NUWC-NPT Technical Report 12,428A
15 December 2023

(Supersedes NUWC-NPT TR 12,428 dated 1 June 2023)

Sea Turtle Distribution and Abundance on the East Coast of the United States

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NEWPORT

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ADMINISTRATIVE INFORMATION

This technical report was prepared under NUWC Division Newport Network Activity No. 100001678464/0010, “Density Modeling for Loggerhead and Leatherback Sea Turtles in the Northwest Atlantic Ocean,” principal investigator Laura M. Sparks (Code 1023). The sponsoring activity is the U.S. Fleet Forces Command, program manager Laura Busch (USFF N465).

The technical reviewer for this report was Tara E. Moll (Code 1023).

ACKNOWLEDGMENTS

The authors thank all the data providers and organizations that contributed line transect survey data, availability bias, and perception bias estimates to this project: Lance Garrison, Heather Hass, Chris Sasso, Robert Kenney, Heather Pettis, Tim Cole, Christin Khan, Meghan Rickard, William McClellan, Ann Pabst, Mitchell Rider, Larisa Avens, Ana Cañadas, Dan Engelhaupt, Amy Engelhaupt, Jessica Aschettino, Mark Cotter, Debi Palka, Josh Hatch, Sue Barco, Sam Chavez, Kristen Hart, Kelsey Roberts, The Southeast and Northeast Fisheries Science Centers, Duke University, The University of Rhode Island, New England Aquarium, The New York Department of Environmental Conservation, The University of North Carolina Wilmington, The University of Miami, HDR Inc., Virginia Aquarium & Marine Science Center, and the United States Geological Survey. Jason Roberts contributed to data processing and provided technical advice. Danielle Jones of Naval Facilities Engineering Systems Command Atlantic assisted with project management and collation of availability bias data.

Reviewed and Approved: 1 March 2024

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REPORT DOCUMENTATION PAGE

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED: START DATE	3. DATES COVERED: END DATE
15-12-2023	Technical Report	18-03-2021	15-12-2023

4. TITLE AND SUBTITLE

Sea Turtle Distribution and Abundance on the East Coast of the United States

5a. CONTRACT NUMBER	5b. GRANT NUMBER	5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER	5e. TASK NUMBER	5f. WORK UNIT NUMBER

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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McLaughlin Research Corporation, 132 Johnny Cake Hill, Middletown, RI 02842

8. PERFORMING ORGANIZATION REPORT NUMBER

TR 12,428

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Fleet Forces Command, 1562 Mitscher Ave., Norfolk, Virginia 23551

10. SPONSOR/MONITOR'S ACRONYM(S)

USFF N465

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

TR 12,428

12. DISTRIBUTION/AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A. Approved for public release: distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Spatially explicit estimates of species distribution and abundance are required to quantify potential impacts from human activities, such as military training and testing. On the US East Coast, four protected species of sea turtles can commonly be found and require impact assessments. An area of 1.2 million kilometers of line transect surveys from seven different survey organizations were collated to create spatial density models for these species. Almost a third of the available sightings were unidentified turtles. A random forest model was used to assign these unidentified sightings to the species level. Hardshell turtles were predicted to be farther south in cool months, moving northwards in late spring and early summer to occupy seasonal nearshore habitats. Leatherback turtles were predicted to be in high abundance off Florida year-round and at low-to-moderate densities off the continental shelf and in the Gulf of Maine year-round. The models presented here are the first to apply availability bias estimates that have been developed in or near the study area and to classify unidentified sightings to the species level in the region, providing an updated, critical tool to managers responsible for the conservation of these species.

15. SUBJECT TERMS

Loggerhead turtle, Green turtle, Kemp's ridley turtle, Leatherback turtle, Turtle, Sea turtle, distance sampling, distribution, habitat based, density, abundance

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	C. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES
Public Release	Public Release	Public Release	SAR	176

19a. NAME OF RESPONSIBLE PERSON	19b. PHONE NUMBER *(Include area code)*
Laura M. Sparks	401-832-7019

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LIST OF ABBREVIATIONS AND ACRONYMS

AFTT	Atlantic Fleet Training and Testing
AIC	Akaike's Information Criteria
AMAPPS	Atlantic Marine Assessment Program for Protected Species
BSS	Beaufort Sea State
CDF	cumulative distribution function
CETMAP	Cetacean Density and Distribution Mapping
CI	confidence interval
CV	coefficient of variation
CVM	Cramér–von Mises
DBDB-V	Digital Bathymetric Data Base Variable Resolution

LIST OF ABBREVIATIONS AND ACRONYMS (Cont'd)

DPS	distinct population segment
edf	effective degrees of freedom
ESA	Endangered Species Act
ESHW	effective strip half-width
ft	foot/feet
GAM	generalized additive model
GEBCO	General Bathymetric Chart of the Oceans
GOMMAPPS	Gulf of Mexico Marine Assessment Program for Protected Species
km	kilometer(s)
km^2	square kilometer(s)
m	meter(s)
MATS	Mid-Atlantic Tursiops Surveys
MD DNR	Maryland Department of Natural Resources
MGEL	Marine Geospatial Ecology Lab
mi	mile(s)
MLD	mixed layer depth
MMPA	Marine Mammal Protection Act
MODIS	Moderate Resolution Imaging Spectroradiometer
NARWSS	North Atlantic Right Whale Sighting Survey
Navy	Department of the Navy
NEFSC	Northeast Fisheries Science Center
NLPSC	Northeast Large Pelagics Survey Collaborative
NMFS	National Marine Fisheries Service
NMSDD	Navy Marine Species Density Database
NODES	Navy OPAREA Density Estimates
NUWC	Naval Undersea Warfare Center
NYBWM	New York Bight Wind Management
TT- NYSDEC	Tetra Tech - New York State Department of Environmental Conservation
OPAREA	Operating Area
Q-Q	quantile-quantile
REML	restricted maximum likelihood
SEFSC	Southeast Fisheries Science Center
UNCW	University of North Carolina Wilmington
US	United States
VA CZM	Virginia Coastal Zone Management
VACAPES	Virginia Capes Range Complex
VAMSC	Virginia Aquarium and Marine Science Center
VGPM	Vertically Generalized Production Model
WGS	World Geodetic System

1. INTRODUCTION

The United States (US) Department of the Navy (DON, but hereafter referred to as the "Navy") requires spatially explicit estimates of species distribution and abundance to assess the impacts associated with training and testing activities in the waters of the US East Coast. The Navy compiles density and abundance estimates into the Navy Marine Species Density Database (NMSDD), which is the authoritative source of marine species density data used in the Navy's quantitative impact analysis.

On the US East Coast, the Navy trains and tests at numerous installations and range complexes (Figure 1) that have defined surface and subsurface areas as well as special use airspace. The Navy complies with environmental laws for testing and training at sea, chiefly the Endangered Species Act (ESA) and Marine Mammal Protection Act (MMPA), which requires an analysis of impacts. This analysis includes a quantification of potential negative interactions between Navy assets using sonar and explosives, as well as other possible negative interactions associated with Naval activities. To evaluate the potential impacts on protected marine species, the Navy identifies spatial density models as the best available science for estimating abundance and distribution of these species.

The Navy requires spatial density models incorporated into the NMSDD to (1) predict absolute density/per square kilometer (km^2) of animals, (2) have a spatial resolution of 10x10 kilometers (km; or 6.2x6.2 miles [mi]) or less where possible, (3) represent a long-term average of density/abundance, and (4) have the finest scale in terms of temporal and taxonomic resolution that is scientifically supportable. The long-term average requirement is based on the seven year permitting process established by the Navy and the federal regulator, National Marine Fisheries Service (NMFS). Animal populations can vary widely inter-annually. Therefore, basing Navy impact assessments on a single year of data may not accurately represent population levels over the length of the permit. Spatial density models are generally derived from line transect data, both aerial and shipboard, and relate animal abundance to environmental covariates. This allows abundance to vary in response to the underlying environmental conditions. Other data types—such as relative density derived from satellite telemetry data coupled with a population estimate—can be used but these alternate data types are less preferable.

Recent work funded by the Navy produced spatial density models for taxa of marine mammals that had sufficient sightings for the US East Coast and broader Atlantic Fleet Training and Testing (AFTT) study area, but the Navy has not produced models for any of the sea turtle species found in the region within the last 15 years. The Navy Operating Area (OPAREA) Density Estimates (NODES) models for sea turtles from 2007 are outdated and should not be used for current Navy impact analyses. A loggerhead turtle spatial density model covering Chesapeake Bay was created in 2014 but covers a limited portion of the AFTT study area and Navy OPAREAs. The work contained in this technical report (TR) fills that gap by developing spatial density models for the four most common species of sea turtles found in waters of the US East Coast: loggerhead turtles (*Caretta caretta*), green turtles (*Chelonia mydas*), Kemp's ridley turtles (*Lepidochelys kempii*), and leatherback turtles (*Dermochelys coriacea*).

The Naval Undersea Warfare Center (NUWC) Division Newport, RI, followed the general approach to fitting spatial density models outlined by Miller et al. (2013). NUWC Division Newport also applied correction factors to the models to account for the possibility that observers may miss sightings directly on the survey trackline, either because animals were submerged and unavailable for detection (e.g., availability bias) or because they were simply hard to detect despite being at the surface (e.g., perception bias).

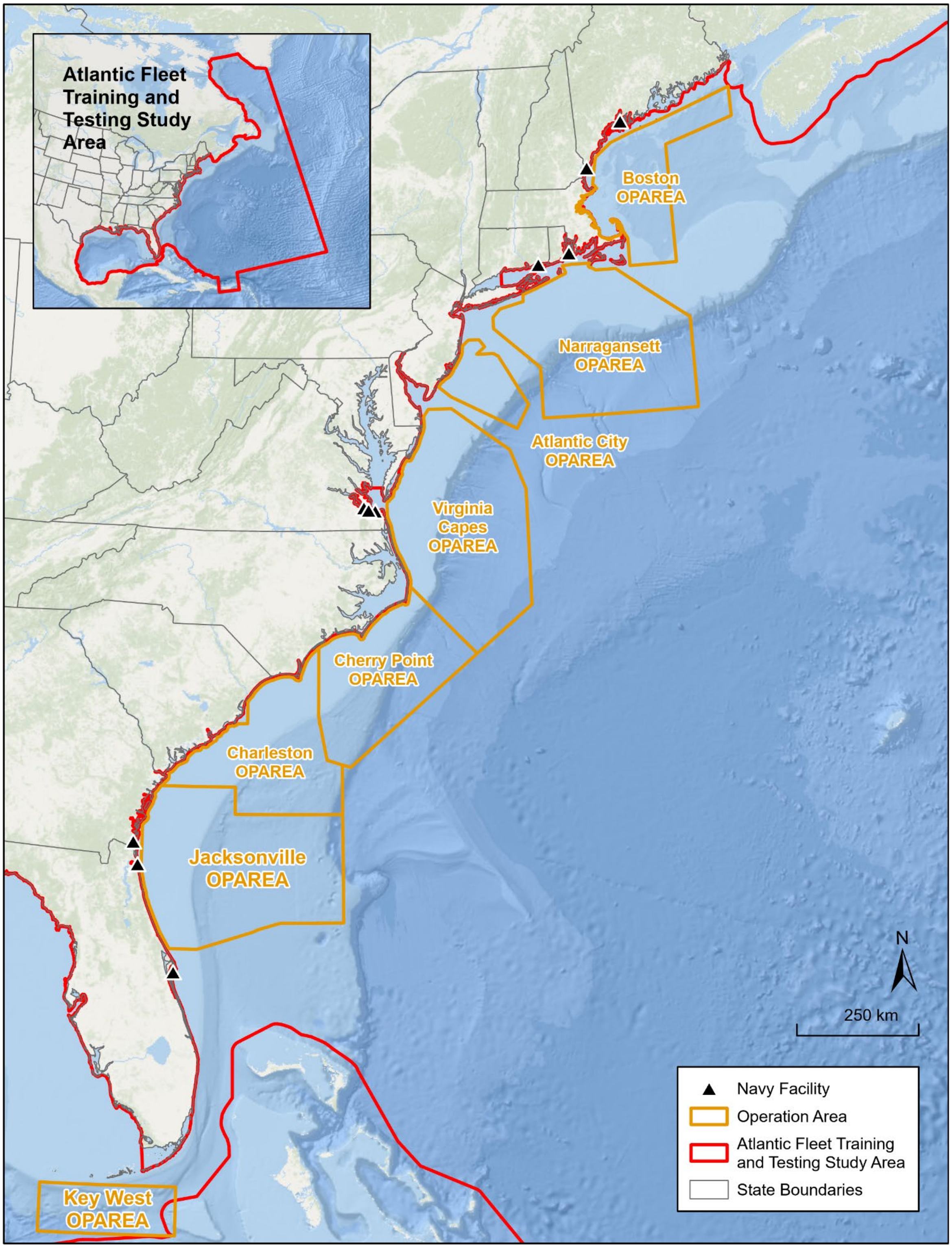

Figure 1. Navy Operating Areas and Installations/Facilities on the US East Coast

2. BACKGROUND

2.1 CHARACTERISTICS OF THE WATERS OFF THE EAST COAST OF THE UNITED STATES

Along the East coast, water temperatures range from warm, subtropical waters in the south off Florida to cold, Northwest Atlantic waters (e.g., Gulf of Maine) farther north up the coast, with various temperature habitats in between. Thus, yielding a diverse environment comprising several distinct ecoregions (Spalding et al. 2007), generally warmer the further south one goes, and colder to the north. However, seasonal temperatures have a wide range, particularly in the mid-Atlantic, and waters are only seasonally warm enough for hardshell sea turtles, especially smaller specimens that have a harder time thermoregulating (Griffin et al. 2019; Montello et al. 2022). Warm waters in the mid-Atlantic are influenced by the Gulf Stream, a current that brings warm water from the shallow Gulf of Mexico up through the mid-Atlantic before spinning off and transporting warm water to Europe. The cold Labrador Current comes down the coast of Canada into the Gulf Maine before turning offshore around Cape Cod, Massachusetts, creating a distinctly colder environment north of Cape Cod and in the Northwest Atlantic.

Numerous estuaries and embayments are found along the east coast, many of which are used by large marine taxa such as sea turtles and marine mammals (Musick and Limpus 1996; Rosel et al. 2011). Notable embayments are Chesapeake Bay, Delaware Bay, Long Island Sound, and Narragansett Bay, all of which host important ports, commercial fisheries, and diverse marine animal and plant communities. Sandy and rocky beaches can be found along the east coast, as well as extensive intertidal zones. Moving offshore, the continental shelf is broad, extending 200 km (124 mi) at its furthest reach around Cape Cod to 30 km (19 mi) at its narrowest by Cape Hatteras, North Carolina. Off the shelf, the continental slope drops rapidly to the abyssal plain reaching depths of 2,000–3,000 meters (m; 6,562–9,843 feet [ft]).

2.2 SEA TURTLE POPULATIONS IN WATERS OF THE EAST COAST OF THE UNITED STATES

Four species of sea turtles can be regularly found in the waters of the US East Coast: the loggerhead turtle (*Caretta caretta*), the green turtle (*Chelonia mydas*), the Kemp's ridley turtle (*Lepidochelys kempii*), and the leatherback turtle (*Dermochelys coriacea*). The hawksbill turtle (*Eretmochelys imbricata*) is an infrequent visitor to the study area, limited to the very southern areas of Florida, and this species will not be discussed further in this report. There were very few sightings of this species and, therefore, it was not included in the model and will not be discussed further in this report. Of the four species considered common, the loggerhead, green, and leatherback turtles regularly nest in the region. Kemp's ridley nests have been discovered on the east coast in New York, Virginia, and North Carolina, but only sporadically (Johnson et al. 1999; Virginia State Parks 2014), in what may be potential colonization from their primary nesting habitat in the Gulf of Mexico, or may just be vagrant animals.

2.2.1 Loggerhead Turtles

Loggerhead turtles are a hardshell species of sea turtle, generally brown to orange in coloration, listed as vulnerable globally (Casale and Tucker 2017). The Northwest Atlantic Distinct Population Segment (DPS), which the animals in the study area belong to, is listed as threatened

(NMFS 2009) under the ESA. Critical habitat has been listed for this species in the region and includes migratory habitat along the Outer Banks of North Carolina, overwintering habitat in the southern waters of North Carolina, breeding habitat including beaches and in-water habitat in Florida, and areas of the Sargassum Sea, offshore, that are important developmental habitat for hatchling and small juvenile turtles.

Primary nesting habitat for loggerhead turtles in the region is in Florida, with roughly 100,000 nests laid annually (Ceriani et al. 2019). Other substantial nesting sites can be found in Georgia and the Carolinas, though not of the same magnitude of nesting in Florida. Nesting rarely occurs further north than the Outer Banks. After developing in offshore areas for several years, loggerhead turtles generally recruit to coastal foraging areas where their preferred prey of benthic invertebrates can be found (McClellan and Read 2007). Loggerheads that are not breeding move from overwintering sites to seasonal foraging habitat in the mid-Atlantic starting in late spring (Mansfield et al. 2009; Griffin et al. 2013). Loggerheads in the region tend to be larger than the other hardshell species. Because of their size, they are less susceptible to cold stunning, allowing them to range far to the north, with sightings of active turtles in the Gulf of Maine and off the waters of Nova Scotia, where many animals have been tracked using satellite tags (Brazner and McMillan 2008). Animals return to warmer waters in late fall, and they risk cold stunning if they remain in the northern waters in the winter.

2.2.2 Green Turtles

Green turtles are a hardshell species of sea turtle, with widely variable coloration, ranging from green to brown to gray and yellow. Green turtles are listed as endangered globally (Seminoff 2004). The North Atlantic DPS, which the animals in the study area belong to, is listed as threatened (Seminoff et al. 2015) under the ESA. Critical habitat has been listed for this species but is not present in the region (National Oceanic and Atmospheric Administration 1998).

Primary nesting habitat for green turtles on the East Coast is in Florida (Johnson and Ehrhart 1996; Brost et al. 2015). Starting in 2013, a large increase in nesting on index beaches in Florida was noted, which began a pattern of high and low nesting every other year. Nesting peaked in 2019 with over 40,000 nests (Florida Fish and Wildlife Commission Research Institute 2022a) while low years generally only see several thousand nests. Infrequent nesting occurs south of Virginia, but on the order of several nests every few years. After developing in offshore areas for several years, green turtles generally recruit to coastal foraging areas where they primarily forage on macroalgae and seagrass (Bolten 2003; Arthur, Boyle, and Limpus 2008). Green turtles move to seasonal foraging habitat in the mid-Atlantic starting in late spring and early summer (Mansfield, Seney, and Musick 2002; Barco et al. 2018b) and are generally not seen north of Cape Cod even in the peak of summer. Animals return to warmer waters in late fall and can cold stun if they remain in northern waters too long.

2.2.3 Kemp's Ridley Turtles

Kemp's ridley turtles are generally the smallest hardshell species of sea turtle in the region, with grayish-green coloration, making them particularly difficult to spot at sea and in turbid water. Kemp's ridley turtles are listed as endangered under the ESA, and comprise a single population ranging from the Gulf of Mexico to the US East Coast (Wallace et al. 2010). Some animals have been found in European Atlantic waters and rarely in the Mediterranean Sea (Tomás and Raga 2008; Carreras et al. 2014), but it is unclear if these animals ever return to US waters. Critical habitat status has not been listed for this species.

There is no primary nesting habitat for Kemp's ridley turtles on the East Coast. Rare nesting occurs from Florida to Maryland, but no beaches have been consistently colonized by this species. After developing in offshore areas for several years, Kemp's ridley turtles generally recruit to coastal foraging areas where they forage on benthic invertebrates, primarily blue crabs (Burke, Morreale, and Standora 1994; Seney and Musick 2005). Kemp's ridley turtles move to seasonal foraging habitat in the mid-Atlantic starting in late spring and early summer (Mansfield, Seney, and Musick 2002; Barco et al. 2018b) and are generally not seen north of Cape Cod even in the peak of summer. Animals return to warmer waters in late fall and can cold stun if they remain in northern waters too long.

2.2.4 Leatherback Turtles

Leatherback turtles are the only non-hardshell species of sea turtle and the largest species in the region. Instead of a shell, leatherback turtles have eponymous dark, leathery skin and are easily characterized by a series of ridges along their back, making them easy to distinguish from other turtle species even in relatively poor sighting conditions. Leatherback turtles are listed as vulnerable globally (Wallace, Tiwari, and Girondot 2013) and endangered under the ESA. No DPSs have been defined for this species. Critical habitat has been listed for this species but is not present in the region (National Oceanic and Atmospheric Administration 2012).

Primary nesting habitat for leatherback turtles on the East Coast is in Florida (Florida Fish and Wildlife Commission Research Institute 2022b) and is around 1,000 nests per year. Infrequent nesting occurs throughout the remainder of the southeastern United States, on the order of dozens of nests each year. Breeding leatherback turtles from the Wider Caribbean region move from Caribbean summer breeding habitat along migratory corridors, including the US East Coast, to foraging grounds in the North Atlantic where they will remain for several years before reversing the migration to breed again (James, Sherrill-Mix, and Myers 2007). With some exceptions, leatherback turtles do not recruit to neritic foraging grounds like other species of sea turtle (James, Andrea Ottensmeyer, and Myers 2005; Dodge et al. 2014; Fossette et al. 2010; Barco et al. 2018a). The leatherback turtle's preferred prey is gelatinous zooplankton (Houghton et al. 2006; Witt et al. 2007).

3. MATERIAL AND METHODS

3.1 STUDY AREA

The study area (Figure 2) for this project (e.g., the area over which density predictions were made) aligns closely with the Navy-funded Roberts, Mannocci, and Halpin (2015) marine mammal spatial density models. The on-effort transect coverage from the available survey data supported the defined area and captured the major operational areas on the US East Coast, an area of particular interest to the Navy.

The study area covers the East Coast from Maine to the southern tip of Florida. Even though there were survey data available in the western Gulf of Mexico and Florida Keys, it was posited that environmental relationships in the Gulf of Mexico may differ from the East Coast, and Gulf of Mexico-specific models were planned by the NMFS Southeast Fisheries Science Center (SEFSC) in a similar timeframe as this project. The study area is delineated to the west by the US coastline as derived by the Navy from the Digital Bathymetric Data Base Variable Resolution (DBDB-V) database. The eastern and northern boundaries of the study area generally follow the US exclusive economic zone even though survey coverage extends beyond this, particularly in the north where surveys for North Atlantic right whales, which also included turtles, ranged extensively into Canadian waters. Future efforts may expand the study area to the full survey coverage footprint, but that expansion was beyond the scope of this effort. Only two species (leatherback and loggerhead turtles) of the four target species are expected to range into Canadian waters.

3.2 SURVEY DATA SUMMARY

3.2.1 Overview of Effort Data

Previous work by the Marine Geospatial Ecology Lab (MGEL) at Duke University funded by the US Navy used line transect surveys from 10 different survey organizations to develop spatial density models for marine mammal taxa on the US East Coast. While many of these surveys contained sightings of sea turtles, the MGEL was not contracted to produce spatial density models for sea turtles. We reached out to seven of these organizations for permission to use the data to create spatial density models for four species of sea turtle. Data from three of the organizations were not appropriate for use in the turtle models for various reasons, and we did not seek their permission or use those data.

Upon receiving permission to use the data, the MGEL team delivered sightings and effort data for the surveys to NUWC Division Newport. The MGEL had previously performed extensive quality checks of these data for their use in spatial density models even though they did not use the sea turtle sightings themselves. In addition to the data, the MGEL provided guidance on handling data from specific surveys. Observations from the University of North Carolina Wilmington (UNCW) were not previously associated with segments due to some unresolved questions regarding group size and how sea turtle sightings were recorded. More detail is provided in Section 3.5.1, but we worked with both the MGEL and UNCW to resolve the extant issues and associated these sightings to effort data, making them usable for this project.

We received line transect data from all seven organizations, which were used in a distance sampling framework for spatial density models. Line transect surveys used in this study covered approximately 1.2 million linear km (770,000 linear mi) of effort, split between 39,831 km (24,749 mi) of shipboard surveys and 1,151,880 km (715,745 mi) of aerial surveys (Figure 2) (Table 1). These surveys occurred from 2003–2019 and covered all months, though generally there was more survey effort in warmer months, particularly for shipboard surveys, when survey conditions in the study area are better. Some of the surveys included effort outside of the study area (Figure *2*), including the west side of Florida and north of the Gulf of Maine. Sightings from these areas were used in the machine learning model used to discriminate ambiguous hardshell turtle sightings (Section 3.4), but neither these sightings (nor the effort from outside the study area) was used in the fitting of spatial density models. Note that 96% of the available survey effort occurred within the boundaries of the study area.

Though older surveys were available, we did not use any data older than 2003 for two reasons: (1) some environmental covariates used in the models were not available in the 1990s, which would limit the model's ability to select the covariates with the most explanatory power; and (2) it is possible sea turtle populations are changing. Though the Navy needs long-term averages of density and distribution, using surveys that are too old may not reasonably inform abundance predictions as survey methodologies improve and population levels change over time. North Atlantic Right Whale Sighting Surveys (NARWSSs) were available in 2018 and 2019. However, these surveys stopped systemically recording sightings of sea turtles after 2017, so later years were not used.

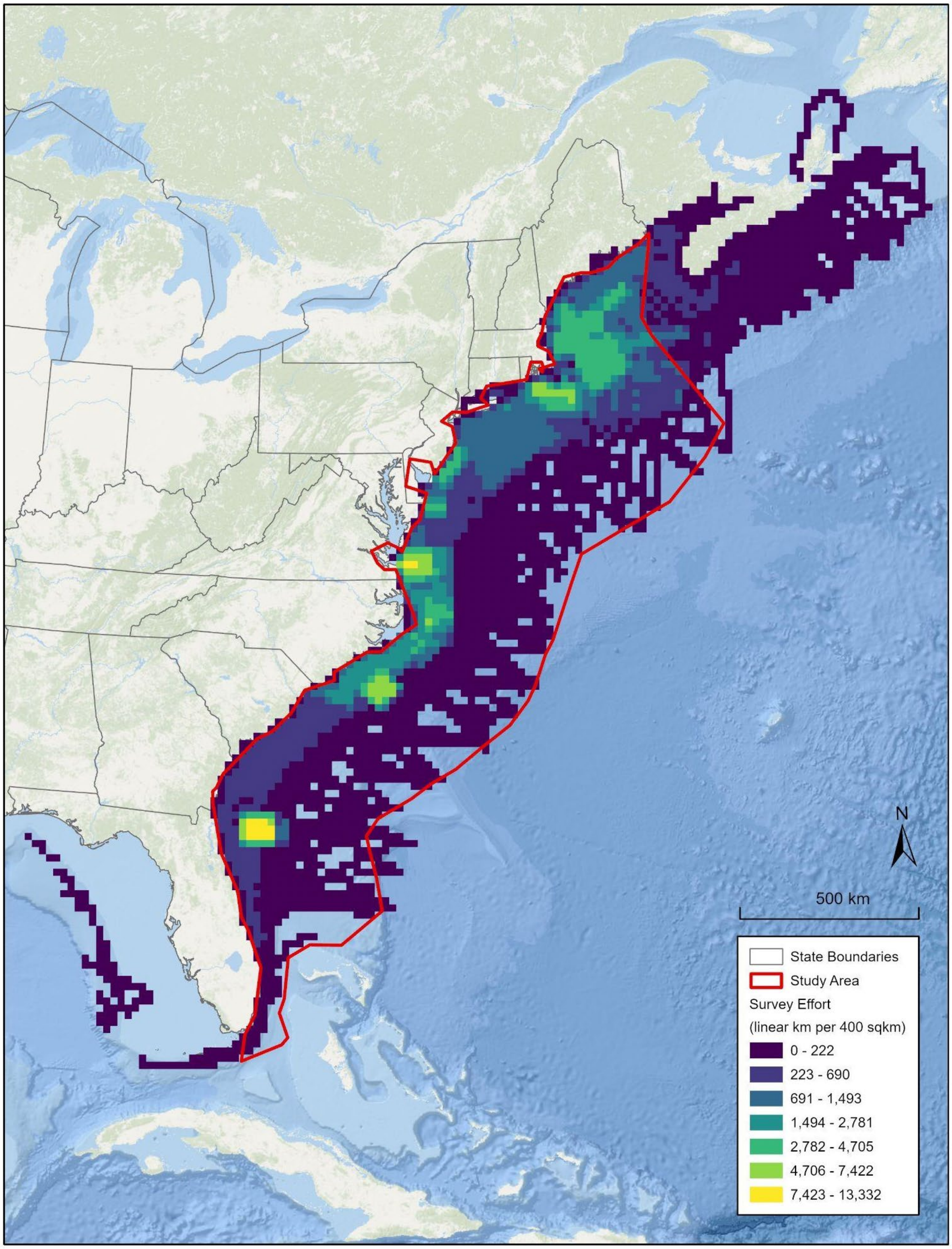

Figure 2. Study Area and Linear Kilometers of Survey Effort

Table 1. Survey Program Data Overview

Survey Provider	Program[1]	Platform	Effort (km)	Years	Months
SEFSC	AMAPPS	Boat	16,892	2011, 2013, 2016	Jun-Sep
NEFSC	AMAPPS	Boat	16,522	2011, 2013, 2014, 2016	Mar-Apr, Jun-Aug
NEFSC	pre-AMAPPS Surveys	Boat	4,011	2004, 2007	Jun-Aug
SEFSC	AMAPPS	Plane	110,876	2010–2019	Jan-Dec
SEFSC	MATS	Plane	13,505	2004–2005	Jan-Mar, Jul-Aug
NEFSC	AMAPPS	Plane	90,564	2010–2012, 2014–2019	Jan-Dec
NEFSC	Pre-AMAPPS Surveys	Plane	34,558	2004, 2006–2008	Jun-Aug
NEFSC	NARWSS	Plane	471,722	2003–2017	Jan-Dec
HDR Inc	Navy Marine Species Monitoring Program	Plane	6,374	2018	Apr-Aug, Oct-Dec
New England Aquarium	NLPSC	Plane	43,309	2011–2015	Jan-Dec
TT-NYSDEC	NYBWM	Plane	57,303	2017–2018	Jan-Dec
UNCW	Navy OPAREA Surveys (VACAPES, Cherry Point and Jacksonville)	Plane	195,497	2009–2017	Jan-Dec
UNCW	Right Whale Surveys	Plane	114,646	2005–2008	Jan-Jun, Oct-Dec
VAMSC	Miscellaneous surveys in the mid-Atlantic	Plane	56,942	2010, 2012–2017	Jan-Dec

[1]See List of Abbreviations and Acronyms for survey and program names.

3.2.2 Overview of Sightings Data

Sightings for sea turtles in the available survey data (n = 25,208) were given as either loggerhead, green, Kemp's ridley, hawksbill, leatherback, or unidentified turtle. There were only six confirmed hawksbill sightings. With so few confirmed sightings, we did not attempt to model that species. Note that 29.7% of sightings were given as unidentified hardshell turtles or unidentified turtles (Table 2), representing a significant fraction of all available data. All unidentified turtles were assumed to be hardshell turtle species, given the distinctive appearance and coloration of leatherback turtles, which makes them distinguishable even at relatively far distances or unfavorable survey conditions. Not accounting for the unidentified sightings would result in a substantial underestimation of abundance for the spatial density models. How unidentified sightings were dealt with is discussed in Section 3.4.

All confirmed sightings of loggerhead, green, Kemp's ridley, and leatherback turtles within the study area (that also passed quality control checks) were used in creating spatial density models for those species. The number of available sightings overall are given in Table 2. Sightings by species (except hawksbill turtles) and season are shown in Figures 3–7.

Some sightings were dropped because they were missing required information, such as perpendicular distance or time, or were greater than 1 km (0.6 mi) from the trackline. In total, 391 sightings (1.5% of all sightings) were removed from the analysis, many of which were off effort and were not going to be used in the spatial density models, though they could have been used in classifying ambiguous sightings to the species level. Any on effort survey segments with dropped sightings were dropped from all subsequent analyses.

We performed a qualitative review of locations by species. As most turtle sightings occur on the continental shelf and south of Cape Cod, we evaluated sightings that fell outside of these areas. All of the confirmed sightings off the continental shelf were either loggerhead or leatherback, which seemed reasonable given the ecology of these species and available tracking data (James, Andrea Ottensmeyer, and Myers 2005; Brazner and McMillan 2008). Confirmed sightings north of Cape Cod were all loggerhead or leatherback except for one green turtle sighting in October. The green turtle would likely have been cold stunned in those waters at that time of year (Niemuth et al. 2020). We considered it an extralimital or erroneous sighting and removed it from the green turtle model. There are regular sightings of loggerhead and leatherback turtles as far north as Nova Scotia, Canada (James, Andrea Ottensmeyer, and Myers 2005; Brazner and McMillan 2008), and leatherbacks are known to forage year round in North Atlantic waters (Eckert 2006; Eckert et al. 2006a). Accordingly, we retained all those sightings.

Group size was predominately one, as turtles are not gregarious creatures with some exceptions such as mating (Bolten 2003). Larger groups were detected, with 14% of sightings having a group size greater than one. There were 92 sightings with a group size larger than 10. This number is greater than we would generally expect to see outside of chance or mating aggregations, and were mostly observations of loggerheads in the HDR and UNCW surveys. In discussions with those survey providers, we found that there were instances where sightings of loggerheads occurred too quickly for observers to log the sightings individually or there were many widely dispersed individuals. Surveyors counted loggerheads until there was a break in which to log a sighting, at which point a sighting with the total number of turtles counted and a nominal distance from the trackline was recorded.

Our concern was that these potentially artificially large group sizes would inflate density on those sections of the surveys and unreasonably influence density predictions, but we were also hesitant to eliminate them and underestimate density given the large numbers of turtles seen. Unfortunately, there was no way to know how much time had passed before the sightings were logged, so there was no way to 'smear' turtles along the exact section of trackline where sightings occurred. We dealt with this by including these sightings in the loggerhead models in two ways: (1) with the sightings given as is (group size potentially too large) and (2) with the sightings smeared over a nominal distance (25 km [15.5 mi]), which resulted in more reasonable group sizes but made assumptions about how turtles were distributed. For the loggerhead model, both treatments were used, and the resulting models were compared for differences in abundance and distribution.

Table 2. Summary of Available Sightings by Species

Species	Count	Proportion of Sightings
Loggerhead turtle	15,458	0.62
Green turtle	598	0.024
Leatherback turtle	1,375	0.054
Hawksbill turtle	6	0.0002
Kemp's ridley turtle	297	0.012
Unidentified turtles	7,474	0.30
TOTAL	**25,208**	

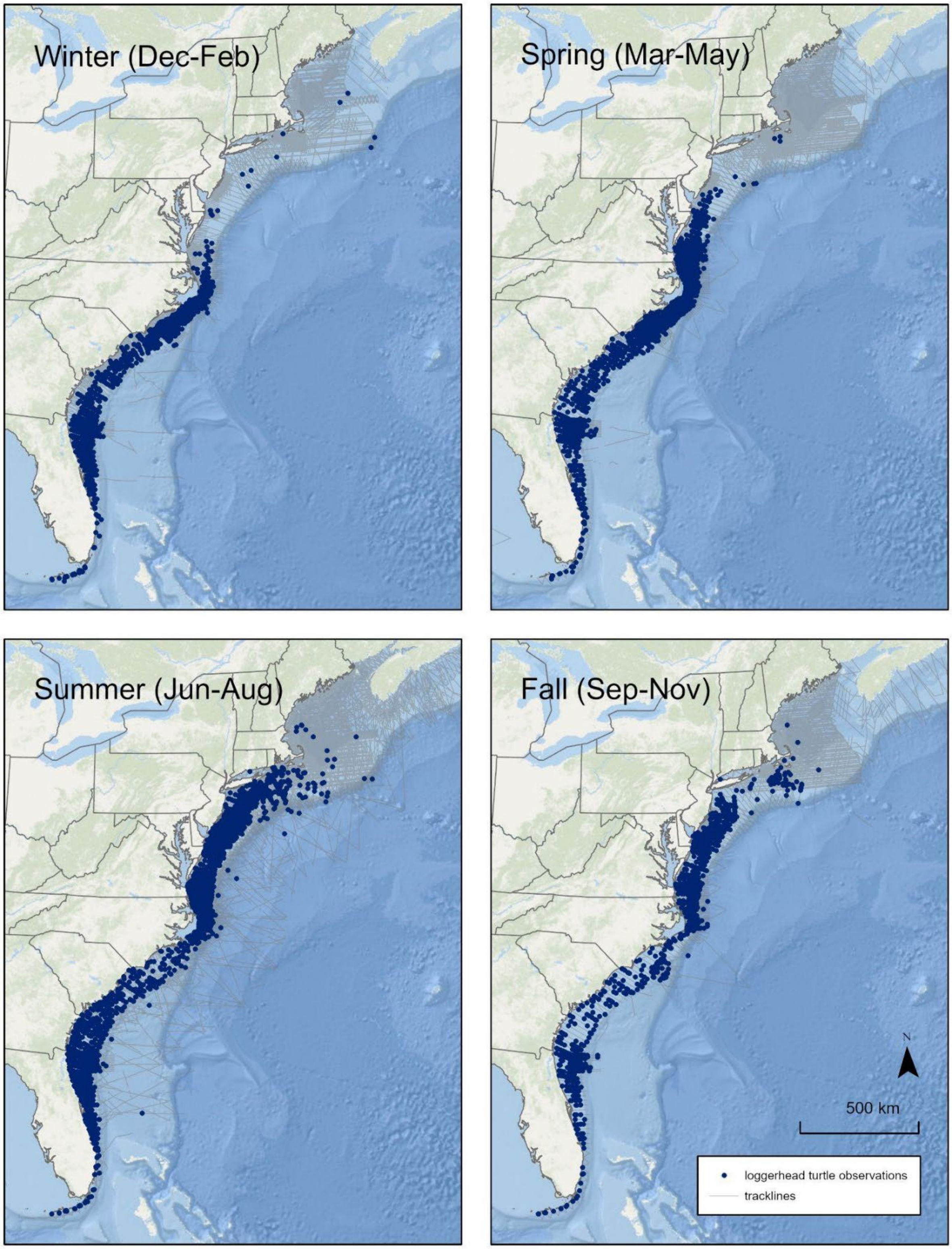

Figure 3. Seasonal Sightings of Loggerhead Turtles

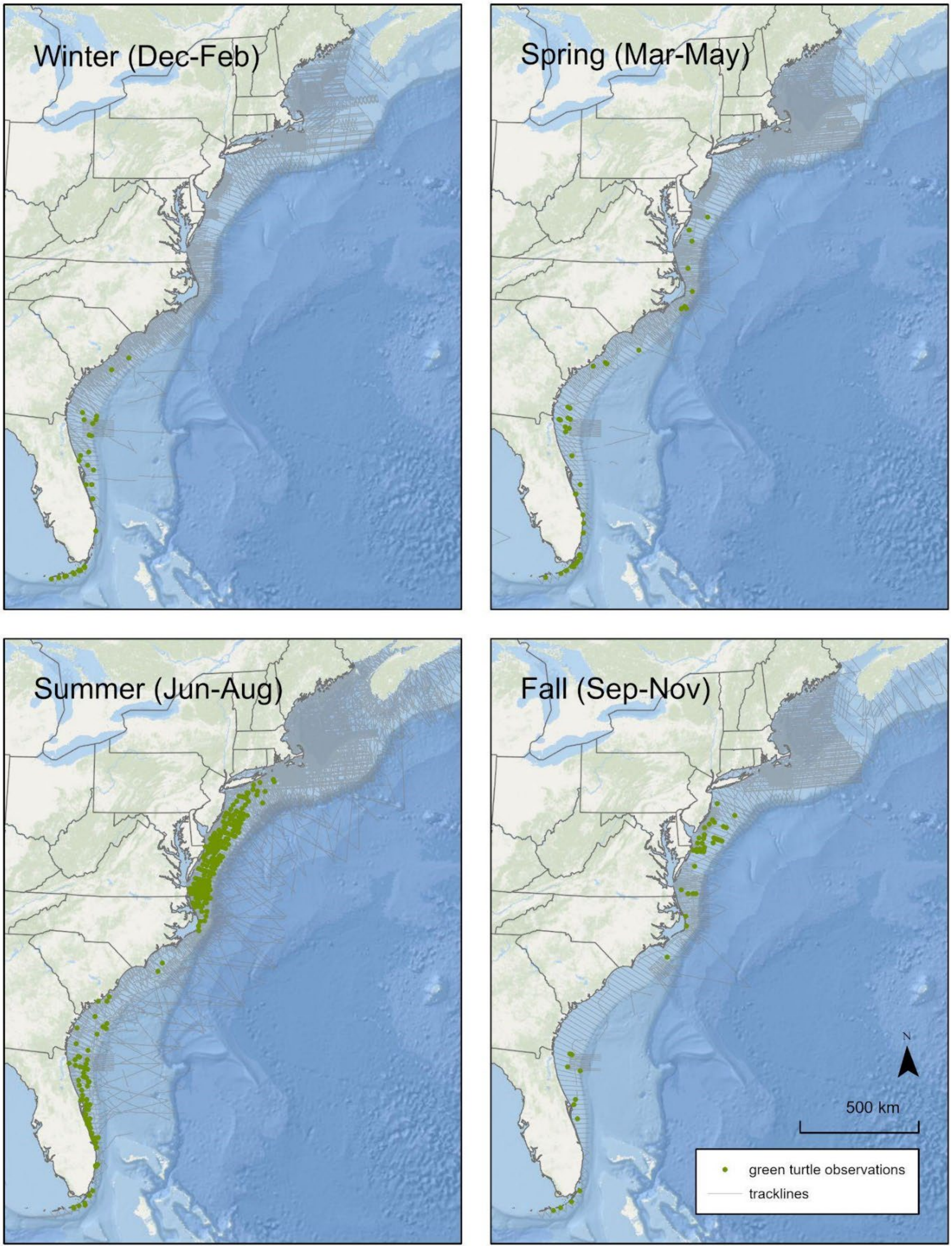

Figure 4. Seasonal Sightings of Green Turtles

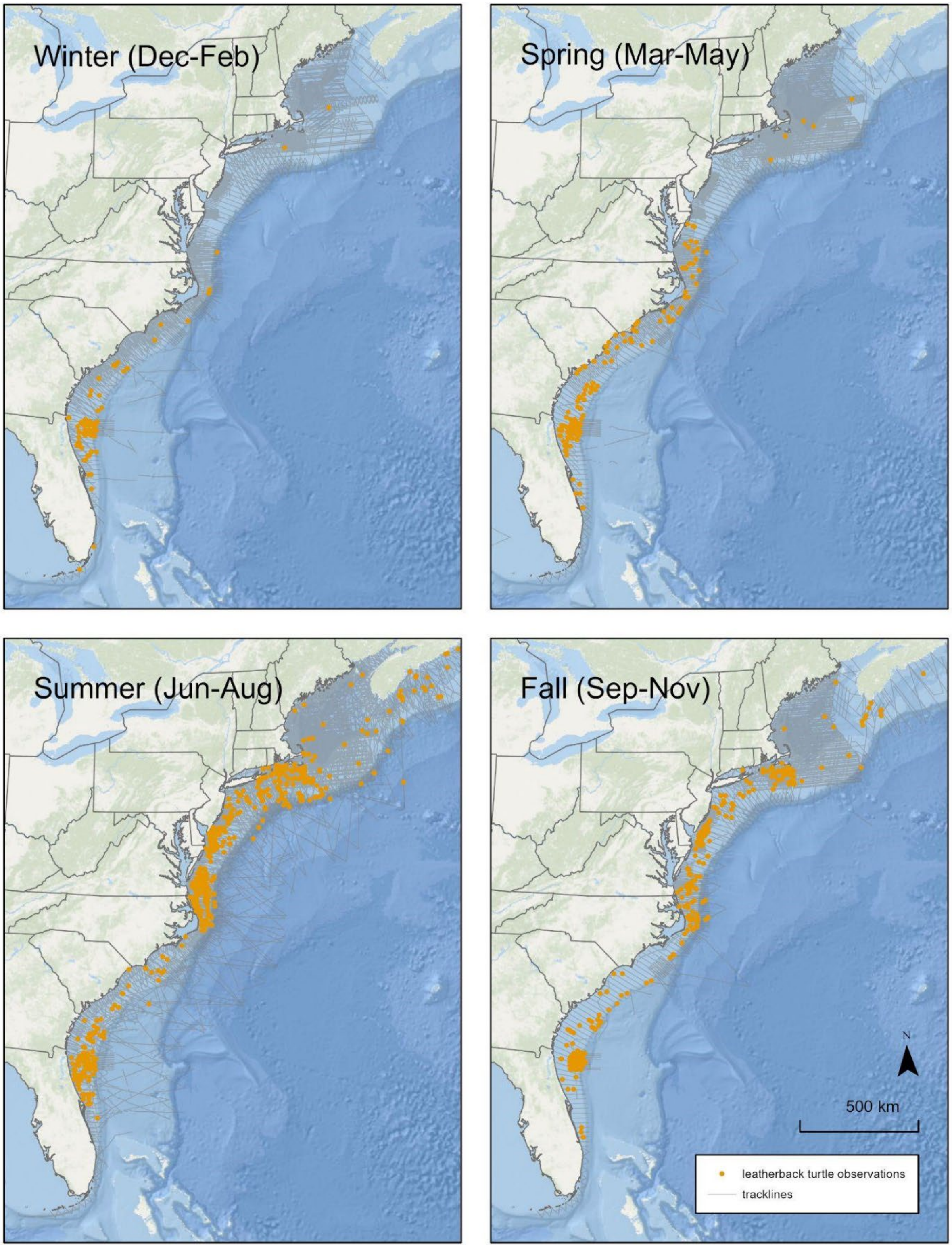

Figure 5. Seasonal Sightings of Leatherback Turtles

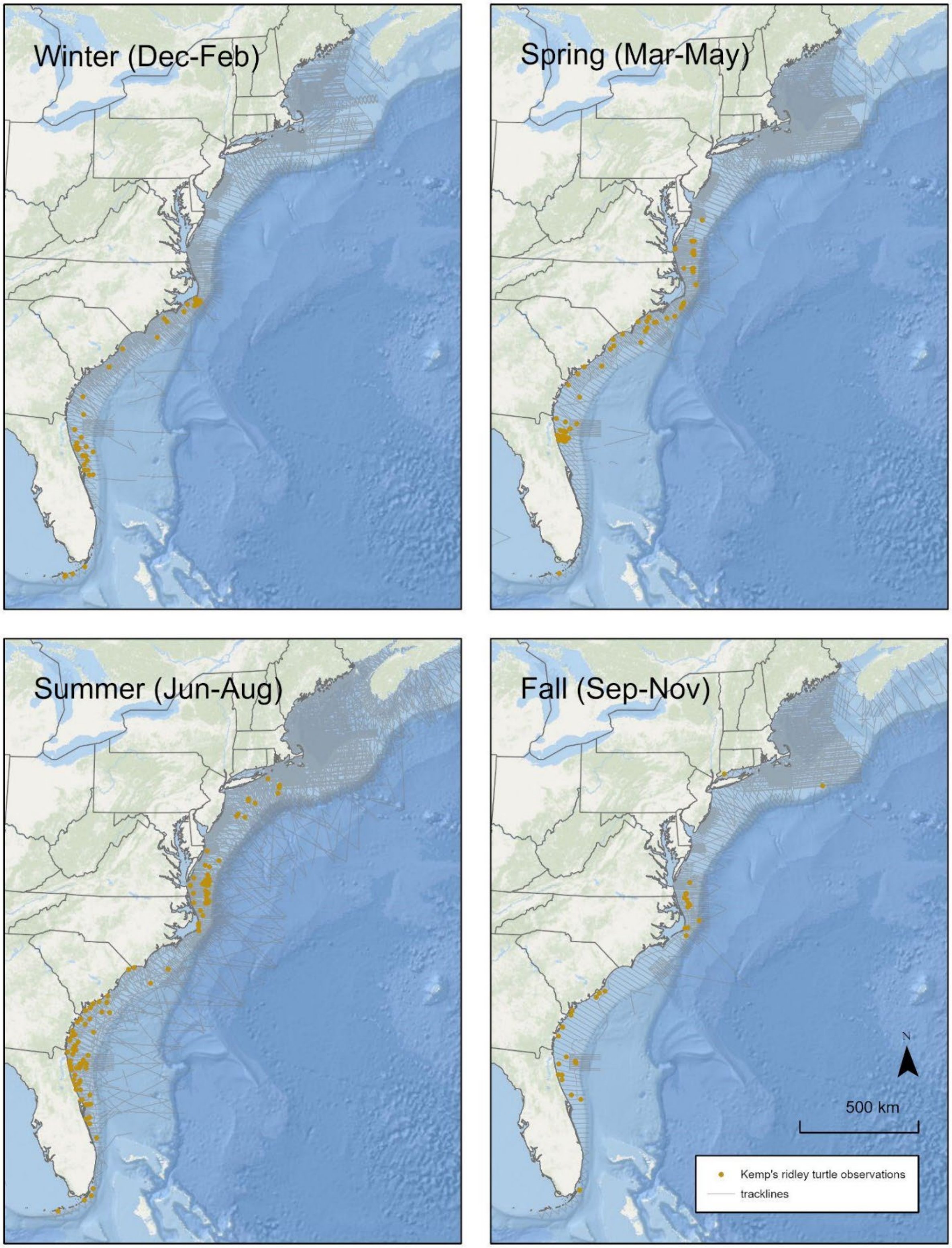

Figure 6. Seasonal Sightings of Kemp's Ridley Turtles

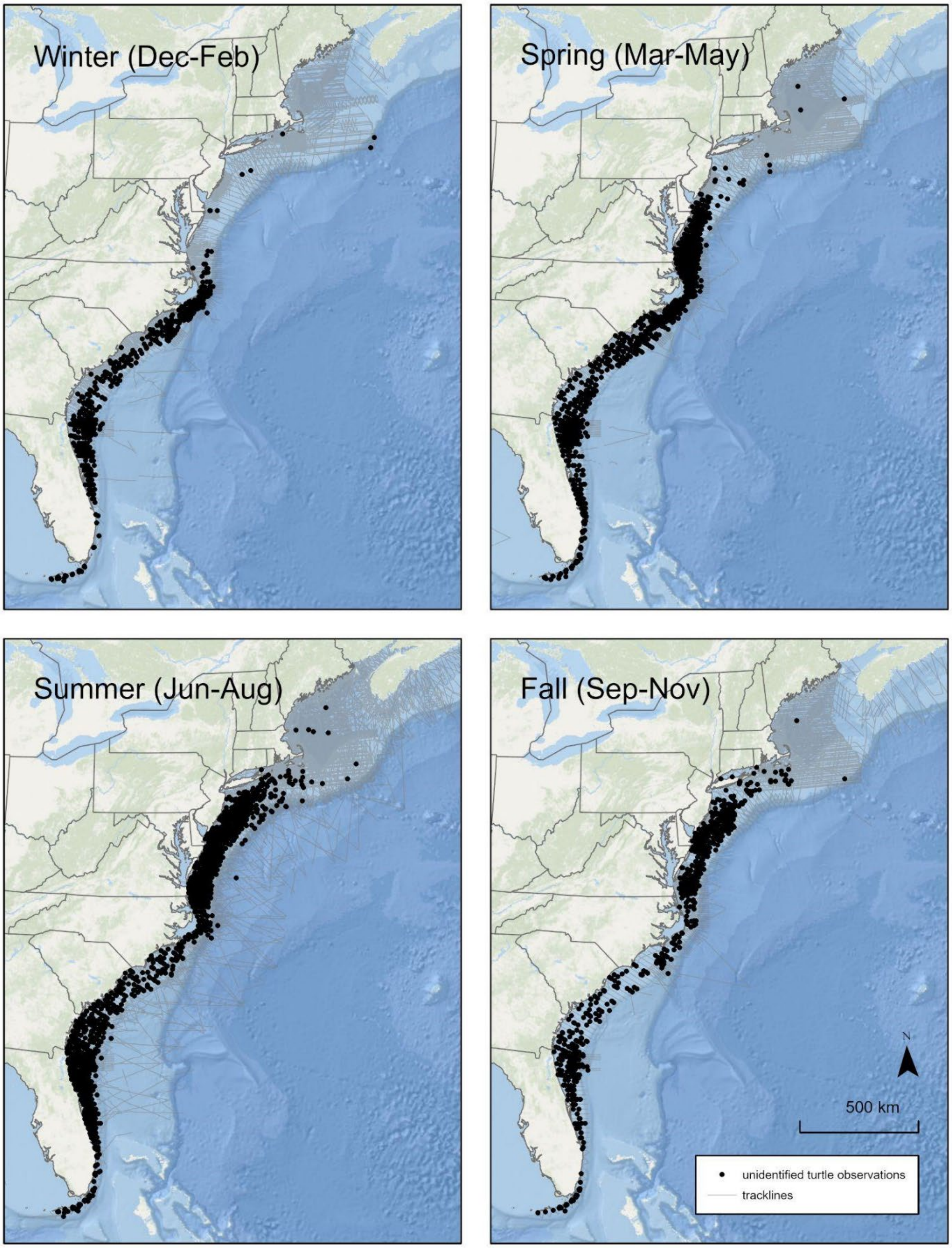

Figure 7. Seasonal Sightings of Unidentified Turtles

3.3 ENVIRONMENTAL COVARIATES

Environmental covariates that could be associated with sea turtle habitat were included as possible explanatory covariates for the spatial density models. A total of 27 environmental covariates were analyzed, which were derived from remotely sensed and ocean data models, and included both static and dynamic covariates (Table 3). Dynamic covariates included both biological and physical candidates, and their temporal coverage ranged from daily to 8-day averages depending on available temporal resolution. Contemporaneous covariates, versus climatological covariates, were selected on the premise that turtles respond more to ephemeral habitat features than long-term averages of environmental conditions (Howell et al. 2015).

All covariates were processed to a 10x10 km (6.2x6.2 mi) grid using a bilinear resampling method and projected into a World Geodetic System (WGS) 84 Albers Equal Area projection, which minimized north/south area distortions for the study area, using ArcGIS version 10.8. The majority of available covariates had a native spatial resolution of 0.25 degrees, which most closely aligned with a 10x10 grid cell. The Marine Geospatial Ecology Tools software (Roberts et al. 2010) custom command prompt scripts and Python scripts were used for additional processing.

Table 3. Environmental Covariates

Candidate Covariates		Source
Abbreviation	Name	
STATIC		
Depth	Depth	Depth of seafloor derived from the General Bathymetric Chart of the Oceans (GEBCO) 2019 (GEBCO Compilation Group 2019).
Dist_1000	Distance to 1000-m isobath	Distance to 1,000-m (3,280 ft) isobath as derived from GEBCO 2019 (GEBCO Compilation Group 2019).
Dist_500	Distance to 500-m isobath	Distance to 500-m (1,640 ft) isobath as derived from GEBCO 2019 (GEBCO Compilation Group 2019).
Dist_Shelf	Distance to Shelf	Distance to shelf break as derived from the Seafloor Geomorphic Features Map (Harris et al. 2014)
Dist_Shore	Distance to Shore	Distance to shore as derived from GEBCO 2019 (GEBCO Compilation Group 2019).
Dist_Canyon	Distance to Canyons	Distance to closest canyon as derived from the Seafloor Geomorphic Features Map (Harris et al. 2014)
Dist_Seamount	Distance to Seamount	Distance to closest seamount as derived from the Seafloor Geomorphic Features Map (Harris et al. 2014)
Slope_Deg	Slope	Slope of seafloor derived from GEBCO 2019 (GEBCO Compilation Group 2019).

Candidate Covariates		Source
Abbreviation	**Name**	
BIOLOGICAL (DYNAMIC)		
CHL_COP_Daily	Chlorophyll Daily	Daily chlorophyll concentration at the ocean surface derived from the Global Ocean Biogeochemistry Hindcast ocean model (Mercator-Ocean n.d.)
CHL_VI	Vertically Integrated Chlorophyll a	Daily chlorophyll concentration in the euphotic zone derived from the Global Ocean Biogeochemistry Hindcast ocean model (Mercator-Ocean n.d.)
MNCK_EPI	Epipelagic Micronekton	Daily epipelagic micronekton derived from the Global low and mid trophic levels biomass hindcast ocean model (Lehodey, Murtugudde, and Senina 2010; Lehodey et al. 2015; Conchon 2016)
MNCK_NPP	Net Primary Productivity	Daily net primary productivity at the ocean surface derived from the Global Ocean Biogeochemistry Hindcast ocean model (Mercator-Ocean n.d.)
MNCK_ZOOC	Zooplankton Biomass	Daily zooplankton biomass derived from the Global low and mid trophic levels biomass hindcast ocean model (Lehodey, Murtugudde, and Senina 2010; Lehodey et al. 2015; Conchon 2016)
MODIS_CHL	Chlorophyll 8-day	Eight-day average of chlorophyll concentration at the ocean surface derived from the Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) satellite (NASA Ocean Biology Processing Group 2020)
NPP_VI	Vertically Integrated Net Primary Productivity	Daily net primary productivity in the euphotic zone derived from the Global Ocean Biogeochemistry Hindcast ocean model (Mercator-Ocean n.d.)
NPPV_COP_Daily	Net Primary Productivity	Daily net primary productivity derived from the Global low and mid trophic levels biomass hindcast ocean model (Lehodey, Murtugudde, and Senina 2010; Lehodey et al. 2015; Conchon 2016)
VGPM	Vertically Generalized Production Model	8-day average of net primary productivity across the water column by the Vertically Generalized Production Model (VGPM) (Behrenfeld and Falkowski 1997)
PHYSICAL (DYNAMIC)		
BSAL_BSO	Bottom Salinity	Weekly average bottom salinity derived from the Multi-Observation Global Ocean 3D Temperature, Salinity, Height, Geocurrent, and Mixed Layer Depth (MLD) ocean model (Guinehut et al. 2012; Mulet et al. 2012)

Candidate Covariates		Source
Abbreviation	Name	
SAL_SO	Surface Salinity	Weekly average surface salinity of the ocean derived from the Multi-Observation Global Ocean 3D Temperature, Salinity, Height, Geocurrent, and MLD ocean model (Guinehut et al. 2012; Mulet et al. 2012)
BTEMP_BSO	Bottom Temperature	Weekly average bottom sea surface temperature derived from the Multi-Observation Global Ocean 3D Temperature, Salinity, Height, Geocurrent, and MLD ocean model (Guinehut et al. 2012; Mulet et al. 2012)
MODIS_SST	Sea Surface Temperature 8-day	8-day average of nightly sea surface temperature derived from the Aqua MODIS Satellite (NASA Ocean Biology Processing Group 2020)
TEMP_TO	Sea Surface Temperature Weekly	Weekly average sea surface temperature derived from the Multi-Observation Global Ocean 3D Temperature, Salinity, Height, Geocurrent, and MLD ocean model (Guinehut et al. 2012; Mulet et al. 2012)
UGO	Geostrophic Zonal Velocity from Thermal Wind	Weekly average of Geostrophic Zonal Velocity from Thermal Wind derived from the Multi-Observation Global Ocean 3D Temperature, Salinity, Height, Geocurrent, and MLD ocean model (Guinehut et al. 2012; Mulet et al. 2012)
VGO	Geostrophic Meridional Velocity from Thermal Wind	Weekly average of Geostrophic Meridional Velocity from Thermal Wind derived from the Multi-Observation Global Ocean 3D Temperature, Salinity, Height, Geocurrent and MLD ocean model (Guinehut et al. 2012; Mulet et al. 2012)
MLOTST	Mixed Layer Depth	Weekly average mixed layer depth derived from the Multi-Observation Global Ocean 3D Temperature, Salinity, Height, Geocurrent, and MLD ocean model (Guinehut et al. 2012; Mulet et al. 2012)
MNCK_ZEU	Euphotic Zone Depth	Daily euphotic zone depth derived from the Global low and mid trophic levels biomass hindcast ocean model (Lehodey, Murtugudde, and Senina 2010; Lehodey et al. 2015; Conchon 2016)
SSH_ZO	Sea Surface Height	Weekly average sea surface height derived from the Multi-Observation Global Ocean 3D Temperature, Salinity, Height, Geocurrent, and MLD ocean model (Guinehut et al. 2012; Mulet et al. 2012)

3.4 CLASSIFICATION OF AMBIGUOUS SIGHTINGS

Given the large percentage of unidentified sightings (29.7%), it was crucial to come up with a method to account for these animals; otherwise, the abundance of hardshell species would be underestimated by a large margin. Previous Navy efforts (NODES) created a hardshell guild model using unidentified sightings. This was not satisfactory as potential takes for Navy impact analyses must be requested at the species or stock level, necessitating post hoc splitting of takes derived from the hardshell guild into species-level takes.

Several options were considered for apportioning these sightings to species specific models. This included:

1. Assume that all unidentified sightings are loggerheads, which are 93% of confirmed sightings. This would overestimate loggerhead abundance and underestimate other hardshell species but would be simple to implement.

2. Randomly assign unidentified sightings to species proportionally. This assumes that hardshell species have similar distributions and similar rates at which they are seen and not identified.

   > **Note:** Option 1 is somewhat reasonable for animals on the continental shelf and south of Cape Cod, which represents the majority of hardshell sightings. However, option 2 is unlikely. In talks with survey providers, they suspect that the rate at which green and Kemp's ridleys cannot be correctly identified is higher than for loggerheads given those species' smaller size and coloration similar to that of seawater.

3. Create a hardshell guild model and apportion abundance based on the underlying abundance of the other three hardshell species models. This assumes that environmental relationships for the three hardshell species are fairly similar and they can be modeled jointly. It also means the unidentified sightings cannot inform models for rarer species.

4. Attempt to classify the unidentified or ambiguous sightings to the species level using confirmed sightings in a machine learning framework. This assumes the available environmental covariates can discriminate between species. This approach has been successful with ambiguous marine mammal sightings in the study area.

Ultimately, we chose option 4, classifying the unidentified sightings to the species level. We were not comfortable with simply assuming all sightings were loggerhead turtles (as there were already few sightings of Kemp's ridleys and green turtles), and survey providers' suspect that Kemp's ridley and green turtles have a higher rate of being recorded as unidentified. We wanted every opportunity to add sightings to the spatial density models for those two species. Apportioning sightings at random was not satisfying given the different foraging ecologies of the hardshell turtle species. That rationale applied to option 3 as well. Instead, we chose to assume that the animals occupied unique-enough habitats that they could be reasonably discriminated by a machine learning model, which may be the case (DiMatteo, Lockhart, and Barco 2022).

The *partykit* package (Hothorn and Zeileis 2015) in R (R Core Team 2022) was used to implement conditional random forest models (Hothorn, Hornik, and Zeileis 2006). Conditional random forests differ from random forests in how base learners are implemented, and aggregation works by averaging observation weights rather than by averaging predictions directly (Hothorn et al. 2004; Meinshausen 2006). Conditional random forests have been shown to be effective in classifying ambiguous sightings of mobile marine taxa (Roberts et al. 2018).

The environmental covariates presented in Section 3.3 were candidate variables for classifying ambiguous sightings, as well as the temporal covariates Julian day and month, and latitude. Covariates were tested for linear correlation. For covariate pairs with a Pearson's correlation coefficient >0.7, only the covariate with the most importance to exploratory models was retained as a candidate for final models. Examination of scatterplots of covariate interactions did not indicate non-linear correlations, though this was not tested empirically. In general, machine learning techniques can handle including correlated covariates, but we opted to produce more parsimonious, and hopefully more interpretable, models.

Our general approach to fitting conditional random forest models was as follows. The underlying environmental covariates were sampled at each sightings location, and sightings were split into training and testing datasets. On the assumption that all unidentified sightings were hardshell species, and that hawksbill were rarely present in the study area, only confirmed sightings of loggerhead, green, and Kemp's ridley turtles were used in fitting classification models. Note that 80% of sightings for each species were randomly selected for model training with 20% retained for model testing.

Candidate models were fit varying the number of trees, depth of trees, and number of covariates to include in the model semi-systematically, with the goal to improve model accuracy. Accuracy was determined by assessing the percentage of correct classifications by the model against the testing dataset. Other considerations were the importance of individual covariates to the model, which led to attempting models with limited numbers of covariates, and the selection of samples (e.g., the sightings used to train the model). Several sampling methods were tried in order to improve model accuracy. Random sampling, including random sampling with equal weights given to all three species (for example in 99 samples, 33 would be drawn from each species), and random sampling with uneven weights (heavier weights given to rarer species), were all attempted.

The model with the highest overall accuracy was selected and then retrained on the full dataset of confirmed sightings. The model was then used to classify unidentified sightings to be either loggerhead, green, or Kemp's ridley turtles. The classification model assigned a probability that an unidentified sighting was each of the three species, and the classification with the highest probability was assigned to that sighting. After classification, classified sightings were qualitatively reviewed for suspicious or spurious predictions based on expert opinion and then combined with confirmed sightings for use in detection function modeling.

3.5 DETECTION FUNCTION MODELING

3.5.1 General Approach to Detection Function Fitting

The first step in spatial density modeling, after preparing survey data and sightings, is to model detectability by fitting detection functions. Detection functions are derived from perpendicular distances and, in some cases, associated covariates (Marques and Buckland 2004), and describe how the probability of detection of targets drops off with increased distance from a survey platform. Density and abundance estimates along the trackline (or segments of the trackline) can then be derived from the number of sightings, any relevant covariates, and the detection function.

The ability to sight animals generally varies by survey platform and protocol. As such, it is desirable to fit separate detection functions by platform and survey if there are enough sightings to meet the recommended 60-sighting threshold for fitting robust detection functions (Buckland et al. 2001). While this threshold is not a hard-and-fast rule, detection functions with fewer sightings can be less robust, and it can be difficult to include survey and sighting covariates in the detection model.

Not all surveys had more than the recommended 60 sightings of each species, so pooling was instituted for some surveys and species. We also pooled multiple years of the same survey program in order to fit more complex detection functions as each survey program used the same or very similar protocols between years. Pooling between survey programs first occurred between similar platforms (survey height, flat windows versus bubble windows) and if the 60 sighting threshold was still not met, pooling between species was considered. If species were pooled, we only pooled sightings of hardshell turtles given the distinct appearance of leatherback turtles. Only sightings with group sizes less than the maximum group size of the target species were used in detection functions with multiple species. Detection functions that pooled species were then applied to sightings of individual species for the relevant models.

In some cases, detection functions with less than 60 sightings were fitted. Instances where less than 60 sightings were used included groups where close to 60 observations were available or if survey protocols between programs were sufficiently different to merit fitting separate detection functions, such as substantially different survey altitudes.

Detection function hierarchies by species indicating which surveys were pooled together can be seen in Figures 8–11 and are detailed in the results for individual detection functions. Only two detection functions (loggerheads and leatherbacks) were fit for shipboard data. All shipboard data came from the Atlantic Marine Assessment Program for Protected Species (AMAPPS), so the survey pooling hierarchies deal only with the aerial surveys.

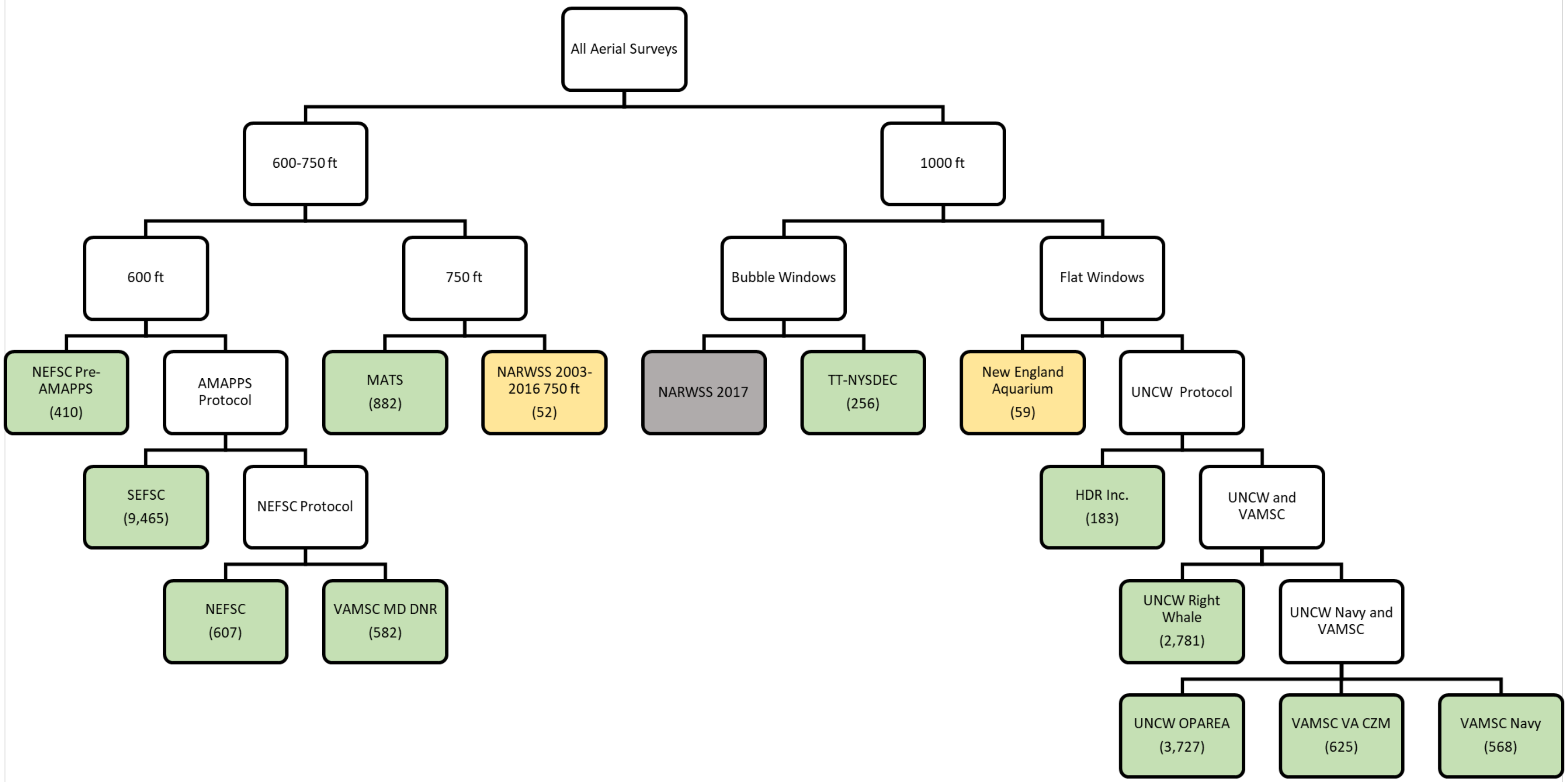

Figure 8. **Detection Function Hierarchy for Loggerhead Turtles**

Color Codes:
GREEN: a detection function with more than 60 sightings was fit;
YELLOW: a detection function with less than 60 sightings was fit;
GRAY: a survey with no sightings.

The number of sightings for each survey or detection function is given in parentheses.

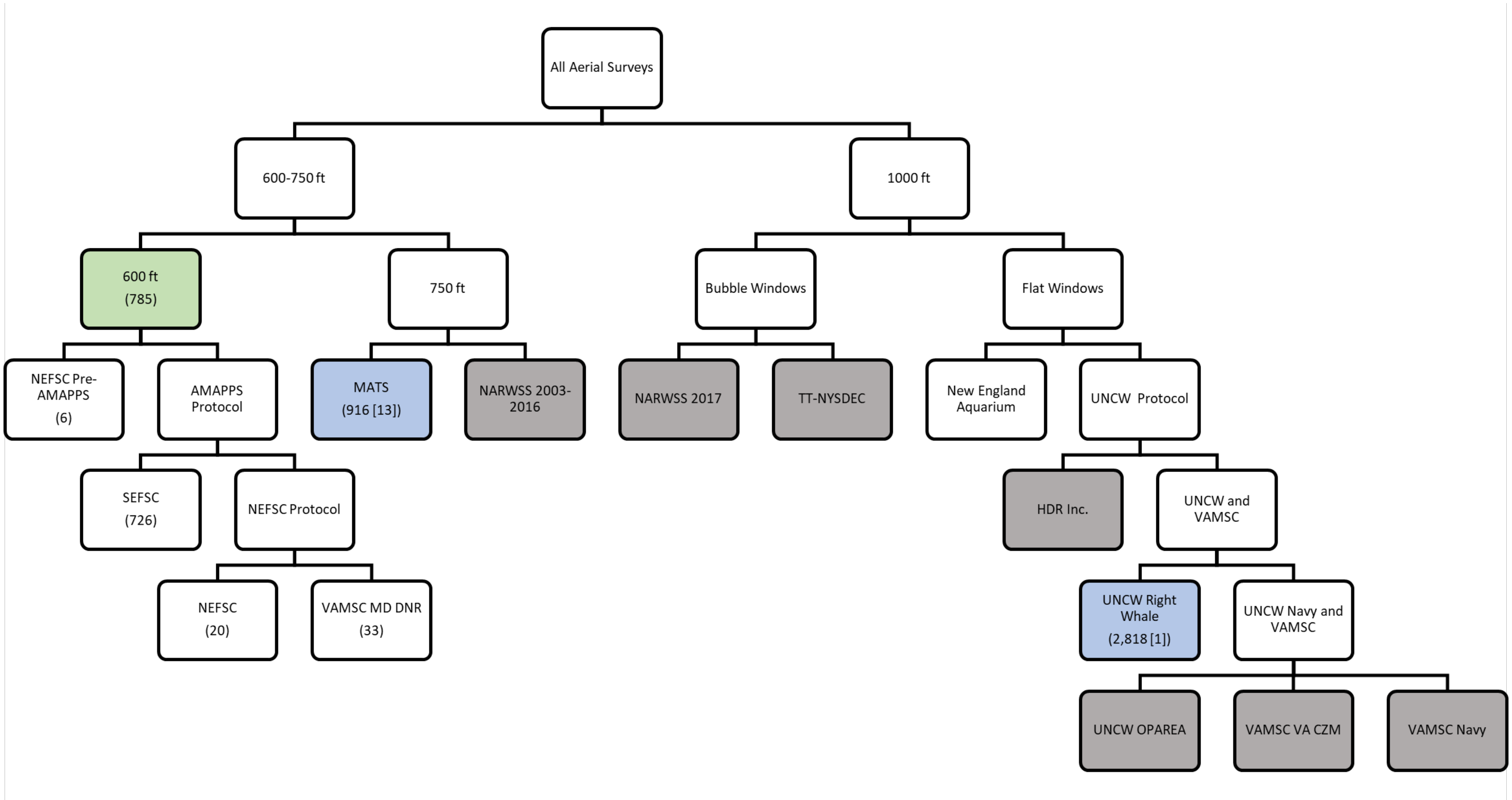

Figure 9. Detection Function Hierarchy for Green Turtles

Color Codes:
GREEN: a detection function with more than 60 sightings was fit;
BLUE: a detection function was fit with hardshell turtle sightings;
GRAY: a survey with no sightings.

The number of sightings for each survey or detection function is given in parentheses. Brackets indicate the number of sightings of the target species when a hardshell guild was used.

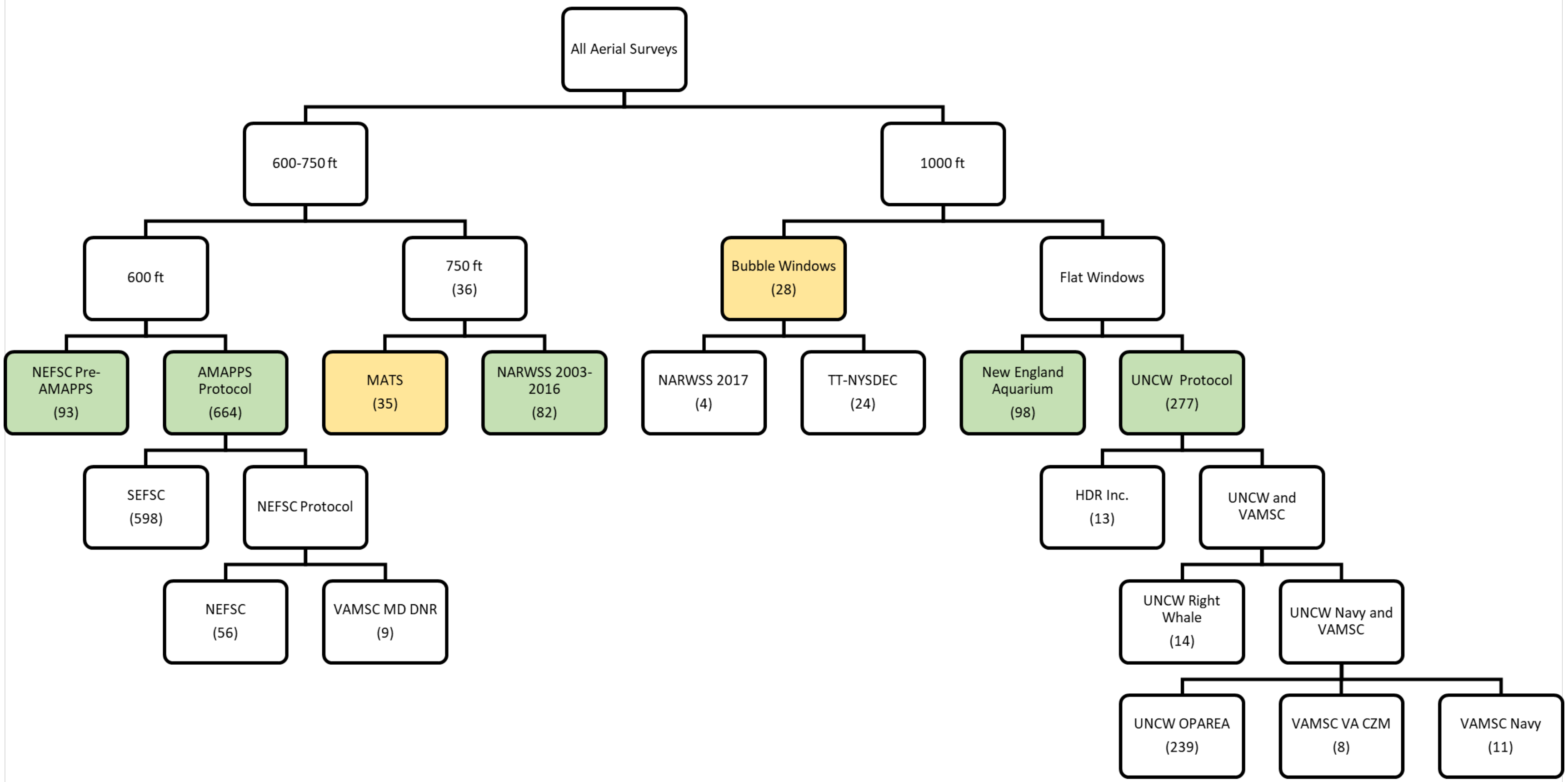

Figure 10. Detection Function Hierarchy for Leatherback Turtles

Color Codes:
GREEN: a detection function with more than 60 sightings was fit;
YELLOW: a detection function with less than 60 sightings was fit.

The number of sightings for each survey or detection function is given in parentheses.

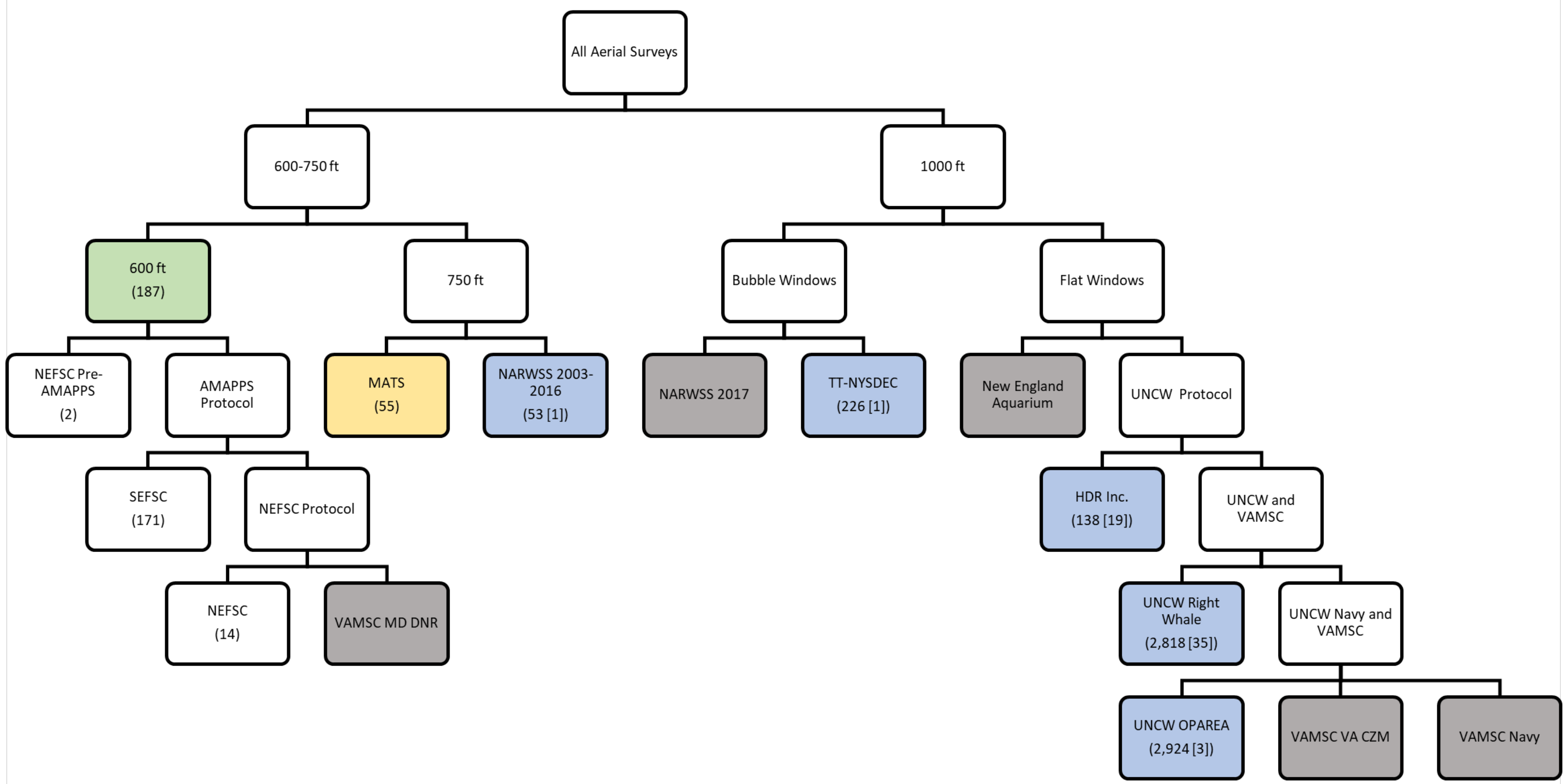

Figure 11. Detection Function Hierarchy for Kemp's Ridley Turtles

Color Codes:
GREEN: a detection function with more than 60 sightings was fit;
YELLOW: a detection function with less than 60 sightings was fit;
BLUE: a detection function was fit with hardshell turtle sightings;
GRAY: a survey with no sightings.

The number of sightings for each survey or detection function is given in parentheses. Brackets indicate the number of sightings of the target species when a hardshell guild was used.

Histograms of perpendicular distances were generated from the available sightings for each detection function to explore the need for truncation. Buckland et al. (2011) recommend truncating distant sightings (‘right truncation’) to maintain a minimum probability of detection of 0.15. Left truncation (e.g., removing sightings near the trackline) is generally only used in special circumstances, such as flat window aerial surveys when the trackline is not visible and was considered for all the flat window survey detection functions.

All surveys had associated survey condition covariates that allowed us to attempt multi-covariate distance sampling (Marques and Buckland 2004). All combinations of up to three survey condition covariates were attempted for both half normal and hazard rate functions, which are the two most common base functions for detection functions (Buckland et al. 2001), unless the detection functions had less than 100 sightings. We allowed up to two covariates for detection functions with 50–100 sightings and one covariate for detection functions with less than 50 sightings. The two base functions—hazard rate and half-normal—were also tested on their own and with cosine adjustments.

Other tested covariates included year (for survey programs with multiple years), month, group size, and whether the sighting was confirmed to species or was classified from an unidentified sighting. Group size was included as a possible covariate (even though turtles are not gregarious creatures) under the premise that even accidental gatherings of turtles may be easier for observers to sight than individual animals. Mating aggregations do occur off the coast of Florida (Eckert et al. 2006; Arendt et al. 2012) and may account for some of the larger group sizes seen in that area. Unidentified versus confirmed sighting was included because unidentified sightings may occur more frequently further from the trackline and was selected for several detection functions.

Ordinal variables, such as Beaufort Sea State (BSS), were also tested as factors. Some surveyors suggested limiting models to survey segments in ‘good’ sighting conditions of less than BSS 2. More than 10% of sightings were made in sighting conditions greater than BSS 2, which we viewed as an unacceptable loss of data, as well as an indication that turtles were regularly being observed in these conditions. Additionally, BSS data were unavailable for 40% of survey segments, making filtering consistently between survey programs impossible. Based on these two factors, we did not filter survey data based on BSS.

Detection function model selection was based on Akaike Information Criteria (AIC), which is used to assess the trade-off between goodness-of-fit and model simplicity. We generally selected the model with the lowest AIC unless there were clear issues with the detection plot. If models had similar AIC (within two) we chose between them based on goodness-of-fit statistics (Cramer-von Mises and Kolmogorov-Smirnoff), and qualitative assessments of detection function plots. Effective strip half-width (ESHW) is reported in the detection plots for each detection function and represents the effective distance at which animals can be sighted based on the detection function and selected covariates. It provides a measure of sightability for a given species and survey (or collection of surveys).

Several surveys (mostly within the UNCW Protocol surveys) were provided as half-width surveys. For these surveys, the left- and right-side observations of the planes were provided independently. This does not affect the fitting of the detection functions but does require adjustments when calculating density on the segments, as the area surveyed is halved. Density for these surveys was adjusted as appropriate prior to fitting spatial density models.

3.5.2 Corrections for Availability and Perception Bias

The probability of detecting an animal on the trackline (i.e., at a perpendicular distance of 0), or g(0), is affected by two factors: (1) availability bias, which is failing to detect animals because they are unavailable to be seen (e.g., hidden or submerged); and (2) perception bias, where observers fail to detect animals present at or near the surface (Pollock et al. 2006). Distance sampling assumes that g(0) = 1, but this is rarely the case in practice. This means g(0) is actually less than 1, and density and abundance will be underestimated unless correction factors are applied.

3.5.3 Corrections for Availability Bias

Availability bias estimates varied in temporal and spatial resolution and came from multiple sources but were all derived from animals tagged with time depth recorders in or near the study area. Here, availability bias estimates are expressed as the proportion of time an animal can be expected to be visible to observers. Availability bias can also be calculated from mean surface and dive intervals, which allows for platform-specific adjustments of availability bias (for example: an animal with short intervals is more likely to be sighted from a ship than an animal with a long interval, even if the overall proportion of surface time is the same). This type of data was not available for all species. Per-segment density estimates are divided by the availability bias (and perception bias) estimates to inflate density prior to spatial density modeling. For example, animals that spend only 25% of their time at the surface yields an availability bias estimate of 0.25, which effectively quadruples density. Availability bias estimates and sources are summarized in Table 4.

Table 4. Availability and Perception Bias Estimates

Species	Availability Bias Estimate	Perception Bias Estimate	Overall g(0)	Sources
Loggerhead turtle	0.07–0.84	0.66	0.046–0.55	Hatch et al. 2022; AMAPPS
Green turtle	0.19	0.32	0.061	Roberts et al. 2022; GOMAPPS
Leatherback turtle	0.07–0.52	0.52	0.013–0.094	AMAPPS; GOMAPPS
Kemp’s ridley turtle	0.17	0.56	0.095	Roberts et al. 2022, GOMAPPS

Loggerhead availability bias estimates were derived from Hatch et al. (2022) and ranged from 0.07 to 0.84. From 2009 to 2018, a group of 245 loggerhead turtles with satellite-linked time depth recording tags were deployed by the Northeast Fisheries Science Center (NEFSC), Southeast Fisheries Science Center (SEFSC), and Coonamessett Farm Foundation at several locations along the US East Coast. The proportion of time at the surface was recorded in 4- or 6-hour bins and linked to hourly interpolated locations from the tags. Only bins that occurred primarily during daylight hours were retained, as this was when aerial surveys would occur. Dives were considered to have started when turtles were below 2 m (6.6 ft), a depth at which animals are generally considered to be visible to aerial observers (Barco et al. 2018a), though the exact depth at which animals are visible is highly condition dependent. This may overestimate availability for shipboard surveys where turtles are often only visible at the surface, unless animals are very close to the platform. Stochastic partial differential equations were used to create spatiotemporal regression models of proportion of time at the surface. Availability bias surfaces were predicted monthly over a grid of 20x20 km (12.4x12.4 mi) cells.

The extent of the models in Hatch et al. (2022) closely matched the extent of available tag data in a given month. As such, not all of the study area was covered month to month. Coverage of the study area by the Hatch et al. (2022) availability bias models ranged from 61% in September to 81% in March with a mean of 70%. Rather than not apply availability bias adjustments to survey segments not covered by the model, a mean value from each month was calculated and applied as appropriate. Only 2% of survey segments with sightings fell within areas not covered by the availability bias models and were generally either off the continental shelf or in the Gulf of Maine. Mean monthly availability bias estimates ranged from 0.43 to 0.52. Availability was generally higher in warm months, presumably when animals were basking at the surface to assist with thermoregulation.

Leatherback availability bias estimates were derived from AMAPPS tagging data (Rider, Haas, and Sasso 2022). Between 2017 and 2019, a group of 29 leatherback turtles were tagged off the coasts of Massachusetts and North Carolina. A description of the tagging methods can be found in Sasso et al. (2021). Turtles ranged from Florida to Nova Scotia with most locations concentrated between Massachusetts and North Carolina and within the boundary of the study area. Locations outside the study area were not filtered and may not be representative of the conditions found on the eastern seaboard. The proportion of time the animals spent at the surface (i.e., upper 2 m [6.6 ft]) was calculated for daytime periods only and averaged monthly from 6-hour bins of time at depth. Availability bias ranged from 0.07 in September to 0.52 in May. Availability was generally higher in warmer months and lower in cooler months but was variable, with standard deviations of availability often meeting or exceeding the mean in many months. This variability is not accounted for in the spatial density models. This dataset and analysis are preliminary and likely to be updated in the future with more tags and advanced analyses.

Availability bias estimates for Kemp's ridley and green turtles are single estimates provided by the Gulf of Mexico Marine Assessment Program for Protected Species (GOMMAPPS) from animals described in Roberts et al. (2022). From 2017 to 2020, 63 Kemp's ridley and 14 green turtles were tagged at sites in Alabama, Florida, Mississippi, and Louisiana with animals ranging from the Dry Tortugas to Cancun, Mexico. Comparable datasets for these species were not available for the study area, and proxy estimates of availability bias were needed. Though animals may behave differently in the East Coast study area than the Gulf of Mexico, the difference is likely smaller than not accounting for availability bias at all.

Animals of both sexes (and both immature and adult individuals) were tagged by GOMMAPPS, though captures were biased towards nesting females. The GOMMAPPS data were used to generate spatial models of availability bias (Roberts et al. 2022), relating environmental covariates to availability across the Gulf of Mexico. We did not feel confident adapting these models for use on the east coast because we did not want to extrapolate environmental relationships from the Gulf of Mexico to the East Coast and preferred the more parsimonious approach of applying a single estimate derived directly from the dive data. Availability bias was 0.19 for Kemp's ridley turtles and 0.17 for green turtles, based on the average time animals spent in the top 2 m (6.6 ft) of the water column.

3.5.3.1 Corrections for Perception Bias

Perception bias estimates came from AMAPPS and GOMMAPPS unpublished estimates derived in-situ from two-observer team aerial surveys, where sightings from one observer team are used as trials to see if the second team detects the same animals. Only loggerhead turtle estimates of perception bias were available from the AMAPPS surveys, which occurred within the study area. Estimates for the other three species came from the GOMMAPPS project as the next best representative estimates. The GOMMAPPS perception bias estimates were geographically close to the study area, and the surveys used the same protocols as the AMAPPS surveys. Perception bias estimates were 0.66 for loggerhead turtles, 0.52 for leatherback turtles, 0.32 for green turtles, and 0.56 for Kemp's ridley turtles. The loggerhead perception bias estimate is derived from AMAPPS surveys from the southeast portion of the study area (SEFSC surveys) as this was where the majority of sightings occurred.

Looking at overall g(0) corrections (Table 4), corrections ranged from a factor of almost 30 for leatherback (though only in the months with very low availability bias), to approximately doubling density for loggerheads. For all species, there were instances where density was inflated by a factor of 10 or more to account for g(0), highlighting the importance of correctly accounting for both availability and perception bias.

3.6 SPATIAL DENSITY MODELS

3.6.1 Survey Segments

Survey tracklines can be more than 100 km (62 mi) long, and survey and environmental conditions can vary widely along this length, making the trackline an inappropriate unit for spatial density modeling. Using custom Python coding, transects were split into roughly 5-km (3.1-mi) segments to better match the potential changes in underlying environment and survey conditions. Because transects lengths were not exactly divisible by five, some segments were slightly longer or shorter. Observations were associated to their corresponding segment, which was done using Python code to iterate through the surveys and match the date and time of an observation to the closest segment both temporally and spatially. Density was predicted for each segment using a Horvitz-Thompson estimator and the appropriate detection function.

Segment density was adjusted for perception and availability bias by dividing the density estimate by the appropriate species specific values. Platform-specific adjustments for availability bias were not made, as they require information on the dive and surface intervals of animals, not just the proportion of time spent below the surface, and this information was not available for all species. The center point for each segment was then calculated and sampled against the environmental covariates. The segment density became the response variable for the subsequent spatial density models with the sampled environmental covariates becoming potential explanatory variables.

3.6.2 Model Fitting and Prediction

We used a generalized additive model (GAM) framework for all spatial density models, fit with the R package *mgcv* (Wood 2011). GAMs fit smooth relationships between the response and explanatory variables, allowing for complex relationships to be explored. The response variable (density on survey segments) was assumed to follow a Tweedie distribution (Foster and Bravington 2013), which handles zero-inflated distributions well. This is useful because most segments had zero sightings and, therefore, a density of zero.

For each species, models were fit to all segments from survey programs with sightings. Survey programs without sightings were not used to avoid exacerbating the zero inflation issue (e.g., fitting a model to many observations of zero). A survey program is all survey effort that fell under a single survey provider and protocol, for example the NEFSC AMAPPS surveys. Generally, the only survey programs missing sightings were surveys limited to the northern extent of the study area, particularly for Kemp's ridley and green turtles, which are considered extralimital in the Gulf of Maine, or geographically limited programs like the Tetra Tech - New York State Department of Environmental Conservation (TT-NYSDEC) New York Bight Wind Management (NYBWM) program.

Because of the large number of available environmental covariates, the number of covariates to be included in each model was limited in several ways *a priori*. Only non-correlated covariates were included in a model. Correlation was examined using Spearman's correlation coefficient, and only one was retained if covariate pairs had a score of 0.7 or higher. Selection between correlated covariates occurred by fitting single covariate models to the data; the covariate with the highest deviance was selected. Restricted maximum likelihood (REML) or AIC was not examined at this stage, preferring to include candidate covariates with higher explanatory power before selecting between models that included multiple covariates. Scatter plots of the covariate interactions did not indicate non-linear relationships, but this was not formally assessed.

After removing correlated covariates, single covariate models were fit to the remaining covariates, and covariates whose models explained less than 2% of deviance were removed. Covariates that were missing data for 10% or more of segments were removed as well as covariates where greater than 25% of prediction locations would be extrapolations outside the range of sampled values. Lastly, covariates were grouped into families or broadly similar categories (Table 5), and only one covariate from each family could be included in a model. Selection within a family was for the covariate whose single covariate model had the highest deviance explained. Productivity covariates were log transformed prior to model fitting, as log transformed covariates performed slightly better in test models.

Table 5. Covariate Families

Family	Covariates
Depth	Depth, Dist_500, Dist_1000, Dist_Shelf, Dist_Shore
Features	Dist_Canyon, Dist_Seamount
Slope	Slope_Deg
Geostrophic Currents	UGO, VGO
Productive Depth	MLOTST, MNCK_ZEU
Sea Surface Height	SSH_ZO
Productivity	CHL_COP_Daily, CHL_VI, MNCK_EPI, MNCK_NPP, MNCK_ZOOC, MODIS_CHL, NPP_VI, NPPV_COP_Daily, VGPM
Salinity	BSAL_BSO, SAL_SO
Temperature	BTEMP_BSO, TEMP_TO_MODIS_SST

Models were fit with thin plate regression splines with shrinkage and a 'k' value of 10 to allow the effect of non-significant covariates to be shrunk away and a fair degree of wiggliness in the covariate/response relationship. If a covariate in the model was found to be non-significant, the covariate was dropped, and the model was refit without it to clarify reporting even though it would have been shrunk to no effect by the model. We assumed turtles may have complex relationships with the underlying environment, which guided the decision to allow for many degrees of freedom in covariate relationships.

Given the large number of covariates available even after thinning, it was infeasible to attempt models with every combination of the covariates. Only a limited number of models were fit and examined for each species. For each species, the following models were fit and compared after thinning the covariates:

1. The best performing covariates from each family that retained covariates, and limited static covariates to a single covariate. The exception was the Kemp's ridley turtle model, which only had 224 segments with sightings and was limited to five covariates to allow for robust parameter estimation.

2. If the best single static covariate was not depth, a model including 'Depth' was fit, replacing the 'best' static covariate. In exploratory models, it was found that while 'Depth' was often not the best of the single static covariate models, it performed better in combination with other covariates.

3. After fitting options 1 and 2 above, the least-significant covariate from the better of the two options was dropped, and the model was refit. If the REML score improved, the process was repeated until the most parsimonious model was found.

4. Lastly, the best model from the previous three models was refit with the addition of a 'smooth of latitude' as a covariate to account for northward range limits not captured by the other covariates.

Latitude was fitted with Duchon splines (Duchon 1977), which fit a smoother relationship than thin plate splines. This was desirable given that latitude as a predictor may only predict positive relationships where sightings occur. Given the somewhat uneven survey coverage used in this project, this approach could lead to strange artifacts in the predictions, even though all latitudes in the study area were covered by the AMAPPS surveys. A cyclic day-of-year covariate was also examined on the recommendation of an early reviewer, but ultimately was not retained in any of the models as it led to the prediction of what we considered to be unreasonable swings in population abundance between months.

The only species with a special consideration was the green turtle model. Green turtles have seen a four-fold increase in their nesting population in Florida in the last 10 years (Florida Fish and Wildlife Commission Research Institute 2022a). While nesting females are a small portion of the overall population (Heppell et al. 2005), it may be that juvenile and subadult turtle populations are increasing as well. Including data from prior to this increase could give a long-term average abundance prediction that is skewed low. Additionally, several surveyors have indicated that they have become better at identifying green turtles from the air in recent years. As such, we limited the green turtle model to survey segments occurring from 2010–2019. Only 17 segments with sightings were removed.

We checked models by examining deviance explained, quantile-quantile (Q-Q) plots, residuals, utilized degrees of freedom, and by qualitatively assessing models' predictions for unrealistic artifacts or predictions. REML was selected as the criteria for estimating smooth parameters and discriminating between models because it penalizes overfitting and leads to more pronounced optima (Wood 2011).

Predictions were made on the finest temporal scale of the selected covariates in each model. All four spatial density models included at least one daily covariate, so all four models were predicted daily for the span of the underlying surveys: 2003–2019 for loggerheads, leatherbacks, and Kemp's ridley turtles; and 2010–2019 for green turtles. Seasonal models were not attempted for two reasons: (1) for Kemp's ridley and green turtles, there were few sightings in cool months, which would have made fitting seasonal models challenging; and (2) the models captured seasonal north-south movements of each species adequately based solely on the fitted environmental relationships. For Kemp's ridley and green turtles, latitudinal cutoffs were employed to remove areas of low, but non-zero, density north of where the species could reasonably be expected to be sighted.

Both temporal and geographic extrapolation occurred in all four models, where predictions were made for locations and times that were not covered by survey estimates. The extent of extrapolation was not formally assessed but, in general, extrapolation occurred in most offshore areas/times, except in those areas/times covered by AMAPPS shipboard surveys including: the Chesapeake and Delaware Bays and parts of Long Island Sound; and coastal grid cells that were missing environmental covariates. The continental shelf was well covered in all seasons and most years via the AMAPPS surveys. The Gulf of Maine was well covered in most years by the NARWSS surveys, particularly in seasons when right whales were expected to be present. Environmental extrapolation was only assessed to the extent that covariate candidates were eliminated if an excessive univariate extrapolation was noted, as described above. Multivariate extrapolation was not assessed but could be informative to covariate selection in future modeling efforts.

Daily predictions were averaged into monthly predictions (averaging across years as well), creating a 'densitology' prediction of long-term density and abundance over the time span of the models.

3.6.3 Uncertainty Estimation

Estimates of the coefficient of variation (CV) for each model were generated from the GAM parameter uncertainty, both as surfaces covering the study area and as single point estimates for the entire model made from the average of all grid cells of all predictions with non-zero density. CV daily surfaces were averaged into monthly surfaces to match the temporal scale of the density predictions. Confidence intervals (CIs) were also calculated for monthly and annual abundance estimates. Other major sources of uncertainty not included in the CVs or CIs are detection function uncertainty, uncertainty in the underlying environment, dive variability, and assignment of unclassified sightings. Recently, new methods have become available to combine these sources of uncertainty with the GAM parameter uncertainty (Bravington, Miller, and Hedley 2021). It is a high priority for future iterations of these models to include some of these sources of uncertainty to better understand model limitations.

4. RESULTS

4.1 CLASSIFICATION OF AMBIGUOUS SIGHTINGS

After removing leatherback and hawksbill turtle sightings, 16,353 confirmed sightings of hardshell species remained. The percentage of the sightings of the three species remaining were 94.5% loggerhead, 3.7% green, and 1.8% Kemp's ridley turtles. If the percentages of the unidentified sightings (n=7,474) were the same as the confirmed sightings, we would expect 7,063 loggerhead, 277 green, and 135 Kemp's ridley turtles to be predicted by the classification model. Proportions of confirmed-versus-unidentified hardshell species may not be the same, as survey providers indicated that green and Kemp's ridley turtles can be harder to discriminate at sea, and a higher proportion of those species may be unidentified. Though the true proportion of species in the unidentified sightings is unknowable, the proportions of confirmed sightings remains a useful point of reference.

The selected classification model had 1,000 trees, gave equal weights to each species, and used the top 10 covariates from test models. The selected covariates, in order of decreasing importance, were, MNCK_EPI, TEMP_TO, Dist_Shore, day of year, SSH_ZO, Dist_Seamount, SAL_SO, NPP_VI, CHL_VI, and latitude. The model's overall accuracy was 95.5%. Accuracy by species was 99.2% for loggerhead turtles, 40.5% for green turtles, and 18.2% for Kemp's ridley turtles. Predicting the classification model to the unidentified sightings, 7,164 loggerhead turtles, 273 green turtles, and 37 Kemp's ridley turtles were predicted. Classified locations can be seen in Figures 12–14.

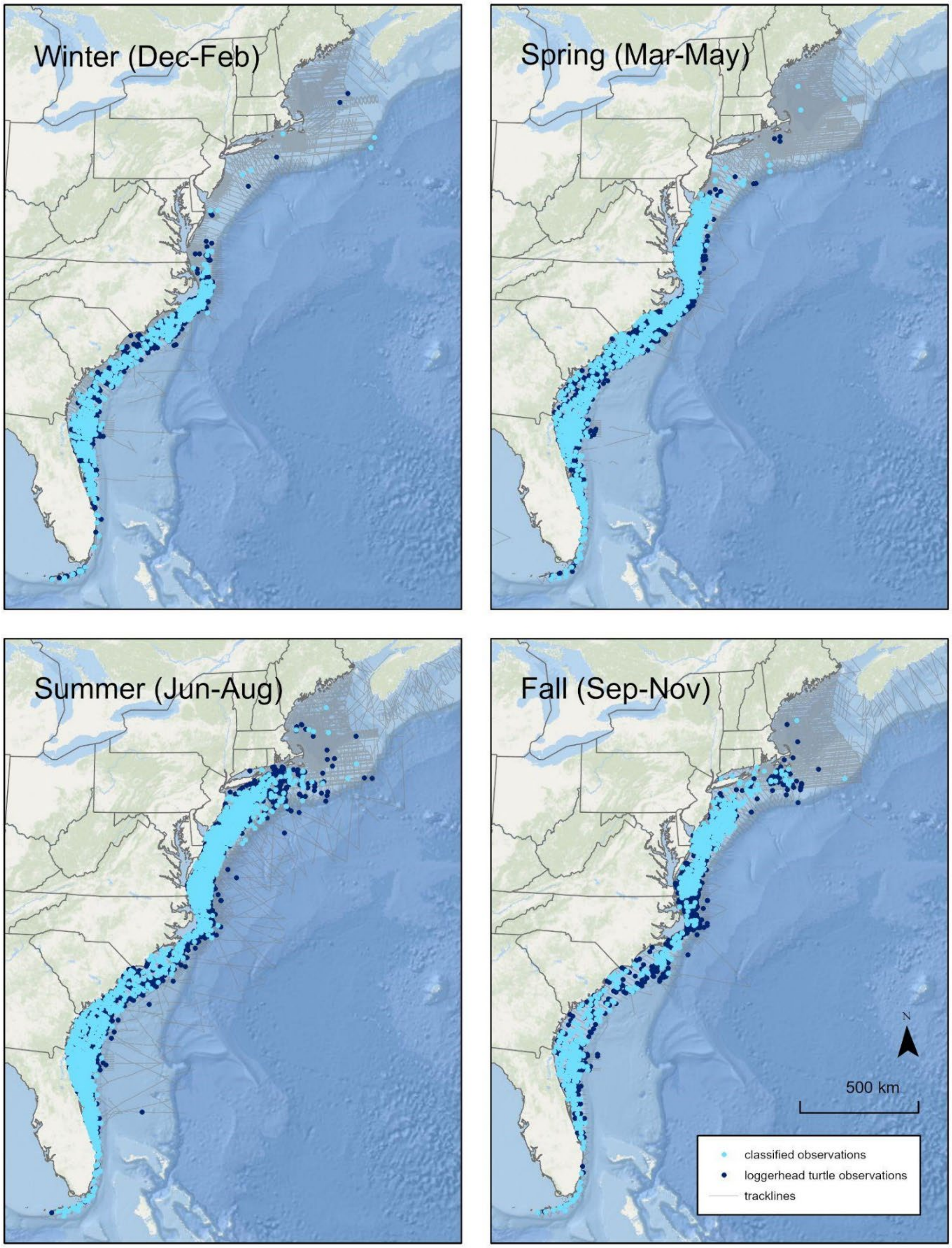

Figure 12. Results of the Machine Learning Framework that Classified Unidentified Observations as Loggerhead Turtles

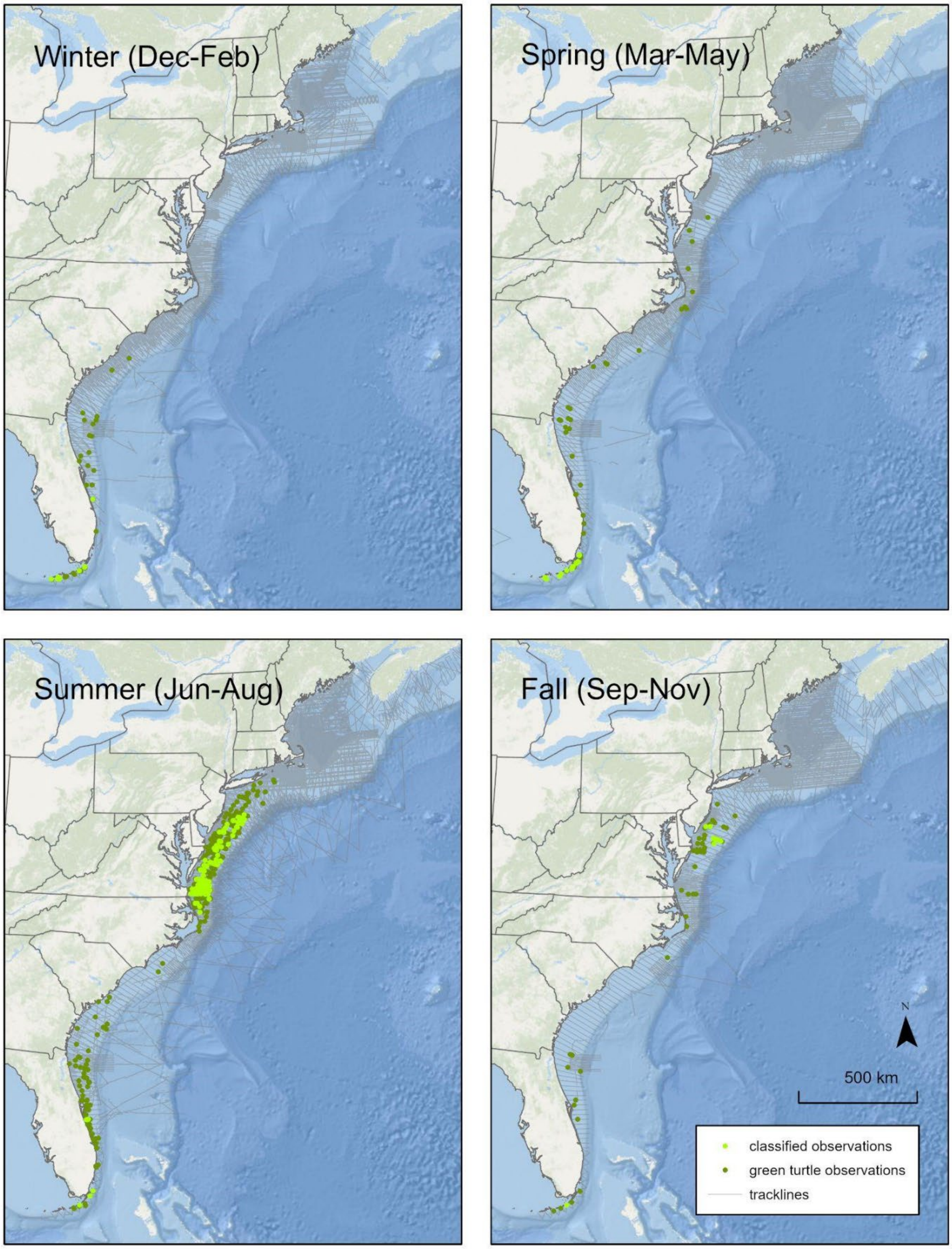

Figure 13. Results of the Machine Learning Framework that Classified Unidentified Observations as Green Turtles

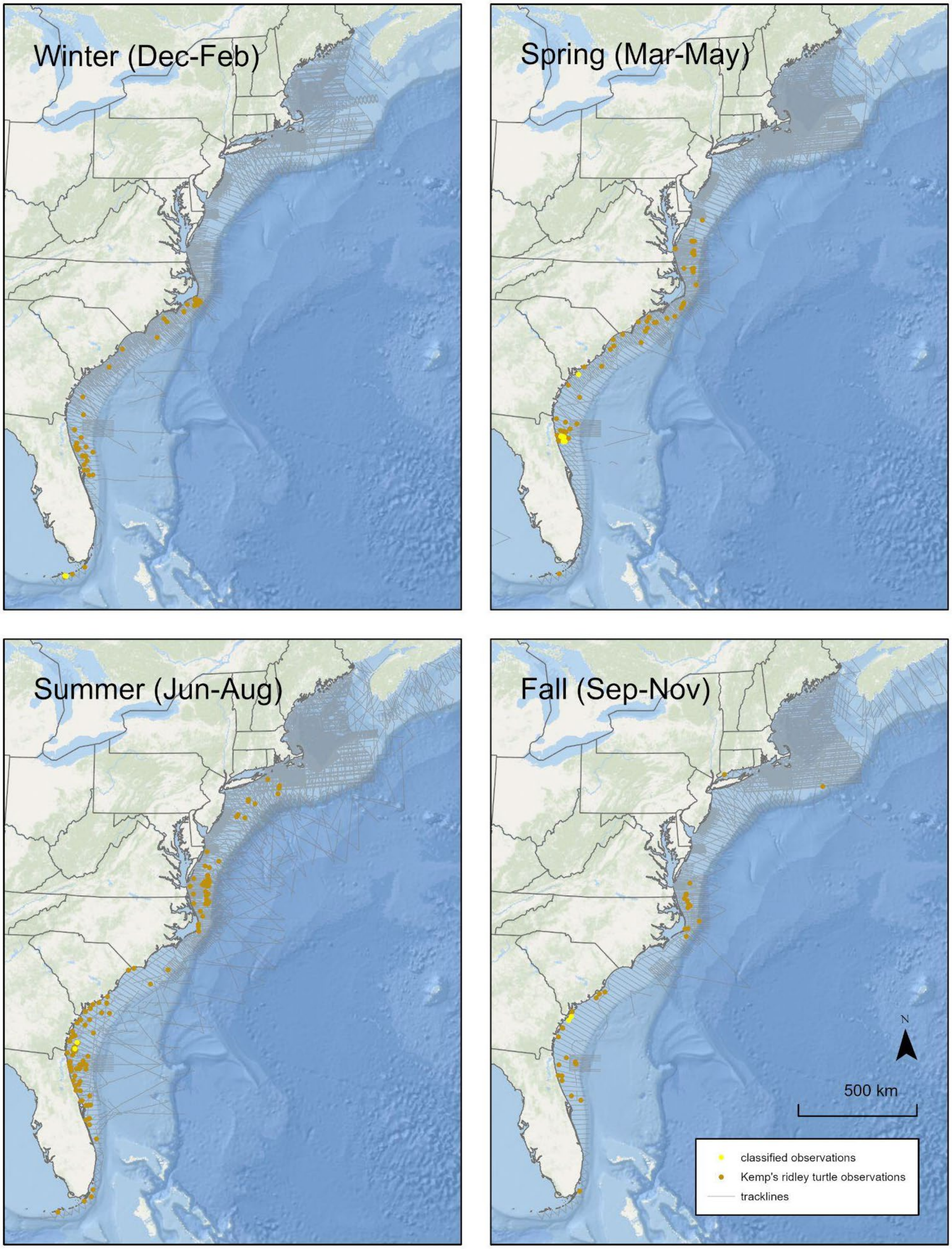

Figure 14. Results of the Machine Learning Framework that Classified Unidentified Observations as Kemp's Ridley Turtles

Classified observations for loggerhead and green turtles generally matched the patterns of confirmed observations of those species within each season. There were too few classified Kemp's ridley turtle observations to make the same assessment. All unclassified observations in the Gulf of Maine were classified as loggerhead turtles, which was appropriate as the other hardshell species are rarely sighted north of Cape Cod and are considered extralimital in the Gulf of Maine.

We surmise that the classification model is underpredicting Kemp's ridley, and possibly green, turtles. Kemp's ridley predictions were well below the expected proportion of sightings (given the assumptions stated above) and the classification model accuracy was low. The number of predicted green turtles was very close to the expected proportion despite low model accuracy. Examination of predictions showed that misclassified loggerheads were most often classified as green turtles, which may have made up the difference.

Other classification models were fitted with unequal weights—weighted towards green and Kemp's ridley turtles—to attempt to increase the accuracy of the models for those two species. While accuracy for those two species was improved, it came at the expense of accuracy for loggerhead turtles, which resulted in hundreds of misclassifications in the testing dataset. This tradeoff did not seem worthwhile, and the unequal weight models were dropped from consideration. The vast majority of sightings being loggerhead turtles may be what is driving the high accuracy for this species, or it may be that green and Kemp's ridley turtles' niches are too similar to discriminate with the available environmental covariates. More research is required to tease these issues apart.

4.2 DETECTION FUNCTIONS

The sections below provide detail on the individual detection functions fit for each species based on the survey detection hierarchies in Figures 8–11. In each section are the surveys included in each detection function, the number of relevant observations, group size information, the covariates available for the detection function, the selected detection function, a plot of the detection function, and a brief assessment of the model and predicted densities on the survey segments. Q-Q plots are presented where relevant, along with any issues or challenges associated with fitting the detection function. Selected detection functions are summarized in Table 6.

Table 6. Summary of Selected Detection Functions

Species Name	Species Group	Included Surveys	Detection Function Shape	Selected Covariates	Effective Strip Half Width (m)	Truncation Distances (m)
Loggerhead	Group 1	All shipboard surveys	half normal	group size, year	1211	right: 2000
Loggerhead	Group 2	HDR Inc.	hazard rate	side, swell	487	right: 800, left: 75
Loggerhead	Group 3	New England Aquarium	half normal	none	358	right: 800, left: 151
Loggerhead	Group 4	NEFSC Pre-AMAPPS	hazard rate	month, confirmed vs. unconfirmed	275	right: 400
Loggerhead	Group 5	NEFSC AMAPPS	hazard rate	BSS, Quality, Year	285	right: 450
Loggerhead	Group 6	2003–2016 NARWSS	half normal	BSS	303	right: 650, left: 75
Loggerhead	Group 7	TT-NYSDEC NYBWM	hazard rate	altitude, side	326	right: 550, left: 75
Loggerhead	Group 8	SEFSC AMAPPS	half normal	group size, month, confirmed vs. unconfirmed	203	right: 300
Loggerhead	Group 9	MATS	hazard rate	side, confirmed vs. unconfirmed	282	right: 350
Loggerhead	Group 10	UNCW OPAREA	hazard rate	year	429	right: 675, left: 150
Loggerhead	Group 11	UNCW Right Whale	half normal	none	150	right: 450, left: 75
Loggerhead	Group 12	VAMSC MD DNR	hazard rate	confirmed vs. unconfirmed	148	right: 275, left: 75
Loggerhead	Group 13	VAMSC Navy VACAPES	hazard rate	none	353	right: 475, left: 50
Loggerhead	Group 14	VAMSC VA CZM	hazard rate	none	363	right: 475, left: 50

Species Name	Species Group	Included Surveys	Detection Function Shape	Selected Covariates	Effective Strip Half Width (m)	Truncation Distances (m)
Green	Group 1	NEFSC and SEFSC AMAPPS, NEFSC Pre-AMAPPS	hazard rate	confirmed vs. unconfirmed, survey ID, group size	211	right: 300
Green*	Group 2	MATS	hazard rate	side, confirmed vs. unconfirmed	282	right: 400
Green*	Group 3	UNCW Right Whale	half normal	observer position, visibility, month	160	right: 450, left: 50
Kemp's ridley*	Group 1	HDR Inc.	hazard rate	swell, observer position	467	right 700: left 75
Kemp's ridley	Group 2	NEFSC and SEFSC AMAPPS, NEFSC Pre-AMAPPS	hazard rate	confirmed vs. unconfirmed	176	right: 305
Kemp's ridley*	Group 3	2003–2016 NARWSS	half normal	none	449	right: 570
Kemp's ridley*	Group 4	TT-NYSDEC NYBWM	hazard rate	BSS	361	right: 550, left: 50
Kemp's ridley	Group 5	MATS	half normal	side	243	right: 330
Kemp's ridley*	Group 6	UNCW OPAREA	hazard rate	year	190	right: 700, left: 200
Kemp's ridley*†	Group 7	UNCW Right Whale	half normal	observer position, visibility, month	160	right: 450, left: 50
Leatherback	Group 1	All shipboard surveys	half normal	year	1085	right: 2,000
Leatherback	Group 2	UNCW Right Whale and OPAREA, HDR Inc., VAMSC VA CZM and Navy	hazard rate	none	391	right: 700, left: 50
Leatherback	Group 3	New England Aquarium	half normal	year	386	right: 695, left: 150
Leatherback	Group 4	NEFSC and SEFSC AMAPPS, VAMSC MD DNR	hazard rate with cosine	none	202	right: 350

Species Name	Species Group	Included Surveys	Detection Function Shape	Selected Covariates	Effective Strip Half Width (m)	Truncation Distances (m)
Leatherback	Group 5	NEFSC Pre-AMAPPS	hazard rate	group size, observation quality	307	no truncation
Leatherback	Group 6	2003–2016 NARWSS	half normal	none	122	right: 650, left: 200
Leatherback	Group 7	MATS	half normal	none	210	right: 300
Leatherback	Group 8	2017–2019 NARWSS, TT-NYSDEC NYBWM	half normal	none	229	right: 600, left: 100

* This detection function was fit as a hardshell guild.

† This is the same detection function as was used for green turtles Group 3.

4.2.1 Loggerhead Turtle Detection Functions

4.2.1.1 Group 1 - AMAPPS and pre-AMAPPS Shipboard Surveys

Surveys in this detection function are the AMAPPS and pre-AMAPPS shipboard surveys. There were 88 total observations with a maximum group size of three. Available covariates were side, observer, swell, wave height, visibility, quality, quality code, glare, glare code, turbidity, clouds, weather, month, year, survey ID, group size, and unidentified versus confirmed sightings. Two covariates were allowed for each candidate detection function.

Observations were right truncated at 2,000 m (6,562 ft), and a half-normal detection function with group size and year as covariates was selected (Figure 15). There were 58 segments with a density greater than one, and a maximum of 2.7 animals/km^2. Mean ESHW was 1,211 m (3,973 ft), reflecting the usage of big eye binoculars in these surveys.

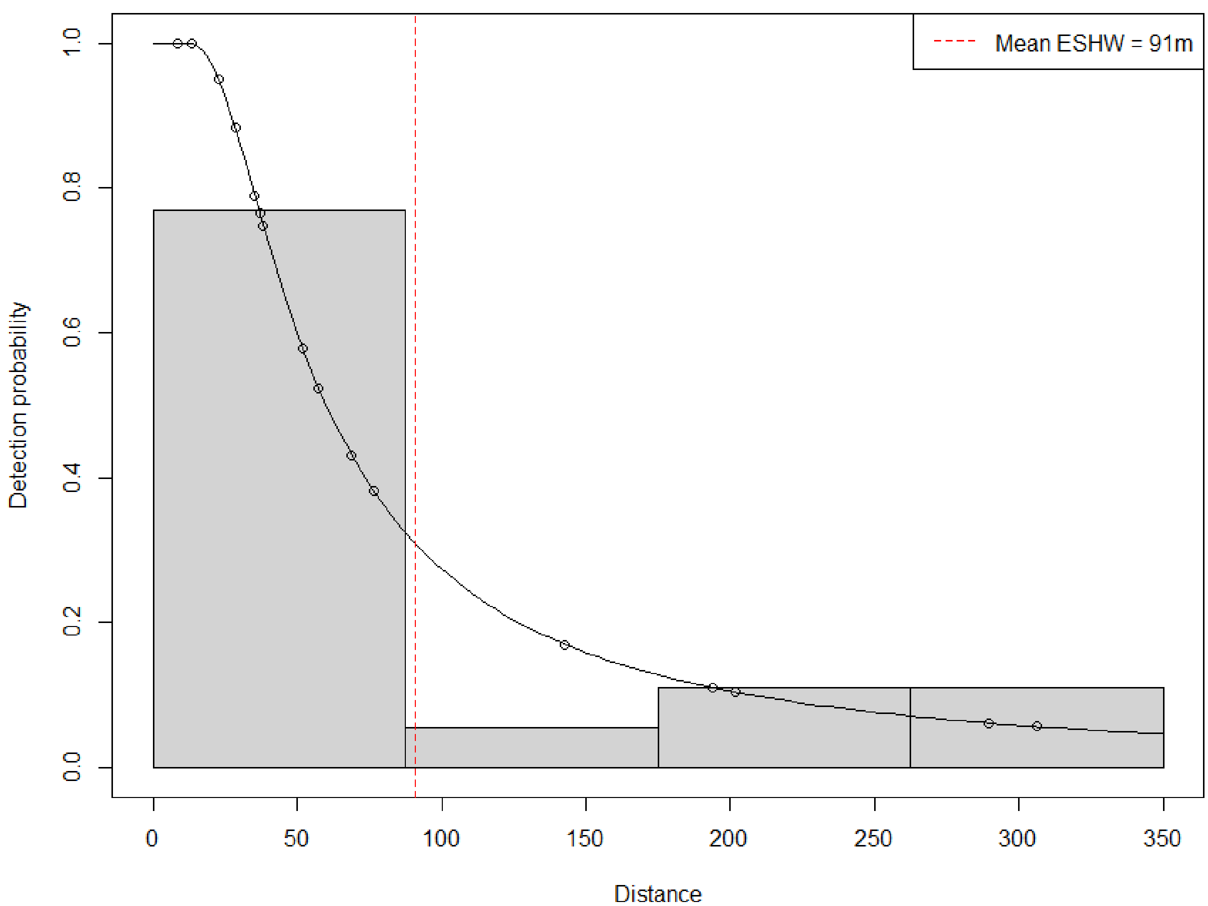

Figure 15a. Loggerhead Turtle Group 1 Detection Function Plot

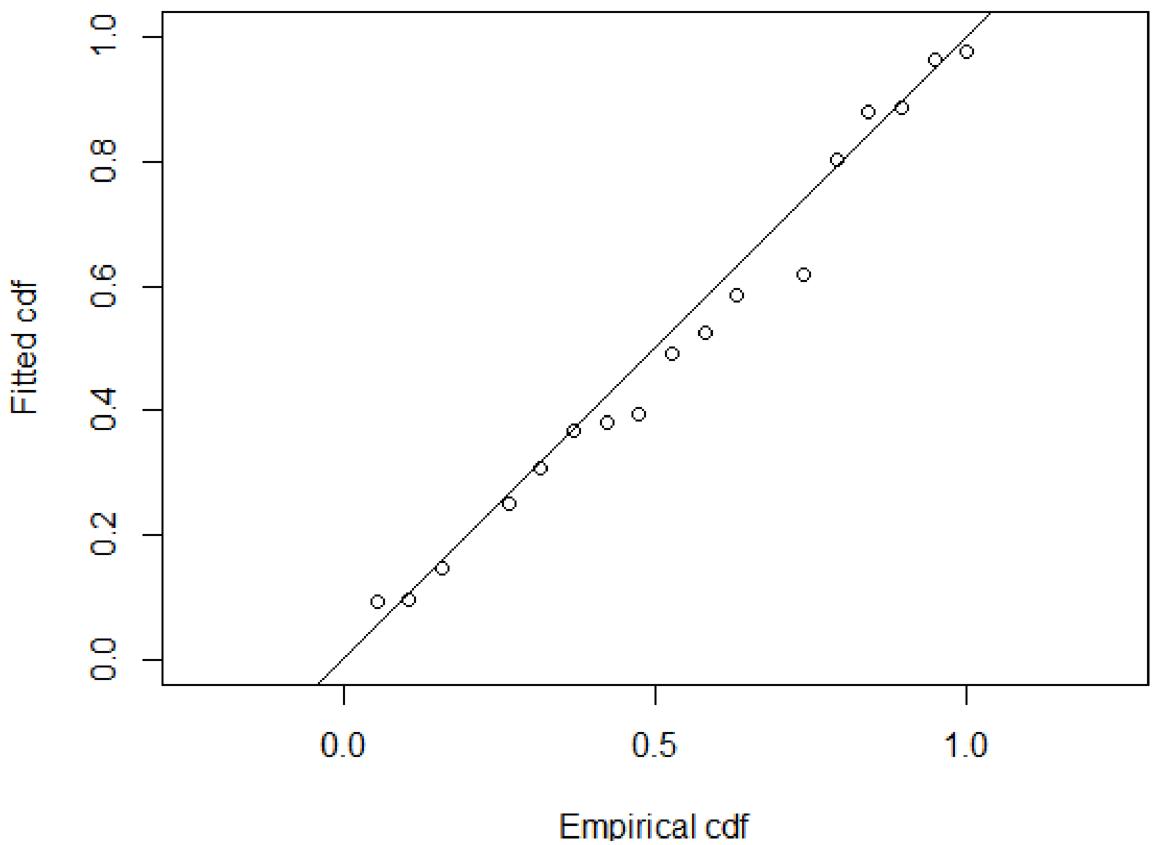

Figure 15b. Loggerhead Turtle Group 1 Q-Q Plot

4.2.1.2 Group 2 - HDR Inc. Surveys

Surveys in this detection function are the HDR Inc. surveys, which was a flat window survey under the UNCW protocol. There were 138 total observations with a maximum group size of 35. Available covariates were side, BSS, swell, wave height, glare, clouds, month, year, visibility, altitude, and confirmed versus unconfirmed observations. Only two covariates were allowed for each candidate detection function.

Some binning exists in the data, most significantly between 100–150 m (328–492 ft) and 250–400 m (820–1,312 ft). Observations were right truncated at 800 m (2,624 ft) and left truncated at 75 m (246 ft) to account for the flat windows where the survey trackline was not visible.

Two detection functions were fit and analyzed. The first was using the observations and group sizes as reported, and a hazard rate detection function with side and swell as covariates was selected (Figure 16a). The Q-Q plot indicated poor fit at middle distances, as expected given the gap in observations (Figure 16b). There were 40 segments with density greater than one, with a maximum of 6.2 animals/km^2. Mean ESHW was 487 m (1,597 ft).

The second detection function used a version of the data where group sizes >10 were smeared across the previous five segments on a trackline, if that many segments were available. A hazard rate detection function with wave height and visibility as covariates was selected (Figure 17). There were 43 segments with a density greater than one, with a maximum of 5.6 animals/km^2. There was a slight improvement in goodness of fit and the detection function plots, but there was not an appreciable difference between the abundances produced by the two detection functions. Mean ESHW was 490 m (1,607 ft).

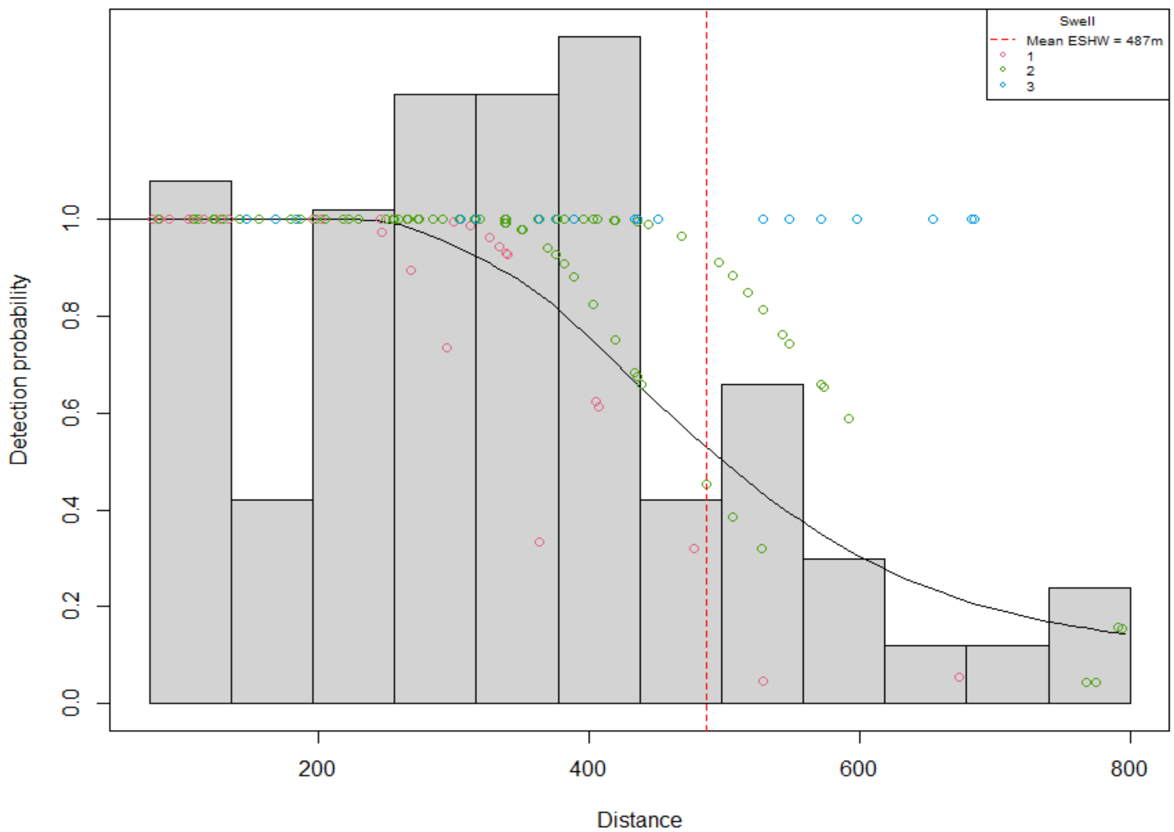

Figure 16a. Loggerhead Turtle Group 2 Detection Function Plot with Original Group Sizes

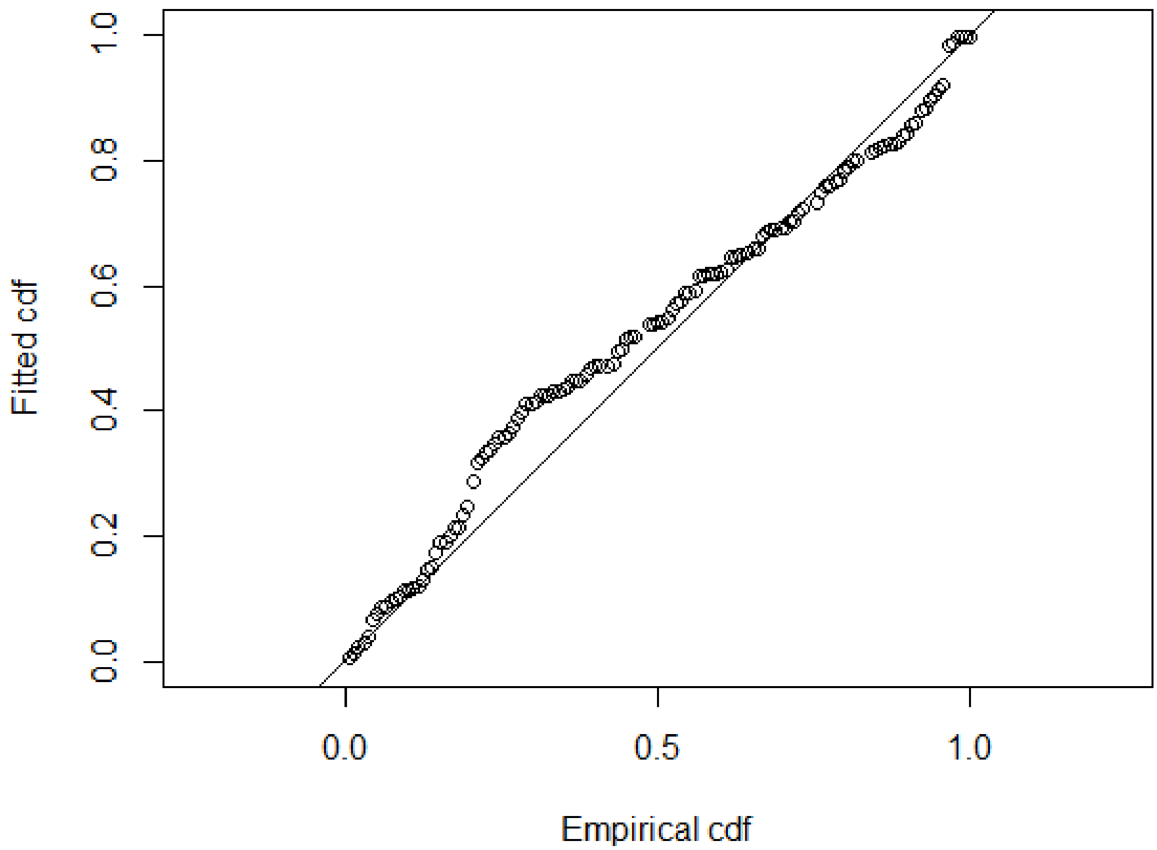

Figure 16b. Loggerhead Turtle Group 2 Q-Q Plot with Original Group Sizes

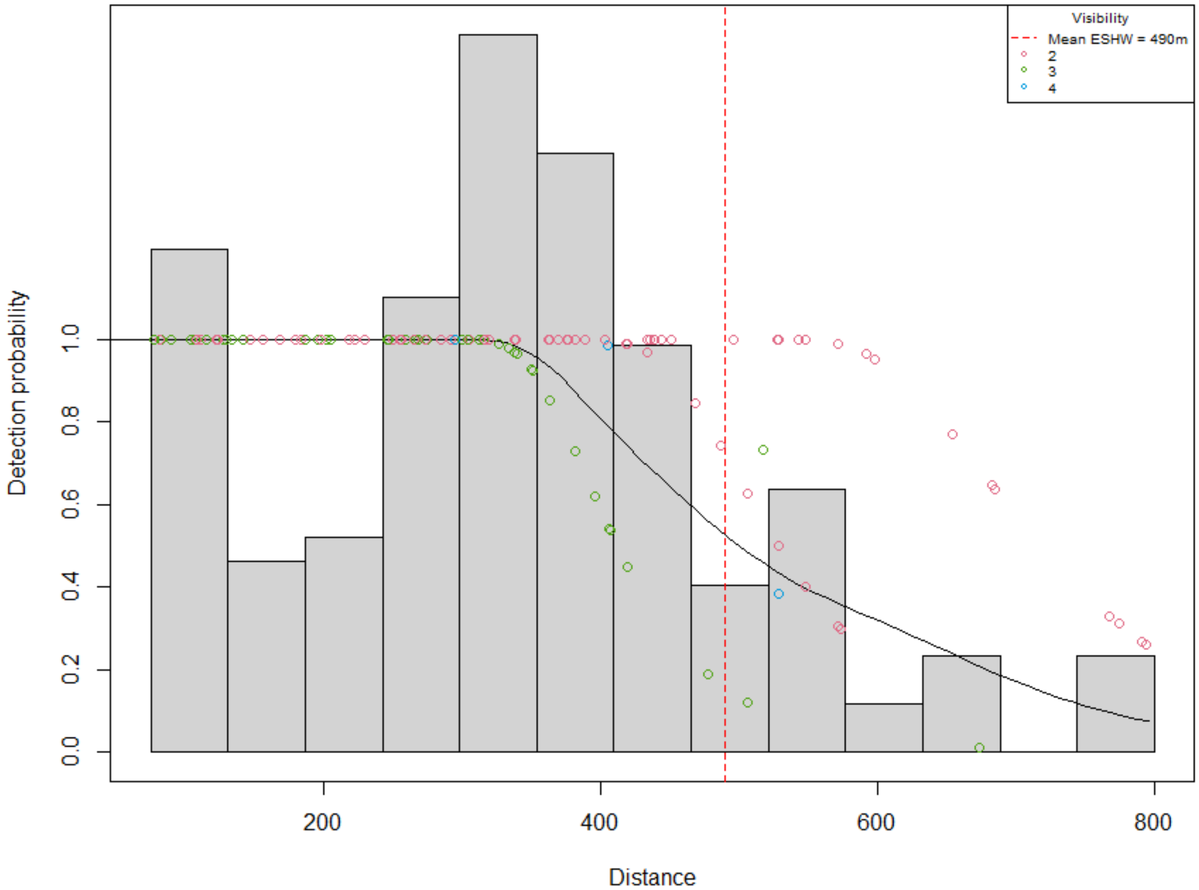

Figure 17a. Loggerhead Turtle Group 2 Detection Function Plot with Smeared Group Sizes

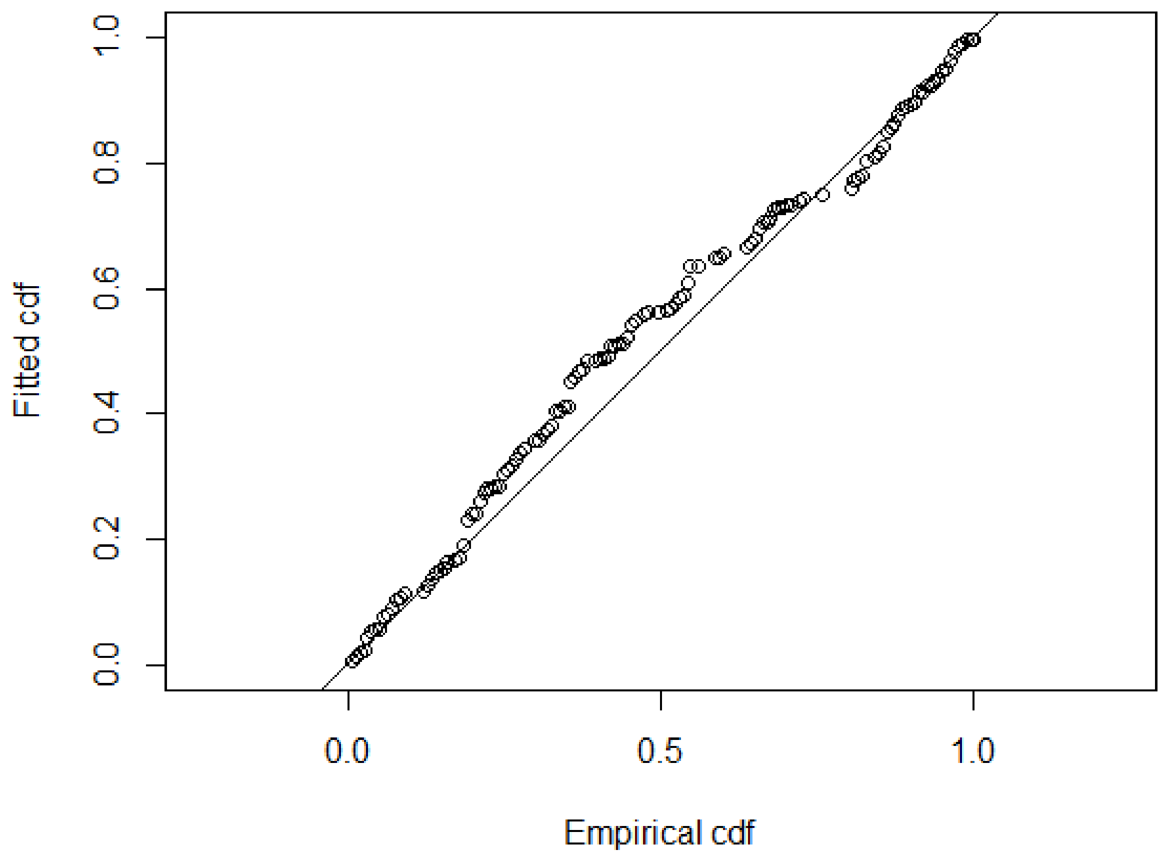

Figure 17b. Loggerhead Turtle Group 2 Q-Q Plot with Smeared Group Sizes

4.2.1.3 Group 3 - New England Aquarium Surveys

Surveys in this detection function are the New England Aquarium flat window surveys. There were a total of 59 sightings, which were binned at three distances (151.25 m [496.23 ft], 347.25 m [1,139.27 ft], and 694.5 m [2,278.5 ft]) and had a maximum group size of two. Available covariates were side-of-aircraft, group size, BSS, glare, clouds, month, year, altitude, and confirmed versus unconfirmed observations. Only a single covariate was allowed for each candidate detection function.

Observations were right truncated at 800 m (2,624 ft) and left truncated at the first bin distance (Figure 18). A right truncation of 800 was chosen as it was a considerable improvement over the detection function plot that retained the furthest distance. A half-normal detection function with no covariates was selected. A Q-Q plot was not generated because the data were binned. There were no segments with a density greater than one, and a maximum of 0.6 animals/km^2. Mean ESHW was 358 m (1,174 ft).

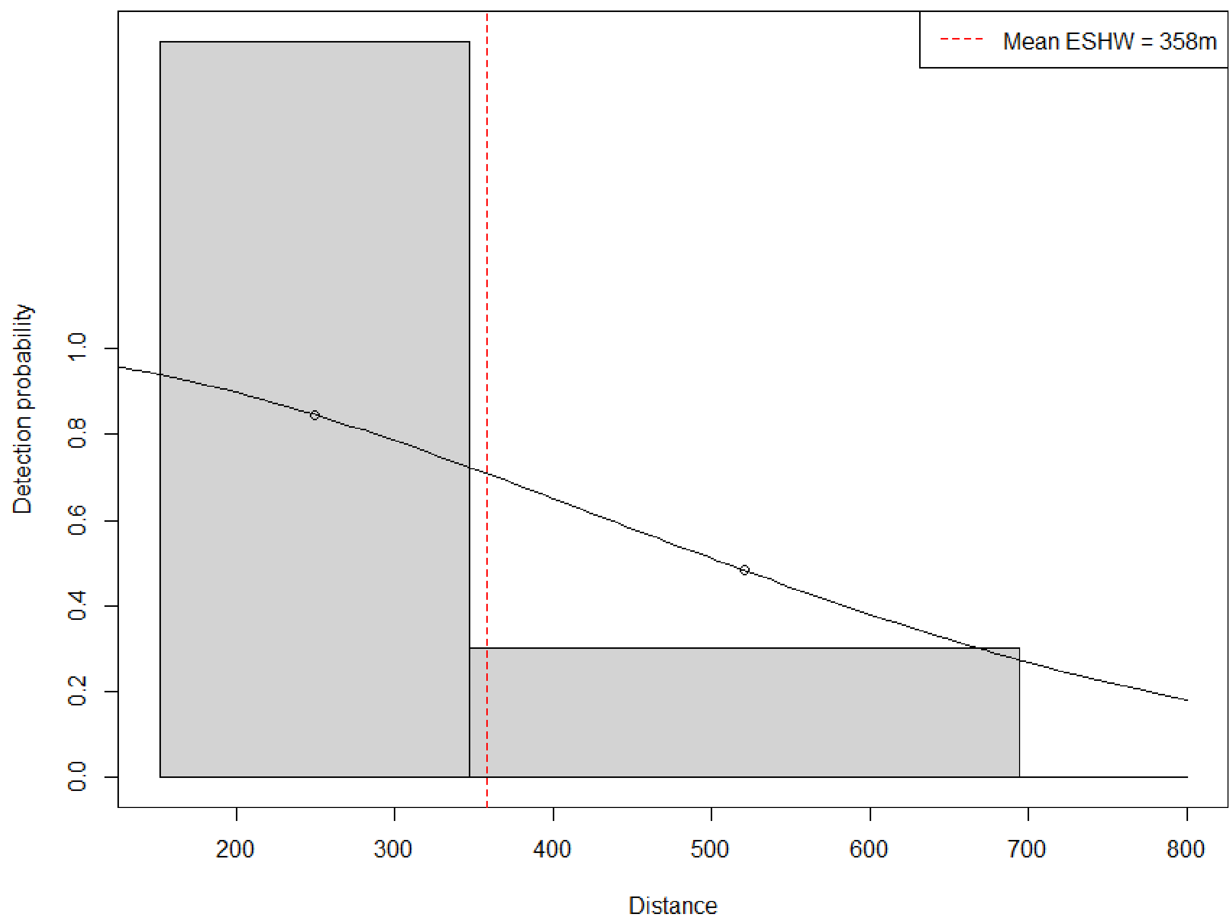

Figure 18. Loggerhead Turtle Group 3 Detection Function Plot

4.2.1.4 Group 4 - NEFSC Pre-AMAPPS Surveys

Surveys in this detection function are the NEFSC pre-AMAPPS surveys. There were 599 total observations with a maximum group size of three. Available covariates were group size, BSS, altitude, month, year, and confirmed versus unconfirmed observations. Up to three covariates were allowed in each candidate detection function.

Observations were right truncated at 400 m (1,312 ft), and a hazard rate detection function with month and confirmed versus unconfirmed observations was selected (Figure 19). There were 326 segments with a density greater than zero, 72 segments with a density greater than one, and a maximum of 13 animals/km^2. There is some heaping present in the histogram. However, the Q-Q plot indicated a good fit, and no issues were noted with the model statistics. Mean ESHW was 275 m (902 ft).

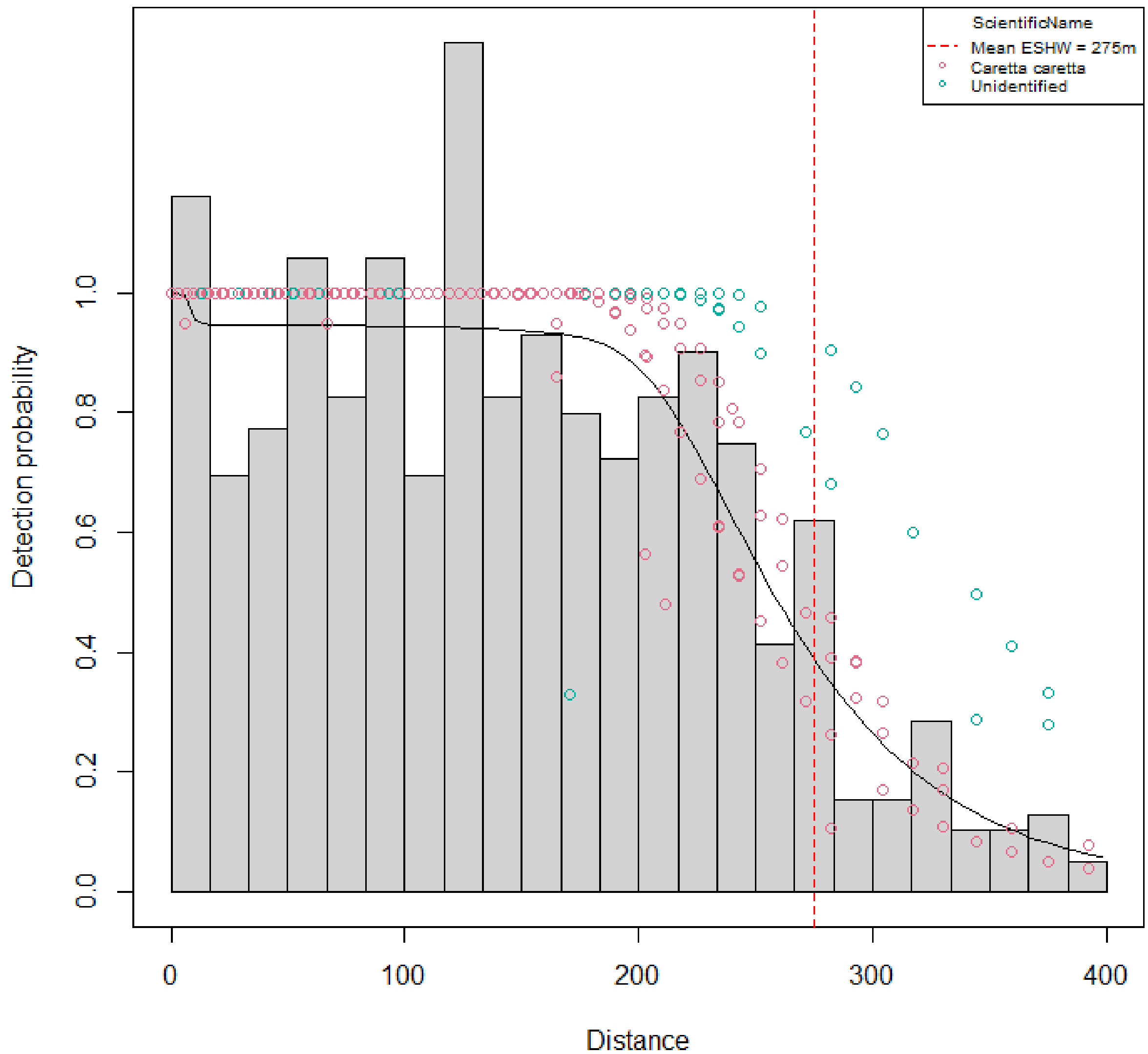

Figure 19a. Loggerhead Turtle Group 4 Detection Function Plot

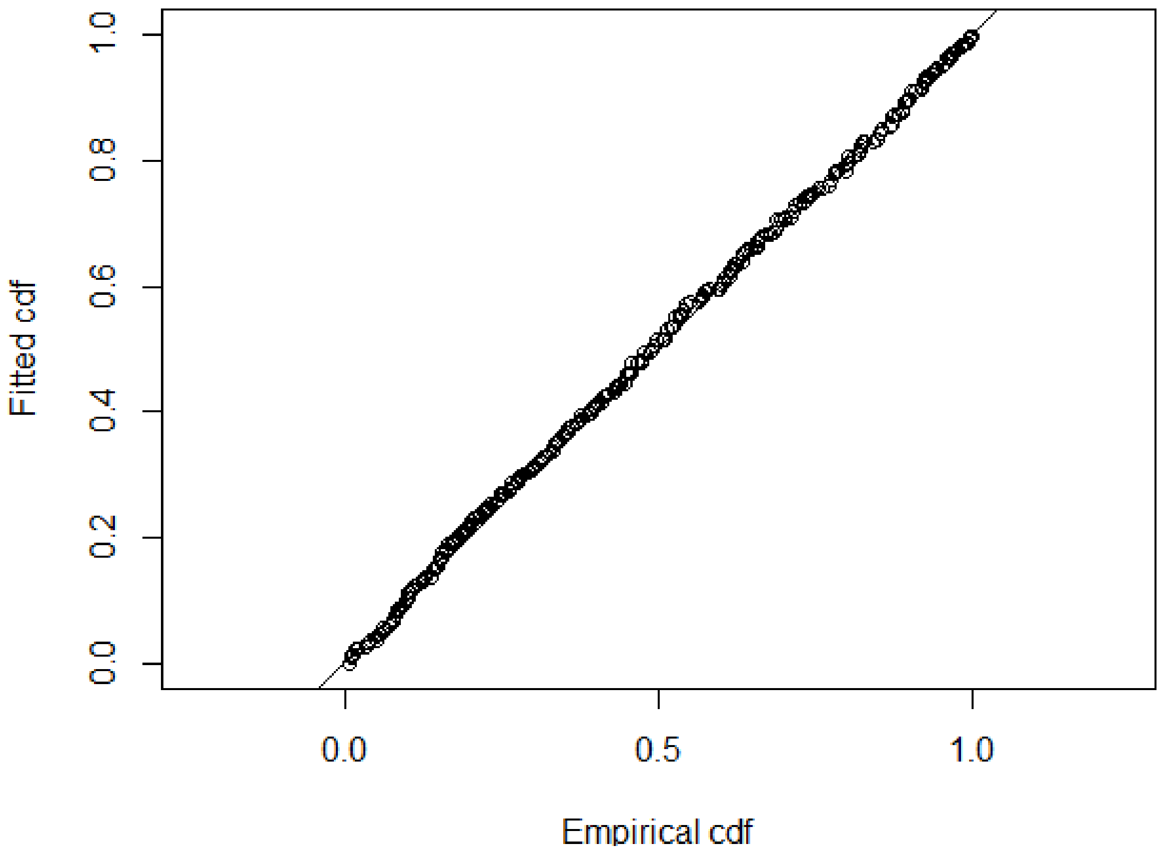

Figure 19b. Loggerhead Turtle Group 4 Q-Q Plot

4.2.1.5 Group 5 - NEFSC AMAPPS Surveys

Surveys in this detection function are the NEFSC AMAPPS surveys with bubble windows. There were 394 total observations with a maximum group size of two. Available covariates were altitude, group size, BSS, quality, Cetacean Density and Distribution Mapping (CETMAP) quality, glare, month, year, and confirmed versus unconfirmed observations. Up to three covariates were allowed in each candidate detection function.

There is some heaping present in the histogram between 150 and 175 m (492 and 574 ft). However, the Q-Q plot indicated a good fit, and no issues were noted with the model statistics.

Observations were right truncated at 450 m (1,476 ft), and a hazard rate detection function with BSS, quality, and year was selected (Figure 20). There were 28 segments with a density greater than one, and a maximum of 4.07 animals/km^2. Mean ESHW was 285 m (935 ft).

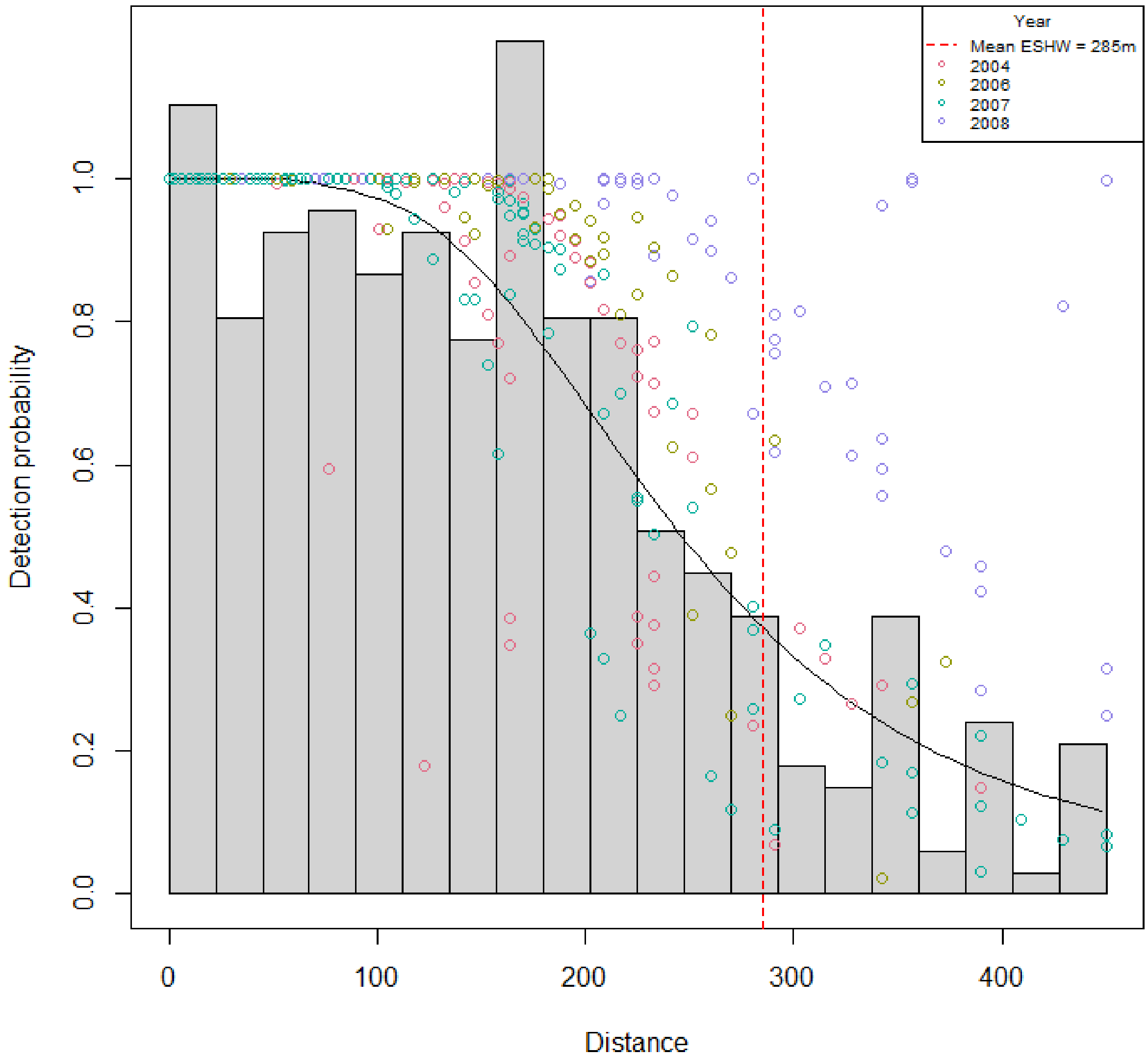

Figure 20a. Loggerhead Turtle Group 5 Detection Function Plot

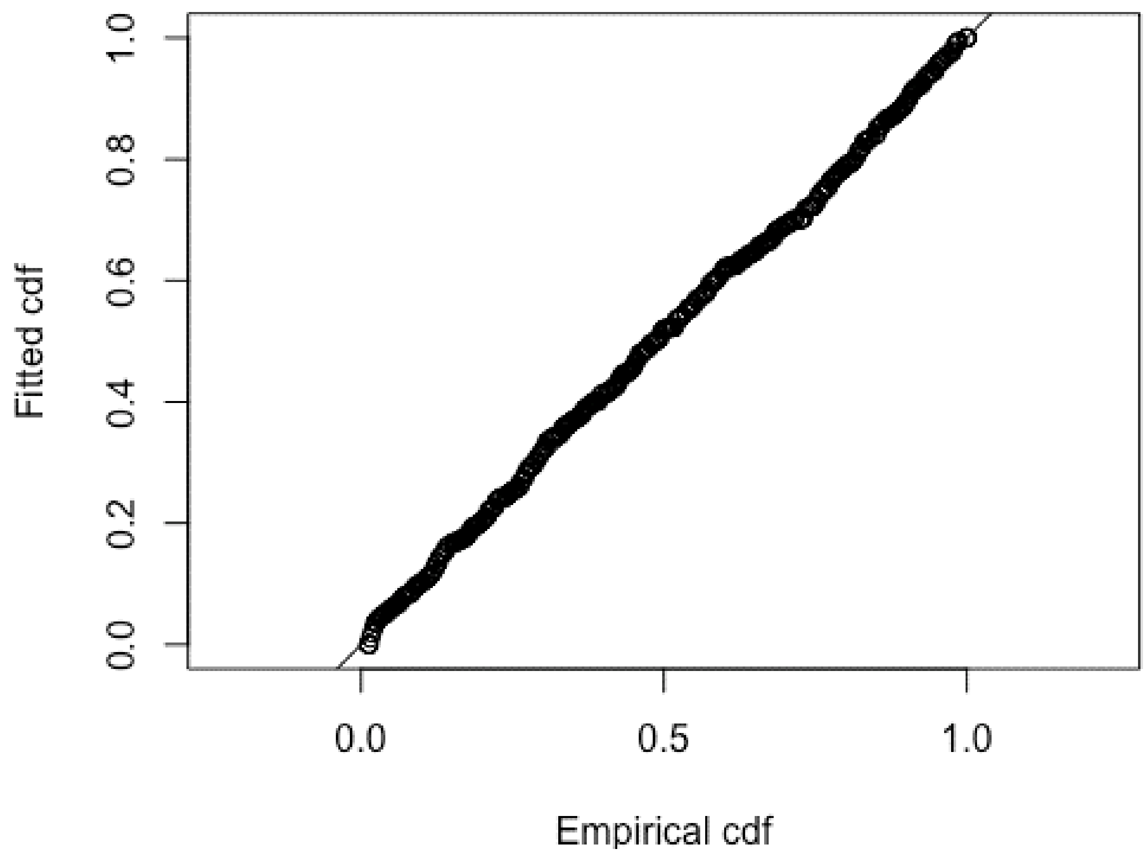

Figure 20b. Loggerhead Turtle Group 5 Q-Q Plot

4.2.1.6 Group 6 - 2003–2016 NARWSS Surveys

Surveys in this detection function are the NEFSC NARWSS surveys. There were 51 total observations with a maximum group size of one. Available covariates were altitude, group size, BSS, quality, CETMAP quality, glare, month, year, and confirmed versus unconfirmed observations. Only a single covariate was allowed for each candidate detection function.

There was a low number of detections close to the trackline, with the highest number of detections grouped at approximately 200–300 m (656–984 ft). We suspect this is because the focus of the NARWSS surveys is the detection of large whales, particularly North Atlantic right whales, and the focus of observers may be further out towards the horizon. Also, sea turtles may be harder to detect directly below the aircraft at higher altitudes, even with bubble windows. Detection functions both with and without left truncation were attempted, and the model improved with left truncation.

Observations were right truncated at 650 m (2,132 ft) and left truncated at 74 m (242 ft). A half-normal detection function with BSS was selected (Figure 21). There were no segments with a density greater than one, and a maximum of 0.89 animals/km^2. The model statistics were acceptable even though the Q-Q plot displayed poor fit at multiple distances. Mean ESHW was 303 m (994 ft).

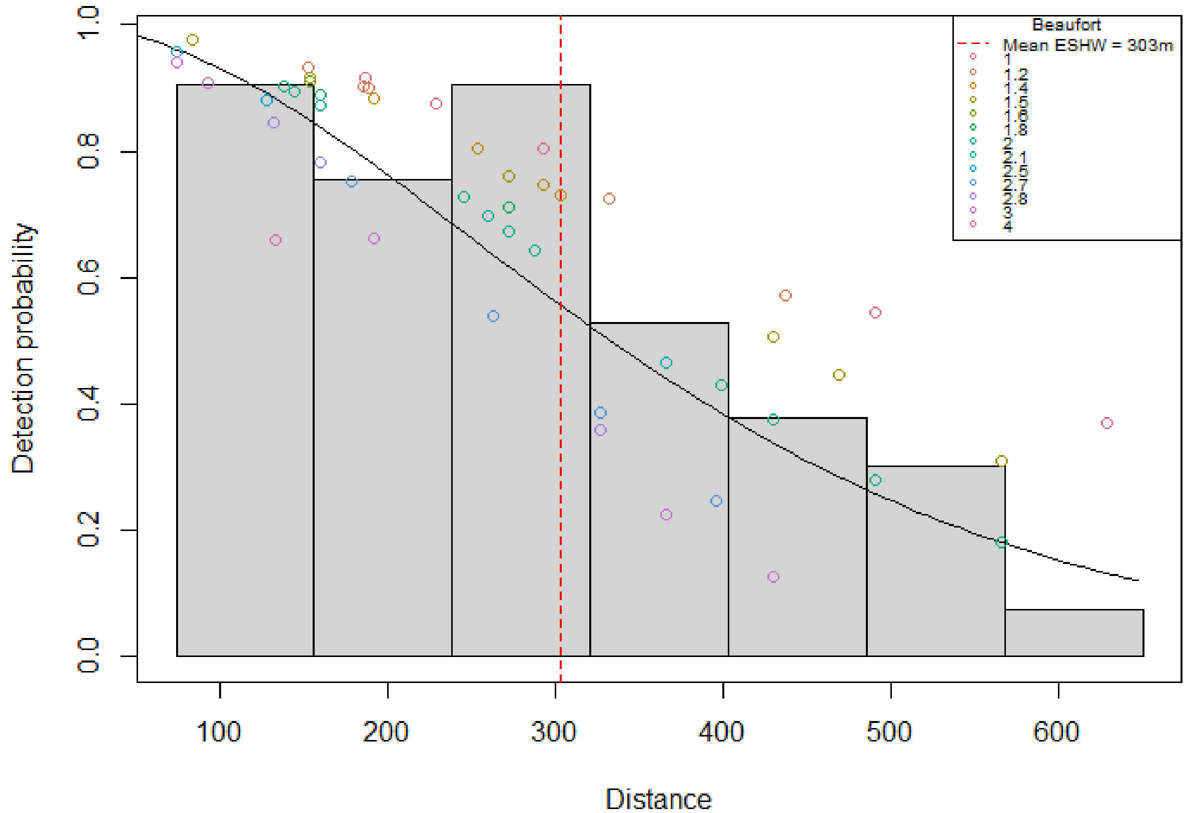

Figure 21a. Loggerhead Turtle Group 6 Detection Function Plot

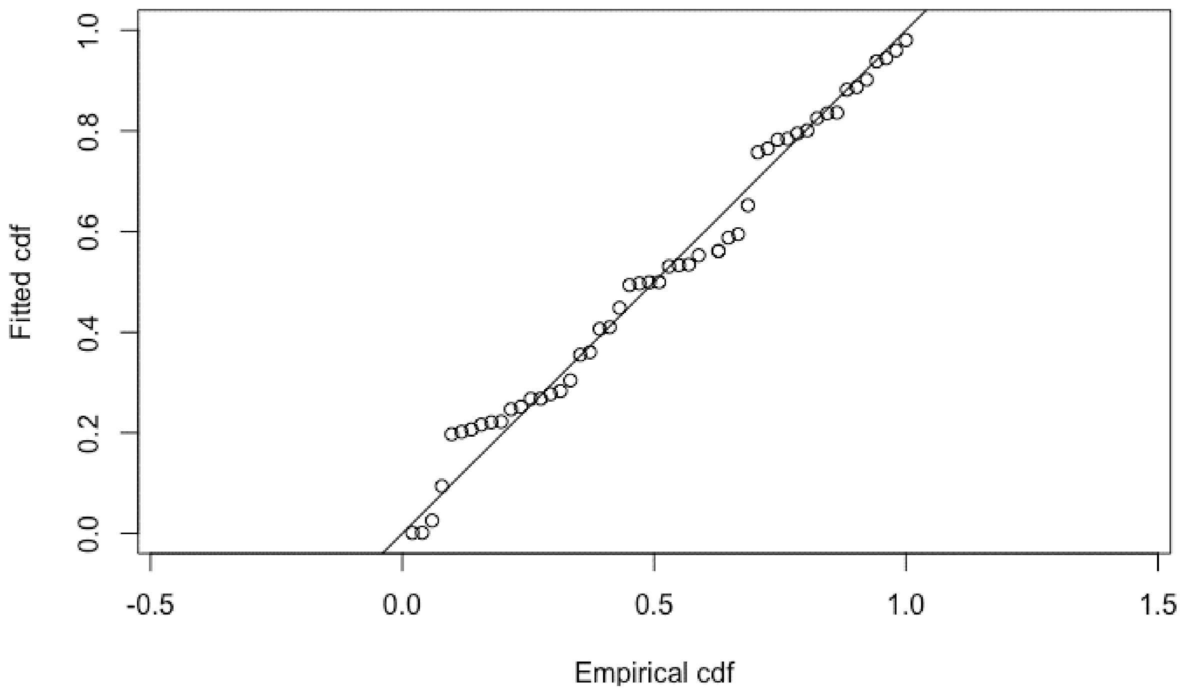

Figure 21b. Loggerhead Turtle Group 6 Q-Q Plot

4.2.1.7 Group 7 – TT-NYSDEC NYBWM Surveys

Surveys in this detection function are the TT-NYCDEC NYBWM surveys. There were 223 total observations with a maximum group size of seven. Available covariates were altitude, side of aircraft, observer position, group size, BSS, visibility, clouds, two measures of glare, month, year, quality, and confirmed versus unconfirmed observations. Turbidity was available as a covariate but was dropped from consideration after a discussion with the MGEL marine mammal modeling team indicated it was not assessed consistently between years. Up to three covariates were allowed in each candidate detection function.

Observations were right truncated at 550 m (1,804 ft) and left truncated at 75 m (246 ft). A hazard rate detection function with altitude and side was selected (Figure 22). There were 10 segments with a density greater than one, a maximum of 3.1 animals/km^2. The model statistics and Q-Q plot were acceptable despite some heaping at intermediate distances. Mean ESHW was 326 m (1,069 ft).

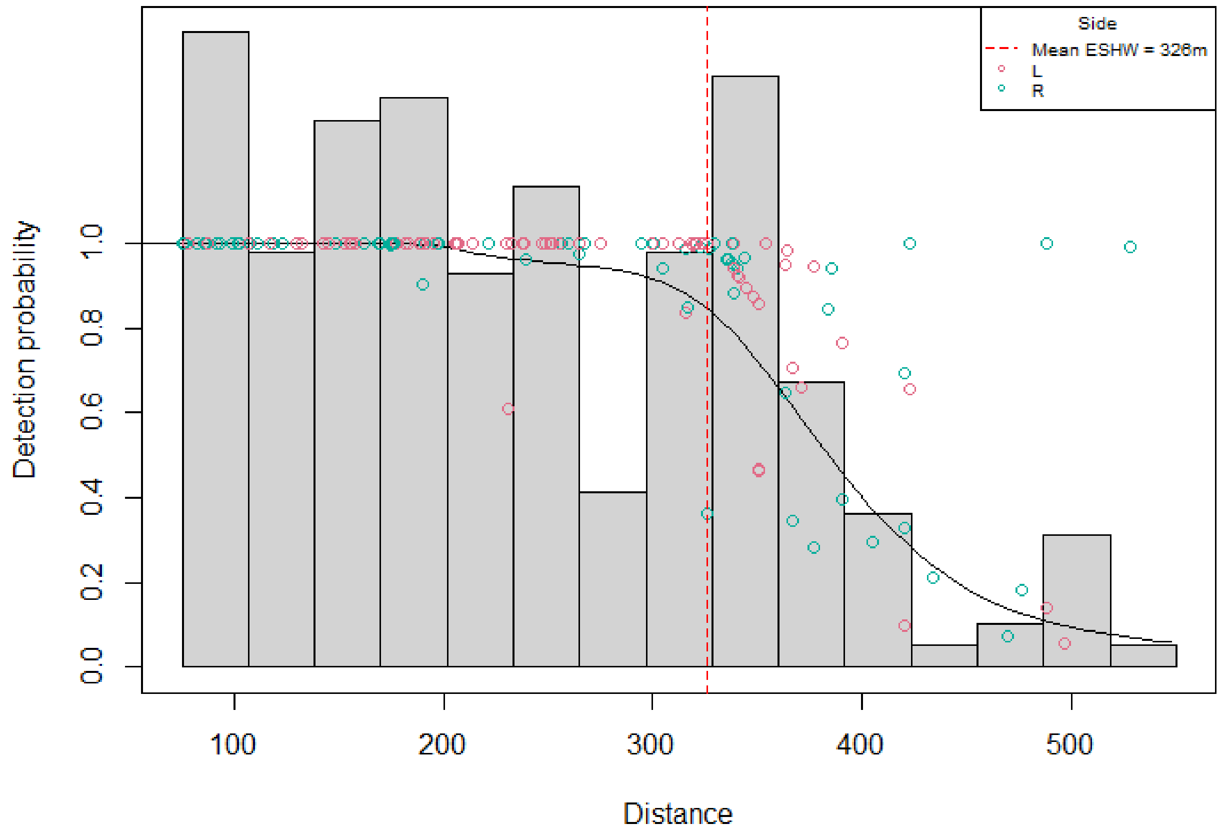

Figure 22a. Loggerhead Turtle Group 7 Detection Function Plot

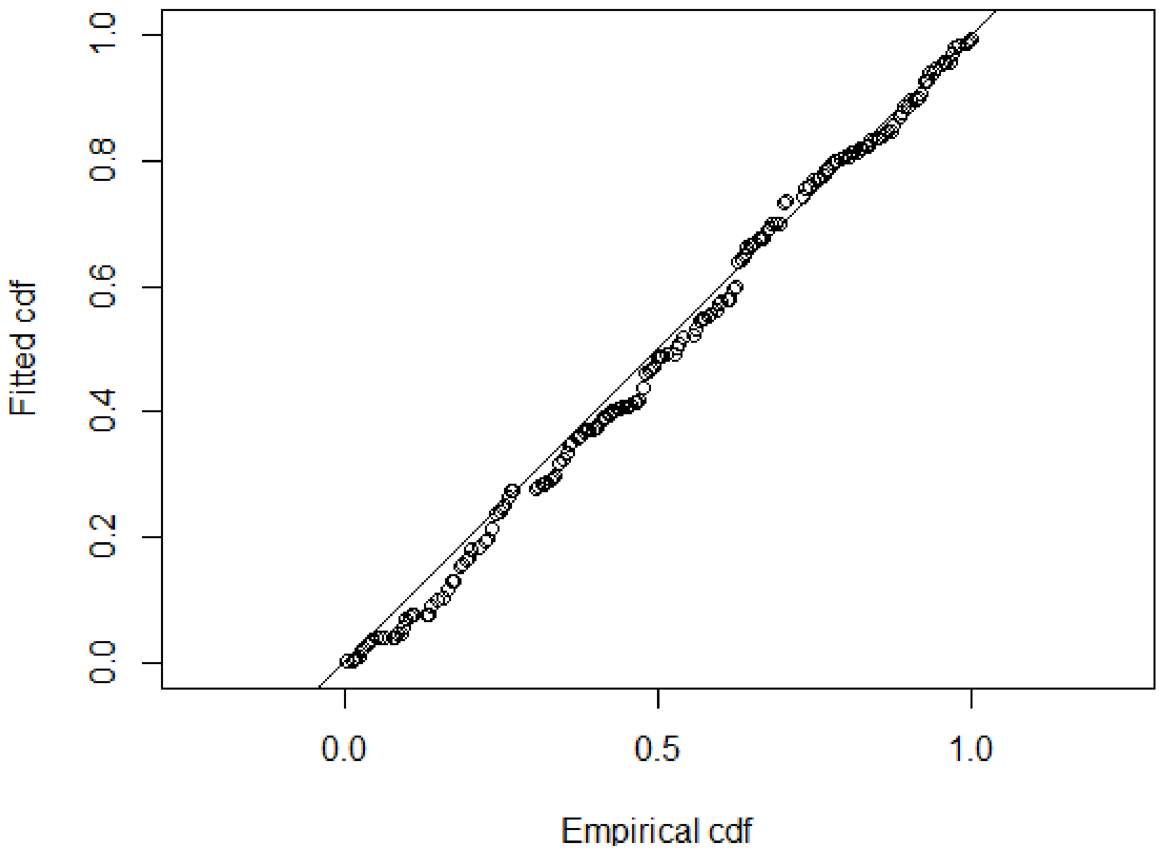

**Figure 22b.	Loggerhead Turtle Group 7 Q-Q Plot**

#### 4.2.1.8	Group 8 - SEFSC AMAPPS Surveys

Surveys in this detection function are the SEFSC AMAPPS surveys. There were 9,465 observations. This is by far the most for any detection functions, potentially making this the most important detection function in the project. There were multiple observations with a group size greater than ten, which may have been nesting or mating aggregations off Florida's east coast, which is a major nesting colony for loggerhead turtles. Available covariates were group size, observer position, month, year, confirmed versus unconfirmed observations, and survey identification. Up to three covariates were allowed in each candidate detection function.

There was some binning in the data with heaping at several distances and few sightings at a distance of zero. Under the AMAPPS protocol, observers record exact distances and do not use wing struts or marking to record distances. It may have been that observers were approximating distances visually and inadvertently heaped the data into bins. Several methods were attempted to avoid binning data given the critical nature of this detection function. These methods included various permutations of left and right truncations, rounding distances to the nearest 10 or 25 m (33 or 82 ft), and less common detection functions (such as exponential curves). None were satisfactory, and eventually a detection function was fit using binned data.

Observations were right truncated at 300 m (984 ft) and placed into 25 m (82 ft) bins. The half-normal detection function with group size, month, and confirmed versus unconfirmed observations as covariates was selected (Figure 23). No issues were noted with the model statistics. A Q-Q plot was not generated because the data were binned. There were 1,691 segments with densities greater than one, with a maximum of 21.4 animals/km^2. Fourteen segments had density values greater than 10 animals/km^2. This is reasonable considering the large aggregations of this species to be found off the coast of Florida. Mean ESHW was 203 m (660 ft).

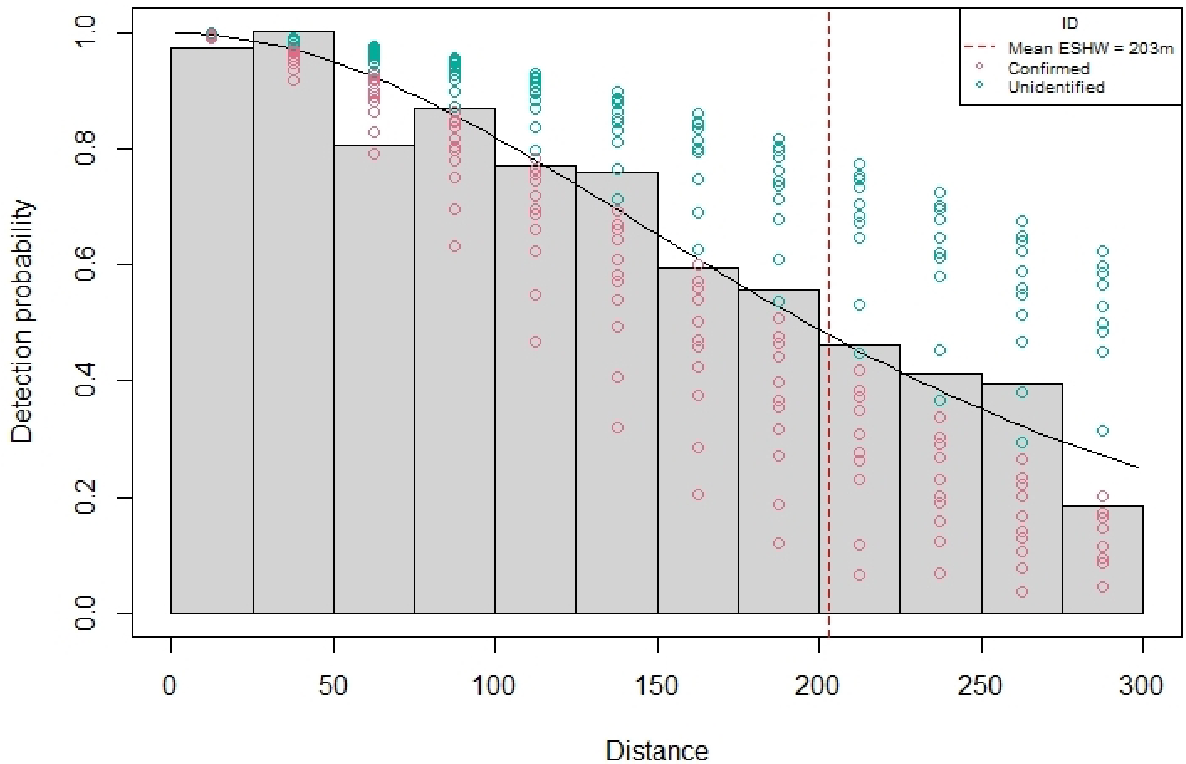

Figure 23. Loggerhead Turtle Group 8 Detection Function Plot

4.2.1.9 Group 9 - Mid-Atlantic Tursiops Surveys

Surveys in this detection function are the SEFSC Mid-Atlantic Tursiops surveys (MATS). There were 882 observations available. The maximum group size was 15, which may have been nesting or mating aggregations off the coast of Florida (a major nesting colony for loggerhead turtles). Available covariates were group size, side of aircraft, observer position, BSS, observation quality, turbidity, weather, confirmed versus unconfirmed observations, month, and year. Up to three covariates were allowed in each candidate detection function.

There was heaping at several distances, as well as other values in between the major heaps. It may have been that observers were alternating between recording exact distances and approximating distances with wing struts or markings. In any case, binning of data was required.

Observations were right truncated at 350 m (1,148 ft) and placed into 50-m (164-ft) bins. The hazard rate detection function with side and confirmed-versus-unconfirmed observations as covariates was selected (Figure 24). No issues were noted with the model statistics. A Q-Q plot was not generated because the data were binned. There were 118 segments with a density greater than one, with a maximum of 8 animals/km^2. Mean ESHW was 282 m (825 ft).

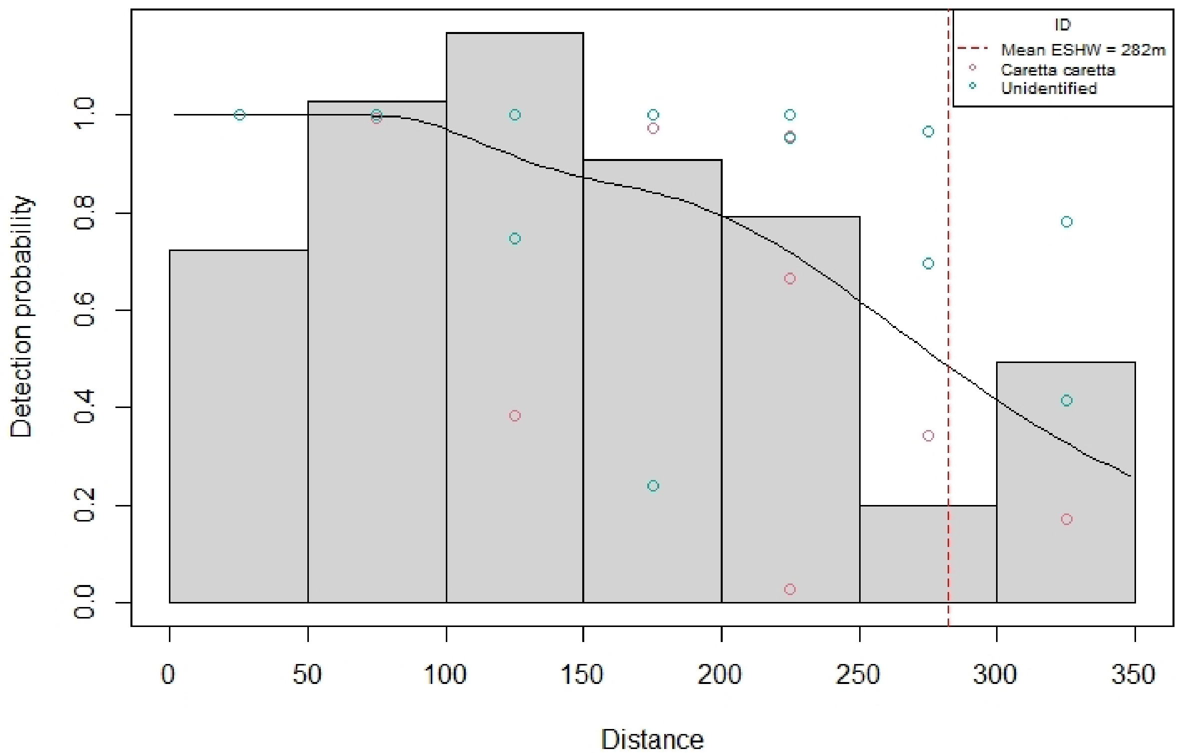

Figure 24. Turtle Group 9 Detection Function Plot

4.2.1.10 Group 10 - UNCW OPAREA Surveys

Surveys in this detection function are the UNCW OPAREA surveys, which were flat window surveys under the UNCW protocol. There were 3,513 total observations with a maximum group size of 20. In the UNCW surveys, most observation distances were binned with recorded distances generating from markings on the windows or struts. Available covariates were altitude, side of aircraft, BSS, visibility, CETMAP quality, month, year, glare, clouds, and confirmed versus unconfirmed observations. Up to three covariates were allowed in each candidate detection function.

Observations were right truncated at 675 m (2,214 ft) and left truncated at 150 m (492 ft) to account for the flat windows obscuring the trackline. Observations were grouped into two 200-m (656-ft) bins and one 125-m (410-ft) bin to capture the major distance groupings of the data and to improve the fit.

Two detection functions were fit and analyzed. The first was using the observations and group sizes as reported, and a hazard rate detection function with year was selected (Figure 25). There were 423 segments with a density greater than one, and a maximum of 9.93 animals/km^2. A Q-Q plot was not generated because the data were binned. Mean ESHW was 429 m (1,407 ft).

The second detection function used a version of the data where group sizes >10 were smeared across up to the previous five segments on a trackline, if available. A hazard rate detection function was selected with side of aircraft, CETMAP quality, and confirmed versus unconfirmed observations as covariates (Figure 26). There were 377 segments with a density greater than one, and a maximum of 4.94 animals/km^2. A Q-Q plot was not generated because the data were binned. Mean ESHW was 436 m (1,430 ft).

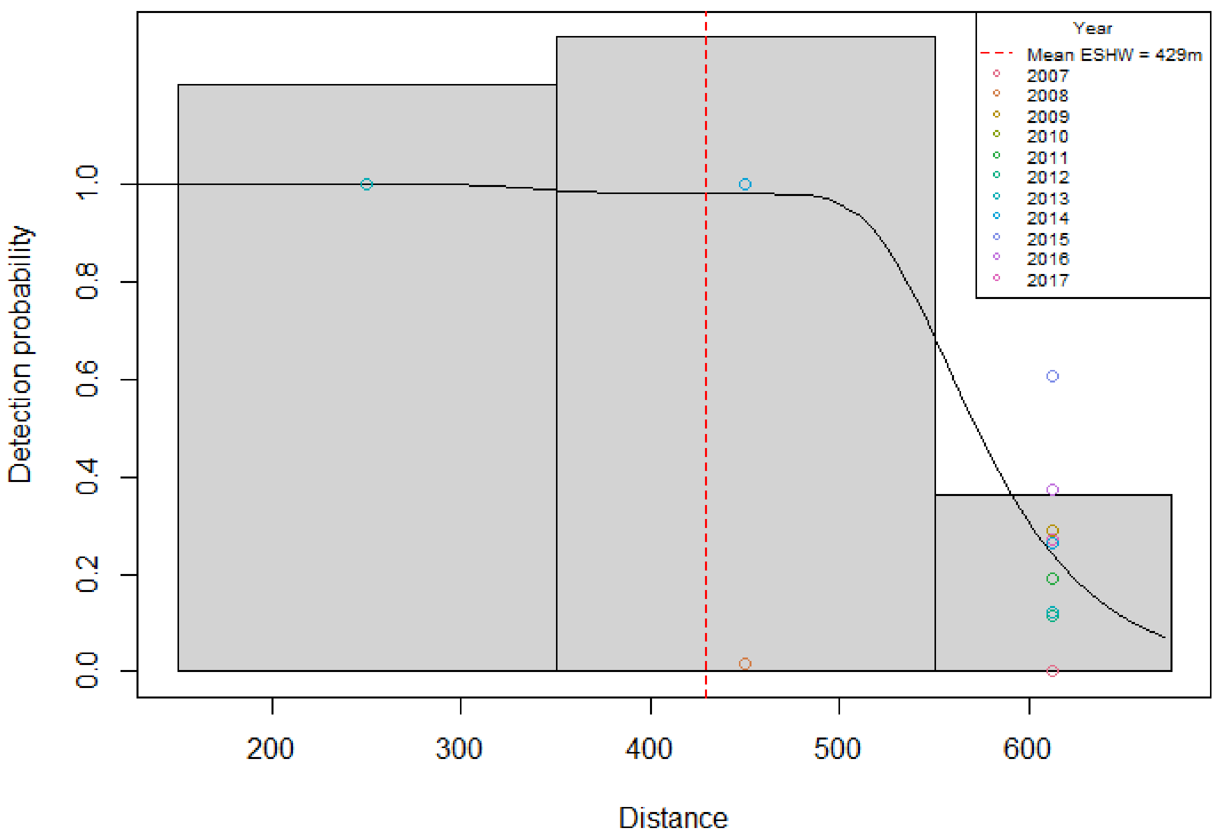

Figure 25. Loggerhead Turtle Group 10 Detection Function Plot with Original Group Sizes

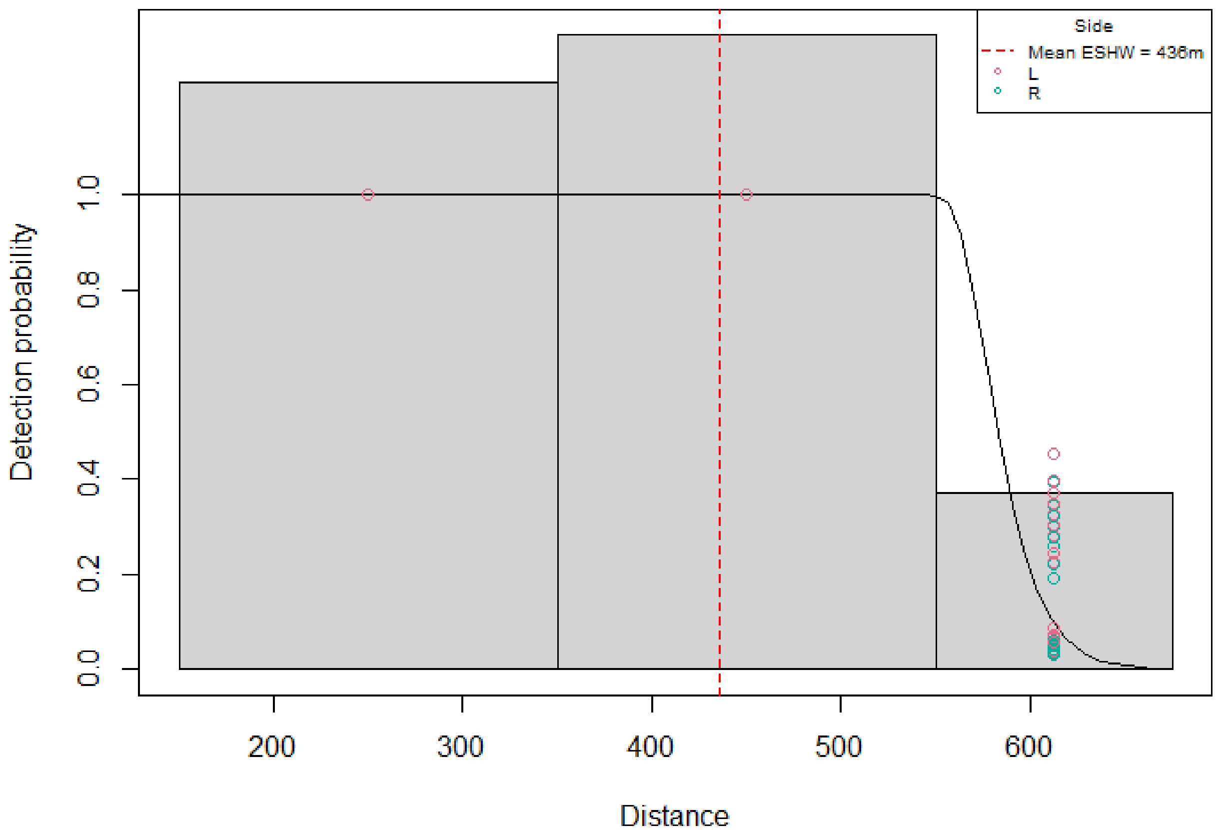

Figure 26. Loggerhead Turtle Group 10 Detection Function Plot with Smeared Group Sizes

4.2.1.11 Group 11 - UNCW Right Whale Surveys

Surveys in this detection function are the UNCW Right Whale surveys, which were flat window surveys under the UNCW protocol. There were 2,757 total observations with a maximum group size of 60. Available covariates were altitude, side of aircraft, BSS, group size, visibility, CETMAP quality, month, year, glare, and confirmed versus unconfirmed observations. Up to three covariates were allowed in each candidate detection function.

Observations were right truncated at 450 m (1,476 ft) and left truncated at 75 m (246 ft) to account for the flat windows where the survey trackline was not visible. Observations were grouped into 100-m (328-ft) bins to capture the major distance groupings of the data.

Two detection functions were fit and analyzed. The first used the observations and group sizes as reported. A half-normal detection function was selected (Figure 27). A Q-Q plot was not generated because the data were binned. There were 2,176 segments with a density greater than one and a maximum of 84.85 animals/km^2. Mean ESHW was 150 m (492 ft).

The second detection function used a version of the data where group sizes exceeding a count of 10 were smeared across up to the previous five segments on the trackline, if available. A hazard rate detection function with no covariates was selected (Figure 28). A Q-Q plot was not generated because the data were binned. There were 2,188 segments with a density greater than one and a maximum of 32.37 animals/km^2. Mean ESHW was 185 m (607 ft).

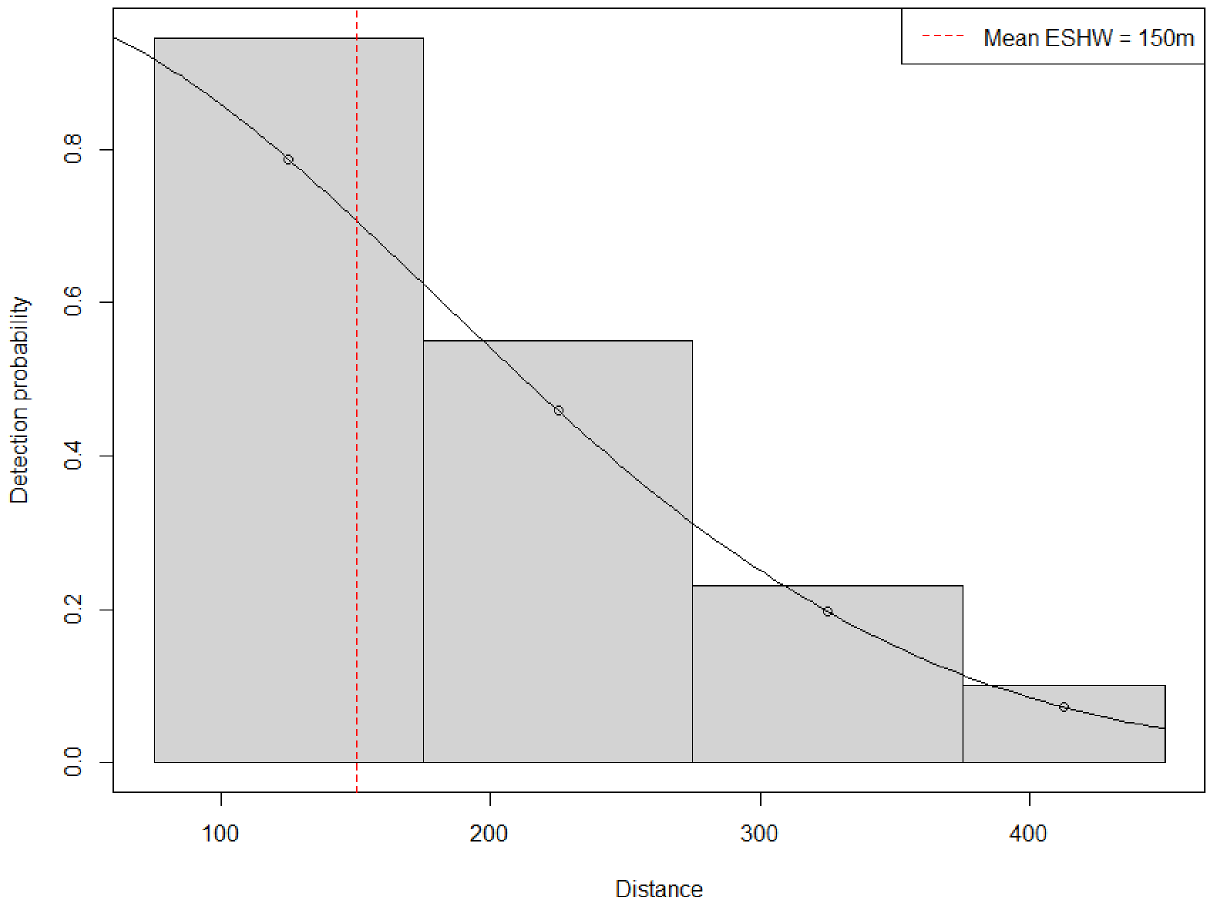

Figure 27. **Loggerhead Turtle Group 11 Detection Function Plot with Original Group Sizes**

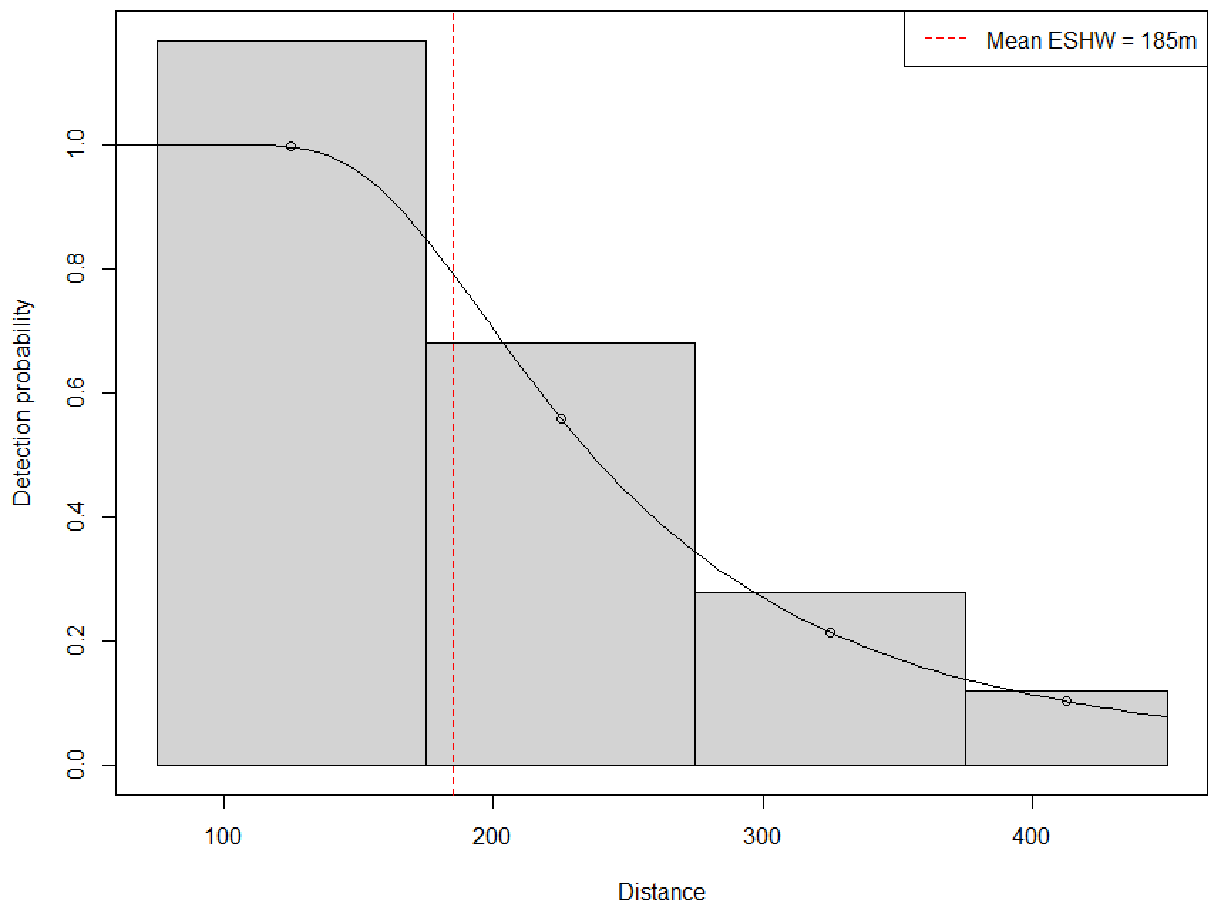

Figure 28. Loggerhead Turtle Group 11 Detection Function Plot with Smeared Group Sizes

4.2.1.12 Group 12 – Virginia Aquarium & Marine Science Center Maryland Department of Natural Resources

Surveys in this detection function are the Virginia Aquarium & Marine Science Center (VAMSC) Maryland Department of Natural Resources (MD DNR) surveys, which were bubble window surveys under the AMAPPS protocol. There were 354 total observations with a maximum group size of 2. Available covariates were altitude, group size, BSS, quality, CETMAP quality, month, year, and confirmed versus unconfirmed observations. Up to three covariates were allowed in each candidate detection function.

Detection functions were originally attempted with no left truncation as these were bubble window surveys; however, an attempt at left truncation was recommended as there was heaping present in the data, with a spike between 75–100 m (246–328 ft). Left truncation appreciably improved the fit of the detection function and was kept.

Observations were right truncated at 275 m (902 ft) and left truncated at 75 m (246 ft); a hazard rate detection function with confirmed versus unconfirmed observations was selected (Figure 29). There were 66 segments with a density greater than one, a maximum of 4 animals/km^2. Mean ESHW was 148 m (485 ft).

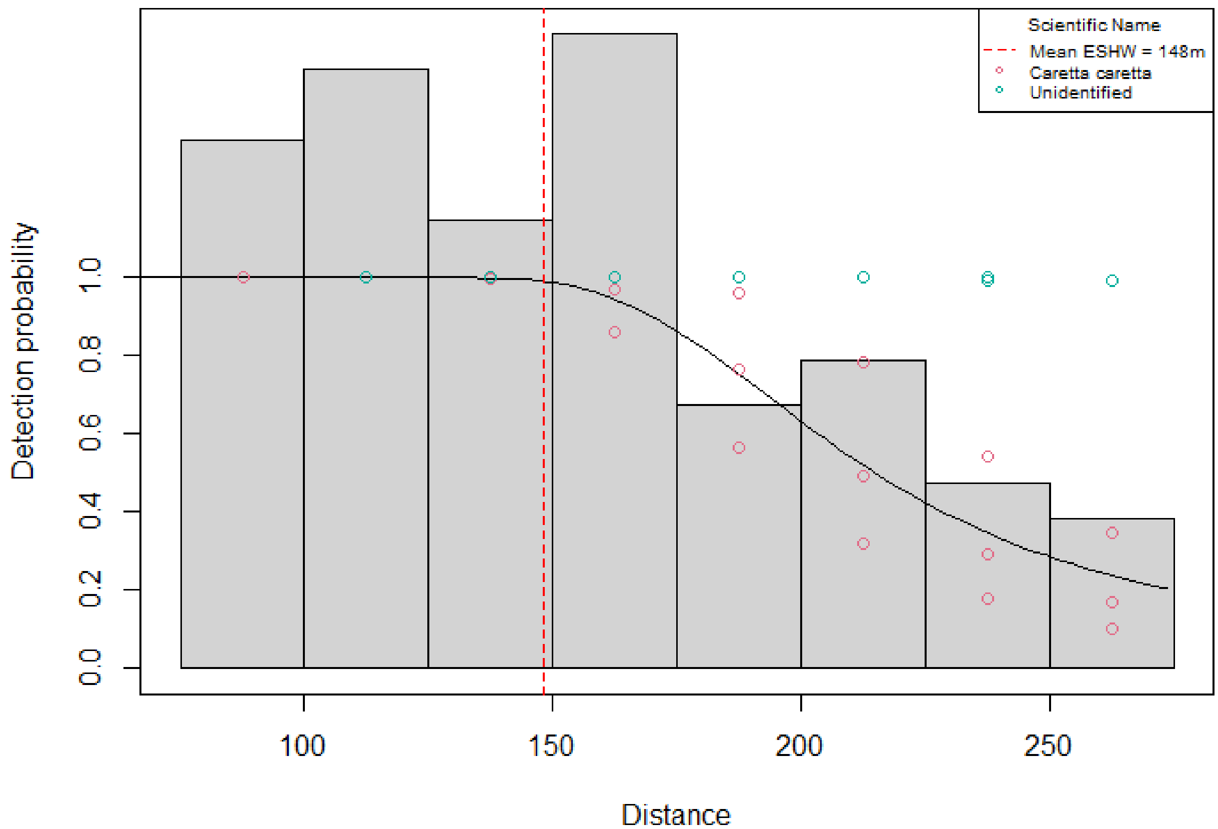

Figure 29a. **Loggerhead Turtle Group 12 Detection Function Plot**

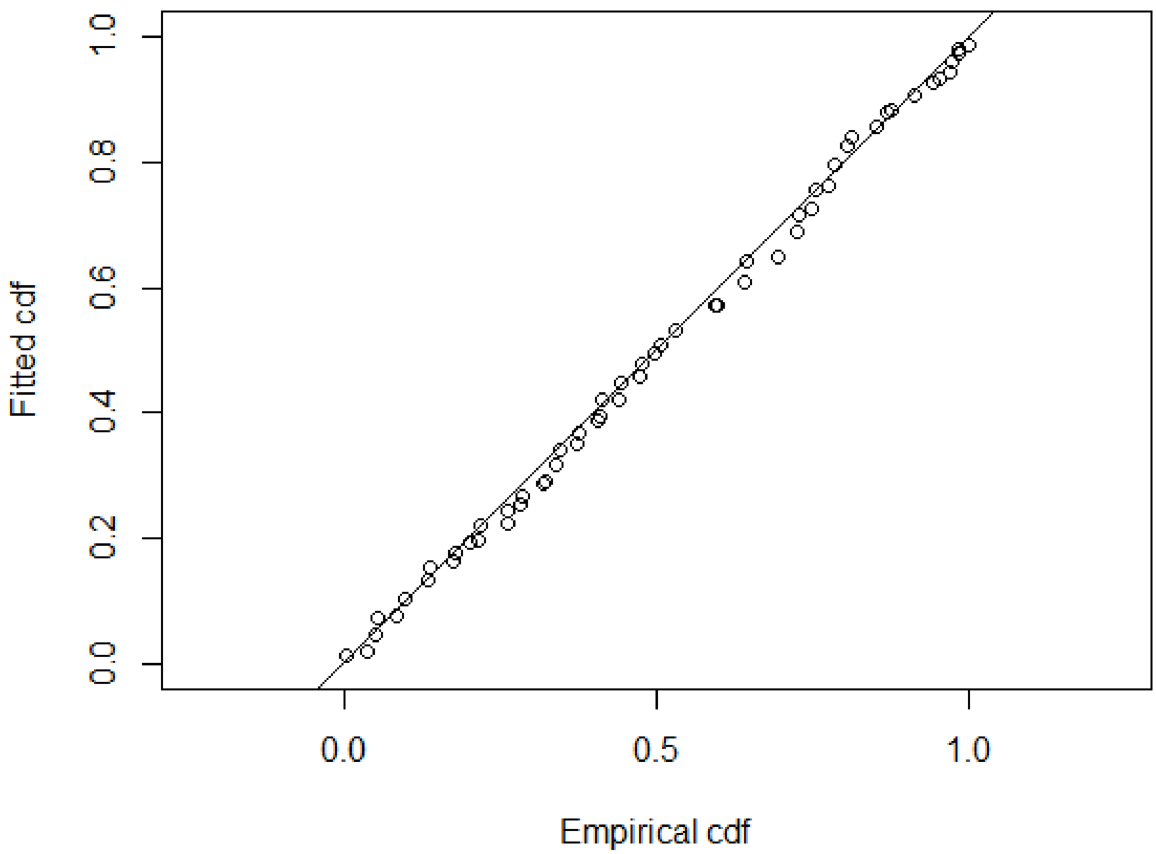

Figure 29b. Loggerhead Turtle Group 12 Q-Q Plot

4.2.1.13 Group 13 - VAMSC Navy Virginia Capes Range Complex

Surveys in this detection function are the VAMSC Navy Virginia Capes Range Complex (VACAPES) surveys, which were flat window surveys under the UNCW protocol. There were 619 total observations with a maximum group size of three. Available covariates were altitude, side of aircraft, group size, BSS, visibility, glare, month, year, clouds, and confirmed versus unconfirmed observations. Up to three covariates were allowed in each candidate detection function.

There was significant heaping in the data between 50–75 m (164–246 ft), 200–225 m (656–738 ft), and 450–475 m (1,476–1,558 ft) that required the data to be binned in order to fit a reasonable detection function. Observations were right truncated at 475 m (1,558 ft) and left truncated at 50 m (164 ft) to account for the flat windows impeding visibility of the trackline. A hazard rate detection function with no covariates was selected (Figure 30). There were 15 segments with a density greater than one, and a maximum of 1.75 animals/km^2. A Q-Q plot was not generated because the data were binned. Mean ESHW was 353 m (1,158 ft).

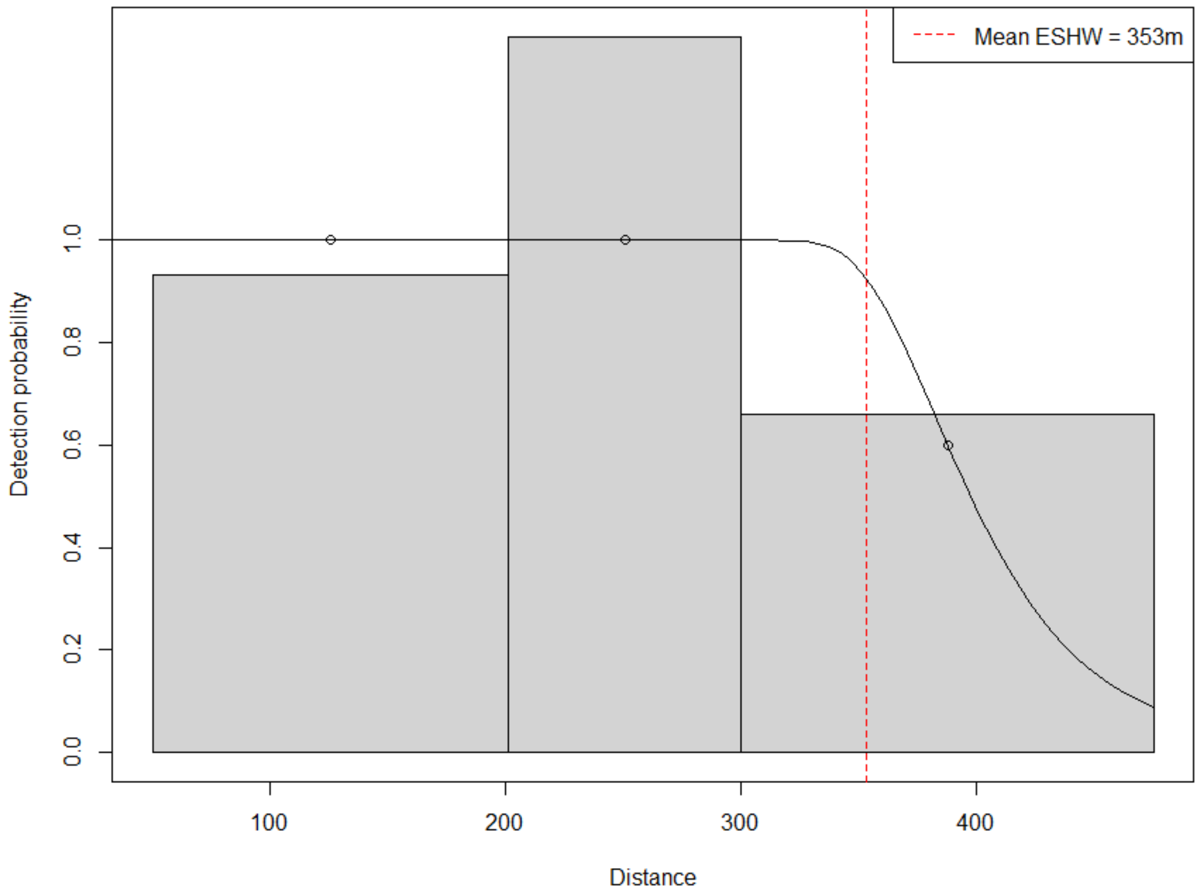

Figure 30. Loggerhead Turtle Group 13 Detection Function Plot

4.2.1.14 Group 14 - VAMSC Virginia Coastal Zone Management

Surveys in this detection function are the VAMSC Virginia Coastal Zone Management (VA CZM) surveys, which were flat window surveys under the UNCW protocol. There were 544 total observations with a maximum group size of 10. Available covariates were altitude, side of aircraft, group size, BSS, visibility, glare, month, year, clouds, and confirmed versus unconfirmed observations. Up to three covariates were allowed in each candidate detection function.

There was significant heaping in the data between 50–75 m (164–246 ft), 200–225 m (656–738 ft), and 450–475 m (1,476–1,558 ft) that required the data to be binned in order to fit a reasonable detection function. Observations were right truncated at 475 m (1,558 ft) and left truncated at 50 m (164 ft) to account for the flat windows impeding visibility of the trackline. A hazard rate detection function with no covariates was selected (Figure 31). There were 35 segments with a density greater than one, and a maximum of 3.33 animals/km^2. A Q-Q plot was not generated because the data were binned. Mean ESHW was 363 m (1,190 ft).

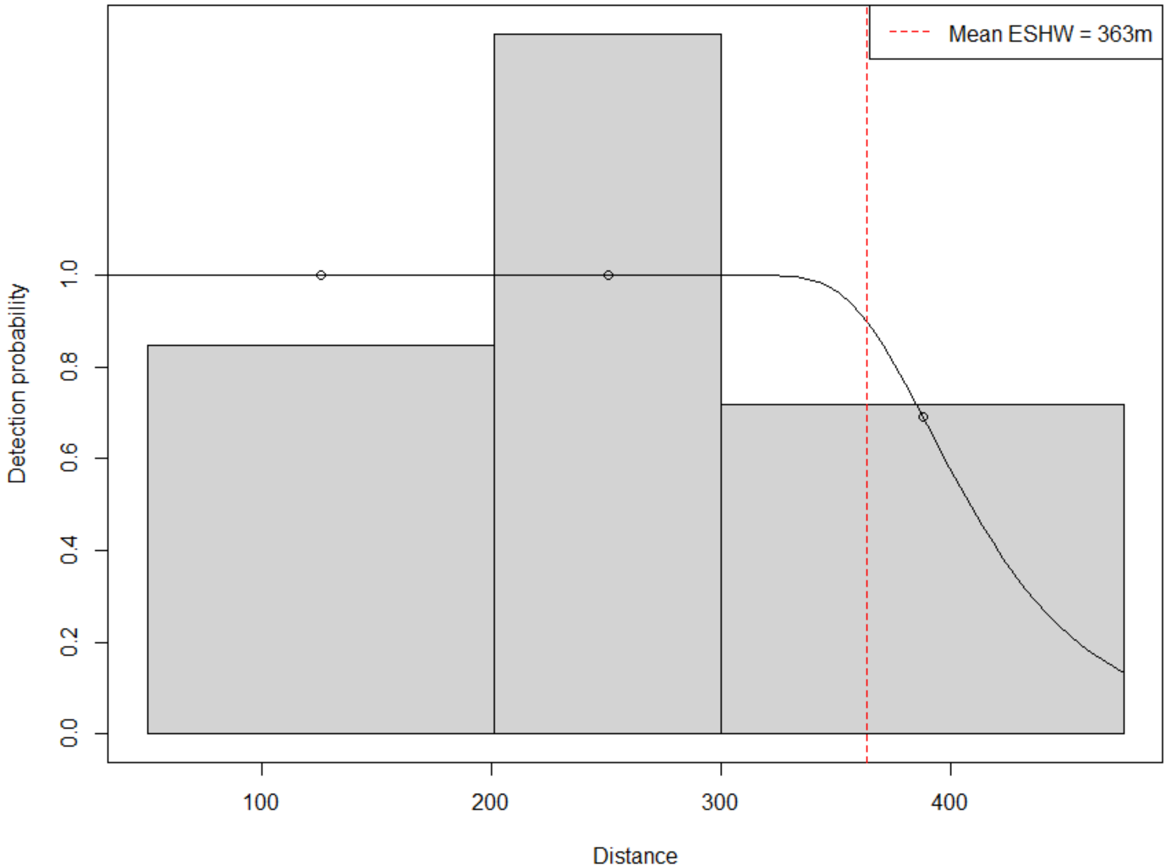

Figure 31. Loggerhead Turtle Group 14 Detection Function Plot

4.2.2 Green Turtle Detection Functions

4.2.2.1 Group 1 - 600 ft Surveys

Surveys in this detection function are all surveys that flew at 183 m (600 ft), including the NEFSC and SEFSC AMAPPS surveys and the pre-AMAPPS NEFSC surveys. There were 785 observations available across the three survey programs. There were enough observations in the SEFSC AMAPPS surveys to fit a detection function, but none of the other 183-m (600-ft) surveys did. Therefore, it was decided to combine them all given their similar altitudes and protocols. There was one group size of 16 that was a confirmed sighting, which we theorize may have been a mating aggregation. All other group sizes were either one or two. Available covariates were group size, observer position, confirmed versus unconfirmed observations, month, year, and survey ID. Up to three covariates were allowed in each candidate detection function. Observations were right truncated at 300 m (984 ft). The hazard rate detection function with the confirmed versus unconfirmed observation, survey ID, and group size covariates was selected (Figure 32a).

There was a spike in observations at 0–50 m (0–164 ft), which was also apparent in the Q-Q plot (Figure 32b). We were hesitant to left truncate these sightings as all surveys were bubble windows and a large proportion of sightings would have been lost. Ultimately, they were retained as model statistics for the selected detection function were acceptable. There were 111 segments with densities greater than one, mostly off the coast of Florida, with a maximum of 88.5 animals/km^2. This high density value was limited to one segment and included the observation of 16 animals. See the results of the green turtle spatial density model for information on how this segment was handled (Section 4.3.2). Mean ESHW was 211 m (692 ft).

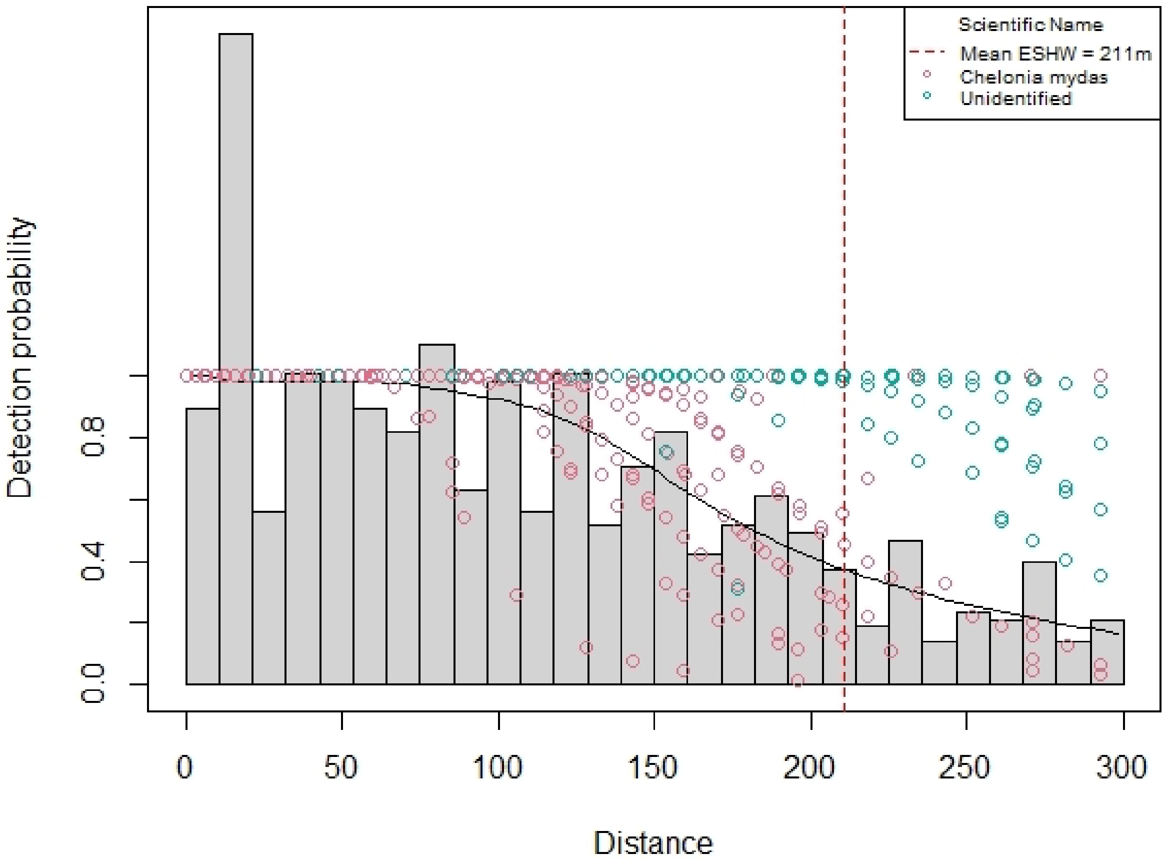

Figure 32a. Green Turtle Group 1 Detection Function Plot

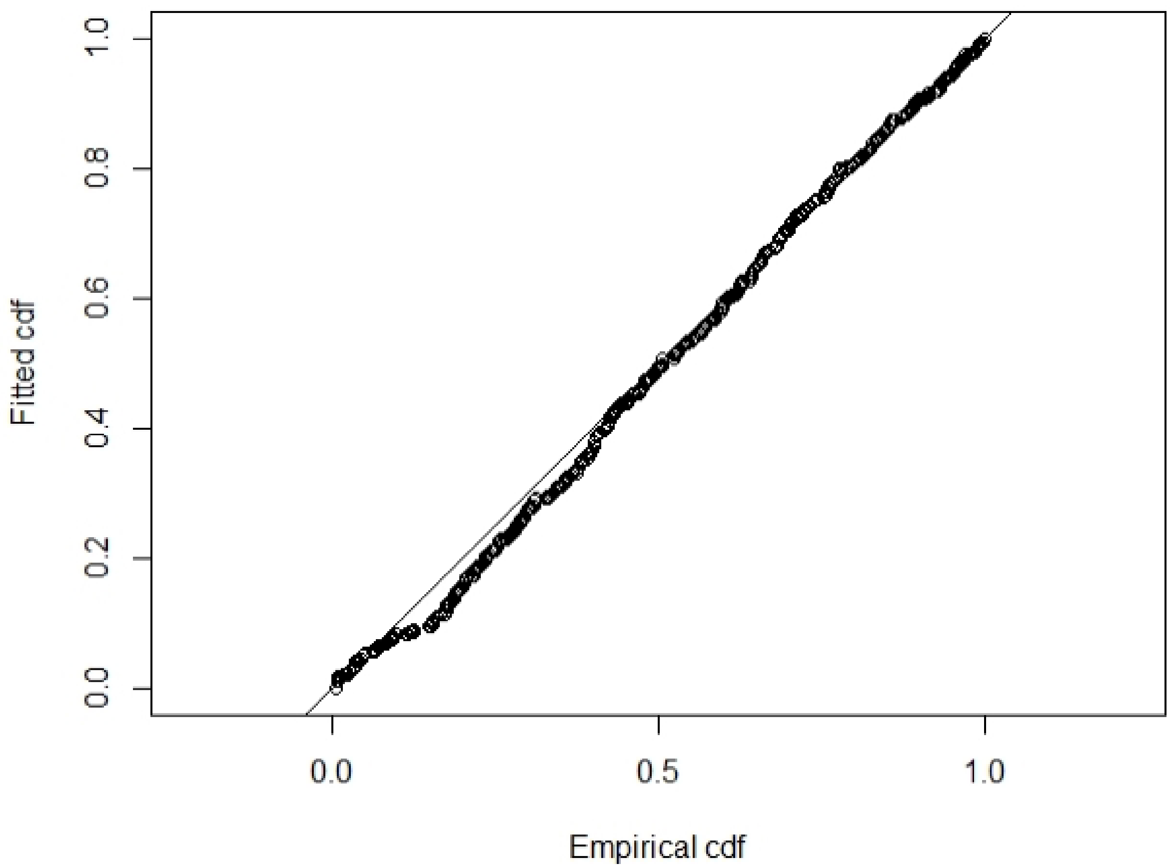

Figure 32b. Green Turtle Group 1 Q-Q Plot

4.2.2.2 Group 2 - MATS Survey Hardshell Guild

Surveys in this detection function included the SEFSC MATS surveys. Fifteen confirmed green turtle observations were available, and no green turtles were detected in the other 229 m (750 ft) surveys. As such, a hardshell guild detection function was fit, with 916 observations, which included 35 green turtle observations. Loggerhead (n=846) and Kemp's ridley (n=55) observations in the detection function were limited to the maximum group size of the confirmed green turtle observations (in this instance, maximum group size is three). Available covariates were group size, altitude, side of aircraft, observer position, BSS, observation quality, turbidity, weather, month, year, species, and confirmed versus unconfirmed observations. Up to three covariates were allowed in each candidate detection function.

Observations were right truncated at 400 m (1,312 ft). The hazard rate detection function with side of observation and confirmed versus unconfirmed sightings as covariates was selected (Figure 33). The model statistics and Q-Q plot were acceptable, though Cramér–von Mises (CVM) was close to being significant. Only one segment had a density value greater than zero. Mean ESHW was 282 m (925 ft).

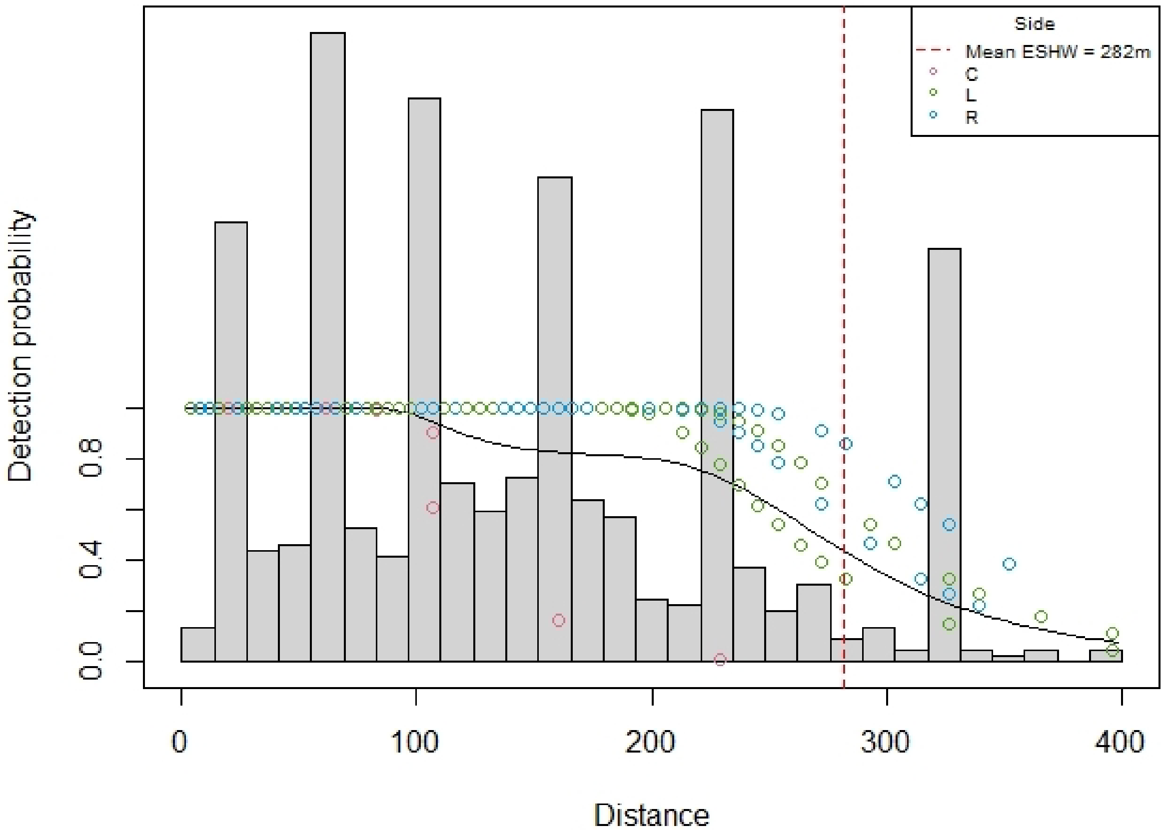

Figure 33a. Green Turtle Group 2 Detection Function Plot

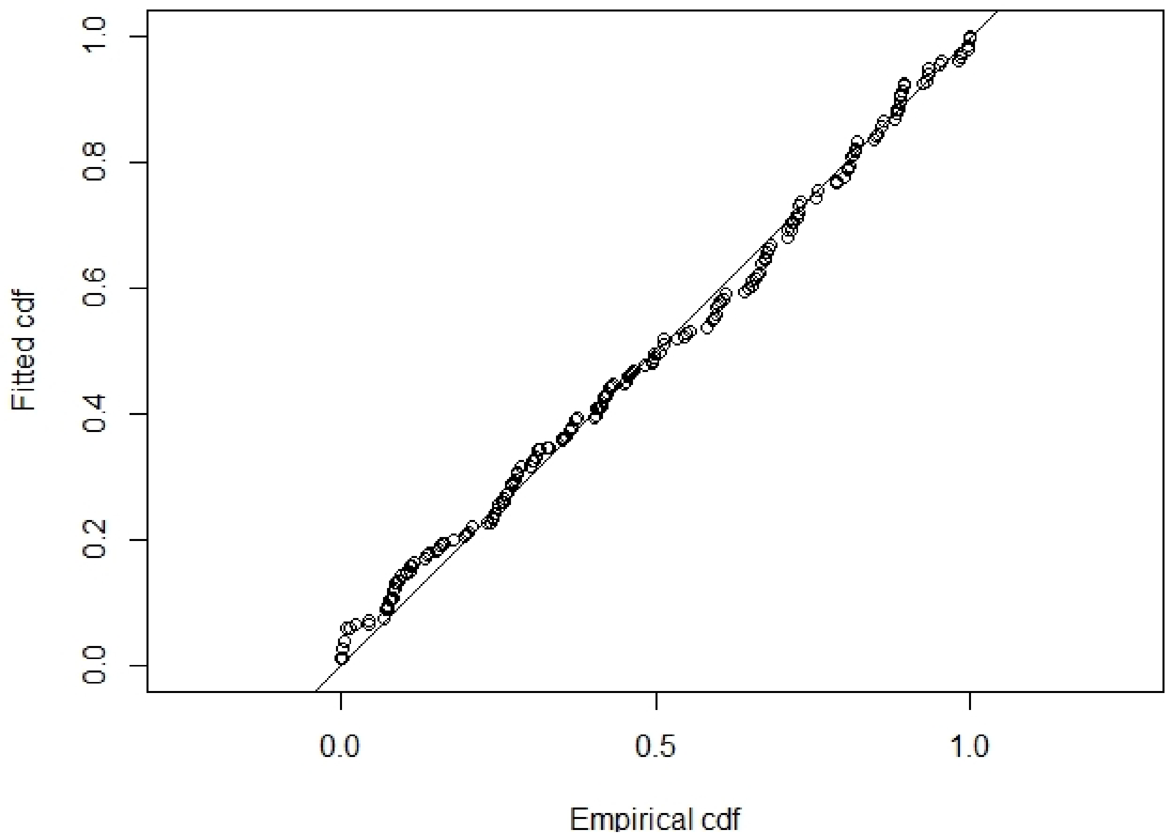

Figure 33b. Green Turtle Group 2 Q-Q Plot

4.2.2.3 Group 3 - UNCW Right Whale Hardshell Guild

Surveys in this detection function included the UNCW Right Whale surveys, which were flat window surveys under the UNCW protocol. In aggregate, the UNCW Right Whale surveys had one green turtle observation, 35 Kemp's ridley turtle observations, and the rest loggerhead turtles, for a total of 2,818 observations. Loggerhead observations were limited to the maximum group size of green and Kemp's ridley turtles (in this instance, maximum group size is one). In the UNCW surveys, most observation distances were binned, recording distances using marking on the windows or struts.

Available covariates were altitude, side of the plane, BSS, observation quality, visibility, glare, month, year, species, and confirmed versus unconfirmed observations. Up to three covariates were allowed in each candidate detection function. Observations were right truncated at 450 m (1,476 ft) and left truncated at 50 m (164 ft) to account for the flat windows where the survey trackline was not visible. Observations were grouped into 100-m (328-ft) bins to capture the major distance groupings of the data. The half-normal detection function with observer position, visibility, and month as covariates was selected (Figure 34). No issues were noted with the model statistics. A Q-Q plot was not generated because of the binned data. Only one segment had predicted density and it was less than one. Mean ESHW was 160 m (525 ft).

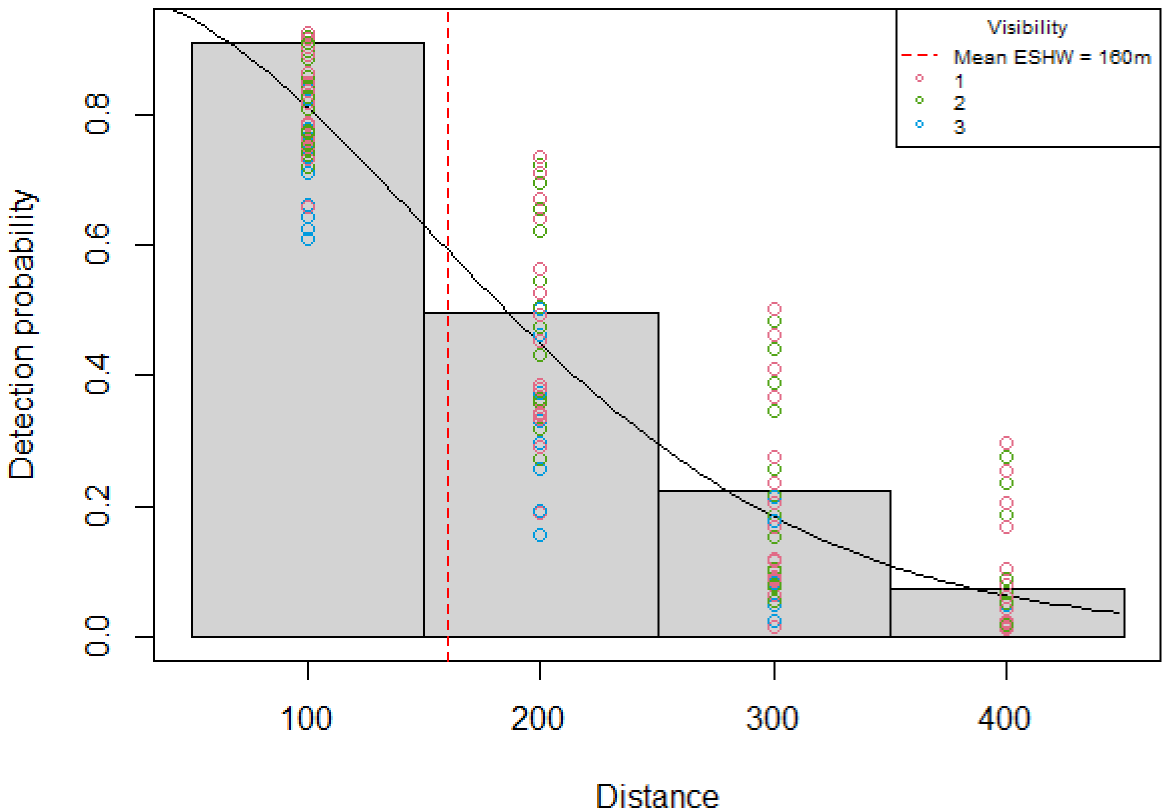

Figure 34. Green Turtle Group 3 Detection Function Plot

4.2.3 Kemp's Ridley Turtle Detection Functions

4.2.3.1 Group 1 - HDR Survey Hardshell Guild

Surveys in this detection function included the HDR Inc. surveys, which was a flat window survey under the UNCW protocol. In aggregate, the UNCW protocol surveys had 57 Kemp's ridley sightings, which may have been enough to fit a reasonable detection function. However, the decision was made to fit hardshell guild detection functions instead, which would allow for more potential covariates, including species identification, and not require binning of data from non-UNCW surveys. In the UNCW surveys, observation distances were binned. Loggerhead observations in the detection function were limited to the maximum group size of the confirmed Kemp's ridley observations (in this instance, maximum group size is five). There were 138 observations available, 19 of which were Kemp's ridley turtles.

Available covariates were group size, altitude, side of aircraft, observer position, BSS, swell, wave height, visibility, glare, month, year, species, and confirmed versus unconfirmed observations. Up to two covariates were allowed in each candidate detection function. Observations were right truncated at 700 m (2,297 ft) and left truncated at 75 m (246 ft) to account for the flat windows where the survey trackline was not visible. The hazard rate detection function with swell and observer position as covariates was selected (Figure 35a).

There was a drop in observations between 150–250 m (492–820 ft), which may have been observers guarding the trackline, or in this instance, the area closest to the aircraft that could be observed with flat windows. This could not be addressed without losing many sightings and impacted the fit of the detection functions. The model statistics indicated a marginal fit to the data (CVM was close to significance). The Q-Q plot indicated poor fit at middle distances, as expected given the gap in observations (Figure 35b). Two segments, of the 16 with Kemp's ridley observations, had density values greater than one. Mean ESHW was 467 m (1,532 ft).

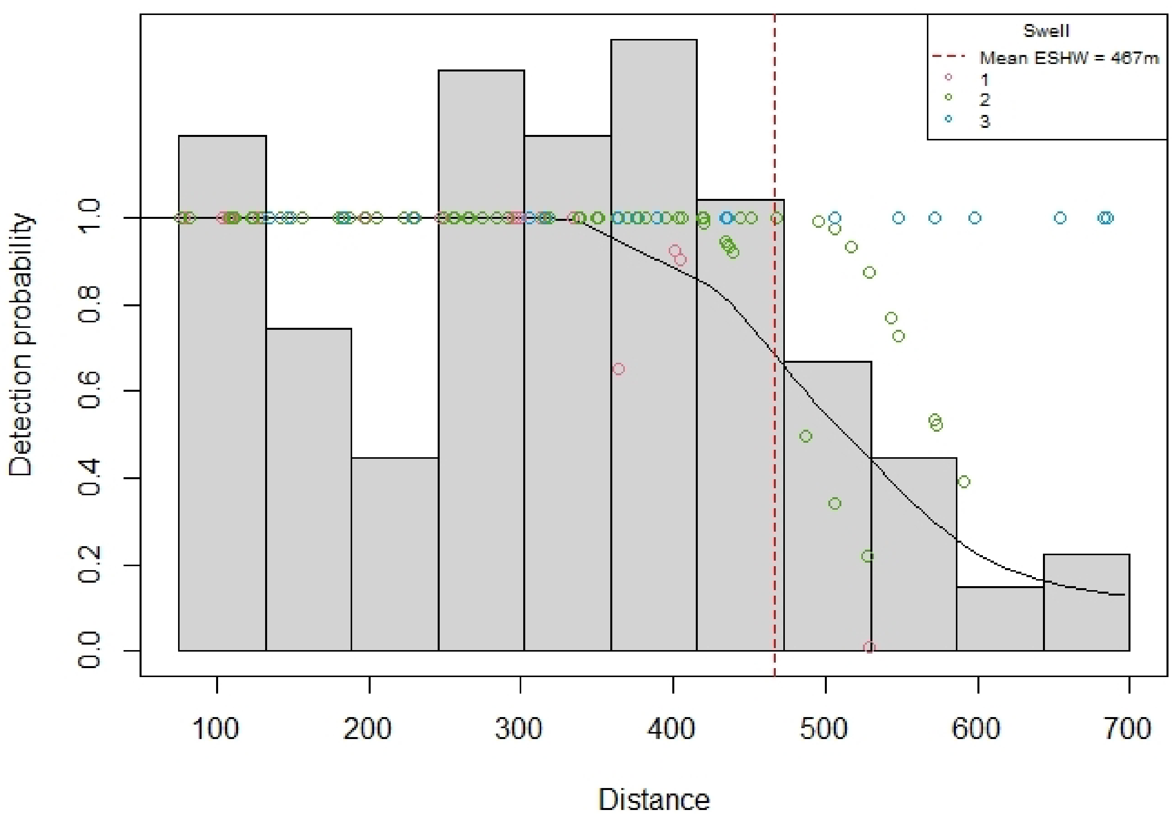

Figure 35a. Kemp's Ridley Group 1 Detection Function Plot

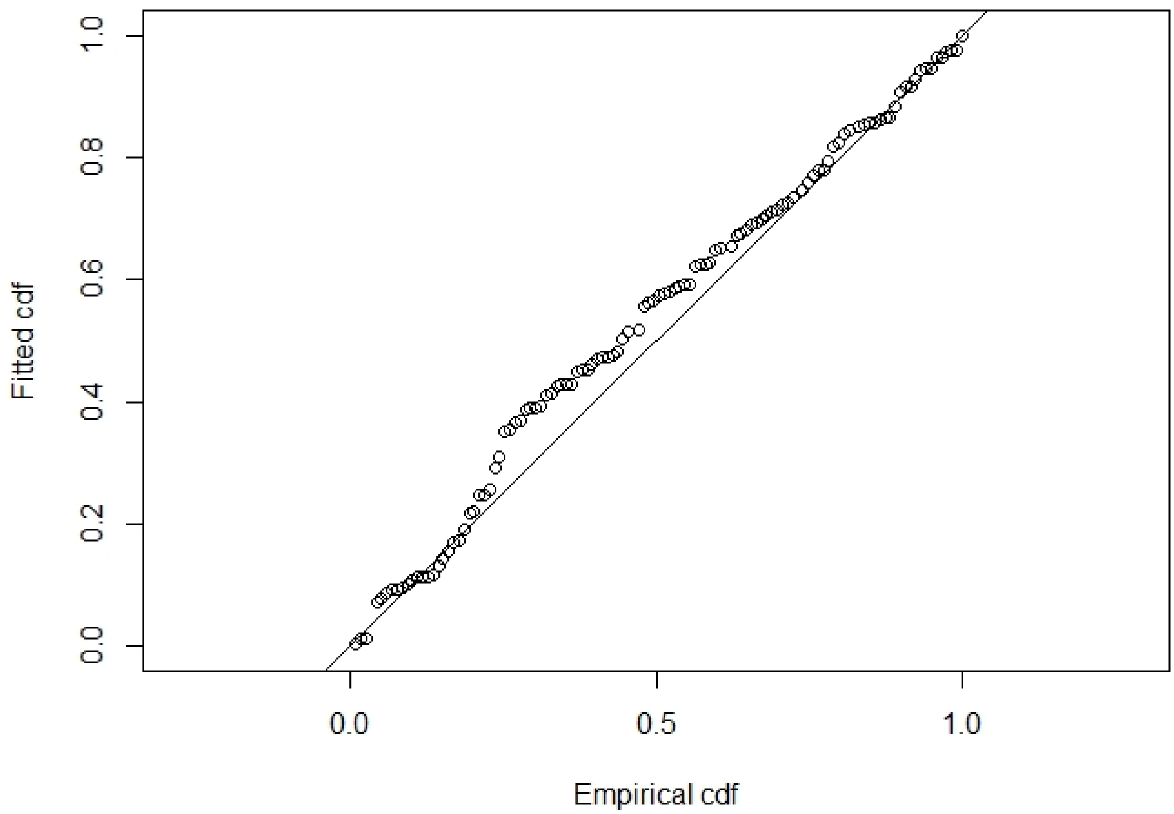

Figure 35b. Kemp's Ridley Group 1 Q-Q Plot

4.2.3.2 Group 2 - 600 ft Surveys

Surveys in this detection function are all surveys that flew at 183 m (600 ft), including the NEFSC and SEFSC AMAPPS surveys and the pre-AMAPPS NEFSC surveys. 187 observations were available across the three survey programs. This is the only Kemp's ridley specific detection function with greater than 60 observations. There were a few larger group sizes of five, six, and eleven respectively. All other group sizes were one. Available covariates were group size, observer position, confirmed versus unconfirmed observations, month, year, and survey ID. Up to two covariates were allowed in each candidate detection function. Observations were right truncated at 305 m (1,001 ft). The hazard rate detection function with the confirmed versus unconfirmed observation covariate was selected (Figure 36a).

No issues were noted with the model statistics or Q-Q plot (Figure 36b). There were 26 segments with densities greater than one, with a maximum of 14 animals/km^2, all with more than one sighting on the segment. The segment with a density of 14 animals/km^2 had 28 animals observed on the segment, which was flown off the coast of Florida in March. We saw no indication in the data that the individual observations on this segment were erroneous and accepted the data as given by the survey providers. Mean ESHW was 176 m (577 ft).

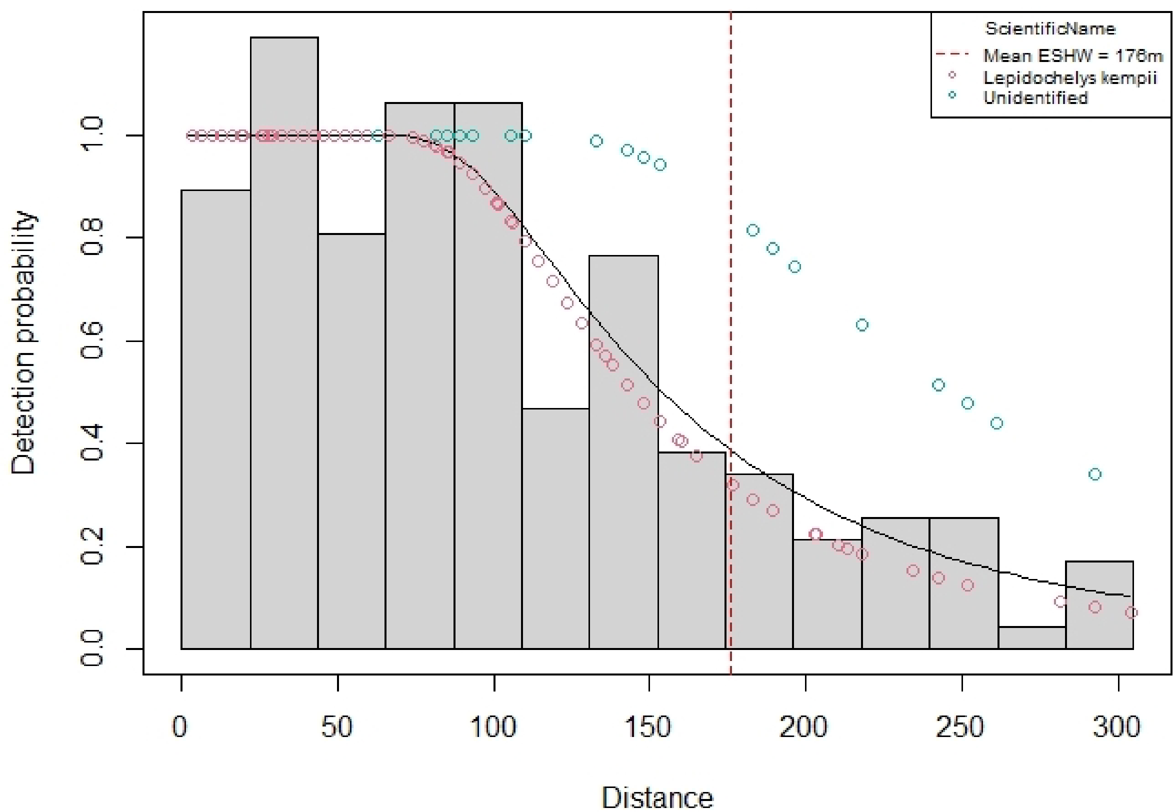

Figure 36a. **Kemp's Ridley Group 2 Detection Function Plot**

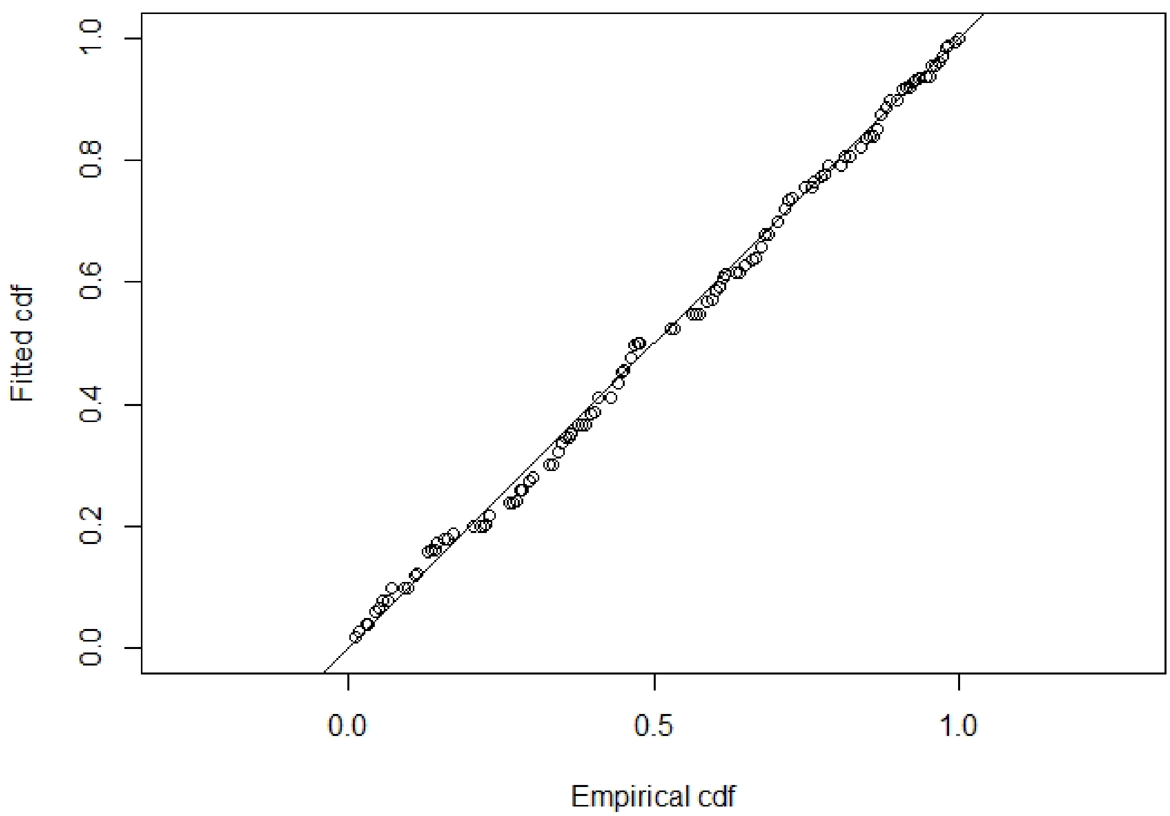

Figure 36b. Kemp’s Ridley Group 2 Q-Q Plot

4.2.3.3 Group 3 - 2003–2016 NARWSS Surveys Hardshell Guild

Surveys in this detection function included the 2003–2016 NARWSS surveys. Only one confirmed Kemp’s ridley sighting was available, which would have not appreciably improved the MATS survey detection function by combining the two programs into a 229-m (750-ft) survey detection function. As such, a hardshell guild detection function was fit for the NARWSS early surveys, with 53 observations. Loggerhead observations in the detection function were limited to the maximum group size of the confirmed Kemp’s ridley observations (in this instance, maximum group size is one).

Available covariates were altitude, side of aircraft, observer position, BSS, visibility, observation quality, glare, month, year, species, and confirmed versus unconfirmed observations. Up to one covariate was allowed in each candidate detection function. There was a low number of detections close to the trackline, with the highest number of detections grouped at approximately 100–300 m (328–984 ft). We suspect this is because the focus of the NARWSS surveys is the detection of large whales, particularly North Atlantic right whales, and the focus of observers may be further out towards the horizon. Because of this, left truncation was considered even though the surveys occurred in bubble window aircraft.

Left truncation did not appreciably improve the fit of candidate detection functions, so it was not implemented in the final model. Observations were right truncated at 570 m (1,870 ft). The half-normal detection function was selected with no covariates or adjustments (Figure 37a). The model statistics indicated a marginal fit to the data (CVM was close to significance). The Q-Q plot indicated poor fit at middle distances, as expected given the gap in observations (Figure 37b). Because there was only one Kemp's ridley observation, only one segment had non-zero density. Mean ESHW was 449 m (1,473 ft).

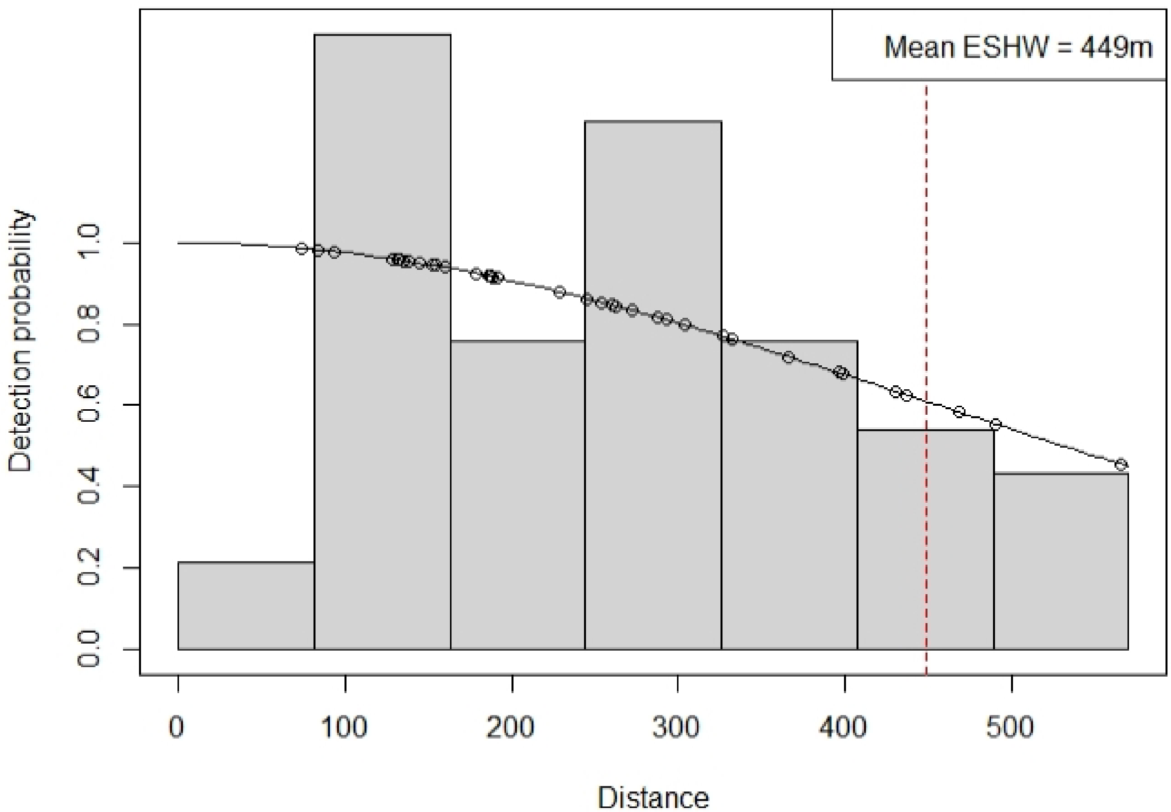

Figure 37a. Kemp's Ridley Group 3 Detection Function Plot

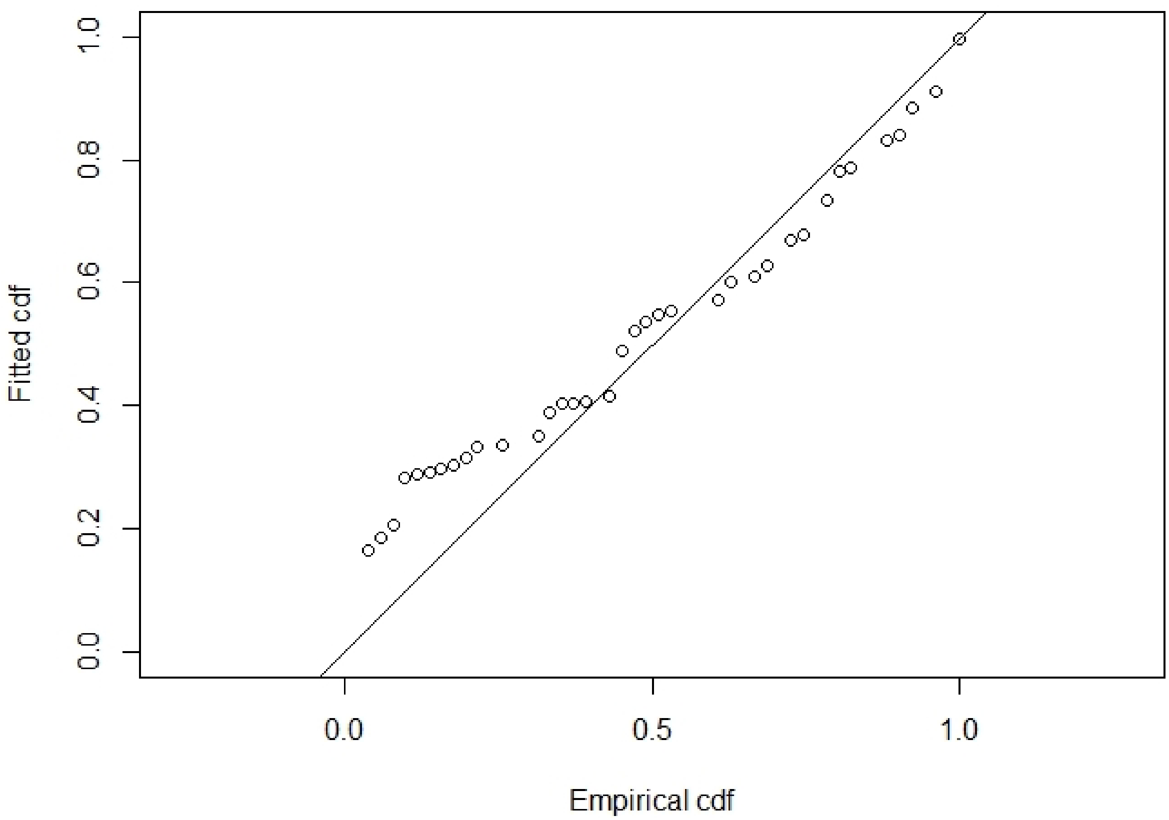

Figure 37b. Kemp's Ridley Group 3 Q-Q Plot

4.2.3.4 Group 4 – TT-NYSDEC NYBWM Hardshell Guild

Surveys in this detection function included the TT-NYSDEC NYBWM surveys. Only one confirmed Kemp's ridley sighting was available, and no Kemp's ridleys were detected in the other 305-m (1,000-ft) surveys. As such, a hardshell guild detection function was fit for the TT-NYSDEC surveys with 226 observations. Loggerhead observations in the detection function were limited to the maximum group size of the confirmed Kemp's ridley observation (in this instance, maximum group size is one).

Available covariates were altitude, side of aircraft, observer position, BSS, visibility, cloud cover, month, year, species, and confirmed versus unconfirmed observations. Turbidity was available as a covariate but was dropped from consideration after discussions with the MGEL marine mammal modeling team indicated it was not assessed consistently between years. Up to two covariates were allowed in each candidate detection function. There was a low number of detections close to the trackline, with the highest number of detections grouped at approximately 200–300 m (656–984 ft). Sea turtles may be harder to detect directly below the aircraft from higher altitudes, even with bubble windows. Because of this, left truncation was considered even though the surveys occurred in bubble window aircraft.

Left truncation at 50 m (164 ft) appreciably improved the fit of candidate detection functions and was implemented in the final model. Observations were right truncated at 550 m (1,804 ft). The hazard rate detection function with BSS as a covariate was selected. The model statistics and Q-Q plot were acceptable despite some potential heaping at intermediate distances (Figure 38). Because there was only one Kemp's ridley observation, only one segment had non-zero density. Mean ESHW was 361 m (1,184 ft).

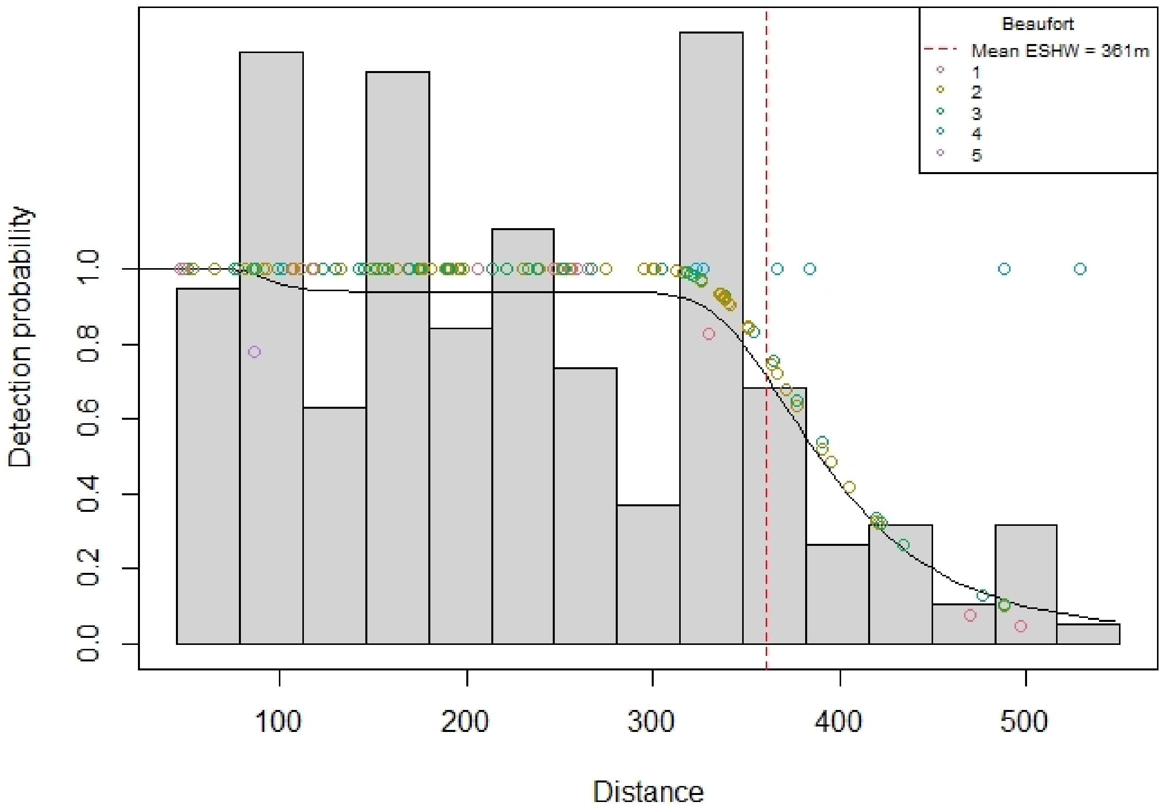

Figure 38a. Kemp's Ridley Group 4 Detection Function Plot

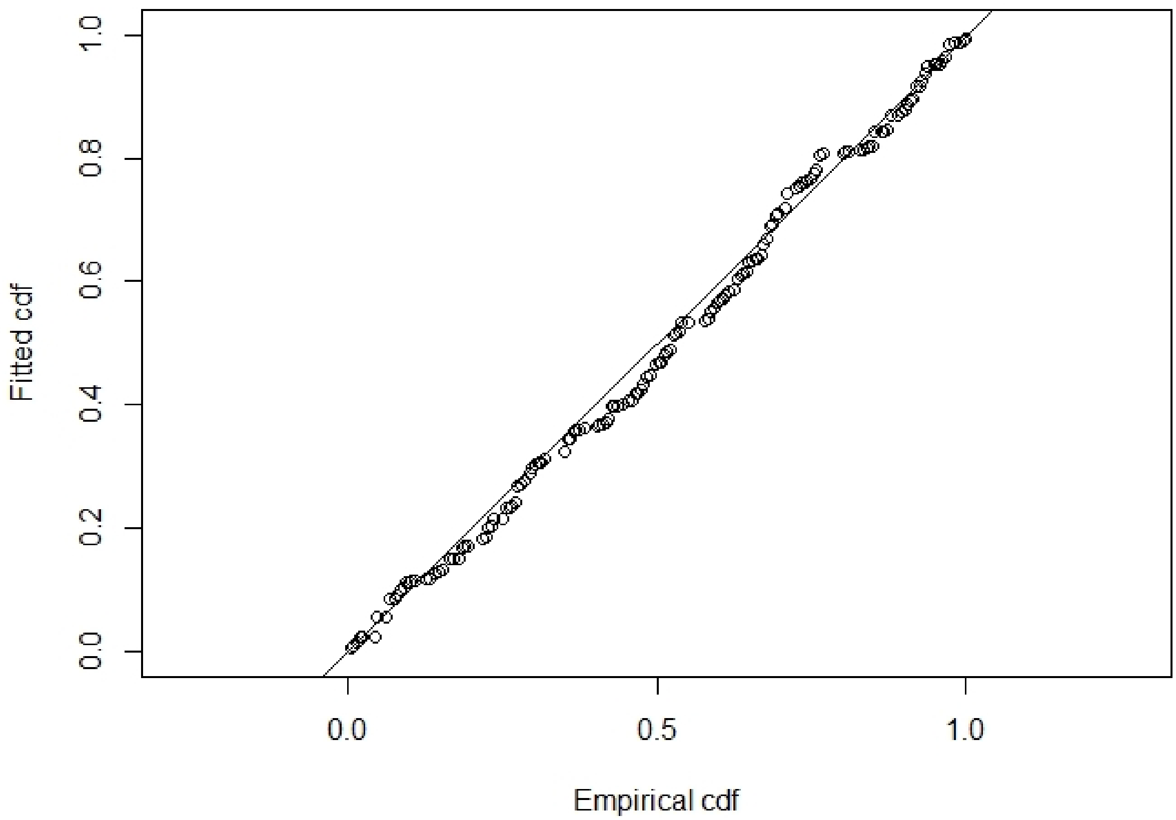

Figure 38b. Kemp's Ridley Group 4 Q-Q Plot

4.2.3.5 Group 5 - MATS Surveys

Surveys in this detection function are the SEFSC MATS surveys. There were 53 observations available, and it was decided to attempt to fit a detection function rather than combine the MATS surveys with the earlier NARWSS surveys (which had a different protocol) or combine this program with surveys flown at different altitudes. The maximum group size was five, but most observations were of single animals. Available covariates were group size, side of aircraft, observer position, BSS, observation quality, turbidity, weather, confirmed versus unconfirmed observations, month, and year. Up to one covariate was allowed in each candidate detection function. Observations were right truncated at 330 m (1,083 ft). The half normal detection functions with side or year were within two AIC of each other. The CVM statistic and Q-Q plot of the half normal detection function with side as a covariate were better, so that detection function was selected.

No issues were noted with the model statistics or Q-Q plot, though with relatively few sightings, the detection plot histogram was somewhat choppy (Figure 39), and the detection function was relatively flat except for observations from the central windows, which had limited visibility to either side of the trackline. Thirteen segments had a density greater than one, with a maximum of 2.4 animals/km^2. Mean ESHW was 243 m (797 ft).

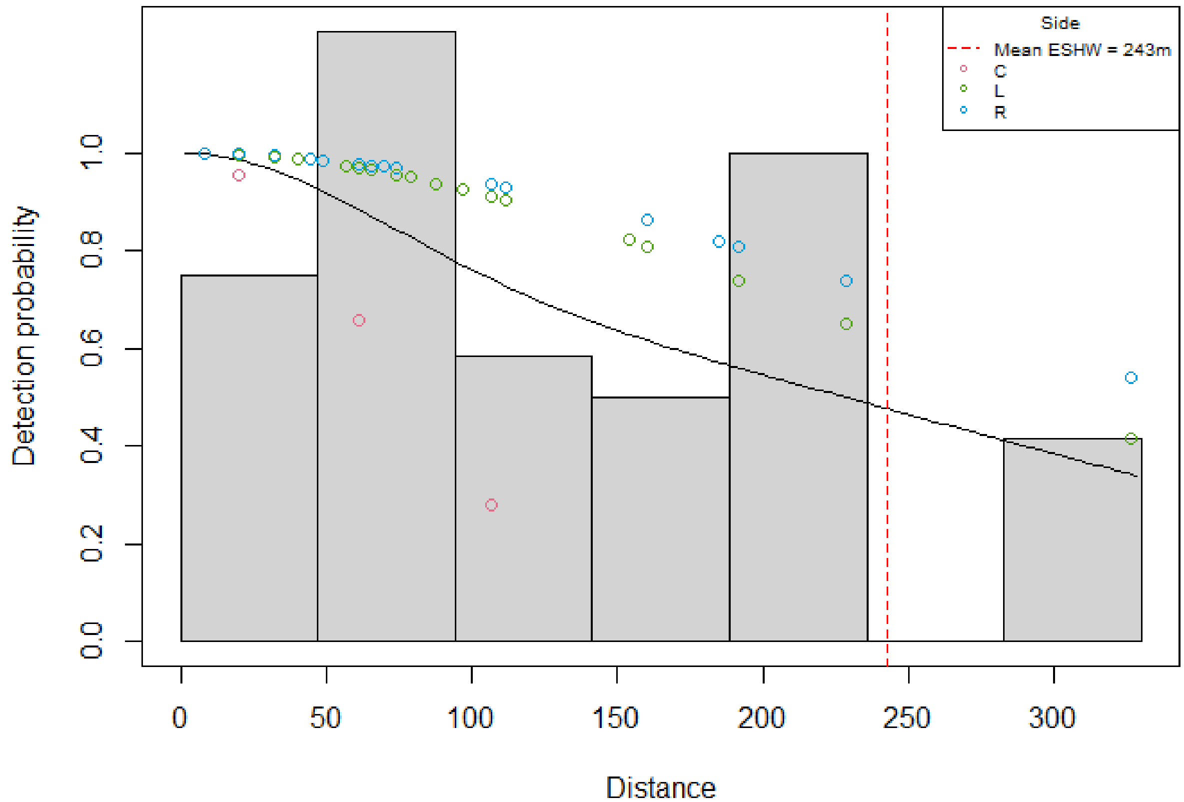

Figure 39a. **Kemp's Ridley Group 5 Detection Function Plot**

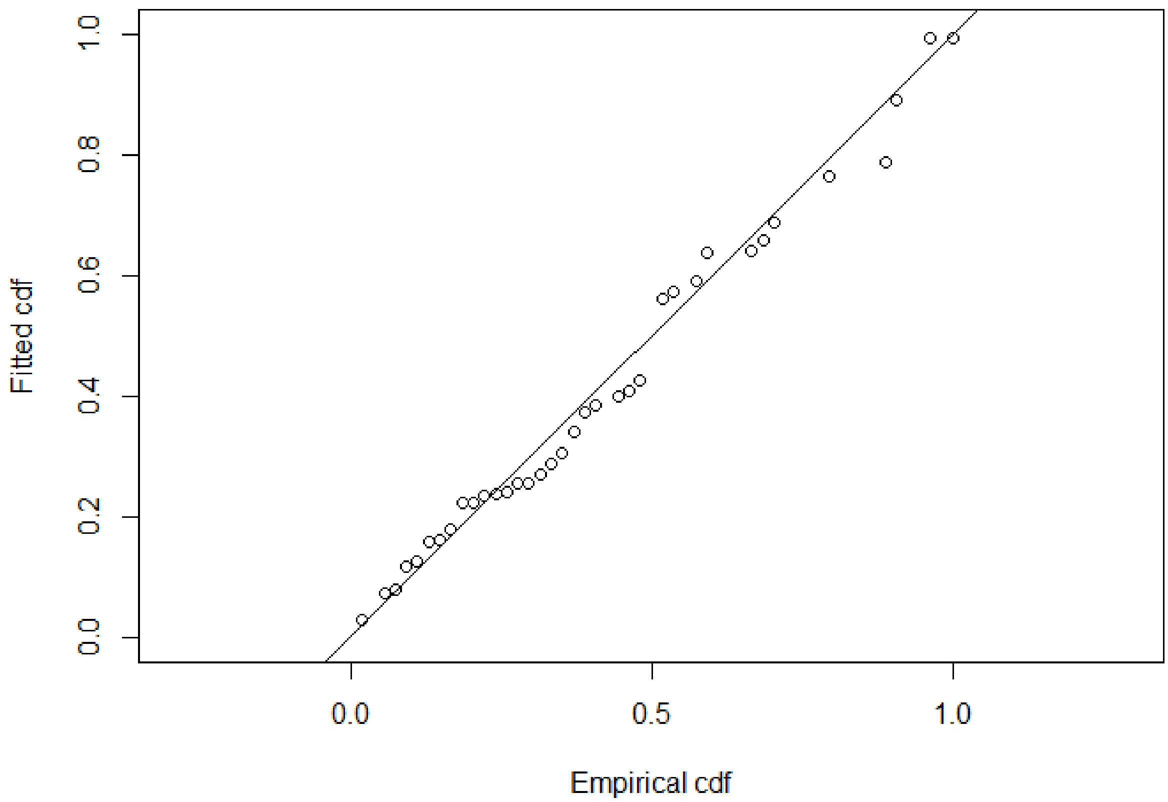

Figure 39b. Kemp's Ridley Group 5 Q-Q Plot

4.2.3.6 Group 6 - UNCW OPAREA Hardshell Guild

Surveys in this detection function included the UNCW OPAREA surveys, which were flat window surveys under the UNCW protocol. In aggregate, the UNCW protocol surveys had 57 Kemp's ridley sightings, which may have been enough to fit a reasonable detection function. However, the decision was made to fit hardshell guild detection functions instead, which would allow for more potential covariates, including species identification. In the UNCW surveys, most observation distances were binned, and distances were recorded using markings on the windows or struts. Loggerhead observations in the detection function were limited to the maximum group size of the confirmed Kemp's ridley observations (in this instance, maximum group size is one). There were 2,924 observations available, three of which were Kemp's ridley turtles. There were no green turtle sightings.

Available covariates were altitude, side of the plane, BSS, observation quality, visibility, glare, month, year, species, and confirmed versus unconfirmed observations. Up to three covariates were allowed in each candidate detection function. Observations were right truncated at 700 m (2,297 ft) and left truncated at 200 m (656 ft) to account for the flat windows where the survey trackline was not visible. Observations were grouped into 100-m (328-ft) bins to capture the major distance groupings of the data. The hazard rate detection function with year as a covariate was selected (Figure 40). No issues were noted with the model statistics. A Q-Q plot was not generated because of the binned data. All three segments with predicted density had values less than 1 animal/km^2. Mean ESHW was 190 m (623 ft).

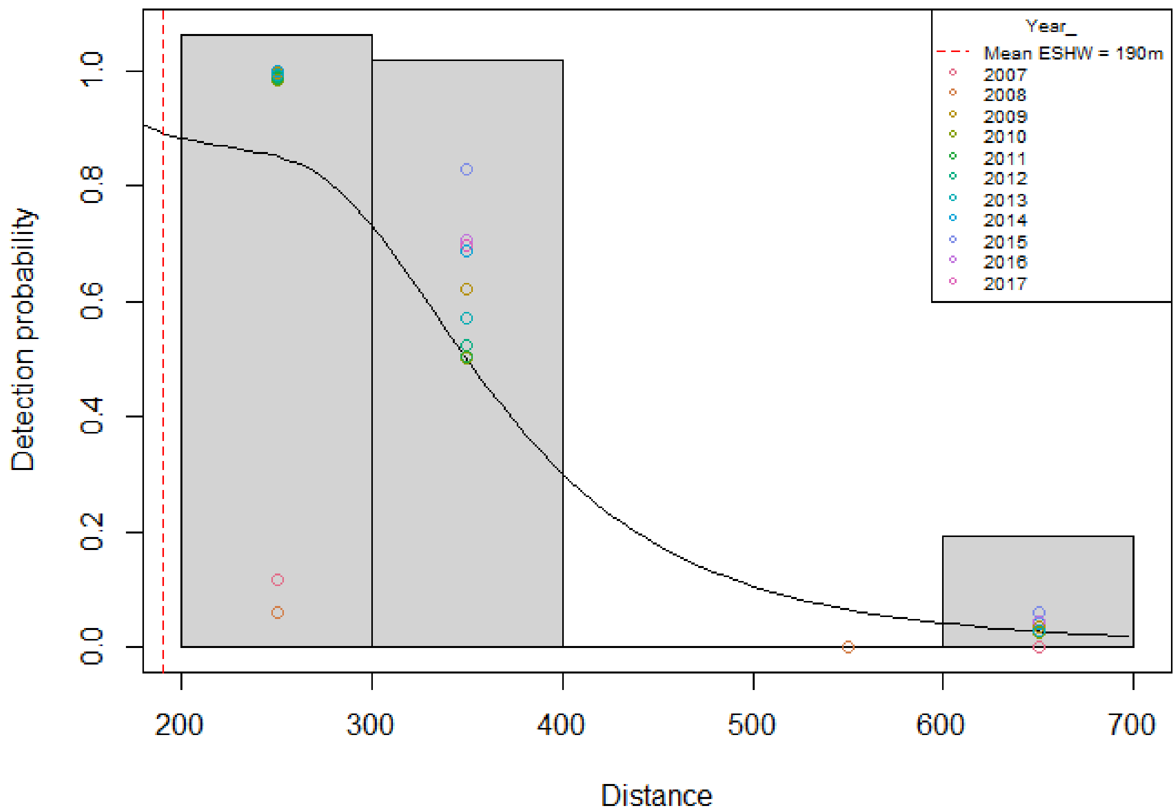

Figure 40. Kemp's Ridley Group 6 Detection Function Plot

4.2.3.7 Group 7 - UNCW Right Whale Hardshell Guild

This detection function is the same as was used for green turtle observations in the UNCW Right Whale surveys (see Section 4.2.2.3 for details). There were 35 observations of Kemp's ridley turtles in that detection function, all with a group size of one. There were 29 segments with predicted density, four of which had a value greater than one. The maximum predicted density was 1.6 animals/km^2.

4.2.4 Leatherback Turtle Detection Functions

4.2.4.1 Group 1 - Shipboard Surveys

Surveys in this detection function are the AMAPPS and pre-AMAPPS shipboard surveys. Initially, observations from these surveys were limited to sightings within 1 km (0.62 mi) of the trackline, which yielded 53 observations. We reconsidered this as these surveys are conducted with big eye binoculars, and leatherback turtles' distinct ridges are likely visible at further distances than hardshell turtles. Including sightings further than 1 km (0.62 mi) yielded 75 sightings with a maximum group size of four.

Available covariates were group size, month, year, and survey ID. Only one covariate was allowed in each candidate detection function. Observations were right truncated at 2,000 m (6,562 ft). The half normal detection function with year as a covariate was selected. No issues were noted with the Q-Q plot or model statistics (Figure 41). All predicted segment abundances, prior to g(0) adjustments, were less than one, with a maximum of 0.8 animals/km^2. Mean ESHW was 1,085 m (3,560 ft).

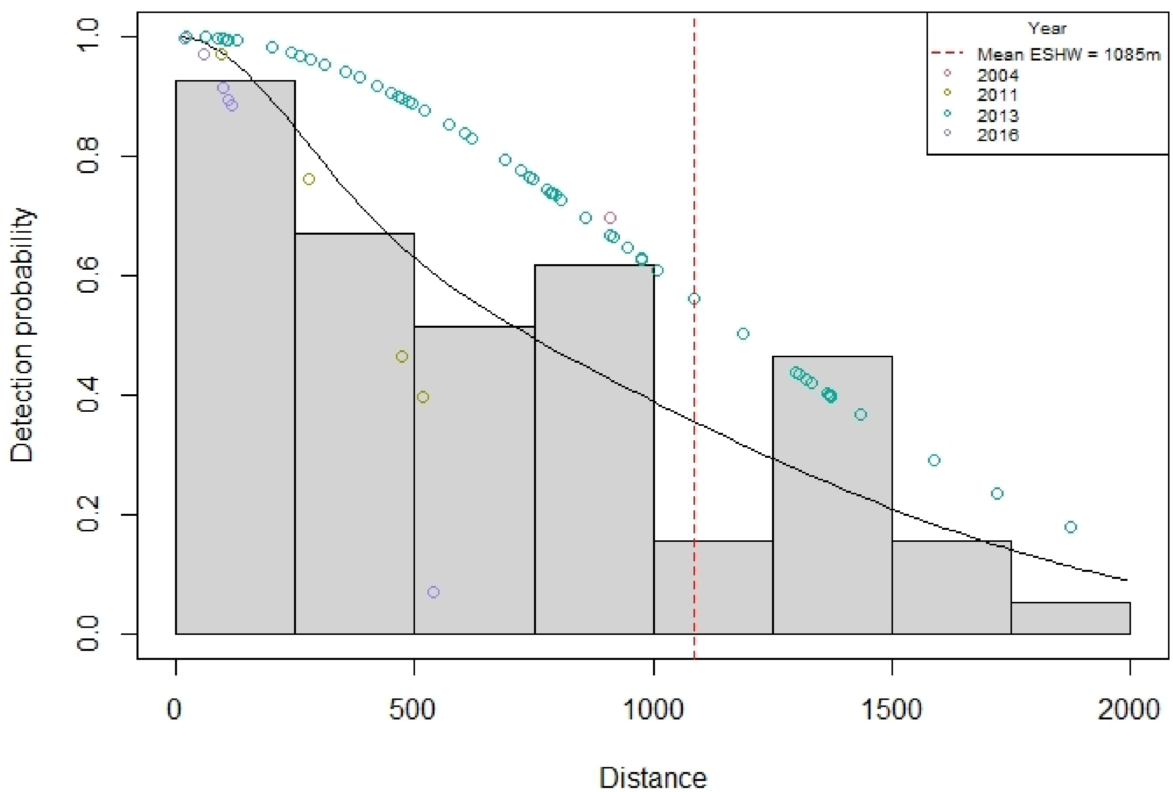

Figure 41a. Leatherback Group 1 Detection Function Plot

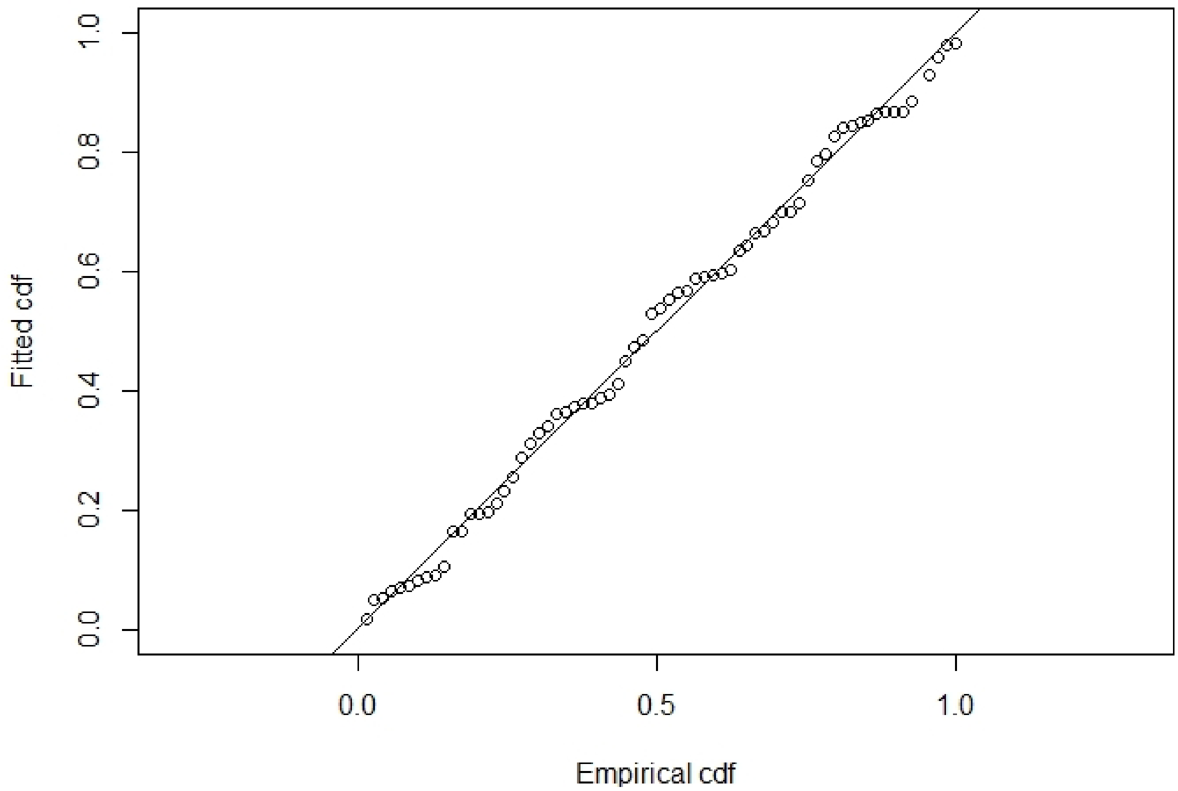

Figure 41b. Leatherback Group 1 Q-Q Plot

4.2.4.2 Group 2 - UNCW Protocol Flat Window Surveys

Surveys in this detection function included the HDR Inc. survey, the UNCW Right Whale and OPAREA surveys, and the VAMSC VA CZM and Navy surveys, all of which were flat window surveys. The UNCW OPAREA surveys had enough observations (n = 239) to fit its own detection function. However, none of the other programs in this group had enough observations to fit its own detection function, so a joint detection function was fit. The maximum group size was two. Grouping observations into bins was required because the UNCW OPAREA surveys (which were the majority of observations) recorded distances using wing or window markings, which lump observations at only a few distances. Observations from the other surveys used exact distances and fell between the UNCW distances, so the histogram of observed distances had several peaks, which needed to be addressed when fitting the detection functions.

Available covariates were group size, altitude, side of the plane, BSS, visibility, month, year, and survey ID. Up to two covariates were allowed in each candidate detection function. Observations were right truncated at 700 m (2,297 ft) and left truncated at 50 m (164 ft) to account for the flat windows where the survey trackline was not visible. Bins were set at 250, 450, and 700 m (820, 1,476, and 2,297 ft) to accommodate the peaks in the UNCW data. The hazard rate detection function with no covariates was selected (Figure 42). No issues were noted with the model statistics. A Q-Q plot was not generated because of the binning of the observations. Eight segments had a density greater than one with a maximum of 1.3 animals/km^2. Mean ESHW was 391 m (1,283 ft).

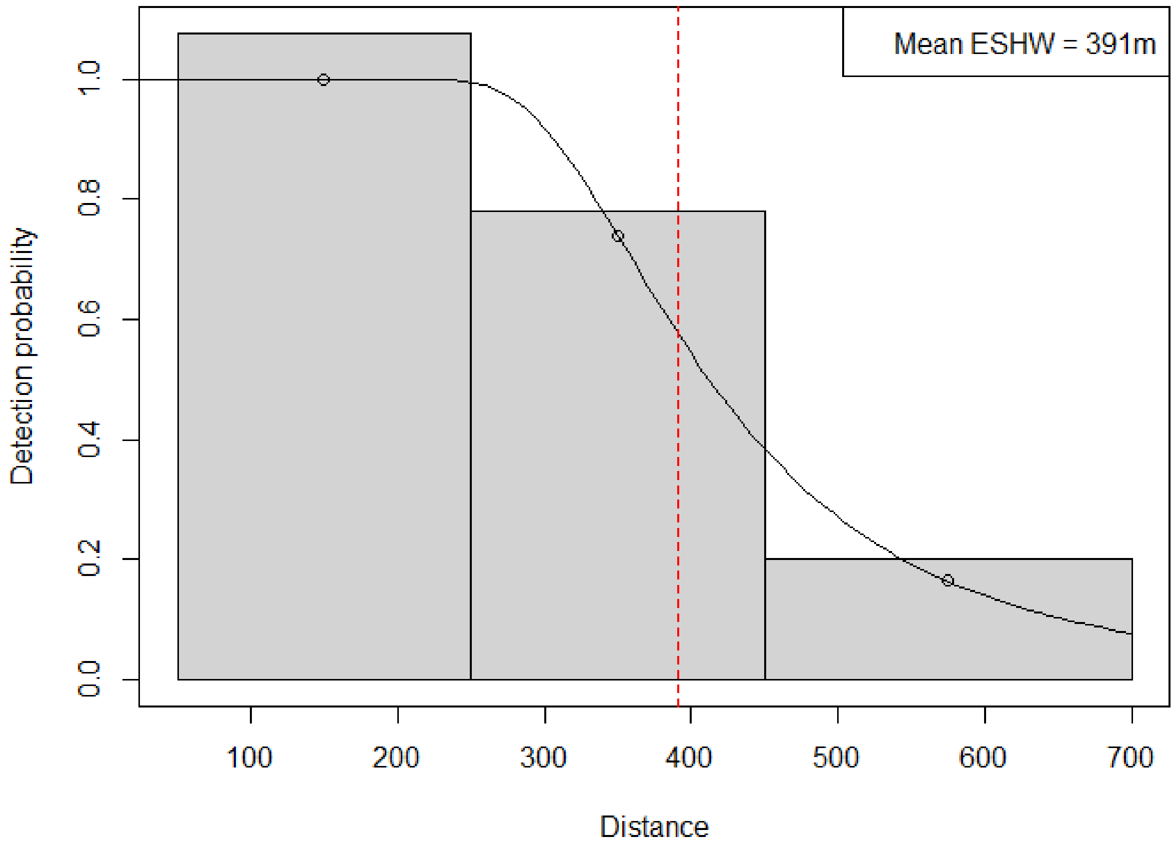

Figure 42. Leatherback Group 2 Detection Function Plot

4.2.4.3 Group 3 - New England Aquarium Surveys

Surveys in this detection function are the New England Aquarium flat window surveys. There were 98 observations available. There was one observation of 14 animals, which was tentatively kept as there was no reason to doubt the sighting. The predicted density of the segment with that observation was reviewed after the detection function was fit to assess if it was a reasonable value. While not gregarious, leatherbacks (like other sea turtle species) can occasionally be seen in groups either by chance, in mating aggregations, or in resource-rich foraging areas. Grouping observations into bins was required because the surveys recorded distances using wing struts as measuring marks, which lump observations at only a few distances.

Available covariates were group size, altitude, side of the plane, observer position, BSS, glare, cloud cover, month, and year. Up to two covariates were allowed in each candidate detection function. Left and right truncation distances were set at the closest and furthest bin distances, 150 m (492 ft) and 695 m (2,280 ft), respectively. Bin cutpoints were set at the exact distances of the observations as there were no observations from other surveys to accommodate. The half-normal detection function with year as a covariate was selected, though there were five other candidates within 2 AIC (Figure 43). Examination of the other detection functions indicated that the other candidate models were no better than the model with the highest AIC.

No issues were noted with the model statistics. A Q-Q plot was not generated because of the binning of the observations. There were 13 segments with densities greater than one, including one segment with a density of 8.2 animals/km^2. The density of the segment with an observation of 14 animals was 5.4 animals/km^2. This was not as high as the highest predicted density in this set of surveys or in other surveys, so we saw no reason to remove the observation. Mean ESHW was 386 m (1,266 ft).

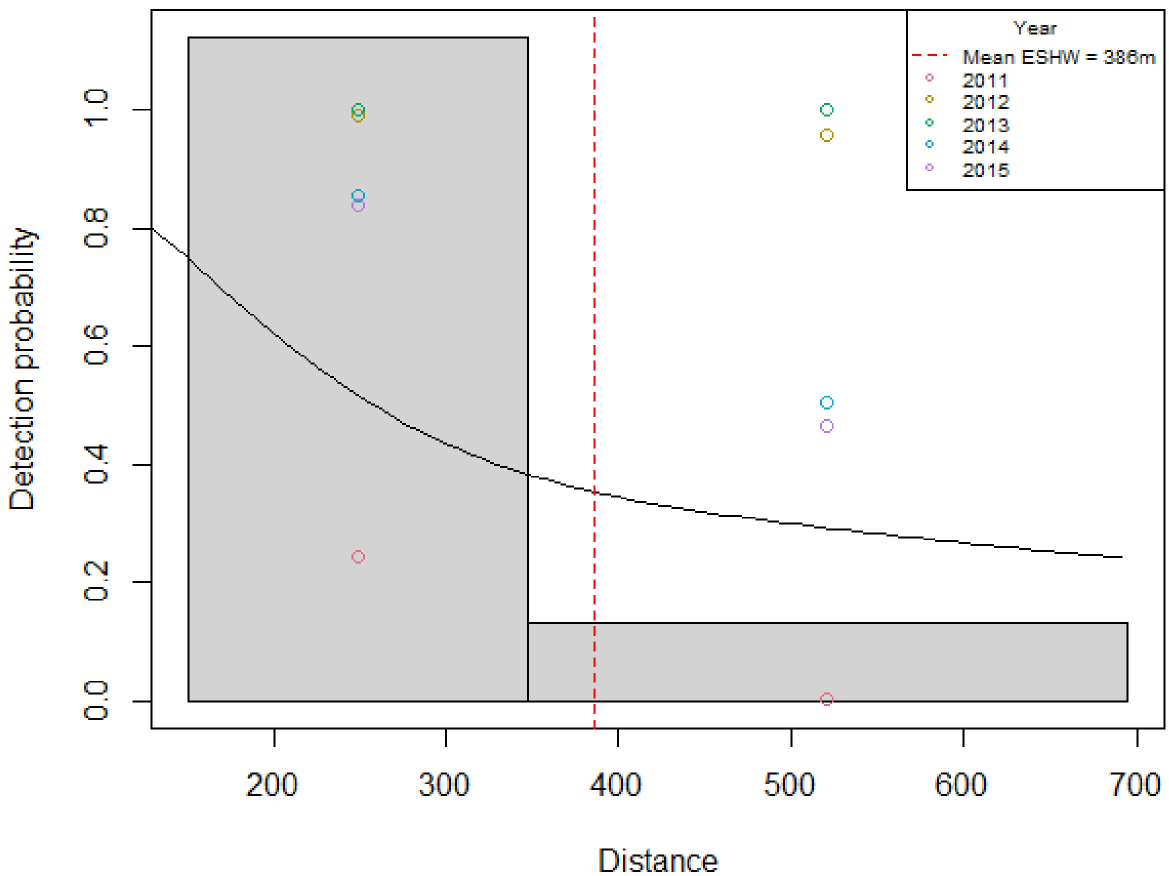

Figure 43. Leatherback Group 3 Detection Function Plot

4.2.4.4 Group 4 - AMAPPS Protocol Surveys

Surveys in this detection function all followed the AMAPPS survey protocols, including the NEFSC and SEFSC AMAPPS surveys and the VAMSC MD DNR survey. There were 664 observations available across the three survey programs. There were almost 60 sightings for the NEFSC AMAPPS surveys, but ultimately it was decided to combine these with the SEFSC AMAPPS surveys given the similarities in protocol and survey platform. The maximum group size was three. Available covariates were group size, observer position, month, year, and survey identification. Up to three covariates were allowed in each candidate detection function. Observations were right truncated at 350 m (1,148 ft). The hazard rate detection function with a cosine adjustment and no covariates was selected (Figure 44a).

No issues were noted with the model statistics or Q-Q plot (Figure 44b). There were 77 segments with densities greater than one, with a maximum of 3 animals/km^2, all with more than one sighting on the segment. Mean ESHW was 202 m (663 ft).

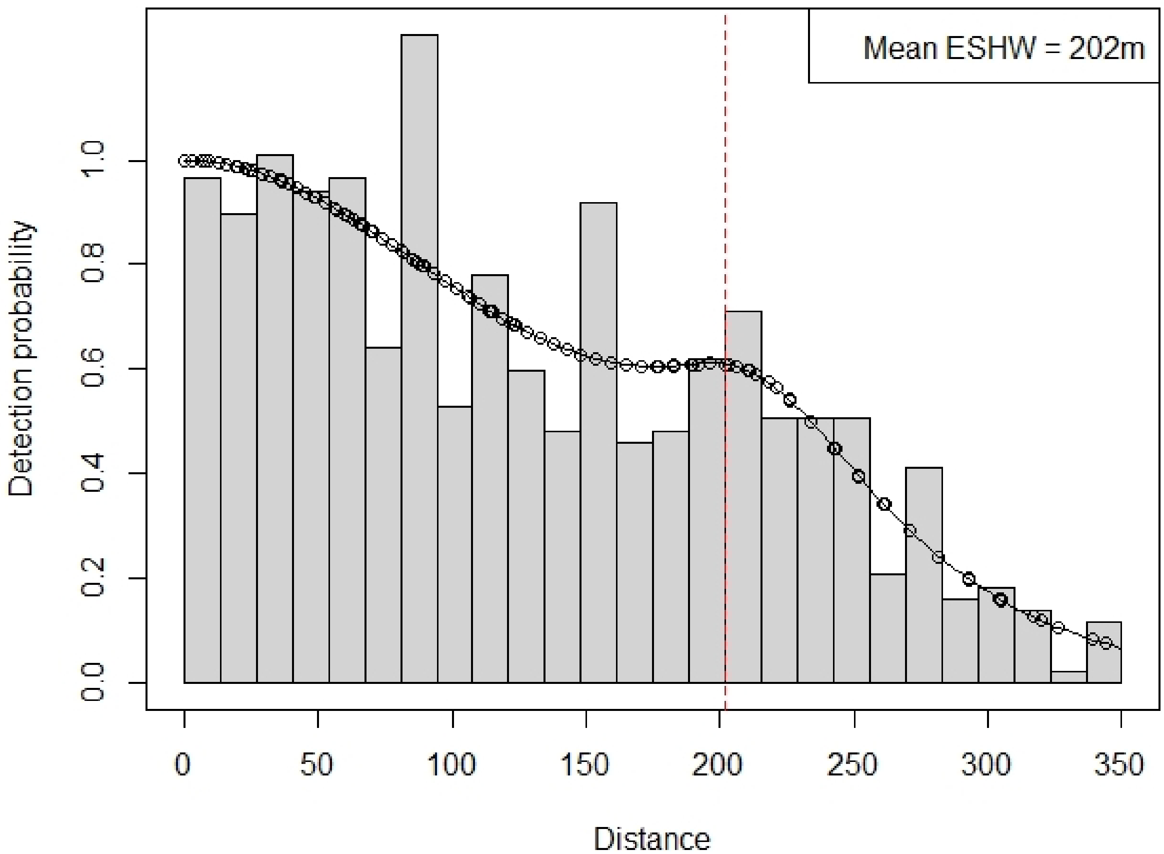

Figure 44a. Leatherback Group 4 Detection Function Plot

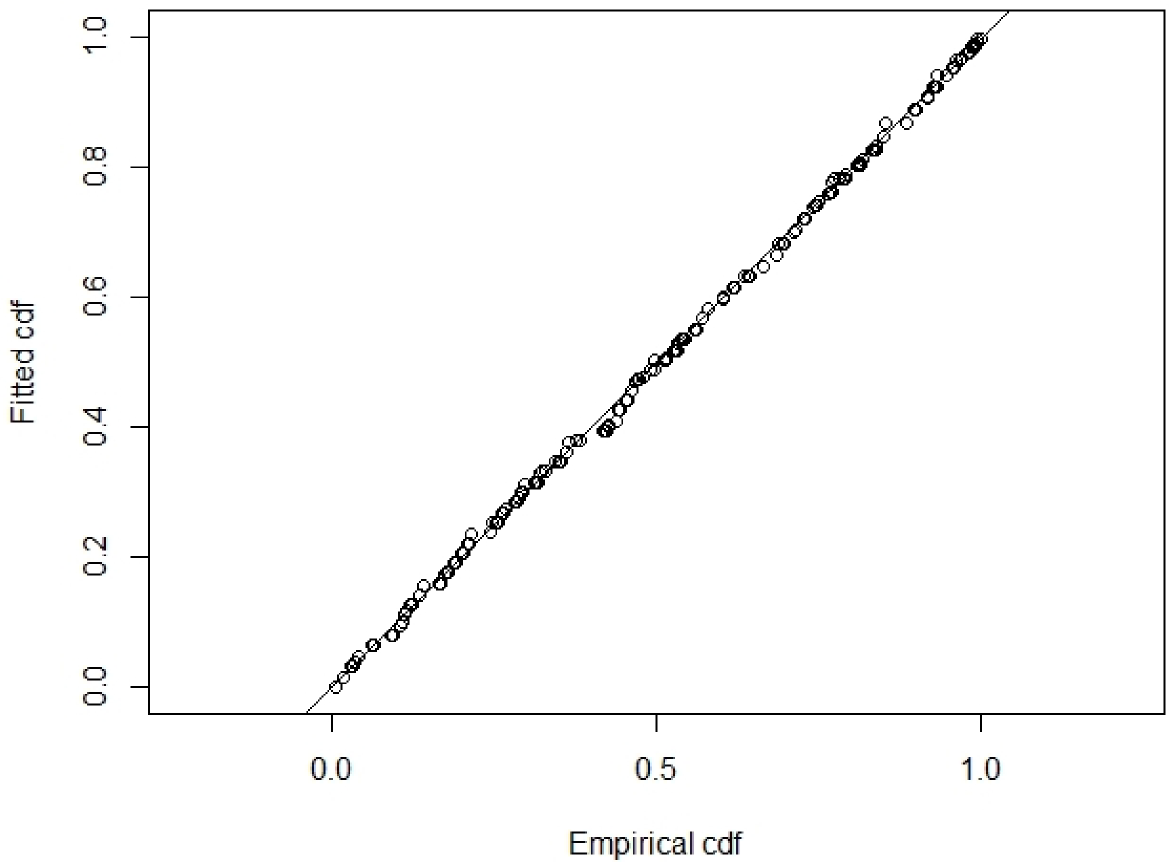

Figure 44b. Leatherback Group 4 Q-Q Plot

4.2.4.5 Group 5 - NEFSC Pre-AMAPPS Surveys

Surveys in this detection function are the NEFSC pre-AMAPPS surveys. There were 93 observations available. There was one observation of two animals. All other group sizes were one. Available covariates were group size, altitude, BSS, glare, observation quality, month, and year. Up to two covariates were allowed in each candidate detection function. Right truncations at 600 and 500 m (1,969 and 1,640 ft) were explored but did not yield improved detection functions. All sightings were retained in the selected detection function even though the probability of detection at far distances was below the recommended 15%. The hazard rate detection function with group size and observation quality as covariates was selected (Figure 45a).

No issues were noted with the model statistics. The Q-Q plot (Figure 45b) indicates poor performance at short distances and underpredicting the density close to the trackline. This was not corrected by right truncating the data, and left truncation was not attempted due to the high number of sightings close to the trackline and bubble windows on the plane. There were six segments with densities greater than one, with a maximum of 6.3 animals/km^2. Mean ESHW was 307 m (1,007 ft).

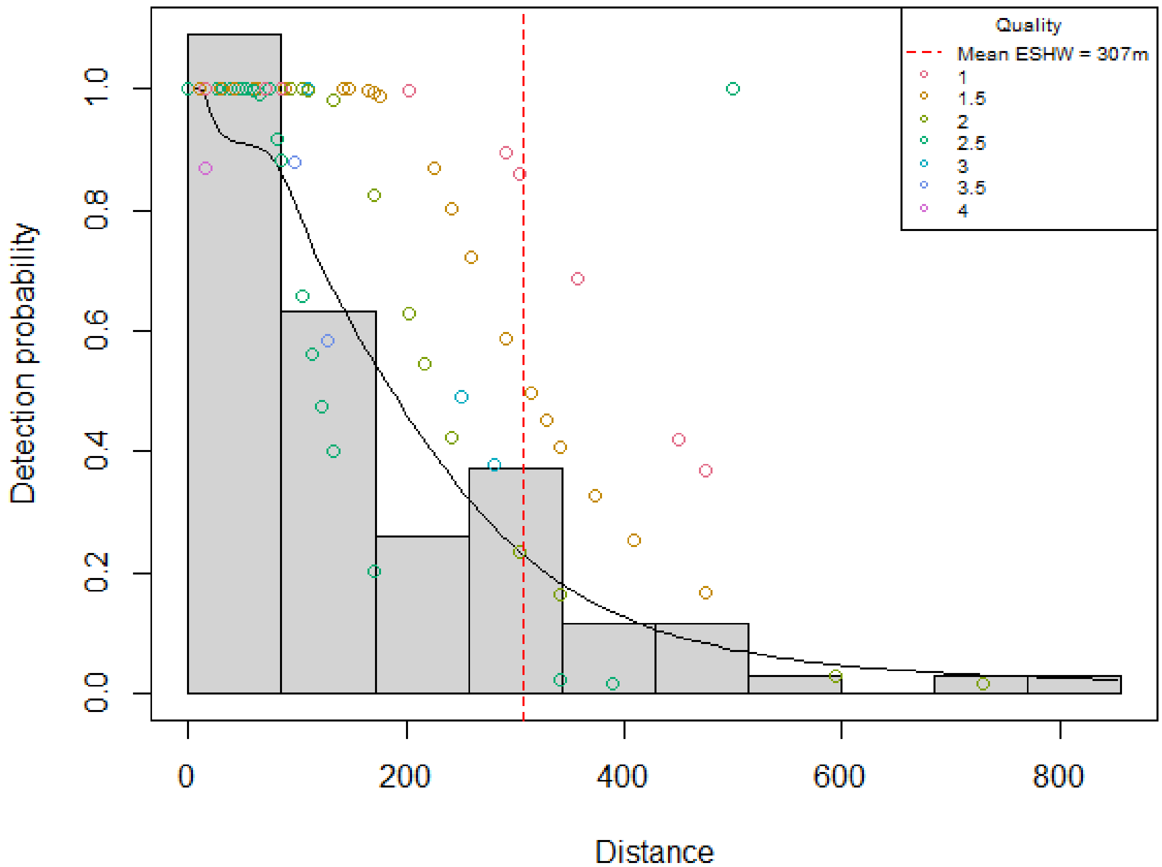

Figure 45a. Leatherback Group 5 Detection Function Plot

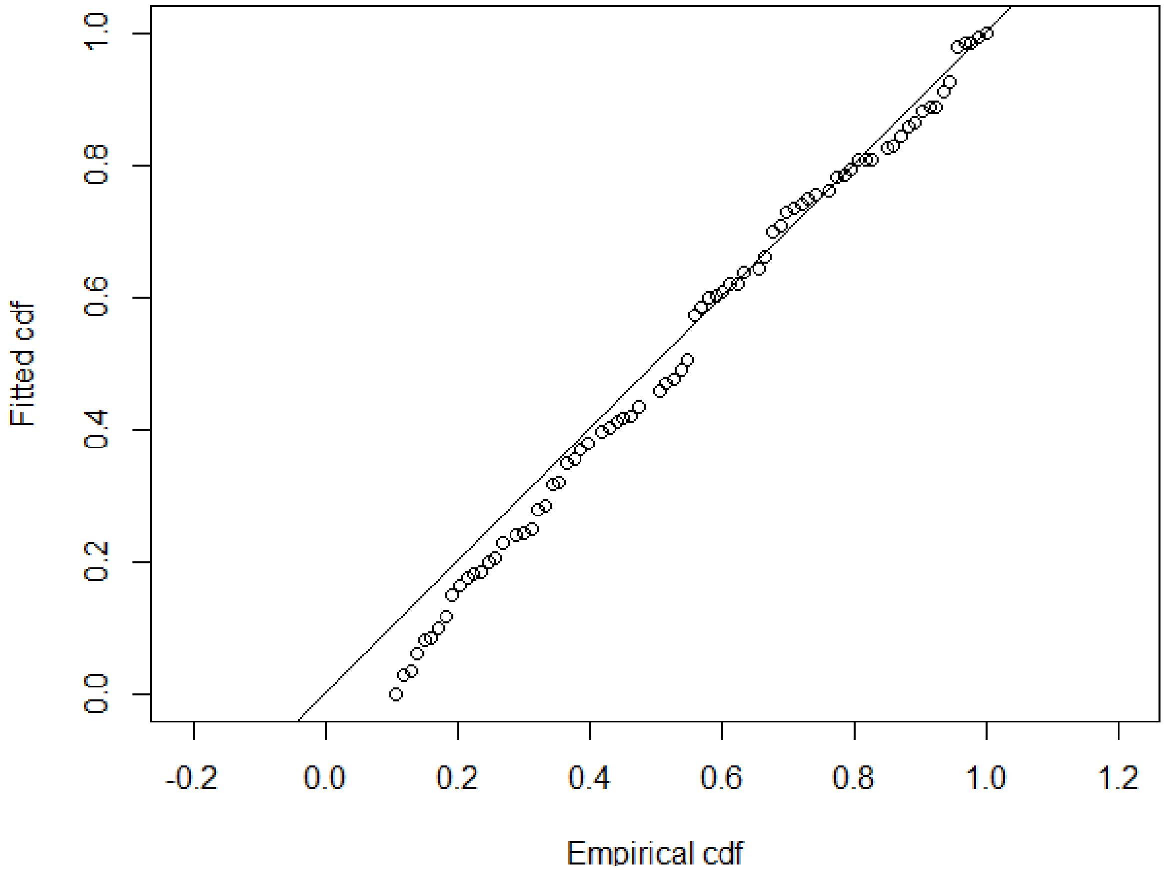

Figure 45b. Leatherback Group 5 Q-Q Plot

4.2.4.6 Group 6 - NARWSS 2003–2016 Surveys

Surveys in this detection function included the 2003–2016 NARWSS surveys. There were 82 observations available, and the maximum group size was one. The SEFSC MATS surveys were not included in this detection function even though they were also flown at 305 m (1,000 ft) and there were fewer than 60 observations in that survey program. This decision was based on survey provider feedback after reviewing draft detection functions and substantive differences in survey protocols. There was a low number of detections close to the trackline, with the highest number of detections grouped at approximately 200–300 m (656–984 ft). We suspect this is because the focus of the NARWSS surveys is the detection of large whales, particularly North Atlantic right whales, and the focus of observers may be further out towards the horizon. Also, sea turtles may be harder to detect directly below the aircraft at higher altitudes, even with bubble windows. Because of this, left truncation was considered even though the surveys occurred in bubble window aircraft.

Available covariates were altitude, side of aircraft, observer position, BSS, group size, visibility, observation quality, glare, month, year, and survey ID. One covariate was allowed in each candidate detection function. Observations were right truncated at 650 m (2,133 ft) and left truncated at 200 m (656 ft) to account for the lower-than-expected number of detections close to the trackline. The half-normal detection function was selected. There were no issues noted with model statistics or the Q-Q plot (Figure 46). No segments had a density value greater than one. Mean ESHW was 122 m (400 ft).

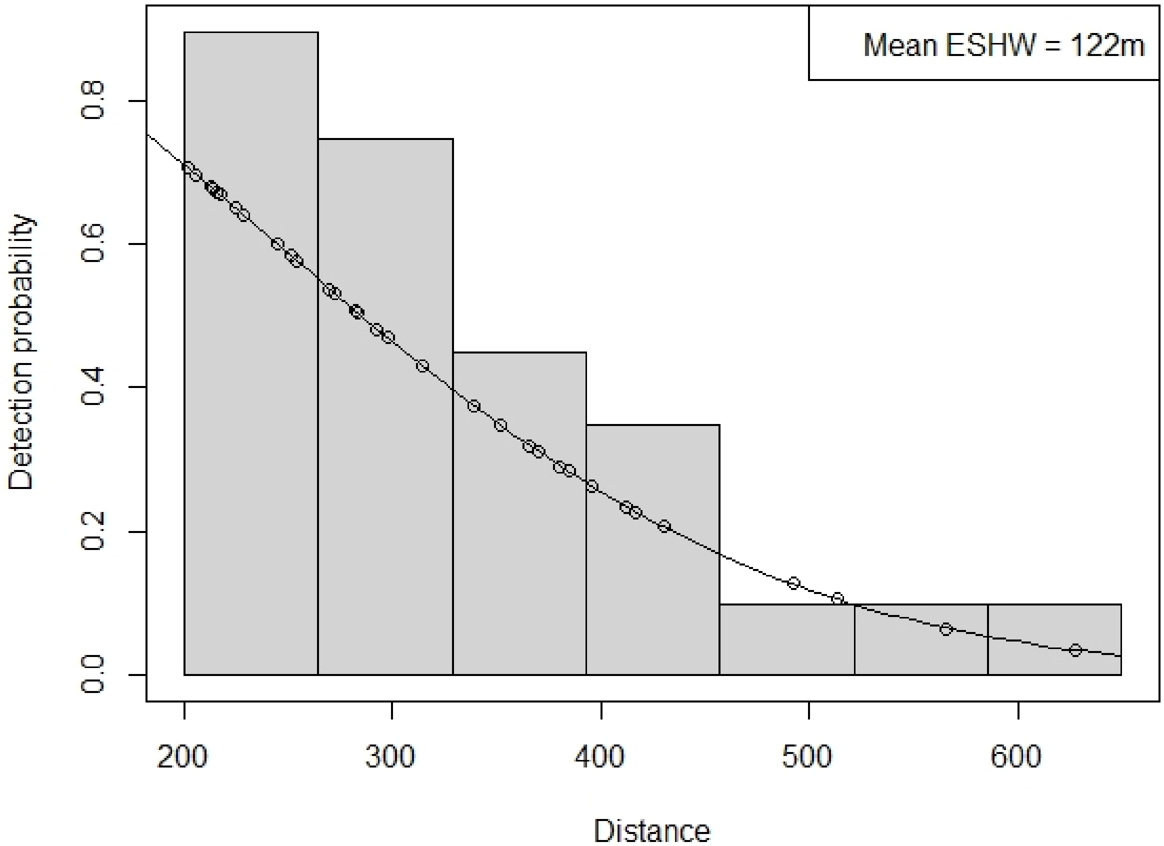

Figure 46a. Leatherback Group 6 Detection Function Plot

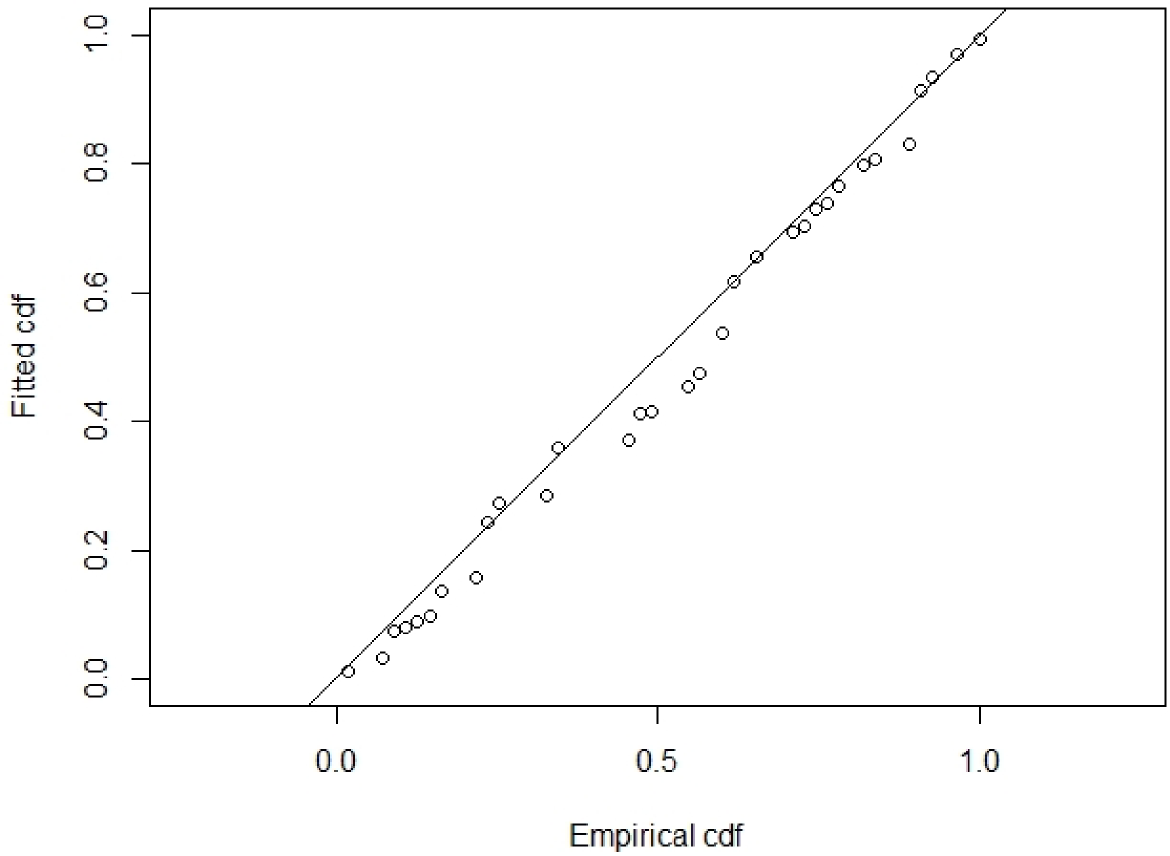

Figure 46b. Leatherback Group 6 Detection Q-Q Plot

4.2.4.7 Group 7 - MATS Surveys

Surveys in this detection function are the SEFSC MATS surveys. Only 35 observations were available. There were three observations with a group size greater than one, with a maximum group size of four. No detection functions with covariates were attempted given the low number of observations. Observations were right truncated at 300 m (984 ft). The half-normal detection function with no adjustments was selected (Figure 47a).

No issues were noted with the model statistics or Q-Q plot (Figure 47b) despite the low number of sightings. There were seven segments with densities greater than one with a maximum of 2.3 animals/km^2, all on segments with more than one animal. Mean ESHW was 210 m (689 ft).

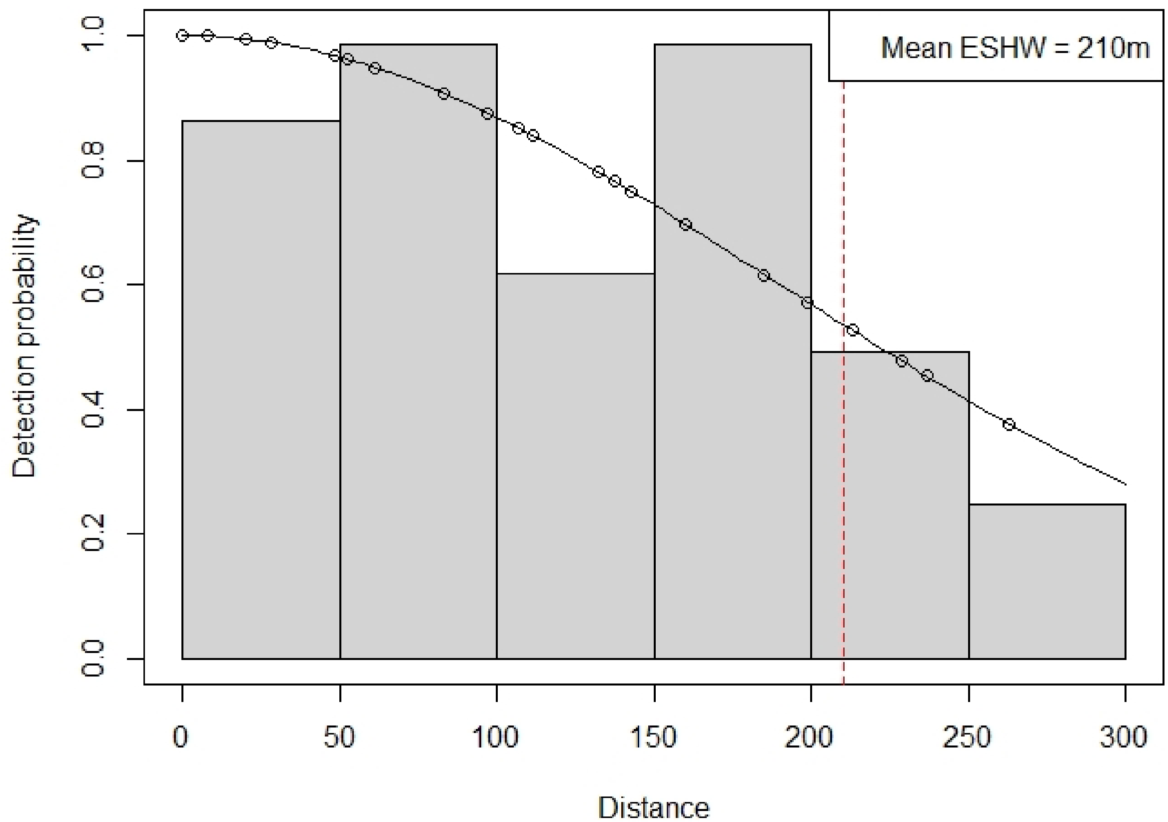

Figure 47a. **Leatherback Group 7 Detection Function Plot**

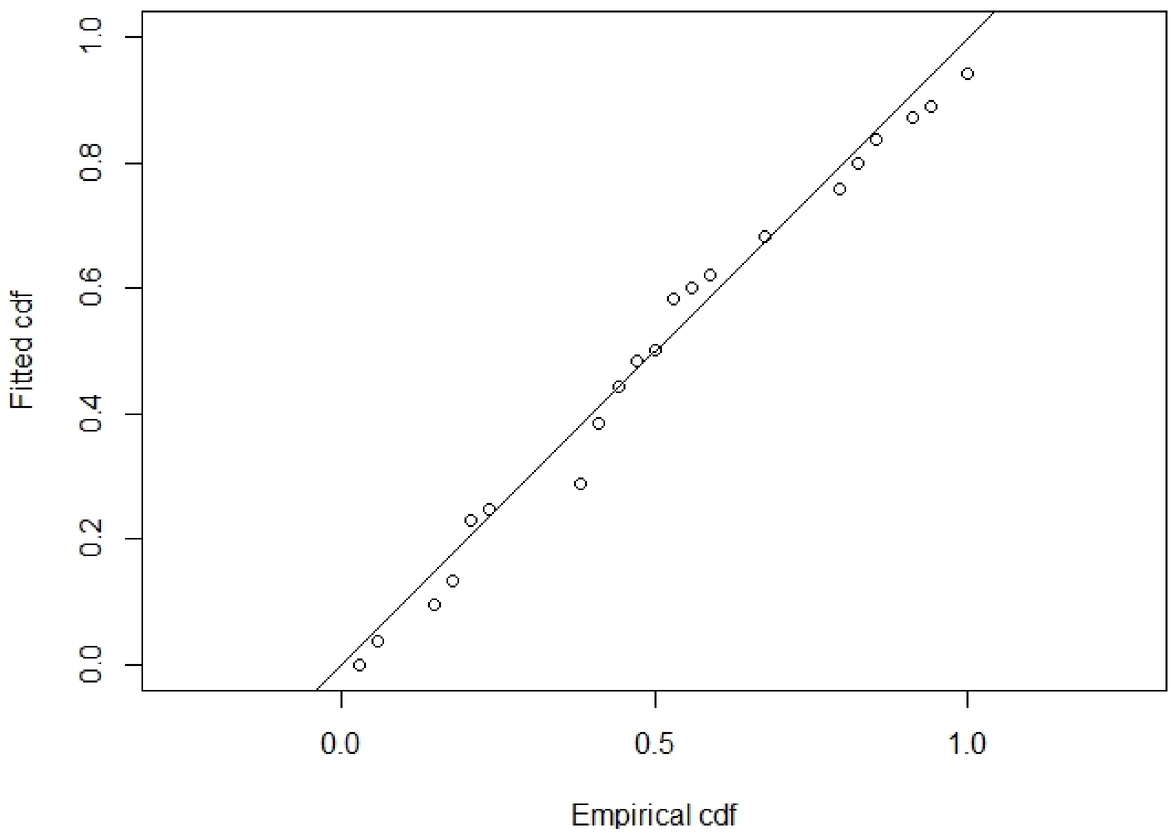

Figure 47b. Leatherback Group 7 Q-Q Plot

4.2.4.8 Group 8 - 2017 NARWSS and TT-NYSDEC Surveys

Surveys in this detection function included the 2017 NARWSS and TT-NYSDEC NYBWM surveys. Only 28 observations were available, and the maximum group size was two. Despite the low number of observations, the decision was made to attempt to fit a detection function given the difference in altitude between other NARWSS surveys and the differences in platform from the other 305-m (1,000-ft) surveys (bubble versus flat windows). There was a low number of detections close to the trackline, with the highest number of detections grouped at approximately 200–300 m (656–984 ft). We suspect this is because the focus of the NARWSS surveys is the detection of large whales, particularly North Atlantic right whales, and the focus of observers may be further out towards the horizon. Also, sea turtles may be harder to detect directly below the aircraft at higher altitudes, even with bubble windows. Because of this, left truncation was considered even though the surveys occurred in bubble window aircraft.

Available covariates were altitude, side of aircraft, observer position, BSS, group size, visibility, observation quality, glare, month, year, and survey identification. No covariates were allowed in each candidate detection function, given the very low number of observations. Observations were right truncated at 600 m (2,461 ft) and left truncated at 100 m (328 ft) to account for the lower-than-expected number of detections close to the trackline. The half-normal detection function was selected. Despite the low number of observations, there were no issues noted with model statistics or the Q-Q plot (Figure 48). Only one segment had a density value greater than one. Mean ESHW was 229 m (751 ft).

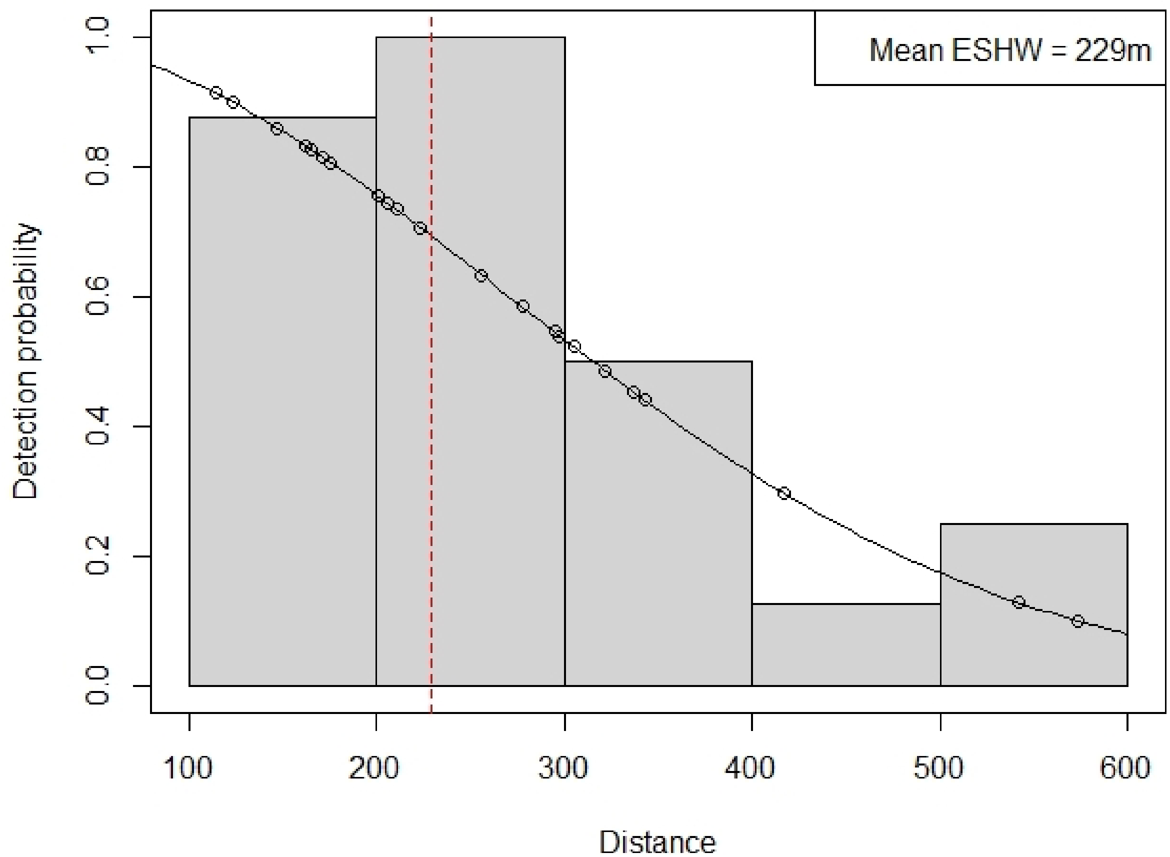

Figure 48a. Leatherback Group 8 Detection Function Plot

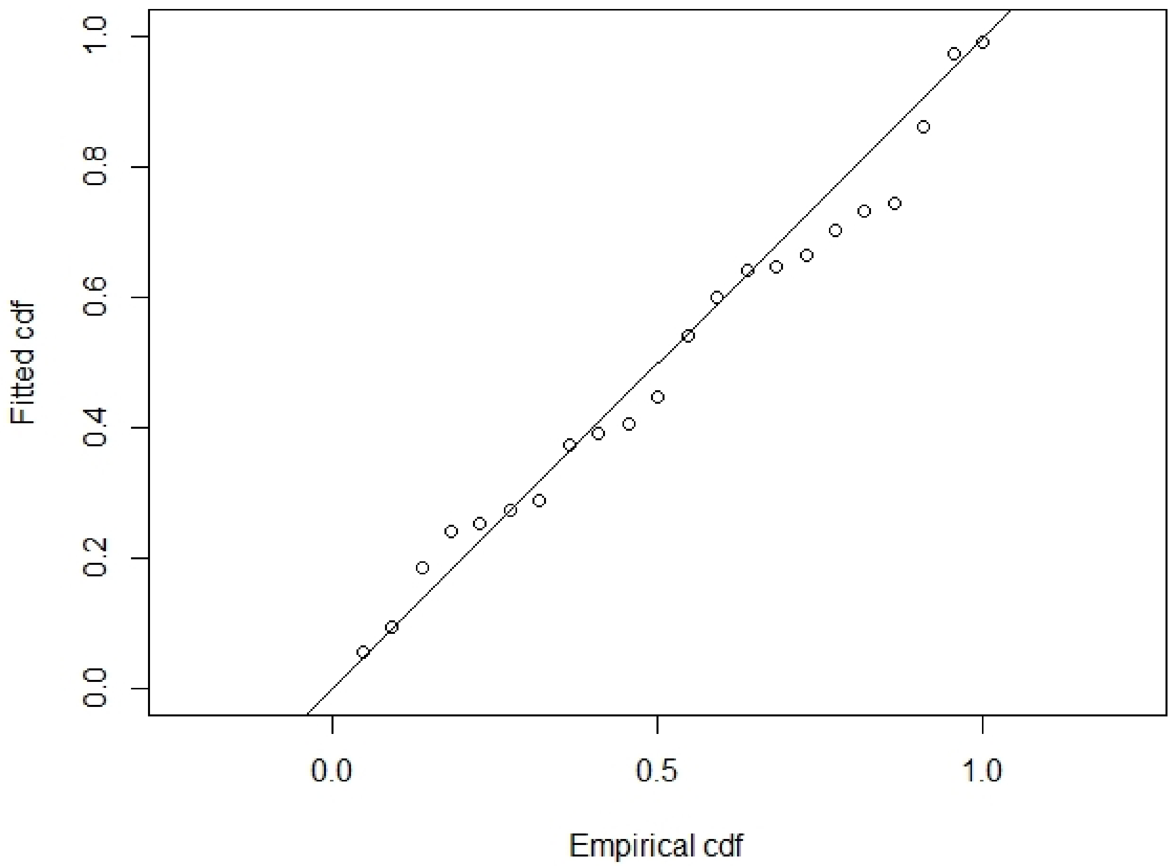

Figure 48b. Leatherback Group 8 Q-Q Plot

4.3 SPATIAL DENSITY MODELS

The sections below detail the spatial density model selection process for each species and present model summaries and covariate relationships. Models that were not selected are not presented in any detail unless pertinent to the discussion of the selected model. Spatial density models were successfully fit for all four species.

4.3.1 Loggerhead Turtle Spatial Model

There were 251,491 segments available over all survey programs that observed loggerhead turtles. Predicted density on these segments were used as the response in a GAM model predicting spatial density. Two sets of segments were used to fit GAMs, one with large group sizes smeared across up to five segments, and one unsmeared (e.g., the data as reported). The reason is explained in detail in Section 3.2.2, but briefly there were instances in the HDR Inc. and UNCW surveys where sightings of loggerheads occurred too quickly for observations to be logged or there were dispersed sightings of large distances. The number of animals was counted over an unknown period of time, until observers had an opportunity to log an observation, at which point all animals were lumped into a single observation with a putative distance. The unsmeared version had 12,535 segments with non-zero density, and the smeared version had 12,557. Models were selected using the smeared segments on the assumption that some turtles appeared in those smeared segments. The selected model was then refitted with the unsmeared data, and predictions were made for both models and compared.

Covariates eliminated include UGO, VGO, and MODIS_CHL for missing data; CHL_VI, MLOTST, VGPM, and MNCK_NPP for deviance explained; SAL_SO, MODIS_SST, Dist_Canyon, MNCK_ZOOC, Dist_1000, NPPV_COP_Daily, and CHL_COP_Daily for correlation with better explanatory covariates; and Dist_Shelf for too high a proportion of cells that would be extrapolated. Covariate families that retained covariates were depth, features, slope, productive depth, sea surface height, productivity, salinity, and temperature.

The selected model included the Depth, TEMP_TO, SSH_ZO, BSAL_BSO, NPP_VI, MNCK_ZEU, and latitude covariates. Covariate relationships can be seen in Figure 49. Ticks along the x-axis are a rug plot indicating sampled values. Deviance explained was 42.2%. All covariates were significant, and TEMP_TO, NPP_VI, and MNCK_ZEU used almost all the available degrees of freedom. The model summary can be seen below.

```
Family: Tweedie(p=1.355)
Link function: log

Formula:
Dhat_g0 ~ s(Depth, k = 10, bs = "ts") + s(TEMP_TO, k = 10, bs =
"ts") +
    s(SSH_ZO, k = 10, bs = "ts") + s(BSAL_BSO, k = 10, bs = "ts") +
    s(NPP_VI, k = 10, bs = "ts") + s(MNCK_ZEU, bs = "ts") + s(y,
    bs = "ds")

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -3.65650    0.05504  -66.43   <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(Depth)     6.284   9.00 209.623  <2e-16 ***
s(TEMP_TO)   8.827   9.00 205.831  <2e-16 ***
s(SSH_ZO)    5.753   9.00  32.921  <2e-16 ***
s(BSAL_BSO)  4.711   9.00   8.541  <2e-16 ***
s(NPP_VI)    8.543   9.00  43.299  <2e-16 ***
s(MNCK_ZEU)  7.994   9.00  61.859  <2e-16 ***
s(y)        10.837  10.98 361.965  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.0481   Deviance explained = 42.2%
-REML =  70048  Scale est. = 9.6422    n = 229957
```

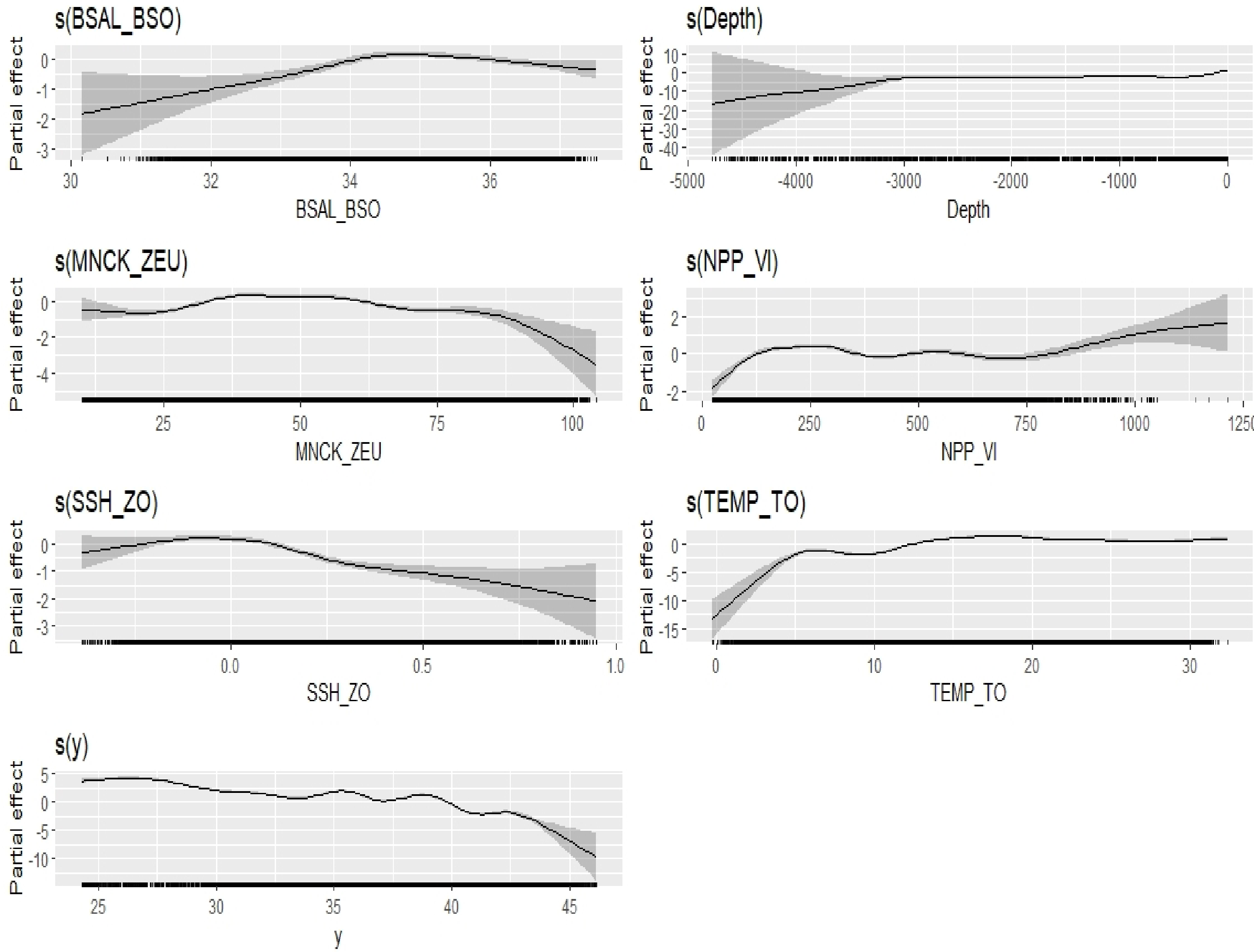

Figure 49. **Covariate Relationships for the Selected Loggerhead Turtle Spatial Density Model**

Based on the selected model, loggerheads exhibited preferences for moderate to high bottom salinities, shallower depths, moderate euphotic zone depth, warm temperatures, and lower latitudes. A strong negative association was seen with depths associated with areas off the continental shelf and areas of low productivity. None of these relationships were contrary to the known ecology of the species. Most of the covariates were well sampled, except for extreme low values of depth, and high values of productivity (NPP_VI).

The Q-Q plot (Figure 50) was skewed at high values, indicating the model did a poor job of predicting high-density values. This was unsurprising given the nature of the observations of turtles, where large groups (and hence high density) were rare. In discussions with other modeling teams, this is not uncommon when modeling taxa where occurrences of large groups occur sporadically. The model performed well at lower densities (which are far more common) and long-term averages of density is what is required for the Navy. This Q-Q plot would be concerning only if attempting to accurately predict the occurrence of large aggregations of turtles, which is outside the scope of this project.

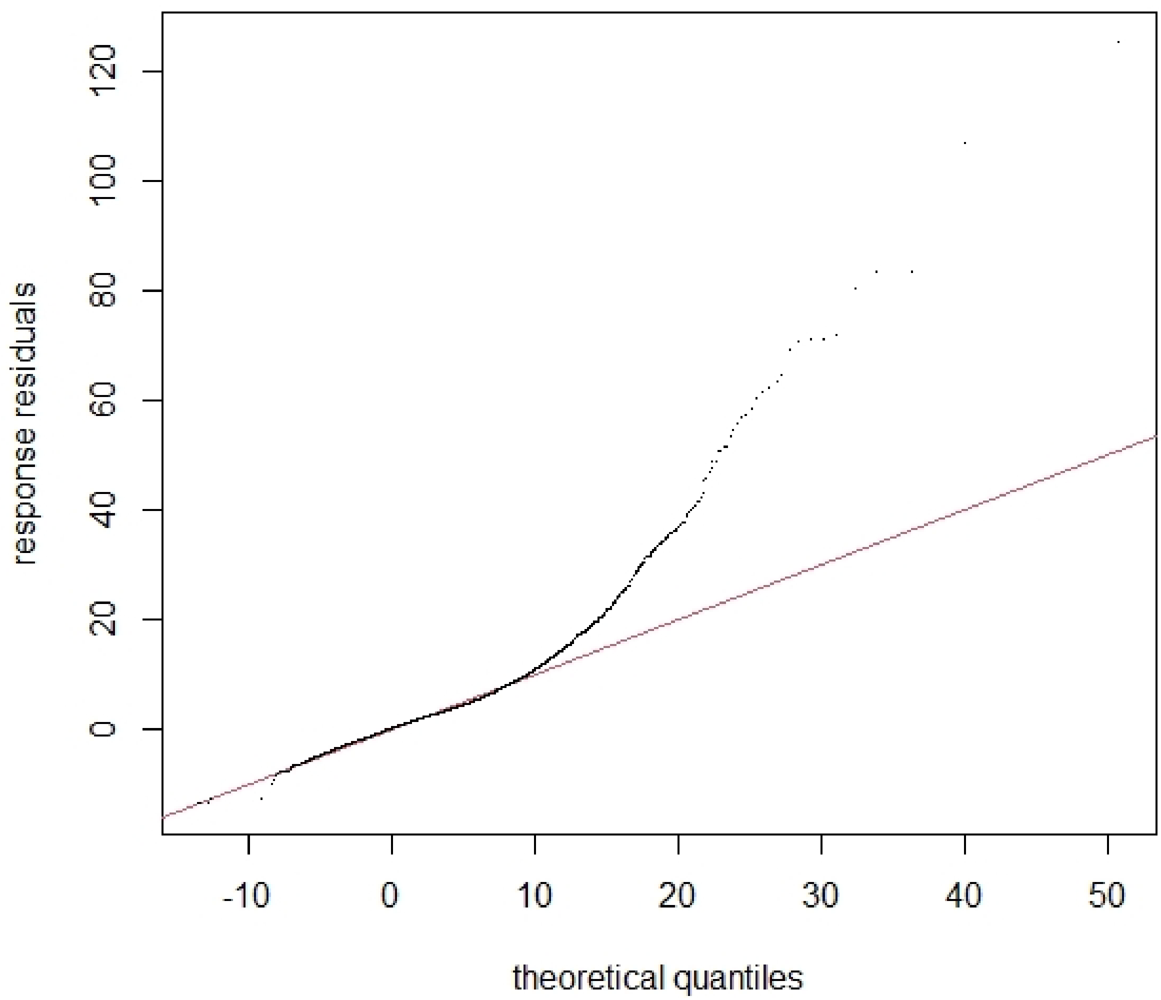

Figure 50. Q-Q Plot of the Selected Loggerhead Turtle Spatial Density Model

The alternative model (using the smeared segments) explained 41.6% of deviance, compared to 42.2% for the unsmeared data, and the REML score was worse. Examining predicted abundance, the smeared and unsmeared abundance estimates were within 2% of each other month to month, and patterns of predicted abundance were similar. As such, the unsmeared (unaltered) data were used in the final model, as this was the approach that required the least intervention, and the model performed slightly better.

4.3.2 Green Turtle Spatial Model

There were 59,624 segments over all survey programs that observed green turtles. Predicted density on these segments were used as the response in a GAM model predicting spatial density. There were 513 segments with non-zero density, the majority of which occurred in warmer months. Recall that segments were limited to those surveys occurring in the last 10 years of available survey data (2010–2019), given the rapid population increase at major nesting rookeries in Florida over that time period.

Covariates eliminated include UGO, VGO, and VGPM for missing data; Dist_Shelf for deviance explained; MODIS_SST, BSAL_BSO, NPPV_COP_Daily, NPP_VI, and MODIS_CHL for correlation with better explanatory covariates; and SSH_ZO and MLOTST for too high a proportion of cells that would be extrapolated. Distance-to-feature covariates were also dropped after discussions with early reviewers revealed that these covariates can be problematic for species that are generally found in shallower environments. Covariate families that retained covariates were depth, slope, productive depth, productivity, salinity, and temperature.

The selected model included the Depth, TEMP_TO, SAL_SO, MNCK_ZOOC, MNCK_ZEU, and latitude covariates. Covariate relationships can be seen in Figure 51. Ticks along the x-axis are a rug plot indicating sampled values. Deviance explained was 48.6%. All covariates were significant, and no covariates used all the available degrees of freedom. Effective degrees of freedom (edf) for depth was close to one, making the relationship effectively linear. The model summary can be seen below.

```
Family: Tweedie(p=1.197)
Link function: log

Formula:
Dhat_g0 ~ s(Depth, k = 10, bs = "ts") + s(TEMP_TO, k = 10,
    bs = "ts") + s(SAL_SO, k = 10, bs = "ts") + s(MNCK_ZEU,
    k = 10, bs = "ts") + s(log10(MNCK_ZOOC), k = 10, bs = "ts") +
    s(POINT_Y, bs = "ds")

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -5.6479     0.6111  -9.241   <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(Depth)             0.9914  8.000 12.793  <2e-16 ***
s(TEMP_TO)           6.8265  9.000 12.579  <2e-16 ***
s(SAL_SO)            7.9821  9.000  8.556  <2e-16 ***
s(MNCK_ZEU)          4.4294  9.000 17.142  <2e-16 ***
s(log10(MNCK_ZOOC)) 5.4702  9.000 10.972  <2e-16 ***
s(POINT_Y)           8.8057  9.398 37.585  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.105   Deviance explained = 48.6%
-REML = 3687.5  Scale est. = 18.383    n = 26422
```

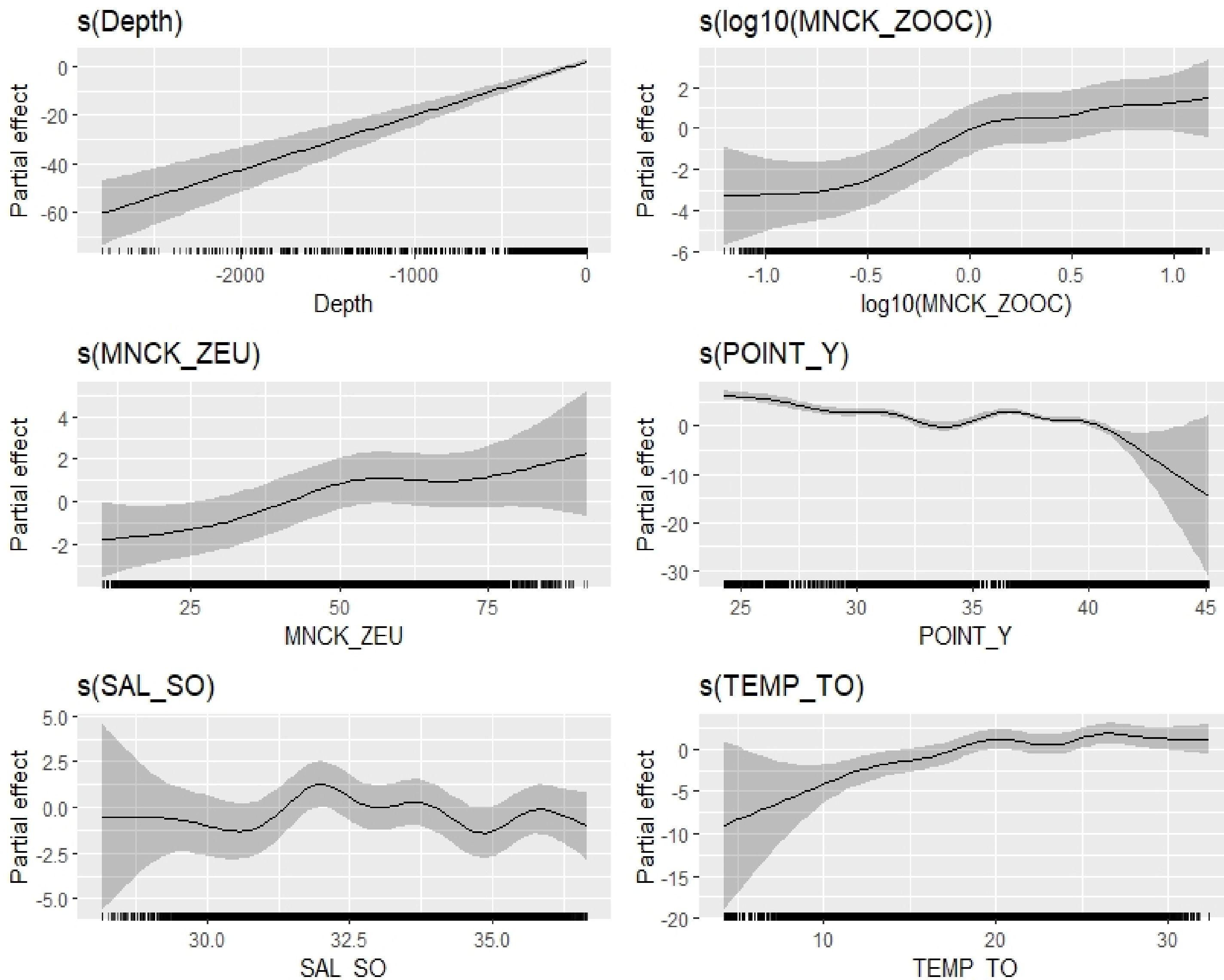

Figure 51. Covariate Relationships for the Selected Green Turtle Spatial Density Model

Based on the selected model, green turtles exhibited preferences for shallow waters, deep productive depths, lower latitudes, moderate salinities, and warmer temperatures, all of which are reasonable given the known ecology of the species. A strong negative association was seen with depths associated with areas off the continental shelf, shallow euphotic zone depth, and areas of low productivity. Given the green turtles' preferred foraging on seagrass and macroalgae beds, selection for shallow, productive areas with high light penetration makes sense. Most of the covariates were well sampled, except for extreme low values of depth.

The Q-Q plot (Figure 52) was skewed at a few high values, indicating the model did a poor job of predicting high-density values. This was unsurprising given the nature of observations of turtles, where large groups (and hence high density) were rare. In discussions with other modeling teams, it was revealed that this is not uncommon when modeling taxa where occurrences of large groups occur sporadically. The model performed well at lower densities (which are far more common) and long-term averages of density is what is required for the Navy. This Q-Q plot would be concerning only if attempting to accurately predict the occurrence of large aggregations of turtles, which is outside the scope of this project.

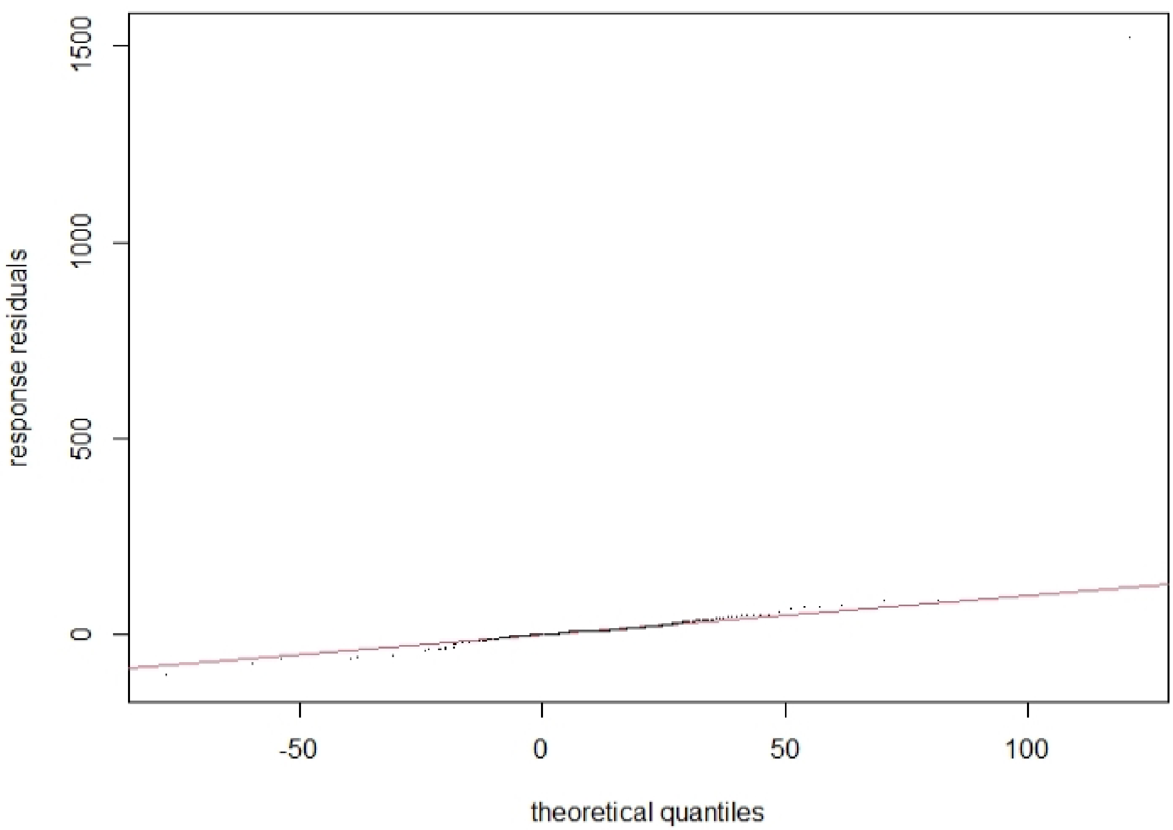

Figure 52. Q-Q Plot of the Selected Green Turtle Spatial Density Model

4.3.3 Kemp's Ridley Turtle Spatial Model

There were 235,733 segments available over all survey programs that observed Kemp's ridley turtles. Predicted density on these segments were used as the response in a GAM model predicting spatial density. There were 224 segments with non-zero density, spread relatively equally across months. Given the relatively low number of segments with sightings, all candidate models were limited to five covariates or less.

Covariates eliminated include UGO, VGO, and MODIS_CHL for missing data; MLOTST and CHL_VI for deviance explained; and nine covariates for correlation with better explanatory covariates. Depth, Dist_Shore, and Dist_Shelf all had high levels of extrapolation relative to other species because there were no sightings of Kemp's ridley turtles in the offshore shipboard surveys. Despite extrapolation at deeper values and far distances from shore or shelf, these variables were retained as a monotonically decreasing relationship was expected at higher values, given that Kemp's ridley turtles' distribution is almost exclusively on the shelf and this species' preference for shallow habitats. Distance-to-features covariates were also dropped after discussions with early reviewers revealed that these covariates can be problematic for species that are generally found in shallower environments. Covariate families that retained covariates were depth, slope, productivity, salinity, and temperature.

The selected model included the Dist_Shore, TEMP_TO, SAL_SO, MNCK_ZOOC, and latitude covariates. Covariate relationships can be seen in Figure 53. Ticks along the x-axis are a rug plot indicating sampled values. Deviance explained was 42.7%. All covariates were significant, and no covariates used all the available degrees of freedom. This was the only hardshell species model where distance to shore was selected over depth. The model summary can be seen below.

```
Family: Tweedie(p=1.171)
Link function: log

Formula:
Dhat_g0 ~ s(Dist_Shore, k = 10, bs = "ts") + s(TEMP_TO,
    k = 10, bs = "ts") + s(SAL_SO, k = 10, bs = "ts") +
    s(log10(MNCK_ZOOC), k = 10, bs = "ts") + s(POINT_Y,
    bs = "ds")

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -9.9063     0.8429  -11.75   <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(Dist_Shore)       5.719   9.00 10.045  <2e-16 ***
s(TEMP_TO)          5.054   9.00  9.997  <2e-16 ***
s(SAL_SO)           4.786   9.00  5.389  <2e-16 ***
s(log10(MNCK_ZOOC)) 2.340   9.00  6.632  <2e-16 ***
s(POINT_Y)          7.352   8.34 24.403  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.0444   Deviance explained = 42.7%
-REML = 1982.8  Scale est. = 17.118    n = 224293
```

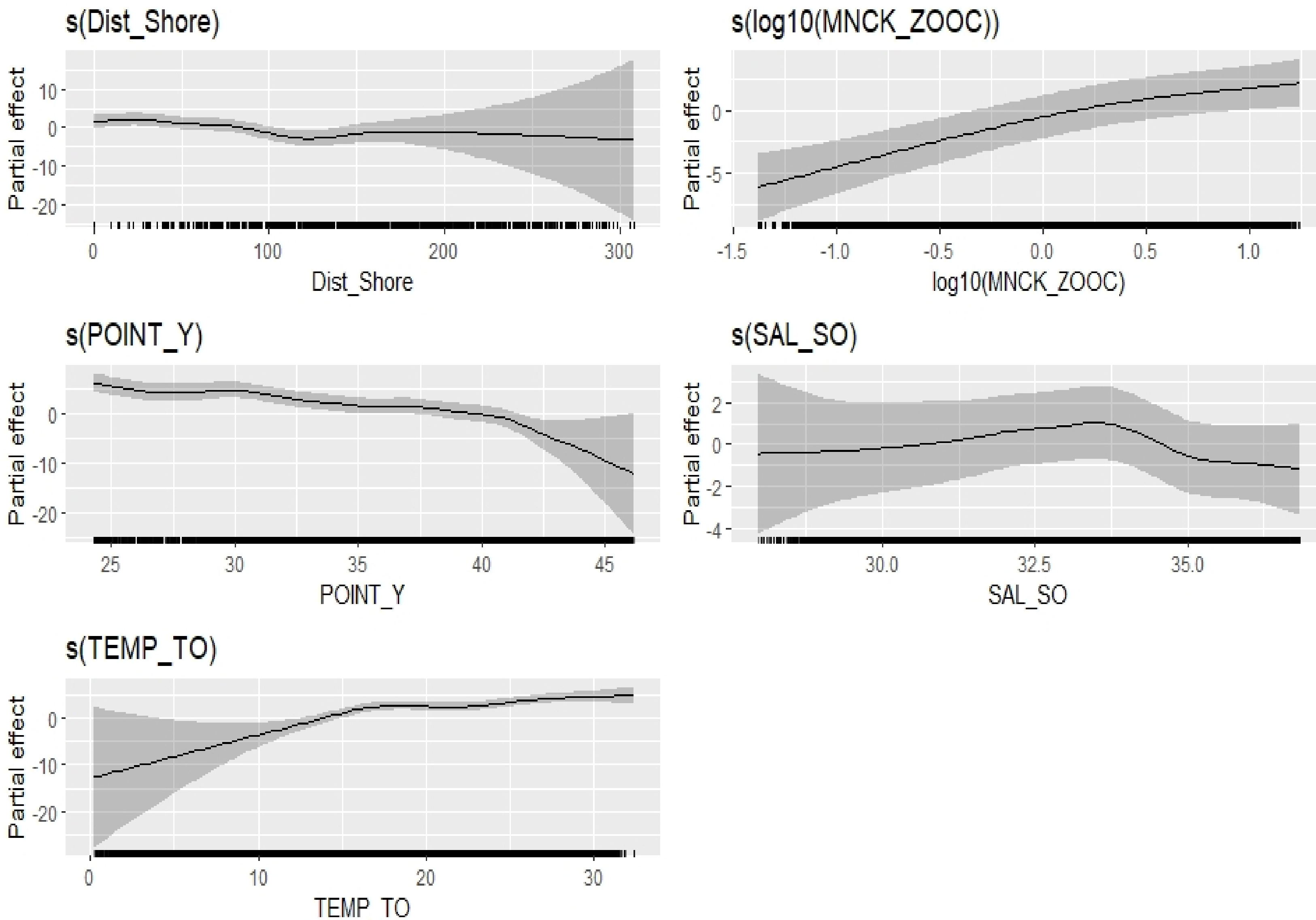

Figure 53. Covariate Relationships for the Selected Kemp's Ridley Turtle Spatial Density Model

Based on the selected model, Kemp's ridley turtles exhibited preferences for productive waters on the continental shelf and closer to shore, lower latitudes, moderate salinities, and warmer temperatures, all of which are reasonable given the known ecology of the species. A strong negative association was seen with areas of low productivity and cooler temperatures. Kemp's ridleys are the smallest turtles in the study area, making them more susceptible to cold stunning, and perhaps making them more inclined to avoid cooler waters. Most of the covariates were well sampled, except for extreme low values of depth.

The Q-Q plot (Figure 54) was skewed at a few high values, indicating the model did a poor job of predicting high density values. This was unsurprising given the nature of observations of turtles, where large groups (and hence high density) were rare. Discussions with other modeling teams revealed that this is not uncommon when modeling taxa where occurrences of large groups occur sporadically. The model performed well at lower densities (which are far more common) and long-term averages of density is what is required for the Navy. This Q-Q plot would be concerning only if attempting to accurately predict the occurrence of large aggregations of turtles, which is outside the scope of this project.

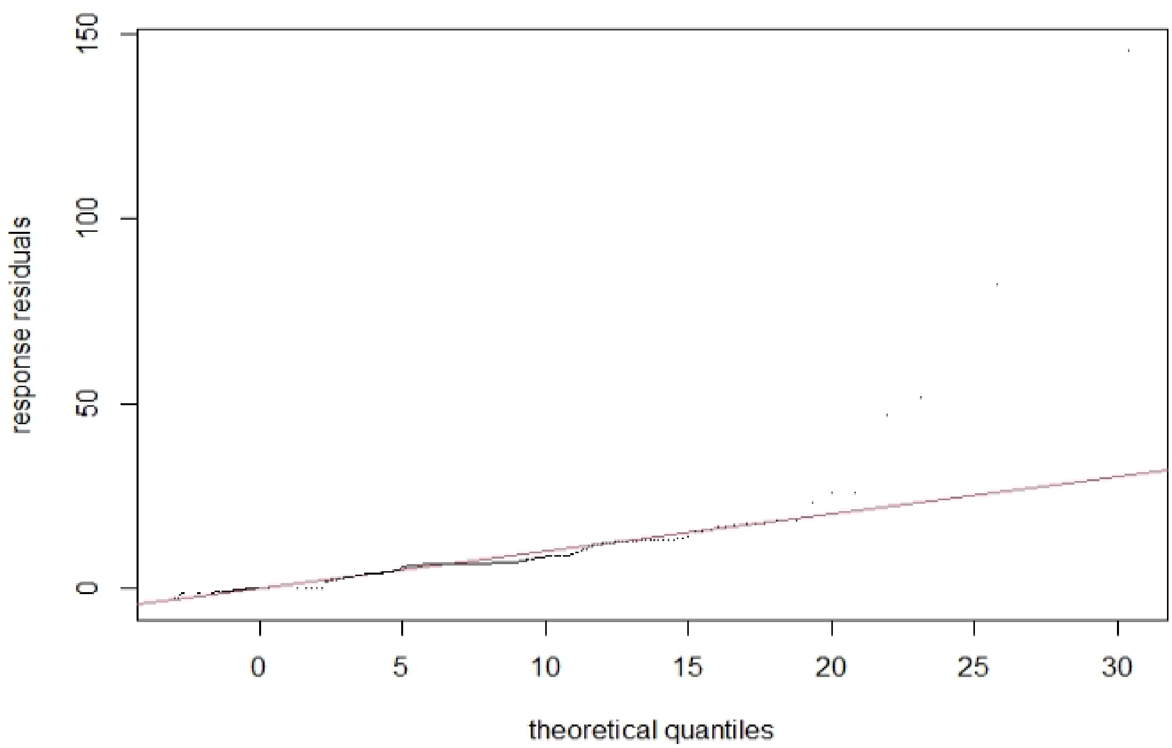

Figure 54. Q-Q Plot of the Selected Kemp's Ridley Turtle Spatial Density Model

4.3.4 *Leatherback Turtle Spatial Model*

There were 281,675 segments over all survey programs that observed leatherback turtles. Predicted density on these segments were used as the response in a GAM model predicting spatial density. There were 1,068 segments with non-zero density, mostly in warmer months when most of the survey effort occurred.

Covariates eliminated include UGO and VGO for missing data; seven covariates[1] for deviance explained, which was generally lower than for hardshell species; and the TEMP_TO, Dist_Seamount, CHL_VI, BSAL_BSO, and Dist_1000 covariates for correlation with better explanatory covariates. Distance-to-feature covariates were retained for leatherback turtles given their distribution further offshore, though models were still limited to a single static covariate on the basis of discussion with early reviewers. Covariate families that retained covariates were depth, features, slope, sea surface height, productive depth, productivity, salinity, and temperature.

The selected model included the Dist_500, SSH_ZO, SAL_SO, MNCK_ZEU, MNCK_ZOOC, MODIS_SST, and latitude covariates. Covariate relationships can be seen in Figure 55. Ticks along the x-axis are a rug plot indicating sampled values. Deviance explained was 32%, the lowest of all models, indicating the available covariates lack explanatory power for leatherback turtles as compared to the hardshell species. All covariates were significant, and latitude used almost all the available degrees of freedom. This may be because of leatherback turtles' distribution further north as compared to hardshell species. Distance to the 500-m (1,640-ft) isobath was selected rather than depth, reflecting the species' more offshore distribution as compared to hardshell turtles. The model summary can be seen below.

[1] They are: MNCK_EPI, MLOTST, NPP_VI, NPPV_COP_Daily, MNCK_NPP, VGPM, and MODIS_CHL.

```
Family: Tweedie(p=1.315)
Link function: log

Formula:
Dhat_g0 ~ s(Dist_500, k = 10, bs = "ts") + s(SSH_ZO, k = 10,
    bs = "ts") + s(MNCK_ZEU, k = 10, bs = "ts") +
    s(MNCK_ZOOC, k = 10, bs = "ts") + s(SAL_SO, k = 10,
    bs = "ts") + s(MODIS_SST, k = 10, bs = "ts") +
    s(POINT_Y, bs = "ds")

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -4.5927     0.1344  -34.17   <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(Dist_500)  6.138   9.00 14.717  <2e-16 ***
s(SSH_ZO)    3.706   9.00  4.594  <2e-16 ***
s(MNCK_ZEU)  5.652   9.00 10.018  <2e-16 ***
s(MNCK_ZOOC) 1.088   9.00  5.156  <2e-16 ***
s(SAL_SO)    7.858   9.00  8.796  <2e-16 ***
s(MODIS_SST) 6.096   9.00 33.607  <2e-16 ***
s(POINT_Y)   8.885  10.14  9.743  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.00616   Deviance explained =   32%
-REML =   9703  Scale est. = 53.94     n = 241886
```

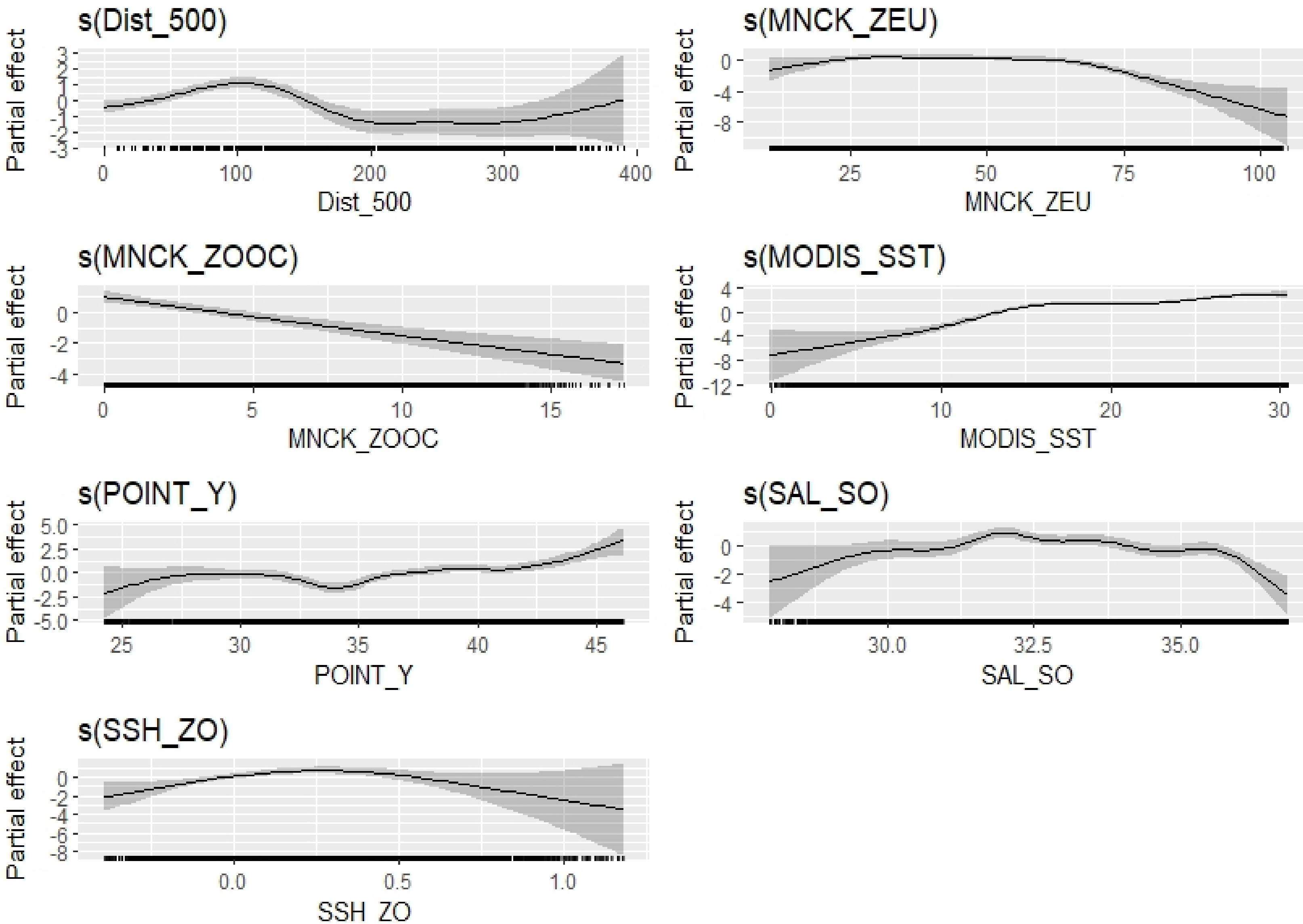

Figure 55. Covariate Relationships for the Selected Leatherback Turtle Spatial Density Model

Based on the selected model, leatherback turtles exhibited preferences for less productive waters on the continental shelf and slope, higher latitudes relative to hardshell species, moderate salinities, and warmer temperatures, all of which are reasonable given the known ecology of the species. The apparent preference for unproductive waters is likely a lag between primary productivity and the leatherback turtles' preferred gelatinous prey. Most of the covariates were well sampled, except for low values of distance to the 500 m (1,640 ft) isobath and high values of productivity.

The Q-Q plot (Figure 56) was skewed at a few high values, indicating the model did a poor job of predicting high density values. This was unsurprising given the nature of observations of turtles, where large groups (and hence high density) were rare. In discussions with other modeling teams, it was revealed that this is not uncommon when modeling taxa where occurrences of large groups occur sporadically. The model performed well at lower densities (which are far more common) and long-term averages of density is what is required for the Navy. This Q-Q plot would be concerning only if attempting to accurately predict the occurrence of large aggregations of turtles, which is outside the scope of this project.

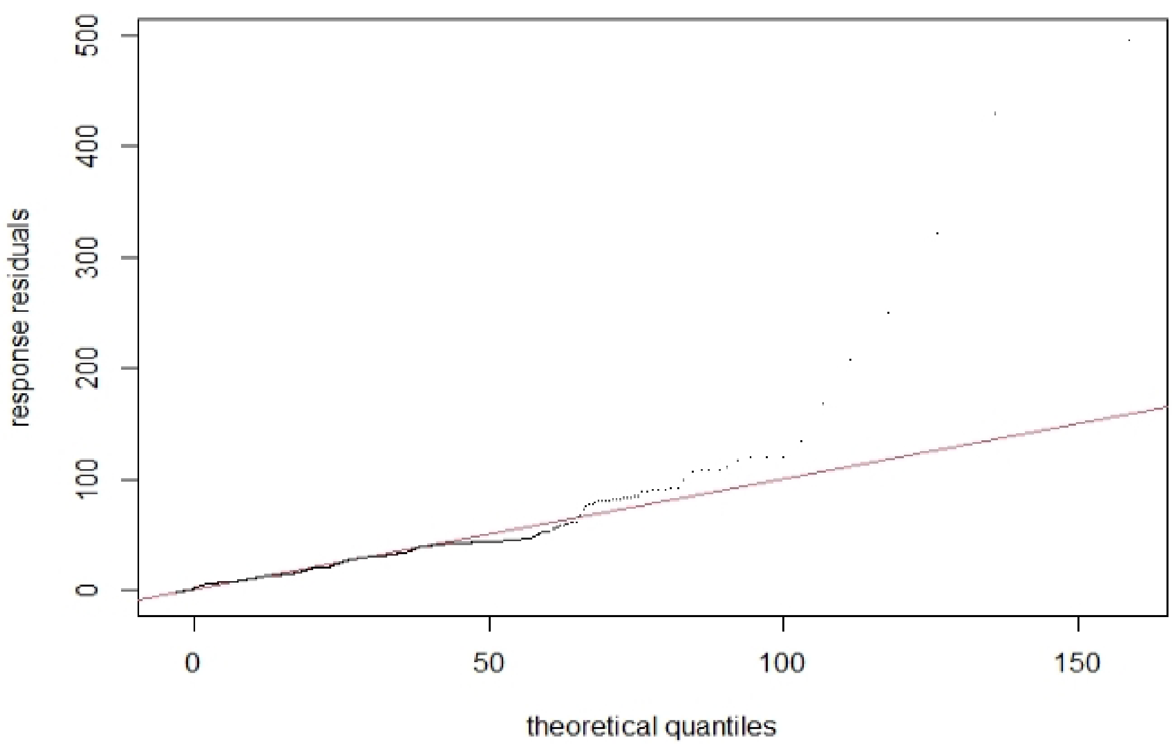

Figure 56. Q-Q Plot of the Selected Leatherback Turtle Spatial Density Model

4.4 PREDICTED DENSITY AND UNCERTAINTY

The sections below detail the predicted abundance and uncertainty of the selected models and present maps of density and CV by month. Maps are presented without observations to provide a better view of the underlying spatial patterns. Maps with observations and survey effort overlaid can be found in the Appendix. Spatial patterns of predictions are discussed as well as any special considerations, such as latitudinal cutoffs, extrapolations, or concerns for each model. Monthly prediction maps are scaled to the highest density value amongst all months so that month-to-month comparisons can be made. In all maps, a category is defined where the model predicted density of 0.000001, functionally zero. Abundance for each month, along with the monthly CI, is presented in the figure headers.

The models were extrapolated into Long Island Sound and Delaware Bay in all months, except where latitudinal cutoffs were applied, parts of the Chesapeake Bay, and a few coastal grid cells where the selected environmental covariates were not consistently available. Areas of extrapolation are detailed in Figure 57.

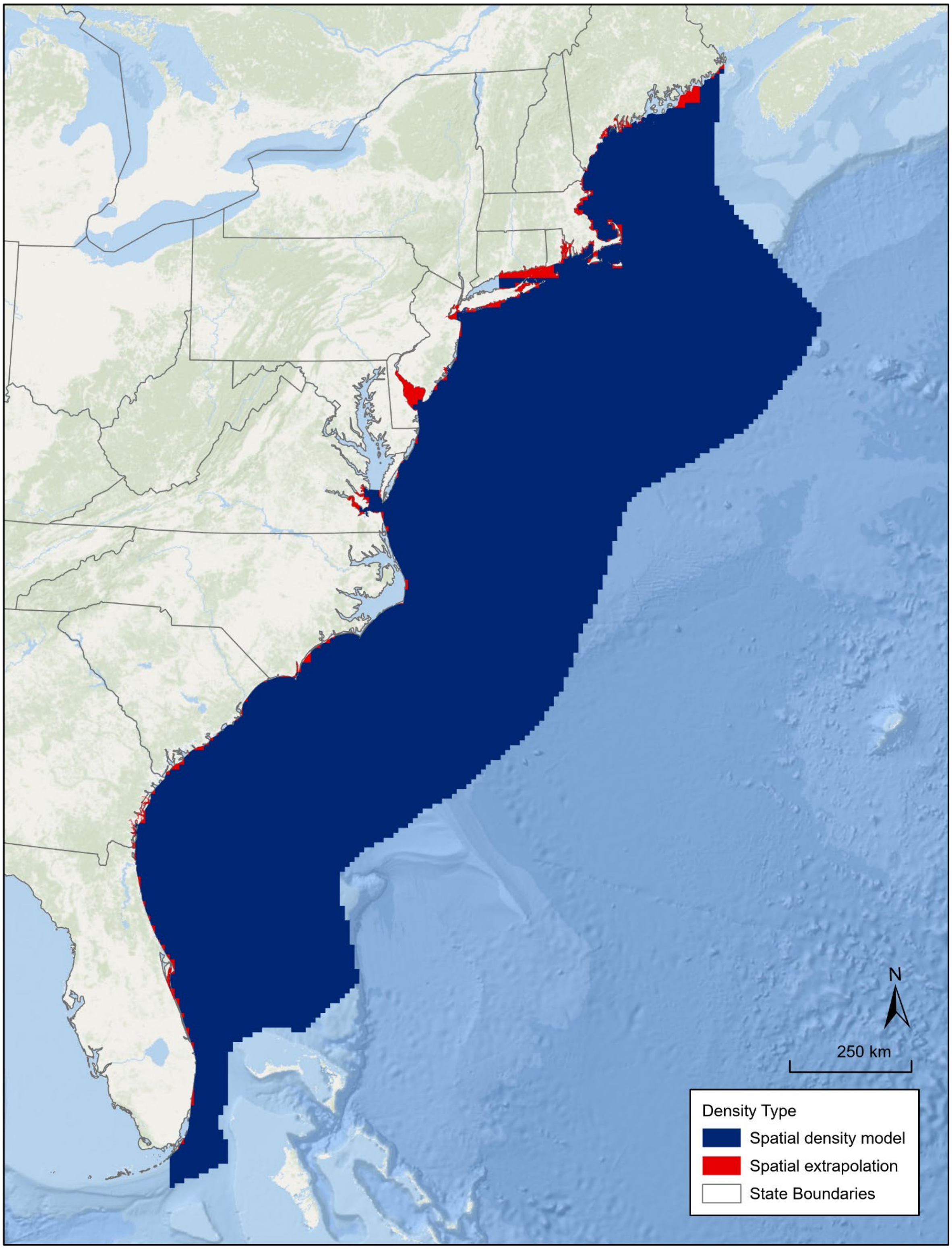

Figure 57. Locations Where the Density Surface Model Was Extrapolated

4.4.1 Loggerhead Turtle Predictions

Mean abundance for the loggerhead turtle model was 193,423 (90% CI =159,158–227,668). Monthly predicted abundance ranged from a high of 245,609 in February to a low of 135,066 in September (Figures 58–60) and was generally higher in cool months and lower in warm months. This was likely driven by lower productivity in warm months. A strong preference for productive areas was predicted by the model.

Density was high off the Florida coast year-round, reflecting that region's importance as a nesting, post-nesting, and transition area for both adults and juveniles (Ceriani et al. 2019), with thousands of sightings in the area. An area south of Cape Hatteras was picked up as an important region in cool months. This area is identified as a critical habitat, designated as an important migratory area, based on satellite tracking data. Concurrence between these two independent data sources further highlights the importance of the Cape Hatteras overwintering area. Moderate densities can be seen north of Cape Hatteras starting in May, with the furthest northward prediction of substantive density occurring in fall. Low but consistent density is predicted in all months north of Long Island and into the Gulf of Maine, which is supported by sightings data (Figures 82–84). These patterns are faint in Figures 58–60 due to the lower overall abundance predicted in warm months and the use of the same color scale between panels. Loggerhead turtles can be regularly captured as far north as Nova Scotia (Brazner and McMillan 2008).

A density of zero was predicted in depths greater than 3,000 m (9,843 ft). There were no sightings in those depths, though effort off the shelf was limited and occurred in June–September only. It is likely that hatchling turtles entrain in those waters where the Gulf Stream and developmental Sargassum habitat are present (Putman et al. 2020), but those turtles are generally not detectable from larger ships and aerial survey platforms. Larger animals have been satellite tracked in those areas (McClellan and Read 2007), but the presence of larger loggerheads off the shelf appears to be limited compared to on the shelf itself.

Uncertainty was highest in waters off the shelf, which were poorly sampled. Mean CV was 1.5 in areas of non-zero density, and CV ranged from 1.1 in August to 1.7 in March (Figures 61–63), though this only accounts for GAM parameter uncertainty and does not include other sources of uncertainty or variability, such as detection function uncertainty, environmental variability, or availability bias variability. Uncertainty was low on the continental shelf where the majority of effort and sightings occurred. Uncertainty was higher the further offshore the model predicted, and somewhat higher in the Gulf of Maine, which was well covered by surveys but had few sightings. Given the high predicted CV offshore, where predicted density was low, CI may be more appropriate to understand the range of predictions for this species.

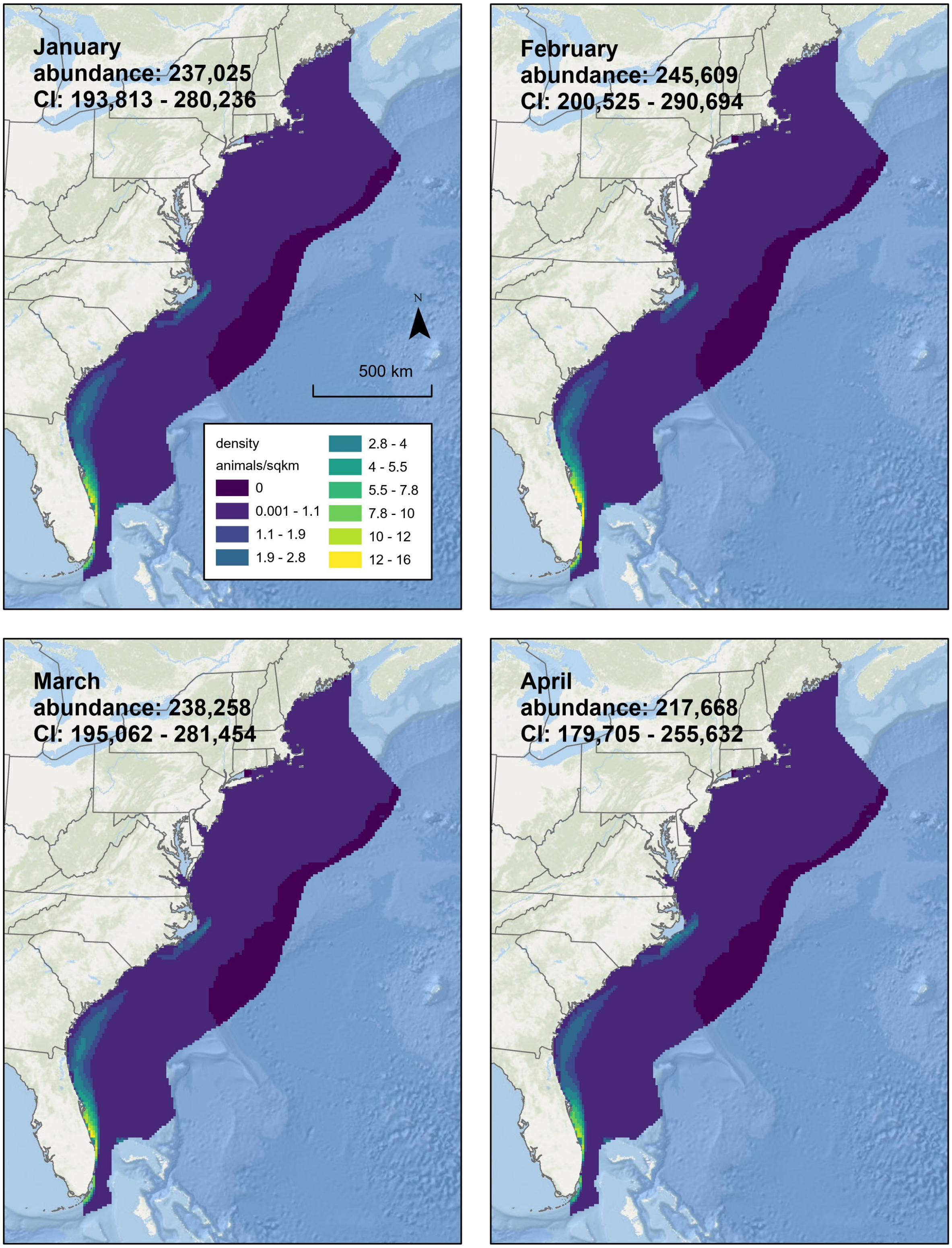

Figure 58. Predicted Loggerhead Turtle Density (January–April)

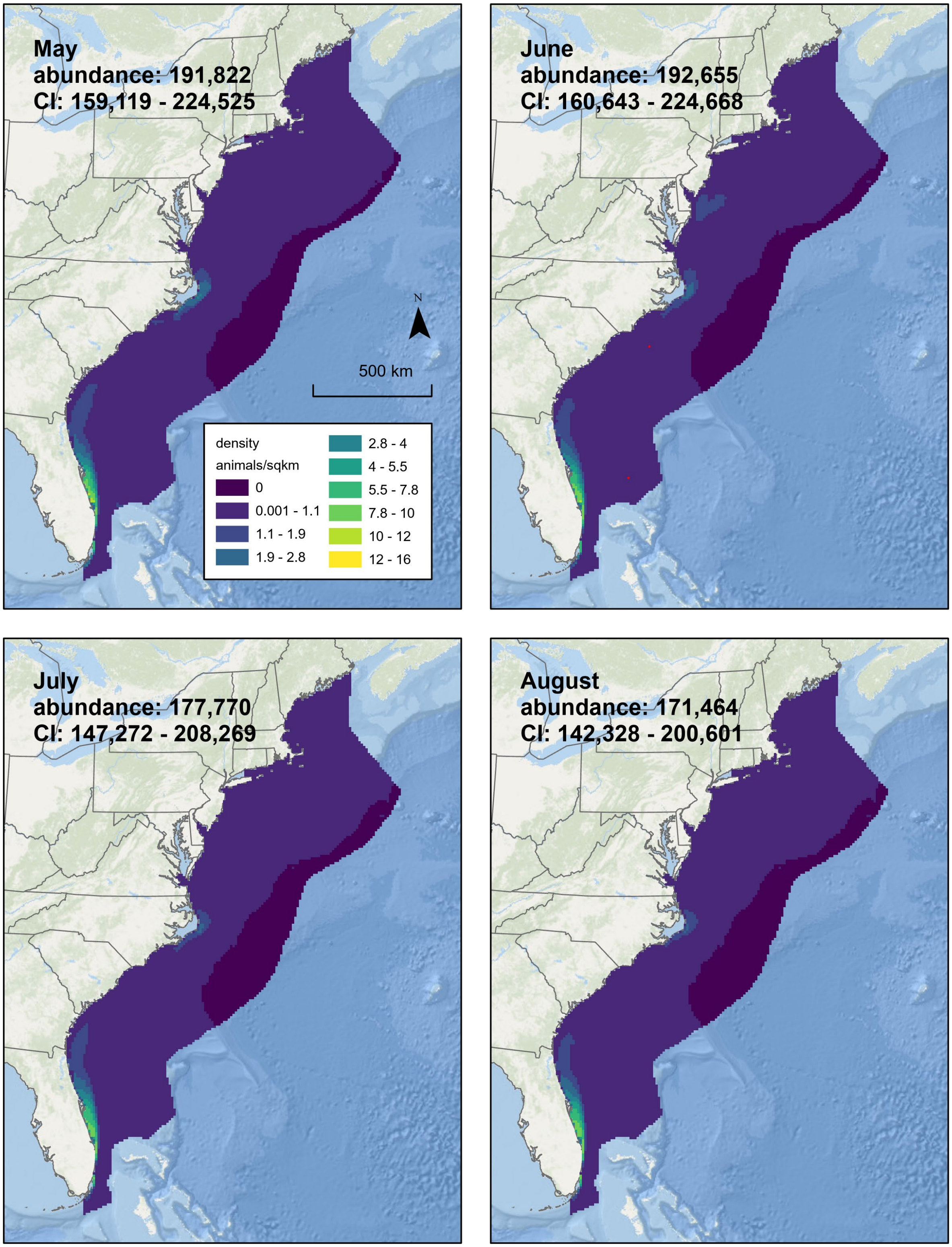

Figure 59. Predicted Loggerhead Turtle Density (May–August)

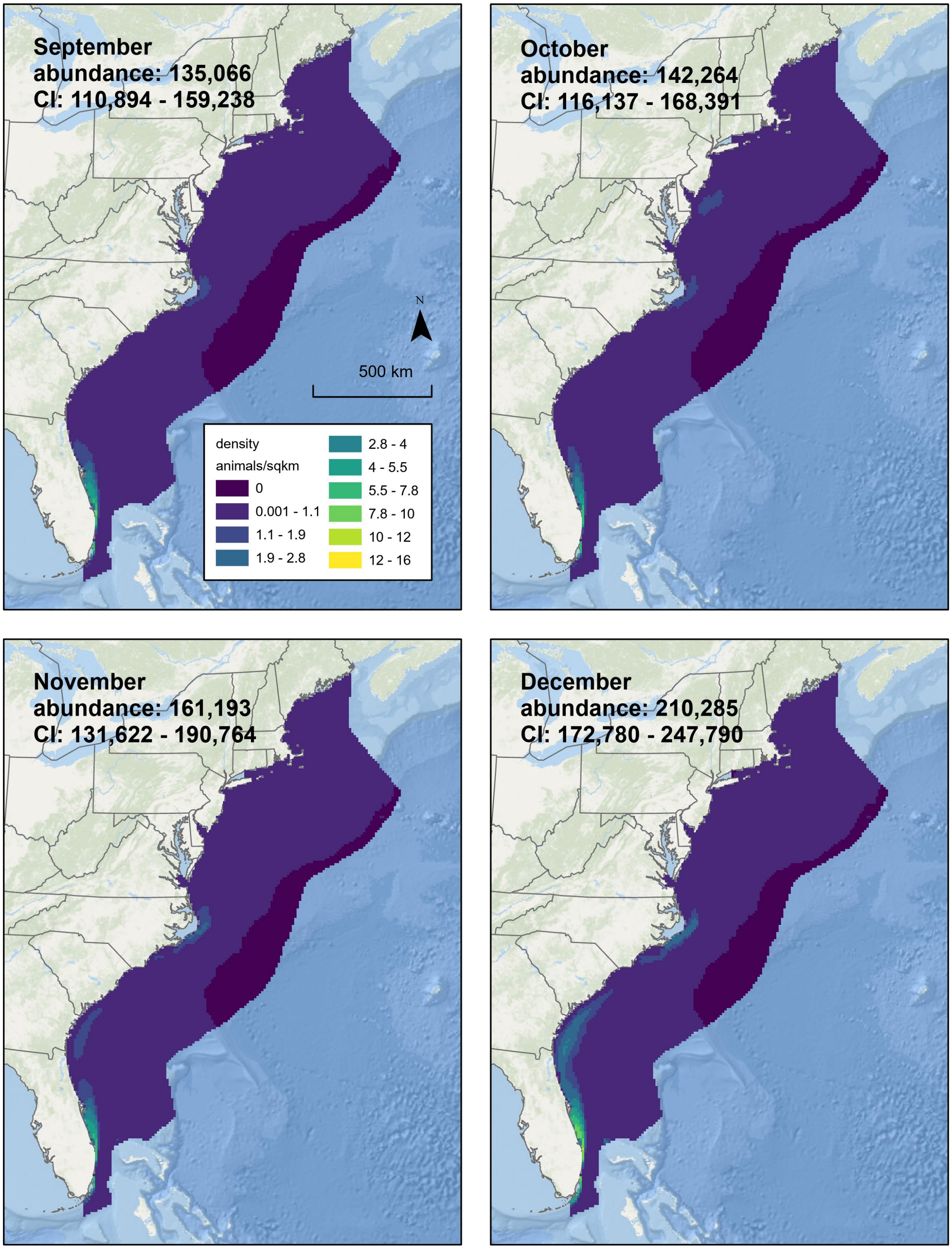

Figure 60. Predicted Loggerhead Turtle Density (September–December)

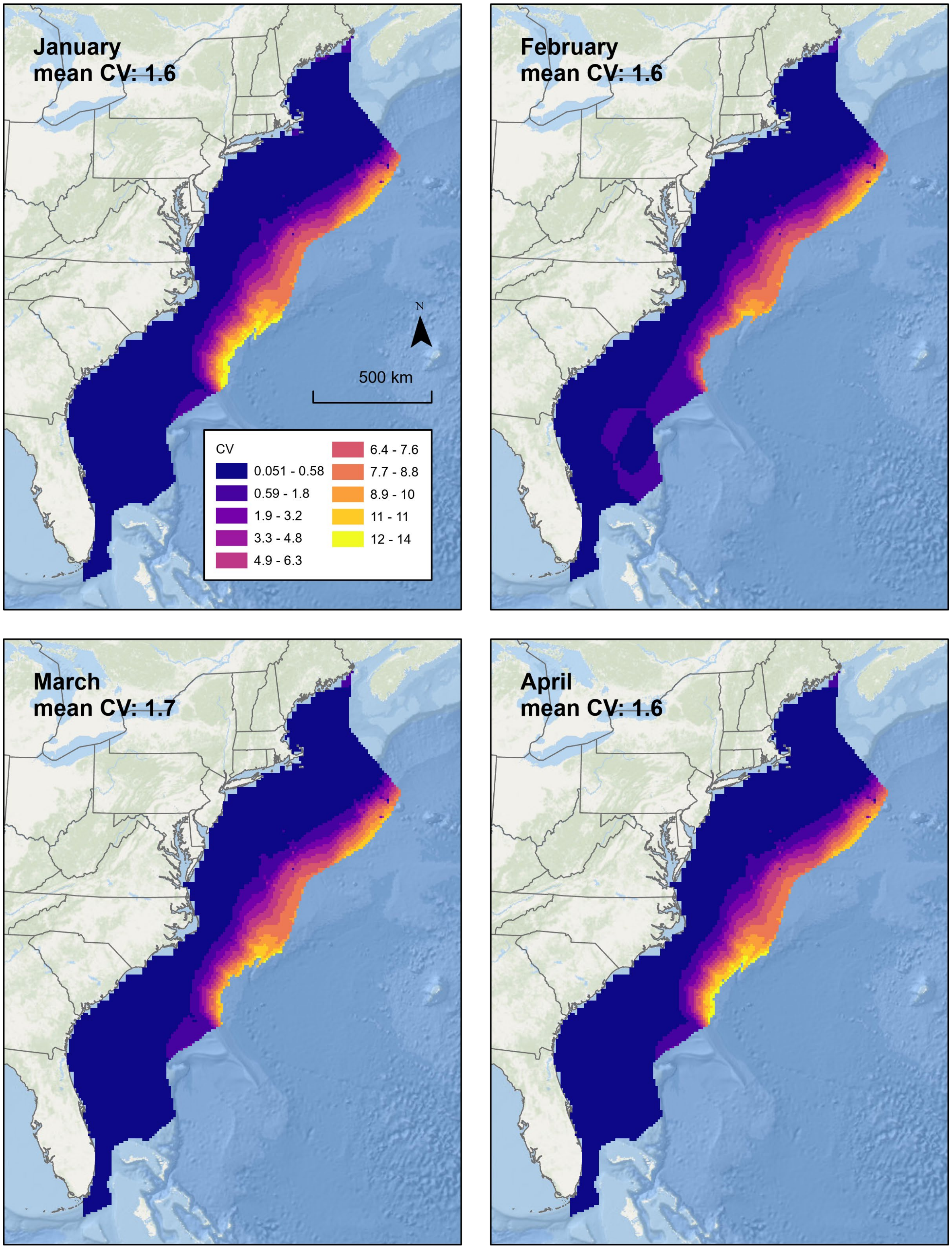

Figure 61. Predicted Loggerhead Turtle Uncertainty (CV; January–April)

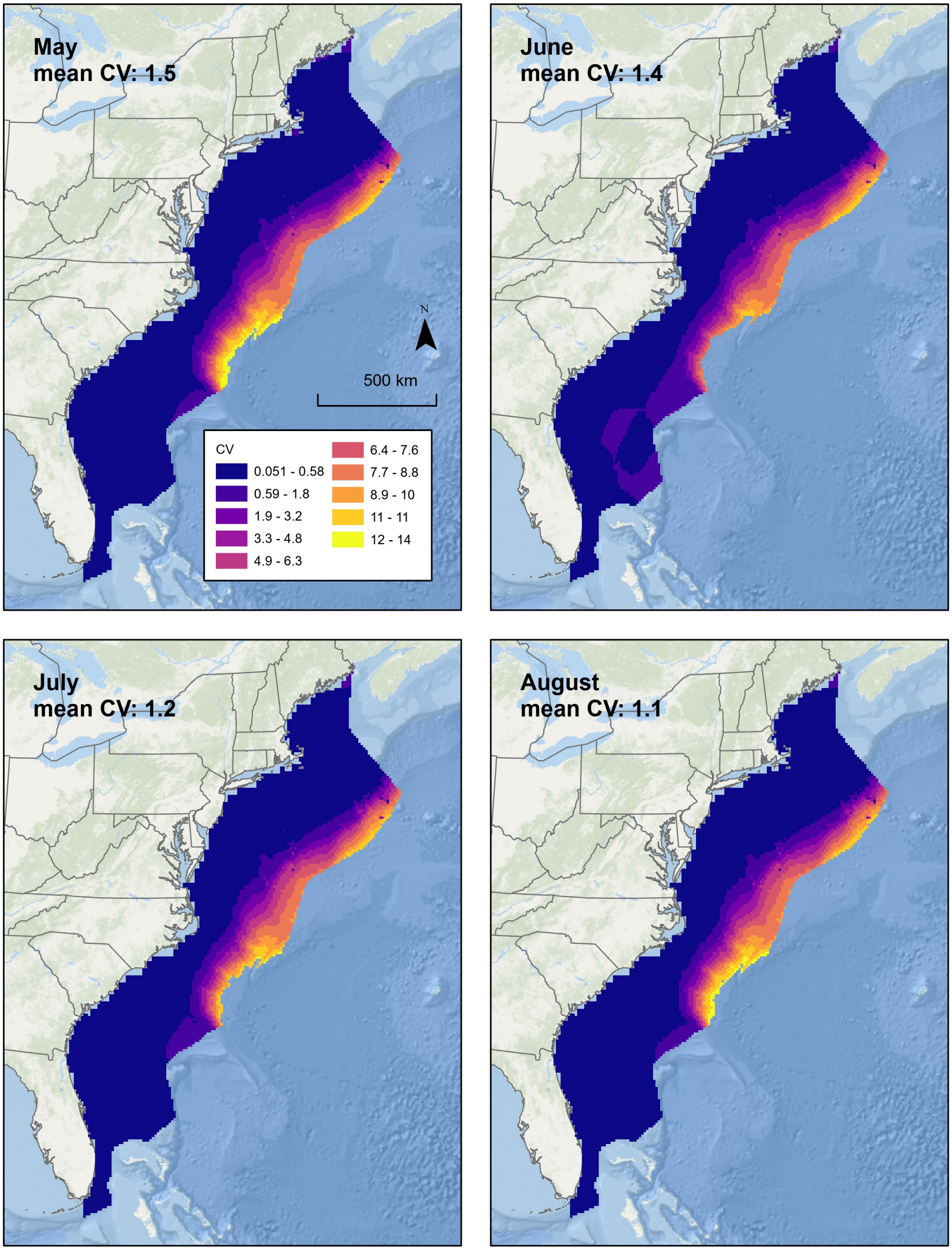

Figure 62. Predicted Loggerhead Turtle Uncertainty (CV; May–August)

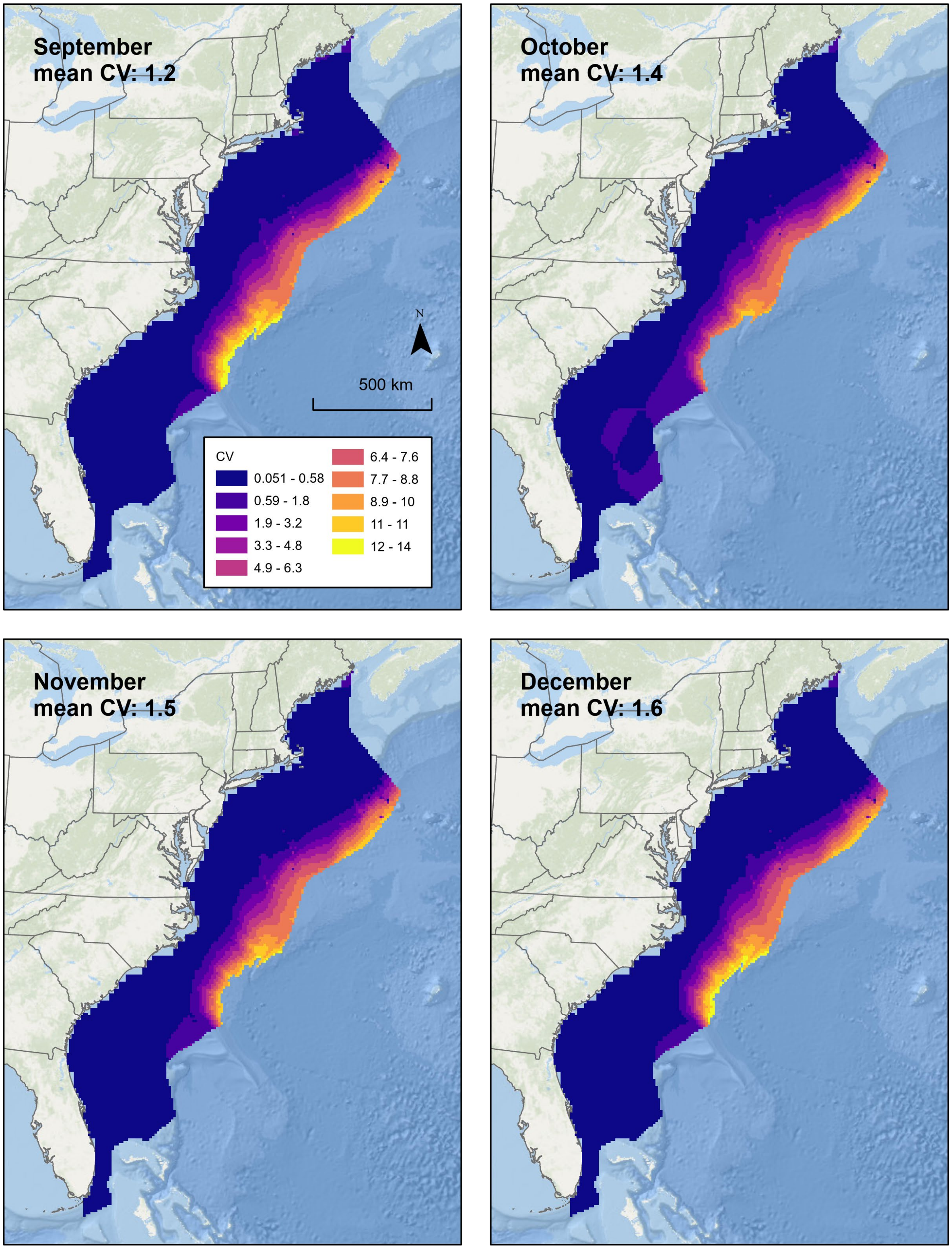

Figure 63. Predicted Loggerhead Turtle Uncertainty (CV; September–December)

4.4.2 *Green Turtle Predictions*

Mean abundance for the green turtle model was 63,674 (90% CI 23,381–117,610). Monthly predicted abundance ranged from a high of 96,935 in July to a low of 49,720 in January (Figures 64–66) and was generally higher in warm months and lower in cool months. These patterns were driven by a strong preference for warm, shallow, productive waters, and an avoidance of cooler deeper waters.

Predicted density was high off of Georgia and Florida coasts year-round, particularly the Florida Keys. The Florida Keys are a known hotspot for green turtles given the abundant seagrass beds, which are a preferred foraging habitat (Herren et al. 2018; Welsh and Mansfield 2022). Animals were predicted to be in the mid-Atlantic from May until October, generally from the Chesapeake Bay north to Long Island. There were no sightings of green turtles north of Cape Cod, consistent with strandings data (Mass Audubon 2022). Green turtles were predicted to move south again, starting in October, when northern waters begin to cool and turtles risk cold stunning if they remain in the area (Milton and Lutz 2003).

A density of zero was predicted off the continental shelf. There were no sightings off the shelf, though effort was limited and occurred in June–September only. It is likely that hatchling turtles entrain in those waters where the Gulf Stream and Sargassum are present (Putman et al. 2020), but those turtles are generally not detectable from larger ships and aerial survey platforms. Larger green turtles recruit to neritic foraging areas rich in macroalgae and seagrass beds, their preferred foraging habitats (Welsh and Mansfield 2022). Adults are rarely seen offshore unless they are migrating to nesting habitats.

The model predicted the presence of animals further north than was supported by the available sightings or a review of satellite tracking data (Halpin et al. 2009). This may be because the habitat there is unsuitable for reasons not discernible by the model or that there are behavioral reasons turtles do not utilize those areas. As such, latitudinal cutoffs were implemented, where the model was forced to zero density above a certain latitude. Cutoffs were applied seasonally and were as follows: ‘winter - Cape Hatteras,’ ‘spring - the Delaware/Maryland border,’ and ‘summer and fall - Narragansett Bay.’

Uncertainty was highest in waters close to the shelf break and in the northern extent for each season, generally where there were fewer sightings. Mean CV was 0.54 in areas of non-zero density, and CV ranged from 0.48 in September and October to 0.82 in March (Figures 67–69), though this only accounts for GAM parameter uncertainty and does not include other sources of uncertainty or variability, such as detection function uncertainty and environmental variability. Uncertainty was low in the middle of the continental shelf where the majority of sightings occurred. Uncertainty was higher in nearshore areas and the western edge of the continental shelf where there were few sightings, and the northern extent of predictions.

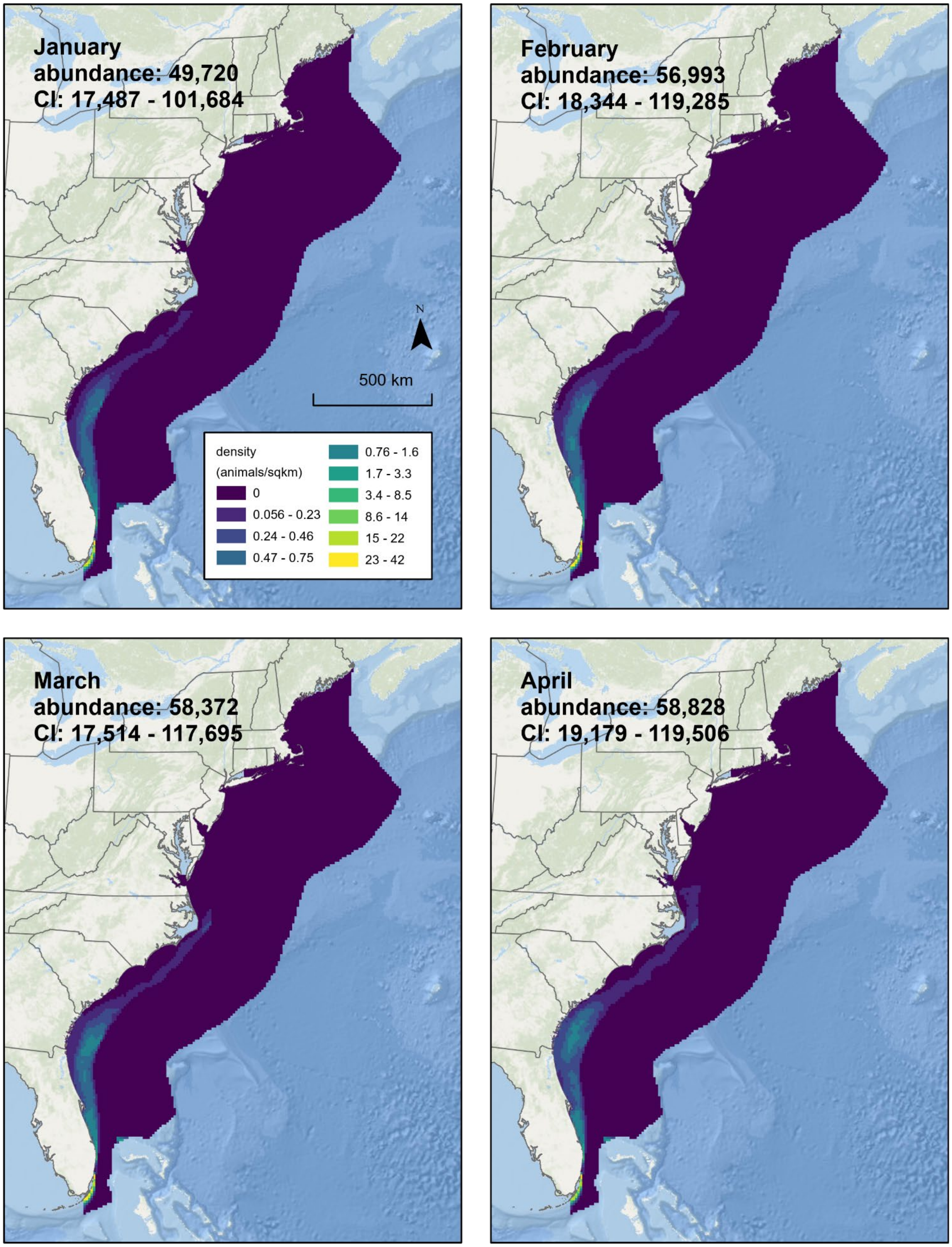

Figure 64. Predicted Green Turtle Density (January–April)

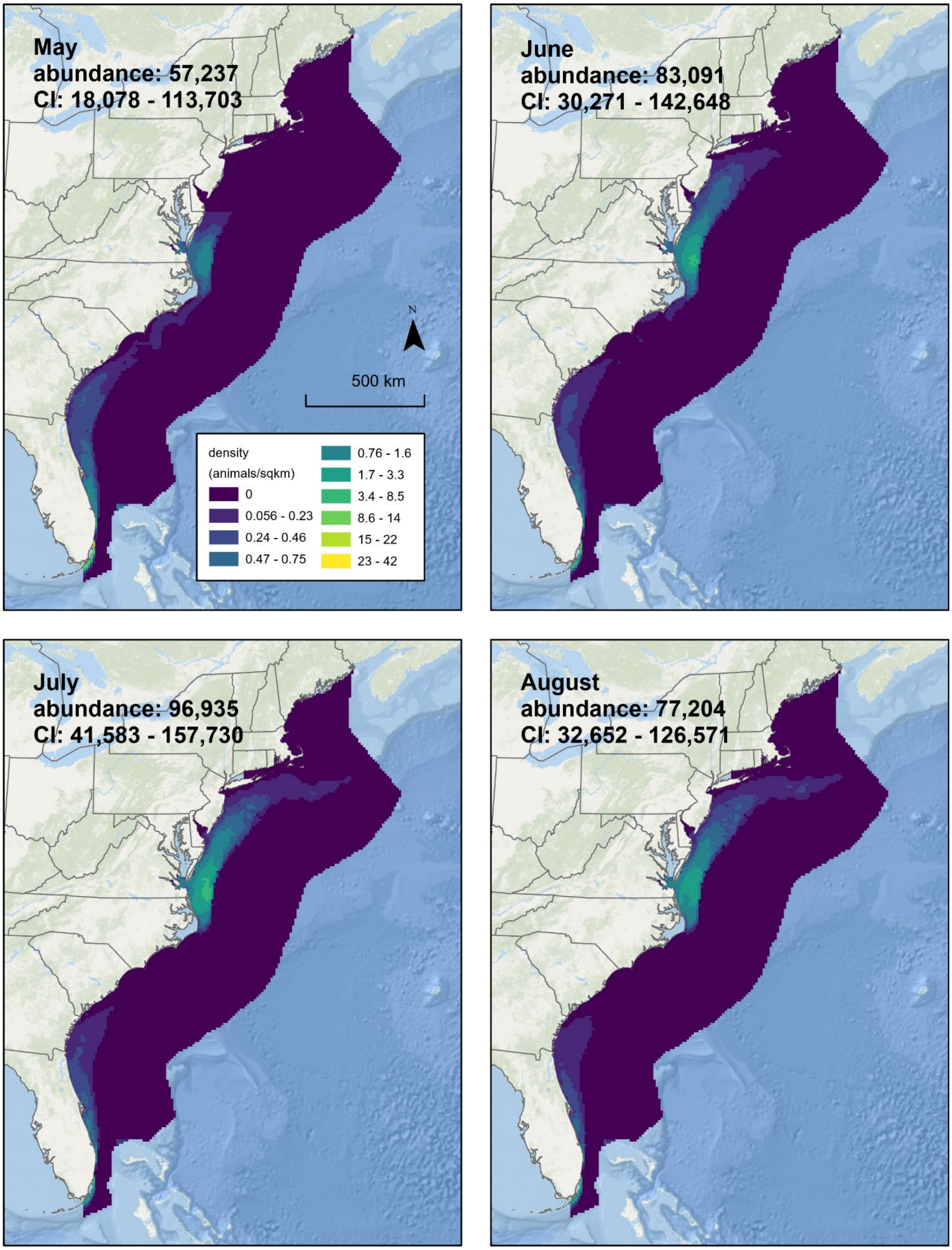

Figure 65. Predicted Green Turtle Density (May–August)

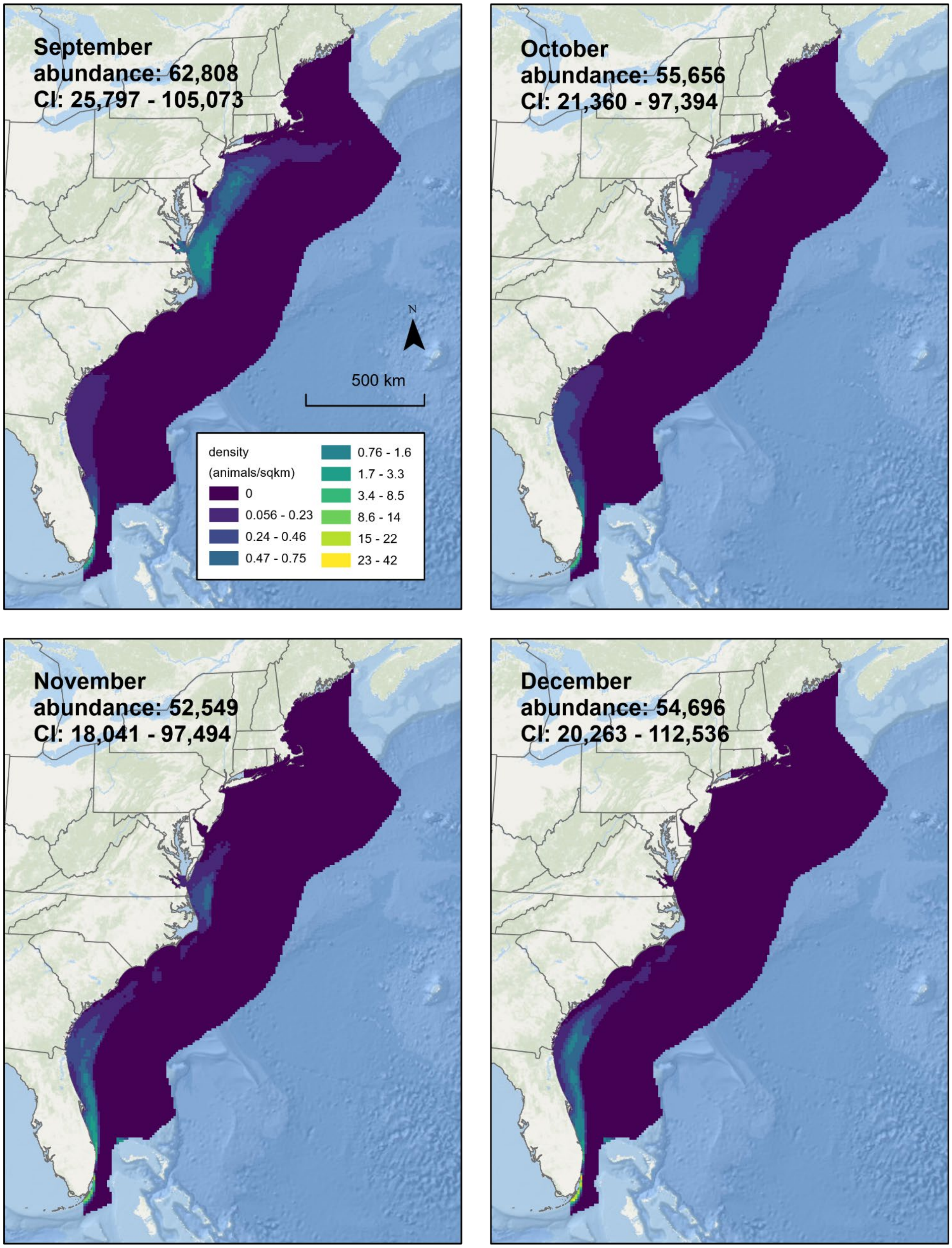

Figure 66. Predicted Green Turtle Density (September–December)

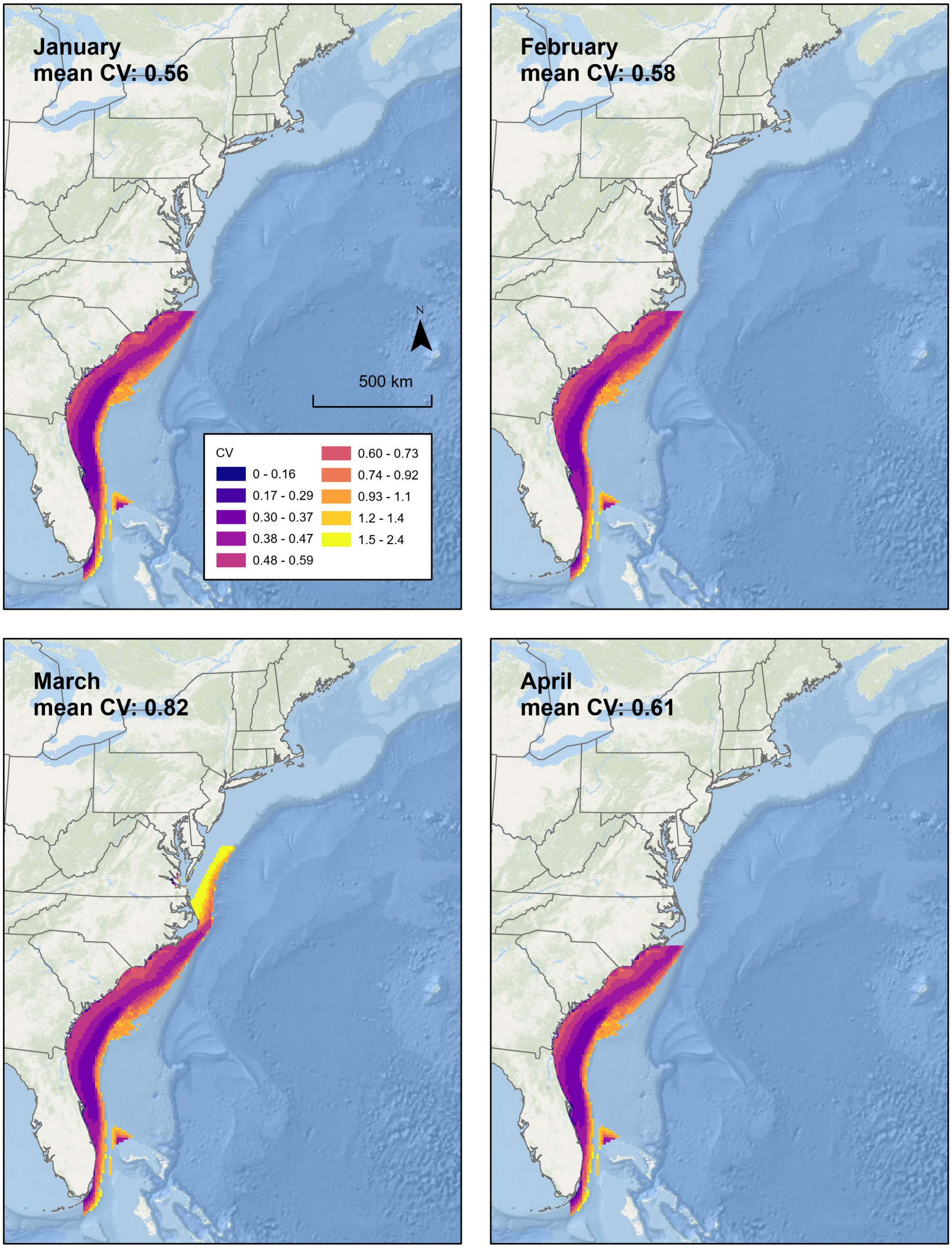

Figure 67. Predicted Green Turtle Uncertainty (CV; January–April)

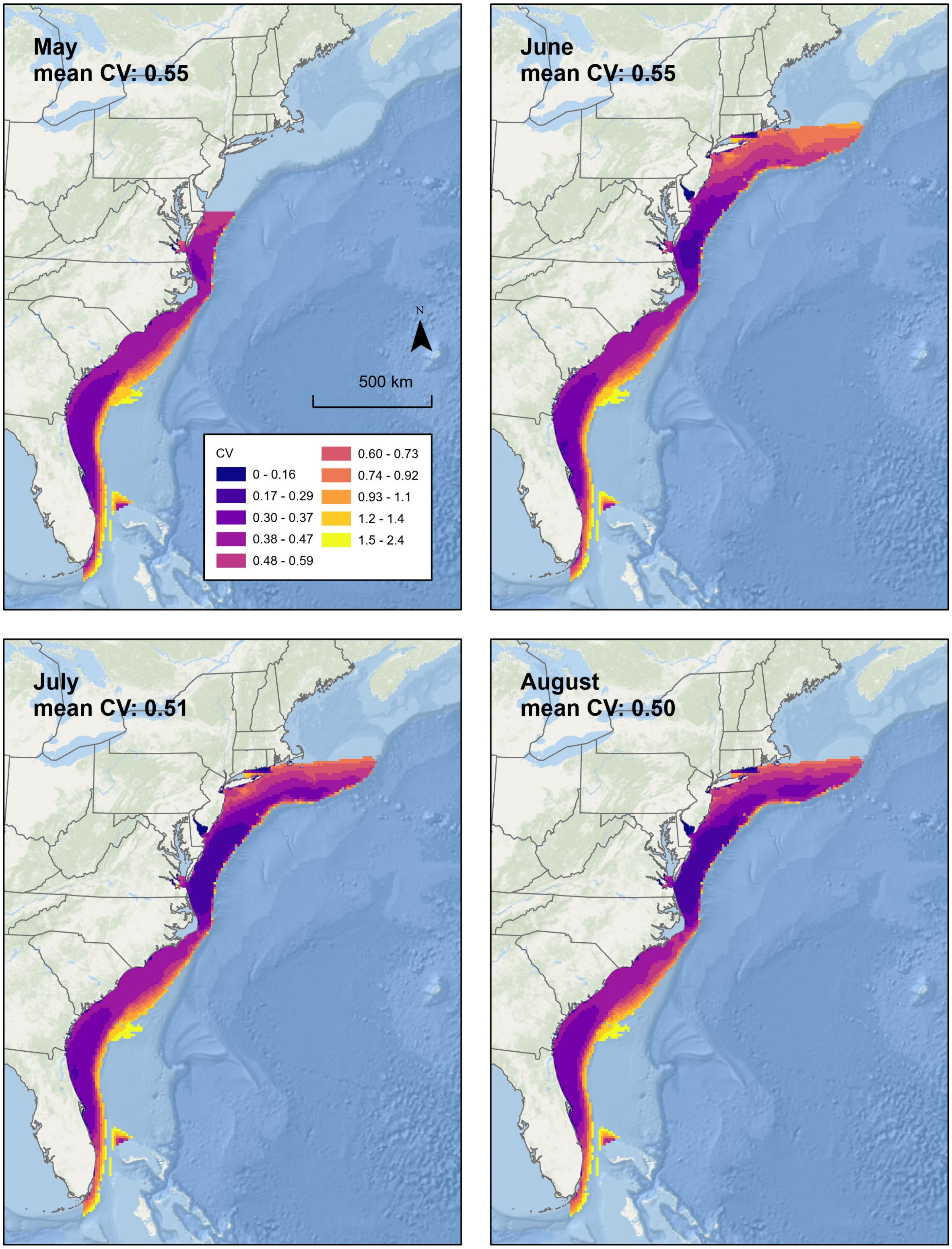

Figure 68. Predicted Green Turtle Uncertainty (CV; May–August)

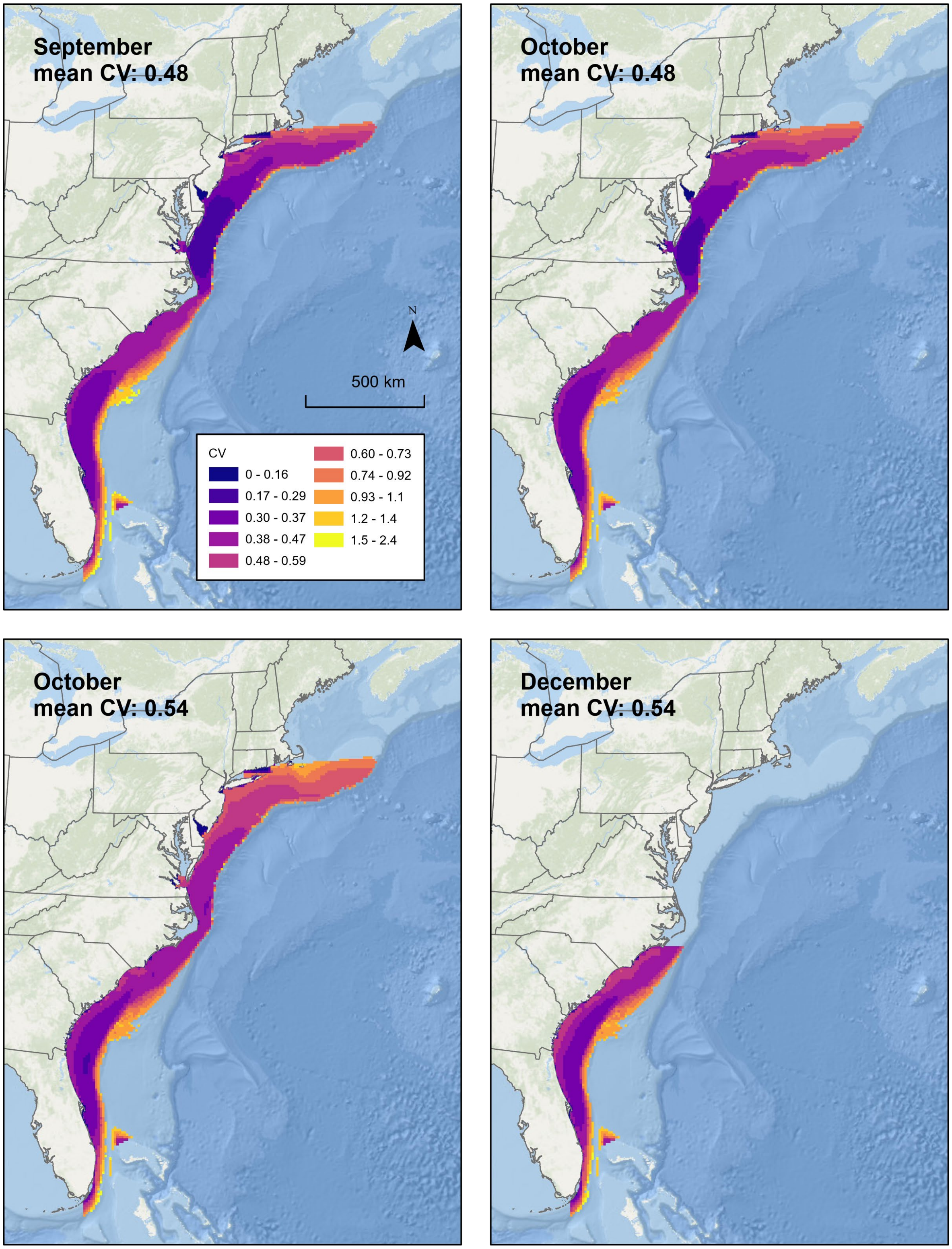

Figure 69. Predicted Green Turtle Uncertainty (CV; September–December)

4.4.3 Kemp's Ridley Turtle Predictions

Mean abundance for the Kemp's ridley turtle model was 10,762 (90% CI 2,620–19,443). Monthly predicted abundance ranged from a high of 13,220 in October to a low of 8,341 in August (Figures 70–72) and was generally higher in spring and fall but only varied by a few thousand animals from month to month. It is unclear from the covariate relationships exactly what is driving the variations in abundance.

Predicted density was high off of southern Georgia and northern Florida coasts year-round, apparently driven by a cluster of sightings in the region (Figures 88–90). The selection of the MNCK_ZOOC covariate (zooplankton biomass) might also drive this pattern, as similar patterns occur in marine mammal models where this covariate was selected (Roberts, Mannocci, and Halpin 2015). Animals were predicted to be in the mid-Atlantic from May until November, generally from the Chesapeake Bay north to Delaware Bay, and as far north as Long Island Sound in summer months. There were no sightings of Kemp's ridley turtles north of Cape Cod, where strandings of that species are rare (Mass Audubon 2022). Kemp's ridley turtles were predicted to move south again starting in November, when northern waters begin to cool and turtles risk cold stunning if they remain in the area (Milton and Lutz 2003).

A very low density, though not zero, was predicted off the continental shelf. There were no sightings off the shelf, though effort was limited and occurred in June–September only. The non-zero density prediction was likely the result of the inclusion of distance to shore (rather than depth) as a static covariate, which did not predict as sharp a delineation in density off the shelf as for the other hardshell species. It is likely that hatchling turtles entrain in those waters where the Gulf Stream and Sargassum are present (Putman et al. 2020), but those turtles are generally not detectable from larger ships and aerial survey platforms.

The model predicted the presence of animals further north than was supported by the available sightings or a review of satellite tracking data (Halpin et al. 2009), though strandings do occasionally occur north of Cape Cod (Mass Audubon 2022). This may be because habitat there is unsuitable for reasons not discernible by the model or that there are behavioral reasons turtles do not utilize those areas. As such, latitudinal cutoffs were implemented, where the model was forced to zero density above a certain latitude. Cutoffs were applied seasonally and were as follows based on the furthest north stranding data: 'winter - Pamlico Sound,' 'spring - the Delaware/Maryland border,' 'summer and fall - slightly north of Cape Cod.' Several turtles have been detected in Chesapeake Bay in December and January on acoustic receiver arrays (Barco et al. 2018A) but at very low rates. There is a good chance these turtles ended up becoming cold stunned. As such, we opted to keep the winter cutoff at Pamlico Sound.

Uncertainty was higher the further from shore the model predicted, reflecting the inclusion of the distance-to-shelf covariate and no sightings in deeper waters. Mean CV was very high (3.8) and ranged from 1.6 in January to 5.0 in March and April (Figures 73–75). This only accounts for GAM parameter uncertainty and does not include other sources of uncertainty or variability, such as detection function uncertainty and environmental variability. These extremely high values of CV are almost exclusively in areas where there are no sightings and close to zero predicted density. CI is better for understanding the true range of predictions for this species. Uncertainty was low on the continental shelf where the majority of effort and sightings occurred. Uncertainty was higher the further offshore the model predicted, driven by the inclusion of the distance to shore covariate and poorly sampled values at far distances.

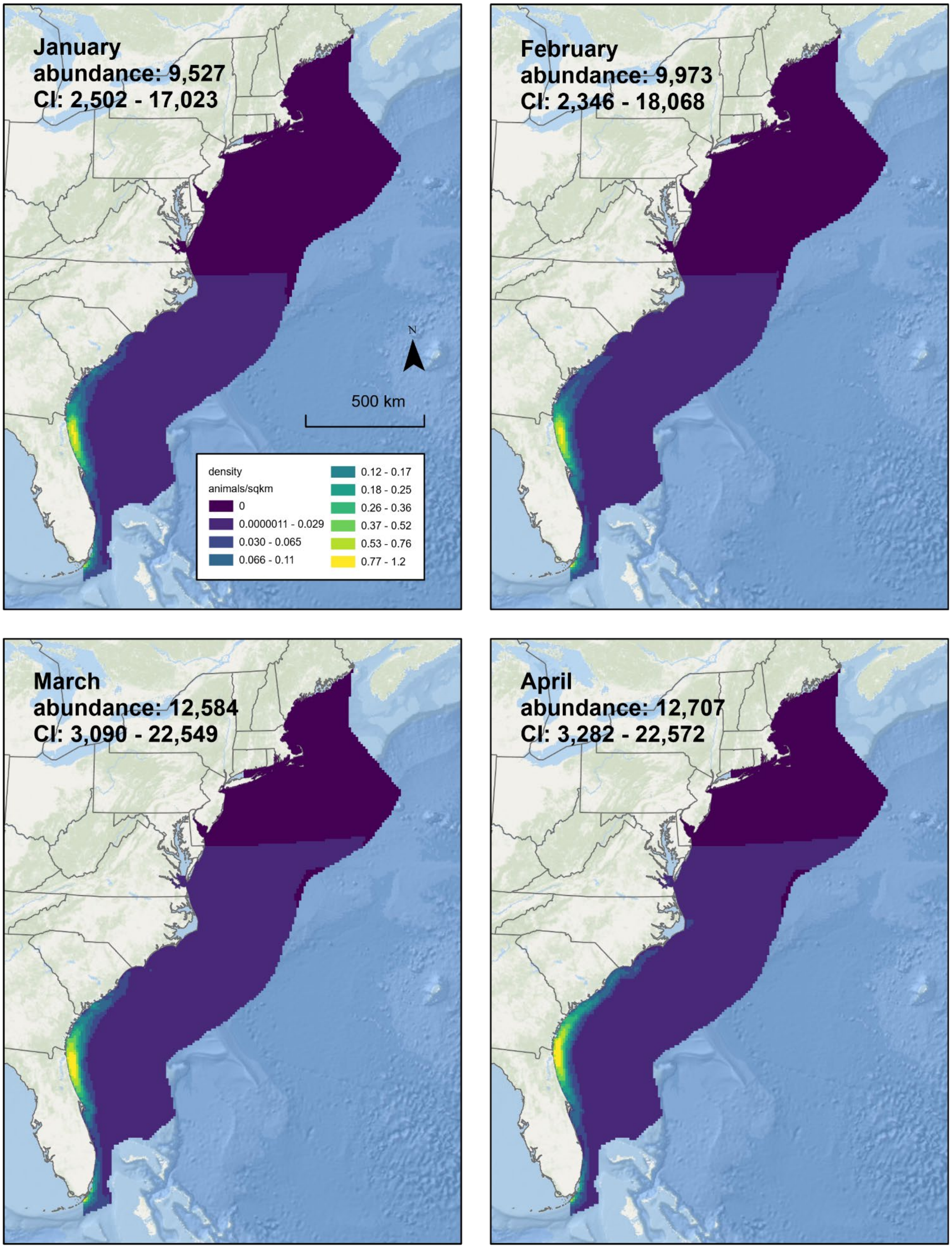

Figure 70. Predicted Kemp's Ridley Turtle Density (January–April)

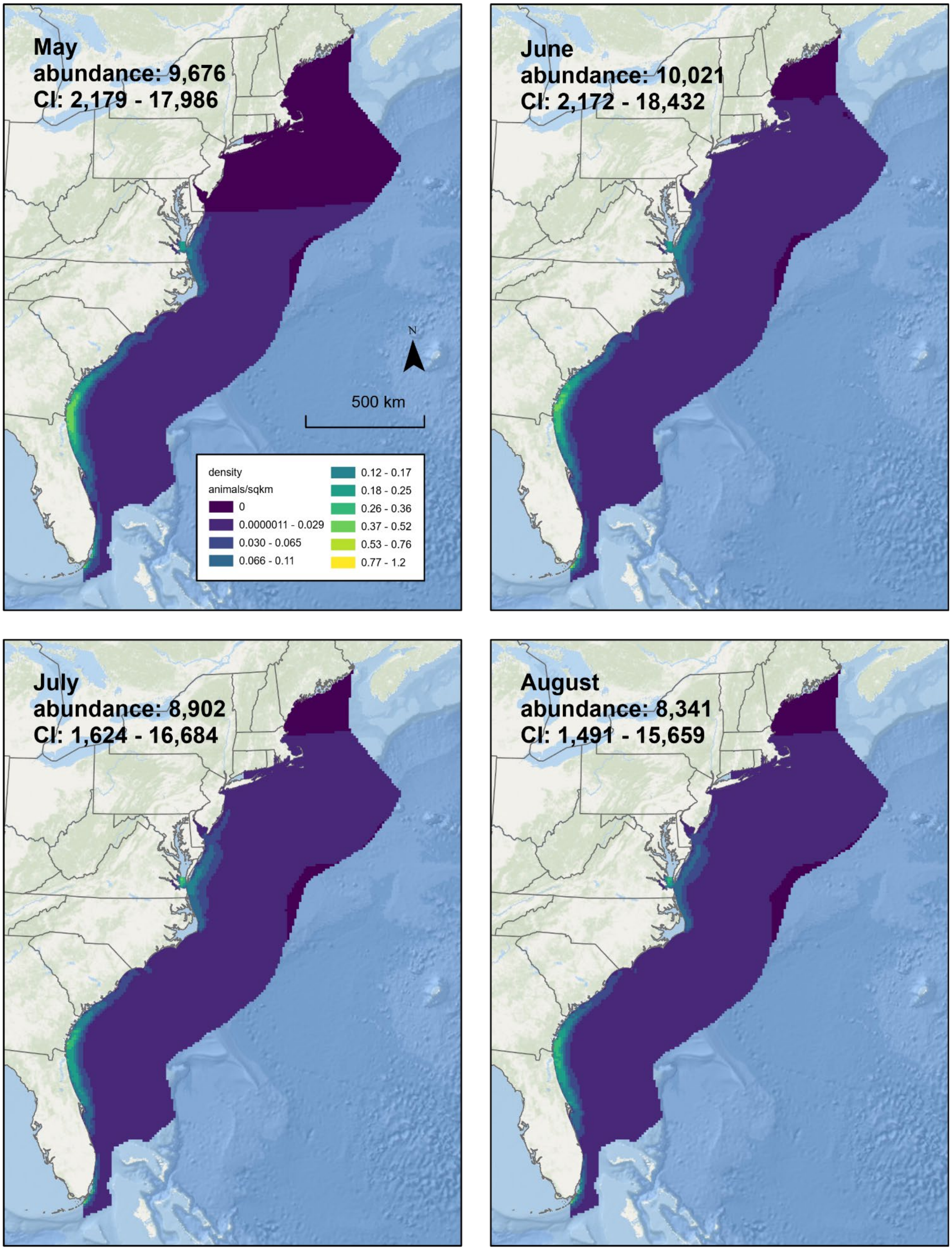

Figure 71. Predicted Kemp's Ridley Turtle Density (May–August)

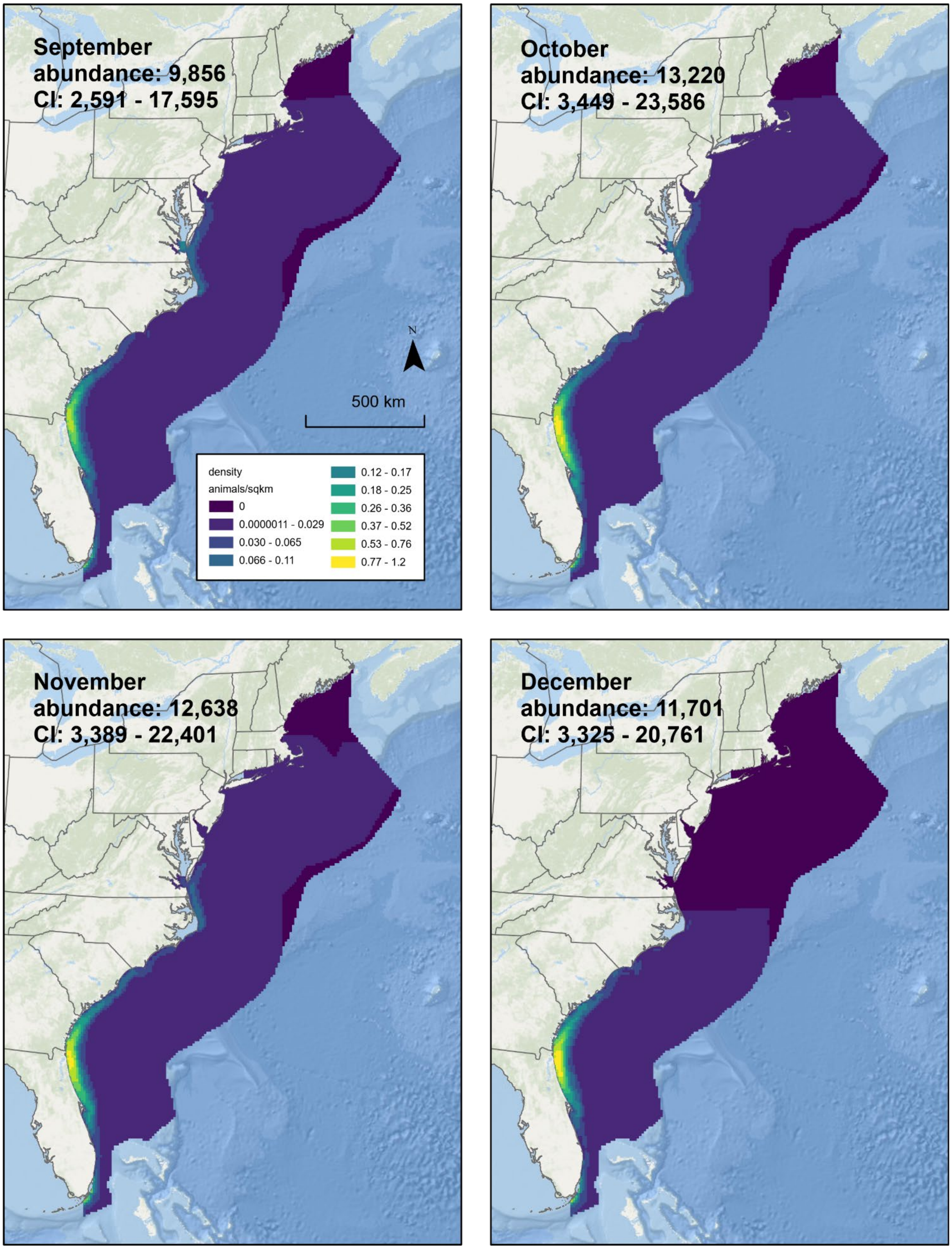

Figure 72. Predicted Kemp's Ridley Turtle Density (September–December)

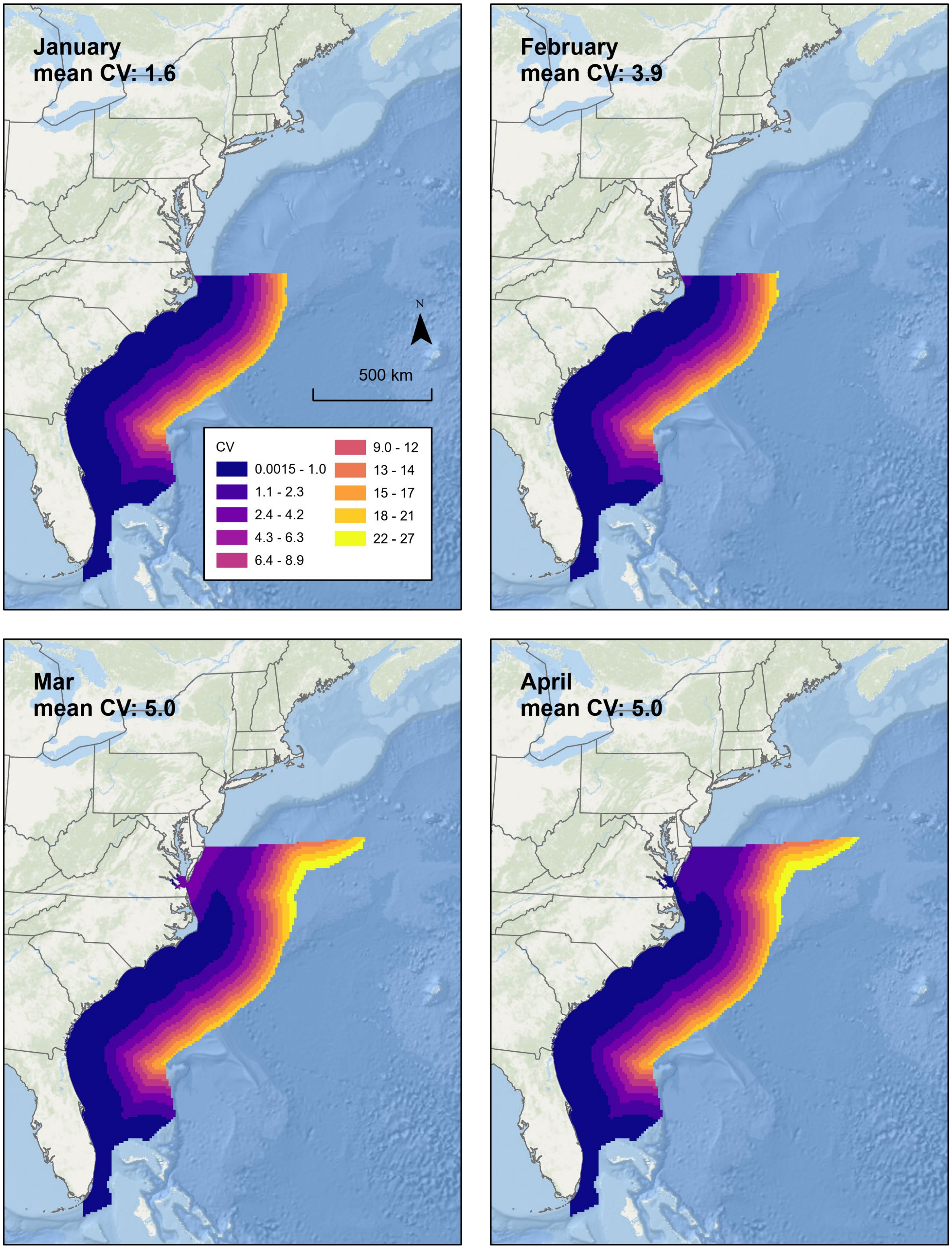

Figure 73. Predicted Kemp's Ridley Turtle Uncertainty (CV; January–April)

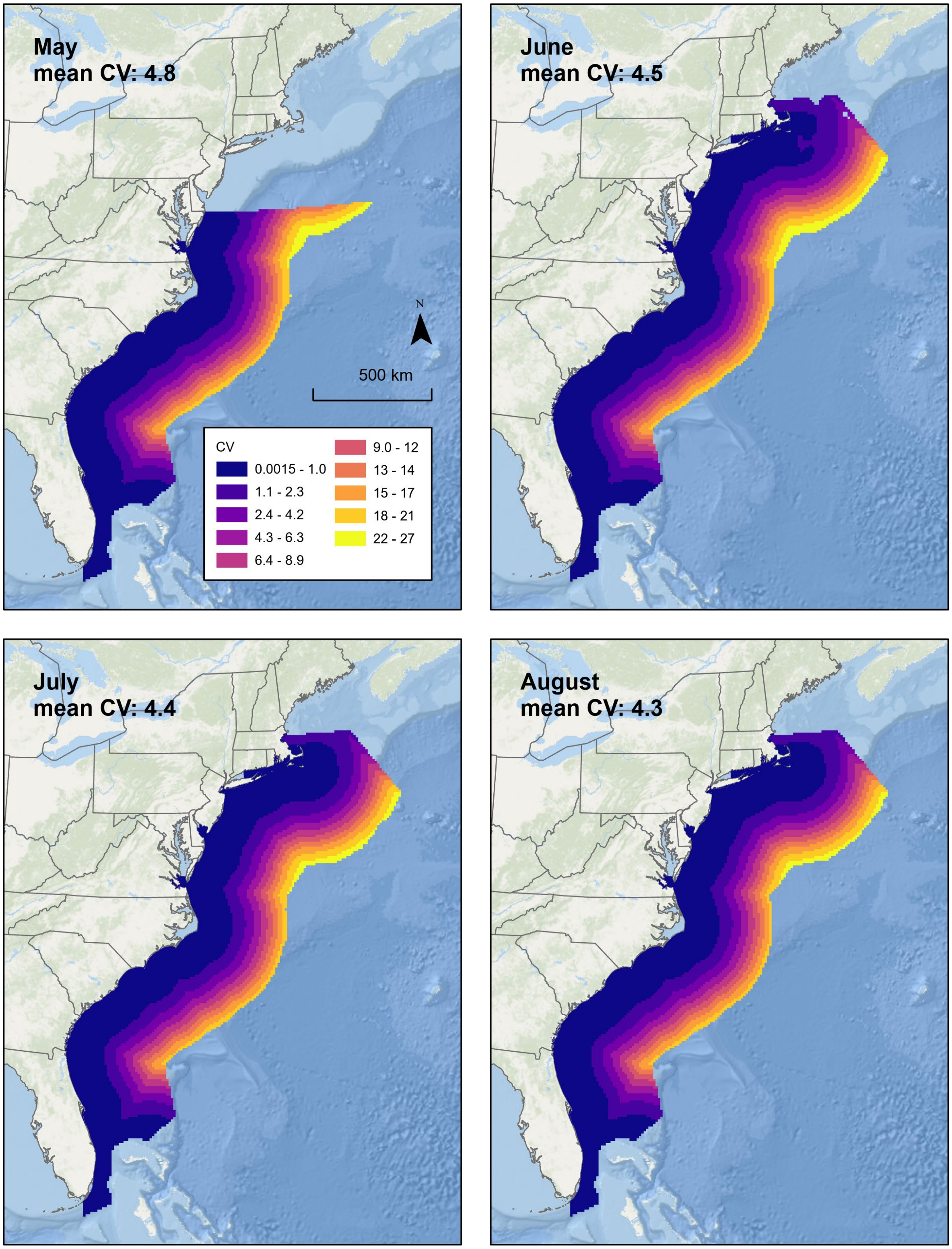

Figure 74. Predicted Kemp's Ridley Turtle Uncertainty (CV; May–August)

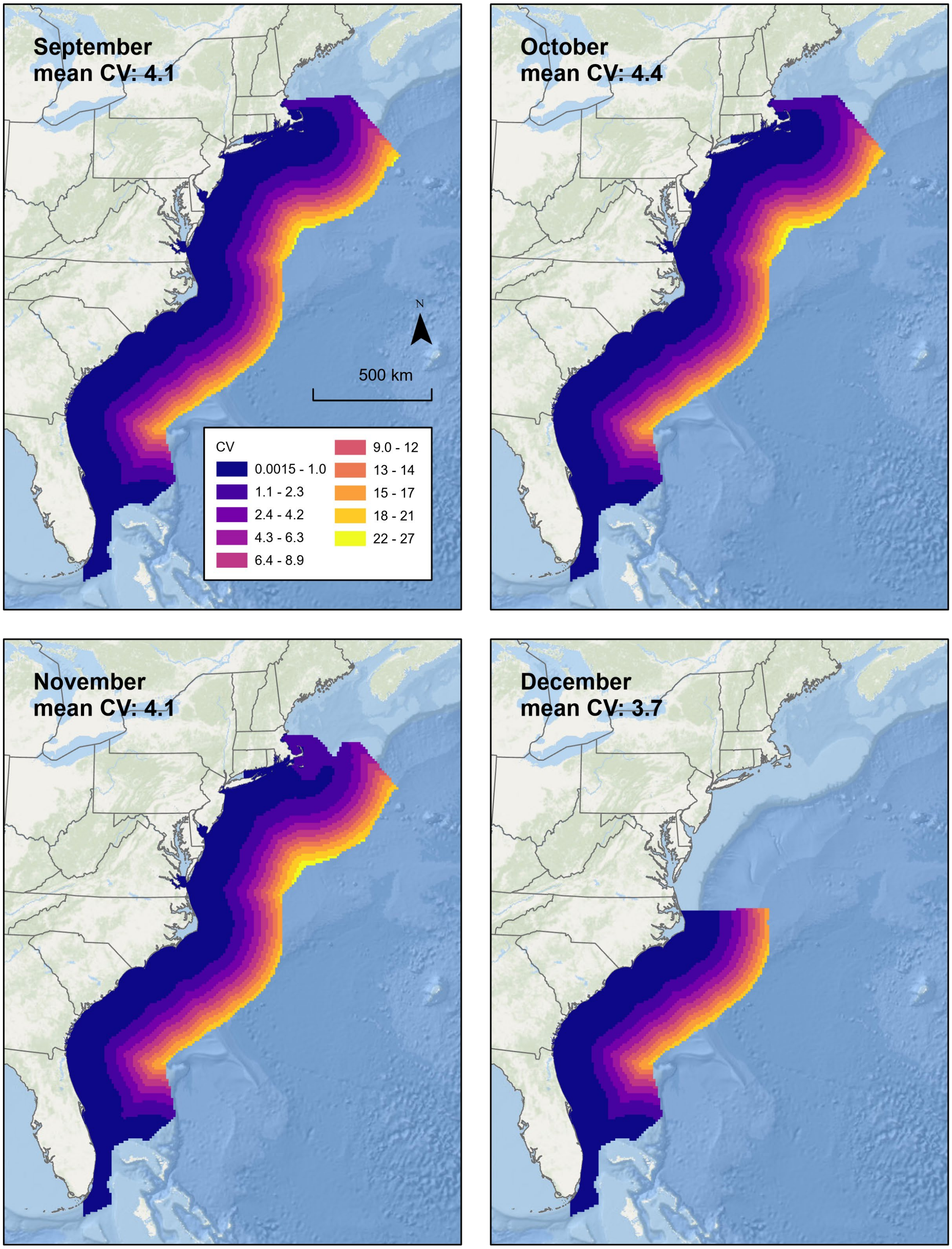

Figure 75. Predicted Kemp's Ridley Turtle Uncertainty (CV; September–December)

4.4.4 Leatherback Turtle Predictions

Mean abundance for the leatherback turtle model was 21,984 (90% CI 10,049–33,600). Monthly predicted abundance ranged from a high of 54,329 in September to a low of 4,655 in February (Figures 76–78) and was generally higher in warm months and lower in cool months. Leatherback turtles have the largest percent change between high- and low-abundance predictions of any species in this study, with monthly estimates spanning a full order of magnitude. This pattern is supported by the sightings data (Figures 91–93) and may reflect the east coast's importance as a nesting and migratory habitat, but not as a foraging habitat, as turtles from the wider Caribbean region migrate to the north Atlantic Ocean basin seasonally to forage (Eckert 2006; Eckert et al. 2006).

Animals were predicted to be off the coast of Georgia and Florida year-round, in low amounts in cool months and high amounts in warm months. Animals were predicted through the entire study area, including offshore areas, except for a few isolated areas in June and July. Dist_500 was the selected static covariate and reflects this species' more offshore distribution compared to the hardshell species. Leatherback turtles feed primarily on pelagic, gelatinous prey distributed in productive offshore areas (Witt et al. 2007). Leatherbacks are also distributed much further north than other sea turtle species (James and Mrosovsky 2004), and they are regularly captured off the coast of Nova Scotia before being tracked into the North Atlantic Gyre (Hamelin et al. 2017), making the year-round predicted presence in the Gulf of Maine reasonable. This is also supported by the sightings data.

Animals were predicted to be in the mid-Atlantic from June until November, generally from the Outer Banks north to Cape Cod as well as offshore in the Gulf Stream in high numbers driven by the relationship with sea surface height. There were numerous sightings of leatherback turtles in the offshore shipboard surveys supporting these predictions.

Uncertainty was higher offshore where there was less survey effort and fewer sightings, as well as in the Gulf of Maine, which had high survey effort but few sightings and may be more driven by poor sampling of environmental covariates in the area. Mean CV was 0.70 and ranged from 0.62 in November to 0.80 in August (Figures 79–81) and only accounts for GAM parameter uncertainty and does not include other sources of uncertainty or variability, such as detection function uncertainty, environmental variability, and dive variability. Uncertainty was low within the Gulf Stream where the majority of sightings occurred. Uncertainty was higher outside of the Gulf Stream, potentially due to poorly sampled values of sea surface height.

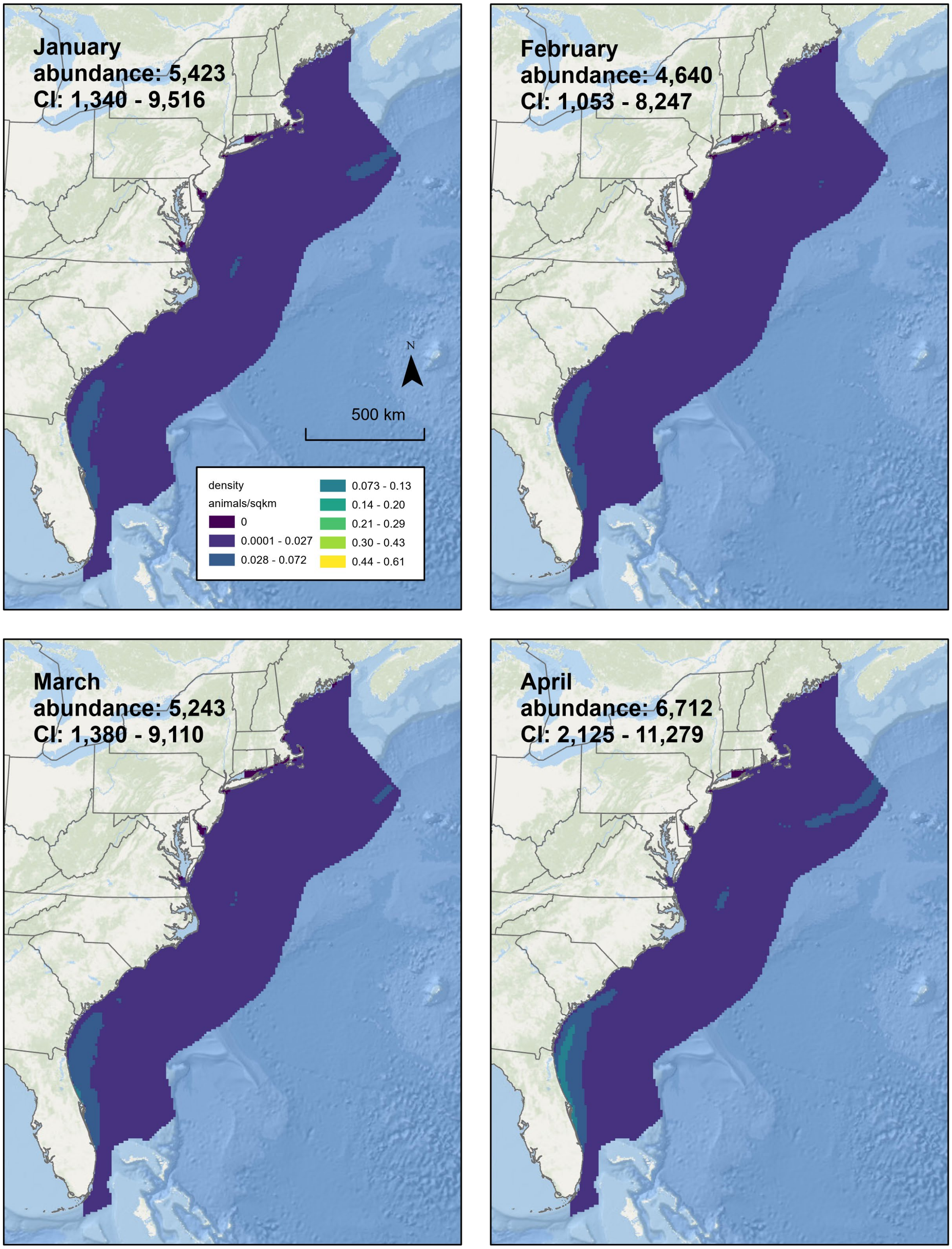

Figure 76. Predicted Leatherback Turtle Density (January–April)

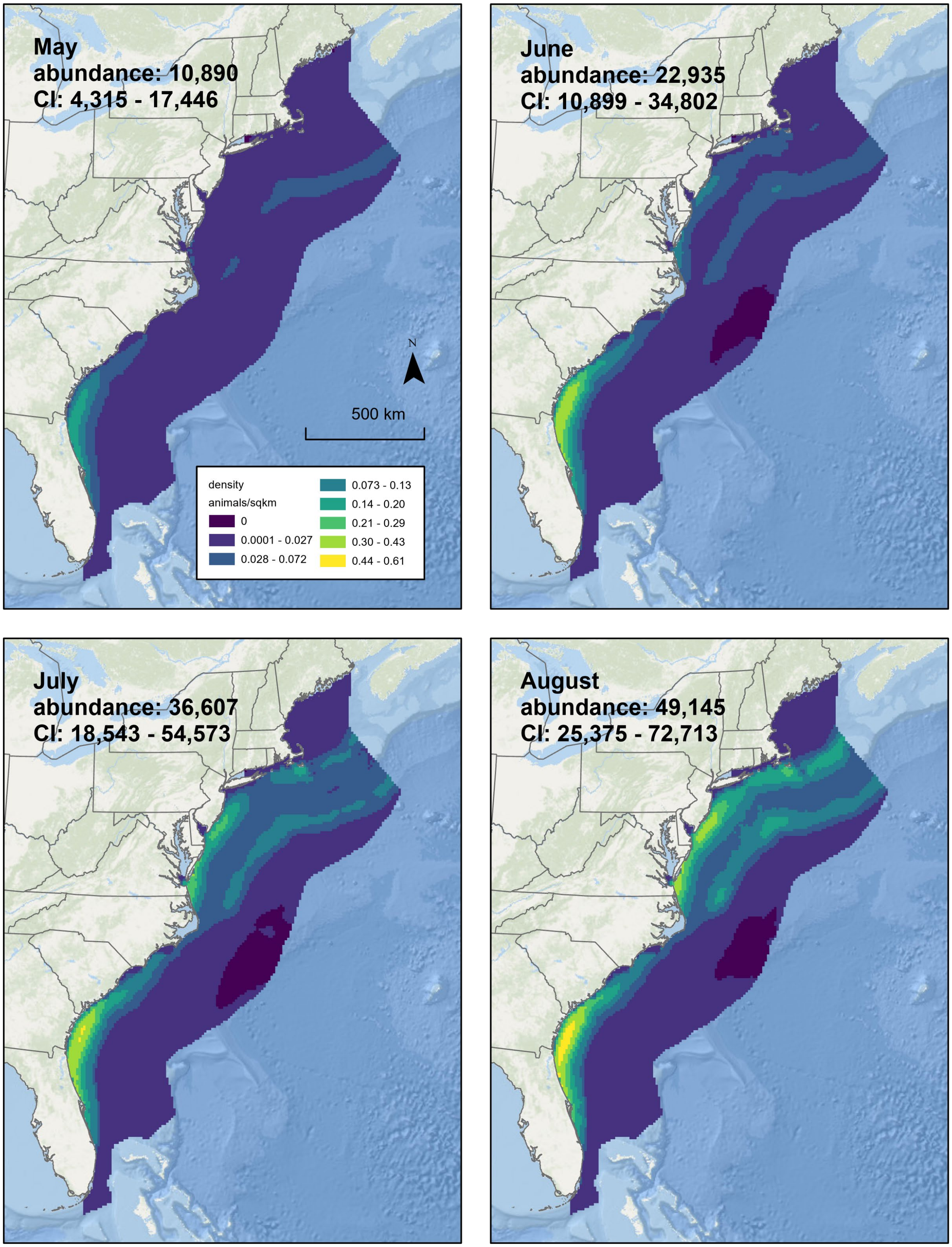

Figure 77. Predicted Leatherback Turtle Density (May–August)

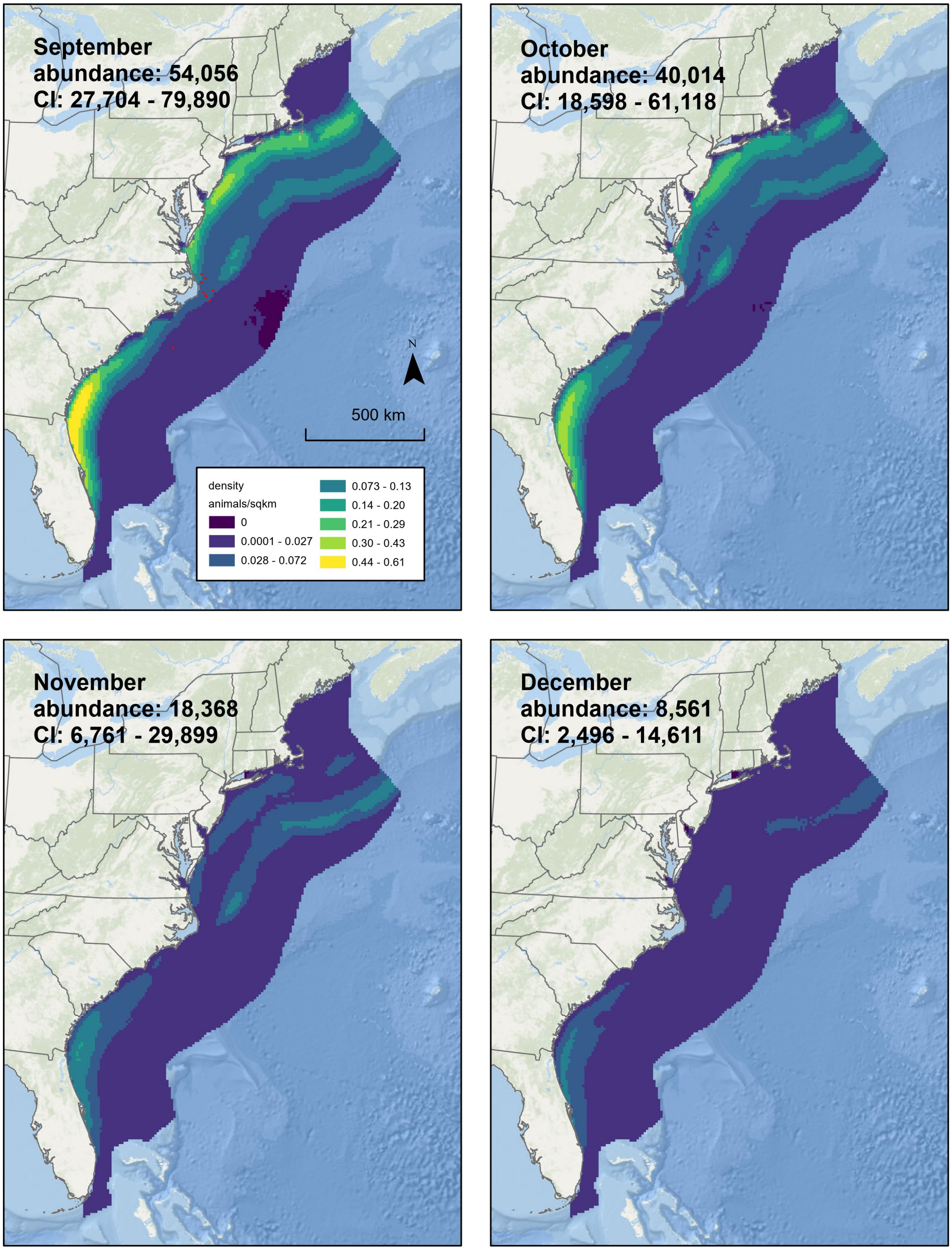

Figure 78. Predicted Leatherback Turtle Density (September–December)

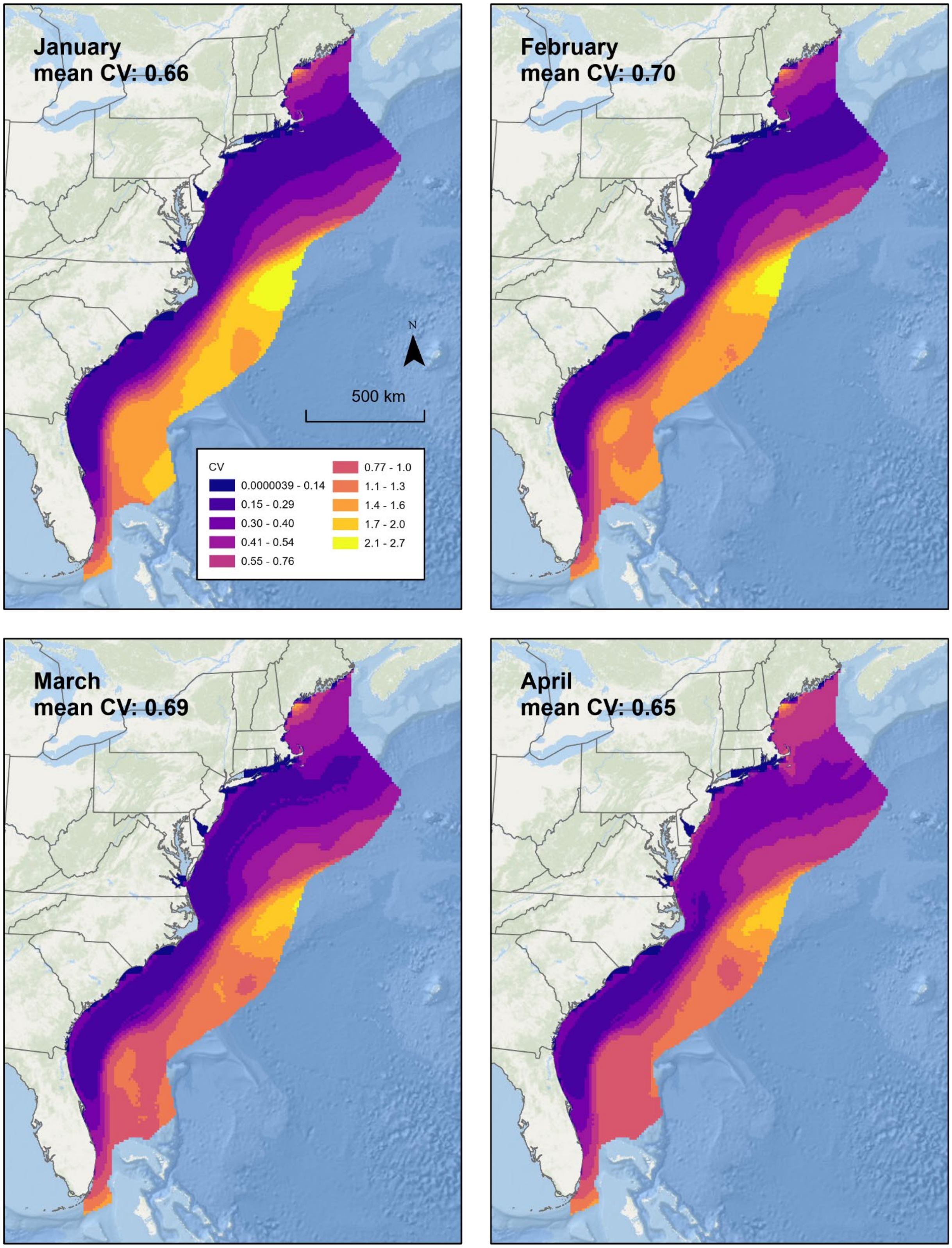

Figure 79. Predicted Leatherback Turtle Uncertainty (CV; January–April)

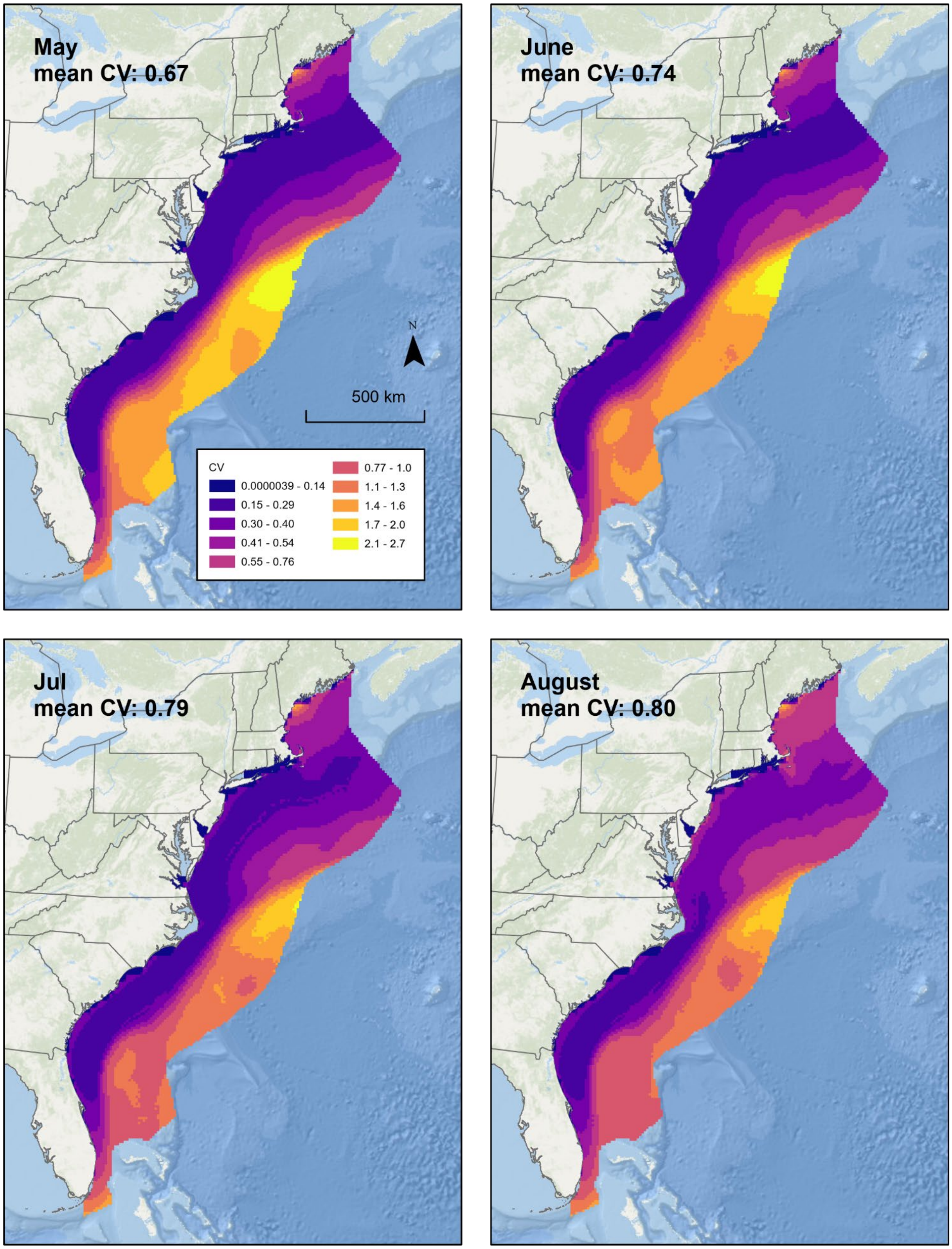

Figure 80. Predicted Leatherback Turtle Uncertainty (CV; May–August)

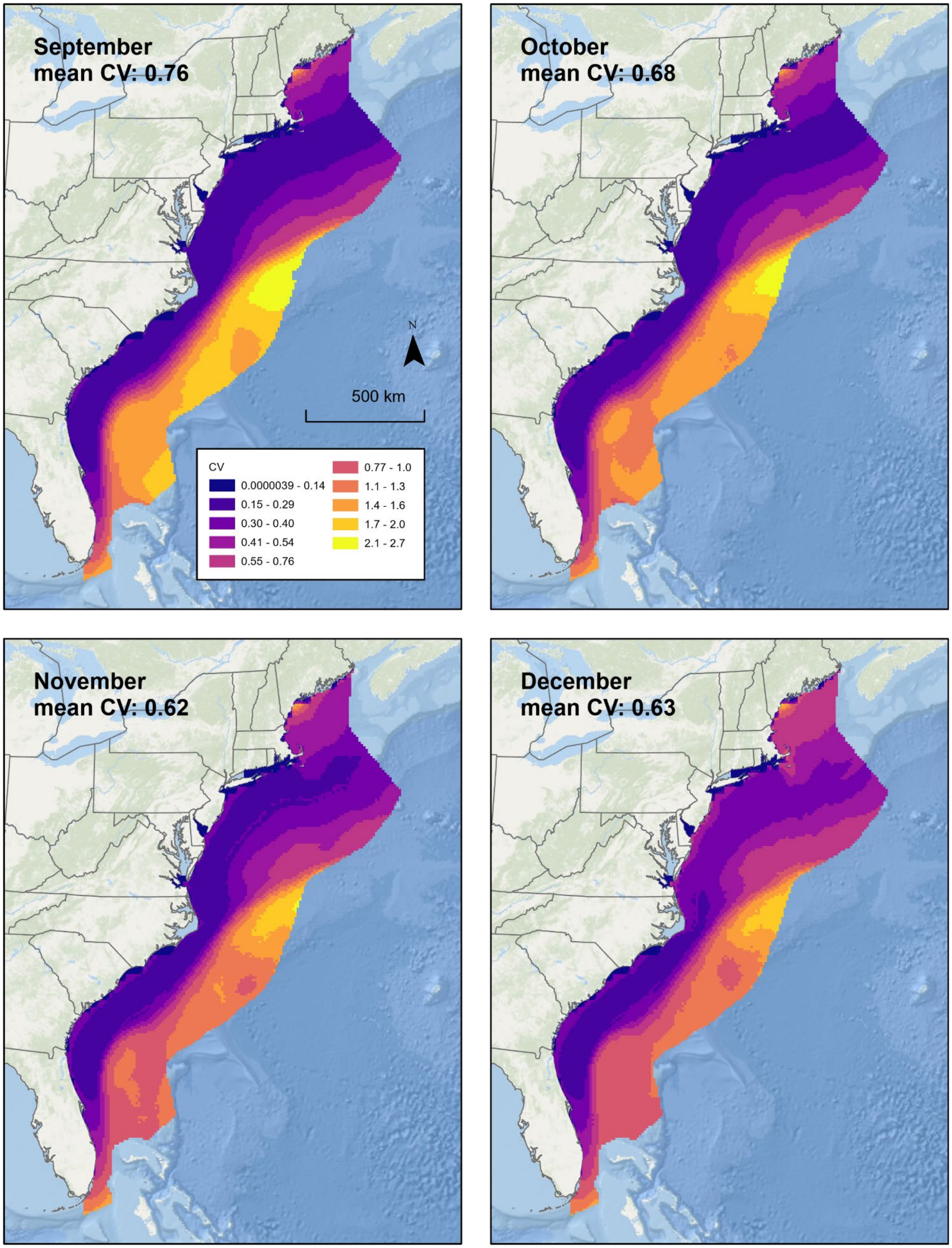

Figure 81. Predicted Leatherback Turtle Uncertainty (CV; September–December)

5. CONCLUSIONS

This project presents the first models of sea turtle density and distribution produced for the US east coast in over a decade (Department of the Navy 2007) and the first to deal with unidentified hardshell turtle sightings in a manner that directly incorporates those sightings into species-specific models. The predicted patterns of density match the underlying sightings reasonably and concur with other, independent datasets, such as satellite telemetry and strandings data. The only exceptions were the predictions of green and Kemp's ridley turtles further north than is known from any sightings, which was dealt with by including latitudinal cutoffs derived from independent data. Predicted abundances ranged from several thousand for Kemp's ridleys to several hundred thousand for loggerheads, and these predictions were in line with the relative abundances of these species known from nesting data in the region (Florida Fish and Wildlife Commission Research Institute 2022a, b).

Few comparisons of abundance to other spatial density models or demographic estimates exist. For loggerhead turtles, the NODES data and Chesapeake Bay-specific estimates from Barco et al. (2018a) were used in the last round of Navy environmental compliance efforts. The NODES data predicted approximately 102,000 loggerheads and 63,000 unidentified hardshell turtles (presumably mostly loggerheads) compared to 138,000 loggerheads predicted here, and the two predictions were statistically similar when accounting for uncertainty. Preliminary AMAPPS estimates provided to the Navy in 2010 predicted approximately 800,000 loggerheads in a similar study area but used a very low estimate for g(0) in the southern portion of the study area (0.07), which we would now consider deprecated based on AMAPPS' own updated data. The early AMAPPS estimate is much higher than the prediction developed here but may be an artifact of using different availability bias estimates.

The NODES estimate for Kemp's ridleys was an annual estimate of 9,601 for turtles on the shelf, compared to 10,762 turtles predicted here, and that estimate did not include unidentified hardshell turtles in any way. The estimates are similar when accounting for uncertainty. There are no comparable estimates for green turtles.

The NODES estimates for leatherback turtles was approximately 4,000 on the shelf for winter and 7,500 on the shelf for summer. At the time of the NODES estimates, offshore survey data was limited, and no attempt was made to model those regions. A smear of values at the edge of the shelf to offshore areas gave estimates of 19,000 animals in the winter and 61,000 in summer. The leatherback model developed here predicted an annual mean of approximately 22,000 animals, similar to the winter abundance predicted by the smeared NODES data. However, because the NODES data was a spatial extrapolation, the comparison may be spurious. A more detailed comparison between NODES and the models developed here will be available in the AFTT Phase IV density technical report, currently under development.

The predicted patterns of density match the underlying sightings reasonably and concur well with other independent datasets, such as satellite telemetry and strandings data. Winton et al. (2018) presented a geostatistical mixed model of relative loggerhead turtle density based on 271 satellite tagged animals deployed in the region and predicted similar north/south movements as the loggerhead spatial density model presented here. Winton et al. (2018) did predict higher relative densities off the continental shelf in cool months, compared to the spatial density model, but the core distributions appear similar. Loggerhead strandings are regularly detected north of Cape Cod (Mass Audubon 2022), supporting the presence of that species in the Gulf of Maine. Loggerheads are also regularly captured in fisheries off the coast of Nova Scotia and have been confirmed to have their origin in the study area (Ceriani et al. 2014). The area south of Cape Hatteras has been designated as critical habitat for overwintering loggerhead turtles based on satellite telemetry data (National Oceanic and Atmospheric Administration 2014) and was picked up by the spatial density model as an area of relatively high density in those months.

Fewer supporting datasets exist for green and Kemp's ridley turtles in the region. The satellite tracks that do exist, as well as acoustic tagging data from the Chesapeake Bay, established similar timing of migration as is predicted by the spatial density models (Barco et al. 2018b). The models did predict green and Kemp's ridley turtles further north than confirmed by sightings and tracking data (e.g., in the Gulf of Maine). These predictions were at very low densities, generally less than 0.005 animals/km^2 and are likely artifacts of covariates relationships.

Recent tracking data indicates the presence of leatherback turtles in the study area year-round (Sasso et al. 2021; Rider, Haas, and Sasso 2022), including migrating through the study area in late summer and early fall. Migratory pathways span close to the coastline to far offshore, beyond the boundaries of the study area (James, Sherrill-Mix, and Myers 2007). Leatherbacks tagged in Massachusetts and North Carolina ranged throughout the study area (Rider, Haas, and Sasso 2022), and nesting areas for nesting females exist off the coast of Florida (Eckert et al. 2006). The spatial density model did not predict north/south shifts in presence so much as increases in abundance in warmer months and less in cooler months, consistent with more animals moving into the study area at the beginning of the warm season to breed and leaving in fall.

It is worth highlighting the sources of uncertainty and variability not accounted for in the CV and CI estimates, which include (1) environmental variability relative to GAM parameter uncertainty, (2) detection function uncertainty, (3) variability and uncertainty in the dive data and models used for availability bias estimates, and (4) misidentification or misclassification of unidentified sightings. The CV and CI estimates presented should be considered minimum estimates until future work can incorporate more sources of uncertainty. Lastly, turtles smaller than 40 centimeters (15.7 inches) are likely being missed by surveys, and they represent a sizable proportion of the population of all sea turtle species. As such, we posit that these models underestimate density to an unknown degree.

Expanded discussion will be available in a peer-reviewed document currently under review.

6. RECOMMENDATIONS

These models are appropriate for use in broad-scale planning and conservation initiatives, such as military training and readiness, offshore energy development, marine spatial planning on the scale of the eastern seaboard or subregions, critical habitat designations, and other applications that require broad-scale estimates of density and distribution. The models should not be used for fine-scale planning (e.g., how many animals are in a single cell) or for trend analysis. The models represent a long-term average of abundance over 16 years, where survey effort was heterogeneous, making this study poorly suited to predict population trends. Repeated, systematic surveys covering the same area are required for trend analyses, such as the AMAPPS surveys.

Priorities for future work include the following:

- Incorporating more sources of uncertainty into the CV and CI estimates, which recent research has shown is possible (Bravington, Miller, and Hedley 2021);
- Creating spatial models of availability bias for the non-loggerhead turtle models;
- Revisiting strategies to deal with unidentified sightings or updating the machine learning model; and
- Incorporating new surveys and survey types as they become available.

As we have seen with similar efforts for marine mammals, there are always improvements to be made as the best available science and methods for creating spatial density models continue to evolve. The models presented here represent a significant improvement both methodologically and in the data used compared to the NODES models of 10 years ago, but many possible improvements remain to be implemented.

APPENDIX A— SPATIAL DENSITY MODEL PREDICTIONS OVERLAID WITH SIGHTINGS AND EFFORT

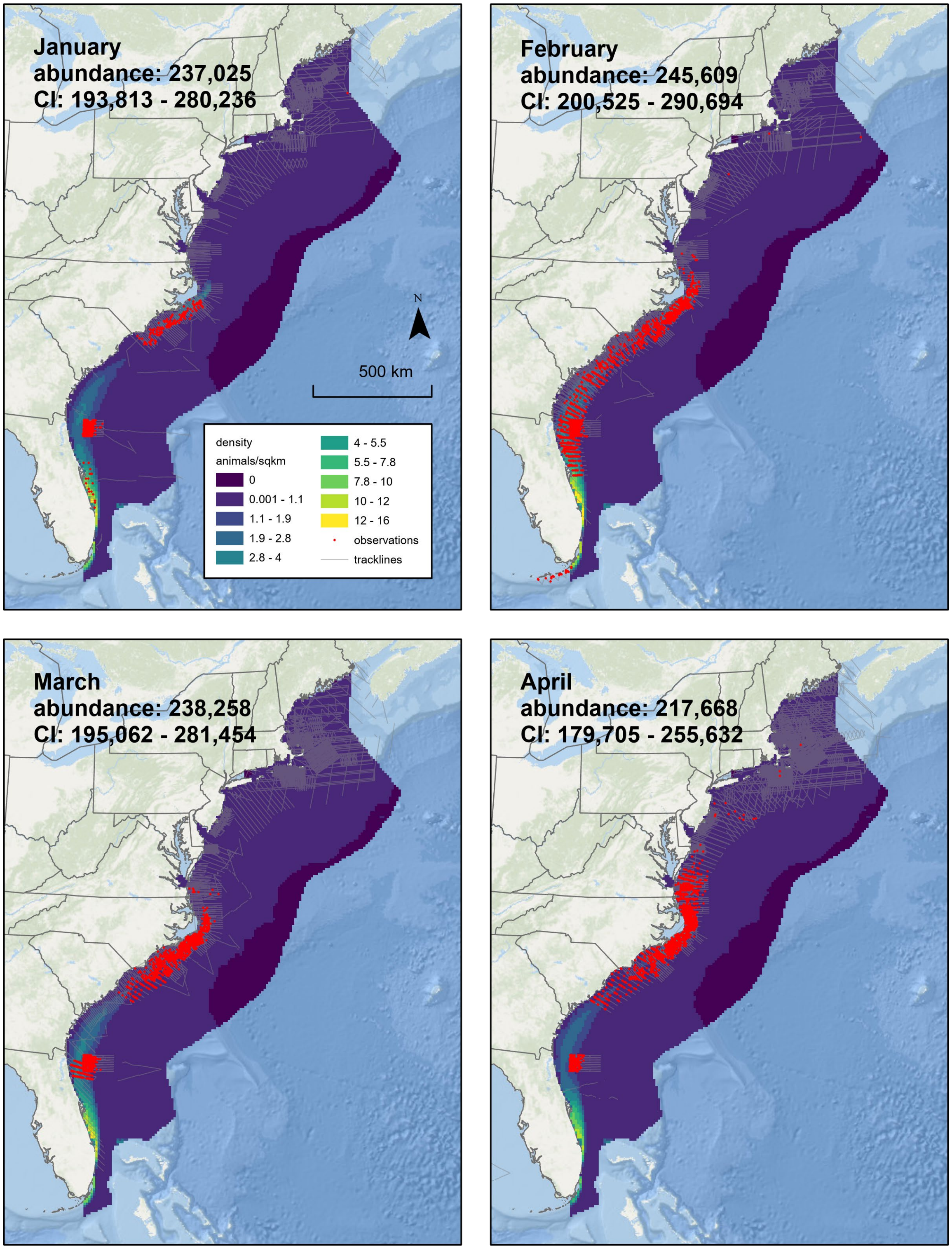

Figure 82. Loggerhead Turtle Spatial Density Model Predictions Overlaid with Sightings and Effort (January–April)

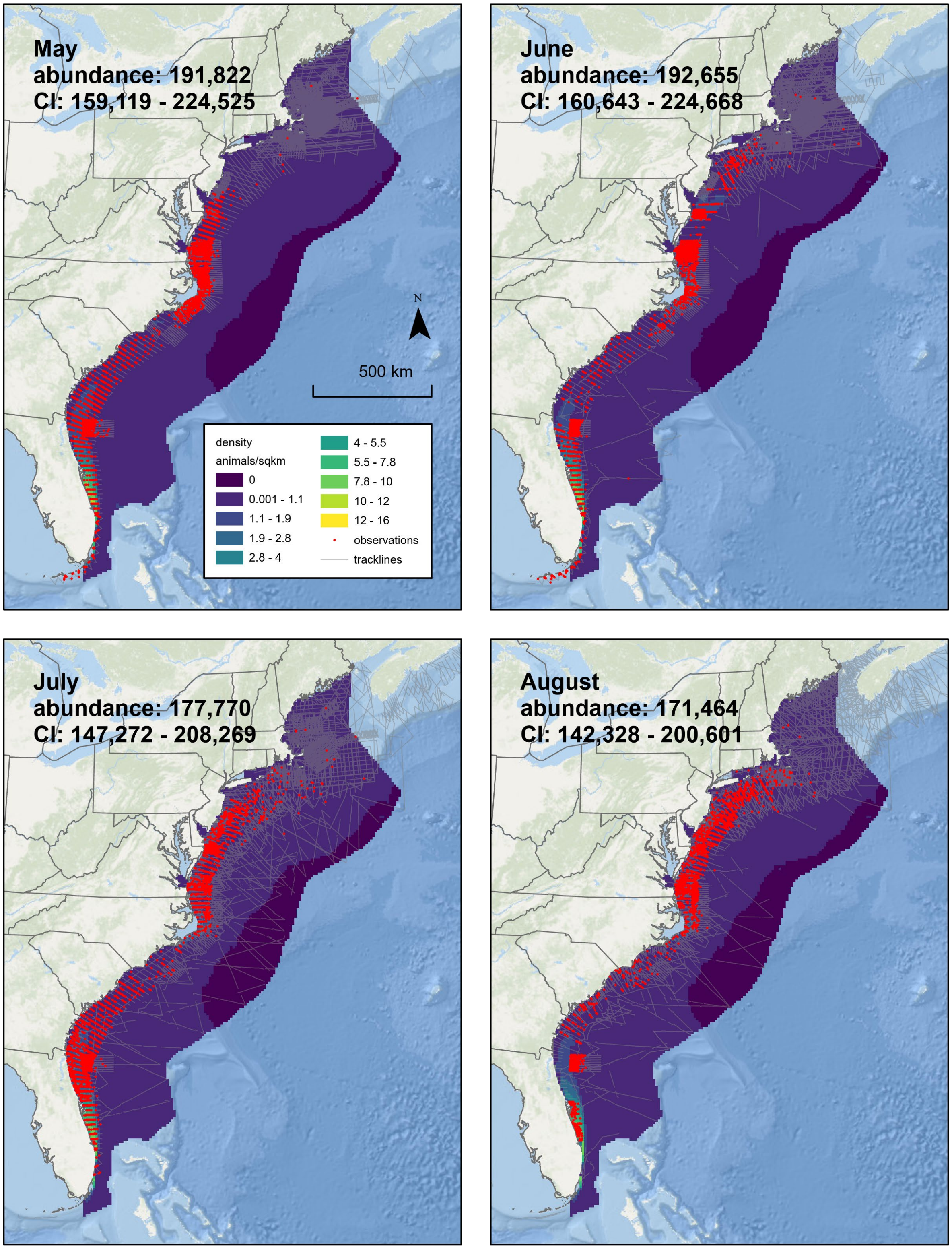

Figure 83. Loggerhead Turtle Spatial Density Model Predictions Overlaid with Sightings and Effort (May–August)

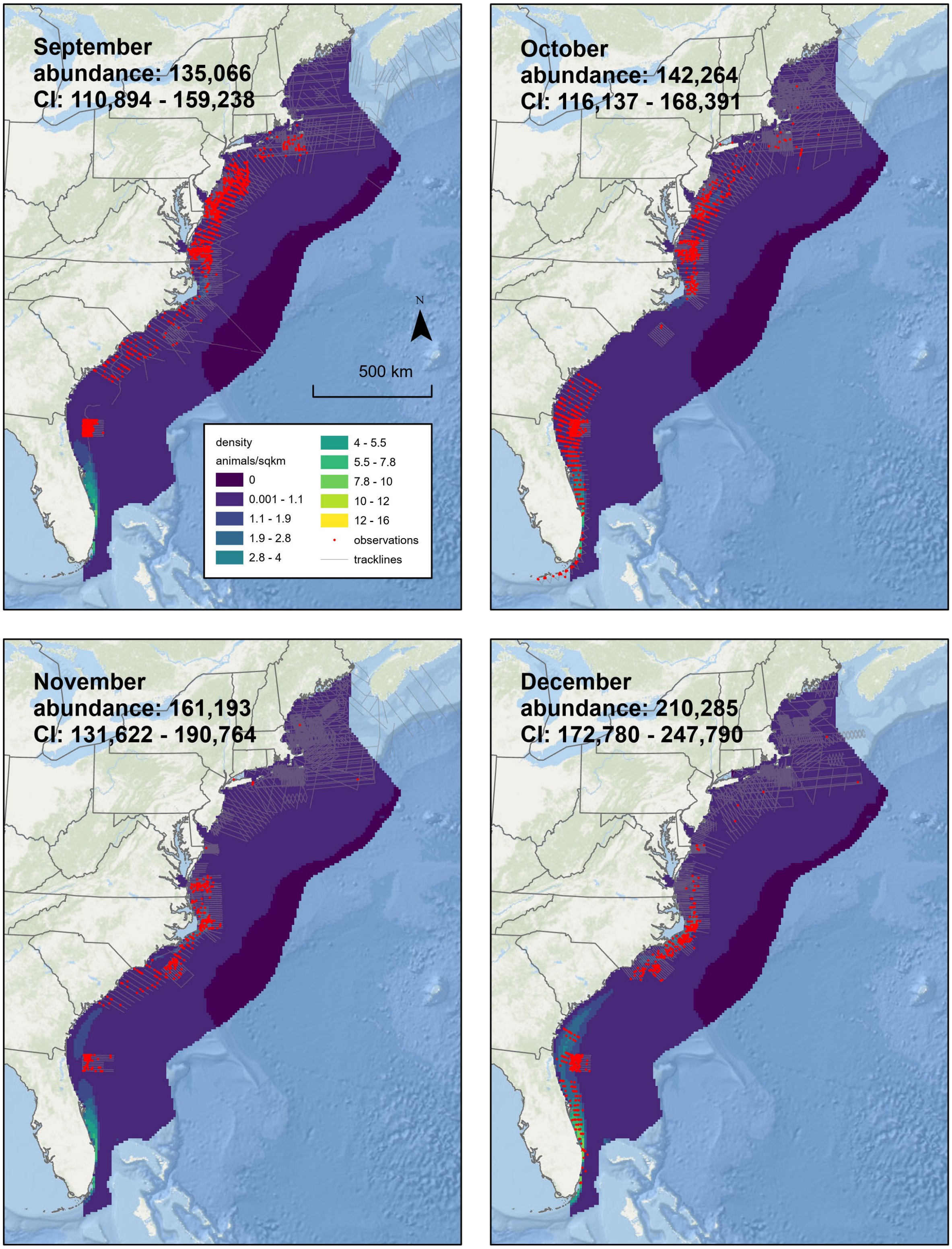

Figure 84. **Loggerhead Turtle Spatial Density Model Predictions Overlaid with Sightings and Effort (September–December)**

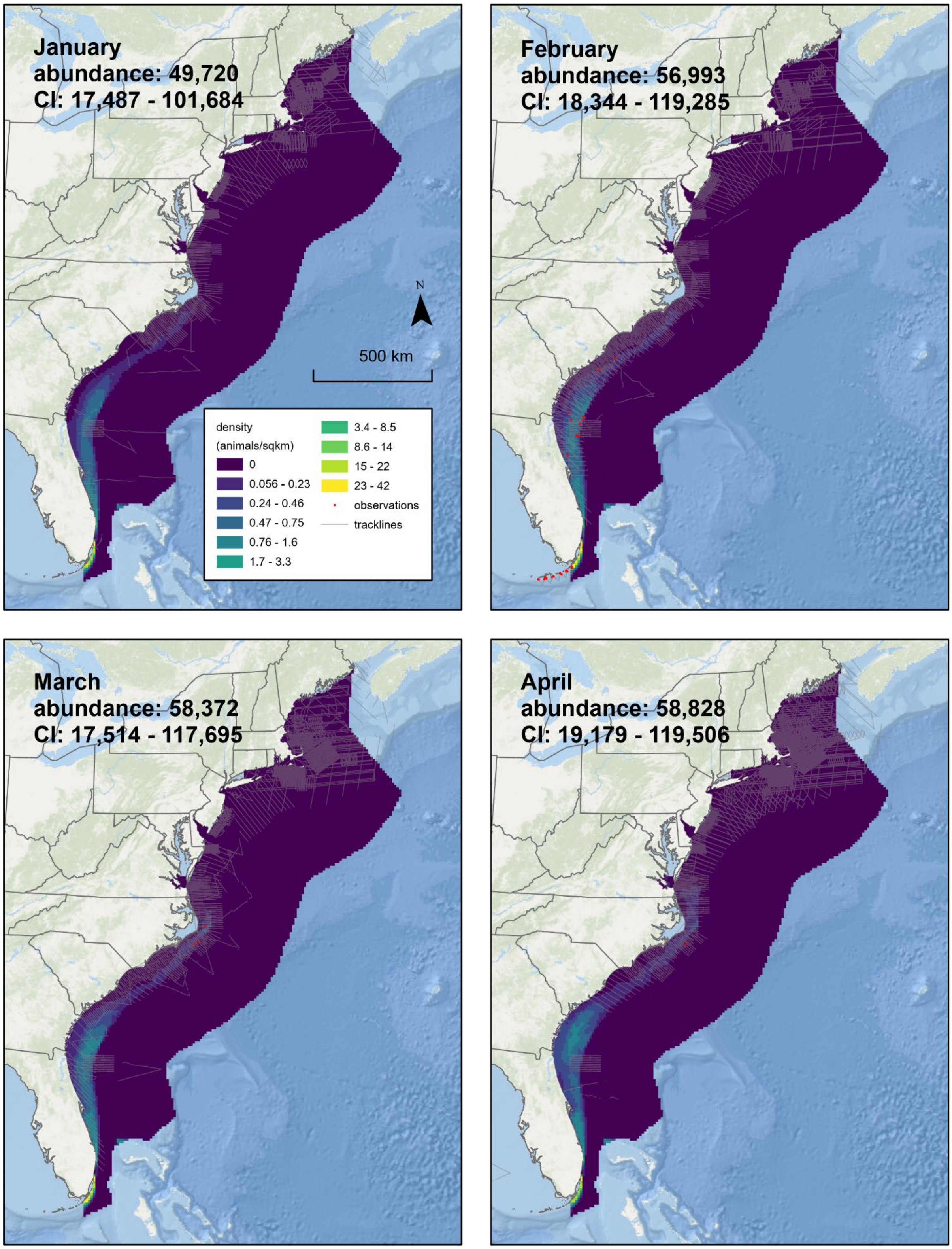

Figure 85. Green Turtle Spatial Density Model Predictions Overlaid with Sightings and Effort (January–April)

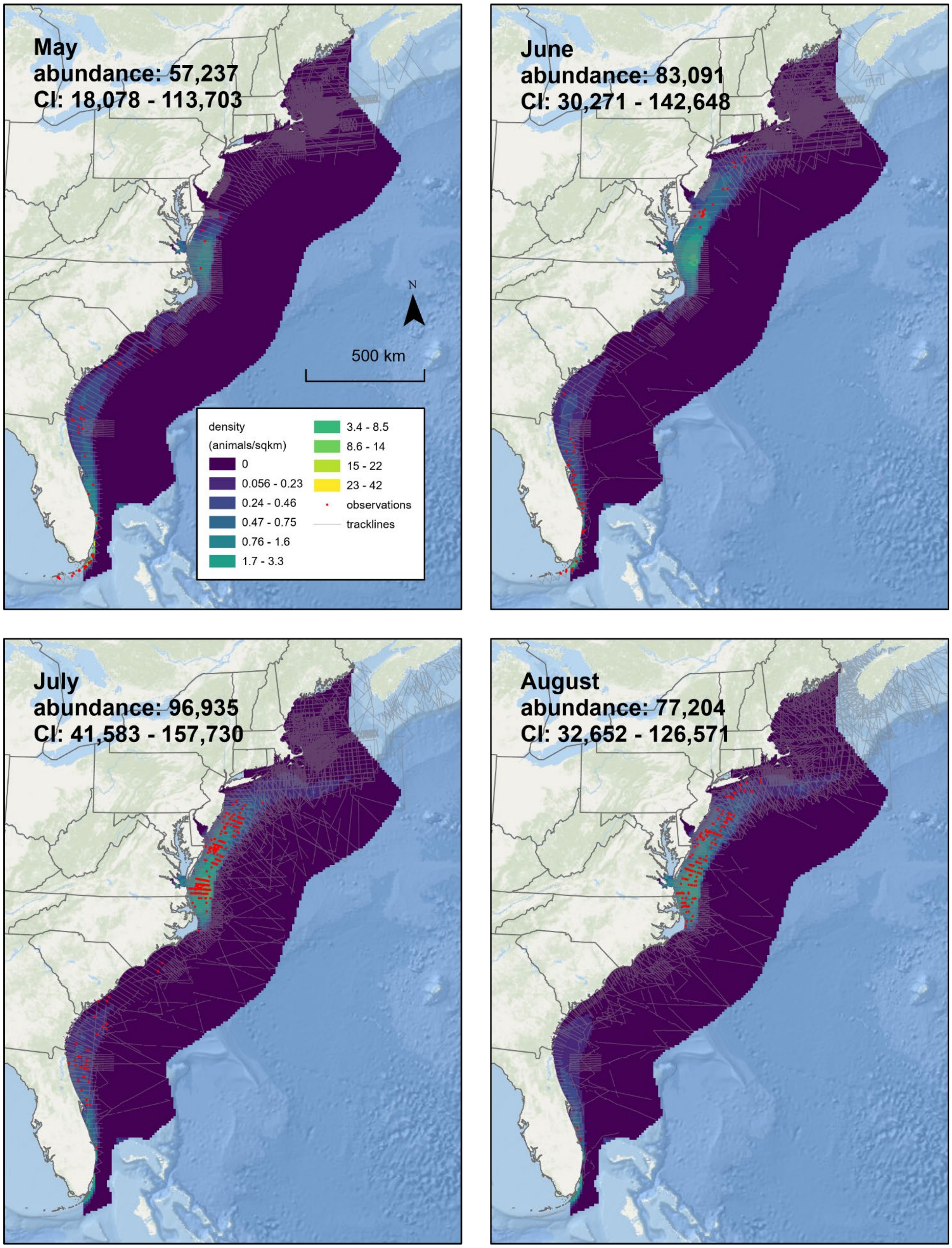

Figure 86. Green Turtle Spatial Density Model Predictions Overlaid with Sightings and Effort (May–August)

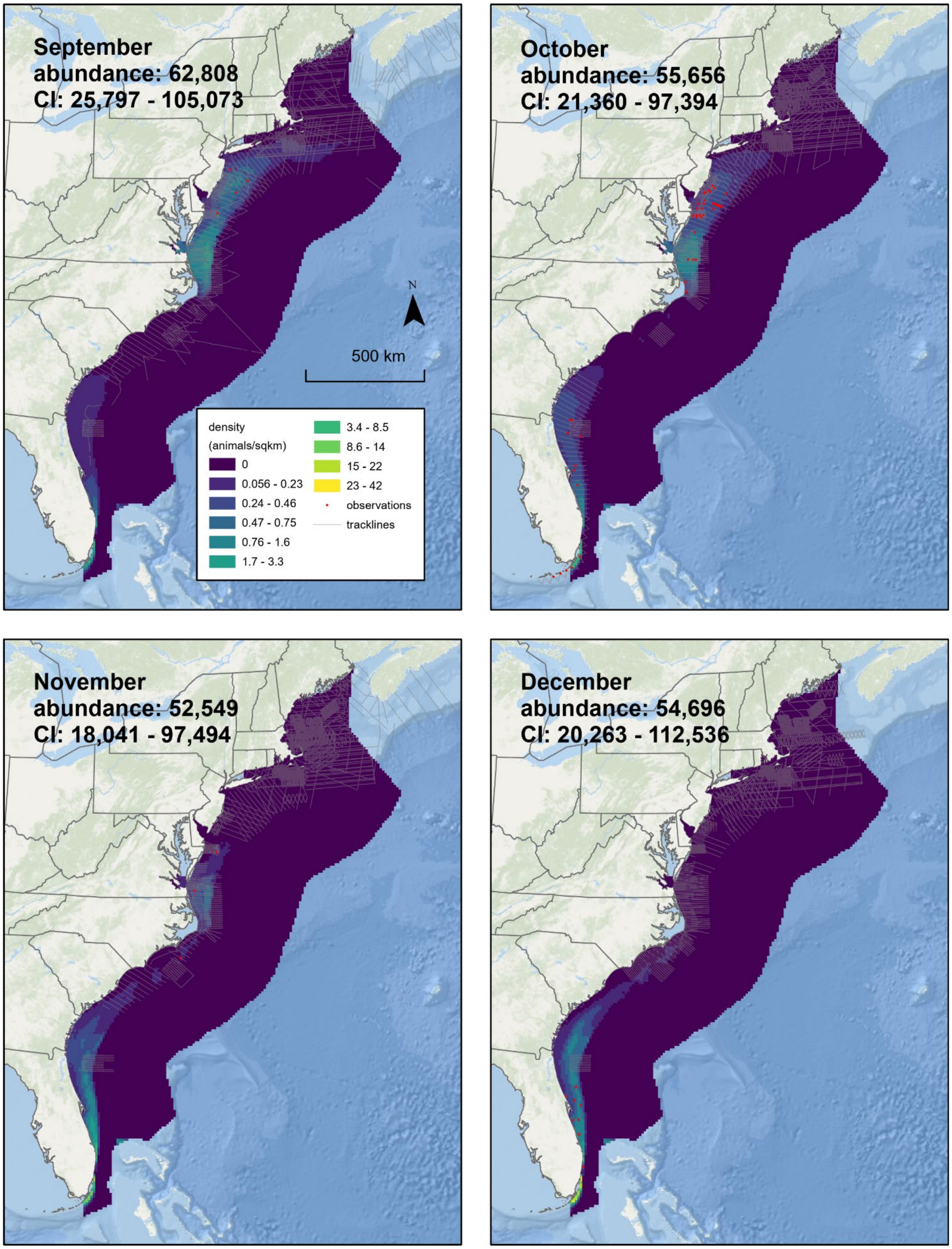

Figure 87. Green Turtle Spatial Density Model Predictions Overlaid with Sightings and Effort (September–December)

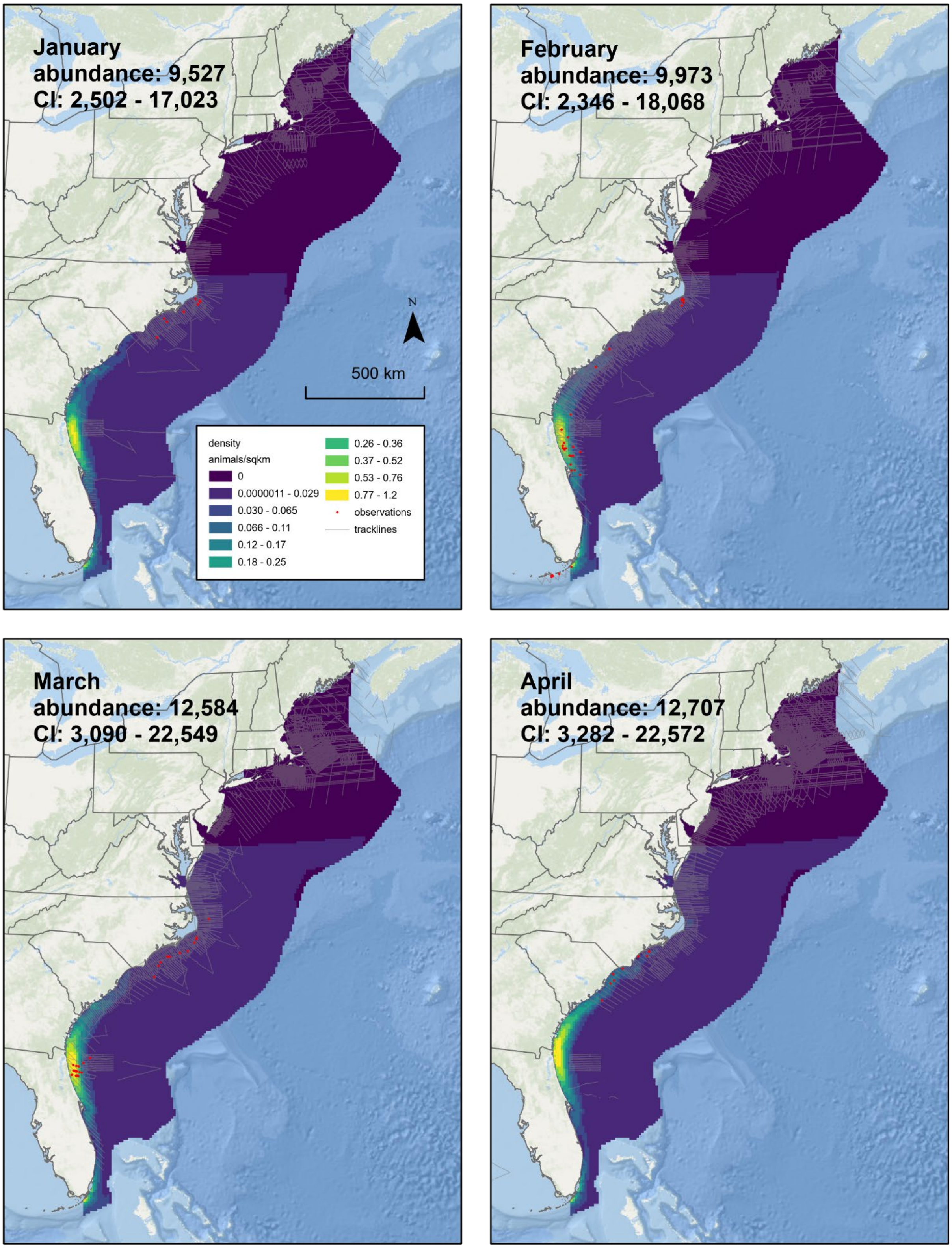

Figure 88. Kemp's Ridley Turtle Spatial Density Model Predictions Overlaid with Sightings and Effort (January–April)

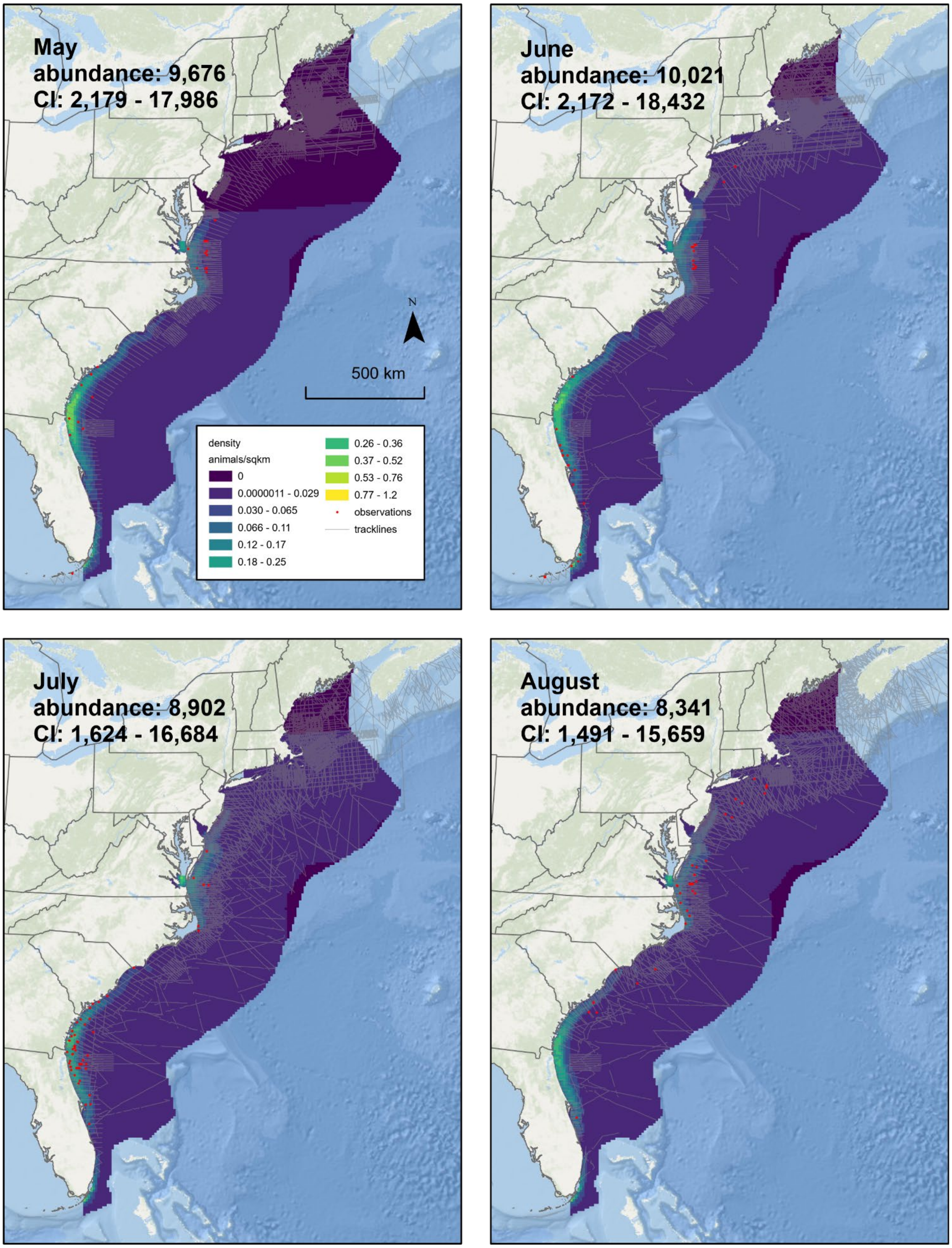

Figure 89. Kemp's Ridley Turtle Spatial Density Model Predictions Overlaid with Sightings and Effort (May–August)

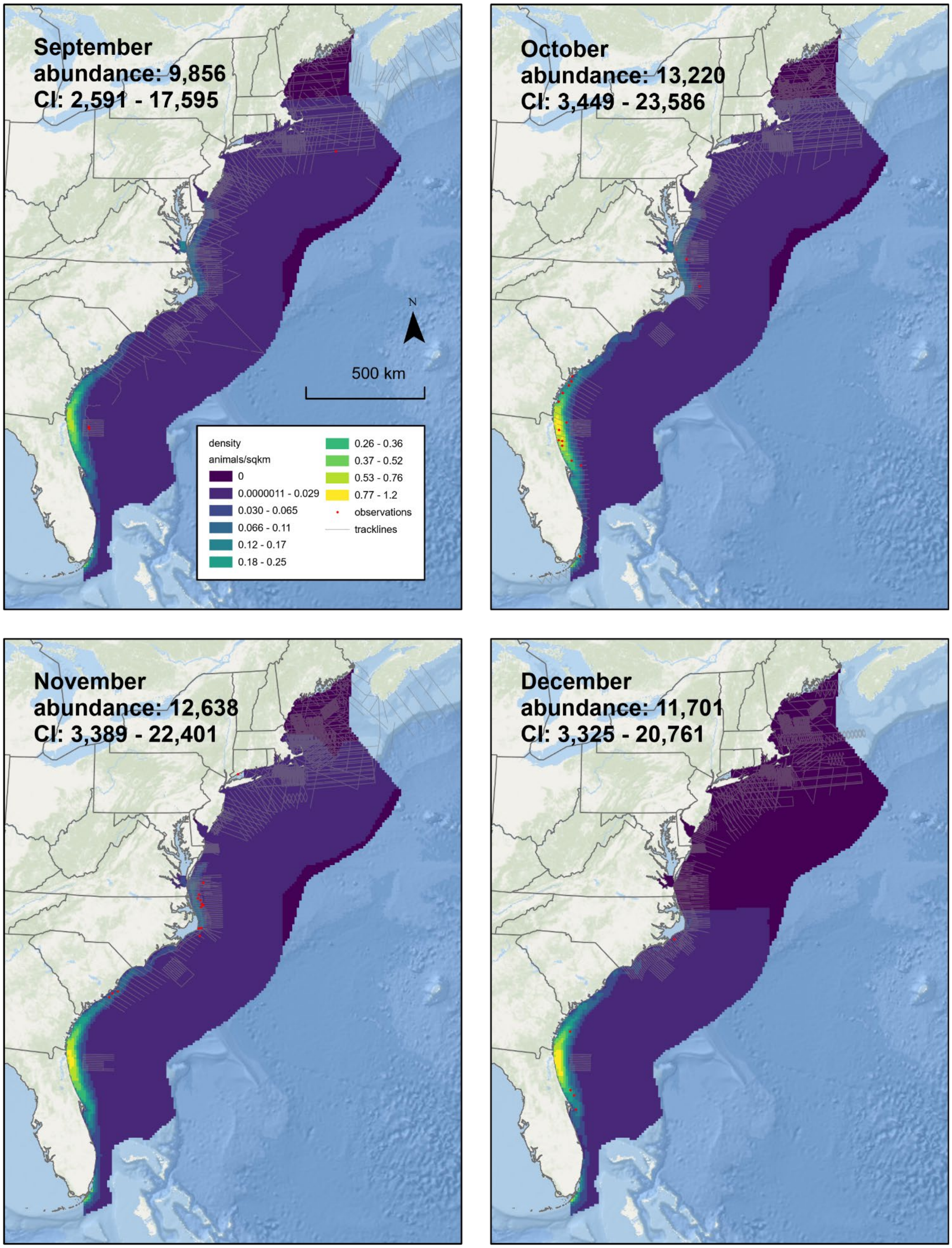

Figure 90. **Kemp's Ridley Turtle Spatial Density Model Predictions Overlaid with Sightings and Effort (September–December)**

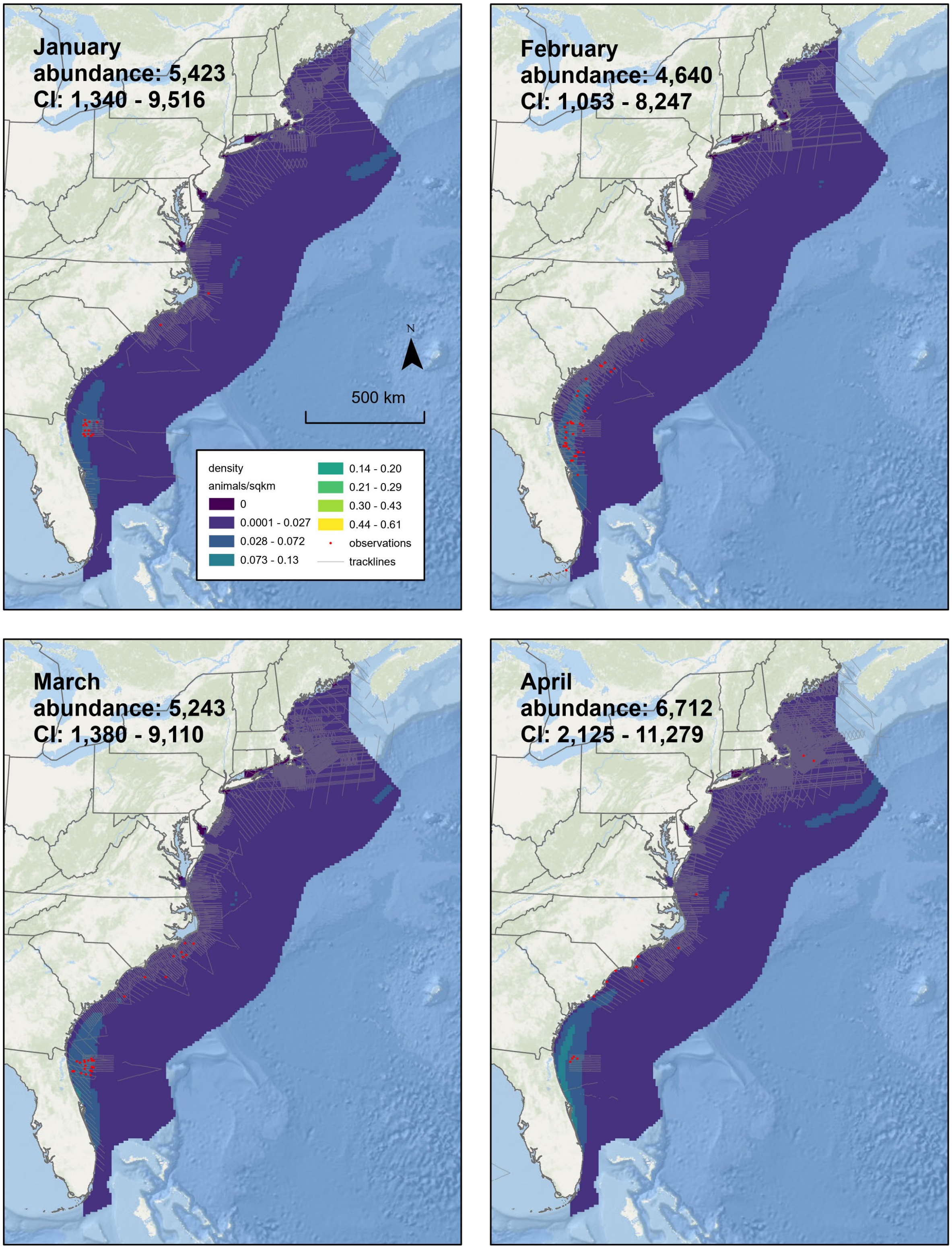

Figure 91. Leatherback Turtle Spatial Density Model Predictions Overlaid with Sightings and Effort (January–April)

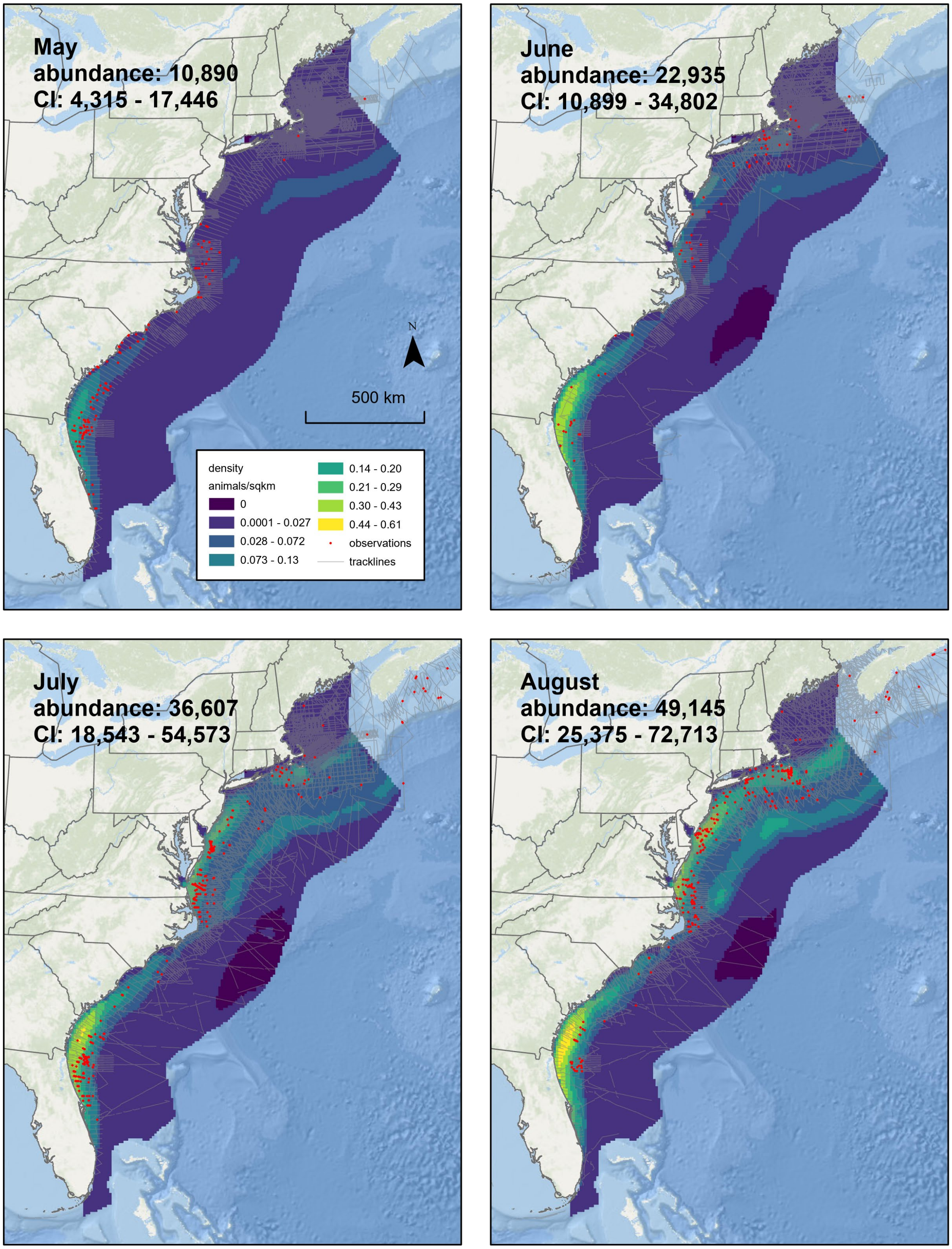

Figure 92. Leatherback Turtle Spatial Density Model Predictions Overlaid with Sightings and Effort (May–August)

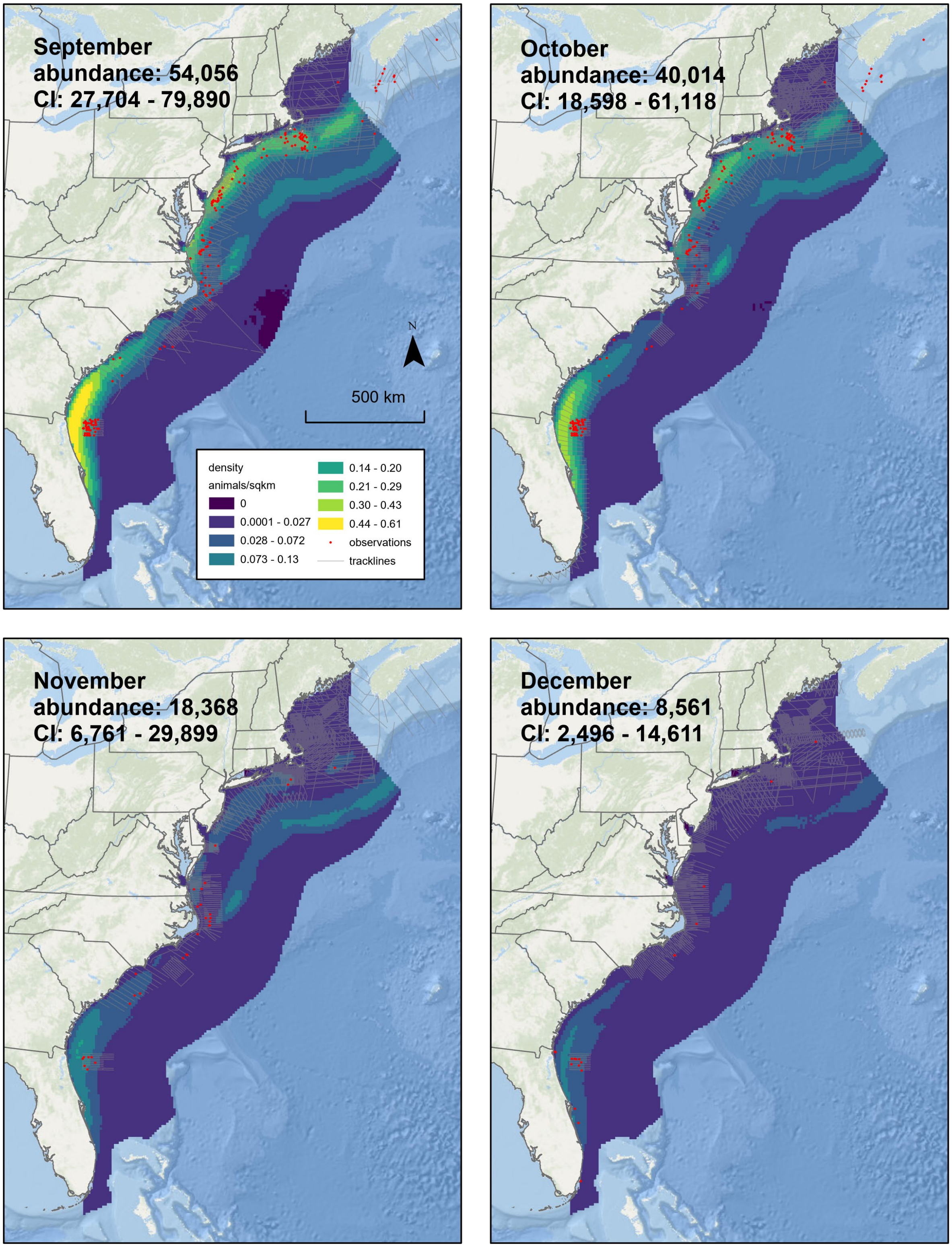

Figure 93. Leatherback Turtle Spatial Density Model Predictions Overlaid with Sightings and Effort (September–December)

APPENDIX B — REVISION CHANGE LOG

REVISION	CHANGE	RELEASE DATE
A	In November 2023, the leatherback sea turtle density predictions were updated to correct a problem where an incorrect perception bias estimate was used.	15 December 2023

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