Density model for White-beaked dolphin in the AFTT area - version 3

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January 23, 2015

This report documents the density model developed for White-beaked dolphin in the AFTT area. It provides information on available data, methodological decisions, the selected model, predictions, uncertainty, model checking and qualitative evaluation of predictions based on the literature. Information on classification of ambiguous sightings, detection function fitting and g(0) estimates can be found in the EEZ model report for this taxon (Roberts et al. 2015).

Citation for this model: Mannocci L, Roberts JJ, Miller DL, Halpin PN (2015) Density model for White-beaked dolphin in the AFTT area. Version 3, 2015-01-23. Marine Geospatial Ecology Lab, Duke University, Durham, NC.

Citation for the related peer-review publication: Mannocci L, Roberts JJ, Miller DL, Halpin PN. Here be dragons: extrapolating cetacean densities into the unsurveyed high seas of the western North Atlantic. Submitted to Ecological Applications.

1- Available data

Table 1: Effort (km) and sightings per region (CAR: Caribbean, EC: East coast, EU: European Atlantic, GM: Gulf of Mexico, MAR: Mid-Atlantic ridge).

Region	Effort	Sightings
EC	1044357.704	12
EU	27526.342	32
MAR	2424.421	4
All regions	1074308.466	48

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

Month	Effort	Sightings
January	71406.04	0
February	96993.70	0
March	98664.69	2
April	105121.39	1
May	107303.24	2
June	119895.45	7
July	140462.97	30
August	110040.12	6
September	52584.62	0
October	57619.14	0
November	60008.94	0
December	54208.17	0
All Months	1074308.47	48

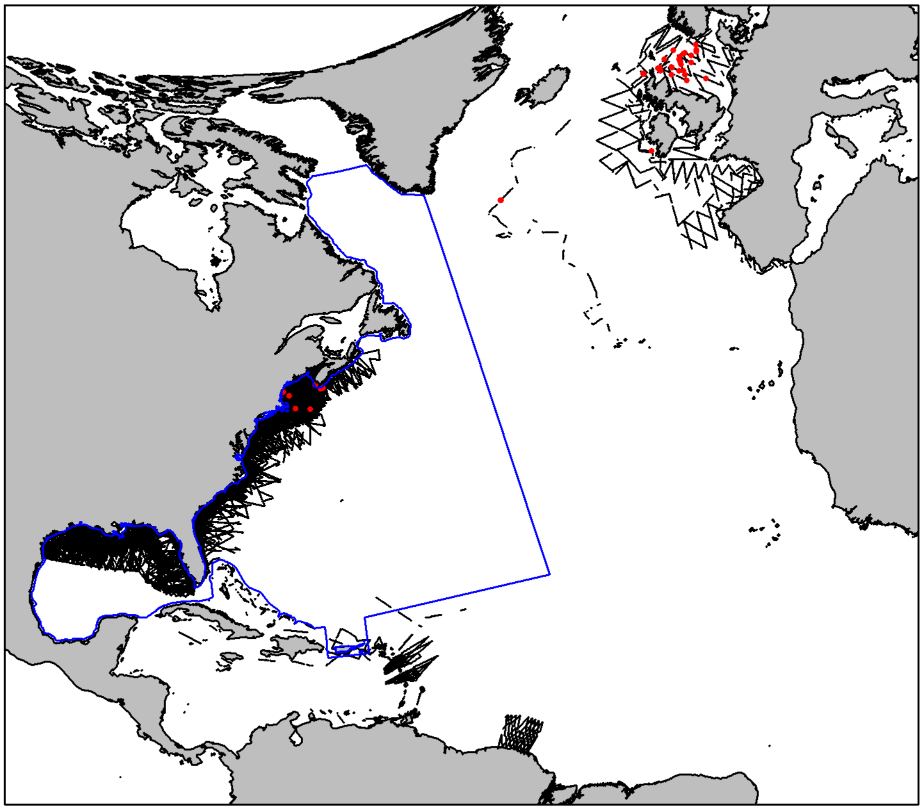


Figure 1: Map of segments (black lines) and sighting locations (red dots). An Albers equal area projection optimized for the AFT area is used.

2- Methodological decisions

Modeled taxon

White-beaked dolphin (*Lagenorhynchus albirostris*)

Model type

Due to the small sample size, we fitted a habitat-based density model limited to two covariates for this taxon.
Modeled season

We fitted a year-round model as we found no evidence in the literature that this taxon undertakes extensive migrations or exhibits contrasting behaviors (e.g. feeding versus breeding) in different seasons .

Segments

We used segments from the east coast, mid-Atlantic ridge and European Atlantic since they all included sightings (75% of the sightings were provided by the European Atlantic segments).

Ad-hoc procedure

Since there were no white-beaked dolphins sighted during the Gulf of Mexico surveys and the species is believed to be absent from this region (Jefferson and Schiro 1997), we assigned null densities to the entire Gulf of Mexico (the model predicted low densities).

Temporal resolution of predictions

Since there was insufficient evidence in the literature to support the monthly variations in predicted densities, we produced a year-round density prediction by averaging the twelve monthly density predictions.

3- Best model

We excluded eddy kinetic energy and standard deviation of sea level anomaly from the candidate covariates because they led to high density predictions in offshore waters to the north of the AFTT area which were not supported by the literature.

- **Selected covariates**: production of epipelagic micronekton, zooplankton biomass
- **Model summary**:

```
##
## Family: Tweedie(p=1.307)
## Link function: log
##
## Formula:
## abundance ~ s(EpiMnkPP, k = 4, bs = "ts") + s(PkPB, k = 4, bs = "ts") +
##     offset(log(area_km2))
## <environment: 0x0677af08>
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -11.0863     0.6918  -16.02   <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(EpiMnkPP) 2.501      3 8.173 3.18e-06 ***
## s(PkPB)     1.556      3 8.700 1.84e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.000242   Deviance explained = 20.6%
## -REML = 412.52  Scale est. = 89.936    n = 95166
```

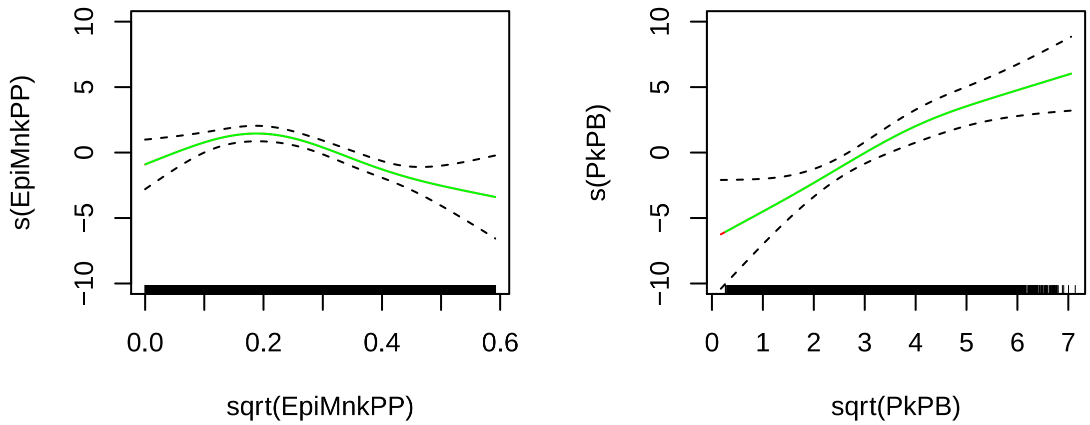
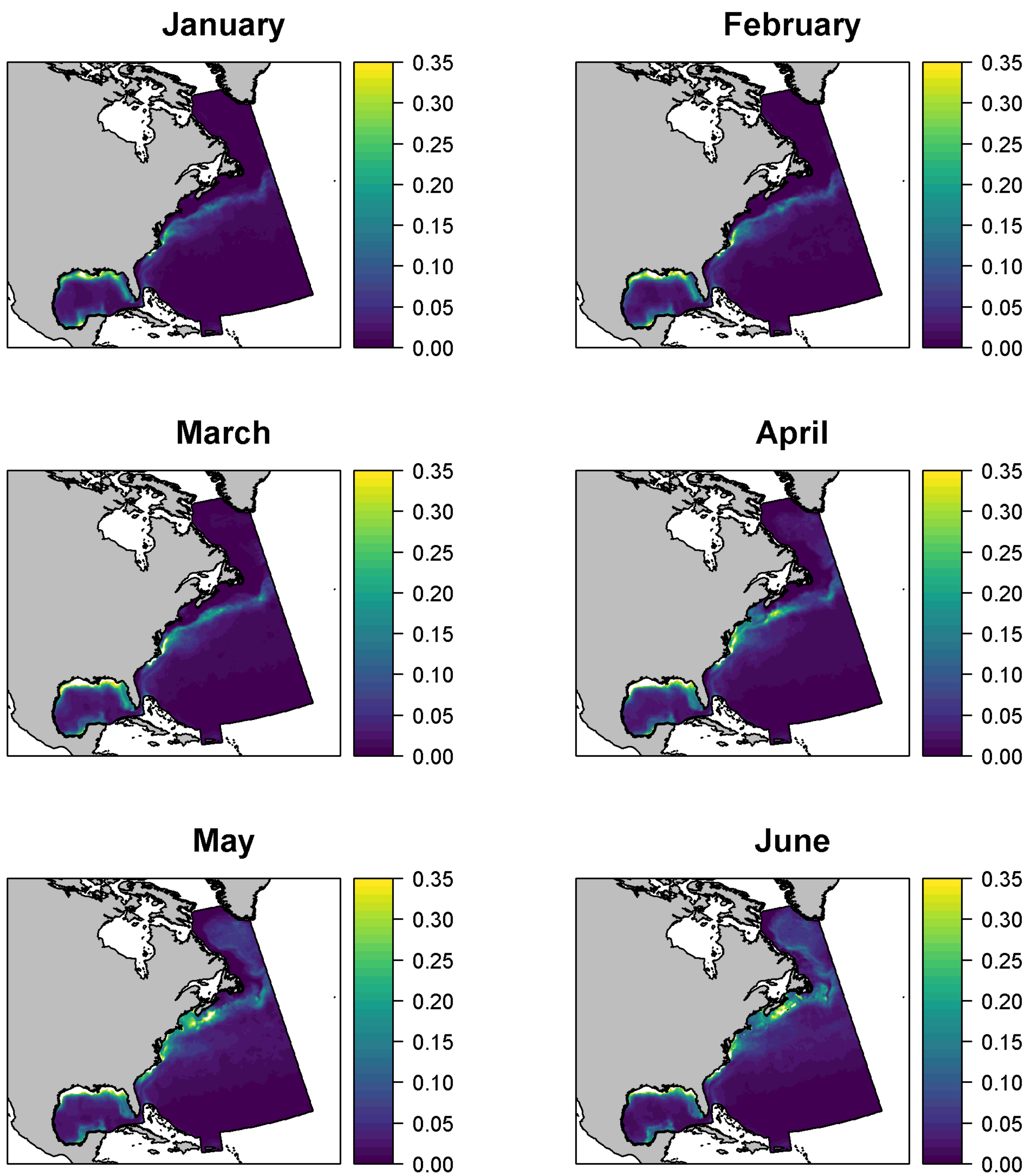


Figure 2: GAM term plots with the log-transformed abundance on the y axis. The solid green line is the smooth function fitted to the data. The solid red line is the smooth function extrapolated to all covariate values in the prediction area. The dashed lines represent the approximate 95% confidence intervals.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

4- Environmental envelopes



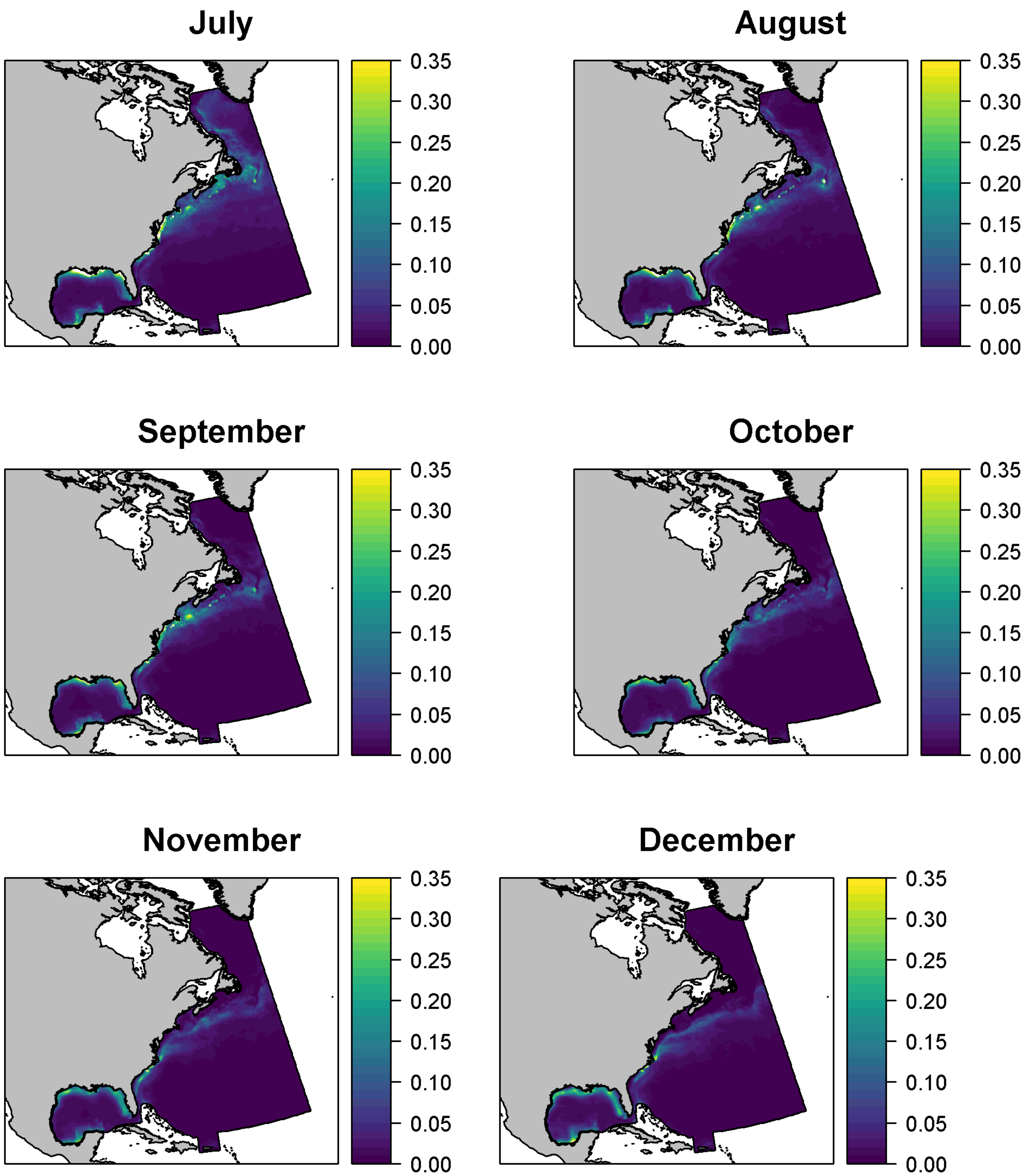
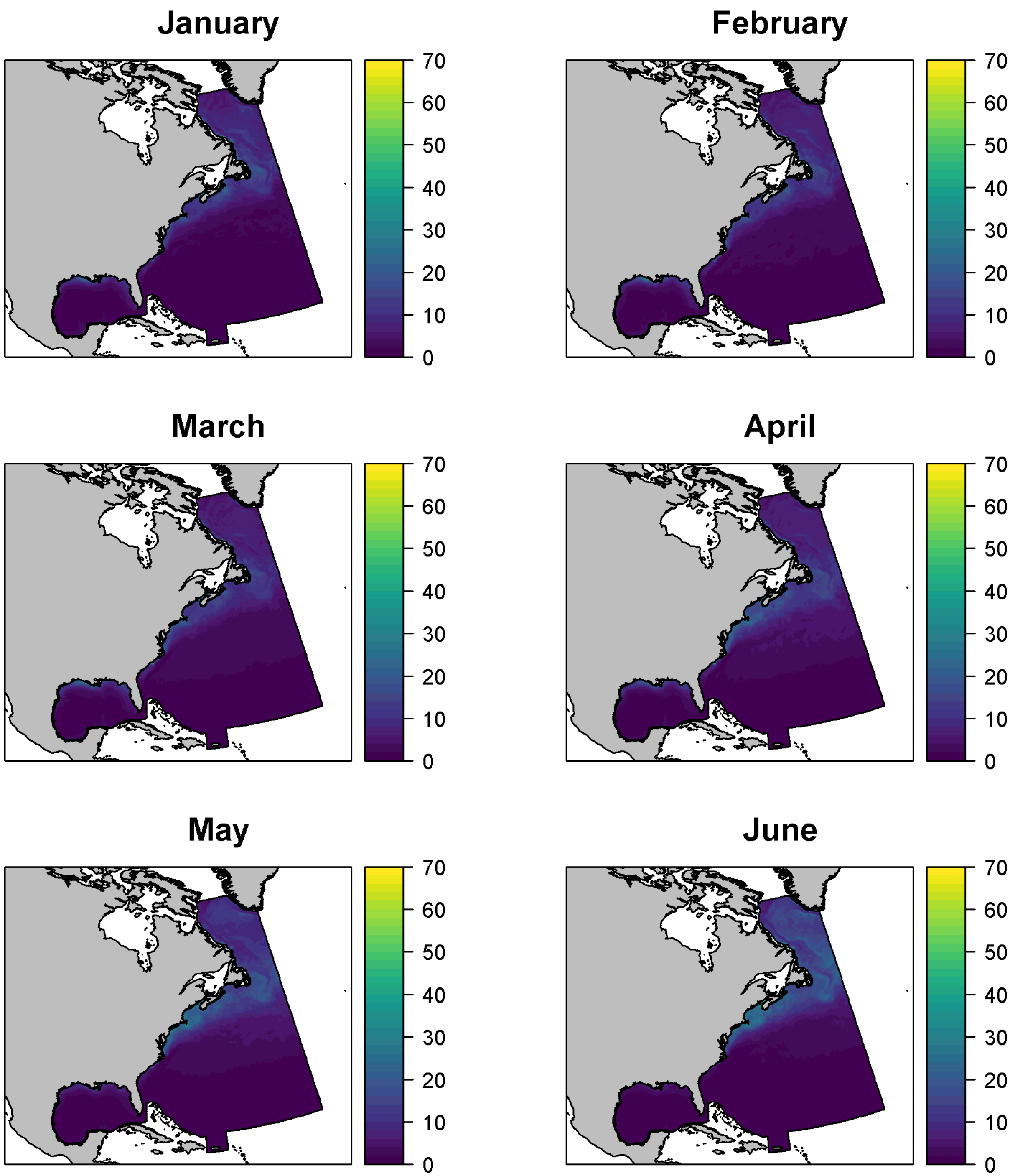


Figure 3: Monthly environmental envelopes for epi_mnk_pp. White cells within the AFTT polygon indicate areas where covariate values fell beyond the range of covariate values sampled by the surveys.


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

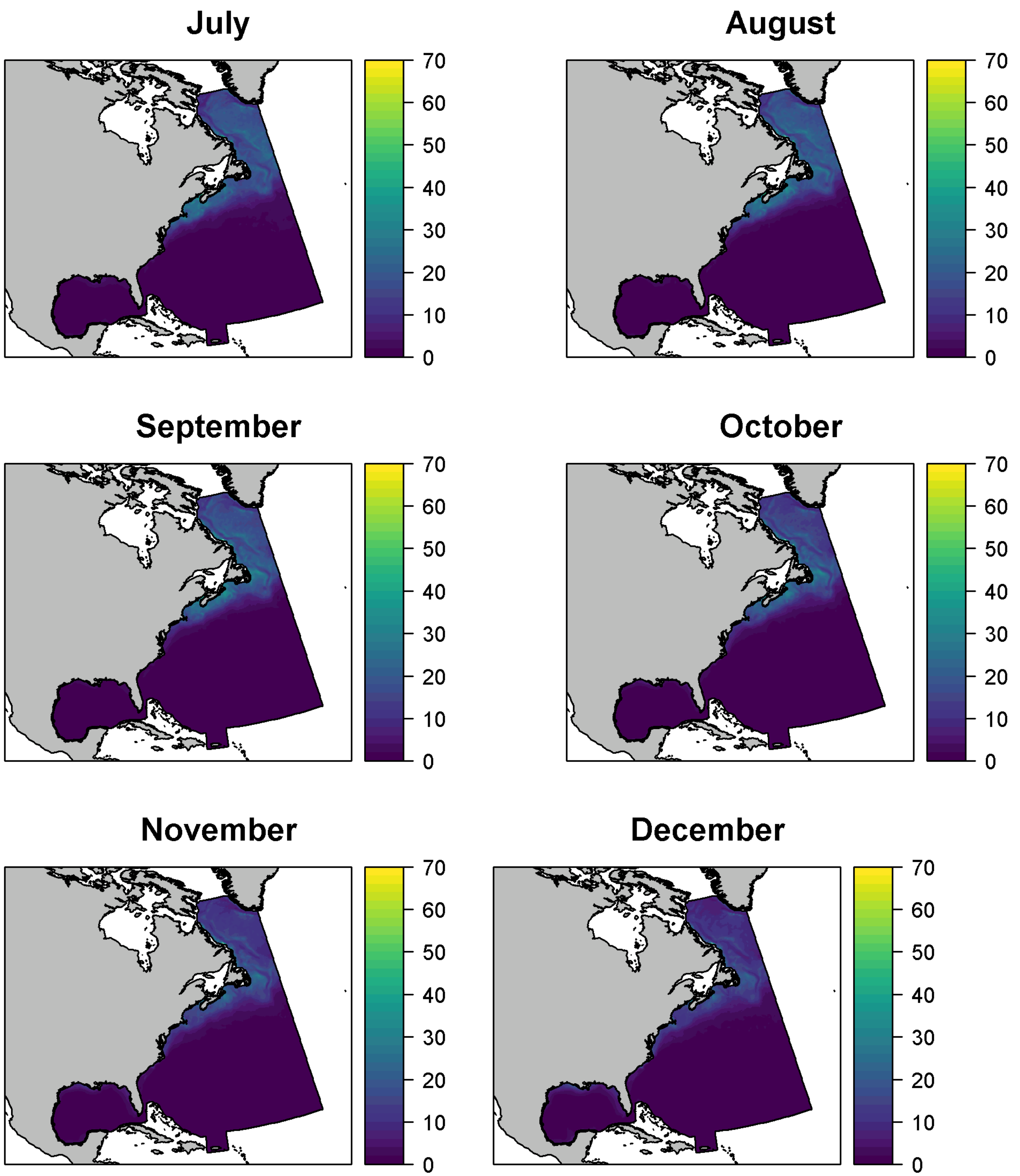


Figure 4: Monthly environmental envelopes for pk_pb. White cells within the AFTT polygon indicate areas where covariate values fell beyond the range of covariate values sampled by the surveys.

5- Predictions

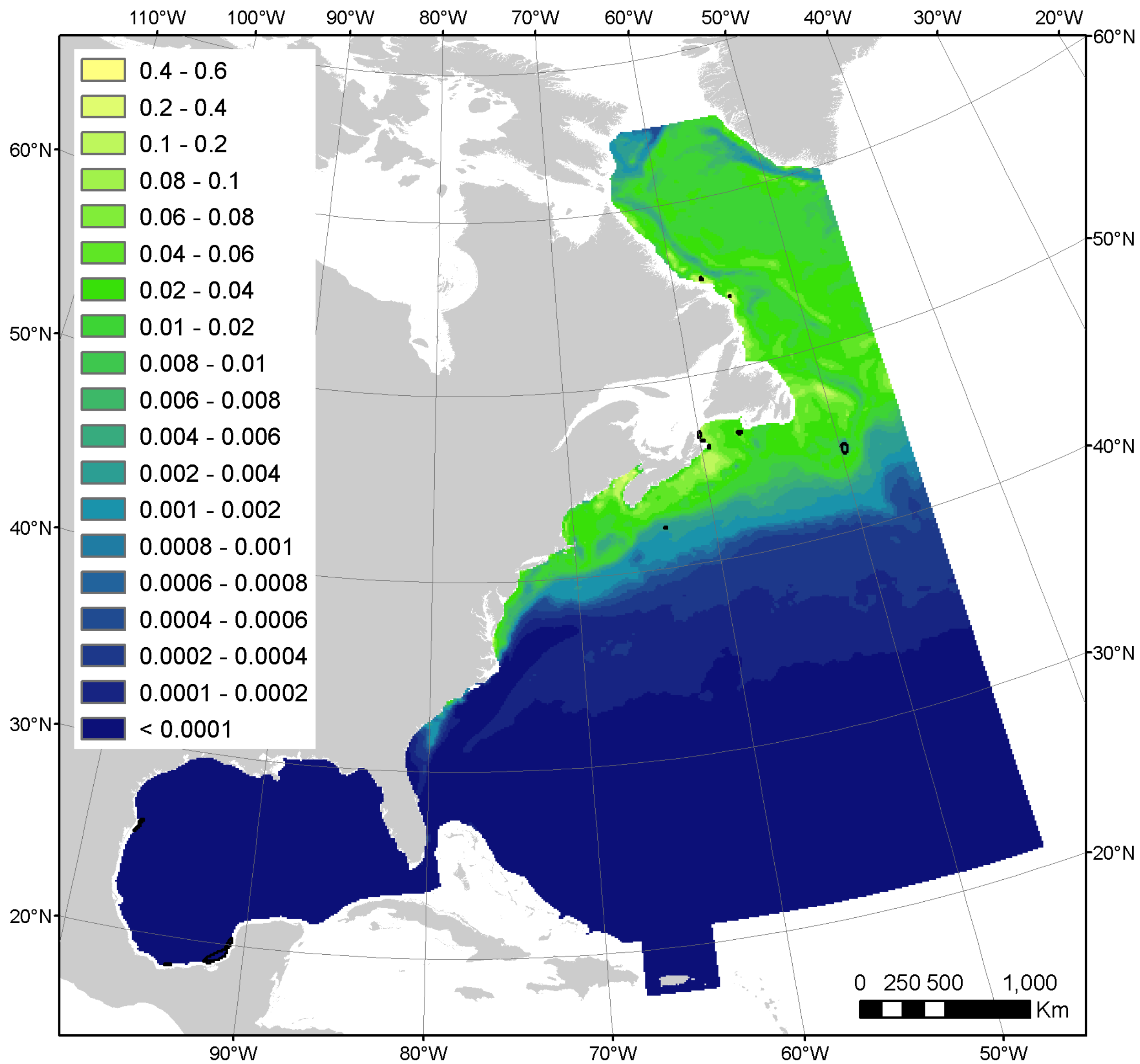


Figure 5: Mean predicted densities (individuals 100 km-2) in the AFTT area. Areas where we extrapolated beyond the sampled covariate ranges are indicated with black crosshatches. An Albers equal area projection is used.

Table 3: Mean predicted abundance (individuals) in the AFTT area and associated coefficient of variation (CV). The CV only reflects uncertainty in the estimated GAM parameters. It does not consider extrapolation beyond the sampled covariate ranges and is therefore strongly underestimated.

Abundance	CV
599	0.271

6- Uncertainty

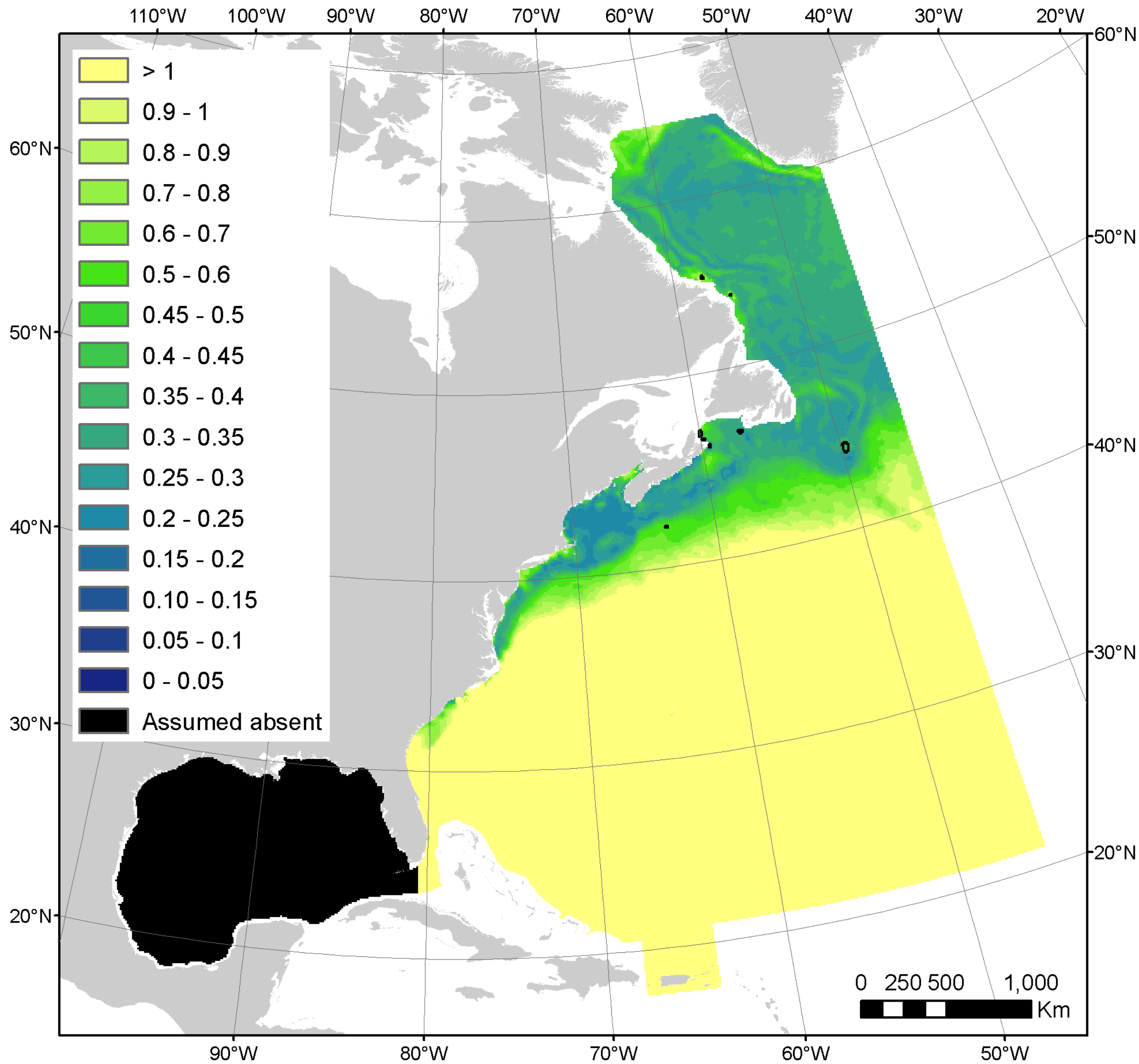


Figure 6: Mean predicted coefficients of variation (unit-less) in the AFTT area. Areas where we extrapolated beyond the sampled covariate ranges are indicated with black crosshatches. An Albers equal area projection is used.

7- Residual diagnostics

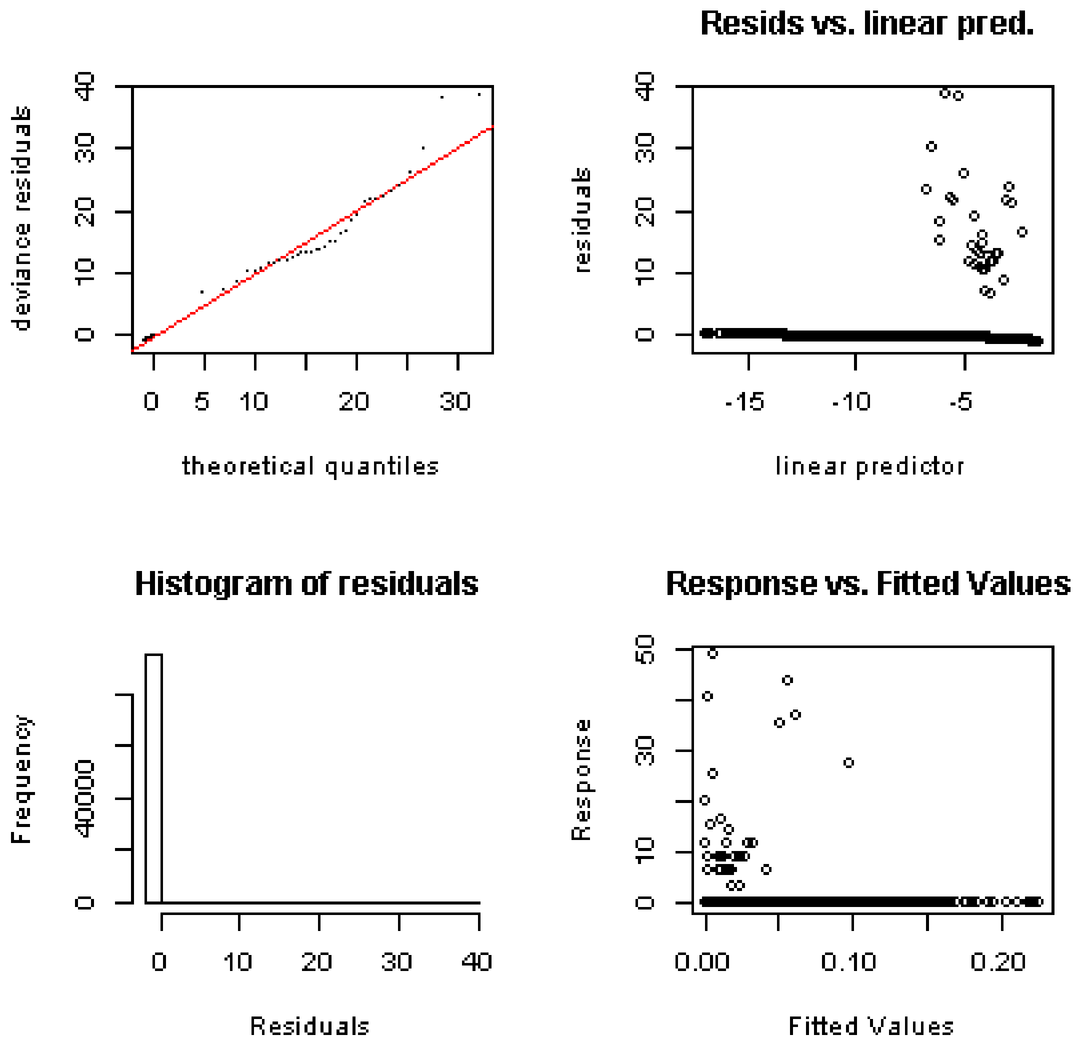


Figure 7: Diagnostic plots of deviance residuals. The normal Q Q plot is useful to assess goodness of fit.

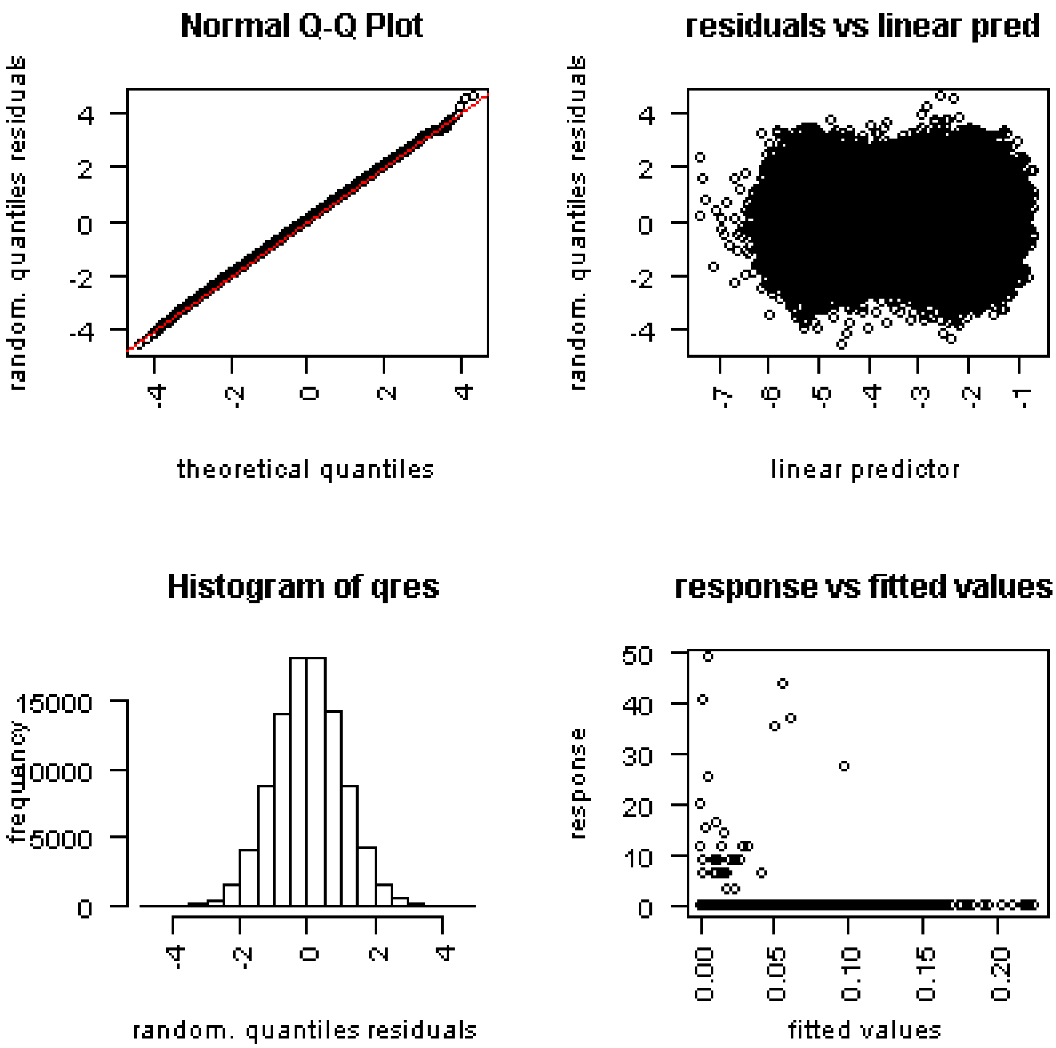


Figure 8: Diagnostic plots of randomized quantile residuals. Randomized quantile residuals (exactly normal residuals) are the most adapted residuals to visualize diagnostic plots of regression models applied to count data. The plots of residuals versus linear predictor and response versus fitted values are useful to investigate patterns in the residuals (e.g. non constant variance).

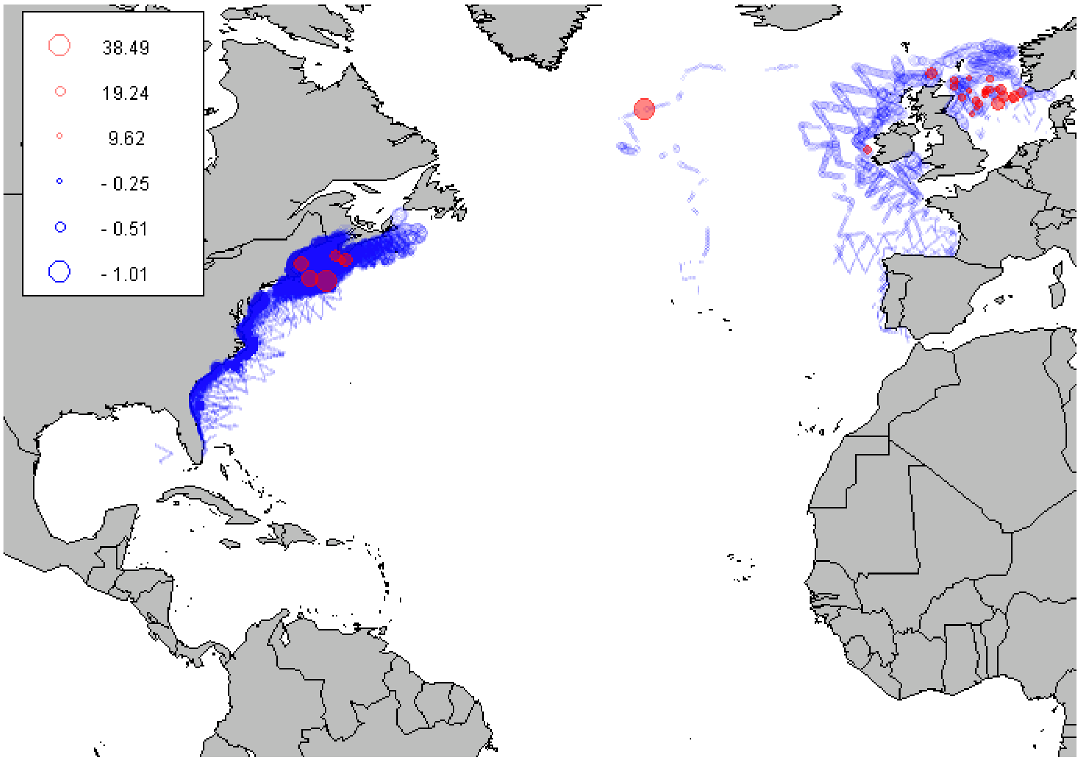


Figure 9: Map showing the spatial distribution of deviance residuals with positive residuals in red and negative residuals in blue.

8- Qualitative evaluation of predictions

The low predicted densities as far south as Georgia do not seem consistent with the reported southernmost sighting of white-beaked dolphin at Cape Cod (Reeves et al. 1998).

Predictions off Labrador and Newfoundland are compatible with sightings from line transect surveys conducted in the summer (Lawson and Gosselin 2009). Predictions off West Greenland are supported by sightings from line transect surveys in the summer, mainly associated with deep waters and steep slopes (Heide-Jørgensen et al. 2008, Hansen and Heide-Jørgensen 2013).

However, stratified abundance estimates reported in the literature suggest that the model largely underestimate white-beaked dolphin abundance in the northern waters of the AFTT area. Lawson and Gosselin (2009) estimated a minimum of 1,360 individuals (95% CI: 825-2,241) in Canadian waters (uncorrected for detection and availability biases). Hansen and Heide-Jørgensen (2013) estimated 11,984 individuals (95% CI 8,285-17,334) in West Greenland (fully corrected estimate).

Future model improvements

Additional data would be needed to fit a habitat-based density model with a full variable selection procedure. Currently, most of the sightings are from European waters and additional sightings from the western side of the basin would help increase the reliability of predictions. The incorporation of line transect survey data from Canada and Greenland would help correct the underestimation of densities in the northern waters of the AFTT area.

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