Density Model for North Atlantic Right Whale (*Eubalaena glacialis*) for the U.S. Navy Atlantic Fleet Testing and Training (AFTT) Study Area: Supplementary Report

Model Version 3

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
2	2015-11-16	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.
3	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 Introduction

The current known range of the North Atlantic right whale (NARW) is restricted to the continental shelf waters of North America, from Florida to the Gulf of St. Lawrence (Kenney et al. 2001; Brillant et al. 2015; Meyer-Gutbrod et al. 2022). Much of this range is covered by the regional East Coast (EC) NARW density model. However, the most recent version (12) of that model only extends northeast of U.S. waters in August and September, and then only as far as La Have basin, owing to a lack of survey data in Canadian waters. When we extrapolated the EC model further north, the predictions were not sufficiently realistic to meet the goal of that model, which was to obtain plausible density predictions at 5 km spatial and monthly temporal resolutions.

As a fallback, we developed the AFTT model documented here. The goal of this project was to build, for the U.S. Navy's AFTT Phase IV Environmental Impact Statement (EIS), a model that would extrapolate estimates into the portion of the AFTT study area not covered by the EC NARW model but likely to be occupied by the NARW. In the Navy Marine Species Density Database (NMSDD), the AFTT model's predictions were underlaid beneath the EC model's predictions, filling the areas missing from the EC model. Given the considerable uncertainty about NARW density in those missing areas in Canada, our approach was to split the year into two seasons, estimate mean density across all surveys that occurred in the Gulf of Maine during each season, and apply each result uniformly across the region likely to be occupied by right whales. Section 2 summarizes the survey programs available for this procedure and section 3 presents the regional strata over which it was performed. Section 4 shows the resulting density estimates, which we discuss in section 5.

2 Survey Data

Around 2010-2011, the NARW population entered decline and seasonal patterns in the species' distribution shifted substantially (Pace et al. 2017; Davis et al. 2017; Ganley et al. 2019; Davies et al. 2019; Gowan et al. 2019; Quintana-Rizzo et al. 2021; Meyer-Gutbrod et al. 2021; O'Brien et al. 2022) (See the EC NARW model's supplementary report for a detailed discussion.) We therefore built this model from data collected in 2011 and later. Because the regional strata extended from the Great South Channel northwards, we constrained our pool of candidate survey programs to those with some effort in the vicinity of the Nantucket Shoals or further northward. (Note that the model was built only from segments that actually occurred within the regional strata; see section 3). 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.

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						
NEAq	CNM	2017-2020	2	0	0	
NEAq	MMS-WEA	2017-2020	37	109	453	4.2
NEAq	NLPSC	2011-2015	43	37	122	3.3
NEFSC	AMAPPS	2011-2019	80	17	26	1.5
NEFSC	NARWSS	2011-2020	209	654	2,582	3.9
		Total	**371**	**817**	**3,183**	**3.9**
Shipboard Surveys						
MCR	SOTW Visual	2012-2012	6	0	0	
NEFSC	AMAPPS	2011-2016	16	20	31	1.6
		Total	**22**	**20**	**31**	**1.6**
		Grand Total	**393**	**837**	**3,214**	**3.8**

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

Institution	Full Name
MCR	Marine Conservation Research
NEAq	New England Aquarium
NEFSC	NOAA Northeast Fisheries 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)
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)
NLPSC	Northeast Large Pelagic Survey Collaborative Aerial Surveys	Leiter et al. (2017), Stone et al. (2017)
SOTW Visual	R/V Song of the Whale Visual Surveys	Ryan et al. (2013)

3 Seasonal and Regional Strata

We split the year into two seasons: Winter (January-May) and Summer (June-December). We placed the May-June transition based on May being the month in which abundance historically peaked in the Great South Channel (Kenney et al. 2001), a pattern that our EC model indicated still held in the modern era (please see the EC model predictions for more detail). We placed the December-January transition based on right whales being sighted in the Gulf of St. Lawrence through December in recent years (Crowe et al. 2021), and also based on January being the month that whales typically start arriving in Cape Cod Bay (Ganley et al. 2019), and the month by which most demographic groups have begun to arrive at the calving grounds in substantial numbers (Krzystan et al. 2018).

We then defined a regional stratum that extended from the southwest edge of the Great South Channel northeast to the Newfoundland side of the Laurentian Channel at the mouth of the Gulf of St. Lawrence. This polygon only extended as far toward the Gulf as the AFTT study area itself extended. Then, for each season, we fitted a density model with no covariates, yielding a uniform density surface.

This stratified approach necessarily assumed that density would be distributed uniformly throughout the stratum. This assumption, if true, would mean we would obtain similar density estimates under any sampling design within the stratum, and therefore it would not matter if there was some heterogeneity in sampling. However, it is clear that this assumption did not hold for the NARW. It is well-known that the species' distribution is very patchy, with whales aggregated in various high quality feeding habitats and found more rarely elsewhere (see the EC NARW model's supplementary report for examples and discussion). In fact, the bulk of the surveying conducted in the Gulf of Maine was from the NARWSS program (section 2), which utilized a sampling scheme that was partially biased toward areas frequented by right whales, to maximize the chance of collecting photographs of right whales needed to drive mark-recapture population models. The EC NARW model was designed to compensate for this problem, but the approach used here was not. Consequently, this approach overestimated right whale density. We discuss this in section 5.

In the remainder of this section, we present maps of each stratum, with tallies of effort and sightings that occurred. We show the resulting density estimates in Section 4.

3.1 Winter-Spring (January-May)

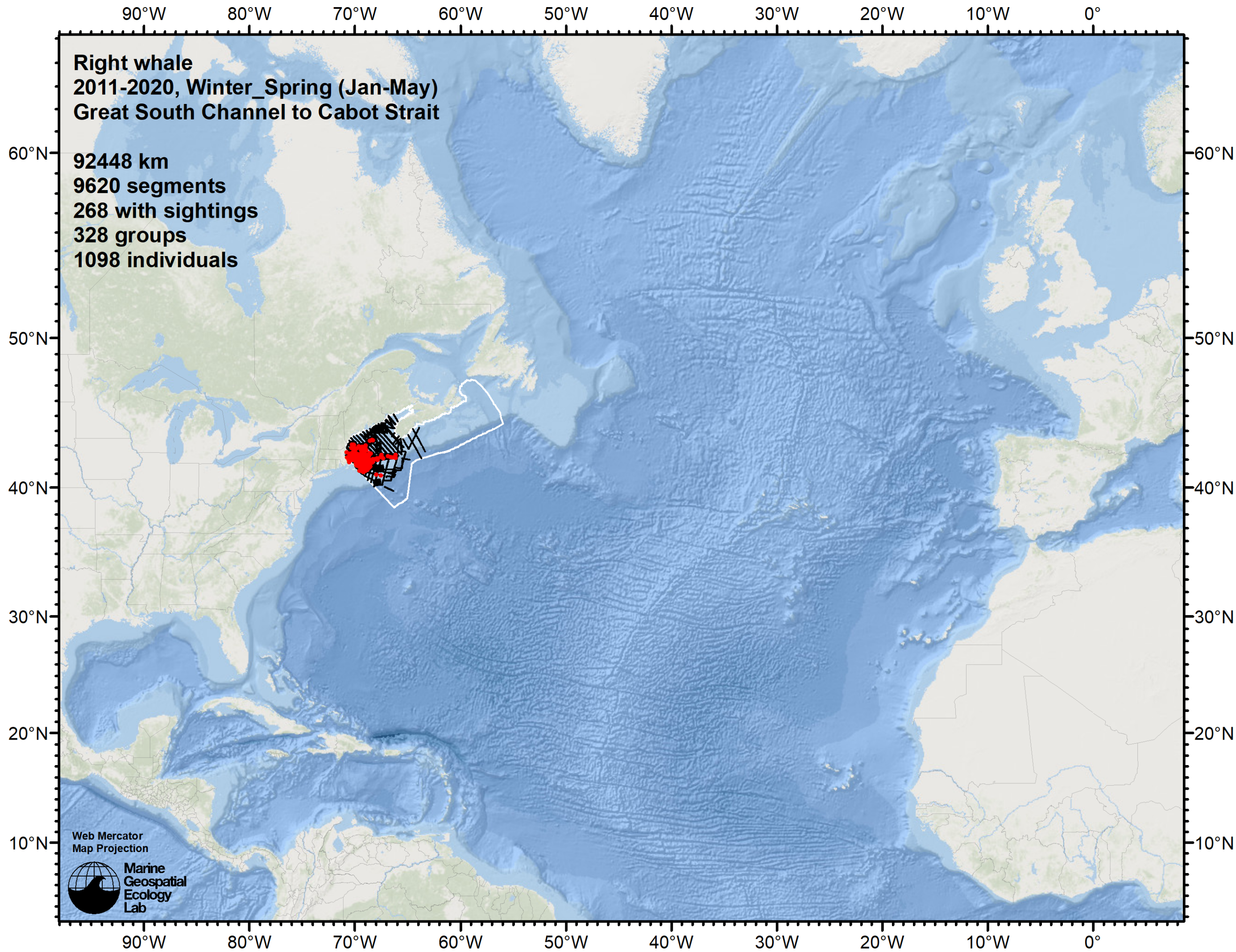

Figure 1: Survey segments and sightings used to estimate North Atlantic right whale density during the Winter-Spring season (January-May). Black lines and red points indicate the segments and sightings used to estimate density. White polygon indicates the region to which the density was applied.

3.2 Summer-Fall (June-December)

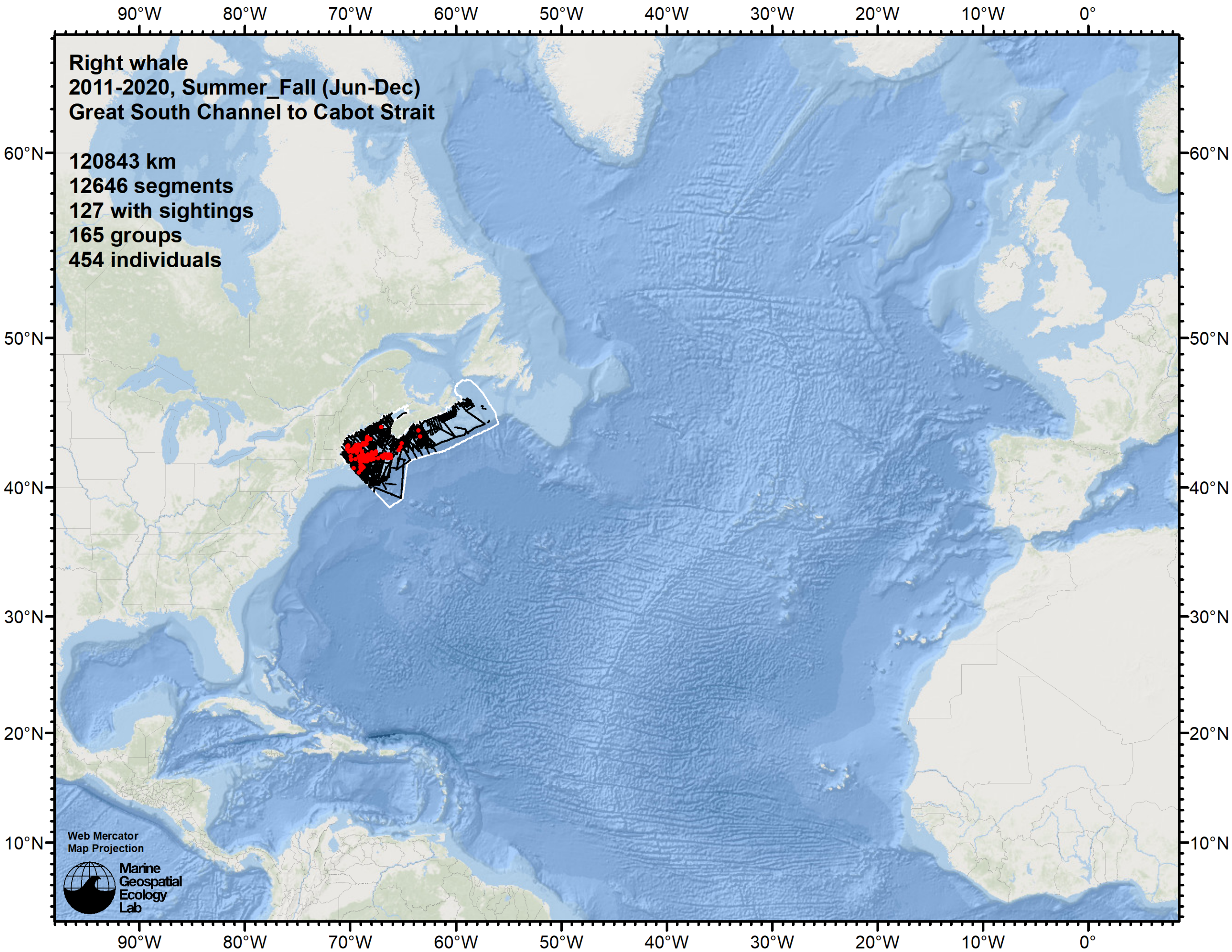

Figure 2: Survey segments and sightings used to estimate North Atlantic right whale density during the Summer-Fall season (June-December). Black lines and red points indicate the segments and sightings used to estimate density. White polygon indicates the region to which the density was applied.

4 Predictions

4.1 Summarized Predictions

4.1.1 Winter-Spring (January-May)

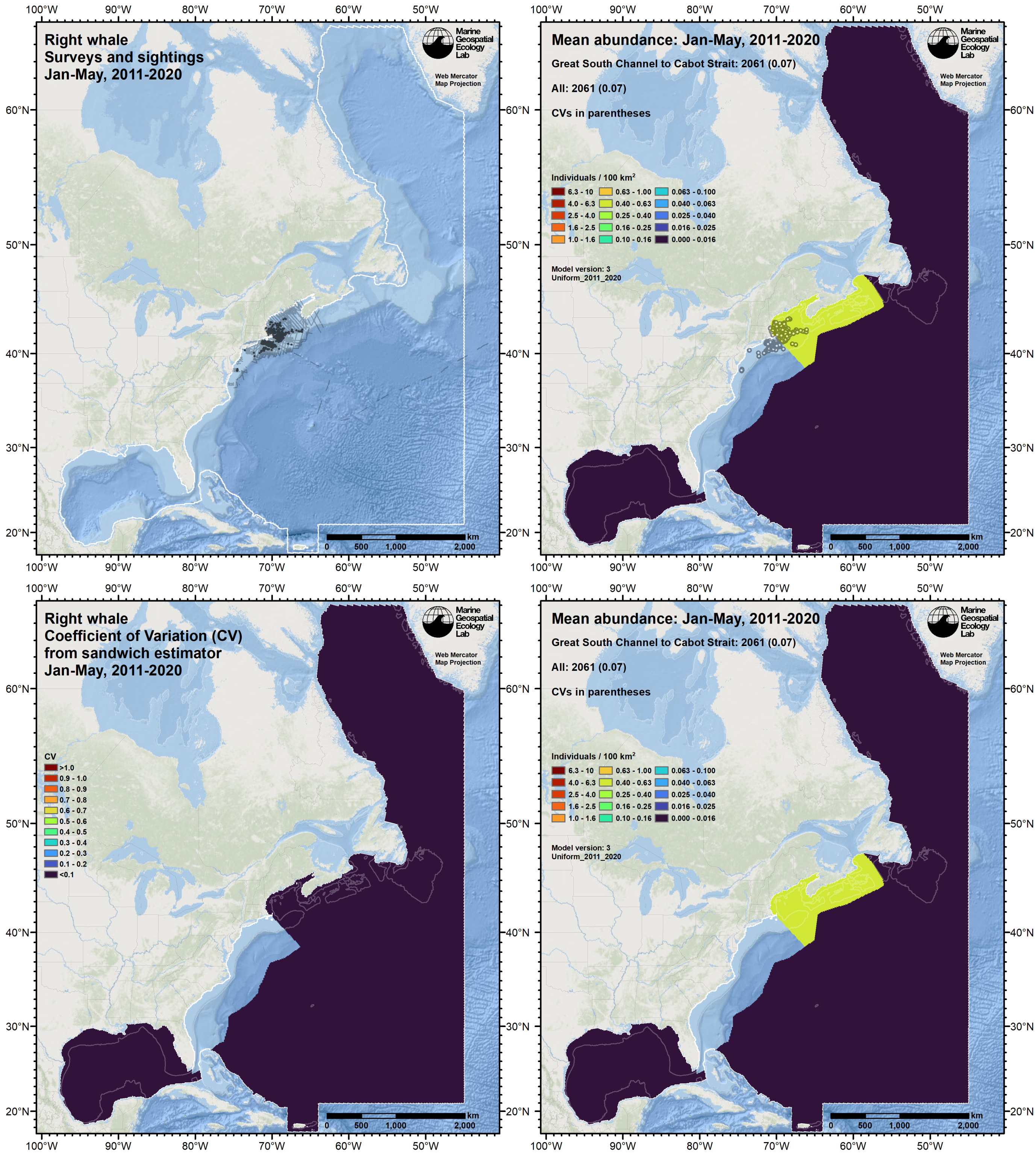

Figure 3: Survey effort and observations (top left), predicted density with observations (top right), predicted density without observations (bottom right), and coefficient of variation of predicted density (bottom left), for Winter-Spring the given era. These maps use a Web Mercator projection but the analysis was conducted in an Albers Equal Area coordinate system appropriate for density modeling.

4.1.2 Summer-Fall (June-December)

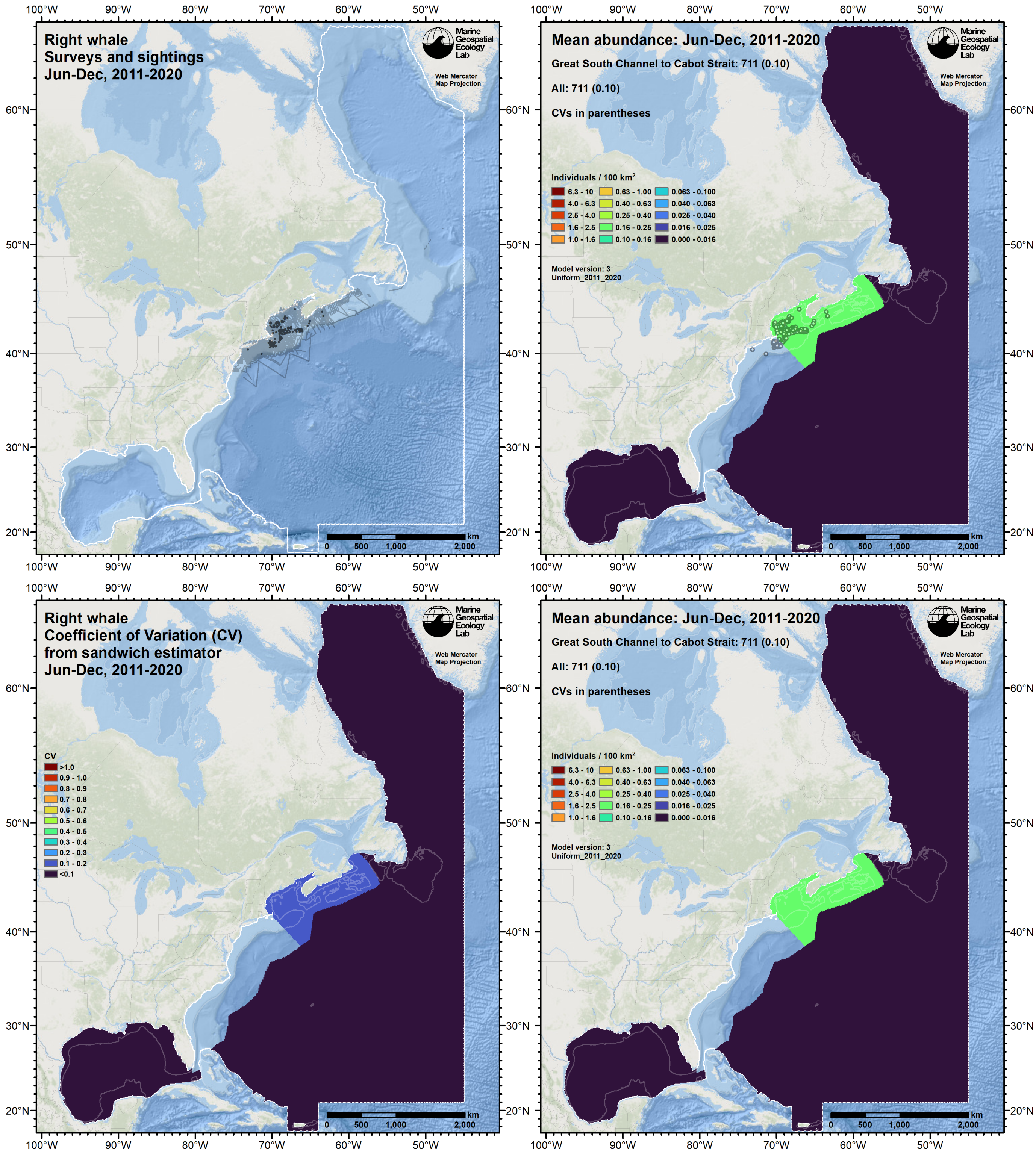

Figure 4: Survey effort and observations (top left), predicted density with observations (top right), predicted density without observations (bottom right), and coefficient of variation of predicted density (bottom left), for Summer-Fall the given era. These maps use a Web Mercator projection but the analysis was conducted in an Albers Equal Area coordinate system appropriate for density modeling.

4.2 Comparison to Previous Density Model

4.2.1 Winter-Spring (January-May)

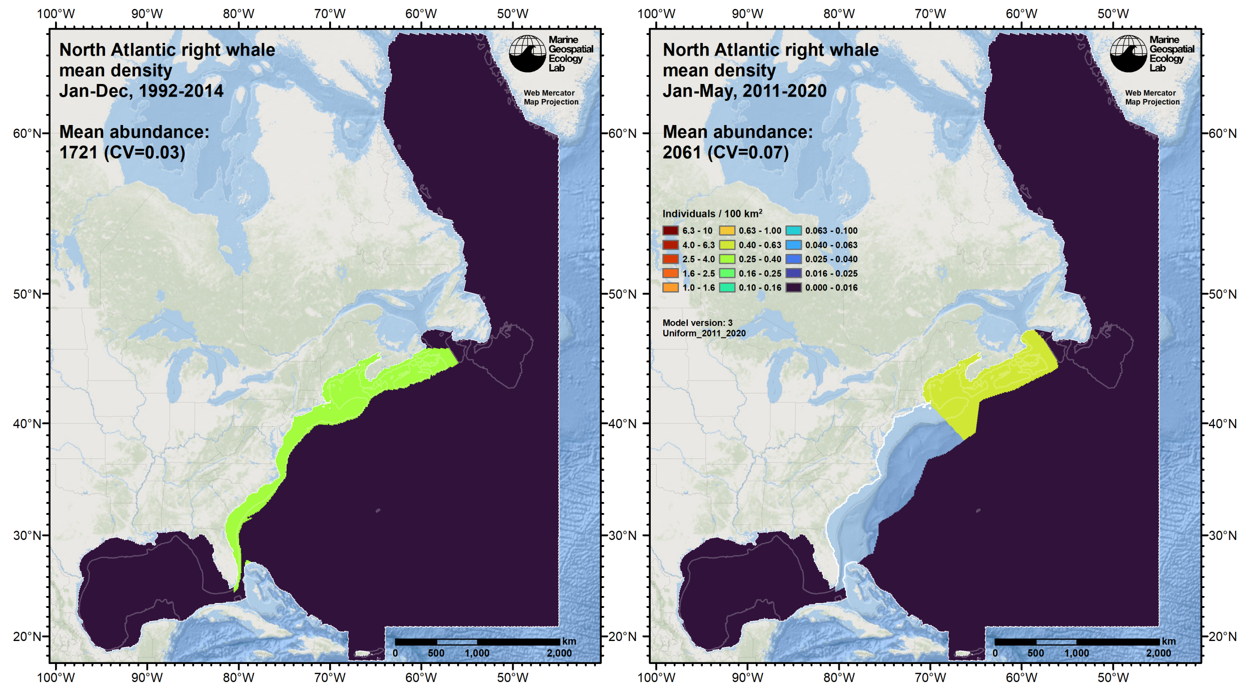

Figure 5: Comparison of the mean density predictions from the previous model (left) to those from this model (right) for the Winter-Spring season (January-May). These maps use a Web Mercator projection but the analysis was conducted in an Albers Equal Area coordinate system appropriate for density modeling.

4.2.2 Summer-Fall (June-December)

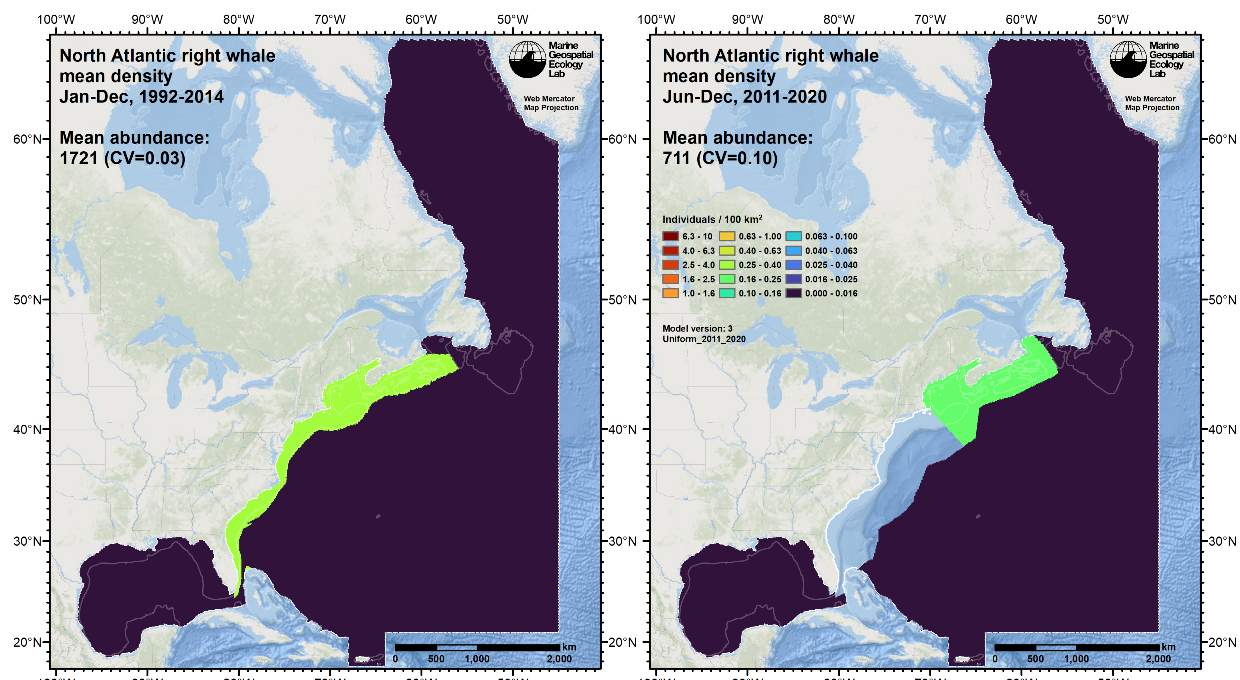

Figure 6: Comparison of the mean density predictions from the previous model (left) to those from this model (right) for the Summer-Fall season (June-December). These maps use a Web Mercator projection but the analysis was conducted in an Albers Equal Area coordinate system appropriate for density modeling.

5 Discussion

The purpose of this model is to provide extrapolated predictions for waters of the AFTT study area occupied by right whales that not already covered by the regional EC NARW model (version 12). Although our figures here show predictions for the EC region (Figures 3, 4), the regional EC model should be used instead wherever it has predictions. It was a traditional density surface model and was summarized into 12 monthly mean density surfaces.

This model substantially overestimates right whale abundance and predicts density uniformly across Canadian waters outside the Gulf of St. Lawrence likely to be occupied by right whales. As such, this model is highly precautionary and designed to ensure that impacts to this critically endangered species from U.S. Navy testing and training exercises, should they ever occur there, are not underestimated. This model is therefore intended to only be used by the U.S. Navy's AFTT Phase IV NMSDD. We recommend non-Navy users interested in this model contact us for advice before using it. For general information on the AFTT Phase IV modeling project, please see Roberts et al. (2023).

In the future, we aim to eliminate this model entirely by expanding the EC model into Canadian waters far enough to fully encompass the areas typically occupied by the NARW. This requires the incorporation of more surveys conducted in Canada. In 2022, with the support of NOAA, we initiated a collaboration with Fisheries and Oceans Canada (DFO) to pursue this. Please contact us if you have questions about this project.

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