Density Model for Blue Whale (*Balaenoptera musculus*) for the U.S. Navy Atlantic Fleet Testing and Training (AFTT) Study Area: Supplementary Report

Model Version 2

Duke University Marine Geospatial Ecology Laboratory*

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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
1	2015-01-23	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.
2	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

The goal of this project was to build, for the U.S. Navy's AFTT Phase IV Environmental Impact Statement (EIS), an update to the model we developed for the AFTT Phase III EIS. The Phase III model was developed using the methodology of Mannocci et al. (2017) by L. Mannocci but not included in the 2017 publication. Following the approach taken by that model, we built this update from data collected in the east coast region, Mid-Atlantic Ridge, and Europe regions. We excluded surveys that did not target blue 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 for the model after most exclusions were applied.

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	1	1	1.0
NEAq	CNM	2017-2020	2	2	2	1.0
NEAq	MMS-WEA	2017-2020	37	0	0	
NEAq	NLPSC	2011-2015	43	0	0	
NEFSC	AMAPPS	2010-2019	89	1	1	1.0
NEFSC	NARWSS	2003-2020	484	8	8	1.0
NEFSC	Pre-AMAPPS	1999-2008	46	0	0	
NJDEP	NJEBS	2008-2009	11	0	0	
NYS-DEC/TT	NYBWM	2017-2020	77	2	2	1.0
SEFSC	AMAPPS	2010-2020	114	0	0	
SEFSC	MATS	1995-2005	34	0	0	
SEFSC	SECAS	1992-1995	8	0	0	
U. La Rochelle	SAMM	2011-2012	66	1	1	1.0
UNCW	MidA Bottlenose	2002-2002	17	0	0	
UNCW	Navy Cape Hatteras	2011-2017	34	0	0	
UNCW	Navy Jacksonville	2009-2017	92	0	0	
UNCW	Navy Norfolk Canyon	2015-2017	14	0	0	
UNCW	Navy Onslow Bay	2007-2011	49	0	0	
UNCW	SEUS NARW EWS	2005-2008	114	0	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	**1,400**	**15**	**15**	**1.0**
Shipboard Surveys						
CODA	CODA	2007-2007	10	0	0	
IMR	MAR-ECO	2004-2004	2	4	4	1.0
MCR	SOTW Visual	2004-2019	29	8	9	1.1
NEFSC	AMAPPS	2011-2016	16	7	7	1.0
NEFSC	Pre-AMAPPS	1995-2007	18	0	0	
NJDEP	NJEBS	2008-2009	14	0	0	
SCANS-II	SCANS-II	2005-2005	18	0	0	
SEFSC	AMAPPS	2011-2016	17	0	0	
SEFSC	Pre-AMAPPS	1992-2006	33	0	0	
		Total	**156**	**19**	**20**	**1.1**
		Grand Total	**1,556**	**34**	**35**	**1.0**

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

Institution	Full Name
CODA	Partners of the CODA project (see Hammond et al. 2009)
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.
SCANS-II	Partners of the SCANS-II project (see Hammond et al. 2013)
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)
CODA	Cetacean Offshore Distribution and Abundance in the European Atlantic	Hammond et al. (2009)
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)
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)
SAMM	Suivi Aérien de la Mégafaune Marine	Pettex et al. (2014)

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

Program	Description	References
SCANS-II	Small Cetaceans in the European Atlantic and North Sea	Hammond et al. (2013)
SECAS	Southeast Cetacean Aerial Surveys	Blaylock and Hoggard (1994)
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)
VA CZM WEA	Virginia CZM Wind Energy Area Surveys	Mallette et al. (2014), Mallette et al. (2015)

2 Geographic Strata

Our objective was to update the Phase III model with new data without revising the model's overall structure. During the Phase III modeling cycle, it was determined that there were too few sightings to fit a traditional density surface model that related density observed on survey segments to environmental covariates. Nor was it possible to make proper design-based abundance estimates using traditional distance sampling (Buckland et al. 2001), because the aggregate surveys provided very heterogeneous coverage that did not together constitute a proper systematic survey design.

To provide interested parties with at least rough estimates of density in ecologically relevant geographic strata, we followed the prior model and assumed that blue whales were present throughout the North Atlantic and surrounding regional seas except for the Gulf of Mexico and Caribbean Sea. We then fitted a model with no covariates to all segments within that region. This approach necessarily assumed that density would be distributed uniformly throughout the region. This assumption, if true, would mean we would obtain similar density estimates under any sampling design, and therefore it would not matter if there was some heterogeneity in sampling. However, we strongly caution that this assumption did not hold for the other, more-common species we successfully modeled with traditional density surface modeling, as evidenced by the non-uniform patterns in density predicted by those species' models. But without more data, we cannot elucidate those patterns confidently through the normal modeling process. Thus, for the much rarer species, such as blue whale documented here, we offer this simplified approach as a rough-and-ready substitute for a full density surface model.

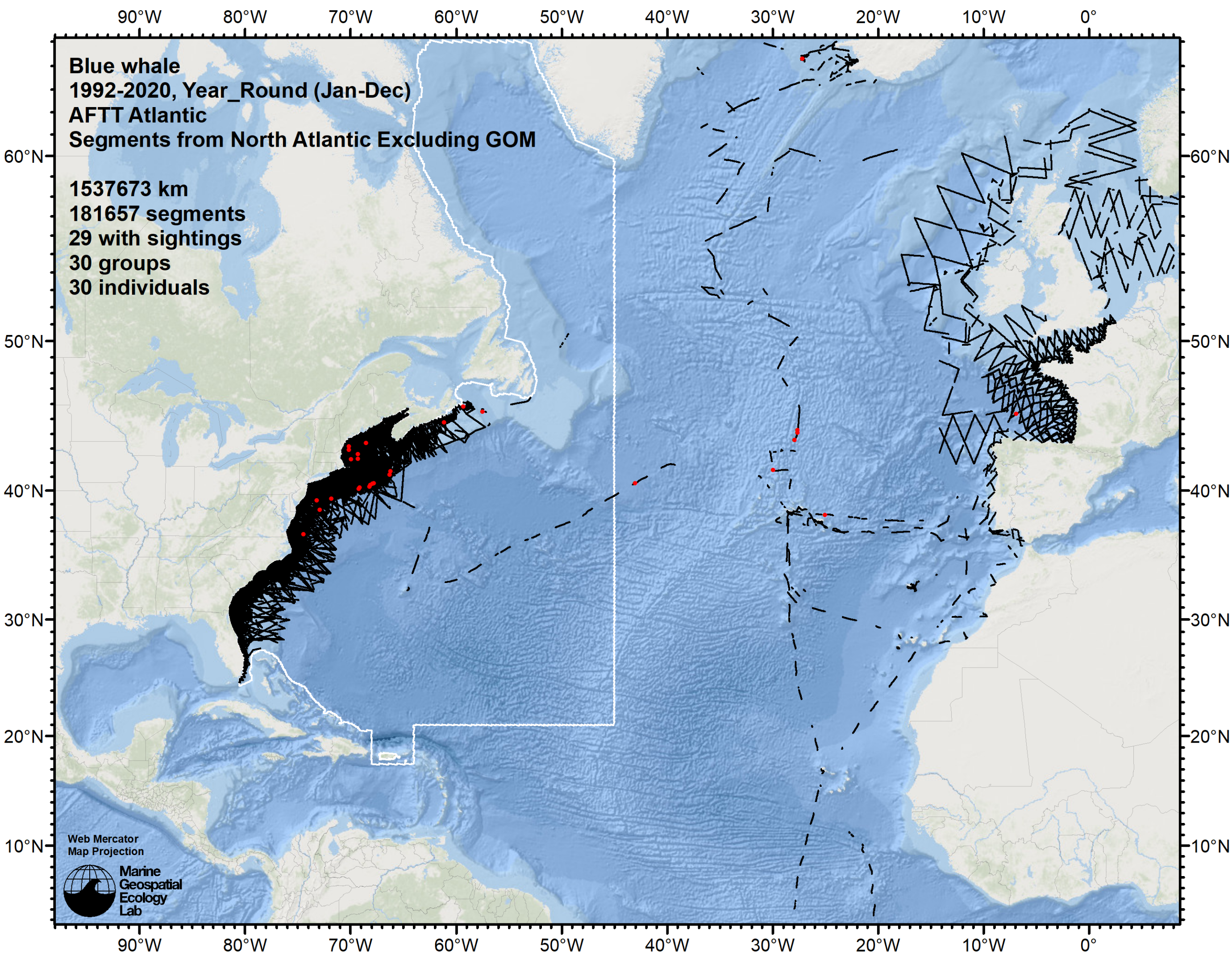

Figure 1: Survey segments and sightings used to estimate Blue whale density. Black lines and red points indicate the segments and sightings used to estimate density. White polygon indicates the region to which the density was applied.

3 Predictions

3.1 Summarized Predictions

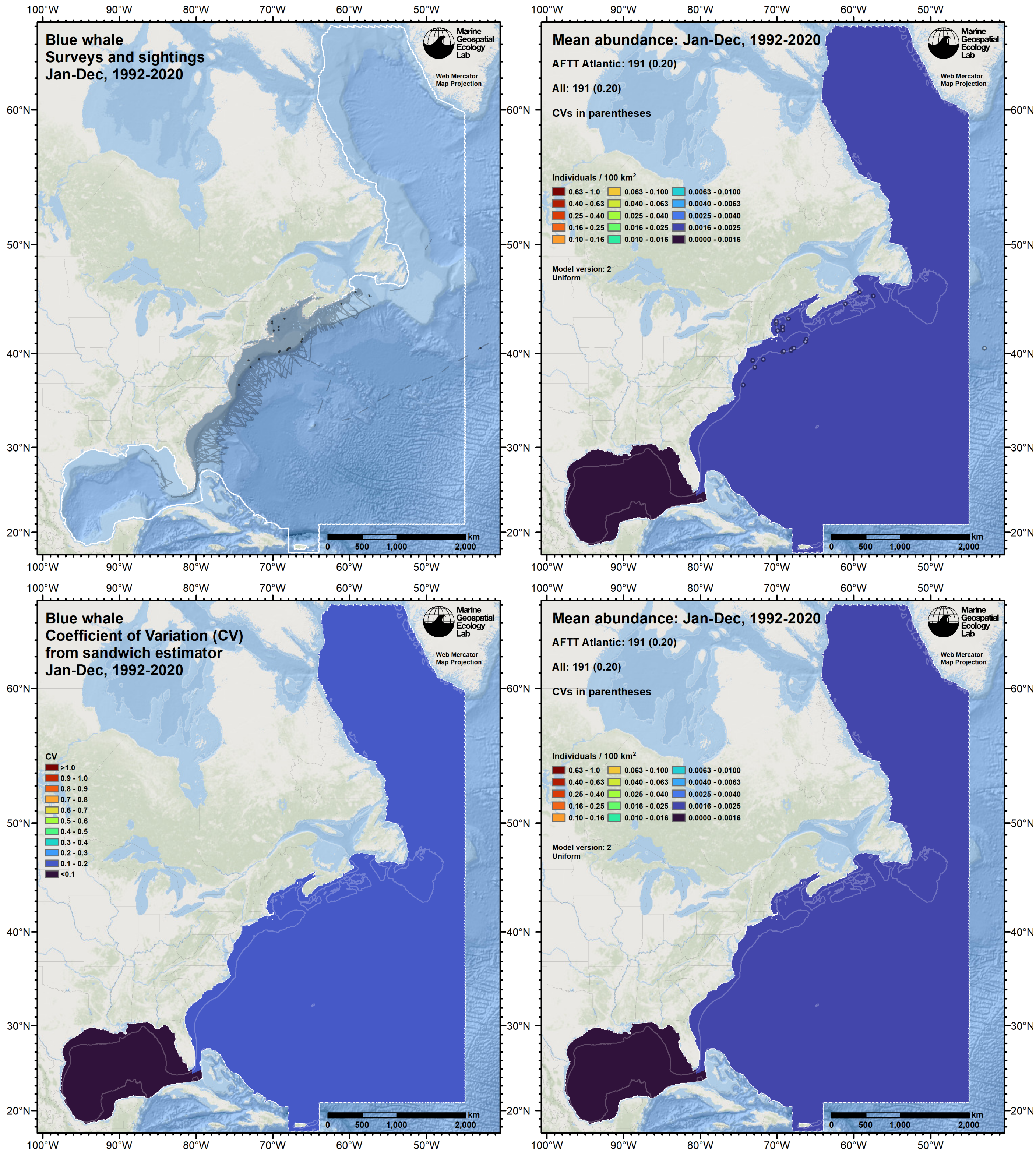

Figure 2: Survey effort and observations (top left), predicted density with observations (top right), predicted density without observations (bottom right), and coefficient of variation of predicted density (bottom left), for the given era. These maps use a Web Mercator projection but the analysis was conducted in an Albers Equal Area coordinate system appropriate for density modeling.

3.2 Comparison to Previous Density Model

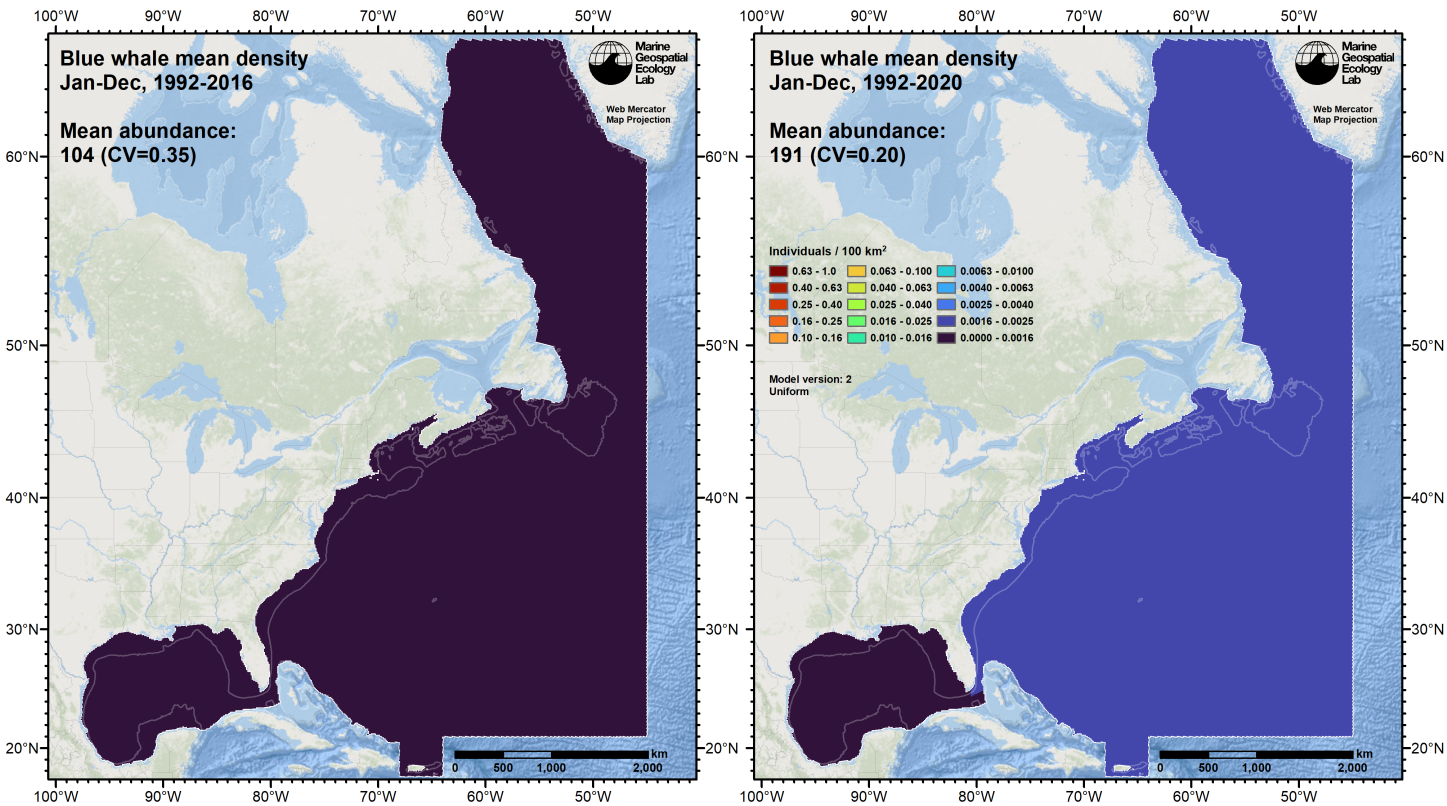

Figure 3: Comparison of the mean density predictions from the previous model (left) to those from this model (right). These maps use a Web Mercator projection but the analysis was conducted in an Albers Equal Area coordinate system appropriate for density modeling.

4 Discussion

Following what was done for the prior model, we summarized this updated model into a single year-round mean density surface (Figure 2). Although our figures show predictions for the East Coast (EC) region, we recommend that the regional EC model be used for the region it covers instead. See Roberts et al. (2023) for more discussion of the models.

The model estimated a total abundance that was about 84% higher than that of the prior model (Figure 3). The new abundance estimate was within the 95% confidence limits of the old estimate. However, neither estimate accounted for temporal variability, so it is highly likely that total uncertainty was underestimated. The migratory behavior of blue whales in the North Atlantic is not well understood, with satellite tagging (Lesage et al. 2016) and passive acoustic monitoring (Clark 1995; Davis et al. 2020) indicating strong seasonal movements but anecdotal sighting reports suggesting some whales remain in summer feeding grounds year-round (Lesage et al. 2018). Until a better understanding can be developed, and sufficient data collected to model it, we advise caution throughout the entire AFTT area outside the Gulf of Mexico.

We recommend additional visual surveying of the continental shelf break and beyond it from the Bahamas through Canada (throughout the exclusive economic zones of the U.S and Canada) in fall, winter, and spring. Aerial surveys of Canadian waters during summers of 2007 and 2015 sighted several blue whales (Lawson and Gosselin 2009, 2018). These surveys were not available for use in this model; future updates would benefit from their inclusion.

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