Density model for Bryde's whale in the AFTT area - version 1

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This report documents the density model developed for Bryde's whale 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 Bryde's whale in the AFTT area. Version 1, 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
CAR	24264.473	5
EC	1044357.704	4
GOM	194715.349	25
MAR	2424.421	1
All regions	1265761.946	35

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

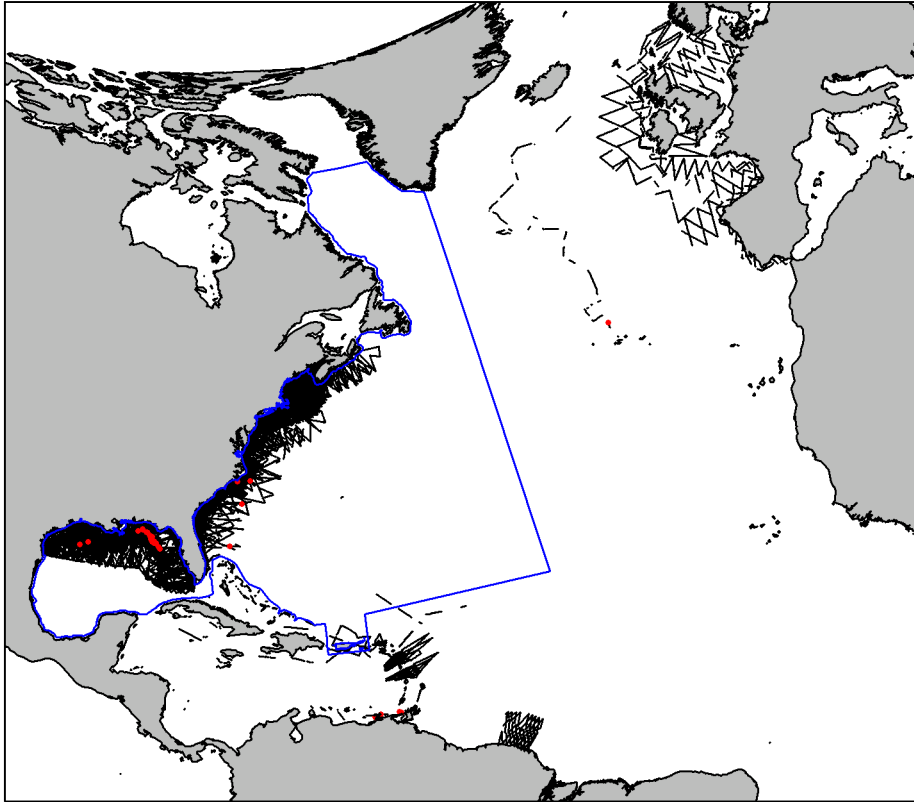| Month	Effort	Sightings
January	77892.79	4
February	123591.37	2
March	117923.54	7
April	117929.72	6
May	149765.03	7
June	131746.32	3
July	135765.64	4
August	129660.43	1
September	71696.07	1
October	82560.18	0
November	69210.92	0
December	58019.93	0
All Months	1265761.95	35

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

Bryde's whale (*Balaenoptera edeni*) NB: The ambiguous sightings of Bryde's whale / sei whale and Balaenoptera spp. in the Gulf of Mexico were treated as Bryde's whale. The ambiguous sightings of Bryde's whale / sei whale in the east coast were used to model both species.

Model type

Due to the small sample size, we fitted a simple habitat-based density model with sea surface temperature (SST) as the single covariate for this taxon. SST was successfully used in predictive distribution models of cetaceans in data poor situations (Kaschner et al. 2006).

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, Gulf of Mexico, Caribbean and mid-Atlantic ridge since these were the four regions that had sightings.

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

- **Selected covariates**: sea surface temperature

- **Model summary**:

```
##
## Family: Tweedie(p=1.143)
## Link function: log
##
## Formula:
## abundance ~ s(SST, k = 4, bs = "ts") + offset(log(area_km2))
## <environment: 0x067e1200>
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  -14.102      1.937  -7.282  3.3e-13 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##          edf Ref.df     F  p-value
## s(SST) 2.006      3 4.503 0.000845 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.000644   Deviance explained = 19.5%
## -REML = 318.77  Scale est. = 17.133    n = 124995
```
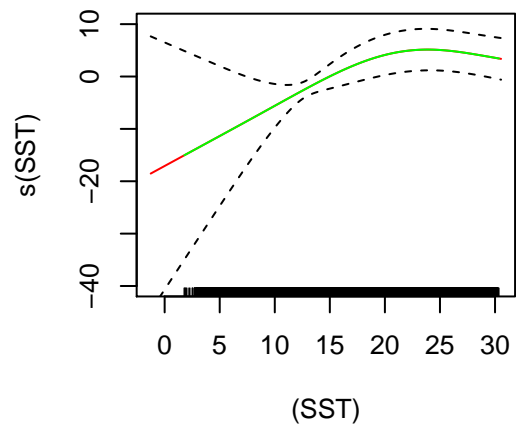
Figure 2: GAM term plots with the log-transformed abundance on the y axis. The solid green line is the smooth function fitted to the data. The solid red line is the smooth function extrapolated to all covariate values in the prediction area. The dashed lines represent the approximate 95% confidence intervals. 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.
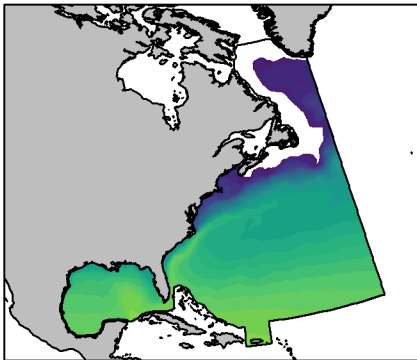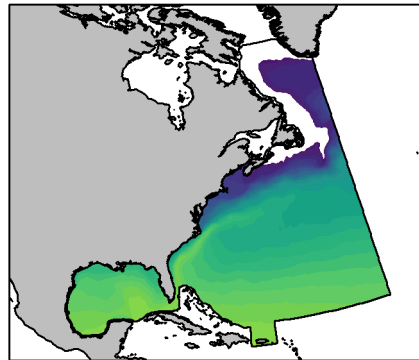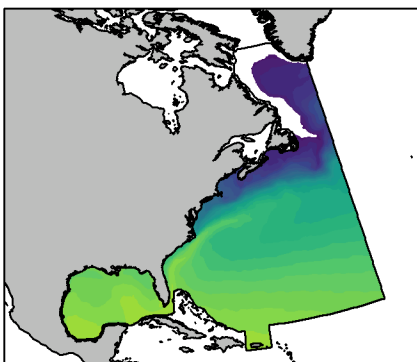
4- Environmental envelopes

January
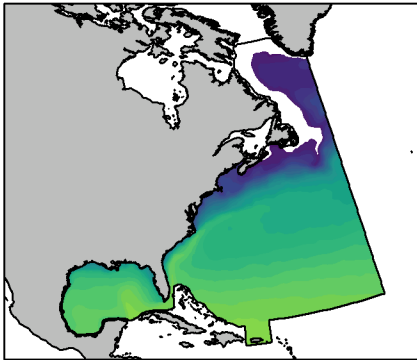
February
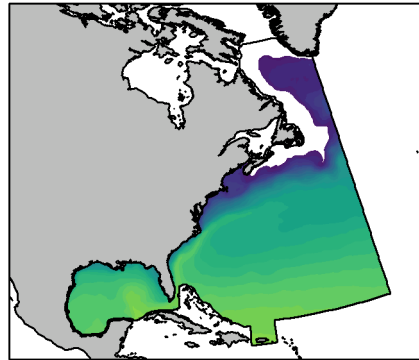
March

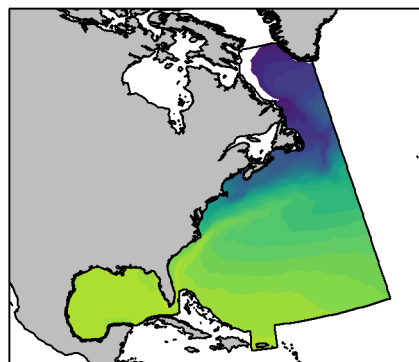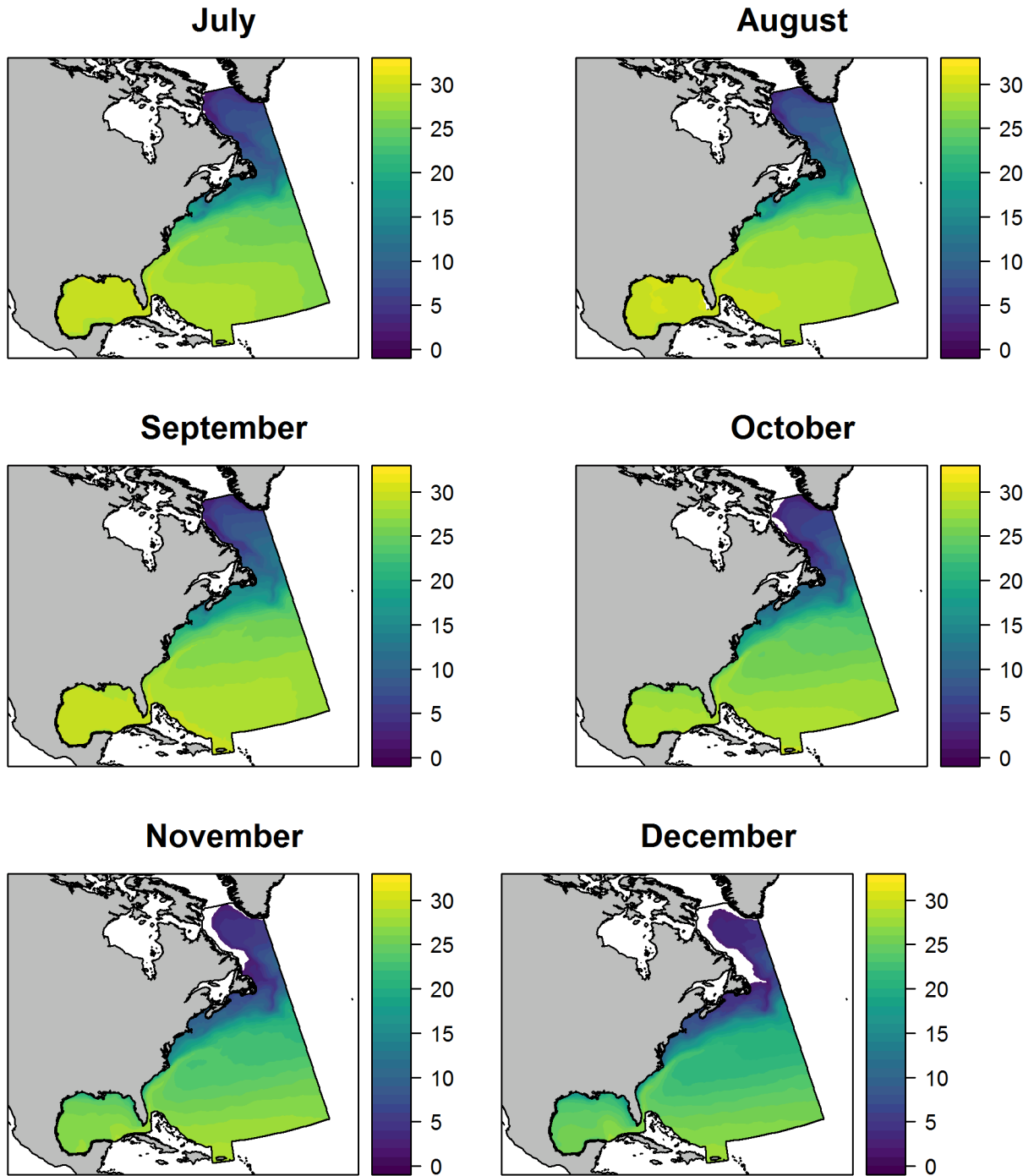## April

May

June

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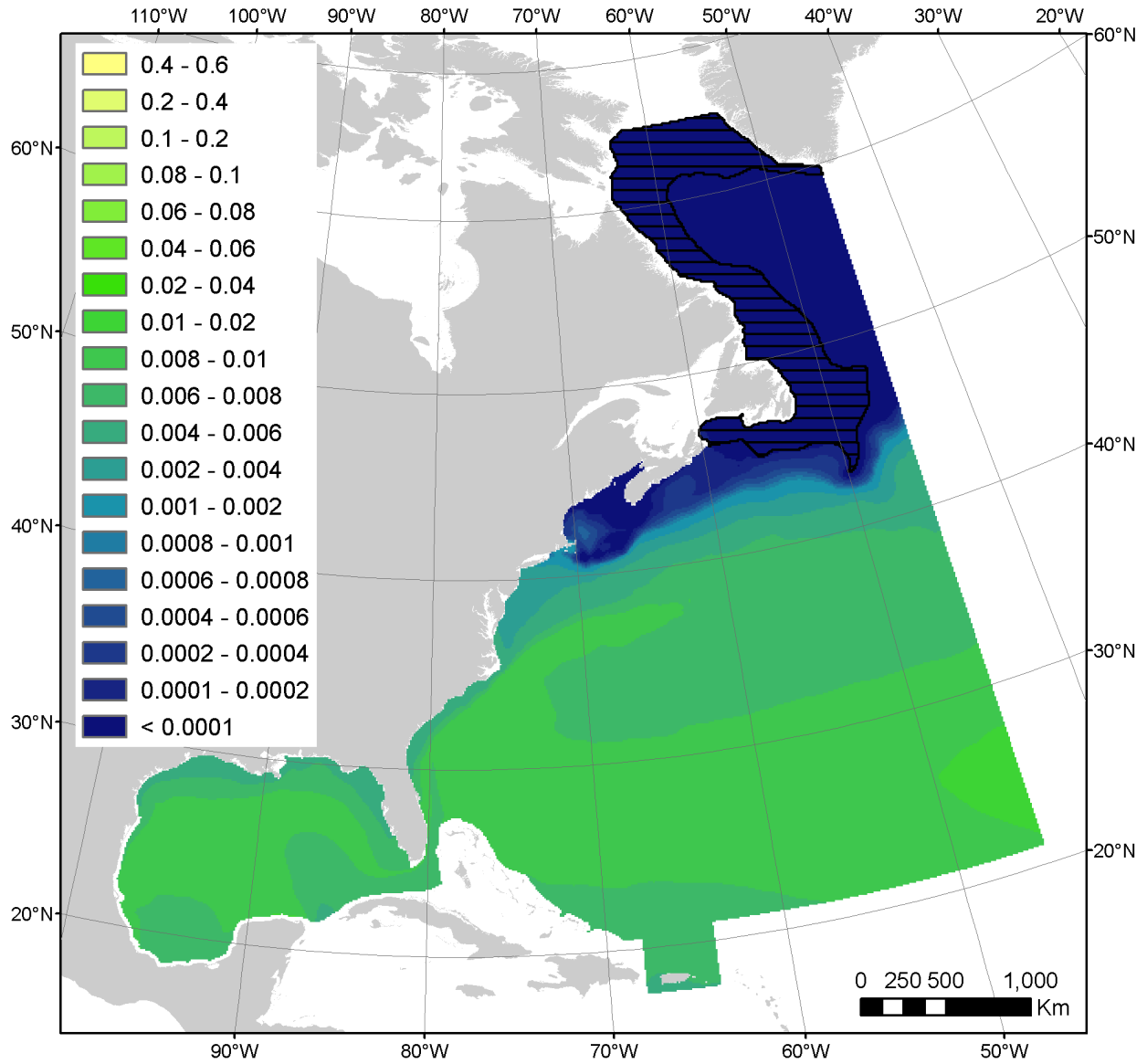
5- Predictions

Figure 4: 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.

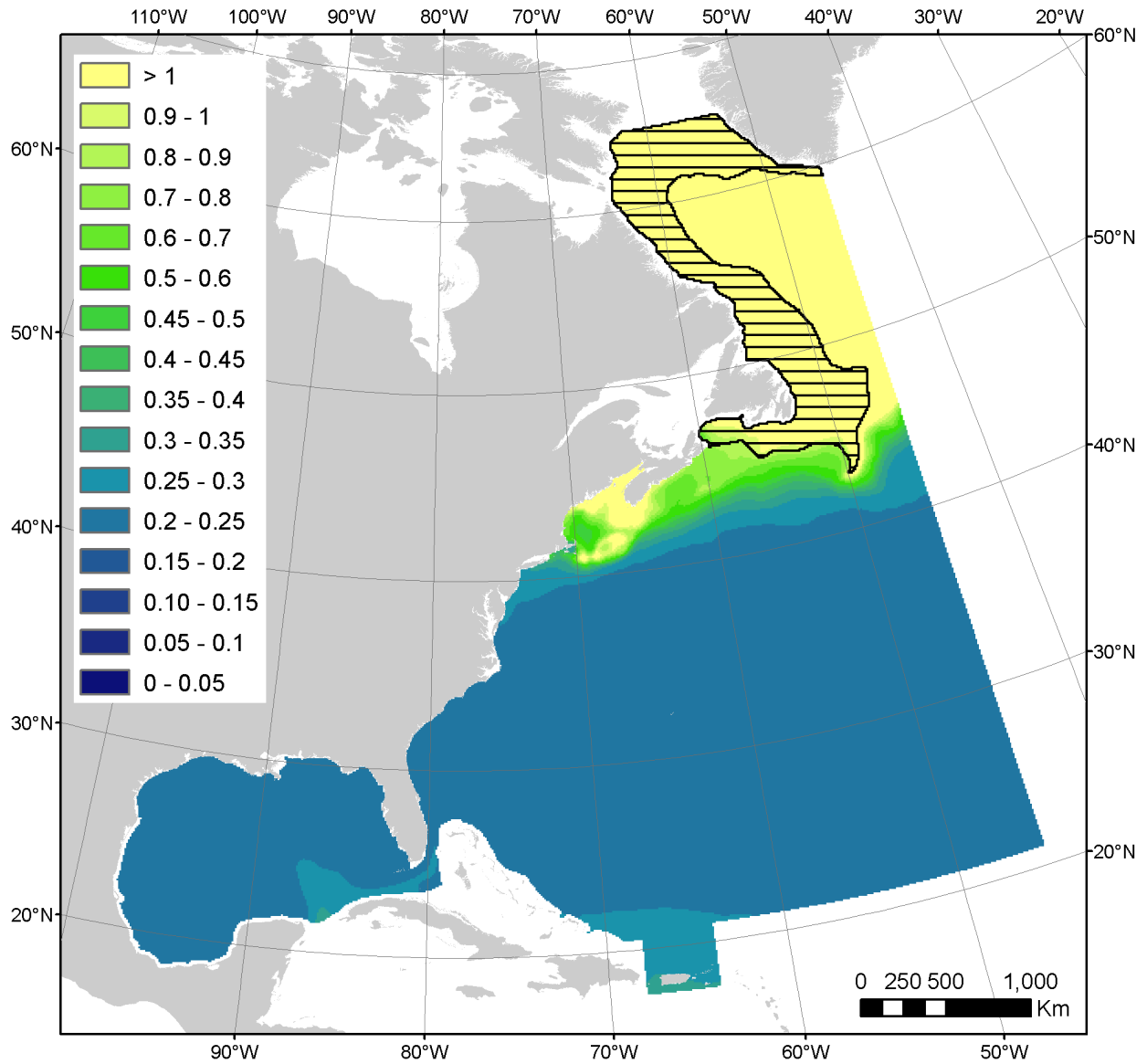| Abundance	CV
677	0.206

6- Uncertainty

Figure 5: 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.
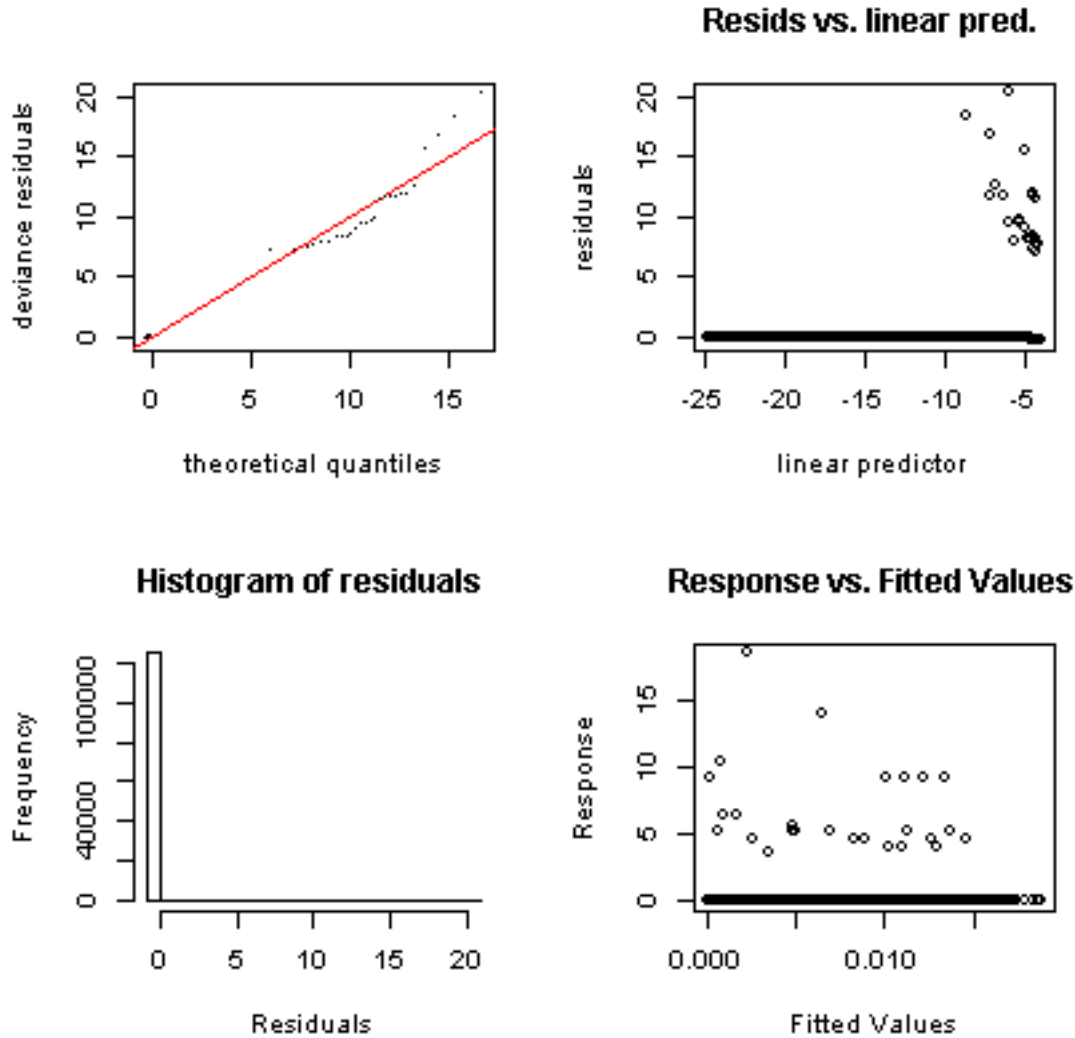
7- Residual diagnostics

Figure 6: Diagnostic plots of deviance residuals. The normal Q Q plot is useful to assess goodness of fit.
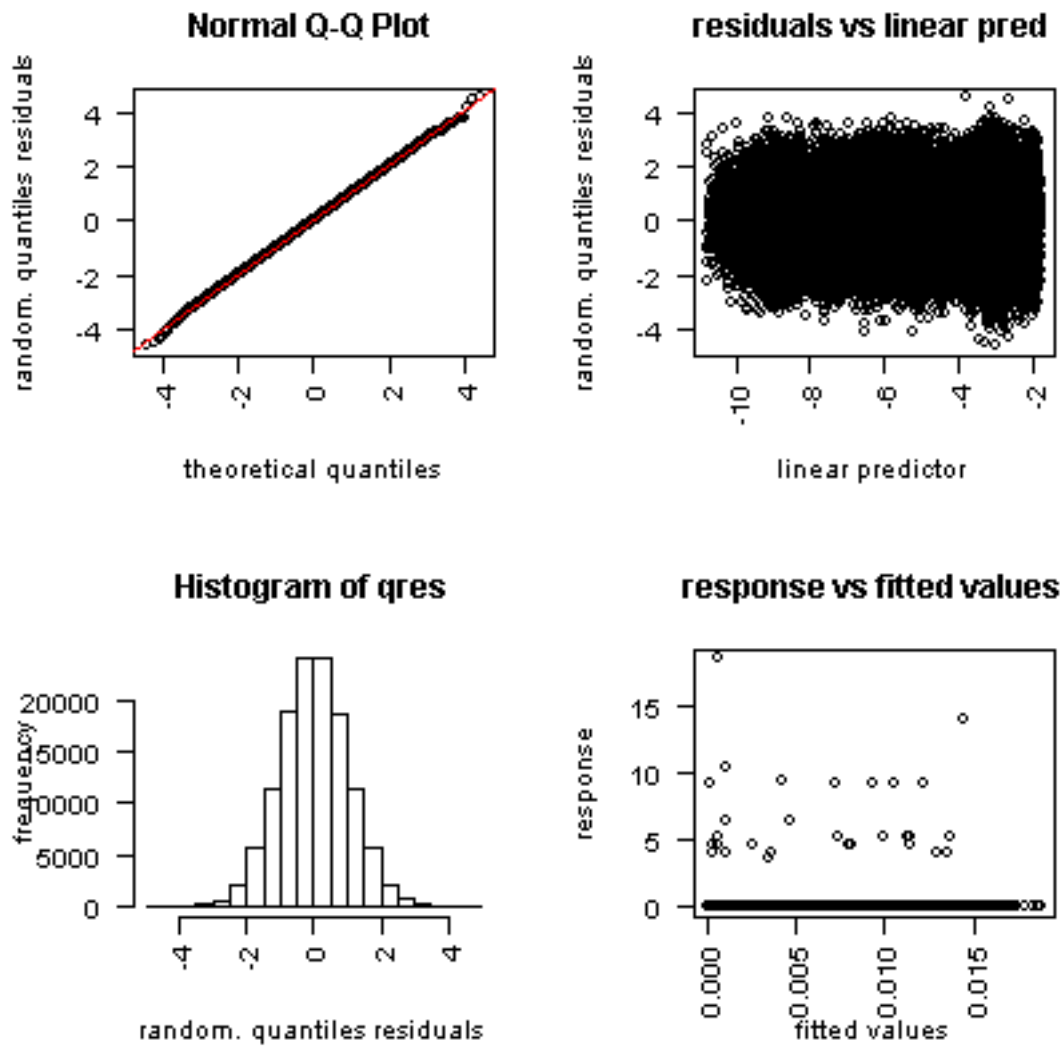
Figure 7: Diagnostic plots of randomized quantile residuals. Randomized quantile residuals (exactly normal residuals) are the most adapted residuals to visualize diagnostic plots of regression models applied to count data. The plots of residuals versus linear predictor and response versus fitted values are useful to investigate patterns in the residuals (e.g. non constant variance).
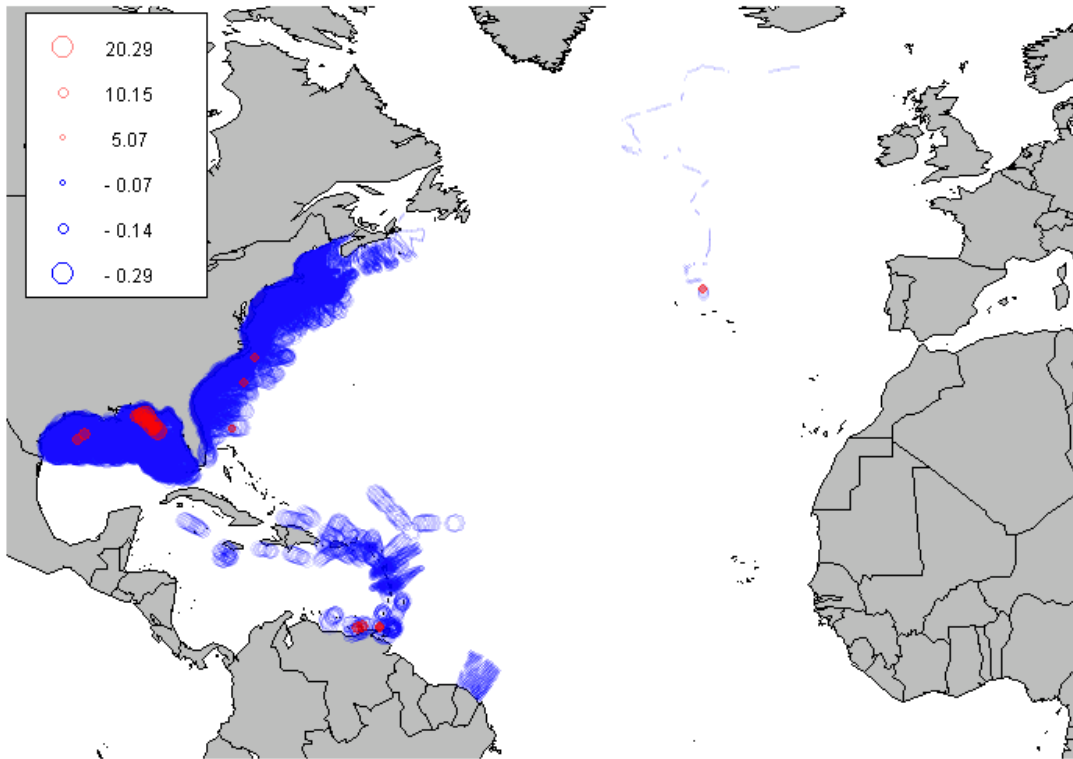
Figure 8: Map showing the spatial distribution of deviance residuals with positive residuals in red and negative residuals in blue.

8- Qualitative evaluation of predictions

Model predictions are consistent with the known year-round occurrence of Bryde's whale throughout tropical and subtropical waters of the North Atlantic (Cummings 1985, Kato and Perrin 2009).

The model may overestimate densities of Bryde's whales in the northern Gulf of Mexico where it is believed to have a severely restricted range (Waring et al. 2015). No data are available to support predictions in the southern Gulf of Mexico, although Bryde's whale has been suggested to occur in both its northern and southern waters (Ortega-Ortiz 2002).

Future model improvements

The implementation of line transect surveys in the southern Gulf of Mexico would help confirm the occurrence of Bryde's whales and increase the reliability of predictions in that region. The continuation of line transect surveys in the U.S. east coast and Gulf of Mexico, with a particular attention to the individual species identification of baleen whales, would increase the sample size and potentially allow fitting a habitat-based density model with a full variable selection procedure.

REFERENCES

Cummings, W. 1985. Bryde's whale. Pages 137-154 Handbook of marine mammals. Sam H. Ridgway and Sir Richard Harrison. Academic Press.

Kaschner, K., R. Watson, A. W. Trites, and D. Pauly. 2006. Mapping world-wide distributions of marine mammal species using a relative environmental suitability (RES) model. Marine Ecology Progress Series 316:285-310.

Kato, H., and W. F. Perrin. 2009. Bryde's whale. Pages 158-163 Encyclopedia of marine mammals 2nd Edition. Academic Press.

Ortega-Ortiz, J. 2002. Multiscale analysis of cetacean distribution in the Gulf of Mexico. PhD dissertation, Texas A&M University.

Waring, G. T., B. Josephson, K. Maze-Foley, and P. E. Rosel. 2015. U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments - 2014.