Extrapolating with density surface models

Laura Mannocci

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Duke University

Workshop on spatial models for distance sampling - Oct 2015 - Duke

Case study

Extrapolating cetacean densities into the unsurveyed high seas of the western North Atlantic

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

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CREEM

Case study

“Here be dragons”

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Acknowledgements

- Observers, crews, funding agencies, and everyone responsible for conducting the surveys:

- Many people who shared surveys, provided advice, and reviewed results: Suzanne Bates, Elizabeth Becker, Tim Cole, Peter Corkeron, Andrew DiMatteo, Megan Ferguson, Karin Forney, Lance Garrison, Tim Gowan, Jim Hain, Phil Hammond, Jolie Harrison, Christin Khan, Anu Kumar, Erin LaBrecque, Claire Lacey, Gwen Lockhart, Bill McLellan, Dave Miller, Richard Pace, Debi Palka, Andy Read, Vincent Ridoux, Rob Schick, Sofie Van Parijs, Gordon Waring, Amy Whitt and many others…

- Our funders:

Fisheries

Ship traffic

Military sonars

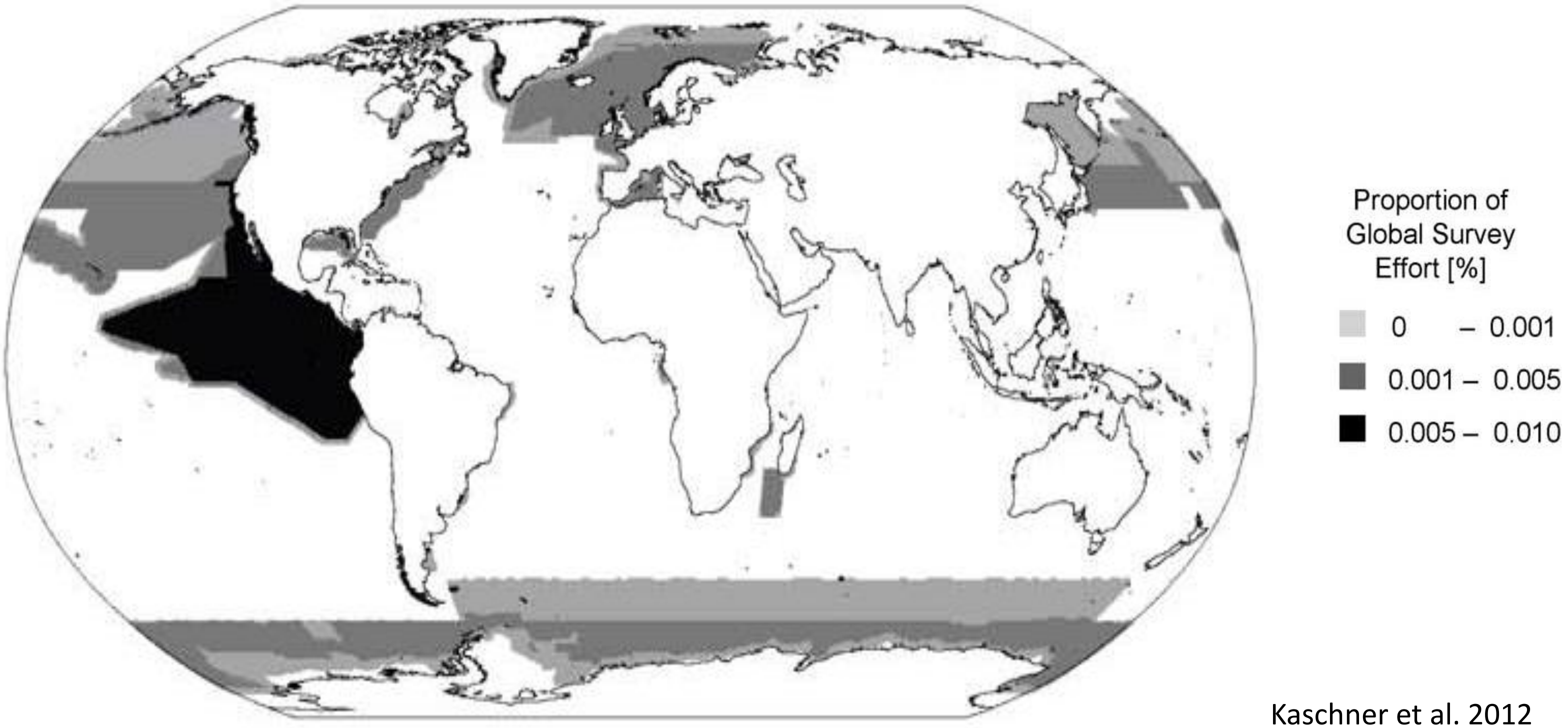
INTRODUCTION

Fisheries

Ship traffic

Military sonars

To evaluate the impacts of these human activities on cetacean populations in the high seas, we need density estimates

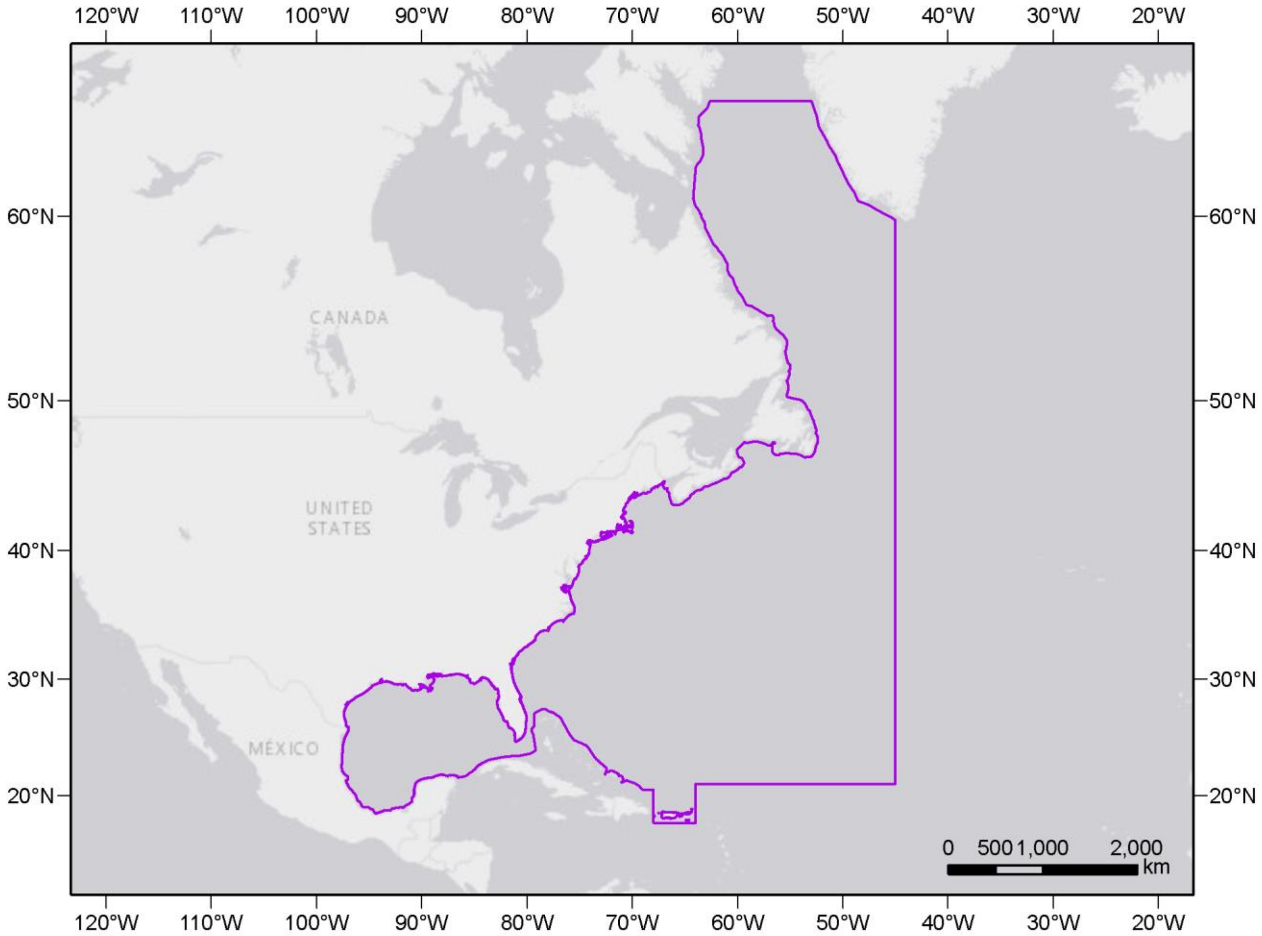


Kaschner et al. 2012

Large regions of the high seas have never been surveyed

Our goal: to produce the most reliable density estimates for all cetacean species in the U.S. Navy AFTT area

NAVY Atlantic Fleet Testing & Training Area



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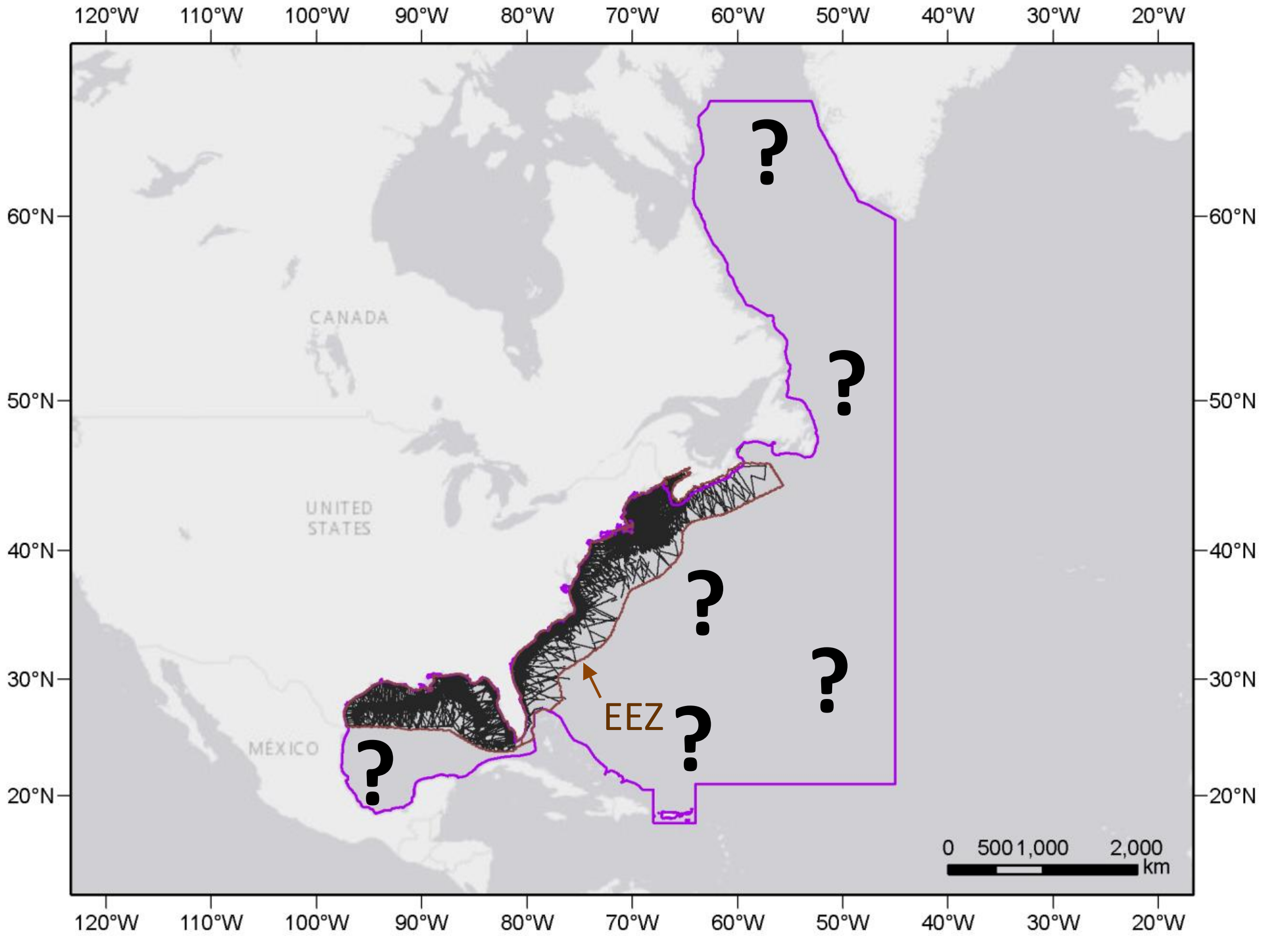

U.S. surveys only covered a fraction of the AFTT area → extrapolate carefully

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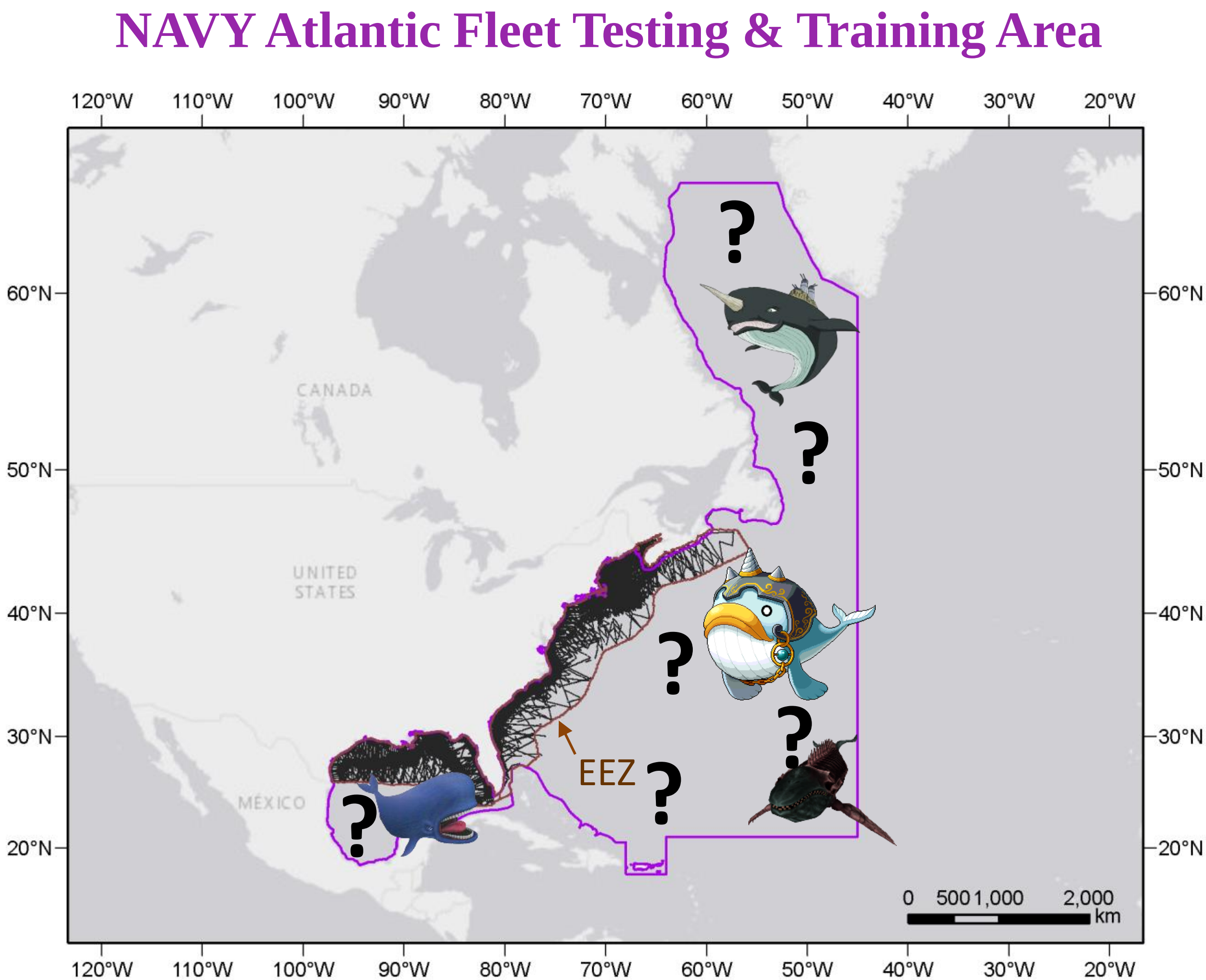

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To extrapolate carefully, we:

(1) Built models with environmental covariates only

Environmental covariates with a broad range of values sampled by the surveys

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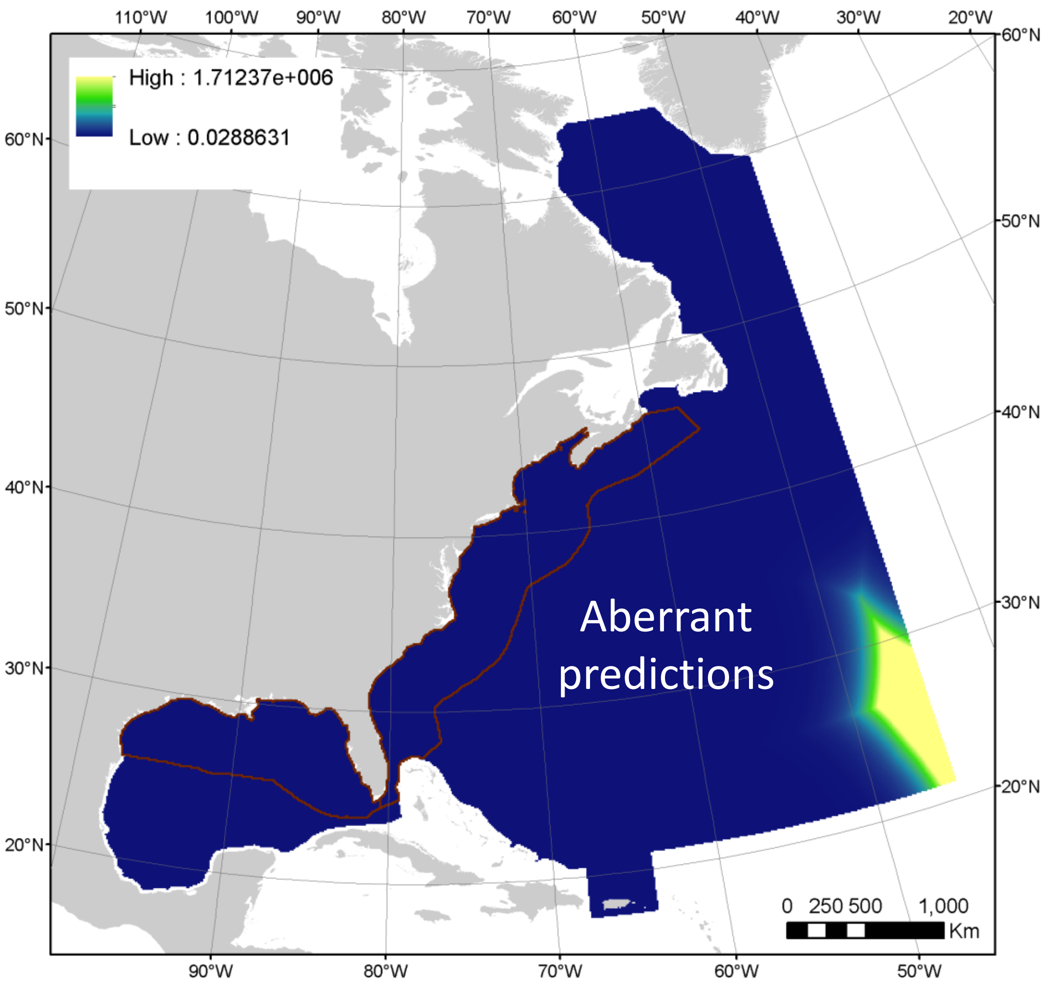
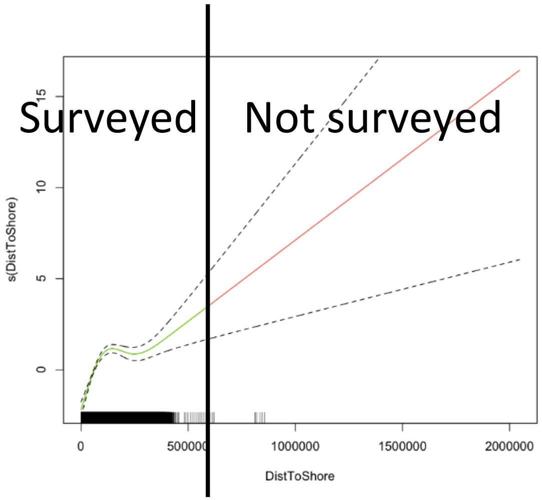
Physiographic covariates	-Depth -Slope ~~-Distance to shore~~ ~~-Distance to isobaths~~

This is what would happen if we use distance to shore as a covariate:

Predicted density map for beaked whales





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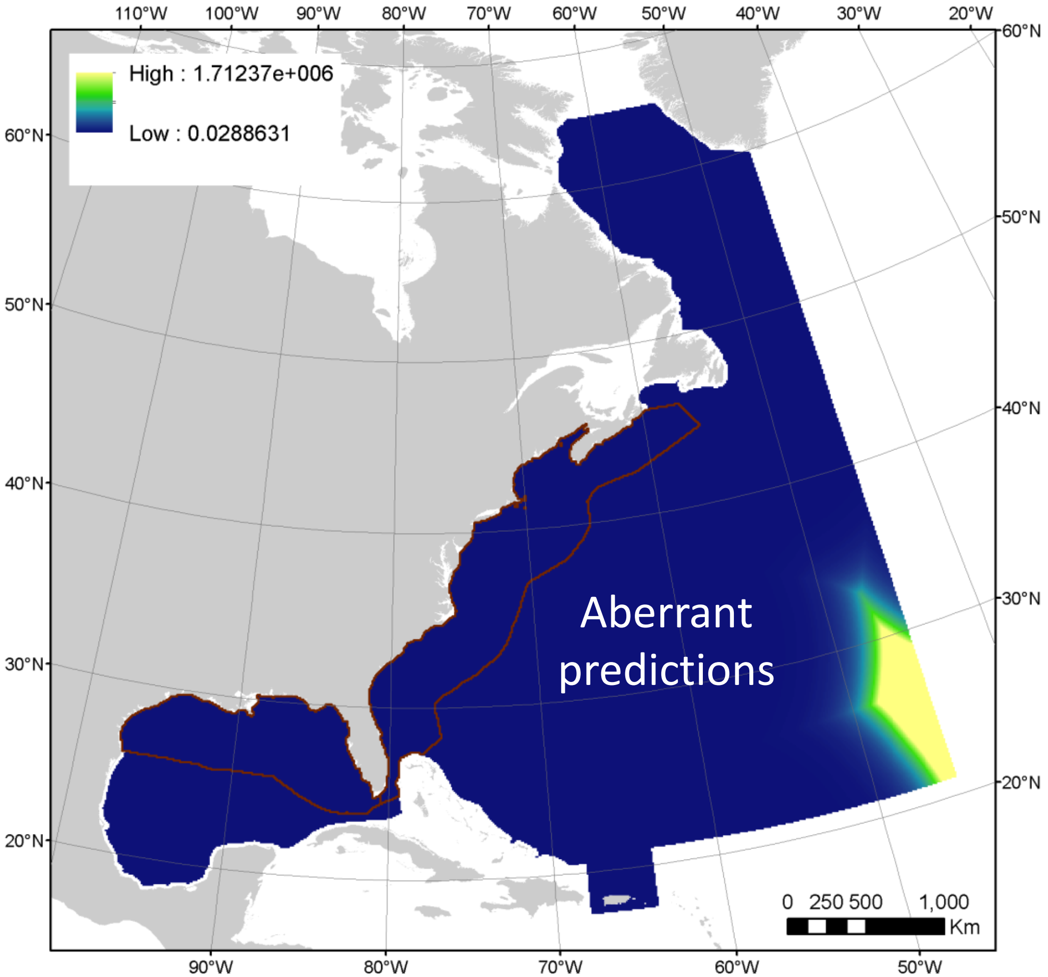

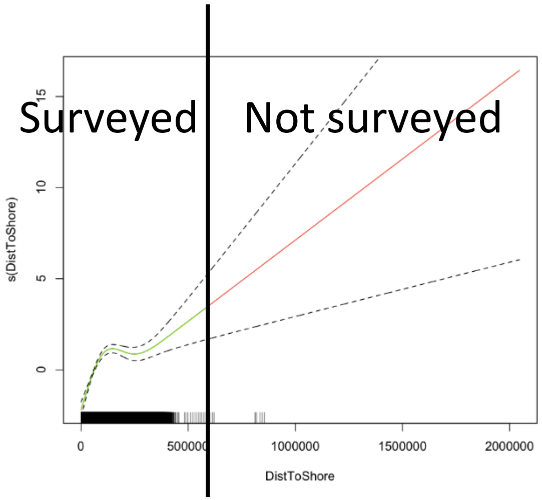

Dangerous extrapolation beyond the covariate values sampled by surveys

Environmental covariates with a broad range of values sampled by the surveys

~~**Spatial covariates**~~	~~-Latitude, Longitude~~
Physiographic covariates	-Depth -Slope ~~-Distance to shore~~ ~~-Distance to isobaths~~
Physical covariates	-Sea surface temperature -Distance to SST fronts -Sea level anomaly

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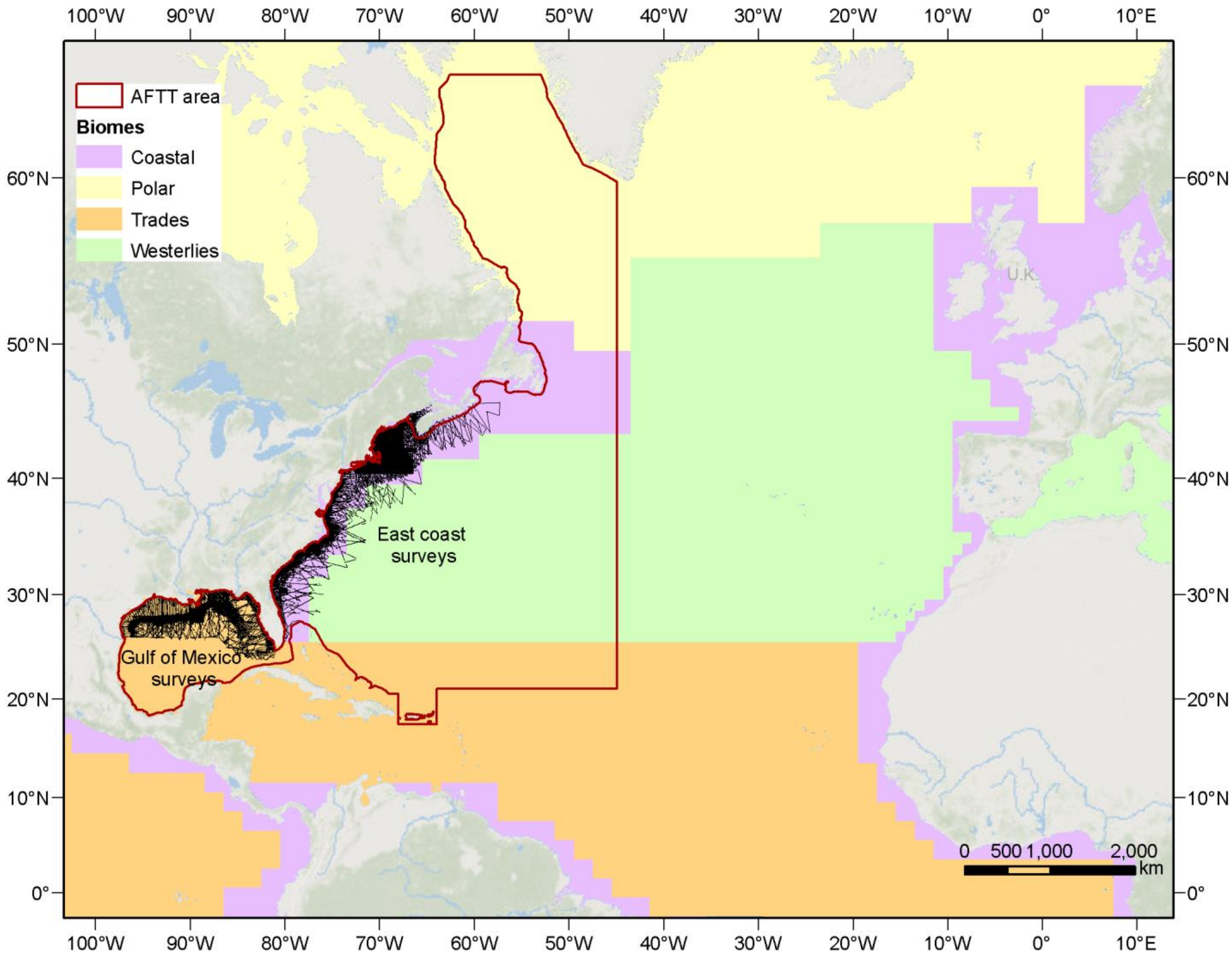
Physiographic covariates	-Depth -Slope ~~-Distance to shore~~ ~~-Distance to isobaths~~
Physical covariates	-Sea surface temperature -Distance to SST fronts -Sea level anomaly
Biological covariates	-Chlorophyll concentration -Primary productivity -Biomass / production of zooplankton and micronekton (SEAPODYM outputs)

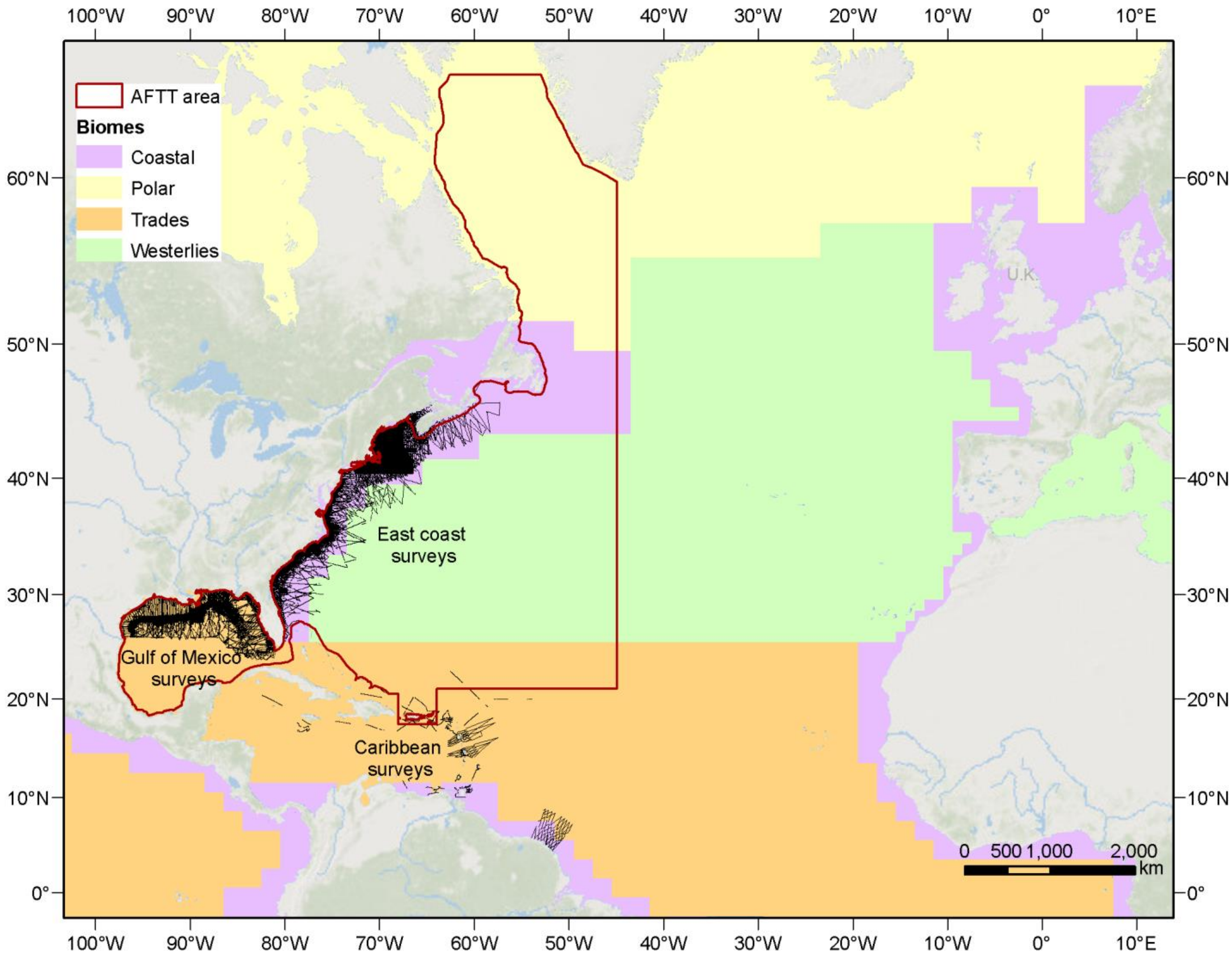
To extrapolate carefully, we:

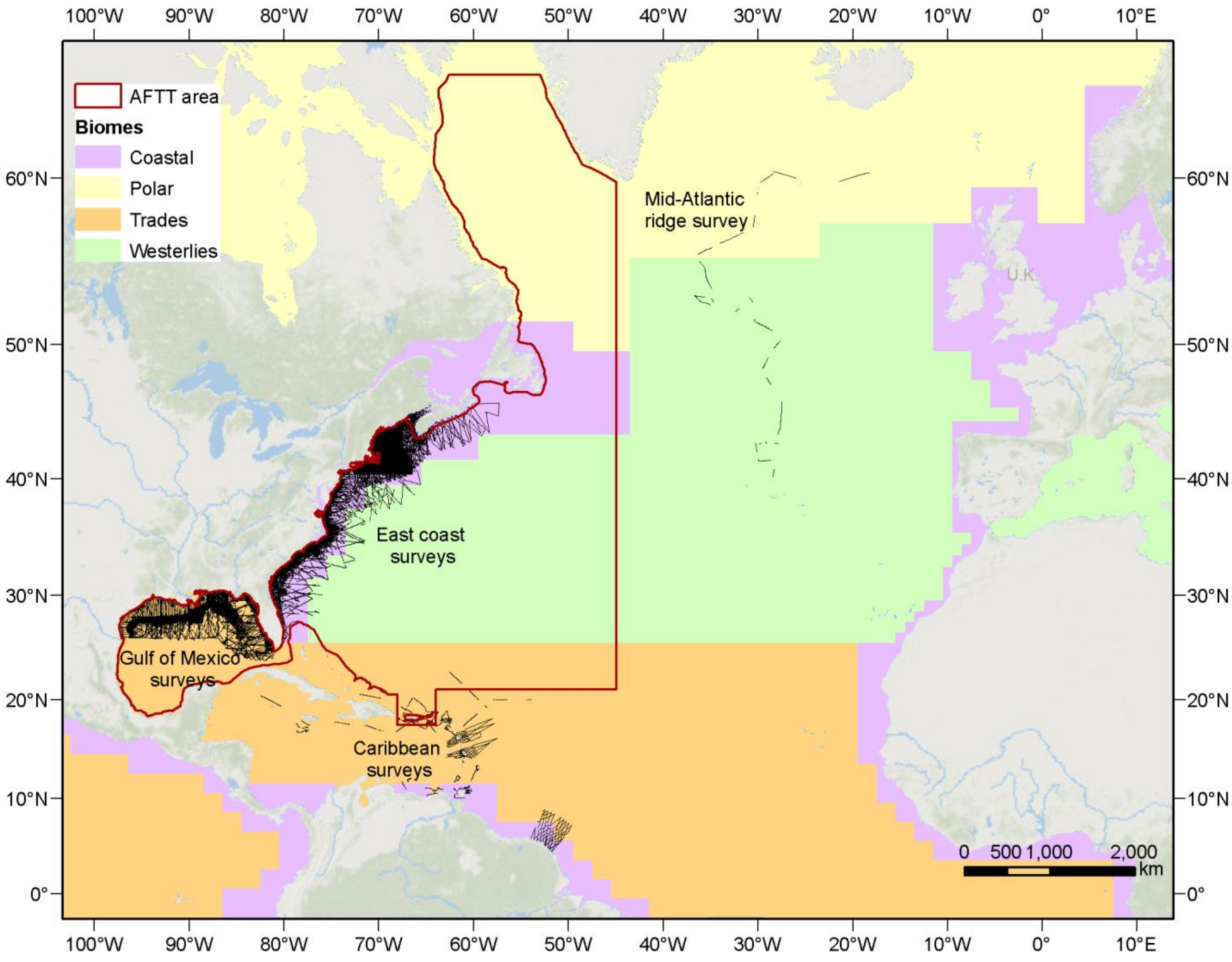
(1) Built models with environmental covariates only

(2) Incorporated surveys from relevant ecological biomes in the North Atlantic


AFTT area
Biomes
Coastal
Polar
Trades
Westerlies
East coast surveys
Gulf of Mexico surveys
U.K.
0 500 1,000 2,000 km
100°W 90°W 80°W 70°W 60°W 50°W 40°W 30°W 20°W 10°W 0° 10°E
60°N 50°N 40°N 30°N 20°N 10°N 0°

MATERIAL AND METHODS





100°W
90°W
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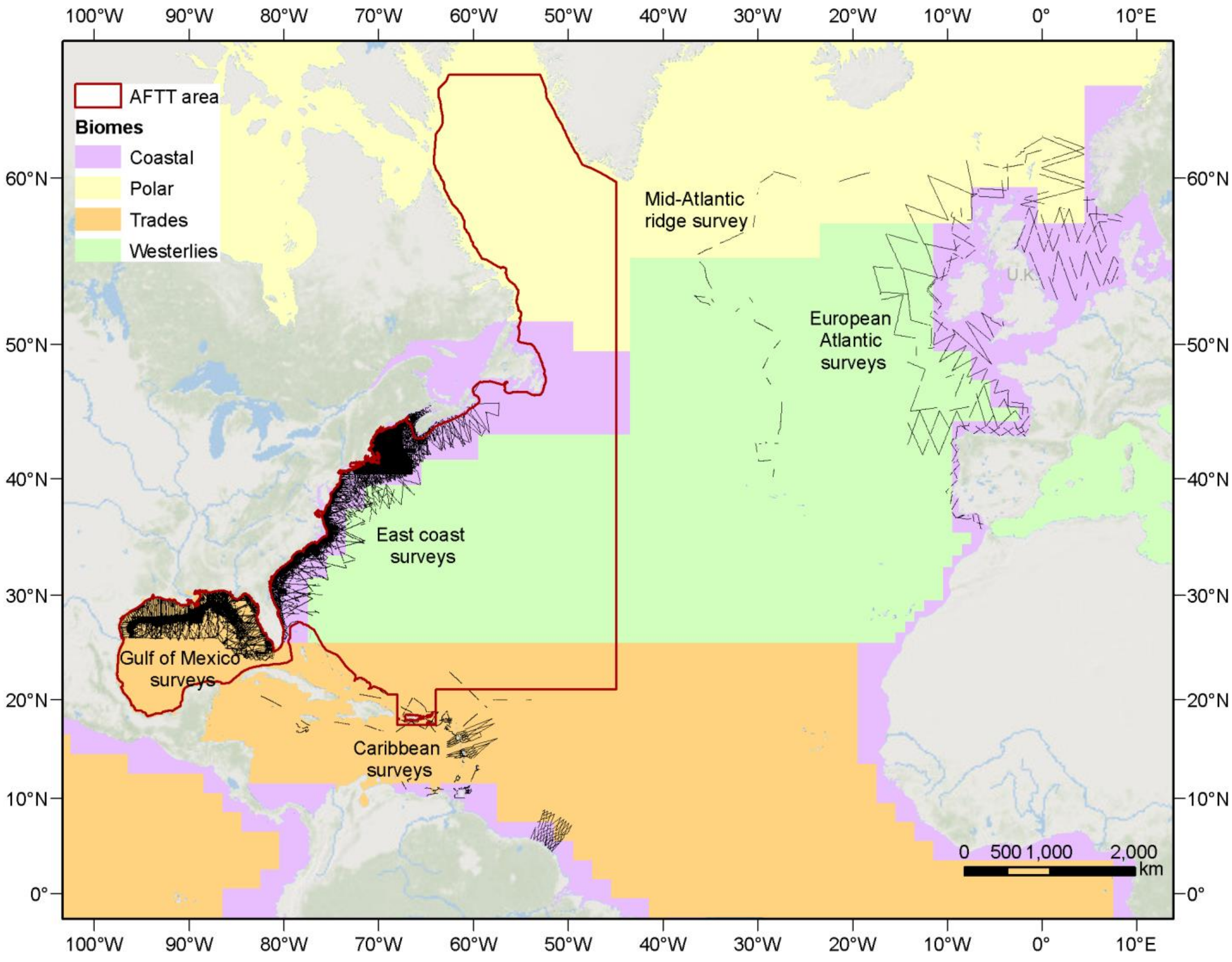
Gulf of Mexico surveys
Caribbean surveys
0 500 1,000 2,000 km



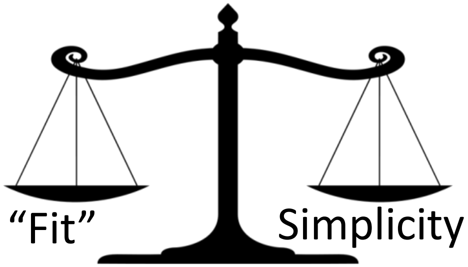
Increase the coverage of ecological biomes encompassed by the AFTT area

To extrapolate carefully, we:

(1) Built models with environmental covariates only

(2) Incorporated line transect surveys from relevant ecological biomes in the North Atlantic

(3) Fitted parsimonious models



Limited the degrees of freedom of smooth functions to mitigate overfitting and avoid reproducing the detailed patterns present in the data

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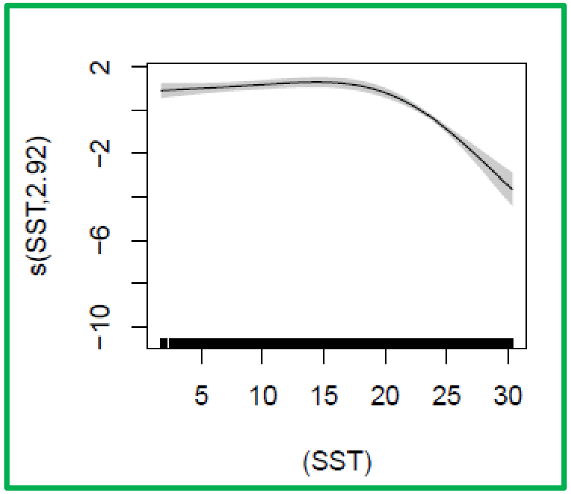

Limited degrees of freedom

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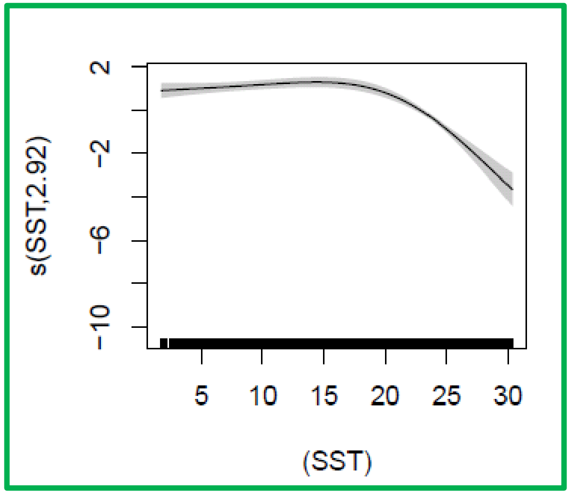

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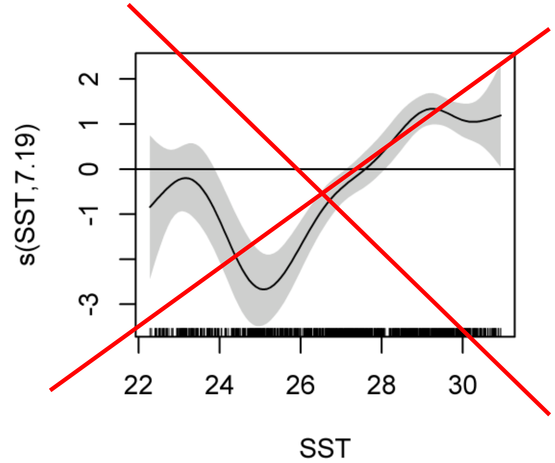

Overfitted

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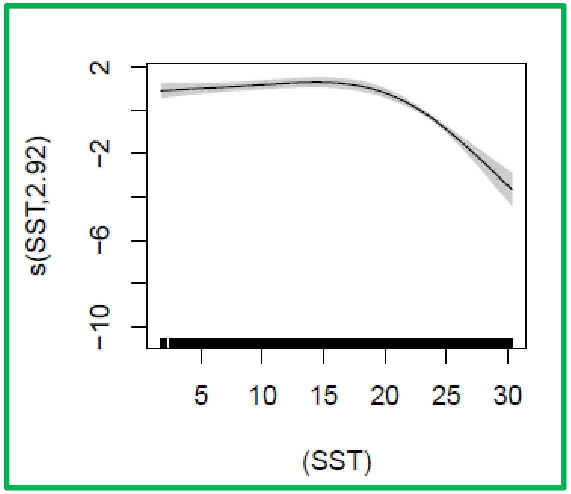

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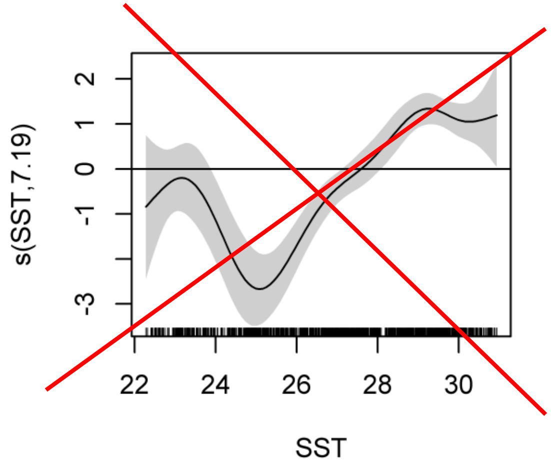

Overfitted

Limited the number of covariates to help understand the primary environmental drivers of cetacean abundances

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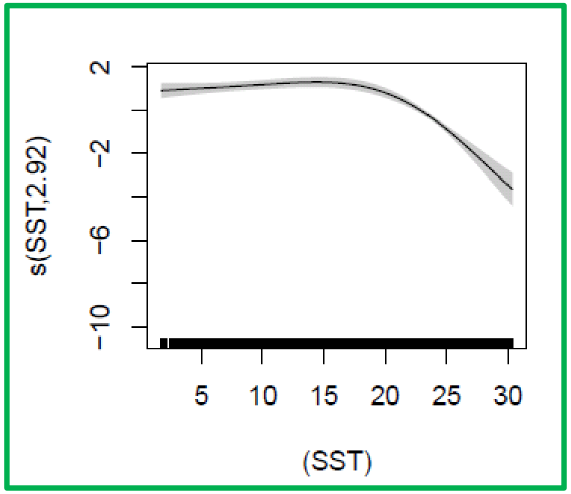

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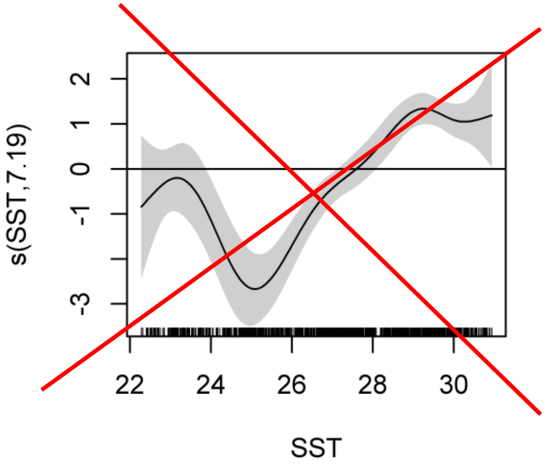

Overfitted

Limited the number of covariates to help understand the primary environmental drivers of cetacean abundances

→ **Better generalize predictions to unsurveyed areas**

In total, we modeled 29 cetacean taxa

Sei whale

Striped dolphin

Sei whale

Summer model

Sei whale

Summer model

Surveys:
EC
GOM
CAR
MAR

Sei whale

Summer model

Surveys:
EC
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Predictors: Expl Dev 38.5%
Depth
Sea level anomaly
Sea surface temperature
Production of micronekton

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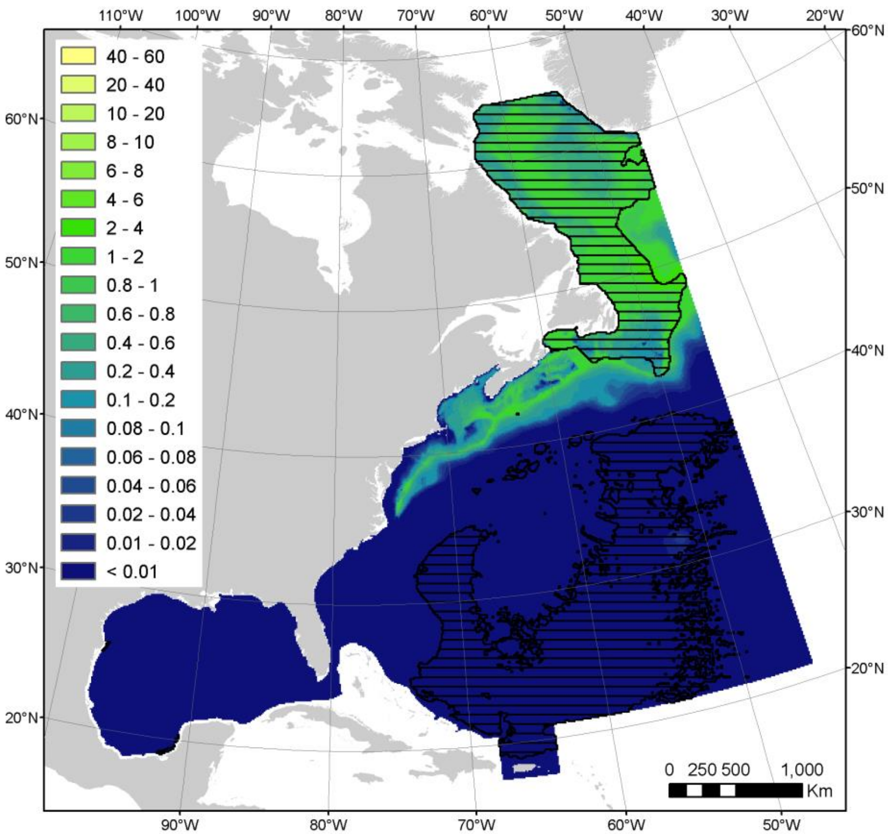
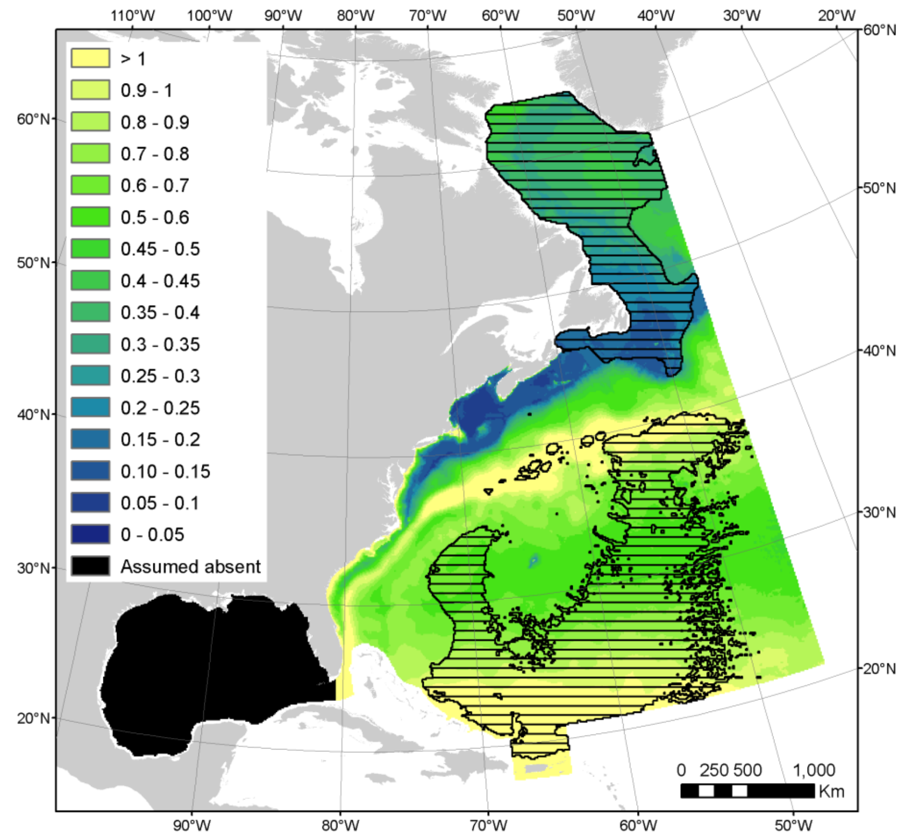


Predicted densities (individuals. 100 km^{-2})



Coefficient of variation

Sei whale

Summer model

Surveys:
EC
GOM
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Predictors: Expl Dev 38.5%
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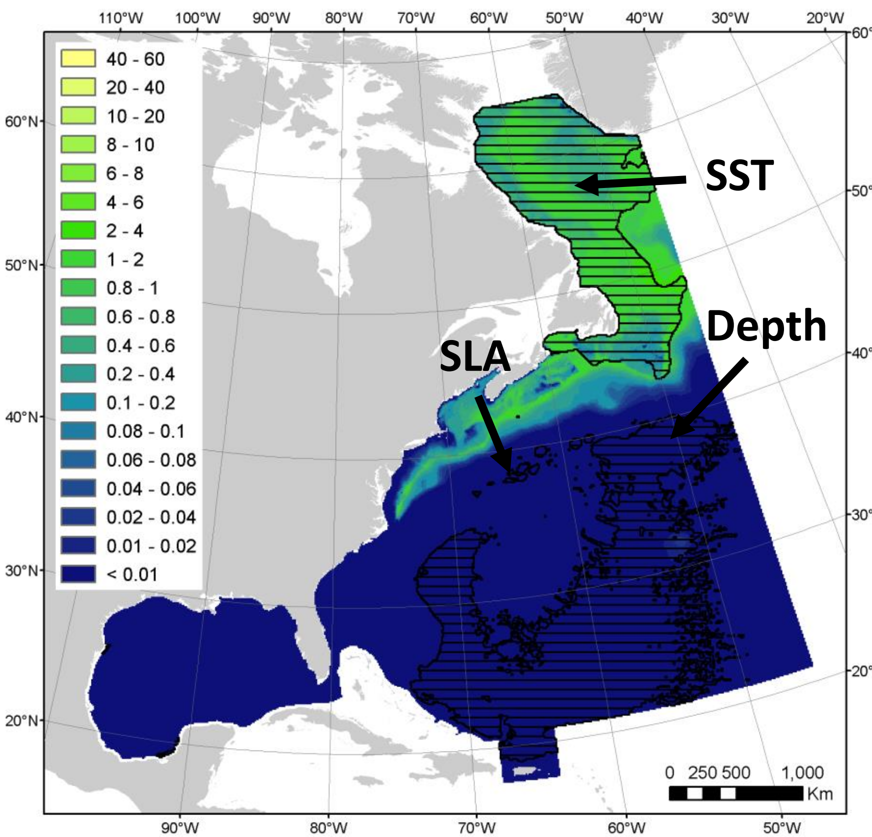

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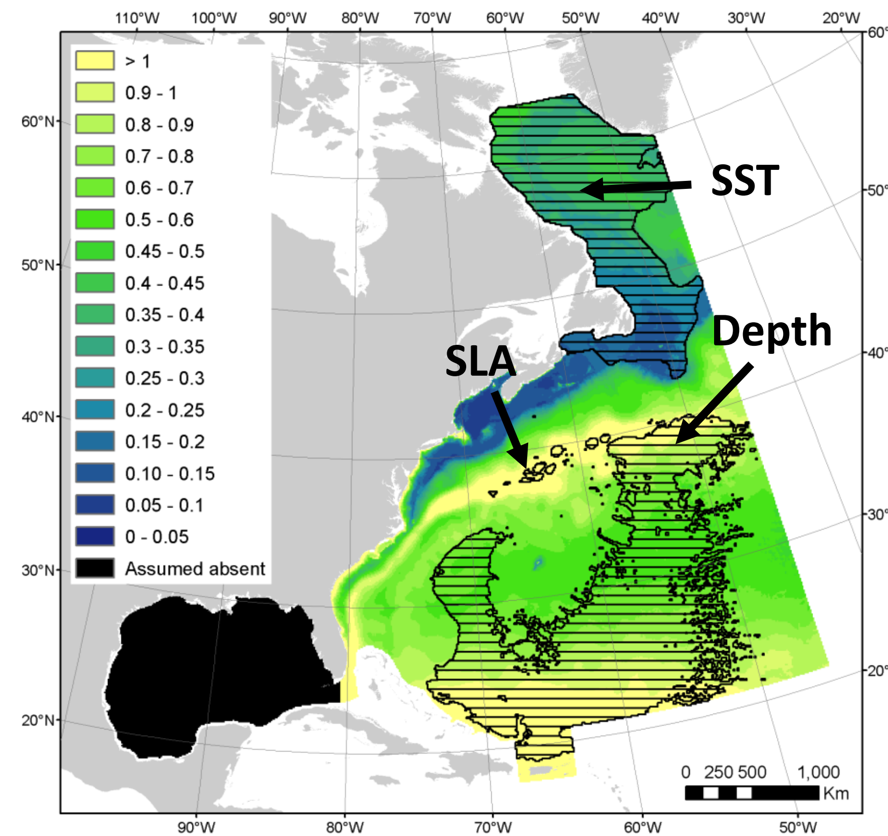

Coefficient of variation

Striped dolphin

Year-round model

Striped dolphin

Year-round model

Surveys:
EC
GOM
CAR
MAR EU

Striped dolphin

Year-round model

Surveys:
EC
GOM
CAR
MAR EU

Predictors: Expl Dev 57%
Depth
Production of micronekton
Chlorophyll concentration
Distance to SST fronts

Striped dolphin

Year-round model

Surveys:
EC
GOM
CAR
MAR EU

Predictors: Expl Dev 57%
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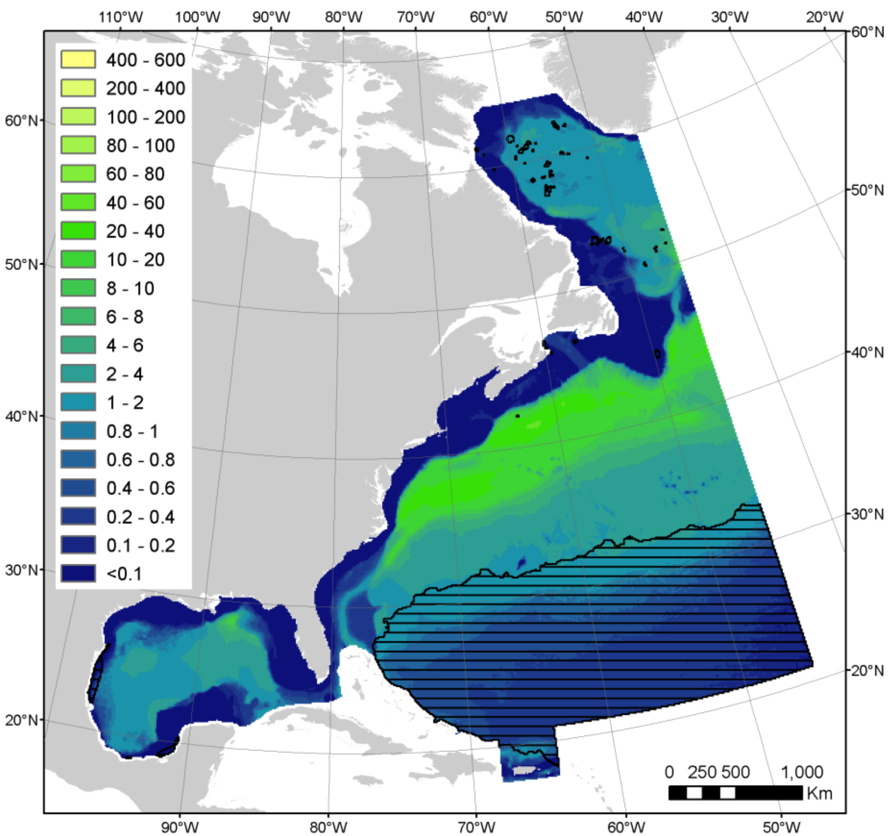

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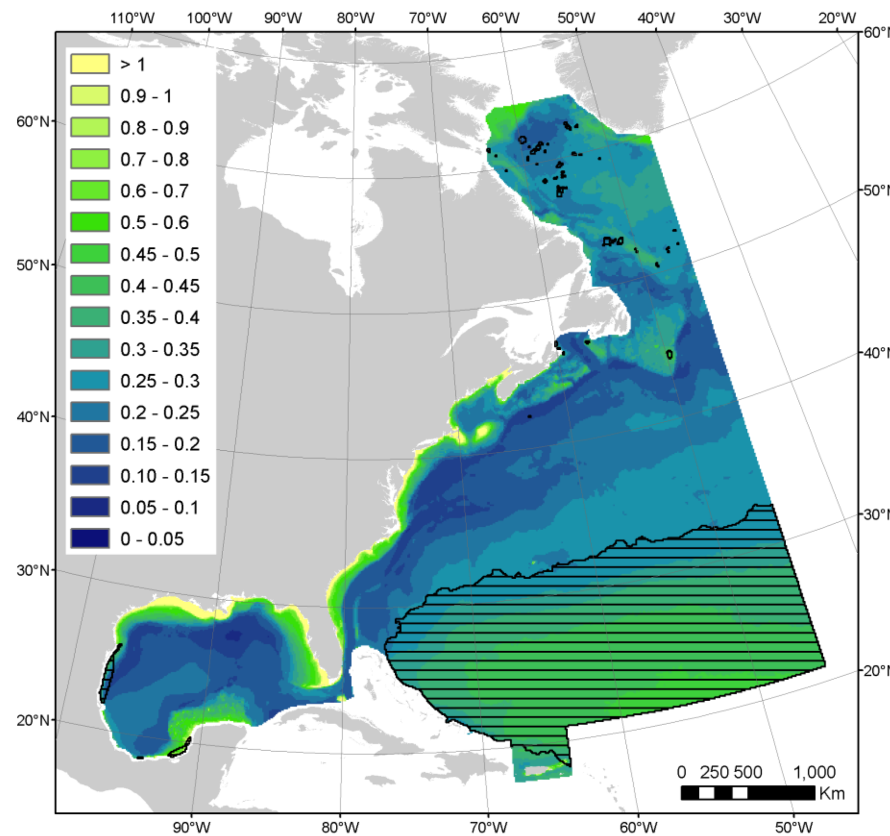

Coefficient of variation

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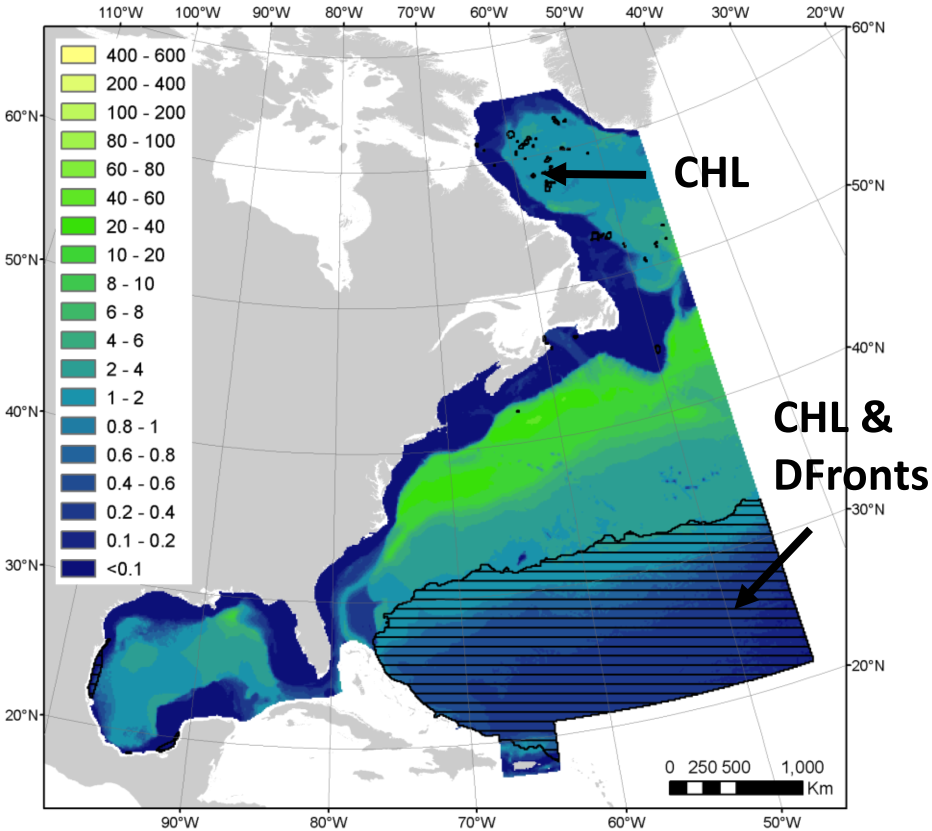

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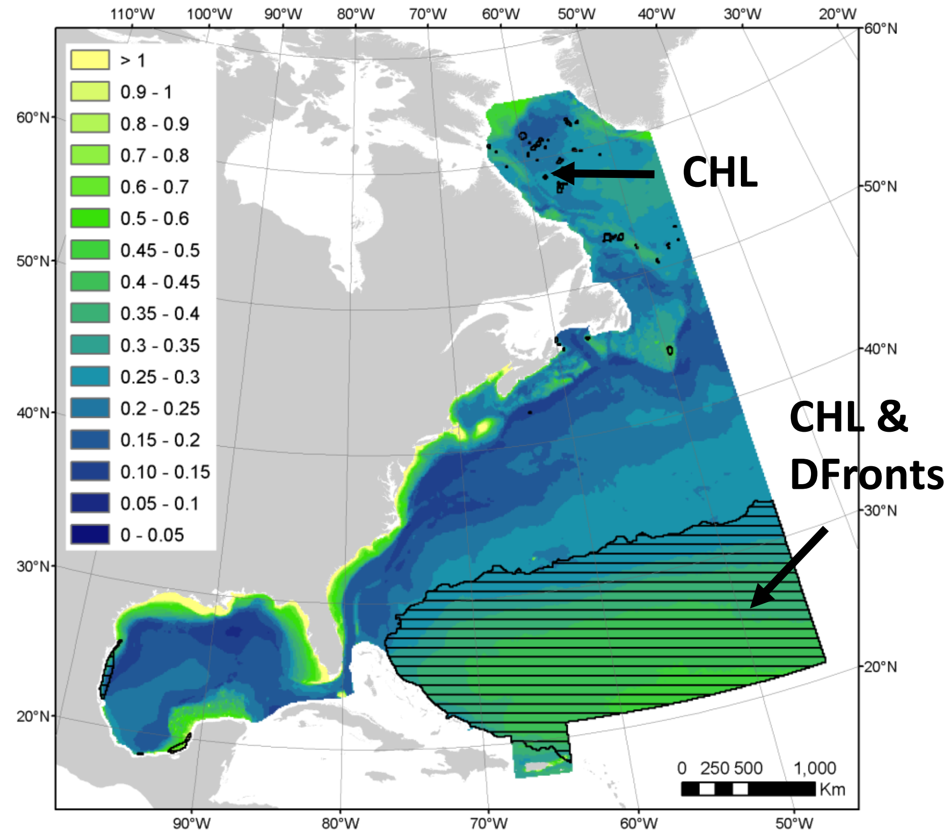
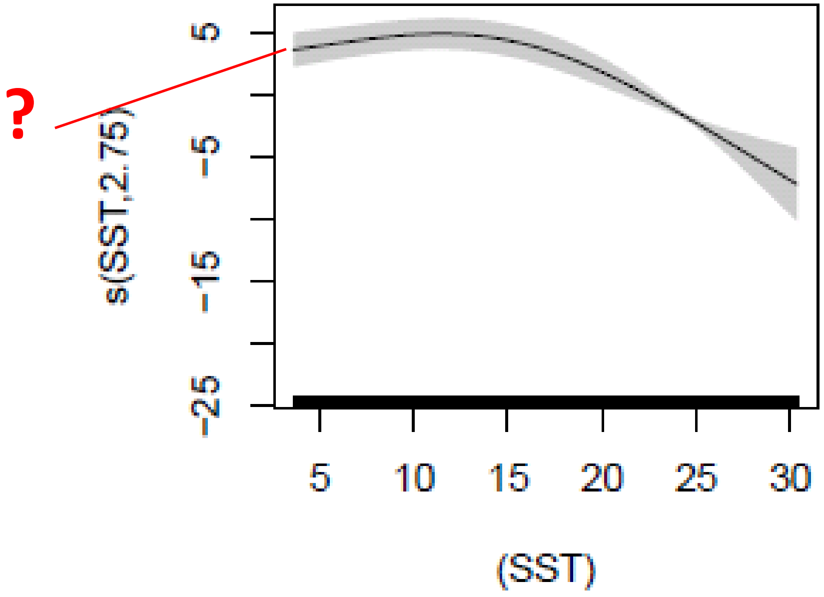


Coefficient of variation

CAVEATS

Strong assumptions on the shapes of cetacean-environment relationships beyond the sampled covariate ranges

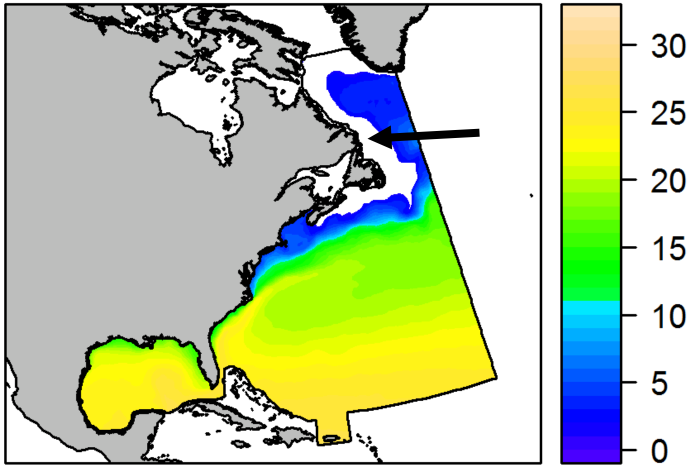
Example: sei whale



Possible underestimation of sei whale abundance in cold northern waters

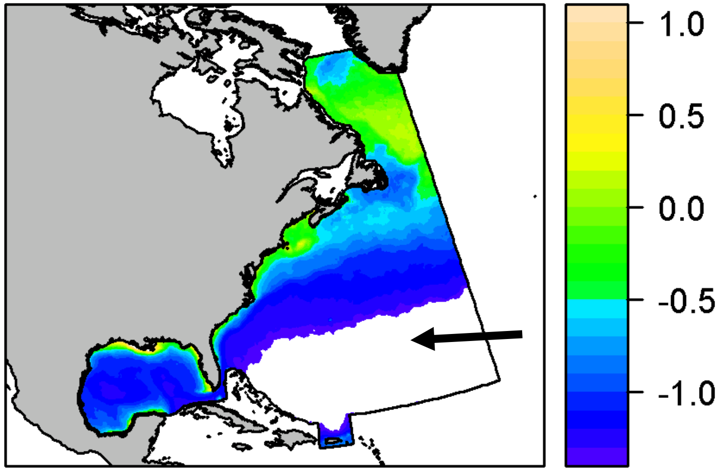
Predictions less reliable in certain areas

SST in February (°C)



Polar waters with colder SST in winter

Log CHL in June (mg.m^{-3})



North Atlantic gyre with lower CHL in summer

Lack of data for evaluating model predictions in the high seas

Qualitative assessment of predictions with presence only data from the literature:

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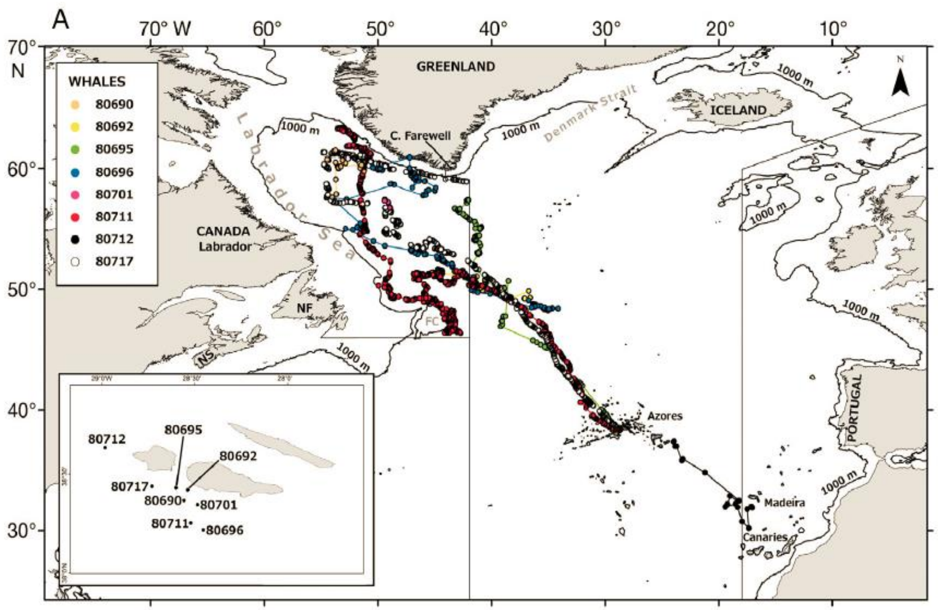
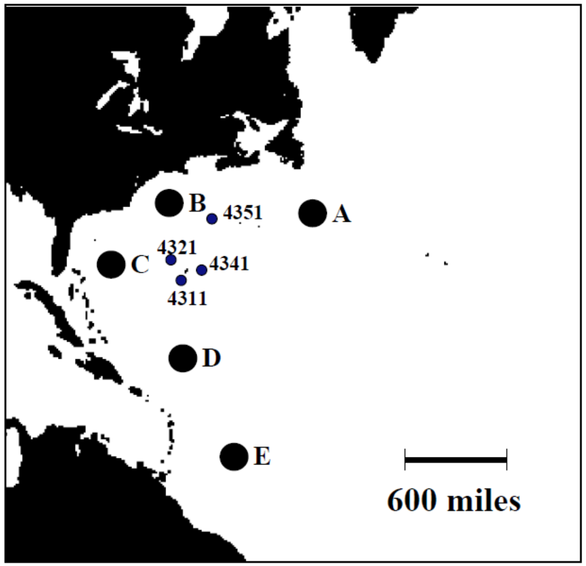


Prieto et al. 2012

Tracks of sei whales tagged in the Azores



Clark and Gagnon 2004

Hydrophones from the Navy SOSUS

APPLICATIONS

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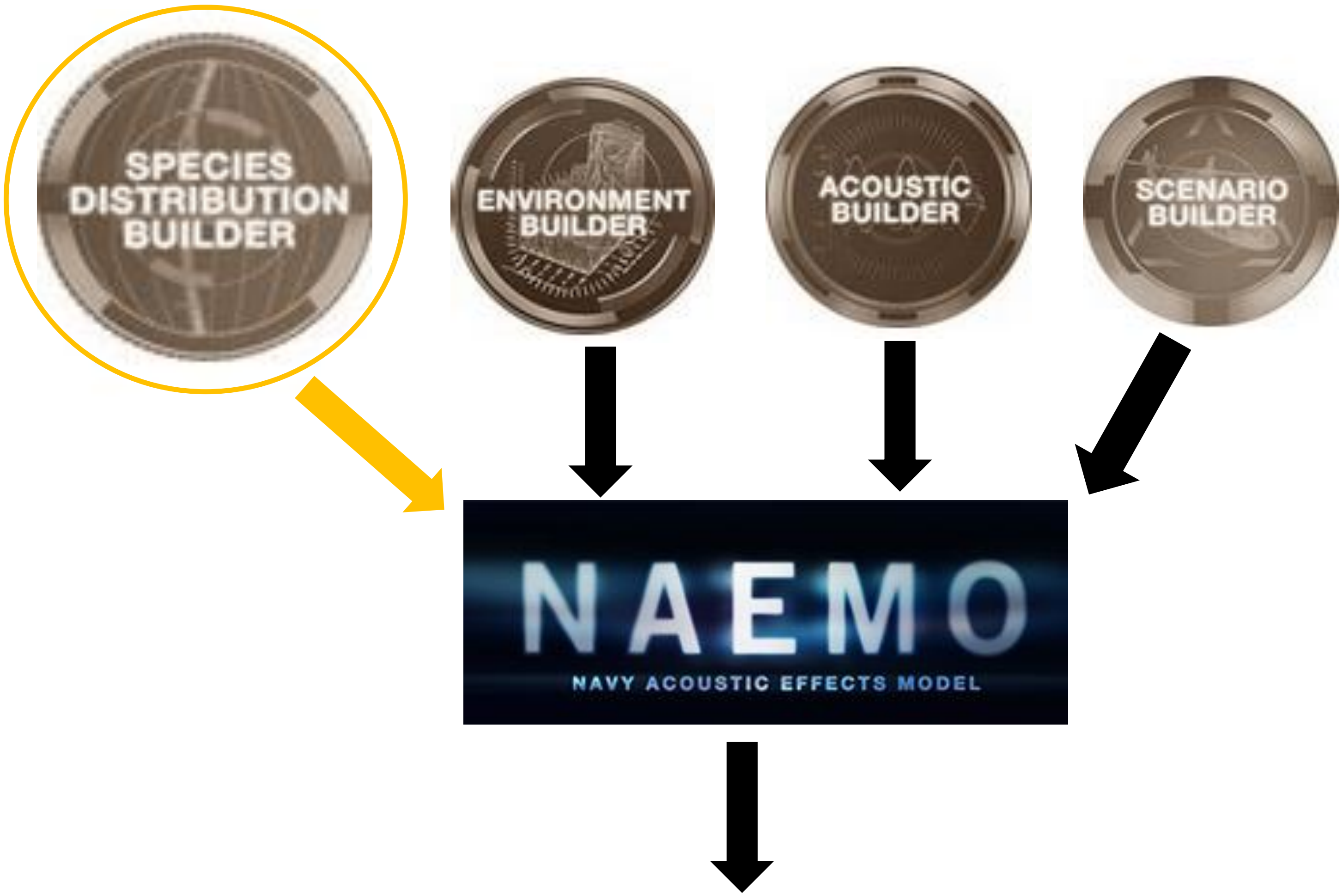
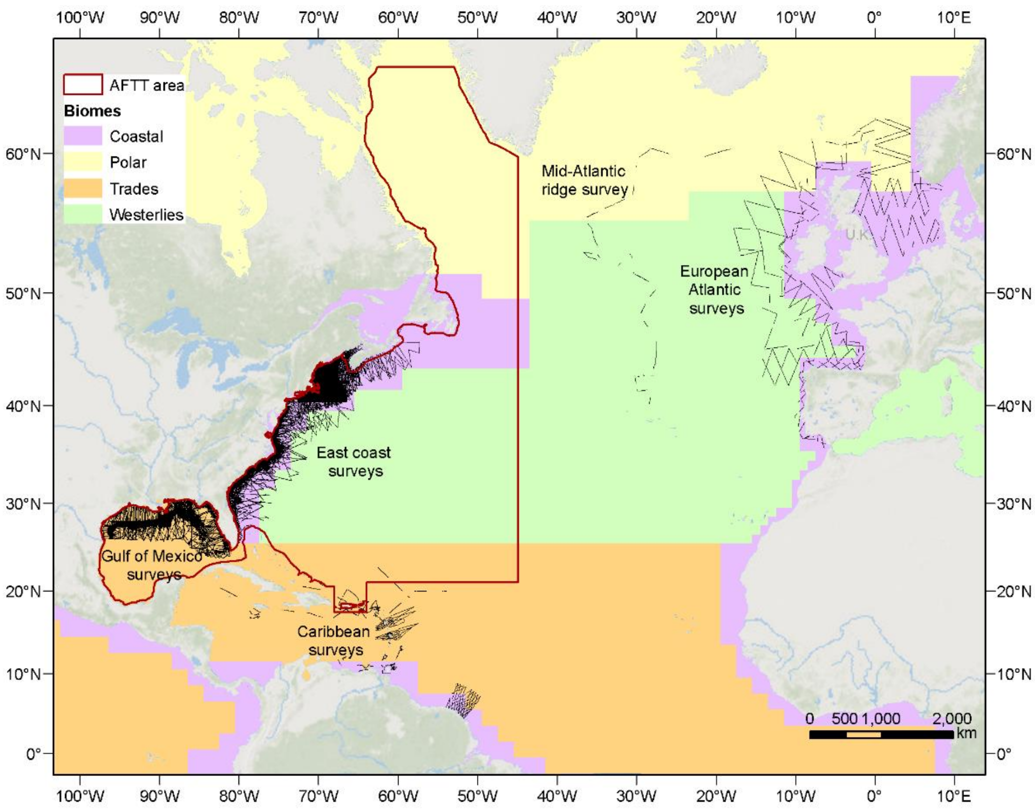
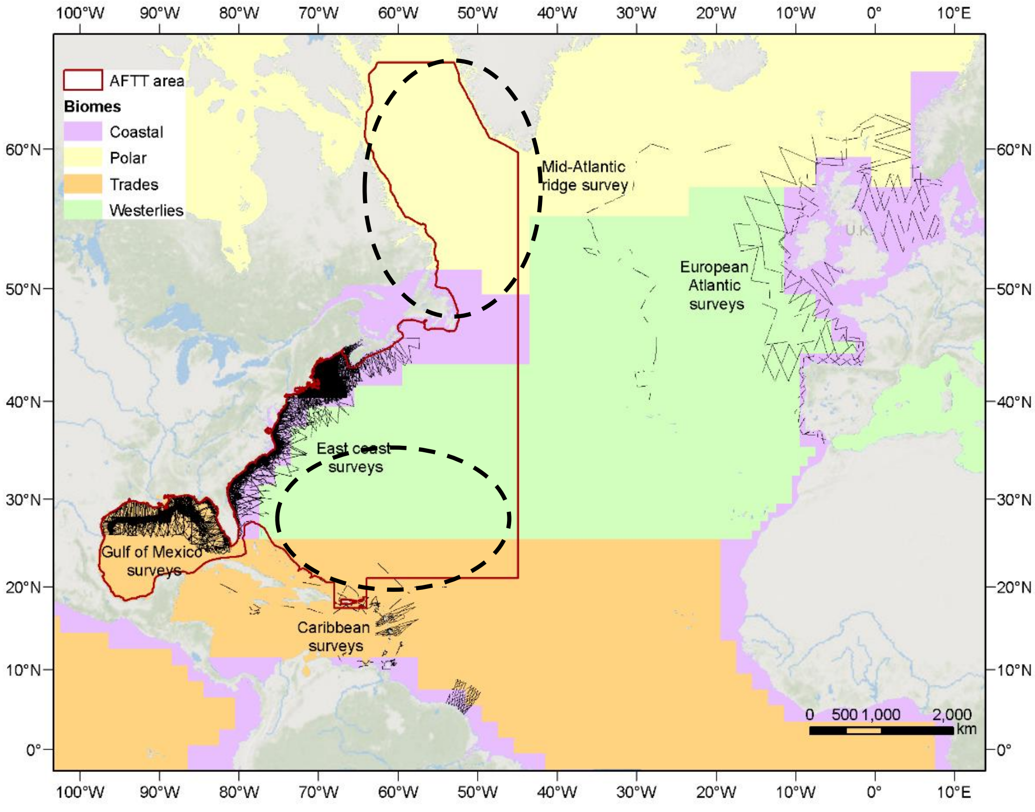
These density estimates will be entered in the Navy Acoustic Effects Model to estimate potential incidental ‘takes’ of marine mammals in the AFTT area



Incidental ‘takes’



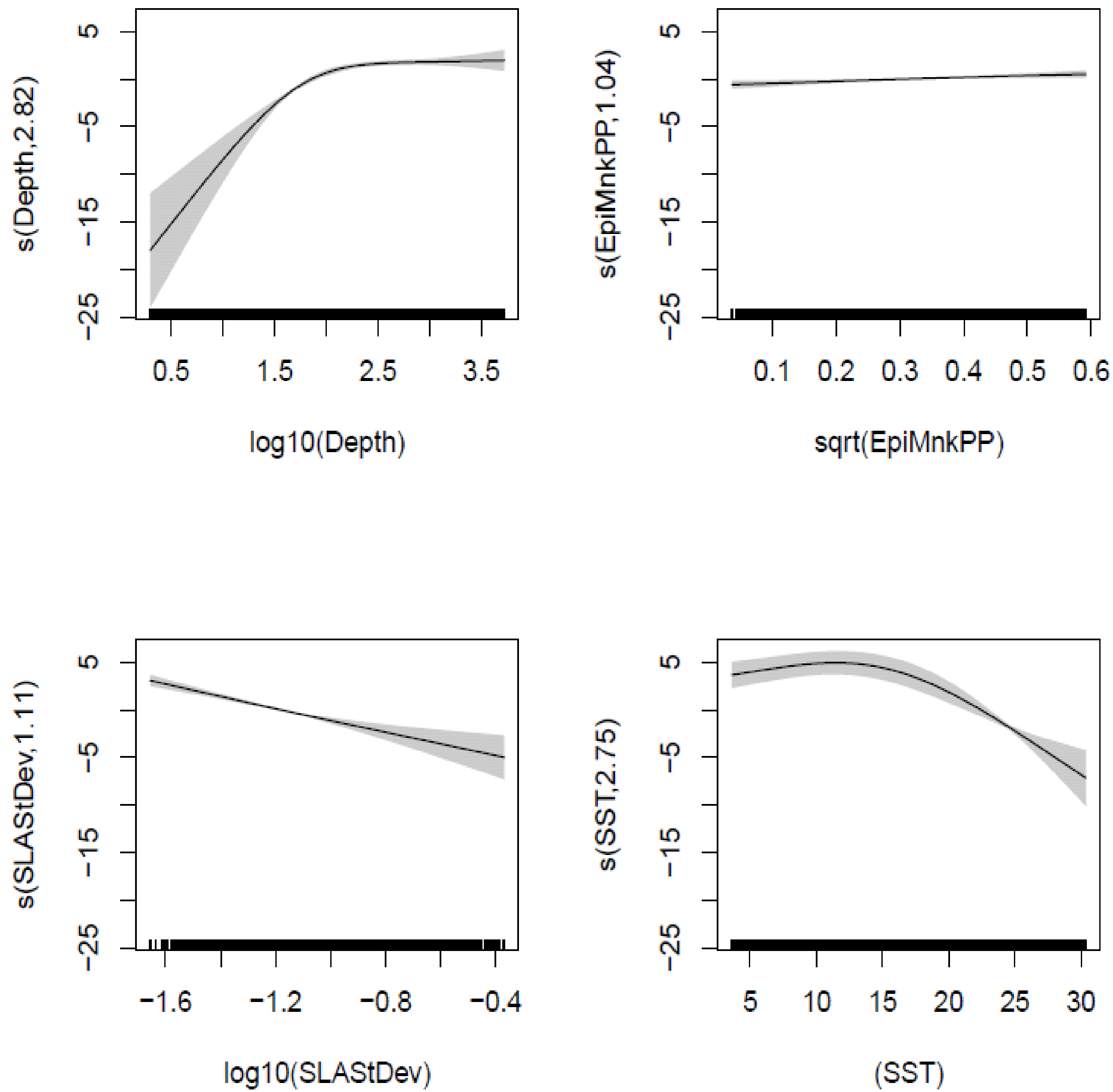
- As new survey data become available, we plan to continuously update and refine our models to provide the most accurate estimates in the AFTT area



- As new survey data become available, we plan to continuously update and refine our models to provide the most accurate estimates in the AFTT area
- **The incorporation of surveys from the North Atlantic gyre and polar waters would greatly improve the models**

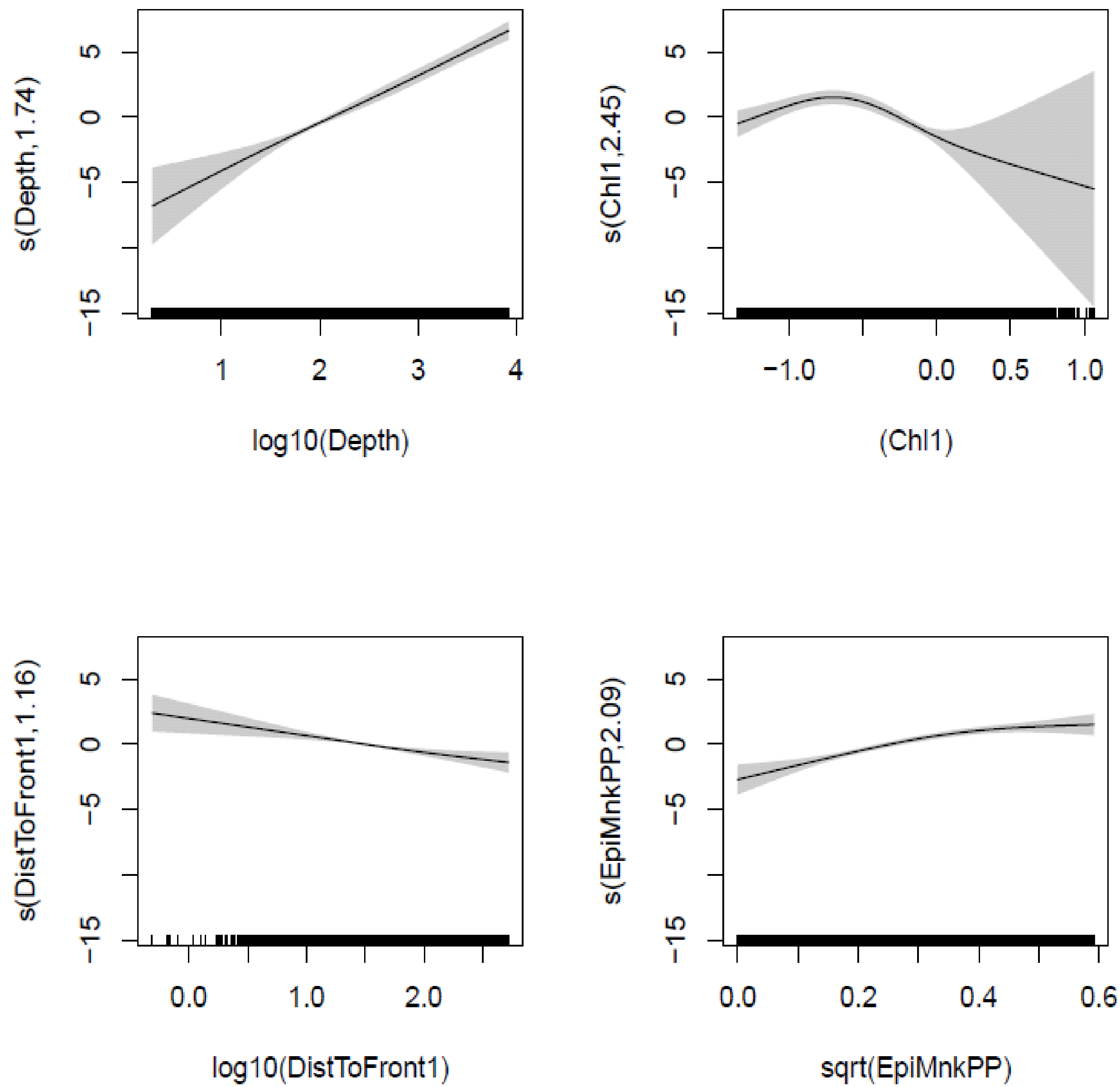
Thank you for your attention!

Sei whale



s(Depth,2.82)
5
−5
−15
−25
0.5
1.5
2.5
3.5
log10(Depth)
s(EpiMnkPP,1.04)
5
−5
−15
−25
0.1
0.2
0.3
0.4
0.5
0.6
sqrt(EpiMnkPP)
s(SLAStDev,1.11)
5
−5
−15
−25
−1.6
−1.2
−0.8
−0.4
log10(SLAStDev)
s(SST,2.75)
5
−5
−15
−25
5
10
15
20
25
30
(SST)

Striped dolphin



Two-stage density surface modeling

(1) Fit detection functions and estimate abundance on segments

$$N_j = \sum_{r=1}^{R_j} \frac{S_{rj}}{g(0)\, p_j}$$

R_j number of observations in segment j
S_{rj} size of the rth group in segment j
p_j probability of detection on segment j
g(0) probability of detection on the trackline

(2) Fit a GAM with estimated abundance as the response and segment area as the offset

$$E(N_j) = Aj \exp[\beta_0 + \sum_k f_k(zjk)]$$

N_j is assumed to follow a Tweedie distribution
The offset A_j is the area of segment j
f_k are smooth functions of the covariates z_{jk}
β_0 is the intercept