Habitat-based density model for Risso's dolphin in the AFTT area

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This report documents the habitat-based density model for Risso's dolphin in the Atlantic Fleet Testing and Training Area (AFTT) area. Information on the first stage of the modeling approach, including classification of ambiguous sightings, detection function fitting and g(0) estimation can be found in individual taxon reports presented in Roberts et al. (2016) for the U.S. Atlantic and Gulf of Mexico.

Citation for this model: Mannocci L, Roberts JJ, Miller DL, Halpin PN (2016). Habitat-based density model for Risso's dolphin in the AFTT area. 2016-10-01. Marine Geospatial Ecology Lab, Duke University, Durham, NC.

Citation for the related publication: Mannocci L, Roberts JJ, Miller DL, Halpin PN. Extrapolating cetacean densities to quantitatively assess human impacts on populations in the high seas. In review in Conservation Biology.

1- Available data

Table 1: Effort (km) and sightings per surveyed region (CAR: Caribbean, EC: East coast, EU: European Atlantic, GM: Gulf of Mexico, MAR: Mid-Atlantic ridge). Details on the origin of sightings used in this study can be found in Table 1 of the associated publication.

Region	Effort	Sightings
CAR	24264.47	2
EC	1044357.70	721
EU	27526.34	9
GOM	194715.35	279
All regions	1290863.87	1011

Table 2: Effort (km) and sightings per month.

Month	Effort	Sightings
January	77892.79	3
February	123591.37	15
March	117923.54	42
April	117929.72	34
May	149765.03	139
June	130361.37	90
July	162252.51	289
August	129660.43	319
September	71696.07	26
October	82560.18	32
November	69210.92	14
December	58019.93	8
All Months	1290863.87	1011

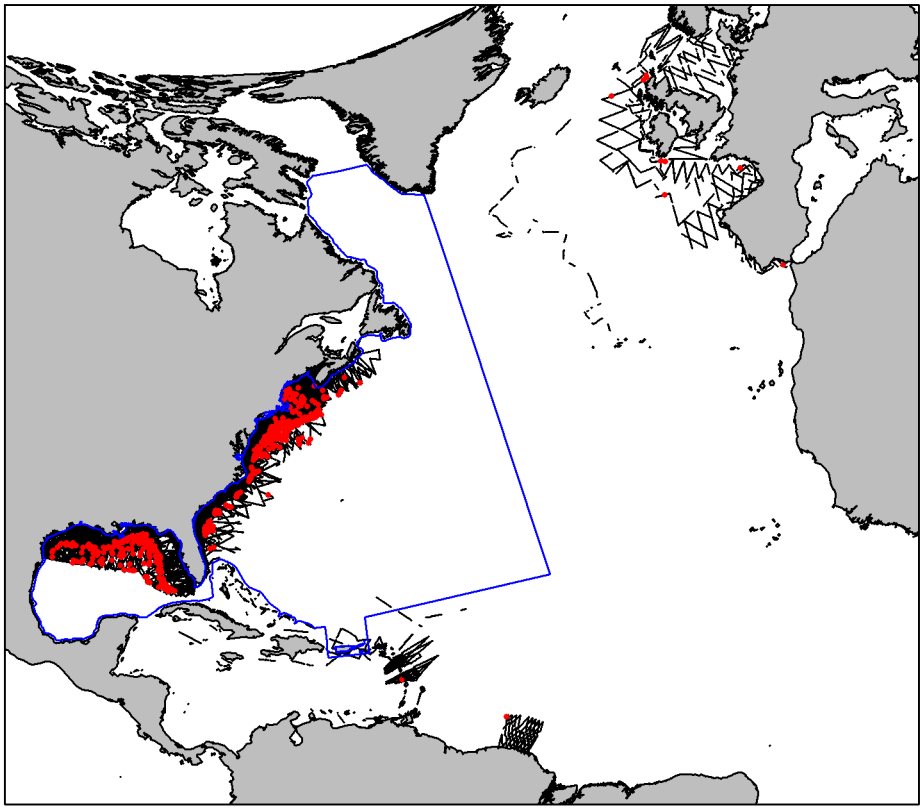


Figure 1: Map of segments (black lines) and sighting locations (red dots). An Albers equal area projection optimized for the AFTT area is used.

2- Methodological decisions

Methodological decisions reported in this section were made according to information available to us in the literature as well as feedback from a number of experts we consulted.

Modeled taxon

Risso's dolphin (*Grampus griseus*)

Modeled season

We fitted a year-round model as we found no evidence in the literature that Risso's dolphin undertakes extensive migrations or exhibits contrasting behaviors (e.g., feeding versus breeding) in different seasons, at the scale of our study area.

Segments

We included segments from the east coast, Gulf of Mexico and Caribbean. Since segments from the western North Atlantic provided an already large number of sightings (Table 1), we did not incorporate segments from the European Atlantic (they would have provided only 9 additional sightings).

3- Best model

- **Predictors**: depth, distance to sea surface temperature fronts (DistToFront), production of epipelagic micronekton (EpiMnkPP), zooplankton production (PKPP)
- **Model summary**:

```
##
## Family: Tweedie(p=1.28)
## Link function: log
##
## Formula:
## abundance ~ s(Depth, k = 4, bs = "ts") + s(DistToFront1, k = 4,
##     bs = "ts") + s(EpiMnkPP, k = 4, bs = "ts") + s(PkPB, k = 4,
##     bs = "ts") + offset(log(area_km2))
## <environment: 0x1a3f9d00>
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  -6.9768     0.1244  -56.08   <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(Depth)        2.839      3 147.39  <2e-16 ***
## s(DistToFront1) 2.796      3  38.77  <2e-16 ***
## s(EpiMnkPP)     2.785      3  43.42  <2e-16 ***
## s(PkPB)         2.955      3  67.03  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.0288   Deviance explained = 38.4%
## -REML = 6783.4  Scale est. = 63.192    n = 113880
```

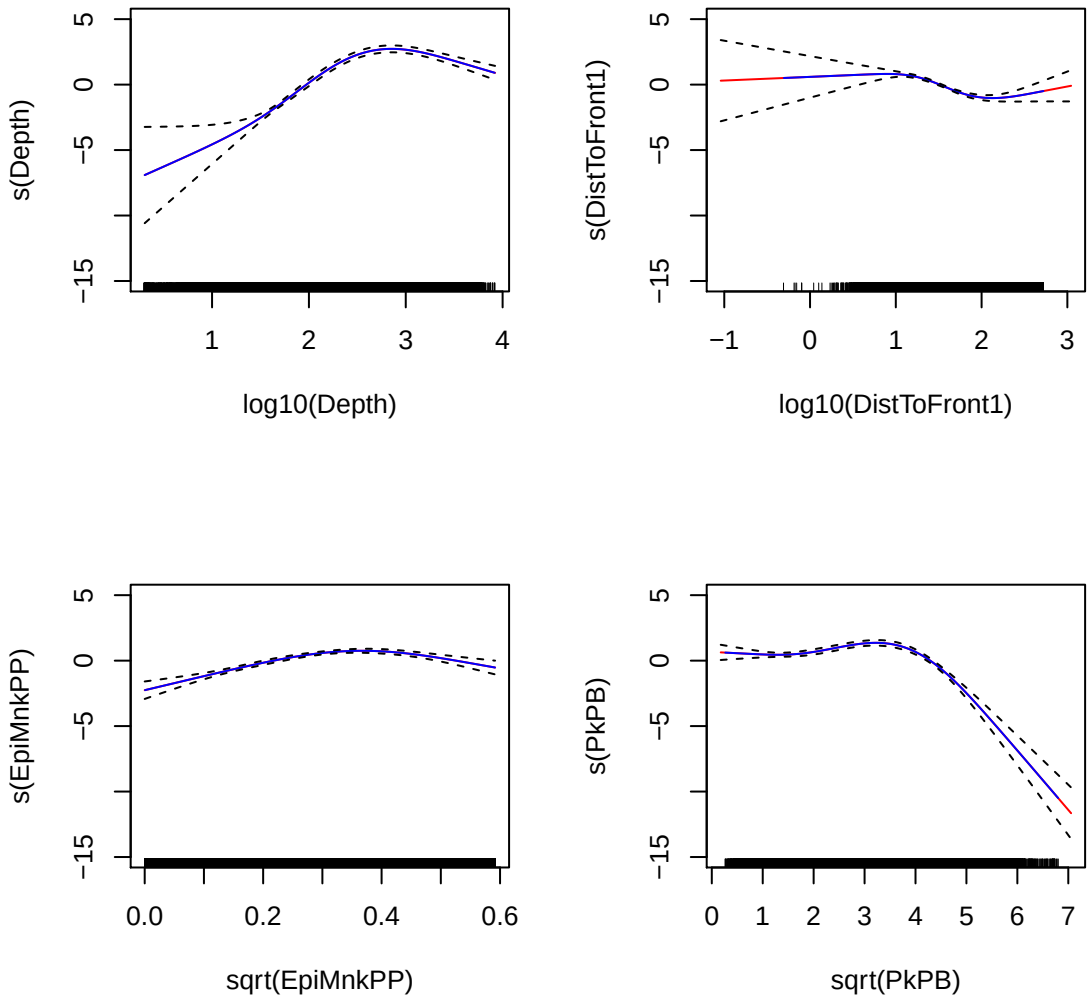


Figure 2: GAM term plots with the log-transformed abundance on the y axis. The solid blue line is the smooth function fitted to the data. The solid red line is the smooth function extrapolated to all covariate values in the prediction area. The dashed lines represent the approximate 95% confidence intervals. The rug plot on the x-axis shows covariate values sampled in the data. Note that transformations were used for some covariates.

4- Environmental envelopes

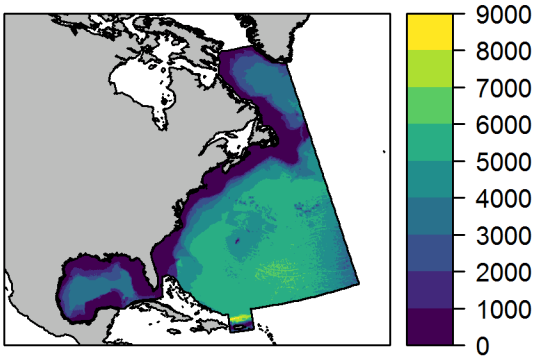
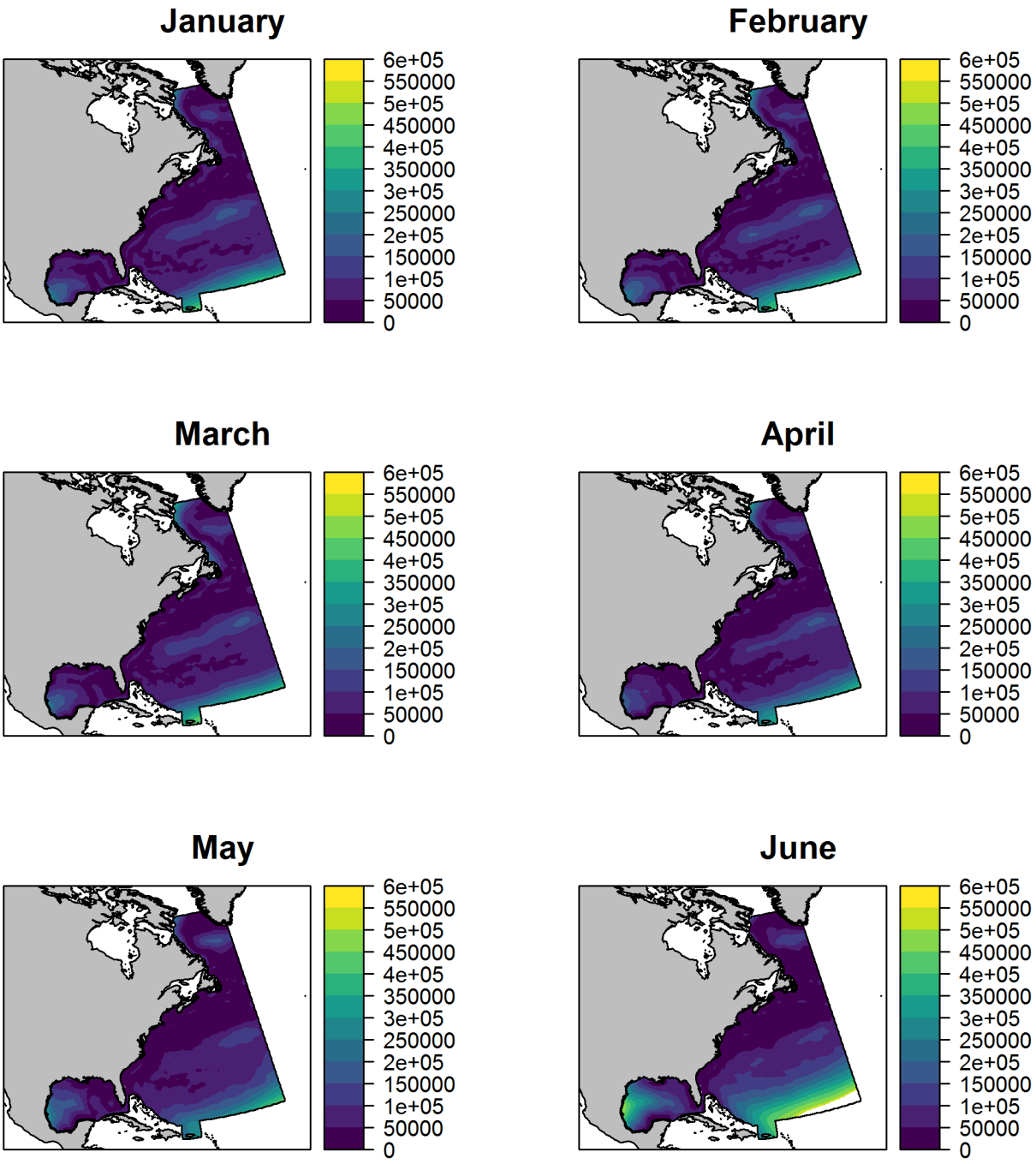


Figure 3: Environmental envelope for depth. White cells within the AFTT polygon indicate areas where covariate values fell beyond the range of covariate values sampled by the surveys.


January
February
March
April
May
June
6e+05
550000
5e+05
450000
4e+05
350000
3e+05
250000
2e+05
150000
1e+05
50000
0

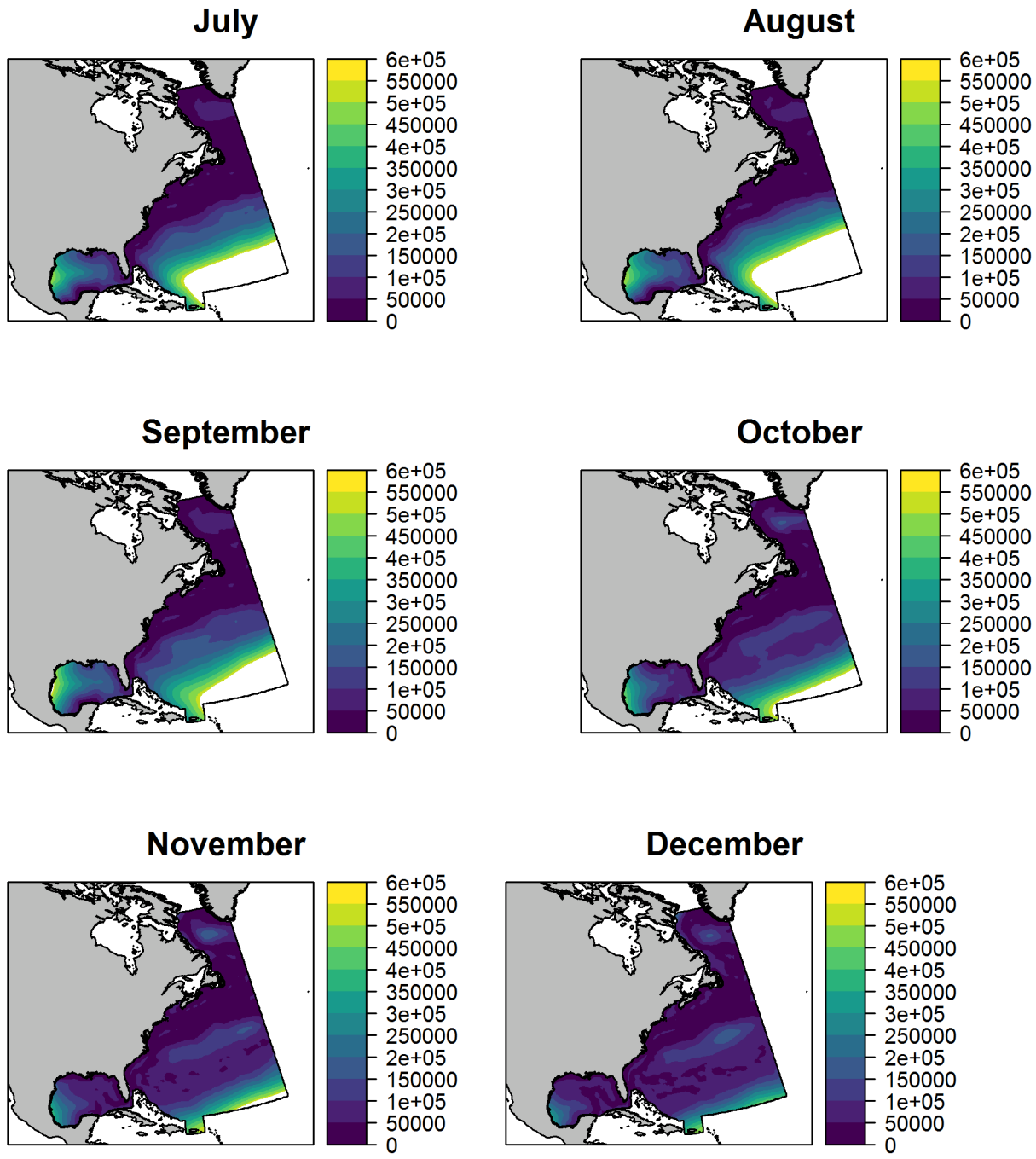
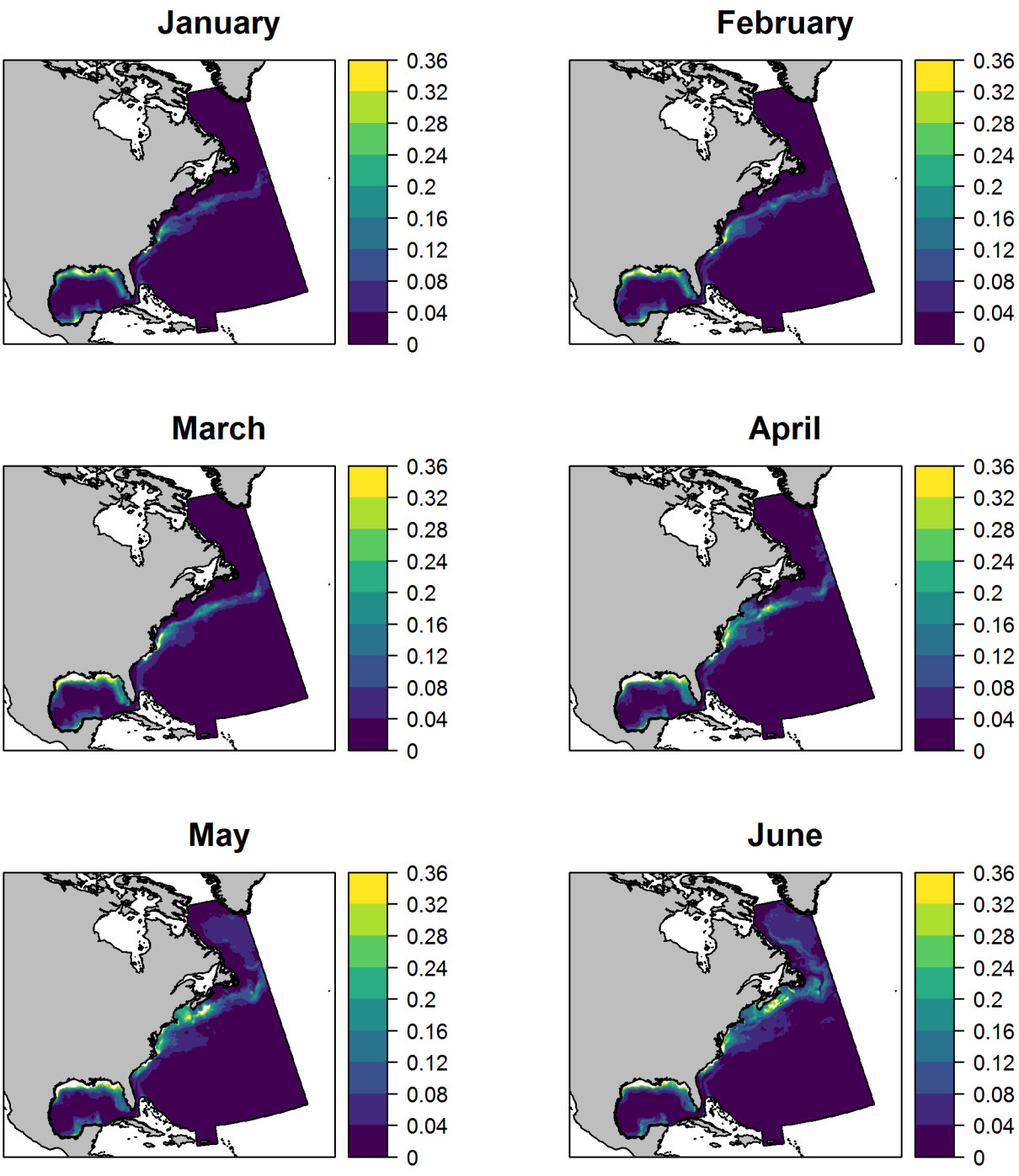


Figure 4: Monthly environmental envelopes for distance to sea surface temperature fronts. White cells within the AFTT polygon indicate areas where covariate values fell beyond the range of covariate values sampled by the surveys.


January
February
March
April
May
June
0.36
0.32
0.28
0.24
0.2
0.16
0.12
0.08
0.04
0

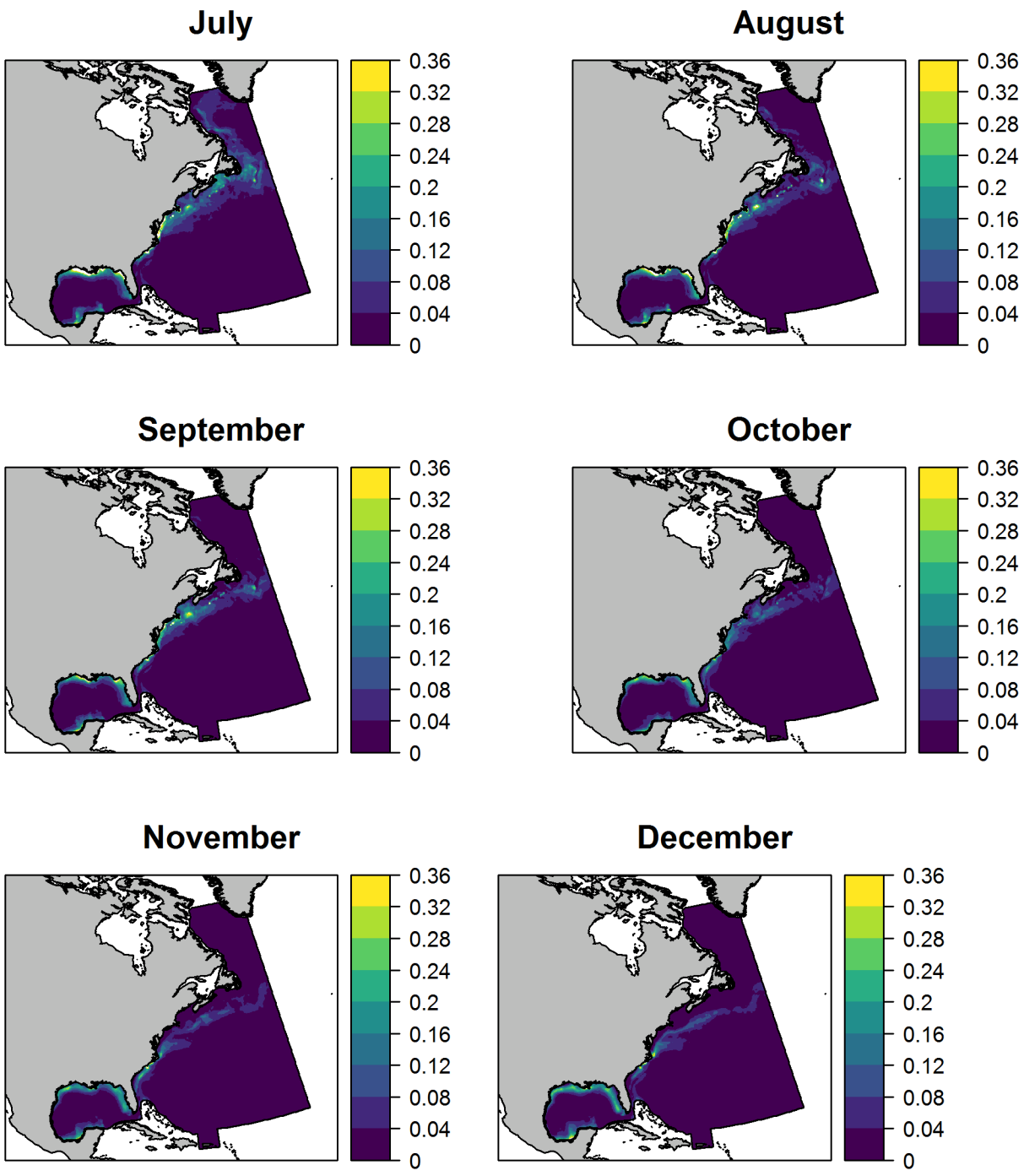
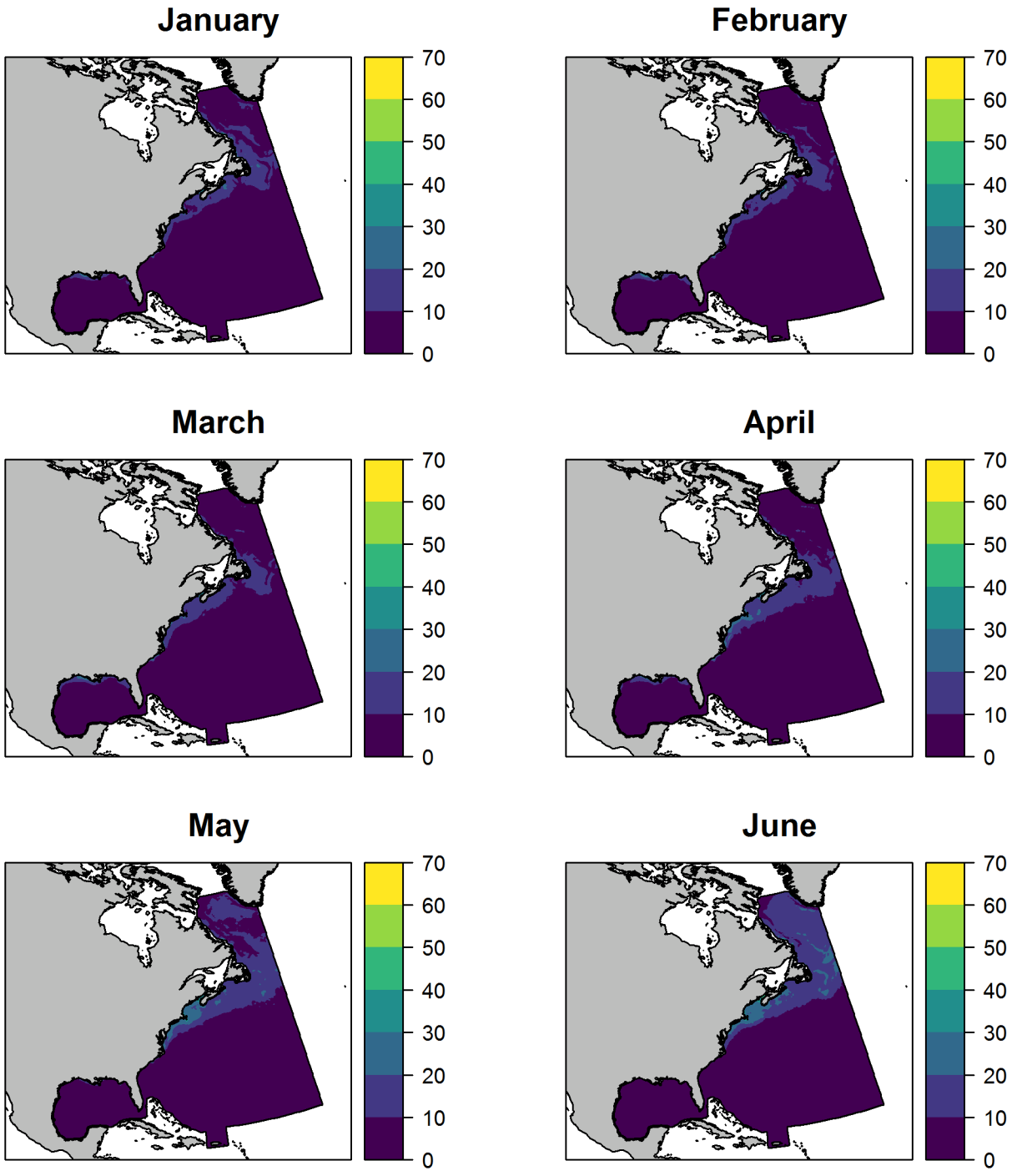


Figure 5: Monthly environmental envelopes for production of epipelagic micronekton. White cells within the AFTT polygon indicate areas where covariate values fell beyond the range of covariate values sampled by the surveys.


January
February
March
April
May
June
70
60
50
40
30
20
10
0

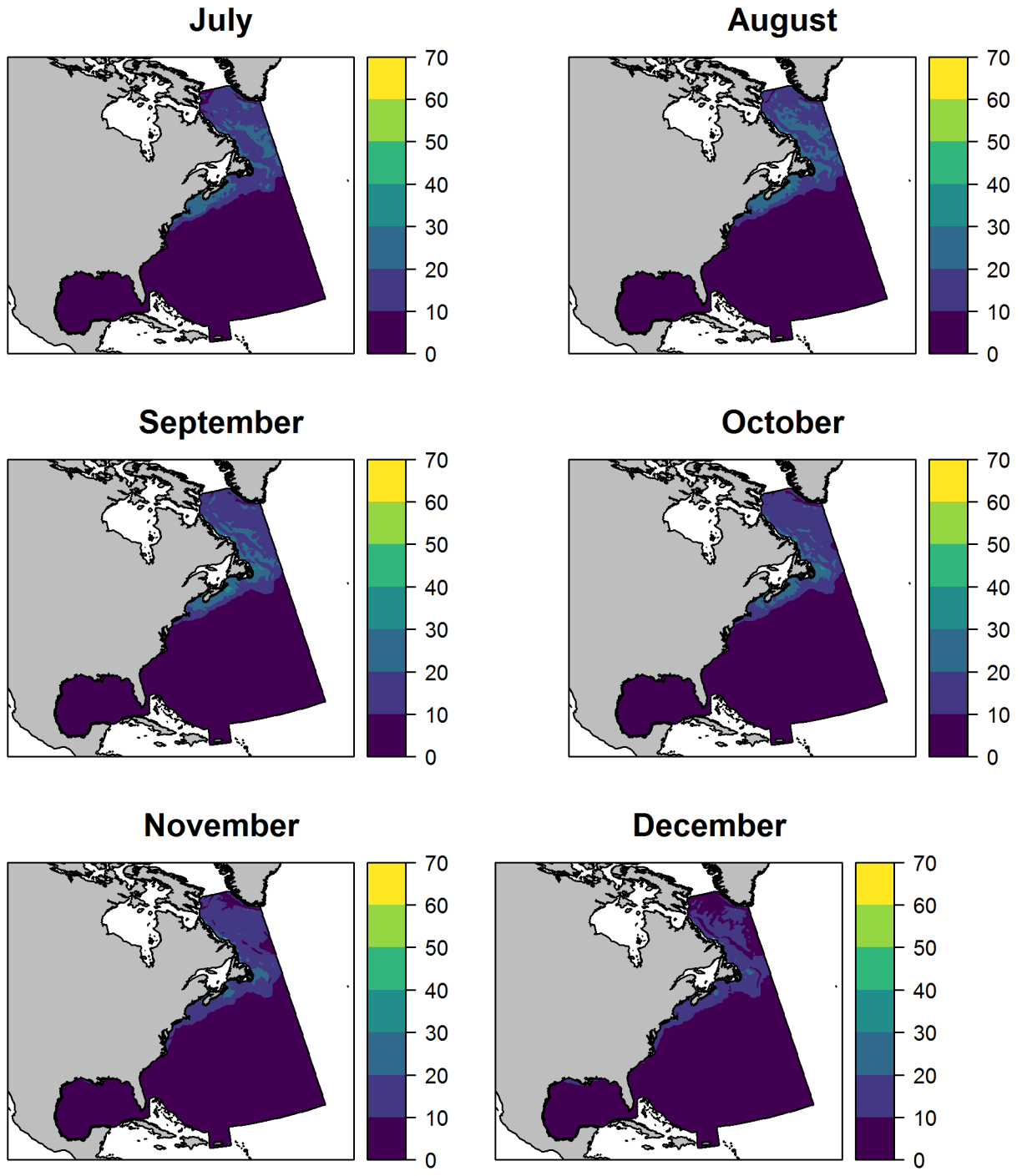


Figure 6: Monthly environmental envelopes for zooplankton production. White cells within the AFTT polygon indicate areas where covariate values fell beyond the range of covariate values sampled by the surveys.

5- Predicted densities

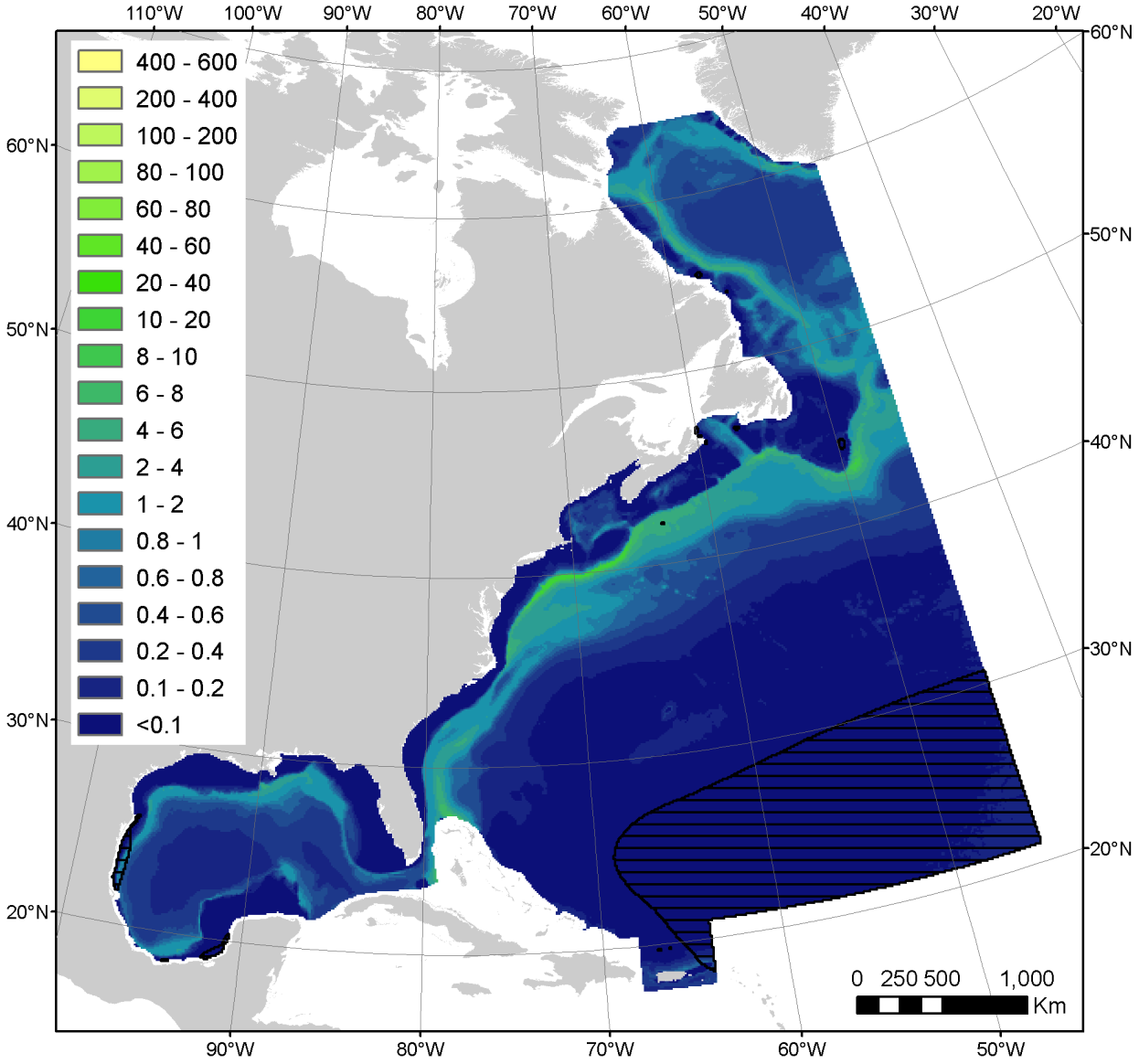


Figure 7: Mean predicted densities (individuals 100 km-2) in the AFTT area. Areas where we extrapolated beyond sampled predictor ranges and predicted densities should not be trusted are indicated with black crosshatches. An Albers equal area projection is used.

6- Coefficients of variation

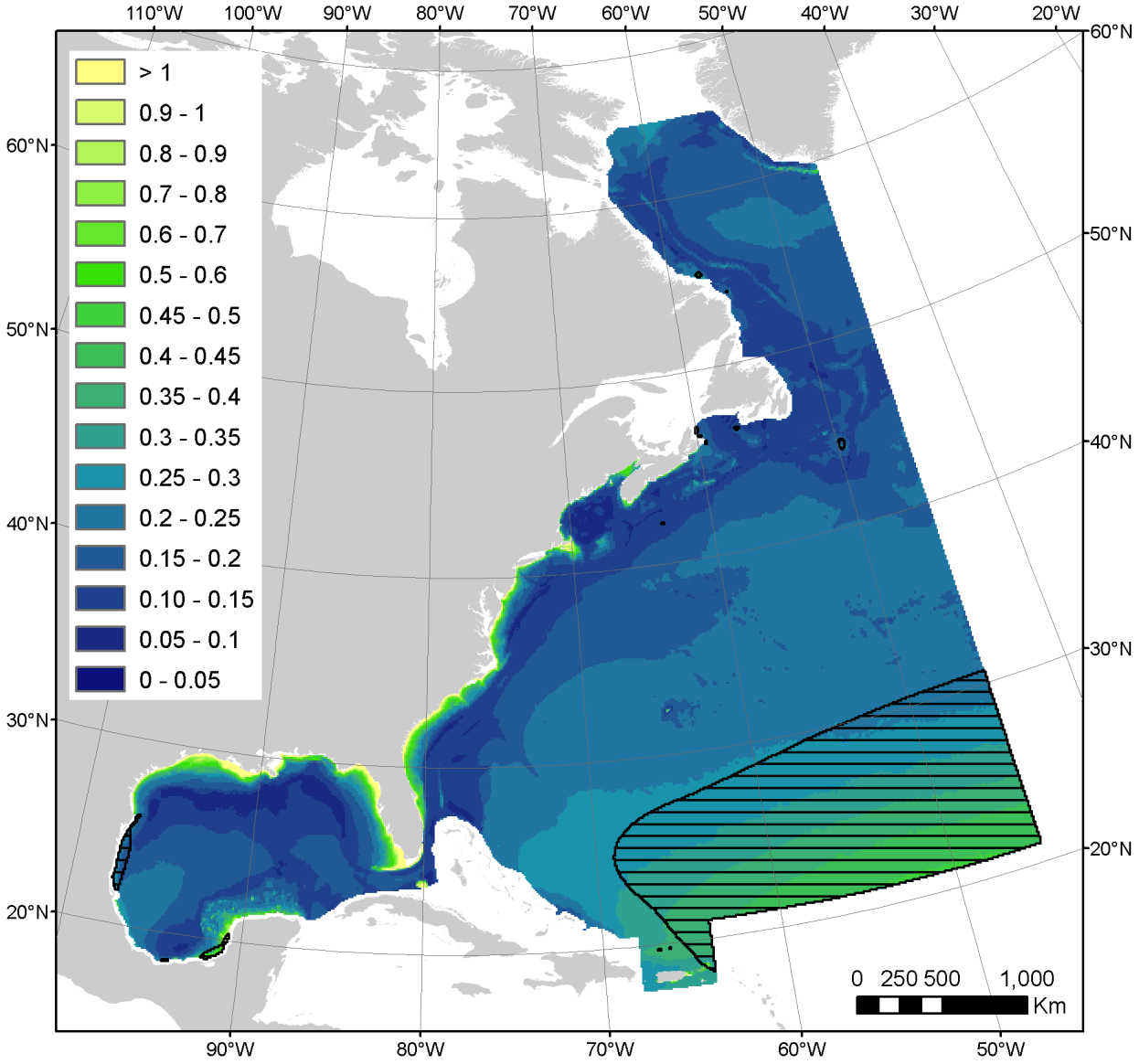


Figure 8: Mean predicted coefficients of variation derived from GAM parameters in the AFTT area. Areas where we extrapolated beyond sampled predictor ranges and coefficients of variation should not be trusted are indicated with black crosshatches. An Albers equal area projection is used.

7- Predicted densities per province

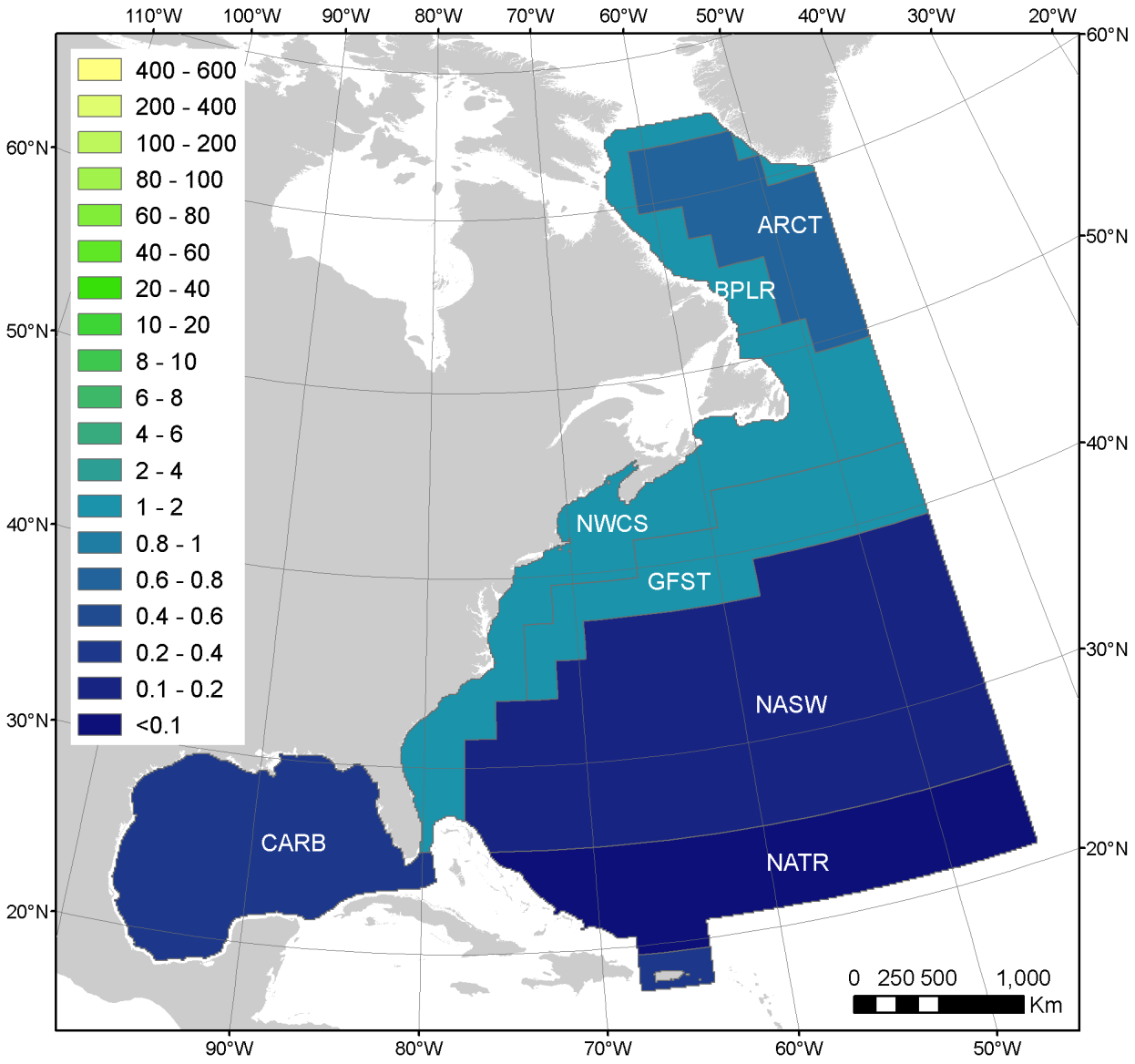


Figure 9: Predicted densities (individuals 100 km-2) averaged per Longhurst's biogeographical province. Note that the color scheme is the same as in Figure 7. Provinces: ARCT: Atlantic Arctic Province; BPLR: Boreal Polar Province; CARB: Caribbean Province; GFST: Gulf Stream Province; NATR: North Atlantic Tropical Gyral Province; NASW: North Atlantic Subtropical Gyral Province (West); NWCS: North West Atlantic Shelves Province.

8- Alternate models

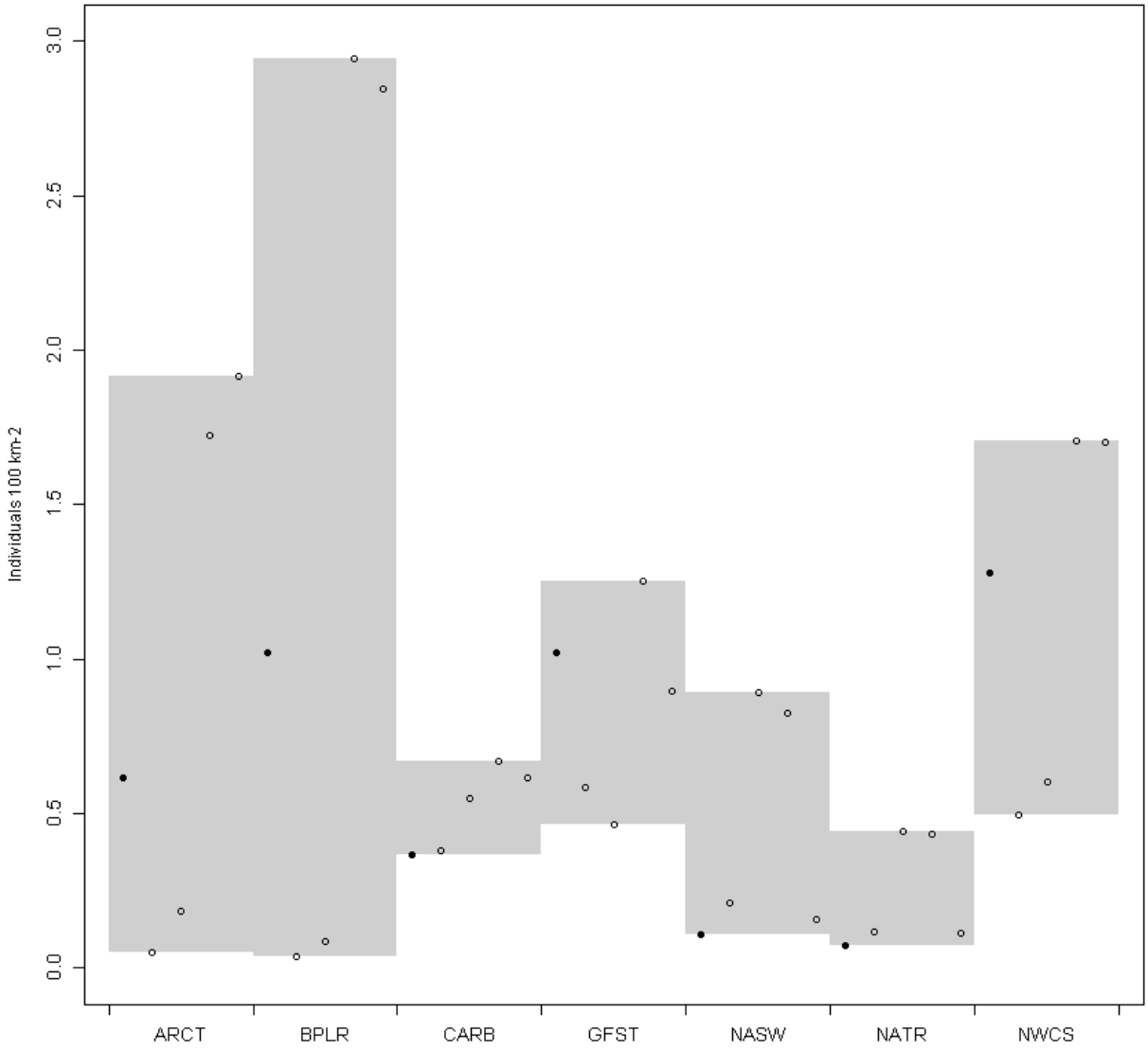


Figure 10: Sensitivity of densities predicted by the five top models per Longhurst's biogeographical province. Points represent predicted densities (individuals 100 km-2) for the five top models listed in Table 3, with the first to fifth models ordered from left to right. Filled points correspond to models with some support (sensu Burnham and Anderson (2002), i.e., delta AIC < 2) while hollow points correspond to models with little support (i.e., delta AIC > 2). The shaded areas indicate the range of densities predicted by the five top models for each province. Provinces: ARCT: Atlantic Arctic Province; BPLR: Boreal Polar Province; CARB: Caribbean Province; GFST: Gulf Stream Province; NATR: North Atlantic Tropical Gyral Province; NASW: North Atlantic Subtropical Gyral Province (West); NWCS: North West Atlantic Shelves Province.

Table 3: List of the five top models with lowest AIC values. Ns: non-significant. Predictor variables: EKE: eddy kinetic energy, SLAStDev: standard error of sea level anomaly, SST: sea surface temperature, PkPP: zooplankton production, PkPB: zooplankton biomass, EpiMnkPP: epipelagic micronekton production, EpiMnkPB: epipelagic micronekton biomass, VGPM: vertically generalized production model, CHL: chlorophyll-a concentration.

		Predictors		AIC	delta AIC
DistToFront1	Depth	EpiMnkPP	PkPB	117827.5	0.0
DistToFront1	Slope	EpiMnkPB	SST	117830.1	2.6
DistToFront1	Slope	CurrentSpeed	SST	117830.3	2.8
DistToFront1	Slope	Chl1	SLAStDev	117833.5	6.0
SLAStDev	Depth	EpiMnkPP	PkPB	117835.2	7.7

9- Residual diagnostics

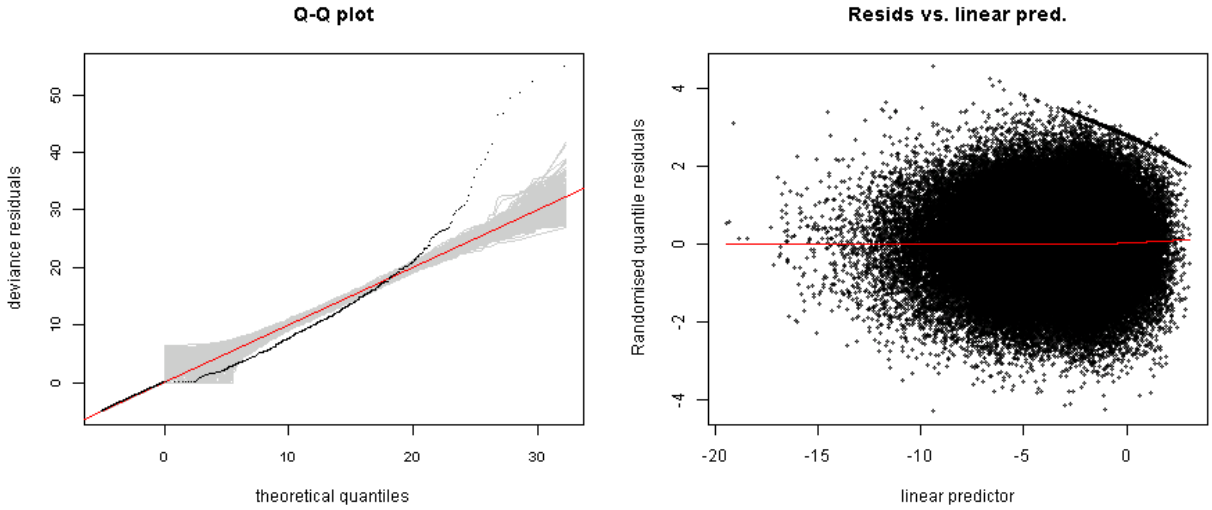


Figure 11: Diagnostic plots of residuals. Left: Quantile-quantile (Q-Q) plot of deviance residuals generated using the qq.gam function with 100 simulations (Augustin et al. 2012). Grey lines are possible simulated Q-Q plots under the assumption that the model is correct. The red reference line indicates perfect agreement between residual and theoretical residual distributions. Points lying away from the red line suggest poor model fit for the corresponding quantiles. Zeros appear to the left of the Q-Q plot in alignment with the reference line. Because, by design, models were not tightly fitted to the data (see discussion of the paper), deviations from the red line may be observed. Specifically, points far above the red line for large quantiles indicate that the model underestimates high abundances observed on some segments. Right: randomized quantile residuals vs. linear predictor. A LOWESS regression is shown as a red line to illustrate any trend in the points. This plot should be generally free of any pattern. Expanding y-range indicates non-constant variance (heteroskedasticity) in the model.

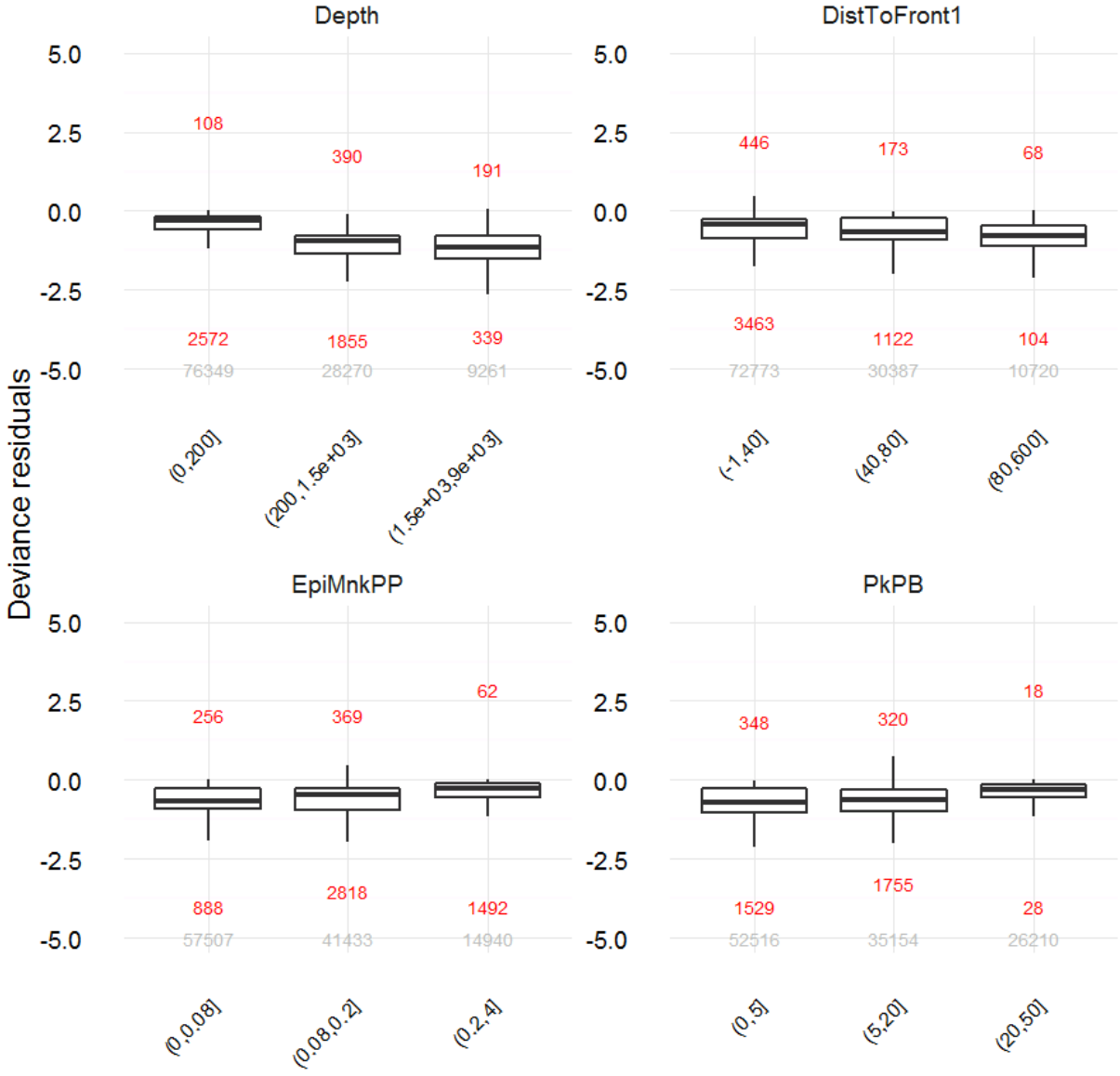


Figure 12: Boxplots of deviance residuals, binned for each predictor. The horizontal line represents the median, and the bottom and top of the box represent the first and third quartiles respectively. Whiskers extend 1.5 times the inter-quartile range following McGill et al. (1978). Total counts of outliers beyond the whiskers are indicated in red. Numbers of segments per bin are indicated in grey. Boxplots for the different bins of predictors should generally overlap. A boxplot having its median away from zero indicates poorer model fit for that predictor bin. Boxplots often have their medians close to zero and fewer outliers for predictor bins characterized by low abundances of the species, suggesting that model fit is generally better in low abundance areas. We believe this is an inherent feature of models applied to count data with numerous zeros.

10- Brief discussion and overall confidence in predictions

Description of confidence levels

We group taxa in three categories reflecting our relative level of confidence in predicted densities.

Level 1

This category includes tropical and warm temperate taxa for which survey data were available within most of the distributional range in the AFTT area. High/intermediate densities predicted beyond surveyed areas were supported by sightings available from OBIS-SEAMAP and the scientific literature. Very low densities predicted at northern latitudes were consistent with the described absence of these taxa. We have a reasonable confidence in predicted densities for these taxa.

Level 2

This category encompasses taxa for which a large part of the distributional range is in cold temperate and sub-polar waters. Models fitted to available survey data and extrapolated to cold temperate and sub-polar waters successfully predicted their occurrence, but predicted densities were largely speculative. The incorporation of line transect survey data from Canada and Greenland would be extremely useful to increase the reliability of predicted densities at northern latitudes. Unfortunately we were unable to obtain permission for using these data in our models. We remain hopeful that collaborations can be established in the future, and that the Canadian and Greenlandic surveys may be incorporated into a new version of our models. We have medium or low confidence in predicted densities for these taxa.

Level 3

This category includes taxa that are not known to primarily occur in cold temperate and sub-polar waters but were predicted in low/intermediate densities at higher latitudes. For these taxa, we believe predicted densities were likely overestimated at higher latitudes. However, predicted densities were supported by sightings available from OBIS-SEAMAP and the scientific literature within their core distributional range. The incorporation of line transect survey data from Canada and Greenland would be extremely useful to help correct the probable overestimation of densities at northern latitudes. We remain hopeful that collaborations can be established in the future, and that the Canadian and Greenlandic surveys may be incorporated into a new version of our models. We have medium or low confidence in predicted densities for these taxa.

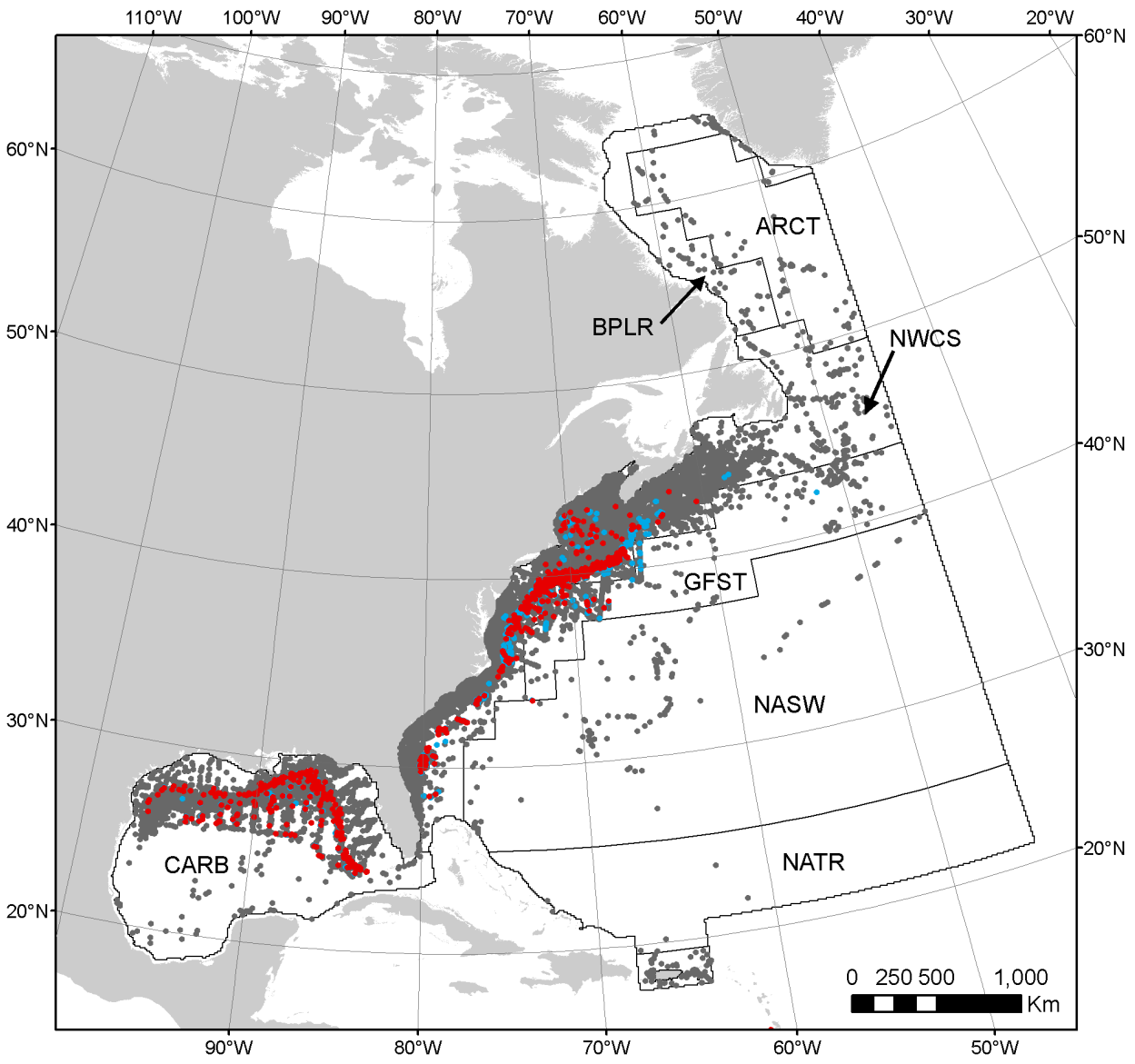


Figure 13: Red points are sightings of the taxon from line transect surveys used in this study. Blue points are sightings of the taxon reported by other datasets not used in our study for 1992-2016 (e.g., because they were not compatible with our methodology). Underlain grey points are sightings of other cetacean species, taken from these other datasets. Blue and grey points were extracted from OBIS-SEAMAP (accessible at http://seamap.env.duke.edu/) (Halpin et al. 2009); citations for individual datasets are provided at the end of this report. Longhurst's biogeographical provinces are shown as polygons. Dense patches of grey points without red or blue points suggest locations where the taxon of interest may be absent, under the presumption that observers who reported other cetacean taxa would have reported this one if sighted. However, important caveats apply: the map does not quantify observation effort, which was not available for all datasets and was very difficult to standardize across disparate sources (e.g., scientific surveys, whale watching logs, opportunistic sightings). The spatial distribution of effort was highly heterogeneous in both space and time. Only openly accessible datasets were considered; other cetacean datasets are known to exist for the AFTT area but have not been released for public use (e.g., the 2007 Trans North Atlantic Sightings Survey (TNASS) in Canada). The presumption that grey dots imply absence may not always hold; for example, if effort conducted in that area was directed towards particular species, sightings of our taxon of

interest may not have been recorded.

General

A relatively large sample size of 1002 sightings was available to fit the habitat-based density model (we note that 72% of the sightings were from surveys in the east coast region). The first or lowest AIC model included depth, zooplankton biomass, micronekton production and distance to fronts (listed in decreasing order of importance according to F-scores) and had an explained deviance of 38.4%. Consistent with other studies (e.g., Baumgartner 1997), we found that depth was an important predictor of Risso's dolphin habitat. This model was the only supported model sensu Burnham and Anderson (2002) (Table 3). Predicted densities from the top five models were quite variable in the various provinces, differing by a factor 19 in the ARCT province, a factor 29 in the BPLR province and factors 1.5-4 in the other provinces (Figure 10). In the BPLR and ARCT provinces, we note that the second and third models predicted low densities while the fourth and fifth model predicted relatively high densities (the first model predicted intermediate densities). These models had a delta AIC >2 and therefore little statistical support sensu Burnham and Anderson (2002).

Jefferson et al. (2014) recently revised the global distribution of Risso's dolphin. In the western North Atlantic, the species ranges from the Gulf of Mexico and Caribbean to southern Newfoundland and Labrador, and mostly inhabits continental shelf and slope waters.

We now discuss the quality of predictions per biogeographic province by comparing them with available literature and observations from OBIS-SEAMAP.

Boreal polar (BPLR) and Atlantic Arctic (ARCT) provinces

Model uncertainty was important in the BPLR and ARCT provinces, resulting in large ranges of potential predicted densities. The best supported model predicted medium densities of Risso's dolphins offshore Canada and Greenland. Risso's dolphin is at the northern limit of its range and described as rare in Canada and Greenland (Jefferson et al. 2014), although it was recorded near Baffin Island as far north as 62°N (Baird and Stacey 1991). No sightings were available in OBIS-SEAMAP for the BPLR and ARCT provinces. Based on this information, we believe the model likely overestimates densities in Canada and Greenland.

North West Atlantic shelves (NWCS) and Gulf Stream (GFST) provinces

Risso's dolphins were predicted in temperate waters from Florida to Newfoundland, with highest densities on the shelf edge and continental slope, corresponding to their core range described by Jefferson et al. (2014).

Predicted densities in the northern part of the NWCS province appeared supported by relatively few sightings. A limited number of sightings were available in OBIS-SEAMAP for the Scotian shelf (Figure 13) and the Canadian TNASS survey recorded an additional 6 sightings (Lawson and Gosselin 2009) (not publically shared in OBIS-SEAMAP).

We note that predicted densities off the continental shelf (western part of the GFST province) coincided with the location of numerous interactions of Risso's dolphins with pelagic longlines (Garrison 2007). One sighting was also reported in the GFST province at 52°W 42°N (Figure 13).

North Atlantic tropical gyral (NATR) and North Atlantic subtropical gyral (NASW) provinces

Predictions in the NATR and NASW provinces appeared consistent with the occurrence of Risso's dolphins in generally low densities in offshore oceanic regions (Jefferson et al. 2014). No sightings were reported in OBIS-SEAMAP in these provinces (but observation effort was extremely sparse) (Figure 13). We warn that extrapolation further from fronts occurred in the eastern parts of the NASW and NATR provinces; therefore, predictions should be considered with extreme caution.

Caribbean (CARB) province

In the Gulf of Mexico, predicted densities were the highest on the continental slope. Given the numerous sightings reported on the continental slope and in oceanic waters of the northern Gulf of Mexico, we believe predicted densities in the southern Gulf of Mexico are not unrealistic. To our knowledge, only two strandings and one sighting have been reported in the southern Gulf of Mexico (Jefferson & Schiro 1997; Ortega-Ortiz 2002). We note that extrapolation beyond predictor ranges occurred in some coastal areas of the western and southern Gulf of Mexico and predictions should be viewed with due caution.

The overall low predicted densities near Puerto Rico appeared compatible with the few opportunistic sightings documented by Mignucci-Giannoni (1998).

Overall confidence level: 3

Predictions were generally in line with Risso's dolphin ecology, i.e., its affinity for the continental shelf edge and the slope in a variety of waters. However, we believe the medium densities predicted in sub-polar waters were likely overestimated. The incorporation of line transect survey data from Canada and Greenland would help correct this possible overestimation. Unfortunately, we were unable to obtain permission for using these data in our model. We remain hopeful that collaborations can be established in the future, and that the Canadian and Greenlandic surveys may be incorporated into a new version of our model.

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