Density model for Humpback whale in the AFTT area - version 3

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This report documents the density model developed for Humpback 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).

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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	16801.89	41
EC	321272.60	147
All regions	338074.49	188

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

	Month	Effort	Sightings
1	January	71848.75	31
2	February	106927.44	32
3	March	105090.12	62
12	December	54208.17	63
13	All Months	338074.49	188

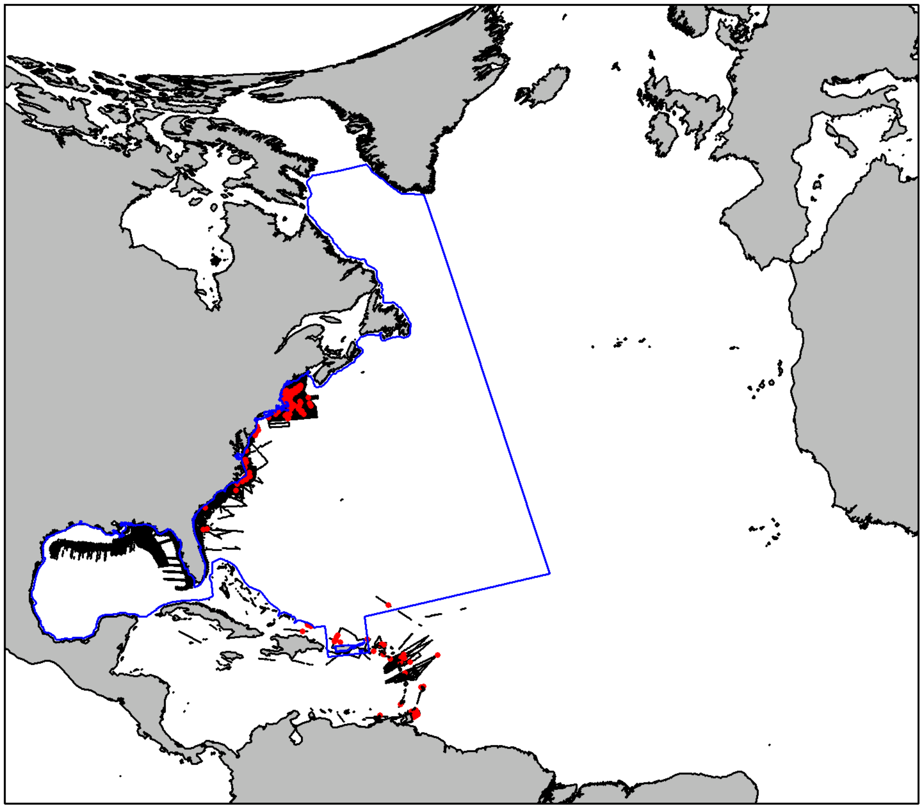

Figure 1: Map of segments (black lines) and sighting locations (red dots). An Albers equal area projection optimized for the AFT area is used.

2- Methodological decisions

Modeled taxon

Humpback whale (*Megaptera novaeangliae*)

Model type

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

Modeled season

Humpback whales travel thousands of kilometers between high-latitude summer feeding grounds and low-latitude winter breeding grounds (major North Atlantic breeding grounds are situated in the Caribbean) (Stevick et al. 1998, Kennedy et al. 2014, Mattila et al. 1989, 1994). In addition there were sufficient sightings in each season so we fitted separate models in summer and winter. We designated December as the first month of winter because the last sightings of female and male migrants in the Gulf of Maine were reported on December 19 and 9, respectively (Robbins 2007).

Segments

We used segments from the east coast, Gulf of Mexico and Caribbean. Although segments from the Gulf of Mexico did not include sightings, their incorporation prevented an increase of the extent of environmental extrapolation and resulted in a negligible drop in the percentage of presence segments (from 0.39% to 0.34% after adding the Gulf of Mexico segments).

Ad-hoc procedure

Since there were no humpback whales sighted during the Gulf of Mexico surveys and the species is only considered of accidental occurrence in the Gulf of Mexico (Jefferson and Schiro 1997), we assigned null densities to the entire Gulf of Mexico.

Temporal resolution of predictions

since there was not sufficiently detailed information in the literature to support the monthly variations in predicted densities, we produced a winter density prediction by averaging the four monthly density predictions.

3- Best model

- **Selected covariates**: sea surface temperature
- **Model summary**:

```
##
## Family: Tweedie(p=1.205)
## Link function: log
##
## Formula:
## abundance ~ s(SST, k = 4, bs = "ts") + offset(log(area_km2))
## <environment: 0x067f91c8>
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  -7.6397     0.1395  -54.76   <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(SST) 2.692      3 11.73 2.4e-08 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.00424   Deviance explained = 9.77%
## -REML = 992.13  Scale est. = 20.52     n = 31011
```

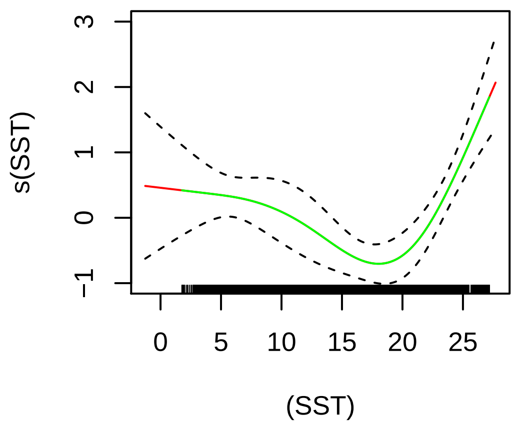

Figure 2: GAM term plots with the log-transformed abundance on the y axis. The solid green line is the smooth function fitted to the data. The solid red line is the smooth function extrapolated to all covariate values in the prediction area. The dashed lines represent the approximate 95% confidence intervals.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

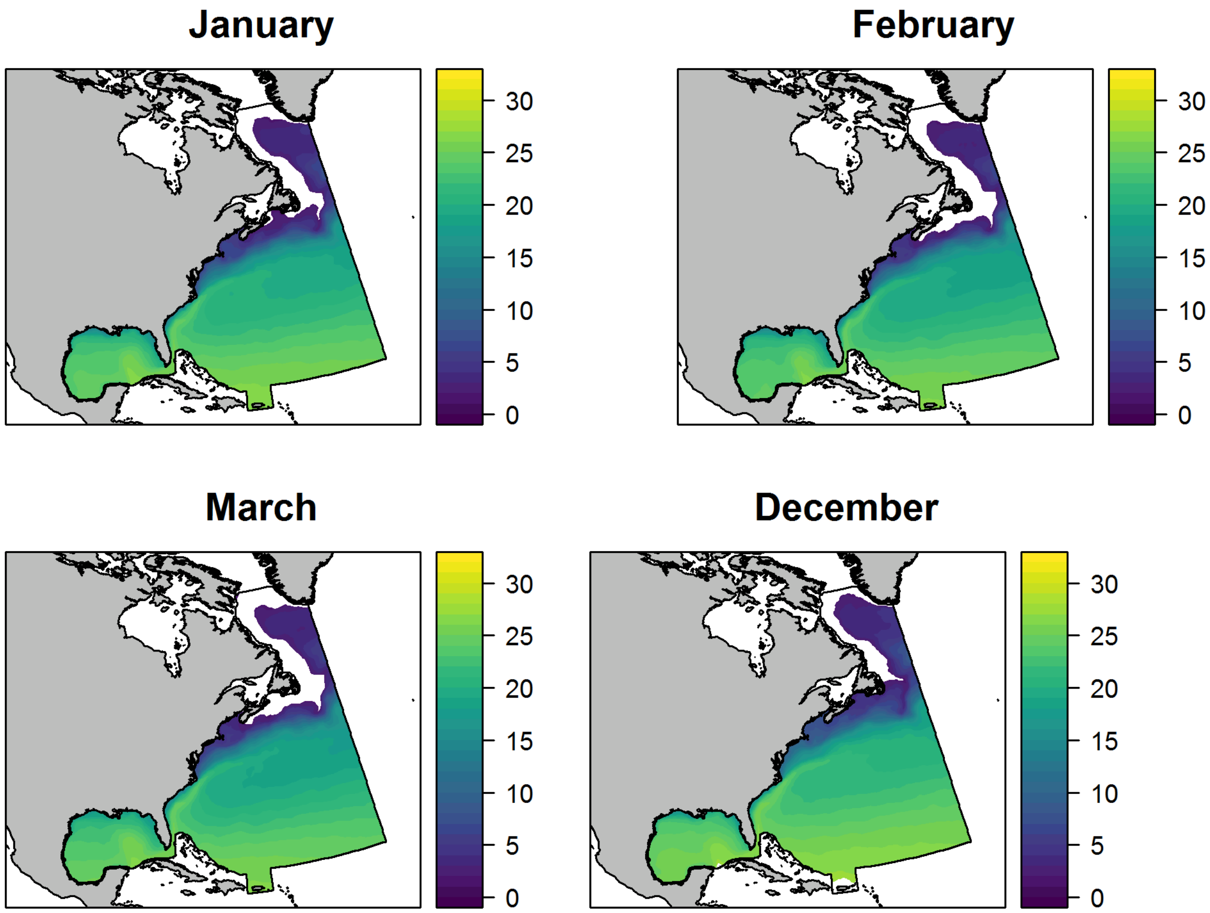

Figure 3: Monthly environmental envelopes for CMC_SST. White cells within the AFTT polygon indicate areas where covariate values fell beyond the range of covariate values sampled by the surveys.

5- Predictions

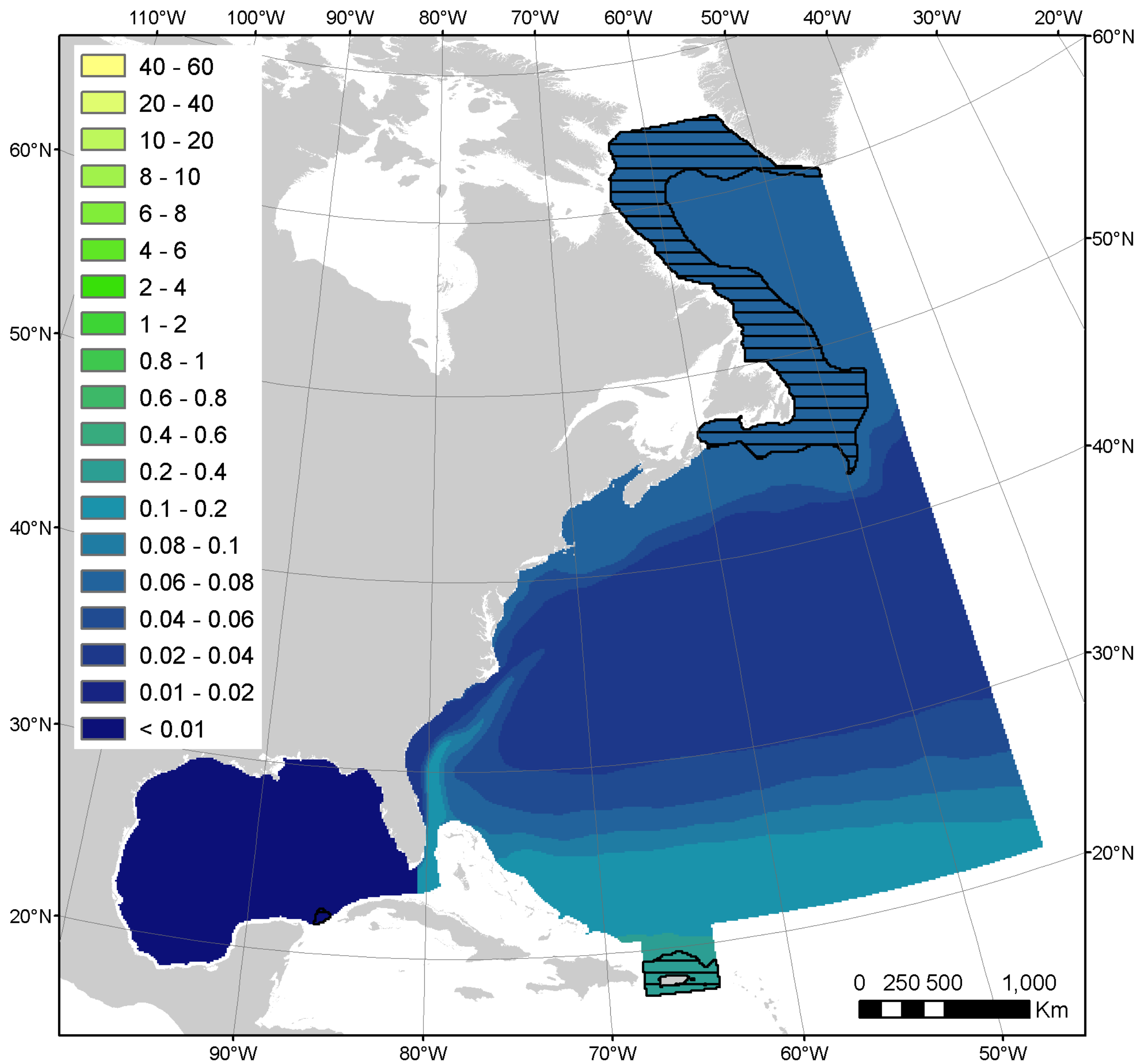

Figure 4: Mean predicted densities (individuals 100 km-2) in the AFTT area. Areas where we extrapolated beyond the sampled covariate ranges are indicated with black crosshatches. An Albers equal area projection is used.

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
6217	0.15

6- Uncertainty

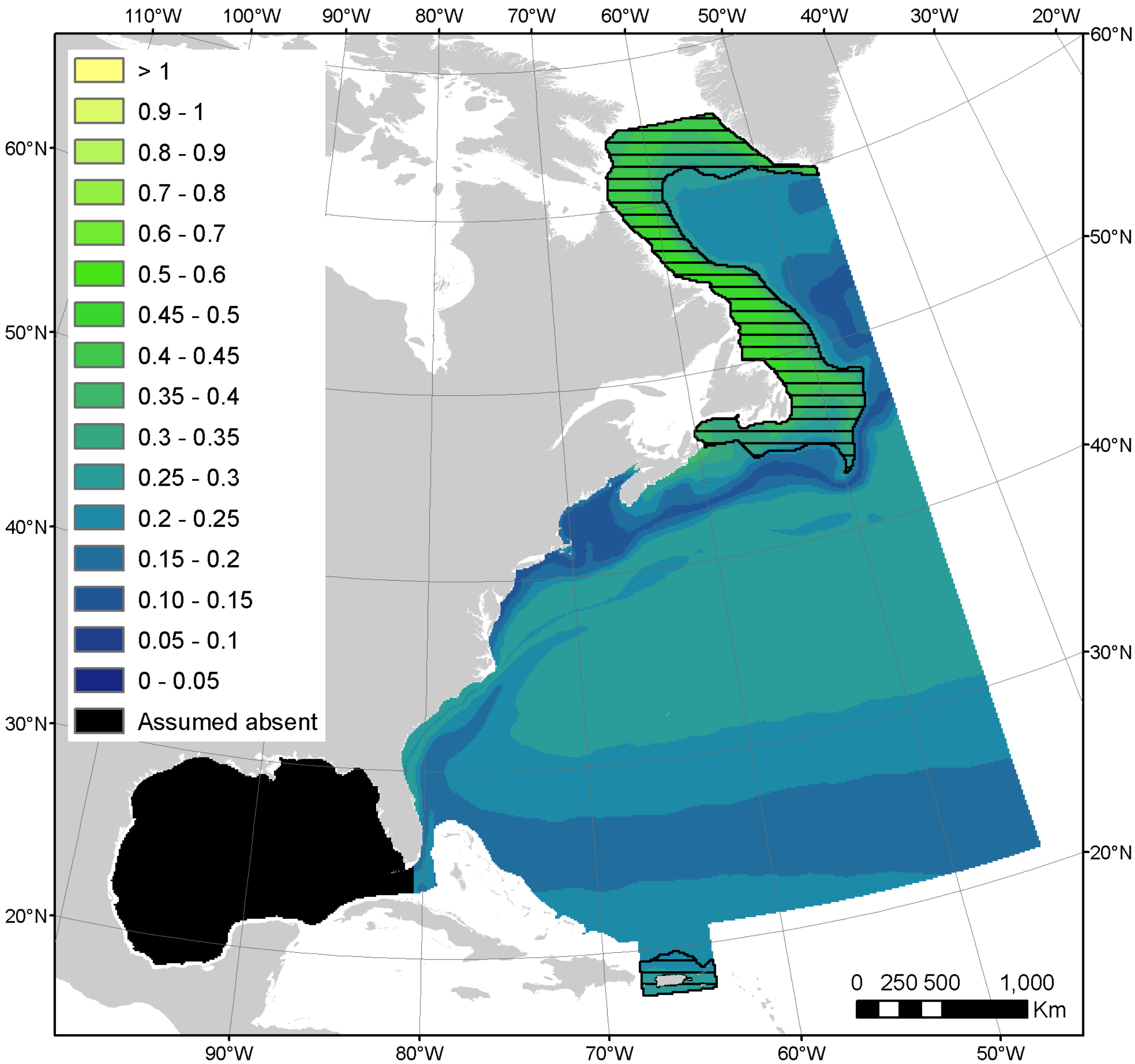

Figure 5: Mean predicted coefficients of variation (unit-less) in the AFTT area. Areas where we extrapolated beyond the sampled covariate ranges are indicated with black crosshatches. An Albers equal area projection is used.

7- Residual diagnostics

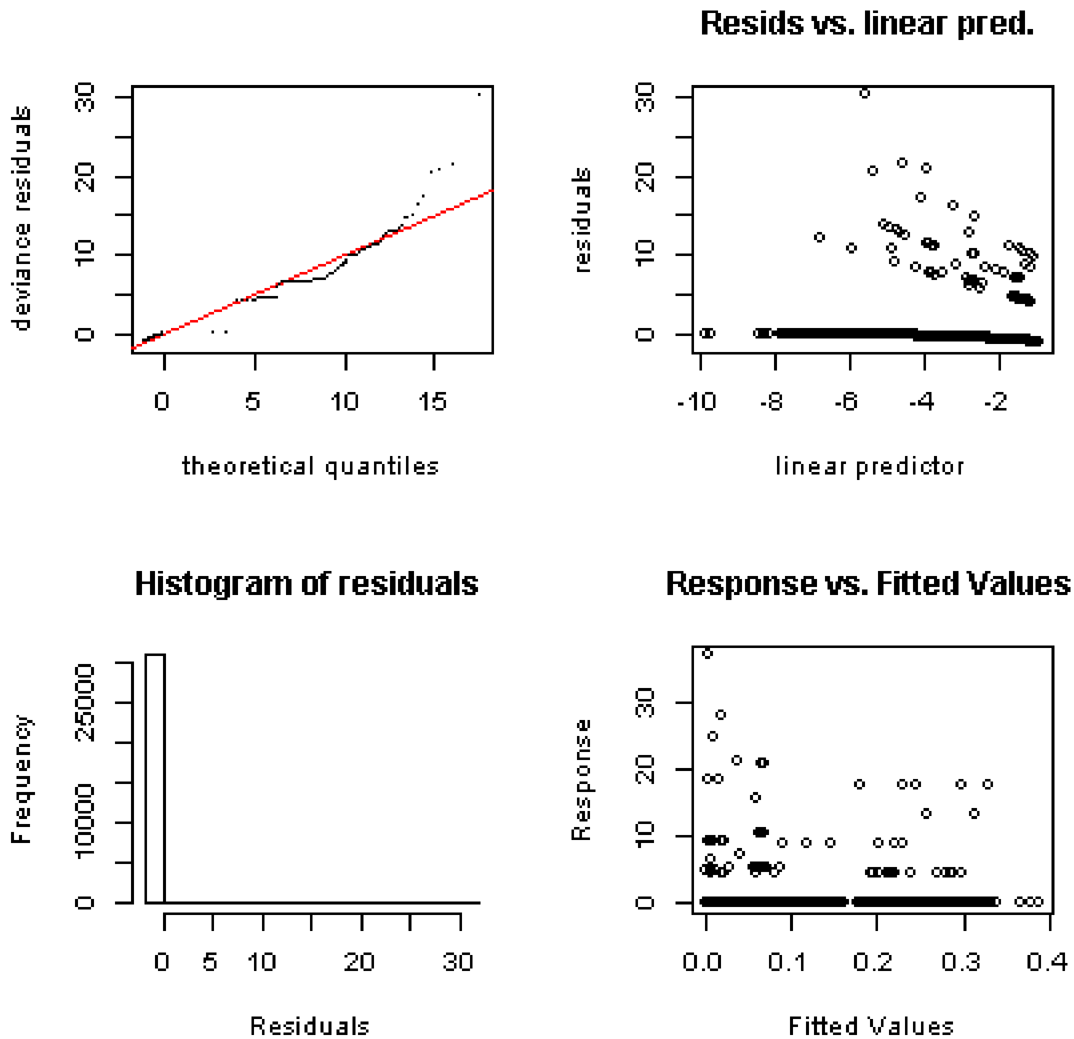

Figure 6: Diagnostic plots of deviance residuals. The normal Q Q plot is useful to assess goodness of fit.

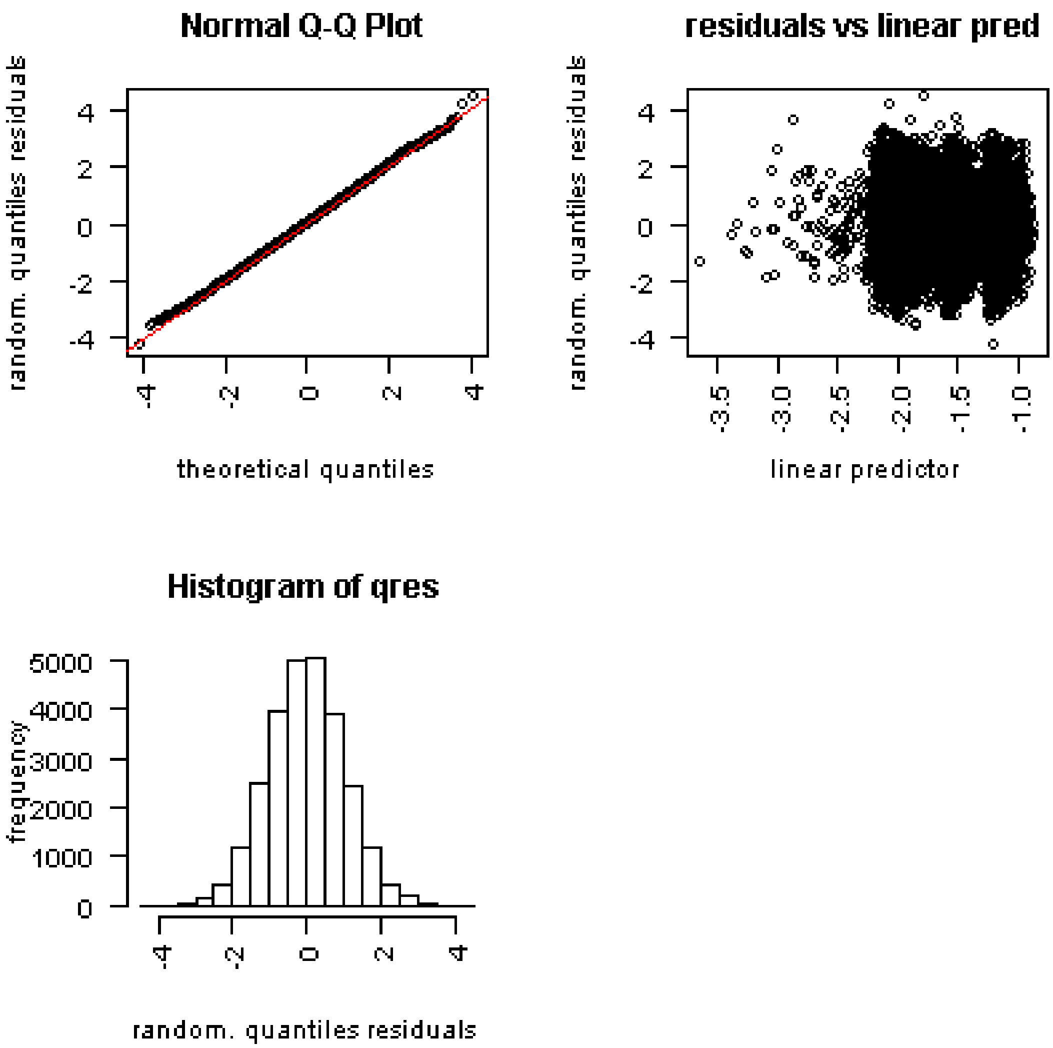

Figure 7: Diagnostic plots of randomized quantile residuals. Randomized quantile residuals (exactly normal residuals) are the most adapted residuals to visualize diagnostic plots of regression models applied to count data. The plots of residuals versus linear predictor and response versus fitted values are useful to investigate patterns in the residuals (e.g. non constant variance).

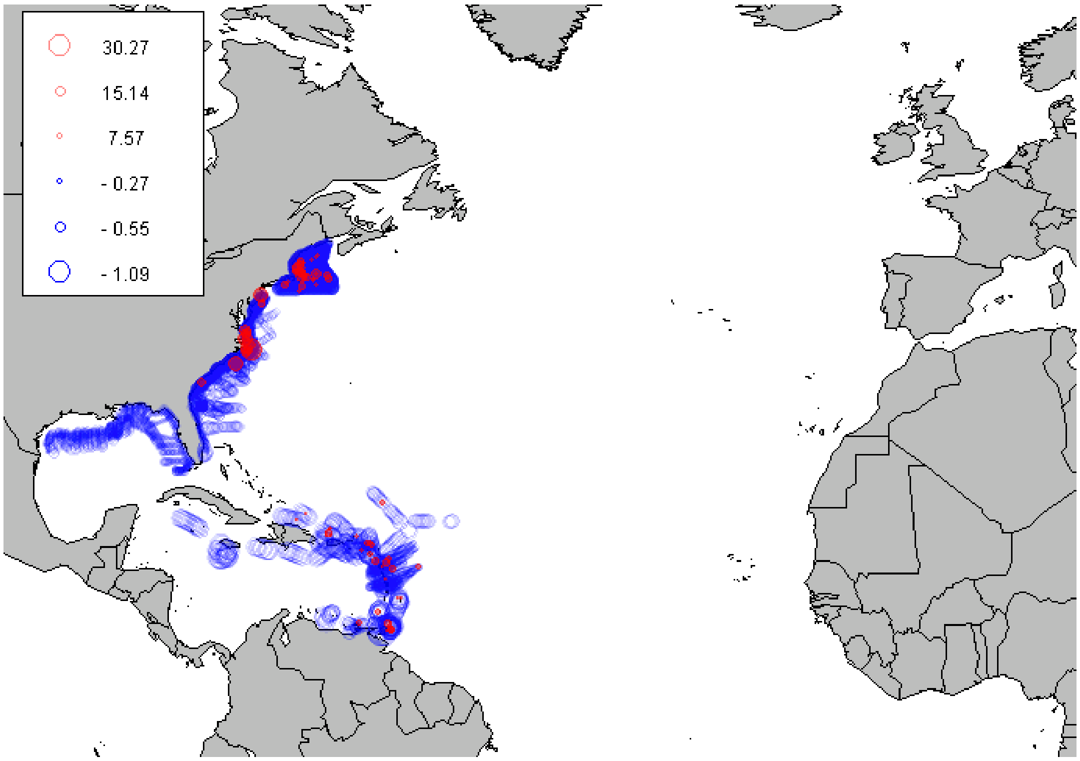

Figure 8: Map showing the spatial distribution of deviance residuals with positive residuals in red and negative residuals in blue.

8- Qualitative evaluation of predictions

Model predictions generally agree with acoustic detections from the U.S. Navy Sound Surveillance System (SOSUS) in the western North Atlantic (Clark and Gagnon 2004). In the winter, more calling humpback whales were detected at low latitudes (North of the Antillean Arc) than high latitudes (off eastern Canada and the northeastern U.S.). This supports the increase of predicted densities south of 30°N, as well as the low predicted densities in northern waters in winter.

Predictions around Puerto Rico are in agreement with numerous sightings recorded in this known wintering ground (Mignucci-Giannoni 1998, Sanders et al. 2005).

Future model improvements

The incorporation of additional survey data from the Caribbean wintering grounds would help increase the reliability of model predictions in winter and potentially allow fitting a habitat-based density model with a full variable selection procedure.

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