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

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This report documents the habitat-based density model for Atlantic white-sided 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 white-sided 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
EC	1044357.704	2235
EU	27526.342	56
MAR	2424.421	7
All regions	1074308.466	2298

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

Month	Effort	Sightings
January	71406.04	53
February	96993.70	32
March	98664.69	59
April	105121.39	125
May	107303.24	436
June	119895.45	762
July	140462.97	292
August	110040.12	152
September	52584.62	12
October	57619.14	68
November	60008.94	245
December	54208.17	62
All Months	1074308.47	2298

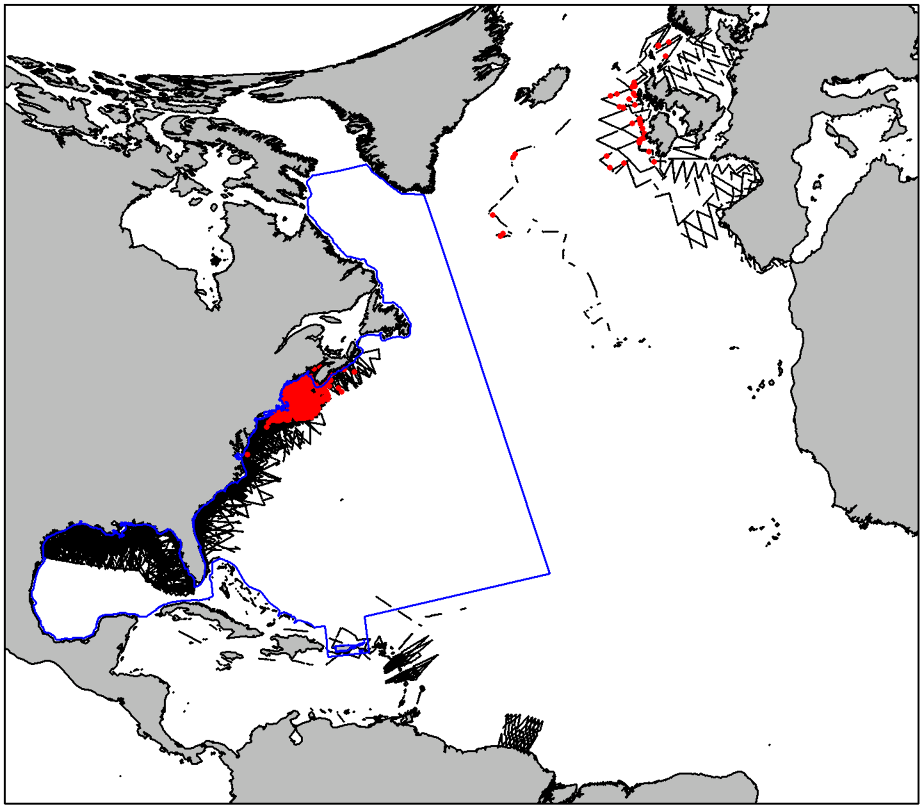


Figure 1: Map of segments (black lines) and sighting locations (red dots). An Albers equal area projection optimized for the AFTT area is used.

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 white-sided dolphin (*Lagenorhynchus acutus*)

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

In addition to segments from the western North Atlantic, we incorporated segments from the mid-Atlantic ridge and European Atlantic to increase the representativeness of offshore waters that constitute a notable habitat for Atlantic white-sided dolphin (Palka et al. 1997; Cipriano 2009).

Special treatment in the Gulf of Mexico

There were no Atlantic white-sided dolphins sighted during the Gulf of Mexico surveys, and the species is believed to be absent from the Gulf of Mexico (Jefferson and Schiro 1997). Based on this information, we assigned zero densities to the entire Gulf of Mexico (the model predicted very low densities).

3- Best model

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

```
##
## Family: Tweedie(p=1.422)
## Link function: log
##
## Formula:
## abundance ~ s(Depth, k = 4, bs = "ts") + s(DistToFront1, k = 4,
##     bs = "ts") + s(EpiMnkPP, k = 4, bs = "ts") + s(SST, k = 4,
##     bs = "ts") + offset(log(area_km2))
## <environment: 0x1e6cdcf8>
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  -7.5389     0.2638  -28.58   <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)        2.966      3 113.79  < 2e-16 ***
## s(DistToFront1) 2.115      3  11.34 8.99e-09 ***
## s(EpiMnkPP)     1.286      3  11.45 1.59e-09 ***
## s(SST)          2.969      3 175.21  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.0103   Deviance explained = 35.2%
## -REML =  13980  Scale est. = 133.87    n = 116739
```

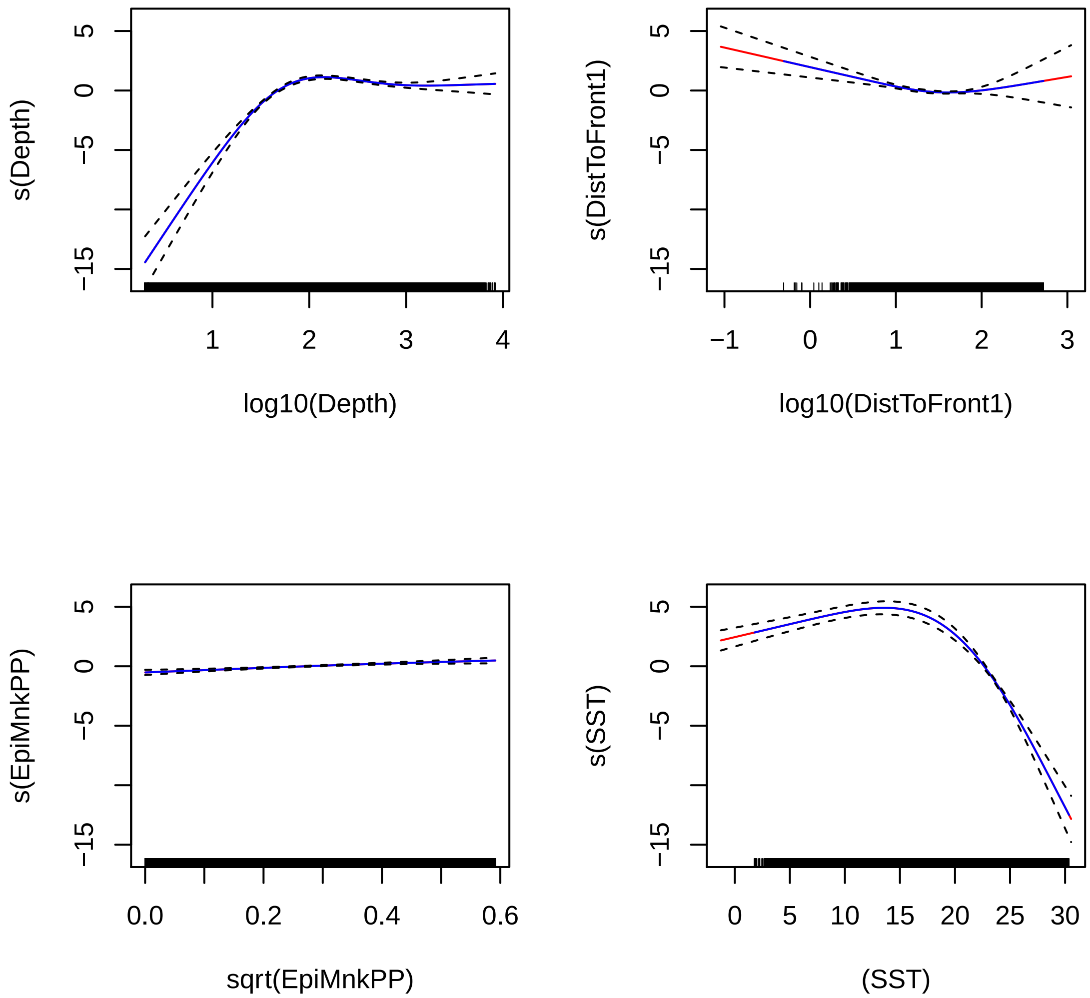


Figure 2: GAM term plots with the log-transformed abundance on the y axis. The solid blue line is the smooth function fitted to the data. The solid red line is the smooth function extrapolated to all covariate values in the prediction area. The dashed lines represent the approximate 95% confidence intervals.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

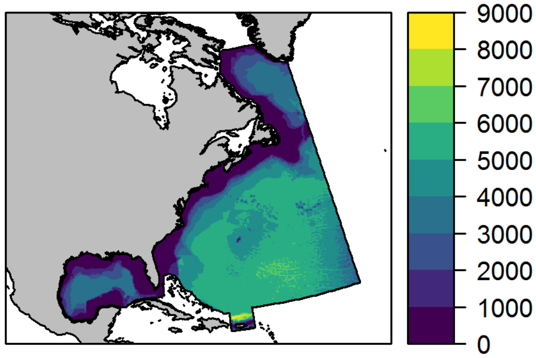
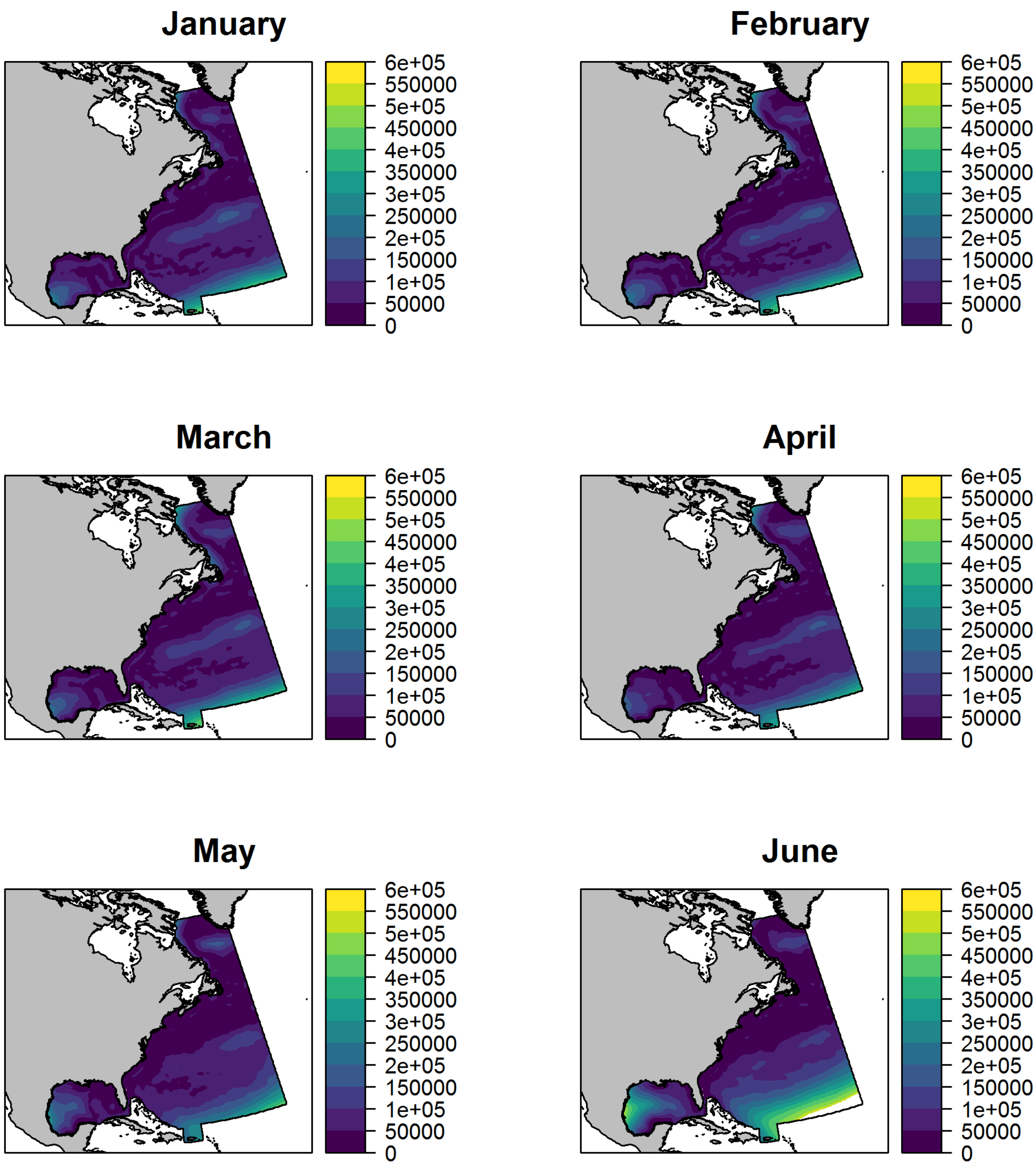


Figure 3: Environmental envelope for depth. White cells within the AFTT polygon indicate areas where covariate values fell beyond the range of covariate values sampled by the surveys.


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

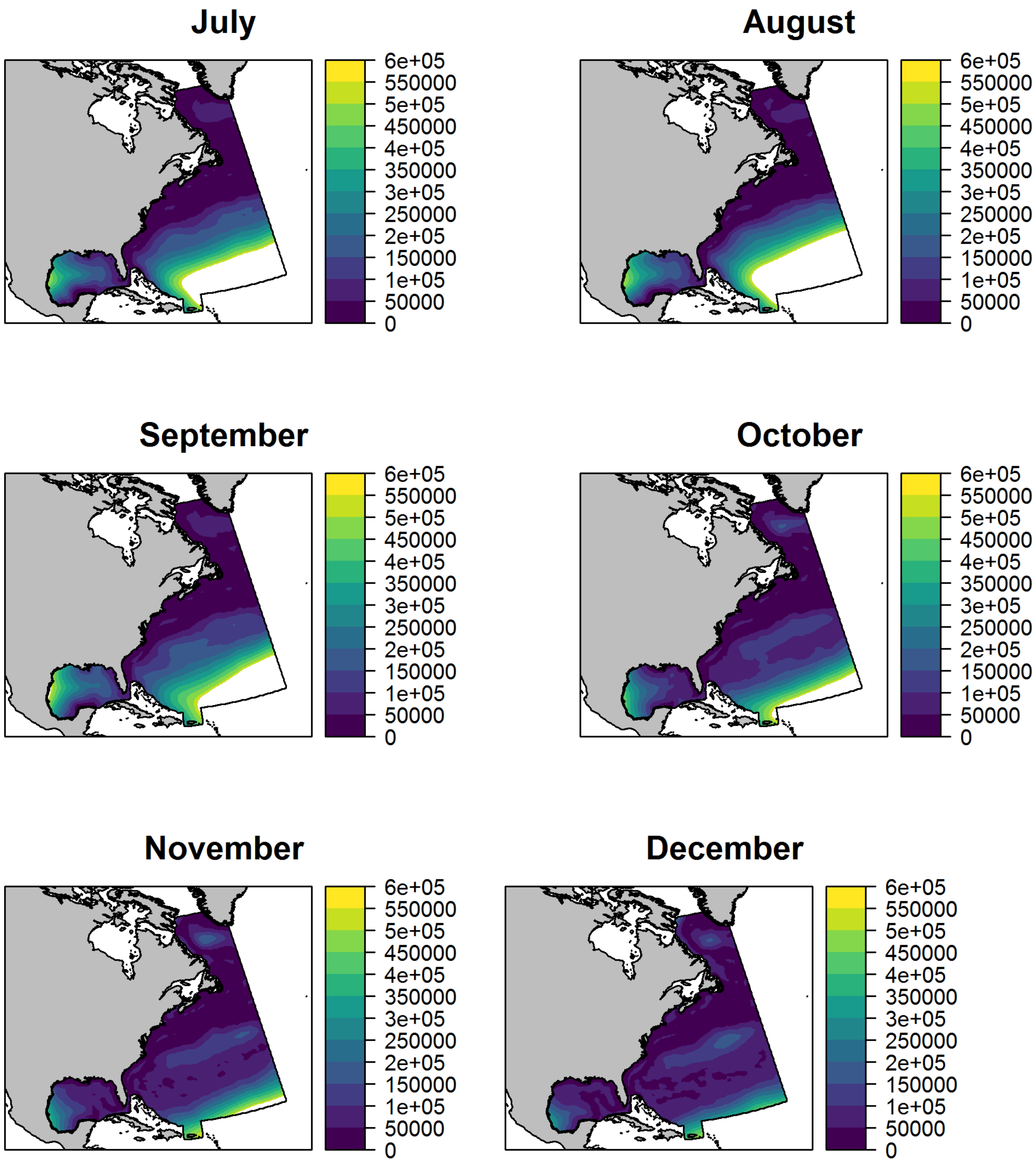
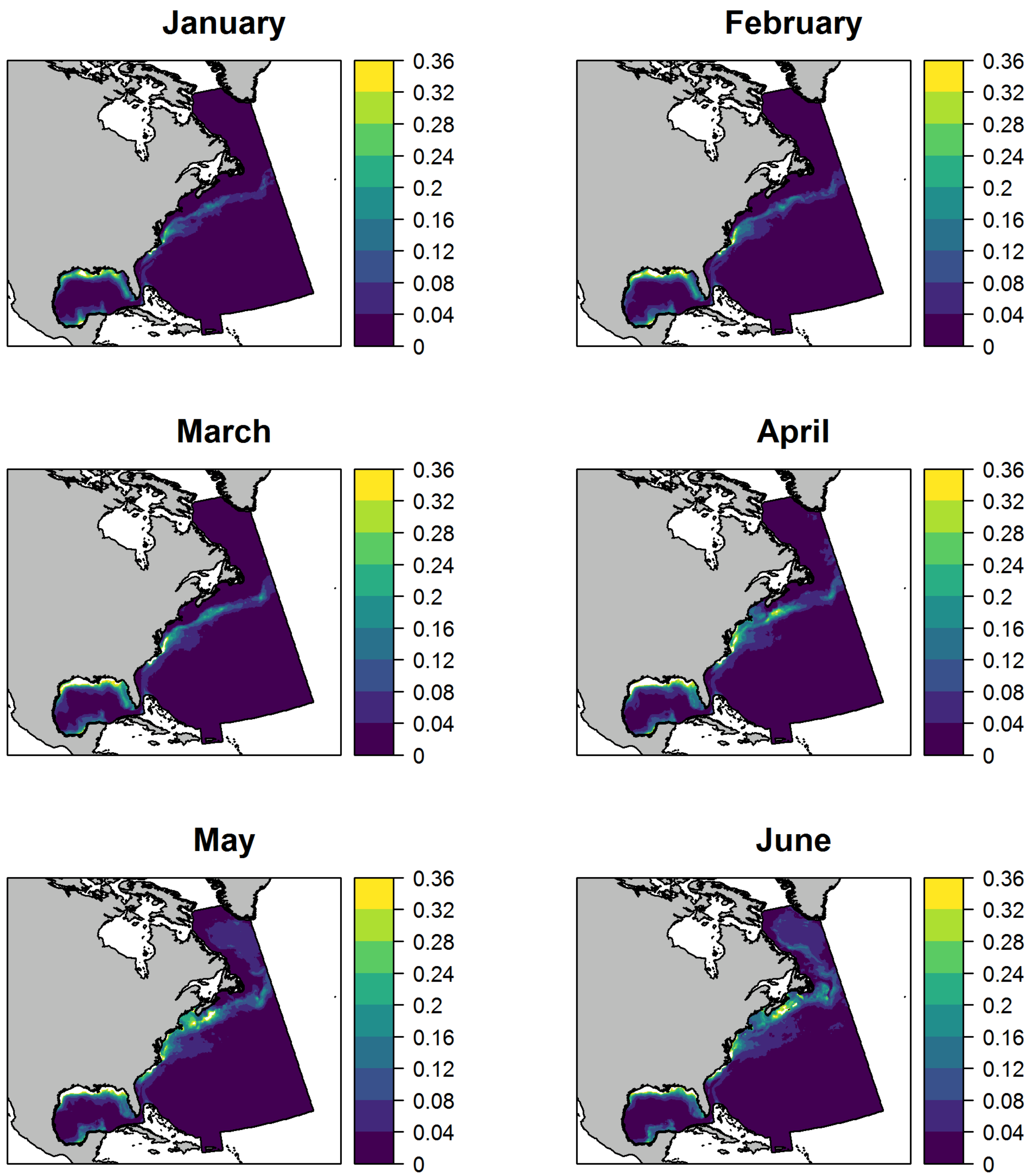


Figure 4: Monthly environmental envelopes for distance to SST fronts. White cells within the AFTT polygon indicate areas where covariate values fell beyond the range of covariate values sampled by the surveys.


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

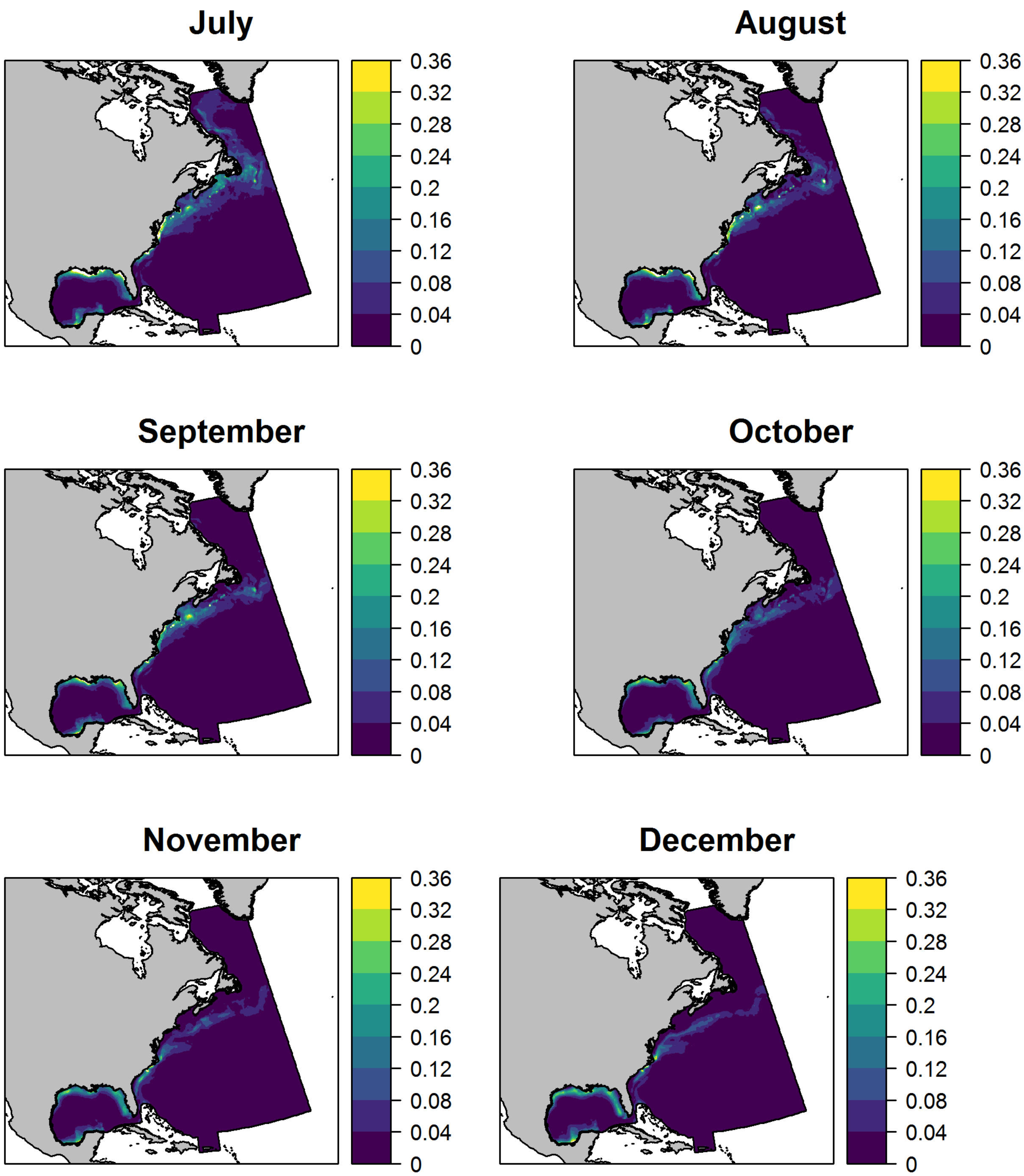
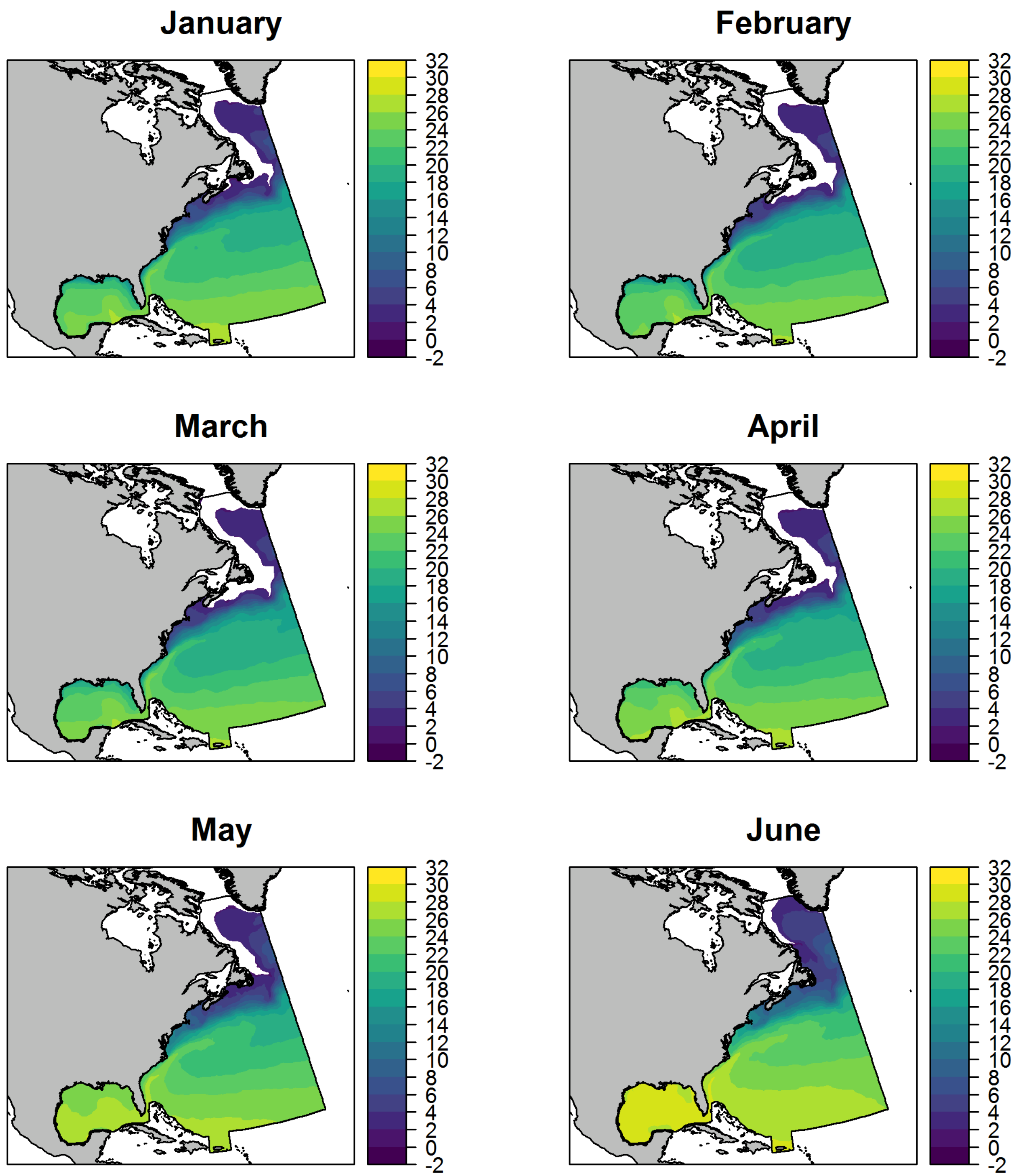


Figure 5: Monthly environmental envelopes for production of epipelagic micronekton. White cells within the AFTT polygon indicate areas where covariate values fell beyond the range of covariate values sampled by the surveys.


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

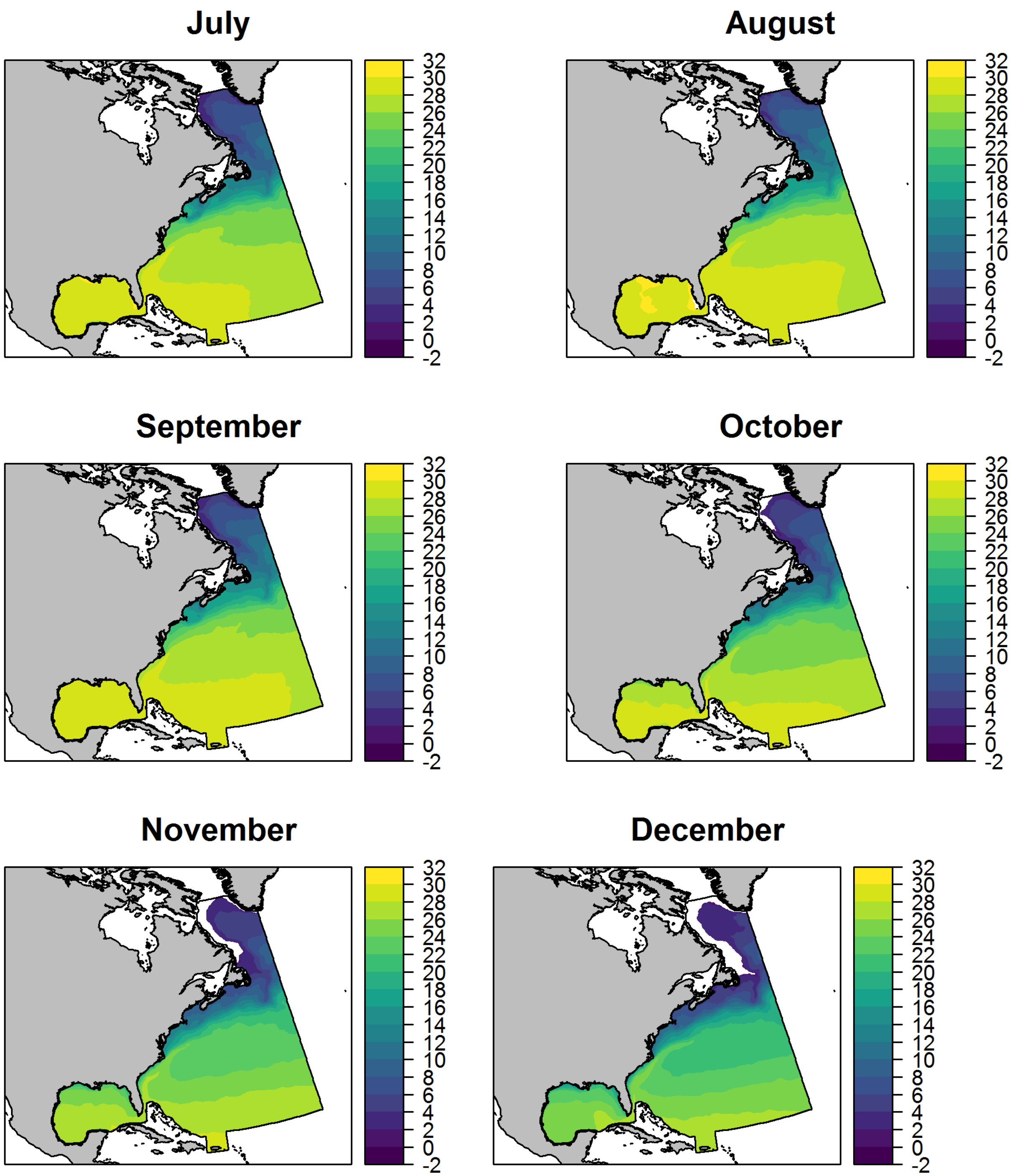


Figure 6: Monthly environmental envelopes for sea surface temperature. White cells within the AFTT polygon indicate areas where covariate values fell beyond the range of covariate values sampled by the surveys.

5- Predicted densities

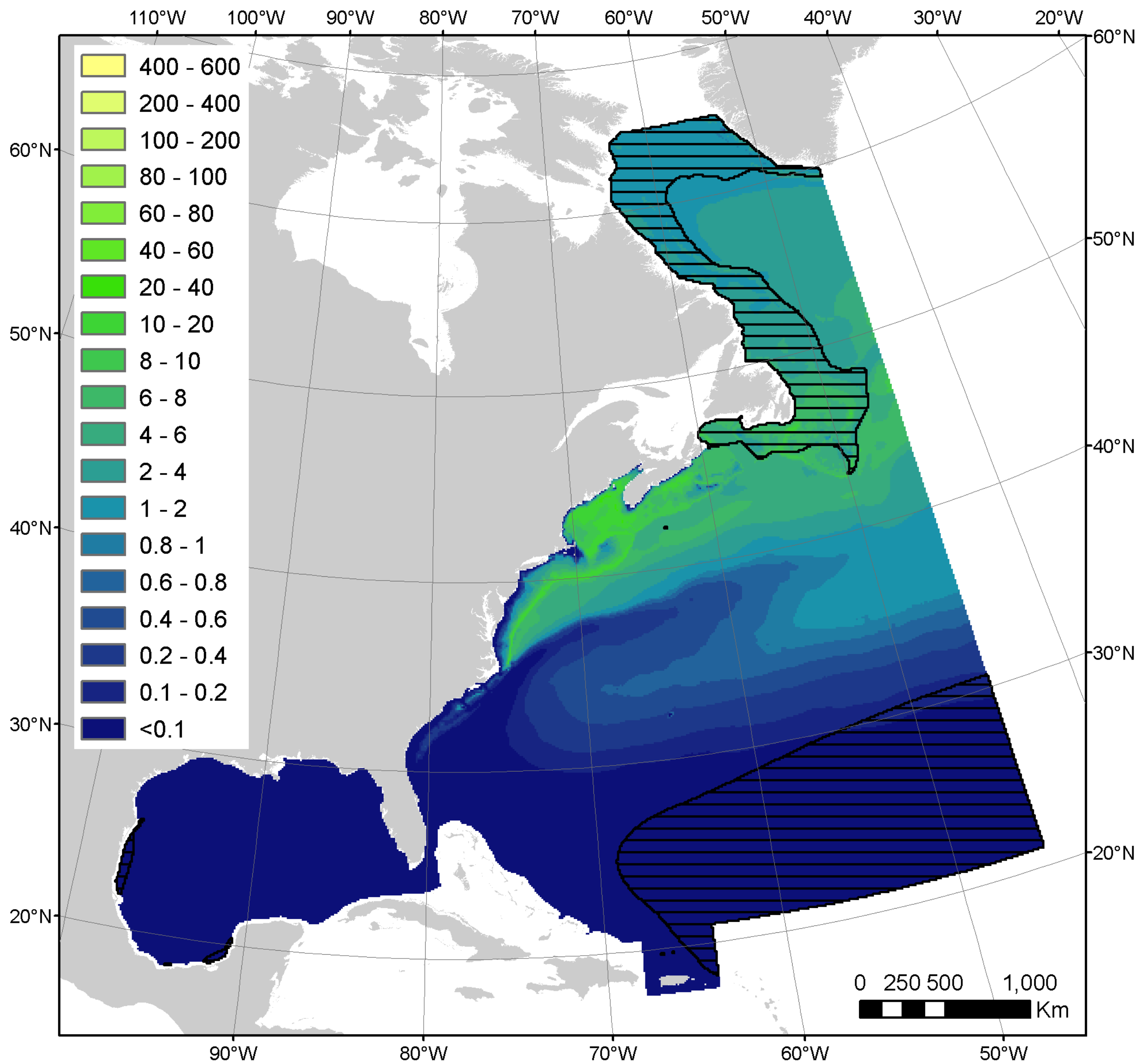


Figure 7: Mean predicted densities (individuals 100 km-2) in the AFTT area. Areas where we extrapolated beyond sampled predictor ranges and predicted densities should not be trusted are indicated with black crosshatches. An Albers equal area projection is used.

6- Coefficients of variation

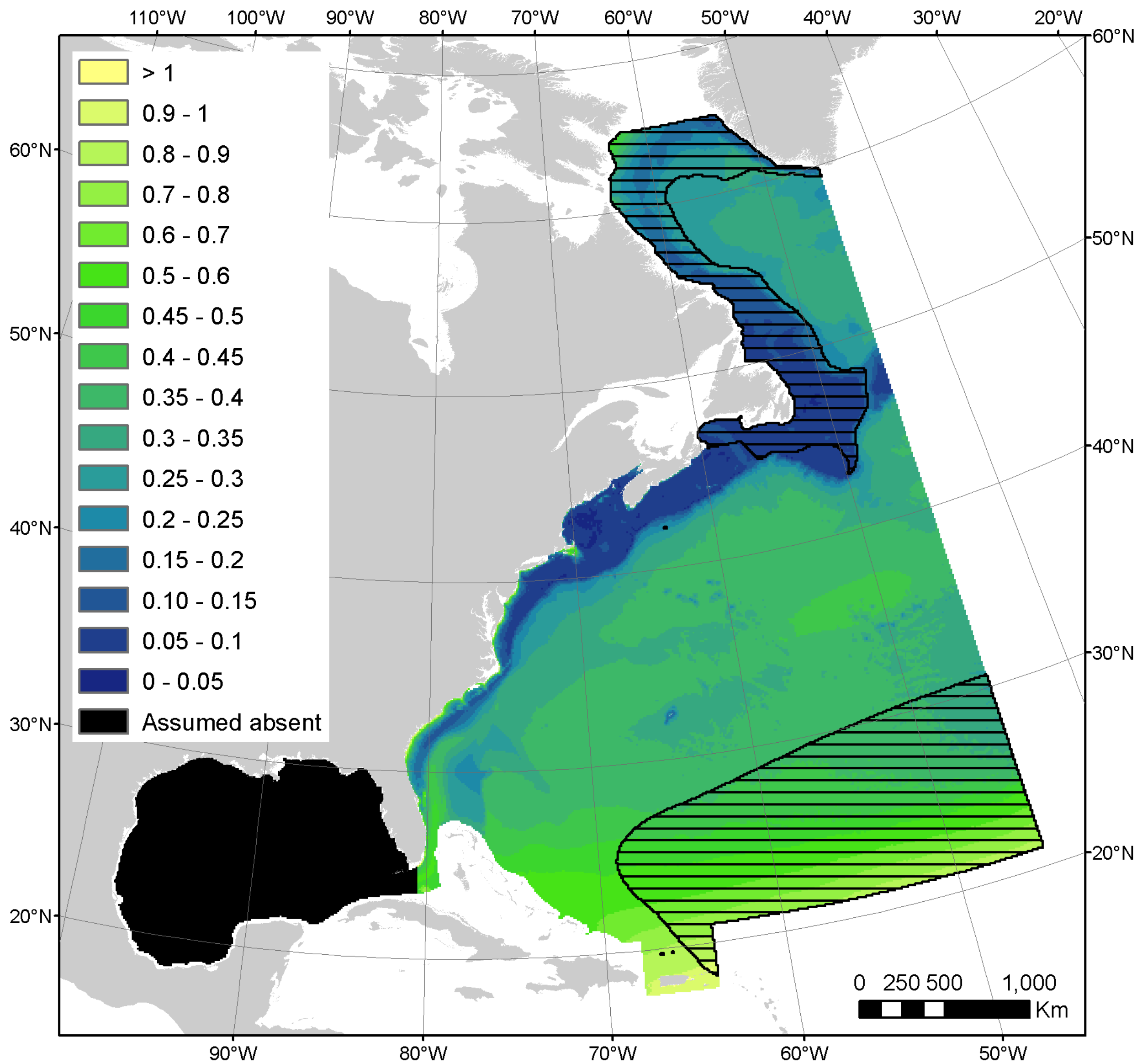


Figure 8: Mean predicted coefficients of variation derived from GAM parameters in the AFTT area. Areas where we extrapolated beyond sampled predictor ranges and coefficients of variation should not be trusted are indicated with black crosshatches. An Albers equal area projection is used.

7- Predicted densities per province

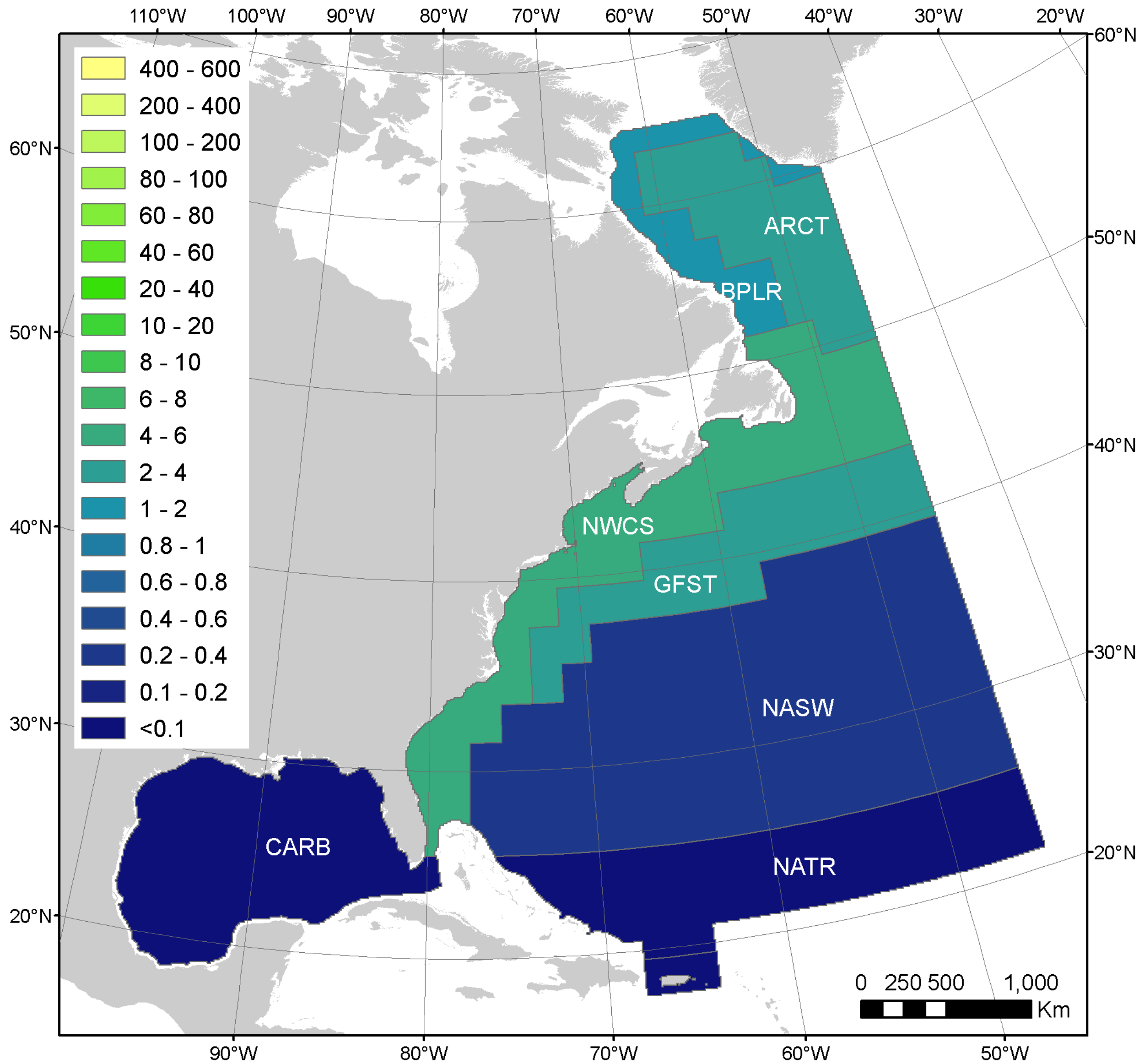


Figure 9: Predicted densities (individuals 100 km-2) averaged per Longhurst's biogeographical province. Note that the color scheme is the same as in Figure 7. Provinces: ARCT: Atlantic Arctic Province; BPLR: Boreal Polar Province; CARB: Caribbean Province; GFST: Gulf Stream Province; NATR: North Atlantic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

8- Alternate models

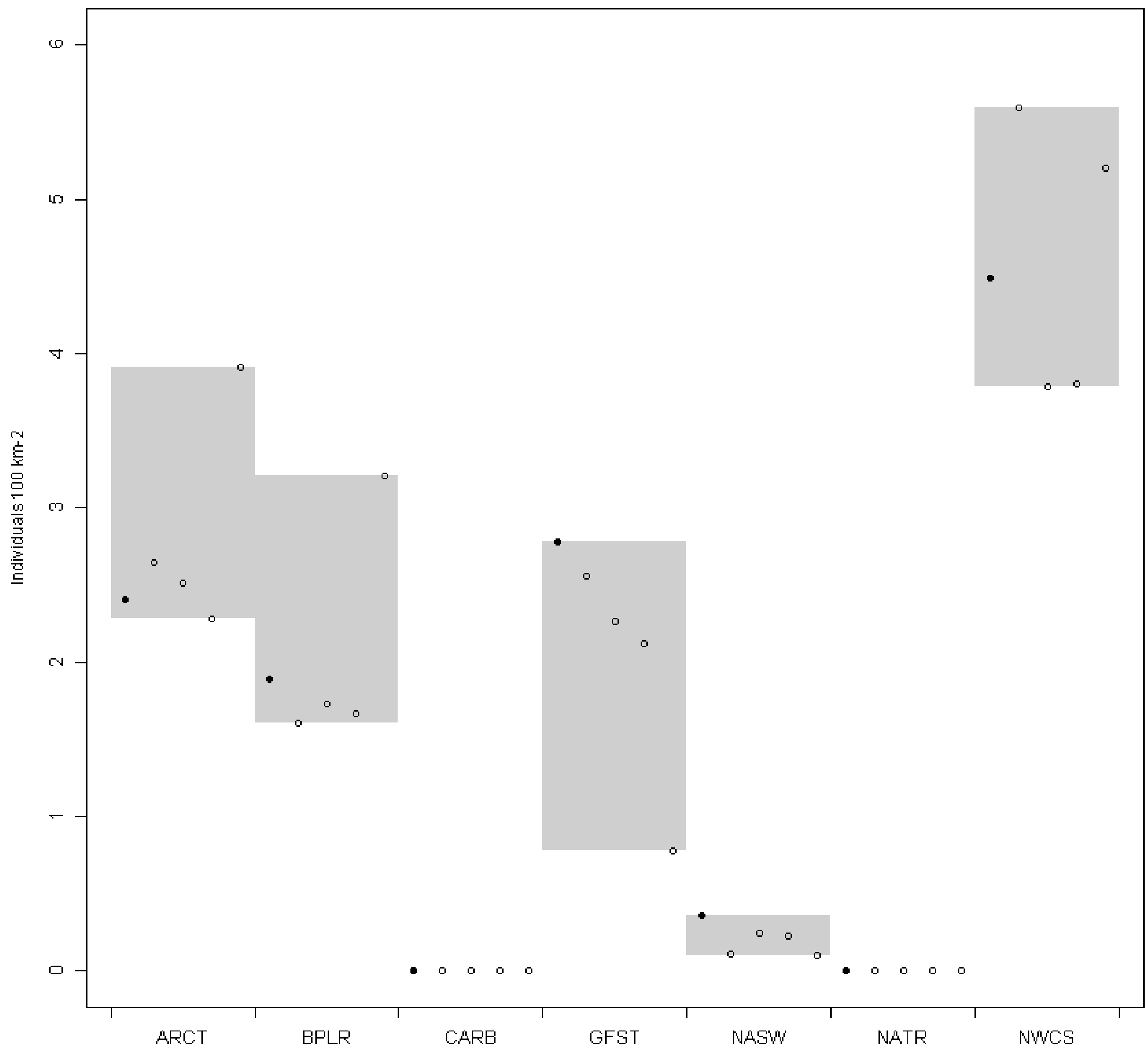


Figure 10: Sensitivity of densities predicted by the five top models per Longhurst's biogeographical province. Points represent predicted densities (individuals 100 km-2) for the five top models listed in Table 3, with the first to fifth models ordered from left to right. Filled points correspond to 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	DistToFront1	SST	EpiMnkPP	128966.7	0.0
Depth	DistToFront1	SST	EpiMnkPB	128970.5	3.8
Depth	DistToFront1	SST	PkPP	128970.8	4.1
Depth	DistToFront1	SST	VGPM	128972.0	5.3
Depth	DistToFront1	SST	SLAStDev	128973.5	6.8

9- Residual diagnostics

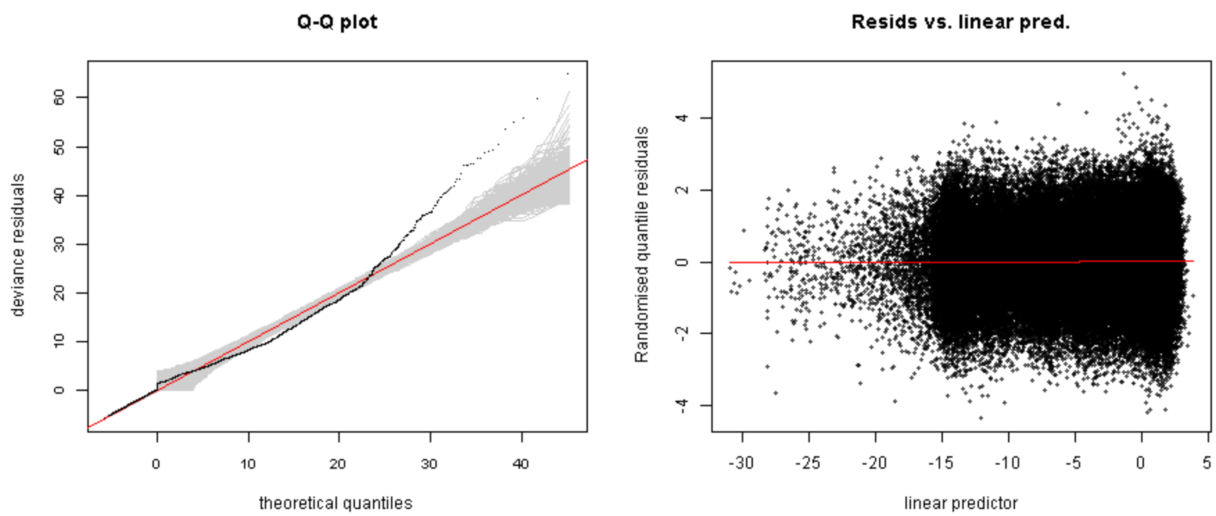


Figure 11: Diagnostic plots of residuals. Left: Quantile-quantile (Q-Q) plot of deviance residuals generated using the qq.gam function with 100 simulations (Augustin et al. 2012). Grey lines are possible simulated Q-Q plots under the assumption that the model is correct. The red reference line indicates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

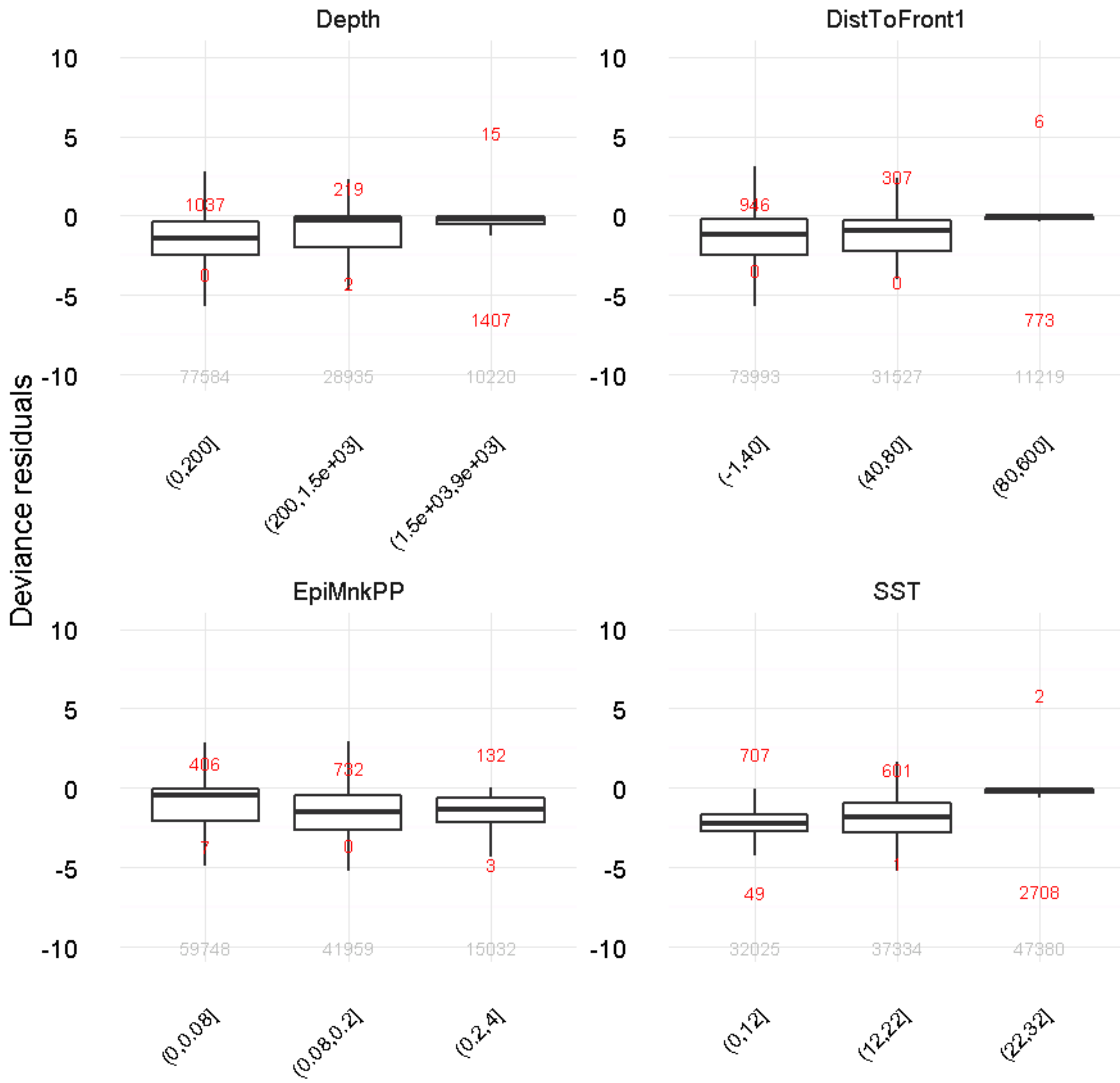


Figure 12: Boxplots of deviance residuals, binned for each predictor. The horizontal line represents the median, and the bottom and top of the box represent the first and third quartiles respectively. Whiskers extend 1.5 times the inter-quartile range following McGill et al. (1978). Total counts of outliers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

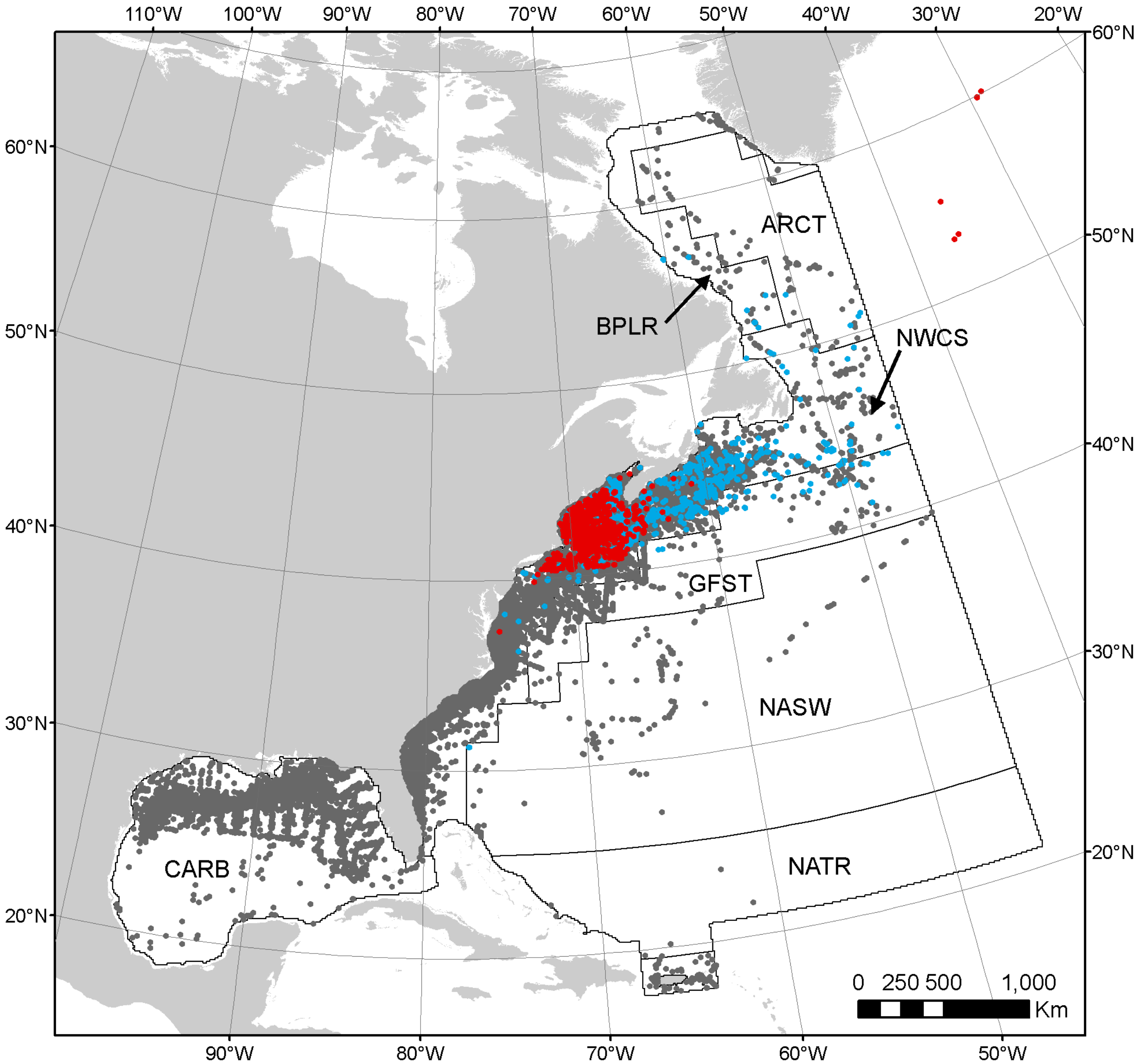


Figure 13: Red points are sightings of the taxon from line transect surveys used in this study. Blue points are sightings of the taxon reported by other datasets not used in our study for 1992-2016 (e.g., because they were not compatible with our methodology). Underlain grey points are sightings of other 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 total of 2298 sightings was available to fit the habitat-based density model (the vast majority of sightings were concentrated on the northeastern U.S. continental shelf and slope, while a few offshore sightings were located along the mid-Atlantic ridge and in the eastern North Atlantic). The first or lowest AIC model included sea surface temperature, depth, micronekton production and distance to fronts (listed in decreasing order of importance according to F-scores) and had an explained deviance of 35.2%. It was the only supported model sensu Burnham & Anderson (2002) (Table 3). All top five models included sea surface temperature, depth and distance to fronts. Predicted densities from all top five models were close to zero in the CARB and NATR provinces and very low in the NASW province (Figure 10). Predicted densities differed by a factor 1.5-2 in the ARCT, BPLR and NWCS provinces and a factor 3.5 in the GFST province (most of the variation was due to the fifth model which had little statistical support and predicted much lower densities). Predictions were generally consistent with the described distribution of Atlantic white-sided dolphin in cold temperate and sub-polar waters of the North Atlantic, mostly on the continental shelf and slope and occasionally in deep oceanic waters (Palka et al. 1997; Cipriano 2009).

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

Atlantic Arctic (ARCT) province

The model predicted medium densities of Atlantic white-sided dolphins in the ARCT province. Although no survey data were available in this province, predictions seemed supported by a few offshore sightings reported in OBIS-SEAMAP to the south of this province (Figure 13). We note that Atlantic white-sided dolphins were sighted on 5 occasions as far north as 60°N during the MAR-ECO cruise along the mid-Atlantic ridge (Waring et al. 2008).

Boreal Polar (BPLR) province

Atlantic white-sided dolphins were recorded on 3 occasions during a line transect survey off West Greenland in summer 2005 (Heide-Jørgensen et al. 2007) and on 1 occasion during the Canadian TNASS survey off Labrador in summer 2007 (Lawson & Gosselin 2009). The overall low densities predicted in the BPLR province seemed compatible with the low abundances suggested by these surveys and the few sightings available in OBIS-SEAMAP (Figure 13).

We warn that extrapolation to colder waters occurred throughout the BPLR province; therefore these predictions are largely speculative and should be considered with extreme caution.

North West Atlantic shelves (NWCS) province

The model predicted relatively high densities of Atlantic white-sided dolphins on the continental shelf and shelf break north of Cape Hatteras, North Carolina.

During the 2007 Canadian TNASS survey, Atlantic white-sided dolphins were recorded on 84 occasions south of Newfoundland and on 7 occasions east of Newfoundland (Lawson & Gosselin 2009) (these sightings were not publically shared in OBIS-SEAMAP and therefore not visible on Figure 13). Sightings available in OBIS-SEAMAP were also abundant east and south of Newfoundland, particularly along the continental slope (Figure 13). Gaskin (1992) documented records of Atlantic white-sided dolphin as far east as the Flemish Cape (47°N and 45°W), suggesting that the medium densities predicted in these offshore waters may be plausible. We caution that extrapolation to colder waters occurred in the northern part of the NWCS province and predictions are largely speculative.

Limited survey effort was available on the Scotian shelf. Nevertheless, the high densities predicted by the model seemed supported by numerous sightings reported in OBIS-SEAMAP (Figure 13). Atlantic white-sided dolphins were also recorded on 15 occasions on the Scotian shelf during the TNASS survey (Lawson & Gosselin 2009) and regularly seen in the Gully canyon, on the edge of the Scotian shelf (Hooker et al. 1999).

We note that the model predicted relatively high densities on the continental shelf break as far south as Cape Hatteras despite few reported sightings (the southernmost sighting reported by a survey was off Virginia)

(Figure 13). We acknowledge that our model may overestimate densities in this area but, in our opinion, these predictions are not completely unrealistic as strandings of Atlantic white-sided dolphins were documented as far south as South Carolina (Powell et al. 2012).

Gulf Stream (GFST) province

Higher predicted densities in the northern part of the GFST province appeared consistent with the species preferences for cold temperate waters (Palka et al. 1997; Cipriano 2009), as well as sightings reported in OBIS-SEAMAP to the north of the Gulf Stream (Figure 13).

North Atlantic subtropical gyral (NASW), North Atlantic tropical gyral (NATR) and Caribbean (CARB) provinces

Low predicted densities in the NASW, NATR and CARB provinces were consistent with the absence of Atlantic white-sided dolphin for warm temperate and tropical waters (Palka et al. 1997; Cipriano 2009) and corroborated by the absence of sightings in OBIS-SEAMAP (one extralimital sighting was reported at 32°N 78°W). We warn that extrapolation further from fronts occurred in the eastern parts of the NASW and NATR provinces; hence, predictions should be considered with due caution.

Overall confidence: level 2

Large numbers of sighting were available for this species but they were concentrated in the southern part of its wider range throughout cold temperate and sub-polar waters. The model successfully predicted its occurrence in northern latitudes but predicted densities were largely speculative as they were derived from extrapolation to colder waters. The incorporation of line transect survey data from Canada and Greenland would be extremely useful to increase the reliability of predicted densities in northern waters. 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 models.

11- References

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