Density Model for Sperm Whale (*Physeter macrocephalus*) 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:

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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.

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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 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	19	50	2.6
NEAq	CNM	2017-2020	2	4	4	1.0
NEAq	MMS-WEA	2017-2020	37	2	6	3.0
NEAq	NLPSC	2011-2015	43	3	8	2.7
NEFSC	AMAPPS	2010-2019	89	12	21	1.8
NEFSC	NARWSS	2003-2020	484	79	91	1.2
NEFSC	Pre-AMAPPS	1999-2008	46	17	21	1.2
NJDEP	NJEBS	2008-2009	11	0	0	
NYS-DEC/TT	NYBWM	2017-2020	77	17	38	2.2
SEFSC	AMAPPS	2010-2020	114	9	9	1.0
SEFSC	GOMEX92-96	1992-1996	27	0	0	
SEFSC	GulfCet I	1992-1994	50	21	43	2.0
SEFSC	GulfCet II	1996-1998	22	5	7	1.4
SEFSC	GulfSCAT 2007	2007-2007	18	0	0	
SEFSC	MATS	1995-2005	34	0	0	
SEFSC	SECAS	1992-1995	8	0	0	
U. La Rochelle	REMMOA	2008-2017	42	19	41	2.2
UNCW	MidA Bottlenose	2002-2002	17	1	1	1.0
UNCW	Navy Cape Hatteras	2011-2017	34	28	45	1.6
UNCW	Navy Jacksonville	2009-2017	92	1	2	2.0
UNCW	Navy Norfolk Canyon	2015-2017	14	13	20	1.5
UNCW	Navy Onslow Bay	2007-2011	49	0	0	
UNCW	SEUS NARW EWS	2005-2008	114	8	12	1.5
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	**1,493**	**258**	**419**	**1.6**
Shipboard Surveys						
IMR	MAR-ECO	2004-2004	2	32	82	2.6
MCR	SOTW Acoustical	2019-2019	4	221	221	1.0
MCR	SOTW Visual	2012-2012	6	12	15	1.2
NEFSC	AMAPPS	2011-2016	16	214	351	1.6
NEFSC	Pre-AMAPPS	1995-2007	18	246	458	1.9
NJDEP	NJEBS	2008-2009	14	0	0	
SEFSC	AMAPPS	2011-2016	17	60	153	2.5
SEFSC	GOM Oceanic CetShip	1992-2001	49	143	423	3.0
SEFSC	GOM Shelf CetShip	1994-2001	10	11	42	3.8
SEFSC	Pre-AMAPPS	1992-2006	33	187	464	2.5
SEFSC	Pre-GoMMAPPS	2003-2009	19	116	336	2.9

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
SEFSC	SEFSC Caribbean	1995-2000	8	21	63	3.0
		Total	**196**	**1,263**	**2,608**	**2.1**
		Grand Total	**1,689**	**1,521**	**3,027**	**2.0**

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
NJDEP	New Jersey Department of Environmental Protection
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)

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

Program	Description	References
Navy Jacksonville	Aerial Surveys of the Navy's Jacksonville Study Area	Foley et al. (2019)
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)
NJEBS	New Jersey Ecological Baseline Study	Geo-Marine, Inc. (2010), Whitt et al. (2015)
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, 3-covariate model that included chlorophyll concentration, depth, and distance to the closest submarine canyon or seamount. The resulting relationships (Figure 2) strongly 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

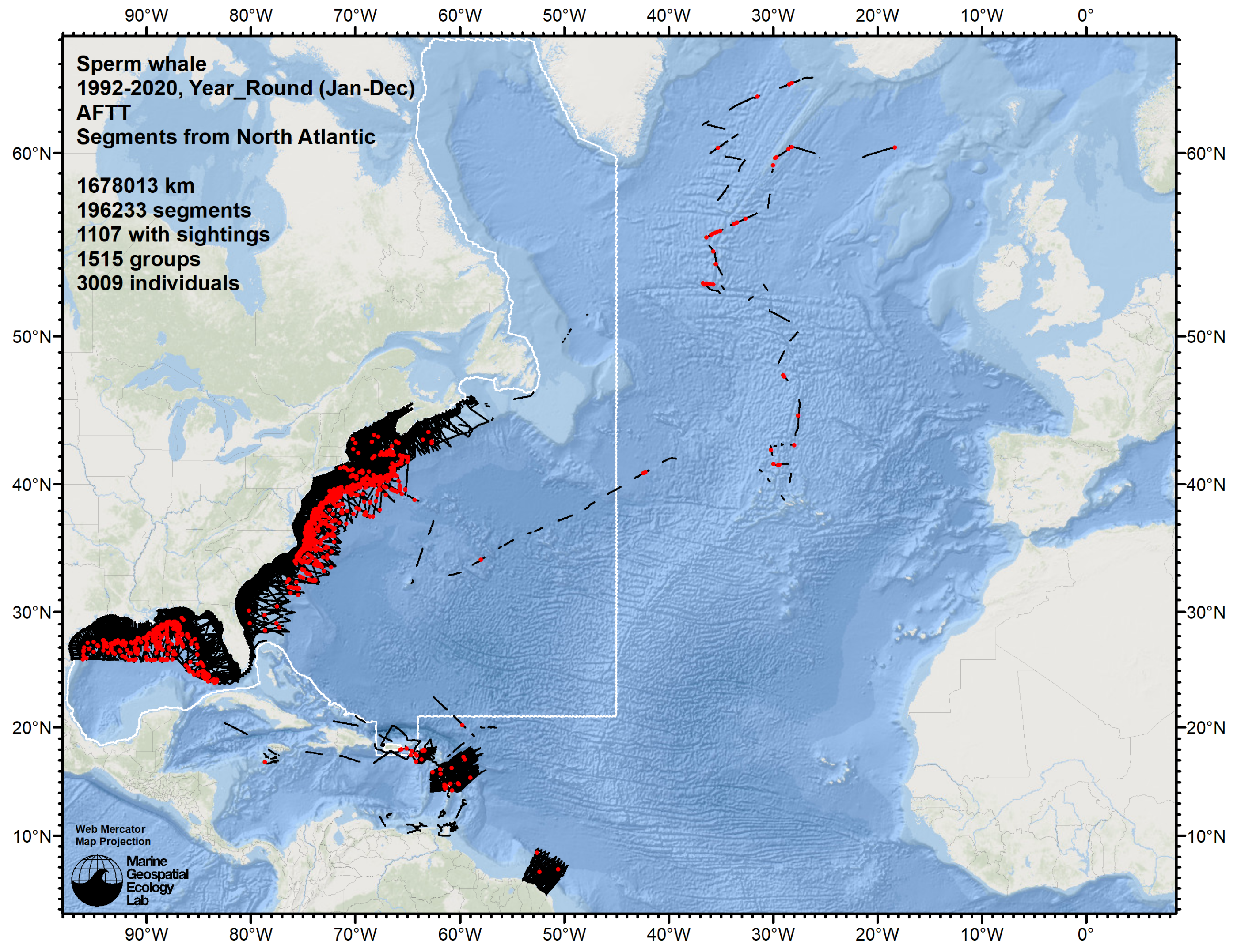
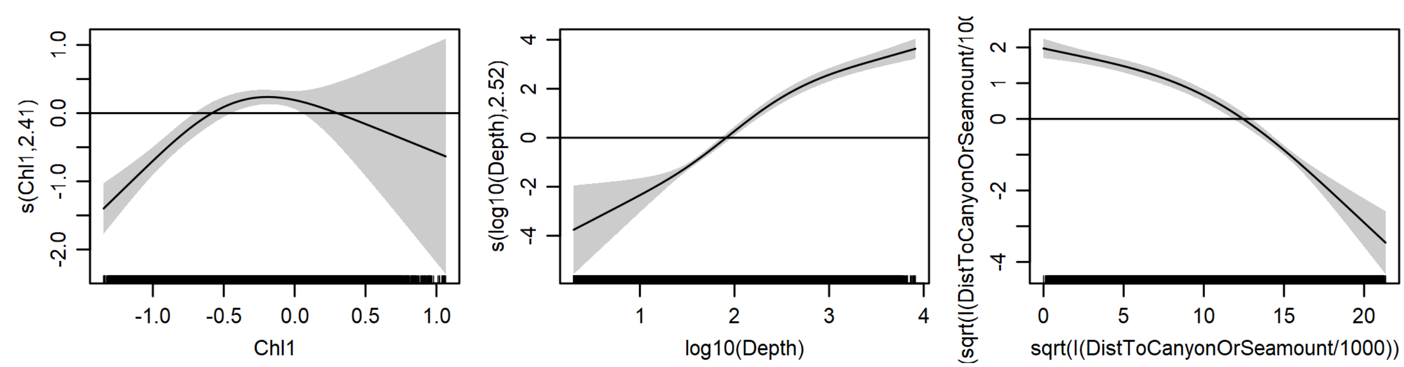


Figure 1: Survey segments (black lines) used to fit the model. Red points indicate segments with observations. This map uses a Web Mercator projection but the analysis was conducted in an Albers Equal Area coordinate system appropriate for density modeling.

Statistical output for this model:

```
Family: Tweedie(p=1.279)
Link function: log

Formula:
IndividualsCorrected ~ offset(log(SegmentArea)) + s(sqrt(I(DistToCanyonOrSeamount/1000)),
```

```
    bs = "ts", k = 4) + s(log10(Depth), bs = "ts", k = 4) + s(Chl1,
    bs = "ts", k = 4)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -22.3859     0.1082  -206.8   <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(sqrt(I(DistToCanyonOrSeamount/1000))) 2.592      3 112.20  <2e-16 ***
s(log10(Depth))                         2.520      3 147.49  <2e-16 ***
s(Chl1)                                 2.415      3  23.95  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.0174   Deviance explained = 34.5%
-REML = 8653.8  Scale est. = 21.454    n = 191092

Method: REML   Optimizer: outer newton
full convergence after 11 iterations.
Gradient range [-8.196919e-06,5.388868e-06]
(score 8653.836 & scale 21.45403).
Hessian positive definite, eigenvalue range [0.9189959,5401.103].
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(sqrt(I(DistToCanyonOrSeamount/1000))) 3.00 2.59    0.74  <2e-16 ***
s(log10(Depth))                         3.00 2.52    0.71  <2e-16 ***
s(Chl1)                                 3.00 2.41    0.81    0.59
---
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. 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). *sqrt* indicates the covariate was square-root transformed. */1000* indicates meters were transformed to kilometers for interpretation convenience.

Table 4: Covariates used in the final model.

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

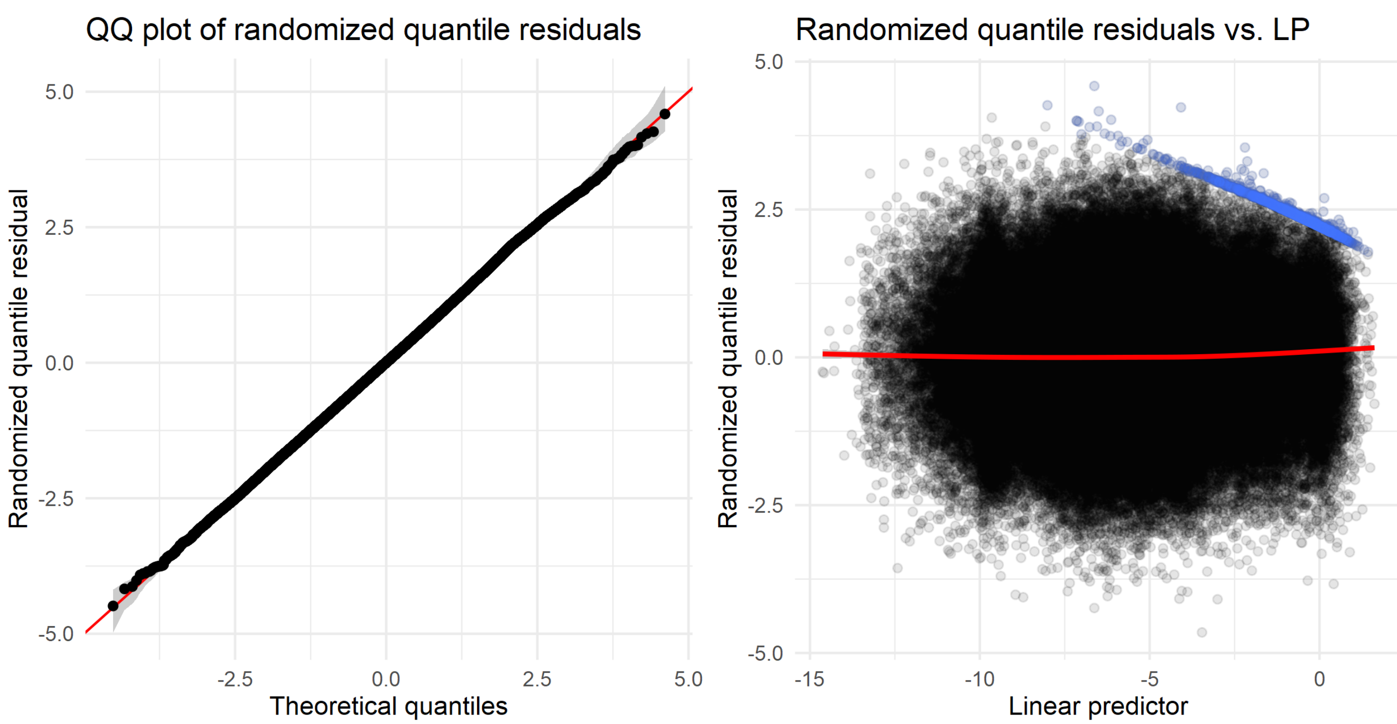


Figure 3: Residual plots for the final model.

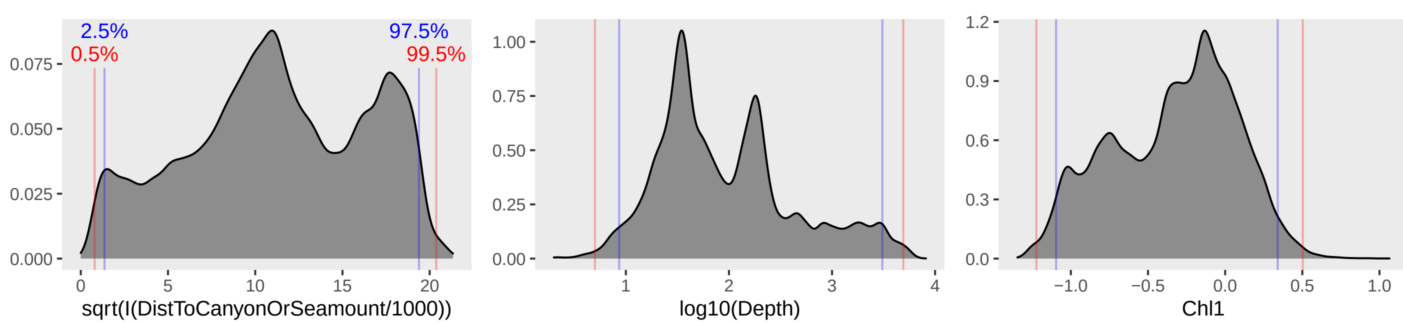


Figure 4: Density histograms showing the distributions of the covariates considered during the final model selection step. The final model may have included only a subset of the covariates shown here (see Figure 2), and additional covariates may have been considered in preceding selection steps. Red 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.

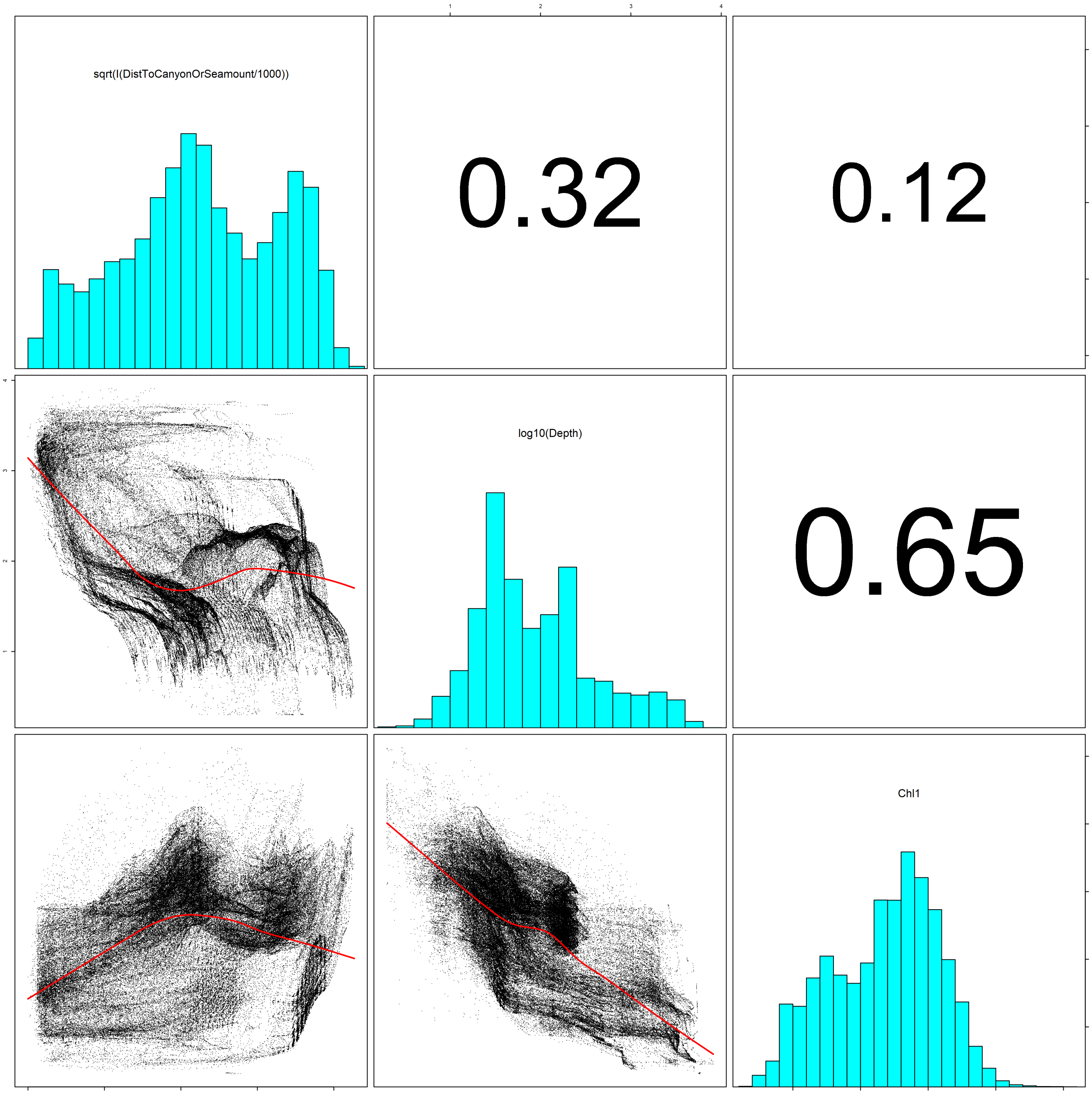


Figure 5: Scatterplot matrix of the covariates considered during the final model selection step. The final model may have included only a subset of the covariates shown here (see Figure 2), and additional covariates may have been considered in preceding selection steps. Covariates are transformed as 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).

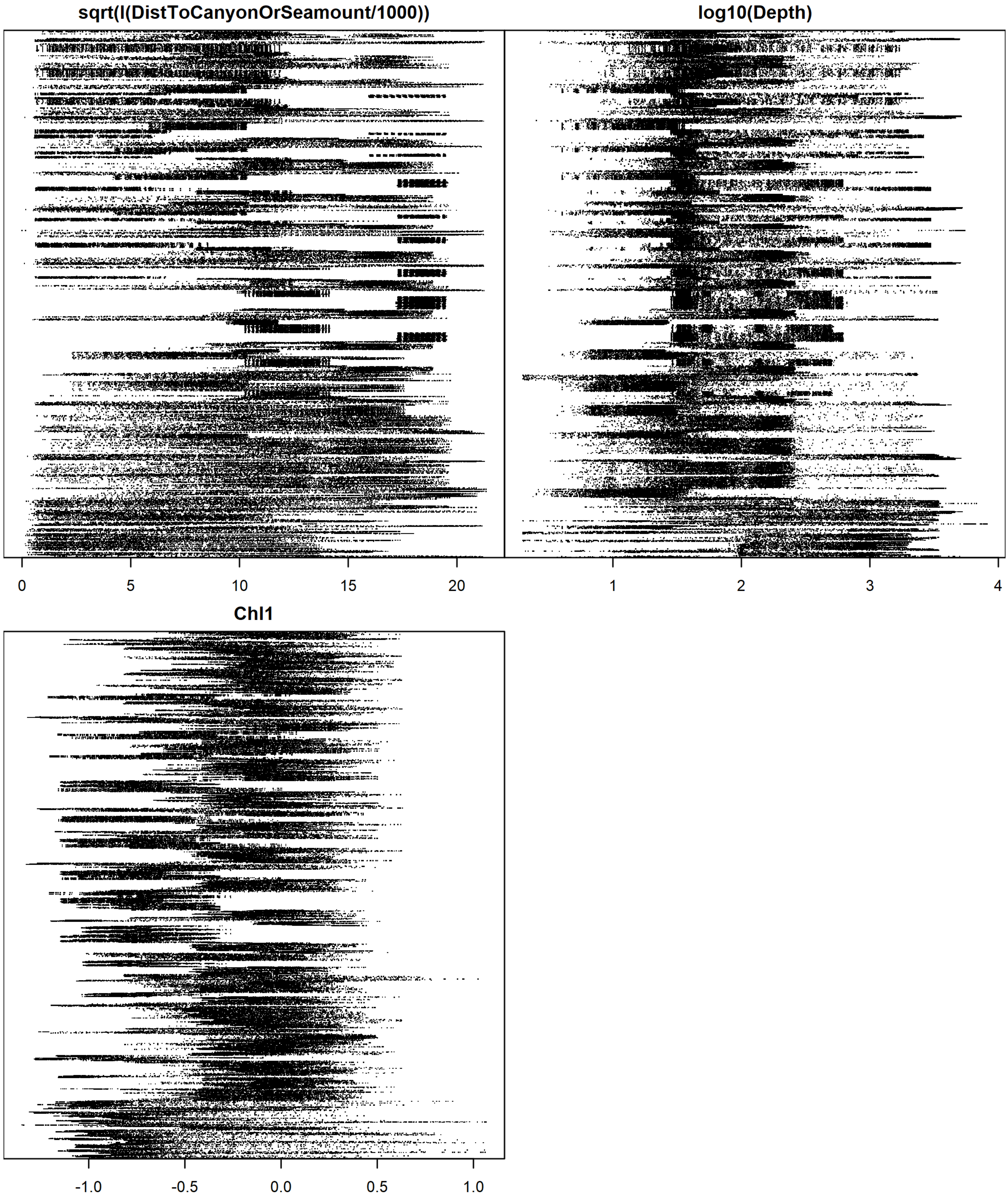
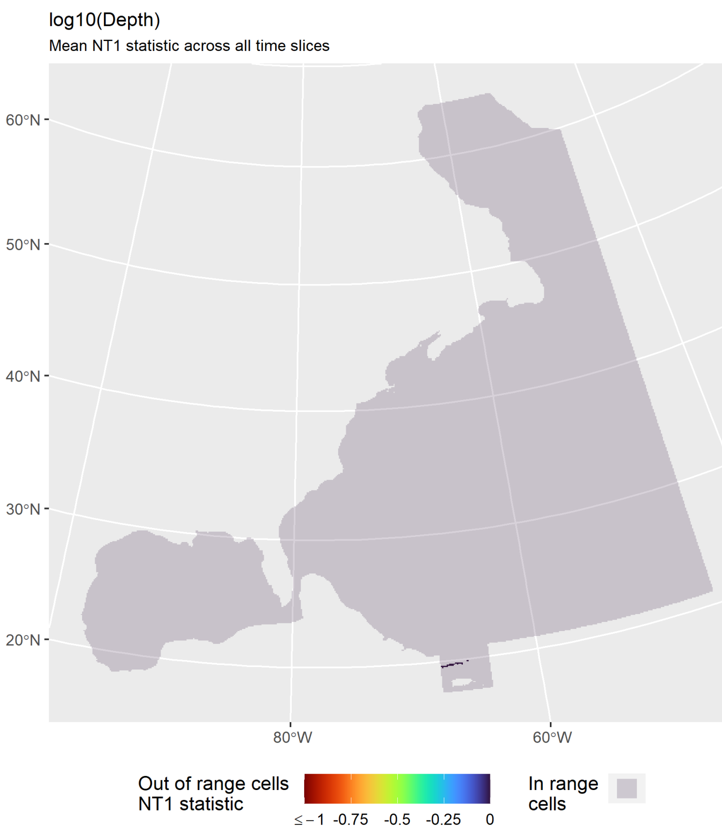


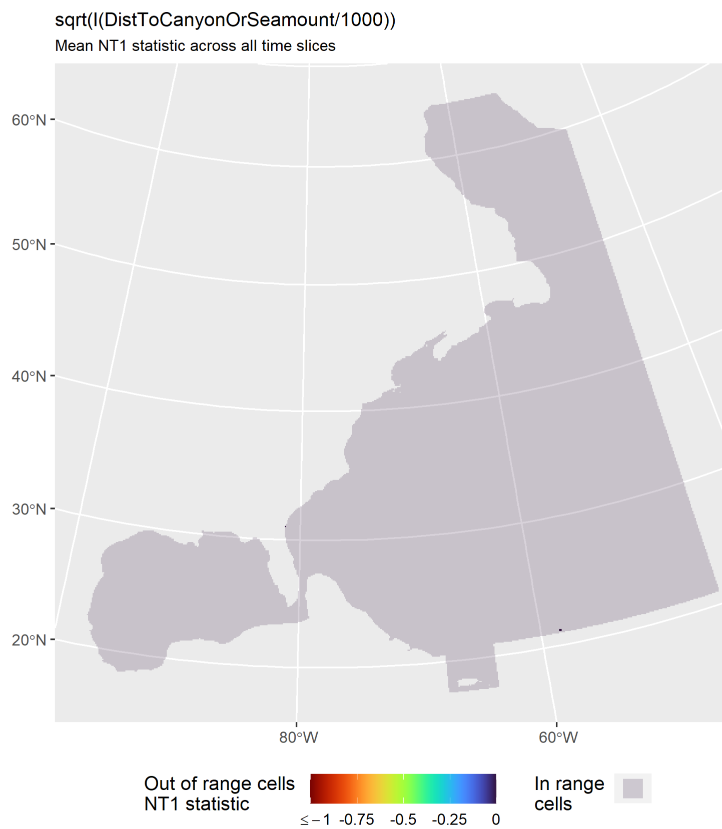
Figure 6: Dotplot of the covariates considered during the final model selection step. The final model may have included only a subset of the covariates shown here (see Figure 2), and additional covariates may have been considered in preceding selection steps. Covariates are transformed as shown in Figure 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

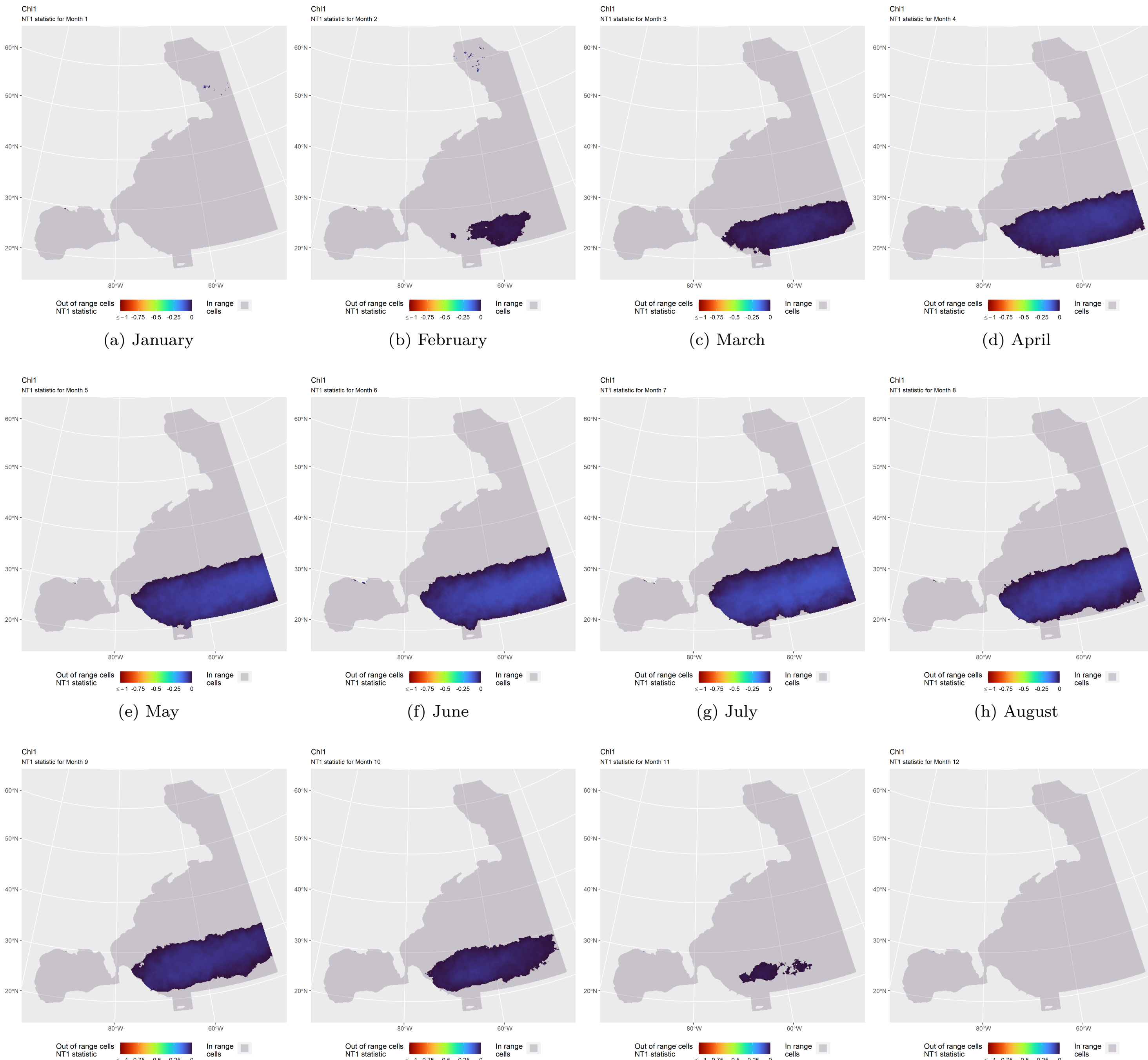


(a) Depth covariate



(b) DistToCanyonOrSeamount covariate

Figure 7: NT1 statistic (Mesgaran et al. (2014)) for static covariates used in the model. 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.



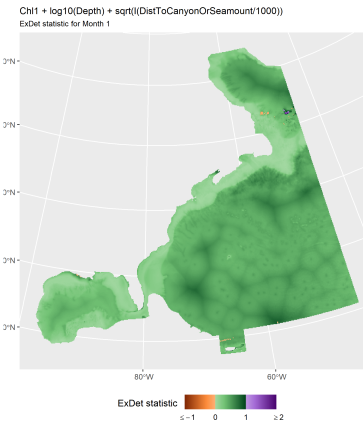
(a) January (b) February (c) March (d) April

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

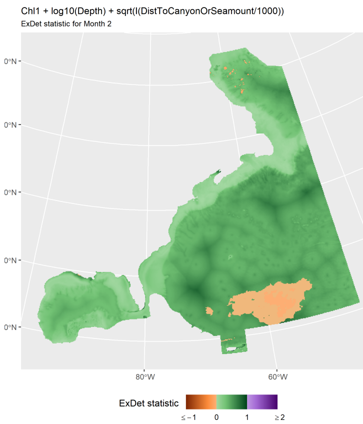
(i) September (j) October (k) November (l) December

Figure 8: NT1 statistic (Mesgaran et al. (2014)) for the Chl1 covariate in the model. 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.

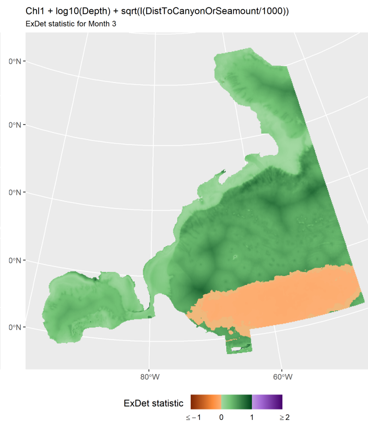
2.3.2 Multivariate Extrapolation



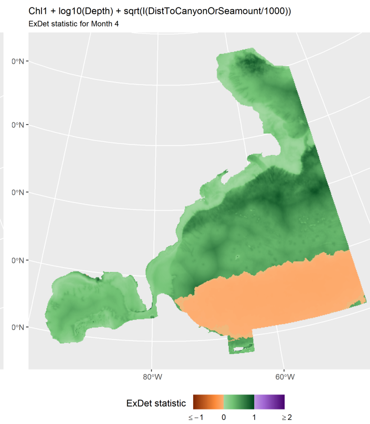
(a) January



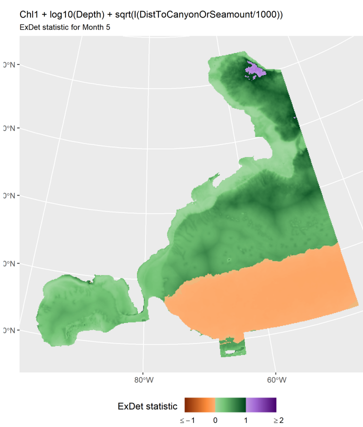
(b) February



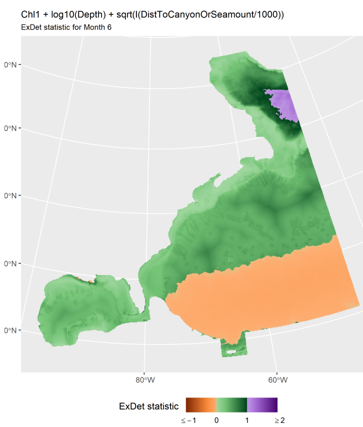
(c) March



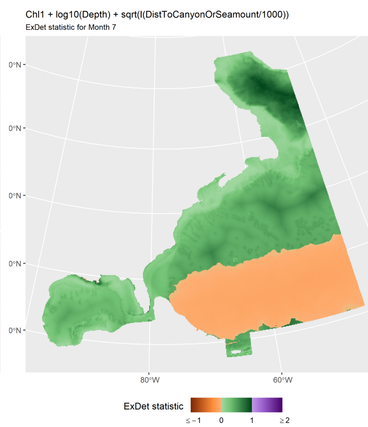
(d) April



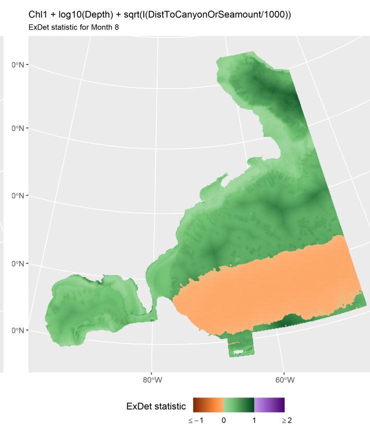
(e) May



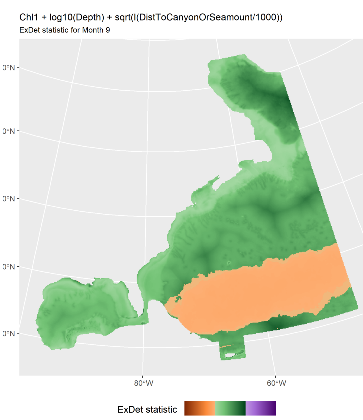
(f) June



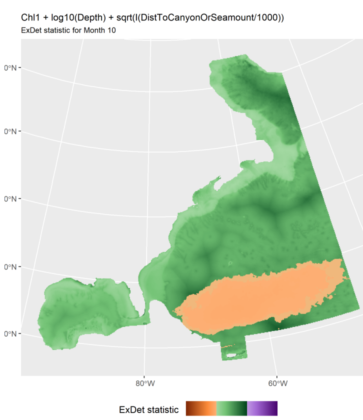
(g) July



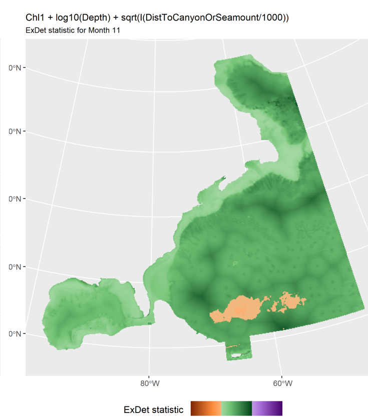
(h) August



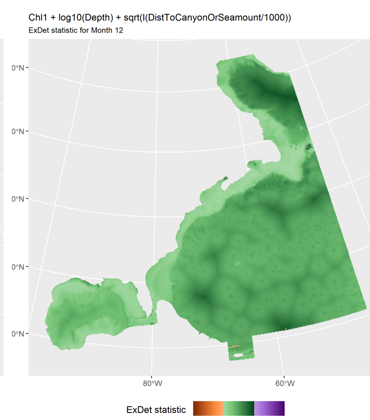
(i) September



(j) October



(k) November



(l) December

Figure 9: ExDet statistic (Mesgaran et al. (2014)) for all of the covariates used in the model. 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

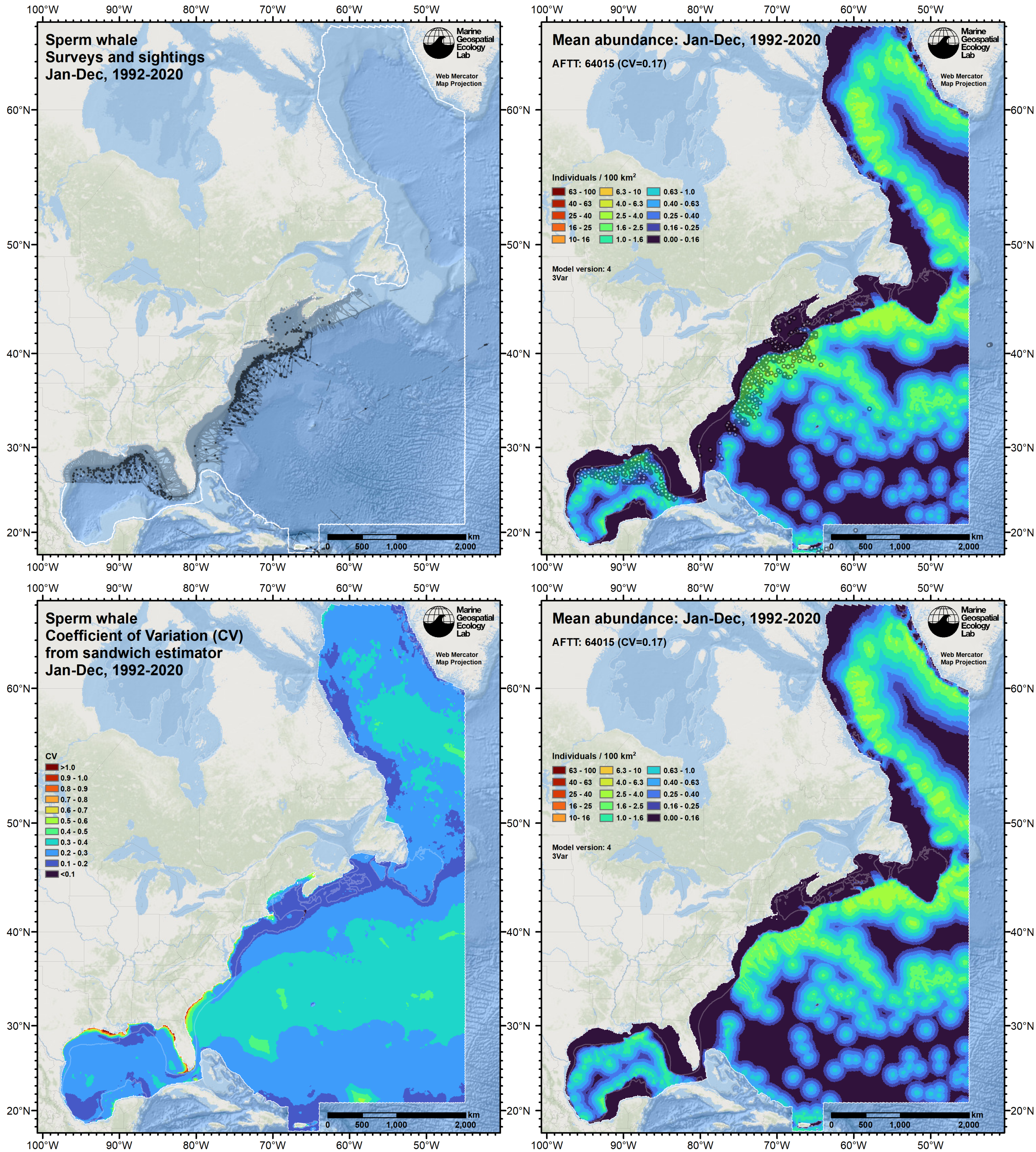


Figure 10: Survey effort and observations (top left), predicted density with observations (top right), predicted density without observations (bottom right), and coefficient of variation of predicted density (bottom left), for the given era. Variance was estimated with the analytic approach given by 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

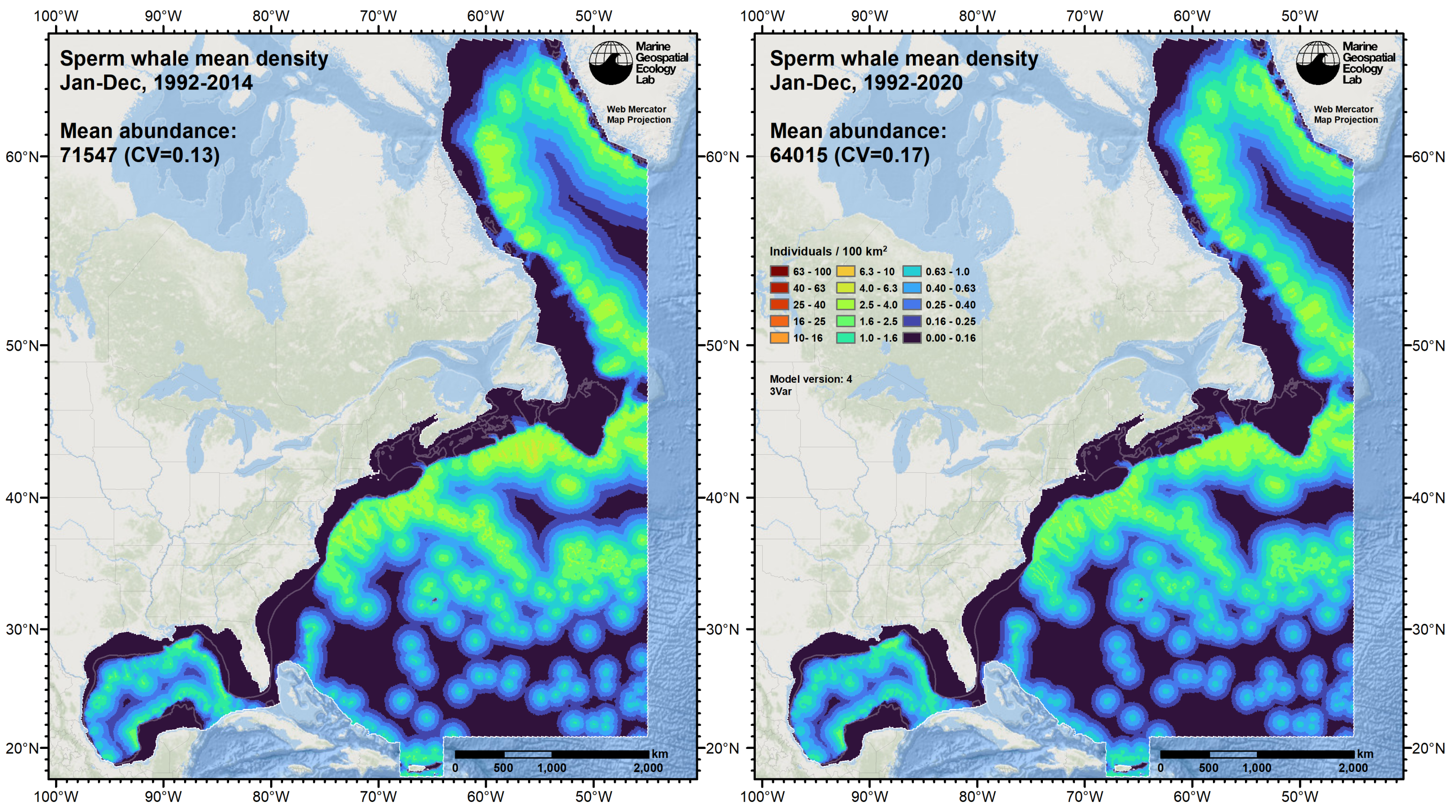


Figure 11: Comparison of the mean density predictions from the previous model (left) released by Mannocci et al. (2017) to those from this model (right). These maps use a Web Mercator projection but the analysis was conducted in an Albers Equal Area coordinate system appropriate for density modeling.

4 Discussion

Following Mannocci et al. (2017), we summarized this model into a single year-round mean density surface (Figure 10). Although our figures show predictions for the entire AFTT study area, we recommend that the regional East Coast (EC) and Gulf of Mexico (GOM) models be used for the waters they cover, and that the AFTT model be used only for waters outside those regions. See Roberts et al. (2023) for more discussion of the models. The EC and GOM models provide predictions as 12 monthly means, rather than a single year-round mean.

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. We note that predictions off Newfoundland, Labrador, and west Greenland were supported by sightings that occurred on systematic surveys of these areas in 2007 and 2015 (Lawson and Gosselin 2009, 2018; Hansen and Heide-Jørgensen 2013; Hansen et al. 2019) but where not available for use in this model. Future updates would benefit from their inclusion. Predictions of sperm whales in these areas were also supported by numerous opportunistic sightings reported in the OBIS-SEAMAP archive (Halpin et al. 2009) (https://seamap.env.duke.edu/species/180488).

The new model estimated about 11% lower abundance than the prior model. We suspect this difference mainly relates to slightly different bias corrections used in the new model, but more investigation is needed to determine the cause definitively. In any case, the abundance estimates of the two models were not significantly different statistically.

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

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.

Geo-Marine, Inc. (2010) New Jersey Department of Environmental Protection Baseline Studies Final Report Volume III: Marine Mammal and Sea Turtle Studies. Geo-Marine, Inc., Plano, TX

Halpin P, Read A, Fujioka E, Best B, Donnelly B, Hazen L, Kot C, Urian K, LaBrecque E, Dimatteo A, Cleary J, Good C, Crowder L, Hyrenbach KD (2009) OBIS-SEAMAP: The World Data Center for Marine Mammal, Sea Bird, and Sea Turtle Distributions. Oceanography 22:104–115. doi: 10.5670/oceanog.2009.42

Hansen RG, Heide-Jørgensen MP (2013) Spatial trends in abundance of long-finned pilot whales, white-beaked dolphins and harbour porpoises in West Greenland. Mar Biol 160:2929–2941. doi: 10.1007/s00227-013-2283-8

Hansen RG, Boye TK, Larsen RS, Nielsen NH, Tervo O, Nielsen RD, Rasmussen MH, Sinding MHS, Heide-Jørgensen MP (2019) Abundance of whales in West and East Greenland in summer 2015. NAMMCO Scientific Publications. doi: 10.7557/3.4689

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

Lawson JW, Gosselin J-F (2009) Distribution and preliminary abundance estimates for cetaceans seen during Canada's Marine Megafauna Survey-A component of the 2007 TNASS. Department of Fisheries and Oceans, St. John's, NL, Canada

Lawson JW, Gosselin J-F (2018) Estimates of cetacean abundance from the 2016 NAISS aerial surveys of eastern Canadian waters, with a comparison to estimates from the 2007 TNASS. NAMMCO SC/25/AE/09. In: Proceedings of the NAMMCO 25th Scientific Committee (SC). North Atlantic Marine Mammal Commission, Bergen-Tromsø, Norway,

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.

Whitt AD, Powell JA, Richardson AG, Bosyk JR (2015) Abundance and distribution of marine mammals in nearshore waters off New Jersey, USA. Journal of Cetacean Research and Management 15:45–59.

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