Habitat-based density model for bottlenose dolphin in the AFTT area

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October 1, 2016

This report documents the habitat-based density model for bottlenose 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 bottlenose 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	84
EC	1044357.70	4591
EU	27526.34	41
GOM	194715.35	1849
All regions	1290863.87	6565

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

Month	Effort	Sightings
January	77892.79	490
February	123591.37	1241
March	117923.54	869
April	117929.72	491
May	149765.03	350
June	130361.37	394
July	162252.51	753
August	129660.43	667
September	71696.07	546
October	82560.18	527
November	69210.92	102
December	58019.93	135
All Months	1290863.87	6565

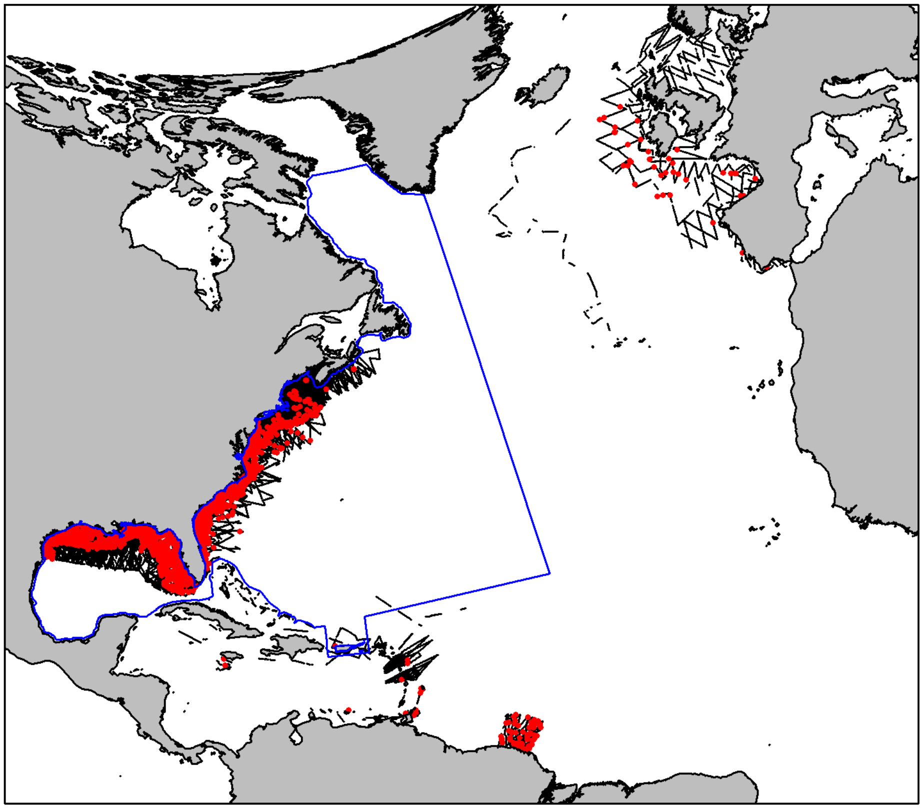


Figure 1: Map of segments (black lines) and sighting locations (red dots). An Albers equal area projection optimized for the AFTT area is used.

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

Bottlenose dolphin (*Tursiops truncatus*)

Two morphologically and genetically distinct morphotypes of bottlenose dolphins, known as the coastal and offshore ecotypes, inhabit the western North Atlantic and Gulf of Mexico (Rosel et al. 2009; Vollmer & Rosel 2013). The offshore ecotype is larger and inhabits off-shelf, slope, and shelf-break waters, as well as outer portions of the continental shelf. The coastal ecotype is smaller and inhabits the inner portions of the continental shelf, bays, sounds, and estuaries. The spatiotemporal extents and dynamics of the distributions of the two ecotypes are not fully determined. Here, we modeled the offshore and inshore ecotypes of bottlenose dolphin together.

Modeled season

We fitted a year-round model as we found no definitive evidence in the literature that this species 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 these 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 a relatively small number of additional sightings).

3- Best model

- **Predictors**: depth, distance to SST fronts (DistToFront), production of epipelagic micronekton (EpiMnkPP), zooplankton biomass (PkPB)
- **Model summary**:

```
##
## Family: Tweedie(p=1.41)
## 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: 0x0fbbcd08>
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -3.71010    0.03023  -122.7   <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)        2.989      3 520.49  <2e-16 ***
## s(DistToFront1) 2.720      3  28.93  <2e-16 ***
## s(EpiMnkPP)     2.760      3 279.93  <2e-16 ***
## s(PkPB)         2.841      3 600.93  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  -0.148   Deviance explained = 25.7%
## -REML =  31705  Scale est. = 68.77     n = 113880
```

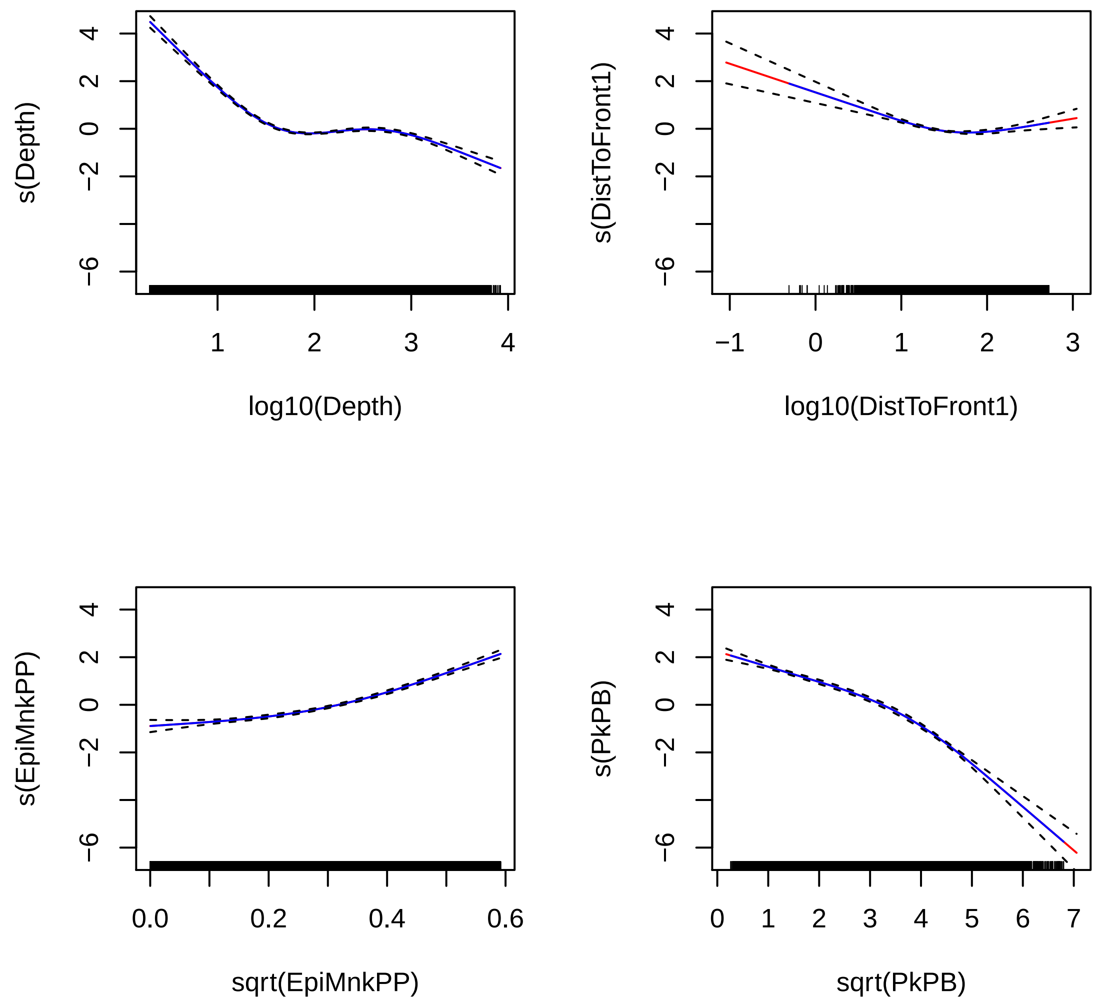


Figure 2: GAM term plots with the log-transformed abundance on the y axis. The solid blue line is the smooth function fitted to the data. The solid red line is the smooth function extrapolated to all covariate values in the prediction area. The dashed lines represent the approximate 95% confidence intervals. 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

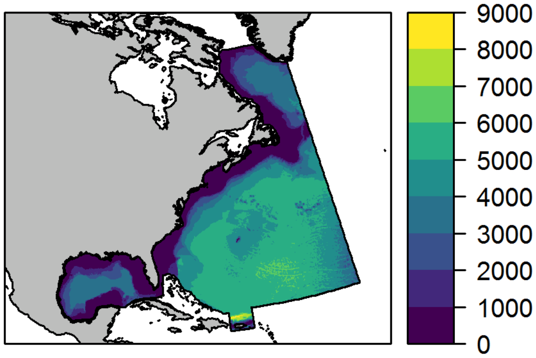
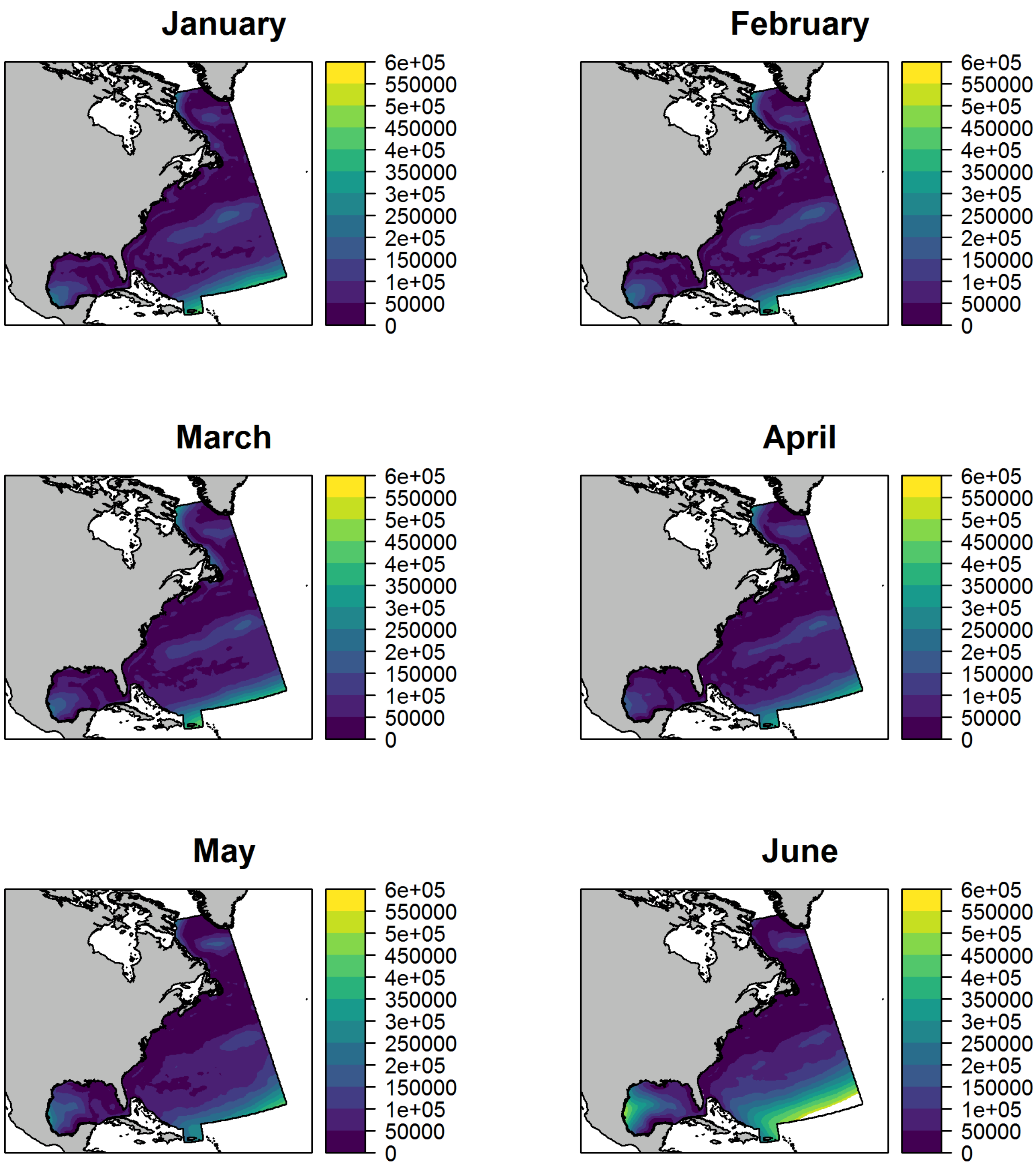


Figure 3: Environmental envelope for depth. White cells within the AFTT polygon indicate areas where covariate values fell beyond the range of covariate values sampled by the surveys.


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

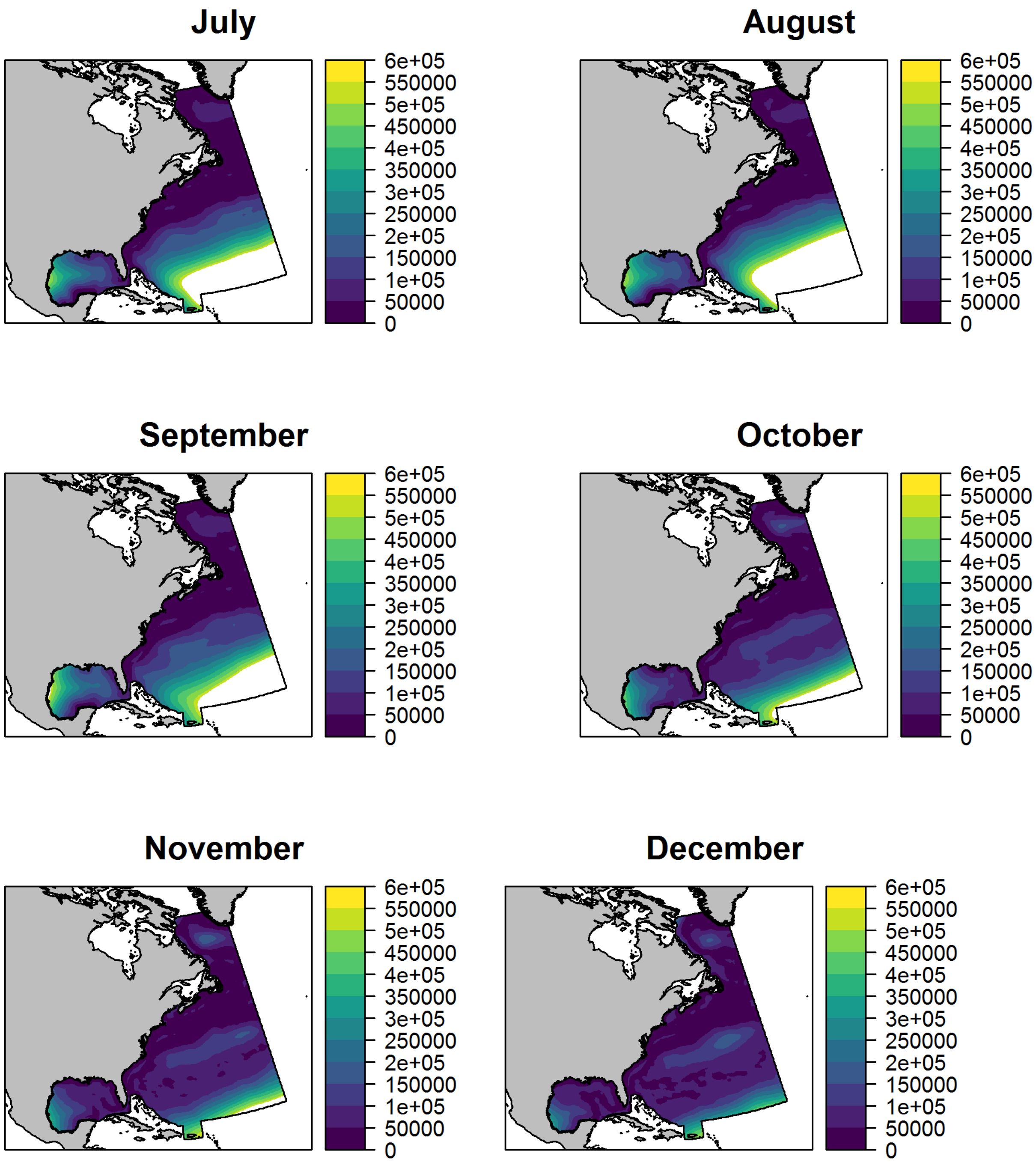
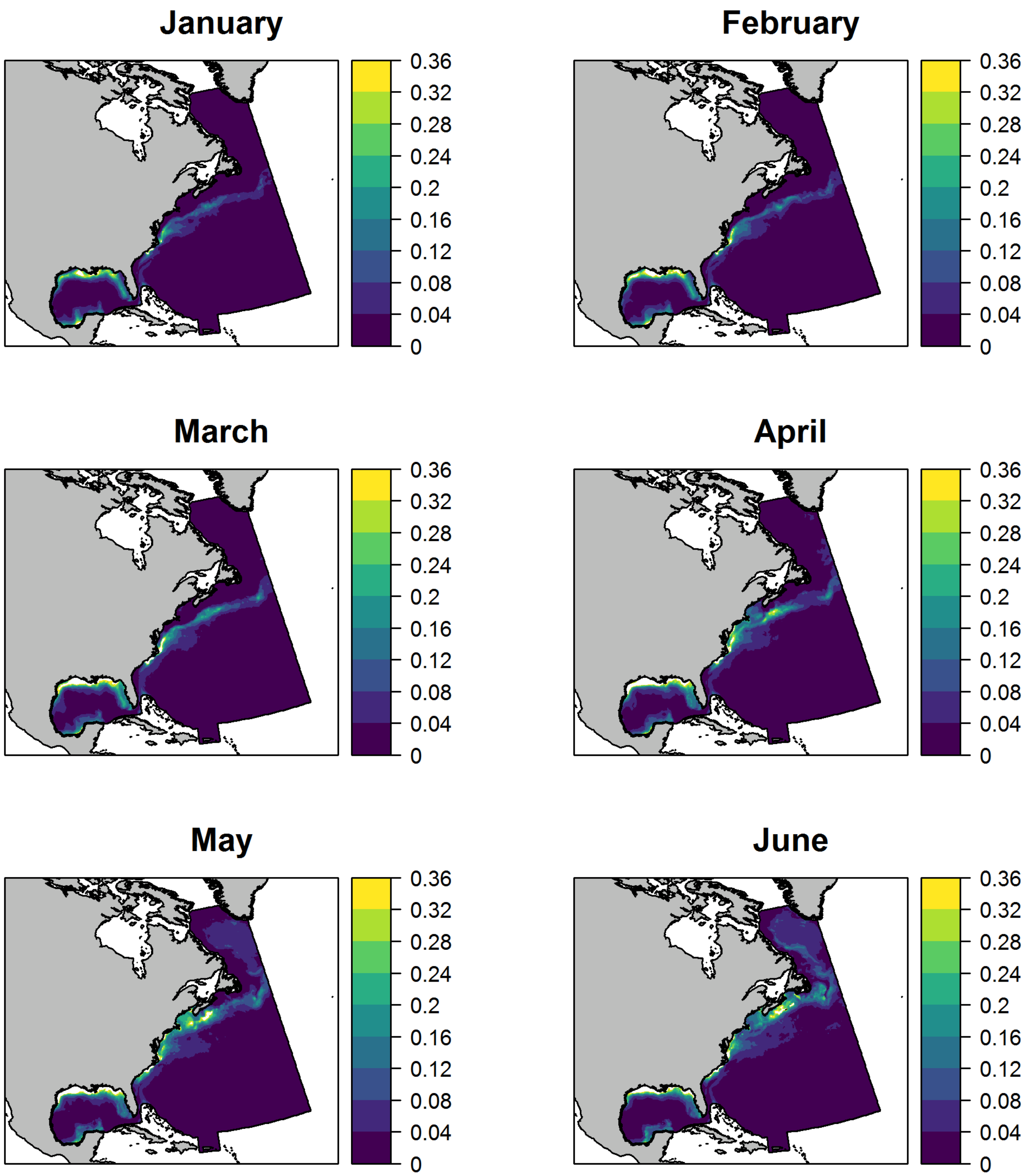


Figure 4: Monthly environmental envelopes for distance to SST fronts. White cells within the AFTT polygon indicate areas where covariate values fell beyond the range of covariate values sampled by the surveys.


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

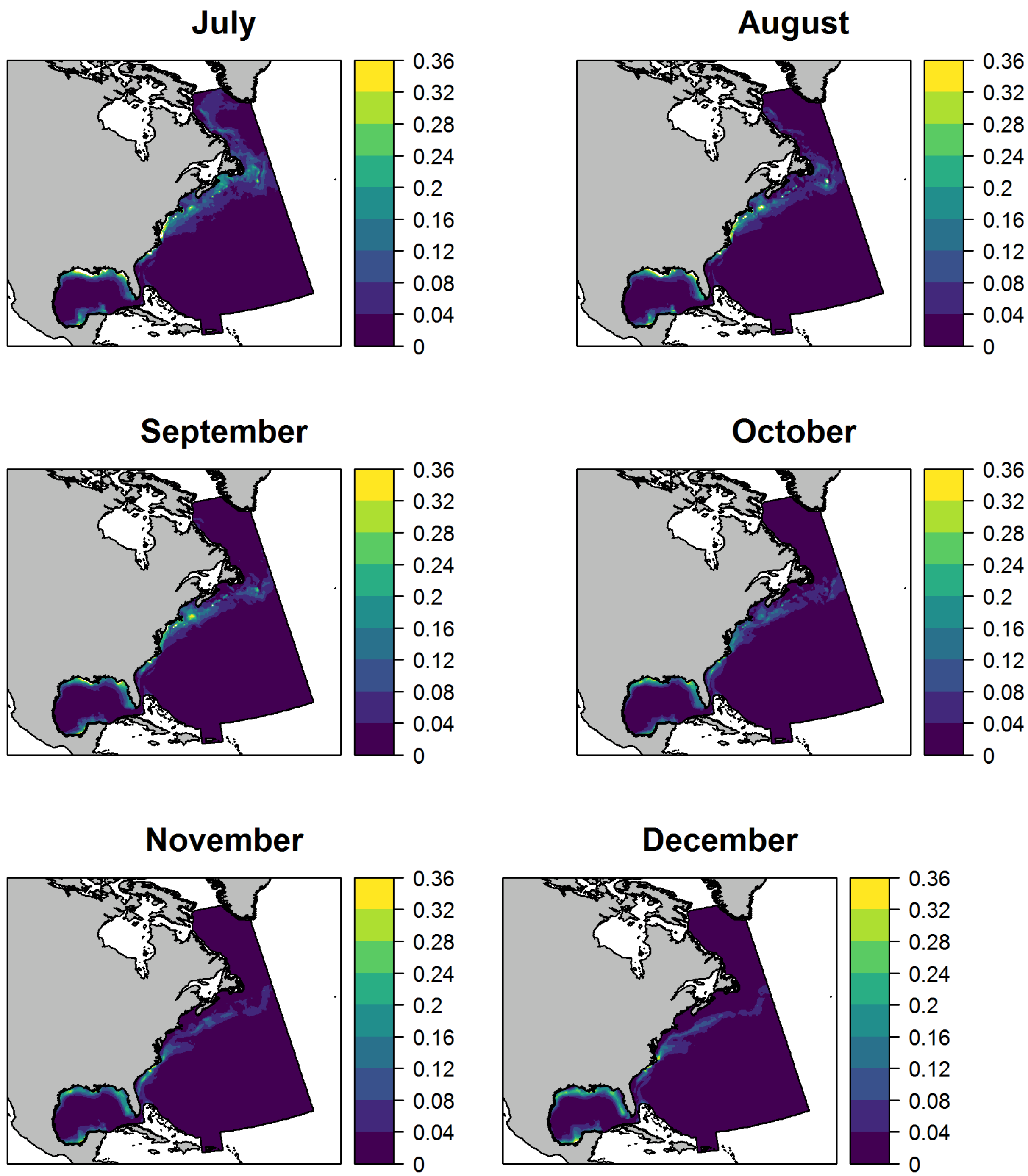
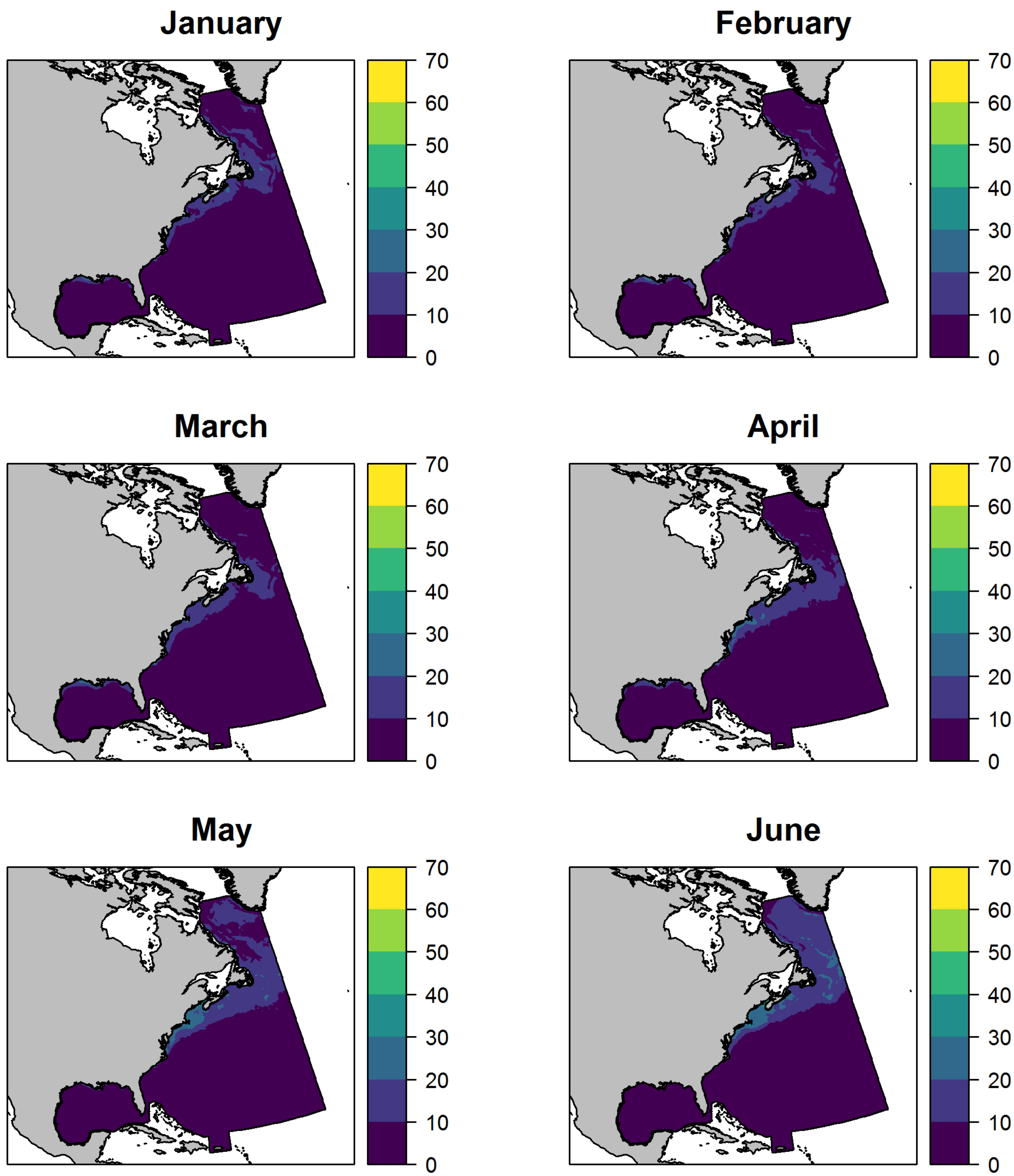


Figure 5: Monthly environmental envelopes for production of epipelagic micronekton. White cells within the AFTT polygon indicate areas where covariate values fell beyond the range of covariate values sampled by the surveys.


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

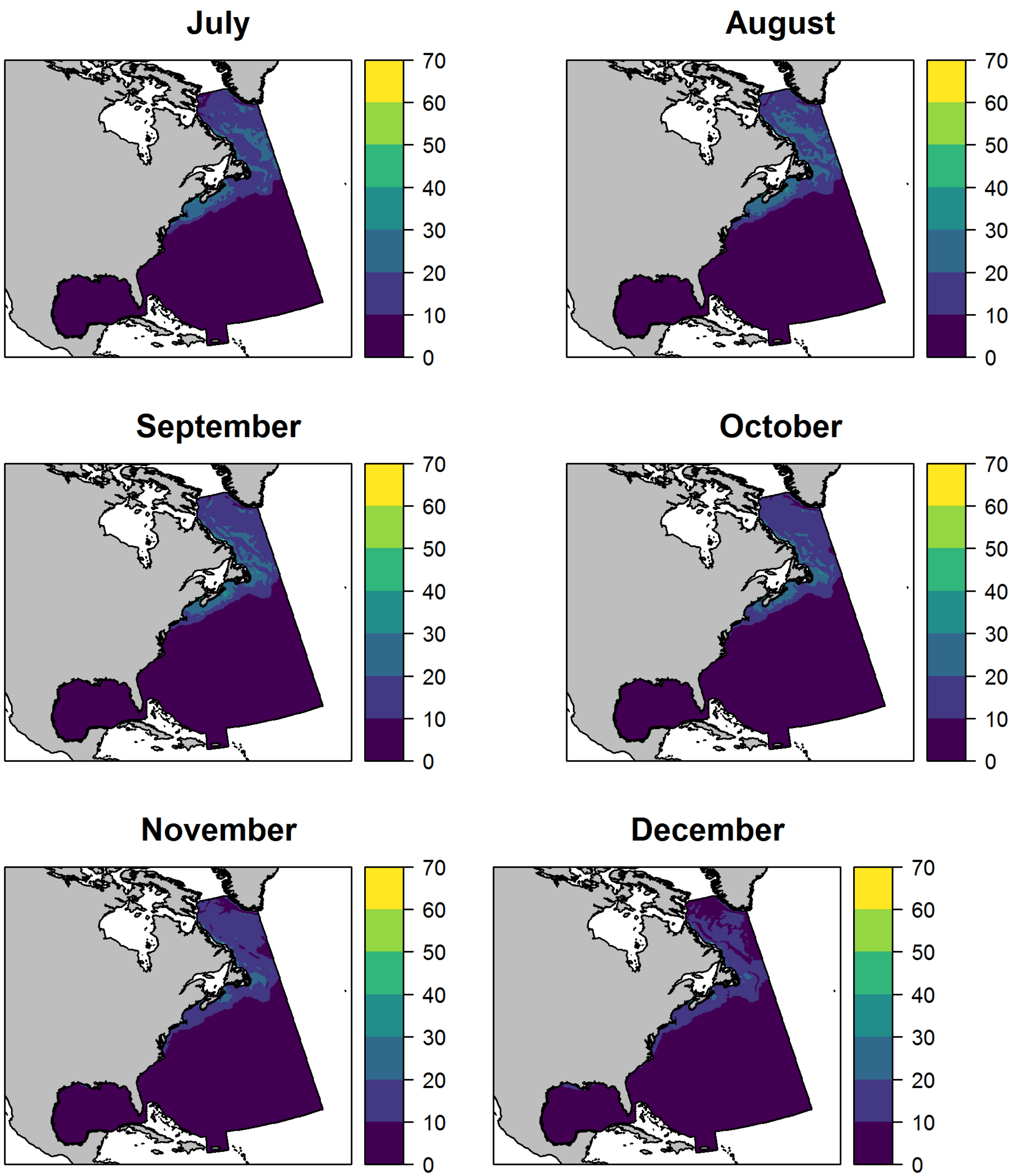


Figure 6: Monthly environmental envelopes for zooplankton biomass. White cells within the AFTT polygon indicate areas where covariate values fell beyond the range of covariate values sampled by the surveys.

5- Predicted densities

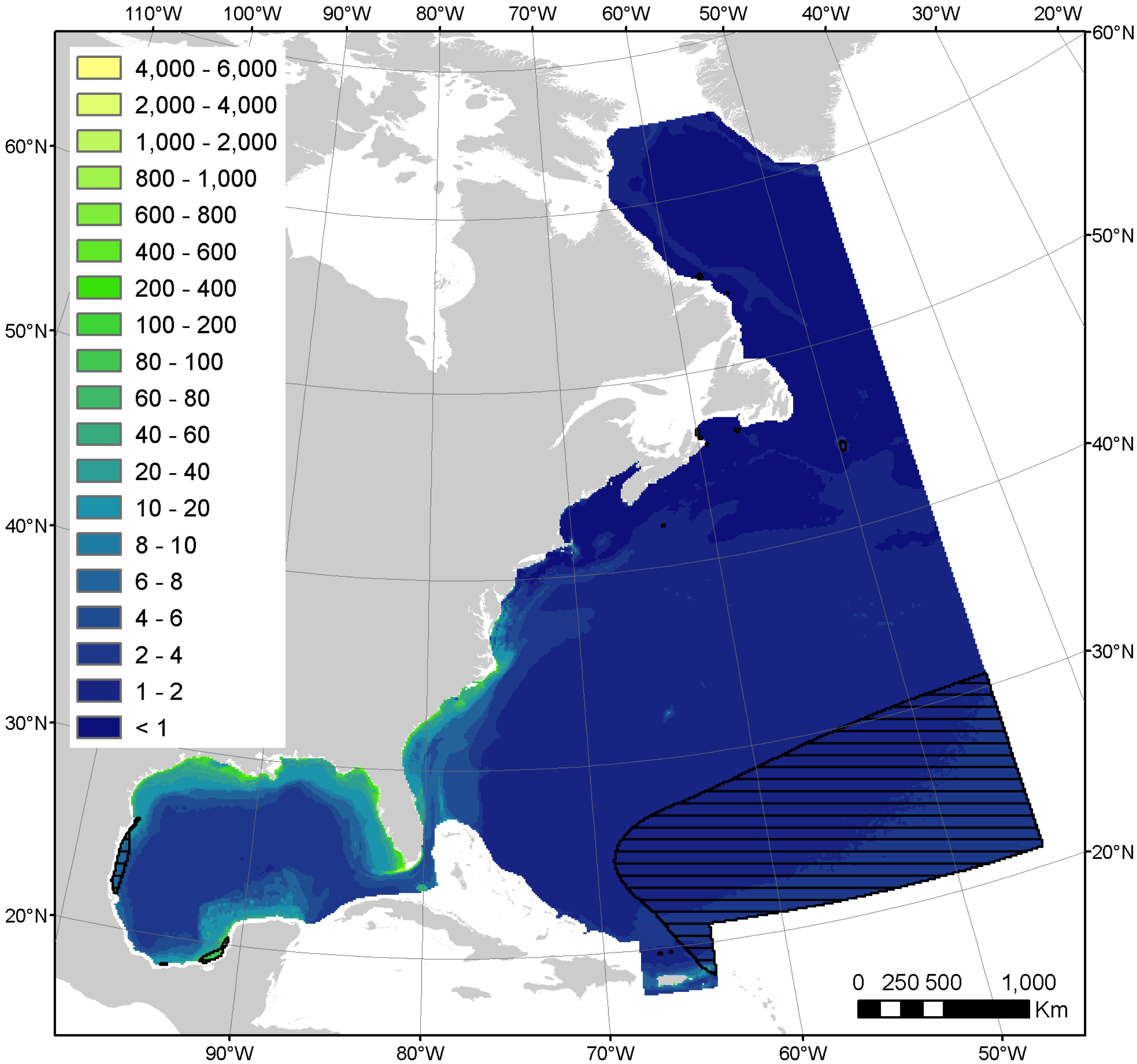


Figure 7: Mean predicted densities (individuals 100 km-2) in the AFTT area. Areas where we extrapolated beyond sampled predictor ranges and predicted densities should not be trusted are indicated with black crosshatches. An Albers equal area projection is used.

6- Coefficients of variation

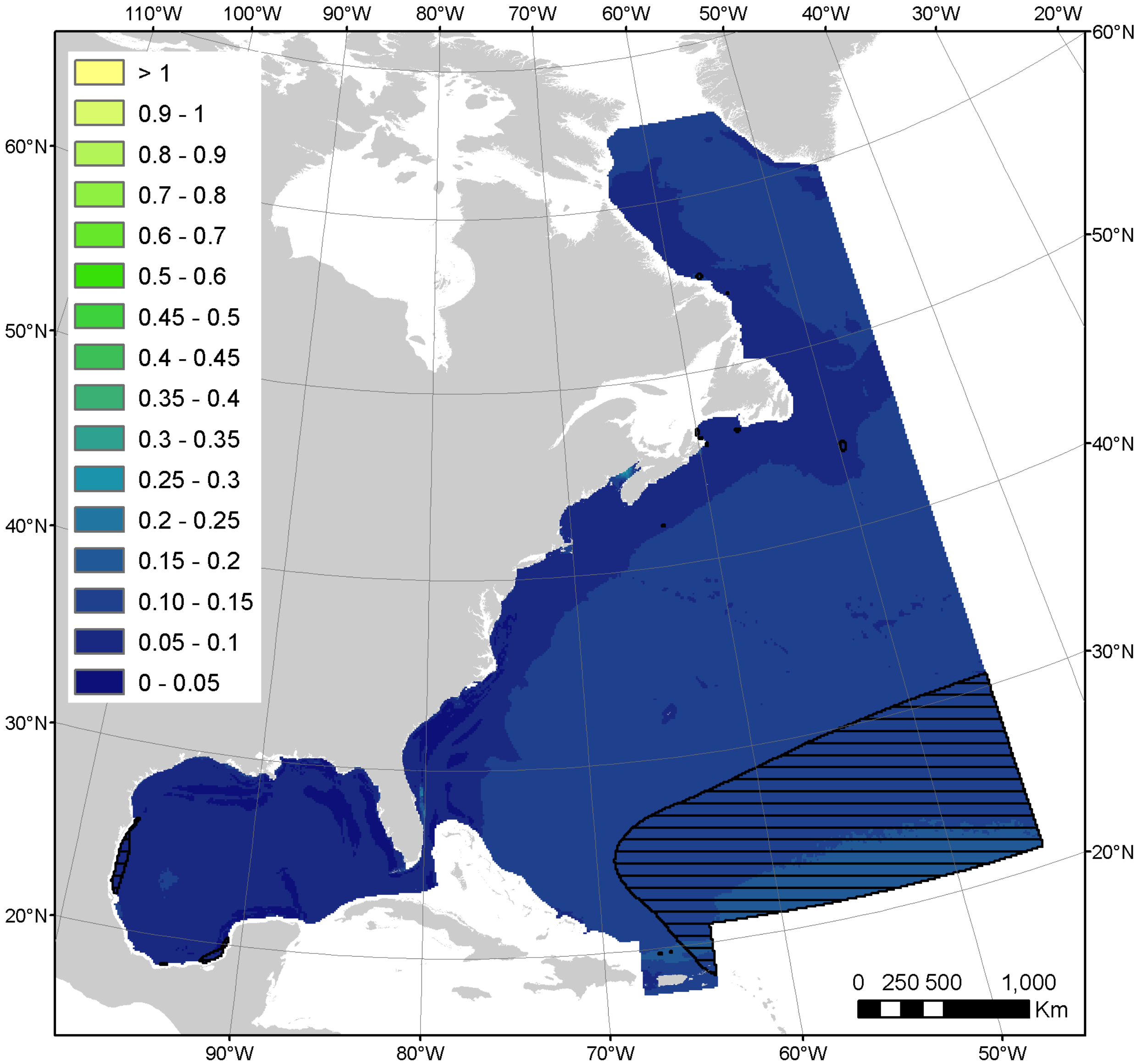


Figure 8: Mean predicted coefficients of variation derived from GAM parameters in the AFTT area. Areas where we extrapolated beyond sampled predictor ranges and coefficients of variation should not be trusted are indicated with black crosshatches. An Albers equal area projection is used.

7- Predicted densities per province

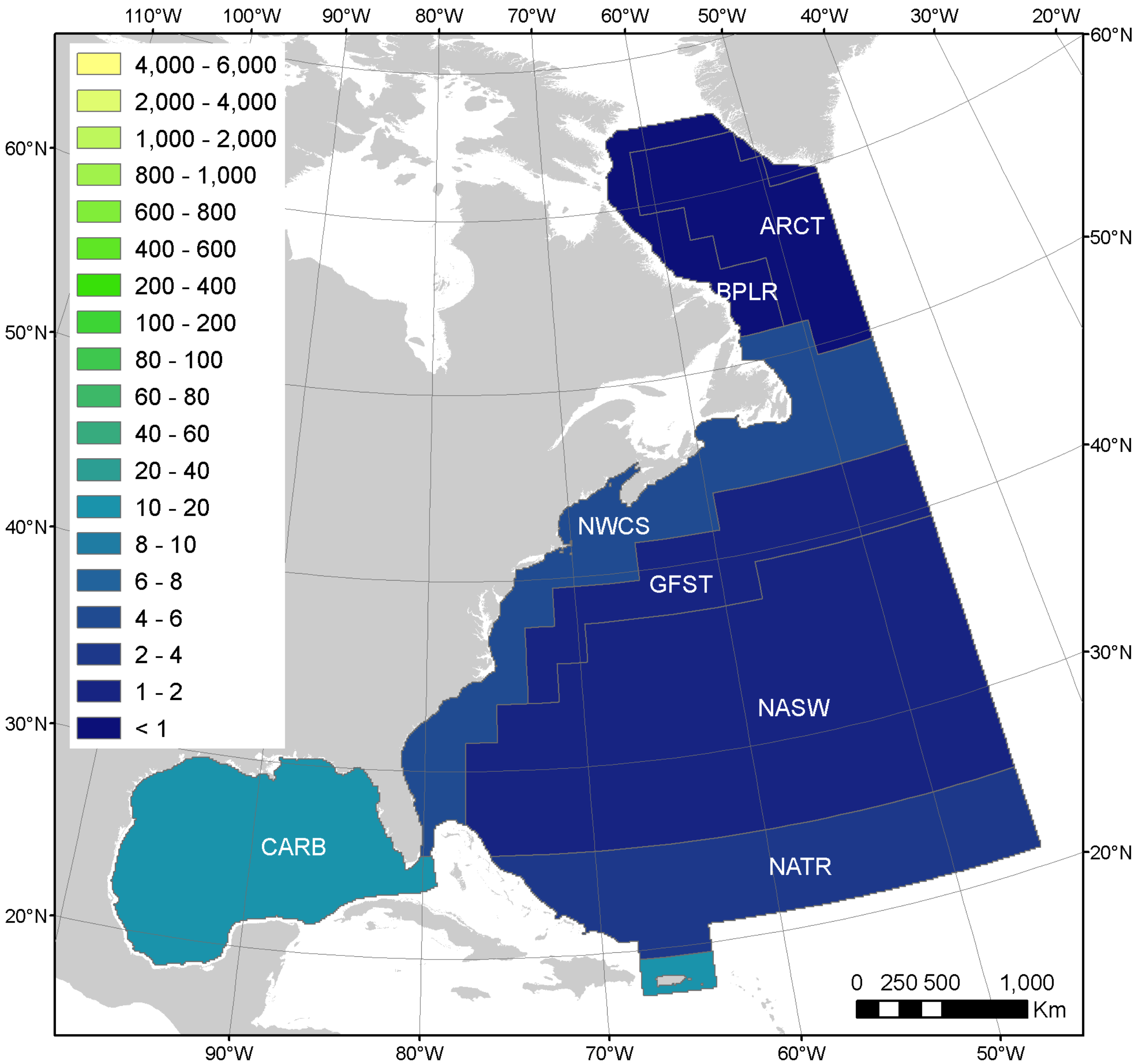


Figure 9: Predicted densities (individuals 100 km-2) averaged per Longhurst's biogeographical province. Note that the color scheme is the same as in Figure 7. Provinces: ARCT: Atlantic Arctic Province; BPLR: Boreal Polar Province; CARB: Caribbean Province; GFST: Gulf Stream Province; NATR: North Atlantic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

8- Alternate models

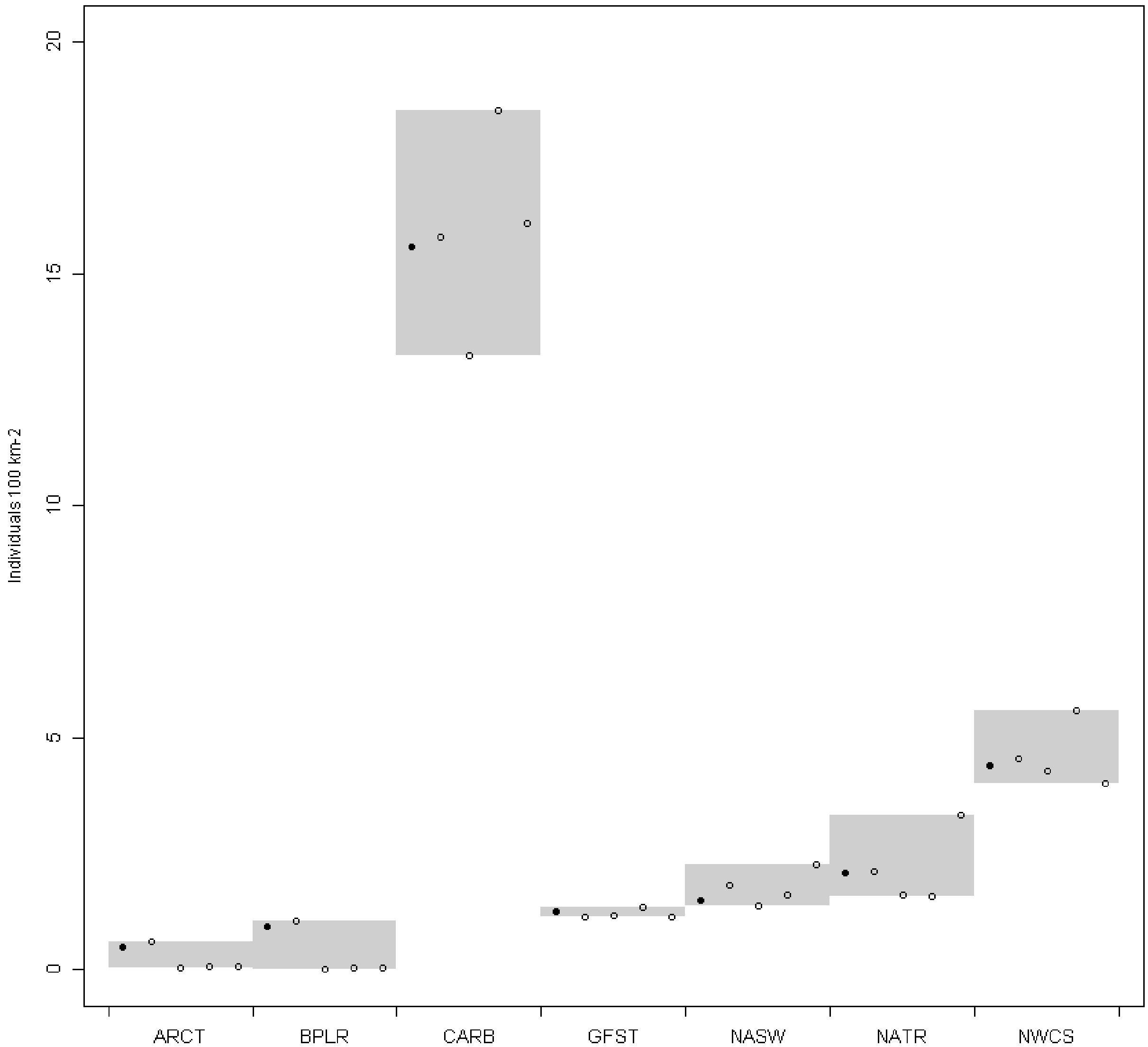


Figure 10: Sensitivity of densities predicted by the five top models per Longhurst's biogeographical province. Points represent predicted densities (individuals 100 km-2) for the five top models listed in Table 3, with the first to fifth models ordered from left to right. Filled points correspond to 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
Depth	EpiMnkPP	PkPB	DistToFront1	144171.5	0.0
Depth	EpiMnkPP	PkPB	SLAStDev	144224.7	53.2
Depth	EpiMnkPP	SST	CurrentSpeed	144249.8	78.3
Depth	EpiMnkPP	SST	VGPM	144274.8	103.3
Depth	EpiMnkPP	SST	EpiMnkPB	144278.9	107.4

9- Residual diagnostics

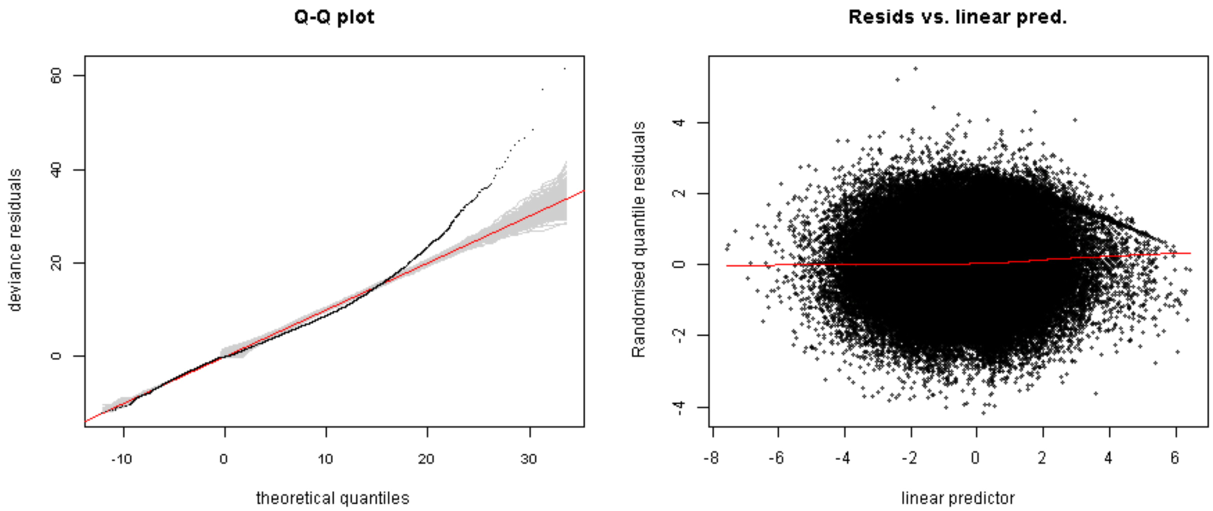


Figure 11: Diagnostic plots of residuals. Left: Quantile-quantile (Q-Q) plot of deviance residuals generated using the qq.gam function with 100 simulations (Augustin et al. 2012). Grey lines are possible simulated Q-Q plots under the assumption that the model is correct. The red reference line indicates 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.

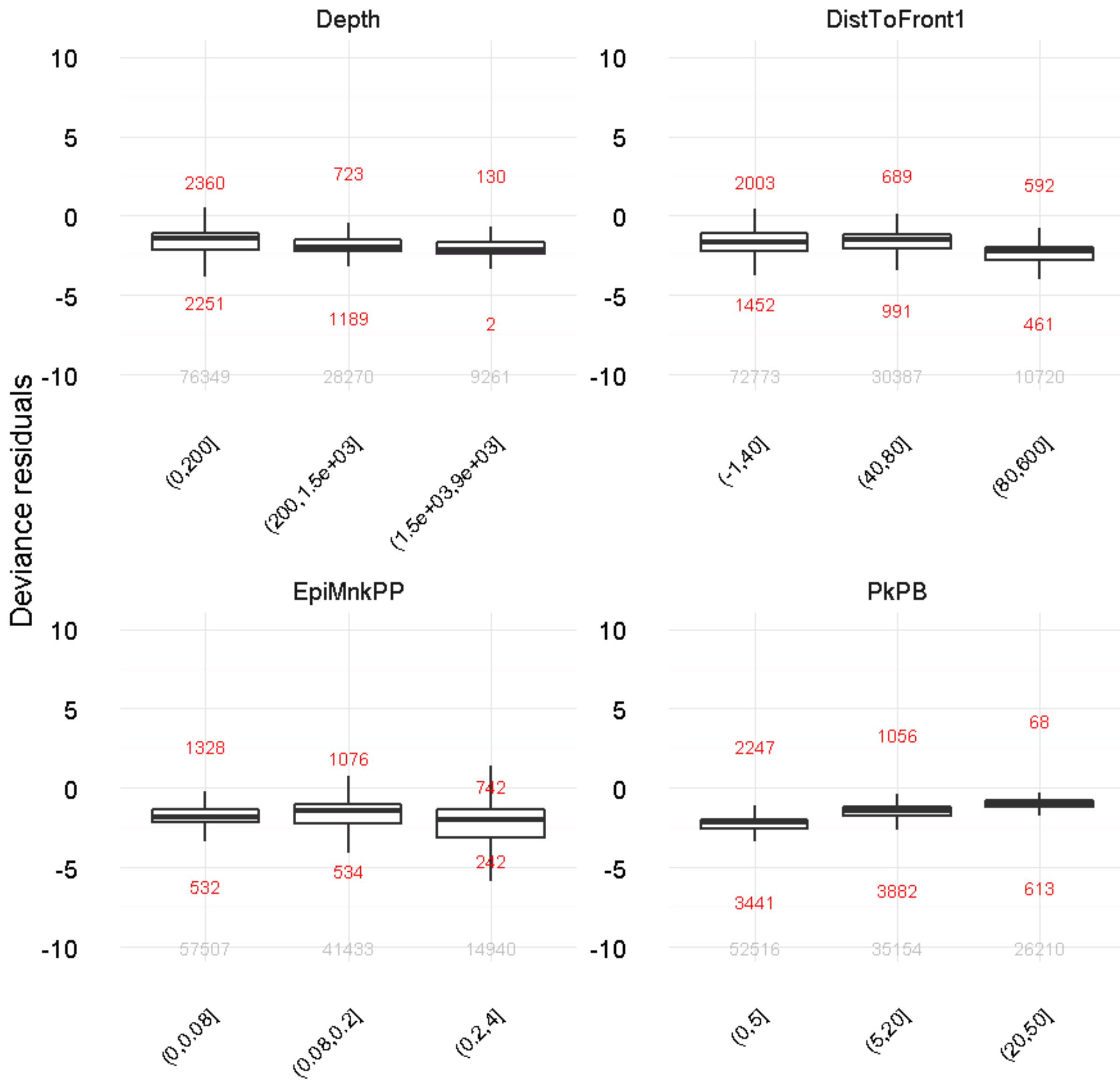


Figure 12: Boxplots of deviance residuals, binned for each predictor. The horizontal line represents the median, and the bottom and top of the box represent the first and third quartiles respectively. Whiskers extend 1.5 times the inter-quartile range following McGill et al. (1978). Total counts of outliers 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.

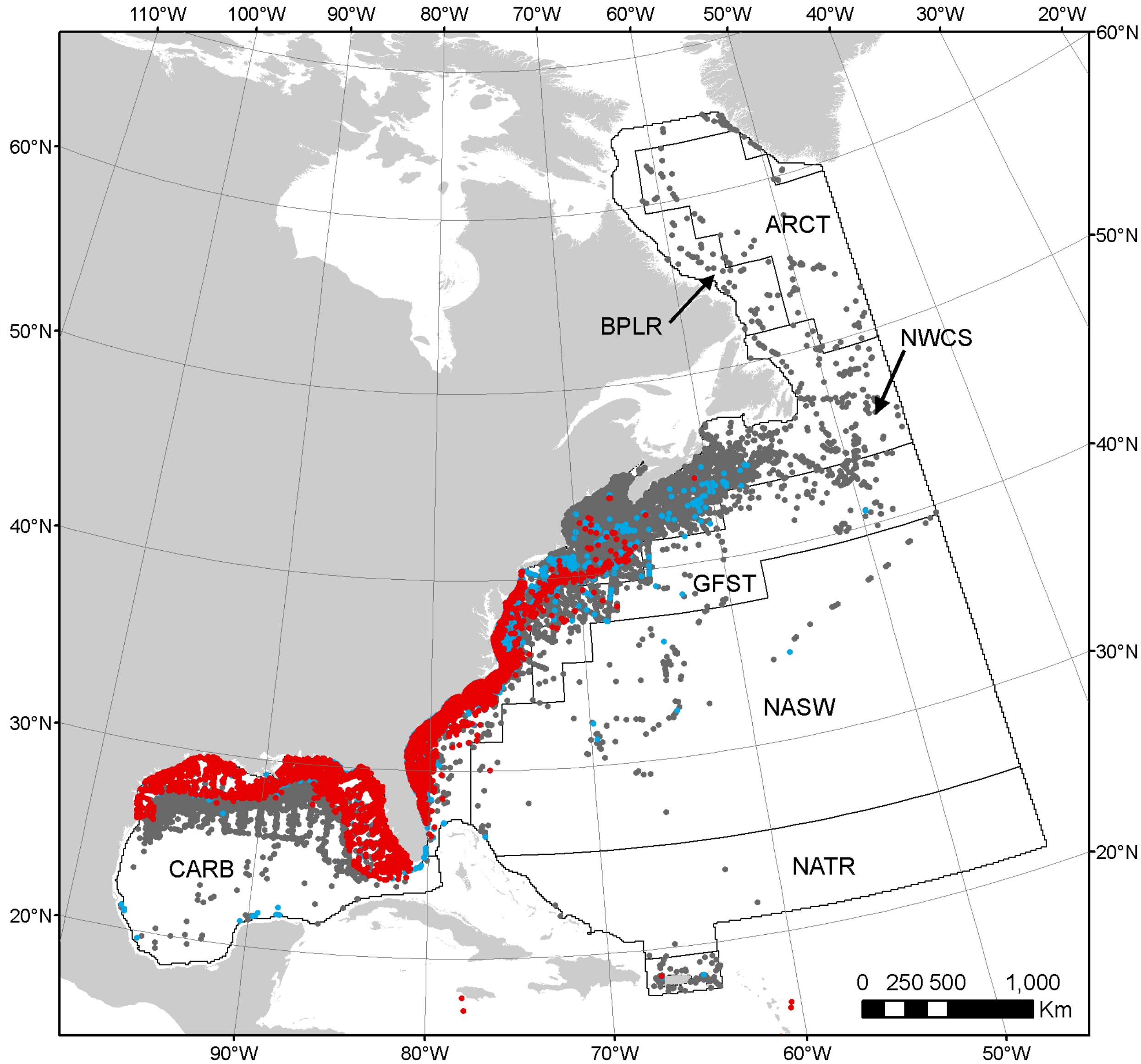


Figure 13: Red points are sightings of the taxon from line transect surveys used in this study. Blue points are sightings of the taxon reported by other datasets not used in our study for 1992-2016 (e.g., because they were not compatible with our methodology). Underlain grey points are sightings of other 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 very large sample size of 6544 sightings distributed in all seasons was used to fit the habitat-based density model. The first or lowest AIC model included zooplankton biomass, depth, micronekton production and distance to fronts (listed in decreasing order of importance according to F-scores) and had an explained deviance of 25.7%. Interestingly, two SEAPODYM covariates were retained in this model. Bottlenose dolphin feed on a variety of fish and squid that form the epipelagic micronekton (Wells & Scott 2009). They do not feed on zooplankton but zooplankton biomass could represent a proxy for another important variable not considered or unavailable for this study.

This model was the only supported model sensu Burnham and Anderson (2002) (Table 3). The second and following models had large delta AIC and therefore statistical little support. All top five models included depth and micronekton production. Predicted densities from the top five models were overall similar. Predicted densities were highest and most variable in the CARB province (Figure 10).

The model predicted lower densities in northern provinces, in accordance with the distribution of bottlenose dolphin throughout temperate and tropical waters (Wells & Scott 2009). Highest densities were predicted on the continental shelf which is described as bottlenose dolphin‘s primary habitat (it also occurs in pelagic waters but in lower numbers) (Wells et al. 1999; Wells & Scott 2009).

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

Low predicted densities in the BPLR and ARCT provinces were consistent with the absence of sightings documented in OBIS-SEAMAP (Figure 13). No bottlenose dolphin sightings were reported from line transect surveys off Labrador (Lawson & Gosselin 2009) and West Greenland (Heide-Jørgensen et al. 2007).

North West Atlantic shelves (NWCS) province

Predicted densities were highest on the continental shelf from to the tip of Florida to North Carolina.

Bottlenose dolphins occur in the northern part of the NWCS province mostly in summer, migrating south in the winter (Wells & Scott 2009). Reproducing these migratory patterns was beyond the scope of our model but we note that lower predicted densities north of 40°N were compatible with the sparser sightings on the Scotian shelf compared to the continental shelf further south (Figure 13). In addition, bottlenose dolphin is described as occasional in eastern Canada in summer (notably near the Gully canyon) (Baird et al. 1993, Hooker et al. 1999). We note that 8 sightings (not contributed to OBIS-SEAMAP) were reported on the Scotian shelf during the Canadian TNASS survey (Lawson & Gosselin 2009).

Gulf Stream (GFST) province

Overall low densities were predicted in the GFST province, apparently in line with the few sightings reported in these offshore waters (Figure 13).

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

Overall low densities were predicted in these provinces. A few offshore sightings were reported in the NASW province and none was available in the NATR province (but observation effort in these provinces was very sparse) (Figure 13). We caution that predictions in the eastern part of these provinces were derived from extrapolation further from fronts and therefore might be unreliable.

Caribbean (CARB) province

On average, predicted densities were the highest in the CARB province.

In the Gulf of Mexico, highest densities were predicted on the inner continental shelf. Bottlenose dolphin is described as the most abundant cetacean species in the Gulf of Mexico (Ortiz-Ortega 2000). In the southern Gulf of Mexico, relatively high predicted densities on the continental shelf appeared consistent with abundant coastal sightings documented in the literature (Delgado Estrella 1997; Ortega-Ortiz 2002; Vital et al. 2015), as well as sightings reported in OBIS-SEAMAP (Figure 13). We warn that extrapolation to higher micronekton biomass and further from fronts occurred in some coastal areas of the southern and western Gulf of Mexico; therefore these predictions should be considered with due caution.

Medium densities predicted near Puerto Rico were compatible with 151 opportunistic sightings documented by Mignucci-Giannoni (1998), mostly on the shelf.

Overall confidence: level 1

Large amounts of survey data and numerous sightings were available within the core distributional range of the species and predicted densities beyond surveyed areas seemed supported by sightings available from OBIS-SEAMAP and the scientific literature. The model predicted very low densities in northern waters, consistent with the described absence of the species. We re-iterate, however, that extrapolation beyond sampled predictor ranges occurred in the NASW and NATR provinces and that predicted densities in these provinces should be considered with extreme caution.

11- References

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