Density Model for Seals (*Phocidae*) Along the U.S. East Coast: Supplementary Information

Duke University Marine Geospatial Ecology Lab*

Model Version 3.2 - 2015-05-14

Model Status and Citation

PRELIMINARY RESULTS. USE WITH CAUTION. PLEASE DO NOT REDISTRIBUTE.

The model documented here is our final version prior to submitting it to a scientific journal for formal peer review and publication. We are in the process of preparing the manuscript for submission; we anticipate submitting it in spring of 2015. The methodology used to produce this model was reviewed informally but extensively with cetacean density modelers and species experts at NOAA NEFSC, SEFSC, and SWFSC and elsewhere. But until the model passes through formal peer review with a journal, these results must be considered preliminary and subject to change.

These preliminary results are intended for private use by specific organizations prior to publication of the manuscript. Please do not redistribute this document or the associated data files without our permission. Please do not use these preliminary results in studies intended for publication in a scientific journal. If you have any questions about redistribution or use of these results, please contact Jason Roberts jason.roberts@duke.edu.

To cite our density models generally, please use this placeholder:

Roberts JJ, Best BD, Mannocci L, Halpin PN, Palka DL, Garrison LP, Mullin KD, Cole TVN, McLellan WM (2015) Habitat-based cetacean density models for the Northwest Atlantic and Northern Gulf of Mexico. Manuscript in preparation.

To cite this specific model:

Roberts JJ, Best BD, Mannocci L, Halpin PN, Palka DL, Garrison LP, Mullin KD, Cole TVN, McLellan WM (2015) Density Model for Seals (*Phocidae*) Along the U.S. East Coast, Preliminary Results, Version 3.2, 2015-05-14. Marine Geospatial Ecology Lab, Duke University, Durham, North Carolina.

Revision History

Version	Date	Description of changes
1	2015-01-22	Initial version.
2	2015-01-23	Added latitude as a predictor variable, to try to obtain a more realistic distribution along the east coast.
3	2015-01-24	Split the data into two seasons (Sep-May, Jun-Aug), based on the NOAA harbor seal stock assessment report.
3.1	2015-03-06	Updated the documentation. No changes to the model.
3.2	2015-05-14	Updated calculation of CVs. Switched density rasters to logarithmic breaks. No changes to the model.

*For questions about this model or report, contact jason.roberts@duke.edu

Survey Data

This analysis only considered effort segments and sightings where beaufort <= 2.

Survey	Period	Length (1000 km)	Hours	Sightings
NEFSC Aerial Surveys	1995-2008	32	192	141
NEFSC NARWSS Harbor Porpoise Survey	1999-1999	3	16	18
NEFSC North Atlantic Right Whale Sighting Survey	1999-2013	117	628	601
NEFSC Shipboard Surveys	1995-2004	3	195	80
NJDEP Aerial Surveys	2008-2009	6	34	0
NJDEP Shipboard Surveys	2008-2009	6	372	2
SEFSC Atlantic Shipboard Surveys	1992-2005	6	420	0
SEFSC Mid Atlantic Tursiops Aerial Surveys	1995-2005	29	168	0
SEFSC Southeast Cetacean Aerial Surveys	1992-1995	6	28	0
UNCW Cape Hatteras Navy Surveys	2011-2013	4	31	0
UNCW Early Marine Mammal Surveys	2002-2002	8	44	0
UNCW Jacksonville Navy Surveys	2009-2013	35	232	0
UNCW Onslow Navy Surveys	2007-2011	19	117	0
UNCW Right Whale Surveys	2005-2008	61	316	0
Virginia Aquarium Aerial Surveys	2012-2014	3	18	0
Total		338	2811	842

Table 2: Survey effort and sightings used in this model. Effort is tallied as the cumulative length of on-effort transects and hours the survey team was on effort. Sightings are the number of on-effort encounters of the modeled species for which a perpendicular sighting distance (PSD) was available. Off effort sightings and those without PSDs were omitted from the analysis.

Season	Months	Length (1000 km)	Hours	Sightings
Winter	Sep Oct Nov Dec Jan Feb Mar Apr May	211	1485	485
Summer	Jun Jul Aug	127	1325	357

Table 3: Survey effort and on-effort sightings having perpendicular sighting distances, summarized by season.

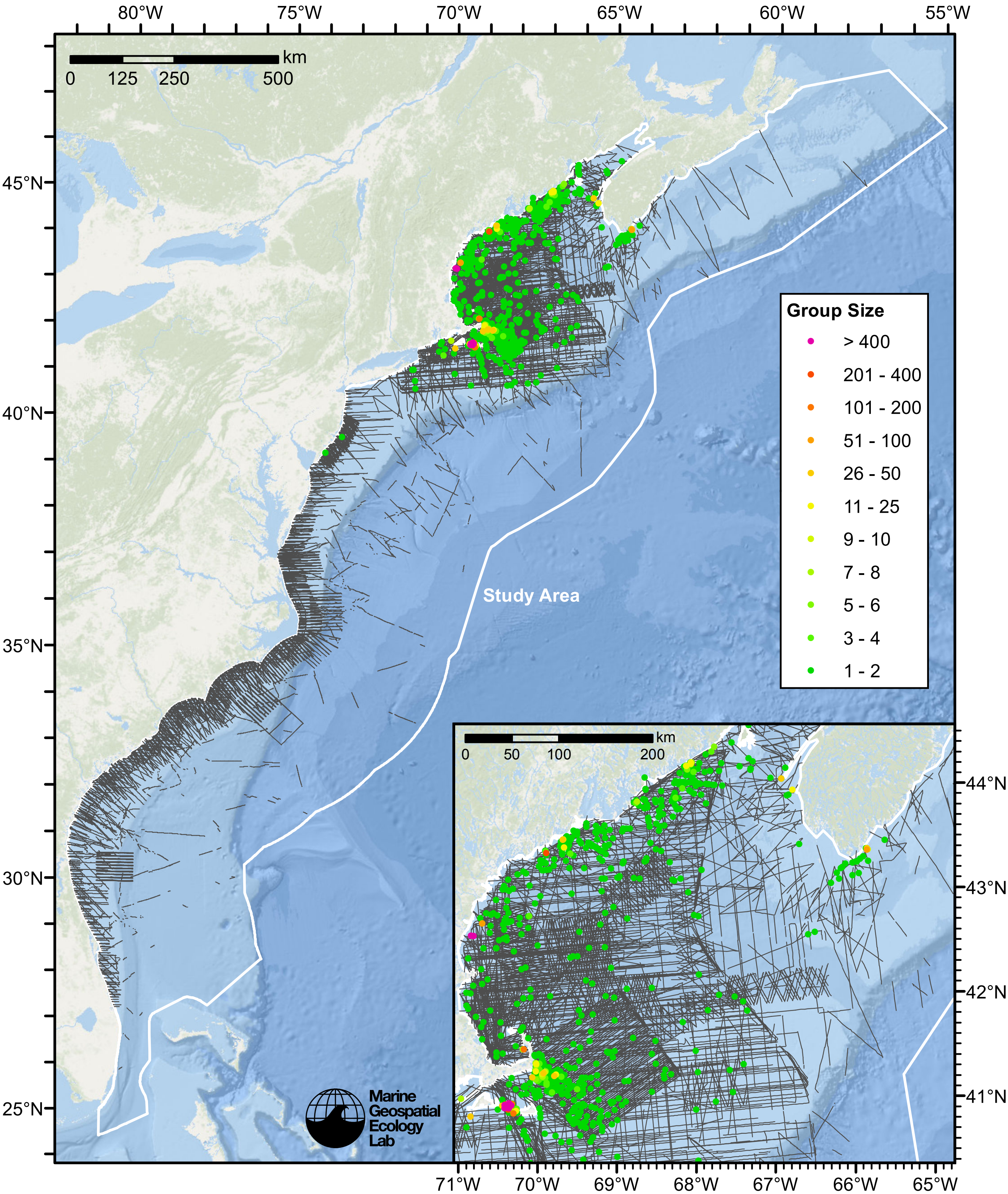


Figure 1: Seals sightings and survey tracklines.

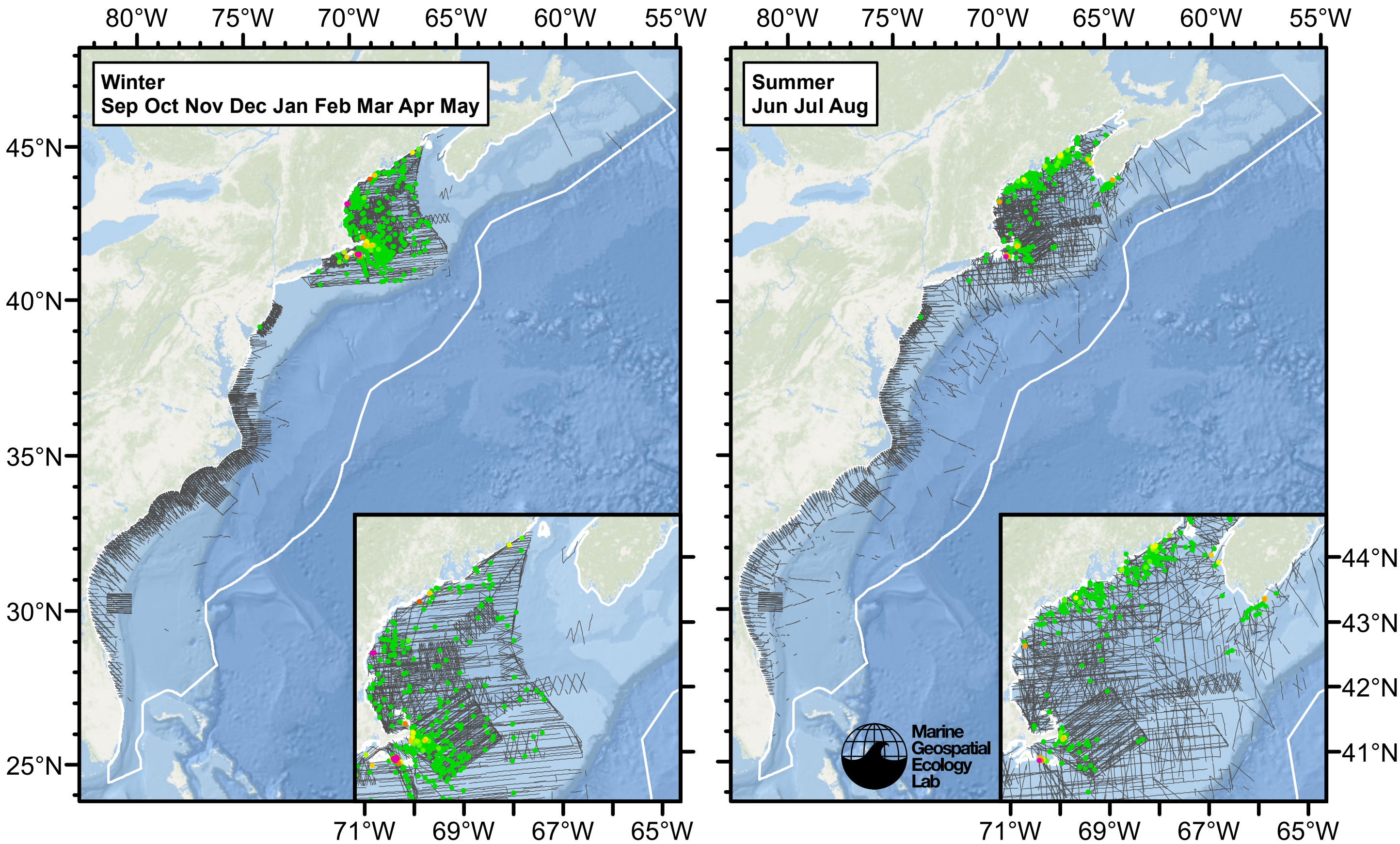


Figure 2: Seals sightings and survey tracklines, by season. Sighting colors are the same as the previous figure.

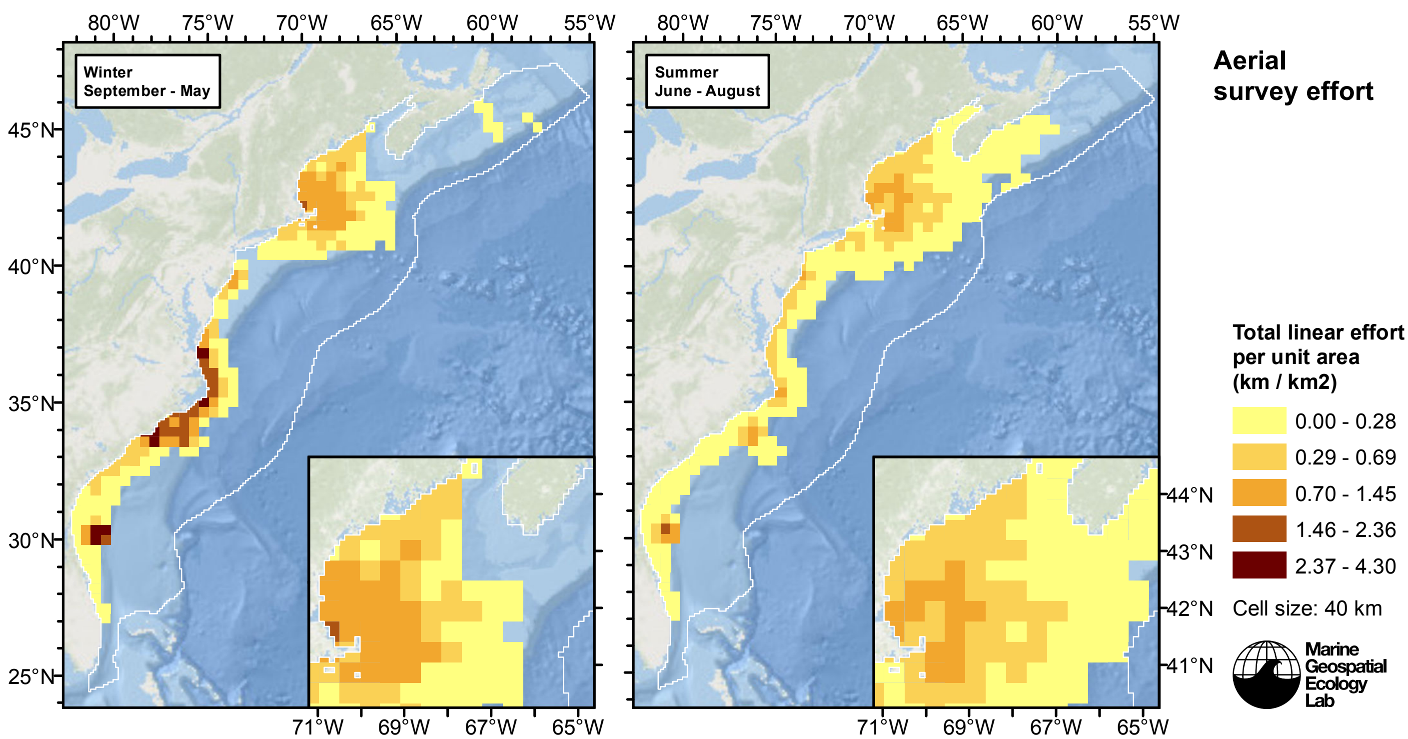


Figure 3: Aerial linear survey effort per unit area.

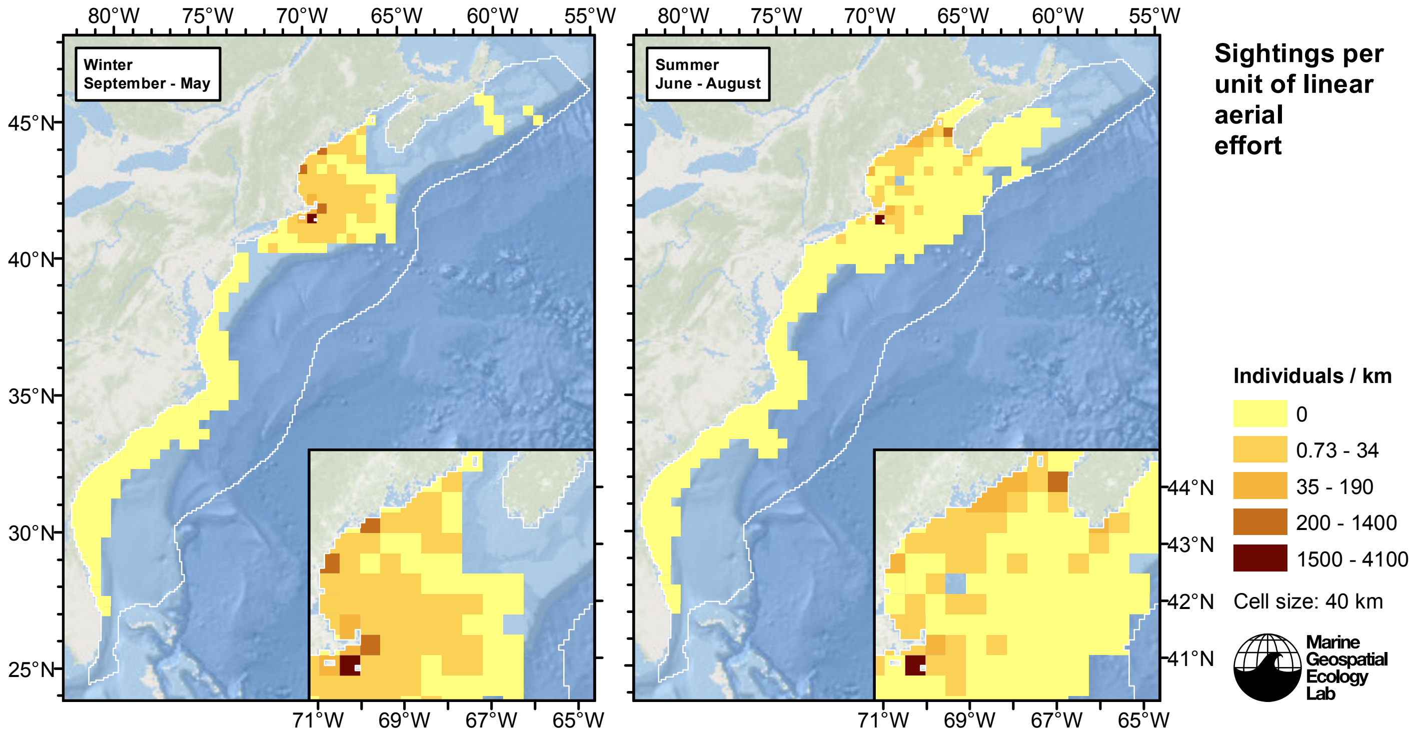


Figure 4: Seals sightings per unit aerial linear survey effort.

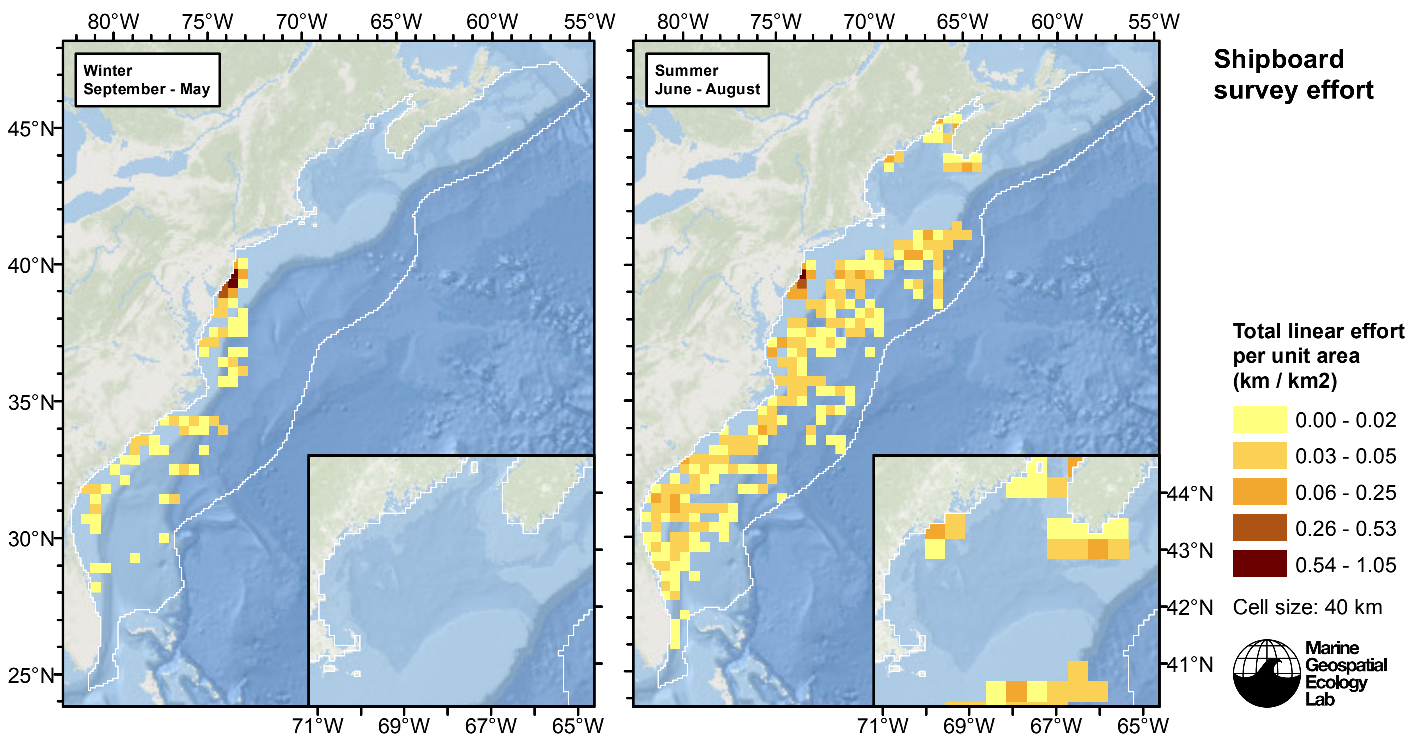


Figure 5: Shipboard linear survey effort per unit area.

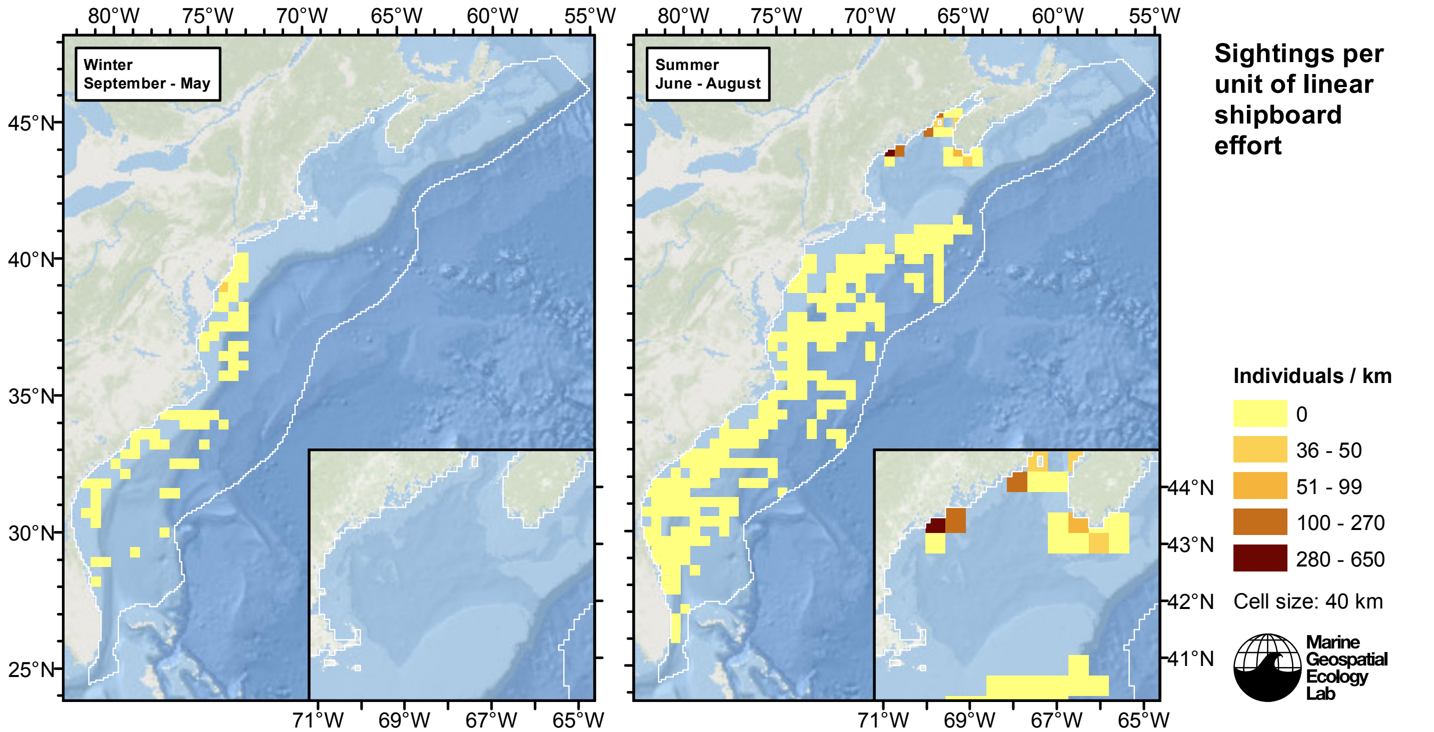


Figure 6: Seals sightings per unit shipboard linear survey effort.

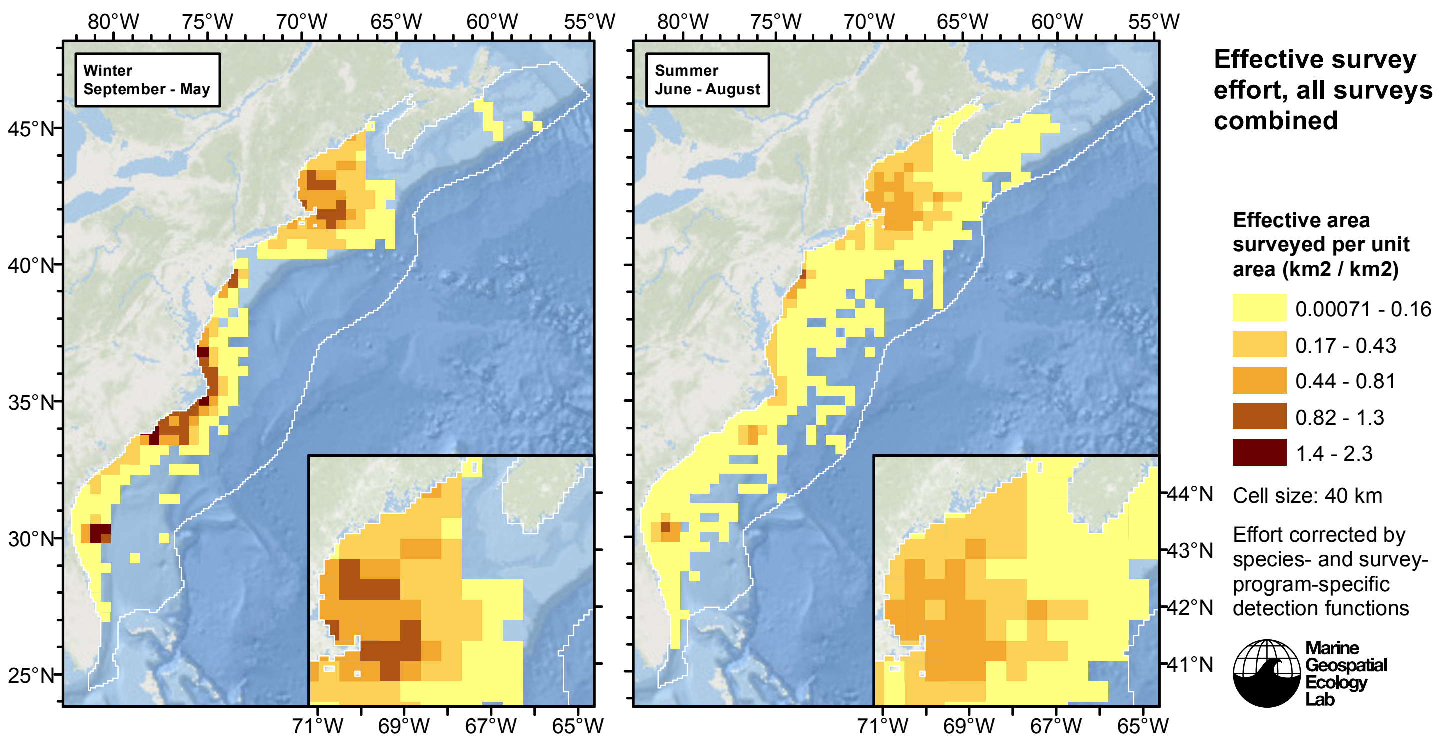


Figure 7: Effective survey effort per unit area, for all surveys combined. Here, effort is corrected by the species- and survey-program-specific detection functions used in fitting the density models.

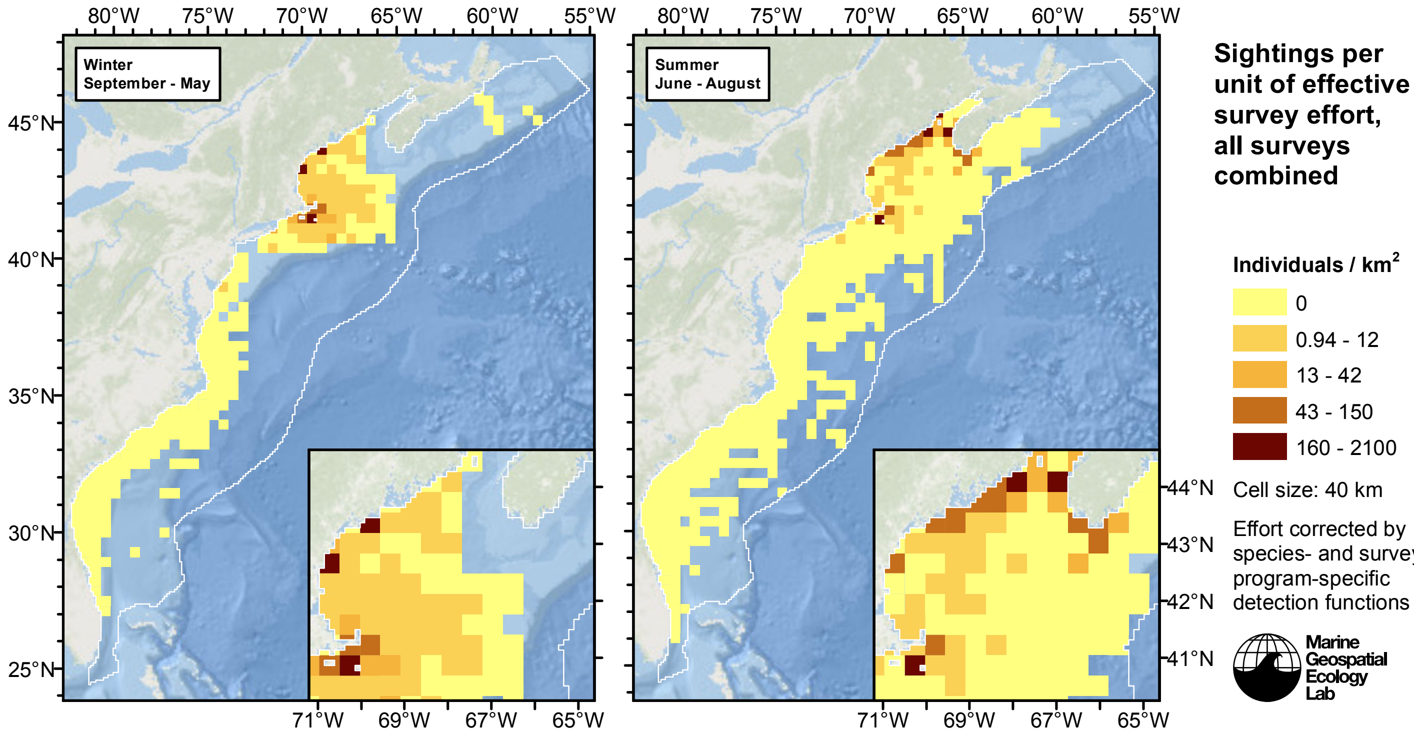


Figure 8: Seals sightings per unit of effective survey effort, for all surveys combined. Here, effort is corrected by the species- and survey-program-specific detection functions used in fitting the density models.

Detection Functions

The detection hierarchy figures below show how sightings from multiple surveys were pooled to try to achieve Buckland et. al's (2001) recommendation that at least 60-80 sightings be used to fit a detection function. Leaf nodes, on the right, usually represent individual surveys, while the hierarchy to the left shows how they have been grouped according to how similar we believed the surveys were to each other in their detection performance.

At each node, the red or green number indicates the total number of sightings below that node in the hierarchy, and is colored green if 70 or more sightings were available, and red otherwise. If a grouping node has zero sightings–i.e. all of the surveys within it had zero sightings–it may be collapsed and shown as a leaf to save space.

Each histogram in the figure indicates a node where a detection function was fitted. The actual detection functions do not appear in this figure; they are presented in subsequent sections. The histogram shows the frequency of sightings by perpendicular sighting distance for all surveys contained by that node. Each survey (leaf node) recieves the detection function that is closest to it up the hierarchy. Thus, for common species, sufficient sightings may be available to fit detection functions deep in the hierarchy, with each function applying to only a few surveys, thereby allowing variability in detection performance between surveys to be addressed relatively finely. For rare species, so few sightings may be available that we have to pool many surveys together to try to meet Buckland's recommendation, and fit only a few coarse detection functions high in the hierarchy.

A blue Proxy Species tag indicates that so few sightings were available that, rather than ascend higher in the hierarchy to a point that we would pool grossly-incompatible surveys together, (e.g. shipboard surveys that used big-eye binoculars with those that used only naked eyes) we pooled sightings of similar species together instead. The list of species pooled is given in following sections.

Shipboard Surveys

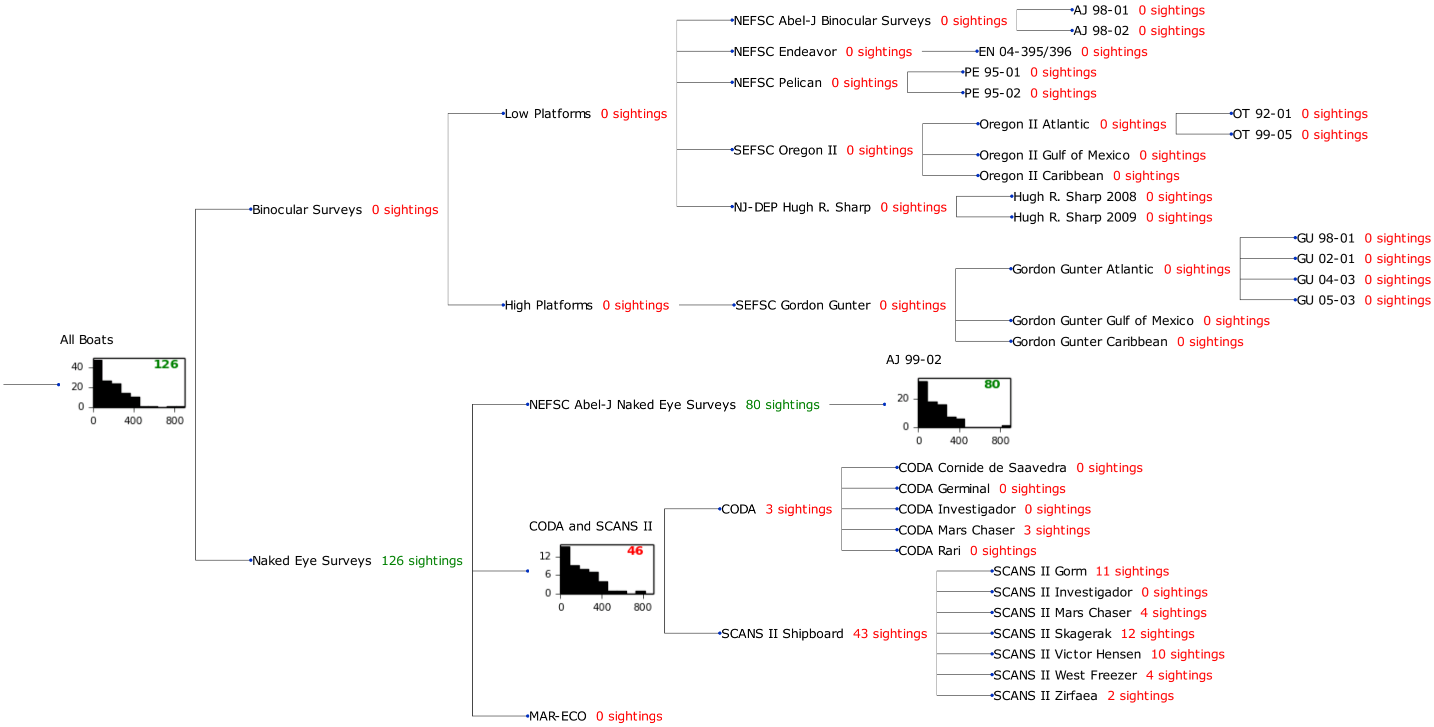


Figure 9: Detection hierarchy for shipboard surveys

NE_aj9902

The sightings were right truncated at 600m.

Covariate	Description
beaufort	Beaufort sea state.
quality	Survey-specific index of the quality of observation conditions, utilizing relevant factors other than Beaufort sea state (see methods).
size	Estimated size (number of individuals) of the sighted group.

Table 4: Covariates tested in candidate "multi-covariate distance sampling" (MCDS) detection functions.

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hn			quality	Yes	0.00	234
hn				Yes	1.77	236
hr			quality	Yes	1.97	243
hn			quality, size	Yes	1.97	234
hn	cos	3		Yes	3.59	221
hn	herm	4		Yes	3.66	241
hn			size	Yes	3.71	236
hn	cos	2		Yes	3.76	237

hr			quality, size	Yes	4.03	248
hr	poly	2		Yes	5.76	243
hr				Yes	6.57	257
hr			size	Yes	8.57	257
hr	poly	4		Yes	44.33	78
hn			beaufort	No		
hr			beaufort	No		
hn			beaufort, quality	No		
hr			beaufort, quality	No		
hn			beaufort, size	No		
hr			beaufort, size	No		
hn			beaufort, quality, size	No		
hr			beaufort, quality, size	No		

Table 5: Candidate detection functions for NE_aj9902. The first one listed was selected for the density model.

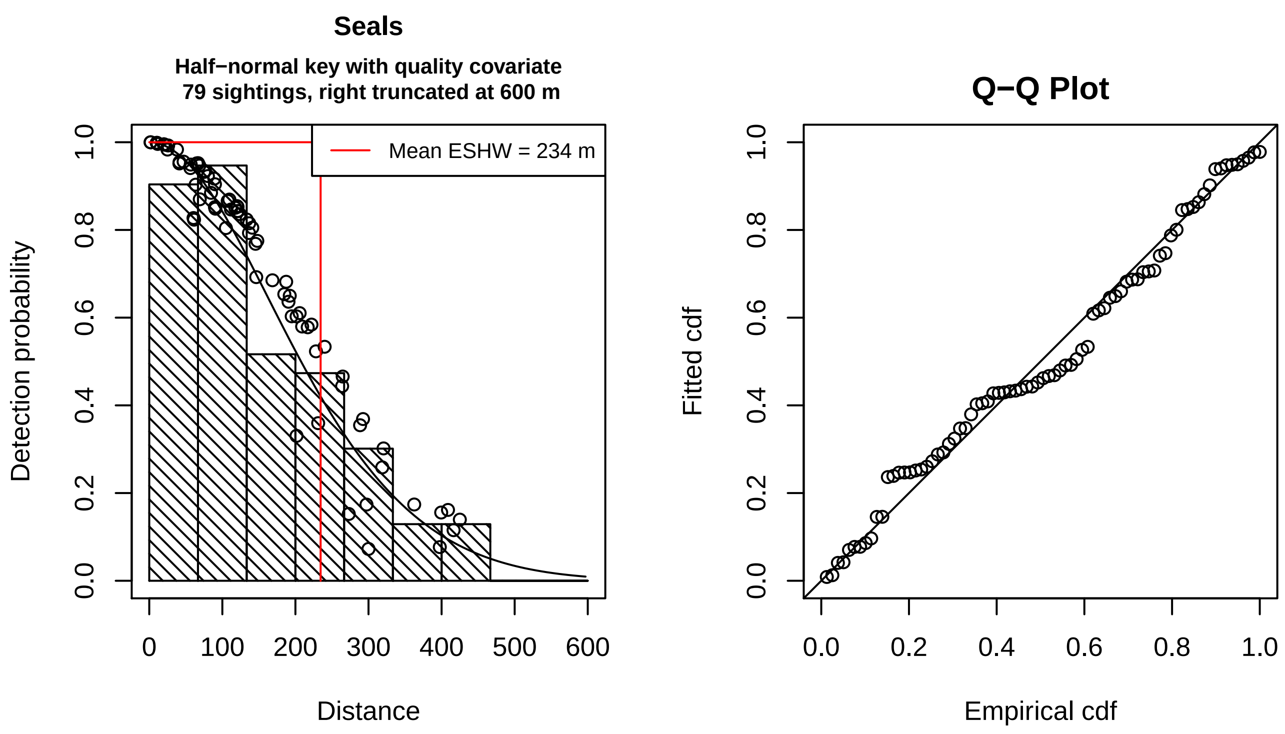


Figure 10: Detection function for NE_aj9902 that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  79
Distance range         :  0  -  600
AIC                    :  940.9377
```

```
Detection function:
 Half-normal key function

Detection function parameters
Scale Coefficients:
              estimate        se
(Intercept)  6.1943278 0.4882377
quality     -0.3477256 0.1631056

                       Estimate          SE         CV
Average p             0.3778055  0.03323179 0.08796006
N in covered region 209.1023121 26.26468056 0.12560684
```

Additional diagnostic plots:

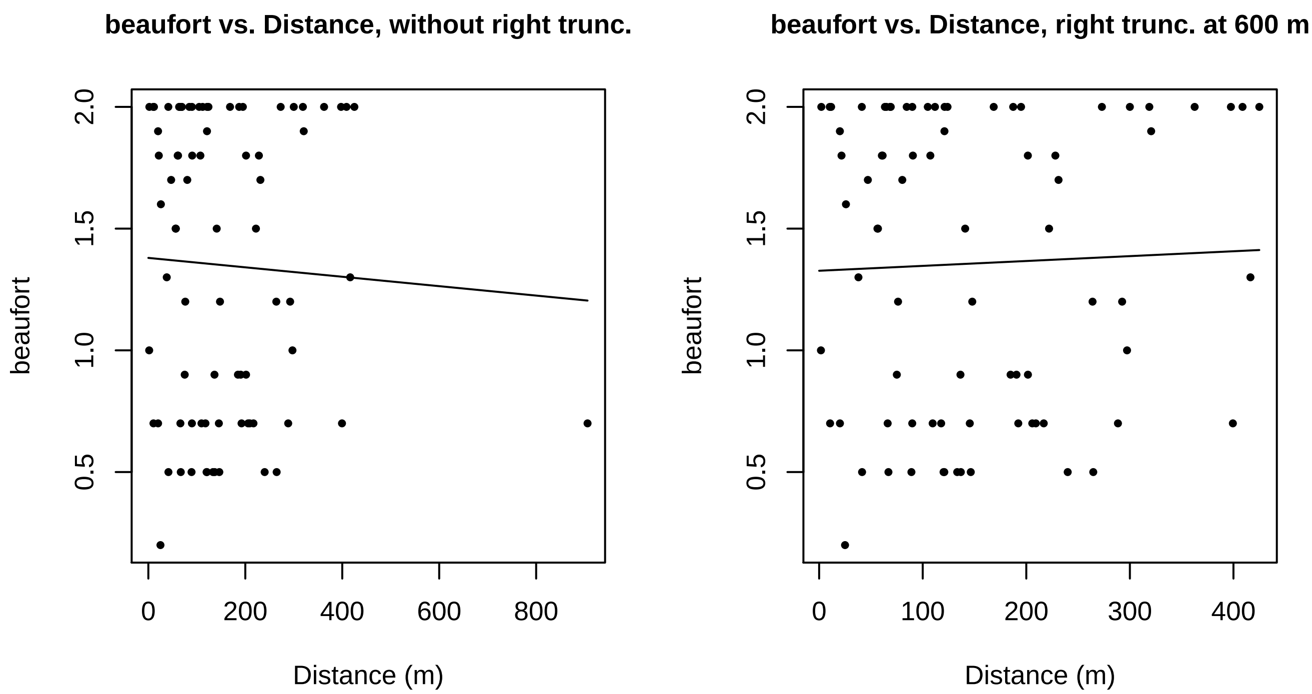


Figure 11: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

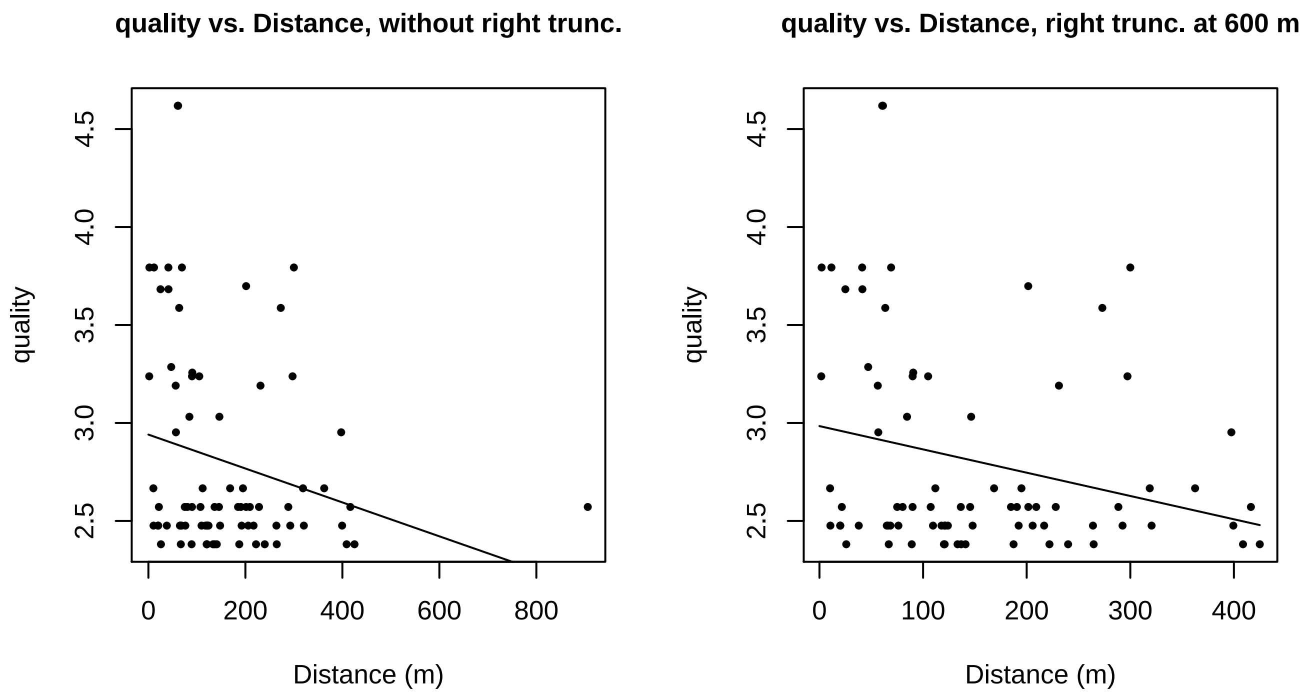


Figure 12: Scatterplots showing the relationship between the survey-specific index of the quality of observation conditions and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). Low values of the quality index correspond to better observation conditions. The line is a simple linear regression.

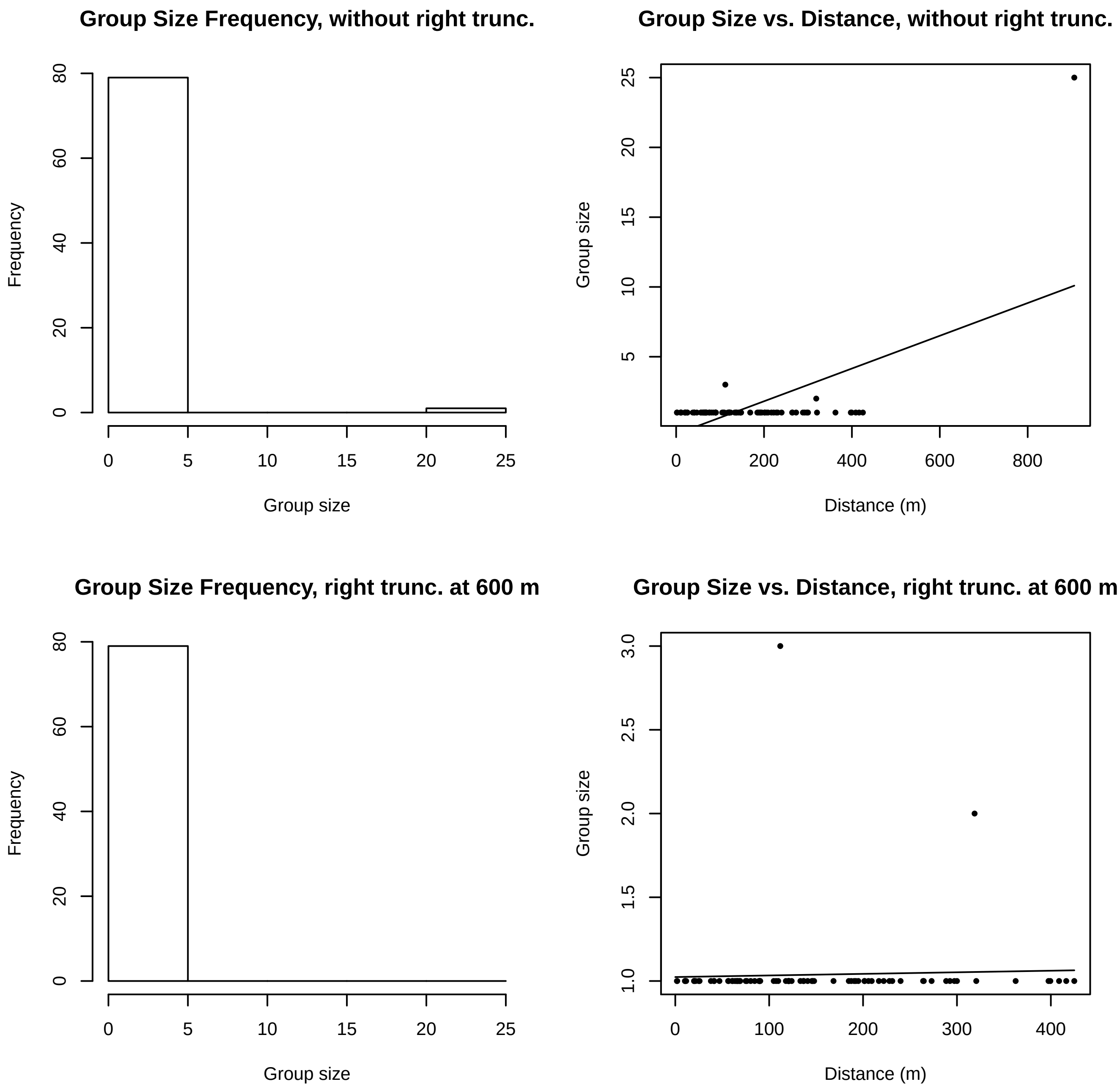


Figure 13: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

CODA and SCANS II

The sightings were right truncated at 600m.

Covariate	Description
beaufort	Beaufort sea state.
quality	Survey-specific index of the quality of observation conditions, utilizing relevant factors other than Beaufort sea state (see methods).
size	Estimated size (number of individuals) of the sighted group.

Table 6: Covariates tested in candidate "multi-covariate distance sampling" (MCDS) detection functions.

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hn				Yes	0.00	322
hn			quality	Yes	0.45	323
hn	cos	3		Yes	1.15	270
hn	cos	2		Yes	1.64	291
hn	herm	4		Yes	1.97	320
hr				Yes	2.10	270
hr			quality	Yes	2.63	246
hr	poly	4		Yes	3.29	262
hr	poly	2		Yes	3.38	271
hr			beaufort	Yes	4.06	262
hr			size	Yes	4.10	270
hr			quality, size	Yes	4.63	246
hr			beaufort, size	Yes	6.06	262
hn			beaufort	No		
hn			size	No		
hn			beaufort, quality	No		
hr			beaufort, quality	No		
hn			beaufort, size	No		
hn			quality, size	No		
hn			beaufort, quality, size	No		
hr			beaufort, quality, size	No		

Table 7: Candidate detection functions for CODA and SCANS II. The first one listed was selected for the density model.

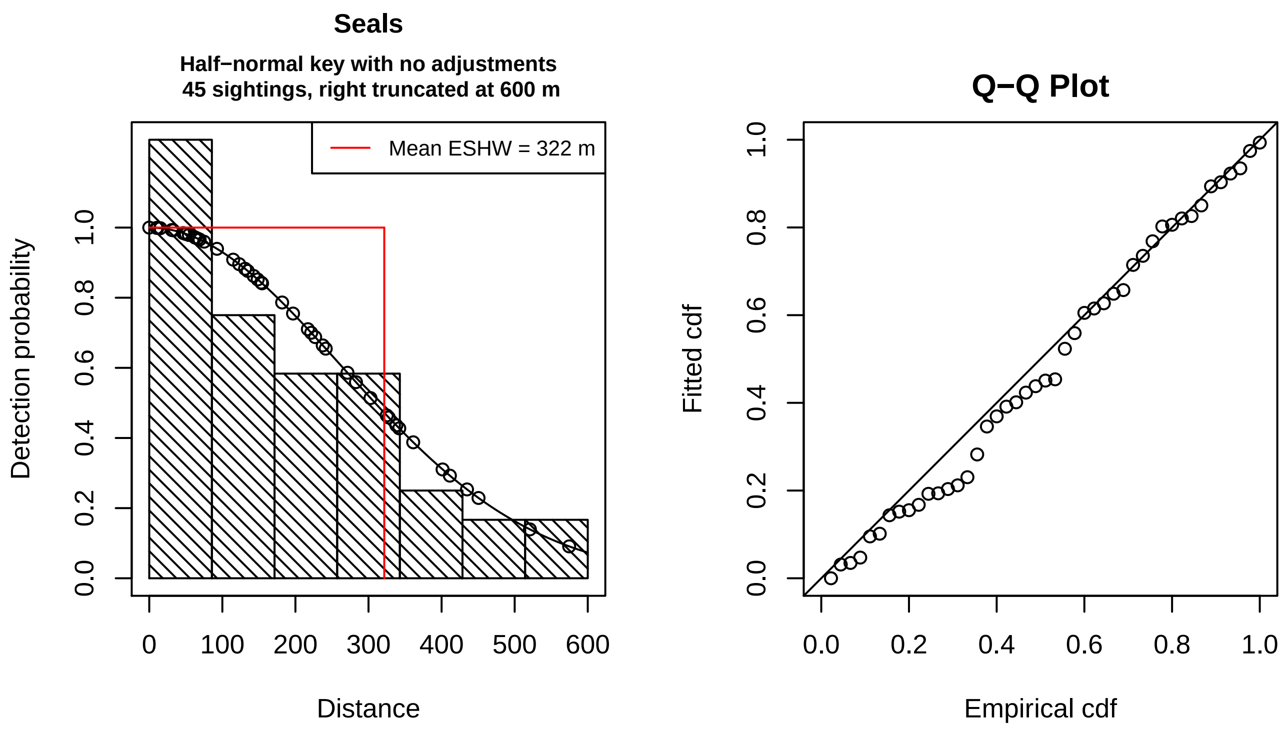


Figure 14: Detection function for CODA and SCANS II that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  45
Distance range         :  0  -  600
AIC                    :  560.4376

Detection function:
 Half-normal key function

Detection function parameters
Scale Coefficients:
            estimate        se
(Intercept) 5.569845 0.1346624

                      Estimate          SE        CV
Average p            0.5359251  0.06231012 0.1162665
N in covered region 83.9669608 12.96213587 0.1543719
```

Additional diagnostic plots:

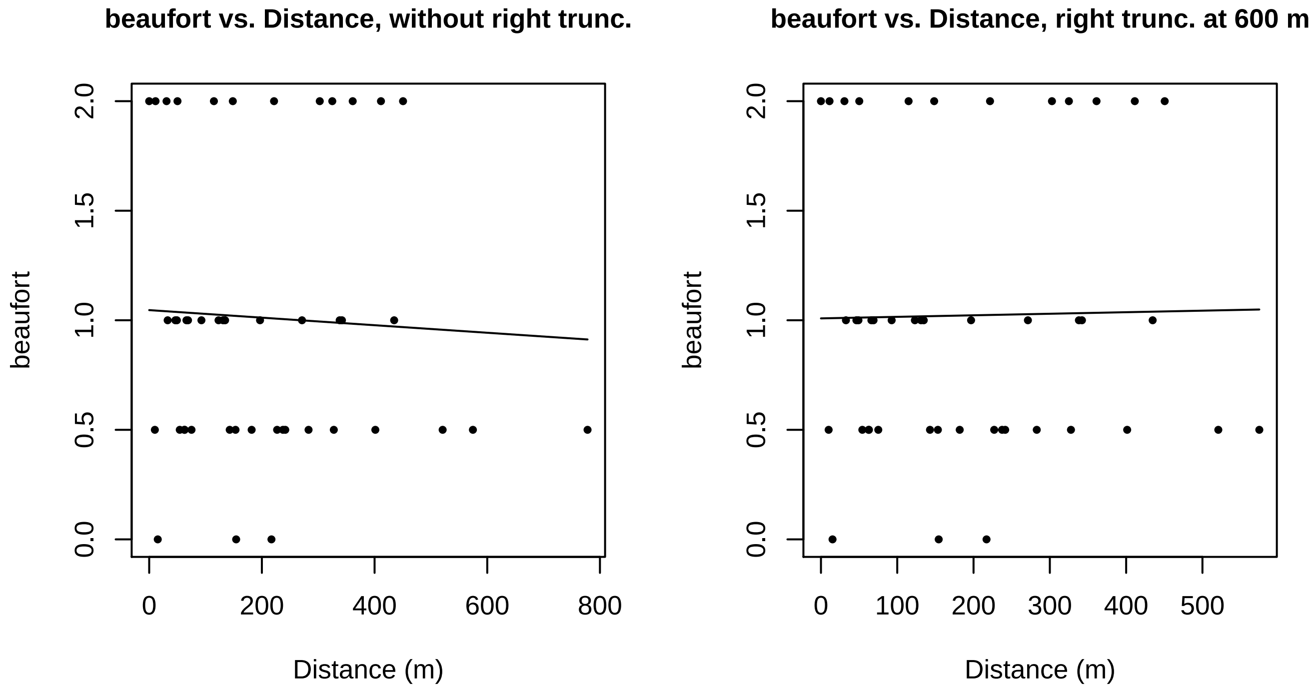


Figure 15: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

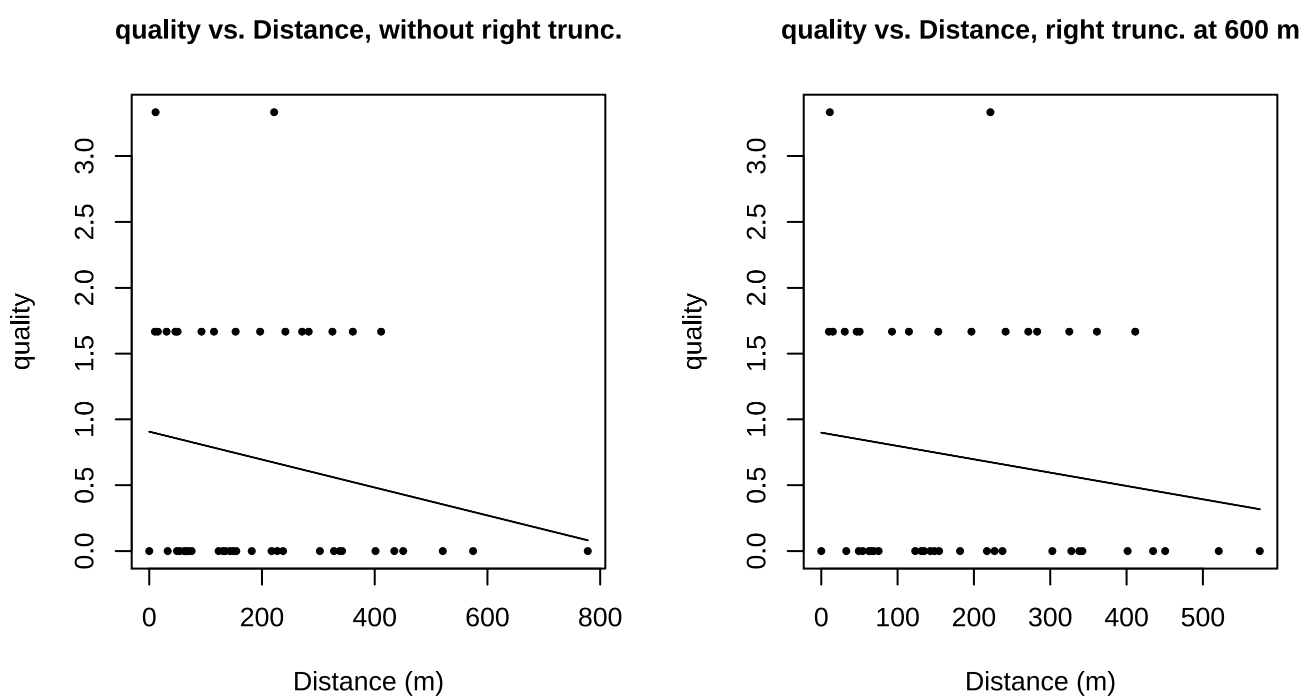


Figure 16: Scatterplots showing the relationship between the survey-specific index of the quality of observation conditions and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). Low values of the quality index correspond to better observation conditions. The line is a simple linear regression.

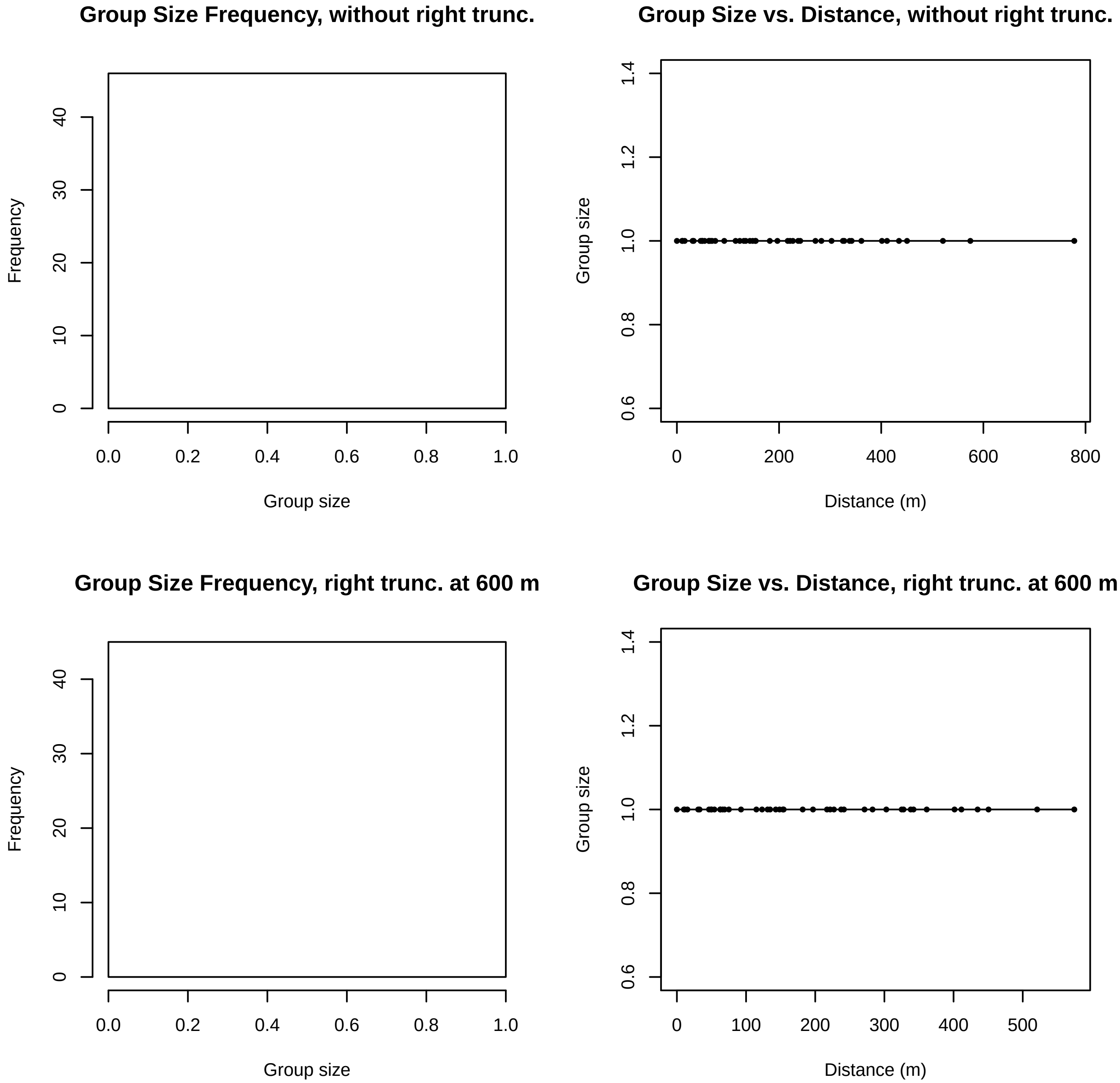


Figure 17: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

All Boats

The sightings were right truncated at 600m.

Covariate	Description
beaufort	Beaufort sea state.
size	Estimated size (number of individuals) of the sighted group.

Table 8: Covariates tested in candidate "multi-covariate distance sampling" (MCDS) detection functions.

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hn				Yes	0.00	267
hn	cos	3		Yes	1.03	238
hn	cos	2		Yes	1.55	251
hn	herm	4		Yes	1.97	266
hr	poly	2		Yes	3.42	250
hr	poly	4		Yes	3.62	253
hr				Yes	4.10	270
hr			beaufort	Yes	5.93	264
hr			beaufort, size	Yes	7.92	264
hn			beaufort	No		
hn			size	No		
hr			size	No		
hn			beaufort, size	No		

Table 9: Candidate detection functions for All Boats. The first one listed was selected for the density model.

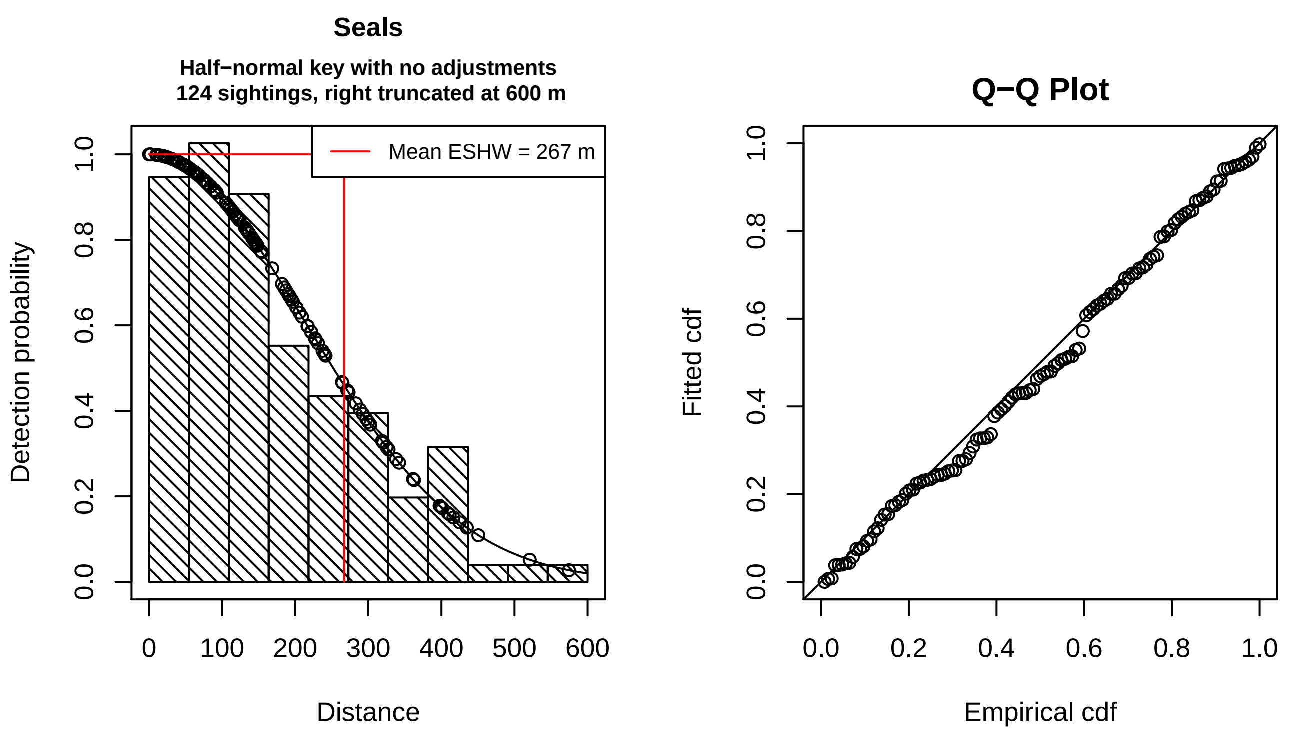


Figure 18: Detection function for All Boats that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
```

```
Number of observations :  124
Distance range         :  0  -  600
AIC                    :  1506.033

Detection function:
 Half-normal key function

Detection function parameters
Scale Coefficients:
            estimate         se
(Intercept) 5.365999 0.06900097

                       Estimate          SE         CV
Average p             0.4447671  0.02933438 0.06595446
N in covered region 278.7975887 26.19462554 0.09395571
```

Additional diagnostic plots:

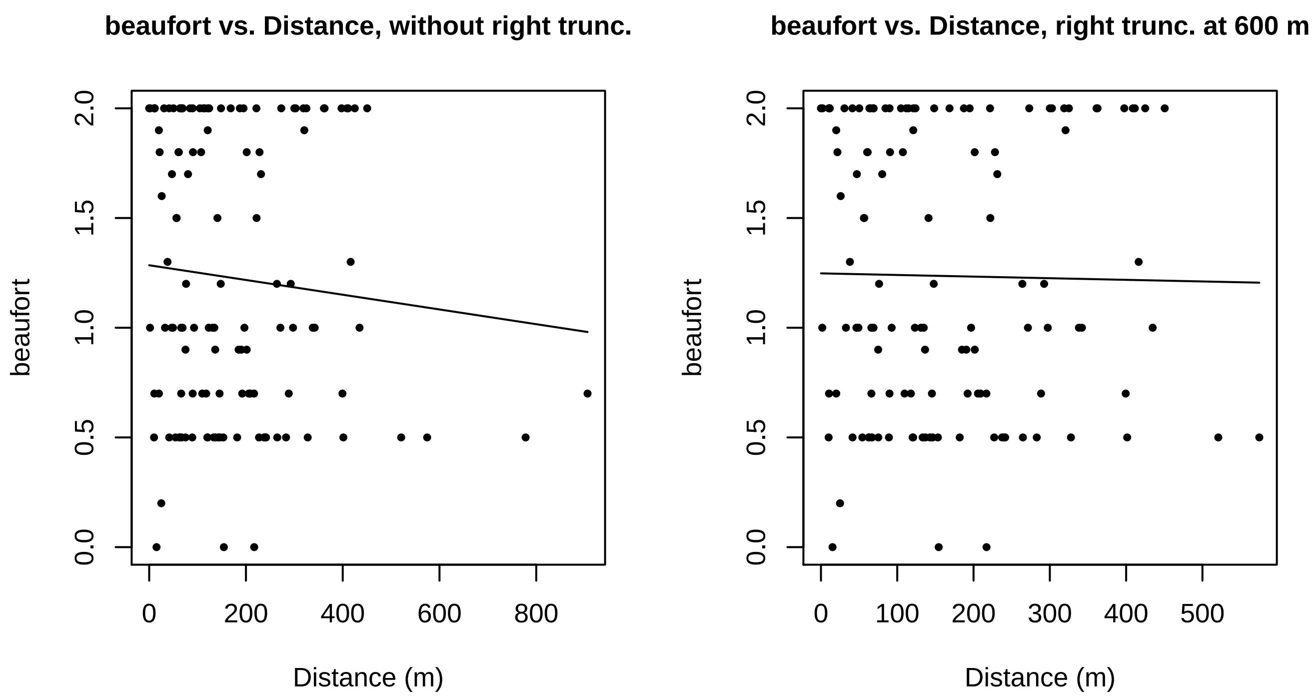


Figure 19: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

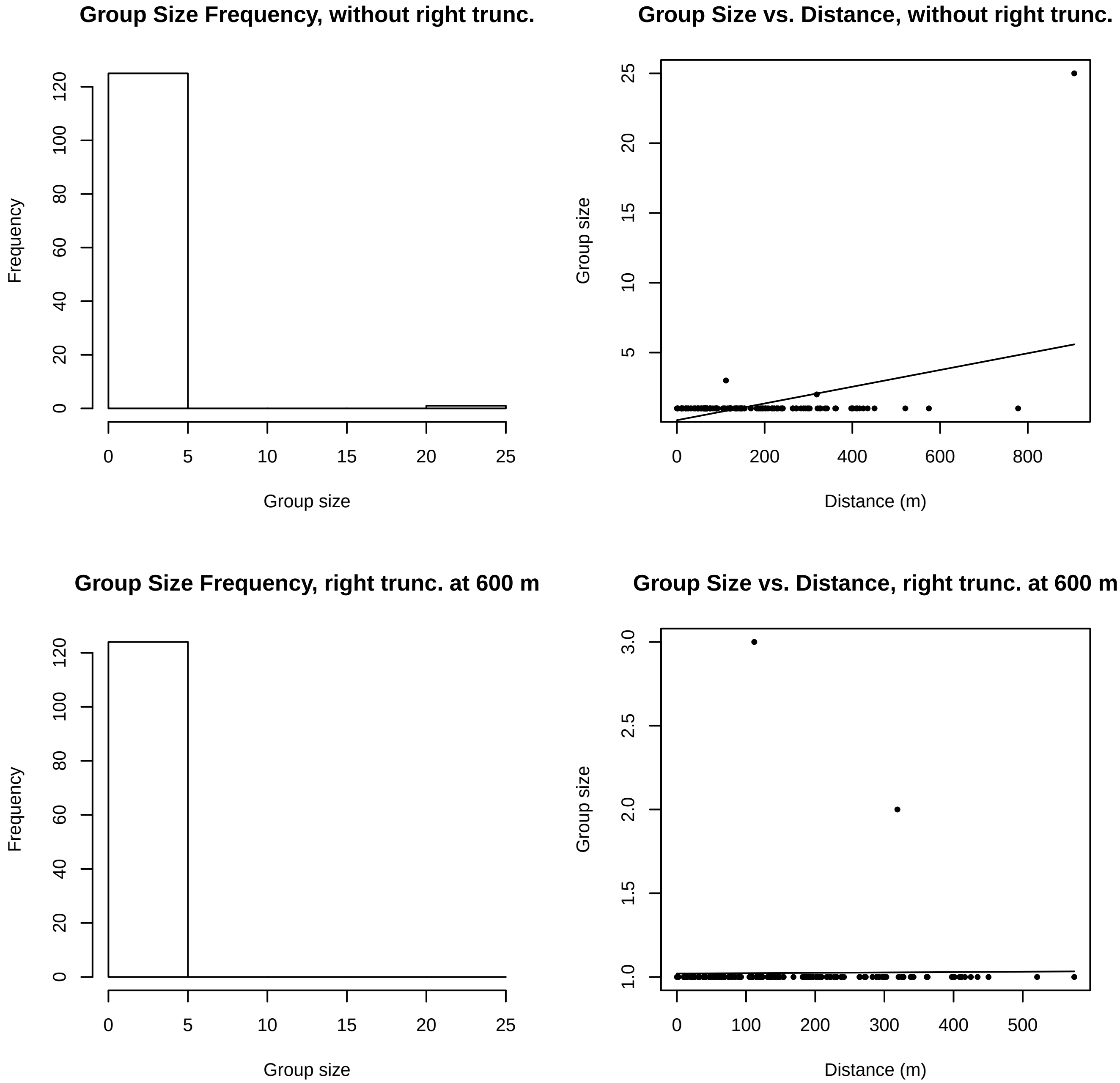


Figure 20: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

Aerial Surveys

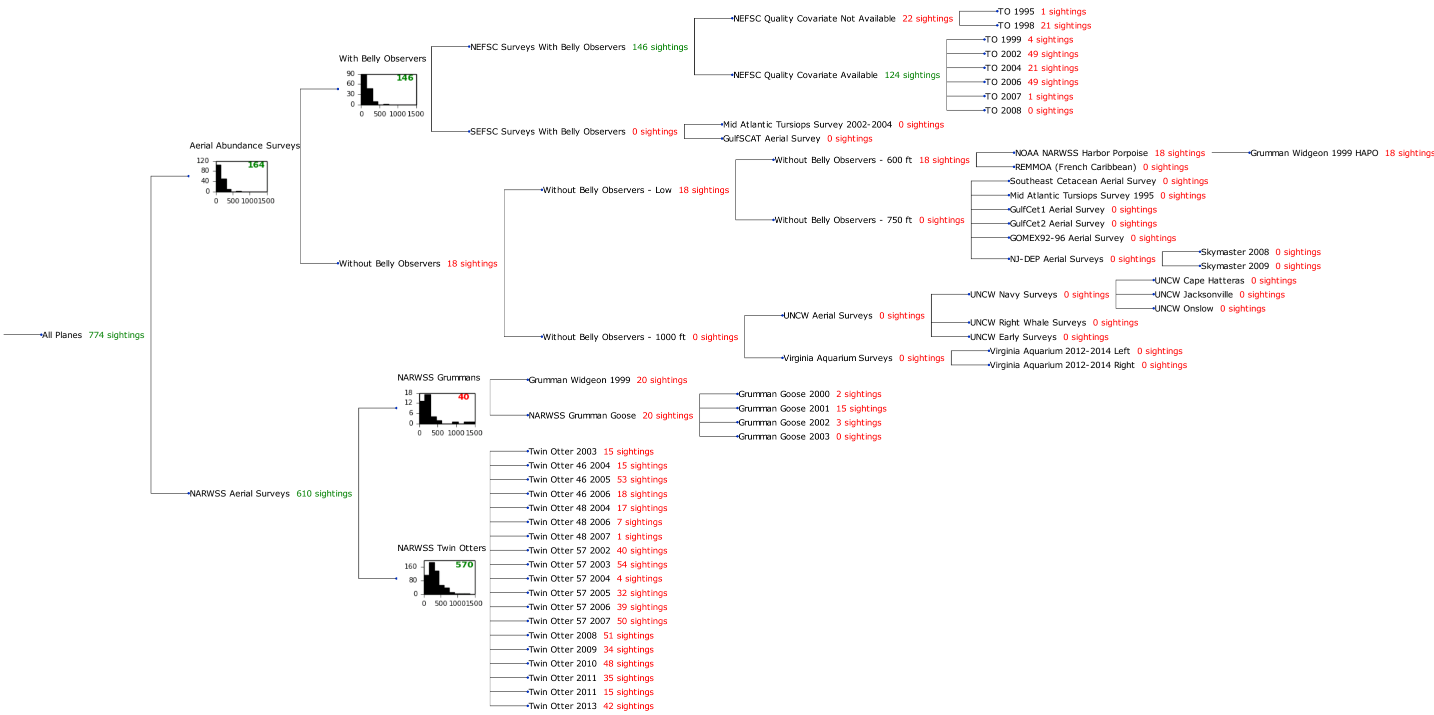


Figure 21: Detection hierarchy for aerial surveys

Aerial Abundance Surveys

The sightings were right truncated at 500m.

Covariate	Description
beaufort	Beaufort sea state.
size	Estimated size (number of individuals) of the sighted group.

Table 10: Covariates tested in candidate "multi-covariate distance sampling" (MCDS) detection functions.

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hr			size	Yes	0.00	267
hn			size	Yes	7.63	198
hn	herm	4		Yes	21.64	220
hn				Yes	21.66	198
hn	cos	2		Yes	21.86	221
hn	cos	3		Yes	23.44	208
hr	poly	2		Yes	23.83	246
hr				Yes	24.30	261
hr	poly	4		Yes	25.42	257
hn			beaufort	No		

hr	beaufort	No
hn	beaufort, size	No
hr	beaufort, size	No

Table 11: Candidate detection functions for Aerial Abundance Surveys. The first one listed was selected for the density model.

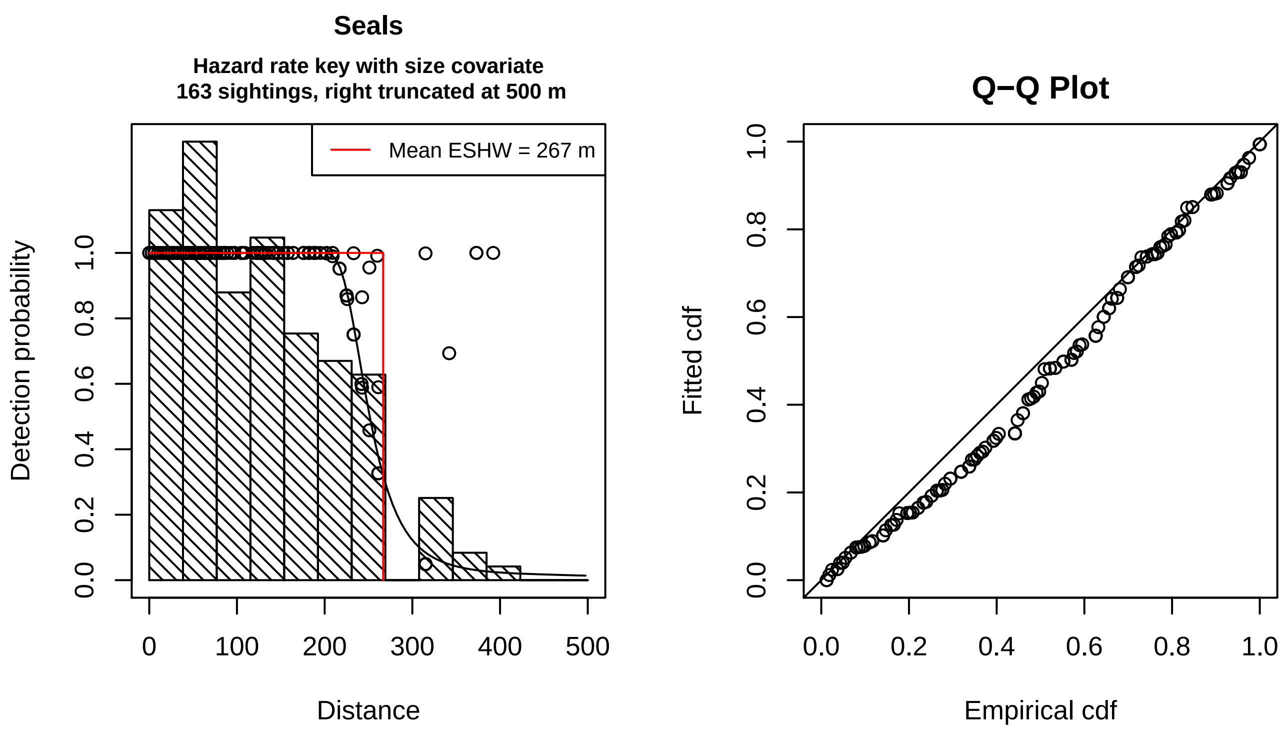


Figure 22: Detection function for Aerial Abundance Surveys that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  163
Distance range         :  0  -  500
AIC                    :  1864.291

Detection function:
 Hazard-rate key function

Detection function parameters
Scale Coefficients:
             estimate         se
(Intercept) 5.4070452 0.06867707
size        0.5004103 0.26824746

Shape parameters:
            estimate        se
(Intercept) 2.397896 0.2307713

                       Estimate          SE         CV
```

```
Average p             0.5250249  0.01824592 0.03475249
N in covered region 310.4614643 20.05668622 0.06460282
```

Additional diagnostic plots:

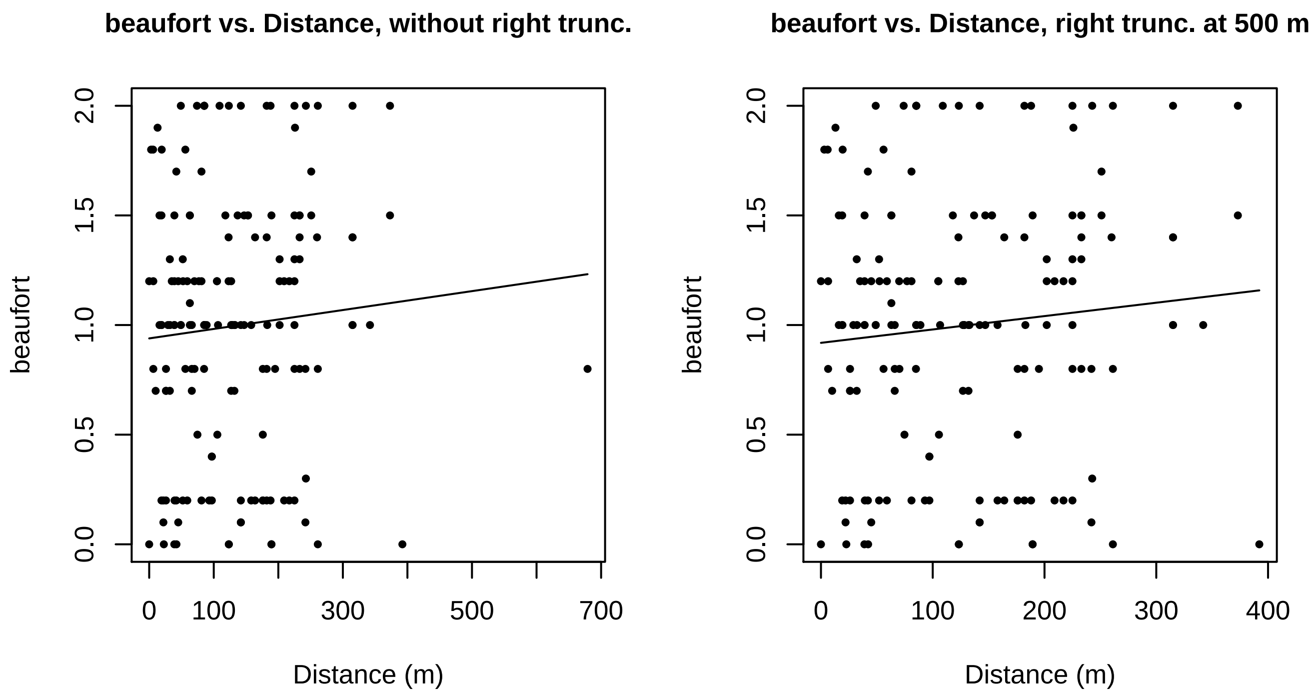


Figure 23: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

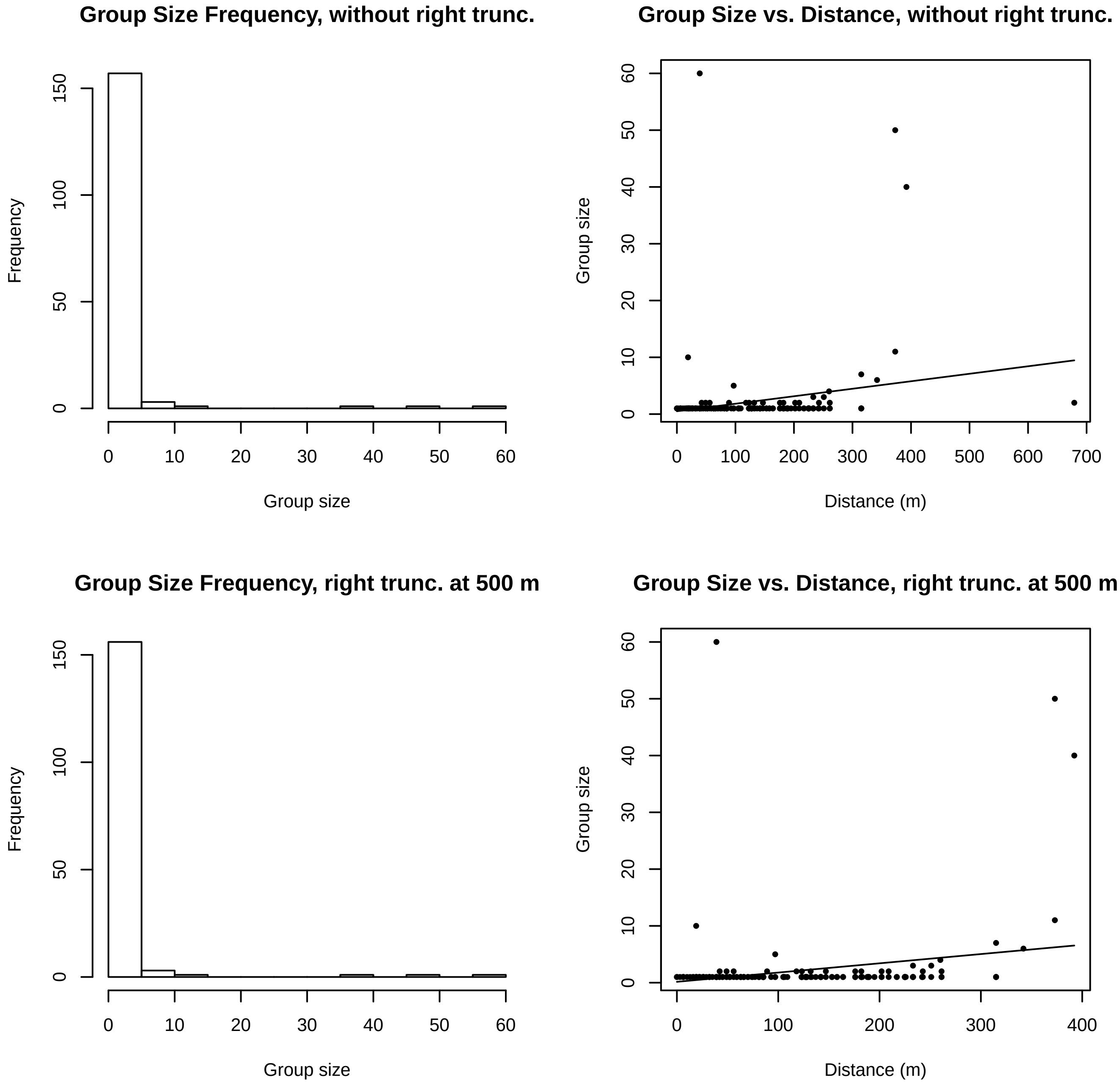


Figure 24: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

With Belly Observers

The sightings were right truncated at 500m.

Covariate	Description
beaufort	Beaufort sea state.
size	Estimated size (number of individuals) of the sighted group.

Table 12: Covariates tested in candidate "multi-covariate distance sampling" (MCDS) detection functions.

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hr			size	Yes	0.00	272
hn			size	Yes	9.12	204
hn	herm	4		Yes	21.74	228
hn				Yes	21.86	204
hn	cos	2		Yes	22.02	230
hr	poly	2		Yes	22.91	253
hr				Yes	22.93	270
hn	cos	3		Yes	23.81	209
hr	poly	4		Yes	24.23	266
hn			beaufort	No		
hr			beaufort	No		
hn			beaufort, size	No		
hr			beaufort, size	No		

Table 13: Candidate detection functions for With Belly Observers. The first one listed was selected for the density model.

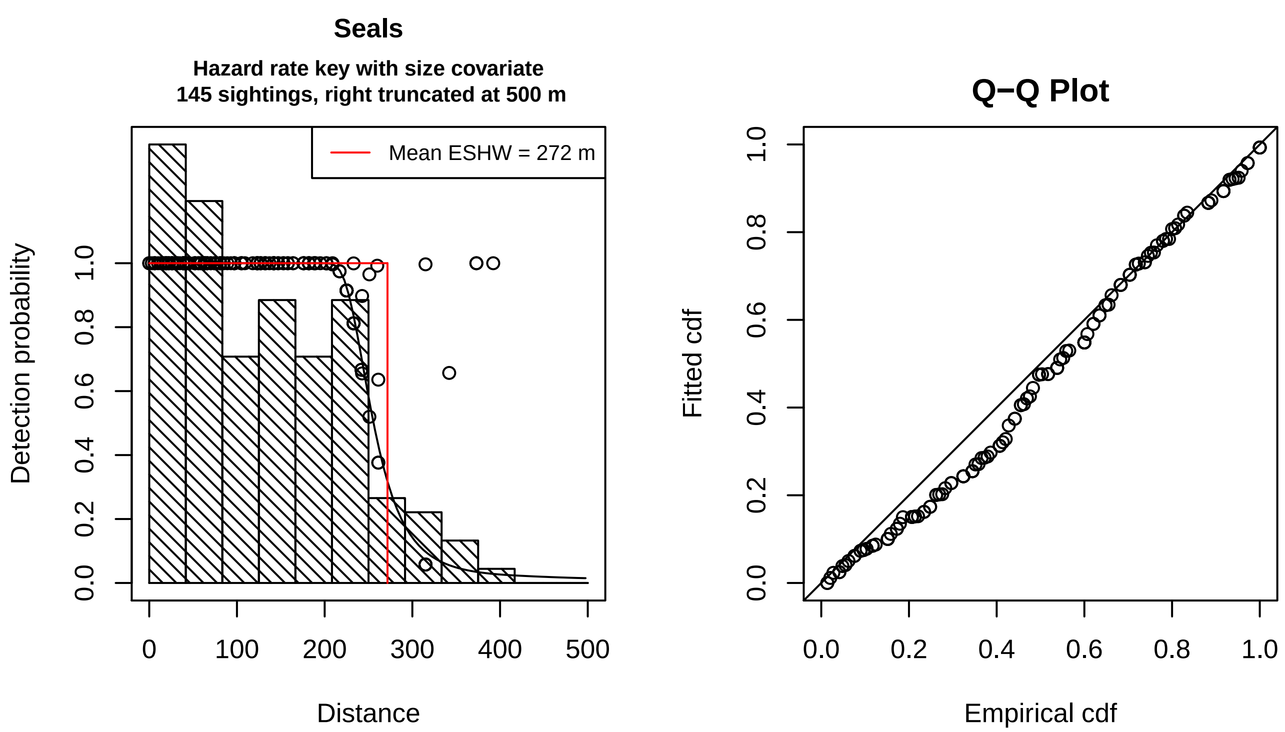


Figure 25: Detection function for With Belly Observers that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
```

```
Number of observations :  145
Distance range         :  0  -  500
AIC                    :  1664.159

Detection function:
 Hazard-rate key function

Detection function parameters
Scale Coefficients:
             estimate         se
(Intercept) 5.4287608 0.07137886
size        0.4928213 0.26580330

Shape parameters:
            estimate        se
(Intercept) 2.404159 0.2556778

                       Estimate          SE         CV
Average p             0.5345334  0.02008756 0.03757961
N in covered region 271.2646256 18.56328606 0.06843239
```

Additional diagnostic plots:

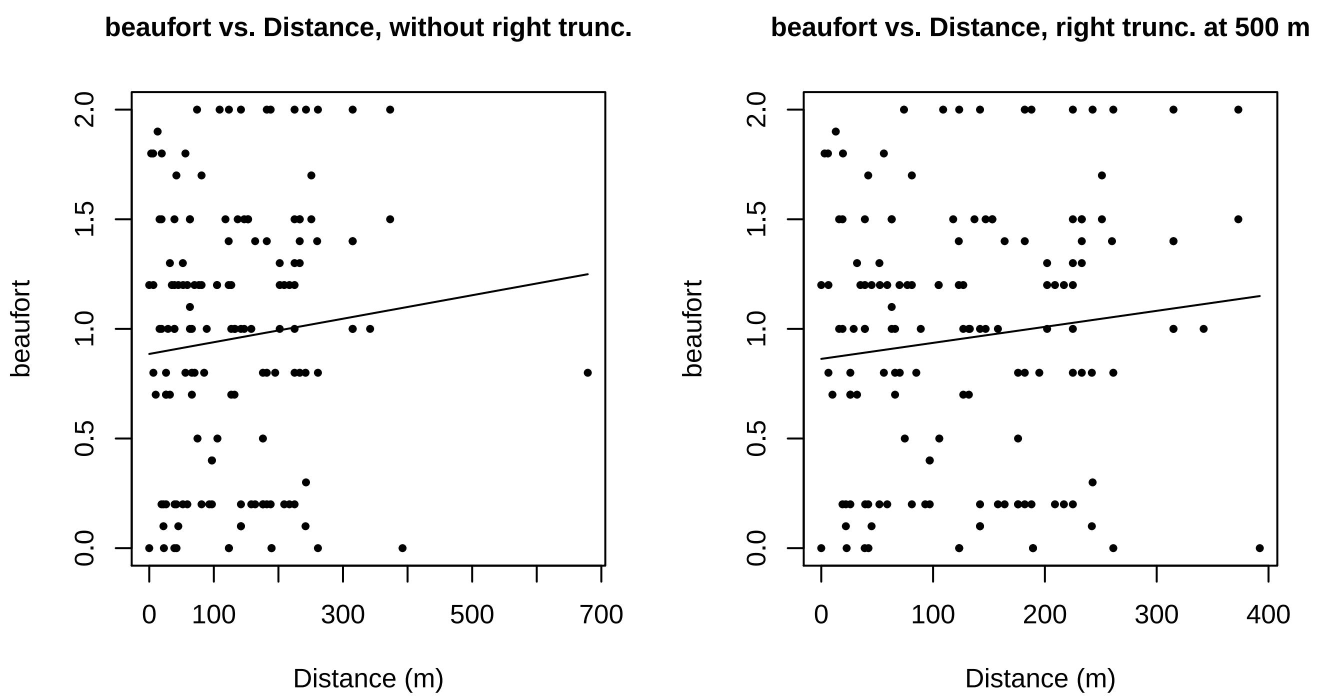


Figure 26: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

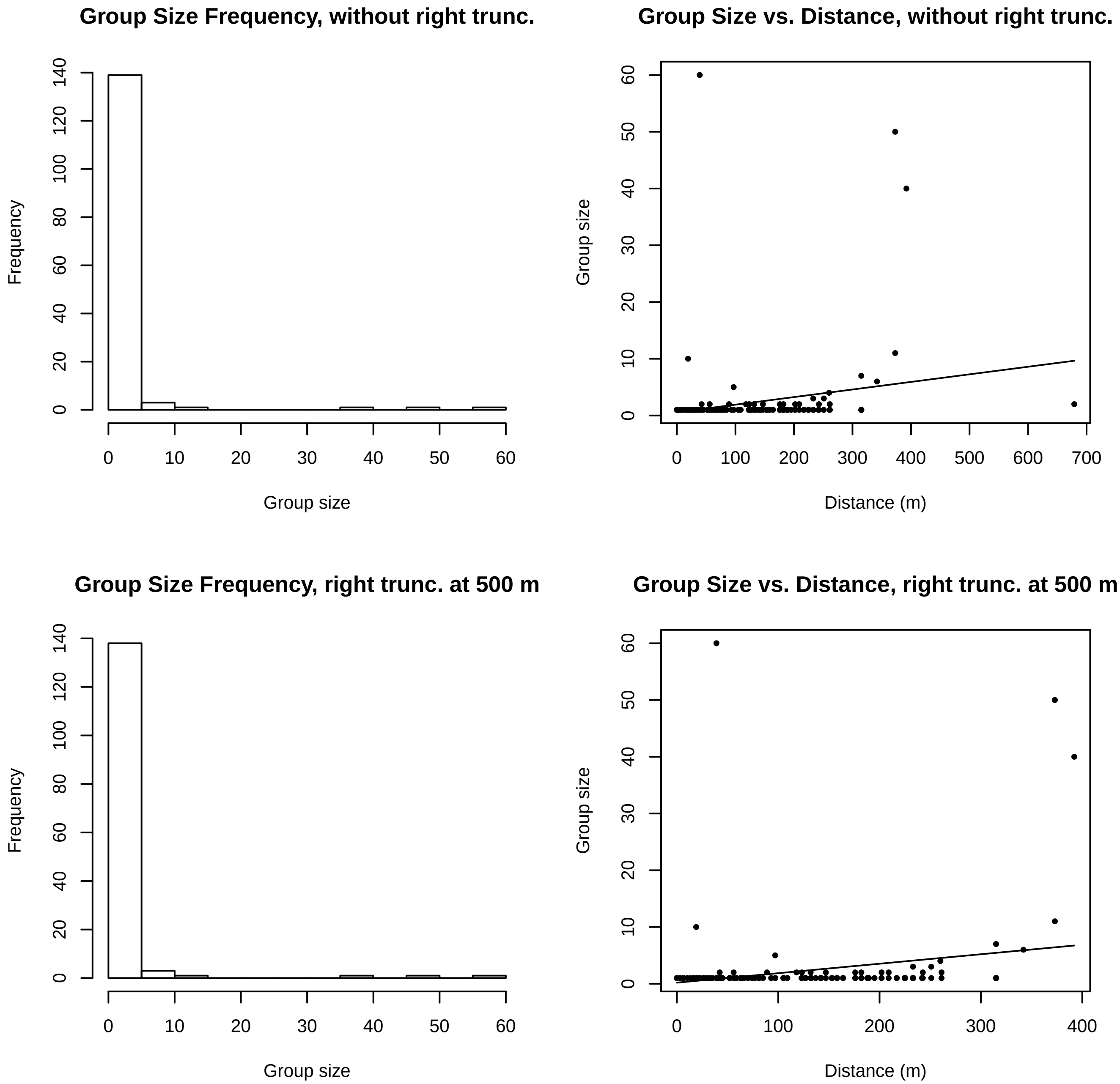


Figure 27: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

NARWSS Grummans

The sightings were right truncated at 600m. Due to a reduced frequency of sightings close to the trackline that plausibly resulted from the behavior of the observers and/or the configuration of the survey platform, the sightings were left truncted as well. Sightings closer than 107 m to the trackline were omitted from the analysis, and it was assumed that the the area closer to the trackline than this was not surveyed. This distance was estimated by inspecting histograms of perpendicular sighting distances.

Covariate	Description

beaufort	Beaufort sea state.
quality	Survey-specific index of the quality of observation conditions, utilizing relevant factors other than Beaufort sea state (see methods).
size	Estimated size (number of individuals) of the sighted group.

Table 14: Covariates tested in candidate "multi-covariate distance sampling" (MCDS) detection functions.

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hn				Yes	0.00	161
hn			quality	Yes	1.32	161
hr				Yes	1.76	184
hn			beaufort	Yes	1.99	161
hn	herm	4		Yes	1.99	160
hn			beaufort, quality	Yes	2.43	166
hr	poly	4		Yes	3.32	177
hr			quality	Yes	3.43	190
hr	poly	2		Yes	3.44	165
hr			size	Yes	3.73	183
hr			quality, size	Yes	5.40	188
hn	cos	2		No		
hn	cos	3		No		
hr			beaufort	No		
hn			size	No		
hr			beaufort, quality	No		
hn			beaufort, size	No		
hr			beaufort, size	No		
hn			quality, size	No		
hn			beaufort, quality, size	No		
hr			beaufort, quality, size	No		

Table 15: Candidate detection functions for NARWSS Grummans. The first one listed was selected for the density model.

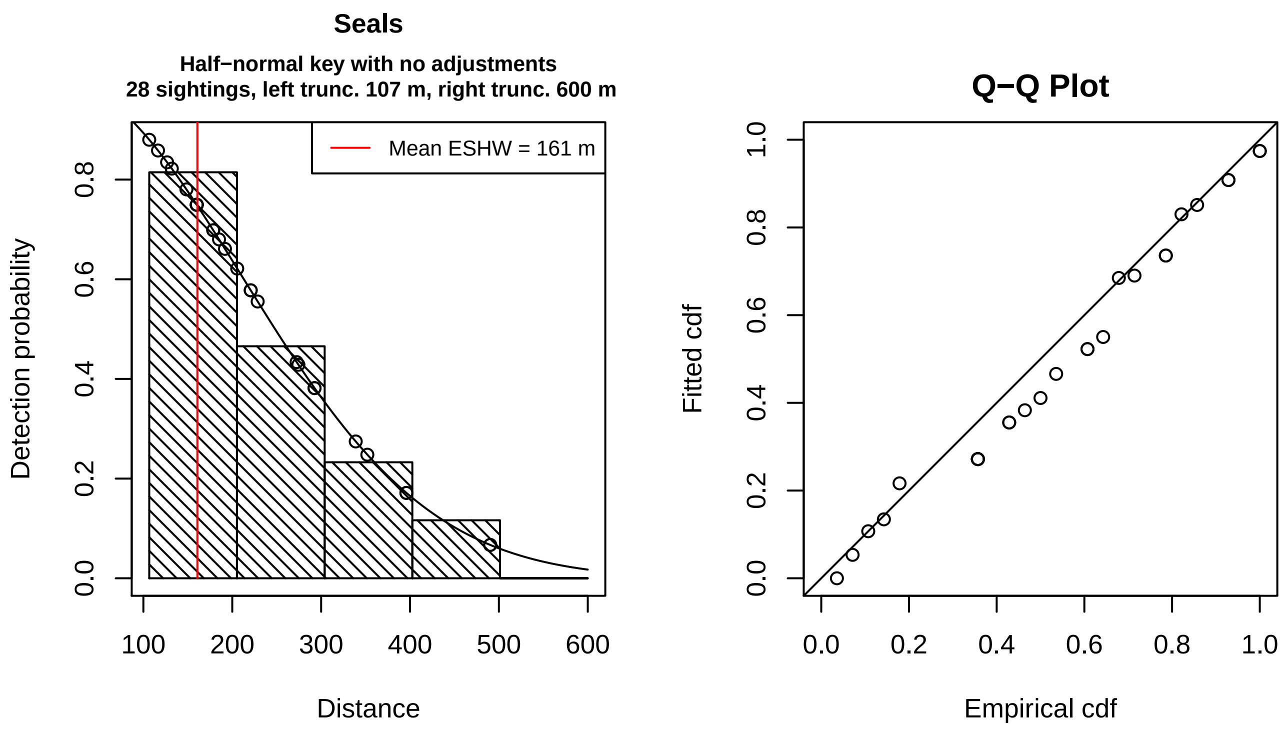


Figure 28: Detection function for NARWSS Grummans that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  28
Distance range         :  106.5979  -  600
AIC                    :  329.0045

Detection function:
 Half-normal key function

Detection function parameters
Scale Coefficients:
            estimate        se
(Intercept) 5.350888 0.1339307

                        Estimate          SE        CV
Average p              0.2680013  0.05450231 0.2033659
N in covered region 104.4771128 27.14404720 0.2598086
```

Additional diagnostic plots:

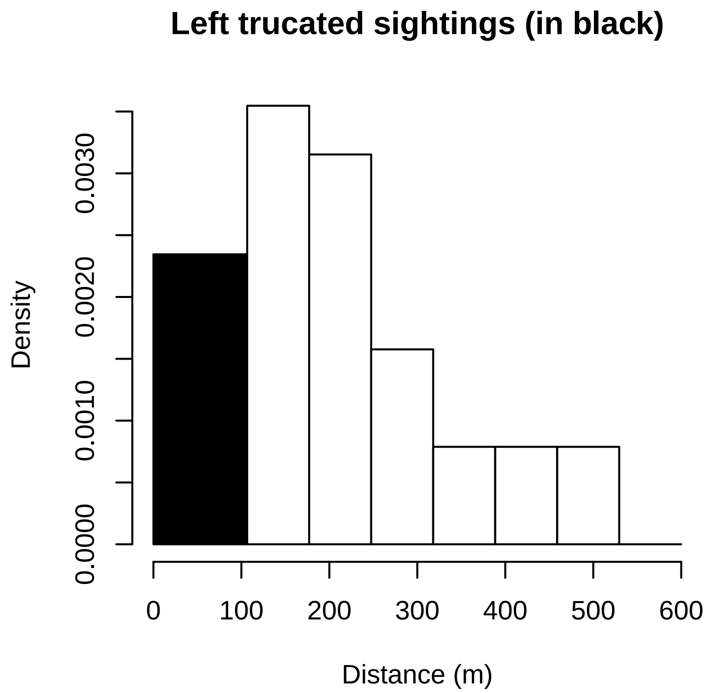


Figure 29: Density of sightings by perpendicular distance for NARWSS Grummans. Black bars on the left show sightings that were left truncated.

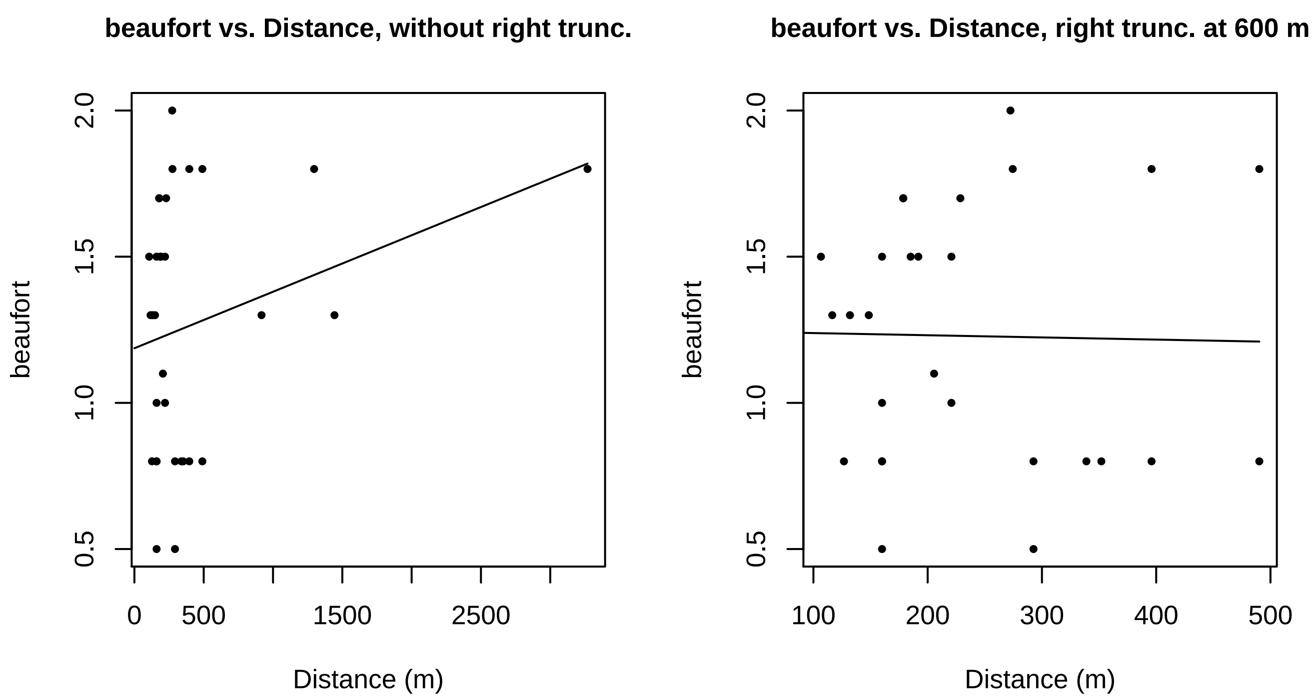


Figure 30: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

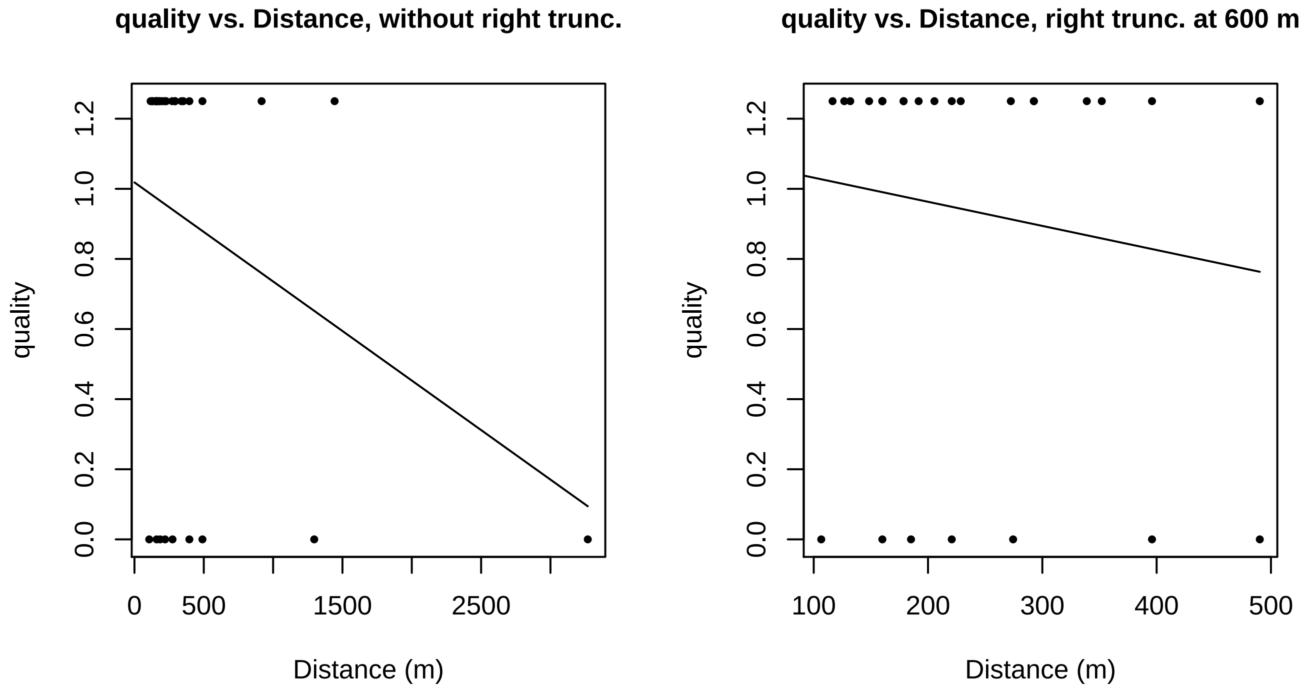


Figure 31: Scatterplots showing the relationship between the survey-specific index of the quality of observation conditions and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). Low values of the quality index correspond to better observation conditions. The line is a simple linear regression.

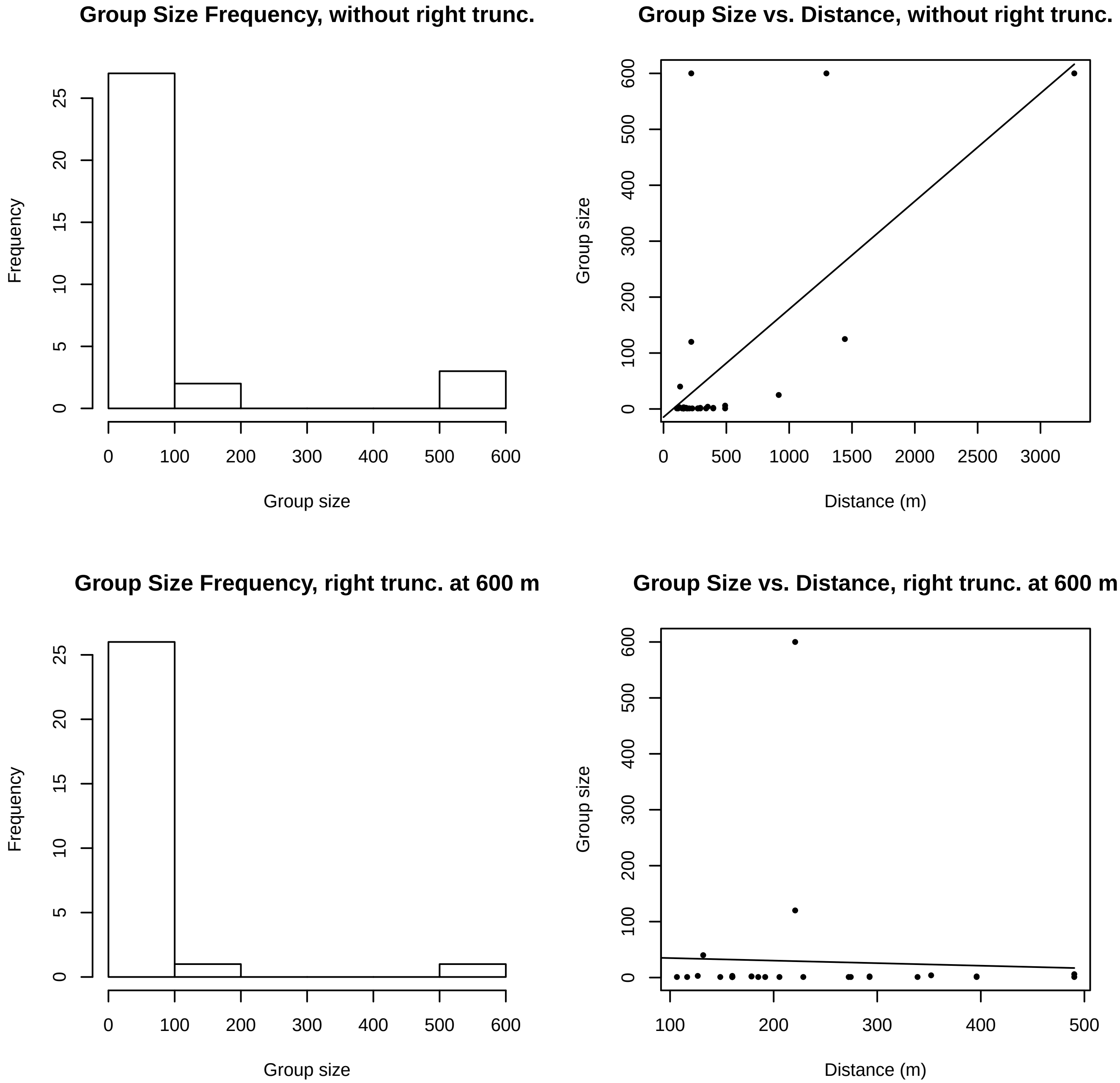


Figure 32: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

NARWSS Twin Otters

The sightings were right truncated at 1366m. Due to a reduced frequency of sightings close to the trackline that plausibly resulted from the behavior of the observers and/or the configuration of the survey platform, the sightings were left truncted as well. Sightings closer than 160 m to the trackline were omitted from the analysis, and it was assumed that the the area closer to the trackline than this was not surveyed. This distance was estimated by inspecting histograms of perpendicular sighting distances. The vertical sighting angles were heaped at 10 degree increments up to 80 degrees and 1 degree increments thereafter, so the candidate detection functions were fitted using linear bins scaled accordingly.

Covariate	Description

beaufort	Beaufort sea state.
quality	Survey-specific index of the quality of observation conditions, utilizing relevant factors other than Beaufort sea state (see methods).
size	Estimated size (number of individuals) of the sighted group.

Table 16: Covariates tested in candidate "multi-covariate distance sampling" (MCDS) detection functions.

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hr			quality, size	Yes	0.00	399
hr			size	Yes	2.55	401
hn			size	Yes	10.50	326
hr				Yes	19.32	368
hr			quality	Yes	19.36	364
hr	poly	4		Yes	21.32	368
hr	poly	2		Yes	21.32	368
hn	cos	2		Yes	24.07	263
hn				Yes	26.73	311
hn			quality	Yes	27.42	310
hn	herm	4		Yes	28.56	310
hn	cos	3		Yes	28.69	302
hn			beaufort	No		
hr			beaufort	No		
hn			beaufort, quality	No		
hr			beaufort, quality	No		
hn			beaufort, size	No		
hr			beaufort, size	No		
hn			quality, size	No		
hn			beaufort, quality, size	No		
hr			beaufort, quality, size	No		

Table 17: Candidate detection functions for NARWSS Twin Otters. The first one listed was selected for the density model.

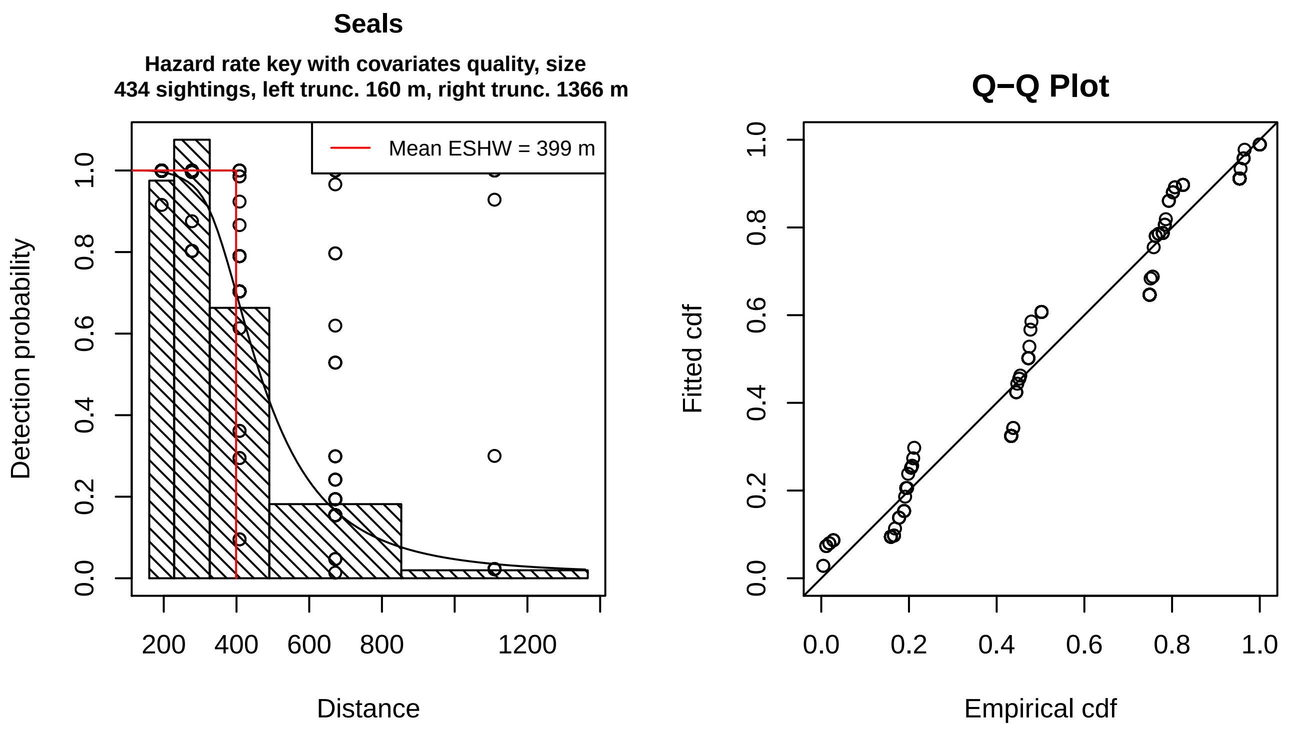


Figure 33: Detection function for NARWSS Twin Otters that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  434
Distance range         :  160.0674  -  1366
AIC                    :  1280.265

Detection function:
 Hazard-rate key function

Detection function parameters
Scale Coefficients:
              estimate         se
(Intercept)  5.9984043 0.06933697
quality     -0.2507717 0.09349205
size         3.1724891 1.34857373

Shape parameters:
            estimate         se
(Intercept) 1.380748 0.09276773

                         Estimate           SE         CV
Average p               0.2654152    0.0171183 0.06449628
N in covered region 1635.1735723 125.7442246 0.07689962
```

Additional diagnostic plots:

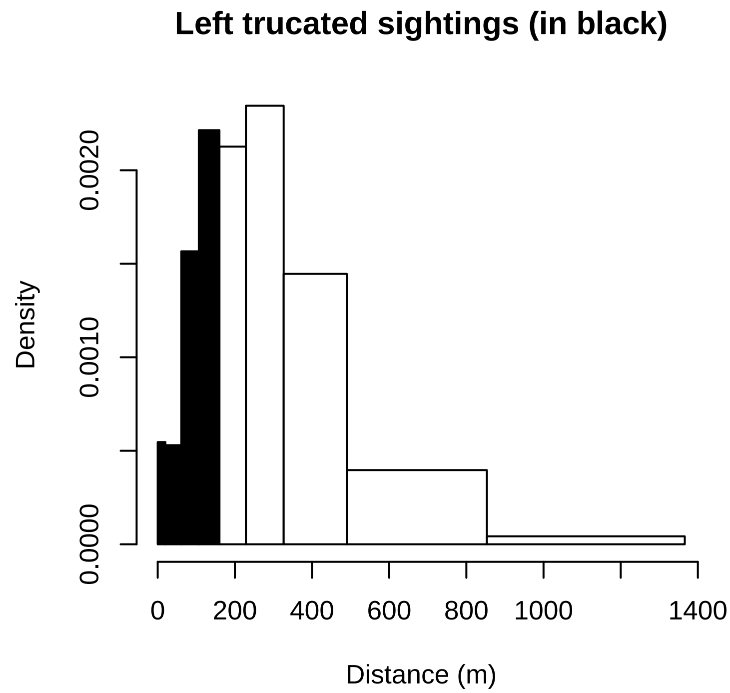


Figure 34: Density of sightings by perpendicular distance for NARWSS Twin Otters. Black bars on the left show sightings that were left truncated.

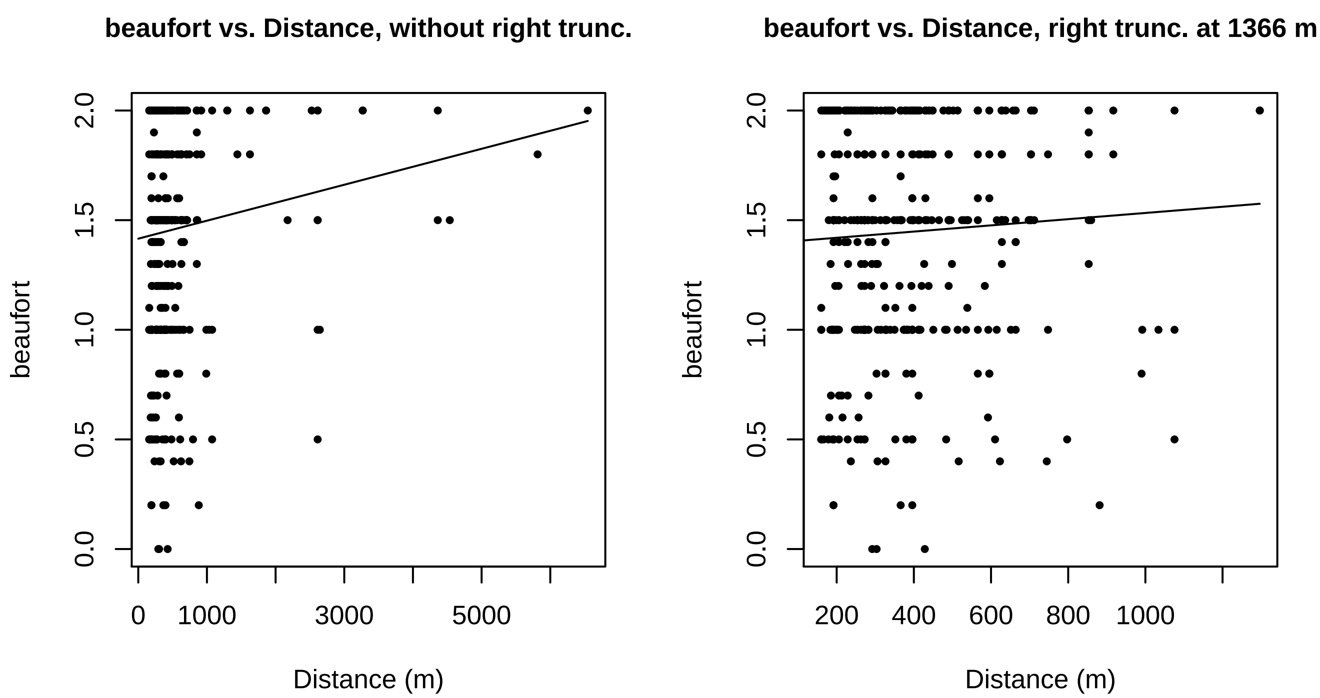


Figure 35: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

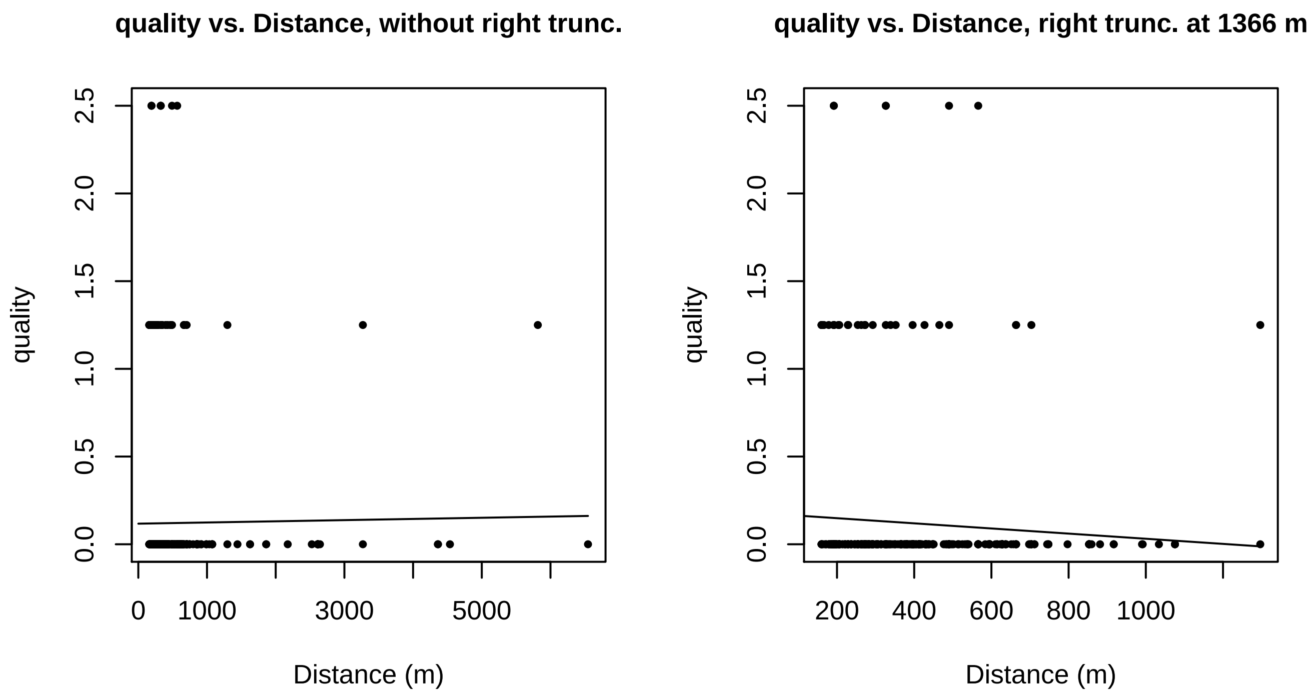


Figure 36: Scatterplots showing the relationship between the survey-specific index of the quality of observation conditions and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). Low values of the quality index correspond to better observation conditions. The line is a simple linear regression.

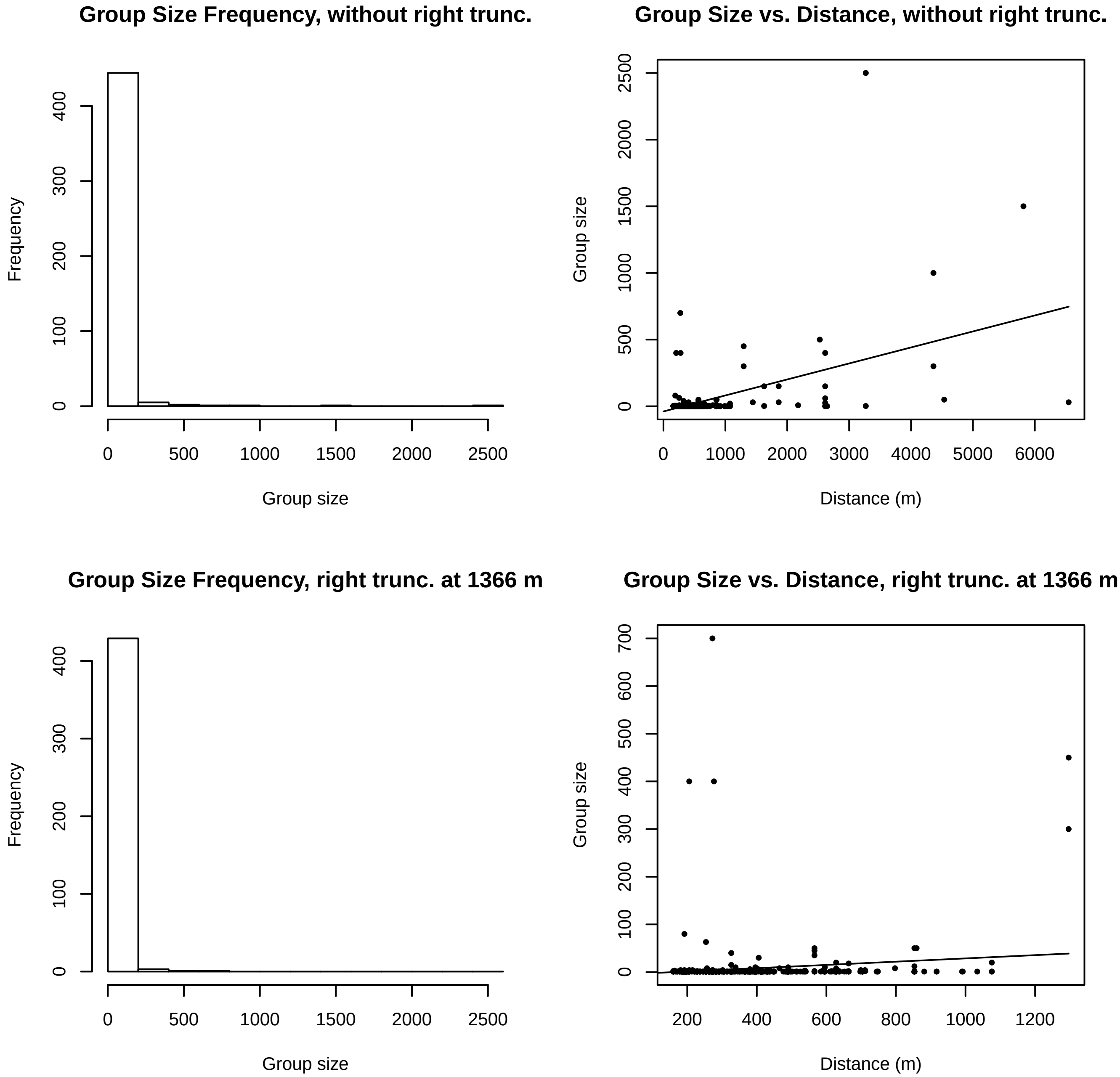


Figure 37: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

g(0) Estimates

Platform	Surveys	Group Size	*g(0)*	Biases Addressed	Source
Shipboard	All	Any	0.843	Perception	Reay (2005)
Aerial	All	1-5	0.281	Both	Carretta et al. (2000)
		>5	1	Both	None

Table 18: Estimates of *g(0)* used in this density model.

We used Reay's (2005) g(0) estimates for grey seals observed on small boat surveys, taking the simple mean of his 2003/04 g(0) at 100m (0.786) and 2005 g(0) at 100m (0.900). Substantial platform and protocol differences existed between his survey and ours, however this was the only g(0) estimate we could locate in the literature for seals observed on shipboard surveys. We contacted the NOAA SWFSC cetacean density modeling team and they indicated they did not have a better estimate (E. Becker, pers. comm.). Our results should be viewed with caution.

For aerial surveys, we used Carretta et al.'s (2000) estimate of the availability bias component of g(0) for harbor seals, estimated from dive data (Stern 1992) for aerial surveys conducted with two observers with bubble windows at an altitude of 213 m (700 ft) and an airspeed of 185 km/hr (100 kts). This estimate addressed both perception and availability biases. The mean size of harbor seal groups in Carretta et al.'s study was 1.0, thus they did not provide a separate estimate for large groups. In our surveys, roughly 25% of the seal sightings were of more than one animal, with roughly 15% being of more than 5 animals, and a maximum size of 2000. To account for the likelihood that large groups are easier to detect on the trackline, we assumed that g(0)=1 for groups of more than 5 animals, under the assumption that large groups of seals are likely to be socializing at the surface and therefore will be highly available and easy to detect. We do not have empirical evidence to support the choice of 5 as the threshold, however Palka (2006) used this threshold in her estimates of cetacean g(0)s.

Density Models

Winter

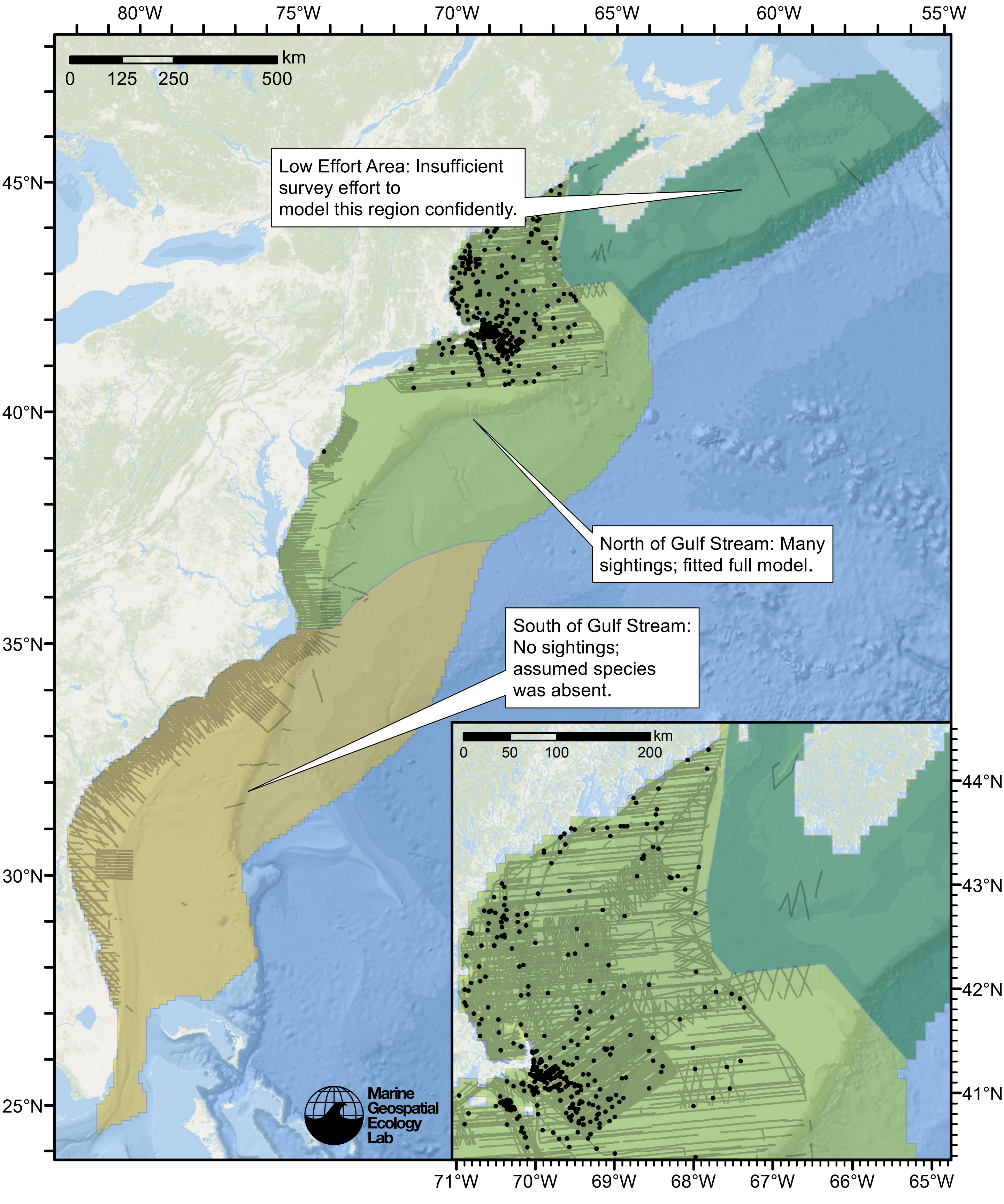


Figure 38: Seals density model schematic for Winter season. All on-effort sightings are shown, including those that were truncated when detection functions were fitted.

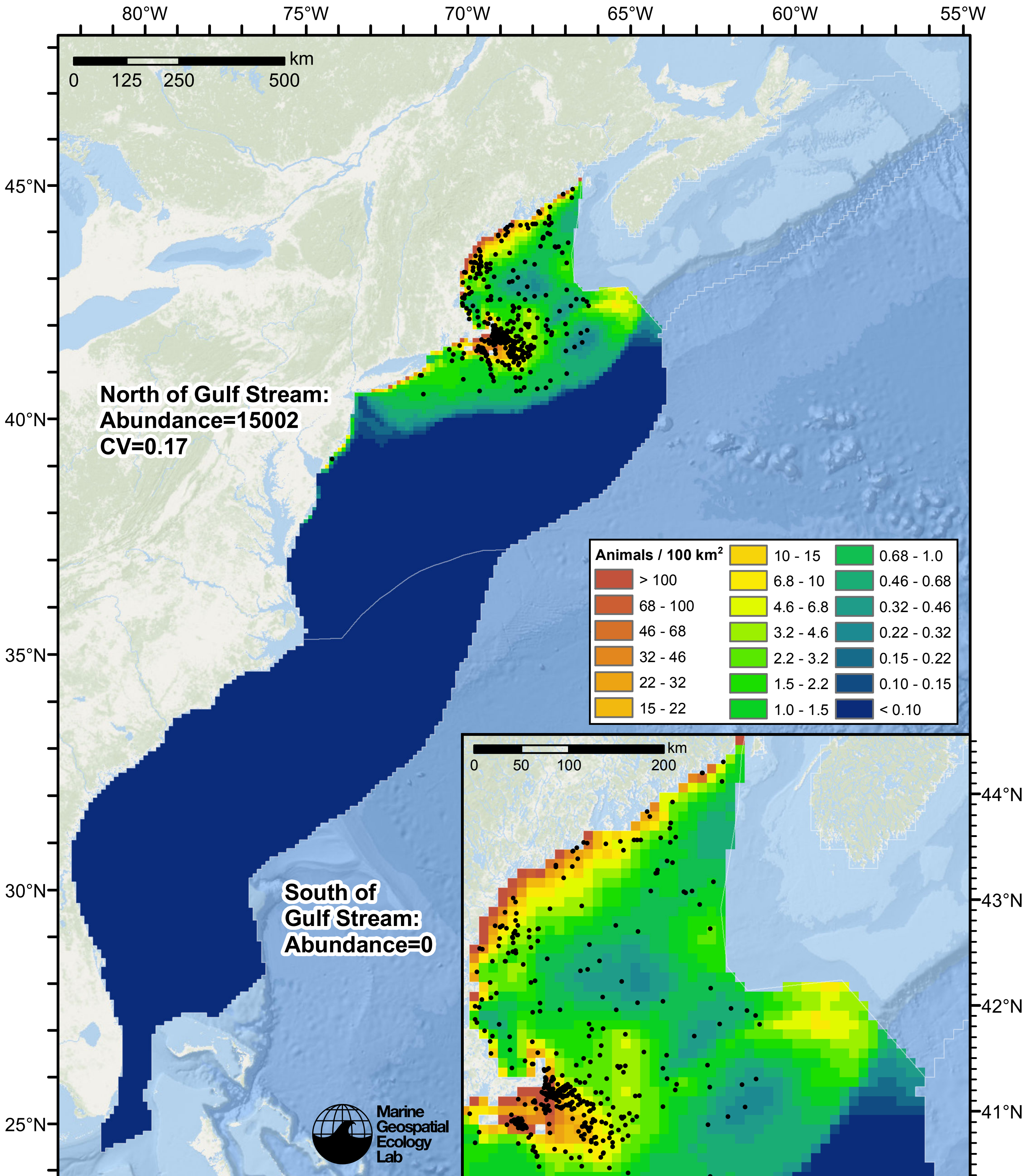


Figure 39: Seals density predicted by the Winter season climatological model that explained the most deviance. Pixels are 10x10 km. The legend gives the estimated individuals per pixel; breaks are logarithmic. The same scale is used for all seasons. Abundance for each region was computed by summing the density cells occuring in that region.

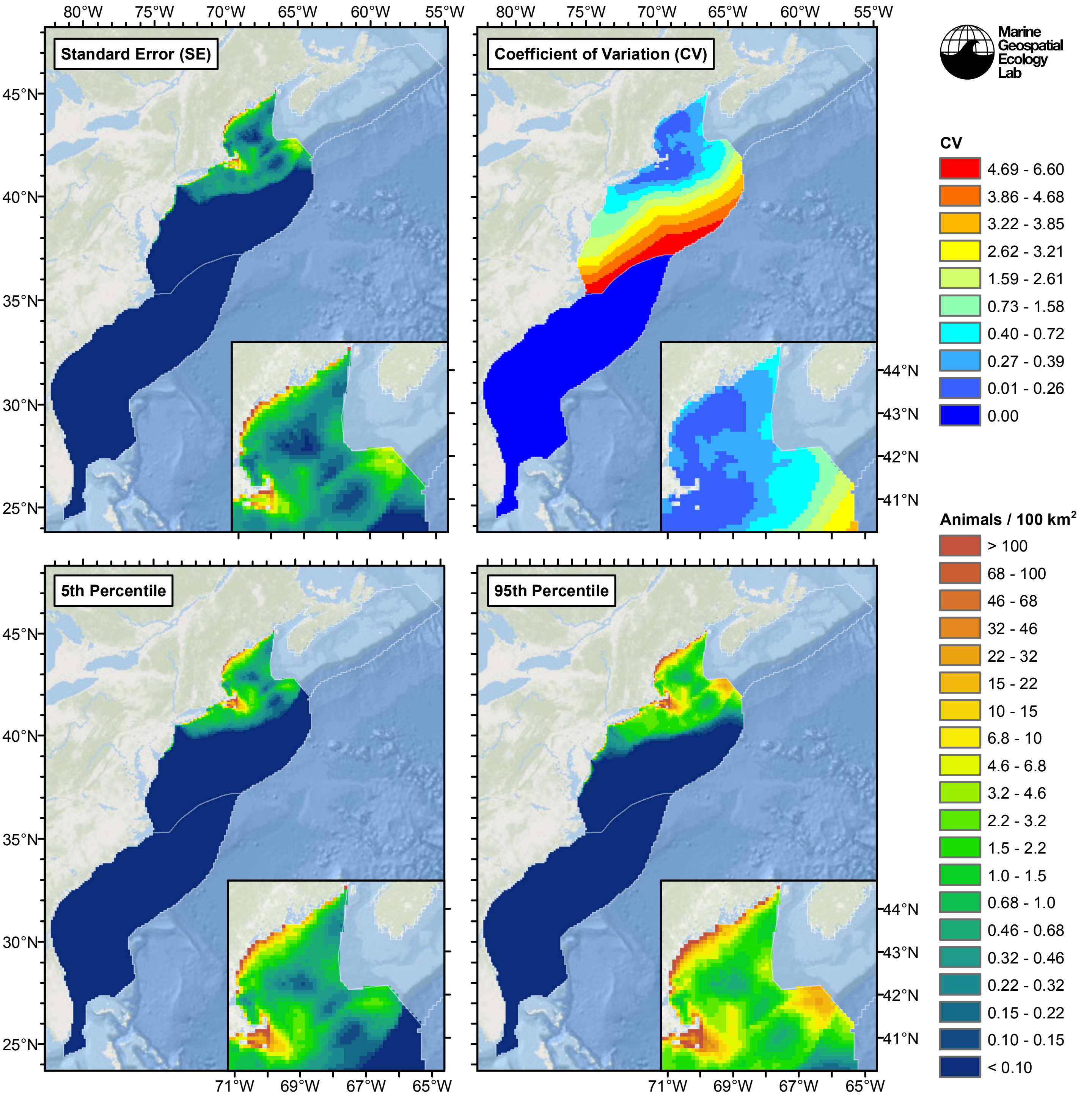


Figure 40: Estimated uncertainty for the Winter season climatological model that explained the most deviance. These estimates only incorporate the statistical uncertainty estimated for the spatial model (by the R mgcv package). They do not incorporate uncertainty in the detection functions, g(0) estimates, predictor variables, and so on.

North of Gulf Stream

Statistical output

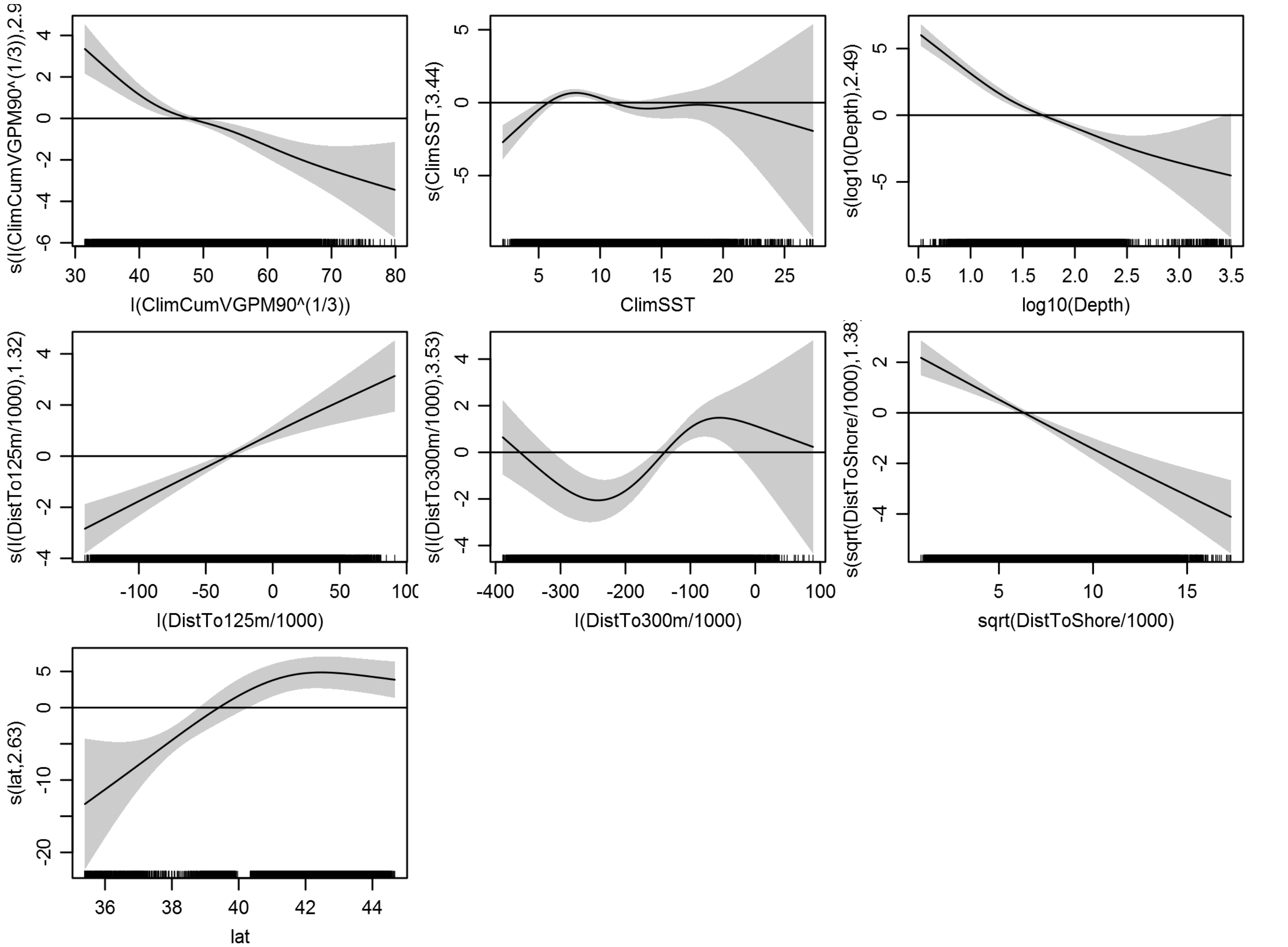
```
Rscript.exe: This is mgcv 1.8-3. For overview type 'help("mgcv-package")'.


Family: Tweedie(p=1.339)
```

```
Link function: log

Formula:
abundance ~ offset(log(area_km2)) + s(lat, bs = "ts", k = 5) +
    s(log10(Depth), bs = "ts", k = 5) + s(sqrt(DistToShore/1000),
    bs = "ts", k = 5) + s(I(DistTo125m/1000), bs = "ts", k = 5) +
    s(I(DistTo300m/1000), bs = "ts", k = 5) + s(ClimSST, bs = "ts",
    k = 5) + s(I(ClimCumVGPM90^(1/3)), bs = "ts", k = 5)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)    -7.72       1.06  -7.286 3.39e-13 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                            edf Ref.df      F  p-value
s(lat)                    2.634      4  8.689 5.41e-09 ***
s(log10(Depth))           2.490      4 54.438  < 2e-16 ***
s(sqrt(DistToShore/1000)) 1.376      4 11.797 4.99e-14 ***
s(I(DistTo125m/1000))     1.321      4  9.524 1.22e-11 ***
s(I(DistTo300m/1000))     3.535      4 15.401 7.76e-16 ***
s(ClimSST)                3.444      4 10.309 1.10e-09 ***
s(I(ClimCumVGPM90^(1/3))) 2.968      4  9.204 2.20e-09 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.0894   Deviance explained = 56.3%
-REML = 2212.3  Scale est. = 31.032    n = 11892

All predictors were significant. This is the final model.
Creating term plots.
Diagnostic output from gam.check():

Method: REML   Optimizer: outer newton
full convergence after 12 iterations.
Gradient range [-0.000394223,0.0002948432]
(score 2212.348 & scale 31.03151).
Hessian positive definite, eigenvalue range [0.5223308,856.2241].
Model rank =  29 / 29

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                             k'   edf k-index p-value
s(lat)                    4.000 2.634   0.787    0.00
s(log10(Depth))           4.000 2.490   0.835    0.04
s(sqrt(DistToShore/1000)) 4.000 1.376   0.846    0.18
s(I(DistTo125m/1000))     4.000 1.321   0.840    0.07
s(I(DistTo300m/1000))     4.000 3.535   0.828    0.02
s(ClimSST)                4.000 3.444   0.829    0.01
s(I(ClimCumVGPM90^(1/3))) 4.000 2.968   0.842    0.10
```

Predictors retained during the model selection procedure: lat, Depth, DistToShore, DistTo125m, DistTo300m, ClimSST, ClimCumVGPM90

Predictors dropped during the model selection procedure: Slope, ClimTKE, ClimDistToFront1

Model term plots



Diagnostic plots

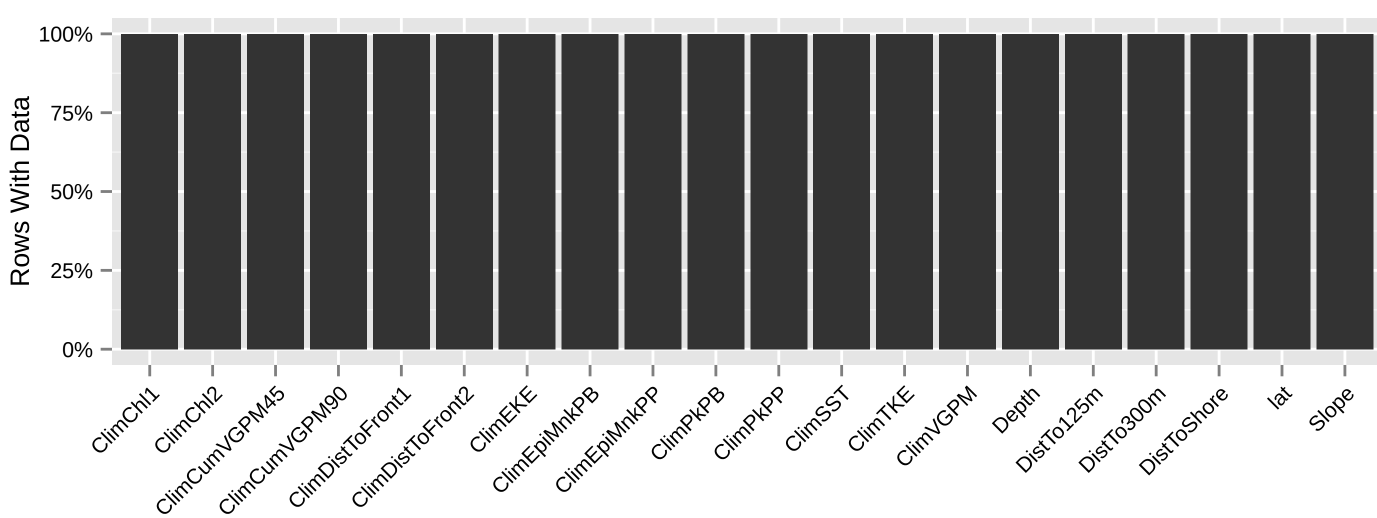


Figure 41: Segments with predictor values for the Seals Climatological model, Winter season, North of Gulf Stream. This plot is used to assess how many segments would be lost by including a given predictor in a model.

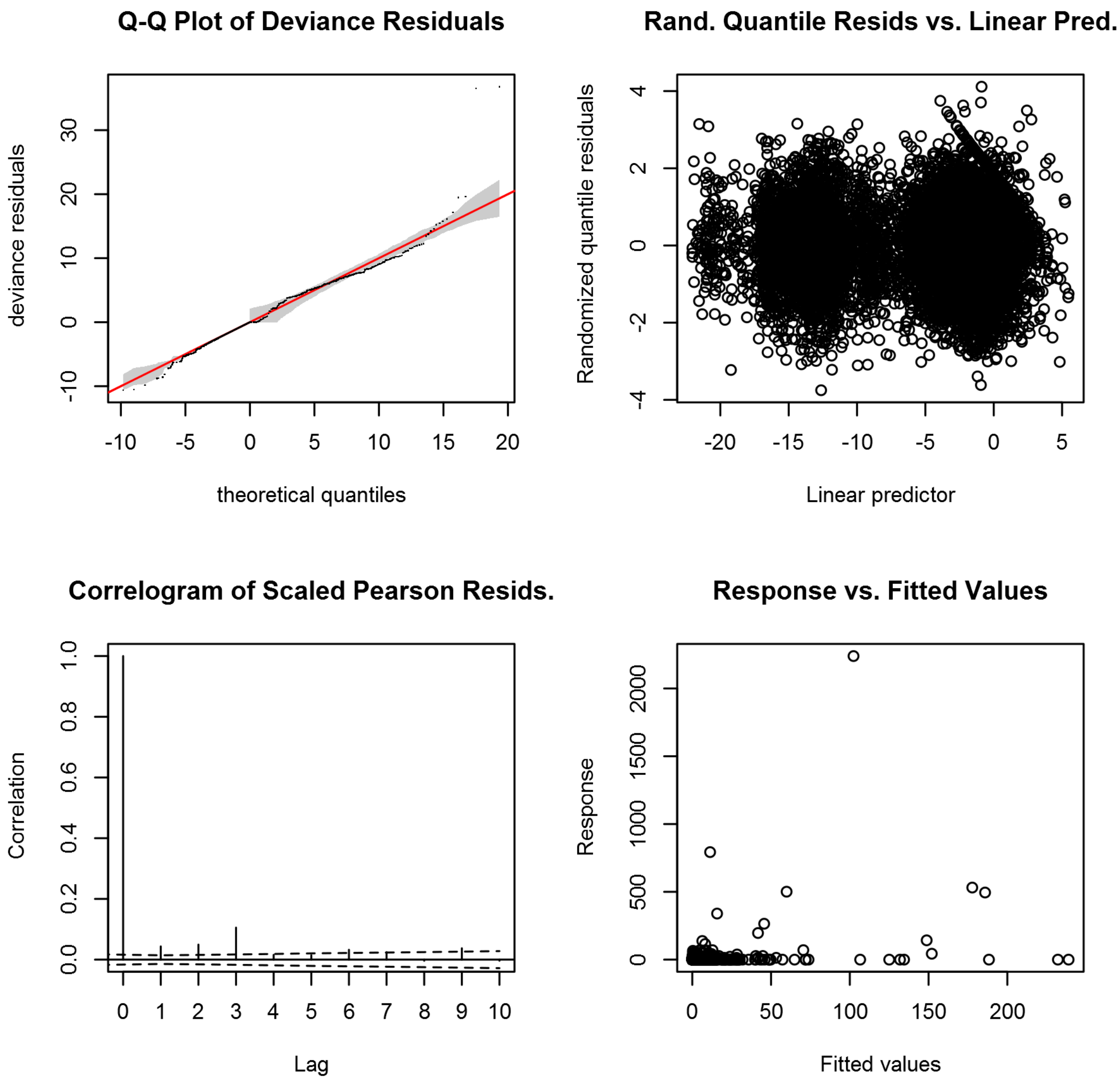


Figure 42: Statistical diagnostic plots for the Seals Climatological model, Winter season, North of Gulf Stream.

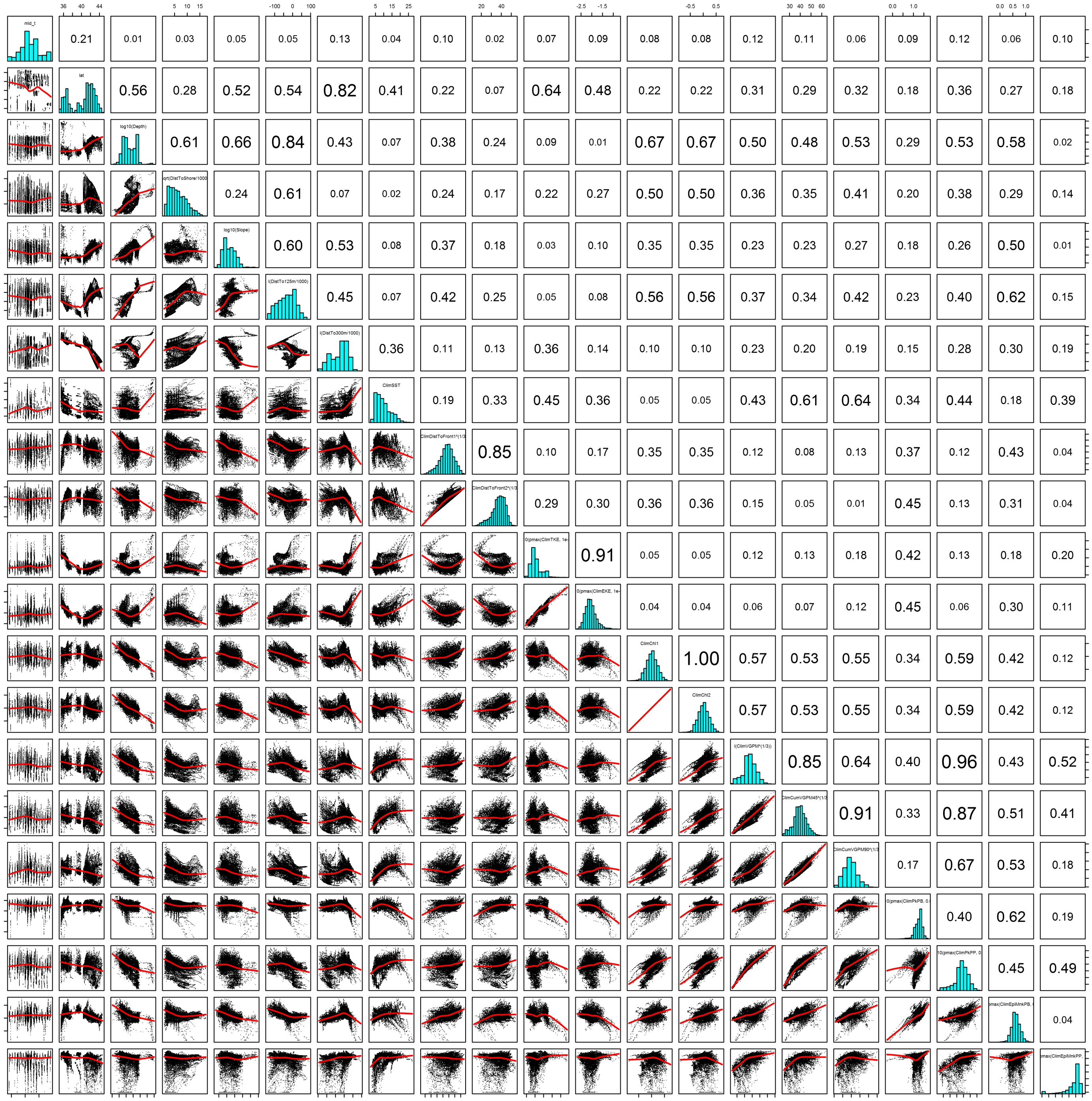


Figure 43: Scatterplot matrix for the Seals Climatological model, Winter season, North of Gulf Stream. This plot is used to inspect the distribution of predictors (via histograms along the diagonal), simple correlation between predictors (via pairwise Pearson coefficients above the diagonal), and linearity of predictor correlations (via scatterplots below the diagonal). This plot is best viewed at high magnification.

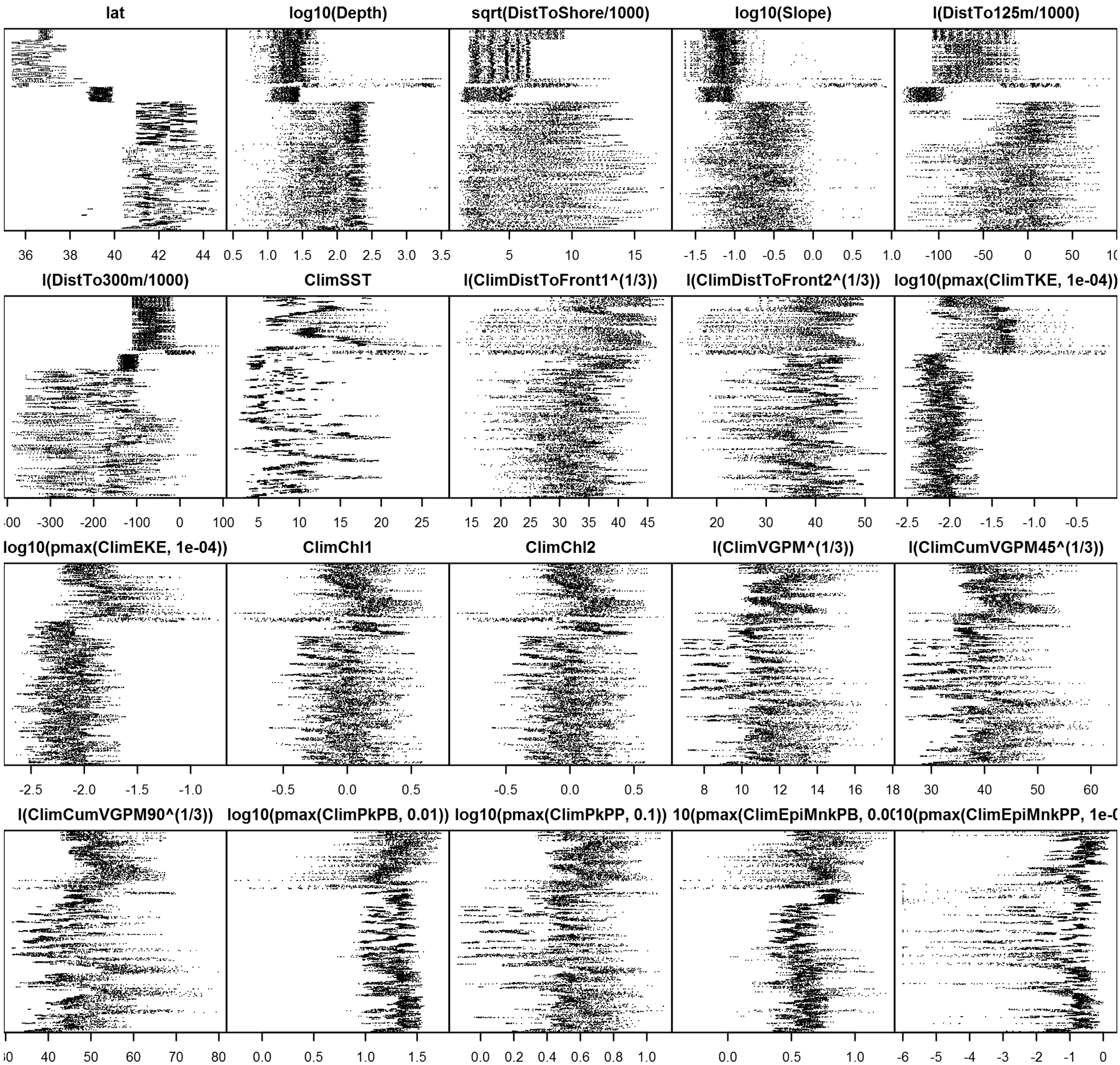


Figure 44: Dotplot for the Seals Climatological model, Winter season, North of Gulf Stream. This plot is used to check for suspicious patterns and outliers in the data. Points are ordered vertically by transect ID, sequentially in time.

South of Gulf Stream

Density assumed to be 0 in this region.

Low Effort Area

Density was not modeled for this region.

Contemporaneous Model

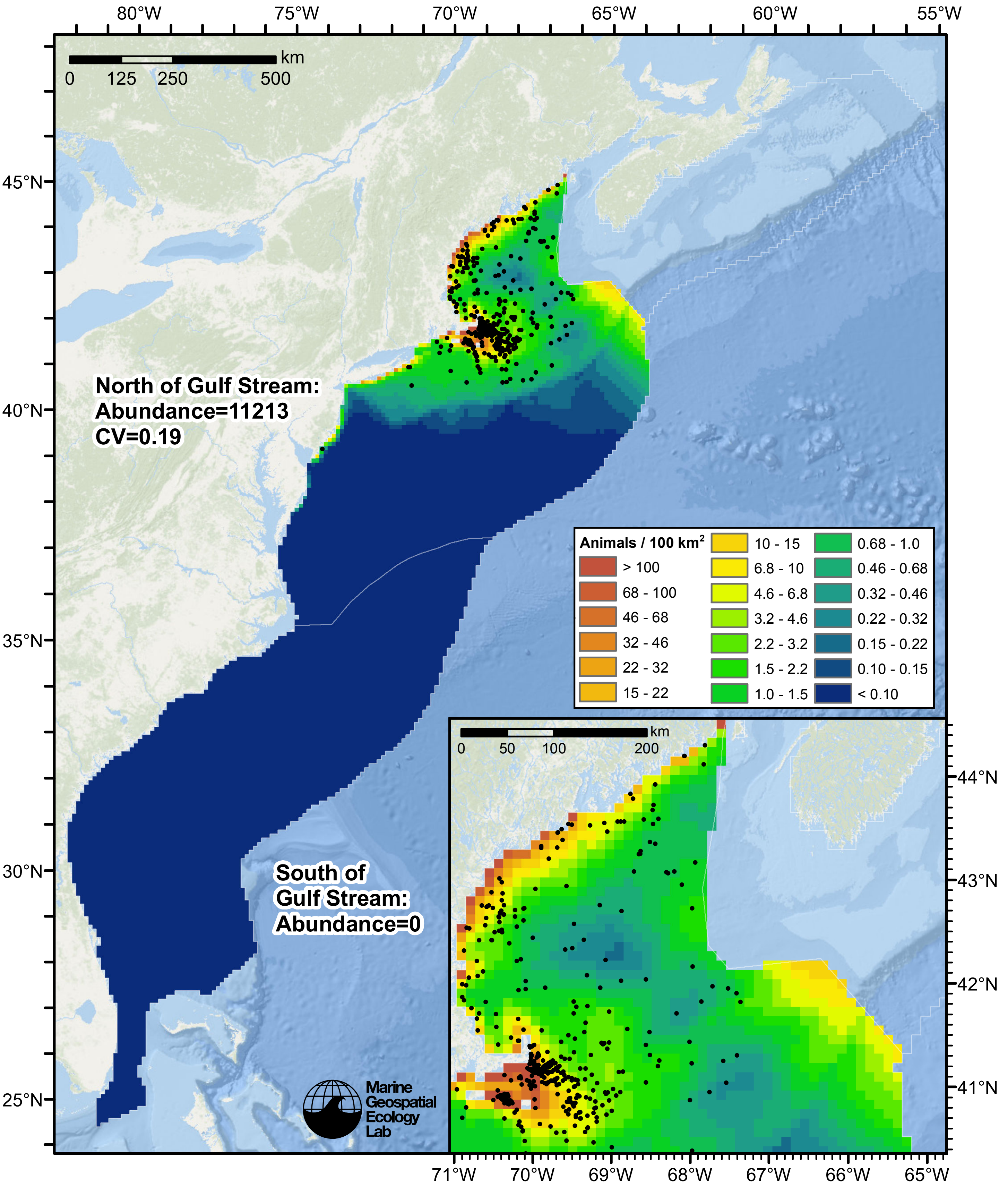


Figure 45: Seals density predicted by the Winter season contemporaneous model that explained the most deviance. Pixels are 10x10 km. The legend gives the estimated individuals per pixel; breaks are logarithmic. The same scale is used for all seasons. Abundance for each region was computed by summing the density cells occuring in that region.

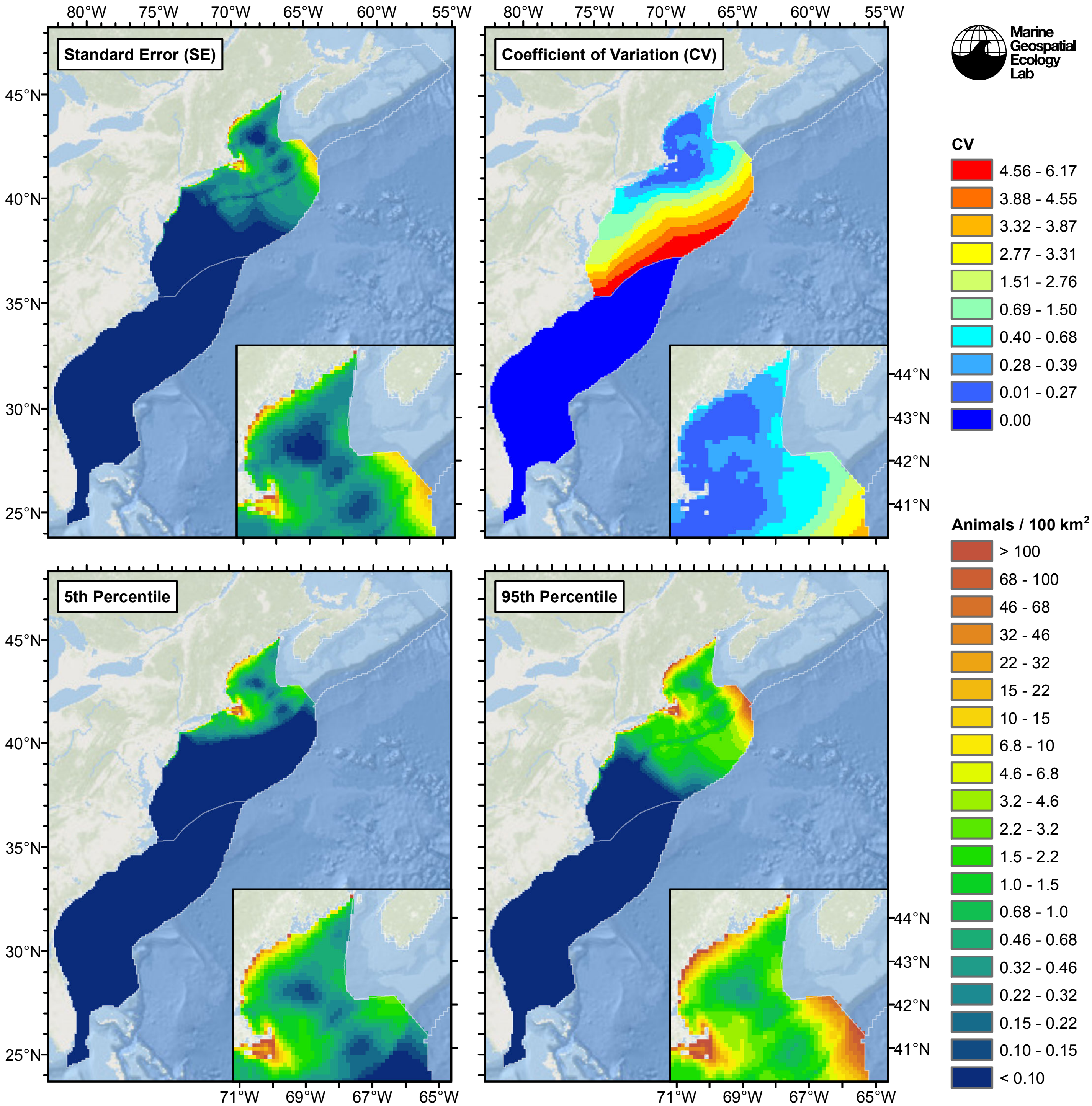


Figure 46: Estimated uncertainty for the Winter season contemporaneous model that explained the most deviance. These estimates only incorporate the statistical uncertainty estimated for the spatial model (by the R mgcv package). They do not incorporate uncertainty in the detection functions, g(0) estimates, predictor variables, and so on.

North of Gulf Stream

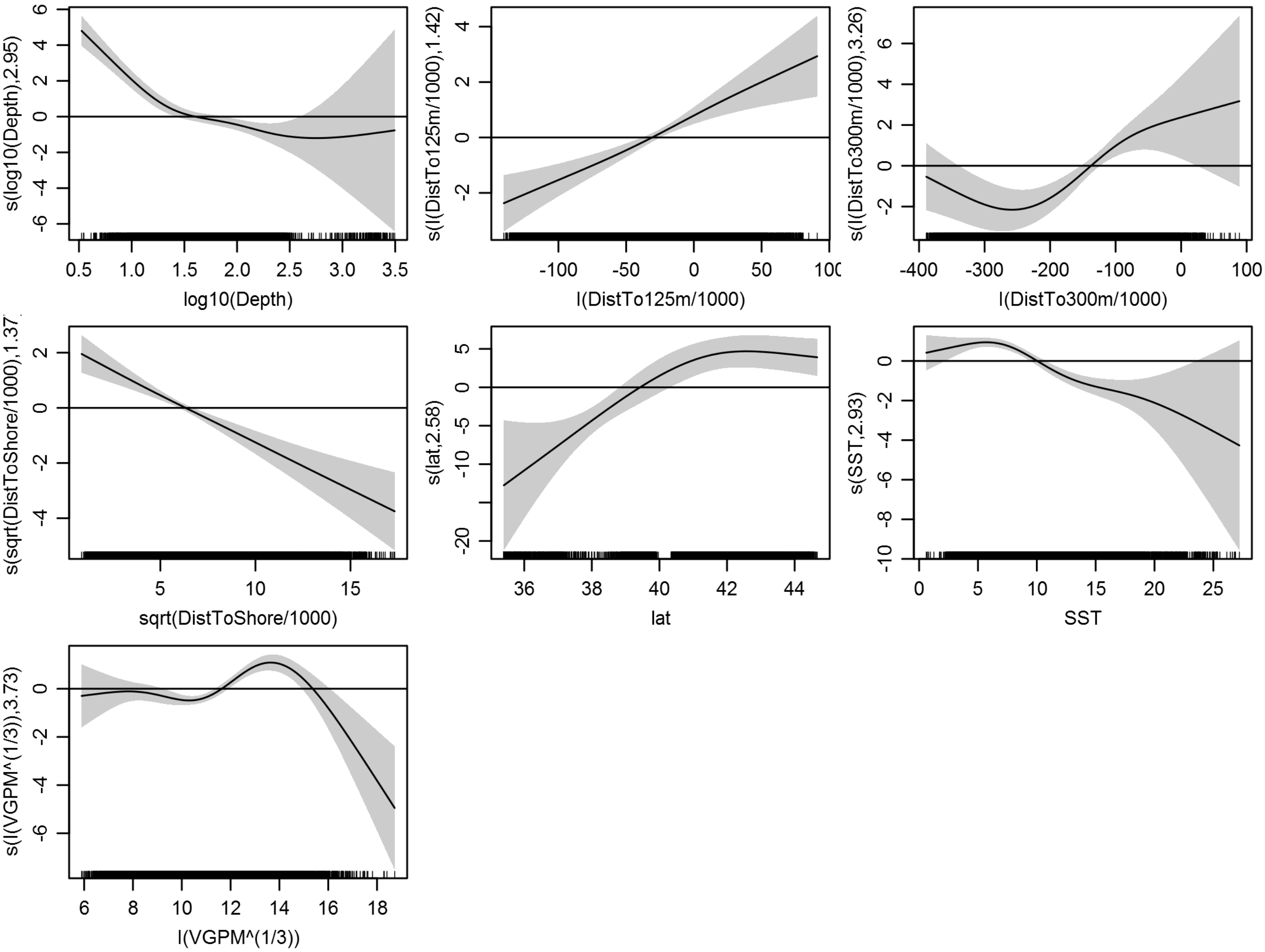
Statistical output

```
Rscript.exe: This is mgcv 1.8-3. For overview type 'help("mgcv-package")'.


Family: Tweedie(p=1.353)
```

```
Link function: log

Formula:
abundance ~ offset(log(area_km2)) + s(lat, bs = "ts", k = 5) +
    s(log10(Depth), bs = "ts", k = 5) + s(sqrt(DistToShore/1000),
    bs = "ts", k = 5) + s(I(DistTo125m/1000), bs = "ts", k = 5) +
    s(I(DistTo300m/1000), bs = "ts", k = 5) + s(SST, bs = "ts",
    k = 5) + s(I(VGPM^(1/3)), bs = "ts", k = 5)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   -7.678      0.999  -7.685 1.65e-14 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                            edf Ref.df      F  p-value
s(lat)                    2.577      4  8.349 1.04e-08 ***
s(log10(Depth))           2.946      4 33.905  < 2e-16 ***
s(sqrt(DistToShore/1000)) 1.367      4  9.675 4.58e-12 ***
s(I(DistTo125m/1000))     1.416      4  6.864 1.38e-08 ***
s(I(DistTo300m/1000))     3.256      4  9.549 2.60e-10 ***
s(SST)                    2.933      4 18.262  < 2e-16 ***
s(I(VGPM^(1/3)))          3.730      4 12.032 1.57e-10 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.0868   Deviance explained = 56.2%
-REML = 2215.9  Scale est. = 31.742    n = 11892

All predictors were significant. This is the final model.
Creating term plots.
Diagnostic output from gam.check():

Method: REML   Optimizer: outer newton
full convergence after 12 iterations.
Gradient range [-0.0007037888,0.0003733743]
(score 2215.908 & scale 31.74162).
Hessian positive definite, eigenvalue range [0.1942887,826.0333].
Model rank =  29 / 29

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                             k'   edf k-index p-value
s(lat)                    4.000 2.577   0.651    0.00
s(log10(Depth))           4.000 2.946   0.712    0.00
s(sqrt(DistToShore/1000)) 4.000 1.367   0.744    0.02
s(I(DistTo125m/1000))     4.000 1.416   0.762    0.26
s(I(DistTo300m/1000))     4.000 3.256   0.673    0.00
s(SST)                    4.000 2.933   0.750    0.04
s(I(VGPM^(1/3)))          4.000 3.730   0.758    0.12
```

```
Predictors retained during the model selection procedure: lat, Depth, DistToShore, DistTo125m,
DistTo300m, SST, VGPM

Predictors dropped during the model selection procedure: Slope, DistToFront1, TKE
```

Model term plots



Diagnostic plots

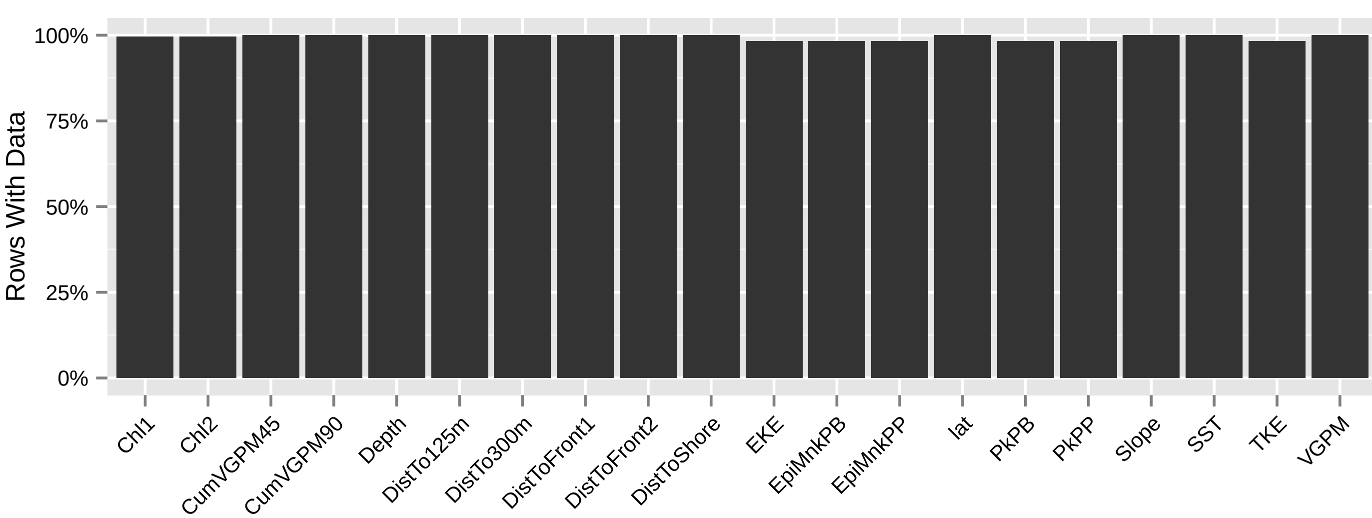


Figure 47: Segments with predictor values for the Seals Contemporaneous model, Winter season, North of Gulf Stream. This plot is used to assess how many segments would be lost by including a given predictor in a model.

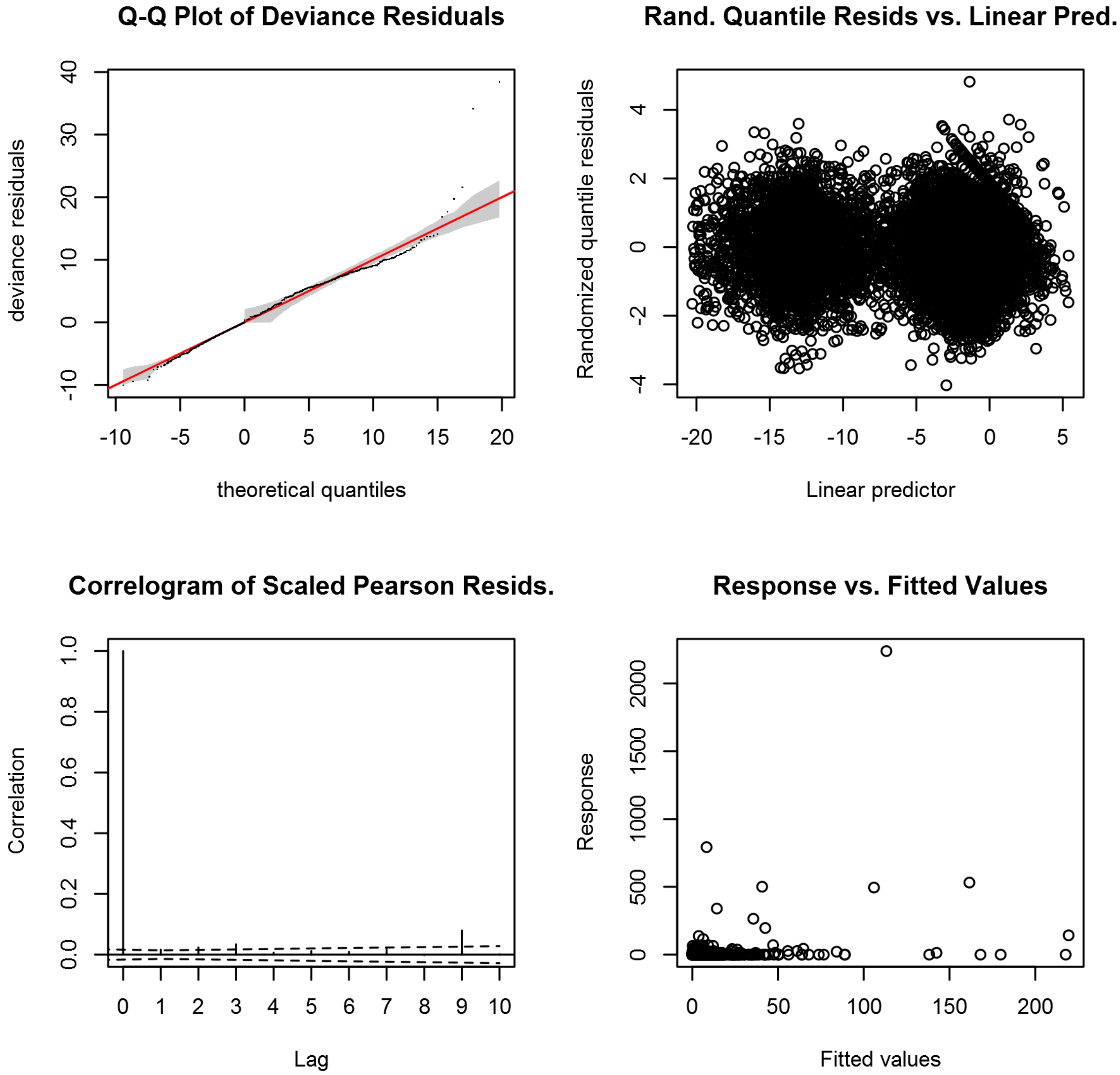


Figure 48: Statistical diagnostic plots for the Seals Contemporaneous model, Winter season, North of Gulf Stream.

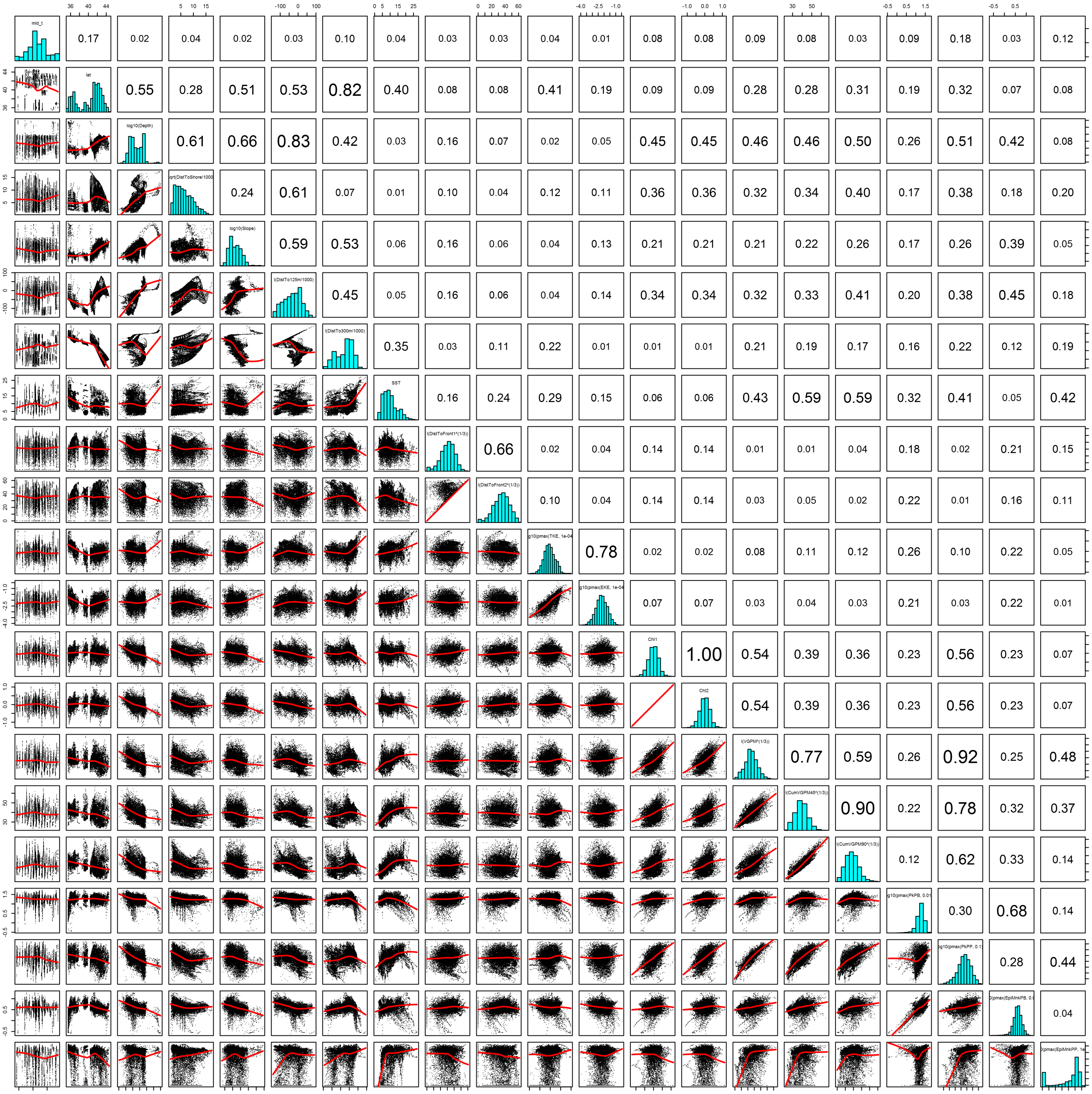


Figure 49: Scatterplot matrix for the Seals Contemporaneous model, Winter season, North of Gulf Stream. This plot is used to inspect the distribution of predictors (via histograms along the diagonal), simple correlation between predictors (via pairwise Pearson coefficients above the diagonal), and linearity of predictor correlations (via scatterplots below the diagonal). This plot is best viewed at high magnification.

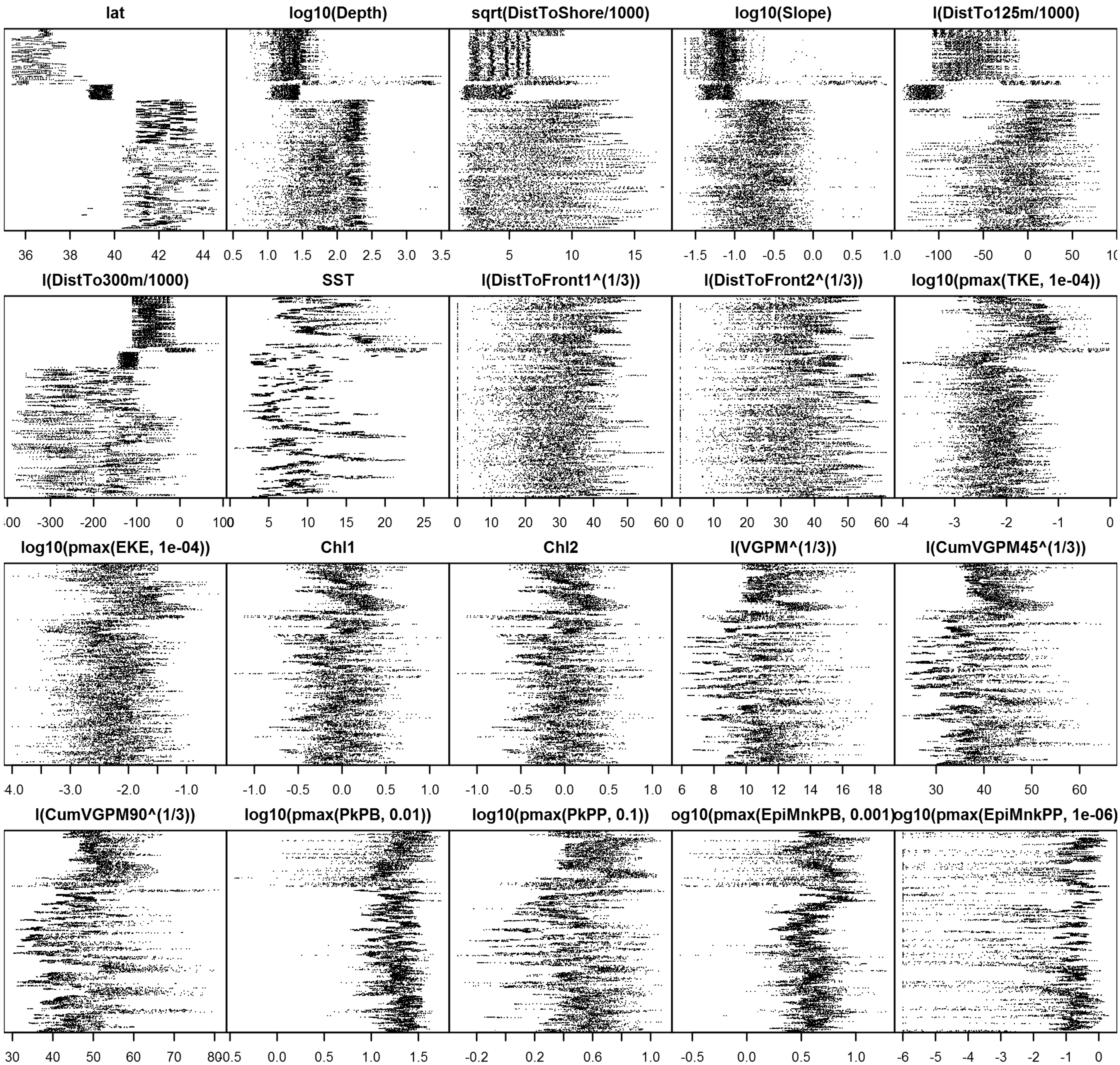


Figure 50: Dotplot for the Seals Contemporaneous model, Winter season, North of Gulf Stream. This plot is used to check for suspicious patterns and outliers in the data. Points are ordered vertically by transect ID, sequentially in time.

South of Gulf Stream

Density assumed to be 0 in this region.

Low Effort Area

Density was not modeled for this region.

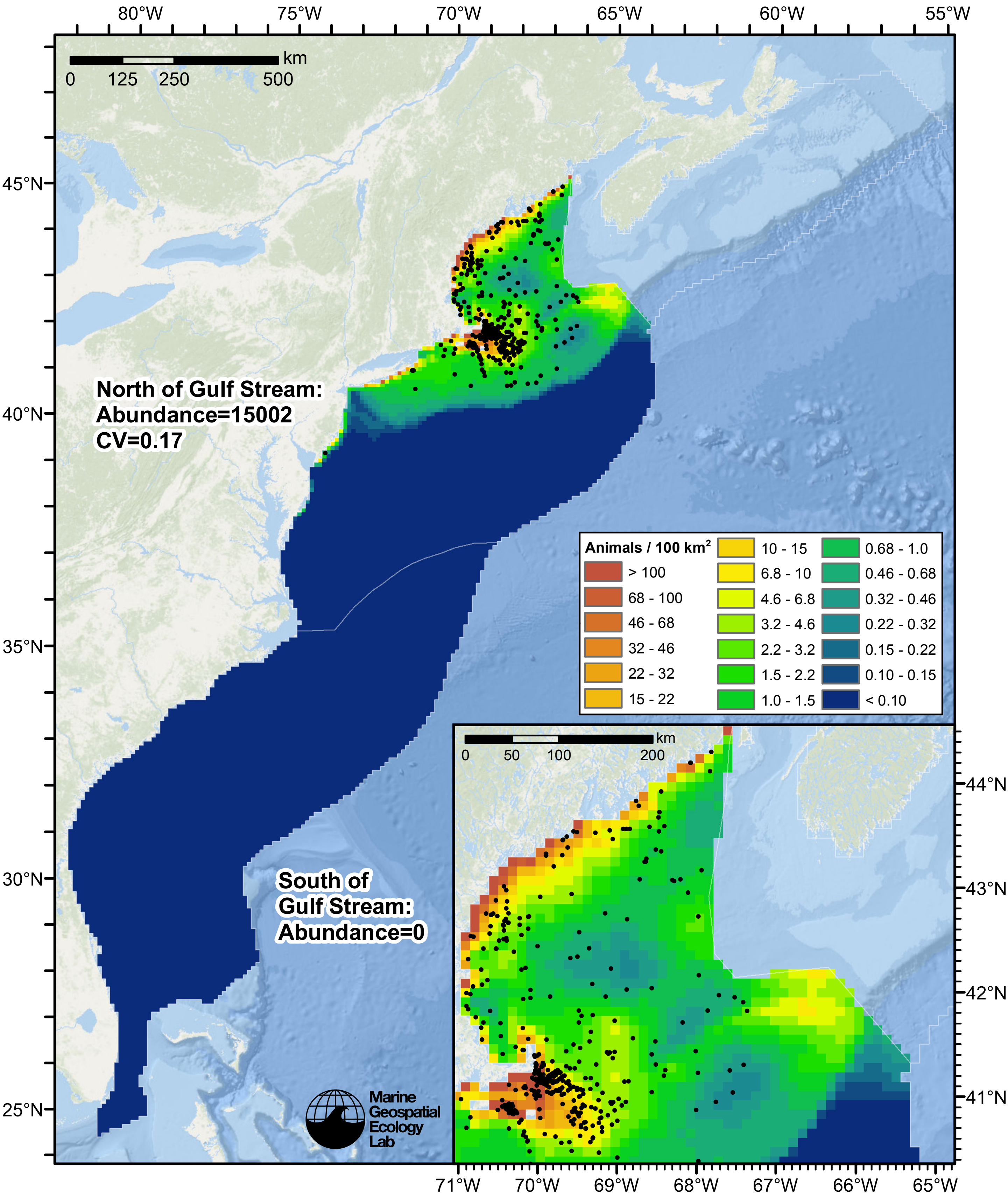


Figure 51: Seals density predicted by the Winter season climatological same segments model that explained the most deviance. Pixels are 10x10 km. The legend gives the estimated individuals per pixel; breaks are logarithmic. The same scale is used for all seasons. Abundance for each region was computed by summing the density cells occuring in that region.

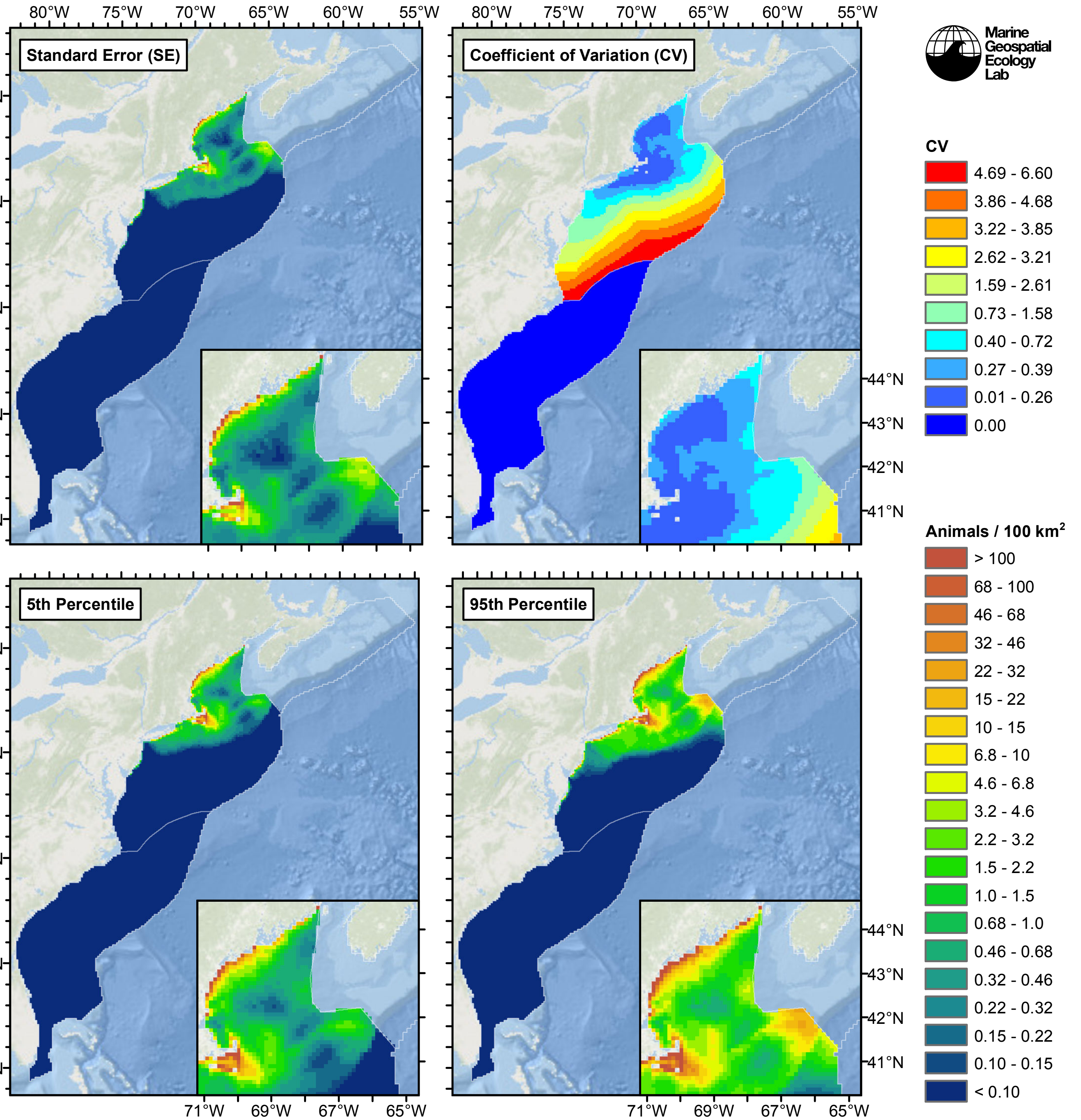


Figure 52: Estimated uncertainty for the Winter season climatological same segments model that explained the most deviance. These estimates only incorporate the statistical uncertainty estimated for the spatial model (by the R mgcv package). They do not incorporate uncertainty in the detection functions, g(0) estimates, predictor variables, and so on.

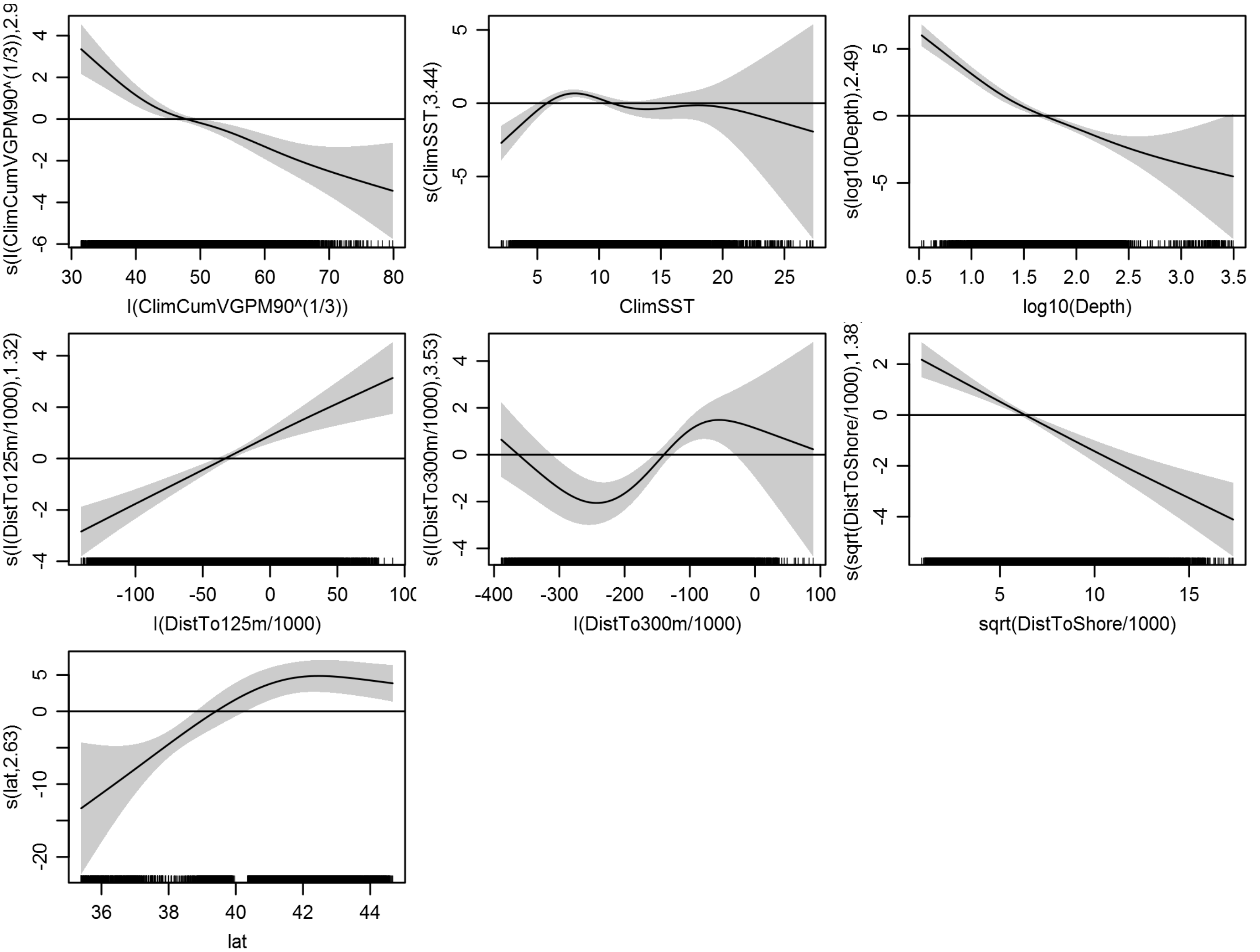
North of Gulf Stream

Statistical output

```
Rscript.exe: This is mgcv 1.8-3. For overview type 'help("mgcv-package")'.


Family: Tweedie(p=1.339)
```

```
Link function: log

Formula:
abundance ~ offset(log(area_km2)) + s(lat, bs = "ts", k = 5) +
    s(log10(Depth), bs = "ts", k = 5) + s(sqrt(DistToShore/1000),
    bs = "ts", k = 5) + s(I(DistTo125m/1000), bs = "ts", k = 5) +
    s(I(DistTo300m/1000), bs = "ts", k = 5) + s(ClimSST, bs = "ts",
    k = 5) + s(I(ClimCumVGPM90^(1/3)), bs = "ts", k = 5)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)    -7.72       1.06  -7.286 3.39e-13 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                            edf Ref.df      F  p-value
s(lat)                    2.634      4  8.689 5.41e-09 ***
s(log10(Depth))           2.490      4 54.438  < 2e-16 ***
s(sqrt(DistToShore/1000)) 1.376      4 11.797 4.99e-14 ***
s(I(DistTo125m/1000))     1.321      4  9.524 1.22e-11 ***
s(I(DistTo300m/1000))     3.535      4 15.401 7.76e-16 ***
s(ClimSST)                3.444      4 10.309 1.10e-09 ***
s(I(ClimCumVGPM90^(1/3))) 2.968      4  9.204 2.20e-09 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.0894   Deviance explained = 56.3%
-REML = 2212.3  Scale est. = 31.032    n = 11892

All predictors were significant. This is the final model.
Creating term plots.
Diagnostic output from gam.check():

Method: REML   Optimizer: outer newton
full convergence after 12 iterations.
Gradient range [-0.000394223,0.0002948432]
(score 2212.348 & scale 31.03151).
Hessian positive definite, eigenvalue range [0.5223308,856.2241].
Model rank =  29 / 29

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                             k'   edf k-index p-value
s(lat)                    4.000 2.634   0.757    0.00
s(log10(Depth))           4.000 2.490   0.799    0.00
s(sqrt(DistToShore/1000)) 4.000 1.376   0.858    0.63
s(I(DistTo125m/1000))     4.000 1.321   0.847    0.22
s(I(DistTo300m/1000))     4.000 3.535   0.799    0.00
s(ClimSST)                4.000 3.444   0.821    0.02
s(I(ClimCumVGPM90^(1/3))) 4.000 2.968   0.844    0.14

Predictors retained during the model selection procedure: lat, Depth, DistToShore, DistTo125m,
DistTo300m, ClimSST, ClimCumVGPM90

Predictors dropped during the model selection procedure: Slope, ClimTKE, ClimDistToFront1
```

Model term plots



Diagnostic plots

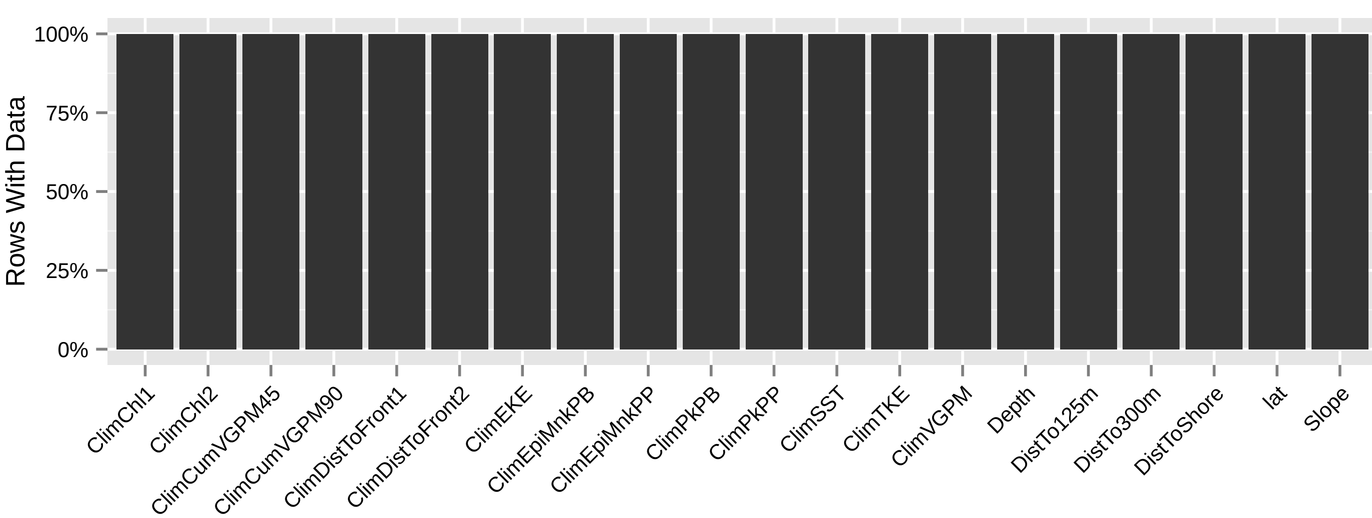


Figure 53: Segments with predictor values for the Seals Climatological model, Winter season, North of Gulf Stream. This plot is used to assess how many segments would be lost by including a given predictor in a model.

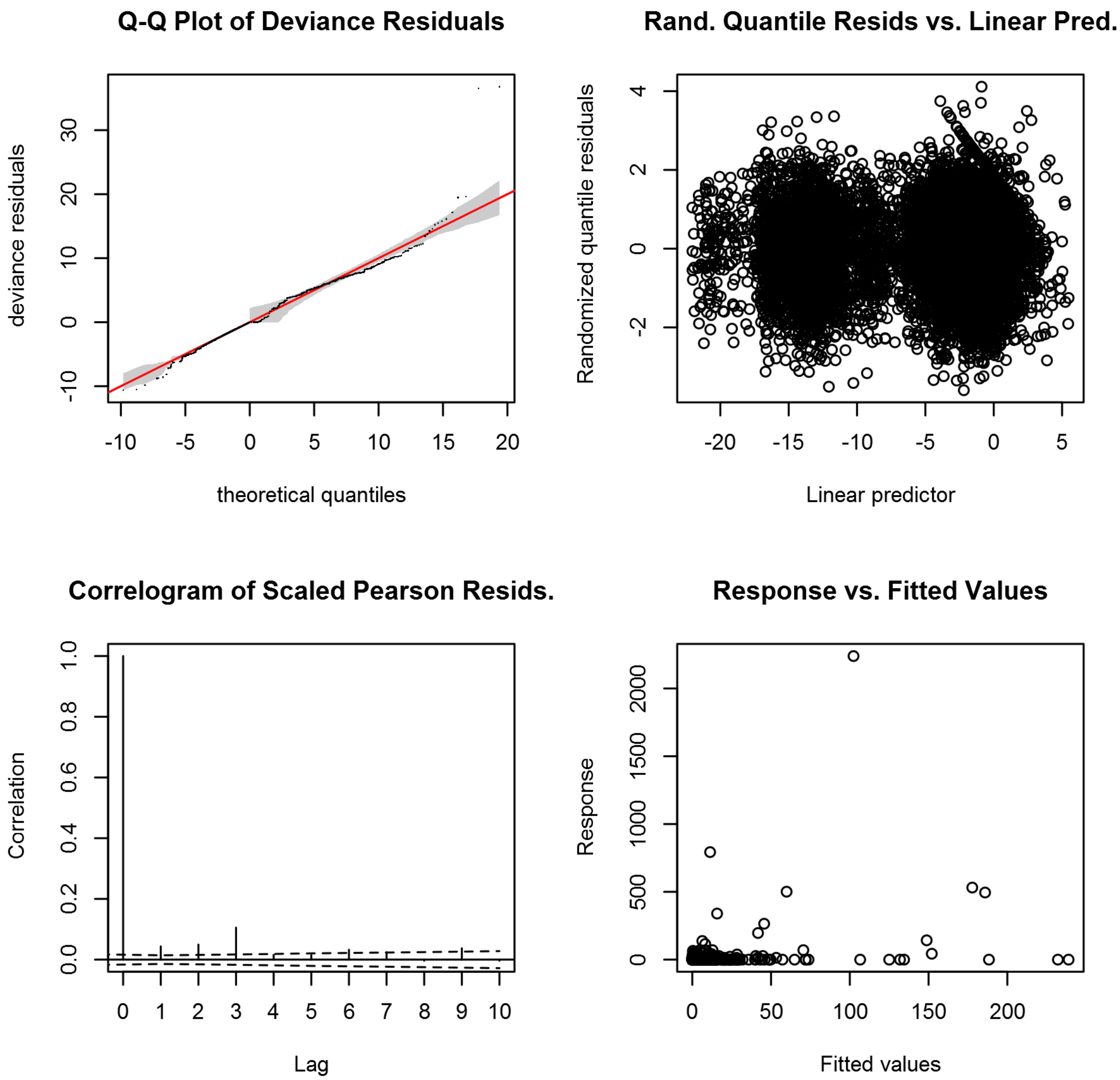


Figure 54: Statistical diagnostic plots for the Seals Climatological model, Winter season, North of Gulf Stream.

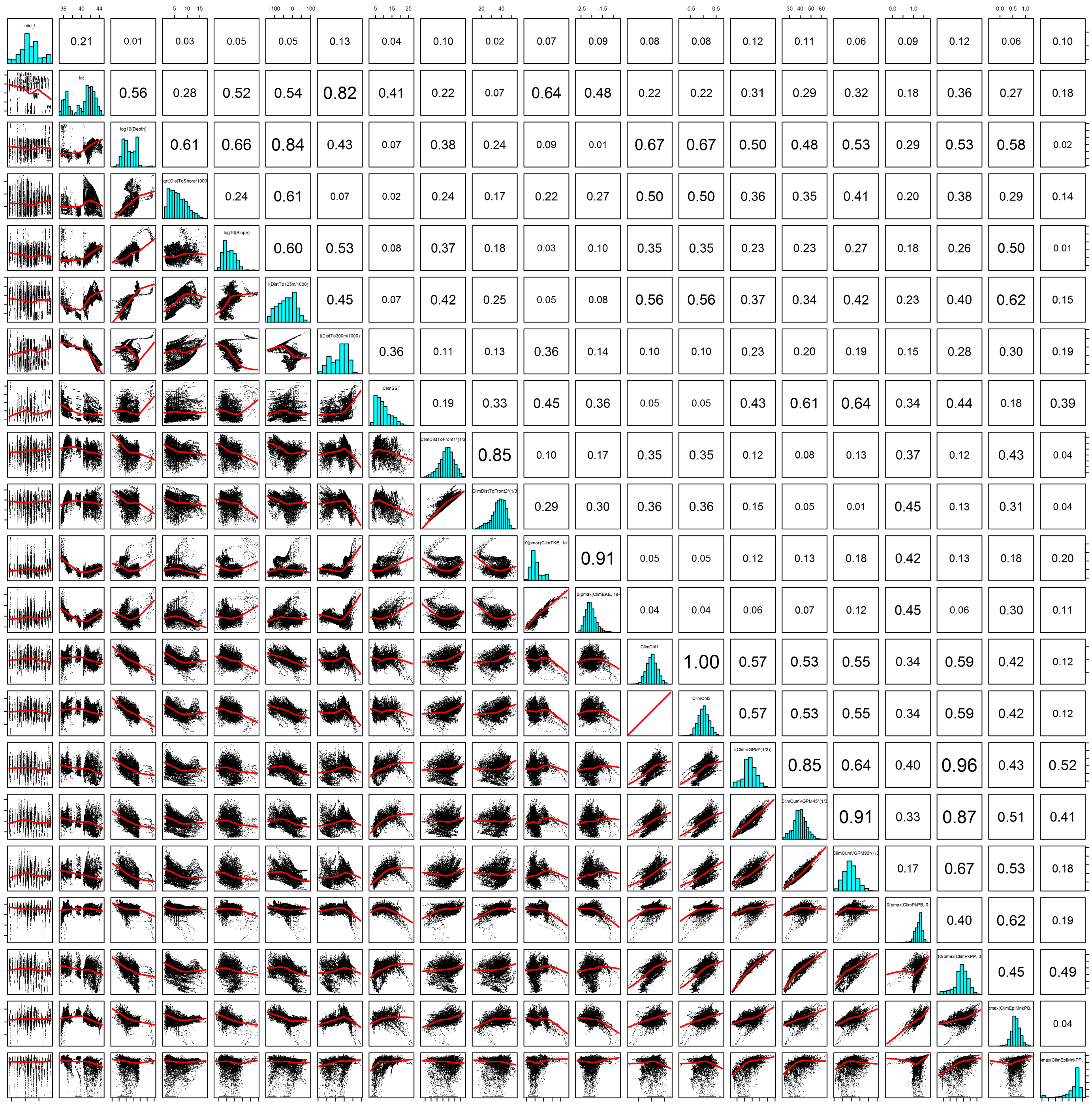


Figure 55: Scatterplot matrix for the Seals Climatological model, Winter season, North of Gulf Stream. This plot is used to inspect the distribution of predictors (via histograms along the diagonal), simple correlation between predictors (via pairwise Pearson coefficients above the diagonal), and linearity of predictor correlations (via scatterplots below the diagonal). This plot is best viewed at high magnification.

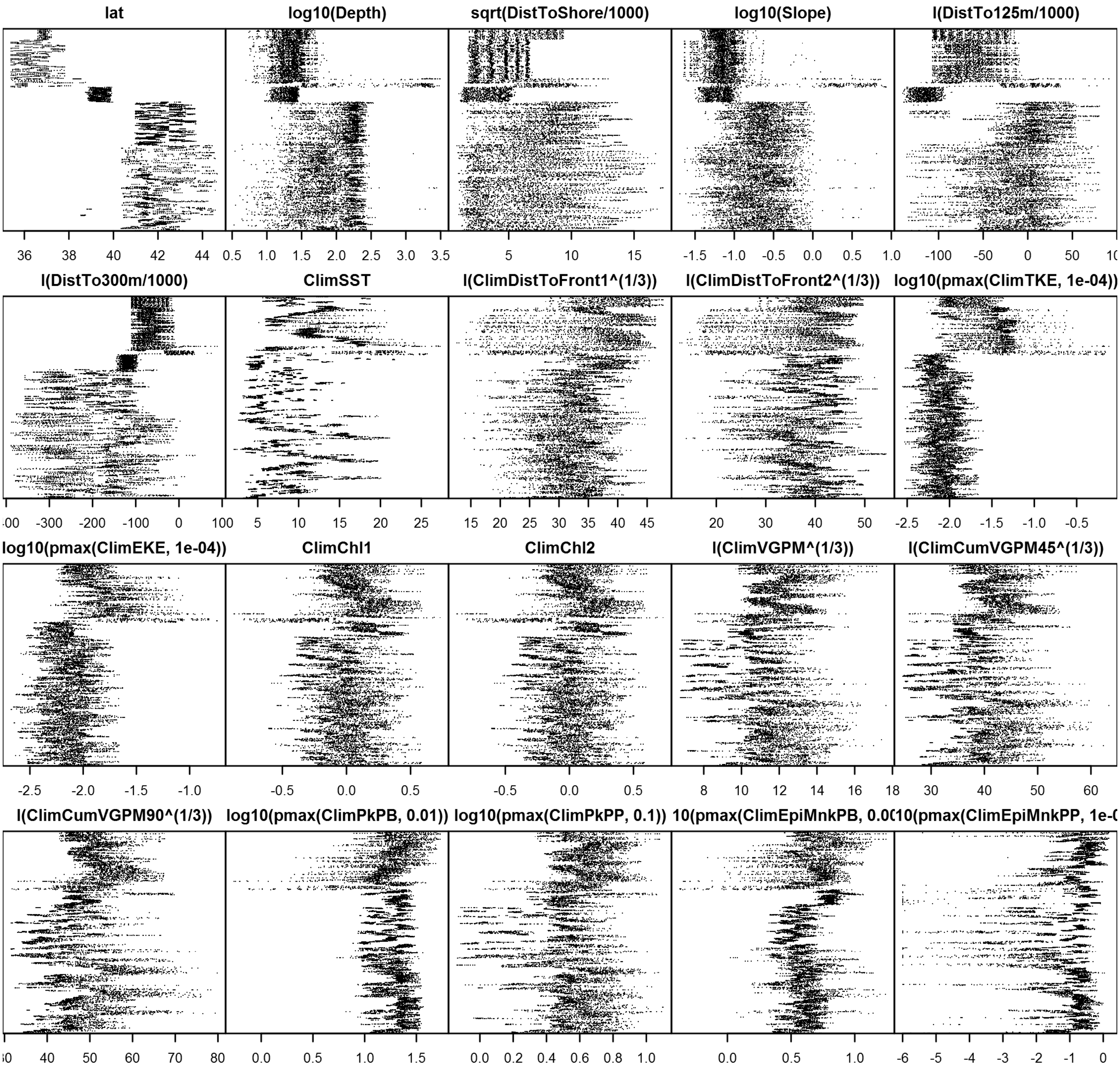


Figure 56: Dotplot for the Seals Climatological model, Winter season, North of Gulf Stream. This plot is used to check for suspicious patterns and outliers in the data. Points are ordered vertically by transect ID, sequentially in time.

South of Gulf Stream

Density assumed to be 0 in this region.

Low Effort Area

Density was not modeled for this region.

Summer

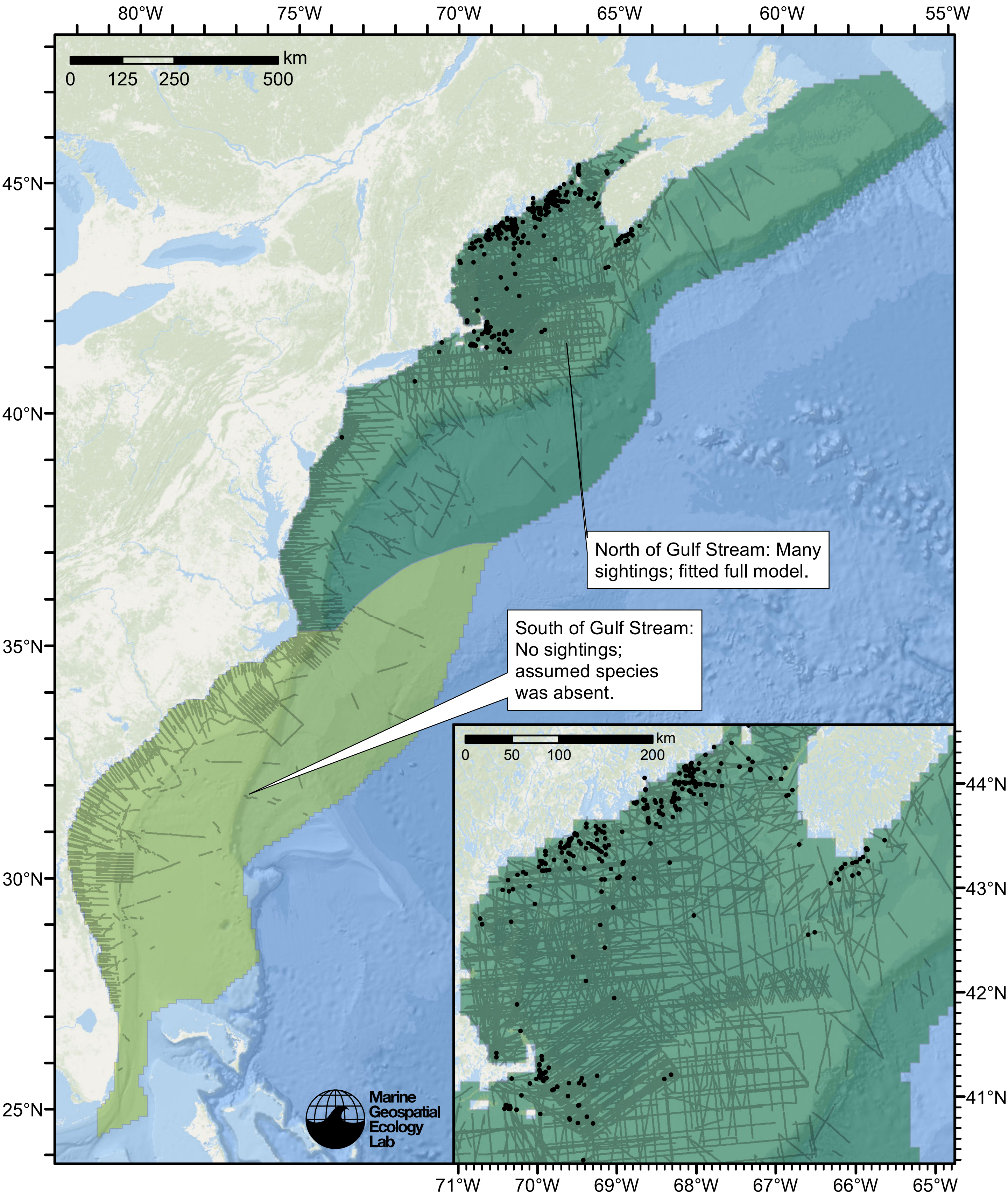


Figure 57: Seals density model schematic for Summer season. All on-effort sightings are shown, including those that were truncated when detection functions were fitted.

Climatological Model

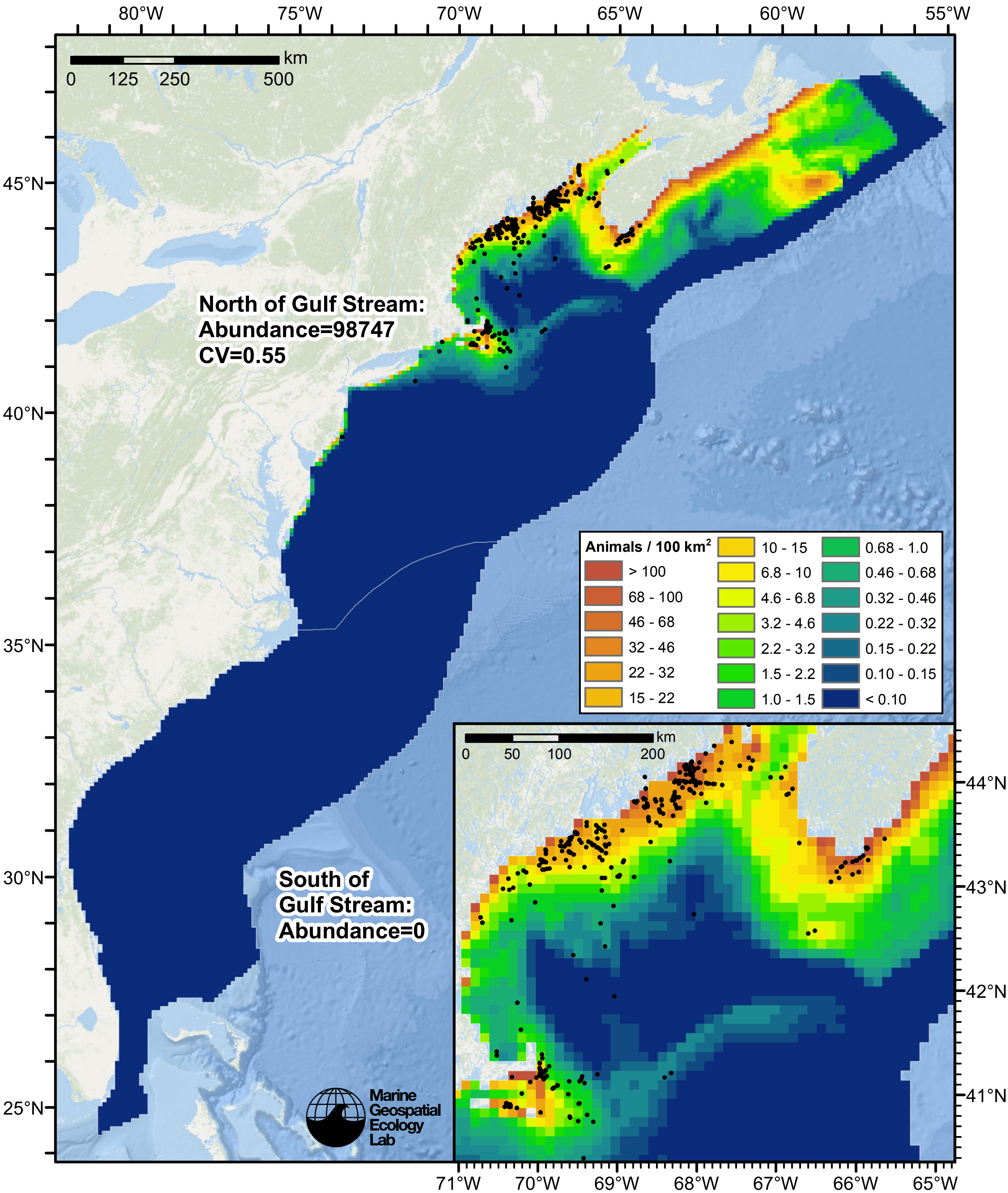


Figure 58: Seals density predicted by the Summer season climatological model that explained the most deviance. Pixels are 10x10 km. The legend gives the estimated individuals per pixel; breaks are logarithmic. The same scale is used for all seasons. Abundance for each region was computed by summing the density cells occuring in that region.

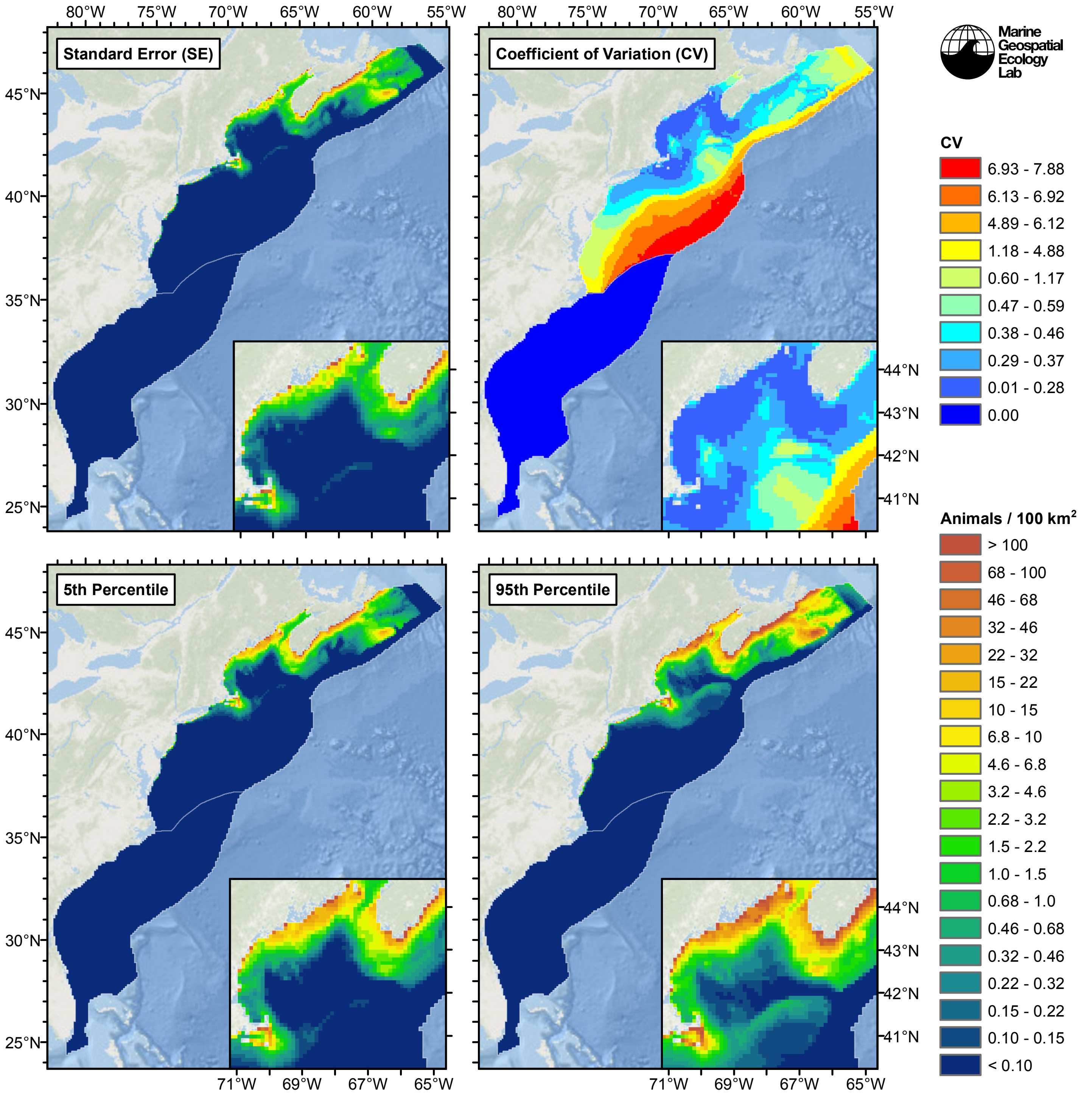


Figure 59: Estimated uncertainty for the Summer season climatological model that explained the most deviance. These estimates only incorporate the statistical uncertainty estimated for the spatial model (by the R mgcv package). They do not incorporate uncertainty in the detection functions, g(0) estimates, predictor variables, and so on.

North of Gulf Stream

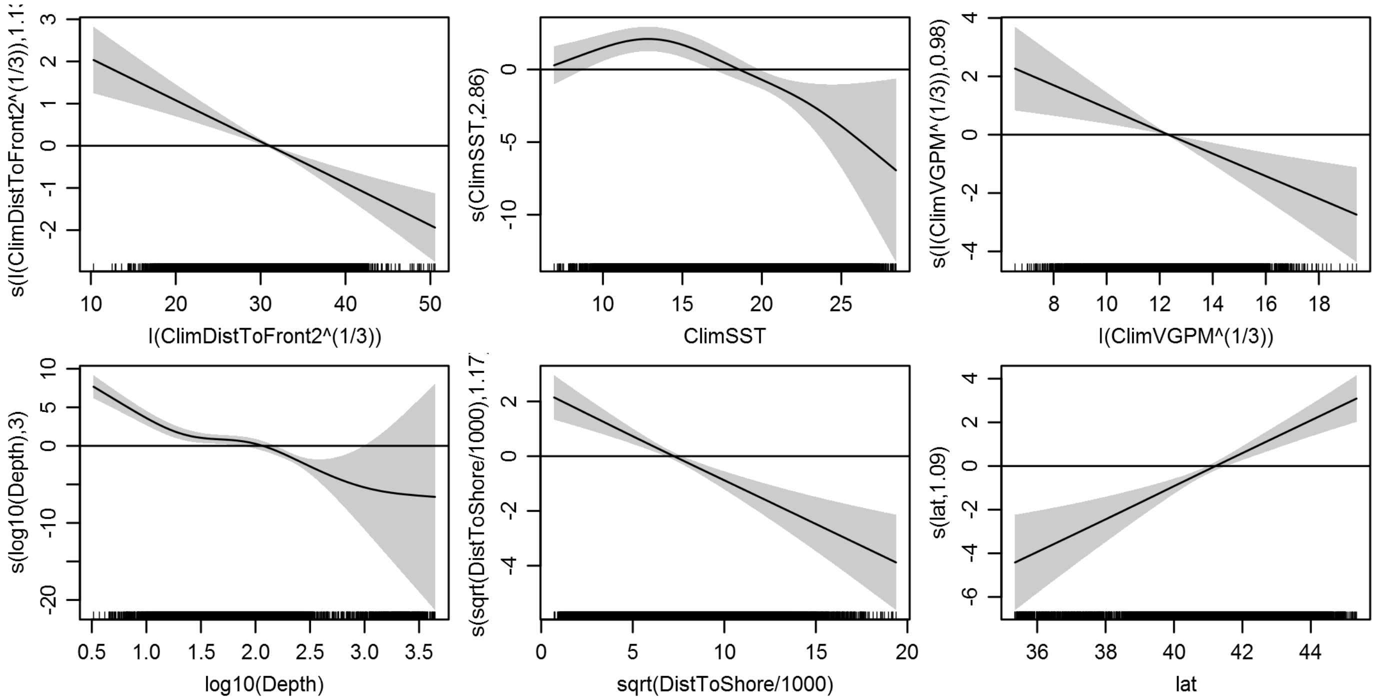
Statistical output

```
Rscript.exe: This is mgcv 1.8-3. For overview type 'help("mgcv-package")'.


Family: Tweedie(p=1.295)
```

```
Link function: log

Formula:
abundance ~ offset(log(area_km2)) + s(lat, bs = "ts", k = 5) +
    s(log10(Depth), bs = "ts", k = 5) + s(sqrt(DistToShore/1000),
    bs = "ts", k = 5) + s(ClimSST, bs = "ts", k = 5) + s(I(ClimDistToFront2^(1/3)),
    bs = "ts", k = 5) + s(I(ClimVGPM^(1/3)), bs = "ts", k = 5)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -7.4023     0.4807   -15.4   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                               edf Ref.df      F  p-value
s(lat)                      1.0868      4  8.552 1.23e-09 ***
s(log10(Depth))             3.0038      4 28.319  < 2e-16 ***
s(sqrt(DistToShore/1000))   1.1665      4  7.595 1.14e-08 ***
s(ClimSST)                  2.8640      4 12.751 2.79e-12 ***
s(I(ClimDistToFront2^(1/3))) 1.1285      4  8.558 1.59e-09 ***
s(I(ClimVGPM^(1/3)))        0.9821      4  3.129 0.000206 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.0315   Deviance explained = 52.8%
-REML = 1322.2  Scale est. = 23.162    n = 9731

All predictors were significant. This is the final model.
Creating term plots.
Diagnostic output from gam.check():

Method: REML   Optimizer: outer newton
full convergence after 12 iterations.
Gradient range [-8.567377e-05,2.862237e-05]
(score 1322.195 & scale 23.16184).
Hessian positive definite, eigenvalue range [0.4404391,612.8826].
Model rank =  25 / 25

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                               k'   edf k-index p-value
s(lat)                      4.000 1.087   0.813    0.00
s(log10(Depth))             4.000 3.004   0.826    0.02
s(sqrt(DistToShore/1000))   4.000 1.166   0.858    0.40
s(ClimSST)                  4.000 2.864   0.803    0.00
s(I(ClimDistToFront2^(1/3))) 4.000 1.129   0.849    0.20
s(I(ClimVGPM^(1/3)))        4.000 0.982   0.865    0.64
```

```
Predictors retained during the model selection procedure: lat, Depth, DistToShore, ClimSST,
ClimDistToFront2, ClimVGPM

Predictors dropped during the model selection procedure: Slope, DistTo125m, DistTo300m, ClimTKE
```

Model term plots



Diagnostic plots

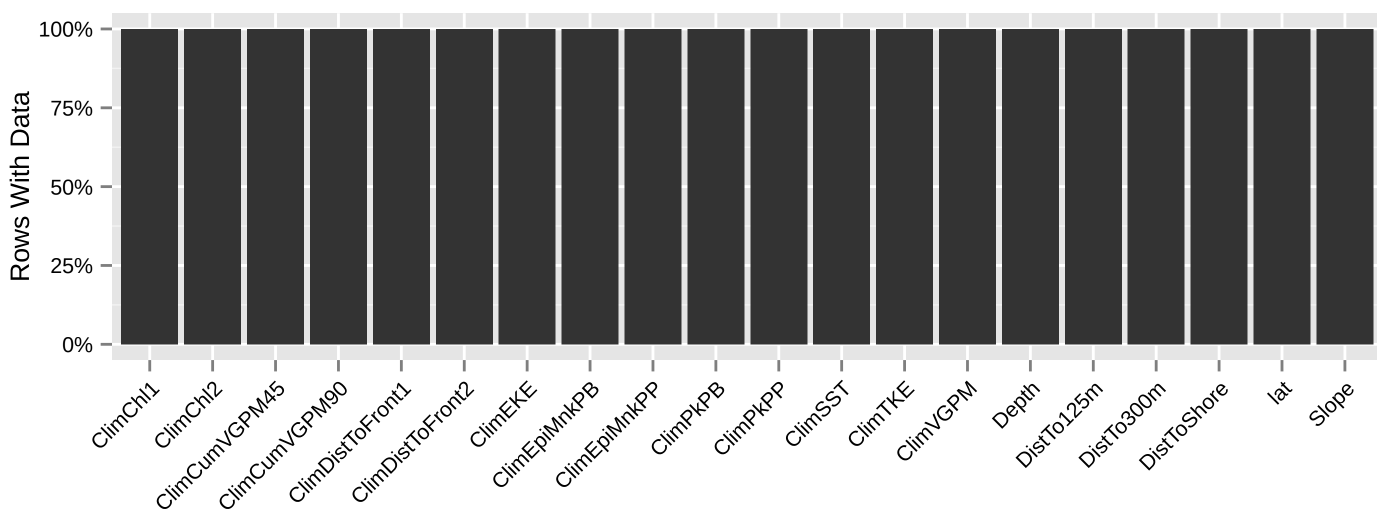


Figure 60: Segments with predictor values for the Seals Climatological model, Summer season, North of Gulf Stream. This plot is used to assess how many segments would be lost by including a given predictor in a model.

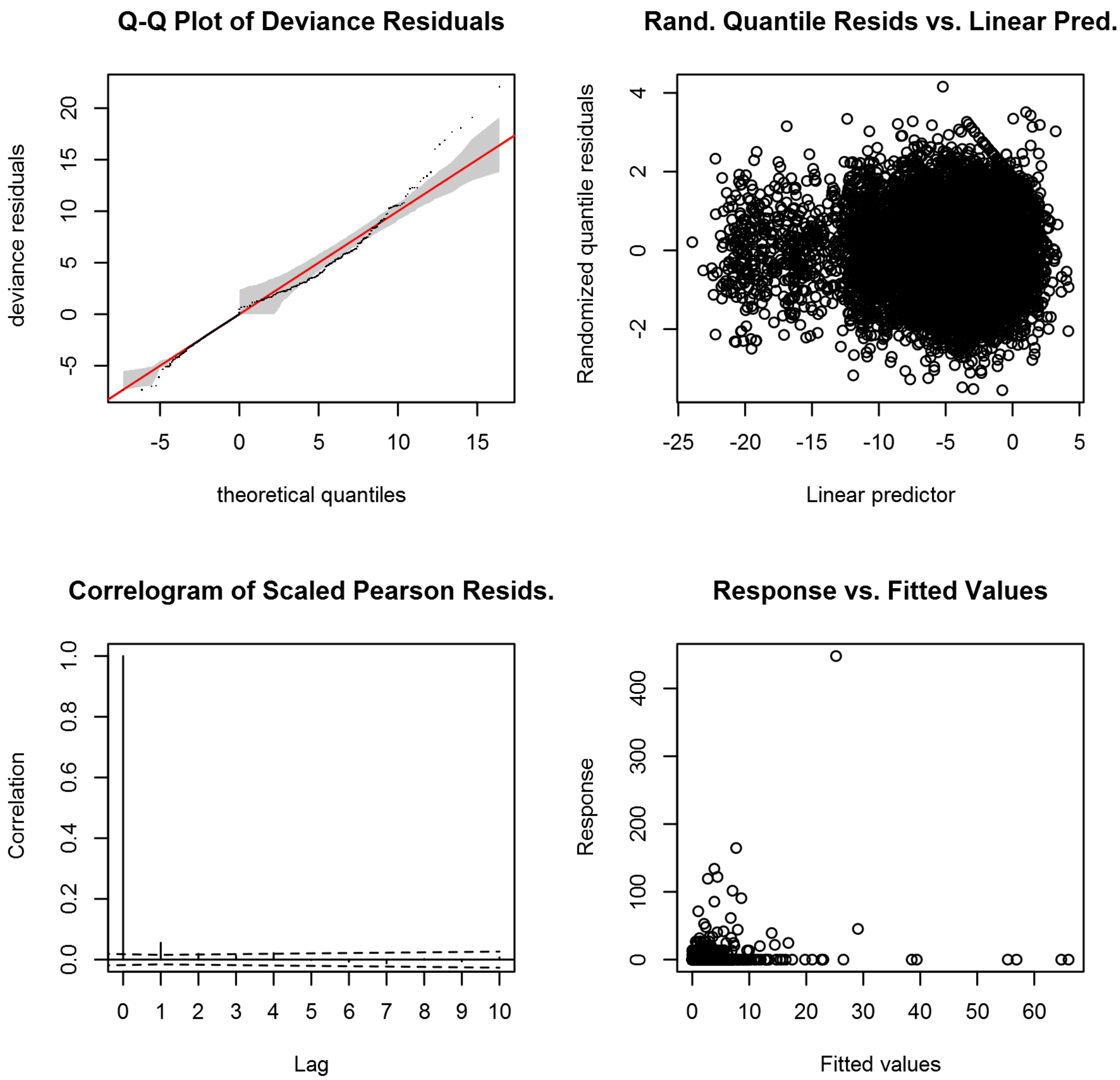


Figure 61: Statistical diagnostic plots for the Seals Climatological model, Summer season, North of Gulf Stream.

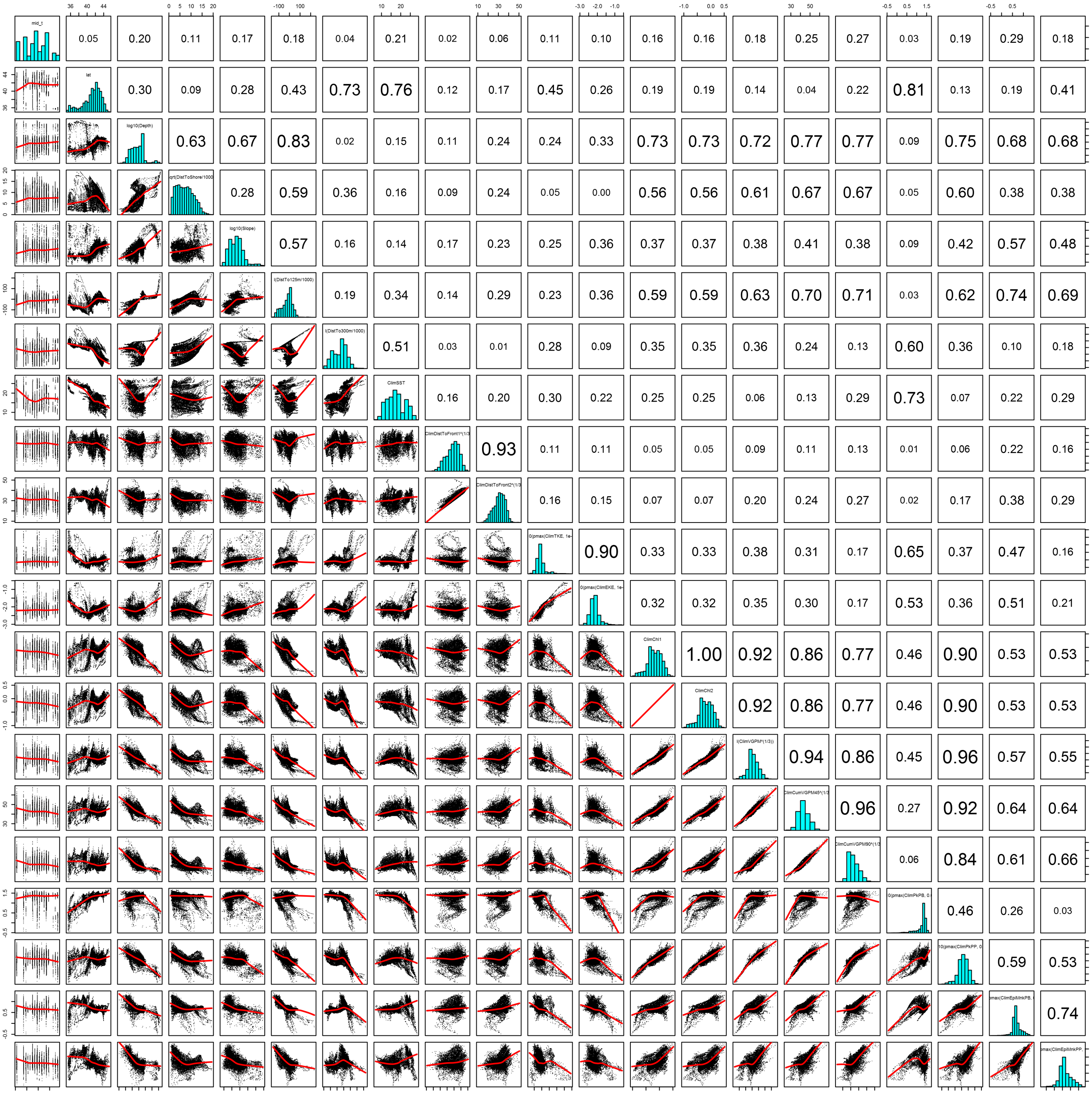


Figure 62: Scatterplot matrix for the Seals Climatological model, Summer season, North of Gulf Stream. This plot is used to inspect the distribution of predictors (via histograms along the diagonal), simple correlation between predictors (via pairwise Pearson coefficients above the diagonal), and linearity of predictor correlations (via scatterplots below the diagonal). This plot is best viewed at high magnification.

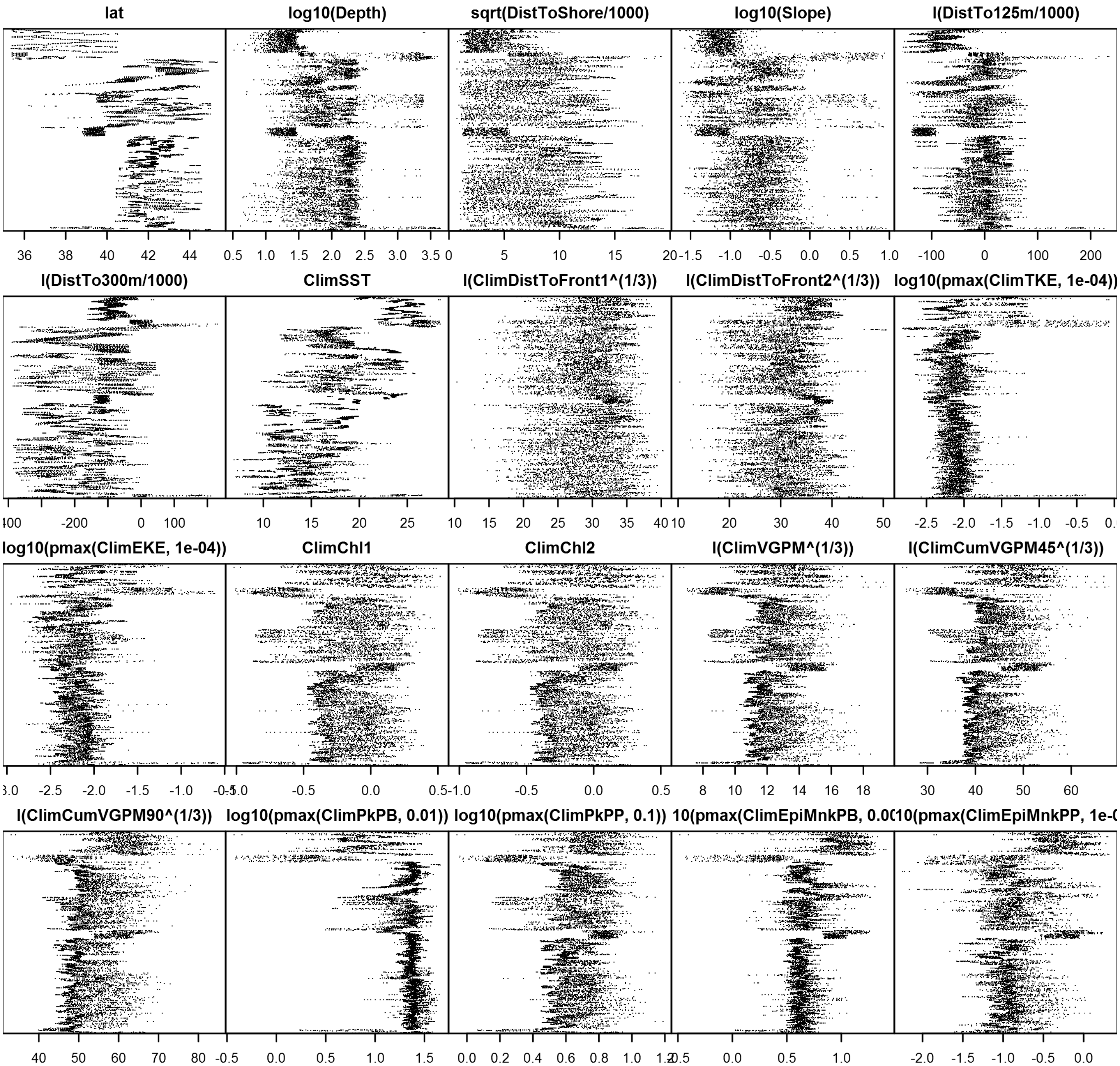


Figure 63: Dotplot for the Seals Climatological model, Summer season, North of Gulf Stream. This plot is used to check for suspicious patterns and outliers in the data. Points are ordered vertically by transect ID, sequentially in time.

South of Gulf Stream

Density assumed to be 0 in this region.

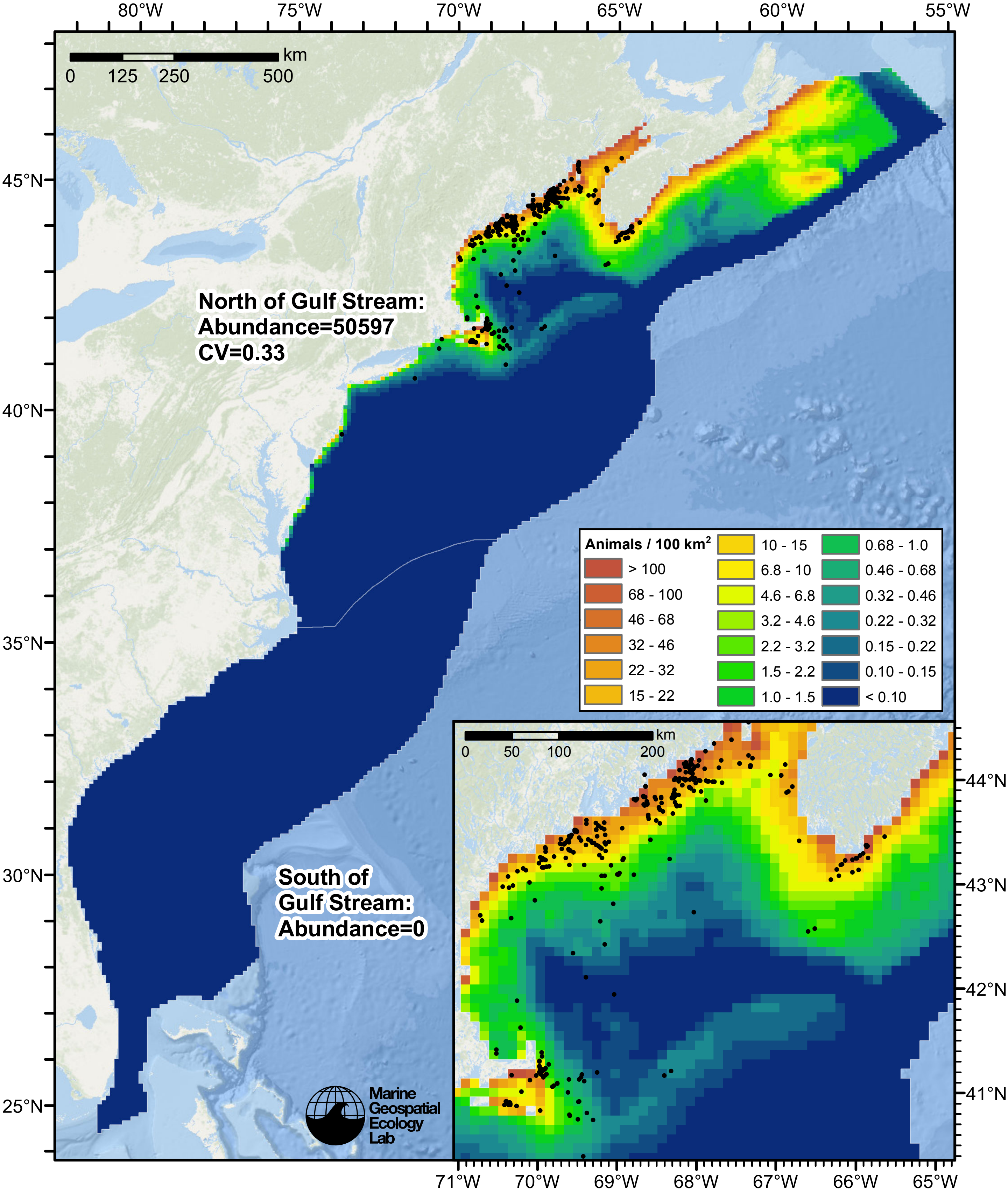


Figure 64: Seals density predicted by the Summer season contemporaneous model that explained the most deviance. Pixels are 10x10 km. The legend gives the estimated individuals per pixel; breaks are logarithmic. The same scale is used for all seasons. Abundance for each region was computed by summing the density cells occuring in that region.

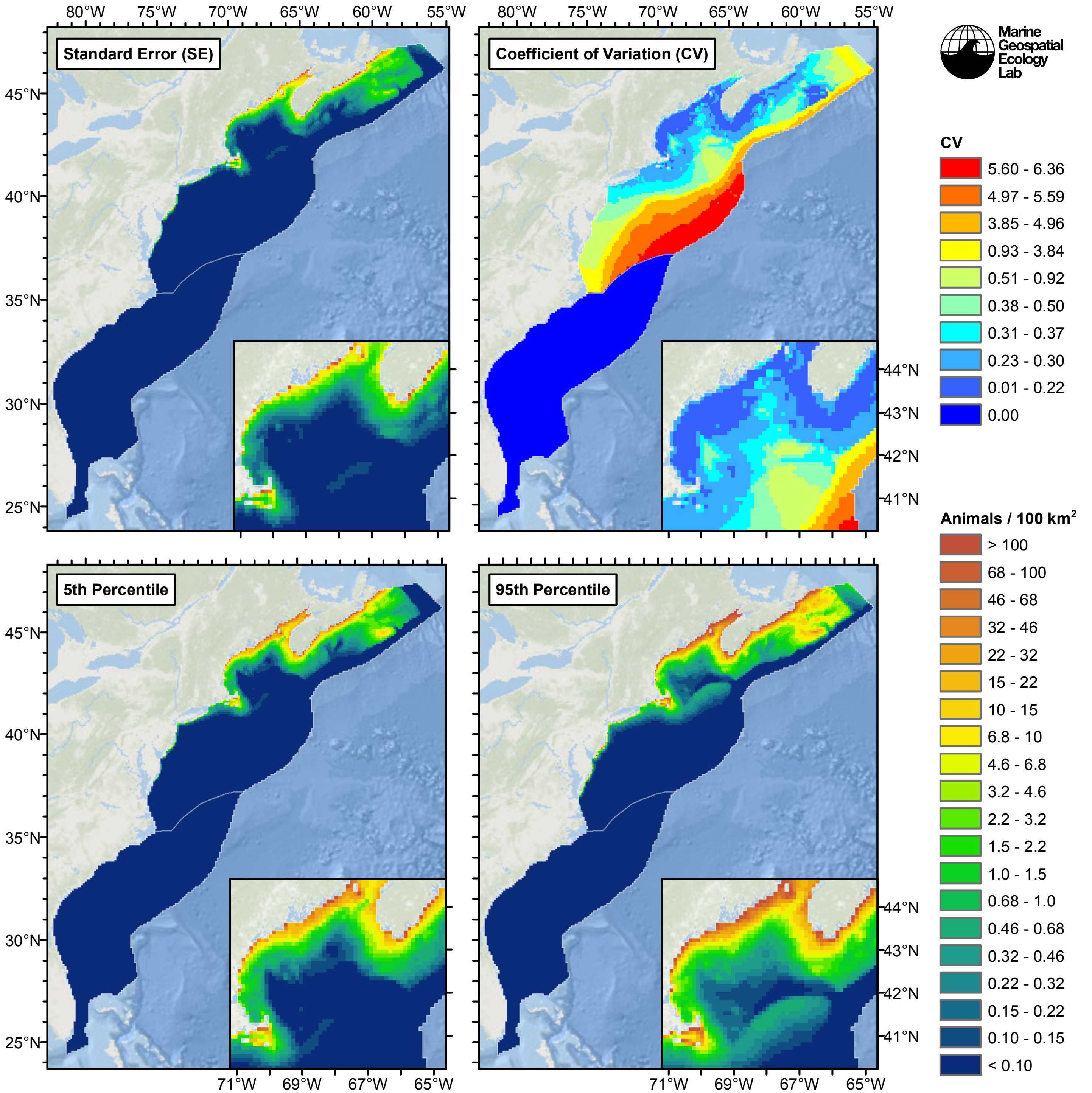


Figure 65: Estimated uncertainty for the Summer season contemporaneous model that explained the most deviance. These estimates only incorporate the statistical uncertainty estimated for the spatial model (by the R mgcv package). They do not incorporate uncertainty in the detection functions, g(0) estimates, predictor variables, and so on.

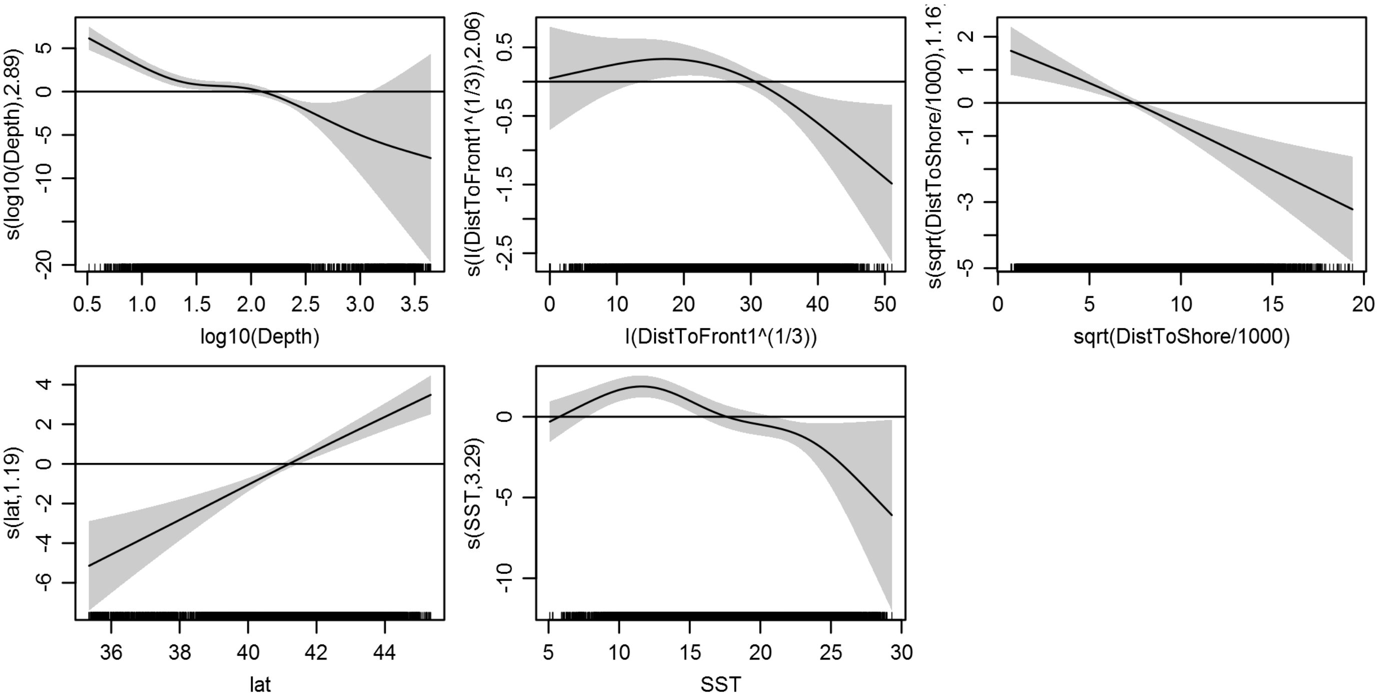
North of Gulf Stream

Statistical output

```
Rscript.exe: This is mgcv 1.8-3. For overview type 'help("mgcv-package")'.


Family: Tweedie(p=1.32)
```

```
Link function: log

Formula:
abundance ~ offset(log(area_km2)) + s(lat, bs = "ts", k = 5) +
    s(log10(Depth), bs = "ts", k = 5) + s(sqrt(DistToShore/1000),
    bs = "ts", k = 5) + s(SST, bs = "ts", k = 5) + s(I(DistToFront1^(1/3)),
    bs = "ts", k = 5)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -7.1242     0.3825  -18.62   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                            edf Ref.df      F  p-value
s(lat)                    1.186      4 12.956 8.16e-14 ***
s(log10(Depth))           2.887      4 21.923  < 2e-16 ***
s(sqrt(DistToShore/1000)) 1.162      4  5.696 9.54e-07 ***
s(SST)                    3.295      4 15.283 4.36e-14 ***
s(I(DistToFront1^(1/3)))  2.057      4  2.542  0.00355 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.00522   Deviance explained = 50.4%
-REML = 1345.3  Scale est. = 25.217    n = 9731

All predictors were significant. This is the final model.
Creating term plots.
Diagnostic output from gam.check():

Method: REML   Optimizer: outer newton
full convergence after 14 iterations.
Gradient range [-4.835687e-05,7.157262e-05]
(score 1345.25 & scale 25.21659).
Hessian positive definite, eigenvalue range [0.2987527,585.1566].
Model rank =  21 / 21

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                             k'   edf k-index p-value
s(lat)                    4.000 1.186   0.758    0.00
s(log10(Depth))           4.000 2.887   0.803    0.11
s(sqrt(DistToShore/1000)) 4.000 1.162   0.824    0.68
s(SST)                    4.000 3.295   0.742    0.00
s(I(DistToFront1^(1/3)))  4.000 2.057   0.804    0.12

Predictors retained during the model selection procedure: lat, Depth, DistToShore, SST, DistToFront1

Predictors dropped during the model selection procedure: Slope, DistTo125m, DistTo300m
```

Model term plots



Diagnostic plots

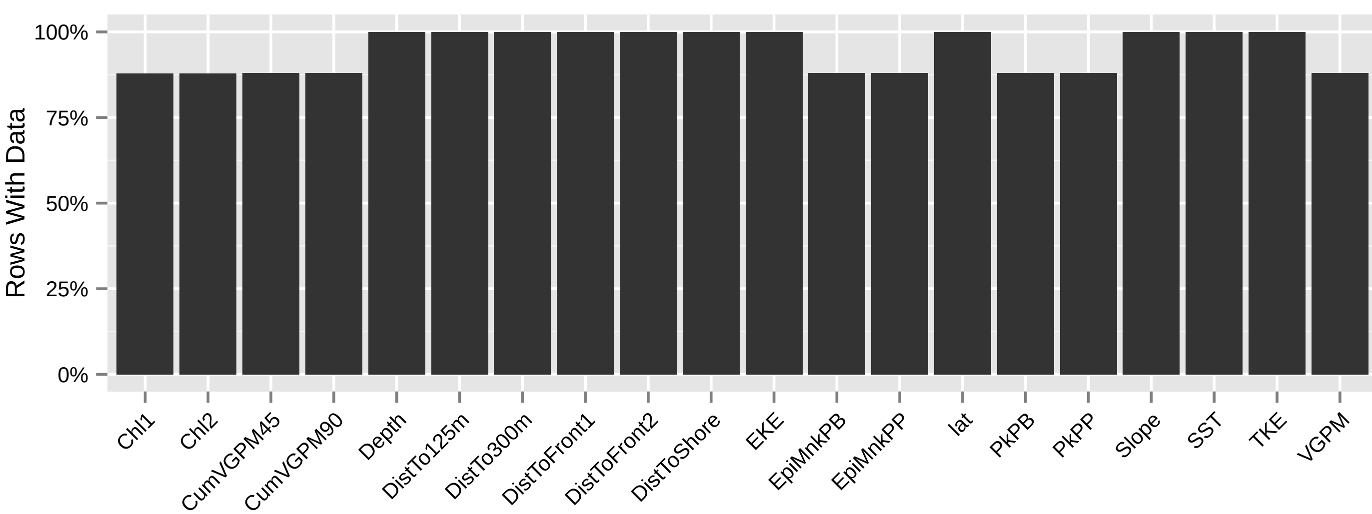


Figure 66: Segments with predictor values for the Seals Contemporaneous model, Summer season, North of Gulf Stream. This plot is used to assess how many segments would be lost by including a given predictor in a model.

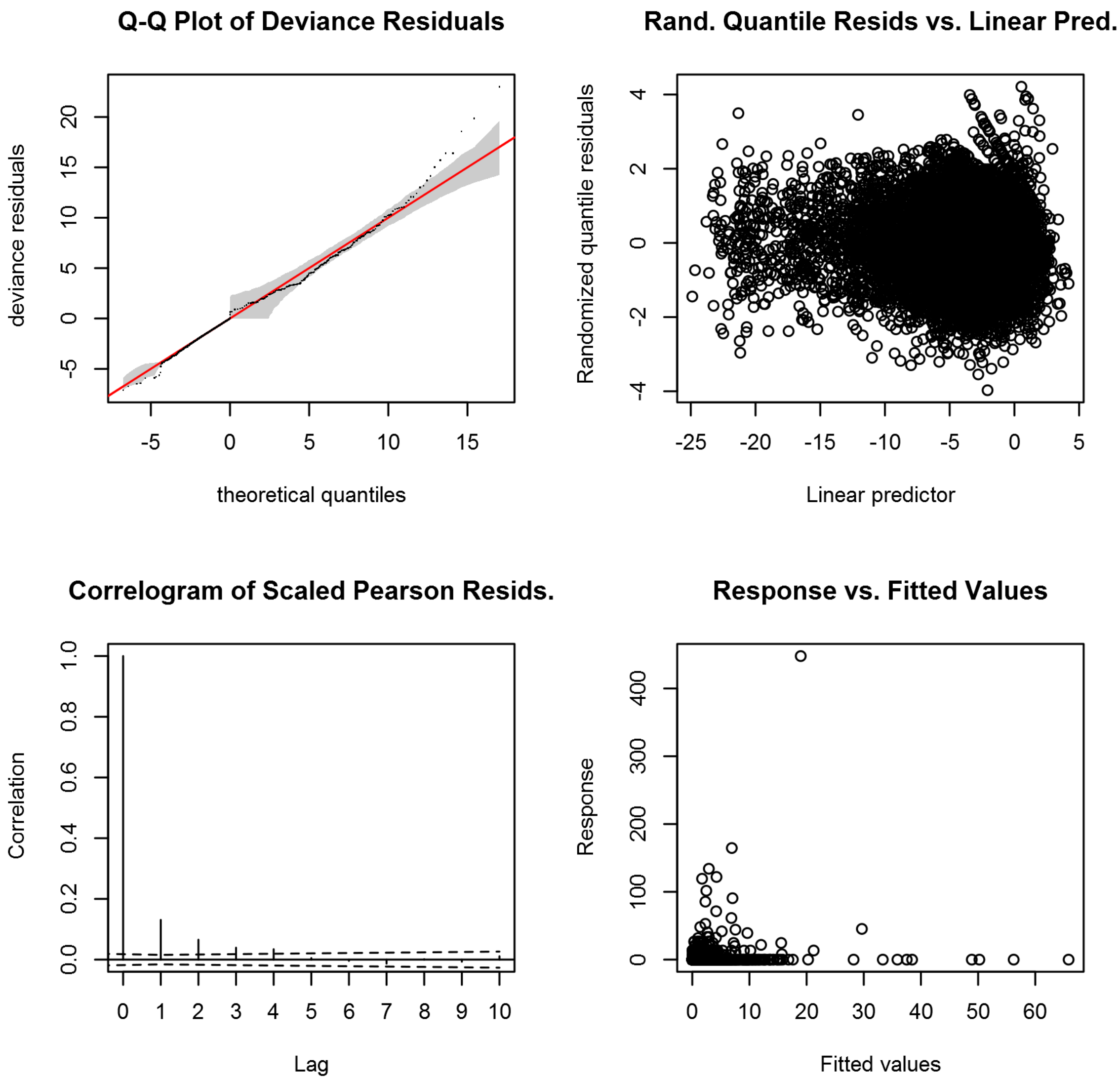


Figure 67: Statistical diagnostic plots for the Seals Contemporaneous model, Summer season, North of Gulf Stream.

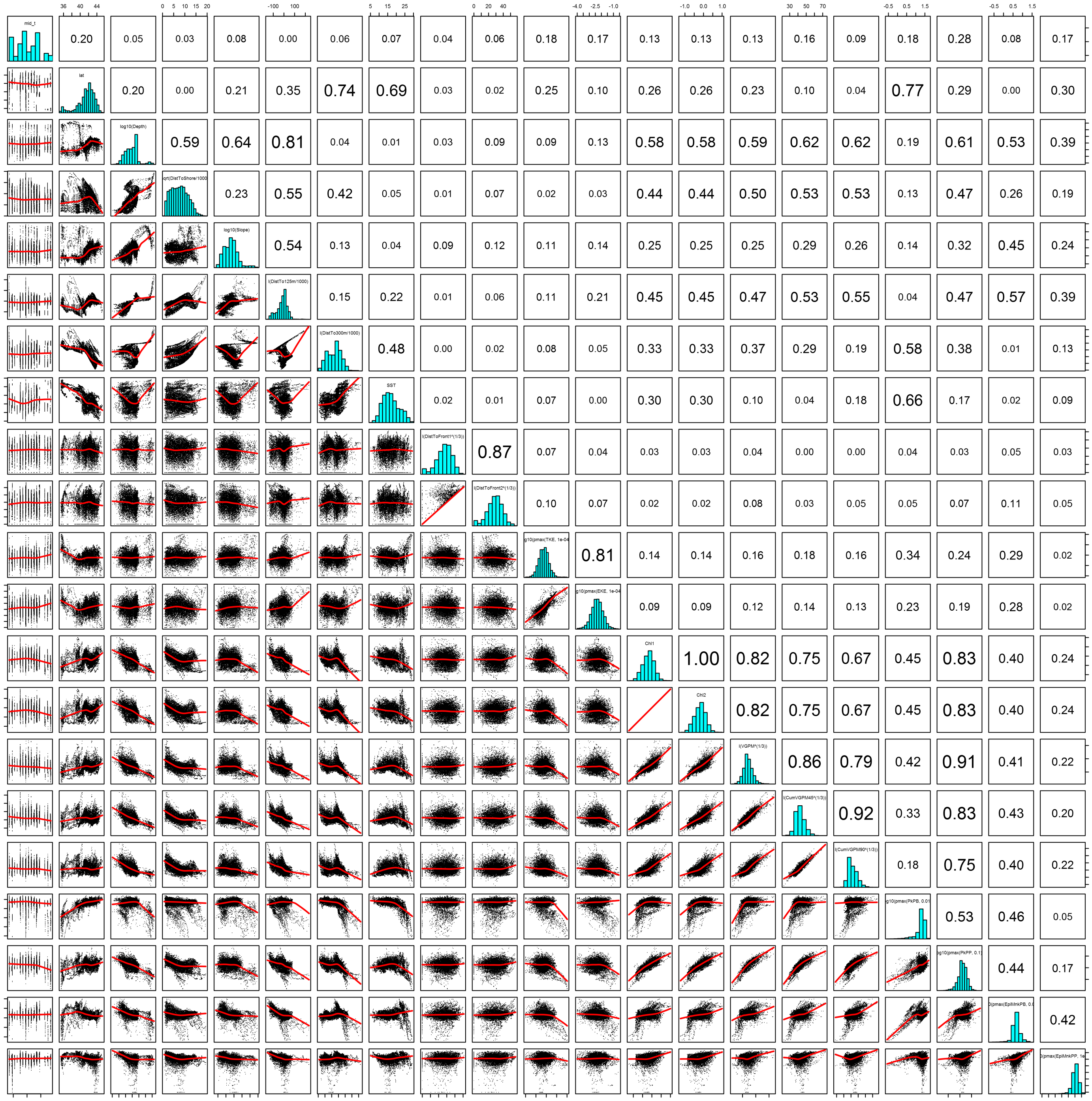


Figure 68: Scatterplot matrix for the Seals Contemporaneous model, Summer season, North of Gulf Stream. This plot is used to inspect the distribution of predictors (via histograms along the diagonal), simple correlation between predictors (via pairwise Pearson coefficients above the diagonal), and linearity of predictor correlations (via scatterplots below the diagonal). This plot is best viewed at high magnification.

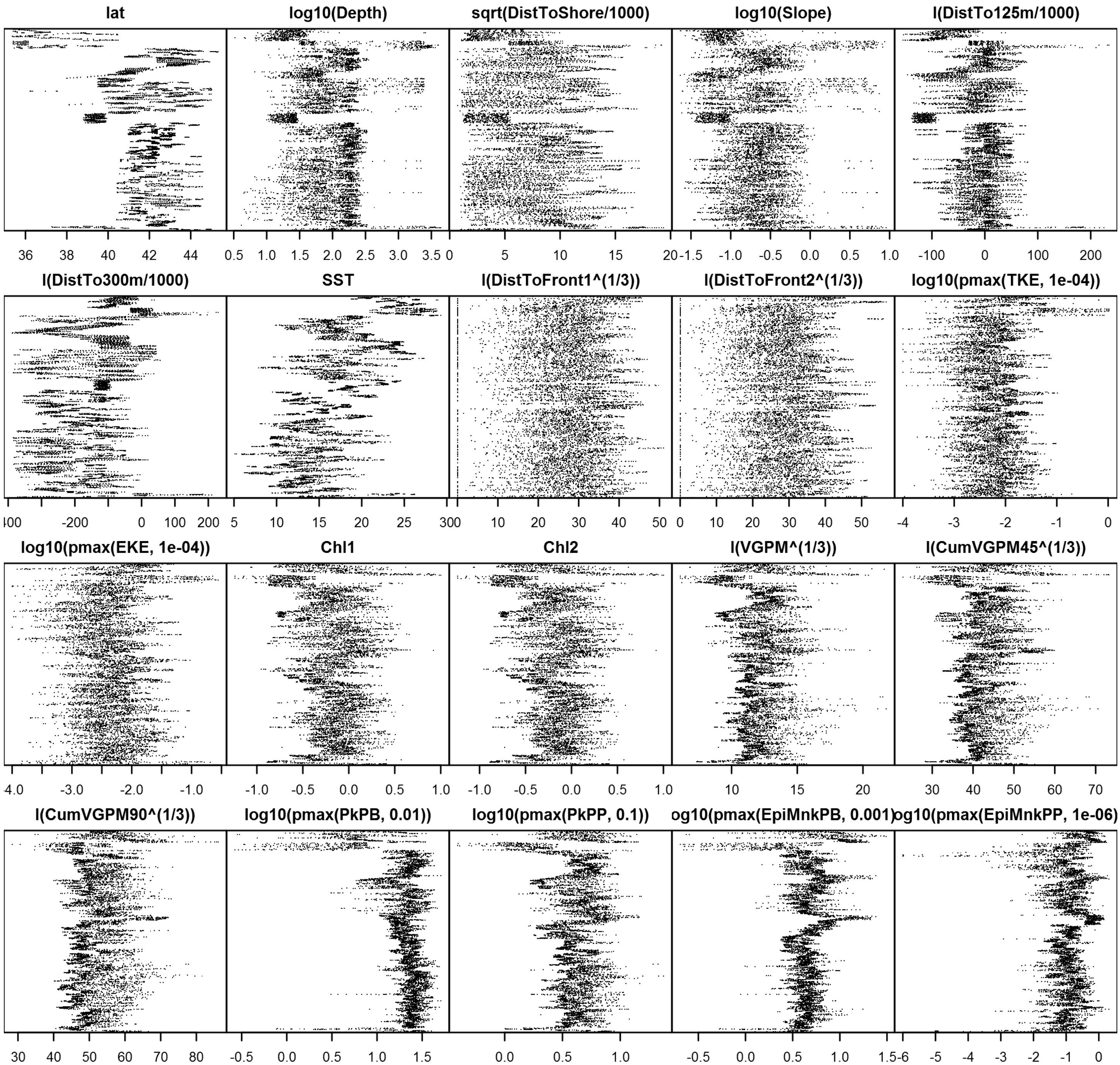


Figure 69: Dotplot for the Seals Contemporaneous model, Summer season, North of Gulf Stream. This plot is used to check for suspicious patterns and outliers in the data. Points are ordered vertically by transect ID, sequentially in time.

South of Gulf Stream

Density assumed to be 0 in this region.

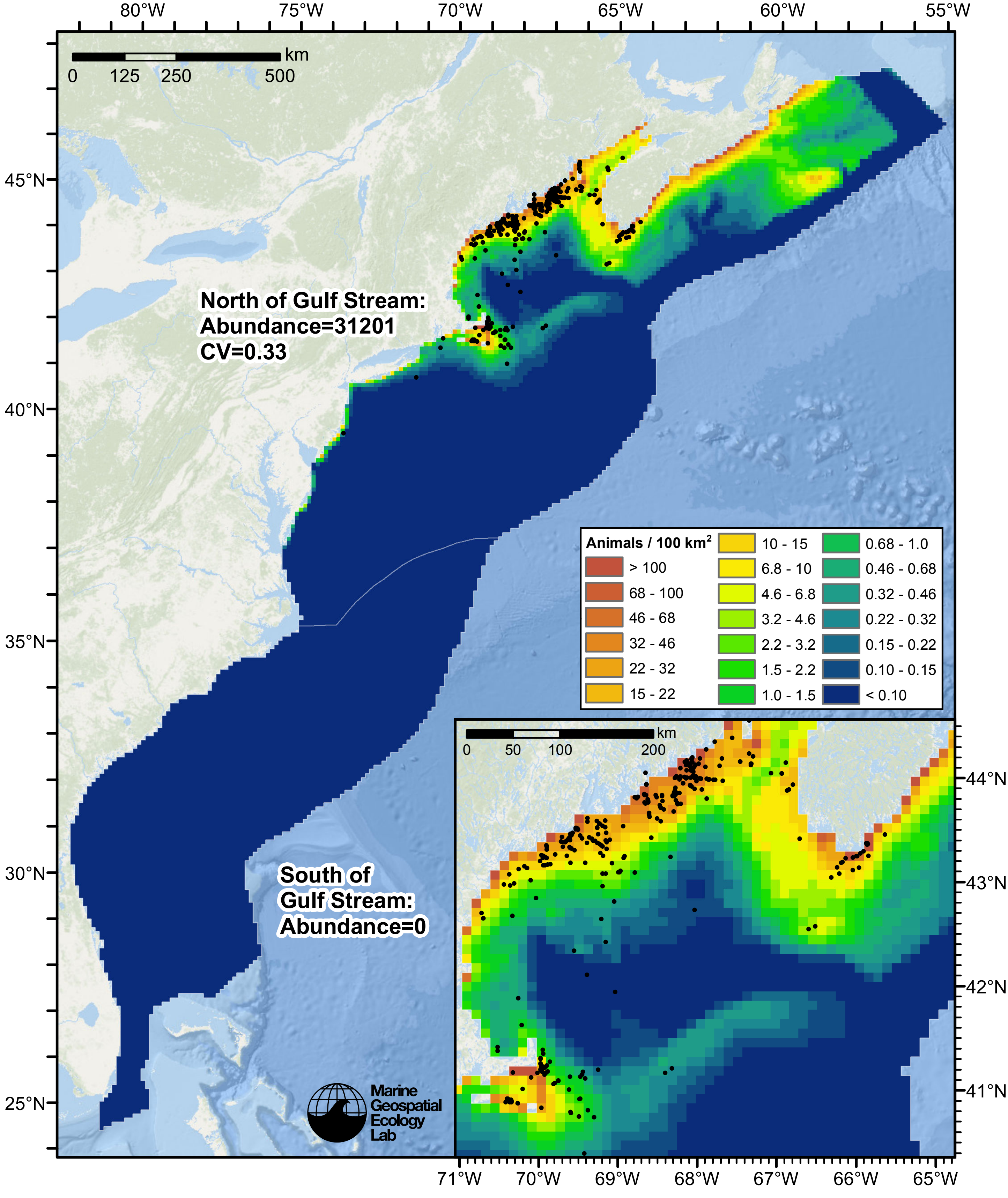


Figure 70: Seals density predicted by the Summer season climatological same segments model that explained the most deviance. Pixels are 10x10 km. The legend gives the estimated individuals per pixel; breaks are logarithmic. The same scale is used for all seasons. Abundance for each region was computed by summing the density cells occuring in that region.

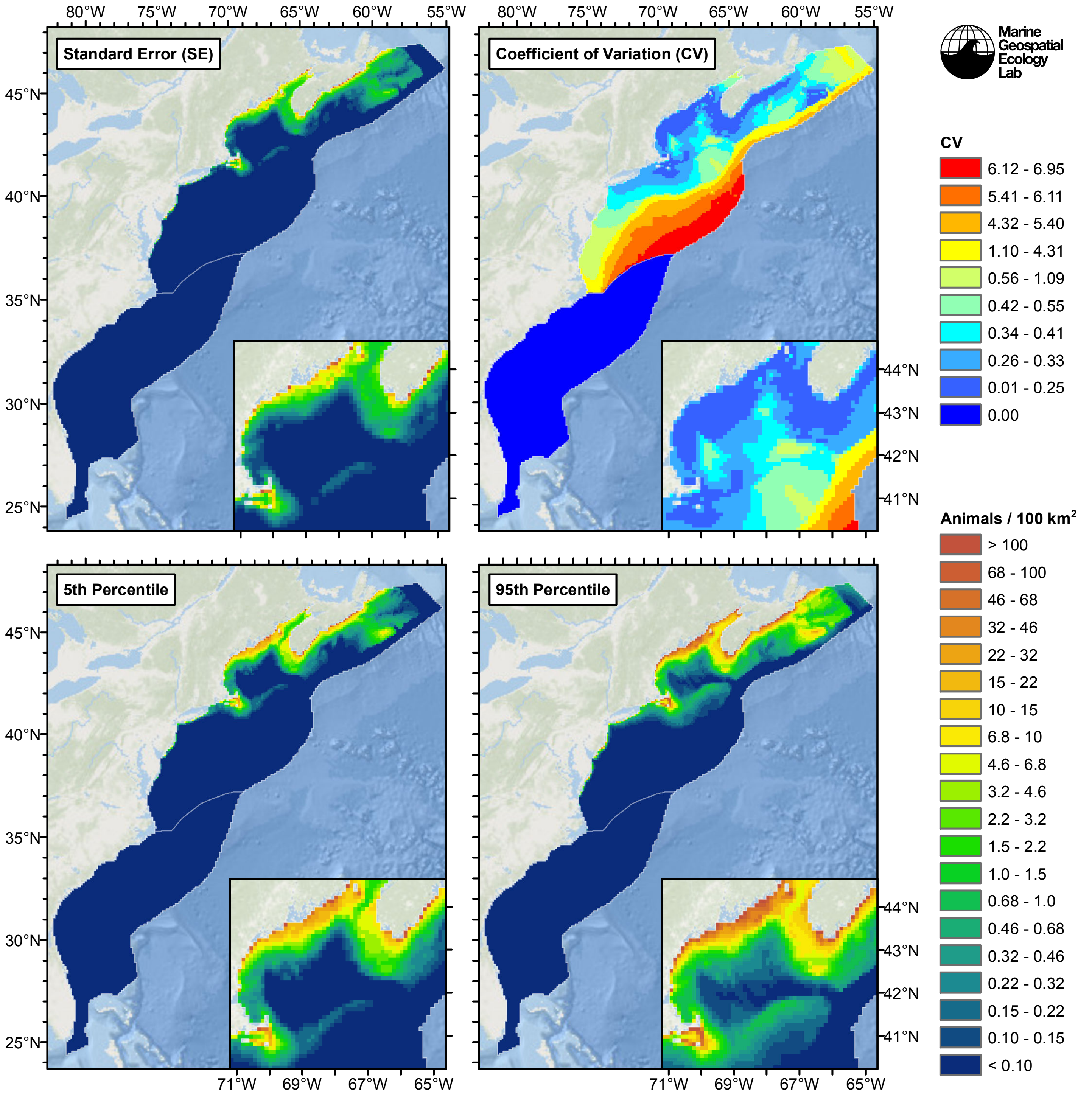


Figure 71: Estimated uncertainty for the Summer season climatological same segments model that explained the most deviance. These estimates only incorporate the statistical uncertainty estimated for the spatial model (by the R mgcv package). They do not incorporate uncertainty in the detection functions, g(0) estimates, predictor variables, and so on.

North of Gulf Stream

Statistical output

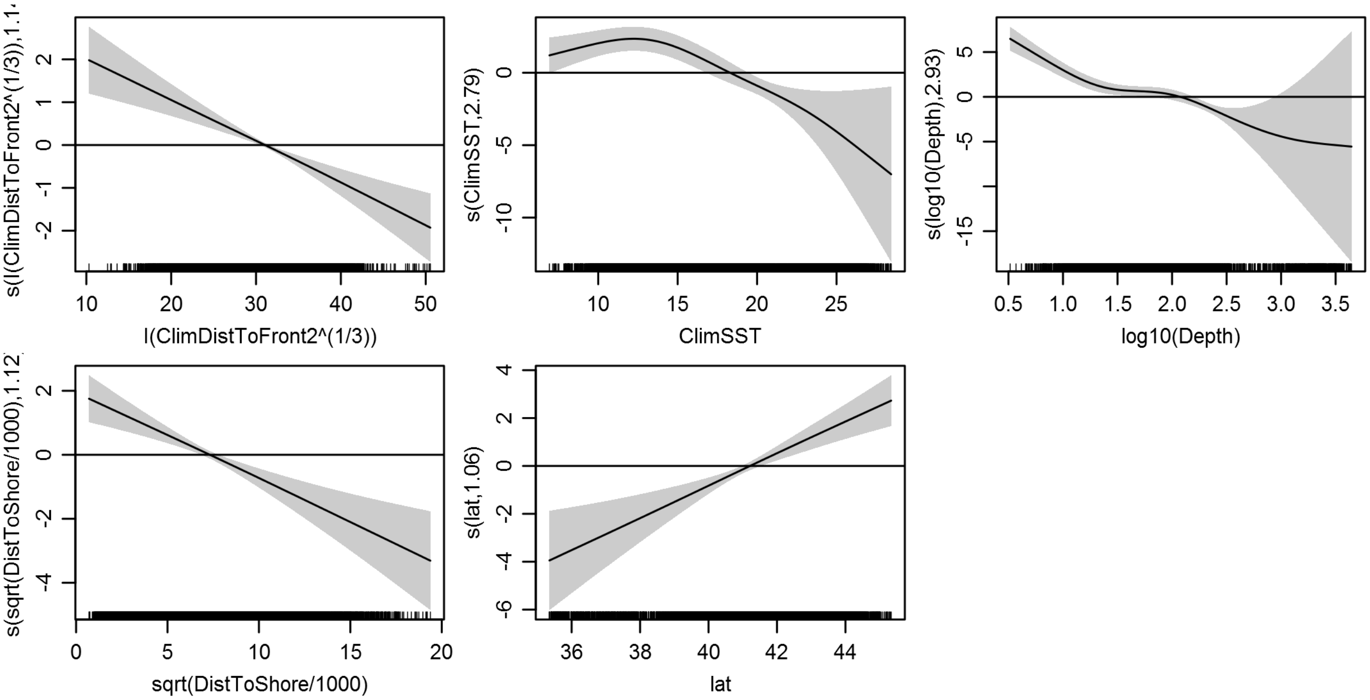
```
Rscript.exe: This is mgcv 1.8-3. For overview type 'help("mgcv-package")'.


Family: Tweedie(p=1.3)
```

```
Link function: log

Formula:
abundance ~ offset(log(area_km2)) + s(lat, bs = "ts", k = 5) +
    s(log10(Depth), bs = "ts", k = 5) + s(sqrt(DistToShore/1000),
    bs = "ts", k = 5) + s(ClimSST, bs = "ts", k = 5) + s(I(ClimDistToFront2^(1/3)),
    bs = "ts", k = 5)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -7.4452     0.4646  -16.02   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                              edf Ref.df      F  p-value
s(lat)                      1.062      4  6.768 5.24e-08 ***
s(log10(Depth))             2.931      4 24.801  < 2e-16 ***
s(sqrt(DistToShore/1000))   1.125      4  6.355 1.83e-07 ***
s(ClimSST)                  2.791      4 15.572 6.35e-15 ***
s(I(ClimDistToFront2^(1/3))) 1.136      4  8.543 1.91e-09 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.0319   Deviance explained =   52%
-REML = 1326.5  Scale est. = 23.663    n = 9731

All predictors were significant. This is the final model.
Creating term plots.
Diagnostic output from gam.check():

Method: REML   Optimizer: outer newton
full convergence after 10 iterations.
Gradient range [-1.207488e-06,1.234101e-06]
(score 1326.49 & scale 23.66349).
Hessian positive definite, eigenvalue range [0.4805945,607.851].
Model rank =  21 / 21

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                                k'   edf k-index p-value
s(lat)                       4.000 1.062   0.755    0.00
s(log10(Depth))              4.000 2.931   0.839    0.39
s(sqrt(DistToShore/1000))    4.000 1.125   0.851    0.84
s(ClimSST)                   4.000 2.791   0.771    0.00
s(I(ClimDistToFront2^(1/3))) 4.000 1.136   0.821    0.02
```

Predictors retained during the model selection procedure: lat, Depth, DistToShore, ClimSST, ClimDistToFront2

Predictors dropped during the model selection procedure: Slope, DistTo125m, DistTo300m

Model term plots



Diagnostic plots

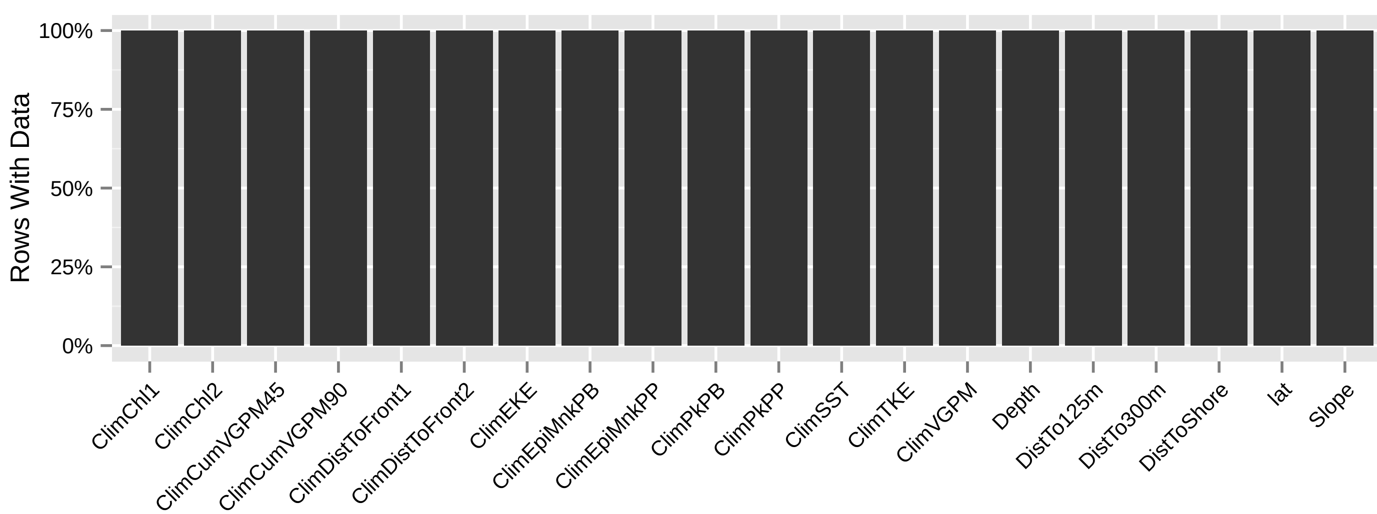


Figure 72: Segments with predictor values for the Seals Climatological model, Summer season, North of Gulf Stream. This plot is used to assess how many segments would be lost by including a given predictor in a model.

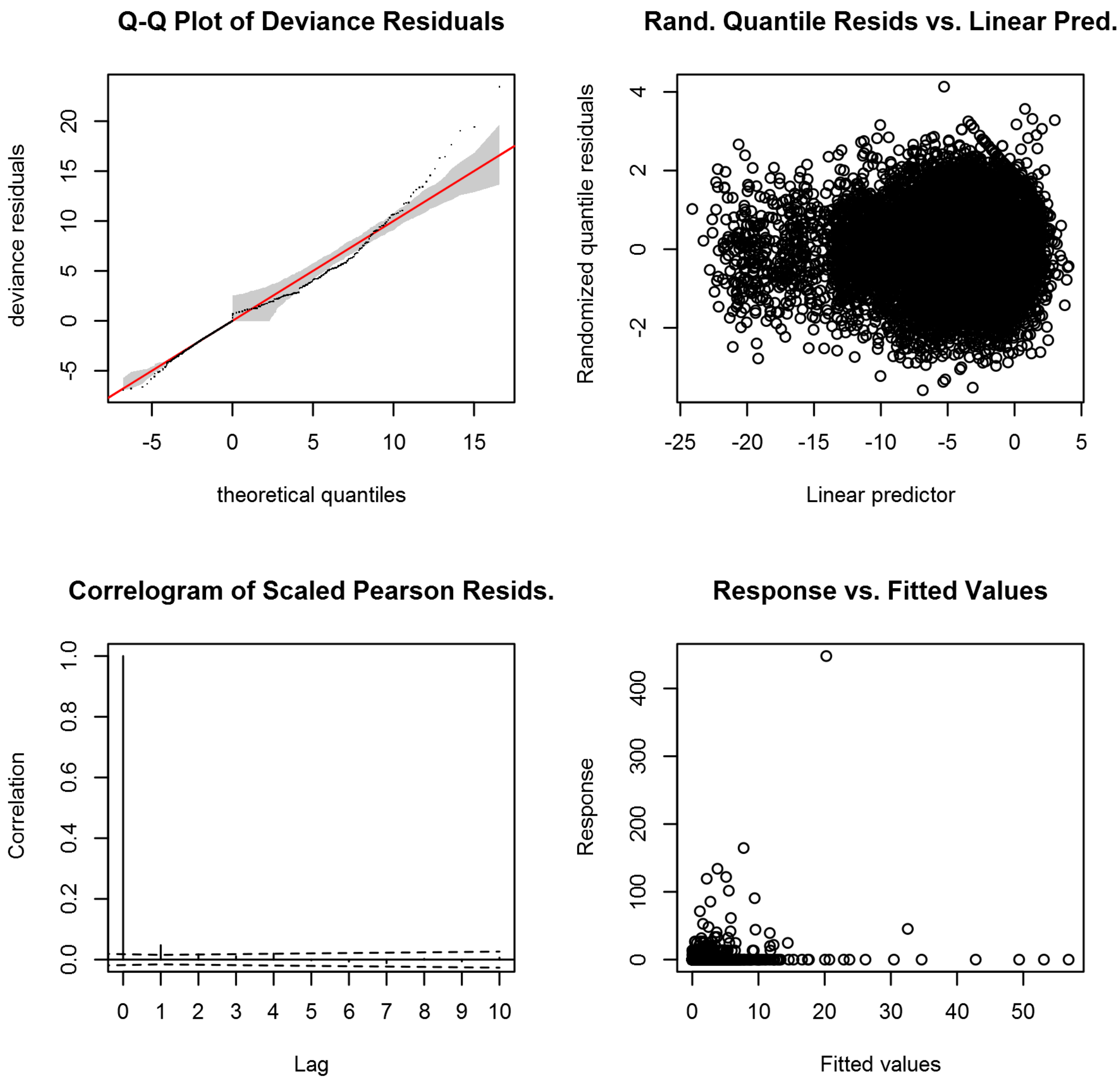


Figure 73: Statistical diagnostic plots for the Seals Climatological model, Summer season, North of Gulf Stream.

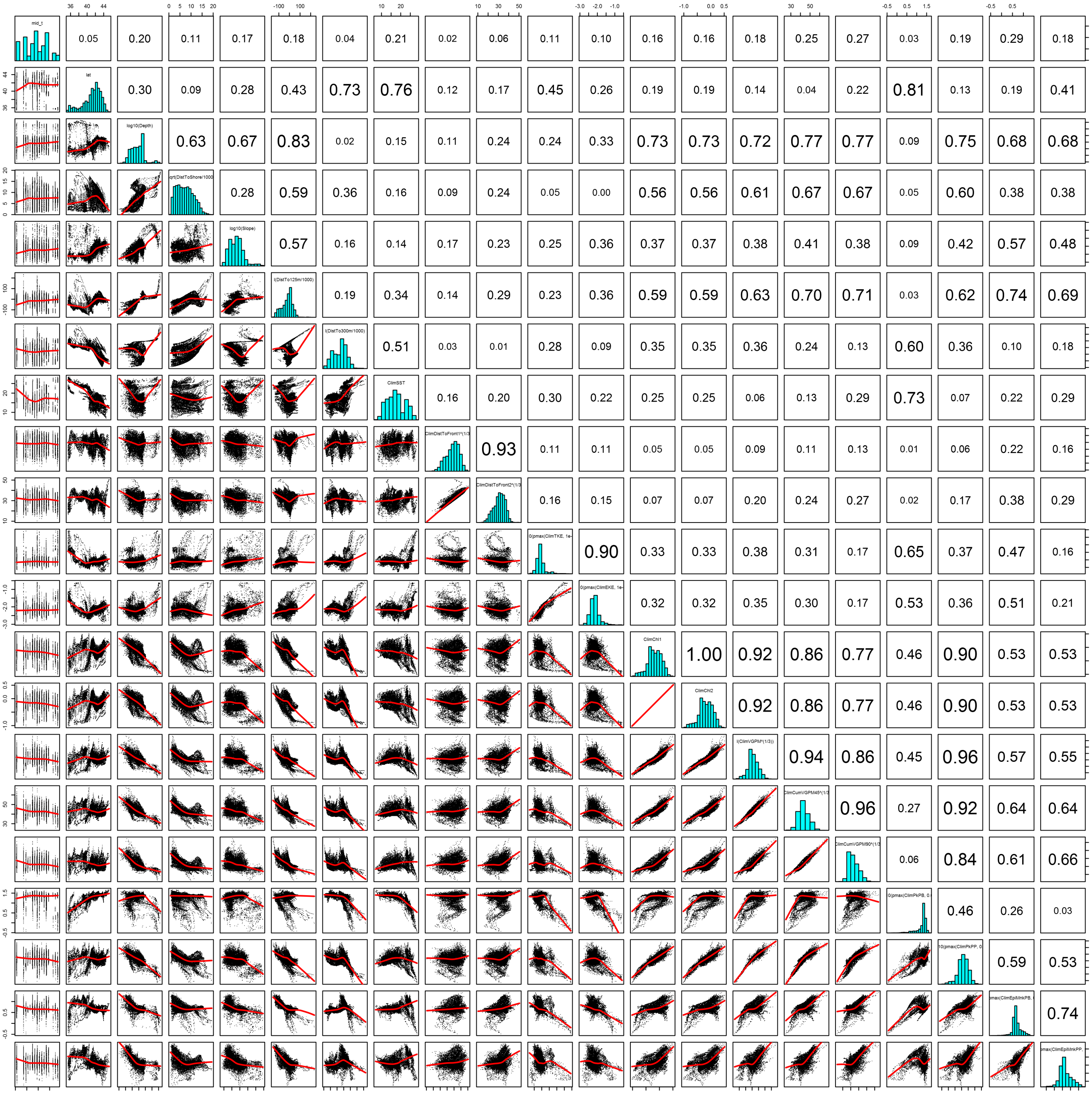


Figure 74: Scatterplot matrix for the Seals Climatological model, Summer season, North of Gulf Stream. This plot is used to inspect the distribution of predictors (via histograms along the diagonal), simple correlation between predictors (via pairwise Pearson coefficients above the diagonal), and linearity of predictor correlations (via scatterplots below the diagonal). This plot is best viewed at high magnification.

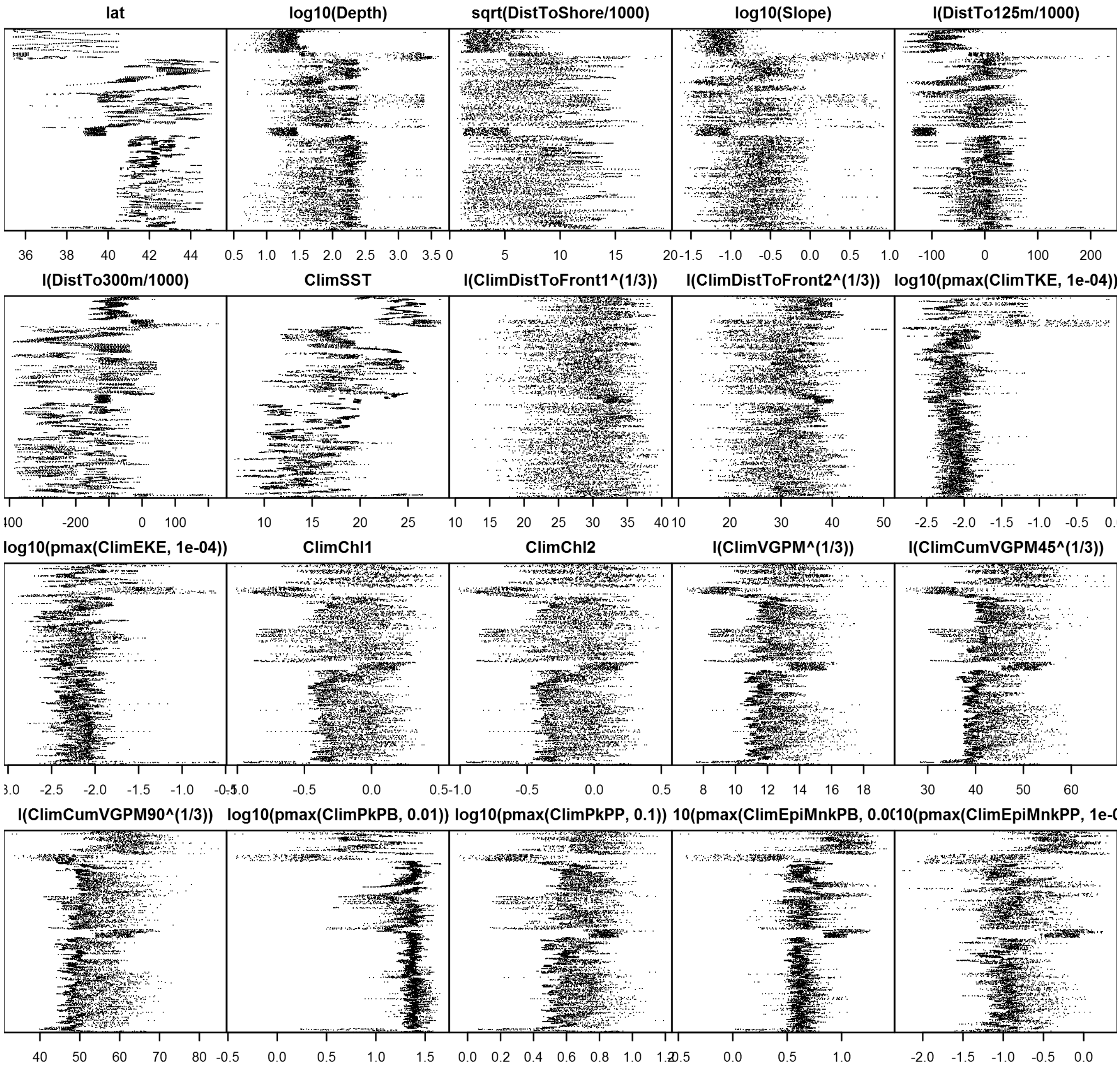


Figure 75: Dotplot for the Seals Climatological model, Summer season, North of Gulf Stream. This plot is used to check for suspicious patterns and outliers in the data. Points are ordered vertically by transect ID, sequentially in time.

South of Gulf Stream

Density assumed to be 0 in this region.

Model Comparison

Spatial Model Performance

The table below summarizes the performance of the candidate spatial models that were tested. For each season, the first model contained only physiographic predictors. Subsequent models added additional suites of predictors of based on when they became available via remote sensing.

For each model, three versions were fitted; the % Dev Expl columns give the % deviance explained by each one. The "climatological" models were fitted to 8-day climatologies of the environmental predictors. Because the environmental predictors were always available, no segments were lost, allowing these models to consider the maximal amount of survey data. The "contemporaneous" models were fitted to day-of-sighting images of the environmental predictors; these were smoothed to reduce data loss due to clouds, but some segments still failed to retrieve environmental values and were lost. Finally, the "climatological same segments" models fitted climatological predictors to the segments retained by the contemporaneous model, so that the explantory power of the two types of predictors could be directly compared. For each of the three models, predictors were selected independently via shrinkage smoothers; thus the three models did not necessarily utilize the same predictors.

Predictors derived from ocean currents first became available in January 1993 after the launch of the TOPEX/Poseidon satellite; productivity predictors first became available in September 1997 after the launch of the SeaWiFS sensor. Contemporaneous and climatological same segments models considering these predictors usually suffered data loss. Date Range shows the years spanned by the retained segments. The Segments column gives the number of segments retained; % Lost gives the percentage lost.

Season	Predictors	Climatol % Dev Expl	Contemp % Dev Expl	Climatol Same Segs % Dev Expl	Segments	% Lost	Date Range
Winter							
	Lat+Phys	51.4			11892		1999-2014
	Lat+Phys+SST	55.4	54.2	55.4	11892	0.0	1999-2014
	Lat+Phys+SST+Curr	55.4	54.2	55.4	11892	0.0	1999-2014
	Lat+Phys+SST+Curr+Prod	56.3	56.2	56.3	11892	0.0	1999-2014
Summer							
	Lat+Phys	45.9			9731		1995-2013
	Lat+Phys+SST	52.0	50.4	52.0	9731	0.0	1995-2013
	Lat+Phys+SST+Curr	52.0	50.4	52.0	9731	0.0	1995-2013
	Lat+Phys+SST+Curr+Prod	52.8	49.7	51.1	8564	12.0	1998-2013

Table 19: Deviance explained by the candidate density models.

Abundance Estimates

The table below shows the estimated mean abundance (number of animals) within the study area, for the models that explained the most deviance for each model type. Mean abundance was calculated by first predicting density maps for a series of time steps, then computing the abundance for each map, and then averaging the abundances. For the climatological models, we used 8-day climatologies, resulting in 46 abundance maps. For the contemporaneous models, we used daily images, resulting in 365 predicted abundance maps per year that the prediction spanned. The Dates column gives the dates to which the estimates apply. For our models, these are the years for which both survey data and remote sensing data were available.

Season	Dates	Model or study	Estimated abundance	CV
Winter				
	1999-2014	Climatological model*	15002	0.17
	1999-2014	Contemporaneous model	11213	0.19
	1999-2014	Climatological same segments model	15002	0.17
Summer				
	1995-2013	Climatological model*	98747	0.55
	1995-2013	Contemporaneous model	50597	0.33
	1995-2013	Climatological same segments model	31201	0.33

Table 20: Estimated mean abundance within the study area. We selected the model marked with * as our best estimate of the abundance and distribution of this taxon. Our coefficients of variation (CVs) underestimate the true uncertainty in our estimates, as they only incorporated the uncertainty of the GAM stage of our models. Other sources of uncertainty include the detection functions and g(0) estimates. It was not possible to incorporate these into our CVs without undertaking a computationally-prohibitive bootstrap; we hope to attempt that in a future version of our models.

Density Maps

Climatological Model

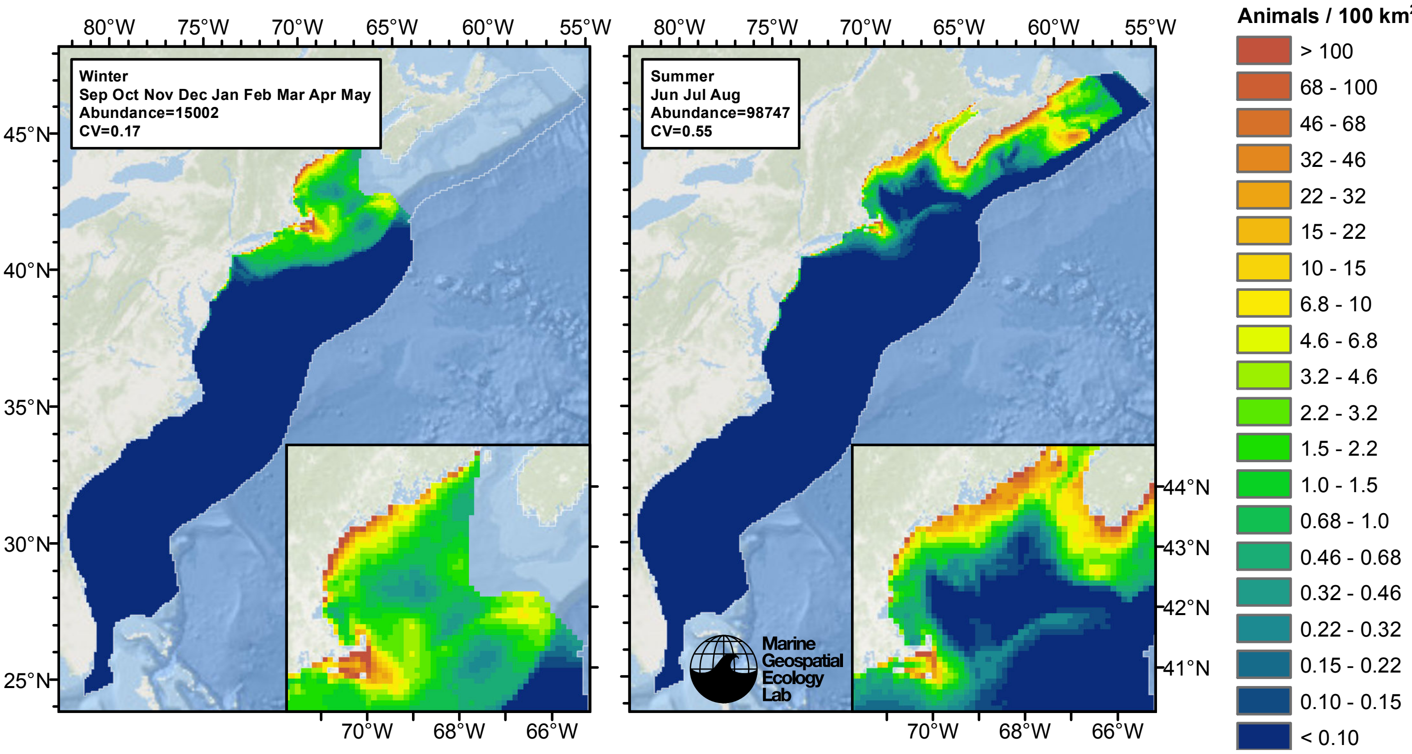


Figure 76: Seals density and abundance predicted by the climatological model that explained the most deviance. Regions inside the study area (white line) where the background map is visible are areas we did not model (see text).

Contemporaneous Model

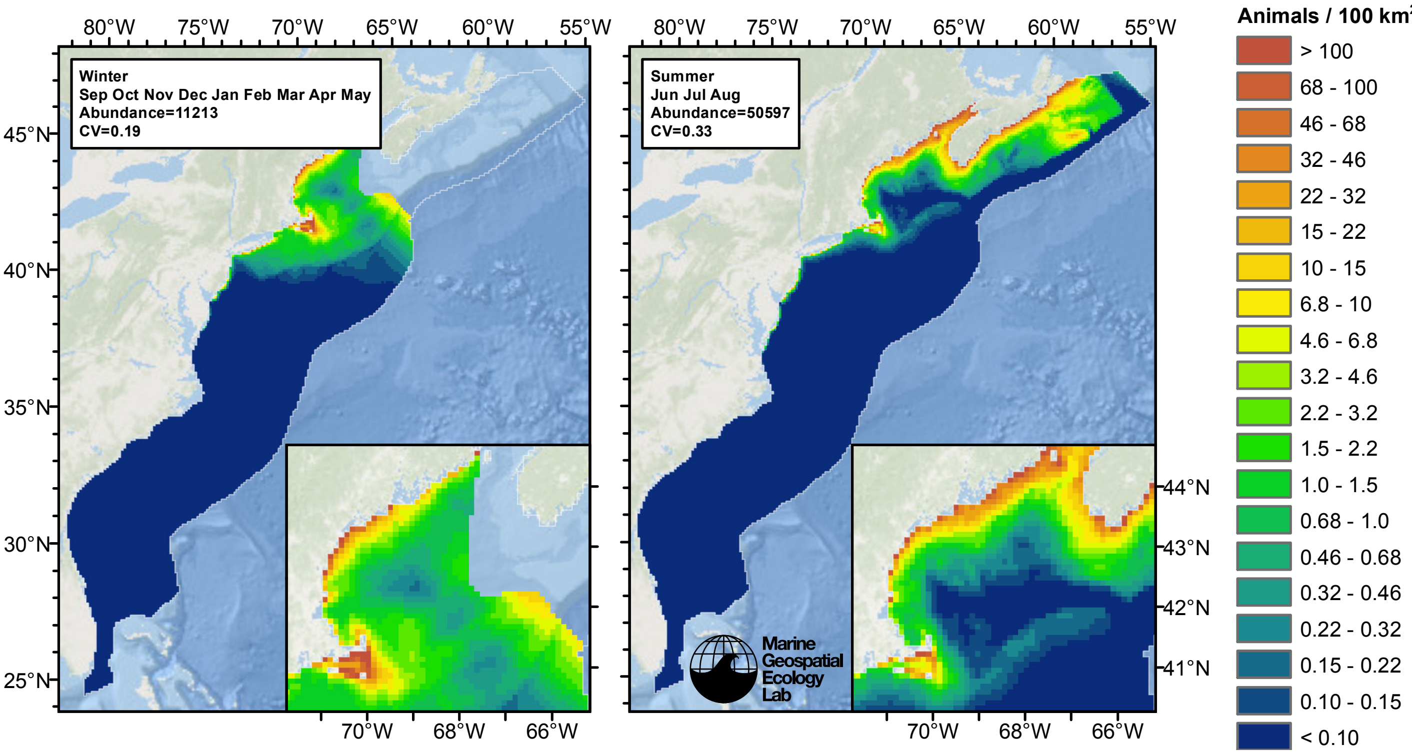


Figure 77: Seals density and abundance predicted by the contemporaneous model that explained the most deviance. Regions inside the study area (white line) where the background map is visible are areas we did not model (see text).

Climatological Same Segments Model

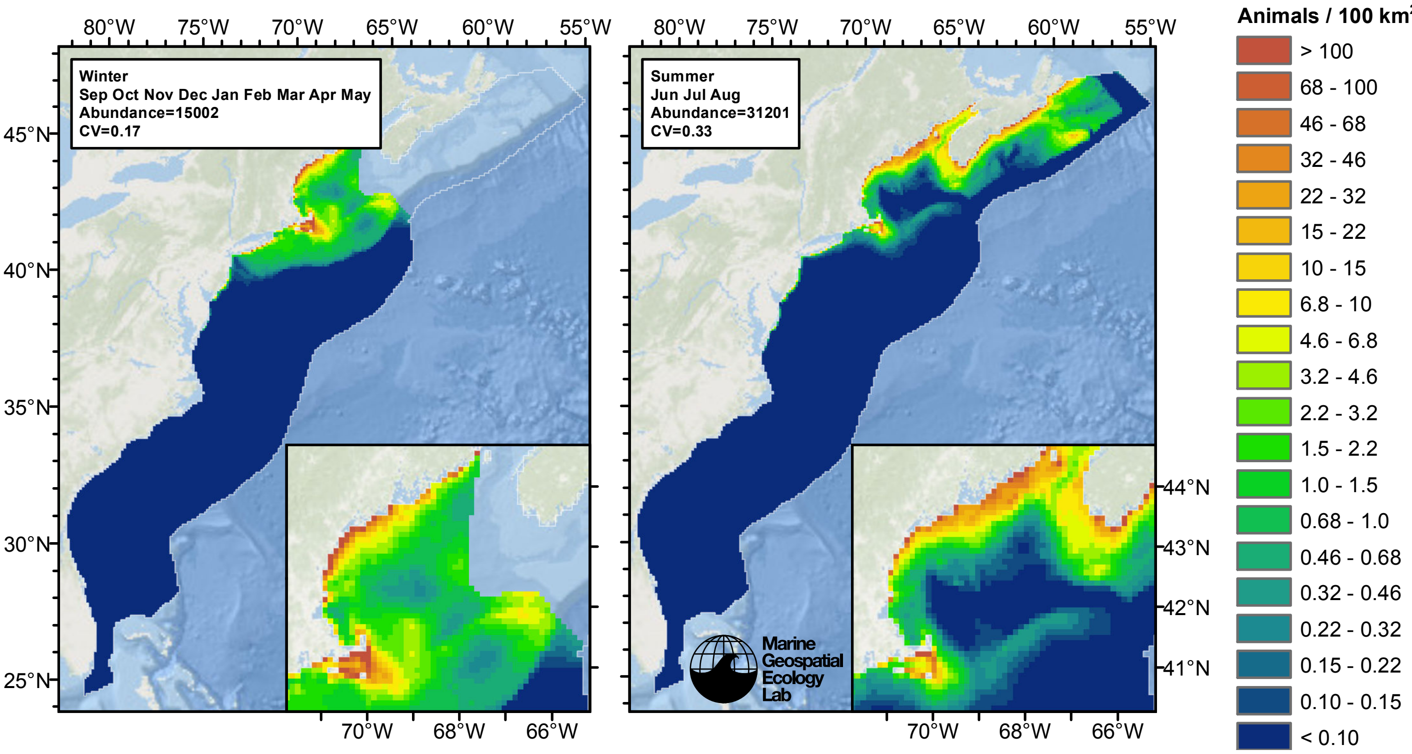


Figure 78: Seals density and abundance predicted by the climatological same segments model that explained the most deviance. Regions inside the study area (white line) where the background map is visible are areas we did not model (see text).

Temporal Variability

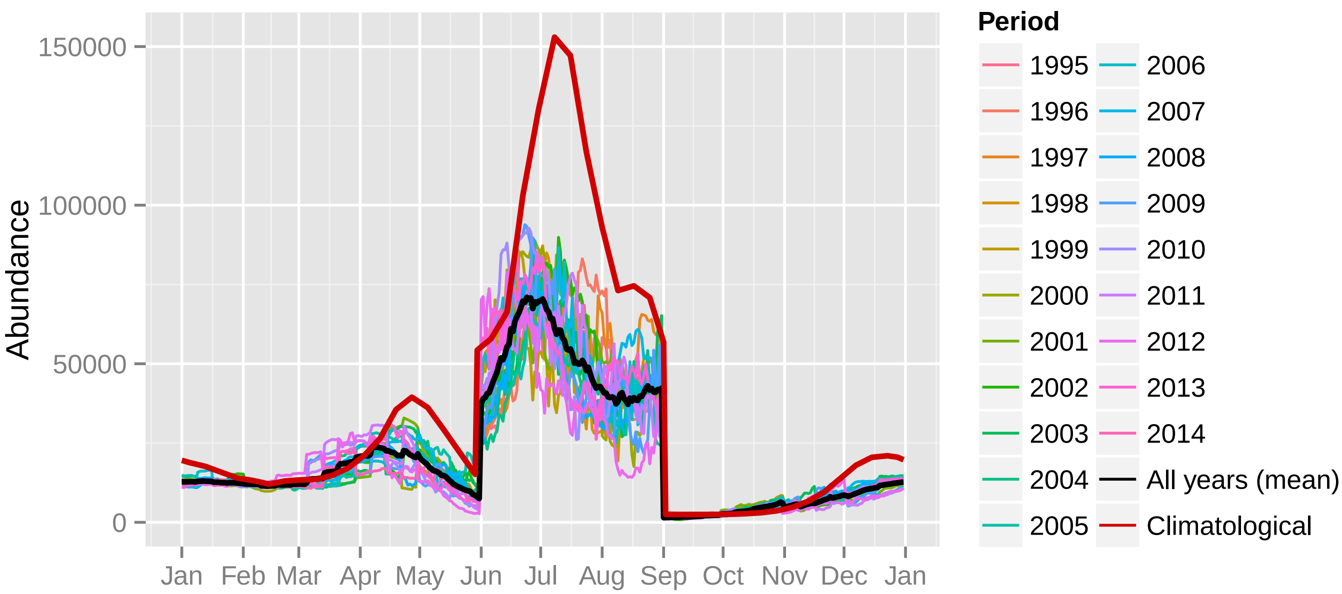


Figure 79: Comparison of Seals abundance predicted at a daily time step for different time periods. Individual years were predicted using contemporaneous models. "All years (mean)" averages the individual years, giving the mean annual abundance of the contemporaneous model. "Climatological" was predicted using the climatological model. The results for the climatological same segments model are not shown.

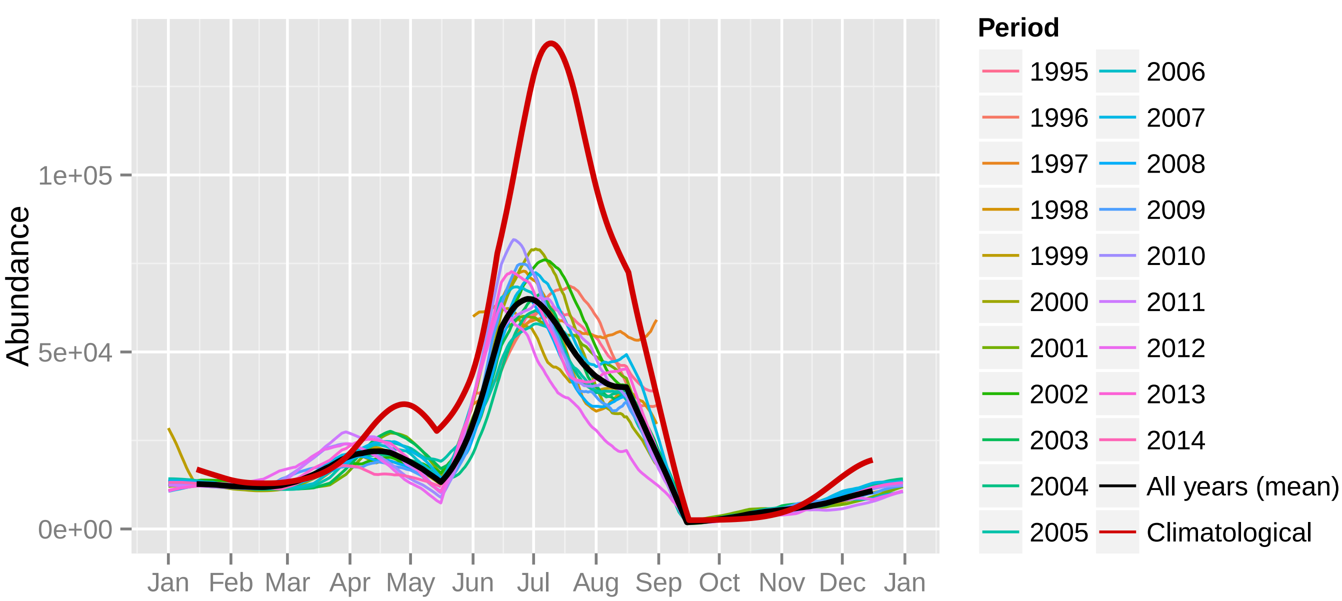
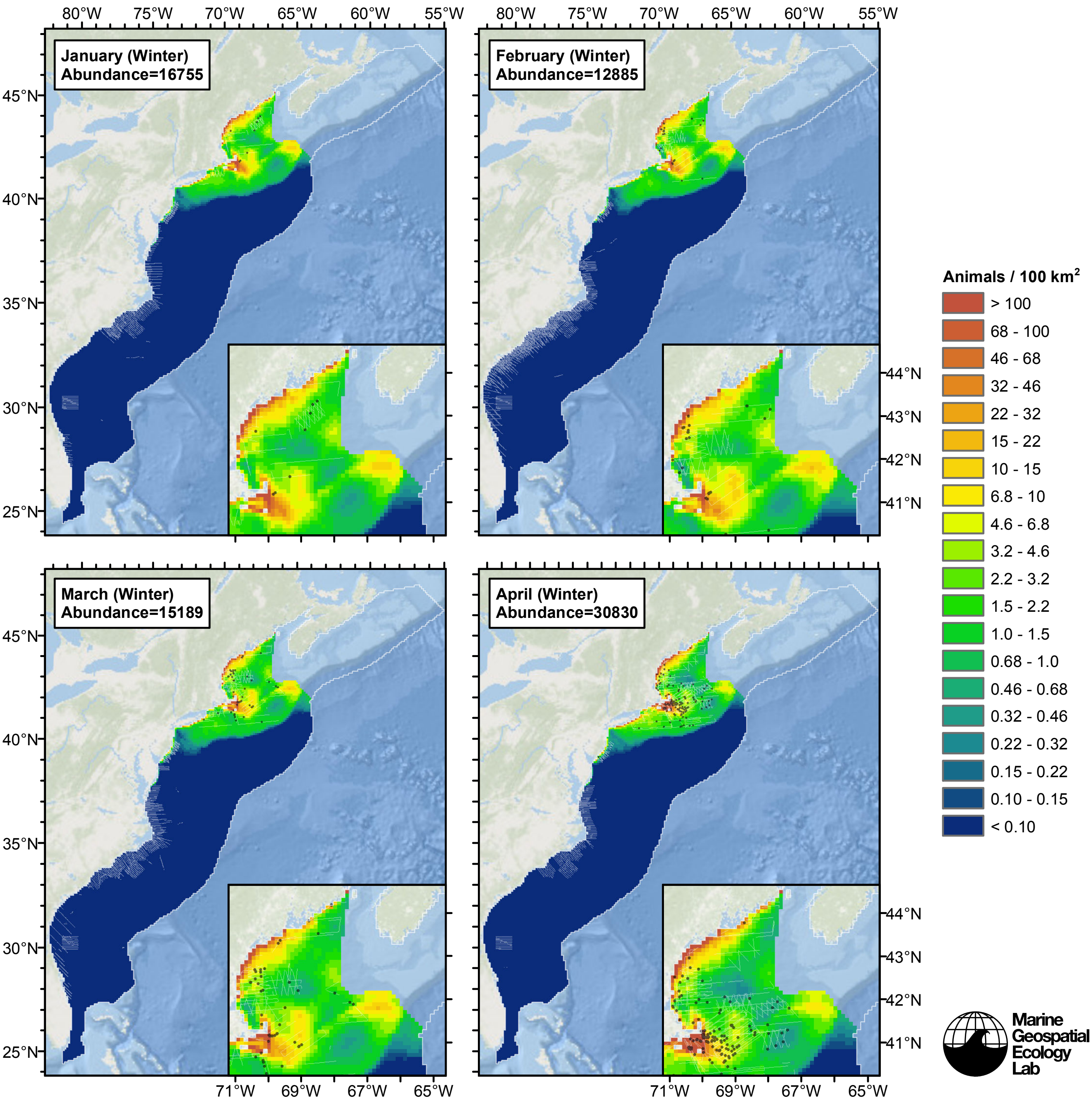
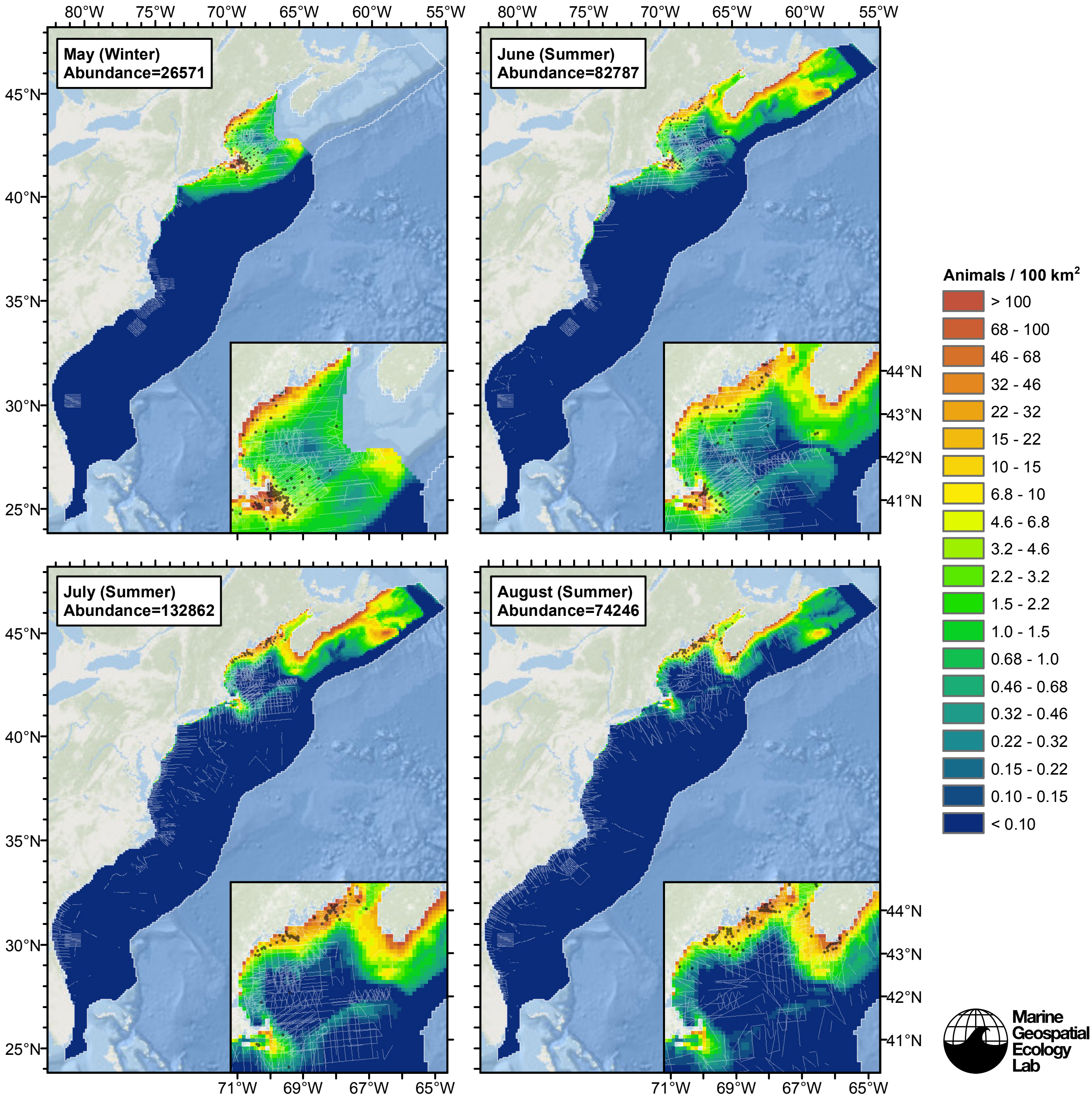


Figure 80: The same data as the preceding figure, but with a 30-day moving average applied.

Climatological Model




May (Winter)
Abundance=26571
June (Summer)
Abundance=82787
July (Summer)
Abundance=132862
August (Summer)
Abundance=74246
80°W
75°W
70°W
65°W
60°W
55°W
45°N
40°N
35°N
30°N
25°N
44°N
43°N
42°N
41°N
71°W
69°W
67°W
65°W
Animals / 100 km²
> 100
68 - 100
46 - 68
32 - 46
22 - 32
15 - 22
10 - 15
6.8 - 10
4.6 - 6.8
3.2 - 4.6
2.2 - 3.2
1.5 - 2.2
1.0 - 1.5
0.68 - 1.0
0.46 - 0.68
0.32 - 0.46
0.22 - 0.32
0.15 - 0.22
0.10 - 0.15
< 0.10
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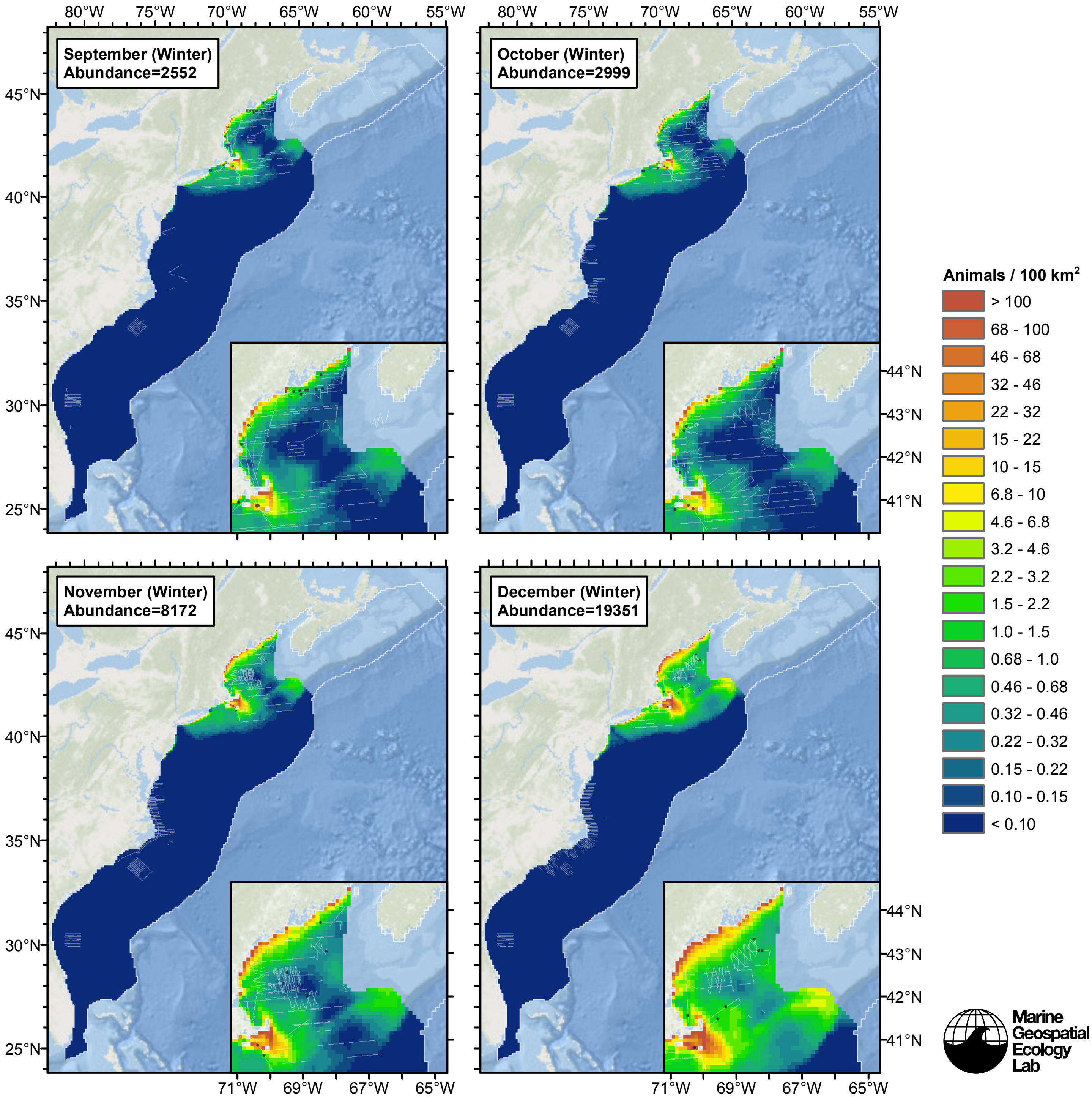
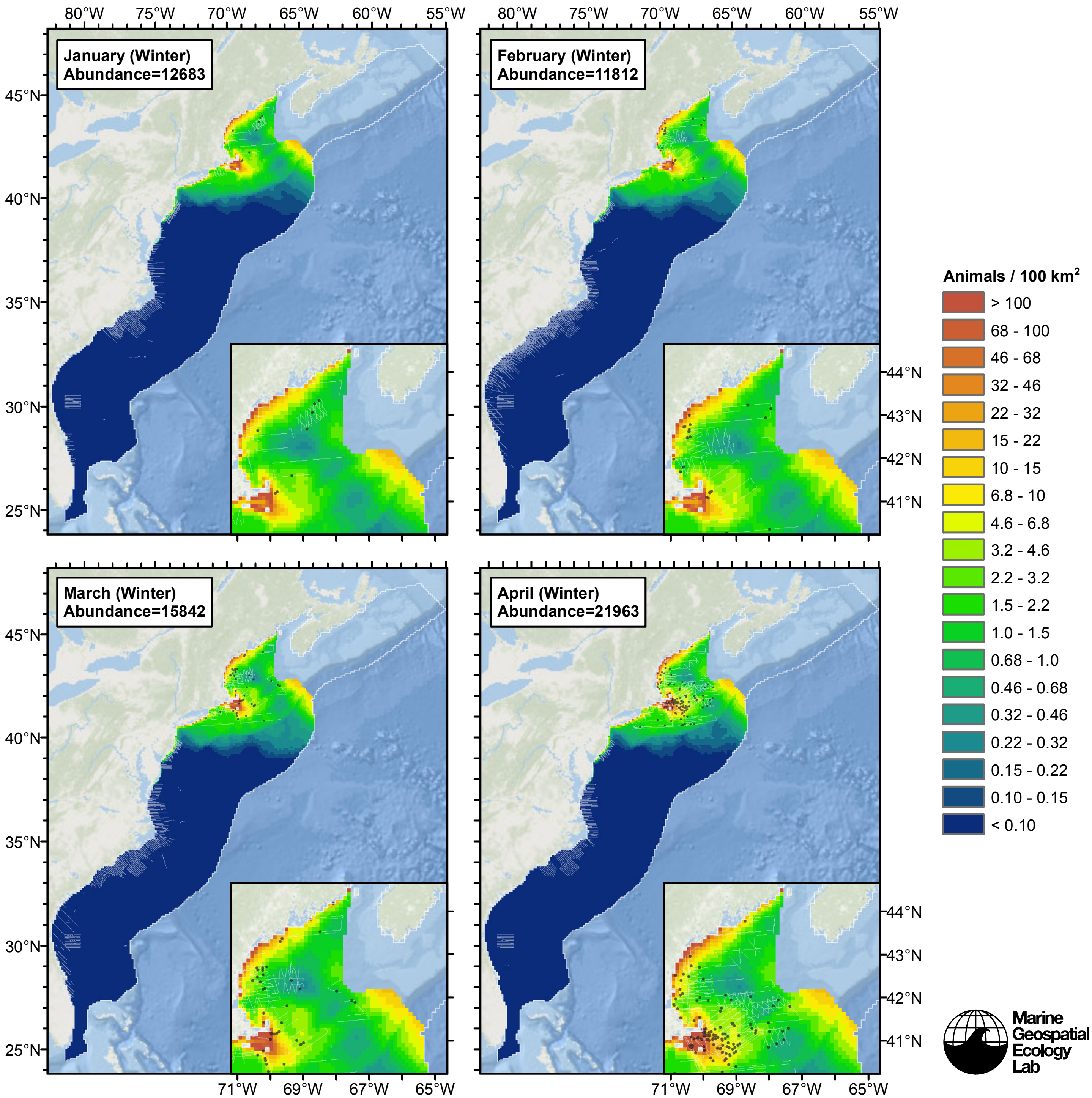
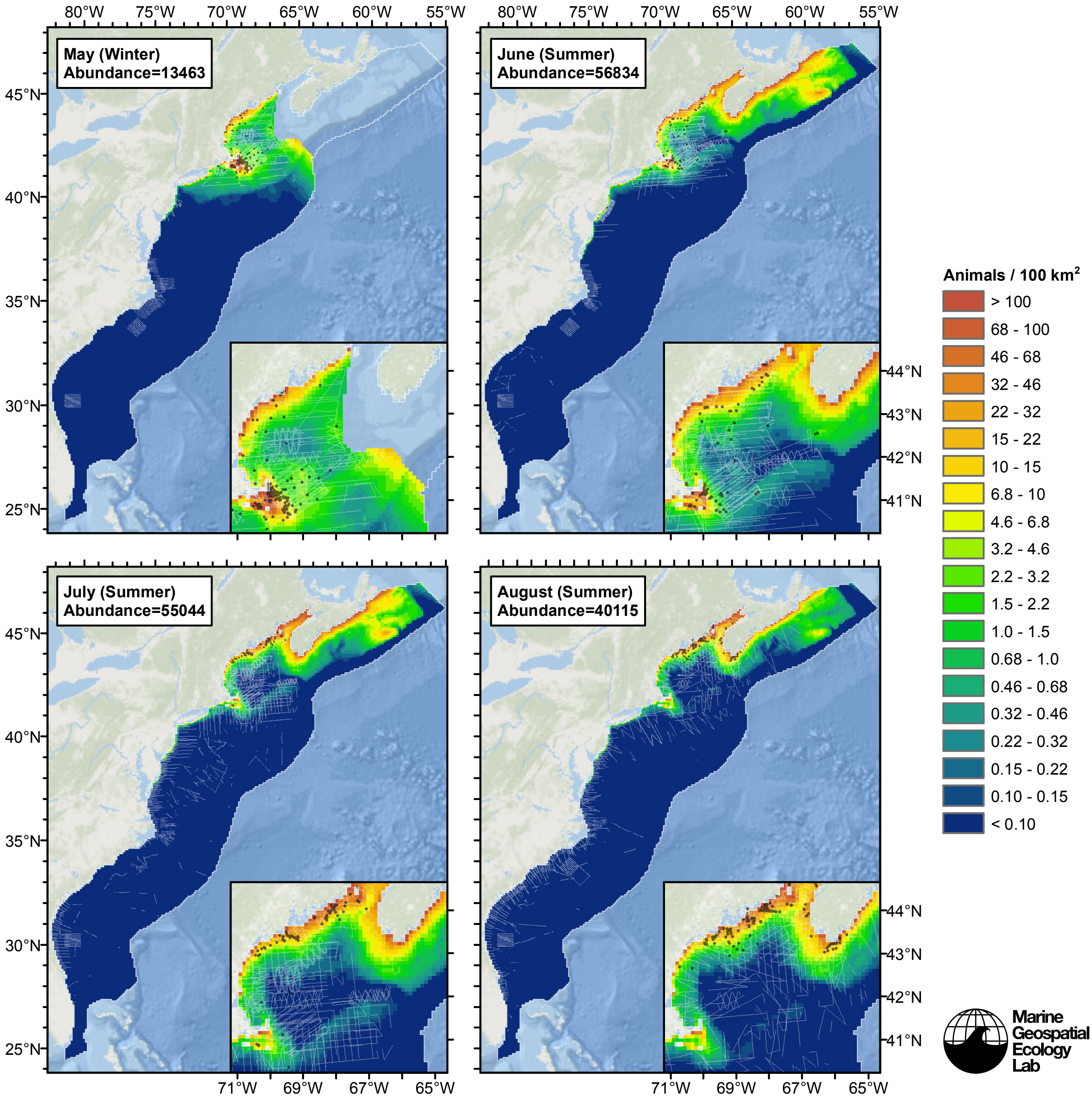
Lab

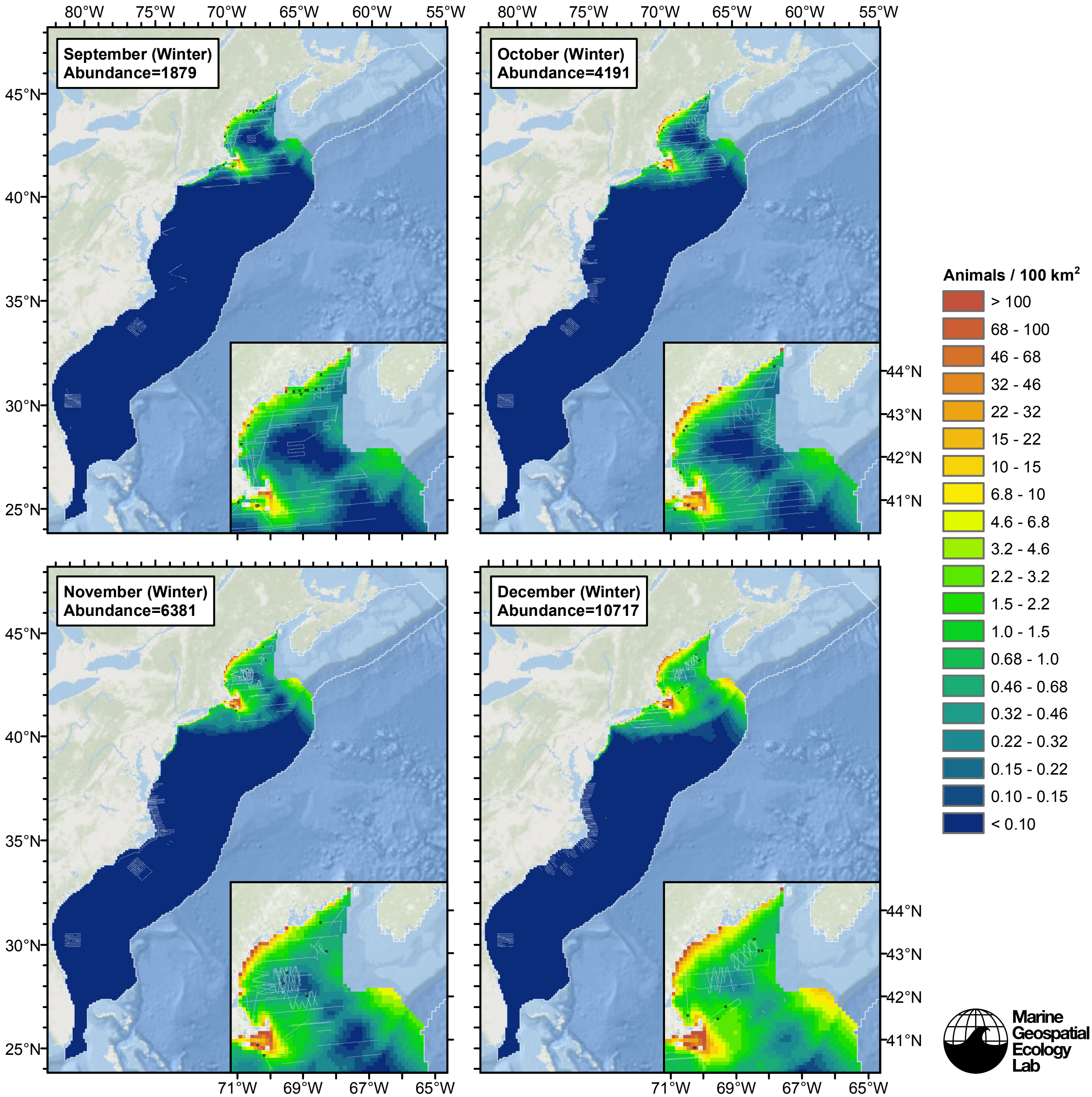

September (Winter)
Abundance=2552
October (Winter)
Abundance=2999
November (Winter)
Abundance=8172
December (Winter)
Abundance=19351
80°W
75°W
70°W
65°W
60°W
55°W
45°N
40°N
35°N
30°N
25°N
44°N
43°N
42°N
41°N
71°W
69°W
67°W
65°W
Animals / 100 km²
> 100
68 - 100
46 - 68
32 - 46
22 - 32
15 - 22
10 - 15
6.8 - 10
4.6 - 6.8
3.2 - 4.6
2.2 - 3.2
1.5 - 2.2
1.0 - 1.5
0.68 - 1.0
0.46 - 0.68
0.32 - 0.46
0.22 - 0.32
0.15 - 0.22
0.10 - 0.15
< 0.10
Marine Geospatial Ecology Lab

Contemporaneous Model





May (Winter)
Abundance=13463
June (Summer)
Abundance=56834
July (Summer)
Abundance=55044
August (Summer)
Abundance=40115
80°W
75°W
70°W
65°W
60°W
55°W
45°N
40°N
35°N
30°N
25°N
44°N
43°N
42°N
41°N
71°W
69°W
67°W
65°W
Animals / 100 km²
> 100
68 - 100
46 - 68
32 - 46
22 - 32
15 - 22
10 - 15
6.8 - 10
4.6 - 6.8
3.2 - 4.6
2.2 - 3.2
1.5 - 2.2
1.0 - 1.5
0.68 - 1.0
0.46 - 0.68
0.32 - 0.46
0.22 - 0.32
0.15 - 0.22
0.10 - 0.15
< 0.10
Marine Geospatial Ecology Lab


September (Winter)
Abundance=1879
October (Winter)
Abundance=4191
November (Winter)
Abundance=6381
December (Winter)
Abundance=10717
80°W
75°W
70°W
65°W
60°W
55°W
45°N
40°N
35°N
30°N
25°N
44°N
43°N
42°N
41°N
71°W
69°W
67°W
65°W
Animals / 100 km²
> 100
68 - 100
46 - 68
32 - 46
22 - 32
15 - 22
10 - 15
6.8 - 10
4.6 - 6.8
3.2 - 4.6
2.2 - 3.2
1.5 - 2.2
1.0 - 1.5
0.68 - 1.0
0.46 - 0.68
0.32 - 0.46
0.22 - 0.32
0.15 - 0.22
0.10 - 0.15
< 0.10
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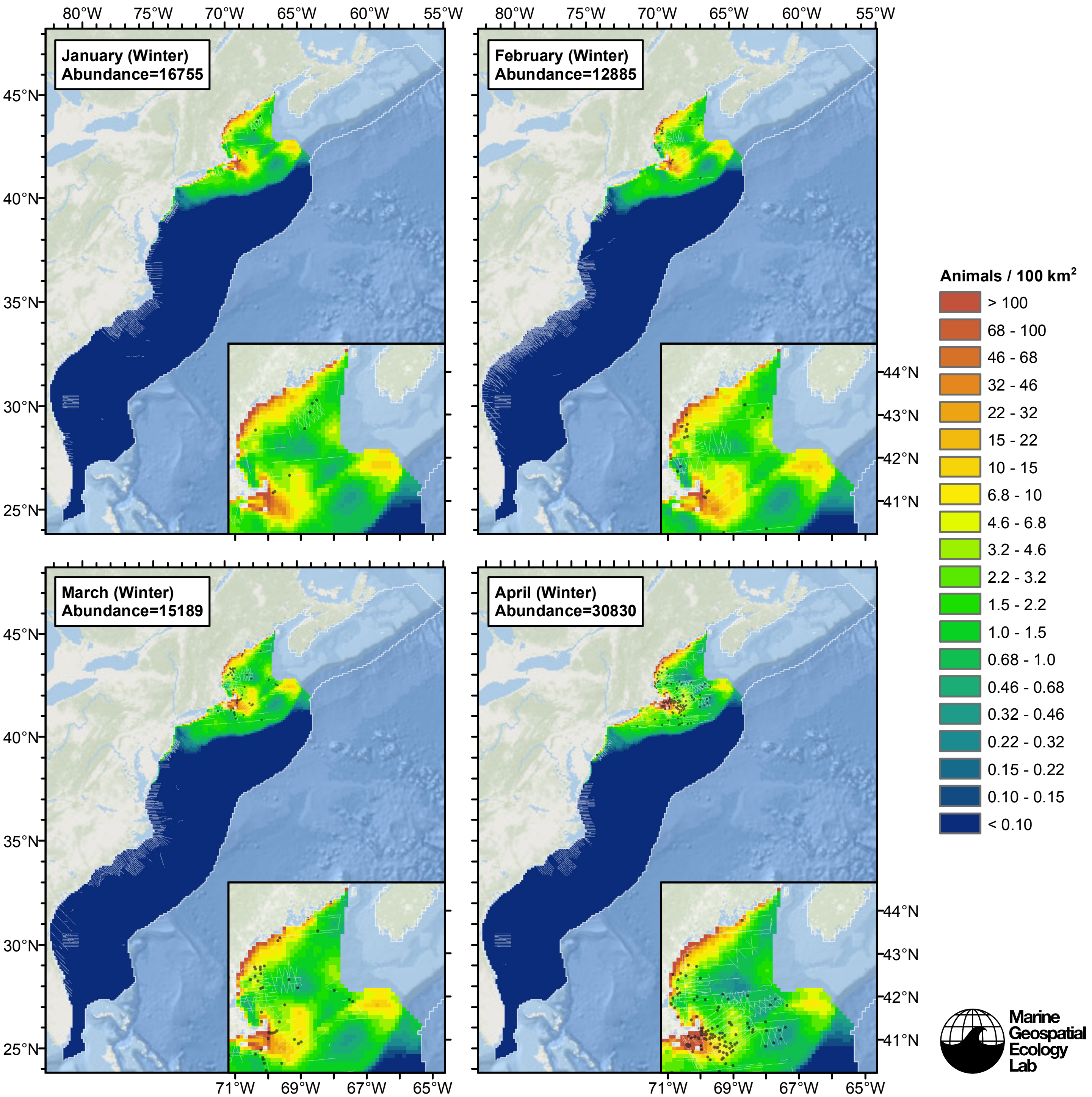
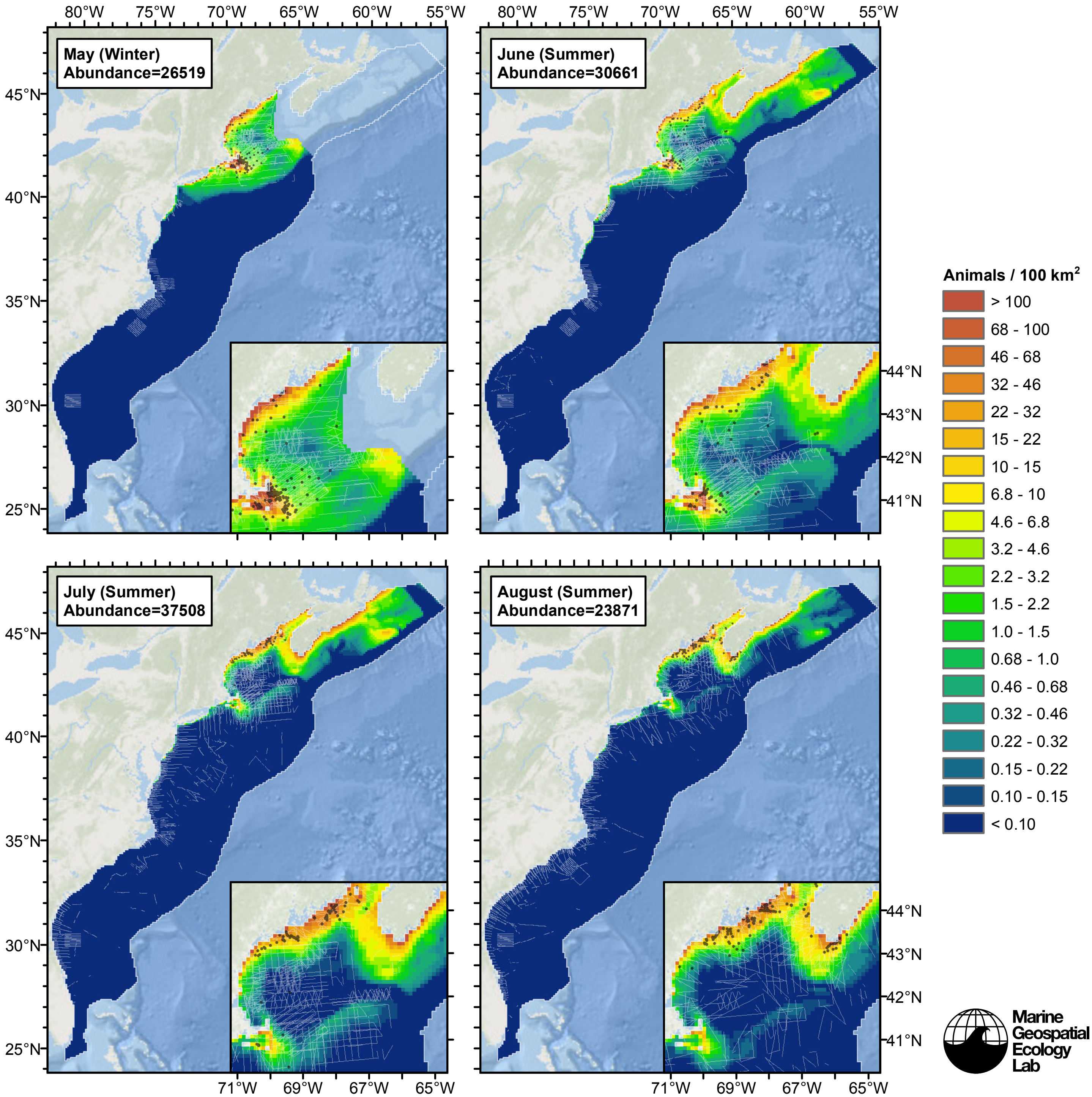
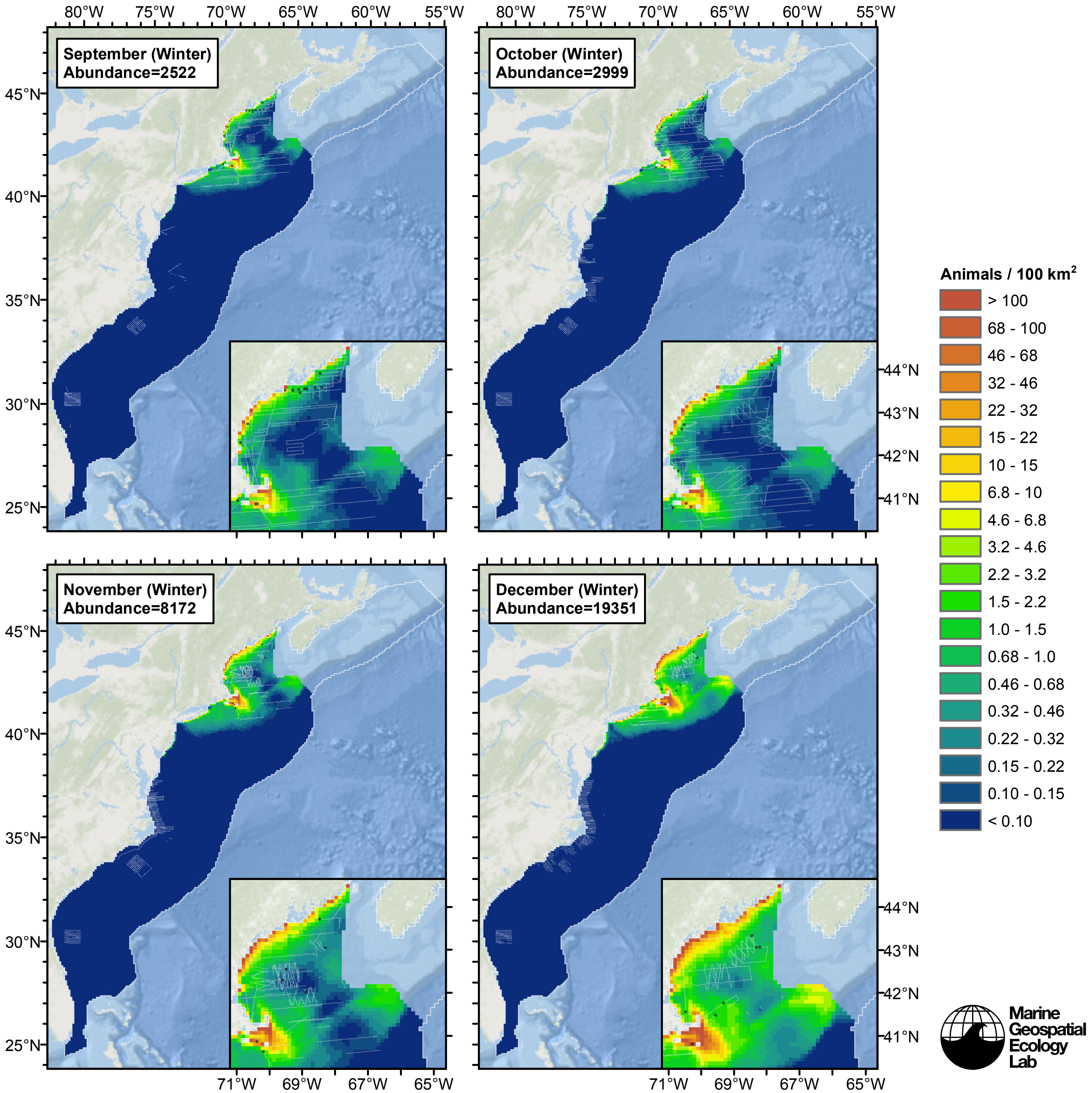
Climatological Same Segments Model




May (Winter)
Abundance=26519
June (Summer)
Abundance=30661
July (Summer)
Abundance=37508
August (Summer)
Abundance=23871
80°W
75°W
70°W
65°W
60°W
55°W
45°N
40°N
35°N
30°N
25°N
44°N
43°N
42°N
41°N
71°W
69°W
67°W
65°W
Animals / 100 km^2
> 100
68 - 100
46 - 68
32 - 46
22 - 32
15 - 22
10 - 15
6.8 - 10
4.6 - 6.8
3.2 - 4.6
2.2 - 3.2
1.5 - 2.2
1.0 - 1.5
0.68 - 1.0
0.46 - 0.68
0.32 - 0.46
0.22 - 0.32
0.15 - 0.22
0.10 - 0.15
< 0.10
Marine Geospatial Ecology Lab



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Stern JS (1992) Surfacing rates and surfacing patterns of minke whales (Balaenoptera acutorostrata) off central California, and the probability of a whale surfacing within visual range. Paper SC/43/Mi2. Rep. Int. Whal. Commn. 42:379-385.