Habitat-based density model for Atlantic spotted dolphin in the AFTT area

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This report documents the habitat-based density model for Atlantic spotted 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 Atlantic spotted 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	11
EC	1044357.70	828
GOM	194715.35	311
All regions	1263337.53	1150

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

Month	Effort	Sightings
January	77892.79	45
February	123591.37	124
March	117923.54	90
April	117929.72	50
May	149765.03	83
June	129393.69	128
July	135693.85	136
August	129660.43	245
September	71696.07	186
October	82560.18	45
November	69210.92	7
December	58019.93	11
All Months	1263337.53	1150

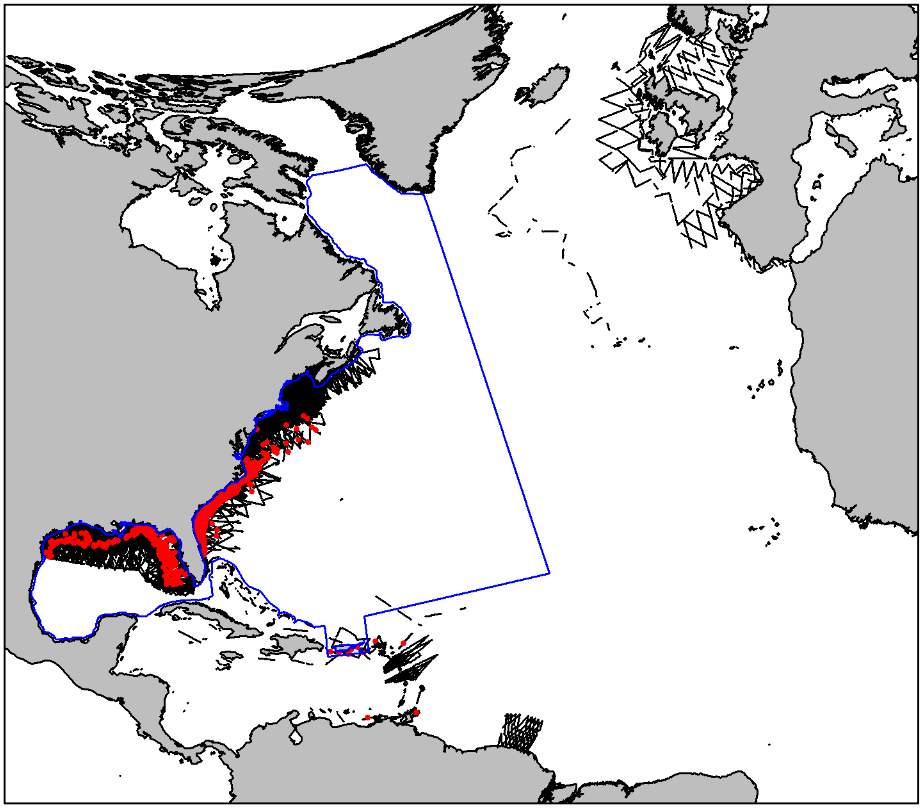


Figure 1: Map of segments (black lines) and sighting locations (red dots). An Albers equal area projection optimized for the AFTT area is used.

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

Atlantic spotted dolphin (*Stenella frontalis*).

We modeled the offshore and inshore ecotypes of Atlantic spotted dolphin documented by Viricel and Rosel (2014) together as they are not differentiable at sea.

Modeled season

We fitted a year-round model as there is no evidence in the literature that this taxon undertakes extensive migrations or exhibits contrasting behaviors (e.g., feeding versus breeding) in different seasons (Viricel and Rosel 2014).

Segments

We incorporated segments from the east coast, Gulf of Mexico and Caribbean where sightings were reported (Table 1).

3- Best model

- **Predictors**: depth, eddy kinetic energy (EKE), production of zooplankton (PkPP), sea surface temperature (SST)
- **Model summary**:

```
##
## Family: Tweedie(p=1.402)
## Link function: log
##
## Formula:
## abundance ~ s(Depth, k = 4, bs = "ts") + s(EKE, k = 4, bs = "ts") +
##     s(PkPP, k = 4, bs = "ts") + s(SST, k = 4, bs = "ts") + offset(log(area_km2))
## <environment: 0x1ea6a754>
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  -5.7144     0.1096  -52.15   <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) 2.970      3 106.66  <2e-16 ***
## s(EKE)   2.919      3  26.69  <2e-16 ***
## s(PkPP)  2.934      3  71.82  <2e-16 ***
## s(SST)   2.908      3 160.83  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.0199   Deviance explained = 41.8%
## -REML =  11080  Scale est. = 128.3     n = 123028
```

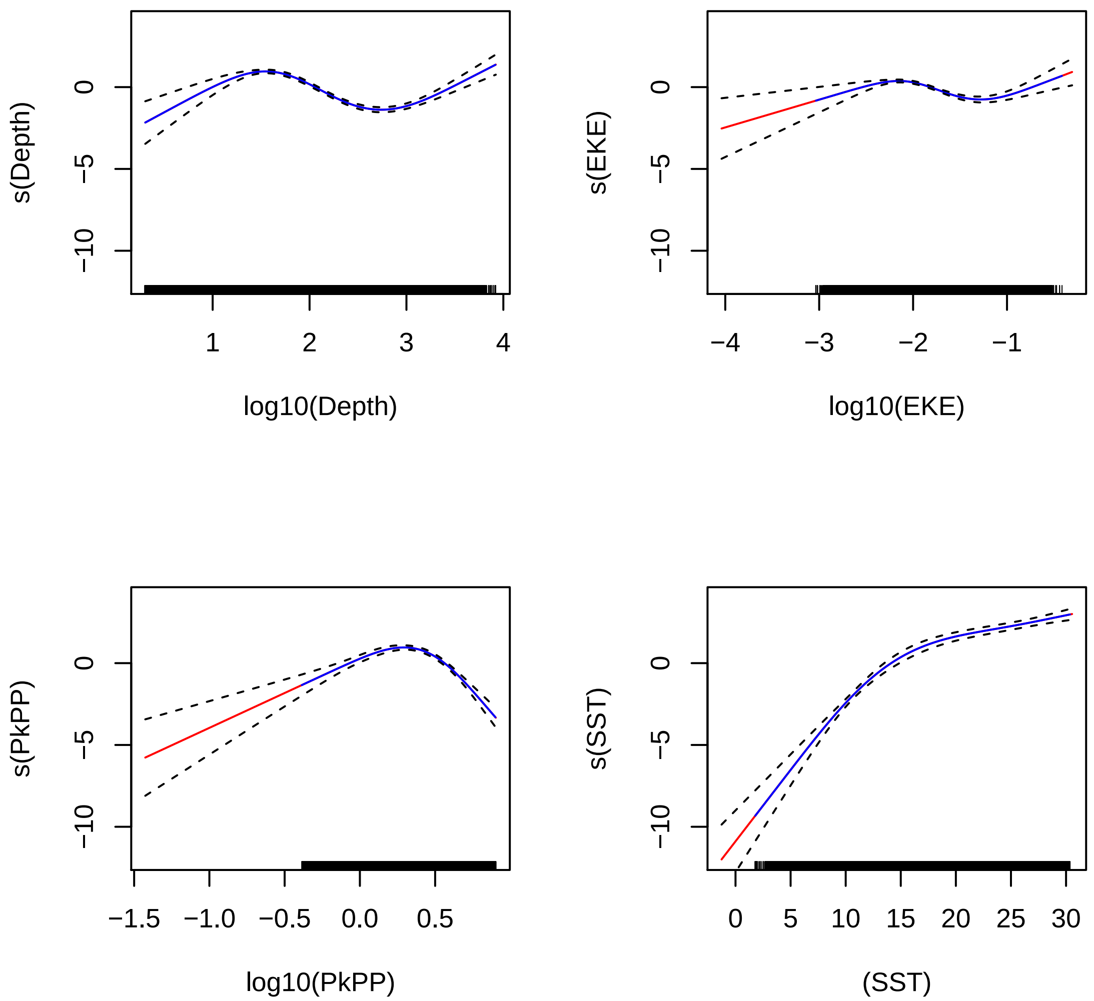


Figure 2: GAM term plots with the log-transformed abundance on the y axis. The solid blue line is the smooth function fitted to the data. The solid red line is the smooth function extrapolated to all covariate values in the prediction area. The dashed lines represent the approximate 95% confidence intervals.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

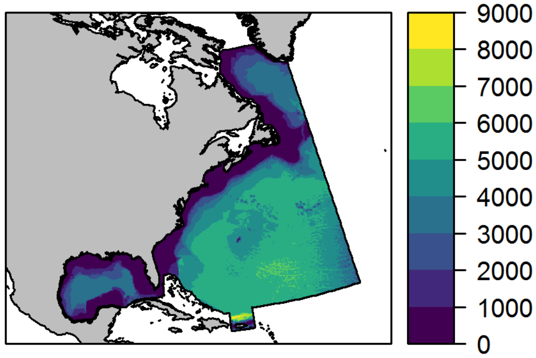
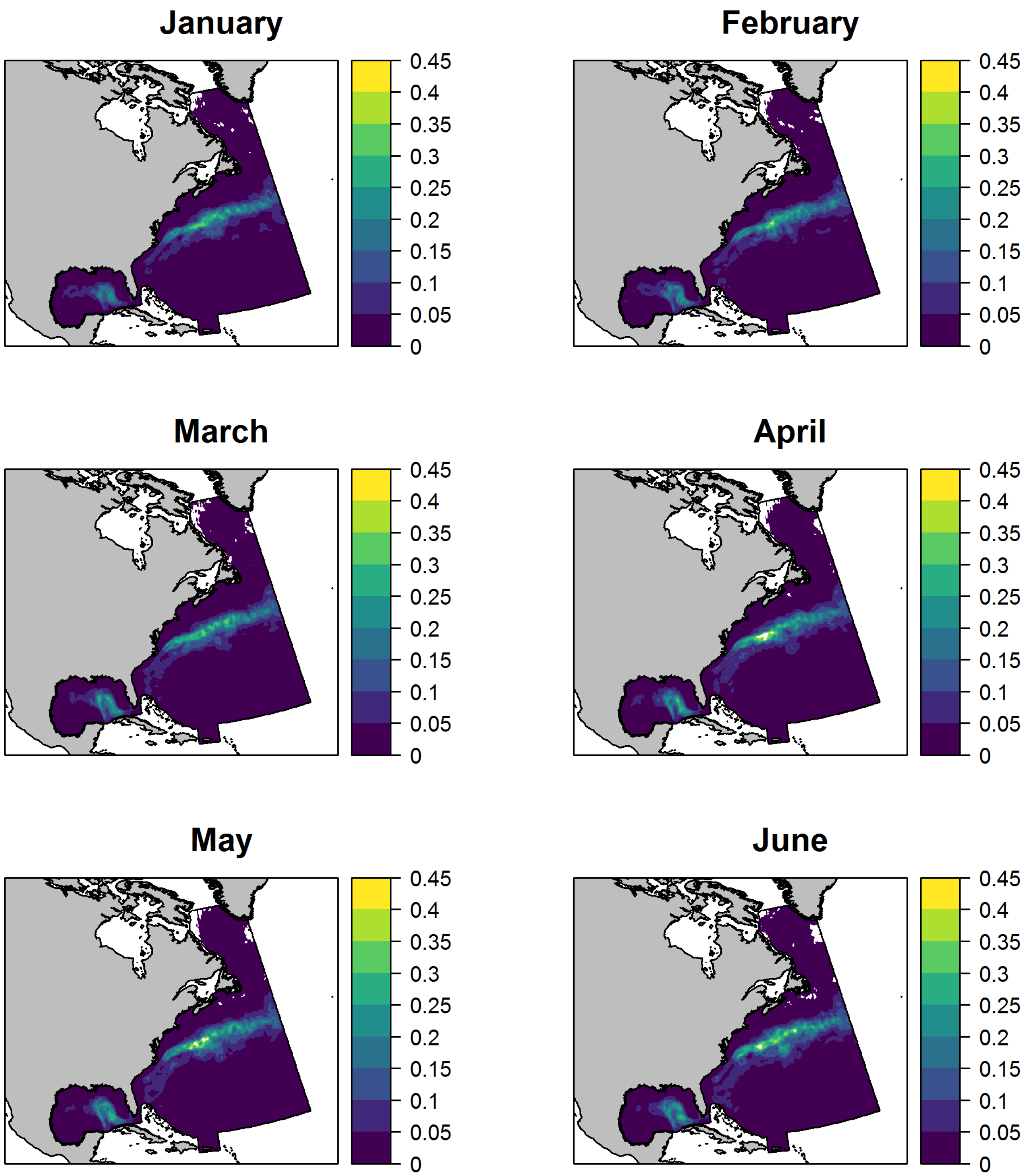


Figure 3: Environmental envelope for depth. White cells within the AFTT polygon indicate areas where covariate values fell beyond the range of covariate values sampled by the surveys.


January
February
March
April
May
June
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0

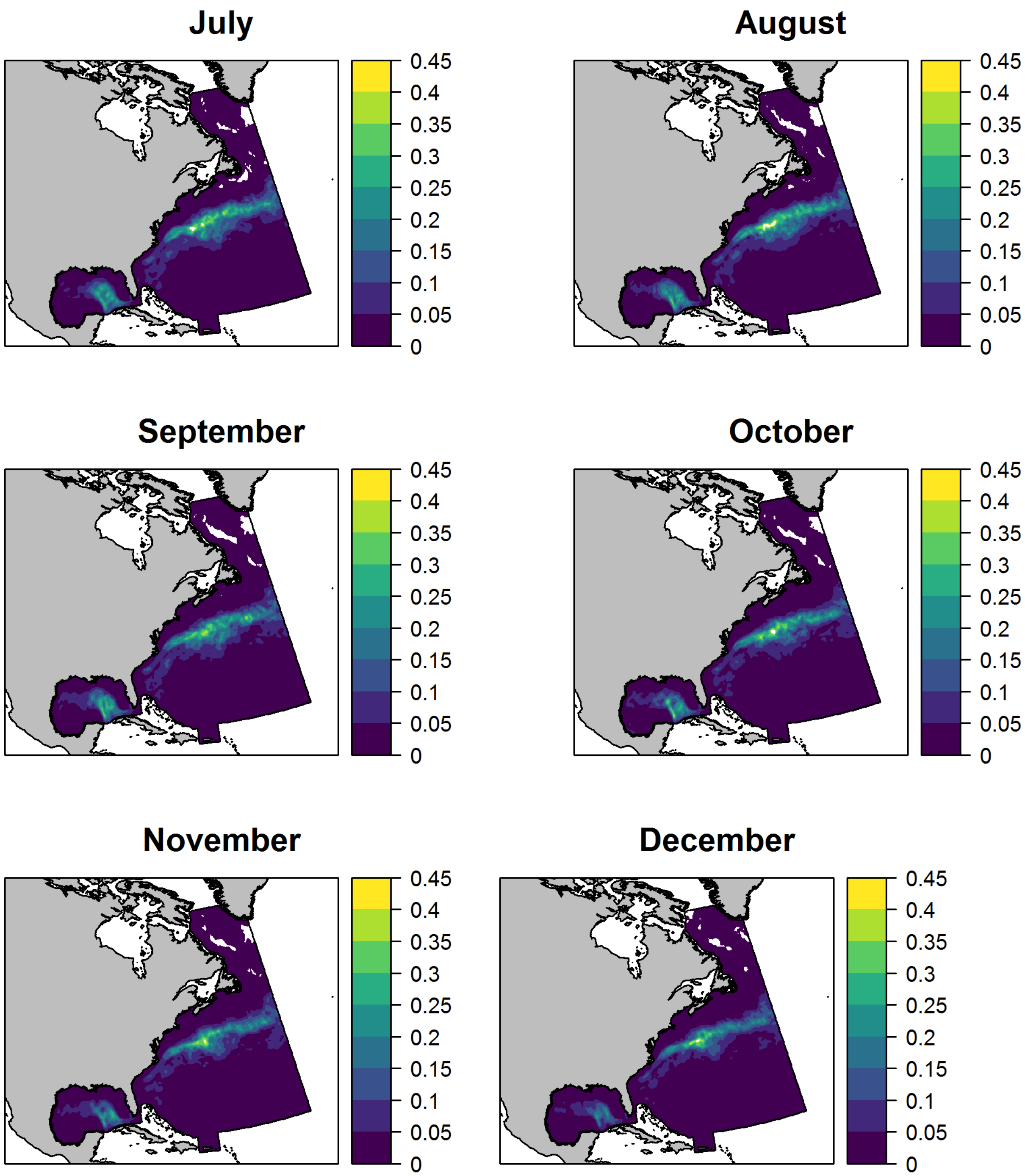
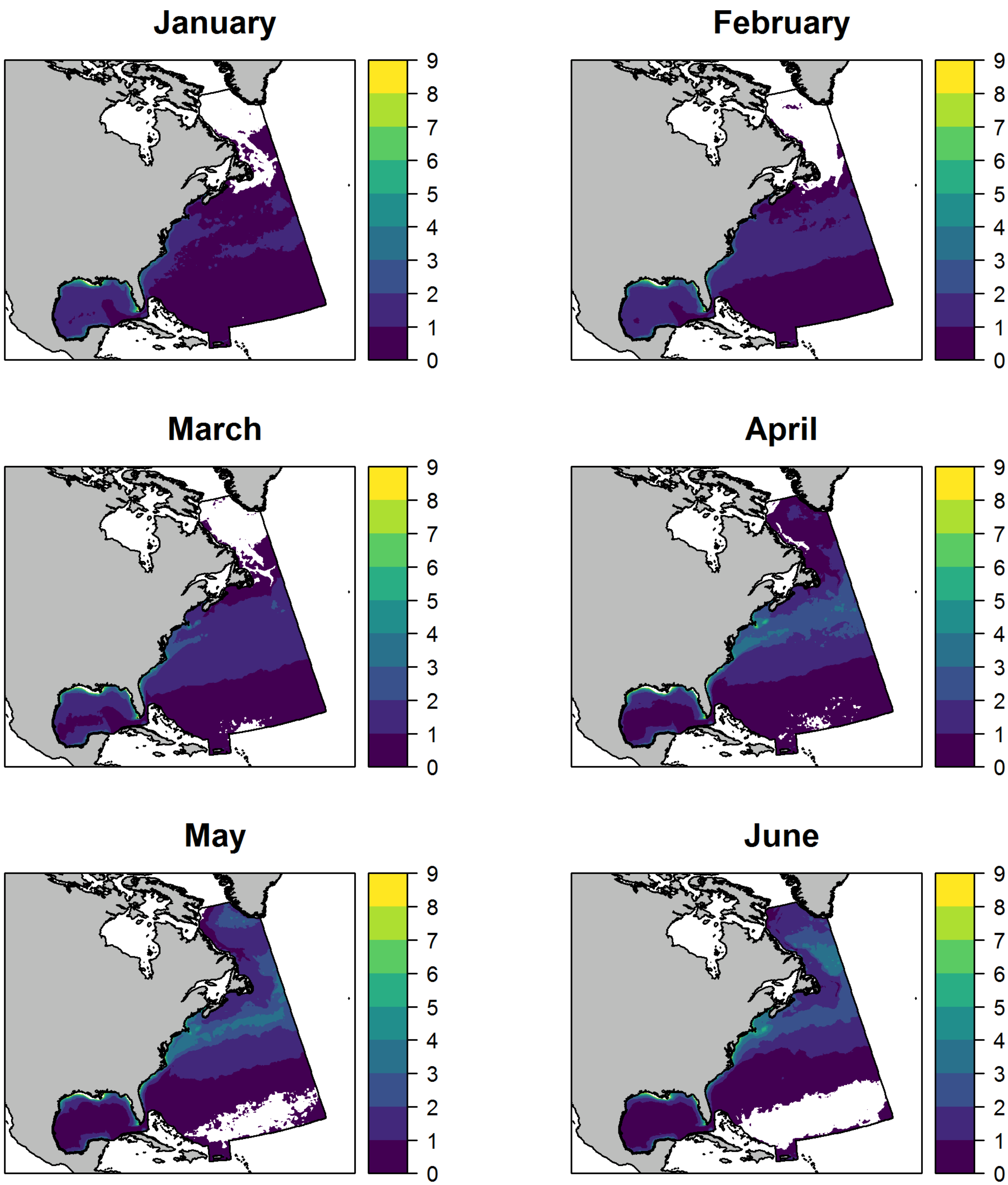


Figure 4: Monthly environmental envelopes for eddy kinetic energy. White cells within the AFTT polygon indicate areas where covariate values fell beyond the range of covariate values sampled by the surveys.


January
February
March
April
May
June
0
1
2
3
4
5
6
7
8
9

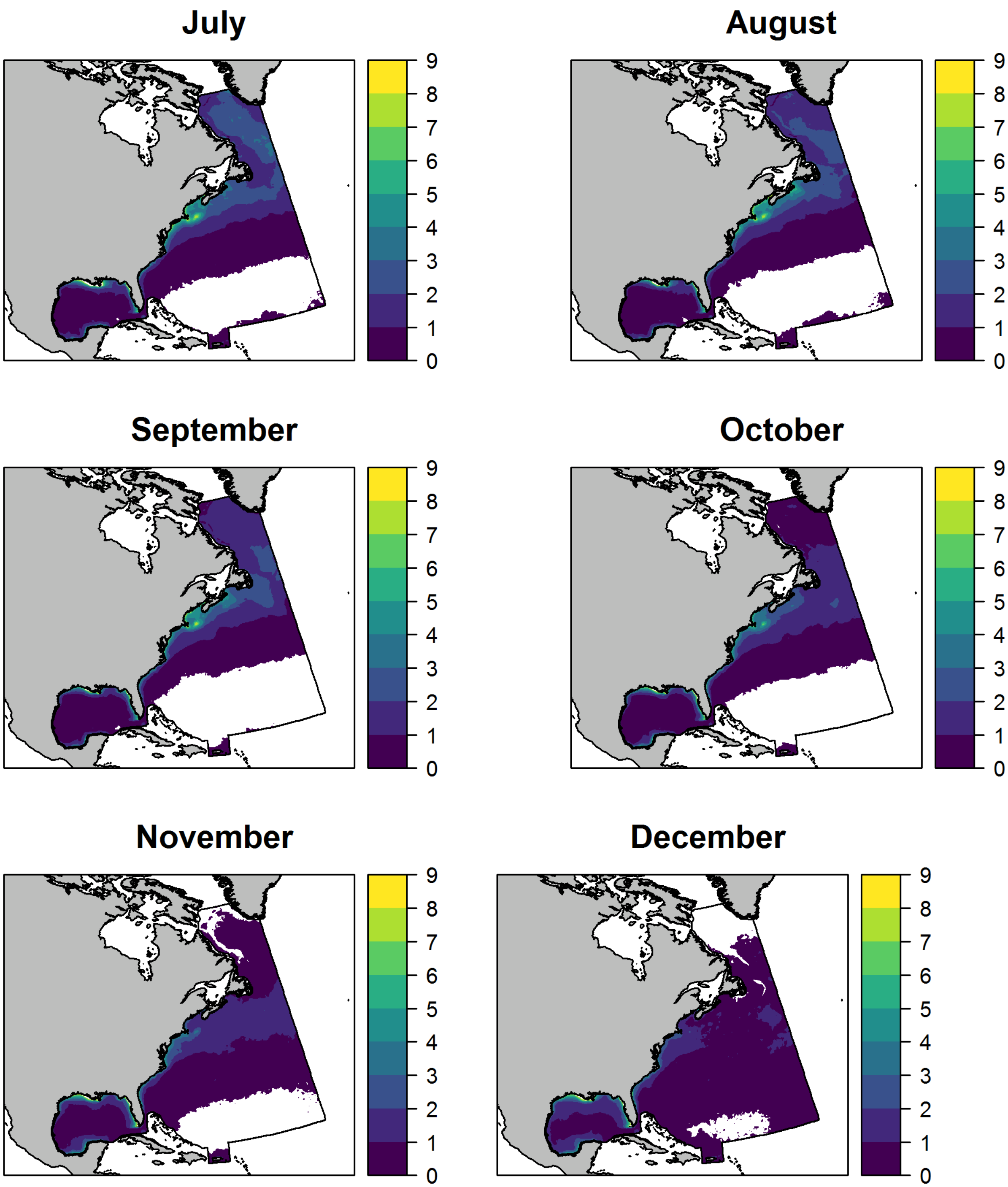
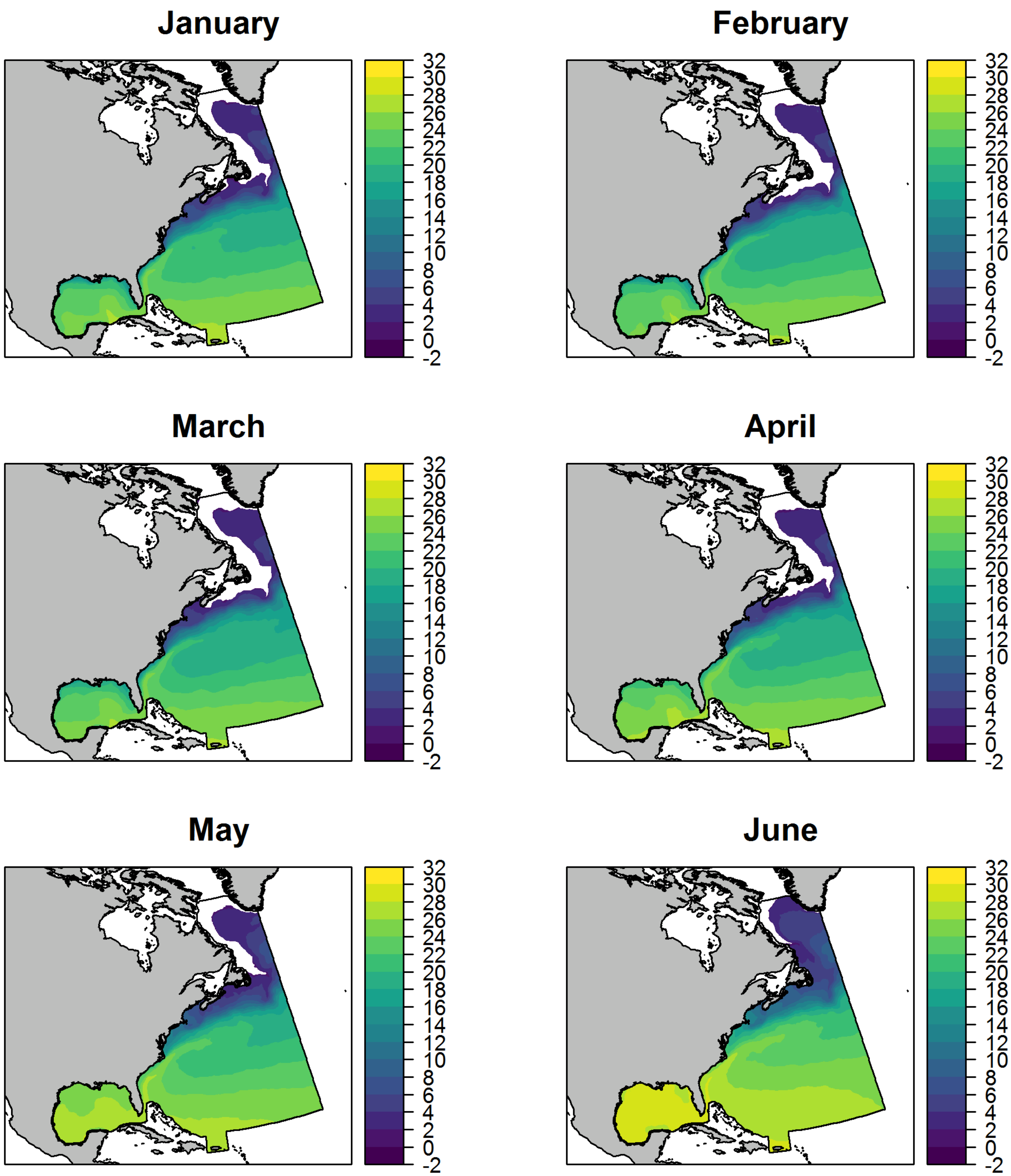


Figure 5: Monthly environmental envelopes for production of zooplankton. White cells within the AFTT polygon indicate areas where covariate values fell beyond the range of covariate values sampled by the surveys.


January
February
March
April
May
June
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2

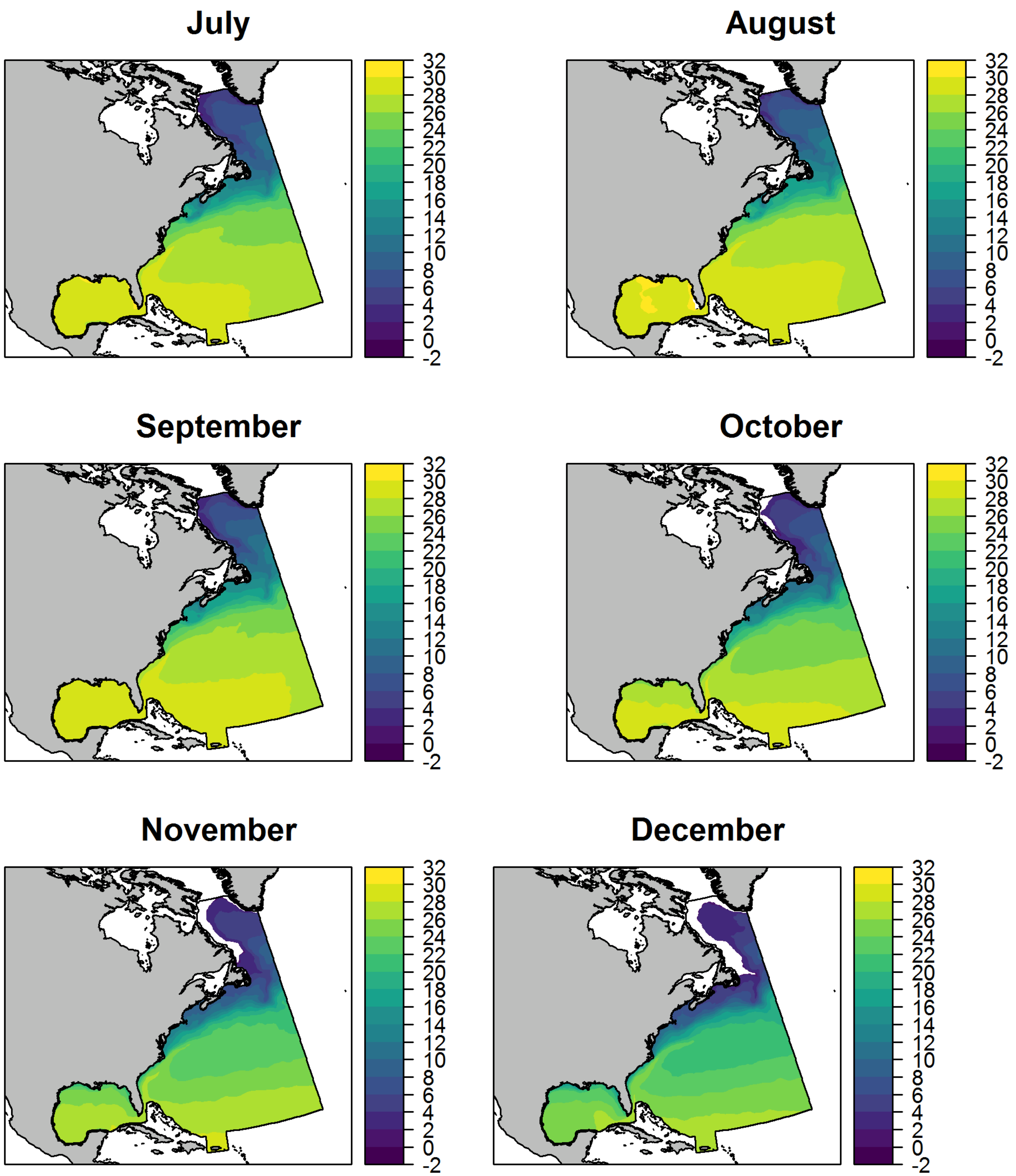


Figure 6: Monthly environmental envelopes for sea surface temperature. White cells within the AFTT polygon indicate areas where covariate values fell beyond the range of covariate values sampled by the surveys.

5- Predicted densities

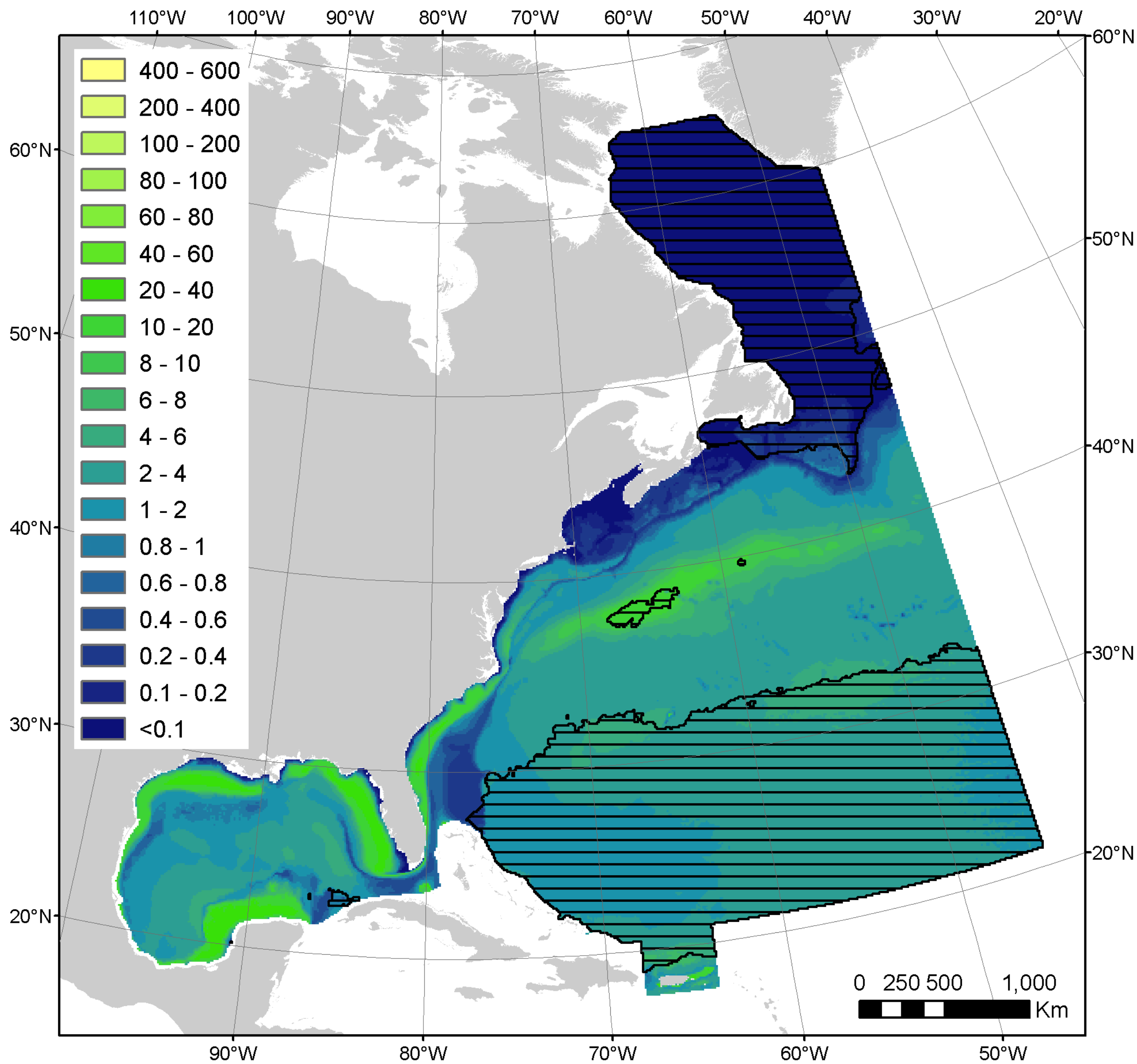


Figure 7: Mean predicted densities (individuals 100 km-2) in the AFTT area. Areas where we extrapolated beyond sampled predictor ranges and predicted densities should not be trusted are indicated with black crosshatches. An Albers equal area projection is used.

6- Coefficients of variation

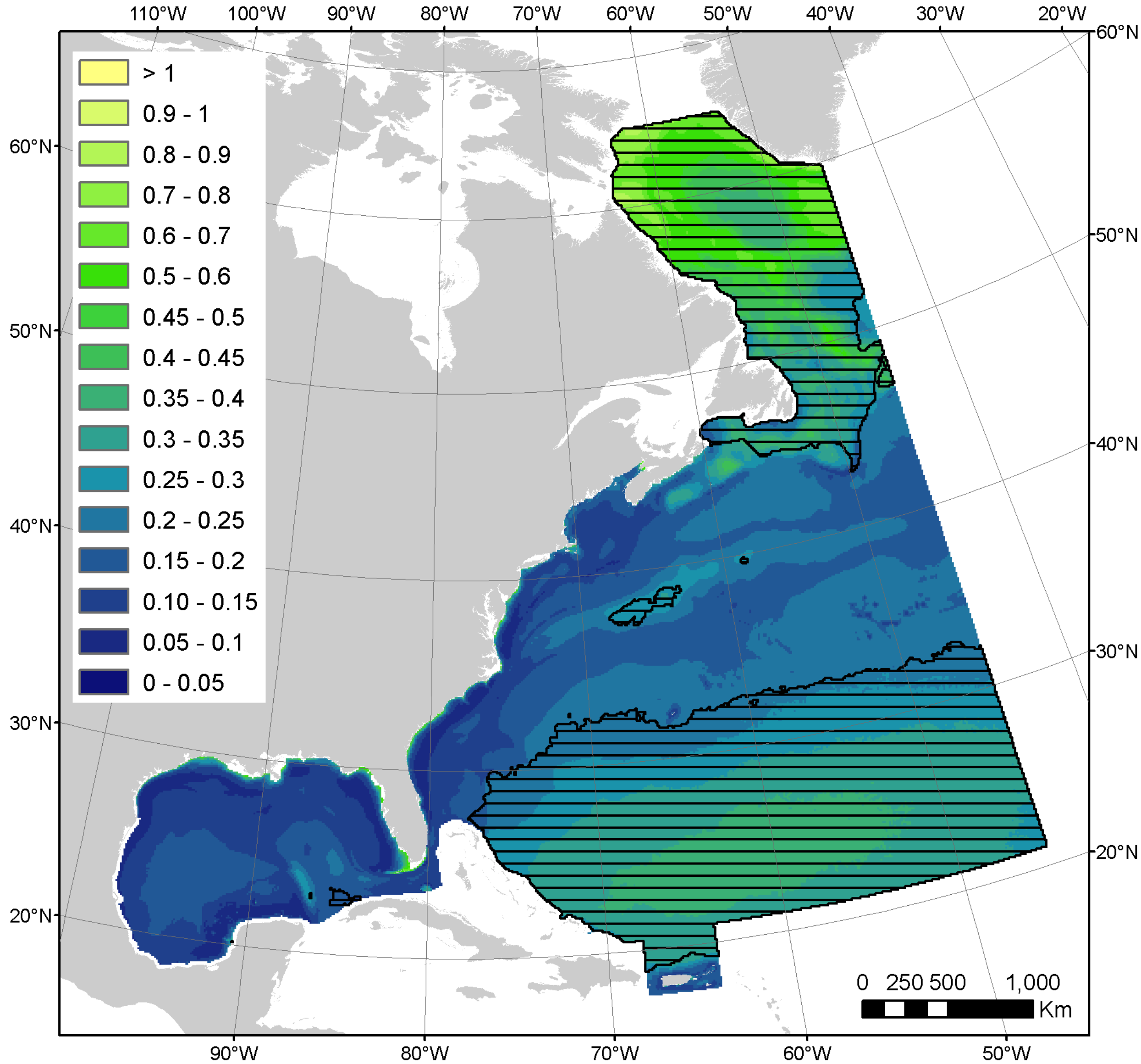


Figure 8: Mean predicted coefficients of variation derived from GAM parameters in the AFTT area. Areas where we extrapolated beyond sampled predictor ranges and coefficients of variation should not be trusted are indicated with black crosshatches. An Albers equal area projection is used.

7- Predicted densities per province

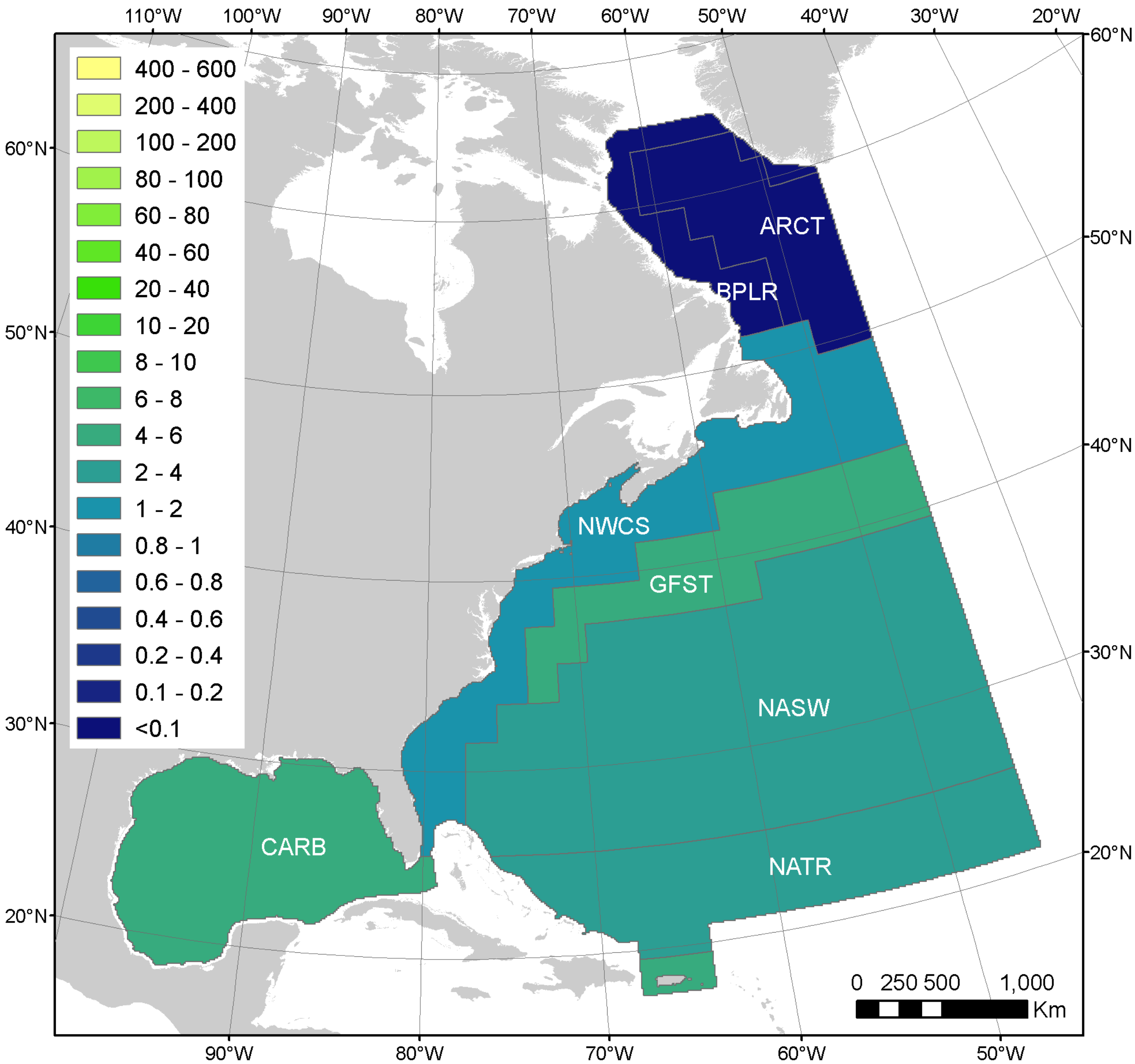


Figure 9: Predicted densities (individuals 100 km-2) averaged per Longhurst's biogeographical province. Note that the color scheme is the same as in Figure 7. Provinces: ARCT: Atlantic Arctic Province; BPLR: Boreal Polar Province; CARB: Caribbean Province; GFST: Gulf Stream Province; NATR: North Atlantic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

8- Alternate models

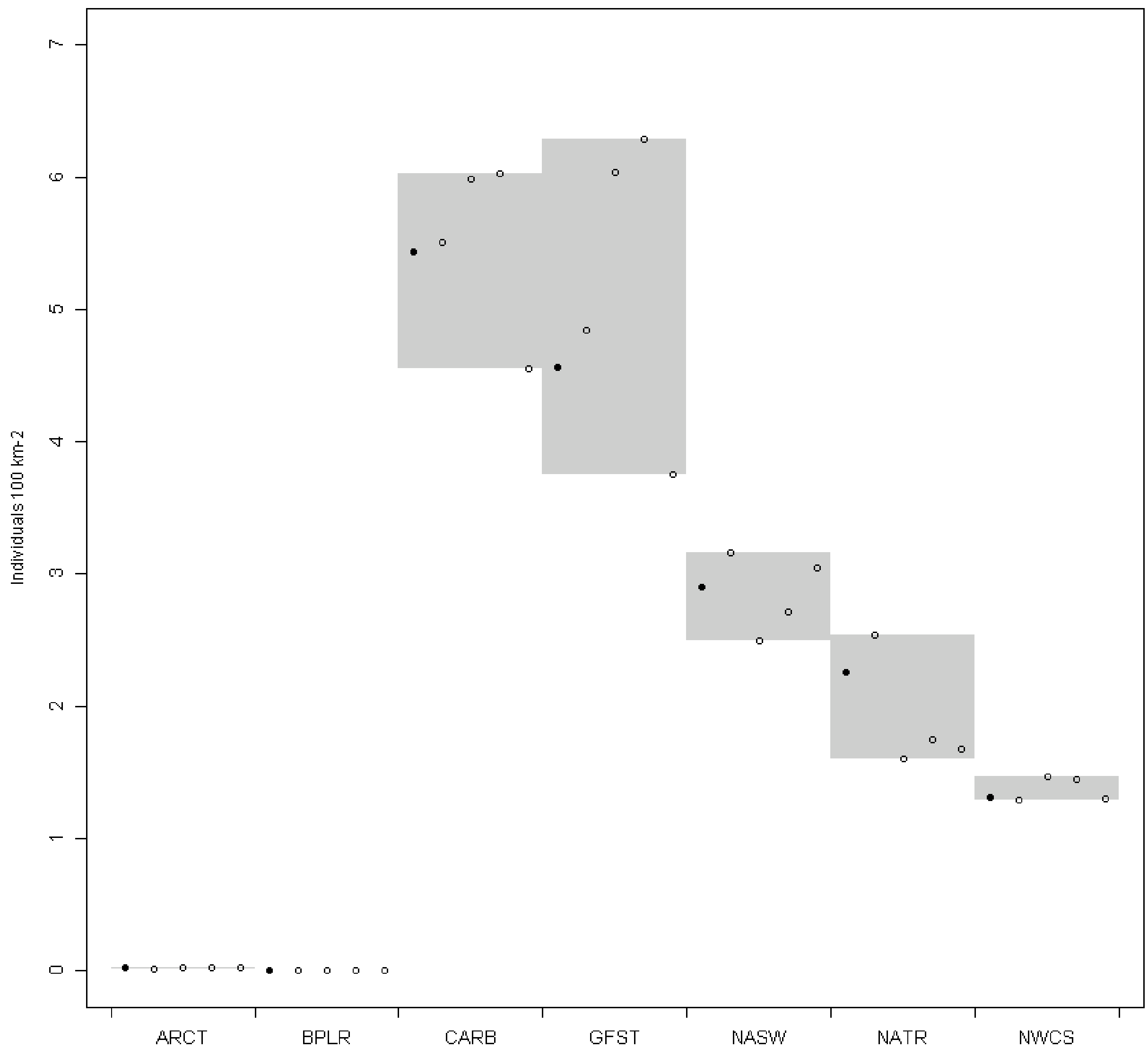


Figure 10: Sensitivity of densities predicted by the five top models per Longhurst's biogeographical province. Points represent predicted densities (individuals 100 km-2) for the five top models listed in Table 3, with the first to fifth models ordered from left to right. Filled points correspond to 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	SST	PkPP	EKE	122305.5	0.0
Depth	SST	EKE	VGPM	122308.0	2.5
Depth	SST	SLAStDev	PkPP	122332.1	26.6
Depth	SST	SLAStDev	VGPM	122334.3	28.8
Depth	SST	PkPP	EpiMnkPP	122338.8	33.3

9- Residual diagnostics

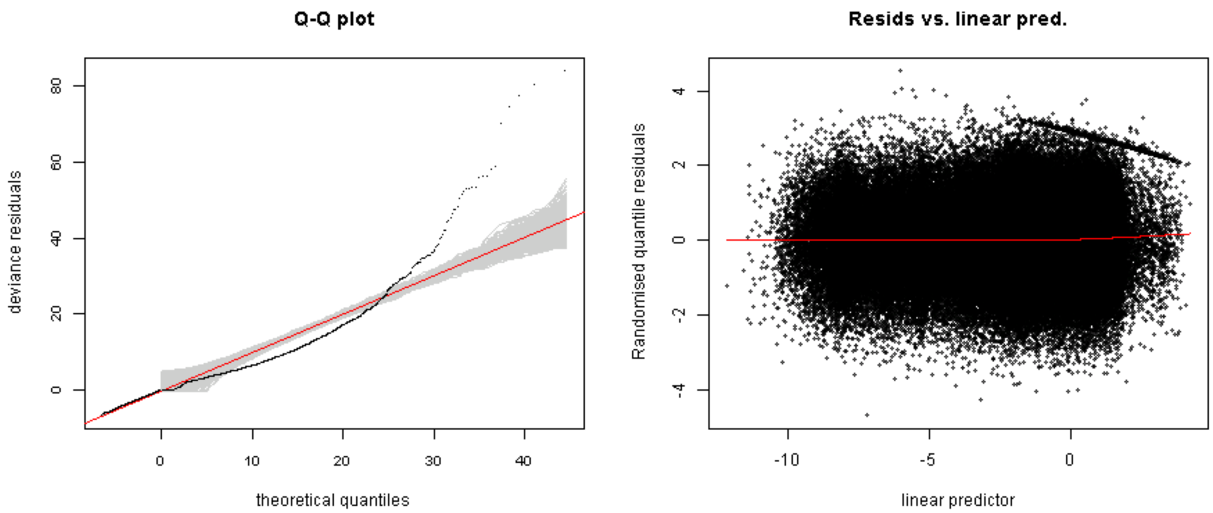


Figure 11: Diagnostic plots of residuals. Left: Quantile-quantile (Q-Q) plot of deviance residuals generated using the qq.gam function with 100 simulations (Augustin et al. 2012). Grey lines are possible simulated Q-Q plots under the assumption that the model is correct. The red reference line indicates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

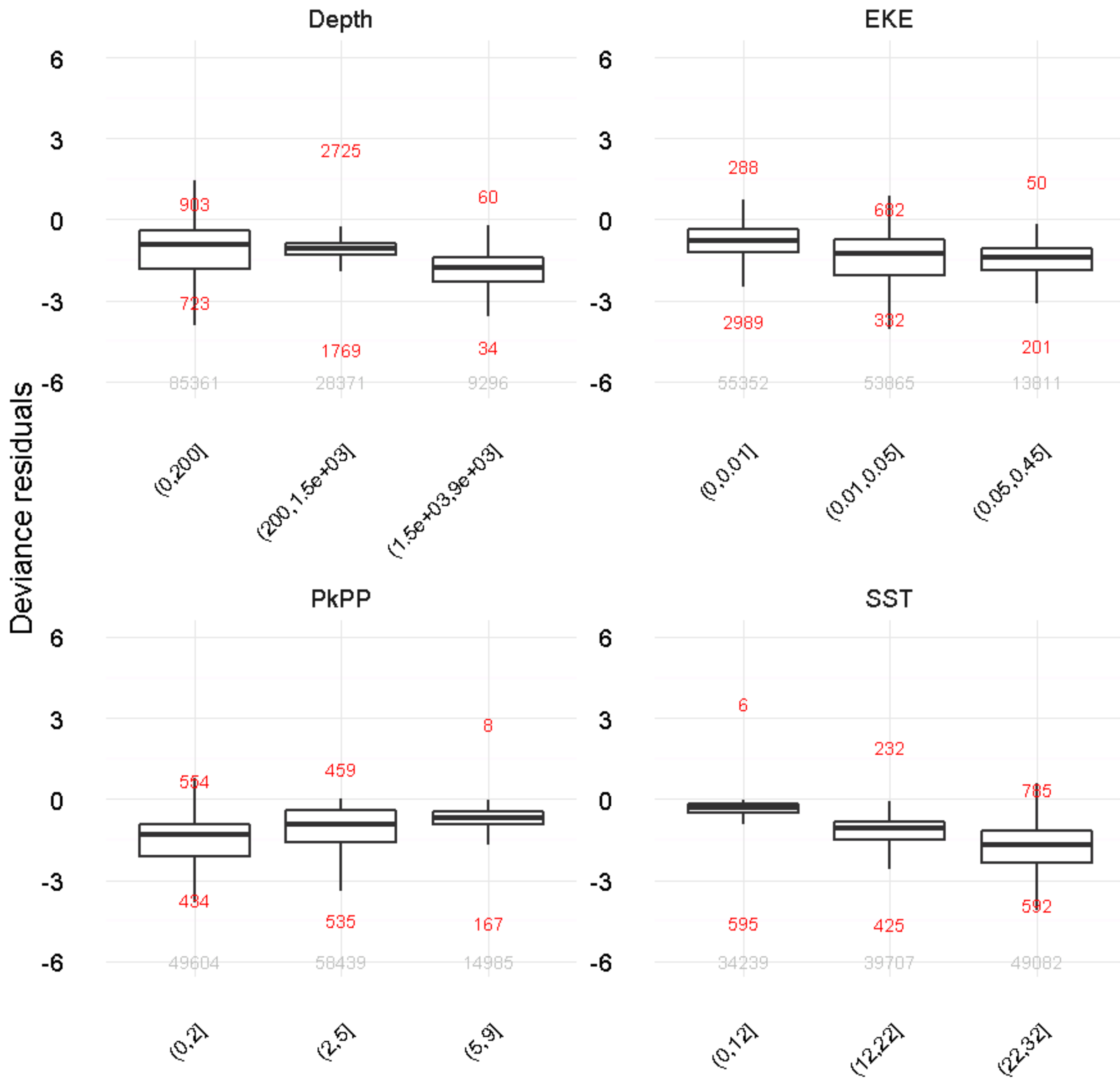


Figure 12: Boxplots of deviance residuals, binned for each predictor. The horizontal line represents the median, and the bottom and top of the box represent the first and third quartiles respectively. Whiskers extend 1.5 times the inter-quartile range following McGill et al. (1978). Total counts of outliers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

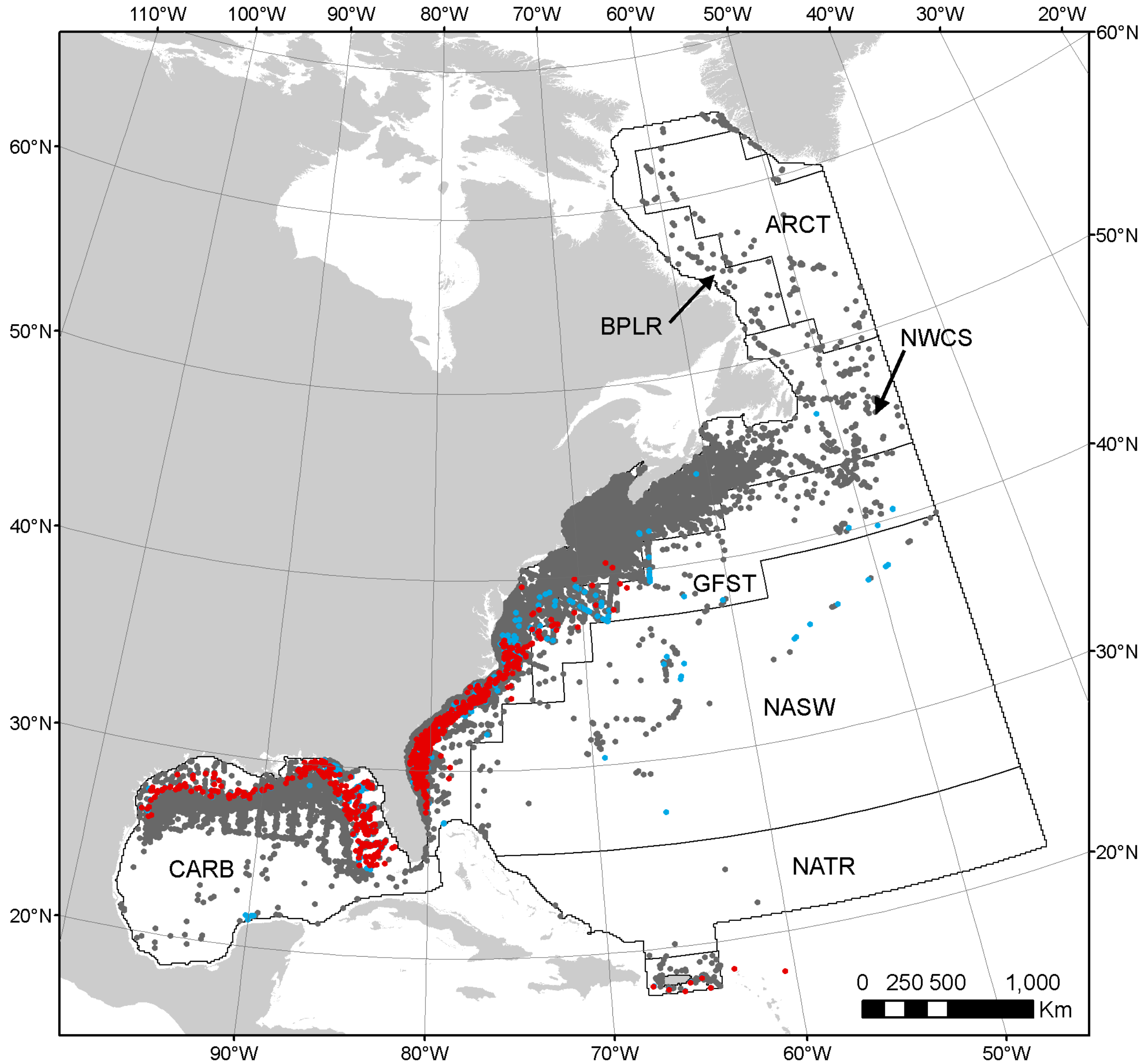


Figure 13: Red points are sightings of the taxon from line transect surveys used in this study. Blue points are sightings of the taxon reported by other datasets not used in our study for 1992-2016 (e.g., because they were not compatible with our methodology). Underlain grey points are sightings of other 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 1150 sightings was available to fit the habitat-based density model (we note that 72% of the sightings came from surveys in the U.S. east coast). The first or lowest AIC model included sea surface temperature, depth, zooplankton production and eddy kinetic energy (listed in decreasing order of importance according to F-scores) and had an explained deviance of 41.8%. This model was the only supported model sensu Burnham and Anderson (2002) (Table 3). All top five models included depth and sea surface temperature. The third, fourth and fifth models had very large delta AIC and therefore little statistical support. Predicted densities from the top five models were close to zero in the ARCT and BPLR provinces and relatively similar in the NWCS, NASW and NATR province (Figure 10). Predicted densities from the top five models differed the most in the GFST province (however most of the variation was due to the fourth and fifth models which had little support). We note that the top two models predicted similar densities in all provinces.

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 province, the ARCT province and the northern part of the NWCS province were consistent with the known distribution of Atlantic spotted dolphins in warm temperate and tropical waters of the Atlantic Ocean (Perrin et al. 1987) and the paucity of sightings reported in OBIS-SEAMAP north of 42°N (Figure 13). We caution, however, that these predictions were derived from extrapolation to colder sea surface temperatures and are largely speculative.

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

South of Cape Hatteras, predicted densities were highest on the continental shelf, while north of Cape Hatteras, they were highest in offshore waters within the Gulf Stream. We believe these predictions are plausible because: (1) Atlantic spotted dolphin occurs both on and off the continental shelf (but its offshore distribution is poorly known) (Perrin et al. 1987) and (2) numerous sightings were reported off the continental shelf north of Cape Hatteras (western part of the GFST province) (Figure 13). We caution that predictions in some parts of the GFST province were derived from extrapolation to higher eddy kinetic energy and should be viewed with due caution.

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

No line transect survey data were available in offshore waters of the NATR and the NASW province where the model predicted medium densities. These predictions were compatible with multiple sightings reported in the NASW province (no sightings were reported in the NATR province but observation effort was almost inexistent in this province). We warn that predictions in the NATR province and the southern part of the NASW province were derived from extrapolations to lower zooplankton production; therefore, they should be considered with extreme caution (Figure 13).

Caribbean (CARB) province

In the Gulf of Mexico, highest densities were predicted on the continental shelf. Predictions in the southern Gulf of Mexico were consistent with documented concentrations of Atlantic spotted dolphins on the Mexican continental shelf (Delgado Estrella 1997; Jefferson & Schiro 1997; Ortega-Ortiz 2002). Coastal sightings were also reported in OBIS-SEAMAP near the Yucatan peninsula (Figure 13). We note that extrapolations to lower zooplankton production occurred in a small area of the southern Gulf of Mexico.

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 50% of the AFTT area and that predicted densities in these extrapolation areas should be interpreted with extreme caution.

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