Density Model for Fin Whale (*Balaenoptera physalus*) 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, and Caribbean and excluded surveys of Europe and the Mid-Atlantic Ridge. We did include segments south of 50 °N and west of 40 °W from a trans-Atlantic survey by R/V Song of the Whale. We excluded surveys that did not target fin whales or were otherwise problematic for modeling them. 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 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	20	35	1.8
NEAq	CNM	2017-2020	2	15	16	1.1
NEAq	MMS-WEA	2017-2020	37	51	93	1.8
NEAq	NLPSC	2011-2015	43	75	126	1.7
NEFSC	AMAPPS	2010-2019	89	131	158	1.2
NEFSC	NARWSS	2003-2020	484	2,192	3,213	1.5
NEFSC	Pre-AMAPPS	1999-2008	46	144	175	1.2
NJDEP	NJEBS	2008-2009	11	1	1	1.0
NYS-DEC/TT	NYBWM	2017-2020	77	82	149	1.8
SEFSC	AMAPPS	2010-2020	114	28	38	1.4
SEFSC	MATS	1995-2005	34	6	13	2.2
SEFSC	SECAS	1992-1995	8	0	0	
U. La Rochelle	REMMOA	2008-2017	42	2	2	1.0
UNCW	MidA Bottlenose	2002-2002	17	1	2	2.0
UNCW	Navy Cape Hatteras	2011-2017	34	5	7	1.4
UNCW	Navy Jacksonville	2009-2017	92	0	0	
UNCW	Navy Norfolk Canyon	2015-2017	14	8	9	1.1
UNCW	Navy Onslow Bay	2007-2011	49	1	1	1.0
UNCW	SEUS NARW EWS	2005-2008	114	12	31	2.6
VAMSC	MD DNR WEA	2013-2015	16	8	13	1.6
VAMSC	Navy VACAPES	2016-2017	19	1	2	2.0
VAMSC	VA CZM WEA	2012-2015	21	11	27	2.5
		Total	**1,376**	**2,794**	**4,111**	**1.5**
Shipboard Surveys						
MCR	SOTW Visual	2012-2019	9	19	29	1.5
NEFSC	AMAPPS	2011-2016	16	259	365	1.4
NEFSC	Pre-AMAPPS	1995-2007	18	160	218	1.4
NJDEP	NJEBS	2008-2009	14	24	35	1.5
SEFSC	AMAPPS	2011-2016	17	5	7	1.4
SEFSC	Pre-AMAPPS	1992-2006	33	11	15	1.4
SEFSC	SEFSC Caribbean	1995-2000	8	1	1	1.0
		Total	**115**	**479**	**670**	**1.4**
		Grand Total	**1,491**	**3,273**	**4,781**	**1.5**

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

Institution	Full Name
HDR	HDR, Inc.

Table 2: Institutions that contributed surveys used in this model. *(continued)*

Institution	Full Name
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)
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)
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)
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 Visual	R/V Song of the Whale Visual Surveys	Ryan et al. (2013)

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

Program	Description	References
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 distance to sea surface temperature (SST) fronts, micronekton productivity, SST, and slope of the seafloor. All covariates were retained during smoothness selection but moderately different relationships were fitted to all covariates except for the distance to fronts covariate (Figure 2), for which the fit was essentially the same as Mannocci et al.'s model. In our model, density decreased sharply as micronekton productivity decreased below 1 g m^{-2} while in Mannocci's, the relationship turned back toward positive. In our model, the influence of SST was weaker and turned negative below 9 °C, while in Mannocci's it remained positive down to the coldest sampled value, and also exerted a stronger negative influence at temperatures greater than about 25 °C. Finally, in our model, the relationship for slope was weaker and hump-shaped, while in Mannocci's it plateaued at high values without turning back negative. These relationships yielded somewhat different predictions in our model (Section 3), which we discuss below (Section 4). Univariate extrapolation analyses (Section 2.3.1) displayed geographic patterns very similar to the environmental envelopes estimated by Mannocci et al. The necessity for univariate environmental extrapolation was driven mainly by a lack of sampling in waters with with very few SST fronts, as occurs in the southeast corner of the AFTT area in summer (Figure 9), and in waters with low sea surface temperatures (Figure 11), as occurs from late fall through spring along the coasts of Newfoundland, Labrador, and Greenland.

2.1 Final Model

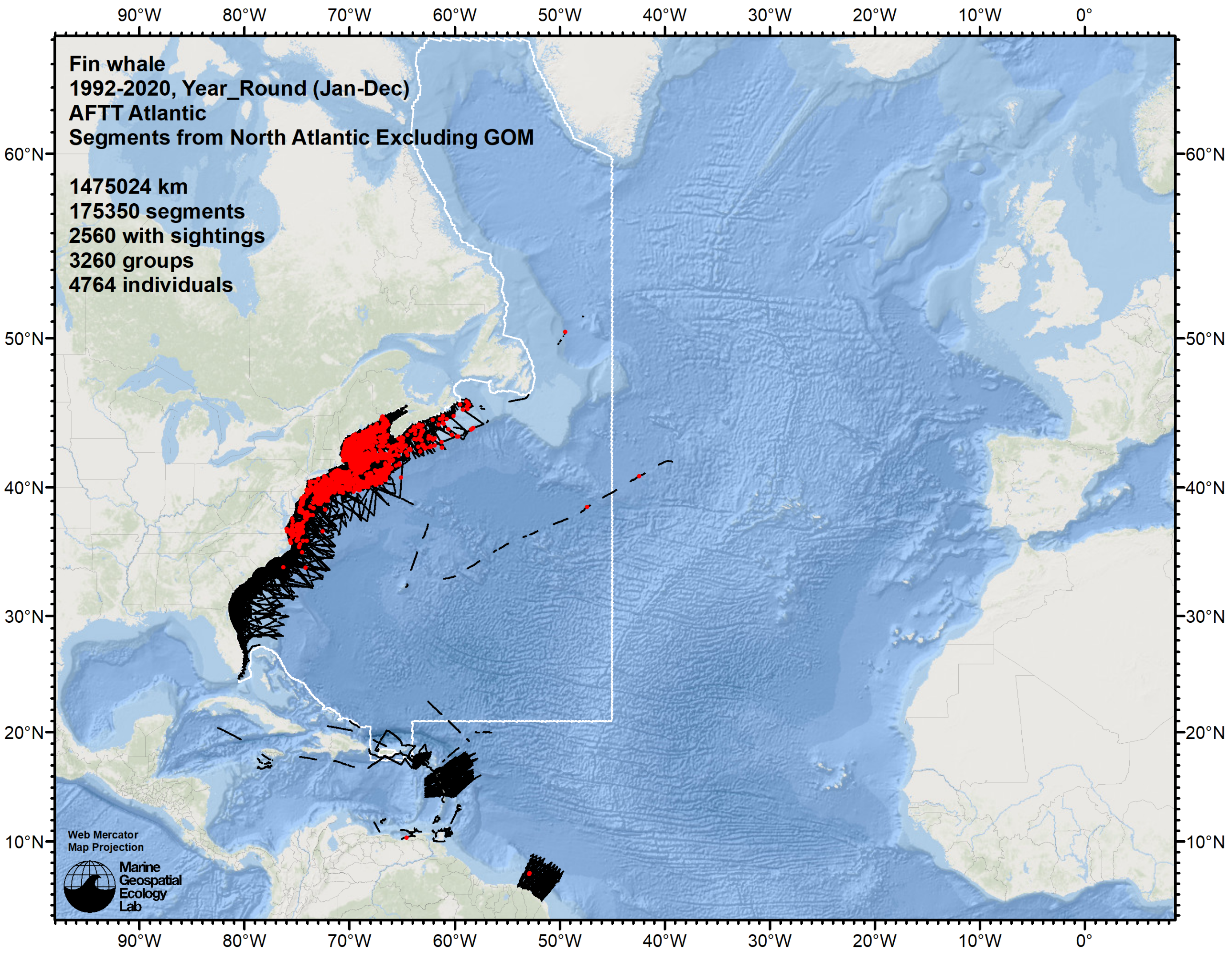
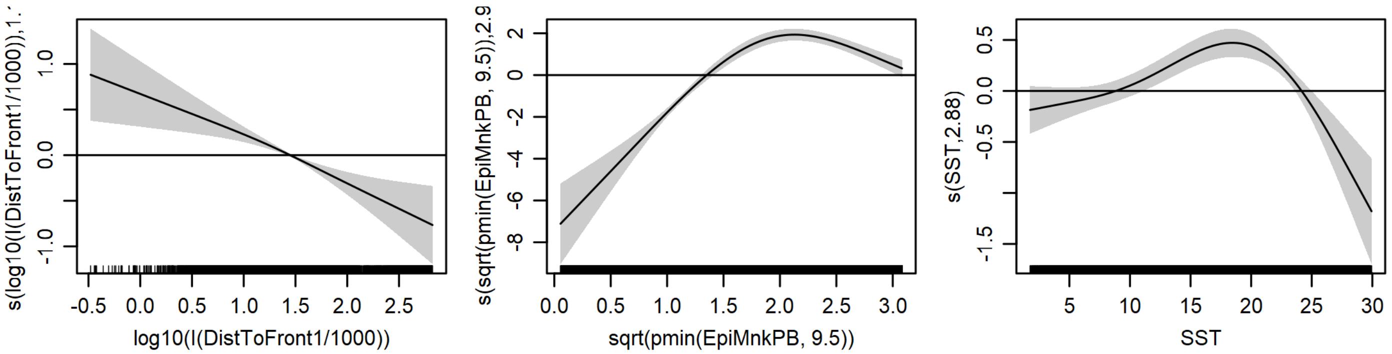


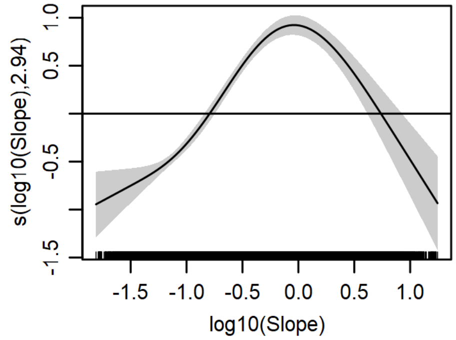
Figure 1: Survey segments (black lines) used to fit the model for the region AFTT Atlantic. Red points indicate segments with observations. This map uses a Web Mercator projection but the analysis was conducted in an Albers Equal Area coordinate system appropriate for density modeling.

Statistical output for this model:

```
Family: Tweedie(p=1.169)
Link function: log

Formula:
IndividualsCorrected ~ offset(log(SegmentArea)) + s(log10(I(DistToFront1/1000)),
    bs = "ts", k = 4) + s(sqrt(pmin(EpiMnkPB, 9.5)), bs = "ts",
    k = 4) + s(log10(Slope), bs = "ts", k = 4) + s(SST, bs = "ts",
    k = 4)

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -21.2419     0.1341  -158.4   <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(I(DistToFront1/1000))) 1.114      3   9.999  <2e-16 ***
s(sqrt(pmin(EpiMnkPB, 9.5)))   2.907      3 110.747  <2e-16 ***
s(log10(Slope))                2.941      3 121.354  <2e-16 ***
s(SST)                         2.878      3  25.327  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.0219   Deviance explained = 12.7%
-REML =  17159  Scale est. = 7.7317    n = 175350

Method: REML   Optimizer: outer newton
full convergence after 10 iterations.
Gradient range [-0.008985177,0.00826217]
(score 17158.71 & scale 7.731674).
Hessian positive definite, eigenvalue range [0.2601506,17124.02].
Model rank =  13 / 13

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(I(DistToFront1/1000))) 3.00 1.11    0.90    0.73
s(sqrt(pmin(EpiMnkPB, 9.5)))   3.00 2.91    0.85    0.01 **
s(log10(Slope))                3.00 2.94    0.88    0.19
s(SST)                         3.00 2.88    0.88    0.17
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```



(a) Climatological distance to SST front (km) (b) Climatological epipelagic micronekton biomass (g m^{-2}) (c) Climatological sea surface temperature (°C)



(d) Seafloor slope (percent rise)

Figure 2: Functional plots for the final model for the region AFTT Atlantic. Transforms and other treatments are indicated in axis labels. *log10* indicates the covariate was $\log_{10}$ transformed. *sqrt* indicates the covariate was square-root transformed. *pmax* and *pmin* indicate the covariate's minimum and maximum values, respectively, were Winsorized to the values shown. Winsorization was used to prevent runaway extrapolations during prediction when covariates exceeded sampled ranges, or for ecological reasons, depending on the covariate. */1000* indicates meters were transformed to kilometers for interpretation convenience.

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

Covariate	Description
DistToFront1	Climatological monthly mean distance (km) to the closest sea surface temperature front detected in daily GHRSST Level 4 CMC0.2deg images (Brasnett (2008); Canada Meteorological Center (2012)) with MGET's implementation of the Canny edge detector (Roberts et al. (2010); Canny (1986))
EpiMnkPB	Climatological monthly mean micronekton biomass in the epipelagic zone (g m^{-2}) from SEAPODYM (Lehodey et al. (2008); Lehodey et al. (2015))
SST	Climatological monthly mean sea surface temperature (°C) from GHRSST Level 4 CMC0.2deg (Brasnett (2008); Canada Meteorological Center (2012))
Slope	Slope (percent rise) of the seafloor, derived from SRTM30_PLUS (Becker et al. (2009))

2.2 Diagnostic Plots

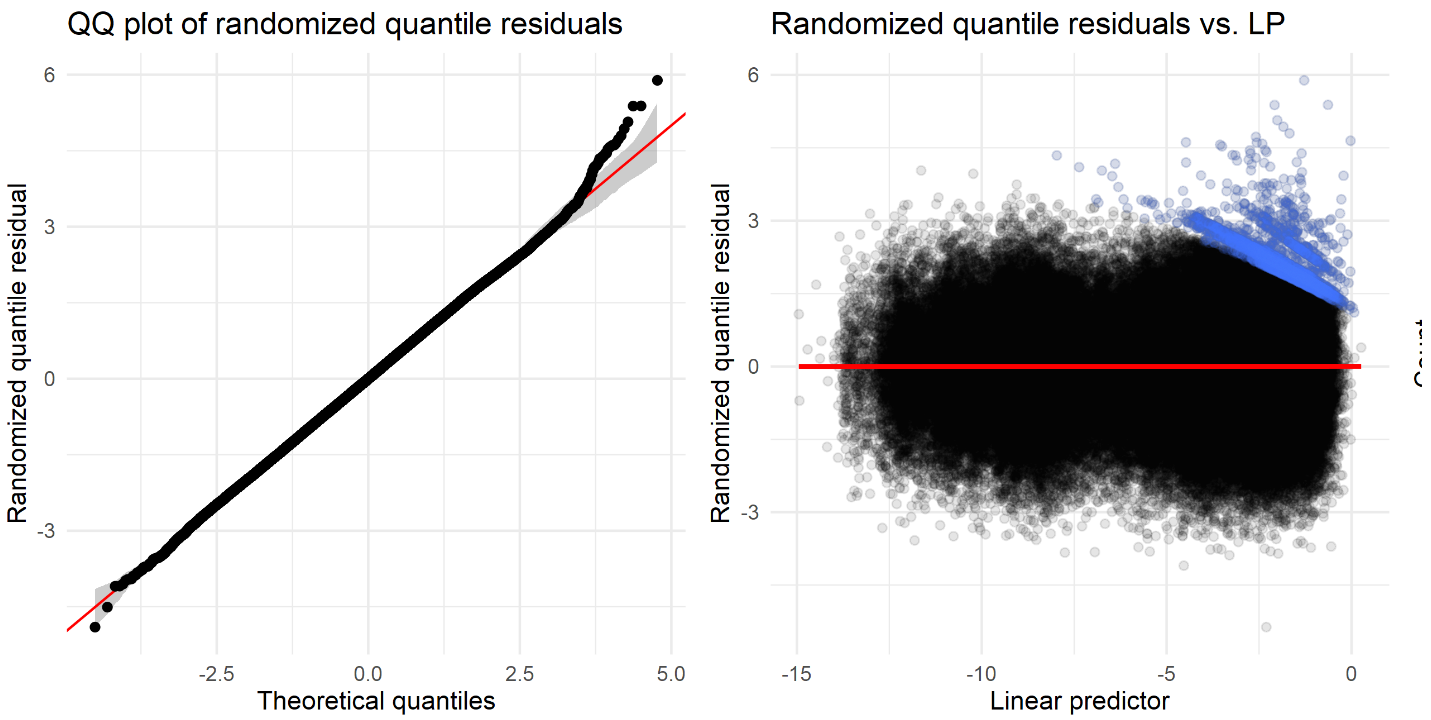


Figure 3: Residual plots for the final model for the region AFTT Atlantic.

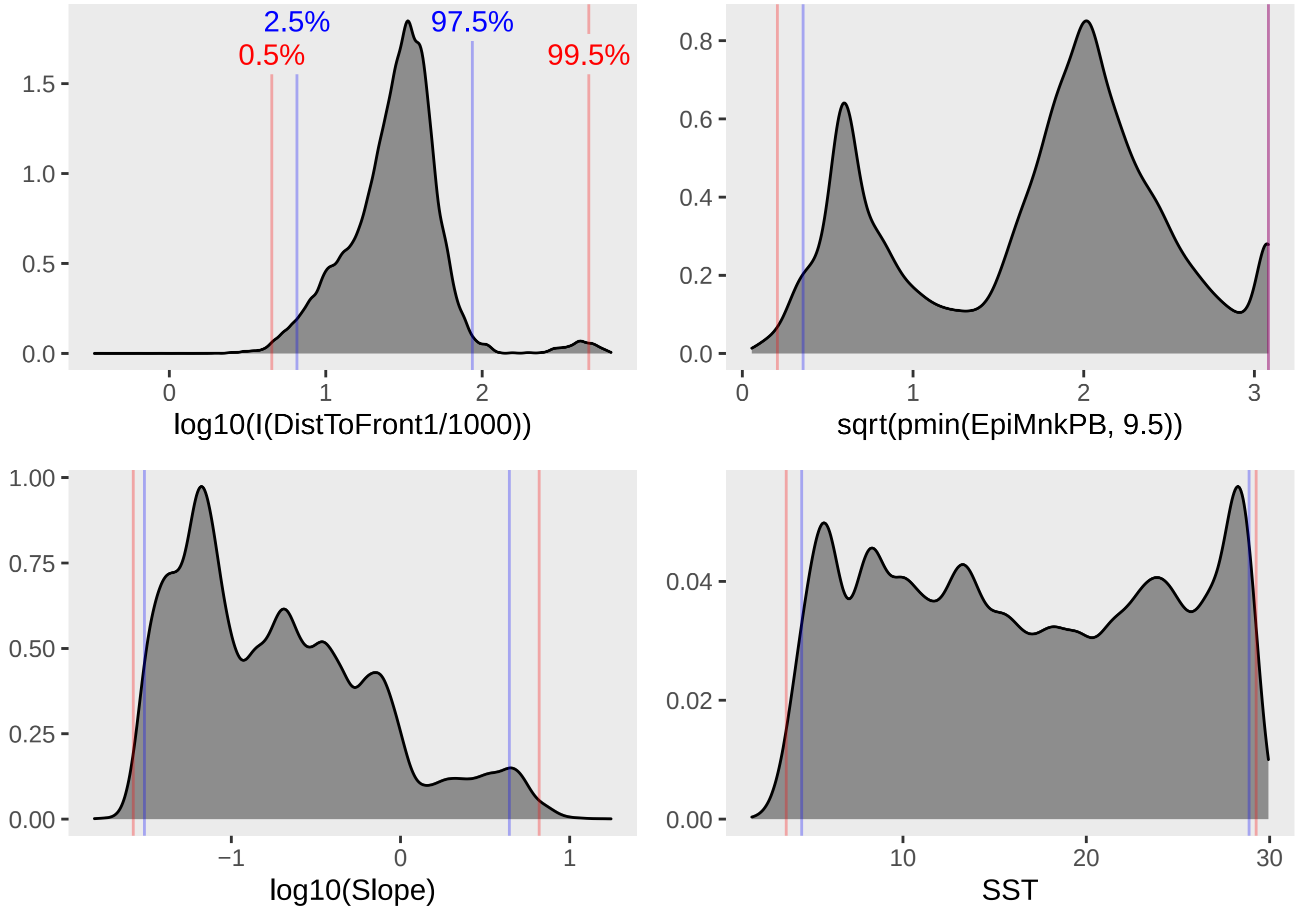


Figure 4: Density histograms showing the distributions of the covariates considered during the final model selection step. The final model may have included only a subset of the covariates shown here (see Figure 2), and additional covariates may have been considered in preceding selection steps. Red 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. *pmax* and *pmin* indicate the covariate's minimum and maximum values, respectively, were Winsorized to the values shown. Winsorization was used to prevent runaway extrapolations during prediction when covariates exceeded sampled ranges, or for ecological reasons, depending on the covariate. */1000* indicates meters were transformed to kilometers for interpretation convenience.

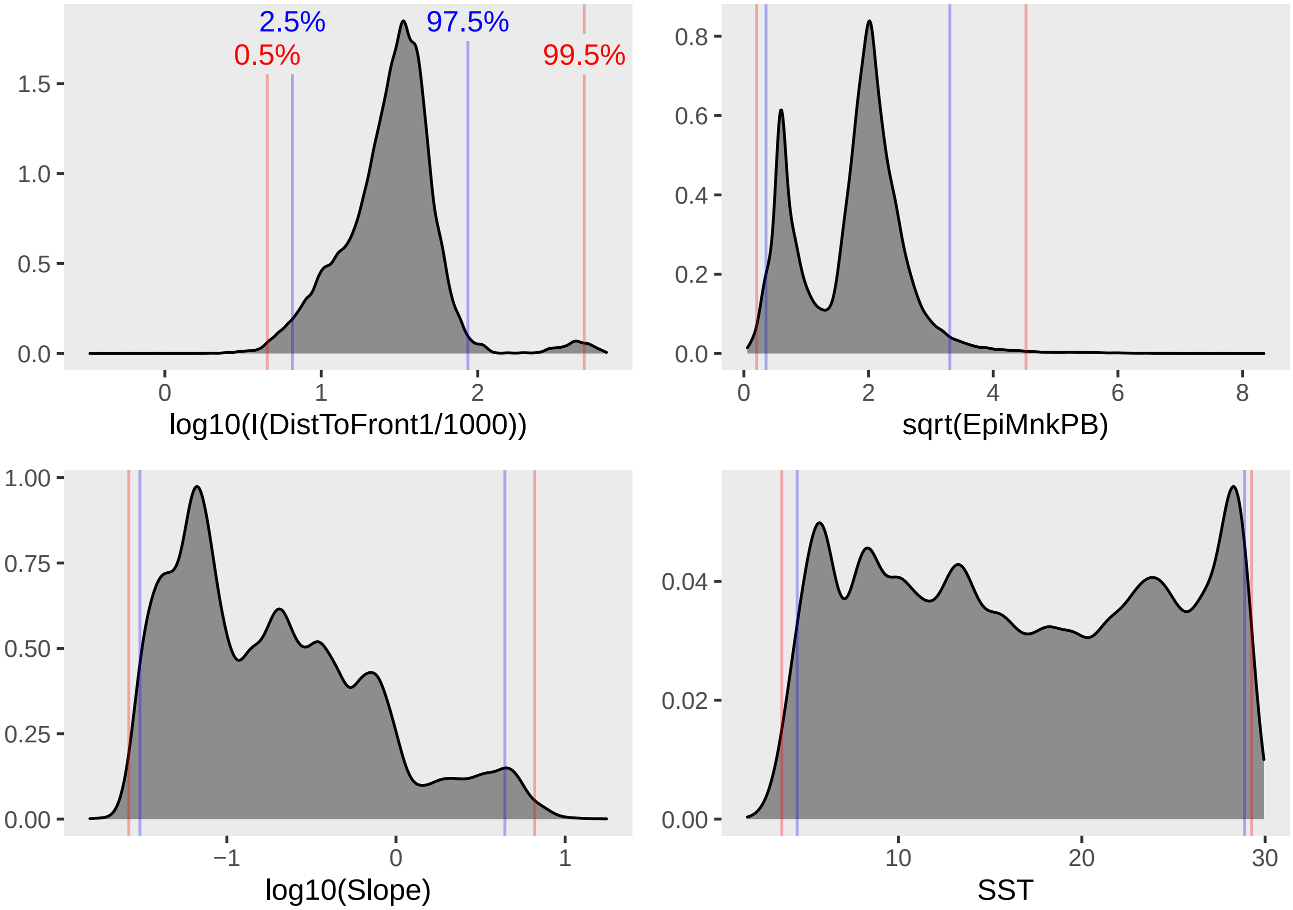


Figure 5: Density histograms shown in Figure 4 replotted without Winsorization, to show the full range of sampling represented by survey segments.

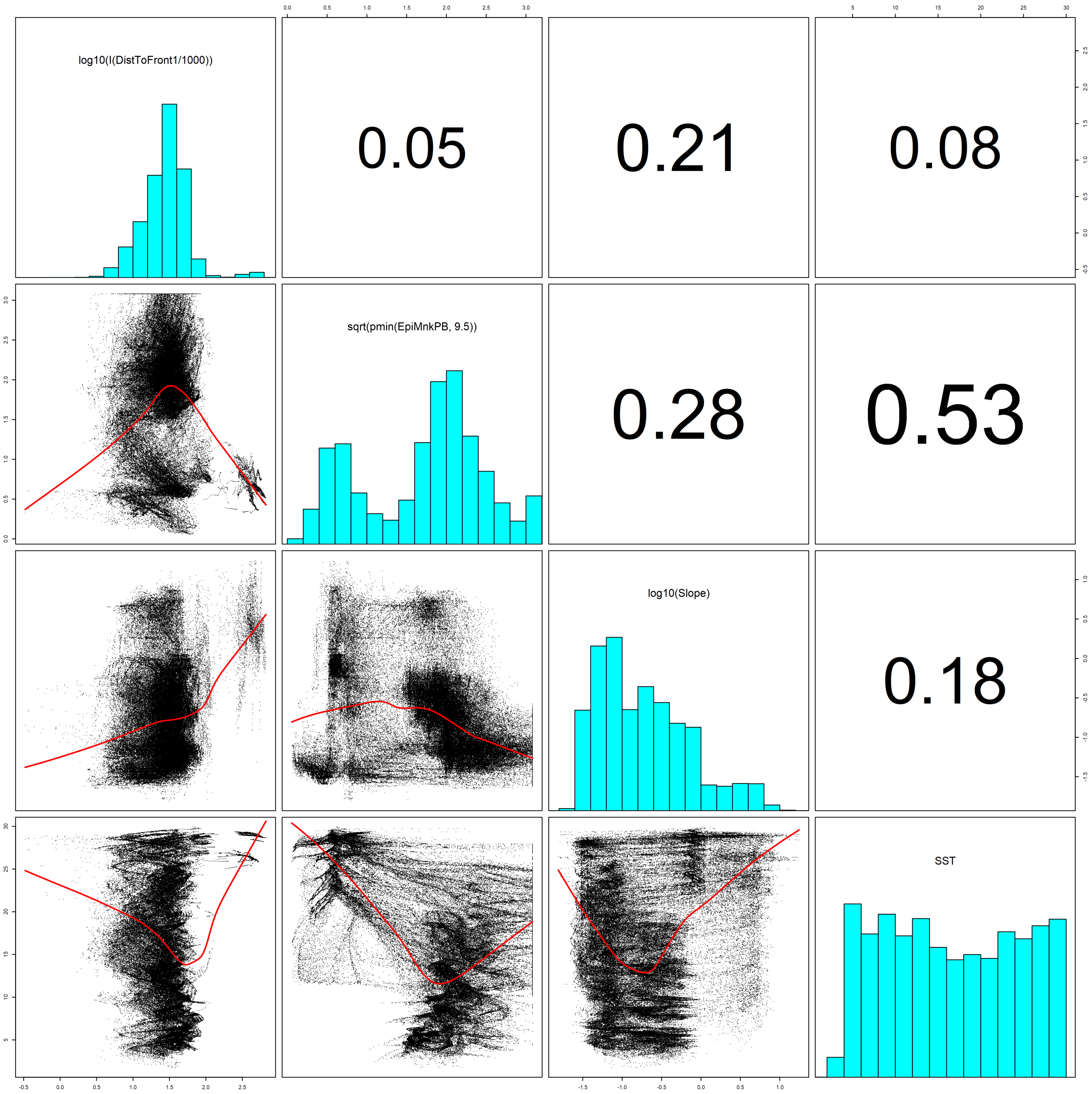


Figure 6: Scatterplot matrix of the covariates considered during the final model selection step. The final model may have included only a subset of the covariates shown here (see Figure 2), and additional covariates may have been considered in preceding selection steps. Covariates are transformed and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

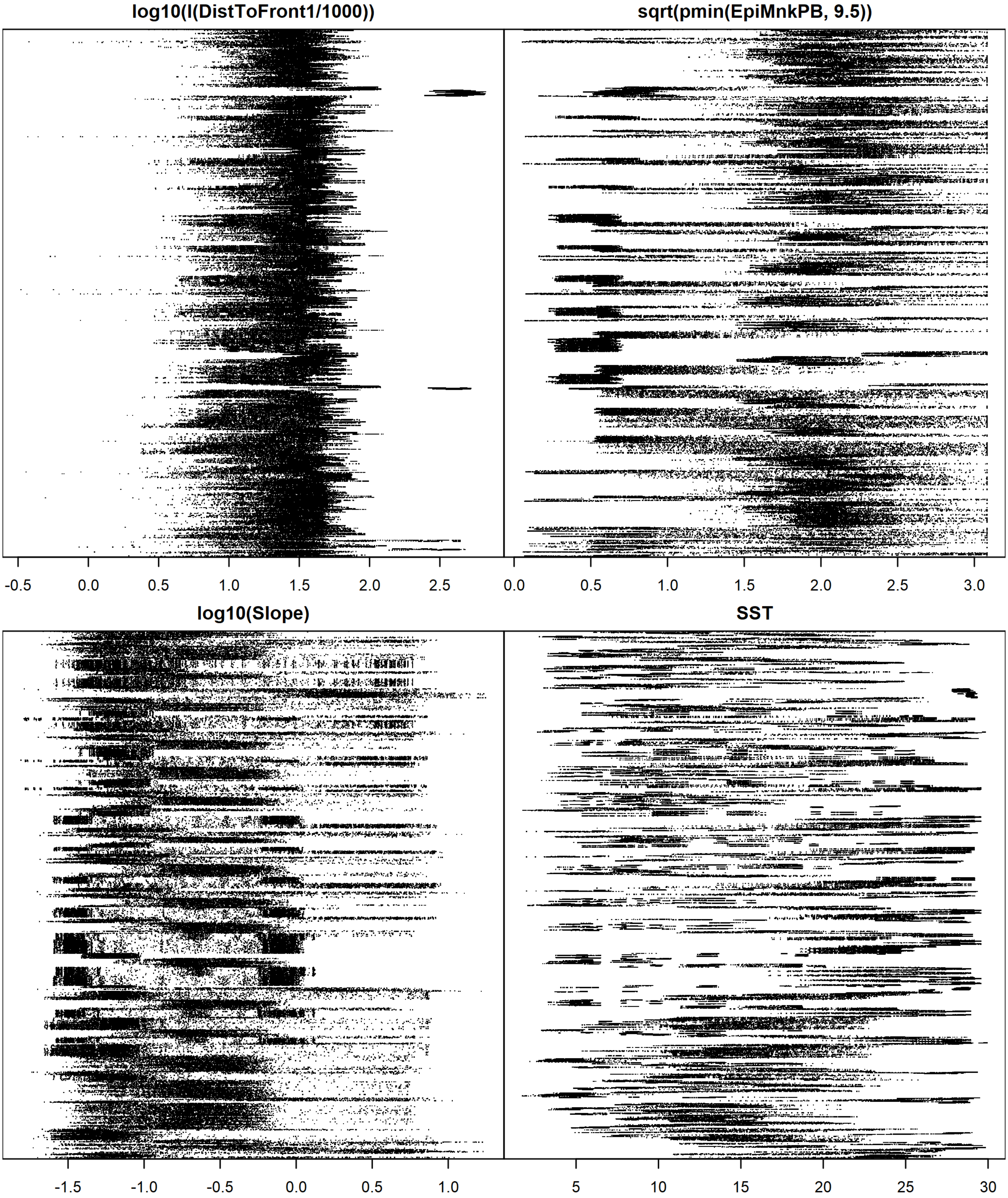


Figure 7: Dotplot of the covariates considered during the final model selection step. The final model may have included only a subset of the covariates shown here (see Figure 2), and additional covariates may have been considered in preceding selection steps. Covariates are transformed and Winsorized 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

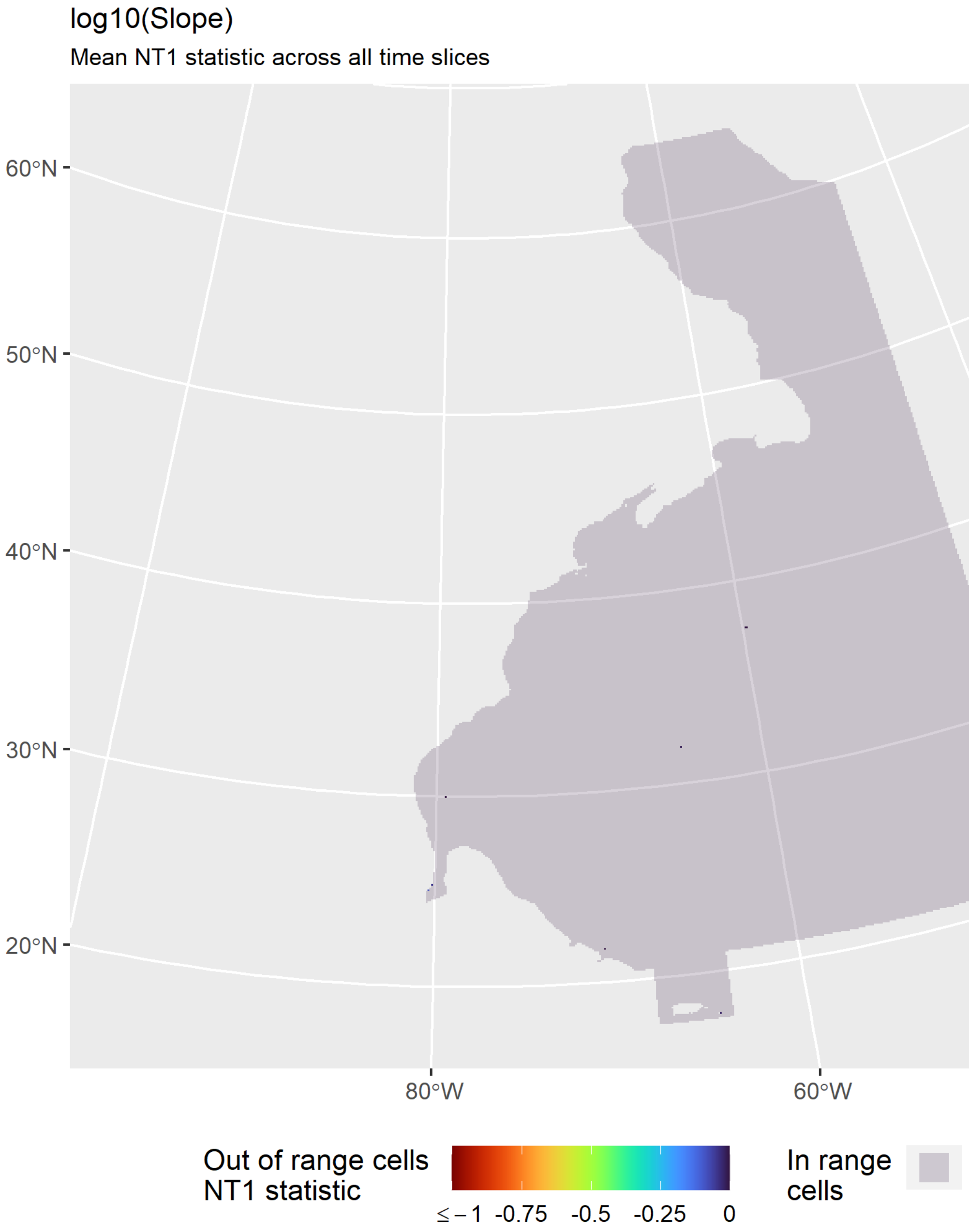
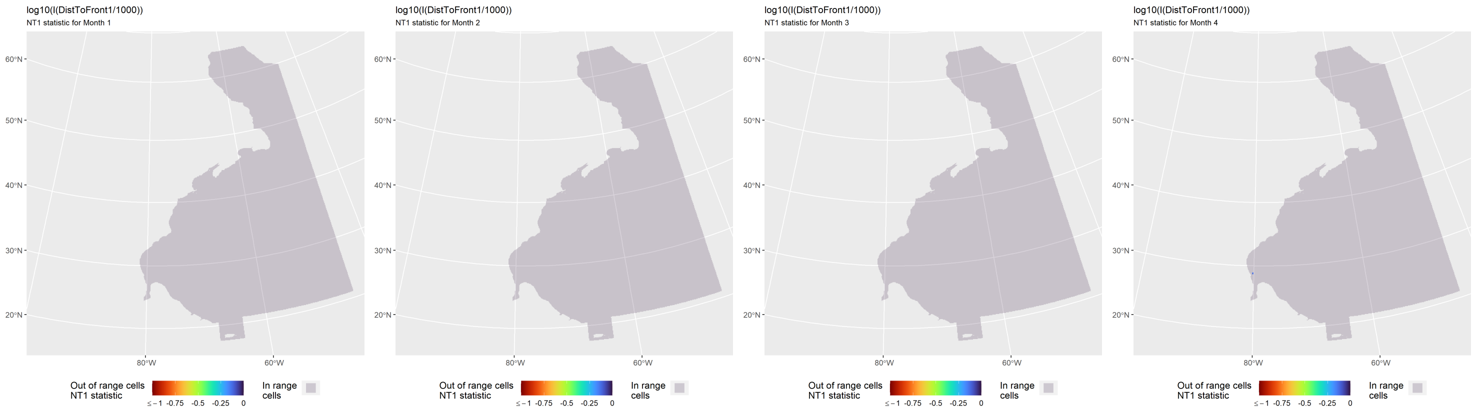
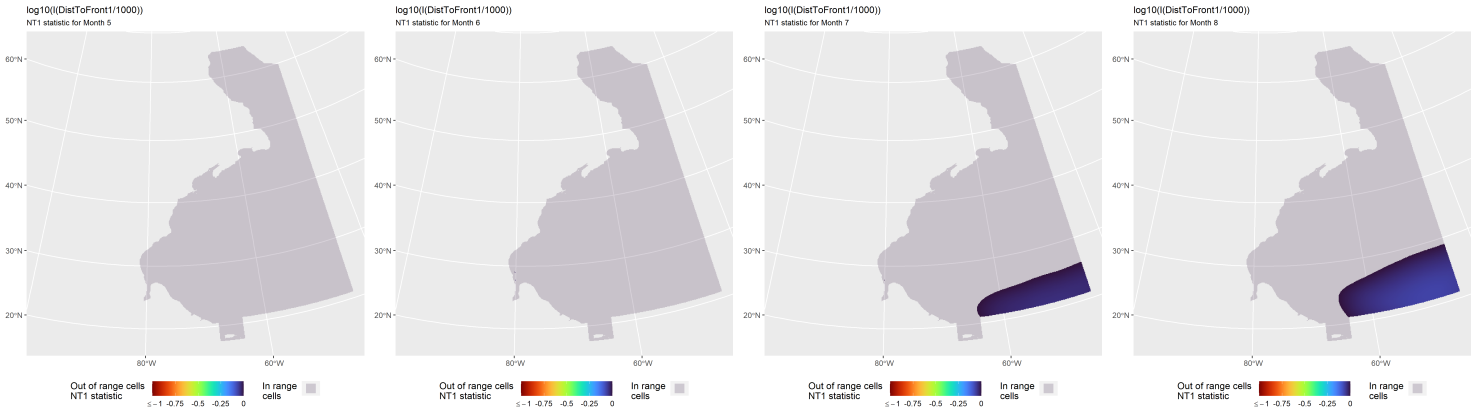


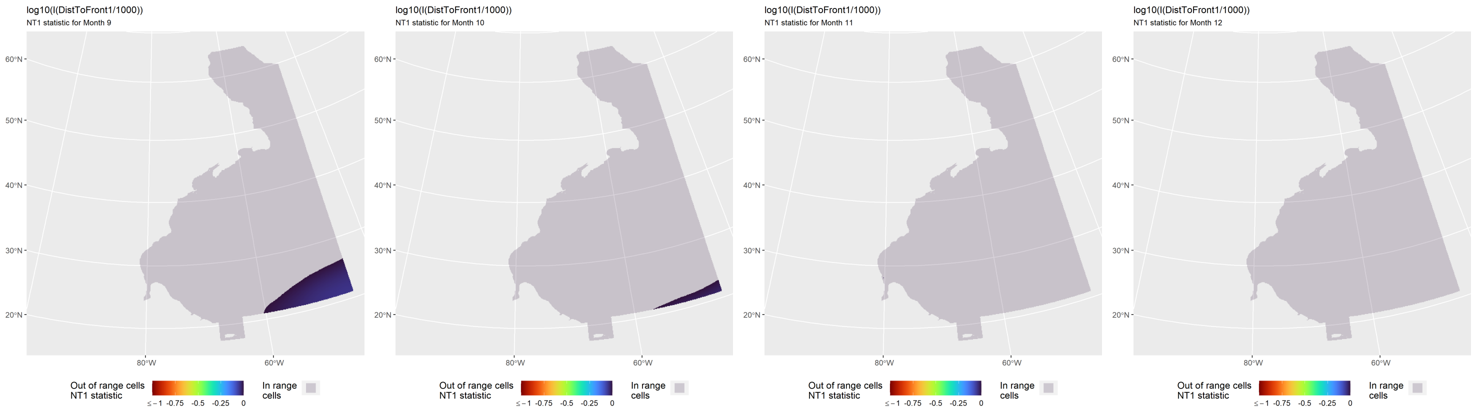
Figure 8: NT1 statistic (Mesgaran et al. (2014)) for static covariates used in the model for the region AFTT Atlantic. Areas outside the sampled range of a covariate appear in color, indicating univariate extrapolation of that covariate occurred there. Areas within the sampled range appear in gray, indicating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



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

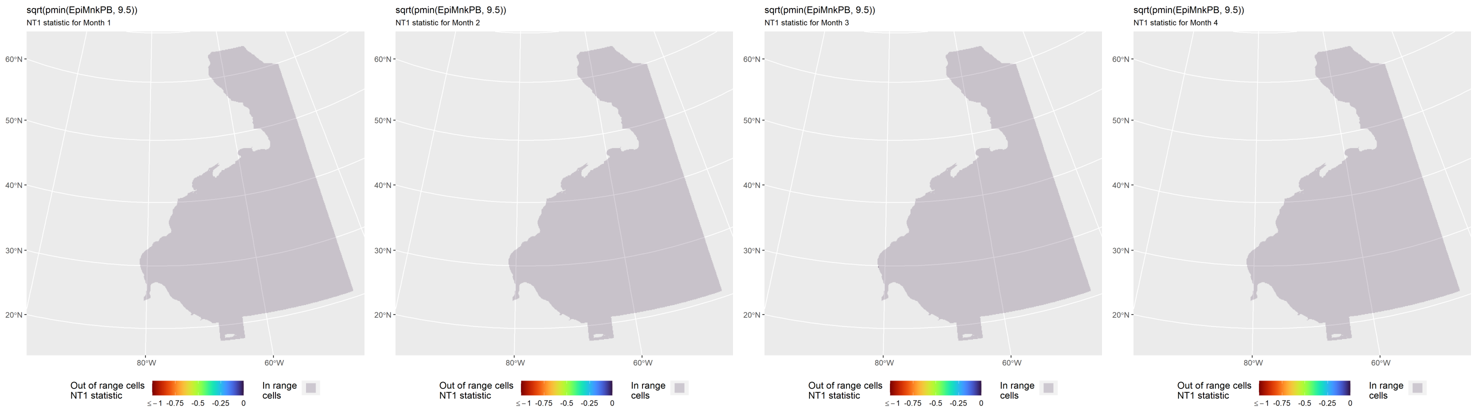


(e) May (f) June (g) July (h) August

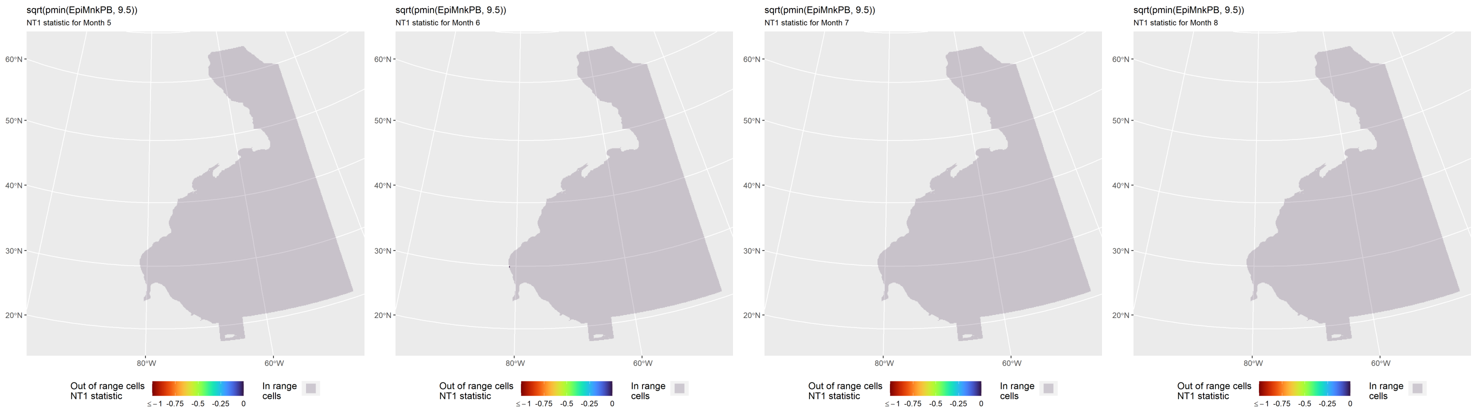


(i) September (j) October (k) November (l) December

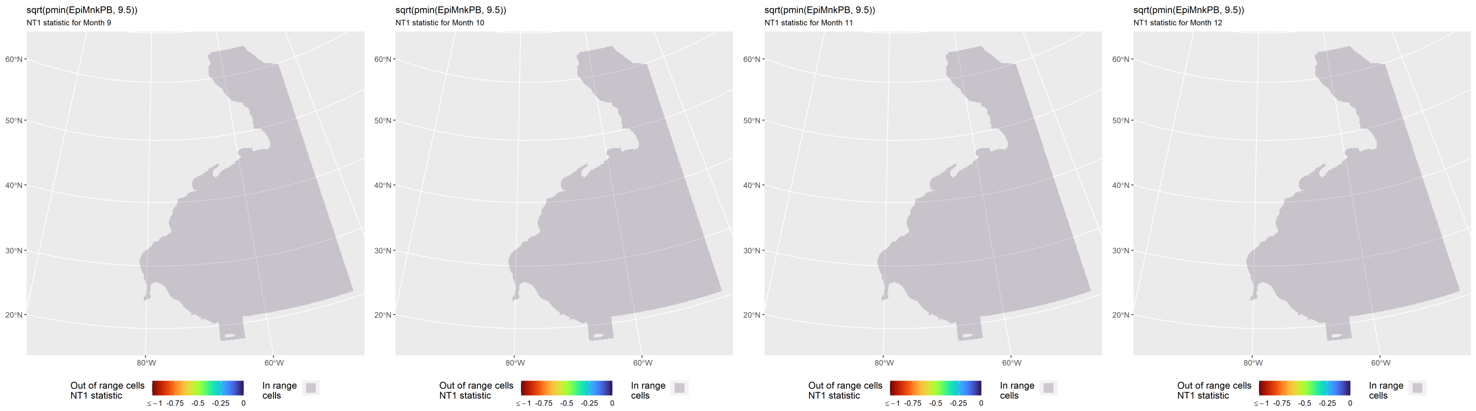
Figure 9: NT1 statistic (Mesgaran et al. (2014)) for the DistToFront1 covariate in the model for the region AFTT Atlantic. Areas outside the sampled range of a covariate appear in color, indicating univariate extrapolation of that covariate occurred there during the month. Areas within the sampled range appear in gray, indicating it did not occur.



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

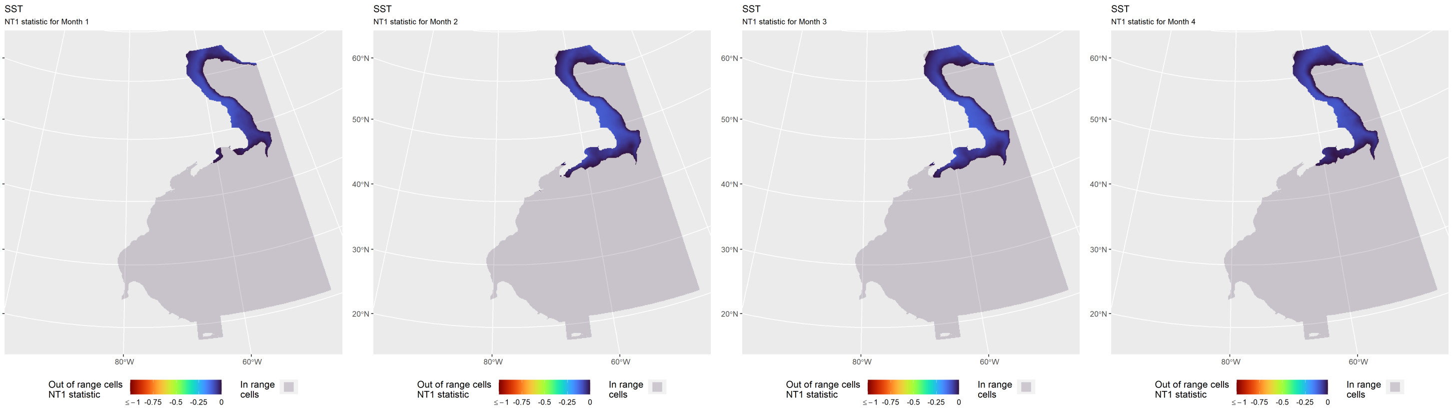


(e) May (f) June (g) July (h) August

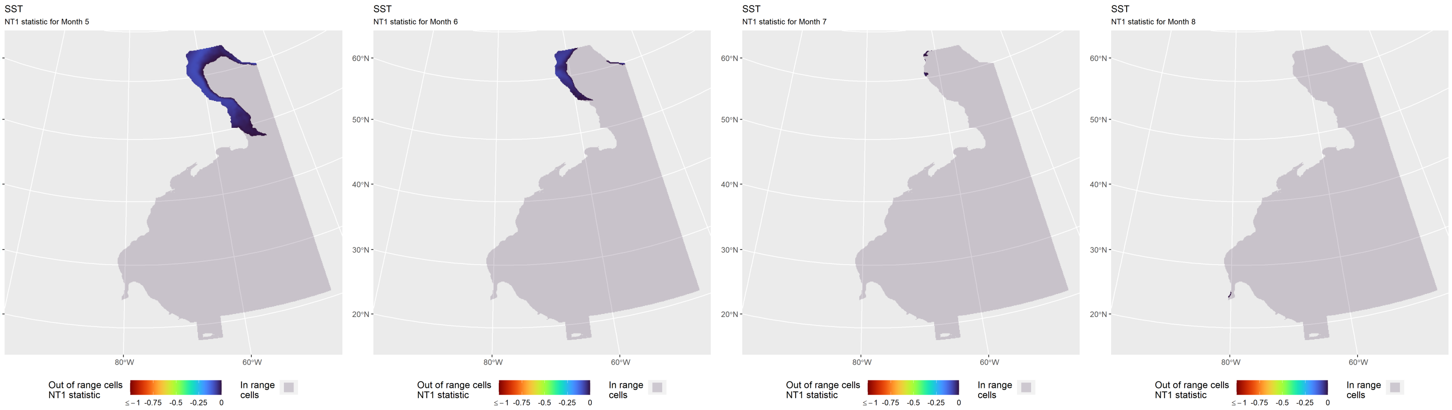


(i) September (j) October (k) November (l) December

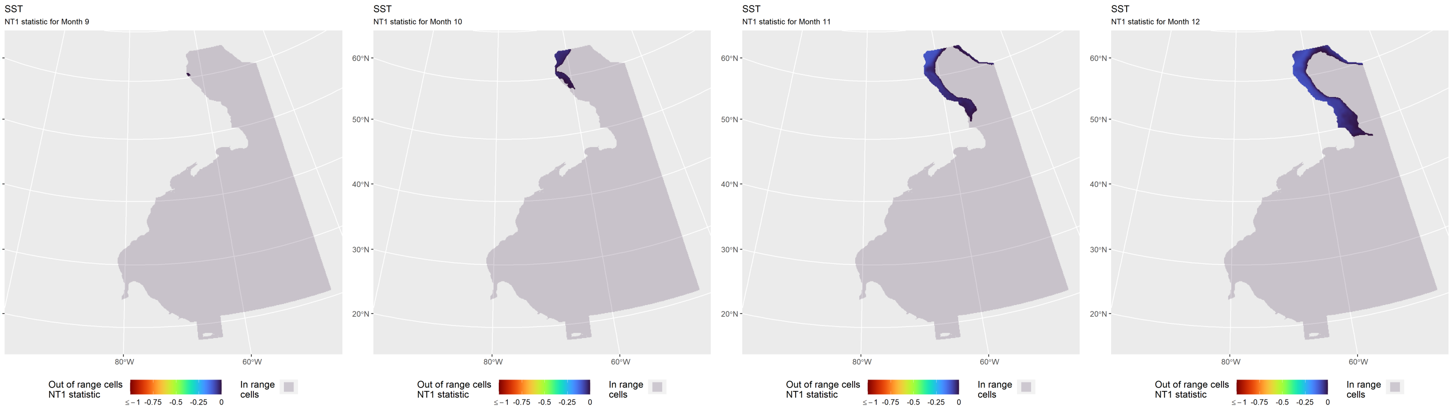
Figure 10: NT1 statistic (Mesgaran et al. (2014)) for the EpiMnkPB covariate in the model for the region AFTT Atlantic. Areas outside the sampled range of a covariate appear in color, indicating univariate extrapolation of that covariate occurred there during the month. Areas within the sampled range appear in gray, indicating it did not occur.



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



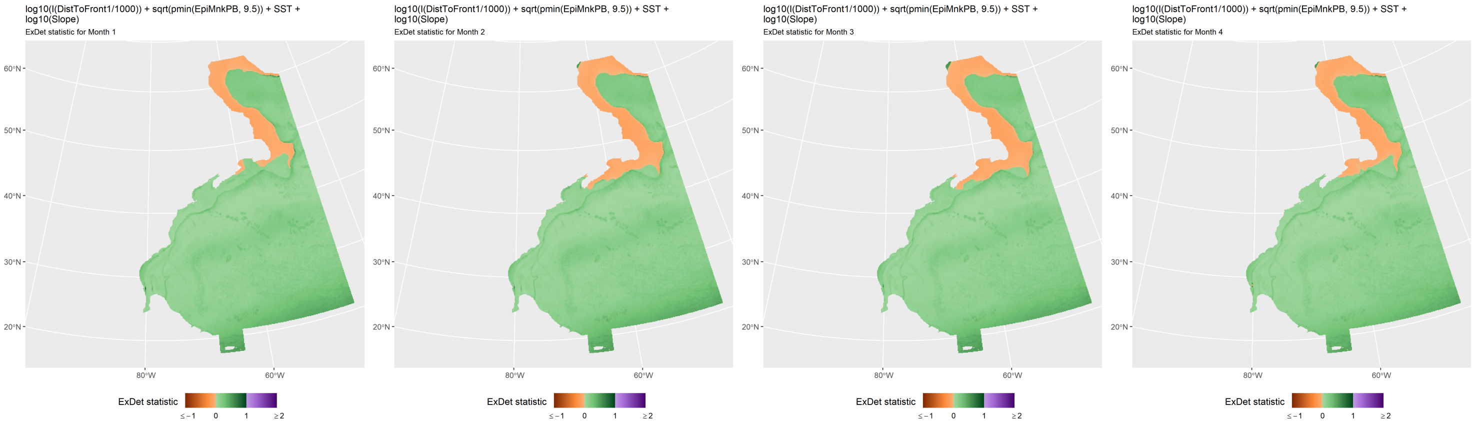
(e) May (f) June (g) July (h) August



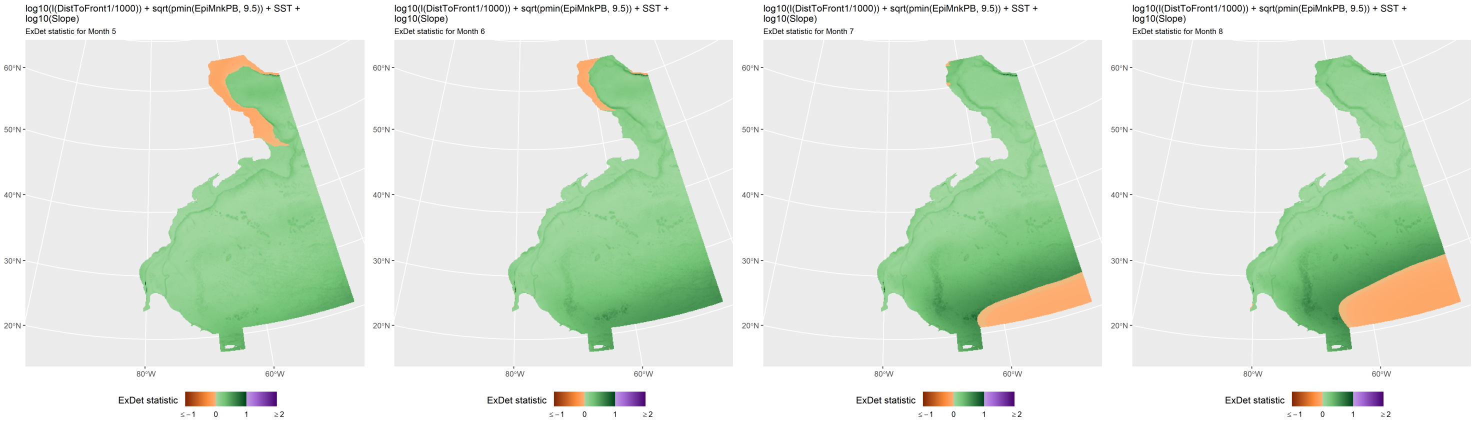
(i) September (j) October (k) November (l) December

Figure 11: NT1 statistic (Mesgaran et al. (2014)) for the SST covariate in the model for the region AFTT Atlantic. 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.

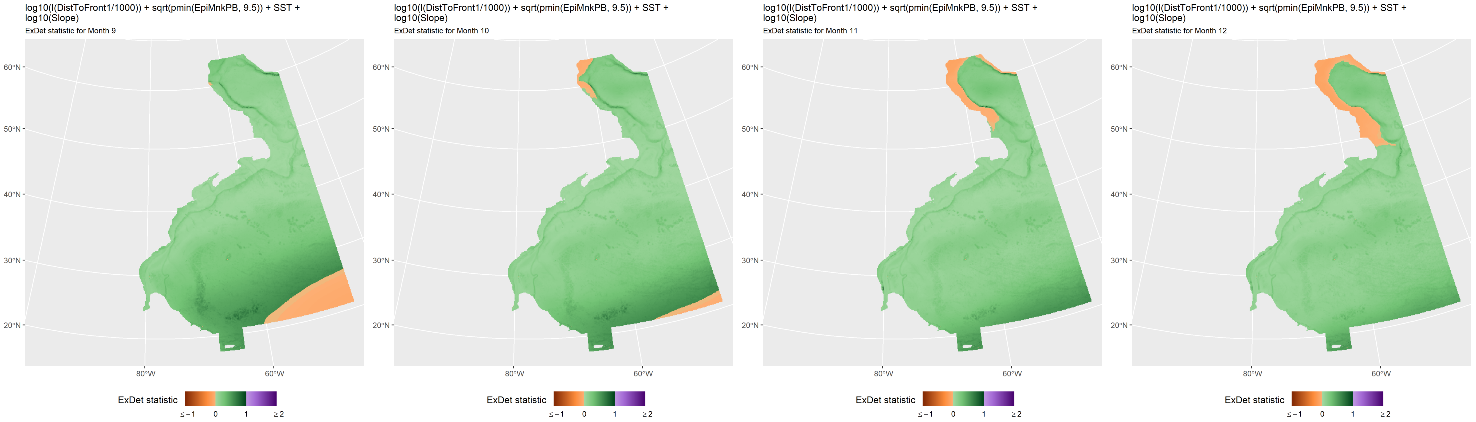
2.3.2 Multivariate Extrapolation



(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 12: ExDet statistic (Mesgaran et al. (2014)) for all of the covariates used in the model for the region AFTT Atlantic. 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

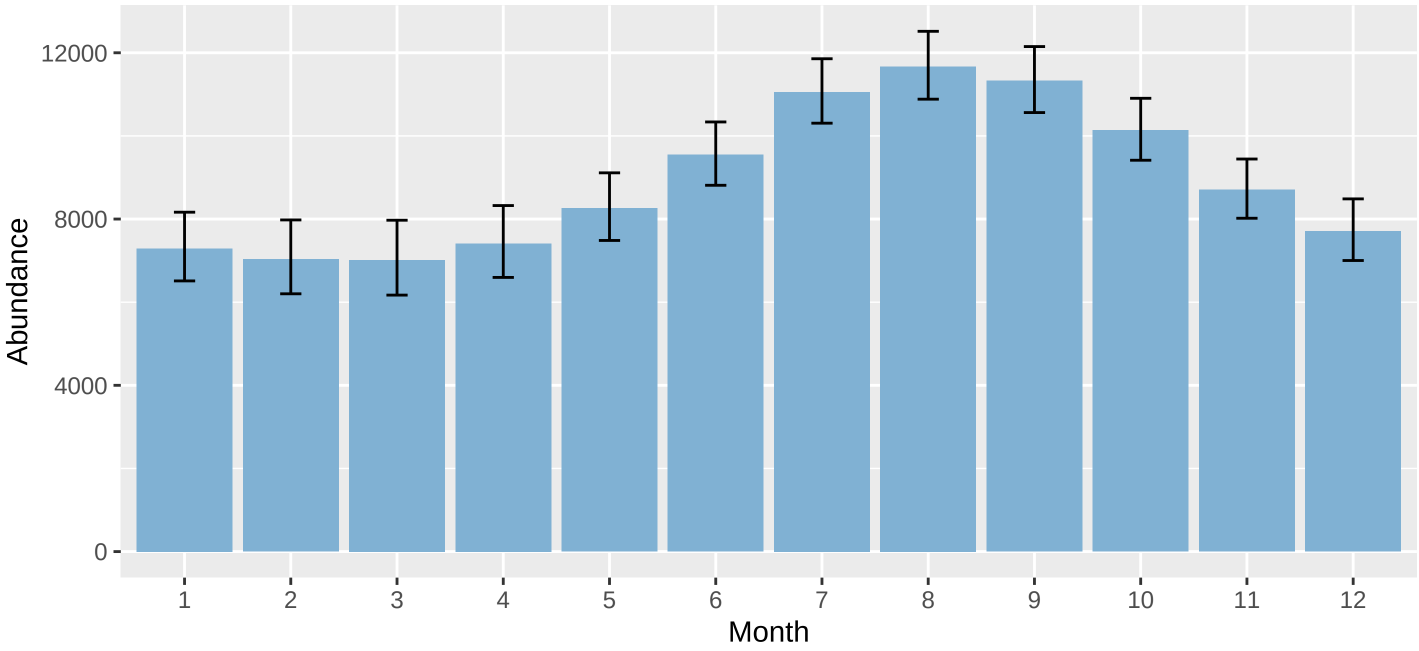


Figure 13: Mean monthly abundance for the prediction area for 1992-2020. Error bars are a 95% interval, made with a log-normal approximation using the prediction's CV. The CV was estimated with the analytic approach given by Miller et al. (2022), Appendix S1, and accounts both for uncertainty in model parameter estimates and for temporal variability in dynamic covariates.

Table 5: Mean monthly abundance and density for the prediction area for 1992-2020. CV and intervals estimated as described for the previous figure.

Month	Abundance	CV	95% Interval	Area (km^2)	Density (individuals / 100 km^2)
1	7,292	0.058	6,512 - 8,165	11,025,400	0.066
2	7,035	0.064	6,202 - 7,979	11,025,400	0.064
3	7,013	0.065	6,170 - 7,972	11,025,400	0.064
4	7,410	0.059	6,596 - 8,325	11,025,400	0.067
5	8,259	0.050	7,485 - 9,112	11,025,400	0.075
6	9,544	0.041	8,812 - 10,336	11,025,400	0.087
7	11,054	0.036	10,307 - 11,856	11,025,400	0.100
8	11,672	0.036	10,884 - 12,516	11,025,400	0.106
9	11,328	0.036	10,562 - 12,149	11,025,400	0.103
10	10,133	0.037	9,415 - 10,905	11,025,400	0.092
11	8,703	0.042	8,020 - 9,444	11,025,400	0.079
12	7,708	0.049	7,003 - 8,486	11,025,400	0.070

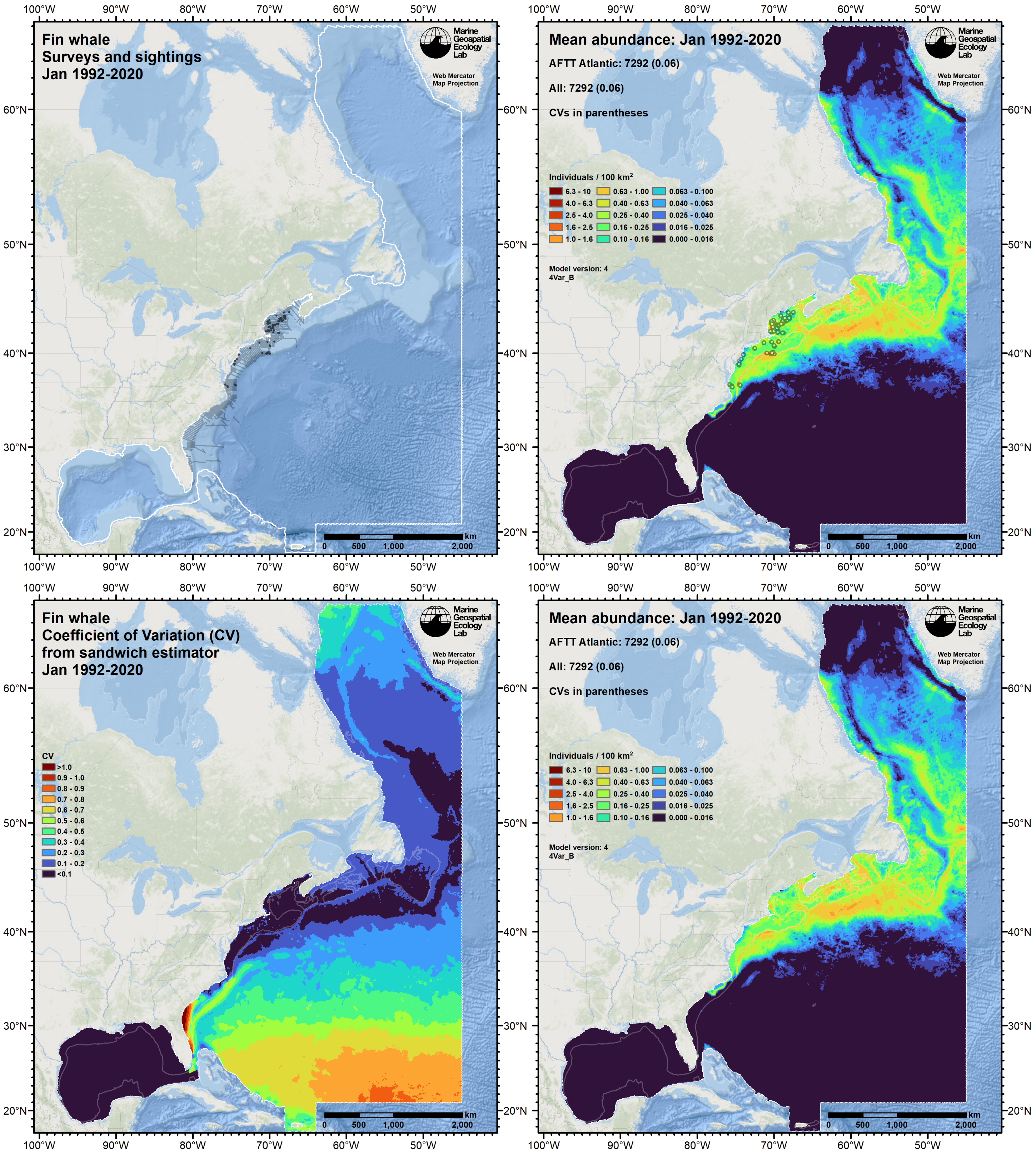


Figure 14: Survey effort and observations (top left), predicted density with observations (top right), predicted density without observations (bottom right), and coefficient of variation of predicted density (bottom left), for the month of January for the given era. Variance was estimated with the analytic 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.

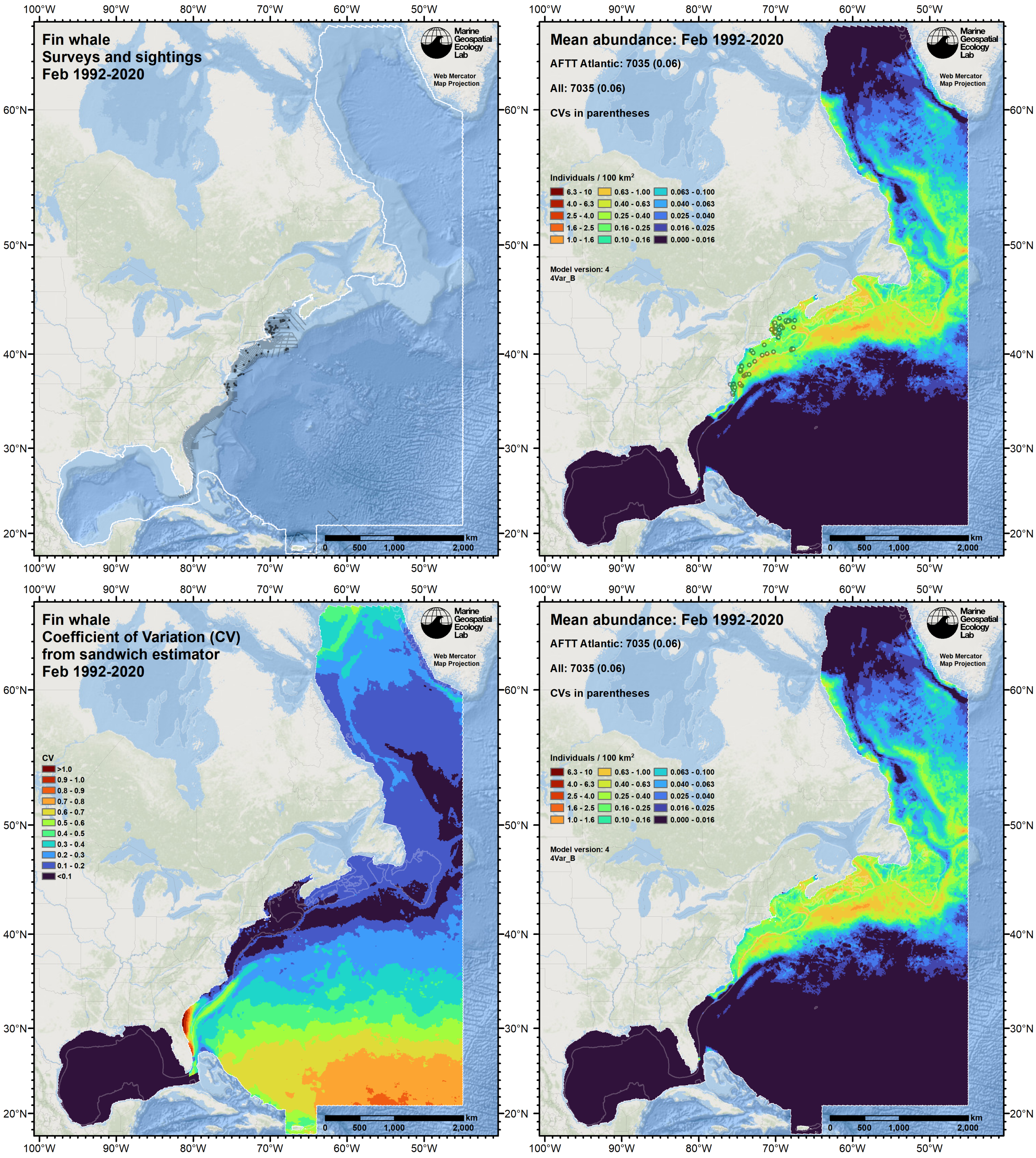


Figure 15: Survey effort and observations (top left), predicted density with observations (top right), predicted density without observations (bottom right), and coefficient of variation of predicted density (bottom left), for the month of February for the given era. Variance was estimated with the analytic 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.

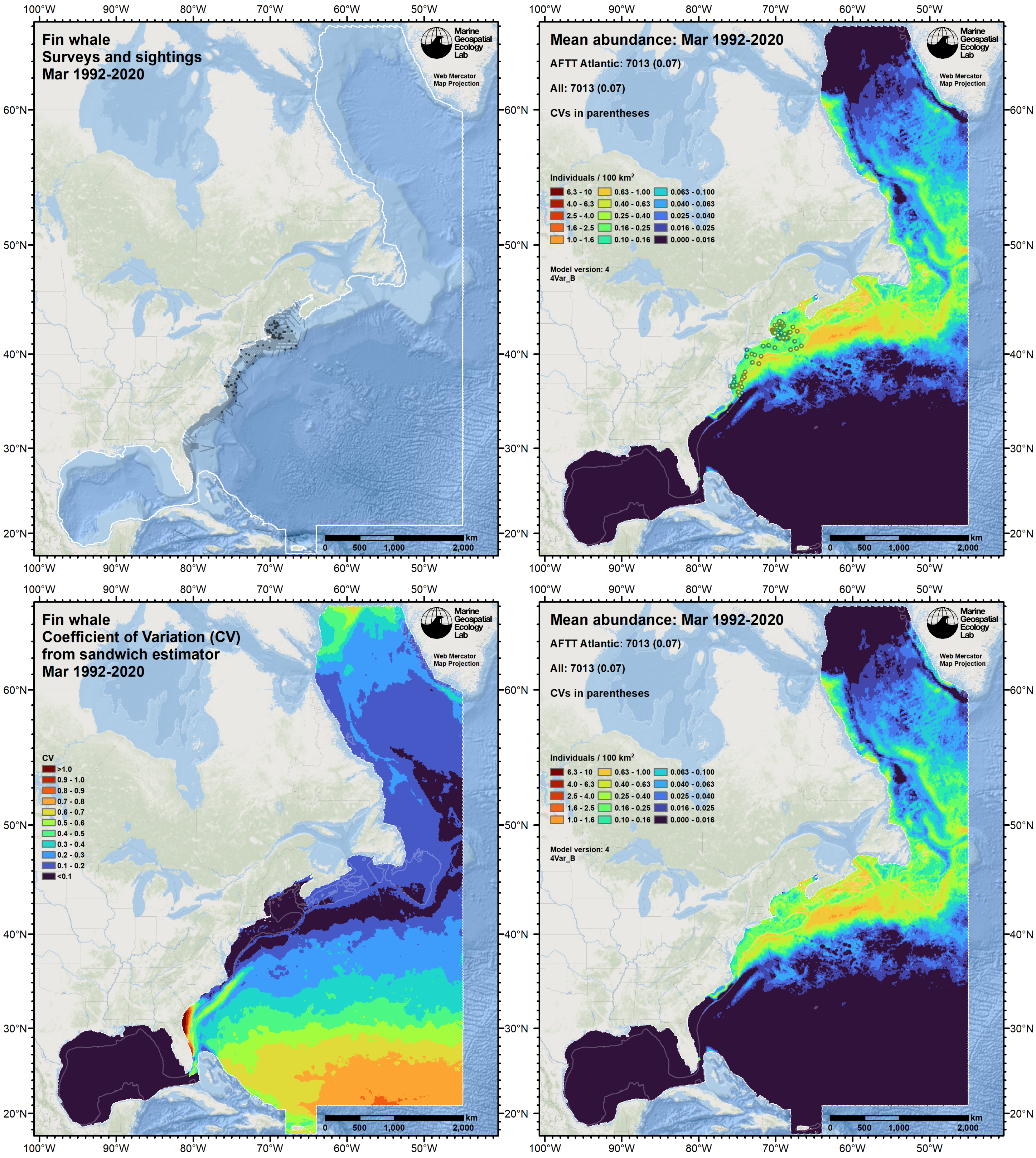


Figure 16: Survey effort and observations (top left), predicted density with observations (top right), predicted density without observations (bottom right), and coefficient of variation of predicted density (bottom left), for the month of March for the given era. Variance was estimated with the analytic 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.

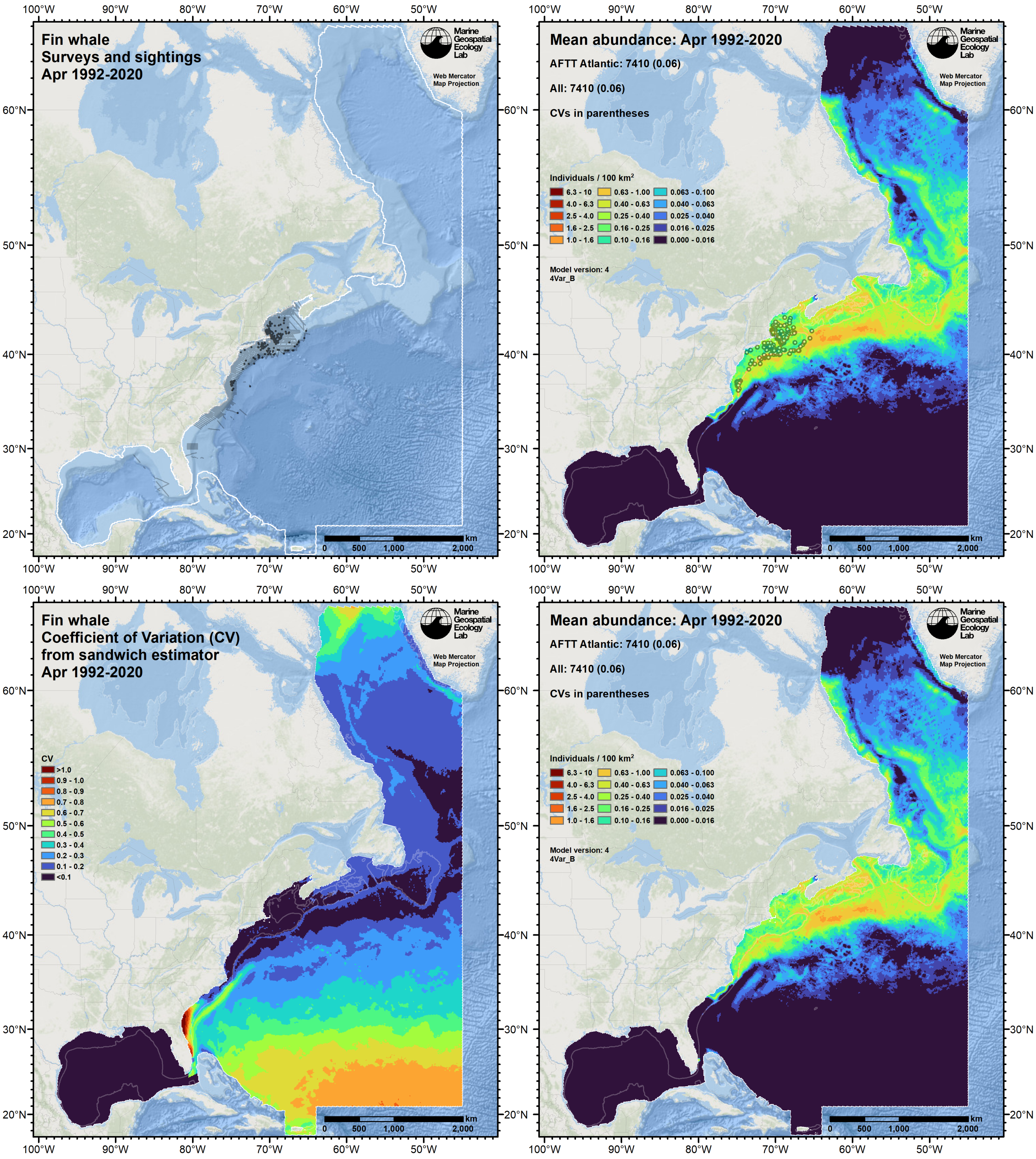


Figure 17: Survey effort and observations (top left), predicted density with observations (top right), predicted density without observations (bottom right), and coefficient of variation of predicted density (bottom left), for the month of April for the given era. Variance was estimated with the analytic 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.

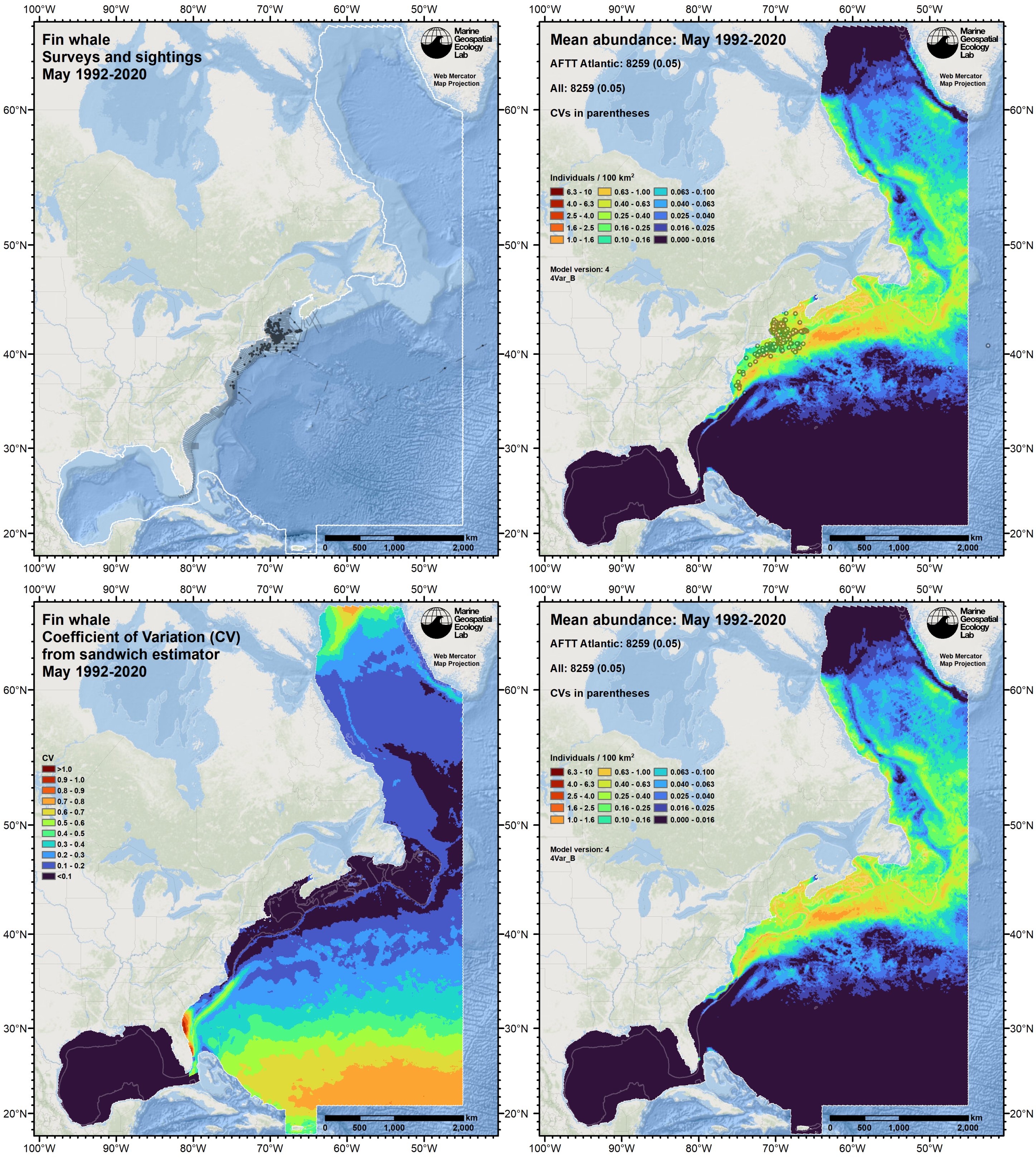


Figure 18: Survey effort and observations (top left), predicted density with observations (top right), predicted density without observations (bottom right), and coefficient of variation of predicted density (bottom left), for the month of May for the given era. Variance was estimated with the analytic 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.

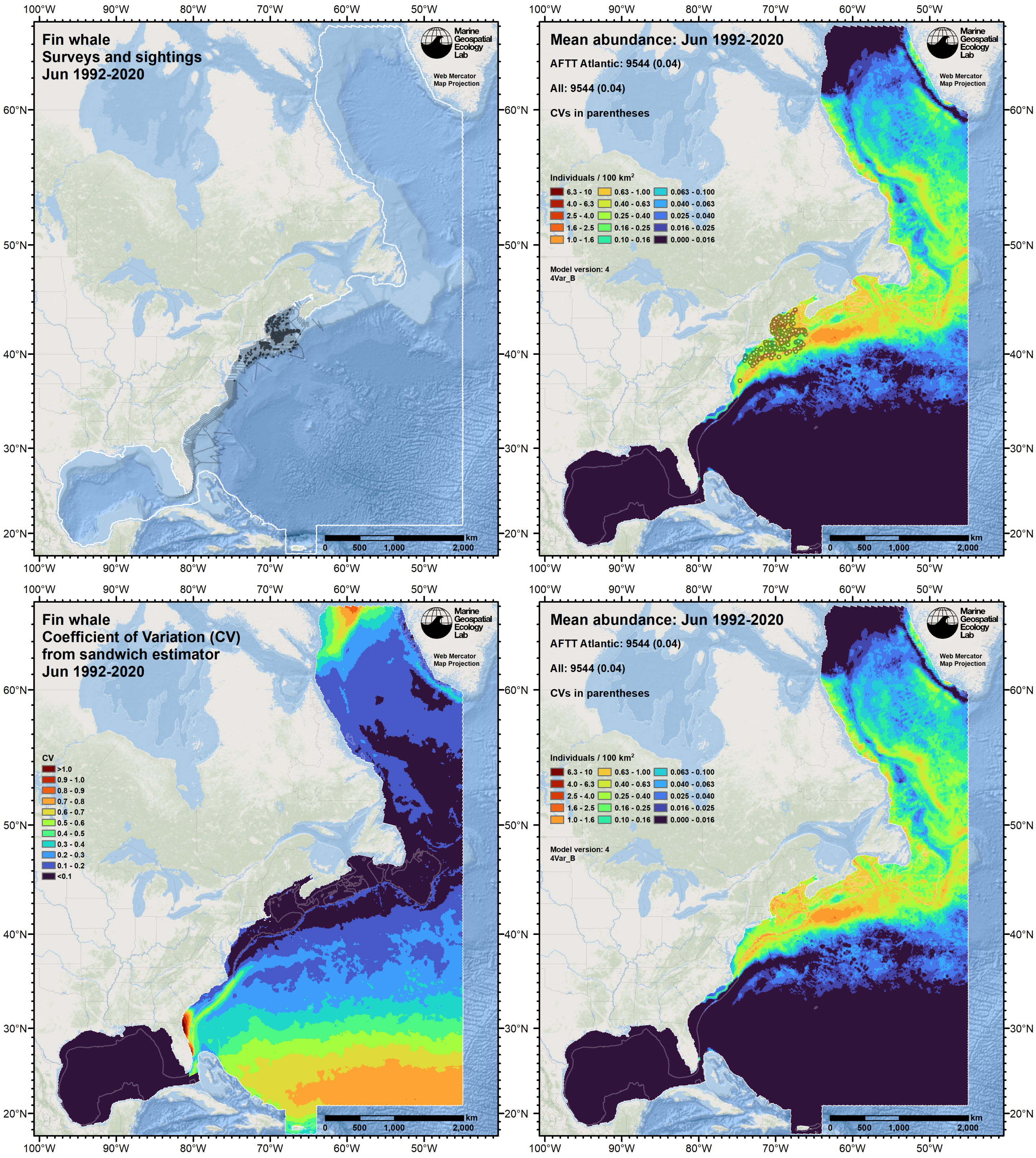


Figure 19: Survey effort and observations (top left), predicted density with observations (top right), predicted density without observations (bottom right), and coefficient of variation of predicted density (bottom left), for the month of June for the given era. Variance was estimated with the analytic 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.

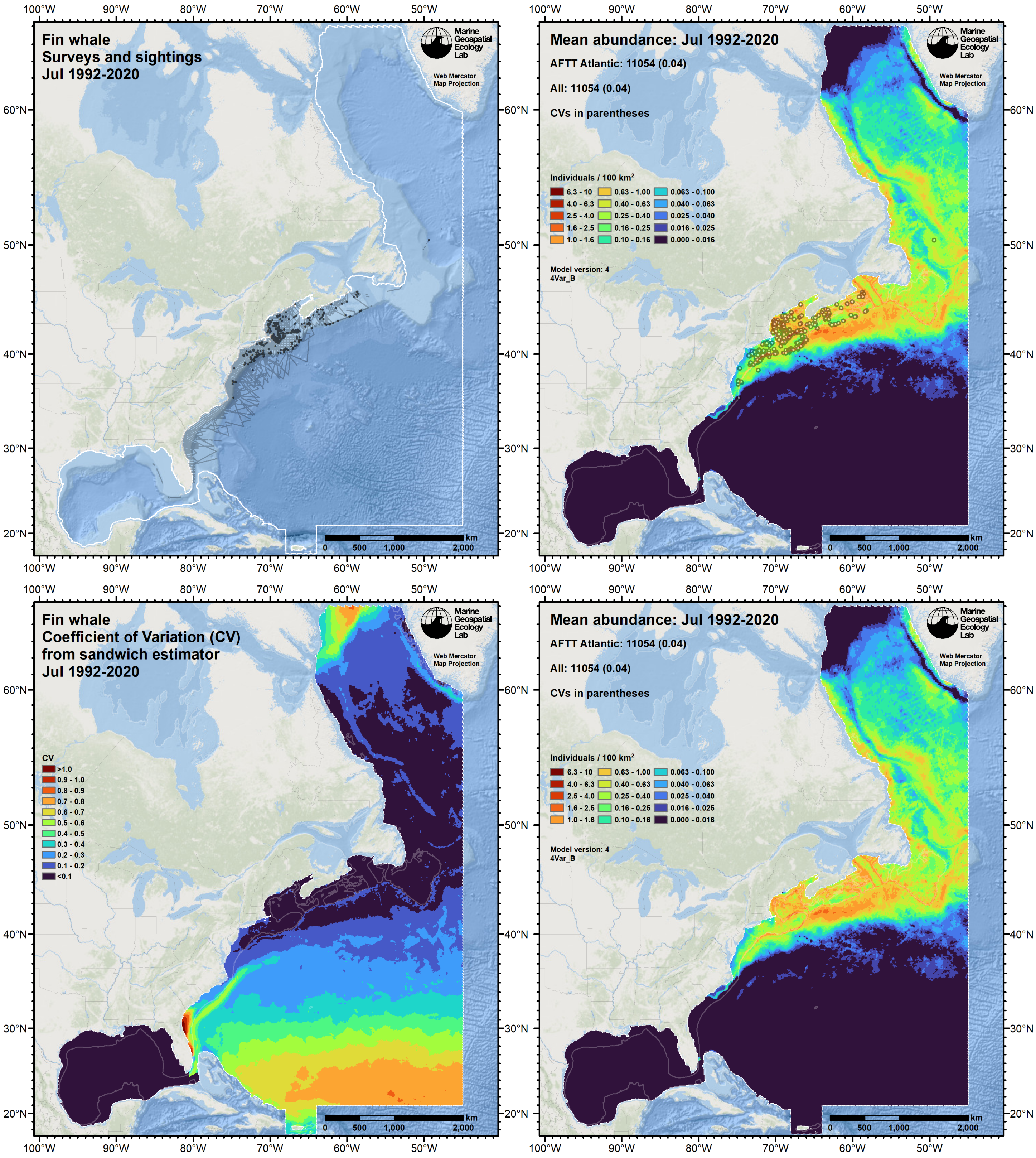


Figure 20: Survey effort and observations (top left), predicted density with observations (top right), predicted density without observations (bottom right), and coefficient of variation of predicted density (bottom left), for the month of July for the given era. Variance was estimated with the analytic 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.

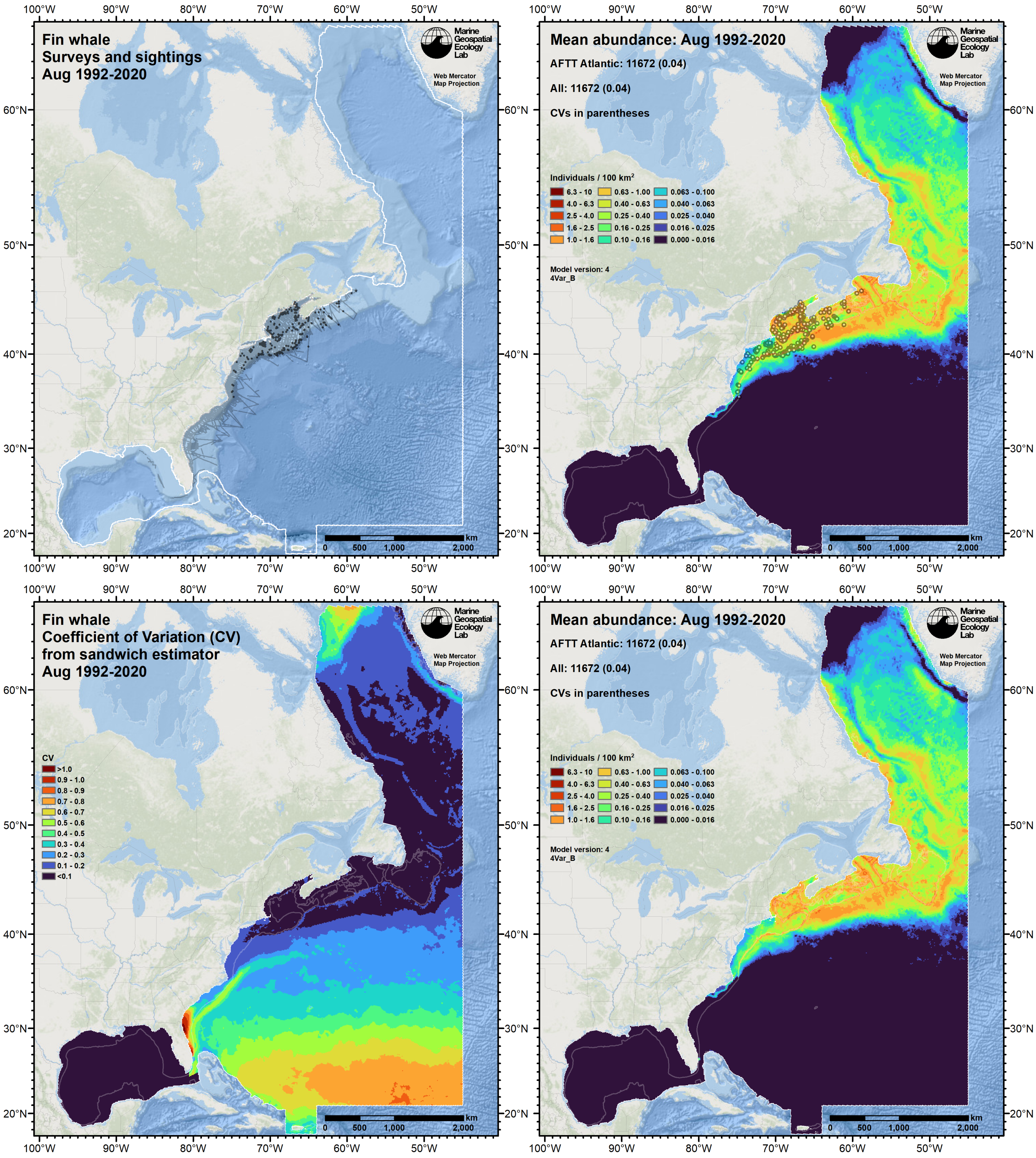


Figure 21: Survey effort and observations (top left), predicted density with observations (top right), predicted density without observations (bottom right), and coefficient of variation of predicted density (bottom left), for the month of August for the given era. Variance was estimated with the analytic 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.

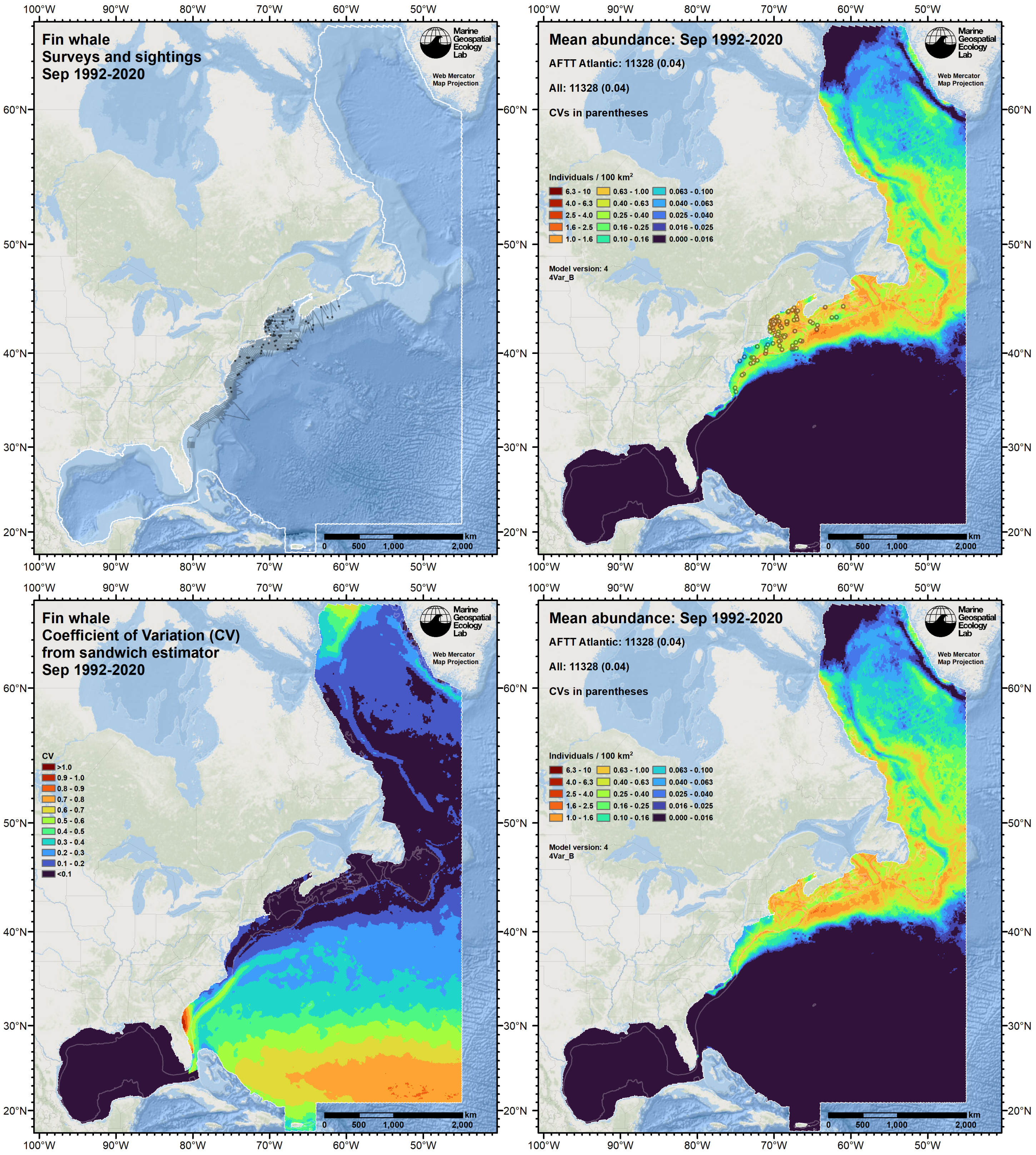


Figure 22: Survey effort and observations (top left), predicted density with observations (top right), predicted density without observations (bottom right), and coefficient of variation of predicted density (bottom left), for the month of September for the given era. Variance was estimated with the 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.

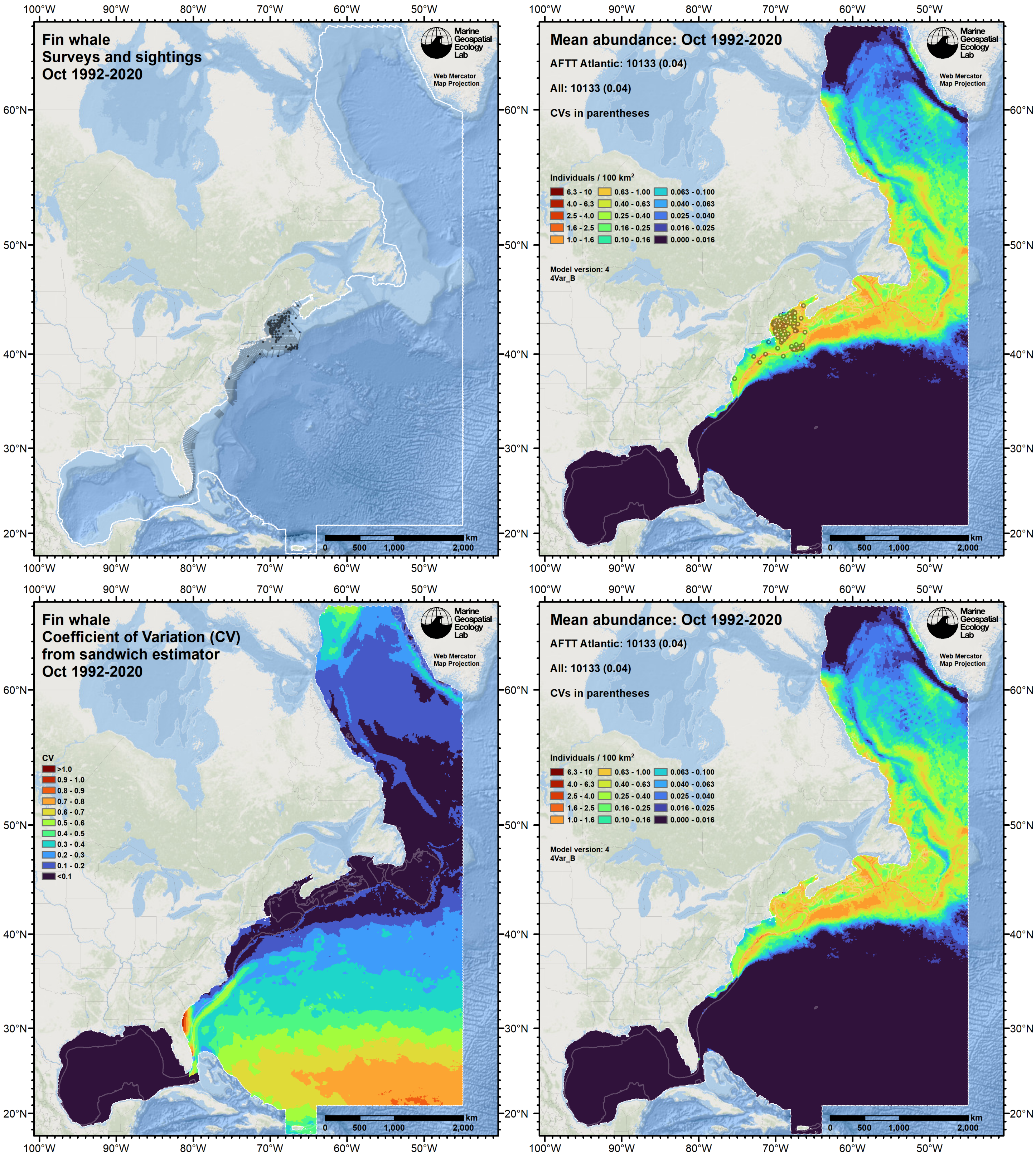


Figure 23: Survey effort and observations (top left), predicted density with observations (top right), predicted density without observations (bottom right), and coefficient of variation of predicted density (bottom left), for the month of October for the given era. Variance was estimated with the analytic 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.

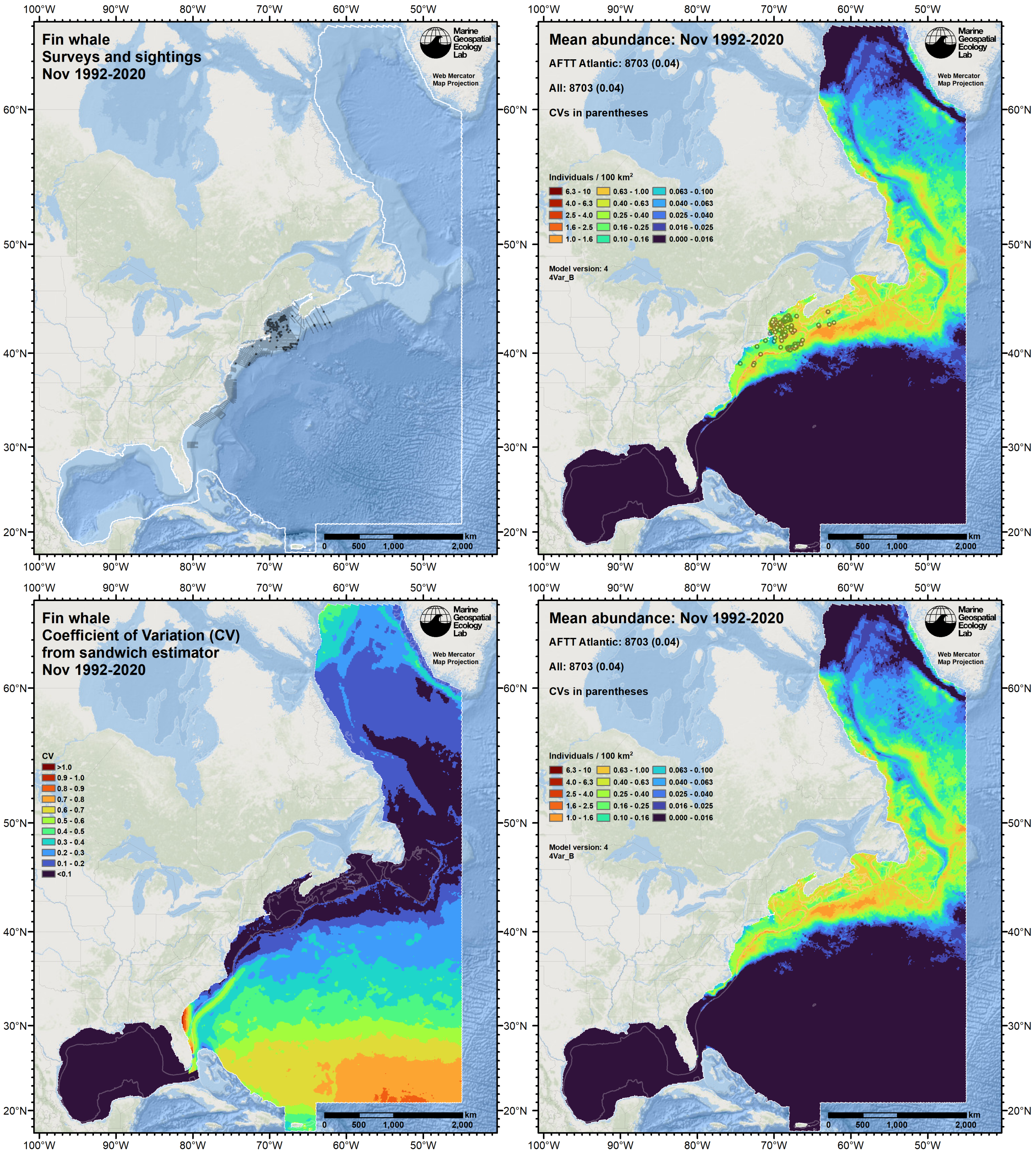


Figure 24: Survey effort and observations (top left), predicted density with observations (top right), predicted density without observations (bottom right), and coefficient of variation of predicted density (bottom left), for the month of November for the given era. Variance was estimated with the analytic 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.

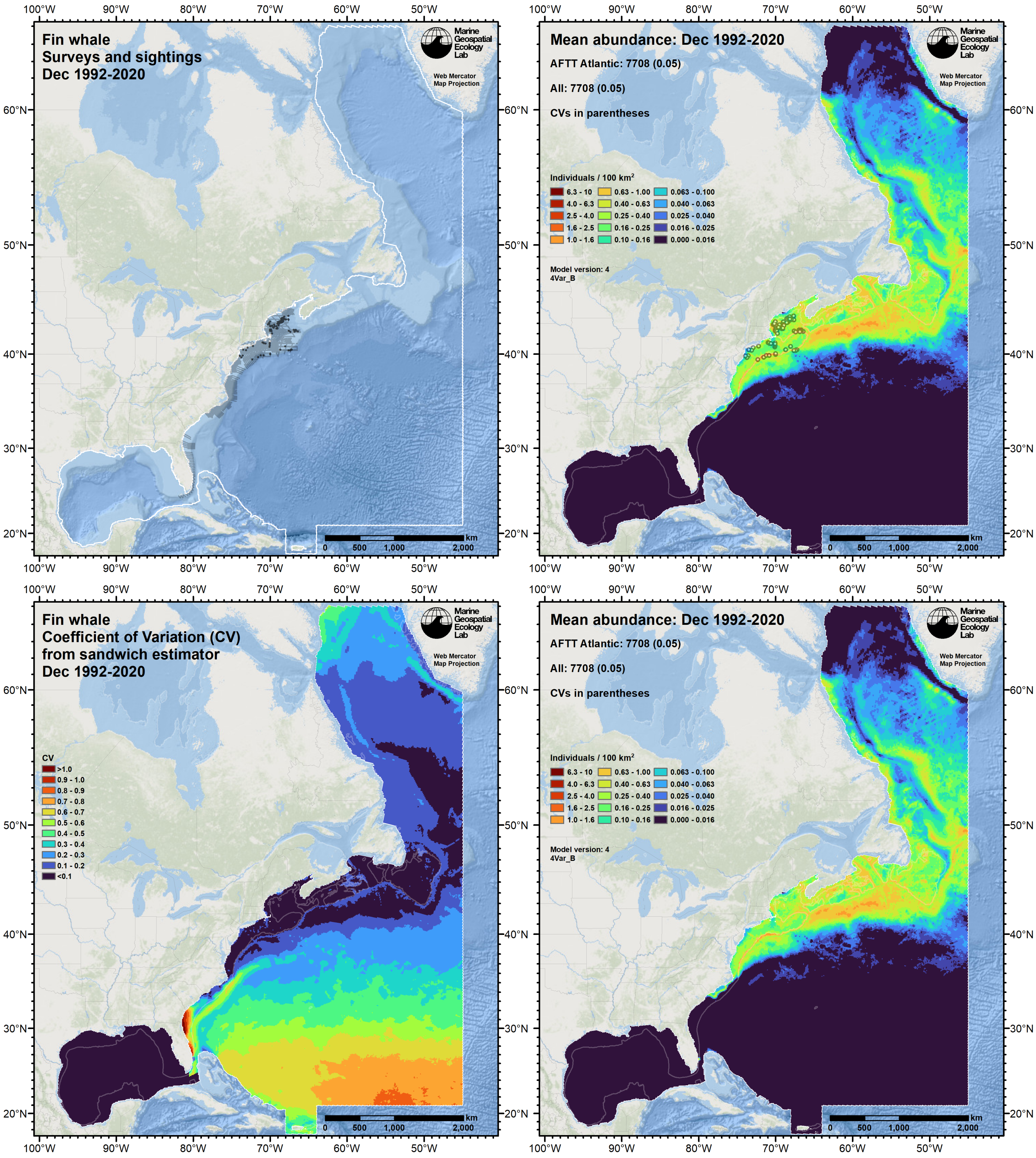


Figure 25: Survey effort and observations (top left), predicted density with observations (top right), predicted density without observations (bottom right), and coefficient of variation of predicted density (bottom left), for the month of December for the given era. Variance was estimated with the analytic 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

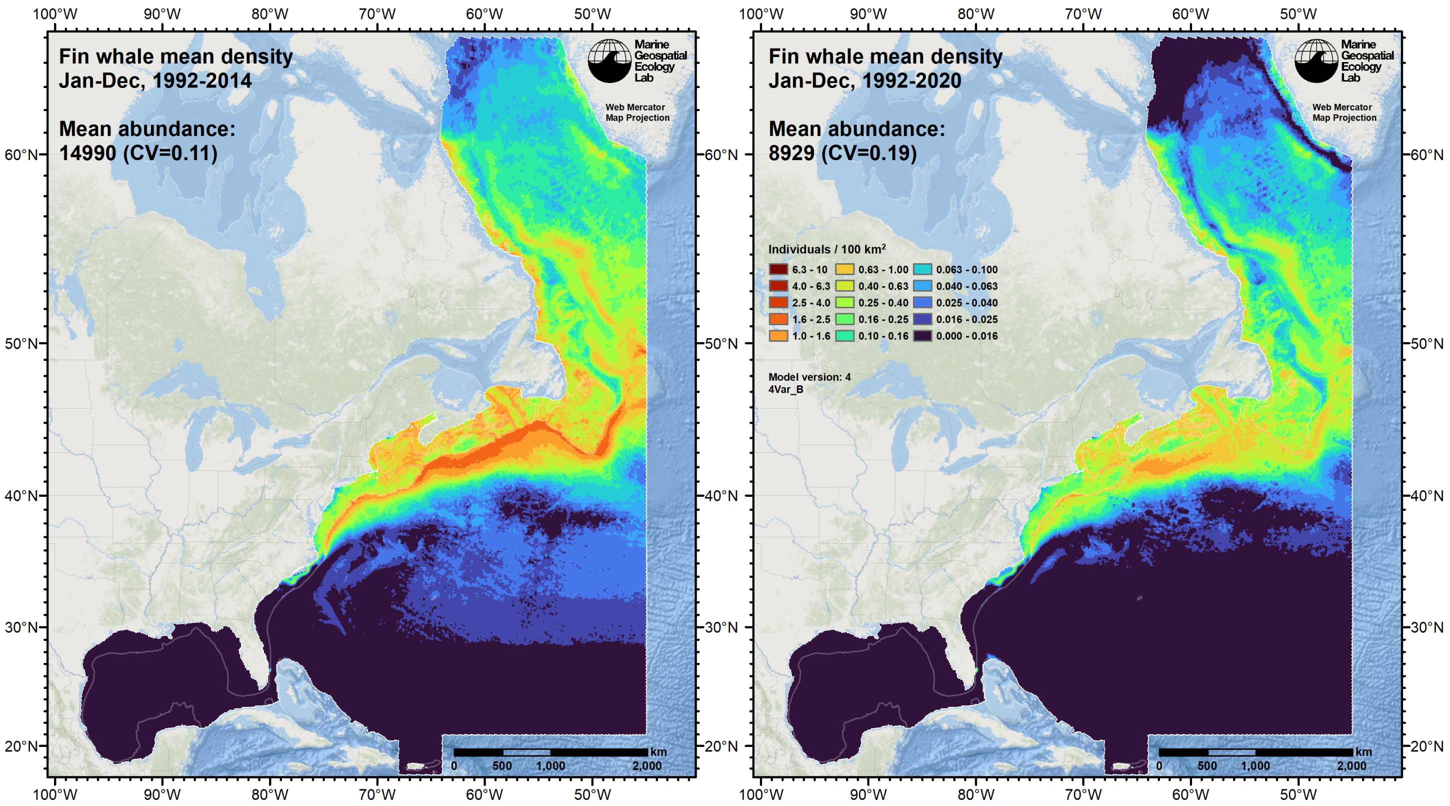


Figure 26: Comparison of the mean density predictions from the previous model (left) released by Mannocci et al. (2017) to those from this model (right). These maps use a Web Mercator projection but the analysis was conducted in an Albers Equal Area coordinate system appropriate for density modeling.

4 Discussion

Following Mannocci et al. (2017), we summarized this model into 12 mean monthly density surfaces (Figures 14-25).[1]. Although our figures show predictions for the entire AFTT study area, we recommend that the regional East Coast (EC) model be used for the waters it covers, and that the AFTT model be used only for waters outside that region. NOAA SEFSC considers fin whales to be absent in the Gulf of Mexico, despite one confirmed sighting occurring there in the 1990s (L. Garrison and K. Mullin, pers. comm.), so no regional model was fitted there. See Roberts et al. (2023) for more discussion of the models.

The predictions generally accorded with what has been reported in the literature and largely resembled the predictions of Mannocci et al. (2017), but with lower density estimated nearly everywhere, leading to a total abundance that was 40% lower than the prior model (Figure 26). We attribute this difference mainly to differences in bias corrections for aerial surveys used by the models. The prior model used a single availability bias correction of $g_0 = 0.251$ for all sightings and assumed that perception bias was negligible. The new model estimated availability bias on a per-sighting basis, based on the altitude and speed of the platform and the size of the sighted group, and perception bias based on the surveyor institution. For sightings of a single fin whale observed by the NEFSC NARWSS program, which reported the largest number of sightings, the availability bias correction was about $g_{0A} = 0.39$ and the perception bias correction was $g_{0P} = 0.67$, yielding a combined correction of $g_0 = 0.261$—not much different than the prior model. However, a substantial number of sightings were reported that had larger group sizes or from survey platforms that had less of a perception bias correction. Across all aerial sightings, the mean correction was $g_0 = 0.399$. The prior model's correction was 37% lower, which, all else being equal, would mostly explain the 40% higher abundance estimated by that model.

We note that the model may underestimate density in the northernmost part of the study area. Sightings were reported by

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[1] In the Mannocci et al. (2017) journal publication, a year-round summarization was included as supplementary information but the monthly summarizations were not. The monthly summarizations are available on our website and are what was used in the U.S. Navy's AFTT Phase III Environmental Impact Statement, for which the model was originally developed. For our updated model, we have included the monthly summarizations directly with the report you are reading.

aerial surveys of the Labrador shelf in 2007 and 2015 (Lawson and Gosselin 2009, 2011, 2018) and of the west Greenland shelf in the same years (Heide-Jørgensen et al. 2010; Hansen et al. 2019). Passive acoustic monitoring indicated fin whales were acoustically present in Davis Strait in all months monitored except April-June (Davis et al. 2020). The OBIS-SEAMAP archive (Halpin et al. 2009) reported numerous sightings along Labrador, in the Labrador Sea, and especially along western Greenland. We urge caution in these areas. None of the surveys of Labrador or Greenland were available for use in our model; future updates would benefit from their inclusion. We note that our model estimated a slightly negative effect on density in waters with SST < 10 °C (Figure 2), while the prior model from Mannocci et al. (2017) estimated a slightly positive effect. If our model included those surveys from cold northern waters in which fin whales were sighted, it is likely that the negative relationship would revert to a neutral or positive relationship, and elevate density in those waters.

We also urge caution between Cape Hatteras and the Bahamas between November-February, during which months passive acoustic monitoring reported occasional fin whale acoustic presence over the Blake Plateau (Kowarski et al. 2022). Like the east coast regional fin whale model, our AFTT model predicted negligible density in this area during these months. We recommend additional surveying in winter of the Blake Plateau and abyssal waters east of it.

Multivariate extrapolation analysis (Figure 12) showed that environmental extrapolation was necessary from Newfoundland northward from October-June. Univariate extrapolation was required along the shelf of Newfoundland, Labrador, Greenland, and the Davis Strait, owing to a lack of sampling in waters with very low sea surface temperatures. We advise caution in the northern part of the study area during these months. Univariate extrapolation was also necessary in the southeast corner of the study area in summer, driven by low SST front activity there during these months. However, it is likely that fin whales are rare in that area during those months, so we do not find this extrapolation as cause for concern.

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