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EAVESDROPPING ON GULF OF MAINE CETACEANS IN THE VICINITY OF MOUNT DESERT ROCK

By

Christopher James Tremblay

B.A. College of the Atlantic, 2003

A THESIS

Submitted in partial Fulfillment of the

Requirements for the Degree of

Master of Science

(in Marine Biology)

The Graduate School

University of Maine

December 2018

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EAVESDROPPING ON GULF OF MAINE CETACEANS IN THE VICINITY OF MOUNT DESERT ROCK

By

Christopher James Tremblay

Thesis Advisor: Dr. Gayle Zydlewski

An Abstract of Thesis Presented
In Partial Fulfillment of the Requirements for the
Degree of Master of Science
(in Marine Biology)
December 2018

Passive acoustic monitoring, the recording and analysis of biological sound, is a standard method of research into the distribution and behavior of cetaceans worldwide. Acoustic monitoring is reliant upon a thorough reference catalog of species vocalizations and an understanding of the temporal and geographic parameters in which vocalizations occur. This study combined a standard cetacean passive acoustic monitoring survey with a concurrent visual survey at a known baleen whale summer feeding ground to determine the annual species and vocal composition, compare species detection rates using each method, and identify and attribute novel vocalizations to species. The survey took place at the Mount Desert Rock marine research station, Gulf of Maine, from July to October 2015 and 2016. Visual and acoustic detections of fin (*Balaenoptera physalus*), minke

(*Balaenoptera acutorostrata*), humpback (*Megaptera Noavaeangliae*), right (*Eubalaena glacialis*), and sei (*Balaenoptera borealis*) whales were assessed. Minke whales were the most frequently seen species (71% of days), followed by fin (51%), humpback (40%), and right (4%). Visual detections of minke and fin whales were more restricted by distance than humpbacks, and fin and humpbacks were sighted significantly more frequently in the northeast quadrant of the survey space, suggesting each species may have fine scale spatial preferences within the survey space. Stereotyped vocalizations of fin, minke, right, and sei whales were recorded, and automatic template detectors were used to evaluate daily and annual occurrence. Fin whales were the most frequently detected (31% of days), followed by minke (22%), right (15%), and sei (2%). Fin and minke whales vocalized primarily in evening and night-time hours, and right whales vocalized primarily during the day. Instances of multi-hour vocalization bouts were also recorded for fin, minke, and right whales. The number of days where each species was detected both visually and acoustically was low, meaning the use of only one method or the other may have resulted in a less precise census.

Five novel vocalizations were identified in the acoustic dataset that occurred on days when only fin or minke whales were visually detected. These were 74 to 34-Hz suspected fin whale downsweeps, 268 to 448-Hz short upsweeps, 415-Hz “whip-cracks”, 498 to 363-Hz long downsweeps, and 257 to 164-Hz long downsweeps. The 74 to 34-Hz downsweep was found to be statistically associated with fin whales ($p = 0.040$, $\Phi = 0.129$), while all other statistical tests were inconclusive. Spatial comparisons between all visually detected fin and minke whales and all locations of novel vocalizations from the study period showed very little spatial overlap, a potential complication to the statistical results. Potential violations of statistical assumptions included non-vocalizing whales, whales vocalizing outside of the observation range, and vocalizations that occurred at night.

The findings of this study suggest that while visual and acoustic surveys are both effective stand-alone techniques for detecting the presence and behavior of baleen whales, a more precise census is achieved when the two are combined. Concurrent visual and acoustic surveys are also an effective method for the identification and attribution of novel baleen whale vocalizations, though species composition, detection probability, and vocalization behavior must be accounted for.

ACKNOWLEDGEMENTS

This project was borne out of brainstorming sessions with Dr. Mark Baumgartner, who provided the opportunity to design and execute this study of a space, and population of animals that I hold near and dear. I would like to thank Dr. Baumgartner for providing the funding for this project and for his many years of support in the field and on shore. My thesis advisor at the University of Maine, Dr. Gayle Zydlewski, was constantly attentive and gave endless support throughout this process. Dr. Zydlewski was always available to help navigate the graduate school process and associated pitfalls, all while being the busiest person I have ever met. Thank you. I would also like to thank my remaining committee members; Dr. Danielle Cholewiak for providing her expertise in bioacoustics and for many years of friendship, and Dr. Emmanuel Boss for advocating my initial acceptance at the University and for providing a much needed outside perspective on my thesis content. Thank you both.

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CHAPTER 1:

VISUAL AND ACOUSTIC DETECTIONS OF BALEEN WHALES IN THE VICINITY OF MOUNT DESERT ROCK

Abstract

The presence of baleen whales in the waters east of Mount Desert Rock was documented utilizing both visual and passive acoustic survey from July to October 2015 and 2016. Concurrent surveys detected the occurrence of fin, minke, humpback, right, and sei whales over the course of the two field seasons. Between 2015 and 2016 there was an increase in visual detections of fin, humpback, and minke whales in the survey space. Probability of detection was significantly different for minke, fin, and humpbacks, and visual detections of fin and humpback whales were significantly higher (Chi-square, $p < 0.0001$) in the northeast survey section relative to the southeast. Using a five-element passive acoustic array the stereotyped vocalizations of fin, humpback, minke, right, and sei whales were logged using automatic template detectors. Hourly acoustic data showed that fin and minke whales typically vocalized in the evening and overnight hours and right whales vocalized most often during daylight hours. Each of these species was also found to produce multi-hour calling bouts during the latter part of the study seasons. A comparison of daily acoustic and visual detections for all species revealed that the percentages of days where both detection types occurred for each species was generally low, indicating that these methodologies are highly complementary to one another when determining baleen whale presence and behavior, and that using one method or the other would have resulted in a less precise census.

Introduction

Mysticetes (*mysteceti*), the baleen whales, make up one of two parvorder of the cetaceans (*cetacea*), the infra-order of finned marine mammals. Currently they form four families, fourteen species, and eighteen sub-species worldwide, though ongoing genetic studies will likely increase these numbers (Corkeron *et al.* 2017, Mead *et al.* 2005). Baleen whales are found in all of the world's oceans but many species prefer temperate and high latitudes (Macleod 2009). In the Gulf of Maine (GOM), a marginal shelf sea in the western North Atlantic Ocean, there are five seasonally resident populations of baleen whale species. They are the fin whale (*Balaenoptera physalus*), humpback whale (*Megaptera novaeangliae*), minke whale (*Balaenoptera acutorostrata*), North Atlantic right whale (*Eubalaena glacialis*), and sei whale (*Balaenoptera borealis*) (Katona *et al.* 1983, Waring *et al.* 2015, Schilling *et al.* 1992). Generally, these species inhabit vast spatial ranges with seasonal migrations across ocean basins from low-latitude winter calving and mating grounds to high latitude summer feeding grounds (Kellogg 1929, Norris 1967, Robbins *et al.* 2011). Baleen whales are distinguished most prominently from their counterpart cetaceans, the *odontocetes* (toothed whales), by the plates of baleen (modified teeth) that act as a filter for capturing prey. There are also distinctions between these groups based on their sound –producing mechanisms (Nummela *et al.* 2007), the characteristics of the sounds they produce (Mellinger *et al.* 2007) and their social structures (Gero *et al.* 2016).

A common approach to distribution, density, and population studies of baleen whales is the use of systematic visual surveys. These types of surveys are commonly used by management organizations such as the National Marine Fisheries Service (NMFS), environmental consulting groups, and academic institutions for stock management and research (Van Parijs *et al.* 2009). Such surveys are conducted via ship, airplane, or from a fixed station on shore. For such surveys, observers keep a systematic watch, marking positions of animal sightings, behavior, and associations (Palka 2012). However, due to large habitat ranges, inherent weather constraints presented by the ocean, and elusive behavior, large baleen whales are generally difficult to study (Nowacek *et al.* 2016, Mellinger and Barlow 2003). Research requires lengthy, multi-year broad-scale surveys (Palka 2012) or the identification and tracking of individual animals (Mann 1999), often resulting in low sample sizes. Due to these difficulties researchers are increasingly turning to remote sensing as a viable option for the study of baleen whales (Gillespie 2001). A popular and technologically advanced type of remote sensing often used to study these species is passive acoustic monitoring (PAM). Passive acoustic monitoring is a broad field of academic study that encompasses the recording and analysis of sound produced by animals. This method has been applied widely in both terrestrial and marine habitats, in native and controlled environments, and to study a great array of species (Blumstein *et al.* 2011). This method is particularly useful for the study of whales where animals are often found in remote areas amongst ever changing environmental conditions. There are also several drawbacks of using acoustic monitoring to survey cetaceans. The ability to detect individuals relies on them making sound, something that is variable by species and by season, time of day, and gender (Stafford *et al.* 2008, Oleson *et al.* 2014). These variables affect the ability to detect number of animals present, making abundance estimates difficult. Species detection is also incumbent on recognizing acoustic signals in a dataset as being produced by a given species, something that for most species is not yet fully understood. Researchers are now seeing the benefit of combining acoustic and visual surveys simultaneously to maximize survey effectiveness (Fleming *et al.* 2018, Moore *et al.* 2010, Barlow and Taylor, 2005).

Baleen whales produce sounds at comparatively low frequencies (~7-Hz – 22 kHz) relative to odontocetes (~75-Hz – 150 kHz) (Mellinger *et al.* 2007). These sounds are stereotyped by species based on frequency, duration, amplitude, and patterning. These vocalizations are species-specific with some intra-species variation in call structure, or pattern, based on stock structure, geography, or season (Stafford *et al.* 2007, Thompson *et al.* 1992, Clark *et al.* 2002, Payne and Guinee 1983). The use of sound by males as a reproductive display, or whale song, is a well-studied area of cetacean research for species such as humpback, fin, and bowhead whales (Stafford *et al.* 2008, Janik 2009, Watkins *et al.* 1987, Payne and McVay 1971). Whale vocalizations are also detected frequently on feeding grounds, though the implications of these sounds are less well understood (Risch *et al.* 2014, Stanistreet *et al.* 2013, Wiley *et al.* 2001, Delarue *et al.* 2009, Parks 2003, Cerchio 2001)

For this project a simultaneous systematic visual and acoustic survey was conducted at a known summer feeding site of several baleen whale species. The survey was used to catalog the presence of baleen whales using both methods and to compare the efficiency of both methods. The study focused on hourly sightings per unit effort, detection probabilities, directionality of visually detected whales, and the hourly detections per unit effort, diel patterning, and behavioral characteristics of vocalizing whales. The study also included an analysis of how each survey method overlapped.

Methods

Visual Survey

Visual surveys for baleen whales were conducted from the Mount Desert Rock (MDR) marine research station (Figure 1-1) from July to October of 2015 and 2016. Survey protocols were based upon methodology utilized for the Atlantic Marine Assessment Program for Protected

Species (AMAPPS) shipboard marine mammal surveys adapted for the MDR fixed-station platform (Palka 2012). All observer personnel were professionally trained in marine mammal identification. Whale sightings were recorded during daylight hours (~0600-1900 EST) and when weather conditions allowed*. The primary survey was focused on an area roughly 7.5

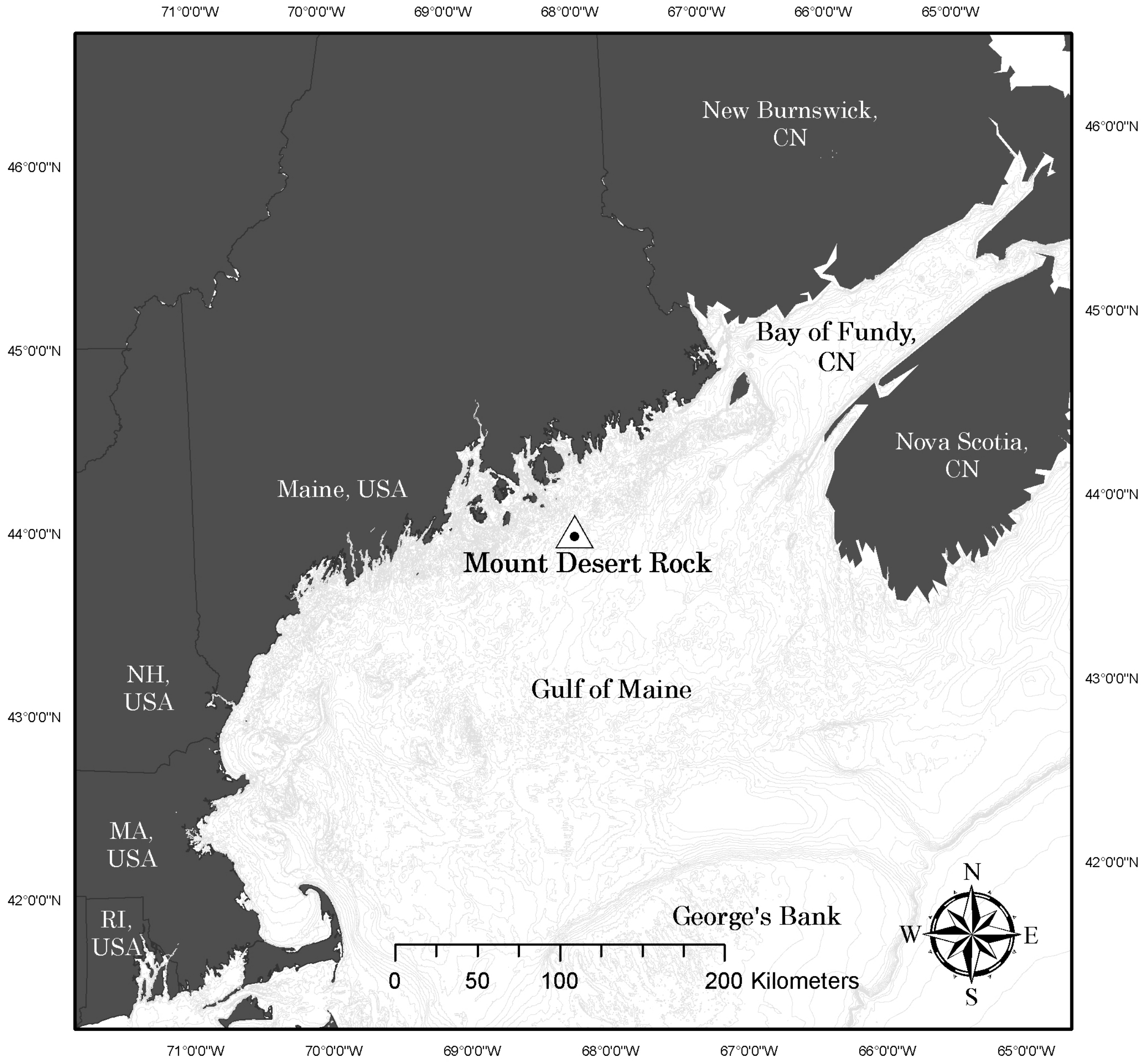

Figure 1-1. Map of the Mount Desert Rock (MDR) Marine Research Station, situated in the Gulf of Maine, USA. MDR is a 3.5-acre island with a lighthouse station owned and operated by the College of the Atlantic (Bar Harbor, Maine). The MDR station has been used as a whale research facility since the early 1970's.

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* Observers also recorded presence of dolphin species and large fish (shark and tuna species)

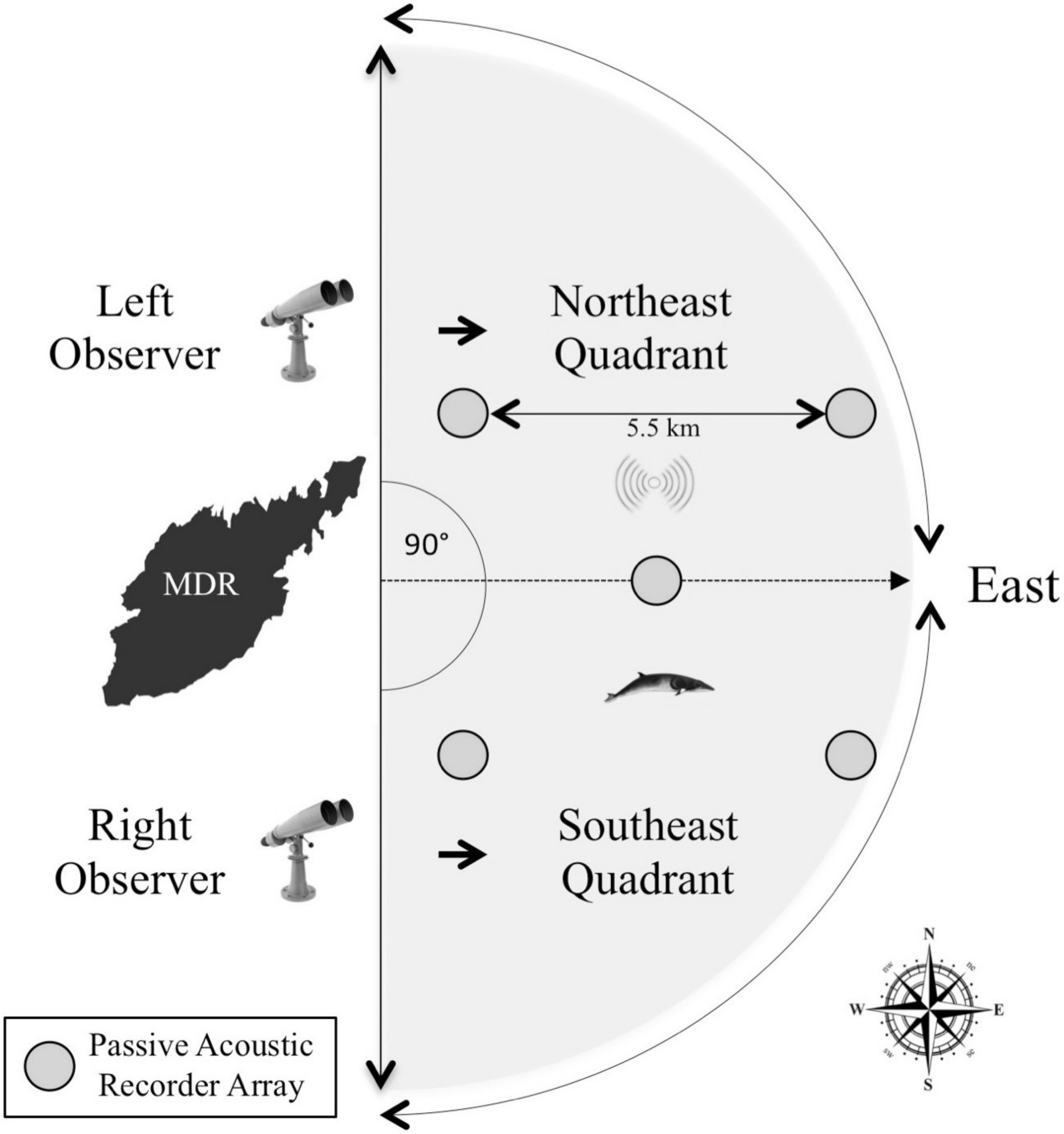


Figure 1-2. Diagram of the survey space relative to the Mount Desert Rock marine research station. Two observers (left and right) simultaneously recorded the sightings of baleen whales in each respective quadrant (northeast and southeast) using big eyes binoculars. Concurrent passive acoustic monitoring was collected an array of underwater recorders (circles).

square kilometers centered due east of MDR where historic survey data suggest the highest seasonal cetacean activity occurs relative to the island (Figure 1-2). Observations were conducted by continuous scanning with two sets of "big-eyes" 25×150 Fujinon binoculars (Moore *et al.* 2002, Palka 2012) mounted on the east side of the lower catwalk of the lighthouse tower. The "big-eyes" lenses were 21.6 m above mean sea level resulting in a maximum viewing range to the horizon of 16.6 km. A typical daily survey included a three-observer rotation of 30-minute shifts at one of three stations during daylight hours. These stations were left observer, data recorder (center), and right observer. Each observer rotated through each station and then took a break. Center data recorder also surveyed the near-field opportunistically with binoculars. Data were recorded using VisSurvey software (Palka 2012) running on a Panasonic Toughbook laptop.

To calculate locations for visual detections, VisSurvey used the height and location of the survey platform (lighthouse tower), the sighting elevation below the horizon using reticles (marked on big eyes lenses), and the sighting bearing angle relative to 0° true north. The big eyes were calibrated to true north using a Trimble GPS. Each observer was responsible for a searching a 100° swath of ocean. Left observer would scan from 0° (true north) to 100° (just south of east), and the right observer would scan from 180° (due south) to 80° (just north of east). The observers overlapped in the easterly direction by 20° as a precautionary measure to not miss sightings at the end of their respective scanning ranges. For large whales, each sighting of an individual, or group of individuals if in the same location, was recorded as a single entry. The primary sighting was recorded as an "original" sighting and any subsequent sightings of the same individual were recorded as a "follow-on" sighting. Observers would not record a "follow-on" to a sighting initiated by a different observer. Effort and weather data (sea state, cloud cover, rain, fog, glare) were also collected at the beginning of each observer shift (every 30 minutes) by the center data recorder.

Visual data were assessed for species presence, for detection probability based on distance relative to the survey platform, and for directionality relative to the survey platform. Daily presence and daily sightings per unit effort (SPUE) were calculated based on number of sightings per species, per hour of effort, per day. Detection probabilities were determined for each species based on distance in meters of all sightings and calculated using the ‘ds’ function in the ‘Distance’ package in R, with distances truncated to 10 km. Directionality of visual detections was plotted using the ‘circular’ function in the package ‘Circular’ in R. This function stacks visual detections based on angle of detection relative to true north. The angle data were then assessed using a chi-square analysis to determine if the number visual detections of each species were dependent upon the northeast or southeast quadrant.

Passive Acoustic Survey

Five passive acoustic recorders were deployed 5.5 km apart in an array centered due east of the MDR lighthouse platform from July 19 – October 9, 2015 and July 13 – October 5, 2016 (Figure 2). The recorders utilized were Marine Autonomous Recording Units (MARUs), developed by the Bioacoustics Research Program at Cornell University (BRP) and leased from BRP by the NOAA Northeast Fisheries Science Center (NEFSC). The MARU recorder system featured an HTI 94-SSQ hydrophone, -168 dB re: 1 V/ 1 µPa sensitivity, 23.5 dB gain, and a 12-bit A/D converter (Calupca *et al.* 2000). Each MARU unit was programmed to record continuous acoustic data to flash memory at an 8 kHz sampling rate. The MARU recordings were time synchronized on land pre- and post-deployment by producing in-air acoustic impulsive sound at known GPS times that each buoy would record simultaneously. Finalized data recordings were synchronized to ±1 ms and merged together to produce a multi-channel acoustic file.

To find baleen whale calls in the dataset the acoustic browsing software Raven 2.0 was used (Bioacoustics Research Program 2017). Raven allows for manual browsing, template detection, and localization of biological sounds in acoustic data sets. The visual dataset was used as a cue to access recordings of each baleen whale species. Acoustic data from days with the highest number of visual detections of fin and minke whale were manually browsed for the presence of each species' recognizable stereotyped calls. A catalog of stereotypical calls was built and used to automate a process to assess whale acoustic presence in the entire dataset. This catalog was based on the acoustic repertoires described for these species in the western North Atlantic Ocean, and included fin whale 20-Hz pulses and higher frequency downsweeps (78 to 34-Hz) (Watkins *et al.* 1987, Watkins *et al.* 1982), North Atlantic minke whale pulse trains (Risch *et al.* 2014), right whales 100 to 300-Hz up-calls (Parks 2003, Clark 1982), and sei whale 82 to 34-Hz downsweeps (Baumgartner *et al.* 2008) (Figure 1-3). Humpback whales were excluded from this analysis due to the variability in their vocal repertoire that made reliable detection difficult. Elements of these vocalizations were used for the automatic detection of each species using the native template detector function within Raven 2.0.

Template detectors were built by selecting stereotyped vocalizations, or sections of stereotyped vocalizations for each species that were found within the MDR acoustic dataset. Using measurements of amplitude within certain frequency band measurements of these selections, with a sensitivity threshold that is set by the user, the template detector matched sound selections within the dataset that were logged for further review. The template detector allowed the user to manually "tune" the sensitivity of the detector. The sensitivity of template

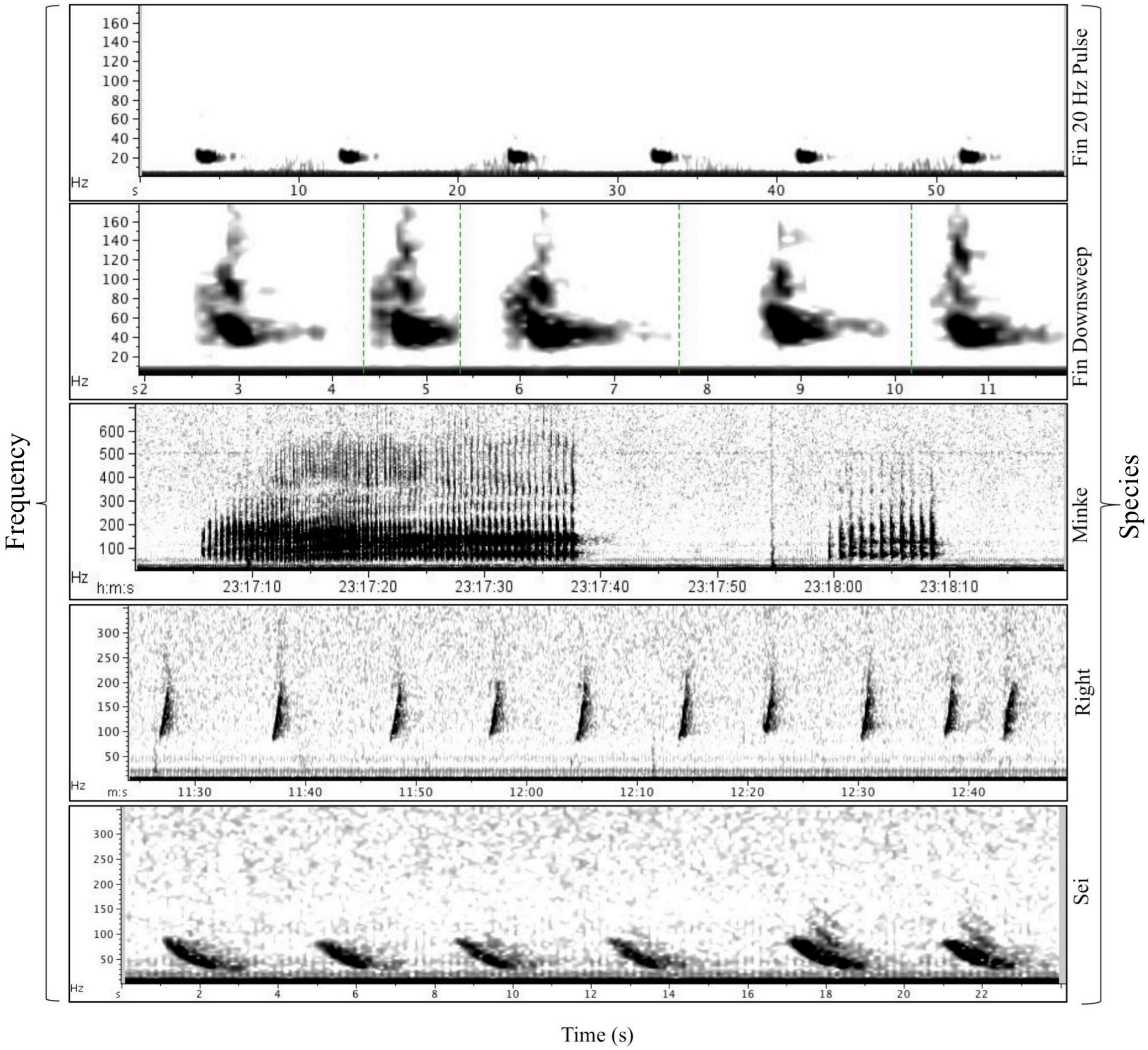


Figure 1-3. Spectrogram images of the stereotyped vocalizations of four species of baleen whales recorded during the survey and used for building automatic detectors. These vocalizations are well-known call types from the western North Atlantic and were each recorded at the Mount Desert Rock site. Two stereotyped vocalizations were utilized for detecting fin whales – standard 20-Hz pulses 74 to 34-Hz downsweeps. Also included were minke whale pulse trains, right whale 100 to 300-Hz up-calls, and sei whale 82 to 34-Hz downsweeps.

detectors built for each species were customized to account for the characteristics of each vocalization type in order to minimize false detections and maximize true detections. This was done by running each template detector across a dataset containing a series of the same category of known vocalization types and documenting the rate of false-positive detections. For fin and minke whales that typically produce series of pulses, the detector was presumed effective at a 50% capture rate, as there are typically multiple examples of each vocalization produced at a time, so the probability of capture is higher. For the more rare right whale and sei whales that typically produce less frequent, longer sweeping vocalizations, where the probability of capture is lower, the detector was presumed effective at 80% capture rate. After tuning each detector to achieve the capture rate goal within the test data set they were utilized for to search the full MDR dataset.

All automatically detected sounds were confirmed or rejected by an analyst, ensuring all data used for further review were true vocalization events. The number of acoustically detected fin, sei, and right whales were binned daily and reported as number of detections per day per unit effort (DPUE). This was determined by dividing the number of detections per day by the number of hours of effort (24 hrs). All detections for each species from the 2015 and 2016 study period were also binned per hour of day and plotted using 24-hour radar plots to document each vocalizations diel pattern. The presence of calling bouts, or instances where an individual animal produced multiple vocalizations events for an extended period of time (> 1 hr), were also reported. Finally, daily visual and acoustic detections of fin, minke, and right whales were compared to evaluate the efficiency of each survey method. Data were compared daily, for each of the 2 years, and across the full survey period, and reported as days when a species was detected only acoustically, only visually, or by both methods.

Results

Visual Survey

There were 56 days (501 hrs) of visual observer effort in 2015 and 60 days (627 hrs) of observer effort in 2016, for a total of 116 days (1,128 hrs) of visual surveys throughout the study. There were four baleen whale species sighted during this project; fin whale (in 2015 n=358, days = 15; in 2016 n=673, days=45; Total n=1,031; days=59), minke whale (in 2015 n=120, days=36; in 2016 n=791, days=46; Total n=911, days=82), humpback whale (in 2015 n=77, days=12; in 2016 n=604, days=35, Total n=681; days=46), and right whale (in 2015 n=10, days=2; in 2016 n=9, days=3; Total n=19; days=5). This translates to minke whales being sighted on 71% of survey days, fin whales sighted on 51% of days, humpback whales on 40% of days, and right whales 4% of days through the project period (Figures 1-4, 1-5).

Histograms were plotted with a probability of detection curve based on the distances of all visual detections of fin, humpback, and minke whales throughout the project period (Figure 1-6). Minke whales had the lowest median distance (1414m), followed by fin whales (2964m), with humpback whales having the highest (4123m). Minke and fin whales had similar probability curves, with a steep decline in the probability of visual detections with distance, while humpback whales showed a more gradual decline in the probability of visual detections over distance (Figure 1-6, panel a). This affect is also shown in the boxplot data (Figure 1-6, panel b), where the difference between 1st and 3rd quartile distances and whiskers are greater for humpback than for fin and minke, which are similar. All species showed an initial increase in detections as distance increased before cresting and falling off again. Finally, 1st quartile, median, and 3rd quartile distances were plotted over the acoustic array space (Figure 1-6, panel c).

Circular plots were generated based on the angles of all visual detections from the survey platform relative to true north for fin, humpback, and minke whale. Each species was sighted more frequently in the northeast quadrant compared to the southeast quadrant. To determine if this result was statistically significant a chi-square test based on two-way contingency table was run for each species. This test compared the number of visual detections that occurred in each quadrant with the number of hours of observer effort per quadrant. For this calculation the number of hours of observer effort was the same for each quadrant and for each species (n=1128), as each quadrant was always surveyed simultaneously and for all species for all hours of effort. This analysis revealed that fin whales (chi-square statistic = 136.082, $p < 0.00001$), and humpback whales (chi-square statistic = 19.4366, $p < 0.00001$) were detected significantly more frequently in the northeast quadrant compared with the southeast. Results for minke whales (chi-square statistic = 0.181, $p < 0.67$) were not significant.

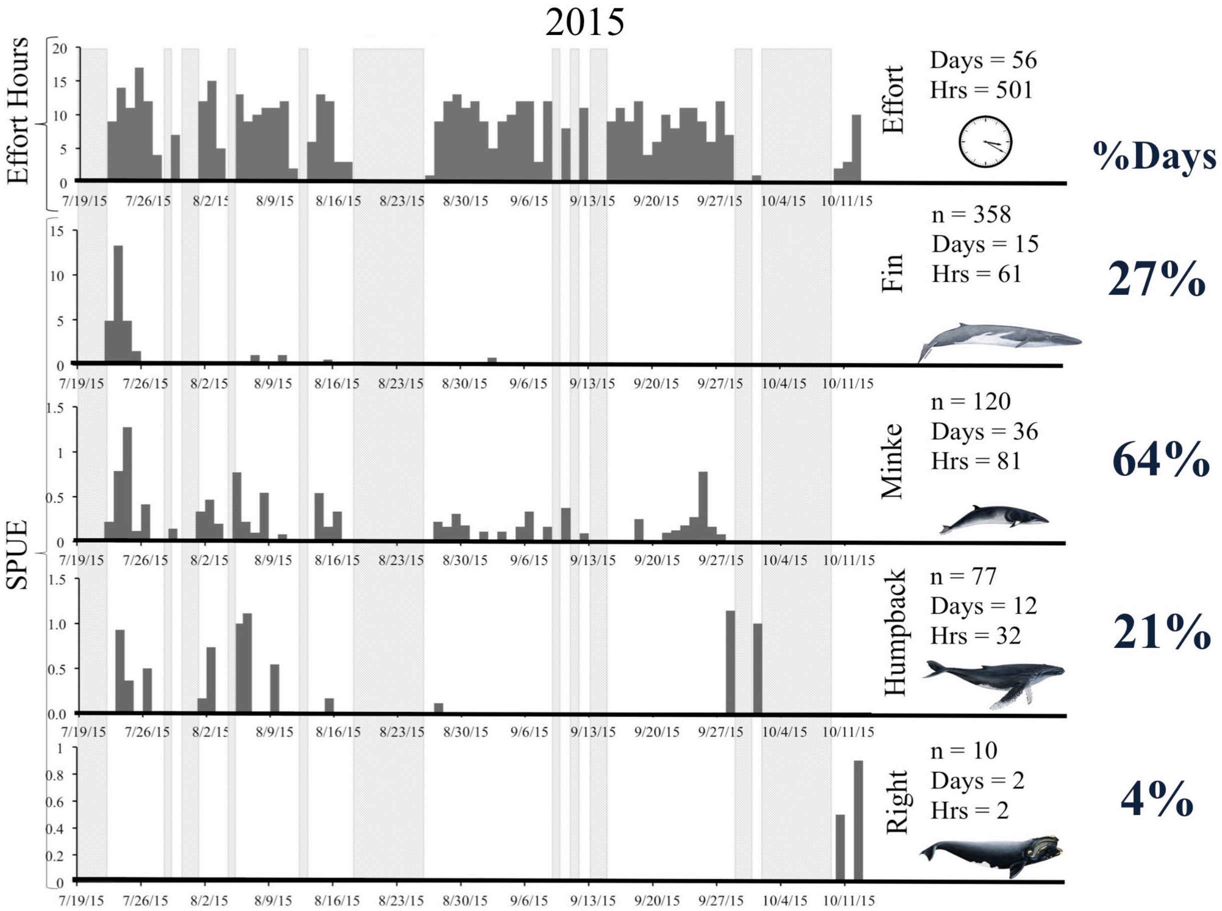


Figure 1-4. Daily visual detections and sightings per unit effort (SPUE) of fin, minke, humpback, and right whales for the 2015 study period. For each species the number of visual detections, number of days of detection, and number of hours of detection are reported. The percentage of days of visual detections that occurred for each species relative to all days of visual effort are reported on the right side of the panel.

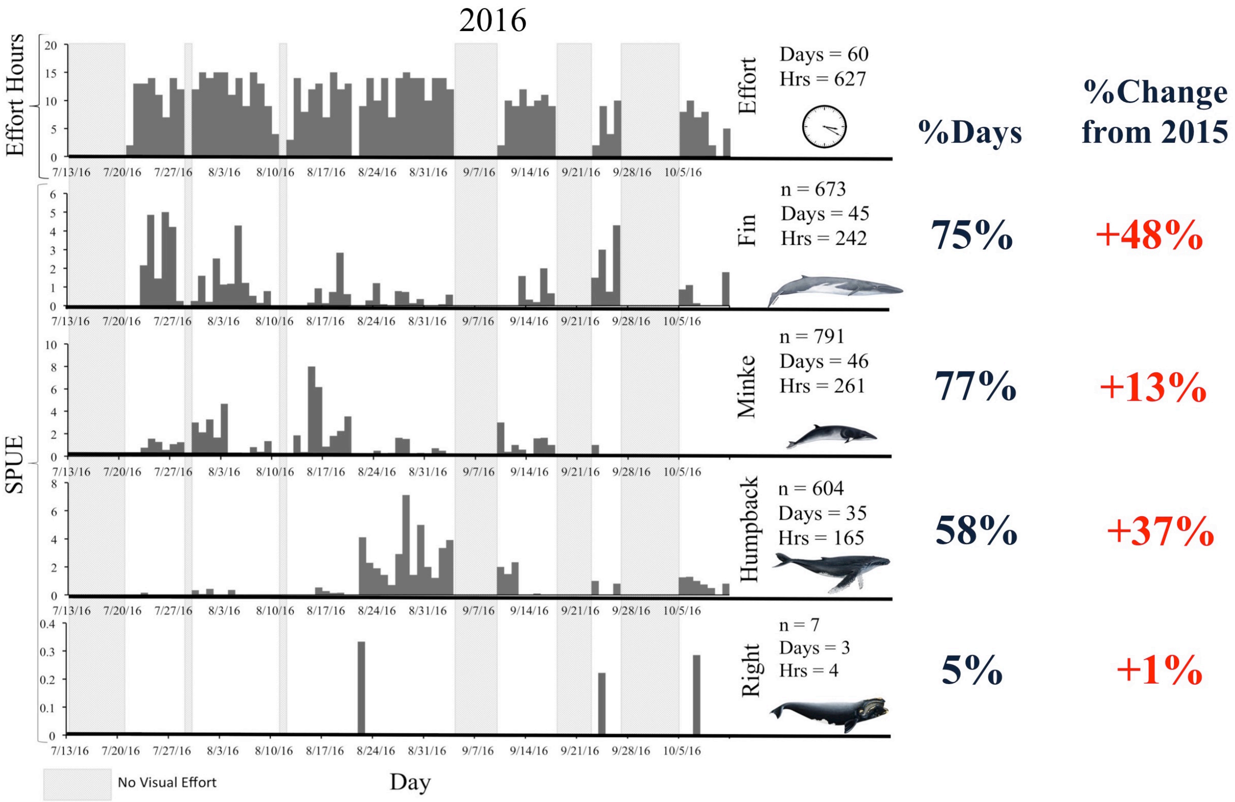


Figure 1-5. Daily visual detections and sightings per unit effort (SPUE) of fin, minke, humpback, and right whales for the 2016 study period. For each species the number of visual detections, number of days of detection, and number of hours of detection are reported. The percentage of days of visual detections that occurred for each species relative to all days of visual effort are reported on the right side of the panel, as well as the percent change in days of detections from the 2015.

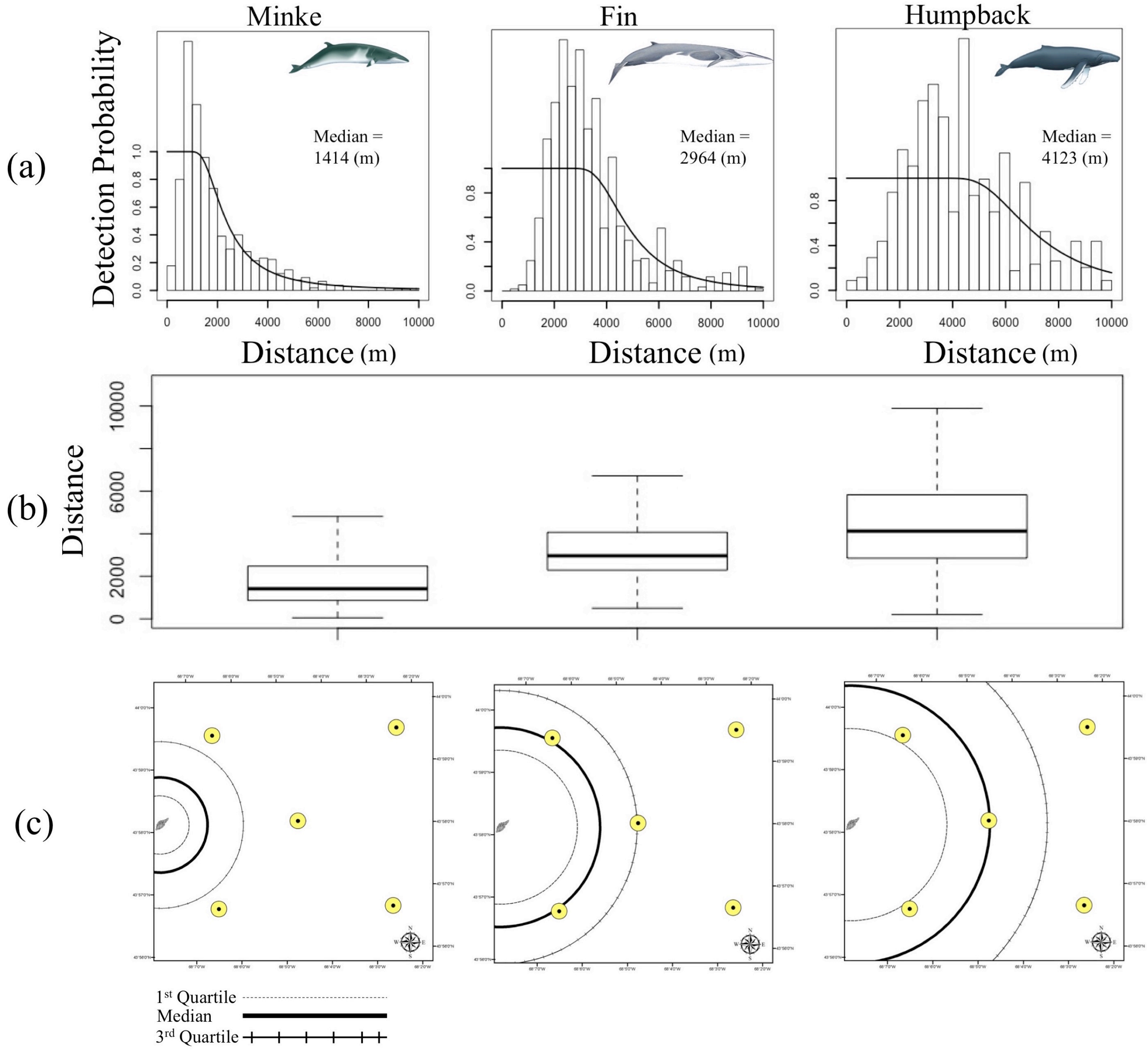
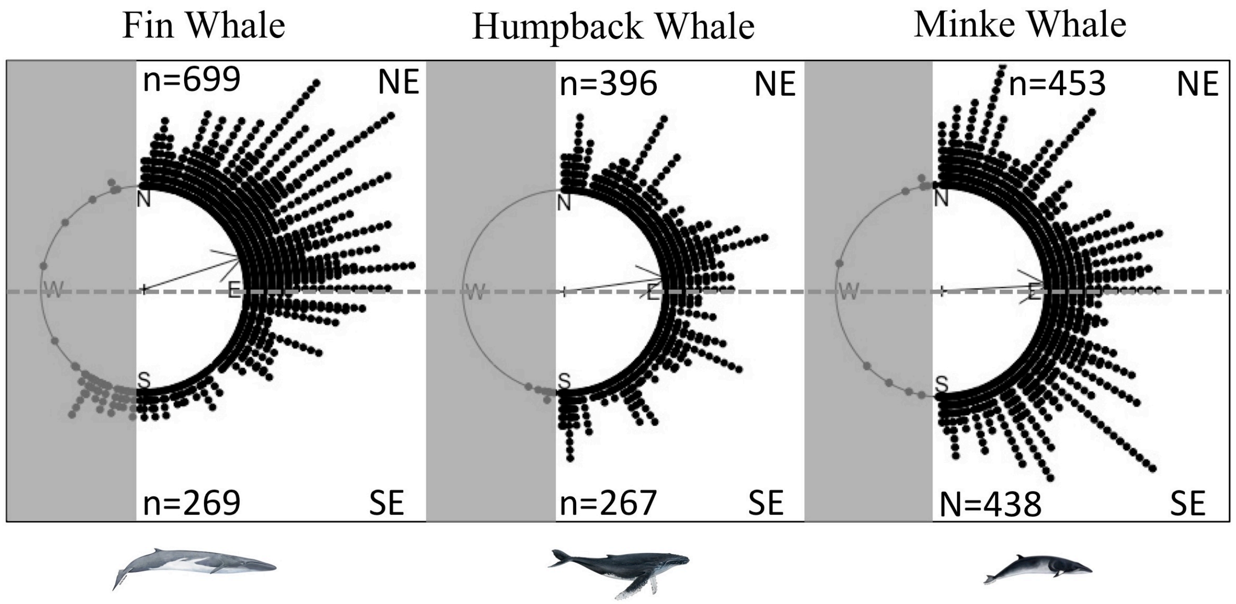


Figure 1-6. Detection probabilities based on distance for fin, humpback, and minke whales for the combined 2015 and 2016 study periods. Panel (a) shows the detection probabilities at distance for each species out to 10 km and associated probability curve. Panel (b) boxplot shows the 1st quartile, median, 3rd quartile, and whiskers (minimum and maximum value) based on detection probability distances for each species (outliers not shown). Panel (c) shows the 1st quartile, median, and 3rd quartile detection probability distances, plotted as a radius from the survey platform extending into the 5-element MARU array.



Fin Whale

	Effort	Sightings	Totals
Northeast	1128	699	1827
Southeast	1228	269	1397
Totals	2256	663	3224

ChiSq Stat 136.082
p-Value < .00001

Significant @ p< .05 ✓

Humpback Whale

	Effort	Sightings	Totals
Northeast	1128	396	1581
Southeast	1228	267	1566
Totals	2256	891	3147

ChiSq Stat 19.4366
p-Value < .00001

Significant @ p< .05 ✓

Minke Whale

	Effort	Sightings	Totals
Northeast	1128	453	1524
Southeast	1228	438	1395
Totals	2256	891	2919

ChiSq Stat 0.181
p-Value 0.670487

Not Significant @ p< .05 ✗

Figure 1-7. Circular plots based on stacked number of visual detections per angle relative to the survey platform for fin, humpback, and minke whales for the combined 2015 and 2016 study period. Number of detections were binned per quadrant (northeast & southeast) and statistically compared using a chi-square test of two-way contingency tables ($p \leq 0.05$). This analysis revealed that fin and humpback whales were detected significantly more frequently in the northeast quadrant than in the southeast.

Passive Acoustic Survey

In 2015, 82 days of audio were recorded (1,968 hrs), and in 2016, 84 days of audio were recorded (2,016 hrs), for a total of 166 days (3,984 hrs) of passive acoustic data. Stereotyped vocalizations for fin, minke, right, and sei whales were found within the data set and used to build automatic template detectors. Humpback whale vocalizations were present within this data set but were excluded from this analysis due to the extensive variability of their vocal repertoire that made automatic detection difficult. These detectors were run across the 2015 and 2016 acoustic data sets. In 2015 fin whales were detected on more days than any other species (23 days) and most frequently by the presence of 74 to 34-Hz downsweeps (21 days). Fin whale 20-Hz pulses were detected on only 4 days. Right whales, only visually detected on two days, were acoustically detected on 15 days. Sei whales, a species never visually detected, were detected acoustically on one day. Minke whales were frequently visually detected in 2015 (32 days) but were only detected acoustically on 4 days. Fin and minke whales both showed a dramatic increase in acoustic detections from 2015 to 2016. Fin whale 20-Hz pulses showed the most increase in overall detections due to the presence of multiple calling bouts, where the 20-Hz pulse is repeated every ~ 10s for multiple hours, though the 20-Hz pulse was also present on 16% more days in 2016 than in 2015. The only species that showed a reduction in both number of overall detections (-41%) and number of days detected (-16%) were right whales. The number of days fin whales were acoustically detected decreased in 2016 (-8%) even though visual detections were up 48%. Sei whales were again acoustically detected on one day and never detected visually. For the combined 2015 and 2016 study period detector results found fin whale 20-Hz pulses (n = 6,651) on 22 days (19%) and downsweeps (n=911) on 36 days (31%). On 14 days (12%) both fin whale vocalization types were found. Minke whale pulse trains (n=448) occurred on 25 days (22%), and right whale 100 to 300-Hz up-calls (n=118) were found on 17 days (15%). Sei whale 80 to 30-Hz downsweeps (n=5) occurred on two days (2%).

Fin whale 20-Hz pulse and 74 to 32-Hz downsweeps were produced much more frequently during overnight hours (20:00 – 06:00), with a small increase in the morning (08:00 – 11:00) (Figure 1-10). Almost no fin calls occurred from 11:00 – 20:00. Minke whale pulse trains were produced in the evening, beginning at 19:00 and ceasing after 23:00. Right whale up-calls were typically produced during the day and evening (10:00 – 21:00), with a peak at 19:00, and virtually none at night (Figure 1-10). Sei whales were excluded from this analysis as only five vocalizations were captured through the project period.

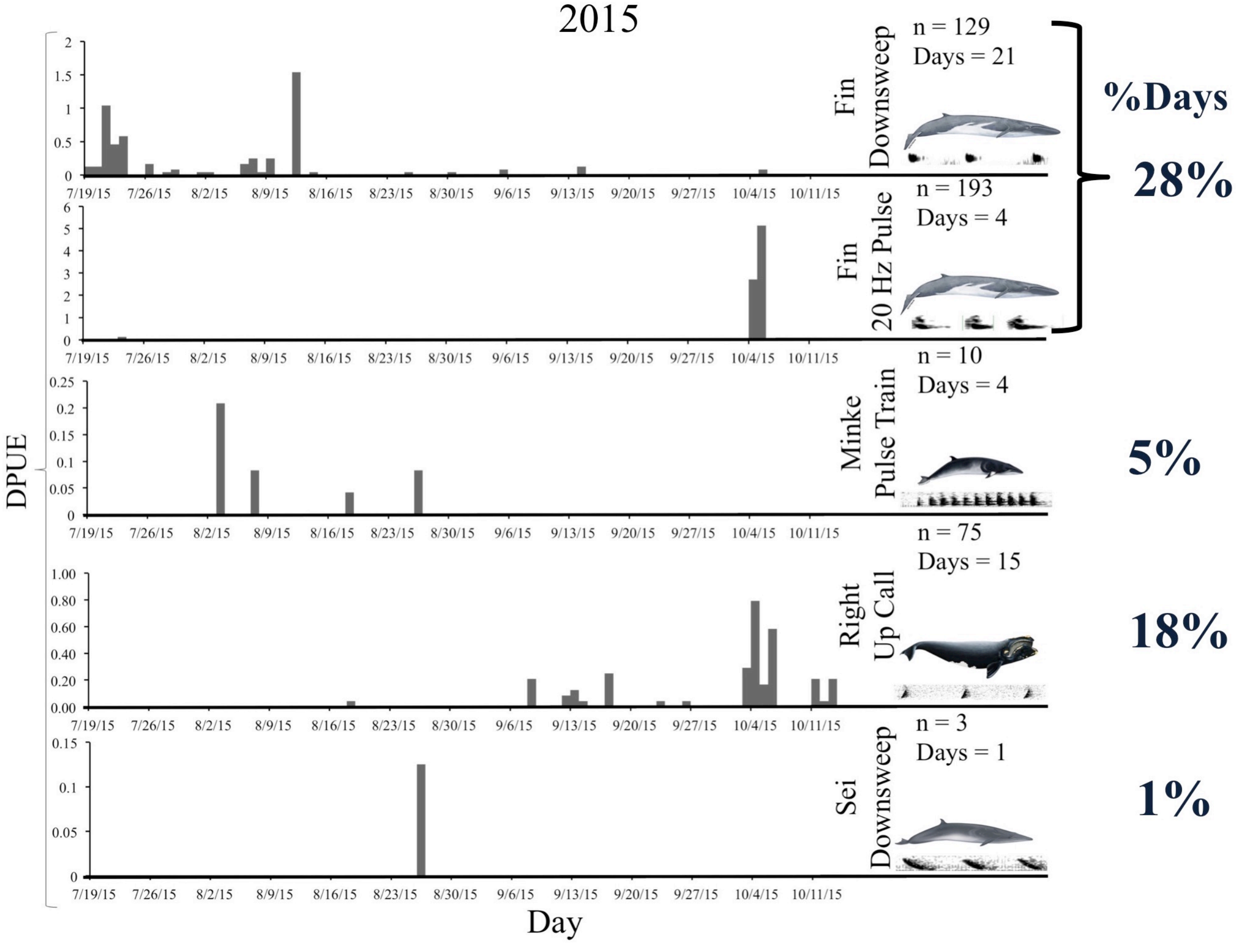


Figure 1-8. Daily acoustic detections and detections per unit effort (DPUE) of fin, minke, humpback, and right whales for the 2015 study period. For each species the number of acoustic detections, number of days of detection, and number of hours of detection are reported. The percentage of days of acoustic detections that occurred for each species relative to all days of visual effort are reported on the right side of the panel. Two graphs are present for fin whales representing both the 20-Hz pulse detections and 74 to 34-Hz downsweep detections. Sei whales were detected acoustically on one day though never detected visually.

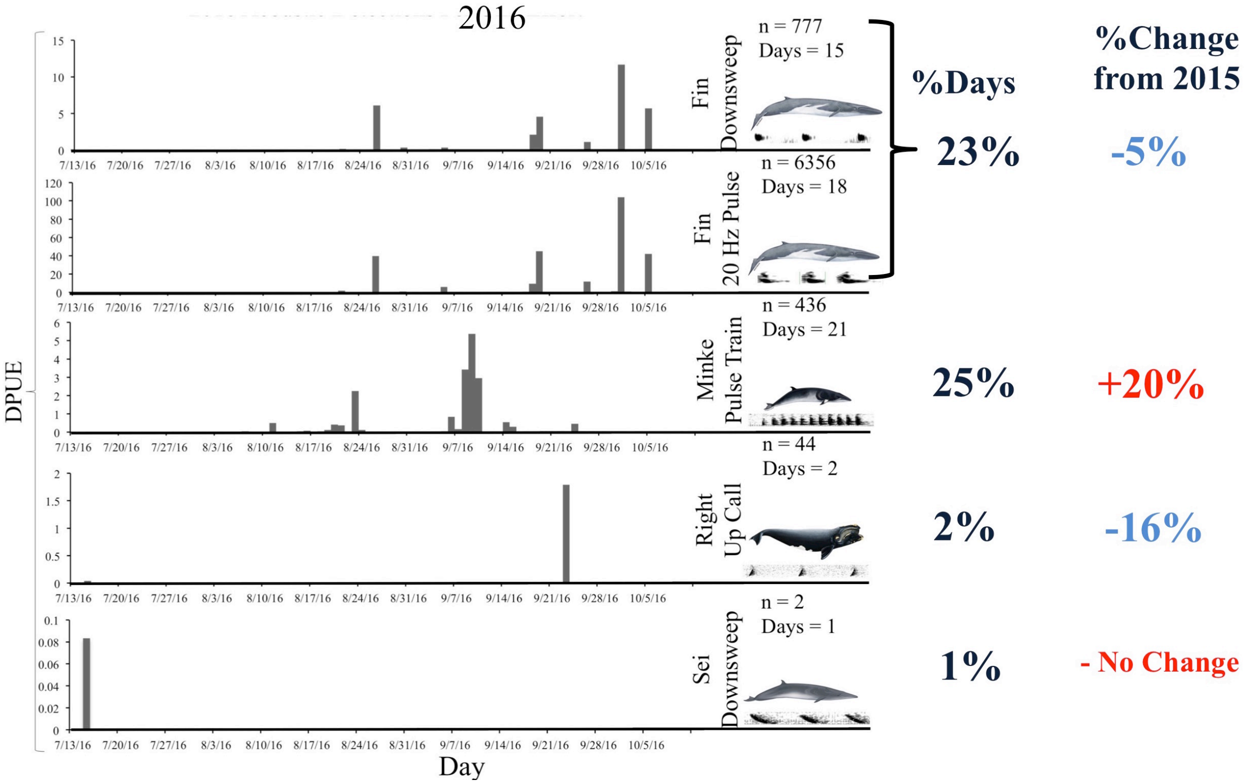


Figure 1-9. Daily acoustic detections and detections per unit effort (DPUE) of fin, minke, humpback, and right whales for the 2016 study period. For each species the number of acoustic detections, number of days of detection, and number of hours of detection are reported. The percentage of days of acoustic detections that occurred for each species relative to all days of visual effort are reported on the right side of the panel, as well as the percent change in days of detections from the previous year. Two graphs are present for fin whales representing both the 20-Hz pulse detections and 74 to 34-Hz downsweep detections. Sei whales were detected acoustically on one day though never detected visually.

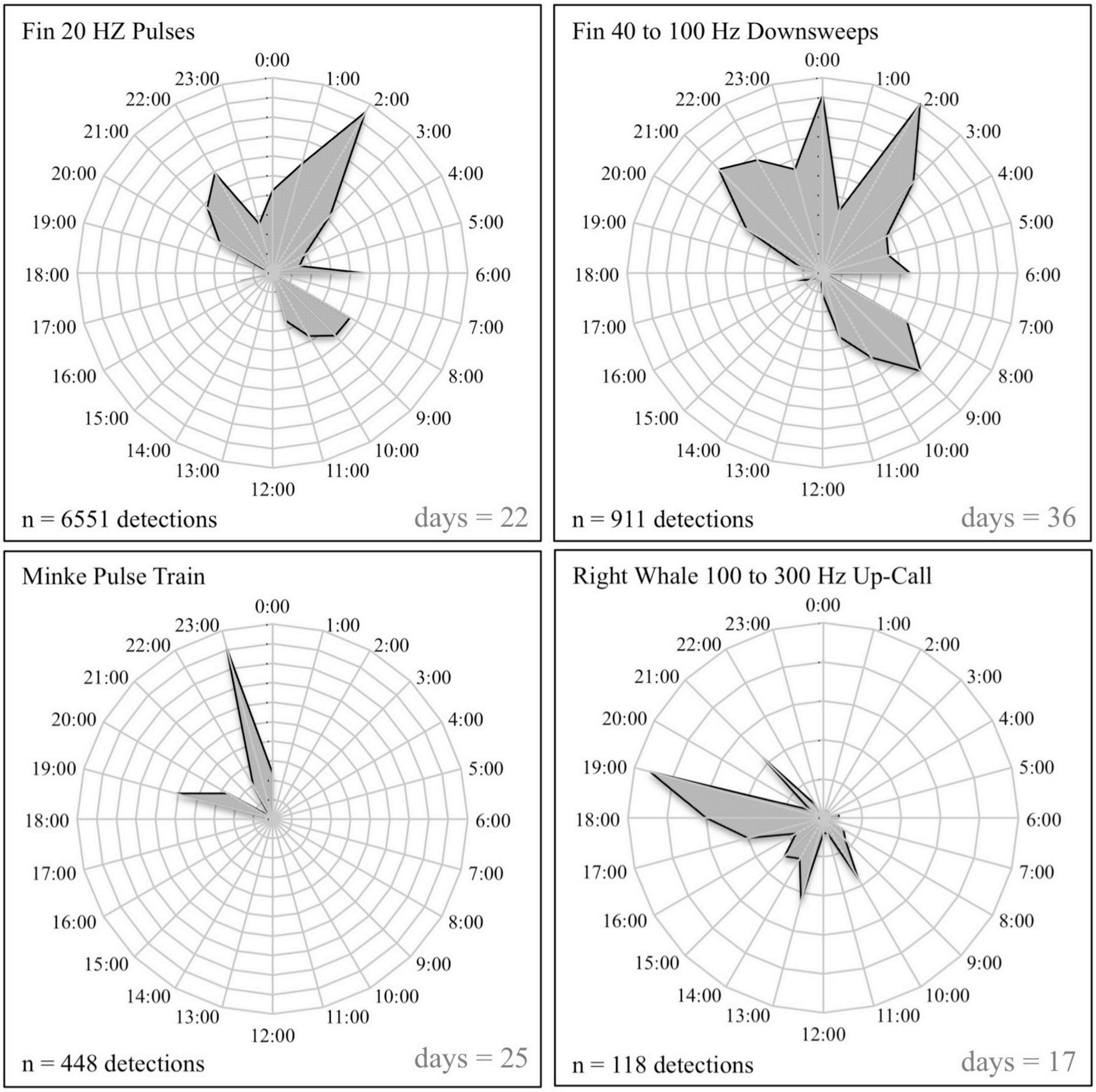


Figure 1-10. Twenty-four hour radar plots showing the diel patterning of vocalization activity for fin, minke, and right whales for the combined 2015 and 2016 study periods. Fin and minke whales vocalizations were detected primarily during evening and overnight hours, while right whale vocalizations were detected primarily during daylight hours. Sei whales were excluded from this analysis as only five vocalizations were captured.

Results of the detector data also revealed instances of calling bouts for fin, minke, and right whales. Calling bouts were defined as a seriees of patterned or semi-patterned stereotyped vocalizations produced by an individual for an extended period of time, typically > 1 hour (Rekdahl *et al.* 2015). Fin whale bouts occurred as a series of 20-Hz pulses produced with regular inter-pulse intervals (IPI) (~ 10s), for up to 12 or 15 minutes, with rests lasting 1 or 2 minutes, repeated for an hour or more (Figure 1-11). There were nine fin whale bouts found in this data set. Minke whale bouts occurred as a series of pulse train calls of variable types, without consistent pattern, with rests between (Figure 1-12). There were two minke whale bouts identified in this dataset. There were also two right whale bouts that occurred, one in 2015 and one in 2016. The 2015 right whale bout was comprised mostly of a series of up-calls while the 2016 bout was more varied, starting with up-calls, progressing to a mixture of moans and screams and gunshots, moving to predominantly gunshots (Figure 1-13). None of these call bout analyses included an assessment of the number of calling animals, which would have required a time-consuming location analysis.

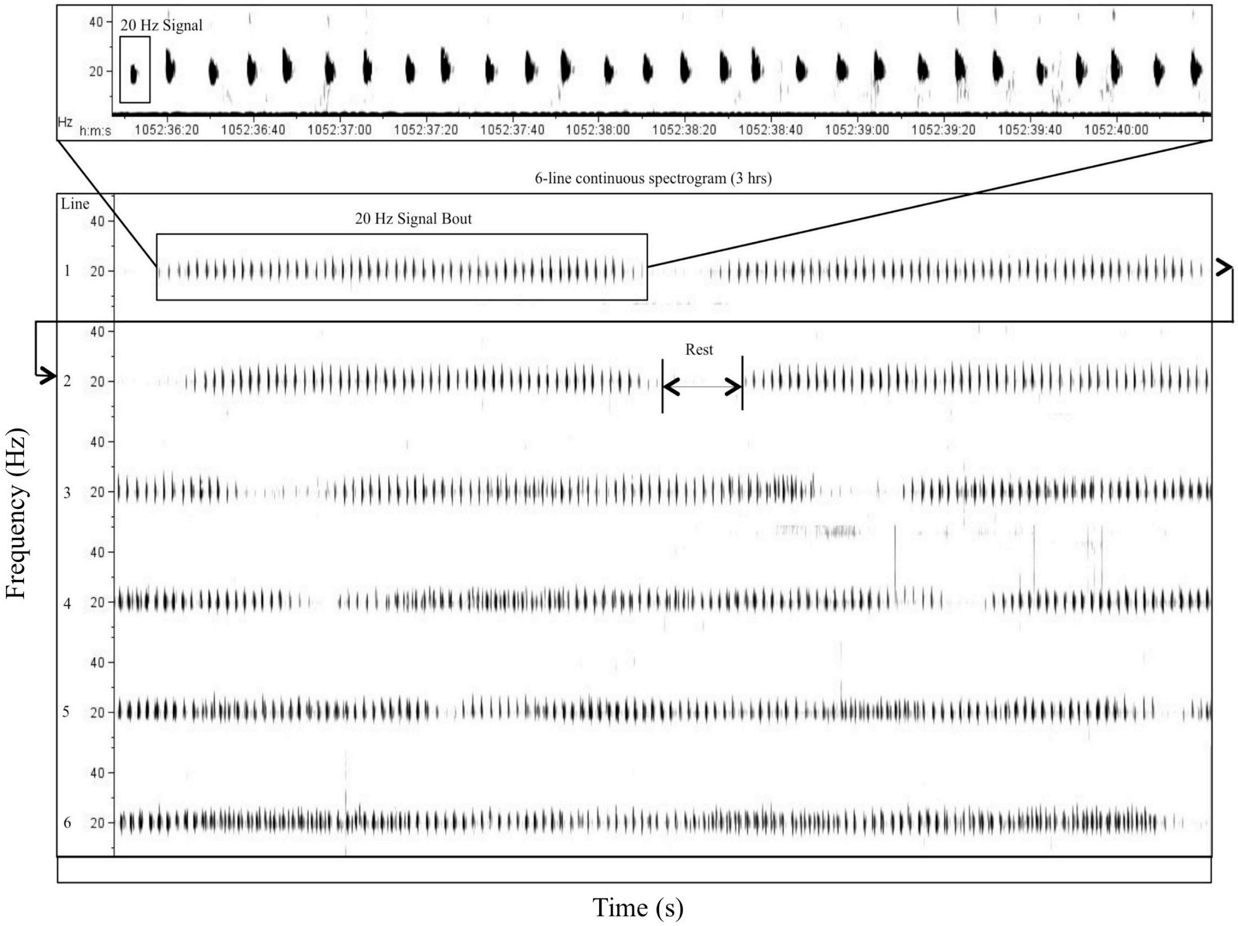


Figure 1-11. Continuous spectrogram example of a fin whale calling bout. Time (s) is represented on the x-axis and frequency (Hz) on the y-axis. Each line (1 to 6) is a continuation in the acoustic data from the previous line. Fin whale calling bouts occurred as a series of 20-Hz pulses produced with regular inter-pulse intervals (IPI) (~ 10s), for up to 12 or 15 minutes, with rests lasting 1 or 2 minutes, repeated for an hour or more.

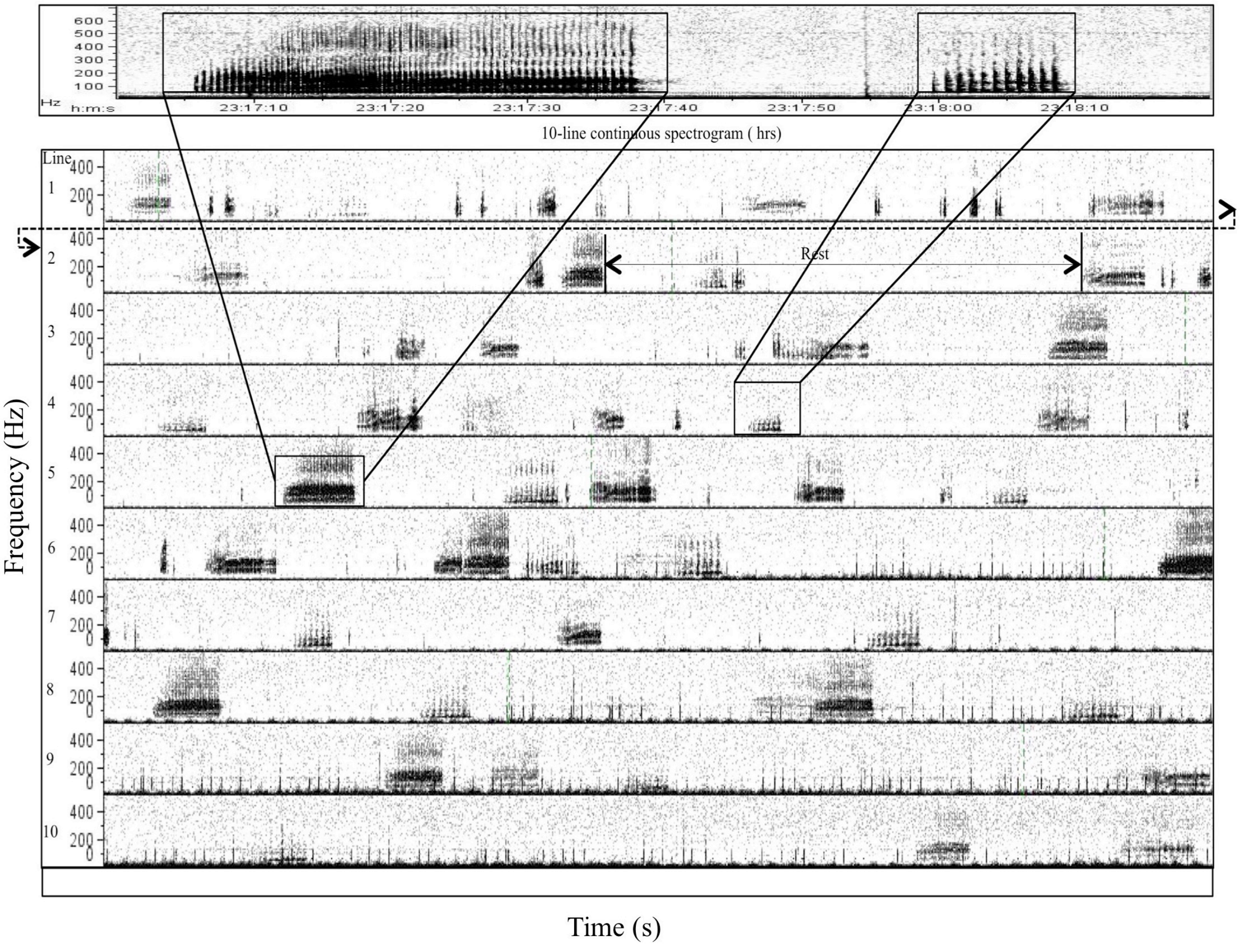


Figure 1-12. Continuous spectrogram example of a minke whale calling bout. Time (s) is represented on the x-axis and frequency (Hz) on the y-axis. Each line (1 to 10) is a continuation in the acoustic data from the previous line. Minke whale bouts occurred as a series of pulse train calls of variable types separated by rests but without consistent pattern. There are likely at least two calling individuals represented in this spectrogram.

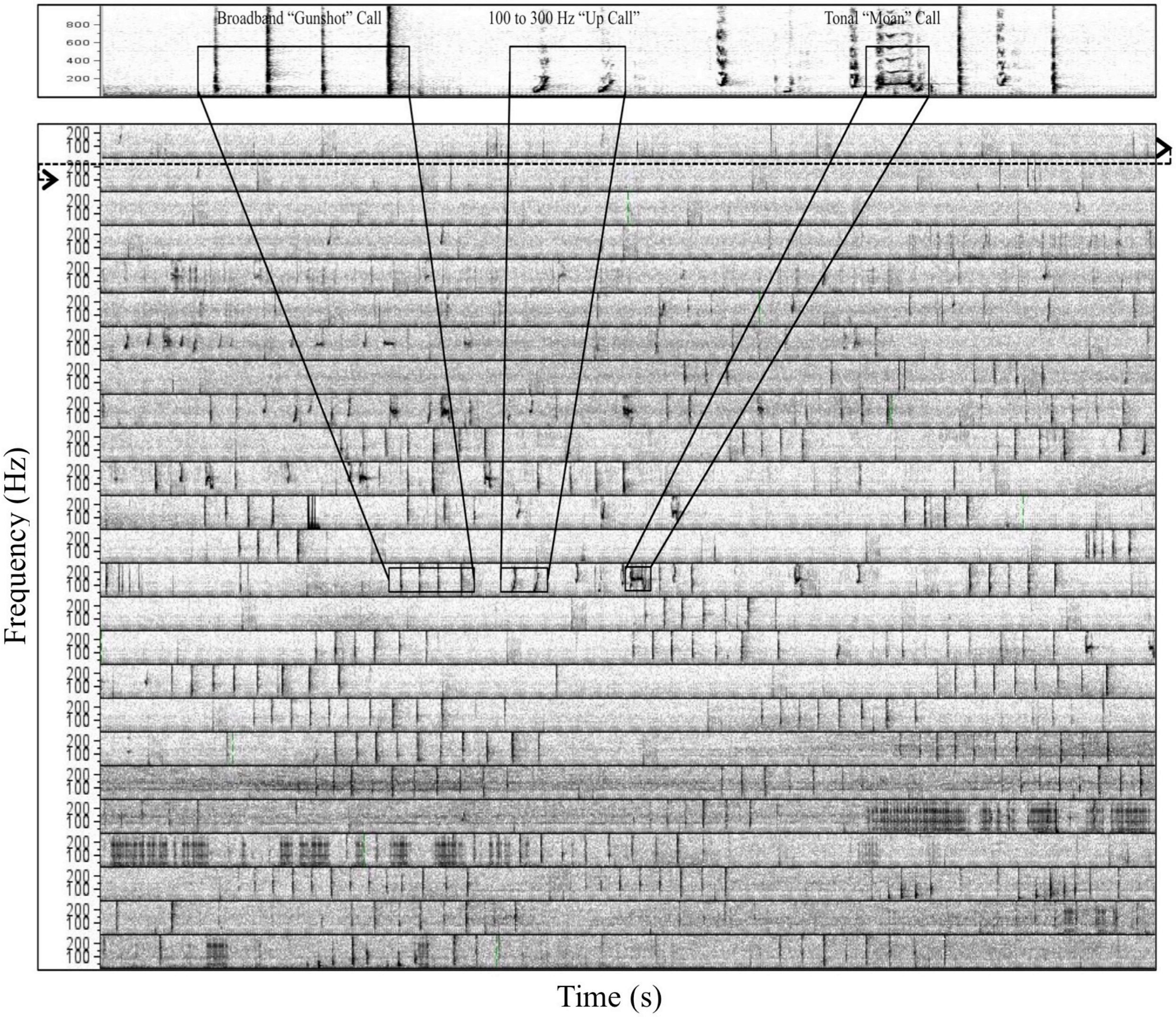


Figure 1-13. Continuous spectrogram example of a right whale calling bout. Time (s) is represented on the x-axis and frequency (Hz) on the y-axis. Each line (1 to 25) is a continuation in the acoustic data from the previous line. This bout occurred in 2016 and began with a series of up-calls, progressing to a mixture of moans and screams and gunshots, and finishing with predominantly gunshots.

Daily visual and acoustic detections of fin, minke, and right whales were compared to determine the effectiveness of each survey method. Data were reported for each day that a species was detected only acoustically, only visually, or by both methods (Figure 1-14). The number of days where fin whales were detected only visually (n=34) was similar as only acoustically (n=28), which differed from minke whales which were detected only visually (n=69) much more often than only acoustically (n=12), and right whales which were detected only visually (n=4) quite less often than only acoustically (n=16). As previously mentioned, sei whales were detected on days only acoustically (n=2) through the 2015 and 2016 study period. Finally, results show that the percentage of days where species were detected using both visual and acoustic methods, out of all days that a species was detected, was relatively low overall (fin=20%, minke=14%, right=5%).

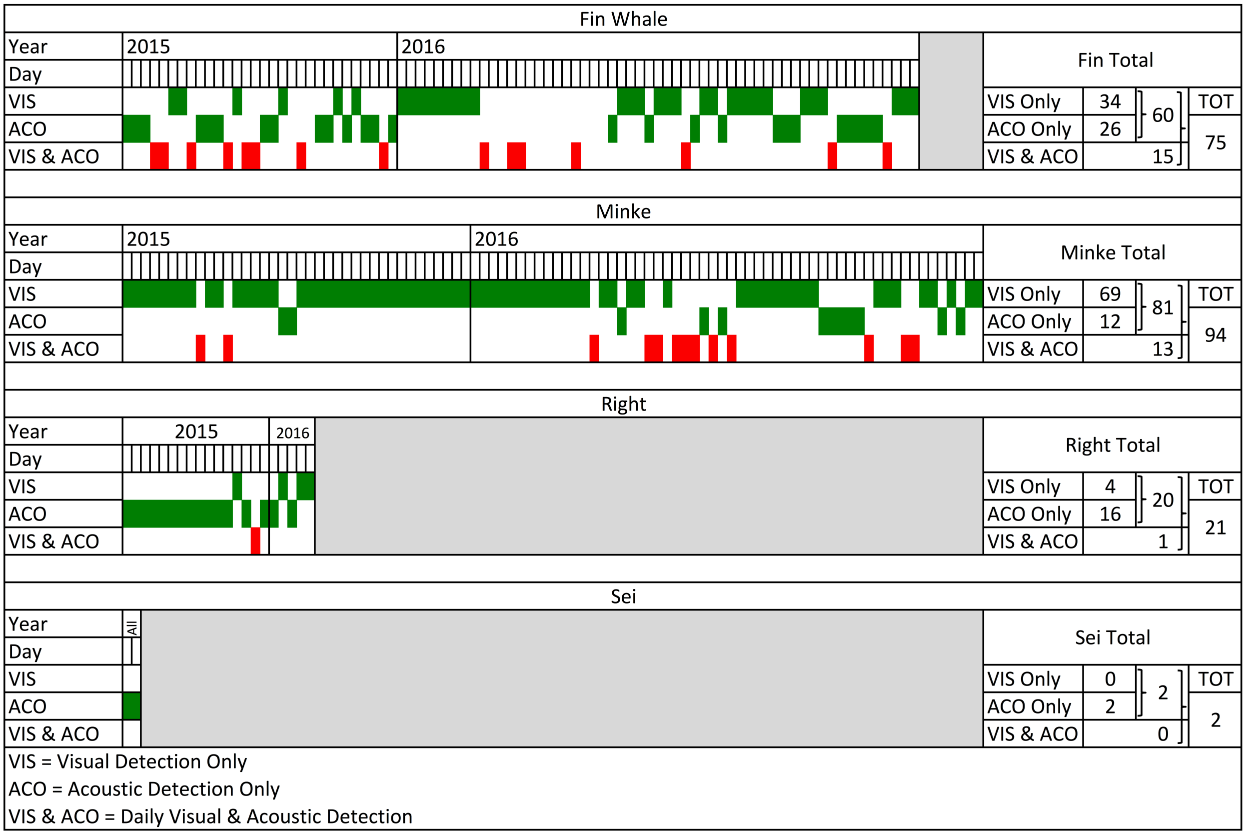


Figure 1-14. Comparison of daily detections of fin, minke, right, and sei whale by survey technique. Green boxes show days where a species was detected either only visually or acoustically, and red boxes show days where species were detected both visually and acoustically. Data are summarized per species in the "total" boxes.

Discussion

Both passive acoustic monitoring and visual survey were effective practices for detecting the presence of baleen whales in this study. Visual methods were more effective at detecting the the common visitors to the study area (fin, humpback, minke), whereas acoustic methods better detected species rarely or never seen (right, sei). Perhaps most interesting is the relatively low number of days of overlap when species were detected both acoustically and visually compared to days where species were detected only visually or only acoustically. For example, fin whales were detected only visually on 34 days, only acoustically on 28 days, and via both methods on 15 days, meaning that if this survey was conducted using one method or the other only, over one-third of fin whale detections would have been missed.

This study would further benefit from a spatial analysis of vocalizations to determine if the whales that were detected only acoustically were outside the visual survey space, which would account for the low numbers of co-occurring visual and acoustic detections. Locations of vocalizing whales can be done by triangulating vocalizations using the multi-buoy acoustic array and calculating time delay of arrival (TDOA) differences (Walker 1963, Patterson and Hamilton 1964; Clark *et al.* 1996, Stanistreet *et al.* 2013). If whales typically vocalize outside of the visual survey space at MDR, it could indicate that vocal behavior is dissociated from the activity within the survey space, presumed to be feeding (Stevick *et al.* 2008). One other possibility is that the stereotyped vocalizations used in this study to acoustically detect each species are not the type of vocalizations that these species use when inside the survey space, and there are other undocumented vocalizations occurring that were not accounted for in this study. Further investigation of this dataset should include an analysis to determine if novel vocalizations are present, as well as a comparison with the confirmed presence of visually detected species.

Histograms of visual detection data and associated detection probability curves show that the ranges of distances at which each baleen whale species were sighted agree with expected distance sampling theory, which states that detections should be low close to the survey station where there is a small survey swath, increase steadily as survey swath area increases, and finally drop steadily as animals become more difficult to detect with distance (Buckland *et al.* 2007). However, there were differences in the detection probability curves for each species. These differences are likely due to a combination of each species physical characteristics, behavior, and groups size, but could also be due to spatial preferences. A minke whale is likely more difficult to detect than a humpback whale because it is a much smaller species, typically has no discernable blow, and often spends little time at the surface, whereas a humpback whale is larger, has a distinctive blow, and often spends long periods at the surface displaying charismatic behavior (Katona *et al.* 1983). Fin whale behavior is more similar to that of a minke than a humpback, however they are much larger and have a very tall, discernable blow. This would explain why fin and minke whales have similar detection curve profiles, but fin whales were detected at greater distances. It has also been shown that sightings of small groups of animals (2 to 3) doubles detection probabilities compared to sightings of single animals (Williams *et al.* 2016). This could be a factor at the MDR site as minke whales are more often sighted as singles whereas fin and humpbacks are commonly sighted in groups of two or more. Alongside the physical and behavioral characteristics, each species spatial preference may also play a role in detection probability. In this study both fin and humpback whales were detected significantly more frequently in the northeast quadrant than the southeast. This suggests that a biological or oceanographic feature in the northeast quadrant may also drive the spatial distribution of each species, another factor that may determine detection probability. Anderwald *et al.* (2012) found that seasonal minke whale habitat use in the eastern North Atlantic was driven by temporally variable parameters such as sea surface temperature and chlorophyll, along with depth and temperature, but that fine scale habitat use was driven by tidal cycle. All of these factors should be considered when interpreting the results of the detection probability data.

During this study there was a two-fold increase in visual detections of baleen whale in the study area from 2015 to 2016, as well as variability in the number of daily detections of each species during each study year. Prey availability and concentration is known to drive aggregations of large whales (Stevick *et al.* 2008), and these aggregations are patchy from year to year (Mayo and Marx 1990). The MDR site sits roughly at the geographical split between the two currents that comprise the Gulf of Maine Coastal Current (GMCC) – the Eastern Maine Coastal Current (EMCC), and the Western Maine Coastal Current (WMCC) (Pettigrew *et al.* 2005, Brown and Irish 1993). Pettigrew *et al.* (2005) describe significant inter-annual variation in the flow through from the EMCC through to the WMCC, and the southerly flow of the EMCC past the MDR region that eventually contributes to the Jordan Basin Gyre. These inter-annual fluctuations affect nutrient flow and primary producers, and may affect production at the MDR site and subsequent prey distribution. Further investigation with this dataset may benefit from a comparison with oceanographic data from the NERACOOS buoys "I" (Eastern Maine Shelf) and "M" (Jordan Basin), to determine if nutrient loads or other factors (temperature, salinity) correlate with either visual or acoustic detections of cetacean species. The visual and acoustic surveys carried out in this study would also be complimented in the future by simultaneous prey sampling (Hazen *et al.* 2009, Friedlander *et al.* 2009, Doniol-Valcroze 2007, Fiedler *et al.* 1998).

Prior passive acoustic studies in the Mount Desert Rock region were focused on the acoustic behavior of single species, such as fin whales (Delarue *et al.* 2009) and right whales

(Bort *et al.* 2015). Delarue *et al.* (2009) reported on the variations in fin whale 20-Hz pulse inter-pulse interval (IPI) duration from the MDR region versus the Gulf of St. Lawrence region, suggesting that these differences in song structure may be an indicator of stock structure partitioning. Cataloging such variations in IPI, as well as note frequency, is a common approach to distinguishing stock structures (Castelllote *et al.* 2012, Thompson *et al.* 1992, Croll *et al.* 2002, Sirovic *et al.* 2017). Little focus has been placed, however, on the broad-scale patterns of long-term bouts first described by Watkins *et al.* (1982), and outlined briefly in this paper, where individuals are producing 20-Hz pulses for regular intervals (~ 12 minutes) with rests (~2 minutes). Previous studies posit that rests are a function of an animal's surfacing and the physiological need to breathe (McDonald *et al.* 1995, Watkins *et al.* 1987), however it is uncertain if the broader pattern of 20-Hz bout intervals are meaningful to overall fin whale song pattern. Each of the minke whale vocalization types described by Risch *et al.* (2014) was recorded at the MDR site. Minke whale calling bouts were comprised of each of these calls, with less of a noticeable pattern than that of fin whales. Multi-hour right whale calling bouts were recorded that included each of the known call types, and exhibited some patterns and variation between bouts. Bort *et al.* (2015) reported very high numbers of right whale calls in a region roughly 50 km southwest of the MDR study site. These included up-calls and gunshots. No review of the other vocalization types (e.g., the low moan and the scream call) was included in that study.

Visual and passive acoustic survey are both standard techniques for the management of whale stocks (Davis *et al.* 2017, Palka 2012, Van Parijs *et al.* 2009). The findings of this study suggest that the two survey techniques are highly complementary to each other, the combination of which resulted in a more precise census. The combined survey results highlight that each species detectabililty may be reliant on a combination of factors including each species physical characteristics and behaviors, the local biological and oceanographic conditions, and each species vocal repertoire.

CHAPTER 2:

VOCALIZATIONS RECORDED IN THE PRESENCE OF FIN (*BALAENOPTERA PHYSALUS*) AND MINKE (*BALAENOPTERA ACUTOROSTRATA*) WHALES IN THE VICINITY OF MOUNT DESERT ROCK

Abstract

Fin (*Balaenoptera physalus*) and minke whales (*Balaenoptera acutorostrata*) use sound as a primary method of communication in a spatially vast, light limited ocean environment. The full extent of these acoustic communications are not well understood. Passive acoustic monitoring (PAM) allows researchers to eavesdrop on these communications to examine animal presence, movements, and behavior. To better understand these species' vocal repertoire, visual detections of fin and minke whales were compared to detections of novel baleen whale vocalizations within a collocated five-element acoustic array. A total of five novel vocalizations were identified and compared, including short 286 to 448-Hz upsweeps, 498 to 363-Hz and 257 to 164-Hz long downsweeps, broadband 415-Hz "whip-cracks", and suspected fin whale 74 to 34-Hz downsweeps. Detailed measurements of each vocalization type were calculated. The 74 to 34-Hz downsweeps were found to be statistically associated with fin whales ($p = 0.040$, $\Phi = 0.129$), while all other tests of association were inconclusive. Plotted locations of visually detected fin and minke whales showed little overlap with locations of novel vocalizations, which may have complicated the statistical test. Non-vocalizing whales and diel periodicity of vocalizations were also potential factors. The continued discovery of undocumented vocalization types for federally managed species supports the need for simultaneous visual and passive acoustic survey, as well as standardized strategies for properly attributing novel vocalizations to species.

Introduction

Fin and minke whales are seasonal residents in the Gulf of Maine, an important feeding ground in the western North Atlantic Ocean in the spring, summer, and fall months where individuals forage on a mixture of herring, sand lance, and krill (Clapham *et al.* 1993, Durbin 1995, Agler 1992, Katona *et al.* 1983). Both fin and minke whales, like all baleen whales, communicate by producing low-frequency vocalizations (Clark *et al.* 2002, Croll *et al.* 2002, Watkins *et al.* 1987). Certain vocalization types produced by these animals, such as the fin whale 20-Hz pulse (Edds 1988, Watkins *et al.* 1987), and the pulse trains of minke whales (Risch *et al.* 2014), are well documented in the western North Atlantic. For baleen whales in general, recording these types of communications can be an effective technique to determine occurrence (Stafford *et al.* 2007, George *et al.* 2004), habitat use (Croll *et al.* 2002), and behavior (Stimpert *et al.* 2007). This passive acoustic monitoring (PAM) of animal sounds using hydrophones and recorders is now a practical and widely used method for the remote monitoring of cetaceans (Van Parijs *et al.* 2009, Mellinger *et al.* 2007). These studies are particularly useful for baleen whales as vast habitat ranges and dynamic weather conditions can make visual surveys for these species difficult. However, a persistent challenge for PAM studies is correctly identifying what species are producing sounds in a given data set (Sousa-Lima *et al.* 2013, Van Parijs *et al.*, 2009, Baumgartner *et al.* 2008). Contemporary PAM studies are often conducted without accompanying visual survey, resulting in no confirmation of what species are present in the acoustic study space, and a lack of opportunity to attribute any newly discovered vocalizations to species.

To truly determine the vocal repertoire of cetaceans there must be associations made between the presence of species and the presence of vocalizations on fine spatiotemporal scales.

This process may take the form of tagging animals with acoustic recorders (Dunn *et al.* 2015, Owen *et al.* 2015, Zimmer *et al.* 2005) or conducting close focal follows of individuals with single hydrophones (Parks *et al.* 2014, Quick *et al.* 2008). Multiple acoustic sensors can also be deployed in an array to enable time-difference-of-arrival (TDOA) methods to calculate the 2D location of vocalizing animals (Watkins and Schevill 1971, Cummings 1968). Individual animals that vocalize frequently can be tracked by following the spatial patterns of vocalization locations over time (Stanistreet *et al.* 2013, Clark *et al.* 1996, Patterson and Hamilton 1964, Walker 1963). Combining acoustic localization with concurrent visual observations to spatiotemporally align sighted species with the vocalizations they produce has also been shown to be an effective method to attribute vocalizations to species (Baumgartner *et al.* 2008, Rankin and Barlow 2005). This study used a similar approach to compare visual detections of fin and minke whales with co-occurring novel vocalizations.

Along with fin and minke whales, the western North Atlantic Ocean supports seasonal groups of humpback (*Megaptera novaeangliae*), right (*Eubalaena glacialis*), and sei (*Balaenoptera borealis*) whales (Waring *et al.* 2015, Katona *et al.* 1983). Each of these co-occurring species has specific vocalizations that must be considered when conducting passive acoustic analysis. Of these five Gulf of Maine baleen whale species, the extent of the acoustic repertoire of the humpback, a gregarious vocalizer, and the right whale, a critically endangered species, are well studied (Au *et al.* 2006, Helweg *et al.* 1992, Payne and McVay 1971, Winn and Winn 1978). The repertoire of fin and minke whales are less well understood. In all of their habitat ranges worldwide, including the Gulf of Maine, fin whales produce stereotyped pulse vocalizations in the 20 to 40-Hz range, with some variation in frequency and inter-pulse interval (IPI), depending upon season and geographic space (Morano *et al.* 2012, Clark *et al.* 2002, Edds

1988, Watkins *et al.* 1987). The 20-Hz vocalization has been hypothesized to function as both a mating display (song) (Croll *et al.* 2002) and a social sound (Edds-Walton 1997, McDonald *et al.* 1995,). Fin whales have also been reported to produce downsweeps in the 75 to 40 Hz range (Ou *et al.* 2015, Watkins *et al.* 1982), however detailed data regarding vocalizations other than the 20-Hz pulses are minimal. The most prevalent and well-documented vocalization types for minke whales in the North Atlantic are variations of low-frequency pulse trains existing within three categories (slow-down, constant, and speed-up) (Risch *et al.* 2014). There are also reports of 5 to 6 kHz clicks (Beamish and Mitchell 1973) and lower frequency 118 to 80-Hz downsweeps (Edds 2000), but these sounds are not well documented.

The goal of this study was to catalog and describe novel vocalizations that co-occurred with confirmed visual detections of fin and minke whales, and to examine these associations statistically. The locations of both visually detected whales and novel vocalizations were also compared.

Methods

Visual and Acoustic Surveys

Access to visual observations of baleen whales in the Gulf of Maine is generally restricted to boat-based surveys. One exception is the Mount Desert Rock marine research station (MDR), a small, treeless island situated 50 km due south of Bar Harbor, Maine (Figure 2-1) that offers elevated viewing from a lighthouse and living quarters. MDR is the most remote lighthouse station on the eastern seaboard of the United States and functions as a marine research

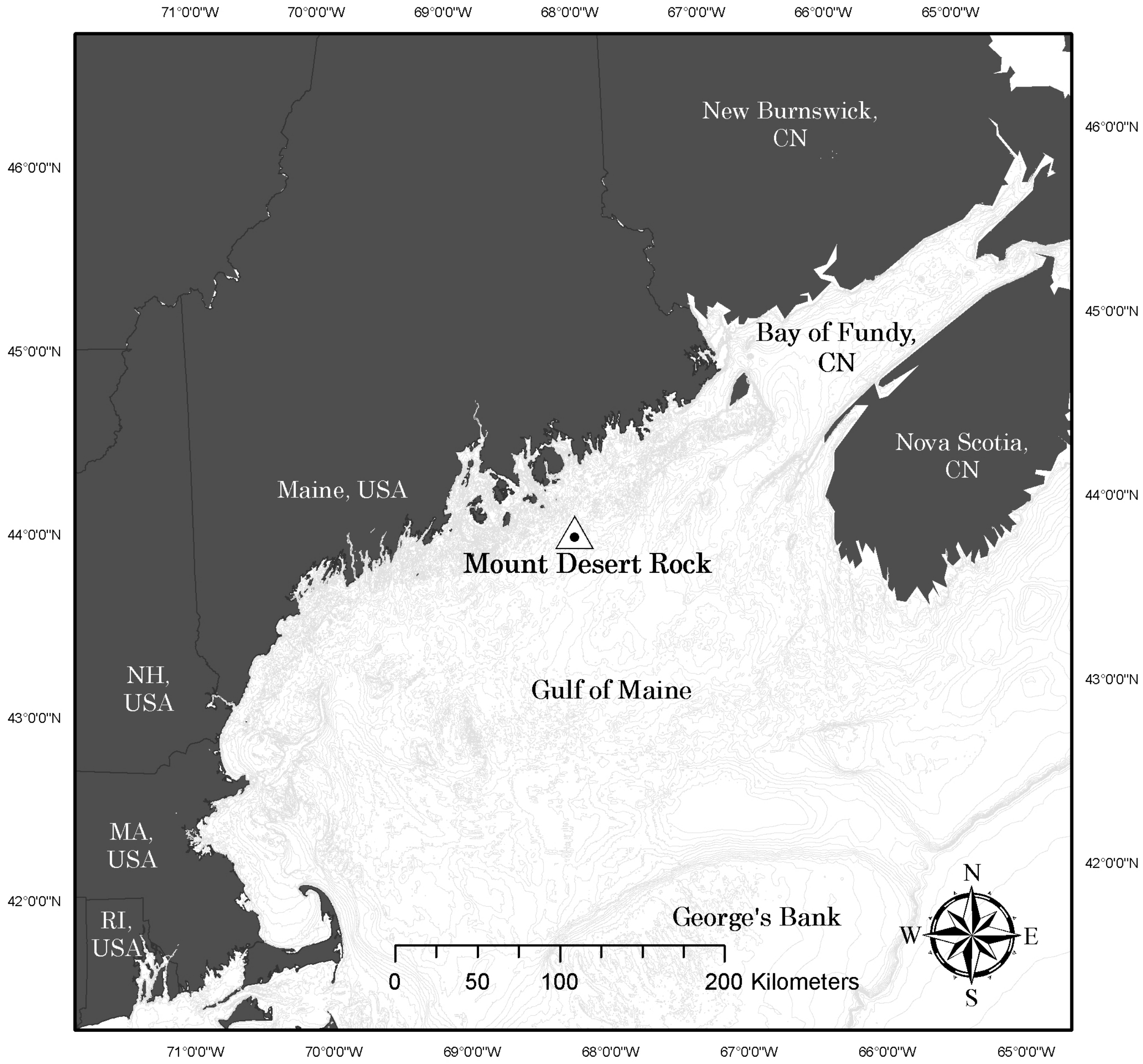


Figure 2-1. Map of the Mount Desert Rock (MDR) Marine Research Station, situated in the Gulf of Maine, USA. MDR is a 3.5-acre island with a lighthouse station owned and operated by the College of the Atlantic (Bar Harbor, Maine). The MDR station has been used as a whale and scientific research facility since the early 1970's.

station for the College of the Atlantic (COA) in the summer months. In the Gulf of Maine, the MDR lighthouse is an unparalleled elevated and unobstructed viewing platform for land-based baleen whale surveys. The MDR station has long been long utilized as an outpost for the photo-identification, biopsy, and acoustic studies of multiple cetacean species (Katona *et al.* 1983, Delarue *et al.* 2009, Bort *et al.* 2015). For this project, concurrent visual and passive acoustic surveys were conducted at the MDR site from July – October in 2015 and 2016 in the waters east and adjacent to the island (Figure 2-2). The visual survey followed observation protocols developed for the Atlantic Marine Assessment Program for Protected Species (AMAPPS) shipboard and aerial surveys, a broad-scale cetacean census conducted by the Northeast Fisheries Science Center (NEFSC), Woods Hole, MA (Palka 2012). Observations of baleen whales were made using two sets of Fujinon MT-50 "big-eyes" binoculars (25 x 150) mounted on the east side of the MDR lighthouse tower catwalk (Palka 2012, Moore *et al.* 2002) (Figure 2). The binocular lenses were 21.6 m above mean sea level resulting in a maximum viewing range to the horizon of 16.6 km (9 nautical miles). Binocular locations were determined to within a meter using a Trimble GPS, and binocular accuracy (error) was determined by sighting known objects (vessels, buoys) at known locations and comparing with locations estimated with the binoculars. Whale detections were recorded and mapped using VisSurvey software (Palka 2012). All observations in the viewing space were cataloged, however statistical tests were performed only on observations that occurred within the acoustic array space.

Daily surveys included 30-minute shifts at each of three stations (northeast binocular, center data recorder, southeast binocular) with a stepped rotation through each station. Each

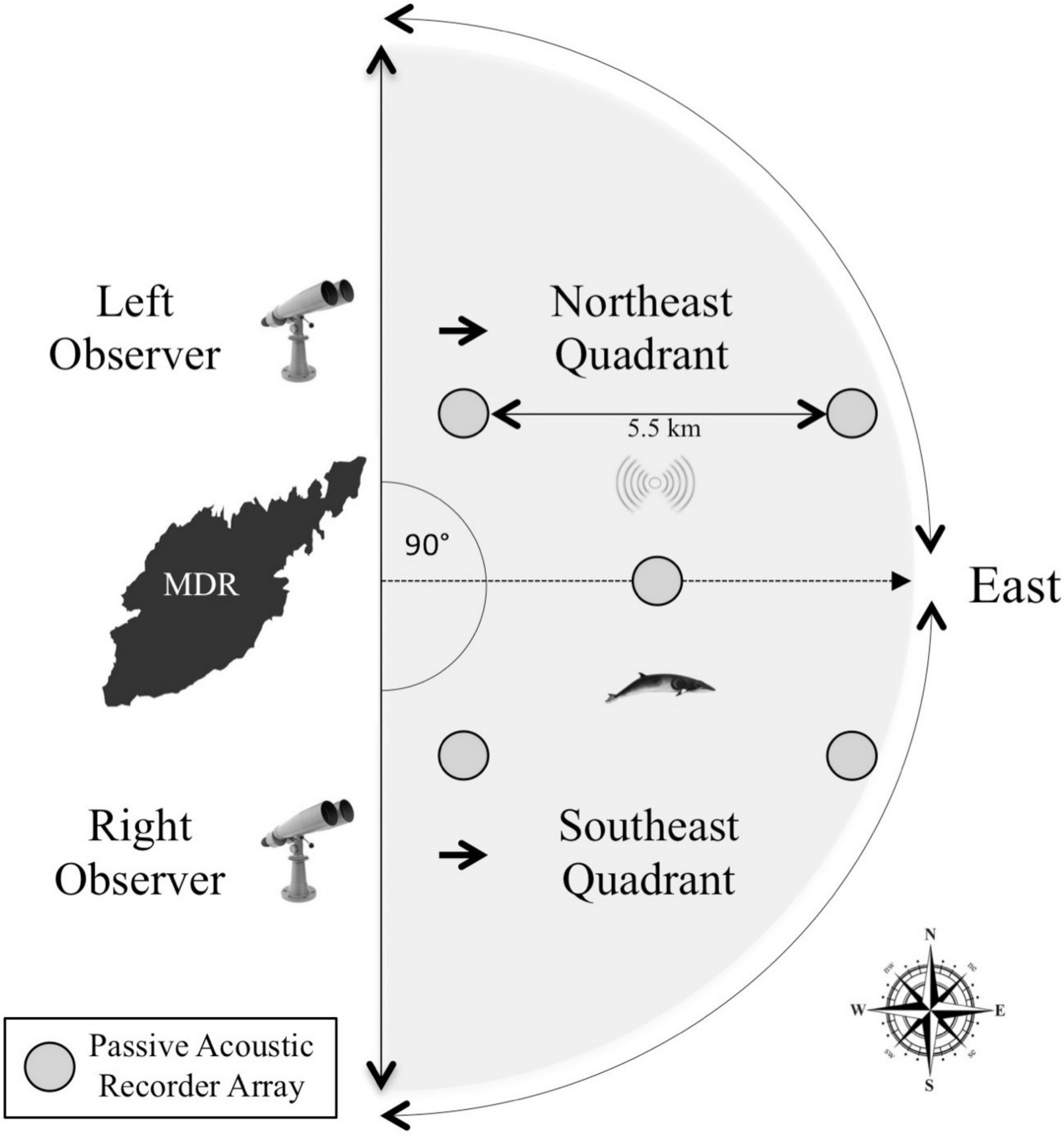


Figure 2-2. Diagram of the survey space relative to the Mount Desert Rock marine research station. Two observers (left and right) would simultaneously record the sightings of baleen whales in each respective quadrant (northeast and southwest) using big eyes binoculars. Concurrent passive acoustic monitoring was collected using a recorder array (circles).

station was manned by an observer at all times when on effort, and each observer was afforded a 1+ hour break after a full rotation (1.5 hr). All observers who participated in this study were trained and experienced in baleen whale identification. The survey was focused on a box roughly 9 kilometers square, centered due east of MDR (Figure 2-2), and situated where historic survey data suggested the highest seasonal baleen whale activity occurred relative to the island. All cetacean sightings were logged during daylight hours (~0600-1900 EST) and in weather conditions < Beaufort 4.

Passive acoustic monitoring data were collected from July – October 2015 and 2016 using five archival Marine Autonomous Recording Units (MARUs) from the Bioacoustics Research Program (BRP) at Cornell University (provided by the NEFSC). The MARUs were deployed in a square array with one sensor at each corner of the box and one sensor in the center (Figure 2-2). The MARU recorder was housed in an 18" glass sphere and features an external HTI 94-SSQ hydrophone, -168 dB re: 1 V/ 1 µPa sensitivity, 23.5 dB gain, and a 12-bit A/D converter (Calupca *et al.* 2000). Each MARU was tethered to a bottom anchor allowing it to float 2m above the sea floor, and was recovered at the end of the deployment using an acoustic release. For this project, each MARU unit recorded continuous audio to flash memory at an 8 kHz sampling rate, designed to sample the majority of the expected baleen whale vocalization frequency range. Sound data files (.aiff) collected using this MARU array was time-synchronized pre- and post-deployment with GPS time. Finalized data recordings were synchronized to ±1 ms and merged together to create a multi-channel acoustic files, allowing for the localization of sounds within the five-element array.

Visual and Acoustic Detection Comparisons

Only days when visual detections of minke whales or fin whales (or both) occurred were considered for this analysis. Days with visual detections of humpbacks were purposefully excluded from the analysis. Audio from the 17 days with the highest number of minke and fin whale visual detections were manually analyzed for baleen whale vocalizations using Raven Pro 2.0 software (Bioacoustics Research Program 2017). Biological sounds that arrived on three or more MARUs were selected for analysis, as these would allow for subsequent localization. Only calls not previously well described in the literature were categorized and organized into a candidate vocalization library[†] (Stafford *et al.* 1999). Each novel vocalization type was given a sequential letter code identifier (A, B, C, etc.).

Two tests were performed to compare the presence of each whale species (fin and minke) and the presence of novel vocalizations. The first test compared the occurrence of whales and vocalizations only located within the acoustic array (*within array*), and the second compared all vocalizations and whales seen regardless of location, i.e., in and outside of the PAM array (*all data*). For the *within array* test, vocalization locations were calculated using the correlation sum estimator (CSE) locator tool within Raven 2.0. The accuracy of the locator tool was quantified by conducting boat-based playbacks of synthetic sweeps over the acoustic array at known locations, finding these acoustic signals in the data set using Raven, and calculating the location of the sweeps using the CSE locator tool. Positions of the sweeps calculated by the locator tool were compared to the known playback location to determine an error rate.

For each test, all candidate vocalizations cataloged and located from all days of processed audio were compiled hourly with corresponding visual data. These data were coded for the

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[†] Known vocalizations were also logged and categorized but were not considered in the comparative analysis.

presence of one of four possible conditions for each vocalization type and per species (fin and minke whales). These conditions were whale detection and vocalization detection present, vocalization detection present and whale detection absent, whale detection present and vocalization detection absent, and whale detection absent and vocalization absent. For every hour of data collected the condition observed was given a value of one, even if the vocalization or animal was detected or sighted more than once in that hour. These values were compiled using two-way contingency tables (Baumgartner *et al.* 2008) (Table 2-2). A one-tailed Fisher's exact test of independence was applied to these data to determine if vocalizations that occurred were dependent upon species presence ($p \leq 0.05$) and a Cramer's V coefficient of associations were used to determine strength of association (Φ) between a particular vocalization and species (Baumgartner *et al.* 2008, Sokal and Rohlf 1995).

Vocalization Measurements

One hundred examples of each novel vocalization were examined to determine mean vocalization characteristics. Measurements of vocalization characteristics included: establishing the low end of the vocalization frequency (frequency 5%), the upper end of the vocalization frequency (frequency 95%), the middle of the vocalization frequency (center frequency), the length of the vocalization (s) (duration 90%), and the frequency at which the highest amplitude occurred (peak frequency). The mean of all measurements for all vocalizations is reported to determine the stereotyped vocalization characteristics. These measurements were completed using native measurement toolboxes in Raven 2.0 (Window = Hann, FFT – variable dependent upon vocalization type).

Spatial Density Comparisons

Locations of novel vocalizations were assessed relative to the positions of visually detected whales in the survey space. Only *in array* localized vocalizations were used for these assessments. Heat maps depicting the density of each vocalization type within the acoustic array were generated using the 'spatstat' and 'raster' package in R Studio 1.0.147. Heat maps were plotted and overlaid with visual detections of fin and minke whales from corresponding days. Maps were built using ArcGIS 9.

Results

Visual and acoustic survey

In 2015 four MARUs recorded continuously for 82 days (1,968 hrs), and in 2016 five MARU recorded for 84 days (2,016 hrs), for a total of 166 days (3,984 hours) of acoustic data. The fifth MARU failed to record in 2015. Visual surveys occurred simultaneously with passive acoustic data collection, but were dependent upon observer availability, weather, and daylight. Of the 166 days of passive acoustic data collection, visual data collection was conducted concurrently on 98 days (1,019 hours). The top 17 days with the highest number of fin and minke whale visual detections were compared hourly with the vocalization results from the simultaneous 24 hr/day passive acoustic monitoring data. Within this dataset fin whales were sighted during 17 days (across 100 hrs), and minke whales were sighted during 15 days (across 69 hrs) (Figure 2-3)

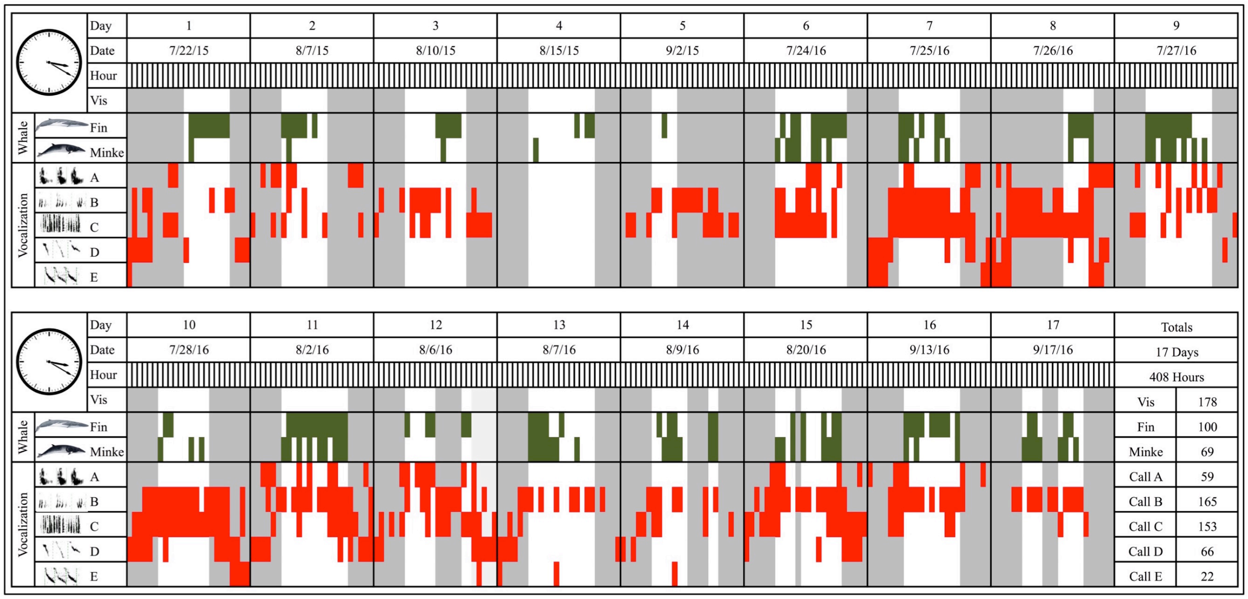


Figure 2-3. Daily occurrence of visual survey effort, fin and minke whale detection, and detection of call types (A – E) from the top 17 days of fin and minke whale visual detections in 2015 and 2016. Area in light gray represent hours when no visual effort occurred. Red boxes represent an hour when a corresponding visual sighting or vocalization event occurred. Red "vocalization" boxes in white areas represent hours when a vocalization event and visual effort co-occurred. These instances represent the data utilized in the Fisher's Exact test of dependence and coefficient of association examination.

Novel Vocalizations

Five stereotyped vocalizations that were under-represented or not represented in scientific literature were cataloged from the 17 days of acoustic data (Figure 3). Type "A" were 74 to 34-Hz downsweeps. Type A were similar to calls categorized as fin whale calls in other studies, particularly by Watkins (1982) (Ou *et al.* 2015; Delarue *et al.* 2009). Type "B" were 286 to 448-Hz upsweep vocalizations, short in duration, and often arriving in pairs or triplets. This suite of vocalizations was initially categorized into three different groups based on peak frequecies of 300-Hz, 355-Hz, and 420-Hz, but were consistent in structure and pattern, and were considered the same type for the association analysis. Type "C" was a high amplitude, 415-Hz peak frequency "whip-crack", similar to a right whale gunshot vocalization (Parks 2003). Type D and E vocalizations were both long downsweeps, with peak frequencies of 430-Hz and 205-Hz respectively. Detailed measurements of each vocalization type were performed in Raven 2.0 based on 100 examples, except for Type D (n=66) (Table 2-1).

Species Presence/Absence Statistical Analyses

Type A vocalizations were found to be significantly dependent upon the presence of fin whales for both the *in array* test ($p = 0.040$, $\Phi = 0.129$) and the *all data* test ($p = 0.025$, $\Phi = 0.143$). Among *All Data* Type B and C vocalizations each co-occurred with the presence of fin whales more often (B=58, C=37) than not (B=47, C=28), but in each of the two-way tests the vocalizations were absent when whales were present more often than not, which contributed to the non-significant result (Table 2-2).

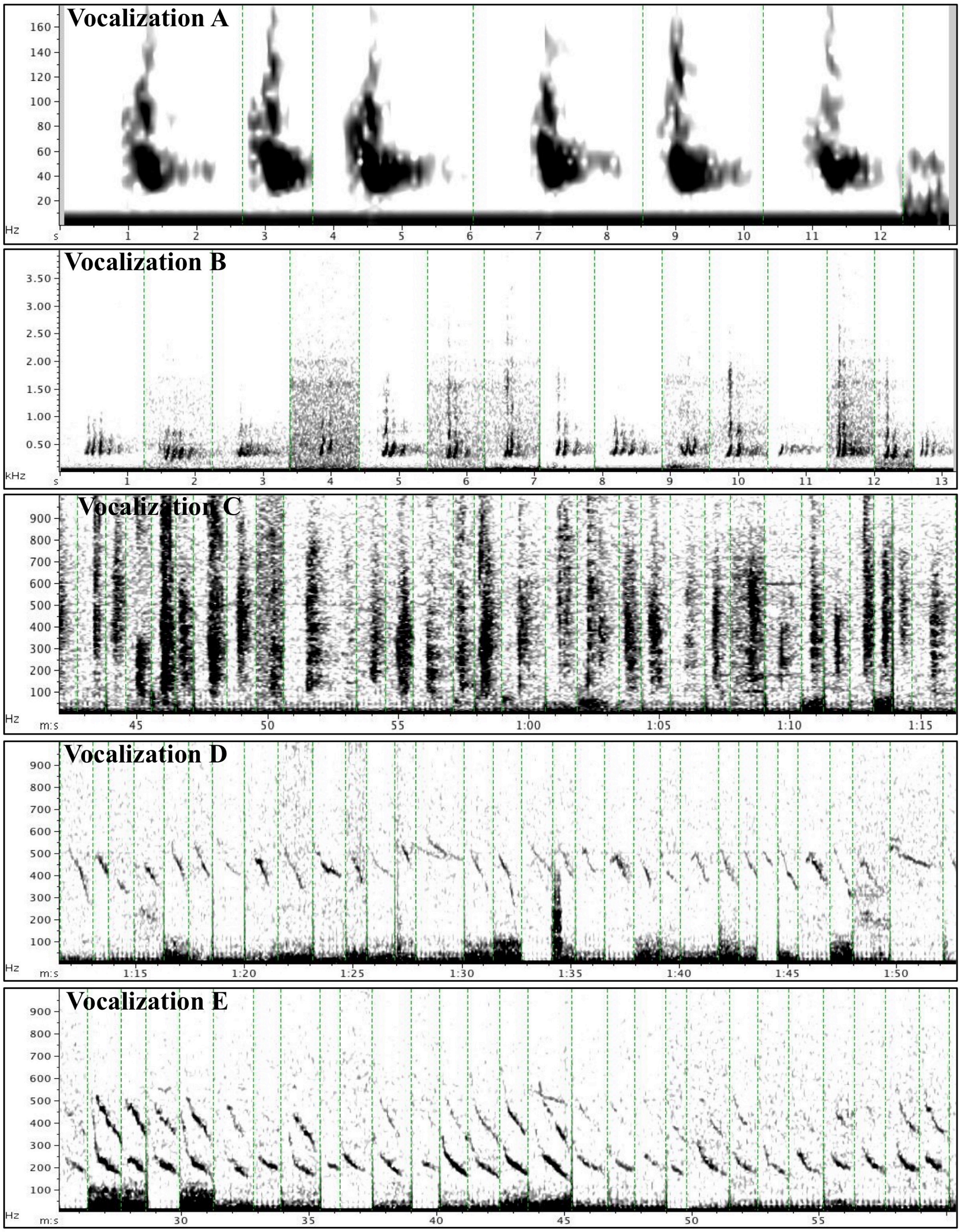
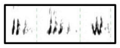


Figure 2-4. Five novel stereotyped vocalizations recorded during the top 17 days of fin and minke whale visual detections. Type A is a suspected fin whale 74 to 34-Hz downsweep, Type B is a 268 to 448-Hz short upsweep, Type C is a 415-Hz "whip crack", Type D is a 498 to 363-Hz long downsweep, and Type E is a 257 to 164-Hz long downsweep.

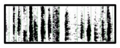
Type A *n=100*

	Center Frequency (Hz)	Duration 90% (s)	Frequency 5% (Hz)	Frequency 95% (Hz)	Peak Frequency (Hz)
 74 to 34-Hz Fin Downsweep	51.5	0.344	42.6	61.3	51.4

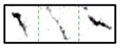
Type B *n=100*

	Center Frequency (Hz)	Duration 90% (s)	Frequency 5% (Hz)	Frequency 95% (Hz)	Peak Frequency (Hz)
 286 to 448-Hz Short Upsweep	360.5	0.050	313.1	424.1	359.1

Type C *n=100*

	Center Frequency (Hz)	Duration 90% (s)	Frequency 5% (Hz)	Frequency 95% (Hz)	Peak Frequency (Hz)
 415 Hz "Whip Crack"	425.3	0.260	240.2	750.3	415.0

Type D *n=100*

	Center Frequency (Hz)	Duration 90% (s)	Frequency 5% (Hz)	Frequency 95% (Hz)	Peak Frequency (Hz)
 498 to 363 Hz Long Downsweep	431.2	0.627	379.8	480.6	429.4

Type E *n=66*

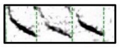
	Center Frequency (Hz)	Duration 90% (s)	Frequency 5% (Hz)	Frequency 95% (Hz)	Peak Frequency (Hz)
 257 to 164 Hz Long Downsweep	204.3	0.615	178.3	238.2	205.3

Table 2-1. Measurements of Center Frequency (Hz), Duration 90% (s), Frequency 5% (Hz), Frequency 95% (Hz), and Peak Frequency (Hz) performed on the five novel vocalization types (A –E).

Spatial Density Estimation

Heat maps depicting the density of all of the located novel vocalizations by type for the study period show they occurred more frequently in the eastern half of the acoustic array (Figure 2-5). Locations of all visually detected fin and minke whales from the study period overlaid with the heat maps showed very little overlap with the density of vocalizations (Figure 2-5), including the density of Type A (74 to 34-Hz downsweeps), the only call to be found statistically associated with detections of fin whales.

Diel Calling Patterns

Analysis of the diel occurrence of each novel vocalization found that Type A (74 to 34-Hz downsweeps) predominantly occurred in the evening between 19:00 – 23:00, where Type B (268 to 448-Hz upsweep) occurred in the early morning hours ~6:00 to 7:00 (Figure 2-7). Type C (415-Hz "Whip Crack") was split between morning (06:00) and evening (19:00), and Type D (498 to 363-Hz downsweeps) and E (257 to 164-Hz downsweeps) both occurred between 20:00 and 03:00.

In Array

A	Call	No Call	Total	*Φ*	*p*
Finback Whale					
Present	8	79	87		
Absent	2	91	93		
Total	10	170	180	**0.129**	**0.040**
Minke Whale					
Present	3	64	67		
Absent	7	106	113		
Total	10	170	180	0.011	0.791
B	Call	No Call	Total	*Φ*	*p*
Finback Whale					
Present	20	67	87		
Absent	34	59	93		
Total	54	126	180	0.136	0.985
Minke Whale					
Present	18	49	67		
Absent	36	77	113		
Total	54	126	180	0.040	0.809
C	Call	No Call	Total	*Φ*	*p*
Finback Whale					
Present	17	70	87		
Absent	20	73	93		
Total	37	143	180	0.010	0.697
Minke Whale					
Present	10	57	67		
Absent	27	86	113		
Total	37	143	180	0.093	0.950
D	Call	No Call	Total	*Φ*	*p*
Finback Whale					
Present					
Absent					
Total		No Data			
Minke Whale					
Present					
Absent					
Total					

All Data

A	Call	No Call	Total	*Φ*	*p*
Finback Whale					
Present	21	81	102		
Absent	7	71	78		
Total	28	152	180	**0.143**	**0.025**
Minke Whale					
Present	14	55	69		
Absent	14	97	111		
Total	28	152	180	0.087	0.122
B	Call	No Call	Total	*Φ*	*p*
Finback Whale					
Present	58	44	102		
Absent	47	31	78		
Total	105	75	180	0.023	0.729
Minke Whale					
Present	43	26	69		
Absent	62	49	111		
Total	105	75	180	0.052	0.243
C	Call	No Call	Total	*Φ*	*p*
Finback Whale					
Present	37	65	102		
Absent	28	50	78		
Total	65	115	180	0.000	0.542
Minke Whale					
Present	25	44	69		
Absent	40	71	111		
Total	65	115	180	0.000	0.552
D	Call	No Call	Total	*Φ*	*p*
Finback Whale					
Present	3	99	102		
Absent	2	76	78		
Total	5	175	180	0.000	0.625
Minke Whale					
Present	3	66	69		
Absent	2	109	111		
Total	5	175	180	0.041	0.287

Table 2-2. Two-way contingency table results from Fisher's exact test of dependence and Cramer's V coefficient of association performed on the set of novel vocalizations (A – E) recorded in the presence of fin and minke whales. The first column represents tests performed on data captured within the acoustic array space (*in array*), and the second column represents tests performed on *all data*. Call "A" was found to be significantly dependent upon the presence of fin whales. The remaining tests were inconclusive.

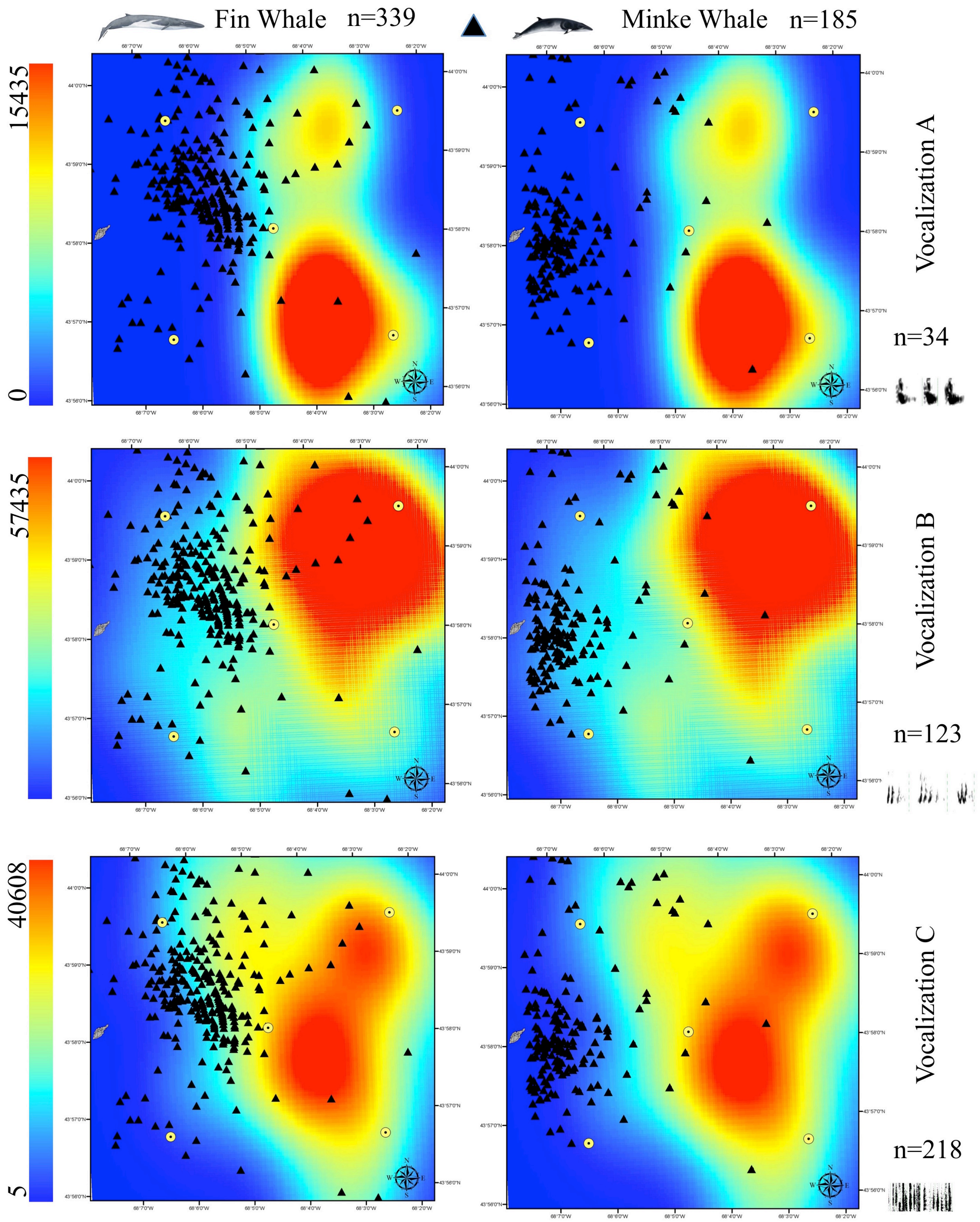


Figure 2-5. Heat maps showing the density of all vocalization by type (A, B, and C) overlaid with all locations of co-occurring fin and minke whales from the study period. Only type A, B, and C sample sizes were sufficient for density mapping. Density maps generated using package “spatstat” and “raster” in R-Studio 1.0.143 and plotted in ArcGIS 9.0.

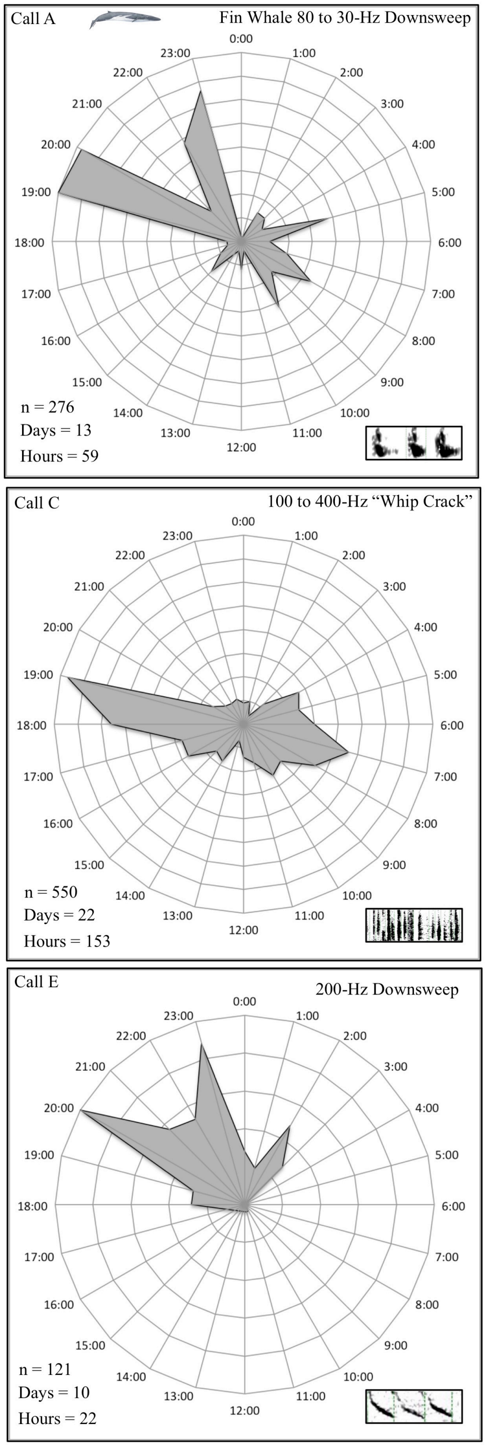


Figure 2-6. Twenty-four hour radar plots showing diel patterns of the five novel vocalizations profiled in this study (Types A – E). Type A predominantly occurs in the evening between 19:00 – 23:00, whereas Type B occurs in the early morning hours ~6:00 to 7:00. Type C is split between morning (06:00) and evening (19:00). Type D and E, both long downsweeps, 430-Hz and 205-Hz respectively, both occur between 20:00 and 03:00.

Discussion

The Type A (74 to 34-Hz downsweep) were found to be statistically associated with the presence of fin whales. The type A vocalization has only been described in in the field by Watkins (1982) from tracking radio-tagged (tracked) whales and drop hydrophones. While referenced in subsequent studies (Ou *et al.* 2015, Edds 1988) this study is the first to statistically associate these downsweeps to fin whales using located sounds from a multi-element acoustic array, and to offer detailed measurements of the vocalization. Watkins (1982) noted that higher frequency fin whale calls were typically associated with individual whales in close proximity to one another, in comparison to the standard 20-Hz pulse vocalizations associated with fin whale song (Morano *et al.* 2012, Delarue *et al.* 2009), which are often produced by lone individuals presumed to be communicating over long distances (Watkins 1982). These behavioral contexts are important when considering how to interpret acoustic data sets, particularly any assumptions about species presence or absence based on the types of vocalizations that are searched for or found. Ou *et al.* (2015) noted the difficulty in distinguishing baleen whale downsweeps in these frequency ranges, as fin, minke, sei, and blue whales all produce similar sounds. This highlights the need for precise measurements and direct observations.

The Type B (286 to 448-Hz upsweep) vocalizations are interesting in that they are highly stereotyped, ubiquitous throughout the dataset and are unlike previous documented call types for either species in this region. The presence of this vocalization was not statistically associated with visual detection of either species. Minke whales do exhibit vocalizations in the Type B frequency ranges in other ocean basins, including the “boing”, “star wars”, and “bioduck” vocalizations (Erbe *et al.* 2017, Martin *et al.* 2013, Gedamke *et al.* 2001). The characteristics of these minke vocalizations are, however, quite different than the Type B up-sweep vocalization.

Fin whales are not known to vocalize regularly in the Type B frequency band, however the *all data* contingency table results reveal that this vocalization did occur during more hours when fin whales were present than not (n=58 present to 47 not present). This scenario highlights a potential violation of assumption of the contingency table test. If a whale is present and sighted within an hour and not producing the vocalization being tested, it will count against the association, as it is present but not being recorded. This may have affected the Type B exact test result for fin whales.

There are other assumptions of the contingency table data that should be considered when examining the exact test results. First is the variability in detection probability. While fin and minke whales were shown to have similar detection probability curves, fin whales were detected at greater distances than minke (Chapter 1, Figure 1-6). Minke whales are likely the most difficult baleen whale species to identify from the field station observation platform based on their small size, lack of visible blow, and sporadic surfacings. It is feasible that observers missed times when animals were present, particularly at the fringes of the observation space, or during poor weather. With that noted, visual detections of minke and fin whales were comparable through this study (minke = 790, fin = 811).

Another assumption was that only fin and minke whale were present in the survey space when novel vocalizations were recorded. The acoustic and visual analyses described here were conducted specifically on days when humpback whales were not visually detected in the study area. While it is possible that observers missed visual detections of humpback whales during these times, it is assumed such incidents were rare as humpbacks are likely the most identifiable baleen whale species in this region due to their large profile, dark color, prominent dorsal fin and pectoral fins, and frequent charismatic behavior (Katona 1983). Humpback whales had a greater probability of being detected across more distances, and at greater distances, than fin or minke whales (Chapter 1, Figure 1-6). It is assumed to be unlikely that professional observers would miss humpback whales consistently enough to bias the statistical analysis. Humpback whales are also gregarious vocalizers, with frequent vocal patterns that are readily identifiable in acoustic data sets (Helweg *et al.* 1992, Winn and Winn 1978, Payne and McVay 1971). Such vocalizations were not found in temporal proximity to the novel vocalizations examined in this study. A primary criterion for cataloging potential whale vocalizations was that the same vocalization was present on three or more acoustic sensors, the assumption being that other marine species do not produce vocalizations at sufficient amplitude to be recorded over such long distances (3.5 to 5.5 km). However recent studies have shown that some breeding vocalizations of harbor seals may reach 129 to 149 dBRMS re 1 lPa (Matthews *et al.* 2017), so it is feasible that seals may be responsible for some undocumented sounds recorded and cataloged during this project.

Vocalization spatial distribution was not homogeneous through the survey space (Figure 2-5). In particular, all vocalization types were more densely located in the eastern half of the survey space. From the visual data we know that fin and minke whales were visually detected in the western portion of the array, so it is not clear why there would not also be a similar density of vocalizations detected in the western portion of the array. The stability of sound waves is particularly susceptible to the affect of bathymetry and fluid dynamics in shallow water systems (Kuperman and Lynch 2004), which could be a factor as the depth decreases towards the island research station. However synthetic calibration sweeps played across the western portion of the array were successfully recorded and located without issue.

The use of sound for baleen whale mating displays (song) has been well documented (Payne and Guinee 1983, Watkins 1987), however the function of many vocalizations produced while on the feeding grounds are not well understood. Humpback whales are known to produce "megapclick" buzz vocalizations during coordinated feeding events (Stimpert *et al.* 2007), and the fin whale 20-Hz pulse has been proposed to be used as both a mating display and a method for male fin whales to attract females to prey aggregations (Croll *et al.* 2002, McDonald *et al.* 1995). As noted earlier, the fin whale Type A 74 to 34-Hz call has been recorded on feeding grounds in Cape Cod (Watkins 1982) and the Gulf of St. Lawrence, in Canada (Edds 1988). Fin and minke whales aggregating at Mount Desert Rock are often observed feeding (personal observation) and the Type B up-sweep vocalization may be related to such behavior, representing individuals that keep in contact during or in-between feeding bouts. This study's project design would benefit greatly from the addition of prey mapping, bottom mapping, and oceanographic sampling to determine if those factors drive baleen whale species composition and vocal activity.

Passive acoustic monitoring is now a standard practice for the management of marine mammal species, particularly in the western North Atlantic Ocean (Davis *et al.* 2017, Van Parijs *et al.* 2009, McDonald and Fox 1999). The effectiveness of this management strategy hinges on the continued investigation of each species' repertoire. As this study shows, acoustic datasets collected in areas of high baleen whale concentrations are often rife with biological sounds that are not attributed to a specific species. The few vocalizations reported here were a subset of the full catalog of undocumented vocalizations cataloged in the MDR dataset. This study highlights the importance of gathering concurrent acoustic and visual surveys, but also the difficulties in properly attributing calls to species.

WORKS CITED

Agler, B. A. 1992. Photographic identification of individual fin whales (*Balaenoptera physalus*) in the Gulf of Maine. Master's thesis. University of Maine, Orono, Maine.

Anderwald, P., Evans, P., Dyer, R., Dale, A., Wright, P., & Hoelzel, A. 2012. Spatial scale and environmental determinants in minke whale habitat use and foraging. *Marine Ecology Progress Series*, 450, 259-274. doi:10.3354/meps09573

Au, W. W. L., Pack, A. A., Lammers, M. O., Herman, L. M., Deakos, M. H., & Andrews, K. 2006. Acoustic properties of humpback whale songs. The Journal of the Acoustical Society of America, 120(2), 1103-1110.

Barlow, J., and Taylor, B. L. 2005. Estimates of Sperm Whale Abundance in the Northeastern Temperate Pacific From a Combined Acoustic and Visual Survey. *Marine Mammal Science*, 21(3), 429-445

Baumgartner, M. F., Van Parijs, S. M., Wenzel, F. W., Tremblay, C. J., Carter Esch, H., & Warde, A. M. 2008. Low frequency vocalizations attributed to sei whales (*Balaenoptera borealis*). *The Journal of the Acoustical Society of America*, 124(2), 1339-1349.

Beamish, P., & Mitchell, E. 1973. Short pulse length audio frequency sounds recorded in the presence of a minke whale (*Balaenoptera acutorostrata*). Deep-Sea Research and Oceanographic Abstracts, 20(4), 375,IN5,381-380,IN10,386.

Bioacoustics Research Program. 2017. Raven Pro: Interactive Sound Analysis Software (Version 2.0) [Computer software]. Ithaca, NY: The Cornell Lab of Ornithology. Pre-release via private communication.

Blumstein, D. T., Mennill, D. J., Clemins, P., Girod, L., Yao, K., Patricelli, G., Kirschel, A. N. G. (2011). Acoustic monitoring in terrestrial environments using microphone arrays: Applications, technological considerations and prospectus. *Journal of Applied Ecology*, 48(3), 758-767.

Brown, W. S., Irish, J. D. 1993. The annual variation of water mass structure in the Gulf of Maine: 1986–1987. *Journal of Marine Research* 51, 53–107.

Buckland, S. T., Anderson, D. R., & Burnham, K. P. 2007. Advanced distance sampling: Estimating abundance of biological populations. *Oxford: Oxford University Press*.

Calupca, T. A., Fristrup, K. M., & Clark, C. W. 2000. A compact digital recording system for autonomous bioacoustic monitoring. *Journal of the Acoustical Society of America*, 108, 2582.

Cerchio, S. and Dahlheim, M. 2001 Variation in feeding vocalizations of humpback whales *(Megaptera novaeangliae*) from southeast Alaska. *Bioacoustics* 11: 277-295.

Clapham, P. J., Christian, M. A., Carlson, C. A., Mayo, C. A., Baraff, L. S., Murphy, M. A., Pittman, S. 1993. Seasonal occurrence and annual return of humpback whales, (*Megaptera novaeangliae*), in the southern gulf of maine. Canadian Journal of Zoology, 71(2), 440-443.

Clark, C. W., Borsani, J. F., and Notarbartolo-Di-sciara, G. 2002. Vocal activity of fin whales, *Balaenoptera physalus*, in the Ligurian *Sea. Marine Mammal Sci*. 18, 286–295.

Clark, C. W. 1999. The application of autonomous seafloor acoustic recorders for monitoring right whales. *Abstract. North Atlantic Right Whale Consortium Meeting, Boston, MA*.

Clark, C. W., Charif, R., Mitchell, S., & Colby, J. 1996. Distribution and behavior of the bowhead whale, *Balaena mysticetus*, based on analysis of acoustic data collected during the 1993 spring migration off Point Barrow, *Alaska. Rep. Int. Whal. Commn.,* 46, 541-554.

Clark C. W. 1982. The acoustic repertoire of the southern right whale, a quantitative analysis. *Anim. Behav*. 30, 1060–1071.doi:10.1016/S0003-3472(82)80196-6

Corkeron, P., Reeves, R. & Rosel, P. 2017. *Balaenoptera edeni* Gulf of Mexico subpopulation. *The IUCN Red List of Threatened Species* 2017: e.T117636167A117636174

Croll, D. A., Tershy, B. R., Hewitt, R. P., Demer, D. A., Fiedler, P. C., Smith, S. E., Armstrong, W., Popp, J. M., Kickhefer, T., Lopez, V. R., Urban, J., Gendron, D. 1998. An integrated approach to the foraging ecology of marine birds and mammals. *Deep-sea Research II*, 45, 1353-1371.

Cummings, W. C. 1968. Requirements of a method for locating underwater bio-acoustic sources. *Naval Undersea Warfare Center, San Diego, TN* 150, 21 pp. mimeographed.

Davis, G. E., Baumgartner, M. F., Bonnell, J. M., Bell, J., Berchok, C., Bort Thornton, J., Van Parijs, S. M. 2017. Long-term passive acoustic recordings track the changing distribution of north atlantic right whales (*eubalaena glacialis*) from 2004 to 2014. *Scientific Reports*, 7(1), 13460-12. doi:10.1038/s41598-017-13359-3

Doniol-Valcroze, T., Berteaux, D., Larouche, P., Sears, R. 2007. Influence of thermal fronts on habitat selection by four rorqual whale species in the Gulf of St. Lawrence. *Marine Ecology Progress Series*. 335:207-216

Durbin, E. G., Gilman, S. L., Campbell, R. G., Durbin, G. 1995 Abundance, biomass, vertical migration, and estimated development rate of the copepod *Calanus finmarchicus* in the southern Gulf of Maine. *Continental shelf research*. 15, 4/5, 571-591.

Edds-Walton, P. L. 2000. vocalizations of menke whales (*Balaenoptera acutorostrata*) in the St. lawrence estuary. Bioacoustics, 11(1), 31. doi:10.1080/09524622.2000.9753448

Edds-Walton, P. L. 1997. acoustic communication signals of mysticete whales. Bioacoustics, \ 8(1-2), 47-60.

Edds, P. L. 1988. Characteristics of finback *Balaenotera physalus* vocalizations in the St. Lawrence Estuary. *Bioacoustics*. 1, 131-149.

Erbe, C., Dunlop, R., Jenner, K. C. S., Jenner, M. M., McCauley, R. D., Parnum, I., Salgado-Kent, C. 2017. Review of underwater and in-air sounds emitted by Australian and Antarctic marine mammals. Acoustics Australia, 45(2), 179-241.

Fiedler P. C., Barlow J., Gerrodette T. 1998. Dolphin prey abundance determined from acoustic backscatter data in eastern Pacific surveys. *Fish Bull (Wash DC)* 96:237–247

Fleming, A. H., Yack, T., Redfern, J. V., Becker, E. A., Moore, T. J., & Barlow, J. 2018. Combining acoustic and visual detections in habitat models of Dall's porpoise. *Ecological Modelling*, 384, 198-208. doi:10.1016/j.ecolmodel.2018.06.014

Friedlaender, A., Hazen, E., Nowacek, D., Halpin, P., Ware, C., Weinrich, M.,Wiley, D. 2009. Diel changes in humpback whale (*Megaptera novaeangliae*) feeding behavior in response to sand lance ammodytes spp. behavior and distribution. Marine Ecology Progress Series, 395, 91-100. doi:10.3354/meps08003

Gedamke, J., Costa, D. P., & Dunstan, A. 2001. Localization and visual verification of a complex minke whale vocalization. The Journal of the Acoustical Society of America, 109(6), 3038-3047.

Gero, S., Whitehead, H., & Rendell, L. 2016. Individual, unit and vocal clan level identity cues in sperm whale codas. *Royal Society Open Science*, 3(1), 150372. doi:10.1098/rsos.150372

Gillespie, T. W. 2001. Remote sensing of animals. *Progress in Physical Geography*. 25, 3, 355–362

Hazen, E. L., Friedlaender, A. S., Thompson, M. A., Ware, C. R., Weinrich, M. T., Halpin, P. N., & Wiley, D. N. 2009. Fine-scale prey aggregations and foraging ecology of humpback whales (*Megaptera novaeangliae*). Marine Ecology Progress Series, 395, 75-89.

Helweg, D., Frankel, A., Mobley, J., Herman, L. M. 1992. Humpback whale song: our current understanding. *Thomas J, Kastelein R, Supin A, editors. Marine Mammal Sensory Systems. New York, NY: Plenum Press*. pp. 459–483

Janik, V. M. 2009. Whale song. *Current Biology*, 19(3), R109-R111. doi:10.1016/j.cub.2008.11.026

Katona, S. K., Rough, V., & Richardson, D. T. 1983. A field guide to the whales, porpoises, and seals of the gulf of maine and eastern canada: Cape cod to newfoundland (3rd ed.). New York: Scribner.

Kellogg, R. 1929. What is known on the migrations of some of the whalebone whales? *Smithsonian Institution Annual Report No. 1928, Washington: U.S.G.P.O.*, pp. 467–494.

Kuperman, W. A., & Lynch, J. F. 2004. Shallow-water acoustics. *Physics Today*, 57(10), 55-61.

MacLeod, C., D. 2009. Global climate change, range changes and potential implications for the conservation of marine cetaceans, a review and synthesis. *Endangered Species Research* 7, 125–136.

Mann, J. 1999. Behavioral sampling methods for cetaceans: A review and critique. *Marine Mammal Science*, 15(1), 102e122.

Martin, S. W., Marques, T. A., Thomas, L., Morrissey, R. P., Jarvis, S., DiMarzio, N., Mellinger, D. K. 2013. Estimating minke whale (balaenoptera acutorostrata) boing sound density using passive acoustic sensors. Marine Mammal Science, 29(1), 142-158.

Matthews, L. P., Parks, S. E., Fournet, M. E. H., Gabriele, C. M., Womble, J. N., & Klinck, H. 2017. Source levels and call parameters of harbor seal breeding vocalizations near a terrestrial haulout site in glacier bay national park and preserve. *The Journal of the Acoustical Society of America*, 141(3), EL274-EL280. doi:10.1121/1.4978299

McDonald, M. A., and Fox, C. G. 1999. Passive acoustic methods applied to fin whale population density estimation, McDonald, 1999. *The Journal of the Acoustical Society of America* 105, 2643

McDonald, M. A., Hildebrand, J. A., & Webb, S. C. 1995. Blue and fin whales observed on a seafloor array in the northeast pacific. *The Journal of the Acoustical Society of America*, 98(2 Pt 1), 712-721. doi:10.1121/1.413565

Mead, J. G., Brownell, R. L. Jr., Wilson, D. E., Reeder D. M. 2005. Order Cetacea. *Mammal Species of the World: A Taxonomic and Geographic Reference*, 3rd ed., vol. 1. 723-743.

Mellinger, D., Stafford, K., Moore, S., Dziak, R., & Matsumoto, H. 2007. An Overview of Fixed Passive Acoustic Observation Methods for Cetaceans. *Oceanography*, 20(4), 36-45.

Mellinger, D., and Barlow, J. 2003. Future directions for acoustic marine mammal surveys: stock assessment and habitat use. *Report of a workshop held in La Jolla, California, 20-22 November 2002*.

Moore, S. E., Stafford, K. M., & Munger, L. M. 2010. Acoustic and visual surveys for bowhead whales in the western beaufort and far northeastern chukchi seas. Deep-Sea Research Part II, 57(1), 153-157. doi:10.1016/j.dsr2.2009.08.013

Moore, S. E., Waite, J. M., Friday, N. A., and Honkalehto, T. 2002. Cetacean distribution and relative abundance on the central eastern and the southeastern Bering Sea shelf with reference to oceanographic domains. *Progress in Oceanography*, 55, 1, 249-261.

Morano, J., Salisbury, D. P., Rice, A. N., Conklin, K . L., Falk, K. L., Clark, C. W. 2012. Seasonal and geographic patterns of fin whale song in the western North Atlantic Ocean. *The Journal of the Acoustical Society of America,* 132, 1207

Norris, K. 1967. Some observations on the migration and orientation of marine mammals. *Animal Orientation and Navigation*, *edited by R. M. Storm University of California Press, Berkeley*, pp. 320–380.

Nowacek, D. P., Christiansen, F., Bejder, L., Goldbogen, J. A., Friedlaender, A. S. 2016. Studying cetacean behaviour: new technological approaches and conservation applications. *Animal Behaviour*, 120, 235-244

Nummela, S., Thewissen, J. G. M, Bajpai, S., Hussain, T., Kumar, K. 2007. Sound transmission in archaic and modern whales: Anatomical adaptations for underwater hearing. *The Anatomical Record*. 290 (6): 716–733.

Oleson EM, Širović A, Bayless AR, Hildebrand JA. 2014. Synchronous Seasonal Change in Fin Whale Song in the North Pacific. *PLOS ONE* 9(12): e115678. https://doi.org/10.1371/journal.pone.0115678

Ou, H., Au, W. W. L., Van Parijs, S., Oleson, E. M., & Rankin, S. 2015. Discrimination of frequency-modulated baleen whale downsweep calls with overlapping frequencies. The Journal of the Acoustical Society of America, 137(6), 3024-3032.

Palka D. 2012. Cetacean abundance estimates in US northwestern Atlantic Ocean waters from summer 2011 line transect survey. *US Dept Commer, Northeast Fish Sci Cent Ref Doc.* 12-29; 37

Parks, S. E. 2003. Acoustic communication in the North Atlantic right whale *Eubalaena glacialis*. *Ph.D. thesis, MIT-WHOI Joint Program in Oceanography, Woods Hole, MA*

Payne, R. S., and Guinee, F. S. 1983. Humpback whale (*Megaptera novaeangliae*) songs as an indicator of'stocks. *Communication and Behavior of Whales, edited by R. Payne*, pp. 333-358.

Payne, R. S., and McVay, S. 1971. Songs of Humpback Whales. Science (New York, N.Y.). 173. 585-97. 10.1126/science.173.3997.585.

Patterson, B., and Hamilton, G. R. 1964. Repetitive 20 cycle per second biological hydroacoustic signals at Bermuda. *In W. N. Tavolga (ed), Marine Bio-acoustics, Pergamon Press, Oxford.* Pp. 125-145

Pettigrew, N. R., Churchill, J. H., Janzen, C. D., Mangum, L. J., Signell, R. P., Thomas, A. C., Townsend, D. W., Wallinga, J. P., Xue, H. 2005. The kinematic and hydrographic structure of the Gulf of Maine. *Deep-sea Reseach II*. 52, 2369-2391.

Rankin, S., & Barlow, J. 2005. Source of the North Pacific "boing" sound attributed to minke whales. *The Journal of the Acoustical Society of America,* 118(5), 3346-3351.

Rekdahl, M. L., Dunlop, R. A., Goldizen, A. W., Garland, E. C., Biassoni, N., Miller, P., & Noad, M. J. 2015. Non-song social call bouts of migrating humpback whales. *The Journal of the Acoustical Society of America*, 137(6), 3042-3053. doi:10.1121/1.4921280

Risch, D., Van Parijs, S. M., Siebert, U., & Parijs, S. M. V. 2014. Individual calling behaviour and movements of North Atlantic minke whales (*Balaenoptera acutorostrata*). *Behaviour*, 151(9), 1-26.

Risch, D., Castellote, M., Clark, C.W. 2014. Seasonal migrations of North Atlantic minke whales: novel insights from large-scale passive acoustic monitoring networks. *Movement Ecology* 2014 2:24.

Robbins, J., Dalla Rosa, L., Allen, J. M., Mattila, D. K., Secchi, E. R., Friedlaender, A. S., *et al.* 2011. Return movement of a humpback whale between the Antarctic Peninsula and American Samoa: A seasonal migration record. *Endangered Species Research*, 13(2), 117e121.

RStudio Team 2015. RStudio: Integrated Development for R. RStudio, Inc., Boston, MA URL http://www.rstudio.com/.

Schilling, M. R., Seipt, I., Weinrich, M. T., Frohock, S. E., Kuhlberg, A. E., and Clapham, P. J. 1992. Behavior of individually identified sei whales, *Balaenoptera borealis*, during an episodic influx into the southern Gulf of Maine in 1986. *Fish. Bull., U.S.*, 90(4): 749-755.

Širović, A, EM Oleson, J Buccowich, A Rice, AR Bayless. 2017. Fin whale song variability in southern California and Gulf of California. Scientific Reports. 7:10126.

Sousa-Lima, R. S., Norris, T. F., Oswald, J. N., and Fernandes, D. P. 2013. A review and inventory of fixed autonomous recorders for passive acoustic monitoring of marine mammals. *Aquat. Mamm*. 39, 23–53.

Stafford, K. M., Moore, S. E., Laidre, K. L., & Heide-Jørgensen, M. P. 2008. Bowhead whale springtime song off west greenland. *The Journal of the Acoustical Society of America*, 124(5), 3315-3323. doi:10.1121/1.2980443

Stafford, Kathleen & Mellinger, David & E Moore, Sue & G Fox, Christopher. 2008. Seasonal variability and detection range modeling of baleen whale calls in the Gulf of Alaska, 1999-2002. *The Journal of the Acoustical Society of America*. 122. 3378-90. 10.1121/1.2799905.

Stafford, K. M., Mellinger, D. K., Moore, S. E., and Fox, C. G. 2007. Seasonal variability and detection range modeling of baleen whale calls in the Gulf of Alaska, 1999–2002. *J. Acoust. Soc. Am.*, 122, 3378–3390.

Stafford, K. M., Moore, S. E., and Fox, C. G. 2005. Diel variation in blue whale calls recorded in the eastern tropical Pacific. *Anim. Behav.* 69, 951–958.

Stafford, K. M., Nieukirk, S. L., and Fox, C. G. 1999. "Low-frequency whale sounds recorded on hydrophones moored in the eastern tropical Pacific," *J. Acoust. Soc. Am.* 106(6), 3687–3698.

Stanistreet, J. E., Risch, D., & Van Parijs, S. M. 2013. Passive acoustic tracking of singing humpback whales (*Megaptera novaeangliae*) on a northwest Atlantic feeding ground. *PloS one*, 8(4), e61263.

Stimpert, A. K., Peavey, L. E., Friedlaender, A. S., Nowacek, D. P. 2012 Humpback Whale Song and Foraging Behavior on an Antarctic Feeding Ground. *PLoS ONE* 7: e51214.

Thompson, P. O., Findley, L. T., and Vidal, O. 1992. 20-Hz pulses and other vocalizations of fin whales, *Balaenoptera physalus*, in the Gulf of Mexico. *J. Acous. Soc. Am.,* 92, 3051-3057.

Van Parijs, S. M., Clark, C. W., Sousa-Lima, R. S., Parks, S. E., Rankin, S., Risch, D., & Van Opzeeland, I. C. 2009. Management and research applications of real-time and archival passive acoustic sensors over varying temporal and spatial scales. *Marine Ecology Progress Series*, 395, 21-36.

Walker, R. A. 1963. Some intense, low-frequency, underwater sounds of wide geographic distribution, apparently of biological origin. *Jour. Acoust. Soc. Amer*., 35, 11, pp. 1816-1824.

Waring, G. T., Josephson, E., Maze-Foley, K., and Rosel, P. E. 2015. US Atlantic and Gulf of Mexico marine mammal stock assessments – 2015. *NOAA Technical Memorandum,* NMFS-NE238.

Watkins, W. A., Fristrup, K. M., Daher, M. A. 1991. Marine Animal Sound Database. *Woods Hole Oceanographic Institution, WHOI Technical Reports*, WHOI-91-21.

Watkins, W. A., Tyack, P., Moore, K. E., and Bird, J. E. 1987. The 20-Hz signals of finback whales (*Balaenoptera physalus*). *J. Acoust. Soc. Am*. 82, 1901–1912.

Watkins, W. A. 1982. Activities and underwater sounds of fin whales. Deep Sea Research Part B. Oceanographic Literature Review, 29(12), 789.

Watkins, W. A., & Schevill, W. E. 1971. Four hydrophone array for acoustic three-dimensional location. *Woods Hole Oceanographic Institution, WHOI Technical Reports,* WHOI-71-60.

Wiley D., Ware C., Bocconcelli, A., Cholewiak, D., Friedlaender, A., Thompson, M., and Weinrich, M. 2011. Underwater components of humpback whale bubble-net feeding behavior. *Behavior.* 148: 575-602.

Williams, S., Gende, S., Lukacs, P., & Webb, K. (2016). Factors affecting whale detection from large ships in alaska with implications for whale avoidance. Endangered Species Research, 30, 209-223.

Winn, H.E., Winn, L.K. 1978. The song of the humpback whale (*Megaptera novaeangliae*) in the West Indies. *Mar Biol* 14: 97–114.

APPENDICES

APPENDIX A:

VISUAL DETECTIONS OF ODONTOCETES AND LARGE FISH IN THE VICINITY OF MOUNT DESERT ROCK

The 2015 to 2016 visual survey reported on in Chapter 1 included numerous detections of odontocetes (toothed whales) and large fish. Odontocete detections included harbor porpoise (*Phocoena phocoena*), Atlantic white-sided dolphin (*Lagenorhynchus acutus*), and pilot whales (*Globicephala spp.*). Large fish detections included basking shark (*Cetorhinus maximus*), and tuna (*Thunnus spp.*). Detections of these species were gathered using the methods outlined in Chapter 1. Data are compiled here for the 2015 (Figure 3-1) and 2016 (Figure 3-2) field seasons.

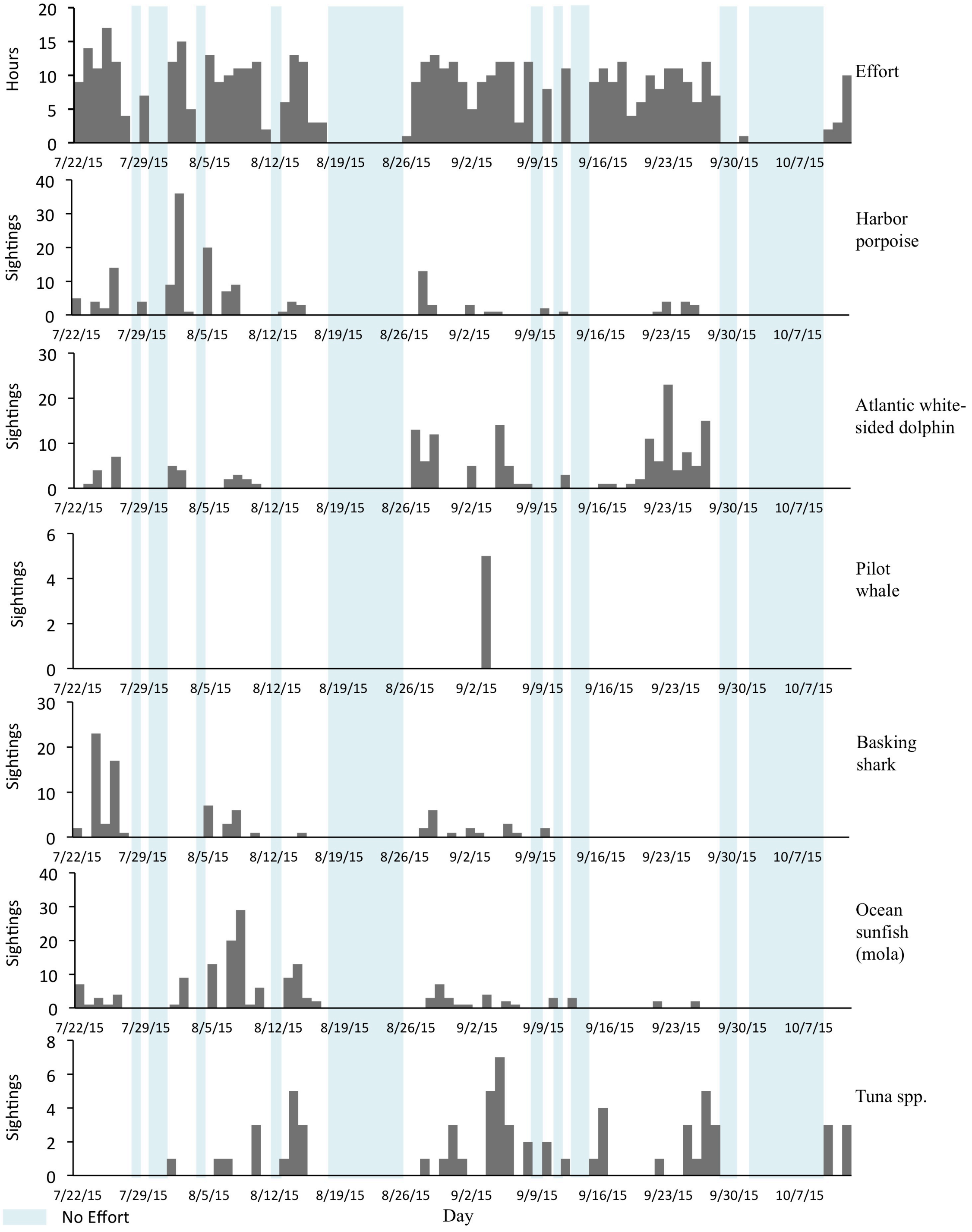


Figure 3-1. Daily and annual visual detections of dolphin and large fish species in the vicinity of Mount Desert Rock in 2015. Number of hours per day of observer effort are depicted in the top panel. Detection data are reported as the number of detections per day.

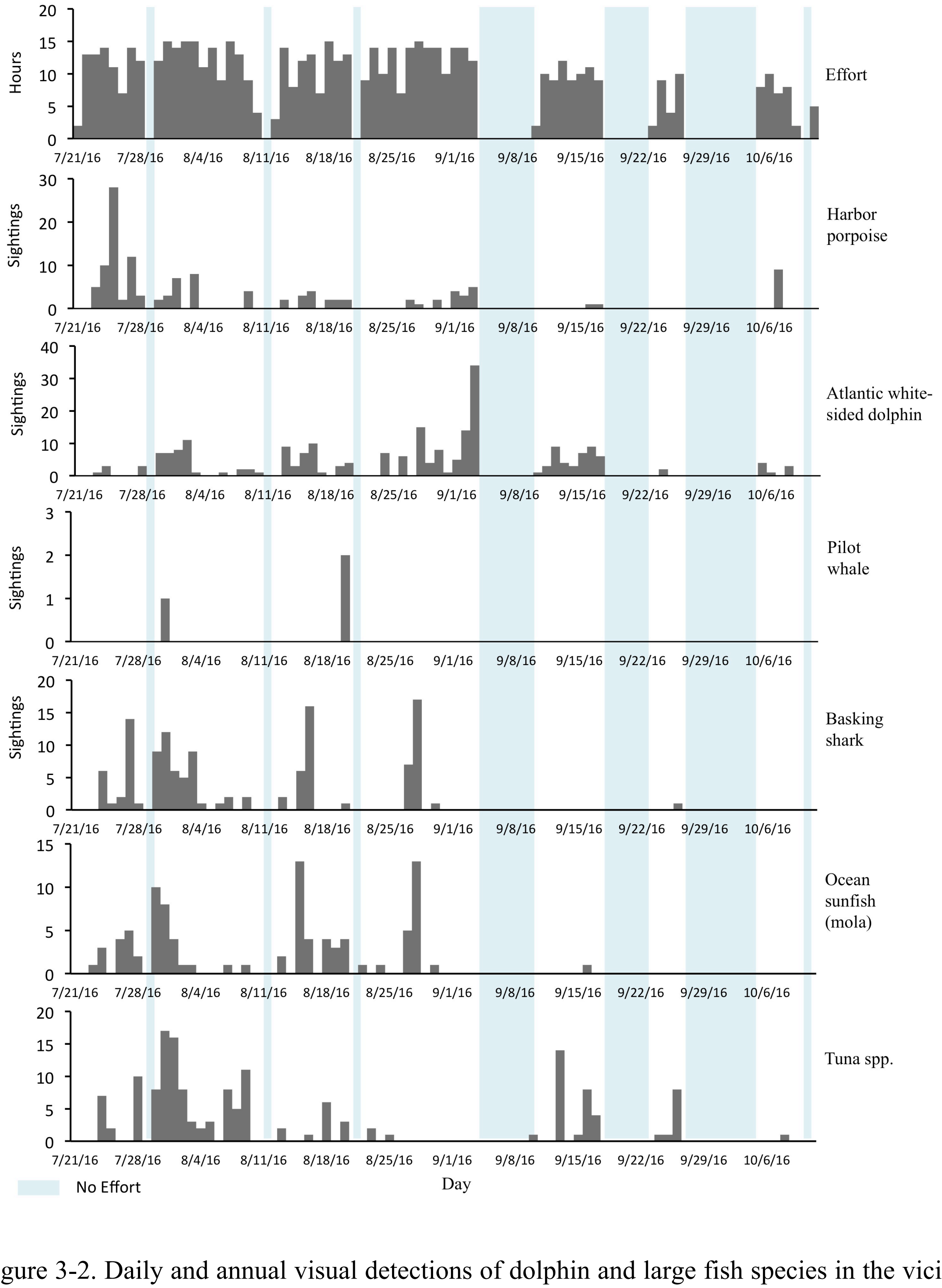


Figure 3-2. Daily and annual visual detections of dolphin and large fish species in the vicinity of Mount Desert Rock in 2016. Number of hours per day of observer effort are depicted in the top panel. Detection data are reported as the number of detections per day.

APPENDIX B:

SURVEY CALIBRATION DATA

Data collected from the passive acoustic and visual surveys were used to determine the location of observed and acoustically detected whales. For each survey type a combination of field equipment and software was used to calculate those positions. Visual survey positions were calculated using the Big Eyes binoculars and VisSurvey software (Palka 2012). The passive acoustic survey positions were calculated using the underwater acoustic recorders (MARUs) and a locator tool within Raven 2.0 software (Cornell Bioacoustics Research Program 2017, Calupca 2000).

To determine the error rate associated with each of these methods simulated events were introduced at field site at known positions. These events were detected using each survey type and a calculated location was determined. For the visual survey a vessel was moved throughout the survey space and stopped at several locations. Once stopped, observers on watch at MDR located the vessel using the Big Eyes binoculars and logged the data to VisSurvey, which calculated the vessel position. For the passive acoustic survey a vessel was also moved throughout the survey space and stopped at different locations. At each site the location of the vessel was noted and a Lubell underwater speaker was lowered to 10 meters depth. A series of underwater acoustic sweeps were played using this speaker from a laptop and amplifier on board the vessel, and these sweeps were recorded on the underwater MARU acoustic recorders. When the acoustic data were retrieved from the MARUs at the end of the field project, the acoustic sweeps were found within the data set using Raven 2.0 software. The CSE locator tool within Raven was then used to determine the location of the vessel where the sweep was played. In each case the calculated locations were compared to the actual location of the event. The discrepancy between the distance (meters) and angle (degree) of the actual location and the calculated location were reported as the error rate (Table 1, Table 2).

Big Eyes Calibration

Date	Time (EDT)	Observer	Vessel	Actual Vessel Distance (km)	Fix Dir (Deg)	Vessel (Actual) Location		Big Eyes (Calculated) Location		Error (km)	Error (m)	Error Dir (Deg) "A" to "B"
						Lat	Long	Lat	Long			
08/27/16	16:47	N/A	Borealis	1.27	88	43.9453	-68.1085	43.9462	-68.1056	0.25	252	246
07/27/16	17:06	Cox	Mirus	1.60	47	43.9784	-68.1097	43.9779	-68.1065	0.26	258	54
07/27/16	18:28	Kocik	Mirus	3.85	109	43.9570	-68.0789	43.9581	-68.0733	0.46	463	256
07/31/16	12:30	Cole	Borealis	4.04	65	43.9838	-68.0784	43.9806	-68.0867	0.75	749	62
07/31/16	11:51	Cox	Borealis	4.24	117	43.9512	-68.0771	43.9518	-68.0766	0.08	81	208
08/27/16	16:22	N/A	Borealis	4.80	99	43.9449	-68.0650	43.9482	-68.0712	0.62	621	127
07/31/16	12:08	Cole	Borealis	5.78	89	43.9696	-68.0521	43.9698	-68.0742	1.77	1769	91
07/27/16	18:16	Gundrum	Mirus	6.64	91	43.9680	-68.0413	43.9686	-68.0544	1.05	1052	93
07/31/16	13:20	Cole	Borealis	7.09	118	43.9384	-68.0462	43.9450	-68.0626	1.50	1503	119

Table 3-1. Results of the Big Eyes calibration exercises carried out in 2016.

Acoustic Locator Tool Calibration

2015 Calibration Sweep Events

Date	Time (GMT)	Volume (MacPro)	Peavey Amp Level	Sweep Actual Location		Sweep Calculated Location		Locator Error (m)	Error Dir (deg)
				Lat	Long	Lat	Long		
10/09/15	12:21	13/16	7	43.9793	-68.0923	43.9794	-68.0936	105	276.0
10/09/15	12:34	13/16	7	43.9553	-68.0617	43.9552	-68.0625	65	260.0

2016 Calibration Sweep Events

Date	Time (GMT)	Volume (MacPro)	Peavey Amp Level	Sweep Actual Location		Sweep Calculated Location		Locator Error (m)	Error Dir (deg)
				Lat	Long	Lat	Long		
07/31/16	15:34	13/16	7	43.9683	-68.0986	43.9679	-68.0965	174	104.0
07/31/16	15:50	13/16	7	43.9510	-68.0772	43.9519	-68.0736	306	70.9
07/31/16	16:06	13/16	7	43.9692	-68.0527	43.9705	-68.0481	396	68.6
07/31/16	16:24	13/16	7	43.9840	-68.0779	43.9837	-68.0739	322	95.9
8/28/16	13:38	13/16	7	43.9734	-68.0983	43.9703	-68.1000	370	201.0
8/28/16	13:55	13/16	7	43.9826	-68.0761	43.9834	-68.0734	234	67.7
8/28/16	14:19	13/16	7	43.9867	-68.0570	43.9843	-68.0530	417	129.8
8/28/16	14:35	13/16	7	43.9528	-68.0778	43.9528	-68.0754	193	90.0

Table 3-2. Results of the passive acoustic array calibration exercises carried out in 2015 and 2016.

BIOGRAPHY OF THE AUTHOR

Christopher James Tremblay was born on October 19, 1978, in Santa Monica, California. He was raised in Peabody, Massachusetts, and graduated from Peabody Veterans Memorial High School in 1996. He attended the College of the Atlantic (COA), in Bar Harbor, Maine and graduated in 2003 with a Bachelor's of Arts degree in Human Ecology. As a student at COA Chris was introduced to the Mount Desert Rock (MDR) Marine Research Station, a place where he spent many subsequent summers (and several winters) as a research assistant and station manager. Studying the photo-identification of fin and humpback whales at MDR was a gateway to working with the NOAA Northeast Fisheries Science Center (NEFSC), in Woods Hole, Massachusetts, where Chris has since participated in dozens of cetacean related research cruises and aerial surveys. In 2006 Chris moved to Ithaca NY, where he worked for Cornell University's Bioacoustics Research Program as a field application engineer, eventually becoming the project coordinator for the right whale listening network and associated large-scale whale acoustic mitigation effort surrounding the construction of liquefied natural gas terminals in Massachusetts Bay. Chris also participated in research cruises in the Bering and Chukchi seas during this time, deploying both archival and real-time acoustic sensors for the detection of North Pacific right whales and Bowhead whales. After departing Cornell University in 2014, Chris worked as a fisheries biologist for the passive acoustics research group at NEFSC, where he focused on the vocal repertoire of sei whales. Chris is a candidate for the Master of Science degree in Marine Biology from the University of Maine in December 2018.