Density Model for Atlantic Spotted Dolphin (*Stenella frontalis*) for the U.S. East Coast: Supplementary Report

Duke University Marine Geospatial Ecology Lab*

Model Version 7.3 - 2015-09-03

Citation

When referencing our methodology or results generally, please cite our open-access article:

Roberts JJ, Best BD, Mannocci L, Fujioka E, Halpin PN, Palka DL, Garrison LP, Mullin KD, Cole TVN, Khan CB, McLellan WM, Pabst DA, Lockhart GG (2016) Habitat-based cetacean density models for the U.S. Atlantic and Gulf of Mexico. Scientific Reports 6: 22615. doi: 10.1038/srep22615

To reference this specific model or Supplementary Report, please cite:

Roberts JJ, Best BD, Mannocci L, Fujioka E, Halpin PN, Palka DL, Garrison LP, Mullin KD, Cole TVN, Khan CB, McLellan WM, Pabst DA, Lockhart GG (2015) Density Model for Atlantic Spotted Dolphin (*Stenella frontalis*) for the U.S. East Coast Version 7.3, 2015-09-03, and Supplementary Report. Marine Geospatial Ecology Lab, Duke University, Durham, North Carolina.

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Revision History

Version	Date	Description of changes
1	2014-05-14	Initial version.
2	2014-09-02	Added surveys: NJ-DEP, Virginia Aquarium, NARWSS 2013, UNCW 2013. Extended study area up Scotian Shelf. Added SEAPODYM predictors. Switched to mgcv estimation of Tweedie p parameter (family=tw()).
3	2014-10-17	Adjusted g(0) estimates based on feedback from September 2014 review. Adjusted proxy species used in certain detection functions to be consistent with other dolphin species. Updated distance to eddy predictors using Chelton et al.'s 2014 database. Removed distance to eddy and wind speed predictors from on shelf model. Fixed missing pixels in several climatological predictors, which led to not all segments being utilized.
4	2014-11-13	Reconfigured detection hierarchy and adjusted NARWSS detection functions based on additional information from Tim Cole. Updated documentation.
5	2014-11-19	Removed CumVGPM180 predictor and refitted models. Updated documentation.
6	2014-12-05	Fixed bug that applied the wrong detection function to segments NE_narwss_1999_widgeon_hapo dataset. Refitted model. Updated documentation.

*For questions, or to offer feedback about this model or report, please contact Jason Roberts (jason.roberts@duke.edu)

7	2015-01-24	Forced abundance to zero in the vicinity of New York-New Jersey Harbor. We found no documentation that Atlantic spotted dolphins occur here, but our model predicts some abundance. We believe this prediction is in error and are manually correcting it.
7.1	2015-03-06	Updated the documentation. No changes to the model.
7.2	2015-05-14	Updated calculation of CVs. Switched density rasters to logarithmic breaks. No changes to the model.
7.3	2015-09-03	Updated the documentation. No changes to the model.

Survey Data

Survey	Period	Length (1000 km)	Hours	Sightings
NEFSC Aerial Surveys	1995-2008	70	412	2
NEFSC NARWSS Harbor Porpoise Survey	1999-1999	6	36	0
NEFSC North Atlantic Right Whale Sighting Survey	1999-2013	432	2330	0
NEFSC Shipboard Surveys	1995-2004	16	1143	25
NJDEP Aerial Surveys	2008-2009	11	60	0
NJDEP Shipboard Surveys	2008-2009	14	836	0
SEFSC Atlantic Shipboard Surveys	1992-2005	28	1731	335
SEFSC Mid Atlantic Tursiops Aerial Surveys	1995-2005	35	196	110
SEFSC Southeast Cetacean Aerial Surveys	1992-1995	8	42	19
UNCW Cape Hatteras Navy Surveys	2011-2013	19	125	19
UNCW Early Marine Mammal Surveys	2002-2002	18	98	1
UNCW Jacksonville Navy Surveys	2009-2013	66	402	258
UNCW Onslow Navy Surveys	2007-2011	49	282	64
UNCW Right Whale Surveys	2005-2008	114	586	5
Virginia Aquarium Aerial Surveys	2012-2014	9	53	0
Total		895	8332	838

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
All_Year	All	897	8332	838

Table 3: Survey effort and on-effort sightings having perpendicular sighting distances.

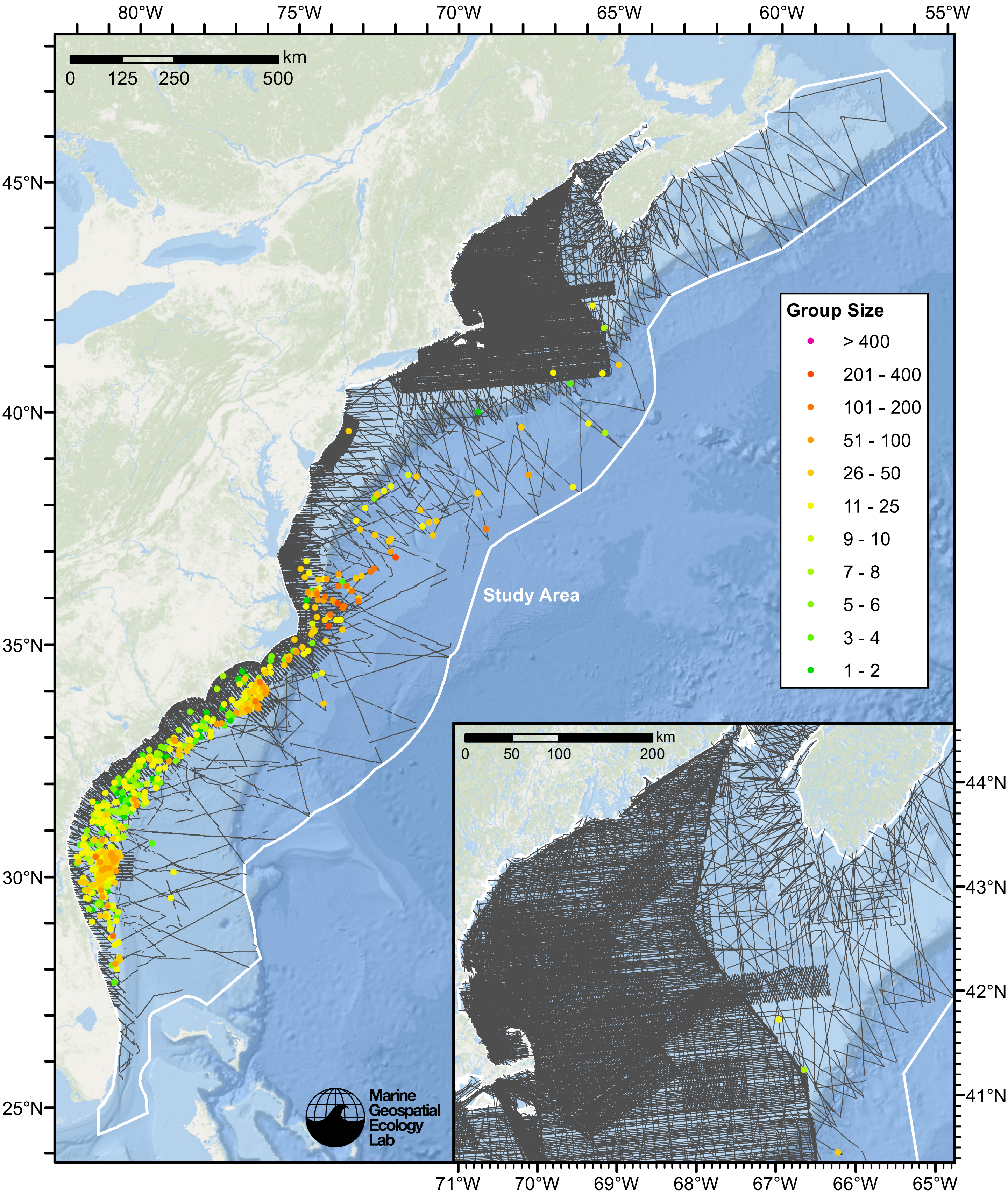


Figure 1: Atlantic spotted dolphin sightings and survey tracklines.

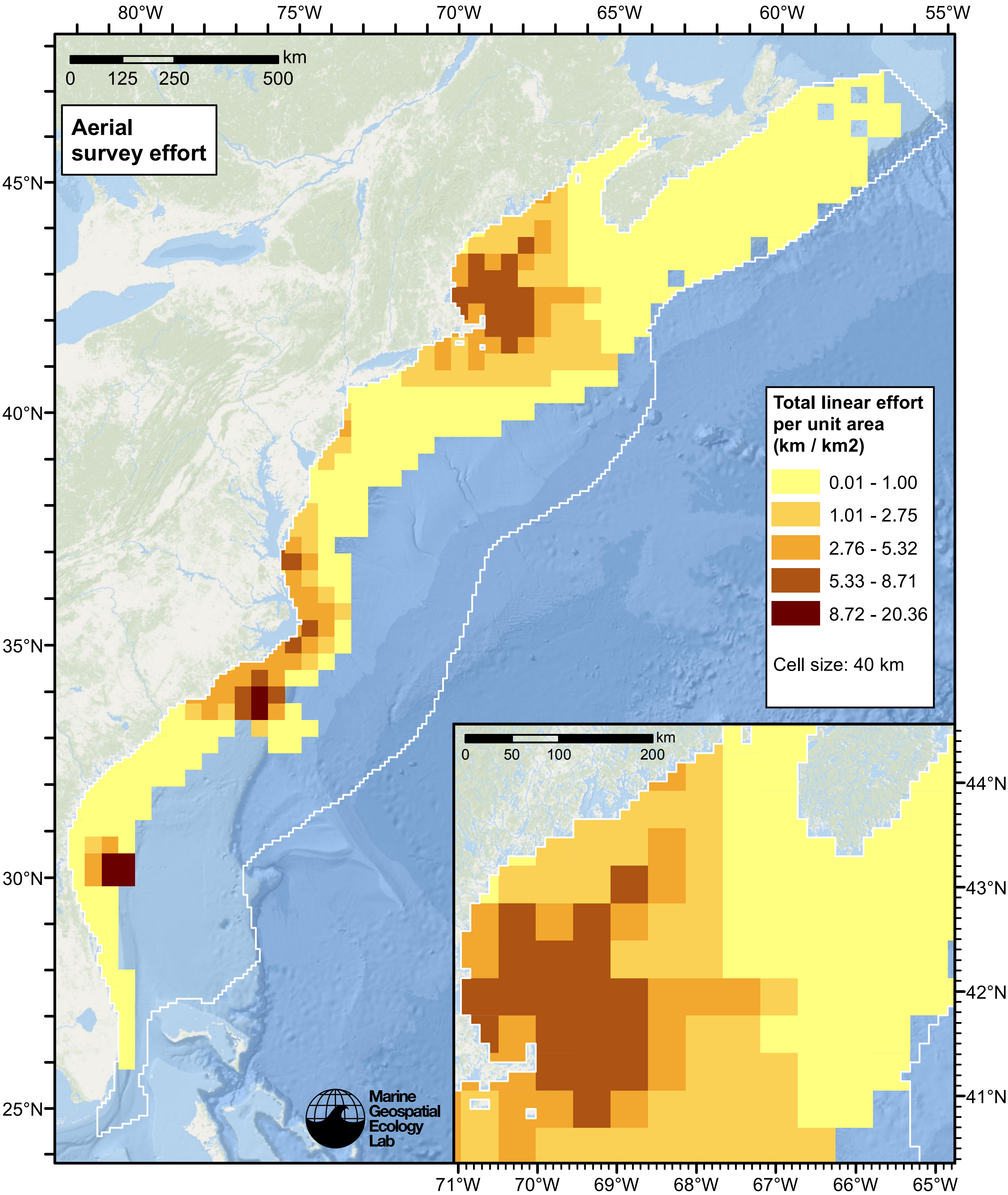


Figure 2: Aerial linear survey effort per unit area.

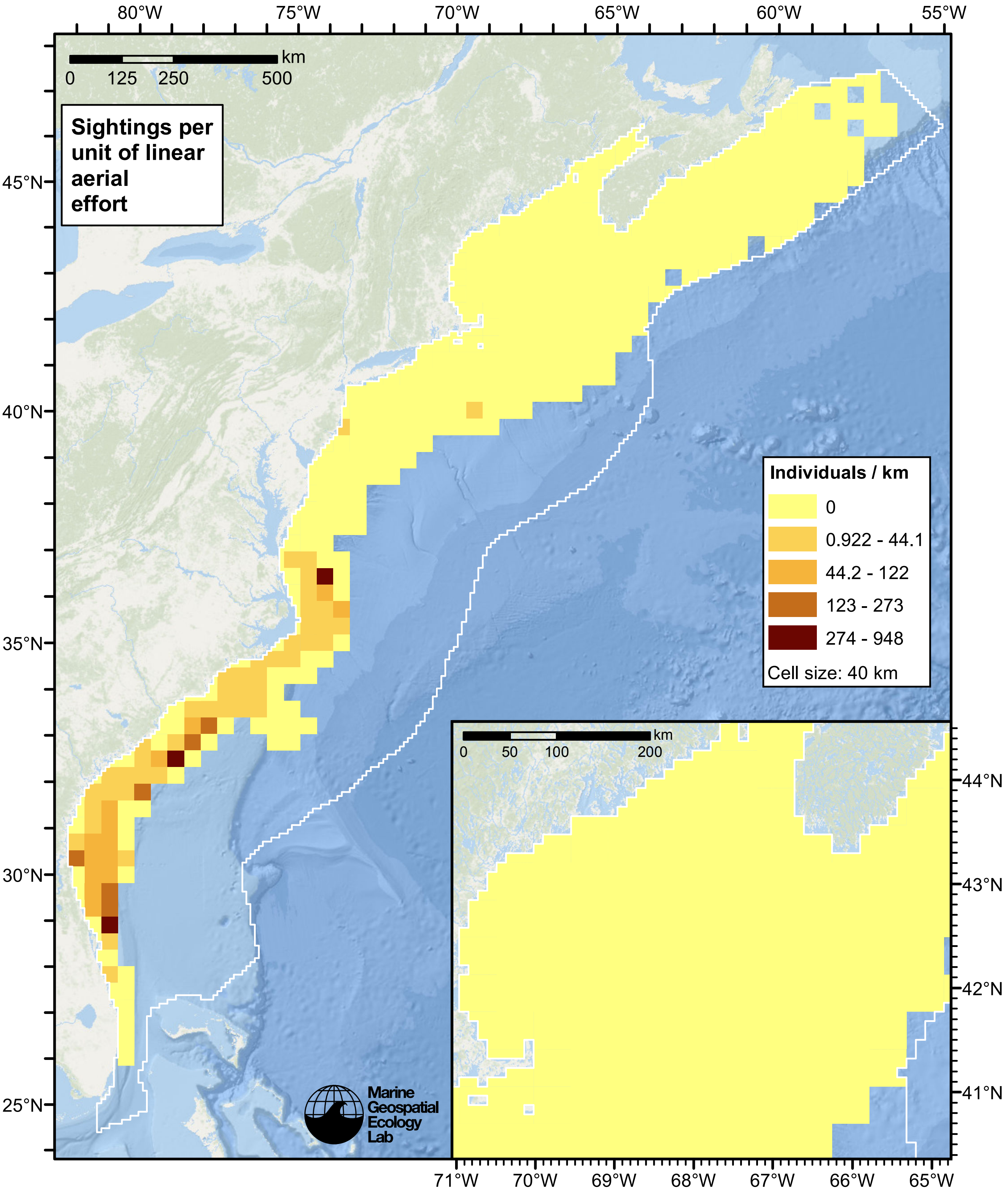


Figure 3: Atlantic spotted dolphin sightings per unit aerial linear survey effort.

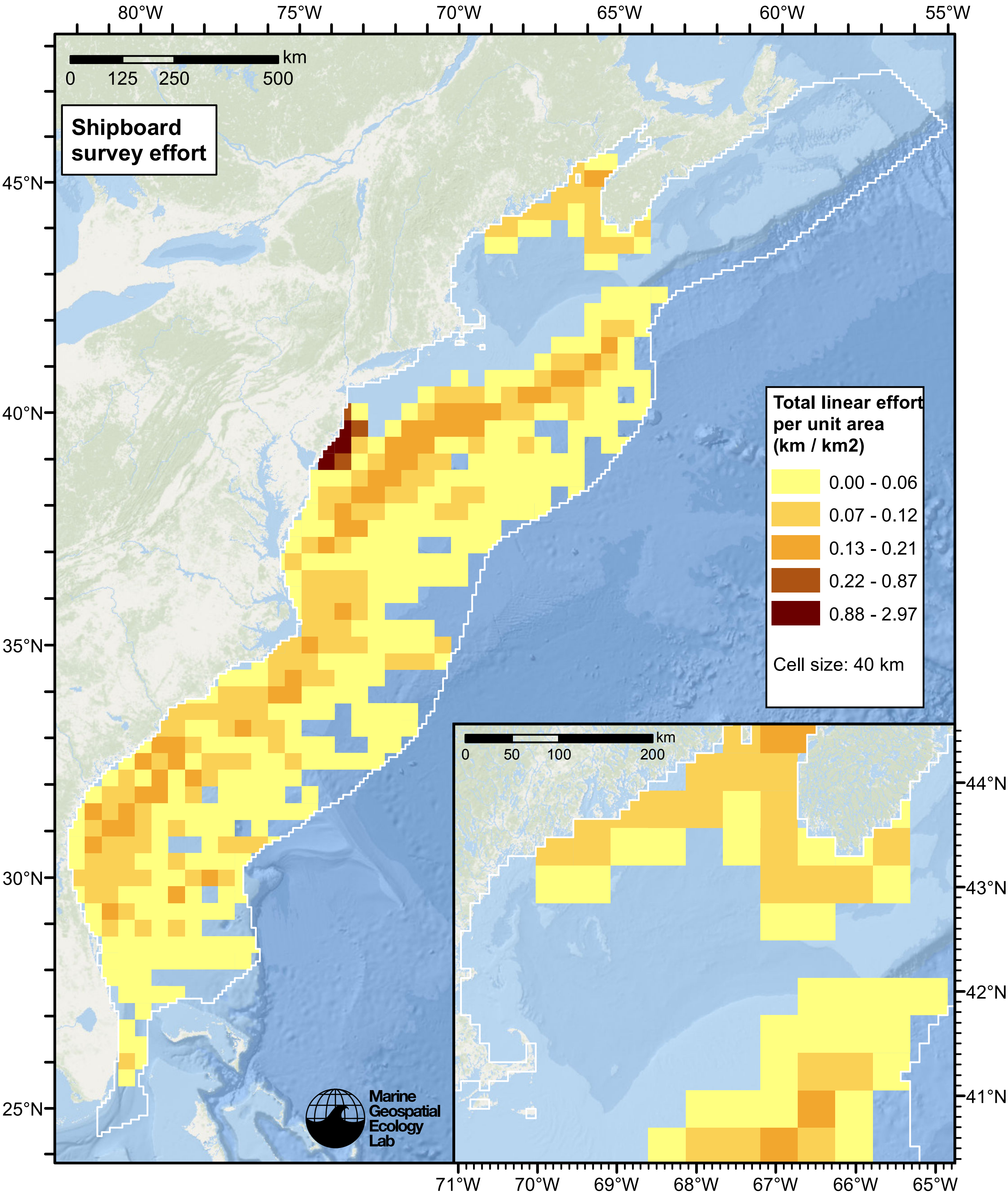


Figure 4: Shipboard linear survey effort per unit area.

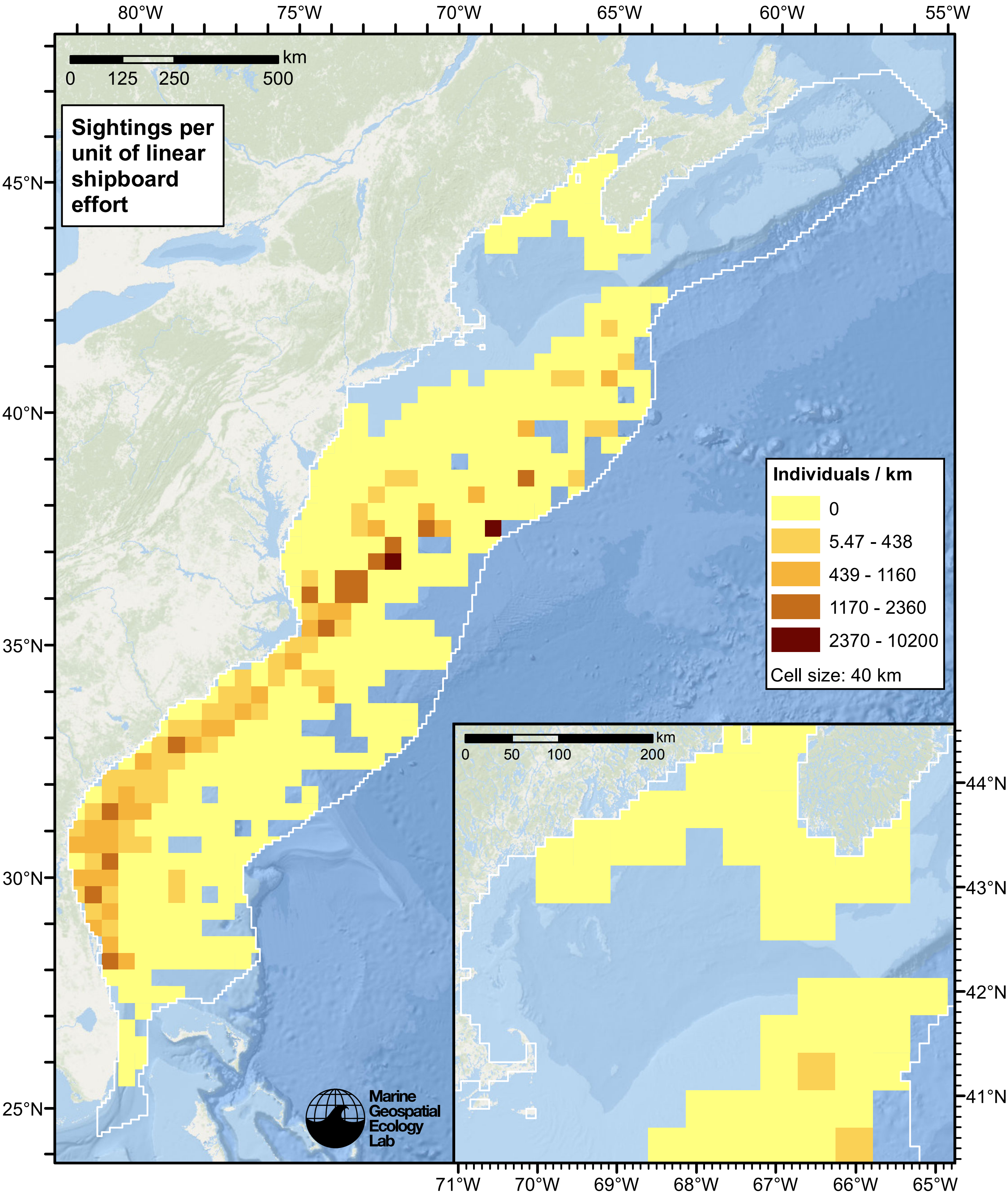


Figure 5: Atlantic spotted dolphin sightings per unit shipboard linear survey effort.

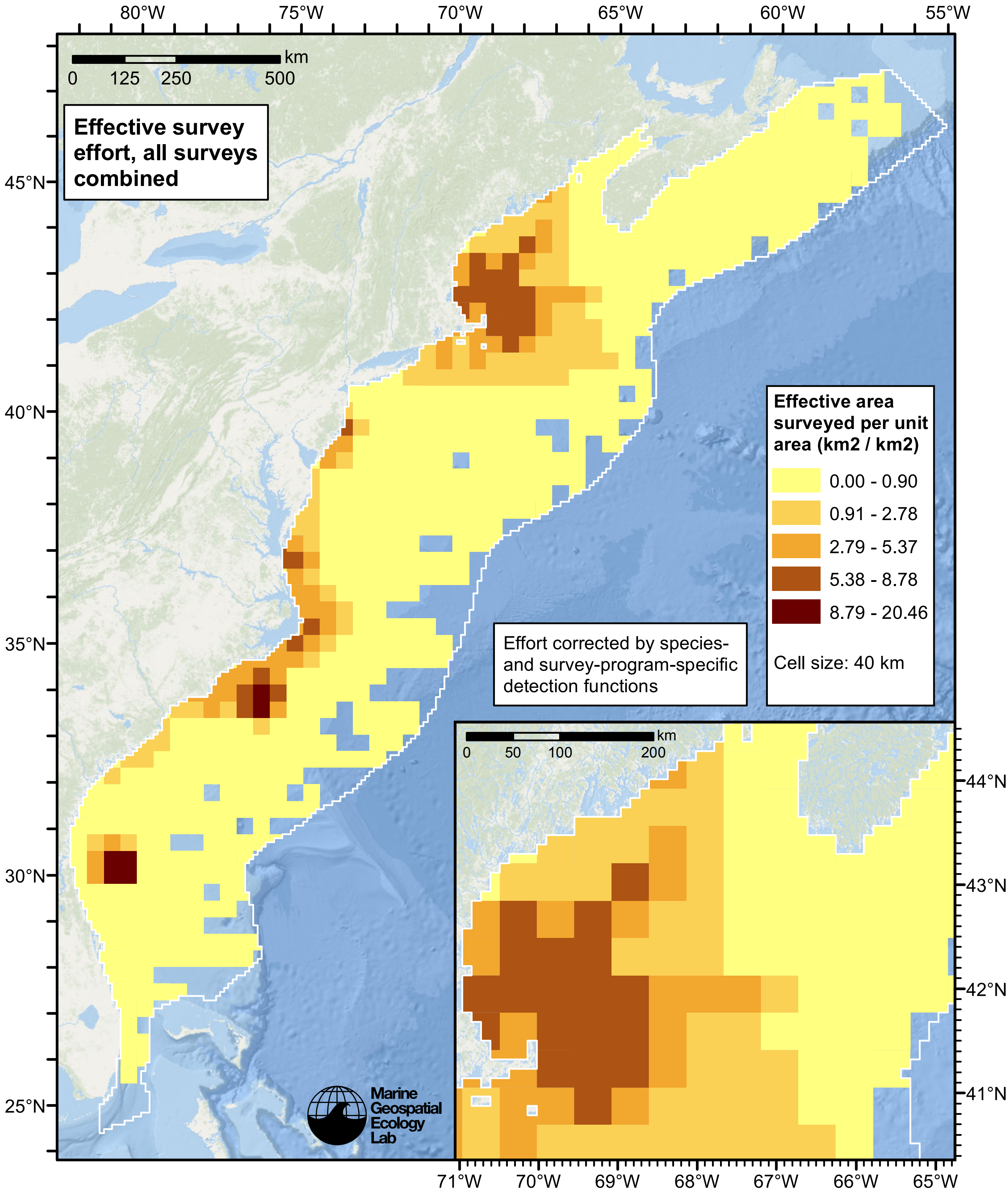


Figure 6: Effective survey effort per unit area, for all surveys combined. Here, effort is corrected by the species- and survey-program-specific detection functions used in fitting the density models.

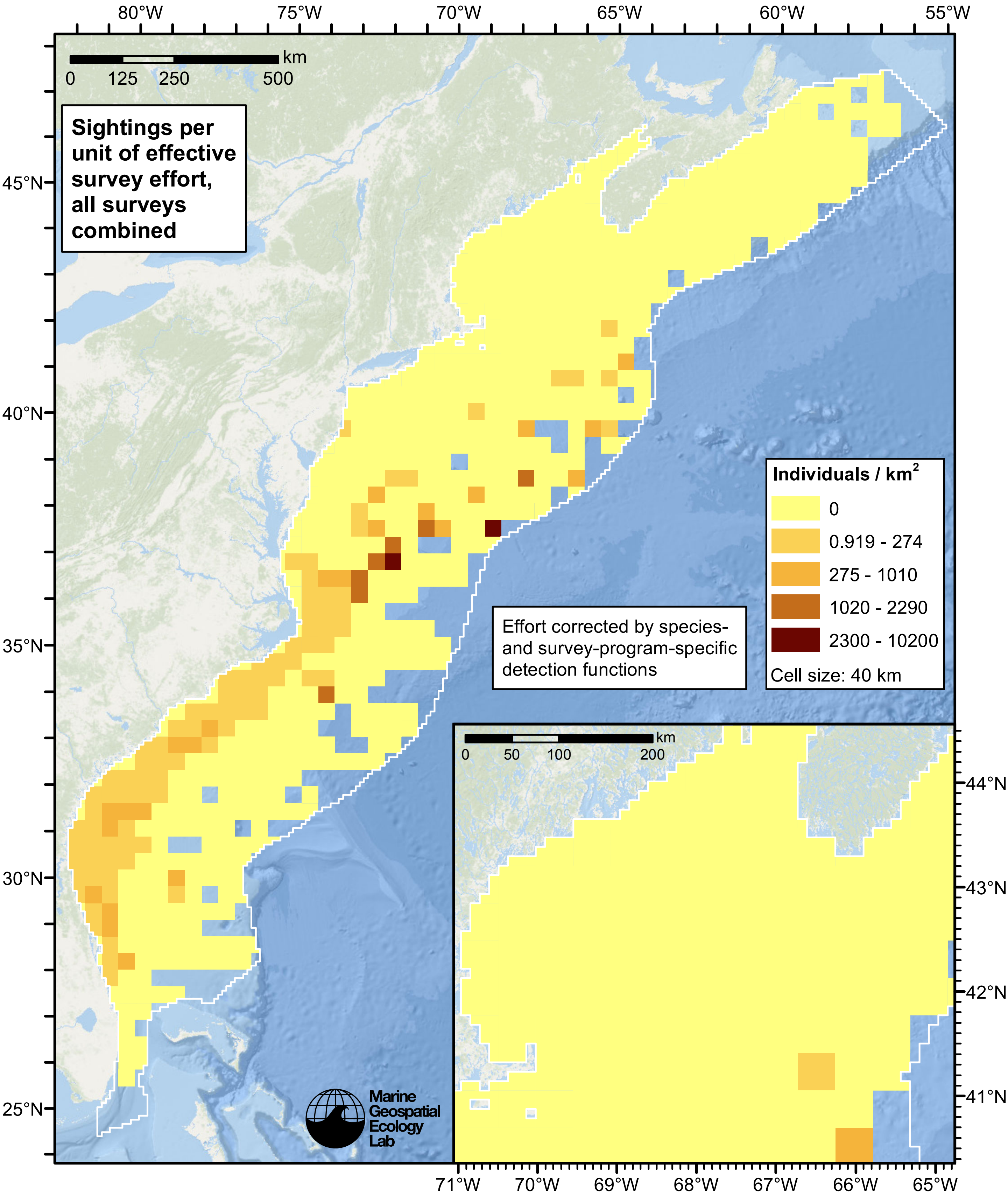


Figure 7: Atlantic spotted dolphin sightings per unit of effective survey effort, for all surveys combined. Here, effort is corrected by the species- and survey-program-specific detection functions used in fitting the density models.

Reclassification of Ambiguous Sightings

Observers occasionally experience difficulty identifying species, due to poor sighting conditions or phenotypic similarities between the possible choices. For example, observers may not always be able to distinguish fin whales from sei whales (Tim Cole, pers. comm.). When this happens, observers will report an ambiguous identification, such as "fin or sei whale".

In our density models, we handled ambiguous identifications in three ways:

1. For sightings with very generic identifications such as "large whale", we discarded the sightings. These sightings represented a clear minority when compared to those with definitive species identifications, but they are uncounted animals and our density models may therefore underestimate density to some degree.
2. For sightings of certain taxa in which a large majority of identifications were ambiguous (e.g. "Globicephala spp.") rather than specific (e.g. "Globicephala melas" or "Globicephala macrorhynchus"), it was not tractable to model the individual species so we modeled the generic taxon instead.
3. For sightings that reported an ambiguous identification of two species (e.g. "fin or sei whale") that are known to exhibit different habitat preferences or typically occur in different group sizes, and for which we had sufficient number of definitive sightings of both species, we fitted a predictive model that classified the ambiguous sightings into one species or the other.

This section describes how we utilized the third category of ambiguous sightings in the density models presented in this report.

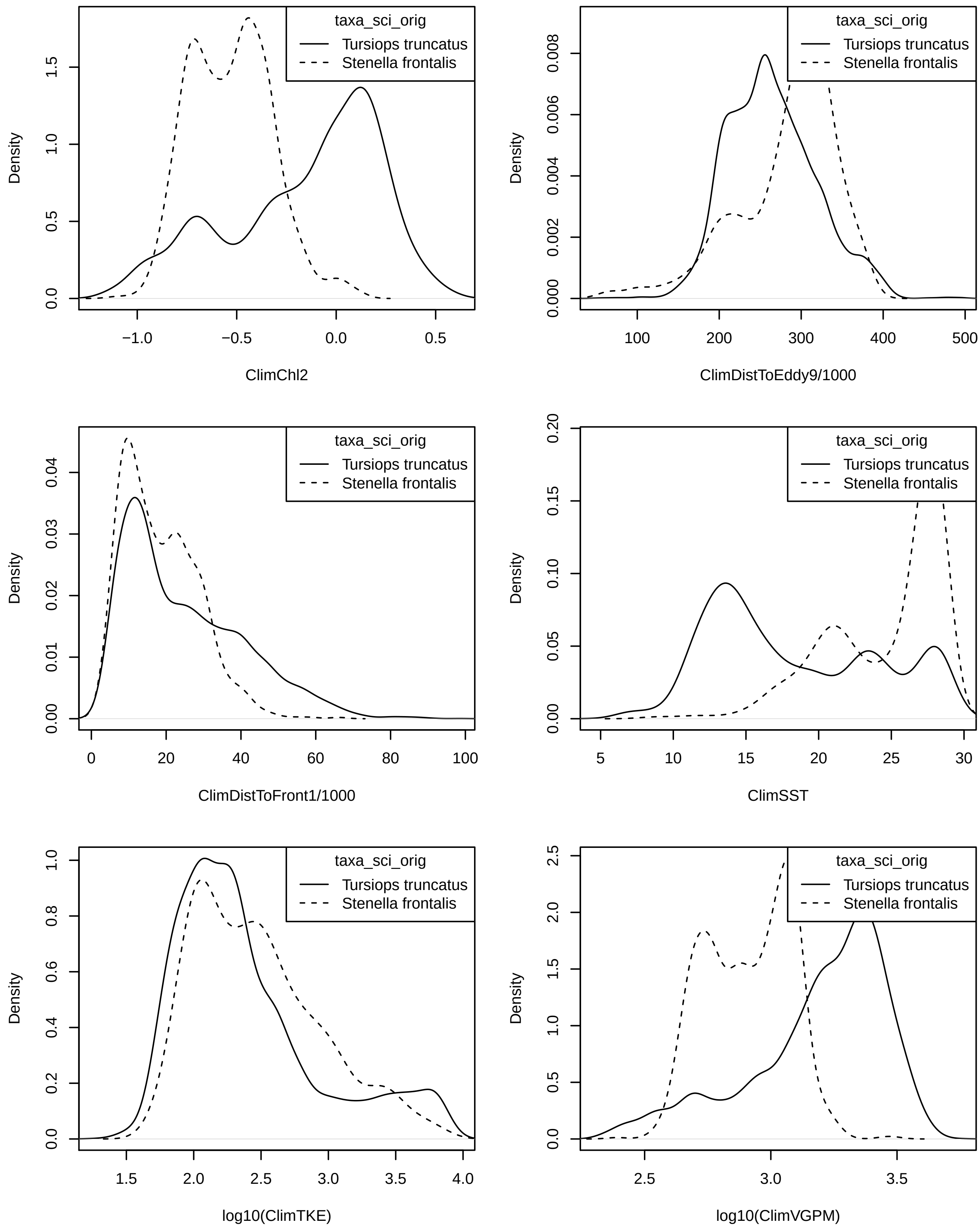
For the predictive model, we used the cforest classifier (Hothorn et al. 2006), an elaboration of the classic random forest classifier (Breiman, 2001). First, we trained a binary classifier using the sightings that reported definitive species identifications (e.g. "fin whale" and "sei whale"). The training data included all on-effort sightings, not just those in the focal study area. We used the species ID as the response variable and oceanographic variables or group size as predictor variables, depending on the species. We used receiver operating characteristic (ROC) curve analysis to select a threshold for classifying the probabilistic predictions of species identifications made by the model into a binary result of one species or another; for the threshold, we selected the value that maximized the Youden index (see Perkins and Schisterman, 2006).

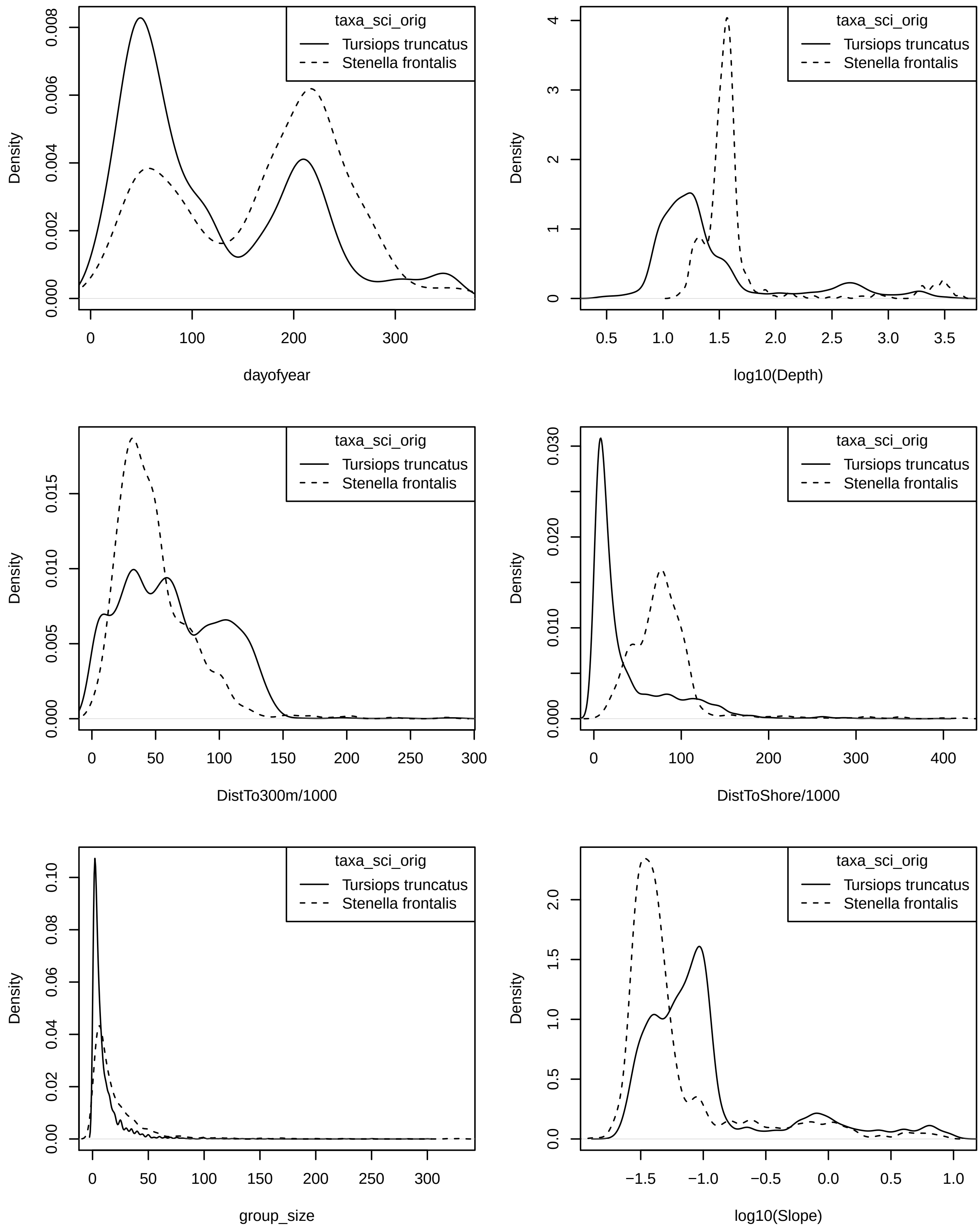
Then, for all sightings reporting the ambiguous identification, we reclassified the sighting as either one species or the other by processing the predictor values observed for that sighting through the fitted model. We then included the reclassified sightings in the detection functions and spatial models of density. The sightings reported elsewhere in this document incorporate both the definitive sightings and the reclassified sightings.

Reclassification of "Stenella frontalis/Tursiops truncatus" in the East Coast Region

Density Histograms

These plots show the per-species distribution of each predictor variable used in the reclassification model. When a variable exhibits a substantially different distribution for each species, it is a good candidate for classifying ambiguous sightings as one species or the other.


taxa_sci_orig
Tursiops truncatus
Stenella frontalis
Density
ClimChl2
ClimDistToEddy9/1000
ClimDistToFront1/1000
ClimSST
log10(ClimTKE)
log10(ClimVGPM)



Statistical output

```
MODEL SUMMARY:
```

```
==============

     Random Forest using Conditional Inference Trees

Number of trees:  1000

Response:  factor(taxa_sci_orig)
Inputs:  group_size, dayofyear, Depth, Slope, DistToShore, DistTo300m, ClimSST, ClimDistToFront1, ClimChl2, Cl
Number of observations:  5265

Number of variables tried at each split: 5

Estimated predictor variable importance (conditional = FALSE):

                 Importance
ClimVGPM            0.02904
group_size          0.02416
ClimSST             0.02001
Slope               0.01773
DistToShore         0.01602
ClimChl2            0.01454
ClimTKE             0.01186
ClimDistToEddy9     0.01108
DistTo300m          0.00874
Depth               0.00641
ClimDistToFront1    0.00525
dayofyear           0.00353

MODEL PERFORMANCE SUMMARY:
==========================

Statistics calculated from the training data.

Area under the ROC curve (auc)           = 0.980
Mean cross-entropy (mxe)                 = 0.137
Precision-recall break-even point (prbe) = 0.966
Root-mean square error (rmse)            = 0.204

Cutoff selected by maximizing the Youden index = 0.838

Confusion matrix for that cutoff:

                              Actual Tursiops truncatus  Actual Stenella frontalis  Total
Predicted Tursiops truncatus                       4080                         47   4127
Predicted Stenella frontalis                        381                        757   1138
Total                                              4461                        804   5265

Model performance statistics for that cutoff:

Accuracy (acc)                                = 0.919
Error rate (err)                              = 0.081
Rate of positive predictions (rpp)            = 0.784
Rate of negative predictions (rnp)            = 0.216

True positive rate (tpr, or sensitivity)      = 0.915
False positive rate (fpr, or fallout)         = 0.058
True negative rate (tnr, or specificity)      = 0.942
False negative rate (fnr, or miss)            = 0.085
```

```
Positive prediction value (ppv, or precision) = 0.989
Negative prediction value (npv)               = 0.665
Prediction-conditioned fallout (pcfall)       = 0.011
Prediction-conditioned miss (pcmiss)          = 0.335

Matthews correlation coefficient (mcc)        = 0.748
Odds ratio (odds)                             = 172.478
SAR                                           = 0.701

Cohen's kappa (K)                             = 0.732
```

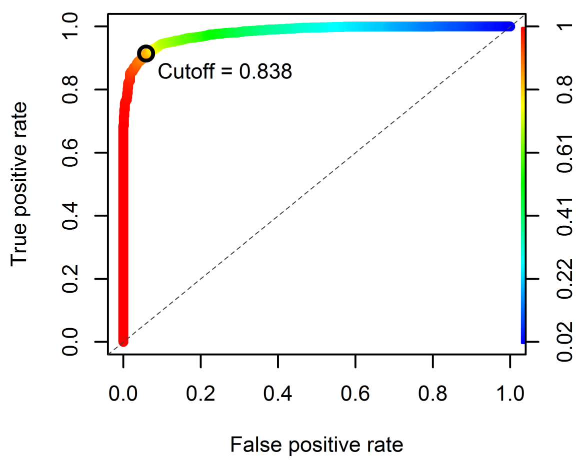


Figure 8: Receiver operating characteristic (ROC) curve illustrating the predictive performance of the model used to reclassify "Stenella frontalis/Tursiops truncatus" sightings into one species or the other.

Reclassifications Performed

Survey	Definitive S. frontalis Sightings	Definitive T. truncatus Sightings	Ambiguous Sightings	Reclassed to S. frontalis	Reclassed to T. truncatus
NEFSC Aerial Surveys	1	99	0	0	0
NEFSC North Atlantic Right Whale Sighting Survey	0	46	0	0	0
NEFSC Shipboard Surveys	16	184	0	0	0
NJDEP Aerial Surveys	0	92	0	0	0
NJDEP Shipboard Surveys	0	174	0	0	0
SEFSC Atlantic Shipboard Surveys	319	355	33	16	17
SEFSC Mid Atlantic Tursiops Aerial Surveys	101	693	20	9	11
SEFSC Southeast Cetacean Aerial Surveys	11	197	39	11	28
UNCW Cape Hatteras Navy Surveys	19	109	0	0	0
UNCW Early Marine Mammal Surveys	1	645	0	0	0
UNCW Jacksonville Navy Surveys	267	325	0	0	0

UNCW Onslow Navy Surveys	65	148	0	0	0
UNCW Right Whale Surveys	5	1847	0	0	0
Virginia Aquarium Aerial Surveys	0	67	0	0	0
Total	805	4981	92	36	56

Table 4: Counts of definitive sightings, ambiguous sightings, and what the ambiguous sightings were reclassified to. Note that this analysis was performed on all on-effort sightings, not just those in the focal study area. These counts may therefore be larger than those presented in the Survey Data section of this report, which are restricted to the focal study area.

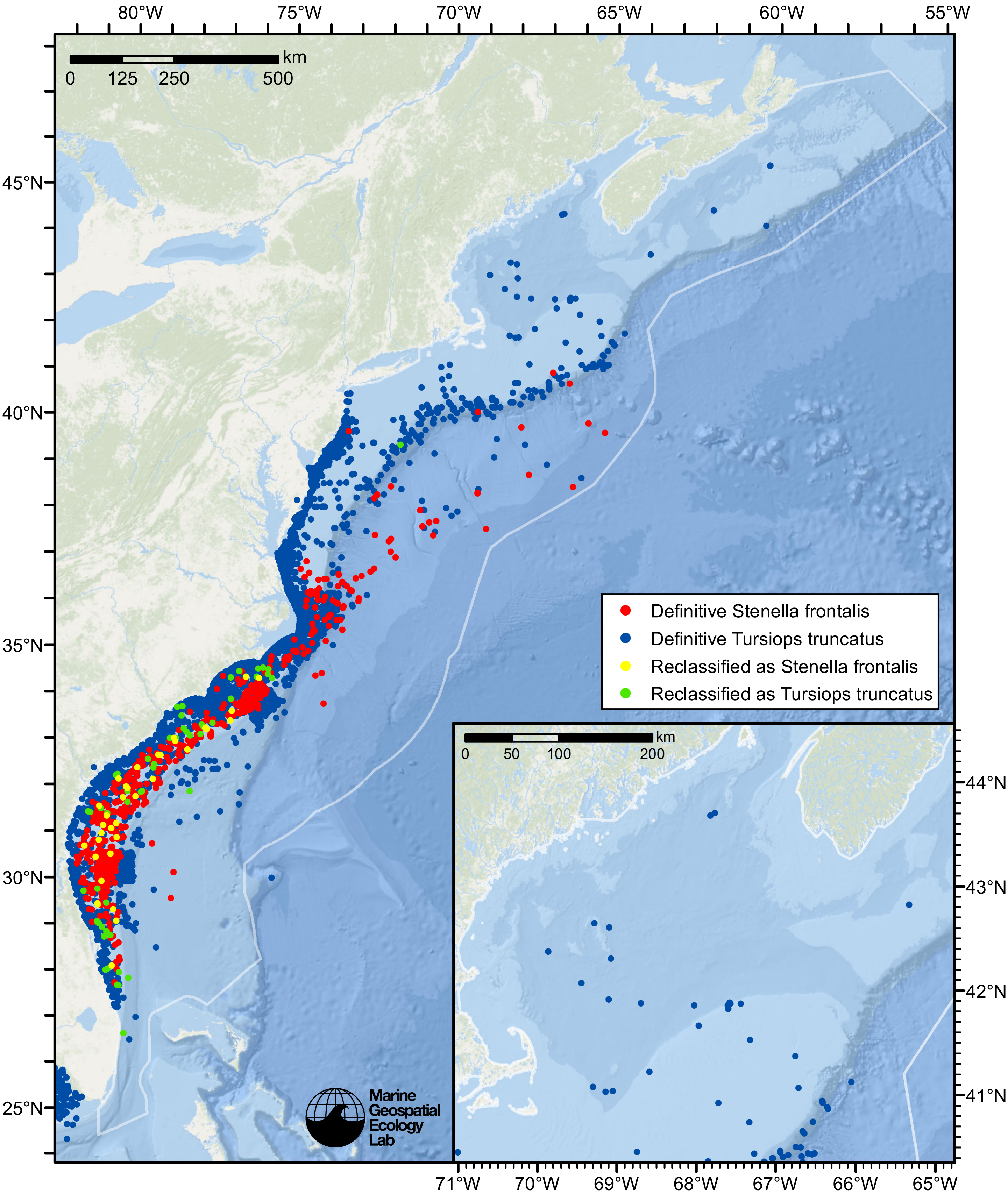
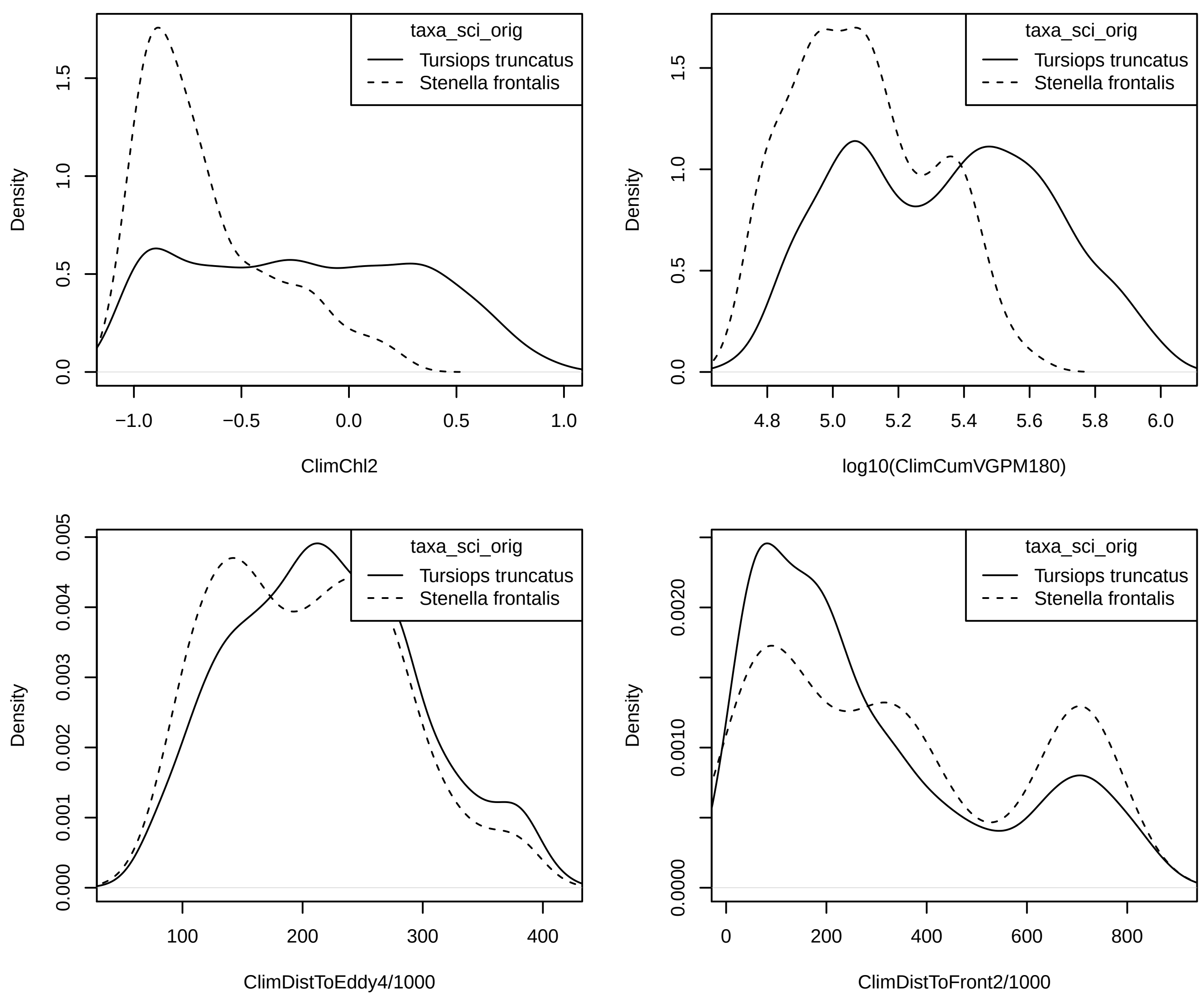


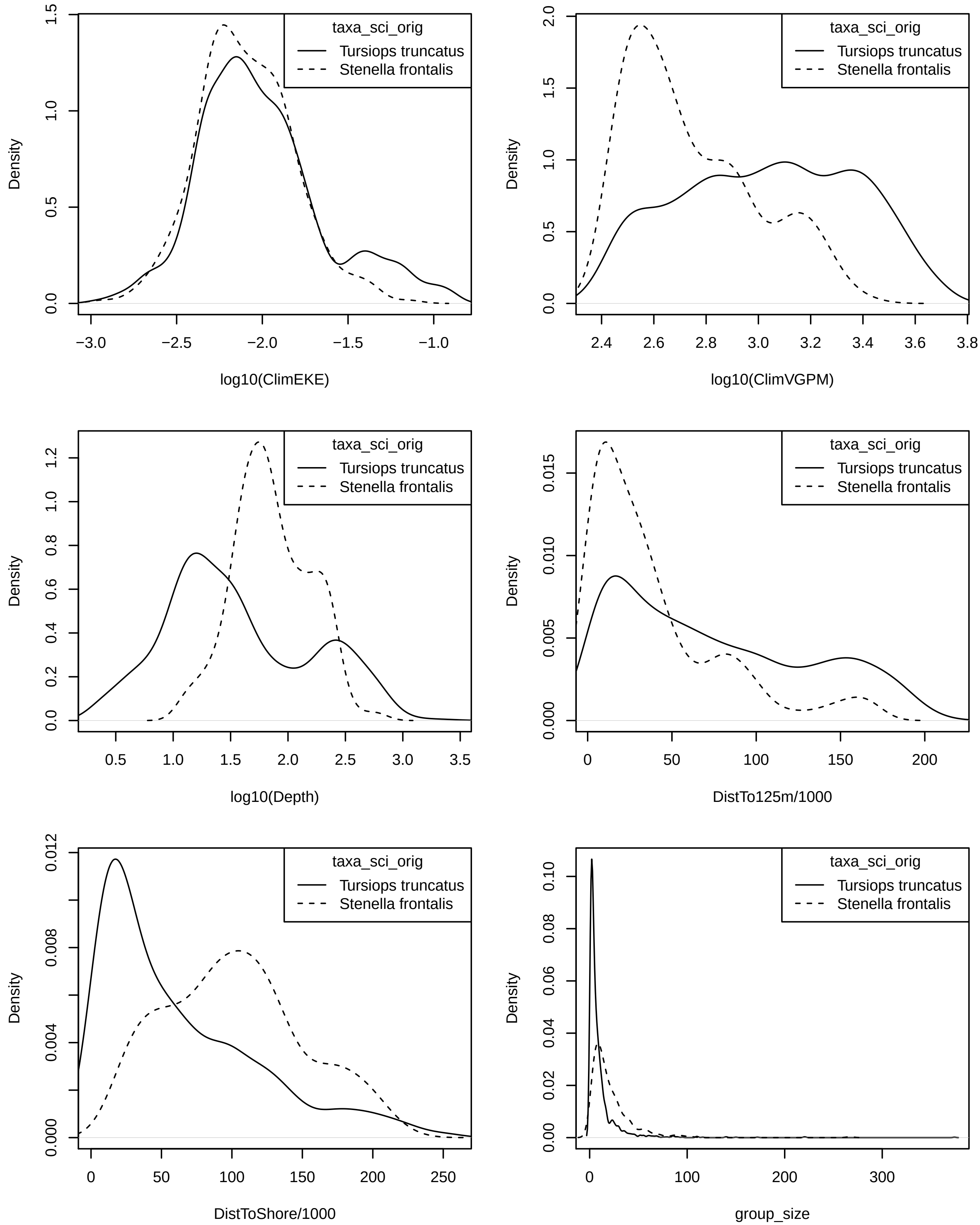
Figure 9: Definitive sightings used to train the model and ambiguous sightings reclassified by the model, by season.

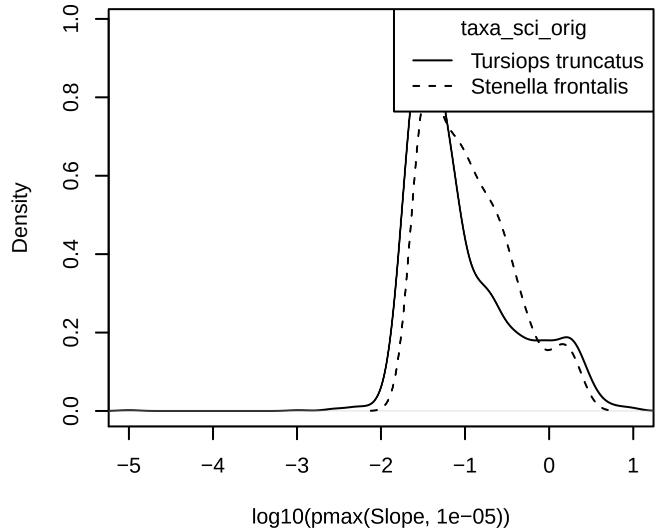
Reclassification of "Stenella frontalis/Tursiops truncatus" in the Gulf of Mexico Region

Density Histograms

These plots show the per-species distribution of each predictor variable used in the reclassification model. When a variable exhibits a substantially different distribution for each species, it is a good candidate for classifying ambiguous sightings as one species or the other.




taxa_sci_orig
Tursiops truncatus
Stenella frontalis
Density
log10(ClimEKE)
taxa_sci_orig
Tursiops truncatus
Stenella frontalis
Density
log10(ClimVGPM)
taxa_sci_orig
Tursiops truncatus
Stenella frontalis
Density
log10(Depth)
taxa_sci_orig
Tursiops truncatus
Stenella frontalis
Density
DistTo125m/1000
taxa_sci_orig
Tursiops truncatus
Stenella frontalis
Density
DistToShore/1000
taxa_sci_orig
Tursiops truncatus
Stenella frontalis
Density
group_size



Statistical output

```
MODEL SUMMARY:
==============

     Random Forest using Conditional Inference Trees

Number of trees:  1000

Response:  factor(taxa_sci_orig)
Inputs:  group_size, ClimChl2, Depth, ClimVGPM, DistTo125m, ClimCumVGPM180, Slope, DistToShore, ClimEKE, ClimD
Number of observations:  1959

Number of variables tried at each split: 5

Estimated predictor variable importance (conditional = FALSE):

                 Importance
group_size          0.04073
ClimChl2            0.03281
Depth               0.02925
ClimVGPM            0.01694
ClimDistToEddy4     0.00976
ClimCumVGPM180      0.00798
Slope               0.00759
DistTo125m          0.00619
ClimEKE             0.00433
DistToShore         0.00361
ClimDistToFront2    0.00314

MODEL PERFORMANCE SUMMARY:
==========================

Statistics calculated from the training data.

Area under the ROC curve (auc)           = 0.961
Mean cross-entropy (mxe)                 = 0.193
Precision-recall break-even point (prbe) = 0.951
Root-mean square error (rmse)            = 0.247
```

Cutoff selected by maximizing the Youden index = 0.910

Confusion matrix for that cutoff:

	Actual Tursiops truncatus	Actual Stenella frontalis	Total
Predicted Tursiops truncatus	1388	17	1405
Predicted Stenella frontalis	256	298	554
Total	1644	315	1959

Model performance statistics for that cutoff:

```
Accuracy (acc)                               = 0.861
Error rate (err)                             = 0.139
Rate of positive predictions (rpp)           = 0.717
Rate of negative predictions (rnp)           = 0.283

True positive rate (tpr, or sensitivity)     = 0.844
False positive rate (fpr, or fallout)        = 0.054
True negative rate (tnr, or specificity)     = 0.946
False negative rate (fnr, or miss)           = 0.156

Positive prediction value (ppv, or precision) = 0.988
Negative prediction value (npv)              = 0.538
Prediction-conditioned fallout (pcfall)      = 0.012
Prediction-conditioned miss (pcmiss)         = 0.462

Matthews correlation coefficient (mcc)       = 0.645
Odds ratio (odds)                            = 95.042
SAR                                          = 0.690

Cohen's kappa (K)                            = 0.605
```

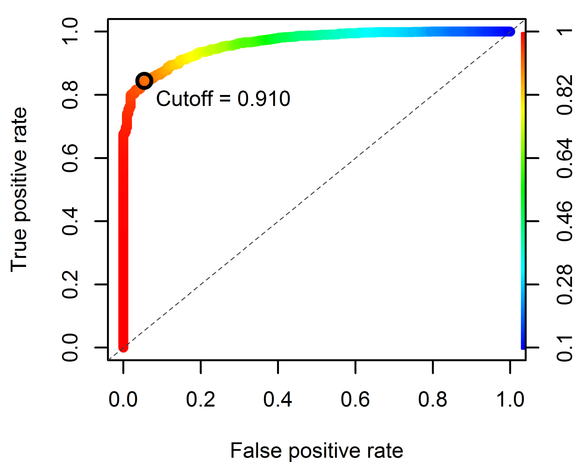


Figure 10: Receiver operating characteristic (ROC) curve illustrating the predictive performance of the model used to reclassify "Stenella frontalis/Tursiops truncatus" sightings into one species or the other.

Reclassifications Performed

Survey	Definitive S. frontalis Sightings	Definitive T. truncatus Sightings	Ambiguous Sightings	Reclassed to S. frontalis	Reclassed to T. truncatus
SEFSC Caribbean Shipboard Surveys	1	0	0	0	0
SEFSC GOMEX92-96 Aerial Surveys	21	608	19	4	15
SEFSC Gulf of Mexico Shipboard Surveys, 2003-2009	10	69	1	1	0
SEFSC GulfCet I Aerial Surveys	12	83	6	1	5
SEFSC GulfCet II Aerial Surveys	24	153	12	0	12
SEFSC GulfSCAT 2007 Aerial Surveys	15	327	5	0	5
SEFSC Oceanic CetShip Surveys	73	247	27	6	21
SEFSC Shelf CetShip Surveys	159	309	86	23	63
Total	315	1796	156	35	121

Table 5: Counts of definitive sightings, ambiguous sightings, and what the ambiguous sightings were reclassified to. Note that this analysis was performed on all on-effort sightings, not just those in the focal study area. These counts may therefore be larger than those presented in the Survey Data section of this report, which are restricted to the focal study area.

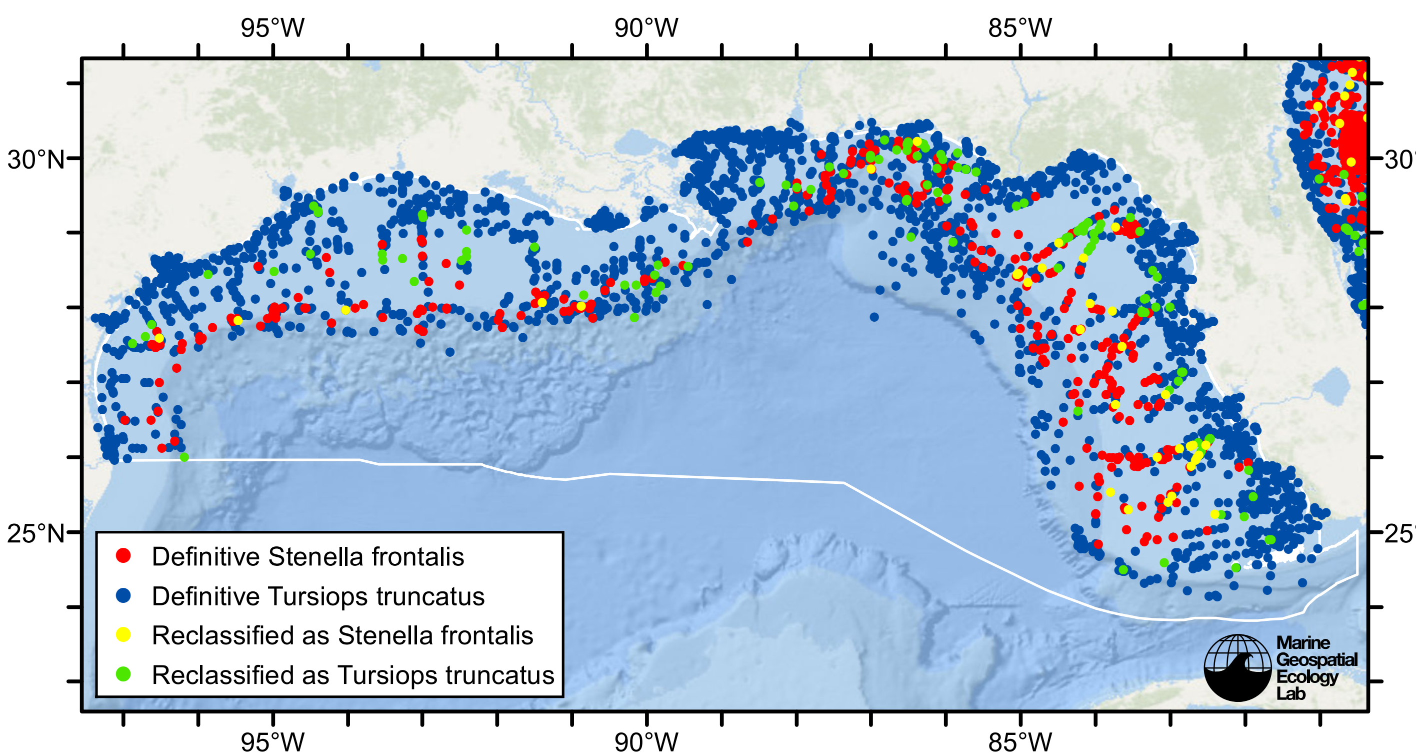


Figure 11: Definitive sightings used to train the model and ambiguous sightings reclassified by the model, by season.

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

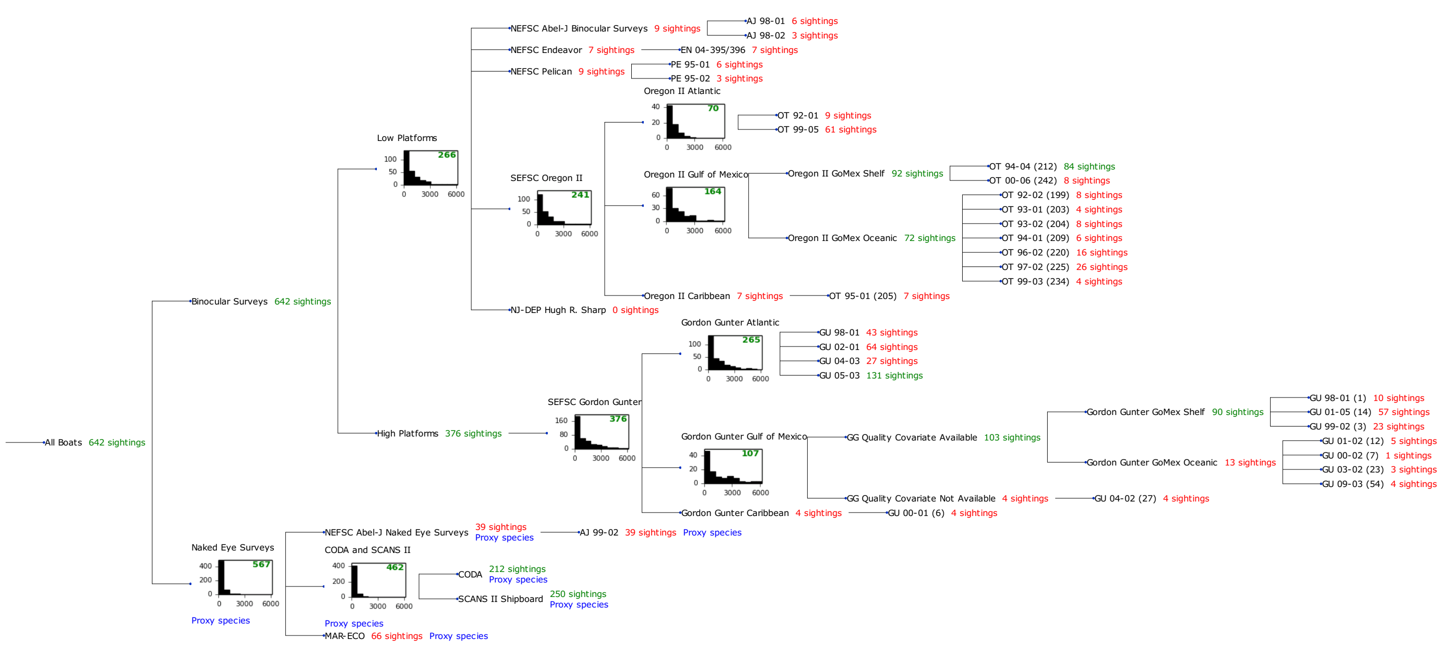


Figure 12: Detection hierarchy for shipboard surveys

Low Platforms

The sightings were right truncated at 3500m.

Covariate	Description

beaufort	Beaufort sea state.
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)
hr			beaufort, size	Yes	0.00	767
hr			beaufort	Yes	9.81	629
hr			size	Yes	21.23	486
hr				Yes	30.33	388
hn	cos	2		Yes	69.74	1147
hn	cos	3		Yes	69.94	1048
hn			beaufort, size	Yes	71.31	1444
hn			beaufort	Yes	74.26	1446
hn			size	Yes	93.29	1463
hn				Yes	93.80	1461
hn	herm	4		Yes	95.34	1457
hr	poly	2		No		
hr	poly	4		No		

Table 7: Candidate detection functions for Low Platforms. The first one listed was selected for the density model.

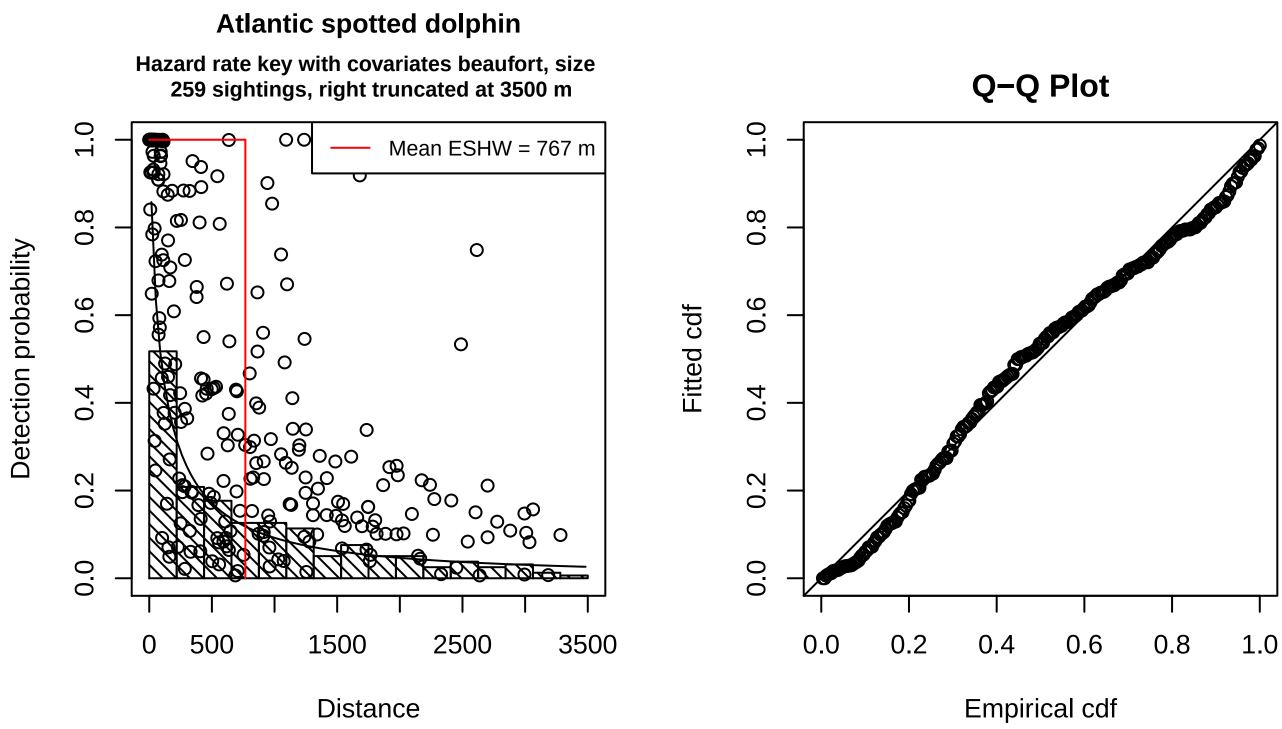


Figure 13: Detection function for Low Platforms that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  259
Distance range         :  0  -  3500
AIC                    :  3934.672

Detection function:
 Hazard-rate key function

Detection function parameters
Scale Coefficients:
              estimate        se
(Intercept)  6.1987970 0.3750537
beaufort    -0.7301309 0.1333202
size         0.7439237 0.2138665

Shape parameters:
             estimate         se
(Intercept) 0.1356227 0.09630708

                          Estimate           SE        CV
Average p                0.1021646   0.02253661 0.2205913
N in covered region 2535.1258023 581.30655037 0.2293009
```

Additional diagnostic plots:

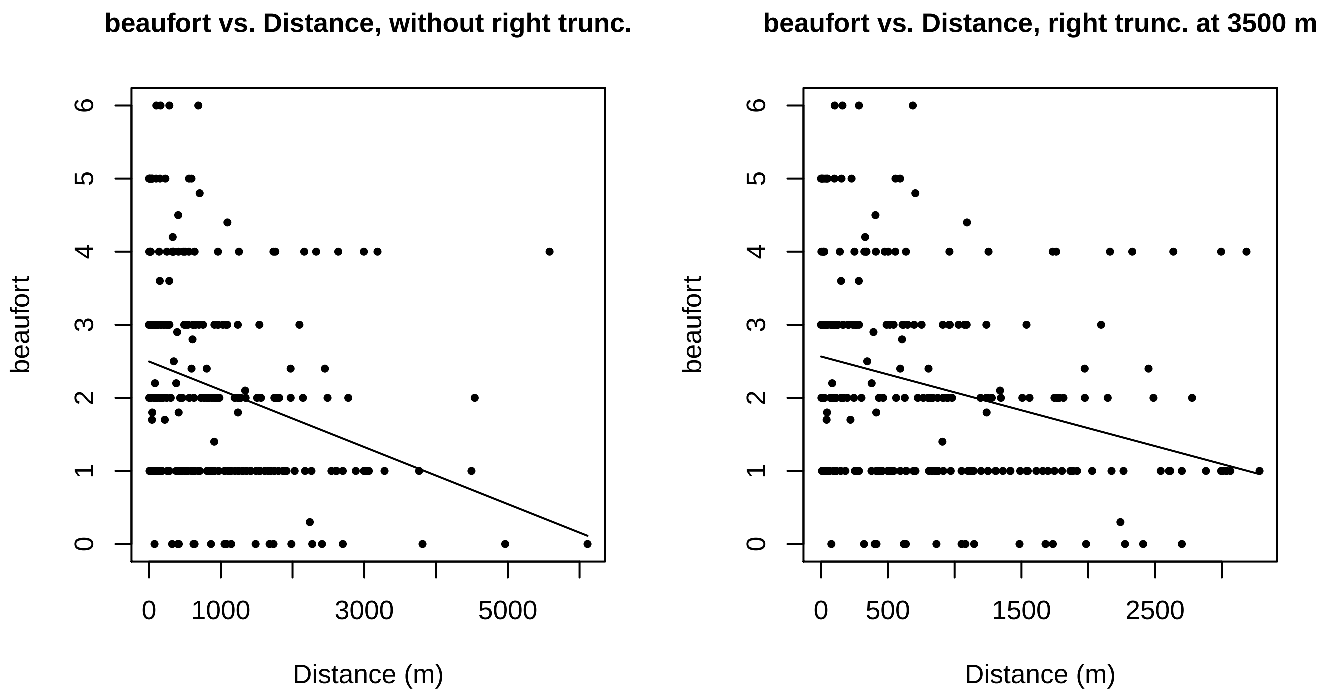


Figure 14: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

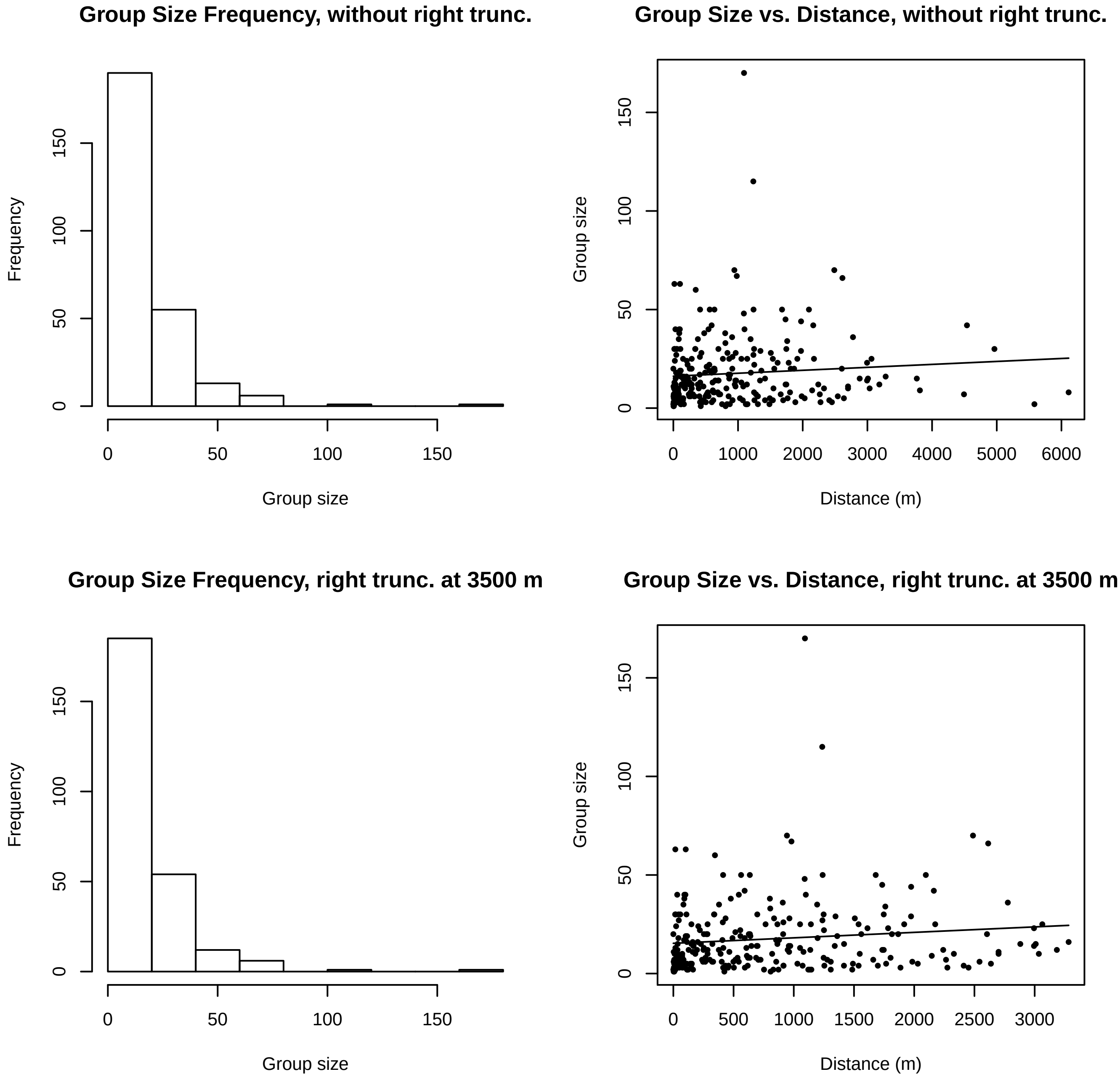


Figure 15: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

SEFSC Oregon II

The sightings were right truncated at 3500m.

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

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hr			beaufort, size	Yes	0.00	1045
hr			beaufort, quality, size	Yes	1.63	1049
hr			beaufort	Yes	13.21	646
hr			beaufort, quality	Yes	13.76	668
hr			quality, size	Yes	23.46	526
hr			size	Yes	23.53	531
hr			quality	Yes	33.33	415
hr				Yes	33.91	381
hn			beaufort, quality, size	Yes	63.98	1482
hn			beaufort, quality	Yes	69.40	1478
hn			beaufort, size	Yes	72.32	1475
hn	cos	2		Yes	73.63	1168
hn	cos	3		Yes	74.76	1076
hn			beaufort	Yes	78.89	1475
hn			quality, size	Yes	80.88	1492
hn			quality	Yes	83.53	1482
hn			size	Yes	90.80	1491
hn				Yes	94.34	1486
hn	herm	4		Yes	95.90	1483
hr	poly	2		No		
hr	poly	4		No		

Table 9: Candidate detection functions for SEFSC Oregon II. The first one listed was selected for the density model.

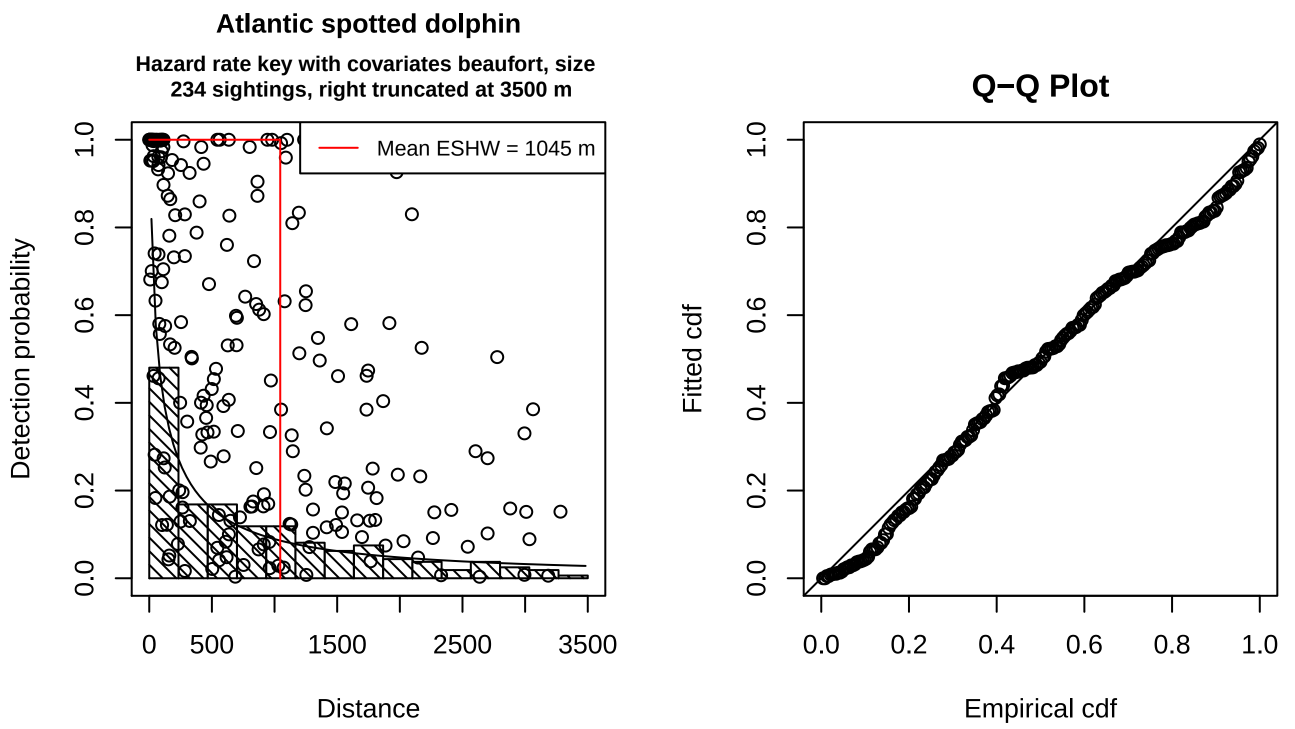


Figure 16: Detection function for SEFSC Oregon II that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  234
Distance range         :  0  -  3500
AIC                    :  3552.709

Detection function:
 Hazard-rate key function

Detection function parameters
Scale Coefficients:
              estimate        se
(Intercept)  6.0025770 0.3644534
beaufort    -0.7854126 0.1285341
size         1.3914717 0.2807420

Shape parameters:
             estimate         se
(Intercept) 0.2173969 0.09741624

                        Estimate           SE        CV
Average p           9.729962e-02   0.02359575 0.2425061
N in covered region 2.404943e+03 606.15807198 0.2520468
```

Additional diagnostic plots:

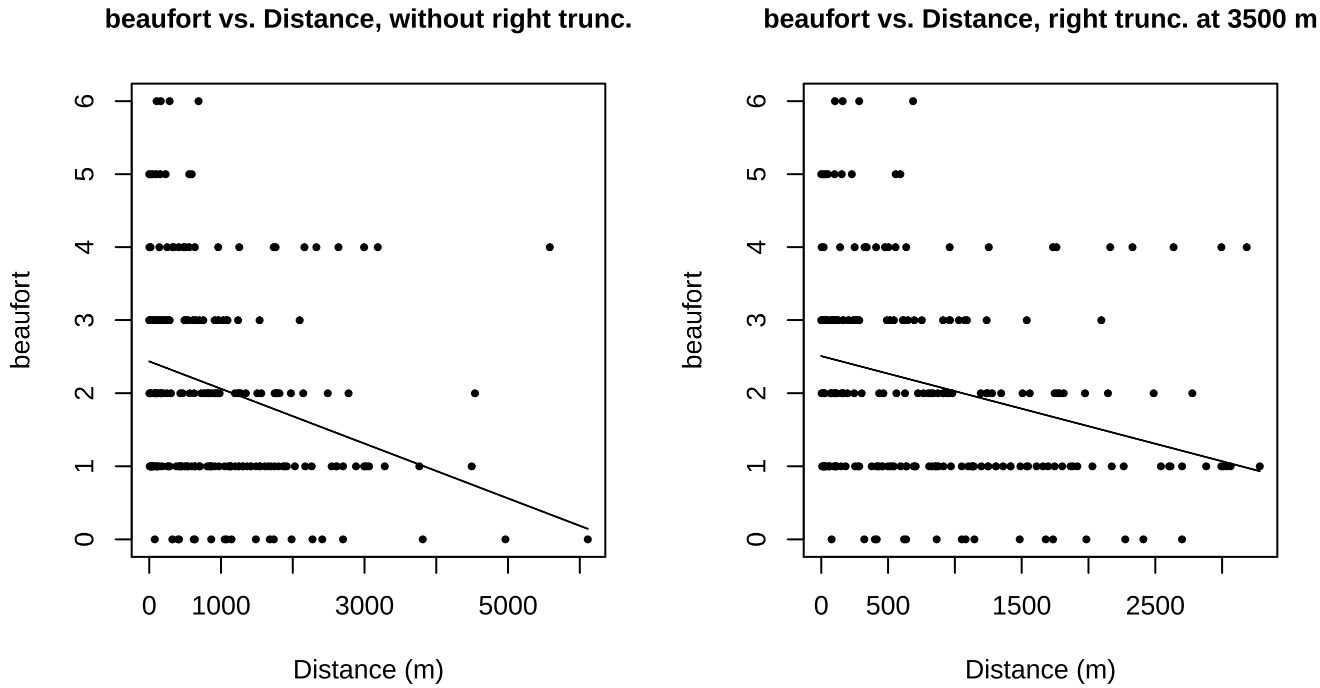


Figure 17: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

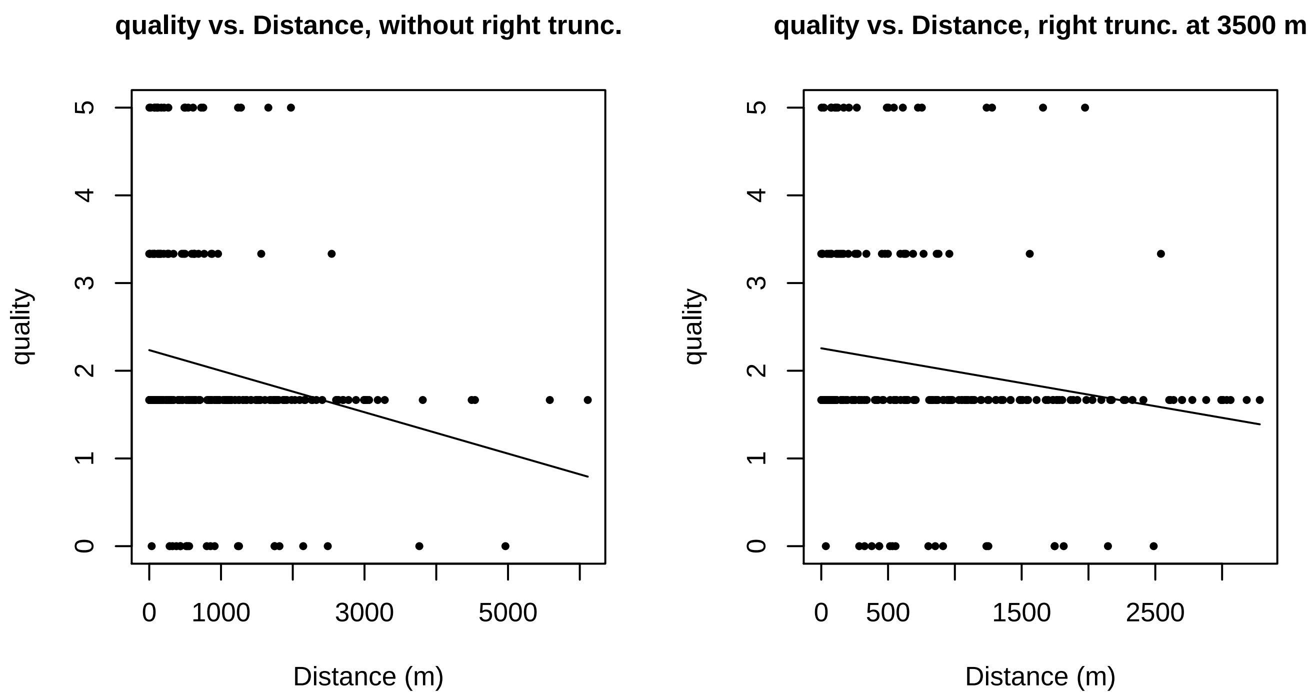


Figure 18: Scatterplots showing the relationship between the survey-specific index of the quality of observation conditions and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). Low values of the quality index correspond to better observation conditions. The line is a simple linear regression.

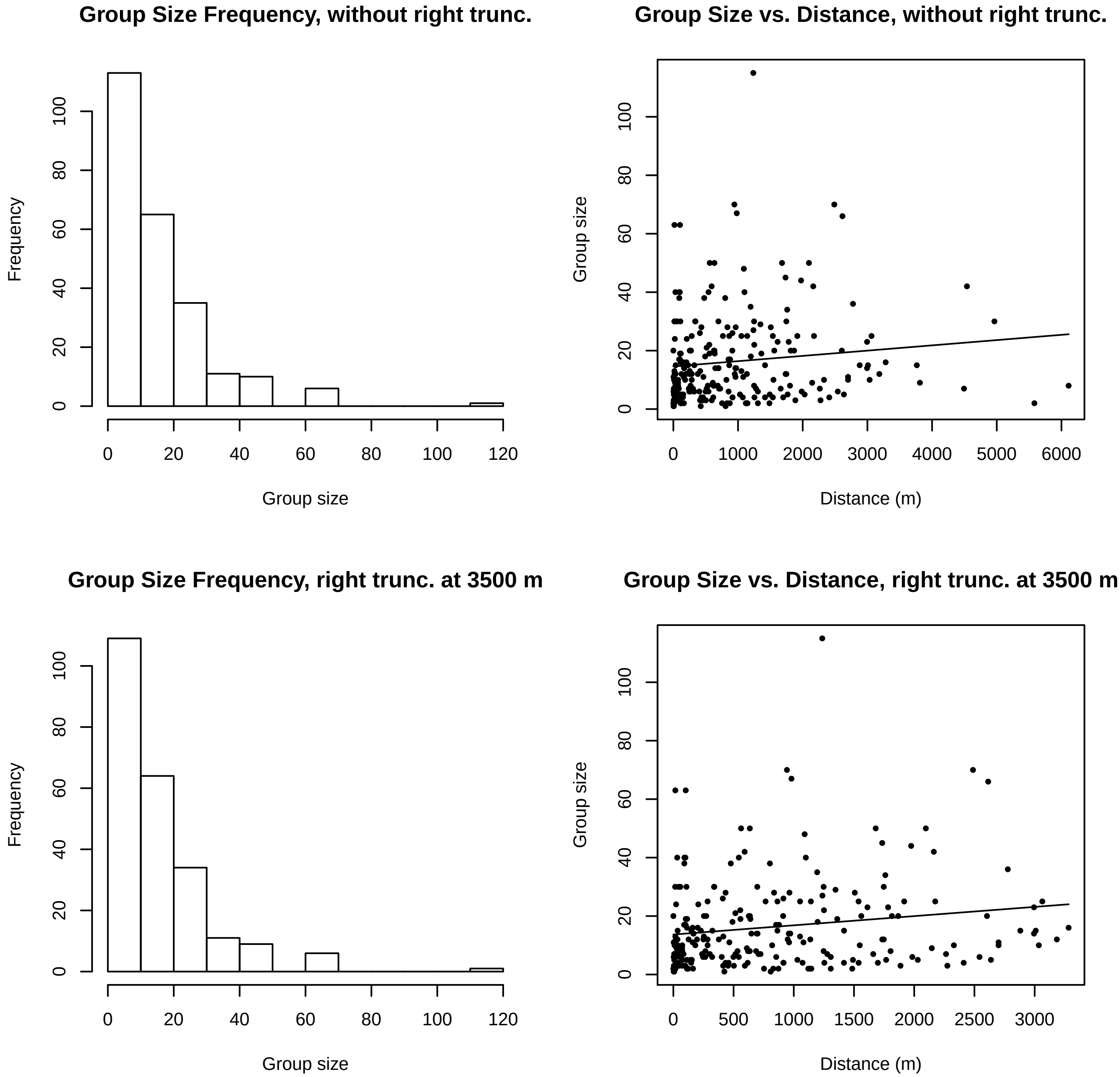


Figure 19: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

Oregon II Atlantic

The sightings were right truncated at 3500m.

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 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	814
hr			beaufort, size	Yes	0.88	789
hn			beaufort, size	Yes	13.04	1071
hr				Yes	16.90	173
hr			beaufort	Yes	18.20	211
hn			size	Yes	23.58	1081
hn			quality, size	Yes	25.58	1080
hn	cos	3		Yes	32.77	824
hn			beaufort	Yes	33.22	1051
hn			beaufort, quality	Yes	33.31	1049
hn	cos	2		Yes	35.97	952
hn				Yes	37.50	1074
hn			quality	Yes	38.29	1069
hn	herm	4		Yes	39.46	1073
hr	poly	2		No		
hr	poly	4		No		
hr			quality	No		
hr			beaufort, quality	No		
hr			quality, size	No		
hr			beaufort, quality, size	No		
hn			beaufort, quality, size	No		

Table 11: Candidate detection functions for Oregon II Atlantic. The first one listed was selected for the density model.

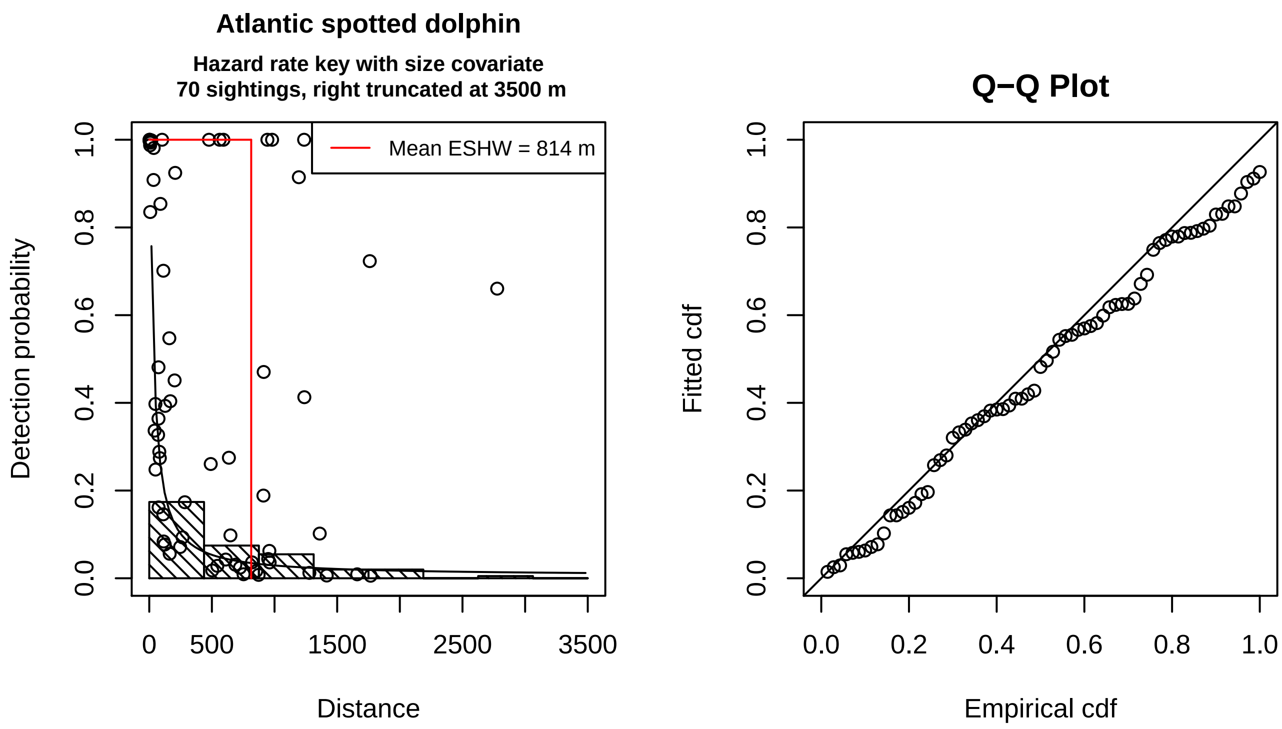


Figure 20: Detection function for Oregon II Atlantic that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  70
Distance range         :  0  -  3500
AIC                    :  1011.49

Detection function:
 Hazard-rate key function

Detection function parameters
Scale Coefficients:
            estimate        se
(Intercept) 2.394626 0.7153392
size        3.141644 0.9720597

Shape parameters:
             estimate        se
(Intercept) 0.1782223 0.1324483

                         Estimate           SE        CV
Average p            4.349464e-02   0.01431976 0.3292304
N in covered region 1.609394e+03 568.45354896 0.3532097
```

Additional diagnostic plots:

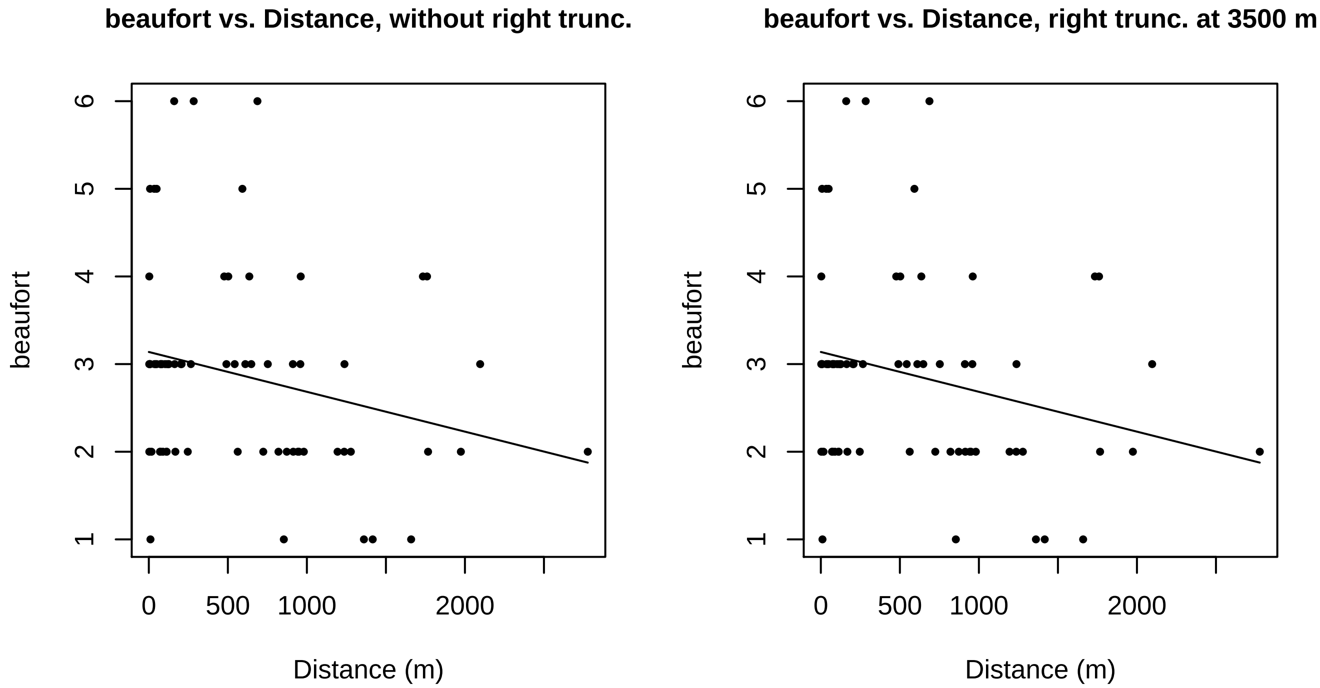


Figure 21: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

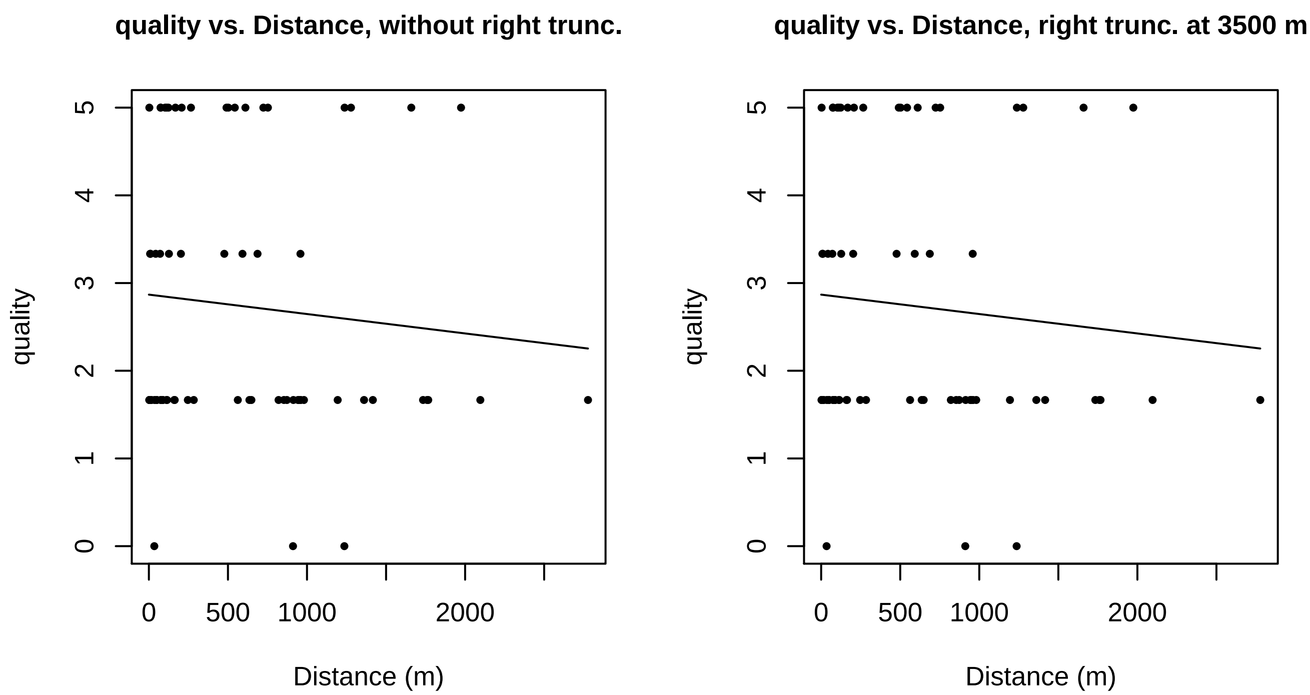


Figure 22: Scatterplots showing the relationship between the survey-specific index of the quality of observation conditions and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). Low values of the quality index correspond to better observation conditions. The line is a simple linear regression.

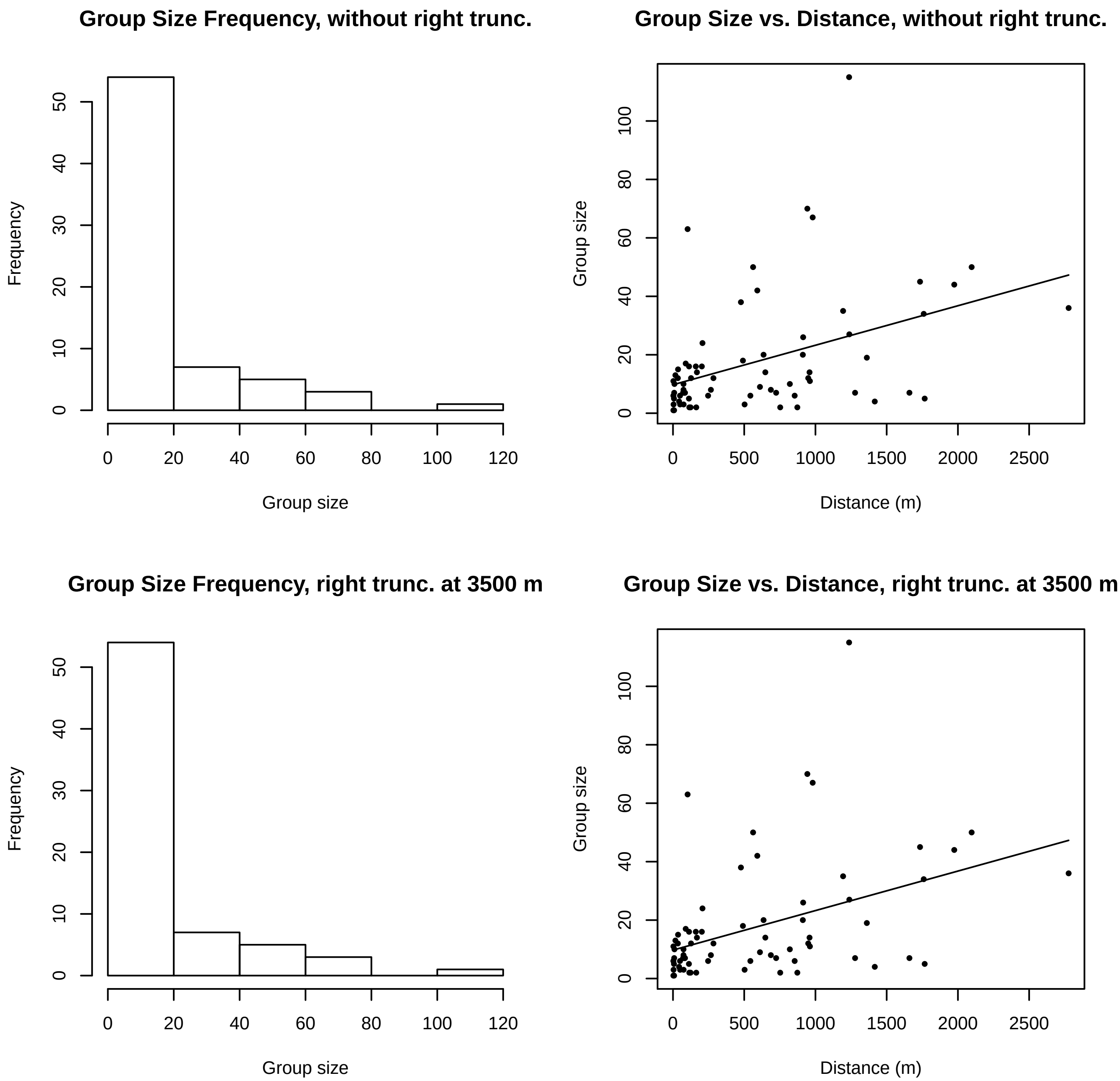


Figure 23: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

Oregon II Gulf of Mexico

The sightings were right truncated at 3500m.

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

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hr			beaufort, size	Yes	0.00	989
hr			beaufort, quality, size	Yes	0.41	978
hr			beaufort, quality	Yes	1.55	910
hr			beaufort	Yes	1.67	876
hr			quality	Yes	16.21	608
hr			quality, size	Yes	17.73	621
hr				Yes	18.75	564
hr			size	Yes	19.53	609
hn	cos	2		Yes	35.87	1288
hn	cos	3		Yes	37.47	1215
hn			beaufort, quality	Yes	41.86	1715
hn			beaufort, quality, size	Yes	43.08	1706
hn			quality	Yes	45.11	1705
hn			beaufort, size	Yes	45.47	1664
hn			beaufort	Yes	45.50	1670
hn			quality, size	Yes	46.27	1702
hn				Yes	48.14	1671
hn			size	Yes	48.19	1672
hn	herm	4		Yes	49.85	1665
hr	poly	2		No		
hr	poly	4		No		

Table 13: Candidate detection functions for Oregon II Gulf of Mexico. The first one listed was selected for the density model.

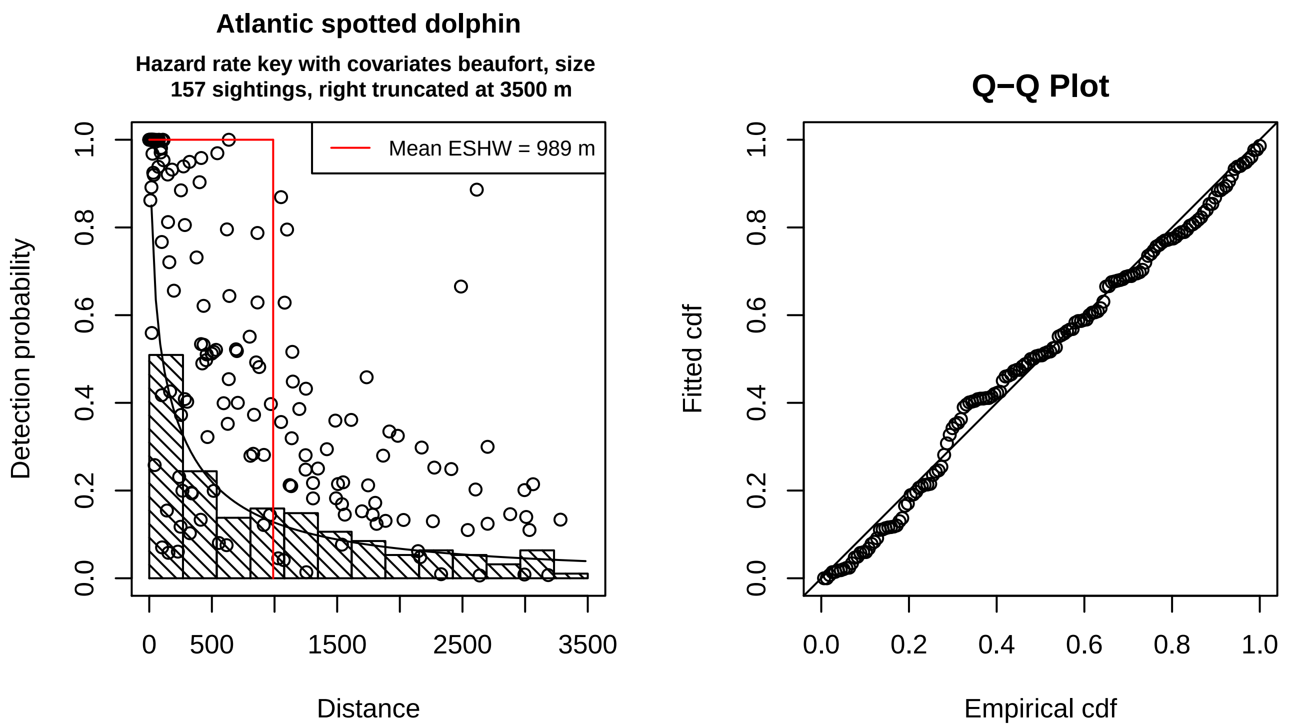


Figure 24: Detection function for Oregon II Gulf of Mexico that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  157
Distance range         :  0  -  3500
AIC                    :  2429.882

Detection function:
 Hazard-rate key function

Detection function parameters
Scale Coefficients:
              estimate        se
(Intercept)  6.4907806 0.4333654
beaufort    -0.8406511 0.1845915
size         0.5730572 0.2287914

Shape parameters:
             estimate        se
(Intercept) 0.1096827 0.1272293

                        Estimate           SE        CV
Average p              0.1281298   0.03959405 0.3090150
N in covered region 1225.3194991 391.38845397 0.3194175
```

Additional diagnostic plots:

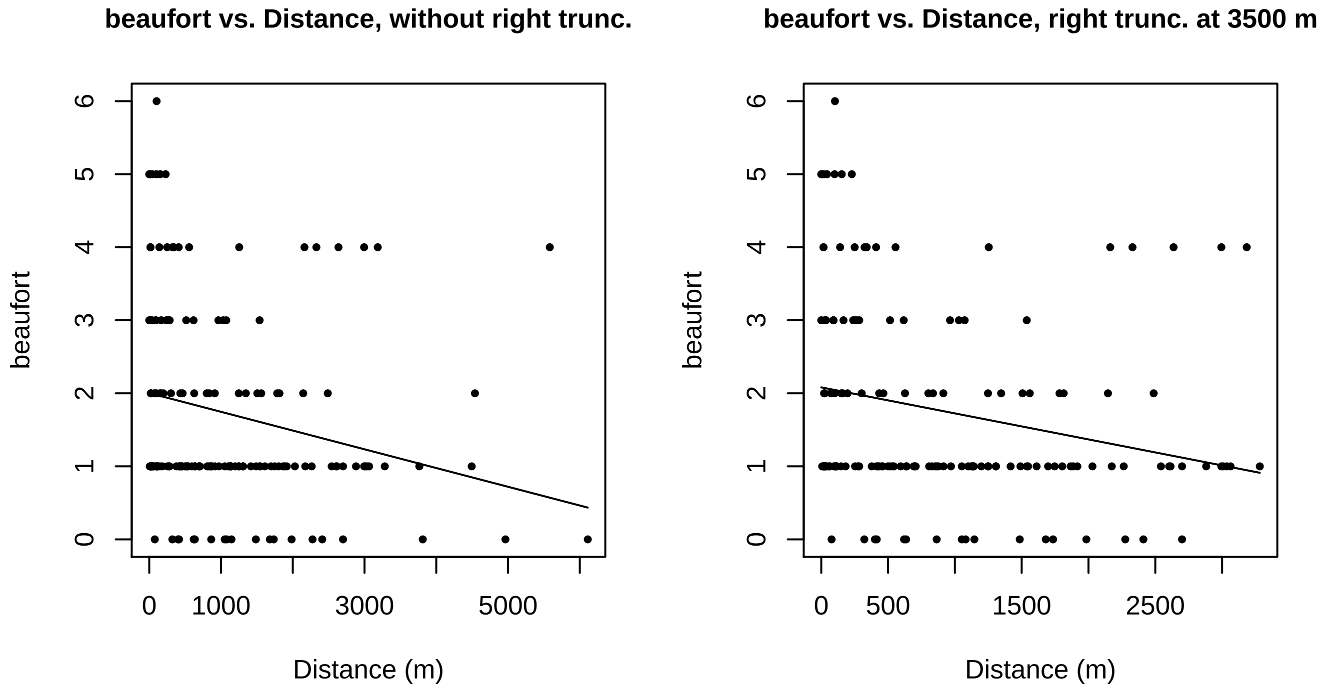


Figure 25: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

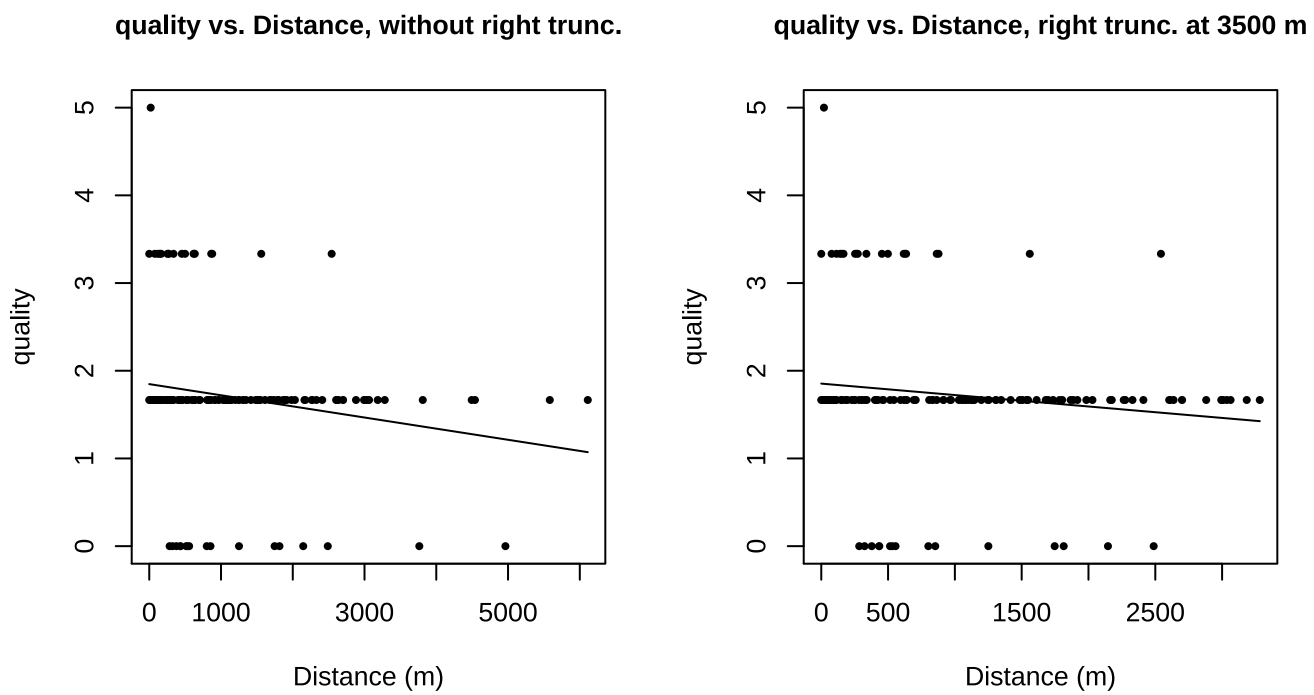


Figure 26: Scatterplots showing the relationship between the survey-specific index of the quality of observation conditions and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). Low values of the quality index correspond to better observation conditions. The line is a simple linear regression.

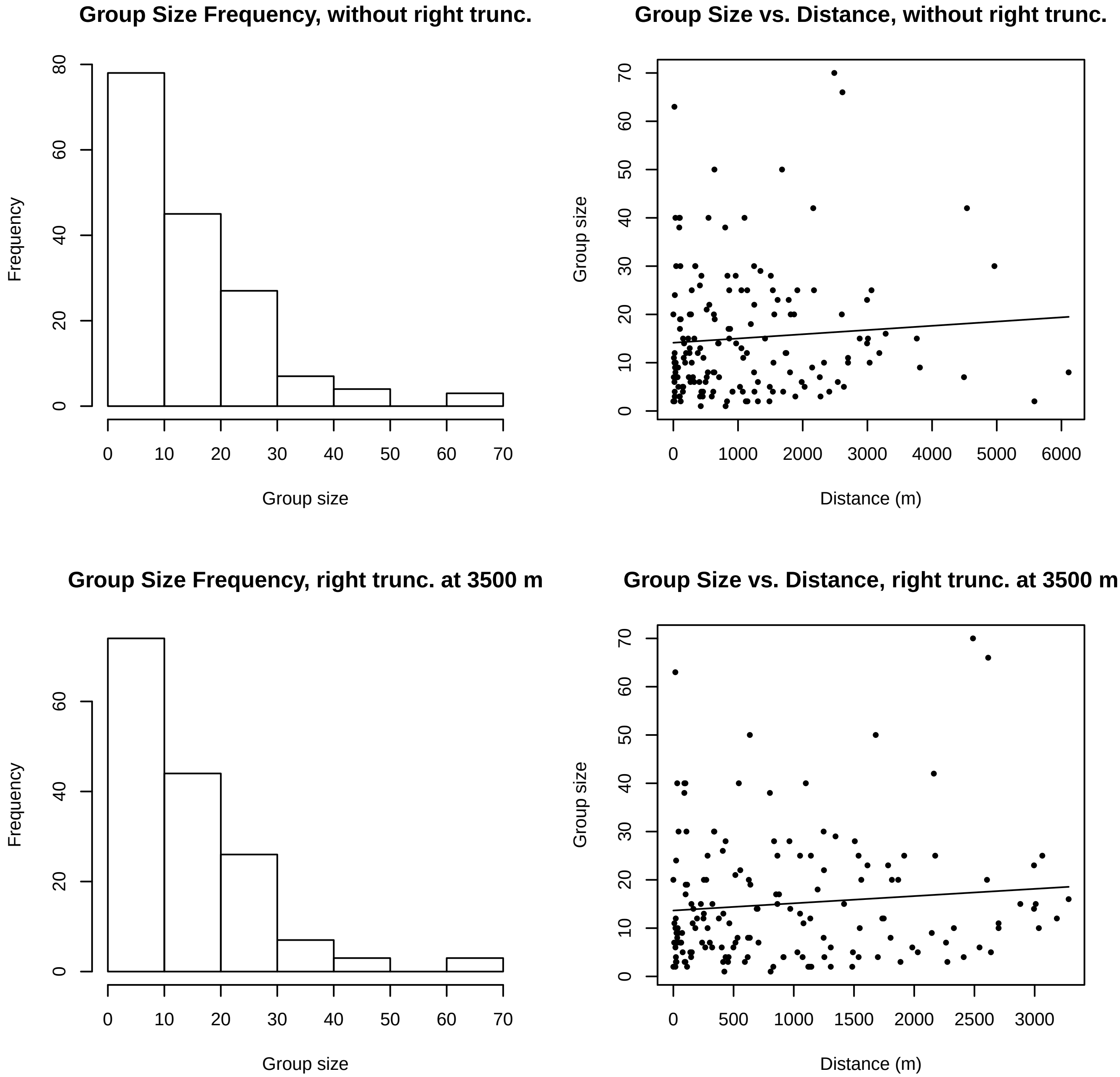


Figure 27: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

SEFSC Gordon Gunter

The sightings were right truncated at 5000m.

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)
hr			beaufort, size	Yes	0.00	967
hr			beaufort, quality, size	Yes	2.00	967
hr			beaufort	Yes	28.85	782
hr			quality, size	Yes	40.92	630
hr			size	Yes	44.48	603
hr			quality	Yes	69.88	427
hr				Yes	70.22	429
hn			beaufort, quality, size	Yes	129.41	1940
hn			beaufort, size	Yes	129.62	1945
hn	cos	3		Yes	134.17	1325
hn	cos	2		Yes	146.53	1538
hn			beaufort	Yes	148.77	1937
hn			beaufort, quality	Yes	150.36	1938
hn			quality, size	Yes	168.07	1979
hn			size	Yes	176.98	1987
hn			quality	Yes	191.56	1973
hn				Yes	193.58	1976
hn	herm	4		Yes	194.80	1972
hr	poly	2		No		
hr	poly	4		No		
hr			beaufort, quality	No		

Table 15: Candidate detection functions for SEFSC Gordon Gunter. The first one listed was selected for the density model.

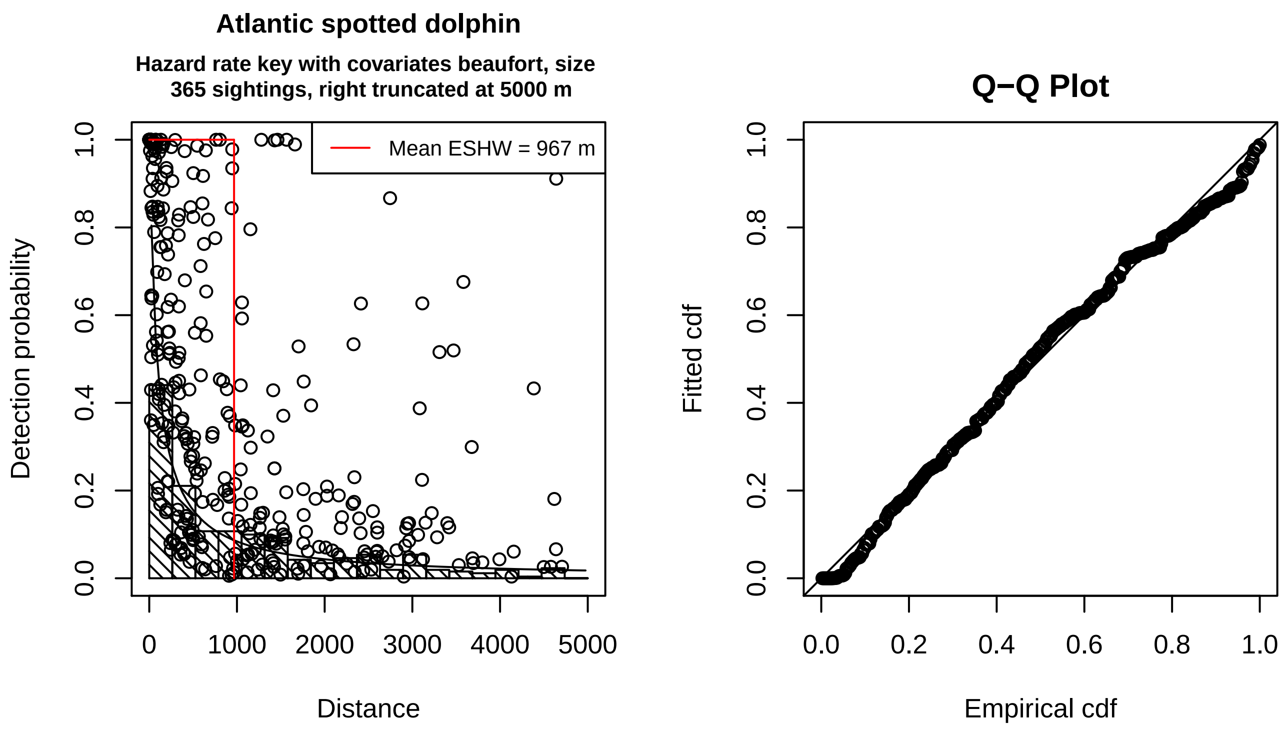


Figure 28: Detection function for SEFSC Gordon Gunter that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  365
Distance range         :  0  -  5000
AIC                    :  5707.216

Detection function:
 Hazard-rate key function

Detection function parameters
Scale Coefficients:
              estimate        se
(Intercept)  6.9882664 0.3585289
beaufort    -0.9728765 0.1306240
size         1.2333979 0.2719346

Shape parameters:
             estimate         se
(Intercept) 0.1427203 0.06892779

                       Estimate           SE        CV
Average p           7.358486e-02   0.01252932 0.1702704
N in covered region 4.960260e+03 885.35176703 0.1784890
```

Additional diagnostic plots:

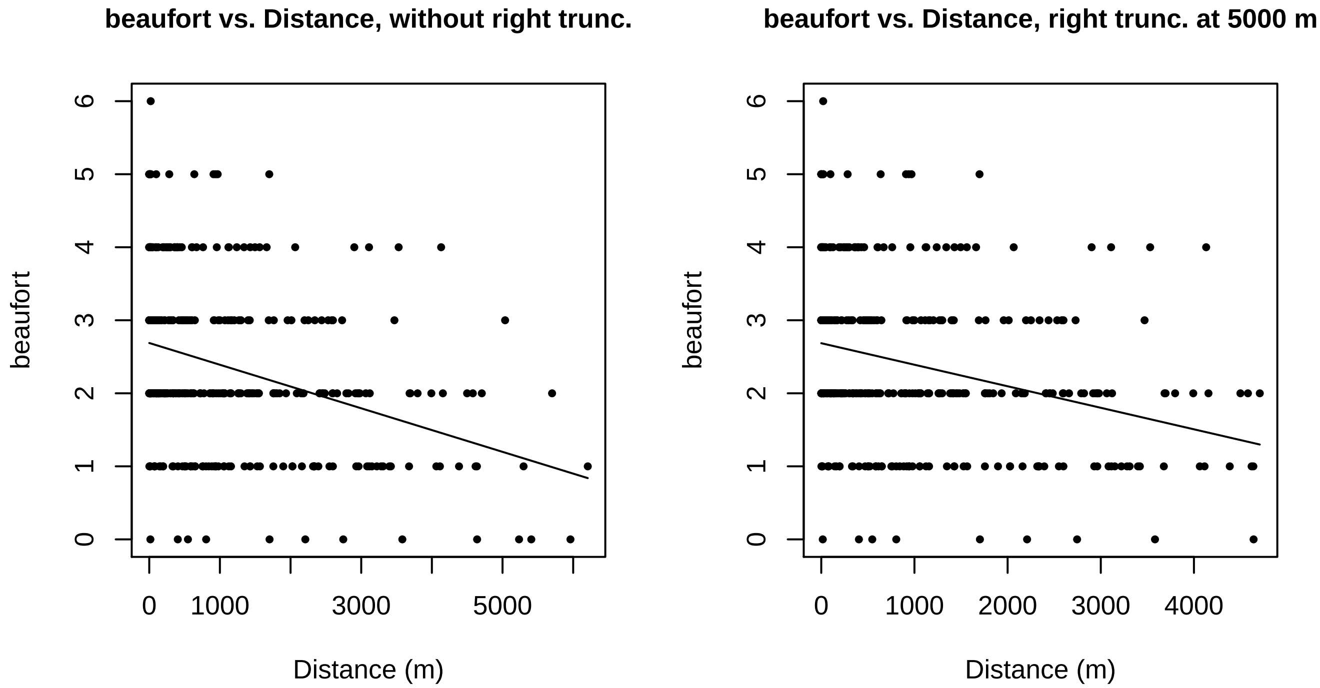


Figure 29: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

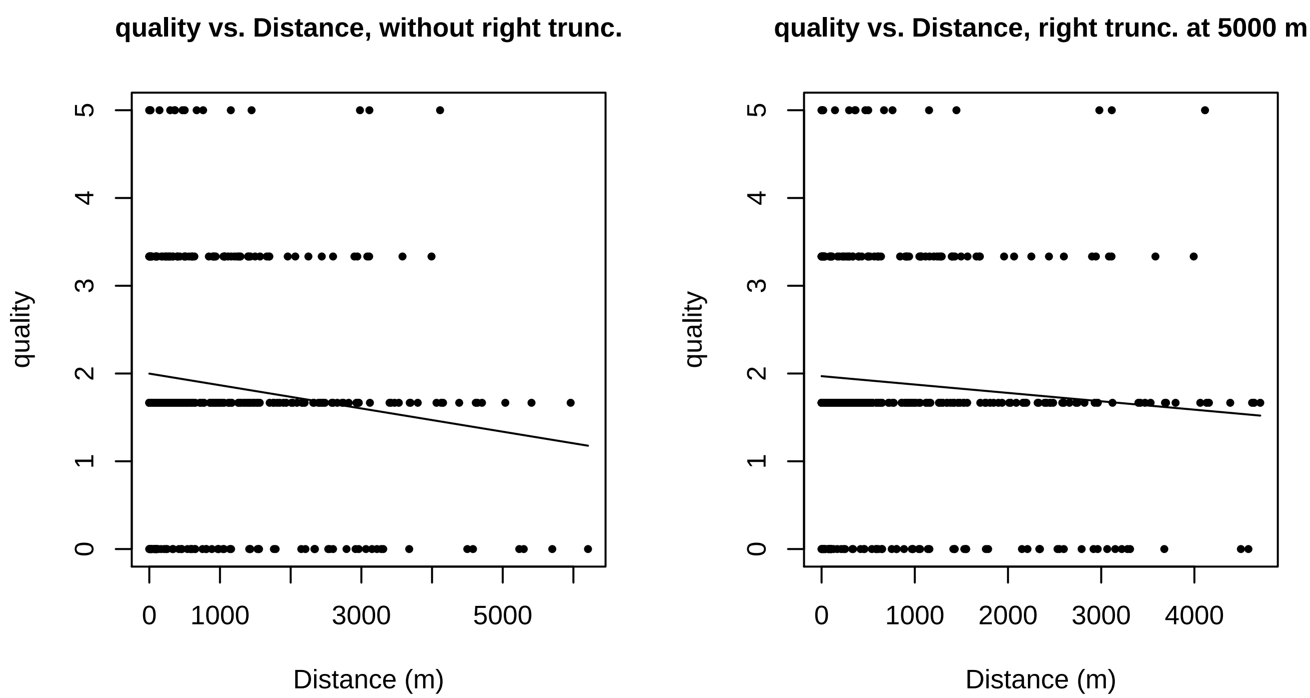


Figure 30: Scatterplots showing the relationship between the survey-specific index of the quality of observation conditions and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). Low values of the quality index correspond to better observation conditions. The line is a simple linear regression.

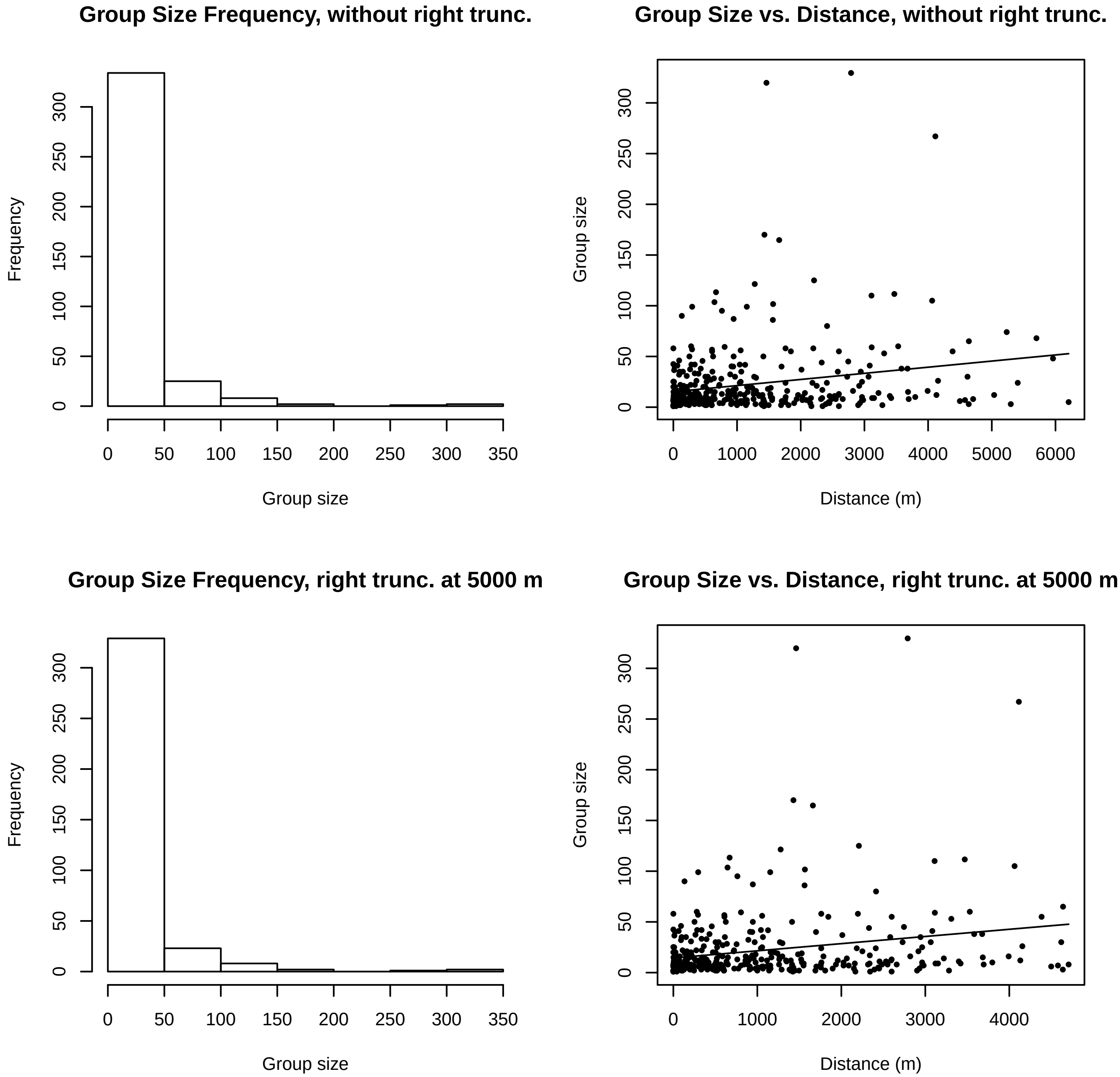


Figure 31: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

Gordon Gunter Atlantic

The sightings were right truncated at 5000m.

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			beaufort, size	Yes	0.00	906
hr			beaufort, quality, size	Yes	2.00	906
hr			beaufort	Yes	19.53	714
hr			quality, size	Yes	33.21	575
hr			size	Yes	35.27	520
hr			quality	Yes	51.63	390
hr				Yes	51.89	373
hn			beaufort, quality, size	Yes	91.88	1826
hn			beaufort, size	Yes	93.18	1836
hn	cos	3		Yes	105.75	1299
hn	cos	2		Yes	107.06	1462
hn			beaufort, quality	Yes	112.55	1808
hn			beaufort	Yes	113.08	1808
hn			quality, size	Yes	119.95	1840
hn			quality	Yes	130.46	1838
hn			size	Yes	131.59	1862
hn				Yes	140.08	1847
hn	herm	4		Yes	141.51	1844
hr	poly	2		No		
hr	poly	4		No		
hr			beaufort, quality	No		

Table 17: Candidate detection functions for Gordon Gunter Atlantic. The first one listed was selected for the density model.

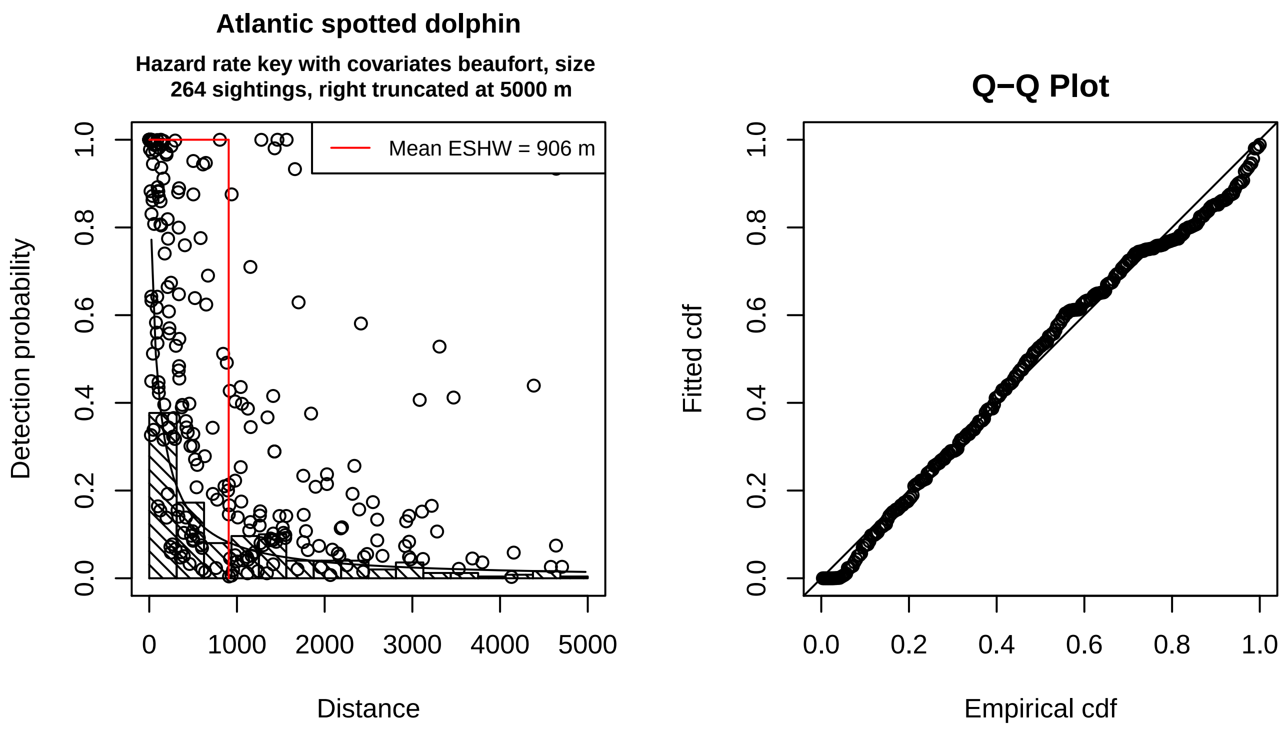


Figure 32: Detection function for Gordon Gunter Atlantic that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  264
Distance range         :  0  -  5000
AIC                    :  4094.918

Detection function:
 Hazard-rate key function

Detection function parameters
Scale Coefficients:
             estimate        se
(Intercept)  7.245851 0.4024413
beaufort    -1.037593 0.1499247
size         1.176621 0.2980893

Shape parameters:
            estimate         se
(Intercept) 0.178641 0.08113012

                        Estimate           SE        CV
Average p           6.617116e-02   0.01309359 0.1978746
N in covered region 3.989654e+03 828.53587482 0.2076711
```

Additional diagnostic plots:

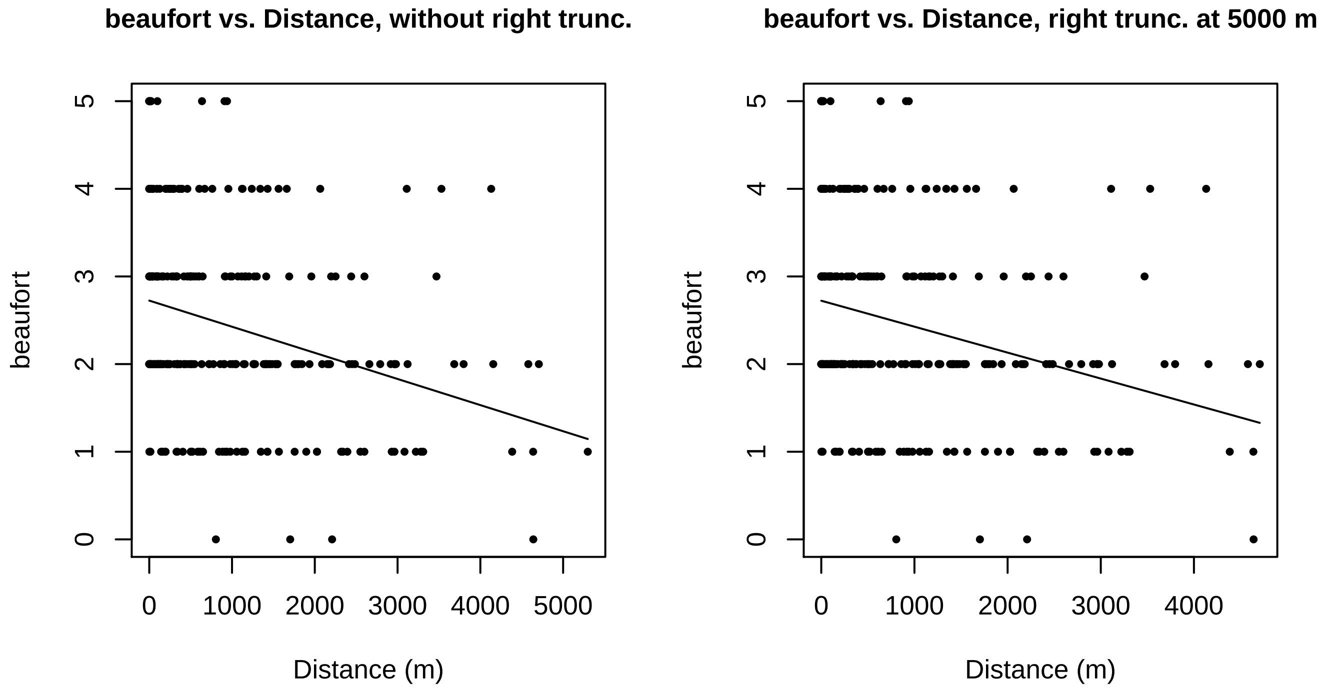


Figure 33: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

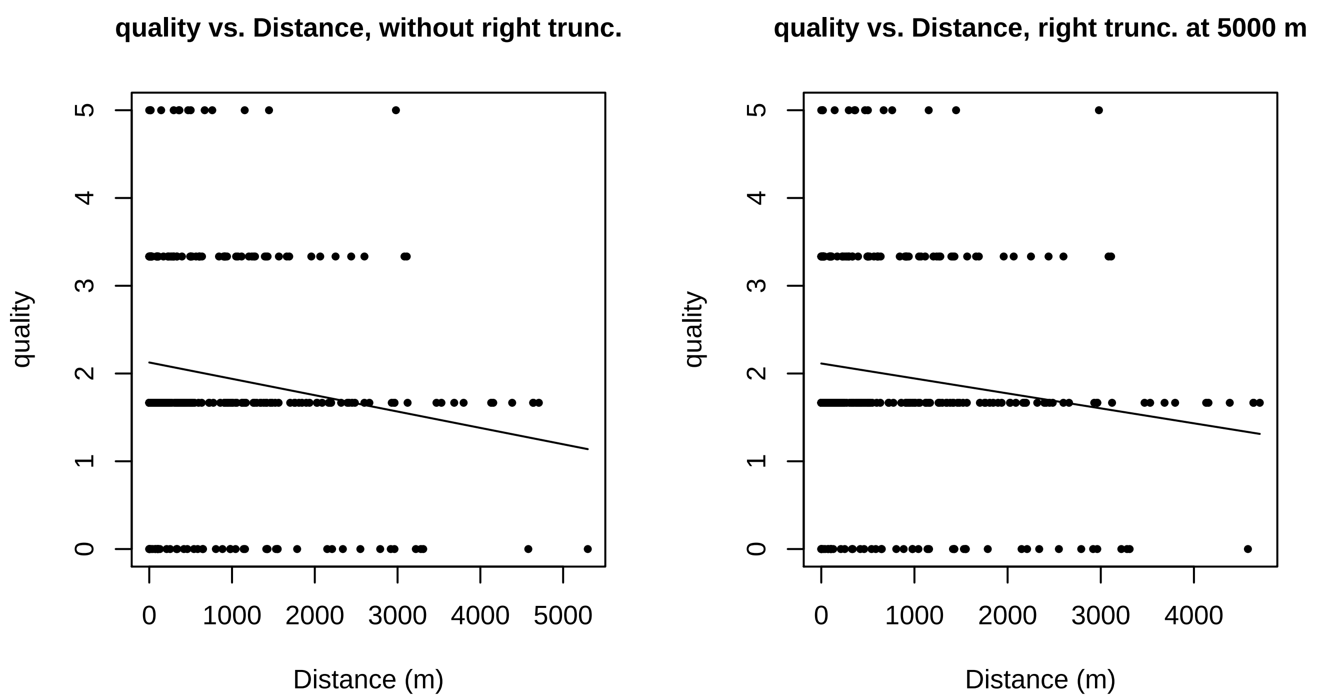


Figure 34: Scatterplots showing the relationship between the survey-specific index of the quality of observation conditions and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). Low values of the quality index correspond to better observation conditions. The line is a simple linear regression.

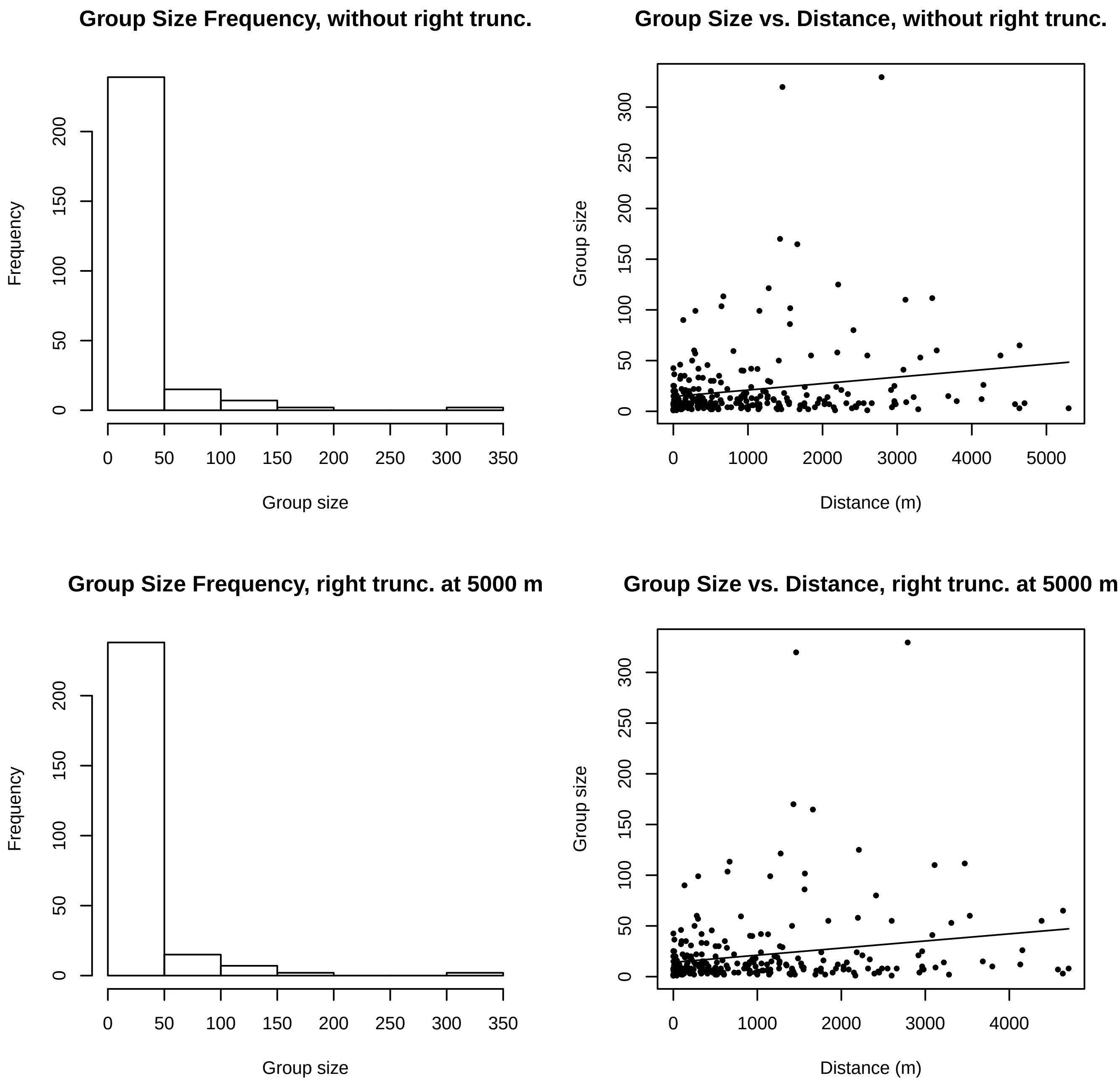


Figure 35: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

Gordon Gunter Gulf of Mexico

The sightings were right truncated at 5000m.

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

Table 18: Covariates tested in candidate “multi-covariate distance sampling” (MCDS) detection functions.

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hr			beaufort, size	Yes	0.00	1106
hr			size	Yes	4.05	935
hr			beaufort	Yes	4.36	1052
hr				Yes	9.79	764
hn	cos	3		Yes	11.64	1416
hr	poly	4		Yes	15.00	630
hn			beaufort	Yes	21.72	2285
hn			beaufort, size	Yes	22.09	2261
hn	cos	2		Yes	23.27	1773
hn			size	Yes	28.64	2286
hn				Yes	32.34	2310
hn	herm	4		Yes	34.18	2303
hr	poly	2		No		

Table 19: Candidate detection functions for Gordon Gunter Gulf of Mexico. The first one listed was selected for the density model.

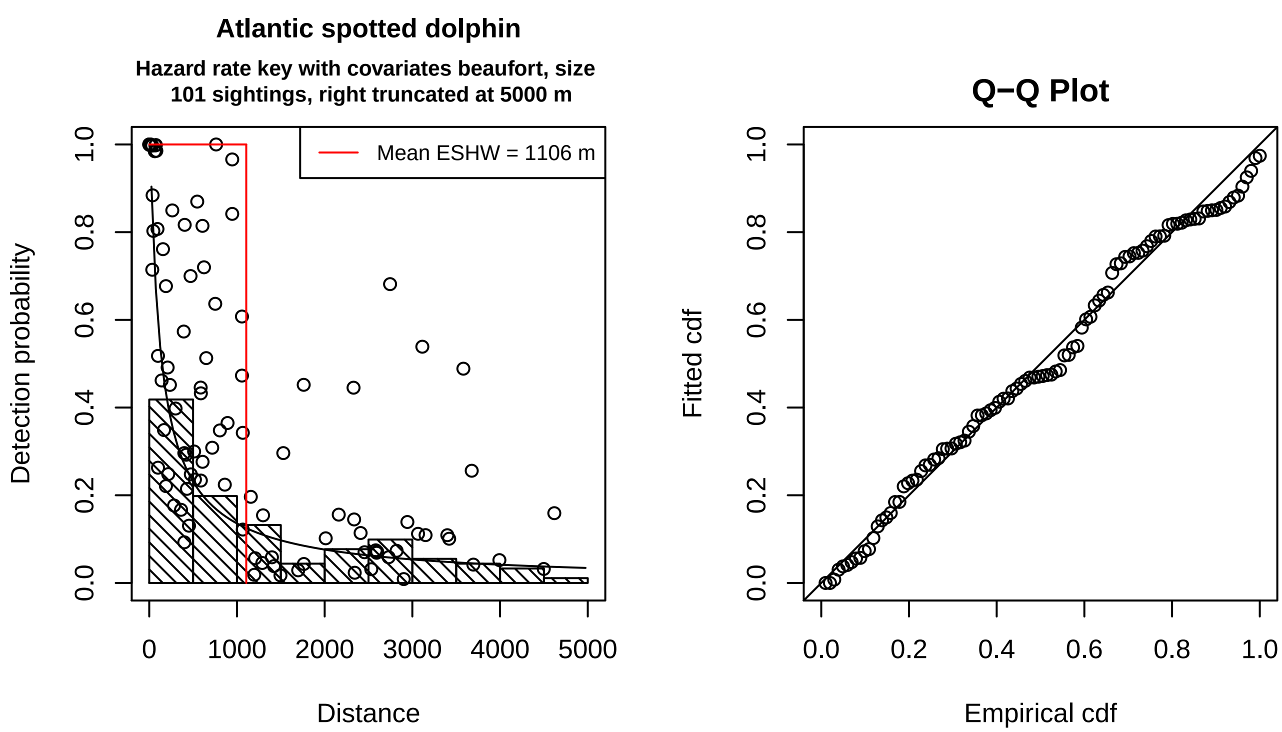


Figure 36: Detection function for Gordon Gunter Gulf of Mexico that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
```

```
Number of observations :  101
Distance range         :  0  -  5000
AIC                    :  1629.305

Detection function:
 Hazard-rate key function

Detection function parameters
Scale Coefficients:
              estimate        se
(Intercept)  6.3739410 0.8496874
beaufort    -0.7814356 0.2858329
size         1.1834310 0.6397898

Shape parameters:
             estimate       se
(Intercept) 0.0140908 0.148917

                       Estimate          SE        CV
Average p             0.1112082   0.0383875 0.3451859
N in covered region 908.2066707 326.2504316 0.3592249
```

Additional diagnostic plots:

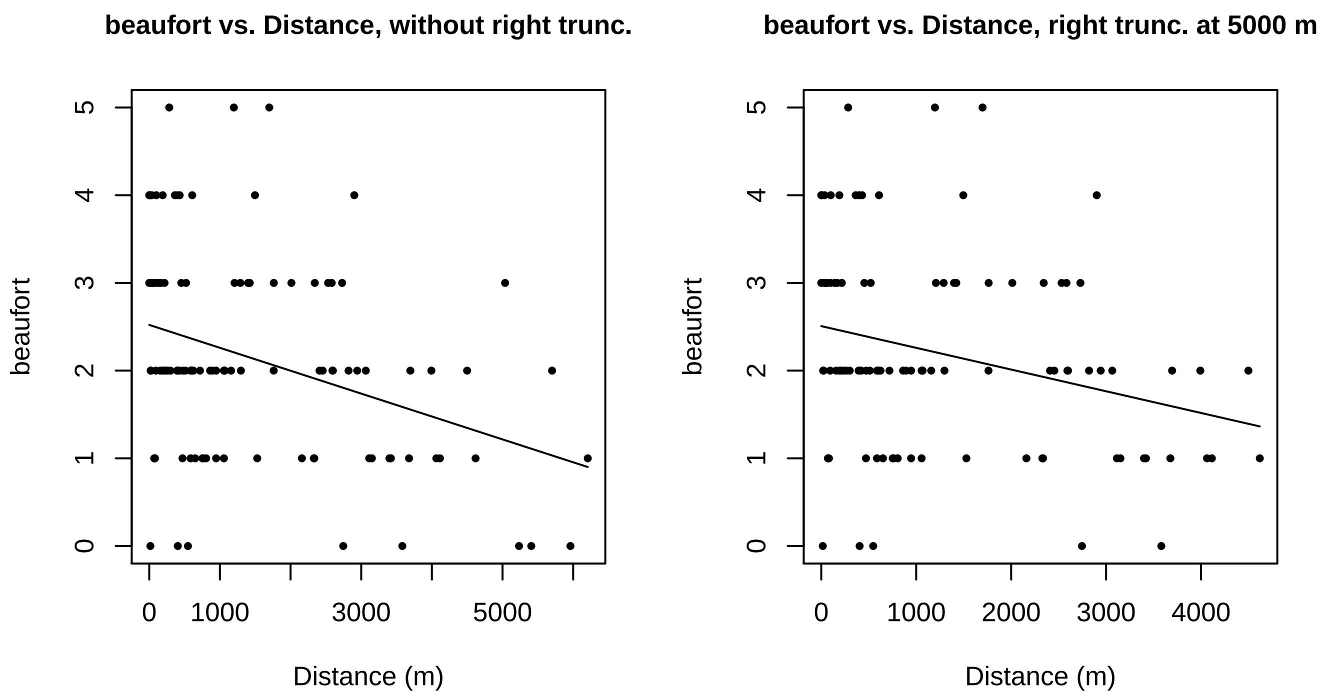


Figure 37: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

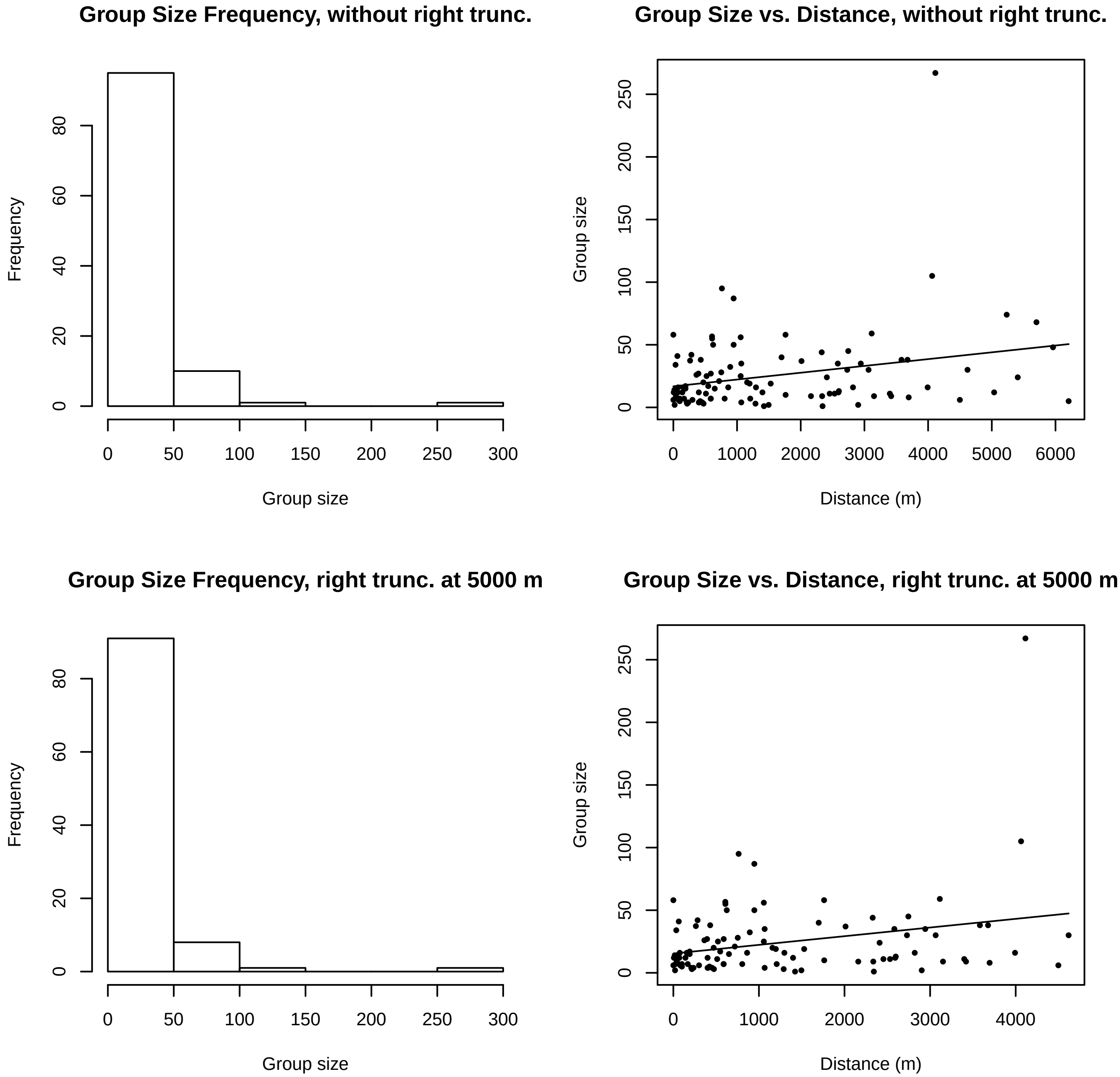


Figure 38: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

Naked Eye Surveys

Because this taxon was sighted too infrequently to fit a detection function to its sightings alone, we fit a detection function to the pooled sightings of several other species that we believed would exhibit similar detectability. These "proxy species" are listed below.

Reported By Observer	Common Name	n
Delphinus delphis	Short-beaked common dolphin	255
Delphinus delphis/Lagenorhynchus acutus	Short-beaked common or Atlantic white-sided dolphin	0

Delphinus delphis/Stenella	Short-beaked common dolphin or Stenella spp.	0
Delphinus delphis/Stenella coeruleoalba	Short-beaked common or striped dolphin	72
Grampus griseus	Risso's dolphin	9
Grampus griseus/Tursiops truncatus	Risso's or Bottlenose dolphin	0
Lagenodelphis hosei	Fraser's dolphin	0
Lagenorhynchus acutus	Atlantic white-sided dolphin	102
Lagenorhynchus albirostris	White-beaked dolphin	36
Lagenorhynchus albirostris/Lagenorhynchus acutus	White-beaked or white-sided dolphin	4
Stenella	Unidentified Stenella	0
Stenella attenuata	Pantropical spotted dolphin	0
Stenella attenuata/frontalis	Pantropical or Atlantic spotted dolphin	0
Stenella clymene	Clymene dolphin	0
Stenella coeruleoalba	Striped dolphin	48
Stenella frontalis	Atlantic spotted dolphin	0
Stenella frontalis/Tursiops truncatus	Atlantic spotted or Bottlenose dolphin	0
Stenella longirostris	Spinner dolphin	0
Steno bredanensis	Rough-toothed dolphin	0
Steno bredanensis/Tursiops truncatus	Bottlenose or rough-toothed dolphin	0
Tursiops truncatus	Bottlenose dolphin	41
Total		567

Table 20: Proxy species used to fit detection functions for Naked Eye Surveys. The number of sightings, n, is before truncation.

The sightings were right truncated at 1000m.

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

Table 21: Covariates tested in candidate "multi-covariate distance sampling" (MCDS) detection functions.

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hr			beaufort, size	Yes	0.00	329
hr			beaufort	Yes	5.52	306
hr			size	Yes	7.76	330
hr	poly	2		Yes	8.35	253
hr	poly	4		Yes	11.34	266
hn	cos	2		Yes	14.63	339
hr				Yes	14.95	308

hn	cos	3		Yes	29.74	330
hn			beaufort, size	Yes	33.37	434
hn			size	Yes	39.64	433
hn			beaufort	Yes	47.43	427
hn				Yes	53.26	426
hn	herm	4		Yes	54.28	425

Table 22: Candidate detection functions for Naked Eye Surveys. The first one listed was selected for the density model.

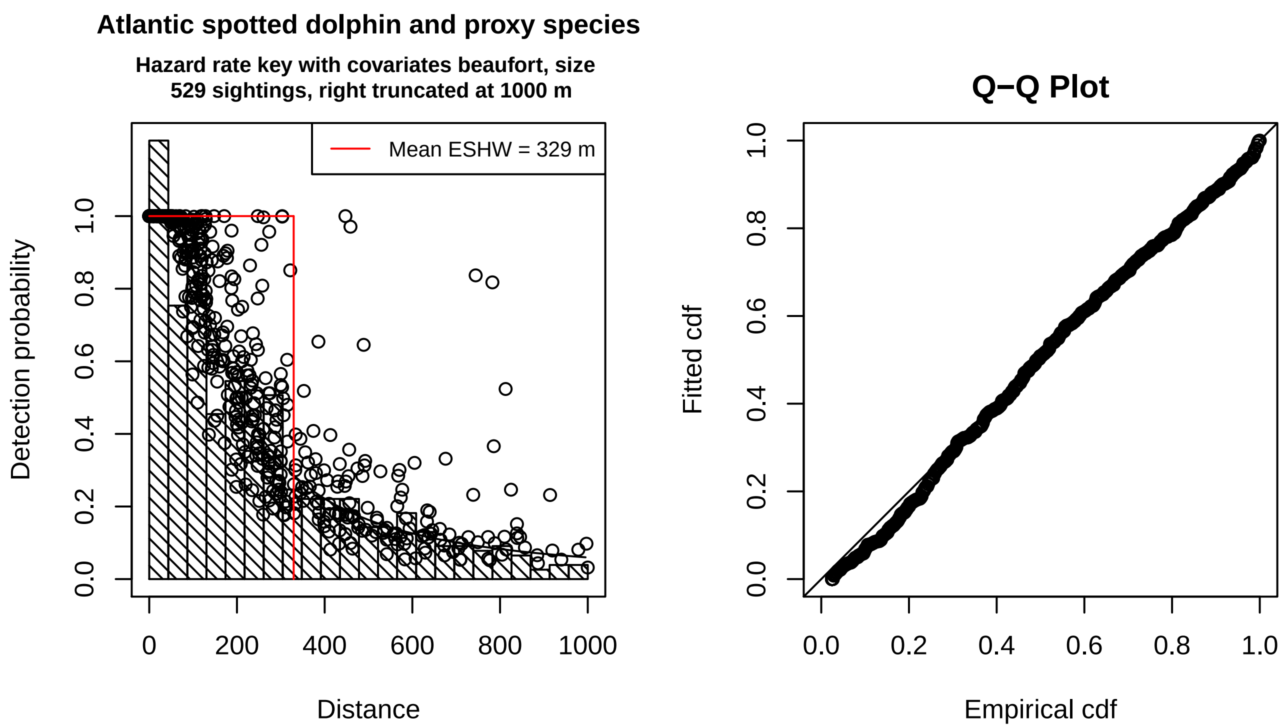


Figure 39: Detection function for Naked Eye Surveys that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  529
Distance range         :  0  -  1000
AIC                    :  6866.942

Detection function:
 Hazard-rate key function

Detection function parameters
Scale Coefficients:
              estimate         se
(Intercept)  5.4796299 0.21489966
beaufort    -0.2095913 0.06594519
size         0.5152091 0.16341040
```

```
Shape parameters:
             estimate         se
(Intercept) 0.4966405 0.08804302

                          Estimate           SE         CV
Average p                0.2987683   0.02050381 0.06862779
N in covered region 1770.6030180 138.21190973 0.07805923
```

Additional diagnostic plots:

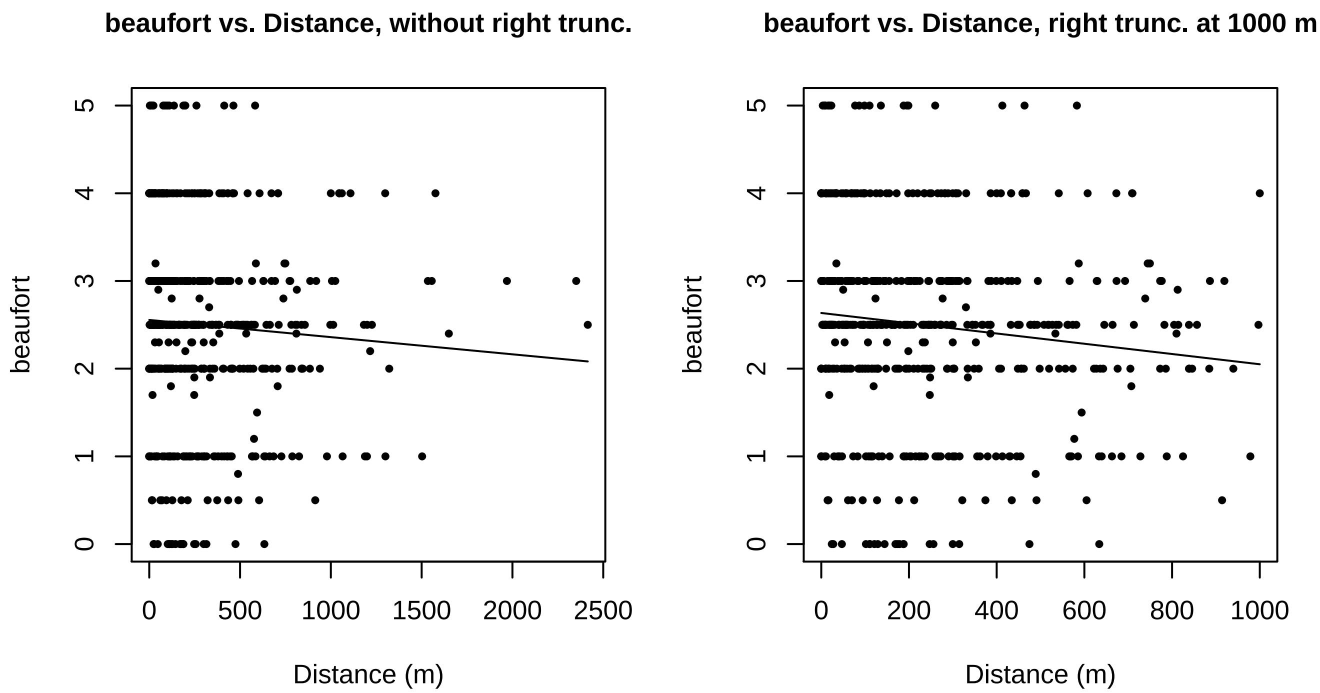


Figure 40: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

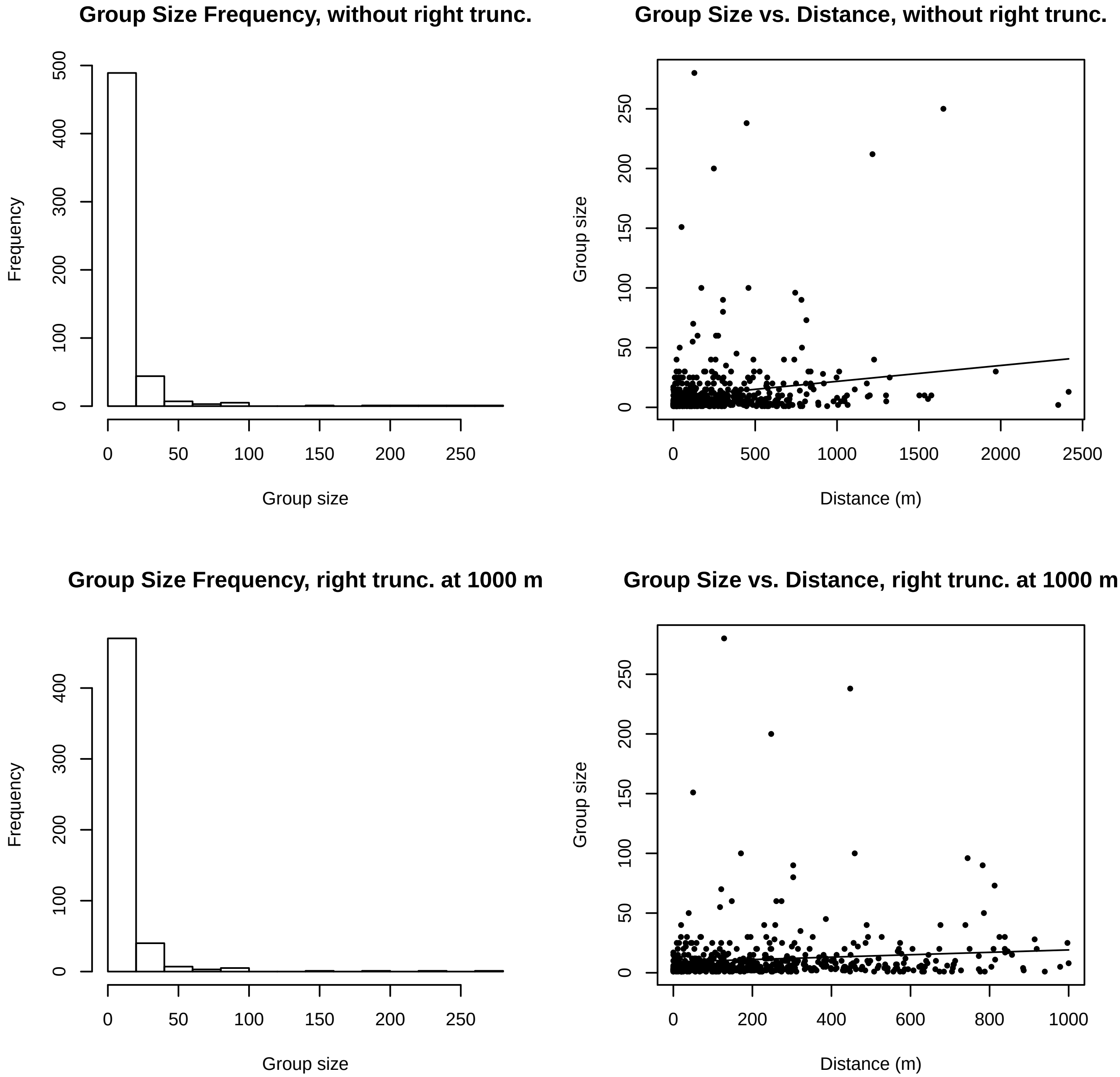


Figure 41: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

CODA and SCANS II

Because this taxon was sighted too infrequently to fit a detection function to its sightings alone, we fit a detection function to the pooled sightings of several other species that we believed would exhibit similar detectability. These "proxy species" are listed below.

Reported By Observer	Common Name	n
Delphinus delphis	Short-beaked common dolphin	227
Delphinus delphis/Lagenorhynchus acutus	Short-beaked common or Atlantic white-sided dolphin	0

Delphinus delphis/Stenella	Short-beaked common dolphin or Stenella spp.	0
Delphinus delphis/Stenella coeruleoalba	Short-beaked common or striped dolphin	57
Grampus griseus	Risso's dolphin	9
Grampus griseus/Tursiops truncatus	Risso's or Bottlenose dolphin	0
Lagenodelphis hosei	Fraser's dolphin	0
Lagenorhynchus acutus	Atlantic white-sided dolphin	56
Lagenorhynchus albirostris	White-beaked dolphin	32
Lagenorhynchus albirostris/Lagenorhynchus acutus	White-beaked or white-sided dolphin	4
Stenella	Unidentified Stenella	0
Stenella attenuata	Pantropical spotted dolphin	0
Stenella attenuata/frontalis	Pantropical or Atlantic spotted dolphin	0
Stenella clymene	Clymene dolphin	0
Stenella coeruleoalba	Striped dolphin	36
Stenella frontalis	Atlantic spotted dolphin	0
Stenella frontalis/Tursiops truncatus	Atlantic spotted or Bottlenose dolphin	0
Stenella longirostris	Spinner dolphin	0
Steno bredanensis	Rough-toothed dolphin	0
Steno bredanensis/Tursiops truncatus	Bottlenose or rough-toothed dolphin	0
Tursiops truncatus	Bottlenose dolphin	41
Total		462

Table 23: Proxy species used to fit detection functions for CODA and SCANS II. The number of sightings, n, is before truncation.

The sightings were right truncated at 1000m.

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 24: 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	326
hr			quality	Yes	0.85	325
hr	poly	2		Yes	2.85	257
hr			beaufort, size	Yes	3.50	319
hr			beaufort	Yes	4.73	315

hr	poly	4		Yes	5.08	288
hn	cos	2		Yes	5.71	335
hr			size	Yes	6.16	322
hr				Yes	7.78	319
hn	cos	3		Yes	15.49	324
hn			quality, size	Yes	21.34	416
hn			beaufort, size	Yes	22.76	417
hn			beaufort, quality, size	Yes	23.17	416
hn			quality	Yes	25.50	413
hn			size	Yes	26.46	418
hn			beaufort, quality	Yes	27.47	413
hn			beaufort	Yes	28.47	414
hn				Yes	32.88	414
hn	herm	4		Yes	34.17	413
hr			beaufort, quality	No		
hr			beaufort, quality, size	No		

Table 25: Candidate detection functions for CODA and SCANS II. The first one listed was selected for the density model.

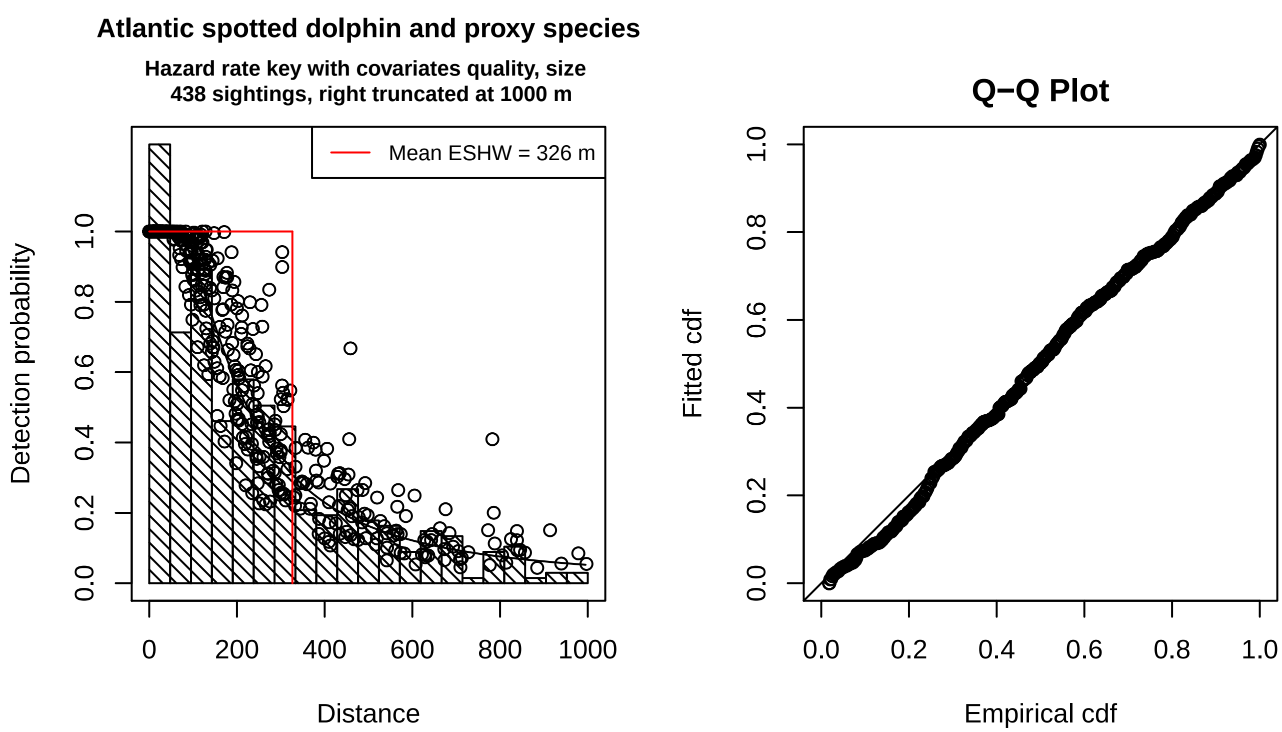


Figure 42: Detection function for CODA and SCANS II that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  438
Distance range         :  0  -  1000
AIC                    :  5674.066

Detection function:
 Hazard-rate key function

Detection function parameters
Scale Coefficients:
              estimate         se
(Intercept)  5.4624136 0.17286880
quality     -0.1426257 0.05036964
size         0.2194236 0.11538504

Shape parameters:
             estimate         se
(Intercept) 0.5741026 0.09733169

                        Estimate           SE         CV
Average p              0.3097732   0.02170451 0.07006582
N in covered region 1413.9378602 114.19755693 0.08076561
```

Additional diagnostic plots:

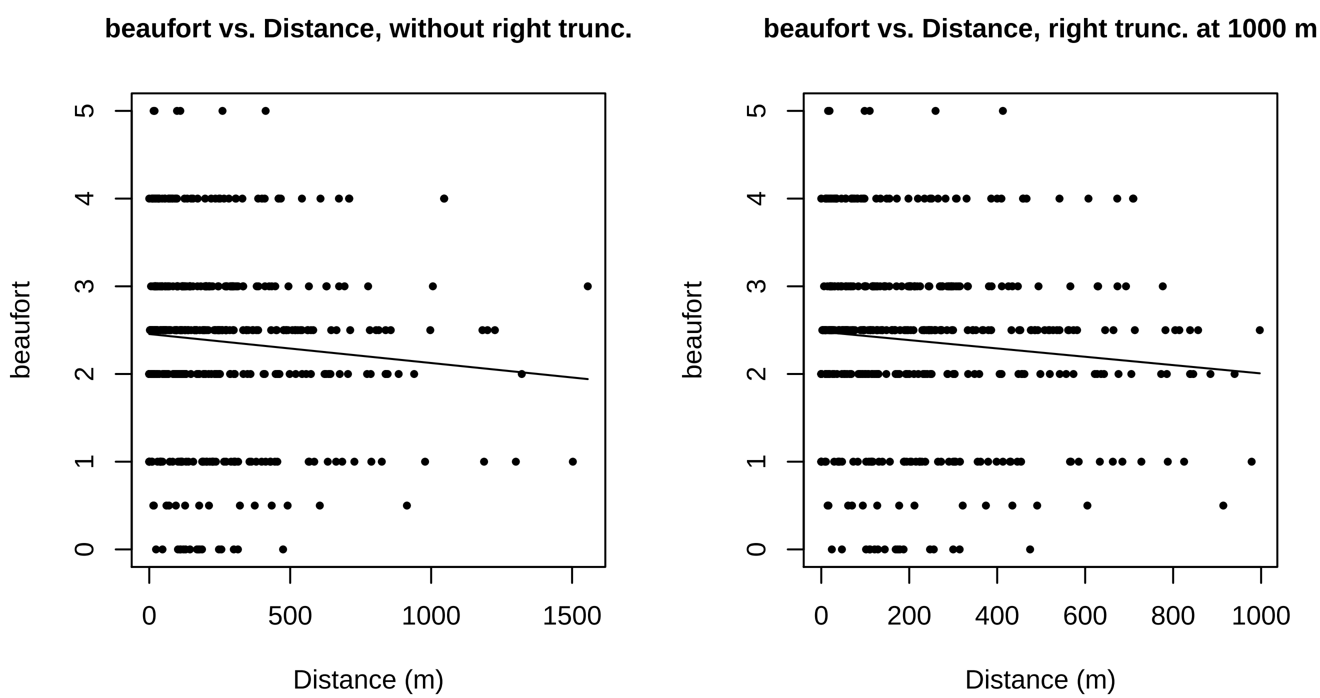


Figure 43: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

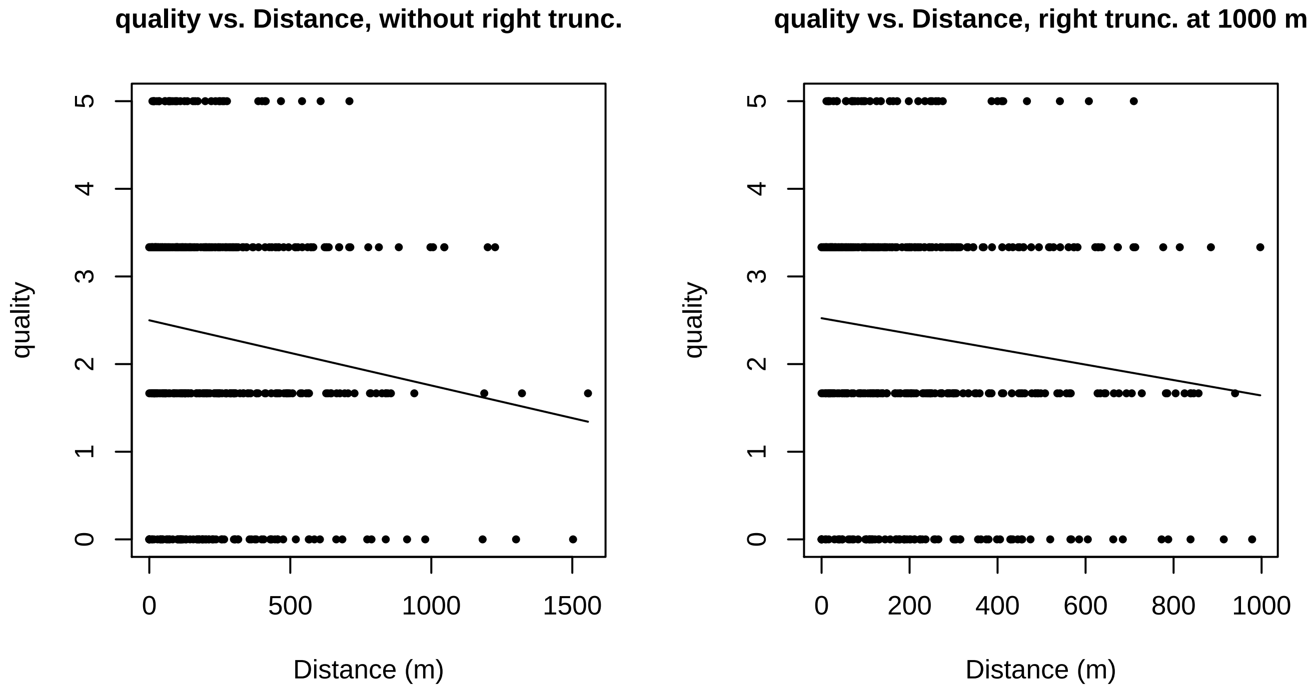


Figure 44: Scatterplots showing the relationship between the survey-specific index of the quality of observation conditions and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). Low values of the quality index correspond to better observation conditions. The line is a simple linear regression.

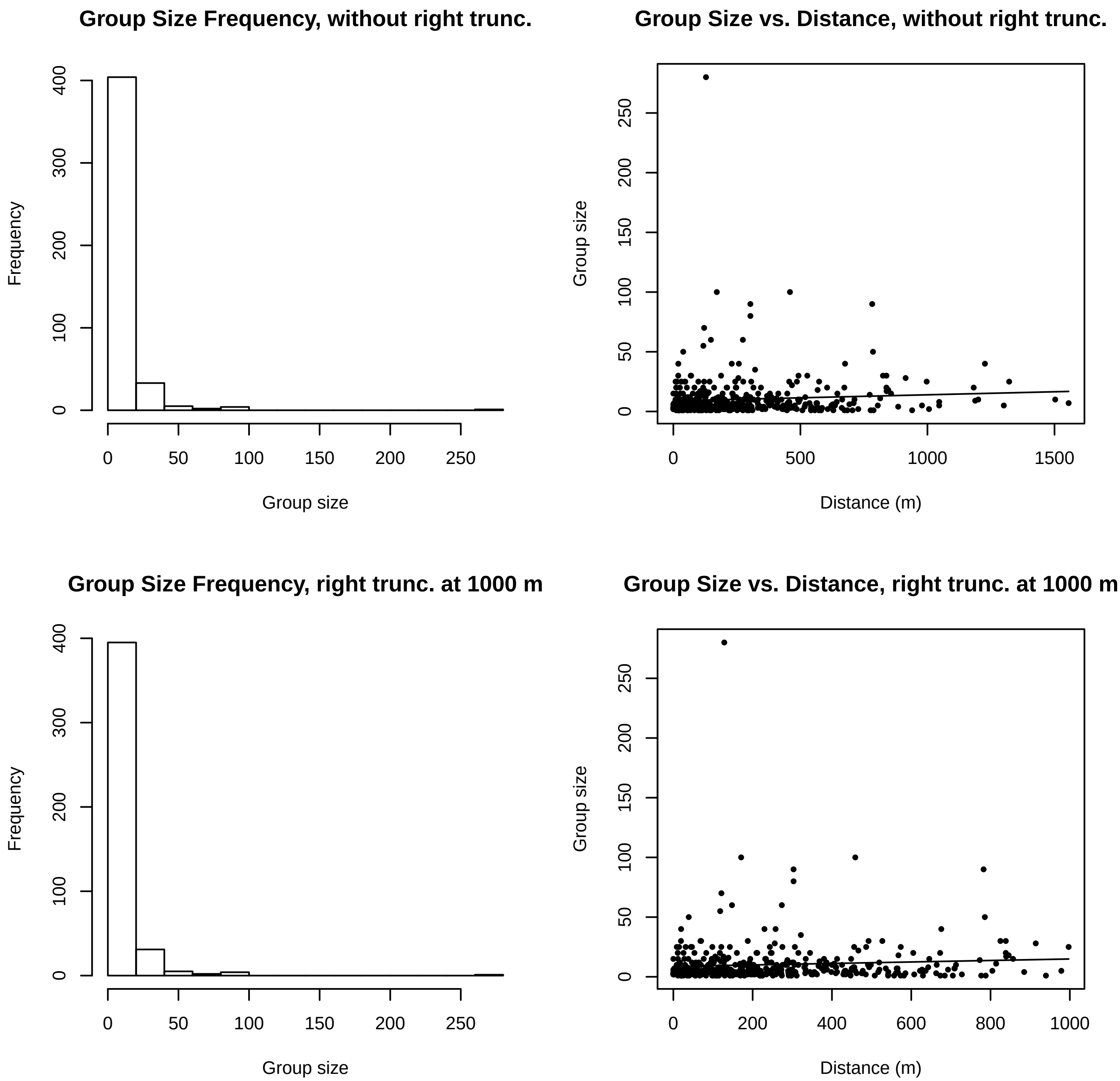


Figure 45: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

Aerial Surveys

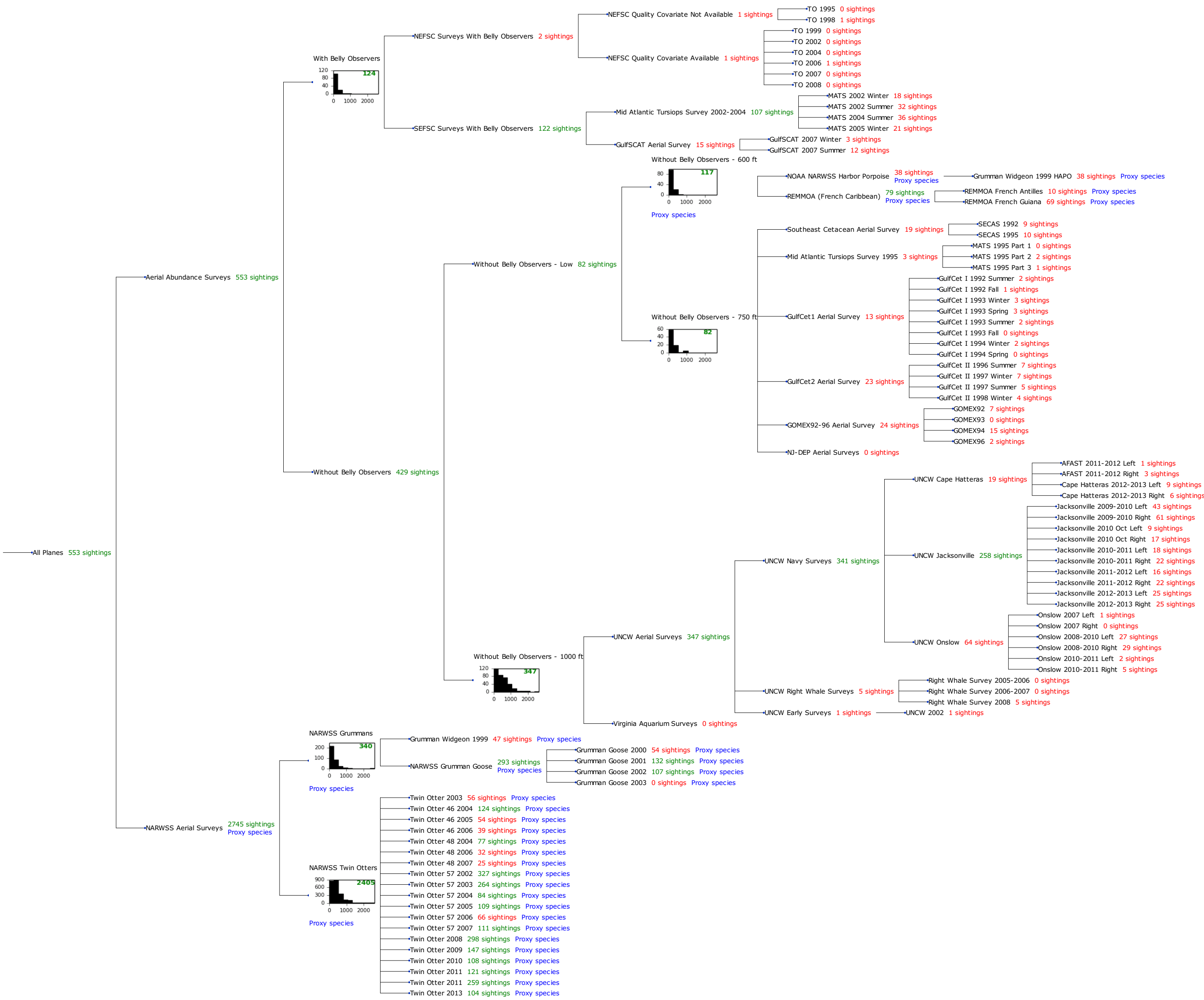


Figure 46: Detection hierarchy for aerial surveys

With Belly Observers

The sightings were right truncated at 628m. The vertical sighting angles were heaped at 10 degree increments, so the candidate detection functions were fitted using linear bins scaled accordingly.

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

Table 26: 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	324
hr			beaufort	Yes	0.08	321
hr				Yes	0.18	322
hr			beaufort, size	Yes	0.31	321
hr	poly	4		Yes	2.18	322
hr	poly	2		Yes	2.18	322
hn	cos	3		Yes	3.50	305
hn			beaufort	Yes	4.38	284
hn				Yes	4.55	284
hn	cos	2		Yes	4.60	320
hn	herm	4		Yes	4.91	321
hn			size	Yes	5.10	284
hn			beaufort, size	Yes	5.50	283

Table 27: Candidate detection functions for With Belly Observers. The first one listed was selected for the density model.

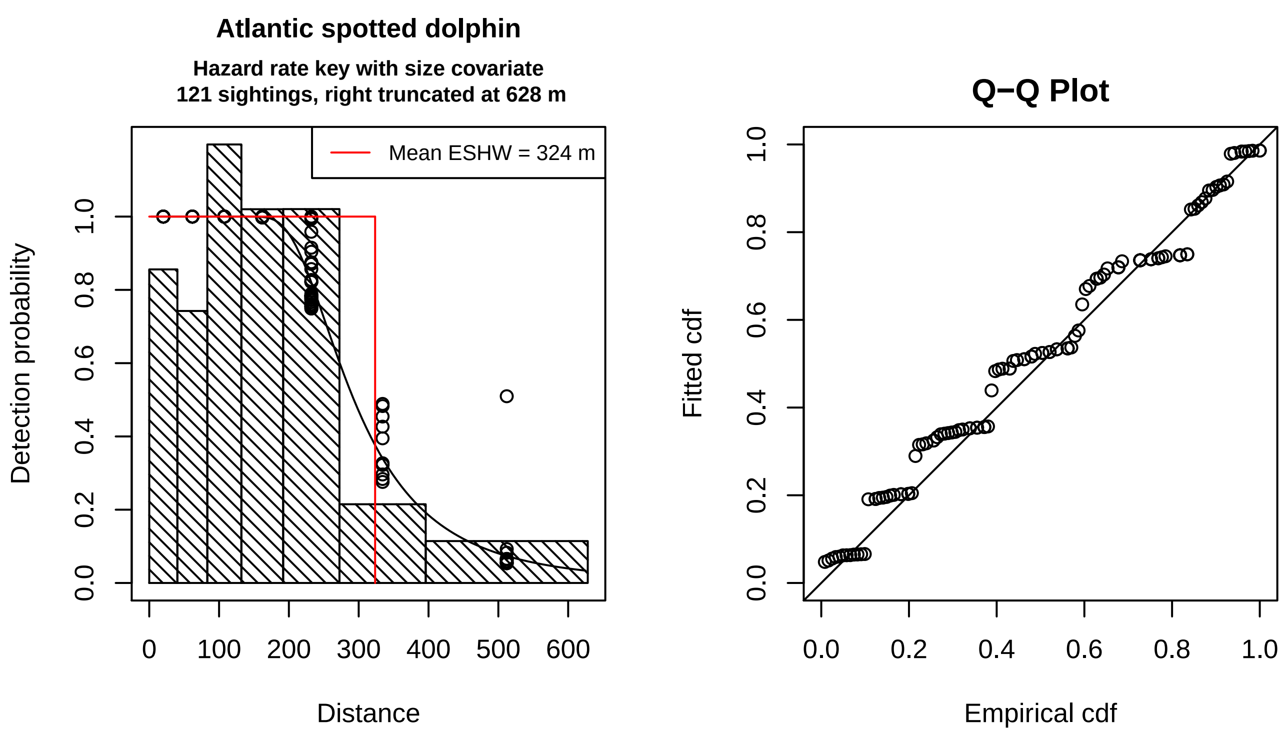


Figure 47: Detection function for With Belly Observers that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
```

```
Number of observations :  121
Distance range         :  0  -  628.0733
AIC                    :  459.4751

Detection function:
 Hazard-rate key function

Detection function parameters
Scale Coefficients:
              estimate         se
(Intercept) 5.52247976 0.12950135
size        0.09705751 0.07394865

Shape parameters:
            estimate       se
(Intercept) 1.407852 0.220681

                      Estimate         SE         CV
Average p             0.511259  0.0400672 0.07836967
N in covered region 236.670649 23.9175034 0.10105817
```

Additional diagnostic plots:

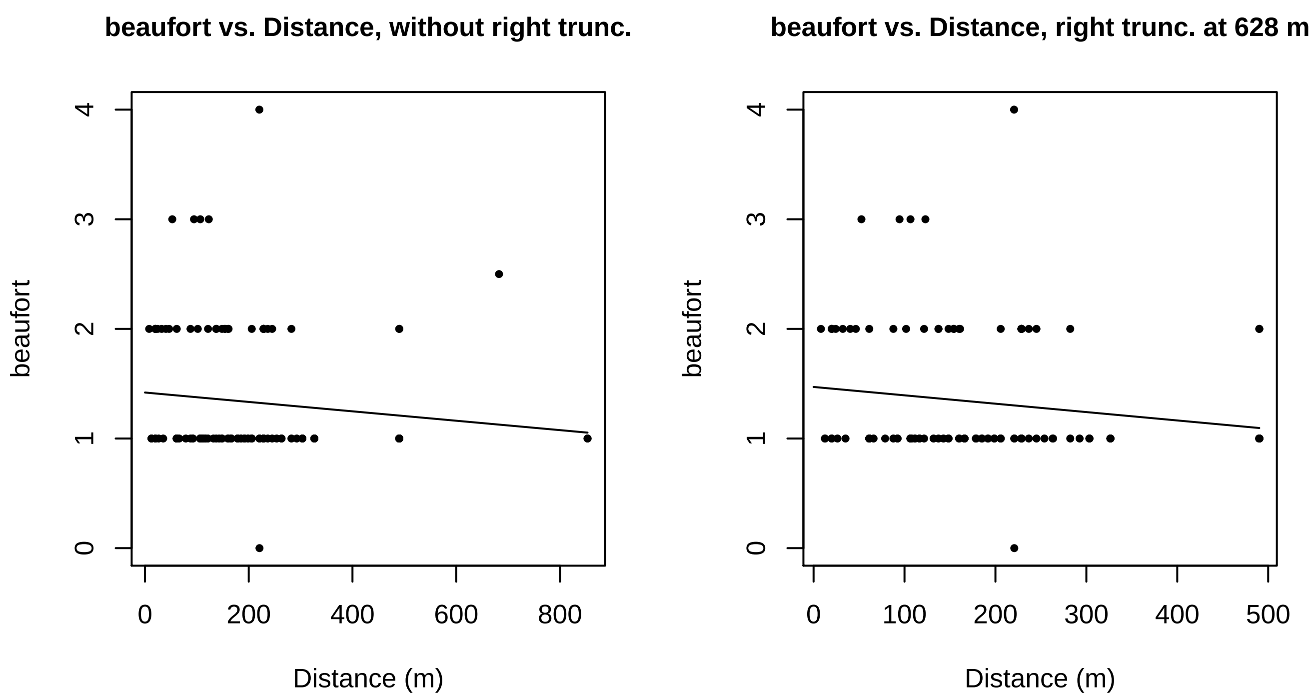


Figure 48: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

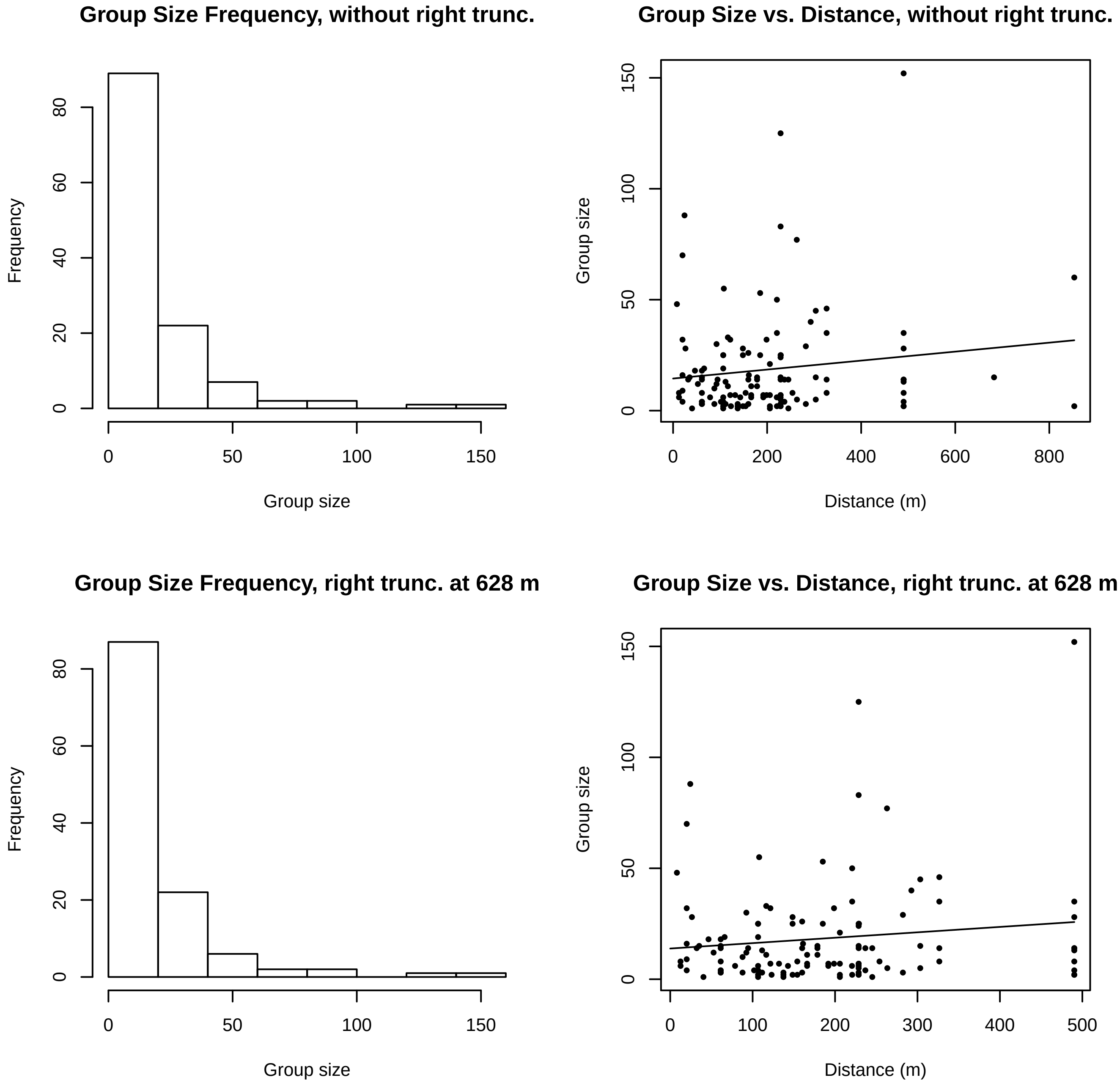


Figure 49: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

Without Belly Observers - 600 ft

Because this taxon was sighted too infrequently to fit a detection function to its sightings alone, we fit a detection function to the pooled sightings of several other species that we believed would exhibit similar detectability. These "proxy species" are listed below.

Reported By Observer	Common Name	n
Delphinus delphis	Short-beaked common dolphin	5
Delphinus delphis/Lagenorhynchus acutus	Short-beaked common or Atlantic white-sided dolphin	0

Delphinus delphis/Stenella	Short-beaked common dolphin or Stenella spp.	0
Delphinus delphis/Stenella coeruleoalba	Short-beaked common or striped dolphin	0
Grampus griseus	Risso's dolphin	3
Grampus griseus/Tursiops truncatus	Risso's or Bottlenose dolphin	0
Lagenodelphis hosei	Fraser's dolphin	4
Lagenorhynchus acutus	Atlantic white-sided dolphin	31
Lagenorhynchus albirostris	White-beaked dolphin	0
Lagenorhynchus albirostris/Lagenorhynchus acutus	White-beaked or white-sided dolphin	0
Stenella	Unidentified Stenella	0
Stenella attenuata	Pantropical spotted dolphin	4
Stenella attenuata/frontalis	Pantropical or Atlantic spotted dolphin	0
Stenella clymene	Clymene dolphin	0
Stenella coeruleoalba	Striped dolphin	0
Stenella frontalis	Atlantic spotted dolphin	0
Stenella frontalis/Tursiops truncatus	Atlantic spotted or Bottlenose dolphin	0
Stenella longirostris	Spinner dolphin	0
Steno bredanensis	Rough-toothed dolphin	0
Steno bredanensis/Tursiops truncatus	Bottlenose or rough-toothed dolphin	0
Tursiops truncatus	Bottlenose dolphin	70
Total		117

Table 28: Proxy species used to fit detection functions for Without Belly Observers - 600 ft. The number of sightings, n, is before truncation.

The sightings were right truncated at 600m.

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

Table 29: 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	273
hr				Yes	0.47	313
hn	cos	3		Yes	0.63	294
hn	cos	2		Yes	1.46	297
hn	herm	4		Yes	1.66	292
hn			beaufort	Yes	1.82	273
hn			size	Yes	1.98	273

hr	poly	4		Yes	2.01	305
hr			beaufort	Yes	2.15	308
hr	poly	2		Yes	2.38	298
hn			beaufort, size	Yes	3.80	273
hr			size	No		
hr			beaufort, size	No		

Table 30: Candidate detection functions for Without Belly Observers - 600 ft. The first one listed was selected for the density model.

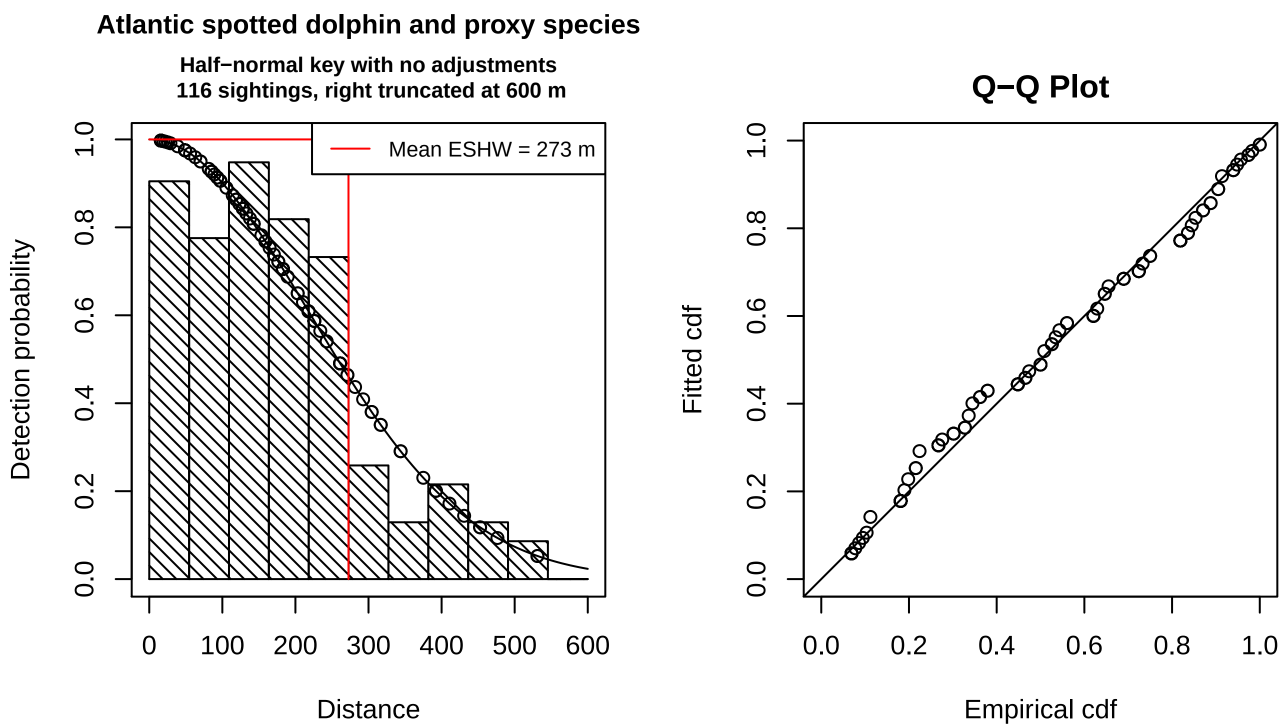


Figure 50: Detection function for Without Belly Observers - 600 ft that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  116
Distance range         :  0  -  600
AIC                    :  1413.111

Detection function:
 Half-normal key function

Detection function parameters
Scale Coefficients:
            estimate         se
(Intercept) 5.388383 0.07654643

                       Estimate          SE         CV
```

```
Average p              0.4543498  0.03299346 0.07261686
N in covered region 255.3098755 25.50172372 0.09988538
```

Additional diagnostic plots:

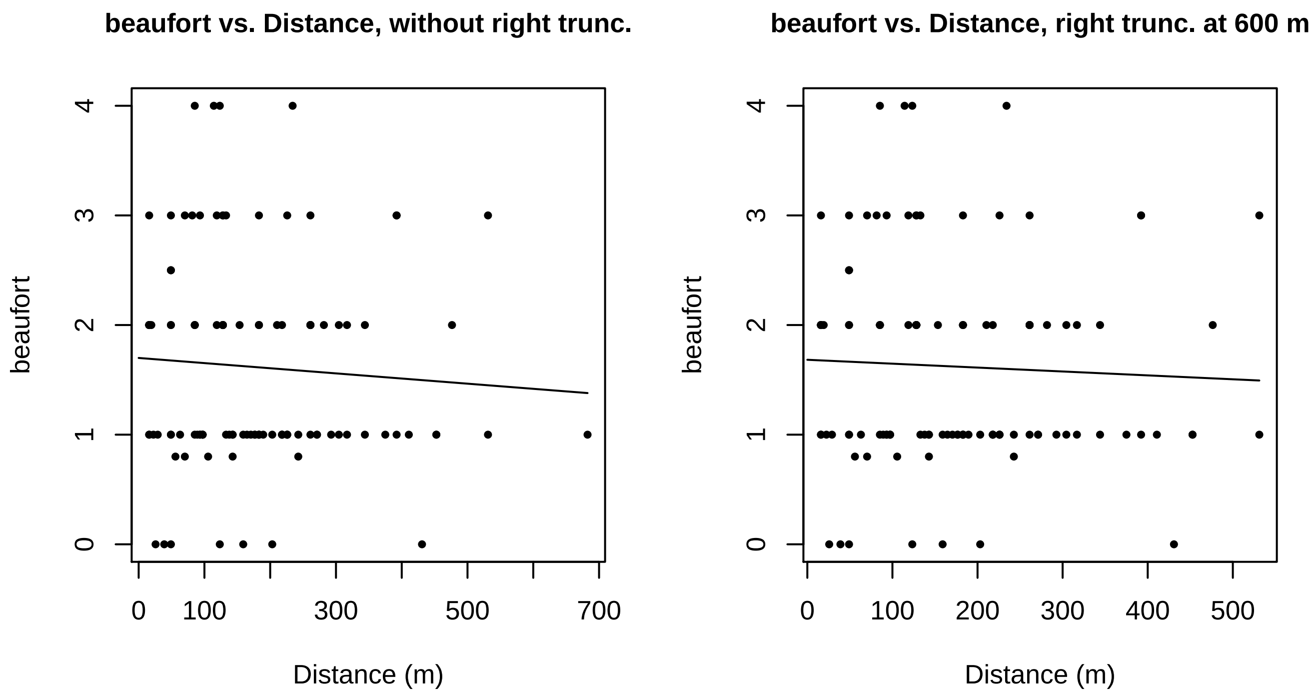


Figure 51: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

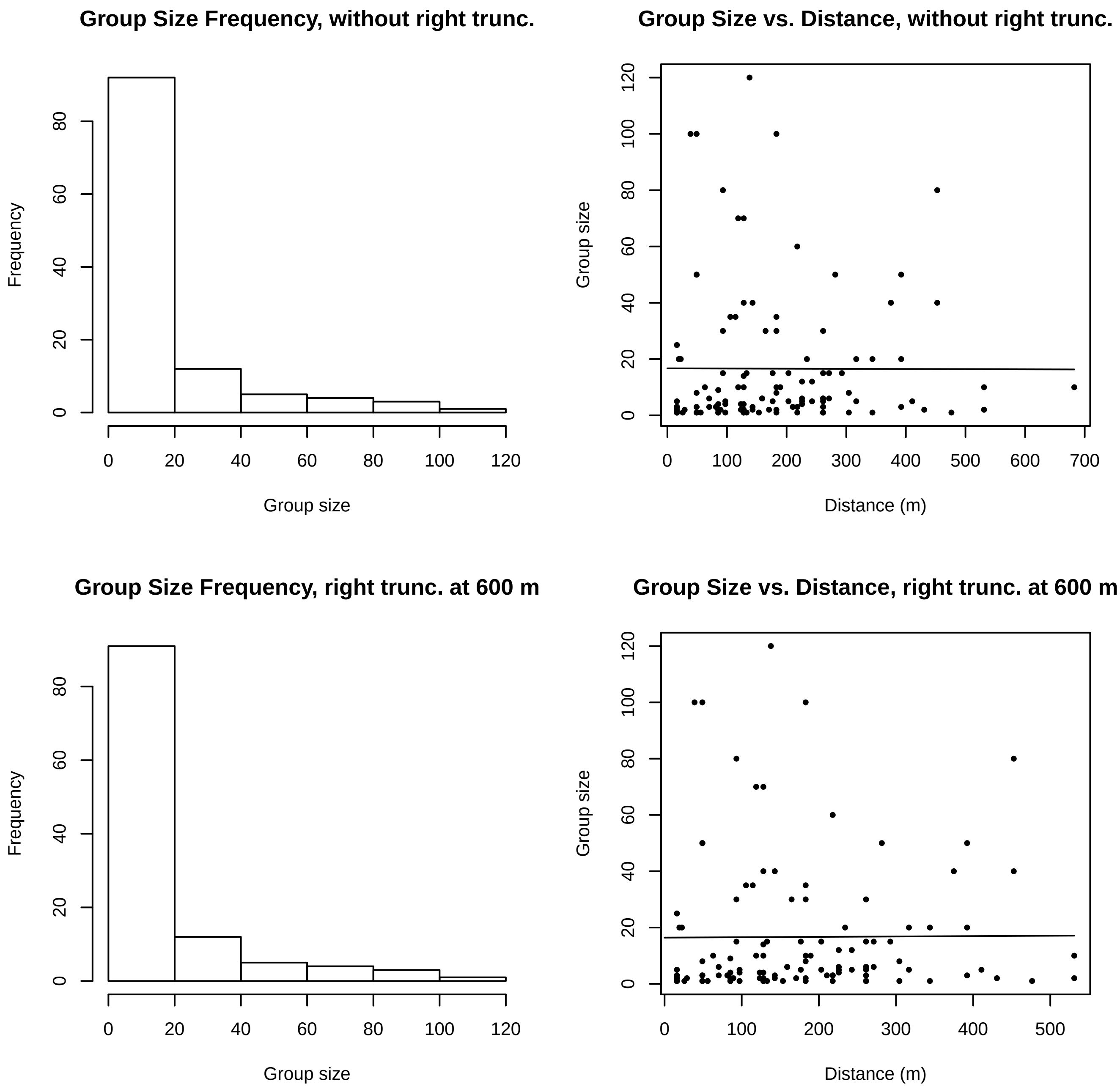


Figure 52: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

Without Belly Observers - 750 ft

The sightings were right truncated at 900m.

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

Table 31: 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	421
hr			beaufort, size	Yes	1.74	425
hn			beaufort, size	Yes	2.88	422
hn			size	Yes	4.03	428
hr				Yes	5.25	357
hr			beaufort	Yes	7.20	358
hr	poly	2		Yes	7.25	357
hr	poly	4		Yes	7.25	357
hn	cos	2		Yes	8.93	334
hn				Yes	12.31	419
hn			beaufort	Yes	13.67	420
hn	herm	4		Yes	13.96	418
hn	cos	3		Yes	14.29	411

Table 32: Candidate detection functions for Without Belly Observers - 750 ft. The first one listed was selected for the density model.

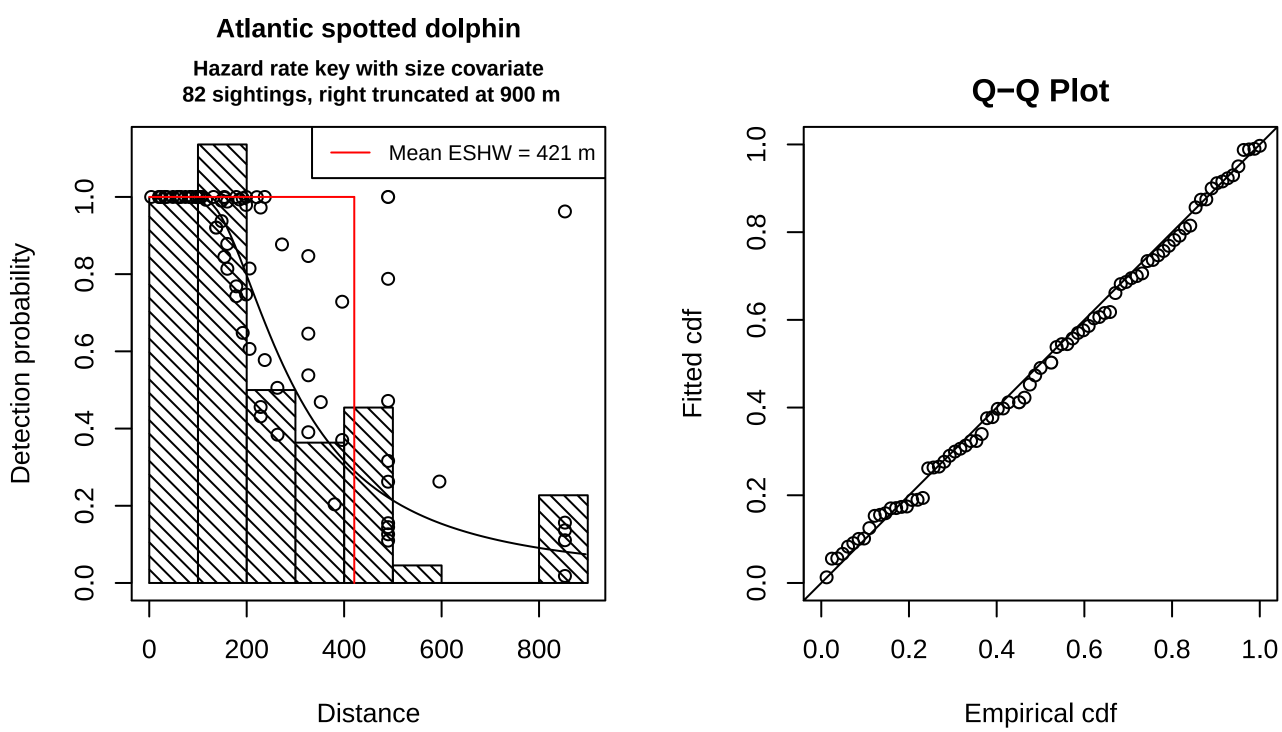


Figure 53: Detection function for Without Belly Observers - 750 ft that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
```

```
Number of observations :  82
Distance range         :  0  -  900
AIC                    :  1057.057

Detection function:
 Hazard-rate key function

Detection function parameters
Scale Coefficients:
             estimate        se
(Intercept) 5.1890598 0.2580057
size        0.7569596 0.3088731

Shape parameters:
             estimate        se
(Intercept) 0.9761337 0.2266399

                       Estimate           SE         CV
Average p             0.4139847  0.05064082 0.1223253
N in covered region 198.0749674 29.88438048 0.1508741
```

Additional diagnostic plots:

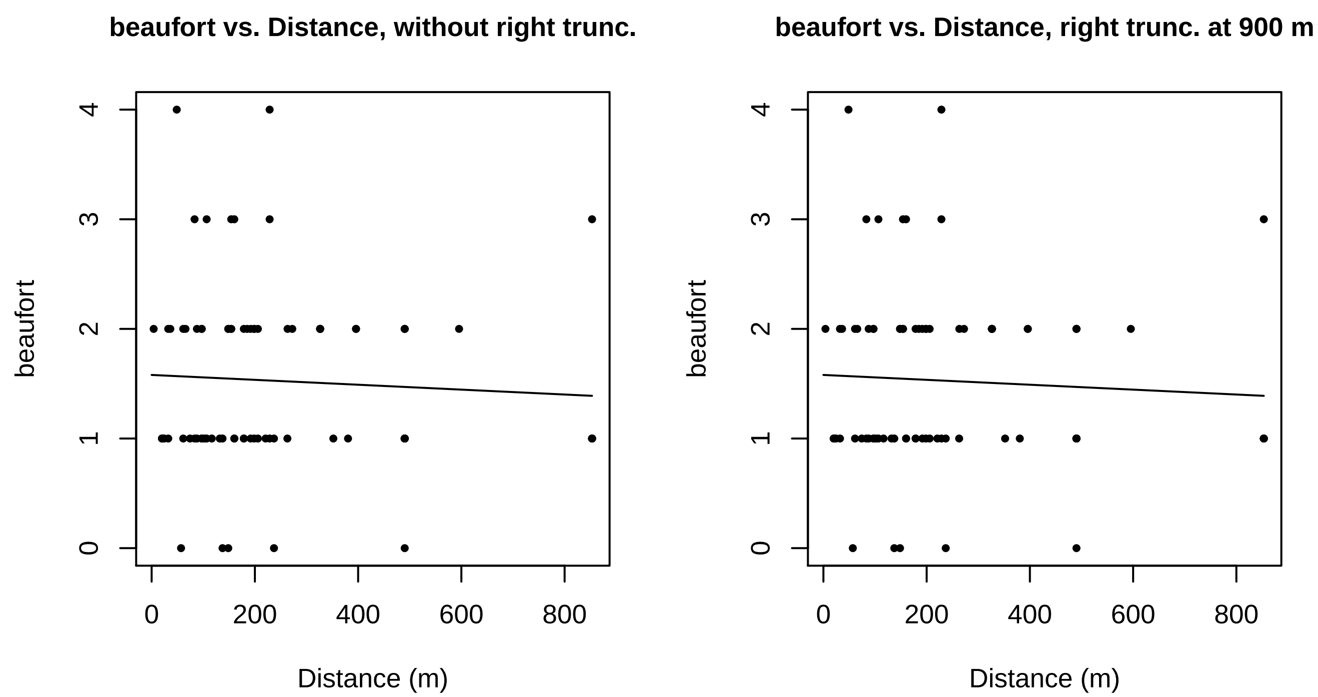


Figure 54: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

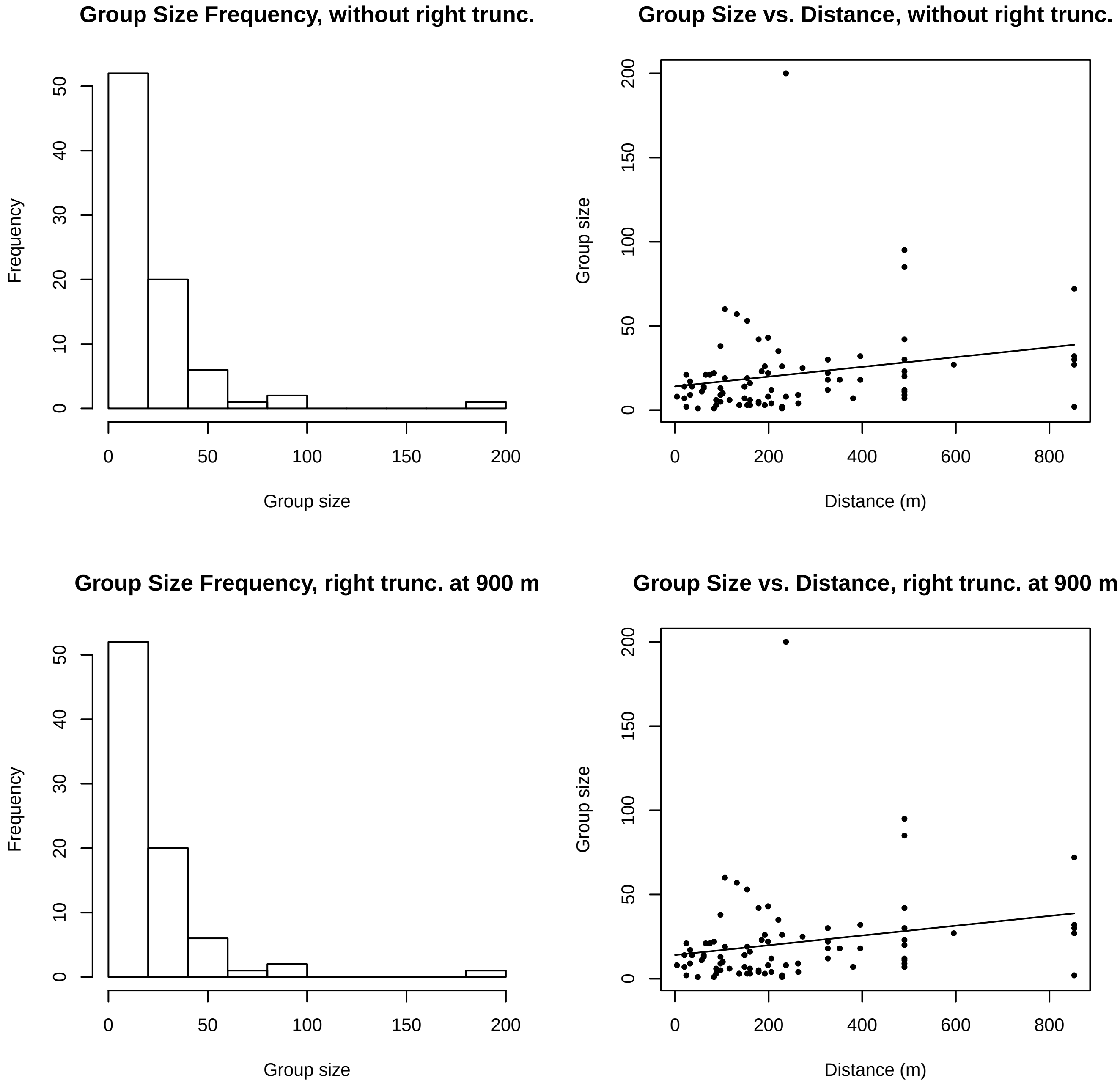


Figure 55: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

Without Belly Observers - 1000 ft

The sightings were right truncated at 1800m.

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

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hn			size	Yes	0.00	778
hn			beaufort, size	Yes	1.61	777
hn				Yes	6.19	774
hn			beaufort	Yes	7.74	774
hn	cos	3		Yes	8.16	764
hn	cos	2		Yes	8.17	769
hr			size	Yes	9.06	934
hr			beaufort, size	Yes	9.75	918
hr				Yes	12.58	903
hr	poly	2		Yes	12.92	870
hr			beaufort	Yes	13.74	897
hr	poly	4		Yes	14.22	890
hn	herm	4		No		
hn			quality	No		
hr			quality	No		
hn			beaufort, quality	No		
hr			beaufort, quality	No		
hn			quality, size	No		
hr			quality, size	No		
hn			beaufort, quality, size	No		
hr			beaufort, quality, size	No		

Table 34: Candidate detection functions for Without Belly Observers - 1000 ft. The first one listed was selected for the density model.

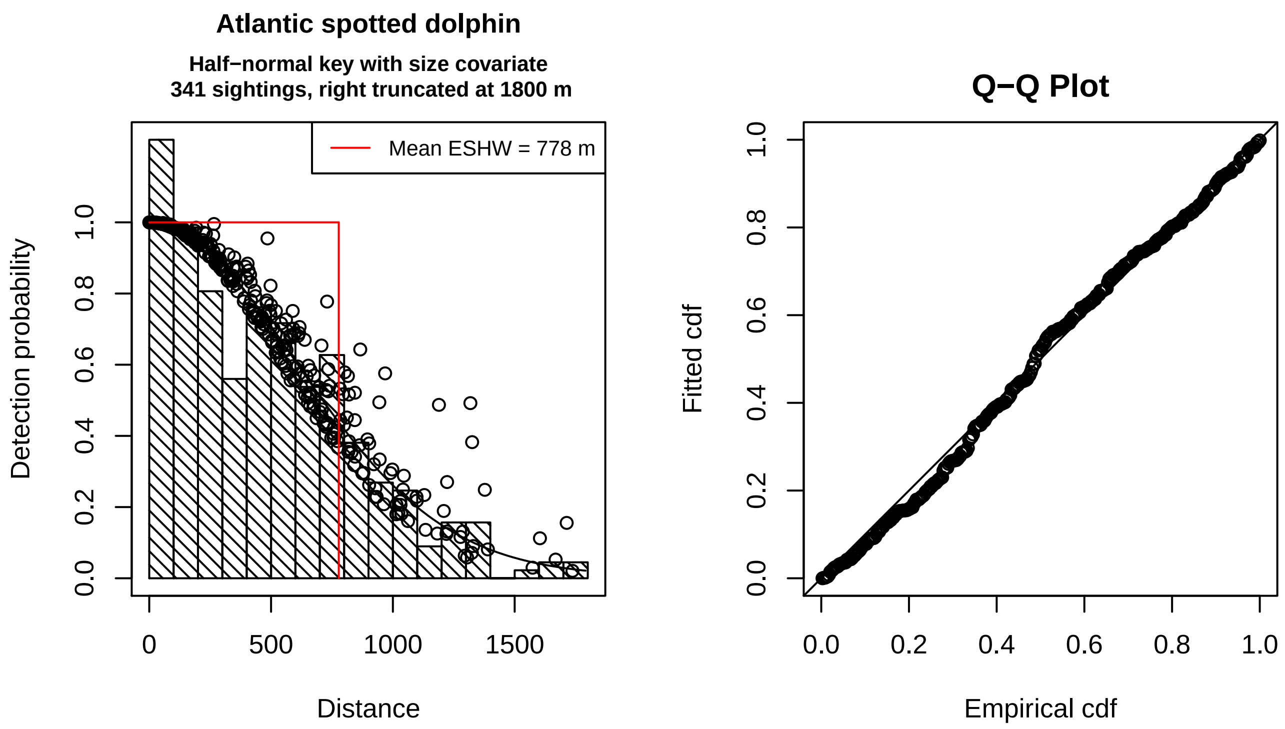


Figure 56: Detection function for Without Belly Observers - 1000 ft that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  341
Distance range         :  0  -  1800
AIC                    :  4861.415

Detection function:
 Half-normal key function

Detection function parameters
Scale Coefficients:
             estimate         se
(Intercept) 6.2759459 0.06914267
size        0.1647205 0.06381071

                       Estimate          SE         CV
Average p             0.4243849  0.01787049 0.04210915
N in covered region 803.5157850 47.42724786 0.05902466
```

Additional diagnostic plots:

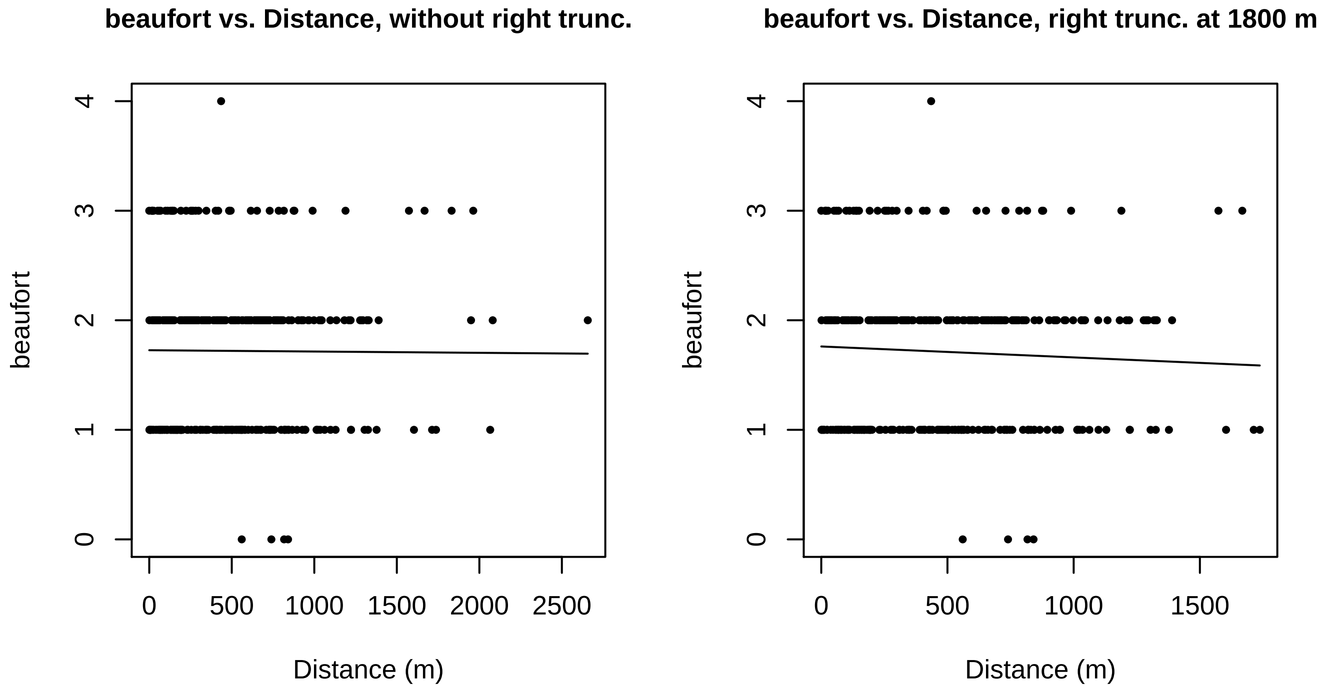


Figure 57: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

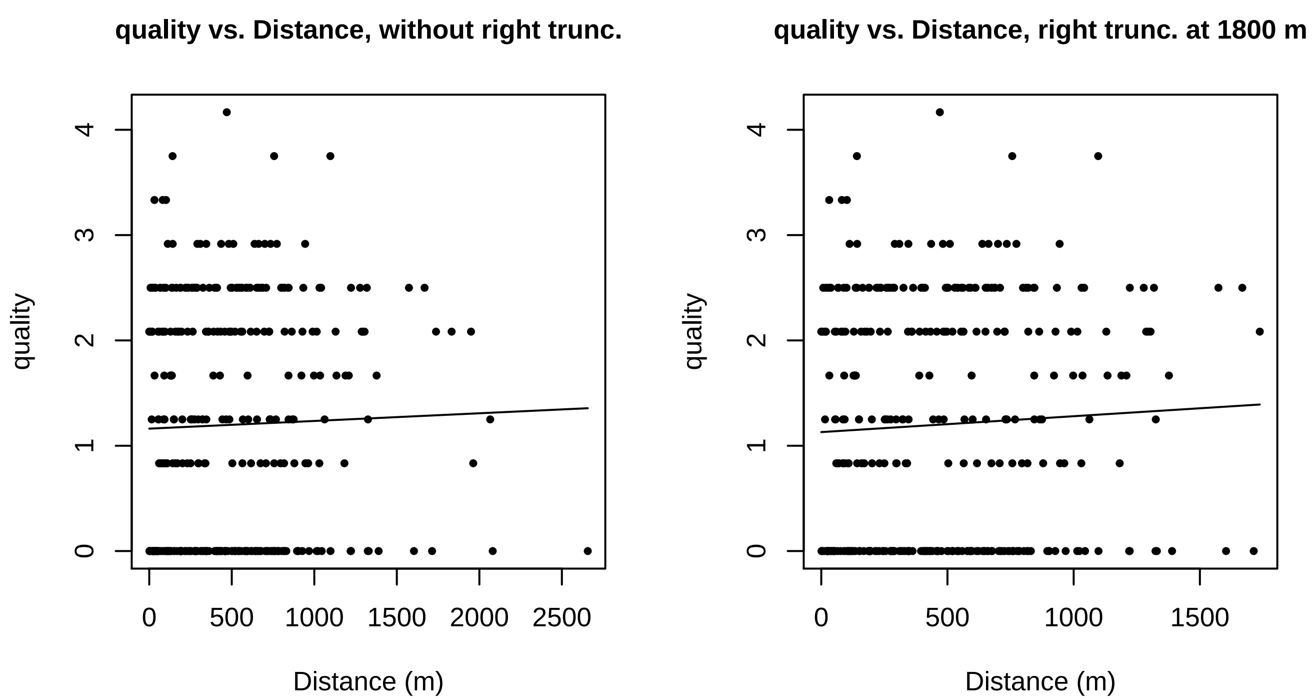


Figure 58: Scatterplots showing the relationship between the survey-specific index of the quality of observation conditions and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). Low values of the quality index correspond to better observation conditions. The line is a simple linear regression.

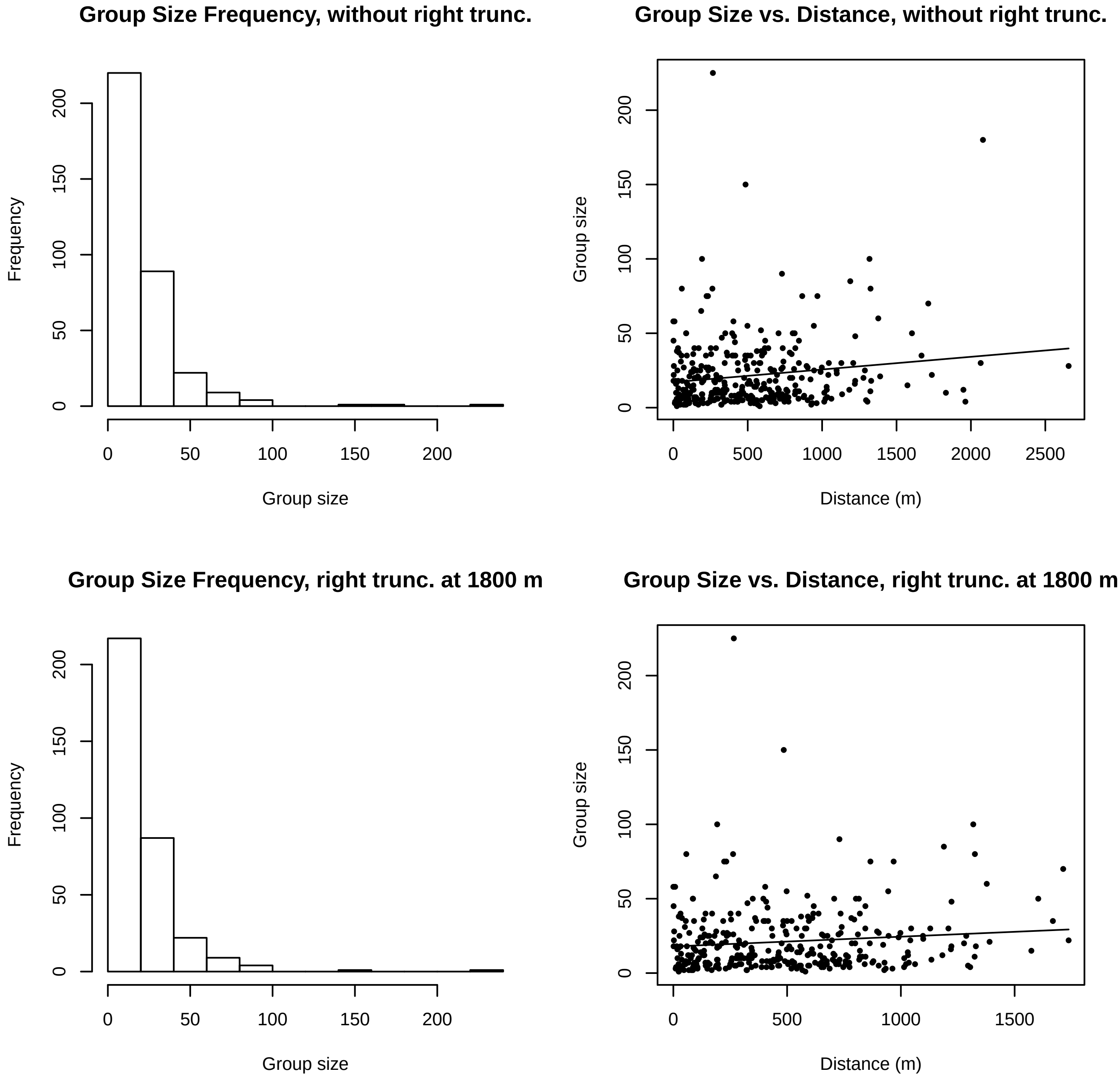


Figure 59: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

NARWSS Grummans

Because this taxon was sighted too infrequently to fit a detection function to its sightings alone, we fit a detection function to the pooled sightings of several other species that we believed would exhibit similar detectability. These "proxy species" are listed below.

Reported By Observer	Common Name	n
Delphinus delphis	Short-beaked common dolphin	42
Delphinus delphis/Lagenorhynchus acutus	Short-beaked common or Atlantic white-sided dolphin	0

Delphinus delphis/Stenella	Short-beaked common dolphin or Stenella spp.	0
Delphinus delphis/Stenella coeruleoalba	Short-beaked common or striped dolphin	0
Grampus griseus	Risso's dolphin	0
Grampus griseus/Tursiops truncatus	Risso's or Bottlenose dolphin	0
Lagenodelphis hosei	Fraser's dolphin	0
Lagenorhynchus acutus	Atlantic white-sided dolphin	288
Lagenorhynchus albirostris	White-beaked dolphin	3
Lagenorhynchus albirostris/Lagenorhynchus acutus	White-beaked or white-sided dolphin	0
Stenella	Unidentified Stenella	0
Stenella attenuata	Pantropical spotted dolphin	0
Stenella attenuata/frontalis	Pantropical or Atlantic spotted dolphin	0
Stenella clymene	Clymene dolphin	0
Stenella coeruleoalba	Striped dolphin	1
Stenella frontalis	Atlantic spotted dolphin	0
Stenella frontalis/Tursiops truncatus	Atlantic spotted or Bottlenose dolphin	0
Stenella longirostris	Spinner dolphin	0
Steno bredanensis	Rough-toothed dolphin	0
Steno bredanensis/Tursiops truncatus	Bottlenose or rough-toothed dolphin	0
Tursiops truncatus	Bottlenose dolphin	6
Total		340

Table 35: Proxy species used to fit detection functions for NARWSS Grummans. The number of sightings, n, is before truncation.

The sightings were right truncated at 800m. 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 36: 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	235
hr			size	Yes	5.95	231

hr			beaufort, size	Yes	7.81	233
hr			quality	Yes	11.76	213
hn			size	Yes	14.26	231
hn			quality, size	Yes	14.51	233
hn			beaufort, size	Yes	16.23	231
hr				Yes	20.06	203
hr	poly	4		Yes	21.78	200
hr			beaufort	Yes	22.05	204
hr	poly	2		Yes	22.06	203
hn				Yes	33.54	223
hn			quality	Yes	33.86	223
hn	herm	4		Yes	35.13	222
hn	cos	2		No		
hn	cos	3		No		
hn			beaufort	No		
hn			beaufort, quality	No		
hr			beaufort, quality	No		
hn			beaufort, quality, size	No		
hr			beaufort, quality, size	No		

Table 37: Candidate detection functions for NARWSS Grummans. The first one listed was selected for the density model.

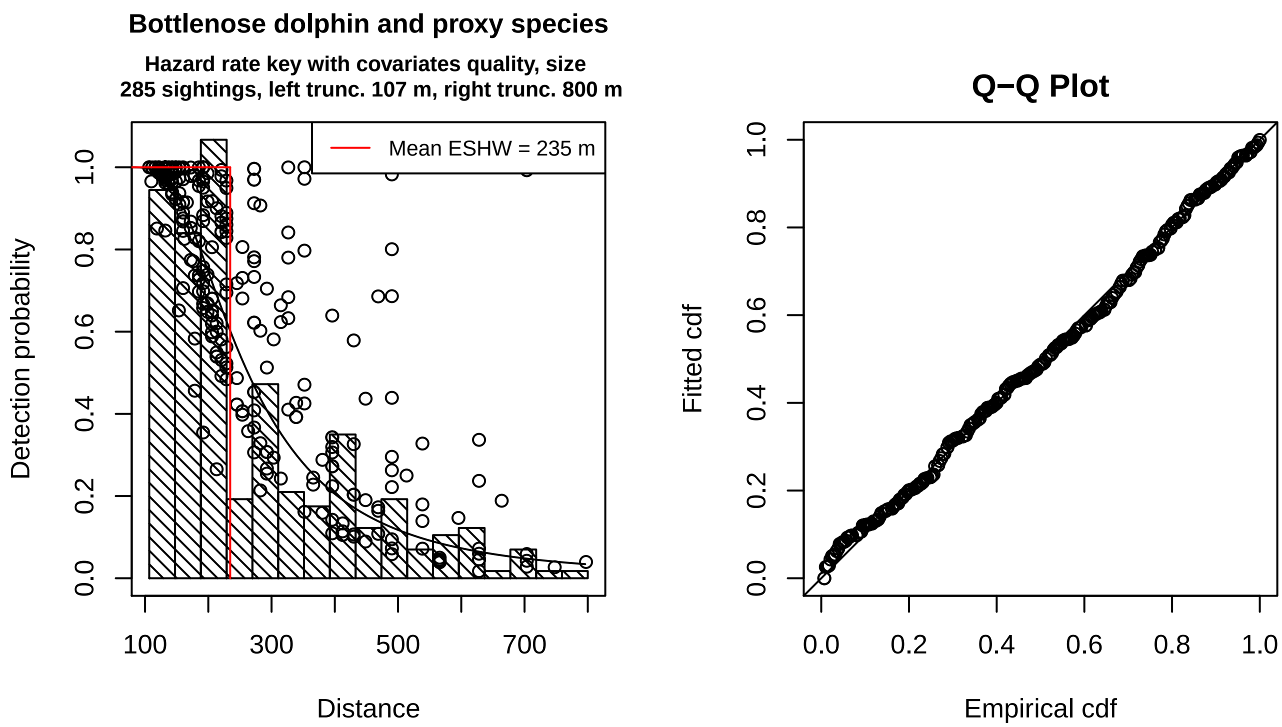


Figure 60: Detection function for NARWSS Grummans that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  285
Distance range         :  106.5979  -  800
AIC                    :  3450.827

Detection function:
 Hazard-rate key function

Detection function parameters
Scale Coefficients:
              estimate         se
(Intercept)  5.5620259 0.12398130
quality     -0.2408179 0.09290192
size         0.2953779 0.09400126

Shape parameters:
            estimate        se
(Intercept) 1.119906 0.1056045

                        Estimate           SE        CV
Average p              0.2541682   0.03062592 0.1204947
N in covered region 1121.3045461 147.37019002 0.1314274
```

Additional diagnostic plots:

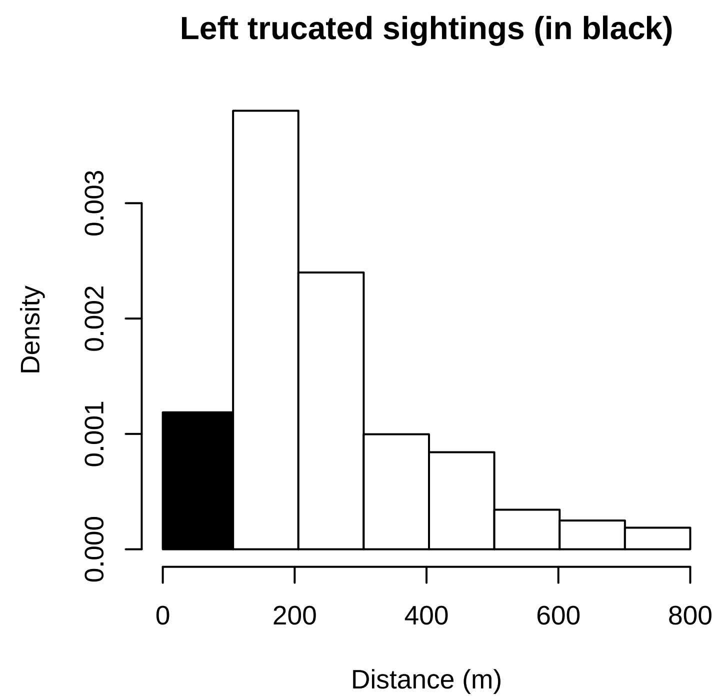


Figure 61: Density of sightings by perpendicular distance for NARWSS Grummans. Black bars on the left show sightings that were left truncated.

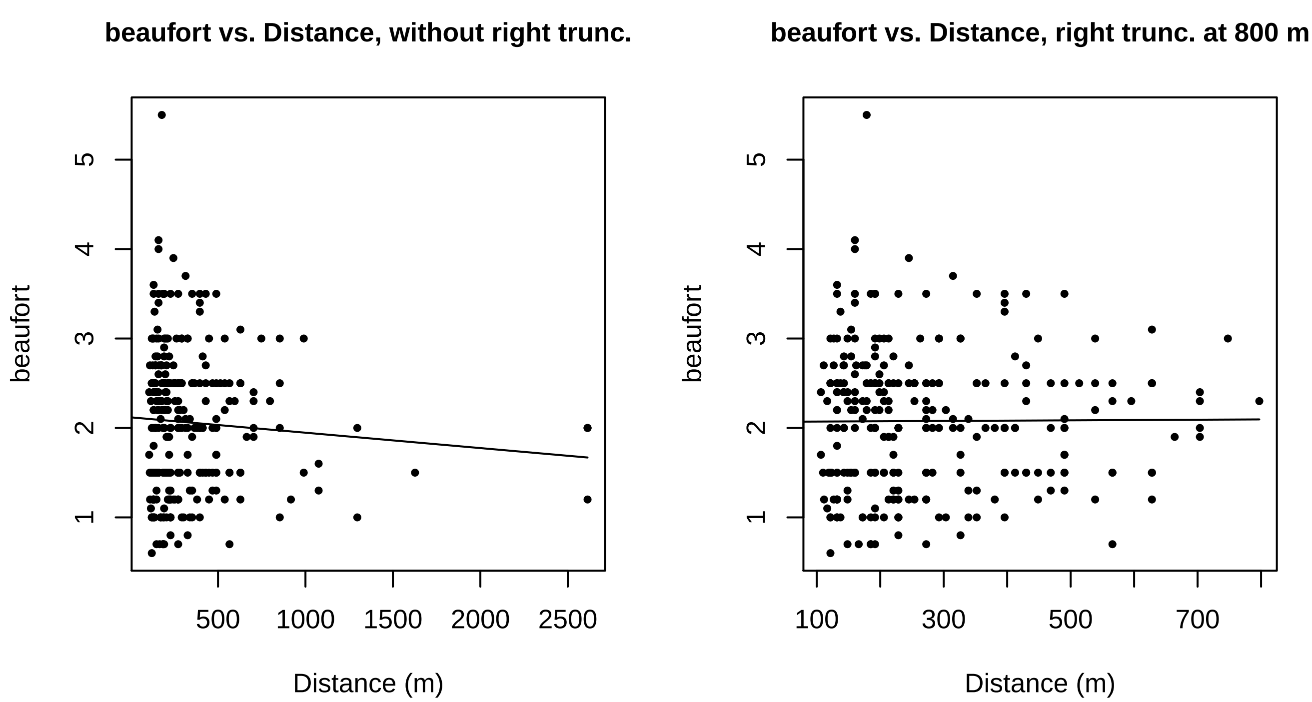


Figure 62: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

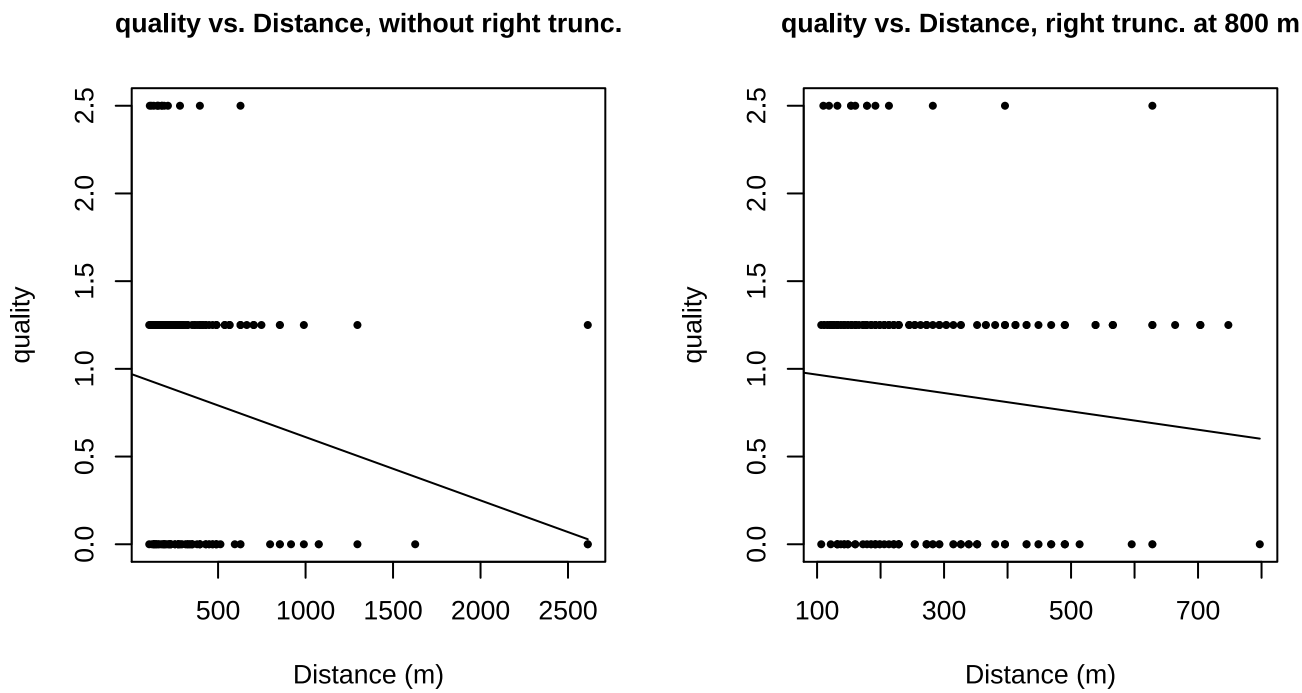


Figure 63: Scatterplots showing the relationship between the survey-specific index of the quality of observation conditions and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). Low values of the quality index correspond to better observation conditions. The line is a simple linear regression.

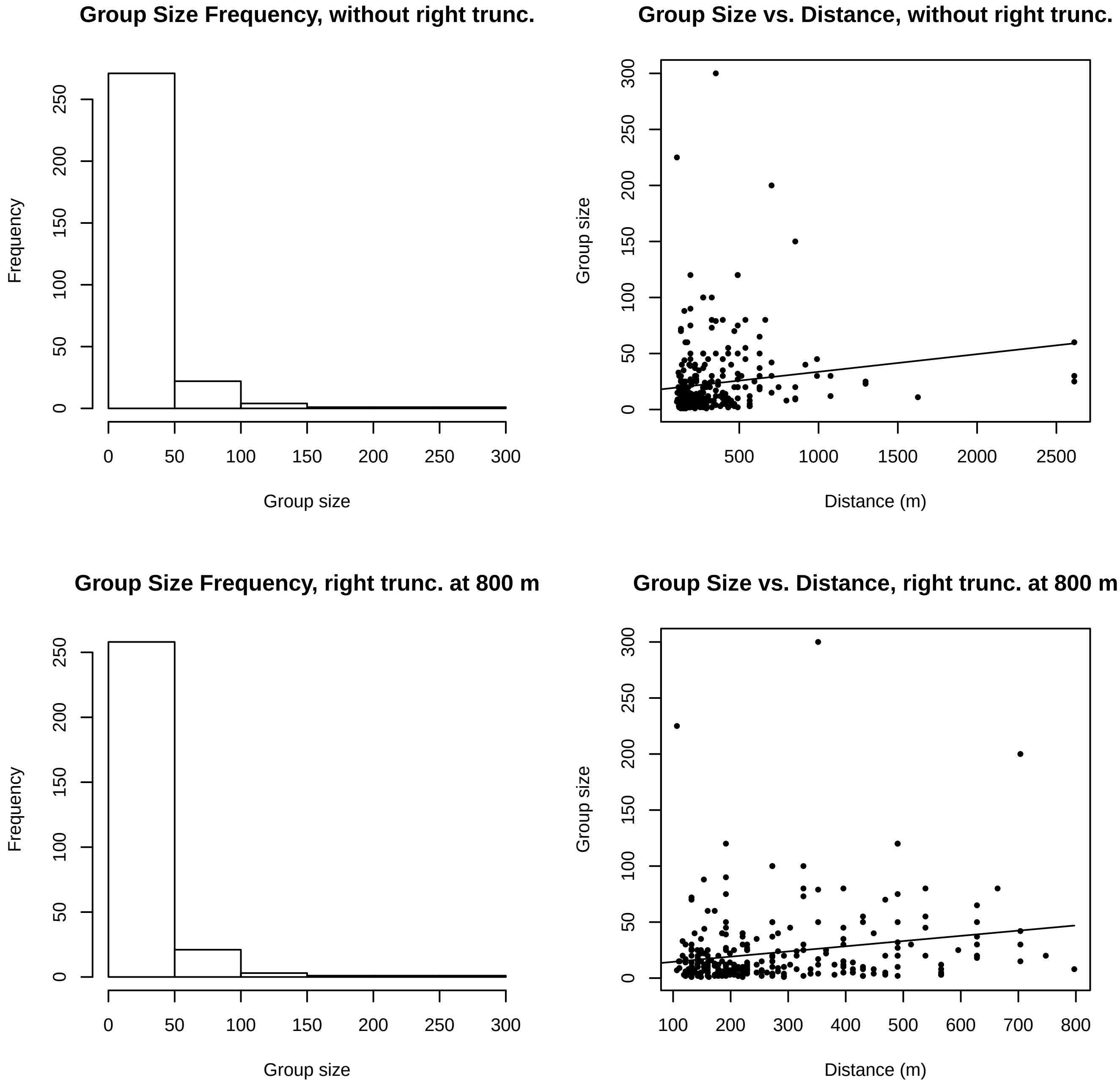


Figure 64: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

NARWSS Twin Otters

Because this taxon was sighted too infrequently to fit a detection function to its sightings alone, we fit a detection function to the pooled sightings of several other species that we believed would exhibit similar detectability. These “proxy species” are listed below.

Reported By Observer	Common Name	n
Delphinus delphis	Short-beaked common dolphin	539
Delphinus delphis/Lagenorhynchus acutus	Short-beaked common or Atlantic white-sided dolphin	0

Delphinus delphis/Stenella	Short-beaked common dolphin or Stenella spp.	0
Delphinus delphis/Stenella coeruleoalba	Short-beaked common or striped dolphin	0
Grampus griseus	Risso's dolphin	86
Grampus griseus/Tursiops truncatus	Risso's or Bottlenose dolphin	0
Lagenodelphis hosei	Fraser's dolphin	0
Lagenorhynchus acutus	Atlantic white-sided dolphin	1732
Lagenorhynchus albirostris	White-beaked dolphin	4
Lagenorhynchus albirostris/Lagenorhynchus acutus	White-beaked or white-sided dolphin	0
Stenella	Unidentified Stenella	1
Stenella attenuata	Pantropical spotted dolphin	0
Stenella attenuata/frontalis	Pantropical or Atlantic spotted dolphin	0
Stenella clymene	Clymene dolphin	0
Stenella coeruleoalba	Striped dolphin	4
Stenella frontalis	Atlantic spotted dolphin	0
Stenella frontalis/Tursiops truncatus	Atlantic spotted or Bottlenose dolphin	0
Stenella longirostris	Spinner dolphin	0
Steno bredanensis	Rough-toothed dolphin	0
Steno bredanensis/Tursiops truncatus	Bottlenose or rough-toothed dolphin	0
Tursiops truncatus	Bottlenose dolphin	39
Total		2405

Table 38: Proxy species used to fit detection functions for NARWSS Twin Otters. The number of sightings, n, is before truncation.

The sightings were right truncated at 2500m. 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 39: Covariates tested in candidate "multi-covariate distance sampling" (MCDS) detection functions.

Key	Adjustment	Order	Covariates	Succeeded	Δ AIC	Mean ESHW (m)
hr			beaufort, size	Yes	0.00	470
hr			size	Yes	5.29	463

hr			quality, size	Yes	7.11	463
hr	poly	2		Yes	9.16	430
hr	poly	4		Yes	10.71	442
hr			beaufort	Yes	17.46	464
hr				Yes	22.55	458
hr			quality	Yes	24.49	458
hn	cos	2		Yes	33.82	434
hn	cos	3		Yes	54.89	361
hn			beaufort, size	Yes	162.73	517
hn			size	Yes	162.85	518
hn			quality, size	Yes	164.00	518
hn			beaufort, quality, size	Yes	164.45	517
hn			beaufort	Yes	185.34	516
hn				Yes	186.28	516
hn	herm	4		Yes	186.91	516
hn			beaufort, quality	Yes	187.34	516
hn			quality	Yes	188.03	516
hr			beaufort, quality	No		
hr			beaufort, quality, size	No		

Table 40: Candidate detection functions for NARWSS Twin Otters. The first one listed was selected for the density model.

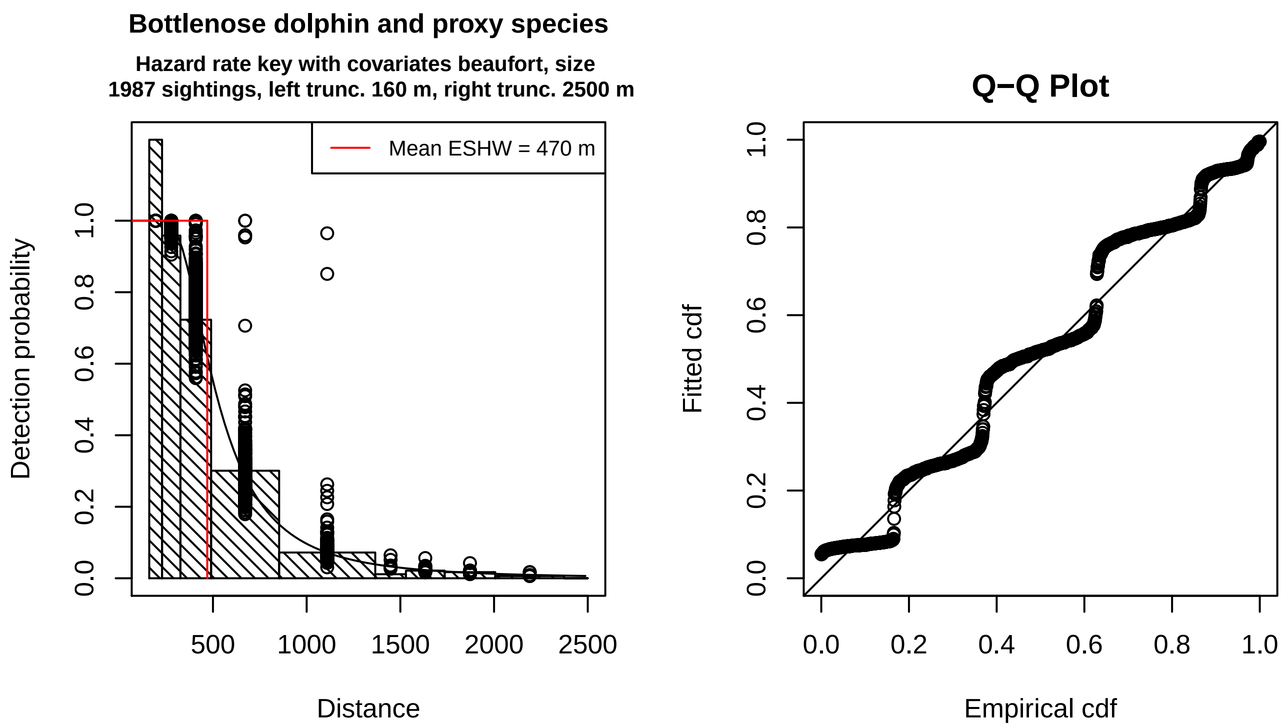


Figure 65: Detection function for NARWSS Twin Otters that was selected for the density model

Statistical output for this detection function:

```
Summary for ds object
Number of observations :  1987
Distance range         :  160.0674  -  2500
AIC                    :  6745.856

Detection function:
 Hazard-rate key function

Detection function parameters
Scale Coefficients:
               estimate         se
(Intercept)  6.26395198 0.06468196
beaufort    -0.07274292 0.02643651
size         0.08974254 0.02445737

Shape parameters:
            estimate        se
(Intercept) 1.110483 0.0356417

                        Estimate           SE         CV
Average p           1.845364e-01 5.774489e-03 0.03129187
N in covered region 1.076752e+04 4.016208e+02 0.03729928
```

Additional diagnostic plots:

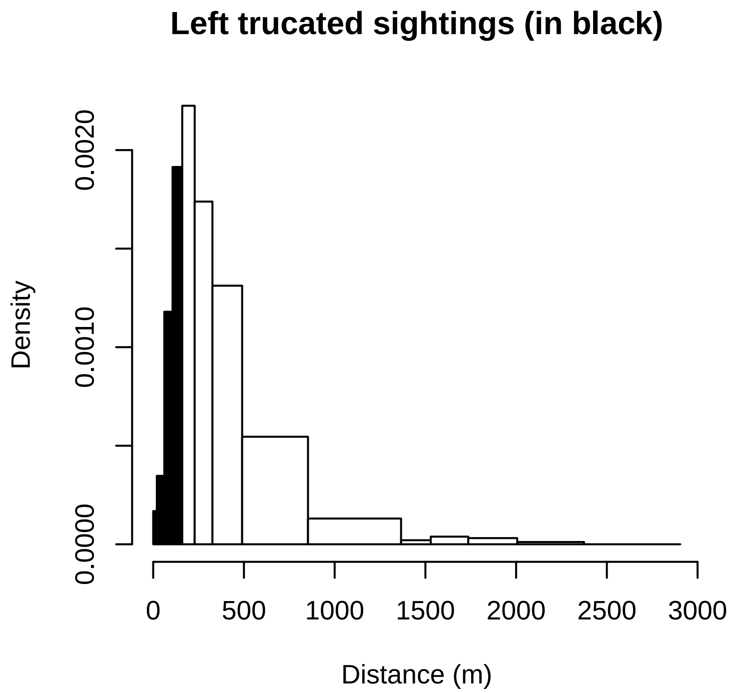


Figure 66: Density of sightings by perpendicular distance for NARWSS Twin Otters. Black bars on the left show sightings that were left truncated.

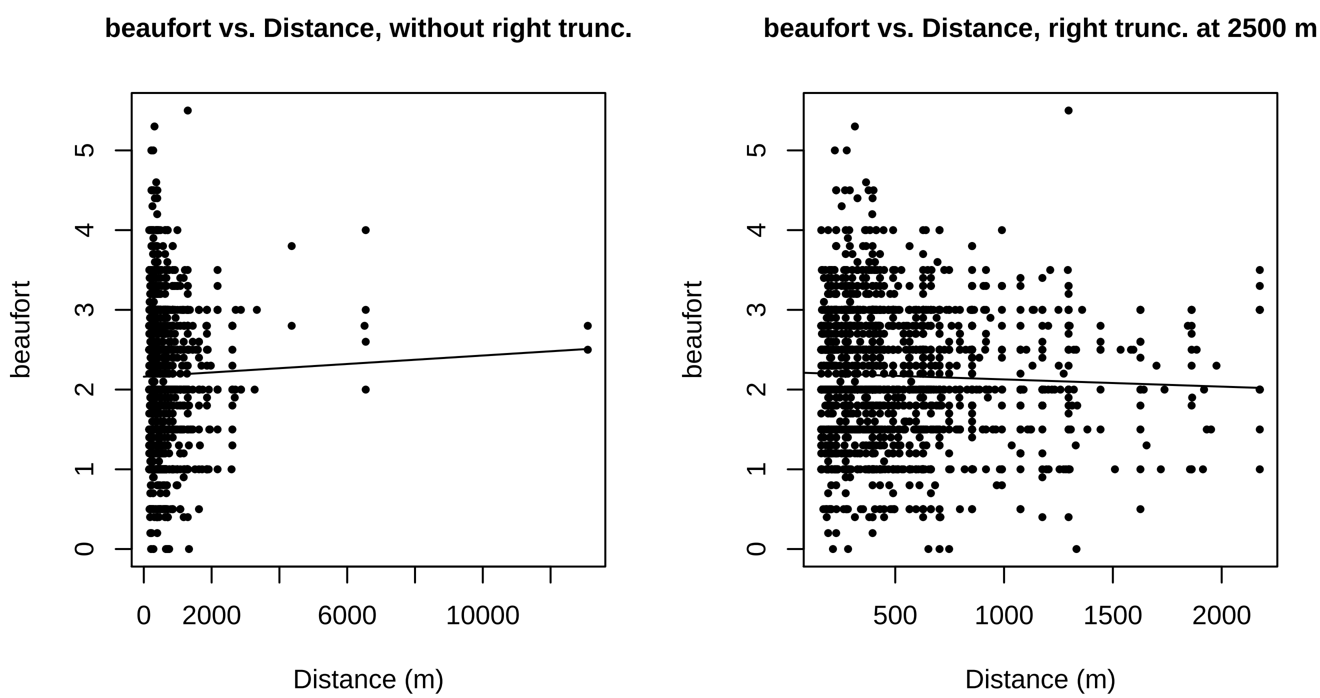


Figure 67: Scatterplots showing the relationship between Beaufort sea state and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). The line is a simple linear regression.

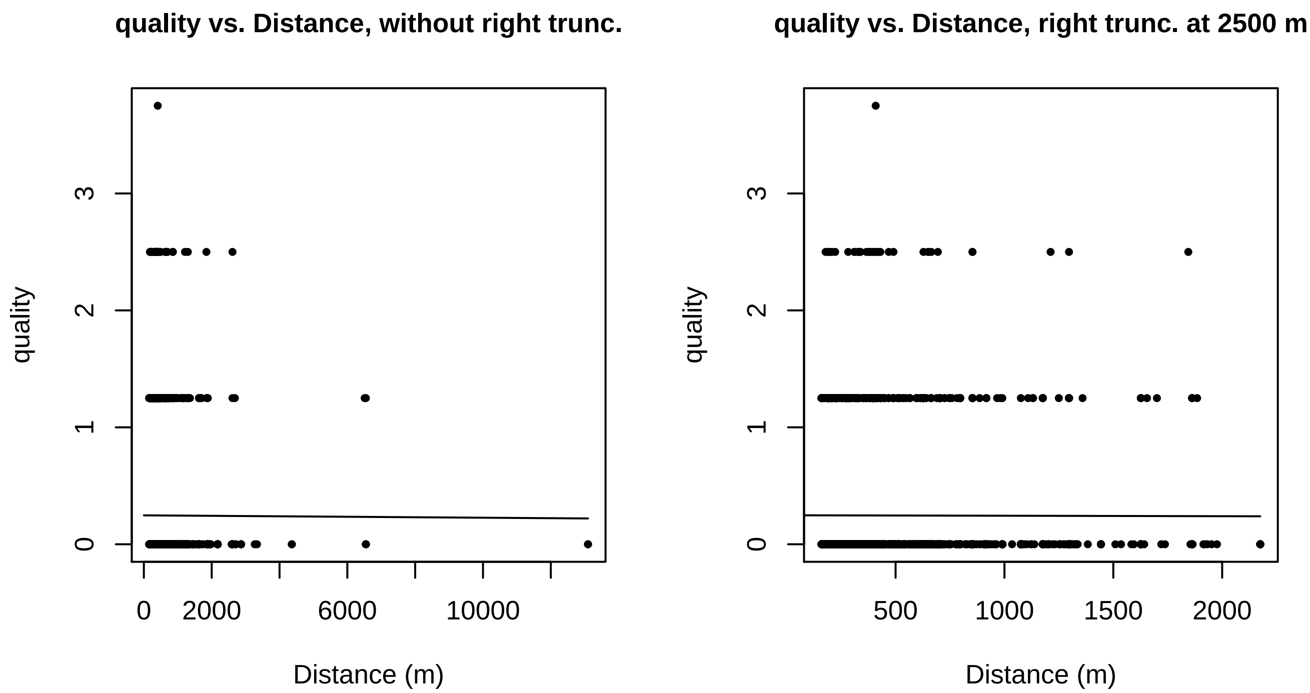


Figure 68: Scatterplots showing the relationship between the survey-specific index of the quality of observation conditions and perpendicular sighting distance, for all sightings (left) and only those not right truncated (right). Low values of the quality index correspond to better observation conditions. The line is a simple linear regression.

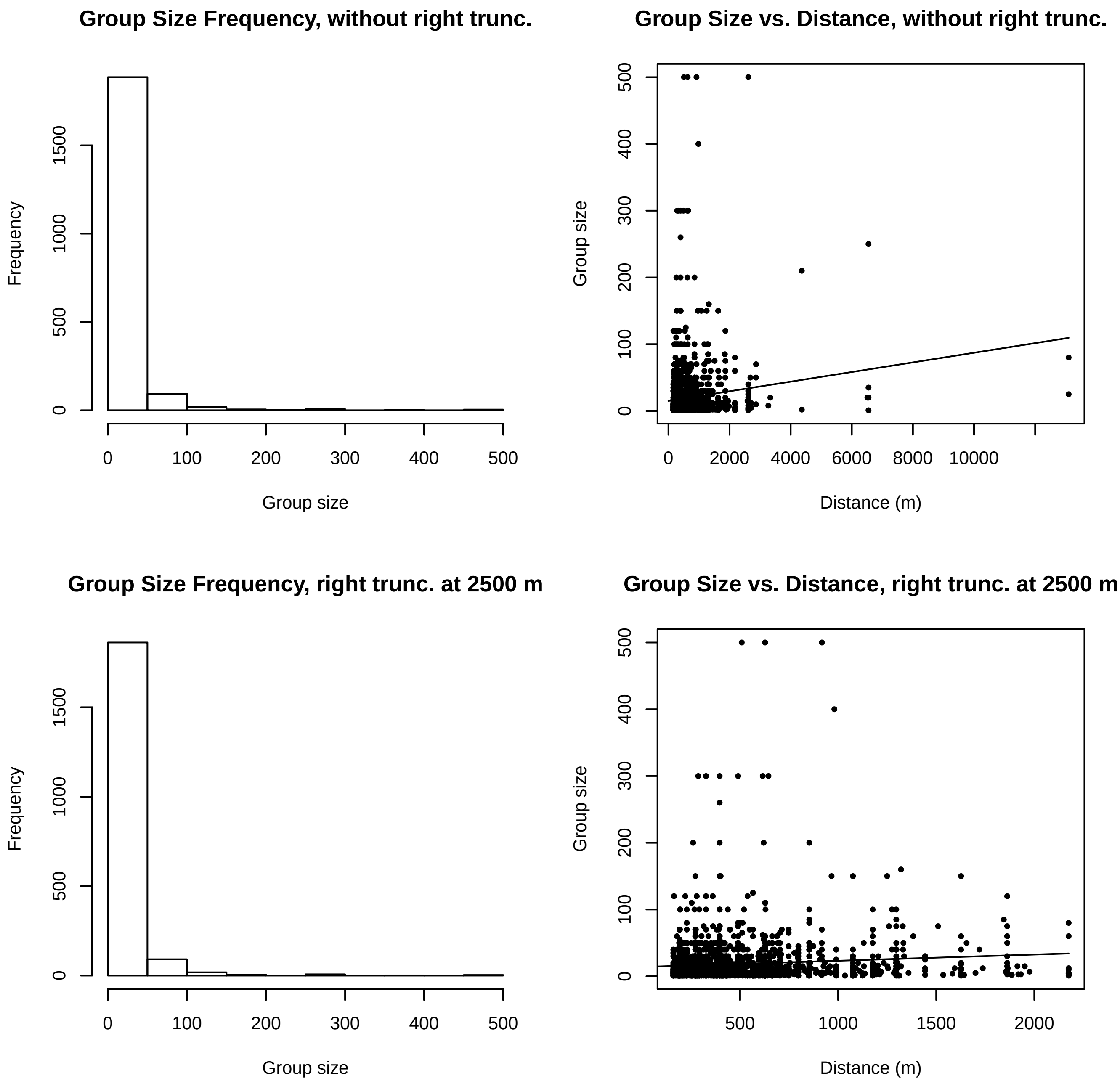


Figure 69: Histograms showing group size frequency and scatterplots showing the relationship between group size and perpendicular sighting distance, for all sightings (top row) and only those not right truncated (bottom row). In the scatterplot, the line is a simple linear regression.

g(0) Estimates

Platform	Surveys	Group Size	*g(0)*	Biases Addressed	Source
Shipboard	All	1-20	0.856	Perception	Barlow and Forney (2007)
		>20	0.970	Perception	Barlow and Forney (2007)
Shipboard	NEFSC Abel-J Binocular Surveys	Any	0.61	Perception	Palka (2006)
Shipboard	NEFSC Endeavor	Any	0.94	Perception	Palka (2006)
Aerial	All	1-5	0.43	Both	Palka (2006)
		>5	0.960	Both	Carretta et al. (2000)

Table 41: Estimates of *g(0)* used in this density model.

For shipboard surveys other than the NOAA NEFSC cruises for which Palka (2006) provided survey-specific estimates of g(0), we utilized Barlow and Forney's (2007) estimates for delphinids, produced from several years of dual-team surveys that used similar binoculars and protocols to the surveys in our study. This study provided separate estimates for small and large groups, but pooled sightings of several species together to provide a generic estimate for all delphinids, due to sample-size limitations. To our knowledge, there is no species-specific shipboard g(0) estimate that treats small and large groups separately, so we believe Barlow and Forney (2007) provide the best general- purpose alternative. Their estimate accounted for perception bias but not availability bias; dive times for dolphins are short enough that availability bias is not expected to be significant for dolphins observed from shipboard surveys.

For aerial surveys, we were unable to locate species-specific g(0) estimates in the literature. For small groups, defined here as 1-5 individuals, we used Palka's (2006) estimate of g(0) for groups of 1-5 small cetaceans, estimated from two years of aerial surveys using the Hiby (1999) circle-back method. This estimate accounted for both availability and perception bias, but pooled sightings of several species together to provide a generic estimate for all delphinids, due to sample-size limitations. For large groups, defined here as greater than 5 individuals, Palka (2006) assumed that g(0) was 1. When we discussed this with NOAA SWFSC reviewers, they agreed that it was safe to assume that the availability bias component of g(0) was 1 but insisted that perception bias should be slightly less than 1, because it was possible to miss large groups. We agreed to take a conservative approach and obtained our g(0) for large groups from Carretta et al. (2000), who estimated g(0) for both small and large groups of delphinids. We used Carretta et al.'s g(0) estimate for groups of 1-25 individuals (0.960), rather than their larger one for more than 25 individuals (0.994), to account for the fact that we were using Palka's definition of large groups as those with more than 5 individuals.

Density Models

The Atlantic spotted dolphin occurs in tropical and temperate waters of the western North Atlantic and the Gulf of Mexico. In the North Atlantic, two ecotypes occur: a large, heavily-spotted form that inhabits the continental shelf and a smaller, less-spotted form that occurs offshore and around islands (Waring et al. 2014). A recent genetic analysis of samples collected in the Gulf of Mexico, the western North Atlantic, and the Azores, confirmed genetic differentiation between the ecotypes (Viricel and Rosel 2014), and an analysis of Atlantic spotted dolphin whistles reported statistically significant differences in several whistle characteristics between the ecotypes (Baron et al. 2008). Consistent with these results, the sightings of Atlantic spotted dolphins in our east coast study area occurred in two clusters. A first, more dense cluster occurred along the continental shelf between Florida and Virginia. A second, more dispersed cluster occurred off the shelf, north of the Gulf Stream, from Cape Hatteras to New England. Given the morphometric, genetic, and acoustic evidence for two population units, we split the study area at the shelf break into an On Shelf subregion and Off Shelf subregion and fitted separate models to them. In the Off Shelf subregion, where sightings were more limited, we constrained the model to utilize no more than four predictors. Finally, because our models predicted anomalously high density in the New York-New Jersey Harbor, an area that we judged them unlikely to occupy, we assumed these predictions were erroneous and forced density in this area to zero.

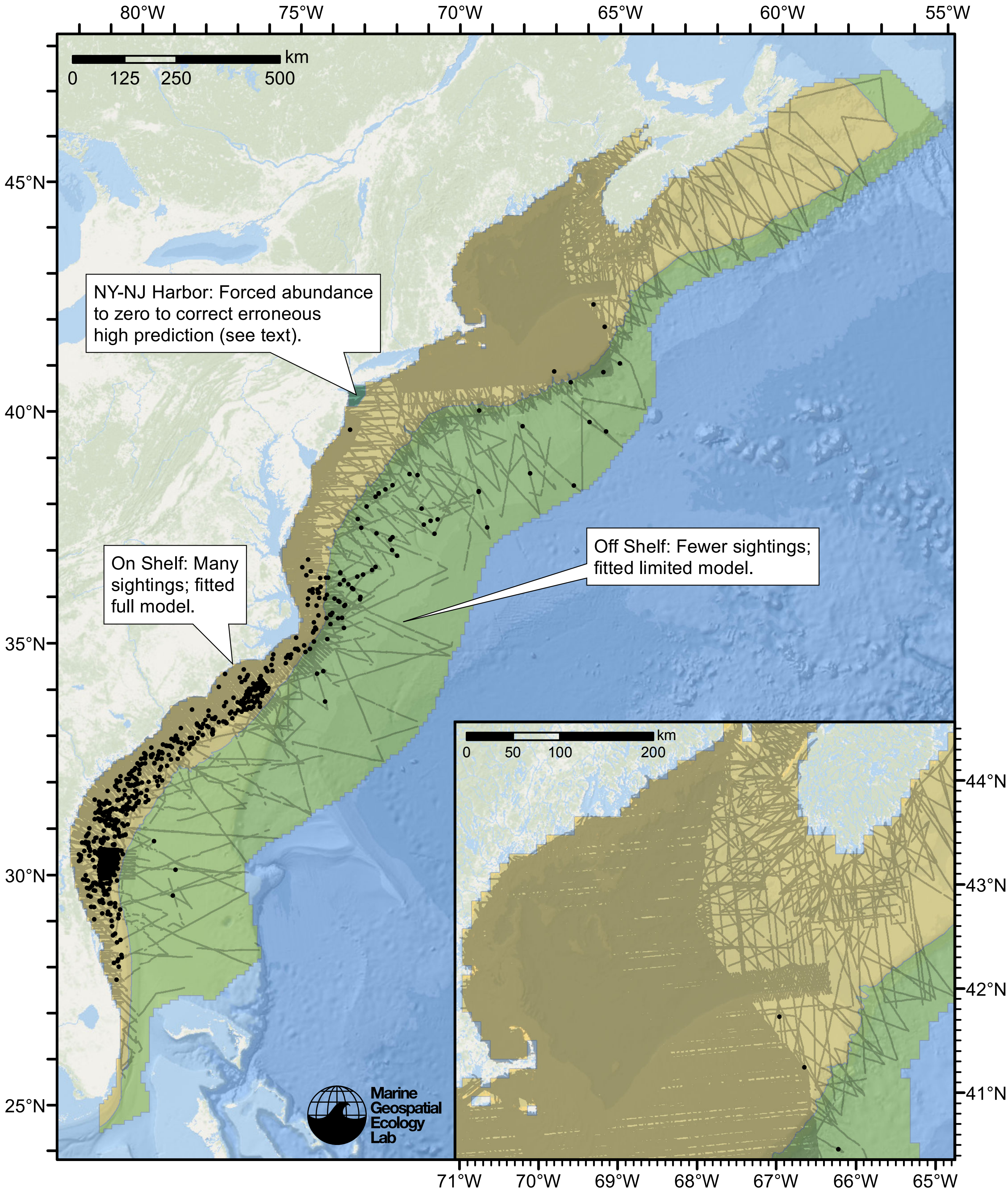


Figure 70: Atlantic spotted dolphin density model schematic. All on-effort sightings are shown, including those that were truncated when detection functions were fitted.

Climatological Model

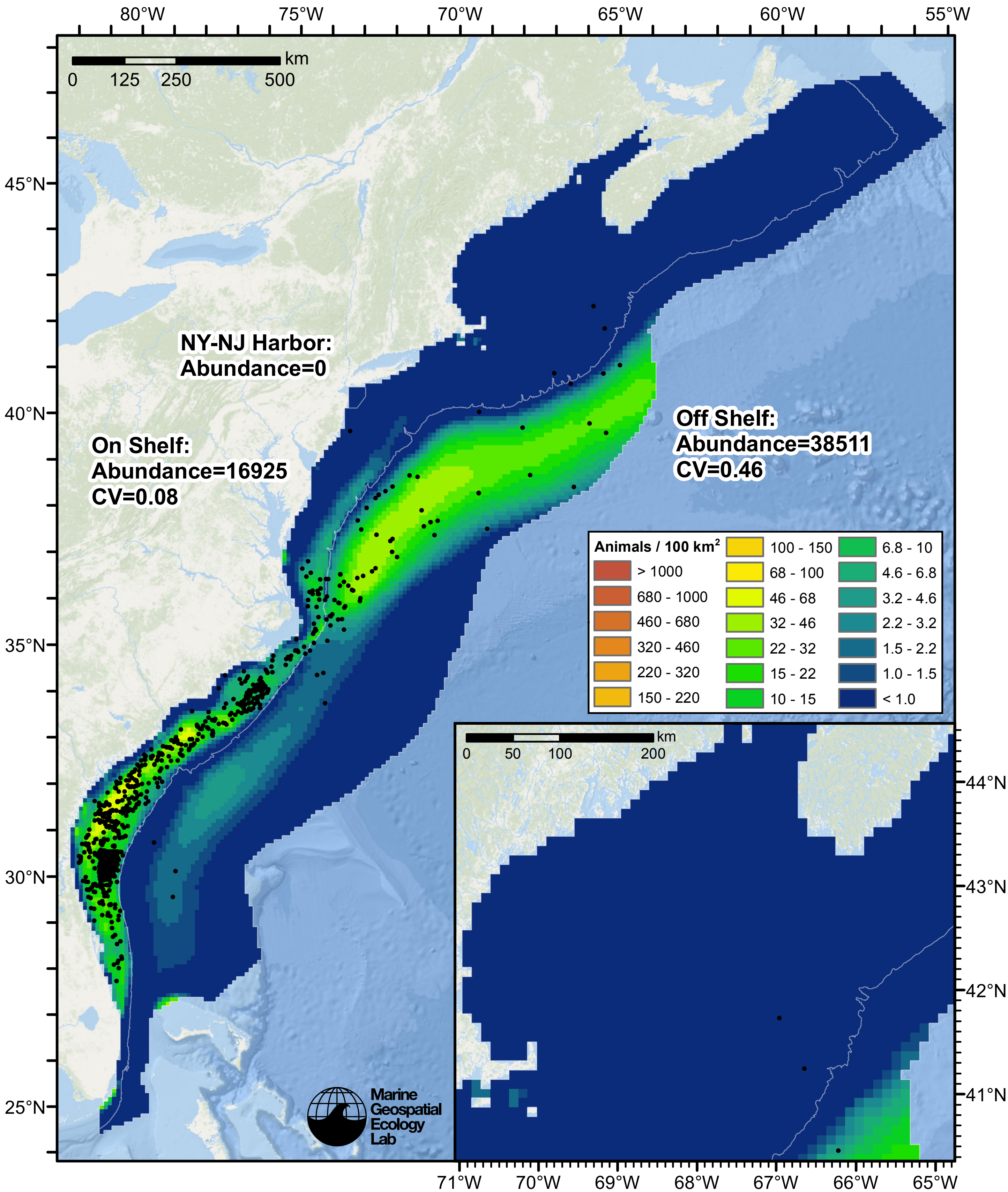


Figure 71: Atlantic spotted dolphin density predicted by the climatological model that explained the most deviance. Pixels are 10x10 km. The legend gives the estimated individuals per pixel; breaks are logarithmic. Abundance for each region was computed by summing the density cells occuring in that region.

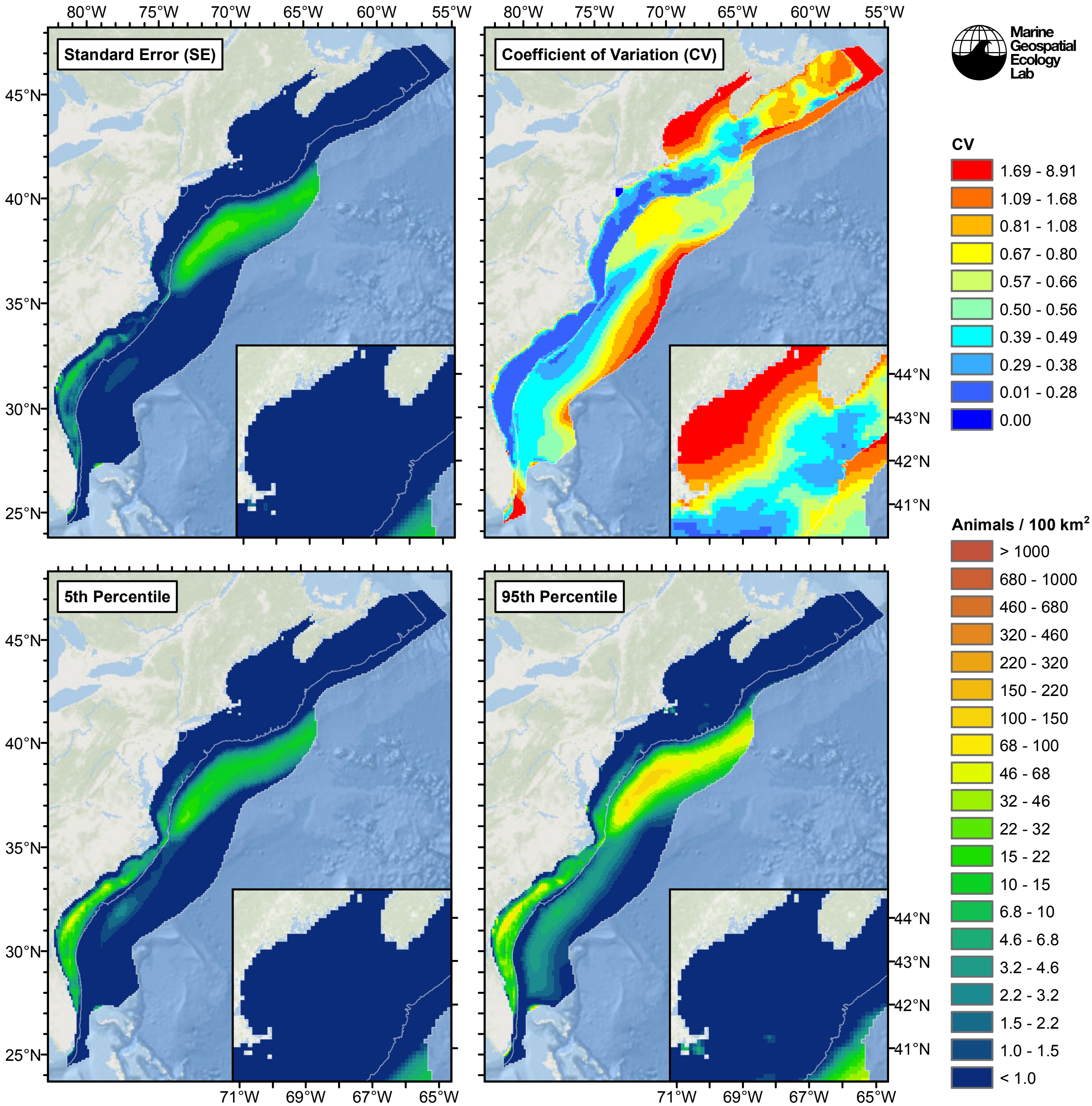


Figure 72: Estimated uncertainty for the climatological model that explained the most deviance. These estimates only incorporate the statistical uncertainty estimated for the spatial model (by the R mgcv package). They do not incorporate uncertainty in the detection functions, g(0) estimates, predictor variables, and so on.

On Shelf

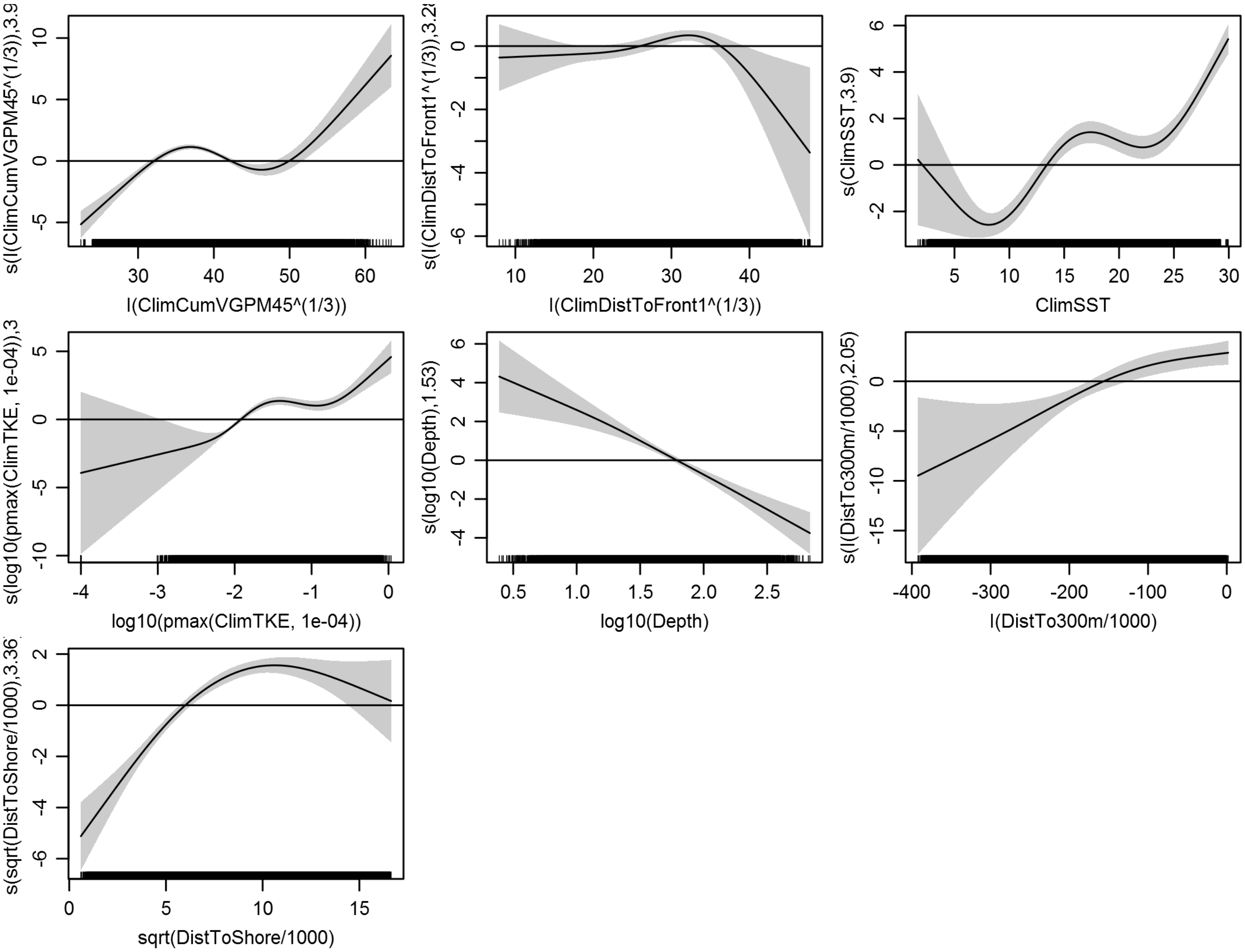
Statistical output

```
Rscript.exe: This is mgcv 1.8-2. For overview type 'help("mgcv-package")'.


Family: Tweedie(p=1.373)
```

```
Link function: log

Formula:
abundance ~ offset(log(area_km2)) + s(log10(Depth), bs = "ts",
    k = 5) + s(sqrt(DistToShore/1000), bs = "ts", k = 5) + s(I(DistTo300m/1000),
    bs = "ts", k = 5) + s(ClimSST, bs = "ts", k = 5) + s(I(ClimDistToFront1^(1/3)),
    bs = "ts", k = 5) + s(log10(pmax(ClimTKE, 1e-04)), bs = "ts",
    k = 5) + s(I(ClimCumVGPM45^(1/3)), bs = "ts", k = 5)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -9.4671     0.5316  -17.81   <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(log10(Depth))                1.533      4 16.231  < 2e-16 ***
s(sqrt(DistToShore/1000))      3.356      4 35.337  < 2e-16 ***
s(I(DistTo300m/1000))          2.051      4  8.130 4.78e-09 ***
s(ClimSST)                     3.898      4 79.909  < 2e-16 ***
s(I(ClimDistToFront1^(1/3)))   3.284      4  4.995 0.000109 ***
s(log10(pmax(ClimTKE, 1e-04))) 3.776      4 31.698  < 2e-16 ***
s(I(ClimCumVGPM45^(1/3)))      3.920      4 54.775  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.055   Deviance explained = 58.4%
-REML = 6722.2  Scale est. = 89.954    n = 91022

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 13 iterations.
Gradient range [-0.0007488592,4.72927e-05]
(score 6722.158 & scale 89.95369).
Hessian positive definite, eigenvalue range [0.1932027,1859.499].
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(log10(Depth))                4.000 1.533   0.814    0.02
s(sqrt(DistToShore/1000))      4.000 3.356   0.827    0.00
s(I(DistTo300m/1000))          4.000 2.051   0.772    0.00
s(ClimSST)                     4.000 3.898   0.769    0.00
s(I(ClimDistToFront1^(1/3)))   4.000 3.284   0.801    0.00
s(log10(pmax(ClimTKE, 1e-04))) 4.000 3.776   0.781    0.00
s(I(ClimCumVGPM45^(1/3)))      4.000 3.920   0.828    0.02
```

```
Predictors retained during the model selection procedure: Depth, DistToShore, DistTo300m, ClimSST,
ClimDistToFront1, ClimTKE, ClimCumVGPM45

Predictors dropped during the model selection procedure: Slope
```

Model term plots



Diagnostic plots

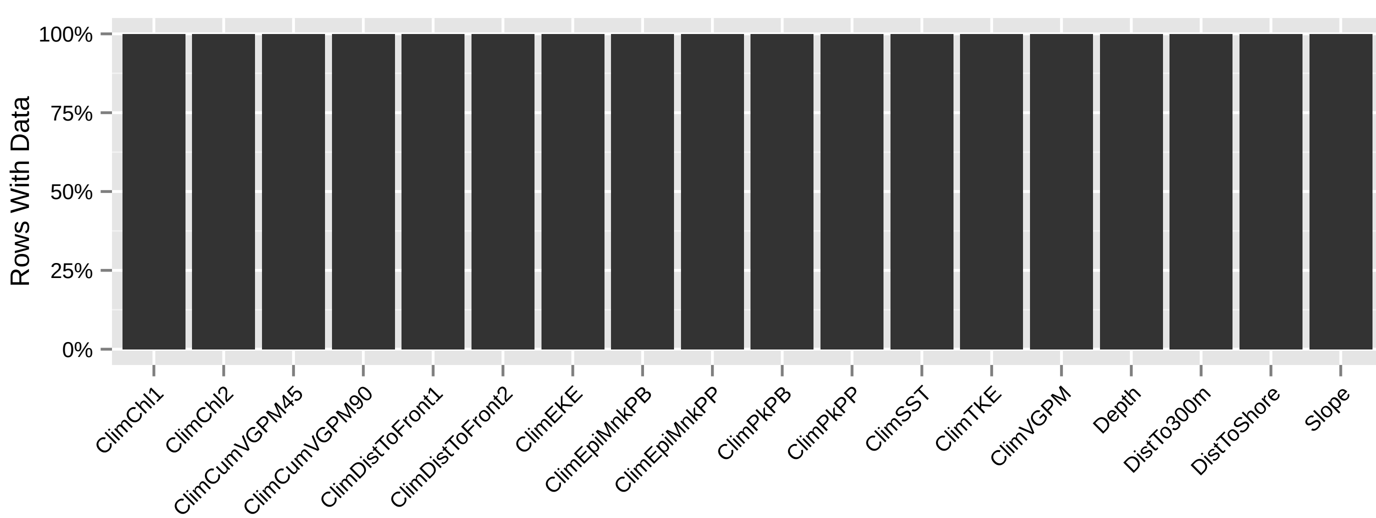


Figure 73: Segments with predictor values for the Atlantic spotted dolphin Climatological model, On Shelf. This plot is used to assess how many segments would be lost by including a given predictor in a model.

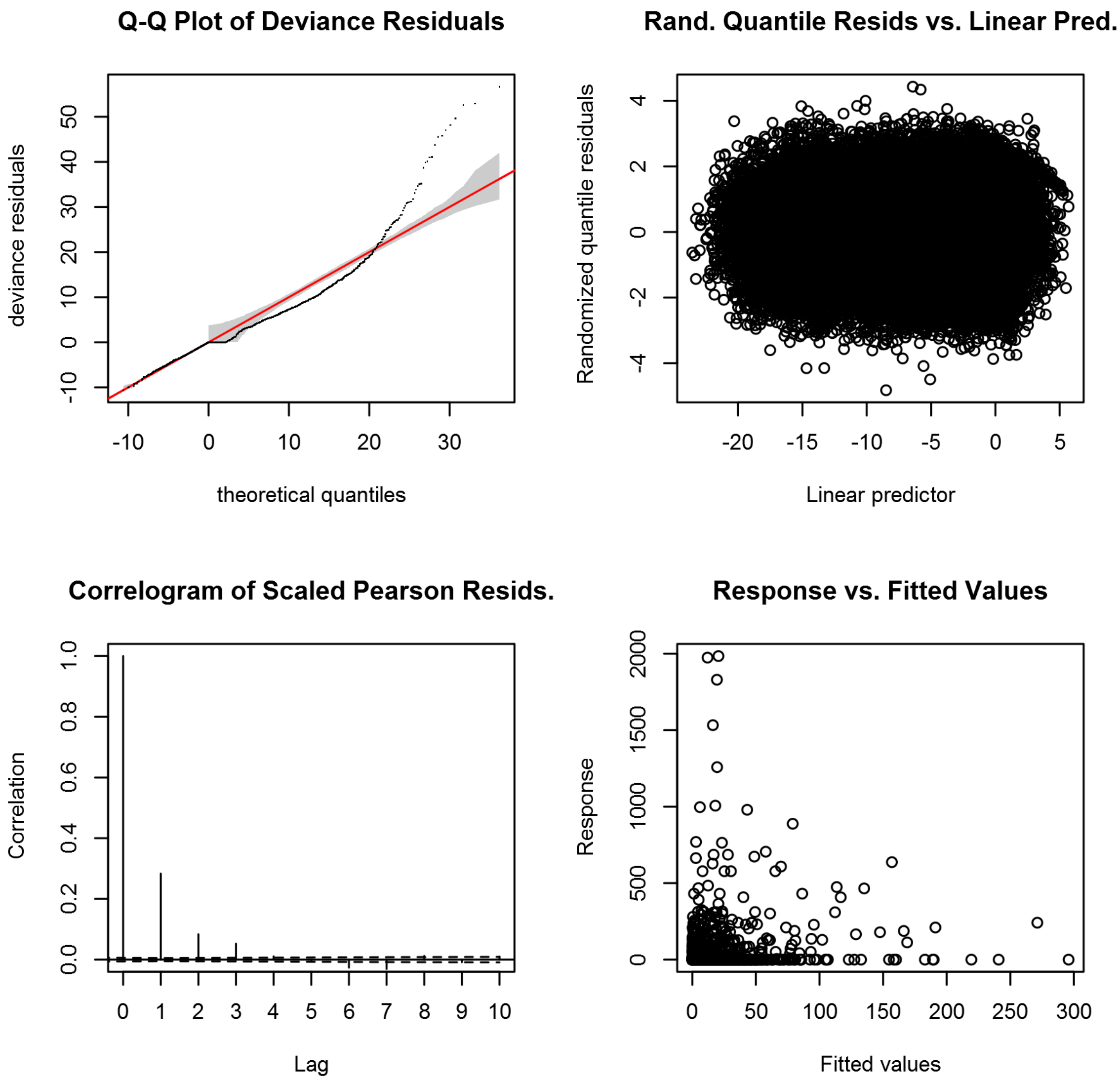


Figure 74: Statistical diagnostic plots for the Atlantic spotted dolphin Climatological model, On Shelf.

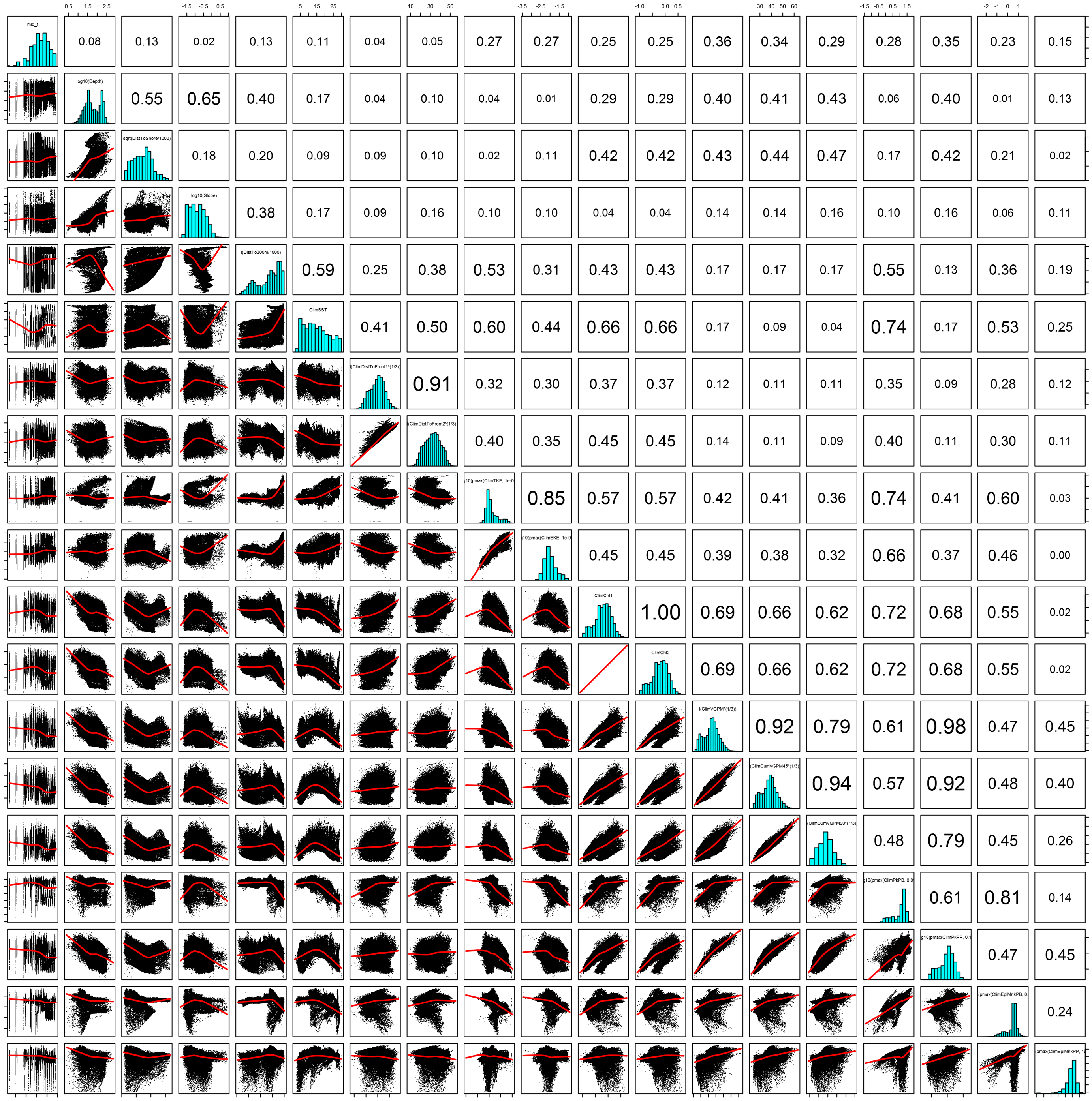


Figure 75: Scatterplot matrix for the Atlantic spotted dolphin Climatological model, On Shelf. This plot is used to inspect the distribution of predictors (via histograms along the diagonal), simple correlation between predictors (via pairwise Pearson coefficients above the diagonal), and linearity of predictor correlations (via scatterplots below the diagonal). This plot is best viewed at high magnification.

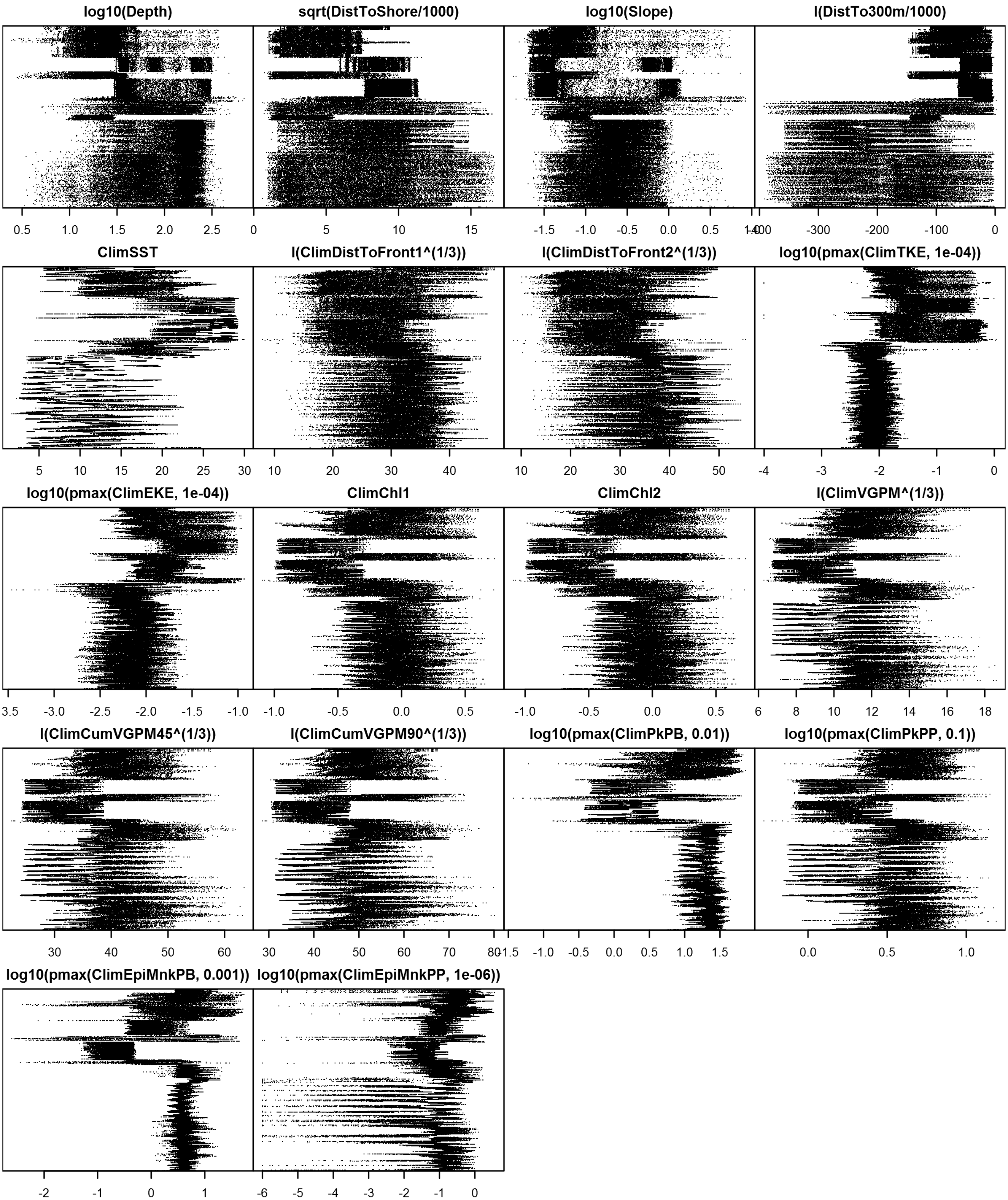


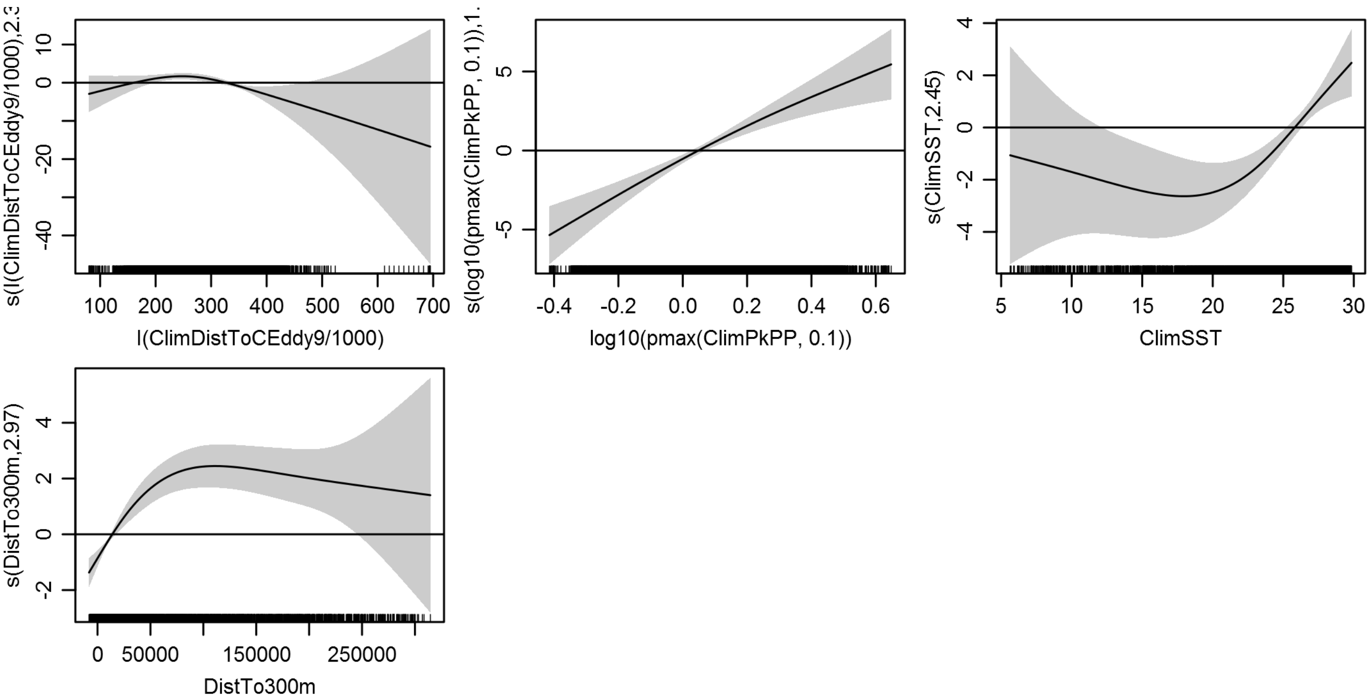
Figure 76: Dotplot for the Atlantic spotted dolphin Climatological model, On Shelf. This plot is used to check for suspicious patterns and outliers in the data. Points are ordered vertically by transect ID, sequentially in time.

Off Shelf

Statistical output

```
Rscript.exe: This is mgcv 1.8-2. For overview type 'help("mgcv-package")'.


Family: Tweedie(p=1.33)
Link function: log

Formula:
abundance ~ offset(log(area_km2)) + s(DistTo300m, bs = "ts",
    k = 5) + s(ClimSST, bs = "ts", k = 5) + s(I(ClimDistToCEddy9/1000),
    bs = "ts", k = 5) + s(log10(pmax(ClimPkPP, 0.1)), bs = "ts",
    k = 5)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -5.7770     0.4137  -13.97   <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(DistTo300m)               2.974      4 12.990 5.08e-13 ***
s(ClimSST)                  2.449      4  6.068 1.50e-06 ***
s(I(ClimDistToCEddy9/1000))   2.370      4  4.915 2.81e-05 ***
s(log10(pmax(ClimPkPP, 0.1))) 1.578      4 11.059 4.80e-13 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.0293   Deviance explained =   48%
-REML = 783.03  Scale est. = 209.96    n = 13144

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 [-0.0003185438,4.696081e-05]
(score 783.0289 & scale 209.9589).
Hessian positive definite, eigenvalue range [0.4116985,197.8062].
Model rank =  17 / 17

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(DistTo300m)                 4.000 2.974   0.784    0.02
s(ClimSST)                    4.000 2.449   0.789    0.00
s(I(ClimDistToCEddy9/1000))   4.000 2.370   0.767    0.01
s(log10(pmax(ClimPkPP, 0.1))) 4.000 1.578   0.802    0.06

Predictors retained during the model selection procedure: DistTo300m, ClimSST, ClimDistToCEddy9,
ClimPkPP

Predictors dropped during the model selection procedure:
```

Model term plots



Diagnostic plots

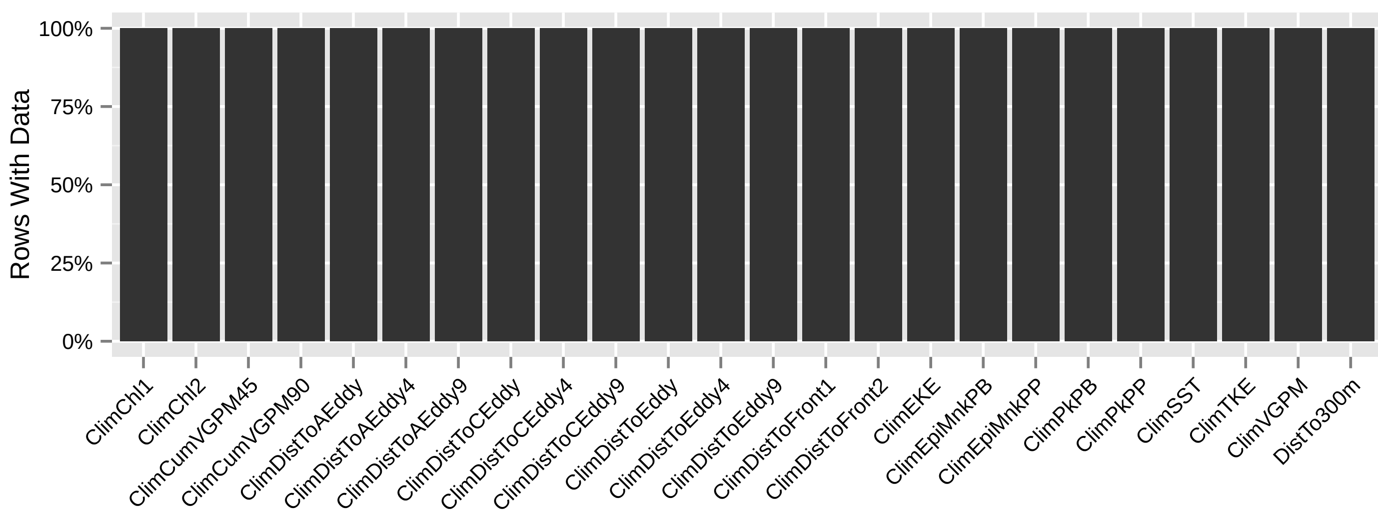


Figure 77: Segments with predictor values for the Atlantic spotted dolphin Climatological model, Off Shelf. This plot is used to assess how many segments would be lost by including a given predictor in a model.

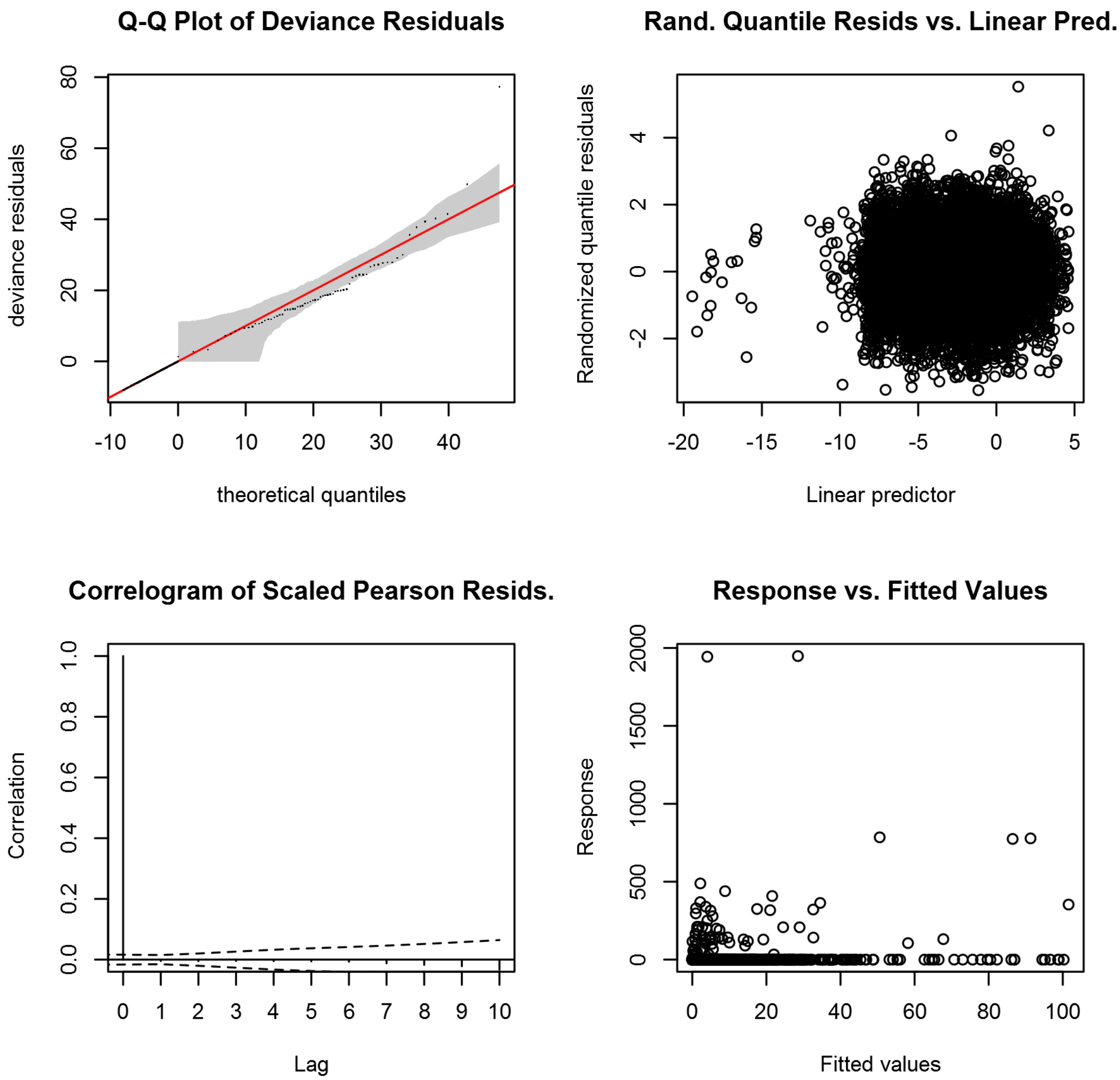


Figure 78: Statistical diagnostic plots for the Atlantic spotted dolphin Climatological model, Off Shelf.

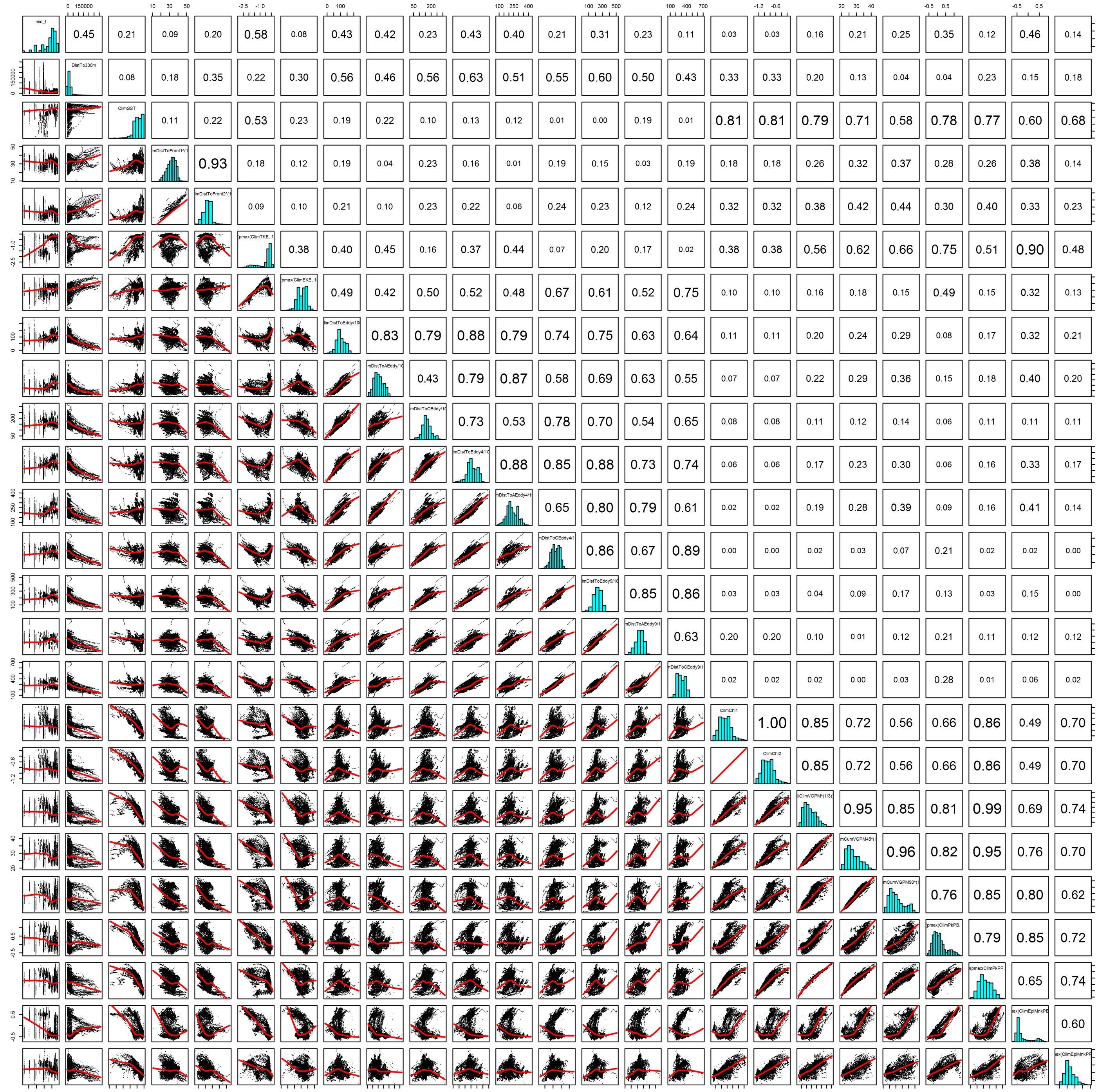


Figure 79: Scatterplot matrix for the Atlantic spotted dolphin Climatological model, Off Shelf. This plot is used to inspect the distribution of predictors (via histograms along the diagonal), simple correlation between predictors (via pairwise Pearson coefficients above the diagonal), and linearity of predictor correlations (via scatterplots below the diagonal). This plot is best viewed at high magnification.

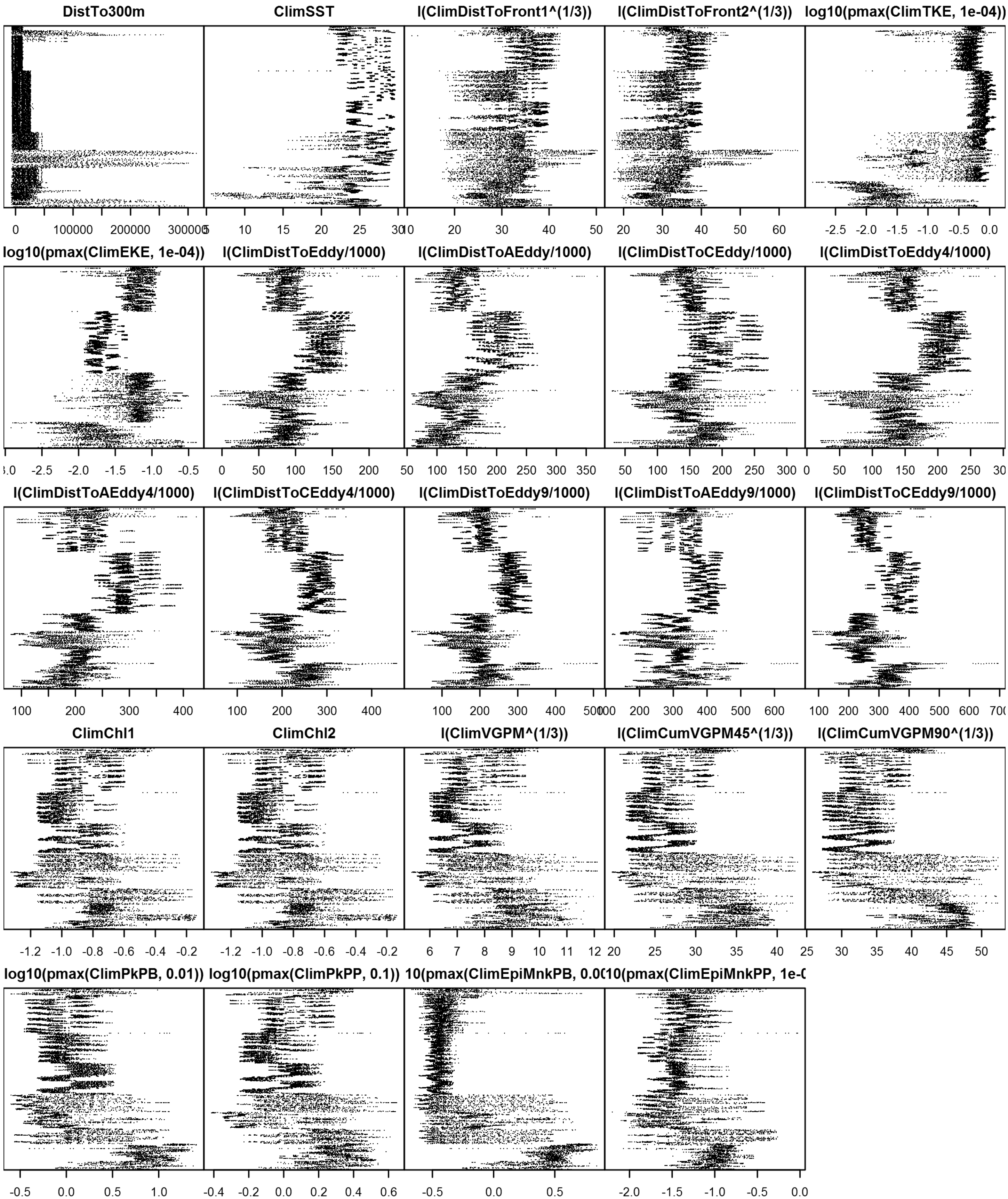


Figure 80: Dotplot for the Atlantic spotted dolphin Climatological model, Off Shelf. This plot is used to check for suspicious patterns and outliers in the data. Points are ordered vertically by transect ID, sequentially in time.

NY-NJ Harbor

Density assumed to be 0 in this region.

Contemporaneous Model

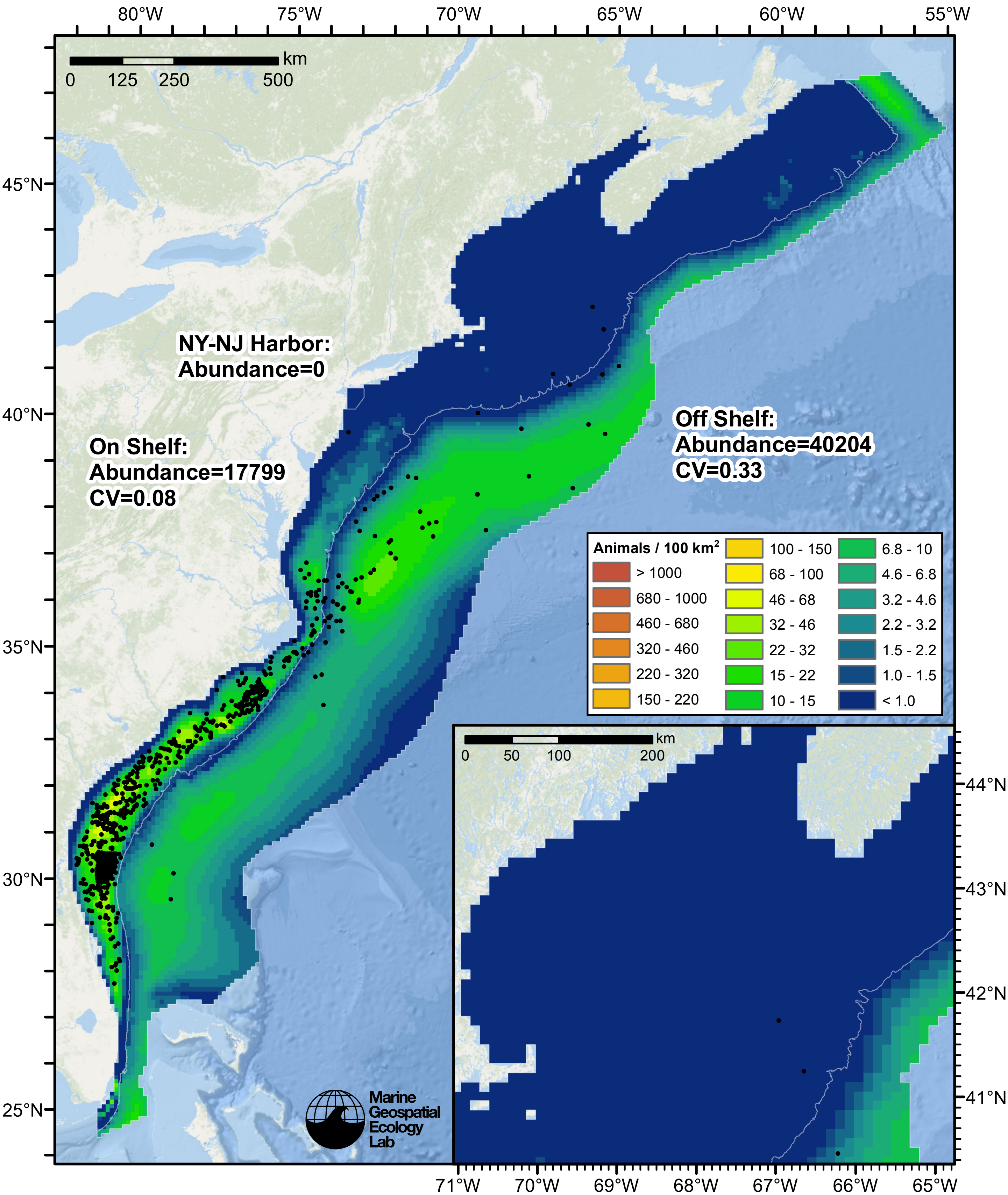


Figure 81: Atlantic spotted dolphin density predicted by the contemporaneous model that explained the most deviance. Pixels are 10x10 km. The legend gives the estimated individuals per pixel; breaks are logarithmic. Abundance for each region was computed by summing the density cells occuring in that region.

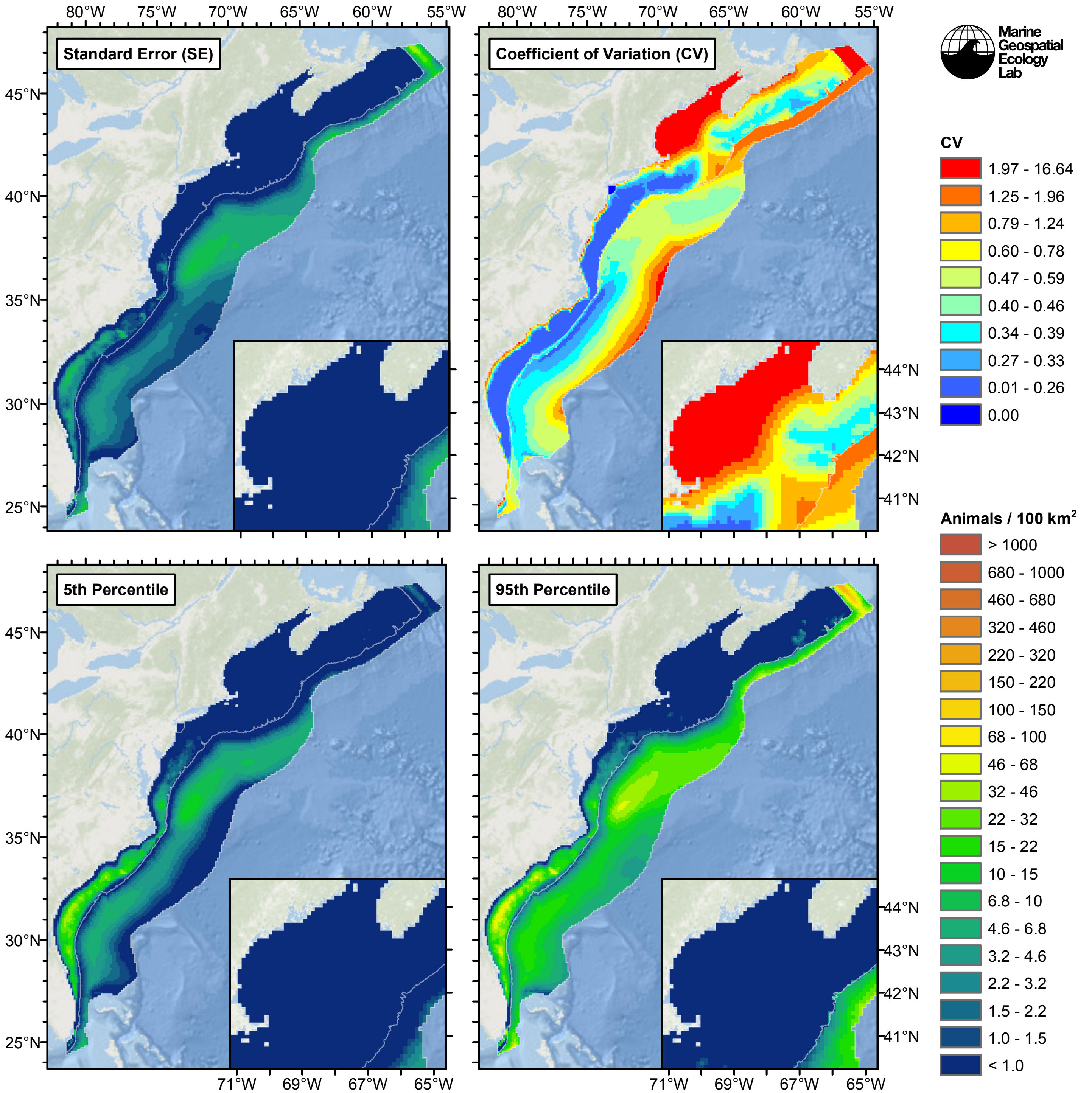


Figure 82: Estimated uncertainty for the contemporaneous model that explained the most deviance. These estimates only incorporate the statistical uncertainty estimated for the spatial model (by the R mgcv package). They do not incorporate uncertainty in the detection functions, g(0) estimates, predictor variables, and so on.

On Shelf

Statistical output

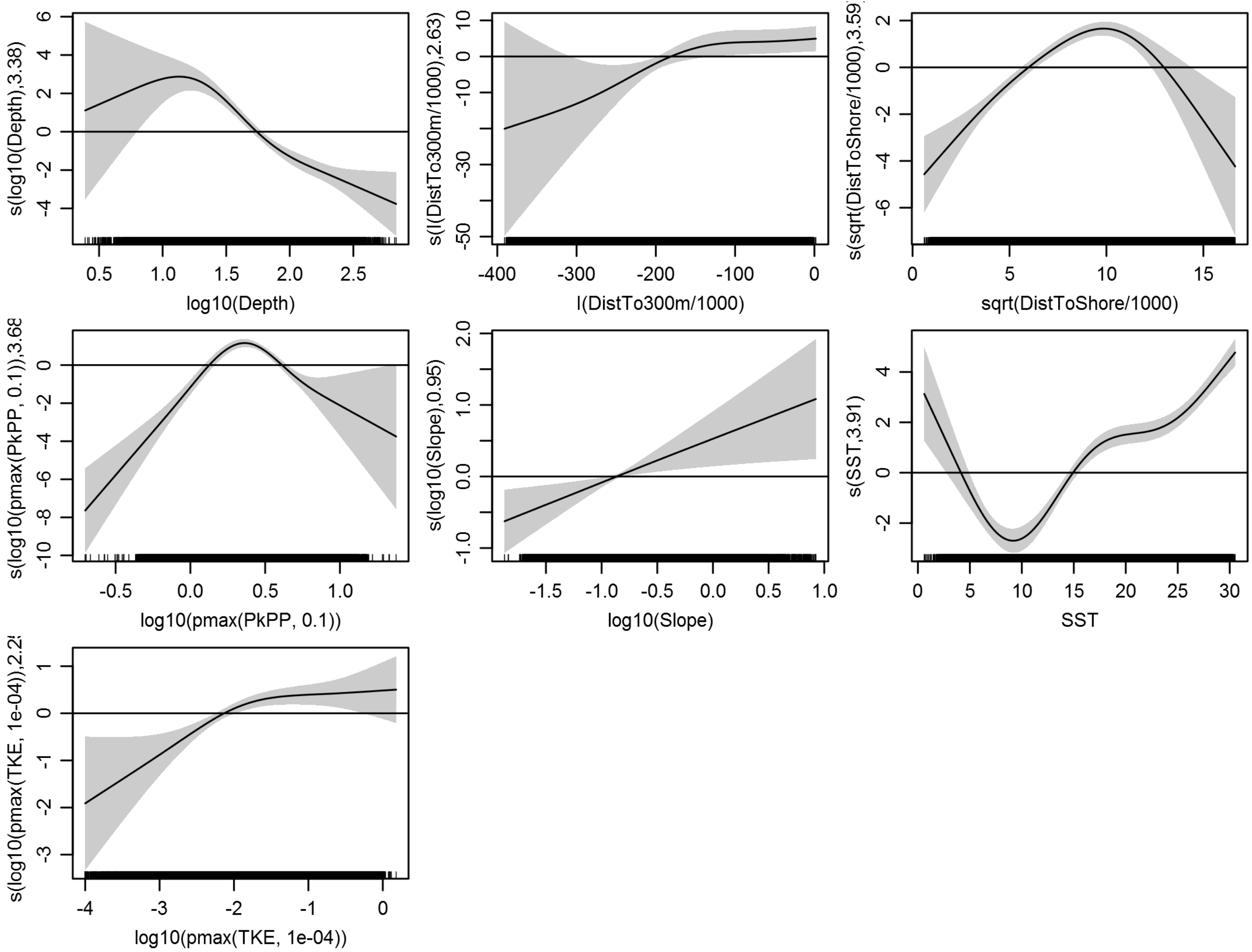
```
Rscript.exe: This is mgcv 1.8-2. For overview type 'help("mgcv-package")'.


Family: Tweedie(p=1.372)
```

```
Link function: log

Formula:
abundance ~ offset(log(area_km2)) + s(log10(Depth), bs = "ts",
    k = 5) + s(sqrt(DistToShore/1000), bs = "ts", k = 5) + s(log10(Slope),
    bs = "ts", k = 5) + s(I(DistTo300m/1000), bs = "ts", k = 5) +
    s(SST, bs = "ts", k = 5) + s(log10(pmax(TKE, 1e-04)), bs = "ts",
    k = 5) + s(log10(pmax(PkPP, 0.1)), bs = "ts", k = 5)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -11.246      1.668  -6.743 1.56e-11 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                              edf Ref.df      F  p-value
s(log10(Depth))            3.3806      4 26.172  < 2e-16 ***
s(sqrt(DistToShore/1000))  3.5909      4 34.154  < 2e-16 ***
s(log10(Slope))            0.9477      4  2.041 0.001814 **
s(I(DistTo300m/1000))      2.6338      4  4.345 0.000182 ***
s(SST)                     3.9148      4 87.336  < 2e-16 ***
s(log10(pmax(TKE, 1e-04))) 2.2494      4  5.341 6.83e-06 ***
s(log10(pmax(PkPP, 0.1)))  3.6801      4 60.521  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.0686   Deviance explained = 58.3%
-REML = 6456.3  Scale est. = 90.94     n = 87314

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 18 iterations.
Gradient range [-0.002964915,0.003040862]
(score 6456.26 & scale 90.94015).
Hessian positive definite, eigenvalue range [0.2829185,1789.313].
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(log10(Depth))            4.000 3.381   0.747    0.00
s(sqrt(DistToShore/1000))  4.000 3.591   0.792    0.00
s(log10(Slope))            4.000 0.948   0.745    0.00
s(I(DistTo300m/1000))      4.000 2.634   0.691    0.00
s(SST)                     4.000 3.915   0.719    0.00
s(log10(pmax(TKE, 1e-04))) 4.000 2.249   0.767    0.02
s(log10(pmax(PkPP, 0.1)))  4.000 3.680   0.806    0.02
```

Predictors retained during the model selection procedure: Depth, DistToShore, Slope, DistTo300m, SST, TKE, PkPP

Predictors dropped during the model selection procedure: DistToFront2

Model term plots



Diagnostic plots

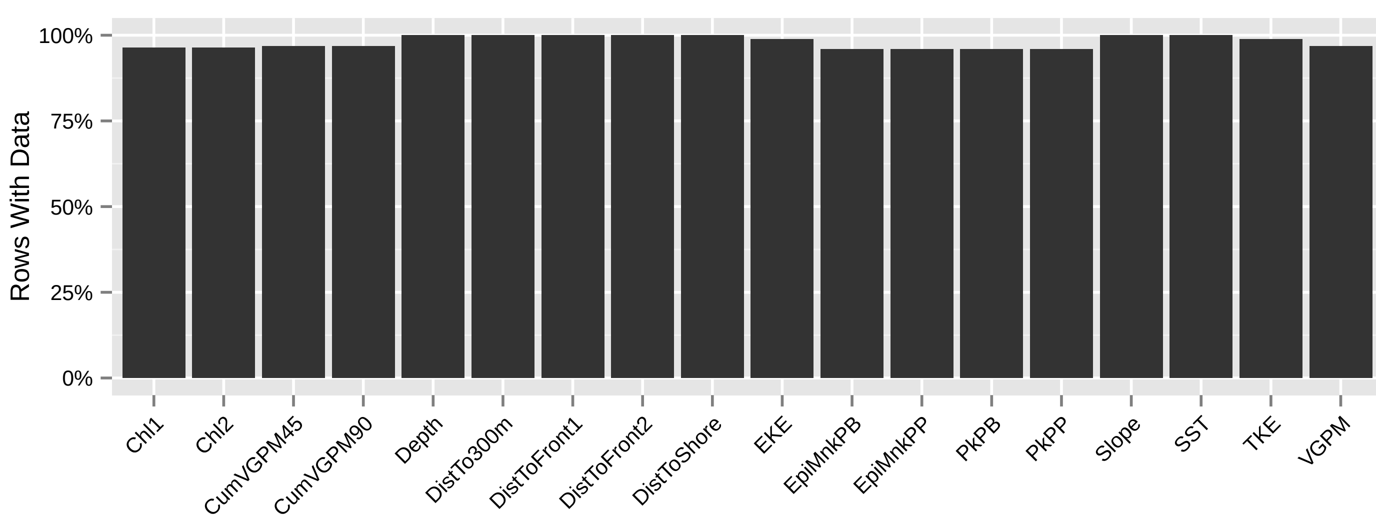


Figure 83: Segments with predictor values for the Atlantic spotted dolphin Contemporaneous model, On Shelf. This plot is used to assess how many segments would be lost by including a given predictor in a model.

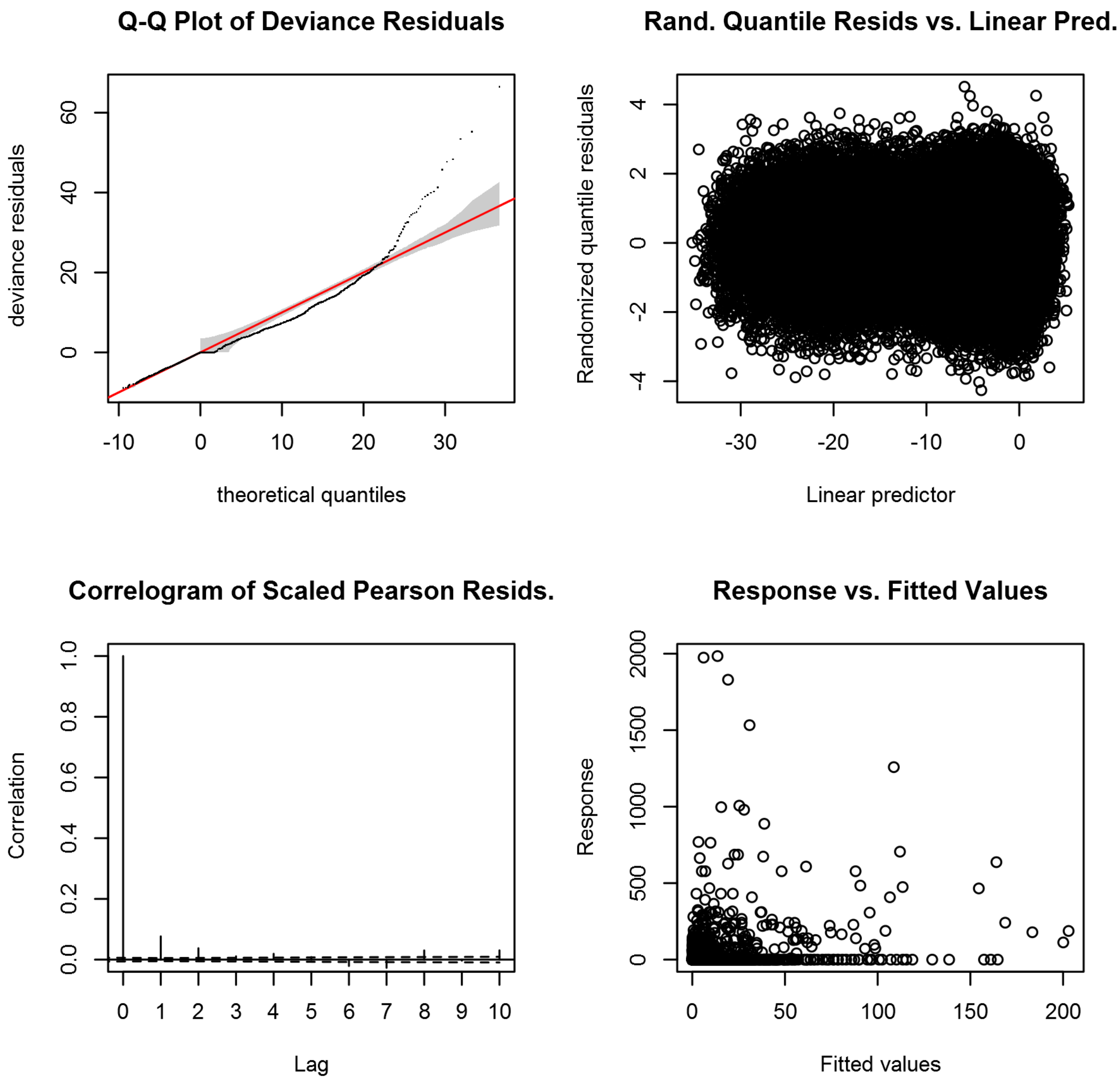


Figure 84: Statistical diagnostic plots for the Atlantic spotted dolphin Contemporaneous model, On Shelf.

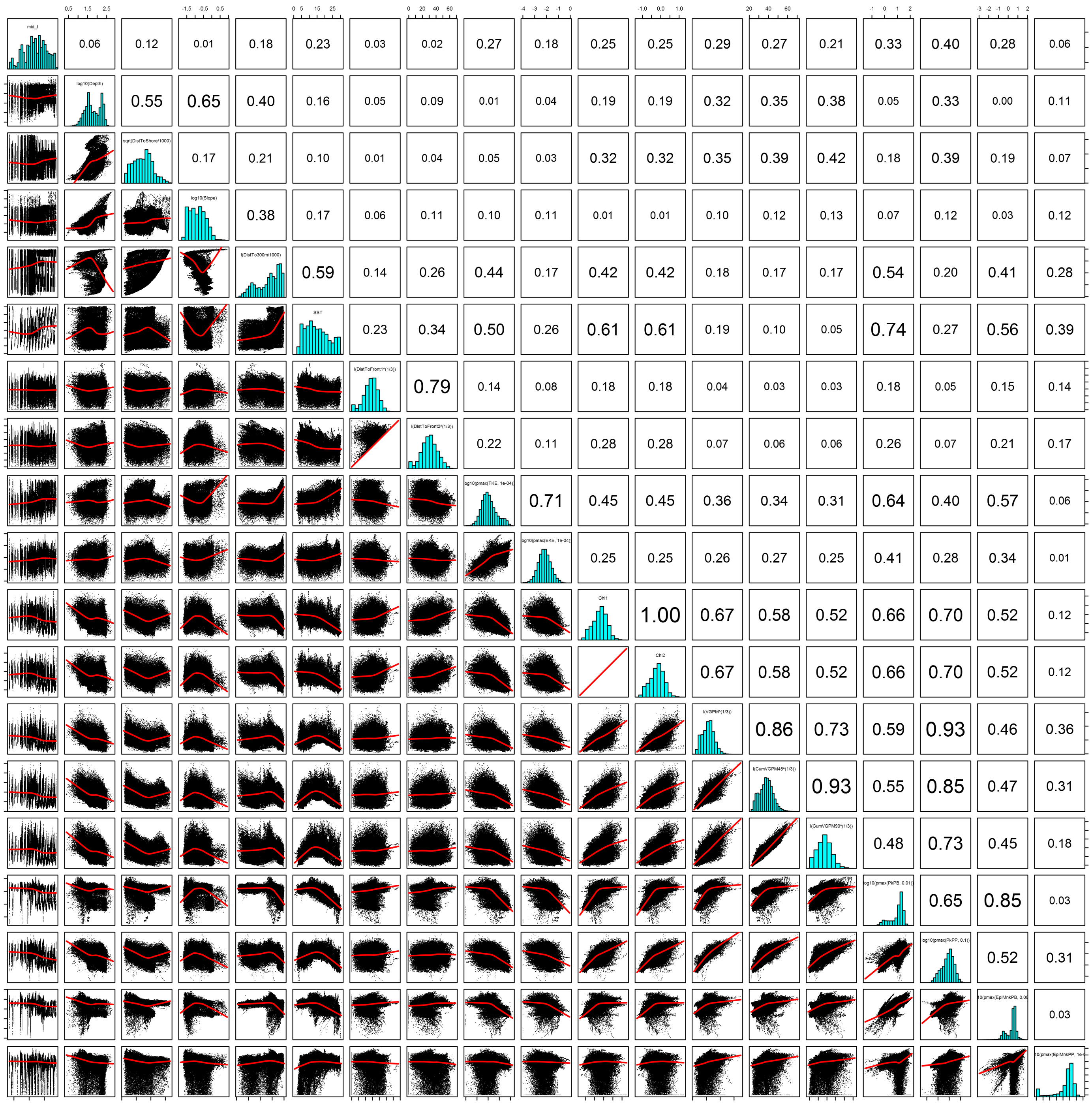


Figure 85: Scatterplot matrix for the Atlantic spotted dolphin Contemporaneous model, On Shelf. This plot is used to inspect the distribution of predictors (via histograms along the diagonal), simple correlation between predictors (via pairwise Pearson coefficients above the diagonal), and linearity of predictor correlations (via scatterplots below the diagonal). This plot is best viewed at high magnification.

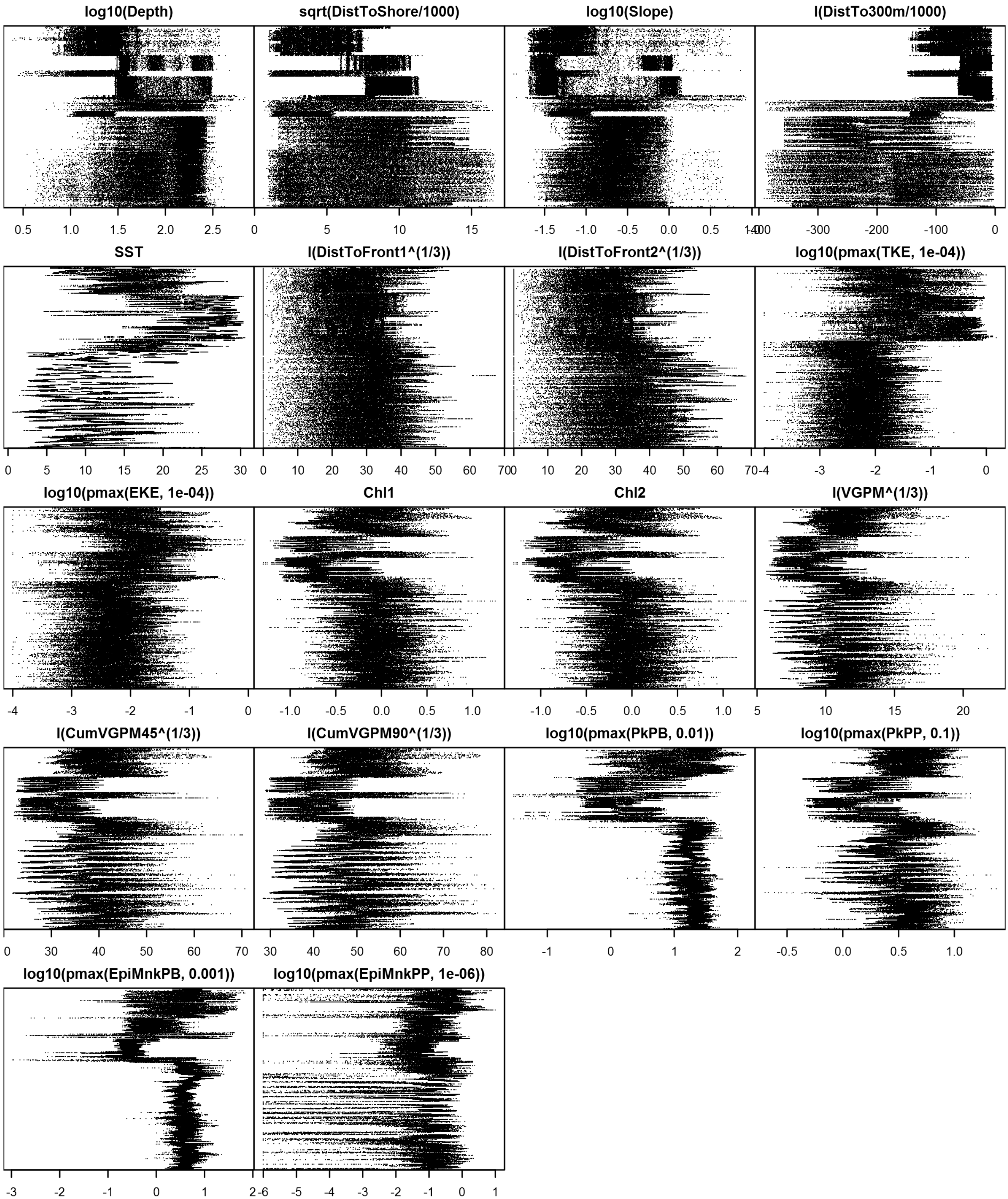


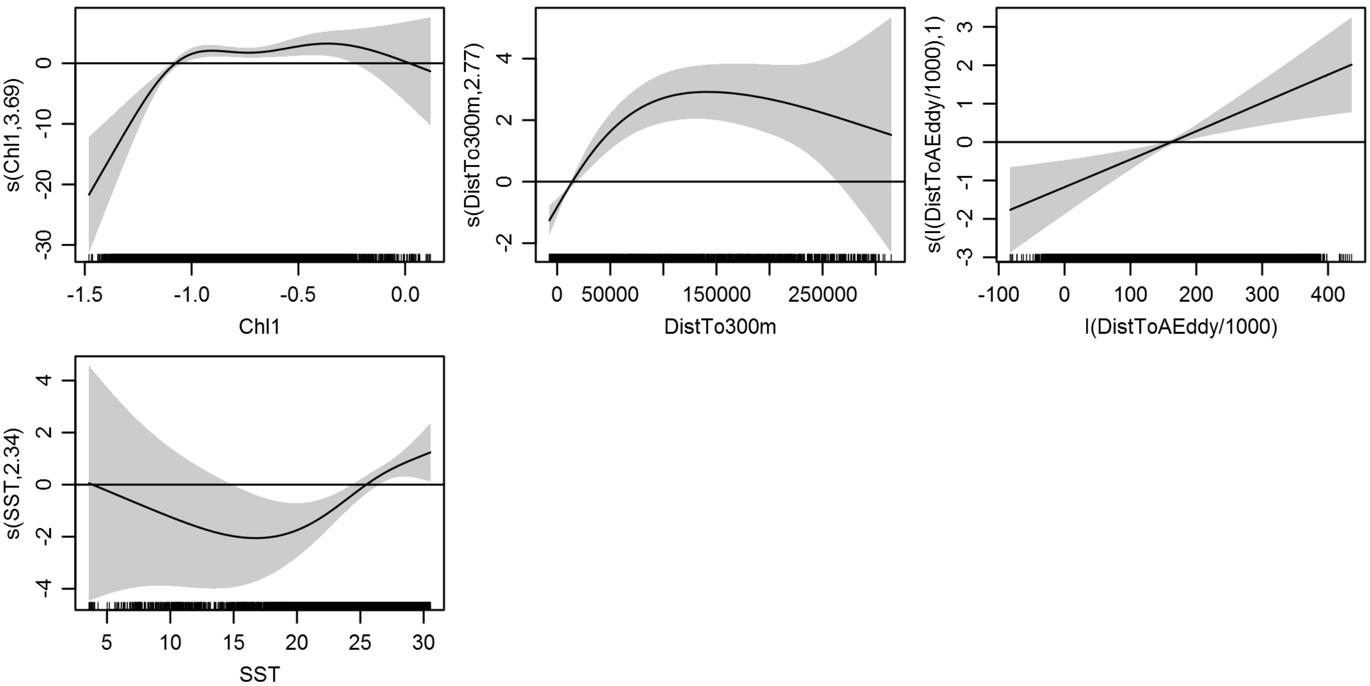
Figure 86: Dotplot for the Atlantic spotted dolphin Contemporaneous model, On Shelf. This plot is used to check for suspicious patterns and outliers in the data. Points are ordered vertically by transect ID, sequentially in time.

Off Shelf

Statistical output

```
Rscript.exe: This is mgcv 1.8-2. For overview type 'help("mgcv-package")'.


Family: Tweedie(p=1.339)
Link function: log

Formula:
abundance ~ offset(log(area_km2)) + s(DistTo300m, bs = "ts",
    k = 5) + s(SST, bs = "ts", k = 5) + s(I(DistToAEddy/1000),
    bs = "ts", k = 5) + s(Chl1, bs = "ts", k = 5)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -5.8193     0.4117  -14.13   <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(DistTo300m)          2.7682      4 14.448 1.67e-14 ***
s(SST)                 2.3411      4  3.287  0.00104 **
s(I(DistToAEddy/1000)) 0.9977      4  3.087  0.00025 ***
s(Chl1)                3.6871      4  6.723 5.81e-06 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.024   Deviance explained = 48.9%
-REML =  639.4  Scale est. = 227.36    n = 12514

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 13 iterations.
Gradient range [-1.3516e-06,6.991363e-07]
(score 639.3969 & scale 227.3649).
Hessian positive definite, eigenvalue range [0.3314745,157.0725].
Model rank =  17 / 17

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(DistTo300m)          4.000 2.768   0.799    0.06
s(SST)                 4.000 2.341   0.815    0.24
s(I(DistToAEddy/1000)) 4.000 0.998   0.817    0.32
s(Chl1)                4.000 3.687   0.779    0.02

Predictors retained during the model selection procedure: DistTo300m, SST, DistToAEddy, Chl1

Predictors dropped during the model selection procedure:
```

Model term plots



Diagnostic plots

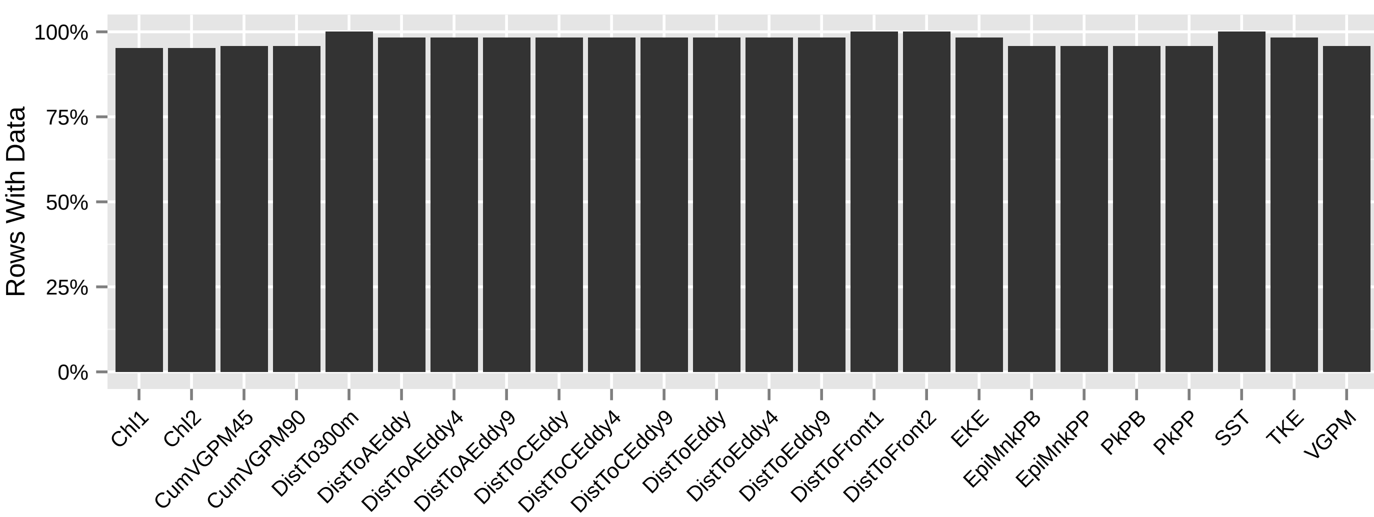


Figure 87: Segments with predictor values for the Atlantic spotted dolphin Contemporaneous model, Off Shelf. This plot is used to assess how many segments would be lost by including a given predictor in a model.

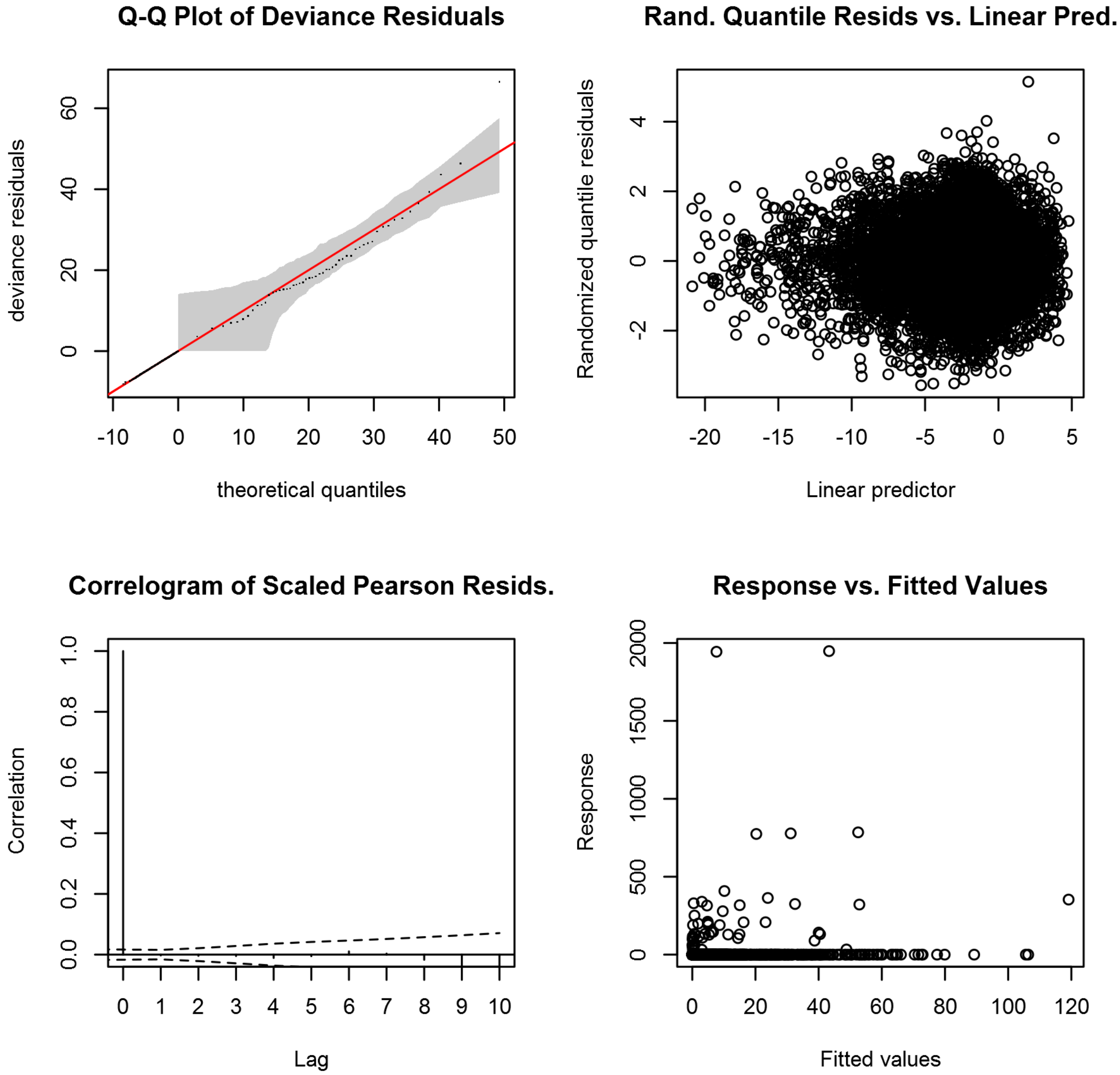


Figure 88: Statistical diagnostic plots for the Atlantic spotted dolphin Contemporaneous model, Off Shelf.

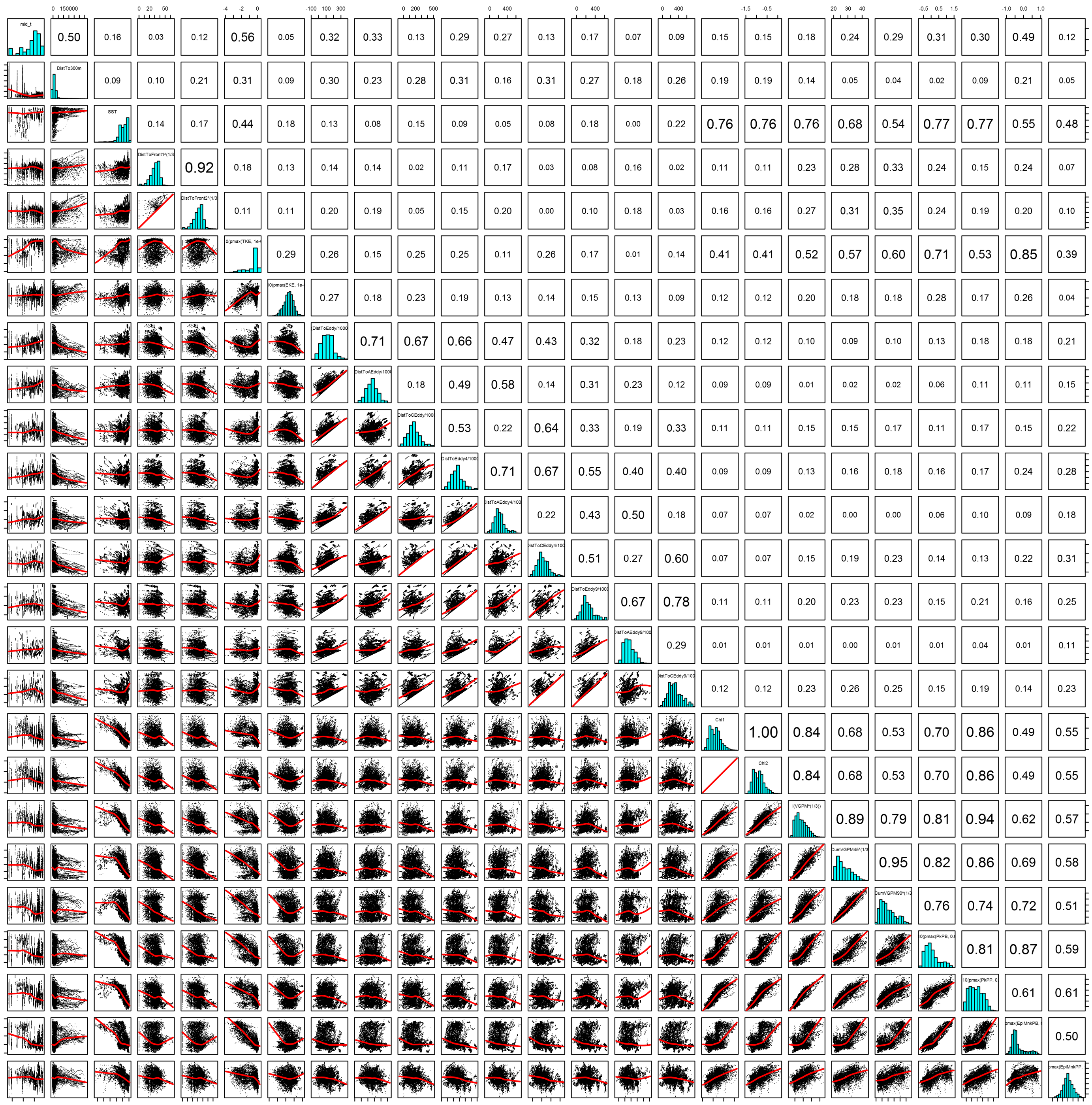


Figure 89: Scatterplot matrix for the Atlantic spotted dolphin Contemporaneous model, Off Shelf. This plot is used to inspect the distribution of predictors (via histograms along the diagonal), simple correlation between predictors (via pairwise Pearson coefficients above the diagonal), and linearity of predictor correlations (via scatterplots below the diagonal). This plot is best viewed at high magnification.

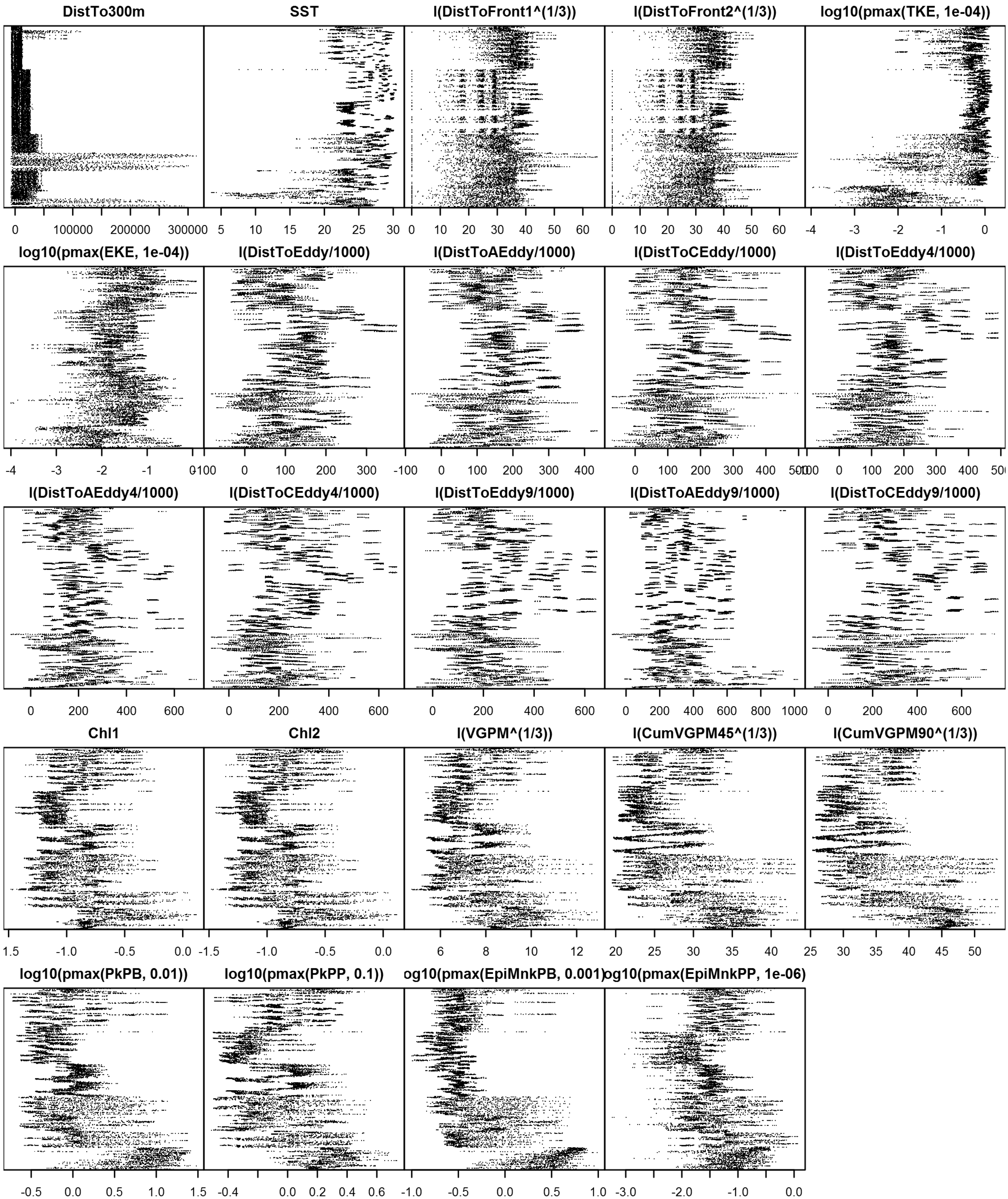


Figure 90: Dotplot for the Atlantic spotted dolphin Contemporaneous model, Off Shelf. This plot is used to check for suspicious patterns and outliers in the data. Points are ordered vertically by transect ID, sequentially in time.

NY-NJ Harbor

Density assumed to be 0 in this region.

Climatological Same Segments Model

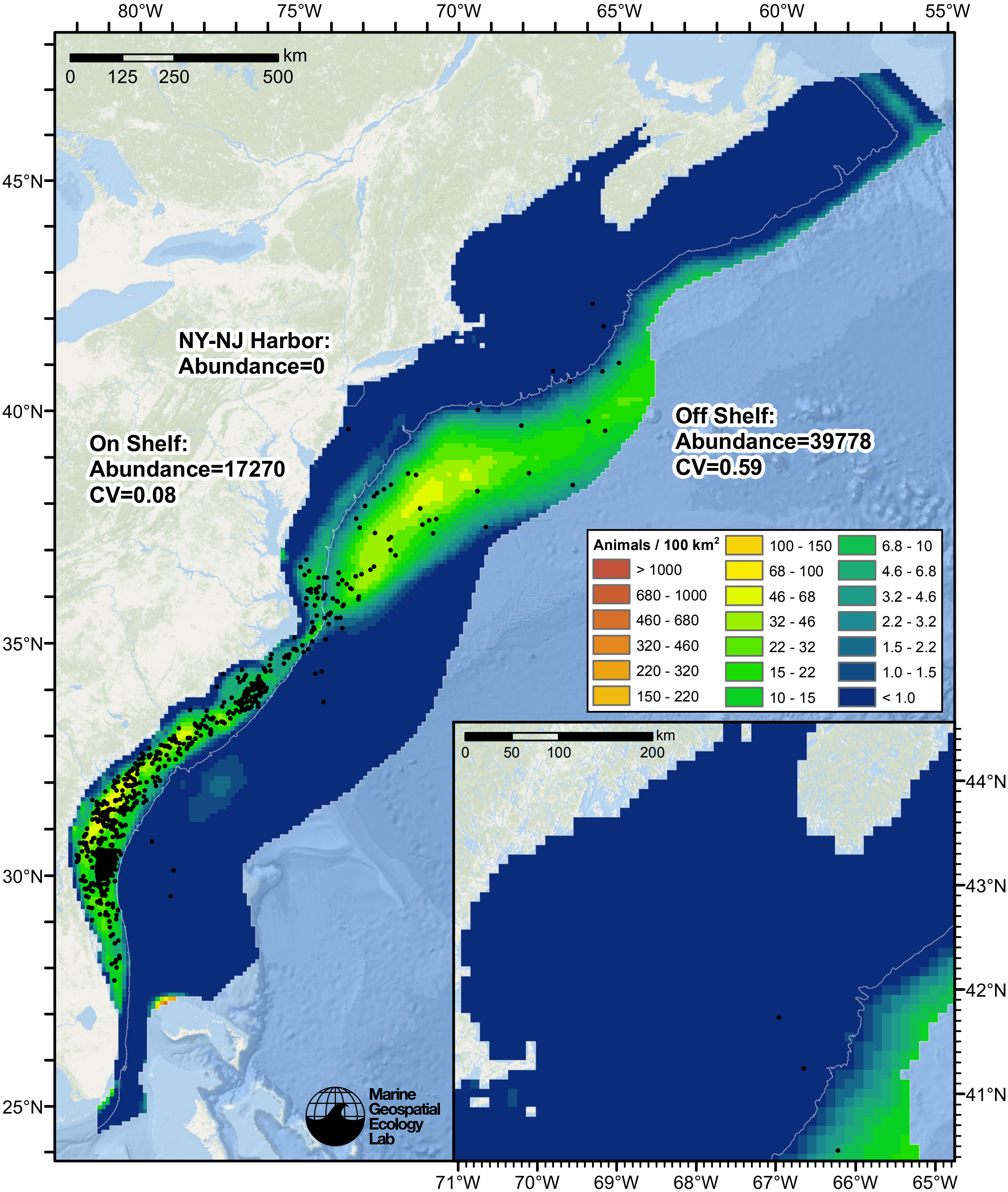


Figure 91: Atlantic spotted dolphin density predicted by the climatological same segments model that explained the most deviance. Pixels are 10x10 km. The legend gives the estimated individuals per pixel; breaks are logarithmic. Abundance for each region was computed by summing the density cells occuring in that region.

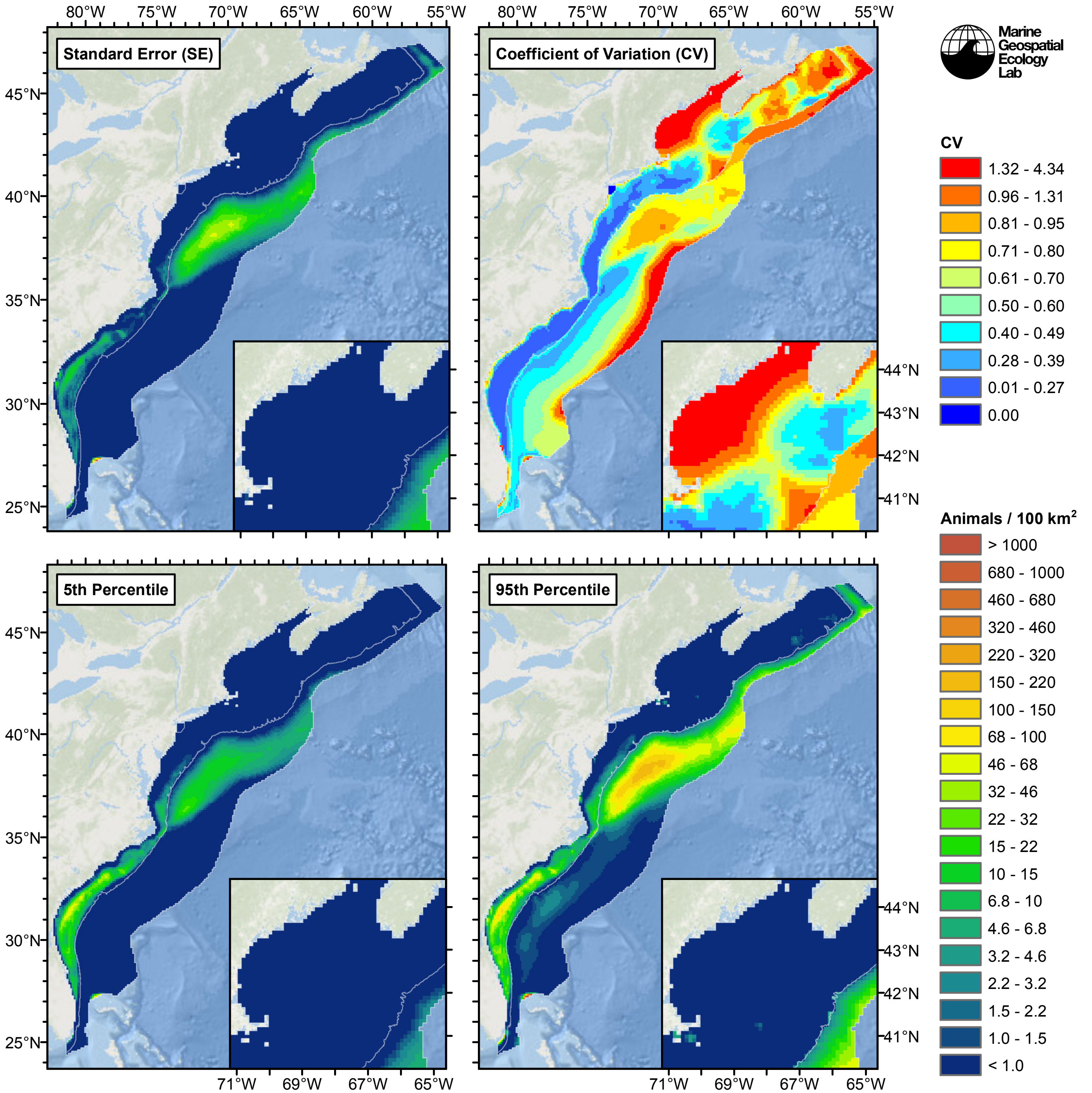


Figure 92: Estimated uncertainty for the climatological same segments model that explained the most deviance. These estimates only incorporate the statistical uncertainty estimated for the spatial model (by the R mgcv package). They do not incorporate uncertainty in the detection functions, g(0) estimates, predictor variables, and so on.

On Shelf

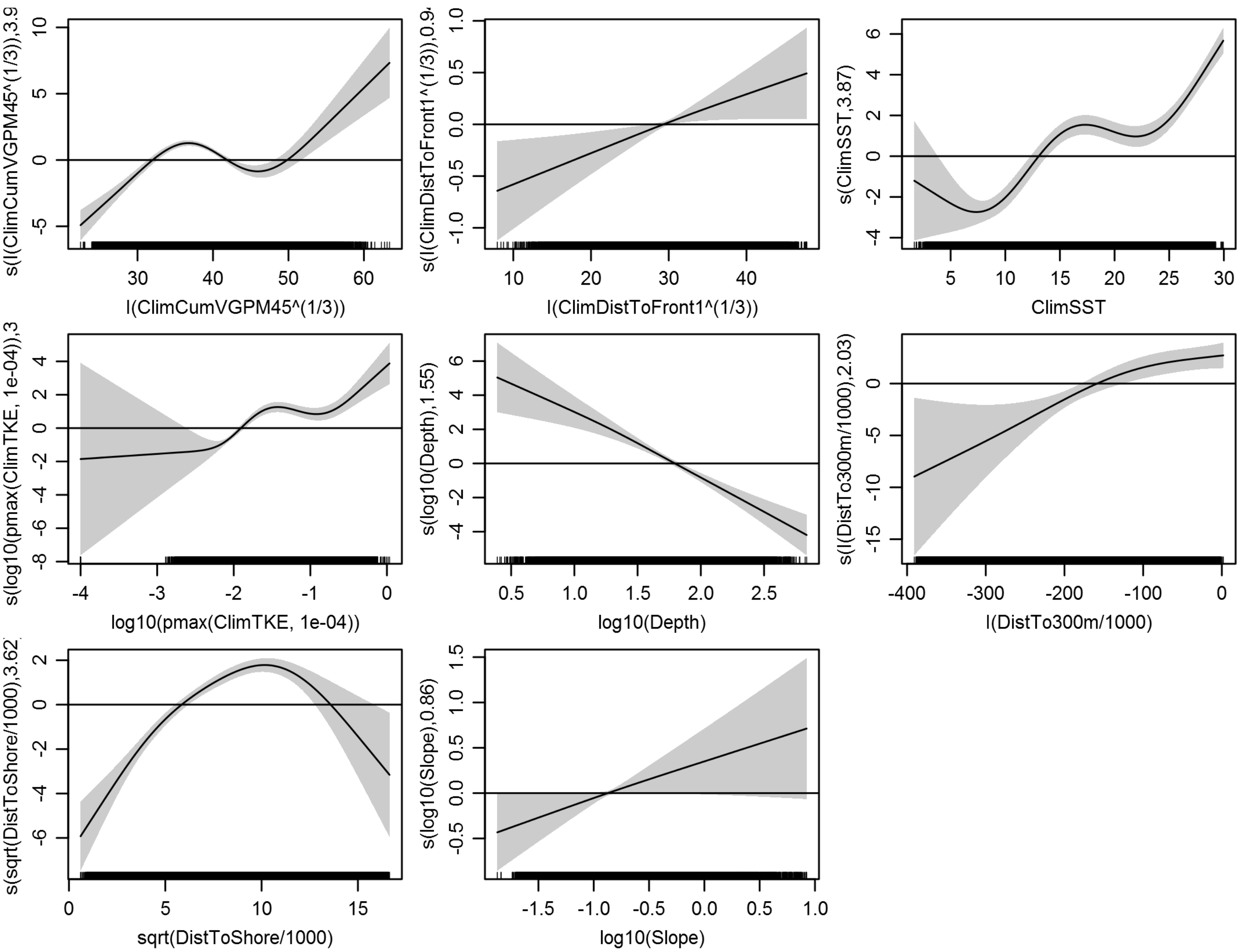
Statistical output

```
Rscript.exe: This is mgcv 1.8-2. For overview type 'help("mgcv-package")'.


Family: Tweedie(p=1.376)
```

```
Link function: log

Formula:
abundance ~ offset(log(area_km2)) + s(log10(Depth), bs = "ts",
    k = 5) + s(sqrt(DistToShore/1000), bs = "ts", k = 5) + s(log10(Slope),
    bs = "ts", k = 5) + s(I(DistTo300m/1000), bs = "ts", k = 5) +
    s(ClimSST, bs = "ts", k = 5) + s(I(ClimDistToFront1^(1/3)),
    bs = "ts", k = 5) + s(log10(pmax(ClimTKE, 1e-04)), bs = "ts",
    k = 5) + s(I(ClimCumVGPM45^(1/3)), bs = "ts", k = 5)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -9.5843     0.5352  -17.91   <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(log10(Depth))              1.5482      4 15.882  < 2e-16 ***
s(sqrt(DistToShore/1000))    3.6151      4 37.556  < 2e-16 ***
s(log10(Slope))              0.8564      4  1.057  0.02002 *
s(I(DistTo300m/1000))        2.0308      4  6.817 1.01e-07 ***
s(ClimSST)                   3.8675      4 87.353  < 2e-16 ***
s(I(ClimDistToFront1^(1/3)))  0.9395      4  1.901  0.00319 **
s(log10(pmax(ClimTKE, 1e-04))) 3.7733      4 24.716  < 2e-16 ***
s(I(ClimCumVGPM45^(1/3)))    3.9228      4 56.398  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.0539   Deviance explained = 58.8%
-REML = 6443.7  Scale est. = 90.528    n = 87314

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 16 iterations.
Gradient range [-0.001850392,0.001155444]
(score 6443.744 & scale 90.52759).
Hessian positive definite, eigenvalue range [0.1998708,1762.885].
Model rank =  33 / 33

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(log10(Depth))              4.000 1.548   0.783    0.00
s(sqrt(DistToShore/1000))    4.000 3.615   0.827    0.26
s(log10(Slope))              4.000 0.856   0.747    0.00
s(I(DistTo300m/1000))        4.000 2.031   0.671    0.00
s(ClimSST)                   4.000 3.867   0.712    0.00
s(I(ClimDistToFront1^(1/3)))  4.000 0.940   0.796    0.00
s(log10(pmax(ClimTKE, 1e-04))) 4.000 3.773   0.754    0.00
s(I(ClimCumVGPM45^(1/3)))    4.000 3.923   0.808    0.02

Predictors retained during the model selection procedure: Depth, DistToShore, Slope, DistTo300m,
ClimSST, ClimDistToFront1, ClimTKE, ClimCumVGPM45
```

```
Predictors dropped during the model selection procedure:
```

Model term plots



Diagnostic plots

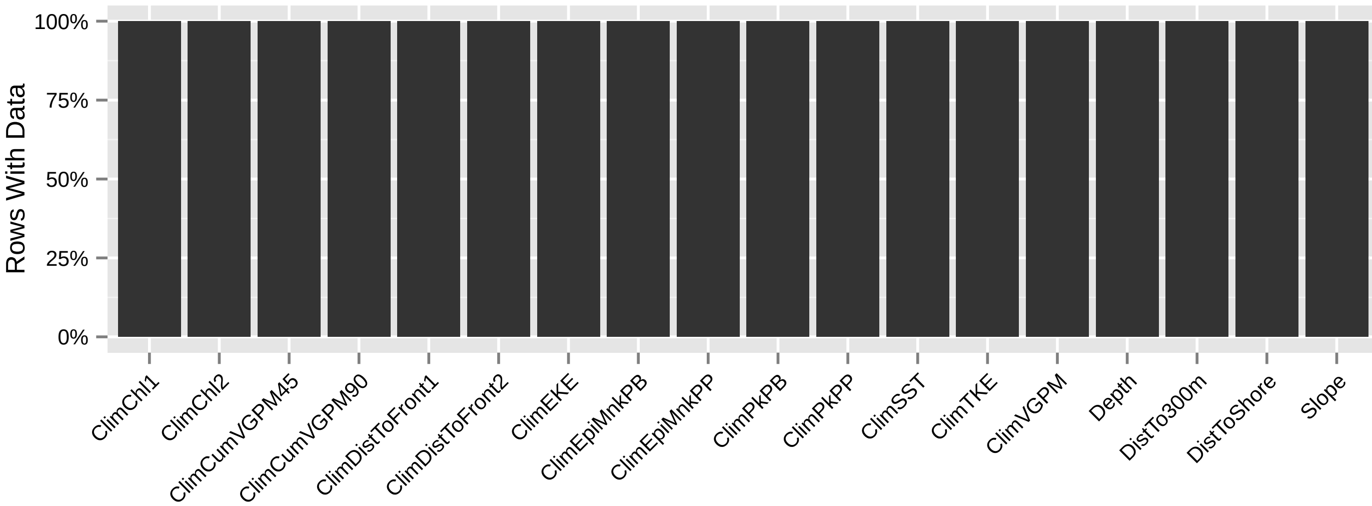


Figure 93: Segments with predictor values for the Atlantic spotted dolphin Climatological model, On Shelf. This plot is used to assess how many segments would be lost by including a given predictor in a model.

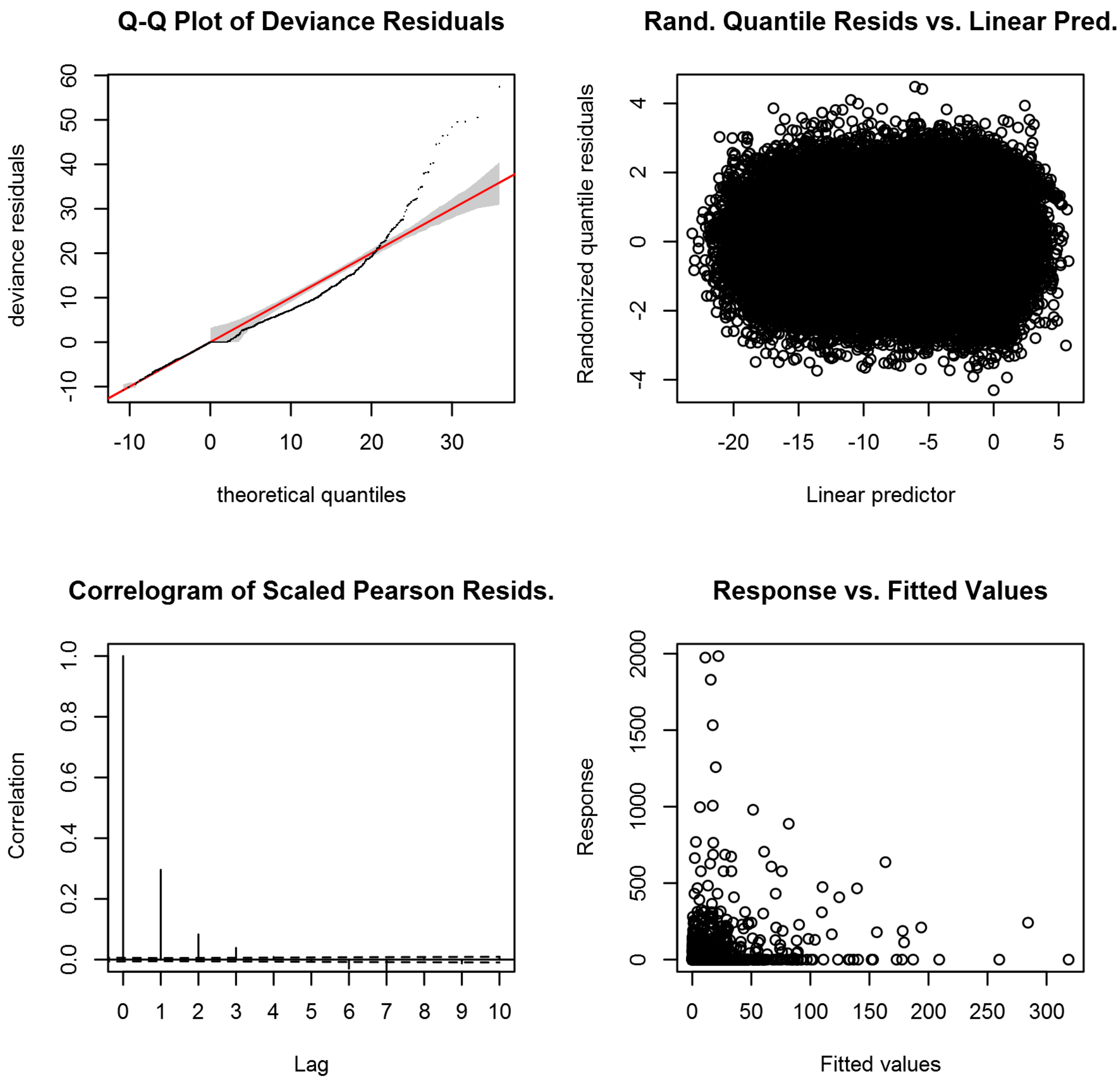


Figure 94: Statistical diagnostic plots for the Atlantic spotted dolphin Climatological model, On Shelf.

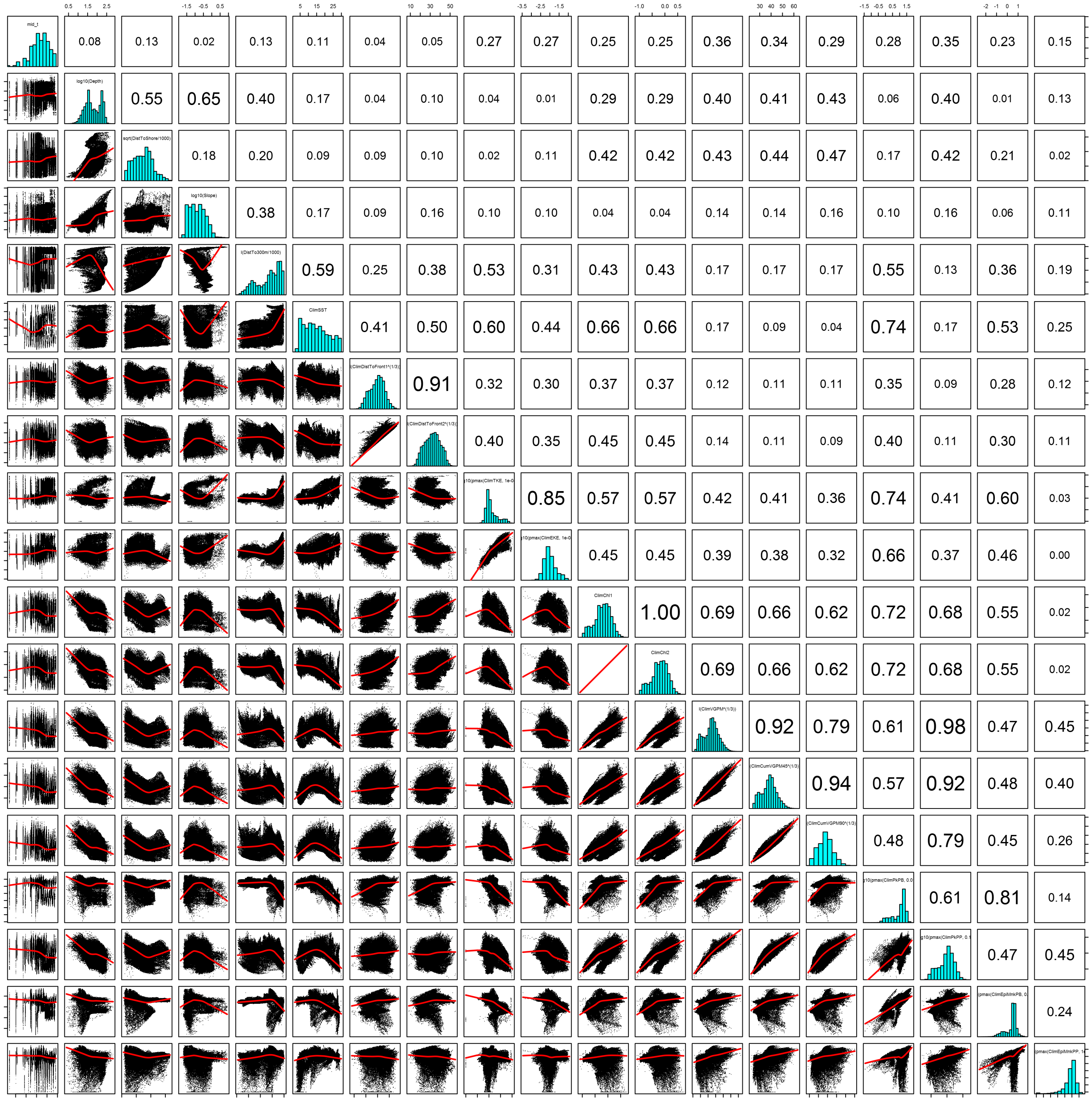


Figure 95: Scatterplot matrix for the Atlantic spotted dolphin Climatological model, On Shelf. This plot is used to inspect the distribution of predictors (via histograms along the diagonal), simple correlation between predictors (via pairwise Pearson coefficients above the diagonal), and linearity of predictor correlations (via scatterplots below the diagonal). This plot is best viewed at high magnification.

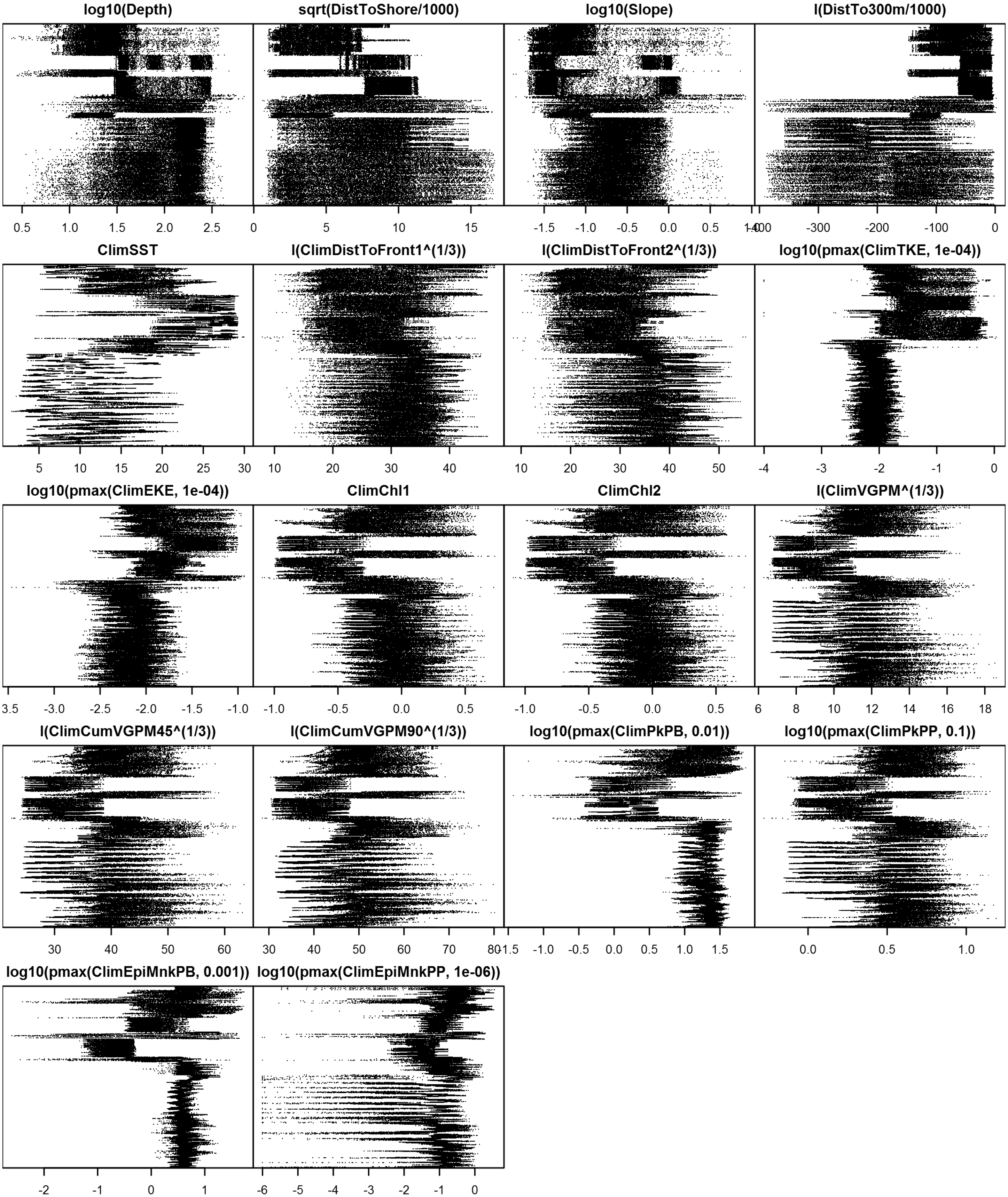


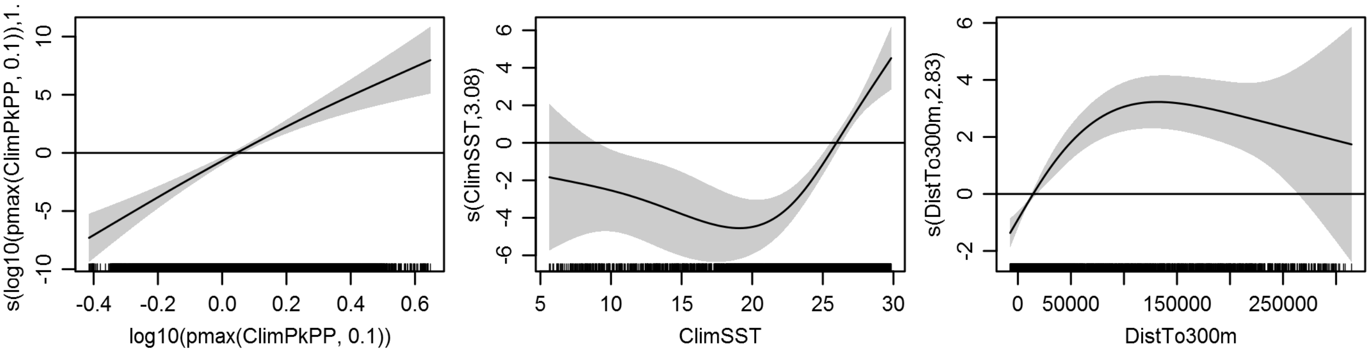
Figure 96: Dotplot for the Atlantic spotted dolphin Climatological model, On Shelf. This plot is used to check for suspicious patterns and outliers in the data. Points are ordered vertically by transect ID, sequentially in time.

Off Shelf

Statistical output

```
Rscript.exe: This is mgcv 1.8-2. For overview type 'help("mgcv-package")'.


Family: Tweedie(p=1.336)
Link function: log

Formula:
abundance ~ offset(log(area_km2)) + s(DistTo300m, bs = "ts",
    k = 5) + s(ClimSST, bs = "ts", k = 5) + s(log10(pmax(ClimPkPP,
    0.1)), bs = "ts", k = 5)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -5.3488     0.2934  -18.23   <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(DistTo300m)               2.833      4 15.06 1.81e-15 ***
s(ClimSST)                  3.081      4 13.41 1.80e-13 ***
s(log10(pmax(ClimPkPP, 0.1))) 1.619      4 16.10  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.0335   Deviance explained = 49.3%
-REML = 631.78  Scale est. = 224.06    n = 12514

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 [-6.332795e-08,4.302204e-08]
(score 631.785 & scale 224.0586).
Hessian positive definite, eigenvalue range [0.5983271,157.4328].
Model rank =  13 / 13

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(DistTo300m)                 4.000 2.833   0.786    0.00
s(ClimSST)                    4.000 3.081   0.813    0.28
s(log10(pmax(ClimPkPP, 0.1))) 4.000 1.619   0.805    0.06

Predictors retained during the model selection procedure: DistTo300m, ClimSST, ClimPkPP

Predictors dropped during the model selection procedure: ClimDistToFront2
```

Model term plots



Diagnostic plots

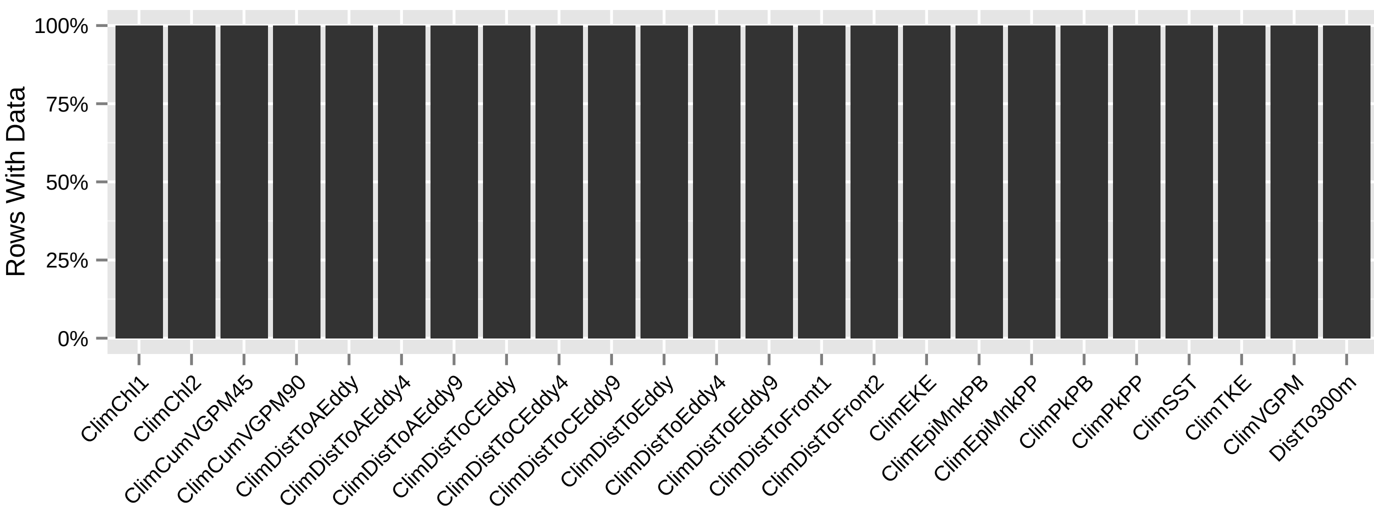


Figure 97: Segments with predictor values for the Atlantic spotted dolphin Climatological model, Off Shelf. This plot is used to assess how many segments would be lost by including a given predictor in a model.

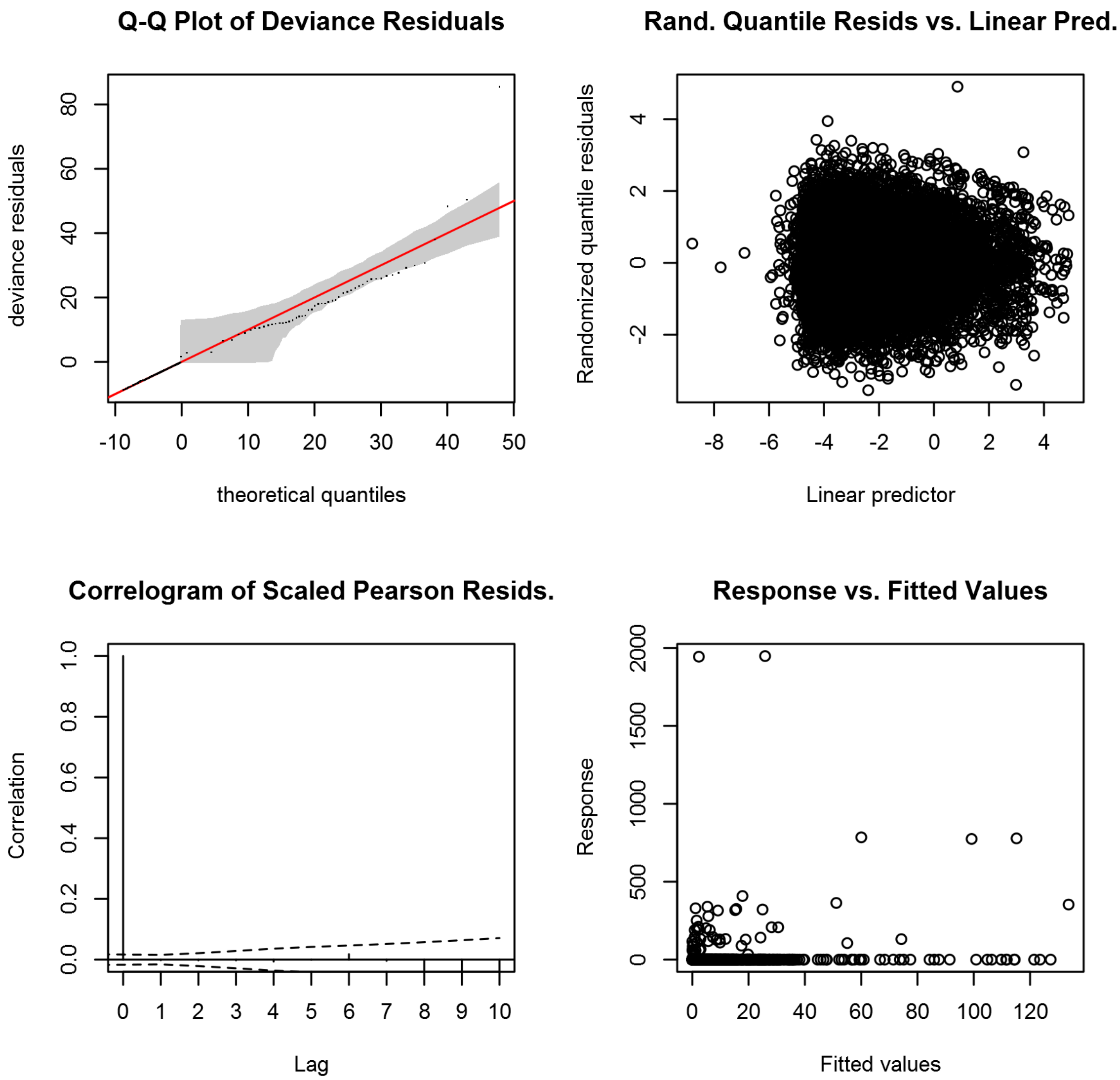


Figure 98: Statistical diagnostic plots for the Atlantic spotted dolphin Climatological model, Off Shelf.

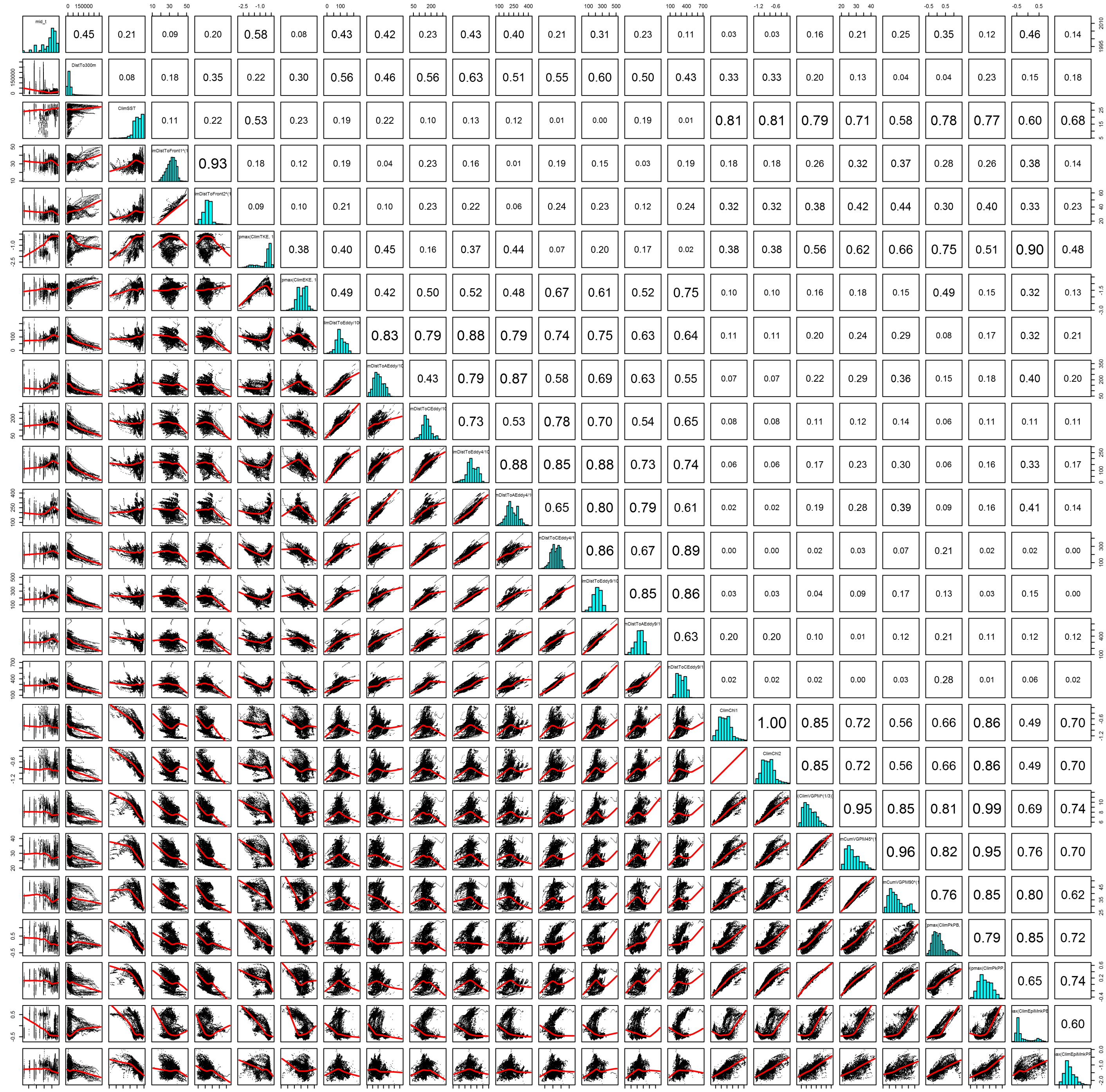


Figure 99: Scatterplot matrix for the Atlantic spotted dolphin Climatological model, Off Shelf. This plot is used to inspect the distribution of predictors (via histograms along the diagonal), simple correlation between predictors (via pairwise Pearson coefficients above the diagonal), and linearity of predictor correlations (via scatterplots below the diagonal). This plot is best viewed at high magnification.

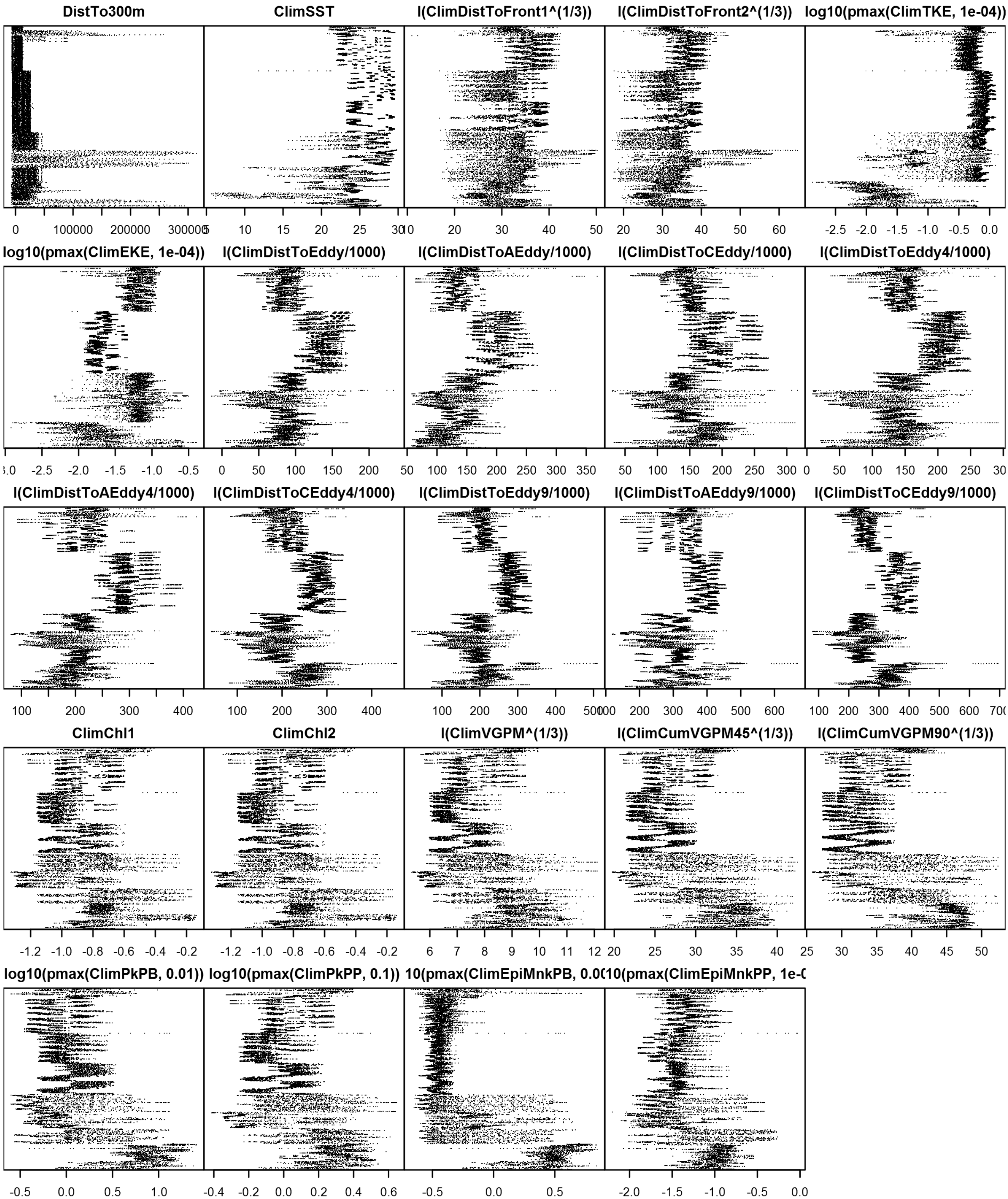


Figure 100: Dotplot for the Atlantic spotted dolphin Climatological model, Off Shelf. This plot is used to check for suspicious patterns and outliers in the data. Points are ordered vertically by transect ID, sequentially in time.

NY-NJ Harbor

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 subregion, 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.

Predictors	Climatol % Dev Expl	Contemp % Dev Expl	Climatol Same Segs % Dev Expl	Segments	% Lost	Date Range
On Shelf:						
Phys	46.0			91022		1992-2014
Phys+SST	53.6	53.4	53.6	91022	0.0	1992-2014
Phys+SST+Curr	56.1	53.8	55.5	89920	1.2	1995-2013
Phys+SST+Curr+Prod	58.4	58.3	58.8	87314	4.1	1998-2013
Off Shelf:						
DistTo300m	28.3			13144		1992-2013
DistTo300m+SST+Curr	38.6	31.6	37.5	12921	1.7	1995-2013
DistTo300m+SST+Curr+Prod	48.0	48.9	49.3	12514	4.8	1998-2013

Table 42: 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.

The Assumed g(0)=1 column specifies whether the abundance estimate assumed that detection was certain along the survey trackline. Studies that assumed this did not correct for availability or perception bias, and therefore underestimated abundance. The In our models column specifies whether the survey data from the study was also used in our models. If not, the study provides a completely independent estimate of abundance.

Dates	Model or study	Estimated abundance	CV	Assumed g(0)=1	In our models
1992-2014	Climatological model*	55436	0.32	No	
1998-2013	Contemporaneous model	58002	0.23	No	
1992-2014	Climatological same segments model	57048	0.41	No	
Jun-Aug 2011	Central Virginia to lower Bay of Fundy (Waring et al. 2014)	26798	0.66	No	No
Jun-Aug 2011	Central Florida to central Virginia (Waring et al. 2014)	17917	0.42	No	No
Jun-Aug 2011	Central Florida to lower Bay of Fundy, combined	44715	0.43	No	No
Jun-Aug 2004	Maryland to Bay of Fundy (Waring et al. 2014)	3578	0.48	No	Yes
Jun-Aug 2004	Florida to Maryland (Waring et al. 2014)	47400	0.45	No	Yes
Jun-Aug 2004	Florida to Bay of Fundy, combined	50978	0.42	No	Yes

Table 43: 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. For comparison, independent abundance estimates from NOAA technical reports and/or the scientific literature are shown. Please see the Discussion section below for our evaluation of our models compared to the other estimates. Note that our abundance estimates are averaged over the whole year, while the other studies may have estimated abundance for specific months or seasons. 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

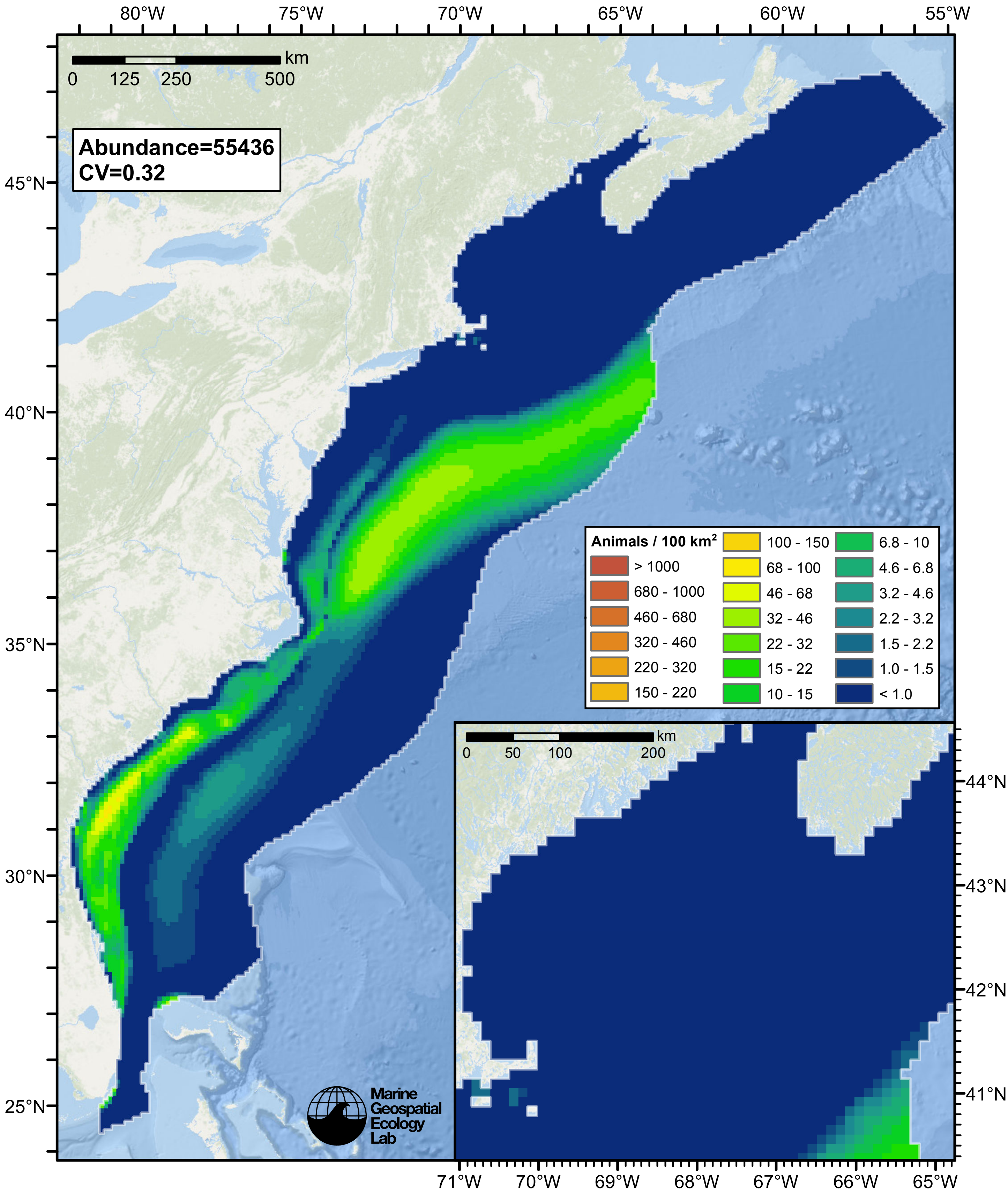


Figure 101: Atlantic spotted dolphin density and abundance predicted by the climatological model that explained the most deviance. Regions inside the study area (white line) where the background map is visible are areas we did not model (see text).

Contemporaneous Model

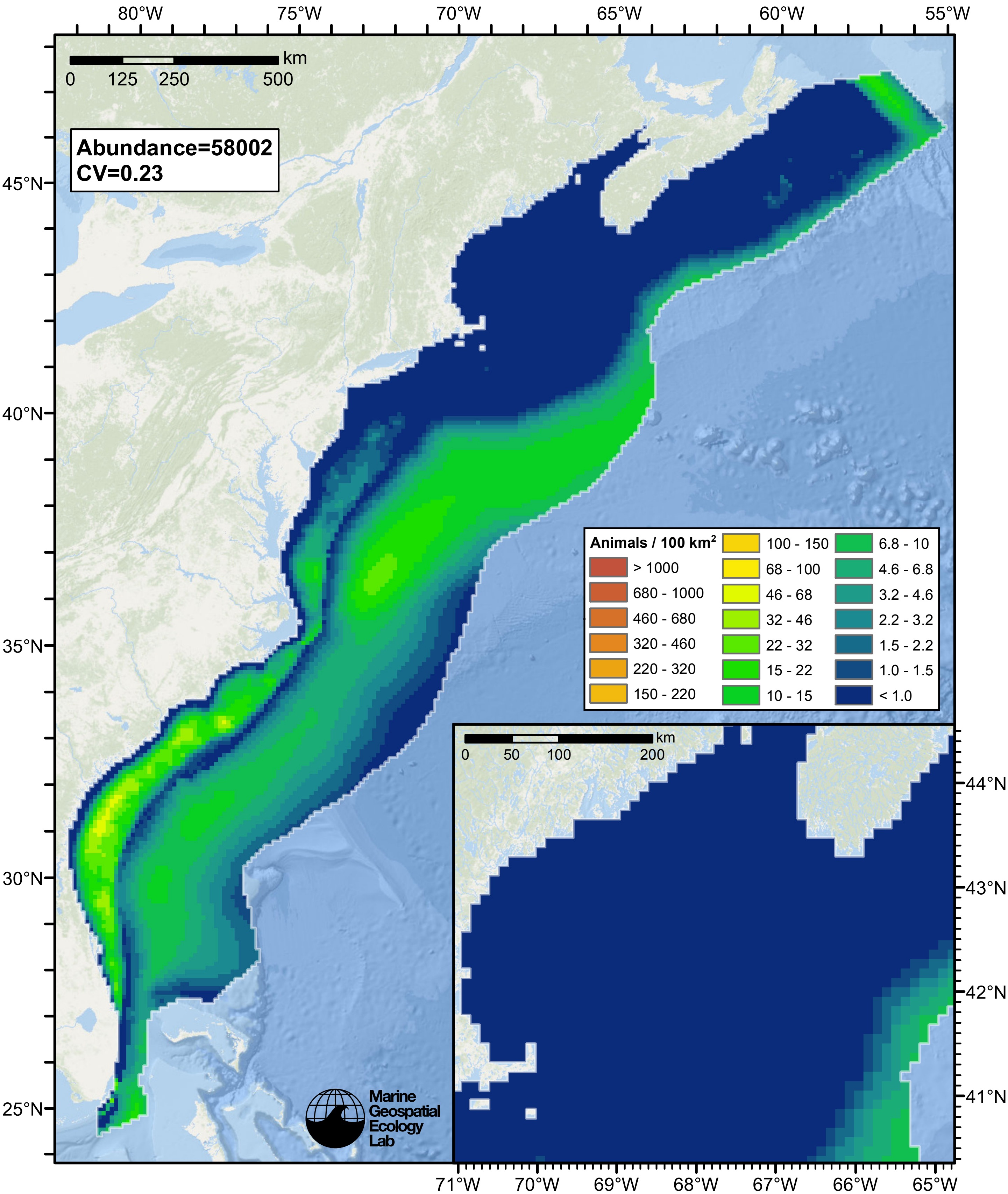


Figure 102: Atlantic spotted dolphin density and abundance predicted by the contemporaneous model that explained the most deviance. Regions inside the study area (white line) where the background map is visible are areas we did not model (see text).

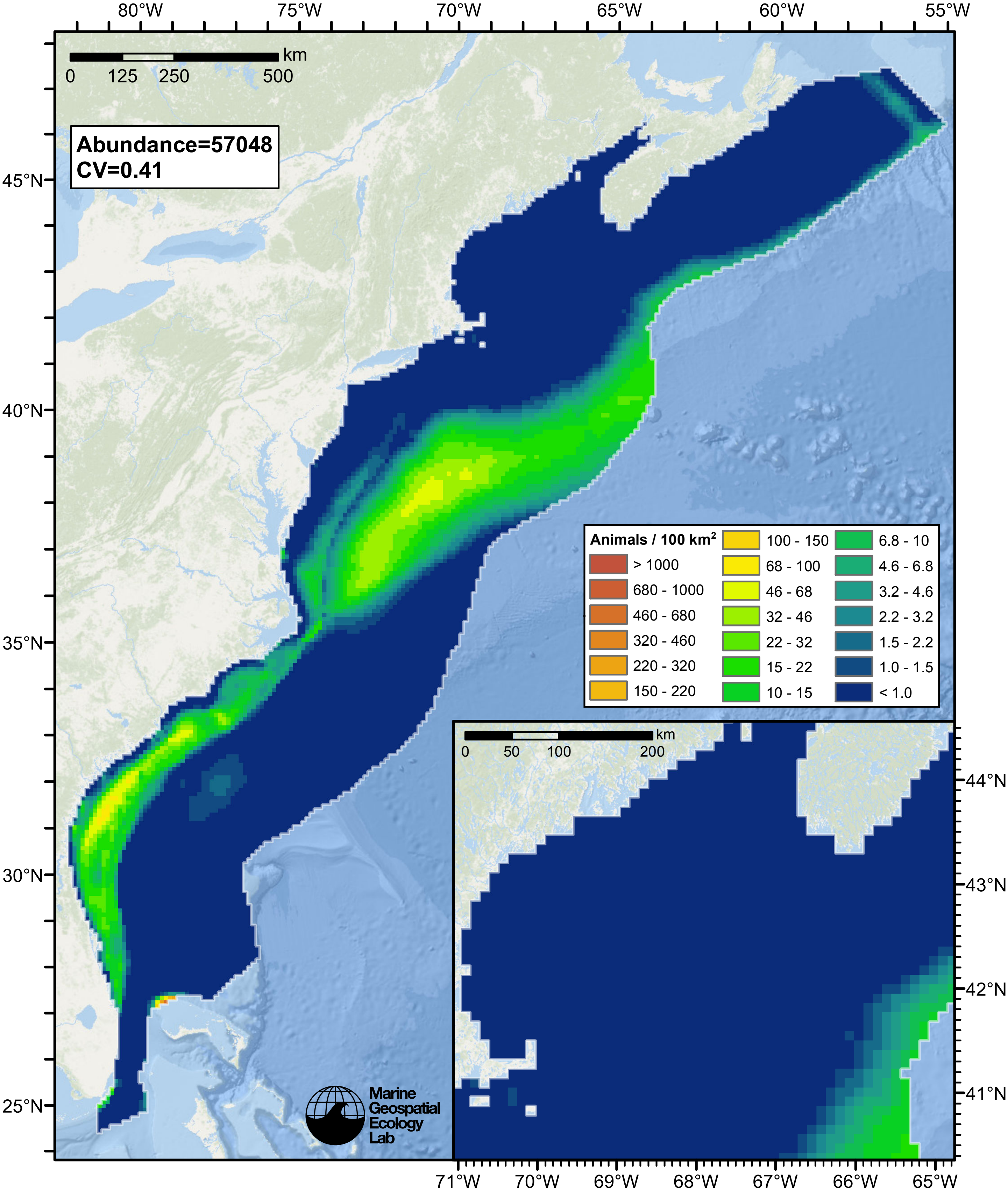


Figure 103: Atlantic spotted dolphin density and abundance predicted by the climatological same segments model that explained the most deviance. Regions inside the study area (white line) where the background map is visible are areas we did not model (see text).

Temporal Variability

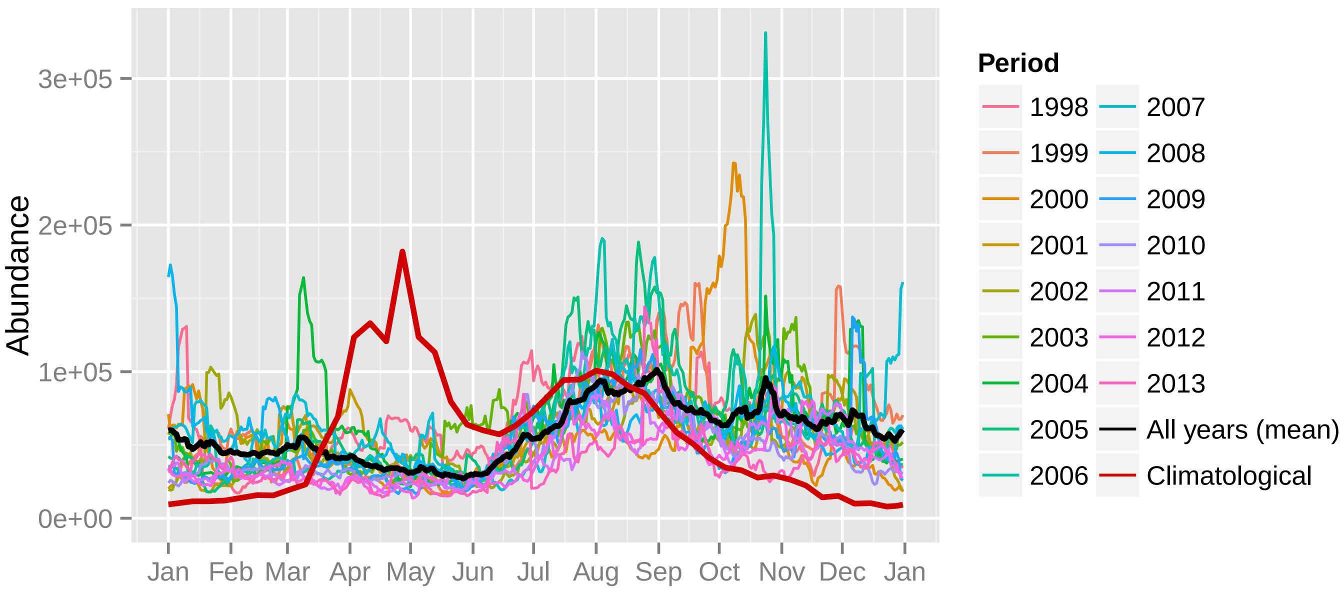


Figure 104: Comparison of Atlantic spotted dolphin abundance predicted at a daily time step for different time periods. Individual years were predicted using contemporaneous models. "All years (mean)" averages the individual years, giving the mean annual abundance of the contemporaneous model. "Climatological" was predicted using the climatological model. The results for the climatological same segments model are not shown.

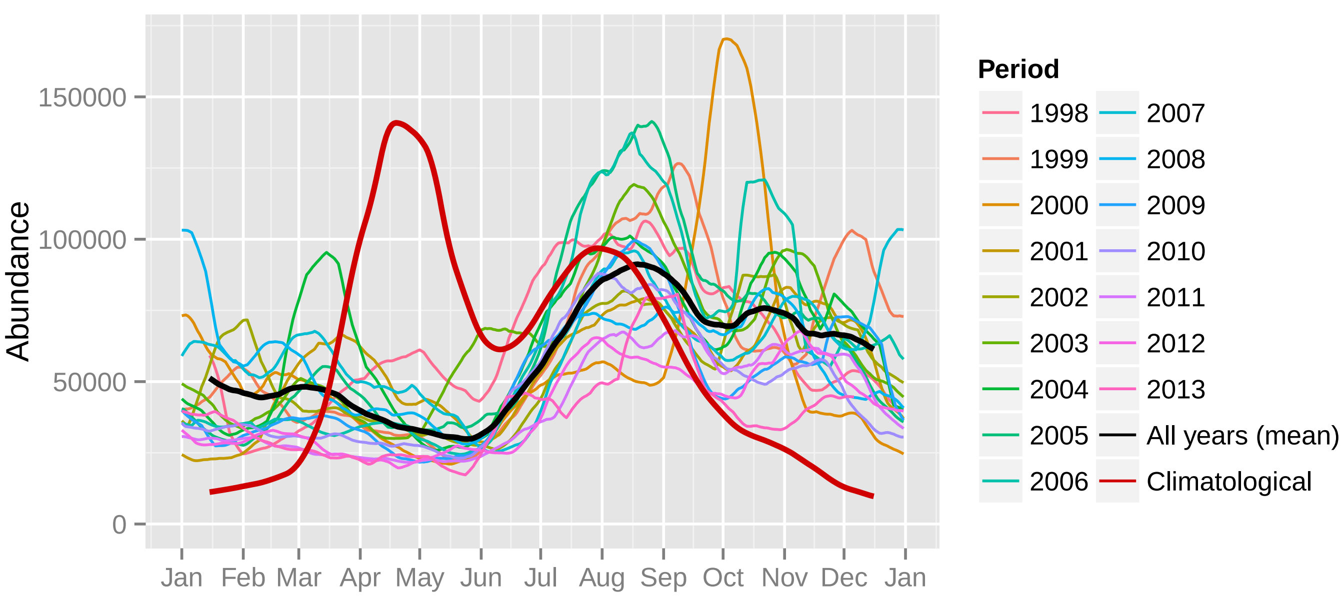
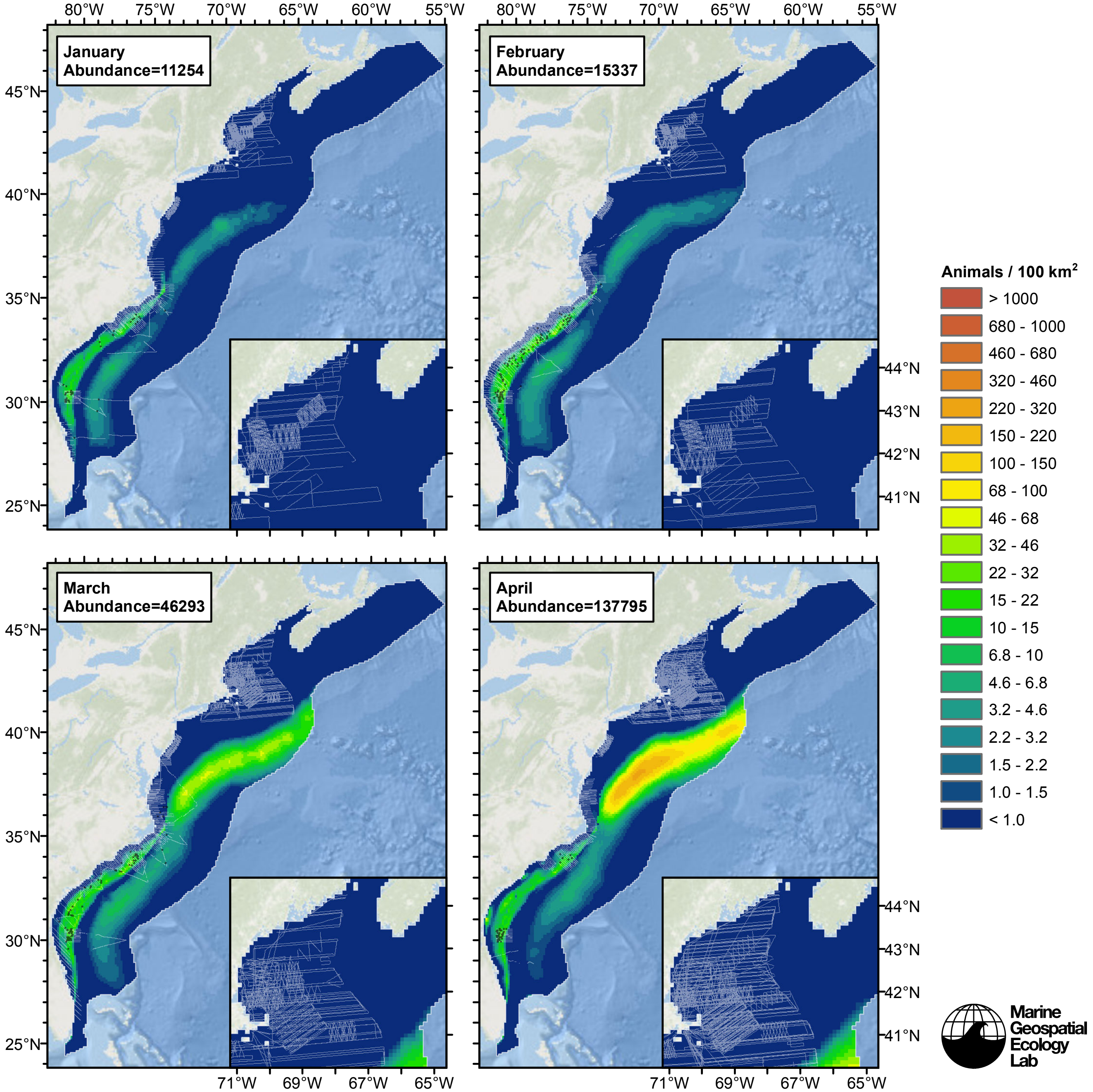
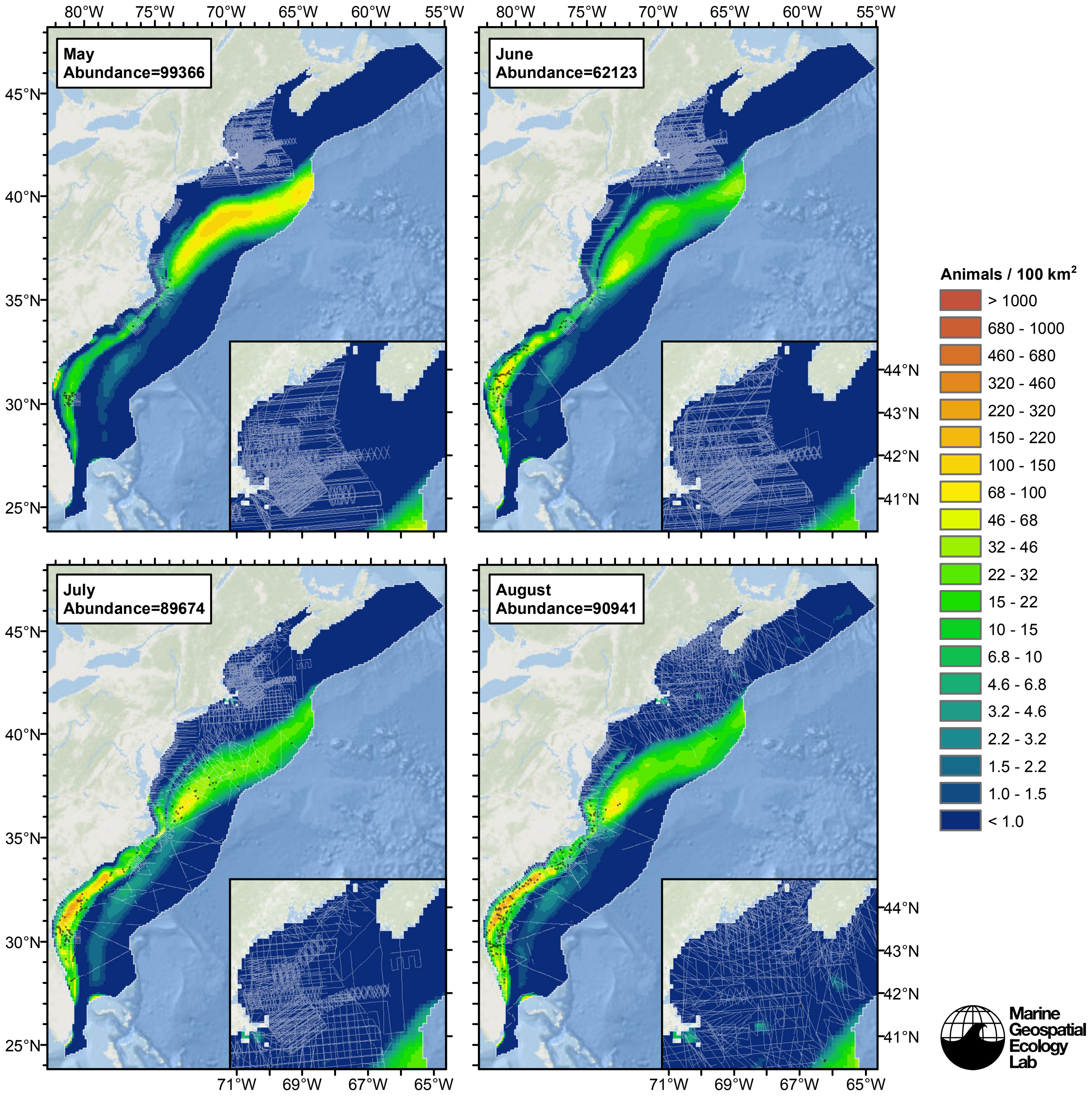


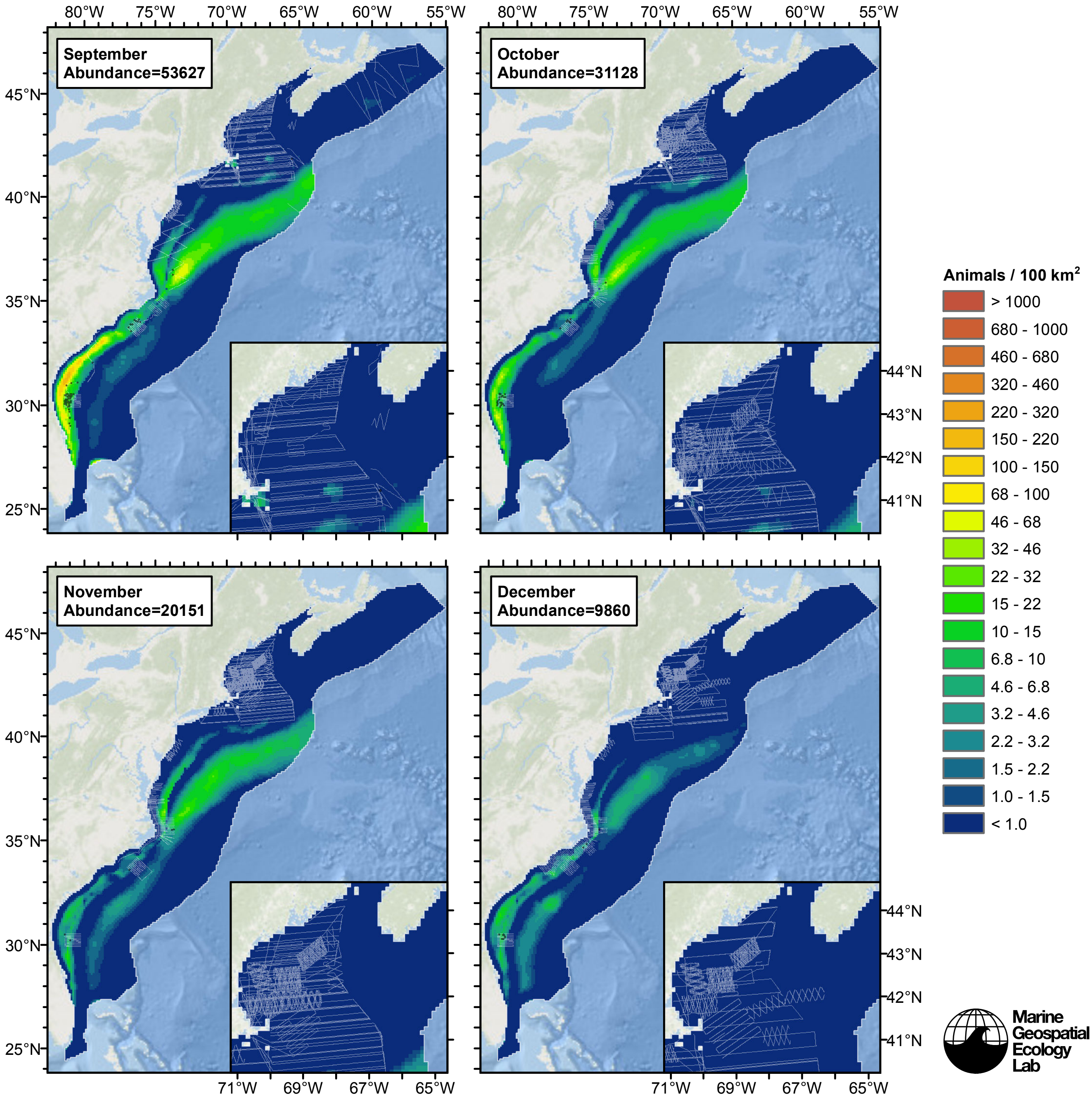
Figure 105: The same data as the preceding figure, but with a 30-day moving average applied.

Climatological Model

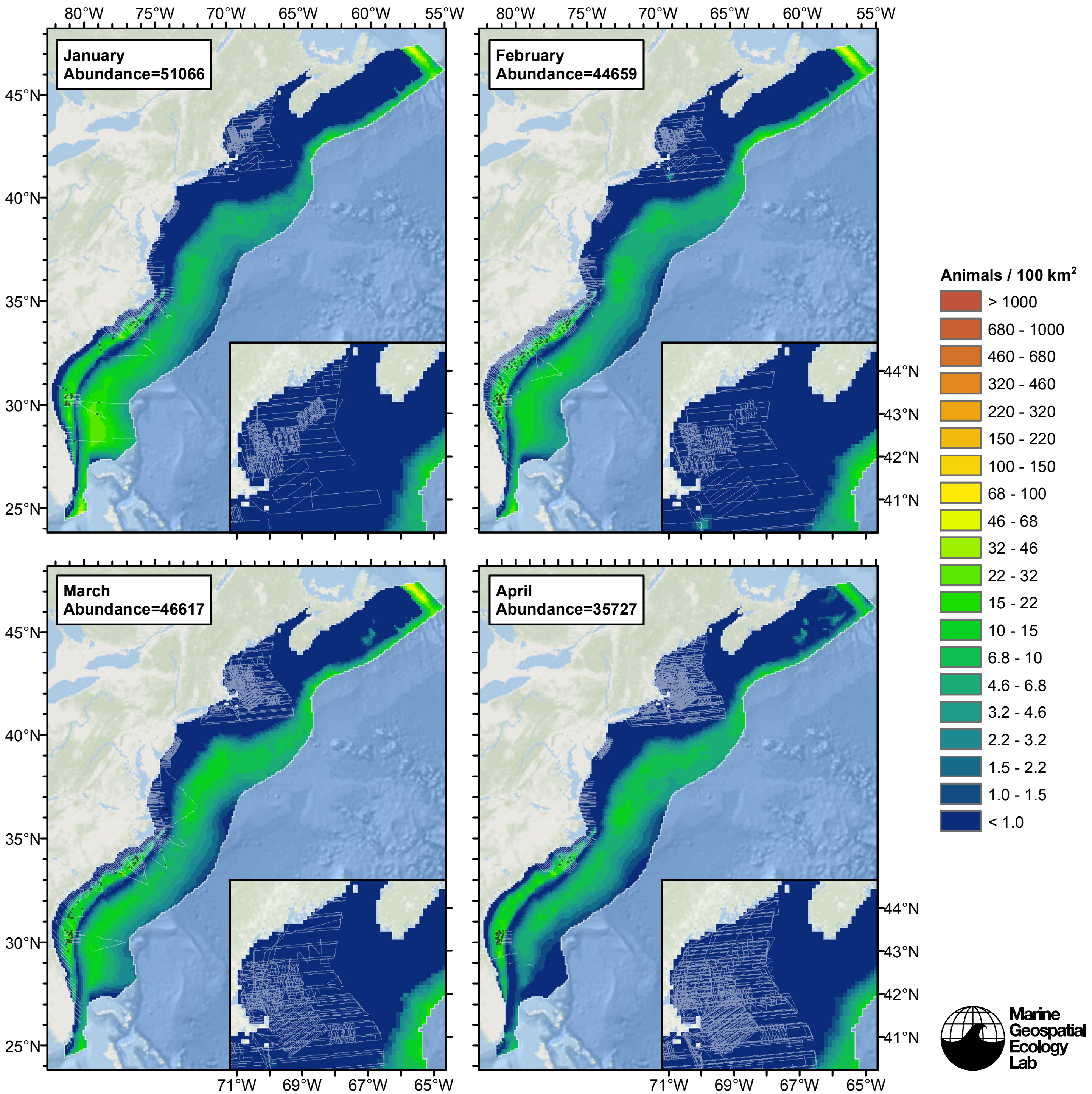


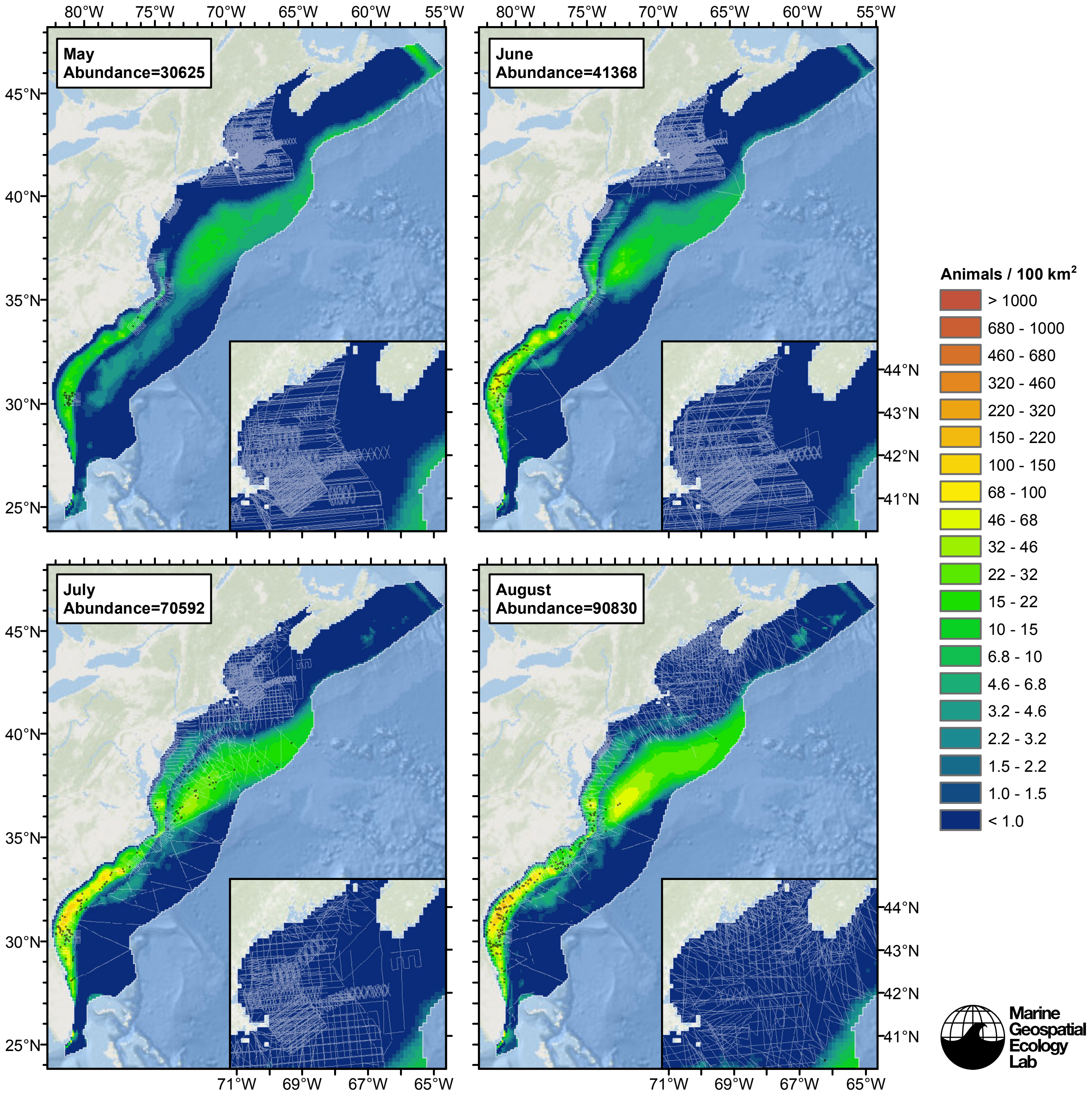


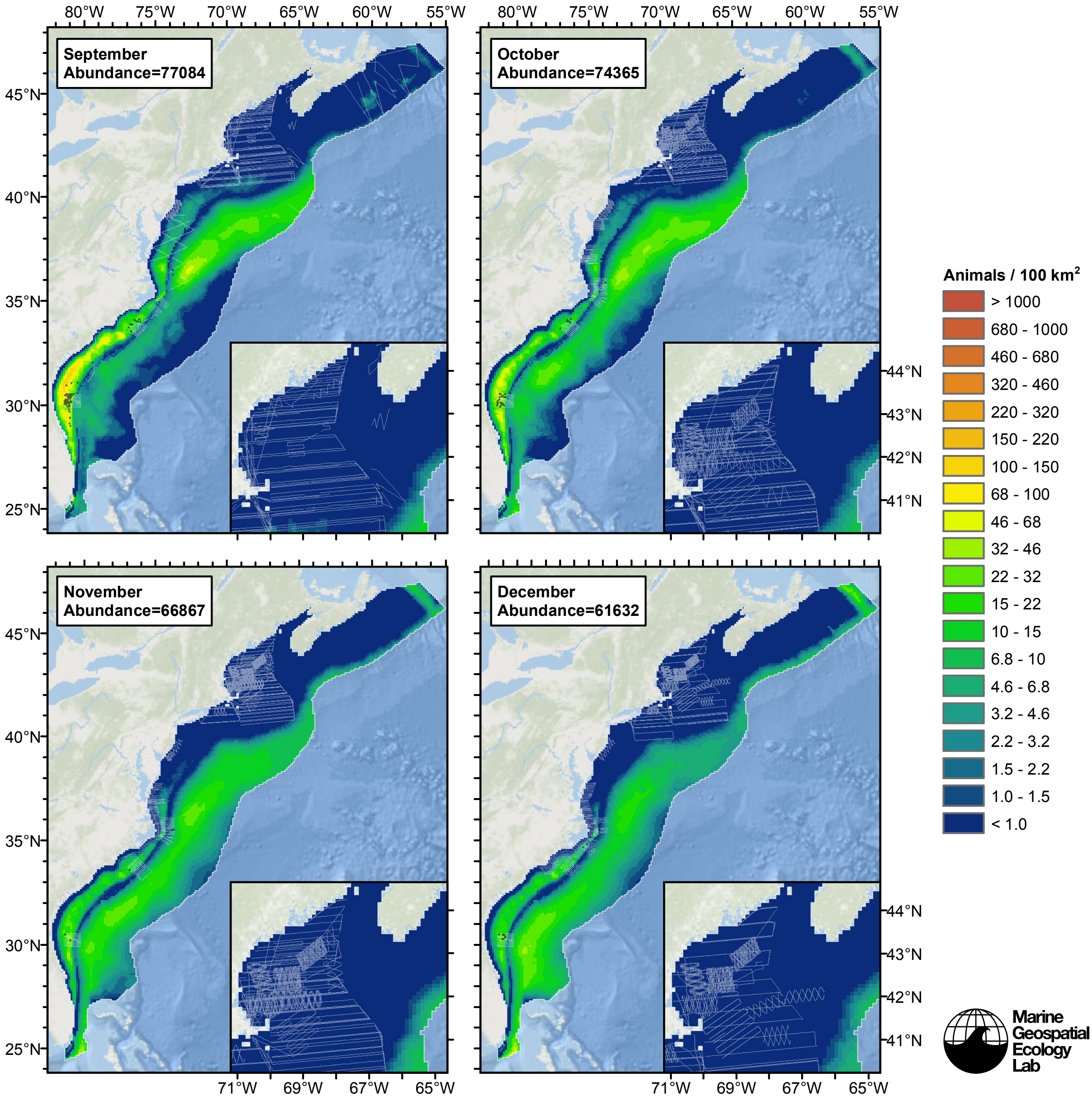
May
Abundance=99366
June
Abundance=62123
July
Abundance=89674
August
Abundance=90941
80°W
75°W
70°W
65°W
60°W
55°W
45°N
40°N
35°N
30°N
25°N
44°N
43°N
42°N
41°N
71°W
69°W
67°W
65°W
Animals / 100 km²
> 1000
680 - 1000
460 - 680
320 - 460
220 - 320
150 - 220
100 - 150
68 - 100
46 - 68
32 - 46
22 - 32
15 - 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
< 1.0
Marine
Geospatial
Ecology
Lab


September
Abundance=53627
October
Abundance=31128
November
Abundance=20151
December
Abundance=9860
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
> 1000
680 - 1000
460 - 680
320 - 460
220 - 320
150 - 220
100 - 150
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
< 1.0
Marine
Geospatial
Ecology
Lab

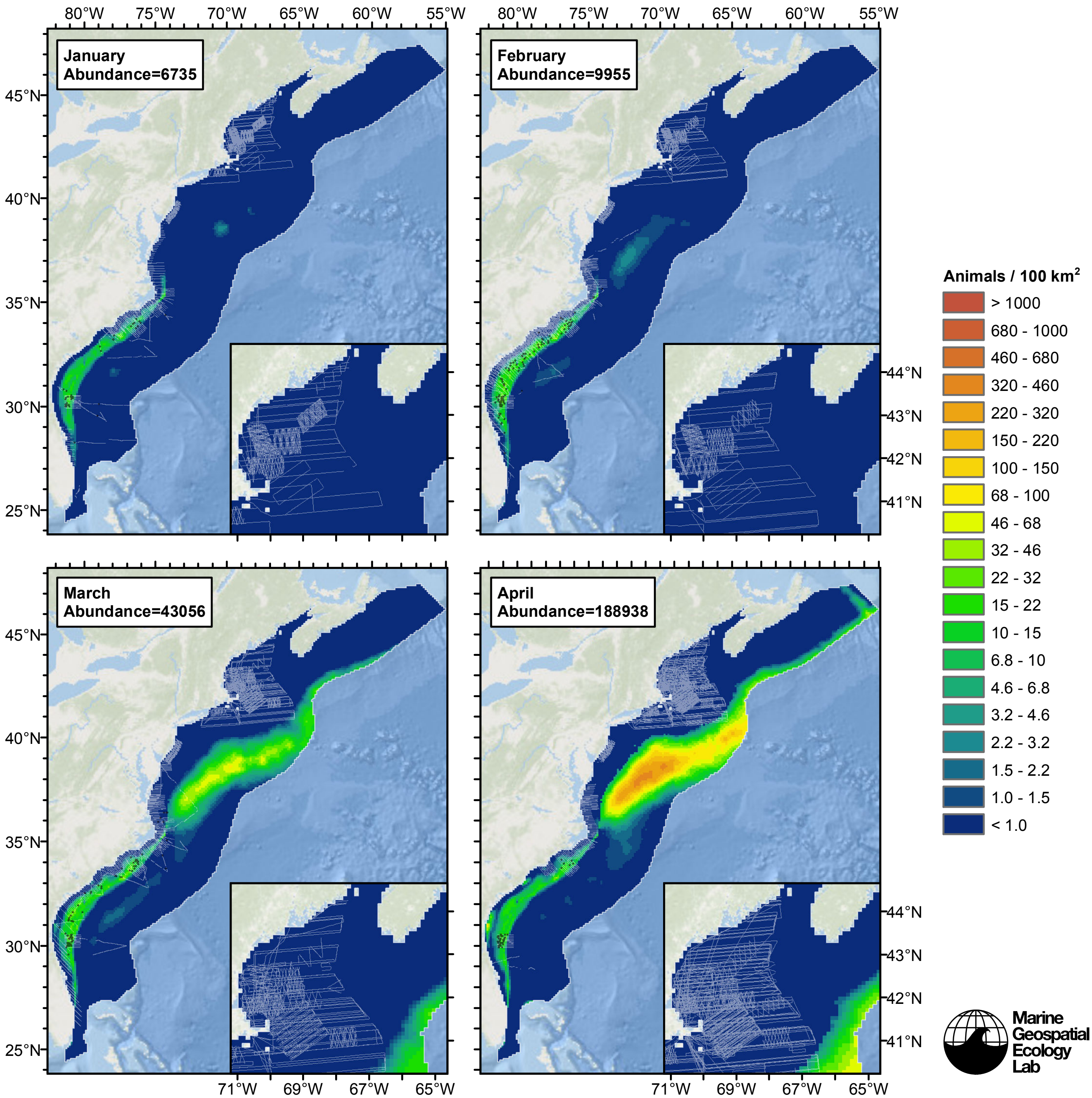
Contemporaneous Model

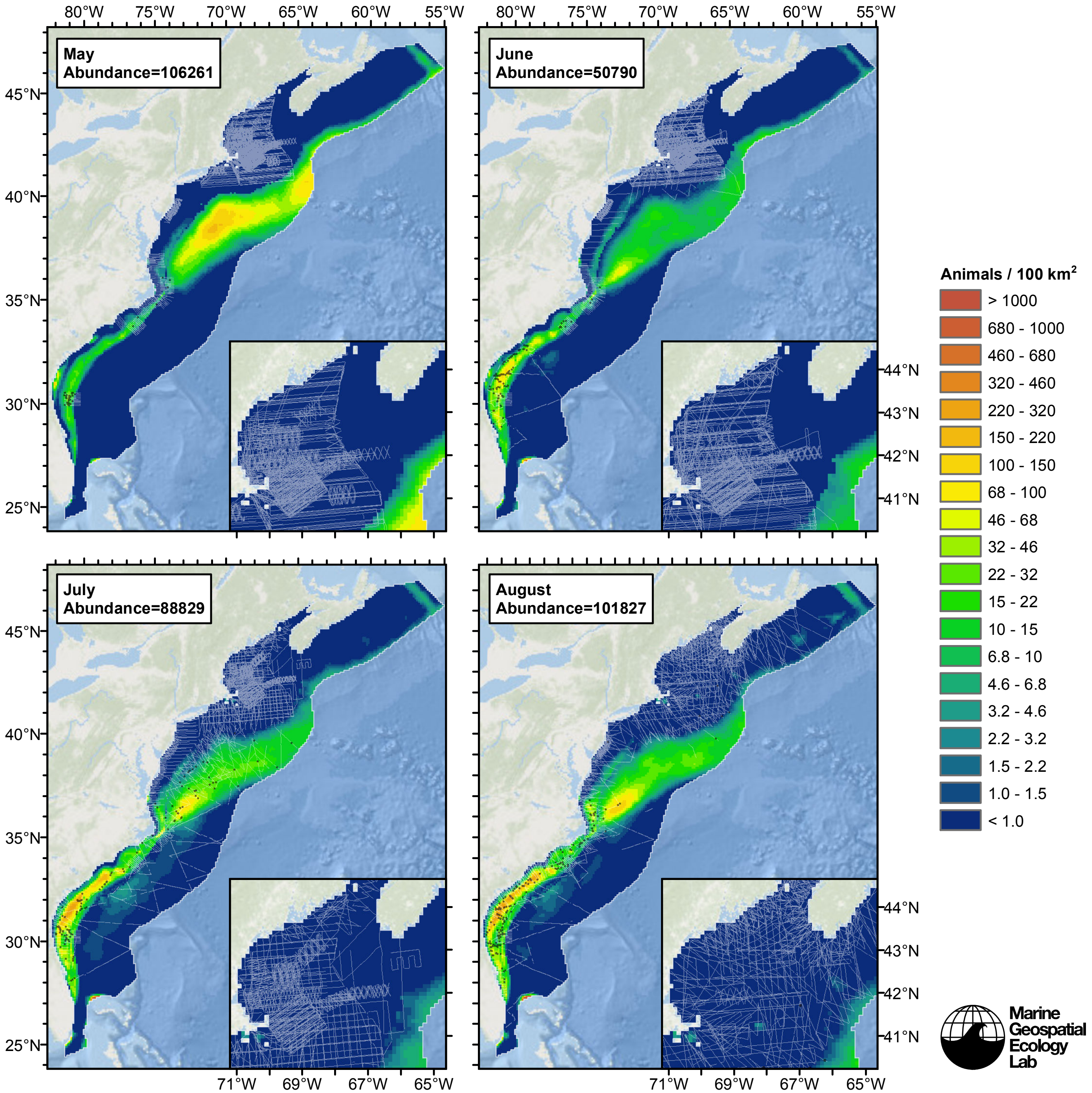


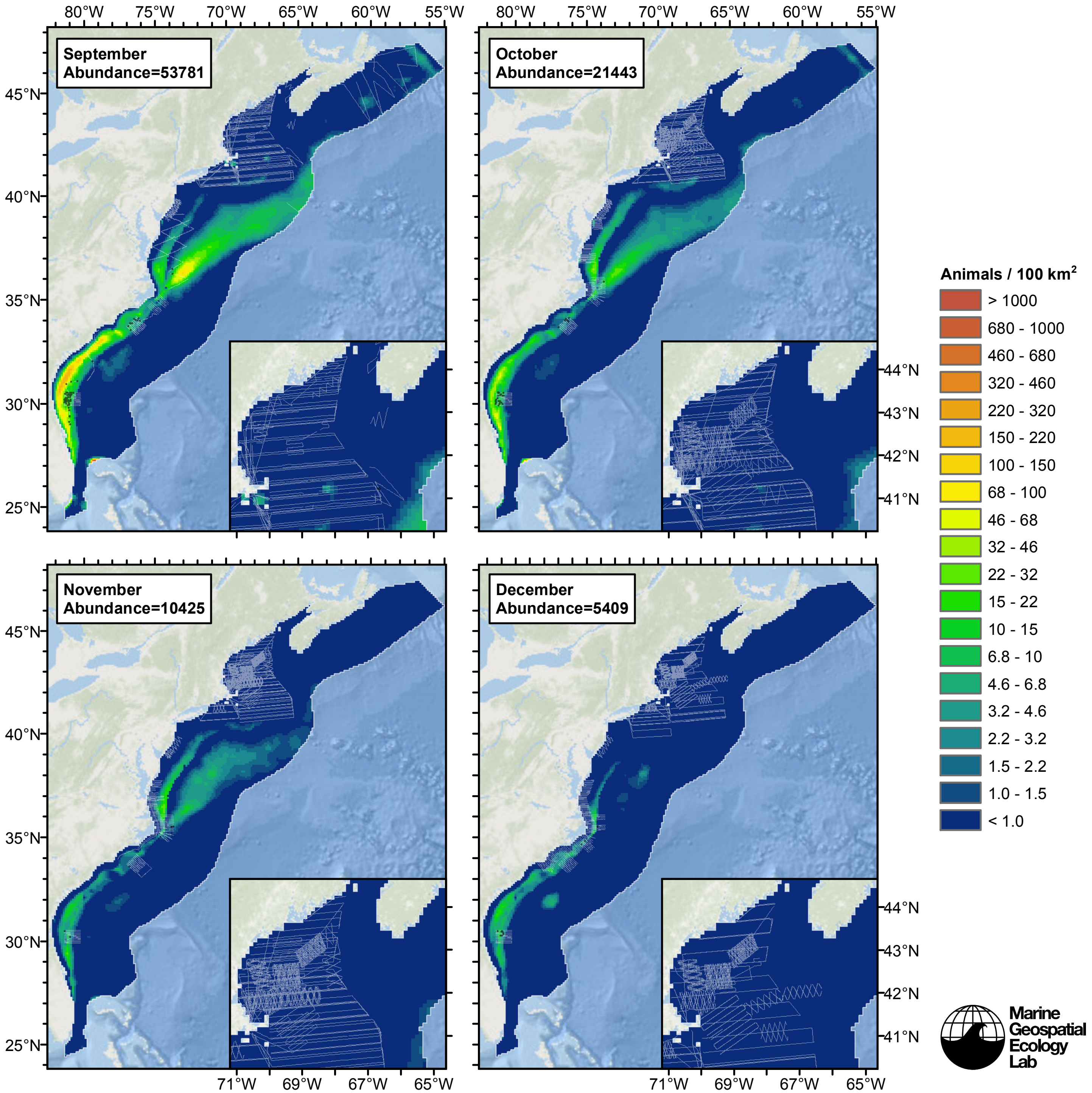

May
Abundance=30625
June
Abundance=41368
July
Abundance=70592
August
Abundance=90830
80°W
75°W
70°W
65°W
60°W
55°W
45°N
40°N
35°N
30°N
25°N
44°N
43°N
42°N
41°N
71°W
69°W
67°W
65°W
Animals / 100 km^2
> 1000
680 - 1000
460 - 680
320 - 460
220 - 320
150 - 220
100 - 150
68 - 100
46 - 68
32 - 46
22 - 32
15 - 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
< 1.0
Marine
Geospatial
Ecology
Lab


September
Abundance=77084
October
Abundance=74365
November
Abundance=66867
December
Abundance=61632
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
> 1000
680 - 1000
460 - 680
320 - 460
220 - 320
150 - 220
100 - 150
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
< 1.0
Marine
Geospatial
Ecology
Lab

Climatological Same Segments Model




May
Abundance=106261
June
Abundance=50790
July
Abundance=88829
August
Abundance=101827
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
> 1000
680 - 1000
460 - 680
320 - 460
220 - 320
150 - 220
100 - 150
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
< 1.0
Marine Geospatial Ecology Lab



Discussion

In both modeled subregions, models built with climatological predictors explained slightly more deviance than models built with contemporaneous predictors. On this basis, we selected the models with with climatological predictors as our best estimate of Atlantic spotted dolphin density and abundance.

The combined predictions for the two subregions predict an interesting pattern of density: low near the shore, high in the mid-shelf, low near the shelf break, then higher again off shore. This is consistent with morphometric, genetic, and acoustic results that suggest that two ecotypes or sub-species inhabit the study area (Viricel and Rosel 2014, Baron et al. 2008). It also contrasts strongly with the predictions of our bottlenose dolphin model, which predicted a pattern of high density near shore, low in the mid-shelf, and high at the shelf break. Habitat partitioning between these species has been suggested for the

Gulf of Mexico, with bottlenose dolphins dominating near-shore waters and Atlantic-spotted dolphins dominating deeper shelf waters (Griffin and Griffin 2003). Our models predict a similar pattern here, but with the offshore bottlenose dolphin ecotype dominating the shelf break.

Given the absence of information about migration patterns for this species (Viricel and Rosel 2014), we do not offer density predictions at a monthly time step for this species, and instead provide a single year-round prediction.

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