OCS Study
BOEM 2017-071

Atlantic Marine Assessment Program for Protected Species: 2010-2014

US Department of the Interior
Bureau of Ocean Energy Management
Headquarters

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DISCLAIMER

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ABOUT THE COVER

The cover is a compilation of various work conducted as part of the AMAPPS project including surveys of cetaceans, sea turtles, seals, seabirds, and general ecosystem conditions. The photos are courtesy of Deborah Palka of the National Marine Fisheries Service and arranged by Stephanie Struthers of BOEM. Surveys and pictures were done under MMPA permit numbers 17355 and 16556 issued to the Northeast Fisheries Science Center and MMPA permit number 14450 issued to the Southeast Fisheries Science Center.

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Abbreviations and Acronyms

AIC	Akaike information criteria
AMAPPS	Atlantic Marine Assessment Program for Protected Species
AMAR	autonomous multichannel acoustic recorder
BEAK	Definite beaked whale acoustic detection
BOEM	Bureau of Ocean Energy Management
CFF	Coonamessett Farm Foundation
CTD	conductivity-temperature-depth
CV	coefficient of variation
CvM	Cramer-von Mises goodness of fit test
DIFAR	Directional frequency analysis and ranging
DS	distance sampling
DTAG	digital acoustic recording tag
EEZ	Exclusive Economic Zone
ESA	Endangered Species Act
FSWH	Fin/sei whale
GAM	generalized additive model
H’	Shannon-Wiener index
HARP	high-frequency acoustic recording package
HSI	hot spot index
HYCOM	HYbrid Coordinate Ocean Model
ICI	inter-click-interval
IKMT	Isaacs-Kidd midwater trawl
K-S	Kolmogorov-Smirnov goodness-of-fit test
LFDCS	low-frequency detection and classification system
MARU	marine autonomous recording units
MMPA	Marine Mammal Protection Act
MOCNESS	Multiple opening/closing net and environmental sensing system
MR	mark-recapture
MRDS	mark-recapture distance sampling
NAO	North Atlantic Oscillation
NE	northeast
NEFSC	Northeast Fisheries Science Center
NMFS	National Marine Fisheries Service
OBIS-SEAMAP	Ocean Biogeographic Information System Spatial Ecological Analysis of Megavertebrate Populations
OCS	Outer Continental Shelf
POBK	Possible beaked whale acoustic detection
PRBK	Probable beaked whale acoustic detection
ROC	Receiver operating characteristic
ROCCA	real-time odontocete call classification algorithm
ROI	regions of interest
SD	Standard deviation
SEFSC	Southeast Fisheries Science Center
SE	southeast
SST	sea surface temperatures
USFWS	United States Fish and Wildlife Service

VHF	Very high frequency
VPR	Video plankton recorder
XBT	Expendable bathy thermography

1 Synthesis and Summary

The Atlantic Marine Assessment Program for Protected Species (AMAPPS) is a comprehensive multi-agency research program on the US Atlantic Outer Continental Shelf (OCS), from Maine to the Florida Keys. The overarching objective of AMAPPS is to assess the abundance, distribution, ecology, and behavior of marine mammals, sea turtles, and seabirds throughout the US Atlantic OCS, to place them in an ecosystem context, and to provide spatially explicit density estimates in a format that can be used when making marine resource management decisions. AMAPPS I was conducted during 2010 – 2014 while AMAPPS II is ongoing from 2015 – 2019. This report documents the data collected and analyses completed under AMAPPS I; in addition to ongoing analyses under AMAPPS II.

The main agencies involved are the National Marine Fisheries Service (NMFS), US Fish and Wildlife Service (USFWS), Bureau of Ocean Energy Management (BOEM), and the US Navy. Collaborations have also been built with numerous other national and international organizations.

Because marine ecosystems are complex and involve dynamic assemblages of many co-existing species, to understand these marine ecosystem processes and achieve the AMAPPS objectives, research was integrated across taxonomic groups, among trophic levels and used a suite of data collection and analytical techniques. To enumerate distribution and abundance, the following types of data were collected: visual sightings of cetaceans, seabirds, sea turtles, and seals from shipboard and aerial surveys (Chapter 5, 6, 7 and 10; Appendix I, II, III and IV); acoustic detections of vocalizing cetaceans and fish from ship-towed and bottom-mounted passive acoustic recorders (Chapter 8); and location/depth information derived from various types of tags (though some of the tags were purchased by projects outside of AMAPPS) that were deployed on turtles (Chapter 9), seals (Chapter 10) and cetaceans (Chapter 5). To place all of these data into an ecosystem context, spatially- and temporally-explicit static and dynamic remotely sensed data were compiled (Chapter 5), *in situ* data were collected on physical oceanographic characteristics and biological data of plankton, fish, and other trophic levels, and these ecosystem habitat-type data were compared to the local densities of target species (Chapter 11; Appendix V). Completed and ongoing analyses of these data are listed in Table 1-1 and summarized below. Published, in-review, and in-prep papers that resulted from this research are listed in Table 1-2.

Cetaceans. Cetacean location data were recorded on NMFS-led surveys during all seasons of the year from about 125,000 km of track line covered during shipboard and aerial surveys that also resulted in about 2000 hours of towed passive acoustic hydrophone data from the shipboard surveys. During the shipboard and aerial surveys, about 60,500 individual cetaceans, 200 seals, 24,500 seabirds, 5500 turtles, 800 ocean sun fish and 200 basking sharks were visually detected. In addition, cetacean presence was documented acoustically at 15 sites for varying periods of time using bottom-mounted recorders, whose deployments/retrievals were conducted during AMAPPS surveys (though the recorders were purchased by projects outside of AMAPPS).

Using shipboard and aerial survey line-transect data, dive time pattern data, and habitat data, spatially- and temporally-explicit density maps and abundance estimates were derived for 18 species or species guilds of cetaceans and seals using mark-recapture, covariate Distance sampling and Generalized Additive Modeling analytical techniques (Chapter 5; Appendix I). Distribution of other rarely detected cetacean species were plotted (Appendix II). The density maps and resulting abundance estimates were depicted as seasonal averages over 2010 – 2013 along with two measures of variability: the coefficient of variation (CV) and the upper and lower 95% confidence estimate. The 2014 survey data were used to investigate the robustness of the models derived from the 2010 – 2013 data. In the case of many species, the abundance estimates presented here are higher than previously published abundance estimates (for example those in Waring et al. 2016). This is primarily because we now reduced the negative bias presented in previous estimates by accounting for availability bias (bias due to animals that are below the surface and therefore not available to be counted from visual observers in the shipboard and aerial surveys). An additional benefit of using the Generalized Additive Model framework to estimate abundance is the ability to derive density maps and abundance estimates over other temporal and spatial scales which can facilitate future management needs.

Passive acoustic monitoring of vocalizing whales using towed and bottom-mounted recorders complement the distribution results from the above visual sighting analyses (Chapter 8). For example, beaked whale guild (*Mesoplodon* and *Ziphius*) density models in Chapter 5 were developed for only summer because this was the time when line transect surveys were in beaked whale habitat (shelf break and deeper waters). To complement the visual analysis, the nearly year-round (July 2014 – May 2015) acoustic detections of vocalizing beaked whales extracted from a bottom-mounted recorder indicated at least some beaked whales are present on the shelf break throughout the year, though the species composition may vary seasonally. To fully utilize the acoustic and visual data, comparisons of the two data types were initiated, though further work is needed. Passive acoustic data may also shed light into population structure. For example, work using towed hydrophone array data collected during shipboard surveys indicated that the characteristics of Risso's dolphin (*Grampus griseus*) echolocation clicks vary geographically. The implications of this new information may influence how future density maps and abundance estimates are interpreted if the variation in vocalizations is associated with different stocks.

Cetacean abundance estimates were derived from several data sources. Abundance estimates were reported as a seasonal average and on a weekly trend basis using line transect data on the broad scale, the entire AMAPPS study area, and on the finer scale of individual wind energy areas (Chapter 5). In addition, the abundance of sperm whales is currently being derived in two additional ways that use data from only towed array passive acoustic and from combining data from visual surveys and towed array passive acoustic data (Chapters 5 and 8).

Work to improve our knowledge of the distribution and abundance of cetaceans is ongoing as part of AMAPPS II (Table 1-1). This includes collecting more visual and passive acoustic data, particularly in times and areas with previously limited effort, and collecting more dive time pattern data from deep diving species. There is also ongoing work to improve analytical methods. For example, a Bayesian hierarchical modeling framework is being developed that estimates the density-habitat distribution and abundance using line transect data that will more fully characterize variance (Chapter 5). An analysis method is being developed that combines passive acoustic and visual line transect data to make more precise abundance estimates of sperm whales that also incorporate availability bias (Chapters 5 and 8). In addition, to more effectively interpret passive acoustic monitoring data, acoustic data are being used to develop species-specific classifiers for odontocete whistles and echolocation clicks, to create a more complete library of large whale vocalizations, and to estimate the depth of deep-diving animals (i.e., beaked whales) using towed array data through new methodology (Chapter 8).

Seabirds. About 130,000 km of track line were surveyed where about 160,000 seabirds were detected. These surveys covered coastal waters (within the 30 m depth contour) with planes and offshore waters (between the 100 m and 4000 m depth contours) with ships.

Spatial distribution patterns were mapped (Appendices III and IV) for many of the seabird species. For the coastal areas, key sites were also identified (Chapter 7 and Appendix IV). The key site analysis showed, depending on the species, high concentrations of individuals off the Outer Banks in North Carolina, in Chesapeake Bay (VA), off eastern Long Island (NY), in the Martha's Vineyard/Nantucket Island region (MA), in Penobscot Bay (ME) and off central coastal Maine. Summer patterns, which changed dramatically from winter patterns, depicted the larger number of seabirds nesting along the coast of Maine. The Shannon Diversity Index showed the seabird diversity was greatest in and offshore of Chesapeake Bay, VA, Cape Cod, MA and Penobscot Bay, ME.

All of the seabird data were supplied to the National Centers for Coastal Ocean Science in Silver Spring, MD and were part of the BOEM study "Modeling At-sea Occurrence and Abundance of Marine Birds to Support Renewable Energy Development" (see Kinlan et al., 2016). Some results of this project are found on the internet at: MarineCadastre.gov (2017).

To assist in developing future abundance estimates, the following issues are being investigated: evaluating statistical distributions that could be used to describe highly right-skewed distribution of flock frequencies (Zipkin et al. 2012); understanding the detectability of the birds and other potential biases; and examining statistical models that could be used to impute species identification on some guilds of species (Chapter 7).

Sea turtles. To document the spatial distribution, dive time patterns and ecology of loggerhead turtles, 180 satellite tags were deployed during 2009 – 2015; 122 were purchased as part of an AMAPPS project and 58 were purchased as part of collaborative project with the Coonamessett Farm Foundation. (Chapter 9). In addition, locations of turtles detected during the shipboard and aerial abundance surveys were plotted (Appendix II).

Daily interpolated positions (n=43,905) from the 169 usable tags were used to estimate relative spatially-explicit densities over the course of the year. During the summer foraging period (May 16 – October 31) relative densities were highest on the continental shelf from Cape Hatteras, NC to Long Island, NY, with additional high density areas along the coast of Georgia and South Carolina. During the rest of the year, relative densities were highest along the coasts of North Carolina and Florida.

Data from these tags were also used in a collaborative investigation into the surface availability of loggerhead turtles, which was part of an ancillary project funded by the US Navy and relevant to AMAPPS (Scott-Hayward et al. 2014). In general, the authors found that the estimated surface availability was highest in the summer months north of Cape Hatteras, NC (north of 38°N) and, when included in the models, at air temperatures between 25°C and 30°C. However, the authors also concluded that, to develop better fitting models, more analytical modeling work and additional tag data from areas with low coverage were needed.

The future plans are to tag loggerheads in the regions of identified gaps in coverage, initiate tagging of other turtle species, and to explore other analytical methods to describe the spatial-temporal distribution of turtles and the spatial-temporal patterns of the availability of turtles to aerial survey observers.

Seals. In 2012, the abundance of harbor seals (*Phoca vitulina*) in the US western North Atlantic was estimated to be 75,834 with a coefficient of variation of 0.153 (Waring et al. 2016). This was estimated by correcting photographic counts of seals on haul-out sites using the fraction of time radio-tagged seals were available to be counted on a haul-out site (Chapter 10).

During June 2013 and January 2015, 10 gray seals (*Halichoerus grypus*) were captured on or near Cape Cod, MA (nine adults in 2013 and one weaned pup in 2015), a suite of biological measurements were collected and the animals were equipped with several types of tags. The locations received from the tags suggest strong site fidelity to Cape Cod waters from summer through late autumn, then movement into Nantucket Sound and adjacent waters, with some trips to offshore waters east/southeast of Nantucket during the pupping/breeding period (about mid-December to early February). Some animals made extended excursions to offshore waters, including one animal that made a round-trip to the vicinity of Sable Island, Nova Scotia. The one weaned pup that was tagged in January 2015 spent most of the month that the tag was active inside the wind energy areas south of Martha's Vineyard (Chapter 10).

A spatially-explicit distribution of seals at-sea was developed by applying the analysis methods described in Chapter 5 to seals sighted at-sea during the aerial abundance surveys (Chapter 10; Appendices I and II). Note this is for any seal species which could be a harbor seal, gray seal or perhaps even harp (*Pagophilus groenlanidicus*) or hooded (*Cystophora cristata*) seals. Seasonal distribution patterns were evident, with concentrations of seals in the summer in waters off Maine and Cape Cod, MA and, in non-summer months, a more dispersed distribution ranging from New York to Nova Scotia.

Ecosystem. To describe the lower trophic levels and oceanographic conditions of the study area and improve our understanding of the spatial linkages among trophic levels, data were compiled from several sources. Satellite imagery, ocean models and bathymetry provided static (e.g., bottom depth and slope) and dynamic (e.g., sea surface temperature and salinity, chlorophyll, and primary productivity) habitat data that were used in the density-habitat models described in Chapter 5. In addition *in situ* sampling was performed during AMAPPS shipboard surveys that included hydrographic, active acoustic backscatter, and plankton data collected using bongo nets, visual plankton recorders, multi opening plankton nets, Isaacs-Kidd midwater trawls, larger midwater trawls and several types of imaging sampling systems (Chapter 11).

Data values from the *in situ* sampling were compared to predicted values from the ocean models and satellite-derived sources. This comparison found that values of some variables like the satellite-derived sea surface temperature were very similar to the *in situ* values for the same time and place. In contrast, some of the ocean model derived factors, such as surface salinity did not correspond as well to the *in situ* values (Chapter 5).

Identification of the ichthyoplankton from these AMAPPS surveys included larval bluefin tuna, *Thynnus thynnus* (Chapter 11). The presence of this species in the off-shelf plankton samples may represent a new slope sea spawning area (Richardson et al. 2016). Further offshore sampling targeting larval bluefin tuna is planned to confirm and delineate the new spawning area. In addition, samples of various salps and fish species were collected for other researchers to further the knowledge on these species and have result in several journal publications and conference presentations (Table 1-2; Chapter 11).

An analysis conducted on data collected from a portion of the 2011 shipboard survey integrated the presence/absence distribution of cetaceans with the distribution of different types of organisms represented by categorized active acoustic backscatter data from the EK60, along with distribution of the physical water characteristics (LaBreque 2016). This analysis showed there was a statistical association between the locations of common dolphins (*Delphinus Delphis*) and Euphausiid-like scattering over the shelf within a cold pool of water, though this does not imply a predator-prey relationship. Euphausiid are small shrimp-like crustaceans that are eaten by most whales and some dolphins. In contrast, the spatial distribution of striped dolphins (*Stenella coeruleoalba*) was statistically associated with fish-like scattering at the shelf break and offshore of the shelf break in warmer waters. The shelf break frontal region appeared to demarcate a transition zone from common dolphin sightings to striped dolphin sightings. Under AMAPPS II, similar analyses that compare the distribution and relative densities of backscatter data to that of cetaceans are currently underway.

Table 1-1 List of AMAPPS I projects completed and ongoing

Category	Project	Current Target species	Chapters and Appendices
Abundance, Distribution, Ecosystem	Distribution and abundance using line transect data in Generalized Additive Model framework	Cetaceans	5, Appendices I and II
Abundance, Distribution, Ecosystem	Distribution and abundance using line transect data in Bayesian hierarchical model framework	Cetaceans	5
Abundance	Abundance of vocalizing sperm whales using only acoustic data	Sperm whales	8
Abundance	Abundance of sperm whales using passive acoustic and visual sightings data	Sperm whales	5, 8
Abundance-supporting	Develop correction factors to account for availability bias of visual survey data	Cetaceans, harbor seal, loggerhead turtles, birds	5, 7, 8, 9
Abundance-supporting	Extract static and dynamic habitat values from satellite-based and model-based online sources	Cetaceans, turtles, birds, seals	5
Abundance-supporting	Evaluate model-based habitat output to *in situ* sources	Cetaceans, turtles, birds, seals	5
Abundance-supporting	Utilize sightings data from groups with ambiguous species identification	Cetaceans	5
Abundance-supporting	Develop methodology for 3-D acoustic localization of deep-diving species to correct perpendicular distance calculation to acoustic detections	Cetaceans	8
Abundance-supporting	Estimate ages of loggerhead turtles expected to be found in AMAPPS study area to include in correction factor for availability	Loggerhead turtles	9
Abundance-supporting	Evaluate statistical distributions describing right-skewed distribution of seabird group sizes	Birds	7
Behavior, Distribution	Within water column distribution of beaked whales using acoustic data	Beaked whales	8

Behavior, Distribution	Within water column distribution of turtles using tag data and underwater remote vehicles	Loggerhead turtles	9
Category	**Project**	**Current Target species**	**Chapters and Appendices**
Distribution	Distribution of cetaceans using acoustic data	Cetaceans	8
Distribution	Distribution of turtles using individual tag data	Loggerhead turtles	9
Distribution-supporting	Characterize acoustic repertoire and vocal behavior	Cetaceans	8
Distribution-supporting	Effects of echosounder use on beaked whale detection rates	Beaked whales	8
Ecosystem	Distribution of protected species relative to other trophic levels and physical oceanographic characteristics	Cetaceans	5, 11
Ecosystem-supporting	Distribution of plankton, fish and other trophic levels	Other trophic levels	11, Appendix V
Ecosystem-supporting	Distribution of *in situ* physical oceanographic characteristics	-	11
Ecosystem-supporting	Ground-truth EK60 echosounder data with sampling	Other trophic levels	11
Outreach	Disseminate maps and abundance estimates to the public	Cetaceans	5

Table 1-2 List of products resulting from data collected under AMAPPS
List of published papers (A), papers in review (B), papers in preparation (C), conference or meeting presentations (D), databases (E), and web sites (F). Authors directly working on AMAPPS projects are in bold.

A. REFEREED/TECHNICAL PAPERS:

1. **Avens L**, Goshe LR, Pajuelo M, Bjorndal KA, MacDonald BD, Lemons GE, Bolten AB, Seminoff JA. 2013. Complementary skeletochronology and stable isotope analyses offer new insight into juvenile loggerhead sea turtle oceanic stage duration and growth dynamics. Mar Ecol Prog Ser. 491: 235-251.

2. Batta-Lona PG, Maas A, O'Neill R, Wiebe PH, Bucklin A. 2016. Transcriptomic profiles of spring and summer populations of the Southern Ocean salp, *Salpa thompsoni*, in the Western Antarctic Peninsula region. Polar Biol. 40: 1261–1276 doi:10.1007/s00300-016-2051-6.

3. **BOEM (Bureau of Ocean Energy Management).** 2012. Surveys and spatial distribution of protected species in the Atlantic. BOEM Ocean Science 9(1). Available online at: https://www.boem.gov/uploadedFiles/BOEM/Newsroom/Publications_Library/Ocean_Science/OS_0901_031512_FINAL_LINKED_WEB.pdf.

4. **BOEM (Bureau of Ocean Energy Management).** 2014**.** AMAPPS findings close critical data gaps. BEOM Ocean Science 11(2). Available online at: https://www.boem.gov/Ocean-Science-Jul-Aug-Sep-2014/.

5. Ceriani SA, Roth JD, **Sasso CR**, McClellan CM, James MC, **Haas HL**, Smolowitz RJ, Evans DR, Addison DS, Bagley DA, Ehrhart LM, Weishampel JF. 2014. Modeling and mapping isotopic patterns in the Northwest Atlantic derived from loggerhead sea turtles. Ecosphere 5(9):122. http://dx.doi.org/10.1890/ES14-00230.1.

6. **Cholewiak D**, Baumann-Pickering S, **Van Parijs SM**. 2013. Description of sounds associated with Sowerby's beaked whales (*Mesoplodon bidens*) in the western North Atlantic. J. Acoust. Soc. Am 134(5): 3905-3912.

7. **Cholewiak D,** Risch D, Valtierra R, **Van Parijs SM**. 2013. Methods for passive acoustic tracking of marine mammals: estimating calling rates, depths and detection probability for density estimation. Chapter 6 in Adam, O. (ed) Detection, Classification and Localization of marine mammals, pp. 107 - 145.

8. **DeAngelis A**, Valtierra R, **Van Parijs S**, **Cholewiak D**. (in press). Using multipath reflections to obtain dive depths of beaked whales from a towed hydrophone array. J. Acoust. Soc. Am 142(2).

9. **Force M**, 2014. Bermuda Petrel in Nova Scotia: first confirmed sighting for Canada. Nova Scotia Birds 56(4): 42-45.

10. **Goodman Hall A**, Belskis LC. 2012. Guide to the aerial identification of sea turtles in the US Atlantic and Gulf of Mexico. NOAA Technical Memorandum NMFS-SEFSC-633, 24 pp. or online at http://www.nefsc.noaa.gov/read/protspp/mainpage/AMAPPS/docs/TM_633_Goodman-Hall_Belskis_Aerial_ID.pdf.

11. Kinlan BP, Winship AJ, White TP, Christensen J. 2016. Modeling At-Sea Occurrence and Abundance of Marine Birds to Support Atlantic Marine Renewable Energy Planning: Phase I Report. U.S. Department of the Interior, Bureau of Ocean Energy Management, Office of Renewable Energy Programs, Sterling, VA. OCS Study BOEM 2016-039. xvii+113 pp.

12. Jue N, Batta-Lona PG, Trusiak S, Obergfell C, Bucklin A, O'Neill MJ, O'Neill RJ. 2016. Rapid evolutionary rates and unique genomic signatures discovered in the first reference genome for the Southern Ocean salp, *Salpa thompsoni* (Urochordata, Thaliacea). Genome Biol. Evol. 8: 3171-3186. doi:10.1093/gbe/evw215.

13. **LaBrecque E**. 2016. Spatial Relationships among Hydroacoustic, Hydrographic and Top Predator Patterns: Cetacean Distributions in the Mid-Atlantic Bight. PhD thesis. Duke University, Durham, NC.

14. **NEFSC and SEFSC (Northeast Fisheries Science Center and Southeast Fisheries Science Center)**. 2011. Preliminary summer 2010 regional abundance estimate of loggerhead turtles (*Caretta caretta*) in northwestern Atlantic Ocean continental shelf waters. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 11-03; 33 p. Available from National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026, or online at http://www.nefsc.noaa.gov/publications/crd/crd1103/.

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19. Patel SH, Dodge KL, **Haas HL**, Smolowitz RJ. 2016. Videography reveals in-water behavior of loggerhead turtles (*Caretta caretta*) at a foraging ground. Front. Mar. Sci, 3, 254.

20. Richardson DE, Marancik KE, Guyon JR, Lutcavage ME, Galuardi B, Lam CH, Walsh HJ, Wildes S, Yates DA, and Hare JA. 2016. Discovery of a spawning ground reveals diverse migration strategies in Atlantic bluefin tuna (*Thunnus thynnus*). PNAS 113: 3299-3304.

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22. Safina C. 2016. Data do not support new claims about bluefin tuna spawning or abundance. PNAS 113(30) E4216, or online at http://www.pnas.org/content/113/30/E4261.extract.

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24. Silverman ED, **Leirness JB**, **Saalfeld DT**, Koneff MD, Richkus KB. 2012. Atlantic Coast Wintering Sea Duck Survey, 2008-2011. Division of Migratory Bird Management U.S. Fish & Wildlife Service, 11510 American Holly Drive, Laurel, MD 20708. Online at http://datadryad.org/bitstream/handle/10255/dryad.48143/Silverman_et_al_2012b_Atlantic%20coast%20wintering%20sea%20duck%20survey%202008-11%20Report.pdf?sequence=1.

25. Silverman ED, **Saalfeld DT**, **Leirness JB**, Koneff MD. 2013. Wintering Sea Duck Distribution along the Atlantic Coast of the United States. Journal of Fish and Wildlife Management June 2013, 4(1): 178-198. http://fwspubs.org/doi/full/10.3996/122012-JFWM-107.

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3. **Cholewiak D,** DeAngelis A, Haver S, Gurnee J, **Van Parijs SM**. Acoustic abundance estimates of sperm whales (*Physeter macrocephalus*) in northeast U.S. Atlantic waters.
4. **Garrison LP**, **Barry K**, Mullin KD. Abundance of cetaceans along the southeastern U.S. coast from aerial and vessel based visual line transect surveys.
5. **LaBrecque E**, Hench J, **Jech JM**, Lawson G, Halpin P. Patterns and spatial scales of biological scattering in the Mid-Atlantic Bight shelf break region.
6. **LaBrecque E**, Lawson G, **Palka D**, Halpin P. Cetaceans at the Mid-Atlantic Bight Shelf Beak: Fine scale habitat partitioning in a dynamic ecosystem.
7. **Palka D**, Warden M**.** Estimates of availability of cetaceans to visual abundance survey observers.
8. Roberts JJ et al. Updating habitat-based cetacean density models for use by US Navy by incorporating new sightings surveys.
9. **Sigourney D, Chavez S, Palka D, Josephson E.** Spatially explicit density-habitat models of cetaceans using a Bayesian hierarchical framework.
10. **Sigourney D, Chavez-Rosales S, Palka D, Lance Garrison L, Josephson E**. Comparison of species distribution models using Bayesian and likelihood frameworks.
11. **Sigourney D, Cholewiak D, Palka D**. Integrating passive acoustic data with visual line transect surveys to refine population estimates and estimate availability bias for sperm whales (*Physeter macrocephalus*).
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D. DATABASES:

1. *Oracle database* (housed at NEFSC) holds the marine mammal, turtle, seal, seabird, plankton, oceanography and environmental data collected in the NEFSC and SEFSC AMAPPS surveys.

2. *TETHYS: Acoustic database* developed by Scripps Institution of Oceanography and the NOAA Science Centers will hold acoustic data (including that collected in AMAPPPs funded surveys) in a standardized format.

3. *Marine Bird Compendium database* originally developed by FWS and currently housed at USGS will hold seabird data collected by NMFS and FWS AMAPPS surveys.

4. *OBIS SEAMAP* holds the marine mammal, turtle and seal visual sighting detected during the shipboard and aerial abundance surveys.

E. WEB PRESENCE:

1. Website with locations of satellite-tagged loggerhead turtles: http://www.nefsc.noaa.gov/psb/turtles/turtleTracks.html.
2. Website with locations of satellite-tagged harbor seal and information on tagging adventures: http://www.nefsc.noaa.gov/psb/seals/GraySealCapture2013.html
3. Website with general information on AMAPPS: http://www.nefsc.noaa.gov/read/protspp/mainpage/AMAPPS/
4. Website with passive acoustic research, papers and updates: http://www.nefsc.noaa.gov/psb/acoustics/
5. Website with currently available cetacean density information (using Atlantic data collected before 2010) and biologically important area information. As new updates are finalized they will be added: cetsound.noaa.gov/
6. Website with the Oceanography CTD/bongo data: https://www.nefsc.noaa.gov/epd/ocean/MainPage/ and ftp://ftp.nefsc.noaa.gov/pub/hydro/
7. Website in development with the seasonal average species density maps resulting from the habitat models output. Site is interactive to allow user to highlight a boxed area of interest and the individual density estimates for each cell in the area of interest.

2 Introduction

The purpose of this report is to document the results of the Atlantic Marine Assessment Program for Protected Species I (AMAPPS) research conducted during 2010 – 2014. AMAPPS is a comprehensive multi-agency research program on the US Atlantic Outer Continental Shelf (OCS), from Maine to the Florida Keys. The program objective is to assess the abundance, distribution, ecology, and behavior of marine mammals, sea turtles, and seabirds throughout the US Atlantic OCS and to place them in an ecosystem context, providing spatially explicit information in a format that can be used when making marine resource management decisions (NMFS 2016). Marine ecosystems are complex and involve dynamic assemblages of many co-existing species. Thus, to understand these marine ecosystem processes, research under AMAPPS integrated across taxonomic groups and among trophic levels and used a suit of data collection and analysis techniques.

AMAPPS I research was supported through inter-agency agreements between four agencies: National Marine Fisheries Service (NMFS) of the National Oceanic and Atmospheric Administration, Department of Commerce; US Fish and Wildlife Service (USFWS) of the Department of the Interior; Bureau of Ocean Energy Management (BOEM) of the Department of the Interior, which was formally known as the Minerals Management Service; and the US Navy of the Department of Defense. The original inter-agency agreements covered 2010 – 2014 (time period referred to as AMAPPS I) and were renewed to cover 2015 – 2019 (referred to as AMAPPS II).

All four of these agencies require information on protected species (marine mammals, sea turtles and seabirds) to implement and support compliance with the Marine Mammal Protection Act (MMPA; NMFS OPR 2017a), Endangered Species Act (ESA; NMFS OPR 2017b), National Environmental Policy Act (NMFS OSF 2017), Migratory Bird Treaty Act, and Executive Order 13186: Responsibilities of Federal Agencies to Protect Migratory Birds (USFWS 2017). In addition, public outreach and education is enhanced by collecting up-to-date information on protected species.

BOEM regulates energy and mineral resources associated with the Atlantic OCS, which is defined as all submerged lands lying seaward of state coastal waters (which extend to three miles offshore) to the Exclusive Economic Zone (EEZ) boundary approximately 200 nm from the coast (BOEM 2017). Activities on the Atlantic OCS under BOEM's jurisdiction can include offshore energy development (such as wind, wave, and conventional energy sources) and marine mineral recovery (such as mining for sand). These activities require permitting which includes environmental impact analyses that need information on marine mammals, sea turtles and seabirds. Areas of particular interest to BOEM include the areas related to development of offshore wind energy (Figures 2-1 and 2-2) and sand mining.

The US Navy requires scientific information on marine mammals, sea turtles, and seabirds to support their environmental compliance documentation for their at-sea training and testing activities in the Atlantic and Gulf of Mexico, to support quantitative modeling of the effects of low-, medium-, and high-frequency sonar and explosives to be reported in compliance documents, and to support in-water construction projects involving pile driving at Navy installations. Areas of particular interest to the Navy are all waters within the US Atlantic exclusive economic zone (EEZ; within 200 miles from shore) and beyond.

The National Marine Fisheries Service (NMFS) requires information on marine mammals, sea turtles and/or seabirds, as mandated by the MMPA, to develop Stock Assessment Reports, monitor and evaluate Take Reduction Plans, and monitor the ship speed reduction regulations to prevent vessel strikes of large whales. In addition, as mandated by the ESA, NMFS develops section 7 consultations (Biological Opinions), critical habitat designations, status reviews, 5-year reviews, and section 10 incidental take permits that also require this type of information. Areas of particular interest to NMFS are waters within the US Atlantic EEZ.

The United States Fish and Wildlife Service (USFWS) has a conservation obligation to evaluate potential local, regional, and cumulative impacts to bird Species of Concern and sea turtles that may be adversely affected by various development activities. With respect to sea turtles, USFWS and NMFS share Federal jurisdiction for sea turtles, with USFWS having lead responsibility on nesting beaches and NMFS having lead responsibility in the marine environment. To assist proponents who intend to site, construct, operate, and maintain, offshore projects, the USFWS provides information empowering these proponents and stakeholders to make informed planning and operation decisions and reduce impacts to trust resources using the offshore environment and nesting beaches of sea turtles. The information needed to help make these decisions includes pre-construction baseline data on birds and turtles and their resources, including distributions, densities, seasonality of use, and behavior. Areas of particular interest to the USFWS are waters within the US Atlantic EEZ.

The primary researchers of the AMAPPS program are from the Northeast Fisheries Science Center (NEFSC) in Woods Hole, MA, the Southeast Fisheries Science Center (SEFSC) in Miami, FL, and the USFWS, Division of Migratory Birds in Laurel, MD. However, nearly all of the projects were collaborative in nature and so the research was conducted and funded by a number of other organizations not involved in the inter-agency agreements, as is more fully detailed in Chapters 5 – 11.

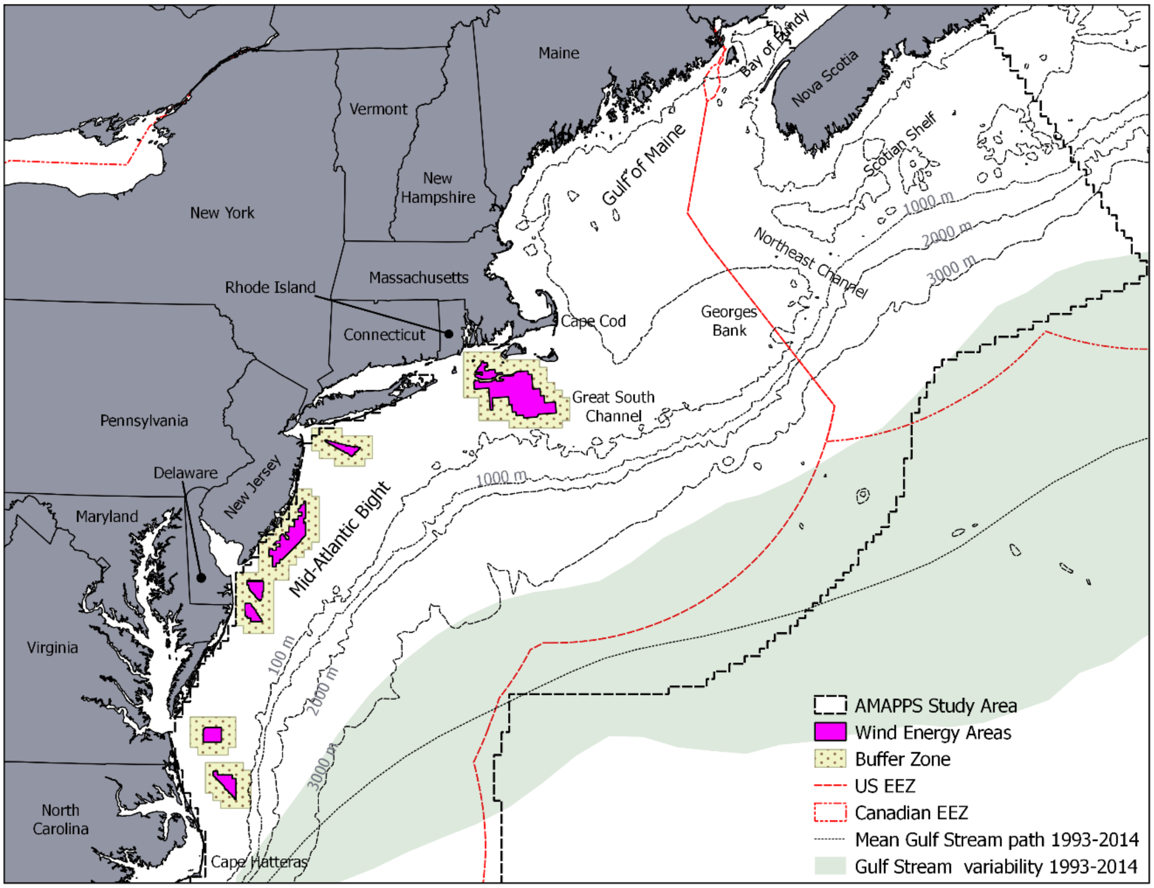

Figure 2-1 Northern portion of the AMAPPS study area
Offshore wind energy areas along with a 10 km buffer (hatched) in relationship to the general location of the Gulf Stream (shaded) are depicted.

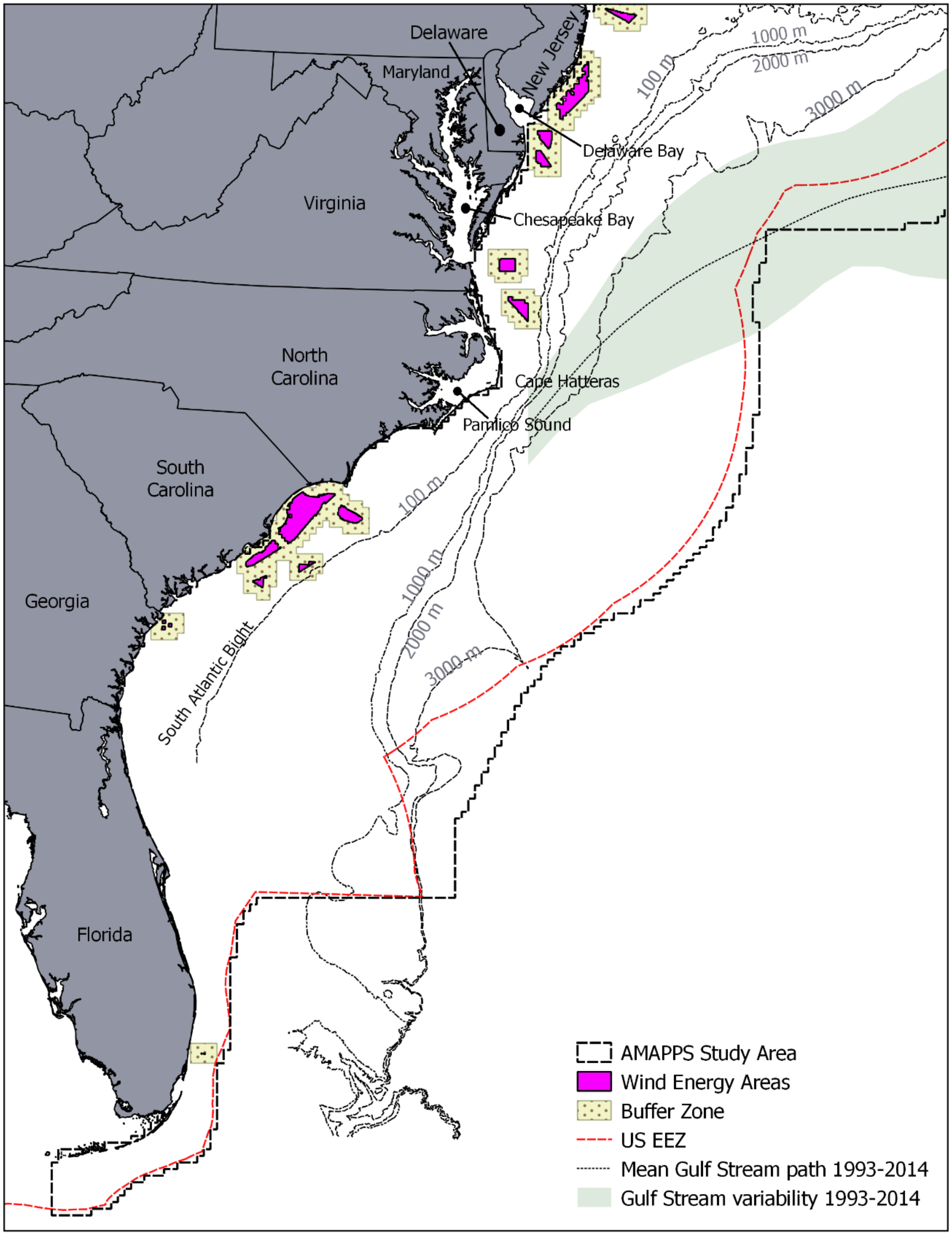

Figure 2-2 Southern portion of the AMAPPS study area
Offshore wind energy areas along with a 10 km buffer in relationship to the general location of the Gulf Stream (shaded) are depicted.

3 Background and Objectives

The US Atlantic Ocean ecosystem is inhabited by many wide-ranging wildlife species that utilize the waters in a variety of ways (feeding, mating, and migrating) and for various amounts of time during their annual cycle. These same waters are also used by humans for a variety of purposes such as commercial and recreational fisheries, shipping, mining, offshore energy development and training by the US Navy. These human-related uses can have positive, negative or no effects on wildlife. For example, offshore wind energy development has the potential positive effect of reducing the impacts of climate change and ocean acidification by lowering global carbon emissions (Pelc and Fujita 2002; IPCC 2014) or by increasing densities of animals inside a wind facility due to the reef or shelter effects, such as that observed for harbor porpoises inside the Dutch wind farm Egmond aan Zee during operations in 2007 – 2009 (Scheidat et al. 2011). There is also the potential negative effect of a decrease in densities of animals, where the spatial and temporal effects of different activities could vary by species. For example, during pile driving for German North Sea offshore wind farms during 2009 – 2013, harbor porpoise densities decreased for about 1 – 2 days within about 20 km of the activities when piling noise was above 143 dB (Brandt et al. 2016). And in the case during summer 2008, where the pauses between pile driving events in the Danish North Sea offshore wind farms were short, harbor porpoise activity and possibly abundance in a region about 20 km around the activities were reduced over the 5-month construction period (Brandt et al. 2011). In general, acoustic disturbance from a variety of human activities has been considered a high potential risk for all marine mammals (Bergström et al. 2014). Effects of acoustic disturbances have been related to physiological stress (Rolland et al. 2012), communication disruptions (Parks et al. 2007; Dilorio and Clark 2010), avoidance behavior (McCauley et al. 2000; Thomsen et al. 2006; Tougaard et al. 2009; Scheidat et al. 2011; Teilmann and Carstensen 2012), and mass strandings (Frantzis, 1998; Cox et al. 2006; Tyack et al. 2011). As a result of this, recent research in mitigation measures to reduce the noise propagation of construction activities has resulted in several methods that appear to be effective to various degrees.

Though researchers are still learning about how offshore energy facilities and other human activities affect marine ecosystems, effects are complicated by many factors. Effects vary by species and may also be compounded by other natural and anthropogenic stressors. To develop effective plans for the safe use of marine resources while still maintaining marine ecosystem resilience (White House Council on Environmental Quality 2010), it is essential to understand the dynamics of the marine ecosystem (National Ocean Council 2013; Ehler and Douvere 2009).

This is particularly important for managing anthropogenic stressors on protected species, such as cetaceans, seals, sea turtles and seabirds. Because these species are typically long-lived, move over broad ranges and feed at a variety of trophic levels, they are impacted by and respond to changes in the biological, physical and chemical marine environment, as well as anthropogenic activities. To understand the effects of anthropogenic activities on wildlife populations within the complexities of their ecosystem require that a range of study methods be used and a range of taxonomic trophic levels be studied (Wiebe et al. 2009). Results from such studies could potentially be used to discriminate between changes in protected species populations due to natural environmental variability and changes due to anthropogenic impacts. Taking this all together, stresses the importance of assessing the abundance, distribution, ecology, and behavior of marine mammals, sea turtles, and seabirds throughout the US Atlantic OCS and placing them in an ecosystem context, which is the overarching aim of the AMAPPS program.

Before AMAPPS, most of the information on distribution and abundance patterns of marine mammals in the US Atlantic OCS was limited to results from summer broad scale surveys (for example, Garrison et al. 2010 and Palka 2012) or fine scale studies (for example, Read et al. 2003). There was a glaring lack of information on distribution patterns during non-summer months and on patterns on a variety of spatial scales, in particular in coastal waters, where most of the human activities occur. To address these data gaps, agencies like BOEM, the Navy, Department of Energy, NMFS and various state governments funded baseline field studies to start filling in these gaps. These studies employed a variety of methodologies including visual aerial and boat-based surveys, as well as radar and acoustic techniques. Some baselines studies were funded to focus on fine scale sites that potentially could be used to build offshore energy installations, such as offshore of Massachusetts and Rhode Island in 2011 - 2015 (Kraus et al. 2016; Veit et al. 2016); offshore of Rhode Island in 2009 – 2012 (Paton et al. 2010; Winiarski et al. 2012; 2013; 2014); offshore of New York (Lagueux et al. 2010); offshore of New Jersey in 2008 – 2009 (Geo-Marine Inc. 2010a; 2010b); offshore of Delaware, Maryland and Virginia in 2012 – 2014 (Williams et al. 2015); offshore of North Carolina and Georgia in 2012 – 2013 (Rice et al. 2014); and additional efforts are currently ongoing offshore of Maryland (BOEM 2016a), Virginia (BOEM 2016b) and New York (Normandeau 2016). Other baseline studies were funded to focus on fine scale sites that potentially will be used by the Navy such as within Chesapeake Bay and the mid-Atlantic region (Aschettino et al. 2015); within bays and offshore of North Carolina (Read et al. 2014; Stanistreet et al. 2016); within Narragnasett Bay, RI; in estuarine and coastal waters near Panama City, FL, and at other mid-Atlantic sites (Navy 2016).

A number of databases have been used to understand the distribution and abundance patterns of marine life in the US Atlantic waters, as well as other conservation and resource management efforts. These databases include:

1) the Ocean Biogeographic Information System Spatial Ecological Analysis of Megavertebrate Populations (OBIS-SEAMAP; Halpin et al. 2009; Fujioka et al. 2014);
2) the Northwest Atlantic Seabird Catalog, formerly known as the Avian Compendium, currently managed by the US Fish and Wildlife Service (USFWS; O'Connell et al. 2009);
3) the Marine Cadastre, a joint initiative of BOEM and NOAA (Marine Cadastre 2017); and
4) the three data portals of the regional ocean planning councils along the east coast: the Northeast Regional Ocean Council (NROC 2016), mid-Atlantic Regional Council on the Ocean (MARCO 2016), and the Governors' South Atlantic Alliance (GSAA 2016).

For example, the OBIS-SEAMAP database was used to estimate abundance and describe distribution patterns of marine mammals throughout the US Atlantic waters (e.g., Kenney and Vigness-Raposa 2010; Lagueux et al. 2010; Best et al. 2012; Michel 2013; Read 2013; Waring et al. 2015b; and Roberts et al. 2016); the Northwest Atlantic Seabird Catalog was used to understand density and distribution of seabirds throughout the Atlantic OCS (e.g., O'Connell et al. 2009; Kinlan et al. 2012; 2016); and these databases have also been used to identify geographic, temporal, and taxon-specific gaps in our knowledge of wildlife along the US Atlantic OCS (Kot et al. 2010).

In the same spirit of addressing these data gaps, the objectives of the AMAPPS I program were to investigate both fine and broad scale patterns. Specifically the objectives were:

1) Collect broad-scale data over multiple years on the seasonal distribution and abundance of marine mammals (cetaceans and pinnipeds), marine turtles, and seabirds using direct aerial and shipboard surveys of coastal US Atlantic Ocean waters;
2) Collect similar data at finer scales at several (~3) sites of particular interest to NOAA's partners using visual and acoustic survey techniques;
3) Conduct tag telemetry studies within surveyed regions of marine turtles, pinnipeds and seabirds to develop corrections for availability bias in the abundance survey data and collect additional data on habitat use and life-history, residence time, and frequency of use;
4) Explore alternative platforms and technologies to improve population assessment studies;
5) Assess the population size of surveyed species at regional scales; and
6) Develop models and associated tools to translate these survey data into seasonal, spatially-explicit density estimates incorporating habitat characteristics.

To achieve the AMAPPS objectives, the focus species were cetaceans, seabirds, sea turtles (in particular loggerhead turtles), and pinnipeds (in particular harbor and gray seals). A variety of types of data were collected using multiple methods. Seasonal and annual distribution and abundance patterns were investigated using data from visual aerial and shipboard sighting (Chapters 5 – 11), photographic surveys (Chapter 10), passive acoustic towed arrays and bottom mounted passive acoustic recorders (Chapter 8), and tagged individual animals (Chapters 5, 9 and 10). To place this information into an ecosystem context, spatially- and temporally-explicit habitat data that were collected include remotely sensed physical and biological factors and *in-situ* collected information on plankton, fish, and other trophic levels (Chapters 5 and 11).

Each of the data types had inherent strengths and weaknesses, so a complimentary suite of data collection and analysis methods were used. The aerial/shipboard visual data provided species-specific estimates of surface abundance, detailed information about distribution, and limited information on behavior and demographics. However, the collection of visual data was constrained by wind and visibility conditions. The passive acoustic data provided detailed information on the spatial/temporal presence/absence of vocalizing species and were not subject to the visual survey constraints. However, passive acoustic data had a limited ability to provide assessments of abundance, behavior, or demographics. The tag data provided individual-specific detailed information about distribution, behavior, and demographics. However, the tag data had limited ability to provide assessments of abundance. Nevertheless, utilizing all of these types of data together provided scientists the best chance to understand the abundance, distribution, ecology, and behavior of these animals within an ecosystem context.

The study area covered by AMAPPS can be spatially divided into six geographic regions (NEFSC 2017; Townsend et al. 2006). Four of the regions are on the continental shelf (Gulf of Maine, Georges Bank, mid-Atlantic Bight, and the South Atlantic Bight). The other two regions are offshore of the continental shelf, a deeper continental slope region and the Gulf Stream region.

The Gulf of Maine region, a semi-enclosed continental shelf sea, is characterized by an extremely complex physiographic structure. Four major freshwater river systems feed into the Gulf of Maine, playing an important role in the oceanography of the coastal Gulf of Maine. Water mass characteristics of the Gulf of Maine are strongly influenced by input of Scotian Shelf water at the surface and continental slope water entering the Gulf through the deep Northeast

Channel. Tides within the Gulf of Maine are among the strongest in the world ocean with the Bay of Fundy having the highest tidal amplitude.

The Georges Bank region is a broad shallow submarine plateau forming the seaward boundary of the Gulf of Maine, delineated to the north and east by the Northeast Channel and to the south and west by the Great South Channel. On Georges Bank, strong tidal forces keep the water on the shallow crest of the bank (<60 m deep) well mixed and isothermal throughout the year. The interaction between the tides and the steep topography sets up a permanent clockwise recirculation around the bank, characterized by a narrow swift jet flowing along the steep northern flank of the bank and yielding to more diffuse flow along the southern flank. This semi-closed gyre holds important implications for the retention of planktonic organisms on the bank.

The mid-Atlantic Bight region spans an area from Cape Cod, MA south to Cape Hatteras, NC and is characterized by a broad expanse of gently-sloping, sandy-bottomed continental shelf that gradually shoals and narrows from north to south. Freshwater discharge from several large estuaries and rivers influence the southern region, including the Hudson River, Delaware Bay, and Chesapeake Bay. A pronounced seasonal cycle of heating and cooling over the region drives seasonal variations in water mass composition and establishes critical habitat for a number of regional fisheries. Intense cooling at the surface results in vertical homogenization of a significant portion of the water column during fall and winter, while surface heating during summer re-stratifies the surface layer, isolating a remnant of the previous winter's colder mixed water at depth. The resulting annual temperature range spans 5 – 30°C, larger than any other location in the Atlantic Ocean. Water entering from the Gulf of Maine and Georges Bank generally flows southwestward through the mid-Atlantic Bight, paralleling the isobaths with the strongest flow concentrated in a narrow jet at the edge of the continental shelf. However, the surface flow is highly variable and may reverse direction at times, most notably due to the influence of winds during the summer months. In some areas such as the coastal waters off New Jersey, summer upwelling is an important process which can stimulate phytoplankton production by delivering deep nutrient rich water upward into the euphotic layer and stimulating new primary production.

The South Atlantic Bight region is a continental shelf extending roughly from Cape Hatteras, NC, to West Palm Beach, FL that varies from 40 to 140 km wide. Rock reefs covered with attached algae and animals comprises up to 20% of the shelf bottom and supports more than 70% of the offshore fisheries. There is a higher percentage of hard bottom than is found in the mid-Atlantic Bight region. The inner shelf, delineated by the 20-m isobath, is characterized by a low-salinity front, resulting from an interaction between freshwater discharge, tidal mixing, and wind forcing. The outer shelf is dominated by the shelf break front between the Gulf Stream and coastal waters. The mid-shelf, between the 20- and 40-m isobaths, is a region influenced by the combined processes on inner and outer shelves. The Gulf Stream flowing at 4 – 5 knots offshore of the shelf break drives significant upwelling at the shelf edge and produces a succession of eddies which separate from its western wall, carrying life from the tropics to the temperate sounds of North Carolina.

The continental slope region, bounded inshore by the continental shelf break, descends rapidly from 100 m to roughly 3000 m depth. The inshore boundary of the continental slope region is delineated by a sharp thermohaline front aligned with the shelf break separating relatively cold, fresh shelf water masses from warmer, more saline slope waters immediately offshore. The sharp discontinuity in water masses is called the shelf-slope front, a persistent feature found along the length of the mid-Atlantic Bight and Georges Bank regions. Submarine canyons incise the continental slope throughout the mid-Atlantic and Georges Banks regions. These deep V-shaped valleys cut into the sediments of the continental slope and shelf approximately perpendicular to the depth contours of those structures. The continental shelf break seaward of Georges Bank is cut with 11 major submarine canyons. In addition, a large number of smaller, unnamed canyons, also called gullies, cross the shelf break in between the larger ones, but do not impinge on the shelf. The continental slope eastward of the South Atlantic Bight varies dramatically, from the phosphorite rocks and outcrops of the Blake Plateau, to the steep mud canyons of the Upper Hatteras Slope.

The Gulf Stream region is dominated by its namesake the Gulf Stream Current, a deep-reaching current responsible for transporting a significant amount of heat from the tropics to higher latitudes. The Gulf Stream exerts important influences on the shelf and slope regions, particularly through the formation of meanders and eddies. Warm core rings (meanders that separate from the Gulf Stream and form a clockwise rotation pattern) can drive cross shelf break exchange, drawing large volumes of shelf water offshore or forcing incursions of warmer slope water onto the shelf, along with phytoplankton, zooplankton and larval fish trapped therein.

4 Organization of the Report

The chapters in this report document research efforts from field work conducted in 2010 – 2014 and results from these data that address one or more of the AMAPPS objectives. Since the inter-agency agreements have been renewed for an additional five years with similar objectives, most of the research projects reported here are ongoing. Thus, in addition to reporting results from the first five years, this report also identifies data gaps and discusses ongoing and future research.

Chapter 5 documents field work and analyses conducted by NMFS to estimate marine mammal abundance and map their spatially-explicit seasonal density distributions. Analyses focused on estimating surface abundance accounting for perception and availability bias and modeled to incorporate habitat characteristics on both the broad scale (US Atlantic) and fine scale (offshore wind energy study areas).

Chapter 6 documents field work conducted by NMFS to document offshore distributions of seabirds.

Chapter 7 documents coastal field work and analyses conducted by USFWS to estimate density and map the spatial distributions of seabirds. Analyses focused on identifying and mapping key seabird sites; developing statistical methods that describe sparse, yet highly aggregated counts of seabirds; and understanding perception and availability biases of seabird count data.

Chapter 8 documents field work and analyses using passive acoustic tools to monitor the spatial temporal distributions of baleen whales and some odontocete species; improve abundance estimates for odontocetes using data collected from towed hydrophone arrays; and provide new information for species classification and stock delineations.

Chapter 9 documents field work to sample and tag loggerhead sea turtles and analyses to improve our understanding of the spatial-temporal patterns in their distribution and to better understand dive patterns that can then be used to define spatially and temporally explicit availability bias correction factors, which will produce more precise abundance estimates and spatial-temporal distribution maps.

Chapter 10 documents field work and analyses focusing on seals: the abundance of harbor seals; tagging gray seals; and mapping the spatial-temporal density of at-sea seals.

Chapter 11 documents field work and analyses to describe the environmental physical and biological characteristics of the water column and the distributions of lower trophic level organisms such as fish and plankton, with the goal to relate these environmental characteristics to distribution patterns of marine mammals, sea turtles and seabirds.

5 Density and Abundance Research using Line Transect Data

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5.1 Introduction

To address several of the AMAPPS objectives in this chapter we report on spatially-explicit density-habitat models of marine mammal species and/or species guilds of the northwest Atlantic that were developed using data collected by NMFS. For more information on the seabird, turtle and seal data collected on these surveys refer to Chapters 6, 9 and 10, respectively.

Modeling these data enabled us to generate average seasonal maps and abundance estimates, along with associated measures of variability. These models also allowed us to explore some of the physical and biological factors related to the distribution and abundance patterns and to define areas of persistent aggregations (hot spots). In addition, we developed an online website that displays the above mentioned species-specific average seasonal maps, abundance estimates and measures of variability. This website also allows a user to draw a user-defined region to display the resulting average seasonal abundance/density estimates for just the user-defined area. The motivation behind this work was to establish a broad baseline from which we may be able to understand and manage the impacts of human activities.

The regions of interest within the northwestern Atlantic waters were on three spatial scales: a broad scale oceanic region covering the US Atlantic OCS and slightly beyond; a series of smaller scale regions covering waters within the US Atlantic OCS that have been designated for development of offshore wind energy; and other user-defined regions within the broad scale region. Focusing on these three scales should be useful to researchers, managers, users carrying out environmental assessments, users conducting ocean planning projects, and others.

In general, distribution and abundance of wildlife is largely driven by physical and biological environmental variables, including climatic weather, habitat characteristics and predator/prey distributions (Ainley et al. 2005). Modeling frameworks have frequently been used in ecological research to describe distributions and abundance of wildlife (Guisan et al. 2002; Forney et al. 2012; Roberts et al. 2016; 2016a). One advantage of modeling frameworks is they are able to incorporate environmental data (covariates) and attempt to account for a variety of biases. We used this type of framework to predict average density and abundances estimates, map the spatial-temporal density patterns, and identify which environmental factors were statistically correlated with the animal's distribution and abundance (Redfern et al. 2006; Mordecai et al. 2011).

One of the goals was to develop a tool box of methods that could be used to model the spatial/temporal distribution of marine mammals, sea turtles and seabirds that incorporate environmental factors. Since each species presents their own particular issues, the hope was that at least one of the modeling frameworks would prove effective at modeling the distribution for each species or species guild. Because the correlations between animal density and environmental data can be complex and nonlinear, two flexible frameworks were developed: a Bayesian hierarchical model and a Generalized Additive Model (GAM). Since the Bayesian hierarchical model is still under development, it will be described in more detail in the discussion and future works sections of this chapter. The results reported in the chapter were developed under the GAM framework.

The GAM framework can be referred to as a “two-stage approach” because this approach separately analyzed the observation and processing aspects. GAMs are extensions of generalized linear models that use smoothing functions to improve model fit when the correlations are complex and nonlinear (Hastie and Tibshirani 1990; Guisan et al. 2002). This is particularly useful for situations with highly non-linear and non-monotonic relationships between predictor and response variables. The GAM framework has previously been used for birds (Clarke et al. 2003) and marine mammals (Ferguson et al. 2006; Becker et al. 2012; Forney et al. 2012; Roberts et al. 2016).

It is important to understand the model uncertainties to ensure the limitations are fully stated when using static maps as representations of a dynamic situation. Uncertainty in predictive models of a dynamic living resource like marine mammals comes from several sources, including sampling, measurement error, and intrinsic dynamics, such as migration and mortalities, in conjunction with natural changes due to the environment (such as inter-annual variability) and even possibly changes due to human interactions. The GAM framework allowed us to produce maps quantifying how uncertainty varies over space and time. We used several types of diagnostic statistics to assess model accuracy, validity and performance, including Akaike Information Criteria (AIC) and cross-validation. Cross-validation diagnostics are particularly useful because they integrate model performance given uncertainties and possible violation of model assumptions. We also investigated the robustness of the model by applying the model that resulted from data collected during 2010 – 2013 to 2014 spring data.

These data and products are being (or shortly will be) publically available on several online databases. Specifically, where there were sufficient sample sizes, the following results were produced for a species or species guild:

1) Maps of the average seasonal spatially-explicit density along with maps of associated metrics of uncertainty - coefficient of variation (CV) along with the 95% lower and upper confidence intervals;
2) Maps of average density overlaid with locations of sightings not used to create the model;
3) Plots of abundance trends for 8-day time periods for each year (and the average trend); and
4) Tables of the average seasonal abundance estimates with associated metrics of uncertainty.

Though not displayed in this report, the models also allow maps of monthly, spatially-explicit density and associated metrics of uncertainty.

When evaluating or managing anthropogenic activities relative to protected species, it is often desirable to quantify areas characterized by persistently elevated abundance, species richness, and/or biodiversity, i.e., “hot spots” (Santora and Veit 2013). For highly mobile top predator animals like marine mammals, sea turtles and seabirds, the concept of using an index to identify hot spots is particularly appealing because of the large variability that is a normal characteristic of the distribution of these species. That is, on one hand, it is highly unlikely that any single survey will be truly representative of what is happening at any particular location at any particular time. But, on the other hand, because of the natural variability, different hot spot indices represent different aspects of diversity and so may not necessary agree with each other, potentially complicating the interpretation of any hot spot index (Tolimieri et al. 2015). As a consequence repeated standardized surveys are needed to determine which areas persistently attract these top predators. As examples of what the data collected under AMAPPS represent, two diversity indices were quantified: an abundance hot spot index and the Shannon-Weiner diversity index, which accounts for both abundance and evenness of the species present. An additional index using the hierarchical Bayesian framework was identified in the discussion section as potential future research.

5.2 Methods

Spatially- and temporally-explicit density models and maps were based on animal density – environmental statistical models that were fit to visual shipboard and aerial survey line-transect data, associated survey conditions, animal group characteristics, spatially- and temporally-explicit static and dynamic environmental data, and species-specific availability bias correction factors. Density models were developed for single species or species guilds, and then combined to produce "hot spot" maps depicting multi-species abundance and diversity patterns. In this chapter, only marine mammal models are discussed, though the method can also be applied to the turtles, large fish, and seabirds also collected during the surveys.

In general, visual line transect data from ships and planes may result in incorrect density estimates when visibility biases are not accounted for. There are two types of visibility bias (McLaren 1961): availability bias (due to animals that were missed because they were submerged and thus not available to be detected), and perception bias (due to animals that were available to be detected but were missed because of a variety of other reasons, such as distance from the platform or poor sighting conditions due to sun glare or sea state). In this analysis, attempts were made to account for both perception and availability bias. Two-team visual line-transect data were used to address perception bias, and ancillary dive time data were used to address availability bias.

The general work flow was as follows:

1) Define the study area and strata by dividing all data into standardized spatial grid cells (10 x 10 km^2) and standardized temporal time periods (8-days), hereafter referred to as spatial-temporal cells.

2) Conduct quality control checks, process, then collate all input data into a common database.

3) Estimate species and platform specific ocean surface density estimates accounting for perception bias for each species (or species guild) within each spatial-temporal cell that had survey effort using Distance analysis techniques (Thomas et al. 2010). There were four platforms (northeast (NE) ship, NE plane, southeast (SE) ship and SE plane), where NE surveys were conducted by the NEFSC and SE surveys were conducted by the SEFSC. The Distance analysis techniques that account for perception bias involve the estimation of a detection function, and *p(0)* - the probability of detecting a group on the

track line – using significant survey related covariates (such as, sighting conditions, group size, animal behavior, etc.).

4) Estimate a species-platform specific availability bias correction factor using information on the average surface and dive times, group sizes, and viewing area from the platform.
5) Estimate the bias-corrected density estimates that account for availability and perception bias for each spatial-temporal cell that had survey effort by applying the species-platform specific availability bias correction factor to the species-platform ocean surface density estimate that accounted for perception bias.
6) Develop an animal density-habitat GAM model using data from each spatial-temporal cell that had survey effort where several goodness-of-fit tests were used to choose the best fitting model of the relationship between the cell's bias-corrected density and associated static and dynamic environmental variables.
7) Predict animal density and the associated measures of uncertainty for all spatial-temporal cells using the GAM modeled animal density-habitat relationship.
8) Calculate seasonal mean density and associated measures of uncertainty for areas of interest.
9) Display results by plotting maps of spatially-explicit densities and associated measures of uncertainty, trend lines of abundance and associated uncertainties, and hot spot maps.
10) Investigate the robustness of the animal density-habitat GAM model by using the 2010 – 2013 data as a "training dataset" to develop an animal density - habitat relationship model and compare it to "test datasets" of the locations of previously detected sightings and future 2014 spring sightings.

These steps are discussed in more detail below.

5.2.1 Study Region and Strata Definitions

The area surveyed ranged from Halifax, Nova Scotia, Canada to the southern tip of Florida; from the coastline to slightly beyond the US exclusive economic zone (about 200 nmi from shore; EEZ; Figure 5-1). The area was surveyed using ships (NOAA ships *Henry B. Bigelow* and *Gordon Gunter*) and aircrafts (NOAA aircraft Twin Otters) in 19 surveys during August 2010 – July 2014 (Figure 5-2; Table 5-1).

The survey data collected during 2010 – 2014 in AMAPPS I was divided into two sets: 2010 – 2013, and 2014. The 2010 – 2013 survey data were considered a "training dataset" which was used to develop the spatial-temporally specific animal density – habitat relationships and abundance estimates. The 2014 spring survey data were considered a "test dataset" that was used to investigate the robustness of the model developed with the "training dataset".

To standardize the multi-year, multi-platform data and minimize natural small-scale fluctuations, yet still capture medium-scale changes, the study area was divided into spatial-temporal cells where each cell was a 10 x10 km^2 oblique Mercator spatial grid cell (Figure 5-1) and an 8-day time period, starting with 4 January of each year. The time periods were also pooled up to a season (Table 5-2).

At this time winter density maps and abundance estimates were only developed for one species because that was the only species with a sufficient sample size of sightings detected in the winter. Winter models and maps are expected to be available later for other species after additional winter surveys have been conducted. This is planned to be completed in AMAPPS II.

The spatially-explicit densities were also summarized for smaller scale regions within the US Atlantic that are being considered for development of offshore wind energy (Figure 5-1). We merged several of the offshore wind energy lease areas/wind planning areas together when the areas were relatively small and close together. In addition a 10 km buffer zone was added to all of these offshore wind energy areas in an attempt to designate a generic area in which an animal may be exposed to offshore wind activities from within the offshore wind energy area. The offshore wind energy area and 10 km buffer zone is referred to as the offshore wind energy study area. The size of an appropriate buffer is dependent on a variety of factors including species-specific factors (such as the species of interest, individual animal's activity and natural short-term foraging and movement patterns which could then influence the animal's response and sensitivity to the activity), and other factors that can influence the sound source level and sound propagation properties (such as ambient noise levels, the type of activity being undertaken in the offshore wind energy area, and the physical topography and oceanographic features). For example, several studies indicate 20 km may be an appropriate buffer when interested in effects of pile driving on harbor porpoises (Brandt et al. 2011; 2016), and perhaps no buffer would be needed for less mobile species or during the operation phase. Given the way in which the model output has been formatted, it is easy to re-estimate the density using another buffer size. However, for simplicity within this report, density of animals within the offshore wind energy study areas that have a 10 km buffer zone will be provided.

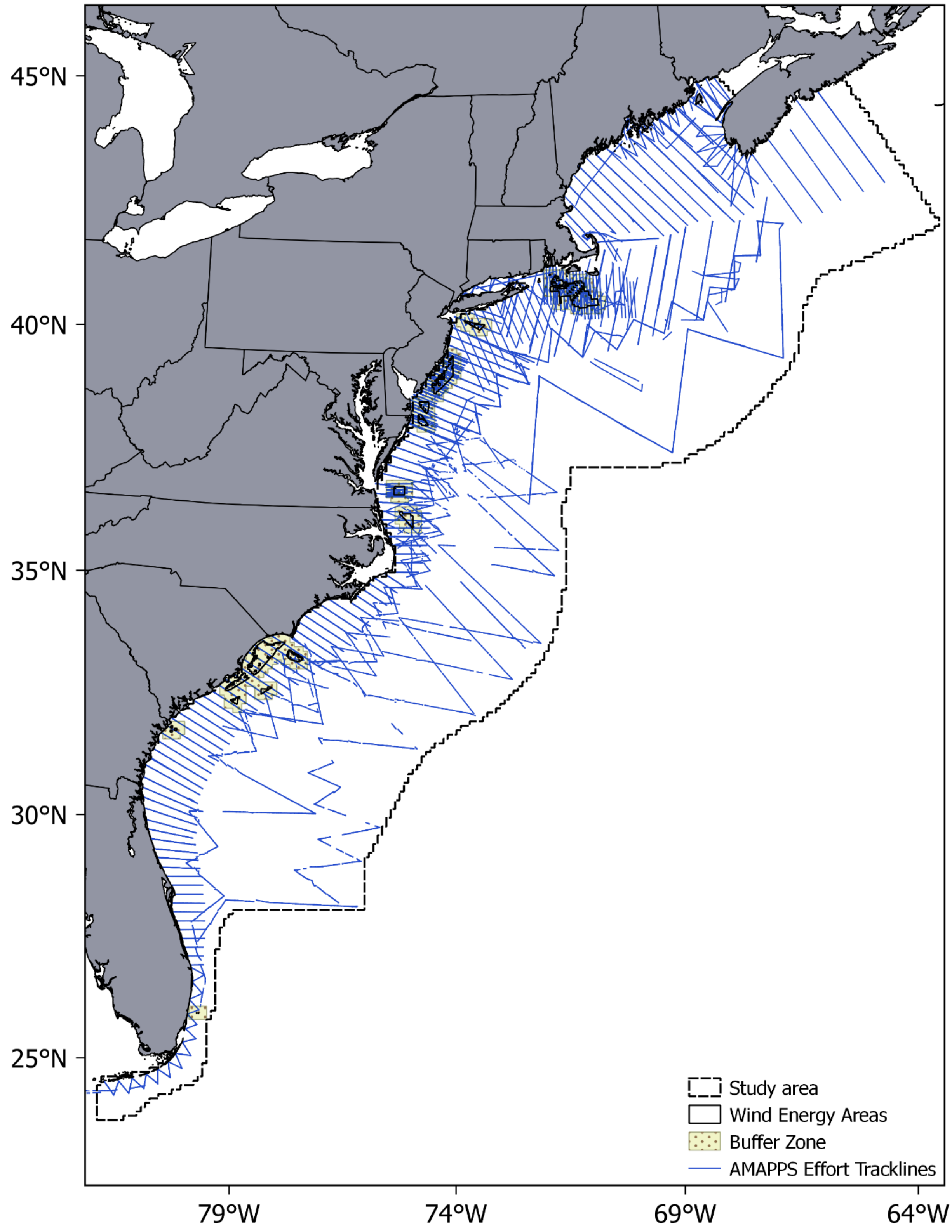


Figure 5-1 Track lines surveyed in the study area during the 2010 – 2013 “training” period

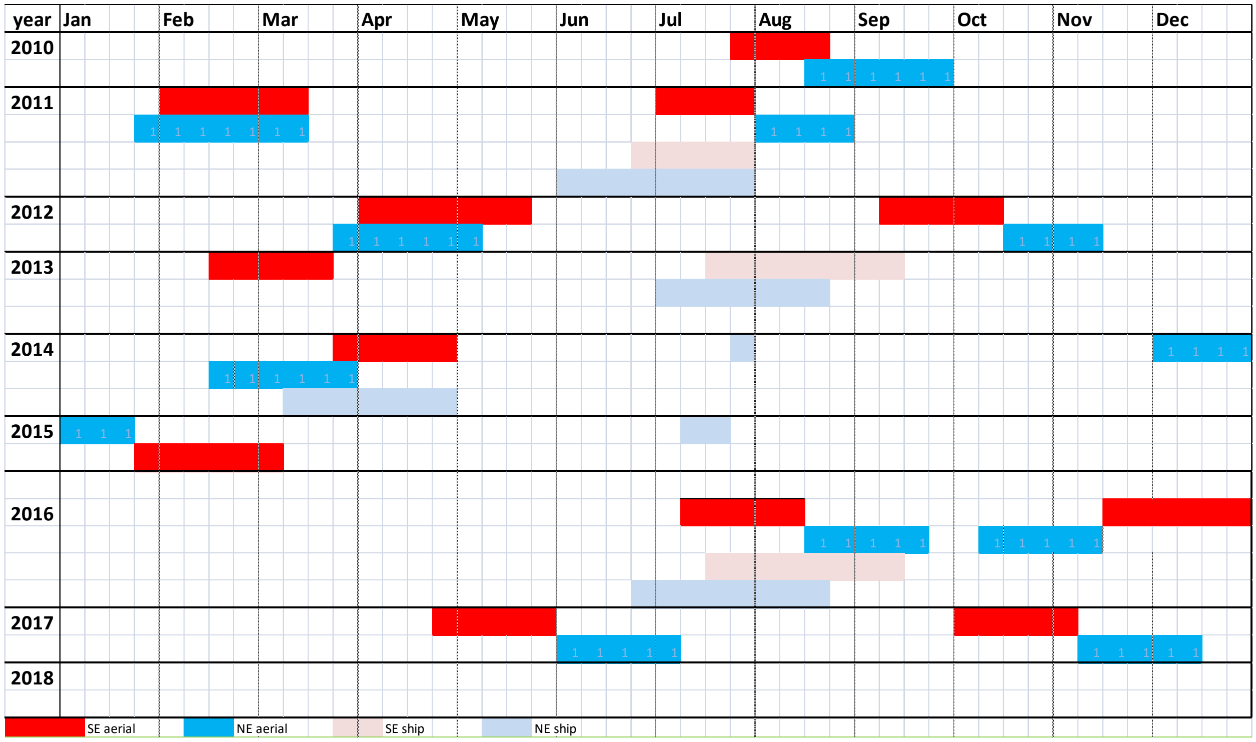


Figure 5-2 Timing of the NMFS NE and SE shipboard and aerial surveys

Table 5-1 Summary of NMFS aerial and shipboard surveys under AMAPPS I

Platform[1]	Region	Date	Track Length (km)	General Location
TO	SE	24 Jul - 14 Aug 2010	7944	Cape Canaveral, FL - Cape May, NJ
TO	NE	17 Aug - 26 Sep 2010	9210	Cape May, NJ - Gulf of St. Lawrence
TO	NE	28 Jan - 15 Mar 2011	4850	Shelf waters NJ - Nova Scotia
TO	SE	7 Feb - 13 Mar 2011	4934	Shelf waters NC - NJ
TO	NE	7 - 26 Aug 2011	6481	Shelf waters NJ - Nova Scotia
TO	SE	6 - 29 Jul 2011	8665	Shelf waters NJ - FL
Bigelow	NE	2 Jun - 1 Aug 2011	5047	Offshore waters NC - MA
Gunter	SE	21 Jun - 2 Aug 2011	5013	Offshore waters NC - FL
TO	NE	28 Mar - 3 May 2012	6806	Shelf waters NJ - Nova Scotia
TO	SE	3 Apr - 21 May 2012	11,252	Shelf waters FL - NJ
TO	NE	17 Oct - 16 Nov 2012	7134	Shelf waters NJ - Nova Scotia
TO	SE	11 Sep - 16 Oct 2012	11,775	Shelf waters FL - NJ
TO	SE	19 Feb - 23 Mar 2013	7284	Shelf waters SC - NJ
Bigelow	NE	1 Jul - 19 Aug 2013	5021	Offshore waters NC - MA
Gunter	SE	13 Jul - 15 Sep 2013	5475	Offshore waters SC - VA
TO	NE	17 Feb - 27 Mar 2014	4905	Shelf waters NJ - Nova Scotia
TO	SE	24 Mar - 28 Apr 2014	7778	Shelf waters FL - NJ
Gunter	NE	11 Mar - 1 May 2014	4014	Shelf and offshore waters NC - MA
Bigelow	NE	25 - 30 Jul 2014	740	Offshore waters on Georges Bank
Total plane			99,018	
Total ship			25,310	
Grand total			124,328	

[1] Platforms are the NOAA Twin Otter aircraft (TO), NOAA ship *Henry B. Bigelow* (Bigelow), and NOAA ship *Gordon Gunter* (Gunter)

Table 5-2 Definitions of the seasons

Season	Start Date	End Date
Spring	1-Mar	31-May
Summer	1-Jun	31-Aug
Fall	1-Sep	30-Nov
Winter	1-Dec	28-Feb[1]

[1] 29-Feb during leap years

5.2.2 Input Data

The input data include sightings and effort survey data collected via aerial and shipboard surveys, environmental data collected from various external internet sources, and dive pattern data collected from tagged individuals.

5.2.2.1 Survey data

Line-transect survey data were collected during 19 aerial and shipboard surveys conducted during 2010 – 2014 (Table 5-1). Aerial surveys were generally conducted over continental shelf waters (out to the 200 to 2000 m depth contours, depending on the region) during all seasons. Shipboard surveys were generally conducted in deeper waters (farther offshore, deeper than the 100 m depth contour) and mostly in the summer (Figure 5-2). For locations of completed track lines for each survey and details on the data collection methods refer to the annual AMAPPS reports (NMFS 2017).

Aerial surveys were aboard a DeHavilland Twin Otter DHC-6 flying at 183 m (600 ft) above the water surface at about 200 kph (100 knts). In addition to two pilots on board the plane, six scientists operated as two independent observation teams. The forward team consisted of two observers stationed in bubble windows on each side of the plane and one recorder. The back team consisted of two observers, one stationed in a rear side bubble window and one in a belly window, and one recorder. This two team data collection method was used to account for visibility bias (Laake and Borchers 2004). Weather and effort data were recorded at the beginning of each leg or when conditions changed. Sightings data were collected for all observed turtles, mammals, and some fish species (Table 5-3).

Shipboard surveys were aboard NOAA research vessels, where two teams of observers were independently visually searching for cetaceans, seals, turtles and some fish species. Each team consisted of two observers using high powered binoculars (25x150). In addition, at least one person recorded data and surveyed using naked eye when not recording data. Weather, effort and sighting data were collected. Also, on most of the shipboard surveys, an independent team of 1 – 2 people were dedicated to conducting a 300 m strip transect survey for birds, which is described in more detail in Chapter 6.

Table 5-3 List of species detected during at least one aerial or shipboard survey

Common Name	Species	Abbreviation
Atlantic spotted dolphin	*Stenella fontalis*	ASDO
Basking shark	*Cetorhinus maximus*	BASH
Blainville's beaked whale	*Mesoplodon densirostris*	BBWH
Blue whale	*Balaenoptera musculus*	BLWH
Bottlenose whale	*Hyperoodon ampullatus*	BOWH
Common bottlenose dolphin	*Tursiops truncates*	CODO
Common dolphin	*Delphinus delphis*	SBCD
Cuvier's beaked whale	*Ziphius cavirostris*	CBWH
Dwarf sperm whale	*Kogia sinus*	DSWH
False killer whale	*Pseudorca crassidens*	FKWH
Fin or sei whale	*Balenoptera physalus* or *B. borialis*	FSWH
Fin whale	*Balenoptera physalus*	FIWH
Gervais' beaked whale	*Mesoplodon europaeus*	GBWH
Gray seal	*Halichoerus grypus*	GRSE
Harbor porpoise	*Phocoena phocoena*	HAPO
Humpback whale	*Megaptera novaeangliae*	HUWH
Harbor seal	*Phoca vitulina*	HASE
Kemp’s ridley turtle	*Lepidochelys kempii*	KRTU
Killer whale	*Orcinus orca*	KIWH
Leatherback turtle	*Dermochelys coriacea*	LETU
Loggerhead turtle	*Caretta caretta*	LOTU
Long- or short-finned pilot whale	Globicephala spp	LSPW
Long-finned pilot whale	*Globicephala melaena*	LFPW
Minke whale	*Balenoptera acutorostrata*	MIWH
Ocean sunfish	*Mola mola*	OCSU
Pantropical spotted dolphin	*Stenella attenuata*	PSDO
Pygmy killer whale	*Feresa attenuata*	PKWH
Pygmy sperm whale	*Kogia breviceps*	PSWH
Right whale	*Eubalaena glacialis*	RIWH
Risso's dolphin	*Grampus griseus*	RIDO
Rough-toothed dolphin	*Steno bredanensis*	RTDO
Sei whale	*Balenoptera borialis*	SEWH
Short-finned pilot whale	*Globicephala macrorhynchus*	SFPW
Sowerby's beaked whale	*Mesoplodon bidens*	SBWH
Sperm whale	*Physeter macrocephalus*	SPWH
Striped dolphin	*Stenella coeruleoalba*	STDO
Unid. beaked whale	*Mesoplodon* or *Ziphius*	UNBW
Unid. common/white-sided dolphin	*D. delphis* or *Lagenorhynchus acutus*	UCWD
Unid seal	Phocidae	UNSE
Unid. pygmy/dwarf sperm whale	*Kogia* spp.	UNKO

White-beaked dolphin	*Lagenorhynchus albirostris*	WBDO
White-sided dolphin	*Lagenorhynchus acutus*	WSDO

5.2.2.2 Environmental Habitat Data

Static (Table 5-4) and dynamic (Table 5-5) environmental variables (Figure 5-3) were considered in the density-habitat models. Environmental variables were downloaded from the internet source specified in Tables 5-4 and 5-5 using a bounding box whose extent covered the AMAPPS study region. Data were then re-sampled to the 10x10 km^2 oblique Mercator grid cells using primarily bilinear interpolation ("spatially synced"). In some cases, a nearest-neighbor interpolation scheme based on the greatest circle chord length between centroids of the data source and grid cells was used.

When possible, the dynamic variable data were derived from already available 8-day composite products. When an 8-day composite product was not available, daily images were downloaded, spatially synced to the 10x10 km^2 grids, then each set of eight days were averaged and the mean and standard deviations stored. These data were stored in stacked rasters in annual raster bricks.

If values of an environmental variable within the AMAPPS study area were missing, a hierarchical spatial-temporal interpolation approach was used to replace missing values. This approach first filled in a missing value using the calculated mean from the nearest-neighbor cells from the same time period that contained non-missing data. Then, if that was not sufficient, the missing value was calculated from the mean value for the grid cell of interest for the 8-day time period before and after. This process provided enough information of the seasonal tendency, without compromising the overall quality of the data.

To assess the accuracy of the remotely-sensed environmental data, values of several satellite-derived and HYCOM (HYbrid Coordinate Ocean Model) derived variables were compared to corresponding *in-situ* values of measured variables from across the Northeast study region (Maine to North Carolina). *In-situ* data were collected from conductivity-temperature-depth (CTD) casts from eight NOAA research cruises during February to November 2013. The comparisons were made on a broad scale – across the entire spatial and temporal domain, and on a finer scale – by month and a 1° latitude and longitude grid. Box plots depicted the spread of differences between the remotely-sensed value and the CTD value.

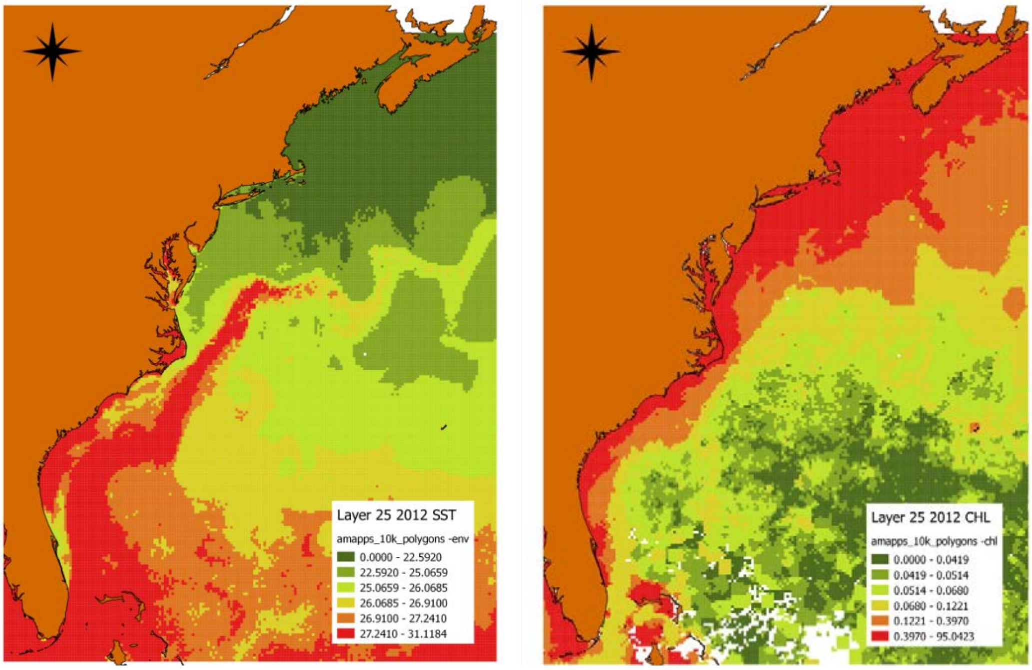
Table 5-4 Dynamic environmental variables considered in the modeling frameworks

Abbreviation	Resolution	Description	Source
SST	0.05° degrees	Sea surface temperature (°C)	http://coastwatch.pfeg.noaa.gov/erddap/griddap/erdGAssta8day.graph
CHLa	2010-11= 0.0125 ° / 2012-13= 0.04166°	Chlorophyll a (mg m-3)	2010-11 = http://coastwatch.pfeg.noaa.gov/erddap/griddap/erdMEchla8day.graph/ 2012-13 = http://coastwatch.pfeg.noaa.gov/erddap/griddap/erdVHchla8day.graph
PP	0.1°	Primary productivity (mgC m^{-2} yr^{-1})	http://coastwatch.pfeg.noaa.gov/erddap/griddap/erdPPbfp28day.graph
PIC	4 km	Particulate inorganic carbon (mol m^{-3})	http://coastwatch.pfeg.noaa.gov/erddap/griddap/erdMPIC8day.graph
POC	4 km	Particulate organic carbon (mg m^{-3})	http://coastwatch.pfeg.noaa.gov/erddap/griddap/erdMPOC8day.graph
BOTTEMP	1/12°	Bottom temperature (°C)	https://hycom.org/data
SALINITY	1/12°	Surface salinity (psu)	https://hycom.org/data
MLD	1/12°	Mix layer depth, depth at which the density changes from the surface by 0.03 kg/m^3 (m)	https://hycom.org/dataserver/glb-analysis
SHA	1/4°	Sea surface height anomaly	http://www.aviso.altimetry.fr/en/data/products/sea-surface-height-products/global/msla.html#c5122

Table 5-5 Static environmental variables considered in the modeling frameworks

Abbreviation	Resolution	Description	Source
DEPTH	3 arc-sec	Bathymetry (m)	http://www.ngdc.noaa.gov/mgg/global/global.html
SLOPE	3 arc-sec	Seafloor slope (°)	http://www.ngdc.noaa.gov/mgg/global/global.html
DIST2SHORE	0.04°	Distance to coastline (m)	http://oceancolor.gsfc.nasa.gov/DOCS/DistFromCoast/
DIST125		Distance to the 125 m isobaths (m)	Calculated
DIST200		Distance to the 200 m isobaths (m)	Calculated
DIST1000		Distance to the 1000 m isobaths (m)	Calculated

A. Sea surface temperature and chlorophyll-a for one 8-day period



B. Particulate organic and inorganic carbon for one 8-day period

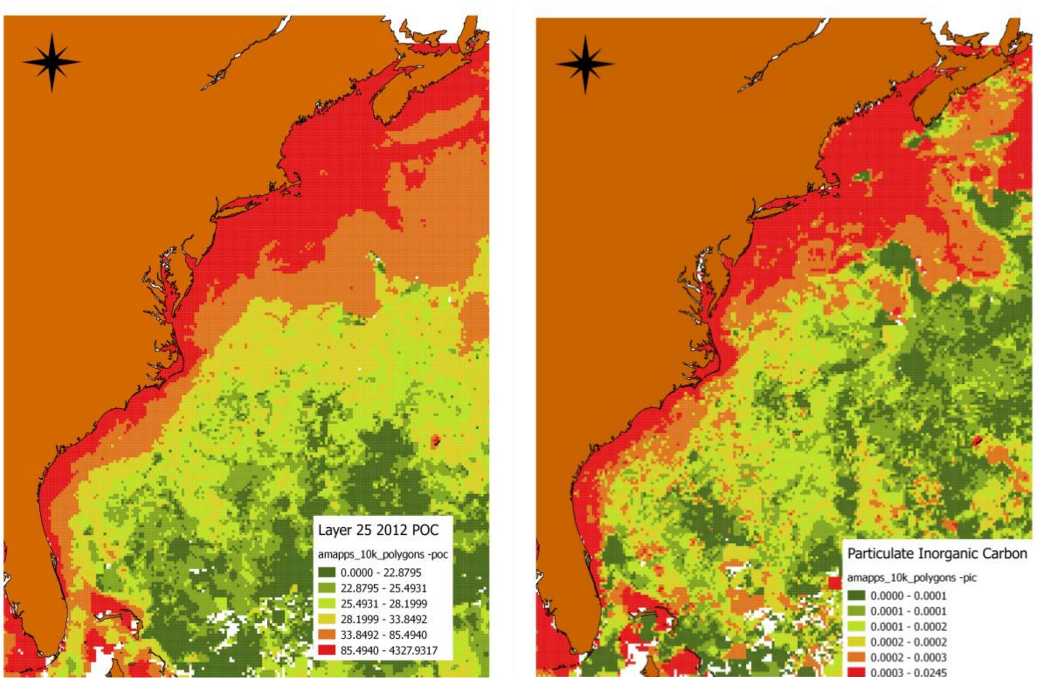
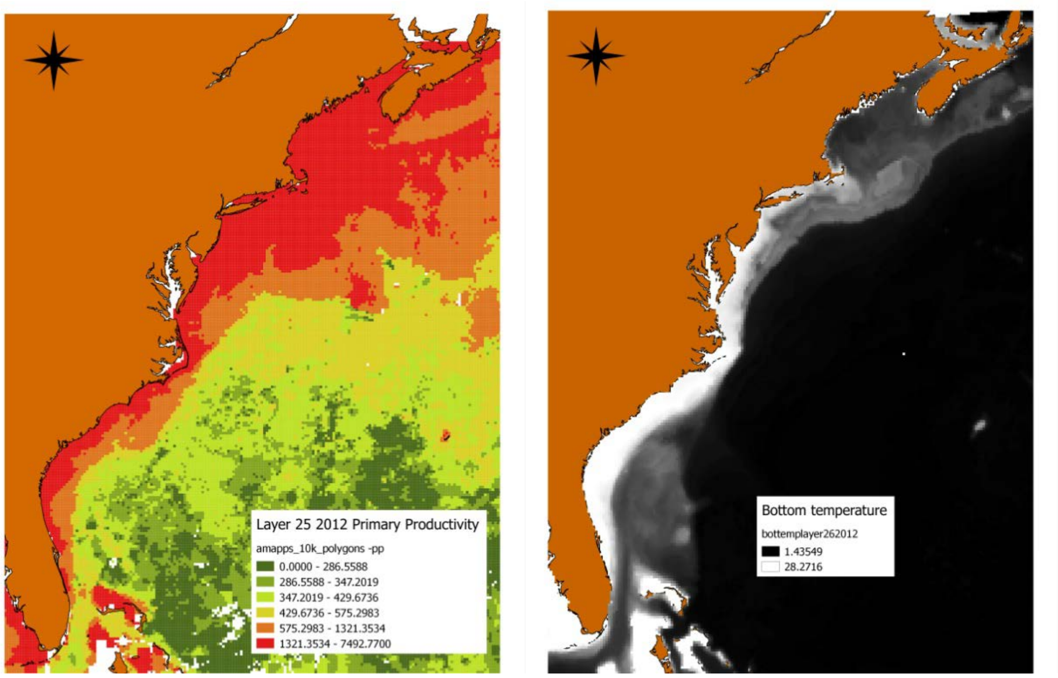


Figure 5-3 Examples of spatial distribution of environmental variables

C. Primary productivity and bottom temperature for one 8-day period



D. Surface salinity and sea level anomaly for one 8-day period

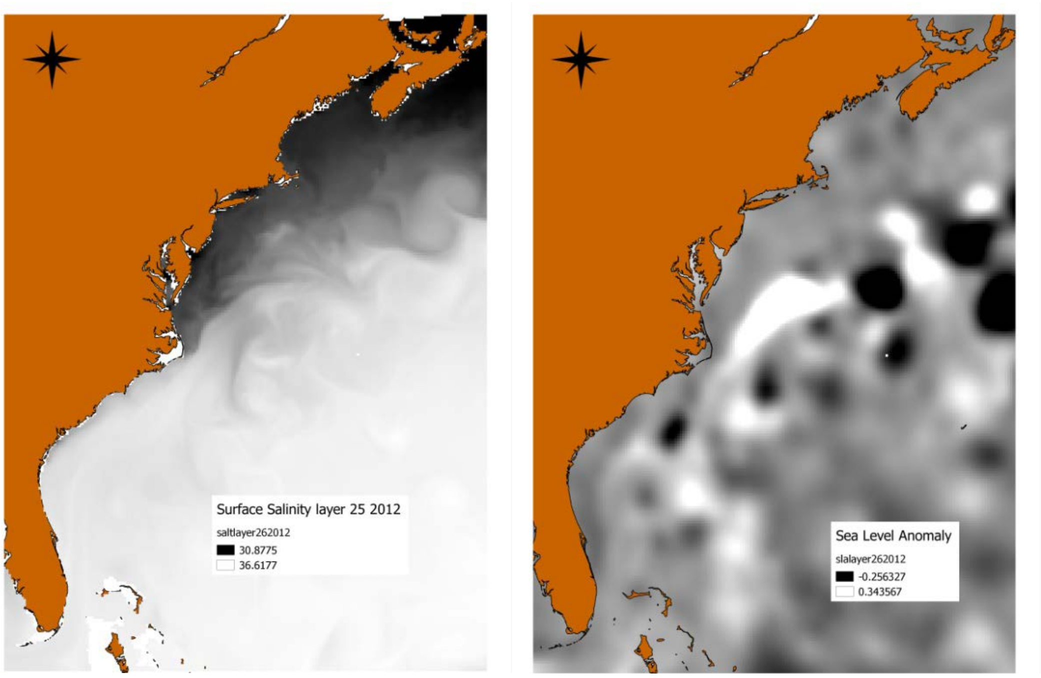
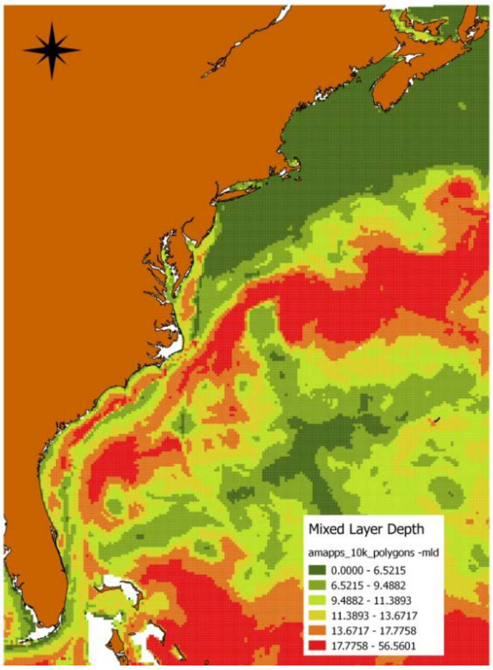
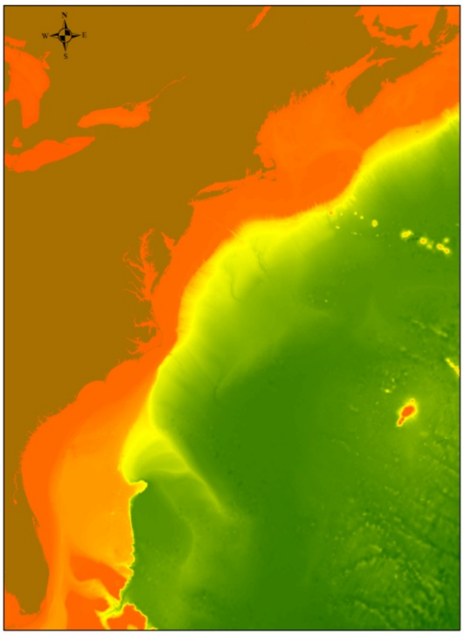


Figure 5-3 cont. Examples of the spatial distribution of environmental variables

E. Mixed-layer depth and sea surface height anomaly for one 8-day period



F. Depth and seafloor slope



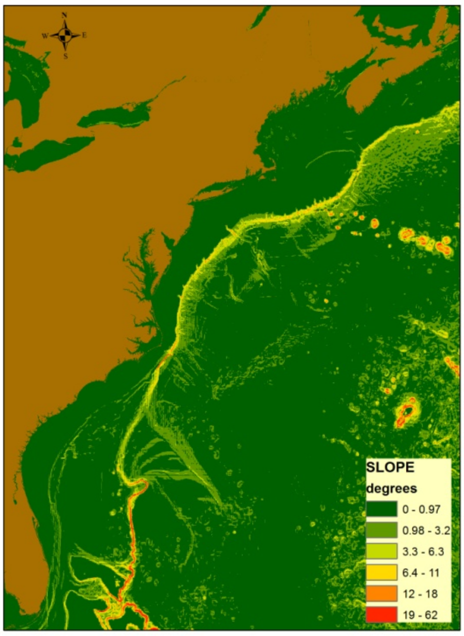


Figure 5-3 cont. Examples of the spatial distribution of environmental variables

5.2.2.3 Availability bias data

Availability bias was accounted for in the density estimate by incorporating an availability correction factor as defined by Laake et al. (1997). The needed species-specific data included: (1) average time at the surface and thus available to be detected; (2) average time below the surface and thus unavailable; and (3) amount of time an animal group remained in view of the observers, which depended on the speed of the observation vessel and the group size of the species of interest.

Average surface and dive times for the following species were estimated using time-at depth data collected from suction cup tags attached to individuals by various investigators (Table 5-6): Atlantic humpback whales, fin whales and pilot whales, and Pacific blue whales, fin whales, Cuvier's beaked whales, Baird's beaked whales and Risso's dolphins. Surface and dive times for other species were obtained from the literature.

The amount of time an animal remained in view of the observer was estimated during the NE aerial and shipboard surveys using the times and places groups were initially detected.

Table 5-6 General information about tag data used to estimate surface and dive times

		Average Time on an Animal (Hours)			Total Time on All Animals	
Species	**Number of Tags**	**Day**	**Night**	**During Experiment**	**Day**	**Night**
Source: M. Thompson (NOAA) Location and Time: Stellwagen Sanctuary 2005-2012						
Humpback whale	61	4.9	6.2	-	304.2	147.8
Source: A Read (Duke Univ) & A. Friedlaender (Oregon State Univ) Location and Time: North Carolina 2010-2012						
Fin whale	3	2.4	-	-	7.3	-
Pilot whales	20	4.2	5.8	-	84.3	40.3
Source: B. Southall (Southall Environmental Associates, Inc.) & A. Friedlaender (Oregon State Univ) Location and Time: Southern California 2011-2014						
Baird's beaked whale	1	45.5	44.0	0.5	45.5	44.0
Blue whale	35	10.6	14.2	0.5	370.4	255.2
Cuvier's beaked whale	4	15.3	11.0	0.5	61.2	44.1
Fin whale	12	39.7	32.1	0.5	475.9	353.4
Risso's dolphin	20	11.5	10.4	0.5	218.7	165.9
TOTAL	156					

5.2.3 Analysis Methods

5.2.3.1 Ocean Surface Densities

The species-specific ocean-surface density estimation of animals in the study area accounting for perception bias was based on the independent observer approach assuming point independence between two teams of observers (Laake and Borchers 2004) and developed using the "training dataset" collected during 2010 – 2013. These analyses were based on the density of groups and average sizes of those groups. The estimated sighting probability included the estimation of the probability of detection of a group on the track line, *p(0)* and sightability covariates, when significant. Detection probabilities were estimated using perpendicular distances that were right truncated, and if necessary left truncated, as suggested in Buckland et al. (2001) and were modeled by either the half-normal or hazard rate model, depending on which model fit the data better.

To ensure accurate estimates of some of the density model parameters, data from similar type species were pooled. In this case, as recommended in Buckland et al. (2001), the strategy for these species was to estimate a single pooled value for the sighting probability and *p(0)* parameter. Then a species-specific density was estimated using these two pooled values and species-specific values of group size and encounter rate. This then allows a species-specific animal-habitat model to be developed in a later step which is discussed below. Only species from the same platform were pooled because of the innate differences between different ships and planes and different sets of observers. Other factors considered when determining which species to pool included the total sample size of the pooled species guild and the species' ability to be detected which was due to species-specific behaviors and group sizes.

Due to the nature of the line transect surveys, environmental conditions, and animal behavior, it is not always possible to identify the species, especially for species with similar physical features. There are three types of ambiguous species identifications. The first type was where it was only possible to indicate that the animal(s) were some sort of whale or dolphin. These unidentified groups were excluded from the present analysis. The second type was where animals were identified to a general guild, such as long/short finned pilot whales (that is, either a short-finned pilot whale or a long-finned pilot whale), pygmy/dwarf sperm whales (either a dwarf sperm whale or pygmy sperm whale), or unidentified beaked whales (among the species of *Mesoplodon* known to be in these waters or a Cuvier's beaked whale). For this type of ambiguous species identification, abundance estimates were developed for the guild, not individual species. For the first and second types of ambiguous species identification, potential ways to develop future species-specific models were presented in the discussion section of this chapter. The third type of ambiguous species identification was where the animal(s) in the group were identified as either a fin or sei whale. Because these two species look similar, especially at a distance and when the animals do not surface often, there were times when an observer could only confidently determine that the animal(s) were either a fin whale or a sei whale (thus, termed a fin/sei whale sighting). For this third type, an additional analytical step was developed to assign the ambiguous fin/sei whale sightings to either a fin whale or a sei whale (see below for more details). Incorporating this process allows density estimates to be developed for each individual species. The fin whale density estimate used data from the definitely identified fin whale sightings plus the fin/sei whale sightings that were assigned to be fin whales. And, an independent density estimate used data from the definitely identified sei whale sightings plus the fin/sei whale sightings that were assigned to be sei whales.

Density estimates for each spatial-temporal cell with survey effort was estimated using two team mark-recapture distance sampling (MRDS) type analysis methods (Burt et al. 2013). The probability of sighting a particular group is the product of two probability components. The first probability component corresponds to the "standard" sighting function (DS = distance sampling), such that the probability of detection declines with increasing distance from the track line following a known functional form (the half-normal or hazard function), where sightability covariates can influence the shape of the functional form. The second probability component (MR = mark-recapture) is the likelihood of detection on the track line, which was modeled using a logistic regression approach and the "capture histories" of each sighting (i.e., seen by one or both teams). The logistic model can also include sightability covariates that affect the probability of detection. Covariates that were explored as main effects or interactions for both of these components were defined in Table 5-7. Diagnostics used to choose significant covariates and the best fitting model included the AIC score (Akaike information criterion; Akaike 1974), Chi-squared test, Kolmogorov-Smirnov goodness-of-fit test (K-S), Cramer-von Mises goodness-of-fit test (CvM) and a visual inspection of the fit, following the methods recommended by Marques and Buckland (2003) and Laake and Borchers (2004).

The shipboard density estimates used standard MRDS methods. However, due to the physical limitations within the plane, the front and back teams were not able to search the exact same patch of water so a two-step MRDS analysis was needed. The front team had full coverage. That is, the front observers searched waters from the horizon on the right side of the plane (90°) down to directly under the plane (on the track line; 0°) then over to the horizon on the left side of the plane (90°). The back team had limited coverage. That is, the back observers searched waters from the horizon on the right side of the plane down under the plane through the track line then over to about 30 – 35° from the track line on the left side of the plane. In other words, the back team could not search waters on the left side of the plane from the horizon down to 65 – 70° below the horizon. Since most sightings were detected within 50 – 60° of the track line on either side, the patches of water searched by the front and back teams were only slightly asymmetric. However, to explicitly account for this asymmetry, the perception bias-corrected density for the aerial data was estimated in two steps.

The first step was to estimate the average probability of the primary team detecting a group given the perpendicular distances and covariates (*p(0)*) using only the data from both teams that were in the area of overlap in a two-team MRDS analysis. The second step was to apply the average estimate of *p(0)* for the primary team as estimated in the first step to the density estimate calculated using only the primary team's data in a standard single team covariate distance sampling analysis. In nearly all cases the front team of the plane (and the upper team on the ship) was the primary team. However, in a couple cases, the front plane team did not detect many small cetaceans (such as harbor porpoises and white-sided dolphins) close to the track line. In these cases, the back team's detection curve was more typically shaped (declining monotonically from the track line) because sufficient numbers of sightings near the track line were detected and thus, the back plane team was designated as the primary team.

5.2.3.2 Fin/Sei Whale Sightings

Because it was not always possible to distinguish fin whales from sei whales in the field, some sightings were identified as either a fin or sei whale (termed a fin/sei whale; FSWH). In an effort to allocate these ambiguous sightings into either a fin or sei whale, an independent process was developed.

First, important environmental covariates were identified that provided the most separation between the two species by inspecting the distribution of the values of the environmental covariates for sighting locations of each of the two positively identified species. The separation was defined as the Euclidean distance (straight-line distance) between the centers of mass of values of an environmental variable for the two positively identified species. Second, the relationship between species identification and environmental variables was quantified by modeling the positively identified sightings and important environmental covariates using a binomial logistic regression (BLR) with a binomial response (either a fin or a sei whale) and logit link between the species identification and values of the environmental covariates. Finally, the binomial generalized linear model was used as a template to separate the ambiguous fin/sei sightings using the values of the environmental covariates of the ambiguous sightings.

This process separated the data into two groups of data that were then used in the animal-density habitat model. One group, later to be considered as fin whales, consisted of the positively identified fin whale sightings and the environmentally similar fin/sei sightings. The other group, later considered as sei whales, consisted of the positively identified sei whales sightings and the environmentally similar fin/sei sightings.

Table 5-7 Definition of covariates explored when modeling the detection function

Covariate	Abbreviation	Description	Platforms	Possible Values
Distance	Distance	Perpendicular distance (m) between the track line and the animal group	Ship and Plane	0-14000 m (integers only)
Observer	Observer	Observer team	Ship and Plane	1=primary team; 2=secondary team
Sea state	SeaState	Apparent Beaufort sea state at time of the sighting	Ship and Plane	0-6, in intervals of 0.1
Cluster size	Size	Best estimate of the group size	Ship and Plane	1-1000 (integers only)
Time of day	TimeOfDay	Time of day sighting was initially detected at	Ship and Plane	0-24 (in intervals of 0.01)
Condition quality	Quality	Average subjective sighting conditions as defined by each observer in each station.	Plane only	1= excellent; 2=good; 3=moderate; 4=fair; 5=poor
Swell height	SwellHt	Height of the ocean swell, estimated by recorder	Ship only	0-5 m (integers only)
Glare severity	Glare	Severity of the patch of glare	Plane only	0=none; 1=slight; 2=moderate; 3=excessive
Swim direction	Swim direction	Direction the animals were swimming when initially detected	Ship and Plane	0-359°; 0° = swimming parallel with ship heading straight ahead; 90° = swimming perpendicular to ship's path and heading toward the right. etc.

5.2.3.3 Availability Bias Correction Factors

Availability bias was accounted for by multiplying the perception-bias corrected abundance estimate (section 5.3.2.1) by an availability correction factor. The correction factor, developed by Laake et al. (1997; equation 7), was defined as the probability that an animal group at a perpendicular distance (x) was at the surface and within the observer's field of view. It was modeled as a 2-state continuous-time Markov process, requiring the average time at the surface (representing time available to be seen), average time at depth (representing time unavailable to be seen), and amount of time a group at perpendicular distance x from the track line remained in view of the observers. Since the average surface and dive times were estimated from individual animals and the correction factor needs to represent a correction for groups (unit used in the surface abundance estimate), the group sizes as observed during the surveys were also accounted for. A manuscript is currently in preparation detailing the analyses related to the availability bias correction factors (Palka et al.: Estimates of a factor to account for availability bias in marine mammal abundance estimates).

We received processed and clean DTAG (digital acoustic recording tag) data (that is, zero-offset corrected and temperature corrected) from the principal investigators that collected the tag data. The depth readings from each tag formed a time series of dives and surface intervals. Data collected during sound experiments were deleted, just in case this stimulus resulted in un-representative dive patterns. Only daytime tag data were used to correspond with the daytime visual sighting data. First, mean depth was calculated from the multiple depth readings per second to obtain one depth reading per second. Then these data were further smoothed by taking a running average over 21 seconds (10 s before and 10 s after each reading). Next, each mean smoothed depth reading was categorized as part of either a dive or a surface interval according to whether it was above or below a defined depth threshold. The thresholds investigated were 2 m, 3 m, 4 m and 5 m. Then, the duration of each dive and each surface interval was calculated for each tag. Next, for each species and time frame (day or night), a random effects model was fit where the surface or dive durations were the response variable and the tag (that is, animal) was a random variable that had normally distributed errors. From this model, the estimated mean surface and dive times (along with measures of variability) were calculated and then used to estimate the species-specific availability bias correction factor using Laake et al.'s equation.

5.2.3.4 Animal Density-Habitat Model

The input data for the animal density-habitat models were the following for each 10x10 km^2 grid cell and 8-day time period that had survey effort during 2010 – 2013 (the "training dataset"): perception- and availability-bias corrected density estimations, static environmental variables (Table 5-4; Figure 5-3), and 8-day means of dynamic environmental variables (Table 5-5; Figure 5-3).

For all species, except harbor porpoises, density estimates and associated environmental variables from all years and all temporal-spatial cells were pooled into one model. Because there were a sufficiently large number of harbor porpoise sightings, three separate models were derived, one for each season. Again, because of a sufficiently large number of sightings, the common bottlenose dolphin model included data from all four seasons, including winter.

All modeling analyses were performed in the R statistical software (R core team, 2014). The GAM models were built using the *mgcv* 1.8-6 package (Wood 2011) and all models followed a Tweedie distribution with the *p* parameter set at 1.2 with null space penalization, thin plate splines with shrinkage (bs="ts") and REML set as optimization criterion. In addition, the *k* value was initially set a 5, limiting the smoothness to 4 degrees of freedom, and later modified, if needed, based on the relationship between the animal densities and the selected habitat covariates. The Tweedie distribution was a compound Poisson (p=1) and Gamma (p=2) distribution. When p was set to values between 1 and 2, the model was able to fit the over-dispersed data, that is, data where there was a distribution in the positive values (e.g., number of dolphins detected were 1, 2, etc.) and also a possible large distribution at zero. This is exactly the situation encountered in abundance surveys.

A collection of quantitative diagnostic methods and criteria were used to identify the best fitting model (Table 5-8). Initially the model complexity was evaluated by examining the number of predictor covariates selected, their associated degrees of freedom and visual inspection of the smooth functions relating the effects of each predictor variable to the response variable. The models with the lowest overall prediction errors and the highest percentage of deviance explained were then selected for further testing. Candidate models were evaluated in terms of their predictive capabilities and overall model performance using all of the data and a subset of the data from the cells with non-zero sightings. Using both sets of data, standard goodness-of-fit statistics were calculated and a k-fold cross-validation process with 25 random subsets of data was also used. Cross-validation has the advantage over conventional validation method to derive a more accurate estimate of model prediction performance especially in cases where there were not enough data available, such as in this study, to partition the data into separate training and test data sets (Seni and Elder 2010).

Table 5-8 Diagnostic tests and criteria used to evaluate density-habitat model performance

Test	Description	Criteria	Calculated From	Formula
DE	Percentage of deviance explained from the model	Higher value	GAM model	
R^2	Coefficient of determination from the model	Higher value	GAM model	
RHO	Spearman's rank correlation	Higher value	None-zero data. 1) Initial testing and; 2) k-fold cross-validation.	
ASPE	Mean square prediction error	Lower value	All data. 1) Initial testing and; 2) k-fold cross-validation	$\sum \frac{(observed - predicted)^2}{n}$
MAPE	Mean absolute percentage error	Lower value	None-zero data. 1) Initial testing and; 2) k-fold cross-validation	$\frac{1}{n}\sum_{i=1}^{n}\left\lvert\frac{observed - predicted}{observed}\right\rvert * 100$
MAE	Mean absolute error	Lower value	All data. 1) Initial testing and; 2) k-fold cross-validation.	$\frac{1}{n}\sum_{i=1}^{n}\lvert observed - predicted\rvert$

Following model selection and validation, estimates for all grid cells in the study area and for all time-periods were generated and plotted on a map. The best fitting model of the relationship between animal density and habitat variables for the spatial-temporal grid cells for which there was survey effort was then used to predict estimates for all spatial-temporal grid cells. Abundance estimates for each spatial-temporal cell were estimated by simply multiplying the predicted density estimate by the cell's area.

Spatial density maps were developed using "tmap" in the R statistical software where the estimated mean density values were classified into 21 categories generated using a geometrical scale. To unify the symbology in the maps among the mean density, lower 2.5% and upper 97.5% maps, the mean density values were binned into 19 categories by using geometric classification, the 1st category was reserved for estimated values of 0, and the 21st category was reserved to range from greater than the maximum mean density value to the maximum density in the upper 97.5% confidence interval.

To inspect the robustness of the model, the predicted modeled spatial distribution was examined in two different ways where a predicted density model was compared to locations of novel sightings that were not used to develop the model. The interpretation of these simple investigations need to recognize that survey effort has not been explicitly accounted for and there is the potential that the true distribution changed over time. One way the robustness was investigated was to compare the seasonal spatial predicted density distribution resulting from the 2010 – 2013 "training dataset" to historical records from 1970 – 2014 that were deposited in OBIS-SEAMAP and were not used to develop the model (Halpin et al. 2009). Specifically, displayed for each species, the seasonal previous novel OBIS-SEAMAP sightings were overlaid on the corresponding seasonal average 2010 – 2013 predicted density map. This type of comparison compares only the spatial distribution of sightings from previous years to the 2010 – 2013 average predicted density map which could indicate the level of stability of the spatial patterns (not the habitat patterns).

The other way the model robustness was investigated was by using the data in the AMAPPS 2014 spring "test dataset". Specifically, the values of the environmental data associated with the 2014 spring time period were applied to the model parameters developed from the 2010 – 2013 "training dataset" density-habitat model. The predicted density patterns for 2014 spring were then plotted using the same scale as used in the "training dataset" maps and finally compared to the locations of the 2014 track lines and sightings by overlaying the actual 2014 spring data on the 2014 spring predicted distribution map. This type of comparison compares the spatial distribution of a future time period to the density-habitat relationship developed using 2010 – 2013 which could indicate the level of stability of the relationship between density of animals and habitat characteristics (which include more than just the spatial distribution).

5.2.3.5 Hot Spots

In an effort to identify areas with increased cetacean activity, that is, "hot spot" areas, we calculated two indices, an abundance hot spot index (HSI), and the Shannon-Wiener index (H') that accounted for both abundance and evenness of the species present.

To focus on species of management interest, not just a particular species or species guild, the HSI was calculated for two groups of species: whales listed in the ESA (humpback whales, fin whales, sei whales and sperm whales) and dolphins categorized as strategic under the MMPA (harbor porpoises, white-sided dolphins, common dolphin and pilot whales – short finned and long finned). Under the MMPA, strategic species were defined as those in which the level of human-caused mortalities exceeded their potential biological removal levels (NMFS 2017; Waring et al. 2016).

The HSI was simply the total number of animals predicted to be present and was calculated for each 10x10 km^2 grid cell for each season for the two groups of species and then mapped. The HSI for a group of species (g), season (s) and grid cell (c) was defined as:

$$HSI_{gsc} = \sum_{i=1}^{n} \widehat{N_{igsc}} \tag{1}$$

where $\widehat{N_{igsc}}$ was the estimated average abundance for season s from a species-specific model in grid cell c for species i within the group of species (g) which included n species.

The Shannon-Weiner diversity index (H') reflected how many different species were predicted in each grid cell and simultaneously accounted for both abundance and evenness of the species present. To derive H' all species must potentially be present in all grid cells. However, since some of the far offshore species (like beaked whales) were only detected in the summer surveys, which were the only surveys conducted in their far offshore habitat, the distributions of these species were only representative of summer conditions. Thus, the Shannon-Wiener index for a 10x10 km^2 grid cell c (H'_c) was defined for only the summer distribution as:

$$H'_c = \sum_{i=1}^{R} p_{ic} \ln(p_{ic}) \quad (2)$$

where p_{ic} was defined within grid cell c as the proportional estimated summer abundance of species i within the R total number of species modeled for their summer distribution, and ln was the natural logarithm.

5.2.4 Website Development

A website (https://www.nefsc.noaa.gov/psb/AMAPPS/) was created to share the results so they would be easily accessible to managers, researchers and the public. The results displayed include the maps of average seasonal density and variability metrics, along with tables of the associated density and abundance estimates. This site allows a user-defined region to be drawn on a seasonal density map for a species. Then, for this user-defined region, the average seasonal density, abundance and associated variability metrics are derived and displayed. In addition, all the information for each of the 10x10 km^2 grid cells within the user-defined region are displayed in a table and can be downloaded.

5.3 Results

A total of 14 models of single species and 4 models of species guilds (long/short finned pilot whales, pygmy/dwarf sperm whales, unidentified beaked whales and seals) were developed using the 2010 – 2013 “training dataset”. Most of the models were derived from data for all three seasons. One exception was three models were derived for harbor porpoises, one for each of the three seasons because the seasonal sample sizes were sufficiently large to support separate models and the seasonal patterns sufficiently different to warrant different models. Another exception was one model was derived for common bottlenose dolphins that used data from all four seasons because there were sufficiently large number of sightings for all seasons including winter. The other type of exception used only summer data because these species and species’ guilds inhabit only deeper slope and Gulf Stream waters, which were surveyed only by summer ship surveys (pygmy/dwarf sperm whales, Cuvier’s beaked whales, Sowerby’s beaked whales, unidentified beaked whales, and striped dolphins). Details for each species or species guild can be found in Appendix I.

Rare species with few sightings (such as, right whales and killer whales) and sightings with broad categories of identification (such as unidentified dolphin or unidentified whales) were not included in the analysis. However possible ways to include these sightings in future analyses were presented in the discussion. Distribution maps of locations of the rare species can be found in Appendix II.

5.3.1 Overview of Input Data

The 2010 – 2013 “training dataset” used to develop the density-habitat models had over 100,000 km of track lines surveyed (Table 5-9A). During these years, most of the survey effort in spring, summer, and fall was on the shelf and shelf break, which was defined as less than 2000 m water depth (Figure 5-4). Nearly 3000 groups of cetaceans were used to develop the spatial-temporal density models, where about 75% of these groups were within the northern shipboard and aerial surveys. These data were divided into analysis sets of similar species within the four area-platforms (NE shipboard, SE shipboard, NE aerial and SE aerial) to estimate perception bias-corrected density estimates using mark-recapture distance sampling analysis methods (Tables 5-10 to 5-13).

The 2014 “test dataset” used to investigate the robustness of the density-habitat models had over 21,000 km of track lines surveyed using ships and planes, of which nearly all were in the spring (Table 5-9B). During these surveys, 945 groups consisting of 8124 individual marine mammals were detected (Table 5-14). At this time these data are not in the current density models but will be included in the next update.

During shipboard surveys conducted during 2010 – 2014, seabird strip transect data were collected and are discussed more fully in Chapter 6. The seabird data collected during these surveys were supplied to the National Centers for Coastal Ocean Science in Silver Spring, MD to be used in a project to develop integrative statistical models and predictive maps of marine bird distributions and abundance on the Atlantic outer continental shelf extending from Maine to Florida (NCCOS 2017). Some results of this project are found on the Marine Cadastre website (Marine Cadastre 2017; Kinlan 2016).

Also, during the shipboard and aerial surveys conducted during 2010 – 2014, about 200 seals, 5500 turtles from 5 species or species guilds, 800 ocean sun fish (*Mola mola*) and 200 basking sharks (*Cetorhinus maximus*) sightings were recorded. Locations of these sightings are mapped and presented in Appendix II. The fish data were not discussed in this report. The turtle data are discussed in this chapter and Chapter 9. The seal data are discussed in this chapter and Chapter 10. The plan is to analyze the rest of the data during AMAPPS II with the goal of estimating abundance and documenting spatial-temporal distribution patterns.

Table 5-9 Summary of research effort by season and platform

A. 2010 – 2013 – "training dataset" used to develop density-habitat models

Platform	Effort (km)				
	Spring	**Summer**	**Fall**	**Winter**	**TOTAL**
NE Shipboard	-	8,146	-	-	8,146
NE Aerial	7,502	10,468	11,038	3,573	32,581
SE Shipboard	-	8,537	2,093	-	10,630
SE Aerial	17,978	16,835	11,818	6,007	52,638
TOTAL	25,480	43,986	24,949	9,580	103,995

B. 2014 – "test dataset" used to investigate robustness of the density-habitat models

Platform	Effort (km)		
	Spring	**Summer**	**TOTAL**
NE Shipboard	4,014	740	4,754
NE Aerial	4,904	-	4,904
SE Aerial	7,778	-	7,778
TOTAL	16,696	740	21,450

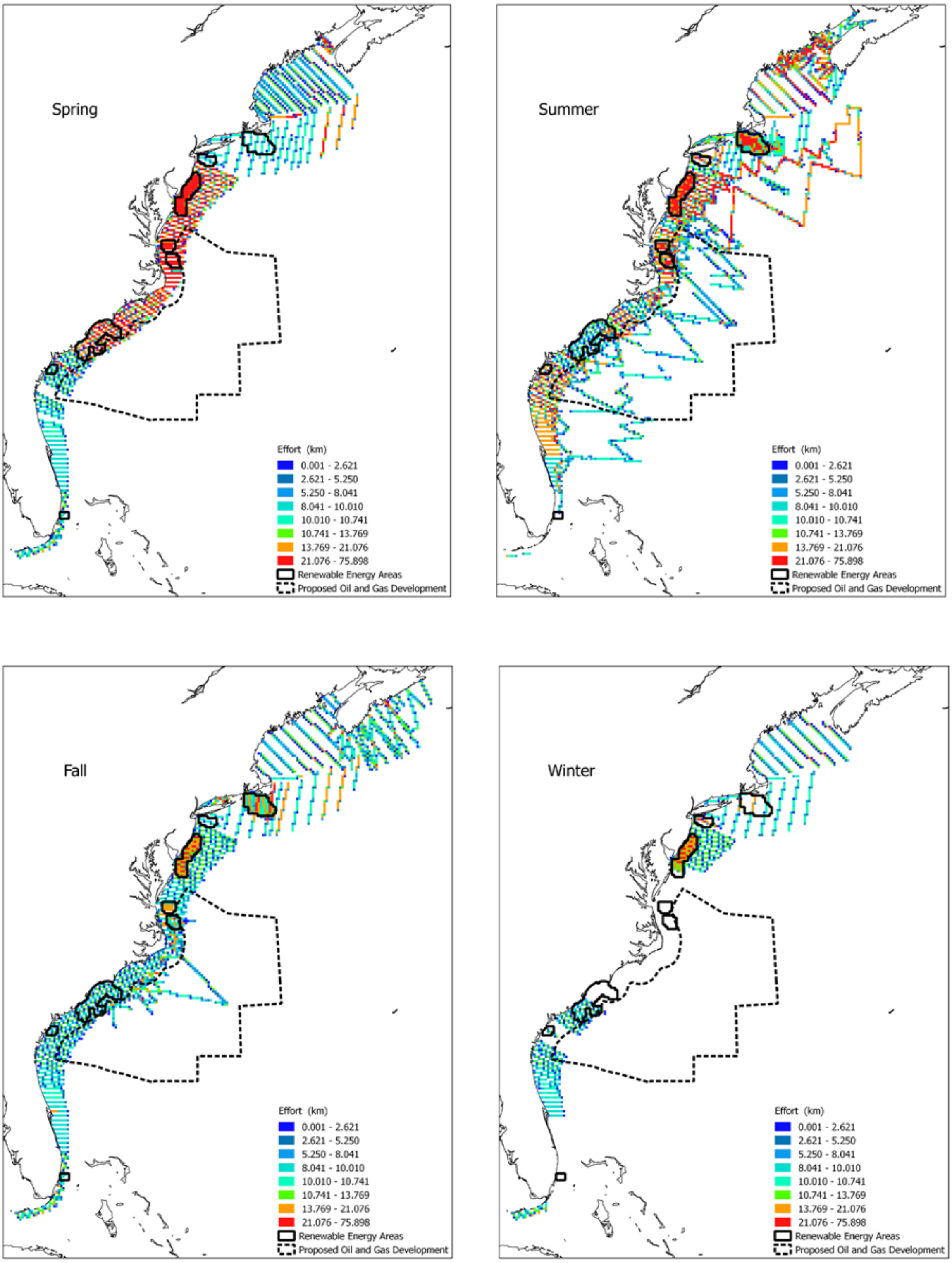


Figure 5-4 Trackline effort (km) surveyed by season from the "training dataset" 2010-2013

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Table 5-10 Species in Northeast shipboard mark-recapture distance sampling analysis sets
From the 2010 – 2013 “training dataset”. No shipboard surveys conducted during spring and winter 2010 – 2013.

Set	Species	Groups/Individuals		
		Summer	**Fall**	**Total**
	NE shipboard			
1	Fin whale	92/127	0	92/127
	Sei whale	9/10	0	9/10
	Fin/Sei whale	23/27	0	23/27
	Minke whale	29/29	0	29/29
	Blue whale	3/3	0	3/3
	Right whale	2/4	0	2/4
2	Humpback whale	57/83	0	57/83
3	Sperm whale	138/208	0	138/208
4	Cuvier's beaked whale	101/246	0	101/246
	Sowerby's beaked whale	27/75	0	27/75
	Unidentified beaked whale	87/230	0	87/230
	Gervais' beaked whale	6/20	0	6/20
	Dwarf sperm whale	20/37	0	20/37
	Pygmy sperm whale	25/33	0	25/33
	Unidentified pygmy/dwarf sperm whale	10/11	0	10/11
5	Long-finned pilot whale	1/17	0	1/17
	Short-finned pilot whale	3/18	0	3/18
	Long/Short finned pilot whale	129/1405	0	129/1405
6	Risso's dolphin	224/1215	0	224/1215
	Rough-toothed dolphin	6/59	0	6/59
	Killer whale	1/4	0	1/4
	Pygmy killer whale	1/1	0	1/1
7	Common dolphin	239/7967	0	239/7967
8	Striped dolphin	133/5218	0	133/5218
9	Atlantic spotted dolphin	46/1334	0	46/1334
10	Common bottlenose dolphin	188/2014	0	188/2014
TOTAL		1600/20,395	0	1600/20,395

Table 5-11 Species in Southeast shipboard mark-recapture distance sampling analysis sets
From the 2010 – 2013 "training dataset". No shipboard surveys conducted during spring and winter 2010 – 2013.

Set	Species	Groups/Individuals Summer	Fall	Total
	SE shipboard			
1	Fin whale	5/8	3/9	8/17
	Humpback whale	1/1	0	1/1
	Right whale	1/1	0	1/1
	Sperm whale	52/126	13/42	65/168
2	Cuvier's beaked whale	2/2	5/9	7/11
	Blainville's beaked whale	4/8	0	4/8
	Unidentified beaked whale	22/48	2/5	24/53
	Dwarf sperm whale	6/9	0	6/9
	Pygmy sperm whale	2/4	0	2/4
	Pygmy/dwarf sperm whale	52/107	2/2	54/109
	Long/short finned pilot whale	44/829	35/467	79/1296
3	Risso's dolphin	21/254	5/44	26/298
	False killer whale	1/11	0	1/11
	Rough-toothed dolphin	4/81	0	4/81
	Atlantic spotted dolphin	66/2380	18/692	84/3072
4	Pantropical spotted dolphin	5/134	0	5/134
	Striped dolphin	6/883	0	6/883
	Common dolphin	2/269	0	2/269
5	Common bottlenose dolphin	102/2149	35/695	137/2844
	TOTAL	398/7144	118/1965	516/9109

Table 5-12 Species in NE and SE aerial mark-recapture distance sampling analysis sets
From the 2010 – 2013 "training dataset".

Set	Species	Groups/Individuals				
		Spring	Summer	Fall	Winter	Total
		NE aerial				
1	Fin whale	23/24	17/17	25/26	1/1	66/68
	Minke whale	7/7	23/23	20/31	1/1	51/62
	Fin/sei whale	7/26	4/5	3/3	0	14/33
	Sei whale	5/6	2/2	3/9	3/6	13/23
	Unidentified beaked whale	4/8	1/1	3/6	0	8/15
	Cuvier's beaked whale	1/1	0	0	0	1/1
	Humpback whale	13/16	28/35	29/43	1/1	71/95
	Sperm whale	3/3	3/6	4/4	0	10/13
	Right whale	3/3	1/1	1/1	0	5/5
2	Long/short finned pilot whale	3/4	2/3	8/45	5/6	18/58
	Risso's dolphin	11/33	1/15	18/143	23/61	53/252
	Common bottlenose dolphin	34/176	3/51	29/370	0	66/967
3	Common dolphin	5/49	16/672	64/1436	17/569	102/2726
	Striped dolphin	1/100	0	7/325	0	8/425
4	White-sided dolphin	37/366	25/408	13/315	18/132	93/1221
	White-beaked dolphin	1/6	0	1/4	0	2/10
	Unidentified common/white-sided dolphin	7/28	4/25	2/29	0	13/82
5	Harbor porpoise	125/175	347/1232	50/128	66/88	588/1623
6	Common bottlenose dolphin	34/176	3/51	29/370	0	66/967
7	Seals	88/117	47/51	10/34	0	145/202
	TOTAL - cetaceans	324/1207	480/2546	306/3282	138/871	1248/7906

Table 5-12 cont'd Species in NE and SE aerial mark-recapture distance sampling analysis sets From the 2010 – 2013 "training dataset".

Set	Species	Groups/Individuals				
		Spring	Summer	Fall	Winter	Total
		SE aerial				
1	Fin whale	8/11	4/5	6/10	3/3	21/29
	Minke whale	5/6	0	3/3	0	8/9
	Cuvier's beaked whale	1/1	0	0	0	1/1
	Humpback whale	6/7	0	2/2	3/3	11/12
	Sperm whale	6/6	2/2	0	0	8/8
	Right whale	5/10	0	0	2/7	7/17
2	Long/short finned pilot whale	1/135	20/538	16/268	0	37/941
	Risso's dolphin	22/106	11/162	1/5	0	34/273
	Rough-toothed dolphin	0	0	0	1/19	1/19
3	Common dolphin	68/3229	7/510	3/89	2/64	80/3892
	Striped dolphin	1/110	0	0	0	1/110
4	Atlantic spotted dolphin	32/481	33/861	22/234	7/385	94/1961
5	Common bottlenose dolphin	219/2046	222/2760	146/1875	82/542	669/7223
	TOTAL	374/6148	299/4838	199/2486	100/1023	972/14,495

Table 5-13 Rare species detected during 2010-2013 but not included in the density analyses

	Groups/Individuals				
Species	Spring	Summer	Fall	Winter	Total
Blue whale	0/0	3/3	0/0	0/0	3/3
False killer whale	0/0	1/11	0/0	0/0	1/11
Pan-tropical spotted dolphin	0/0	6/137	0/0	0/0	6/137
Pygmy killer whale	0/0	1/1	0/0	0/0	1/1
Right whale	8/13	6/7	1/1	2/7	17/28
Rough-toothed dolphin	0/0	11/159	0/0	0/0	11/159
White-beaked dolphin	1/6	0/0	2/21	0/0	3/27
TOTAL	9/19	28/318	3/22	2/7	42/366

Table 5-14 Species detected in the 2014 "test dataset"

	Groups/Individuals			
	Spring			Summer
Species	**SE aerial**	**NE aerial**	**NE ship**	**NE ship**
Atlantic spotted dolphin	1/40	0/0	1/7	1/35
Blue whale	0/0	0/0	1/1	0/0
Bottlenose whale	0/0	0/0	2/6	0/0
Common bottlenose dolphin	67/719	4/50	32/439	9/145
Cuvier's beaked whale	2/5	0/0	7/13	14/45
False killer whale	1/13	0/0	0/0	0/0
Fin whale	2/4	2/2	46/61	17/30
Fin or sei whale	0/0	0/0	26/31	0/0
Harbor porpoise	2/3	47/72	12/22	0/0
Humpback whale	3/5	0/0	60/93	1/1
Killer whale	0/0	0/0	1/4	0/0
Minke whale	2/2	3/4	11/15	1/1
Pilot whales	4/43	0/0	60/396	4/28
Pygmy sperm whale	0/0	0/0	1/2	0/0
Right whale	2/2	8/19	33/44	0/0
Risso's dolphin	3/26	0/0	24/112	18/120
Sei whale	0/0	0/0	13/14	0/0
Common dolphin	31/1221	0/0	103/2746	26/683
Sowerby's beaked whale	0/0	0/0	1/3	3/9
Sperm whale	2/2	0/0	46/57	19/38
Striped dolphin	0/0	0/0	0/0	1/25
True's beaked whale	0/0	0/0	1/3	0/0
Unid. bottlenose or Atl. spotted dolphin	2/38	0/0	0/0	0/0
Unid. beaked whale	0/0	0/0	23/28	10/22
Unid. common or white-sided dolphin	0/0	4/14	0/0	0/0
White-sided dolphin	0/0	24/162	31/328	0/0
Gray seal	0/0	0/0	14/15	0/0
Harbor seal	0/0	0/0	7/7	0/0
Unid seal	0/0	45/45	4/4	0/0
TOTAL	124/2123	137/368	560/4451	124/1182

The accuracy of several remotely-sensed environmental variables derived from satellites and the HYCOM ocean model was compared to spatially- and temporally- corresponding *in-situ* measured values. Sea surface temperature acquired from geostationary operational environmental satellites at a 0.05° resolution over an 8-day period appeared to be an accurate reflection of the instantaneous *in-situ* measurements (Table 5-15). With the exception of very few outliers in March and October, there did not appear to be any biases in the sea surface temperature (SST) data with respect to spatial or temporal comparisons. Bottom temperature, salinity, and mixed layer depth measurements derived from the HYCOM model, however, were not as accurate when compared to the *in-situ* measurements. Furthermore, the inaccuracies did not appear to be uniform across the spatial and temporal domain. For example, on a fine scale, for bottom temperature and surface salinity, there were larger differences in summer months and in southern latitudes, while with mixed layer depth the difference was greatest in late winter and spring months in more northern latitudes.

Table 5-15 Coefficient of determination (R^2) between remotely sensed and *in-situ* data

Variable	Sample size	R^2
Satellite-derived SST	1574	0.97
HYCOM bottom temperature	1366	0.61
HYCOM salinity	1572	0.45
HYCOM mixed layer depth	1366	0.42

For sightings detected from an aircraft, availability bias correction factors ranged from less than 0.2 (a large correction) for sperm whales and beaked whales to over 0.9 (nearly no correction) for striped dolphins and common dolphins (Table 5-16), where the theoretical range of the correction factor was 0 – 1.0. The higher values were for species with large group sizes and/or short dive times, thus they were available to be detected most of the time that they were within the strip of the ocean for which animals could be detected. For example, the average group size of the detected striped dolphins was about 58 animals. An availability correction factor of 0.9 for striped dolphin’s means, nearly all of the time it was likely that at least one animal of this species was at the surface and thus that group was available to be detected nearly all the time. For sightings detected from the ship, the availability bias correction factor was one (that is, no correction) for most species because the ship was traveling at only 10 knots and observers were using high powered binoculars that could detect groups several miles away from the ship. Thus, because the search area was large and scanned multiple times, there was a good chance that at least one animal in the group was at the surface at some time while in range and thus the group was available to be detected (though the group could still be missed due to perception bias). The exceptions were for the deep diving species, like sperm whales, beaked whales, and pygmy/dwarf sperm whales. Shipboard availability correction factors for these three species ranged from 0.54 to 0.77 (Table 5-17).

Table 5-16 Average surface and dive times and aerial availability bias correction factor

Species	Surface and Dive Average Times (sec)							Aerial Correction Factor	
	E(s)	CV	E(d)	CV	% Surface Time	CV	Source	Factor	CV
Common bottlenose dolphin	3.03	0.23	26.6	0.02	0.1	0.38	A	0.785	0.364
Cuvier's beaked whale	107.88	0.07	1764.35	0.09	0.06	0.33	B	0.142	0.462
Fin whale	51.74	0.09	173.49	0.13	0.23	0.18	C	0.374	0.336
Harbor porpoise	49	-	64	-	0.43	-	D	0.628	0.299
Humpback whale	144.55	0.12	175.55	0.04	0.39	0.05	B	0.649	0.185
Long/short finned pilot whale	351.7	0.25	326.28	0.16	0.49	0.08	B	0.679	0.241
Minke whale	26.76	0.61	116.37	0.53	0.19		E	0.307	0.397
Risso's dolphin	322.05	0.18	175.07	0.1	0.63	0.05	B	0.850	0.173
Right whale	228.76	0.28	730.2	0.18	0.24		F	0.265	0.060
Sei whale	72.89	0.11	331.54	.011	0.17	0.18	C	0.417	0.517
Common dolphin	44	-	59.4	-	0.43	-	G	0.930	0.138
Sperm whale	426	-	2676	-	0.14	-	H	0.145	0.005
Striped dolphin	44	-	59.4	-	0.43	-	G	1.000	0.000
Pygmy/dwarf sperm whale	78	-	654	-	0.11	-	I	-	-
White-sided dolphin	4.8	-	38.8	-	0.11	-	J	0.890	0.186

A: Mate et al. 1995; B: Palka et al. (in review); C: Kopelman and Sadove 1995; D: Westgate 1995; E: Lybas and Slvestre 1988; F: Baumgartner and Mate 2003; G: Scott and Chivers 2009; H: Palka and Johnston 2007; I: Barlow 1999; J: Mate et al. 1994.

Table 5-17 Estimated shipboard availability bias correction factor

Species	Ship Factor	
	a_{group}	CV
Cuvier's beaked whale	0.764	0.246
Sperm whale	0.613	0.247
Pygmy/dwarf sperm whale	0.539	0.307

5.3.2 Fin/Sei Whale Sightings

There was a habitat and spatial overlap between the environmental covariates at the locations of positively identified fin and sei whales. Using the Euclidean distances, the environmental covariates that provided the most separation between the species included mix-layer depth, sea surface temperature, chlorophyll, distance to the shore, and to a lower degree particulate organic carbon and primary productivity (Table 5-18).

To quantify the relationship between the values of environmental variables at locations of positively identified fin and sei whales and the species identification, the best BLR model included sea surface temperature, distance to the shore and primary productivity (Table 5-19). This model was selected by several criteria (AIC, McFadden pseudo R^2 and the area under the ROC (receiver operating characteristic) curve. The linearity of the independent variables and log odds assumption was evaluated using the Box Tidwell criteria for the covariates in the best model. A confusion matrix indicated that the model was 79.3% accurate when the model was applied to the “training dataset” of sightings of known species identification (Table 5-20). The area under the ROC curve was 0.77 (Figure 5-5), indicating a good fit.

To assign a species identification to the fin/sei sightings, the environmental covariate values at the fin/sei sighting locations were used in a best fitting BLR model. An individual group with an estimated probability of < 0.8 was assigned to be like-sei whale, and any individual group with estimated probability of ≥ 0.8 was assigned to be like-fin whale. This threshold was set to 0.8 by using k-cross validation to maximize the accuracy of the assignment of the “training dataset”.

Based on applying the best BLR model to the 28 groups that were identified as either a fin or sei whale, 9 groups were assigned to be like-sei whale and 19 to be like-fin whale. These newly assigned groups were then included as input data for the fin and sei GAM models.

Table 5-18 Mean and standard deviation of the environmental covariates for each species
Each covariate was standardized to mean=0 and standard deviation=1.

Means:						
Species	chl	sst	pp	poc	mld	dist2shore
Fin whale	-0.08	0.08	-0.03	-0.04	-0.09	-0.05
Sei whale	0.49	-0.50	0.22	0.25	0.61	0.33
Standard deviations:						
Species	chl	sst	pp	poc	mld	dist2shore
Fin whale	0.58	1.00	0.89	0.97	0.75	1.00
Sei whale	2.29	0.84	1.56	1.18	1.89	0.97

Table 5-19 Best model output of the binomial logistic regression to separate species

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	1.859365	0.782097	2.377	0.01743	*
sst	0.184967	0.063947	2.892	0.00382	**
pp	-0.00054	0.000295	-1.817	0.06918	.
dist2shore	-0.01039	0.00445	-2.334	0.01957	*

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

Null deviance: 106.022 on 134 degrees of freedom
Residual deviance: 91.757 on 131 degrees of freedom

Table 5-20 Confusion matrix of separation of species

Observed Species	Total	Predicted Fin Whale	Predicted Sei Whale
Fin whale	117	96	21
Sei whale	18	7	11
Accuracy of the model = 79.3%			
Miss-classification error = 20.7%			

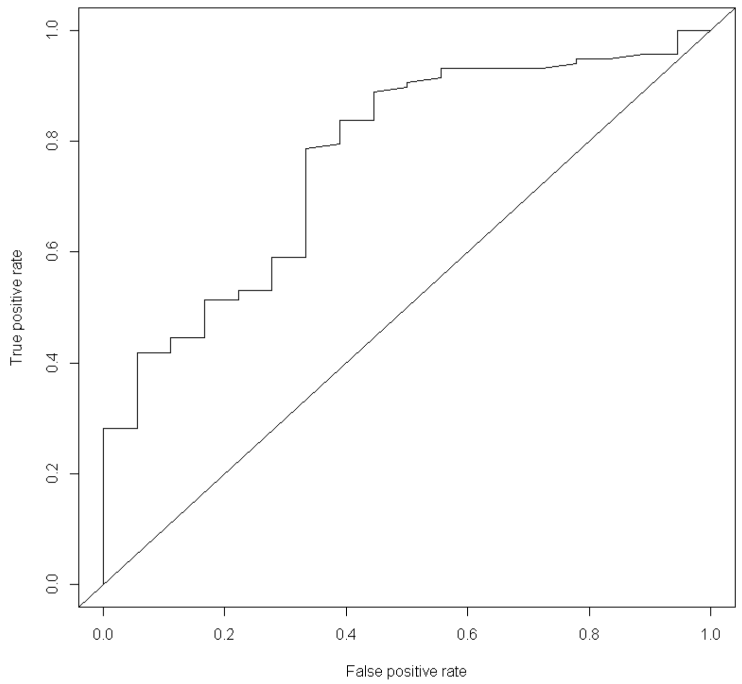


Figure 5-5 Area under the ROC curve for best binomial logistic regression when applying model to “training dataset”

5.3.3 Important Variables and Abundance

The MRDS models used to estimate the perception bias corrected densities of the spatial-temporal cells that had survey effort fit the data well according to the Chi-squared, K-S and CvM goodness-of-fit tests (Table 5-21). Sighting conditions such as Beaufort sea state, amount of glare, time of day, and swell height were common significant covariates that were needed to model the distance sampling detection function component. For the mark recapture component models, observer team was a significant covariate in about half of the cases, indicating the position of the teams and/or observer composition within the teams resulted in different shapes of the detection function.

The GAM models of the relationship between the bias-corrected density estimates and environmental habitat factors fit well according to the four diagnostic tests employed (Table 5-22). Latitude and SST were the most frequently found significant environmental variables. In contrast, surface salinity and sea surface height anomaly were the least frequently chosen.

The two ways that the robustness of the density-habitat model were investigated involved comparing sightings locations collected from times different than that used to develop the model. Previously most surveys that are in the OBIS-SEAMAP dataset were conducted close to shore and so it is expected most sightings will be in these areas. Thus, because effort has not been accounted for the magnitude of previous sightings does not necessarily indicate densities levels. Recognizing this issue, for all species the general large scale spatial patterns detected in the past support the models developed with the 2010 – 2013 data; though there are finer spatial and/or temporal scale differences, some of which appear to be distribution shifts. That is, the general large scale north-south, onshore-offshore gradient patterns appear to be fairly stable. In fact, in some cases, such as for fin whales in the spring along the northern edge of George's Bank, novel sightings detected both previously and in the future (relative to the 2010 – 2013 time period) were located on this northern edge in an area that the 2010 – 2013 model predicted was a medium to high density area but few sightings were detected in 2010 – 2013; thus, confirming the predicted density-habitat model is robust. In other cases, the 2010 – 2013 model appears to be robust and represent current conditions even though there appears to be some evidence of distribution shifts over the years at least in parts of the study area particularly in the Gulf of Maine. Such as for white-sided dolphins in all seasons the 2010 – 2013 data and model indicate relatively high densities off Maine and lower densities south of New Hampshire while the previous novel sightings showed the opposite relationship. The 2010 – 2013 pattern was still evident in spring 2014. For common dolphins and pilot whales in the spring and summer previous sightings were common in the southern Gulf of Maine, off Cape Cod, and the northern edge of Georges Bank; in contrast, more recently since 2010, they were rarely seen that far north. Distribution shifts is discussed more fully below.

For bottlenose dolphins the 2010 – 2013 model applied to the spring 2014 environmental data predicted the distribution of animals along New Jersey's coast was less than that predicted and observed during 2010 – 2013. The actual spring 2014 AMAPPS data support this change. In addition, along North Carolina coastline the spring 2014 predicted distribution indicated a higher density right along the coast and then farther offshore with a lower density strip in between. This is in contrast to the 2010 – 2013 pattern that had a broader high density band without a lower dip in the middle. Again the actual spring sightings data support both of these pattern; thus, suggesting the model is robust.

Average seasonal abundance estimates for the entire AMAPPS study area for all the cetacean species and species guilds are found in Table 5-23. From the cetacean results pygmy/dwarf sperm whales, beaked whales and striped dolphins were nearly always found in deep offshore waters which were predominately surveyed only in the summer. Consequently, we were only able to confidently estimate the abundance of these species for the summer time. Of the species that were detected year round, various distribution/abundance patterns were observed. For example, seasonal migrations were documented for species like sei whales that spent the spring in US Atlantic waters then nearly completely disappeared from US waters in other seasons.

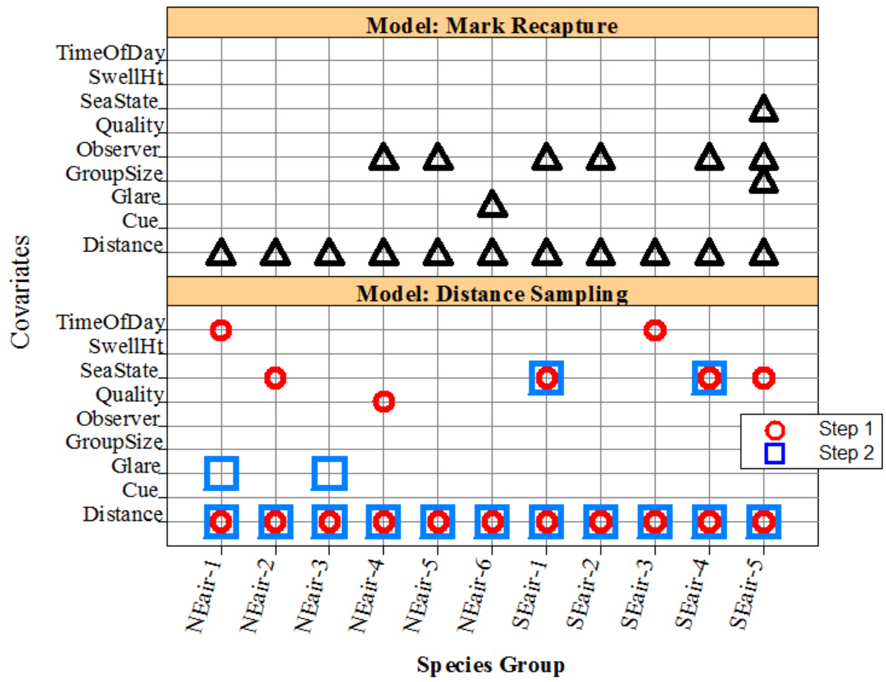
The modeled temporal trends for several species predicted that the abundance estimates during late spring/early summer (April – June) was larger than that predicted for later in the summer, August – September (Appendix I). This pattern was observed for humpback whales, sei whales, minke whales, sperm whales, white sided dolphins, and common dolphins. In contrast, within the study area, some species appeared to have fairly consistent abundance estimates in all seasons (fin whales, long/short finned pilot whales, and Atlantic spotted dolphins), while others have higher abundance in US waters in the late summer (Risso’s dolphins and harbor porpoises).

Table 5-21 Results of the mark-recapture distance sampling analyses

Analysis Set	Step	Truncation (m)	Primary *p(0)*	CV	CvM p-value
NE aerial-1	1	900	0.503	0.168	0.985
	2	5240	-	-	0.905
NE aerial-2	1	LT[1]35-861	0.647	0.147	0.958
	2	861	-	-	0.765
NE aerial-3	1	LT10-500	0.706	0.151	0.861
	2	LT10-500	-	-	0.618
NE aerial-4	1	1000	0.600	0.196	0.465
	2	600	-	-	0.960
NE aerial-5	1	600	0.399	0.208	0.773
	2	300	-	-	0.615
NE aerial-6	1	LT50-350	0.657	0.183	0.542
	2	LT50-350	-	-	0.661
SE aerial-1	1	400	0.898	0.091	0.671
	2	562	-	-	0.758
SE aerial-2	-	400	0.712	0.171	0.389
SE aerial-3	1	330	0.859	0.065	0.986
	2	330	-	-	0.710
SE aerial-4	1	LT50-392	0.843	0.101	0.974
	2	392	-	-	0.766
SE aerial-5	1	400	0.814	0.039	0.671
	2	400	-	-	0.667

Analysis Set	Truncation (m)	Primary *p(0)*	CV	CvM p-value
NE ship-1	4000	0.513	0.136	0.979
NE ship-2	7600	0.361	0.315	0.994
NE ship-3	7600	0.605	0.131	0.969
NE ship-4	6000	0.554	0.105	0.867
NE ship-5	5000	0.740	0.090	0.942
NE ship-6	5000	0.674	0.073	0.880
NE ship-7	6000	0.600	0.073	0.806
NE ship-8	5000	0.764	0.064	0.990
NE ship-9	4984	0.924	0.049	0.953
NE ship-10	5000	0.643	0.105	0.929
SE ship-1	8840	0.472	0.228	0.137
SE ship-2	8310	0.355	0.403	0.918
SE ship-3	5000	0.671	0.114	0.925
SE ship-4	4500	0.722	0.100	0.969
SE ship-5	4300	0.609	0.110	0.975

[1]LT = left truncation



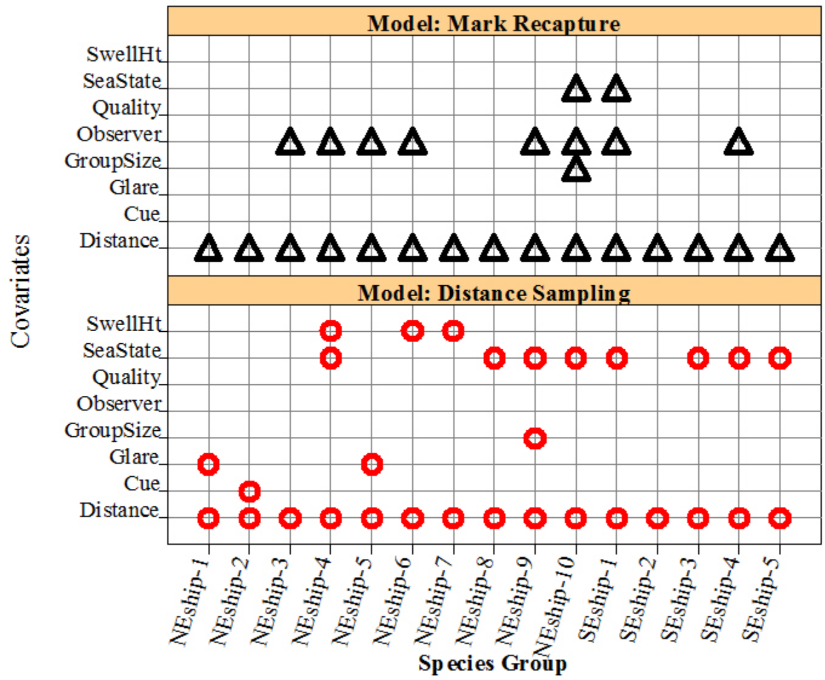


Figure 5-6 Significant covariates for distance sampling and mark recapture models
(Top) Aerial; (Bottom) Shipboard

Table 5-22 Results of diagnostic tests to evaluate fit of the density-environmental GAMs

Color coding is:

RHO:	Poor= x<0.05	Fair to good =0.05<=x<0.3	Excellent= x>0.3
MAPE:	Poor= x>150%	Fair to good= 150%>=x>50%	Excellent= x<=50%
MAE:	Poor= x>1	Fair to good = 1>=x>0.25	Excellent= x<=0.25

	Diagnostic Test			
	Non-Zero Data		25 Random Samples	
Species	**RHO**	**MAPE**	**RHO**	**MAE**
Atlantic spotted dolphin	0.272	87.86	0.131	0.193
Cuvier's beaked whale	0.090	86.03	0.190	0.010
Sowerby's beaked whale	0.378	92.23	0.127	0.030
Unidentified beaked whales	0.428	81.19	0.181	0.010
Common bottlenose dolphin	0.314	77.60	0.187	0.386
Fin whale	0.117	88.72	0.128	0.006
Harbor porpoise - Fall	0.178	85.77	0.163	0.047
Harbor porpoise - Spring	0.241	87.97	0.171	0.048
Harbor porpoise - Summer	0.260	80.40	0.252	0.127
Humpback whale	0.277	91.90	0.070	0.003
Pygmy/dwarf sperm whale	0.403	82.28	0.195	0.017
Minke whale	0.500	94.59	0.088	0.006
Long/short pilot whale	0.529	88.92	0.148	0.097
Risso's dolphin	0.102	85.38	0.186	0.076
Sei whale	0.239	87.17	0.070	0.003
Common dolphin	0.191	104.38	0.187	0.268
Sperm whale	0.227	82.01	0.157	0.050
Striped dolphin	0.289	76.43	0.209	0.062
White-sided dolphin	0.313	86.47	0.079	0.329

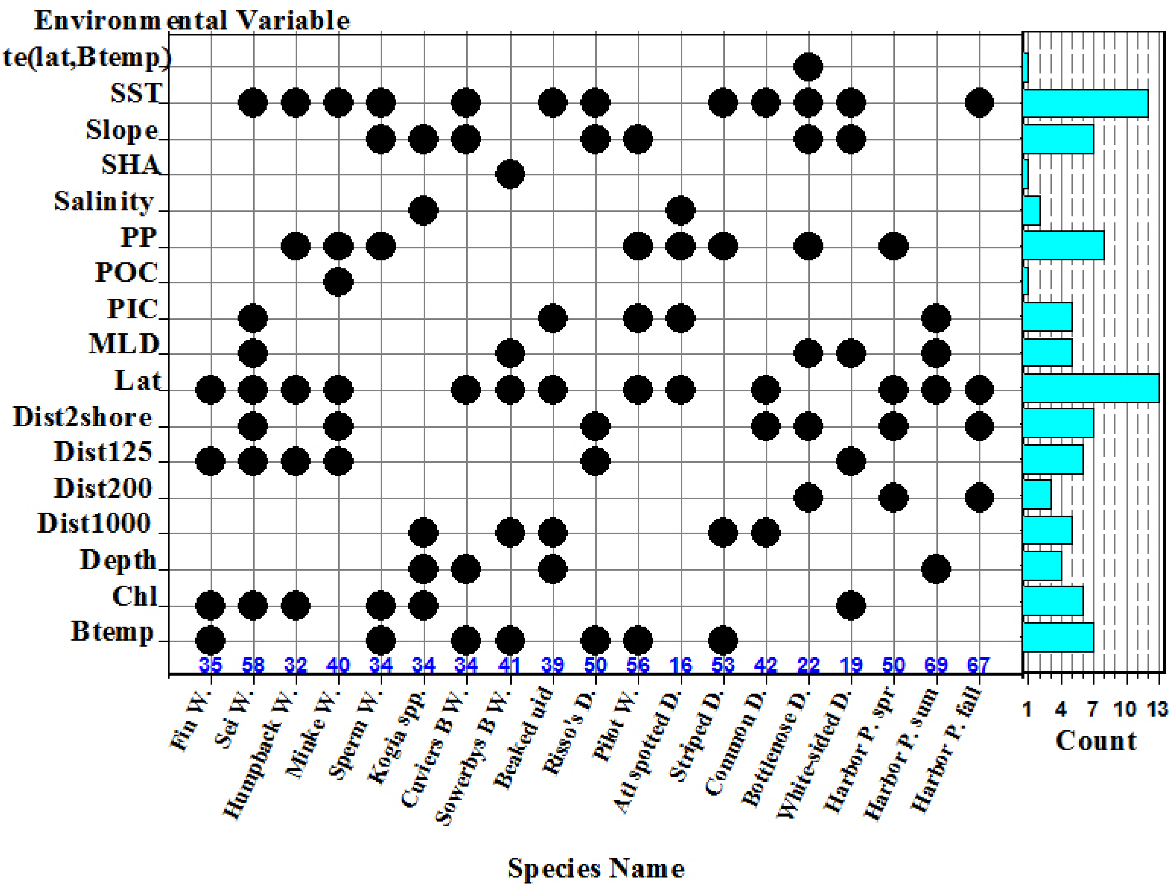


Figure 5-7 Significant habitat covariates for the density-habitat GAM model
Percent deviance (in blue numbers) and summary of number of models with significant variables (on right).

Table 5-23 Average 2010 – 2013 seasonal abundances for each species or species guild

Season	Abundance	CV	CI 2.5%	CI 97.5%
Atlantic spotted dolphin				
Spring (Mar-May)	65,948	0.16	48,703	89,299
Summer (Jun-Aug)	54,731	0.15	40,633	73,720
Fall (Sep-Nov)	56,372	0.16	40,868	77,758
Beaked whales - summer				
Cuvier's	3,425	0.30	1,920	6,108
Sowerby's	679	0.38	328	1,405
Unidentified	6,987	0.28	4,051	12,051
Sum of above	11,091	0.20	6,299	19,564
Common bottlenose dolphin				
Spring	111,7209	0.38	54,756	227,943
Summer	138,700	0.36	69,417	277,133
Fall	104,971	0.24	65,967	167,038
Winter	110,485	0.54	41,027	297,536
Common dolphin				
Spring	111,041	0.22	73,071	168,741
Summer	118,695	0.21	78,890	179,494
Fall	183,509	0.18	127,981	263,128
Fin whale				
Spring	3,817	0.22	2,508	5,809
Summer	4,718	0.13	3,667	6,070
Fall	4,514	0.12	3,545	5,742
Harbor porpoise				
Spring	30,126	0.20	20,646	43,959
Summer	83,250	0.18	59,139	117,191
Fall	17,943	0.49	7,287	44,180
Humpback whale				
Spring	1,510	0.29	859	2,655
Summer	1,246	0.18	883	1,758
Fall	1,399	0.17	1,001	1,955
Pygmy/dwarf sperm whale				
Summer	9,951	0.21	6,661	14,865
Minke whale				
Spring	1,484	0.58	518	4,251
Summer	2,834	0.25	1,760	4,563
Fall	2,829	0.26	1,729	4,630

Season	Abundance	CV	CI 2.5%	CI 97.5%
Long/short finned pilot whale				
Spring	26,441	0.40	12,525	55,820
Summer	24,670	0.29	14,052	43,311
Fall	29,559	0.30	16,489	52,989
Risso's dolphin				
Spring	12,759	0.21	8,540	19,061
Summer	36,785	0.20	24,738	54,699
Fall	29,093	0.21	19,551	43,292
Sei whale				
Spring	6,292	1.02	1,209	32,733
Summer	1,872	0.42	849	4,129
Fall	2,489	0.49	1,006	6,158
Sperm whale				
Spring	4,766	0.45	2,058	11,039
Summer	3,663	0.14	2,772	4,841
Fall	3,557	0.15	2,669	4,741
Striped dolphin				
Summer	81,512	0.12	64,365	103,227
White-sided dolphin				
Spring	47,370	0.67	14,454	155,248
Summer	42,985	0.46	18,128	101,923
Fall	44,276	0.39	21,047	93,144

The at-sea distribution patterns of the detected seals are discussed in Chapter 10.

Using only 2010 data, abundance of loggerhead turtles was estimated, though these estimates are considered as preliminary (Northeast and Southeast Fisheries Science Centers 2011). The 2010 summer aerial line transect data from Maine to Florida were used to estimate the abundance of loggerheads at the surface using standard mark-recapture analysis methods. The 2010 dive pattern data collected from tagged individual loggerheads were used to estimate preliminary correction factors for availability bias (see Chapter 9 for more details). Applying these preliminary correction factors for availability bias to the surface abundance estimates derived from the aerial line transect data resulted in a preliminary estimate of 588,000 individual loggerheads (approximate inter-quartile range of 382,000 – 817,000) based on only the positively identified loggerhead sightings and about 801,000 individuals (approximate inter-quartile range of 521,000 – 1,111,000) when based on the positively identified loggerheads and a portion of the unidentified turtle sightings (Northeast and Southeast Fisheries Science Centers 2011).

5.3.4 Fine Scale Inferences

Since most of the offshore wind energy study areas are close to the shore, the species that visit these areas are limited to those species that inhabit the relatively shallow continental shelf waters. The Rhode Island/ Massachusetts area had the highest diversity, where humpback whales, fin whales, minke whales, sperm whales, pilot whales, white sided dolphins, common dolphins, Atlantic spotted dolphins, striped dolphins, and harbor porpoises were commonly found in parts of the offshore wind energy study area. In contrast, the models predicted that the offshore wind energy study areas south of North Carolina had not only fewer species but also lower levels of abundance of those species. The wind energy study areas offshore of northern North Carolina and Virginia demonstrated an intermediate situation. It was predicted there was on average quite a few animals in the North Carolina areas, particularly pilot whales, Risso's dolphins, white sided dolphins, common dolphins and Atlantic spotted dolphins. Though the models predicted most of these animals were on the offshore edges of the wind energy study areas. Interestingly, the models also predicted sperm whales (a frequent deep water species) were present at very low to low densities in some of the wind energy study areas, particularly in the spring and fall and only at the offshore edges of the wind energy study areas that were either close to the shelf break or extended into deeper waters like the Rhode Island/Massachusetts and North Carolina offshore wind energy study areas.

5.3.5 Hot Spot Patterns

The HSI maps showed that on average year-round some 5 – 15 ESA whales (humpback whales, fin whales, sei whales and sperm whales) per 10x10 km^2 were predicted to utilize waters that were predominately on or near the shelf break between North Carolina and Nova Scotia, particularly in regions with high bottom relief such as the northern and southern edges of Georges Bank (Figures 5-8 – 5-10). However, lower numbers (some 1 – 4 animals per 10x10 km^2) were also found on the mid-Atlantic shelf and in the southern Gulf of Maine. The numbers of ESA whales in US waters were predicted to be the highest during spring. The HSI maps predicted that on average the offshore portions of the wind energy study areas had only a few ESA whales, where the Massachusetts/Rhode Island wind energy study area had the highest numbers and the areas south of North Carolina had on average no ESA whales.

The HSI maps showed the MMPA strategic dolphins (harbor porpoises, white-sided dolphins, common dolphin, common bottlenose dolphins, and pilot whales – short finned and long finned) had a different hot spot pattern than the ESA whales and were found in much larger numbers than the ESA whales (with peaks of over 300 animals per 10x10 km^2 grid cell). Year-round, the strategic dolphins were much more widely spread out throughout the waters off the US and Nova Scotia, with the lowest numbers very close and very far from shore (Figures 5-11 – 5-13). The seasonal north-south migration of these species were highlighted in the HIS maps. In the spring and fall, the "hottest" spots were on the shelf break north of Cape Hatteras off North Carolina and Virginia. In the summer, when the overall numbers were the largest, the hottest spots were on the southern flank of Georges Bank and throughout the Gulf of Maine, particularly off the coasts of Maine and Nova Scotia.

The Shannon-Weiner diversity index (H') reflected how many different species were predicted in each grid cell and simultaneously accounted for both abundance and evenness of the species present. During summer, the H' pattern indicated the shelf break off the mid-Atlantic states and around Georges Bank, as well as the ledges off New Hampshire and Massachusetts in the Gulf of Maine and sea mounts south of Georges Bank had the greatest diversity index (Figure 5-14). The offshore wind energy study areas that were entirely or partially on the shelf in shallow waters had a lower level of diversity then the shelf break portions of the offshore wind energy study areas. Of the offshore wind energy study areas, those located off Massachusetts/Rhode Island, northern North Carolina, Virginia, and

Delaware had the highest diversity, while those off New York and south of Cape Hatteras had the least diversity.

A manuscript documenting the results of these analyses is currently in preparation (Chavez-Rosales et al., Environmental predictors of habitat suitability and cetacean occurrence in waters of the northeastern coast of the United States).

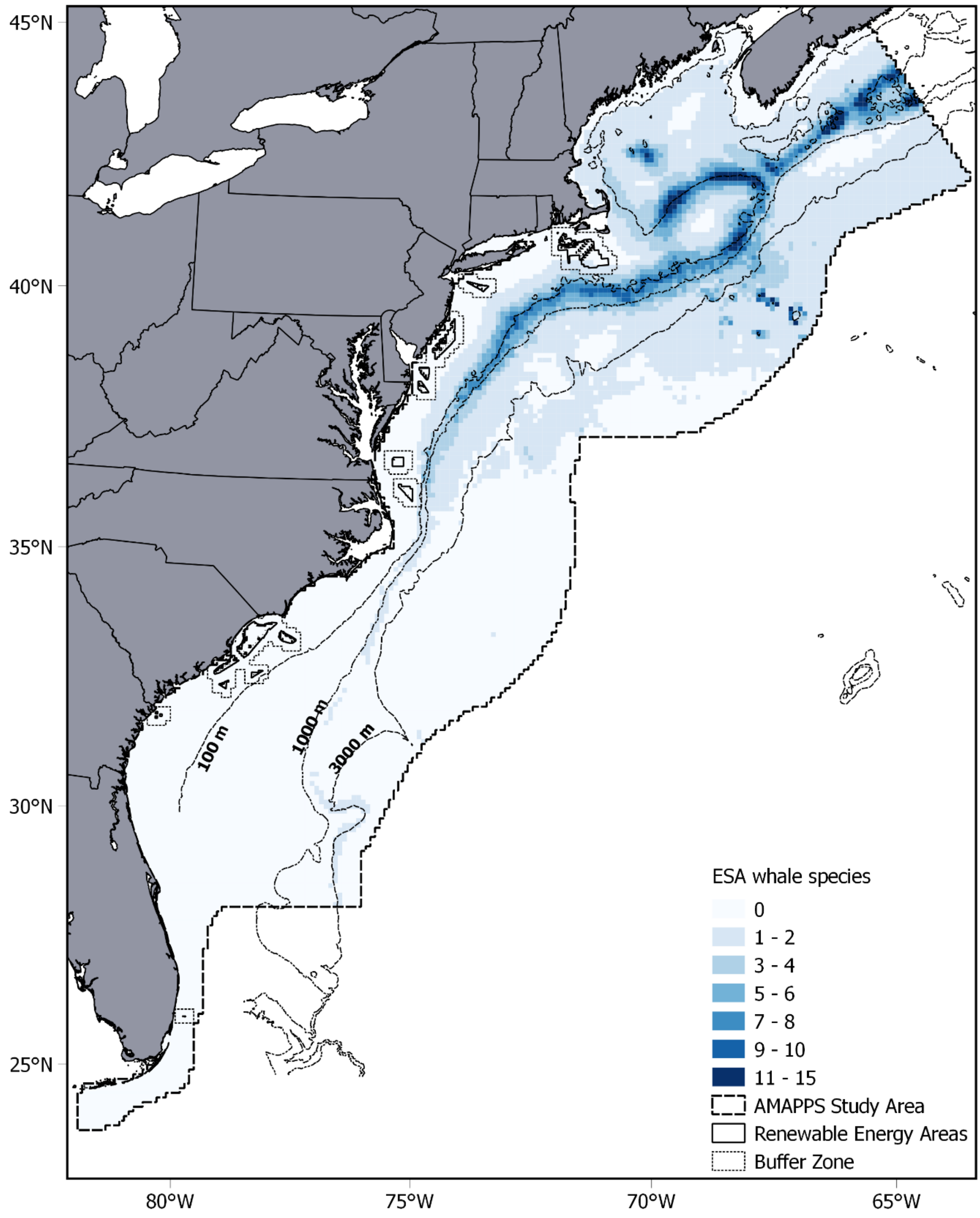


Figure 5-8 Spring abundance hot spot index (HSI) for ESA whales
(humpback, fin, sei and sperm whales)

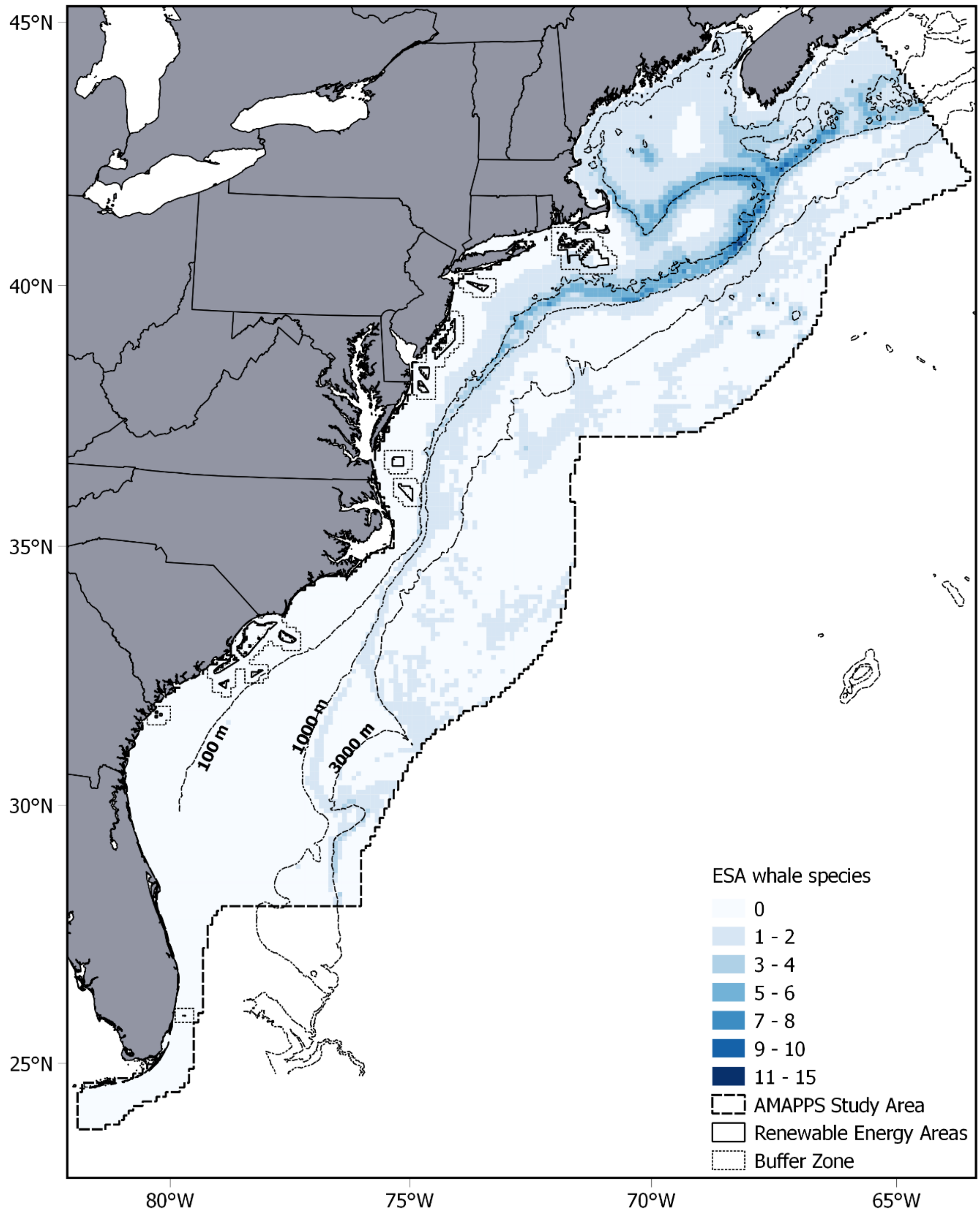


Figure 5-9 Summer abundance hot spot index (HSI) for ESA whales
(humpback, fin, sei and sperm whales)

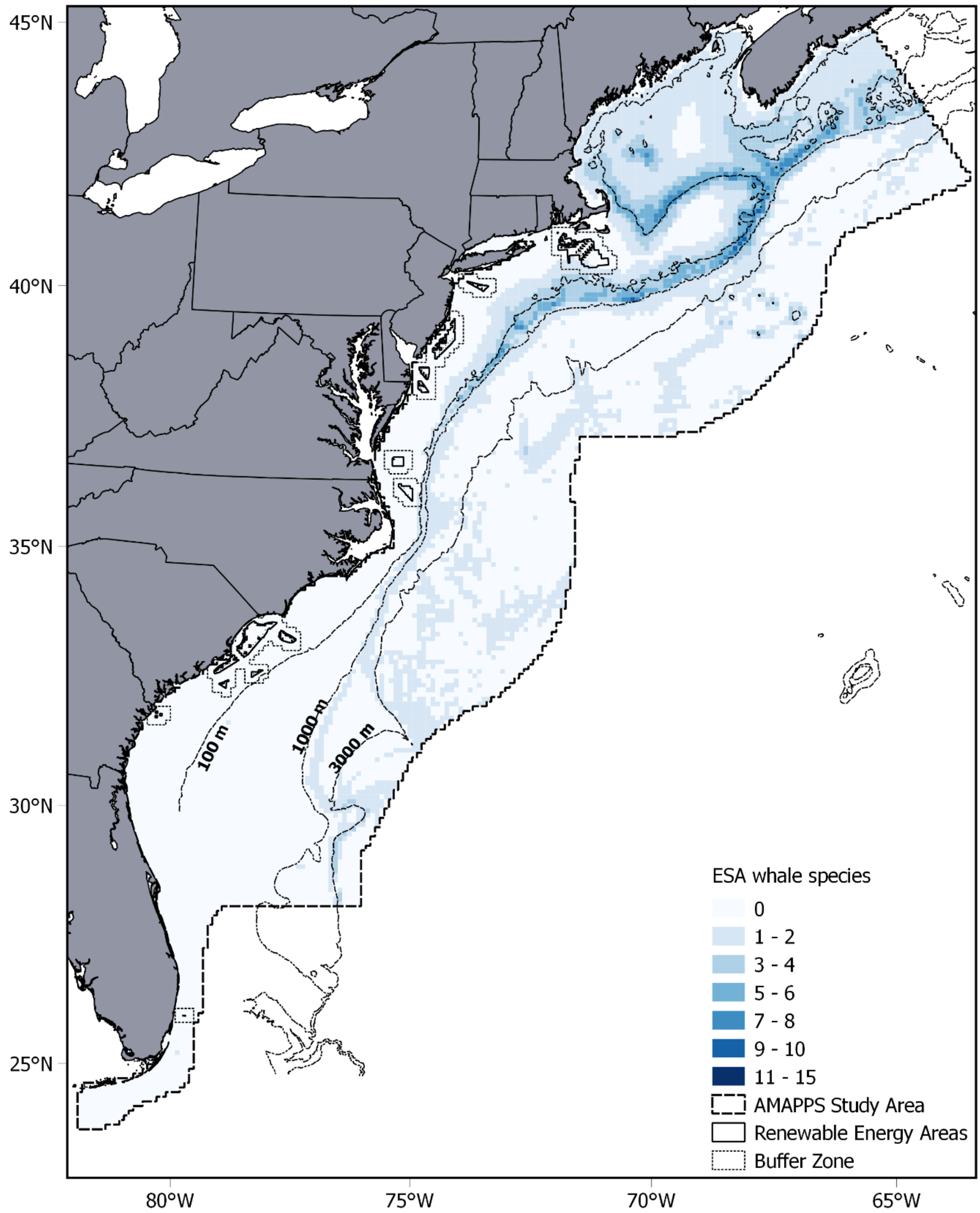


Figure 5-10 Fall abundance hot spot index (HSI) for ESA whales
(humpback, fin, sei and sperm whales)

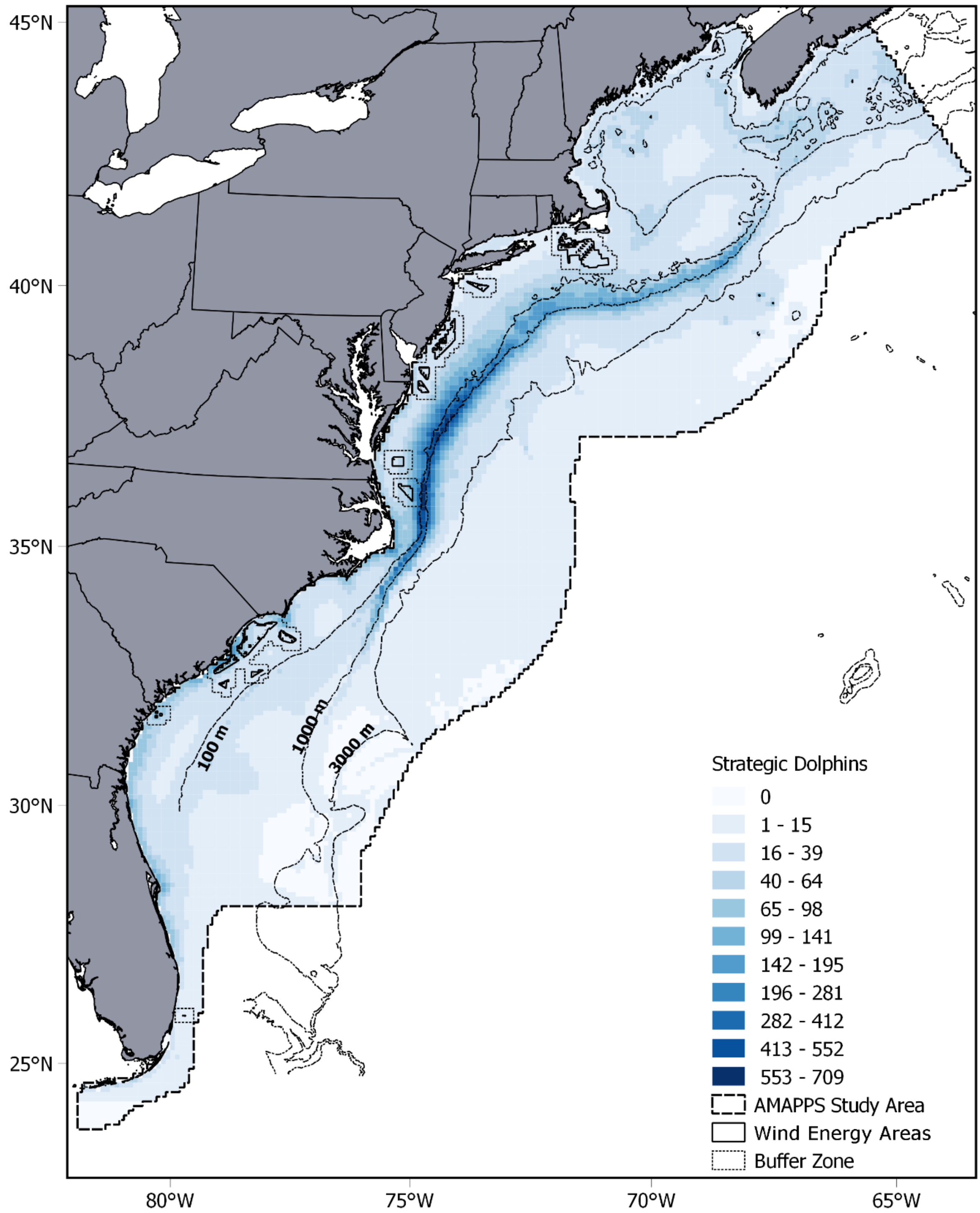


Figure 5-11 Spring abundance hot spot index (HIS) for MMPA strategic dolphins
(harbor porpoises, white-sided dolphins, common dolphins and long/short finned pilot whales)

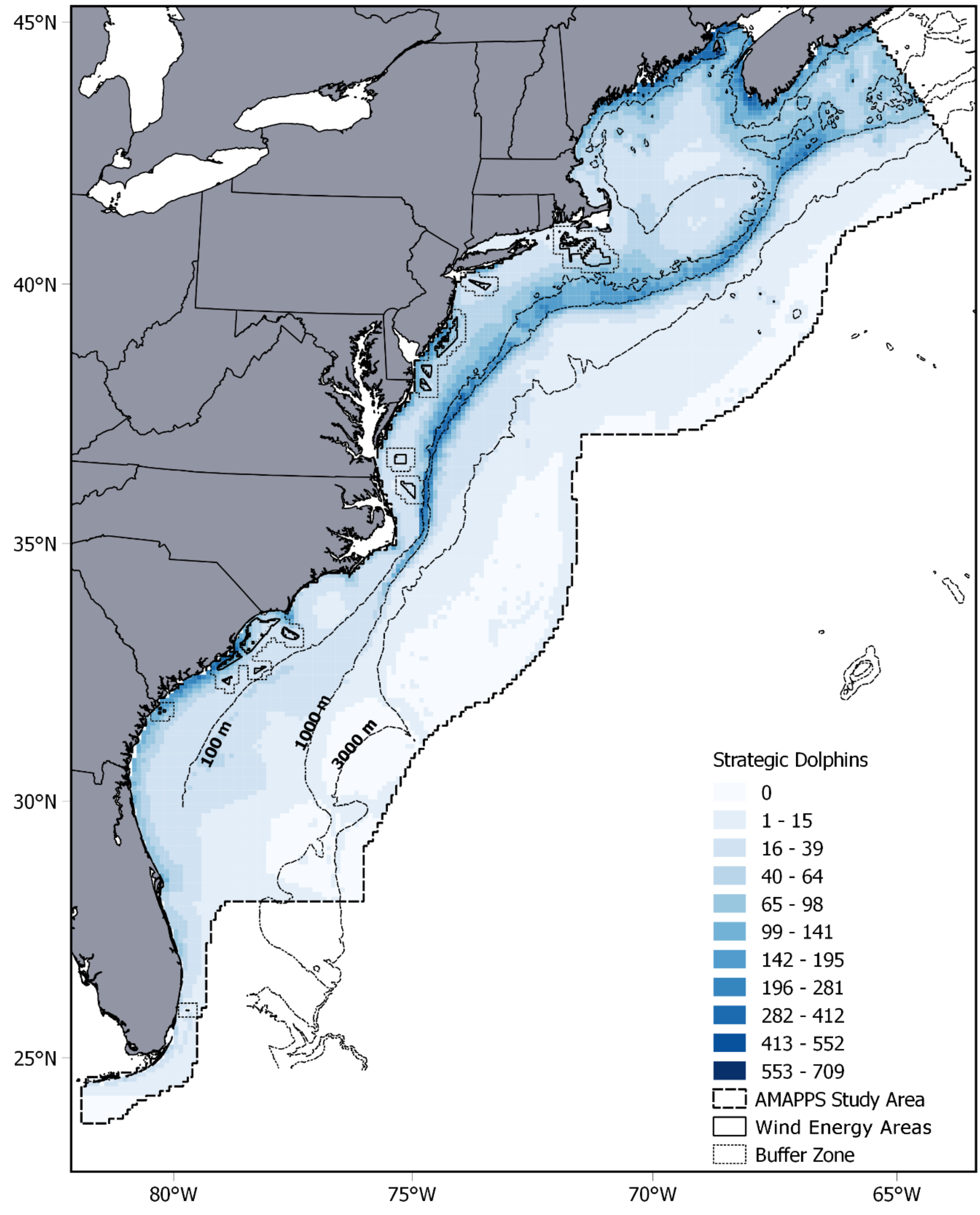


Figure 5-12 Summer abundance hot spot index (HSI) for MMPA strategic dolphins (harbor porpoises, white-sided dolphins, common dolphins and long/short finned pilot whales)

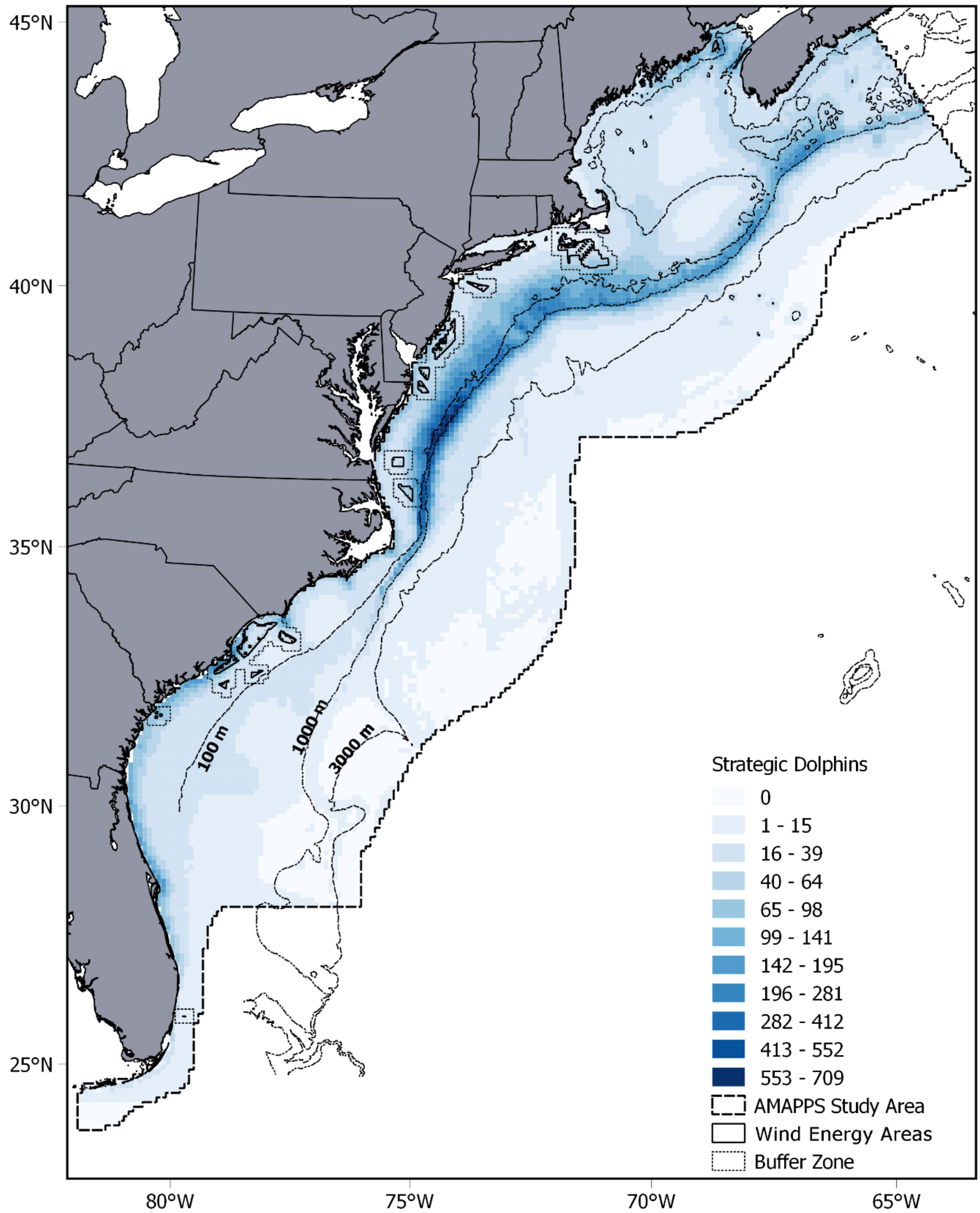


Figure 5-13 Fall abundance hot spot index (HSI) for MMPA strategic dolphins
(harbor porpoises, white-sided dolphins, common dolphins and long/short finned pilot whales)

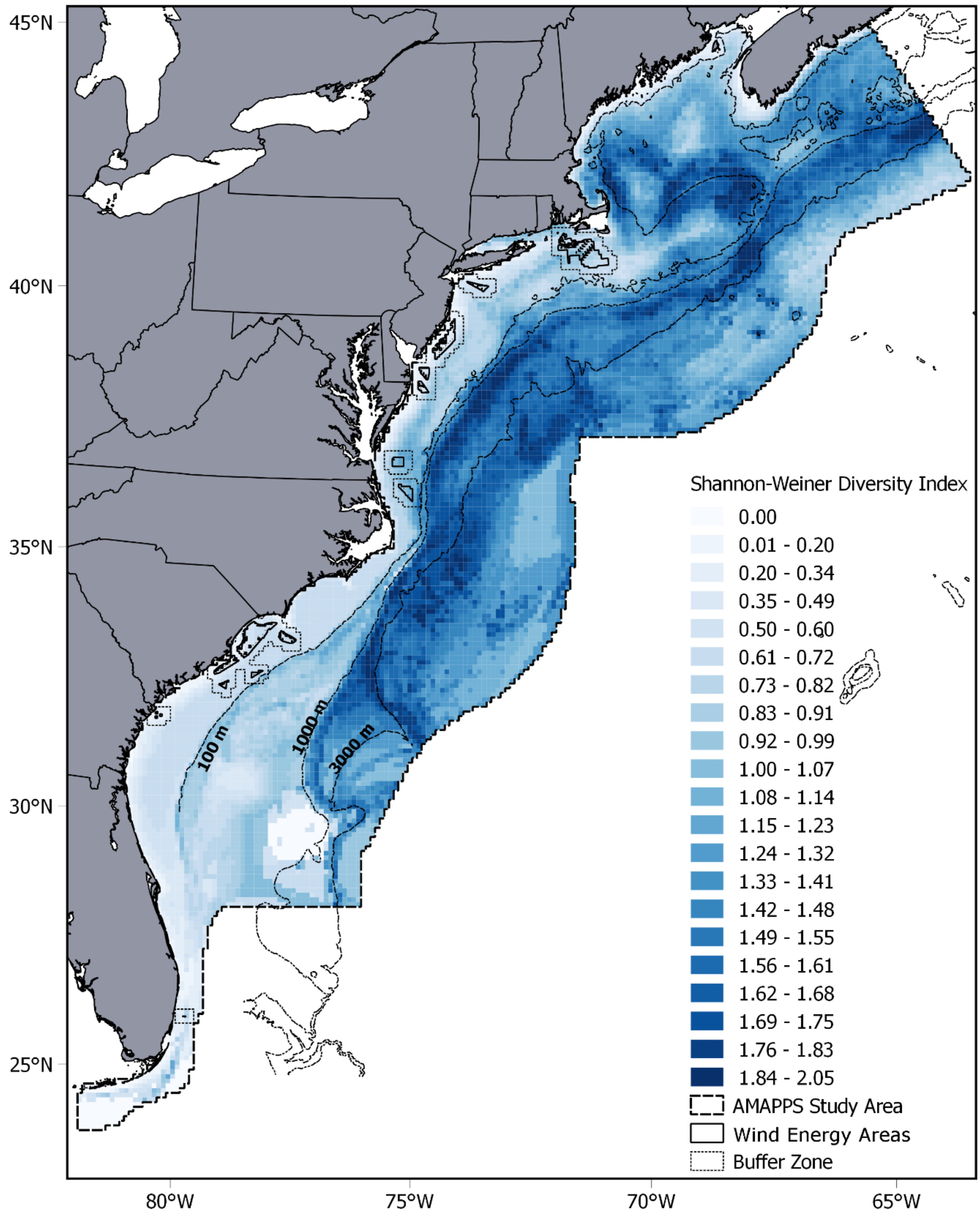


Figure 5-14 Shannon-Weiner diversity index (H') of all cetaceans during summer

5.3.6 Web Site

To display the seasonal spatially-explicit density distribution maps and summarize the density/abundance estimates a website was created that displays the seasonal maps found in Appendix I (Figure 5-15). To facilitate ease for a user to query a map to obtain detailed information on specific areas of interest, the web page has the capability for a user to draw a box around an area of interest. Then for that user-defined area, the density and abundance estimates are summarized, and all of the information for each grid cell within the area are displayed and are able to be downloaded (Figure 5-16).

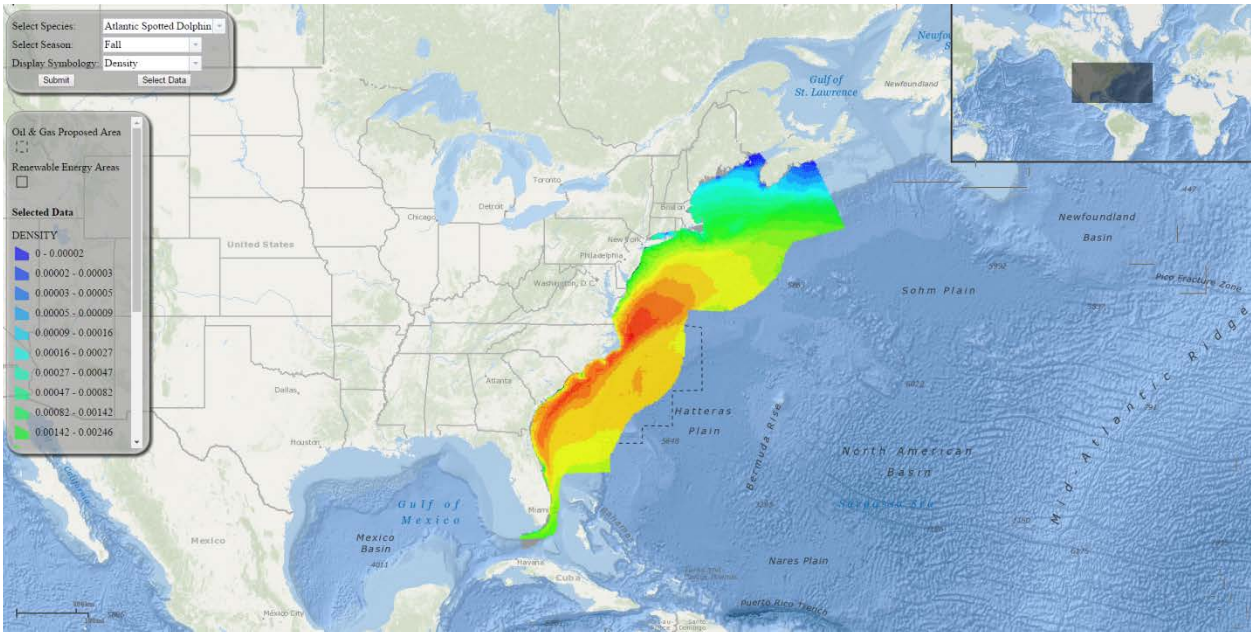


Figure 5-15 Example display of beta-website showing a seasonal density map

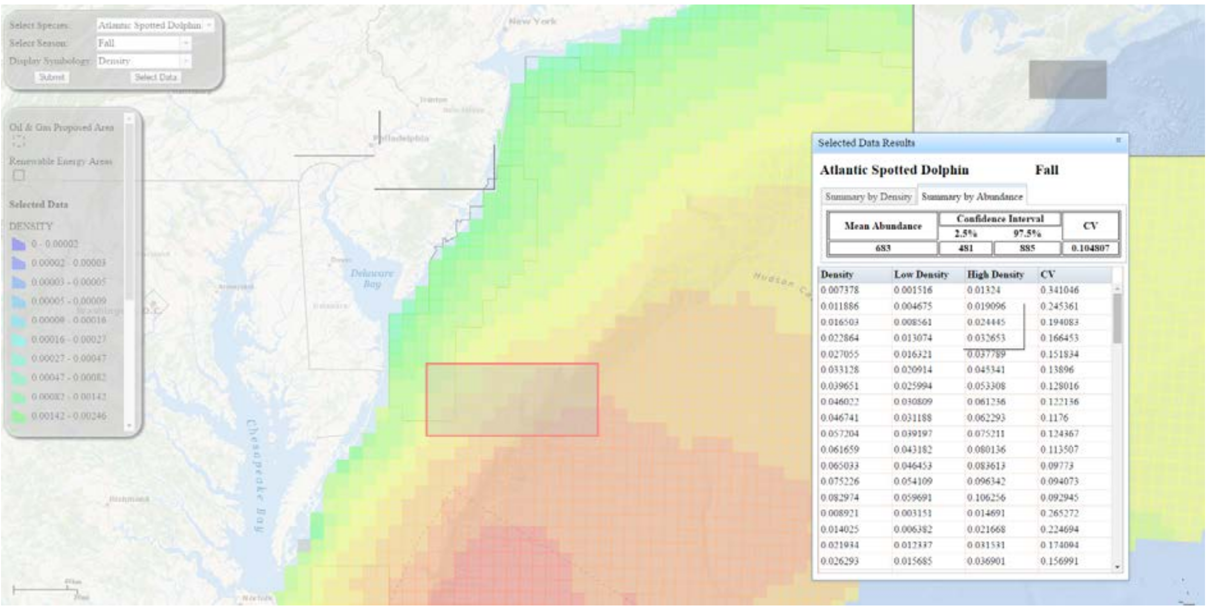


Figure 5-16 Example display of results from a user defined box outlined in red

5.4 Discussion

The density-habitat models, spatial-temporal maps, and abundance estimates for species and species guilds from northwestern North Atlantic waters that are presented here have several unique characteristics. Firstly, the sightings and environmental data were examined at a fine scale (10x10 km^2 grid cell and 8-day time periods) and data were collected recently (2010 – 2014) from various times of the year. In addition, the analysis methods included accounting for perception bias using concurrently collected data thus, insuring the corrections were appropriate; and the analysis accounted for availability bias by estimating species-specific correction factors, of which some were estimated from recently tagged animals. Finally, the environmental data that were associated with the sightings data included both static and dynamic variables obtained from satellites and ocean models and some of these variables were assessed by comparing them to *in-situ* measurements made at a broad and fine spatial-temporal scale.

In general, as seen in the AMAPPS analyses and as is becoming more and more obvious as more data are being collected using a variety of methods, marine mammals of some species or another inhabit waters in nearly all parts of the US Atlantic at nearly all times of the year, though the species composition and magnitude of abundance vary greatly both spatially and temporally.

5.4.1 Density Models

Due to the nature of line transect surveys, environmental conditions and animal behavior, it was not always possible to identify the species of all detected groups. In the case of whales identified as either a fin or sei whale, it was possible to identify different environmental characteristics related to the location of the positively identified fin whales and sei whales. This allowed a way to categorize the ambiguous sighting as either a like-fin or like-sei whale. This same type of approach has been initiated to attempt identifying ambiguous pygmy/dwarf sperm whale sightings, and could also be attempted for other general guilds, like pilot whale spp., beaked whales, and possibly also the very generalized unidentified whale or unidentified dolphin. We have also had success incorporating this categorization process into the Bayesian framework (discussed below) which took advantage of the information from the ambiguous sightings while accounting for the uncertainty in species identification. Additional separation approaches that may be investigated during AMAPPS II include using various classification statistical techniques such as Random Forests, support vector methods and other machine learning techniques. This strategy could result in more realistic and accurate species assignments which will increase the data available for the models and hopefully also decrease the levels of uncertainty in the density estimates.

Despite the year-round coverage of this study, the winter data available during 2010 – 2014 was limited, thus winter distribution maps for only one species has been produced at this time. The effect of the low search effort was compounded by the fact that the densities of marine mammals in the study area are naturally low during winter. Thus, more winter data are needed to produce accurate winter density maps and abundance estimates. To improve this situation, additional winter data have already been collected and more winter surveys are scheduled during AMAPPS II. It is expected when more winter data become available, models for this season will be able to be created.

We were not able to produce habitat models and abundance estimates of species that were rarely seen. As more sightings of these species become available it may be possible to generate spatial-temporal density-habitat models using the methods presented in this document. However, there are several alternatives that could also be explored but will require some compromises/assumptions. For example, future and past sightings of these species could be used or the seasonal abundance could be derived using standard distance sampling with the data pooled over the entire study area or perhaps pooled with other species that have similar detection behaviors. On the other hand, novel methods using presence only or presence/absence of a species to develop a habitat relationship are also worth exploring, with techniques like support vector machine methods, a type of machine learning process, that has successfully been used to model and map rare events, with as few as 20 occurrences of rare plant species (Pouteau et al. 2012). Or, an ensemble of small models may also be a viable approach to modeling the distribution of rare species (Breiner et al. 2015).

The correction factors to account for availability bias were not spatially and temporally contemporaneous, though they were species-specific using information collected from Atlantic Ocean animals in most cases. It is expected that the true availability correction factors would be spatially and temporally variable to some unknown degree. To address this uncertainty, additional dive pattern data should be collected from animals in the western North Atlantic, particularly species that have a large correction factor such as sperm whales, the various beaked whale species, pygmy/dwarf sperm whale species, and turtles. NMFS is proposing to collect tag data from Sowerby's beaked whale during the summers of 2017 and 2018. It would be ideal to have spatially and/or temporally specific correction factors, especially if the differences over space or time are considerably large. To evaluate whether spatially-explicit corrections are needed for sperm whales, we have started a project that is investigating if it is possible to use concurrently collected passive acoustic and visual data to examine the probabilities of transitioning from the surface to below the surface using Hidden Markov Models in a Bayesian framework. This work is being jointly funded as a project under AMAPPS and by NMFS. Using this method, we may be able to combine the passive acoustic data with the visual sightings data to obtain more accurate and precise estimates of spatially-explicit densities and associated availability bias. These results should be available under AMAPPS II.

The comparison between remote-sensed dynamic environmental variables and *in-situ* measurements indicated that the HYCOM ocean model-derived variables (bottom temperature, surface salinity, and mixed layer depth) are not as accurate as the satellite-derived SST measurements; at least at the fine scale that we tested the data. Further assessments should be undertaken to explore whether the species distribution models are sensitive to uncertainties in these environmental parameters and what effect the scale of the ocean model-derived variables has on the relationships with species distributions and abundances. In a separate ongoing analysis investigating the effects of the scale of satellite-derived SST and Chlorophyll a measurements on predicted marine mammal bycatch estimates, it was determined that the scales used in this paper did not significantly affect the predicted estimates.

Additional physical and biological environmental variables could be included in the models to evaluate if they are better indicators to changes in density. For example, animal density may be better predicted by its relationship to temperature/salinity fronts or to densities of fish or krill or other potential prey species. Relationships to potential prey are currently being investigated by comparing marine mammal distributions to the concurrently collected EK60 back scatter data (that describe fish and plankton distributions) and samples collected from a visual plankton recorder, bongo tows, and various trawl tows. This is further explored in the ecosystem discussion in Chapter 11 of this document. It is possible these types of relationships could be used to develop better predictions.

One important assumption about regression type models, like those presented in this document, is that the models assume the relationships between animal density and environmental habitat factors have consistent statistical correlations within the spatial-temporal variables included in the model. Given this assumption, it is then possible to predict the average density in locations or time periods where surveys did not actually occur (Guisan et al. 2002). This means a causal or mechanistic relationship is not explicitly assumed. Consequentially, the type of model used in this document does not attempt to predict the location of individual animals at a particular time; rather the model results in an average predicted pattern. In most cases this average pattern is sufficient to assess anthropogenic effects on the wildlife.

Changes in abiotic variables, such as sea surface temperature can alter marine ecosystems and atmospheric patterns. The importance of certain environmental variables, such as sea surface temperature, in predicting animal distributions indicates that these species may well respond to future environmental shifts brought about by anthropogenic effects and climatic change (Griffies 2004; Tallis et al. 2010). For example, changes in the North Atlantic Oscillation (NAO) are related to changes in the ocean circulation, affecting the replenishment of nutrients in marine ecosystems by modifying ocean stratification. The consequences of these changes are expected to vary regionally (Ostrander et al. 2000; Pratchett et al 2004; Friedland and Hare 2007). In addition, abiotic variables might also affect the relative timing of the production cycles of the base of the food chain and consumers, thus affecting their growth and survival and the inter-annual changes and abundance of species (Ballance et al. 2006; Nye et al. 2009; Hurrell and Deser 2010). Over the last several decades, NAO has been in a positive state with records of warm water temperatures during this period, particularly in nearshore areas. Long-term sea surface temperature records at shore stations in Massachusetts and Maine indicate a general warming trend over the last century with superimposed decadal-scale fluctuations. A shorter time series available for Virginia indicates a steady increase in temperature over the last four decades (Nixon et al. 2004; Friedland and Hare 2007). A recorded example of the nature of the changes promoted by changes in the environment can be seen in the relationship of the copepod *Calanus finmarchicus* and changes in the physical oceanography of the Northwest Atlantic related to the NAO. Positive NAO states result in higher *Calanus* abundance and negative NAO to lower abundance (Fromentin and Planque 1996; Greene and Pershing 2000). Change in the abundance of *C. finmarchicus* cascade up the food chain and have been linked to reproduction in the endangered North Atlantic right whale, *Eubalaena glacialis* (Wishner et al. 1995; Baumgartner et al. 2003). Due to these changes, it is unclear how useful descriptions of past distributions that do not account for environmental habitat characteristics will be for predicting future distributions. This can be investigated in several ways. For example, we can use current models to predict spatial patterns and abundance from past and/or future times and areas for which distribution/abundance data were collected so that the predicted and actual data can be compared to validate the usefulness of the model and determine how robust the models are. Also, a logical extension of the modeling framework used in this analysis is to capture these changes, if they occur, by allowing for spatial-temporal trends using either space or time explicitly in the models or use environmental habitat factors that are proxies for climatic changes, if they are occurring.

5.4.2 Hot Spots

Factors potentially causing the formation and maintenance of hot spots may include interactions between species such as competition and mutualism (Reed and Dobson 1993; Ainley et al. 2006), in addition to physical and biological dynamics as used in the abundance models developed in this Chapter. Despite the fact that it is currently not possible to know what caused the hot spots depicted in the two indices explored, over all patterns become obvious. There are seasonal movement/migration patterns with north-south and onshore-offshore gradients that change throughout the year. These patterns could be utilized to determine when activities such as pile driving could be carried out in times and places that minimize the expose to protected species. To more fully understand the mechanisms behind the formation and maintenance of hot spots, fine-scale multi-trophic level ecosystem studies appear to be needed.

5.4.3 Bayesian Hierarchical Framework

A Bayesian hierarchical framework is currently being developed as another method to estimate the spatially-explicit density. In contrast to the “two-stage approach” used in the GAM framework described above, a Bayesian hierarchical framework can be referred to as a “one-stage approach”. The hierarchical aspect isolates the biological or ecological dynamic (state) process from the observational process (describes the probability of observing the individuals given the true density and detection process involved in a line-transect survey), yet fits the parameters in a single step (Miller et al. 2013). Also because of the Bayesian framework, estimating summaries of uncertainty via credible intervals is straightforward and can be derived directly from the posterior estimators (Gardner et al. 2008; Zipkin et al. 2010). In the case of marine mammals, recent Bayesian hierarchical methods have combined traditional distance sampling approaches with generalized linear models relating density to habitat variables (Eguchi et al. 2009; Moore and Barlow 2011; 2014; Conn et al. 2012; Pardo et al. 2015).

A Bayesian hierarchical modeling framework has been developed and applied to the large whale visual data collected in the AMAPPS surveys and has produced maps of density estimates with associated measures of uncertainty. They have not been presented in this document because preliminary posterior abundance estimates appear to be unrealistically skewed. The posterior estimates of the seasonal average abundance and spatial density patterns were generally comparable to those produced from the GAM modeling framework. However, the abundance estimates were highly skewed where a small percentage of posterior density estimates was unrealistically large. To account for the skewness and large numbers of zeros in the input data, we explored a number of probability models including zero-inflated and hurdle models, negative binomial and over-dispersed Poisson. We have worked on several ways to understand the cause of the skewness and where possible reduce the uncertainty. These approaches included redefining the study site for each species to only include areas where each species is likely to occur (as has been done for the GAM models), and looking more closely at the environmental covariates and investigating possible interactions and reducing the set of covariates to a smaller set of most likely predictors; thus removing covariates that have small but highly variable relationships. We also restricted the spatial-temporal predictions to fall within the generalized independent variable hull such that combinations of covariates for unobserved grid cells were consistent with characteristics of the data (Conn et al. 2015). In addition, simulation testing and independent reviews of the code verified that there were no coding errors and the models were working appropriately. Unfortunately, the skewness found in this study of Bayesian hierarchical models is not unique. Recently other researchers have shown that the Bayesian hierarchical framework commonly results in skewed estimates and hence large uncertainty bounds (Conn et al. 2015). Hence, we have begun exploring alternative approaches within this framework such as incorporating more flexibility, like incorporating GAMs and the Tweedie distribution. This flexibility has the ability to fit the data better particularly when there are non-unimodal and spatially varying relationships, as is the case for most marine mammal-environmental distributions.

In addition, future plans also include accounting for spatial autocorrelation in the model (Shelton et al. 2014; Thorson et al. 2015). Our current model framework does not explicitly account for autocorrelation that could occur at varying spatial and temporal scales. One reason for excluding spatial autocorrelation is that these models can be slow to converge using the current Bayesian approach that we have adopted. Fortunately, there have been recent modeling advances that have decreased computation time and made it plausible to include autocorrelation functions directly into the modeling framework using Guassian random fields (Lindgren et al. 2011). In some case these models have produced more precise estimates of spatially-explicit density than less sophisticated models that ignore this autocorrelation (Thorson et al. 2015). These models can be fit using the R-INLA package and the software program template model builder. We plan to modify the current Bayesian hierarchical model to include spatio-temporal autocorrelation by refitting the data using the template model builder software package. This new approach will still account for detection uncertainty but also included non-parametric covariance functions to address the spatial uncertainty that could not be fit using the available predictor variables. A similar approach has successfully been applied to data on blue whales in the Pacific Ocean (Yuan et al. 2016).

An advantage of the Bayesian hierarchical framework is its ability to communicate the results in the context of a risk analysis. Because the posterior distributions from a Bayesian analysis can be easily interpreted in terms of probabilities, it is possible to make inferences by drawing from the posterior distribution to quantify the probability within a specific area. Depending on the scientific or management question, this approach could be utilized to assess the risk of encounter. For example, this type of model can easily map out a specific area, say, the Massachusetts-Rhode Island offshore wind energy study area, and display where there is predicted to be at least one humpback whale on a random day within the summer (Figure 5-17). Another example would be mapping the hot spots of a species, where a hot spot could be a management-defined value. This method for quantifying the uncertainty in the output of a Bayesian spatial density model was successfully applied to multiple species of seabirds (Balderama et al. 2012).

One of the reasons a higher level of uncertainty is expected in the Bayesian hierarchical framework is variability from all inputs, including uncertainty in the detection model and regression model selection which are able to be accounted for in the Bayesian framework. This is in contrast to the results for the GAM framework developed here and in other spatial density modeling applications that only account for modeling and not uncertainty. That is, the variability in the first step in the GAM framework (density estimate derived using distance sampling) is not fully propagated through the second step (GAM habitat model). Because understanding and acknowledging the uncertainty in the results is important, especially when making management decisions, several strategies are being developed to more fully incorporate and understand the full extent of the variability within the GAM framework.

One strategy is to further develop the statistical models to incorporate the variability within the GAM framework. For example, the framework could incorporate the variability due to the density estimates that are used as input into the GAM density-habitat model; incorporate model selection variability; and incorporate/account for spatial autocorrelation. Currently these aspects have not been incorporated in most marine mammal spatial modeling exercises that have been published.

Another strategy that could reduce or at least help to more fully understand the variability in either the GAM or Bayesian hierarchical framework is to include other variables that may further refine the density-habitat relationship. Other variables of particular interest are dynamic environmental variables such as ocean fronts or ocean modeled productivity variables. In addition, other variables that could provide more explanation of the density-habitat relationship are biological-related variables that represent the prey field. Further investigations into this are discussed in Chapter 11.

A manuscript is currently in preparation documenting the development of and results from applying the Bayesian hierarchical framework to the AMAPPS line transect data, which also compares the variance estimates between the Bayesian hierarchical and GAM frameworks (Sigouney et al: Bayesian hierarchical methods to estimate marine mammal abundance).

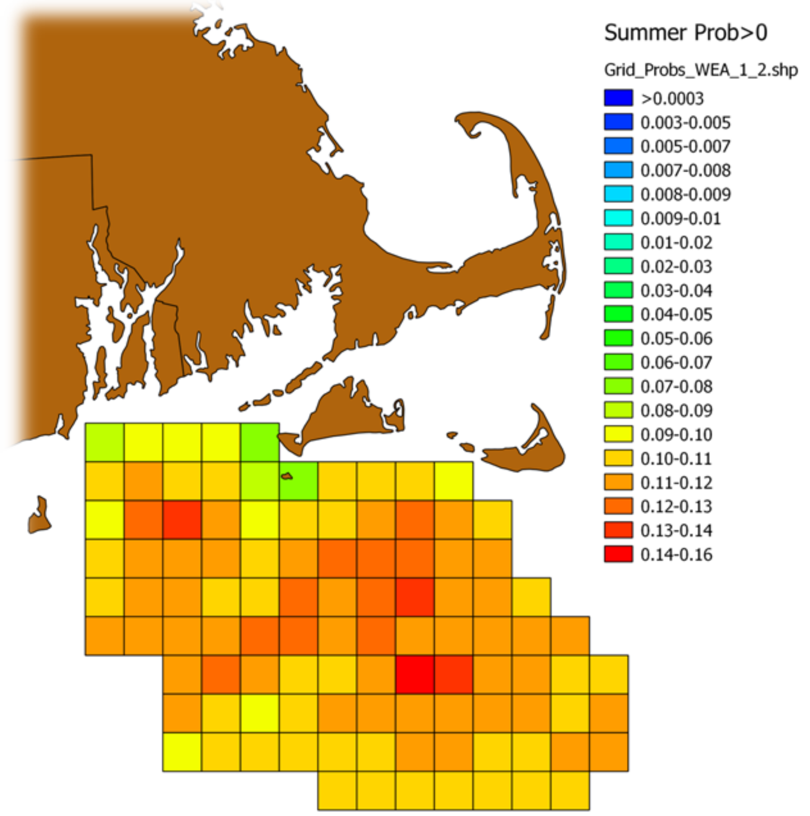


Figure 5-17 Daily risk (probability) of at least one humpback whale
in the Rhode Island-Massachusetts offshore wind energy study area in summer

5.4.4 Comparison with Other Studies

Research documented in this chapter has resulted in abundance estimates and spatial distribution maps at both a broad scale (US Atlantic OCS and slightly beyond) and fine scale (offshore wind energy study areas). This has allowed a comparison of the AMAPPS density-habitat distribution patterns and abundance estimates with other broad scale and fine scale visual and passive acoustic projects.

5.4.4.1 Broad scale – visual surveys

In regards to the broad scale AMAPPS abundance estimates and spatial-temporal patterns, recently published estimates are in general similar (Table 5-24). However, direct comparisons are complicated due to a variety of technical and presentation differences.

Table 5-24 Comparison of broad scale AMAPPS abundance estimates to previous estimates

Species	AMAPPS Avg Summer 2010-2013	Roberts et al. Avg Annual 1992-2009	2011 SAR Summer 2011	CETAP Avg of Peak Seasons 1978-1982
Atlantic spotted dolphin	54,731 (0.15)	55,436 (0.32)	48,415 (0.43)	6,107 (0.27)
Beaked whales (all)	11,091 (0.20)	14,491 (0.17)	13,624 (0.43)	120 (0.71)
Common bottlenose dolphin	138,700 (0.36)	97,476 (0.06)	77,532 (0.40)	7,676 (0.58)
Fin whale	4,718 (0.13)	5,746 (0.08)	1,595 (0.33)	4,680 (0.23)
Harbor porpoise	62,469 (0.23)	48,049 (0.12)	79,883 (0.32)	2240 (0.15)
Humpback whale	1,246 (0.17)	1,637 (0.07)	335 (0.42)	294 (0.45)
Pygmy/dwarf sperm whale	9,951 (0.21)	678 (0.23)	3,785 (0.47)	41 (-)
Minke whale	2,834 (0.25)	2,112 (0.05)	2,591 (0.81)	320 (0.23)
Long/short finned pilot whale	24,670 (0.29)	18,977 (0.11)	21,515 (0.37)	11,120 (0.29)
Risso's dolphin	36,785 (0.20)	7,732 (0.09)	18,250 (0.46)	4,980 (0.34)
Sei whale	1,872 (0.42)	717 (0.30)	357 (0.52)	253 (0.63)
Common dolphin	118,695 (0.21)	86,098 (0.12)	70,184 (0.28)	29,610 (0.39)
Sperm whale	3,663 (0.14)	5,353 (0.12)	2,288 (0.28)	219 (0.36)
Striped dolphin	81,512 (0.12)	75,657 (0.21)	54,807 (0.30)	37,780 (0.27)
White-sided dolphin	42,985 (0.46)	37,180 (0.07)	48,819 (0.61)	28,600 (0.21)

In particular, the older estimates such as CeTAP from 1979 – 1982 (CeTAP 1984; Waring et al. 1997) did not account for perception bias for any species or do not account for availability bias for dolphins and small whales. Consequentially, aerial surveys like CeTAP would result in abundance that is under-estimated. Thus, it is expected that more recent estimates which account, at least partially, for these biases would be larger than CeTAP estimates. Plus it is assumed that abundance has changed over the last 30 year, though the amount and direction of change is unknown.

The 2011 abundance estimates that are reported in the US Stock Assessment Reports (Palka 2012; Waring et al. 2013) account for perception bias that were internally calculated from the same 2011 data (insuring appropriate estimates); however, availability bias was not accounted for. Again, it is expected that the 2011 estimates are under-representations especially for animals with long dive times like beaked whales, sperm whales, and pygmy/dwarf sperm whales.

The Roberts et al. (2016; 2016a) estimates account for both perception and availability bias, thus direct comparisons with the AMAPPS estimates are easier. In many cases the abundance estimates and spatial patterns are similar. However, there are a variety of presentation and technical differences complicating the comparisons. These differences include: (A) Difference in presentation: average annual and monthly estimates were presented in Roberts et al. (2016), in contract to seasonal estimates from the AMAPPS data. (B) Differences in spatial and temporal coverage: most of the data used to develop the Roberts et al. (2016) models were collected earlier, from 1995 to 2009, though there is some data from some species that came from up to 2014. In addition, data from surveys conducted all over the Atlantic from the US to Europe to the Gulf of Mexico were included in some components in the Roberts et al. (2016) results. And (C) differences in analysis strategies and methods: the general strategy of the Roberts et al. (2016) analysis was to use only a single team's data and apply estimates to account for perception and availability bias. In contrast, the two team approach that was used under AMAPPS used the same set of data to estimate abundance and account for perception bias. In some cases Roberts et al. (2016) applied perception and availability bias correction factors from surveys conducted in the Pacific to the Atlantic and Gulf of Mexico abundance data, which may result in incorrect or unrepresentative corrections because of differences between the survey methods and animal's behavior. Though in all cases Roberts et al. (2016) attempted to use the best available data and make logical assumptions and decisions. The effects of all of these differences result in species-specific differences in abundance estimates and distribution maps. Examples of effects of each of these issues are discussed in more detail below.

(A) In general, the average annual estimates from Roberts et al. (2016) are the most different from the seasonal AMAPPS estimates for species that migrate out of US waters during some parts of a year. Thus, this suggests seasonal (like those in this report) or monthly estimates (like those in Roberts et al., supplement (2016)) should be utilized for most applications of the abundance results. For example, many Atlantic white-sided dolphins move to Canadian waters outside of the study area, so the average of the Roberts et al. (2016) monthly estimates for June to September (50,827; Roberts 2016) was much closer to the AMAPPS summer seasonal estimate (42,985), in contrast to the 37,180 annual average from Roberts et al. (2016).

(B) In some cases, it appears that the older data represent a slightly different spatial distribution pattern. For example, in more recent years, particularly in the summer, humpback whales have been seen more frequently in summer waters just south of Cape Cod, MA and on the southern edge of Georges Bank. This more recent pattern is better represented in the AMAPPS distribution map which uses only more recent data. Another example is shown by white-sided dolphins. In more recent years, white-sided dolphins are in higher densities in the spring time (May – June) in southern Gulf of Maine, in contrast, in the 1990's and early 2000's white-sided dolphins were in higher densities in the northern Gulf of Maine in summertime (July – August). The more recent data used in AMAPPS appear to more correctly depict the current distribution patterns.

(C) In some cases such as for Risso's dolphins, several issues appear to explain why the AMAPPS summer estimate was much larger than Roberts et al. (2016) annual estimate. One contributing issue is the value of the *g(0)* correction factor used in the Roberts et al. (2016) analysis for some of the shipboard surveys included in the models, which was small and not estimated from the data used in the analysis; resulting in low abundance estimates. Thus, highlighting the preference to, whenever possible, estimate correction factors from the data used to estimate the abundance to ensure species-survey-specific appropriate corrections. Both AMAPPS and Roberts et al. (2016) predicted large seasonal changes with the highest abundance in the summer. Summer estimates were more comparable between the two analyses, though AMAPPS was still higher than the Roberts et al. (2016) preferred climatological model. This highlights the effect of an annual estimate and the seasonal variability of this species. Both analyses predicted high abundance along the shelf break on the Canadian Scotian shelf, where limited data were available. Thus, highlighting the importance to collaborate with the Canadians and collect more data from this region to fully understand what is happening in these waters. The Roberts et al. (2016) analyses produced three models with very different results for this species. One of the non-preferred models, the contemporaneous model, particularly for several years, produced very similar abundance estimates and within-year temporal patterns to that developed using the AMAPPS more recent data. This highlights the possibility of large inter-annual differences for this species and the effects of different density-environment models.

(D) For pygmy/dwarf sperm whales, several technical issues can explain the large differences between the abundance estimates from AMAPPS and Roberts et al. (2016). The Roberts et al. (2016) and previous other estimates for shipboard surveys, where most of the sightings came from, did not account for availability bias, while the AMAPPS estimate did include an estimate which is relatively large (0.54 as reported in this paper). In addition, observers are becoming more experienced and cameras can take high resolution pictures, which have enabled identifying these species more often than in the past, and even at times identifying the animals to species (pygmy sperm whale versus dwarf sperm whale). So, groups that in the past were identified as unidentified whale are now identified as a pygmy/dwarf sperm whale or perhaps a confirmed pygmy sperm whale or dwarf sperm whale. Thus, it is not surprising the AMAPPS estimate is larger and reflects a better representation of this species.

5.4.4.2 Fine scale – visual surveys

On the smaller spatial scale within the coastal mid-Atlantic region, spatial encounter rate patterns were derived within the Mid-Atlantic Wildlife Studies (Williams et al. 2015a, b, c) that covered the region between the Delaware and Virginia wind energy area during 2012 – 2014. These surveys used shipboard and aerial platforms employing both visual and digital photographic recordings of sightings. Relative abundance and spatial distribution patterns were derived from the New Jersey Ocean wind power ecological baseline study (Geo-Marine 2010) that covered waters off New Jersey using shipboard and aerial platforms in addition to passive acoustics. Our data supports these projects conclusions on the general temporal patterns; such as common dolphins are in these mid-Atlantic offshore wind energy study areas mostly in the cooler months and less in the summertime and are found mostly in the offshore edges of the wind energy study areas. In contrast common bottlenose dolphins have the opposite pattern, with peak abundance in the summer and in the shallow nearshore waters. In addition, AMAPPS and these other studies documented that several of the large whales like right, fin and humpback whales are found at low densities in these regions during most times of the year, with the peaks in cooler months. As stated in these other reports, their abundance estimates are under-estimates because of the lack of accounting for availability bias (Table 5-25). Again our report supports this, as our analysis estimated more animals in each of the offshore wind energy study areas during the various seasons of overlap. Our data have provided an extension to the Williams et al. (2015) conclusions by documenting that during the summer the common dolphins that do not appear in the mid-Atlantic offshore wind energy study areas appear to have traveled farther offshore to the shelf break. Plus, the AMAPPS data indicate more species infrequently use the New Jersey to Maryland offshore wind energy study areas, such as, pilot and minke whales.

Table 5-25 Comparison of abundance estimates for the New Jersey wind energy study area

Species	Geo-Marine (2010)		AMAPPS	
	Abun Estimate	**Time frame period**	**Abun Estimate**	**Time frame**
Humpback whale	1	Yr-round	5.3	Avg spring to fall
Fin whale	2	Yr-round	4.0	Avg spring to fall
Common dolphin	82	Winter	736	Avg spring and fall only
Common bottlenose dolphin	722	Spring	1169	Spring
	289	Summer	6106	Summer
	1297	Summer (aerial)	2428	Fall
Harbor porpoise	98	Winter	21.5	Avg spring and fall only

In the Rhode Island/Massachusetts offshore wind energy study area, cetaceans have been observed during most times of the year, though primarily in spring, summer and fall (Kenney and Vigness-Raposa 2010; Kraus et al. 2016). During October 2011 to June 2015, Kraus et al. (2016) collected data to investigate the distribution and abundance of cetaceans and sea turtles in this offshore wind energy area using aerial visual line transect surveys and bottom mounted hydrophones. When comparing the Kraus et al. (2016) sightings per unit effort maps and seasonal abundance estimates to the AMAPPS density maps and abundance estimates, the AMAPPS results provided corroboration for their resulting general spatial distribution patterns and patterns of relative abundance. In nearly every case, the Kraus et al. (2016) abundance estimates were smaller than those from the AMAPPS analyses, though this is because Kraus did not account for perception and availability bias (Table 5-26). The only exception is that Kraus et al. (2016) estimated a few more sei whale individuals than the AMAPPS estimates, though all estimates were below 10 individuals.

Table 5-26 Abundance comparison for Rhode Island/Massachusetts wind energy study area

	Spring		Summer		Fall	
Species	**AMAPPS**	**Kraus**	**AMAPPS**	**Kraus**	**AMAPPS**	**Kraus**
Atlantic white-sided dolphin	254	P	107	P	134	P
Common bottlenose dolphin	246	52	1110	26	777	51
Fin whale	48	14	50	27	34	2
Harbor porpoise	1478	P	26	0	21	P
Humpback whale	37	25	22	10	32	2
Minke whale	62	P	83	P	97	P
Pilot whale	8	P	37	P	47	0
Risso's dolphin	0	P	1	0	1	0
Sei whale	1	5	0	9	0	0
Common dolphin	1161	180	3246	1034	3760	282
Sperm whale	11	P[1]	15	P	22	P

[1]P = species detected by abundance not estimates

5.4.4.3 Fine scale – Passive acoustic projects

Recent results from passive acoustic studies in the same general times and areas (Chapter 8) as the visual surveys (this chapter) allow a comparison of cetacean detections by these two platforms. As previously discussed, these two platforms each have advantages and limitations, but the ultimate goal is to be able to utilize the information generated by both of these platforms to more fully document the spatial-temporal distribution and abundance of cetacean species. While these analyses are in preliminary stages, the following are examples of several acoustic datasets that can be compared with the results of visual-based models.

The abundance of sperm whales using only passive acoustic detections is currently being estimated using line and point transect methodologies (Chapter 8). When these estimates are finalized, they will be able to be compared to visual-based abundance estimates that account for availability bias as was done in this chapter.

Acoustic detections of vocalizing fin whales and sei whales were recorded from May – July 2013 from bottom-mounted archival recorders at three sites on Georges Bank south and east of Cape Cod, MA and one site in the Great South Chanel (Figure 8-9). In the same general time and area, the GAM models derived from visual data predicted the presence of both species (Appendix I). The number of days per week with sei whale vocalizations were highest in May and sharply declined by early July. Whether this indicates a shift in distribution or in vocal activity is unknown. To assist in interpreting the acoustic patterns, further study is required to better understand sei whale acoustic behavior. Only one call type is currently known for sei whales and it is unknown whether this call is produced by both sexes and during which months. In addition, it is currently not possible to translate number of detections into numbers of unique animals, as we lack data on variation in calling rates. However, despite these uncertainties, the same basic pattern was observed for sei whales in both the predicted GAM annual abundance trend and the patterns in vocal activity for the time and areas where data overlap.

In contrast, there was poor correspondence for fin whales between acoustic and visual detections using the same two data sources. The bottom-mounted archival recorders on Georges Bank detected only a few fin whale vocalizations within the study time period May – July 2013 (Figure 8-9). This pattern was not reflected in the visual sightings and predicted GAM density-habitat models (Appendix I). Fin whales were visually detected and therefore also predicted in the models for the spring and summer in the general vicinity of the four recorder sites. One likely reason for this discrepancy is that the acoustic signal associated with fin whale detections is part of the male breeding display song. As breeding is seasonal, song occurrences are also expected to be seasonal and the production of these signals in non-breeding contexts is not well understood. Therefore, the low number of fin whale acoustic detections may underrepresent the actual occurrence of this species in the area.

Sperm whale acoustic detections were extracted from a bottom-mounted recorder deployed on Georges Bank during 26 April – 9 September 2014 (Figures 8-10). Sperm whales were acoustically detected at this site in all six months, though number of days per month with detections decreased from May through August (Table 8-5). The regular presence of sperm whale vocalizations in that area is consistent with the predictions from the visual-based models (Appendix I).

From a bottom-mounted recorder (AMAR) deployed from July 2014 – May 2015 on the shelf break near Lydonia Canyon, initial analyses focused on extracting detections of beaked whales, specifically Cuvier’s beaked whale, Sowerby’s beaked whale and Gervais’ beaked whale (Figures 8-9 and 8-11). The shipboard visual data and GAM density-habitat model for these species only covered summer (June – August; Appendix I), so there is limited overlap between these two platforms. During July – August 2014, only Sowerby’s beaked whales were acoustically detected on the AMAR. Similarly, Sowerby’s were also detected visually on track lines near this site on multiple surveys. However, Cuvier’s beaked whales were also sighted in this region during the summer (Appendix I). While Cuvier’s beaked whales were acoustically detected from December through May (2015), with detection days peaking in January, they were not detected in the summer months (July – August 2014). This discrepancy may be due to the fact that the AMAR was recording at a relatively low duty cycle (19%), so acoustic presence of any species may be underrepresented. Furthermore, beaked whales produce high-frequency, highly directional signals, with limited propagation range. It is possible that a small shift away from the AMAR during summer months may have taken the Cuvier’s beaked whales out of the detection range of the AMAR. Ongoing recording efforts that include continuous, multi-year sampling should provide a more complete picture of beaked whale presence at this site.

5.4.5 Significant Findings

Several of the objectives of AMAPPS were to collect seasonal distribution and abundance data from the US Atlantic OCS on a broad and fine scale, assess the corresponding population sizes, and develop models and associated tools to translate these survey data into seasonal, spatially explicit density estimates incorporating habitat characteristics. These objectives have been met. Under AMAPPS during 2010 – 2014, about 125,000 km of shipboard and aerial track lines were covered by visual line transect abundance surveys in the US Atlantic waters and slightly beyond. During the shipboard and aerial surveys, a total of about 60,500 individual cetaceans and seals, 24,500 seabirds, 5500 turtles, 800 ocean sun fish and 200 basking sharks were visually detected. Seasonal spatially explicit density models and maps have been produced for 18 marine mammal species or species guilds. And for each species or species guilds, the models have also resulted in abundance estimates for the entire region and for 10 sub-regions of particular interest.

The seabird data collected during these surveys (Chapter 6) were supplied to the National Centers for Coastal Ocean Science in Silver Spring, MD to be used in a project to develop integrative statistical models and predictive maps of marine bird distributions and abundance on the Atlantic OCS extending from Maine to Florida. The turtle data (particularly the loggerhead turtle data) will be focused on during AMAPPS II at which time the visual sightings and individual tagged data will be integrated to document abundance and spatial-temporal distribution patterns.

AMAPPS is an important first step towards understanding how marine mammal, turtle and bird populations in the Atlantic may be exposed to anthropogenic activities. Risk to wildlife from offshore development has been thought of as an interaction of three factors (Fox et al. 2006): 1) exposure of individuals; 2) hazards posed to individuals; and 3) vulnerability of populations to individual-level effects. The results from AMAPPS will be able to be used in future assessments of risk for marine mammals, sea turtles and seabirds. It also is a starting point to identify areas/taxon that may be at more risk and thus in need for more site-specific studies or risk analyses.

Comparing the distribution patterns resulting from the visual surveys and passive acoustic studies conducted at the same time and area showed similar patterns for sei, sperm and Sowerby’s beaked whales. However, patterns were different for fin and Cuvier’s beaked whales. These types of comparisons are helpful in determining how to interpret and integrate results from these two platforms, since both platforms have different advantages and limitations.

Due to the broad scale and fine scale surveys that were conducted in a uniform and consistent manner, it is possible to easily compare the distribution and abundance of different areas and times. For example, these data indicate that, in general, the shelf break waters (deeper than 100 m) are more frequently used by whales and dolphins in comparison to the shallower continental shelf, where many human activities take place. Even still, the offshore wind energy study areas on the continental shelf are utilized by at least 15 cetacean species, where the Rhode Island/Massachusetts area had the highest diversity and abundance, and the areas south of North Carolina had the lowest diversity and abundance.

The recent finer scale research projects (Geo Marine 2010; Williams et al. 2015; and Kraus et al. 2016) discussed the difficulties of producing abundance estimates and spatial patterns of most cetaceans due to small sample sizes, even though their surveys were conducted more frequently than the AMAPPS surveys. The advantage of the AMAPPS strategy that used a dual-scale design (broad scale + fine scale) was this allowed larger sample sizes to be collected, thus using the detection function and environmental relationship information from the entire area to better inform the results for these small scale regions of interest.

Static and dynamic environmental variables that are most highly related to the distribution and abundance of cetaceans are static variables like latitude and bottom slope, while dynamic variables like ocean temperature (both at the surface and the bottom) and levels of primary productivity were also related to cetaceans. Given these significant relationships it is expected that changes in the water temperature may likely cause distribution changes of the cetaceans.

5.4.6 Data Gaps and Future Research

Though many of objectives of AMAPPS have been met, additional work is needed to expand and refine the results. Data gaps that could be addressed in the near future are listed below. More details of each item are described in the discussion section above.

1. For most species, more sightings data need to be collected during winter to develop accurate winter models, maps and abundance estimates.
2. More data from the Canadian Scotian shelf are needed to confirm existing models and/or improve future models. The Canadian Department of Fisheries and Oceans conducted an extensive aerial survey from Nova Scotia to Newfoundland during the summer of 2016. We will be collaborating with the Canadian scientists to share and compare data and results.
3. More dive and surface times for many species that inhabit the western North Atlantic are needed. This is particularly true for long divers such as sperm whales, pygmy/dwarf sperm whales, beaked whales, and turtles.
4. Other static and dynamic environmental variables are needed to evaluate their importance in the density-habitat models. In addition the reliability and sensitivity of their uncertainties and spatial-temporal scale could be evaluated.

Future analytical research ideas that could be addressed in the near future are listed below. More details of each item are described in the discussion section above.

1. Investigate the spatial-temporal variability in availability correction factors, particularly for long-diving species, and evaluate the sensitivity of the spatially-temporally varying availability factors in the species density-environmental relationships.
2. Investigate the possibilities of classifying ambiguous species identifications (e.g., pygmy/dwarf sperm whale) to a specific species (e.g. either a pygmy sperm whale or dwarf sperm whale) by using environmental factors within a statistical framework.
3. Incorporate other sources of variance.
4. Investigate whether the species distribution models are sensitive to uncertainties in these environmental parameters and what effect the scale of the ocean model-derived variables has on the relationships with species distributions.
5. Investigate trophic relationships between marine mammals and their potential prey, which could begin development of causal models and/or could be used in the current density-habitat models as an additional variable.
6. Investigate methods to develop spatial/temporal distribution maps and abundance estimates of rarely seen species.
7. Investigate methods to more fully utilize both passive acoustic vocalization detections and visual detections to document the spatial-temporal distribution patterns.
8. Validate and/or improve the density-habitat models using other data sources, like Canadian line transect sightings data, passive acoustic data collected via towed arrays or bottom mounted arrays, previously or more recently collected line transect sighting data, individual tagged data, or bycatch interactions data.
9. Explore incorporating new, semi-parametric methods that directly model spatial-temporal autocorrelation into the Bayesian framework (e.g., Yuan et al. 2016).
10. Utilize the predicted modeled data to investigate annual trend patterns.
11. Investigate whether it is possible to assess spatial/temporal changes in distribution that are due to climatic changes or to trends due to other factors.
12. Investigate data on presence of calves collected during the surveys to define areas important to this vulnerable life stage.

5.5 Acknowledgments

The work documented in this chapter would not have been possible without the dedication and hard work of those that collected the aerial and shipboard data. This includes the NOAA pilots that flew the airplanes, staff at the Aircraft Operations, and the crews of the NOAA ships *Henry B. Bigelow* and *Gordon Gunter*. In addition there is a long list of scientists that were instrumental in collecting these data.

We also would like to thank those that funded this work. The data collection and analyses were funded by the Bureau of Ocean Energy Management (BOEM) and the US Navy through two Interagency Agreements for the AMAPPS project and by the NOAA Fisheries Service at both the Northeast Fisheries Science Center and the Southeast Fisheries Science Center.

6 Offshore Seabird Research

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6.1 Introduction

This chapter focuses on the seabird distribution data collected on the National Marine Fisheries Service (NMFS) shipboard surveys conducted by the Northeast Fisheries Science Center (NEFSC) and Southeast Fisheries Science Center (SEFSC). Discussion of the US Fish and Wildlife Service (USFWS) aerial surveys are in Chapter 7. The NMFS shipboard surveys were conducted farther offshore then the USFWS flights, thus attempting to obtain a more complete spatial coverage to achieve one of the AMAPPS objectives: collect data over multiple years on the seasonal distribution and abundance of seabirds using directed aerial and shipboard surveys.

6.2 Methods

During NMFS shipboard abundance surveys, an independent team was dedicated to collecting seabird data. For a more complete description of the NMFS shipboard surveys refer to Chapter 5. From an observation station on the flying bridge of either the NOAA ship *Henry B. Bigelow* or the NOAA ship *Gordon Gunter*, one on-effort seabird observer conducted a visual daylight survey for seabirds during approximately 0600 – 1800. Seabird data were collected that could be used in both a 300 m strip transect and a line-transect analysis. All birds detected were identified and enumerated within a 300 m arc on one side of the bow while the ship was underway in Beaufort sea state conditions of 7 or below. The side of the bow used was the side with the least glare and best sighting conditions. In addition to identify what part of the 300 m strip a bird was located (used in a strip transect analysis), the angle between the location of the bird group and the track line was also recorded, which could then be used in a line-transect analysis or at least be used to investigate the strip transect assumptions.

Seabird observers maintained a visual unaided eye watch of the 300 m survey strip, with frequent scans of the perimeter using hand-held binoculars for cryptic and/or hard to detect species. Binoculars were used for distant scanning and to confirm species identification. Birds outside the 300 m strip were also recorded. Ship-following species were counted once and subsequently carefully monitored to prevent re-counts. All birds, including non-marine species such as raptors, doves, and passerines were recorded.

Data were entered in real time into a laptop running *Seebird* (vers 4.3.7), a data collection program developed at the Southwest Fisheries Science Center. The software was linked to the ship's navigation system via a serial cable. The following data were collected for each sighting:

1) Species identification,
2) Number of birds within a group,
3) Distance between the observer and the group, recorded as categories,
4) Angle between the track line and the line of sight to the group,
5) Behavior,

6) Flight direction,
7) Flight height,
8) Age, sex and, if possible, molt condition.

Sighting records received a corresponding time and GPS fix once the observer accepted the record and the software wrote it to disk. *Seebird* also added a time and location fix every five minutes. *Seebird* incorporated a time synchronization feature to ensure the computer clock matched the GPS clock to assist with merging the seabird data with other ship's data.

All data underwent a quality assurance and data integrity check each evening and were saved to disk and to an external backup dataset.

The seabird data collected during these surveys were archived in the NEFSC AMAPPS ORACLE relational database. They were also sent to the Northwest Atlantic Seabird Catalog, formerly known as the Avian Compendium, currently managed by the US Fish and Wildlife Service (O'Connell et al., 2009).

6.3 Results

During 2010 – 2014 NMFS collected seabird data: during the following shipboard surveys: 2 June – 2 August 2011 (summer) conducted by NEFSC and SEFSC, 1 July – 15 September 2013 (summer and fall) conducted by NEFSC and SEFSC, and 11 Mar – 1 May 2014 (spring) conducted by NEFSC (Tables 5.1 and 6.1).

The surveys covered waters from Massachusetts to Florida in mostly waters deeper than 100 m, out to and slightly beyond the US Exclusive Economic Zone (EEZ) line (Figure 6.1). About 24,000 birds were recorded from at least 50 species or species guilds (Table 6.2). For more information on these surveys, see the AMAPPS' annual reports (NMFS 2016). The most common species observed included Great Shearwater (*Puffinus gravis*), Cory's shearwater (*Calonectris diomedea*), Audubon shearwater (*Puffinus lherminieri*), Wilson's storm-petrel (*Oceanites oceanicus*), Black-capped storm petrel (*Pterodroma hasitata*), and Band-rumped storm petrel (*Oceanodroma castro*).

The distribution of the seabird sightings seen during the first two surveys that were conducted during June – September are plotted by species or species guild in figures in Appendix III; an example is displayed in Figure 6.1.

The spring 2014 survey covered waters from Massachusetts to North Carolina from near the shore line to about the 2000 m depth contour. See the 2014 AMAPPS annual report for maps of location of the sightings (NMFS 2016).

In addition, these data were supplied to the National Centers for Coastal Ocean Science in Silver Spring, MD to be used in a project to develop integrative statistical models and predictive maps of marine bird distributions and abundance on the Atlantic outer continental shelf extending from Maine to Florida (NCCOS 2017). Some results of this project are found at the Marine Cadastre website (Marine Cadastre 2017).

6.4 Acknowledgments

The work documented in this chapter would not have been possible without the dedication and hard work of those that collected the shipboard seabird data. This includes the crews of the NOAA ships *Henry B. Bigelow* and *Gordon Gunter*. In addition there is a long list of scientists that were instrumental in collecting these data.

We also would like to thank those that funded this work. The data collection and analyses were funded by the Bureau of Ocean Energy Management (BOEM) and the US Navy through two Interagency Agreements for the AMAPPS project and by the NOAA Fisheries Service at both the Northeast Fisheries Science Center and the Southeast Fisheries Science Center.

Table 6-1 Track line (in km) covered during NMFS shipboard surveys during 2010 - 2014

Platform	Track line length (km)		
	Spring (Mar – May)	**Summer (Jun – Aug)**	**Fall (Sep – Nov)**
NE Shipboard	4,014	8,146	0
SE Shipboard	0	8,537	2,093

Table 6-2 Numbers of seabirds detected during NMFS offshore abundance surveys

Species	2011 SE+NE summer		2013 SE+NE summer		2014 NE spring	
	groups	animals	groups	animals	groups	animals
American redstart			1	1		
Arctic tern	2	2	1	1	2	4
Atlantic puffin	1	1			150	228
Audubon shearwater	204	297	464	1117	1	1
Baird's sandpiper			1	1		
Band-rumped storm-petrel	65	107	197	344		
Barn swallow	10	11	13	19		
Barolo shearwater	1	1	7	7		
Bermuda petrel			1	1	1	1
Black guillemot					1	1
Black scoter					24	143
Black tern	1	1	4	16		
Black-bellied plover			1	3		
Black-capped petrel	159	267	169	232	9	9
Black-legged kittiwake					2	13
Black-throated blue warbler			1	1		
Blue-winged teal			2	16		
Bonaparte's gull	1	1			88	339
Bridled tern	19	29	22	26		
Brown booby	2	3				
Brown noddy	4	5				
Brown-headed cowbird	2	1	9	10	2	2
Canada goose					1	1
Cattle egret	1	1				
Cliff swallow			1	1		
Common Eider					5	14
Common gallinule			1	1		
Common loon					50	65
Common murre					24	34
Common nighthawk			2	2		
Common tern	14	15	20	41		

Species	2011 SE+NE summer		2013 SE+NE summer		2014 NE spring	
	groups	animals	groups	animals	groups	animals
Cory's shearwater	577	1010	781	2538		
Double-crested cormorant	3	5	1	1	2	62
Dovekie	11	14			203	936
Dowitcher			1	1		
Fea's petrel	4	4	1	1		
Glaucous gull					1	1
Great black-backed gull	6	3	24	35	201	279
Great blue heron			1	1		
Great shearwater	874	2096	295	765		
Great skua	2	3				
Greater yellowlegs			1	1		
Green Heron	1	2				
Herring gull	6	4	33	46	532	1099
Iceland gull					5	5
Laughing gull	24	26	16	19	7	96
Leach's storm-petrel	529	776	535	785	40	58
Leach's/Hartcourt's storm-petrel	1	1	30	35	1	2
Least sandpiper	1	2	4	7		
Least tern	5	7	2	3		
Lesser black-backed gull					6	6
Lesser yellowlegs			2	13		
Little blue heron	2	4				
Long-tailed Duck					10	35
Long-tailed jaeger	14	14	3	4	5	6
Magnificent frigatebird	4	4				
Manx shearwater	58	58	23	23	35	43
Masked booby	2	10000	1	1		
Merlin			3	3		
Non-marine non-passerine	2	2	1	1	2	2
Northern fulmar	3	3			146	313
Northern gannet	4	3	4	4	484	778
Northern harrier			1	1		
Northern waterthrush			1	1		
Orchard oriole			1	1		
Osprey					1	1
Parasitic jaeger	5	9	13	16	1	1
Passerine (land bird)	9	9	10	10	16	19
Pectoral sandpiper			1	10		
Pomarine jaeger	20	20	13	15	24	25
Prairie warbler			1	1		
Razorbill					84	228
Red phalarope	4	4	2	3	121	1281
Red-billed tropicbird	3	3	3	3		

Species	2011 SE+NE summer		2013 SE+NE summer		2014 NE spring	
	groups	**animals**	**groups**	**animals**	**groups**	**animals**
Red-breasted merganser					1	1
Red-necked phalarope			15	136		
Red-throated loon					18	23
Royal tern	5	7	15	23		
Ruddy turnstone			2	7		
Sabine's gull			1	1		
Sanderling			1	1		
Sandwich tern	1	1	1	1		
Semipalmated plover			1	4		
Semipalmated sandpiper			5	10		
Shorebird	10	14	16	41	1	1
Snowy egret	1	1	1	2		
Sooty shearwater	80	155	24	34	42	131
Sooty tern	49	167	14	33		
South polar skua	18	19	3	3	1	1
Stilt sandpiper			2	2		
Surf scoter					8	65
Thick-billed murre					29	41
Trinidad petrel	26	42	29	35		
Unidentified alcid					3	3
Unidentified bird	1	1	5	5		
Unidentified duck					3	10008
Unidentified jaeger	1	1	2	2		
Unidentified large gull					1	1
Unidentified murre					1	1
Unidentified petrel	2	3	1	1		
Unidentified phalarope			2	6	7	76
Unidentified Pterodroma					2	2
Unidentified shearwater	15	226	24	417	3	10
Unidentified skua	2	2			2	2
Unidentified storm-petrel	19	41	29	119	2	2
Unidentified tern	7	21	9	25		
Unidentified tropicbird			3	3		
Whimbrel			2	3		
White-faced storm petrel	1	2	19	19		
White-tailed tropicbird	37	42	28	29		
White-winged dove			1	1		
White-winged scoter					52	217
Willet			1	1		
Wilson's storm-petrel	694	1183	593	1849	26	235
Yellow-breasted chat			1	1		
Yellow-crowned night heron	5	14				
TOTAL	3,635	16,771	3,578	9,057	2,489	16,951

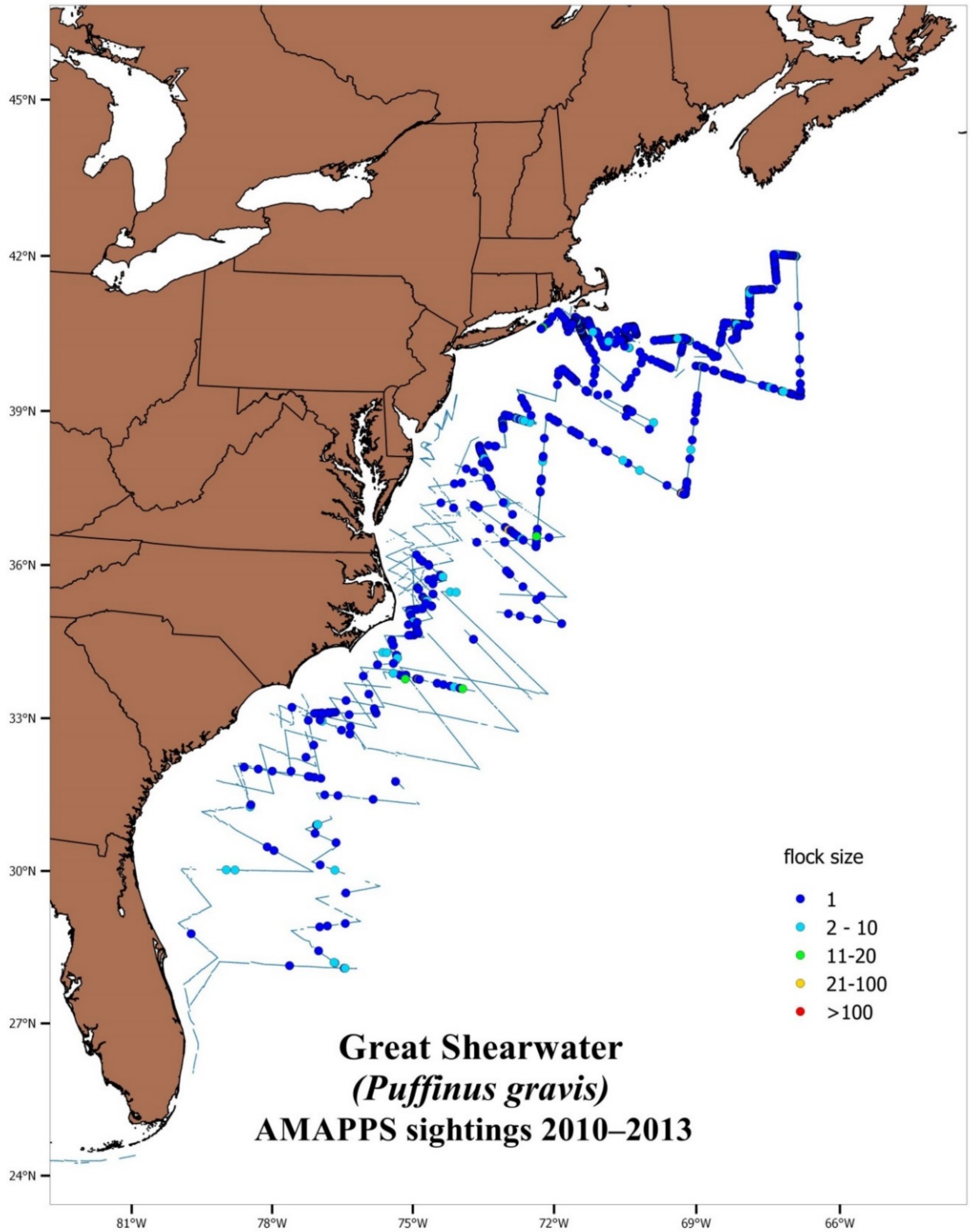

Figure 6-1 Location of offshore Great Shearwater (*Puffinus gravis*) sightings
Track lines surveyed during June – September 2011 and 2013 NMFS shipboard surveys.

7 Coastal Seabird Research

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7.1 Introduction

The AMAPPS program described in this chapter was designed as a comprehensive effort to collect data required to estimate abundance and develop seasonally specific, localized density estimates for marine mammals, marine turtles, and seabirds. AMAPPS coordinated data collection and analysis efforts of the NMFS Northeast and Southeast Fisheries Science Centers and the USFWS Division of Migratory Birds. This chapter focuses on the USFWS surveys, while Chapter 6 focuses on the NMFS seabird surveys.

To achieve the objectives related to the distribution and abundance of seabirds, in addition to the NMFS shipboard and aerial surveys described in Chapters 5 and 6, the USFWS flew nine surveys between August 2010 and October 2014. USFWS crews flew 103,634 km (55,958 nm) of strip transect surveys recording locations of seabirds, sea turtles and marine mammals. Our database, not including two surveys, contains more than 780,000 records of seabird observations. USFWS Division of Migratory Bird staff members are currently processing data from the final two surveys. All error-checked data have been submitted the Northwest Atlantic Seabird Catalog at the request of BOEM. These data and data from other sources were then used in the BOEM study “Modeling At-sea Occurrence and Abundance of Marine Birds to Support Renewable Energy Development” (Kinlan et al. 2016).

7.2 Methods

7.2.1 Survey Design

Transects extend from Cape Canaveral, FL to the US-Canada border. Transects were located at 5' (minutes of latitude; about 5 nm) intervals at every *1' and *6' minute of latitude and extend out to the 30 m depth contour or not more than 50 nm from the nearest land (Figure 7.1). Transects generally extended 30 nm offshore. Transects were numbered by their latitude ID (degrees/minutes, e.g., 3436 for 34°36'N); two additional digits were also added at the end that indexed segments within a transect. Most transects had only a single segment, which was identified by 00. For transects with multiple segments (which may have been separated by land or open water or may be contiguous), the digits 00 identified the most westerly transect, 01 indicated the next transect to the east, etc. Continuous transects may have been divided into multiple sections that crossed survey strata (e.g., 365600, 365601, and 365602 at the mouth of the Chesapeake Bay). The start and stop points of each segment were recorded, even if counting was not interrupted.

7.2.2 Survey Procedures

Surveys were flown in USFWS fleet Kodiak amphibious aircraft, Quest Inc., with the exception of the summer 2010 surveys (Figure 7.2). The summer 2010 surveys were flown using older fleet aircraft: a twin engine Partenavia P68 Observer and a Cessna amphibious aircraft. All surveys were flown at a height of 200 ft above sea level and at a speed of 110 kts. All seabirds, turtles and marine mammals observed within a 400 m wide strip (200 m on either side of the track line) were recorded to the lowest taxonomic level possible along with numbers of individuals and for all observers, other than the pilot, the distance band. Our survey specific procedures are outlined below. Each survey crew was provided a set of maps depicting each transect overlaid on aviation maps as well as a set of GPX files that could be loaded on each aircraft's GPS unit for navigation (Figure 7.3).

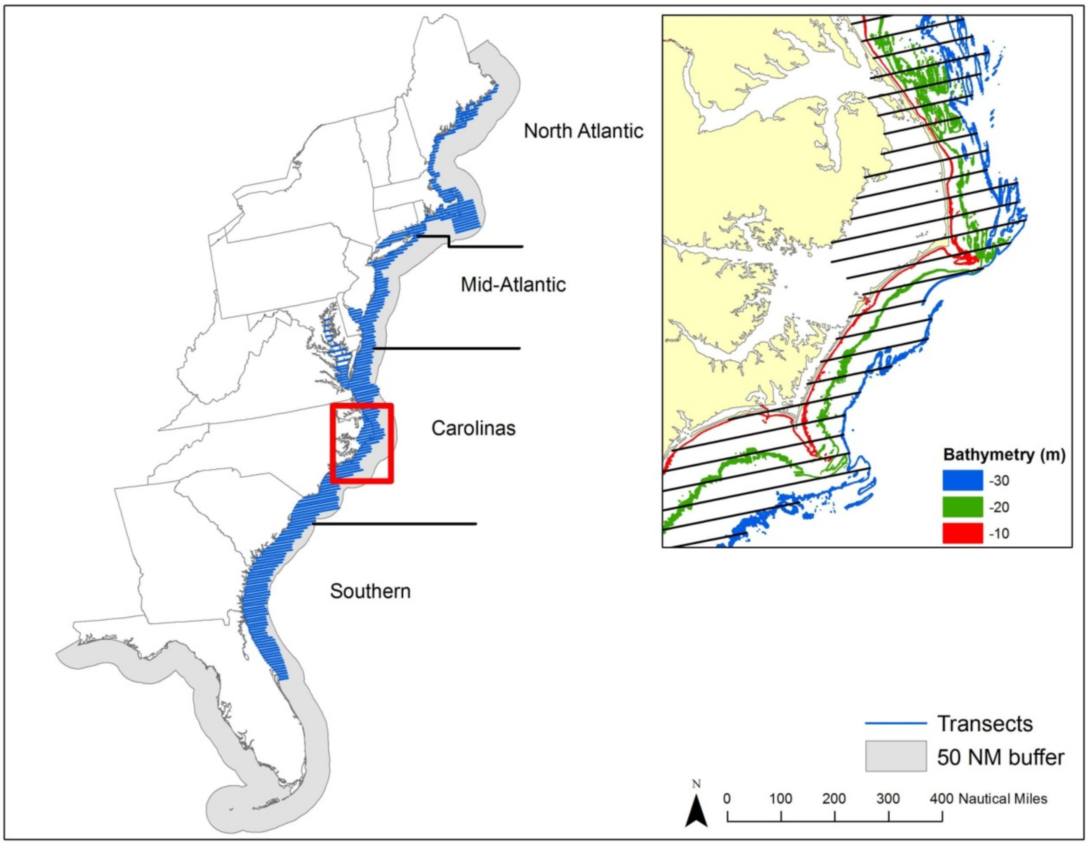

Figure 7-1 USFWS AMAPPS seabird survey design

Transect width distance bands were marked on either the wing strut or window using a grease pencil or dry erase marker. Crew members were required to mark the 200 m outer edge of the transect width before starting the first transect in their crew area. This was done with the use of a standard inclinometer and marking a 17° angle on some portion of the aircraft. Preferably this was done while on the ground to eliminate the effect of any turbulence. Observers on the right side of the aircraft also had to mark the 100 m boundary (31° angle) since they recorded data into multiple distance bins.

All data were recorded to hard drives using software developed by the USFWS for aerial surveys. Observations were recorded using the program Record (Version 6.4, 2/11/2009) that stores each detection in a WAV file while GPS coordinates, GPS error and time since midnight were logged for every observation. Afterwards, the observer used a program, Transcribe (Version 3.1, 3/13/2008), that allowed the user to enter the data recorded on each WAV file and merged those data with the appropriate GPS location and timestamp information.

Summary of survey procedures:

- Surveys were flown at 110 kts, at an altitude of 200 ft.
- Surveys were initiated when wind speed was $\leq$ 15 kts and were discontinued if winds exceed 20 kts.
- Transect **width** was 200 m on either side of the aircraft. (The approximate *actual* transect width was determined by the observer's ability to see under the plane. If available, an inclinometer was used to estimate inner transect boundary.) At an altitude of 200 ft, the 200 m boundary was at a 17° angle from horizontal and the 100 m boundary was at 31°.
- Observers recorded "**BEGSEG"** and "**ENDSEG"** (required by recording program used in USFWS aircraft) at the start and finish of each east-west transect, including continuous lines broken into distinct transects, such as those over Pamlico Sound and the mouths of Chesapeake and Delaware Bay. This information was transcribed into the species/type field.
- Observers transcribed the six digit segment number (e.g., 382100) in the count field for every BEGSEG and ENDSEG record.
- If counting was suspended for any reason between the BEGSEG and ENDSEG (technical difficulties, airsickness, flying over land, etc.), "**ENDCNT**" was recorded to mark the break. Then "**BEGCNT**" was recorded when surveying resumed.
- Observers recorded all **sea ducks**, **diving ducks**, and other **seabirds** observed from the edge of the coastline eastward, including birds associated with exposed shoals. Species codes are listed in Appendix IV, Part 1. Birds sitting on pilings, jetties, beaches, boats, and in trees were not recorded. That is, the birds recorded were those in the air over water or on the water.
- Birds flying above the plane were also recorded, if they were within the transect strip width.
- All marine mammals and turtles observed on transect were also recorded.
- All commercial fishing boats were recorded with the code TRAWL along with the perpendicular distance (nm) from the transect line (including boats >200 m from the plane).
- Balloons (deflated, floating on the surface) within the transect strip width were recorded with the code BALN.
- All sea ducks and seabirds were identified to the lowest taxonomic level possible.
- See Appendix IV for a list of species abbreviations.
- For **mixed flocks** seen within the transect strip width boundaries:
    - Species code MIXD was used
    - In the count field the entire mixed flock size was recorded
    - A comment was added to the end of that transcribed record with species proportions e.g., MIX; 500; 25% SUSC; 50% BLSC; 25% WWSC. Exact counts of species were preferable, if known. It was also preferable to record

the comment without commas, as the *Transcribe* program used commas to delimit variable fields.

- Observation conditions were recorded on a 5-point Likert scale in the “Condition” header field. All factors influencing observation conditions were considered when recording this field (e.g., sea state, glare, observer alertness, etc). Codes were: 1, 2, 3, 4, 5 with 1 = Worst observation conditions, 3 = Average condition, and 5 = Best observation conditions.
- Condition codes were recorded in the condition field at the start of each transect and for each observation. When conditions changed the code **COCH** was used in the species/type field to indicate “condition change.” The new condition value was recorded in both the condition field and the count field.
- Observers recorded two additional pieces of information with each record (i.e., pilots excluded):
    - The 100 m band within which the bird was observed: 0 = within 200 m band unknown; 1 = [0,100 m]; 2 = (100, 200 m]. (Any birds recorded outside the 200 m band was coded as band = 3 and the offline code was “y” to indicate these records were not within the survey protocol.)
    - If the bird was flying: F =flying; S = non-flying; or 0 = unknown.

Figure 7-2 USFWS fleet aircraft used in AMAPPS aerial seabird surveys
Counterclockwise from bottom left: Quest Kodiak, Partenavia P68 Observer, Cessna 206 Amphib.

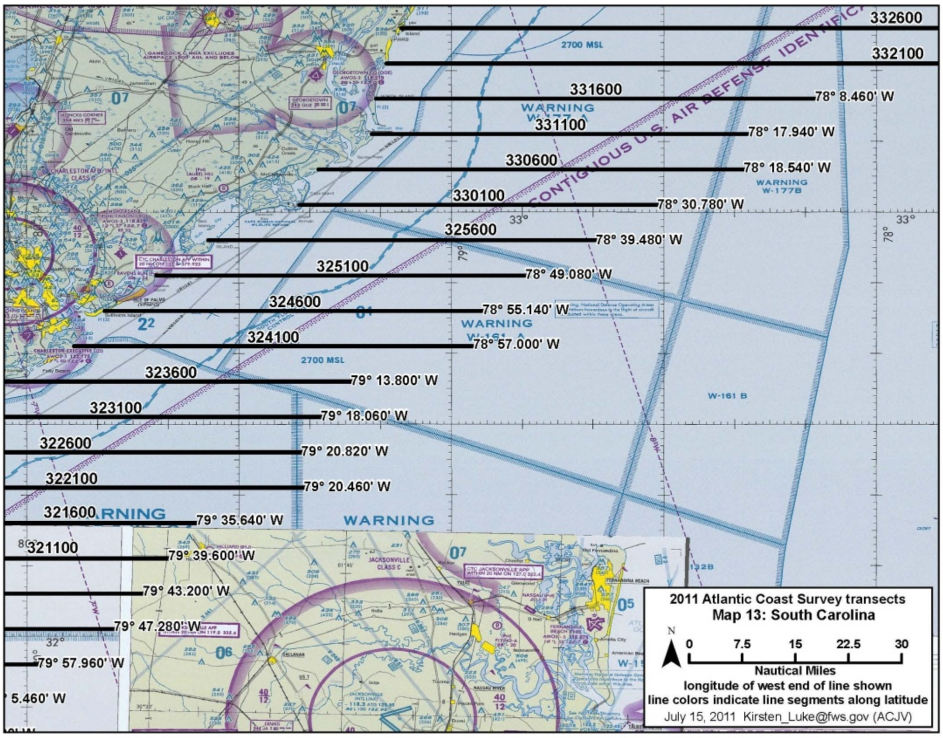

Figure 7-3 Example crew map of transects on aviation charts for Charleston, SC area

7.2.3 Data and File Management

All files on the aircraft computer were backed up daily by the flight crew onto USB drives and then copied to a hard drive on a laptop. At the end of the survey all files including the raw WAV, track files and transcribed data files were uploaded to the Department of the Interior AMAPPS SharePoint site by crew area. Once the files were received by staff at Patuxent Wildlife Research Center, a series of R programs were run to check for data entry errors and to format the raw data for input into a Microsoft Access (MS Access Version 14.0.7143.5000) database (Appendix IV Part 2).

We also maintained a geodatabase representing all spatial information related to survey design transects, what we actually flew each survey (tracks) and observations. This geodatabase was created and maintained using ESRI ArcGIS (Version 10.2.2). For each observation we used the geodatabase to calculate distance to the coast, water depth and bottom slope.

Each computer's time and date were corrected and synchronized with the data entry program and GPS. Crew names were designated by the four digit latitude of the northernmost transect. For example, the northern crew was Crew4446, which is the northernmost survey line. Partial or missed transects were recorded in the *SurveyNotes.xls* file, along with any other deviations from the survey protocols and relevant survey details/comments. Each observer had one data file for each survey day, which was named **Crew####**_MODAYEAR_birds.txt**, where Crew### was the crew name (see above), ** = lf for the pilot and rf (or rr, or lr) for the observer, MO = two digit month, DA = two digit day (e.g., 01 for the first day of the month), and YEAR = four digit year. For example, *Crew4446lf_02082012_birds.txt* included the pilot's observations for Feb 8, 2012 Crew4446. There were two track files submitted for every survey day with corresponding names like **Crew####**_MODAYEAR_track.txt**. Backups of all files (track and sound files, as well as any transcribed files) from each computer were made nightly onto the USB drive that belonged to that computer. Transcribed data files and pilot and observer track files were then uploaded regularly to the survey sharepoint site, not less than every five survey days. At the end of the survey, a zipped file containing all ASCII data files, the pilot and observer track files, and the *SurveyNotes CREWAREA.xls* file were sent to the survey coordinator.

Order of data fields in the transcribed file:

Header fields:

- Year (4 digits, 2011)
- Month (1 digit, 1 or 2) no leading zeros
- Day (1 or 2 digits) no leading zeros
- Seat (2 digits, lf, rf, rr, or lr)
- Observer (3 initials in lowercase letters)
- Transect (6 digits, line #s will be the latitude degrees concatenated with the latitude minutes and then with the segment number [00, 01, etc.]. Typically there will be just one line segment “00,” but when more than one segment occurs on the same latitude you might also have segment “01”, etc., e.g., line on 36 deg 21 min, segment 00 = 362100.
- Observation condition (1 digit, 1-5)
- Offline (1 character, “n” = online/within the 200m width while on transect, “y” = offline)

Fields created by Hodge’s programs automatically:

- Species/type code
- Count (this is the count entered into the count window in Hodge’s program – if a flock crosses the 200 m transect edge, include only those birds within the transect)

Additional fields:

- Distance Band (1 – 0-100m, 2- 100-200m, or 0 if unknown)
- Bird flight status (F = flying; S = sitting on water; 0 = unknown)
- Comment on composition of MIXD records

7.2.4 Training

In February 2012, we held a field training event for USFWS observers and pilots on the Outer Banks of North Carolina. The goals of this training were to: a) increase the identification ability of our biologist-pilots and observers and b) expose new observers to aerial survey experience. USFWS biologist-pilots have been using aerial surveys to count breeding and non-breeding waterfowl for more than 50 years and sea ducks for more than 4 years. Seabirds represented a new and unfamiliar group of birds rarely encountered by our biologist-pilots and observers. We contracted with Brian Patteson, an expert in seabird identification that runs a pelagic birding company out of Hatteras, NC. The first day of the training consisted of reviewing our survey protocols and a presentation by Brian Patteson reviewing the likely seabirds that could be encountered along the US Atlantic Coast. During this presentation, he reviewed the range of the species and identification tips. The second day was spent aboard the Stormy Petrel II for our biologist-pilots and observers to see a wide array of seabirds (Figures 7.4 and 7.5). The third day we introduced the observers, who had never participated in an aerial survey, the chance to experience survey conditions. All flights were conducted from Dare County Regional Airport in Manteo, NC. Due to water temperatures, all participants were required to wear survival suits and practiced identifying and counting seabirds on two transects just off of the coast near the airport. Observers were introduced to aircraft safety procedures as well as using the computers for recording data.

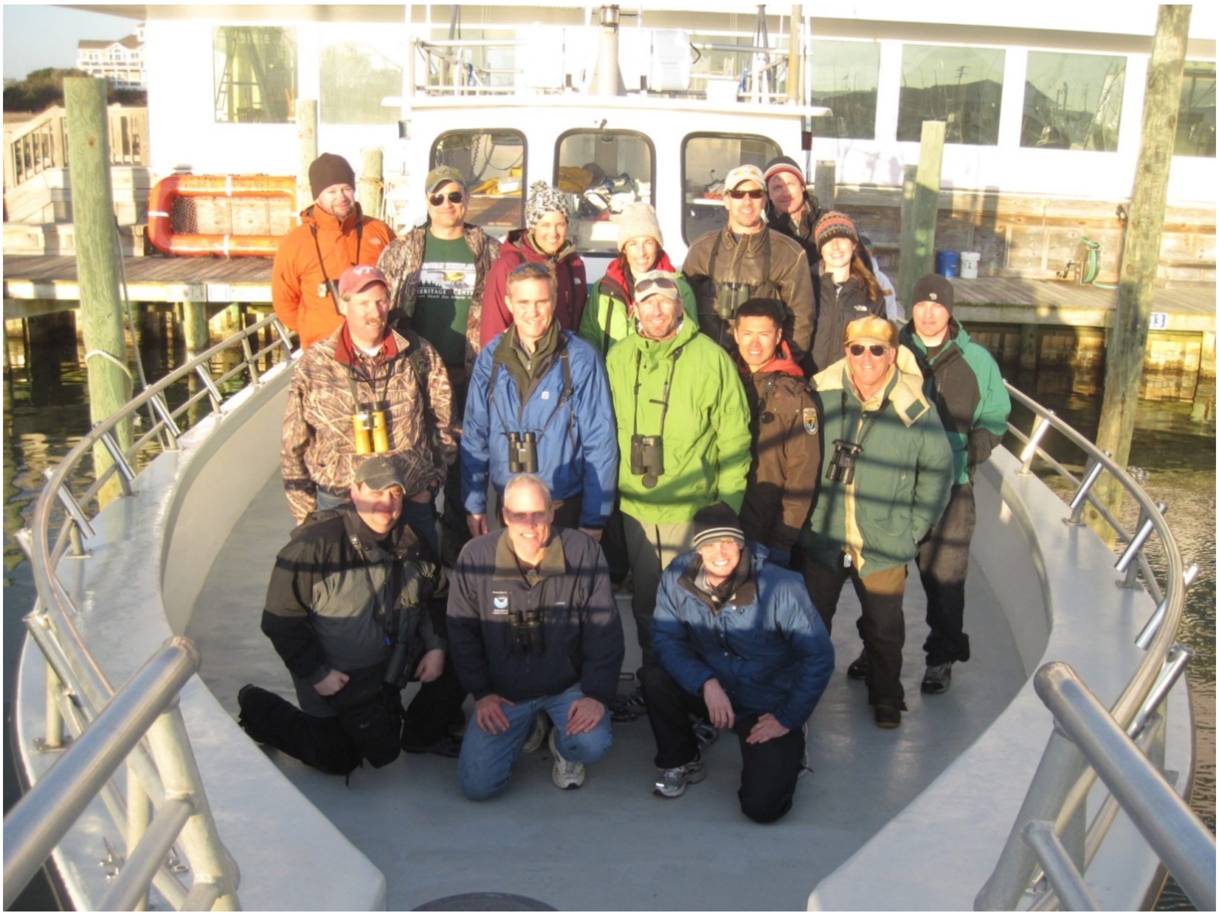

Figure 7-4 Participants of seabird survey training in February 2012
Back row from left to right: Troy Wilson, Mark Koneff, Melanie Steinkamp, Emily Silverman, Jim Wortham, Dean Demarest, and Sarah Yates. Middle row from left to right: Walt Rhodes, Tim Jones, Steve Earsom, Mao Lin, Tim White, Holiday Obrecht. Front row from left to right: Eric Kirshner, Jeff Shenot and Jeff Leirness.

Figure 7-5 Seabirds observed during identification training session off Cape Hatteras, NC
A) Common loon; B) adult Northern Gannet; C) juvenile Northern Gannet; D) Great Shearwater.

7.2.5 Seabird Key Site Maps

Analyses focused on how to describe sparse, yet highly aggregated counts of seabirds. Such patterns of abundance make estimating total numbers of individuals difficult and may provide biased estimates of uncertainty. Staff worked with personnel from the USGS Patuxent Wildlife Research Center to evaluate a set of statistical distributions that describe highly right-skewed distribution of flock frequencies (Zipkin et al. 2012; 2014). Current efforts are focused on understand detectability and biases associated with our fleet aircraft. We also are examining whether we can develop a statistical model that would allow us to impute species identification on some guilds of species.

Survey tracks were divided into units equal to 1 km^2 of area surveyed by a single observer (5 km segment length * 200 m strip width). Seabird observations on each transect were paired to segments by spatial proximity and then associated with the segment midpoint. Each segment midpoint was plotted in blue, representing survey effort, while key seabird sites were overlaid in red.

Key sites were defined as segments belonging to the smallest amount of area containing the greatest number of birds, up to a given threshold. Each set of plots included a map displaying these sites related to three different thresholds: 50% of total individuals sighted; 90% of total individuals sighted; and the proportion of individuals sighted corresponding to the "optimal" area considered a key site based on the law of diminishing returns. That is, the point at which the total proportion of individuals included begins to decrease relative to the total proportion of area included. This optimal area varied depending on the species and/or survey season, but typically included in excess of 90% of total individuals observed due to the highly aggregated nature of seabird populations. See the example plot below showing where this threshold occurred for northern gannets (Figure 7.6).

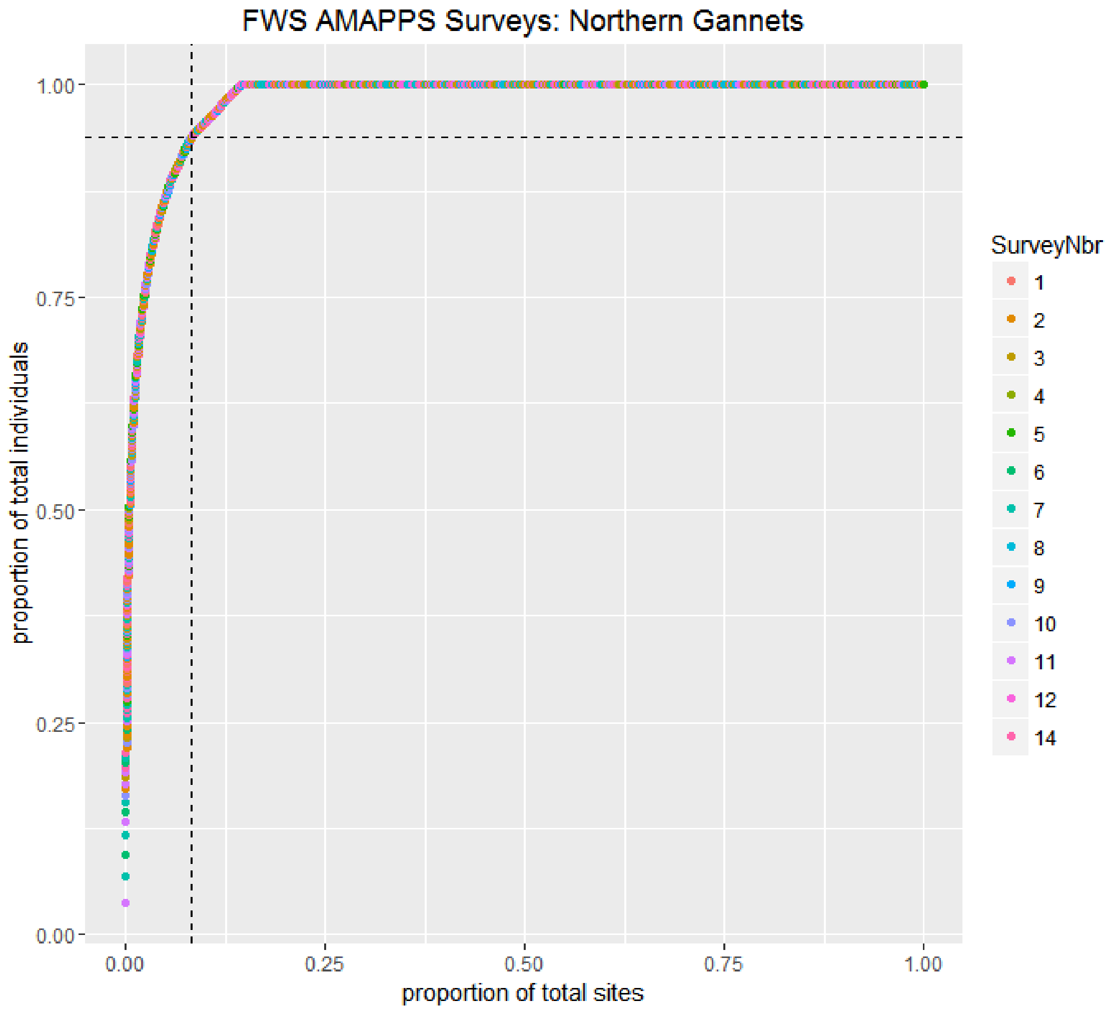

Figure 7-6 Example plot used to determine the "optimal" area considered in a key site

7.3 Results

7.3.1 Field Work

USFWS conducted nine seabird surveys between August 2010 and October 2014 (Table 7.1). Crews flew 103,634 km (55,958 nm) of strip transects survey seabirds, sea turtles and marine mammals. The surveys in August 2010 did not conform to our survey design due to the Gulf Oil Spill. In response to that incident, BOEM agreed to our shifting the survey transect south and into the eastern Gulf of Mexico (Figure 7.7A). In December 2010, we flew our first flight that went further than 8 – 10 nm offshore (Figure 7.7B). The remainder of the surveys generally followed the survey design but varied due to weather or mechanical difficulties with the aircraft (Figures 7.7C – 7.7H). Due to availability we were not able to maintain consistent crews over all the surveys but tracked observers to account for different detection probabilities among observers (Table 7.2).

Table 7-1 Surveys flown by the US Fish and Wildlife Service as part of AMAPPS

Survey	Start Date	End Date	Survey Distance (km)	Number of Transects	Number of Replicates
2010 August	August 3	August 24	5,421	115	62
2010 December	December 3	December 11	2,164	89	0
2011 January	January 16	January 17	619	22	0
2011 August	July 30	August 23	13,979	267	8
2012 March	March 15	March 31	13,784	282	0
2012 October	September 29	October 12	13,914	283	0
2013 September	September 16	September 28	17,112	266	0
2014 February	January 28	February 12	20,564	285	0
2014 October	October 6	October 22	16,077	189	0

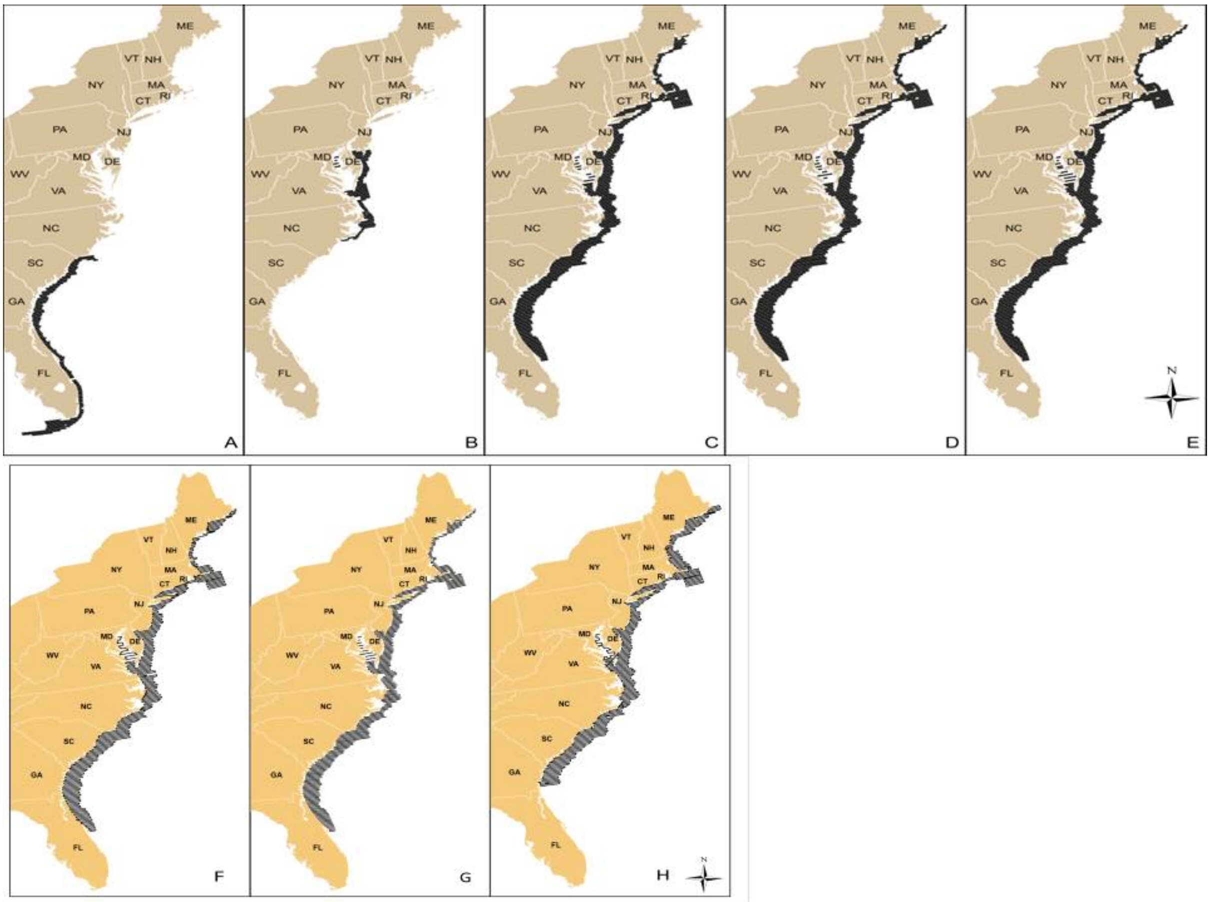

Figure 7-7 Transect lines flown by the US Fish and Wildlife Service as part of AMAPPS
(A) August 2010; (B) December 2010 and January 2011; (C) August 2011; (D) March 2012; (E) October 2012; (F) September 2013; (G) February 2014; and (H) October 2014.

Table 7-2 Survey crews

Survey	Crew*	Pilot(s)	Observer(s)
2010 August	2941	Mark D. Koneff	Doug J. Forsell
	3351	James S. Wortham	Emily R. Bjerre
2010 December	3916	James S. Wortham	Doug J. Forsell, M. Tim Jones
2011 January	3726	James S. Wortham	Timothy P. White
2011 August	3606	Walt E. Rhodes	M. Tim Jones
	4116	James S. Wortham	Dean W. Demarest
	4311	Fred H. Roetker	Holliday H. Obrecht
2012 March	3316	Walt E. Rhodes	M. Tim Jones
	3651	Stephen D. Earsom	Eric. L. Kershner
	4056	James S. Wortham & Mark D. Koneff	Caleb S. Speigel, Dean W. Demarest, Melanie J. Steinkamp
	4446	Mark D. Koneff	Mao T. Lin & Sarah F. Yates
2012 October	3316	Walt E. Rhodes	M. Tim Jones
	3756	Stephen D. Earsom	Eric. L. Kershner
	4056	James S. Wortham	Mao T. Lin
	4446	Mark D. Koneff	Sarah F. Yates
2013 September	3316	Fred H. Roetker	M. Tim Jones
	3651	James S. Wortham	Pam Loring
	4056	Stephen D. Earsom	Mao T. Lin
	4446	Mark D. Koneff	Mao T. Lin
2014 February	3316	Fred H. Roetker	Caleb S. Speigel
	3651	James S. Wortham	Robert Simmons
	4056	Stephen D. Earsom	Mike Chouinard
	4446	Mark D. Koneff	Mao T. Lin
2014 October	3521	James S. Wortham	Fred H. Roetker & M. Tim Jones
	4126	Stephen D. Earsom	M. Tim Jones
	4446	Mark D. Koneff	Sarah F. Yates

*Numbers indicate the latitude (degrees-minutes) of the northernmost transect in the crew area.

Total counts and number transects for each species or species guild observed are presented in Tables 7.3 – 7.7. Due to our data analyst leaving, these summaries are not available for the 2013 and 2014 surveys at this time. Number of marine mammals and sea turtles observed during all surveys between 2010 and 2012 are presented in Table 7.8.

Table 7-3 Total count (number of transects) during August 2010 survey

Species Guild	Species	Crew2941	Crew3351	Total
Alcids	Unidentified large alcid	-	89 (20)	89 (20)
Larids	Black Skimmer	15 (1)	-	15 (1)
	Herring Gull	1 (1)	65 (24)	66 (25)
	Laughing Gull	51 (15)	-	51 (15)
	Ring-billed Gull	8 (5)	9 (1)	17 (6)
	Unidentified black-backed gull	-	183 (18)	183 (18)
	Unidentified large gull	10 (4)	8 (8)	18 (12)
	Unidentified small gull	-	42 (10)	42 (10)
	Unidentified gull	-	1,125 (32)	1,125 (32)
	Brown Noddy	2 (2)	-	2 (2)
	Bridled Tern	2 (2)	-	2 (2)
	Least Tern	2 (1)	-	2 (1)
	Roseate Tern	66 (21)	-	66 (21)
	Unidentified large tern	33 (12)	22 (10)	55 (22)
	Unidentified small tern	9 (8)	3 (3)	12 (11)
	Unidentified tern	10 (5)	33 (15)	43 (20)
Pelicaniforms	Northern Gannet	5 (4)	284 (42)	289 (46)
	Brown Booby	1 (1)	-	1 (1)
	Double-crested Cormorant	109 (8)	-	109 (8)
	Unidentified cormorant	1 (1)	-	1 (1)
	Magnificent Frigatebird	15 (8)	-	15 (8)
	Brown Pelican	66 (15)	269 (20)	335 (35)
Tubenoses	Unidentified petrel	1 (1)	-	1 (1)
	Unidentified shearwater	4 (4)	1 (1)	5 (5)
	Wilson's Storm-petrel	4 (3)	-	4 (3)
	Unidentified storm-petrel	-	6 (3)	6 (3)
	Unidentified seabird or diving duck	20 (24)	564 (37)	584 (61)
	Unidentified phalarope	-	1 (1)	1 (1)
TOTAL				3,139

Table 7-4 Total count (number of transects) during December 2010/January 2011 surveys

Species Guild	Species	Crew3726	Crew3916	Total
Sea ducks	Bufflehead	4 (1)	723 (16)	727 (17)
	Long-tailed Duck	1 (1)	34 (8)	35 (9)
	King Eider	-	6 (1)	6 (1)
	Common Goldeneye	-	49 (6)	49 (6)
	Unidentified goldeneye	-	32 (4)	32 (4)
	Red-breasted Merganser	-	9 (2)	9 (2)
	Unidentified merganser	-	3 (1)	3 (1)
	Unidentified goldeneye or merganser	-	9 (2)	9 (2)
	Black Scoter	6 (1)	717 (24)	723 (25)
	Surf Scoter	26 (5)	458 (12)	484 (17)
	White-winged Scoter	-	3 (1)	3 (1)
	Dark-winged Scoter	-	9 (1)	9 (1)
	Unidentified scoter	-	88 (4)	88 (4)
	Unidentified sea duck	7 (2)	10 (5)	17 (7)
Diving ducks	Unidentified scaup	-	197 (4)	197 (4)
Loons	Common Loon	66 (15)	33 (11)	99 (26)
	Red-throated Loon	16 (6)	194 (33)	210 (35)
	Unidentified loon	57 (14)	283 (45)	340 (51)
Alcids	Razorbill	3 (2)	-	3 (2)
	Unidentified large alcid	3 (3)	-	3 (3)
	Unidentified alcid	-	5 (1)	5 (1)
Larids	Bonaparte's Gull	-	510 (50)	510 (50)
	Great Black-backed Gull	4 (2)	40 (17)	44 (19)
	Herring Gull	55 (4)	71 (30)	126 (34)
	Laughing Gull	-	36 (17)	36 (17)
	Ring-billed Gull	-	508 (37)	508 (37)
	Unidentified black-backed gull	-	13 (9)	13 (9)
	Unidentified large gull	31 (1)	55 (16)	86 (17)
	Unidentified small gull	-	9 (7)	9 (7)
	Unidentified gull	35 (13)	536 (54)	571 (61)
	Black-legged Kittiwake	17 (9)	-	17 (9)
	Forster's Tern	-	6 (1)	6 (1)
	Royal Tern	-	10 (3)	10 (3)
	Unidentified large tern	-	21 (8)	21 (8)
	Unidentified small tern	-	36 (8)	36 (8)
	Unidentified tern	-	37 (15)	37 (15)
Pelicaniforms	Northern Gannet	2,237 (15)	1,566 (61)	3,803 (63)
	Double-crested Cormorant	3 (2)	155 (9)	158 (11)
	Unidentified cormorant	1 (1)	167 (7)	168 (8)
	Brown Pelican	-	23 (7)	23 (7)
Tubenoses	Unidentified shearwater	-	99 (3)	99 (3)
	Unidentified storm-petrel	-	1 (1)	1 (1)
	Unidentified seabird or diving duck	13 (5)	851 (59)	864 (59)
TOTAL				10,197

Table 7-5 Total count (unique number of transects) of seabirds during August 2011 survey

Species Guild	Species	Crew3606	Crew4116	Crew4311	Total
Sea ducks	Bufflehead	-	8 (1)	-	8 (1)
	Long-tailed Duck	-	-	1 (1)	1 (1)
	Common Eider	-	-	264 (7)	264 (7)
	Unidentified eider	-	-	153 (4)	153 (4)
	Unidentified merganser	-	-	6 (3)	6 (3)
	Black Scoter	-	-	248 (17)	248 (17)
	Unidentified scoter	-	-	61 (2)	61 (2)
Loons	Common Loon	-	-	2 (2)	2 (2)
	Red-throated Loon	-	-	16 (7)	16 (7)
	Unidentified loon	-	-	3 (3)	3 (3)
Alcids	Dovekie	-	-	1 (1)	1 (1)
	Unidentified alcid	-	-	32 (7)	32 (7)
Larids	Great Black-backed Gull	10 (4)	113 (32)	204 (42)	327 (77)
	Herring Gull	9 (5)	269 (50)	687 (65)	965 (116)
	Iceland Gull	1 (1)	-	-	1 (1)
	Laughing Gull	565 (77)	8 (5)	3 (1)	576 (83)
	Ring-billed Gull	1 (1)	36 (16)	62 (22)	99 (39)
	Unidentified black-backed gull	-	1 (1)	135 (23)	136 (24)
	Unidentified large gull	5 (4)	60 (18)	478 (27)	543 (48)
	Unidentified small gull	-	1 (1)	283 (28)	284 (29)
	Unidentified gull	309 (13)	419 (26)	1,876 (48)	2,604 (83)
	Caspian Tern	3 (3)	-	-	3 (3)
	Common Tern	-	-	8 (3)	8 (3)
	Forster's Tern	18 (8)	-	1 (1)	19 (9)
	Gull-billed Tern	25 (6)	-	-	25 (6)
	Least Tern	347 (36)	6 (2)	32 (16)	385 (54)
	Royal Tern	38 (24)	4 (4)	-	42 (28)
	Unidentified large tern	690 (77)	218 (37)	3 (3)	911 (117)
	Unidentified medium tern	80 (31)	-	-	80 (31)
	Unidentified small tern	103 (25)	314 (56)	32 (7)	449 (88)
	Unidentified tern	352 (55)	7 (3)	958 (58)	1,317 (115)
Pelicaniforms	Northern Gannet	-	2 (2)	252 (30)	254 (32)
	Double-crested Cormorant	16 (6)	40 (8)	105 (14)	161 (27)
	Unidentified cormorant	3 (1)	51 (10)	402 (34)	456 (44)
	Brown Pelican	470 (48)	121 (9)	-	591 (57)
	White-tailed Tropicbird	1 (1)	-	-	1 (1)
Tubenoses	Northern Fulmar	-	-	14 (6)	14 (6)
	Black-capped Petrel	1 (1)	-	-	1 (1)
	Audubon's Shearwater	2 (2)	-	-	2 (2)
	Cory's Shearwater	169 (29)	-	23 (8)	192 (37)
	Great Shearwater	6 (3)	-	221 (34)	227 (37)
	Sooty Shearwater	-	-	14 (8)	14 (8)
	Unidentified shearwater	45 (9)	-	463 (40)	508 (49)
	Unidentified storm-petrel	-	90 (21)	274 (36)	364 (57)
	Unidentified seabird or diving duck	87 (30)	40 (6)	1 (1)	128 (37)
	Unidentified phalarope	186 (23)	130 (1)	61 (13)	377 (37)
TOTAL					12,859

Table 7-6 Total count (unique number of transects) for seabirds during March 2012 survey

Species Guild	Species	Crew3316	Crew3651	Crew4056	Crew4446	Total
Sea ducks	Bufflehead	-	593 (12)	1,036 (11)	75 (8)	1,704 (31)
	Harlequin Duck	-	-	65 (2)	-	65 (2)
	Long-tailed Duck	-	13 (2)	224 (9)	2,345 (43)	2,582 (54)
	Common Eider	-	-	-	5,714 (53)	5,714 (53)
	Unidentified eider	-	-	-	25 (2)	25 (2)
	Common Goldeneye	-	3 (2)	13 (3)	29 (6)	45 (11)
	Unidentified goldeneye	-	-	-	24 (4)	24 (4)
	Common Merganser	-	12 (2)	-	14 (2)	26 (4)
	Red-breasted Merganser	-	105 (6)	3 (1)	872 (33)	980 (40)
	Unidentified merganser	-	55 (10)	13 (8)	17 (3)	85 (21)
	Black Scoter	40 (4)	2,285 (11)	370 (15)	283 (10)	2,978 (40)
	Surf Scoter	-	279 (8)	1,855 (21)	213 (7)	2,347 (36)
	White-winged Scoter	-	2 (2)	26 (5)	898 (24)	926 (31)
	Dark-winged Scoter	-	-	110 (11)	1,375 (18)	1,485 (29)
	Unidentified Scoter	-	1,004 (9)	1,385 (21)	468 (21)	2,857 (51)
	Unidentified sea duck	25 (1)	106 (6)	12 (4)	3 (1)	146 (12)
Diving ducks	Redhead	-	-	3 (1)	-	3 (1)
	Unidentified scaup	8 (1)	-	509 (4)	34 (3)	551 (8)
Grebes	Red-necked Grebe	-	-	4 (2)	-	4 (2)
	Unidentified grebe	-	-	1 (1)	2 (1)	3 (2)
Loons	Common Loon	28 (16)	381 (47)	155 (45)	320 (56)	884 (164)
	Red-throated Loon	242 (34)	977 (56)	586 (46)	693 (37)	2,498 (173)
	Unidentified loon	69 (8)	10,084 (20)	278 (37)	25 (8)	10,456 (73)
Alcids	Dovekie	-	-	-	67 (12)	67 (12)
	Razorbill	-	1 (1)	-	527 (13)	528 (14)
	Black Guillemot	-	-	-	60 (9)	60 (9)
	Unidentified murre	-	-	-	124 (11)	124 (11)
	Atlantic Puffin	-	-	-	14 (4)	14 (4)
	Unidentified alcid	-	2 (2)	91 (9)	465 (27)	558 (38)
Larids	Bonaparte's Gull	117 (25)	2,051 (30)	36 (4)	2 (2)	2,206 (61)
	Great Black-backed Gull	-	27 (17)	82 (19)	1 (1)	110 (37)
	Herring Gull	28 (16)	3,174 (54)	477 (48)	3,636 (65)	7,315 (183)
	Laughing Gull	95 (26)	4 (3)	3 (2)	-	102 (31)
	Lesser Black-backed Gull	1 (1)	-	1 (1)	-	2 (2)
	Ring-billed Gull	221 (38)	-	15 (4)	333 (23)	569 (65)
	Unidentified black-backed gull	2 (2)	7 (4)	36 (10)	131 (37)	176 (53)
	Unidentified large gull	-	-	35 (14)	-	35 (14)
	Unidentified small gull	1 (1)	3 (2)	99 (20)	79 (8)	182 (31)
	Unidentified gull	66 (31)	3,125 (63)	109 (26)	1 (1)	3,301 (121)

Table 7-6 (cont) Total count (unique number of transects) for seabirds during March 2012 survey

Species Guild	Species	Crew3316	Crew3651	Crew4056	Crew4446	Total
Larids	Parasitic Jaeger	-	1 (1)	-	-	1 (1)
	Pomarine Jaeger	-	1 (1)	-	-	1 (1)
	Black-legged Kittiwake	-	-	1 (1)	303 (15)	304 (16)
	Caspian Tern	1 (1)	-	-	-	1 (1)
	Forster's Tern	1 (1)	-	-	-	1 (1)
	Least Tern	2 (2)	-	-	-	2 (2)
	Royal Tern	223 (47)	114 (32)	-	-	337 (79)
	Unidentified large tern	92 (35)	5 (4)	14 (9)	-	111 (48)
	Unidentified small tern	21 (11)	38 (16)	-	-	59 (27)
	Unidentified tern	177 (40)	96 (33)	51 (11)	-	324 (84)
Pelicani-forms	Northern Gannet	634 (51)	5,156 (67)	2,433 (62)	287 (38)	8,510 (218)
	Double-crested Cormorant	98 (11)	25 (10)	50 (7)	-	173 (28)
	Unidentified cormorant	-	3 (1)	45 (5)	6 (2)	54 (8)
	Brown Pelican	192 (33)	49 (15)	63 (2)	-	304 (50)
	Unidentified albatross	-	1 (1)	-	-	1 (1)
	Northern Fulmar	-	-	7 (2)	-	7 (2)
	Audubon's Shearwater	1 (1)	-	-	-	1 (1)
	Cory's Shearwater	2 (2)	5 (3)	-	-	7 (5)
	Great Shearwater	-	3 (3)	6 (3)	-	9 (6)
	Manx Shearwater	-	1 (1)	-	-	1 (1)
Tubenoses	Unidentified shearwater	1 (1)	1 (1)	2 (2)	-	4 (4)
	Unidentified storm-petrel	-	-	1 (1)	-	1 (1)
	Unidentified seabird or diving duck	29 (11)	47 (19)	41 (20)	24 (14)	141 (64)
	Unidentified phalarope	1,592 (17)	4,484 (22)	21 (5)	-	6,097 (44)
	Unidentified albatross	-	1 (1)	-	-	1 (1)
	Northern Fulmar	-	-	7 (2)	-	7 (2)
	Audubon's Shearwater	1 (1)	-	-	-	1 (1)
	Cory's Shearwater	2 (2)	5 (3)	-	-	7 (5)
	Great Shearwater	-	3 (3)	6 (3)	-	9 (6)
	Manx Shearwater	-	1 (1)	-	-	1 (1)
	Unidentified shearwater	1 (1)	1 (1)	2 (2)	-	4 (4)
	Unidentified storm-petrel	-	-	1 (1)	-	1 (1)
TOTAL						68,219

Table 7-7 Total count (unique number of transects) for seabirds during October 2012 survey

Species Guild	Species	Crew3316	Crew3756	Crew4056	Crew4446	Total
Sea ducks	Long-tailed Duck	-	-	-	5 (1)	5 (1)
	Common Eider	-	-	-	322 (19)	322 (19)
	White-winged Scoter	-	-	-	8 (2)	8 (2)
	Unidentified scoter	-	-	-	98 (10)	98 (10)
	Unidentified sea duck	-	-	-	12 (1)	12 (1)
Grebes	Unidentified grebe	-	-	-	1 (1)	1 (1)
Loons	Common Loon	-	-	-	41 (22)	41 (22)
	Red-throated Loon	-	-	12 (5)	1 (1)	13 (6)
	Unidentified loon	-	-	3 (2)	3 (2)	6 (4)
Alcids	Dovekie	-	-	-	1 (1)	1 (1)
	Black Guillemot	-	-	-	9 (5)	9 (5)
	Unidentified alcid	-	-	-	20 (6)	20 (6)
Larids	Bonaparte's Gull	143 (6)	164 (11)	-	-	307 (17)
	Glaucous Gull	-	7 (1)	-	-	7 (1)
	Great Black-backed Gull	1 (1)	248 (31)	75 (21)	-	324 (53)
	Herring Gull	685 (14)	183 (31)	758 (49)	1,014 (73)	2,640 (167)
	Laughing Gull	688 (45)	18 (8)	14 (4)	1 (1)	721 (58)
	Lesser Black-backed Gull	-	-	84 (13)	-	84 (13)
	Little Gull	-	-	2 (2)	-	2 (2)
	Ring-billed Gull	5 (3)	12 (2)	76 (26)	133 (22)	226 (53)
	Unidentified black-backed gull	-	14 (9)	1 (1)	169 (33)	184 (43)
	Unidentified large gull	4 (2)	20 (1)	-	-	24 (3)
	Unidentified small gull	2 (1)	2 (2)	75 (25)	-	79 (28)
	Unidentified gull	293 (14)	1,806 (51)	504 (14)	19 (12)	2,622 (91)
	Black-legged Kittiwake	-	-	-	153 (20)	153 (20)
	Caspian Tern	2 (1)	-	-	-	2 (1)
	Least Tern	590 (14)	-	-	-	590 (14)
	Little Tern	12 (1)	-	-	-	12 (1)
	Roseate Tern	-	1 (1)	-	-	1 (1)
	Royal Tern	71 (20)	193 (46)	-	-	264 (66)
	Unidentified large tern	1,835 (53)	30 (11)	1 (1)	59 (5)	1,925 (70)
	Unidentified medium tern	5 (2)	-	-	-	5 (2)
	Unidentified small tern	268 (19)	37 (11)	1 (1)	3 (2)	309 (33)
	Unidentified tern	978 (35)	418 (26)	38 (11)	21 (4)	1,455 (76)

Table 7-7 (cont) Total count (unique number of transects) for seabirds during October 2012 survey.

Species Guild	Species	Crew3316	Crew3756	Crew4056	Crew4446	Total
Pelicaniforms	Northern Gannet	-	1 (1)	247 (50)	240 (41)	488 (92)
	Double-Crested Cormorant	-	5,757 (14)	-	303 (3)	6,060 (17)
	Unidentified cormorant	-	-	90 (7)	64 (9)	154 (16)
	Magnificent Frigatebird	1 (1)	-	-	-	1 (1)
	American White Pelican	-	70 (1)	-	-	70 (1)
	Brown Pelican	108 (20)	1,000 (22)	11 (4)	-	1,119 (46)
Tubenoses	Audubon's Shearwater	8 (5)	-	-	-	8 (5)
	Cory's Shearwater	97 (21)	81 (11)	-	-	178 (32)
	Great Shearwater	2 (2)	-	-	6 (4)	8 (6)
	Unidentified shearwater	17 (6)	1 (1)	6 (6)	24 (12)	48 (25)
	Unidentified storm-petrel	-	-	1 (1)	1 (1)	2 (2)
	Unidentified seabird or diving duck	41 (3)	9 (1)	38 (18)	5 (4)	93 (26)
	Unidentified phalarope	149 (20)	17 (2)	-	5 (2)	171 (24)
TOTAL						21,466

Table 7-8 Total count for all marine mammals and sea turtles identified

Species Guild	Species	Aug 2010	Dec 2010 & Jan 2011	Aug 2011	March 2012	Oct 2012
Marine mammals	Bottlenose dolphin	24	16	-	-	48
	Risso's dolphin	-	-	-	-	6
	Unidentified spotted dolphin	2	-	-	-	-
	Unidentified dolphin	145	31	626	336	182
	West Indian manatee	3	-	-	-	-
	Unidentified porpoise	-	-	5	1	2
	Unidentified seal	-	-	-	11	7
	Common minke whale	-	-	1	-	-
	Fin whale	-	-	-	1	-
	Humpback whale	-	-	1	1	-
	Unidentified whale	-	-	6	3	2
	Unidentified marine mammal	1	-	-	-	-
Sea turtles	Green sea turtle	7	-	-	5	15
	Kemp's ridley sea turtle	2	-	2	1	1
	Leatherback sea turtle	3	-	22	7	6
	Loggerhead sea turtle	152	1	184	92	184
	Unidentified sea turtle	182	-	248	262	72

7.3.2 Raw Density Estimates

Raw density estimates per square kilometer were calculated for all aerial surveys from 2010 through 2012 (Appendix IV Part 3). Until we can correct these raw densities based on detectability the only species we are comfortable mapping individually is Northern Gannet. All other species were grouped into higher taxonomic groupings that included: alcids; gulls; loons; terns, sea and diving ducks; marine mammals and sea turtles (Appendix IV Figures 3-1 – 3-11). Density estimates are much higher on our transect segments compared to other recent seabird surveys off the Northwestern Atlantic coast (Veit et al. 2015). We suspect these differences are due to the difference in spatial sampling domain. Veit et al. (2015) surveyed seabirds from ships in generally much deeper waters or further offshore than we covered in our USFWS aircraft.

7.3.3 Seabird Key Site Maps

Analysis of key sites for all species using all three thresholds (50% of total individuals sighted; 90% of total individuals sighted; and the proportion of individuals sighted corresponding to the “optimal” area considered a key site based on the law of diminishing returns) indicated high concentrations of individuals off the Outer Banks in North Carolina, in the Chesapeake Bay and off the Eastern Shore of Virginia, Delaware Bay, Coastal New Jersey, eastern Long Island and in the Martha’s Vineyard/Nantucket area and Penobscot Bay and Downeast, Maine (Figures 7-8 – 7-10 and Appendix IV Figures 4-1 – 4-3). Similar patterns of sites that consistently account for the majority of individuals observed during aerial AMAPPS surveys were seen seasonally (Appendix IV, Figures 5-1 – 5-6 and 5-10 – 5-12) with the exception of summer (Appendix IV Figures 5-7 – 5-9). Summer patterns changed dramatically and depicted the larger number of seabirds nesting along the coast of Maine. A large majority of the seabirds observed in the nonbreeding period nest off the Atlantic coast (e.g., Northern Gannets) of Canada or in interior wetlands (e.g., sea ducks).

Maps of key sites for individual species (Appendix IV Figures 6-1 – 12-3) generally show similar patterns to the overall key sites analyses (Appendix IV Figures 4-1 – 4-3) with the exception of those species that breed along the coast of Maine (e.g., eiders, Appendix IV Figures 6-1 – 6-3). Given the lack of spatial overlap between our survey design and recent offshore surveys completed in 2013 (Veit et al. 2013), there is limited overlap between key areas identified for seabirds. The key sites that overlapped between these two studies included: Nantucket Sound/Shoals, Outer Banks, NC (i.e., Cape Hatteras), the mouth of the Chesapeake Bay, and off the coast of New Jersey.

The Shannon Index (Figure 7-11) shows the seabird diversity is greatest in and offshore of Chesapeake Bay, VA, Cape Cod, MA and Penobscot Bay, ME.

7.4 Acknowledgments

The work documented in this chapter would not have been possible without the dedication and hard work of those that collected the aerial survey data. This includes the USFWS pilots that flew the airplanes, in addition to the scientists that were instrumental in collecting and analyzing these data.

We also would like to thank those that funded this work. The data collection and analyses were funded by the USFWS and Bureau of Ocean Energy Management (BOEM) through the Interagency Agreements between the Northeast Fisheries Science Center and BOEM and between the Northeast Fisheries Science Center and USFWS.

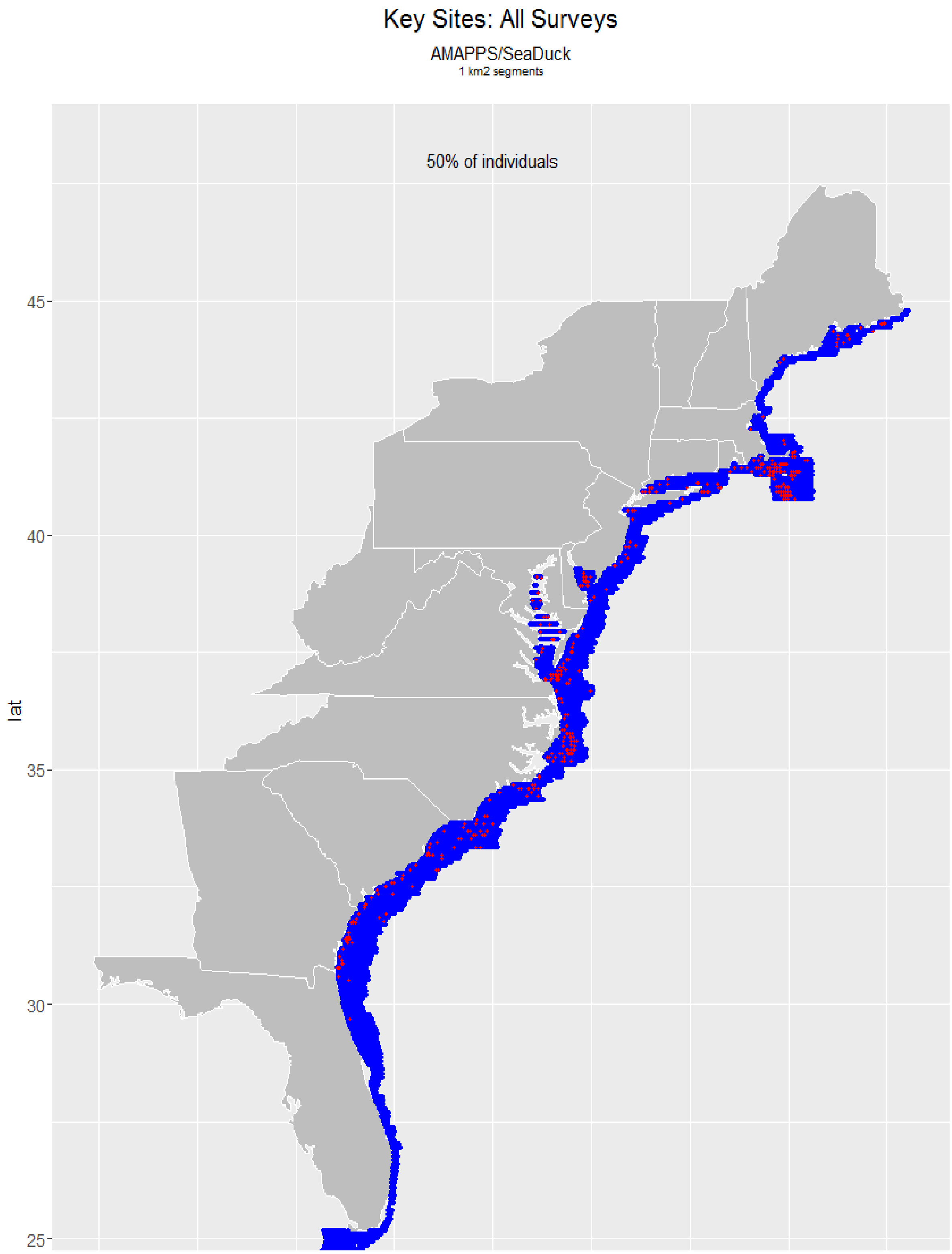

Figure 7-8 Key sites (50% of the individuals) for all seabirds from all surveys

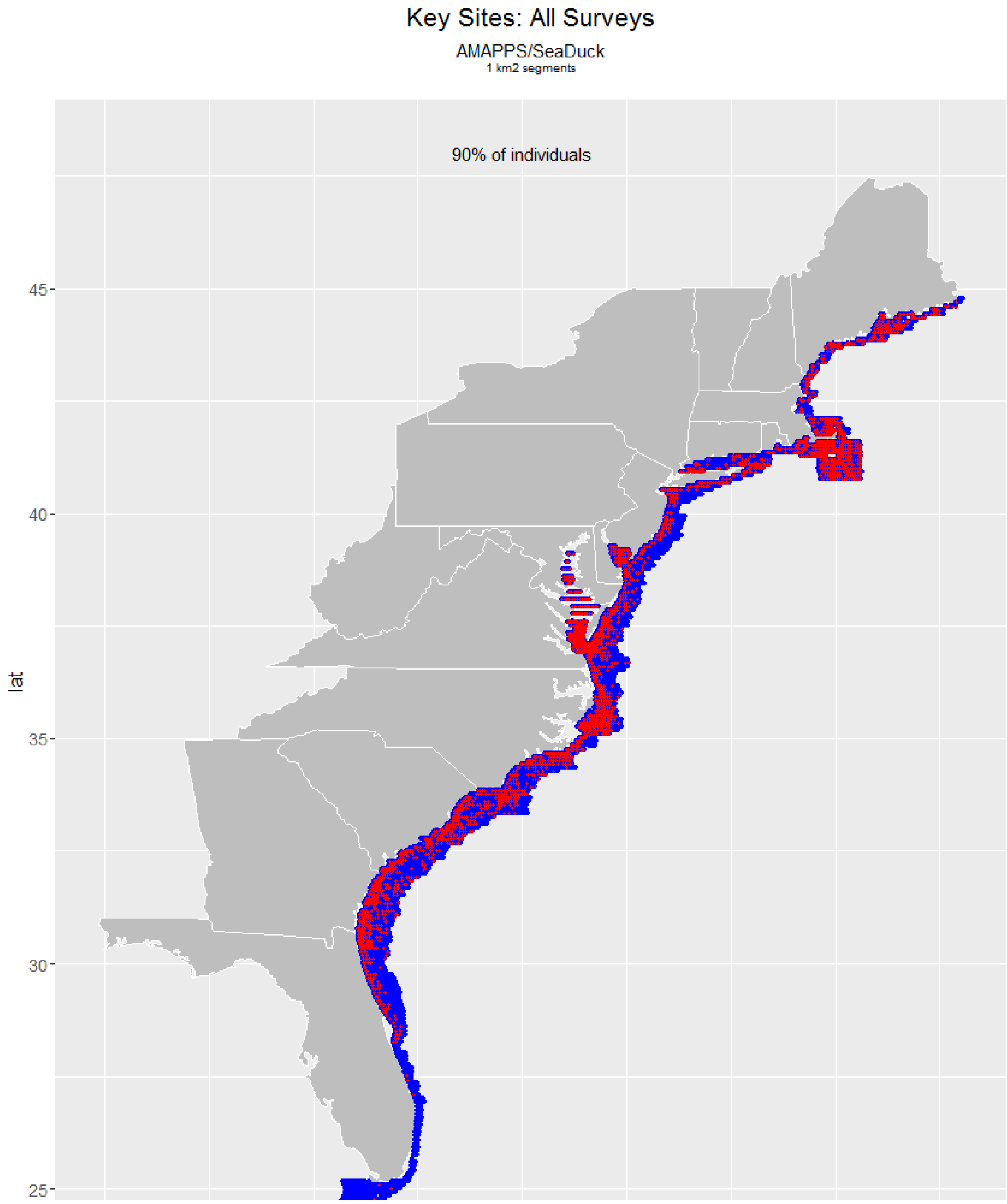

Figure 7-9 Key sites (90% of the individuals) for all seabirds from all surveys

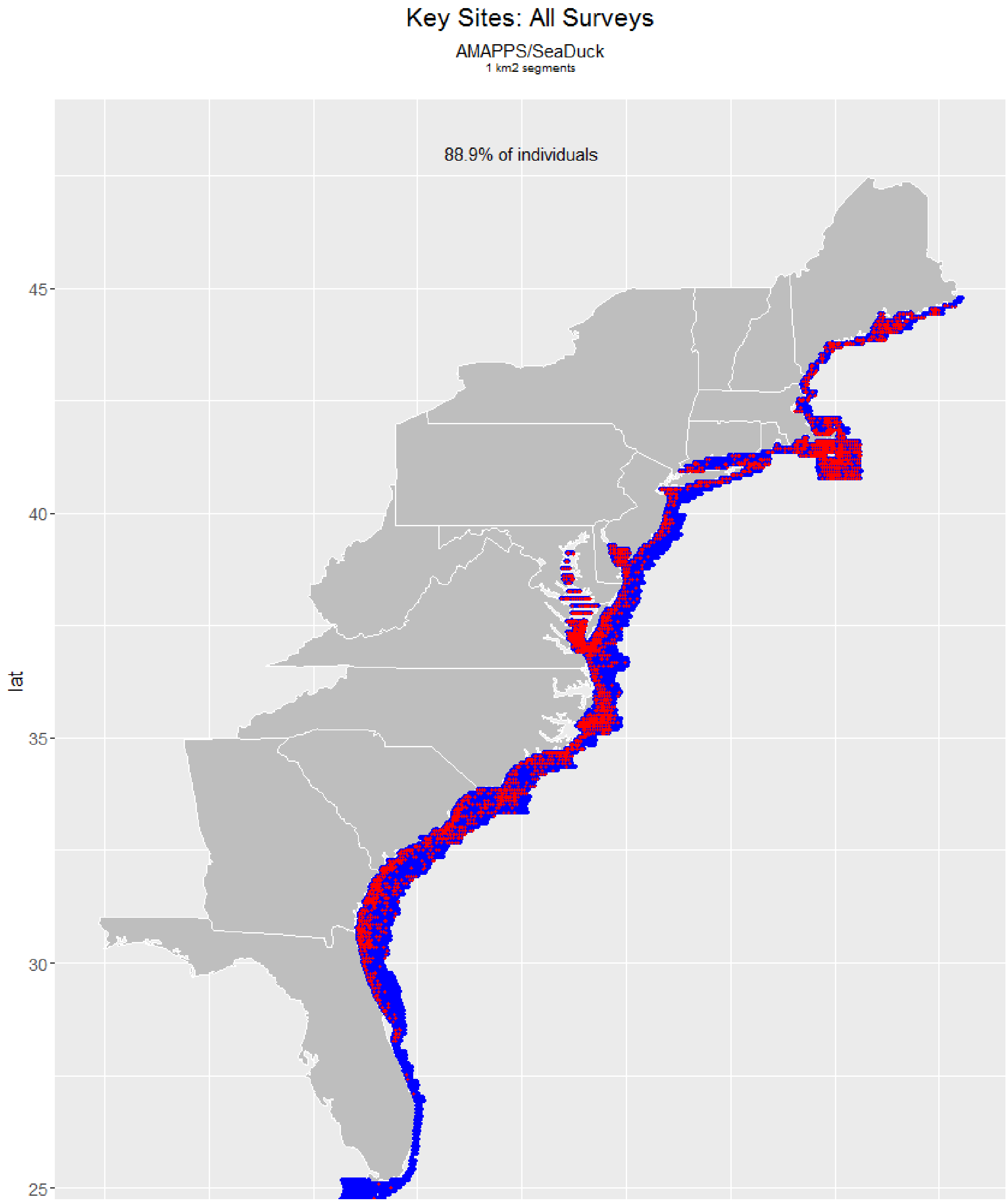

Figure 7-10 Keys sites (with optimal individuals) of all seabirds from all surveys

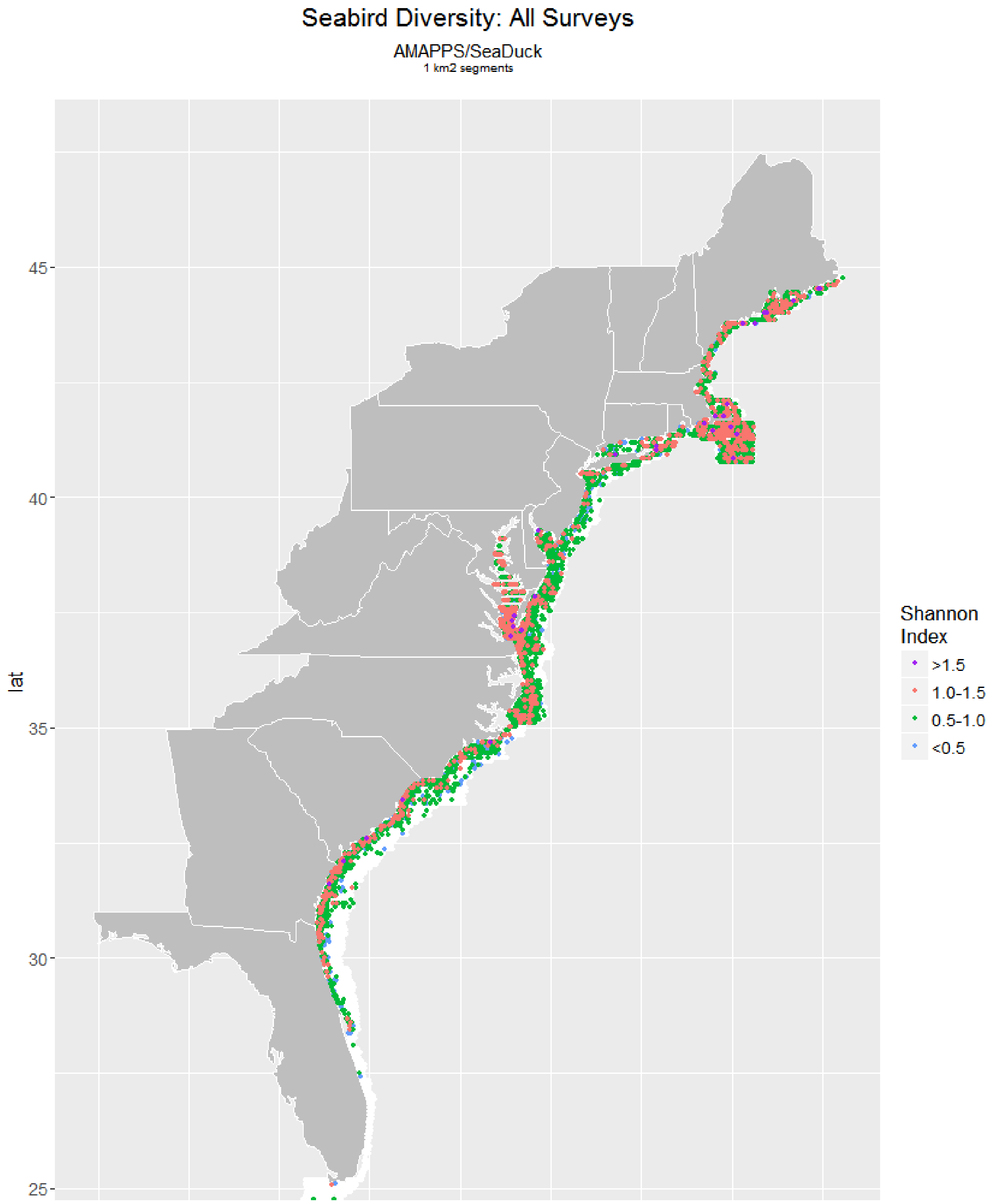

Figure 7-11 Shannon Index of seabird diversity

8 Passive Acoustic Research

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8.1 Introduction

There is a growing need to improve marine mammal monitoring programs throughout US waters, as anthropogenic activities are steadily increasing along coastal and offshore areas concurrent with cetacean habitats. Effective monitoring programs are needed to assess both species distribution and the potential effects of anthropogenic impacts. Passive acoustic technologies have become a key component of marine mammal monitoring, providing valuable information about the spatial and temporal distribution of a variety of species, as well as contributing new insights into their behavior and ecology.

Marine mammal surveys have traditionally been conducted visually, from either aerial or vessel platforms. However, visual-based sighting methodologies are limited by daylight and weather, as well as by the amount of time an animal may spend at the surface. Cryptic species, such as beaked whales, typically have low visual detection rates even under good conditions (Barlow et al. 2005); while even more reliably-sighted species cannot be detected visually at night or when conditions are poor. Acoustic technologies, on the other hand, are not limited by daylight or environmental conditions, and therefore offer the opportunity to collect data on occurrence and distribution of vocalizing cetaceans that complements traditional visual survey methodologies. However, acoustic technologies are limited to recording only vocalizing animals, and analytical techniques to estimate density and abundance using acoustic data are still being developed.

In the western North Atlantic, data collected from acoustic studies have already provided important new insights on species distributions, including demonstrating the extended occurrence and persistence of baleen whales beyond seasons and regions where they were previously documented (e.g., Morano et al. 2012; Mussoline et al. 2012; Risch et al. 2013; Risch et al. 2014). In addition, acoustic data have been used to estimate population abundance for species that are difficult to detect visually (e.g., Marques et al. 2009), collect data on the presence of species in regions that are difficult to otherwise survey (e.g., Moore et al. 2012), and help us better understand the response of individuals to anthropogenic activities that produce underwater sound (e.g., Pirotta et al. 2012; Risch et al. 2012; Cerchio et al. 2014; Quick et al. 2016). Work conducted during AMAPPS I contributes to all of these types of efforts.

Multiple types of recording devices were employed during the five year AMAPPS I project. These include: towed hydrophone arrays, drifting recorders (sonobuoys), and fixed archival recorders, including Autonomous Multichannel Acoustic Recorders (AMAR; Jasco Applied Sciences) and Marine Autonomous Recording Units (MARUs; Cornell University; Figure 8-1). Detailed information on the recording systems and analyses are found in the AMAPPS annual reports (NMFS 2017), therefore, only a short summary is replicated here.

Figure 8-1 Examples of passive acoustic recording equipment employed during AMAPPS I
Left side: active section of a custom-built towed hydrophone array. Center: Marine Autonomous Recording Unit (MARU, Cornell University). Right side: Autonomous Multichannel Acoustic Recorder (AMAR, Jasco Applied Sciences).

The goals of the passive acoustic research conducted at the Northeast and Southeast Fisheries Science Centers include improving our understanding of cetacean acoustic ecology, so that passive acoustic data may be integrated with visual data where appropriate, and can supplement visual data elsewhere. At both Centers, the passive acoustic program extends beyond the work conducted under the umbrella of AMAPPS. However, the main foci of the work conducted within AMAPPS includes deriving estimates of abundance for sperm whales using acoustic data, evaluating the distribution of beaked whales, investigating geographic variation in the characteristics of odonotocete echolocation clicks (initial focus on Risso’s dolphins), and developing species-specific automated acoustic classifiers to facilitate more thorough use of passive acoustic data. The research involving towed hydrophone arrays and archival recorders are summarized below.

8.2 Towed Hydrophone Array Projects

8.2.1 Field Activities

Towed passive acoustic arrays have been deployed on most recent marine mammal surveys, particularly those in waters deeper than 100 m. In 2011, the NEFSC and SEFSC had different towed array designs, but in 2012, the Southwest Fisheries Science Center organized a workshop to standardize array design between all NMFS Science Centers. Each of the Centers built new towed arrays (Rankin et al. 2013), which were used in all subsequent years. The standardized arrays were comprised of two oil-filled, modular sections, separated by 20 – 30 m of cable. The “end array” included five elements: three APC International Ltd hydrophones (model 21-1021, flat frequency response (+/- 4 dB) from 1 to 45 kHz, -212 dB re: 1 V/µPa sensitivity) and two Reson hydrophones (model TC4013, flat frequency response (+/- 2 dB) from 5 to 160 kHz -212 dB re 1 V/µPa sensitivity). Custom-built pre-amplifiers provided a high pass filter with 35 – 45 dB gain above 5 kHz for the APC elements, and 35 – 50 dB gain above 5 kHz for the Reson elements. The “in-line” array consisted of three APC elements (described above), though this section of the array was not used in all surveys. Each array also included an OEM pressure transducer (Keller America PA7FLE) for continuous collection of array depth data. Arrays were typically deployed in waters of 75 m or greater, and were towed 300 m behind the ship during normal survey operations.

Towed array data were collected in real-time by a team of acousticians, using a suite of software packages, including PAMGuard, Ishmael, WhalTrack, RainbowClick and Logger. On the NEFSC surveys, data were typically collected during daytime hours only, with opportunistic nighttime data collection. On the SEFSC surveys, towed array data were typically collected 24 hrs /day. Each recording system incorporated two soundcards; one sampled the mid-frequency channels at 192 kHz (RME Fireface UC, MOTU HD-896, or National Instruments USB-6356), while the second (National Instruments USB-6356 or USB-6351) sampled the high-frequency data at 500 kHz. Both systems recorded at a resolution of either 16 or 24 bits.

During AMAPPS I, the SEFSC also employed expendable Directional Frequency Analysis and Ranging (DIFAR) sonobuoys (model AN/SSQ-53E) to aid in the detection of baleen whales. Sonobuoys transmit acoustic signals back to the ship using VHF (very high frequency) radio frequencies. Signals were received at the ship via VHF antenna, amplified using an ARS P160VDG preamplifier, and were routed to an ICOM R100 radio with a flat frequency response from 10 Hz to 20 kHz (customized and calibrated by Greeneridge Sciences). Sonobuoys were recorded through a Sound Blaster Audigy soundcard at 16 bit, 48 kHz sample rate, with a 10 – 7500 Hz recording bandwidth.

Both the NEFSC and SEFSC deployed towed hydrophone arrays during their summer cetacean shipboard abundance surveys in 2011 and 2013. In addition, in 2014 the NEFSC conducted a spring cetacean abundance survey, and a short (4 day) summer survey focusing on beaked whales, in which towed hydrophone array data were also collected (Table 8.1; Figure 8.2).

Table 8-1 Numbers of hours of towed hydrophone array data collected during AMAPPS I

	Hours of Towed Array Recordings	
Year	**NEFSC**	**SEFSC**
2011	312	594
2013	323	592
2014 spring	114	N/A
2014 summer	43	N/A

In 2011, real-time monitoring during the NEFSC shipboard survey resulted in the detection of 356 acoustic groups. Of these, approximately 37% corresponded to the visual detection of small odontocetes, including 8 species of delphinids, and 1 species of beaked whale. Sperm whales comprised an additional 24% of acoustic detections, with a total of 87 different individuals or groups of individuals tracked. Approximately 11 of these groups were detected visually; therefore approximately 87% of sperm whale detections were solely acoustic.

In 2013, real-time monitoring during the NEFSC survey resulted in the detection of 263 groups of vocally-active odontocetes. Of these, approximately 22% corresponded to simultaneous visual detection of groups, including seven species of delphinids, sperm whales, and beaked whales. Sperm whales were detected on at least 25 survey days, for a total of 65 vocally-active groups. In many cases, these acoustic events represented multiple individuals. Real-time monitoring during the SEFSC survey resulted in a total of 729 groups.

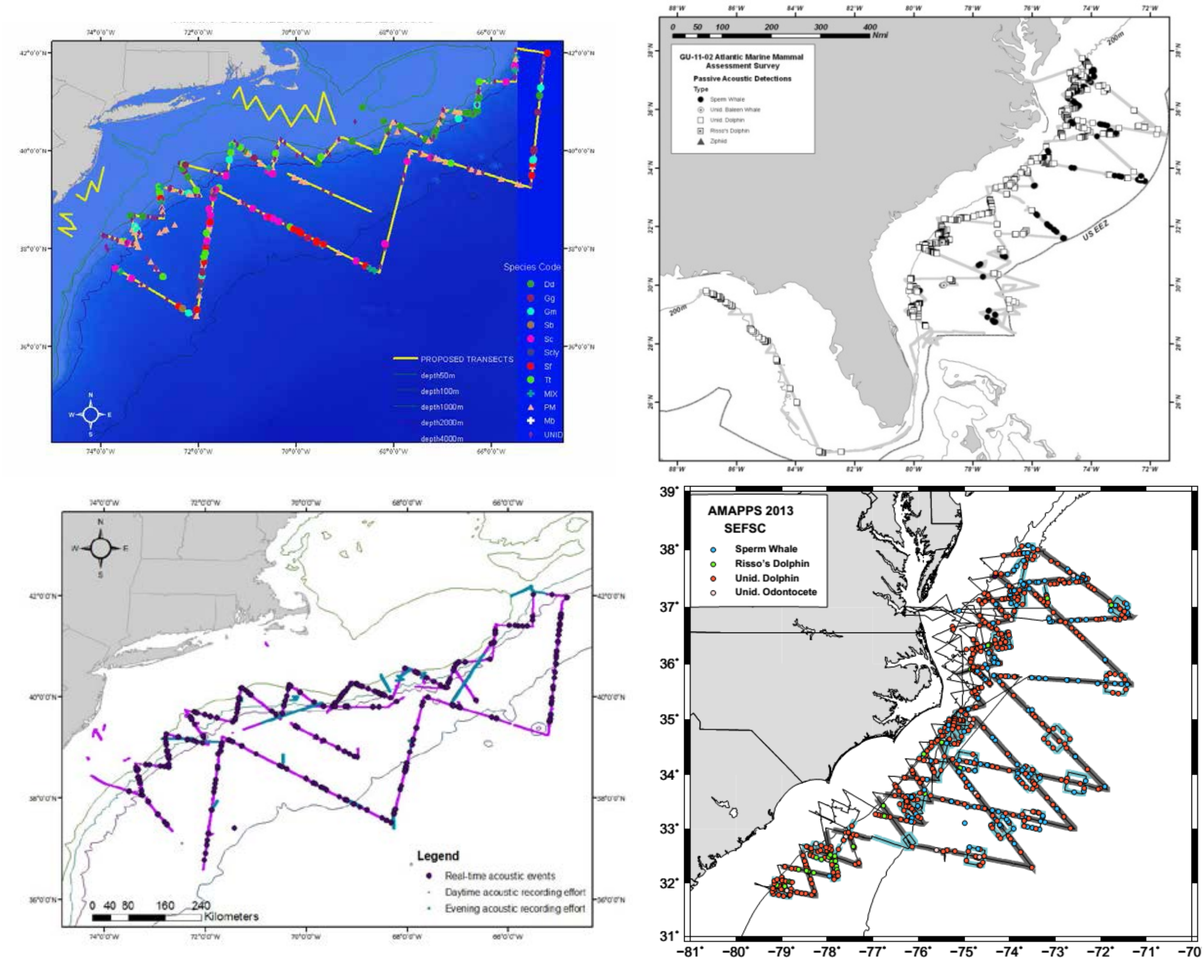

Figure 8-2 Tracklines and real-time acoustic detections from the 2011 and 2013 surveys
A) HB11-03 b) GU11-03, c) HB13-03, d) GU13-03. Dark gray line indicates visual and acoustic effort; blue line represents acoustic effort only (e.g. night or poor weather).

In the NEFSC spring AMAPPS survey in 2014, acoustic monitoring effort was conducted on only 17 of 33 survey days, due to weather conditions and time spent surveying inshore track lines that precluded deployment of the hydrophone array. Evening recordings were made opportunistically on 10 occasions. Real-time monitoring resulted in the detection of 54 groups of vocally-active odontocetes. Of these, approximately 11% corresponded to simultaneous visual detection of groups, allowing for species assignment. Sperm whales were detected in real-time on only 8 of 17 days, for a total of 19 vocally-active groups.

In 2014 during a five-day survey, the acoustic array was deployed for 800 km of survey effort, once the ship reached the shelf-break region. Real-time monitoring during the survey resulted in the detection of 51 groups of vocally-active odontocetes, including four groups of beaked whales. Sperm whales were detected on 4 out of the 5 survey days; they were not detected the day when the ship transited out to the study area.

8.2.2 Sperm Whale Acoustic Abundance Estimate

The largest of the odontocetes, sperm whales are deep-diving animals that have a worldwide distribution. Within an ocean basin, their distribution varies by sex and age class, depending on prey availability and oceanic conditions. Male sperm whales are generally solitary after reaching sexual maturity, but mature females are found year-round in social groups with calves and immature animals. Although not well-understood, migration patterns differ between males and females. In general, female groups are found in temperate/tropical waters year-round, while males range into high-latitude waters. In summer, both sexes are found at the highest latitudes of their range, while in the winter female/immature groups are thought to migrate close to equatorial waters. Within the western North Atlantic, this means that in the winter, most animals are thought to be concentrated east and northeast of Cape Hatteras, North Carolina while in the summer their distribution shifts to include the waters east and north of Georges Bank and into the Northeast Channel and Gulf of Maine region.

Stock structure of the Atlantic population is poorly understood. The International Whaling Commission recognizes one stock for the entire North Atlantic Ocean, but whether population in the western North Atlantic is discrete from the population in the eastern North Atlantic is still considered unresolved (Waring et al. 2015a). In any case, the portion of the population that ranges within the US EEZ likely represents a fraction of a larger stock in the western North Atlantic.

Population abundance estimation for sperm whales is complicated by the fact that these animals engage in long, deep foraging dives, for upwards of 45 minutes or more (Watwood et al. 2006). This behavior results in a relatively small proportion of time at the surface, which decreases availability for visual detection on standard line-transect visual surveys. As was presented in Chapter 5, sperm whales were on average at the surface about 14% of the time, where the average dive time was 44.6 minutes and the average time at the surface was 7.1 minutes. However, sperm whales are acoustically active when undertaking foraging dives, and passive acoustic methodologies have proven to be effective at detecting and localizing vocal individuals (Barlow and Taylor 2005). Therefore, they are an ideal species for acoustic abundance estimation using towed hydrophone arrays, and abundance estimates have been generated in other regions using this methodology (e.g. Gannier et al. 2002; Barlow and Taylor 2005; Lewis et al. 2007)

Towed hydrophone array data from the large-scale AMAPPS abundance surveys conducted in 2011 and 2013 are being analyzed to generate acoustic abundance estimates of sperm whales. Acoustic data were post-processed using the software package PAMGuard (Gillespie et al. 2009). The PAMGuard click detector was run over all sound files (pre-filter: bandpass 2 – 15 kHz; trigger filter: 3 – 11 kHz) and detections were manually reviewed by a trained analyst. Sperm whale clicks were identified based on spectral and temporal characteristics (peak frequency, waveform, and inter-pulse interval). Acoustic detections of sperm whales were made throughout both the NEFSC and SEFSC surveys (Figure 8.3).

Clicks were grouped into click trains if they had a consistent inter-pulse interval and change in bearing (Figure 8.4). Click trains from individual animals were localized with target motion analysis, using either least squares or 2-D simplex algorithms. The resulting perpendicular distances were used as input in the software package DISTANCE. Detection functions were fit to the distribution of perpendicular distances for each dataset, both stratified according to shelf break/offshore strata, as well as pooled.

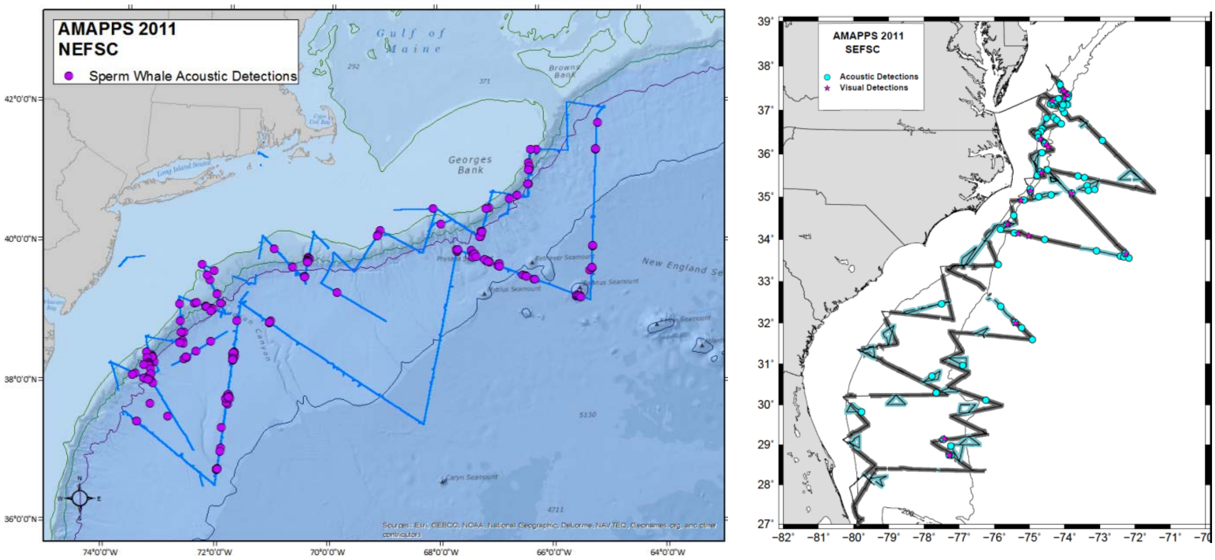

Figure 8-3 AMAPPS 2011 shipboard tracklines and acoustic detections of sperm whales
NEFSC (left) and SEFSC (right).

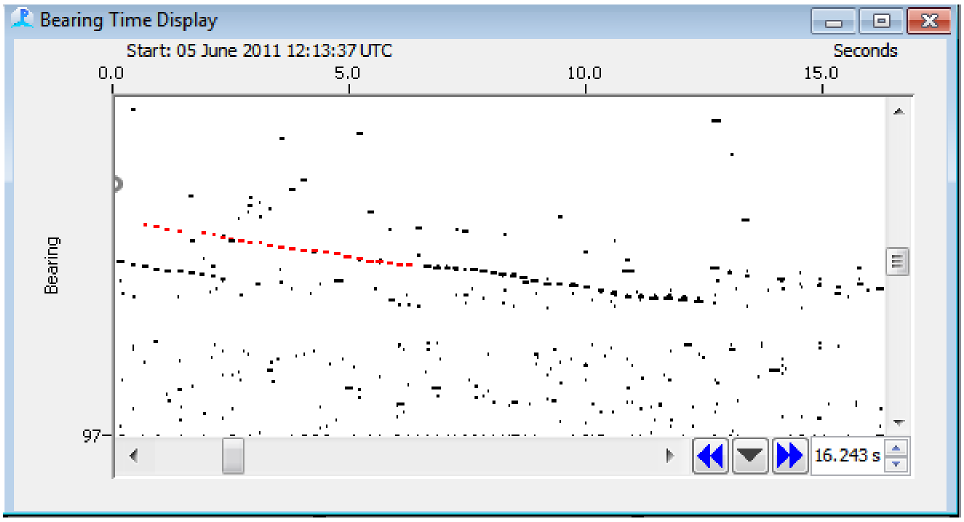

Figure 8-4 Time-bearing plot of sperm whale acoustic detections in PAMGuard software
Time is on the x-axis, bearing (relative to the ship) is on the y-axis. Dark black dots and red dots indicate sperm whale echolocation clicks. The tracks of two individuals can clearly be seen in this display. Small scattered dots are noise.

Several analyses are being conducted to develop abundance estimates using acoustic data. The first analysis treats the acoustic data as traditional line-transect data, with distances to localized sperm whales treated as true perpendicular distances. This is the most typical approach for these species using towed array data, which has been applied in other studies. However, due to the nature of 2-D localization using towed hydrophone array data, the perpendicular distances are more accurately considered as slant ranges. For deep-diving species, the use of slant ranges can bias density estimates. Given the typical detection ranges for sperm whales, the depth of the animal may have little effect on abundance estimation (Barlow and Taylor 2005). However, it may be more appropriate to treat the acoustic data for deep divers as point transect data, which properly accounts for the use of slant ranges. This work is continuing under AMAPPS II, and abundance estimates produced by both methods will be compared. Finally, work is also being initiated as part of AMAPPS II to integrate visual and acoustic detections to generate combined abundance estimations, which should be more accurate than either platform individually.

8.2.3 Distribution of Passive Acoustic Detections of Beaked Whales

Passive acoustic data were used to improve information on beaked whale occurrence and distribution. Like sperm whales, beaked whales undertake long, deep foraging dives. This behavior, combined with their generally cryptic behavior at the surface, makes them challenging to reliably detect via visual surveys. Visual detection rates of beaked whales are highly dependent on sea state conditions, with sighting rates decreasing substantially as sea state deteriorates (Barlow et al. 2006). Furthermore, developing a better understanding of the distribution and occurrence of beaked whales is needed for effective management and mitigation from anthropogenic activities, as these species have been shown to be sensitive to a variety of anthropogenic disturbances. Thus, to provide additional information on the distribution of beaked whales byond that determined by the visual surveys, the passive acoustic data were investigated.

Acoustic data were post-processed using the software package PAMGuard (Gillespie et al. 2009), using a two-step procedure. The PAMGuard click detector was run over all sound files (pre-filter: 16-90 kHz; trigger filter: 20-90 kHz; and threshold 13 dB); click detection data were then analyzed to identify putative beaked whale events. Clicks were clustered into click trains if the inter-click-interval (ICI) was between 0.2 – 0.6 s, as described for several species of beaked whales (Johnson et al. 2004; Zimmer et al. 2005; Johnson et al. 2006) and were in relatively the same bearing. Events were assigned to one of three categories, which were conservative by definition so as to minimize the chance of misassignment: 1) definite beaked whale (BEAK), in which an event had 10+ clicks with a consistent ICI and at least five of those clicks containing upsweeps, 2) probable beaked whale (PRBK), in which an event had more than five clicks with either a consistent or inconsistent ICI and at least three of the clicks containing upsweeps, or 3) possible beaked whale (POBK), where an event had 1 – 5 clicks with a consistent ICI and all of the clicks in the event containing upsweeps.

Data were analyzed from four surveys (Table 8.2): NEFSC summer 2013 AMAPPS abundance survey (HB13-03), the SEFSC summer 2013 AMAPPS abundance survey (GU13-03), the NEFSC spring 2014 abundance survey (GU14-02), and a dedicated beaked whale survey in the summer of 2014 (HB14-03). Occasionally, periods of acoustic data could not be analyzed for beaked whale presence due to interfering noise. This occurred primarily when very vocal schools of dolphins persisted near the ship, masking other acoustic signals. These data segments comprised 0.5% – 8% of the data analyzed, depending on the survey.

Table 8-2 AMAPPS datasets reviewed for presence of beaked whales

Cruise	Number of Days Surveyed Acoustically	Hours of Data Collected	Hours That Could Not Be Analyzed
HB13-03	33	316.25	1.81
GU13-03*	27	411.43	6.08
GU14-02	16	136.66	11.96
HB14-03	4	45.77	1.41

* only 27 days were currently analyzed due to time constraints

Beaked whales were detected in all surveys analyzed, with the highest detection rates during the NEFSC HB13-03 abundance survey, with 125 definite beaked whale events, and over 70 probable and possible events combined (Table 8.3). The fewest beaked whales were detected in the GU14-02 abundance survey, with no definitive beaked whale events. Events were classified into one of three beaked whale species categories: Cuvier's, Gervais'/True's, and

Blainville's. Although there are no published records of True's beaked whale vocalizations, encounters during later NEFSC surveys suggest that their click characteristics may be similar to Gervais'. Detailed analyses are pending. When possible, individual animals were tracked and localized, so that perpendicular slant ranges from the ship could be obtained and used for future abundance analyses once corrected. Maps showing survey track lines and positions of beaked whale detection events are shown in Figure 8.5.

Table 8-3 Summary of beaked whale acoustic detection events in four shipboard surveys Parentheses indicate the number of events that were localized.

	Definite	**Probable**	**Possible**
HB13-03 Total	125 (103)	32 (23)	39 (8)
Cuvier's	71 (58)	26 (19)	28 (6)
Gervais'/True's	54 (45)	6 (4)	11 (2)
GG13-03* Total	7 (3)	8 (1)	2 (0)
Cuvier's	5 (1)	8 (1)	2 (0)
Gervais'/True's	0 (0)	0 (0)	0 (0)
Blainville's	2 (1)	0 (0)	0 (0)
GG14-02 Total	0 (0)	2 (1)	1 (0)
Cuvier's	0 (0)	1 (0)	1 (0)
Gervais'/True's	0 (0)	1 (1)	0 (0)
HB14-03 Total	6 (4)	7 (4)	10 (0)
Cuvier's	4 (3)	5 (2)	8 (0)
Gervais'/True's	2 (1)	2 (2)	2 (0)

*numbers reported are only for the 27 days analyzed

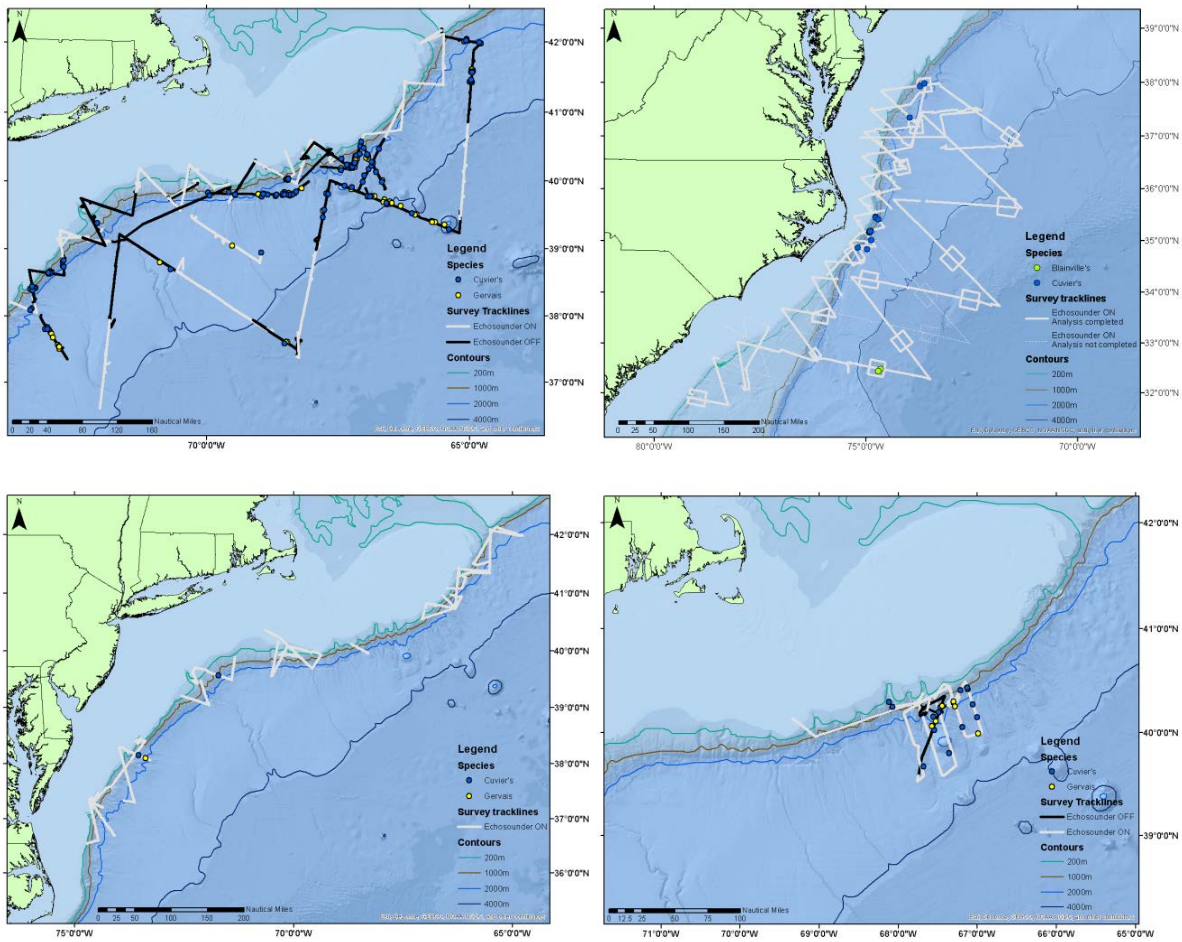

Figure 8-5 Survey tracklines and locations of beaked whale acoustic detections
Top left: HB13-03; Top right: GU13-03; Bottom left: GU14-02; Bottom right: HB14-03. Blue dots indicate Cuvier's beaked whales, yellow dots indicate Blainville's (for GU13-03) or Gervais'/Trues' (for all other surveys). Gray lines track lines are those in which shipboard echosounders were active; black track lines are those in which echosounders were not active.

8.2.4 Effect of Echosounders on Detection Rates

Passive acoustic data were used to investigate the effects of shipboard echosounder use on beaked whale detection rates. Beaked whales are known to be sensitive to a variety of anthropogenic sounds. Behavioral responses have been documented in conjunction with naval activities utilizing mid-frequency active sonar, sometimes resulting in strandings and/or death of the animals (Frantzis 1998; Cox et al. 2006). Foraging behavior of Blainville's beaked whales have been documented to respond to intense broadband vessel-generated noises (Pirotta et al. 2012). This study found that the duration of foraging bouts were not significantly different but there was a significant change in the beaked whale's behavior up to at least 5.2 kilometers away from the vessel. The authors suggested that the observed changes could potentially correspond to a restriction in the movement of groups, a period of more directional travel, a reduction in the number of individuals clicking within the group, or a response to changes in prey movement. Another study conducted in the Pacific Ocean found that the use of acoustic pingers on gillnets completely eliminated bycatch of beaked whale species, suggesting that they can detect and avoid those signals (Carretta et al. 2008). In addition, other species have been documented to respond to echosounders. For example, Quick et al. (2016) showed a consistent increase in heading variance of short-finned pilot whales (another deep diving cetacean) during exposure to an EK60 echosounder. The authors suggested that, regardless of behavioral state, the short-finned pilot whales changed their heading more frequently when the echosounder was active, where this response could represent increased vigilance in which whales maintained awareness of echosounder location by increasing their heading variance. To investigate the potential effects of the ship's echosounder, the visual and acoustic detection rates were investigated.

In 2011 and 2013, the NEFSC undertook a controlled experiment during AMAPPS surveys on the NOAA ship *Henry B. Bigelow* to determine whether the use of shipboard EK60 echosounders affects visual or acoustic detection rates of beaked whales. Every other survey day during daylight hours, across both surveys, echosounders were alternated between active mode (transmitted signals) and passive mode (recording data but do not transmitting). The EK60 echosounder system consists of five split-beam transducers operating at 18, 38, 70, 120, and 200 kHz which transmit from a location 6 – 9 m below the surface when in active mode.

Data analysis included 63 days of visual data from the 2011 and 2013 surveys combined, and 35 days with acoustic data from 2013 (Table 8.4). Statistical analyses included a regression analysis using generalized linear models, conducted using the software package R (R Core Development Team 2010). Covariates included echosounder state, habitat type (slope/abyssal), median daily sea state (low: 0 – 2, high: 3 – 5), and survey leg, while year was also included in the visual model.

Table 8-4 Summary of beaked whale detections relative to echosounder state
From the NEFSC 2011 and 2013 AMAPPS abundance surveys

	EK60 on	**EK60 off**	**Total**
Number of groups visually sighted (2011)	39	42	81
Number of groups visually sighted (2013)	61	114	175
TOTAL	100	156	256
All acoustic beaked whale events (2013)	7	176	183
Acoustic BEAK-only events (2013)	4	114	118

Visual detections were primarily predicted by sea state ($p=2.106 \times 10^{-5}$), though 73% of the survey effort was conducted in high sea states. Echosounder state was not significant at the 95% level (p=0.06). For acoustic detections, echosounder state (passive or active) was the most significant predictor ($p_{BEAK} = 1.475 \times 10^{-5}$); survey leg was also significant at the 95% level ($p_{BEAK} = 0.0177$). Due to small sample size of definite beaked whale events when the echosounders were active, the duration of these events could not be statistically tested, although it appeared to be shorter on days when echosounders were active (mean duration when active = 49 s versus when passive = 172 s). In accordance with the observation of shorter durations, the change in received click bearings of the definite beaked whale events over the course of a detection was smaller when the echosounders were active (average change in bearing while active = 12° versus when passive = 114°). These results suggest that beaked whales are detecting and responding to the presence of echosounders, though the mechanism of response is as-yet unknown. A manuscript documenting the results of these analyses has been submitted to a journal (Cholewiak et al. in review).

8.2.5 3-D Localization of Beaked Whales

Passive acoustic data were used to derive 3-D localizations of beaked whales. For deep-diving species such as sperm whales and beaked whales, standard two-dimensional localization techniques can lead to an overestimation of the distance between the animal and the trackline, as slant range may be confounded with horizontal range (Barlow and Taylor 2005). This introduces errors in density and abundance estimation, resulting from a biased detection function. Dive depth data have traditionally been collected using time-depth recording tags; however, the use of towed array data allows for the estimation of dive depths from a greater sample of individuals.

Towed hydrophone array data from the NEFSC 2013 abundance survey were also analyzed to obtain dive depths of beaked whales, using multi-path arrivals of surface-reflected echoes. Detections of beaked whale clicks were localized in 2-D using the software package PAMGuard, with the Target Motion Analysis module. Multipath arrivals were identified and corresponding time delays were measured using custom-written MATLAB (Mathworks, Inc.) scripts. A total of 39 detections comprising of Cuvier's and Gervais'/True's beaked whales were localized in 2-D and contained multipath arrivals to determine their depth. Cuvier's on average were detected at 1158 m (weighted standard deviation = 287 m) and Gervais'/True's at 870 m (weighted standard deviation = 151 m). A manuscript documenting the results of these analyses has been published (DeAngelis et al. 2017).

8.2.6 First Acoustic Characterization of Sowerby's Beaked Whales

Prior to our work, there was only one descriptive record of the diving behavior of Sowerby's beaked whales in the wild (Hooker and Baird 1999). To date, little is known about the life history patterns and social structure for most beaked whales, but recent studies have started to reveal information about their acoustic behavior, critical for passive acoustic monitoring. During the NEFSC AMAPPS 2011 survey, the NOAA ship *Henry B. Bigelow* encountered several small groups of Sowerby's beaked whales off the continental shelf of the eastern United States, near Georges Bank. Over half an hour, at least three groups of animals were sighted, distributed over several kilometers. Several animals crossed the track line, approximately 300 m from the ship. Thirty minutes of continuous acoustic data encompassing and following the period of the visual encounter were subsequently analyzed. Data were manually reviewed using PAMGuard and echolocation trains were identified for further analysis. Data were then post-processed using custom-built MATLAB routines. Individual echolocation clicks and 1000 points of noise before each click were digitally filtered with a 10-pole Butterworth band-pass filter between 3 kHz and 95 kHz. Spectra of each detected click were calculated and the following variables measured: peak frequency, center frequency, -3 dB and -10 dB bandwidths, and duration. The root-mean-square level of each click and its preceding noise were used to calculate signal-to-noise ratios. Inter-click intervals were also calculated using the time between the start of one click and the previous click.

A total of 2969 clicks were used in the final analyses. Spectral analyses revealed a distribution of four subsets of clicks based on their peak frequencies (Figure 8.6). For further details on the analyses and results, readers are referred to Cholewiak et al. (2013).

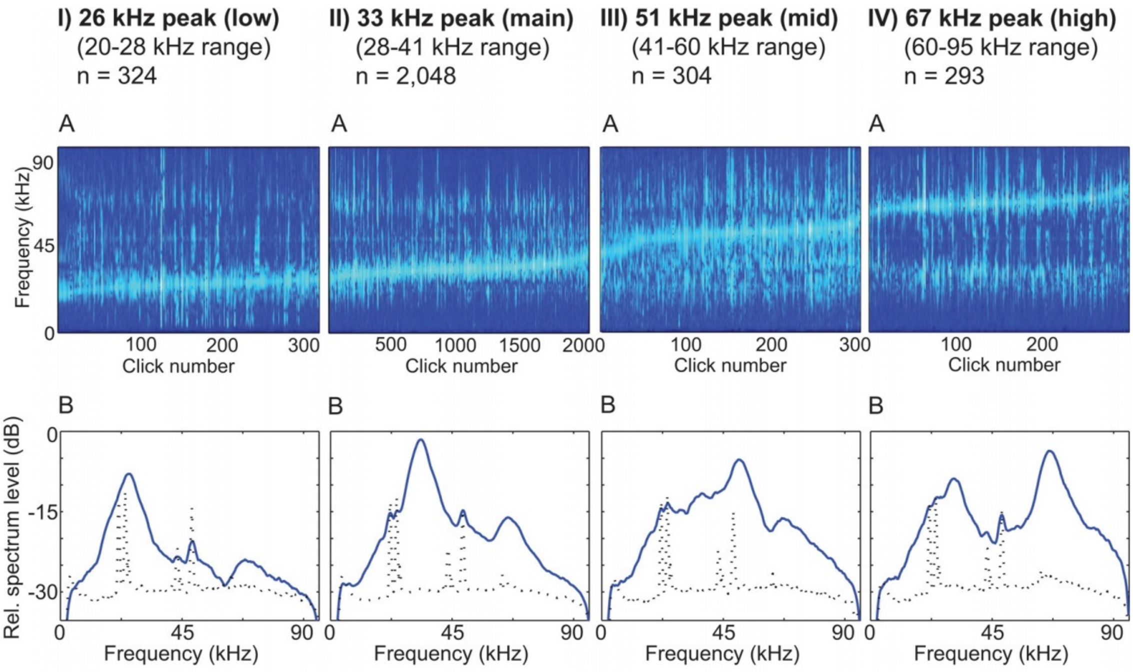

Figure 8-6 Examples of concatenated echolocation clicks
for each category (top panel) and mean spectra (bottom panel) for clicks (solid line) and noise (dashed line). Adapted from Figure 3 in Cholewiak et al. 2013.

8.2.7 Geographic Variation in Risso's Dolphin Echolocation

Passive acoustic monitoring for density and abundance estimation using towed arrays is particularly successful for acoustically-active deep-diving species with a known visual detection bias (e.g., low *g(0)*) and call types that are identified to species. Methods have been most successful for sperm whales and beaked whales, but may also be applicable to other species such as Risso's dolphins. Additionally, autonomous fixed sensors can be deployed to evaluate spatial-temporal trends in odonotocete occurrence when call types are distinctive. A limitation to these methods has been the ability to assign call types to delphinid species, and the NEFSC and SEFSC are actively collaborating with universities and independent researchers to develop whistle and click classifiers from high-quality visually-verified delphinid recordings. Risso's dolphins are one delphinid species for which click classification is particularly promising; with species-specific clicks having been identified for dolphins inhabiting the Southern California Bight (Soldevilla et al. 2008; Figure 8.7). From the AMAPPS Risso's dolphin clicks there appears to be geographic variability in spectral content, and so we are evaluating the extent of geographic variability in light of development of location-specific classifiers and hypothetical population boundaries.

Preliminary results from the AMAPPS passive acoustic research indicate that there may be differentiation between Risso's populations in southeast US waters and the Gulf of Mexico, based on differences in their echolocation click characteristics. However, geographic variation between northeast US and southeast US is more difficult to interpret, and results suggest further investigation may be warranted.

These results will be applied when developing click classifiers and in evaluating spatial-temporal trends in occurrence for autonomous HARPs (high-frequency acoustic recording package) that are being deployed along the western Atlantic shelf-break. Additionally, classified Risso's dolphin clicks may be used to develop methods for density estimation of delphinids from towed array survey data. For further details, readers are referred to Soldevilla et al. (2017).

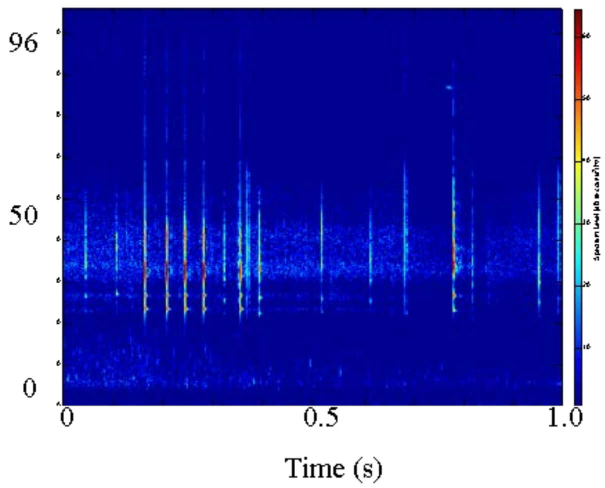

Figure 8-7 Spectrogram example of Risso's dolphin echolocation clicks

8.2.8 Contribution to Atlantic Delphinid Classifier Development

The ability to correctly assign acoustic detections to species is critical for fully maturing a passive acoustic monitoring strategy. To date, the ability to acoustically distinguish delphinid species in the absence of corresponding visual detections has been lacking for most species. However, efforts towards acoustic classification have been underway by a number of researchers, and AMAPPS acoustic data have been contributed towards these efforts. An algorithm for classifying delphinid whistles to species called the Real-time Odontocete Call Classification Algorithm (ROCCA) has been developed by Dr. Julie Oswald (Biowaves). Twenty-eight encounters from the AMAPPS 2011 shipboard survey data were extracted to provide over 1200 whistles to Dr. Oswald for development of an Atlantic species-specific version of ROCCA. The first Atlantic version of ROCCA was completed and implemented into the software platform PAMGuard in 2013. This version included automated whistle classifiers for five species (pilot whales, common bottlenose dolphins, common dolphins, Atlantic spotted dolphins, and striped dolphins). NEFSC tested the performance of ROCCA using data collected during the AMAPPS 2013 shipboard surveys. Specific criteria were applied to select appropriate encounters for acoustic analyses (including: distance from vessel, distance to other groups, visual sighting conditions, etc.). Twenty-four separate encounters met these criteria. Results were used to improve a subsequent version of ROCCA, which is now being expanded to include both whistles and echolocation clicks. Classifier development is ongoing and the AMAPPS data will continue to contribute to its development.

8.3 Archival Recorder Projects

In 2014 – 2015, the NEFSC deployed multiple bottom-mounted recorders along the northern shelf break region (north of Hudson Canyon), 10 MARUs and 1 AMAR. While neither of these projects were funded by AMAPPS, the recorder deployments and/or recoveries were conducted during AMAPPS surveys; therefore, summary data from these projects are included here.

In 2013, five archival MARUs were deployed during the NEFSC North Atlantic right whale survey in May, in the region of the Great South Channel and the shelf break edge of Georges Bank (Figure 8.8). MARU placement was designed to overlap with planned AMAPPS 2013 shipboard survey lines, to facilitate retrieval later in the summer. MARUs recorded continuously at a sampling rate of 2 kHz, with the goal of assessing baleen whale presence in shelf break waters during the summer months. Four of the five MARUs were retrieved in August during the AMAPPS survey; the last unit at site 5 was not found.

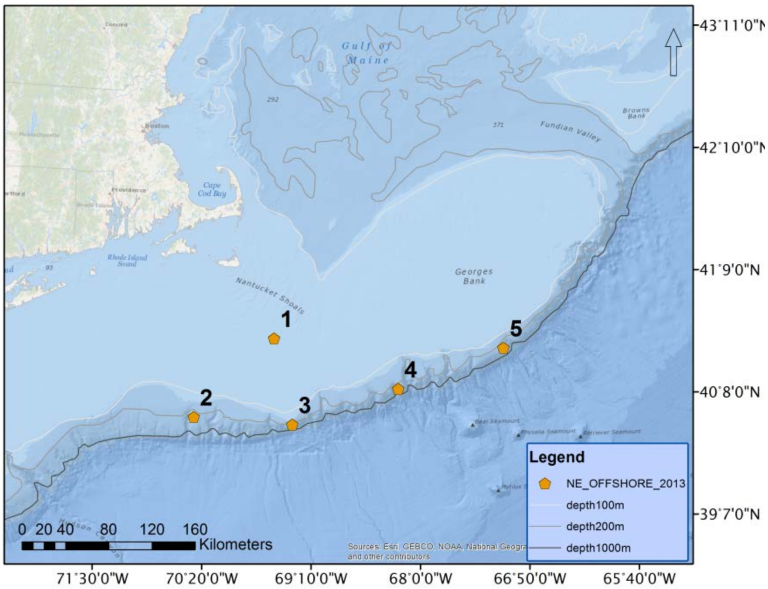

Figure 8-8 Sites of five MARU deployments from May – August 2013

Upon retrieval of the units, data were extracted and post-processed. The Low-Frequency Detection and Classification System (LFDCS; Baumgartner and Mussoline 2011) was run over the entire dataset for each unit. The detector conditioned a spectrogram, drew contour lines ("pitch-tracks") through high energy sounds, and classified these pitch-tracks based on a call library for target species. The detector output was also manually screened to verify true pitch-track classifications.

To date, these data have been analyzed for daily presence of North Atlantic right whales, sei whales, and fin whales. North Atlantic right whale daily presence was determined by three or more correct up-call detections, while 1 – 2 correct detections were considered sufficient for determining daily presence of the other species.

North Atlantic right whales were detected at all four sites, but predominantly at Site 2. They were detected on 41 days overall, with 26 days at Site 2, 10 days at Site 1, 3 days at Site 3, and 2 days at Site 4 (Figure 8.9). Sei whales were the predominant species detected, with an overall total of 203 detection days across all sites. They were detected on at least one recorder in all weeks except for the final week of July 30th. Detections were fairly evenly distributed among Site 1 (60 days), Site 2 (50 days) and Site 4 (55 days), though there were detected on 38 days at Site 3. The number of sei whale calls per day ranged from 0 to a maximum of 426, with an average number of calls per day ranging from 6.5 (site 3) to 63.3 (site 2). Fin whales were rarely acoustically detected, only 6 days across sites overall. These were distributed among Site 1 (4 days) and Site 4 (2 days). Further analyses for additional species are forthcoming.

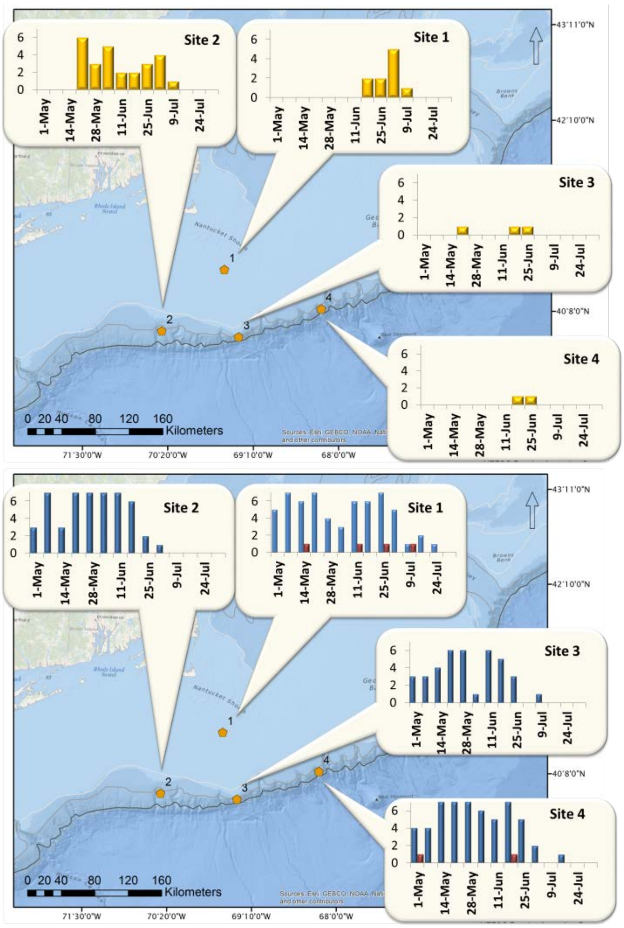

Figure 8-9 Number of days per week with detections by site
Top panel: North Atlantic right whales. Bottom panel: Sei whale (blue) and fin whale (red) detections.

In 2014, ten MARUs were deployed along the shelf break from the northern region of Georges Bank to Hudson Canyon, during the NEFSC AMAPPS shipboard survey in April. Bottom depths ranged from 300 – 432 m, except for Site 1, which was 47 m. The units were programmed to record continuously at a sampling rate of 2 kHz. Nine units were successfully recovered in September 2014 (all but Site 9); of these, eight recorded for the entire deployment period, while one unit failed several weeks after the initial deployment. In addition, one AMAR was deployed off Georges Bank and recorded data from July 2014 – May 2015. This unit recorded on a duty cycle, sampling both at 250 kHz (340 s / 30 min) and 16 kHz (160 s / 30 min; Figure 8.10).

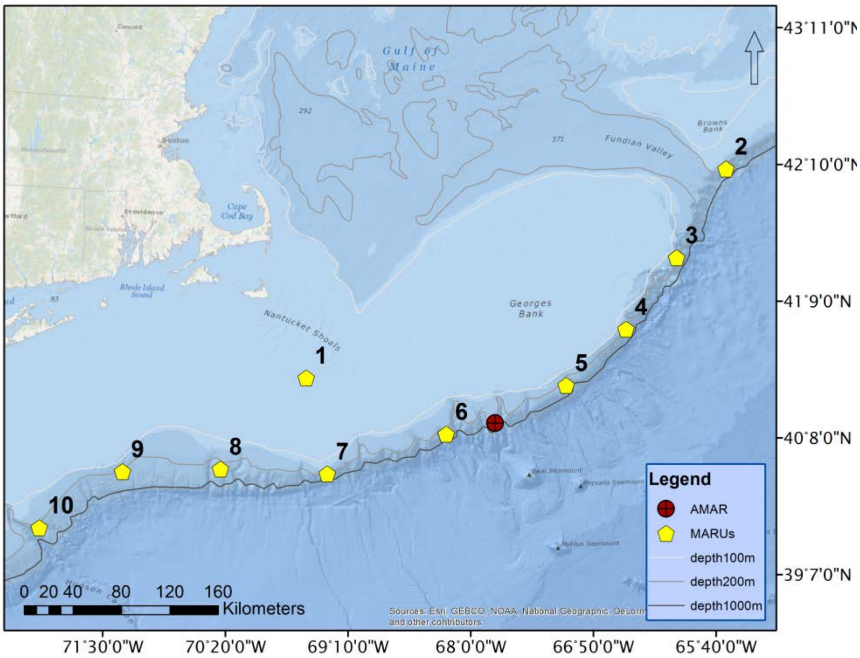

Figure 8-10 Sites of MARU (yellow pentagons) and AMAR (red circle) deployed in 2014

Upon retrieval of the units, data were extracted and post-processed. As with the 2013 dataset, the LFDCS was run over the entire dataset for each unit. North Atlantic right whales were scarcely detected, for a total of 29 detection days across all sites. MARU Sites 1, 4, and 7 had no North Atlantic right whale detections. Sites 2 and 10 had detections on 10 days each; the remaining four sites had detections on 5 days or less. The AMAR had zero days with confirmed North Atlantic right whale detections. Five days had possible detections, but calls were faint and could have been confused with humpback whales. Analyses are ongoing to extract detections of additional species from these sites, including baleen whales.

Site 6 was also manually reviewed for the presence of sperm whales. Across the entire deployment period (n=136 days), sperm whales were detected on 74 days across 6 months (Table 8-5). Note that the unit was deployed on April 26th and recovered on September 9th, so there were few days with available data in those two months. Further analyses may be conducted, pending funding.

Table 8-5 Numbers of days per month with sperm whale detections on Site 6

Month (Number of days)	Number of Days with Sperm Whale Detections
April (5)	1
May (31)	24
June (30)	15
July (31)	18
August (31)	12
September (9)	4

In addition, the AMAR data were analyzed for the presence of odontocetes, where these data contributed to a broader-scale analysis of beaked whale occurrence in the western North Atlantic derived from bottom-mounted recorder data. Analyses to date have included identification of all beaked whale events, using a multi-step approach utilizing custom-written MATLAB routines to identify and extract click events, and the software program Triton (Scripps Institution of Oceanography) to review all events. A manuscript is currently in review by the lead author, and includes full details on the analysis regime (J. Stanistreet et al. in review: Using passive acoustic monitoring to document the distribution of beaked whale species in the western North Atlantic Ocean).

Beaked whales were detected on a total of 80 of the 304 deployment days. This includes 48 days with Sowerby's beaked whale detections, 38 days with Cuvier's beaked whale detections, and one day with Gervais' beaked whale detections. More than one species was detected on 7 days, and in one instance both Sowerby's and Gervais' beaked whales were detected in the same acoustic file. Detections covered all 11 months of the deployment period, though the seasonal patterns varied between Cuvier's and Sowerby's events (Figure 8-11). Due to the low duty cycle of this recorder (~19%), detections of these species are likely highly underrepresented.

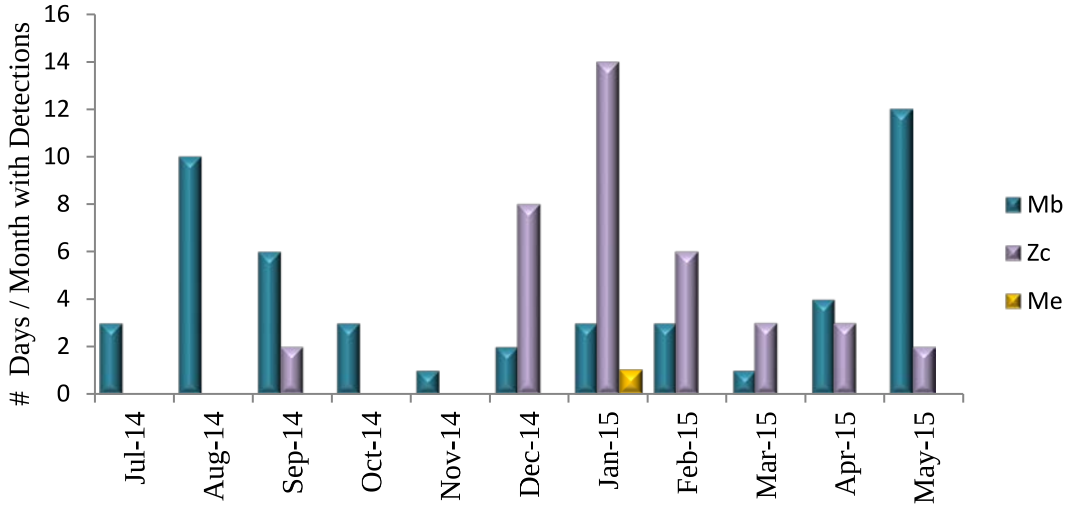

Figure 8-11 Numbers of days per month with detections of beaked whales
Sowerby's beaked whale (Mb), Cuvier's beaked whale (Zc) and Gervais' beaked whale (Me), recorded on an AMAR deployed on Georges Bank shelf break. Note that the Me category may also include True's beaked whale (Mm), as those species were not distinguished in this analysis.

Collectively, these bottom-mounted recorder data are providing insights into the seasonality and distribution of a number of species, in waters that are difficult and/or expensive to access frequently via visual survey platforms. Ultimately, these data will inform the visual-based habitat density modeling efforts, and an initial comparison against the seasonal predictions from those models is discussed under 5.4.4.3.

The analyses of occurrence of North Atlantic right whales and other baleen whales form components of a larger analysis of historic baleen whale migration patterns along the entire eastern seaboard, from 2004 – 2014. That effort, currently ongoing and funded entirely separately from AMAPPS, includes archival data from a number of collaborators.

Starting in 2015, a coherent, large-scale study of baleen whale migratory routes along the eastern seaboard was funded in part by AMAPPS II. This project builds on the existing analysis of historic data, to describe the current migratory timing and pathway of baleen whales along the eastern seaboard, and to assess changes in movement patterns of animals compared to the past 10 years. Five lines of MARUs are distributed between Nantucket, MA and Brunswick, GA (Figure 8-12). Each line is comprised of 5 – 7 MARUs, programmed to record continuously at a sampling rate of 2 kHz for up to 6 months. Initial results from the first deployment of these recorders are included in the online AMAPPS 2016 Annual Report.

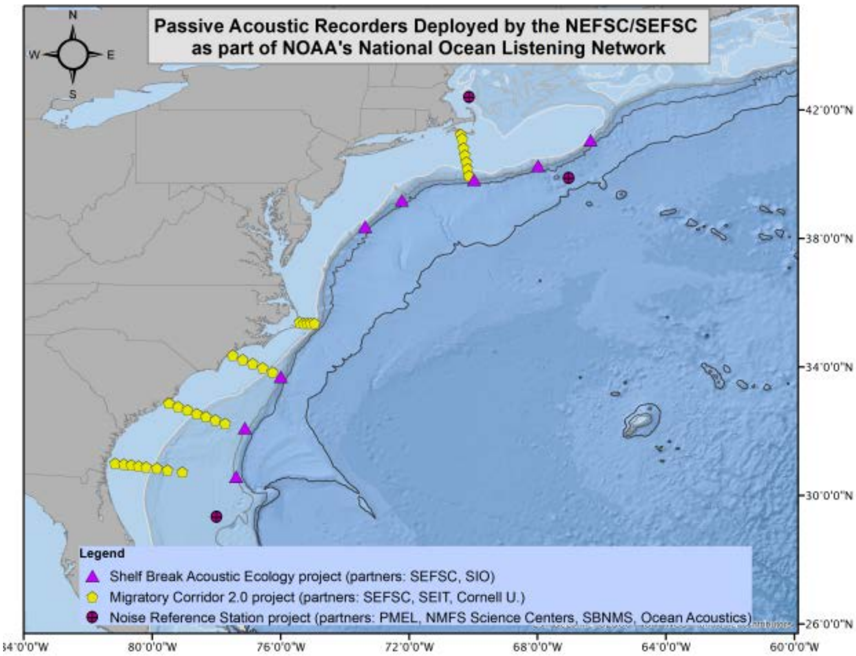

Figure 8-12 Sites of MARU deployments in the Migratory Corridor 2.0 project
Are in yellow (partial funded by AMAPPS II). Additional recorder sites include 8 HARPs deployed under the Shelf Break Acoustic Ecology project, and 2 NOAA Pacific Marine Environmental Laboratory low-frequency (10-2500Hz) passive acoustic recorders under the Noise Reference Station project that are part of the NOAA-wide acoustic monitoring network.

8.4 Discussion

It is important to keep in mind that presence of species as determined by passive acoustic data only indicates presence of vocalizing animals; non-vocalizing animals are of course not detected by these platforms. To fully utilize the passive acoustic data, the vocalizations need to be properly interpreted. For example, for fin whales the signals that are typically used for passive acoustic monitoring are male song patterns. As breeding is seasonal, song occurrence varies seasonally as well; therefore, the low number of fin whale acoustic detections underrepresent the actual occurrence of this species. As another example, sei whale vocalization patterns are also poorly understood as only one call type is currently used for acoustic monitoring, and it is unknown whether this call is produced by both sexes. Consequently, the current distribution patterns for these two species when derived from passive acoustic data are potentially negatively biased since only a portion of the vocalizing animals has been recognized.

Conversely, the acoustic signals that are used for detection of North Atlantic right whales are considered to be “contact calls”, produced by both sexes in a variety of circumstances and throughout the year. For odontocetes, acoustic detections are often based on foraging signals, such as echolocation clicks (as is the case with sperm and beaked whales). Unlike many baleen whales, these species do not fast seasonally; therefore, foraging clicks should provide a reliable year-round acoustic signal. Consequently, the current distribution patterns for these species when derived from passive acoustic data are unbiased if contact calls and foraging are conducted consistently in space and time.

8.4.1 Significant Findings

The work presented in this chapter represent many different components of a larger effort to better document the occurrence and distribution of cetacean populations in the western North Atlantic using passive acoustics. As such, many of these efforts are ongoing, and will continue throughout the AMAPPS II project period. Some of the significant contributions from these data during the first stage of AMAPPS are discussed below.

1. The development and implementation of a reliable towed hydrophone array program to simultaneously collect passive acoustic data with visual data during shipboard surveys. While the development and construction of the current towed hydrophone array systems was conducted external to AMAPPS, the ability to collect standardized passive acoustic data across the NEFSC and SEFSC is an important step towards utilizing these data to address management goals.
2. The first acoustic abundance estimates for sperm whales in the western North Atlantic are being calculated. These methods have been applied in few studies to date, but holds great potential for improving our understanding of sperm whale distribution. Current work is ongoing and it is expected these analyses will be finalized shortly. In addition, simultaneous efforts are being made to integrate the passive acoustic data into the visual abundance estimates during AMAPPS II (see Future Research below).
3. Substantial improvements have been made in our understanding of beaked whale distribution. Data collected during AMAPPS have facilitated the acoustic identification of previously-undocumented Sowerby’s beaked whales; have described the acoustic occurrence of multiple species of beaked whales and the effects that echosounders have on our ability to detect them during shipboard surveys; have implemented techniques for 3-D localization of beaked whales, an important component of abundance estimation and contributor to understanding diving ecology; have described the year-round occurrence of two species at a single site near the canyons of Georges Bank, near what is now the new Northeast Canyons and Seamounts Marine National Monument. Collectively, all of these steps are contributing to a better understanding of beaked whales along the eastern seaboard.
4. Improvements were made in our ability to assign passive acoustic data to species, and to document the geographic variation in acoustic characteristics of Risso’s dolphins.
5. Large whale occurrence were documented along the continental shelf break using bottom-mounted archival recorders, in regions that are difficult to continuously systematically survey using shipboard or aerial platforms. While these analyses are ongoing, they are already helping to refine our understanding of North Atlantic right whale habitat use, the extensive occurrence of sei whales along the shelf break region south of the Great South Channel, and the persistence of sperm whales over a six-month period off Georges Bank. These analyses are ongoing, and as they are completed they will contribute to a more complete picture of large whale occurrence along the New England shelf break region.

8.4.2 Data Gaps and Future Research

While there have been significant advancements in the collection, analysis and interpretation of passive acoustic data during AMAPPS I, substantial data gaps still exist and additional research is needed. Some of these data gaps will be addressed during AMAPPS II; others will require longer-term studies.

1. Further work is needed in the integration of passive acoustic and visual data to produce more accurate abundance estimates of deep diving animals. The field of ecological statistics has now matured to the point where integration of these types of data is becoming possible for multiple species. The greatest promise currently exists for odontocetes, particularly species such as sperm whales and beaked whales. Both of these taxa are often difficult to detect visually due to their long dive times, yet they are reliably detected acoustically while conducting foraging dives. Efforts to effectively combine towed hydrophone array data and visual sightings data for these taxa are being undertaken during AMAPPS II.
2. Better understanding of the acoustic repertoire and vocal behavior is needed to fully utilize and interpret the passive acoustic data. This is particularly true for several large whale species, such as fin and sei whales. To address these uncertainties and properly interpret the passive acoustic datasets, dedicated studies need to be undertaken to document the acoustic ecology of these species.
3. Better understanding of the offshore distribution and seasonal movements of cetaceans is needed to fully understand the movements and migration patterns of species that utilize these offshore waters. This can be facilitated by further efforts to deploy archival passive acoustic systems in deep waters. Currently, the entirety of our understanding of the offshore distribution of cetaceans comes from relatively infrequent shipboard surveys, which are typically conducted in these regions only during the summer. Our understanding of the movements and migratory patterns of several species is hindered by our lack of data beyond the shelf break, which contributes to an incomplete understanding of stock structure and population size. Long-term passive acoustic data collection in the offshore regions can help to fill these gaps, but resources to conduct such studies are limited.

8.5 Acknowledgements

The work highlighted in this chapter would not have been possible without extensive additional contributions in both time and funds. For contributions to data collection and/or analyses, we'd like to thank Julie Cossavella, Julianne Gurnee, Samara Haver, Holger Klink, Eric Matzen, Joy Stanistreet, Robert Valtierria, the Cornell University Bioacoustics Program, and the crews of the NOAA ships *Henry B. Bigelow* and *Gordon Gunter*. Shannon Rankin and Jay Barlow conducted the towed hydrophone workshop, which allowed for standardization of array hardware across the Science Centers. Funding for this workshop was received from the Applied Science and Technology Working Group (ASTWG) program. Additional funding for data collection and analyses was received from NOAA and the Navy's N45 and LMR programs.

9 Marine Turtle Tagging Research

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9.1 Introduction

The turtle tagging program within the AMAPPS I program has focused the first five years to data collection primarily on loggerhead sea turtles, though utilizing leatherback turtle tag data were also investigated. We selected loggerhead sea turtles to focus on because of their abundance, distribution, and management concerns throughout the US Atlantic coast. Our primary motivation was to obtain loggerhead behavioral information which can be analyzed during AMAPPS II. Here we list a summary of the information collected in AMAPPS I. In AMAPPS II we intend to analyze the data collected during AMAPPS I and also expand data collection to more northern waters as well as other turtle species.

As described in Chapters 5 and 6, line transect aerial surveys conducted for protected species result in estimates of abundance of animals at the surface. These surface estimates can be corrected for availability bias, which is bias due to missing animals because they were below the surface and thus not available to be detected (Marsh and Sinclair 1989; Thomson et al. 2012; Thomson et al. 2013; Innes et al. 2014; Fuentes et al. 2015). Availability bias was discussed for the cetaceans in Chapter 5. However, to account for availability of sea turtles, more dive time information was needed. A preliminary loggerhead abundance estimate using dive time and visual aerial line transect data collected in 2010 is presented in a report by the Northeast and Southeast Fisheries Science Centers (2011). Thus, a major effort was undertaken to tag loggerhead turtles to collect data to better understand their availability bias and produce more precise abundance estimates.

Because of their thermoregulatory behavior, sea turtles may represent the complicated end of the spectrum when it comes to estimating availability to visual observers. Like other ectothermic reptiles, hard-shelled sea turtles rely on external heat sources to maintain their internal body temperature (Pough 1980). Turtles can produce heat through metabolism (Sato et al. 1995) and retain some of it with large body mass (Sato 2014) and changes in blood flow patterns (Hochscheid et al. 2002). However, they generally modify their behavior in relation to environmental conditions to maintain their body temperature within narrow physiological limits. Many factors, including sea surface temperature, thermocline conditions, migratory cues, prey availability, and anaerobic activity (Hochscheid et al. 2010) may play a role in determining surface patterns.

Reptilian basking (laying nearly still at the surface for periods of time) is related to environmental conditions in the air and in the water, as well as the physical and physiological characteristics of the turtle (Spotila and Standora 1985). Above the water, the light intensity, angle of incidence, wind, and air temperature all influence the amount of heat available to basking animals, though the most important factor is likely cloudiness (Boyer 1965). When loggerheads bask in the sun, they can raise body temperatures about 3.8° C above the water temperature (Spotila and Standora 1985). When it is overcast, basking at the surface does not warm body temperature beyond that of the surrounding water (Sapsford and Van der Riet

1979). Even passing, isolated clouds can prevent turtles from absorbing heat from the sun (Boyer 1965). Basking is also related to thresholds in water temperature as well as the relationships between water temperature, air temperature, and the body temperature of the turtle (Boyer 1965). For example, a turtle is not likely to bask in the sun if the water temperature or its own temperature is sub-optimal. These multi-faceted forcing functions add to the complexity of understanding sea turtle basking as one of the primary components of sea turtle availability to visual observers.

Because of the complex nature of sea turtle surface behavior, the results of observational studies can be site-specific, ambiguous, and highly variable. Green and loggerhead turtles in Western Australia (Thomson et al. 2012) have availability correction factors that are highly heterogeneous, with larger corrections in colder, deeper waters. However, there was no significant correlation between sea temperature and time spent near the surface for a pooled dataset from green turtles at multiple locations (Fuentes et al. 2015). Similarly, a study classifying basking as extended surface times exceeding 10 minutes was unable to describe any general temporal or spatial pattern because of the variability in individual turtle behavior (Hochscheid et al. 2010). These diverse findings highlight the need for behavioral data from the spatial and temporal areas of interest.

Much of our effort under AMAPPS I has been to collect data to increase our understanding of site-specific sea turtle behaviors relative to local ecological processes. We hope these data can help explain and possibly forecast seasonal and spatial variability in sea turtle surface/basking times, which may lead to improved correction factors for availability bias, population assessments at regional scales, and development of tools to translate survey data into seasonal, spatially-explicit density estimates incorporating habitat characteristics. In addition to providing the basis to translate sea turtle surface density estimates to a water column density, the field work undertaken in AMAPPS I will also be influential in establishing baselines for movement, diet, and health status which can be used for post-construction monitoring.

9.2 Methods

9.2.1 Field Operations

In general, we focused our captures and deployments in areas that historically had not been well sampled. Details of the field operations are available in each annual report (NEFSC 2010, 2011, 2012, 2013, 2014, 2015, and 2016). Our sampling focused on demographic units (juveniles and males) which had not been well-sampled in the past. In the northeast, we focused on offshore deployments (> 20 miles from shore) because we suspected inshore/offshore population structuring and there was a complete lack of offshore sampling in the mid-Atlantic waters.

We partnered to optimize resources (details in the annual reports). During AMAPPS I turtle, tagging research collaborations were between SEFSC, NEFSC, Coonamessett Farm Foundation, and Virginia Aquarium & Marine Science Center. More recently, during AMAPPS II we are also partnering on data sharing and analysis between these same organizations with the addition of Michael Arendt of the South Carolina Department of Natural Resources and Michael James of Fisheries and Oceans Canada.

While at sea, especially in offshore situations, we partnered with colleagues to opportunistically collect additional biological and behavioral samples. When feasible, we collected morphometric measurements, blood for health assessment and sex determinations, multiple tissues for stable isotopes and genetic analysis, and behavioral data.

9.2.2 Seasonal Distribution

To create seasonal distribution maps of loggerheads, we pooled data from tags purchased with AMAPPS funds plus those purchased by Coonamessett Farm Foundation (to fulfill Atlantic Sea Scallop Research Set Aside objectives).

To remove unlikely Argos locations, data were filtered using a speed-distance-angle filtering algorithm developed by Freitas et al. (2008) and implemented in the “argosfilter” package (Freitas 2012) in R (R Core Team 2014). Prior to filtering, all invalid locations (Argos location class “Z”) were excluded, as were all locations reported during the first 24 hrs after tagging, which could have been unrepresentative of normal behavior due to tagging-induced stress (TEWG 2009). For filtering, a speed threshold of 4.5 m/s was used (consistent with TEWG 2009); the default turning angles (i.e., all locations more than 2500 or 5000 m from the previous location and requiring turning angles greater than 165˚ or 155˚, respectively) were assumed. For each turtle, daily positions were then linearly interpolated over the entire filtered track duration using the R package “adehabitat” (Calenge 2006).

Based on daily interpolated positions, relative densities were estimated by summing the number of daily positions in each 10 x 10 km^2 AMAPPS grid cell. To account for differences in the spatial distribution of the species over the course of the year, relative densities were estimated separately for each of four “turtle seasons”, which were defined based on the typical timing of migration to and from summer foraging and overwintering grounds. The seasons were defined as follows: migration to summer foraging grounds (April 16 – May 15); summer foraging (May 16 – October 31); migration to overwintering grounds (November 1-30); and overwintering (December 1 – April 15).

In AMAPPS II, we have a contract in place to estimate the distribution of loggerheads using at least two different methodologies, evaluate how sensitive the results are to the methodologies, and select a preferred approach for this application. The simplest method for examining loggerhead distribution within the mid-Atlantic is to calculate the density of filtered daily locations, as was done for this current report. Simple track densities, however, do not account for biases associated with initial tagging locations. As with most tagging studies, the initial deployments of our satellite tags are not randomly distributed as they reflect the locations where we were able to capture turtles. When the initial deployments are not randomly distributed, using satellite tag data to describe the distribution or relative density of animals may result in biased estimates (Whitehead and Jonsen 2013). To address this possibility, the contractor will also analyze the filtered locations using a simple Markov-chain method that produce unbiased measures of relative density from tracking data.

In AMAPPS II, we will also create loggerhead turtle density maps that are informed by line transect surveys, satellite telemetry, and bycatch analyses. While analysis of aerial line transect surveys may produce robust density estimates for the discrete time period of the survey, this snapshot sampling approach may not effectively predict animal density outside of the short sampling period. To produce density estimates over a broader time and area, two methods will be explored. First is the methodology described in Chapter 5, where the line transect shipboard and aerial survey data will be analyzed using standard mark-recapture distance sampling, resulting density estimates corrected with an appropriate correction factor for availability bias, these density estimates and associated habitat factors are modeled using GAMs, then the model results are used to predict the spatial-temporal density distribution.

Another methodology that will be explored involves combining multiple independently-collected data sources to produce the density estimates (Gopalaswamy et al. 2012; Ivan et al. 2013). Satellite-relayed data about loggerhead behavior can be used to fill in the temporal gaps left by infrequent, discontinuous line transect survey efforts. Since satellite tags sample turtle behavior every day of the year, the data represent the location of animals even as transient relationships with the environment (e.g., salinity, depth, etc.) change with physiological demands imposed by migrations and fluctuating food sources. In AMAPPS II, the contractor would use appropriate statistical approaches to combine these multiple data streams (satellite telemetry, bycatch rates, and line transect survey results) to produce a robust spatially- and temporally-explicit estimate of loggerhead density in the US mid-Atlantic region.

9.2.3 Availability to Aerial Surveys

In a preliminary AMAPPS I analysis, the NEFSC and SEFSC estimated correction factors for loggerhead availability bias and applied these factors to estimates of surface abundance derived from aerial abundance surveys (NEFSC and SEFSC 2011). The correction factors were derived from satellite tag data collected during 2010, where the tags recorded the amount of time the tag was in depth categories. These data were then summarized into correction factors which were the percentages of time loggerheads were within the top 2 m of the water column during 8 am and 8 pm (when the daylight surveys occurred). This analysis found the availability correction factor differed by an order of magnitude between the South Atlantic and mid-Atlantic. This has a large driving effect on the regional abundance estimates. At present, this abundance estimate is considered preliminary, mostly because of the uncertainties associated with the highly influential estimated correction factors for availability bias.

To address the uncertainty in the surfacing patterns, together with collaborators supported by ESA Section 7 grants, and Sea Scallop Research Set Aside funds, we were able to build a robust availability dataset for loggerheads found from Long Island, NY through Florida, referred to as the mid-Atlantic region. However, we still lack data from tagged turtles to correct the aerial surveys that are from Long Island, NY through Nova Scotia, which will be referred to as the NE region. This gap in the NE is also evident throughout the literature (e.g., McClellen and Read 2007; TEWG 2009; Hawkes et al. 2011; Arendt et al. 2012; Griffin et al. 2013). One approach to filling the information gap in the NE region would be to use data from the mid-Atlantic region. However, we caution against this approach as we hypothesize that loggerheads in the NE and mid-Atlantic regions represent distinct demographic groups which may exhibit markedly different behavior. Another approach to fill in the data gap in the NE region is to conduct focused cruises in the NE region to deploy tags on loggerheads. This approach is being used in AMAPPS II.

We had hoped to sample loggerheads destined for the NE in our AMAPPS I efforts by capturing actively migrating turtles. We sampled turtles off Virginia in late May and early June during their migration and are confident that we caught turtles while migrating because they subsequently dispersed widely throughout the mid-Atlantic Bight. Several individuals reached Long Island, NY before the end of June, but until 2015, none of the turtles we tagged (n=104) moved north of Long Island. They either stayed relatively stationary south of Long Island or they circled back south. It is unlikely that sampling earlier in the season would allow us to capture turtles destined for the NE because we were already sampling near the beginning of the migration into the mid-Atlantic shelf, when sea surface temperatures were still cold (SST as low as 14.8°C). Despite having sufficient time and warm water to do so, none of our tagged loggerheads followed the shelf northeast onto Georges Bank. This lack of connectivity from the mid-Atlantic and NE further supports the need to find additional ways to sample NE loggerheads.

The tag data collected here were also used in a collaborative investigation (not funded by AMAPPS) into the availability of loggerheads at the surface, with the hope of using these results to adjust the visual abundance estimate of the surface-detected animals.

9.3 Results

9.3.1 Field Operations

Counting only the tags that were purchased by Coonamessett Farm Foundation (CFF) and AMAPPS, we deployed 180 tags on loggerhead turtles (Table 9.1). The CFF and NEFSC tags were deployed primarily in the offshore mid-Atlantic region from commercial scallop vessels working on cooperative research. The SEFSC tags were primarily deployed in association with the South Carolina Department of Natural Resources cruises or with SEFSC turtle excluder testing. The tagged turtles ranged from 52.5 cm to 100.8 cm straight carapace length notch to tip, where the average was 72.4 cm.

Table 9-1 Total number of tags deployed by purchasing agency

Year	Tag Purchaser			
Deployed	CFF	NEFSC	SEFSC	Total
2009	2	0	0	2
2010	0	14	30	44
2011	10	16	0	26
2012	15	17	0	32
2013	10	6	30	46
2014	13	7	0	20
2015	8	2	0	10
TOTAL	58	62	60	180

There were often several other active partners (such as the Virginia Aquarium & Marine Science Center, Fisheries and Oceans Canada, or the South Carolina Department of Natural Resources) working collaboratively with the organizations that purchased the tags. All tags listed as purchased by NEFSC and SEFSC were procured with AMAPPS funds.

9.3.2 Seasonal Distribution

Of the 180 total tags deployed, 11 were excluded from this analysis due to tag damage, failure or loss. From the remaining 169 tags, there were 43,905 daily interpolated positions that were used to estimate relative densities over the course of the year (Table 9-2).

Table 9-2 Number of daily interpolated loggerhead positions by season

Season	Daily Interpolated Positions
April 16 – May 15	2,769
May 16 – October 31	25,113
November	3,252
December 1 – April 15	12,771

The distribution of tagged loggerheads ranged from the Scotian Shelf to the Gulf of Mexico (Figures 9.1 and 9.2). With the exception of the summer foraging period (Figures 9.3 and 9.4), relative densities were highest along the coasts of North Carolina and Florida. During the summer foraging time period, relative densities were highest on the continental shelf from Cape Hatteras, NC, to Long Island, NY with additional high density areas along the coast of Georgia and South Carolina.

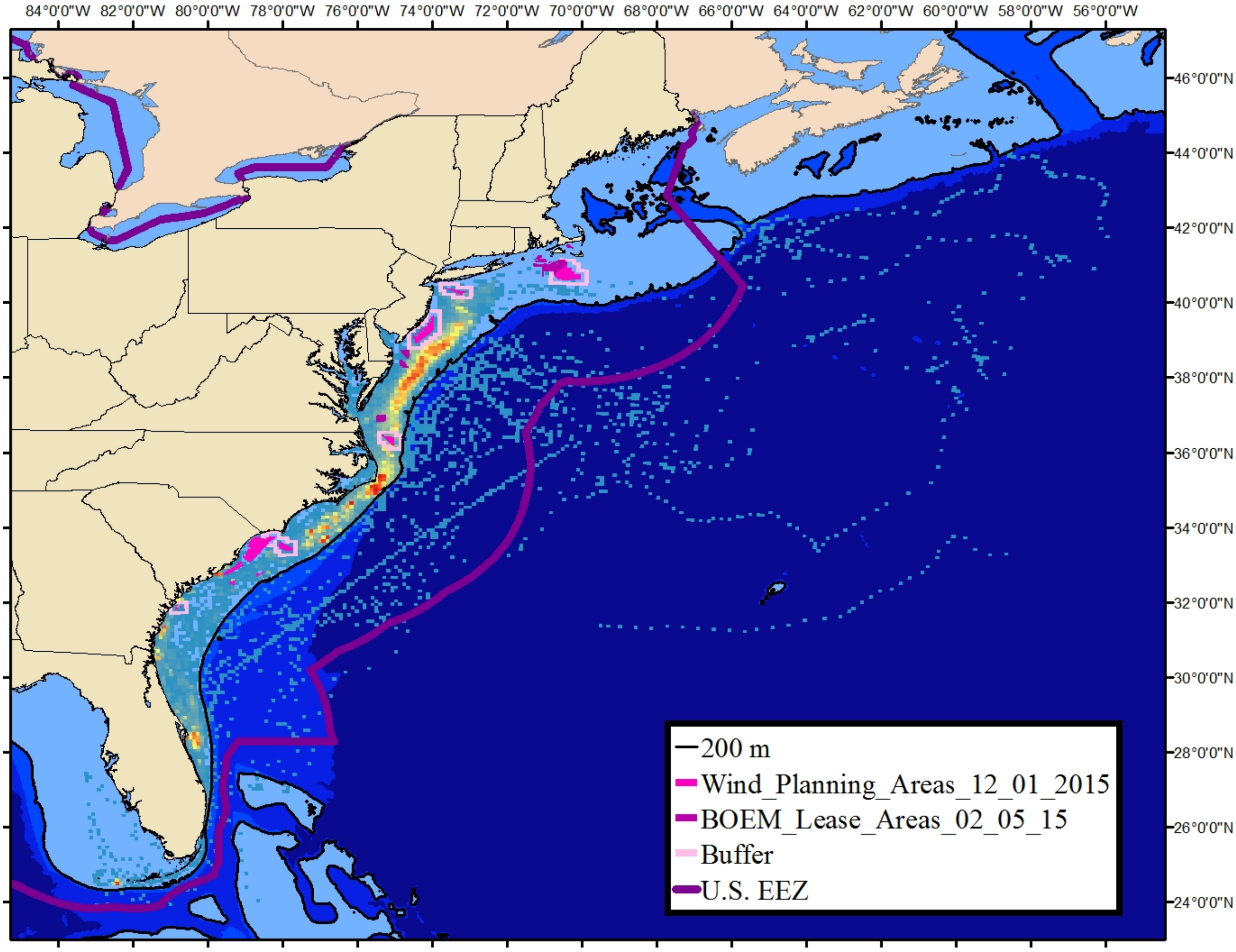

Figure 9-1 Year round distribution of tagged loggerhead turtles
BOEM wind planning and lease areas highlighted. Turtle densities are shown as interpolated daily positions in a color ramp from blue (1 position per 100 km^2) to red (643 positions per 100 km^2).

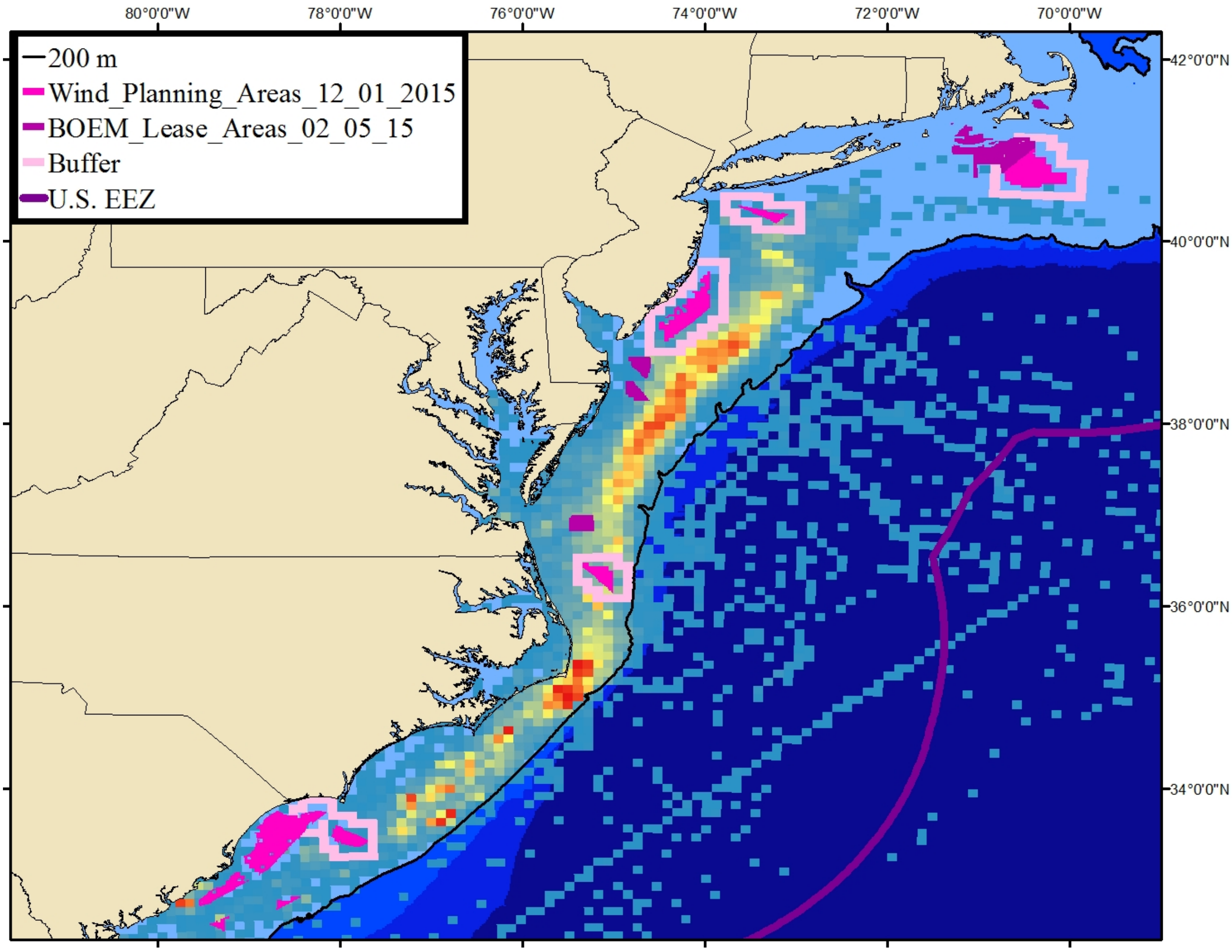

Figure 9-2 Year round mid-Atlantic distribution of tagged loggerhead turtles

BOEM wind planning and lease areas highlighted. Turtle densities are shown as interpolated daily positions in a color ramp from blue (1 position per 100 km^2) to red (643 positions per 100 km^2).

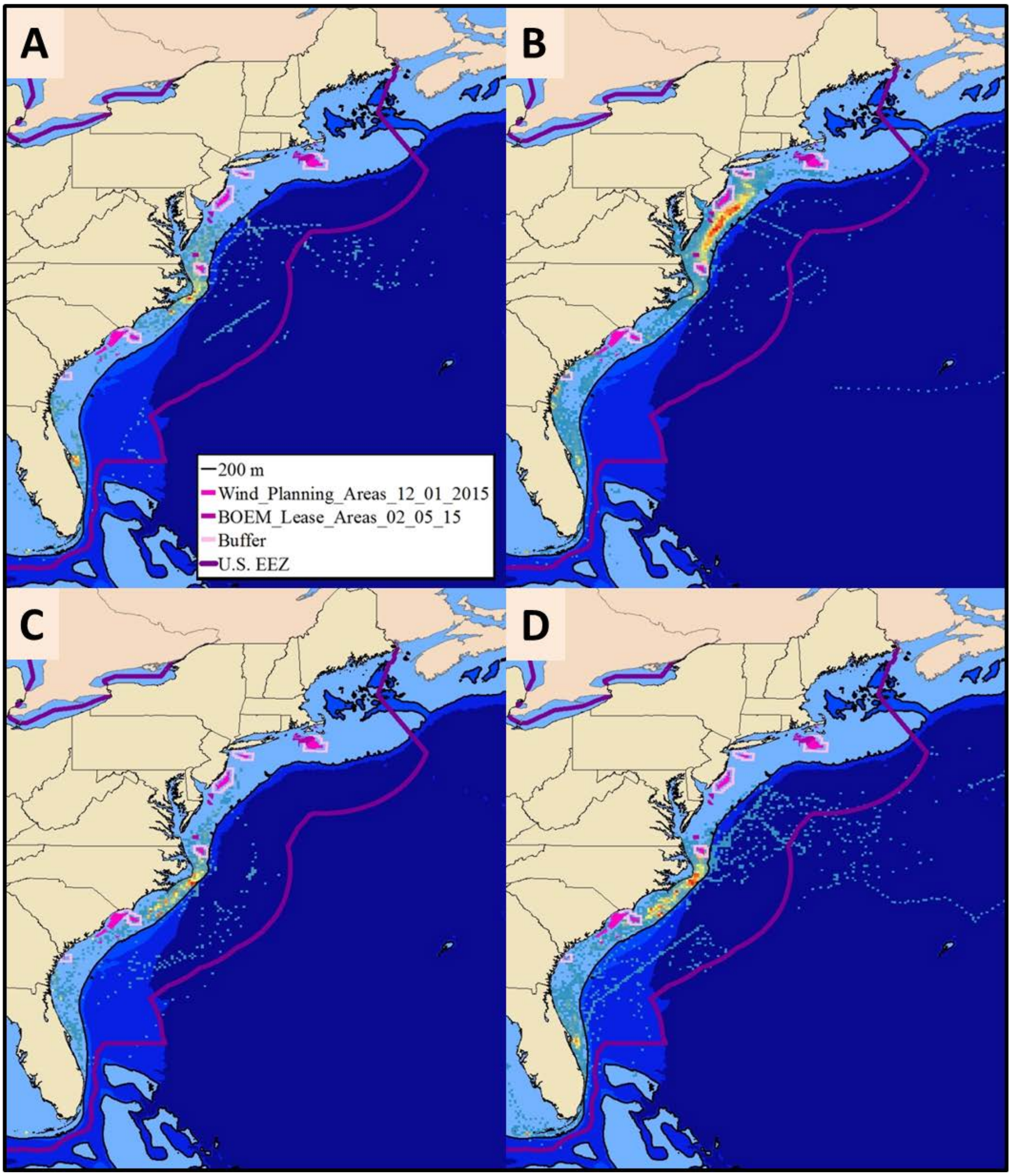

Figure 9-3 Seasonal distributions of tagged loggerhead turtles
BOEM wind planning and lease areas highlighted. Panel A. Spring migration to foraging grounds (April 16 – May 15) shown from blue (1 position per 100 km^2) to red (52 positions per 100 km^2). Panel B. Summer foraging areas (May 16 – October 31) shown from blue (1 position per 100 km^2) to red (225 positions per 100 km^2). Panel C. Fall migration to overwinter grounds (November 1-30) shown from blue (1 position per 100 km^2) to red (140 positions per 100 km^2). Panel D. Overwintering grounds (December 1 – April 15) shown from blue (1 position per 100 km^2) to red (140 positions per 483 km^2).

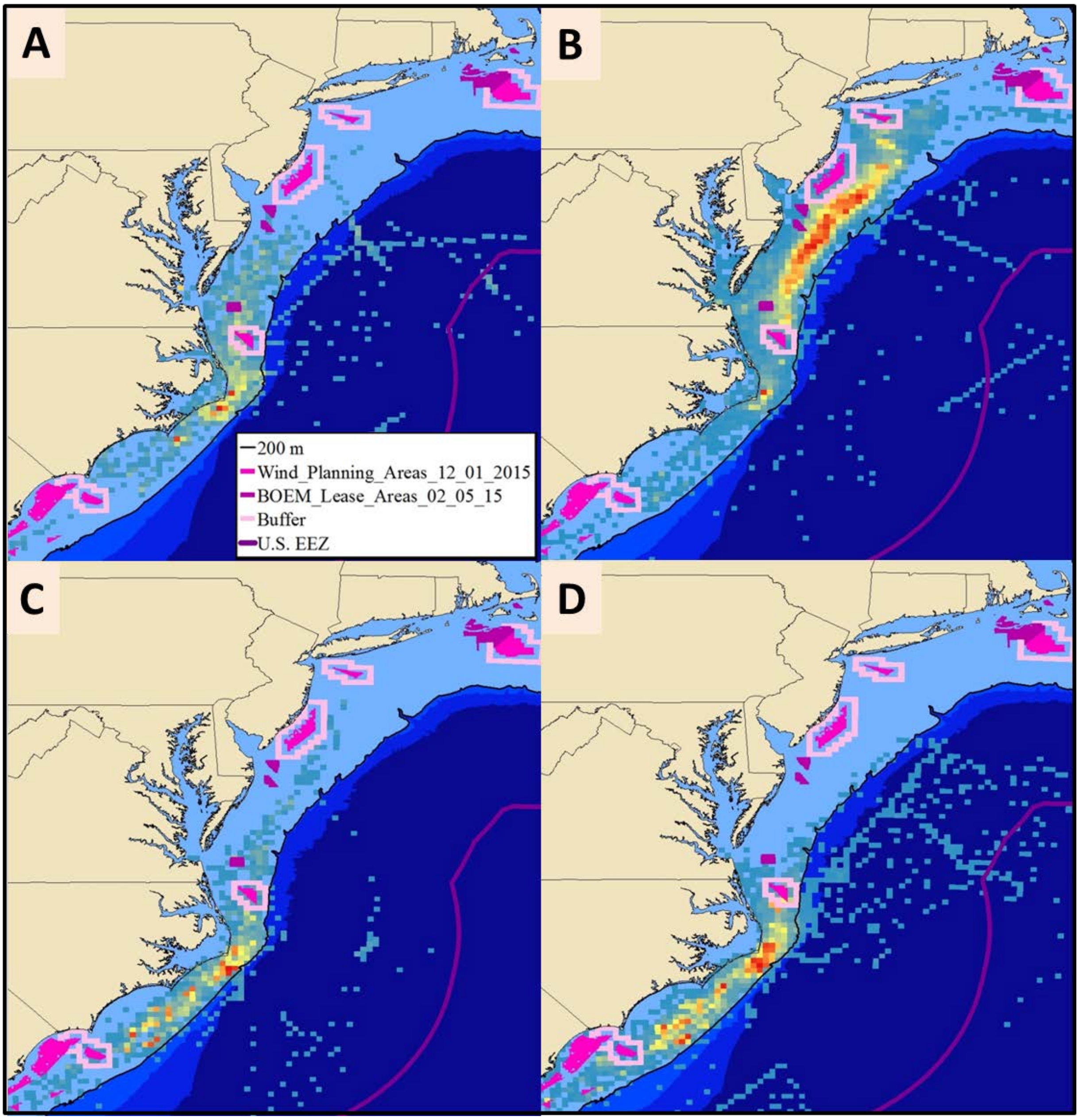

Figure 9-4 Seasonal mid-Atlantic distribution of tagged loggerhead turtles
BOEM wind planning and lease areas highlighted. Panel A. Spring migration to foraging grounds. Panel B. Summer foraging areas (May 16 – October 31). Panel C. Fall migration to overwinter grounds (November 1-30). Panel D. Overwintering grounds (December 1 – April 15).

To facilitate interpreting the spatial-temporal distribution patterns of loggerheads, AMAPPS I supported some of the analytic costs associated with Avens et al. (2014) and Smolowitz et al. (2015). Avens et al. (2014) relates to AMAPPS goals in that it estimated the ages of loggerheads that are expected to be found in continental shelf waters off the eastern United States, that is, within the AMAPPS study area. For juvenile loggerheads in the western North Atlantic, initial transition from oceanic to neritic habitat is estimated to occur at a mean age of 12.4 years and mean carapace length of 55.3 cm.

Smolowitz et al. (2015) relates to AMAPPS goals in that it examined loggerhead behavior in the US mid-Atlantic region. Tracked turtles often remained within about 10 m of the surface;

though, some were tracked to the seafloor including times when the bottom water was consistent with cold-stunning temperatures. Loggerheads were observed feeding pelagically on lion's mane jellies (*Cyanea capillata*), comb jellies (*Ctenophora*), and salps (*Salpidae*). When at the bottom they were observed feeding on hermit crabs (*Paguroidea*), rock crabs (*Cancer irroratus*), and Atlantic sea scallops (*Placopecten magellanicus*).

9.3.3 Availability to Aerial Surveys

Using only the 2010 loggerhead satellite dive time data, the median percent surface time during August in the mid-Atlantic region between Long Island, NY and Cape Hatteras, NC was 67% with an inter-quartile range of 57 – 77%. In contrast, the median percent surface time in waters south of Cape Hatteras, NC was about 7% with an inter-quartile range of 5 – 11% (NEFSC and SEFSC 2011). These estimates are considered preliminary due to several issues: data from only one year and for a limited region and the analysis did not account for the individual effects on the repeated dive time measures. These preliminary estimates were applied to aerial line transect data to calculate a preliminary abundance estimate of loggerheads (see Chapter 5 for more information).

To address some of the limitations in the NEFSC and SEFSC (2011) analysis, tag data from 156 loggerheads that were collected during June 2010 to January 2014 under AMAPPS and other projects were used in a collaborative investigation (not funded by AMAPPS) into the availability of loggerheads at the surface, with the hope of using these results to adjust the visual abundance estimate of the surface-detected animals. The dive and surface time patterns of the loggerhead satellite tags were modeled using a zero- and one-inflated beta regression with a turtle random effect and smooth functions of covariates (Scott-Hayward et al. 2014). In general, they found that the estimated availability was highest in the summer months, north of Cape Hatteras, NC (north of 38°N) and, when included in the models, at air temperatures between 25°C and 30°C. In addition, they concluded that this initial study suggested that ignoring availability of turtles may substantially under estimate the abundance estimate. However, the amount of underestimation is still uncertain because more work is needed to develop an appropriate model of turtle availability and more tag data are needed from animals utilizing under-represented portions of the AMAPPS study area.

In AMAPPS II, we will build on and extend our current research related to sea turtle availability to visual observers. To fill in the spatial gaps we plan to extend the spatial extent of our loggerhead sampling further north by partnering with Fisheries and Oceans Canada, directing capture effort in northern regions, and exploring whether Gulf Stream sampling may target turtles bound for northern waters. We also plan to begin obtaining behavioral data for other key species, starting with leatherbacks and expanding to pilot work on other hard-shell species. In AMAPPS II, we will continue analysis of loggerhead availability.

9.4 Acknowledgements

This research is part of a collaborative effort to learn more about sea turtles in Northeastern US regional waters. The funds for the tags and biological sampling came from BOEM. Considerable staff time was provided by NOAA/NMFS/NEFSC. Funds for vessel time, crew, and many tags were supplied by the Coonamessett Farm Foundation, working with the sea scallop industry through the Sea Scallop Research Set-Aside program.

We owe special thanks to James Gutowski, Captain Michael Francis, Eric Matzen, and Henry Milliken, who have been critical field partners through the five years. Matthew Weeks was influential in establishing our field protocols. Substantial contributions were made by Susan

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10 Seal Research

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10.1 Introduction

The overarching goal of AMAPPS is to assess the abundance, distribution, ecology, and behavior of marine mammals, sea turtles, and seabirds throughout the US Atlantic and to place them in an ecosystem context, providing spatially explicit information in a format that can be used when making marine resource management decisions. BOEM and the US Navy need this kind of information on seals to inform the required permits and environmental impacts on seals from, for example, the development of offshore wind energy or Navy at-sea training and testing activities. One reason NMFS requires this type of information on seals is because it is mandated to monitor the status of marine mammals and guidelines require abundance estimates to be generated at a maximum of 8-year intervals. In 2001, the harbor seal population (*Phoca vitulina*) along the coast of Maine was estimated to be 99,340 including 23,722 pups. (Gilbert et al. 2005). Thus an updated estimate was expected in 2009, which did not happen.

To address all of these needs, three types of projects focusing on seals were conducted under AMAPPS. During 2012 an abundance survey for harbor seals was conducted using funds from both NMFS and AMAPPS. During 2013 and 2015, 10 gray seals (*Halichoerus grypus*) were equipped with several types of tag to document daily movements. Using sightings of seals (harbor, gray and unidentified seals) detected during the AMAPPS aerial surveys, spatially-explicit density maps of seals at-sea were developed. This chapter describes these three projects.

10.2 Methods

10.2.1 Harbor Seal Abundance

Abundance of seals has commonly been estimated by correcting counts of seals that are on haul-out sites (Huber et al. 2001; Hammill et al. 2007). This strategy was followed in this survey. Counts of harbor seals were derived from aerial photographs of haul-out sites. These counts were corrected for animals not on the haul-out sites using fractions of times radio-tagged seals were available to be counted on a haul-out site.

Aerial photographic surveys of haul-out sites of harbor seals along the coast of Maine were conducted during 27 May – 2 June 2012 which was when midday low tide times were within the peak pupping season. Midday low tides were needed to ensure the haul-out sites would be maximally occupied during the best time of the day to take photographs. Surveying was performed during the pupping season to ensure the maximum number of adults and pups were hauled out. A NOAA Twin Otter surveyed the seal haul-out sites at an altitude of 225 m. Oblique photographs were taken from a left side rear pop-out window using a Canon 7D and 300 mm stabilized lens. In light of the large number of haul-out sites and the need to survey in only good weather conditions during the short time period when the tides were favorable, the survey was designed to photograph a stratified random sample of the haul-out sites. Sample haul-out units were selected for photographing with the probability proportional to the relative number of adult harbor seals estimated for the unit in the 2001 abundance survey. Details of the sampling scheme are reported in Waring et al. (2015).

Counting the aerial images involved visual inspection, determination of species, age class and image overlap, and manual marking of seals in photo editing software. Marked images were archived. Blind duplicate counts of most of the larger haul-out sites were completed by a second counter for quality control.

To correct for animals not hauled-out, a sample of harbor seals were captured and radio-tagged prior to the aerial survey. Captures took place in 2012 in two locations: Chatham Harbor, MA and western Penobscot Bay, ME. Each seal was tagged with both a flipper tag and coded VHF transmitter (radio tag). A USFWS Kodiak airplane was used for radio tracking using wing-mounted omnidirectional antennas that were cabled to a Lotek receiver (model SRX400) to scan for transmissions from radio-tagged seals. In addition, a single omnidirectional antenna was mounted in the belly port of the Twin Otter and connected to an auto-logging receiver. The USFWS Kodiak searched for radio-tagged seals by flying a loop, altitude of 300 m, extending from Cape Elizabeth, ME to Frenchman's Bay, ME.

A Hanson-Horvitz estimator was used to estimate abundance. This estimator included the probability of selecting a haul-out site and the probability of detecting a seal using the radio-tagged seal data (Thompson 2012; Waring et al. 2015a).

10.2.2 Tagged Gray Seals

In Chatham Harbor, MA from 13 – 17 June 2013, a multi-agency team conducted the first non-pup gray seal live capture, tagging, and biological sampling in US waters using funds from multiple sources including AMAPPS. Twenty-seven seals were captured, of which six escaped, five were intentionally released, fifteen were sampled, and one accidentally drowned in the capture net. A suite of biological measurements and samples (e.g., weight, lengths, girth, blood, hair, skin, blubber, tooth, whisker, and mucous swabs) were collected, as feasible, from the fifteen seals for various studies including: health assessment, diet, disease, age, and genetics. Nine animals in good condition were selected for the following for deployment of electronic tag types: seven Sea Mammal Research Unit1 (SMRU) GPS Cell Phone (GPS) Tags; one SMRU GPS Satellite Relay Data Logger (SRDL); and one Wildlife Computers Smart Position or Temperature Transmitting (Spot) Tag. More details of this can be found in the report by NEFSC and SEFSC (2014).

During 11 – 17 January 2015, a non-AMAPPS multi-agency team conducted a gray seal weaned pup live capture and biological sampling on Muskeget Island, MA and South Monomoy Island, MA. More details of this can be found in the report by NEFSC and SEFSC (2015). During the field work on Muskeget Island, one fully-molted female gray seal pup was satellite-tagged on 14 January 2015 using an unused tag purchased with AMAPPS funds for turtles (Figure 10-1).

Figure 10-1 Satellite tagged weaned gray seal pup
Photo credit: Sophie Whoriskey, Mystic Aquarium.

10.2.3 Spatial Distribution of Seals When At-Sea

As much as possible the Generalized Additive Model methods detailed in Chapter 5 were used to predict the at-sea uncorrected density distribution of seals using data collected from the line transect aerial surveys. Differences between the seal model and models used on cetaceans as described in Chapter 5 are detailed below.

Because small gray seals are sometime difficult to distinguish from harbor seals when viewed from 600 ft altitude during an at-sea line transect abundance survey, many seals detected during these aerial surveys were assigned an ambiguous species identification (unidentified seal). Thus, the distribution maps were for a generic seal, which could include harbor seals, gray seals, and perhaps even harp (*Pagophilus groenlanidicus*) or hooded (*Cystophora cristata*) seals.

In contrast to the results described in Chapter 5, the at-sea seal density maps display a relative measure because they are not corrected for availability bias due to animals missed. Specifically, seals were missed during the at-sea aerial surveys due to two reasons: one, seals that were at-sea and below the surface were missed and thus not available to be detected by the aerial survey observers (in the same way cetaceans can be missed); and two, other seals were missed because they were on land hauled-out.

10.3 Results and Discussion

10.3.1 Harbor Seal Abundance

In Chatham Harbor, MA, 17 harbor seals (9 males and 8 females) were equipped with flipper and radio tags (Figure 10-2). In western Penobscot Bay, ME, 12 harbor seals (6 males and 6 females) were equipped with flipper and radio tags. Of these, 20 were adults and 9 were juveniles. Nine seals tagged near Chatham, MA and 9 in Penobscot Bay, ME were in the photographic study area during the survey period. The other 11 radio-tagged seals were never detected in the sampled surveyed units and were presumed to be absent from the photographic survey area. Individual seals were detected between 0.167 and 0.833 of the time available. The bootstrap estimate of the fraction of seals available to be counted was 0.429 (CV = 0.128).

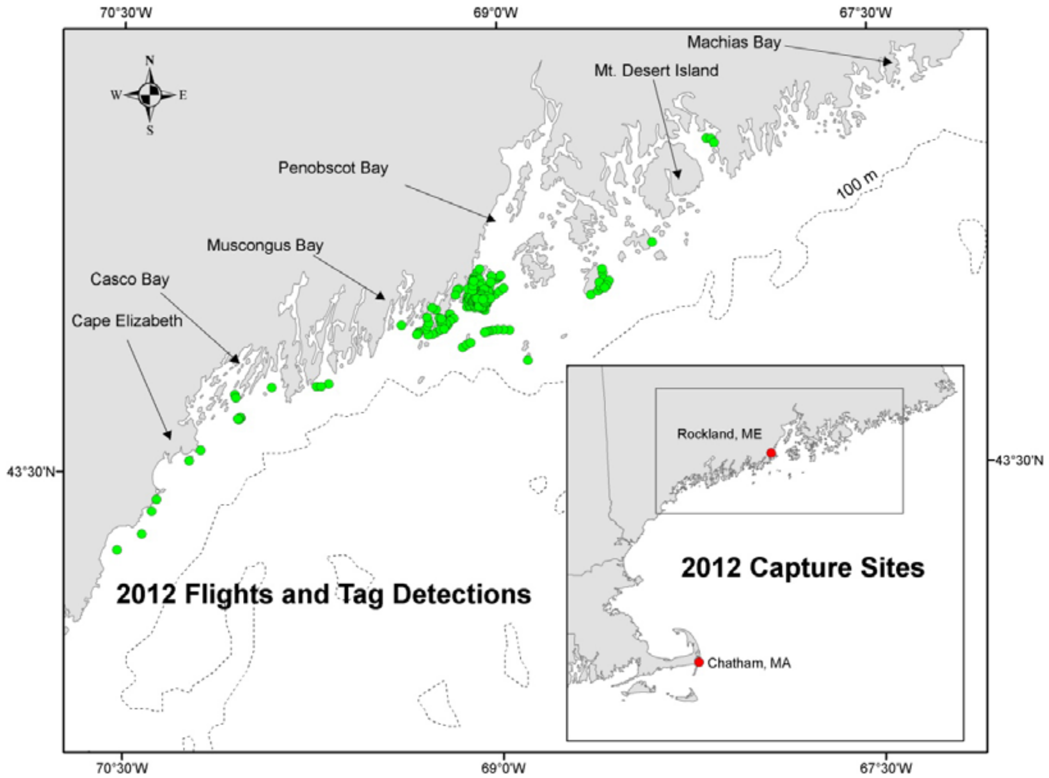

Figure 10-2 Locations of radio-tagged and recaptured harbor seals
Capture sites during 2012 were Chatham MA and Rockland ME. The green dot indicates each location of the radio-tagged seals (9 captured in Chatham and 9 captured in Rockland) during the survey days.

Using the Hanson-Horowitz estimator, the estimate of seals on haul-out sites throughout the study area was estimated to be 32,533 (2732 standard deviation (sd)). Combining the Hanson-Horwitz estimate and the bootstrap estimate of the fraction of seals out of the water resulted in a 2012 harbor seal abundance estimate of 75,834 (11,625 sd; 0.153 CV).

The 2012 population estimate of 75,834 (0.153 CV) was not significantly different from the 99,340 (0.091 CV) reported for 2001 (Gilbert et al. 2005). This could imply the population size is stable, at least statistically. However, given the levels of confidence it is possible the population has declined.

Waring et al. (2016) discussed possible reasons for the difference between the estimated number of harbor seals in 2001 and 2012, assuming the difference is real. One, the 2012 estimate may be biased by erroneous assumptions about seal distribution. Two, the estimated correction factor was different in the two surveys (2.54 in 2001 and 2.33 in 2012). Three, not all seals were in the study area during the survey period. And four, the harbor seal population is no longer growing and has, in fact, declined.

10.3.2 Tagged Gray Seals

For several months the adult gray seals tagged in June 2013 remained within or adjacent to the capture region. One of the cell phone-tagged seals died from a fatal shark bite and stranded in Chatham Harbor, MA in early August. The remaining seals exhibited longer distance excursions to offshore waters. This included one that traveled to the vicinity of Sable Island, and others that used haul-out sites in eastern Nantucket Sound, MA in late autumn, prior to the start of the December-February pupping and breeding period.

Preliminary analysis of the electronic tagging data provided new insight on the ecology of gray seals occupying Cape Cod waters. The data suggest strong site fidelity to Cape Cod waters from summer through late autumn, then movement into Nantucket Sound and adjacent waters, with some trips to offshore waters east/southeast of Nantucket Island, MA during the pupping/breeding period (about mid-December to early February). Subsequently, some animals were making extended excursions to offshore waters, including one animal that made a round-trip to the vicinity of Sable Island, Nova Scotia. Gray seal movements between Sable Island and Cape Cod waters have previously been documented by Sable Island marked seals (e.g., brands, electronic tags) and genetics (Wood et al. 2002; Wood LaFond 2009; Wood et al. 2011; Rough 1995; NMFS unpublished data).

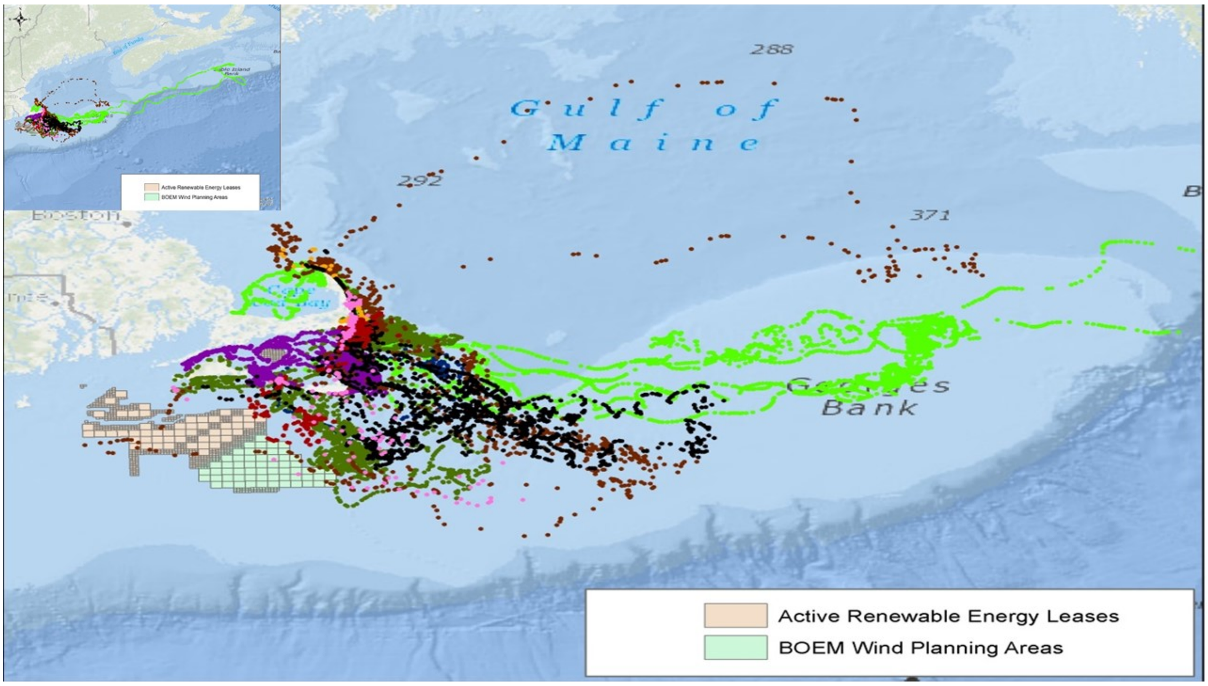

Figure 10-3 Locations of gray seals tagged in Chatham, MA 2013
Each color is a different animal. Orange and green cells are the wind energy areas. Cell phone tag data courtesy J.Moxley, Duke University.

The satellite-tagged weaned gray seal pup tagged on 14 January 2015 was tracked for approximately one month before transmission ended. Upon leaving Muskeget, MA she travelled in the waters south of Martha’s Vineyard and Nantucket and spent most of the time within the wind energy areas (Figure 10-4).

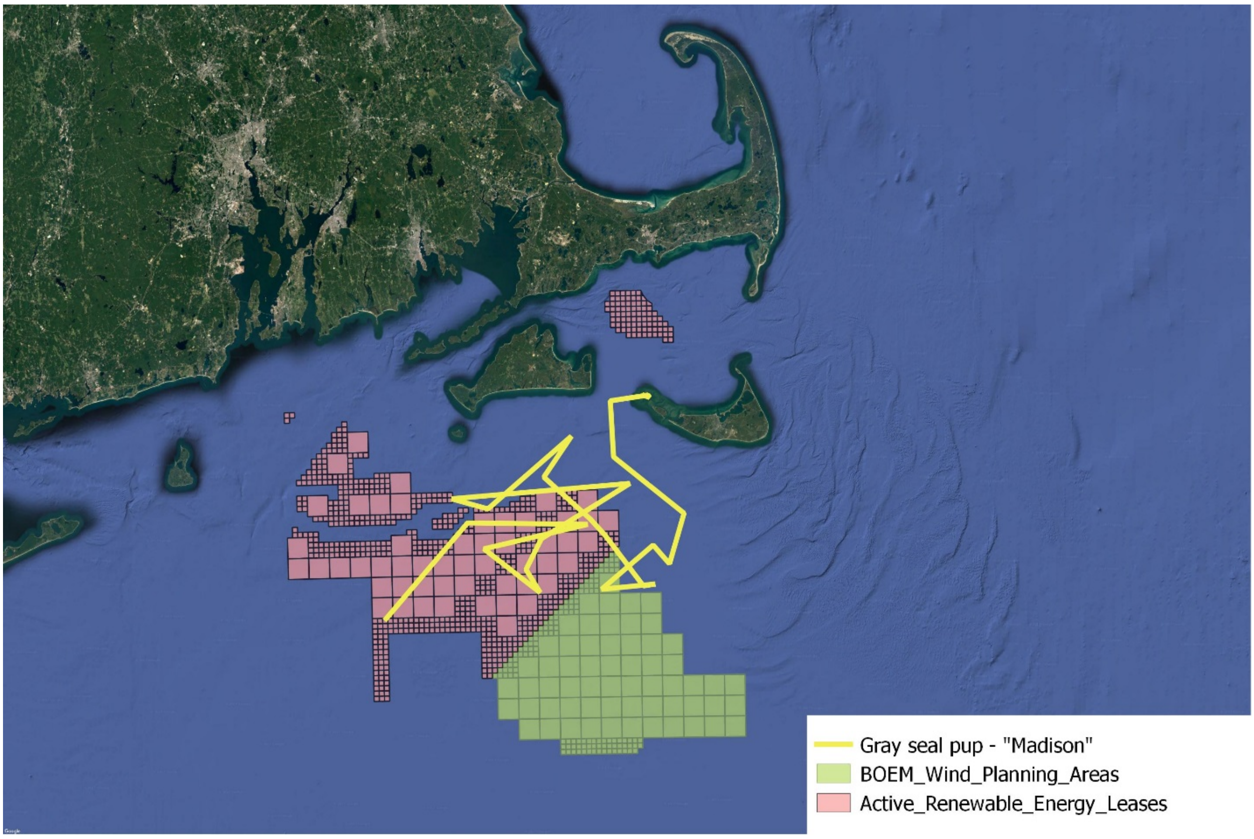

Figure 10-4 Track of satellite-tagged weaned gray seal pup relative to wind energy areas

10.3.3 Spatial Distribution of Seals When At-Sea

Seals of any species that were at-sea (not on land) were recorded in the NE AMPPS aerial surveys during spring, summer and fall. Most observations were in the spring (88 groups of 117 individuals) and summer (47 groups of 51 individuals), with only 10 groups in the fall (Appendix I, Chapter 18). Using the two-independent team mark-recapture distance sampling analysis methods, the estimate of *p(0)* that accounts for perception bias and not availability bias was 0.18 (CV=0.44).

The significant covariates were perpendicular distance and subjective overall sighting quality for the distance sampling sub-model (DS) and an interaction between perpendicular distance and observer team for the mark-recapture sub-model (MR). The significant covariates for the density-habitat GAM model included SST, particulate inorganic carbon, primary productivity, distance to the 200 m depth contour and latitude.

Seasonal distribution patterns were evident in the predicted spatial models. There were concentrations of seals observed in the summer in waters off Maine and Cape Cod, MA and a more dispersed distribution in non-summer months that ranged from New York to Nova Scotia.

Interestingly, the summer density model predicted medium levels of densities of seals south of Nantucket, MA and on the northern edge of Georges Bank during the summer due to habitat characteristics of the waters, even though there were no at-sea seals recorded in the summer AMAPPS aerial sighting surveys conducted during 2010 - 2013 (Appendix I Figure 18-10). However, seals have been seen in these two regions in the summer, as is documented by locations of seals that were recorded in previous abundance surveys (Appendix I Figure 18-13), seals detected during the 2011 AMAPPS shipboard sighting survey, and the locations of the summer tagged gray seals during summer 2013 (this Chapter Figure 10-3). These data provide validation that the habitat model used to predict the density map is accurate.

Estimates of average seasonal abundance were calculated (Appendix I) for unspecified seals that were at-sea. However, these numbers cannot provide information on the abundance of only gray seals or only harbor seals, and do not include availability correction factors. Consequently, population abundance estimates of harbor seals and gray seals are currently being calculated using more traditional methods applicable for seals.

10.4 Acknowledgments

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11 Ecosystem Research

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11.1 Introduction

An overarching goal of AMAPPS is to assess the abundance, distribution, ecology, and behavior of marine mammals, sea turtles, and seabirds throughout the US Atlantic Outer Continental Shelf (OCS) and to place them in an ecosystem context, providing spatially explicit information in a format that can be used when making marine resource management decisions. One way to place the spatial-temporal distributions developed in Chapters 5 – 10 into an ecosystem context is to understand how environmental habitat characteristics relate to the distribution and density of marine mammals, sea turtles, and seabirds. Such an understanding could potentially allow the discrimination between changes in cetacean populations due to natural environmental variability and changes due to anthropogenic impacts. If possible, this could greatly facilitate resource management decisions.

Within this chapter, the environmental, physical, and biological characteristics of the water column and the distributions of lower trophic level organisms such as fish and plankton are documented. In addition, ongoing work is introduced that relates these water characteristics to distribution patterns of the cetaceans.

To describe the lower trophic levels and oceanographic conditions of the study area and improve our understanding of the spatial linkages among trophic levels, hydrographic, active acoustic, and plankton data were collected during the shipboard surveys. Multi-frequency echosounder data were collected continuously using an EK60 in active and passive modes throughout the surveys to characterize the planktonic and nektonic trophic levels. Conductivity, temperature, depth (CTD) casts were made in conjunction with all plankton sampling casts along the visual transect lines to provide depth delimited oceanographic conditions in the study area. To characterize the lower trophic levels of the ecosystem, plankton sampling using a 61cm bongo net was deployed along the visual sighting transect lines daily at dawn, noon, and dusk. Due to the depth of important phototrophic species such as euphausiids[1] and myctophiids[2] during the daylight hours, additional plankton sampling using a variety of tools were conducted during the hours of darkness when visual transects were not being conducted. In addition, larger midwater trawls and several types of imaging sampling systems were used at night to create a spatially detailed characterization of the plankton and nekton from the surface to 600 m depth. These data will be used to help verify the species composition of the acoustic backscatter EK60 data and increase the spatial coverage of the lower trophic level categorization.

[1] Small shrimp-like crustaceans, such as krill
[2] Small mesopelagic fish, such as lanternfish

11.2 Methods

11.2.1 EK60

Acoustic backscatter data were collected using multi-frequency Simrad EK60 echosounders on the NOAA ship *Henry B. Bigelow* and the NOAA ship *Gordon Gunter*. On the NOAA ship *Henry B. Bigelow*, the EK60 system consists of five split-beam transducers operating at 18, 38, 70, 120, and 200 kHz. The transducers are co-located on the ship's retractable centerboard. When the centerboard is flush with the hull, the transducers are six meters below the waterline, and when the centerboard is in its intermediate position the transducers are nine meters below the waterline. On the NOAA ship *Gordon Gunter*, the EK60 system consists of four spilt-beam transducers operating at 18, 38, 120, and 200 kHz. The transducers are co-located flush with the ship's hull five meters below the waterline. On both the NOAA ships *Henry B. Bigelow* and *Gordon Gunter*, the beam width for the 38, 70, 120, and 200 kHz transducers is 7^0, and the beam width for the 18 kHz transducers is 11^0. The EK60s were set to either active or passive mode during the cruise, or fully secured. In active mode, all transducers simultaneously transmitted a sound pulse (i.e., "ping") and recorded the echo (i.e., "backscatter"). The EK60s were set to transmit at a rate of 1 ping per second, the fastest possible ping rate. In actuality, the EK60s ping rate varied from 1 ping every 5 – 6 sec when on the continental shelf to 1 ping every 1 – 2 sec when farther offshore. In active mode, each frequency transmitted a 1-ms CW pulse. In passive mode, the transducers did not transmit pings, they only recorded sound received. When fully secured, the transducers do not transmit pings and received sounds are not recorded.

In 2009 (HB09-03), 2011 (HB11-03), and 2013 (HB13-03), active acoustic data were collected continuously after marine mammal operations ended for the day and during nighttime operations. In addition an experiment was conducted, where active acoustic data were collected during daytime operations on every second day to assess whether or not using the EK60 systems affected passive acoustic (towed hydrophone array) and/or visual marine mammal detections. See Chapter 8 for more information on this experiment. Active acoustic data were also recorded during transits (non-surveying sections of track lines). During 2014 (GU1402 and HB1403), active acoustic data were collected continuously throughout the cruises, mostly in active mode and occasionally in passive mode.

The EK60s were calibrated at the end of GU14-02, at the beginning of HB1403, and at the beginning of HB1503 using the standard target method at a site near the Newport Naval Base, where the ship is docked (Foote 1990). A 38.1-mm tungsten carbide with 6% cobalt binder sphere was suspended at about 20 m range from the transducers and was used to calibrate all frequencies. A wireless calibration system, consisting of three remotely controlled downriggers, and automated software were used to initially position the target under the split-beam transducers and the software automatically moved the sphere throughout the acoustic beams. The data were collected and then the Simrad Lobe program was used during data playback for each EK60 individually.

11.2.2 Imaging

11.2.2.1 VPR

Video plankton recorder (VPR) tows were conducted with a Seascan V-fin mounted, internally recording, black and white VPR. The VPR was also equipped with a Seabird Fastcat CTD, a Wetlabs fluorometer / turbidity sensor, and a Benthos altimeter. The VPR sampled at 16 frames per second. Thus, each frame representing a specific water volume determined by the camera setting and ship's speed. A SEACAT 19+ CTD profiler was mounted above the V-fin to provide real time data on gear depth and oceanographic conditions. Tows were conducted at 3 – 4 knots speed through the water to maximize sampling area and to minimize image frame overlap. VPR haul depth was limited to 300 m but the maximum depth of most hauls was less than 100 m to maximize sampling time in the densest biological layers.

Two types of tows were conducted. The first type was a single depth tow to target distinct layers of backscattering seen on the 120 and 200 kHz EK60 frequencies with the goal to quantify EK60 signal strength and to study plankton patchiness. The second type was tow-yo haul that was towed obliquely through biological layers seen on the EK60 with the goal to quantify plankton vertical distributions. Because the net samplers were negatively impacted by large numbers of salps that were present in nearly all years, the VPR was also used to quickly survey the gelatinous zooplankton densities in the sampling area before deciding to deploy the larger net samplers.

Upon retrieval, the compressed video data were downloaded to specialized image processing computers. Data were decompressed, oceanographic data files were created, and in focus regions of interest (ROIs) were extracted from each image frame using Autodeck programming from Seascan. Interpolated profiles of temperature, salinity, density, raw chlorophyll and raw turbidity values were created for each haul using MATLAB. Each ROI set was hand processed to remove images of air bubbles and duplicate images. ROIs were then identified to general taxonomic grouping using a modified version of Visual Plankton developed by Cabell Davis of the Woods Hole Oceanographic Institution.

11.2.2.2 Didson/Go-Pro

Macrozooplankton were targeted using a dual visual sampling platform during the 2015 NOAA ship *Henry B. Bigelow* cruise. The first system was a Sound Metrics Didson 300 imaging sonar mounted in a steel cage. The Didson was set to sample a small area, with a focus of 1.04 m. The second system was a video net. It consisted of two Go-Pros facing each other separated by 148.2 cm and boomed out 70 cm. With the cameras set to 1080 wide and the refraction of the water, this allowed the overlapping video coverage of the two cameras to record one square meter when dropped vertically through the water column. A Star-Oddi DST–CTD was also attached to the platform to record water quality. A mechanical flow meter was mounted on a rod perpendicular to the Go-Pro booms to measure the water current during cast stops. Both the Didson 300 and the Go-Pro video system sampled the same area. During a cast, the platform was lowered to 100 m then brought to the surface pausing for 2 min at 7 depths (100, 75, 50, 40, 30, 20, and 10 m).

11.2.3 Net Samplers

11.2.3.1 Bongo Net

Sampling was conducted by making double oblique tows using the 61 cm bongo net equipped with 333 µm nets and a Seabird 19+ CTD mounted 1 m above the net. The tows were made to approximately 5 m above the bottom or to a maximum depth of 200 m. All plankton tows were conducted at a ship speed of 1.5 – 2.0 knots. The bongo was deployed approximately three times a day: once before the day's surveying started (about 0500 – 0530), at lunch time (about 1200 when the ship stopped surveying), and again after surveying was completed for the day (approximately 1800, depending on weather and timing of the sunset). Bongos were also deployed at night to fill special sample requests or increase geographical coverage.

The plankton samples were rinsed from the nets using the lowest water pressure possible and immediately preserved in 5% formalin and seawater. Samples were shipped to the Polish Sorting Center for processing. One net was designated for zooplankton sampling. Zooplankton from this net were split to subsamples of 500 – 1000 individuals and identified to the lowest possible taxonomic and life stage level possible and enumerated. The second net was designated for ichthyoplankton sampling. All ichthyoplankton from this net was identified to the lowest taxonomic level possible, enumerated, and the standard lengths of a subset measured.

11.2.3.2 MOCNESS

During a 2013 cruise, macroplankton was sampled utilizing a 1m MOCNESS (Multiple Opening/Closing Net and Environmental Sensing System) equipped with nine 333 µm nets. The MOCNESS system was also equipped with a color VPR and strobes. Strobes were used to increase the catchability of euphausiids and mesopelagic fish such as myctophiids. The gear was towed at a ships speed of 1 – 1.5 knots to maintain a 45º net angle. The 1 m MOCNESS was deployed in canyons and cross shelf transect areas to identify, classify and quantify the acoustic backscatter data from the EK60's 120 and 200 kHz frequencies. Deployments were a single double-oblique tow to depths around 500 m. One net remained open during the downcast, while the 8 remaining nets were opened sequentially during the upcast to provide vertically discrete plankton samples. Depths selected for net opening and closing were based on oceanographic features and backscattering layers seen on the EK60.

11.2.3.3 IKMT

During 2013 and 2014, macroplankton in the canyon and cross shelf transect areas was also sampled using an 6 ft beam Isaacs-Kidd midwater trawl (IKMT) with a ¼ inch mesh net and 1 mm mesh cod end. The IKMT was deployed off of the side sampling station in a single double-oblique tow. Sampling depth was determined by targeting the deepest scattering layer above 350 m seen on the 38 kHz frequency of the EK60. The IKMT can be towed at speeds up to 3.5 knots and has a larger mouth opening so it can be more successful at capturing mesopelagic fish than the 1 m MOCNESS.

In 2014, a larger IKMT with a 10 ft beam was deployed off the stern of the ship. The stern deployment allowed faster tow speeds and deeper hauls. This sampling method combined with the larger net area significantly increased the catches of mesopelagic fish and larger pelagic crustaceans such as shrimp that are a primary food of some cetaceans.

11.2.3.4 Midwater Trawl

During 2014 and 2015, a modified Marinovich midwater trawl (referred to as a "shallow water midwater trawl") was used as the primary trawl to sample pelagic fish and macrozooplankton. The shallow water midwater trawl was deployed with 1.8 m superkrub doors, 100 lb tom weights, 30 fathom bridles, and was fished at about 3 kts. The mouth opening when fishing was approximately 6 x 8 m (horizontal x vertical). The codend liner was ¼ in (0.625 cm) knotless nylon. A polytron midwater rope trawl was brought as a backup, but was not deployed. The midwater trawl was monitored during deployment by a Simrad FS70 trawl sonar mounted on the head rope, and by two Vemco temperature-depth recorders with one mounted on the head rope and one on the foot rope. The FS70 provided real-time data, which were recorded to a file and archived at the NEFSC. The Vemco recorders were initialized immediately prior to each deployment and the data were downloaded to a computer after each deployment.

Midwater trawls were deployed to sample acoustic backscatter observed in the multi-frequency EK60 backscatter acoustic data. Decisions on where and when to sample were made on an *ad hoc* basis depending on the observed backscattering patterns. Thus trawl tow depths and durations varied depending on the targets observed on the EK60.

11.2.4 Physical Oceanography

11.2.4.1 Seacat 19+ CTD

A Seabird Seacat 19+ was mounted on the wire above the sampling gear on all bongo, IKMT, and VPR hauls. The 19+ provided real time double-oblique profiles of pressure (depth), temperature and conductivity (salinity) and aided in the accurate deployment of net and imaging systems. Water samples were taken twice daily to provide salinity calibration data for the conductivity sensor. In addition, temperature and salinity data from CTD casts were used to calculate through-water sound speed for the active and passive acoustic teams.

11.2.4.2 Seabird 911 CTD

A Seabird 911 CTD with a 12 Niskin bottle rosette, Benthos altimeter, WetLabs Fluorometer-Transmissometer, oxygen sensor and light sensor was deployed to within 10 m of the bottom in a vertical fashion when the ship was holding station. Generally a series of deployments were made to document oceanographic changes across canyons, across the shelf slope area or across features like the Gulf Steam or warm core rings.

11.2.4.3 XBT

During only 2011, Sippican T-7 expendable bathy thermograph (XBT) probes were launched on the third leg of the HB1103 to record temperature profiles during four shelf break crossings. Three XBT transects were sampled while marine mammal observers were on-effort. One XBT transect was sampled during a nighttime, oblique shelf break crossing. Sippican T-7 probes record temperature and depth of the water to 760 meters with a vertical resolution of 65 cm while the ship is traveling less than 15 knots. On 21 July 2011 as a calibration, an XBT was launched during a day-time CTD station to compare the calibrated up-cast CTD temperature and XBT data. Temperature profiles for all XBT transects were interpolated and contoured to examine the thermal structure of shelf break regions within the mid-Atlantic Bight and Georges Bank. XBT’s were also launched on the SE shipboard surveys on a routine basis.

11.2.5 Relating Habitat to Marine Mammal Distribution

Work has begun to relate marine mammal presence to prey items in the shelf break region. As part of a recently completed PhD thesis (LaBrecque 2016), the mid-Atlantic Bight shelf break region was targeted because of the high biodiversity of marine mammals and the increased heterogeneity of the EK60 data. In addition, plans proposed for a recently started PhD thesis on this topic is presented in the discussion section.

In brief, LaBrecque (2016) first processed the EK60 data to classify organism types by following the methods outlined in Jech and Michaels (2006). Then the spatial distributions of these organism types were related to the dynamic hydrographic processes of the shelf-slope region. And finally the coupled active acoustic and hydrographic data were related to marine mammal distributions which ultimately described the fine scale distribution of marine mammals in a rich ecosystem context.

11.3 Results

Status of oceanographic data from the NEFSC shipboard surveys and net sample processing is summarized in Table 11.1.

11.3.1 EK60

Multi-frequency EK60 echosounder data were collected intermittently during HB09-03 (Appendix V Figure 1-1). During HB11-03, data were collected on a two day cycle, with continuous day and night acquisition on day “1” and with the echosounders secured during daylight observation efforts on day “2” (Appendix V Figure 2-1). EK60 data were collected continuously throughout each survey in 2013 and 2014 (Appendix V Figures 3-1 – 5-2), with intervals of active and passive modes. EK60 data were collected continuously in either active or passive mode during leg 1 of HB15-03 (Appendix V Figure 6-1). Data during 11 – 15 June 2015 and 18 – 19 June 2015 were collected to 500 m and to 2500 m at other times. The depth of 500 m was selected for data collected on the continental shelf and Georges Bank, while 2500 m was selected for data collected at the shelf break and in deeper water. All data on the shelf and on Georges Bank were collected in active mode. Data collected at the shelf break and in deeper water were collected in either active or passive mode.

Post processing EK60 data has been prioritized based on area, time, and activities. Post processing includes removing the echo from the seabed and any electronic, acoustic, or bubble noise. All data collected during HB14-03 were post processed daily at sea, whereas no HB09-03 or GU14-02 data have yet been post processed. The majority of data collected during daylight hours have been post processed for HB11-03 and HB13-03. For HB13-03 some night data have been post processed, such as during times canyons were surveyed or during cross-shelf transects at selected sites.

All EK60 data were stored on a portable hard drive, archived at the NEFSC, and sent to NOAA's National Center for Environmental Information (aka National Geophysical Data Center in Boulder, CO) for permanent archive.

Representative echograms for 2013 are shown in Figure 11-1. Warmer colors represents greater intensity of backscatter. Localized surveys of canyons show spatial distributions of organisms within canyons and often show disparities in acoustic backscatter between sides of the canyon and/or longitudinal location within the canyon.

Representative echograms for 2014 are shown in Figures 11-2 – 11-3. Shelf-break regions typically had increased acoustic backscatter (Figure 11-2), which is due to a combination of higher densities of organisms as well as greater diversity of organisms. Echograms from the daytime in oceanic water typically showed the deep scattering layer between 400 and 600 m depth. At dusk a portion of this layer did not vertically migrate to the near surface waters. In addition, echograms showed layers in the top 300 m that often vertically migrated at dawn and dusk (Figure 11-3). These layers were sampled with a midwater trawl and an Isaacs-Kidd net in 2014.

Multi-frequency backscatter volume (Sv) echograms from 2015 highlight a variety of acoustic backscattering patterns that are indicative of the spatial and temporal distributions of multiple trophic levels, and some of the patterns are unique to specific species, times, and locations (Figures 11.4 – 11.6). Figure 11.4 upper panel highlights a biophysical interaction with small gas-bearing organisms (e.g., siphonophores) entrained in an internal wave near the sea surface, as well as “speckles” of individual gas-bearing fish just beneath the internal wave (upper left). A layer of small gas-bearing organisms in the mid water column are highlighted in the lower left panel, and fish without a gas-filled swimbladder such as butterfish (*Peprilus* *triacanthus*) and/or Atlantic mackerel (*Scomber scombrus*) are near the bottom in the lower right panel.

A spawning aggregation of Atlantic herring (*Clupea harengus*) on Georges Bank was observed acoustically (Figure 11.5) and from trawl catches. Atlantic herring are not thought to spawn during spring in the Gulf of Maine (or spring spawning is inconsequential to the population) so this provides direct evidence of at least some spawning on Georges Bank occurs in the spring/early summer.

Mesopelagic fish dominate acoustic backscatter at/near the shelf break (Figure 11.6), where certain species (primarily myctophid species) migrate from 400 – 600 m depths to near the surface at night and other species stay at depth. The relative frequency responses suggest small organisms and fish with gas-bearing swim bladders.

Table 11-1 Oceanographic and net sampling collected from 2009 – 2015 NE cruises

Cruise		HB0903	HB1103	HB1303	GU1402	HB1403	HB1503
CTD	# Sta	65	104	242	202	15	53
	Status	complete	complete	complete	complete	complete	complete
XBT	# Sta	0	43	0	0	0	0
	Status	NA	complete	NA	NA	NA	NA
Bongo Z	# Sta	25	85	83	125	11	26
	Status	identified	identified	identified	identified	identified	identified
Bongo I	# Sta	24	84	81	125	11	26
	Status	identified	identified	identified	identified	identified	identified
VPR	# Sta	25	46	16	10	none	4
TowYo	Status	complete	complete	complete	complete	NA	complete
VPR Fixed	# Sta	0	35	14	0	0	0
	Status	NA	complete	complete	NA	NA	NA
MOC 1m I	# Sta	0	0	8	1	none	none
	Status	NA	NA	77 nets id	7 nets id	NA	NA
MOC 1m Z	# Sta	0	0	8	1	0	0
	Status	NA	NA	75 nets id	7 nets id	NA	NA
MOC/VPR	# Sta	0	0	8	0	0	0
	Status	NA	NA	processing	NA	NA	NA
IKMT 6'	# Sta	0	0	10	1	0	0
	Status	NA	NA	identified	identified	NA	NA
IKMT 10'	# Sta	0	0	0	0	1	0
	Status	NA	NA	NA	NA	identified	NA
Midwater	# Sta	0	0	0	0	3	21
	Status	NA	NA	NA	NA	identified	identified
Didson	# Sta	0	0	0	0	0	8
	Status	NA	NA	NA	NA	NA	processing
Go-Pro	# Sta	0	0	0	0	0	16
	Status	NA	NA	NA	NA	NA	processing

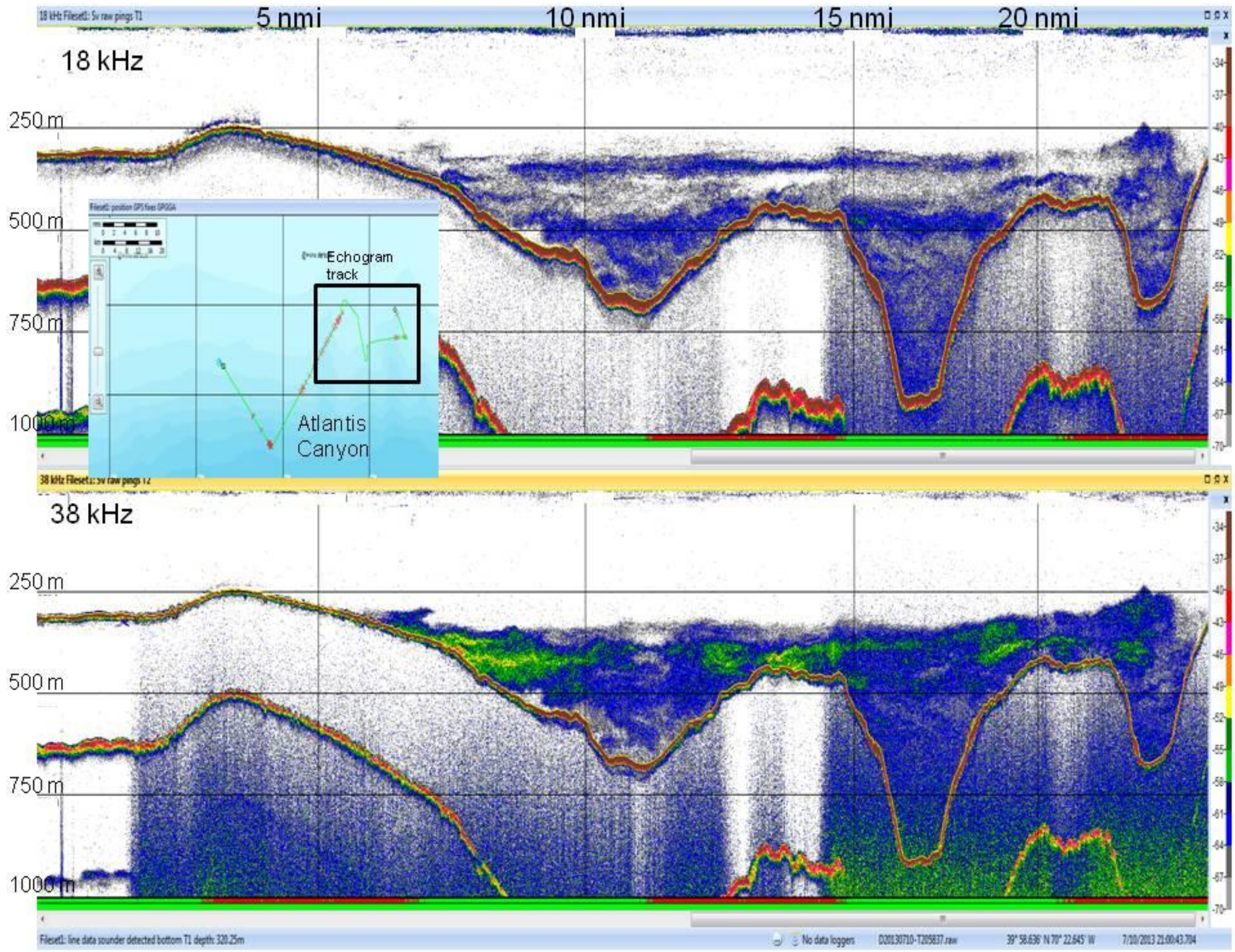

Figure 11-1 Multifrequency echograms of Simrad EK60 echosounder from 10 July 2013

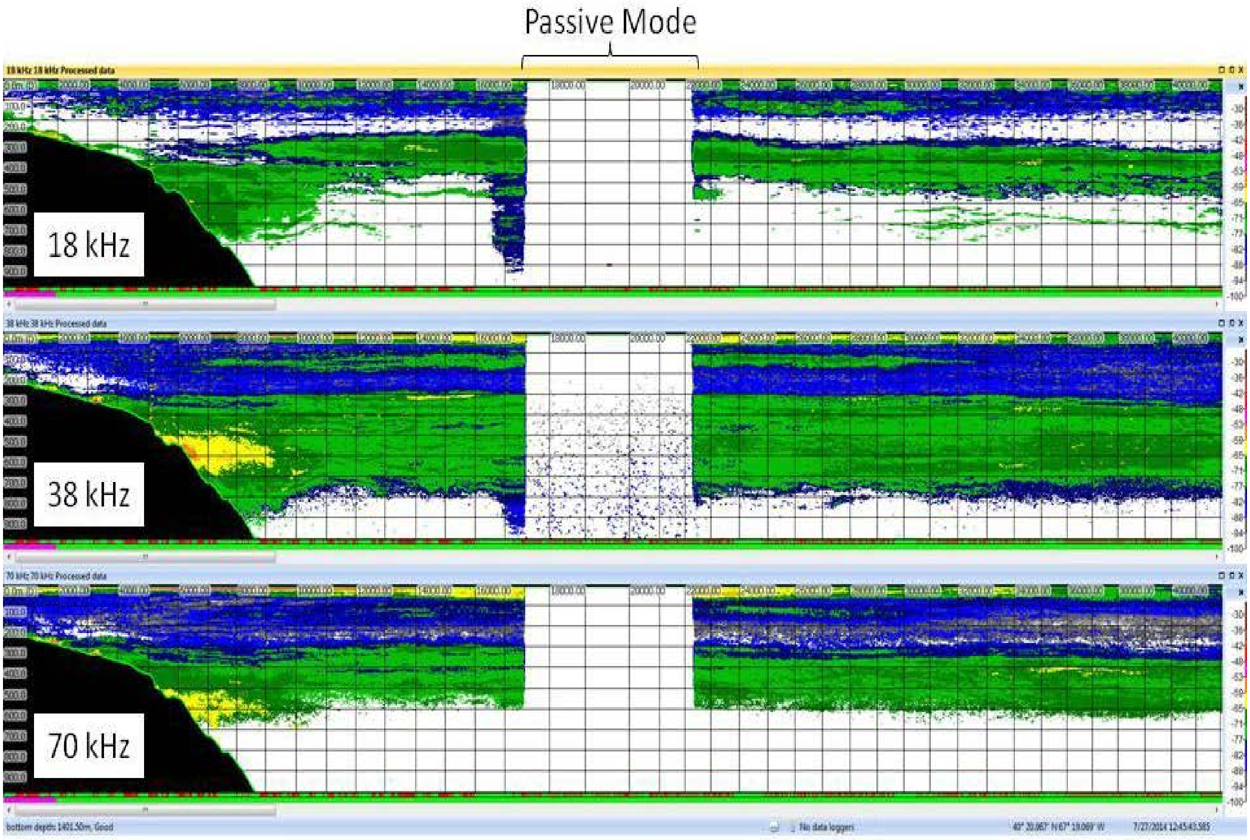

Figure 11-2 Multi-frequency echograms from 27 July 2014 near shelf break
The “empty” segment represents the EK60s set to passive mode. Each vertical line represents 1 km distance intervals and each horizontal line represents 100 m depth intervals.

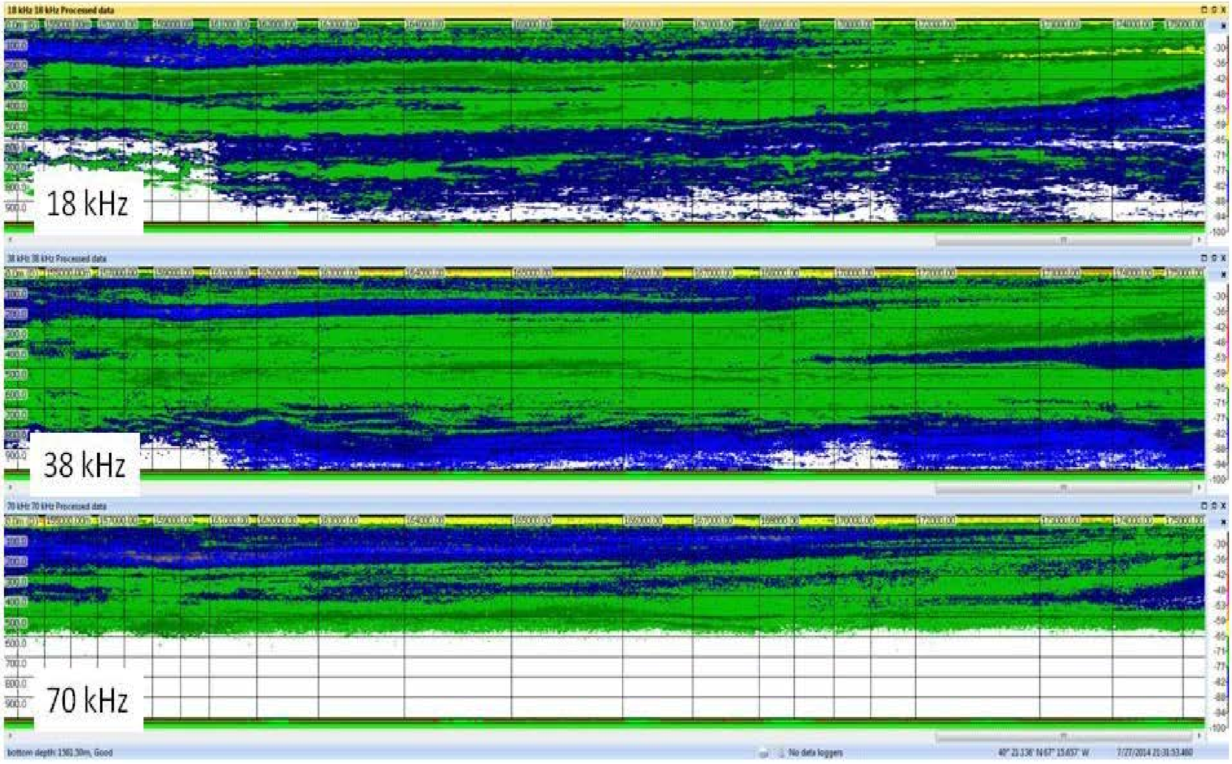

Figure 11-3 Multi-frequency echograms from 27 July 2014 in deep oceanic waters
Each vertical line represents 1 km distance intervals and each horizontal line represents 100 m depth intervals.

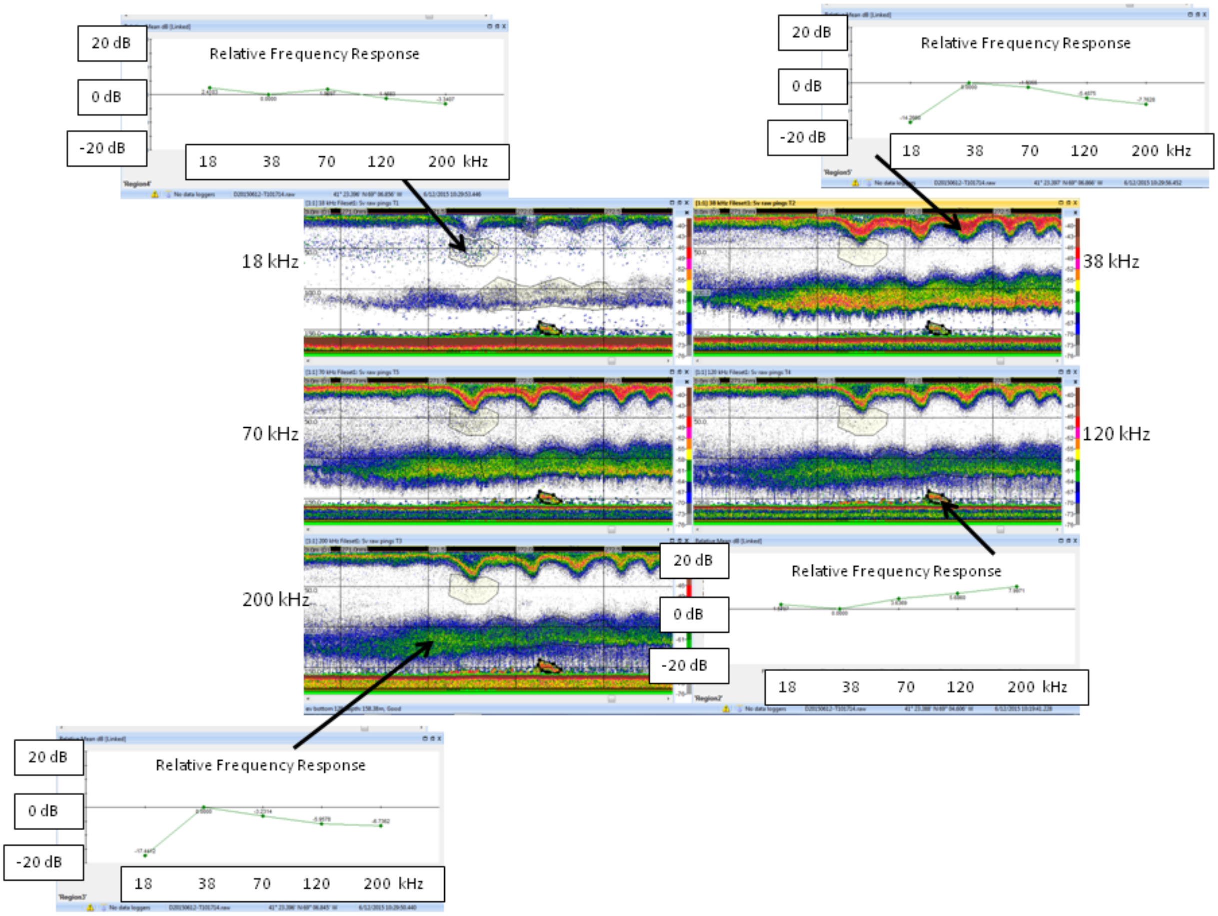

Figure 11-4 Sv echograms and frequency responses from 12Jun2015 in Great South Channel
The depth of the echograms is 175 m and horizontal lines are at 50-m intervals.

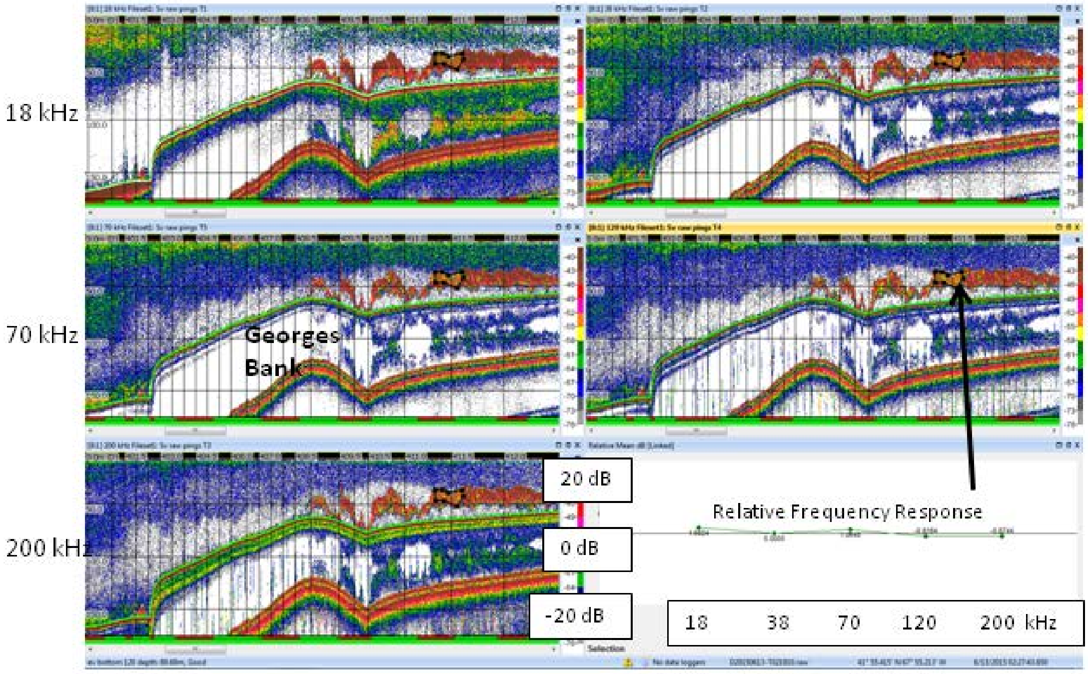

Figure 11-5 Sv echograms and frequency responses from 13 Jun 2015 on Georges Bank
The depth of the echograms is 175 m and the horizontal lines are at 50-m intervals.

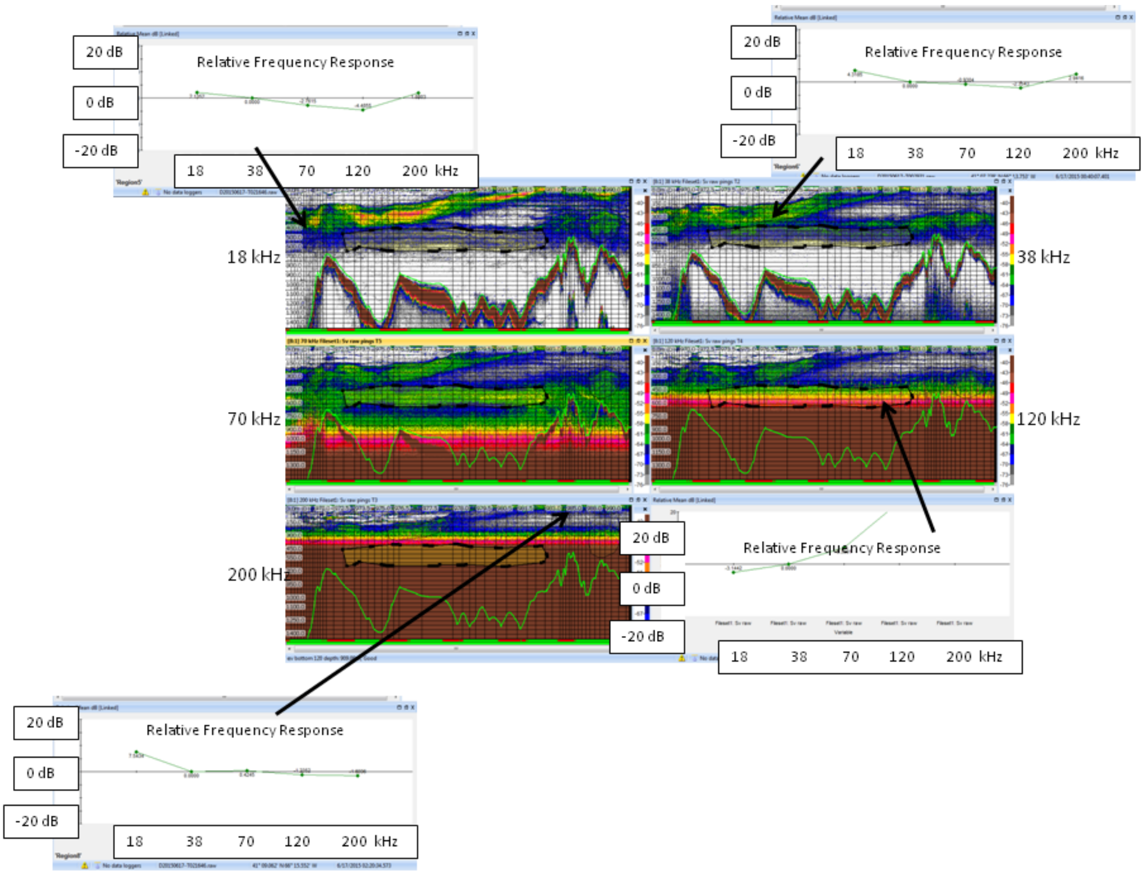

Figure 11-6 Sv echograms and frequency responses from 16 – 17 Jun 2015 on shelf break
Depth of the echograms is 1500 m and each horizontal lines is at 50-m intervals.

11.3.2 Imaging

11.3.2.1 VPR

A total of 101 tow-yo type and 49 single depth VPR hauls were conducted between 2009 and 2015 (Figure 11-7). All hauls have been processed to graph oceanography, create ROIs, remove duplicate ROIs, remove ROIs of air bubbles and deck images, and identify species in ROIs. Hauls from HB13-03, GU14-02, and HB15-03 had the automated ROI identifications hand corrected. Graphs and spreadsheets of oceanographic properties and plankton densities have been created for each haul and are available upon request to the NEFSC Oceanography Branch.

VPR data are being used to increase the geographical coverage of plankton nets to more accurately describe the plankton component of the ecosystem in the study area. VPR data provides closely coupled stratified plankton and oceanographic data. In general, plankton was plentiful at the shelf slope front and was characterized by distinct layers. Plankton densities in water characterized as slope water or Gulf Stream water were extremely low. Inshore areas off Delaware Bay or Nantucket shoals were characterized by high densities of marine snow, ichthyoplankton, and high species diversity. Throughout the years of the AMAPPS program the VPR showed plankton densities were highly correlated with the depth and strength of the thermocline. Macroplankton such as salps, euphausiids and myctophiids, which are common species in the study area, are known to be strong vertical migrators residing at 300 – 1000 m during the day and rising to near the surface at night. VPR sampling was conducted after the dusk migration was completed so these species were within the sampling range of the gear. Gelatinous zooplankton such as ctenophores, siphonophores, and hydromedusa were seen in the top 10 m while smaller plankton like copepods and pteropods were found in and just below the thermocline. Euphausiids and myctophids were found in layers beginning a distance below the thermocline.

The VPR proved to be highly effective in imaging gelatinous zooplankton such as salps, siphonophores, hydromedusa, and ctenophores which are damaged or destroyed by net sampling. While it does not quantitatively sample larger salp chains or the colonial siphonophores it clearly shows their structures and can be used for species identification (Figure 11.8). The VPR was valuable for quickly determining if the densities of gelatinous zooplankton were too high to deploy net samplers.

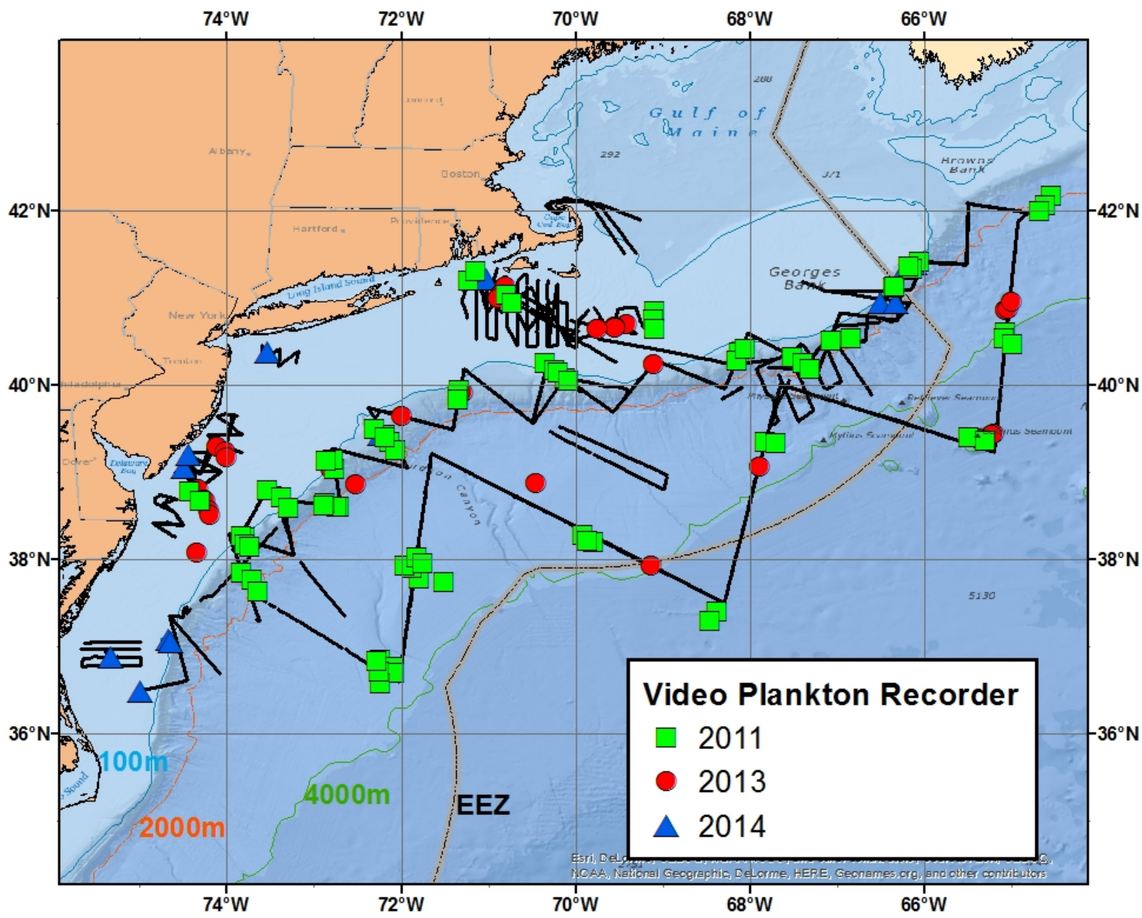

Figure 11-7 Locations of VPR deployments during 2011 – 2014

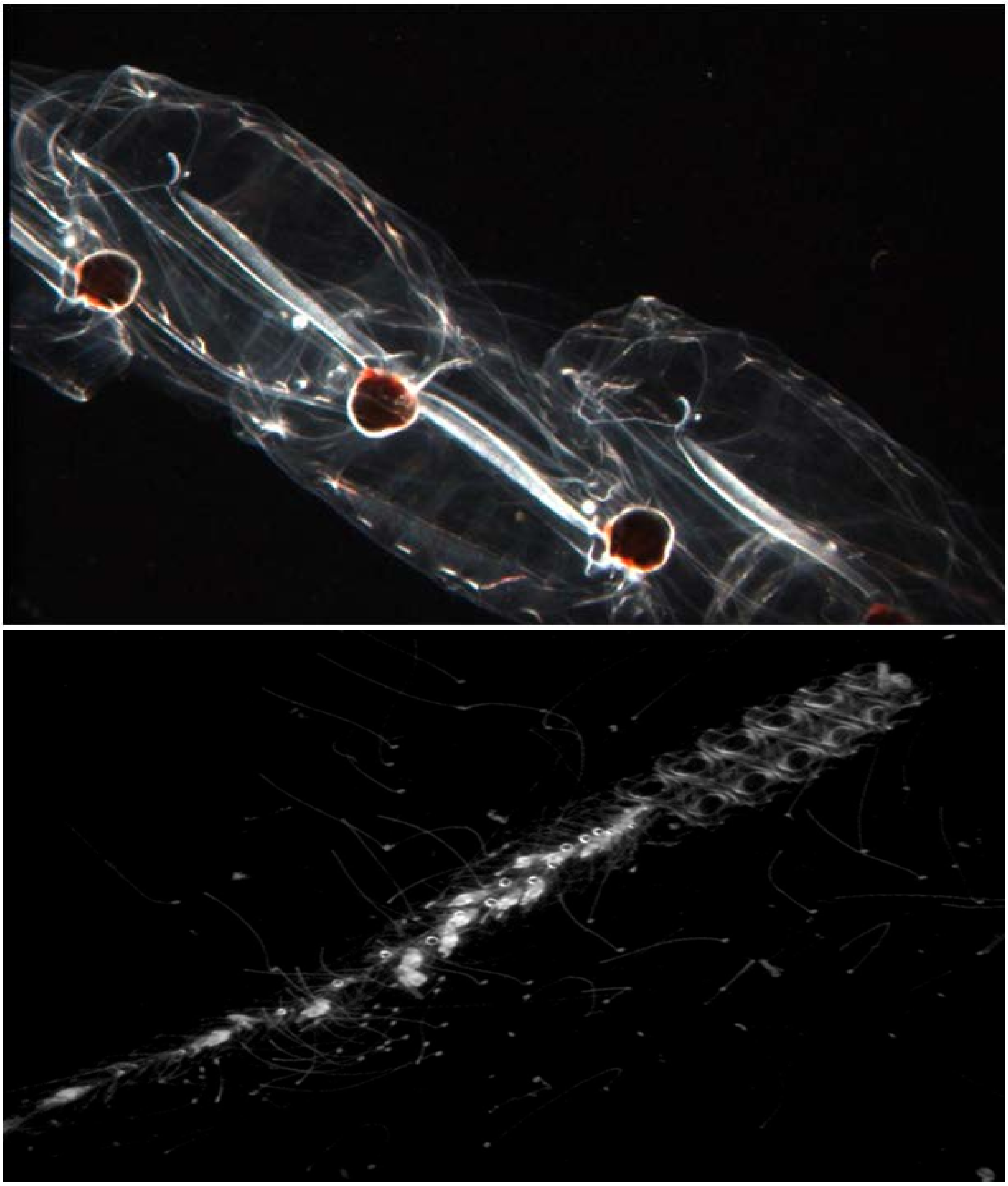

Figure 11-8 VPR images
(Top) *Salpa aspera* aggregate form. (Bottom) siphonophore from the Agalmidae family (bottom).

Use of the VPR during AMAPPS cruises has allowed many improvements to be made to gear deployment methods, processing protocols, and the VPR software. These improvements have increased deck safety and decreased the time required to produce usable data. Processing protocols have been adapted to decrease the amount of redundancy in image processing.

A new MATLAB based program was developed to provide near real time graphs of oceanographic conditions recorded by the VPR sensors (Figure 11.9). Changes were made to the Visual Plankton processing program to create spreadsheets and graphs of plankton densities in a format compatible with the Oceanography Branch Oracle plankton database.

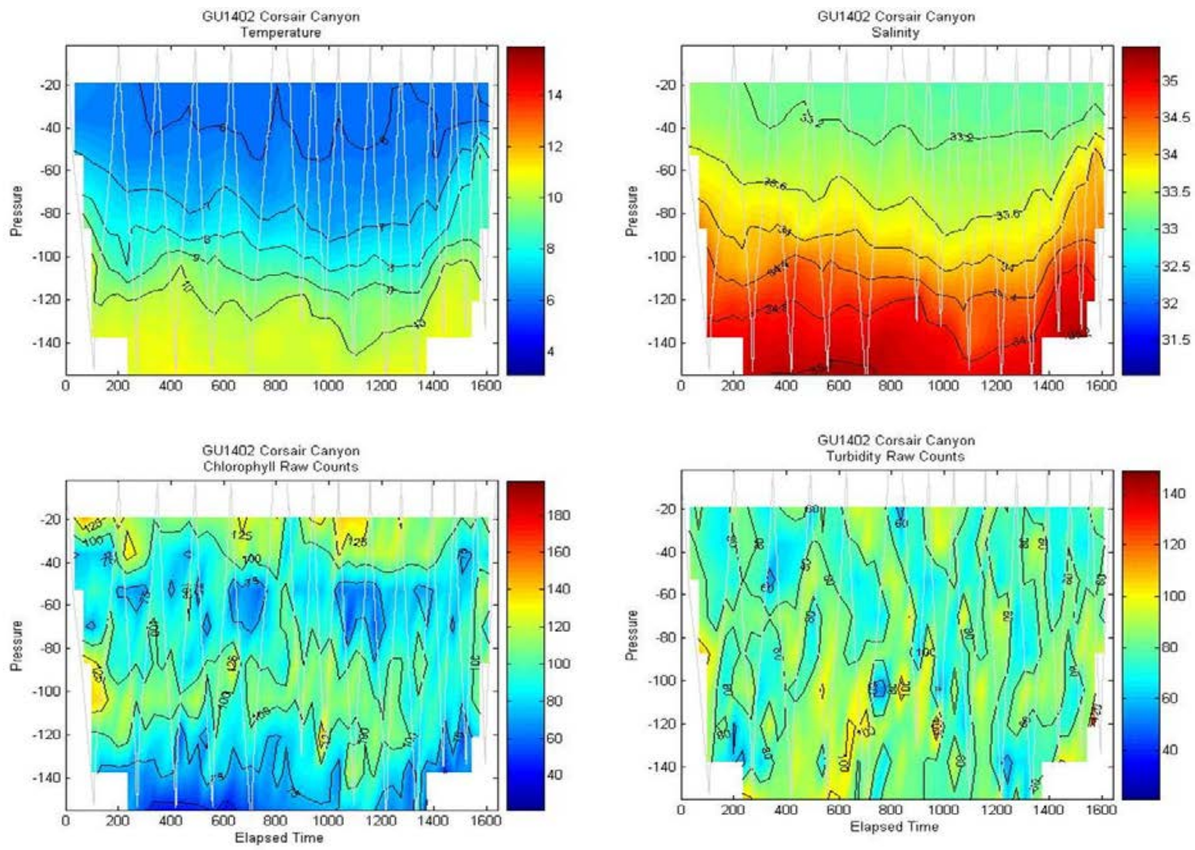

Figure 11-9 Conditions along a VPR transect across Corsair Canyon, April 2014

A growing set of classifiers, ranging from basic to site-specific, have been created using Visual Plankton and the ROIs from the AMAPPS cruises. The catalog of classifiers can be brought to sea so new classifiers do not have to be created from scratch. Using the documented descriptions, an appropriate classifier can be selected for use or one that is close to what is needed can be quickly adapted to fit current plankton assemblages. A library of over 17,000 ROIs categorized by camera setting and taxonomic groupings has also been created. This library will be used for training and to decrease the amount of time needed to create new classifiers.

It was noted during processing that hauls with large amounts of marine snow did not seem to be as accurately identified as those with lower densities. Multiple classifiers, each changing the identification category of marine snow, were used in an effort to understand how the program responded to increase identification accuracy. To quantify identification error, a ROI identification accuracy quality control study is ongoing. The study will compare the VPR casts from HB13-03 that have been processed with the same classifier using three methods: the processed Visual Plankton; processed by Visual Plankton with a confusion matrix correction; and processed by Visual Plankton then hand corrected.

Data from the HB13-03 cruise is being prepared to be compared with data from the EK60 data. Plankton densities based on counts and area are being binned to match the corresponding EK60 values taking into account the frequency-dependent nature of acoustic scattering and the likely relative contributions to measure backscattering of the different sizes and types of plankton present. Plankton categories in the classifier were selected to sort plankton by size and type (chitinous, gelatinous, or other). Categories will be added or removed to obtain the closest match possible to the EK60 data. The study should provide plankton density data to associate with EK60 signal strength, reveal the size or density detection limitations of the EK60 being used on NOAA research vessels, and show any signal strength differences between soft bodied plankton such as salps and hard bodied zooplankton such as euphausiids.

The ability of VPR data to be binned in very small scale time and depth categories that can be closely tied to oceanographic conditions makes this data ideal to study small scale plankton processes. Casts were selected from the inshore sampling stations near Delaware Bay and Nantucket shoals to be initially analyzed based on their high densities and species diversity. Comparisons of patchiness of inert particles like marine snow with more mobile plankton such as newly spawned gastropod veligers, actively swarming gammarid amphipods, and ichthyoplankton are being conducted to find if there are notable differences. Oceanographic conditions will be compared to plankton densities to determine their effect on patchiness and layering.

11.3.2.2 Didson/ Go-Pro

Analysis of the imaging systems data is still ongoing. There were few large organisms present in the water column during the HB15-03 cruise, thus it is hard to assess the effectiveness of the Didson acoustic imaging. The Go-Pro system was able to capture images of some small organisms but image blurring makes identification of macroplankton difficult. A fish imaged by both systems gives an example of the potential of this system (Figures 11.10 – 11.11) to image mesopelagic fish and gelatinous zooplankton too large to be seen by the VPR.

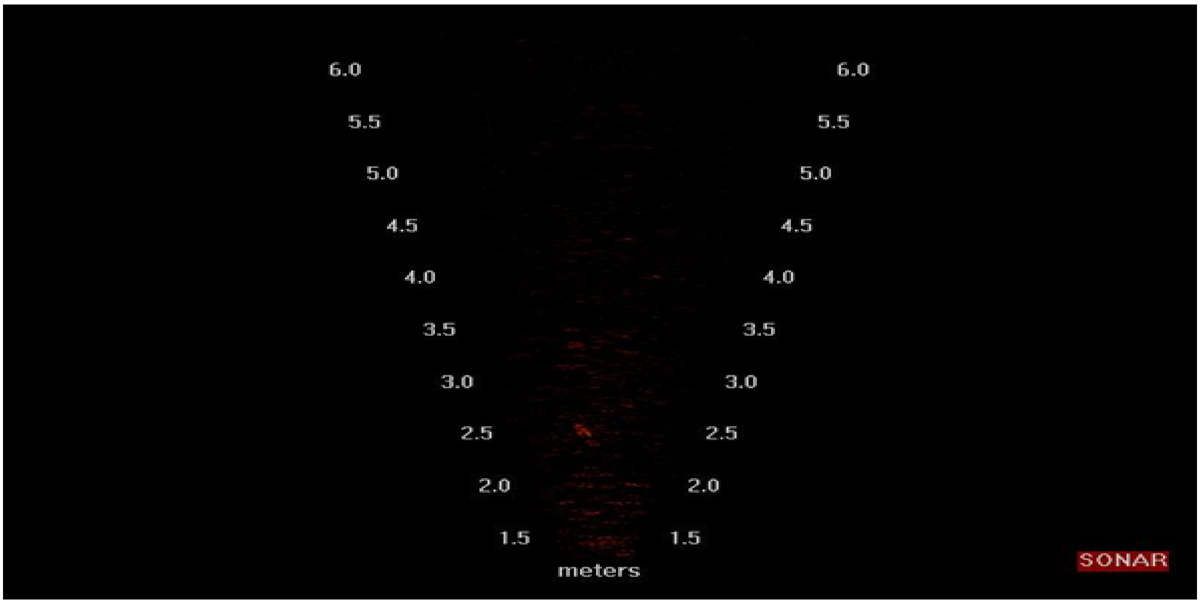

Figure 11-10 Didson imaging sonar scan of a fish

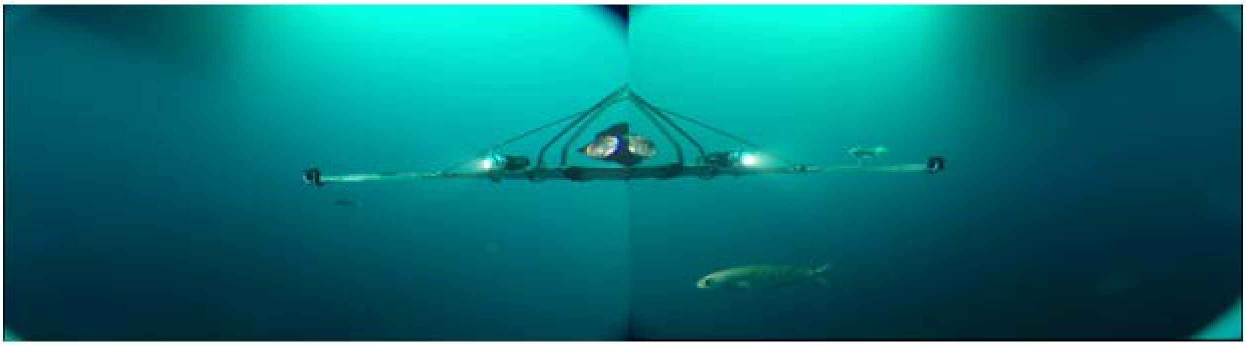

Figure 11-11 Split screen view of same fish as in Figure 9-9 from the two GoPros

11.3.3 Net Samplers

11.3.3.1 Bongo Net

A total of 355 bongo tows were completed during cruises from 2009 – 2015 (Figure 11-12). All ichthyoplankton were removed, identified and measured. Ichthyoplankton were preserved in ethanol alcohol. All zooplankton were identified and enumerated. All processed bongo samples and ichthyoplankton samples were archived at the NEFSC Narragansett Laboratory. Plankton data are being added to the NEFSC plankton Oracle database or are available upon request from the NEFSC Oceanography Branch.

Bongo tows from the AMAPPS cruises have extended the range of plankton sampling conducted by the NEFSC Oceanography Branch to include the area of the Northwest Atlantic extending from Nova Scotia to the mid-Atlantic Bight between the shelf slope and the Gulf Stream.

Targeted sampling has provided special samples of gelatinous zooplankton and euphausiids for researchers at the Woods Hole Oceanographic Institution, University of Connecticut, University of Maryland Center for Environmental Science, Rutgers Institute of Marine and Coastal Sciences, Auburn University, and the NMFS Office of Science and Technology.

For example, samples (sometimes sub-samples or selected specimens) have been preserved in undenatured alcohol for Dr. Ann Bucklin (University of Connecticut) and colleagues. In nearly all cases, Dr. Bucklin requested samples containing various salps (Tunicata, Thaliacea), which have been used for genetic and genomic analysis (Govindarajan et al. 2011). Specifically, the Northwest Atlantic salps have been – and are still being – used for comparative analysis with the Southern Ocean salp, *Salpa thompsoni*, which is the focus of NSF-funded efforts led by Dr. Bucklin (Batta-Lona et al. 2016; PLR-1044982 and PLR-1643825). These efforts seek to investigate the genomic basis of adaptation, and to explore the relationship between the rapid genomic evolution typical of salps, their unique life history, and their potential for adaptation to environmental conditions and climate change (Jue et al. 2016). In support of another project in Dr. Bucklin's lab, in collaboration with Annette Govindarajan (Woods Hole Oceanographic Institution), the AMAPPS salp samples are providing an opportunity to develop DNA barcodes for identification of salp species, which continues to be challenging even for taxonomic experts.

Samples of mesopelagic fishes were used for another NSF-funded project on the importance of gelatinous prey. Martha Hauff (now at Stonehill College) presented preliminary results at several meetings (Hauff et al. 2013; 2014; 2015) and is close to a publishable dataset.

11.3.3.2 MOCNESS

A total of nine MOCNESS hauls were conducted in 2013 and 2014. All ichthyoplankton were removed, identified, measured and preserved in ethanol alcohol. A subset of the zooplankton from each net have been identified. Data are available upon request from the NEFSC Oceanography Branch.

MOCNESS hauls were conducted along the west side of canyons where EK60 transects revealed higher concentrations of macrozooplankton and mesopelagic fish. Data are being used by researchers at Woods Hole Oceanographic Institution and NEFSC to characterize the plankton populations in canyon areas relative to the oceanographic processes that may affect distributions of the plankton.

11.3.3.3 IKMT

Eleven samples from the 6 ft IKMT and one sample from the 10 ft IKMT from 2013 and 2014 were processed. All ichthyoplankton were removed, identified to the lowest taxonomic level possible, enumerated, and preserved in ethanol alcohol for additional study (Table 11.1). Each net sample was split to subsamples of 500 – 1000 individuals that were identified to the lowest possible taxonomic and life stage-level possible and enumerated. Data were loaded into the NMFS Oracle plankton database. The zooplankton data will be used in conjunction with the bongo, midwater trawl, and MOCNESS data to aid in the ground truthing of the EK60 sorting categories: fish-like, euphausiid-like/ micronekton, copepod-like/zooplankton, and other.

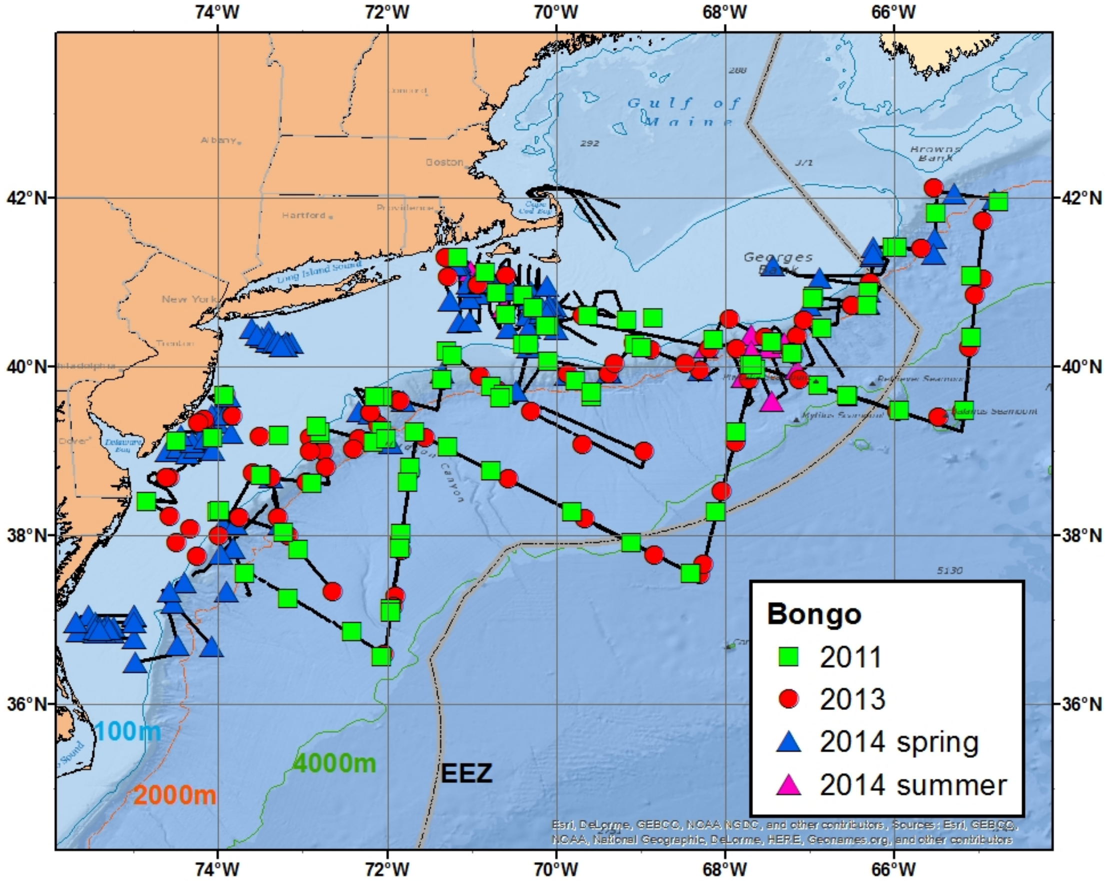

Figure 11-12 Location of bongo deployments during 2011 - 2014

11.3.3.4 Midwater Trawl

Four midwater trawl deployments were conducted in July 2014 on HB-1403 (Figure 11.13). Two tows sampled the acoustic scattering layer between 500 and 600 m, and two tows sampled acoustic scattering layers between 50 and 100 m. The deep tows captured shortfin squid, other cephalopod species, and a number of mesopelagic fish species, such as slender snipe eels, ridgehead species (Melamphaidae), and viperfish species (*Chauliodus*). The shallow tows were dominated by myctophids such as *Benthosema* and *Diaphus* species.

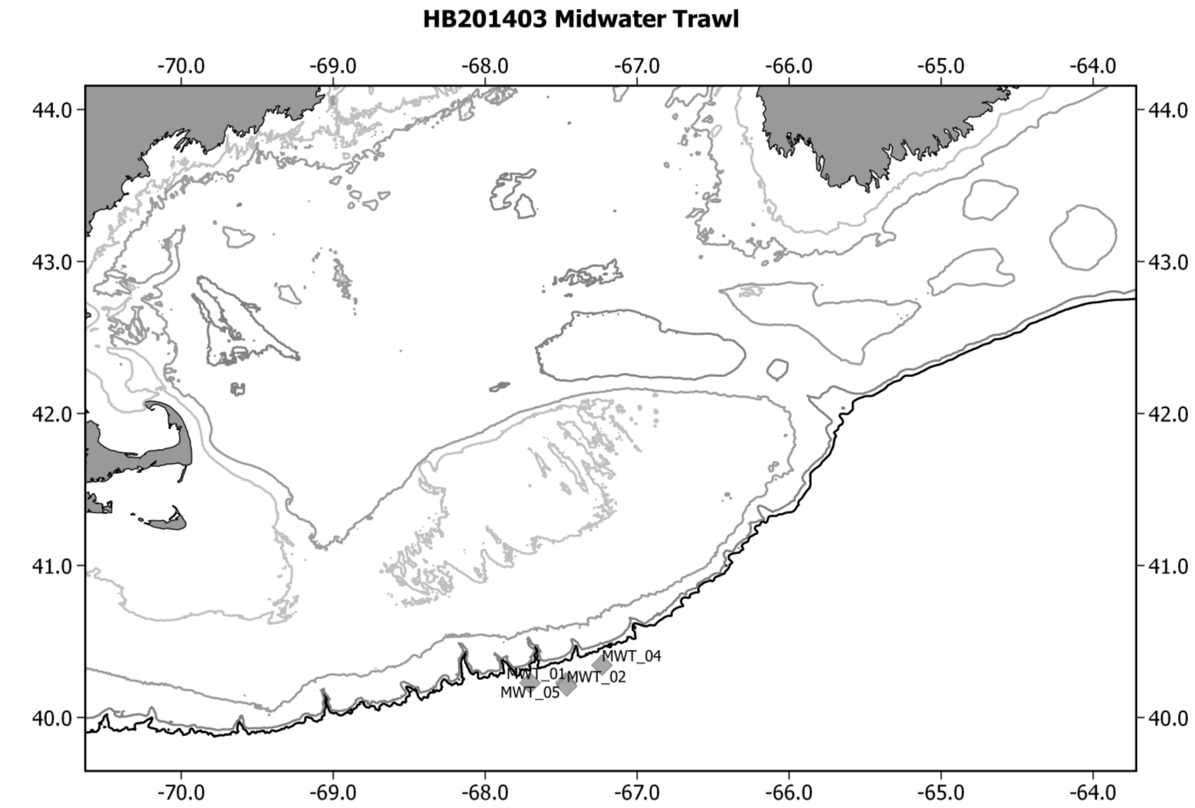

Figure 11-13 Midwater trawl locations (diamond symbols) from HB14-03

Twenty-one midwater trawl deployments were conducted in June 2015 (Figure 11.14). Trawl catches were sorted to species, each species weighed *en masse*, and up to 150 individuals were randomly (or all if less than 150 individuals) selected for fork length measurements. Species composition reflected the area where the tows occurred. In the Georges Bank area (tows 2 – 15), tows consisted of krill (*Meganyctiphanes norvegica* and likely other species), shrimp (*Pandalus* sp.), gelatinous zooplankton (primarily salps), and fish species such as Atlantic herring (*Clupea harengus*), butterfish (*Peprilus triacanthus*), silver hake (*Merluccius bilinearis*), and Acadian redfish (*Sebastes fasciatus*). The tows at the shelf break and deeper (tows 17 – 24) were dominated by mesopelagic species such as lanternfish (Myctophidae), snipe eels (*Nemichthys scolopaceus*), bristlemouths (Gonostomatidae), dragonfish (Stomiidae), marine hatchetfish (Sternoptychidae), as well as invertebrate squid and octopus species.

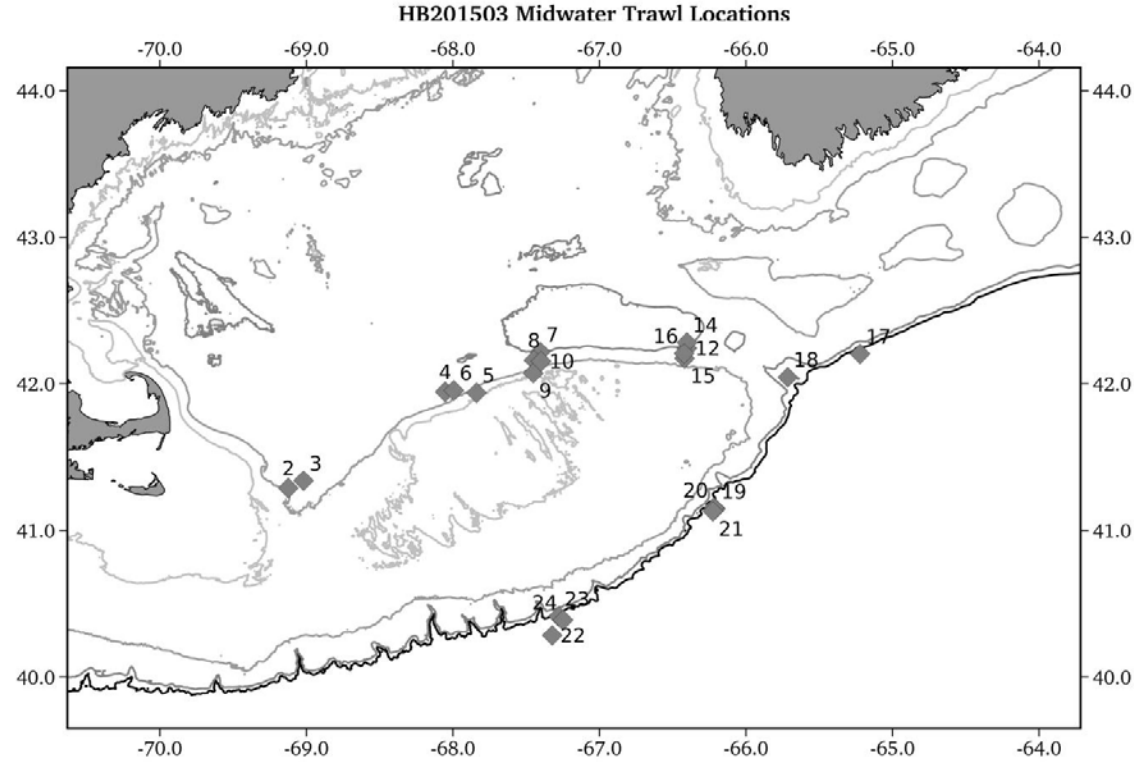

Figure 11-14 Midwater trawl locations for HB15-03

11.3.4 Physical Oceanography

11.3.4.1 Seacat 19+ CTD

A total of 623 Seacat 19+ casts were conducted. The 19+ provided real time oceanographic and depth data to the shipboard operator conducting the associated bongo, VPR, Niskin, and IKMT sampling. Data from the first upcast of all casts were processed and posted to the NMFS Oracle physical oceanography database.

11.3.4.2 Seabird 911 CTD

A total of 58 casts were conducted in the shelf break region, as part of two types of sampling transects. Canyon transects include a series of five CTD casts made across the width of the canyon parallel to the shelf break proper, consisting of one cast on the rim on each side, one about halfway down the slope on each side, and one in the axis at the deepest point. Cross shelf transects consisted of CTD casts spaced 3 nm, beginning at the 80 m isobath and extending across the shelf to the 1500 m isobath. The upcast from each deployment was processed and data posted to the NMFS Oracle physical oceanography database.

11.3.4.3 XBT

When comparing XBT data to calibrated CTD data from the same time and place, it was determined the XBT data were accurate. The mean difference between the values from the XBT and the values from the co-located and calibrated CTD up-cast was 0.023˚C (CTD – XBT) with a standard deviation of 0.42.

Analysis of the XBT data showed the thermal structure of the daytime shelf break track lines that were sampled. XBT line 3 (Figure 11.15), off the east side of Georges Bank, showed typical summer thermal stratification over the shelf with the entrapment of the cold pool (< 10 °C) between 25 – 100 m, that protruded several kilometers offshore of the shelf break. Warmer surface waters offshore were concentrated in the top 100 m of the water column and extend to approximately 200 m. On XBT line 7 (Figure 11.16), which crossed Lydonia Canyon, the cold pool was pushed onto the shelf from an encroaching warm-core ring filament. Thermal stratification was evident in the offshore section of trackline 11 (Figure 11.17), but the cold pool was not as well defined as compared to the other XBT transects.

Ongoing work includes overlaying the thermal structure of all three daytime transects on the EK60 data to determine the spatial distribution of acoustic back scatter within the thermal structure of these tracklines.

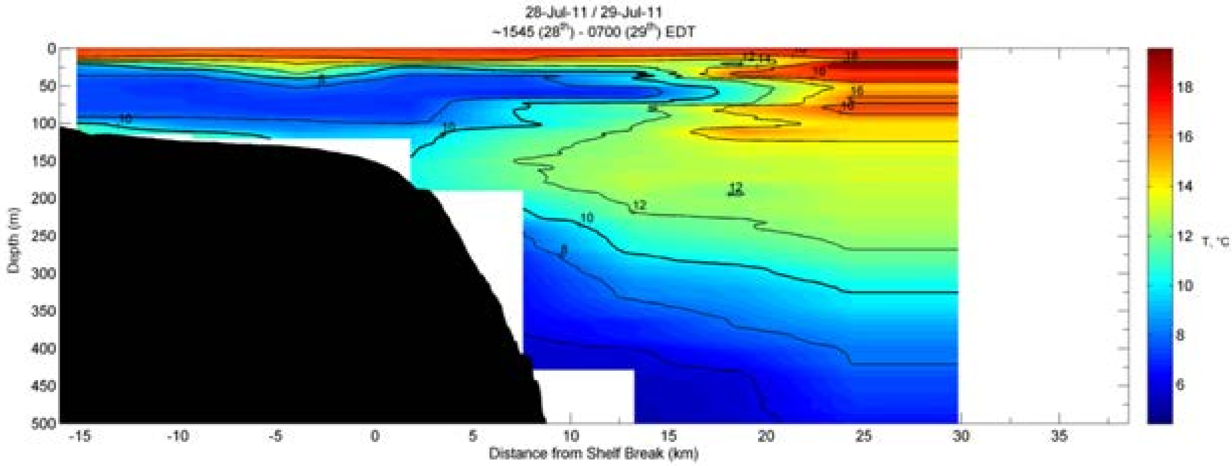

Figure 11-15 Temperature (°C) along XBT line 3 off Georges Bank

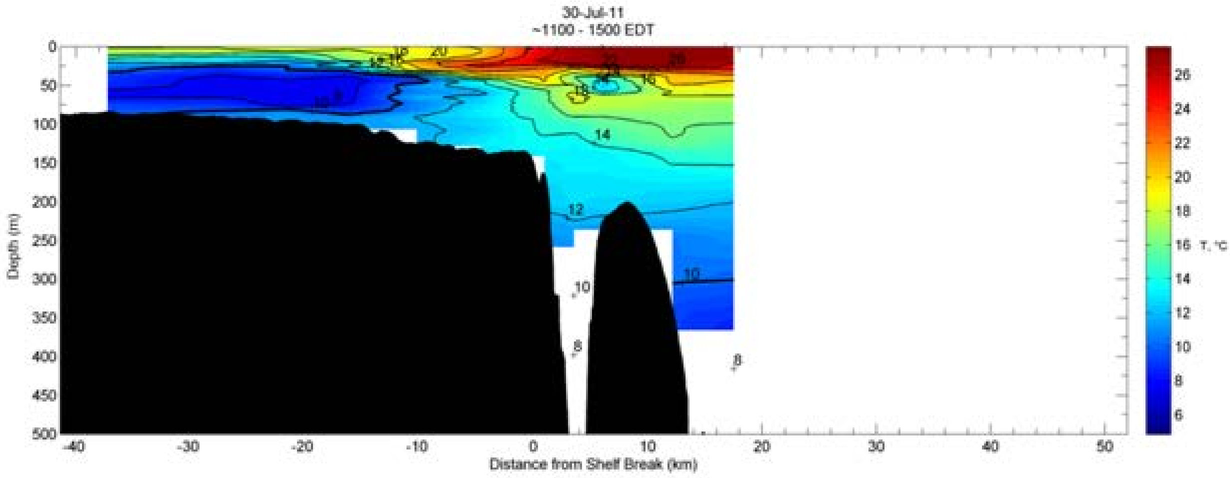

Figure 11-16 Temperature (°C) along XBT line 7 crossing Lydonia Canyon

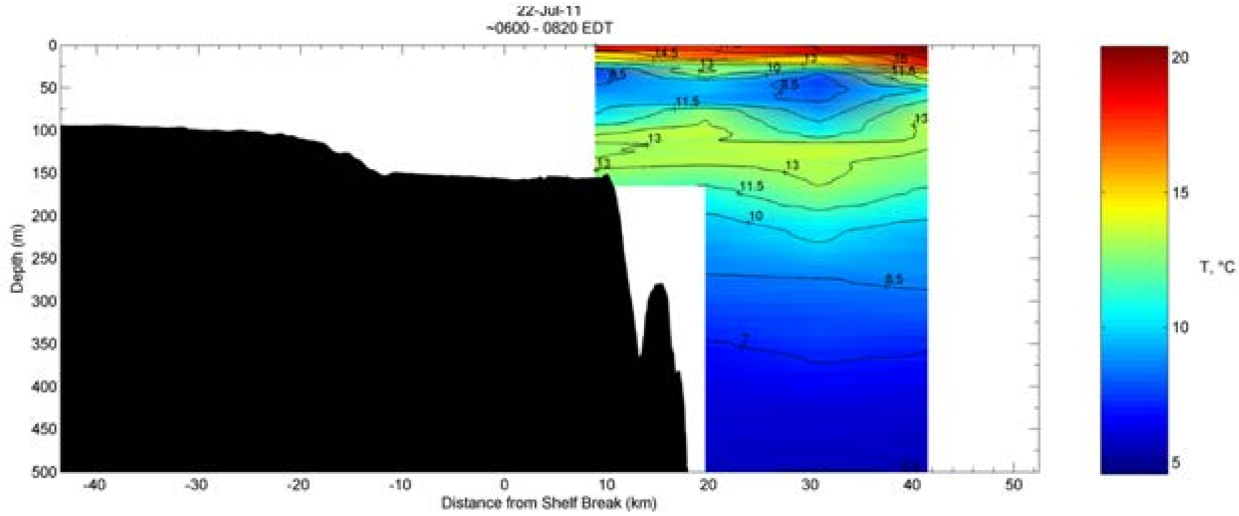

Figure 11-17 Temperature (°C) along half of XBT line 11 near Veatch Canyon

11.3.5 Data Synthesis

Work has begun to ground-truth the classified organism types from the echosounder EK60 data with the midwater trawls, 10 ft IKMT and MOCNESS data.

Work has also begun to synthesize the biological and physical oceanographic data collected in the canyon areas. Data are being studied to reveal the oceanographic processes that affect transport and aggregation of planktonic and mesopelagic prey. Future studies plan to link these environmental data to the visual and passive acoustic records and to use the data to parameterize models.

In addition, work has begun to utilize the data collected from the cross shelf CTD transects to describe shelf slope front oceanographic and transport processes.

Other synthesis work includes improving the speed and accuracy of the automatic classification programs used on the VPR data.

11.3.6 Relating Habitat to Marine Mammal Distribution

Figure 11.18 presents backscatter volume S_v data from the 18, 38, and 120 kHz transducers from a shelf break transect off Georges Bank collected on 28 and 29 July 2011. High intensity scattering (yellow-red colors) is prevalent in the 18 and 38 kHz echograms at the shelf break and offshore of the shelf break between 100 m and 300 m. High intensity scattering in the 18 kHz also occurs in the top 50 m of the water column offshore. High intensity scattering in the 120 kHz echogram is more prevalent at the shelf break and directly over the shelf.

To interpret these intensity backscatter patterns, Jech and Michaels (2006) was followed to develop a color-coded presence, absence or combination of backscatter that represent different types of organisms (Figure 11.19). Color-coding is based on frequency combinations where “1”, “2”, and “3” denote backscatter above the -66 dB threshold for 18, 38, and 120 kHz respectively. The dash, “-“, indicates the absence of a frequency. Areas where all three frequencies are above the threshold (light blue) are hypothesized to be Atlantic herring (Jech and Michaels 2006) or, in general, fish with swim-bladders. Areas where the 120 kHz is above the threshold (red) are assumed to be Euphausiids. While, areas with both the 38 kHz and 120 kHz dominating the backscatter (dark blue) Euphausiids or shrimp are assumed. The black band across the surface is the upper 10 m of the water column that was removed due to low quality of backscatter information. The color-coded echogram highlights the spatial distributions of categorized acoustic scattering. Euphausiid-like scattering is present over the shelf just above the sea floor and directly off the shelf break at 300 – 400 m. Discrete patches of fish-like scattering are present off the shelf break and intermixed within areas of scattering where only 18 kHz data were present. Because of the intensity of scattering of the 18 kHz data, light purple areas are hypothesized to be areas of fish-like scattering or mixed species assemblages.

Marine mammal sightings also show spatial patterning along this track line. Common dolphins (green crosses in top panel of Figure 11.19; Table 11.2) were more frequently sighted over the shelf and shelf break. In contrast, striped dolphins (blue squares) were sighted less frequently but mostly offshore of the shelf break. Common dolphins were spatially associated with Euphausiid-like scattering over the shelf, while striped dolphins were spatially associated with fish-like scattering at the shelf break and offshore of the shelf break. Although Euphausiids have not been reported in the stomach contents of common dolphins, it is possible that the dolphins are feeding on mackerel or squid (Overholtz and Waring, 1991) which do feed on Euphausiids. Because mackerel do not have a swim-bladder, they would not be classified in this categorization scheme.

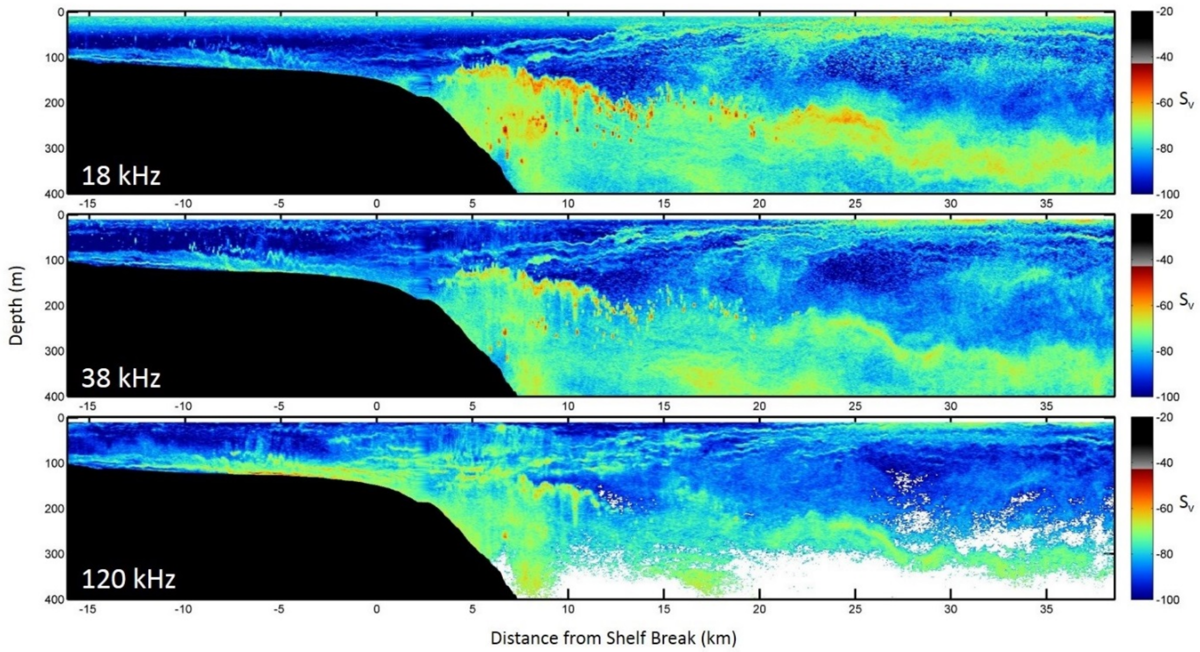

Figure 11-18 18, 38 and 120 kHz Sv from a shelf break transect off Georges Bank

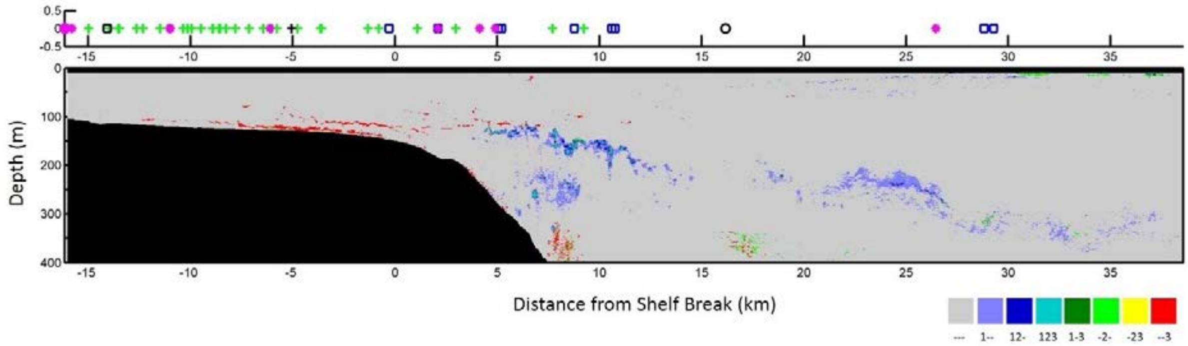

Figure 11-19 Marine mammal sightings along trackline and categorized acoustic backscatter

Table 11-2 Key to markers representing locations of cetaceans in Figures 11-19 and 11-20

Species	Marker
Striped dolphin (*Stenella coeruleoalba*)	blue square
Common dolphin (*Delphius delphis*)	green cross
Pilot whale (*Globicephala sp.*)	magenta star
Sperm whale (*Physeter macrocephalus*)	magenta
Fin whale (*Balaenoptera physalus*)	black cross
Fin/Sei whale (*Balaenoptera physalus/borealis*)	black circle
Sei whale (*Balaenoptera borealis*)	black x
Minke whale (*Balaenoptera acutorostrata*)	black square

By combining the marine mammal sighting data and the acoustic scattering data, we begin to recognize spatial patterns of both predator and prey that enrich our knowledge of top predator distributions. By including hydrographic data collected throughout the water column, we add another dimension, allowing a more in depth investigation into processes that might influence the distribution of marine mammals and other top predators in the shelf break region. In the bottom panel of Figure 11.20, water temperature isotherm contours were overlaid on the categorized scattering data in 2° C increments. A cold pool of water, formed from the winter remnants of shelf water trapped by summer warming of surface waters, is generally defined by the 10°C isotherm (Linder and Gawarkiewicz 1998). Figure 11.20 indicates a cold pool is over the shelf and extends to about 20 km off shore of the shelf break. The shelf break front can clearly be seen as the offshore protrusion of the cold pool. Euphausiid-like scattering was detected within the cold pool over the shelf and fish-like scatterings were detected in the slope waters near the shelf break. In this transect, there is a clear spatial delineation between the Euphausiid-like scattering regions in the cold pool and fish-like scattering regions offshore of the shelf break front. This shelf break frontal region also demarcated a transition zone from common dolphin sightings to striped dolphin sightings.

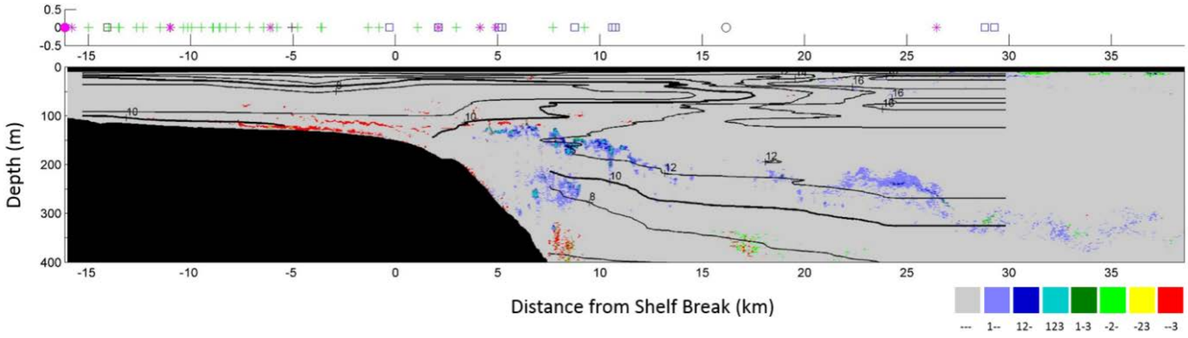

Figure 11-20 Added isotherms interpolated from XBT profiles to Figure 11-17

The spatial relationships and variability among acoustic backscatter along transects was investigated using wavelet analysis (LaBrecque 2016) and is being prepared for publication. Initial findings from the shelf break transects (cruise HB11-03) indicated that significant scales of acoustic spatial pattern varied among transects. Within transects, patterns of spatial scales varied between fish-like scattering (Figure 11.21) and nekton-like scattering (Figure 11.22). Panel A of both of these figures shows the Lg1ln16, 38 kHz normalized Sv. Panel B is the local wavelet power spectrum using the Morelet wavelet. This produces a representation of the area where warmer colors are regions with larger coefficients. The white line encloses the region with greater than a 95% confidence level for a red-noise process. The black semicircle is the cone of influence, where regions below the black line should not be trusted. Panel C is the global wavelet spectrum averaged over the entire transect. What these analyses show is scales of 1 – 4 km were significant for both fish-like and nekton-like scattering along transects assessed, although the variability of the pattern varied along transects. Additional work linking scales of acoustic patterns to marine mammal distributions within the shelf break region is ongoing.

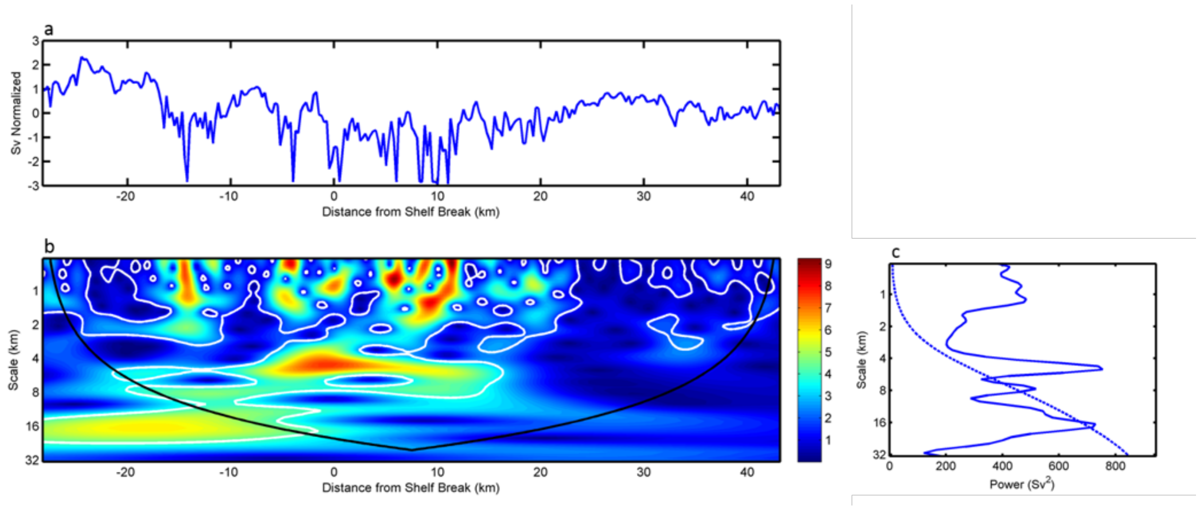

Figure 11-21 Wavelet analysis using fish-like scattering normalized Sv

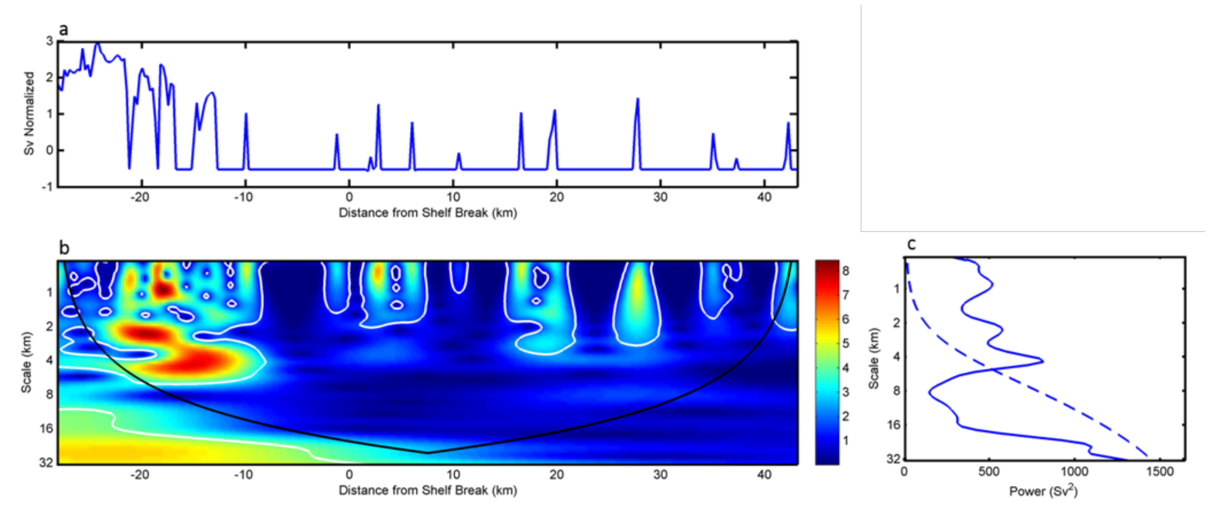

Figure 11-22 Wavelet analysis using a nekton-like scattering normalized Sv

Using the processed EK60 and marine mammal data, the presence or absence of potential marine mammal prey variables were incorporated in habitat models for common dolphins, Risso's dolphins and sperm whales within the shelf break region using data collected during HB11-03 (LaBreque 2016). The plan during 2017 is to expand and publish these habitat models.

11.4 Discussion

11.4.1 Significant Findings

During the AMAPPS shipboard surveys, a wealth of physical and biological oceanographic data were collected that is being used to describe these relatively unknown habitats.

Identification of the ichthyoplankton from the 2011 and 2013 cruises included larval bluefin tuna, *Thynnus thynnus* (Figure 11.23). The known spawning area for northwestern Atlantic (west of 45° W) population of Atlantic bluefin tuna is April-May in the Gulf of Mexico. Transport times derived from drifter tracks and the length derived age of the larvae suggest these larvae were not transported by the Gulf Stream from the Gulf of Mexico spawning area. The presence of this species in the off-shelf plankton samples may represent a new slope sea spawning area (Richardson et al. 2016). Further offshore sampling targeting larval bluefin tuna is planned to confirm and delineate the new spawning area.

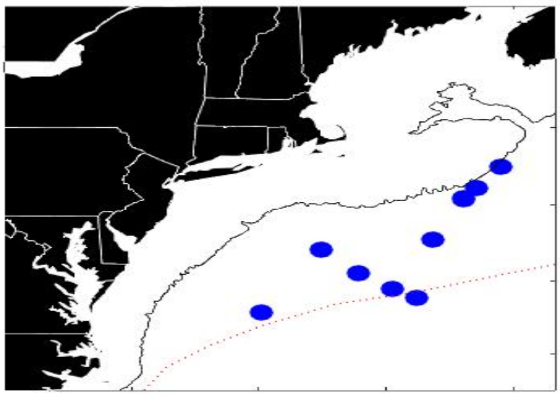

Figure 11-23 Locations of larval bluefin tuna from HB1103 and HB1303
The black line is the shelf break and the dotted line is the average Gulf Stream edge position.

Salpa aspera is known to swarm in large numbers along the NW Atlantic shelf break. Salps are noted but not identified to species or quantitatively sampled in the current NEFSC plankton sampling protocols. Even if identifying salps was added to the protocols, accurate quantitative sampling with plankton nets would still be problematic because some species are damaged and all aggregate forms are broken apart by net sampling. The image data from the VPR clearly shows the solitary and aggregate forms of the salps providing both accurate species identification and quantitative data. Data from the VPR hauls conducted during the AMAPPS surveys has shown that the geographical range of the swarming is more extensive than has been documented and that *S.aspera* is not the only species which swarms in the study area (Table 11.3). HB09-03 and HB11-03 samples were dominated by *Thalia democratica*. HB1303 had some *T. democratica* in the area of the Great South Channel, *Salpa aspera* was the dominant species offshore and along the shelfbreak. Only *Salpa aspera* was seen during the limited sampling in 2014 and 2015. It is important to continue the monitoring of the shelf break Thaliacean blooms to document the periodicity and species composition of these swarming events.

Relating the physical and biological habitat to visual detections of cetaceans has shown there is fine scale habitat partitioning within the shelf break region among the species investigated (LaBreque 2016).

Table 11-3 Dominant Thaliacea species during summer by year and area

Area Type	2009	2011	2013	2015
	Georges Bank			
Shelf break	*Thalia democratica*	*Thalia democratica*	*Salpa aspera, Thalia democratica*	*Salpa aspera*
Offshore		Doliolidae	*Salpa aspera*	
	Nantucket Shoals			
Shelf			*Thalia democratica*	
	Mid-Atlantic Bight			
Shelf break	*Thalia democratica*	*Thalia democratica*	*Salpa aspera*	
Offshore		Doliolidae	*Salpa aspera,* Doliolidae	

11.4.2 Data Gaps and Future Research

Currently there is limited knowledge of physical and biological characteristics of the shelf break and farther offshore habitats. Enhancing the ecosystem descriptions of these areas are needed to understanding and accurately describe protected species that inhabit these waters. Broad scale geographic and long time scale data can be used to understand the large scale processes that affect protected species and also to parameterize models seeking to describe smaller scale effects.

Work has begun on analyzing plankton patchiness and stratification patterns. The VPR allows fine scale analyses of plankton distributions as related to the surrounding oceanographic conditions. For example, an analysis of a half hour of VPR data from a single depth haul shows the fine scale distribution (Figure 11.24). Larger time bins reveal the general patterns of patchiness but hide the patches with very high plankton densities and thus, hides the strong variability that occurs on smaller scales. Continued sampling with the VPR has the potential to reveal areas of oceanographic conditions that can concentrate the planktonic prey.

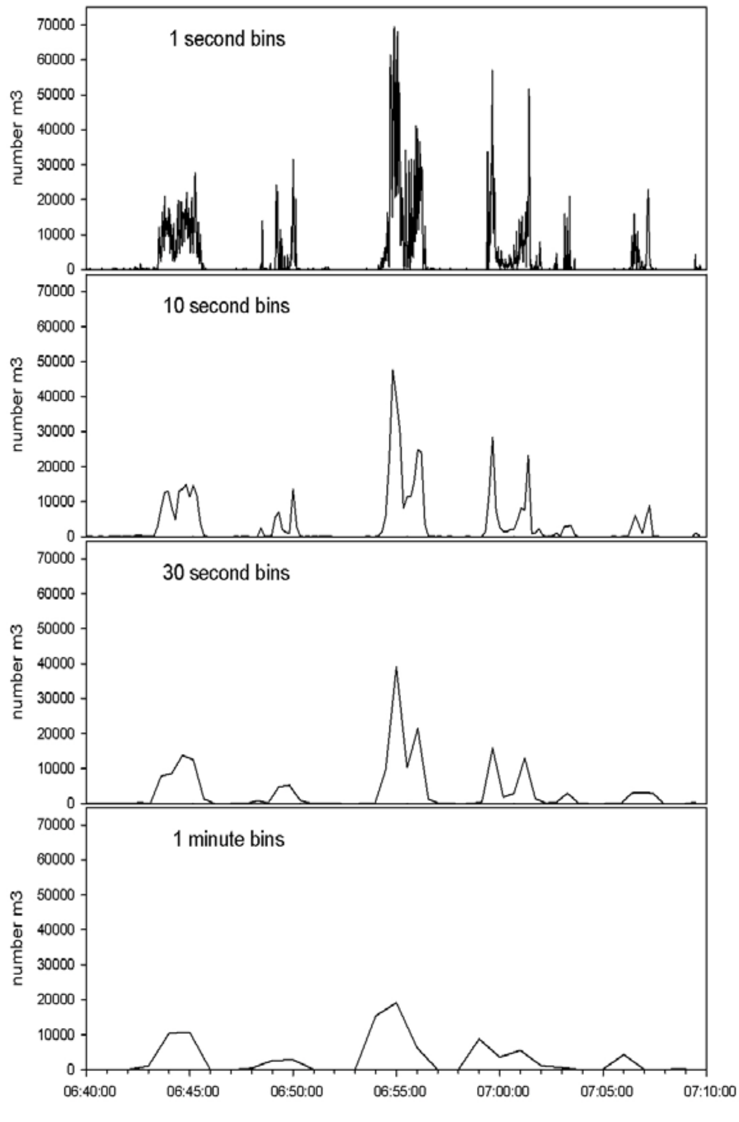

Figure 11-24 Mean densities of gastropod veligers in four sized time bins
Data from a VPR near surface tow (mean depth 2.8 m) on Nantucket Shoals on July 31, 2013.

Longer term data sets are needed to distinguish anomalous events from more persistent processes. For example, limited analysis of the VPR data comparing an offshore area in the middle of visual transect line 25 show inter-annual density variations (Figure 11.25). A longer time series is needed to determine if one year is an anomaly or there is normally a wide inter-annual variance in plankton densities offshore. Data from the CTD transects along the shelf break are being studied to characterize the dominant oceanographic processes driving both the shelf and offshore ecosystems. The geographic sparseness of the current data limits our ability to form a spatially coherent description of the habitat underlying species distributions and/or investigate inter-annual variations and their potential causes.

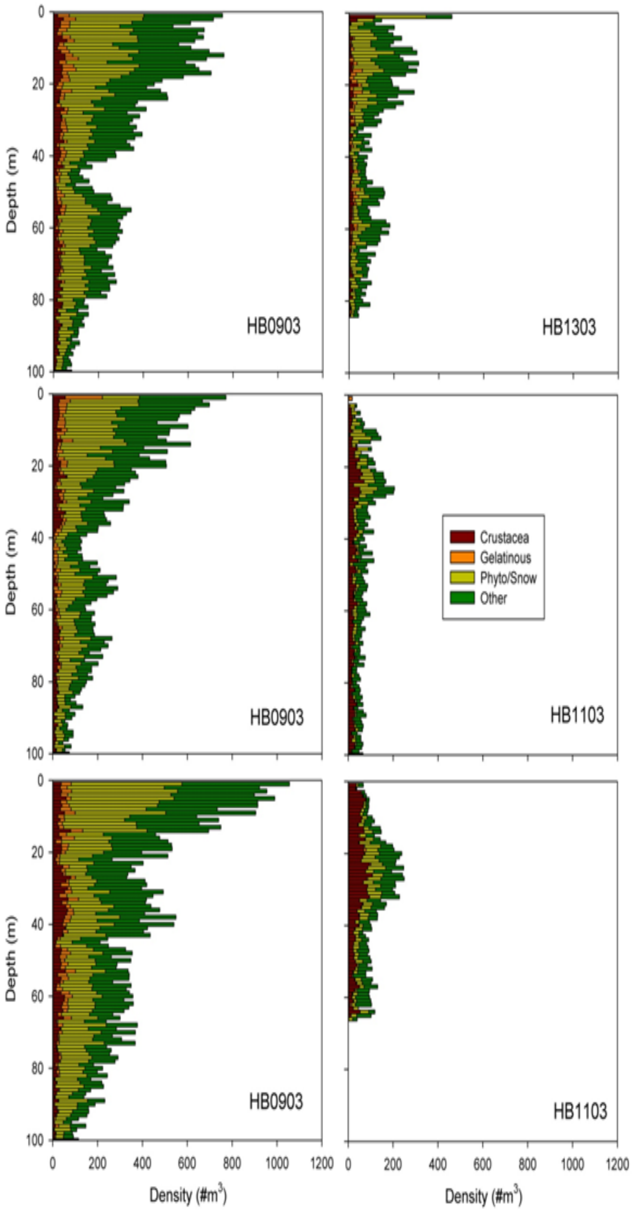

Figure 11-25 Mean plankton densities from VPR in July 2009 and 2011

One of the objectives of ecosystem research within AMAPPS was to understand how the environment influences the distribution and density of marine mammals, sea turtles, and seabirds. In support of this objective, various components of ecosystem research, from mapping water mass properties and quantifying plankton distributions to determining the spatial scales of potential marine mammal prey patterns have begun. For example, ongoing current work includes developing objective and automated classification algorithms to process multifrequency active acoustic data; analyzing the multifrequency active acoustic and trawl data to describe the horizontal and vertical spatial distribution of meso- and bathypelagic prey species of cetaceans, developing methods to calculate absolute density and abundance estimates of meso- and bathypelagic fish species; and updating the biological and trawl databases at the Northeast Fisheries Science Center to include the meso- and bathypelagic fish and cephalopod species.

The next step in support of ecosystem research objectives for AMAPPS is to further integrate the datasets described in this section, both spatially and temporally to examine the relationships between cetaceans, their potential prey and their physical environment. For example, fine-scale distribution models for several species of marine mammals were built for the shelf break region using data from HB11-03 (LaBreque 2016). Currently, these models use presence and absence of potential prey variables, determined from analyzing the EK60 data, and surface hydrographic variables calculated from a flow-through thermosalinograph. Additional work is needed to validate these models using subsequent summer cruise data and to develop different prey metrics that would better inform the models.

There are also current plans for another PhD project to work on these data. The general plans of this project are to use methods from Trenkel and Berger (2013) on the EK60 data from some of the 2010 – 2016 NE shipboard surveys to classify organism types into at least four major scattering groups using distinctive acoustic frequency responses from each group (Figure 11.26). The groups include swim bladder fish, small gas bearing organisms such as larval fish or phytoplankton, fluid-like zooplankton such as copepods and euphausids, and larger fish without a swim bladder, such as mackerel. Further classification algorithms are planned to be developed to examine beaked whale prey at depth because not all the frequencies used in the Trenkel and Berger (2013) algorithm reach the depth at which beaked whales feed. The visual survey track lines will then be processed to identify schools of prey and quantify prey density, biomass, and prey depth. The spatial scale of these prey fields will be examined along with those of marine mammal observations. By providing information on spatial scales of observations along the trackline, this research will provide insight into the optimal spatial scales for modelling marine mammal distribution. These echosounder data will also be complemented by data collected at point locations or over short distances such as CTDs, XBTs, VPR, and net tows. In addition to the visual marine mammal sightings data, it is proposed to use the passive acoustic detections to develop multi-species or multi-guild habitat models for the shelf break region along the track lines. These models will be based primarily on measures of prey in the water column in an attempt to discern ecological niches. They would complement current abundance models and in the future could provide a prey component that could be incorporated as an additional parameter into current abundance modeling techniques.

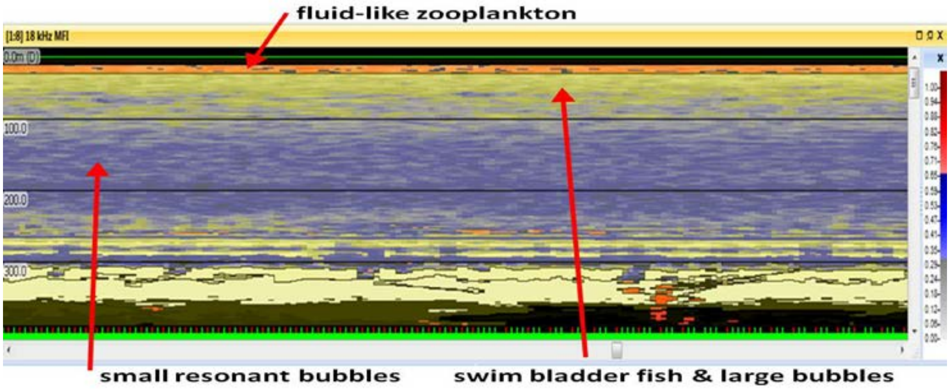

Figure 11-26 Animal classifications
using Trenkel and Berger (2013) classification algorithms

11.5 Acknowledgements

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Appendix I – Density Models and Maps

Appendix II – Cetacean, Pinniped, Sea turtle and Fish Sightings

Appendix III – Offshore Seabird Sightings

Appendix IV – Coastal Seabird Research Results

Appendix V – Active Acoustic Data Collection Summaries

Department of the Interior (DOI)
The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

Bureau of Ocean Energy Management (BOEM)
The mission of the Bureau of Ocean Energy Management is to manage development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way.

BOEM Environmental Studies Program
The mission of the Environmental Studies Program is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments. The proposal, selection, research, review, collaboration, production, and dissemination of each of BOEM's Environmental Studies follows the DOI Code of Scientific and Scholarly Conduct, in support of a culture of scientific and professional integrity, as set out in the DOI Departmental Manual (305 DM 3).