Density Model for Beaked Whales (*Mesoplodon spp. and Ziphius cavirostris*) for the U.S. Navy Atlantic Fleet Testing and Training (AFTT) Study Area: Supplementary Report

Model Version 4

Duke University Marine Geospatial Ecology Laboratory*

2022-06-20

Citation

When referencing our methodology or results generally, please cite Roberts et al. (2023), which documented the modeling cycle we completed in the 2022 for the U.S. Navy AFTT Phase IV Environmental Impact Statement, and Mannocci et al. (2017), which developed the original methodology and models upon which the 2022 models were based. The full citations appear in the References section at the end of this document.

To independently reference this specific model or Supplementary Report, please cite:

Roberts JJ, Yack TM, Halpin PN (2022) Density Model for Beaked Whales (*Mesoplodon spp. and Ziphius cavirostris*) for the U.S. Navy's AFTT Phase IV Study Area, Version 4, 2022-06-20, and Supplementary Report. Marine Geospatial Ecology Laboratory, Duke University, Durham, North Carolina.

Copyright and License

Model Version History

Version	Date	Description
3	2016-10-01	First publicly-released version of this model, released in 2015 as part of the final delivery of the U.S. Navy Marine Species Density Database (NMSDD) for the Atlantic Fleet Testing and Training (AFTT) Phase III Environmental Impact Statement, and again as part of Mannocci et al. (2017).
4	2022-06-20	Updated the AFTT Phase III model with many additional surveys contributed since that time. Please see Roberts et al. (2022, 2023) for details. This update was released as part of the final delivery of the NMSDD for the AFTT Phase IV Environmental Impact Statement.

*For questions or to offer feedback please contact Jason Roberts (jason.roberts@duke.edu) and Tina Yack (tina.yack@duke.edu)

1 Survey Data

Following Mannocci et al. (2017), whose model we were updating, we built this model from data collected in the east coast, Gulf of Mexico, Caribbean, and Mid-Atlantic Ridge, and excluded surveys of Europe for the reasons outlined by those authors. We did include segments west of the Mid-Atlantic Ridge from a trans-Atlantic survey by R/V Song of the Whale, as well as passive acoustical survey conducted off the U.S. east coast by that vessel in winter and spring 2019 (please see the East Coast regional model report for more information.) We excluded surveys that did not target beaked whales. We restricted the model to survey transects with sea states of Beaufort 5 or less (for a few surveys we used Beaufort 4 or less) for both aerial and shipboard surveys. We also excluded transects with poor weather or visibility for surveys that reported those conditions. Table 1 summarizes the survey effort and sightings available for the model after most exclusions were applied. Figure 1 shows the data actually used to fit the model.

Table 1: Survey effort and observations considered for this model. Effort is tallied as the cumulative length of on-effort transects. Observations are the number of groups and individuals encountered while on effort. Off effort observations and those lacking an estimate of group size or distance to the group were excluded.

			Effort	Observations		
Institution	Program	Period	1000s km	Groups	Individuals	Mean Group Size
Aerial Surveys						
HDR	Navy Norfolk Canyon	2018-2019	11	6	16	2.7
NEAq	CNM	2017-2020	2	10	31	3.1
NEAq	MMS-WEA	2017-2020	37	0	0	
NEAq	NLPSC	2011-2015	43	0	0	
NEFSC	AMAPPS	2010-2019	89	15	29	1.9
NEFSC	NARWSS	2003-2020	448	7	11	1.6
NEFSC	Pre-AMAPPS	1999-2008	46	11	33	3.0
NYS-DEC/TT	NYBWM	2017-2020	60	3	12	4.0
SEFSC	AMAPPS	2010-2020	114	7	17	2.4
SEFSC	GOMEX92-96	1992-1996	27	0	0	
SEFSC	GulfCet I	1992-1994	50	12	36	3.0
SEFSC	GulfCet II	1996-1998	22	7	15	2.1
SEFSC	GulfSCAT 2007	2007-2007	18	0	0	
SEFSC	MATS	1995-2005	34	0	0	
SEFSC	SECAS	1992-1995	8	1	1	1.0
U. La Rochelle	REMMOA	2008-2017	42	26	41	1.6
UNCW	MidA Bottlenose	2002-2002	17	0	0	
UNCW	Navy Cape Hatteras	2011-2017	34	84	215	2.6
UNCW	Navy Jacksonville	2009-2017	92	0	0	
UNCW	Navy Norfolk Canyon	2015-2017	14	5	12	2.4
UNCW	Navy Onslow Bay	2007-2011	49	3	10	3.3
UNCW	SEUS NARW EWS	2005-2008	114	2	2	1.0
VAMSC	MD DNR WEA	2013-2015	16	0	0	
VAMSC	Navy VACAPES	2016-2017	19	0	0	
VAMSC	VA CZM WEA	2012-2015	21	0	0	
		Total	**1,429**	**199**	**481**	**2.4**
Shipboard Surveys						
IMR	MAR-ECO	2004-2004	2	8	14	1.8
MCR	SOTW Acoustical	2019-2019	4	37	56	1.5
MCR	SOTW Visual	2012-2012	6	5	13	2.6
NEFSC	AMAPPS	2011-2016	14	272	718	2.6
NEFSC	Pre-AMAPPS	1995-2007	16	126	344	2.7
SEFSC	AMAPPS	2011-2016	14	73	154	2.1
SEFSC	GOM Oceanic CetShip	1992-2001	49	61	132	2.2
SEFSC	GOM Shelf CetShip	1994-2001	10	4	6	1.5
SEFSC	Pre-AMAPPS	1992-2006	29	39	88	2.3
SEFSC	Pre-GoMMAPPS	2003-2009	19	25	64	2.6
SEFSC	SEFSC Caribbean	1995-2000	6	1	2	2.0
		Total	**169**	**651**	**1,592**	**2.4**

Table 1: Survey effort and observations considered for this model. Effort is tallied as the cumulative length of on-effort transects. Observations are the number of groups and individuals encountered while on effort. Off effort observations and those lacking an estimate of group size or distance to the group were excluded. *(continued)*

			Effort	Observations		
Institution	Program	Period	1000s km	Groups	Individuals	Mean Group Size
		Grand Total	**1,599**	**850**	**2,072**	**2.4**

Table 2: Institutions that contributed surveys used in this model.

Institution	Full Name
HDR	HDR, Inc.
IMR	Norway Institute of Marine Research
MCR	Marine Conservation Research
NEAq	New England Aquarium
NEFSC	NOAA Northeast Fisheries Science Center
NYS-DEC/TT	New York State Department of Environmental Conservation and Tetra Tech, Inc.
SEFSC	NOAA Southeast Fisheries Science Center
U. La Rochelle	University of La Rochelle
UNCW	University of North Carolina Wilmington
VAMSC	Virginia Aquarium & Marine Science Center

Table 3: Descriptions and references for survey programs used in this model.

Program	Description	References
AMAPPS	Atlantic Marine Assessment Program for Protected Species	Palka et al. (2017), Palka et al. (2021)
CNM	Northeast Canyons Marine National Monument Aerial Surveys	Redfern et al. (2021)
GOM Oceanic CetShip	Gulf of Mexico Oceanic CetShip Surveys	Mullin and Fulling (2004)
GOM Shelf CetShip	Gulf of Mexico Shelf CetShip Surveys	Fulling et al. (2003)
GOMEX92-96	GOMEX 1992-1996 Aerial Surveys	Blaylock and Hoggard (1994)
GulfCet I	GulfCet I Aerial Surveys	Davis and Fargion (1996)
GulfCet II	GulfCet II Aerial Surveys	Davis et al. (2000)
GulfSCAT 2007	GulfSCAT 2007 Aerial Surveys	
MAR-ECO	Census of Marine Life Mid-Atlantic Ridge Ecology Program	Waring et al. (2008)
MATS	Mid-Atlantic Tursiops Surveys	
MD DNR WEA	Aerial Surveys of the Maryland Wind Energy Area	Barco et al. (2015)
MidA Bottlenose	Mid-Atlantic Onshore/Offshore Bottlenose Dolphin Surveys	Torres et al. (2005)
MMS-WEA	Marine Mammal Surveys of the MA and RI Wind Energy Areas	Quintana-Rizzo et al. (2021), O'Brien et al. (2022)
NARWSS	North Atlantic Right Whale Sighting Surveys	Cole et al. (2007)
Navy Cape Hatteras	Aerial Surveys of the Navy's Cape Hatteras Study Area	McLellan et al. (2018)
Navy Jacksonville	Aerial Surveys of the Navy's Jacksonville Study Area	Foley et al. (2019)

Table 3: Descriptions and references for survey programs used in this model. *(continued)*

Program	Description	References
Navy Norfolk Canyon	Aerial Surveys of the Navy's Norfolk Canyon Study Area	Cotter (2019), McAlarney et al. (2018)
Navy Onslow Bay	Aerial Surveys of the Navy's Onslow Bay Study Area	Read et al. (2014)
Navy VACAPES	Aerial Survey Baseline Monitoring in the Continental Shelf Region of the VACAPES OPAREA	Mallette et al. (2017)
NLPSC	Northeast Large Pelagic Survey Collaborative Aerial Surveys	Leiter et al. (2017), Stone et al. (2017)
NYBWM	New York Bight Whale Monitoring Surveys	Zoidis et al. (2021)
Pre-AMAPPS	Pre-AMAPPS Marine Mammal Abundance Surveys	Mullin and Fulling (2003), Garrison et al. (2010), Palka (2006)
Pre-GoMMAPPS	Pre-GoMMAPPS Marine Mammal Abundance Surveys	Mullin (2007)
REMMOA	REcensement des Mammifères marins et autre Mégafaune pélagique par Observation Aérienne	Mannocci et al. (2013), Laran et al. (2019)
SECAS	Southeast Cetacean Aerial Surveys	Blaylock and Hoggard (1994)
SEFSC Caribbean	SEFSC Surveys of the Caribbean Sea	Mullin (1995), Swartz and Burks (2000)
SEUS NARW EWS	Southeast U.S. Right Whale Early Warning System Surveys	
SOTW Acoustical	R/V Song of the Whale Passive Acoustical Surveys	Boisseau et al. (in review)
SOTW Visual	R/V Song of the Whale Visual Surveys	Ryan et al. (2013)
VA CZM WEA	Virginia CZM Wind Energy Area Surveys	Mallette et al. (2014), Mallette et al. (2015)

2 Density Model

Our objective was to update the model of Mannocci et al. (2017) with new data without repeating the covariate selection exercise performed by those authors. We therefore fitted a year-round, 4-covariate model that included depth, distance to the closest submarine canyon or seamount, chlorophyll concentration, and current speed. During smoothness selection, the current speed covariate was shrunk to zero and removed from the model, indicating the influence of this covariate was not statistically significant for the survey data used in this model. The resulting relationships for the other three terms (Figure 2) generally resembled those of Mannocci et al.'s model. Model predictions are shown in Section 3. Univariate extrapolation analyses (Section 2.3.1) displayed geographic patterns very similar to the environmental envelopes estimated by Mannocci et al. The necessity for environmental extrapolation was driven mainly by a lack of sampling in waters with low chlorophyll concentration (Figure 8).

2.1 Final Model

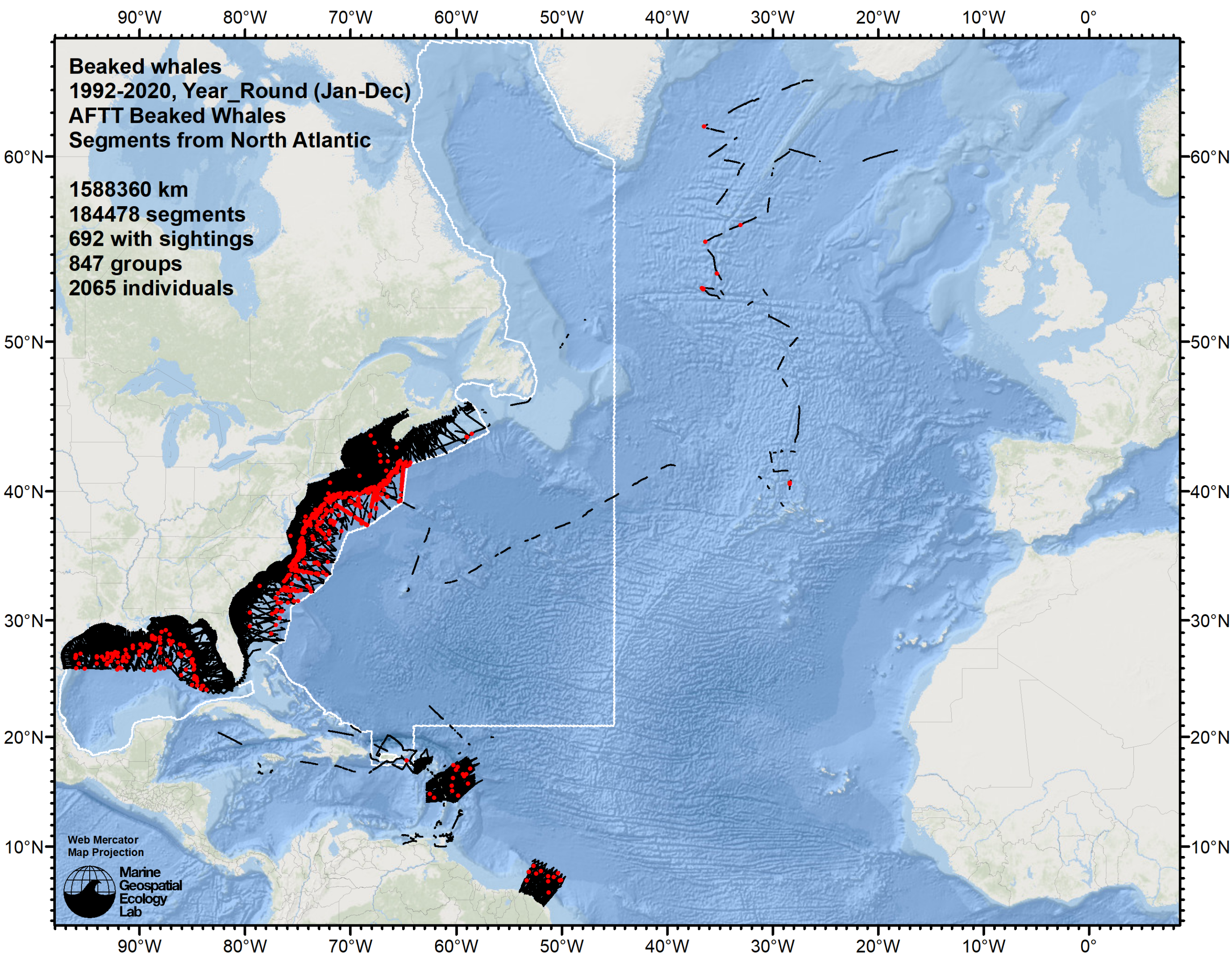
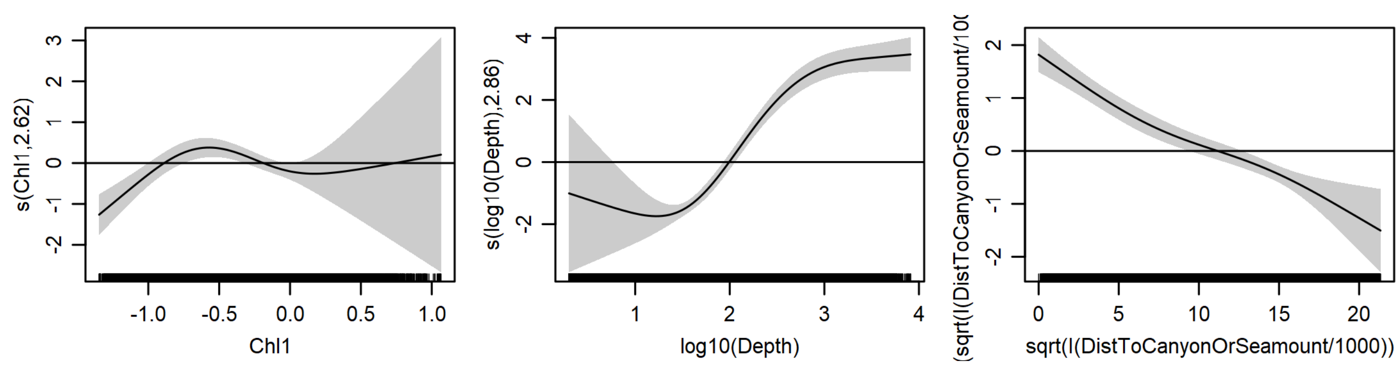


Figure 1: Survey segments (black lines) used to fit the model for the region AFTT Beaked Whales. Red points indicate segments with observations. This map uses a Web Mercator projection but the analysis was conducted in an Albers Equal Area coordinate system appropriate for density modeling.

Statistical output for this model:

```
Family: Tweedie(p=1.33)
Link function: log
```

```
Formula:
IndividualsCorrected ~ offset(log(SegmentArea)) + s(log10(Depth),
    bs = "ts", k = 4) + s(sqrt(I(DistToCanyonOrSeamount/1000)),
    bs = "ts", k = 4) + s(Chl1, bs = "ts", k = 4)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -22.1757     0.1419  -156.3   <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(log10(Depth))                         2.859      3 89.53  <2e-16 ***
s(sqrt(I(DistToCanyonOrSeamount/1000))) 2.150      3 41.82  <2e-16 ***
s(Chl1)                                 2.621      3 12.74  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.00665   Deviance explained = 36.7%
-REML = 5938.7  Scale est. = 37.619    n = 179570

Method: REML   Optimizer: outer newton
full convergence after 13 iterations.
Gradient range [-5.316351e-05,0.0001951849]
(score 5938.738 & scale 37.61949).
Hessian positive definite, eigenvalue range [0.2568925,3112.767].
Model rank =  10 / 10

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                                          k'  edf k-index p-value
s(log10(Depth))                         3.00 2.86    0.55  <2e-16 ***
s(sqrt(I(DistToCanyonOrSeamount/1000))) 3.00 2.15    0.65  <2e-16 ***
s(Chl1)                                 3.00 2.62    0.68  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```



(a) Climatological chlorophyll a concentration ($\log_{10}$ mg m^{-3})

(b) Seafloor depth (m)

(c) Distance to canyon or seamount (km)

Figure 2: Functional plots for the final model for the region AFTT Beaked Whales. Transforms and other treatments are indicated in axis labels. *log10* indicates the covariate was $\log_{10}$ transformed (Chl1 was already provided in $\log_{10}$ scale by the covariate developer). */1000* indicates meters were transformed to kilometers for interpretation convenience.

Table 4: Covariates used in the final model for the region AFTT Beaked Whales.

Covariate	Description
Chl1	Climatological mean monthly merged SeaWiFS/Aqua/MERIS/VIIRS chlorophyll-a concentration ($\log_{10}$ mg m^{-3}) from GSM (Maritorena et al. (2010)), smoothed with 3D Gaussian smoother to reduce daily data loss to < 10%
Depth	Depth (m) of the seafloor, from SRTM30_PLUS (Becker et al. (2009))
DistToCanyonOrSeamount	Distance (km) to the closest submarine canyon or seamount, derived from the Harris et al. (2014) geomorphology

2.2 Diagnostic Plots

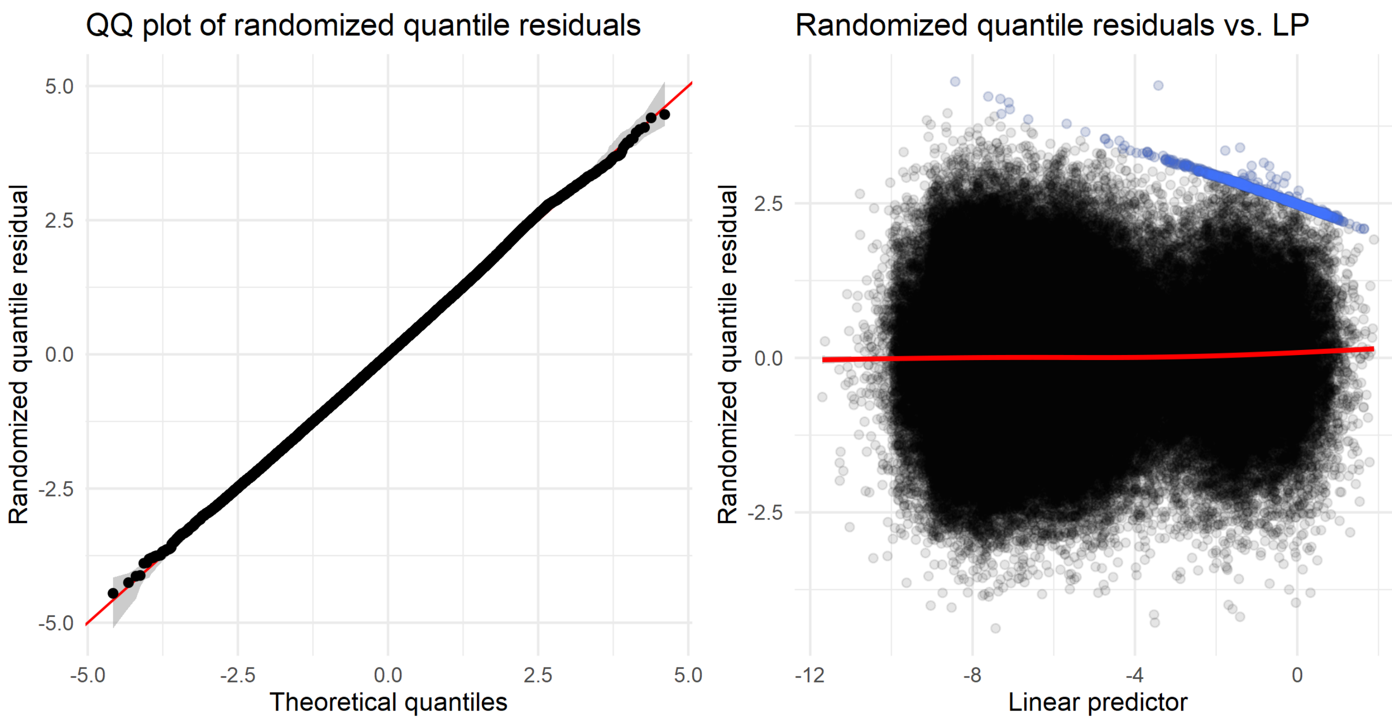


Figure 3: Residual plots for the final model for the region AFTT Beaked Whales.

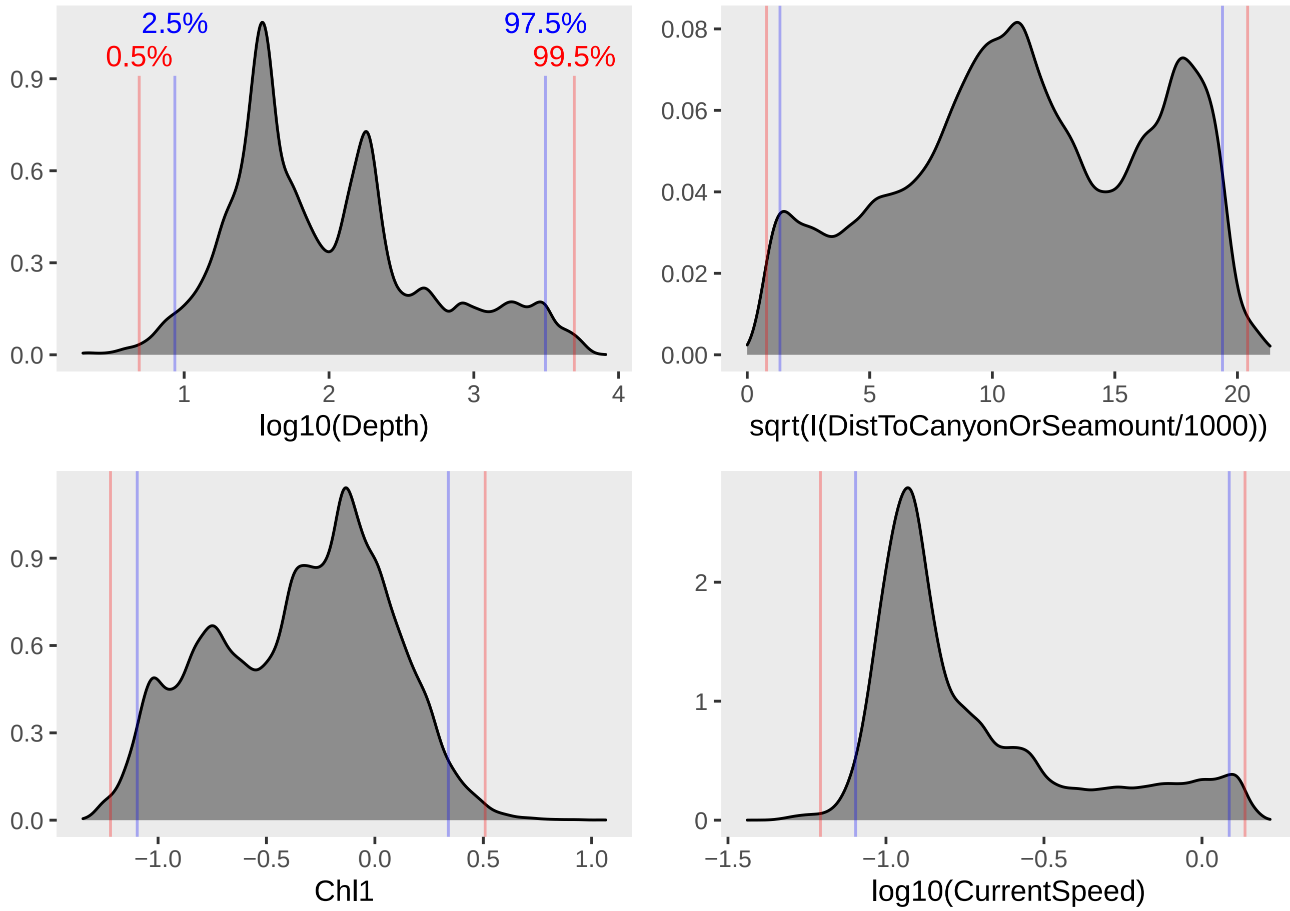


Figure 4: Density histograms showing the distributions of the covariates considered during the final model selection step. The final model may have included only a subset of the covariates shown here (see Figure 2), and additional covariates may have been considered in preceding selection steps. Red and blue lines enclose 99% and 95% of the distributions, respectively. Transforms and other treatments are indicated in axis labels. *log10* indicates the covariate was $\log_{10}$ transformed. */1000* indicates meters were transformed to kilometers for interpretation convenience.

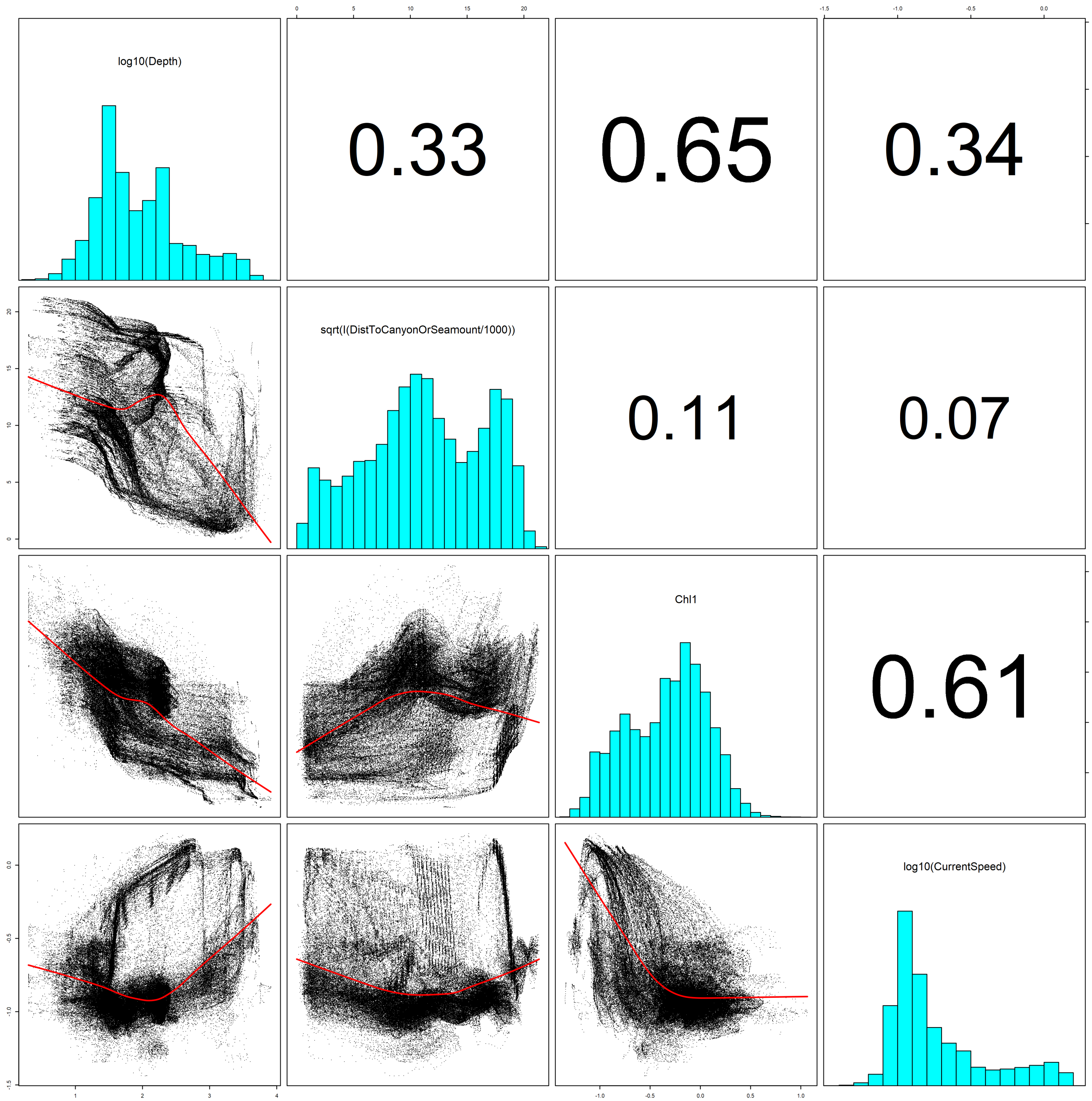


Figure 5: Scatterplot matrix of the covariates considered during the final model selection step. The final model may have included only a subset of the covariates shown here (see Figure 2), and additional covariates may have been considered in preceding selection steps. Covariates are transformed as shown in Figure 4. This plot is used to check simple correlations between covariates (via pairwise Pearson coefficients above the diagonal) and visually inspect for concurvity (via scatterplots and red lowess curves below the diagonal).

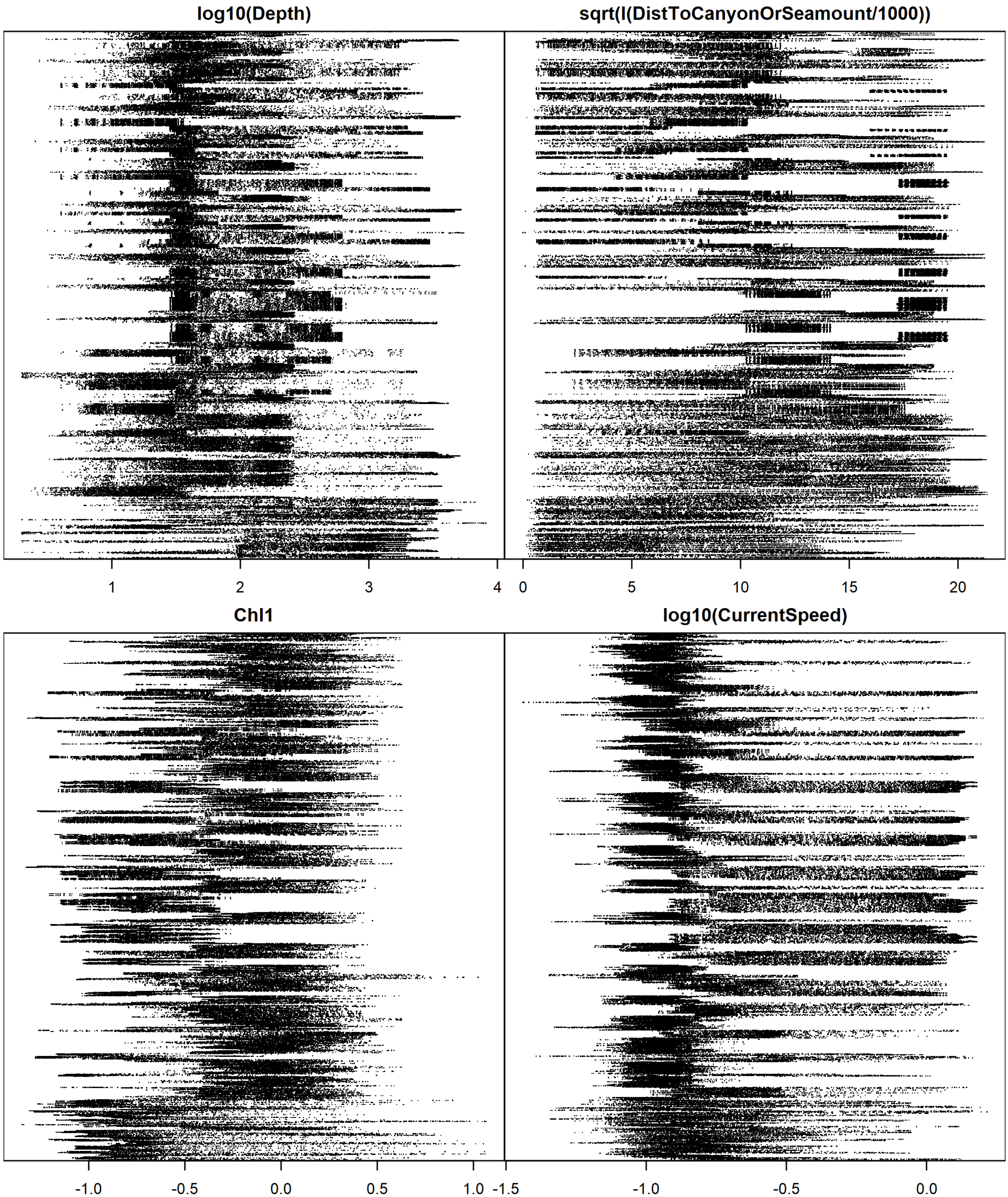
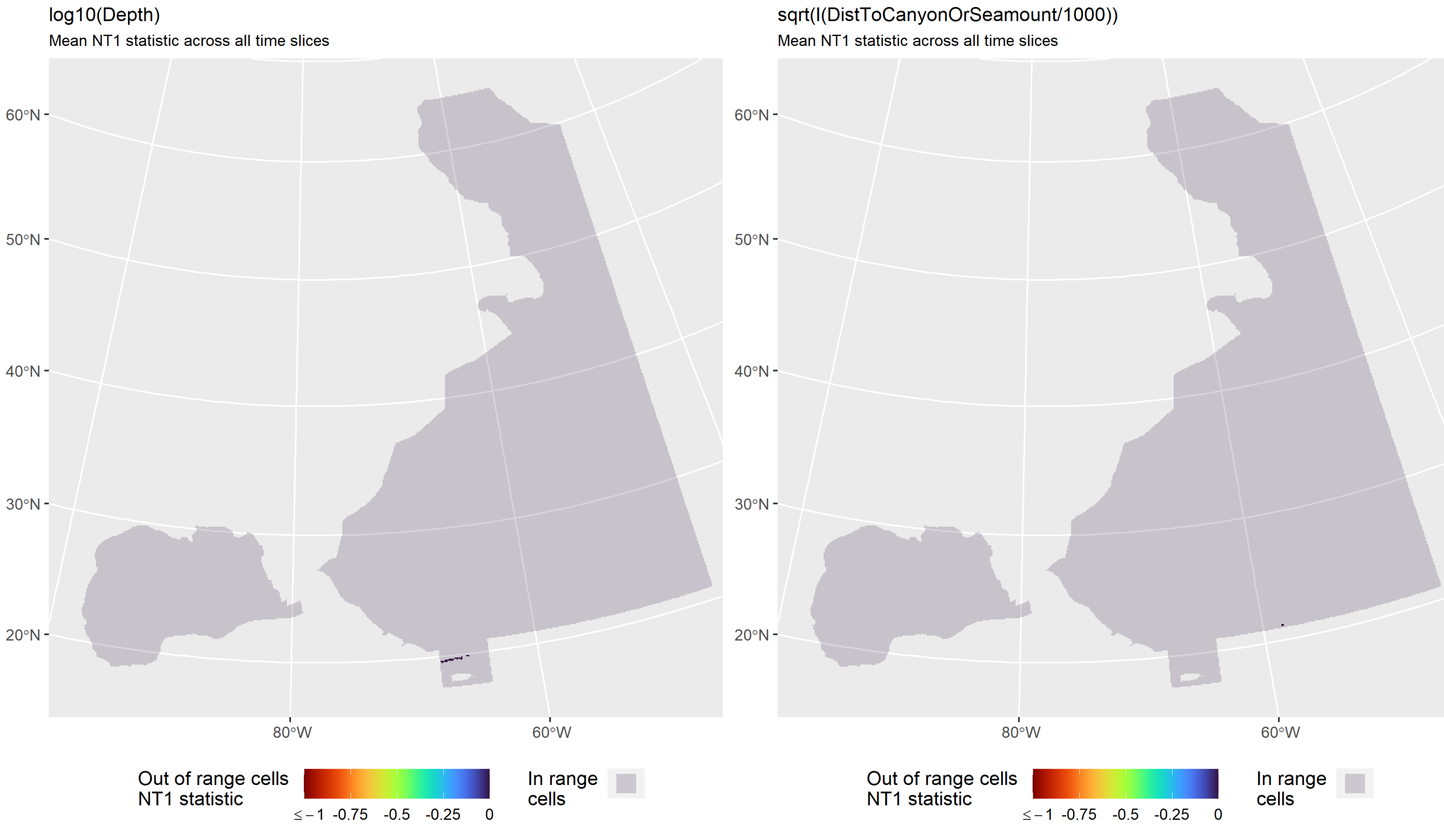


Figure 6: Dotplot of the covariates considered during the final model selection step. The final model may have included only a subset of the covariates shown here (see Figure 2), and additional covariates may have been considered in preceding selection steps. Covariates are transformed as shown in Figure 4. This plot is used to check for suspicious patterns and outliers in the data. Points are ordered vertically by segment ID, sequentially in time.

2.3 Extrapolation Diagnostics

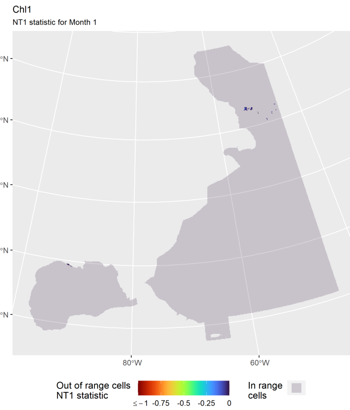
2.3.1 Univariate Extrapolation



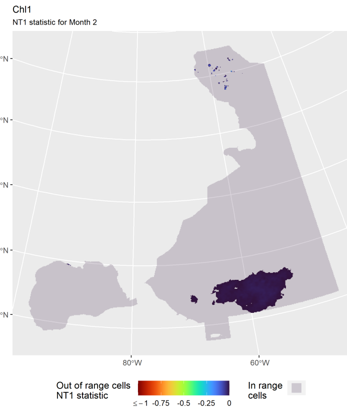
(a) Depth covariate

(b) DistToCanyonOrSeamount covariate

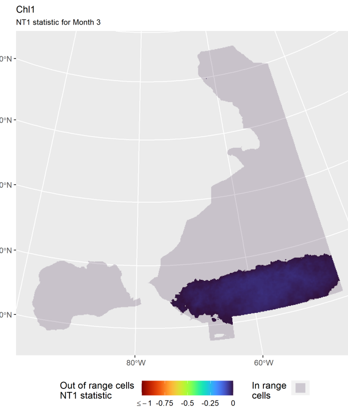
Figure 7: NT1 statistic (Mesgaran et al. (2014)) for static covariates used in the model for the region AFTT Beaked Whales. Areas outside the sampled range of a covariate appear in color, indicating univariate extrapolation of that covariate occurred there. Areas within the sampled range appear in gray, indicating it did not occur.



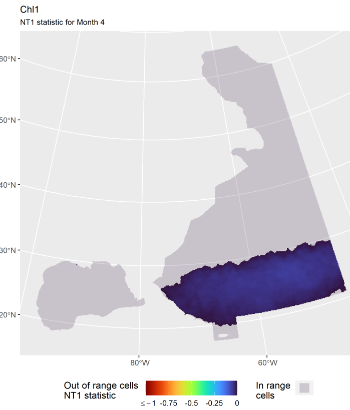
(a) January



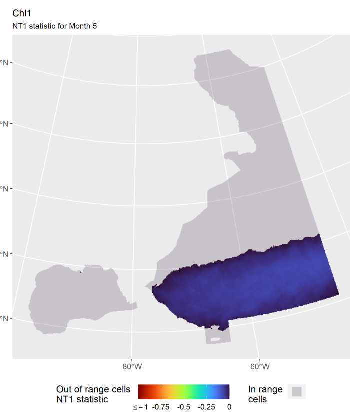
(b) February



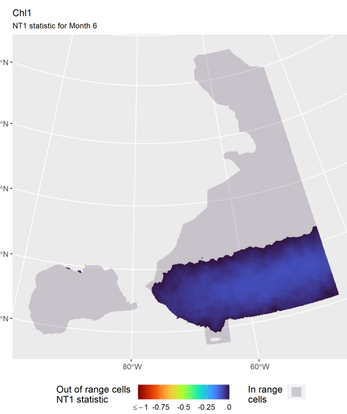
(c) March



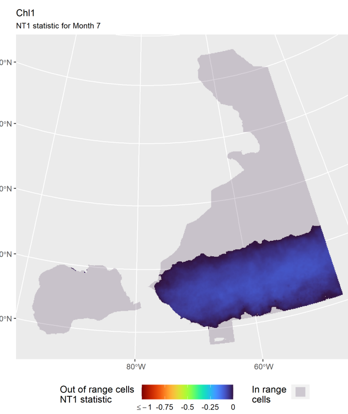
(d) April



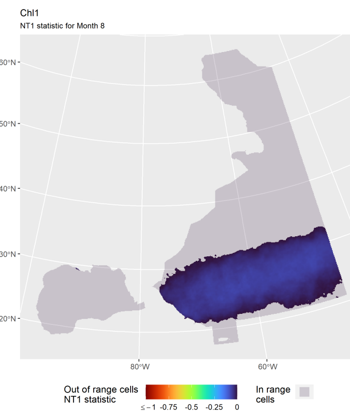
(e) May



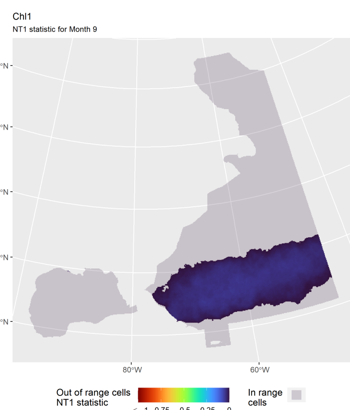
(f) June



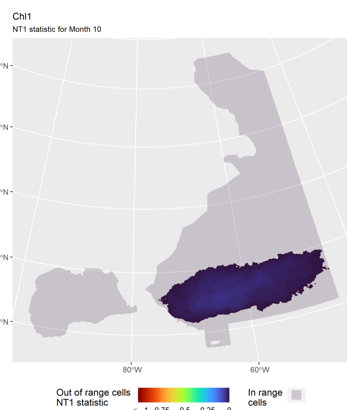
(g) July



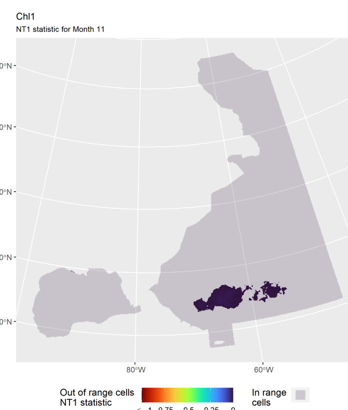
(h) August



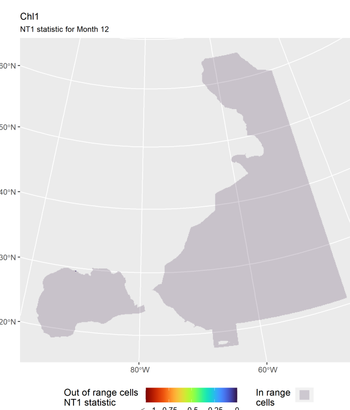
(i) September



(j) October



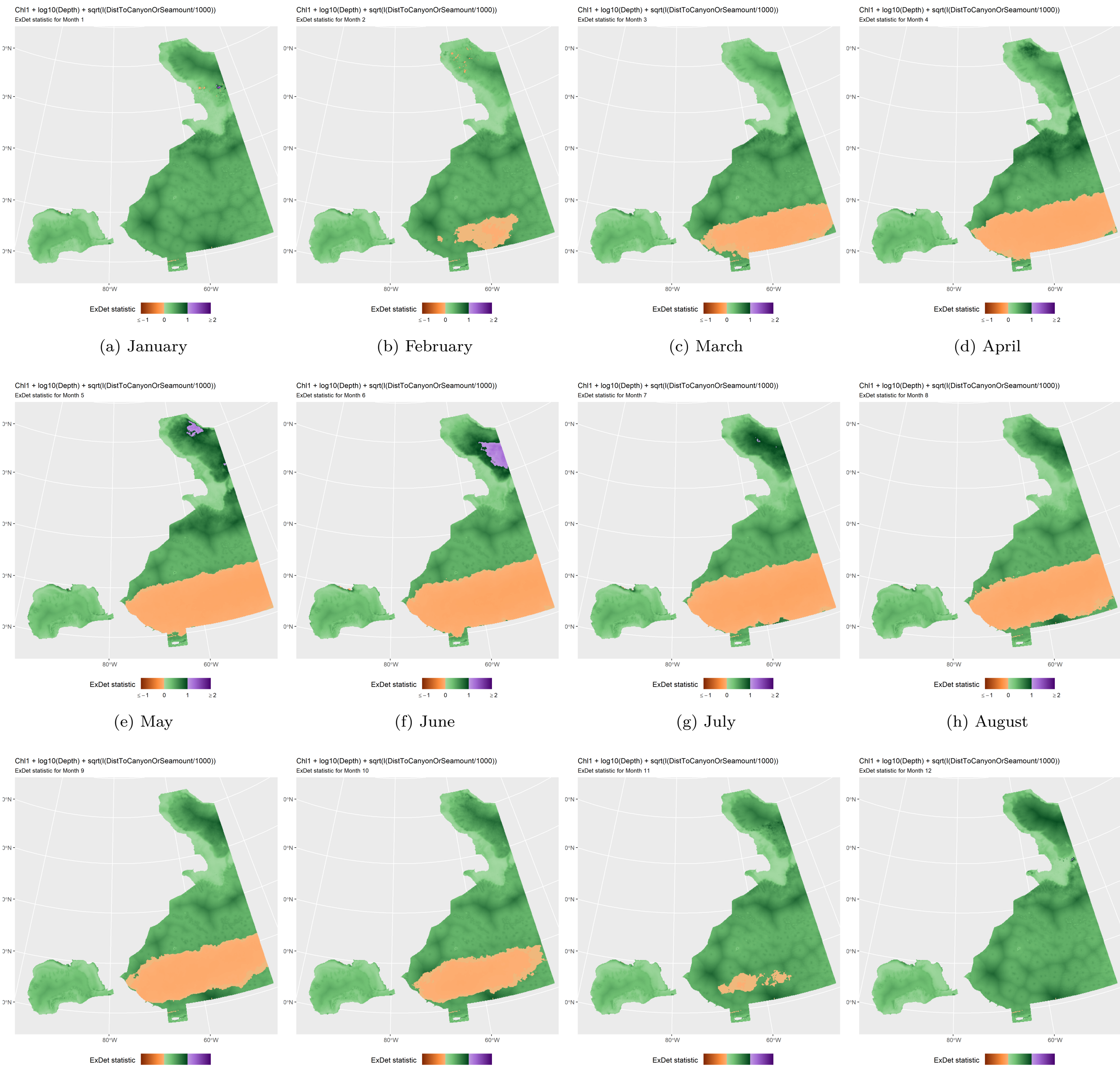
(k) November



(l) December

Figure 8: NT1 statistic (Mesgaran et al. (2014)) for the Chl1 covariate in the model for the region AFTT Beaked Whales. Areas outside the sampled range of a covariate appear in color, indicating univariate extrapolation of that covariate occurred there during the month. Areas within the sampled range appear in gray, indicating it did not occur.

2.3.2 Multivariate Extrapolation



(a) January (b) February (c) March (d) April

(e) May (f) June (g) July (h) August

(i) September (j) October (k) November (l) December

Figure 9: ExDet statistic (Mesgaran et al. (2014)) for all of the covariates used in the model for the region AFTT Beaked Whales. Areas in orange (ExDet < 0) required univariate extrapolation of one or more covariates (see previous section). Areas in purple (ExDet > 1), did not require univariate extrapolation but did require multivariate extrapolation, by virtue of having novel combinations of covariates not represented in the survey data, according to the NT2 statistic (Mesgaran et al. (2014)). Areas in green ($0 \geq$ ExDet ≤ 1) did not require either type of extrapolation.

3 Predictions

3.1 Summarized Predictions

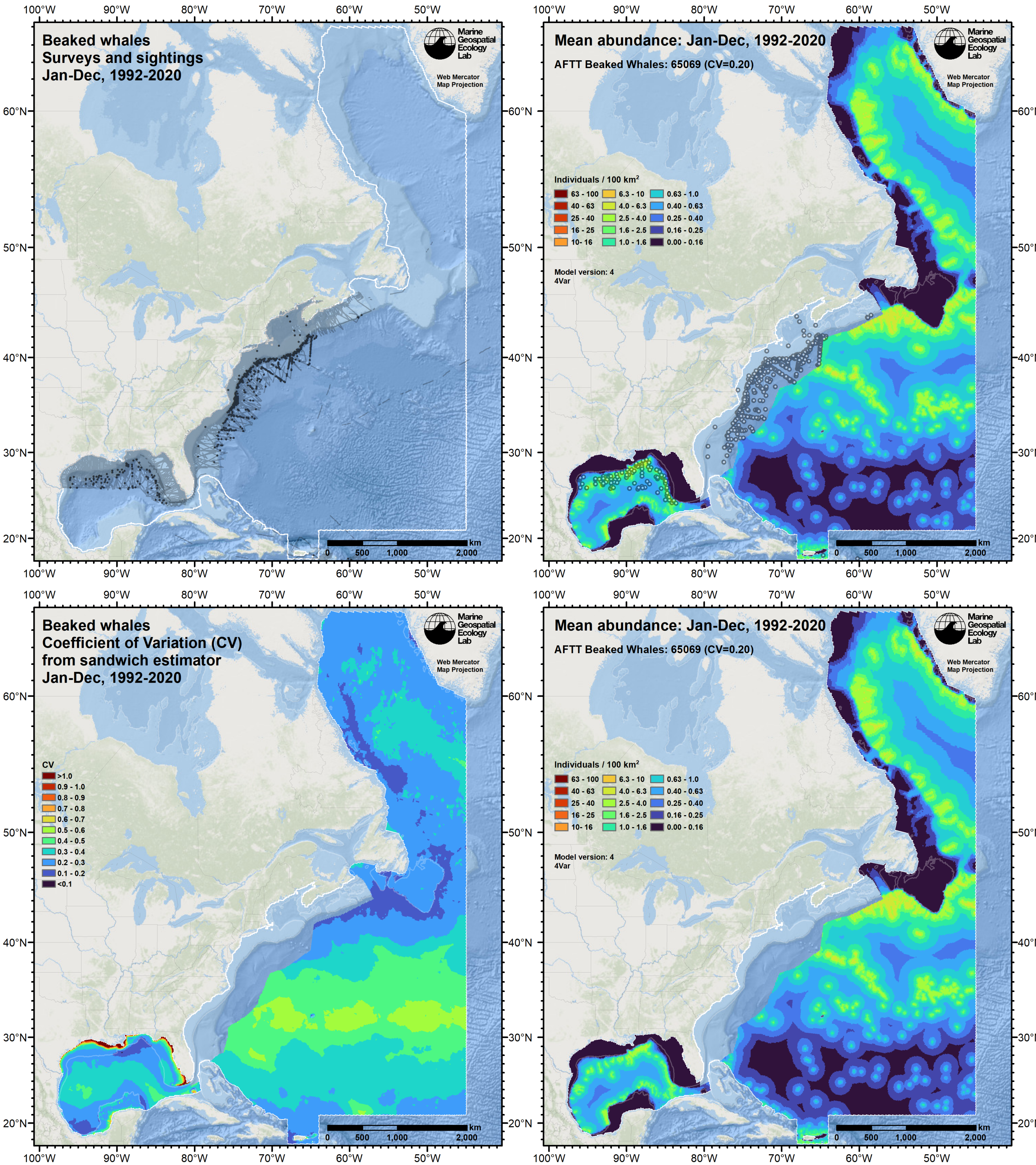


Figure 10: Survey effort and observations (top left), predicted density with observations (top right), predicted density without observations (bottom right), and coefficient of variation of predicted density (bottom left), for the given era. Variance was estimated with the analytic approach given by Miller et al. (2022), Appendix S1, and accounts both for uncertainty in model parameter estimates and for temporal variability in dynamic covariates. These maps use a Web Mercator projection but the analysis was conducted in an Albers Equal Area coordinate system appropriate for density modeling.

3.2 Comparison to Previous Density Model

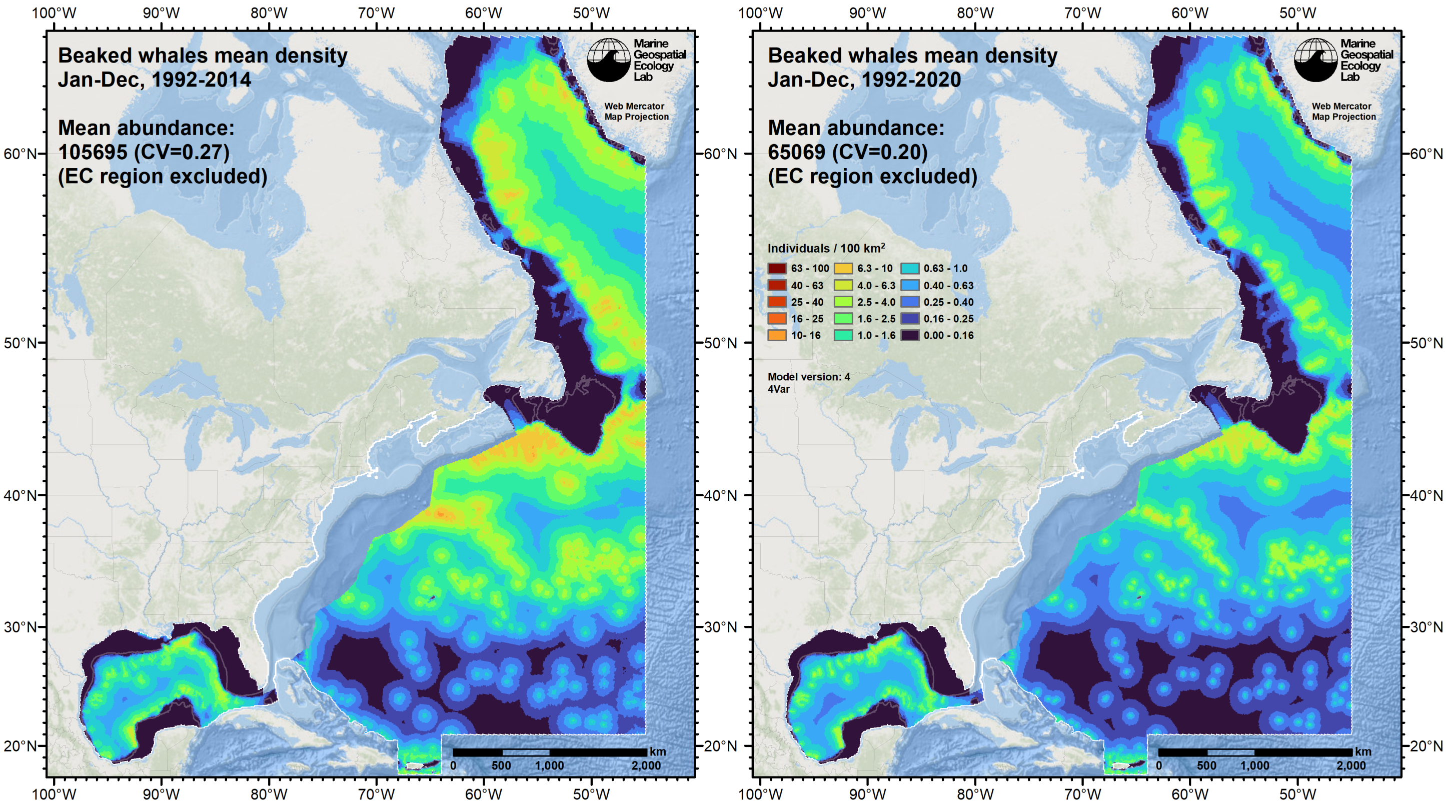


Figure 11: Comparison of the mean density predictions from the previous model (left) released by Mannocci et al. (2017) to those from this model (right). This model was not predicted in the East Coast (EC) region but the previous model was. For consistency in this comparison, those predictions have been excluded. These maps use a Web Mercator projection but the analyses were conducted in an Albers Equal Area coordinate system appropriate for density modeling.

4 Discussion

Following Mannocci et al. (2017), we summarized this model into a single year-round mean density surface (Figure 10). Predictions were not made for the East Coast (EC) region of the AFTT study area. Readers interested in that region should use the regional EC model instead. Predictions were made for the Gulf of Mexico (GOM) region but we also recommend that those interested in that region use the regional GOM model from the NOAA SEFSC GoMMAPPS project instead. See Roberts et al. (2023) for more discussion of the models.

The predictions generally accorded with what has been reported in the literature and strongly resembled the predictions of Mannocci et al. (2017) (Figure 11). Please see Mannocci et al. (2017) for a detailed discussion of the predictions as compared to the literature. However, the new model estimated about 39% lower abundance than the prior model. This difference likely resulted from the different bias corrections used used for shipboard surveys by the two models. In the prior model, many shipboard surveys were corrected with a combined correction of $g_0 = 0.23$ taken from Barlow (1999), which was based on data in the Pacific. For the current model, we utilized corrections ranging from $g_0 = 0.22$ to $g_0 = 0.41$, depending on the survey program and the species sighted, taken from Palka et al. (2021). These were based on AMAPPS surveys conducted along the east coast. The usually weaker corrections applied in the current model resulted in lower estimated abundances on survey transects, resulting in a generally lower density across the study area. Because these corrections were made from surveys used to fit the model, rather than taken from surveys from a different ocean basin, the density and abundance estimated by the new model are likely to be more accurate.

Extrapolation analysis (Figure 9) showed that univariate environmental extrapolation was necessary in the southern half of the Atlantic waters of the study area (e.g. the Sargasso Sea) except in winter, driven by a lack of surveying in waters with low chlorophyll concentration. Some multivariate extrapolation occurred in May and June in the Labrador Sea, driven by the unsampled combination of deep water with high chlorophyll concentration. We therefore advise caution in these areas. Future updates would benefit from the inclusion of survey data from these areas (no such data were available for our use in this analysis).

References

Barco SG, Burt L, DePerte A, Digiovanni R Jr. (2015) Marine Mammal and Sea Turtle Sightings in the Vicinity of the Maryland Wind Energy Area July 2013-June 2015, VAQF Scientific Report #2015-06. Virginia Aquarium & Marine Science Center Foundation, Virginia Beach, VA

Barlow J (1999) Trackline detection probability for long-diving whales. In: Marine Mammal Survey and Assessment Methods. Balkema, Rotterdam, The Netherlands, pp 209–221

Becker JJ, Sandwell DT, Smith WHF, Braud J, Binder B, Depner J, Fabre D, Factor J, Ingalls S, Kim S-H, Ladner R, Marks K, Nelson S, Pharaoh A, Trimmer R, Von Rosenberg J, Wallace G, Weatherall P (2009) Global Bathymetry and Elevation Data at 30 Arc Seconds Resolution: SRTM30_PLUS. Marine Geodesy 32:355–371. doi: 10.1080/01490410903297766

Blaylock RA, Hoggard W (1994) Preliminary Estimates of Bottlenose Dolphin Abundance in Southern U.S. Atlantic and Gulf of Mexico Continental Shelf Waters: NOAA Technical Memorandum NMFS-SEFSC-356. NOAA National Marine Fisheries Service, Southeast Fisheries Science Center, Miami, FL

Boisseau O, Nowacek D, Roberts J, Pabst DA, Clabaugh A, Moscrop A, McLanaghan R, Yack T, Levenson JJ (in review) Acoustic density estimates of beaked whales off the mid-Atlantic coast of the USA in winter and spring.

Cole T, Gerrior P, Merrick RL (2007) Methodologies of the NOAA National Marine Fisheries Service Aerial Survey Program for Right Whales (Eubalaena glacialis) in the Northeast U.S., 1998-2006. U.S. Department of Commerce, Woods Hole, MA

Cotter MP (2019) Aerial Surveys for Protected Marine Species in the Norfolk Canyon Region: 2018–2019 Final Report. HDR, Inc., Virginia Beach, VA

Davis R, Fargion G (1996) Distribution and Abundance of Cetaceans in the North-Central and Western Gulf of Mexico, Final Report Volume II: Technical Report. OCS Study MMS 96-0027. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA

Davis RW, Evans WE, Würsig B (2000) Cetaceans, Sea Turtles and Seabirds in the Northern Gulf of Mexico: Distribution, Abundance and Habitat Associations. Volume II: Technical Report. OCS Study MMS 2000-003. U.S. Department of the Interior, Geological Survey, Biological Resources Division, USGS/BED/CR-1999-0006 and Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA

Foley HJ, Paxton CGM, McAlarney RJ, Pabst DA, Read AJ (2019) Occurrence, Distribution, and Density of Protected Species in the Jacksonville, Florida, Atlantic Fleet Training and Testing (AFTT) Study Area. Duke University Marine Lab, Beaufort, NC

Fulling GL, Mullin KD, Hubard CW (2003) Abundance and distribution of cetaceans in outer continental shelf waters of the US Gulf of Mexico. Fishery Bulletin 101:923–932.

Garrison LP, Martinez A, Maze-Foley K (2010) Habitat and abundance of cetaceans in Atlantic Ocean continental slope waters off the eastern USA. Journal of Cetacean Research and Management 11:267–277.

Harris PT, Macmillan-Lawler M, Rupp J, Baker EK (2014) Geomorphology of the oceans. Marine Geology 352:4–24. doi: 10.1016/j.margeo.2014.01.011

Laran S, Bassols N, Dorémus G, Authier M, Ridoux V, Van Canneyt O (2019) Distribution et abondance de la mégafaune marine aux Petites Antilles et en Guyane: REMMOA-II Petites Antilles & Guyane - 2017: Rapport final. Observatoire Pelagis, Université de La Rochelle, La Rochelle, France

Leiter S, Stone K, Thompson J, Accardo C, Wikgren B, Zani M, Cole T, Kenney R, Mayo C, Kraus S (2017) North Atlantic right whale Eubalaena glacialis occurrence in offshore wind energy areas near Massachusetts and Rhode Island, USA. Endang Species Res 34:45–59. doi: 10.3354/esr00827

Mallette SD, Lockhart GG, McAlarney RJ, Cummings EW, McLellan WA, Pabst DA, Barco SG (2014) Documenting Whale Migration off Virginia's Coast for Use in Marine Spatial Planning: Aerial and Vessel Surveys in the Proximity of the Virginia Wind Energy Area (VA WEA), VAQF Scientific Report 2014-08. Virginia Aquarium & Marine Science Center Foundation, Virginia Beach, VA

Mallette SD, Lockhart GG, McAlarney RJ, Cummings EW, McLellan WA, Pabst DA, Barco SG (2015) Documenting Whale Migration off Virginia's Coast for Use in Marine Spatial Planning: Aerial Surveys in the Proximity of the Virginia Wind Energy Area (VA WEA) Survey/Reporting Period: May 2014 - December 2014, VAQF Scientific Report 2015-02. Virginia Aquarium & Marine Science Center Foundation, Virginia Beach, VA

Mallette SD, McAlarney RJ, Lockhart GG, Cummings EW, Pabst DA, McLellan WA, Barco SG (2017) Aerial Survey Baseline Monitoring in the Continental Shelf Region of the VACAPES OPAREA: 2016 Annual Progress Report. Virginia Aquarium & Marine Science Center Foundation, Virginia Beach, VA

Mannocci L, Monestiez P, Bolaños-Jiménez J, Dorémus G, Jeremie S, Laran S, Rinaldi R, Van Canneyt O, Ridoux V (2013) Megavertebrate communities from two contrasting ecosystems in the western tropical Atlantic. Journal of Marine Systems 111–112:208–222. doi: 10.1016/j.jmarsys.2012.11.002

Mannocci L, Roberts JJ, Miller DL, Halpin PN (2017) Extrapolating cetacean densities to quantitatively assess human impacts on populations in the high seas. Conservation Biology 31:601–614. doi: 10.1111/cobi.12856

Maritorena S, d'Andon OHF, Mangin A, Siegel DA (2010) Merged satellite ocean color data products using a bio-optical model: Characteristics, benefits and issues. Remote Sensing of Environment 114:1791–1804. doi: 10.1016/j.rse.2010.04.002

McAlarney R, Cummings E, McLellan W, Pabst A (2018) Aerial Surveys for Protected Marine Species in the Norfolk Canyon Region: 2017 Annual Progress Report. University of North Carolina Wilmington, Wilmington, NC

McLellan WA, McAlarney RJ, Cummings EW, Read AJ, Paxton CGM, Bell JT, Pabst DA (2018) Distribution and abundance of beaked whales (Family Ziphiidae) Off Cape Hatteras, North Carolina, U.S.A. Marine Mammal Science. doi: 10.1111/mms.12500

Mesgaran MB, Cousens RD, Webber BL (2014) Here be dragons: A tool for quantifying novelty due to covariate range and correlation change when projecting species distribution models. Diversity Distrib 20:1147–1159. doi: 10.1111/ddi.12209

Miller DL, Becker EA, Forney KA, Roberts JJ, Cañadas A, Schick RS (2022) Estimating uncertainty in density surface models. PeerJ 10:e13950. doi: 10.7717/peerj.13950

Mullin KD (1995) Cruise Report: Oregon II Cruise 215 (95-01): 26 January - 11 March 1995. NOAA National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula, MS

Mullin KD (2007) Abundance of Cetaceans in the Oceanic Northern Gulf of Mexico from 2003 and 2004 Ship Surveys. Southeast Fisheries Science Center Reference Document PRBD-2016-03. NOAA National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula, MS

Mullin KD, Fulling GL (2003) Abundance of cetaceans in the southern U.S. North Atlantic Ocean during summer 1998. Fishery Bulletin 101:603–613.

Mullin KD, Fulling GL (2004) Abundance of cetaceans in the oceanic northern Gulf of Mexico, 1996–2001. Marine Mammal Science 20:787–807. doi: 10.1111/j.1748-7692.2004.tb01193.x

O'Brien O, Pendleton DE, Ganley LC, McKenna KR, Kenney RD, Quintana-Rizzo E, Mayo CA, Kraus SD, Redfern JV (2022) Repatriation of a historical North Atlantic right whale habitat during an era of rapid climate change. Sci Rep 12:12407. doi: 10.1038/s41598-022-16200-8

Palka D, Aichinger Dias L, Broughton E, Chavez-Rosales S, Cholewiak D, Davis G, DeAngelis A, Garrison L, Haas H, Hatch J, Hyde K, Jech M, Josephson E, Mueller-Brennan L, Orphanides C, Pegg N, Sasso C, Sigourney D, Soldevilla M, Walsh H (2021) Atlantic Marine Assessment Program for Protected Species: FY15 – FY19 (OCS Study BOEM 2021-051). U.S. Deptartment of the Interior, Bureau of Ocean Energy Management, Washington, DC

Palka DL (2006) Summer abundance estimates of cetaceans in US North Atlantic navy operating areas (NEFSC Reference Document 06-03). U.S. Department of Commerce, Northeast Fisheries Science Center, Woods Hole, MA

Palka DL, Chavez-Rosales S, Josephson E, Cholewiak D, Haas HL, Garrison L, Jones M, Sigourney D, Waring G, Jech M, Broughton E, Soldevilla M, Davis G, DeAngelis A, Sasso CR, Winton MV, Smolowitz RJ, Fay G, LaBrecque E, Leiness JB, Dettloff K, Warden M, Murray K, Orphanides C (2017) Atlantic Marine Assessment Program for Protected Species: 2010-2014 (OCS Study BOEM 2017-071). U.S. Deptartment of the Interior, Bureau of Ocean Energy Management, Washington, DC

Quintana-Rizzo E, Leiter S, Cole T, Hagbloom M, Knowlton A, Nagelkirk P, O'Brien O, Khan C, Henry A, Duley P, Crowe L, Mayo C, Kraus S (2021) Residency, demographics, and movement patterns of North Atlantic right whales Eubalaena glacialis in an offshore wind energy development area in southern New England, USA. Endang Species Res 45:251–268. doi: 10.3354/esr01137

Read AJ, Barco S, Bell J, Borchers DL, Burt ML, Cummings EW, Dunn J, Fougeres EM, Hazen L, Hodge LEW, Laura A-M, McAlarney RJ, Peter N, Pabst DA, Paxton CGM, Schneider SZ, Urian KW, Waples DM, McLellan WA (2014) Occurrence, distribution and abundance of cetaceans in Onslow Bay, North Carolina, USA. Journal of Cetacean Research and Management 14:23–35.

Redfern JV, Kryc KA, Weiss L, Hodge BC, O'Brien O, Kraus SD, Quintana-Rizzo E, Auster PJ (2021) Opening a Marine Monument to Commercial Fishing Compromises Species Protections. Front Mar Sci 8:645314. doi: 10.3389/fmars.2021.645314

Roberts JJ, Yack TM, Halpin PN (2023) Marine mammal density models for the U.S. Navy Atlantic Fleet Training and Testing (AFTT) study area for the Phase IV Navy Marine Species Density Database (NMSDD), Document Version 1.3. Duke University Marine Geospatial Ecology Lab, Durham, NC

Ryan C, Boisseau O, Cucknell A, Romagosa M, Moscrop A, McLanaghan R (2013) Final report for trans-Atlantic research passages between the UK and USA via the Azores and Iceland, conducted from R/V Song of the Whale 26 March to 28 September 2012. Marine Conservation Research International, Essex, UK

Stone KM, Leiter SM, Kenney RD, Wikgren BC, Thompson JL, Taylor JKD, Kraus SD (2017) Distribution and abundance of cetaceans in a wind energy development area offshore of Massachusetts and Rhode Island. J Coast Conserv 21:527–543. doi: 10.1007/s11852-017-0526-4

Swartz SL, Burks C (2000) Cruise Results: Windwards Humpback (Megaptera novaeangliae) Survey: NOAA Ship Gordon Gunter Cruise GU-00-01: 9 February to 3 April 2000 (NOAA Technical Memorandum NMFS-SEFSC-438). NOAA National Marine Fisheries Service, Southeast Fisheries Science Center, Miami, FL

Torres LG, Mclellan WA, Meagher E, Pabst DA (2005) Seasonal distribution and relative abundance of bottlenose dolphins, Tursiops truncatus, along the US mid-Atlantic coast. Journal of Cetacean Research and Management 7:153.

Waring GT, Nøttestad L, Olsen E, Skov H, Vikingsson G (2008) Distribution and density estimates of cetaceans along the mid-Atlantic Ridge during summer 2004. Journal of Cetacean Research and Management 10:137–146.

Zoidis AM, Lomac-MacNair KS, Ireland DS, Rickard ME, McKown KA, Schlesinger MD (2021) Distribution and density of six large whale species in the New York Bight from monthly aerial surveys 2017 to 2020. Continental Shelf Research 230:104572. doi: 10.1016/j.csr.2021.104572