FIELD SURVEYS OF WHALES AND SEA TURTLES FOR OFFSHORE WIND ENERGY PLANNING IN MASSACHUSETTS

2011-2012

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Abstract

To assess the distribution and abundance of marine mammals and sea turtles in the Massachusetts Wind Energy Study Area (MA WESA), aerial survey and passive acoustic methods were used. We chose to use a multi-pronged approach for this assessment, including aerial surveys with new vertical photographic capabilities to enhance data collection on sea turtles and dolphins. In addition, because weather can ground aerial surveys for extended periods, continuously recording underwater acoustic-recording devices were deployed for most of the year to detect large whale presence throughout the survey area. Although not all large whales vocalize, many do, and the underwater recording effort provided an additional independent data stream on large whales. The NEAq and PCCS conducted aerial surveys over the MA WESA and surrounding waters for whales and sea turtles from 9 October 2011 to 17 September 2012 twice a month, weather permitting. The Cornell University Bioacoustics Team placed Marine Autonomous Recording Units (MARUs) at 6 locations within the MA WESA on 9 November 2011, which recorded any anthropogenic and biological sounds (including large whale sounds) passively and continuously (with a single day swap-over break) through 3 October 2012.

The aerial surveys recorded right, humpback, fin, minke, sei, and sperm whales during the year. The bulk of these large whale sightings occurred in the period from March through June, with scattered sightings at other times of year. The surveys also recorded leatherback, loggerhead, and Kemp's ridley sea turtles. Most sightings of sea turtles occurred in the late summer, primarily August and September. A wide diversity of delphinids and one phocoenid were observed, including bottlenose, white-sided, common, and Risso's dolphins, pilot whales, and harbor porpoise.

The acoustic study detected at least 7 large whale species, including right, fin, minke, humpback, blue, sei, and sperm whales. The presence of these species varied over time, but vocalizations were generally detected more often during the winter and spring months. These data indicate that all of the large whale species known to occur within the temperate waters of the western North Atlantic Ocean can be detected from subsurface hydrophones deployed within the MA WESA, indicating that this area is frequently used and may be ecologically important for these species.

This report is divided into three sections: 1) Executive Summary, 2) Aerial Surveys for Marine Mammals and Sea Turtles, and 3) Passive Acoustic Monitoring for Marine Mammals. Appendices are attached.

Section 1. Executive Summary

The development of offshore alternative energy sources is an essential part of the U.S strategy for energy independence. However, such development requires comprehensive assessments of biological resources in suitable energy areas, to identify and mitigate any potential effects of that development on wildlife and fisheries. Here we report on a one-year assessment of the spatial and temporal patterns of marine fauna occurrence (with a particular emphasis on large whales and sea turtles) in the Massachusetts Wind Energy Area (MA WEA) and surrounding waters south of Martha's Vineyard.

A pre-assessment evaluation of survey data collected in the region over the previous 30 years revealed that little systematic work had previously been done in the MA WEA. The study area is somewhat larger than the MA WEA and is called the MA Wind Energy Study Area in this report (MA WESA). This one-year study included 24 aerial surveys and 11 months of continuous underwater acoustic recording to assess the presence of large whales in the gaps between the surveys. We collected three primary data streams for this assessment: traditional aerial surveys using standard visual observation methods, vertical photographic sampling during the aerial surveys, and in-water passive-acoustic monitoring. The vertical imagery greatly enhanced data collection on sea turtles and dolphins, and also provided a wealth of information on sharks, fish, and fixed fishing gear. Underwater recording acoustic devices were deployed for most of the year to detect vocalizing large whales not visually detected by the aerial surveys. The aerial surveys from this year resulted in more than a tenfold increase in survey effort in the area compared to previous surveys for marine mammals and turtles in the last 30 years combined

In the aerial survey analyses with relatively uniform survey coverage, raw sighting data are an appropriate metric for distribution. Over the longer term, and with a variety of data collection platforms, sightings per unit of effort (SPUE) analyses and density estimates are appropriate methods for assessing distribution and abundance of the surveyed area. However, because a single year of surveys represents a snapshot, not an average, we have little confidence in the distribution patterns. Likewise, for density estimations, there were an inadequate number of sightings to estimate density for all species except leatherback and loggerhead turtles; basking, blue, and dusky sharks; and ocean sunfish. We are hopeful that the second year of surveys will provide us with enough sightings data to estimate effective survey strip width, and to then calculate density estimates for the more abundant species, including several of the large whales.

The aerial surveys recorded six large whale species during the year: right, humpback, finback, minke, sei, and sperm whales. The majority of these large whale sightings occurred in the period from March through June, with scattered sightings at other times of year. From the acoustic effort, the presence of seven large whale species was verified from known vocalizations: right, fin, sei, minke, humpback, blue, and sperm whales. The acoustic detections of these species varied over time, but vocalizations were generally detected more often during the spring and winter months. The acoustic data indicate that many of the large whale species known to occur within the Western North Atlantic Ocean were detected from subsurface hydrophones deployed within the MA WESA. The aerial data confirm the presence of 6 of these species in the area.

The right whales observed in the survey area included 24-28 individuals, 18 of which have been identified. The identified whales included 5 females (3 known to be reproductive females), 10 males, and 3 whales of unknown sex. Activities observed included surface active groups (a behavior associated with mating), feeding, breaching, flipper slapping, and travelling. Based on NEAq catalog data, nine of these whales were observed in the same year in the southern Gulf of Maine, including several that appeared to be going back and forth between Cape Cod Bay, the Great South Channel, and the MA WESA. From Nov 2011 to Oct 2012 right whales used the MA WESA, primarily in the spring for feeding and social behavior.

The aerial surveys recorded leatherback, loggerhead, and kemps ridley sea turtles. Most sightings of sea turtles occurred in the late summer, primarily August and September. A wide diversity of delphinids and one phocoenid were observed, including bottlenose, Atlantic white-sided, common, and Risso's dolphins, pilot whales, and harbor porpoise. Delphinids were observed throughout the year and the area, although warmer water animals (common dolphins) were seen primarily in the late summer. Pilot whales and Risso's dolphins (which have been known to travel together) were seen primarily in the spring, and harbor porpoise were observed from late fall to early spring. Because these sightings are collected from a single year, any patterns of distribution or seasonality must be interpreted with caution.

In the acoustic data, the specific locations of vocalizing whales were not determined, although in some cases their general location can be estimated. In the case of right whales, enough detailed information was collected to demonstrate that right whales were more commonly found at or near site M02, in the northeast corner of the MA WESA. The fin whale and humpback whale vocalizations were loudest at sites M05 and M06, indicating that the vocalizing individuals were positioned farther offshore, in deeper water.

Different marine mammal species have different acoustic signals, and there are also multiple physical variables that can affect the actual detection ranges (Marques et al. 2012) (e.g. source levels, frequency, source level and depth of vocalizing whale, sound speed profiles, bathymetry). Therefore, we did not measure the detection range of the MARUs; instead we used the estimated detection ranges available in the literature. We estimate that the right whales can be detected by a MARU up to approximately 25 km away (Laurinolli et al. 2003). In the case of fin whales and blue whales, species whose calls propagate for long distances (Payne & Webb 1971; Širovic et al. 2007), individuals could have been vocalizing either near the array, or up to tens or hundreds of kilometers away. Using estimates of the detectable ranges for humpback and minke whale vocalizations found in the literature ((Marques et al. 2012), we estimate that the humpback and minke whale calls could have originated from up to 12 km to 25 km from the nearest MARU, respectively.

In both aerial and acoustic data, right, minke and humpback whales showed somewhat similar seasonal trends, with maximum occurrences in the spring (March and April) (Figure E1). In all three of these species, their calls are relatively short-range (<25 km), so we expect their acoustic presence to match well with the sightings records. In the case of fin whales, acoustic data showed a consistent occurrence of fin whale vocalizations throughout the year, although with a decline in early summer (Figure E1). This is in contrast to the aerial survey data, in which most fin whales were observed in the spring and early summer. Because fin whale vocalizations are very low frequency and may be detected several hundred km away, this disparity between sightings and acoustic detections is not surprising. Fin whale vocalizations are associated with mid-winter mating. It is possible the MARUs detected an offshore aggregation of calling fin whales, which then moved onto the shelf and into the MA WESA in late spring. Finally, the acoustic presence of blue whales was detected only in

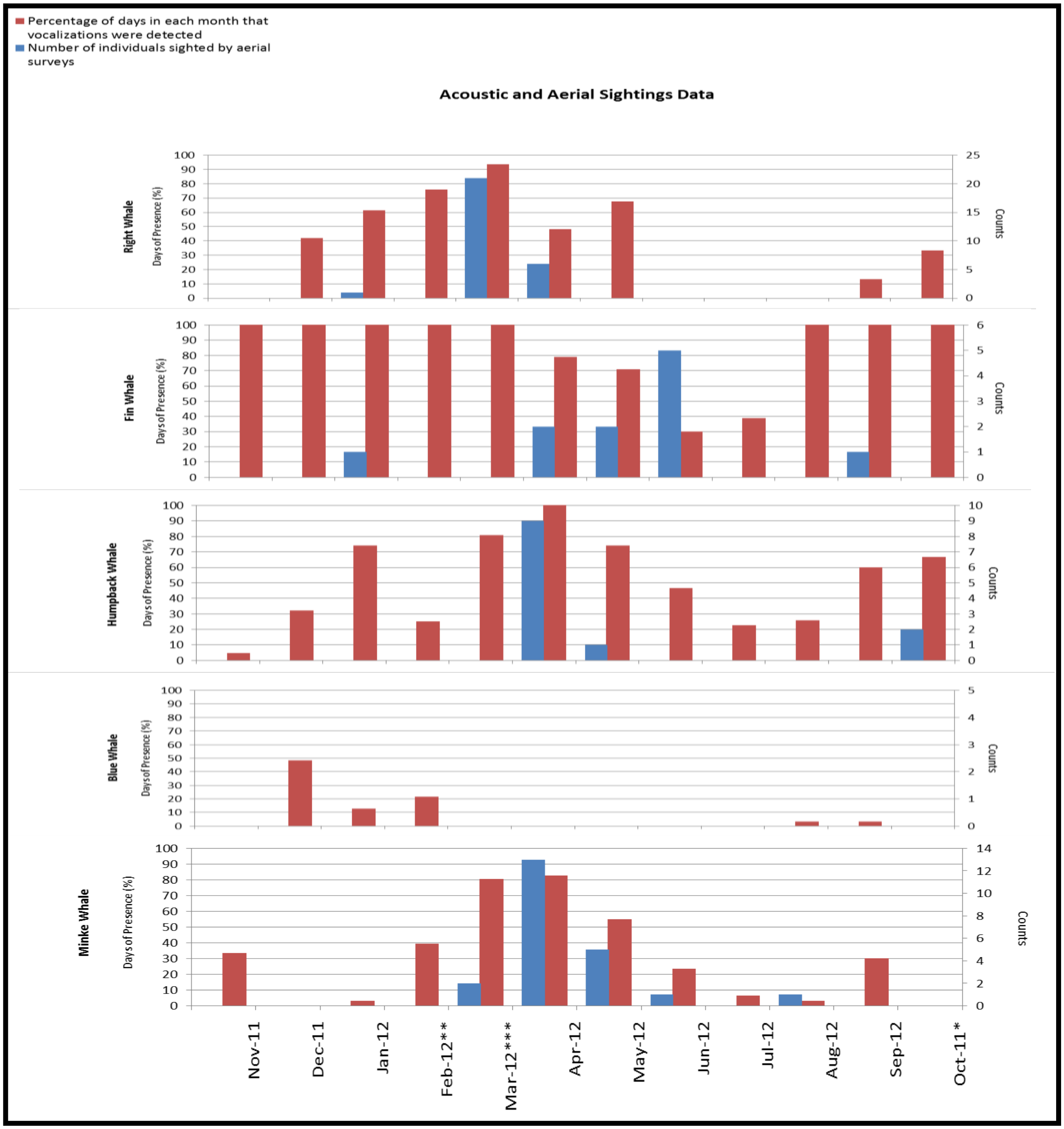

Figure E1. Comparison of the large whale sightings and acoustic data collected during the NPLSC study October 2011-September 2012. * October 2011 has been placed at the end of the horizontal axis for comparison sake but we are comparing the same month between different years (Oct 2011 aerial data and three days of acoustic recordings in Oct 2012). ** Only one flight was flown in February. *** Three flights were flown in March.

winter (December-February) and late summer (August and September), although no sightings were recorded by the aerial survey team (Figure E1). This species' vocalizations probably travel farther than any other whale (up to a 1000 km), so the detections may be attributed to animals at some distance from the MA WESA. Thus, this result shows that a combined acoustic and sightings survey approach can yield a more comprehensive picture of whale occurrence in and around the MA WESA.

The ambient noise analysis of the MA WESA area showed temporal and spatial variability. Changes in the relative sound levels at 50 Hz (a frequency consistent with noise produced by shipping traffic) across the MARU array indicates that shipping activity occurred nearest to MARUs in the southeast region of the area. The decreased ability of animals to detect sounds made by conspecifics due to loud noise in a species communication band is otherwise known as masking (Hatch et al. 2008). Due to the proximity of shipping traffic, masking in the low frequencies (where many whales produce sounds) may result in an under-representation of whale calls in the MA WESA.

The data from this study reveal seasonal patterns of occurrence for five whale species over an 11-month period. Both aerial and acoustic data are largely in agreement about the occurrence of the most abundant large whale species. The varying patterns of occurrence between species suggest that differing environmental factors may be driving whale presence. Future comparisons of the acoustic and aerial survey data collected in this study with environmental factors such as prey species and ocean temperature could provide valuable information in understanding and predicting whale behavior and occurrence.

The ambient noise analysis from this study demonstrated that the MA WESA recording area is a biologically rich marine environment, with relatively moderate anthropogenic noise levels from shipping and other activities. High levels of ambient noise from anthropogenic activities can also contribute to masking of marine mammal communication (Clark et al. 2009), potentially resulting in behavioral and physiological stress responses (Kight & Swaddle 2011; Rolland et al. 2012). Future studies on how increases in anthropogenic activity can affect ambient noise and marine mammal presence will be important to inform future resource management decisions in the MA WESA.

A single year of acoustic and survey assessment data, as rich as it appears, provides only a preliminary biological characterization for the MA WESA. Inter-annual variability, both spatially and temporally, can be high in mobile upper trophic level animals, and multiple years of survey effort are needed to understand and develop any confidence in averages and/or trends of marine animal distributions. This is particularly true for marine mammals (e.g., Baumgartner & Mate 2003; Keiper et al. 2005). In addition, the high levels of variability in the New England marine ecosystem (particularly temperature) over the last 5 years make this caveat especially important when reviewing the results of this single year survey.

Section 2: Aerial Surveys for Whales and Sea Turtles for Offshore Alternative Energy Planning in Massachusetts

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INTRODUCTION

In December 2010, the Federal Bureau of Ocean Energy Management (BOEM) issued a Request for Interest (RFI) from industry on offshore wind-energy development in the waters off southern Massachusetts. The initial area was revised in response to comments from key stakeholders and the public, including environmental organizations, scientists with expertise in the area, and commercial and recreational fishermen. The BOEM Massachusetts Renewable Energy Taskforce was created to facilitate communication amongst federal, state, local and tribal governments regarding renewable energy activities on the Outer Continental Shelf (OCS). The taskforce serves as a forum to identify and address stakeholder issues, exchange data pertaining to biological and physical resources, and human uses in order to inform renewable energy leasing and development activities, and facilitate an ongoing dialogue throughout the leasing process.

The expanse of OCS federal waters under consideration lies approximately 12 nautical miles (nm) south of Martha's Vineyard and Nantucket, extending 33 nm southward to the 60-meter depth contour, with an east/west extent of 47 nm, and a total area of approximately 877 square nautical miles (3,009 square kilometers). In February 2011, the Massachusetts Clean Energy Center (MassCEC) and the Executive Office of Energy and Environmental Affairs (EEA) requested proposals for field survey work to characterize marine resources in this Wind Energy Area south of Massachusetts (MA WEA).

Determining spatial and temporal patterns of marine fauna occurrence in the MA WEA is a critical first step in understanding any potential effects that wind farm development might have on the behavior and ecology of resident or migratory species of marine mammals, sea turtles, and birds (see Appendix 1 for a list of species). In August 2011, MassCEC awarded the New England Aquarium (NEAq) and the Northeast Large Pelagics Survey Collaborative (NLPSC—including Cornell University, University of Rhode Island, and the Provincetown Center for Coastal Studies (see Appendix 2 for a list of acronyms) a contract to collect year-long sightings and acoustic data on large whales and turtles in the MA WEA (see Appendix 4 for a list of all collaborators).

Under the National Environmental Policy Act, Federal agencies are required to develop environmental assessments of impacts from proposed actions. Under the Marine Mammal Protection Act and the Endangered Species Act (ESA), many species that occur in the MA WEA have special legal protections. Understanding the distribution, abundance, and seasonality of endangered whales and sea turtles is critical to developing operational plans for different stages of wind farm development, and to inform mitigation planning to minimize potential impacts. In particular, the Massachusetts Renewable Energy Task Force identified the need to address potential impacts of acoustic disturbance on marine mammals, and the importance of continued study of marine species and habitats in the MA WEA.

Large mysticete (baleen) whales that frequent offshore waters of southern New England include the fin, sei, North Atlantic right, humpback, and minke whales, with occasional sightings of blue whales and at least two records of Bryde's whales (CETAP, 1982; Galagan et al., 2010; Kenney and Vigness-Raposa, 2010; Lagueux et al., 2010). Of these, the blue, fin, sei, humpback, and right whales are endangered under the ESA. Of particular concern, approximately 500 North Atlantic right whales survive today (Pettis, 2012). There are several known right whale feeding habitats in the Gulf of Maine: Cape Cod Bay, the Great South Channel, Jordan Basin, the Bay of

Fundy, and Roseway Basin (Cole et al., in press; Hamilton et al. 2007). However, pregnant female right whales may pass near or through the MA WEA en route to the calving grounds off the southeastern U.S. in late fall, and when they return north with newborn calves after the winter. Further, occasional "hotspots" of right whale activity have occurred south of Cape Cod and near the MA WEA in the spring, possibly due to feeding opportunities (Kenney, 2010). In general, right whale movement patterns in southern New England waters during the winter and spring months remain unknown.

Sea turtles regularly found in the northeastern United States waters include the loggerhead, leatherback, Kemp's Ridley, and green turtle, with occasional reports of hawksbill turtles from stranding records (Lazell, 1980; Shoop and Kenney, 1992; see review in Kenney and Vigness-Raposa, 2010). Leatherbacks, Kemp's ridleys, and hawksbills are classified as endangered under the ESA and western North Atlantic loggerheads are classified as threatened. Green turtles are classified as threatened at the species level, however the Florida nesting population is considered to be endangered.

To assess the distribution and abundance of marine mammals and sea turtles in the Massachusetts Wind Energy Area (MA WEA), aerial survey and passive acoustic methods were used. The study area was expanded to cover areas around the MA WEA, and is called the MA Wind Energy Study Area in this report (MA WESA) We chose to use a multi-pronged approach for this assessment, including aerial surveys with new vertical photographic capabilities to enhance data collection on sea turtles and dolphins. In addition, because weather can ground aerial surveys for extended periods and currently can only be conducted during daylight hours, continuously recording underwater acoustic-recording devices were deployed for most of the year to detect large whale presence throughout the survey area. Although not all large whales vocalize, many do, and the underwater recording effort provided an additional independent data stream on large whales independent of aerial surveys. The NEAq and PCCS conducted aerial surveys over the MA WESA and surrounding waters for whales and sea turtles from 9 October 2011 to 17 September 2012 twice a month, weather permitting. The Cornell University Bioacoustics Team placed Marine Autonomous Recording Units (MARUs) at 6 locations within the MA WESA on 10 November 2011, which recorded any anthropogenic and biological sounds (including large whale sounds) passively and continuously (with a single day swap-over break) through 3 October 2012. This report summarizes the methods and findings of both the aerial surveys and the acoustic surveys.

METHODS

Assessing the seasonal distribution and abundance of marine animals is difficult, as animals can be sparsely distributed over large areas of ocean, or they can be highly aggregated in small portions of a large survey area. To minimize the effects and biases that result from such variable conditions, we used a combination of aerial observer surveys, vertical photographs, and acoustic methods to collect data on the distribution, abundance, and seasonality of large whales and sea turtles in the study area. The integration of data from the aerial, photographic and acoustic surveys overcame the limitations of each method if used alone. Aerial surveys can sample for marine mammals and sea turtles, but are weather and daylight dependent, and sighting detectability of the different species varies widely. Acoustic data monitoring is independent of weather and availability of light, but cannot detect turtles because they do not produce sounds. For large whales, acoustic monitoring is effective for detecting whale occurrence, but is not for estimating animal density (Clark et al. 2009), and may not be effective for certain demographic groups, e.g., mothers and calves. Therefore, this combination of data provides the presence or absence of calling whales throughout the year, spatial and seasonal information on whales and turtles during survey and photographic effort, demographic information on right whales and preliminary data on "biological hotspots".

Study Area

The MA WEA is located in the Nantucket Shelf Region, which includes Vineyard Sound, Nantucket Shoals and the continental shelf south of Martha's Vineyard and Nantucket (Figure 1). The study area (MA WESA) was expanded to include a substantial buffer around the MA WEA, and is shown in Figure 2. Two areas in addition to the main survey area were also surveyed: Muskeget Channel and the Northeast Offshore Renewable Energy Innovation Zone (NOREIZ), both of which are potential sites for tidal energy generation (Figures 1 and 3). This coastal shelf region is a dynamic transition zone between the cold waters of the Gulf of Maine to the north, and the warmer waters of the middle Atlantic and Gulf Stream to the south. It includes water depths from 10 to 225 ft, and the distance to shore ranges from 15 to 80 miles. The survey lines were spaced approximately 7 nm (13 km) apart to best cover the MA WESA in a single day (an example survey is shown in Figure 4). A full survey flight covered approximately 314.5 nm (582.5 km), and included eight transect lines of 37 nm (68.5 km) each, plus the Muskeget Channel and NOREIZ areas. Lengths of the Muskeget and NOREIZ transect lines were 10.5 nm (19.4 km) and 8 nm (14.8 km), respectively. This report includes sightings and survey data from the entire survey area, of which the MA WEA is a smaller subset. For reference purposes, the Rhode Island Wind Energy Area (RI WEA) is shown on Figure 1. Although the RI WEA was not surveyed in the work described here, it is being surveyed in Year 2 of these surveys, and will be included in the next years report.

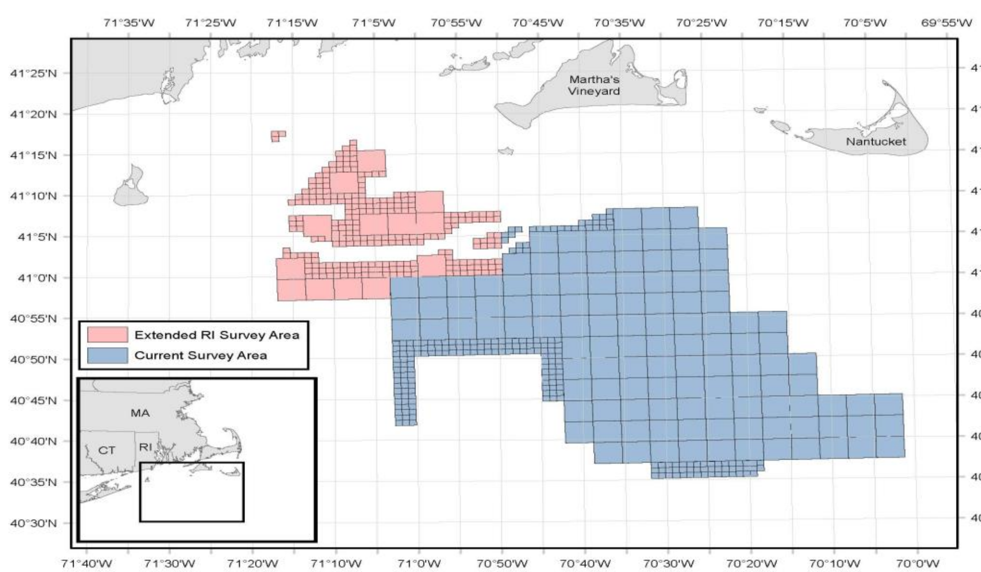

Figure 1. Massachusetts Wind Energy Area (MA WEA) is shown in blue. The Rhode Island Wind Energy Area is shown in red. Although the surveys and results described in this report focused on the MA WESA, southeastern portions of the RI WEA were surveyed, and 2013 surveys have been expanded to cover the entire RI WEA.

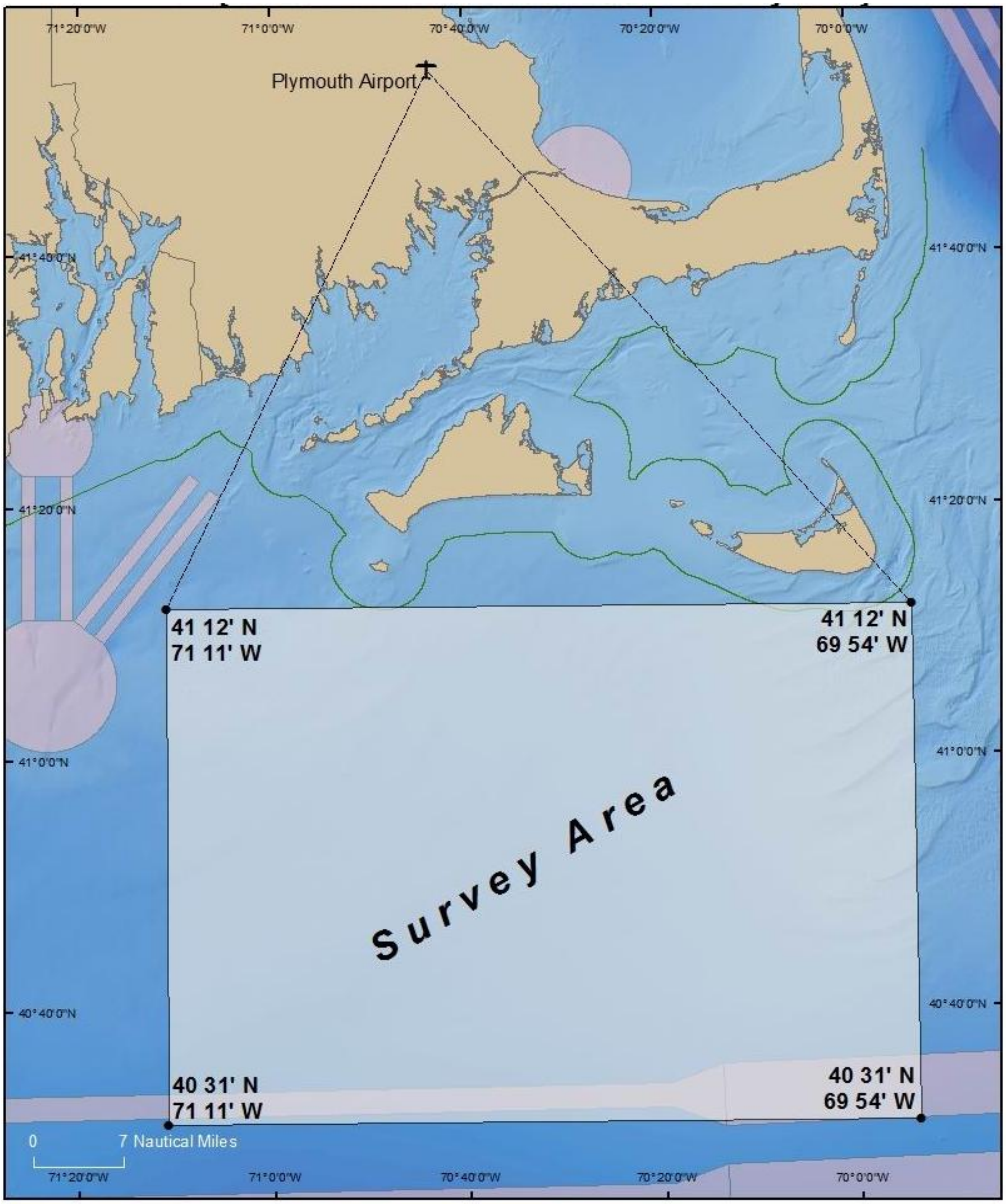

Figure 2. Entire MA Wind Energy Study Area (MA WESA)

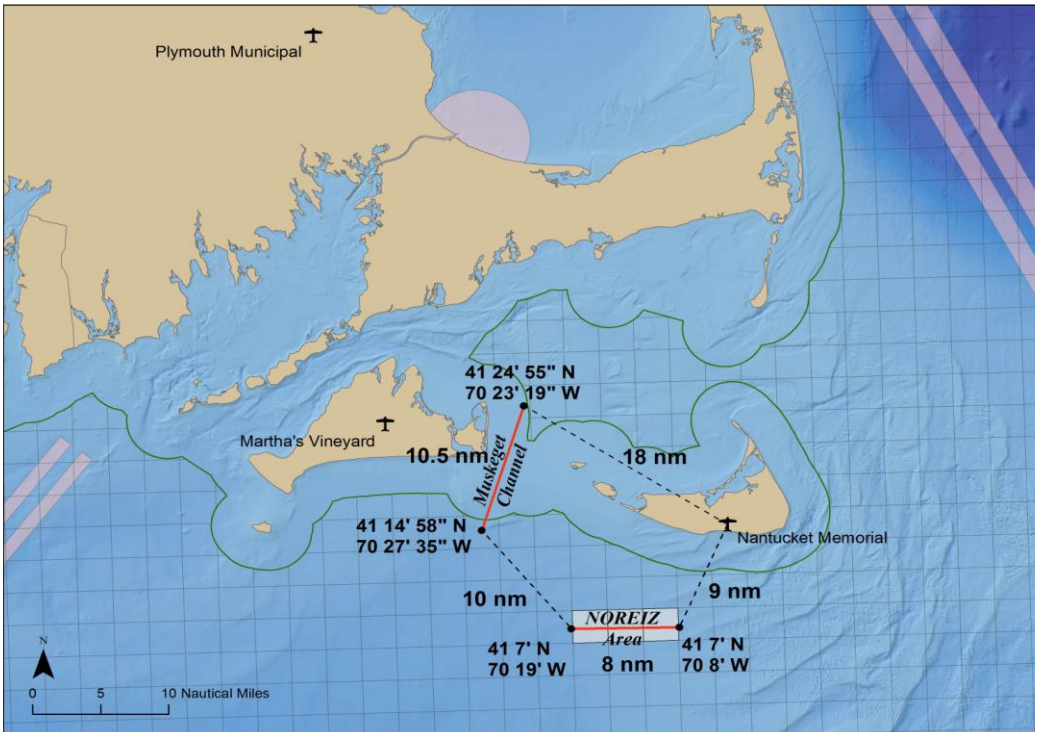

Figure 3. Additional Alternative Energy Areas of Interest

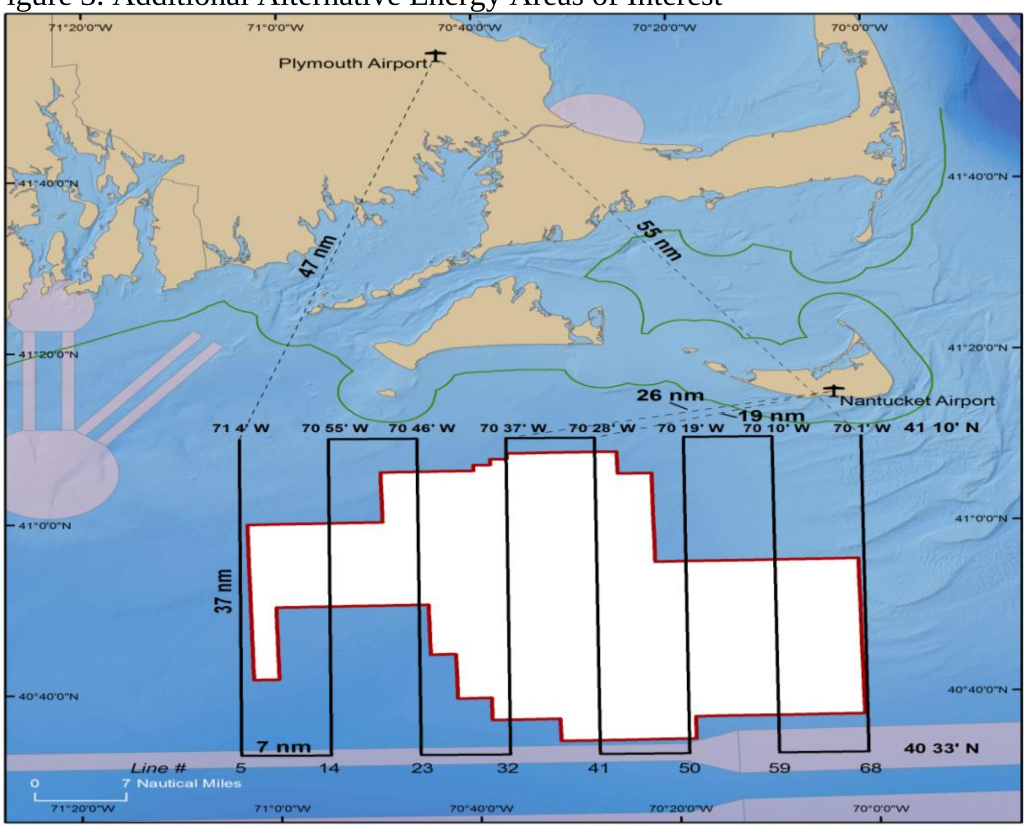

Figure 4. Example of aerial survey tracklines with the MA WEA shown in white .

Aerial Surveys

Aerial surveys were conducted on average twice per month in the MA wind energy survey area (MA WESA) (Figures 1 and 2). Surveys were flown in a Cessna O-2A Skymaster, an aircraft with high wings and centerline configured twin engines, making it an appropriate platform for large whale surveys. The O-2A model has an existing camera port in the belly that needed minimal structural modification for the use of vertical photography equipment, and has an operational flight range of 6.5 hours. Flight operations for any NLPSC survey were not permitted to extend beyond 45 minutes reserve fuel at 120 knots at sea level, and the aircraft was required to be over land one hour before sunset.

The aircraft was based out of Concord, New Hampshire, and the flight base of operations for surveys was Plymouth, Massachusetts, Municipal Airport, where the flight crew convened on the day of a survey. The NLPSC team monitored weather forecast websites consistently for suitable flight conditions in the survey area, and the pilots additionally monitored conditions for the transit between Concord and Plymouth. Surveys were flown under visual flight rules (VFR), and necessary flight conditions included a minimum ceiling of 2,000 feet (610 m), and visibility greater than 5 nm (9 km). Preferably wind speed was less than 10 kts with a Beaufort sea state of less than 3, although wind direction and swell were factors in assessing suitable sighting conditions. Survey crew were on stand-by to fly every day of the year except for four holidays (Christmas Day, New Year's Day, July 4th, and Thanksgiving). Necessary routine maintenance procedures were planned around periods of poor weather whenever possible. Prior to an anticipated flight, all survey crew were alerted at least 24 h beforehand, and placed on stand-by. Scheduled time of take-off from Plymouth depended on sunrise and sunset times.

All flight crew were certified in safety and emergency egress training within the previous five years, and safety equipment was provided in accordance with the NOAA Aircraft Operations Center's safe-operating standards. The aircraft was equipped with a GPS, full IFR instrumentation, VHF marine and aviation radios, noise-reduction intercom headsets, life raft, PFDs, a medical kit, a waterproof VHF marine radio, a portable EPIRB, and an aircraft mounted ELT. Automated flight following (spidertracks.com) was activated and monitored by the ground contact during each survey flight to allow ground team members to track the aircraft's location in near-real-time (2-minute lag). Coast Guard Sector Southeastern New England was hailed periodically every 15 to 60 minutes in-flight by observers on the marine radio to provide position updates. Pilot-in-command (PIC) and second-in-command (SIC) sat forward. The two observers sat directly aft, scanning with the naked eye and using binoculars to confirm sighting cues.

In order to adopt best safety and scientific practice, it was necessary to coordinate closely with various state and federal agencies and research organizations operating in the area. An initial email was distributed to interested personnel prior to commencing survey flights in October 2011. Subsequently, an email was distributed on the morning of each flight with information about the flight plan. The Chief Survey Scientist coordinated with other aerial teams in order to prevent overlapping flight plans, including:

- National Marine Fisheries Service (NMFS) Atlantic Marine Assessment Program for Protected Species (AMAPPS);
- NMFS, Northeast Fisheries Science Center (NEFSC), North Atlantic Right Whale Sighting Survey (NARWSS);
- URI Department of Natural Resources Science, for the Rhode Island Coastal Resources Management Council, avian research project;

- University of New Hampshire (UNH), leatherback turtle spotter surveys; and
- Naval Undersea Warfare Center, Division Newport.

The NMFS Regional Stranding Coordinators were also informed of flight activity. The NLPSC team assisted in other areas of research by providing information about survey coverage and sighting details to other agencies and organizations, including PCCS (the humpback whale research program); Massachusetts Division of Marine Fisheries (shark research program); NEFSC (NARWSS staff, right whale Sightings Advisory System); and UNH (leatherback turtle program) (Appendix 3 *Project Personnel and Associated Scientists*).

Survey Design

Surveys were flown at an altitude of 1,000 feet (305 m) and all attempts were made to maintain a groundspeed of 185 km/h (100 kt). Line-transect methods were followed to allow for the calculation of statistically rigorous density and abundance estimates. For right whale sampling from a Skymaster flying at 750 feet (230 m) during the SCOPEX program, f(0)[1] was 0.4760 (Kenney et al., 1995). The inverse is 2.101 km (1.13 nm), effectively the strip width of large whale visibility on one side of the aircraft. Based on those data (collected by the same aircraft type in a similar area) and the slightly higher survey altitude of 1,000 ft (305 m), we expected that observers could see all large whales at the surface out to slightly over one nautical mile. For survey design purposes, this means that each survey transect has a total effective strip width (ESW) of approximately 2 nm (3.7 km), although data collected during the survey would be used to derive survey-specific estimates of f(0) and ESW for analysis. Data-recording procedures for line-transect surveys adhered to strict rules to enhance statistical rigor. Only sightings made by dedicated observers during standardized, pre-defined census transects were used in density estimates. Different leg types were recorded (off watch, in transit, on transect line, on crossleg, circling), as well as particular leg stages (not on transect line, start, continue, break, resume, end) to differentiate those sightings for inclusion or exclusion in density estimates (Kenney, 2011).

Observers adopted a scanning pattern for large whales out to at least 2 nm (3.7 km) from the transect line, repeatedly sweeping forward and aft of a line perpendicular to the trackline. Sightings of species other than large whales were recorded opportunistically, but a 2-nm search pattern was maintained to prevent missing sightings while concentrating on nearby water. Using the described survey aircraft and configuration, a strip approximately 465 ft wide is obscured directly beneath the aircraft. To cover this area missed by observers, and to collect systematic information on the distribution and abundance of sea turtles, an automated digital camera photographed vertical images directly beneath the flight path. Vertical images were processed post-flight for marine animals (sea birds, fish, sharks, turtles, and marine mammals), fishing gear, and vessels.

A randomized start point was selected for each flight. Possible transects to be flown were defined at each minute of longitude within the survey area from 71°08' to 69°57', and were

[1] Probability of detection of animals or groups declines with their distance from the transect. In line-transect (or distance) sampling theory, f(0) is the probability density function of right-angle sighting distances (for that species and platform) evaluated at a distance of 0. The reciprocal of f(0) is the “effective strip width,” a statistical estimate of the area effectively searched on either side of the transect. For more detailed but simplified summary of line-transect methods, see Kenney and Shoop (2012), available at http://www.gso.uri.edu/~rkenney/reprints/.

designated as line numbers (LEGNOs) 1 through 72 from west to east. A single survey day was 8 transects spaced at 9 minutes of longitude apart (6.77 nm [12.54 km] at the northern ends of the lines and 6.84 nm [12.67 km] at the southern ends) (Figure 4). A survey option number was randomly selected, with options 1 through 9 being flown in a west to east direction (starting with LEGNO 1-9), and options 10 through 18 flown in an east to west direction (starting with LEGNO 72-64). By varying time of day for take-off, direction of flight, and starting transects, survey coverage was not biased and particular sections of the survey area were not overlooked repeatedly at the same time of day, allowing for an unbiased sample of the study area. Other sources of bias in these surveys (glare, wind, swell) were minimized by setting survey criteria to only fly in very good weather conditions.

Each survey used a data-collection system which integrated the GPS, digital vertical camera, forward motion compensation (FMC) camera mount, remote key pads, and Panasonic Toughbook computer using a custom data acquisition program, *D-tracker*. Automated data logs tracked effort throughout the survey, whereas sighting data logs were prompted by observers. Data collection in-flight was designed to limit distractions to observers' scanning pattern. All sighting entries were initiated using remote key pads mounted on each side of the aircraft so that observers did not have to remove their gaze from the window, reducing the chance of missing a sighting. Sighting details were dictated into digital voice recorders and transcribed post-flight using *e-tracker*, a data editing program. *D-tracker* program functions and output format were designed for compatibility with the North Atlantic Right Whale Consortium (NARWC) database at the University of Rhode Island (details in Appendix 5; see also (http://www.narwc.org/pdf/consortium_database.pdf).

D-tracker enabled user-defined parameters to be modified via the laptop, such as vertical camera trigger intervals, display of latitude or longitude in degrees,minutes, seconds or decimal degrees (Appendix 6, *Camera Mount and D-tracker interface*). The mount system GPS output a proprietary formatted data file that included the estimated horizontal and vertical position error in meters in order to record positional accuracy of the data. Altitude was recorded from the mount system GPS since the aircraft did not have a radar altimeter. At each data sample, *D-tracker* recorded: time, latitude, longitude, GPS ground speed, GPS quality, GPS number of satellites, GPS altitude, GPS heading, magnetic heading, lens focal length, ground covered sideways, ground covered forward, picture interval, and picture count. Data were stored to a comma-delimited text file format (CSV). All data were recorded each time the camera fired, when prompted by an observer, and at regular user-defined intervals, to allow for calculations of overall survey effort and species density. Raw data were transcribed, proofed, and backed-up immediately after each flight. *D-tracker* created a KML file of sightings recorded by observers, viewable in Google Earth, and a GPX file for geo-referencing the vertical image database. Following the vertical image raw data processing, the CSV file was amended to include all of those fields defined in Appendix 4, combining sightings made by observers and those detected in vertical photography.

Aerial Observer Methods

Nikon binoculars (8 x 42, 6.3°) were used to confirm sighting cues. A data record was created at the time a sighting was first seen from the transect line. If sighted forward of right angles to the trackline, the aircraft continued heading along the transect line until the sighting was abeam, at which point the observer measured the distance from the transect line and recorded another data entry at the right-angle location. If the animal was suspected to be a right whale, the aircraft broke from the transect line to circle in the vicinity to confirm species identification and/or for observers to photograph. If the animal was verifiably not a right whale, the aircraft did not break from the transect line, rather a distance was recorded when the sighting was at a right angle, and the aircraft continued heading on track. Distances from the transect line were estimated using calibrations on the wing strut (Mbugua, 1996; Ridgway, 2010). Distances (in nautical miles) were recorded by observers in the following classifications: within 1/8; 1/8 to 1/4; 1/4 to 1/2; 1/2 to 1; 1 to 2; 2 to 4; and more than 4, also indicating port or starboard.

Observers photographed right whales using a Nikon D300 or D300s with a 300-mm Nikkor lens and 1.7 x teleconverter, for a resulting focal length of 500 mm. Observers photographed out of an open window while the aircraft circled overhead. Photographers collected oblique photographs of the entire rostral callosity pattern of each right whale sighted, and any other scars or markings that were obvious. Every attempt was made to document each individual within a given aggregation. While one observer photographed, the other maintained a written record of frame numbers, initial time and location of sighting, and event duration; and noted behaviors, group composition, direction of travel, and distinguishing features such as scars whenever applicable. Every whale photographed on a single survey received a sequential letter designation beginning at ‘A.’ If a whale was not noted by observers during the survey, but later discovered in photographic analysis, the whale received a number, starting with #1 for the first undetected individual. During photographic documentation, circling of right whales was limited to the minimum amount of time necessary to obtain photographs and complete the survey. At the conclusion of photographic work the aircraft returned to the transect line at the point of departure, and a data point recording “resumption of survey effort” was logged. These methods conform to research protocols followed by the NARWC and are consistent with the aerial survey protocols followed by the NMFS, NEFSC. After surveys were completed, right whale images were uploaded and processed in the NARWC Catalog, and were compared to other records in the Catalog to identify individuals.

Sightings of fish, rays, sharks, turtles, seals, dolphins, and large whales (that were not right whales) were recorded and passed without breaking from the transect line in order to maximize flight time available. Vessels that were estimated to be over 100 ft in length were recorded by observers. No fishing gear was recorded by observers in flight, although unusual debris or pollution was noted, such as oil slicks. Sightings of fixed fishing gear were recorded in vertical images. Associated sighting data was taken for all of those factors described in Appendix 5 when relevant, including: human activity code, species or taxa (SPECCODE); confidence in the reliability of species identified (IDREL); estimated abundance (NUMBER); and confidence in the count (CONFIDNC). Uncertainty was recorded at the discretion of the observers.

Aerial Vertical Photography Methods

The military 02-A version of the Skymaster 337 has in-built camera ports, and only minimal modifications were required to adapt NLPSC vertical photography equipment to fit into the existing camera port. A quarter-inch thick optical glass plate was modified for installation in the ventral opening of the fuselage. The FMC mount was adapted so that the camera, mount housing, and mechanisms fit into the existing port, and was secured to the floor panels without obstructing the SIC’s seat rails (Appendix 5, *Camera Mount and D-tracker interface*). The FMC mount was powered using the aircraft’s 28V DC electrical system.

A full-frame digital SLR camera was mounted in the FMC unit for vertical photography. The mount and camera were remotely operated by *D-tracker* and EOS Utility programs running on the laptop, with the main functions controlled using remote key pads. A Canon EOS 5D Mark II camera, equipped with a Zeiss 85-mm manual-focus telephoto lens (f/1.4), was set to shoot at either 0% overlap (i.e., back-to-back images) or any user-defined intervals while on track. Since the aircraft was already transiting the region in a systematic fashion, the extra photographic data collection could be obtained at no additional cost. Therefore, starting on April 6th 2012, we reduced the shutter interval to get 0% photographic overlap, so that the entire length of the transect line was covered. At the survey altitude of 1,000 feet (305 m), each image covered an area 424 by 282 ft (129 by 86 m) directly beneath the aircraft (0.0111 km^2 or 0.00324 nm^2). Images were either be downloaded directly to the camera's memory card and backed up in-flight to the Panasonic toughbook laptop or backed up post-flight during data transcription. Vertical images were run through GPicSync, a software program that uses the GPX record to insert locations into the images' metadata.

Photo Analysis (PA) was conducted to count and identify all marine wildlife recorded in the vertical images. PA was performed on a 24-inch or larger monitor screen, using FastStone Image Viewer for Windows. Only the 99,321 images collected on-track (excluding those collected during circling, cross-legs, or transits) were processed (Table 1). PA was completed between survey flights and consisted of biotic and abiotic sighting counts per image, categorized by species code (including vessels or other human activities), with the area in the image noted for reference. Like the visual sighting data, confidence levels were allocated for species identification and abundance certainties. Image quality was assessed based on amount of glare that occupied the frame, and overall quality that might be affected by cloud cover, time of day, or sea state. Observers recorded detections in vertical images of all the same species and taxa that were noted during aerial surveys, but in addition fishing gear and all vessels (even if smaller than 100 ft) captured in images were recorded. Fixed fishing gear was recorded when detected in vertical images, and not in flight to allow for accurate density estimates due to a known coverage with equally distributed effort.

Total Flight Hours to Date	134
Average Flight Hours/Survey	5.75
Total Images to Date	143,905
Average Images Taken/Survey	6,220
Total Unique Images Analyzed	99,321
Average Images Analyzed/Survey at 5 sec intervals	2,962
Average Images Analyzed/Survey at 0 % overlap	6,639
Total nm of trackline flown	7,059

Table 1. Summary statistics of flight and vertical photographs taken and analyzed during the 2011-2012 MA CEC aerial surveys.

Data Products

Sightings and Effort Database

Data management procedures followed the NARWC protocols established in 1986 and regularly modified and improved since that time (Kenney, 2001, 2011). Although this data management system has evolved to standardize data collection on right whales, it includes sighting information on all species of marine mammals and sea turtles from most systematic survey efforts along the east coast of the U.S since 1978. The NARWC Database incorporates sighting and survey ("effort") data within a single archived dataset. It is widely used by federal and state agencies as the source of data on those species for environmental assessments, and by researchers within and outside of the NARWC for a wide variety of scientific projects and publications. Right whale sightings in the NARWC Database are linked to the DIGITS catalog every year or two and discrepancies are corrected.

Information on survey effort and sightings of all species recorded during NLPSC aerial surveys will be stored in the NARWC Database at URI after the completion of the project, but at the current time they are being maintained in separate files. The survey team performed initial proofing of survey data tables before submitting to Dr. Robert Kenney at URI's Graduate School of Oceanography for quality assurance and checking (QA/QC). Standard practice for most NARWC data contributions is to submit one year's survey data as a single package, however the NLPSC team submitted individual survey data tables to URI throughout the year. This allowed for ongoing feedback and improvements to data collection methods, preventing mistakes from recurring. Data were submitted approximately three weeks after the date of a survey flight to allow time for the task of vertical photography data processing, which was performed by two observers. Once confirmed to the appropriate level of confidence, sightings were inserted at the relevant line of data that corresponded to the image. At the conclusion of Year 1, a comparison was performed between the datasets at NEAq and URI to correct any inconsistencies.

Vertical Photography Database

The vertical photographs were used to collect data on smaller marine animals that were less visible to observers, and were the primary source of data on sea turtles. The raw database of JPG vertical images included all images from activation to shut-down (n=143,905), whereas the culled database included only those taken while on a transect line (LEGTYPE = 2) (n=99,321). The raw database was burned onto a series of DVD-Rs, and both the raw and culled images were backed up to 2-TB external hard drives. Photoanalysis (PA) was performed by the observers on the culled images for SPUE analysis and density estimations of the target species. All images containing target biotic and abiotic sighting detections were filed for reference. Although seabirds were not a focus of PA, observers incidentally recorded sightings of birds. Bird sightings were not included in the CSV data table, but images were burnt to disc and mailed to interested parties for analysis (T. Studds and T. French; see Appendix 3, *Project Personnel and Associated Scientists*).

Following photo analysis, recorded sightings were submitted in an excel table to the Chief Survey Scientist for verification. In cases where the NLPSC survey team was uncertain of species identification, advice was sought from experts in the field for opinions on species identification and reliability. The Chief Survey Scientist compared detection rates and quality of data between the two observers for consistency. Initial survey dataset analyses were conducted by two observers until the cross-observer validation of target species detections exceeded 90%. After observers were trained, experienced, and the cross validation rates were near unity, the vertical image collection interval was reduced from one every 5 seconds to one every 2 seconds (essentially the vertical images collected at this rate are non-overlapping and adjacent, effectively covering the entire trackline strip not visible to the observers under the aircraft), collecting over twice as many images per survey as initially proposed. When collecting this greater volume of images, the dataset was split between the two observers, with photoanalysis for one transect line duplicated by both observers for ongoing validation.

Right Whale Catalog, Photographic Database

Photographs of right whale callosity patterns were used as a basis for identification and cataloging of individuals, following methods developed by Payne et al. (1983) and Kraus et al. (1986). A new whale is added to the right whale catalog when there is enough photographic information to confirm beyond doubt that it does not already match an existing cataloged whale, and documentation provides enough information for future sightings to be matched. This conservative approach ensures that data analyses for the population are based on robust identifications with a high probability of re-identification if a whale is photographed in the future (Hamilton et al., 2007).

Right whale images are stored by NEAq in a data management program, Digital Image Gathering and Information Tracking System (DIGITS), which is curated by NEAq (Hamilton et al., 2007). This software system is used to process, match and track digital images and data for individual identification studies. DIGITS includes data from 313 different contributors, dating back to the first recorded event on 24 March 1935. Identification data on the individual right whales reported in this document, including age, sex, and reproductive status, should be considered preliminary. The MA WESA is included in the DIGITS regional classification of southern New England (SNE) (Figure 5). Sighting data were entered and processed in DIGITS by the NLPSC aerial survey team throughout the year. Confirmation of whales is being performed by NEAq researchers under a different contract. An open-access online version of confirmed sightings can be viewed at http://rwcatalog.neaq.org/Terms.aspx.

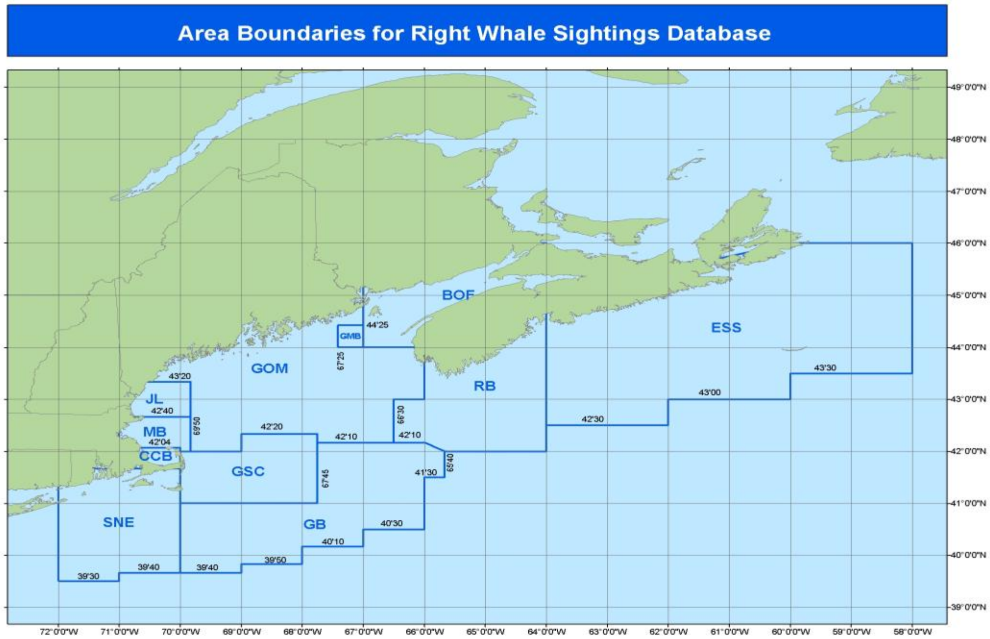

Figure 5. Areas of the Northeast Region as defined in DIGITS.

Sightings per Unit Effort (SPUE)

To get a true sense of marine animal distribution and relative abundance (unbiased by where people have looked intensively, or perhaps not at all), the number of animals sighted must be scaled for spatially and temporally differing levels of survey effort – resulting in a quantitative index of sightings per unit effort (SPUE). The method is well-established, and has been used in a wide variety of analyses of western North Atlantic marine fauna (CETAP, 1982; Kenney and Winn, 1986; Winn et al., 1986; Kenney, 1990; Hain et al., 1992; Shoop and Kenney, 1992; Kraus et al., 1993; DoN, 2005; Pittman et al., 2006; Nichols et al., 2008; Galagan et al., 2010; Lagueux et al., 2010; Kenney and Vigness-Raposa, 2010). However, robust SPUE analyses are dependent upon relatively high numbers of sightings, since we need to divide the sightings data sets into seasons (at a minimum), which reduces sample size for each grid cell. For this analysis, we partitioned the study area into gridded cells measuring 5 minutes of latitude (5 nm, 9.3 km) by 5 minutes of longitude (approximately 3.7 nm, 6.9 km). Grid size is a compromise – smaller cells increase resolution, larger cells increase sample sizes. Effort is measured in kilometers of track line flown within each 5x5-min cell, including defined survey lines, cross-legs, transits, and circling. Only segments of trackline meeting defined criteria are included: observers on watch in acceptable sighting conditions (visibility at least 2 nm, Beaufort sea state less than 4, and altitude below 1200 ft [366 m]). SPUE is calculated by dividing the number of individual animals sighted within a cell and time period by the effort in the same cell and period:

$$1000 \quad X \quad \frac{\text{Number of Individuals Sighted}}{\text{Effort (km)}}$$

SPUE is the number of animals sighted per 1,000 km (of track line); the factor of 1,000 was included to avoid having index values that are very small decimals. Sightings assessed as “definite” or “probable” species identifications are included, but those judged as “possible” IDs are not. SPUEs were calculated for each season and for the entire year of surveys combined. Seasons were defined as: Spring is March to May; Summer is June to August; Autumn is September to November; and Winter is December to February. Seasonal and full-year SPUE values were then mapped for those species with sufficient numbers of sightings.

Animal Density Estimation

Vertical photographic and visual sighting methods were employed simultaneously during this project, and both methods can be used to develop density estimates. The **density** (**d**, number of individuals per unit area) of animals within a specified region (the study area) is estimated from the number of animals counted (**n**) within the area of the sample (**a**) (Eberhardt et al. 1979; Seber 1982):

$$\mathbf{d = n / a} \qquad \mathbf{(1)}$$

A density estimate for the region or study area (usually designated A) is calculated from the mean density estimate for the sampled area, which when multiplied by A, results in study area abundance estimate. Sighting numbers in this year were inadequate to calculate large whale densities.

For density estimates from the vertical photography, the area sampled for a given transect is simply the number of photographs times the area of a single photograph. For our camera system, the area covered by a photo taken from the defined survey altitude of 305 m (1,000 ft) is 424 x 282 ft (119,568 ft^2 or 11,108.3 m^2). In addition, we assigned a photo-quality code (PH_QUAL, with 0=very poor, 1=poor, 2=good, 3=excellent) to each vertical photograph, incorporating all factors including glare, sea state, and image brightness. Very poor or poor-quality photos were eliminated from the density analysis. Every sighting that was detected from a vertical photograph was identifiable by a unique value of the LEGSTAGE variable (7). For each transect surveyed, the number of individuals counted in good or excellent photos was summed (**n** in equation 1). Similarly, the area sampled per transect (**a** in equation 1) was the sum of the individual areas of all the good and excellent photos. The density for each species was then calculated by dividing **n** by **a**, then multiplying by 10^6 to convert from animals/m^2 to animals/km^2.

Visual surveys are used to estimate density using **line-transects** (also known as **distance**) methods (Gates 1979; Seber 1982; Burnham et al. 1985; Buckland et al. 1993, 2001; Laake et al. 1993; Garner et al. 1999; Thomas et al. 2010). As the aircraft flies along the transect line**,** the observer measures the right-angle distance (**x**) to each sighting. A detection probability function (**g[x]**, the probability of detection at a given distance from the transect) is derived by evaluating the goodness-of-fit between the distribution of observed perpendicular distances and a variety of alternative statistical models, assuming that the detection probability on the trackline is 100 percent (or **g(0) = 1**). This **g(x)** function in turn is rescaled into a probability density function **f(x)** that integrates to 1 over the entire range of **x**, which is then solved for **f(0)**, or the **perpendicular distance probability density function evaluated at zero distance**. The reciprocal of **f(0)** is **ESW**, the **effective strip width**. The area sampled for a transect of known length (**L**) can be expressed in two ways:

$$\mathbf{a = 2 \times L \times ESW} \quad \mathbf{(2)}$$

or

$$\mathbf{a = (2 \times L) / f(0)} \quad \mathbf{(3)}$$

Therefore, sample density can be calculated by either of two equivalent formulas:

$$\mathbf{d = n / (2 \times L \times ESW)} \quad \mathbf{(4)}$$

or

$$\mathbf{d = [n \times f(0)] / (2 \times L)} \quad \mathbf{(5)}$$

The value for **f(0)** for a given species, or for a set of species with similar sightability characteristics, is estimated from the distribution of right-angle sighting distances using DISTANCE software (Laake et al. 1993; Thomas et al. 2010). To minimize variance of the **f(0)** estimate it is necessary to have an adequate sample size – minimally 25–30 sightings per species, and ideally 40–100 or more (Eberhardt et al. 1979). The primary targets of our visual surveys were large endangered whales. For those species, the numbers of sightings within the defined conditions needed for inclusion in the line-transect density estimation procedure (during a defined census track; Beaufort sea state of 3 or lower; clear visibility of at least 2 nautical miles; species ID reliability "definite" or "probable;" and a measured right-angle distance) were far too few. Only one species had over 100 usable sightings – basking shark, which was not a target species for the project.

Sighting densities detected in vertical images are provided in Appendix 7.
Note that the effect of sea state and glare on photo quality is completely different than the effect of sea state on visual sightability (and therefore on sighting distances). Thus, while data from vertical photographs and observer sightings could be shown together in plots of total sightings, combining them into a single density estimation procedure becomes much more complex, if it is possible at all, because they are being done under different sets of assumptions.

Results (NLPSC Aerial Surveys)

Aerial Observer and Photographic Surveys

Twenty-four surveys— numbered consecutively from the first flight, NLPSC001, to the final, NLPSC024—were flown between October 2011 and September 2012 – nineteen complete and five partial flights (Table 2). A survey was considered to be partial if any of the eight transect lines and/or additional areas of particular interest were reduced. Surveys were conducted twice in all months except February 2012, when only one survey was flown due to aircraft maintenance, and March 2012, when three surveys were flown in response to the combination of right whale presence and good Weather conditions.

A full survey flight covered about 314.5 nm (582.5 km), and included at a minimum: eight transect lines of 37 nm (68.5 km) each, plus the two additional areas of particular interest – Muskeget Channel and NOREIZ (Figure 3). The total on-transect distance flown for the entire year was 7,059 nm (13,073 km) (Table 1) – this does not include distances when the aircraft was in transit, on cross-legs, or after breaking from the transect line to investigate a sighting, although observers remained on watch during these times. An average full survey took 6.0 hours, ranging from the winter average of 4.7 h, to the spring average of 6.2 h (seasonal averages include partial surveys).

A total of 143,905 vertical camera images were collected, averaging 9.5 MB per image. A total of 99,321 on-transect images were collected, ranging from 2,111 collected per full flight at 5-second shutter intervals to 7,939 collected with a 0% overlap (1-2 second intervals) (Table 2). Those photographs collected while off track or during crosslegs between tracklines were considered "off-transect" and were not analyzed for SPUE or density estimates. At 5-sec

		Large Whale Sightings (incl EG)	Turtle Sightings		No. of Images Analyzed	
DATE	NLPSC #		Sighted by Observers	Vertical Photographs		Hours Flown
9-Oct-11	001	2	18	5	2330	5.3
23-Oct-11	002	0	2	2	2128	5.5
6-Nov-11	003	0	5	0	2296	5.5
26-Nov-11	004	0	0	1	2407	5.1
5-Dec-11	005	0	0	0	136	1.2
12-Dec-11	006	0	0	0	2754	7.2
9-Jan-12	007	0	0	0	2131	4.8
26-Jan-12	008	2	0	0	1868	4.8
5-Feb-12	009	0	0	0	2270	5.5
6-Mar-12	010	0	0	0	1321	4.3
23-Mar-12	011	20	0	0	2111	7
24-Mar-12	012	8	0	0	2253	7
1-Apr-12	013	6	0	0	2287	6.7
6-Apr-12	014	25	1	0	6264	6.4
7-May-12	015	9	1	0	6454	6.4
18-May-12	016	0	0	0	6800	5.6
10-Jun-12	017	3	1	1	6764	5.5
24-Jun-12	018	3	3	2	6509	5.7
3-Jul-12	019	0	2	1	6518	5.5
13-Jul-12	020	0	0	4	5937	4.8
7-Aug-12	021	5	25	12	6522	5.8
23-Aug-12	022	3	18	15	7939	7.1
12-Sep-12	023	1	45	12	6661	5.6
17-Sep-12	024	1	9	6	6661	5.2
TOTAL		88	130	61	99321	133.5

Table 2. A summary of the dates, sighting numbers for large whales and sea turtles, sightings, images, and hours flown for the 2011-2012 MassCEC aerial surveys.

intervals, an observer analyzed an average of 2,316 images per full flight, and the full dataset of image analysis was done by both observers for inter-observer cross-validation. After the interval was decreased so that images were adjacent to one another with no overlap, the image datastream became too large for the allotted analysis time. Therefore, images were divided between two observers and only images from one transect line were analyzed by both observers for the cross-validation procedure. This approach provided a more comprehensive survey, in that adjacent vertical photographs collected data from the entire trackline, just as the observers did. The number of images analyzed per observer per full flight at 0% overlap ranged from 2,543 to 5,565, averaging 3,772. The number of images from the validation transect scanned by both observers averaged 787.

Aerial Survey Effort: One Year's Contribution

The NPLSC survey effort compared to all previous years is shown in Figure 6, where effort is measured by kilometers of survey when observers were on transect and on-watch. It uses historical data from the NARWC Database, which includes all standardized survey effort from 1978 to 2008. Data that had been quality checked and assured were not available between 2008 and 2011.

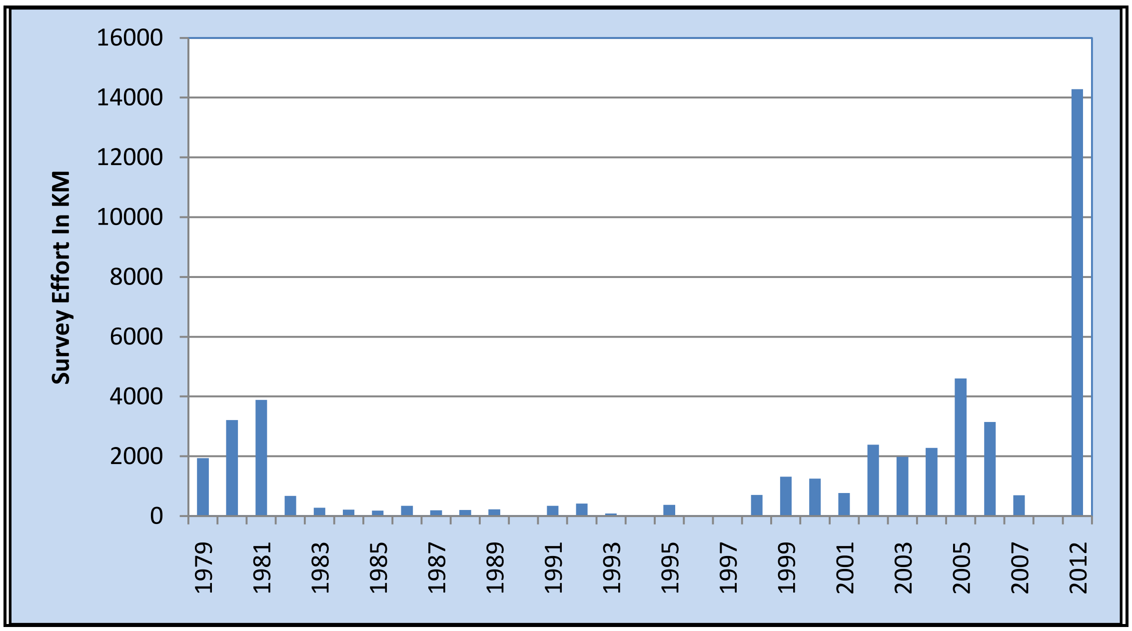

Figure 6. Comparison of historic effort (1979 - 2007), and the first year survey effort data from the NLPSC survey (far right).Bars represent kilometers of survey while on transect and on watch under suitable survey conditions.

Survey effort can also be examined by season as shown in Figure 7. Survey effort is shown in 5 minute squares throughout the MA WESA, coded by color (light pink is low effort, dark red is higher – see the legend in the lower right for reference). This provides a good visual depiction of the spatial survey effort and allows comparison between the seasons. Survey effort was highest in the spring, summer, and fall, and lower in winter due to poor weather. The cumulative effort during this year long survey is depicted in the lower left corner of Figure 7, and shows the relative consistency of survey coverage over the entire year.

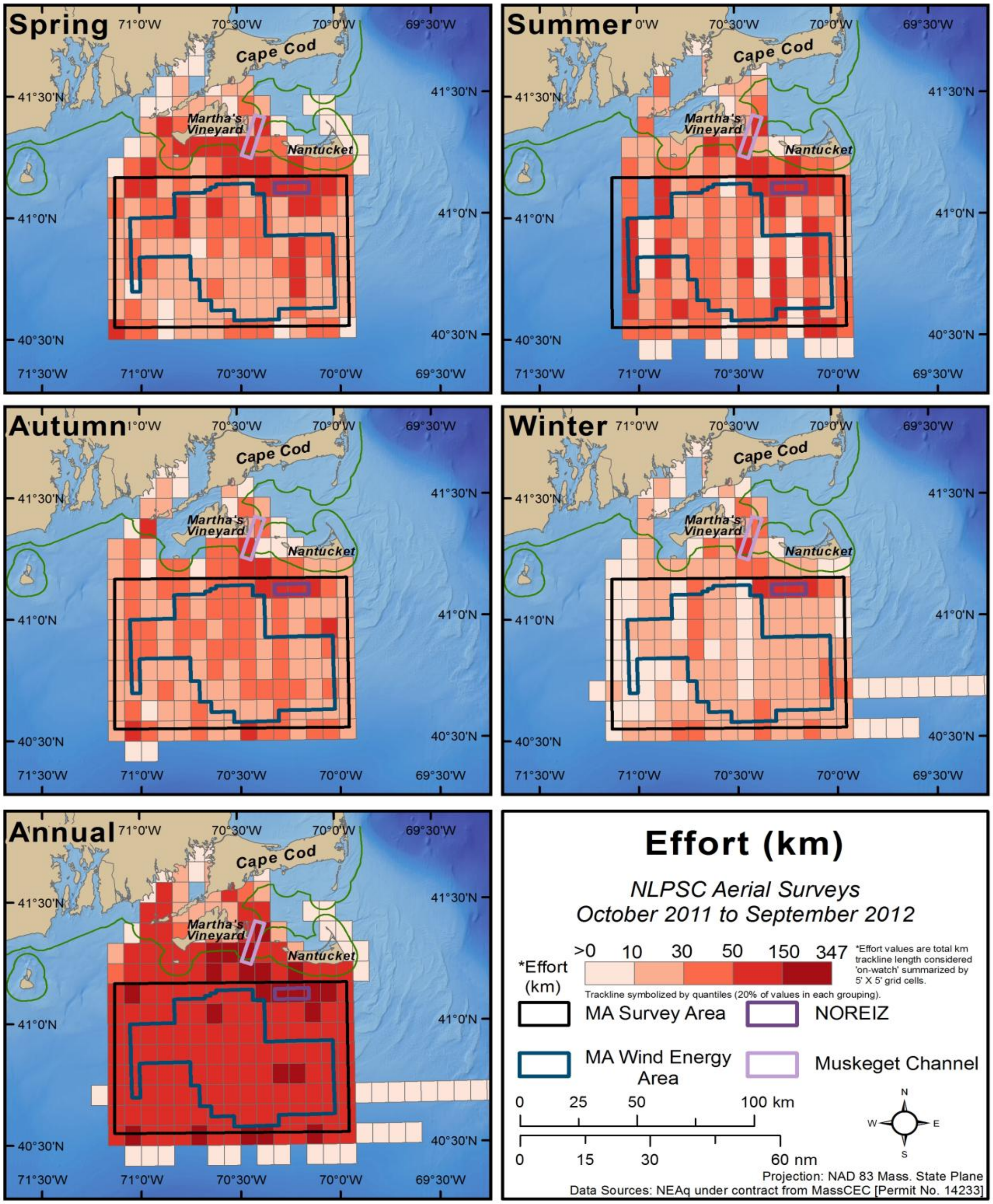

Figure 7. Survey effort (Km of trackine in each 5' by 5' cell) in the MA WESA by season and summarized for the entire 2011-2012 survey period.

Sightings

A total of 1,035 animals were sighted throughout the year, with the lowest number in winter (n=44) and the highest in summer (n=619). On-transect effort was the lowest in winter (1,216 nm), followed by autumn (1,887 nm) and spring (2,043 nm), with the highest in summer (1,913 nm). Therefore seasonal variation in sightings may be partly due to seasonal changes in survey effort. A total of 60 large and medium sized whales were detected during these surveys.

Summaries of all sightings by species, counts, and survey date for large whales, sea turtles, and smaller cetaceans are shown in Tables 3, 4, and 5. Each table is followed by a map showing distribution of those sightings in the MA WESA (Figures 8, 9, and 10). Only one whale was captured in the vertical images and not detected by observers (a right whale adjacent to another observed right whale sighting), so a separate map was not created for the photographic detections. For sea turtles and delphinids, sightings tables include all animals detected by observers in-flight and in the vertical images during post-flight analysis, including possible, probable and definite identifications to species.

Survey Name	Date	Right Whale	Fin Whale	Sei Whale	Humpback Whale	Minke Whale	Sperm Whale	Unidentified Large Whale	Unidentified Medium Whale	Total
NLPSC001	10/9/2011				2					**2**
NLPSC002	10/23/2011									**0**
NLPSC003	11/6/2011									**0**
NLPSC004	11/26/2011									**0**
NLPSC005	12/5/2011									**0**
NLPSC006	12/12/2011									**0**
NLPSC007	1/9/2012									**0**
NLPSC008	1/26/2012	1	1							**2**
NLPSC009	2/5/2012									**0**
NLPSC010	3/6/2012									**0**
NLPSC011	3/23/2012	7		1		2		2		**12**
NLPSC012	3/24/2012	3						2		**5**
NLPSC013	4/1/2012	2			3				1	**6**
NLPSC014	4/6/2012	2	2		3	5		1		**13**
NLPSC015	5/7/2012		2		1	4		1		**8**
NLPSC016	5/18/2012									**0**
NLPSC017	6/10/2012		1			1				**2**
NLPSC018	6/24/2012		3							**3**
NLPSC019	7/3/2012									**0**
NLPSC020	7/13/2012									**0**
NLPSC021	8/7/2012						2			**2**
NLPSC022	8/23/2012					1			2	**3**
NLPSC023	9/12/2012		1							**1**
NLPSC024	9/17/2012						1			**1**
	Total	**15**	**10**	**1**	**9**	**13**	**3**	**6**	**3**	**60**

Table 3. Large and medium whale sightings by species and survey date over the MA WESA during 2011 and 2012.

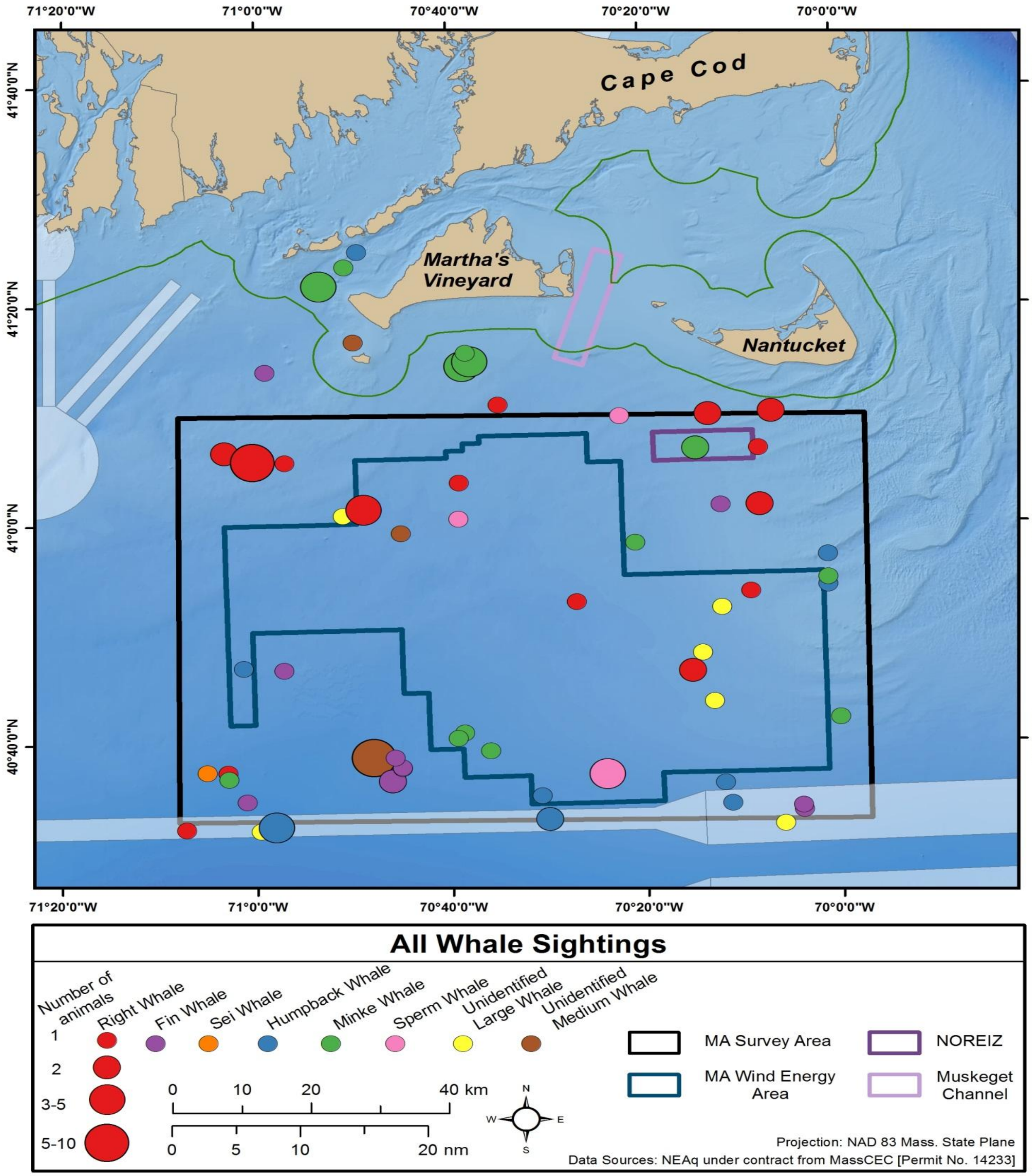

Figure 8. Large and medium whale sightings in the MA WESA during the 2011-2012 aerial surveys. The sighting location indicates the species and number of animals sighted at each location by the size and color of the circle.

Survey Name	Date	Leatherback Turtle	Loggerhead Turtle	Kemp's Ridley Turtle	Unidentified Turtle	Total
NLPSC001	10/9/2011	20				**20**
NLPSC002	10/23/2011	4				**4**
NLPSC003	11/6/2011	3				**3**
NLPSC004	11/26/2011		1			**1**
NLPSC005	12/5/2011					**0**
NLPSC006	12/12/2011					**0**
NLPSC007	1/9/2012					**0**
NLPSC008	1/26/2012					**0**
NLPSC009	2/5/2012					**0**
NLPSC010	3/6/2012					**0**
NLPSC011	3/23/2012					**0**
NLPSC012	3/24/2012					**0**
NLPSC013	4/1/2012					**0**
NLPSC014	4/6/2012		1			**1**
NLPSC015	5/7/2012		1			**1**
NLPSC016	5/18/2012					**0**
NLPSC017	6/10/2012	2				**2**
NLPSC018	6/24/2012	4			1	**5**
NLPSC019	7/3/2012	3				**3**
NLPSC020	7/13/2012		4			**4**
NLPSC021	8/7/2012	30	6			**36**
NLPSC022	8/23/2012	14	16	1	2	**33**
NLPSC023	9/12/2012	6	40	4	6	**56**
NLPSC024	9/17/2012	7	7	1		**15**
	Total	**93**	**76**	**6**	**9**	**184**

Table 4. Sea turtle sightings by species and survey date over the MA WESA during 2011 and 2012.

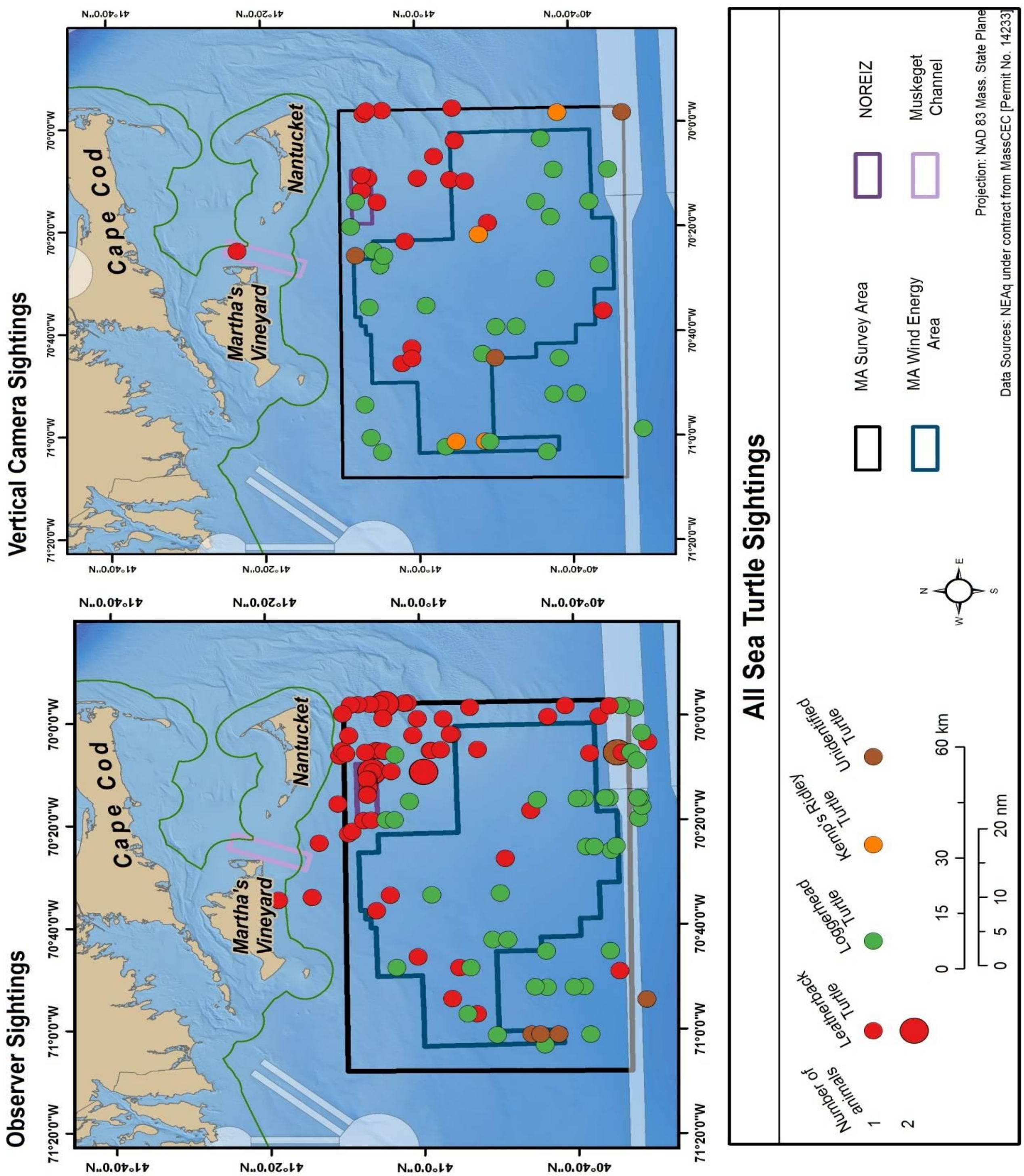

Figure 9. Sea turtle sightings in the MA WESA during the 2011-2012 aerial surveys. The sighting location indicates the species and number of animals sighted at each location by the size and color of the circle.

Survey Name	Date	Pilot Whale	Risso's Dolphin	Bottlenose Dolphin	Common Dolphin	Atlantic white-sided Dolphin	Harbor Porpoise	Unidentified Dolphin	Total
NLPSC001	10/9/2011			1				1	**2**
NLPSC002	10/23/2011			1			1	2	**4**
NLPSC003	11/6/2011			2		1		7	**10**
NLPSC004	11/26/2011						2	2	**4**
NLPSC005	12/5/2011								**0**
NLPSC006	12/12/2011				1		1	11	**13**
NLPSC007	1/9/2012						1	5	**6**
NLPSC008	1/26/2012							5	**5**
NLPSC009	2/5/2012							1	**1**
NLPSC010	3/6/2012							2	**2**
NLPSC011	3/23/2012	3					1	6	**10**
NLPSC012	3/24/2012								**0**
NLPSC013	4/1/2012	1			2			5	**8**
NLPSC014	4/6/2012	2	3					19	**24**
NLPSC015	5/7/2012			1				23	**24**
NLPSC016	5/18/2012								**0**
NLPSC017	6/10/2012	1						8	**9**
NLPSC018	6/24/2012							5	**5**
NLPSC019	7/3/2012							7	**7**
NLPSC020	7/13/2012							3	**3**
NLPSC021	8/7/2012				7			11	**18**
NLPSC022	8/23/2012			2	2			8	**12**
NLPSC023	9/12/2012			2	2			4	**8**
NLPSC024	9/17/2012				7			8	**15**
	Total	**7**	**3**	**9**	**21**	**1**	**6**	**143**	**190**

Table 5. Delphinid and harbor porpoise sightings by species and survey date over the MA WESA during 2011 and 2012.

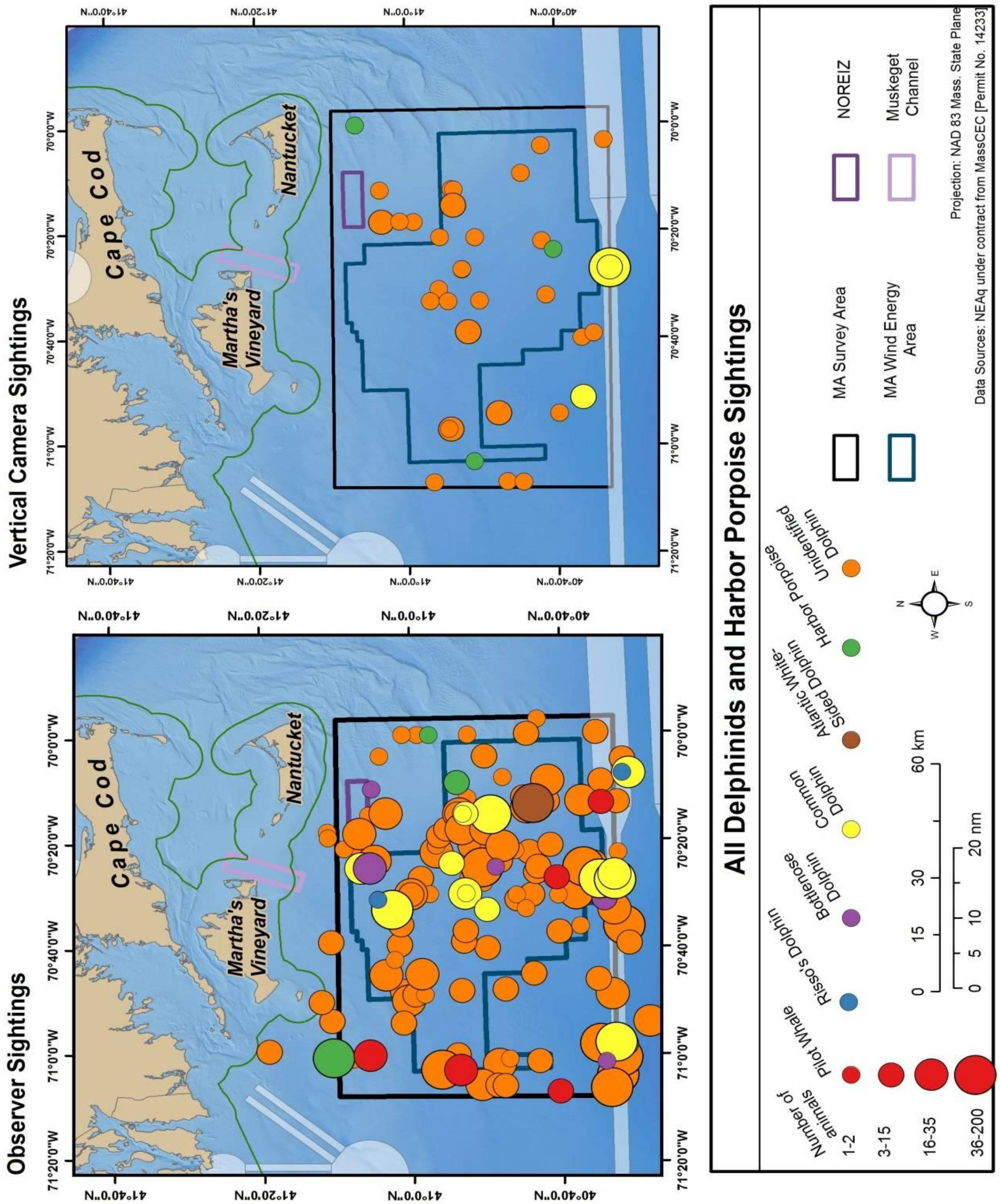

Figure 10. Delphinid and harbor porpoise sightings in the MA WESA during the 2011-2012 aerial surveys. The sighting location indicates the species and number of animals sighted at each location by the size and color of the circle.

In addition to the data presented above, these surveys collected sightings of seals, fish, sharks, fishing gear, and large vessel traffic. The tables and maps for these groups can be found in Appendix 6. Areas of high seal density occurred on and around seal haul-outs, such as in the Muskeget Channel, and to a lesser extent on Nomans Land southwest of Martha's Vineyard. Shark and fish sightings were dense along transect lines, as it was uncommon for observers to detect them away from the trackline. Fixed fishing gear was only recorded when detected during post-flight analysis of vertical images, and not by observers in flight. Only vessels over 100 ft were recorded by observers. Sightings from the Muskeget Channel and the Northeast Offshore Renewable Energy Innovation Zone (NOREIZ), (Figure 3) were collected and archived, but not analyzed under this contract.

Right Whale Photoidentifications

Twenty-four unique individual right whales were recorded in 13 sightings between 26 January 2012 and 6 April 2012. There were an additional four un-photographed individuals that could have been unique, or duplicates. Fifteen have been preliminarily identified, three are confirmed matches, and six are currently unmatched (Table 6). Of the 18 matched; 55.5% were males (n=10), 28% females (n=5), and 16.5% of unknown sex (n=3). Half of the matched whales were adults (n=9), and just under half were juveniles (n=8), with only one of unknown

EGNo	Name	Sex	Calving Female	Age	Born	Age Class
1613		M	N	26	1986	A
1617	ORANGEPEEL	M	N	A	U	A
1804	KATZ	M	N	24	1988	A
2370		U	N	A	U	A
3110		M	N	11	2001	A
3423		M	N	8	2004	J
3450	CLIPPER	F	N	A	U	A
3460		M	N	8	2004	J
3570		M	N	7	2005	J
3580		M	N	7	2005	J
3593**		U	N	U	U	U
3770		M	N	5	2007	J
3934		F	N	3	2009	J
3991*		U	N	3	2009	J
4070		M	N	2	2010	J
1970	PALMETTO	F	Y	A	U	A
2223	CALVIN	F	Y	20	1992	A
2605*	SMOKE	F	Y	16	1996	A

* Confirmed
** Catalog ID Created and Confirmed

Table 6: Preliminary identifications and demographic data on right whales sighted by the NLPSC aerial team during 2011 and 2012.

Sight No.	EGNo	Date	Time	ID	Latitude	Longitude	Behaviors
1	3991*	1/26/2012	1041	A	41.1151	70.138	Breaching, Flipper Slapping
2	3423	3/23/2012	1130	A	41.0984	71.0051	SAG, With un-photo'd Whale
	3110	3/23/2012	1130	B	41.0984	71.0051	SAG, With un-photo'dWhale
	3580	3/23/2012	1130	C	41.0984	71.0051	SAG, With un-photo'd Whale
	1804	3/23/2012	1130	D	41.0984	71.0051	Male, SAG, White Chin, With un-photo'd whale
	2223	3/23/2012	1130	E	41.0984	71.0051	Black belly, Focal Female, SAG, With un-photo'd whale
	Unident.						SAG
3	3570	3/23/2012	1238	H	40.6326	71.0523	
4	1970	3/23/2012	1528	I	41.1841	70.5819	Linear Travel
5	1617	3/23/2012	1549	J	40.8817	70.4441	Subsurface Feeding
6		3/23/2012	1648	K	41.0345	70.1387	SAG
		3/23/2012	1648	L	41.0345	70.1387	Black belly, Focal female, SAG
		3/23/2012	1648	#1	41.0345	70.1387	SAG
7		3/23/2012	1700	#2	40.8978	70.1505	
8	1613	3/24/2012	1028	A	41.1682	70.2199	
	3460	3/24/2012	1028	B	41.1682	70.2199	Rolling
9	2370	3/24/2012	1111	C	40.7717	70.2224	
	3593**	3/24/2012	1111	D	40.7717	70.2224	
10	4070	4/1/2012	0943	A	41.0974	70.9731	Linear Travel
11	2605*	4/1/2012	1107	B	41.0683	70.653	Subsurface Feeding
12	3450	4/6/2012	1112	A	40.5386	71.1214	
13	3934	4/6/2012	1152	B	41.0264	70.8037	White chin
	3770	4/6/2012	1152	C	41.0264	70.8037	
		4/6/2012	1152	D	41.0264	70.8037	

* Confirmed

** Created and Confirmed

Table 7: Sighting information on right whales sighted by the NLPSC aerial team during 2011 and 2012.

age class. Of the five known females, three were reproductively active (EGNO 1970, 2223, 2605) and had produced 4, 2, and 2 calves, respectively. The year of birth was known for 13 of the 18 matched. The two oldest were a 26 year old male (EGNO 1613) and a 24 year old male (EGNO 1804), and the youngest was a 2-year-old male (EGNO 4070) (Table 7).

Nine of the eighteen matched whales had confirmed sightings in other habitats in 2012. The youngest whale, (EGNO 4070 sighted on 6 April 2012) was sighted in the southeastern U.S. coastal waters earlier in the 2012 season, on the 17th of January. Right whales observed in the MA WESA were also seen in 2012 in Cape Cod Bay/Massachusetts Bay (n = 7), Great South Channel (n = 1), and Jeffreys Ledge (n = 1). The closest sighting record to the date seen by the NLPSC team was of EGNO 2223, who was documented seven days later in Massachusetts Bay. Nine of the 24 individuals were involved in surface active groups (SAG), and two were subsurface feeding.

In some cases right whales were observed but not photographed for identification. For example, in sighting # 2 (Table 7), observers estimated that seven whales were involved in this SAG. In post-flight review there were five individuals sufficiently documented for identification. During photo-analysis an image of a whale’s white chin was discovered that did not belong to any of the other five whales, but there was insufficient information to make a phtoidentificaiton. Therefore, this 6th whale was recorded as un-photographed. In addition, the one whale recorded by the vertical camera (sighting # 7 in Table 6) was detected in the vertical image database during photoanalysis but not seen in flight by observers. Although a positive species identification could be made from the tailstock and flukes, it is unlikely that this sighting will ever be matched to a cataloged whale.

Sightings per Unit Effort (SPUE) Analyses

Because the numbers of sightings are influenced by the amount of time spent looking, SPUE analyses are useful for teasing out average seasonal and distribution patterns from multiple years of survey data with high interannual and inter-survey variation. Because these analyses use a single year of data, sightings numbers were insufficient to conduct SPUE analyses by month, so the results are partitioned by season.

SPUE calculations were performed on all taxa that had more than 10 sightings throughout the year (except humpbacks which had nine). However, only the SPUE analyses for endangered right whales, the delphinids, and the leatherback and loggerhead sea turtles are shown in the body of this report as Figures 11, 12, 13 and 14. All other large whale SPUE analyses are based on a limited number of sightings from this single year, and are therefore less informative about seasonality and distribution. The SPUE analyses for all other large whales, seals, sharks, and ocean sunfish can be found in Appendix 7.

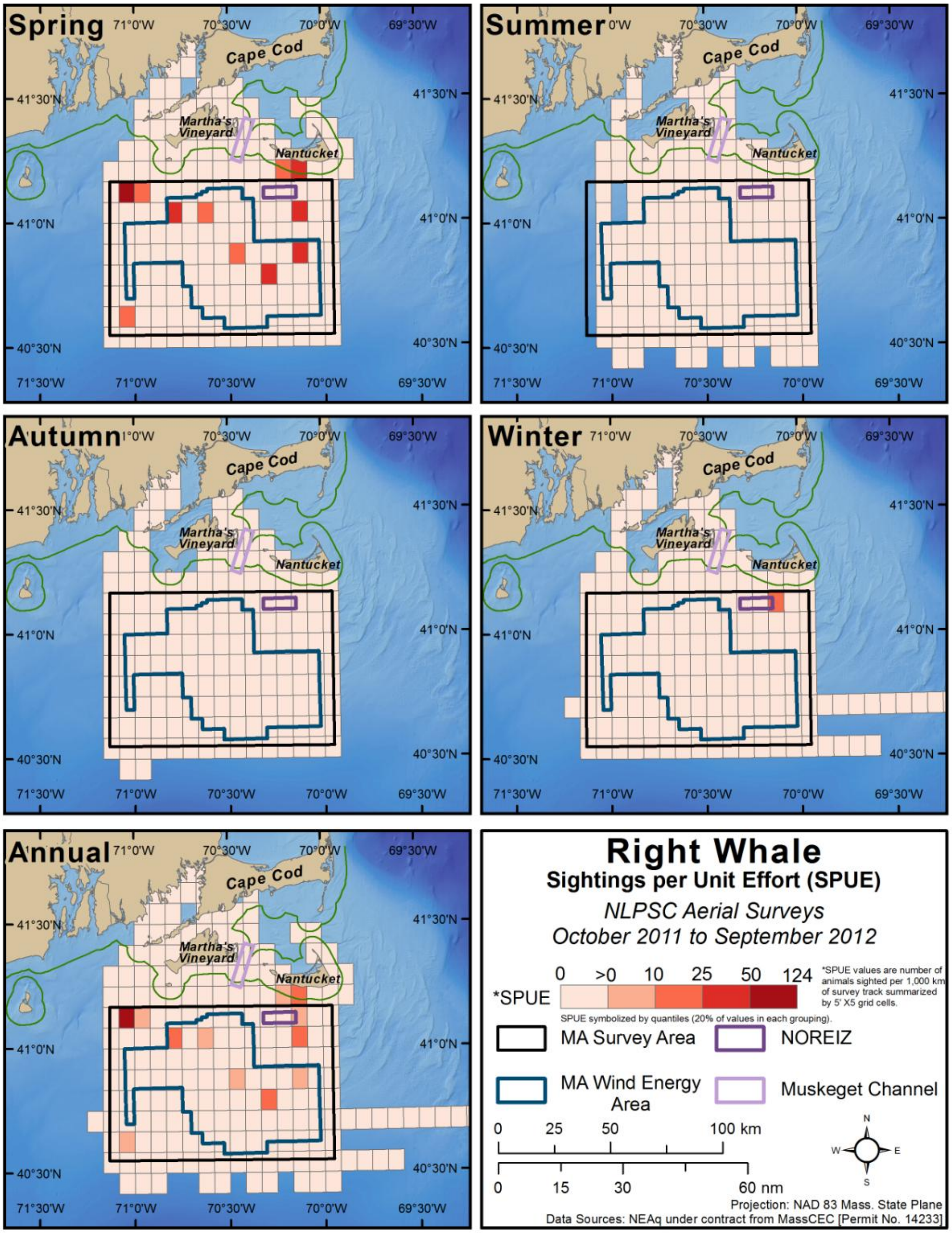

Figure 11. Sightings per Unit of Effort analyses for the North Atlantic right whale in the MA WESA between October 2011 and September 2012.

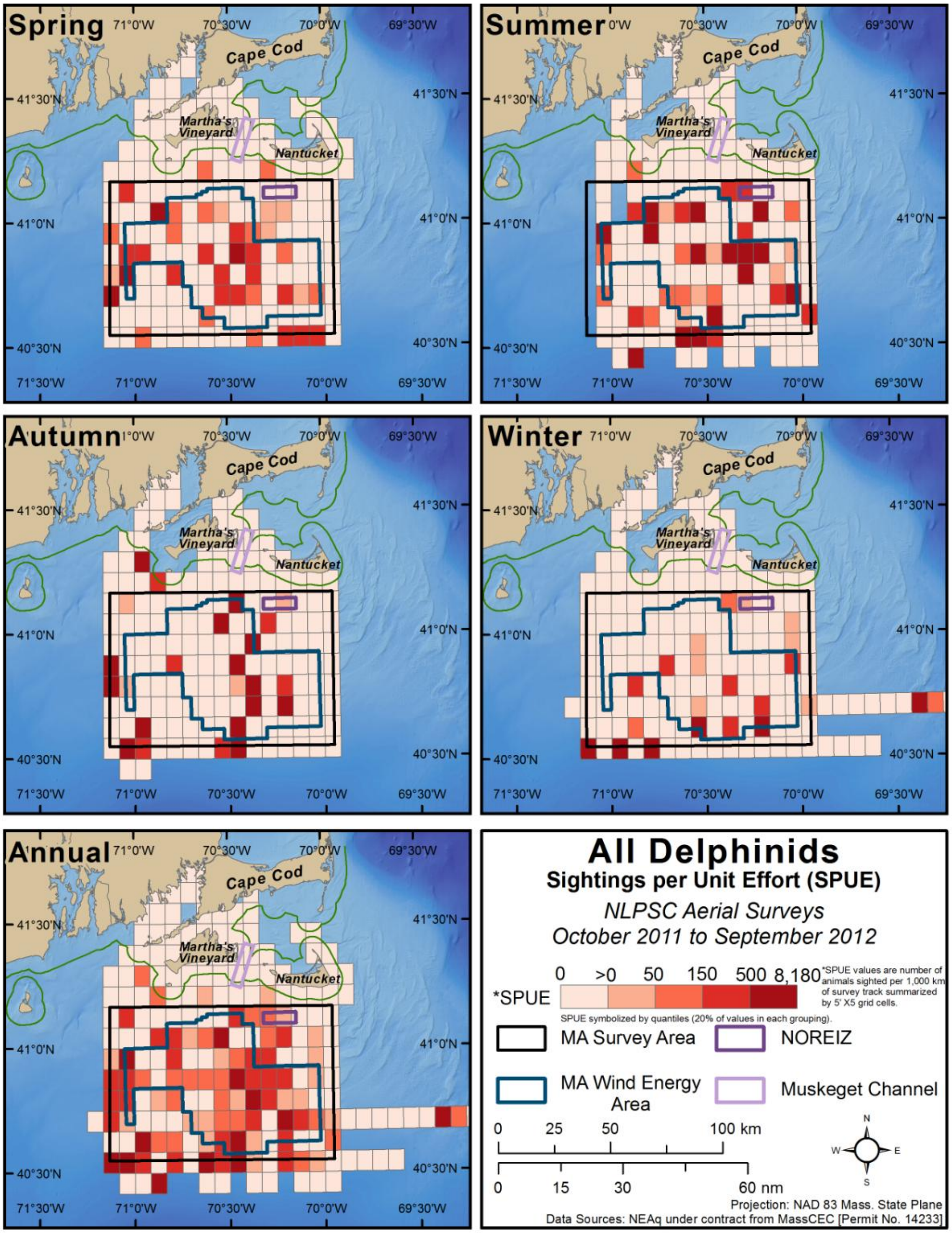

Figure 12. Sightings per Unit of Effort analyses for all delphinids in the MA WESA between October 2011 and September 2012.

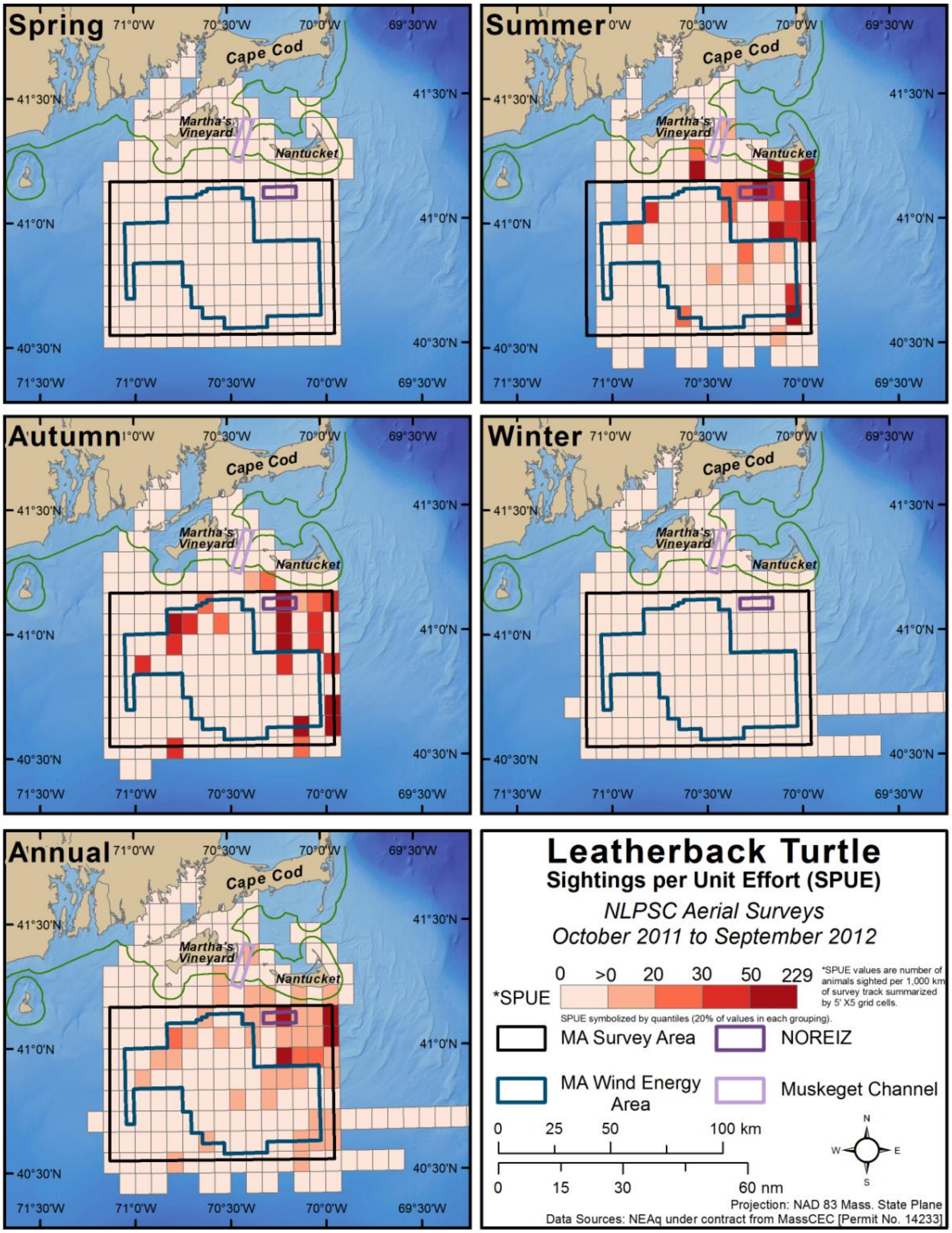

Figure 13. Sightings per Unit of Effort analyses for all leatherback turtles in the MA WESA between October 2011 and September 2012.

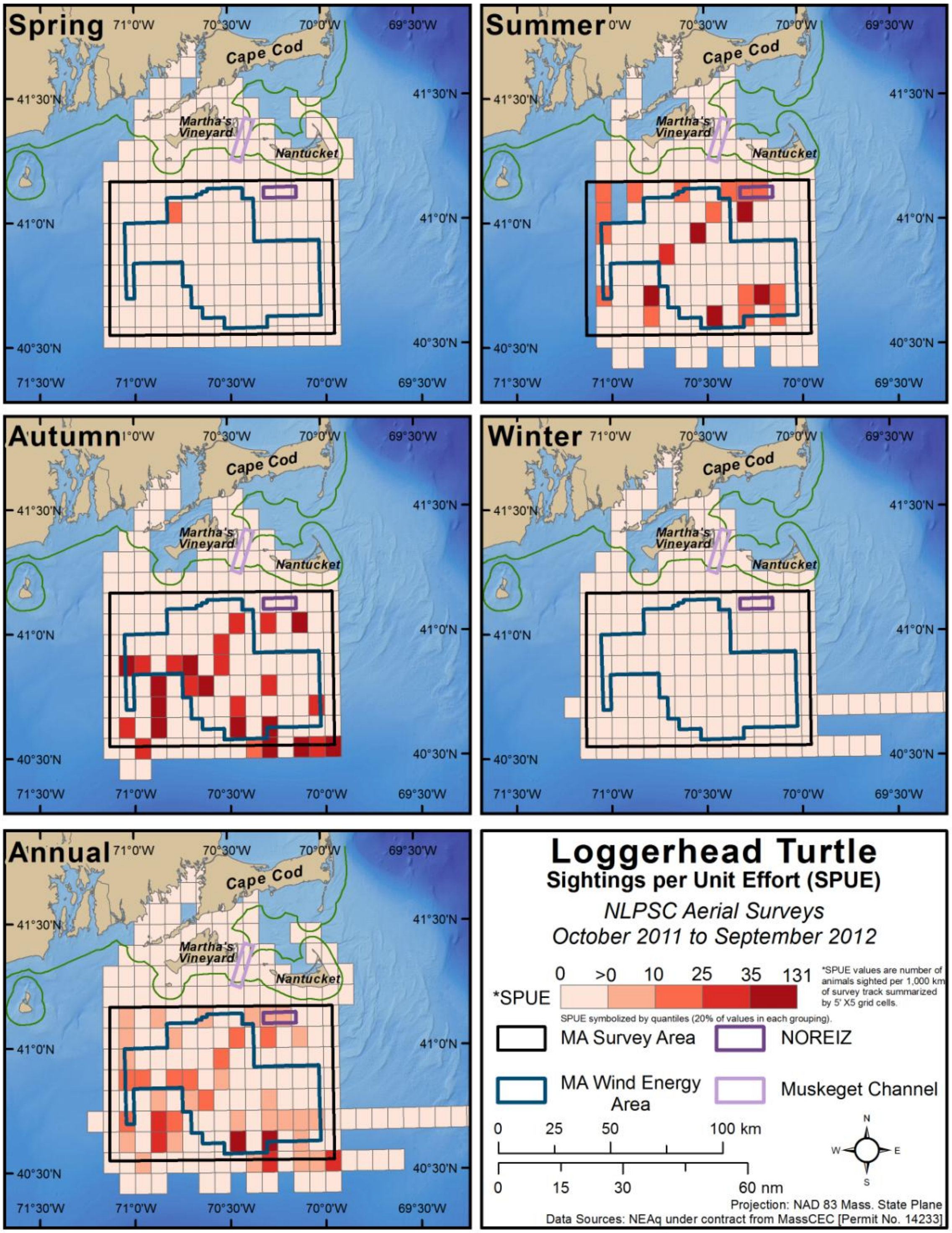

Figure 14. Sightings per Unit of Effort analyses for all loggerhead turtles in the MA WESA between October 2011 and September 2012.

Animal Density Estimation

Only six species had sufficient numbers of vertical photographic sightings to make density estimates. These included leatherback and loggerhead sea turtles and four large fishes (basking shark, blue shark, dusky shark, and ocean sunfish). For those six, photographic density estimates were calculated for 202 survey transects across all the surveys, including the Muskeget (LEGNO = 111) and NOREIZ (LEGNO = 222) transects, with a majority of zero estimates. The averaged density estimates by season are given in Tables 8 (for sea turtles) and 9 (for the sharks and ocean sunfish). No photographic densities could be estimated for the large whales or delphinids because too few of them were detected in the vertical photographs.

SEASON	LEGS	LETU		LOTU	
		MEAN	SD	MEAN	SD
Winter	32	0.000000	0.0	0.000000	0.0
Spring	45	0.000000	0.0	0.000000	0.0
Summer	30	0.033103	204.1	0.071724	256.3
Fall	48	0.037367	375.0	0.037367	159.0

Table 8. Averaged density estimates and standard deviations by season for leatherback sea turtles (LETU) and loggerhead sea turtles (LOTU) derived From the 2011-2012 vertical photographs collected in the MA WESA by the aerial surveys.

SEASON	LEGS	BASH		BLSH		DUSH		OCSU	
		MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
Winter	32	0.000000	0.0	0.00000	0.0	0.00000	0.0	0.015490	110.3
Spring	45	0.011178	100.7	0.00559	51.2	0.00000	0.0	0.000000	0.0
Summer	30	0.033103	224.8	0.19862	850.5	0.22069	1515.0	0.055172	356.8
Fall	48	0.009342	96.9	0.01401	95.4	0.00000	0.0	0.032696	177.2

Table 9. Averaged density estimates and standard deviations by season for basking (BASH), blue (BLSH), and dusky (DUSH) sharks, and ocean sunfish (OCSU) derived from the 2011-2012 vertical photographs collected in the MA WESA by the aerial surveys.

No density estimates were available from the observer data, since the calculation of f(o) (the perpendicular distance probability density function evaluated at zero distance), which is used to estimate strip width, requires an adequate number of sightings to minimize variance in the estimation (ca 40-50 sightings of a similar sightability category). Additional survey data may add sufficient numbers for us to make density estimates in the future.

Sighting Distances

There were insufficient observer sightings collected during the first year of surveys to estimate sighting distance probabilities by species (or groups of species with similar sighting characteristics). Because such estimates provide a strip width within which observers can reliably detect different animals, they are a critical step in calculating estimates of marine animal abundance in the MA WEA, The detection of an animal at distance is also dependent upon the Beaufort sea state, where higher winds make animals more difficult to detect. Over 90% of all NPLSC surveys were flown in Beaufort sea state 3 or better (less than 7-10 kts of wind), and most of the remaining 9% were flown in 11-16 kts of wind. Our survey protocols emphasize flying when winds are low to help minimize the effects of wind and sea state on sighting detections.

Sighting distance and sea state data for sightings collected in the MA WESA are summarized by taxonomic groups that are similar in sighting characteristics (large and medium sized whales, sea turtles, and delphinids) in Figures 15, 16, and 17. Only sightings made while on-transect had a distance estimated from the point of detection.

There were 15 sightings comprised of 197 +/- 60 individuals, detected at distances greater than 1 nm from the transect line. All of these were groups of marine mammals except two sightings of individual basking sharks, both of which were breaching when detected. In the case of large and medium sized whales, most sightings were made within one nautical mile, and most were made in Beaufort sea state 2 (Figure 15). Most sea turtles were seen by observers within ½ of a nm of the trackline, and all but three were observed in Beaufort sea state 2 or better (4-6 kts of wind or less) (Figure 16). Delphinids, because many of them travel in groups which make a larger target at the surface, are somewhat easier to detect at distance. The data shows dolphins are frequently seen out to 1 nm in sea states up to Beaufort 3 (Figure 17).

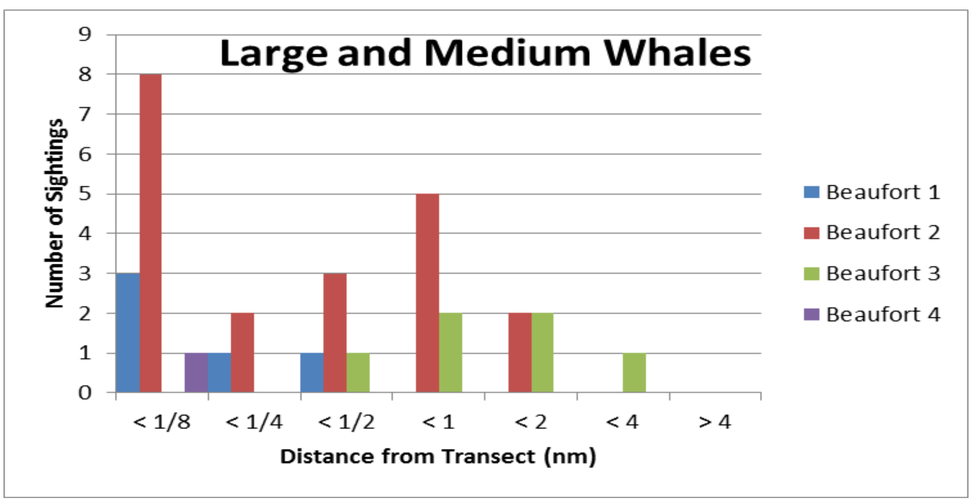

Figure 15. Sighting distances for large and medium whales by Beaufort sea states.

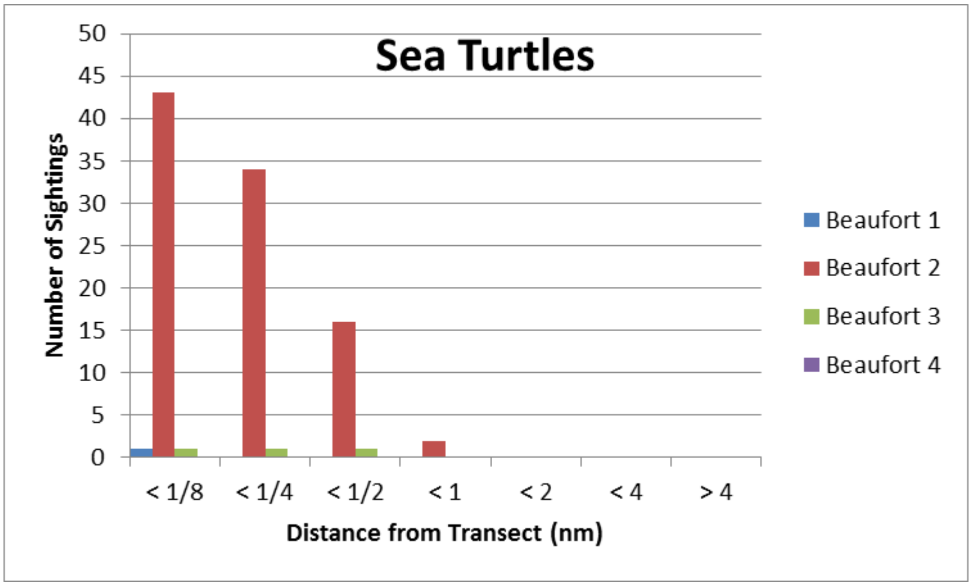

Figure 16. Sighting distances for sea turtles in various Beaufort sea states.

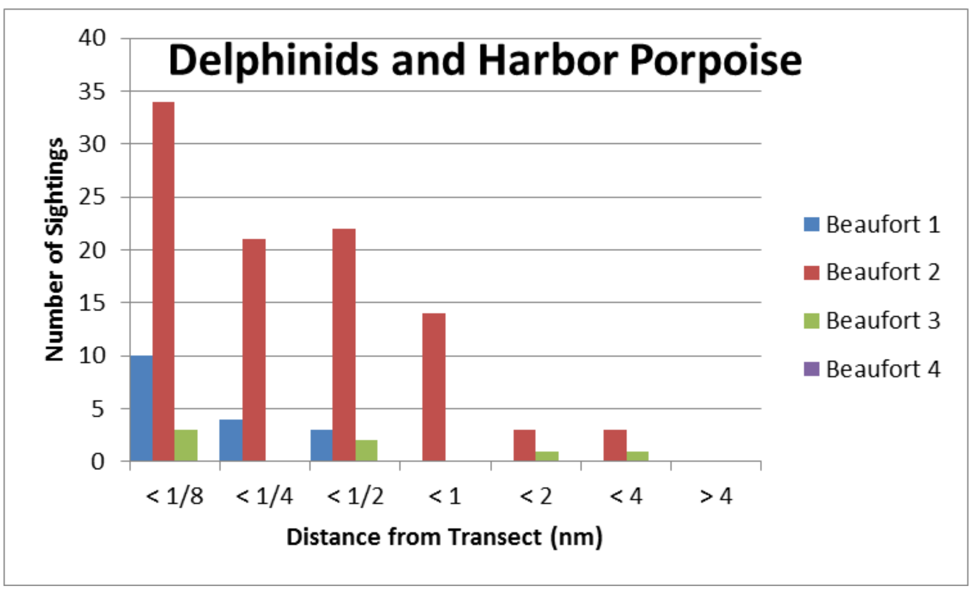

Figure 17. Sighting distances for dolphins and porpoises in various Beaufort sea states.

DISCUSSION

The development of offshore alternative energy sources is an essential part of the U.S strategy for energy independence. Such development requires comprehensive assessments of biological resources in suitable energy areas, to identify and mitigate any potential effects of that development on wildlife and fisheries. Here we report on a one year assessment of the spatial and temporal patterns of marine fauna occurrence in the Massachusetts Wind Energy Area (MA WESA) south of Martha's Vineyard. A pre-survey evaluation of survey data collected in the region over the previous 30 years revealed that limited systematic aerial survey work had been done over the MA WESA. This one year effort, comprised of 24 aerial surveys, resulted in more than a tenfold increase in survey effort in the area over all previous surveys for marine mammals and turtles combined.

We chose to use an innovative multi-pronged approach for this assessment. Aerial surveys are a well-proven approach, but by taking advantage of new camera technology, vertical photographic capabilities were added to standard observation methods. This provided two simultaneous and independent data collection streams, and greatly enhanced data collection on sea turtles and dolphins, which are difficult for observers to detect along the trackline because they are small and frequently submerged. In the process of analysis, we discovered that the vertical imagery also provided a wealth of information on sharks, fish, and fixed fishing gear. The combination of full-frame high-resolution digital SLR cameras, newly developed motion compensation equipment, and new integrated logging programs represents a breakthrough in low-cost aerial survey methods. The main limitations of aerial surveys are poor weather periods and the availability of daylight that preclude flying, and variable sighing conditions that can reduce observer capabilities (e.g. glare, wind, and animal size and behavior). Therefore we added a full year of underwater acoustic recordings to fill in some of those gaps for large whales. The main limitation of underwater recording systems is that they only detect the presence of vocalizing animals, and they cannot detect sea turtles. Thus the combined use of acoustic and aerial monitoring utilizes the complementary strengths of each to provide a comprehensive approach to the assessment of marine wildlife in the MA WESA.

Aerial Surveys

The aerial surveys recorded right, humpback, fin, minke, sei, and sperm whales during the year. The bulk of these large whale sightings occurred in the period from March through June, with scattered sightings at other times of year (Figure 18). Aerial surveys also recorded leatherback, loggerhead, and kemps ridley sea turtles. Most sightings of sea turtles occurred in the late summer, primarily August and September. A wide diversity of delphinids and one phocoenid were observed, including bottlenose, Atlantic white-sided, common, and Risso's dolphins, pilot whales, and harbor porpoise. Delphinids were observed throughout the year and the area, although warmer water animals (common dolphins) were seen primarily in the late summer. Pilot whales and Risso's dolphins (which have been observed travelling together) were seen primarily in the spring, and harbor porpoise were observed from late fall to early spring.

These records are largely consistent with the findings of a review by Kenney and Vigness-Raposa (2010) for common cetacean and sea turtle occurrence within the region, although they represent somewhat less diversity than the 40 species recorded as having occurred at least once in the broader area. This is not surprising, and many marine mammals are rare or infrequent visitors to the southern New England shelf. Further, because these sightings are collected from a single year, any patterns of distribution or seasonality must be interpreted with caution.

There were between 24 and 28 individual right whales observed in the survey area, 18 of which have been identified. The identified whales included 5 females (3 known to be reproductive females), 10 males, and 3 whales of unknown sex. Activities observed included surface active groups (a behavior associated with mating), feeding, breaching, flipper-slapping, and travelling. A total of 9 of these whales had been observed in the same year in the southern Gulf of Maine, including several that appeared to be going back and forth between Cape Cod Bay, the Great South Channel, and the MA WESA survey area. One whale had been seen earlier in the year off the southeastern U.S wintering ground, suggesting this is part of a migratory route for some right whales.

To minimize biases in the aerial surveys, we minimized the effects of sea state on the large whale SPUE data by discarding effort and sightings collecting in sea states of Beaufort 4 or higher. For the photographic density estimates, the effect of sea state was minimized by excluding the poor- and very poor-quality photos from the analysis. Sea state also impacts the sighting distances and therefore visual density estimates, but there were not enough sightings to estimate those. With sufficient data, one can model the effects of sea state (and other environmental parameters, such as water depth and sea surface temperature) into density estimates (e.g., CETAP, 1982), however such analyses require much larger sample sizes.

Sightings per unit of effort (SPUE) analyses and density estimates are the most appropriate methods for assessing distribution and abundance respectively, of the surveyed area. However, there are no SPUE estimates for separate months and small sample sizes compromise both methods. SPUE analyses are not like sighting locations, which show single days or very short periods, because the resulting maps will be very sparse (i.e., lots of zero-effort blocks) and will provide little information beyond the raw sighting plots. The value of the SPUE method is the ability to aggregate multiple surveys into a single index, which is also corrected for spatial variability in sampling effort. Even at the level of seasonal resolution for a single year of sampling, each dataset only includes an average of six survey days. In this case, SPUE analyses are provided, but because a single year of surveys represents a snapshot, not an average, we cannot assign any confidence to those distribution patterns.

Density estimations were made for leatherback and loggerhead turtles, basking, blue and dusky sharks, and ocean sunfish, but there were inadequate numbers of sightings to estimate density for all other species. All of these density estimations were based upon the vertical photographic analyses. Density estimations from observer data require more sightings with known distances from the trackline to calculate effective sighting strip width. We anticipate that the second year of surveys will provide us with enough sightings data to estimate effective strip width, and to then calculate density estimations for the more abundant large whales.

Acoustic Study

In the acoustic data, the specific locations of vocalizing whales were not determined, although in right minke and humpback whales, the limited detection range means their general location can be estimated. In the case of right whales, enough detailed information was collected to demonstrate that right whales were more commonly found at or near site M02, in the northeast corner of the MA WESA. The fin whale and humpback whale vocalizations were loudest at sites M05 and M06, indicating that the vocalizing individuals were positioned farther offshore, in deeper water.

Different marine mammal species have different acoustic signals, and there are also multiple physical variables that can affect the actual detection ranges (Marques et al. 2012) (e.g. source levels, frequency, source level and depth of vocalizing whale, sound speed profiles, bathymetry). We did not measure the detection range of the MARUs, but rather estimated detection ranges were based on the scientific literature as follows. We estimate that the right whales can be detected by a MARU up to approximately 25 km away (Laurinolli et al. 2003). In the case of fin whales and blue whales, species whose calls propagate for long distances (Payne & Webb 1971; Širovic et al. 2007), individuals could have been vocalizing either near the array, or up to tens or hundreds of kilometers away. Using estimates of the detectable ranges for humpback and minke whale vocalizations found in the literature ((Marques et al. 2012), we estimate that the humpback and minke whale calls could have originated from up to 12 km to 25 km from the nearest MARU, respectively.

The acoustic presence of at least seven large whales was verified using both systematic analysis and opportunistic observations of known species' vocalizations. The focal species of this study included North Atlantic right whale, fin whale, minke whale, humpback whale, and blue whale. The acoustic presence of these species varied over time, but vocalizations were generally detected more often during the spring and winter months than the summer and fall months (Figure 18). Fin whales and humpback whales were present at least one day in all of the 12 months of this study, while right whales were present for eight months, and minke and blue whales were present 10 and five out of the 12 months, respectively. In addition, sperm whale and sei whale vocalizations were identified opportunistically.

The ambient noise analysis of the MA WESA area showed temporal and spatial variability. Changes in the relative sound levels at 50 Hz (a frequency consistent with noise produced by shipping traffic) across the MARU array indicates that shipping activity occurred nearest to MARUs in the southeast region of the area. The decreased ability of animals to detect sounds made by conspecifics due to loud noise in a species communication band is otherwise known as masking (Hatch et al. 2008). Due to the proximity of shipping traffic, masking in the low frequencies (where many whales make sounds) may result in an under-representation of whale calls in the MA-WESA.

Comparison of Aerial and Acoustic Data

In both aerial and acoustic data, right, minke and humpback whales showed somewhat similar seasonal trends, with maximum occurrences in the spring (March and April) (Figure E1). In all three of these species, their calls are relatively short-range (<25 km), so we expect their acoustic presence to match well with the sightings records. In the case of fin whales, acoustic data showed a consistent occurrence of fin whale vocalizations throughout the year, although with a decline in early summer (Figure 18). This is in contrast to the aerial survey data, in which most fin whales were observed in the spring and early summer. Because fin whale vocalizations are very low frequency and may be detected several hundred km away, this disparity between sightings and acoustic detections is not surprising. Fin whale vocalizations are associated with mid-winter mating, and a some evidence suggests a winter distribution off New York and mid-Atlantic (CeTAP, 1982). It is possible the MARUs are detecting an offshore aggregation of calling fin whales, which then move onto the shelf and into the MA WESA in late spring. Finally, the acoustic presence of blue whales was detected in winter (December-February)

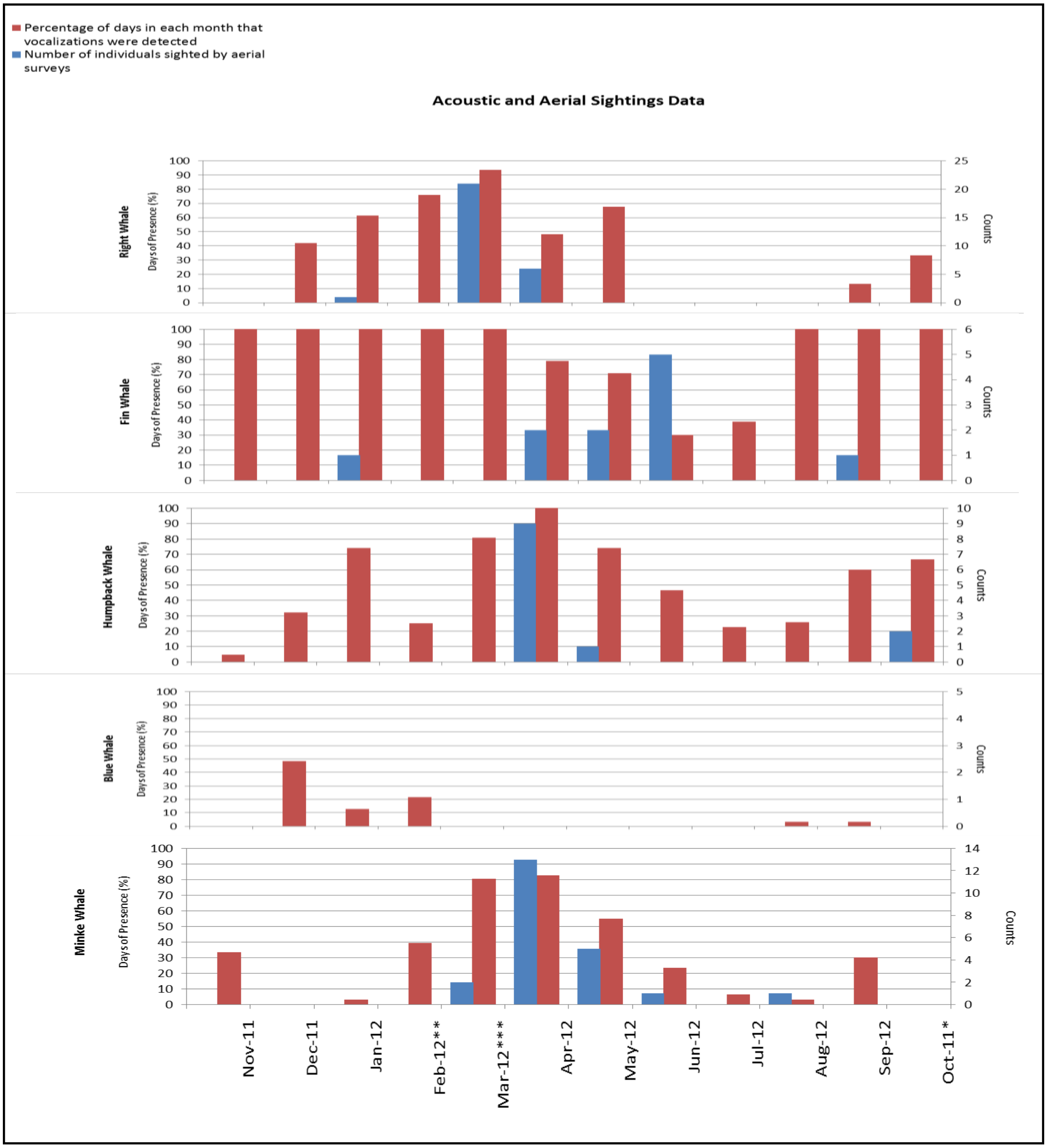

Figure 18. Comparison of the large whale sightings and acoustic data collected during the NPLSC study October 2011-September 2012. * October 2011 has been placed at the end of the horizontal axis for comparison sake but we are comparing the same month between different years. ** Only one flight was flown in February (5.5 h) *** Three flights were flown in March (18.3 h)

and late summer (August and September), although no sightings were recorded by the aerial survey team (Figure 18). This species' vocalizations probably travel farther than any other whale (up to a 1000 km), so the detections are likely to be attributed to animals at some distance from the MA WESA. Thus, this result shows that a combined acoustic and sightings survey approach can yield a more comprehensive picture of whale occurrence in and around the MA WESA.

Conclusions

The aerial survey sightings from year one included several species of large whales, sea turtles, dolphins, sharks, and fish, indicating an area rich in upper trophic level biological diversity. The sightings data from this study show the occurrence of six whale species and three sea turtle species in the ME WESA in the 2011-2012 study period. Acoustic data verified the acoustic signals of all 6 species seen by the aerial team, and added blue whales to this list, although none were detected from the aircraft. Both aerial and acoustic data are largely in agreement about the occurrence of the most abundant large whale species, although the acoustic data shows longer residence times in the area for most species. The varying patterns of occurrence between species suggest that differing environmental or behavioral factors may be driving whale presence. For example, we suspect, but cannot prove, that the movement and occurrence of right and minke whales are due to prey species abundance at certain times of year. Additionally, we suspect that some humpbacks are migrating through the area, and that fin may use offshore waters during the winter mating season. Future work on prey species, oceanography, and species-specific behavioral characteristics, when compared to the acoustic and aerial survey data collected in this study, could provide valuable information in understanding and predicting whale behavior and occurrence.

The ambient noise analysis from this study demonstrated that the MA WESA area is a biologically rich marine environment, with relatively moderate anthropogenic noise levels from shipping and other activities. High levels of ambient noise from anthropogenic activities can contribute to masking of marine mammal communication (Clark et al. 2009), potentially resulting in behavioral and physiological stress responses (Kight & Swaddle 2011; Rolland et al. 2012), and modifications to auditory sensitivity (Lucke et al. 2009; Mooney et al. 2009). Future studies on how increases in anthropogenic activity can affect ambient noise and marine mammal presence will be important to inform future resource management decisions in the MA WESA area.

Inter-annual variability, both spatially and temporally, can be high in mobile upper trophic level animals, and multiple years of survey effort are needed to understand and develop any confidence in averages and/or trends of marine animal distributions. This is particularly true for marine mammals (e.g., Baumgartner & Mate 2003; Keiper et al. 2005). The high levels of variability in the New England marine ecosystem (particularly temperature) over the last 5 years make this caveat especially important when reviewing the results of this study. If current warming trends continue, the Gulf of Maine ecosystem is projected to undergo a transition in species composition and food web structure (Morrison et al., 2012). Direct effects of warming could include alterations of growth, molting and reproduction cycles, as well as species shifts in local spatial distribution and biogeographic range (Lucey and Nye, 2010). The changes may particularly impacts species that reside at the southern extent of their biogeographic range, several of which can be found in the MA WEA. Thus a single year of acoustic and survey assessment data, as rich as it appears, provides only a very preliminary biological characterization for the MA WESA.

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Section 3: Passive Acoustic Monitoring for Marine Mammals in the Massachusetts Wind Energy Area: November 2011 – October 2012

Bioacoustics Research Program
Technical Report 13-01

Final Report
June 5th 2013

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Background and Objectives

The following is a report summarizing the scientific efforts to collect and analyze passive acoustic recording data in the Massachusetts Wind Energy Area (MA WEA). The focus of the analysis was to collect acoustic data to supplement broader efforts to characterize patterns of occurrence of marine mammal species, and characterize the existing ambient noise environment in the MA WEA. This information will be used to establish baseline information to assess potential influences of anthropogenic noises produced by the construction and operation of future Offshore Renewable Energy (ORE) developments. Determining patterns of marine mammal occurrence is a critical first step in order to determine any potential effects that an ORE development might have on the behavior and ecology of resident or migratory species of marine vertebrates.

This report focuses on 5 key species of marine mammals: North Atlantic right whales (*Eubalaena glacialis*), fin whales (*Balaenoptera physalus*), minke whales (*Balaenoptera acutorostrata*), humpback whales (*Megaptera novaeangliae*), and blue whales (*Balaenoptera musculus*). All 5 taxa produce species-specific vocalizations, and have been the subject of intensive study through passive acoustic monitoring by the Bioacoustics Research Program at Cornell University, with many automated data processing routines in place for the identification of their vocalizations (e.g., Urazghildiiev & Clark 2006; Urazghildiiev & Clark 2007a; Urazghildiiev et al. 2009). Of these species, the North Atlantic right whale is the most heavily endangered, with approximately only 500 individuals remaining (Kraus et al. 2005), thus understanding the occurrence of this species is critical.
The specific scientific objectives of the project presented here include:

1) Determine the occurrence and relative distributions of acoustically active right whales.
2) Determine the hourly occurrence of acoustically active fin whales.
3) Determine the daily occurrence and relative distributions of acoustically active humpback whales, blue whales, and minke whales.
4) Document the ambient noise environment throughout the MA WEA.

Sound Recording Methods

Recording System

Acoustic data were collected using marine autonomous recording units (MARUs). A MARU is a digital audio recording system contained in a positively buoyant 17” glass sphere that is deployed on the bottom of the ocean for periods of weeks to months (Figure 1, Calupca et al. 2000). A hydrophone mounted outside the sphere is the mechanism for acquiring sounds that are recorded and these sounds are then stored in a binary digital audio format on internal electronic storage media. The MARU can be programmed to record on a specific schedule and deployed in a remote environment, where it is held in place by an anchor. At the conclusion of a deployment, the MARU is sent an acoustic command to release itself from its anchor and float to the surface for recovery. After the recovery, the MARU data are extracted, converted into audio files and stored on a server for analysis. The unit is then refurbished (batteries and hard drive replaced, etc.) in preparation for a subsequent deployment. Data recorded by a MARU are thus accessible only after the device is retrieved.

Figure 1. (A) External and (B) internal views of the Marine Autonomous Recording Unit (MARU) used for sound data recordings in this project.

Deployment and Recovery of MARUs

MARUs recorded sound in an array of 6 sites distributed in areas in or near the MA WEA (Figure 2). The locations of the MARUs and the total area in which the MARUs are able to detect sounds are hereafter referred to as the “survey area”. MARUs were anchored at depths ranging between 43 m and 59 m, and recording sites were between 12 km and 30 km apart from each other. The 6 MARUs were deployed at these 6 sites (hereafter referred to as the “MARU array”) in 2 deployment periods (Dep-01, Dep-02) from 10 November 2011 through 03 October 2012. MARUs in Dep-01 recorded sound from 10 November 2011– 25 April 2012

(Table 1). MARUs in Dep-02 recorded sound from 27 April – 03 October 2012 (Table 2). The sound data from April 26, 2012, was not analyzed due to the lapse in continuous recordings as a result of the scheduled swapping of MARUs between Dep-01 to Dep-02.

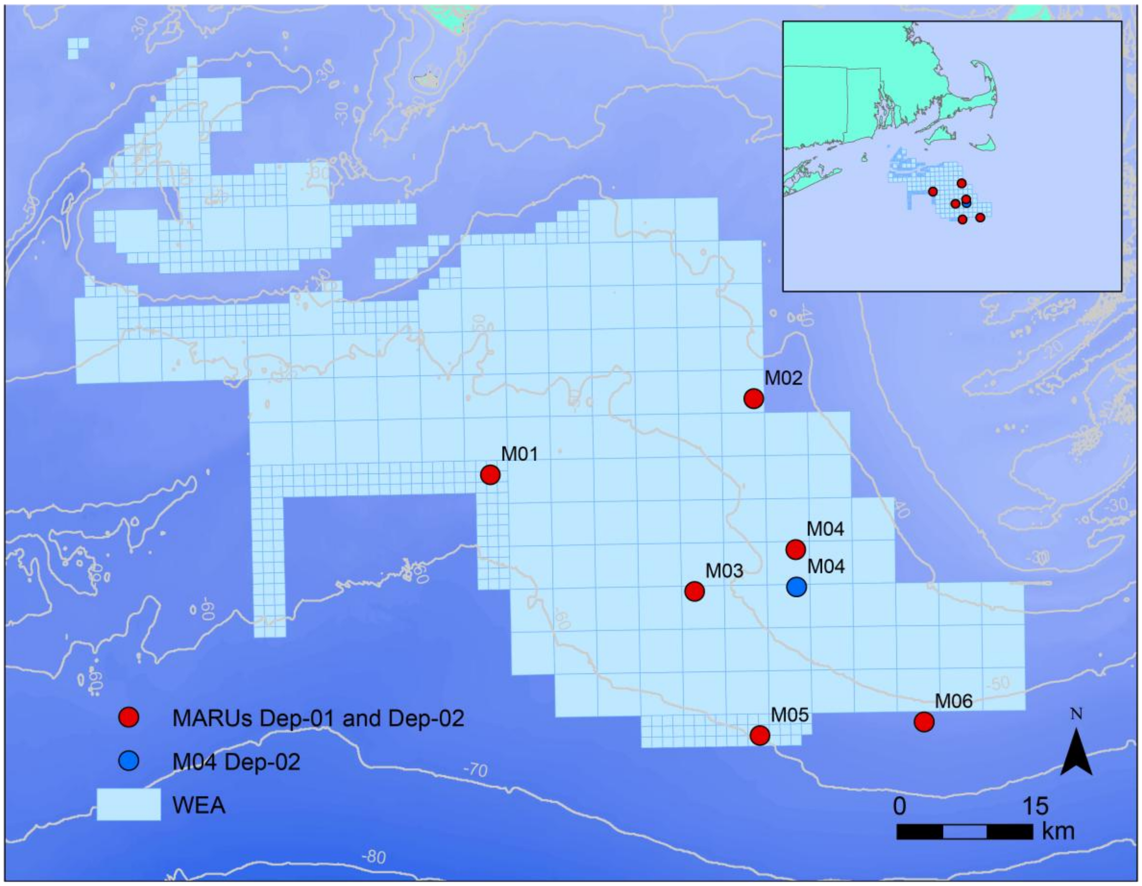


Figure 2. Map of MARU deployment sites. All locations remained the same through Dep-01 and Dep-02 (in red) except for the location of site M04 (as indicated on the map in blue). White lines represent isobaths in 10 m intervals. Both the MA and Rhode Island (RI) WEA are shown.

Table 1. MARU details for Dep-01.

MARU Site ID	Sample Rate	Depth (m)	Latitude (Decimal °)	Longitude (Decimal °)	Start Analysis Date	End Analysis Date	Total Days
M01	2 kHz	53.0	40.861153	-70.731355	11/10/11	04/25/12	168
M02	2 kHz	43.5	40.937497	-70.381737	11/10/11	04/25/12	168
M03	2 kHz	51.0	40.743865	-70.460382	11/10/11	04/25/12	168
M04	2 kHz	47.9	40.748645	-70.325957	11/10/11	04/25/12	168
M05	2 kHz	59.3	40.598968	-70.373767	11/10/11	04/25/12	168
M06	2 kHz	53.0	40.612642	-70.155803	11/10/11	04/25/12	168

Table 2. MARU details for Dep-02.

MARU Site ID	Sample Rate	Depth (m)	Latitude (°)	Longitude (°)	Start Analysis Date	End Analysis Date	Total Days
M01	2 kHz	53	40.861122	-70.730675	04/27/12	10/03/12	160
M02	2 kHz	43.5	40.937277	-70.381443	04/27/12	10/03/12	160
M03	2 kHz	51	40.74385	-70.460660	04/27/12	10/03/12	160
M04	2 kHz	47.9	40.748428	-70.325302	04/27/12	10/03/12	160
M05	2 kHz	59.3	40.598985	-70.374470	04/27/12	10/03/12	160
M06	2 kHz	53	40.61281	-70.156442	04/27/12	10/03/12	160

MARU Settings

MARUs were programmed to record continuously at a sampling rate of 2 kHz. 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. MARUs recorded for 168 days in the first deployment, after which point they swapped with new MARUs to result in near continuous recordings from 10 November 2011 to 03 October 2012 (328 days).

Data Processing

Sound data from the MARUs were extracted and converted into continuous sounds files containing all 6 MARUs. Figure 3 shows a 2-minute spectrogram of all 6 MARUs. During this particular time period, minke, fin, and humpback whales were vocalizing simultaneously. A total of 47,232 hours of sound data were recorded and analyzed. Unless otherwise noted, all times are represented in Greenwich Mean Time (GMT).

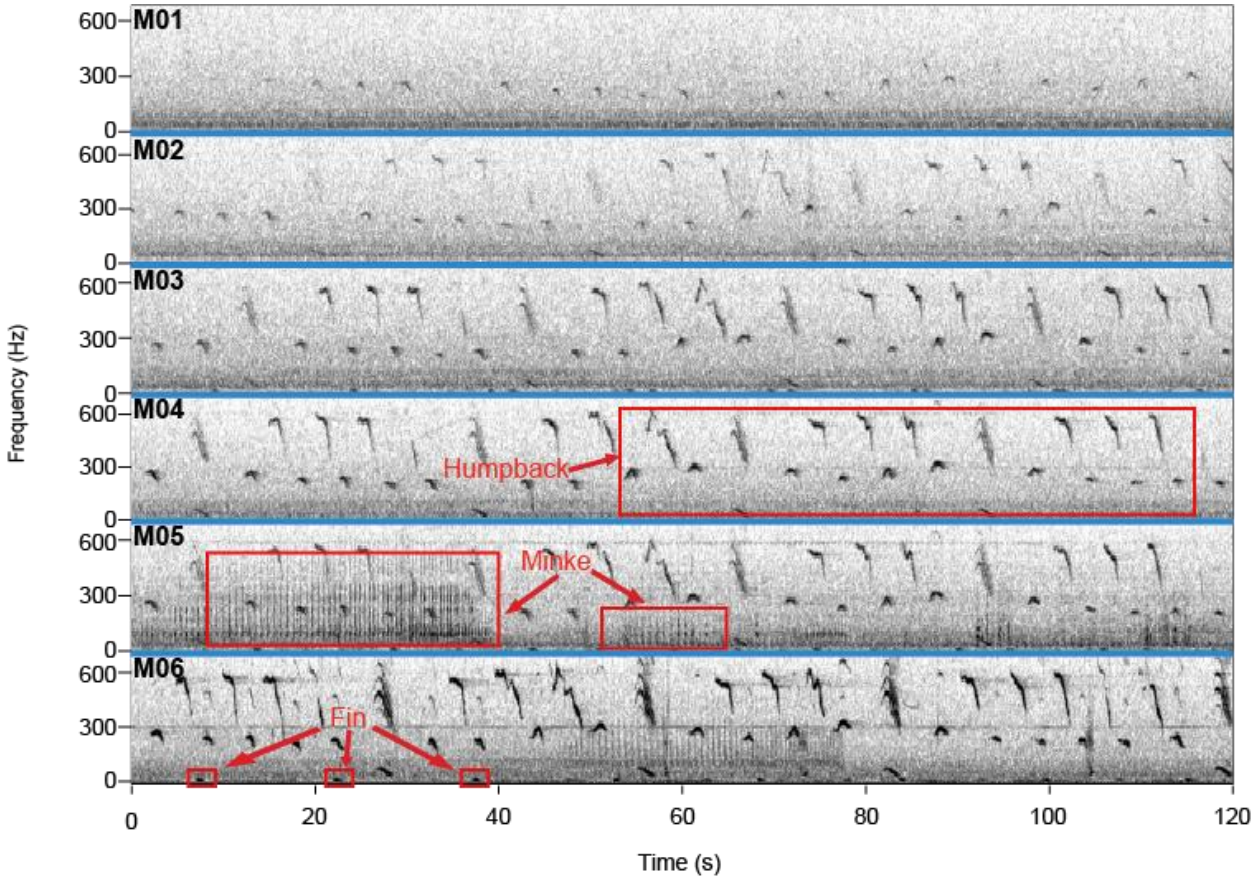


Figure 3. A representative two minute duration spectrogram of all 6 MARUs deployed in the project area on 16 March 2012. As identified in the figure, three species of whale (humpback, minke, and fin) were vocalizing during the same 2 minute period.

Sound Analysis Methods

Determination of Species Presence

The determination of presence of a whale species depended on the ability to identify characteristic vocalizations in the audio data for each of the 5 focal species. In this analysis, a confirmed vocalization of a whale species meant at least one or more individuals of that species was present at that time. This analysis did not attempt to determine the number of animals vocalizing, as it is impossible to determine if one whale is calling one hundred times, or one hundred whales are each calling once, and calling rates are not known for most species. Also, the absence of species vocalizations did not confirm that one or more whale species were absent during that time, but could have also indicated 1) a whale was present but not vocalizing, or 2) a whale was present and vocalized but the sound was not recorded by the hydrophone due to amplitude, propagation, or other issues (following Mellinger et al. 2007). The confirmed vocalizing of one or more whales is referred to as *acoustic presence* in the remainder of this report.

The detection range or listening area of a species is the distance a specific type of vocalization can propagate and be recorded by a hydrophone. Calculation and modeling of a detection range for a hydrophone is dependent on several known environmental parameters specific to the recording area, and the source level of the vocalizing whale. The determination of detection ranges specific to the MARU array was beyond the scope and budget of this project. However, in place of an extensive modeling effort, detection ranges for each species are inferred based on previous research. The following list gives an estimate of the potential distances a whale species may be from a recorder, but still record their sounds. These are estimates based on site conditions, source levels, and performance of hydrophones specific to the studies that are cited. The purpose of these estimates is to understand that some recorded vocalizations may have originated inside or outside of the MA WESA.

- Right whale calls: up to 25 km (Laurinolli et al. 2003)
- Humpback whale song: 12-29 km (Stafford et al. 2007; Clark & Clapham 2004)
- Minke whale “boings” (not pulse trains): up to 25 km (Martin et al. 2013)
- Fin whale 20-Hz notes : >100 km (Payne & Webb 1971; Širovic et al. 2007)
- Blue whale song: >100 km (Payne & Webb 1971; Širovic et al. 2007)

The MARU array was configured to be able to record vocalizations from within the MA WESA, but may also record vocalizations from farther outside the MA WESA. Figure 4 shows the MARU array in relation to the MA WEA. Reference lines were added at two distances from the MARU array to be able to compare the MA WESA with estimated detection ranges for the different species mentioned above. The red line represents a 25 km boundary around the MARU array where all five whale species’ vocalizations could be detected under low ambient noise conditions. Based on the literature (referenced above), vocalizations from right, minke, and humpback whales may not be recorded beyond this 25 km range. The black line represents a 50 km boundary around the MARU array. According to the literature, a fin whale and blue whale may be detected outside of this 50 km range.

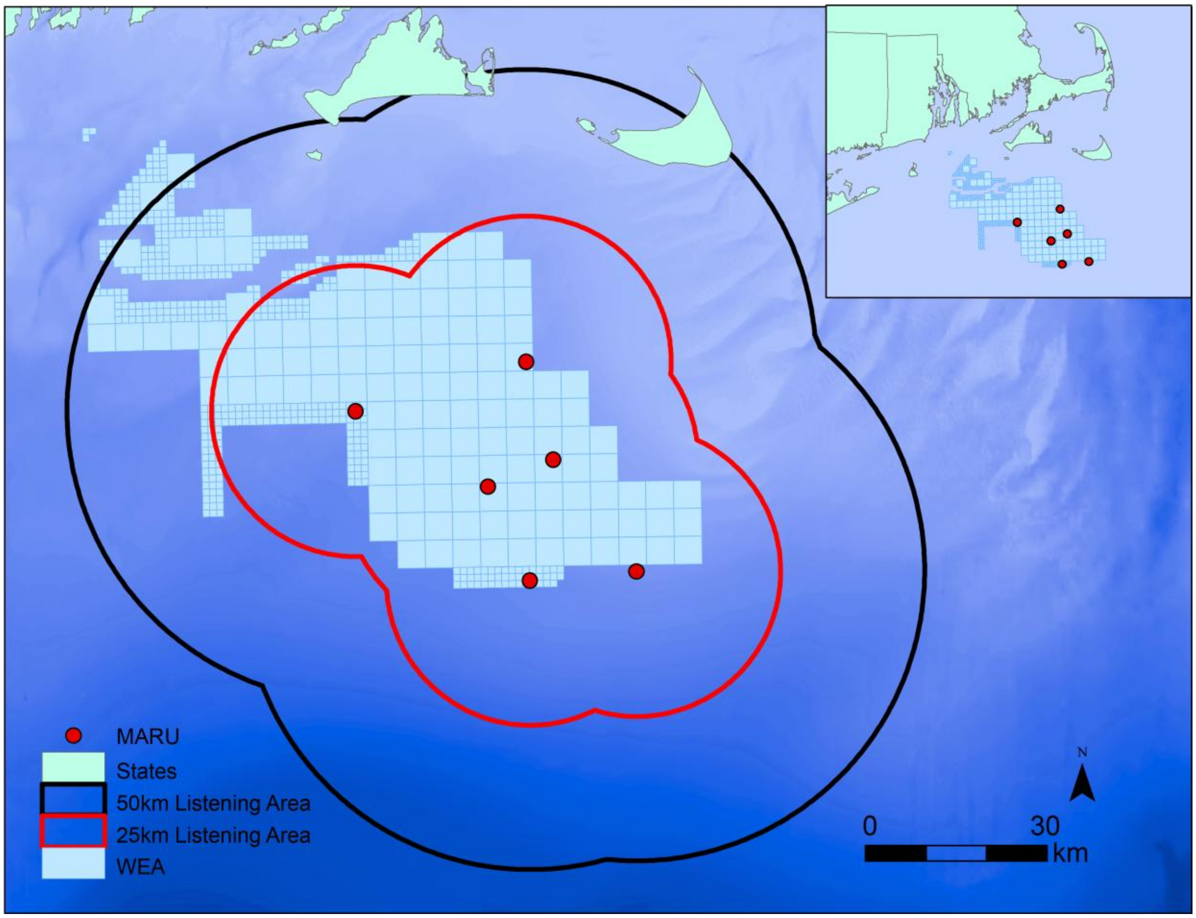


Figure 4. Map showing potential estimated listening areas at 25 km (red line) and 50 km (black line) from the MARU array, based on the published or theoretical properties of the propagation range of calls from the focal species of interest. However, it should be noted that the detection range of the MARUs will be influenced by weather, changes in background noise levels (both environmental and anthropogenic), level of depth and position of the vocalizing whales, and whale source levels.

Species Identification

The identification of each species was accomplished by either (1) automated detectors trained in detecting specific sounds with verification by trained human analysts, or by (2) visual inspection of the sound by trained human analysts without the aid of an automated detector. The sections below describe the methods by which each species of whale was identified to determine acoustic presence.

The temporal and spatial resolution at which the acoustic presence of each species was determined varied depending on a number of factors, including the availability of automated detectors, characteristics of species vocalizations, and in the case of right whales, our desire to collect finer resolution of acoustic presence information because of their endangered status under the Endangered Species Act (Kraus et al. 2005).

Table **3** provides a summary table of the temporal and spatial resolution of acoustic presence that was determined for each whale species in this analysis.

Table 3. Temporal and spatial data collection resolution of acoustic presence

Whale Species	Temporal Resolution	Spatial Resolution
Right Whale	Instantaneous	Determined acoustic presence at each MARU
Fin Whale	Hourly	MARU array[1]
Minke Whale	Daily	MARU array[1]
Humpback Whale	Daily	MARU array[1]
Blue Whale	Daily	MARU array[1]

[1]*MARU array* indicates that acoustic presence was determined by finding a vocalization at any one of the 6 MARUs in the array, not at each of the 6 individual MARUs.

Acoustic Presence by Automated Detectors

Right whale

The acoustic presence of right whales was determined by using software that automatically detects right whale contact calls. Contact calls (example, Figure 5) are the most common calls produced by right whales (Clark 1982; Parks & Tyack 2005; Parks & Clark 2007), and are used frequently to determine acoustic presence of right whales in an area (Clark et al. 2007; Mellinger et al. 2011; Morano et al. 2012a; Mussoline et al. 2012). The detector was used to find contact calls recorded on all 6 channels (a channel referring to recordings from a single MARU) for the entire sampling period. All detections were then reviewed by human analysts to determine any instance in which a right whale was producing contact calls, and to ensure that no false positive detections were included in the analysis.

The automated detection process consisted of two stages. In the first analysis stage, the 6-channel MARU data were processed by a customized, Matlab-based right whale detection algorithm referred to as ISRAT (Urazghildiiev & Clark 2006; Urazghildiiev & Clark 2007a; Urazghildiiev & Clark 2007b; Urazghildiiev et al. 2009). The result of this stage was a file containing all potential ISRAT-detected right whale contact calls. For the second stage, the detections from ISRAT were configured to operate in conjunction with the interactive sound visualization tools provided by the Raven Software package (Bioacoustics Research Program 2011). The ISRAT-detected right whale contact call events were carefully evaluated in Raven by analysts with expertise in the recognition of whale sounds. To distinguish right whale contact calls from humpback vocalizations, analysts used a number of spectrographic characteristics including frequency and duration, concentration of energy within the calls, arrival patterns (following Urazghildiiev et al. 2009), contextual information of humpback and right whale acoustic presence in and around the period when the call was detected, as well as the aural characteristics of the detected sound.

In analyzing the detections in Raven, a specialized viewing tool was implemented to allow the user to simultaneously view both thumbnail spectrogram views of the detected event and a larger context view of the spectrogram. The context view included additional time before and after the event from all 6 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 for the thumbnail view 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 90-seconds, frequency range of 10-450 Hz, and FFT size and window setting of 512. The occurrences of confirmed right whale contact calls were used to complete the task of determining right whale instantaneous presence near each of the 6 MARUs.

In some instances, the contact call could have been produced with enough intensity and from a location in the array that could cause a single contact call to have been recorded on multiple MARUs. To eliminate this pseudoreplication of a contact call and thus over-estimating right whale acoustic presence in our analyses, analysts reviewed all contact calls that were automatically detected as described above, but recorded only the first arrival of the contact call (following Morano et al. 2012a). In addition to preventing the pseudoreplication of acoustic presence, recording only the first arrival of a contact call also provided information on the approximate location of the calling right whale as being within the recording radius of the nearest MARU to where the call was detected.

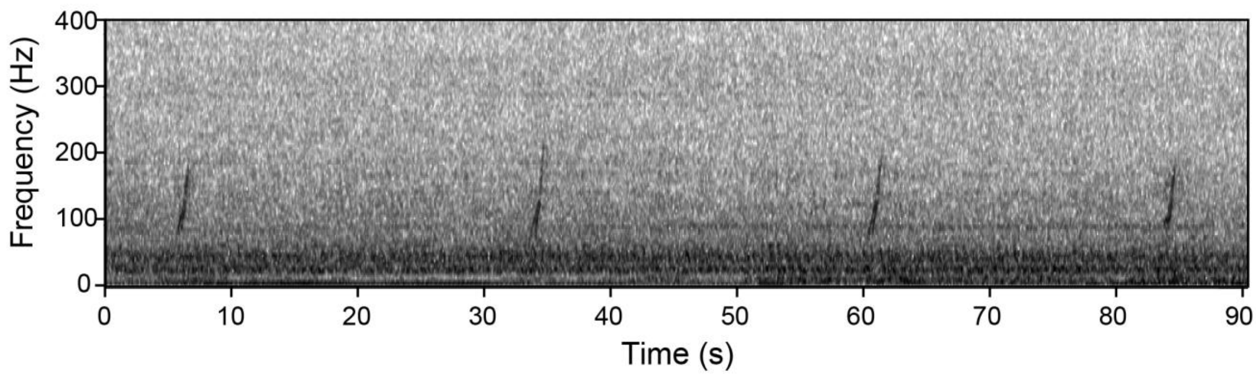


Figure 5. A 90-s spectrogram showing an example of four right whale contact calls recorded on M02 on 14 May 2012.

Fin Whale

The occurrence of fin whale song, which is comprised of a series of 20-Hz notes, was the basis for determining if a fin whale was present on any one or more of the 6 MARUs on an hourly basis for each day (Watkins et al. 1987; McDonald et al. 1995; Clark et al. 2002). Figure 6 shows an example of a series of 20-Hz notes that are part of a fin whale song. Because of the high amplitude and propagation distance of the fin whale song (Payne & Webb 1971; Širovic et al. 2007), the resulting arrival of the same sound on multiple MARUs, and the long duration of the songs (typically 1-20 min., Watkins et al. 1987), determining the first arrival of a song was not completed and therefore the estimated location of the animals within the array was not determined.

To identify 20-Hz notes in an automated way, XBAT (eXtensible BioAcoustic Tool, Bioacoustics Research Program 2012) matched-filter data template detector was applied to the acoustic data from all 6 MARUs in the array. The detector is trained using multiple exemplars of 20-Hz fin notes and is able to detect sounds with similar characteristics. Each detected

sound is given a match-filter score based on its similarity to the characteristics of the exemplars. The 10 acoustic events with the highest matched-filter score for each hour of data on any one of the 6 MARUs in the array were then evaluated by expert analysts using the interactive sound visualization tools provided by the Raven software environment.
The detections were reviewed in Raven, as described for right whales (see above). 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 fin whale hourly acoustic presence in the array.

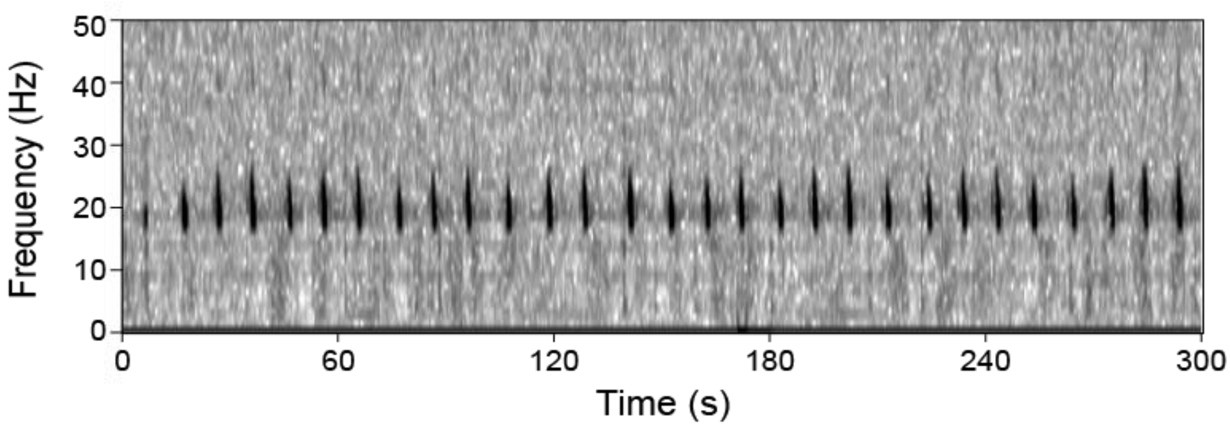


Figure 6. A 300-s spectrogram showing a segment of fin whale song recorded at M01 on 16 March 2012. The song shown in this figure is characterized by a long sequence of 20-Hz notes occurring at regular intervals of *ca*. 11-seconds.

Minke Whale
The occurrence of minke whale pulse train vocalizations was the basis for determining if a minke whale was present on any one of the 6 MARUs on a daily basis during the sampling period (Mellinger et al. 2000). Figure 7 shows an example of a minke whale pulse train. An automatic detection procedure was applied to the 6-channel MARU acoustic data in order to identify minke pulse train vocalizations. The automatic detection was implemented in a high performance computing (HPC) platform using a custom built algorithm that operates within Matlab R2012b (Dugan et al., in prep.). The algorithm comprised the following stages: digital signal processing/signal conditioning of acoustical sound data, transformation to the spectrogram domain using Short-Time Fourier Transform (STFT), detection of vocalizations using region of interest (ROI) image and projection processing, feature extraction of the identified area, and finally classification of detected signatures. These stages were applied to the acoustical data at 30-second frames and when a minke vocalization was detected it was marked as an event in the spectrogram. These events, which represented possible pulse trains, were evaluated by trained human analysts using the interactive sound visualization tool provided by the Raven software environment.

The detections were reviewed in Raven, as described for right whales (see above). 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 trains were used to complete the task of determining daily acoustic presence in the array.

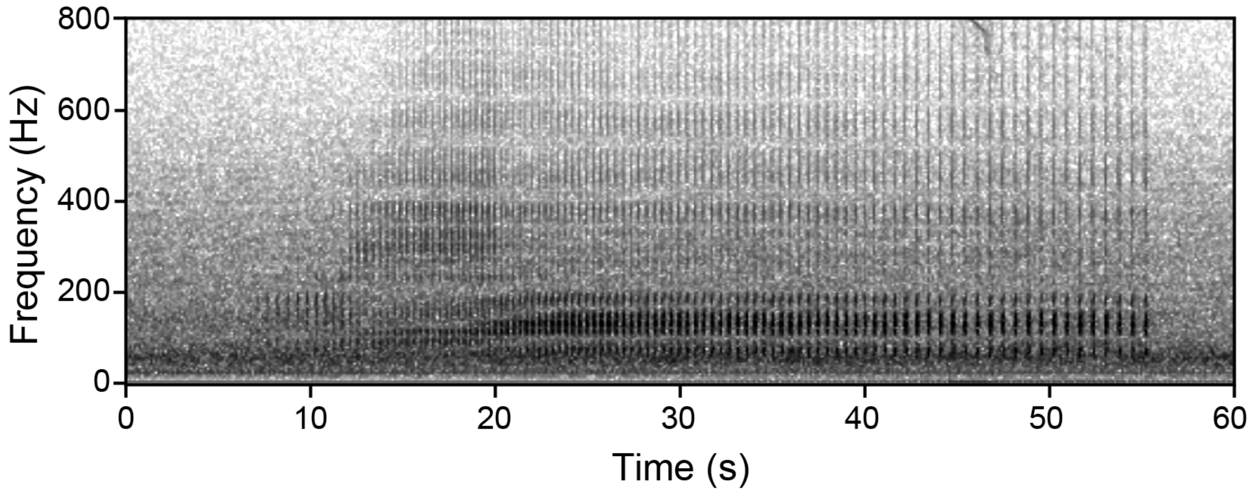


Figure 7. A 60-second spectrogram showing an example of a minke pulse train recorded at M03 on 20 March 2012.

Acoustic presence by Visual Inspection

Humpback Whale

The humpback whale acoustic presence task was accomplished by detecting the occurrence of humpback whale sounds on any one of the 6 MARUs for each day of analysis. Humpback whales produce a complex and variable suite of vocalizations that are difficult to successfully and consistently detect in an automated way. Because of this, humpback vocalizations were investigated by visual inspection of the entire sound stream. There were two major types of humpback whale calls considered: songs and social calls, as shown in Figure 8 and Figure 9. Figure 8 shows an example of a series of humpback whale calls that are part of a humpback whale song (Payne & McVay 1971; Cholewiak et al. 2012), and Figure 9 shows examples of humpback whale social calls (Silber 1986; Chabot 1988).

Two procedures were used for the humpback whale detection analysis, neither of which made use of a humpback-specific automated detection process. In the first procedure, analysts took advantage of the fin whale and right whale auto-detection efforts. During the course of these analyses, any opportunistically identified and confirmed instances of humpback whale sounds were noted and used to complete the task of determining daily acoustic presence for humpback whales on any one of the MARUs in the array. If during the fin or right whale analyses there was no detection of a humpback whale call on a particular date, then a second procedure was conducted. In the second procedure, analysts used Raven to browse through the 6 channel spectrogram display to search for humpback whale species-specific sounds throughout the day using a 10-minute spectrogram window duration, frequency range of 10-600 Hz, and a FFT size and window setting of 512. When an instance of either a humpback song or social call was identified on any one of the 6 MARUs for that day, the analyst marked the vocalization for acoustic presence and moved to the next day. The occurrences of confirmed humpback whale song or social calls were used to complete the task of determining daily acoustic presence in the array.

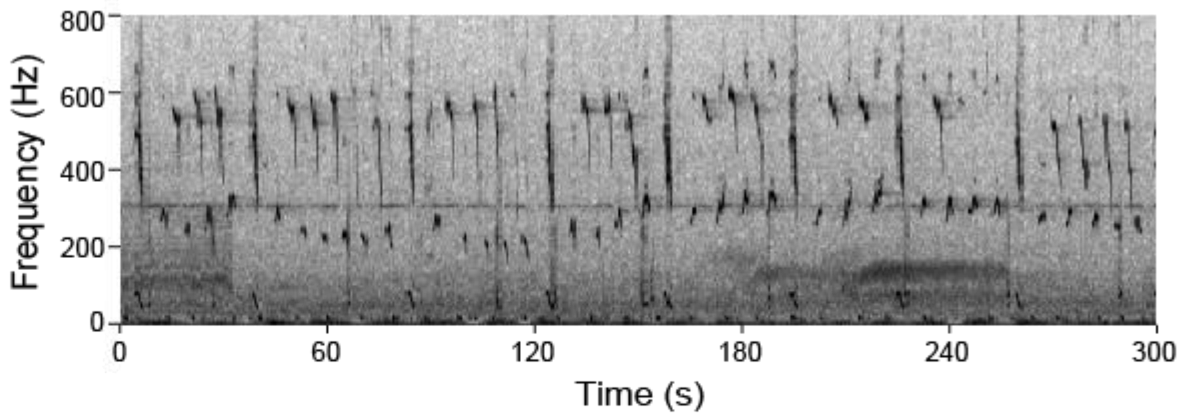


Figure 8. A 5-minute spectrogram recorded at M06 on 16 March 2012 showing characteristic repeated sound patterns in a segment of humpback whale song. Also visible in this spectrogram are fin whale 20-Hz song notes at the bottom of the spectrogram.

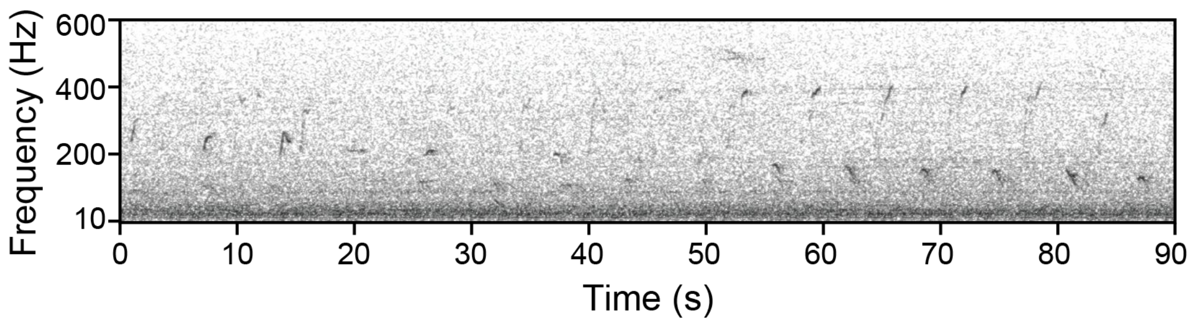


Figure 9. A 90-second spectrogram showing several humpback whale social calls at M06 on 30 April 2012.

Blue Whale

The occurrence of blue whale song was the basis for determining if a blue whale was present on any one of the 6 MARUs on a daily basis during the sampling period. Blue whale song was characterized by sequence phrases between 15 and 20 Hz (Mellinger & Clark 2003) (Figure 10). 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 resampled version of the data from the original 2000 Hz down to 100 Hz. The resampling 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 at approximately 17-18 Hz (Figure 10). Analysts then used the interactive sound visualization tools provided by the Raven 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. The occurrences of confirmed blue whale song were used to complete the task of determining daily acoustic presence in the array.

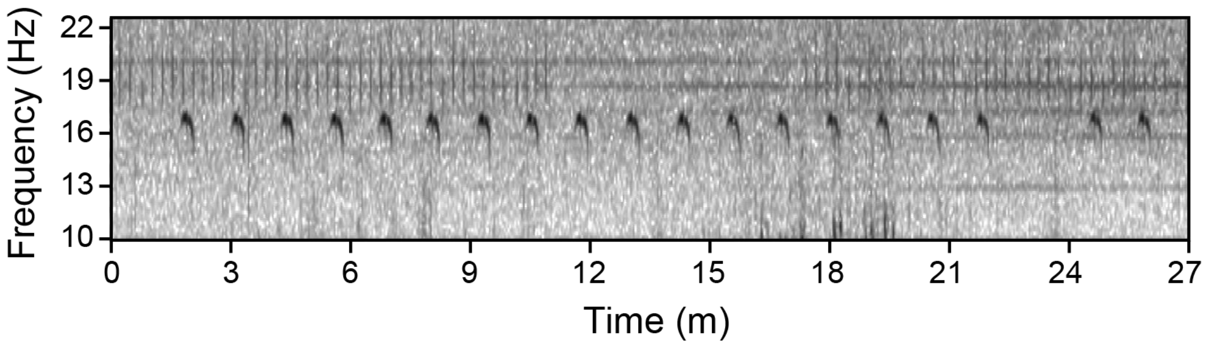


Figure 10. A 27-minute spectrogram showing an example of a blue whale song recorded at M04 on 23 December 2011.

Data Synthesis

Monthly Acoustic presence (% days/month) for All Species

Once the identification of the 5 species was accomplished as described in section 3.2, the species acoustic presence information was synthesized and converted to examine the data at different temporal and spatial scales. The instantaneous acoustic presence information collected for right whales and the hourly acoustic presence data collected for fin whales was converted to daily acoustic presence to allow for comparisons to minke, humpback, and blue whale daily acoustic presence. In this way, the daily acoustic presence of all 5 species was determined for the entire project period. Daily acoustic presence indicated that one or more whales were present within the MARU array and produced a recordable call. Daily acoustic presence was then converted to monthly acoustic presence for each month. The percentage of time that whales were detected per month, was referred to as the "monthly acoustic presence", and calculated as follows:

$$\text{Monthly acoustic presence} = \frac{Number\ of\ days\ per\ month\ with\ acoustic\ presence}{Number\ of\ days\ recorded\ per\ month} \text{ x } 100$$

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

Right Whale Vocal activity and Diel Occurrence

The higher resolution acoustic presence information collected for right whales was used to analyze their (1) daily and monthly vocal activity and (2) diel vocal activity. Looking at the right whale vocal activity is different than acoustic presence in that it not only provides information about whether a right whale is present, but also provides information on when and how often right whales are vocalizing. To compare the vocal activity of right whales over time on a daily basis, the total number of detected first arrival contact calls was summed for each day and analyzed. To compare the vocal activity of right whales over time on a monthly basis, the total number of detected first arrival contact calls was summed for each month, with acoustic presence normalized by the total number of days sampled in each month (the number of contact calls divided by the number of days sampled). The diel pattern was determined by calculating the total number of first arrival calls detected within each hour for all days analyzed. Times in the diel analysis are reported in Eastern Standard Time (EST) zone, with no correction for Daylight Saving Time.

Spatial Acoustic presence for Right Whales

Additional analysis was performed for right whales to understand which MARU right whales were closest to when vocalizing in the survey area. The MARU where the contact call arrived first was considered to be the closest location to where the right whale was at the time of the vocalization. The total number of first arrival contact calls at each MARU was summed for the entire sampling period to determine where the most first-arrival contact calls occurred in the array.

Fin Whale hourly acoustic presence

The higher resolution of acoustic presence information collected for fin whales (hourly acoustic presence in the array) was used to determine the number of hours of vocal acoustic presence per day. To compare changes in the number of hours of acoustic presence per day over time, the total number of hours with fin acoustic presence in each day was summed.

Ambient Noise Analysis

Sound is a critical component of the broader marine environment, and many, if not most, marine animals use sound in different aspects of their life history. 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 (for example, see reviews by Wenz 1962; Wenz 1972; 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 (e.g., 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.

Acoustical Signal Processing

Acoustic data were processed using the Noise Analysis tools within the SEDNA toolbox for Matlab (Dugan et al. 2011) using a Hann window, a FFT size of 2048 samples, a time resolution of 10.24 seconds, a frequency resolution of 0.98 Hz, and a recorded sample rate of 2 kHz. For the ambient noise analysis, 3 different visual representations of sound were used: (1) frequency vs. time (spectrogram), (2) 1/3rd octave frequency band vs. time (1/3rd octave) and (3) power vs. frequency (power spectra).

Spectrograms

Spectrograms represent sound data with frequency as a function of time and amplitude represented by a color scale (Figures 19-34, Panel A). Long-term spectrograms that span the duration of the analysis period for Dep-01 (168 days) and for Dep-02 (160 days) were created for each MARU using 1-hour integration time slices and a FFT of 2048 samples. For particular days of interest on specific channels (n=4), long-term spectrograms comprising of a 24-hour period were generated using 2-minute integration time slices and a FFT of 2048. These days of interest (refer to Section 4.6.2 for detail) included a day with low overall acoustic activity (11

November 2011), a day with high levels of biological acoustic activity (20 March 2012), a day with high levels of anthropogenic acoustic activity (28 May 2012), and a day with overlapping biological and anthropogenic acoustic activities (14 March 2012). The frequency scale for these long-term spectrograms is linear with frequencies between 0-1 kHz. The color scale in the spectrogram ranges from blue (lower dB levels) to red (higher dB levels).

1/3rd Octave Bands

Traditional signal processing methods use the approach of dividing up the acoustic signal into bands, which divides the spectrum into smaller individual bands (based on octaves) for analysis. This reduces the amount of data being analyzed for greater ease in processing and interpretation (Peterson & Gross 1978). Dividing the sound into third octave bands is also useful when looking at noise in a biological context. Third octave bands are commonly used for two principal reasons: (1) use of these bands cover a 10-to-1 frequency range, and reduces the amount of time required for computation and processing (Peterson & Gross 1978) and (2) the function of the mammalian ear can be approximated as a set of bandpass filters with a sensitivity of approximately $1/3^{rd}$ of an octave (Richardson et al. 1995; Madsen et al. 2006). The acoustic data for this project was post processed to produce figures that show the noise at the $1/3^{rd}$ octave frequency bands (3rd OBC Freq) between 10-708 Hz as a function of time (Figures 19-34, Panel B). The color scale for the $1/3^{rd}$ octave figures, which indicates changes in amplitude, match the color scale used for the spectrograms mentioned above.

Power Spectral Density

The power spectral density illustrates relative sound levels as a function of frequency (Figures 19-34, Panel C). Data are represented using a spectral series of lower 5^{th}, median 50^{th}, and upper 95^{th} percentiles. The spectral series relates the relative sound level (power) to a frequency value based on the relative ambient noise measurements within the sound data. The 5^{th} percentile represents the relative sound level in which 5% of the ambient noise falls under in a given frequency in the data set. The 50^{th} percentile represents the relative sound level in which 50% of the ambient noise falls under in a particular frequency. The 95^{th} percentile represents the relative sound level in which 95% of the ambient noise falls under in a given frequency. In order to understand the variation in relative sound levels and frequency distribution across the project area, we generated power spectral densities for all 6 MARUs for the duration of Dep-01 and Dep-02, and for the four 24-hour days of interest.

Results

Monthly Acoustic Presence (% days/month) for All Species

All 5 focal species were observed during the recording period, but showed differing patterns of acoustic presence over the year. Figure 11 presents the monthly acoustic presence (percentage of days in each month, normalized for the recording effort) for all 5 whale species. Right, minke, and humpback whales show similar seasonal patterns of monthly acoustic presence, with an increase in acoustic presence in the spring months of March and April, and a decrease in the summer months of June and July. Fin whale was the species most acoustically present throughout the sampling period with 100% monthly acoustic presence for 8 out of the 12 months sampled. The highest monthly acoustic presence for right, fin, minke, and humpback whale occurred in March with acoustic presence on >80% of the days sampled. The lowest monthly acoustic presence for these same 4 species occurred in the months of June and July with acoustic presence on <46% of the days sampled. Fin whale and humpback whale were present in all of the 12 months sampled. Right whale was present in 8 out of the 12 months sampled. Minke whale was present in all months except December 2011 and October 2012. Blue whale was present the least of the 5 species, with monthly acoustic presence in 5 out of the 12 months sampled. Blue whale monthly acoustic presence occurred in the winter months (December 2011 through February 2012) and fall (August through October 2012). The highest acoustic presence for blue whale was in December 2011 (48%).

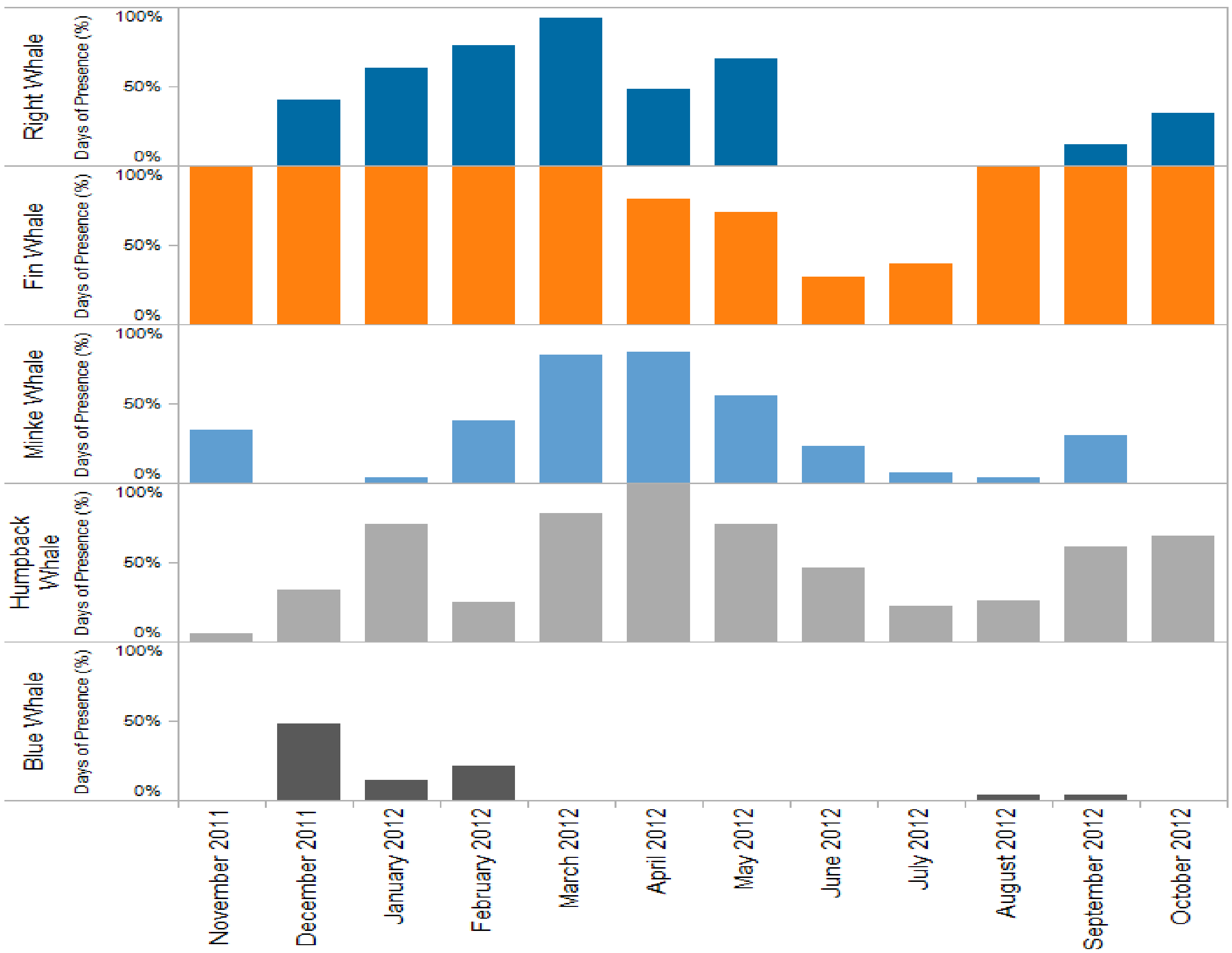


Figure 11. Percentage of days in each month that right whale contact calls, fin whale 20-hz notes, minke whale pulse trains, humpback song and social calls, and blue whale song were detected. The percentage is normalized for recording effort (the number of days with acoustic presence divided by the number of days sampled x 100).

Right Whale Vocal Activity and Diel Occurrence

A total of 6,149 first arrival contact calls were confirmed during the entire sampling period (n = 328 days). Of those, the day with the highest number of contact calls occurred on 25 March 2012, with a total of 563 calls (Figure 12). On a month-to-month scale, the highest number of contact calls occurred in March (3,598), accounting for 58% of the total number of contact calls out of the entire recording period. Three days in March (23-25 March 2012) had >400 calls on each day. Of the 328 total days of recordings (Dep-01, Dep-02), 123 days (37%) had at least 1 contact call and 205 days (62%) had 0 contact calls. There were no contact calls detected during the months of November 2011, and June through August 2012.

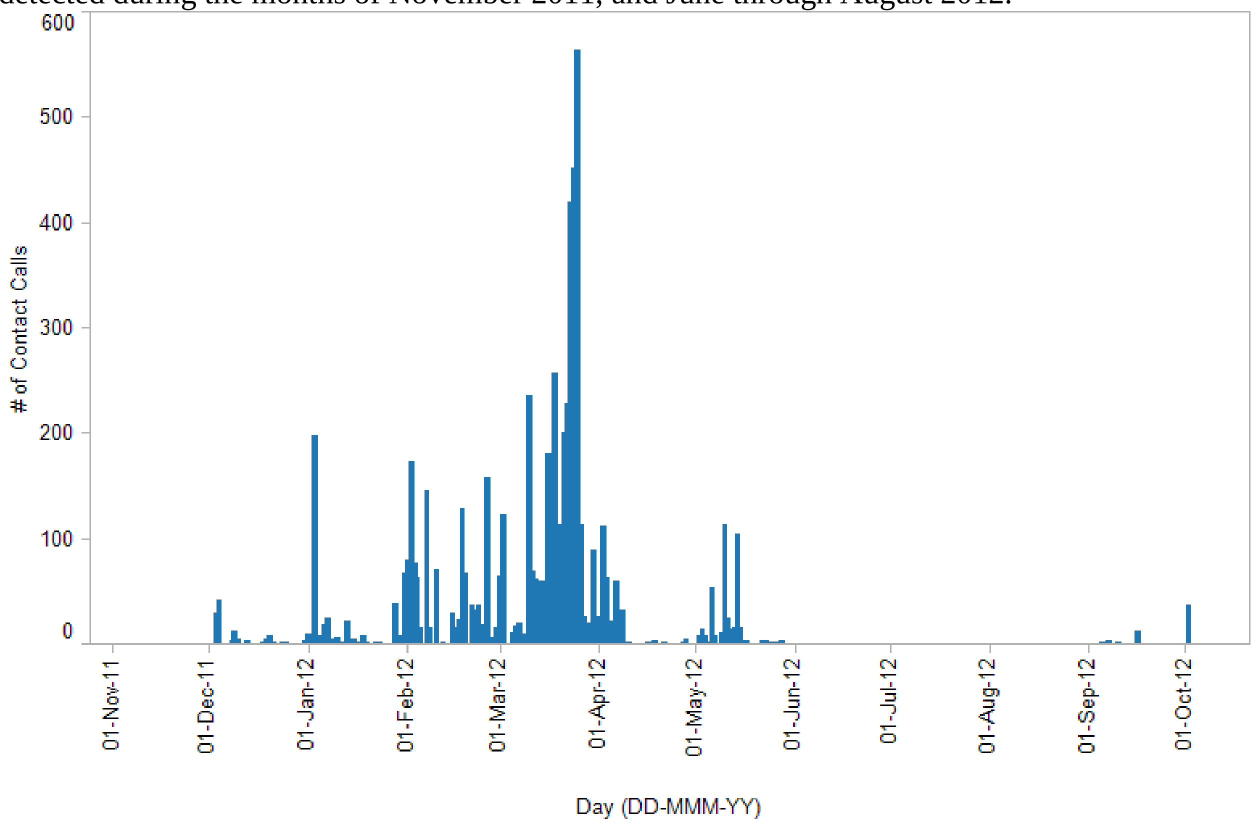


Figure 12. Total number of first arrival right whale contact calls in each day analyzed (10 November 2011 - 03 October 2012).

A similar pattern was observed when comparing monthly vocal activity normalized for days sampled (Figure 13). There was an increase in vocal activity from January to March 2012, peaking in March 2012 (n=116), and then a decrease in vocal activity from April through September 2012. A small increase occurred in the month of October 2012 (n=12) when compared to September. However, it should be noted that there were only 3 days of recordings in October 2012 prior to MARU retreival

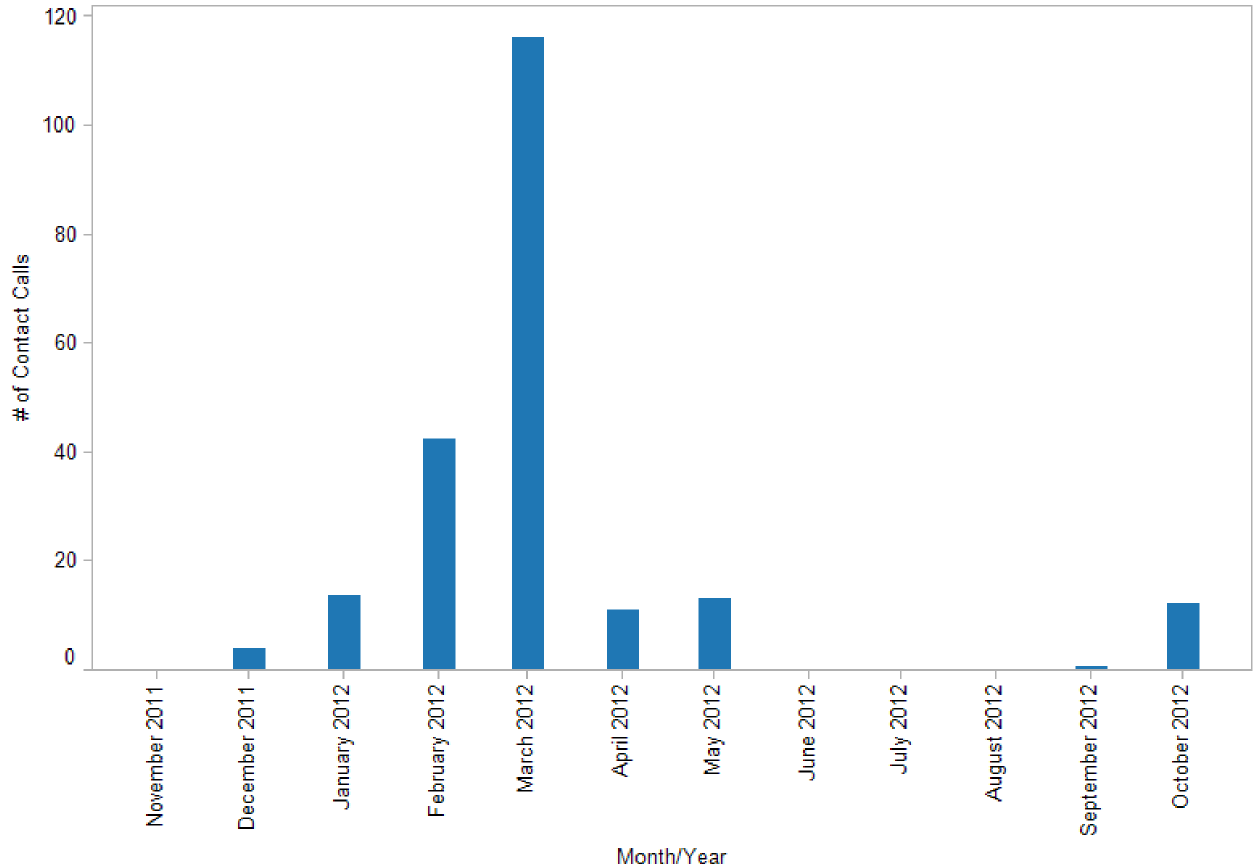


Figure 13. Total number of right whale calls in each month normalized for recording effort (number of calls divided by number of days sampled) for all days analyzed (10 November 2011 - 03 October 2012).

The analysis of diel vocal activity of right whales revealed a distinct vocalization pattern. Vocal activity was highest between 1700 and 2000 (Figure 14). Of the 6,149 contact calls detected in the sampling period, 2,045 (33%) occurred during these hours. The maximum number of calls occurred between 1800 and 1900 with 961 calls. Fewer than 100 calls were detected in each of the hours between 0700 and 1000.The minimum number of calls occurred between 0700 and 0800, with 86 calls.

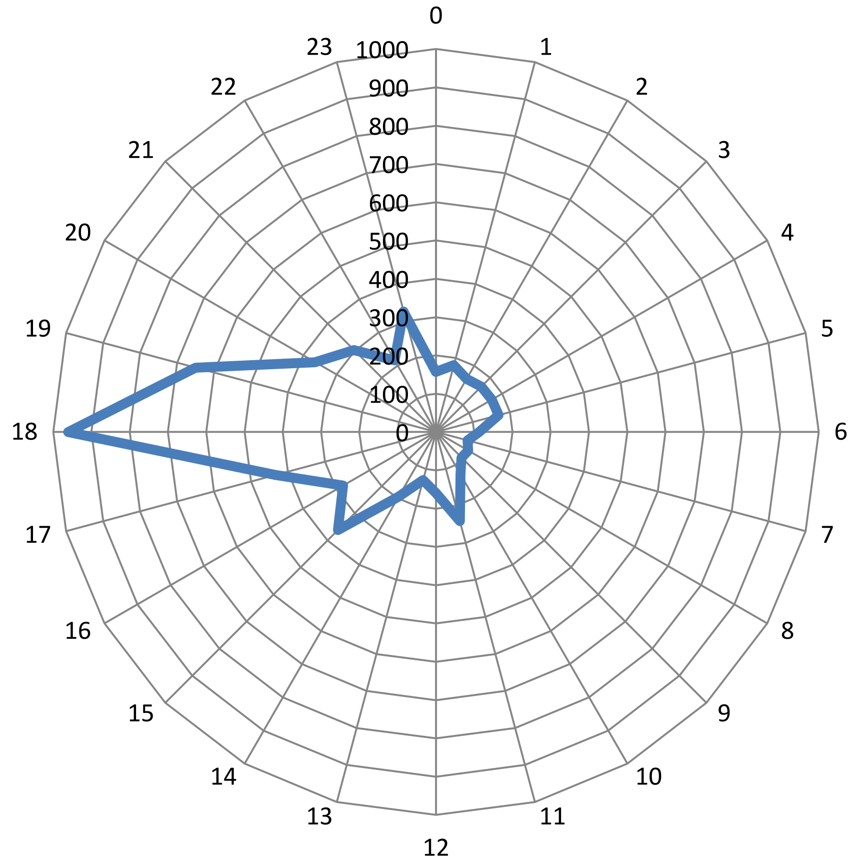


Figure 14. Number of right whale contact calls per hour (in EST) for all days analyzed (10 November 2011 - 03 October 2012). Radial axes show number of calls in increments as indicated.

Spatial Distribution of Right Whale Vocal Activity

Figure 15 shows the spatial distribution of right whale first arrival contact calls for the entire sampling period. Right whales were detected on all 6 MARUs in the array. The acoustic presence of right whales was greatest in the northeast corner of the array at Site M02 (3,161 calls), followed by Site M01 (1,689 calls) approximately 30 km to the southeast. The number of contact calls decreased at the sites in the southern end of the array, with the lowest number of contact calls occurring at Site M05 in the southwest corner (229 calls).

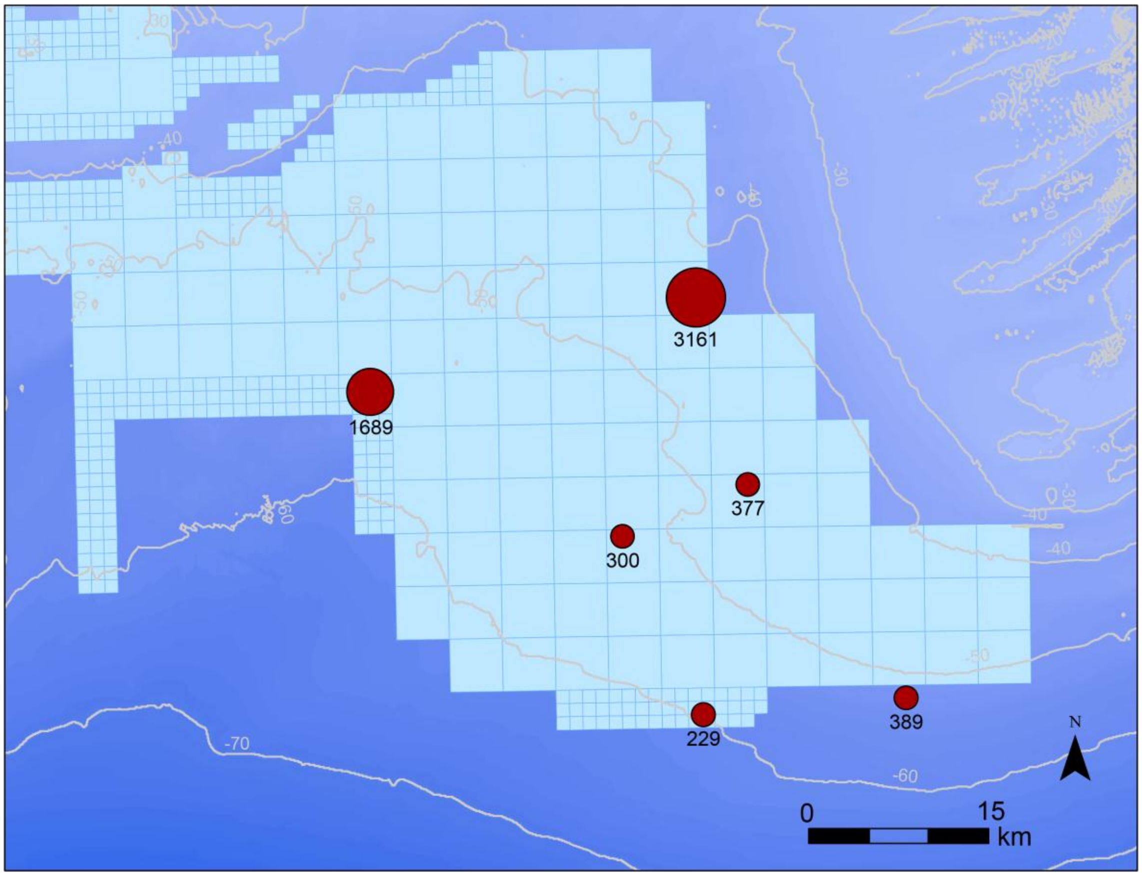


Figure 15. Number of first arrival right whale contact calls detected on each MARU for all days analyzed (10 November 2011 - 03 October 2012).

Fin Whale Hourly Acoustic presence

The hourly acoustic presence of fin whale 20-Hz notes varied seasonally (Figure 16). Acoustic presence was highest from mid-December through early April and lowest from mid-April through late July. There were a total of 52 days (16%) when fin whales were detected in all 24 hours of the day. There were a total of 55 days (17%) when there were no fin whales detected in any hour of the day. There were 113 days (34%) in the sampling period when fin whales were detected in 20 or more hours of the day.

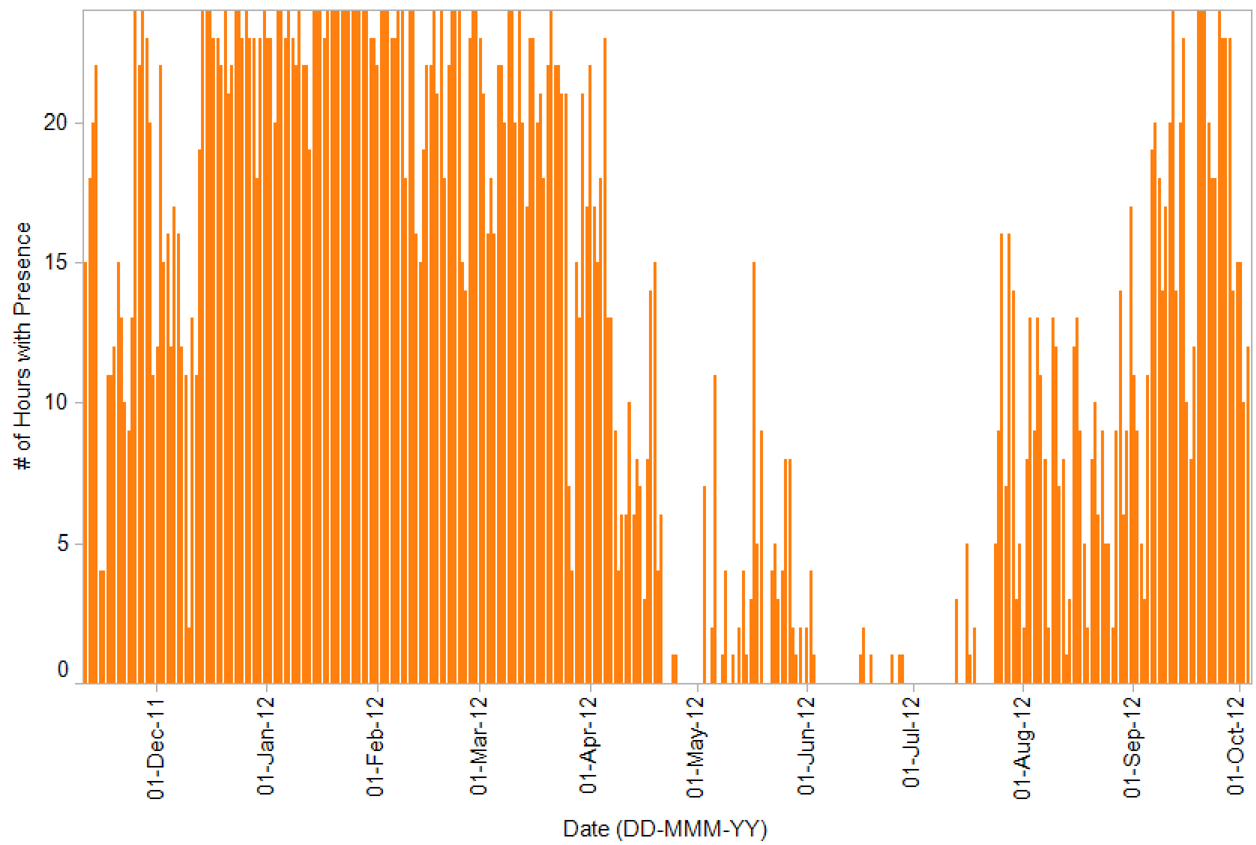


Figure 16. Number of hours in each day that fin whale 20-hz song was detected for all days analyzed (10 November 2011 - 03 October 2012).

Additional Species Identified

During the sound analysis of the 5 focal species, analysts identified additional marine mammal species of interest that were not a focus of this study. The identification of the vocalizations of species other than the 5 focal species was done opportunistically. If an analyst observed an identifiable vocalization from another species, a note was made in a tracking spreadsheet to be able to refer back to the day the vocalization occurred. The images below give examples of vocalizations from two species opportunistically observed during analysis: sei whale (Figure 17) and sperm whale (Figure 18). Additional biological sounds were observed but were not definitively identified. Examples of additional sounds include multiple low frequency tonal sounds and also sequences of low frequency pulses. The characteristics of these sounds indicate there may be additional marine mammal and/or fish vocalizations in the MA WEA.

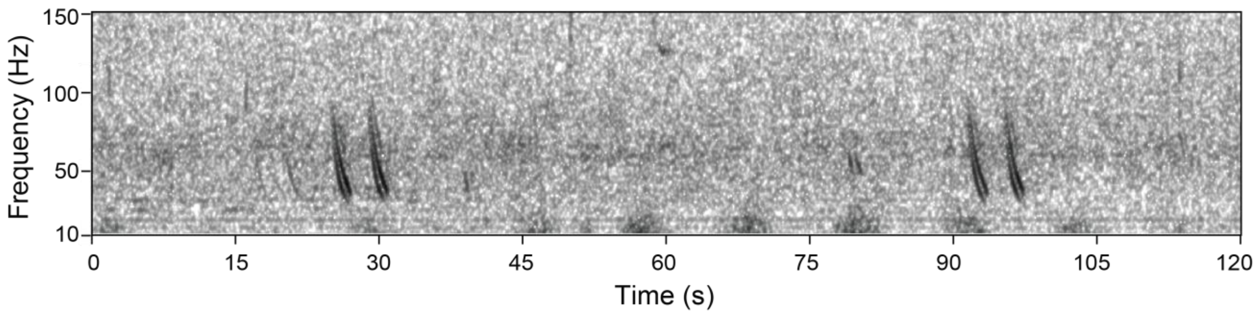


Figure 17. A 27-second spectrogram showing an example of a potential sei whale downsweeps (Baumgartner et al. 2008) recorded at M05 on 11 May 2011.

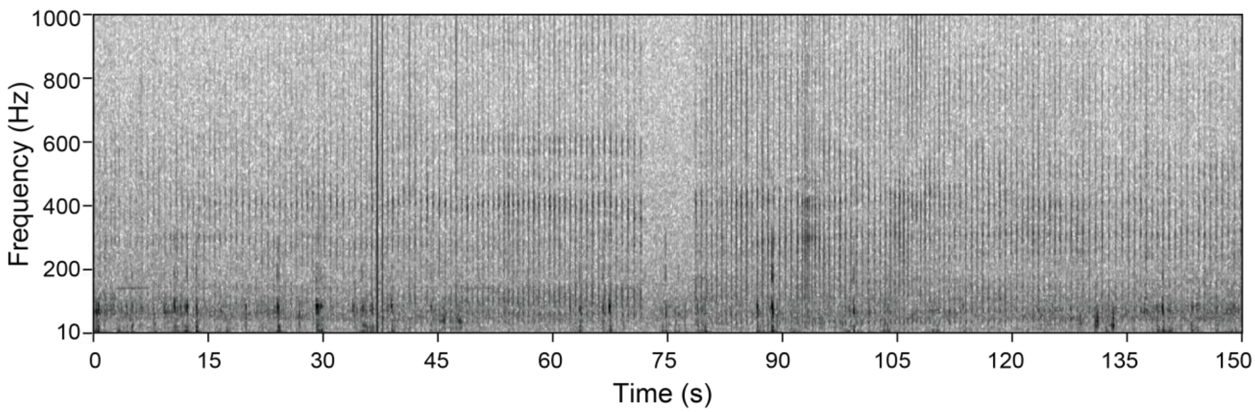


Figure 18. A 150-second spectrogram showing an example of a sperm whale click train (darker vertical pulses) (Watkins & Schevill 1977; Goold & Jones 1995; Newcomb et al. 2002) recorded at M01 on 09 September 2012.

Ambient Noise

Long-Term Ambient Noise Analysis for Dep-01 and Dep-02

The survey area represents a dynamic ambient noise environment, with noise contributions from a diverse biological community of vocalizing animals. Also present were periodic anthropogenic sources of sound that contributed at varying levels to the sound environment. In both deployments, MARUs that were stationed closer to the Ambrose-Nantucket Traffic Separation Scheme (TSS) recorded markedly louder ambient noise levels than those further from the TSS. When looking specifically at the 50 Hz frequency band (a frequency typically representative of shipping noise (Wenz 1962)), relative sound levels for MARUs M01 and M02 (located nearest to the shore) measured similarly at approximately 94 dB; relative sound levels for MARUs M03 and M04 measured an average of 100 dB; and relative sound levels for MARUs M05 and M06 (located nearest to the TSS) measured approximately 110 dB.

Noise activities in the lower frequency range (below 200 Hz), also increased in MARUs closer to the TSS, which is evident by the warmer colors of the spectrogram at M05 and M06 (Panel A, Figures 23, 24, 29, 30), and this increase remained relatively stable throughout the duration of the recording period. Acoustic events above 200 Hz showed little variation in sound levels between deployments, with the exception of the noise contribution of humpback whale song, which appears on spectrograms for M02, M03, M04, M05, and most prominently on M06 in mid-March of Dep-01 (Figures 19-24).

The spectrograms showing noise levels specifically in the 1/3rd octave frequency bands (Panel B) clearly illustrates the contribution of fin whale vocalizations to the overall ambient noise environment, visible in the 20 Hz frequency range throughout Dep-01. The loudest 20-Hz notes (represented by red color bars along the 20 Hz frequency band) occurred between December 2011 and February 2012 (Figures 19-24, Panel B). Peak relative sound levels (approximately 105 dB) at 20 Hz occurred on MARUs M04, M05 and M06 (Figures 22-24, Panel B), indicating that the fin whale vocalizations likely originated closest to those recording units. The humpback whale song in Dep-01 mentioned above is also visible in the 1/3rd octave figure as a contribution to the overall noise environment (Figures 19-24, Panel B).

On each of the 6 MARUs, the 5th, 50th, and 95th percentiles presented in the power spectral density figures (Panel C) showed consistent relative sound levels between Dep-01 and Dep-02 at frequency ranges between 25 - 100 Hz (Figures 19-30, Panel C). In Dep-01, all MARUs have a noticeable spike in sound level near 20 Hz as a result of fin whale vocal activity (Figures 19-24, Panel C). At times when humpback song occurred, there was a decrease in the 95th percentile around 575 Hz on MARUs M02 – M05 (Figures 20-23, Panel C), which is the upper frequency limit of the humpback song. The power density figures for each MARU (Figures 19-30, Panel C) for both deployments, consistently shows an increase in relative sound levels between 0 and 50 Hz and a steep decrease from 50 to 150 Hz. Each MARU recorded some degree of self-noise for both deployments. The self-noise is generated internally and subsequently recorded, and can be seen by the small peaks in the 5th percentile power spectra between 910 Hz and 1000 Hz.

Representative 24-hour Ambient Noise Analysis

Four, representative 24-hour spectrograms from a single MARU were chosen to illustrate variations in ambient noise sources and noise levels. The 4 days included a day with low acoustic activity (Figure 31), a day with high levels of biological acoustic activity (Figure 32), a day with high levels of anthropogenic acoustic activity (Figure 33), and a day with overlapping biological and anthropogenic acoustic activities (Figure 34).

MARU M01 on 11 November 2011 was chosen to represent a quiet day, in which relative sound levels did not exceed approximately 90 dB for the 95th percentile (Figure 31, Panel C). There were a few faint shipping events that occurred at the beginning of the 24-hour period, but they were not close enough to the MARU to generate high recordable sound levels. No obvious biological sounds were represented in this figure, though there was an acoustic event that occurred around 80 Hz throughout most of the day, which is visible on panels A, B and C. Due to the continuous nature and acoustic characteristics of the sound, the source of this signal is suspected to be debris that repeatedly bumped into the suspended MARU as a result of wave action or tidal activity.

MARU M03 on 20 March 2012 represents a biologically active sound day, where humpback whale song, minke pulse trains, and fin whale 20-Hz notes were visible in both the spectrograms and the power density spectrum figures (Figure 32, Panel A, B and C).

Humpback whale song occurred throughout most of the 24-hour period. In the power density spectrum figure (Panel C), there is a decrease in relative amplitude around 575 Hz at the 95th percentile, that corresponds with the maximum frequency range of the humpback whale song on this day. Minke whale pulse trains occurred at the beginning of the 24-hour period, with bouts of vocal activity visible between hours 00:00 and 03:00, and between 05:30 and 06:00. In the 1/3rd octave figure (Figure 32, Panel B), the higher amplitude component of the minke whale vocalization is visible between 100 and 160 Hz. Fin whale 20-Hz notes occurred throughout most of the 24-hour period. The 20-Hz notes are visible in the 1/3rd octave figure (Figure 32, Panel B) and the power density spectrum (Figure 32, Panel C) in the 20 Hz frequency band. Relative sound levels reached 100 dB between 50 and 100 Hz in the power density spectrum, which corresponds with the frequency range of the visible anthropogenic activity that occurred throughout the day.

MARU M06 on 28 May 2012 represents an anthropogenic active sound day occurred (Figure 33). Noise levels frequently reached above a relative sound level of 100 dB for the 95th percentile between 0 and 125 Hz (Figure 33, Panel C). There were no obvious biological acoustic signals visible during this 24-hour recording period.

MARU M06 on 14 March 2012 represents a day of both high biological and anthropogenic activity (Figure 34). Humpback whale song occurred throughout the day, with brief breaks between song that can be seen in the spectrogram and the 1/3rd octave figures (Figure 34, Panels A and B). There was also a decrease in the relative sound level of the 95th percentile 575 Hz, which was roughly the maximum frequency of the humpback whale song on this day. Fin whale 20-Hz notes occurred throughout the 24-hour period and can be seen in the 1/3rd octave figure (Figure 34, Panel B) and the power density spectrum (Figure 34, Panel C) near the 20 Hz frequency band. Shipping noise and other anthropogenic sounds occurred throughout the day, which caused relative sound levels below approximately 125 Hz to exceed 100 dB. At times, shipping noise exceeded the amplitude of the humpback whale song, preventing the humpback song from being distinguishable from the shipping noise in the spectrogram.

Figure 19

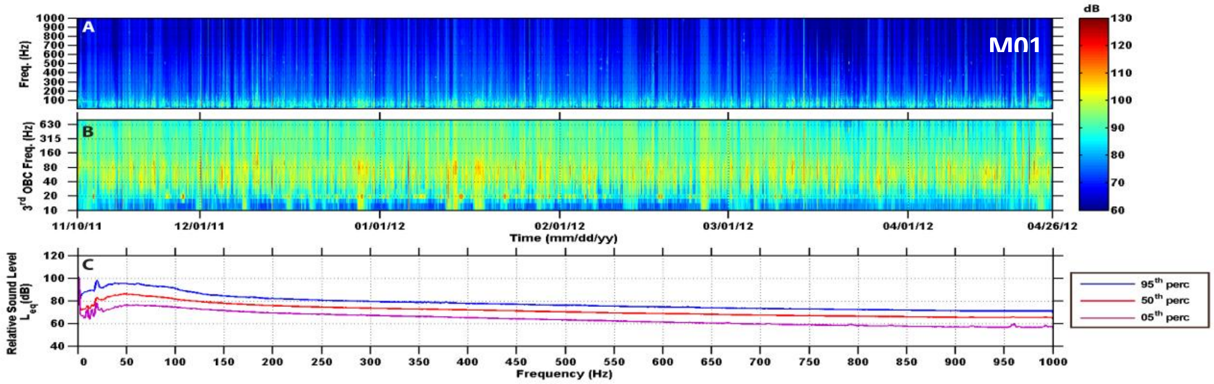


Figure 20

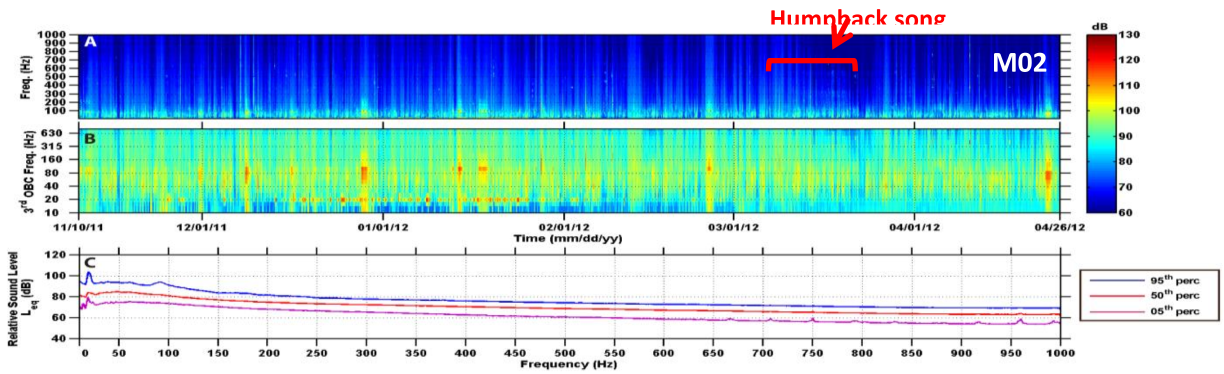


Figure 21

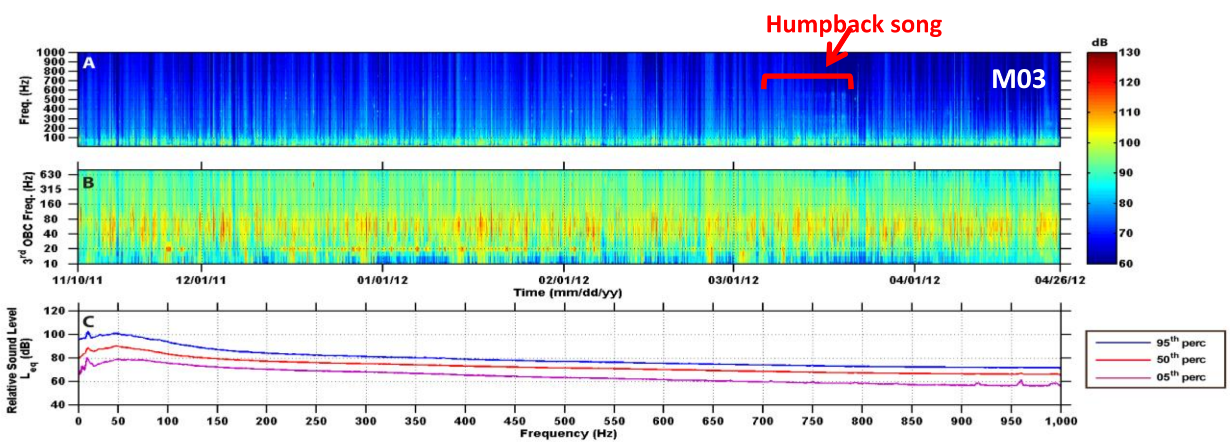


Figure 22

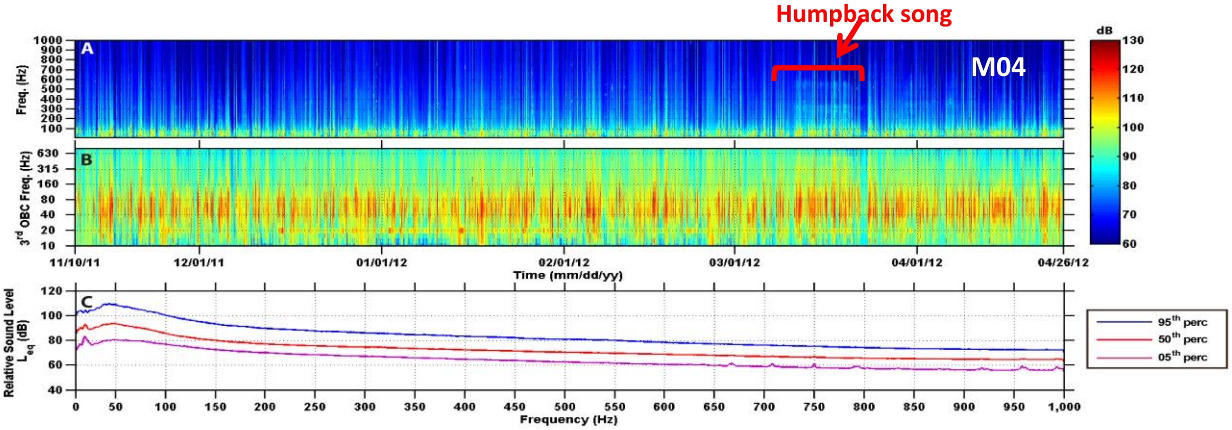


Figure 23

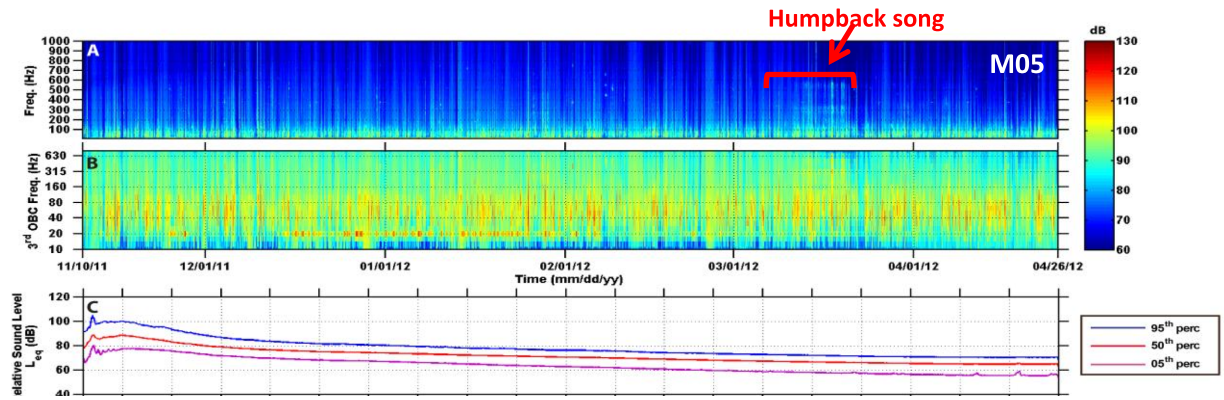
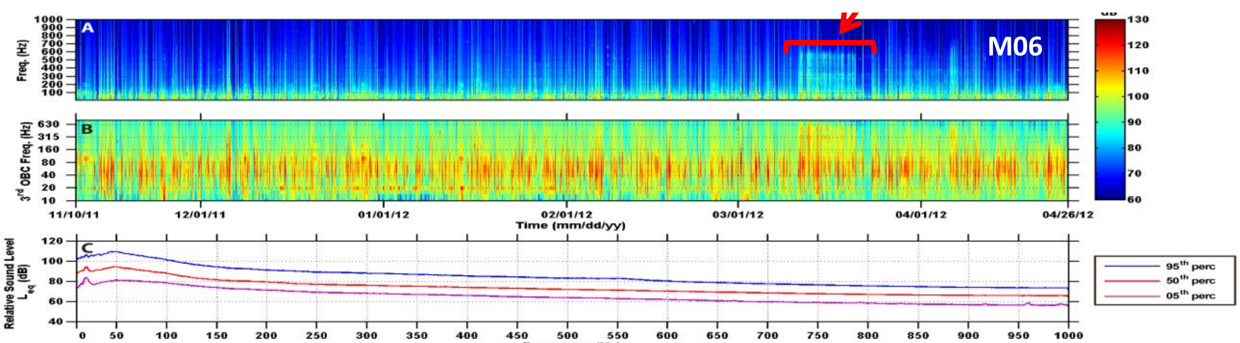


Figure 24



Figures 19 – 24. Ambient noise analysis figures showing different acoustic events occurring at sites M01 – M06 throughout the 168-day duration of Dep-01 (10 November 2011 – 26 April 2012). A) A spectrogram with 10 – 1000 Hz linear frequency range along the y-axis and linear time scale along the x-axis. B) A spectrogram using a 1/3rd octave frequency scale from 10 – 708Hz (3rd OBC Freq) along the y-axis and a linear time scale along the x-axis for the same data in panel A. C) A power density spectrum with relative sound levels (dB) along the y-axis, and a linear 0 – 1000 Hz frequency scale along the x-axis. The intensity of sound in the spectrograms is represented by color, with warmer colors indicating higher relative amplitude levels and cooler colors representing lower relative amplitude levels.

Figure 25

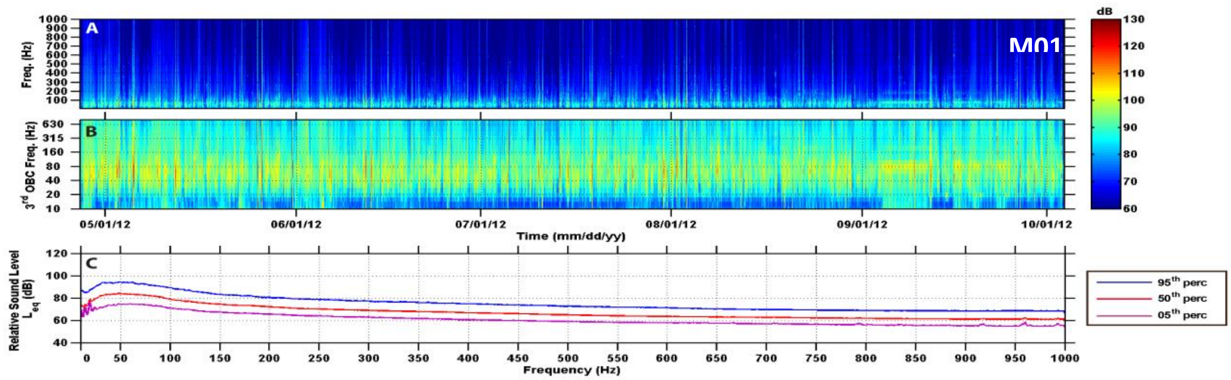


Figure 26

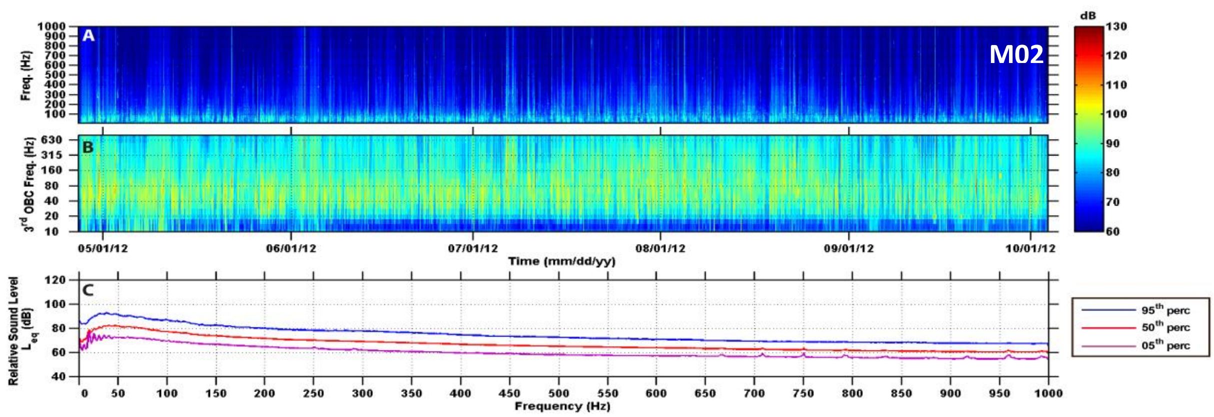


Figure 27

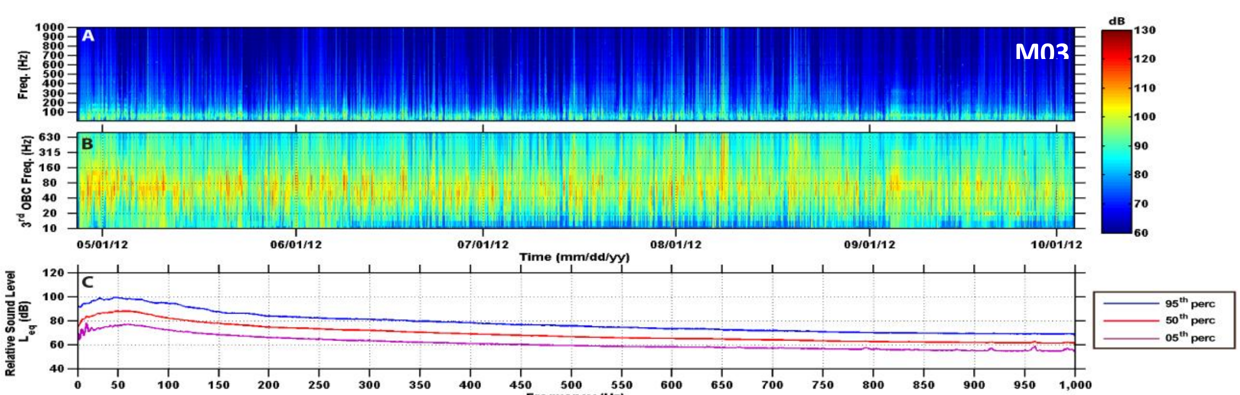


Figure 28

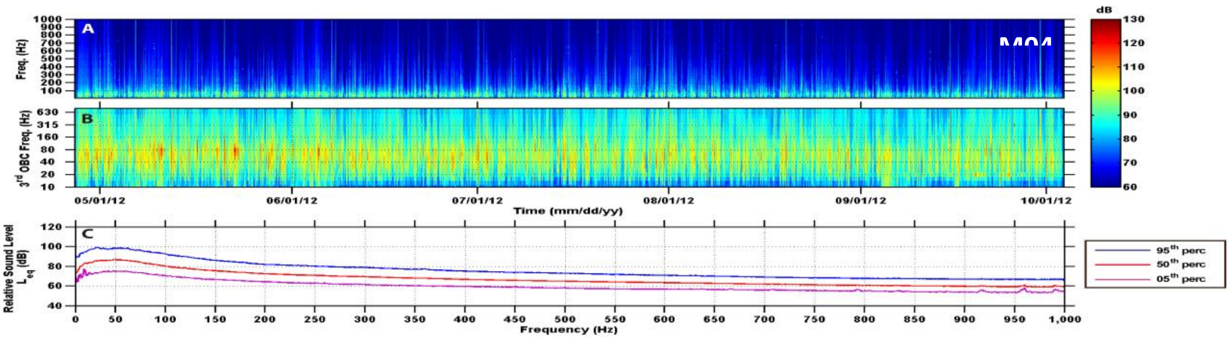


Figure 29

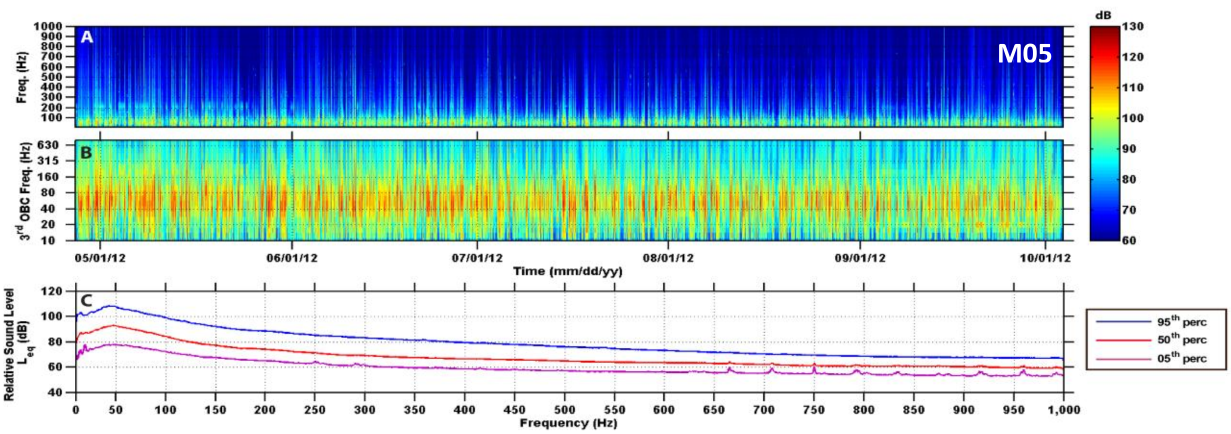
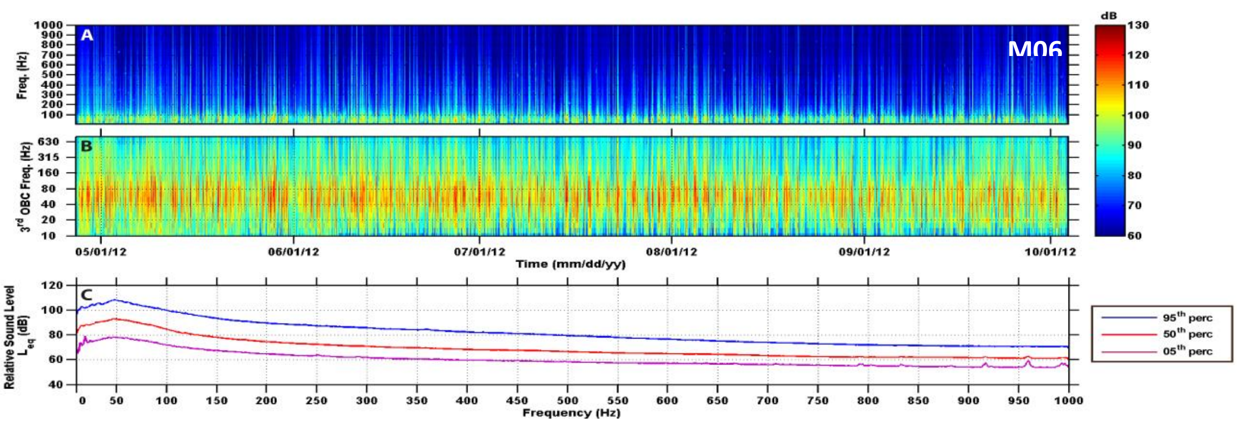


Figure 30



Figures 25 – 30. Ambient noise analysis figures showing different acoustic events occurring at sites M01 – M06 throughout the 160-day duration of Dep-02 (27 April 2012 – 3 October 2012). A) A spectrogram with a 10 – 1000 Hz linear frequency range along the y-axis and linear time scale along the x-axis. B) A spectrogram using a 1/3rd octave frequency scale from 10 – 708Hz (3rd OBC Freq) along the y-axis and a linear time scale along the x-axis for the same data in panel A. C) A power density spectrum with relative sound levels (dB) along the y-axis, and a linear 0 –1000 Hz frequency scale along the x-axis. The intensity of sound in the spectrograms is represented by color, with warmer colors indicating higher relative amplitude levels and cooler colors representing lower relative amplitude levels.

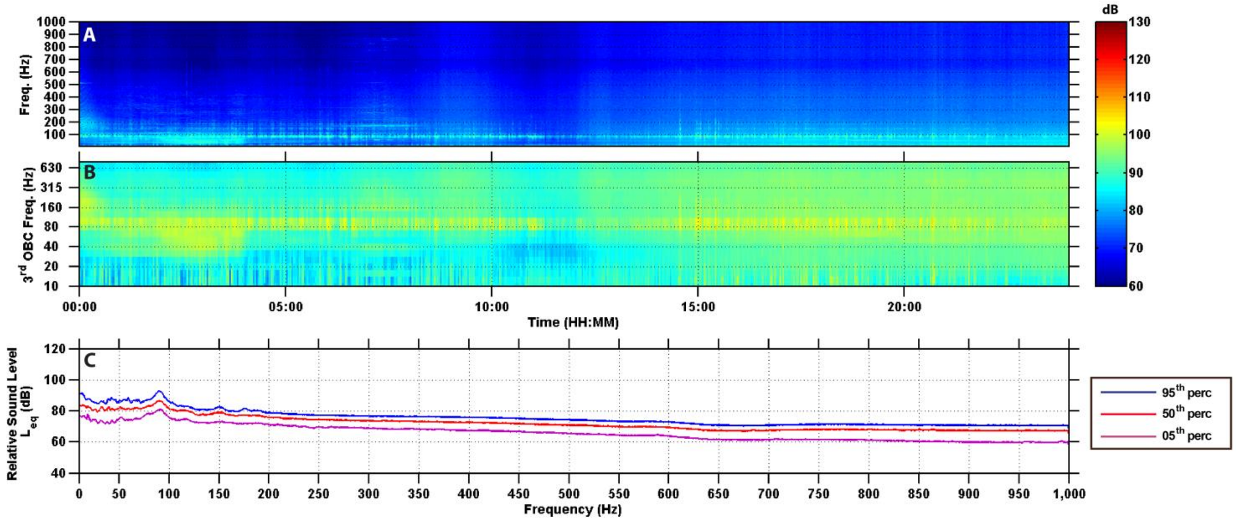


Figure 31. Ambient noise analysis figures for a 24-hour recording period at site M01 on 11 November 2011. These figures show little variation in ambient noise activity occurring at this recording station throughout the 24-hour period; representing a relatively quiet sound day.

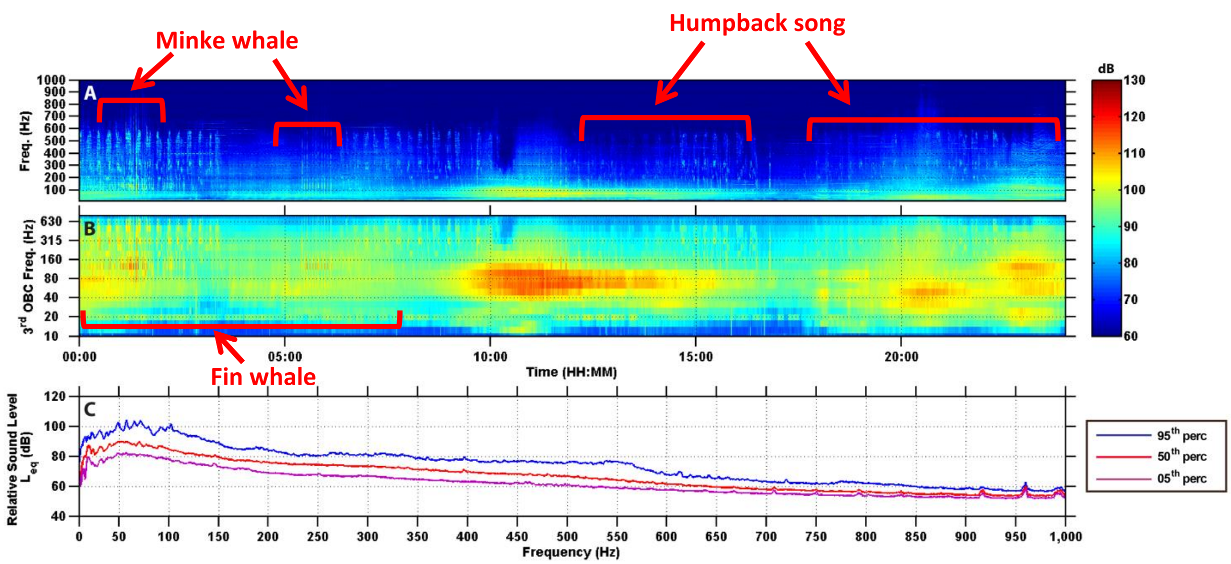


Figure 32. Ambient noise analysis figures for a 24-hour recording period at site M03 on 20 March 2012. This figure represents a biologically diverse sound day, with humpback song, minke whale pulse trains, and fin whale 20-Hz notes. Some anthropogenic activity is also visible.

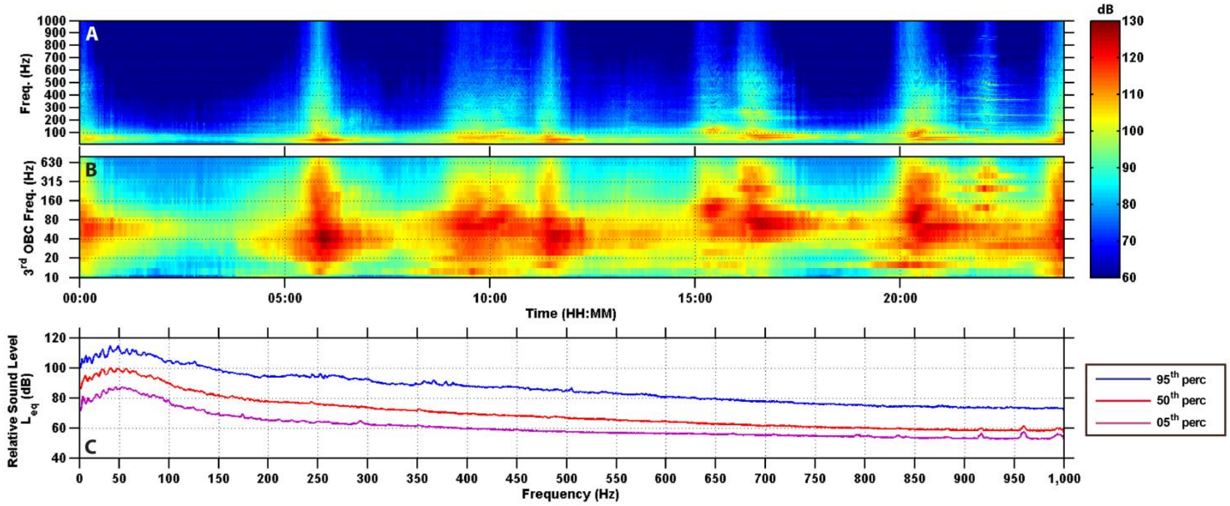


Figure 33. Ambient noise analysis figures for a 24-hour recording period at site M06 on 28 May 2012. This figure illustrates increased noise from anthropogenic activities such as shipping; which appear as red and yellow events in the spectrograms (Panel A and B).

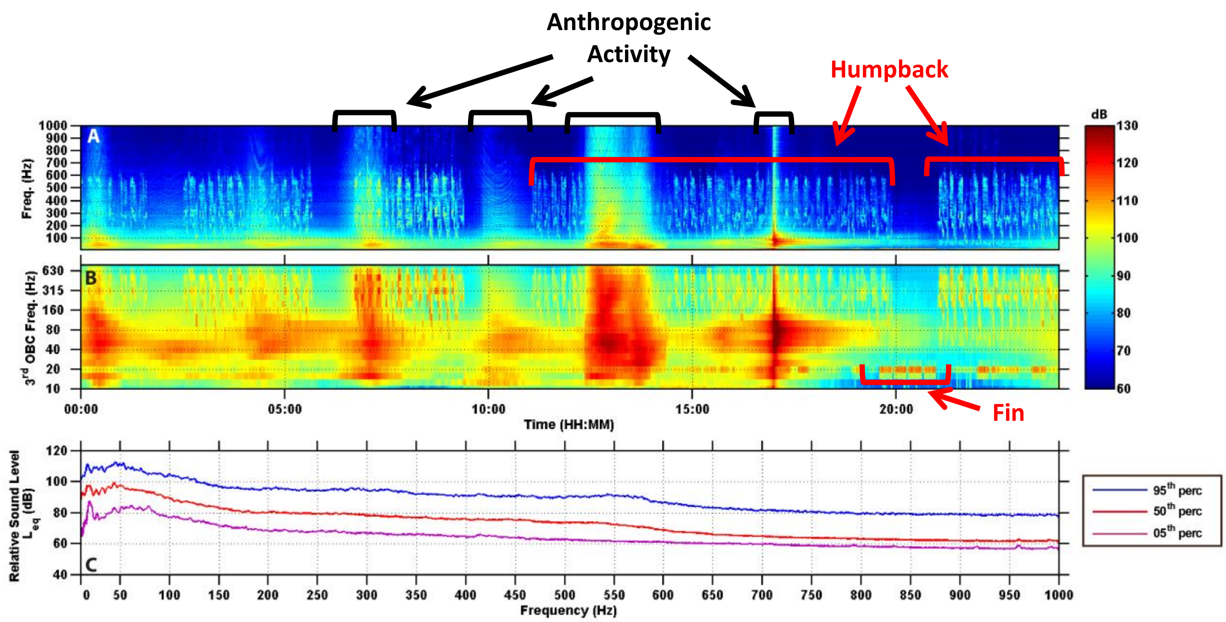


Figure 34. Ambient noise analysis figures for a 24-hour recording period on 14 March 2012 at site M06. This figure shows a variety of both anthropogenic and biological acoustic events that occurred throughout the 24-hour period.

Discussion

Patterns of whale acoustic presence

The results of this study show that a rich diversity of marine mammal species spends time in or near the MA WESA throughout the year. The acoustic presence of at least 7 large whales was verified using both systematic analysis and opportunistic observations of known species' vocalizations. The focal species of this study included North Atlantic right whale, fin whale, minke whale, humpback whale, and blue whale. The acoustic presence of these species varied over time, but vocalizations were generally detected more often during the spring and winter months than the summer and fall months. Fin whales and humpback whales were present at least 1 day in all of the 12 months of this study, while right whales were present 8 months, and minke and blue whales were present 10 and 5 out of the 12 months, respectively. In addition, sperm whale and sei whale vocalizations were identified opportunistically. These data indicate that most of the large whale species known to occur within the Western North Atlantic Ocean were detected from subsurface hydrophones deployed within MA WESA, suggesting that this area is likely ecologically important for these species.

The acoustic presence of right, fin, minke and humpback whales showed somewhat similar seasonal trends, with maximum acoustic presence in the spring (March and April), and decreased acoustic presence during the summer (June and July). Fin whales showed an elevated level of acoustic presence during the fall, winter and spring months. The acoustic presence of blue whales followed a completely different pattern than the other species, with acoustic presence detected only in winter (December-February) and late summer/fall (August and September), suggesting blue whales may use this area as a migration corridor, rather than remain in the area for extended periods of time. Alternatively, we could be detecting blue whales from other areas (further away) as their calls have the ability to propagate great distances.

Similar acoustic surveys were conducted in Massachusetts Bay, approximately 175 km north of the MA WESA, to determine the seasonal patterns of acoustic presence for right whales (Morano et al. 2012a), fin whales (Morano et al. 2012b), and humpback whales (Murray et al. 2013). Murray et al. (2013) found that humpbacks were present in all months of the year, with 100% monthly presence in April through November, and decreased presence in the months of January, February, and March. These results differ from the MA WESA in that there was greater overall monthly presence in the Murray study and the decreases in monthly presence in the MA WESA occurred in the months of November, February, July, and August. This could be explained by differences in total numbers, yearly differences (data were from 2007-2009), or the result of the two areas being used by humpbacks in different ways. Morano et al. (2012a) found similar trends in right whale monthly acoustic presence to the MA WESA in that the highest monthly acoustic presence occurred in March and the lowest in June, July, and August. As with fin whale presence in the MA WESA, Morano et al. (2012b) found the acoustic presence of fin whale to be common both spatially and temporally, finding 20-Hz notes present in 814 out of 817 analyzed days in Massachusetts Bay.

The specific locations of whales relative to the MA WESA were not determined, however in some cases their general location can be estimated (see Morano et al. 2012a). Because of the varying acoustic properties of different marine mammal species, different species can be acoustically detected at vastly different ranges. Therefore, the locations of the vocalizing whales from the 5 focal species (right, fin, minke, humpback, and blue whales) could have occurred from varying distances in or around the MA WESA. We did not measure the detection range of the MARUs, however there is literature proposing estimated detection ranges using localization (Laurinolli et al. 2003; Clark & Clapham 2004; Munger et al. 2011), or sound propagation modeling (Stafford et al. 2007; Širovic et al. 2007; Munger et al. 2011). Although there are multiple variables that can affect the actual detection range values (Marques et al. 2012) (e.g. source levels, frequency, source level and depth of vocalizing whale, sound speed profiles, bathymetry), we reference these published values and describe the generally approximated detection range of our MARUs for each species.

In the case of right whales, enough detailed information was collected to demonstrate that acoustic presence of right whales were more commonly found at or near site M02, in the northeast corner of the MA WESA. We estimate that the right whales can be detected by a MARU up to approximately 25 km from the MARU array (Laurinolli et al. 2003). In the case of fin whales and blue whales, species whose calls propagate for long distances (Payne & Webb 1971; Širovic et al. 2007), individuals could have been vocalizing either near the MARU array, or up to tens or hundreds of kilometers away. Using estimates of the detectable ranges for humpback and minke whale vocalizations found in the literature (Marques et al. 2012), we estimate that the humpback and minke whales could have originated from up to 12 km to 29 km from the nearest MARU, respectively.

Ambient Noise

Temporal and spatial variability are principle characteristics of the ambient noise environment, and thus, long term studies are needed to statistically characterize the ambient noise variability within different environments (Wenz 1972). In these long-term acoustic data collection efforts, analysis of ambient noise allows for the opportunity to broadly evaluate the periodicity of physical environmental processes, vocally active biological constituents of an acoustic environment, and the contribution of anthropogenic sounds to the ambient noise environment. The combined analysis of biological acoustic activity in relation to different anthropogenic or environmental sound levels offers the opportunity to examine how increases in noise levels may impact behavior of vocal and non-vocal species.

The ambient noise analysis of the MA WESA showed temporal and spatial variability between seasons and between the recording sites of the 6 MARUs. Relative background ambient noise levels were consistent throughout the recording period, while recorded biological events varied seasonally, suggesting that the acoustic environment of the recorded area did not vary considerably as a result of anthropogenic activity or sea state (Richardson et al. 1995), but reveals variation in biological use of the habitat. MARUs further offshore recorded higher noise levels, indicating that some biological and mechanical acoustic events originated closer to the southeast region of the recording area. The fin whale and humpback whale vocalizations were loudest on MARUs M05 and M06, signifying that the vocalizing individuals were positioned farther offshore, in deeper water. The prevalence in relative sound levels from 0-50

Hz on all MARUs is likely a result of the noise contribution from shipping traffic (Andrew et al. 2011). When comparing the relative sound levels at 50 Hz, M01 and M02 (in the northwest) recorded the lowest levels and M05 and M06 (in the southeast) recorded the highest levels, implying that the shipping activity occurred nearest to MARUs in the southeast region of the array.

Overall, anthropogenic noise levels from shipping and other activities were somewhat moderate compared to recordings of heavily trafficked shipping corridors. However, there were several instances in which a loud recorded shipping event occurred simultaneously with a vocalizing whale, making the biological signal indistinguishable among the shipping noise, and thus decreasing the detection probability of the call both to other whales and the MARU. The decreased detection ability of animal sounds to conspecifics is known as masking (Hatch et al. 2008; Clark et al. 2009). Since whales rely on acoustic communication as part of their life histories (Clark et al. 2009), it is thought that masking may have significant ecological impact for these species.

Future Directions

The data from this study reveal seasonal patterns of acoustic presence occurrence for 5 focal whale species over a 12 month period. The varying patterns of vocalization between species suggest that differing environmental factors may be driving whale vocalization. Future comparisons of the data collected in this study to various environmental factors (such as water temperature, distribution of prey, oceanographic patterns) could provide valuable information in understanding and predicting whale behavior and occurrence, particularly when combined with visual survey observations and results. In addition, the high degree of interannual variability, both spatially and temporally, of marine mammals (e.g., Baumgartner & Mate 2003; Keiper et al. 2005) requires the collection of multiple years of data to understand patterns of occurrence by marine mammals in the MA WEA. Data collection at these larger temporal scales can bring additional resolution to decision-making regarding ORE development and minimize potential impacts to marine mammals and their habitat.

The ambient noise analysis from this study demonstrated that the MA WESA survey area is a biologically diverse marine environment. Long-term measurements of ambient noise can provide a mechanism to document baseline sound levels to compare against future possible changes and perturbations, which may be critical in evaluating the status of marine ecosystems (McDonald et al. 2008). Chronically high levels of ambient noise can contribute to masking of marine mammal communication (Clark et al. 2009), potentially resulting in behavioral and physiological stress responses (Kight & Swaddle 2011; Rolland et al. 2012), therefore is it important to characterize the acoustic environment of biologically active habitats. Future data collection to better understand the ambient noise environment and how increases in anthropogenic activity can affect marine mammal acoustic presence will be important to inform future resource management decisions in the MA WESA.

Credits & Acknowledgements

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