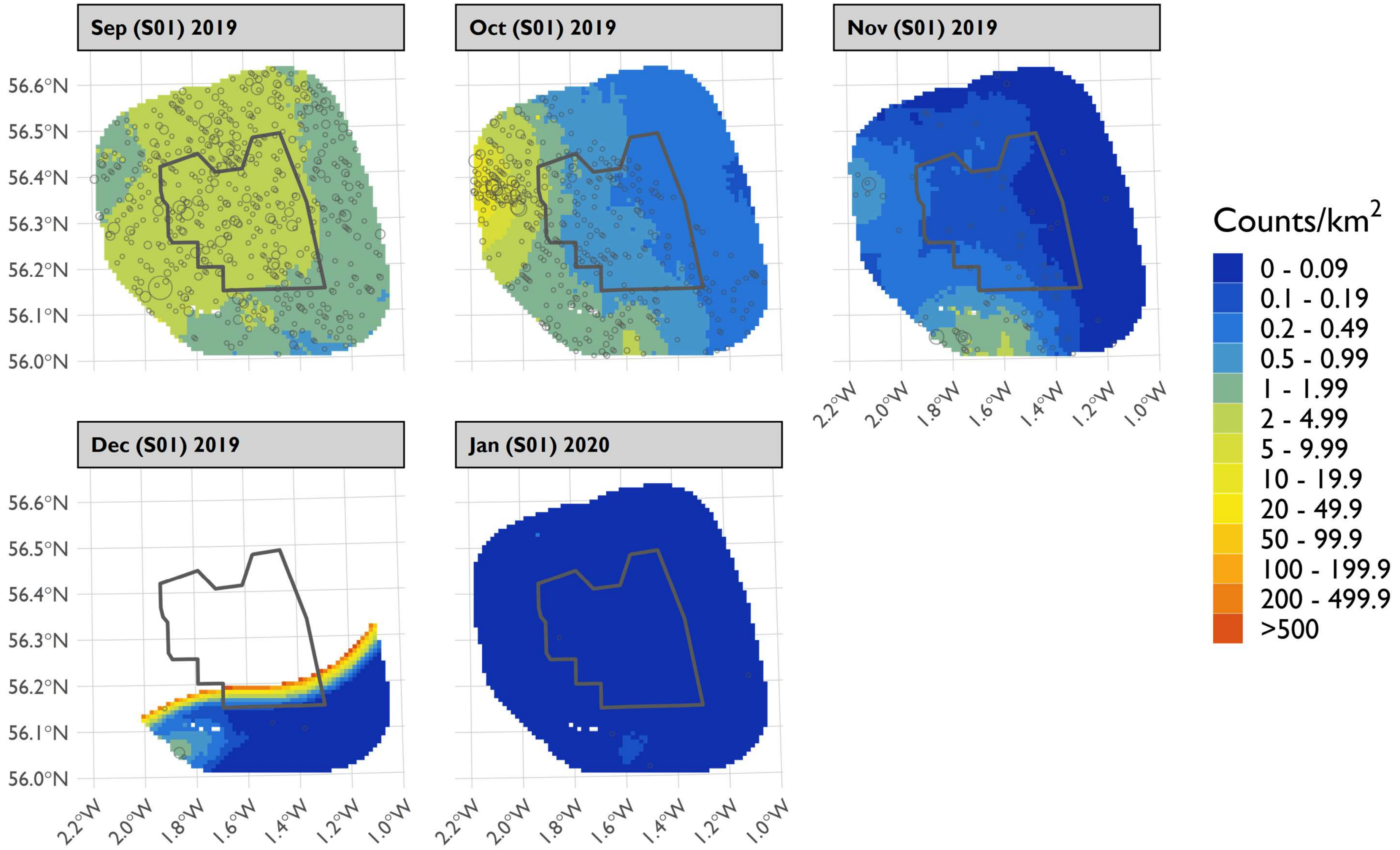

Figure 94 **Mean density of gannets across the Offshore Ornithology Study Area between September 2019 and January 2020, modelled using MRSea**

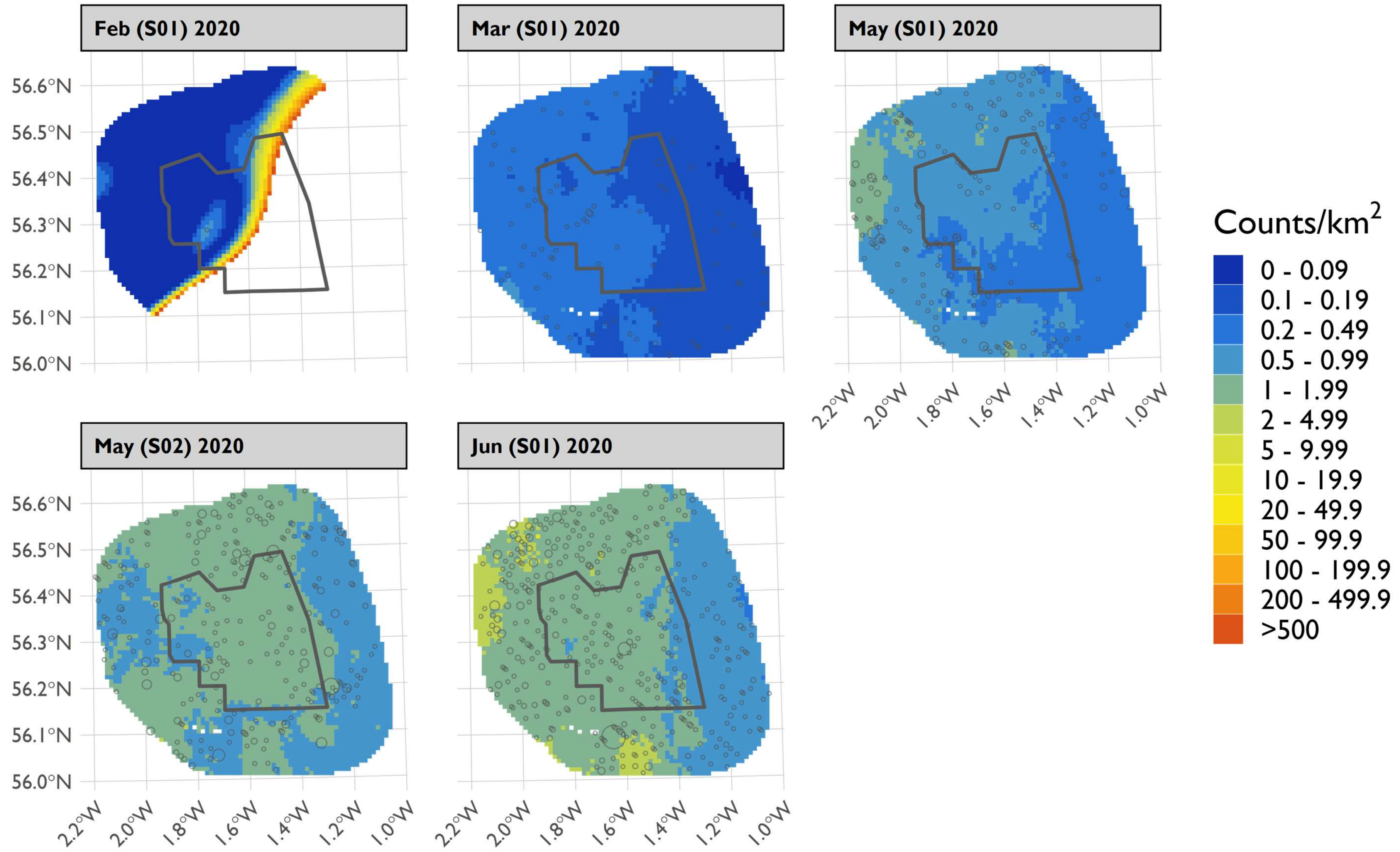

Figure 95 Mean density of gannets across the Offshore Ornithology Study Area between February and June 2020, modelled using MRSea

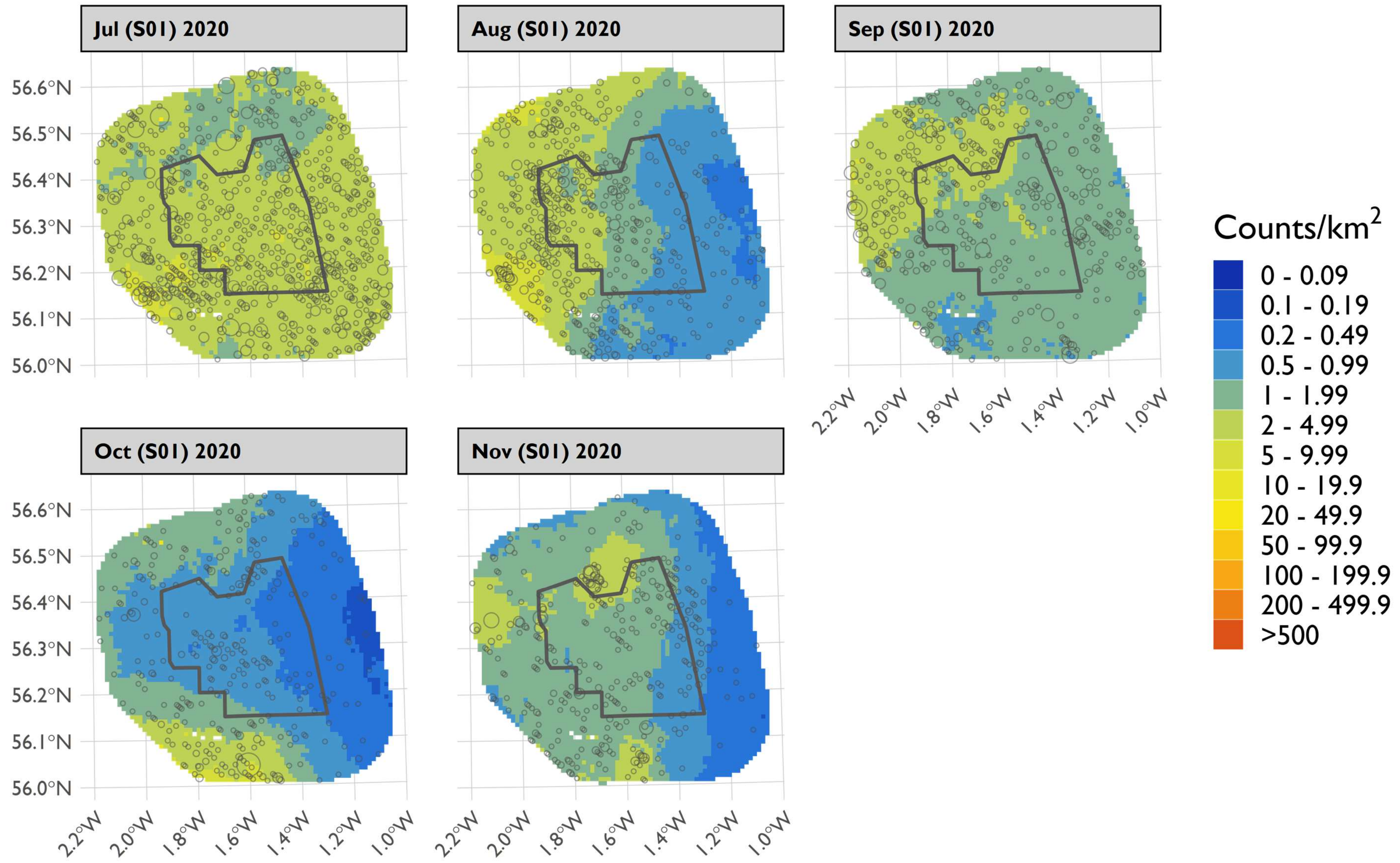

Figure 96 **Mean density of gannets across the Offshore Ornithology Study Area between July and November 2020, modelled using MRSea**

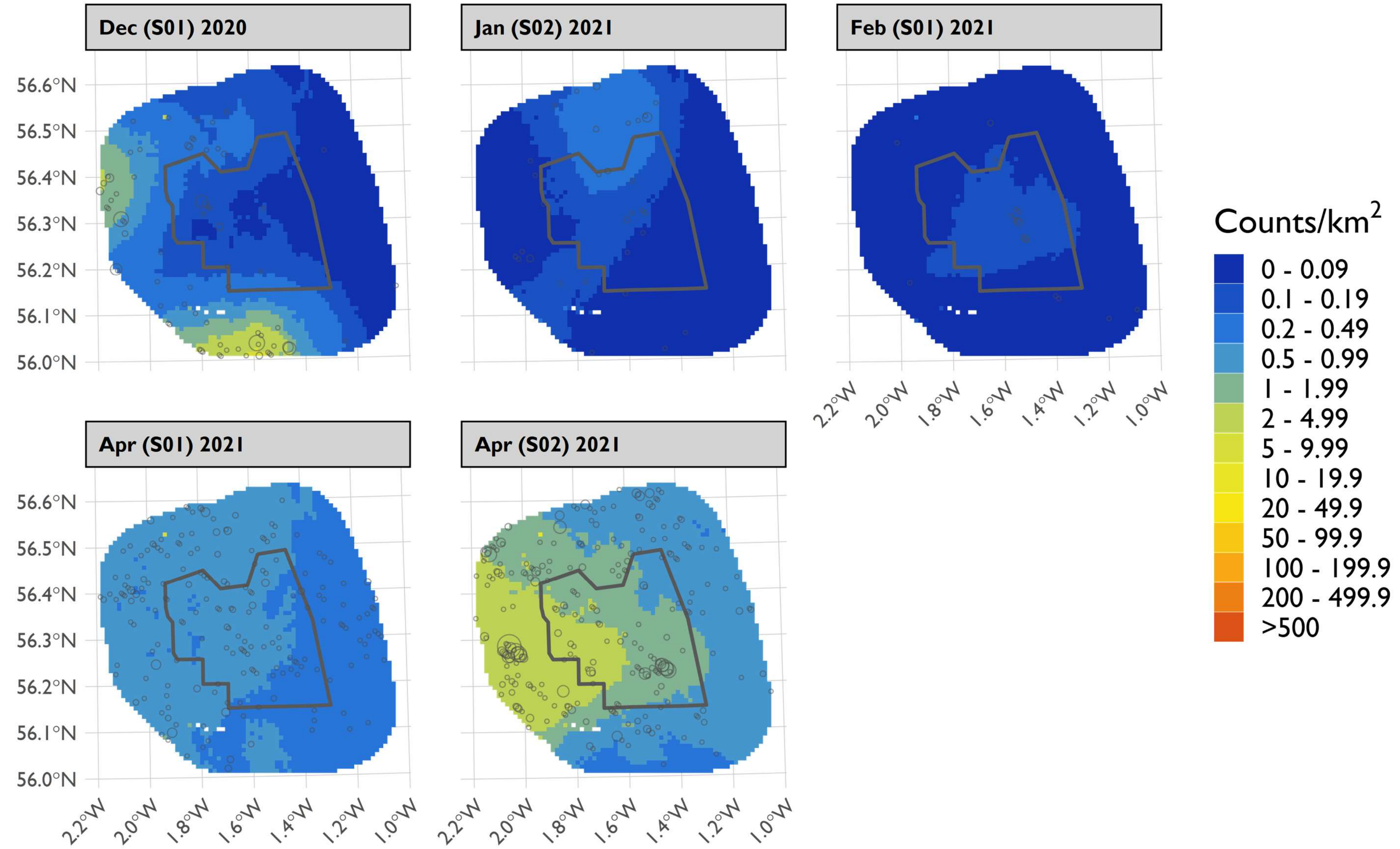

Figure 97 Mean density of gannets across the Offshore Ornithology Study Area between December 2020 and April S02 2021, modelled using MRSea

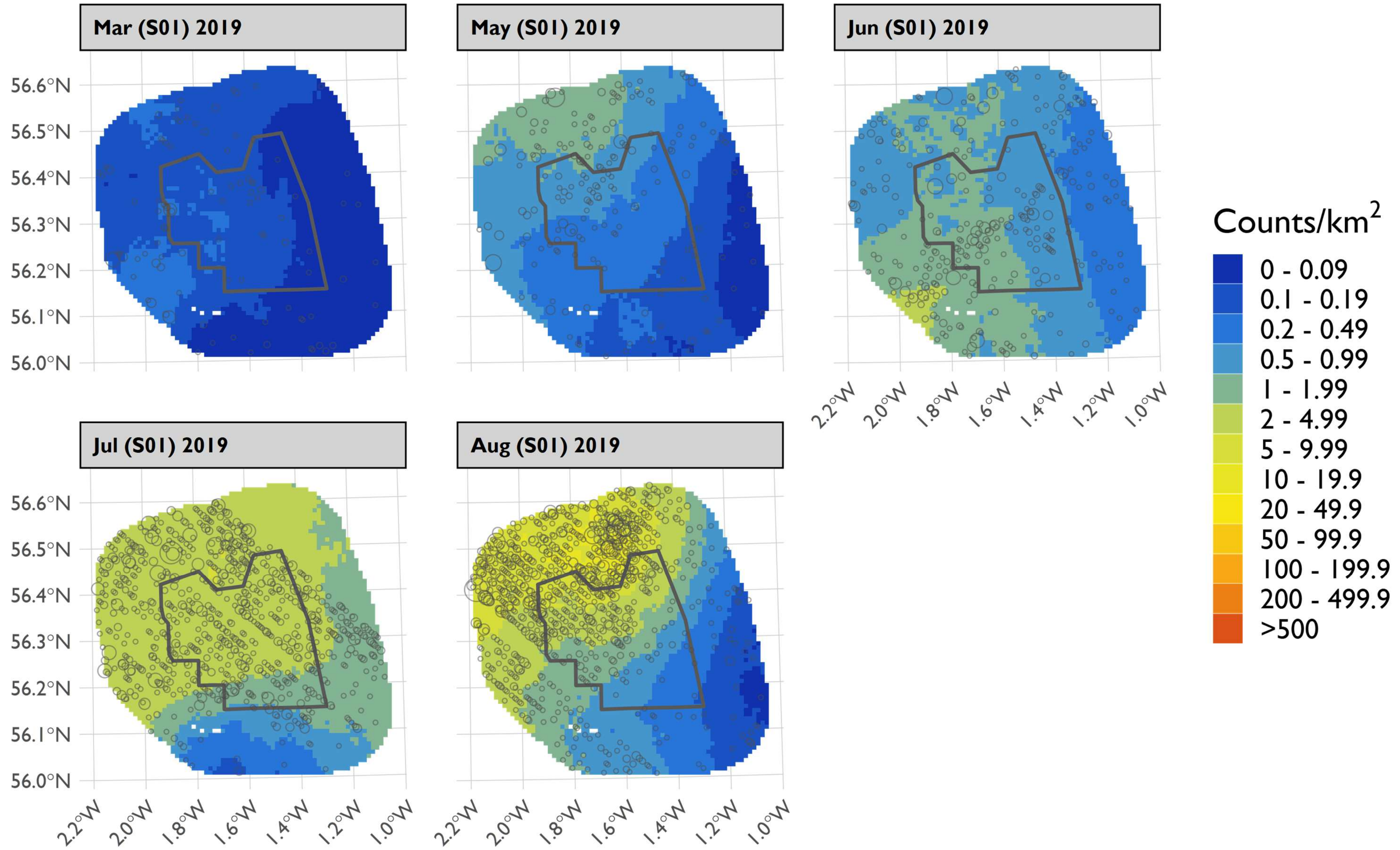

Figure 98 Lower confidence limit of density of gannets across the Offshore Ornithology Study Area between March and August 2019, modelled using MRSea

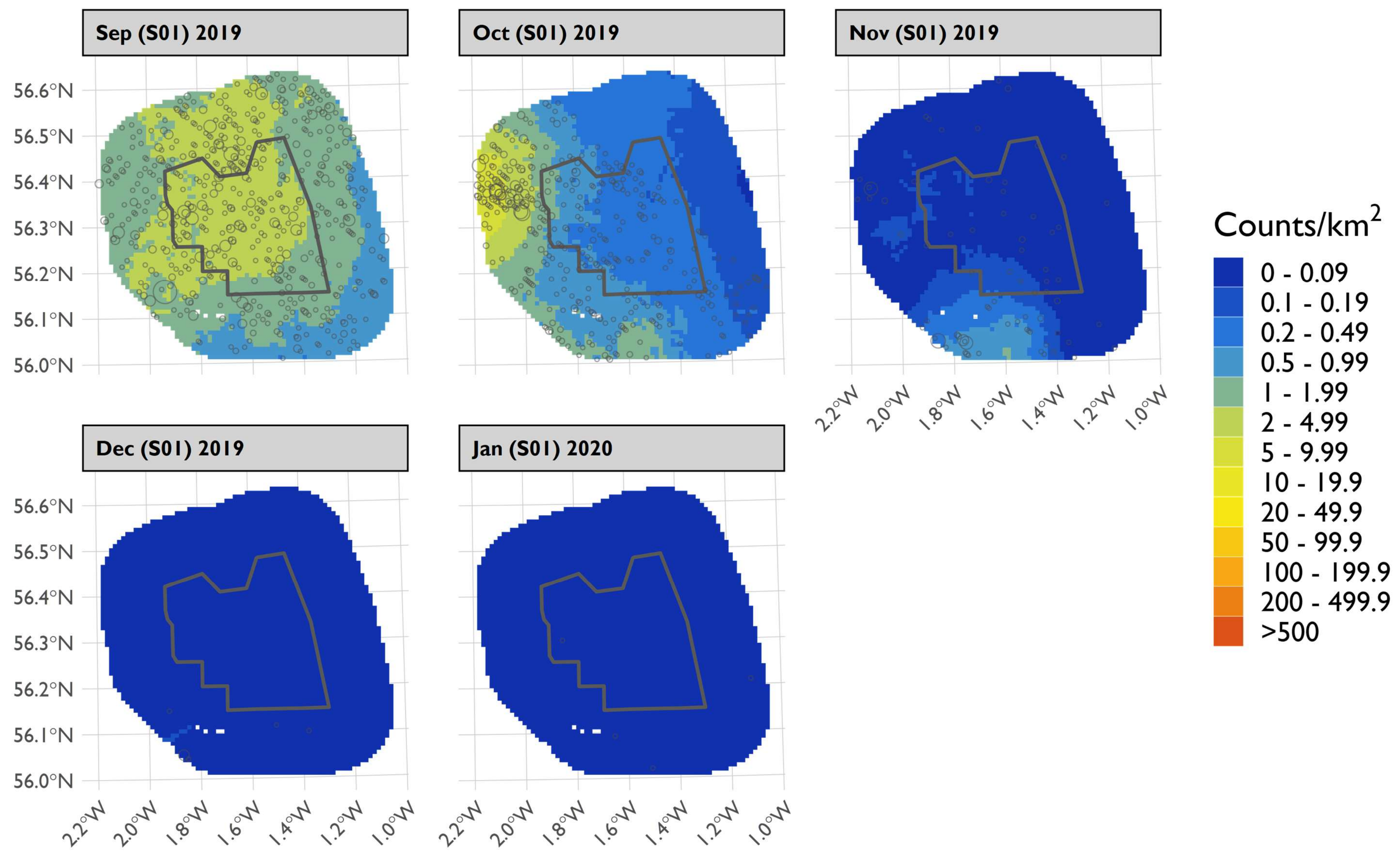

Figure 99 Lower confidence limit of density of gannets across the Offshore Ornithology Study Area between September 2019 and January 2020, modelled using MRSea

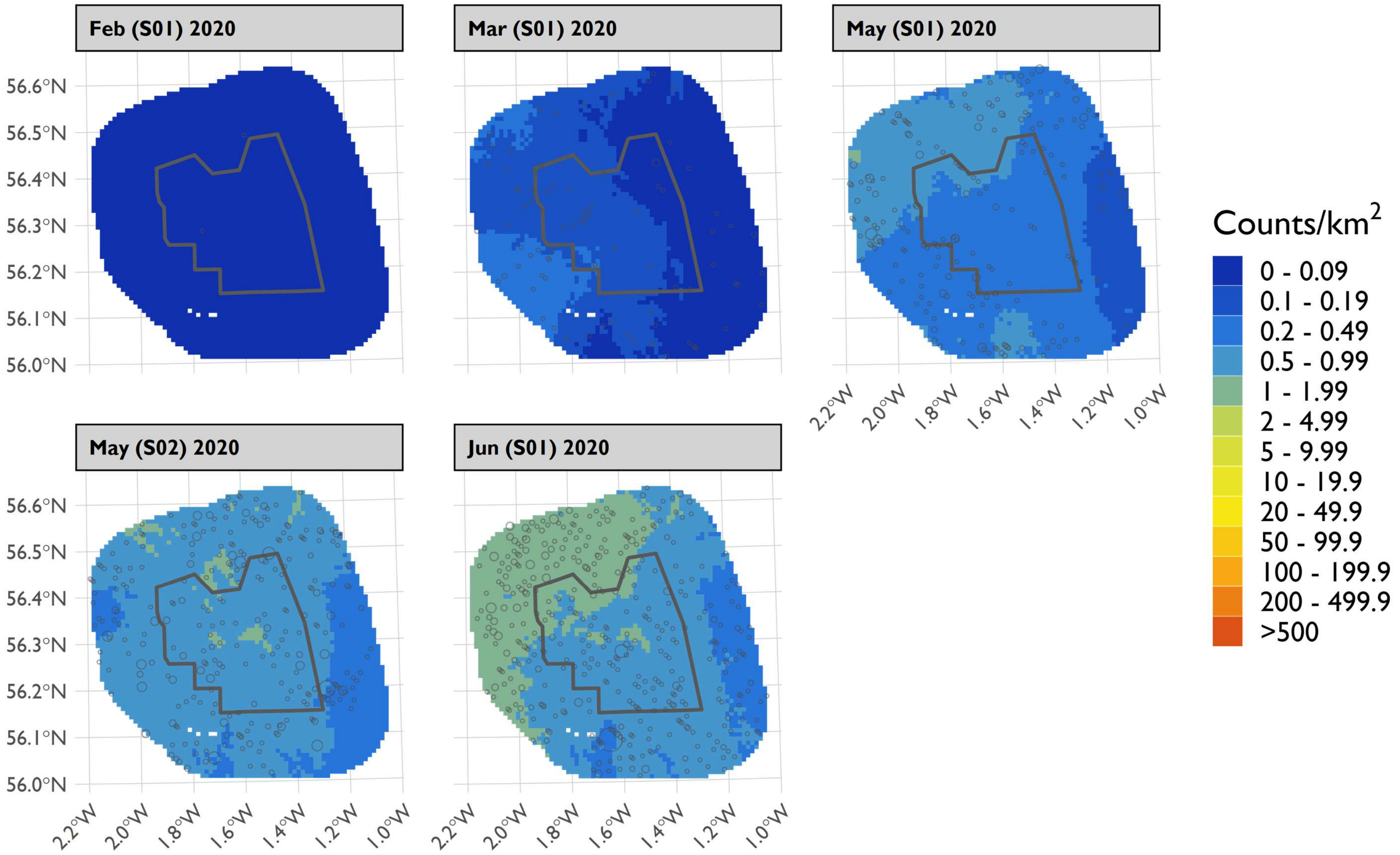

Figure 100 Lower confidence limit of density of gannets across the Offshore Ornithology Study Area between February and June 2020, modelled using MRSea

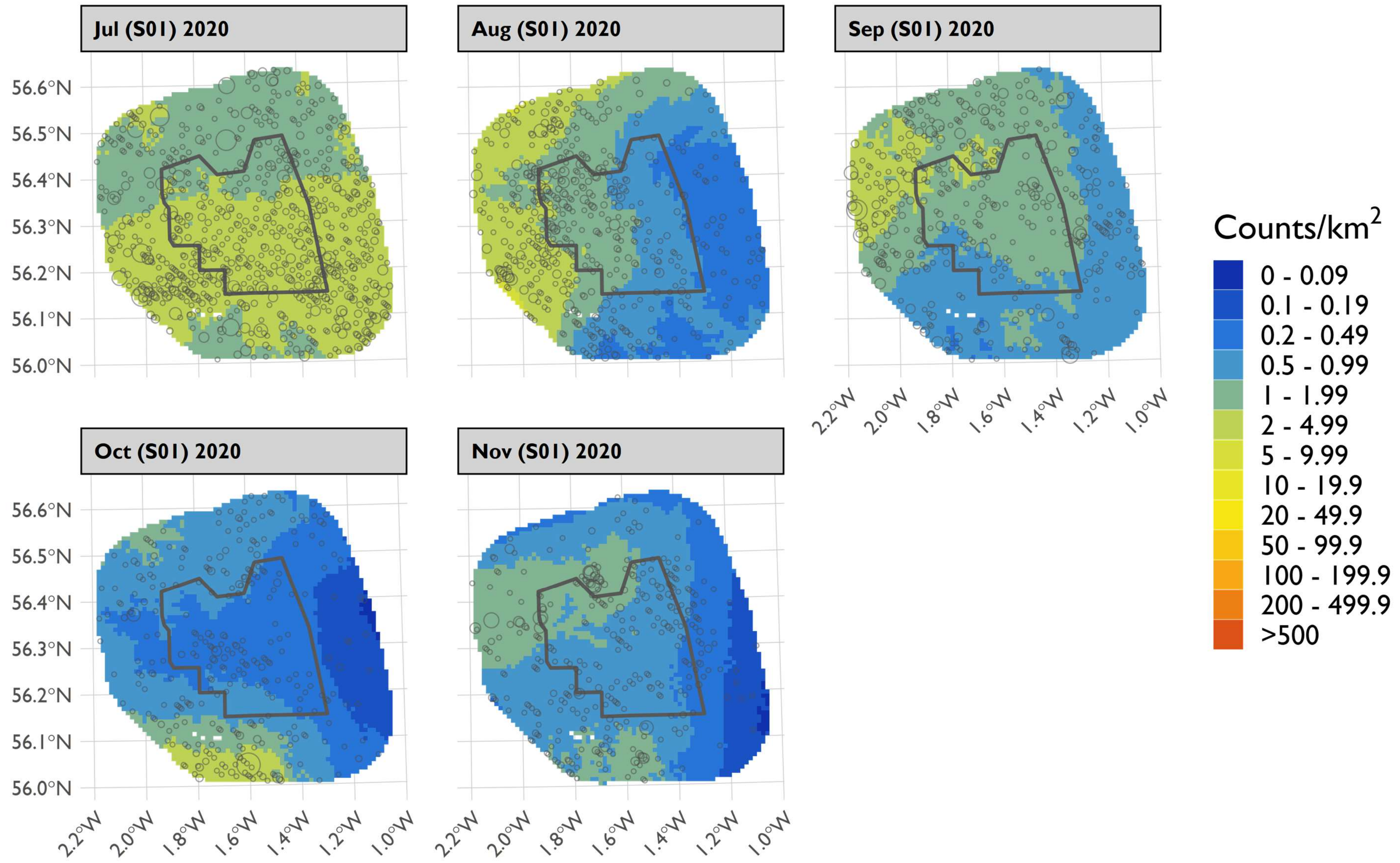

Figure 101 Lower confidence limit of density of gannets across the Offshore Ornithology Study Area between July and November 2020, modelled using MRSea

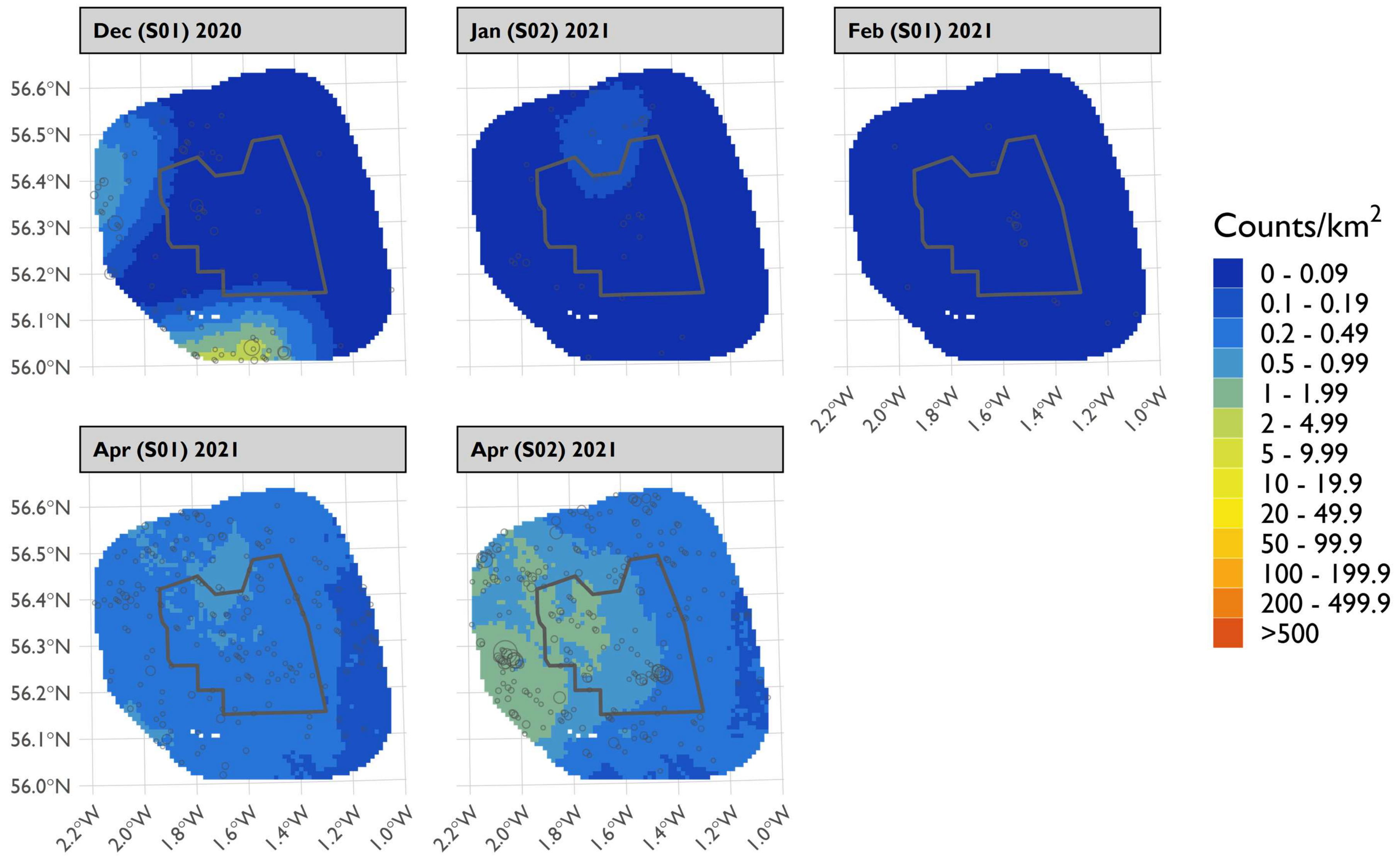

Figure 102 Lower confidence limit of density of gannets across the Offshore Ornithology Study Area between December 2020 and April S02 2021, modelled using MRSea

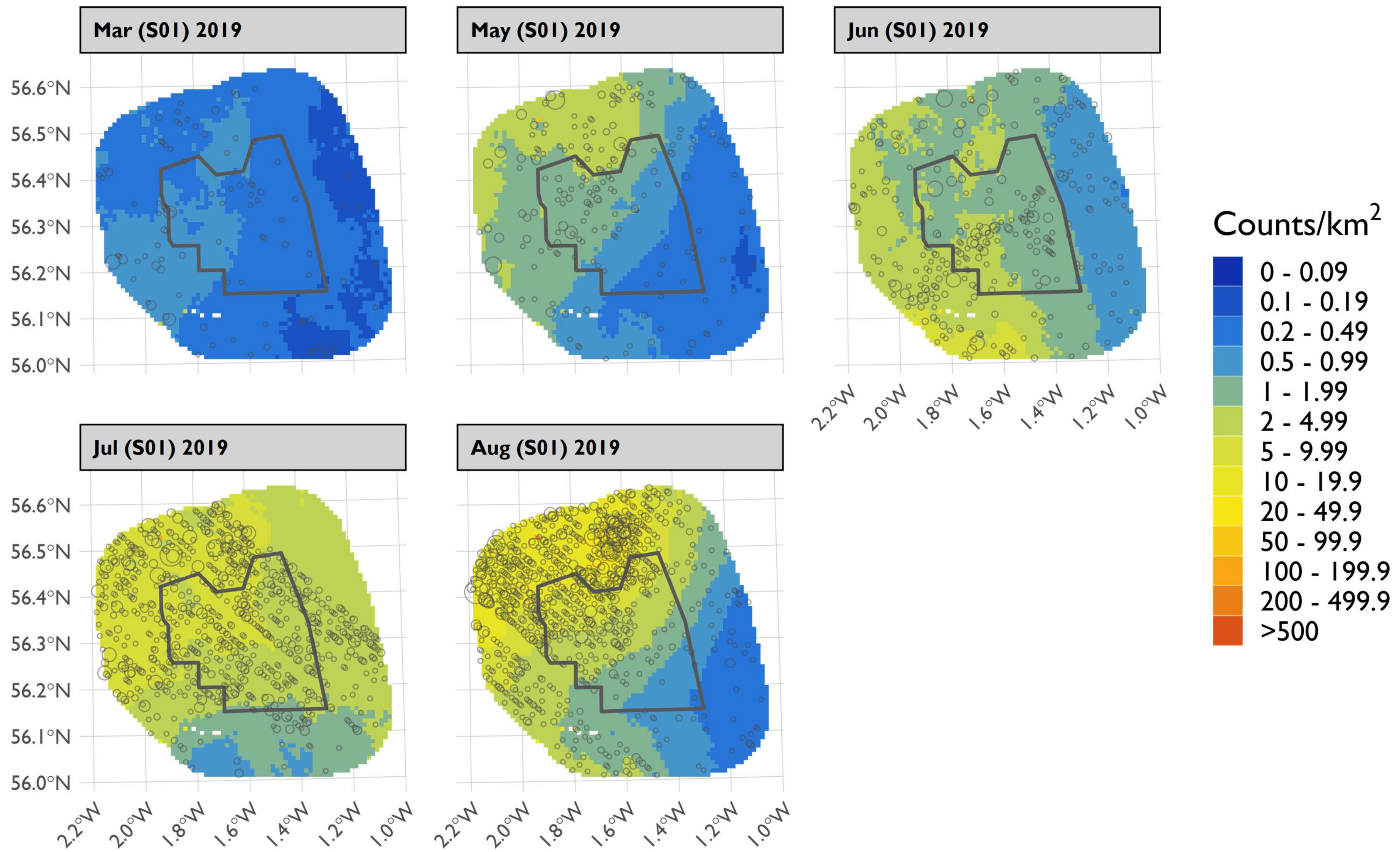

Figure 103 Upper confidence limit of density of gannets across the Offshore Ornithology Study Area between March and August 2019, modelled using MRSea

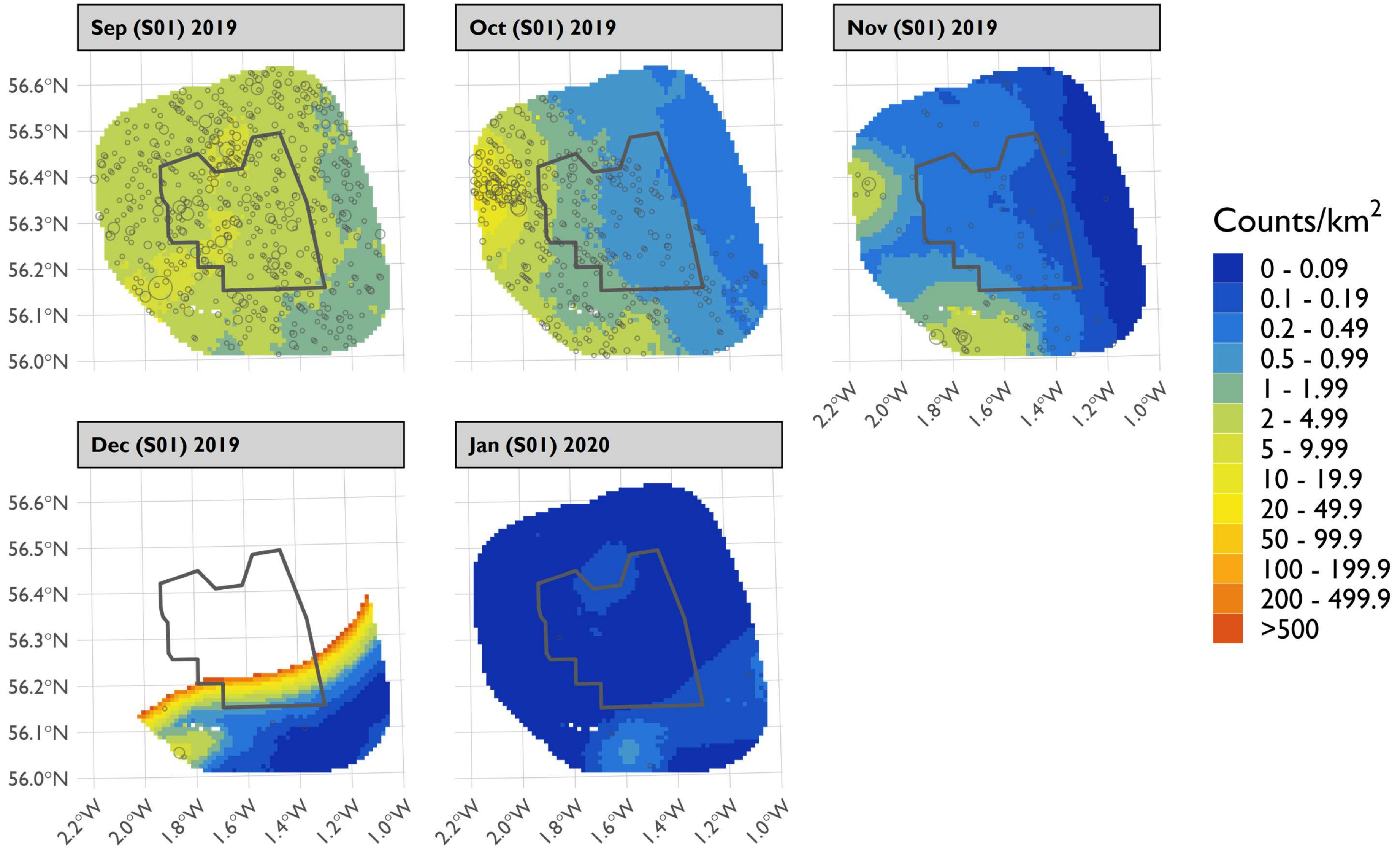

Figure 104 **Upper confidence limit of density of gannets across the Offshore Ornithology Study Area between September 2019 and January 2020, modelled using MRSea**

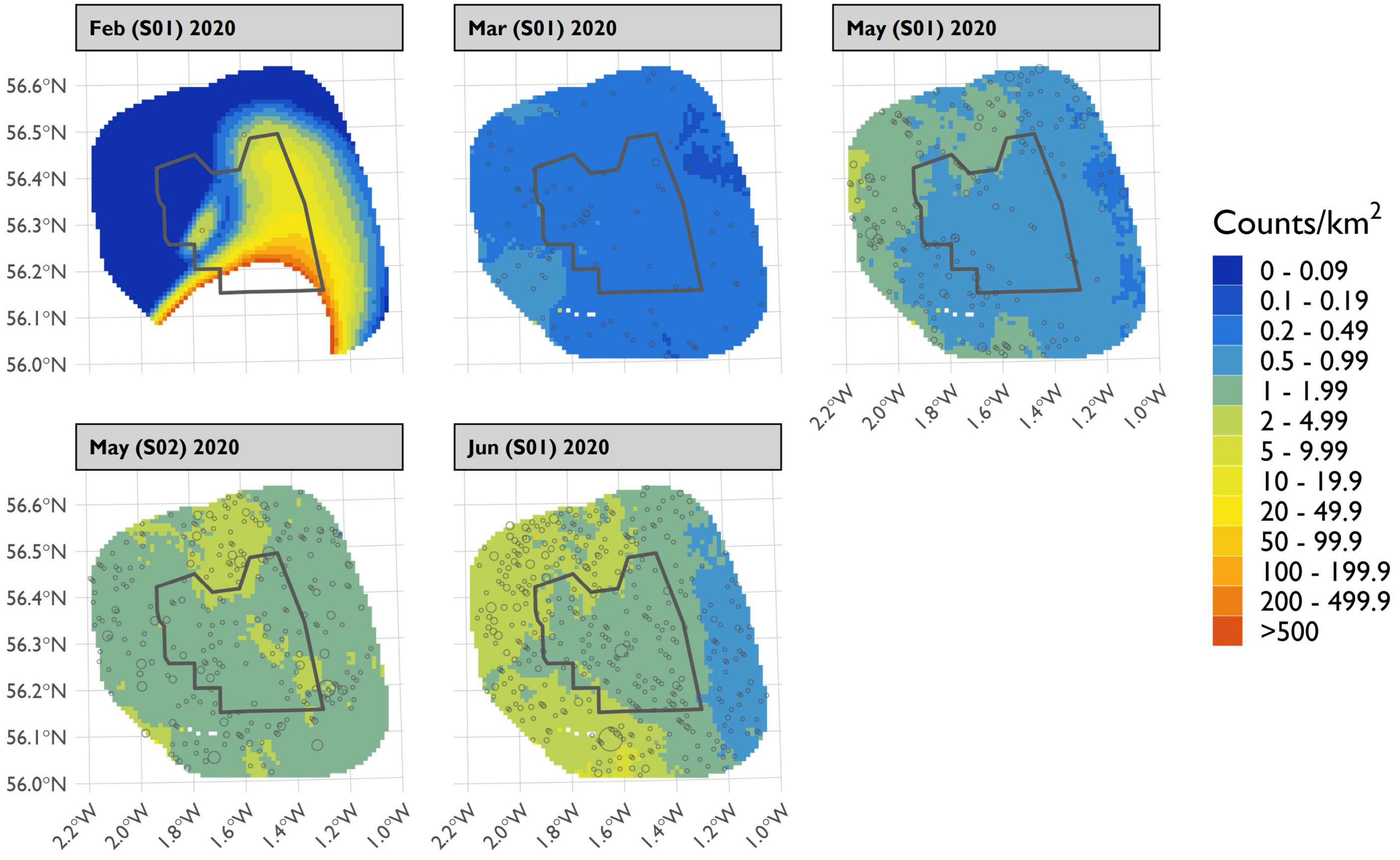

Figure 105 Upper confidence limit of density of gannets across the Offshore Ornithology Study Area between February and June 2020, modelled using MRSea

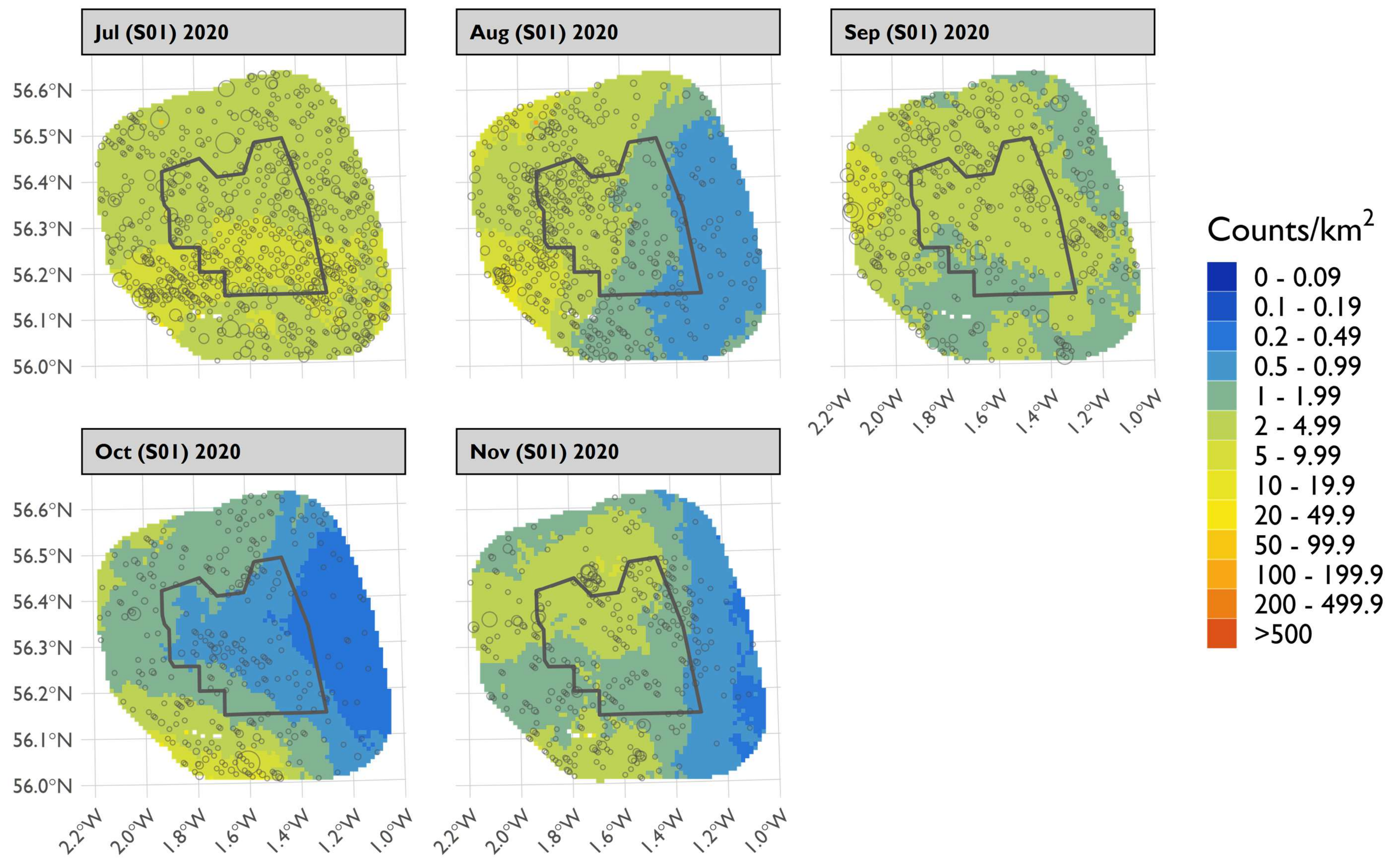

Figure 106 Upper confidence limit of density of gannets across the Offshore Ornithology Study Area between July and November 2020, modelled using MRSea

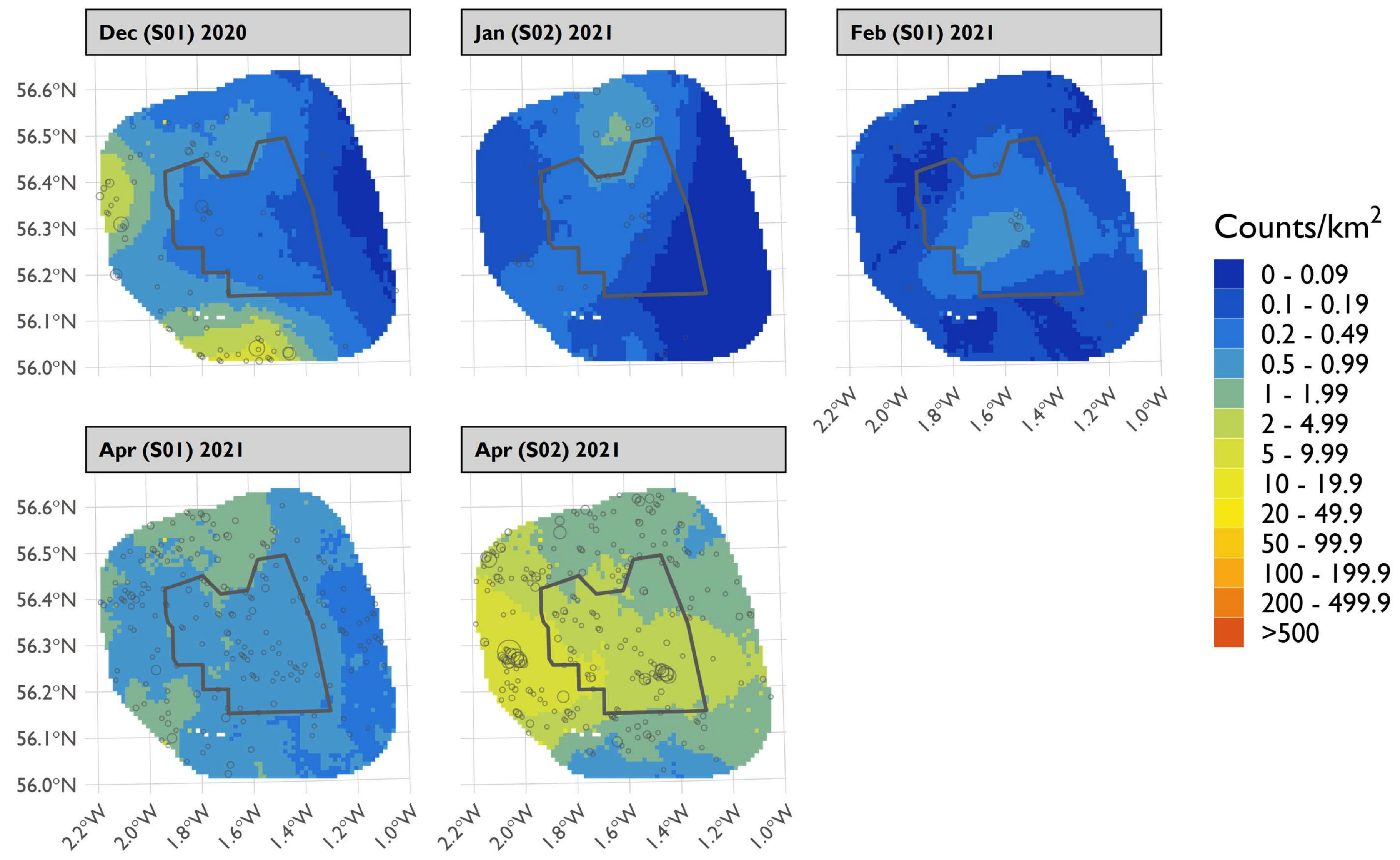

Figure 107 **Upper confidence limit of density of gannets across the Offshore Ornithology Study Area between December 2020 and April S02 2021, modelled using MRSea**

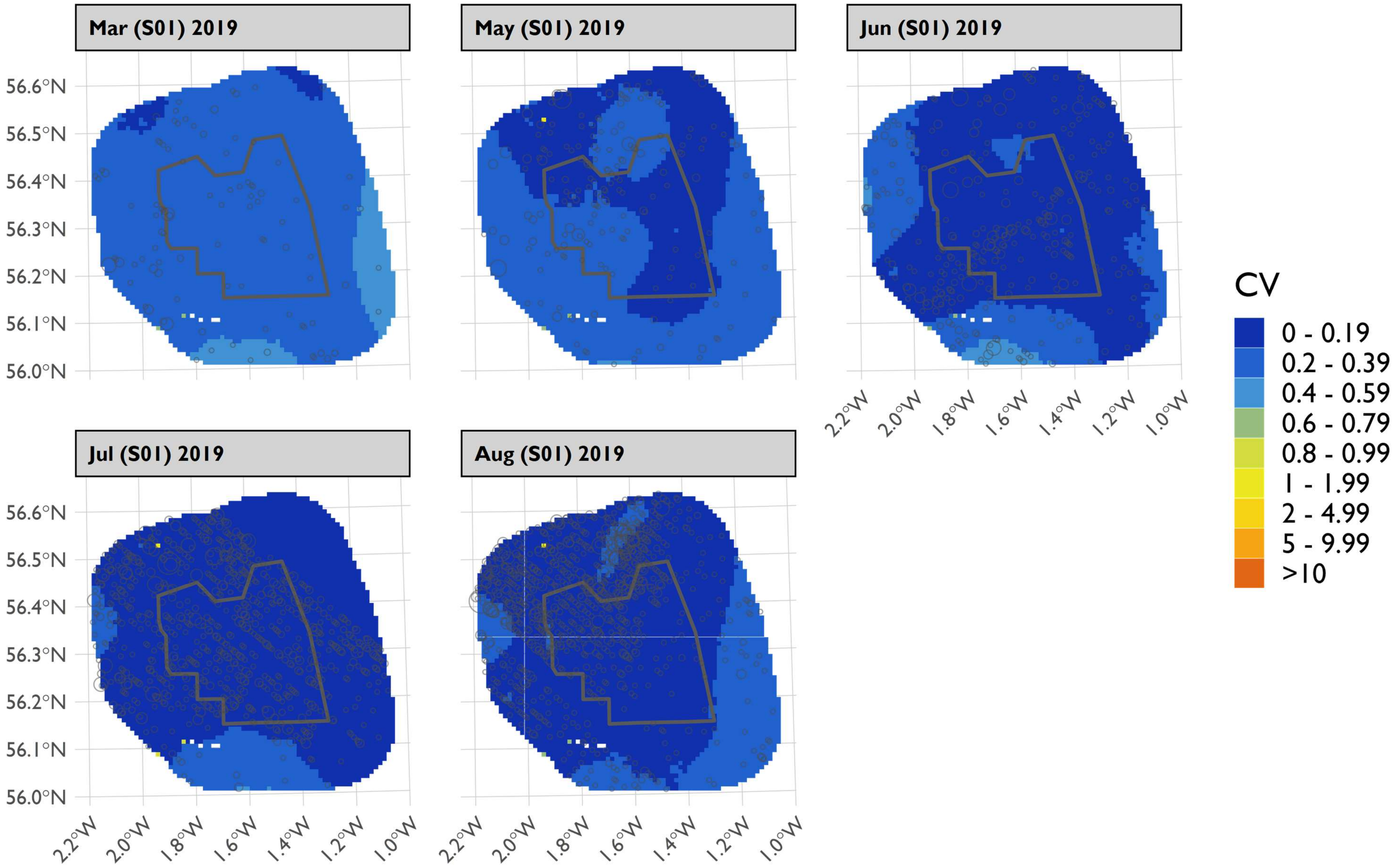

Figure 108 Spatial coefficient of variation of predicted gannet densities from MRSea across the Offshore Ornithology Study Area between March and August 2019

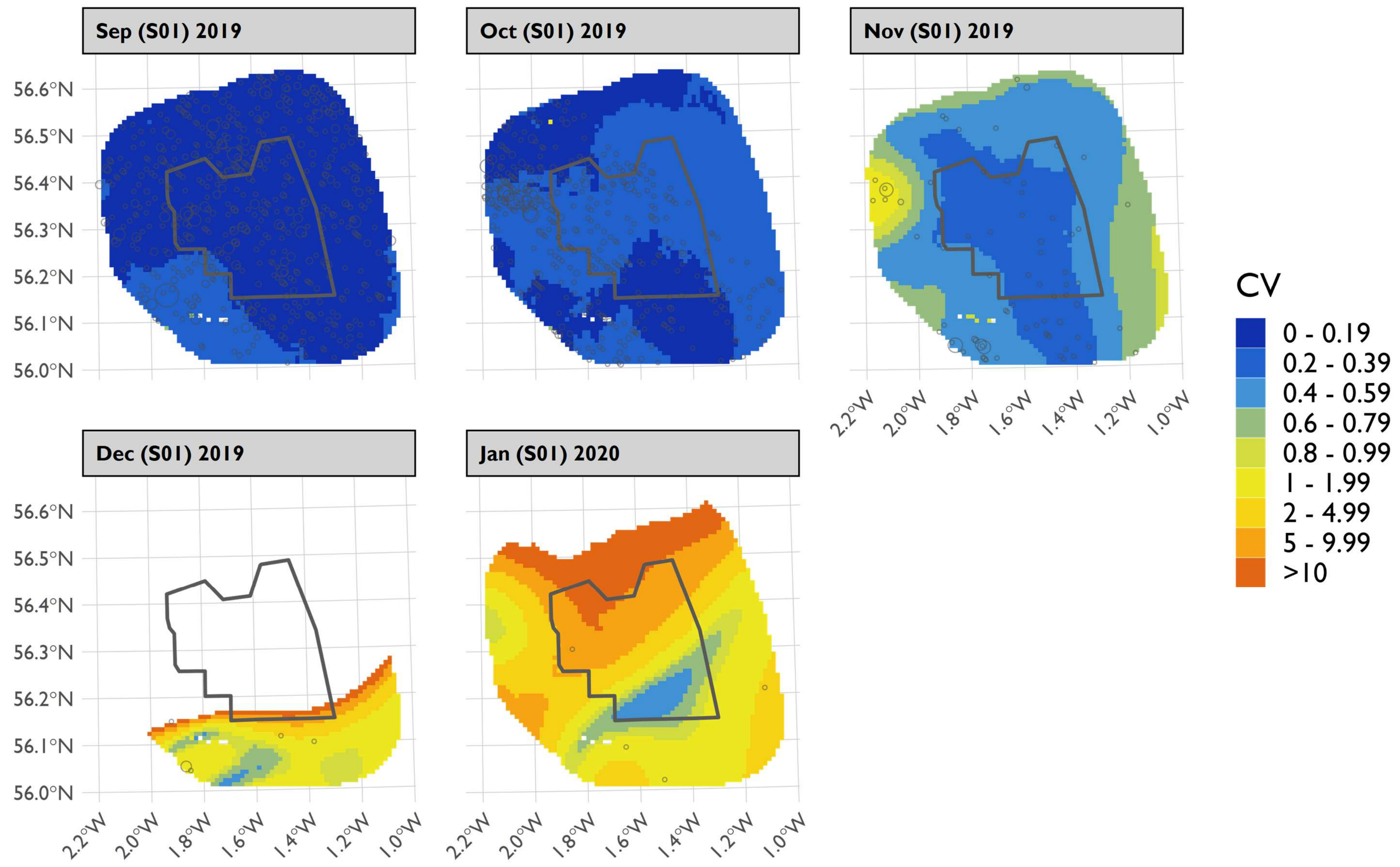

Figure 109 Spatial coefficient of variation of predicted gannet densities from MRSea across the Offshore Ornithology Study Area between September 2019 and January 2020

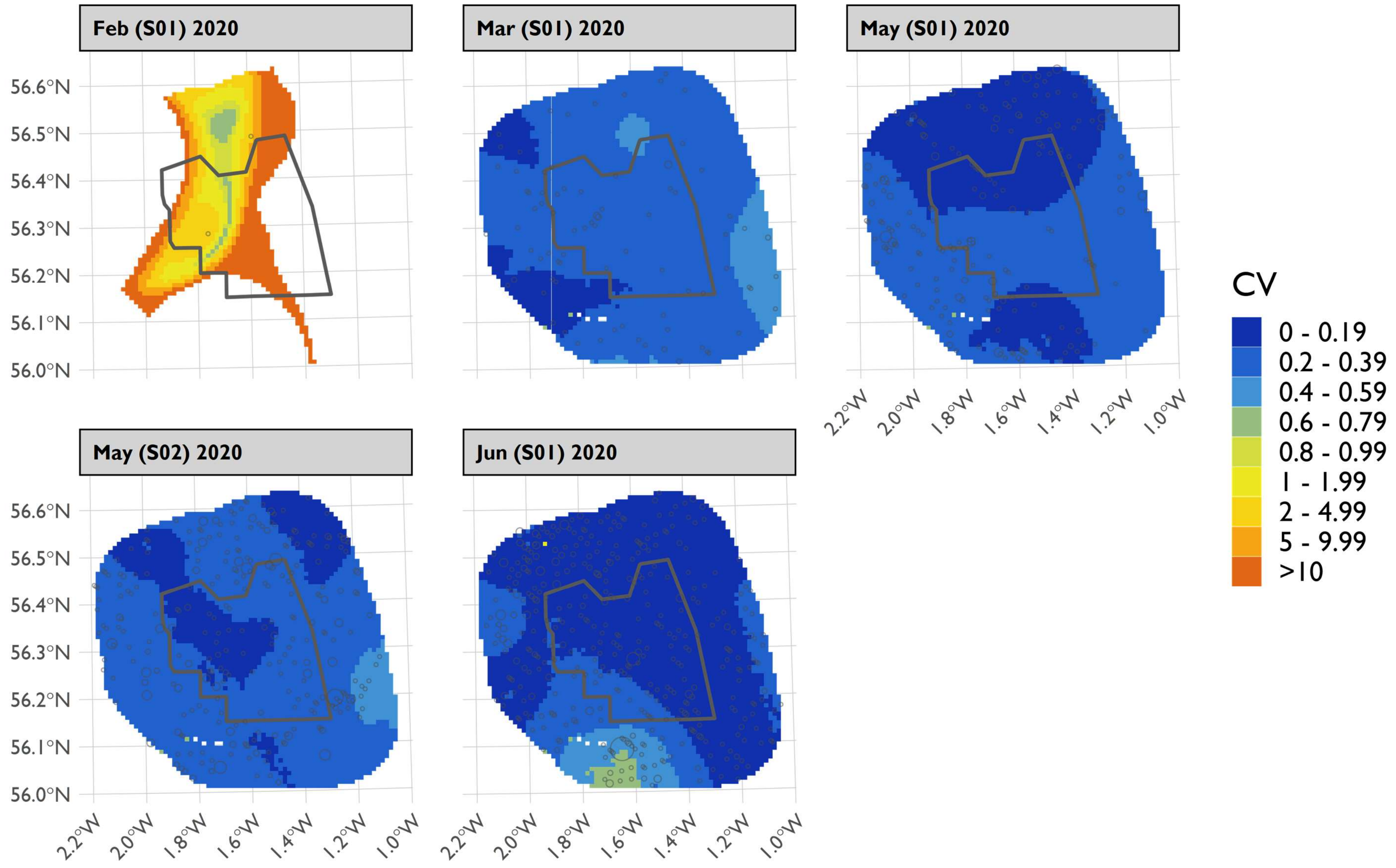

Figure 110 **Spatial coefficient of variation of predicted gannet densities from MRSea across the Offshore Ornithology Study Area between February and June 2020**

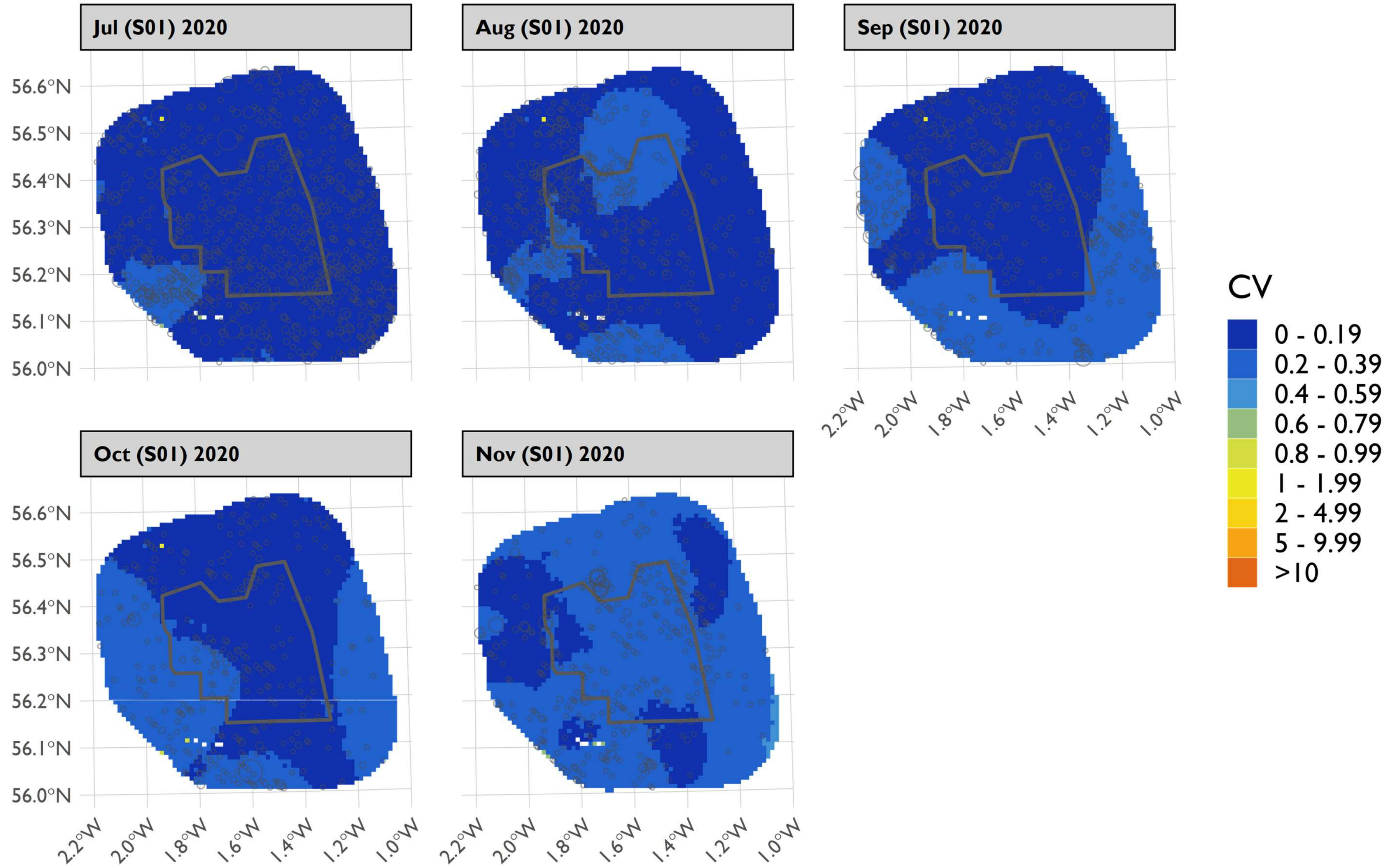

Figure 111 Spatial coefficient of variation of predicted gannet densities from MRSea across the Offshore Ornithology Study Area between July and November 2020

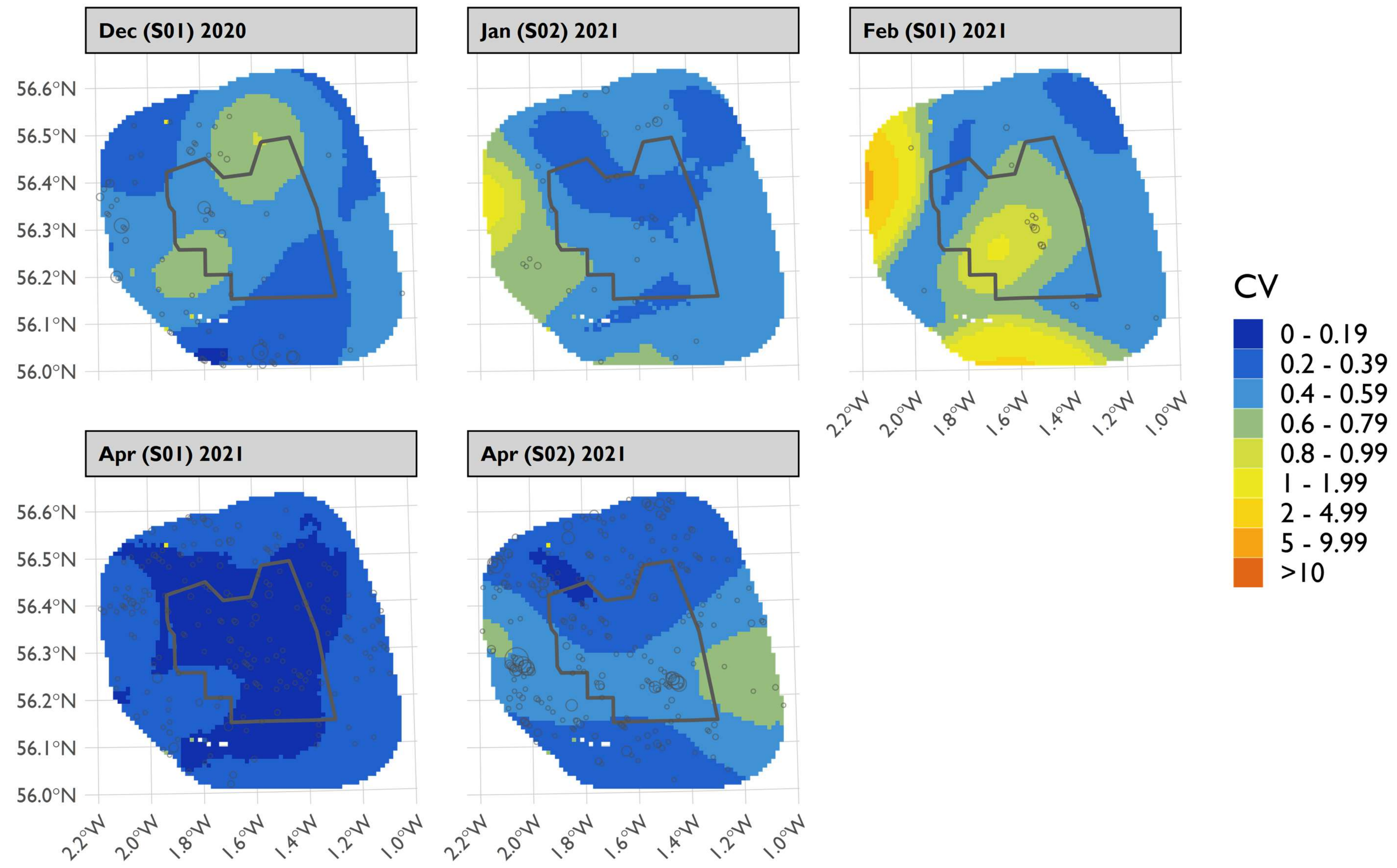

Figure 112 Spatial coefficient of variation of predicted gannet densities from MRSea across the Offshore Ornithology Study Area between December 2020 and April S02 2021

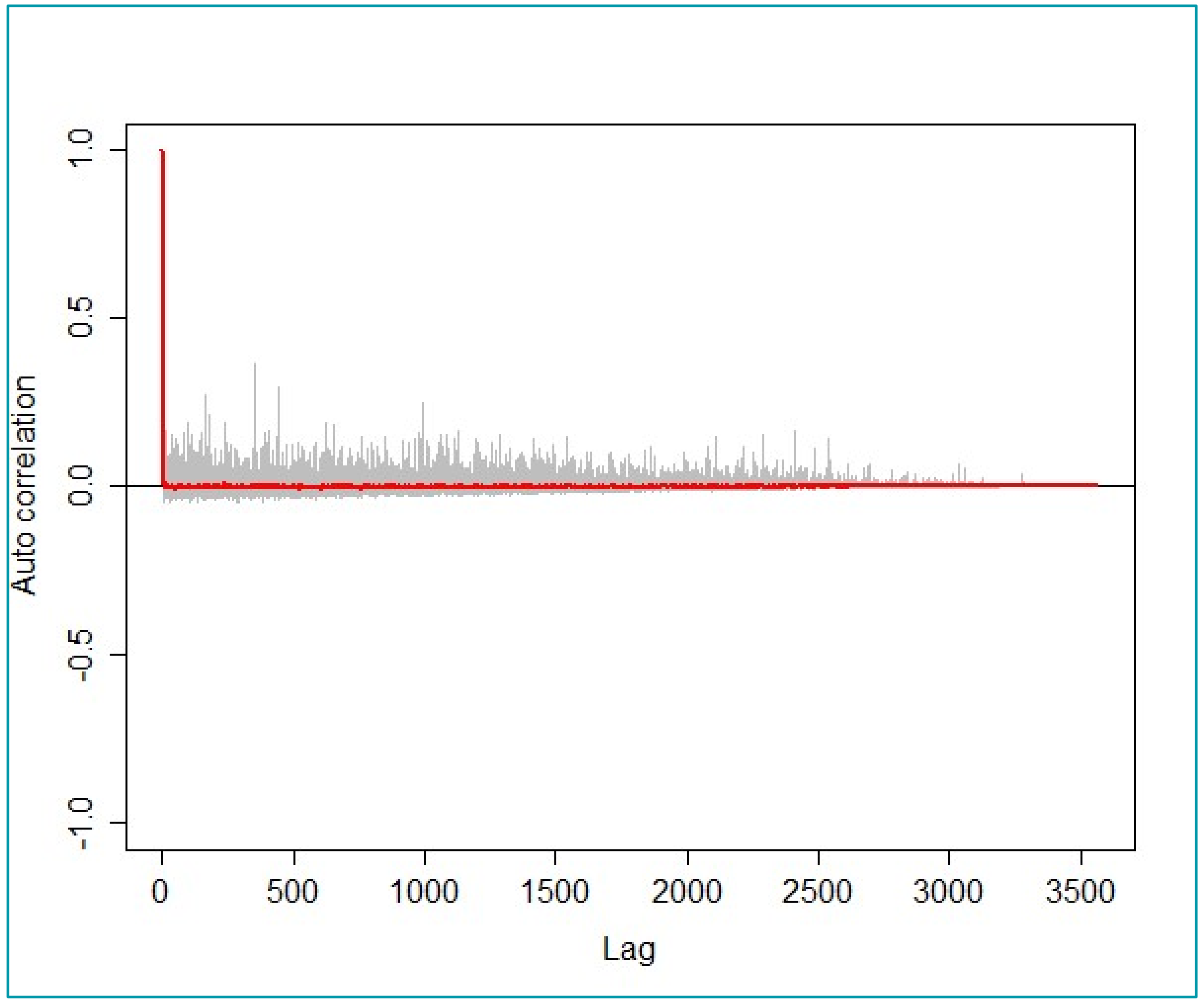

Figure 113 Autocorrelation test for gannet density surface models when using transect as a blocking feature in MRSea showing no significant correlation. A Runs test on the data prior to using transect as a blocking feature gave a p-value of << 0.0001 (i.e., that the data were significantly autocorrelated when not using a blocking feature)

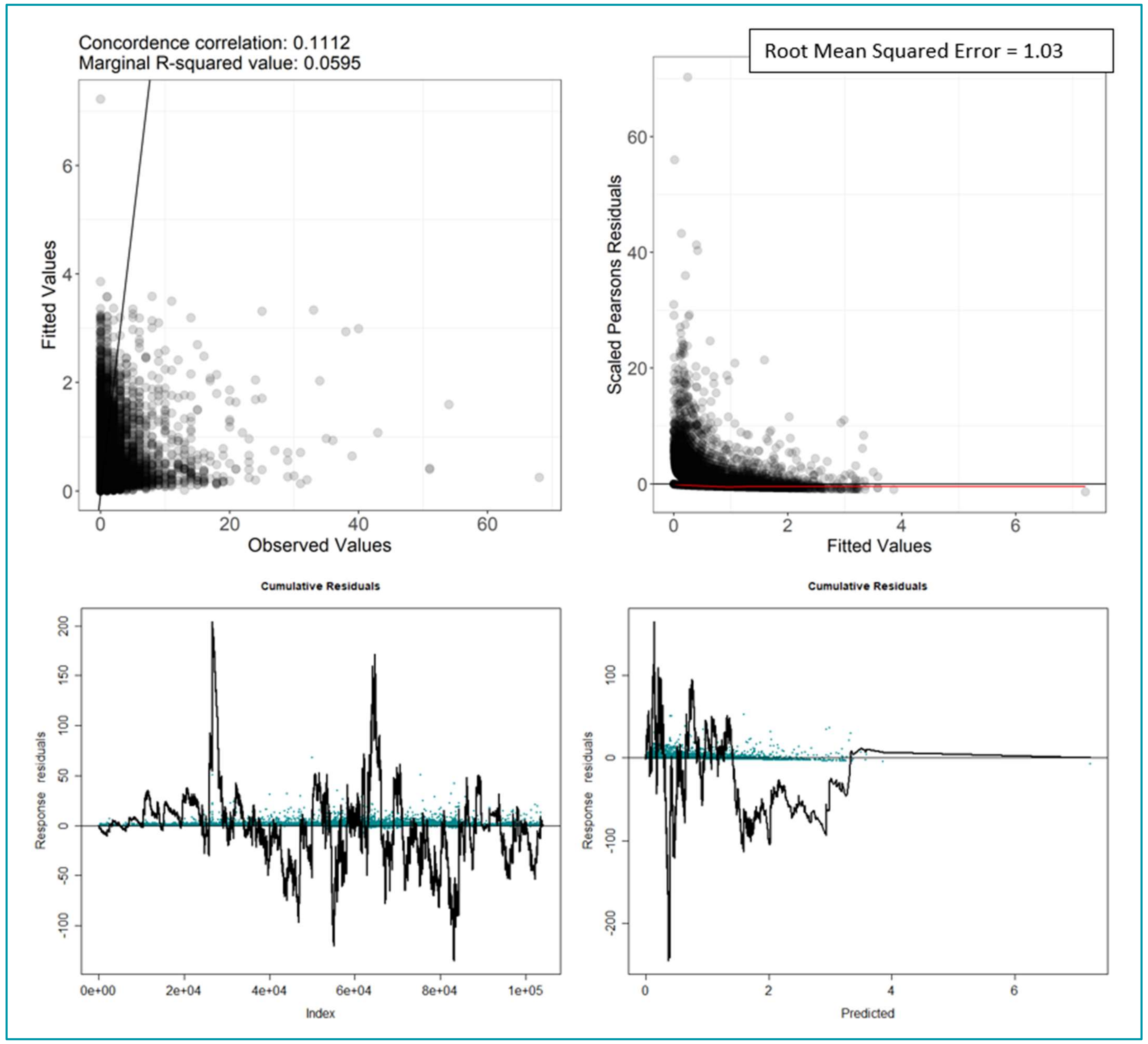

Figure 114 Fitted (MRSea predictions) versus observed counts of gannets (top left), and residual plots from MRSea

Table 16 ANOVA results from the best MRSea model for gannet as selected by cross-validation

Variable	Degrees of Freedom	Chi-square	P value
Sediment type	3	4.3	0.23
Bathymetry	4	81.9	<< 0.001
SST gradient	1	53.5	<< 0.001
Distance to coast	3	140.0	<< 0.001
X/Y (location)	4	-	<< 0.001

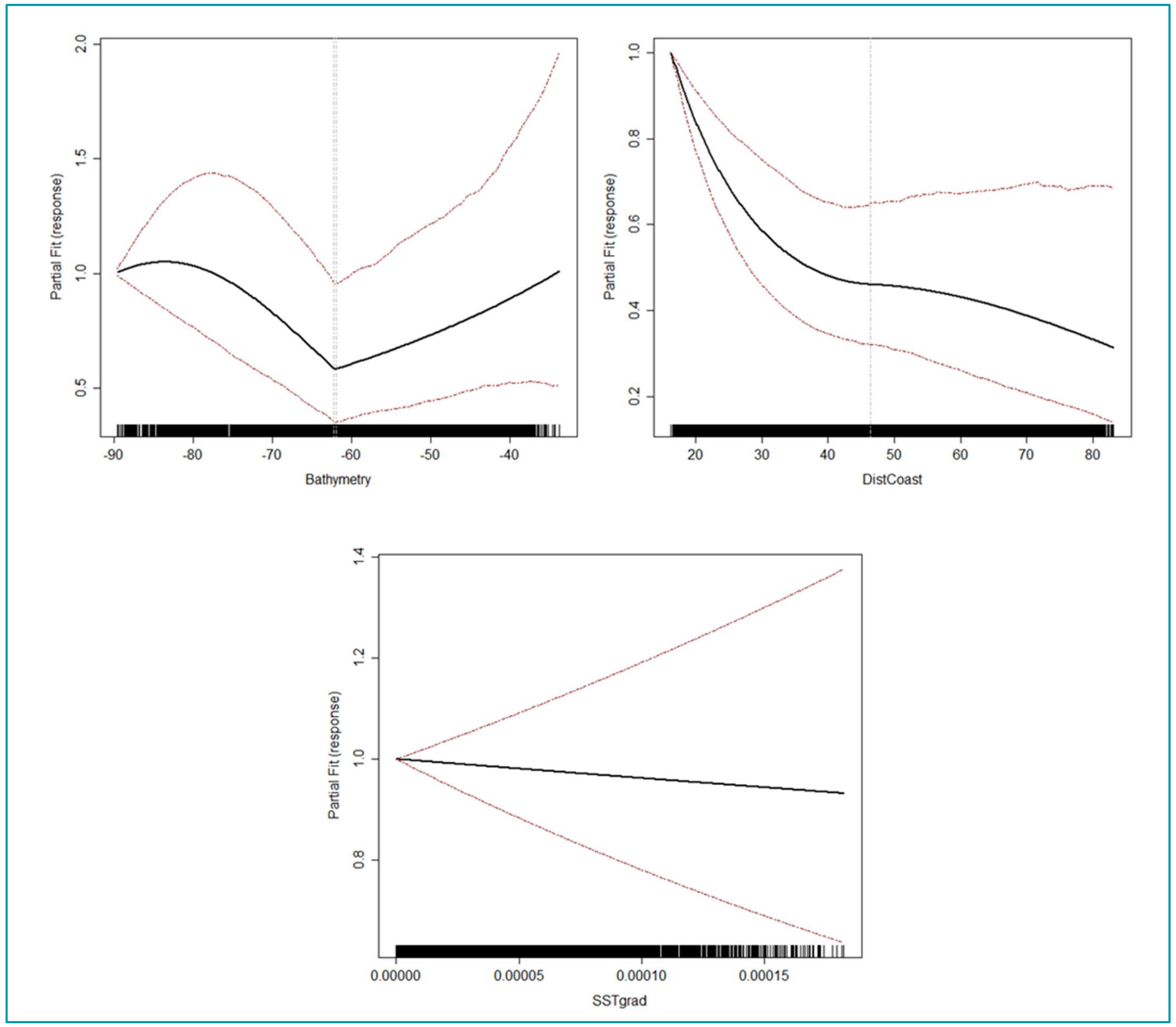

Figure 115 **Partial dependence plots for significant variables for gannet from MRSea models**

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