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NORTHEAST LARGE PELAGIC SURVEY COLLABORATIVE AERIAL AND ACOUSTIC SURVEYS FOR LARGE WHALES AND SEA TURTLES

FINAL REPORT

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Northeast Large Pelagic Survey Collaborative Aerial and Acoustic Surveys for Large Whales and Sea Turtles

Final Report

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DISCLAIMER

This report was prepared for the Massachusetts Clean Energy Center and Bureau of Ocean and Energy Management under Cooperative Agreement number M12AC00024 by the Northeast Large Pelagic Survey Collaborative comprised of the New England Aquarium, Cornell University's Bioacoustics Research Program, the University of Rhode Island and the Center for Coastal Studies. This report has been technically reviewed by BOEM and it has been approved for publication. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the US Government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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Cover Photo: North Atlantic Right Whale, Jessica Thompson, Center for Coastal Studies

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LIST OF ACRONYMS

#	number of vertical photographs
a	Area sampled (in density calculations)
A	number of animals observed (sightings tables)
A	adult (right whale demographics tables)
BODO	bottlenose dolphin
BOEM	Bureau of Ocean and Energy Management
C	calf (right whale demographics tables)
CI95	95% confidence interval
CCS	Center for Coastal Studies
CETAP	Cetacean and Turtle Assessment Program
CSV	comma separated value (file format)
CV	coefficient of variation
d	density (number of individuals per unit area)
D	density in animals/km^2
dB	decibel
DIGITS	Digital Image Gathering Information System
ESA	Endangered Species Act
EST	Eastern Standard Time
ESW	Estimated Strip Width
$f(0)$	probability density function evaluated at zero distance
FFT	fast Fourier transform
FIWH	fin whale
ft	feet
FMC	Forward Motion Compensation
G	number of groups sighted
g	average group size (in density calculations)
G_i^*	The Getis-Ord local statistic (HotSpot analysis)
GRAM	Risso’s dolphin
GPS	global positioning system
H	depth of source
HAPO	harbor porpoise
HUWH	humpback whale
Hz	hertz
I	number of individuals sighted
J	Juvenile (right whale demographics tables)
kHz	kilohertz
km	kilometer
KML	keyhole markup language (file format)
L	length of transect (in density calculations)
LETU	leatherback sea turtle
L_{eq}	equivalent continuous sound pressure level
LOTU	loggerhead sea turtle
m	meter
mm	millimeter

MA Array	the array of 6 MARUs deployed within the MA WEA
MA- #	MARU buoy deployed in the MA WEA
MassCEC	Massachusetts Clean Energy Center
MARU	Marine Autonomous Recording Unit
MA WEA	Massachusetts wind energy area
MIWH	minke whale
NARW	North Atlantic right whale
NARWC	North Atlantic Right Whale Consortium
N	estimated abundance
°N	degrees North
n	number (of animals/groups sighted/features)
nm	nautical mile
NEAq	New England Aquarium
NLPSC	Northeast Large Pelagic Survey Collaborative
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOREIZ	Northeast Offshore Renewable Energy Innovative Zone
NS	not significant
NSPs	normalized site-presence (by individual season)
NSPt	normalized site-presence (across all seasons)
p	pressure
PIWH	pilot whale
p_m	measured sound pressure
p_{ref}	reference pressure of 1 µPa
PSD	power spectral density
QA/QC	Quality Assurance /Quality Control
R	range of source to receiver
r^2	coefficient of determination (fitted regression line analysis)
RI Array	the array of 3 MARUs deployed in the RIMA WEA
RI- #	MARU buoy deployed in the RIMA WEA
RIMA	Rhode Island Massachusetts wind energy area
RITU	Kemp’s ridley sea turtle
RIWH	North Atlantic right whale
rms	root mean square
s	second
S	number of sightings
SA	study area
SADO	common dolphin
SAG	surface active group
SEWH	sei whale
SP	survey period
SPWH	sperm whale
SPUE	Sightings per unit of effort
SR	Sighting rates
SE	Standard error
T	number of transects flown

T	time interval
t	time
TL	transmission loss
TSS	traffic separation scheme
U	Unknown age class (right whale demographics tables)
UNDO	unidentified dolphin species
UNLW	unidentified large whale species
UNTU	unidentified sea turtle species
μPa	micro Pascal (SI measure of pressure and stress)
URI	University of Rhode Island
USCG	United States Coast Guard
V	Variance of the density
Var	Variance
VFR	visual flight rules
VHF	very high frequency
°W	degrees West
WEA	wind energy area
$ww_{ii,j}$	spatial weight between features (HotSpot analysis)
WSDO	Atlantic white-sided dolphin
x_j	attribute value for feature (HotSpot analysis)

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BACKGROUND

The Bureau of Ocean and Energy Management (BOEM) designated two wind energy areas (WEAs) in New England: one offshore of Massachusetts (MA WEA) and the other offshore of both Rhode Island and Massachusetts (RIMA WEA). Under the National Environmental Policy Act of 1969 (42 U.S.C. 4371 et seq.), BOEM and other relevant federal agencies are required to conduct environmental assessments of offshore development and construction plans. Offshore wind-energy planning and development is new in the United States and comprehensive assessments of biological resources within wind energy areas are needed to identify and mitigate potential effects of development on marine species.

In anticipation of these requirements, the Massachusetts Clean Energy Center (MassCEC) and the Executive Office of Energy and Environmental Affairs (EEA) established an agreement with the New England Aquarium (NEAq) in August of 2011 to conduct field surveys of marine life in the MA WEA as part of the Northeast Large Pelagic Survey Collaborative (NLPSC). In December of 2012, MassCEC and the EEA entered into a cooperative agreement with BOEM that expanded the survey area to include the adjacent RIMA WEA and extended the survey period through 30 June 2015. These surveys included two renewable energy sites known as Muskeget Channel and NOREIZ (Northeast Offshore Renewable Energy Innovation Zone). The WEAs, Muskeget, NOREIZ, and their immediately surrounding waters are together referred to as the study area (SA) (Figure 1). The MA WEA boundary depicted in Figure 1 is the original lease area used in the survey design, while the Zones 1 – 4 boundaries depict the current lease areas. Prior to these surveys, systematic effort in the area was relatively sparse, beginning with the Cetacean and Turtle Assessment Program in 1978–1982 (CETAP, 1982).

Under the Marine Mammal Protection Act of 1972 (MMPA) and the Endangered Species Act of 1973 (ESA), many species that occur in the SA are afforded legal protections. The WEAs are inhabited regularly and consistently by six species of large whale and five species of sea turtle that are listed as *Endangered* or *Threatened* under the ESA (Lazell, 1980; CETAP, 1982; Kenney and Winn, 1986; Waring et al., 2015; LaBrecque et al. 2015). The whales found in the area include the fin whale (*Balaenoptera physalus*), sei whale (*B. borealis*), North Atlantic right whale (*Eubalaena glacialis*), humpback whale (*Megaptera novaeangliae*), minke whale (*B. acutorostrata*), sperm whale (*Physeter macrocephalus*), and on rare occasion the blue whale (*B. musculus*). Of these, all but the minke whale are listed as *Endangered* under the ESA (NMFS OPR, 2016a). Sea turtles regularly found in southern New England waters include the loggerhead (*Caretta caretta*), leatherback (*Dermochelys coriacea*), Kemp’s ridley (*Lepidochelys kempii*), and green (*Chelonia mydas*) turtles, with occasional reports of hawksbill turtles (*Eretmochelys imbricata*) from stranding records. All of these sea turtles are listed as *Endangered* or *Threatened* under the ESA (NMFS OPR, 2016b).

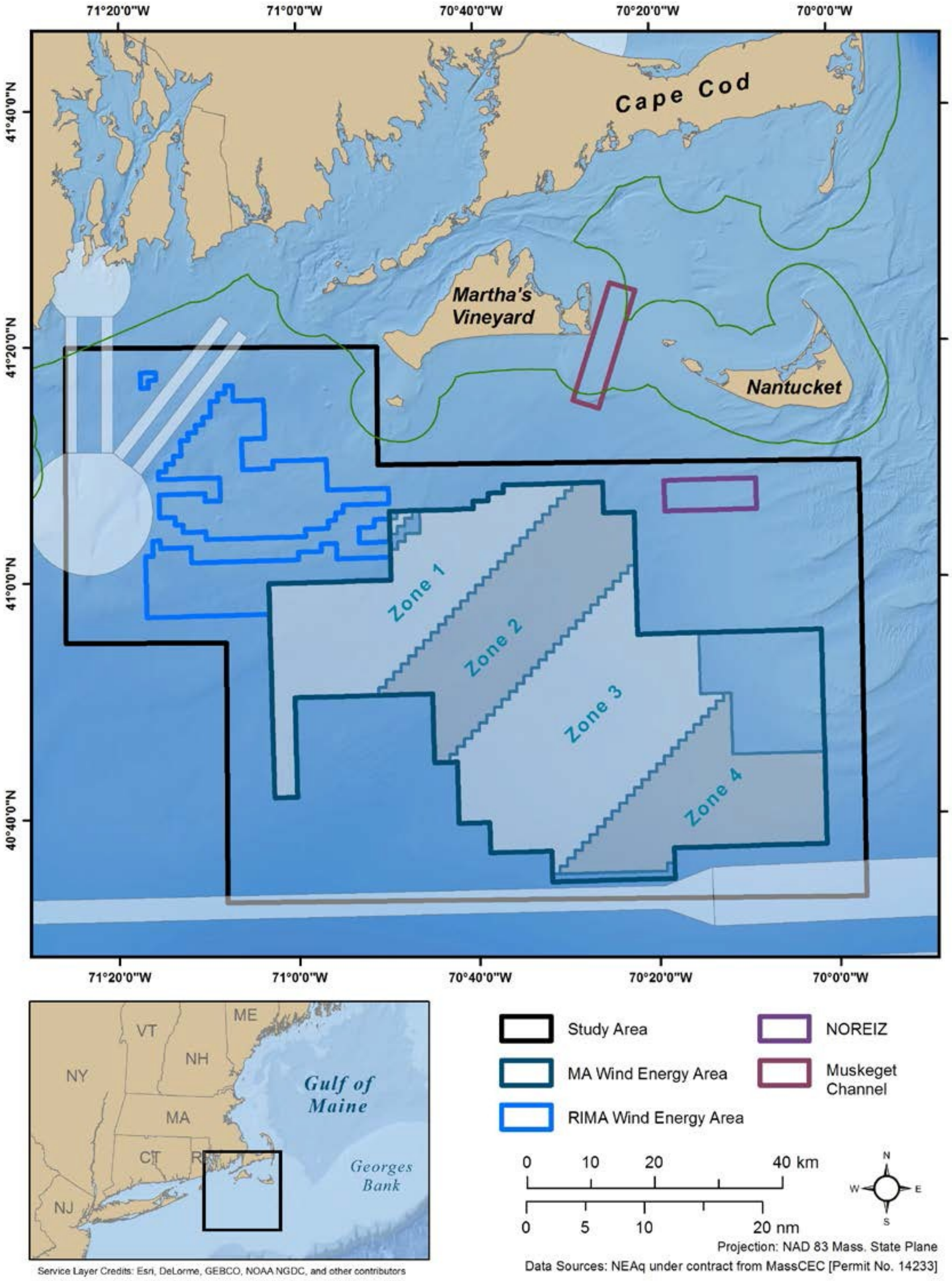


Figure 1. Wind energy areas (WEAs) offshore of Massachusetts (MA WEA) and Rhode Island (RIMA WEA), Muskeget Channel, NOREIZ, and the study area (SA) designed by the NLPSC. (Note: The original MA WEA is depicted by the dark blue line and existing lease areas are depicted as Zones 1 – 2).

One concern with the development of wind energy or other offshore renewable energy facilities is the potential impact of noise produced by their construction and operation on marine wildlife. Although there are both regulatory and industry efforts to minimize the habitat-level impacts of wind facility development and operations, the extent of these impacts on endangered marine life and biodiversity is not well understood. Other than harbor porpoise and seals (Carstenson et al. 2006; Mann and Tielmann, 2013), information to understand the impact of wind energy development-related stressors on marine mammals is limited, and for most endangered species, is non-existent. The range of impacts of wind energy development during construction and operational phases may vary widely, and may affect abundance, distribution, and prey dynamics of marine mammal species (Bergstrom et al. 2014). Stressors such as acoustic disturbance and physical habitat alteration may have chronic and/or acute impacts and temporarily or permanently impact the movement and distribution of marine mammals in the proposed wind energy development area. However, a comprehensive baseline characterization of species occurrence in any wind energy development area is the foundation of an informed management strategy to mitigate potential impacts on those species (Bonar et al. 2015).

OBJECTIVES

The main objective of this study was to collect visual and acoustic baseline data on distribution, abundance, and temporal occurrence patterns of marine mammals, in particular endangered whales and sea turtles, in the MA WEA and RIMA WEA. Secondary objectives were 1) to assess the degree of inter-annual variability in animal distributions, and 2) to integrate aerial survey, acoustic, and photographic survey data on endangered large whales and sea turtles to provide an overview of habitat-use patterns.

METHODS

AERIAL SURVEYS

Line-transect aerial surveys were designed to cover the WEAs and surrounding waters, and were conducted from a Cessna Skymaster 337 0-2A. This aircraft model has high wings and centerline-configured twin engines, which optimizes visibility for observers. Surveys were flown at an altitude of 1,000 feet (305 m) and a groundspeed of 100 knots (185 km/h). Surveys were flown under visual flight rules (VFR), and required flight conditions included a minimum ceiling of 2,000 feet (610 m), and visibility greater than 5 nautical miles (nm) (9 km). Preferred weather parameters included a wind speed less than 10 knots (19 km/h) and a Beaufort sea state of 4 or less.

Two observers positioned on either side of the aircraft aft of each pilot employed a scanning pattern out to 2 nm (3.7 km), repeatedly sweeping forward and aft of perpendicular. Nikon binoculars (8 x 42, 6.3° field of view) were used to confirm sightings and species. Sightings of marine species were recorded in a format consistent with the North Atlantic Right Whale Consortium (NARWC) Database guidelines (Kenney, 2010a). A computer data-logger system (Taylor et al. 2014) automatically recorded survey parameters (time, latitude, longitude, heading, altitude) at frequent intervals (every 2–5 sec). Sighting locations were added into the data log by remote keypads when the detection was abeam of the aircraft, and the observer estimated distance from the transect line using calibrated markings on the wing strut (Mbugua, 1996; Ridgway, 2010). Distance intervals were recorded in nm in the following classes: within 1/8; 1/8 to 1/4; 1/4 to 1/2; 1/2 to 1; 1 to 2; 2 to 4; and >4, indicating port or starboard. Survey, environmental, and sighting data were recorded via digital voice recorder and transcribed into the data log post-flight. Survey parameters included type of flight leg (transit, transect, cross-leg, or circling), transect number, and specific points of a given transect (begin, end, break off, or resume). Environmental data parameters included general weather conditions, visibility, Beaufort sea state, cloud cover, and sun glare. Sighting data include species identification to the lowest taxonomic level possible, the reliability of that identification (*definite*, *probable*, *possible*), a count of individuals in the group, an index of the precision of that count, the number of calves or juveniles, heading of the animal or group, whether or not photographs were taken, and notes on behaviors. All data were submitted to the NARWC Database, where they underwent an extensive QA/QC protocol.

North Atlantic right whales were a primary target species of the study, and the aircraft deviated from transects so observers could obtain photographs of the animal(s) for individual identification (Kraus et al., 1986). Observers photographed through an open window on the starboard side of the aircraft using a Nikon D300 hand-held camera. Photographers collected oblique photographs of the entire rostral callosity pattern of each right whale sighted, and any other scars or markings that were obvious, and attempts were made to document each individual within a given aggregation. Following photographic documentation, the aircraft resumed the transect line at the point of departure for that sighting.

Because the observers in this aircraft configuration are unable to see directly under the aircraft, the standard aerial survey method was supplemented by the addition of an automated vertical photography system equipped with a Canon EOS 5D Mark II or Mark III camera with a Zeiss 85-mm lens and polarizing filter (Taylor et al, 2014). A forward motion compensating (FMC) system was used to reduce motion blur, so the vertically mounted camera could capture sightings data on the strip of ocean unavailable to observer, particularly of smaller and subsurface species, including sea turtles. The vertical camera system was integrated with a GPS, a Panasonic Toughbook laptop or Getac E110 Rugged tablet, and observer sighting buttons via the custom data-logging software *d-Tracker*. Transcription occurred post-flight and observer sightings were integrated using a custom program, *e-Tracker*, which converts logged data into comma-separated value (.CSV) and keyhole markup language (.KML) file formats.

Analytical Methods for Aerial Detections

The complete NLPSC aerial survey and sighting dataset was archived at the URI Graduate School of Oceanography. The database structure followed that established for the North Atlantic Right Whale Consortium (NARWC) data management system (Kenney, 2001, 2010a) with a few added refinements that were specific to this project. The dataset was archived as a SAS dataset, and all data management and analysis tasks were accomplished using procedures in SAS for Windows version 9.2 (SAS Institute, Inc., Cary, NC), with purpose-written macros and program code designed specifically for each type of analysis.

Visual Sightings by Observers

All sightings recorded by observers were integrated into a single data table spanning the entire survey (October 2011–June 2015) and are listed in the Sightings Data Table in Appendix A. Sighting totals and sighting rates were calculated and reported by taxonomic group for large whales, small cetaceans, and sea turtles at the beginning of their respective sections below.

Additional sections describe results for each species where adequate data was collected for analysis. In order to depict seasonal presence, seasonal histograms were created for each of these taxonomic groups, as well as for specific endangered species. Seasonal histograms included sightings summed across the entire study period, and throughout the entire study area, for all levels of identification reliability from *possible* to *definite*. Similarly, monthly sighting histograms were created for individual species accounts across the entire study period and study area. Sightings detected in the vertical camera photographs were also included in these histograms.

Vertical Photographs

Vertical photographs collected were geotagged using a d-tracker file output format and a freeware program called GPicSync (gpicsync.software.informer.com). Photos were then analyzed by trained observers for detections of marine species and fixed fishing gear using the program FastStone Image Viewer (www.faststone.org). Photo analysis consisted of scanning each of the individual images that were collected on track and by using the program's zoom function in cases of elevated glare and/or sea state. All detections were then recorded in a photo analysis table that included species, identification reliability, and number of animals with an estimate of the level of confidence in the count, frame number, time, observer, and area of image. The Chief Survey Scientist reviewed all detections for accuracy and consistency. Detections of marine species and fishing gear were incorporated into the final .CSV data table (with time to the second) for each survey, and are also included in the Sightings Data Table (Appendix A). Tables of all vertical camera sightings were created for the Small Cetaceans and Sea Turtles.

Hand-held Identification Photographs of North Atlantic right whales

Right whale images from the Nikon D300 hand-held camera were uploaded and processed in the NARWC Catalog (Hamilton et al., 2007), and were compared to other records in the Catalog to identify individuals using a program called DIGITS (Digital Image Gathering and Information Tracking System). Each individual that was photographed was assigned a letter code, and all photographs of that individual were uploaded to the matching console within DIGITS. Trained photo analysts annotated photographs, and used this console to match the individual to a known individual within the catalog. Once matched, demographics information such as sex, age, and reproductive status were obtained. Sighting and calving histories were also obtained for matched individuals.

Sighting Rates and Variability

In order to account for variability in sampling effort when making comparisons between surveys or time periods, sighting rates (SR) were calculated for all species or species groups with at least 25 sightings, and are reported by species at the start of their respective sections within this report. The species and groups included were (ESA-listed species in boldface): **North Atlantic right whale**, **humpback whale**, **fin whale**, **sei whale**, minke whale, **all large whales**, bottlenose dolphin (*Tursiops truncatus*), short-beaked common dolphin (*Delphinus delphis*), harbor porpoise (*Phocoena phocoena*), all dolphins and porpoises, **loggerhead turtle**, **leatherback turtle**, **all sea turtles**, gray seal (*Halichoerus grypus*), and all seals. The species included within each of the pooled groups were:

- *All large whales*: right whale, humpback whale, fin whale, sei whale, sperm whale, unidentified fin or sei whale, unid. rorqual, unid. large whale, and unid. whale;

- *All dolphins and porpoises*: bottlenose dolphin, common dolphin, harbor porpoise, Risso's dolphin (*Grampus griseus*), pilot whale (*Globicephala* sp.), Atlantic white-sided dolphin (*Lagenorhynchus acutus*), unid. common or white-sided dolphin, and unid. dolphin/porpoise;
- *All sea turtles*: loggerhead turtle, leatherback turtle, Kemp's ridley turtle, and unid. turtle;
- *All seals*: gray seal, harbor seal (*Phoca vitulina*), and unid. seal.

SR represents the number of individual animals sighted within a survey day divided by amount of effort during the same day (multiplied by 1000 to avoid working with very small decimal values). Sighting rates are therefore presented as the numbers of animals observed per 1000 km of survey. Effort was defined as the total distance flown by the aircraft, in km, including transects, transits, cross-legs, and circling, in all sea states up to and including Beaufort 4. Only sightings identified as *definite* or *probable* were included, except for pooled categories that also included unidentified (e.g., unid. large whale) or partly identified (e.g., unid. fin or sei whale) sightings. Pooled average SR was calculated for months, seasons, years, or season-year by effort-weighted means of the individual survey days. Monthly sighting rates for large whales that were sighted more than 25 times are reported in the largewhale section of the report.

For this and all other analyses, seasons were defined as Winter = December, January, February; Spring = March, April, May; Summer = June, July, August; and Autumn = September, October, November. For season-year, winter for any year included December of the previous calendar year (e.g., Winter-2013 included December 2012, January 2013, and February 2013). The calculated sighting rates were analyzed using non-parametric ANOVA (Kruskal Wallis test) in the SAS *NPAR1WAY* procedure to test for significant variability between years, seasons, month, and season-years, and between years for each season separately. Least-squares linear regressions in the SAS *GLM* procedure were used to test for significant long-term trends by year and by survey day (from 0 for the first survey on 9 October 2011 to 1354 for the last survey on 24 June 2015).

Sightings Per Unit Effort

In order to assess relative abundance and distribution patterns of individual species within the SA, an index of sightings per unit effort (SPUE) was calculated for species that were sighted 25 or more times in order to ensure a sufficient sample size. The species and group categories are the same as for SR analyses listed above, but with three additional pooled groups added:

- *Endangered baleen whales*: right whale, humpback whale, fin whale, sei whale, unid. fin or sei whale, and unid. rorqual;
- *All baleen whales*: *endangered baleen whales* plus minke whale;
- *All odontocetes*: *all dolphins and porpoises* plus sperm whale.

SPUE analyses use the SR data to assess spatial patterns. The study area was divided into a grid of cells or blocks measuring 5 minutes of latitude (9.3 km) by 5 minutes of longitude (approximately 7.0 km, narrowing slightly from south to north). All aircraft flight segments were partitioned into the grid cells, limited to segments with altitude below 366 m (1200 ft), clear visibility out to at least 2 nm (3.7 km), and sea state up to and including Beaufort 3. All sightings during those same track segments were also assigned to the 5x5-minute cells, again limited to *definite* and *probable* identifications except for the pooled groups. The numbers of animals sighted and total km of effort were summed within each grid cell by season and overall across all years of the survey. The SPUE in each cell, in animals per 1000 km of effort, was calculated by dividing animals sighted within that cell by effort in the cell and multiplying by 1000 (as in SR calculations)

Hot Spot Analysis

To identify areas with statistically higher animal clustering than surrounding regions, a Hot Spot Analysis was performed for the two endangered species that appeared to show clustered distribution within the study area—the North Atlantic right whale and the leatherback turtle. ESRI ArcMap v. 10.3.1 (ESRI, Redlands, CA) was used to run a Hot Spot Analysis to test for hot spots and cold spots in the SPUE data using the Getis-Ord *Gi** statistic. This statistic identifies statistically significant spatial clusters of high values (hot spots) and low values (cold spots). For each 5x5-min SPUE cell the Getis-Ord *Gi** was calculated, resulting in z-scores and p-values identifying where cells with either high or low values clustered spatially. A cell with a high z-score and small p-value indicates significant spatial clustering of high values. A negative z-score and small p-value indicates significant spatial clustering of low values. The higher or lower the z-score, the more intense the clustering. Cells were categorized into bins reflecting statistically significant confidence levels: 99%, 95%, 90%, or not statistically significant.

Spatial relationships between cells were modeled using the *contiguity edges/corners* option, where cells that share a boundary or corner influence the computations for the target cells. This option is best when polygons are similar in size and distribution, and when spatial interaction increases if the polygons share a boundary. This is appropriate here, as whales found in one 5x5-min cell could easily move into an adjoining cell. The Euclidean Distance (straight line) method was used to calculate distances from each cell to neighboring cells.

The Getis-Ord local statistic is given as:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j}x_j - \bar{X}\sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{n\sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2}{n-1}}} \tag{1}$$

where X_j is the attribute value (here, either the number of animals or the number of species) for cell *j*, $W_{i,j}$ is the spatial weight between cells *i* and *j*, and *n* is equal to the total number of cells and:

$$\bar{X} = \frac{\sum_{j-1}^{n} x_j}{n} \tag{2}$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{X})^2} \tag{3}$$

Density and Abundance Estimations

In order to estimate the number of animals in the study area, density and abundance estimates were calculated using line-transect methods for species with sufficient numbers of sightings from defined tracklines. The density (*d*, number of individuals per unit area) of animals in a population within an area can be estimated by dividing the number of animals counted (*n*) by the area sampled (*a*) (Eberhardt et al., 1979; Seber, 1982). Defining the area sampled during a line-transect survey is complex, since the probability of detecting a given group of animals decreases with distance from the trackline. We used the observed distribution of right-angle sighting distances in DISTANCE software version 6.2 (Laake et al., 1993; Thomas et al., 2010) to estimate the width of the strip effectively sampled on each side of the transect (Estimated strip width, or *ESW*) and its inverse, *f(0)*, the probability density function evaluated at zero distance.

To minimize variance of the *f(0)* estimate, an adequate sample size is necessary, minimally 25–30 sightings (Buckland et al., 2001), and ideally 40–100 or more (Eberhardt et al., 1979). To maximize the sample size, all on-transect sightings of large whales with right-angle distance classifications were pooled, using the same set of species pooled as *all large whales* for the sighting rate analysis (see *Sighting Rates and Variability* section). For the dolphins, an initial step was to look for significant differences in group sizes, because group size affects sightability. Common dolphins occurred in significantly larger groups and were analyzed separately in DISTANCE from the pooled set of dolphin species. For each group of sightings—*all large whales*, common dolphins, *all other dolphins*, and *all turtles*, DISTANCE software was used to fit the observed probability distribution of right-angle distances to different statistical models and truncation schemes, selecting the output with the lowest AIC score to estimate *f(0)* and its variance. The calculated ESWs that were used for specific species are reported in the species accounts in the Results section of the report.

An estimate of density (*d*, in individuals/km^2) of a given species was calculated for each survey transect line by:

$$d = \frac{n \cdot g \cdot f(0)}{2\,L} \tag{4}$$

where *n* is the number of groups sighted during the transect, *g* is the average group size for the species across all sightings during the study, *f(0)* is the appropriate pooled or unpooled value output from DISTANCE, and *L* is the length of the transect. Only sightings meeting the following criteria were included in the estimation: collected during a defined census track; Beaufort sea state of 3 or lower; clear visibility of at least 2 nm; and *definite* or *probable* species identification. The Muskeget and NOREIZ tracklines were not included in these analyses. The variance of the density estimate was calculated additively from the variances of the component parameters:

$$\mathrm{Var}\,(d) = \sqrt{\frac{\mathrm{Var}\,(n)}{n^2} + \frac{\mathrm{Var}\,(g)}{g^2} + \frac{\mathrm{Var}\,[f(0)]}{f(0)^2}} \tag{5}$$

The values of *n* and *g*, and their variances, were computed empirically from the survey data; the values for *f(0)* and its variance were from the DISTANCE output.

The average density for a given survey day, or any combination of days (year, season, month, season-year) was calculated as the mean of the individual transect densities, weighted by the transect lengths. The variance of the mean density was similarly calculated as the length-weighted average of the transect variances. Abundance was computed as the weighted mean density times the survey area—6,910.78 km^2 for the first 25 surveys or 7,789.19 km^2 after the

RIMA WEA was included. Upper and lower 95% confidence limits on the abundance estimates were calculated from weighted average variance by the student's-T method based on the total number of transects flown during the time period in question.

Species Richness

In order to define the parts of the study area with high biological importance, two maps of species richness were created based on detections across the entire study period, one for endangered species, and one for all species. The total numbers of species sighted were calculated and summarized using ESRI ArcGIS v. 10.3.1 into 10-km x 10-km grid cells. The grid cell value represents the total number of species sighted, or species richness, within that grid cell. Only sightings with *definite* or *probable* identifications were included in this analysis, and none of the unidentified groups were included. The endangered species analyses included all endangered whales and sea turtles, from the lists for the SR and SPUE analyses above. The "all species" analysis included all whales, dolphins and turtles, as well as several species of seals, sharks and other large fish that we are otherwise not analyzing in this report: harbor seal (*Phoca vitulina*), grey seal (*Halichoerus grypus*), thresher shark (*Alopias* sp.), white shark (*Carcharodon carcharias*), hammerhead shark (*Sphyrna* sp.), basking shark (*Cetorhinus maximus*), blue shark (*Prionace glauca*), dusky shark (*Carcharhinus obscurus*), spiny dogfish (*Squalus acanthias*), ocean sunfish (*Mola mola*), and tuna (*Thunnus* sp.).

ACOUSTIC SURVEYS

We collected passive acoustic data between 2011 and 2015 (referred to as the *study period*) to complement aerial efforts to characterize patterns baleen whale occurrence, and the ambient noise environment in the vicinity of MA WEA and RIMA WEA. The acoustic analyses focused on five whale species: North Atlantic right, humpback, fin, blue, and minke whales—with all but minke whales listed as endangered (NMFS OPR, 2016a). Minke whales are listed as data deficient according to the 2013 stock assessment report (Waring et al. 2015), therefore, minke whale presence and distribution were included in our study. Among the five focal species, the North Atlantic right whale is considered to be one of the most endangered large whale species in the world (Waring et al. 2015), with approximately 500 individuals remaining (Pettis and Hamilton 2015).

While sei whales (*Balaenoptera borealis*) are listed as endangered and are known to occur in North Atlantic U.S. waters, their vocal repertoire is not well understood (Baumgartner et al. 2008), and were therefore not included in this acoustic study. Although sperm whales (*Physeter macrocephalus*) are listed as endangered and occur in U.S Atlantic waters, their high-frequency clicks exceed the maximum frequency of our recording equipment settings, so sperm whale acoustic presence was also not documented during this study.

Acoustic data were collected using marine autonomous recording units (MARUs) (Calupca et al. 2000). Between November 2011 and October 2012, an array of 6 MARUs was deployed at 6 sites in or near the MA WEA. Due to a broadening of the scope of the project at the request of BOEM, between February 2013 and March 2015, three additional MARUs were deployed at 3 sites in the RIMA WEA (Table 1), in addition to the existing array of six MARUs in the MA WEA. The two arrays are hereafter referred to as the MA array and RIMA array (Figure 2). The locations of the MARUs, and the total acoustic survey area in which the MARUs are able to detect sounds are referred to as the “acoustic study area” in this report.

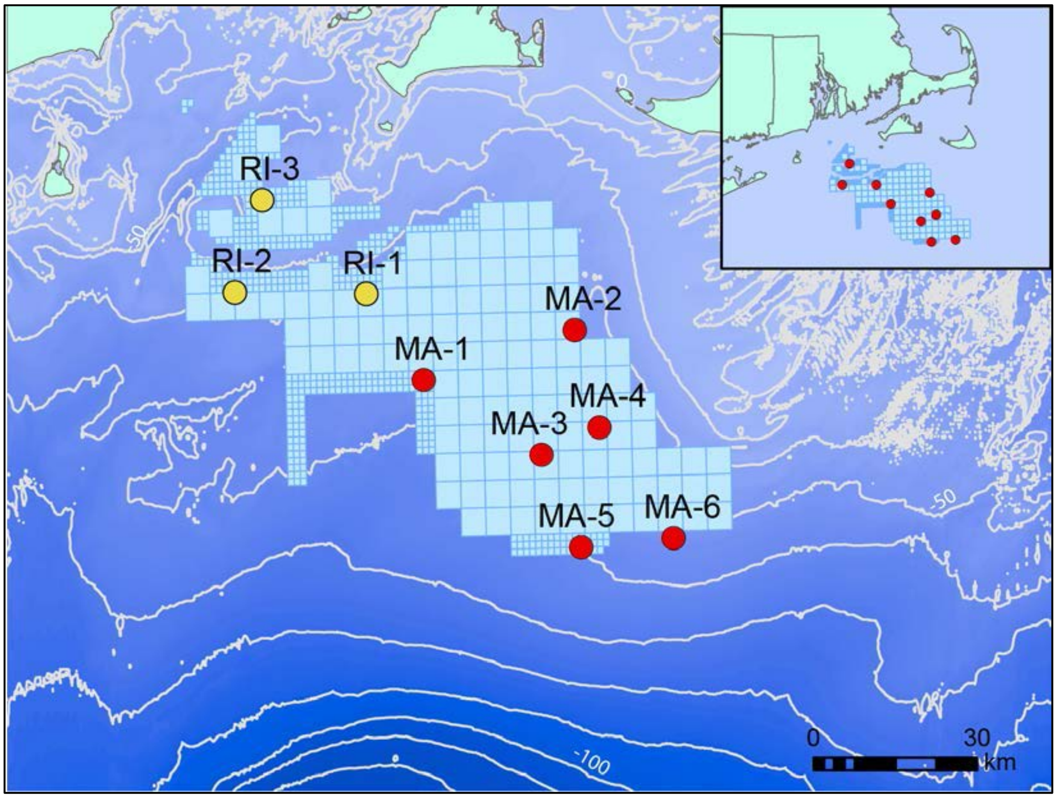


Figure 2. Map of the MA array of MARUs within the MA WEA (red circles) and the RIMA array of MARUs within the RIMA WEA (yellow circles). Gray lines represent isobaths in 10-m intervals. The blue squares represent lease sub-blocks within the wind energy area.

Table 1. MARU location summary.

Site ID	Latitude **(°N)**	Longitude **(°W)**	Depth (m)	Total days analyzed
MA-1	40.8612	70.7315	54	837
MA-2	40.9421	70.3821	44	837
MA-3	40.7436	70.4607	52	1004
MA-4	40.7859	70.3259	47	837
MA-5	40.5993	70.2617	59	1032
MA-6	40.6125	70.1553	53	669
RI-1	40.9955	70.8642	50	699
RI-2	40.9978	71.1683	51	363
RI-3	41.1421	71.1038	33	704

MARUs were programmed to run continuously at a sampling rate of 2 kHz. Each unit was programmed with a gain setting of 23.5 dB re: 1 μPa, and had a system sensitivity of -168 dB re: 1 V/μPa, which varied by approximately ± 3 dB between 10 and 1,000 Hz. Each MARU had a 10-Hz high-pass filter to reduce electrical interference from the recording unit and an 800-Hz low-pass filter to prevent aliasing artificial spread of energy to lower frequencies, for an effective acoustic recording bandwidth of 10–800 Hz.

Analyses of Acoustic Recordings

The acoustic occurrence of the five focal whale species was analyzed in the MA and RIMA arrays based on the positive identification of a species-specific vocalization. A confirmed vocalization of a whale species meant that one or more individuals of that species was present near that sensor at that time. The identification of each species was accomplished by either (1) automated detectors trained in detecting specific sounds with the verification of the detections by trained humans (for right, fin, and minke whales), or (2) visual inspection of the sound by expert human analysts without the aid of an automated detector (for humpback and blue whales). Quantitative criteria were used to identify species-specific calls. Localization of animals or determining the number of vocalizing animals was outside the scope of this project.

Determination of Species Presence

Right whales

The acoustic presence of right whales was determined by a customized, Matlab-based Feature Vector-Transform algorithm created for detecting right whale upcalls (Urazghildiiev and Clark 2007, Urazghildiiev et al. 2009) (Figure 3). These sounds are characterized by a frequency-modulated upsweep with a duration of 0.3–1.5 seconds, frequency band from 50 to 250 Hz, and a bandwidth of 100 ± 37 Hz (Urazghildiiev and Clark 2006, 2007, Urazghildiiev et al. 2009). Upcalls are the most common calls produced by right whales (Parks and Tyack 2005, Parks and Clark 2007, Urazghildiiev et al. 2009), and are frequently used to determine acoustic presence of right whales in an area (Clark 1982, Parks and Tyack 2005, Parks and Clark 2007).

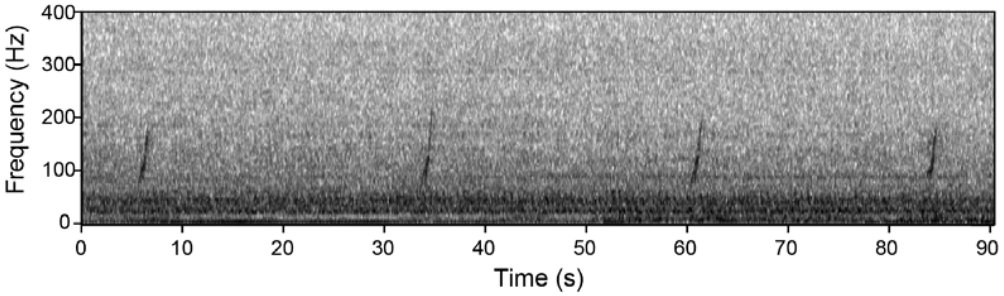


Figure 3. Spectrogram showing an example of four right whale contact calls ("upcalls") recorded on MA-2 on 14 May 2012.

Automated detection of right whale upcalls can falsely detect humpback whale signals with similar acoustic properties in geographic regions where the two species overlap (Mellinger et al. 2011, Mussoline et al. 2012). To avoid the inclusion of humpback signals in the right whale dataset, analysts utilized a range of criteria to distinguish right whale contact calls from humpback vocalizations. These criteria include: frequency bandwidth and duration, arrival patterns, repetition rate, broader acoustic context, and harmonic structure of the upcalls under review. Ambiguous signals were excluded from the analysis. For the visual inspection of upcalls and to review the presence of humpback whale vocalizations we have adopted an analysis protocol similar to the methods described in Clark et al. (2007), Mellinger et al. (2011), Morano et al. (2012), and Mussoline et al. (2012).

In analyzing spectrograms of detection events, a specialized viewing tool was implemented in Raven Pro version 1.5 (Bioacoustics Research Program, 2014) to allow the user to simultaneously view both thumbnail spectrogram views of the detected event and a larger temporal context view of the spectrogram. The context view included a fixed amount of additional time before and after the event from all MARUs in the array. Having both views provided additional information to help classify acoustic detections, including being able to view the acoustic presence of calling patterns over time, arrivals on multiple MARUs, and potential vocalizations from other species. The spectrogram settings to view the event detection included a duration equivalent to the detected event plus 3 seconds before and after the event, a 50–400 Hz frequency range, and FFT size and window setting of 512. The spectrogram settings for the context view included a page duration of 5 minutes, frequency range of 10–450 Hz, and FFT size and window setting of 512.

The configuration of the array was such that a single upcall produced by one right whale could propagate to multiple MARU locations, and therefore arrive at multiple channels. To eliminate the pseudoreplication from this situation, only the first arrival of a detected upcall was accepted in the analysis (following Morano et al. 2012). A “first-arrival” is the first temporal instance of an upcall that propagated to two or more sites (Figure 4). All vocalizations that were identified as right whale upcalls were then subject to a second manual verification by a second analyst to ensure high accuracy.

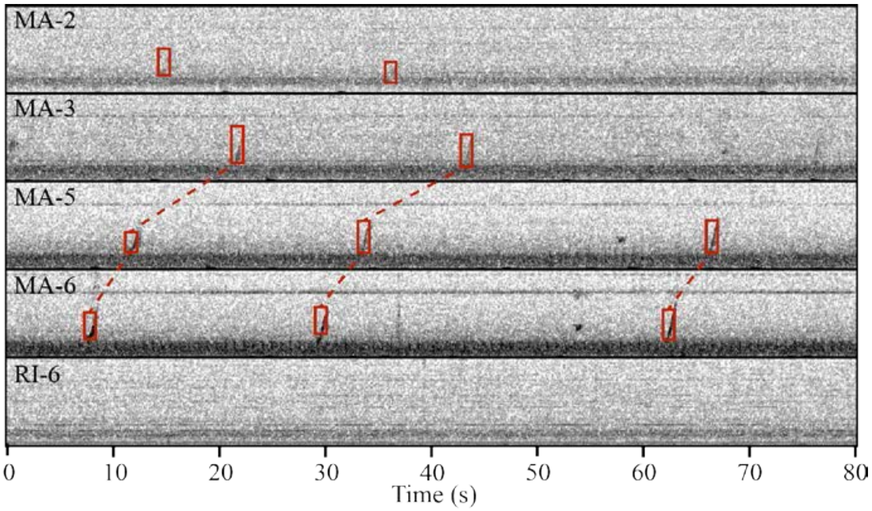


Figure 4. Spectrogram showing an example of a right whale upcall arriving on multiple channels (sound from 12 November 2014). In this instance a right whale vocalization is arriving first on channel MA-6, then also arriving later on channels MA-5 and MA-3. This arrival pattern indicates that the right whale is closest to channel MA-6. In the presence analysis, only the first arrival would be counted for right whale acoustic presence.

Fin whales

Fin whale song is comprised of long sequences of individual 20-Hz notes (Figure 5) (Watkins et al. 1987, McDonald et al. 1995, Clark et al. 2002). We used a matched-filter data-template detection algorithm running in the XBAT sound analysis environment (Bioacoustics Research Program 2012, Barker et al. 2014) to automatically identify 20-Hz notes in the acoustic data. The detector is trained using multiple exemplars of 20-Hz fin whale notes and is able to detect sounds with similar characteristics. The spectrograms of automated detections were reviewed as thumbnails in Raven Pro, as described above for right whales. The spectrogram settings for the thumbnail view included a page duration of 2 seconds before and after the detected event, 8–30 Hz frequency range, and FFT size and window setting of 512. The spectrogram parameters for the context view included a 120-second spectrogram window duration, frequency range of 0–50 Hz, and FFT size and window setting of 97. The occurrences of confirmed fin whale 20-Hz notes were used to complete the task of determining daily fin acoustic presence.

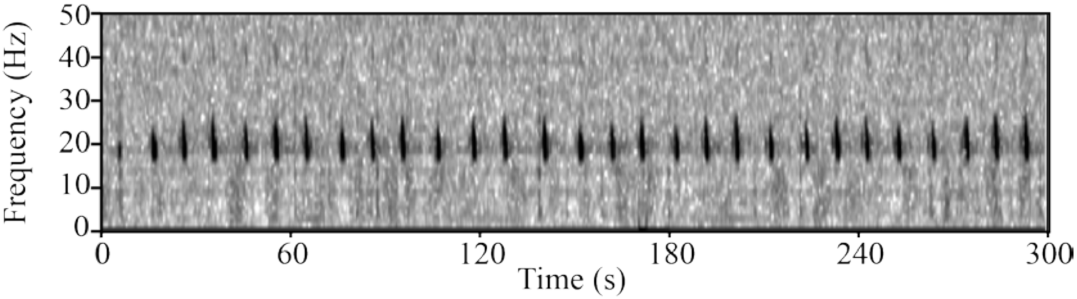


Figure 5. Example of a segment of fin whale song recorded at MA-1 on 16 March 2012. The song shown in this figure is characterized by a long sequence of 20-Hz notes occurring at regular intervals of *ca*. 11 seconds.

Minke whales

Minke whales produce a series of pulsed signals, called a “pulse train” (Figure 6), which are the most well-understood vocalization of minke whales in the North Atlantic and are commonly used to indicate minke whale presence (Risch et al. 2014). An automatic detection procedure was applied to the multi-channel MARU acoustic data in order to identify minke pulse-train vocalizations. The automatic detection was implemented in a high-performance computing platform using a custom-built algorithm (Dugan et al. 2013, Popescu et al. 2013). The detections were then reviewed in Raven Pro. The spectrographic settings for the thumbnail view included a page duration of 3 seconds before and after the detected event, 25–500 Hz frequency range, and FFT size and window setting of 512. The spectrogram settings for the context view included a spectrogram window duration of 60 seconds, a frequency range of 25–500 Hz, and a FFT size and window setting of 512. The occurrences of confirmed minke whale pulse train sounds were used to complete the task of determining daily acoustic presence.

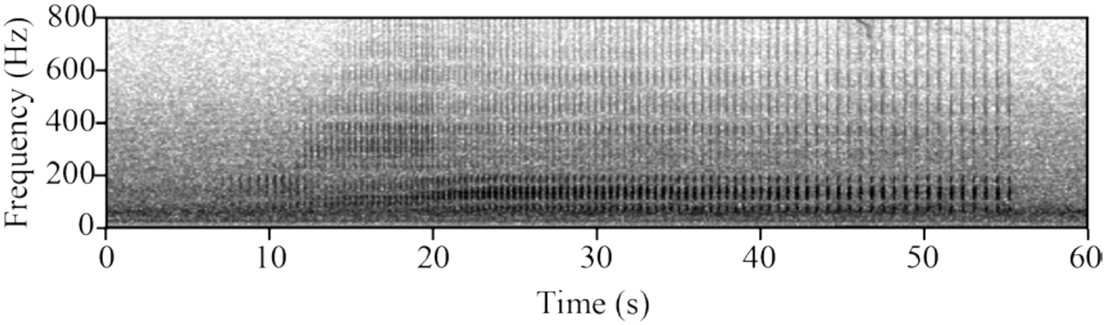


Figure 6. A 60-second spectrogram showing an example of a minke whale pulse train recorded at MA-3 on 20 March 2012.

Humpback whales

There were two types of humpback whale sounds used to establish their presence: songs and social calls (Payne and McVay 1971, Silber 1986, Chabot 1988). Analysts used Raven Pro to manually browse through the multi-channel spectrogram to search for humpback whale species-specific sounds throughout the day. Spectrogram settings included a 5-minute window duration, frequency range of 10–600 Hz, and a FFT size of 512. When an instance of either a humpback song or social call was identified on that day (Figure 7, Figure 8), the analyst marked the vocalization for acoustic presence and moved to the next day. All vocalizations that were identified as humpback whale were then subject to a second verification by an additional analyst to ensure data accuracy.

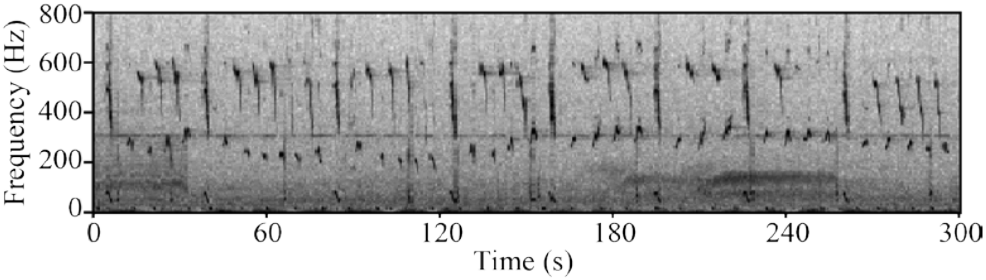


Figure 7. A 5-minute spectrogram recorded at MA-6 on 16 March 2012, showing characteristic repeated sound patterns in a segment of humpback whale song. Also visible in this spectrogram are fin whale 20-Hz song notes at the bottom of the spectrogram.

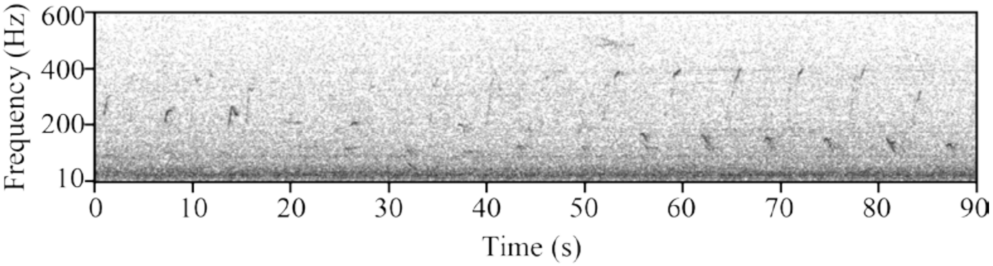


Figure 8. A 90-second spectrogram showing several humpback whale social calls on 30 April 2012 at MA-6.

Blue whales

Blue whale song is characterized by sequence phrases between 15 and 20 Hz (Mellinger and Clark 2003). The determination of daily acoustic presence of blue whale song on each MARU was accomplished by applying a standardized set of spectrogram analysis parameters to a version of the data decimated from the original 2000 Hz down to 100 Hz (Figure 9). The decimating was done in order to yield a higher-resolution spectrogram focused on the low-frequency region occupied by blue whale phrase sequences, which have a dominant frequency of approximately 17–18 Hz. Analysts then used the interactive sound visualization tools provided by the Raven Pro software environment to search for characteristic patterns of 14–22 Hz blue whale sounds. In analyzing these data, a page length of 2 hours and a frequency range of 10–25 Hz were used. The FFT size and window were set to 512 points.

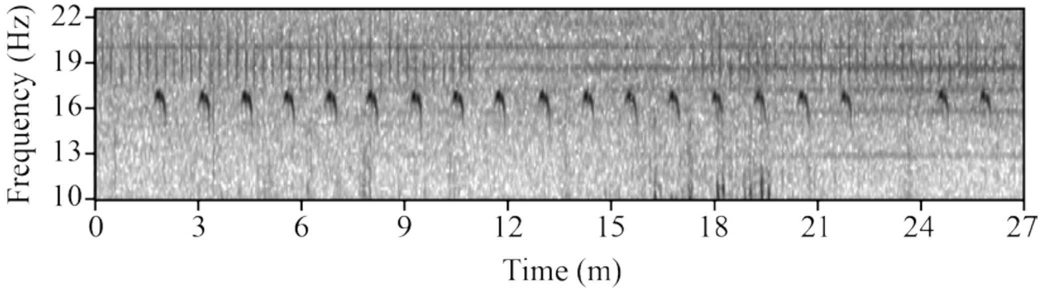


Figure 9. A 27-minute spectrogram showing an example of a blue whale song recorded at MA-4 on 23 December 2011.

Acoustic Data Analysis for Five Whale Species

Monthly Acoustic Presence

For each of the 5 baleen whale species, daily presence data were collected. *Daily acoustic presence* was determined for each species if one or more target vocalization was found at any recording site during a 24-hour day. The daily acoustic presence data were then synthesized and converted to *monthly acoustic presence*, which is the total number of days a whale was detected in a month compared to the total number of days with recorded sound in that same month:

$$\textit{Monthly acoustic presence } (\%) = \frac{\text{\# of days per month with acoustic presence}}{\text{Number of days recorded per month}} \times 100 \quad (6)$$

Using this metric, a month in which acoustic presence was found on all days that were recorded in that month would result in 100% monthly acoustic presence. Zero days with acoustic presence on all days recorded in a month would result in a monthly acoustic presence value of 0%.

To assess the variability of monthly acoustic presence between years for each month and for each of the 5 species, the coefficient of variation (CV) was calculated. Only months when data were collected for 3 years at 5 or more MARU recording sites were used to calculate the CV. This included the months of February through July (see Table 2 for a list of sites and dates used). The CV was calculated as:

$$\text{CV of monthly acoustic presence} = \frac{\text{Standard deviation of monthly presence}}{\text{Mean of monthly presence}} \qquad (7)$$

Table 2. The month, year, and site of acoustic data used to calculate the coefficient of variation (CV) of percent monthly presence for each species. Check (✓) marks denote recording sites that were included in the CV calculation. The (X) mark denotes recording sites that were not included in the CV calculation.

Month	Years	MA-1	MA-2	MA-3	MA-3	MA-5	MA-6	RI-1	RI-2	RI-3
Feb	2012	✓	✓	✓	✓	✓	✓	X	X	X
	2013	✓	✓	✓	✓	✓	✓	✓	X	✓
	2015	✓	✓	✓	✓	✓	✓	✓	X	✓
Mar	2012	✓	✓	✓	✓	✓	✓	X	X	X
	2013	✓	✓	✓	✓	✓	✓	✓	X	✓
	2015	✓	✓	✓	✓	✓	✓	✓	X	✓
Apr	2012	✓	✓	✓	✓	✓	✓	X	X	X
	2013	✓	✓	✓	✓	✓	✓	✓	X	✓
	2014	✓	✓	✓	✓	✓	X	✓	✓	✓
May	2012	✓	✓	✓	✓	✓	✓	X	X	X
	2013	✓	✓	✓	✓	✓	✓	✓	X	✓
	2014	✓	✓	✓	✓	✓	X	✓	✓	✓
Jun	2012	✓	✓	✓	✓	✓	✓	X	X	X
	2013	✓	✓	✓	✓	✓	✓	✓	X	✓
	2014	✓	✓	✓	✓	✓	X	✓	✓	✓
Jul	2012	✓	✓	✓	✓	✓	✓	X	X	X
	2013	✓	✓	✓	✓	✓	✓	✓	X	✓
	2014	✓	✓	✓	✓	✓	X	✓	✓	✓

Right Whale Analysis

Since North Atlantic right whales are the most endangered whale species found in the acoustic study area, additional analyses were conducted to obtain a higher-resolution view of temporal and spatial trends within the WEAs throughout the duration of the study period.

Daily Call Rate

For this analysis, the sum of confirmed first-arrival upcalls detected in each day was averaged within each calendar month (*mean daily call rate*) and then normalized over the number of MARU recording sites that recorded during each corresponding month, resulting in an *effort-adjusted mean daily call rate* per month. Analysis of both the percent monthly presence and the total number of calls per month can illustrate variation in presence and potential shifts in behavior over time.

Diel Acoustic Presence

To gain a more comprehensive understanding of when right whales in the proposed WEAs may be most vocal during a 24-hour period, we evaluated diel trends in acoustic presence at differing times of the year. Here, we summed the number of upcalls detected for each hour (0–23, EST) and day. To adjust for the variation in call rates between days, a *mean-adjusted hourly call rate* (similar to Stafford et al. 2005, Risch et al. 2014) was used, where the mean number of upcalls for each day was subtracted from the total upcalls of each hour from the corresponding day. Days when no upcalls were detected were excluded from this analysis. To see the effects of season on diel trends, we separated the data into 4 groups of 3 consecutive months based on season (as defined earlier).

Spatial Acoustic Presence

To provide insight into seasonal spatial distribution of right whales in the context of spatial planning, acoustic presence at each recording site was examined for each season. To account for the gaps in recording time among the sites, upcalls were summed for each site and then divided by the number of recording days for the corresponding site. This resulted in a ratio of calling rates per site to the recording effort at that site, hereafter referred to as *normalized site-presence*.

Acoustic Detector Evaluation

We used a supervised automated detection approach for right whales, fin whales, and minke whales (meaning that all automated detection events were validated by expert analysts), so the true detections from each detector were determined during the analysis of the detector output, and false positives were eliminated. However, the true detections that the detector missed, also known as the *missed detections* (or false negatives), are not known *a priori*, and can result in an underestimation of the number of days with presence. To evaluate the number of missed detections, a representative subset of days were selected where no presence was found (true negatives) after analysis of the detector output, and each entire day was visually inspected by expert analysts. The result of this effort is a determination of the total number of days with missed detections. That number was then converted to a missed detection rate for each species detector:

$$\textit{Daily Missed Detection Rate} = \frac{\text{Days with Missed detections}}{\text{True negatives + Missed detections}} \text{ x } 100 \qquad (8)$$

All three species for which an automated approach was used had some degree of missed detections associated with the detection algorithm. For example, the highest missed detection rate was from the fin whale detector (18%). The missed detections indicate that the total number of days of presence reported for right, minke, and fin whales may be underestimated.

Acoustic Detection Range

The detection range or “listening area” of a species is the maximum distance a specific type of vocalization can propagate and be recorded by a MARU. Calculation and modeling of a detection range for a MARU is dependent on several known environmental parameters specific to the recording area, and the estimated or modeled source level of the vocalizing whale. We estimated the detection range at all recording sites using a simple model of spherical transmission loss as described in Urick (1986) and Mellinger and Clark (2003). The spreading loss value of 17 $\log_{10}$ was applied (i.e., a 17 dB loss per tenfold increase in distance). This same value was used for a site with similar bathymetric conditions and for purposes of low-frequency noise in the Cape Wind Noise Report (USACE 2004). Detection range estimates were derived from the transmission loss calculation formula below.

In cases where bottom depth is greater than the distance of the whale to the sensor, we used the following transmission loss (*TL*) calculation:

$$\mathrm{TL} = 20\log_{10}(\mathrm{H}) \tag{9}$$

In cases where bottom depth is less than the distance of the whale to the sensor, we used the following *TL* calculation:

$$\mathrm{TL} = 20\log_{10}(\mathrm{H}) + 17\log_{10}\left(\frac{\mathrm{R}}{\mathrm{H}}\right) \tag{10}$$

where *H* represents the depth of the signal source to the sea floor (transition range from spherical to intermediate (spherical/cylindrical), and *R* represents the range of the signal source to the receiver. These calculations take into account measured local ambient noise levels at each location. Ambient noise measurements from species-specific bandwidths (Table 3) were calculated from 7 consecutive days each in a representative month from each season (January, April, July, October) to capture variations in noise levels and sound speed profiles. Using the 10th percentile of those noise levels (the level that is exceeded 90% of the time), detection range was calculated for 8 bearings from each recording site. We averaged the distance from those 8 bearings at each site and month and added the upper bound of the 95% confidence interval to estimate detection range.

Table 3. Source levels and species specific bandwidths used in the detection range calculations for all five whale species.

Species	Source Levels	Species Specific Bandwidth
Right whale	172 dB (Hatch et al. 2012)	71 - 224 Hz (Hatch et al. 2012)
Fin whale	189 dB (Weirathmueller et al. 2013)	15 - 25 Hz (Weirathmueller et al. 2013)
Minke whale	168 dB (Risch et al. 2014)	50 - 300 Hz (Risch et al. 2014)
Humpback whale	173 dB (Au et al. 2006)	20 - 600 Hz (Thompson et al. 1986)
Blue whale	194 dB (McDonald et al. 2008)	15 - 28 Hz (Mellinger and Clark 2003)

AERIAL AND ACOUSTIC DATA SYNTHESIS

Monthly effort-weighted mean sighting rates for right, minke, and humpback whales were correlated with the *monthly acoustic presence* of that species. Blue whales were not analyzed, since there were no sightings from the aerial surveys. The two datasets were restricted to only those months between October 2011 and June 2015 when both MARUs were in the water and aerial surveys were taking place (see Figure 13). Because the RIMA array was only in the water for two year, the data were further limited to only the *monthly acoustic presence* data from the MA array and the monthly effort-weighted mean sighting rate data from transects in the defined Massachusetts survey stratum (equivalent to the entire survey area in the first year of the study). This created the longest and best matched dataset for further analysis, with 35 months of overlapping acoustic presence and sighting rate data.

To determine the level of concurrence between the acoustic presence and the sighting datasets, we ran both Spearman product-moment correlations using the SAS CORR procedure, as well as least-squares linear regressions using the GLM procedure, both with and without an intercept term specified in the regression models. The Spearman correlation statistic is a non-parametric analysis that does not presume linear relationships, normal distributions, and homogenous variances. In the regression analyses, acoustic presence was defined as the independent variable and sighting rate was the dependent variable. This analysis tested whether the relative abundance of a whale species in the study area could be predicted from acoustic monitoring. In the first round of tests an intercept term was not specified (the intercept was forced through 0, indicating that no acoustic detections would mean no whales present) In the second round of regressions, the models included an intercept term dictated by the analysis.

AMBIENT NOISE ANALYSIS

Measurements of ocean ambient noise (inclusive of environmental, biological, and anthropogenic sounds), have long been used to characterize different geographic areas from an oceanographic or physical perspective (see reviews by Wenz 1972 and Urick 1986). These measurements are now being calculated in different ecosystems to evaluate how marine animals may be influenced by sound from environmental and anthropogenic processes (Samuel et al. 2005, Simard et al. 2010, Clark et al. 2011). Analysis of the ambient noise environment over large spatial and temporal scales provides a broad, but revealing perspective on biological and anthropogenic habitat use. In this case, baseline ambient noise data is critical to compare against both construction and operation noise conditions and help inform management decisions and provide crucial data for impact assessments. The analytical details are provided below.

Acoustic Signal Processing

Acoustic data were processed within the Raven-X toolset (Ponirakis et al. 2015) in MATLAB using a Hann window with zero overlap, a fast Fourier transform (FFT) size where Δ *time* = 1 s and Δ *frequency* = 1 Hz. We used the metric of equivalent continuous sound pressure level or L_{eq} (dB re: 1 µPa [rms]) to represent the average unweighted sound level of a continuous time-varying signal of pressure (Morfey 2001) over specified time intervals. The resulting root-mean-square pressure is expressed by:

$$L_{eq} = 10\log_{10}\frac{1}{T}\int_{0}^{T}\left(\frac{p_m(t)}{p_{ref}}\right)^2 dt \tag{11}$$

where T is the time interval, p_m is the measured sound pressure, t refers to time, and p_{ref} is the reference pressure of 1 µPa.

Spectral Trends

To statistically compare the dominant frequencies of each site, we generated a power spectral density plot of sound pressure levels. The plot captures variation of sound pressure levels across the frequency domain of long-term ambient noise data (Wenz 1972) by representing the sound pressure level (dB re: 1µPa^2/Hz) as a function of frequency in the signal (Merchant et al. 2012). Here, data from the entire recording period for each site are represented using the median percentiles.

Cumulative Percent Distribution

To illustrate the overall variation in ambient noise levels between sites, we calculated the cumulative percent distribution of L_{eq} values at each recording site and frequency band, which illustrates the percentage of time that sound pressure levels reached a particular L_{eq} value. The cumulative percent distribution allows for a direct comparison of the statistical noise characteristics of each site within a particular frequency band. For this analysis, we selected a frequency bandwidth of 20 – 447 Hz, because that bandwidth encompasses the frequency range of target vocalizations for all five focal whale species (McDonald et al. 1995, Thompson et al. 1996, Hatch et al. 2012, Weirathmueller et al. 2013, Risch et al. 2014).

RESULTS

AERIAL SURVEY EFFORT

A total of 76 aerial surveys were conducted in the study area between October 2011 and June 2015 (Appendix C). Effort conducted during each survey is listed in kilometers (km) and includes transect lines, transit, circling and cross-legs. Survey effort throughout the study period is shown (in km) in Figure 10. Gaps in aerial survey data collection (due to weather or aircraft maintenance) occurred during the period between November 2012 and January 2013, in December 2013, and in February 2015. Survey data collection started in the RIMA WEA in December 2012. When summed across all years by month, the greatest amount of survey effort was conducted during the spring and summer, while winter and autumn surveys were typically reduced by weather factors. Due to the surveys starting in October and ending in June, the months of July, August, and September had one year less of effort when summed across the entire project. The additional shortage of effort in July, when weather is typically reliable, was caused by both the lack of a fifth year of surveys and a bout of severe thunderstorms in July 2013.

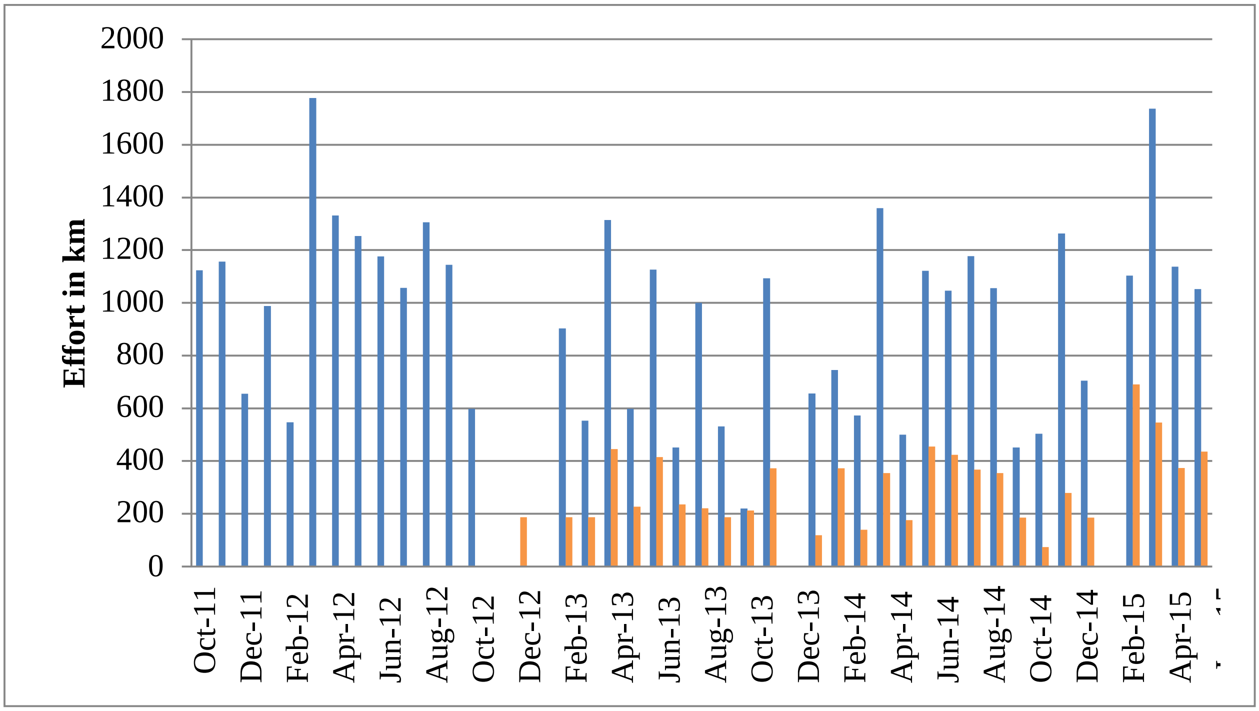


Figure 10. Effort (km) by month and year in the MA WEA (blue) and RIMA WEA (orange).

Aerial Detections

Aerial survey statistics, including total effort and sighting totals, are provided in Table 4 and Figure 12.There were 4,452 detections (species, fishing gear, and vessels) collected over the course of the entire study period (October 2011–June 2015). A total of 2,886 sightings of marine biota (fishing gear, vessels, and debris excluded) comprised of at least 20,183 animals that were detected during aerial surveys. This number is a minimum count, and schools of fish were not counted. In total, 347,641 of the 379,593 vertical images collected during aerial surveys were analyzed.

Observers visually detected the majority of sightings (80%), with 62% of these sightings occurring on track and 18% occurring off-track. The addition of the vertical camera to the survey increased the sighting total by another 20%. Visual and vertical camera sightings were combined and reported in the All Sightings Table (Appendix A), which includes all recorded detections, including fishing gear and vessels and all levels of identification reliability (*definite*, *probable*, and *possible*). Maps of all sighting locations, by species, for all detections listed in Appendix A table are included in Appendix B.

Table 4. Summary of aerial survey statistics (sightings include marine species, fishing gear, and vessels).

Category	Total
Total Number of Surveys	76
Total Flight Hours	436.2
Average Flight Hours per Survey	5.7
Total of All Survey Effort (km)	67,524.50
Total of Transect-Line Effort (km)	42,616.20
Total Number of Vertical Images Collected	379,593
Total Number of Vertical Images Analyzed (On-Track)	347,641
Total Number of Detections (vertical camera & observer sightings)	4,452
Total Number of Animals/Objects Detected	24,612
Number of Visual Detections	3,544
Total Number of Animals/Objects Detected Visually	21,506
Total Number of Vertical Camera Detections	908
Total Number of Animals/Objects Detected in Vertical Photos	3,106

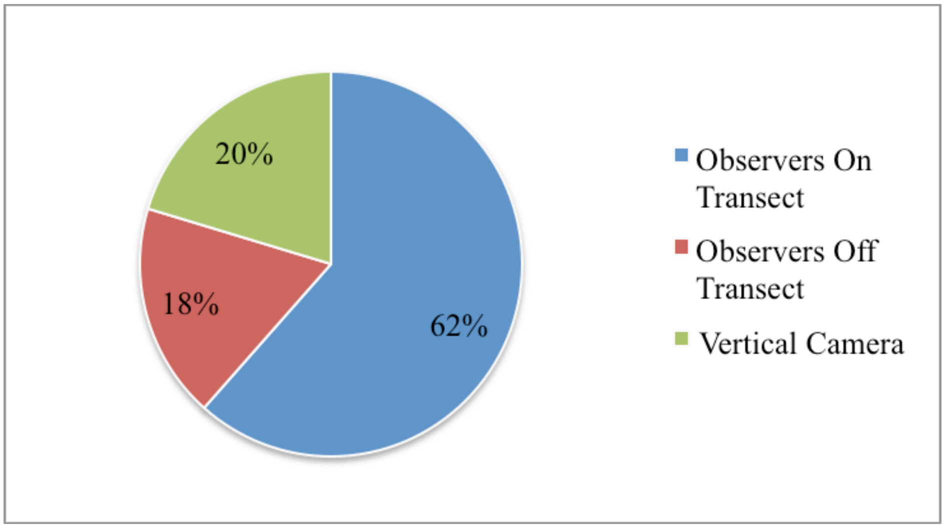


Figure 11. Aerial survey sightings by mode of detection (observers vs. vertical camera).

ACOUSTIC SURVEY EFFORT

MARUs recorded for 5-6 consecutive months at a time during six separate deployments from November 2011 to March 2015 (Figure 13) for a total of 6,894 days of sound recordings for all sites combined, covering 1,010 calendar days. Sound data from all MARUs in a deployment were extracted and concatenated into one sound file for analysis. There were a number of time periods during the study when either no sound data was collected because MARUs were not deployed, or there was MARU malfunction resulting in the loss of sound data (see Figure 13 for data gaps). No MARUs were deployed from October 2012 through January 2013 and during March 2014 because of delays in contracts to continue with data collection. Figure 13 shows the MARUs that were recording in each month and year in both the MA and RIMA WEA arrays. To account for these data gaps, we normalized our data based on recording effort where appropriate (described in analysis methods above).

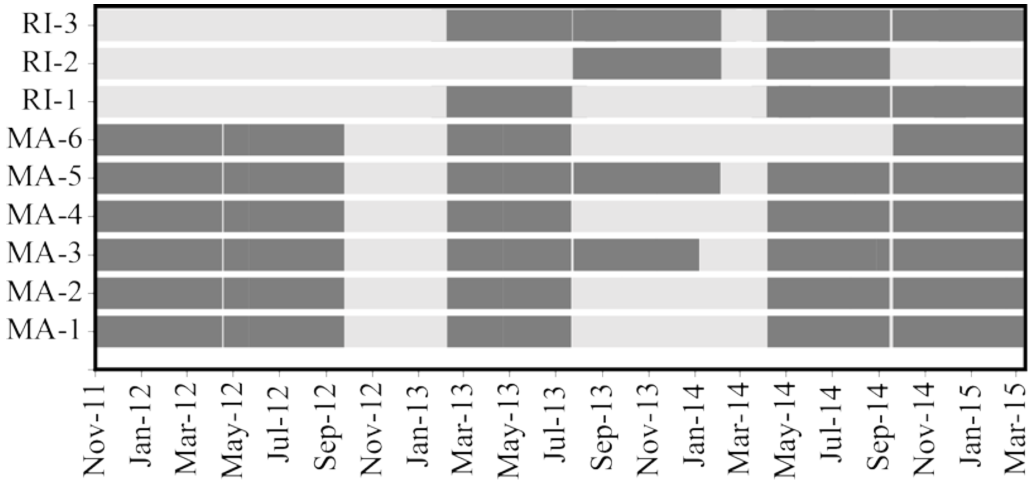


Figure 12. Summary of acoustic recording effort per site throughout the study period. The dark gray bars indicate time periods when a MARU was recording at a given site. The light bars indicate time periods when a MARU was not recording at a given site.

LARGE AND MEDIUM WHALES

Sightings and Sighting Rates of Whales

Six species of large and medium-sized whales were sighted in the study area: the North Atlantic right whale, humpback whale, fin whale, sei whale, minke whale, and sperm whale (sightings point maps, Appendix B). There were large whale sightings during all seasons of the year, with the majority in spring and summer, with occasional sightings in the autumn (Table 5, Figure 14). The exception to this seasonal trend was the North Atlantic right whale, which was only sighted in winter and spring. There were also no sperm whale sightings during spring months. The variability in average sighting rate by month was significant for each species tested (right whales, fin whales, minke whales, sei whales, and humpback whales), which further demonstrates the seasonal nature of their occurrence in the SA. The monthly mean sighting rate for each of the large whale species with 25 or more sightings is reported to further depict seasonal presence by each species (Table 6).

Table 5. Effort-weighted average sighting rates (SR, the number of animals per 1000 km), numbers of sightings (S), and numbers of animals observed (A) for six whale species (only *definite* and *probable* identifications) and all large whales combined by season. Total effort (km) is shown below each season name.

Species	Autumn (13,298.08 km)			Winter (11,846.17 km)			Spring (23,348.20 km)			Summer (18,683.15 km)		
	SR	**S**	**A**	**SR**	**S**	**A**	**SR**	**S**	**A**	**SR**	**S**	**A**
Right whale	0	0	0	4.31	25	54	3.58	35	91	0	0	0
Humpback whale	0.17	2	2	0.13	2	2	3.96	53	83	4.61	25	73
Fin whale	0.19	2	2	0.09	1	1	2.70	35	60	4.75	48	92
Sei whale	0	0	0	0	0	0	0.10	12	22	0.78	13	19
Minke whale	0.06	1	1	0	0	0	3.14	61	76	1.42	21	26
Sperm whale	NA	1	1	NA	0	0	NA	0	0	NA	3	8
All large whales	0.61	8	8	4.91	33	62	11.98	215	362	11.53	128	237

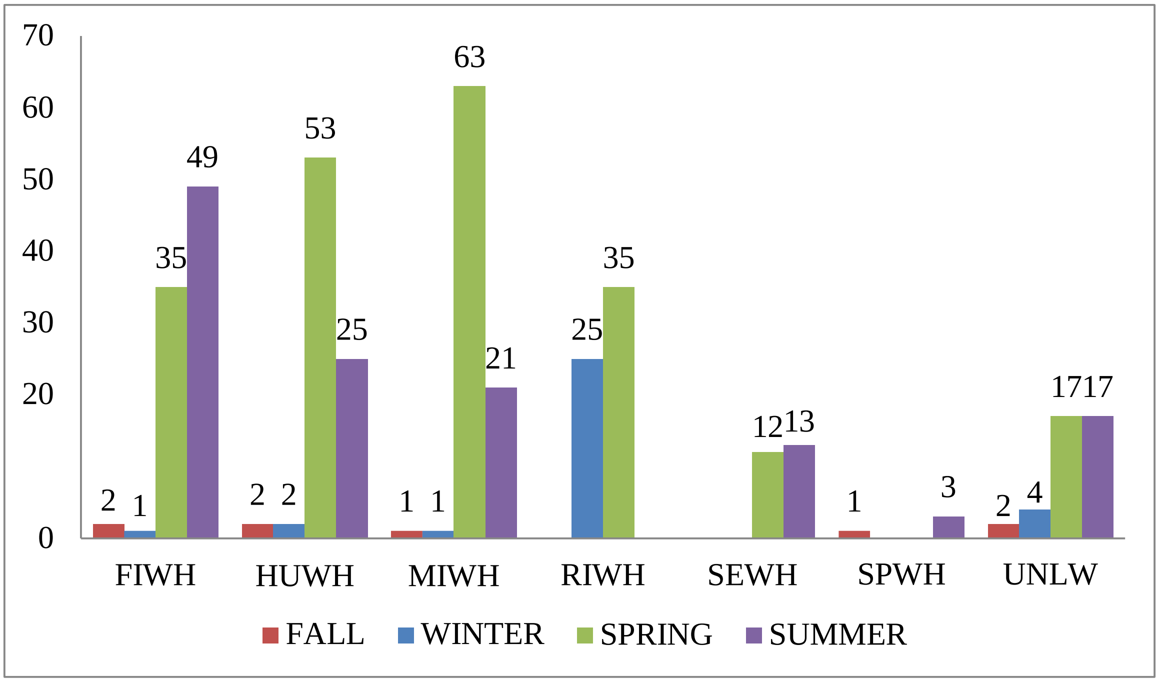


Figure 13**. Numbers of whale sightings in the study area by season across all years (FIWH = fin whale, HUWH = humpback whale, MIWH = minke whale, RIWH = North Atlantic right whale, SEWH = sei whale, SPWH = sperm whale, UNLW = any whale sightings not identified to species).**

Table 6. Mean sighting rates by month for five large whale species and all large whales combined (including unidentified sightings). *P* is the probability from a Kruskal-Wallis test for significant variability in sighting rate among months.

Month	Mean SR					
	RIWH	HUWH	FIWH	SEWH	MIWH	All
January	4.557	0.194	0.227	0.000	0.000	5.852
February	6.684	0.000	0.000	0.000	0.000	6.684
March	8.425	0.416	0.000	0.137	0.409	9.763
April	2.543	5.926	2.816	0.793	3.092	12.730
May	0.000	4.162	5.617	2.373	6.406	13.080
June	0.000	9.431	5.468	1.726	1.939	17.960
July	0.000	1.447	5.102	0.000	1.627	7.393
August	0.000	0.000	3.372	0.000	0.472	5.326
September	0.000	0.000	0.230	0.000	0.191	0.460
October	0.000	0.503	0.328	0.000	0.000	1.159
November	0.000	0.000	0.000	0.000	0.000	0.203
December	1.647	0.183	0.000	0.000	0.000	2.013
P	<0.001	<0.001	<0.001	0.079	<0.001	0.002

Vertical Camera Detections of Large Whales

Large whales were only detected in the vertical camera photographs three times. One right whale was found in a photo from Survey 11 on 23 March 2012. A pair of fin whales was detected in a photo from Survey 56 on 18 July 2014. Finally, one minke whale was found in a photo from Survey 73 on 3 May 2015.

Variability of Large Whale Sighting Rates

There was significant annual, monthly, and seasonal variability in the occurrence of large whale species (Table 6). Variability was also significant by season-year. When tested by season among years, large whale presence varied significantly during the autumn ($P = 0.022$), but not in any other season (Table 7).

Table 7. Summarized results for analyses of variability and trends in sighting rates for all large whale species combined. Each table entry for the Kruskal-Wallis tests is the *P*-value testing whether there is significant variability in sighting rate among the respective time intervals. The two right columns show the results of least-squares linear regression of sighting rate vs. survey day or year. Each cell shows whether the trend was positive or negative, and the *P*-value (NS = non-significant at $P \geq 0.10$).

Kruskal-Wallis ANOVA				Regression	
Year	Month	Season	Season-Yr	Survey Day	Year
0.003	0.002	<0.001	0.001	+,0.013	+,0.003
Kruskal-Wallis ANOVA, among Years by Season					
Winter	Spring	Summer	Autumn		
0.354	0.213	0.303	0.022		

Endangered Large Whale Sightings per Unit Effort

Viewed seasonally across all years, the majority of large whale sightings took place during the spring and summer months (Figure 15). The winter distribution was almost entirely right whales. In the spring, distribution tended to be clustered farther offshore in the southern portion of the study area, and in the summer months concentrations were seen closer to shore. When viewed annually across all years, relative abundance was widespread throughout the study area.

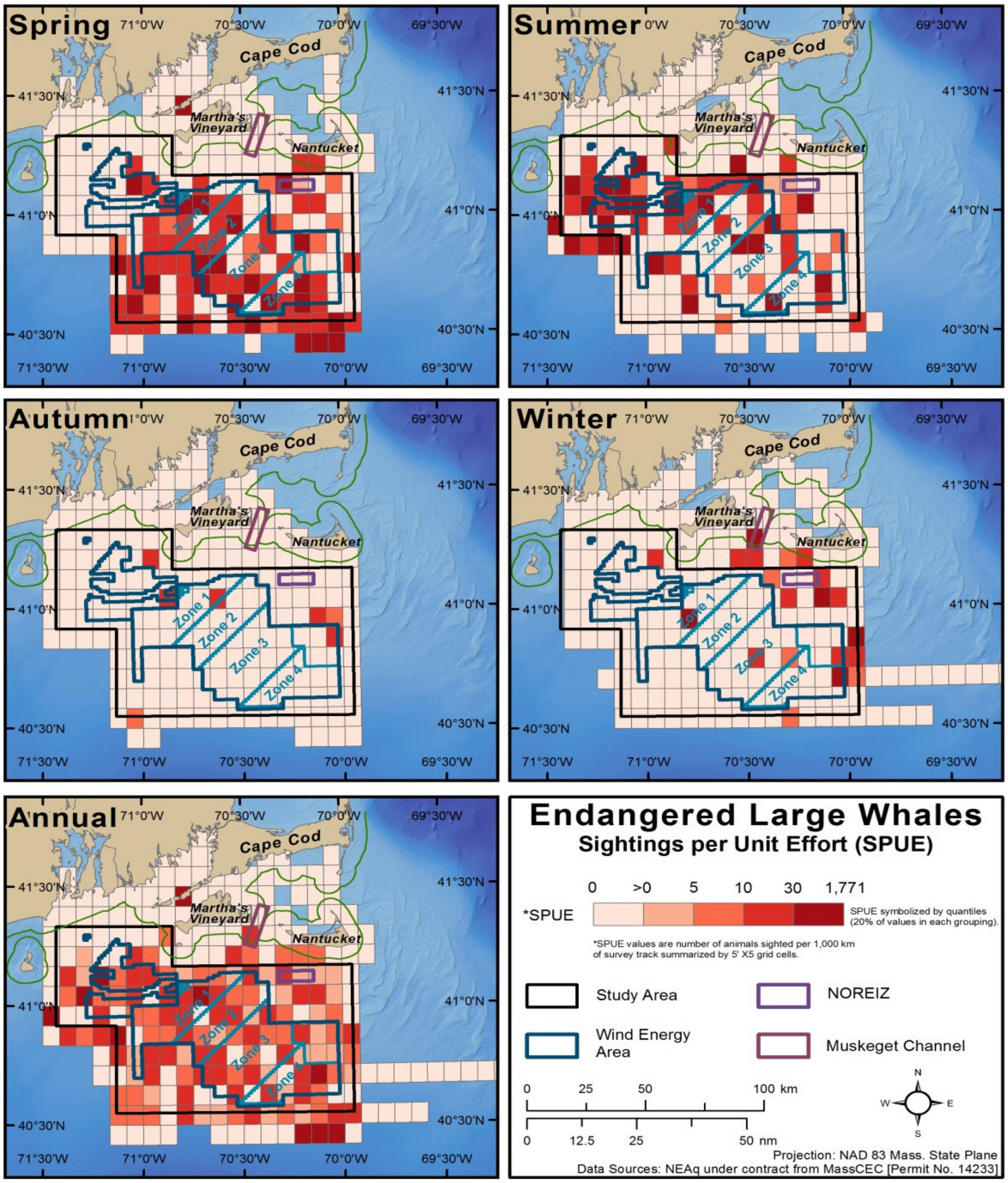


Figure 14. Sightings per Unit Effort of endangered large whales (fin whale, humpback whale, sei whale, sperm whale, and North Atlantic right whale) shown seasonally and annually for all years combined (October 2011–June 2015).

Large whales with Calves

Four large whale species were observed with calves during the study period. There were 18 total sightings of calves, including humpback whales (*n* = 10), fin whales (*n* = 3), sei whales (*n* = 3), and minke whales (*n* = 2). Large whale calves were only observed during the spring and summer months, and June was the month with the highest number of sightings.

Behavior of Large and Medium Whales

Five whale species were observed feeding in the survey area during the project. Observers documented 36 instances of feeding-related behaviors by fin whales (*n* = 9), humpback whales (*n* = 10), right whales (*n* = 6), sei whales (*n* = 4), and minke whales (*n* = 2). Feeding behaviors were observed in all seasons except for autumn. Across all years, the majority of feeding-related sightings occurred in the spring months and the lowest numbers were in winter.

There were 12 sightings of large whales exhibiting courtship behavior during the project. While right whales (*n* = 11) whales participating in SAGs (Surface Active Groups) were the most common species observed exhibiting courtship behavior, a single humpback whale was also observed displaying courtship behavior in the survey area. The majority of courtship behaviors were observed in the spring.

Summary of Large and Medium Whale Presence

Large and medium whales were sighted in the study area during all seasons, and were most frequently sighted in spring and summer. There was significant variation in the presence of this group of animals from year to year during autumn. The five most frequently sighted species displayed significant seasonality by month within the study area. Large whale distribution was recorded in all of the lease areas during the spring and summer, with slightly greater numbers of animals in the RIMA WEA and Zone 1 of the MA WEA during the summer. During autumn and winter, both abundance and relative abundances were reduced. Four different species of whales were sighted in the study area with calves. Feeding was observed for five different species of large whales, and courtship behaviors for two.

NORTH ATLANTIC RIGHT WHALE (*EUBALAENA GLACIALIS*)

Aerial Sightings of North Atlantic Right Whales

North Atlantic right whales were only sighted in the study area during winter and spring seasons (Table 3). Right whale sightings began in December and continued through the month of April, and the greatest number of sightings occurred in March (Figure 16).

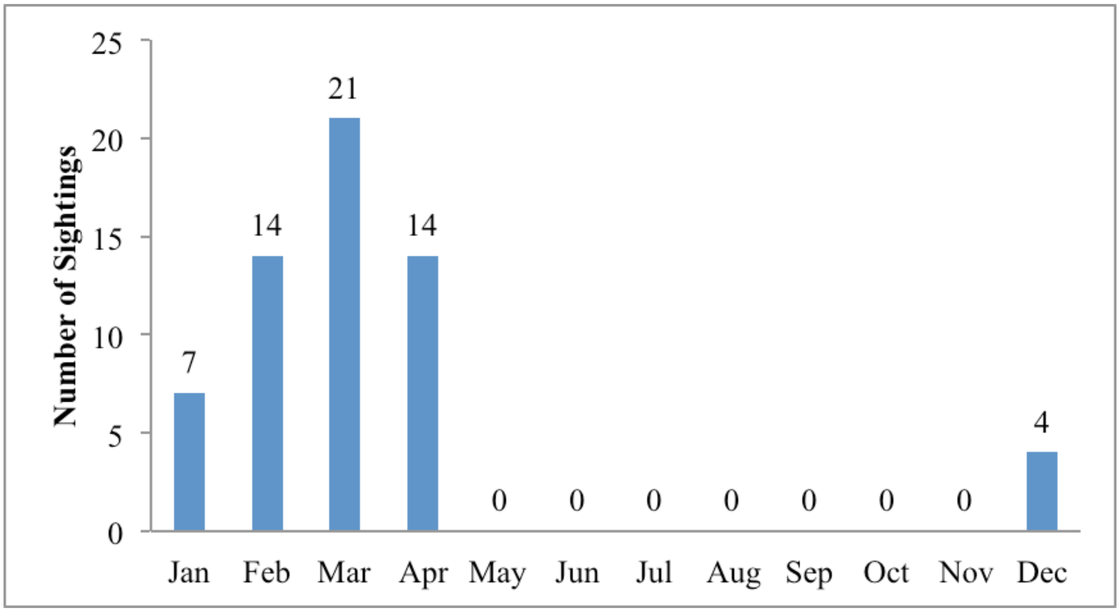


Figure 15. Right whale sighting totals by month, combined across all survey years (October 2011–June 2015).

Right Whale Sighting Rates and Variability

Right whale mean sighting rates were highest in winter (4.31) and spring (3.58) (Table 5), and were zero for both summer and autumn. There was not significant variability in sighting rate among years (Table 8), suggesting consistent annual seasonal use of the area. However there was significant variability in sighting rate by month, season, and season-year. Similarly, there was no significant inter-annual variability within any one season (Table 8).

Table 8. Summarized results for analyses of variability and trends in sighting rates for North Atlantic right whales. Each table entry for the Kruskal-Wallis tests is the *P*-value testing whether there is significant variability in sighting rate among the respective time intervals. The two right columns show the results of least-squares linear regression of sighting rate vs. survey day or year. Each cell shows whether the trend was positive or negative, and the *P*-value (NS = non-significant at *P* ≥ 0.10).

Kruskal-Wallis ANOVA				**Regression**	
Year	Month	Season	Season-Yr	Survey Day	Year
0.304	<0.001	<0.001	0.01	NS	+,0.060

Kruskal-Wallis ANOVA, among Years by Season			
Winter	Spring	Summer	Autumn
0.193	0.297	1.000	1.000

Right Whale Sightings Per Unit Effort

Right whale relative abundance in the winter and spring was clustered in the northern and eastern portions of the study area (Figure 17).

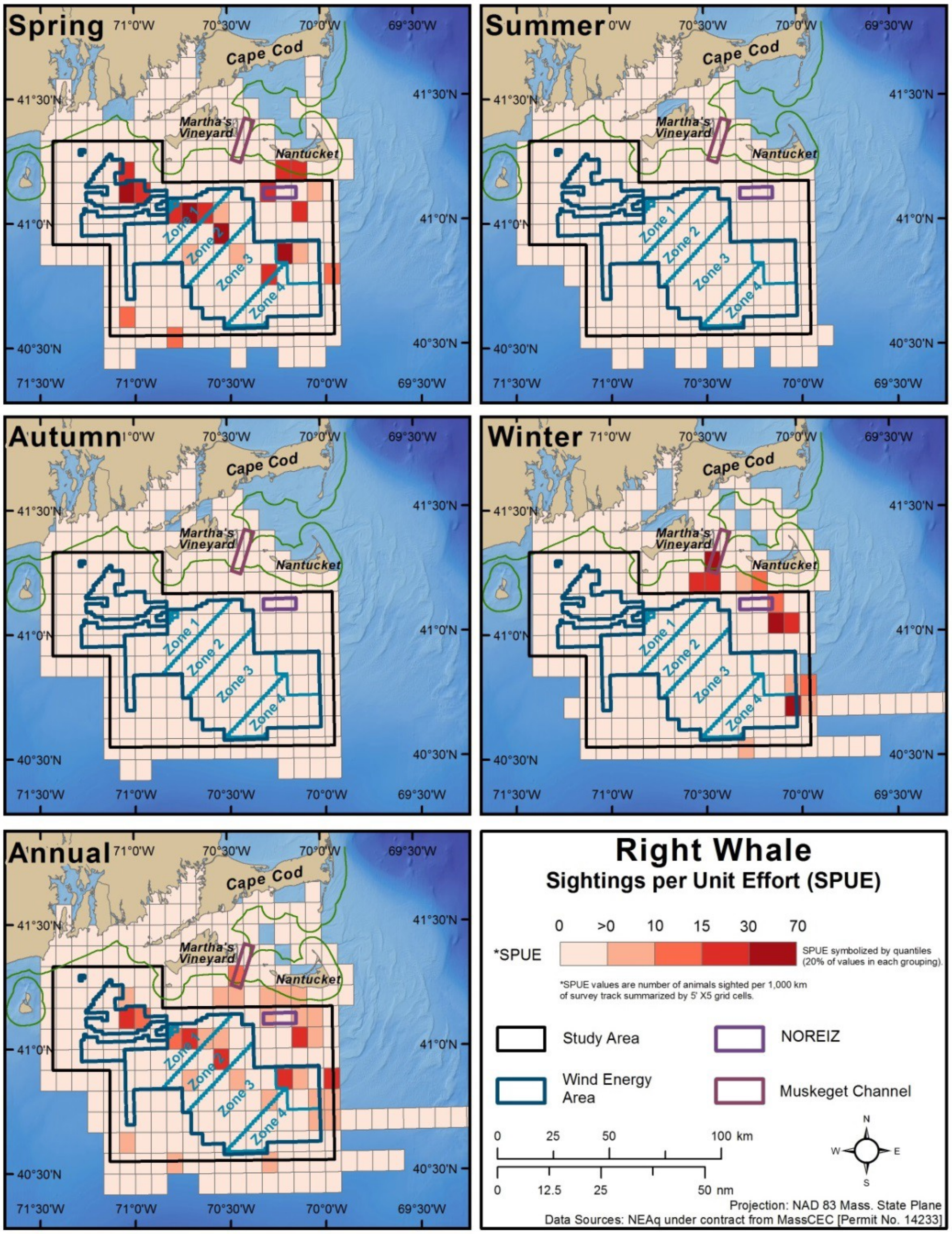


Figure 16. Right whale SPUE by 5-minute squares partitioned by season across all years and with all seasons combined.

Hot Spot Analysis

The seasonal and annual patterns of relative abundance shown by the SPUE maps (Figure 17) prompted a Hot Spot Analysis to further define areas of importance by season and year (Figure 18). Hot Spots were identified within both of the WEAs in spring, and outside of the WEAs in winter—both just offshore of the Muskeget Channel and south of Nantucket and along the eastern limit of the study area. When viewed annually, hot spots persist in the MA WEA and in the northeastern corner of the study area.

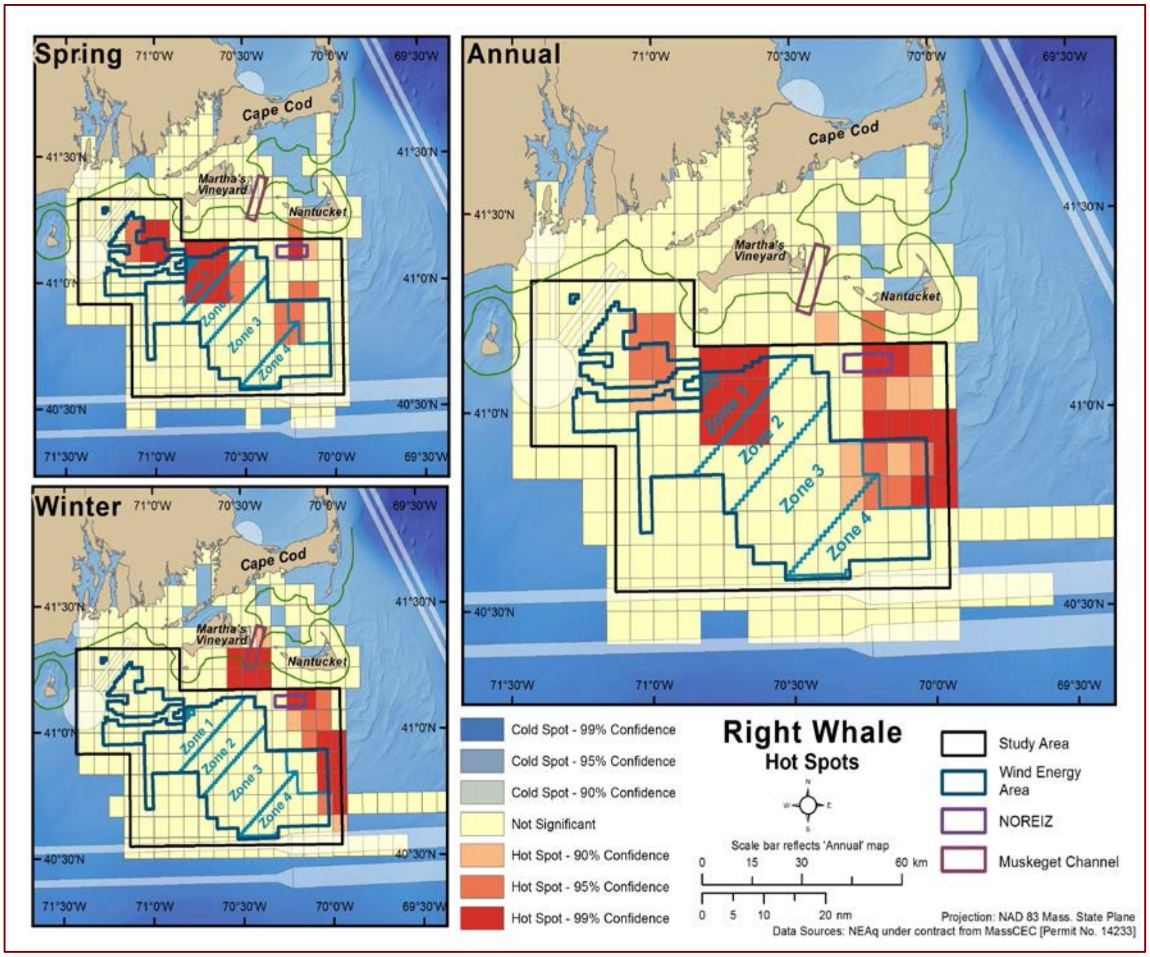


Figure 17. Hot Spot analysis of North Atlantic right whale SPUE data showing spring, winter, and annual patterns (2012-2015).

Abundance of North Atlantic Right Whales

Seasonal abundance estimates of North Atlantic right whales in the SA were calculated for most winter and spring seasons, and ranged from 0 to 35 animals with 95% confidence intervals up to 269 (Table 9). For the most part, estimates tended to be higher in the spring season.

Table 9. Density and abundance of North Atlantic right whales (*Eubalaena glacialis*) by season-year. Density and variance are the means of the transect estimates, weighted by transect lengths. Multiple surveys are included in each season, so estimates (N) and 95% C.I.'s are based upon multiple surveys/season. T = number of transects used in the analysis; G, I = number of groups and individuals (based upon photo-identification data, not transect data) sighted; D = density in animals/km^2 for each season; V = variance of the density; N = estimated abundance in the study area by season; CI95 = 95% confidence interval, with the lower limit changed to zero if it was negative.

Season-Year	T	G, I	D	V	N	CI95
Autumn-2011	32	0, 0	0	–	0	–
Winter-2012	30	0, 0	0	–	0	–
Spring-2012	56	8, 13	0.0035	0.0027	24	0–118
Summer-2012	48	0, 0	0	–	0	–
Autumn-2012	24	0, 0	0	–	0	–
Winter-2013	16	3, 5	0.0045	0.004	35	0–296
Spring-2013	39	1, 1	0.0005	0.0003	4	0–43
Summer-2013	46	0, 0	0	–	0	–
Autumn-2013	36	0, 0	0	–	0	–
Winter-2014	26	1, 3	0.0008	0.0006	7	0–83
Spring-2014	41	4, 11	0.0019	0.0016	15	0–109
Summer-2014	60	0, 0	0	–	0	–
Autumn-2014	39	0, 0	0	–	0	–
Winter-2015	28	4, 15	0.0027	0.002	21	0–155
Spring-2015	65	10, 44	0.0029	0.0021	23	0–111

Demographics

A total of 77 unique individuals were sighted in the study area over the course of the study period (October 2011–June 2015) (Appendix E). The most recent "best estimate" for the North Atlantic right whale population was 526 individuals, and this count constitutes 15% of that estimate (NARWC Report Card, 2015). Of the individuals sighted, 43 were males, 27 were females, and 7 were of unknown sex (Table 10). Of the 27 females identified, 12 are known reproductive females ("cows") (Table 10). Eleven individuals were sighted in the study area in two different years, and two of these individuals were seen in a third year.

Table 10. Age class by sex of photo-identified North Atlantic right whales at time of sighting within the Study Area. Individuals observed on multiple dates are counted only once. A = adult, J = juvenile, C = calf, U = unknown age.

Sex	Age Class			
	A	J	C	U
Female (non-cow)	4	10	0	1
Female (cow)	12	0	0	0
Male	28	14	0	1
Unknown	2	1	0	4
Total	**46**	**25**	**0**	**6**

Acoustic Detections of Right Whales

Between November 2011 and March 2015, North Atlantic right whale upcalls were detected on approximately 47% (n = 478) of the 1,020 days of recording in the study area. Upcalls were detected on approximately 43% (n = 443) and 27% (n = 190) of the days recorded in the MA WEA and the RIMA WEA, respectively. Since October 2012 had only 3 days of acoustic recordings (due to the MARU retrieval schedule), it was excluded from the *monthly acoustic presence* data. Right whales were acoustically detected in 30 out of the 36 recorded months, in 17 of which right whales were present on at least 50% of the days per month (Figure 19, bars). Months with the greatest monthly acoustic presence (> 90%) occurred in the late winter/early spring (March 2012, February – March 2013, April 2014, and February – March 2015). In November and December of 2014, *monthly acoustic presence* was 84% and 90%, exhibiting a steeper increase in acoustic presence than in the same two months of previously recorded years. Months with the lowest levels of acoustic presence (<10%) mostly occurred during summer and autumn (November 2011, June – August 2012, August – September 2013, and July – August 2014).

The adjusted mean daily call rates (Figure 19) reflected the seasonal trends in the monthly acoustic presence data, but demonstrated a greater magnitude of variation in acoustic presence between months. During this study, 46,324 first-arrival upcalls were detected. February and March consistently had the most upcalls, accounting for approximately 67% of all upcalls detected during the study period. The months of June, July, and August comprised the fewest calls (4%). Interestingly, during the last 3 months of the study, the number of right whale upcalls per month drastically increased in comparison to the previous months and years, and comprised more than half the total number of upcalls. Between the start of the acoustic survey (November 2011) and December 2014, 25,005 right whale upcalls were detected. Between January 2015 and early March 2015, however, 21,283 first-arrival upcalls were detected, accounting for approximately 53% of all upcalls detected throughout the study period. In February 2015 alone, the total number of upcalls reached 11,025, accounting for approximately 23% of all upcalls.

Right whales exhibited strong seasonality in acoustic presence. The mean monthly acoustic presence (Figure 20) was highest in January (mean = 74%, SE = 7%), February (mean = 86%, SE = 9%), and March (mean = 97%, SE = 2%). Those three months comprise the upper 25% of the data. The lowest mean monthly presence occurred during the months of July (mean = 16%, SE = 16%), August (mean = 2%, SE = 1%), and September (mean = 12%, SE = 3%).

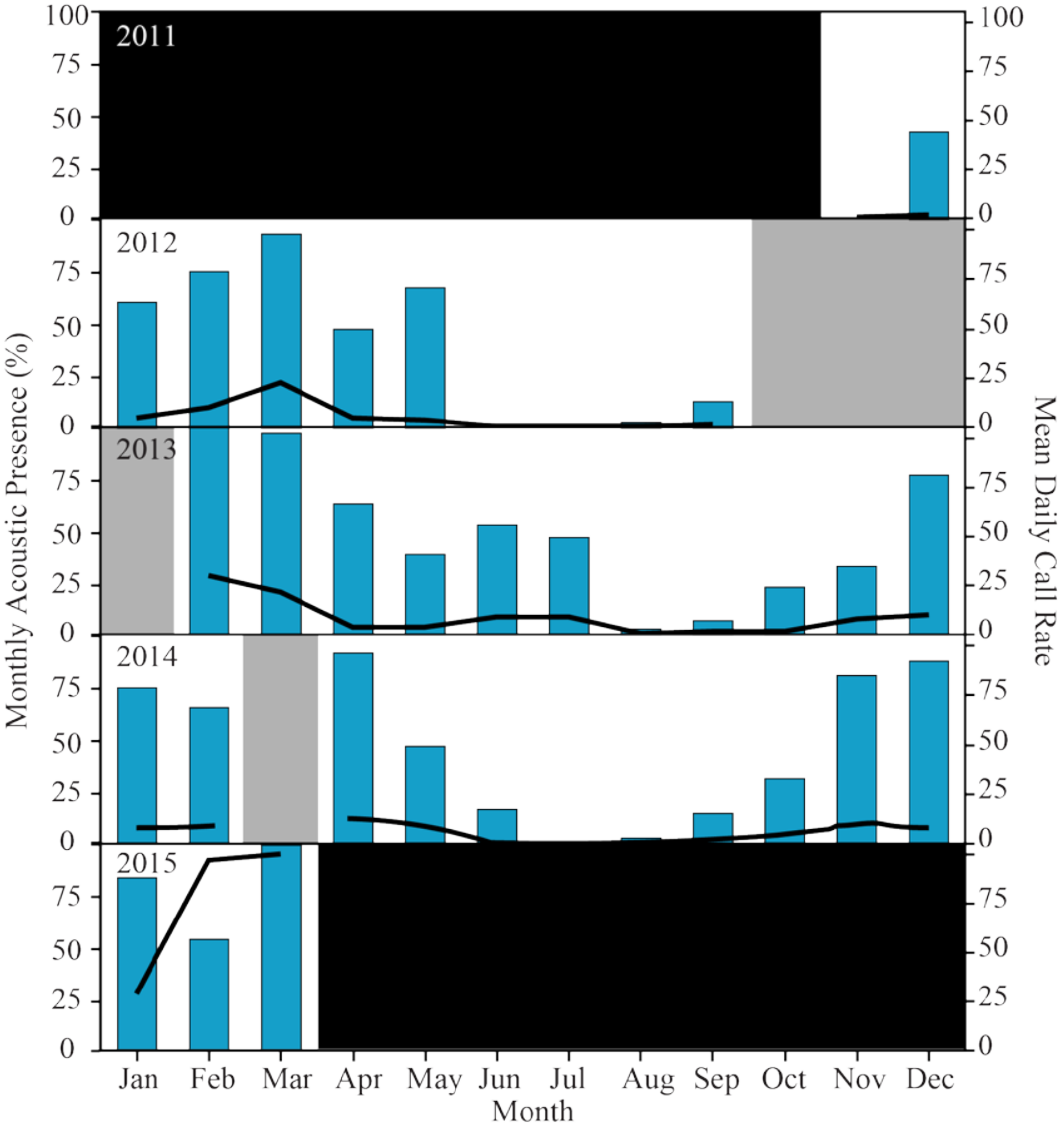


Figure 18. Percent of days with right whale upcall presence per month (primary y-axis, bars), and the mean daily call rate of detected right whale upcalls per month (secondary y-axis, shown with the black line) during each year of the study period. The grey areas represent time periods when MARUs were not recording and the black areas represent time periods outside the study period.

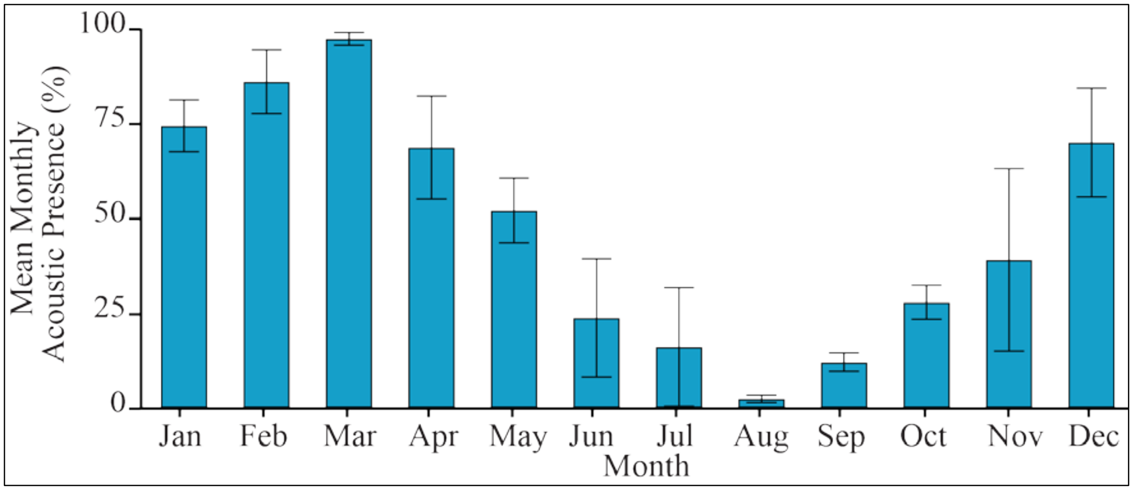


Figure 19. Right whale mean monthly acoustic presence ± standard error for all years combined.

Variability in Acoustic Presence

The coefficient of variation (Figure 21) illustrates that the highest variation in right whale acoustic presence among years occurred during July and June. This reflects nearly 50% presence during those months in 2013 and 0 - 25% presence during those months in 2012 and 2014. Monthly acoustic presence in March had much less variation.

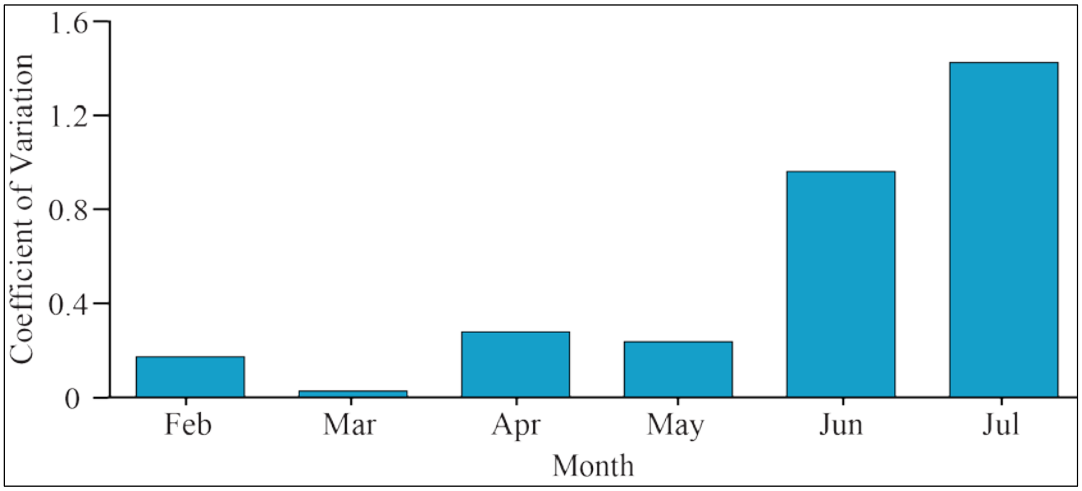


Figure 20. Coefficient of variation for North Atlantic right whale monthly acoustic presence, limited to months that were sampled over three years during the study period and included five or more recording sites.

Diel Acoustic Presence

Right whale acoustic presence exhibited strong diel trends (Figure 22), where most of the upcalls occurred during hour 18:00 (EST), comprising approximately twice as many calls (*n* = 3,842) as most hours. Hour 12:00 had the lowest level amount of acoustic presence (*n* = 1,250), followed by 07 (*n* = 1,302), 08 (*n* = 1,332), 09 (*n* = 1,357), and 04 (*n* = 1,383), each of which accounted for less than 3% of the total upcalls.

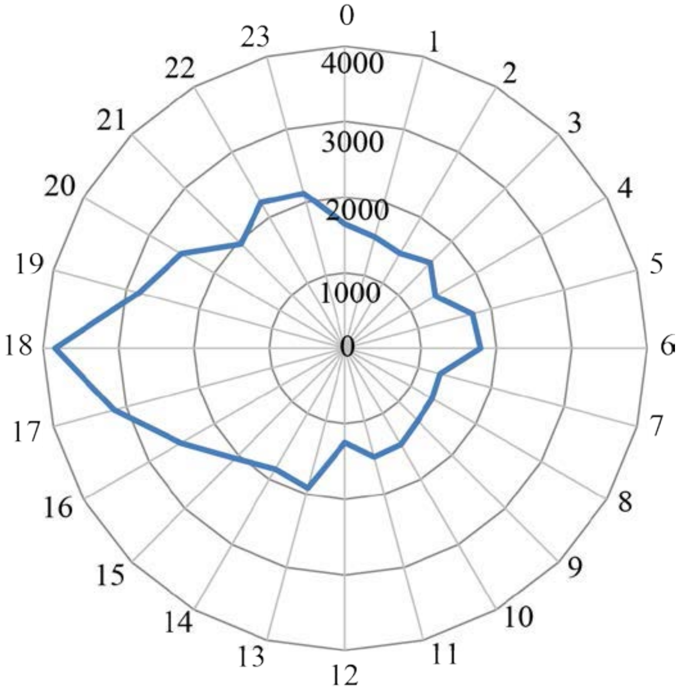


Figure 21. Radial plot of the total numbers of detected right whale upcalls per hour (00–23 EST) from November 2011 through March 2015.

The *mean-adjusted hourly call-rate* (i.e., scaled by the daily average to account for variation between days) revealed the same peak hour (18:00 EST) as the total upcalls per hour data (Figure 23). Seasonal variation was evident for diel acoustic trends, where the peak hour of acoustic presence varied slightly between seasons. During the spring, the season with the most upcalls, the highest *mean-adjusted hourly call rate* occurred during hour 18:00. During the season with the lowest upcall occurrence (summer), the *mean-adjusted hourly call-rates* were highest at hours 11:00, 20:00, 21:00, and 22:00 EST.

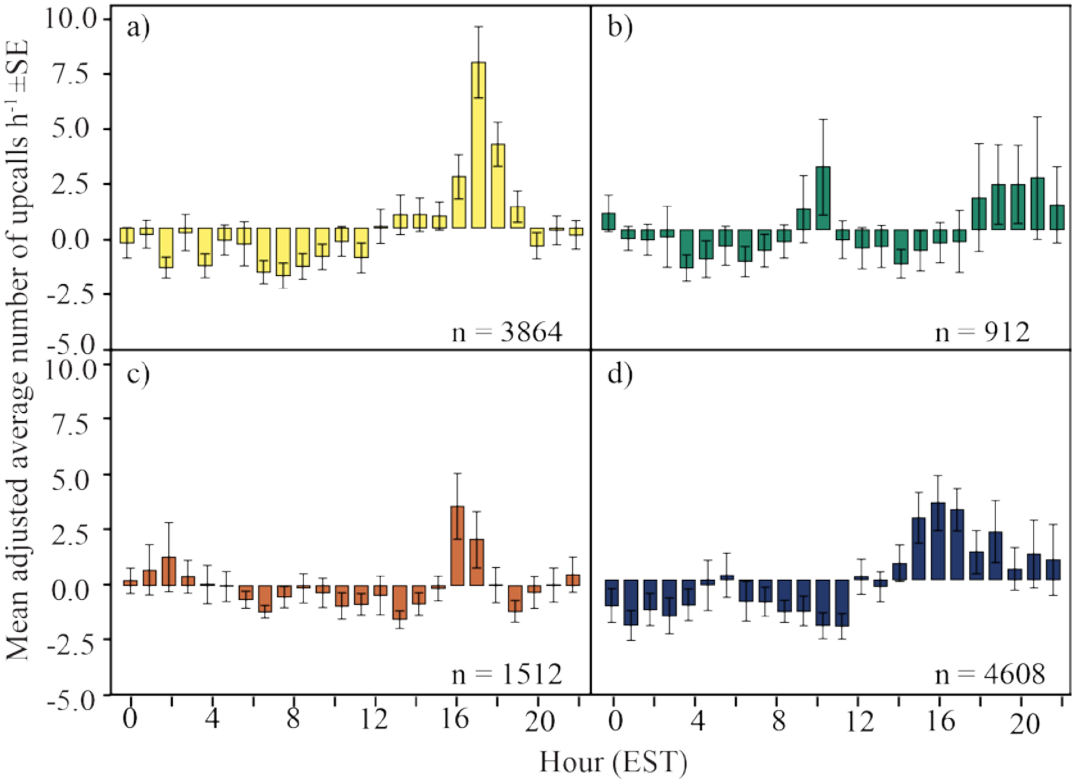


Figure 22. Bar plots of the right whale *mean-adjusted hourly call-rate* (± standard error) for each hour (00–23, EST) within four seasons; a) Spring, b) Summer, c) Autumn, d) Winter. N = the total number of hours within each season with recorded upcalls.

Spatial Presence of Right Whales

Overall, most of the upcalls were detected at site MA-2 (*n* = 13,657), where the *normalized site presence total* (across all four seasons) was 16, comprising 29% of the total number of upcalls (Table 11; Figure 24). Site RI-2 had the fewest detected upcalls (*n* = 654) with *normalized site presence total* of 2, and accounted for approximately 1% of the total number of upcalls. Site MA-5 recorded 2,477 upcalls (5%), and also recorded a *normalized site-presence total* of 2. Winter had the most acoustic activity, comprising 54% of all upcalls, with *normalized site-presence* of 15. Summer recorded the lowest vocal activity, with only 4% of all upcalls, and *normalized site-presence* of 1. During the spring, autumn, and winter seasons most calls were detected at site MA-2 (*n* = 5,269, *n* = 813, and *n* = 7,289, respectively). During the summer, most upcalls were detected at site MA-6 (*n* = 578).

Table 11. Summaries of *normalized site-presence* data for North Atlantic right whales at nine MARU sites in four seasons. Calls = number of upcalls recorded at that site/season. Days = total number of recording days at that site/season. NSPs = *normalized site-presence* (%) at that site/season, scaled to the number of days recorded that site/season. NSPt = *normalized site-presence* (%) for the total number of days recorded at that site across all four seasons.

Site	Winter			Spring			mer			Autumn			Total		
	Calls	Days	NSPs	Calls	Days	NSPs	Calls	Days	NSPs	Calls	Days	NSPs	Calls	Days	NSPt
MA-1	827	194	4	3211	249	13	59	244	0	149	141	1	4246	828	5
MA-2	7289	194	39	5269	249	21	286	244	1	813	141	6	13657	828	16
MA-3	1801	240	8	747	249	3	145	274	1	222	232	1	2915	995	3
MA-4	3540	194	18	1388	249	6	531	244	2	47	141	0	5406	828	7
MA-5	1326	268	5	467	249	2	404	274	1	280	232	1	2477	1023	2
MA-6	4788	194	25	1099	202	5	578	152	4	749	118	6	7214	666	11
RI-1	3203	172	19	2447	158	15	9	166	0	202	178	1	5861	674	9
RI-2	462	74	6	185	47	4	0	122	0	7	114	0	654	357	2
RI-3	1763	177	10	1888	158	12	1	182	0	242	178	1	3894	695	6
Total	**24999**	**1707**	**15**	**16701**	**1810**	**9**	**1913**	**1902**	**1**	**2711**	**1475**	**2**	**46324**	**6894**	

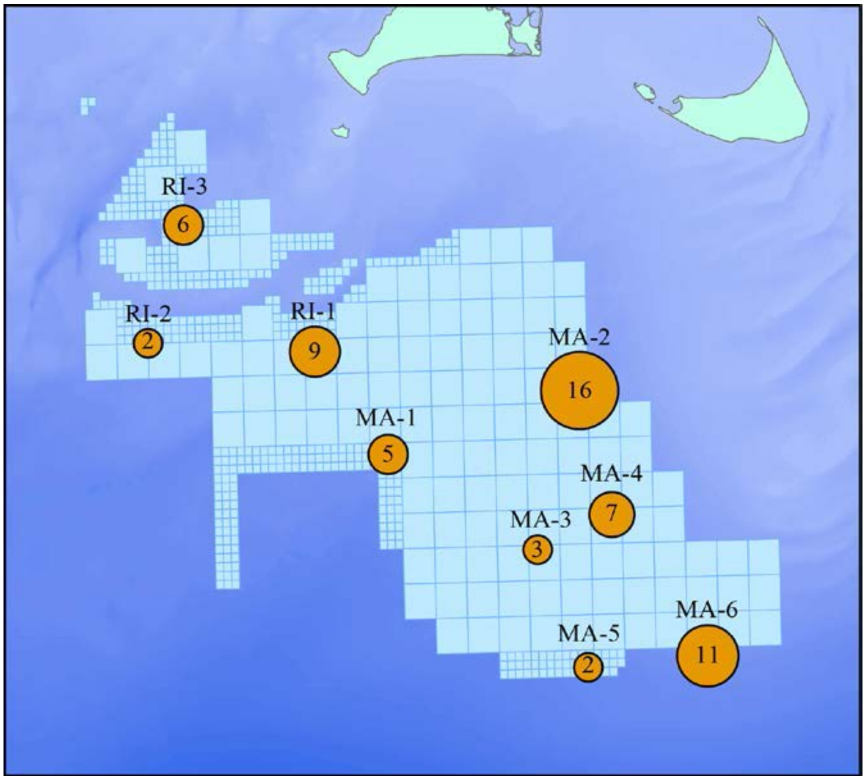


Figure 23. Normalized right whale upcalls (the sum of right whale upcalls divided by the number of acoustic recording days) at each site (from Normalized Site Presence totals in Table 11). The size of each circle indicates relative acoustic presence at each site summed across all seasons and years. The value within each circle represents the Normalized Site Presence.

Summary of North Atlantic Right Whale Presence

Based on aerial observations and acoustic presence, North Atlantic right whales appear to have a distinct seasonal occurrence in the SA during winter and spring between December and May. Tests for variability in annual sighting presence showed no significant variation from year to year, indicating a fairly consistent presence. During spring right whales were widely distributed throughout the SA and were detected in each of the lease areas (RIMA WEA and MA WEA Zones 1 – 4), however during winter, distribution was shifted out of most of the lease areas (MA WEA Zone 4 excepted) to the waters south of Martha's Vineyard and Nantucket and to the east. The hot spot analysis showed further resolution of these seasonal clusters of distribution, demonstrating that hot spots within lease areas occurred during spring in the RIMA WEA and MA WEA Zones 1 and 2. Abundance tended to be higher in spring. Observers were not able to photograph all of the right whales sighted, and of those photographed whales not all could be matched to individuals in the catalogue. However, the average number of identified individuals per year (*n* = 15.4) is consistent with the abundance estimates. Acoustic detections found that right whales are present within or near the WEAs during all months of the year, implying that aerial surveys missed individual animals or small groups outside of the window of greatest seasonal presence. When normalized, the spatial patterns of right whale acoustic detections in the SA were consistent with aerial detections and the hot spot results. Right whales showed diel patterns vocal activity, in which they were most vocally active during the evening hours.

FIN WHALE (*BALAENOPTERA PHYSALUS*)

Aerial Sightings of Fin Whales

Fin whales are the largest of the baleen whales observed in the study area. This species was observed every year, and sightings occurred in every season (Table 5), with the greatest numbers of sightings during the spring (*n* = 35) and summer (*n* = 49) months. One detection of two fin whales was obtained from the vertical camera during the entire study. Fin whale presence appears to peak between April and August, with occasional sightings in other months of the year (Figure 25.)

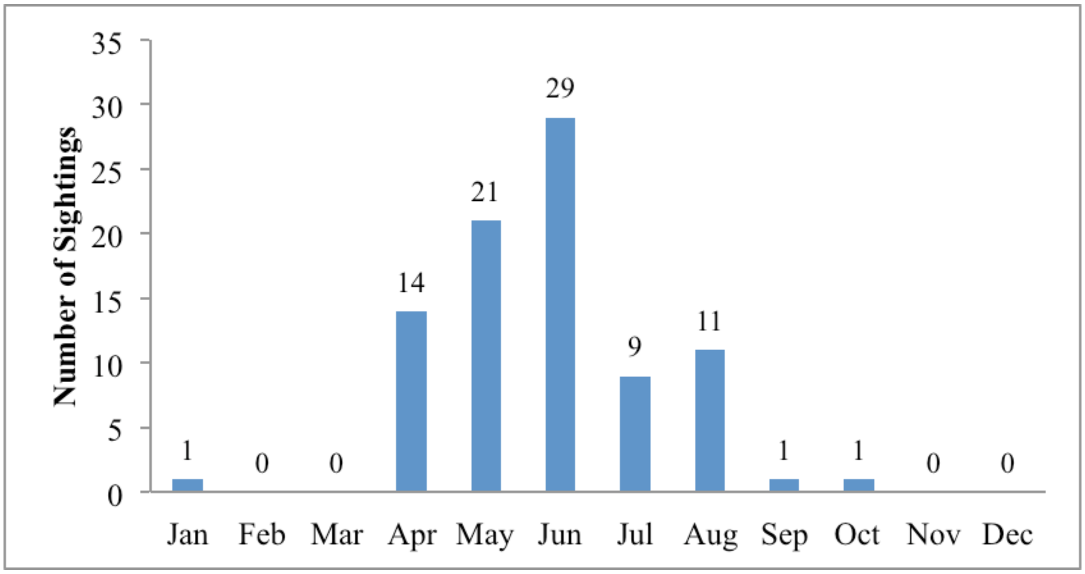


Figure 24. Fin whale sighting totals by month, combined across all survey years (October 2011–June 2015).

Fin Whale Sighting Rates and Variability

Fin whale sighting rates were also highest in spring and summer (Table 3). Variability in sighting rate was not significant between years for fin whales. However, there was significant variability in sighting rate by month, season, and season-year. Fin whales showed significant inter-annual variability during summer, but not in any other season (Table 12).

Table 12. Summarized results for analyses of variability and trends in sighting rates for fin whales. Each table entry for the Kruskal-Wallis tests is the *P*-value testing whether there is significant variability in sighting rate among the respective time intervals. The two right columns show the results of least-squares linear regression of sighting rate vs. survey day or year. Each cell shows whether the trend was positive or negative, and the *P*-value (NS = non-significant at *P* ≥ 0.10).

Kruskal-Wallis ANOVA				**Regression**	
Year	Month	Season	Season-Yr	Survey Day	Year
0.137	<0.001	<0.001	0.001	+,0.012	+,0.013

Kruskal-Wallis ANOVA, among Years by Season			
Winter	Spring	Summer	Autumn
0.558	0.255	0.023	0.48

Fin Whale Sightings per Unit Effort

The spatial visual of mapped SPUE demonstrate that fin whale relative abundance tended to be farther offshore during the spring, and closer to shore during the summer (Figure 26). The species was largely absent from the study area in autumn and winter. When all seasons were combined to create and annual picture of SPUE, the distribution of fin whales is spread across the entire study area.

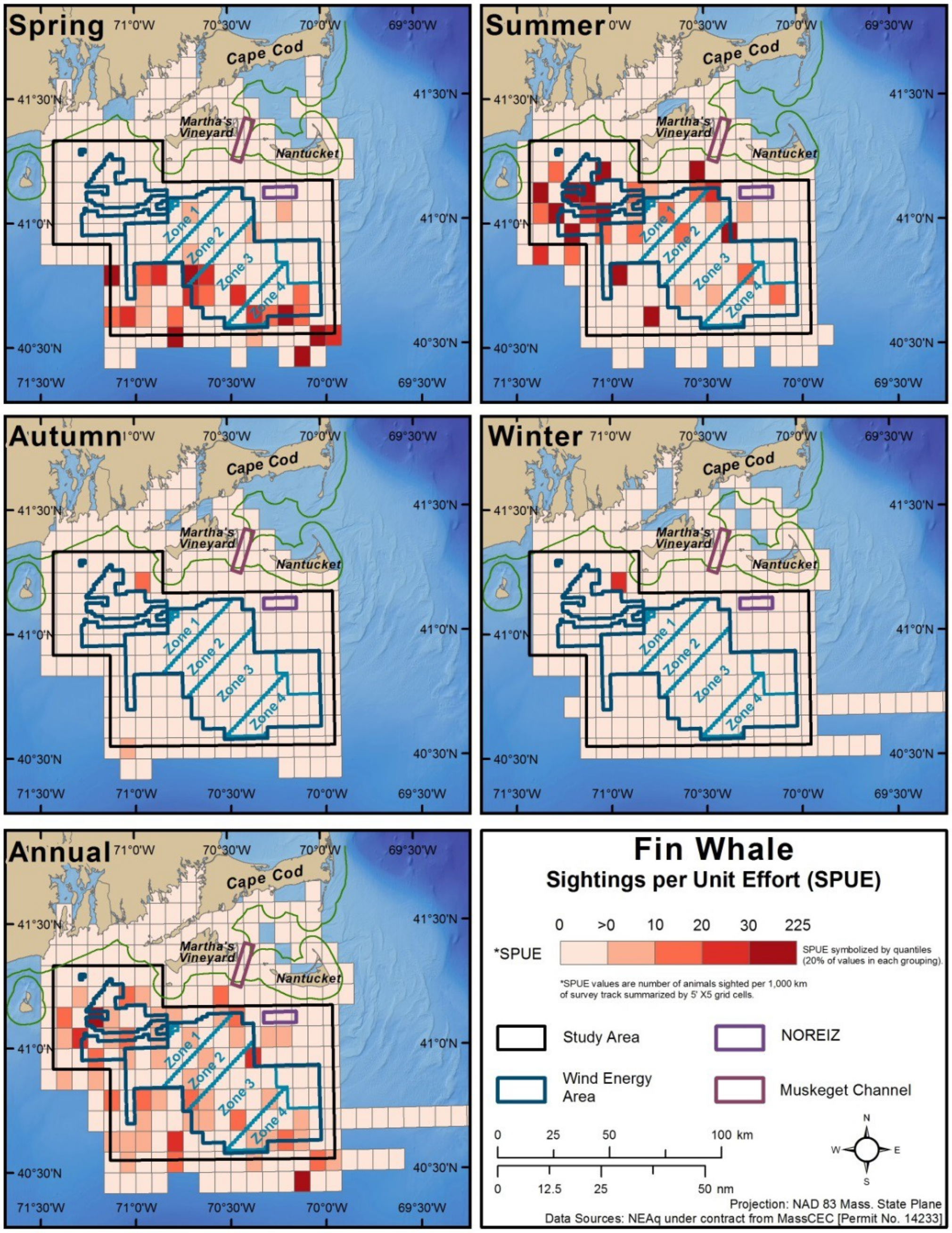


Figure 25. Fin whale SPUE by 5-minute squares partitioned by seasons across all years and with all seasons combined.

Abundance of Fin Whales

Seasonal abundance estimates of fin whales ranged from 0 to 59 animals with upper 95% confidence limits ranging up to 267 (Table 13). These estimates tended to be highest in spring and summer. Abundance was estimated at zero during the winter months.

Table 13. Density and abundance of fin whales (*Balaenoptera physalus*) by season-year. Density and variance are the means of the transect estimates, weighted by transect lengths. T = number of transects flown; G, I = number of groups and individuals sighted; D = density in animals/km^2; V = variance of the density; N = estimated abundance in the study area; CI95=95% confidence interval, with the lower limit changed to zero if it was negative.

Season-Year	T	G, I	D	V	N	CI95
Autumn-2011	32	0, 0	0	–	0	–
Winter-2012	30	0, 0	0	–	0	–
Spring-2012	56	4, 4	0.0013	0.0005	9	0–48
Summer-2012	48	4, 5	0.0012	0.0007	8	0–60
Autumn-2012	24	1, 1	0.0006	0.0001	4	0–38
Winter-2013	16	0, 0	0	–	0	–
Spring-2013	39	6, 12	0.0022	0.0005	17	0–70
Summer-2013	46	3, 15	0.0009	0.0002	7	0–41
Autumn-2013	36	1, 1	0.0004	0.0001	3	0–25
Winter-2014	26	0, 0	0	–	0	–
Spring-2014	41	7, 10	0.0025	0.0011	19	0–98
Summer-2014	60	18, 34	0.0042	0.0018	32	0–116
Autumn-2014	39	0, 0	0	–	0	–
Winter-2015	28	0, 0	0	–	0	–
Spring-2015	65	7, 11	0.0015	0.0005	12	0–56
Summer-2015	17	8, 9	0.0076	0.0027	59	0–267

Acoustic Recordings

Monthly Acoustic Presence

Fin whales were acoustically detected in all sampled months in both the MA and RIMA arrays, and presence in most of those months exceeded 80 % monthly presence (Figure 27). They were present on 87% of the days analyzed in the study period in the MA array (889 days out of 1,020) and 80% of the days analyzed in RIMA array (558 days out of 695). The mean monthly acoustic presence (Figure 28) for all of the data reveals no strong seasonal trends, with year-round presence and a slight decrease in the months of April through July.

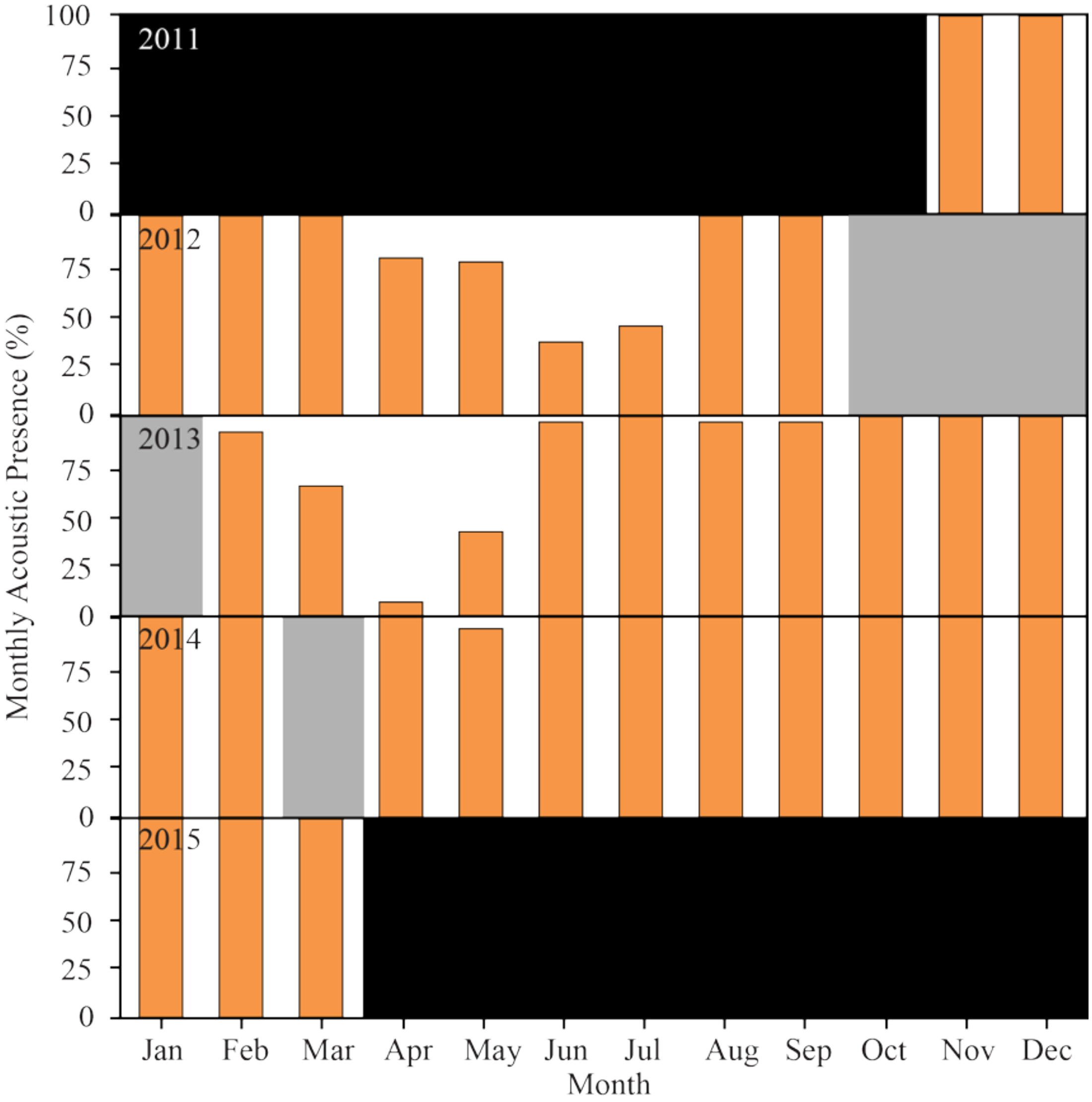


Figure 26. Monthly acoustic presence (%) of fin whale 20-Hz pulses recorded between November 2011 and March 2015. The grey areas represent time periods when MARUs were not recording and the black areas represent time periods outside the study period.

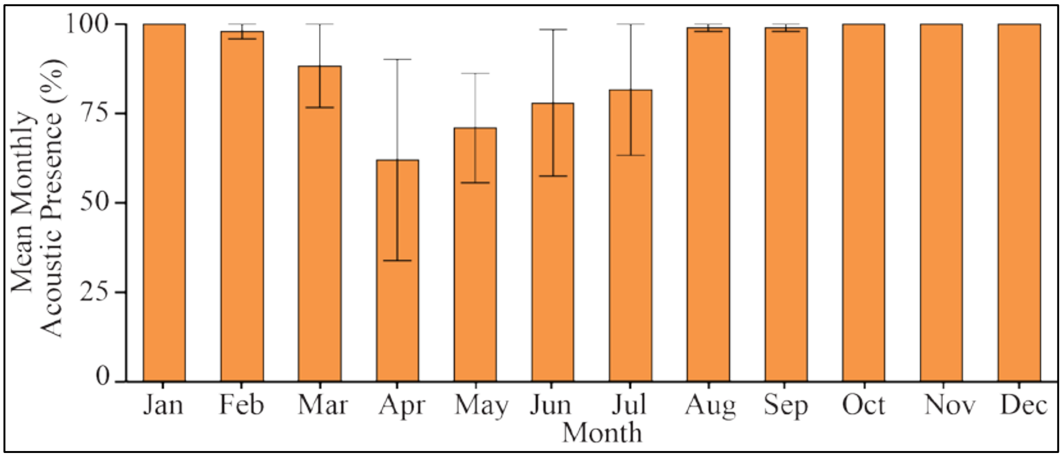


Figure 27. Fin whale mean monthly acoustic presence (± SE) between November 2011 and March 2015.

Variability in Acoustic Presence

The coefficient of variation for fin whale acoustic presence (Figure 29) illustrates that fin whale acoustic presence fluctuated the most between years during the month of April, but presence remained most consistent between years during the month of February. The higher CV is due to the low (7%) monthly acoustic presence of fin whale pulses during April 2013, and high (>75%) monthly acoustic presence of detected pulses in April 2012 and 2014.

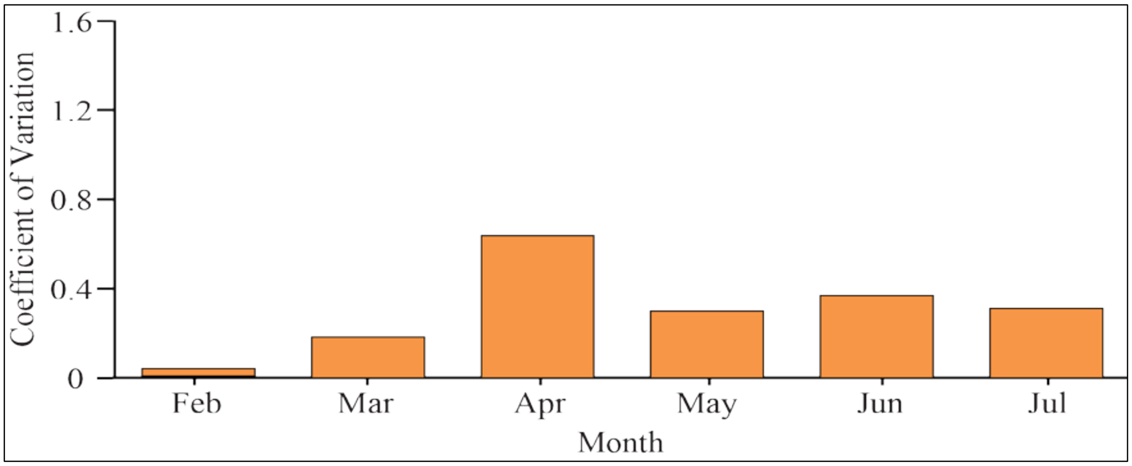


Figure 28. Coefficient of variation for fin whale monthly acoustic presence, limited to months that were sampled over three years during the study period and included five or more recording sites.

Summary of Fin Whale Occurrence

Fin whales were visually observed in the MA WEA during the spring months of April and May in the offshore portions of the Lease Zones 3 and 4. They were either absent or present at very low densities in the RIMA WEA in the spring. During the summer months, when estimated abundances were highest, fin whales were more likely to be observed in the RIMA WEA and to a lesser extent, in the MA WEA, Zones 1–4. Fin whales were acoustically detected throughout the year, however, due to estimated detection ranges in excess of 200 km, the detections do not confirm that fin whales were vocalizing within the WEAs. However, in many cases, the arrival patterns of fin whale pulses received by the acoustic sensors indicated that fin whales were vocalizing from within the SA.

HUMPBACK WHALE (*MEGAPTERA NOVAEANGLIAE*)

Aerial Sightings of Humpback Whales

Humpback whales were sighted in the SA during all seasons, however they were primarily sighted in the spring and summer seasons (Table 5). The greatest number of sightings of humpback whales occurred during the month of April (*n* = 33), and their presence in the area seemed to start in March and end in July (Figure 30).

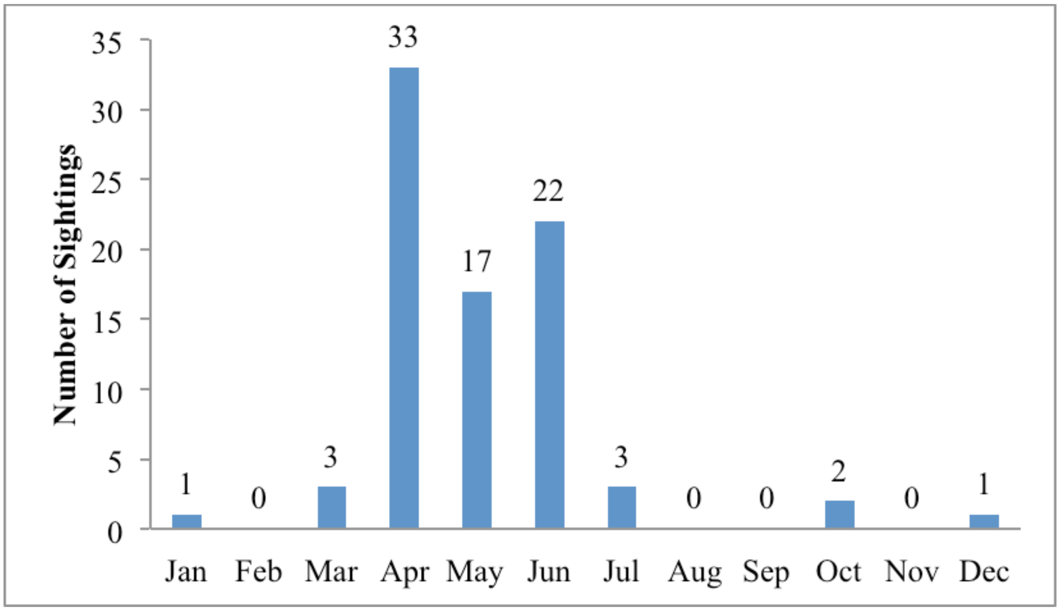


Figure 29. Humpback whale sighting totals by month, combined across all survey years (October 2011–June 2015).

Humpback Whale Sighting Rates and Variability

Like fin whales, humpback sighting rates were also highest in spring and summer (Table 5). Variability in sighting rate was not significant between years, but was significant between months, seasons, and season-years (Table 14). Inter-annual variability approached significance only during spring (*P* = 0.058).

Table 14. Summarized results for analyses of variability and trends in sighting rates for humpback whales. Each table entry for the Kruskal-Wallis tests is the *P*-value testing whether there is significant variability in sighting rate among the respective time intervals. The two right columns show the results of least-squares linear regression of sighting rate vs. survey day or year. Each cell shows whether the trend was positive or negative, and the *P*-value (NS = non-significant at *P* ≥ 0.10).

Kruskal-Wallis ANOVA				**Regression**	
Year	Month	Season	Season-Yr	Survey Day	Year
0.075	<0.001	<0.001	0.002	NS	NS
Kruskal-Wallis ANOVA, among Years by Season					
Winter	Spring	Summer	Autumn		
0.415	0.058	0.158	0.432		

Humpback Whale Sightings per Unit Effort

The SPUE patterns showed that humpback whales were distributed throughout the study area during summer and spring and nearly absent in autumn and winter, with a slight concentration in the southern portion of the study area in spring (Figure 31). When months were combined and viewed annually, humpbacks appear to be evenly distributed throughout the study area, with a reflection of the offshore concentration seen in summer months.

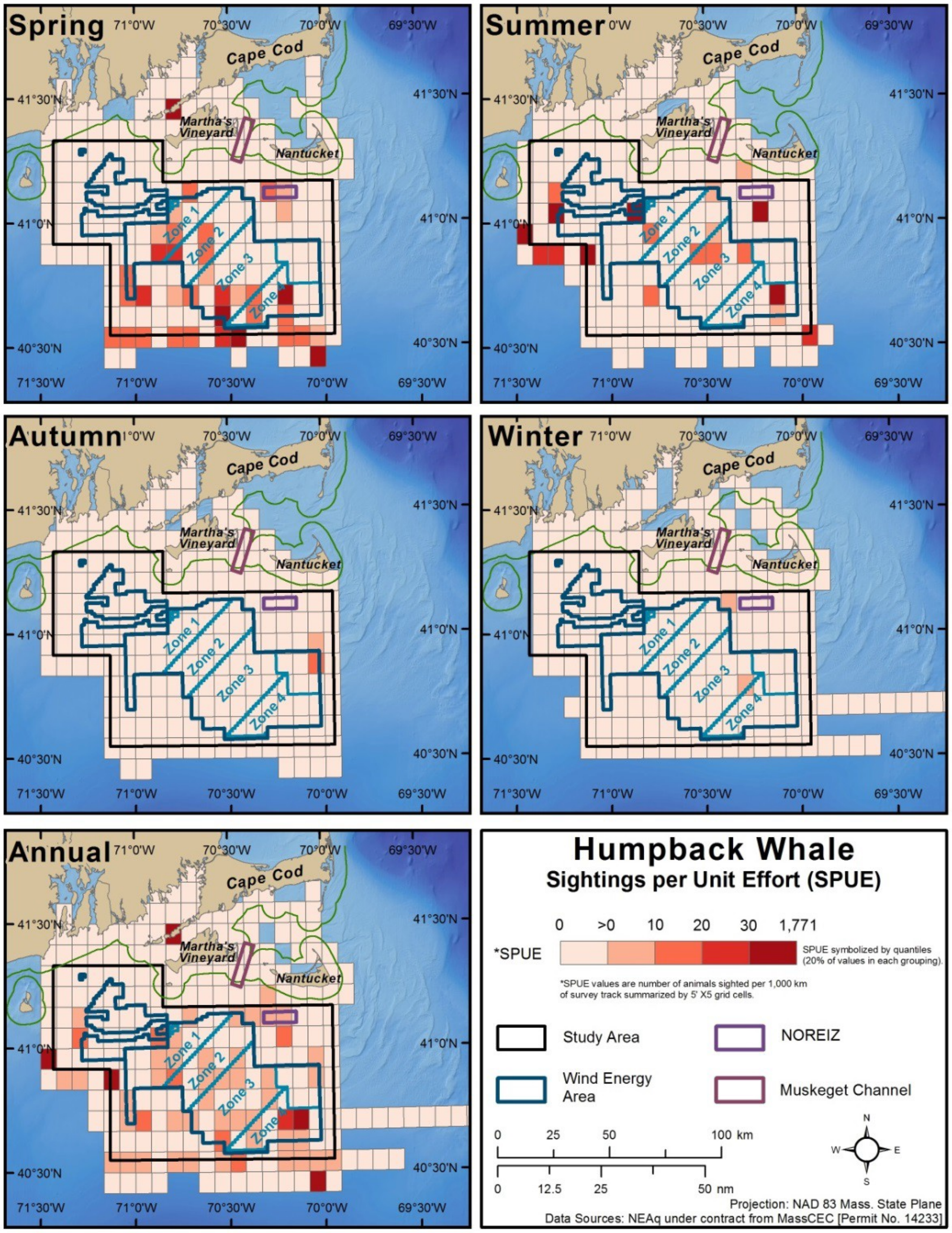


Figure 30. Humpback whale SPUE by 5-minute squares partitioned by season across all years and with all seasons combined.

Abundance of Humpback Whales

Seasonal abundance estimates of humpback whales ranged from 0 to 41, with 95% upper confidence intervals of up to 168 (Table 15). These estimates tended to be highest in spring and summer with some exceptions.

Table 15. Density and abundance of humpback whales (*Megaptera novaeangliae*) by season-year. Density and variance are the means of the transect estimates, weighted by transect lengths. T = number of transects flown; G, I = number of groups and individuals sighted; D = density in animals/km^2; V = variance of the density; N = estimated abundance in the study area; CI95=95% confidence interval, with the lower limit changed to zero if it was negative.

Season-Year	T	G, I	D	V	N	CI95
Autumn-2011	32	2, 2	0.001	0.0006	7	0–66
Winter-2012	30	0, 0	0	–	0	–
Spring-2012	56	3, 4	0.0011	0.0003	7	0–39
Summer-2012	48	0, 0	0	–	0	–
Autumn-2012	24	0, 0	0	–	0	–
Winter-2013	16	0, 0	0	–	0	–
Spring-2013	39	14, 21	0.0052	0.0024	41	0–160
Summer-2013	46	13, 17	0.0034	0.0021	26	0–128
Autumn-2013	36	0, 0	0	–	0	–
Winter-2014	26	0, 0	0	–	0	–
Spring-2014	41	13, 17	0.005	0.0029	39	0–168
Summer-2014	60	7, 29	0.0018	0.0011	14	0–79
Autumn-2014	39	0, 0	0	–	0	–
Winter-2015	28	2, 2	0.0011	0.0003	9	0–63
Spring-2015	65	6, 13	0.0014	0.0005	11	0–55
Summer-2015	17	0, 0	0	–	0	–

Acoustic Recordings of Humpback Whales

Monthly Acoustic Presence

Humpback whales were acoustically detected in 35 out of the 36 total months that were analyzed in the MA array and 23 out of 25 months in the RIMA array (Figure 32). Humpback whales were present on 56% of the days analyzed (566 of 1,020) in the MA array and 49% of the days analyzed (343 of 695) in the RIMA array. There was a gradual increase in presence from December through March (except for a small decrease in February in the MA array), peaking in April, and a gradual decrease from May through November (with a small increase in September in the MA array).

The mean monthly acoustic presence plot (Figure 33) illustrates high monthly acoustic presence during the winter through early summer months (December–June), with mean monthly presence exceeding 50% in each month. Mean monthly acoustic presence was lowest during the autumn at less than 25%.

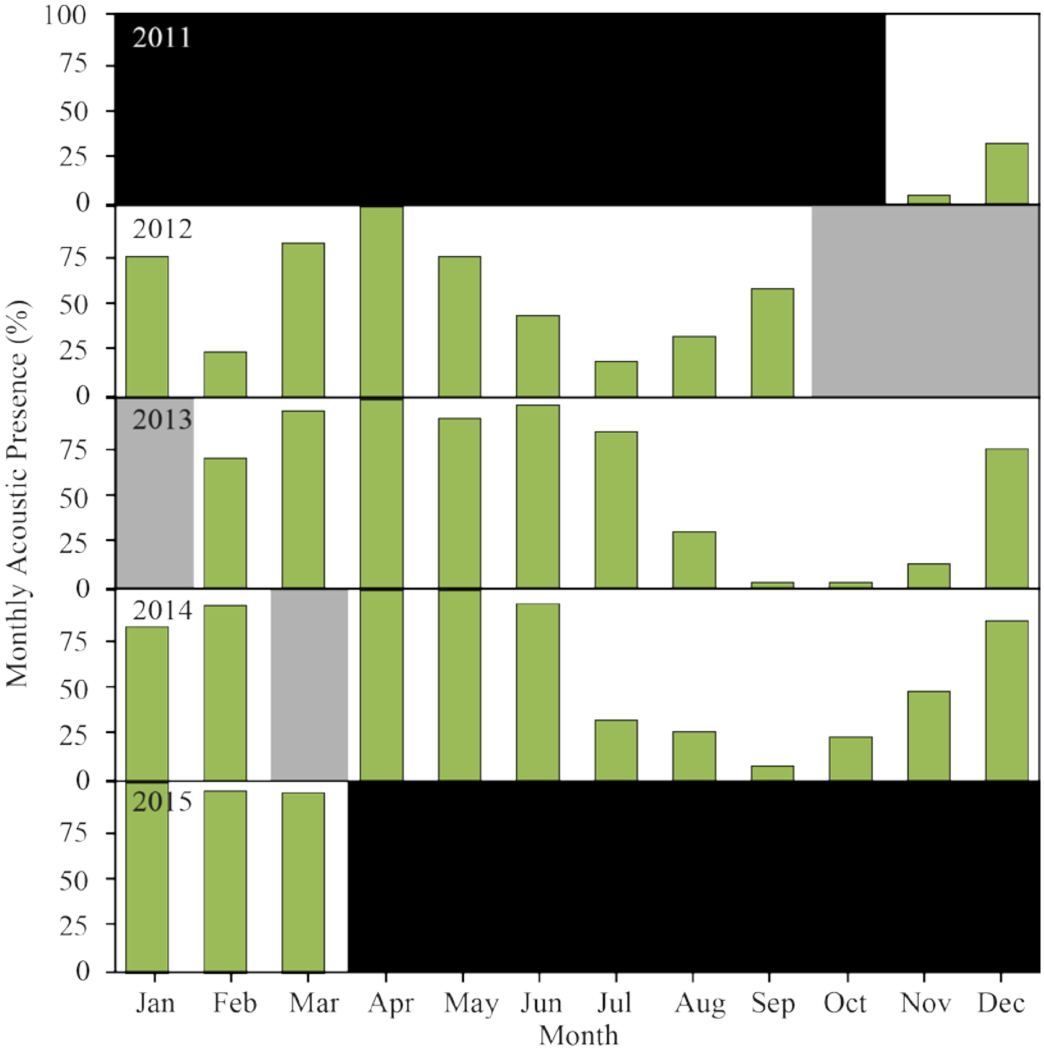


Figure 31. Monthly acoustic presence (%) for humpback whale sounds recorded between November 2011 and March 2015. The grey areas represent time periods when MARUs were not recording and the black areas represent time periods outside the study period.

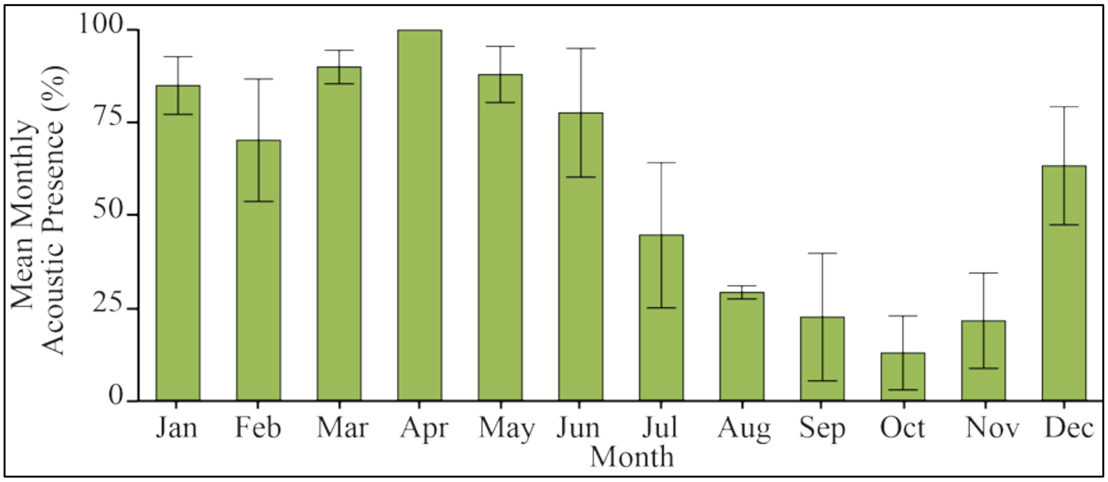


Figure 32. Mean monthly acoustic presence (± SE) for humpback whales between November 2011 and March 2015.

Variability in Acoustic Presence

The coefficient of variation for humpback whale acoustic detections (Figure 34) revealed little variability in monthly acoustic presence during April, and more variation during the months of February and July. This is consistent with the high (>75%) monthly acoustic presence of humpback signals in July 2013 and low (<25%) monthly acoustic presence during July 2012 and July 2014. Similarly, February had high monthly acoustic presence in 2014 and 2015, but low presence in 2012.

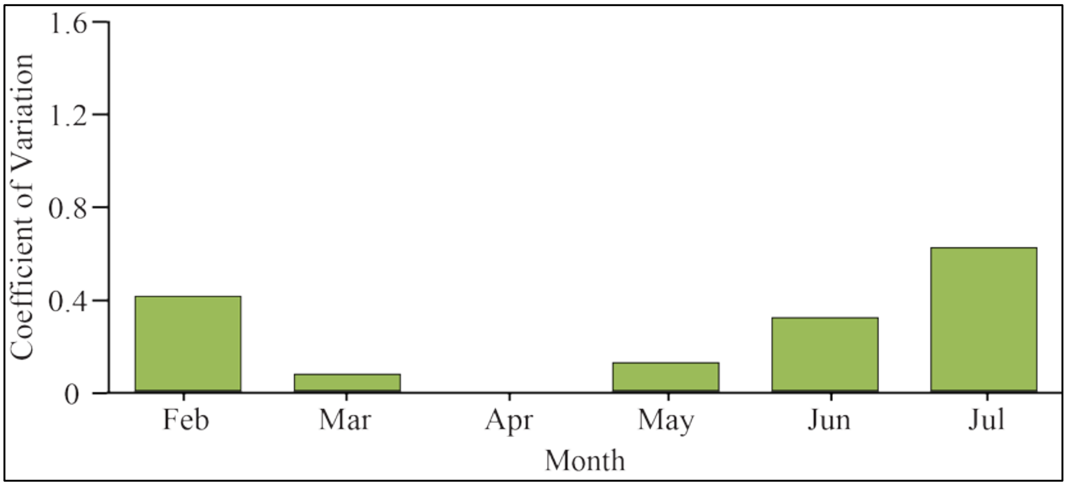


Figure 33. Coefficient of variation for humpback whale monthly acoustic presence, limited to months that were sampled over three years during the study period and included five or more recording sites.

Summary of Humpback Whales

Based on aerial detections of humpback whales, this species appears to use the study area primarily from April through June. High variability in sighting rate by month and season further evidences this seasonal residence pattern. The distribution of animals tended to be farther offshore in spring, although detections occurred in both the RIMA WEA and Zones 1–4 of the MA WEA. Aerial detections in the RIMA WEA occurred only in summer. Abundance estimates tended to be highest in spring and summer. Acoustic detections of humpback whales occurred over a longer seasonal period (more total months), and were similar for both the RIMA WEA Array and the MA WEA Array. Acoustic presence data suggest a stronger presence of humpback whales in the winter (December through February) than aerial detections indicated. There was little variation in humpback acoustic presence among years.

MINKE WHALE (*BALAENOPTERA ACUTOROSTRATA*)

Aerial Sightings of Minke Whales

Minke whales are the smallest of the baleen whales observed in the study area, and were seen primarily during the spring and summer seasons (Table 5; Figure 35). There was one detection of a single minke whale in vertical photographs during NLPSC073 on 3 May 2015. Minke whale presence was recorded in the study area between March and September, and the greatest number of sightings occurred in May (n = 38) (Figure 35).

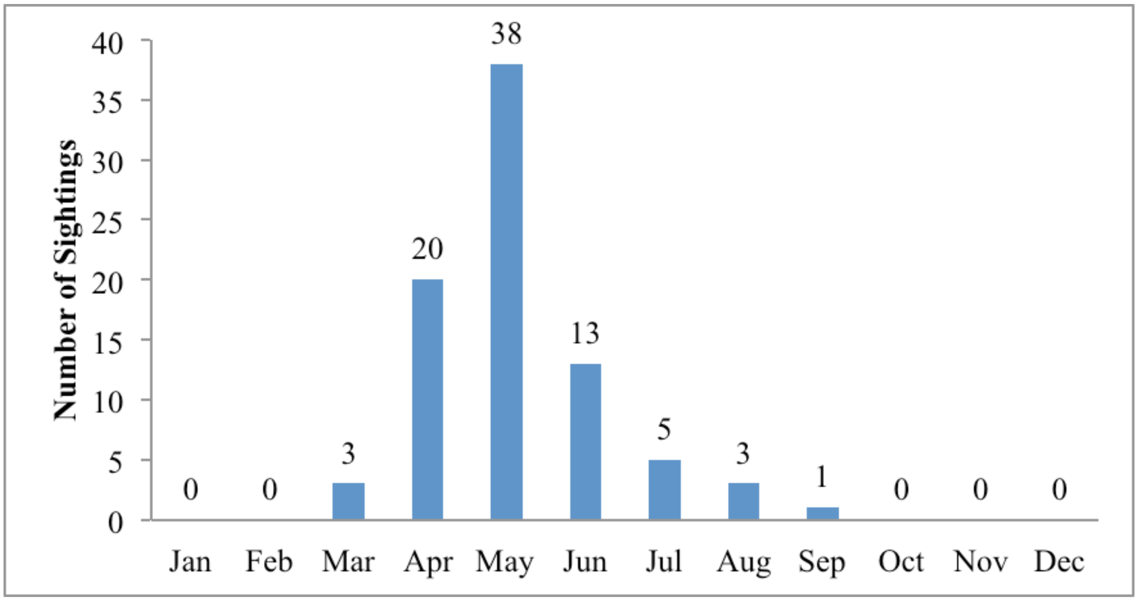


Figure 34. Minke whale sighting totals by month, combined across all survey years (October 2011–June 2015).

Minke Whale Sighting Rates and Variability

When corrected for effort as sighting rates per 1000 km, rates were highest in spring and summer (Table 5). Variability in sighting rate was not significant between years, but was significant between months, seasons, and season-years ($P < 0.05$) (Table 16). There was no significant inter-annual variability in any one season. The regression trend analysis showed a statistically significant trend by year ($P = 0.046$), and an increasing trend approaching significance ($P = 0.079$) by day of the survey (Table 16).

Table 16. Summarized results for analyses of variability and trends in sighting rates for minke whales. Each table entry for the Kruskal-Wallis tests is the *P*-value testing whether there is significant variability in sighting rate among the respective time intervals. The two right columns show the results of least-squares linear regression of sighting rate vs. survey day or year. Each cell shows whether the trend was positive or negative, and the *P*-value (NS = non-significant at *P* ≥ 0.10)

Kruskal-Wallis ANOVA				Regression	
Year	Month	Season	Season-Yr	Survey Day	Year
0.183	<0.001	<0.001	0.029	+,0.079	+,0.046
Kruskal-Wallis ANOVA, among Years by Season					
Winter	Spring	Summer	Autumn		
1.000	0.840	0.117	0.432		

Minke Whale Sightings per Unit Effort

Relative abundance patterns showed minke whales throughout the study area in spring and summer—very widespread in spring and more localized in summer (Figure 36). The annual distribution of minke whales was fairly uniform throughout the study area.

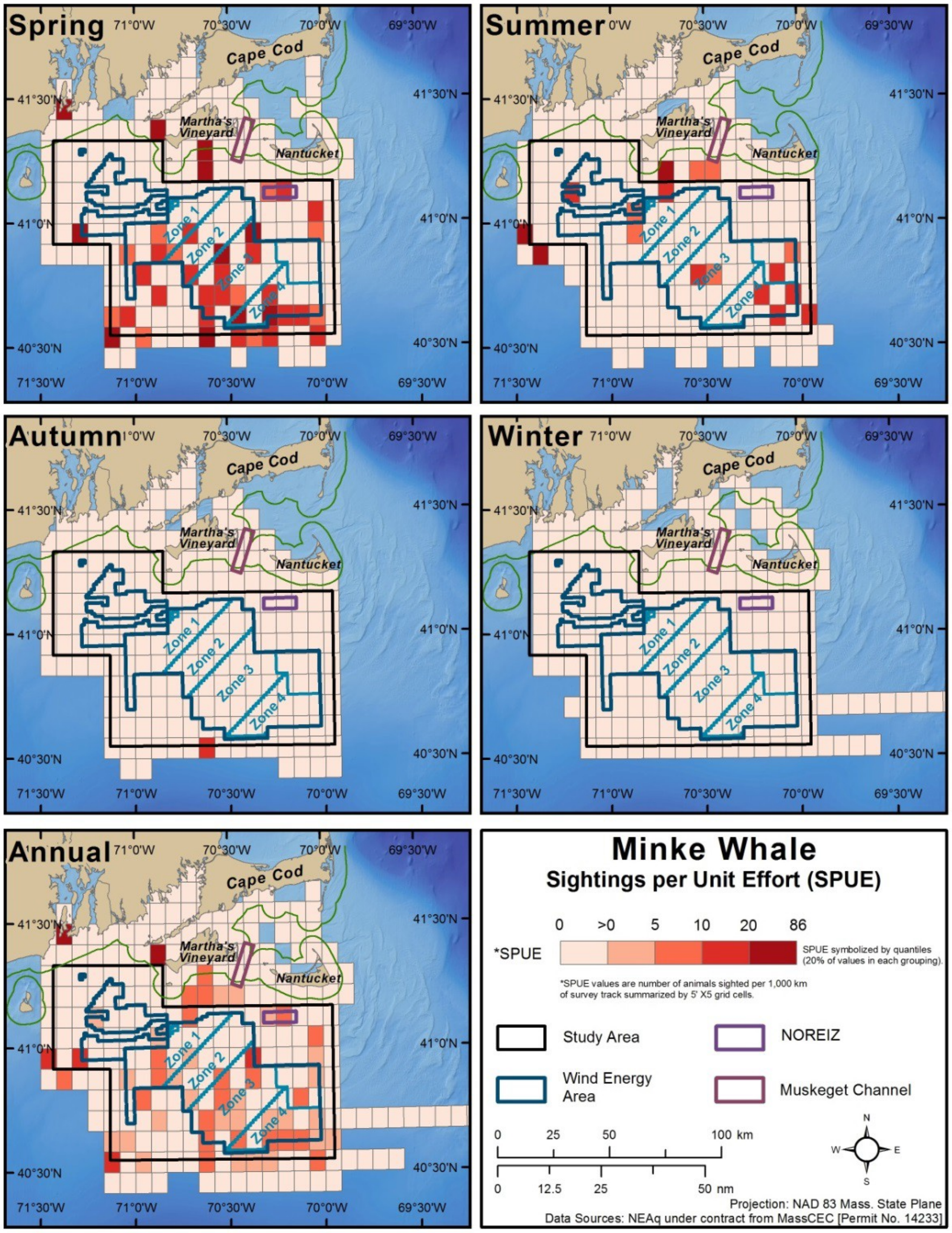


Figure 35. Minke whale SPUE by 5-minute squares partitioned by season across all years and with all seasons combined.

Acoustic Recordings of Minke Whales

Monthly Acoustic Presence

Minke whales were acoustically detected in 29 out of the 36 total months analyzed (81%) in the MA array, and 12 out of 25 total months (48%) in the RIMA array (Figure 37). Minke whales were present on 28% of the days analyzed (291 of 1020) in the MA array and 9.5% of days analyzed (66 of 695) in the RIMA array.

The mean monthly presence for all the data (Figure 38) shows an overall trend of a gradual increase in presence starting in February, peaking in April, and then gradually decreasing through the summer. There is another slight increase in September and October. December and January are the months with the lowest mean monthly presence.

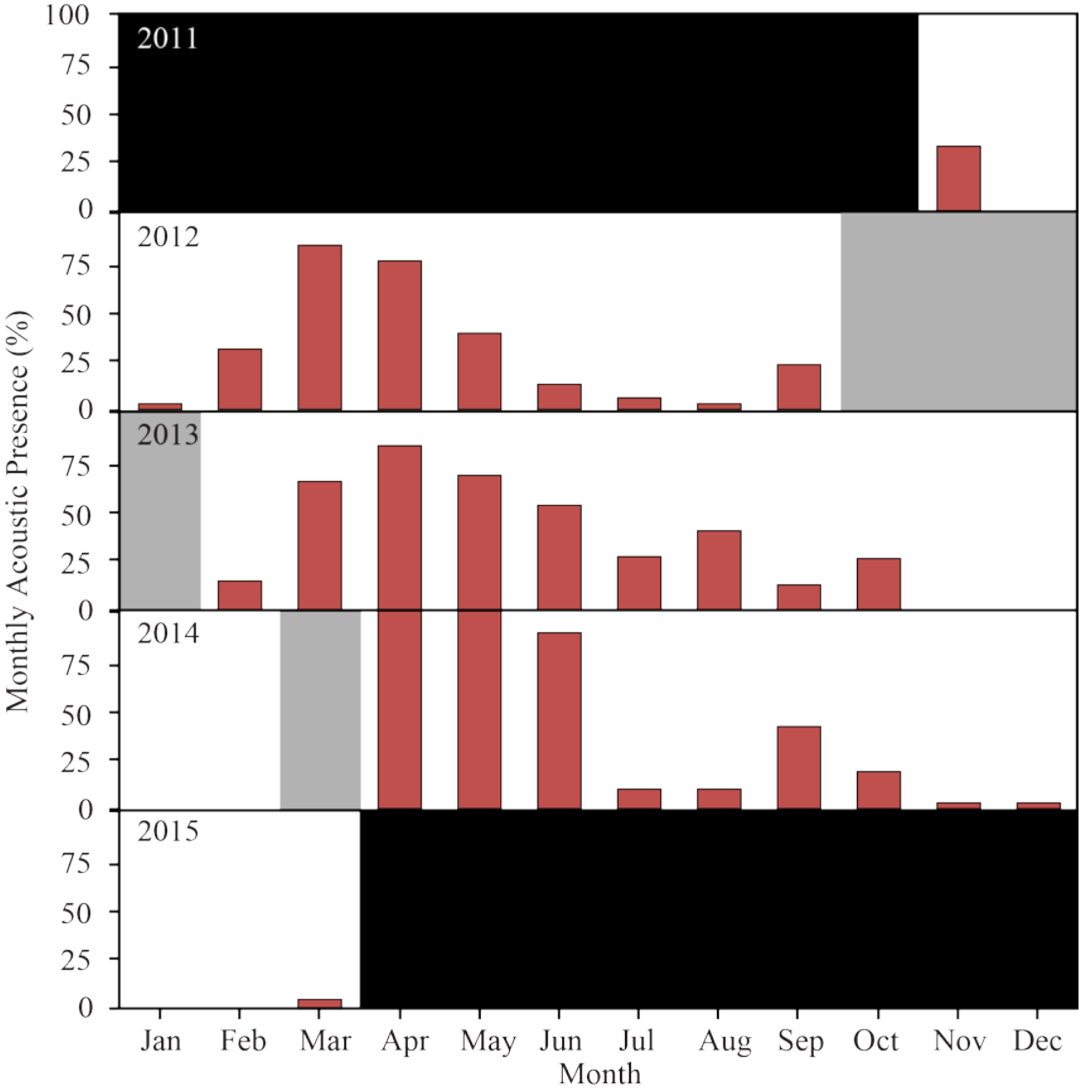


Figure 36. Monthly acoustic presence (%) of minke whale sounds recorded between November 2011 and March 2015. The grey areas represent time periods when MARUs were not recording and the black areas represent time periods outside the study period.

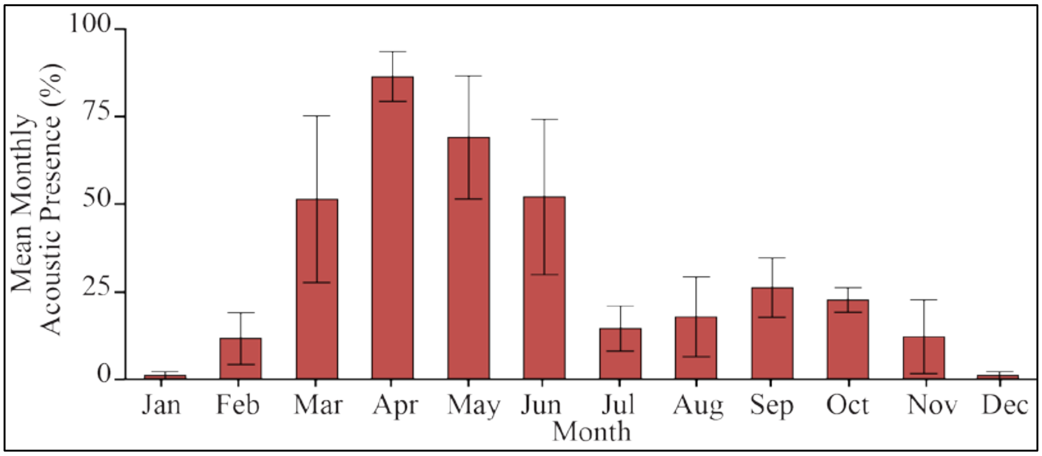


Figure 37. Minke whale mean monthly acoustic presence (± SE) between November 2011 and March 2015

Variability in Acoustic Presence

Minke whales exhibited higher variation in monthly acoustic presence during February and the least amount of variability during April (Figure 39). This is due to the low (<15%) monthly acoustic presence during February of 2013 and 2015, and higher presence (31%) in 2012.

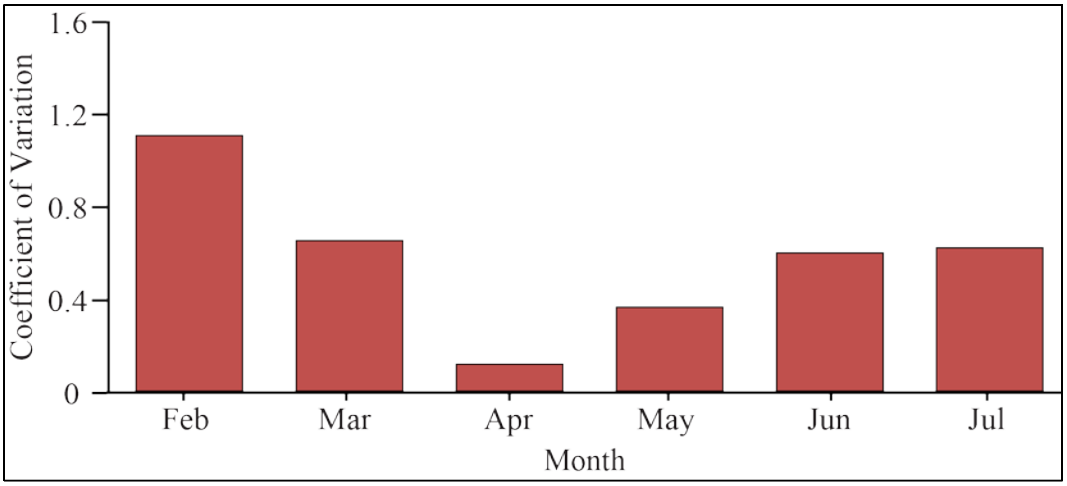


Figure 38. Coefficient of variation for minke whale monthly acoustic presence, limited to months that were sampled over three years during the study period and included five or more recording sites.

Summary of Minke Whale Occurrence

Based on the aerial detections of minke whales, minke whales occurred in the study area between March and September, with a peak in May. Highly significant ($P < 0.001$) variation in sighting rate by month and season also support this distinct seasonal presence, which appears to be consistent from year to year. Distribution appears to be slightly more concentrated in the southern portion of the study area in spring, although sightings were reported in the RIMA WEA and all four Zones of the MA WEA during that season. During summer, Zone 2 was the only designated area with no sightings of minke whales. Acoustic detections of minke whales suggest a stronger presence in and around the MA WEA Array than the RIMA WEA Array. Acoustic detections occurred in more months of the year than visual observations, with additional acoustic detections in October and November, and a few acoustic detections in the winter months.

BLUE WHALE (*BALAENOPTERA MUSCULUS*)

Aerial Sightings of Blue Whales

There were no aerial detections of blue whales during the study.

Acoustic Recordings of Blue Whales

Monthly Acoustic Presence

Blue whales were the least acoustically present of the five focal whale species in both the MA and RIMA arrays. Blue whales were acoustically detected in only 10 out of the 36 (Figure 40) total months analyzed (28%), and only on 3.9% of the days analyzed (40 days out of the 1020 total days analyzed). The mean monthly presence for all our data shows no obvious trends in blue whale presence (Figure 41), although monthly presence was highest in the winter months (December through February) and lowest in the months of August, September and November.

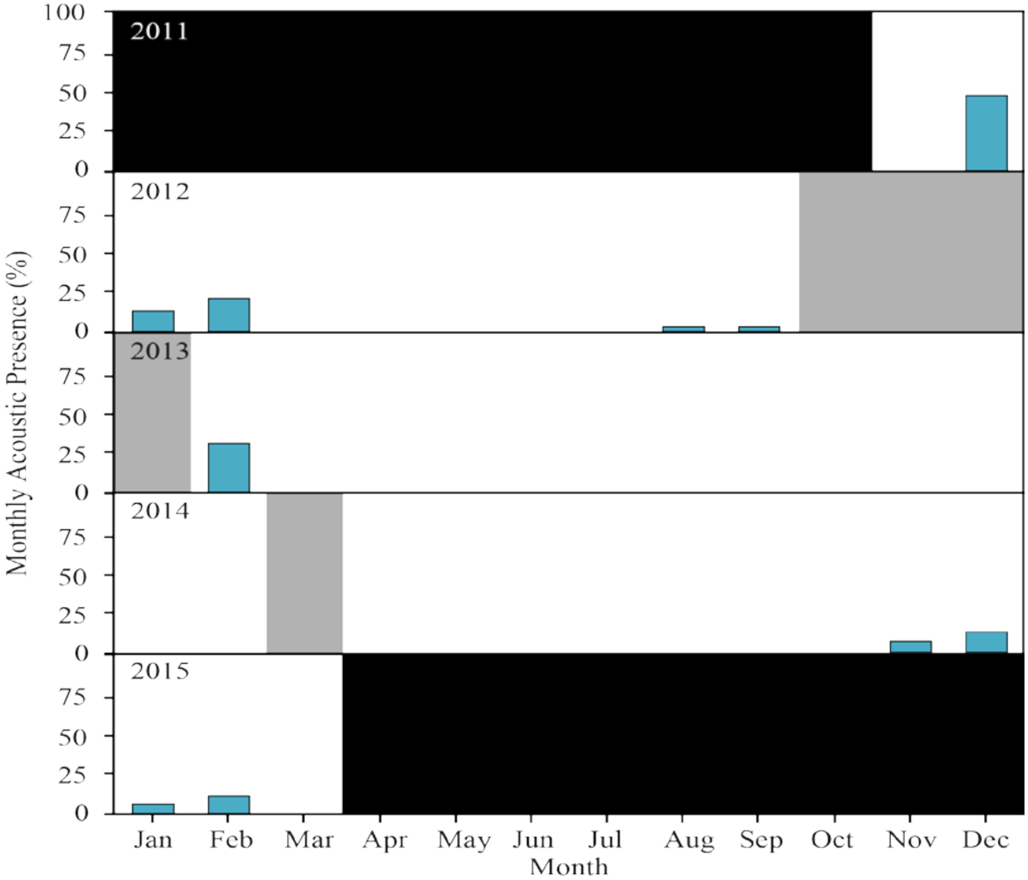


Figure 39. Percent monthly acoustic presence for blue whales recorded between November 2011 and March 2015. The grey areas represent time periods when MARUs were not recording and the black areas represent time periods outside the study period.

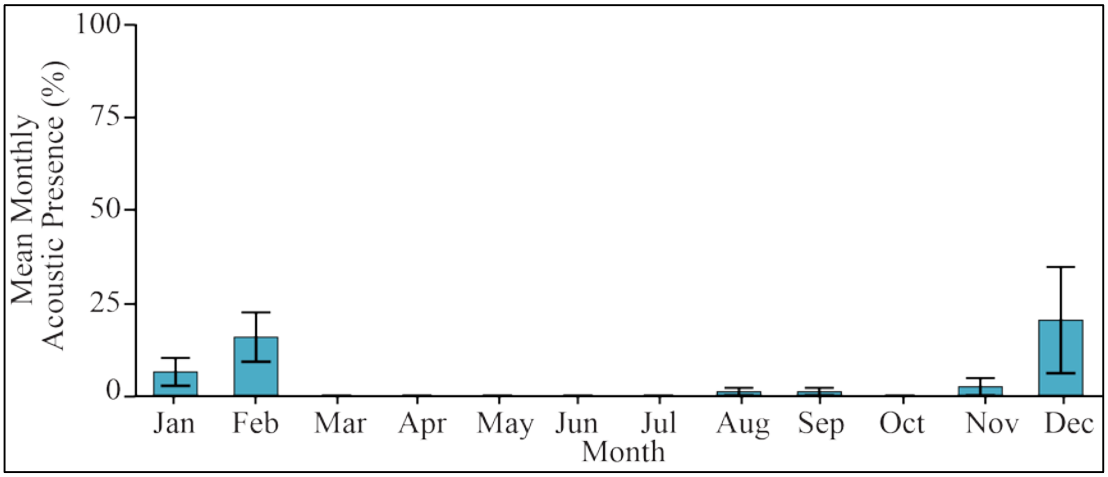


Figure 40. Mean monthly acoustic presence (± SE) for blue whales between November 2011 and March 2015

Variability in Acoustic Presence

Since blue whales were only sparsely detected in the acoustic recordings area during the months that were selected for a variability analysis, the only month that exhibited variation in monthly acoustic presence was February (Figure 42). This is because during February of 2012 and 2013, blue whales had 21% and 31% monthly acoustic presence, respectively. During February of 2014, there were no detected blue whale signals, and during 2015, February only had 7% monthly acoustic presence.

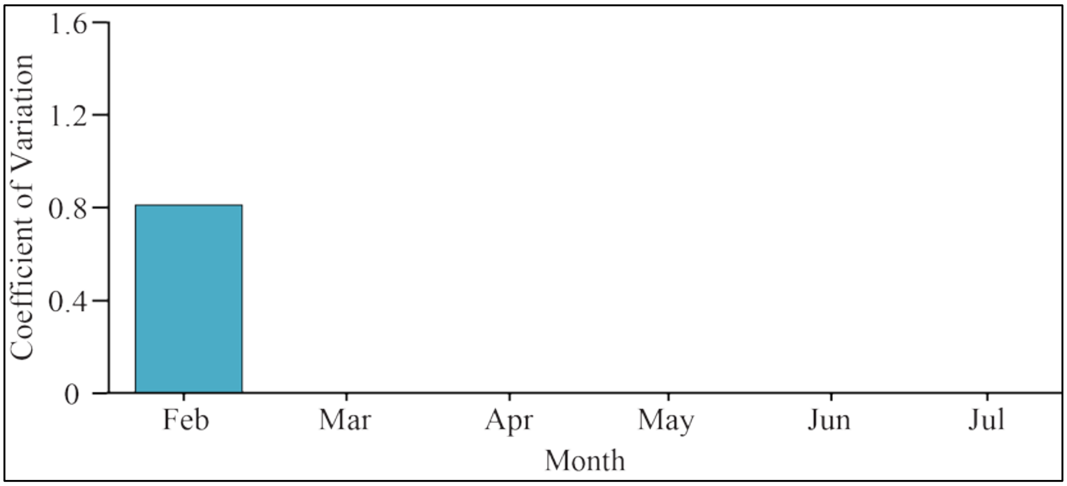


Figure 41. Coefficient of variation for blue whale monthly acoustic presence, limited to months that were sampled over three years during the study period and included five or more recording sites.

Summary of Blue Whale Occurrence

Since blue whales were not visually observed during the aerial surveys, and were sparsely acoustically detected during the study period, these data suggest that blue whales are rarely, if at all, present in the WEAs. Although they were acoustically detected in the winter, the estimated detection range of a blue whale vocalization (>200 km) means the vocalizing whale(s) may have been distant from the WEAs.

SEI WHALE (*BALAENOPTERA BOREALIS*)

Aerial Sightings of Sei Whales

Sei whales were only sighted during the spring and summer (Table 5). Sei whales were observed between March and June, with the greatest number of sightings in May (*n* = 8) and June (*n* = 13) (Figure 43). There were no sightings of sei whales in the summer months of July or August, or during the autumn or winter seasons.

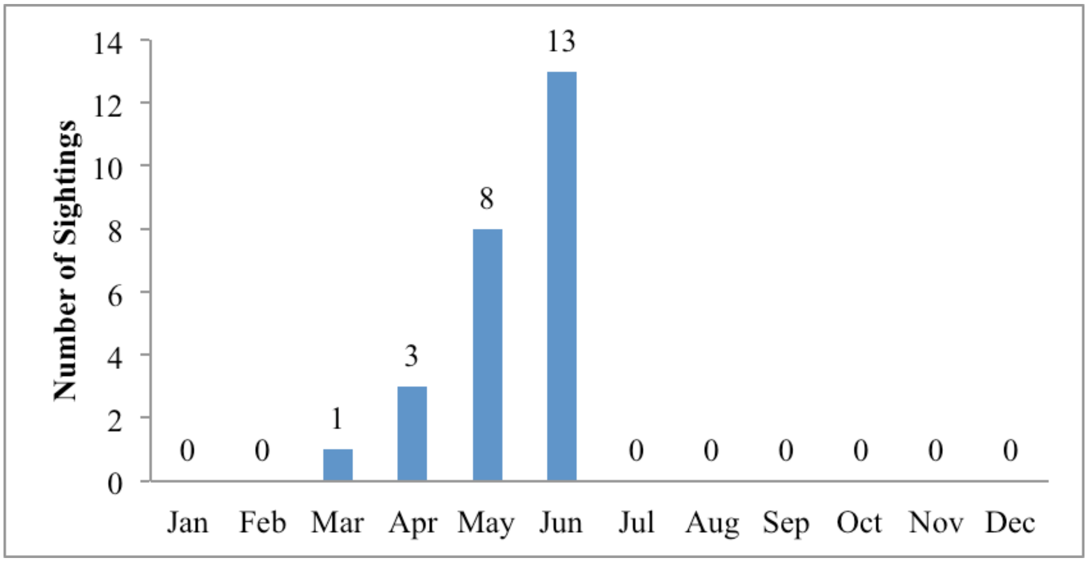


Figure 42. Sei whale sighting totals by month, combined across all survey years (October 2011–June 2015).

Sei Whale Sighting Rates and Variability

Sei whale sighting rates were highest in spring and summer and zero in autumn and winter (Table 5), but the rates were much lower than for any other baleen whale (spring = 0.01 whales/1000 km; summer = 0.78). Variability in sighting rate was not significant between years, months, seasons, or season-years for sei whales, although the test results approached significance for both months and seasons (Table 17). There was an increasing trend approaching statistical significance both by survey day and year (Table 17).

Table 17. Summarized results for analyses of variability and trends in sighting rates for sei whales. Each table entry for the Kruskal-Wallis tests is the *P*-value testing whether there is significant variability in sighting rate among the respective time intervals. The two right columns show the results of least-squares linear regression of sighting rate vs. survey day or year. Each cell shows whether the trend was positive or negative, and the *P*-value (NS = non-significant at *P* ≥ 0.10).

Kruskal-Wallis ANOVA				**Regression**	
Year	Month	Season	Season-Yr	Survey Day	Year
0.585	0.079	0.053	0.174	+,0.093	+,0.078
Kruskal-Wallis ANOVA, among Years by Season					
Winter	Spring	Summer	Autumn		
1.000	0.353	0.151	1.000		

Sei Whale Sightings per Unit Effort

The sei whale SPUE distribution is scattered throughout the study area in spring and summer, but appears to be slightly farther north during the summer (Figure 44). When all seasons were combined, distribution does not follow a pattern or concentrate in a particular area, and is dispersed throughout the study area.

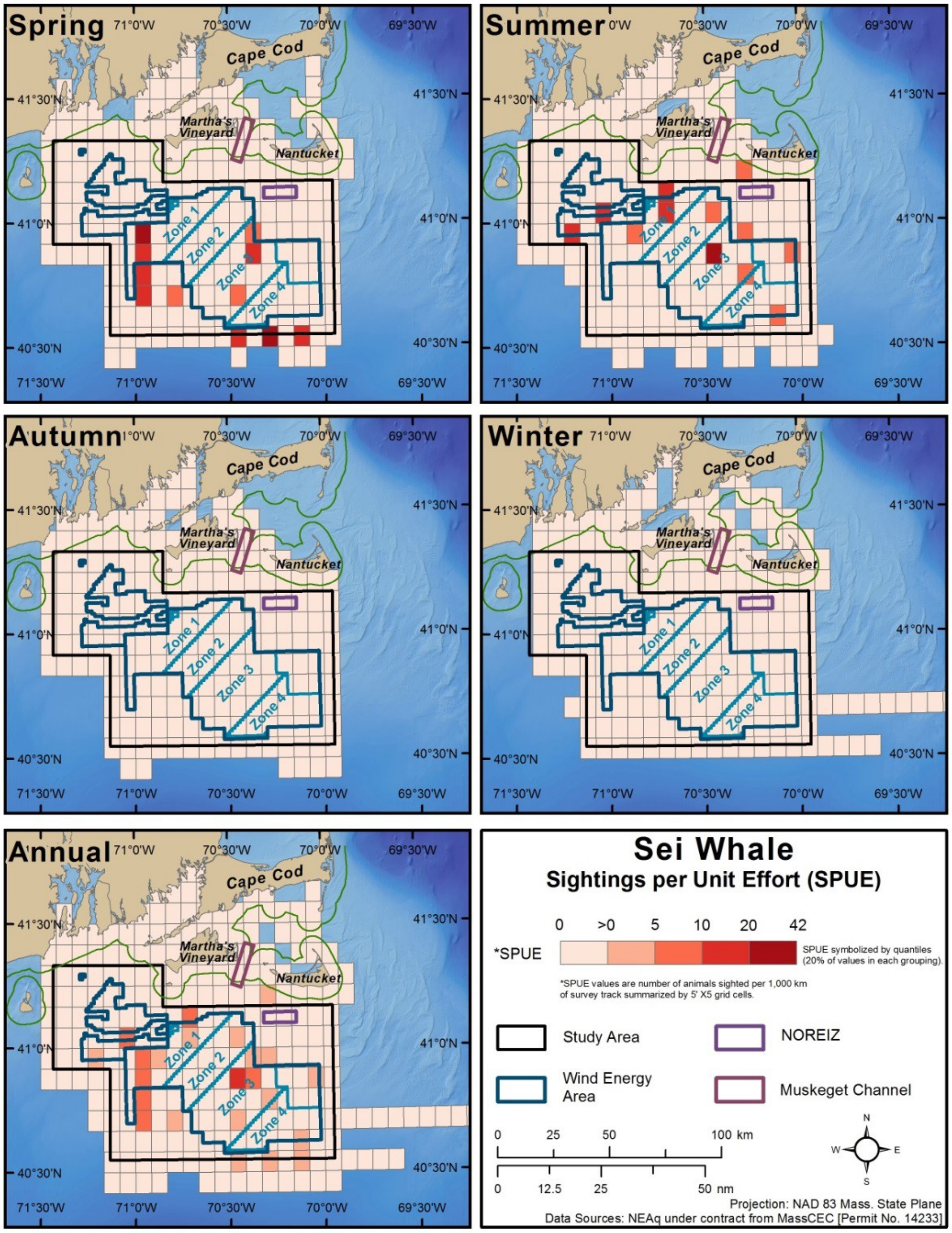


Figure 43. Sei whale SPUE by 5-minute squares partitioned by season across all years and with all seasons combined.

Abundance of Sei Whales

Seasonal abundance estimates of sei whales ranged from 0 to 27 animals with upper 95% confidence limits ranging up to 202 (Table 18). These estimates were only calculated during spring and summer when animals were seen, and there were no sightings available in spring and summer of 2012.

Table 18. Density and abundance of sei whales (*Balaenoptera borealis*) by season-year. Density and variance are the means of the transect estimates, weighted by transect lengths. T = number of transects flown; G, I = number of groups and individuals sighted; D = density in animals/km^2; V = variance of the density; N = estimated abundance in the study area; CI95=95% confidence interval, with the lower limit changed to zero if it was negative.

Season-Year	T	G, I	D	V	N	CI95
Autumn-2011	32	0, 0	0	–	0	–
Winter-2012	30	0, 0	0	–	0	–
Spring-2012	56	0, 0	0	–	0	–
Summer-2012	48	0, 0	0	–	0	–
Autumn-2012	24	0, 0	0	–	0	–
Winter-2013	16	0, 0	0	–	0	–
Spring-2013	39	4, 6	0.0013	0.0007	10	0–75
Summer-2013	46	0	0	–	0	–
Autumn-2013	36	0	0	–	0	–
Winter-2014	26	0	0	–	0	–
Spring-2014	41	1, 2	0.0003	0.0004	3	0–48
Summer-2014	60	6, 12	0.0013	0.0013	10	0–80
Autumn-2014	39	0	0	–	0	–
Winter-2015	28	0	0	–	0	–
Spring-2015	65	3, 7	0.0006	0.0005	5	0–47
Summer-2015	17	4, 4	0.0035	0.0019	27	0–202

Summary of Sei Whale Occurrence

Sei whales appear to only frequent the study area in spring and early summer. Significant variation was not detected for any of the parameters tested, although that may be due to small sample sizes. The distribution of sei whales was throughout the study area, and abundance estimates of sei whales tended to be higher in the summer than in the spring. Due to the uncertainty associated with sei whale vocalization, they were not included as one of the focal species for systematic acoustic surveys.

SPERM WHALE (*PHYSETER MACROCEPHALUS*)

Aerial Sightings of Sperm Whales

Sperm whale sightings only occurred during the summer and autumn (Table 5), with three of the four sightings within a single year. There were two sightings on 7 August 2012, of 4 and 1 individuals, and one sighting of a single whale on 17 September 2012. The last sperm whale sighting was a group of 3 individuals observed on 20 June 2015. Due to this limited sample size, SR and SPUE could not be calculated, no tests for variability in sighting rate could be performed, and abundance of this species could not be calculated.

OTHER CETACEANS

Sightings and Sighting Rates of Small Cetaceans

The majority of the small cetaceans sighted during the study could not be identified to species due to their size and the fact that, since they were not a target species group of the study, the surveys generally did not break off from the trackline and circle the sightings for closer examination. Those sightings were recorded as unidentified dolphins (*n* = 369). There were five species of delphinids sighted in the study area; bottlenose dolphin (*Tursiops truncates),* short-beaked common dolphin *(Delphinus delphis)*, Atlantic white-sided dolphin (*Lagenorhynchus acutus*), Risso's dolphin *(Grampus griseus)*, and pilot whale (*Globicephala sp*.) (sightings point maps, Appendix B; Table 19). There was one species of porpoise sighted, the harbor porpoise *(Phocoena phocoena)*. The "all small cetaceans" category in Table 19 sums the sightings from the six previous rows, all sightings of unidentified dolphins, and sightings identified to species with only *possible* reliability. Small cetaceans were sighted during all seasons, particularly in summer and autumn (Figure 45). Harbor porpoises were the only exception to this trend, with the majority of sightings in winter and spring.

Table 19. Effort-weighted average sighting rates (SR, the number of animals per 1000 km), numbers of sightings (S), and numbers of animals observed (A) for six small cetacean species (only *definite* and *probable* identifications) and all small cetaceans combined, by season. Total effort (km) is shown below each season.

Species	**Autumn**			**Winter**			**Spring**			**Summer**		
	(13,298.08 km)			(11,846.17 km)			(23,348.20 km)			(18,683.15 km)		
	SR	S	A	SR	S	A	SR	S	A	SR	S	A
Bottlenose dolphin	4.55	8	59	1.77	5	29	3.64	10	81	4.80	10	90
Common dolphin	53.79	19	725	8.54	11	132	3.18	11	75	85.86	42	1964
Harbor porpoise	3.72	6	49	2.81	20	35	1.47	18	36	0.05	1	1
Pilot whale	NA	0	0	NA	0	0	NA	11	96	NA	3	21
White-sided dolphin	NA	2	70	NA	0	0	NA	3	41	NA	3	112
Risso's dolphin	NA	0	0	NA	0	0	NA	2	2	NA	0	0
All small cetaceans	298.3	143	4026	42.41	96	600	29.55	165	734	201.4	181	4232

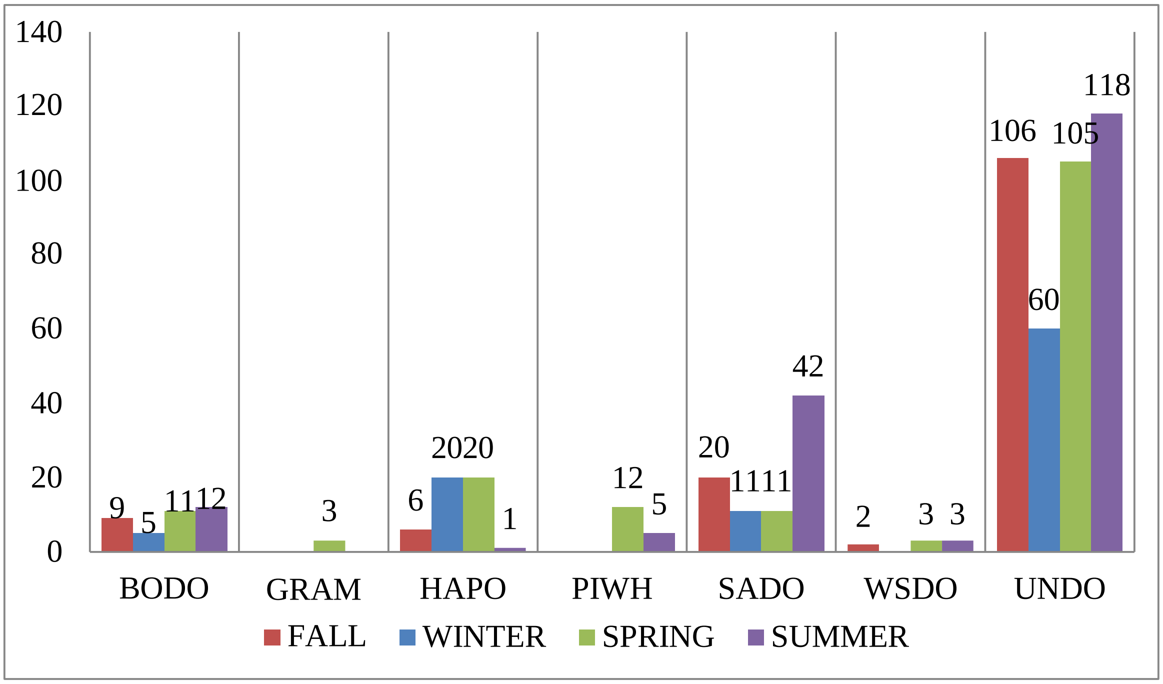


Figure 44. Small cetacean sightings in the study area by season across all years (BODO = bottlenose dolphin, GRAM = Risso's dolphin, HAPO = harbor porpoise, PIWH = pilot whale, SADO = short-beaked common dolphin, WSDO = Atlantic white-sided dolphin, UNDO = any small cetacean sightings not identified to species or identified to species with only a *possible* reliability level).

Variability of Small Cetacean Sighting Rates

Sighting rates for all cetaceans were pooled in order to test variability of the group as a whole (Table 20). When all species of small cetaceans were pooled for sighting rates and tested for variability, there was no significant variability in annual sighting rates (Table 20). There was, however, significant variability by month, season, and season-year. There was no significant inter-annual variability in sighting rate for any one season, and no significant long-term trend (Table 20).

Table 20. Summarized results for analyses of variability and trends in sighting rates for all small cetaceans combined. Each table entry for the Kruskal-Wallis tests is the *P*-value testing whether there is significant variability in sighting rate among the respective time intervals. The two right columns show the results of least-squares linear regression of sighting rate vs. survey day or year. Each cell shows whether the trend was positive or negative, and the *P*-value (NS = non-significant at $P \geq 0.10$).

Kruskal-Wallis ANOVA				**Regression**	
Year	Month	Season	Season-Yr	Survey Day	Year
0.887	0.002	<0.001	0.001	NS	NS
Kruskal-Wallis ANOVA, among Years by Season					
Winter	Spring	Summer	Autumn		
0.592	0.721	0.176	0.087		

Vertical Camera Detections of Small Cetaceans

There were detections of all species of small cetaceans with the exception of Risso’s dolphins in the vertical camera database during many of the surveys conducted (Table 21). The most commonly detected species was harbor porpoise, followed by common dolphins. Many of the detections could not be identified to species and were listed as unidentified dolphins (UNDOs).

Table 21. Vertical camera detections of small cetaceans by date for surveys with vertical camera detections are listed (n = 44), but photos from all 76 NPLSC surveys were analyzed. WSDO = Atlantic white-sided dolphin, BODO =bottlenose dolphin, SADO = short-beaked common dolphin, HAPO = harbor porpoise, PIWH = pilot whale, UNDO = unidentified dolphin, # = number of photos, A = number of animals).

Date	WSDO		BODO		SADO		HAPO		PIWH		UNDO	
	#	A	#	A	#	A	#	A	#	A	#	A
26-Nov-2011							2	3			2	7
12-Dec-2011							1	1			1	1
09-Jan-2012											2	5
26-Jan-2012											1	1
05-Feb-2012											1	1
06-Mar-2012											2	3
23-Mar-2012											4	5
01-Apr-2012									1	1	4	7
06-Apr-2012											6	8
07-May-2012											6	10
07-Aug-2012					1	10					1	3
17-Sep-2012					8	84						
15-Feb-2013							5	6			1	1
26-Feb-2013							1	1			5	8
29-Mar-2013							2	2			2	2
18-Apr-2013											1	3
26-Apr-2013					1	1	2	2			2	5
29-Apr-2013											2	2
18-May-2013											2	3
0-Jun-2013									1	3		
07-Aug-2013											1	8
20-Aug-2013											1	16
18-Sep-2013											4	25
22-Oct-2013					2	58						
05-Nov-2013					1	20						
21-Nov-2013					1	5	1	3				
15-Jan-2014							2	2			2	2
17-Jan-2014							1	1				
01-Feb-2014					1	3	1	1				
04-Feb-2014					2	10						
01-Mar-2014											1	2

Date	WSDO		BODO		SADO		HAPO		PIWH		UNDO	
	#	**A**	**#**	**A**	**#**	**A**	**#**	**A**	**#**	**A**	**#**	**A**
02-Apr-2014							1	8			1	2
22-Apr-2014											1	1
07-May-2014							1	1				
20-Jun-2014					2	22						
24-Jun-2014					1	23						
25-Jul-2014					2	49					1	9
01-Aug-2014					1	2						
26-Aug-2014							1	1			1	13
28-Oct-2014			2	12							1	38
29-Nov-2014											1	2
27-Dec-2014							2	2				
16-Apr-2015							2	2			1	1
26-Apr-2015	1	1	1	1	1	1	2	2			2	3
Total	**1**	**1**	**3**	**13**	**24**	**288**	**27**	**38**	**2**	**4**	**63**	**197**

Sightings per Unit Effort for Small Cetaceans

Small cetaceans were widely dispersed throughout the study area from spring through autumn, with the highest relative abundance in summer, followed by autumn and spring (Figure 46). Relative abundance was lowest and most dispersed in winter. The distribution of this group in winter and spring tended to be somewhat more concentrated farther from shore in the southern portion of the study area.

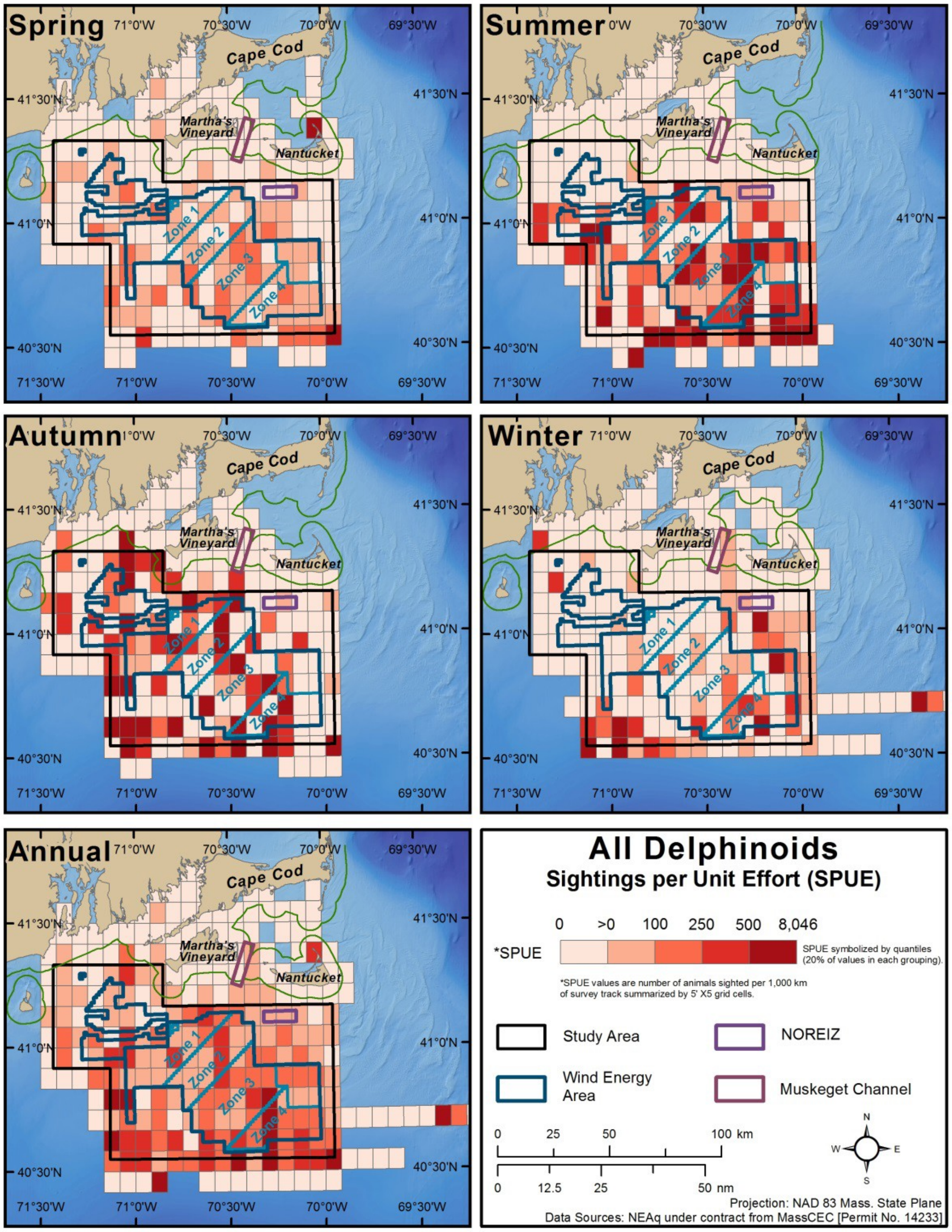


Figure 45. Sightings per Unit Effort for all small cetacean species combined (includes all dolphin species, harbor porpoise, pilot whales, and sightings of small cetaceans not identified to species) shown seasonally and annually for the entire study period (October 2011–June 2015).

Small Cetaceans with Calves

Multiple small cetacean species were observed with calves throughout the project. There were 9 sightings of small cetaceans with calves, including bottlenose dolphins (n = 1), pilot whales (*n* = 2), common dolphins (*n* = 4), and unidentified delphinids (*n* = 2). Small cetacean calves were observed in all seasons throughout the project, but a majority of these observations were in the spring and autumn months.

Behavior of Small Cetaceans

Behavior of small cetaceans was only occasionally documented by observers, as they were not a target species of the study. Observers documented 3 instances of feeding related behaviors by small cetaceans, including common dolphins (*n* = 2) and unidentified delphinids (*n* = 1). Feeding behaviors were only documented in autumn and spring. There were 4 sightings of small cetaceans exhibiting mating behavior during the project. These sightings consisted of two species of dolphin. Common dolphins were the most documented (*n* = 3), and one instance of bottlenose dolphins displaying mating behavior.

Summary of Small Cetaceans

Small cetaceans were not target species of the study and are difficult to identify to species at a distance from the aircraft and without photographs. This resulted in classifying a large number of the small cetaceans as unidentified dolphins (UNDOs). Sightings of small cetaceans were documented all year long, particularly in summer and autumn. There were 120 detections of small cetaceans in the vertical camera database. Small cetaceans were observed in the RIMA WEA and the MA WEA (Zones 1 – 4) during all seasons of the year. Use of the area by small cetaceans did not vary significantly from year to year. There were three different small cetacean species sighted with calves. Though the survey design did not allow for thorough documentation of behaviors exhibited by small cetaceans, both feeding and mating behaviors were observed.

The following sections are species accounts of short-beaked common dolphin, bottlenose dolphin, and harbor porpoise. Since there were too few sightings of other cetacean species to run analyses of SPUE, SR or variance, and since none are listed as *Endangered*, no additional species have separate accounts here. Sighting maps for all species are located in Appendix B.

SHORT-BEAKED COMMON DOLPHIN (*DELPHINUS DELPHIS*)

Aerial Sightings of Common Dolphins

Common dolphins were the most frequently observed species of dolphin in the study area. The greatest number of sightings occurred during the summer months (*n* = 42) (Table 19). Common dolphins were detected in the vertical camera on thirteen different survey days, and there were 24 detections with a total count of at least 288 animals (Table 21). Sightings appear to peak in the summer between June and August, although there were sightings of this species in nearly every month of the year (Figure 47).

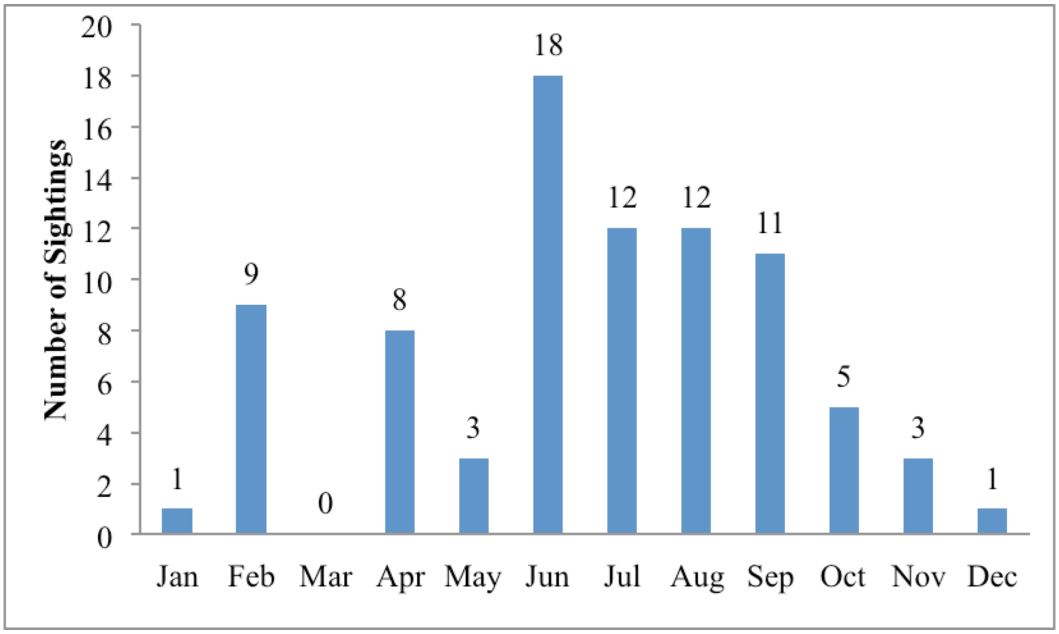


Figure 46. Common dolphin sighting totals by month, combined across all survey years (October 2011–June 2015).

Common Dolphin Sighting Rates and Variability

Common dolphin sighting rates were highest in summer and autumn (Table 19). Variability was not significant between years or months, but was significant between both seasons (P = 0.059) and season-year (P = 0.005) (Table 22). There was also significant inter-annual variability in autumn and almost in summer, but not in winter or spring. There was no evidence for any long-term trend in sighting rates (Table 22).

Table 22. Summarized results for analyses of variability and trends in sighting rates for short-beaked common dolphins. Each table entry for the Kruskal-Wallis tests is the *P*-value testing whether there is significant variability in sighting rate among the respective time intervals. The two right columns show the results of least-squares linear regression of sighting rate vs. survey day or year. Each cell shows whether the trend was positive or negative, and the *P*-value (NS = non-significant at *P* ≥ 0.10).

Kruskal-Wallis ANOVA				**Regression**	
Year	Month	Season	Season-Yr	Survey Day	Year
0.782	0.241	0.059	0.005	NS	NS
Kruskal-Wallis ANOVA, among Years by Season					
Winter	Spring	Summer	Autumn		
0.558	0.273	0.056	0.032		

Common Dolphin Sightings per Unit Effort

Seasonal relative abundance of common dolphins was fairly scattered and clustered offshore during the summer and autumn seasons, with a few spots in the mid-northern portion of the study area (Figure 48). Viewed annually, distribution appears to be primarily offshore in the southern portion of the study area.

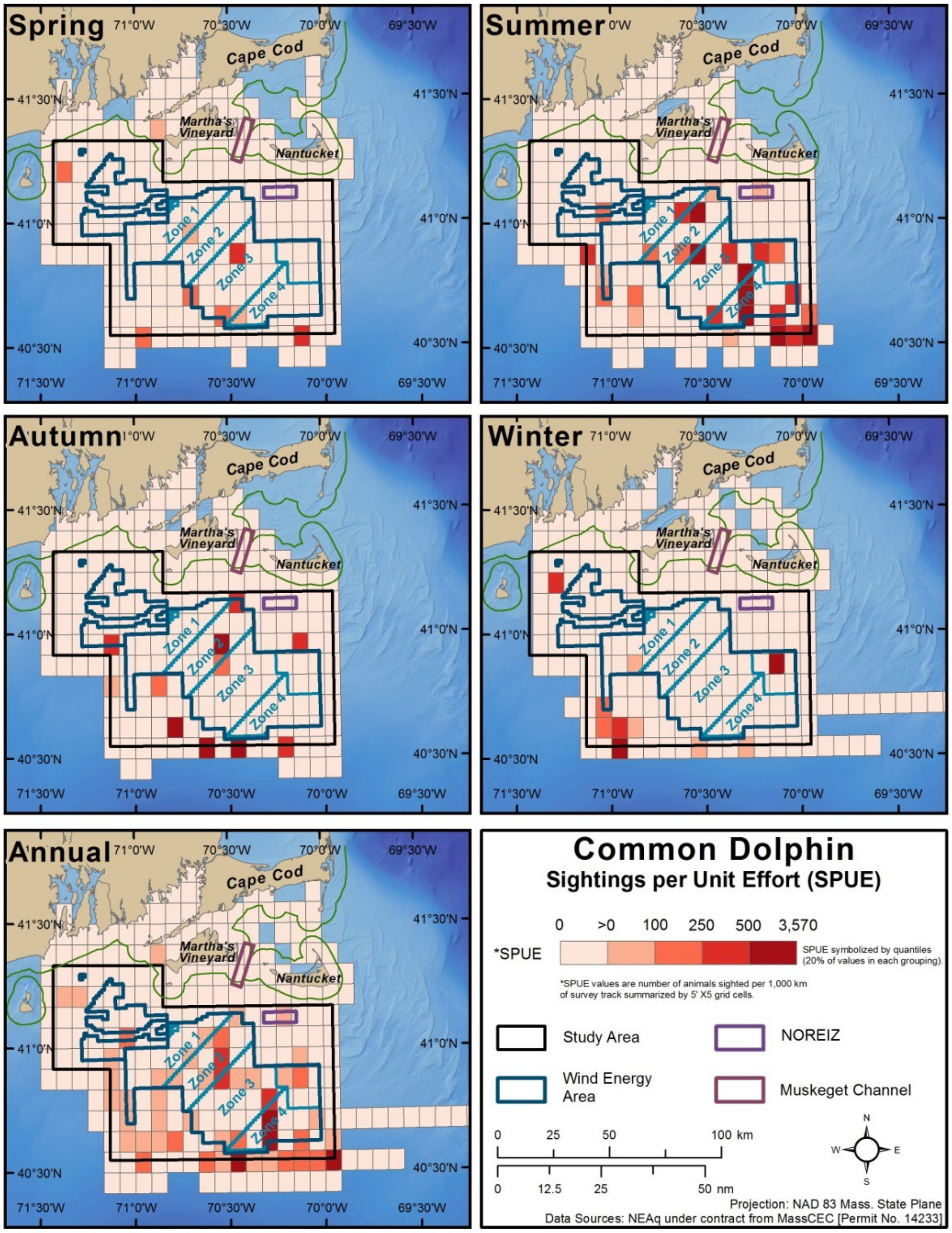


Figure 47. Common dolphin SPUE by 5-minute squares partitioned by season across all years and with all seasons combined.

Abundance of Common Dolphins

Seasonal abundance estimates of common dolphins ranged from 0 to 2,685 animals with upper 95% confidence limits ranging up to 15,485 (Table 23). Estimates were highly variable, and there were estimates of zero at least once during each of the seasonal periods.

Table 23. Density and abundance of short-beaked common dolphins (*Delphinus delphis*) by season-year. Density and variance are the means of the transect estimates, weighted by transect lengths. T = number of transects flown; G,I = number of groups and individuals sighted; D = density in animals/km^2; V = variance of the density; N = estimated abundance in the study area; CI95=95% confidence interval, with the lower limit changed to zero if it was negative.

Season-Year	T	G, I	D	V	N	CI95
Autumn-2011	32	0, 0	0	–	0	–
Winter-2012	30	0, 0	0	–	0	–
Spring-2012	56	2, 22	0.0293	0.8699	202	0–1890
Summer-2012	48	7, 202	0.0922	2.9316	637	0–3984
Autumn-2012	24	3,70	0.1025	1.5186	709	0–4306
Winter-2013	16	1, 10	0.0496	0.5839	387	0–3558
Spring-2013	39	4, 18	0.0665	1.0896	518	0–3070
Summer-2013	46	0, 0	0	–	0	–
Autumn-2013	36	1, 150	0.0172	0.2585	134	0–1428
Winter-2014	26	4, 15	0.1118	3.2689	871	0–6560
Spring-2014	41	0, 0	0	–	0	–
Summer-2014	60	10, 642	0.1044	1.8242	813	0–3475
Autumn-2014	39	2, 33	0.0368	0.5472	286	0–2094
Winter-2015	28	1, 40	0.0227	0.3376	177	0–1932
Spring-2015	65	0, 0	0	–	0	–
Summer-2015	17	8, 657	0.3447	10.2147	2685	0–15485

Summary of Common Dolphin Occurrence

Common dolphins appear to use the study area fairly consistently throughout the year, and were detected most frequently between April and November. Their presence was only significantly variable from year to year during autumn, and nearly significantly variable in summer. Distribution tended to be further offshore in autumn, although this was also the only season in which visual detections also occurred in the RIMA WEA. Detections occurred in Zones 1–4 of the MA WEA during spring and summer, in only Zones 2 and 3 in autumn, and in Zone 1 in winter.

BOTTLENOSE DOLPHIN (*TURSIOPS TRUNCATUS*)

Aerial Sightings of Bottlenose Dolphins

Bottlenose dolphins were the second most frequently observed species of dolphin in the study area. These dolphins were observed in every season of the year (Table 19, Figure 49). There were 3 detections of bottlenose dolphins in vertical photographs, on two different survey days, yielding a minimum count of 13 animals (Table 21). There were only two months in which bottlenose dolphins were not sighted (January and March), and the greatest number of sightings occurred during the month of April (n = 6).

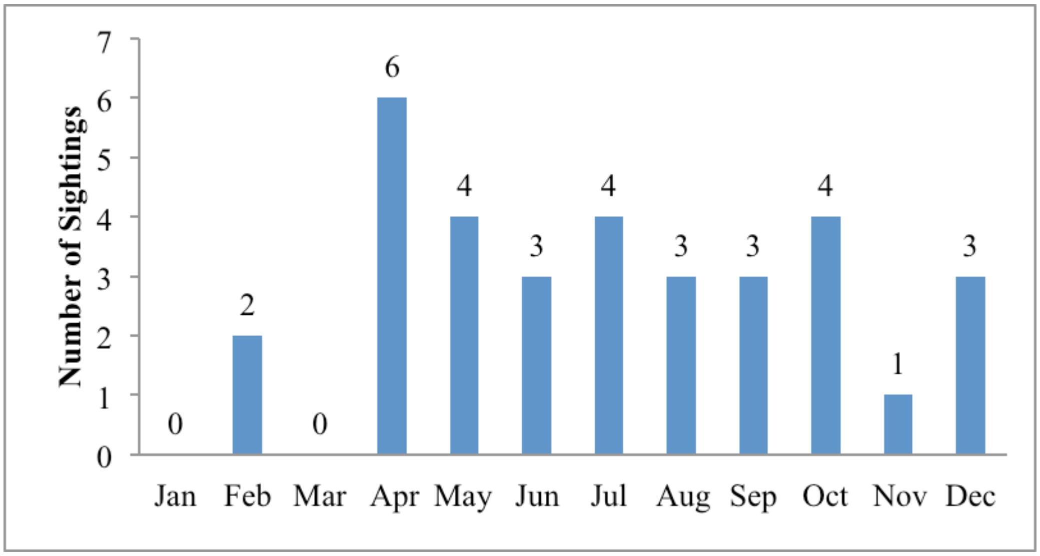


Figure 48. Bottlenose dolphin sighting totals by month, combined across all survey years (October 2011–June 2015).

Bottlenose Dolphin Sighting Rates and Variability

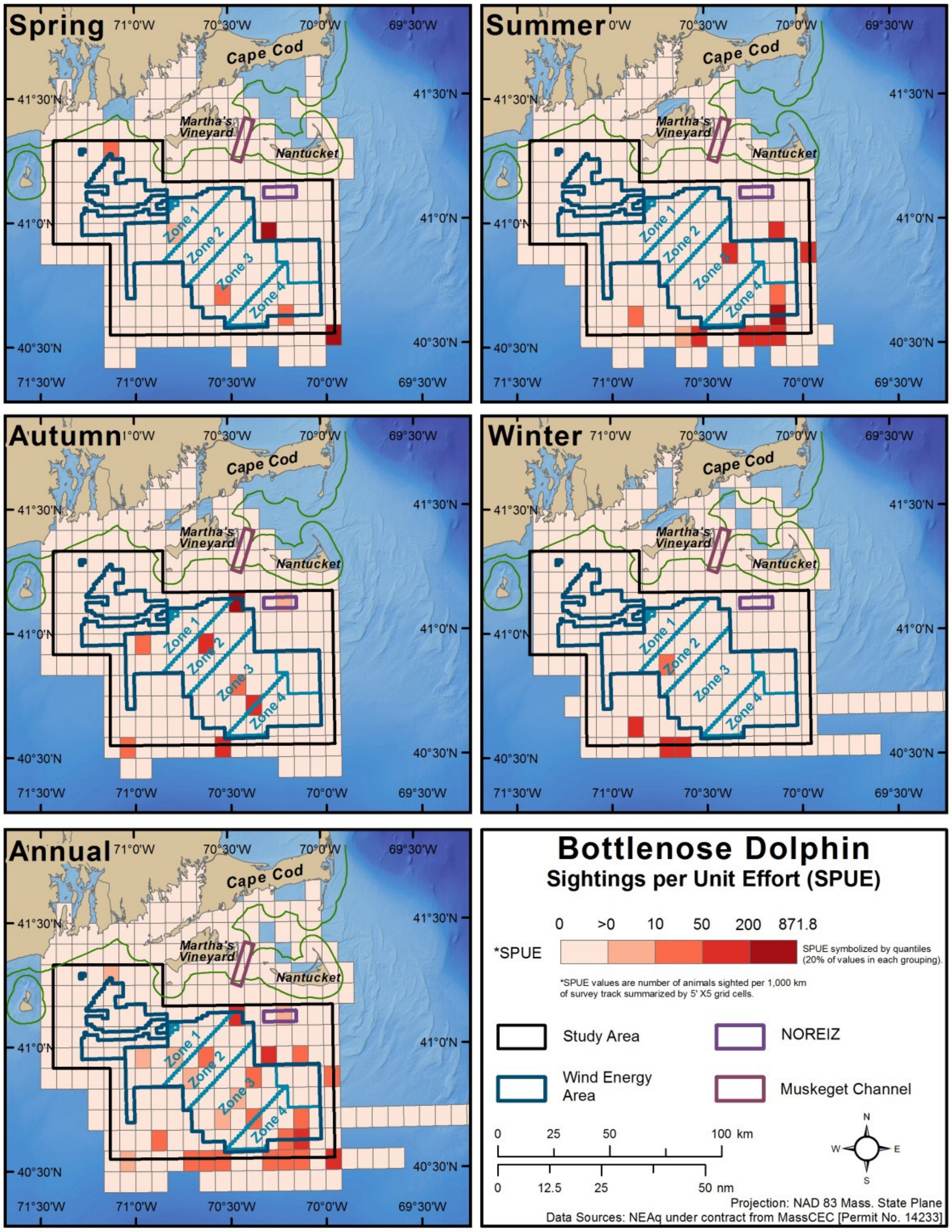
Bottlenose dolphin seasonal sighting rates were relatively stable across all seasons—highest in summer (4.80) and autumn (4.55), followed by spring (3.64) and winter (1.77) (Table 19). Those rates were an order of magnitude lower than the peak seasonal sighting rates for common dolphins. Sighting rates did not vary significantly by year, month, season, or season-year for bottlenose dolphins (Table 24). There was also no significant inter-annual variability in any season, no any evidence for long-term trends.

Table 24. Summarized results for analyses of variability and trends in sighting rates for bottlenose dolphins. Each table entry for the Kruskal-Wallis tests is the *P*-value testing whether there is significant variability in sighting rate among the respective time intervals. The two right columns show the results of least-squares linear regression of sighting rate vs. survey day or year. Each cell shows whether the trend was positive or negative, and the *P*-value (NS = non-significant at $P \geq 0.10$).

Kruskal-Wallis ANOVA				**Regression**	
Year	Month	Season	Season-Yr	Survey Day	Year
0.143	0.591	0.371	0.249	NS	NS
Kruskal-Wallis ANOVA, among Years by Season					
Winter	Spring	Summer	Autumn		
0.470	0.417	0.157	0.341		

Bottlenose Dolphin Sightings per Unit Effort

Bottlenose dolphin relative abundance was highest and most widely distributed in the study area during the spring, with some small concentrations offshore (Figure 50).When all seasons were combined, bottlenose dolphins appear to be located throughout the study area and surrounding waters, with some evidence of more concentrations along the southernmost boundary.



Projection: NAD 83 Mass. State Plane
Data Sources: NEAq under contract from MassCEC [Permit No. 14233]

Figure 49. Bottlenose dolphin SPUE by 5-minute squares partitioned by season across all years and with all seasons combined.

Abundance of Bottlenose Dolphins

Seasonal abundance estimates of bottlenose dolphins varied greatly, and ranged from 0 to 118 animals, with upper 95% confidence limits ranging up to 1,020 (Table 25). During most seasons in 2012, estimates were zero. The highest estimates calculated in any year were in autumn 2011 (*N* = 118), summer 2014 (*N* = 109), and spring 2015 (*N* = 103).

Table 25. Density and abundance of bottlenose dolphins (*Tursiops truncatus*) by season-year. Density and variance are the means of the transect estimates, weighted by transect lengths. T = number of transects flown; G, I = number of groups and individuals sighted; D = density in animals/km^2; V = variance of the density; N = estimated abundance in the study area; CI95=95% confidence interval, with the lower limit changed to zero if it was negative.

Season-Year	T	G, I	D	V	N	CI95
Autumn-2011	32	3, 9	0.0171	0.1374	118	0–1006
Winter-2012	30	0, 0	0	–	0	–
Spring-2012	56	0, 0	0	–	0	–
Summer-2012	48	0, 0	0	–	0	–
Autumn-2012	24	1, 30	0.0069	0.0552	48	0–734
Winter-2013	16	0, 0	0	–	0	–
Spring-2013	39	2, 43	0.0089	0.1434	70	0–996
Summer-2013	46	3, 21	0.0113	0.091	88	0–767
Autumn-2013	36	0, 0	0	–	0	–
Winter-2014	26	1, 5	0.0075	0.0475	58	0–743
Spring-2014	41	1, 1	0.0043	0.0513	34	0–574
Summer-2014	60	5, 50	0.0140	0.3981	109	0–1353
Autumn-2014	39	3, 18	0.0049	0.0397	38	0–525
Winter-2015	28	1, 2	0.0061	0.0491	47	0–717
Spring-2015	65	6, 34	0.0132	0.2343	103	0–1020
Summer-2015	17	0, 0	0	–	0	–

Summary of Bottlenose Dolphin Occurrence

Bottlenose dolphins seem to occur in the study area throughout the year, and appear to be located throughout the area, with greatest concentrations in the southernmost part of the SA. Tests for variability suggest that presence does not vary from year to year, and has little seasonality. Bottlenose dolphins appear to use both the RIMA WEA and Zones 1–4 of the MA WEA within the SA. Abundance estimates were > 0 for a great deal of the season-years, and though these have wide confidence intervals, suggests a fairly consistent presence of this species in the SA.

HARBOR PORPOISE (*PHOCOENA PHOCOENA*)

Aerial Sightings of Harbor Porpoise

Harbor porpoise were sighted within the study area. The greatest number of sightings occurred during winter (*n* = 20) and spring (*n* = 18) months (Table 19). There were harbor porpoise detections (*n* = 27) in the vertical camera on sixteen different survey days, and these detections yielded a total count of at least 38 animals (Table 21). Sightings of harbor porpoise occurred from November through May, with almost none during June–September (Figure 50). The highest number of detections occurred in April (*n* = 11). There were insufficient harbor porpoise visual sightings to model sighting probability in DISTANCE and generate density and abundance estimates.

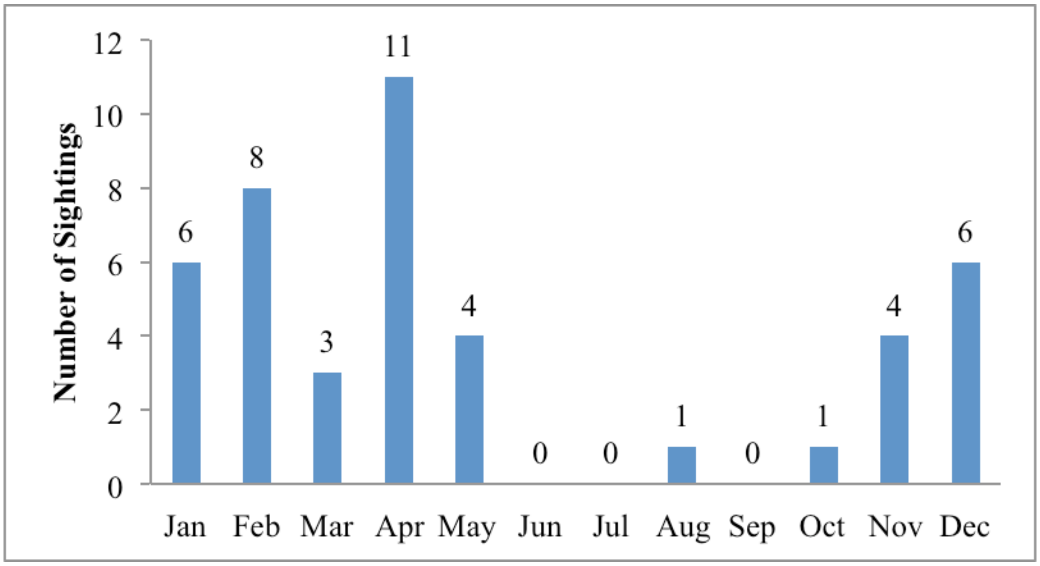


Figure 50. Harbor porpoise sighting totals by month, combined across all survey years (October 2011–June 2015).

Harbor Porpoise Sighting Rates and Variability

Harbor porpoise sighting rates were highest in autumn and winter, somewhat lower in spring, and near zero in summer (Table 19). Variability in harbor porpoise sighting rate was not significant between years, but there was significant variability ($P < 0.05$) between months, seasons, and season-years (Table 26). There was no inter-annual variability in sighting rate for any season, and no evidence for long-term trends (Table 26).

Table 26. Summarized results for analyses of variability and trends in sighting rates for harbor porpoise. Each table entry for the Kruskal-Wallis tests is the *P*-value testing whether there is significant variability in sighting rate among the respective time intervals. The two right columns show the results of least-squares linear regression of sighting rate vs. survey day or year. Each cell shows whether the trend was positive or negative, and the *P*-value (NS = non-significant at $P \geq 0.10$).

Kruskal-Wallis ANOVA				Regression	
Year	Month	Season	Season-Yr	Survey Day	Year
0.143	0.036	0.001	0.023	NS	NS
Kruskal-Wallis ANOVA, among Years by Season					
Winter	Spring	Summer	Autumn		
0.123	0.287	0.506	0.496		

Harbor Porpoise Sightings per Unit Effort

Seasonally, harbor porpoise relative abundance seemed to be widely scattered throughout the survey area with a slight concentration toward the east in the winter and spring (Figure 51). Harbor porpoise are largely absent from the SA during the summer months. The annual SPUE map reflects the widely scattered occurrences in the north and the east.

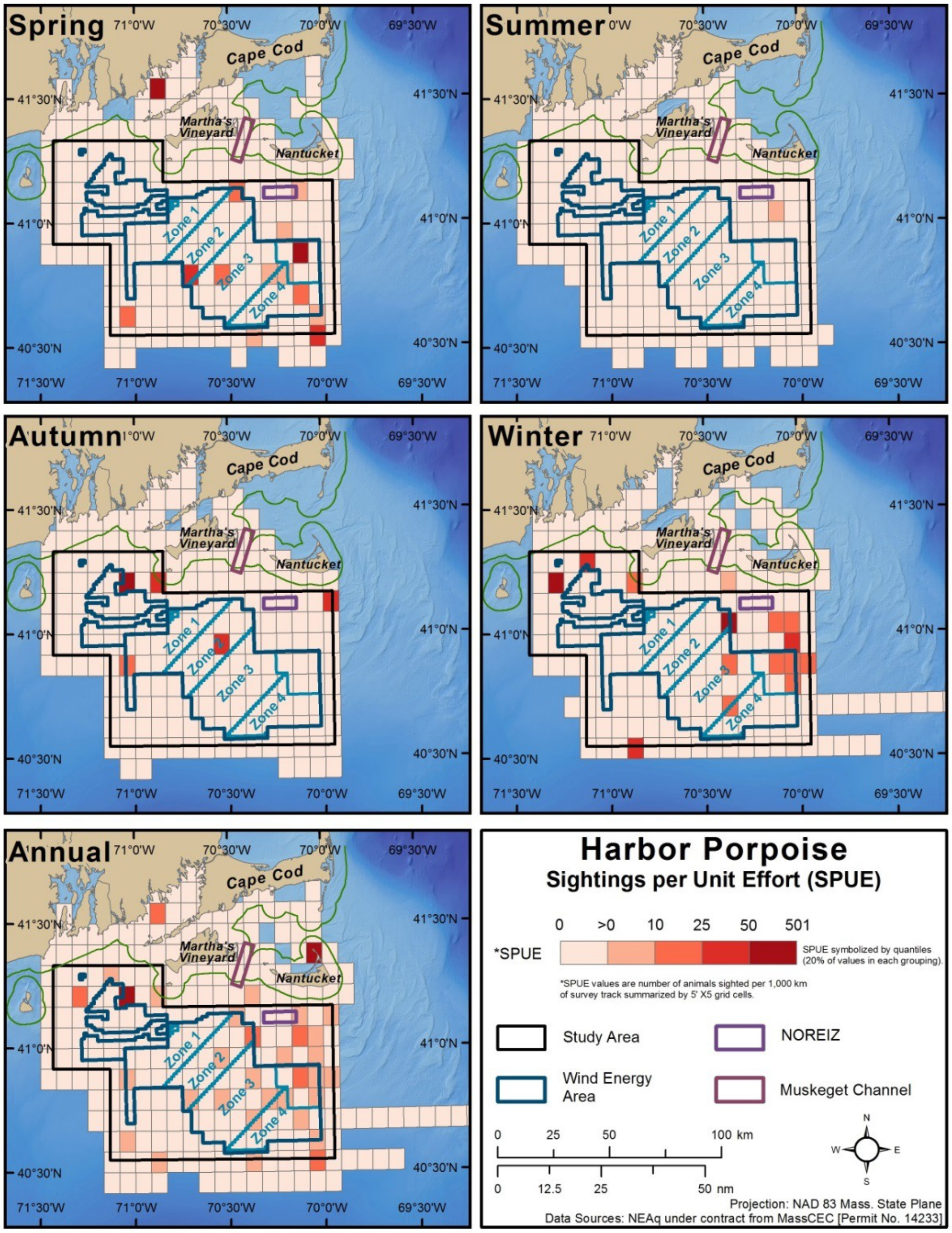


Figure 51. Harbor porpoise SPUE by 5-minute squares partitioned by season across all years and with all seasons combined.

Summary of Harbor Porpoise Occurrence

Harbor porpoise appear to use the study area consistently in all seasons but summer. Though aerial detections occurred consistently in three of the four seasons, the only sightings in and immediately surrounding the RIMA WEA were in autumn and winter. Harbor porpoise were seen in Zone 1 of the MA WEA in autumn and in Zone 2 in spring and autumn. Zone 3 and 4 had no aerial detections in summer or autumn.

SEA TURTLES

Sightings and Sighting Rates of Sea Turtles

There were three species of sea turtles sighted in the study area; leatherback turtle, loggerhead turtle, and Kemp's ridley turtle (sightings point maps, Appendix B; Table 27). Leatherback turtles were the most commonly sighted, followed by loggerheads. Both of these species were sighted primarily during summer and autumn (Figure 52). There were no sightings of any species of sea turtle during the winter season.

Table 27. Effort-weighted average sighting rates (SR, the number of animals per 1000 km), numbers of sightings (S), and numbers of animals observed (A) for three sea turtle species (only *definite* and *probable* identifications) and all sea turtles combined, by season. Total effort (km) is shown below each season name.

Species	**Autumn**			**Winter**			**Spring**			**Summer**		
	(13,298.08 km)			(11,846.17 km)			(23,348.20 km)			(18,683.15 km)		
	SR	**S**	**A**	**SR**	**S**	**A**	**SR**	**S**	**A**	**SR**	**S**	**A**
Leatherback	4.59	59	62	0	0	0	0.08	2	2	4.65	92	95
Loggerhead	3.97	45	45	0	0	0	0.07	2	2	1.52	31	31
Kemp's Ridley	NA	4	4	NA	0	0	NA	0	0	NA	0	0
All turtles	10.46	133	140	0	0	0	0.19	5	5	8.66	146	165

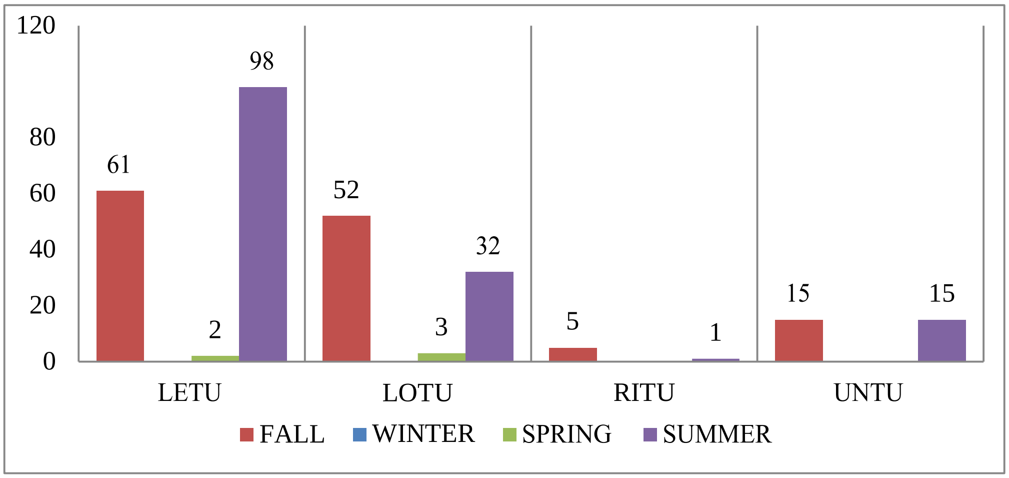


Figure 52. Sea turtle sightings in the study area by season across all years (LETU = leatherback turtle, LOTU = loggerhead turtle, RITU = Kemp's ridley turtle, UNTU = any sea turtle sightings not identified to species)

Vertical Camera Detections of Sea Turtles

The number of sea turtle sightings was substantially increased by detections in the vertical camera. There were detections of leatherbacks (*n* = 24), loggerheads (*n* = 33) and Kemp's ridley turtles (*n* = 6) (Table 28). The only detections of Kemp's ridley turtles were in vertical photographs.

Table 28. Vertical camera detections of sea turtles by date. Only dates for surveys with vertical camera detections are listed (*n* = 14), but photos from all 76 NPLSC surveys were analyzed. (# = number of photos, A = number of animals).

Date	Leatherback Turtle		d		Kemp's Un Ridley Turtle			identified Turtle	
	#	A	#	A	#	A	#		
09-Oct-2011	5	5							
23-Oct-2011	2	2							
26-Nov-2011			1	1					
10-Jun-2012	1	1							
24-Jun-2012	2	2							
03-Jul-2012	1	1							
13-Jul-2012			4	4					
07-Aug-2012	6	6	6	6					
23-Aug-2012	3	3	10	10	1	1	1		
12-Sep-2012			7	7	4	4	2		
17-Sep-2012	1	1	4	4	1	1			
20-Aug-2013	2	2							
20-Jun-2014	1	1							
04-Sep-2014			1	1					
Total	**24**	**24**	**33**	**33**	**6**	**6**	**3**		

Variability of Sea Turtle Sighting Rates

Sighting rates of all sea turtles combined were high in summer and autumn, zero in winter, and nearly zero in spring (Table 27). Sighting rates of sea turtles as a group did not vary significantly from year to year, however variability was highly significant ($P < 0.001$) between months, seasons, and season-years (Table 29). There was no significant inter-annual variability for any season. The linear regression analysis for long-term trends showed a nearly significant decreasing trend across years, but no significant trend across days of the study.

Table 29. Summarized results for analyses of variability and trends in sighting rates for all sea turtles combined. Each table entry for the Kruskal-Wallis tests is the *P*-value testing whether there is significant variability in sighting rate among the respective time intervals. The two right columns show the results of least-squares linear regression of sighting rate vs. survey day or year. Each cell shows whether the trend was positive or negative, and the *P*-value (NS = non-significant at $P \geq 0.10$).

Kruskal-Wallis ANOVA				Regression	
Year	Month	Season	Season-Yr	Survey Day	Year
0.190	<0.001	<0.001	<0.001	NS	–,0.053
Kruskal-Wallis ANOVA, among Years by Season					
Winter	Spring	Summer	Autumn		
1.000	0.593	0.133	0.371		

Sightings per Unit Effort for Sea Turtles

Distribution of the combined sea turtle SPUE indicates they are rare in the SA in the spring (Figure 53). During both summer and autumn, sea turtle relative density was distributed throughout the study area, with some clustering south of Nantucket, which is probably due to the high abundance of leatherback in that area in some years.

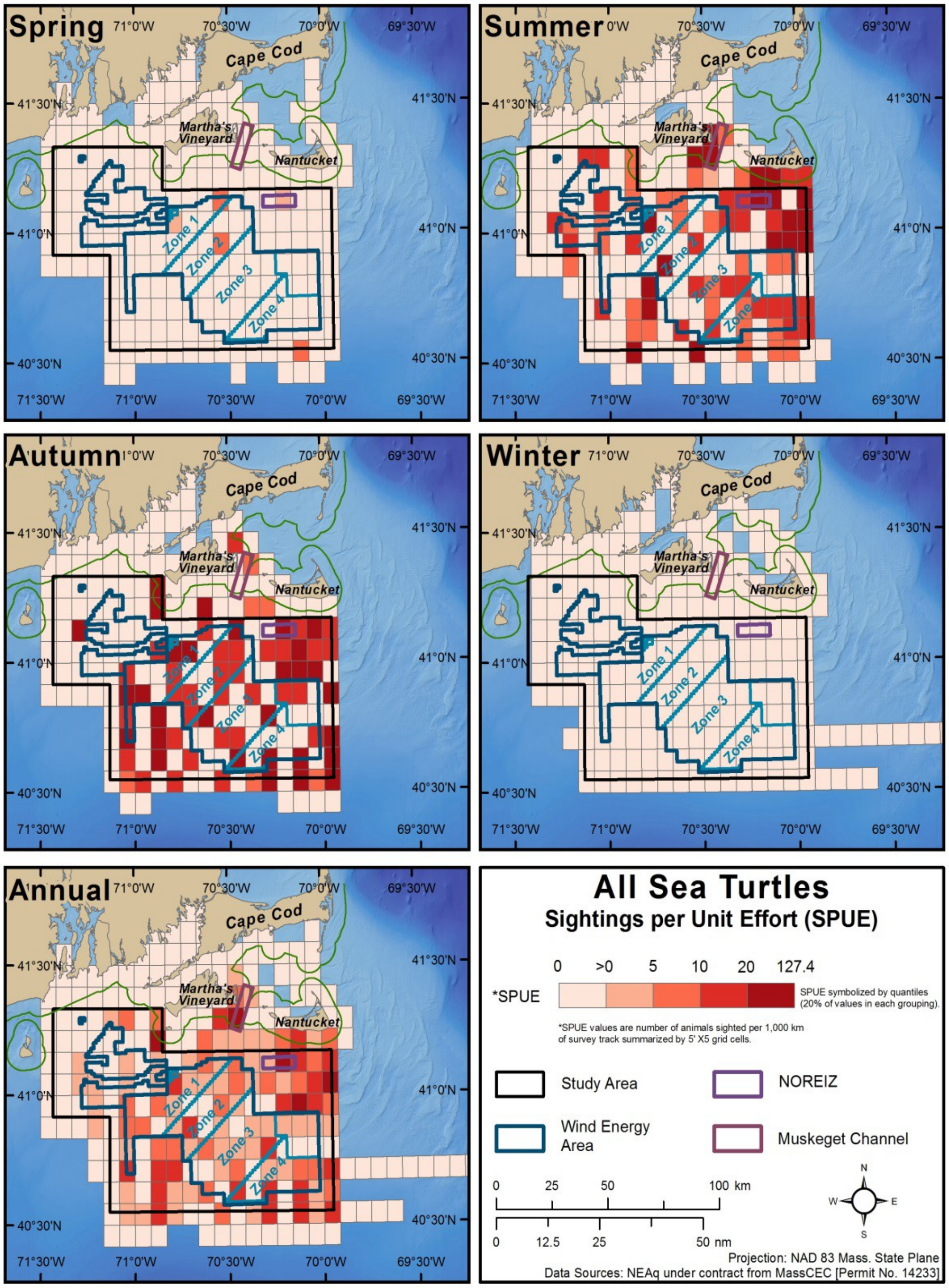


Figure 53. Sightings per Unit Effort for all sea turtle species combined by 5-minute squares, partitioned by season across all years and with all seasons combined.

Summary of Sea Turtles

Using both observer and vertical camera data, sea turtles were sighted in all seasons but winter, and most frequently sighted in summer and autumn. When all species were grouped, sea turtle presence in the study area did not significantly vary from year to year, demonstrating consistent use of the area. Turtles were distributed throughout the RIMA WEA and MA WEA Zones 1 – 4 in both summer and autumn. Turtles were only present in MA WEA Zone 1 and 2 in spring. Sea turtle species accounts are in the sections that follow, and were created for all turtles that were identified to species.

LEATHERBACK SEA TURTLE (*DERMOCHELYS CORIACEA*)

Aerial Sightings of Leatherback Turtles

Leatherback sea turtles were the most frequently sighted species of turtle sighted in the study area and were mostly sighted during the summer and autumn, rarely in the spring, and not at all in winter (Table 27). Leatherback turtles were detected in the vertical camera (*n* = 24) during ten different survey days (Table 28). Leatherback turtles were only sighted between May and November, with a strong peak in August (*n* = 71) (Figure 54).

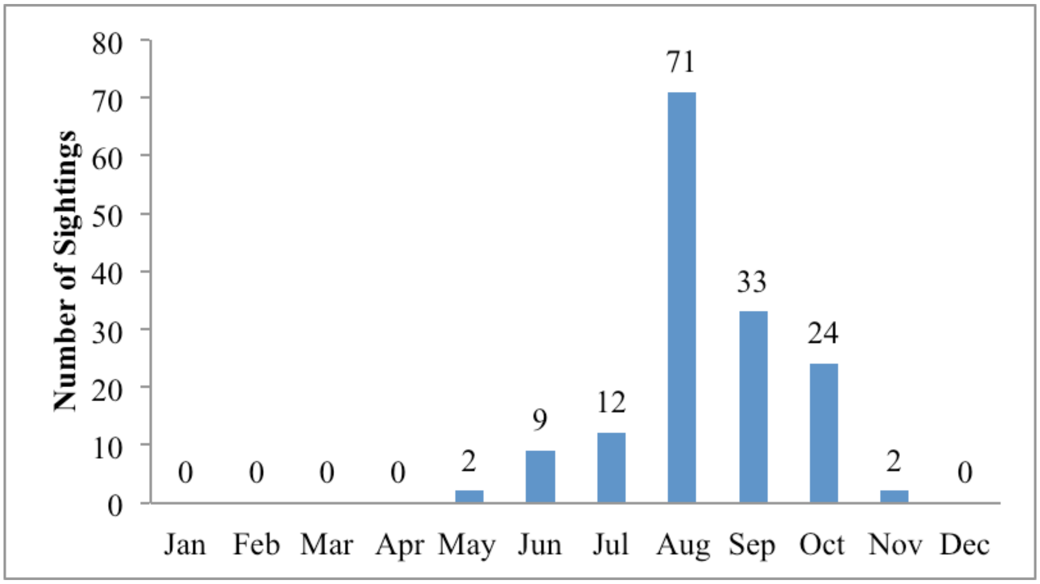


Figure 54. Leatherback turtle sighting totals by month, combined across all survey years (October 2011–June 2015).

Leatherback Turtle Sighting Rates and Variability

Like with sightings, leatherback turtle sighting rates were also highest in summer and autumn (Table 27). Variability in sighting rate was not significant between years for leatherbacks (Table 30). However, there was significant variability in sighting rate between months, seasons, and season-years. There was no significant inter-annual variability in any one season, and no significant long-term trend.

Table 30. Summarized results for analyses of variability and trends in sighting rates for leatherback sea turtles. Each table entry for the Kruskal-Wallis tests is the *P*-value testing whether there is significant variability in sighting rate among the respective time intervals. The two right columns show the results of least-squares linear regression of sighting rate vs. survey day or year. Each cell shows whether the trend was positive or negative, and the *P*-value (NS = non-significant at $P \geq 0.10$).

Kruskal-Wallis ANOVA				**Regression**	
Year	Month	Season	Season-Yr	Survey Day	Year
0.365	<0.001	<0.001	0.001	NS	–,0.098
Kruskal-Wallis ANOVA, among Years by Season					
Winter	Spring	Summer	Autumn		
1.000	0.485	0.338	0.339		

Leatherback Turtle Sightings per Unit Effort and Hot Spot Analysis

Leatherbacks occurred throughout the study area in the summer, with a higher concentration of sightings in the northeastern corner in the area just south of Nantucket (Figure 55). In autumn, the concentration condensed into an area south of Nantucket, and some dispersion into the north-central portion of the study area. The Hot Spot Analysis demonstrated the significant clustering of leatherback distribution south of Nantucket (Figure 56).

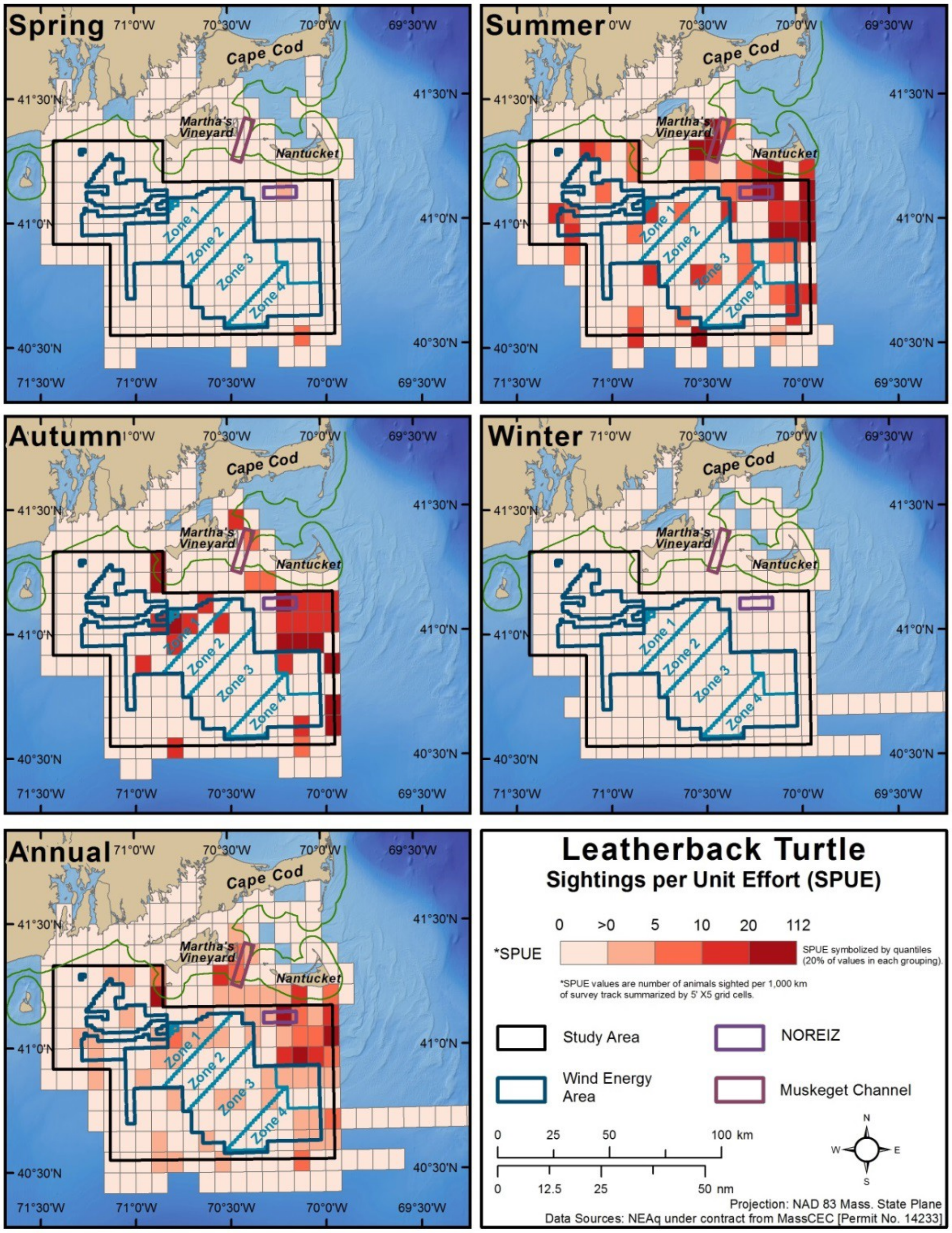


Figure 55. Leatherback turtle SPUE by 5-minute squares, partitioned by season across all years and with all seasons combined.

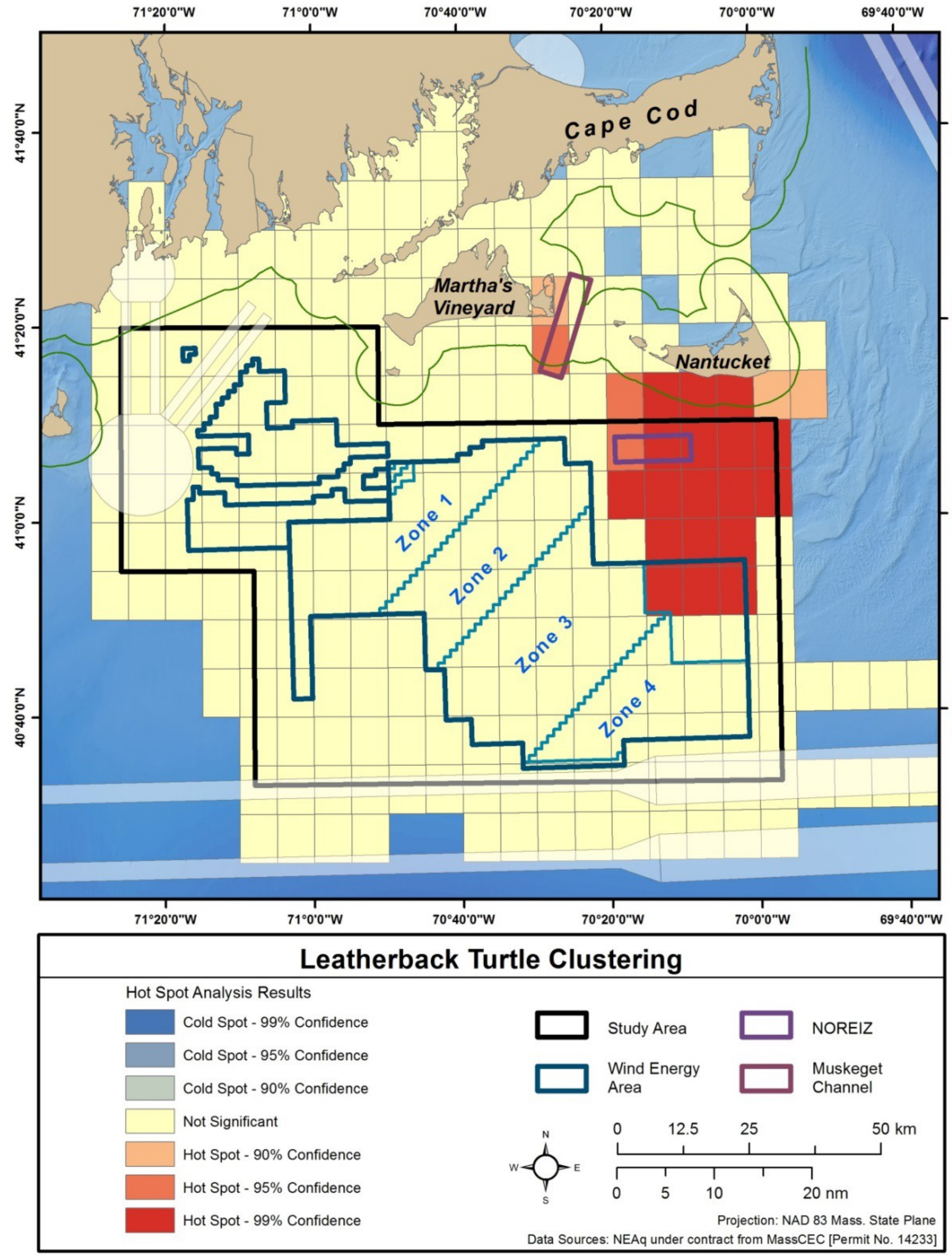


Figure 56. Hot Spot Analysis of leatherback turtle distribution in the study area.

Abundance of Leatherback Turtles

Seasonal abundance estimates of leatherbacks ranged from 0 to 99 animals, with upper 95% confidence limits ranging up to 616 (Table 31). Abundance estimates were highest in 2012 and 2014.

Table 31. Density and abundance of leatherback sea turtles (*Dermochelys coriacea*) by season-year. Density and variance are the means of the transect estimates, weighted by transect lengths. T = number of transects flown; G, I = number of groups and individuals sighted; D = density in animals/km^2; V = variance of the density; N = estimated abundance in the study area; CI95=95% confidence interval, with the lower limit changed to zero if it was negative.

Season-Year	T	G, I	D	V	N	CI95
Autumn-2011	32	9, 12	0.0082	0.0220	57	0–412
Winter-2012	30	0, 0	0	–	0	–
Spring-2012	56	0, 0	0	–	0	–
Summer-2012	48	24, 25	0.0131	0.0579	90	0–560
Autumn-2012	24	12, 12	0.0133	0.0322	92	0–616
Winter-2013	16	0, 0	0	–	0	–
Spring-2013	39	0, 0	0	–	0	–
Summer-2013	46	2, 2	0.0012	0.0009	9	0–79
Autumn-2013	36	1, 1	0.0007	0.0005	6	0–61
Winter-2014	26	0, 0	0	–	0	–
Spring-2014	41	0, 0	0	–	0	–
Summer-2014	60	16, 16	0.0072	0.0087	56	0–239
Autumn-2014	39	16, 16	0.0127	0.0643	99	0–719
Winter-2015	28	0, 0	0	–	0	–
Spring-2015	65	0, 0	0	–	0	–
Summer-2015	17	2, 2	0.0037	0.0034	29	0–263

Summary of Leatherback Turtle Occurrence

Leatherback turtles have a distinct seasonal occurrence in the study area between May and November, peaking in late summer. This seasonality is confirmed by the highly significant ($P < 0.001$) variability in sighting rates between months and seasons, and this pattern appears to be consistent from year to year. During this seasonal occurrence in the SA, leatherback turtles were most highly concentrated south of Nantucket, as shown by the Hot Spot Analysis. In addition to this obvious hot spot, turtles were also detected in both the RIMA WEA and Zones 1–4 of the MA WEA during both summer and autumn.

LOGGERHEAD SEA TURTLE (*CARETTA CARETTA*)

Aerial Sightings of Loggerhead Turtles

Loggerhead sea turtles were sighted in the survey area during the spring, summer, and autumn seasons (Table 27), and were detected in the vertical camera (*n* = 33) during seven different survey days (Table 28). Nearly all of the loggerhead detections were during only two months of the year in late summer and early autumn—August (*n* = 27) and September (*n* = 45) (Figure 57).

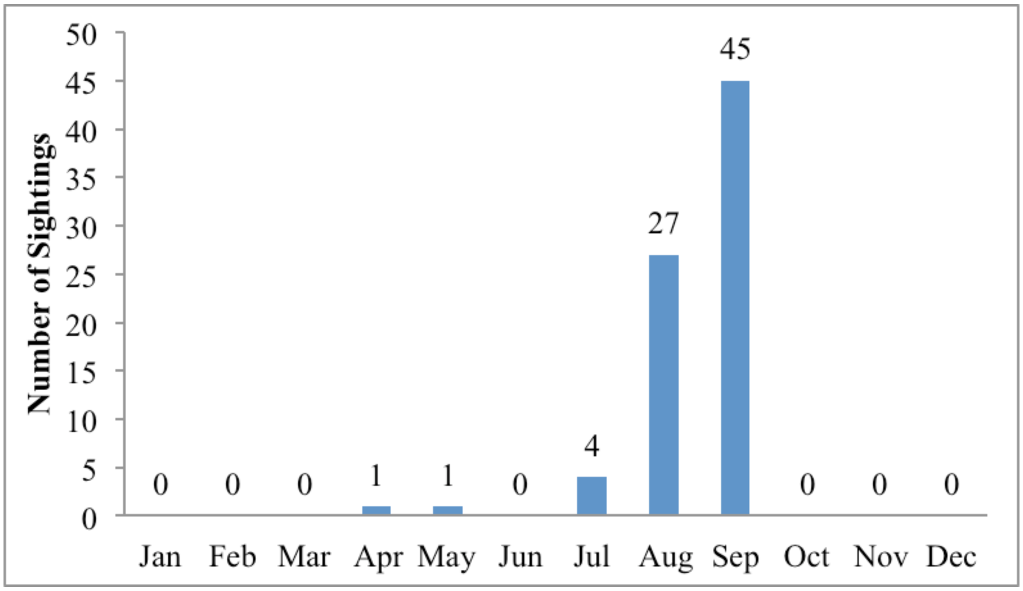


Figure 57. Loggerhead turtle sighting totals by month, combined across all survey years (October 2011–June 2015).

Loggerhead Turtle Sighting Rates and Variability

Loggerhead turtle sighting rates were by far the highest in autumn (3.97), and were only about 38% as high in summer (1.52) (Table 27). Variability in sighting rate was not significantly variable between years or season-year for loggerheads (Table 32). However, there was significant variability in sighting rate between month and season. There was no significant inter-annual variability in sighting rate in any season, and no evidence for any long-term trend.

Table 32. Summarized results for analyses of variability and trends in sighting rates for loggerhead sea turtles. Each table entry for the Kruskal-Wallis tests is the *P*-value testing whether there is significant variability in sighting rate among the respective time intervals. The two right columns show the results of least-squares linear regression of sighting rate vs. survey day or year. Each cell shows whether the trend was positive or negative, and the *P*-value (NS = non-significant at $P \geq 0.10$).

Kruskal-Wallis ANOVA				**Regression**	
Year	Month	Season	Season-Yr	Survey Day	Year
0.2	<0.001	0.030	0.124	NS	NS
Kruskal-Wallis ANOVA, among Years by Season					
Winter	Spring	Summer	Autumn		
1.000	0.650	0.347	0.192		

Loggerhead Turtle Sightings per Unit Effort

Loggerhead turtle relative abundance distribution was throughout the study area in both summer and autumn, perhaps slightly more offshore in autumn (Figure 58). When viewed annually, this trend was also observed, with a small concentration offshore in the southeastern corner of the study area.

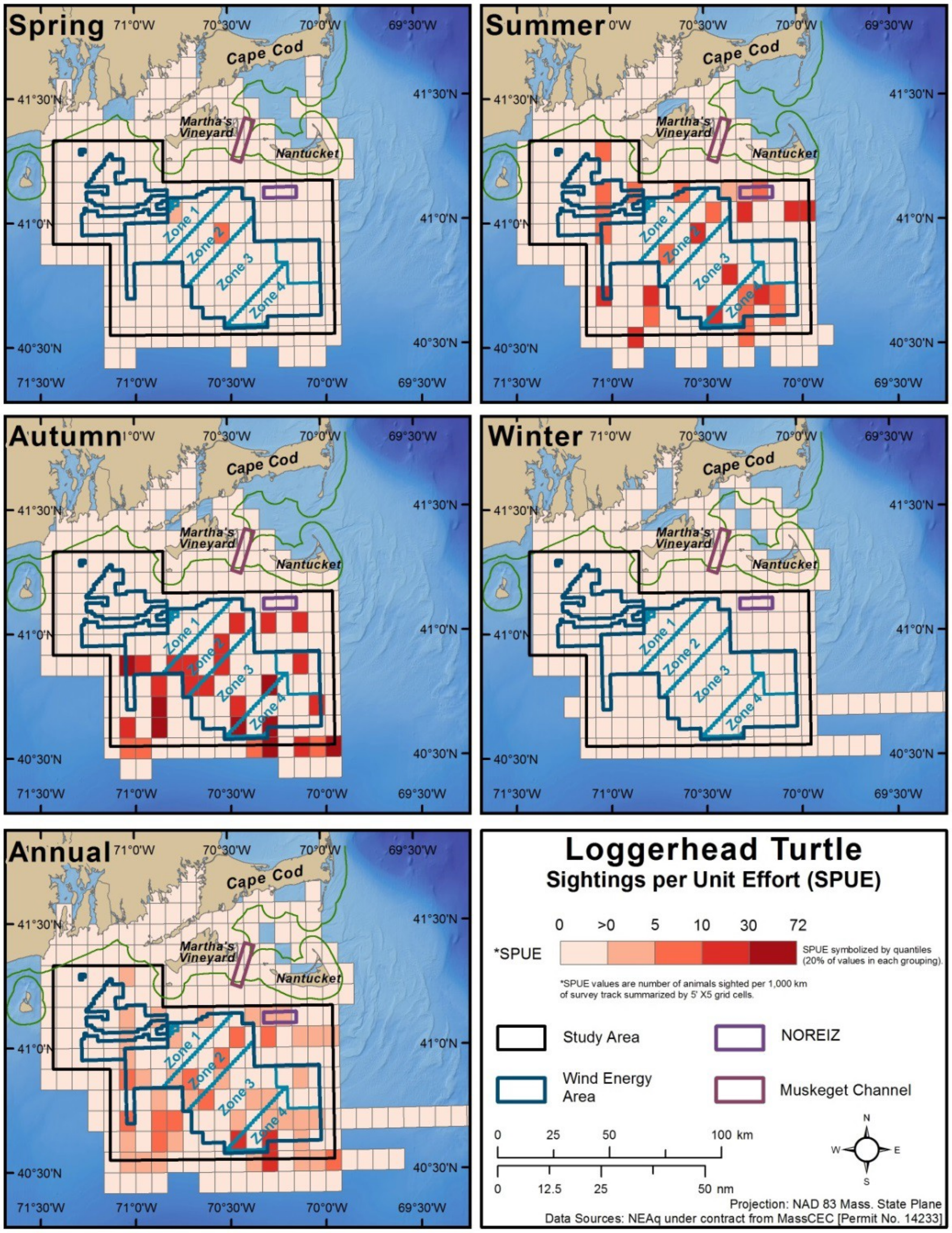


Figure 58. Loggerhead turtle SPUE by 5-minute squares partitioned by season across all years and with all seasons combined.

Summary of Loggerhead Turtle Occurrence

Loggerhead turtles primarily occur in the study area in August and September. Variability in sighting rates was highly significant ($P = < 0.001$) between months, further demonstrating a short window of occurrence. Distribution of turtles was widely dispersed throughout the study area, and was only detected in the RIMA WEA during the summer. Loggerhead turtles were found in Zones 1–4 of the MA WEA in both summer and autumn.

KEMP'S RIDLEY TURTLE (*LEPIDOCHELYS KEMPII*)

The only confirmed detections (not recorded as unidentified turtle) of Kemp's ridley turtles were in the vertical camera photographs (Table 28). All of those photographic detections were from a span of less than one month in 2012—one on 23 August, four on 12 September, and one on 17 September (Table 28). There were insufficient data for sighting rate, SPUE, or density/abundance analyses.

OTHER SPECIES

Both observers and the vertical camera were able to detect species in addition the whales, small cetaceans, and sea turtles detailed above. Detections of all species are listed in the data table in Appendix A. There were detections of seals in the study area including harbor seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*). Sharks detected included the basking shark (*Cetorhinus maximus*), white shark (*Carcharodon carcharias*), blue shark (*Prionace glauca*), dusky shark (*Carcharhinus obscurus*), hammerhead shark (*Sphyrna zygaena),* thresher shark (*Alopias vulpinus)*and spiny dogfish *(Squalus acanthias)*(sightings maps, Appendix B). Species of sharks that had enough sightings (*n* > 25) for SPUE maps were the basking shark, blue shark, dusky shark, and spiny dogfish (Appendix D). Ocean sunfish (*Mola mola*) were also detected in great numbers throughout the project. A sightings map (Appendix B) and SPUE map (Appendix D) were created for this species. Single rays, schools of fish and groups of tuna (sightings map, Appendix B) were also detected, however, these animals could not be identified to species.

SPECIES RICHNESS

When all sightings of identified species were combined, areas of relatively high species richness were identified. The two highest square counts were > 10 species per 10 x 10 km square and the area of the highest species richness was located in the southern portion of MA WEA Zone 2 (Figure 59). Other areas of high species richness were located just south of Nantucket in the northeastern portion of the study area, in the middle of Zones 2 and 3, and throughout most of Zone 4 and the southeastern corner of the SA.

Species richness was also assessed in the same manner for endangered species only, and areas used by several endangered species were identified (Figure 60). The areas of highest endangered species richness (5 species) were located in MA WEA Zone 1 and Zone 4, as well as south of the lease areas along the southern boundary of the study area. The species richness analysis is based upon data from all seasons and all years of the study, so seasonal variability is lost. Because species specific variability is shown elsewhere in this report, it is unlikely that the highest numbers of species would ever occur simultaneously in a given block.

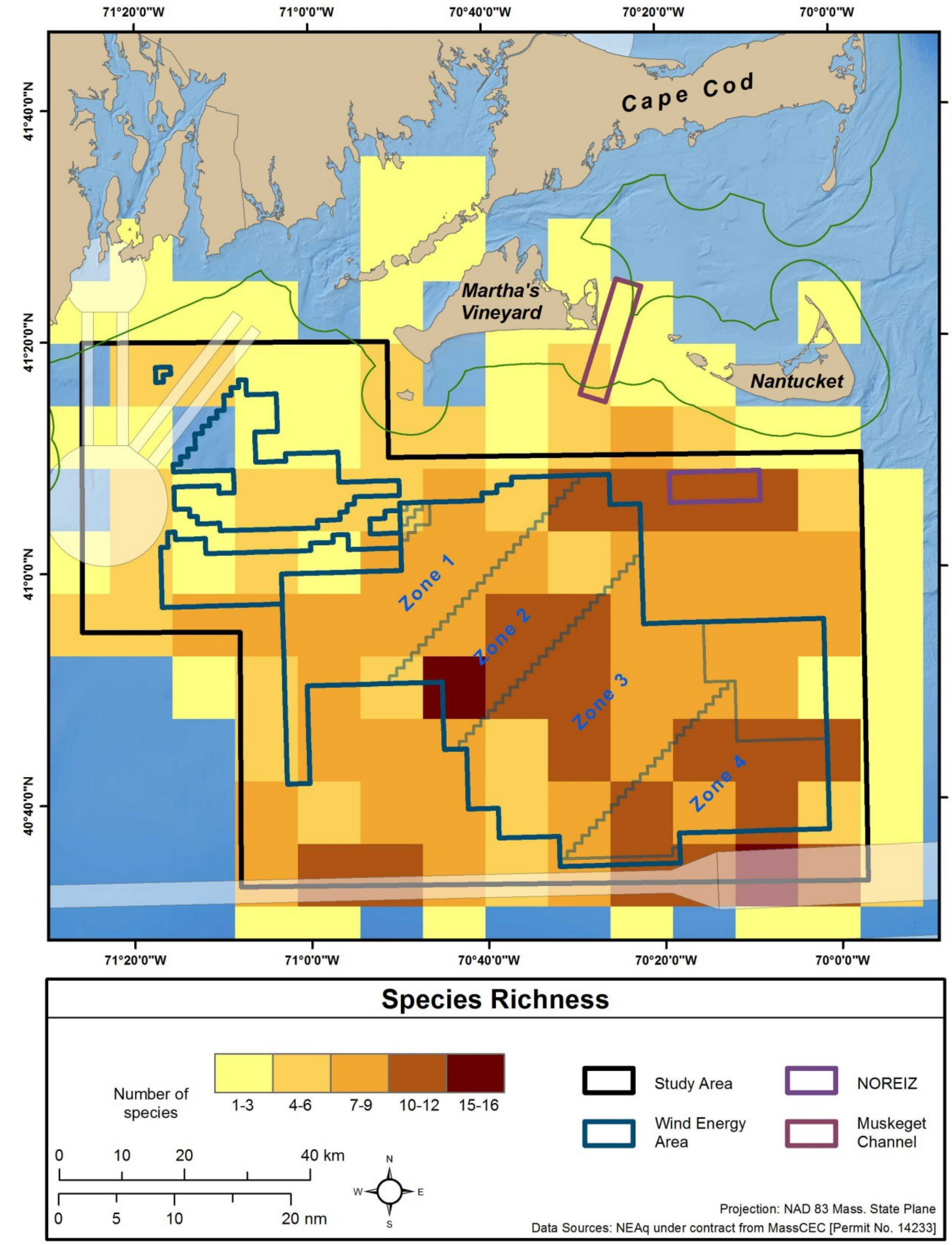


Figure 59. Species Richness: All marine mammal, sea turtle, and large fish species.

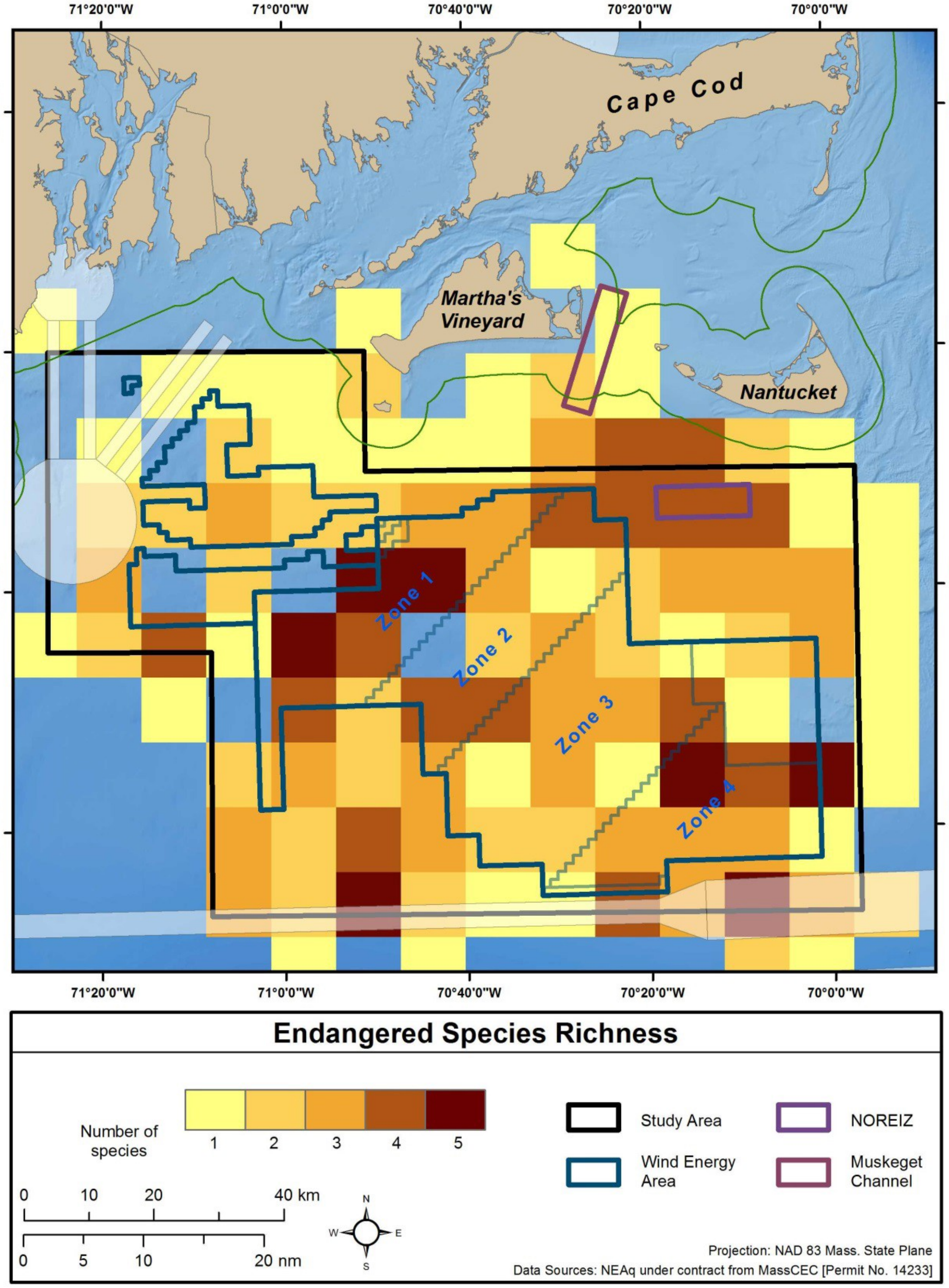


Figure 60. Species Richness: Endangered whale and sea turtles only

COMPARISON OF AERIAL AND ACOUSTIC DETECTIONS OF LARGE WHALES

ACOUSTIC DETECTION RANGE

Estimated detections ranges for all 5 species are listed below in Table 33. Detection range is influenced by a number of acoustic and physical habitat parameters, including the frequency range of the calling species, frequency range of ambient background noise (including anthropogenic noise), depth, water temperature, and bottom cover.

Table 33. The mean detection range (km) for each species, and the upper 95% confidence interval (CI) bound for each estimated detection range per site.

	Right		**Minke**		**Humpback**		**Fin**		**Blue**	
Site	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**
MA-1	21	3	8	1	26	4	364	23	798	39
MA-2	24	3	9	1	36	5	320	53	775	152
MA-3	17	2	7	1	26	4	254	36	458	76
MA-4	15	3	6	1	28	5	147	46	219	102
MA-5	16	2	6	1	31	3	203	31	388	54
MA-6	17	3	6	1	30	4	344	147	652	649

The detection radius estimates (Table 33 and Figure 61) indicate that acoustic detections of humpbacks, minke, and right whale signals most likely originated from animals that were within the study area, and therefore available to the aircraft observers. Humpback detection ranges were on the order of 30 – 40 km, and right whale detection ranges were 18 – 29 km, such that acoustic coverage of the study area was high. Minke whale detection ranges are substantially smaller (6 – 11 km), so it is possible that some minke sightings within the study area occurred outside the detection radius of the MARUs.

Over 99% of the minke whale detection ranges for all MARUs (as seen in Figure 61) was within the SA, so any minke whale acoustic detection was certainly within the SA. In the case of right whales, the estimated acoustic detection ranges indicate that 86% of the detections were produced by right whales within the SA. For humpback whales, these estimated detection ranges indicate that 63% of all acoustic detections were made by humpback whales vocalizing within the study area. The detection radius for fin whales and blue whales were estimated to exceed 140 km, therefore it is likely that the MARUs detected singing fin whales and blue whales that were located beyond the study area.

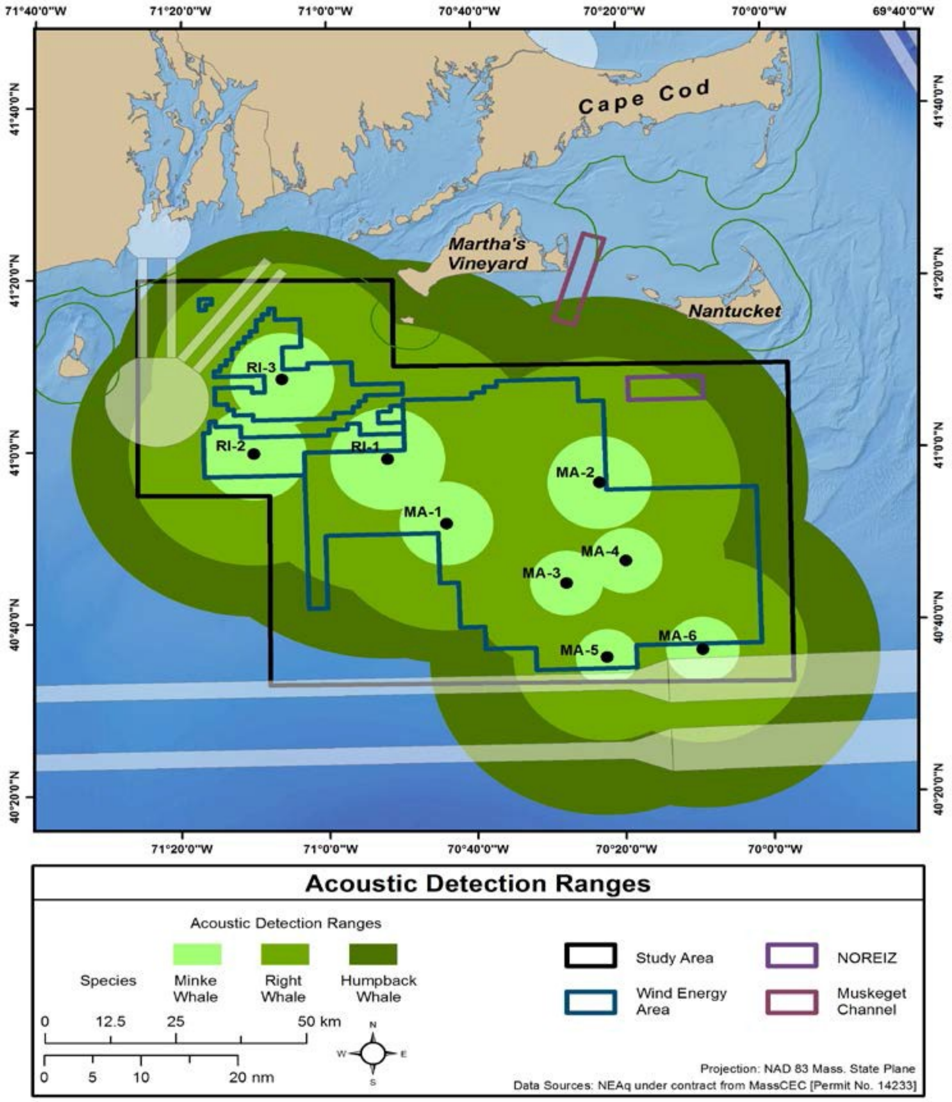


Figure 61. Map of the MA and RIMA MARU recording arrays (black dots with labels). Detection ranges for the MARUs are shown in light green for minke whales, medium green for right whales, and dark green for humpback whales. Right and humpback whale detection ranges encompass nearly all of the aerial survey area shown in the bold black outline, and all of the WEAs outlined in blue.

Data Selection

The three best candidate species for this comparison were North Atlantic right whales, humpback whales, and minke whales, for the following reasons. 1) Each species had a relatively well-defined acoustic detection radius where we could be confident that sounds detected from any of these species were more likely than not to be within the aerial survey area (Figure 61). 2) There were adequate numbers of sightings in the aerial survey database. 3) The acoustic characteristics of each species are well-defined, so there was little or no chance of confusing species calls. Fin whales fit criteria 2 and 3, but not 1, because their acoustic detection ranges (estimated 147-364 km) mean that animals producing detectable sounds could be well outside the SA. Nevertheless, because fin whales were relatively frequent visitors to the area, we conducted a comparable analysis to explore the available data. Blue whales were excluded from this comparison because they did not meet criteria 1 and 2.

Data Correlations

For each of the three whale species during the 35 months of over-lapping acoustic and sightings data in the Massachusetts WEA, *monthly acoustic presence* was correlated and regressed against the effort-weighted monthly mean sighting rate (Table 34). There are two potential sources of bias in this analysis; 1) non-vocalizing whales may reduce the observed acoustic presence, and 2) missed whales due to surfacing intervals or weather may reduce sighting rates. Nevertheless, for North Atlantic right, humpback, and minke whales, there were statistically significant positive correlations; for fin whales the correlation was negative (i.e., the two parameters tended to vary in opposite directions), but the slope was not statistically significant (Table 34).

In the regression analyses, acoustic presence (the independent variable) and sighting rate (the dependent variable) were analyzed to determine whether the relative abundance of a whale species in the study area could be predicted from acoustic monitoring. In the first round of tests, an intercept term was forced through zero (i.e., no acoustic detections means no whales present). For right, humpback, and minke whales, the slope of the regression line was positive and significantly different from 0 ($P < 0.0001$ for all three), and the r^2 values indicated that about 38–40% of sighting rates could be predicted from acoustic presence (Table 34). For fin whales, the magnitude of slope was smaller (0.0153) although still significant ($P = 0.0492$), and the goodness-of-fit was much lower ($r^2 = 0.1091$)(Table 34).

In the second round of regressions, the models included an intercept term, which meant no assumptions were made that the absence of sounds predicted an absence of sightings. For right, humpback, and minke whales, the slopes were still positive and significantly different from 0, however the intercepts were not significant and the r^2 values were all lower, i.e., less predictive.

However, for fin whales, the second regression model resulted in a much better fit. The slope was negative (–0.1007) and significantly different from 0 ($P = 0.0018$), indicating that higher acoustic presence was correlated with lower fin whale sighting rates in the study area. The intercept was also significantly different from 0 ($P = 0.0003$) - showing that the monthly fin whale sighting rate in the study area would be about 11 whales/1000 km when the monthly acoustic detection rate was zero. Since the estimated acoustic detection ranges of fin whales were all in excess of 140 km, it is likely that many of the detections originated with fin whales outside of the study area. One possibility is that fin whales sing more when offshore and beyond the study area and tend to be silent when in shallower waters over the continental shelf. There may also be a seasonal component to this as Watkins (1981 reported that most 20-Hz “song” produced by fin whales was seasonal in the winter, likely related to mating. In this case, almost no fin whales were observed in the fall and winter in the SA, indicating a movement offshore.

Table 34. Results of statistical analyses relating *monthly acoustic presence* recorded in the MA array and effort-weighted mean monthly sighting rate in the Massachusetts aerial survey stratum, for four whale species. The best regression model for each species is highlighted in red boldface.

Statistic	Whale Species			
	Right	Humpback	Minke	Fin
Correlations:				
Spearman *r*	0.6558	0.6772	0.5113	-0.2528
r^2	0.4301	0.4586	0.2614	0.0639
P^a	<0.0001	<0.0001	0.0017	0.1428
Regressions, no intercept term:				
r^2	**0.3903**	**0.3763**	**0.3974**	0.1091
slope	**0.0956**	**0.0585**	**0.0487**	0.0153
SE of *slope*	**0.0206**	**0.0129**	**0.0102**	0.0075
P^b	**<0.0001**	**<0.0001**	**<0.0001**	0.0492
Regressions, intercept term included:				
r^2	0.3129	0.2486	0.2772	**0.2600**
slope	0.1268	0.0776	0.0511	**-0.1007**
SE of *slope*	0.0327	0.0235	0.0144	**0.0296**
P^b	0.0005	0.0023	0.0012	**0.0018**
intercept	-2.7337	-1.3935	-0.1472	**11.1777**
SE of *intercept*	1.8002	1.4281	0.6116	**2.7842**
P^c	0.2358	0.3363	0.8113	**0.0003**

a. Null hypothesis being tested (H_0): $r = 0$ (no correlation)
b. H_0: *slope* = 0
c. H_0: *intercept* = 0

AMBIENT NOISE ANALYSIS

This acoustically surveyed study area shows the MA WEA and RIMA WEA as part of a dynamic ambient noise environment, with contributions originating from a diverse biological community of vocalizing cetaceans. However, some anthropogenic sound sources were also present that contributed at varying levels to the sound environment. Long-term spectrograms for each MARU are presented in Appendix G.

Spectral Trends

The power spectral density plot (Figure 62) represents the 50th percentile sound levels at each MARU site throughout the entire study period. The median percentile curves revealed that power spectrum levels above 200 Hz did not differ greatly across recording sites within the study area. Below 100 Hz, however, sites MA-5 and MA-6, which are positioned closest to the Ambrose-Nantucket Traffic Separation Scheme, a high-use shipping lane, had the highest sound levels of all sites. Sound levels at sites RI-3 and RI-1, however, recorded the lowest overall noise levels. The slight increase in power spectrum levels around 20 Hz at all sites is most likely due to the persistent 20 - Hz fin whale pulses that were recorded throughout the study period.

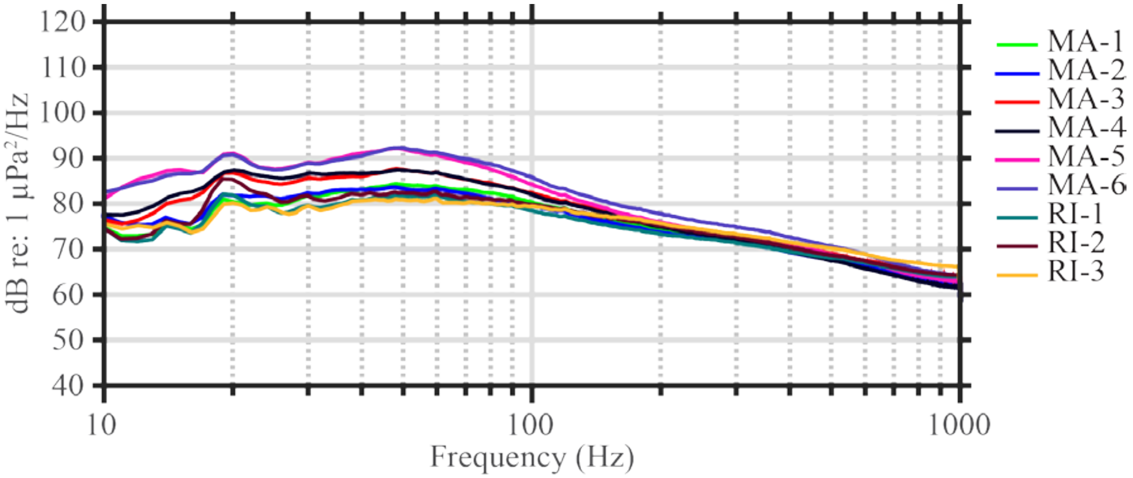


Figure 62. Power spectral density plot representing the 50th percentile power spectrum levels throughout the study period (November 2011–March 2015) for each recording site.

Cumulative Percent Distribution

The cumulative percent distribution plot of sound levels illustrates the cumulative percentage of time each site recorded sound at a specific L_{eq} value (dB re: 1μPa). Sound levels in the 70.8–224 Hz frequency band for all sites varied between 96 dB and 103 dB during 50% of the recording time between November 2011 and March 2015 (Figure 63). Here, sites RI-1 and RI-3 recorded the lowest L_{eq} values, with sound pressure levels of approximately 95 dB or less 40% of the time, and above 104 dB approximately 10% of the recording time. Sites MA-5 and MA-6 consistently recorded the loudest L_{eq} values a majority of the time, with sound levels of approximately 102 dB 40% of the time or less, and noise levels of approximately 115 dB and above approximately 10% of the recording time. Sites MA-3 and MA-4 shared similar noise trends, as did sites MA-1, MA-2, and RI-2. While this plot identified the same four sites as loudest (MA-5, MA-6) and quietest (RI-1, RI-3) as the power spectral density plot, the cumulative percent distribution plot distinguishes the recorded sound levels even further between each site by illustrating the variability in time for which sound pressure levels reach a certain value at each recording site.

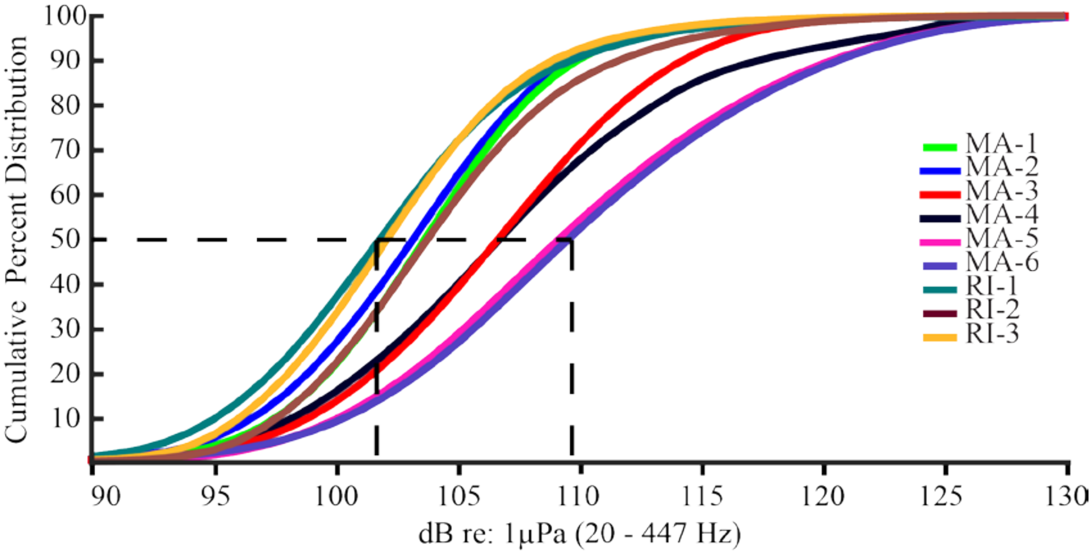


Figure 63. Cumulative percent distribution plot of sound levels (dB re: 1µPa) within a 20 - 477 Hz frequency band for each recording site throughout the entire study period (November 2011–March 2015).

DISCUSSION

This study has made a major advance of marine mammal and sea turtle distribution and abundance in a broad area south of Cape Cod and Rhode Island, in what was largely a previously unsurveyed and uncharacterized habitat. In particular, it has revealed new information on right whale habitat-use patterns, demonstrating consistent winter and spring use of portions of the SA. However, given recent changing patterns of oceanography due to a changing climate, it is likely that future marine mammal and sea turtle seasonal distribution and abundance patterns may shift. Over the last five years, changes in right whale distribution and occurrence have occurred throughout the Northwestern Atlantic. These ongoing changes argue for continued monitoring of the WEAs' marine fauna.

As renewable energy development moves into the oceans, there is concern regarding the potential impacts on marine animals and endangered species. There is no doubt that the consequences of climate change are an existential threat to ocean ecosystems, and that carbon-free energy generation is an essential part of mitigating that threat. Nevertheless, regulators are still required to assess the effects of wind facility construction and operation on the marine environment. Marine mammals and sea turtles are subject to particular scrutiny for two reasons. First, the Marine Mammal Protection Act and the Endangered Species Act, both laws unique to the United States, require special considerations that limit "taking" in both taxonomic groups, where "taking" is broadly defined to include disturbance. Second, the European experience of ocean wind facility installations does not inform the question of effects on these two groups of animals, as no endangered whales or sea turtles occur in Europeans waters with regularity.

This project embodies the proactive step of planning for an environmental assessment before development activities occur. This study was undertaken with the goal of addressing known gaps in information about the distribution and abundance of large whales and turtles, in the

Massachusetts and Rhode Island WEAs south of New England. The results show that the study objectives, to assess the seasonal distribution and abundance of marine mammals and sea turtles in these areas, were successfully met. An additional wealth of supplementary information was obtained on sharks, pinnipeds, seabirds, vessel traffic, fishing gear, ambient noise, aerial survey methods, and comparisons of acoustic and aerial survey data collection.

LARGE WHALES AND OTHER CETACEANS

A notable finding of this study was the consistent spring and summer presence of the relatively large numbers and diversity of marine mammals in the area corroborated by both survey methods. The aerial surveys collected a total of nearly a thousand records comprised of twelve different species, representing both odontocetes and mysticetes, in all seasons of the year during the study period. Six species of large whale and six species of delphinoids were observed during the study. This is consistent with the Kenney and Vigness-Raposa (2010) report, where they reviewed available sources of information on the occurrence of marine mammals and sea turtles in the waters south of Rhode Island encompassing nearby coastal and continental shelf areas. Sixteen species of cetaceans and sea turtles were categorized as common to abundant, and another six as regular. However, this survey effort over the last 4 years represents more than 5 times all previous survey effort combined within the SA, and it provides a robust baseline assessment for future comparisons.

The distributions of most endangered whales (fin, humpback, sei, and sperm whales) showed relatively widespread occurrence throughout the study area in the spring and summer. Right whales were an exception, and were present in the winter and spring, with highest sighting rates and estimates of abundance in the spring. Certainly for right whales, the high level of occurrence during the spring time periods in this area is not surprising, as they are migrating north across the mid-Atlantic bight (Hodge et al. 2015; Salisbury et al. 2016), before heading into the feeding grounds of Cape Cod Bay (e.g., Nichols et al. 2008). Fin and sei whales are present in the spring, with a slight increase in numbers during the summer. Humpback and minke whales are present in the spring, and in significantly more diminished numbers in the summer. The distributional data show a tendency for large whale species other than right whales to be farther offshore in the spring, then to become distributed more inshore and west into the RIMA WEA during the summer, with diminished numbers in the MA WEA lease areas. The acoustic data showed similar trends for all large whale species in both the seasonality of occurrence, and distribution.

Observations of feeding (in five large whale species) and courtship (two whale species), as well as sightings of 18 cow/calf pairs (four whale species), demonstrate that the area is used by some individuals from multiple species for behaviors which support species survival. Similar observations of dolphin behavior were also documented, indicating this habitat may be important to small cetaceans as well. However, given the extended temporal use of this geographical region by marine mammals, continued survey efforts can help clarify what role this habitat plays in their ecology and migratory behavior.

SEA TURTLES

Detections of sea turtles were enhanced by the application of a vertical camera for capturing and identifying smaller marine animals that occurred on the trackline under the aircraft (Taylor et al., 2014).Three species of endangered sea turtle were observed during this study. Most turtles were observed during the summer and autumn, with no significant inter-annual variability. Leatherback abundance estimates for the SA ranged from 9 to 90 during the summers and from 6 to 99 in autumn, with an apparent preference for the northeastern corner of the SA. This spatial clustering of leatherbacks is consistent with results from a concurrent tagging study on leatherbacks in the area (Dodge et al., 2014). These results suggest an important foraging habitat for leatherbacks adjacent to the northeastern edge of the MA WEA south of Nantucket. Although based on sparser survey effort, Shoop and Kenney (1992) showed a very similar concentration of leatherback SPUE just south of Nantucket.

Loggerheads were primarily seen in August and September, and did not show any significant spatial patterns other than a slight tendency to move offshore in September. The only year in which loggerheads were detected in high numbers was during 2012, which could be explained by the warm water anomaly documented in the North Atlantic that year (Mills et al. 2013). Turtles, particularly leatherbacks and loggerheads, use this area consistently from year to year.

NORTH ATLANTIC RIGHT WHALES

Historically, right whales have been regularly reported off of southern New England, where they were targets of whaling beginning early in the colonial era. Reeves and Mitchell (1986) summarized the available information on shore whaling for right whales in southeastern Long Island, New York, from 1650 to 1924. Whaling was seasonal, from early winter to May with a peak in April. More recently, an aggregation of feeding right whales that persisted for about two weeks was seen just east of Block Island in April 1998. The whales were first seen by fishermen, who reported their observations to the R.I. Division of Fish & Wildlife (RIDFW), who then passed on the reports to NMFS. A NMFS survey aircraft, on the 19th of April, saw at least 16 whales feeding at and just below the surface (Kenney and Raposa, 2010). Further, in 2010, the year before this study started, a NOAA survey crew sighted 96 right whales on April 20th in five separate aggregations—three in Rhode Island Sound, one more offshore over the inner shelf, and one at the entrance to Vineyard Sound (Kenney and Raposa, 2010).

During the NLPSC surveys North Atlantic right whales were consistently detected by observers in the study area during the winter and spring seasons. Based solely on aerial survey detections, it appears that right whales begin to arrive in the SA in December and remain in the area through April. Acoustic detections of right whales occurred during all months of the year, although the highest number of detections typically occurred between December and late May. In this way, the acoustic data collected aligns with the aerial data collected. The winter distribution of right whales sighted in and around the SA appears to be found primarily in the northeastern section of the study area, near Nantucket, and mostly outside of the WEAs. By spring, right whales are distributed across the northern portions of the SA and WEAs, and hot spot analyses indicate that consistent aggregations of right whales occur in the RIMA WEA, in the Northwestern section of the MA WEA, and in the eastern part of the SA. Although there is variability in right whale distribution patterns among years, and some aggregations appear to be ephemeral, the hot spot analysis suggests that there is some regularity in right whale use of this region when averaged over several years of consistent effort (October 2011 -June 2015). Thus right whale aggregations in the SA are markedly seasonal, although the acoustic data suggest year-round visitations by scattered individuals travelling through the area. The marked seasonality of right whale occurrence in the area is likely due to food, as the behavioral data suggest that animals observed before April and May are sometimes engaged in social behavior, whereas during those two months, feeding is the dominant behavior. The seasonal and inter-annual distribution shifts of right whales are likely to be food related, however the lack of oceanographic and prey data hinders our attempts to understand why they are occurring. Determination of the ecological characteristics of this habitat that could be used to predict right whale distributions will require systematic oceanographic sampling (Pendleton et al., 2012).

Abundance point estimates for right whales in the SA ranged from 4 to 35 with confidence intervals from 0 to 296, and these estimates tended to be higher during the spring. Individual survey counts (e.g., 44 animals from Spring 2015) exceed the highest point estimate for that season (23) because abundance point estimates are derived from "on-transect" sightings data, and many whales are seen and photographed after the aircraft breaks from track to investigate sightings. Further, due to long dive times, it is relatively common for multiple right whales to be submerged in the vicinity of the single observed right whale. Further, none of the abundance estimates are corrected for perception bias (i.e., animals on the track and available but simply missed), or availability bias (animals missed because they were diving). The correction factors for the CETAP (1982) surveys were 2.997 for right whales, 3.645 for humpbacks, and 4.846 for fin whales. Kenney et al. (1995) used the fin whale factor for sei, minke, and sperm whales. Thus for all of these analyses, while the point estimate is a good statistical guess of abundance, it likely substantially under-represents the actual number of right whales in the SA. It is not possible to parse these estimates into subsets of the WEAs in order to provide lease site-specific estimates of whale abundance for any species. This is because the estimation procedures require a minimum number of sightings in any area to be reliable, and subset of the transect data from any single lease zone would be inadequate.

Photographic analysis of individual right whales observed in these surveys alone yielded a total count over the study period of 77 individual right whales, some of which were seen multiple times over several of the survey years. The NLPSC was not the only effort in the SA that produced right whale demographics data. Other right whale sightings were collected opportunistically and by occasional National Marine Fisheries Service (NMFS) surveys during the last five years. A comprehensive view of these sightings showed that 202 individuals (which include the 77 NLPSC detected individuals) were recorded in the SA. The annual average number of individuals observed in the SA between 2010 and 2015 was 42. This complete subset of identified animals (n = 202) represents 41% of the current population that is presumed alive (M. Zani, New England Aquarium, pers. comm.; NARWC Catalog, 2014). Demographic analyses of the NPLSC survey data indicate that the area is being used by every age, sex, and reproductive class within the population; including a high percentage of reproductive females. Although no cows with calves were observed during the NPLSC surveys, reports from other sources indicate that ten cow/calves have been observed in the SA over the last 5 years (NARWC Report Card, 2011-2015). Climate change may be shifting right whale distributions to the northern portion of their range, and there have been two records of right whales calving in the winter around Cape Cod in the last decade (Patrician et al., 2009; R. Asmutis-Silva, Whale and

Dolphin Conservation, pers. comm.). It is difficult to predict how climate-induced ocean changes will continue to influence the distribution of calving females.

The North Atlantic Right Whale Consortium (NARWC) catalog and sightings databases contain over 35 years of data on right whales (Hamilton et al., 2007), which have provided information on population growth and demographics, as well as the effects of human activities on health and mortality (Schick et al., 2013; Robbins et al., 2015; Rolland et al., 2016). Until 2008 when NMFS regulated shipping speed in right whales habitats, the leading causes of mortality in right whales were collisions with ships and entanglements in fishing gear (Van der Hoop et al., 2013). Since then, deaths from U.S. vessel strikes have nearly ceased (Laist et al., 2014; Van der Hoop et al., 2015). However, entanglement rates continue to increase in severity (Knowlton et al., 2012; Van der Hoop et al., 2013), with no evidence that current fishing regulations have reduced mortality (Pace et al., 2014). Further, sub-lethal entanglement effects on health cause reproductive failure and declining health long after the entanglement is over (Rolland et al., 2016; Van der Hoop et al., in press).

Until 2010, this population was growing at 2–3%/year. However, since then it appears that this growth has stopped, and the NMFS minimum number alive model shows a population decline (NARWC Report Card, 2015). These factors indicate this is a whale population still vulnerable to chronic fishing entanglements, acoustic disturbance, and other human activities, and care to minimize the any additional cumulative effects in their habitat will be critical to their long-term survival.

AERIAL/ACOUSTIC COMPARISON

The aerial data provided species-specific estimates of abundance, and detailed information about distribution, behavior, and demographics, but were periodically limited by wind and visibility conditions. The acoustic data provided long-term monitoring of the presence of multiple species independent of visual survey constraints, but could not provide assessments of abundance, behavior, or demographics. We compared the acoustic detections and sightings data within the MA stratum of the SA, in order to use the most comprehensive data to determine if the two data streams were consistent, or if there were differences that would be valuable for assessing whale occurrence in the SA.

For right and minke whales, detection ranges indicated that those whales heard on the MARUs were almost certainly within the survey area, and therefore available for detection. Humpback acoustic detections were likely produced by whales within the SA 63% of the time. The comparison analysis for those three species showed statistically high ($p < 0.0001$) levels of correlation between the monthly acoustic presence (the number of days a whale was acoustically detected/the total number of days with recorded sound) and the effort-weighted mean monthly sighting rate. The analysis showed that 38% to 40% of the sightings data could be predicted from the acoustic data, and suggests that the two data streams were largely consistent with one another. Because sounds of finback whales were detectable at ranges well beyond 100 km, comparisons of the acoustic and sightings data for assessing the presence of those species within the SA was challenging. The fin whale sightings and acoustic data were negatively correlated—when sightings were made, fin whales tended to be quiet. This surprising finding may indicate that fin whales are silent when in shallower shelf waters, and sing more when offshore in deeper water (also where low-frequency sounds carry farther).

It appears that the high correlations between the number of animals and the number of acoustic detections was largely influenced by the days on which there were both high numbers of sightings and detections. This finding does suggest that the two data streams are reasonable proxies for one another in the context of periods when whales are abundant. In other words, if there are many whales (of rights, humpbacks, or minkes), there will be many calls, and vice versa.

In addition to providing complementary data streams on marine mammals in the SA, the combined use of acoustic and enhanced aerial survey methods generally confirmed the temporal occurrence and abundance patterns documented by each for right, humpback, and minke whales. The use of these methods is dependent upon species specific detection distances and capabilities by either observers or listening devices. Generally, aerial survey data provides good information on abundance and distribution, and acoustics provide occurrence, or presence data that covers the inevitable gaps in survey data, which are always limited by weather and other factors.

RECOMMENDATIONS

1) The seasonality and spatial distribution of marine mammals in the area suggests that seasonal and spatial management of survey and construction activities should be considered for implementation during environmental review and permitting.

2) The long-term impacts of wind farm installations should be carefully assessed to understand the consequences of such development on marine mammal and sea turtle distribution, abundance, behavior, and communications. Using this study as a baseline, a long-term study on potential displacement and disturbance should be designed and implemented. It will require comparable, but targeted surveys both during construction and after full operations have commenced to answer the questions about wind farm effects on large whales and sea turtles.

3) Special attention should be paid to right whales in the SA. Their occurrence in the region was poorly known only a decade ago, and the reasons for their occurrence and distribution here are still subject to speculation. This study suggests a substantial number of them are regular visitors, and that the habitat may be more important than recognized.

4) We recommend some focused oceanographic studies in the SA, in order to interpret the occurrence of endangered whales in the SA. Most importantly for future wind farm development, it will be important to separate two hypotheses. One, do wind farms alter the acoustic or physical characteristics in ways that cause displacement of whales to other areas? Two, are whale distributions food dependent, and the changes in distribution and/or behavior are due to changes in prey species in the area? Distinguishing between these two hypotheses will be important in the context of managing future development.

5) Related to the oceanographic issues above, ongoing climatological changes argue for continued monitoring of the WEAs' marine fauna, as it will be important to determine the underlying causes of any observed changes to come.

6) Electromagnetic fields created by underwater power cables should be assessed for their effects on turtles. Loggerheads have been shown to use geomagnetic fields to navigate and Leatherbacks likely employ similar mechanisms. Since Leatherback turtle survival in the Atlantic is likely dependent on important foraging areas, and we identified a hotspot for this species near Nantucket shoals, this may be important.

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The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under US administration.

The Bureau of Ocean Energy Management

As a bureau of the Department of the Interior, the Bureau of Ocean Energy (BOEM) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS) in an environmentally sound and safe manner.