Habitat-based density model for short-beaked common dolphin dolphin in the AFTT area

Laura Mannocci, Jason J Roberts, David L Miller, Patrick N Halpin

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This report documents the habitat-based density model for Short-beaked common dolphin 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 Short-beaked common dolphin 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	1168
EU	27526.342	227
MAR	2424.421	28
All regions	1074308.466	1423

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

Month	Effort	Sightings
January	71406.04	21
February	96993.70	44
March	98664.69	38
April	105121.39	19
May	107303.24	61
June	119895.45	255
July	140462.97	481
August	110040.12	249
September	52584.62	33
October	57619.14	49
November	60008.94	53
December	54208.17	120
All Months	1074308.47	1423

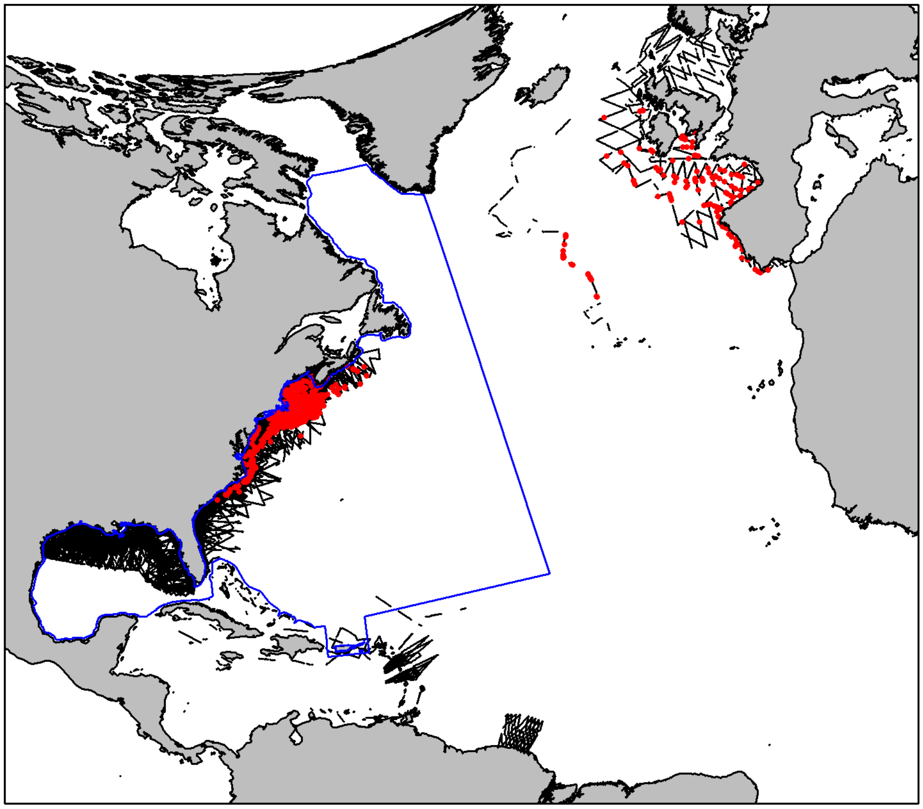


Figure 1: Map of segments (black lines) and sighting locations (red dots). An Albers equal area projection optimized for the AFTT area is used.

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

Short-beaked common dolphin (*Delphinus delphis*)

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 European Atlantic and the mid-Atlantic ridge to increase sighting numbers and the representativeness of offshore waters which constitute an important habitat for short-beaked common dolphins (Jefferson et al. 2009).

Special treatment in the Gulf of Mexico

There were no short-beaked common dolphins sighted during the Gulf of Mexico surveys and the species is described as absent from the Gulf of Mexico (Jefferson and Schiro 1997, Jefferson et al. 2009). Based on this information, we assigned zero densities to the entire Gulf of Mexico (the model predicted very low densities).

3- Best model

- **Predictors**: slope, chlorophyll concentration (chl), distance to sea surface temperature fronts (DistToFront), standard deviation of sea level anomaly (SLAStDev)
- **Model summary**:

```
##
## Family: Tweedie(p=1.499)
## Link function: log
##
## Formula:
## abundance ~ s(Slope, k = 4, bs = "ts") + s(Chl1, k = 4, bs = "ts") +
##     s(DistToFront1, k = 4, bs = "ts") + s(SLAStDev, k = 4, bs = "ts") +
##     offset(log(area_km2))
## <environment: 0x20c8a564>
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -4.85453    0.07905  -61.41   <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(Slope)        2.890      3 148.51  <2e-16 ***
## s(Chl1)         2.950      3  64.25  <2e-16 ***
## s(DistToFront1) 2.896      3  43.12  <2e-16 ***
## s(SLAStDev)     1.503      3  78.59  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  -0.016   Deviance explained = 36.6%
## -REML = 9795.5  Scale est. = 231.82    n = 127753
```

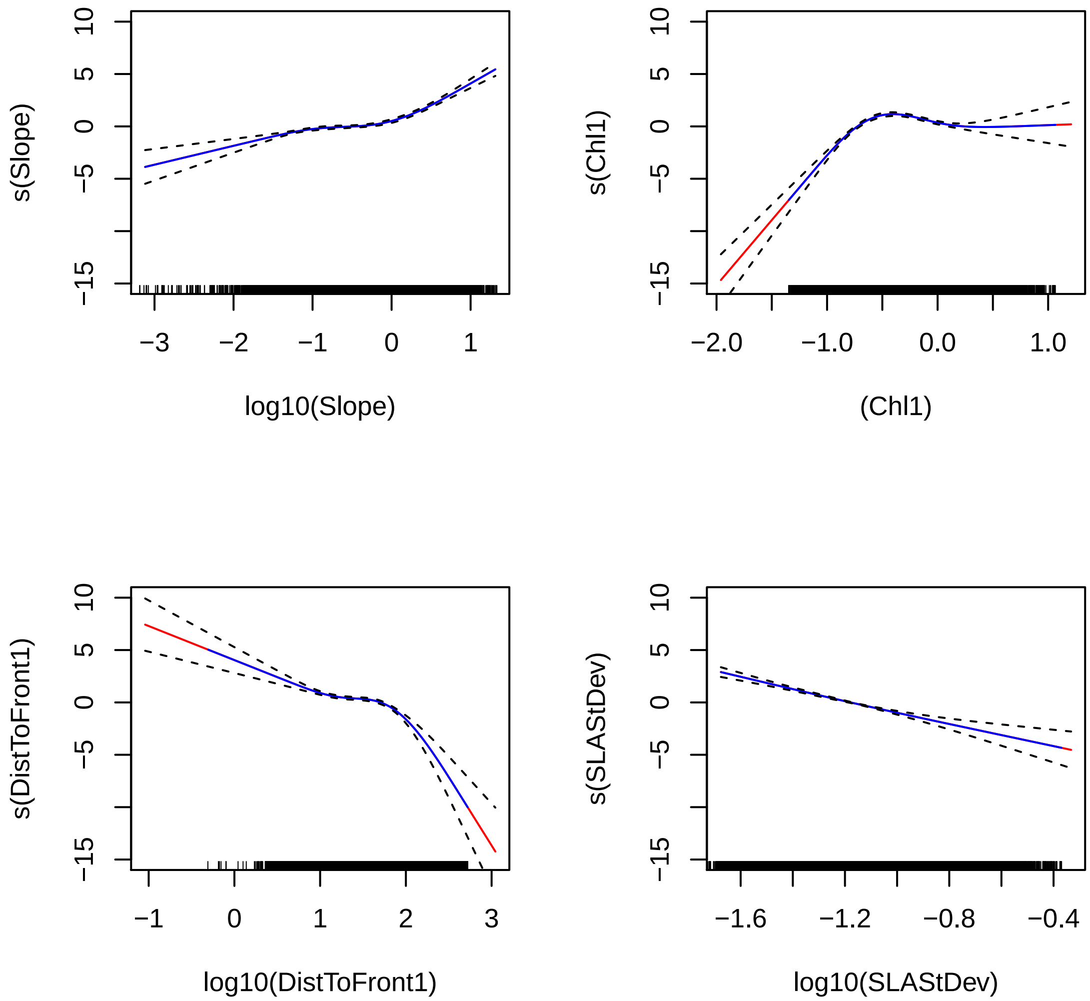


Figure 2: GAM term plots with the log-transformed abundance on the y axis. The solid blue line is the smooth function fitted to the data. The solid red line is the smooth function extrapolated to all covariate values in the prediction area. The dashed lines represent the approximate 95% confidence intervals.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

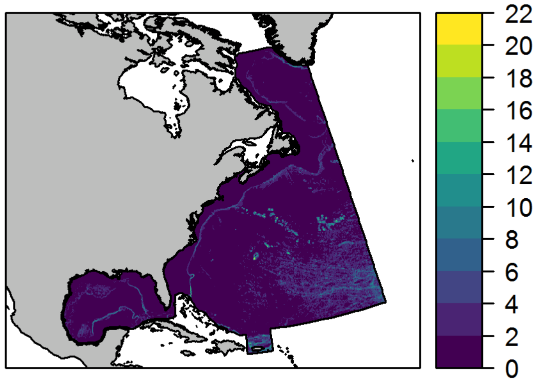
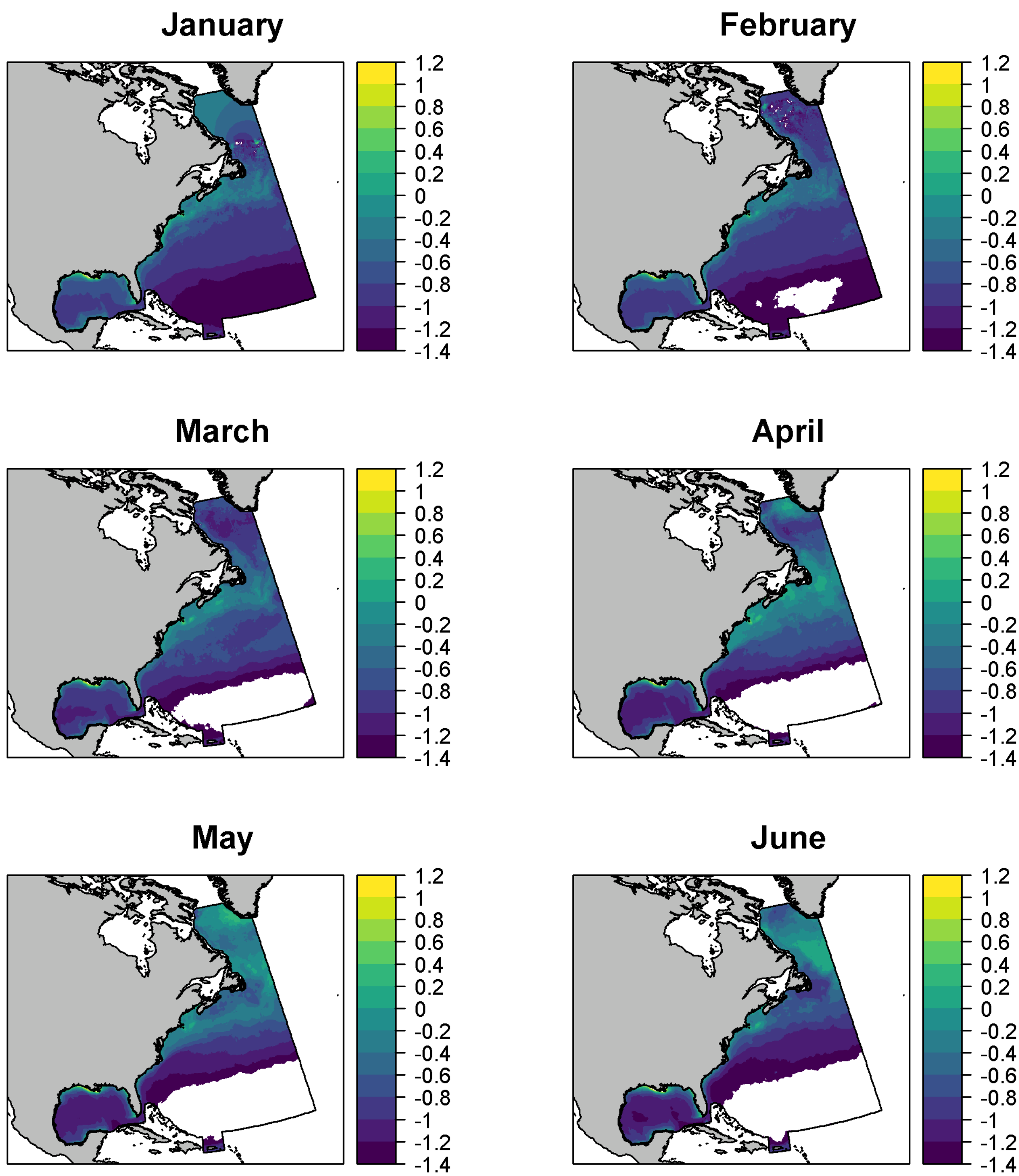


Figure 3: Environmental envelope for slope. White cells within the AFTT polygon indicate areas where covariate values fell beyond the range of covariate values sampled by the surveys.


January
February
March
April
May
June
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4

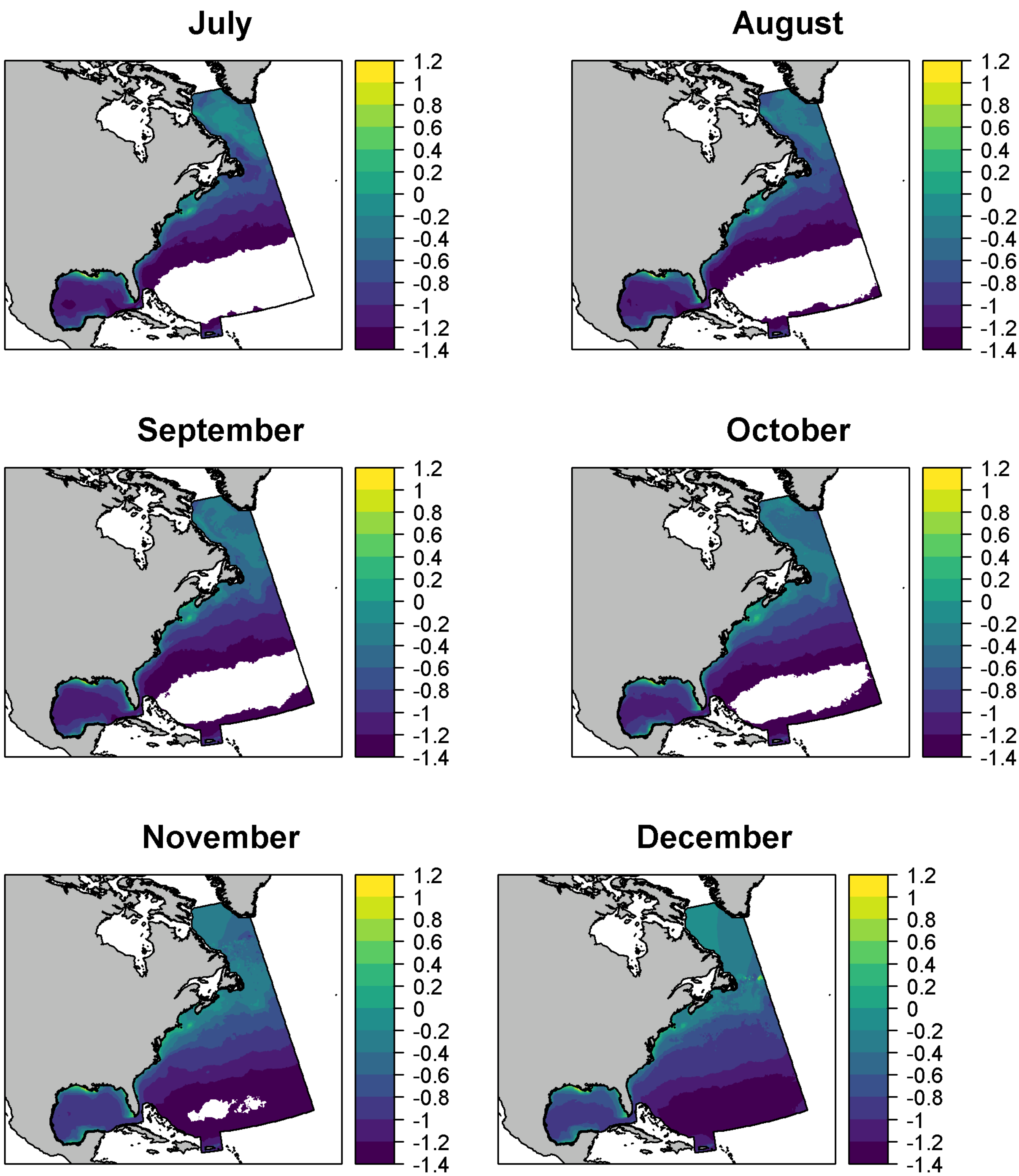
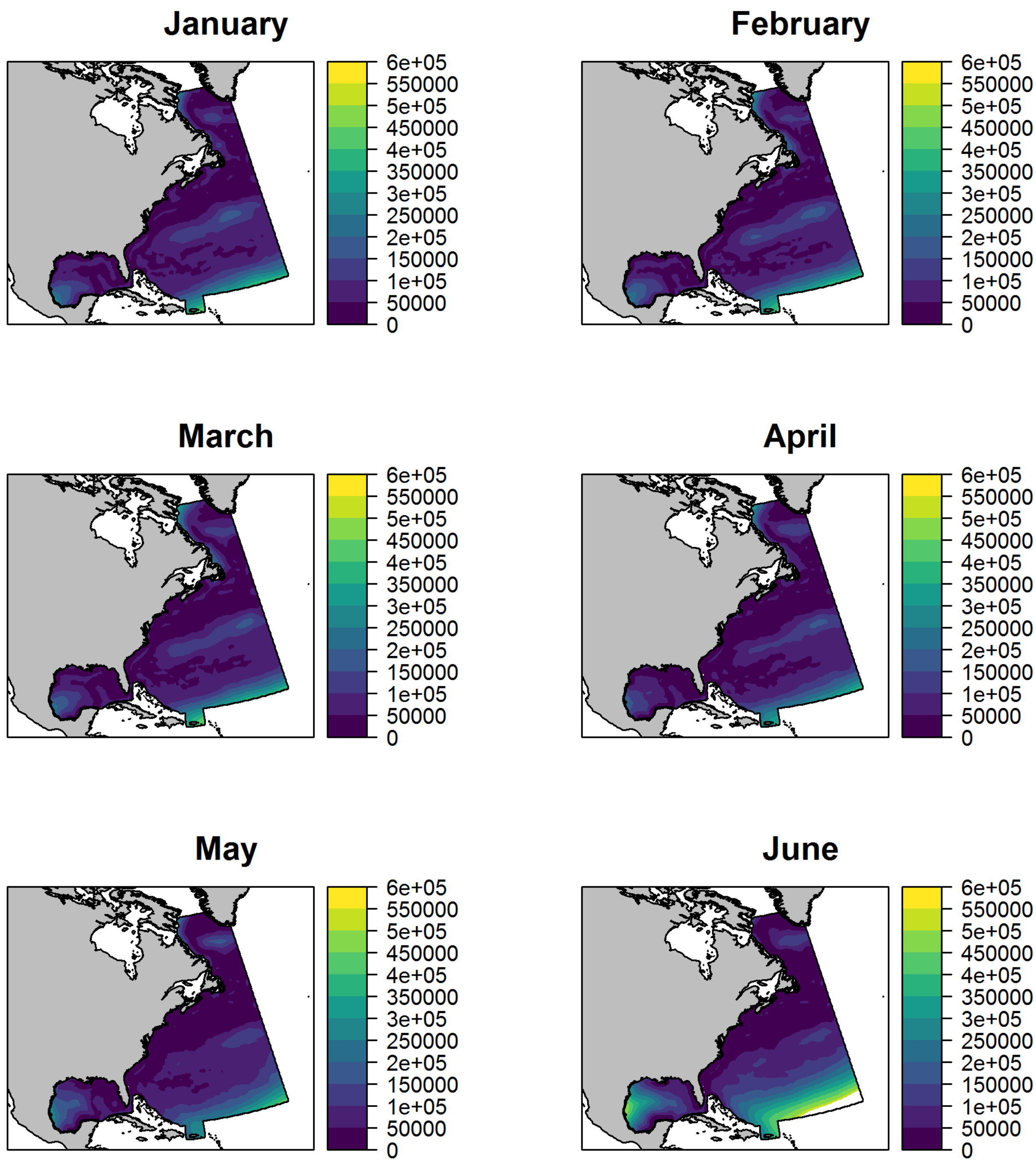


Figure 4: Monthly environmental envelopes for chlorophyll concentration. White cells within the AFTT polygon indicate areas where covariate values fell beyond the range of covariate values sampled by the surveys.


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

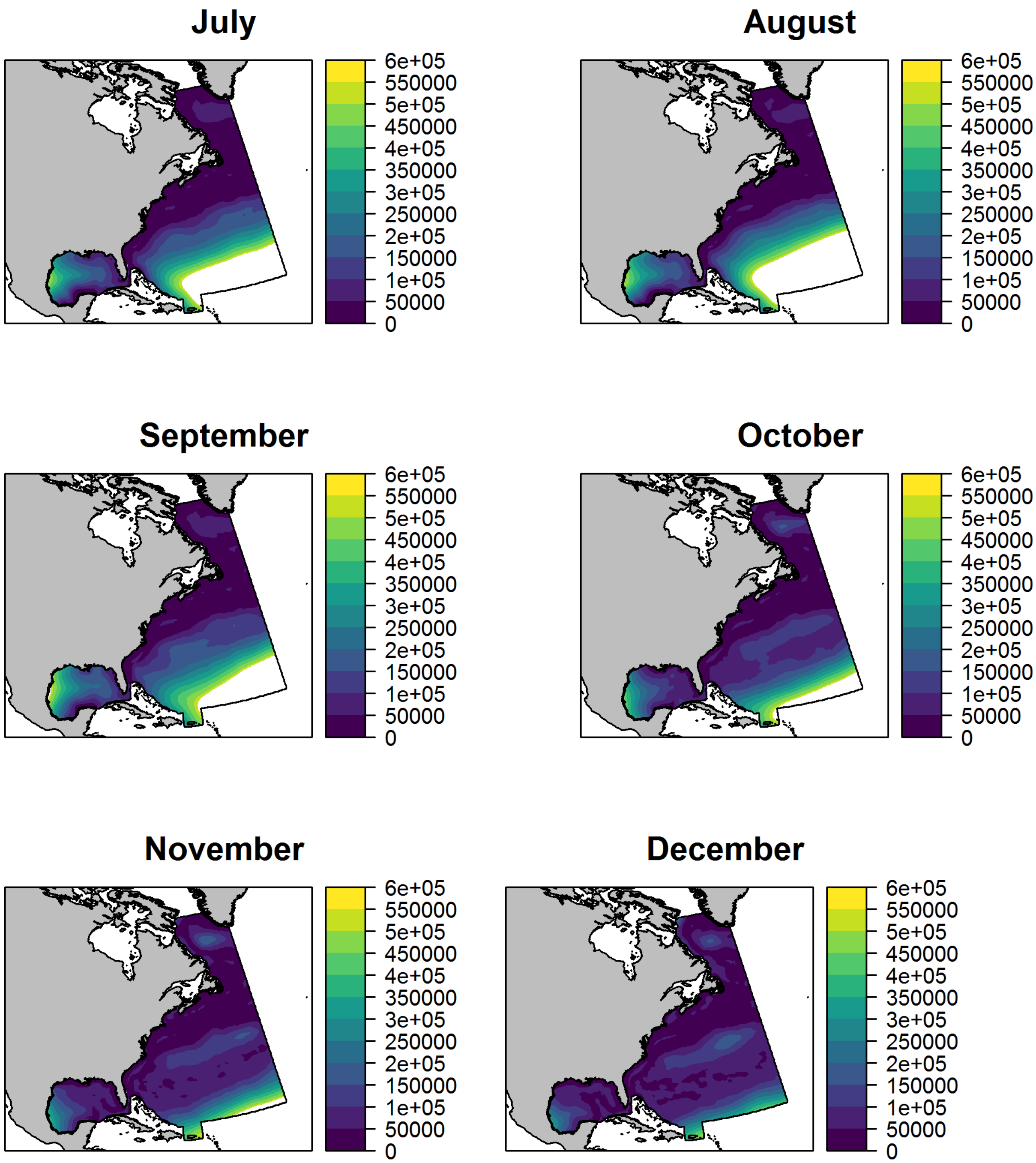
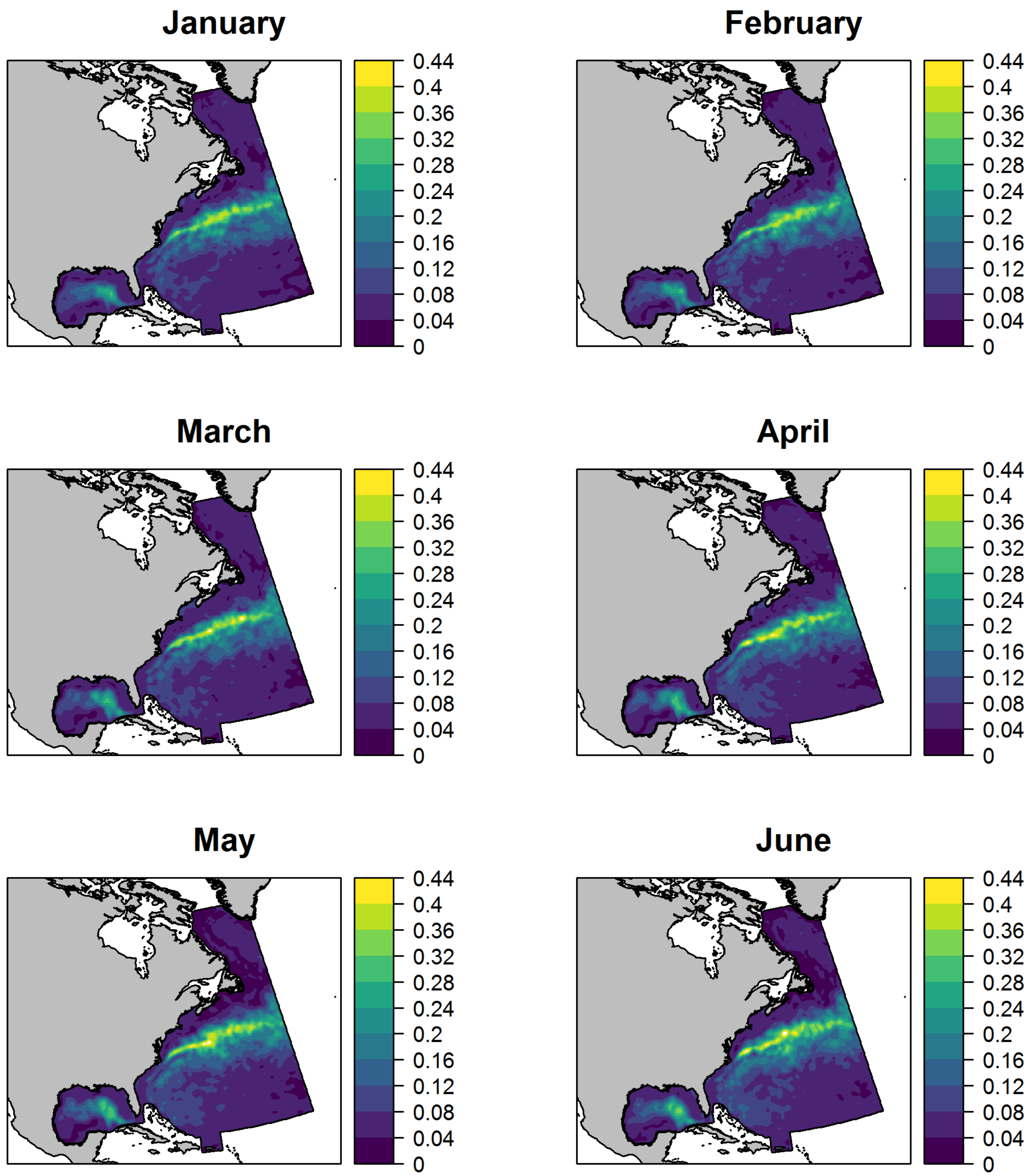


Figure 5: Monthly environmental envelopes for distance to sea surface temperature fronts. White cells within the AFTT polygon indicate areas where covariate values fell beyond the range of covariate values sampled by the surveys.


January
February
March
April
May
June
0.44
0.4
0.36
0.32
0.28
0.24
0.2
0.16
0.12
0.08
0.04
0

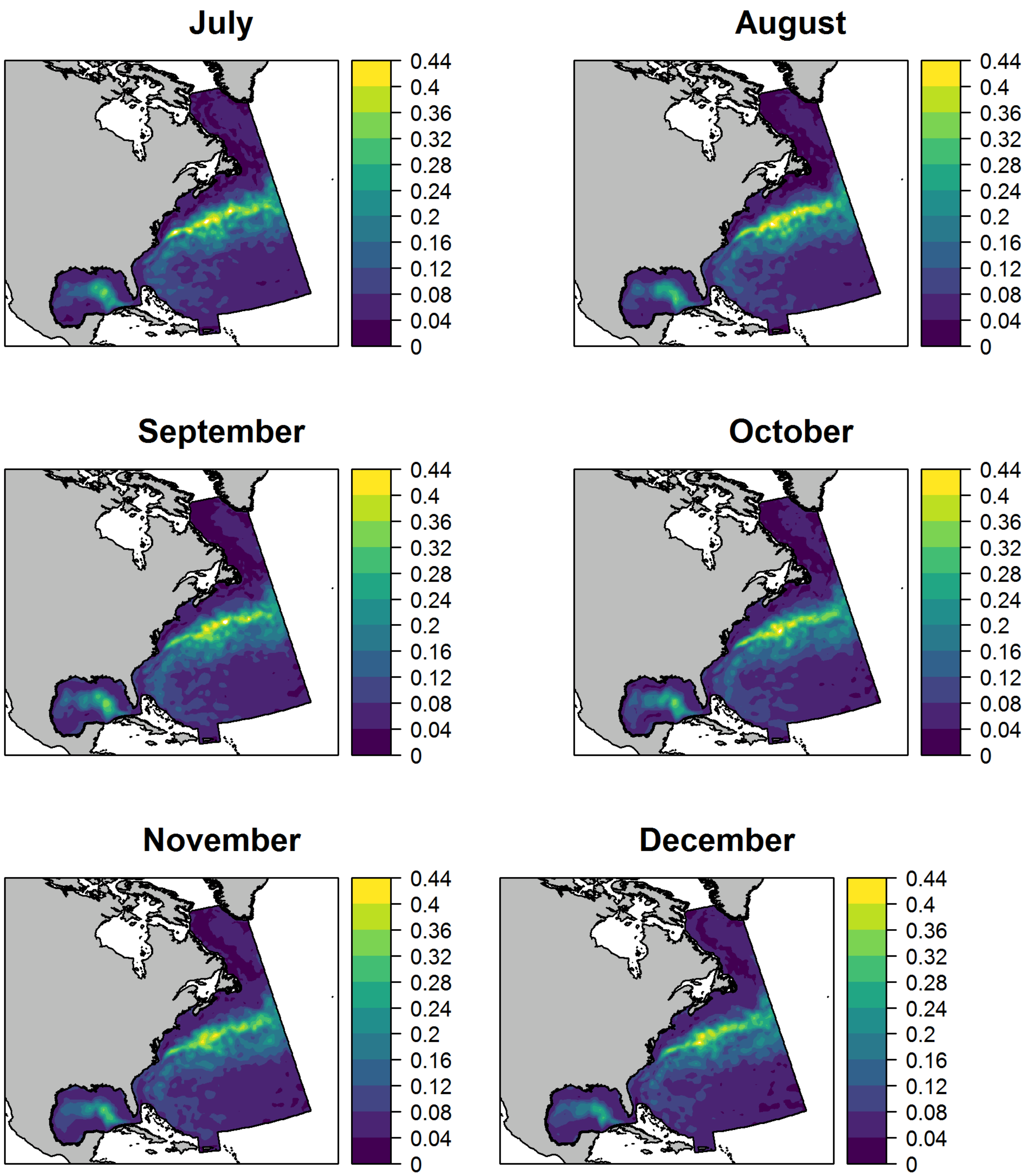


Figure 6: Monthly environmental envelopes for standard deviation of sea level anomaly. White cells within the AFTT polygon indicate areas where covariate values fell beyond the range of covariate values sampled by the surveys.

5- Predicted densities

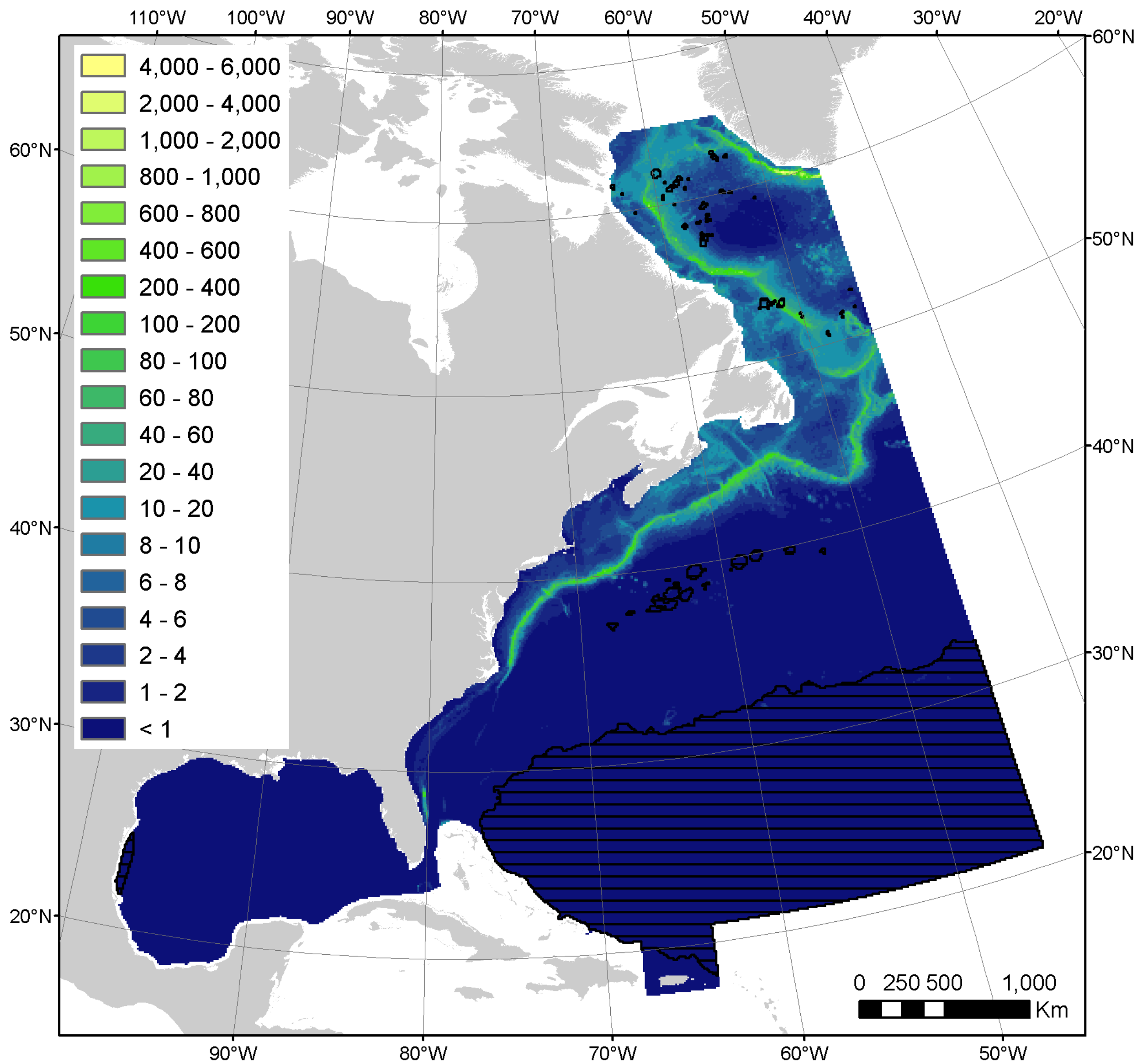


Figure 7: Mean predicted densities (individuals 100 km-2) in the AFTT area. Areas where we extrapolated beyond sampled predictor ranges and predicted densities should not be trusted are indicated with black crosshatches. An Albers equal area projection is used.

6- Coefficients of variation

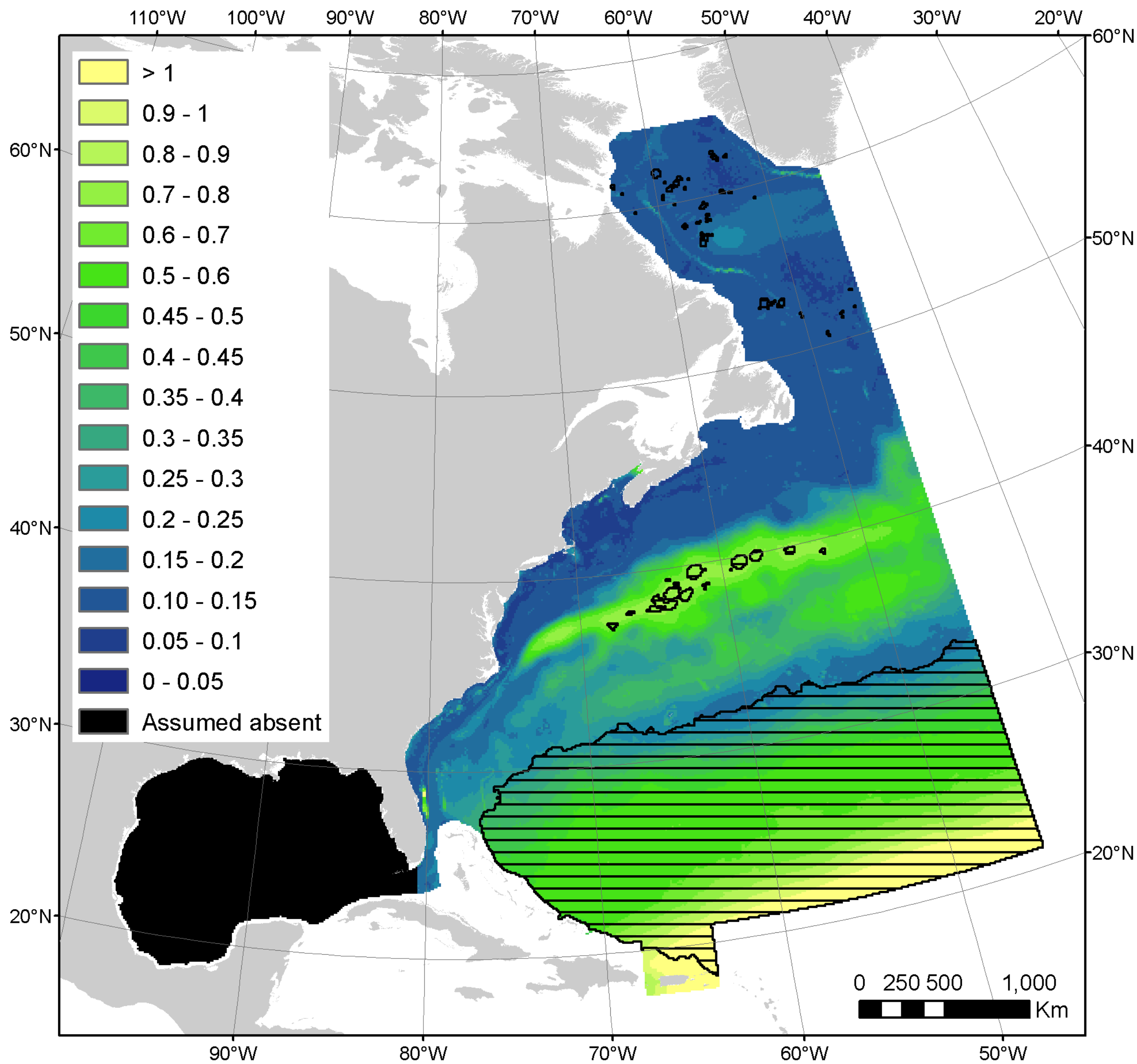


Figure 8: Mean predicted coefficients of variation derived from GAM parameters in the AFTT area. Areas where we extrapolated beyond sampled predictor ranges and coefficients of variation should not be trusted are indicated with black crosshatches. An Albers equal area projection is used.

7- Predicted densities per province

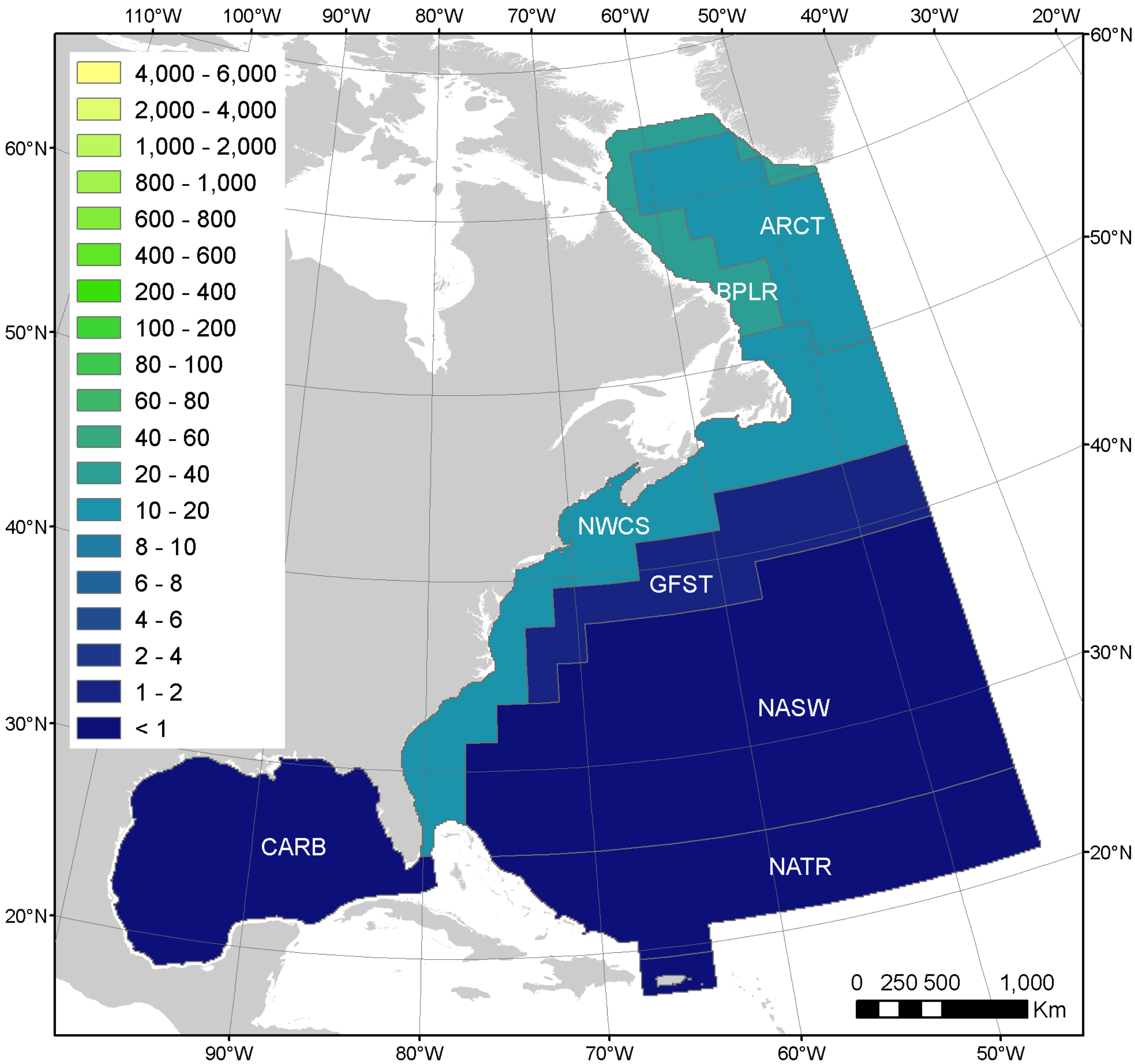


Figure 9: Predicted densities (individuals 100 km-2) averaged per Longhurst's biogeographical province. Note that the color scheme is the same as in Figure 7. Provinces: ARCT: Atlantic Arctic Province; BPLR: Boreal Polar Province; CARB: Caribbean Province; GFST: Gulf Stream Province; NATR: North Atlantic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

8- Alternate models

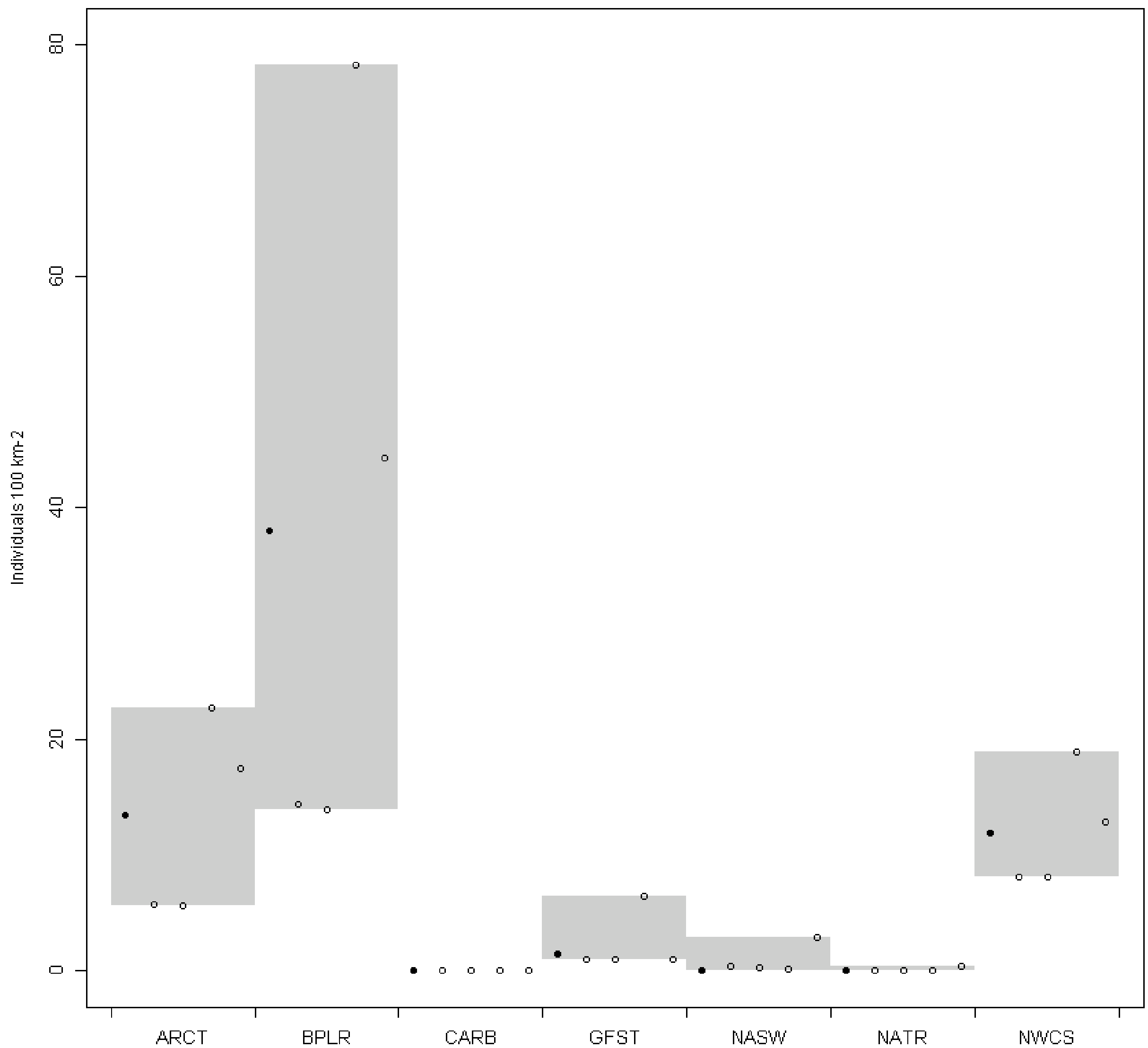


Figure 10: Sensitivity of densities predicted by the five top models per Longhurst's biogeographical province. Points represent predicted densities (individuals 100 km-2) for the five top models listed in Table 3, with the first to fifth models ordered from left to right. Filled points correspond to 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
Slope	DistToFront1	SLAStDev	Chl1	124166.0	0.0
Slope	DistToFront1	SLAStDev	VGPM	124200.8	34.8
Slope	DistToFront1	SLAStDev	PkPP	124201.9	35.9
Slope	DistToFront1	EKE	Chl1	124206.3	40.3
Slope	DistToFront1	SLAStDev	EpiMnkPP	124210.5	44.5

9- Residual diagnostics

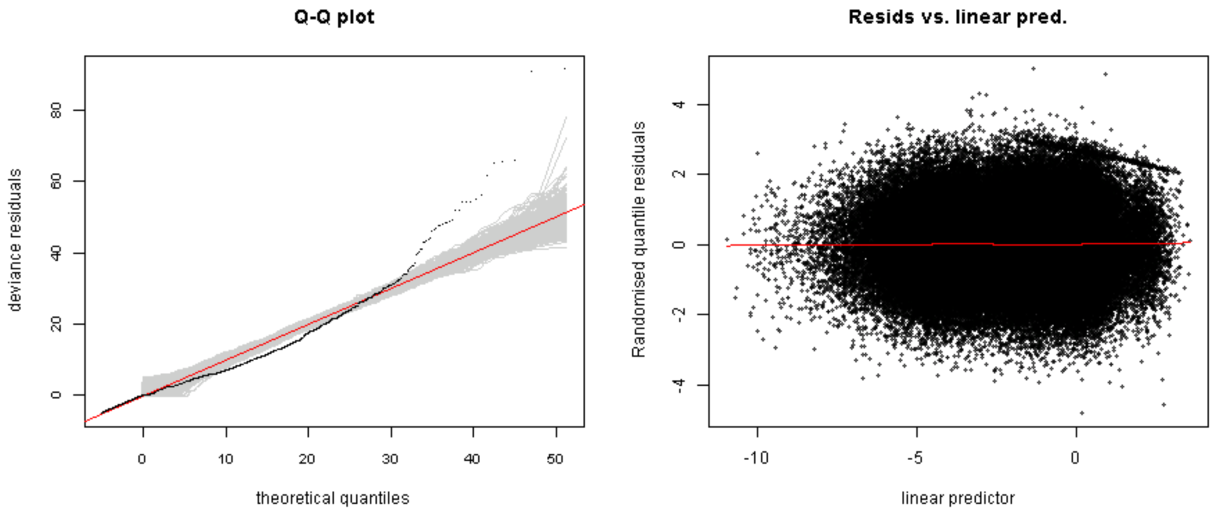


Figure 11: Diagnostic plots of residuals. Left: Quantile-quantile (Q-Q) plot of deviance residuals generated using the qq.gam function with 100 simulations (Augustin et al. 2012). Grey lines are possible simulated Q-Q plots under the assumption that the model is correct. The red reference line indicates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

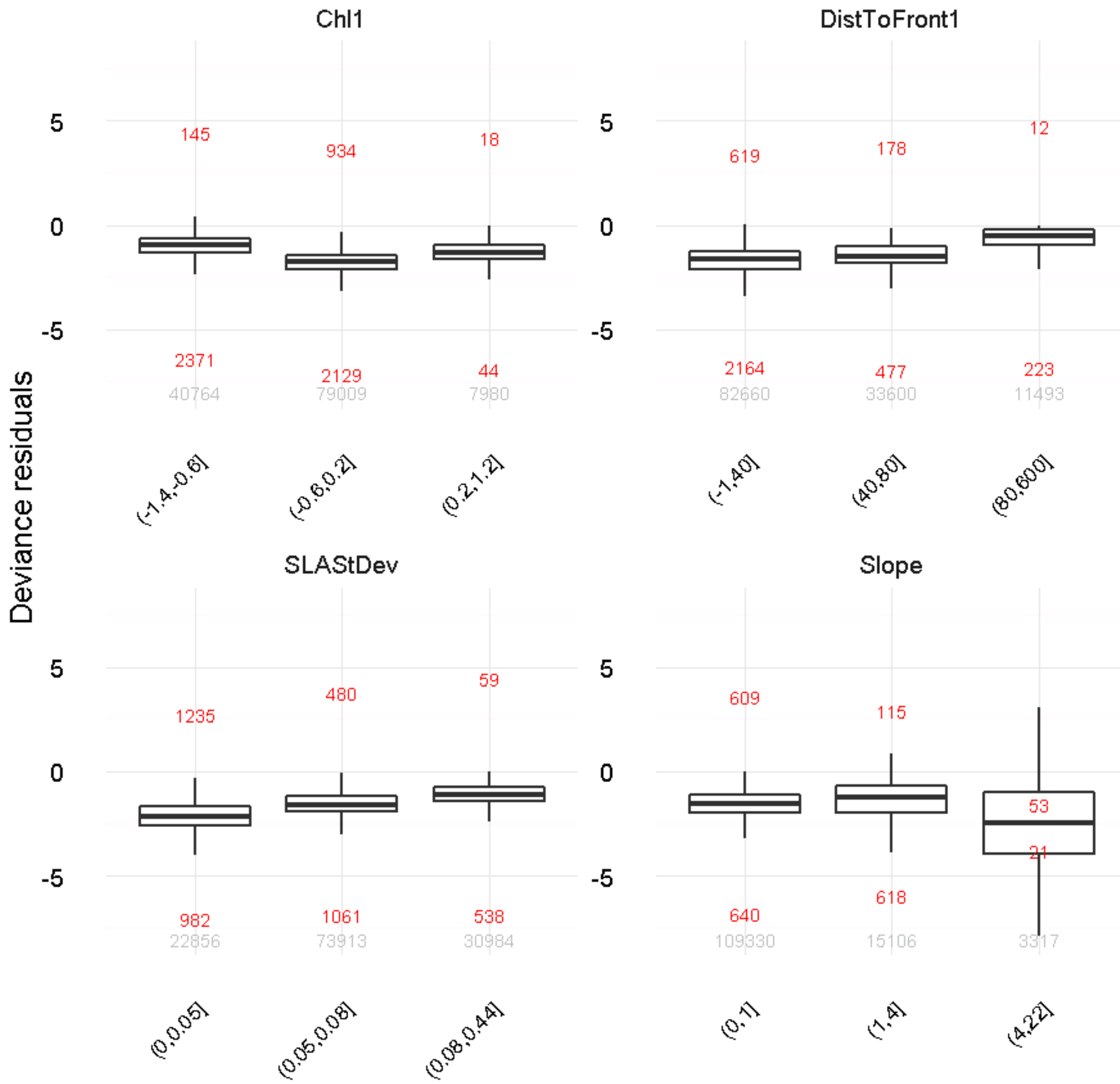


Figure 12: Boxplots of deviance residuals, binned for each predictor. The horizontal line represents the median, and the bottom and top of the box represent the first and third quartiles respectively. Whiskers extend 1.5 times the inter-quartile range following McGill et al. (1978). Total counts of outliers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

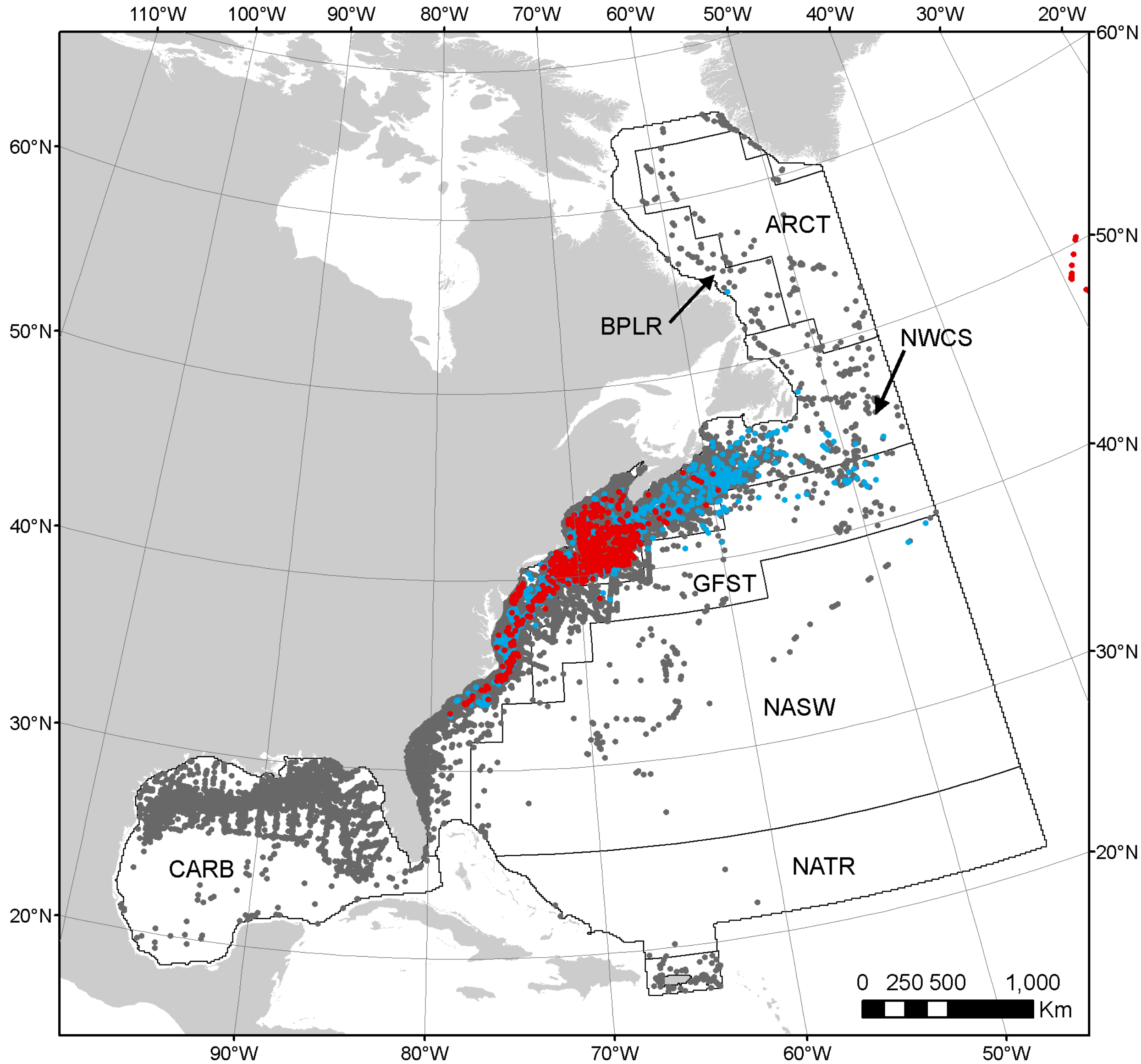


Figure 13: Red points are sightings of the taxon from line transect surveys used in this study. Blue points are sightings of the taxon reported by other datasets not used in our study for 1992-2016 (e.g., because they were not compatible with our methodology). Underlain grey points are sightings of other 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 1423 sightings was available to fit the habitat-based density model (we note that 82% of the sightings were from the east coast region). The lowest AIC model included slope, standard error of sea level anomaly, chlorophyll concentration and distance to fronts (listed in decreasing order of importance according to F-scores) and had an explained deviance of 36.6%. This model was the only supported model sensu Burnham and Anderson (2002) (Table 3). All top five models included slope and distance to fronts. Predicted densities from all top five models were close to zero in the CARB and NATR provinces and relatively low in the GFST and NASW provinces (although the fifth model predicted noticeably higher densities) (Figure 10). Predicted densities from the top five models differed by a factor 2.2 in the NWCS province, a factor 3.6 in the ARCT province and a factor 5.5 in the BPLR province. When examining these results, it is important to keep in mind that the second, third, fourth and fifth models had a large delta AIC and therefore little statistical support sensu Burnham and Anderson (2002).

Due to misidentifications with dolphins of the *Stenella* genus, the distribution of short-beaked common dolphin in the western north Atlantic has long been erroneously documented. After an extensive revision of existing records, Jefferson et al. (2009) described its contemporary distribution from the Georgia/South Carolina border north to about 47-50°N off the Canadian coast, with an apparent absence from tropical and subtropical waters (Jefferson et al. 2009). The model successfully predicted the species' absence from tropical and subtropical waters but appeared to overestimate densities in cold temperate and sub-polar waters.

Densities showed an increasing relationship with slope (most important predictor of our model), resulting in highest predicted densities near high slope values. Short-beaked common dolphin is known to occupy a wide range of habitats including oceanic regions, the continental shelf, the continental shelf break and slope, and associate with prominent underwater topographic features (e.g., the mid-Atlantic Ridge) (Jefferson et al. 2009). Predictions appeared generally in line with these described habitat preferences, although we think the model predicts short-beaked common dolphins in tighter association with high slopes than they actually are.

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

Short-beaked commons dolphins were sighted on 2 occasions off Labrador during the TNASS survey in summer 2007 (Lawson & Gosselin 2009). One sighting was also reported in OBIS-SEAMAP for the BPLR province (but observation effort was very sparse) (Figure 13). Short-beaked common dolphin is considered to be an occasional visitor to eastern Canada (Gaskin 1992) and there is no evidence that it reaches as far north as Greenland (Heide-Jørgensen 1990). Therefore, we believe the model likely overestimates densities in these Northern provinces. We note, however, that short beaked common dolphins were sighted on 26 occasions as far north as 51°N during the MAR-ECO cruise along the mid-Atlantic ridge, where they concentrated in warmer more saline waters (Waring et al. 2008).

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

Predictions in the NWCS province appeared concordant with the preference of short-beaked common dolphin for cooler waters off the North American east coast, with a primary distribution between the 200 and 2000 m isobaths (Jefferson et al. 2009), corresponding roughly to the continental slope where highest densities were predicted. As mentioned above, we believe the model may predict short-beaked common dolphins in tighter association with high slopes than they actually are.

Short-beaked common dolphin is known to shift northwards onto the Scotian Shelf in summer and fall (Selzer & Payne 1988; Gowans & Whitehead 1995). We did not seek to model these seasonal movements (this was beyond the scope of the present study) and proposed a year-round prediction derived from a model incorporating all available data.

Numerous sightings were reported in OBIS-SEAMAP on the Scotian shelf and continental slope where the model predicted intermediate to high densities (Figure 13). During the TNASS 2007 survey, short-beaked common dolphins were sighted on 198 occasions on the Scotian shelf (it was the most sighted cetacean), 25 occasions south of Newfoundland and 1 occasion east of Newfoundland (Lawson & Gosselin 2009) (these sightings were not contributed to OBIS-SEAMAP and therefore are not visible on Figure 13). Predictions seemed compatible with the frequent occurrence of short-beaked common dolphin near the Gully canyon off the Scotian shelf (Gowan and Whitehead 1995; Hooker et al. 1999).

It is interesting to notice that the low predicted densities off Florida are not supported by contemporary sightings (Figure 13), but the species was recorded as far south as Miami in the first half of the 20th century (Jefferson et al. 2009). The apparent contemporary absence off Florida is not well understood and various explanations have been suggested, including increasing water temperatures in the past decades and displacement by dolphins of the *Stenella* genus (Jefferson et al. 2009 and references therein).

Finally, we note that some sightings were reported in OBIS-SEAMAP (Figure 13) in oceanic waters beyond the continental slope, corresponding to the northern part of the GFST province. Extrapolation occurred in some areas of the Gulf Stream and hence, predictions in these areas should be considered with due caution.

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

Low predicted densities in these provinces appeared consistent with the species' absence from tropical and subtropical waters (Jefferson et al. 2009). We note that extrapolation beyond predictor ranges occurred in these provinces and therefore predictions should be considered with due caution.

Caribbean (CARB) province There is no evidence that short-beaked common dolphin occurs in the Gulf of Mexico or near Puerto Rico (Mignucci-Giannoni 1998; Jefferson et al. 2009).

Overall confidence: level 3

Predictions were generally in line with the occurrence of short-beaked common dolphin in a variety of habitats, from the continental shelf to pelagic waters. However, we believe the model likely overestimates predicted densities in sub-polar waters. 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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