OCS Study
BOEM 2019-007

Understanding Marine Mammal Presence in the Virginia Offshore Wind Energy Area

US Department of the Interior
Bureau of Ocean Energy Management
Office of Renewable Energy Programs

OCS Study
BOEM 2019-007

Understanding Marine Mammal Presence in the Virginia Offshore Wind Energy Area

September 2018

Authors:
Daniel P. Salisbury, Bobbi J. Estabrook, Holger Klinck, Aaron N. Rice

Prepared under Cooperative Agreement M15AC00010
By
Bioacoustics Research Program
Cornell Lab of Ornithology
Cornell University
159 Sapsucker Woods Rd
Ithaca, NY 14850

US Department of the Interior
Bureau of Ocean Energy Management
Office of Renewable Energy Programs

DISCLAIMER

Study collaboration and funding were provided by the US Department of the Interior, Bureau of Ocean Energy Management (BOEM), Environmental Studies Program, Washington, DC, under Cooperative Agreement Number M15AC00010. Funding for additional analysis was also provided by U.S. Fleet Forces Command, Norfolk, VA. This report has been technically reviewed by BOEM, and it has been approved for publication. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the US Government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

REPORT AVAILABILITY

To download a PDF file of this report, go to the US Department of the Interior, Bureau of Ocean Energy Management Data and Information Systems webpage (http://www.boem.gov/Environmental-Studies-EnvData/), click on the link for the Environmental Studies Program Information System (ESPIS), and search on 2019-007. The report is also available at the National Technical Reports Library at https://ntrl.ntis.gov/NTRL/.

CITATION

Salisbury, D.P., Estabrook, B.J., Klinck, H., Rice, A.N. 2018. Understanding marine mammal presence in the Virginia Offshore Wind Energy Area. Sterling (VA): US Department of the Interior, Bureau of Ocean Energy Management. OCS Study BOEM 2019-007. 103 p.

ABOUT THE COVER

Left panel: Jetty and approach to inlet in Virginia Beach, VA. Photo credit: Derek Jaskula. Right panel: Transom of the R/V Jaeger off the coast of Virginia awaiting to deploy recording units. Photo credit: Kristin B. Hodge.

ACKNOWLEDGMENTS

Bioacoustics Research Program, Cornell Laboratory of Ornithology

Director: Holger Klinck, Ph.D.

Program Manager: Deborah Cipolla-Dennis

Principle Investigator: Aaron N. Rice, Ph.D.

Senior Scientist: Christopher W. Clark, Ph.D.

Administration: Tish Klein, Linda Harris

Report Authors: Daniel S. Salisbury, Bobbi J. Estabrook, Holger Klinck, Aaron N. Rice.

Data Analysis: Russ Charif, Bobbi Estabrook, Kristin Hodge, Karolin Klinck, Chris Pelkie, Charles Muirhead, Ashakur Rahaman, Daniel Salisbury, Jamey Tielens

Deployment and Fabrication: David Doxey, Derek Jaskula, Edward Moore, Christopher Tessaglia-Hymes, Captain Fred Channell

Hardware Engineering: Rob Koch, Raymond Mack, Jim Lowe

Software Engineering: Peter Dugan, Ph.D., Dean Hawthorne, Ph.D., Michael Pitzrick, Dimitri Ponirakis, Yu Shiu, Ph.D., John Zollweg, Ph.D.

U.S. Navy

This project is partially funded by US Fleet Forces Command and managed by Naval Facilities Engineering Command Atlantic as part of the U.S. Navy’s marine species monitoring program.

Contents

List of Figures

List of Tables

List of Abbreviations and Acronyms

AIFF	Audio Interchange File Format
AMAR	Autonomous Multichannel Acoustic Recorder
BOEM	Bureau of Ocean Energy Management
BRP	Bioacoustics Research Program, Cornell University
CMSP	Coastal and Marine Spatial Planning
CTD	Conductivity, Temperature, Depth Data Logger
dB	Decibel (referenced to 1 µPa in underwater acoustics)
DOI	US Department of the Interior
ESP	Environmental Studies Program
ESPIS	Environmental Studies Program Information System
FFT	Fast Fourier Transform
MARAD	U.S. Department of Transportation Maritime Administration
MARU	Marine Autonomous Recording Unit
NARW	North Atlantic Right Whale
NMFS	U.S. National Marine Fisheries Service
NOAA	U.S. National Oceanic and Atmospheric Administration
OPAREA	U.S. Navy Operations Area
PAM	Passive Acoustic Monitoring
SNR	Signal to Noise Ratio
SST	Sea Surface Temperature
TDOA	Time Difference of Arrival
WEA	Wind Energy Area

Executive Summary

This study found ample evidence of vocally active right whales, humpback whales and fin whales and the abundance of detected calls showed patterns of seasonality and inter-annual variation. While, minke whales were not detected at the frequency level of the other species, their presence was confirmed in the study area, especially in waters further offshore. Peak presence in the winter months was contrasted by low periods of presence in the summer months, and while periods of time existed when no whales were detected, the variability between seasons and years, as well as the conservative approach to our study design supports a conclusion that for any given time, there is a chance of baleen whale presence in the area. Within the study area, whales were found across the recording transect, with different species having different distributions. Only the right whale had the largest proportion of detected presence within the WEA, but all four species did have some minimum level of presence inside the WEA. Our recommendations from these temporal and spatial results are that wind energy development poses the highest risks to right whales during their peak seasonal presence from November through April. Humpback, fin and minke whales are also at highest risk during their peak seasonal occurrence in the area, however that risk is somewhat lessened by their probability of being detected further offshore from the WEA. We caution that the variability between years makes defining peak seasonal presence difficult, and the potential environmental, anthropogenic or biological drivers of this variability are poorly understood. Based on the variable low-level monthly presence during the summer offseason months, we conclude that the risk posed by wind energy development cannot be completely mitigated through seasonal planning of activities.

Baseline ambient noise for the study area revealed a very high level of background noise at low frequencies, especially in the communication bandwidth of the right whale, minke whale and humpback whales. While we still do not fully understand how the current chronic noise conditions affect the whales on a population scale, we can conclude that the addition of turbine construction and operation would not represent a large increase in ambient noise levels, due to the current high levels of noise. We recommend measures that would mitigate risks to whales from pile driving and acute noise events and caution that even modest increases in ambient noise levels within the WEA may elicit behavioral responses from whales. Therefore, the risks of noise increases are highest for right whales that have the largest distribution in the WEA, and that further studies or analyses may be warranted to understand the potential impacts from these risks. Adding additional protections such as extending speed-restricted seasonal management areas boundaries to the WEA may mitigate some of the risks.

Odontocete acoustic signals were recorded along the continental shelf at all four high-frequency transect recording sites. Given visually observed occurrence of odontocete species in this region, we determined the ROCCA was not appropriate for signal classification on the species-level in this region. The ROCCA classified most signals as species that are less common, and infrequently classified the more common species in this region.

1 Background and Objectives

As the development of U.S. Offshore Wind Energy expands and approaches industry-scale implementation, there remains a need to balance exploiting available wind energy with minimizing or mitigating impacts to both habitats and protected species (Foley et al. 2010). The Wind Energy Area (WEA) off the coast of Virginia was one of the first wind energy areas in federal waters with research and lease development, and as such, has led the way in identifying natural resource management needs or concerns associated with wind energy development.

To mitigate potential environmental impacts in WEA developments, an assessment of protected species that occur in or around the WEA is a vital step to identify potential environmental risks of offshore wind construction or installation. Installation of wind turbines involves several steps which may influence the behavior or ecology of different marine organisms. This may include an increase in anthropogenic sound associated with construction or servicing the site (such as pile driving or increases boat traffic associated with construction or operations activities), as well as physical habitat modification to the wind planning area (such as from dredging or the presence of many different wind turbines). Extensive studies on impact evaluation of marine construction activities and observations on the offshore wind energy development in Europe have identified possible impact or injury mechanisms to marine wildlife (Madsen et al. 2006; Punt et al. 2009; Robinson et al. 2007; Thompson et al. 2010; Tougaard et al. 2009) and have determined that accurate environmental risk and impact assessment is dependent on an understanding how different protected species may use a particular habitat sited for energy development. A principal challenge facing development of wind planning areas, including the Virginia WEA, is a lack of substantial data to inform risks to protected marine species. For taxa that are data-poor or difficult to study, such as marine mammals, the lack of data presents a significant information need.

There have been 24 species of marine mammals observed in Virginia coastal waters (Ambler 2011; Blaylock 1988; Roberts et al. 2016), ranging from the very shallow waters to the continental shelf. However, most of the cetacean visual surveys conducted in Virginia have documented inconclusive and variable patterns of species occurrence (Ambler 2011; Blaylock 1988; Roberts et al. 2016). Virginia waters represent a migratory corridor for several whale species, such as minke whales, humpback whales and North Atlantic right whales (LaBrecque et al. 2015), yet the timing and duration of their occurrence in Virginia has been unclear. Other large whales, such as fin whales, occur in this area, but it is unclear exactly how they are using this habitat. For right whales in particular, the entire U.S. Atlantic coast represents a Biologically Important Area (LaBrecque et al. 2015), and Virginia waters are an important part of their migratory corridor as they move between summer feeding grounds in the north and calving grounds in the south, with recent research suggesting variation in population movement patterns (Davis et al. 2017; Salisbury et al. 2016). However, despite the known occurrence of whale species, and the extensive human use of the area, there have been few systematic studies in this area to document whale phenology or spatial patterns of habitat use.

For long term and broad spatial scale surveys for marine mammals, passive acoustic monitoring (PAM) has emerged as a data-rich methodology for establishing trends in marine mammal occurrence within particular areas. In recent years, PAM has been used to identify temporal and spatial patterns of marine mammal occurrence in a number of high-human use areas along the U.S. Atlantic Coast, and is being used with increasing frequency to document baseline occurrence of marine mammals in wind planning areas (Kraus et al. 2016; Rice et al. 2014a; Salisbury et al. 2016; Whitt et al. 2013; Wingfield et al. 2017). A recent PAM study along the continental shelf of Virginia identified that North Atlantic right whales were detected in every month of the year over a year-long survey (2012-2013) (Salisbury et al. 2016); it is unclear whether there is a constant flux of right whales through the area throughout the year, or whether there are a combination of both migratory and resident right whales that spend time in the area. There still remains a need to characterize the baseline seasonal and spatial patterns of marine mammal occurrence before wind energy development begins.

1.1 Project Objectives and Approach

In order to provide an understanding of current, pre-construction conditions and activity of protected cetacean species within the Virginia WEA and along the continental shelf, and to identify risks and potential human impacts of wind energy development, we conducted a multi-year pre-construction passive acoustic survey to characterize patterns of spatial and temporal occurrence of baleen whales in the VA WEA. Additionally, ambient noise levels of the environment before the start of wind energy development were documented. A transect of four stationary, bottom-mounted recorders were deployed across the continental shelf to detect baleen and toothed whales, and a synchronized array of six recorders was deployed within the wind planning area to localize marine mammals. Additionally, as part of this survey, we incorporated three years of previously collected PAM data from 2012-2015 (Salisbury et al. 2016) into to the analysis of newly collected data from 2015-2017. These different passive acoustic survey datasets were analyzed to answer the following questions:

1. Which baleen whale species occur within the WEA and surrounding area? (Section 4)
2. When do baleen whales occur within the WEA and surrounding area? (Section 4)
3. How long do whales stay within the WEA and surrounding area? (Section 4, Section 5)
4. What are the relative amounts of whales that use the habitat within the WEA and surrounding area? (Section 5)
5. What are the ambient noise characteristics of the Virginia WEA before construction begins? Would underwater noise generated by construction and operation of a wind energy facility be detectable above current ambient noise levels? (Section 7)
6. Are there any observable changes in whale occurrence or noise levels associated with High Resolution Geophysical bottom-profiling surveys within the WEA? (Section 7)
7. What are the temporal and spatial occurrence patterns of odontocetes in this area? (Sections 6, funded by U.S. Fleet Forces Command)[1].

This information will help inform the wind energy development process to help mitigate impacts on marine protected species and inform broader Atlantic-coast assessments of how marine mammals use this geographical area.

---

[1] Analysis for this research objective was funded by U.S. Fleet Forces Command under Federal contract number N62470-15-D-8006, Task Order No. 0032 to HDR, Inc. and Cornell University.

2 Ecosystem Assessment

2.1 Physical Characteristics

The Virginia Wind Energy Area (WEA) is located at the north end of the Curritick Sound Protraction block (NJ18-11). From west to east, the width of the Outer Continental Shelf off of Virginia is approximately 120 km, from the shore of Virginia Beach to the OCS edge. The WEA is approximately 450 km^2, 24 km across from east to west, and 19 km north to south (Figure 2.1). The western margin of the WEA is located approximately 44 km due east of Virginia Beach.

The substrate within the WEA is a combination of both hard and soft bottom, providing a range of habitats for Mid-Atlantic fauna (Figure 2.1). Water depths within the WEA range from approximately 25-35 m.

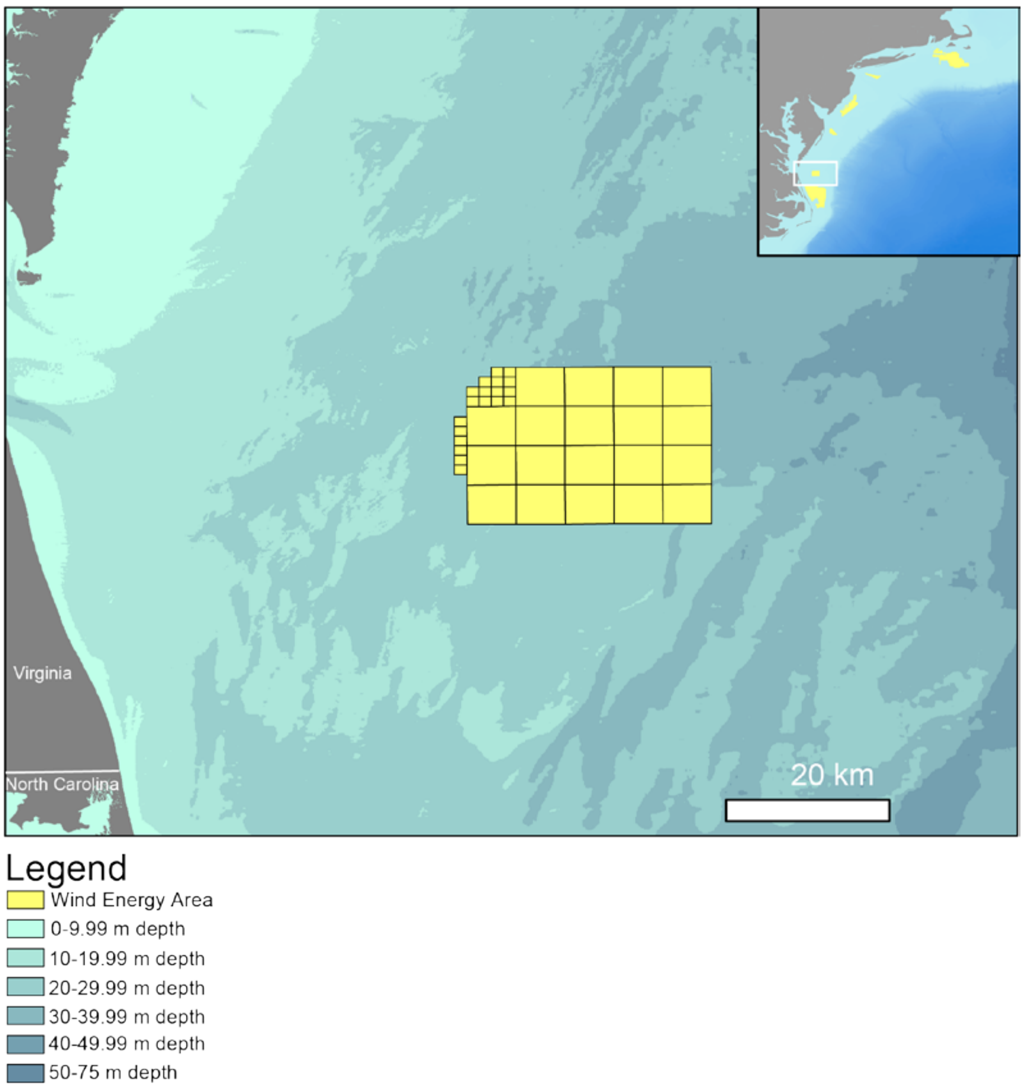


Figure 2.1. Map of Virginia Wind Energy Area and bathymetry.
Data from MARCO data portal (http://midatlanticocean.org/). Inset shows Mid-Atlantic bight, with the project area denoted by a white box, and the Mid-Atlantic BOEM wind energy areas (in yellow).

Biological Characteristics

A moderate taxonomic diversity of marine mammals is found off the coast of Virginia (Blaylock 1985; Department of the Navy 2009; Roberts et al. 2016), though little is known about how the majority of species use the area. Whale abundance and diversity is variable (Roberts et al. 2016). North Atlantic right whales and humpback whales mostly migrate through the area between northern feeding grounds and summer calving grounds (Davis et al. 2017; Salisbury et al. 2016), but North Atlantic right whales were detected year round in 2012-2013 (Salisbury 2016). Minke whales also appear to migrate through the area, but are likely further offshore (Risch et al. 2014). Visual observations have documented fin whales in depths of less than 10 m immediately off of Virginia Beach (Ambler 2011), and whale watching for humpback whales is popular in the area (Ambler 2011). Yet, other than the Salisbury et al. (2016) PAM survey for right whales in Virginia waters, there is not a well-established understanding of seasonal or inter-annual trends in whale occurrence in this area.

2.2 Human Activity in Area

The WEA is located between the North and South areas of U.S. Navy Virginia Capes Range Complex Operations Area (Figure 2.1), where extensive U.S. Navy activities occur including vessel training operations, aerial overflights, weapons training, submarine activity, and mine detonation exercises (Department of the Navy 2009; Lammers et al. 2017; National Marine Fisheries Service 2018). As Norfolk represents the third busiest shipping port along the U.S. Atlantic Coast (after New York and Savannah; MARAD 2013), there is extensive shipping activity (and consequently shipping noise) near the WEA (Figure 2.1B). With the high diversity and abundance of fish stocks in the area, coastal Virginia supports large commercial and recreational fisheries. The area is within the proposed survey area for oil and gas surveys, and thus susceptible to noise radiating from seismic air guns.

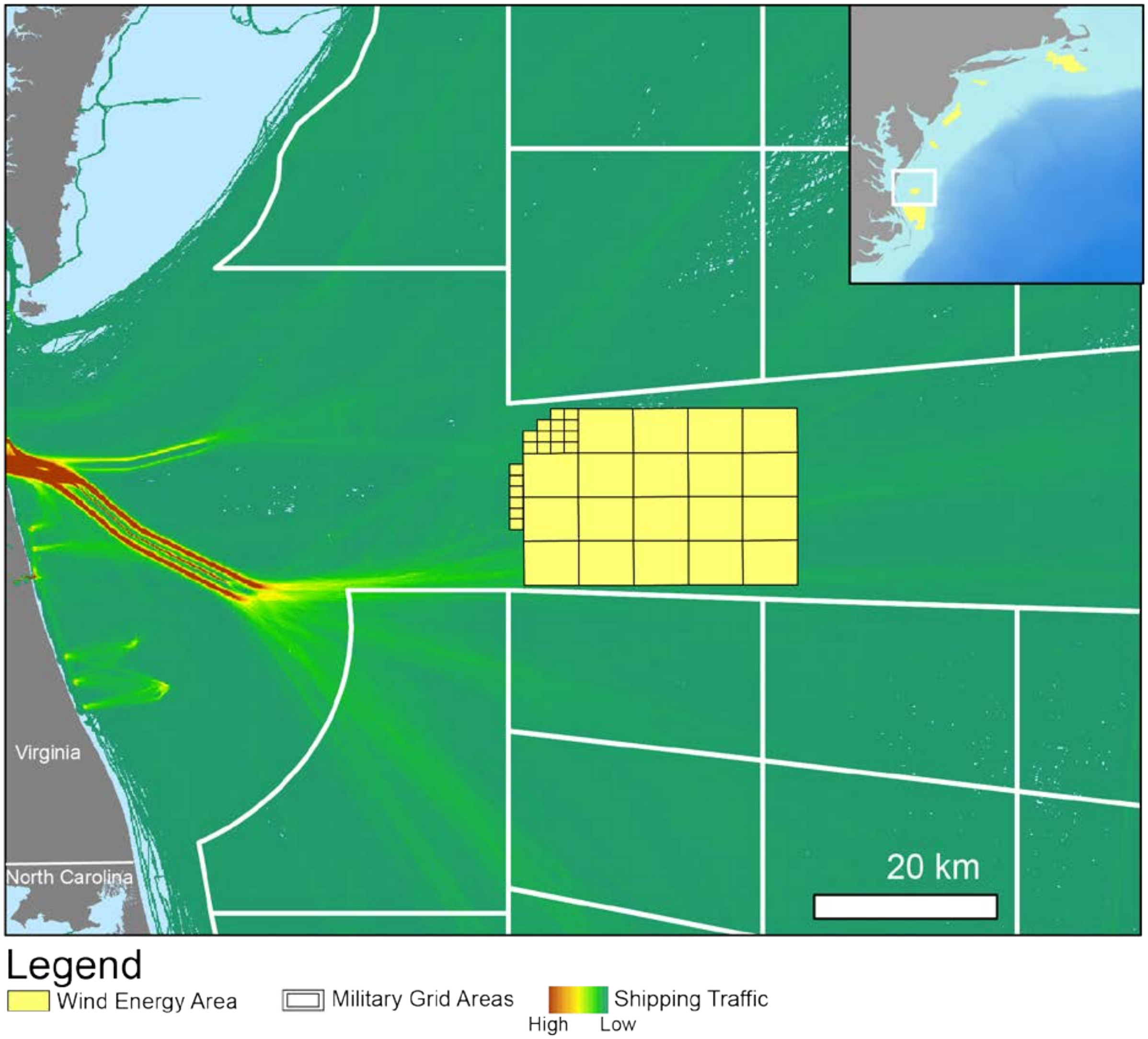


Figure 2.2. Map of human use near the Virginia Wind Energy Area.
Data from MARCO data portal (http://midatlanticocean.org/). Inset shows Mid-Atlantic bight, with the project area denoted by a white box, and the Mid-Atlantic BOEM wind energy areas (in yellow). Intensity of shipping data are represented by 2013 AIS data for all vessels (data from marinecadastre.gov).

3 Sound Recording Methods

We used passive acoustic monitoring (PAM) to collect data on baleen whale temporal and spatial patterns, and to measure a baseline ambient noise profile for the study area. PAM has several advantages over traditional survey methods such as aerial flights because acoustic recording provides continuous coverage for a large detection range and is independent of weather events such as poor visibility or poor sea states which make it challenging to visually detect marine mammals. While providing many benefits, including being cost-effective, PAM has limitations as well. Detection of focal species are dependent on the vocalization behavior of the species and the detection range can be variable depending on ambient noise levels. In very loud environments, acoustic masking can reduce our ability to detect whale calls above background noise (Clark et al. 2009).

Acoustic data were collected using two different recording units: Marine autonomous recording units (MARUs) and Autonomous multichannel acoustic recorders (AMARs, JASCO Applied Sciences, http://www.jasco.com/amar Jasco Inc.) (Figures 3.1, 3.2). MARUs are a digital audio recording system contained in a positively buoyant 43 cm glass sphere that is deployed on the bottom of the ocean for periods of weeks to months (Calupca et al. 2000). A hydrophone mounted outside the sphere is the mechanism for acquiring sounds that are recorded and stored in a binary digital audio format on internal electronic storage media. The MARU can be programmed to record on a daily schedule and deployed in a remote environment, where it is held in place by an anchor, suspended approximately 2 m above the seafloor. At the conclusion of a deployment, the MARU is sent an acoustic command to release itself from its anchor and float to the surface for recovery. After the recovery, the MARU data are extracted, converted into audio files and stored on a server for analysis. The unit is then refurbished (batteries and hard drive replaced, etc.) in preparation for a subsequent deployment. Data recorded by a MARU are thus accessible only after the device is retrieved. Deployed MARUs recorded at a 2 kHz sample rate with high-pass and low-pass filters set at 10 Hz and 800 Hz respectively and a bit depth of 12 bits. The high-pass filter was implemented to reduce electrical interference produced by the MARU, while the low-pass filter reduced aliasing. The effective recording bandwidth of 10 Hz to 800 Hz had a sensitivity of -168 dB (re: 1V/µPa) with a flat frequency response ± 3.0 dB re 1 µPa.

AMARs function similarly to MARUs, but have increased capacity for battery storage, which allows for collecting data for longer periods of time, or at higher sampling rates. AMARs are contained in a PVC, anodized aluminum and stainless steel tube measuring 16.5 cm in diameter and 57.2 cm in length. AMARs are attached to a weighted sled to anchor at the bottom of the ocean and are retrieved by catching an attached tow line via a dragged grapple hook and winch. An external mounted hydrophone sits approximately 1 m above the seafloor and records .wav sound files to storage media.. AMARs recorded on a duty-cycled sample rate scheme, with approximately 11 minutes recorded at 8 kHz followed by 1.3 minutes recorded at 375 kHz. The 8 kHz data had a bit depth of 24 bits, while the 375 kHz data was recorded at 16 bits. The AMAR hydrophones were calibrated with a sensitivity of -164 dB re 1V/µPa at 1 kHz. The combination of hydrophone calibration and high bit-depth allows for collection of high resolution ambient noise data. While the MARUs and AMARs recorded at different sample rates, they both covered the low frequency range needed for baleen whale and ambient noise analysis.

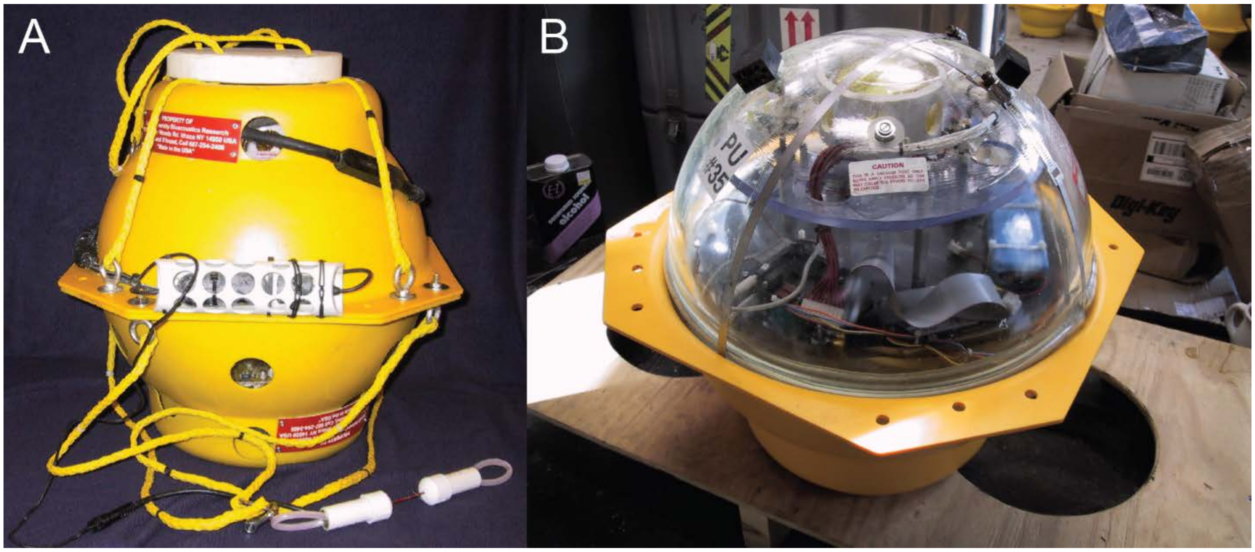


Figure 3.1 Views of the MARU
A) External and B) Internal views of the MARU.

Figure 3.2 View of the AMAR
External view of the AMAR mounted to the mooring sled. Photo credit: Fred Channell.

Three different configurations of acoustic recorders were used for the duration of the project. The "Historical Transect" had five deployments consisting of five MARUs each, recording from June 2012 – January 2015. These MARUs were deployed in a west-east transect that bisected the WEA and ranged from near shore to the edge of the continental shelf (Figure 3.3, Table 3.1). The "Transect" configuration had three deployments of four AMARs and one deployment of four MARUs that recorded from July

2015 – July 2017 for a total recording length of 24 months. These recording units were also deployed in a west-east transect that bisected the WEA and covered the continental shelf (Figure 3.4, Table 3.1).

A west-east transect configuration of recording units is optimal for collecting data on whale temporal patterns, since it spans a wide area of acoustic coverage. However, it is not optimal for collecting data on whale spatial patterns (i.e., localizations), which are obtained by using multiple arrivals of the same call on different recording units to estimate their locations. To do this, a separate configuration is needed, one with recording units spaced closer together and in offset vertical and horizontal planes. The "Array" configuration had four deployments of six MARUs each and recorded from July 2015 – May 2017. These six MARUs were deployed within the WEA with a central MARU surrounded by five MARUs in a modified pentagon shape (Figure 3.4, Table 3.1). Both the central array MARU (Site A2) and the transect AMAR (Site T2) were deployed at the same drop coordinates. This allowed us to cross-validate received sound levels from both recording unit types.

Table 3.1. Coordinates and depths of MARUs and AMARs deployed off the coast of Virginia.

Site ID	Site Description	Coordinates (N Latitude, E Longitude) (in decimal degrees)	Depth (m)
H1	Historical transect	36.864040, -75.665217	21
H2	Historical transect	36.934093, -75.424915	28
H3	Historical transect	36.867935, -75.274958	31
H4	Historical transect	36.921393, -75.103695	35
H5	Historical transect	36.918492, -74.838428	50
T1	Transect	36.899900, -75.677000	21
T2	Transect	36.899400, -75.352100	32
T3	Transect	36.899900, -75.010900	39
T4	Transect	36.893400, -74.811000	55
A1	Array	36.933800, -75.449300	26
A2	Array	36.842300, -75.414400	22
A3	Array	36.840400, -75.281000	25
A4	Array	36.935400, -75.250000	30
A5	Array	36.983300, -75.350700	27
A6	Array	36.900500, -75.347900	29

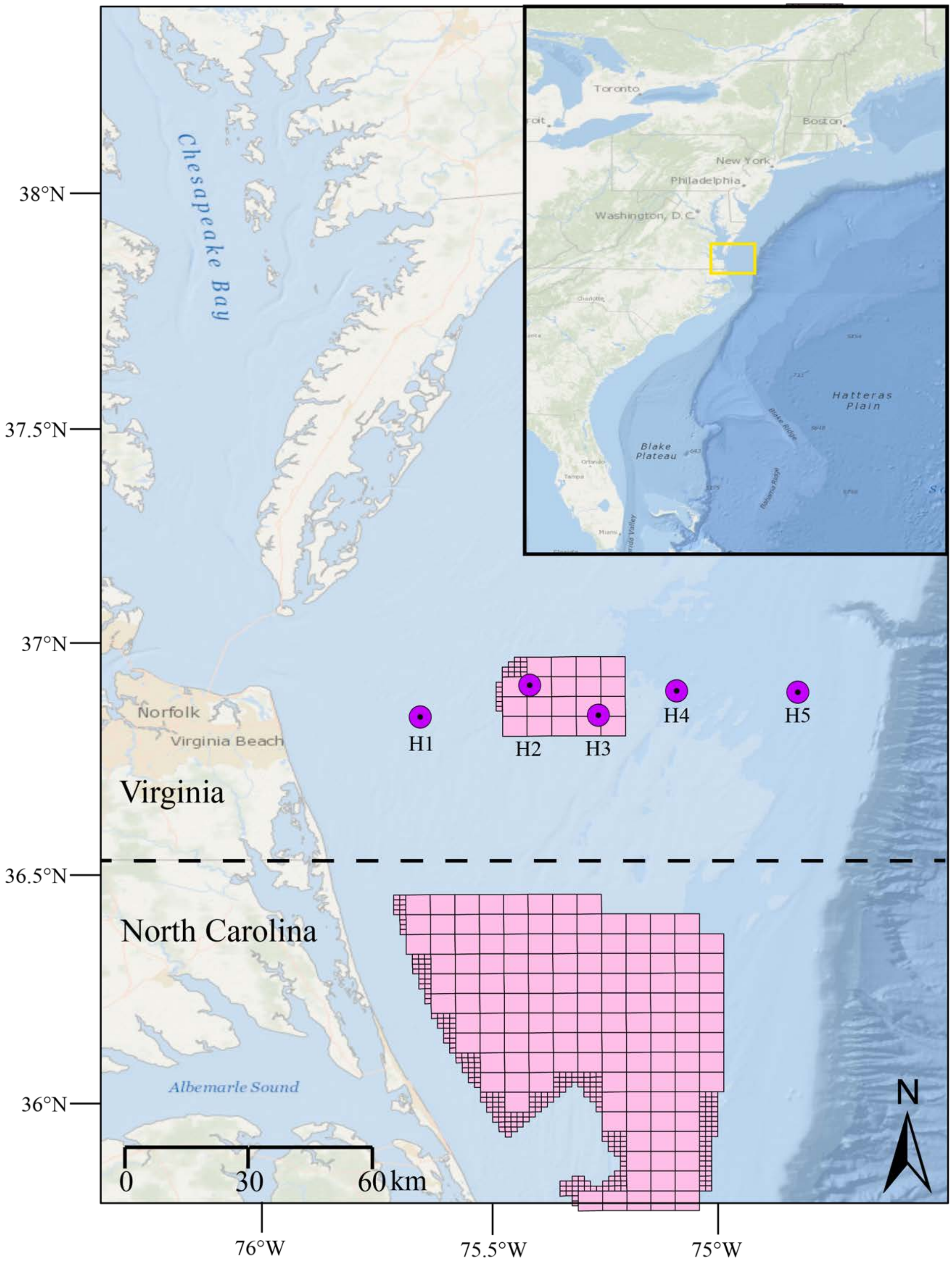


Figure 3.3 Map of the Historical Transect Area
The purple circles show drop locations for the 5 MARU recorders H1-H5 in the historical transect configuration. The dashed line separates Virginia from North Carolina (shown for general reference) and the pink squares represent WEA lease blocks in both states.

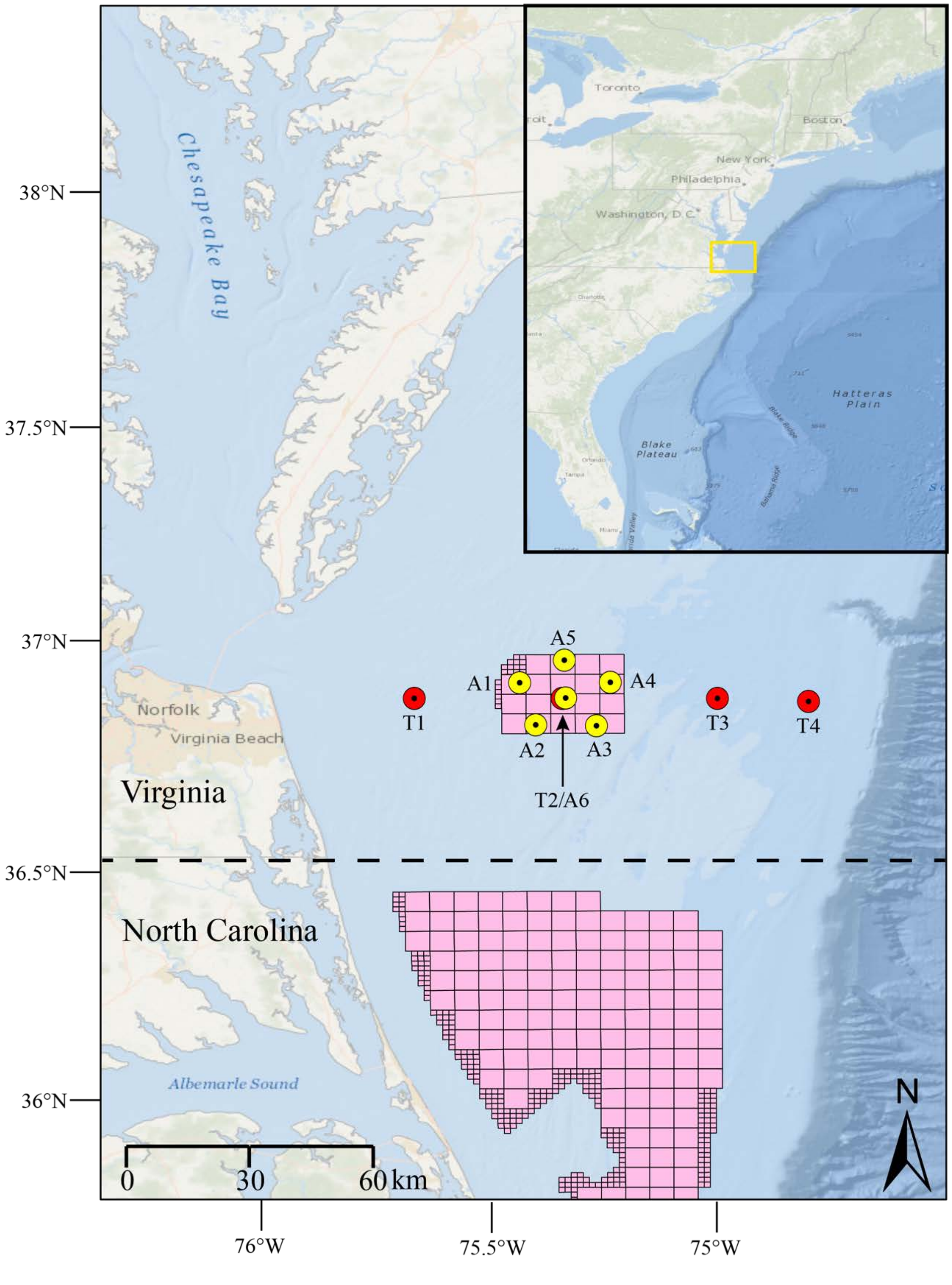


Figure 3.4 Map of the Transect and Array Area
The red circles show drop locations for the AMARs T1-T4 in the transect configuration. The yellow circles show drop locations for the MARUs A1-A6 in the array configuration. Pink squares represent WEA lease blocks. The dashed line separates Virginia from North Carolina (shown for general reference) and the pink squares represent WEA lease blocks in both states. Site A2 and T6 are co-located in the center of the WEA.

3.1 Data Processing

Acoustic data from the MARU Array deployments were extracted from the on-board storage devices and concatenated in multi-channel .AIFF sound files for browsing. Each MARU was aligned to a known timestamped synchronization tone that was played at the beginning, middle and end of each deployment (Table 3.2). This corrects for the minimal amount of clock drift that naturally occurs on each battery powered unit and allows for the potential to locate sounds of interest that are recorded across multiple units (Marchetto et al. 2012). Acoustic data from the AMAR transect deployments were recovered from the on-board storage devices and are available as single channel .WAV audio files. Both .AIFF and .WAV sound files are loss-less uncompressed audio formats and there were no challenges or problems in comparing data between the two file-types. Both AMAR and MARU audio files contained data that overlapped in the 1-1000 Hz frequency range.

Table 3.2. Synchronization tone times.

Deployment	Start Sync Date Time	Mid Sync Date Time	End Sync Date Time
1	2015-07-03T18:05:32 UTC	2015-09-30T15:04:26 UTC	2015-12-07T17:21:06 UTC
2	2015-12-07T17:21:06 UTC	2016-03-10T17:12:41 UTC	2016-05-24T16:11:19 UTC
3	2016-05-24T16:11:19 UTC	n/a*	2016-11-17T19:02:35 UTC
4	2016-11-18T16:12:09 UTC	2017-03-26T18:18:50 UTC	2017-04-29T13:40:19 UTC

*Due to poor weather and field conditions, no mid-deployment sync tones were played for deployment 3.

3.2 Data Gaps and Field Issues

Field work for the 2015-2017 deployments was conducted aboard Cornell's R/V Jaeger (Figure 3.5). Due to poor weather and field conditions during scheduled sensor redeployments, data gaps exist due to the inability to access deployment sites to deploy or retrieve recording units on schedule, or the failure to retrieve an acoustic recorder altogether due to equipment failure (3 out of 8 sensor-deployments, Figure 3.6, 3.7). The two largest data gaps exist between deployment 1 and 2 and between deployment 2 and 3 of the AMAR transect deployments due to poor weather conditions. We failed to recover sites T3 for deployment 2, A4 for deployment 3, H2 for deployment 2 and H4 for deployment 2 and 3. Also, there are small data gaps at sites T1 and T3 for deployment 3 and A5 for deployment 2 due to battery and hydrophone hardware failures on the recording units. There are several very small data gaps, usually only 1-2 days in the historical transect data set that are considered routine gaps due to normal deployment and recovery procedures. Lastly, there was a malfunction in the hydrophone assemblies for the first deployment of AMARs for the transect recording sites. This resulted in data with an increased level of internal noise, manifested as visually observable vertical bands of noise within the individual sound files (Table 3.3, Figure 3.6, 3.7, 3.8). When calculating long-term noise averages and plotting long-term noise measurements over periods of days and weeks, the noise measurements were slightly higher at all frequencies compared to other deployments. This suggests that the internal noise may have contributed to measured background noise conditions and will be need to be accounted for in relevant results and discussions (see section 7).

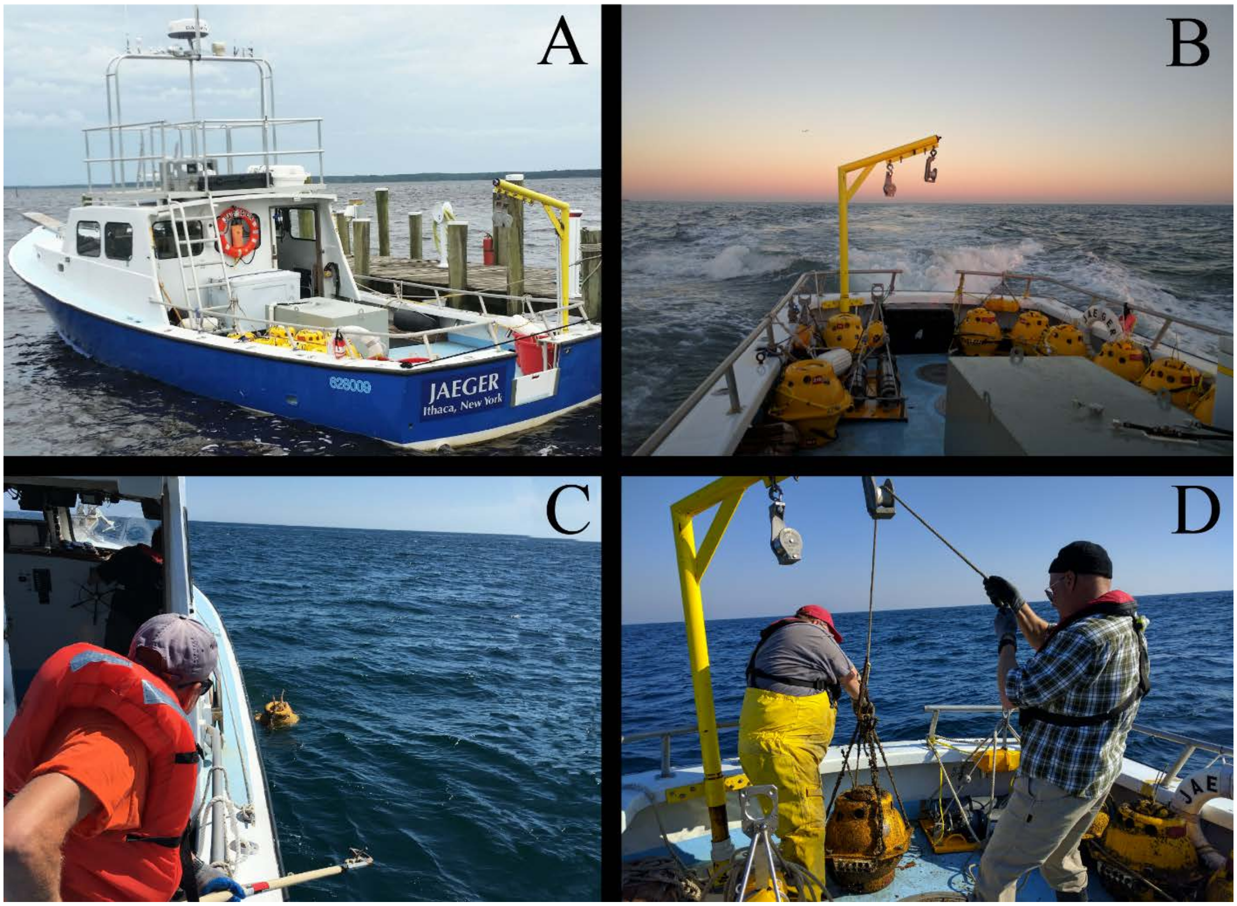


Figure 3.5. Field Operations Photos.
A) Cornell's research vessel used for deployment and recovery of recording equipment, the R/V Jaeger. B) The deck of the R/V Jaeger loaded with MARUs and AMARs. C) A field technician recovers a MARU. D) The recovered MARU is hauled on deck. Photo credits: Fred Channell (A); Kristin Hodge (B, C, D).

Table 3.3 Acoustic Survey Coverage Dates

Deployment	Deployment Description	Deployment Start Date	Deployment End Date
1	Historical transect	2012-06-01	2012-11-10
2	Historical transect	2012-11-10	2013-06-12
3	Historical transect	2013-06-12	2014-01-09
4	Historical transect	2014-01-08	2014-07-10
5	Historical transect	2014-07-09	2015-01-22
1	Transect	2015-07-03	2016-01-23
2	Transect	2016-03-09	2016-09-28
3	Transect	2016-10-21	2017-05-03
4	Transect	2017-05-02	2017-07-25
1	Array	2015-07-01	2015-12-07
2	Array	2015-12-07	2016-05-25
3	Array	2016-05-24	2016-11-19
4	Array	2016-11-18	2017-04-30

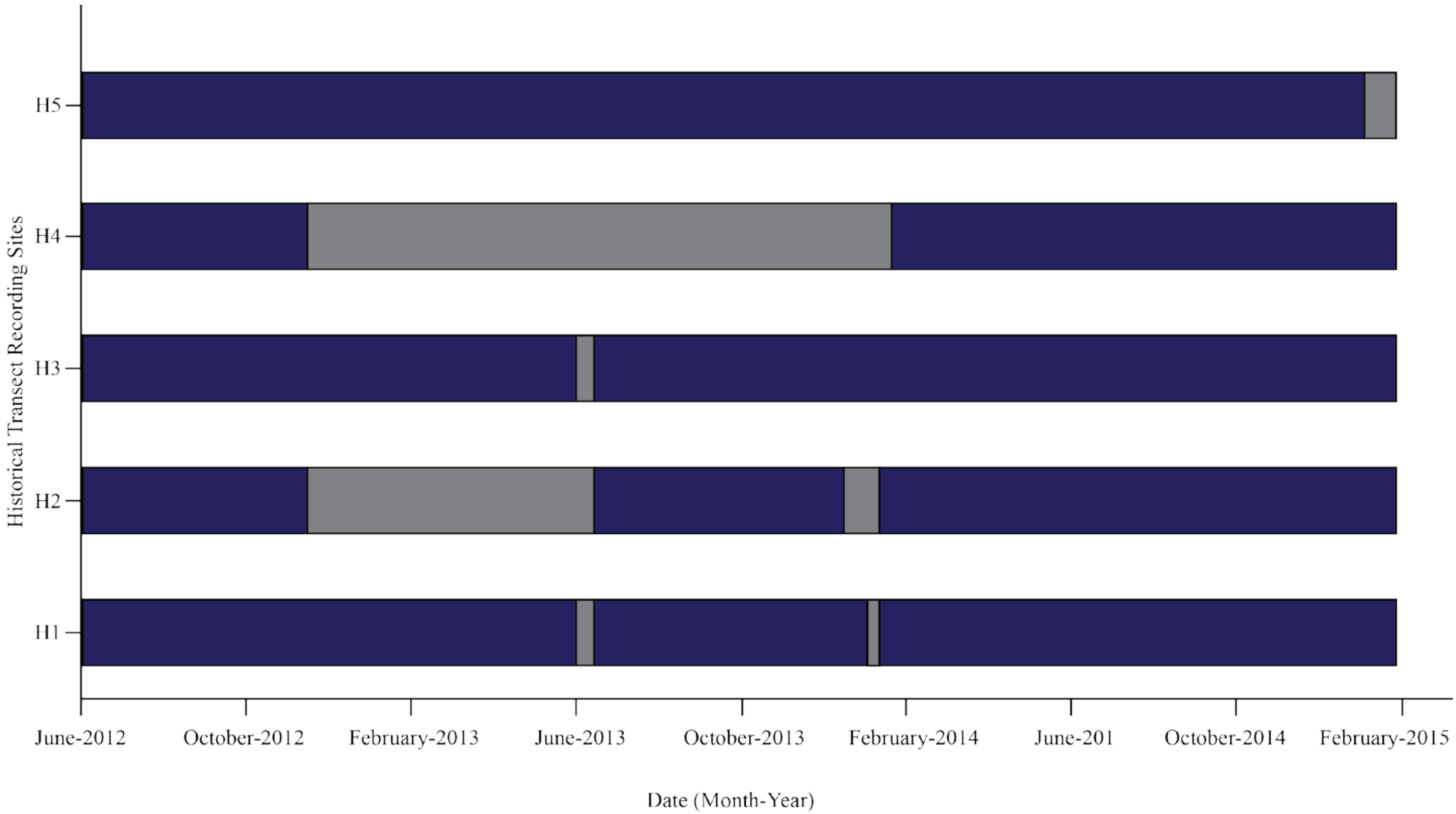


Figure 3.6. Data Coverage and Quality Chart of the Historical Transect
Blue bars represent periods of time where acoustic data was successfully collected. Gray bars represent periods of time when no data exists for that recording site.

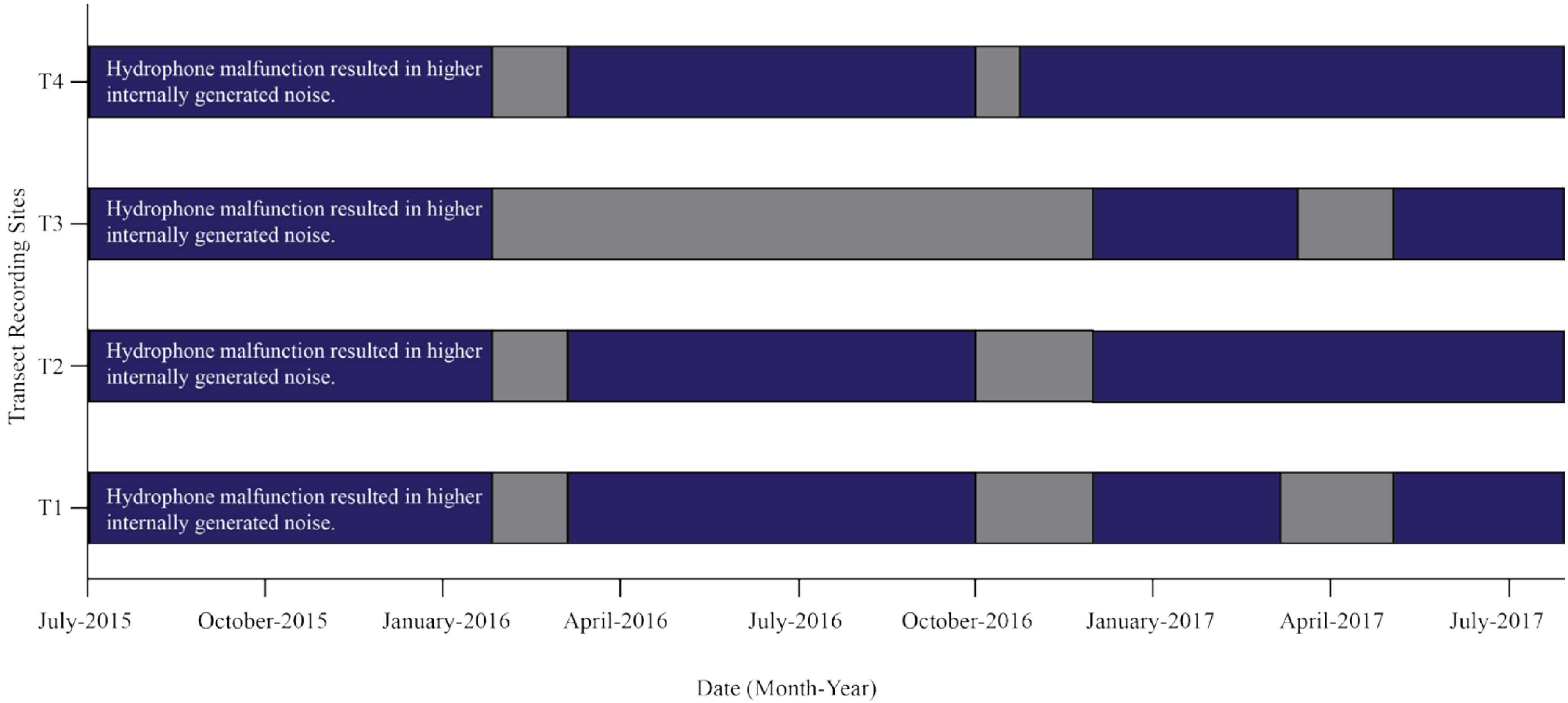


Figure 3.7. Data Coverage and Quality Chart of the Transect

Blue bars represent periods of time where acoustic data was successfully collected. Gray bars represent periods of time when no data exists for that recording site. Note for the first deployment from July 2015 – January 2016, a hydrophone malfunction resulted in increased noise in the data set for all four transect recording sites.

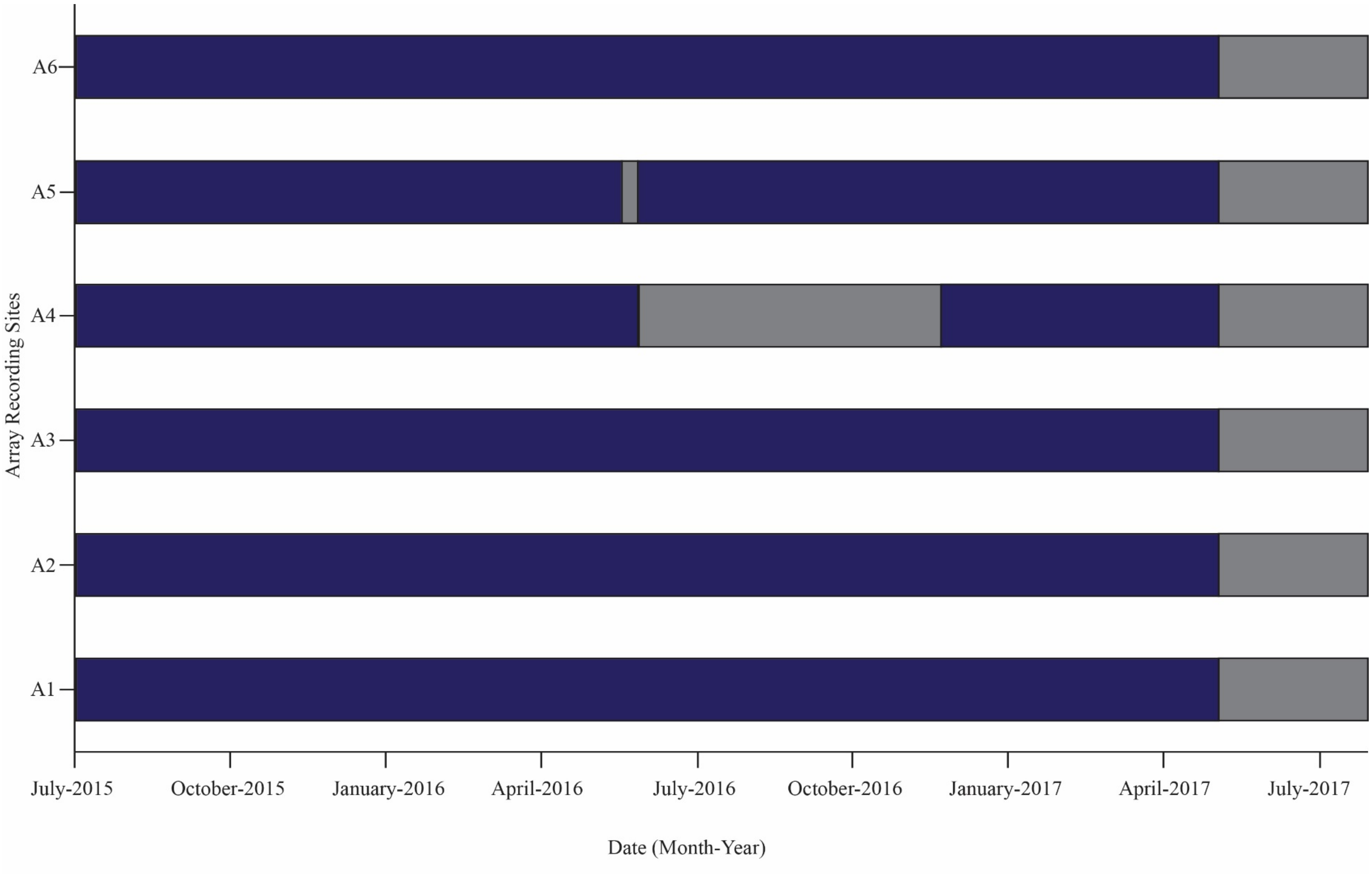


Figure 3.8. Data Coverage and Quality Chart of the Array
Blue bars represent periods of time where acoustic data was successfully collected. Gray bars represent periods of time when no data exists for that recording site.

4 Baleen Whale Temporal Patterns

4.1 Introduction

This study focused on four baleen whale species that are known to use the habitat off the coast of Virginia in some capacity. They include the North Atlantic right whale (*Eubalaena glacialis*), minke whale (*Balaenoptera acutorostrata*), fin whale (*Balaenoptera physalus*) and humpback whale (*Megaptera novaeangliae*). Previous studies on the lifestyle, habitat preferences, movement, and behavior trends in the Western North Atlantic give us some insight into temporal patterns of presence off the coast of Virginia.

Right whales are one of the most critically endangered large whales in the world (Kraus et al. 2005). A recent stock assessment for the Western Atlantic estimates their population numbers at approximately 465 individuals and at this size, even the mortality of a few individuals are significant to the genetic stability of the population (Waring et al. 2014). A portion of the population undertakes a seasonal migration from northern feeding grounds in the Great South Channel, Cape Cod Bay, Gulf of Maine and Bay of Fundy (Winn et al. 1986) down through the mid-Atlantic to the warm water calving grounds off the coast of Georgia and Florida (Kraus et al. 1986). Many aerial and shipboard surveys in the southern habitat report mother-calf pairs, suggesting that mainly pregnant females undertake the southern migration, however the rest of the population's winter habitat use is much more variable with some animals occurring year-round in the northern feeding grounds (Bort et al. 2015; Clark et al. 2010; Cole et al. 2013; Morano et al. 2012a; Mussoline et al. 2012). In the mid-Atlantic migration corridor, evidence of skim feeding and year-round presence off the coast of New Jersey and North Carolina suggest a more complex usage pattern throughout the mid-Atlantic (Hodge et al. 2015; Whitt et al. 2013). Since 2010, there has been an increased level of right whale presence in the mid-Atlantic (Davis et al. 2017), suggesting movement patterns may be shifting. Previous research in the Virginia WEA showed a seasonal trend of higher presence from October through March, with low levels of presence year round (Salisbury et al. 2016) and observations from whale watching ships showed right whale sightings, including mother-calf pairs during this time period (Ambler 2011).

Minke whales, similar to right whales, exhibit presence throughout the Western North Atlantic, from Baffin Bay to the Caribbean, and there is evidence of seasonal patterns and migration between northern feeding and southern calving grounds (Risch et al. 2013). However, the distribution and occurrence of minke whales are generally poorly understood, especially in the mid-Atlantic.

Fin whales are the largest of the four focal species and range from the Gulf of Maine down to Cape Hatteras, but a very rare sighting of an individual occurred in the northern Gulf of Mexico (Roberts et al. 2016). Fin whale population dynamics are poorly understood, but feeding aggregations in the Gulf of St. Lawrence and Gulf of Maine have been observed (Delarue et al. 2009). Regular occurrence within Massachusetts Bay and New York Bight have also been reported (Hain et al. 1992; Morano et al. 2012b). In Virginia, fin whales are commonly seen during whale watching tours and while they are likely distributed far offshore, an example of a juvenile fin whale feeding close to shore in Rudee Inlet, Virginia has been documented (Ambler 2011).

Humpback whales exhibit similar seasonal patterns to right whales and have been documented throughout the Western North Atlantic (Clark and Gagnon 2002; Dunlop et al. 2008). In Virginia, humpback whales are the most commonly seen baleen whale during whale watching tours and are found in the shallowest waters (Ambler 2011).

Of the studies conducted off the coast of Virginia, while seasonal patterns have been shown to exist for right whales (Salisbury et al. 2016), other baleen whale species have not been closely studied. The inter-annual variability which has been documented in right whales in the Western North Atlantic (Davis et al. 2017) has not specifically been explored in Virginia for all of the four focal species. Learning more about whale temporal patterns across a longer period of time will help understand the potential range of variability.

4.2 Methods

To evaluate temporal patterns of baleen whale presence, we used a combination of automated detectors and manual human analyst browsing to record daily presence of North Atlantic right whales, minke whales, fin whales and humpback whales across all recording sites of the historical transect and transect datasets from both the AMAR and MARU recording units. Sound files were browsed using Raven Pro 1.5 (Bioacoustics Research Program 2015).

Daily presence of right whales at each transect recording site was determined by identifying contact calls (up-calls), the predominant call type of the species (Mellinger et al. 2007; Parks and Clark 2007). To distinguish up-calls from other biological and anthropogenic sounds, we used the following set of criteria: (i) starting frequency occurred between 65-170 Hz; (ii) minimum and maximum frequencies differed by 75-200 Hz; (iii) duration ranged from 0.3-1.3 s; (iv) energy was concentrated in the lower portion of the signal; and (v) signal contour sloped upward (Figure 4.1). To minimize potential confusion with humpback vocalizations, which share similar acoustic properties in areas where the two species overlap (Mussoline et al. 2012), we used additional criteria to evaluate the signals including frequency bandwidth and duration, repetition rate, broader acoustic context, and harmonic structure to differentiate between the two species. A custom MATLAB-based automated detector was used to detect up-calls (Dugan et al. 2013) and was applied to every day and recorder of both the historical transect and transect datasets. Detections were reviewed and validated by analysts using the selection review tool in Raven Pro. This tool has a thumbnail view of the detected event, as well as a larger context view of the spectrogram around the time of the detected event. The spectrographic settings for the thumbnail view included a page duration of 2 seconds before and after the detected event, 10–450 Hz frequency range, and Fast Fourier Transform (FFT) size and window setting of 512 points. The spectrogram settings for the context view included a spectrogram window duration of 120 seconds, a frequency range of 10–450 Hz, and a FFT size and window setting of 512. In addition to validating the automated detector results, a 25% stratified subsample (every 4^{th} analysis day) of the transect dataset was manually browsed by analysts to evaluate the detector performance.

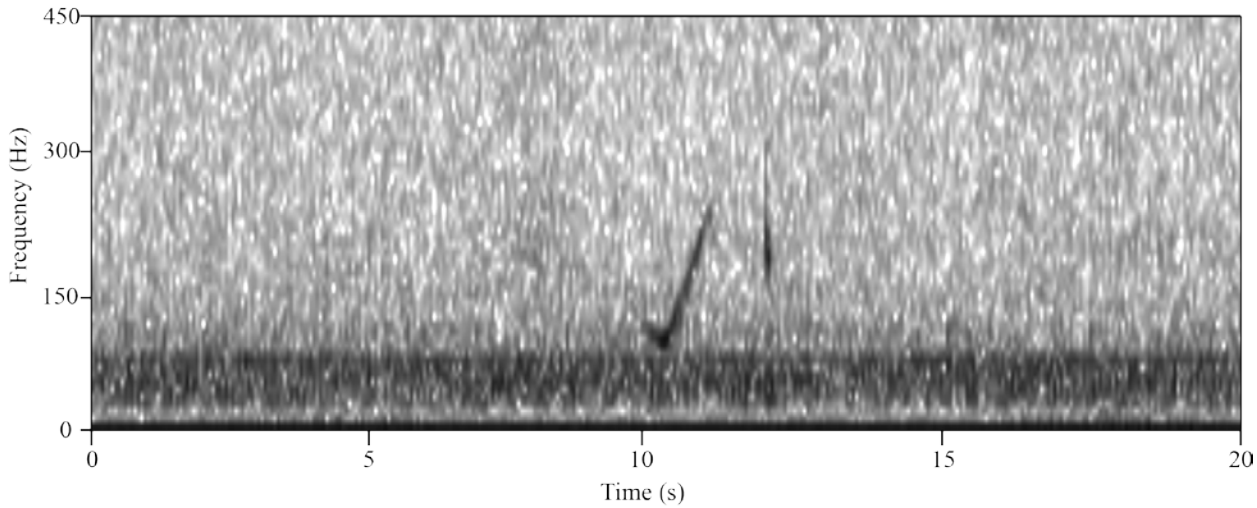


Figure 4.1 North Atlantic right whale up-call
An example of a typical right whale up-call, recorded from site M3 on January 14, 2017.

Minke whales produce a series of pulsed signals, called a "pulse train" (Figure 4.2), which are the most well-understood vocalization of North Atlantic minke whales and are commonly used to indicate minke whale presence (Risch et al. 2014; Risch et al. 2013). An automatic detection procedure was applied to the historical transect and transect datasets in order to identify minke pulse-train vocalizations. The automatic detector was implemented in a high-performance computing platform using a custom-built algorithm (Dugan et al. 2013; Popescu et al. 2013). The detections were then reviewed in the Raven Pro selection review tool. The spectrographic settings for the thumbnail view included a page duration of 2 seconds before and after the detected event, 25–500 Hz frequency range, and FFT size and window setting of 512. The spectrogram settings for the context view included a spectrogram window duration of 60 seconds, a frequency range of 25–500 Hz, and a FFT size and window setting of 512. A 25% stratified subsample (every 4^{th} analysis day) of the transect dataset was also manually browsed by analysts to evaluate the detector performance.

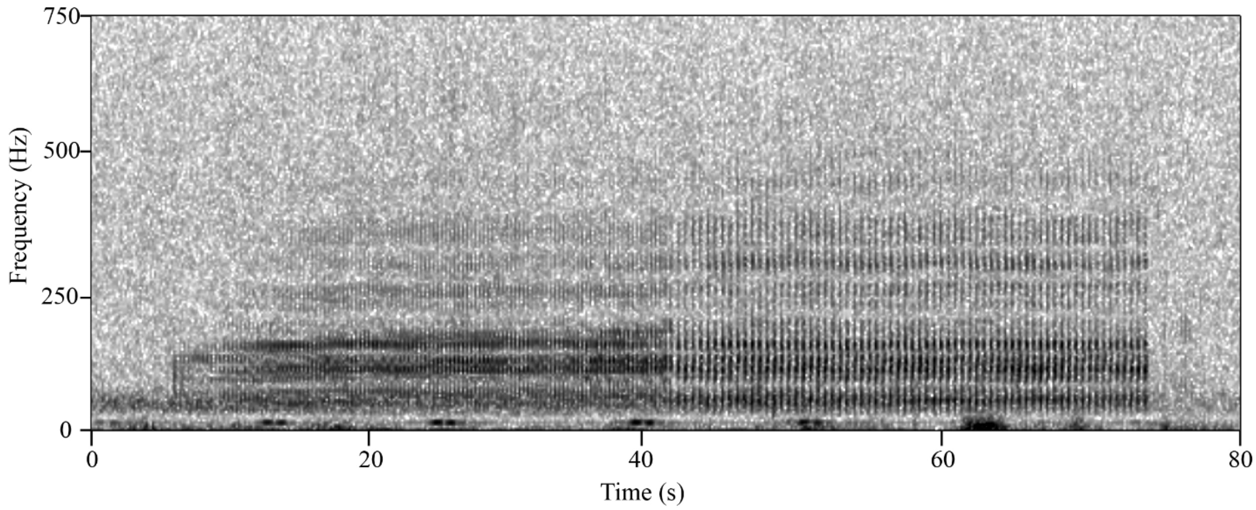


Figure 4.2 Minke whale pulse-train
An example of a typical minke whale pulse-train, recorded from site M3 on January 14, 2017.

Fin whale song is comprised of long sequences of individual 20-Hz notes (Figure 4.3) (Clark and Gagnon 2002; McDonald et al. 1995; Watkins et al. 1987). We used a matched-filter data- template detection algorithm running in the XBAT sound analysis environment (Barker et al. 2014; Bioacoustics Research Program 2012) to automatically identify 20-Hz notes in the historical transect and transect datasets. The detector is trained using multiple exemplars of 20-Hz fin whale notes and is able to detect sounds with similar characteristics. The spectrograms of automated detections were reviewed as thumbnails in Raven Pro, as described above for right whales and minke whales. The spectrogram settings for the thumbnail view included a page duration of 2 seconds before and after the detected event, 8–50 Hz frequency range, and FFT size and window setting of 2048. The spectrogram parameters for the context view included a 120-second spectrogram window duration, frequency range of 0–50 Hz, and FFT size and window setting of 2048. The same 25% stratified subsample (every 4th analysis day) of the transect dataset manually browsed by analysts for right whales and minke whales was completed for fin whales.

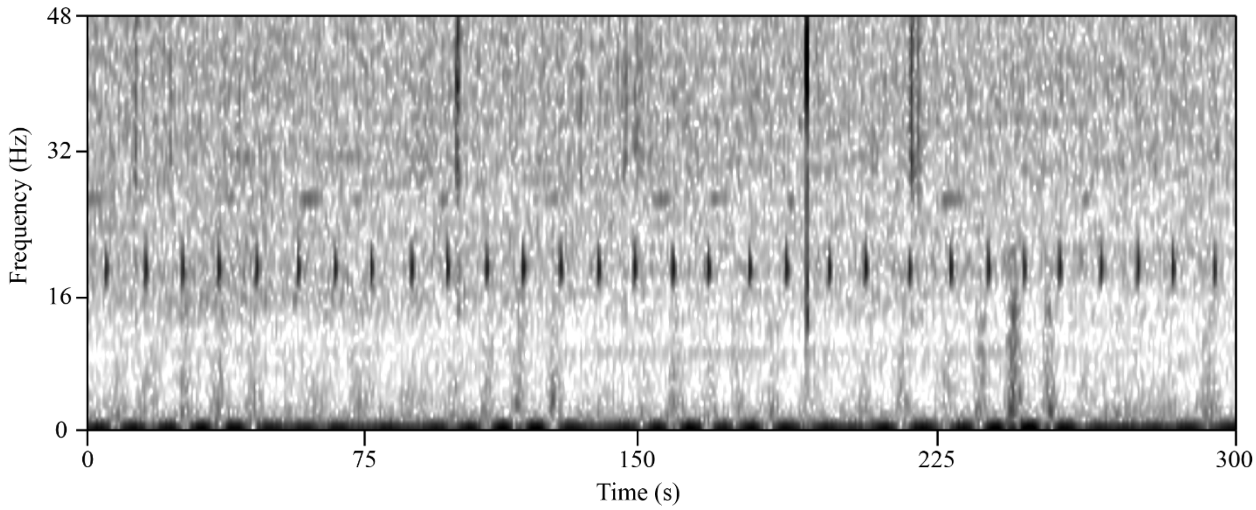


Figure 4.3 Fin whale 20 Hz pulse song
An example of a typical fin whale pulse song, recorded from site A4 on October 22, 2016.

There were two types of humpback whale sounds used to establish their presence: songs and social calls (Chabot 1988; Dunlop et al. 2007; Dunlop et al. 2008;Payne and McVay 1971; Silber 1986) (Figure 4.4, Figure 4.5). Analysts used Raven Pro to manually browse through the spectrogram to search for humpback whale species- specific sounds throughout the day. Spectrogram settings included a 5-minute window duration, frequency range of 10–600 Hz, and a FFT size of 512 points. For the transect dataset, this manual browsing was limited to the 25% stratified subsample (every 4th analysis day). For the historical transect dataset, humpback songs and social calls were only marked opportunistically, so we collected presence, but not absence data. In both analyses, the unavailability of a reliable automated detector and the amount of time needed to manually browse the datasets necessitated the development of a subsampling scheme. We compensated for sampling scheme when comparing results with other species by correcting for sampling effort to normalize the results.

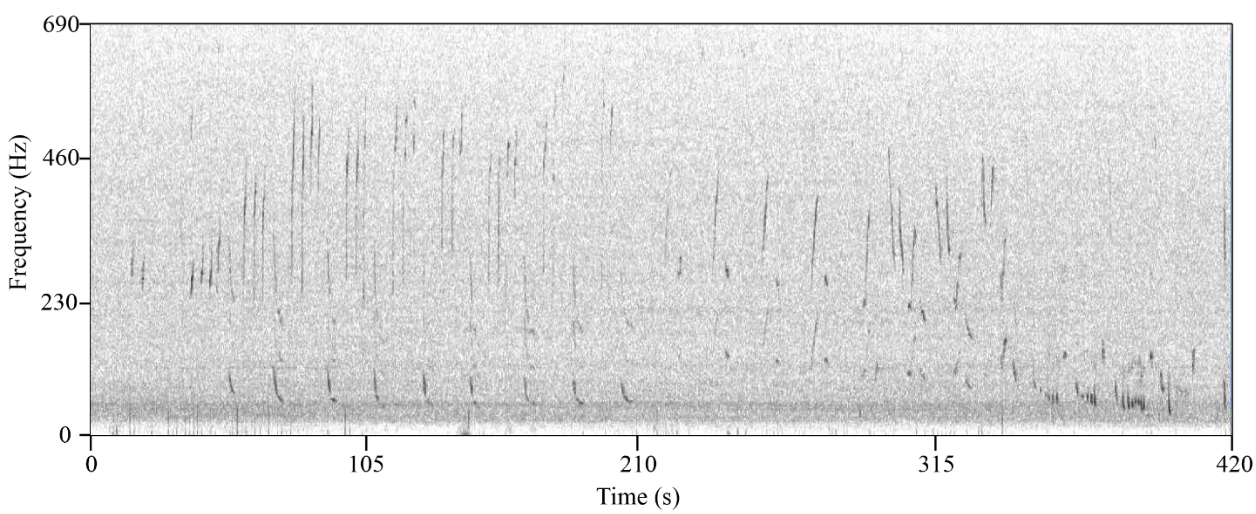


Figure 4.4 Humpback whale song
An example of a typical humpback whale song, recorded from site A4 on April 16, 2017.

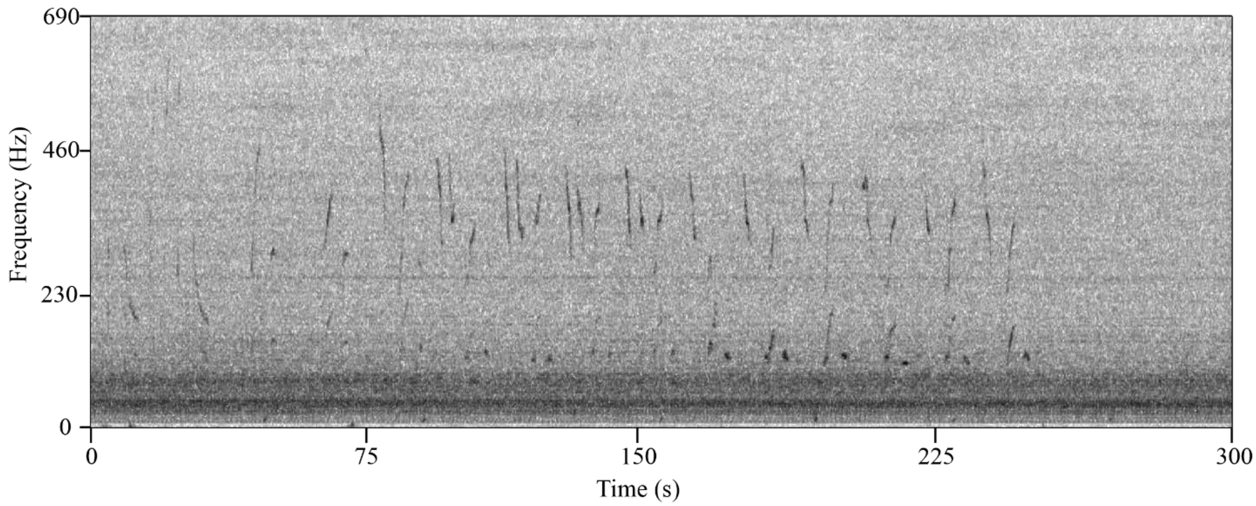


Figure 4.5 Humpback whale social calls
Examples of typical humpback whale social calls recorded from site A4 on April 16, 2017.

4.2.1 Automated Detector Performance

To test the performance of the three automated detectors used (right whale, minke whale and fin whale), we compared the daily presence and absence results of the 25% stratified subsample manually browsed dataset to the corresponding results from the automatic detection analysis. Treating the manually browsed results as a truth set, we calculated the percentage of days where each detector correctly identified whether the species call was present or absent. For each true positive detection and manually browsed signal, we used Raven Pro to add a set of robust measurements including bandwidth, duration, 5^{th} and 95^{th} frequency percentiles, center and peak frequency, and signal to noise ratio. These measurements were used to explore possible differences between the detection probabilities of automated versus manual browsed datasets. We compared detector performance between the AMAR transect and MARU array to test for potential differences in recorder type.

4.2.2 Temporal Acoustic Presence Analysis

Daily presence data for each of the four baleen whale species was converted to percent monthly acoustic presence, which is the total number of days a whale was detected in a month compared to the total number of days with recorded sound in that same month. Using this metric, a month in which acoustic presence was found on all days that were recorded in that month would result in 100% monthly acoustic presence. Zero days with acoustic presence on all days recorded in a month would result in a monthly acoustic presence value of 0%. Results were plotted with JMP and a smoothing line was fit to the data to remove outliers. Sea surface temperature (SST) data collected from NOAA weather buoys (44099, 44093; www.ndbc.noaa.gov) located in the study area were used to compare seasonal trends in whale presence. Weekly presence was also calculated from the daily presence data for each species to show finer resolution and variability within each monthly presence value.

4.2.3 Inter-annual Variation Analysis

To assess inter-annual variation among the four focal whale species, we averaged mean monthly presence across months for all years and ran a two-way ANOVA and Tukey's HSD post hoc test to statistically examine the potential differences between years and species. Additionally, we plotted average annual presence per season: Autumn (September 21-December 20), Winter (December 21 – March 20), Spring (March 21-June 20) and Summer (June 21-September 20) to compare seasons across years.

4.3 Results

4.3.1 Detector Performance Results

Results for the three automated detectors were summarized on a daily presence performance level for both AMAR and MARU subsets of data (Table 4.1). The fin whale detector performed the best, with an average success rate of 99% between both MARU and AMAR datasets, meaning that in 99% of days where fin whale calls were manually found, the detector also found a fin whale call. It also had the greatest sample size with 117 days of presence tested. The right whale up-call detector performed with an average success rate of 85%, with the detector performing better on the MARU dataset (94%) than the AMAR dataset (76%). The minke whale detector had an average success rate of 87.5%, but the sample size was very low, with only 6 days of presence in the truth set.

Table 4.1. Detector Performance Results.

Species	Recorder Type	Days of Presence in Truth Set	Days of Presence in Detector Set	Detector Success Rate
Fin	AMAR	68	68	100
Fin	MARU	50	49	98
Right	AMAR	33	25	76
Right	MARU	33	31	94
Minke	AMAR	4	3	75
Minke	MARU	2	2	100

Of the many robust call characteristics that were measured from both the manually browsed and automatically detected datasets, SNR showed the strongest association in differentiating between the two methods of whale detection. Manually browsed detections of all species combined had on average, lower SNR (mean=14.90 dB, n=450) compared to automated detector events (20.55dB, n=596). A one-way ANOVA compared the means and found them statistically different ($p<0.0001$) (Figure 4.6).

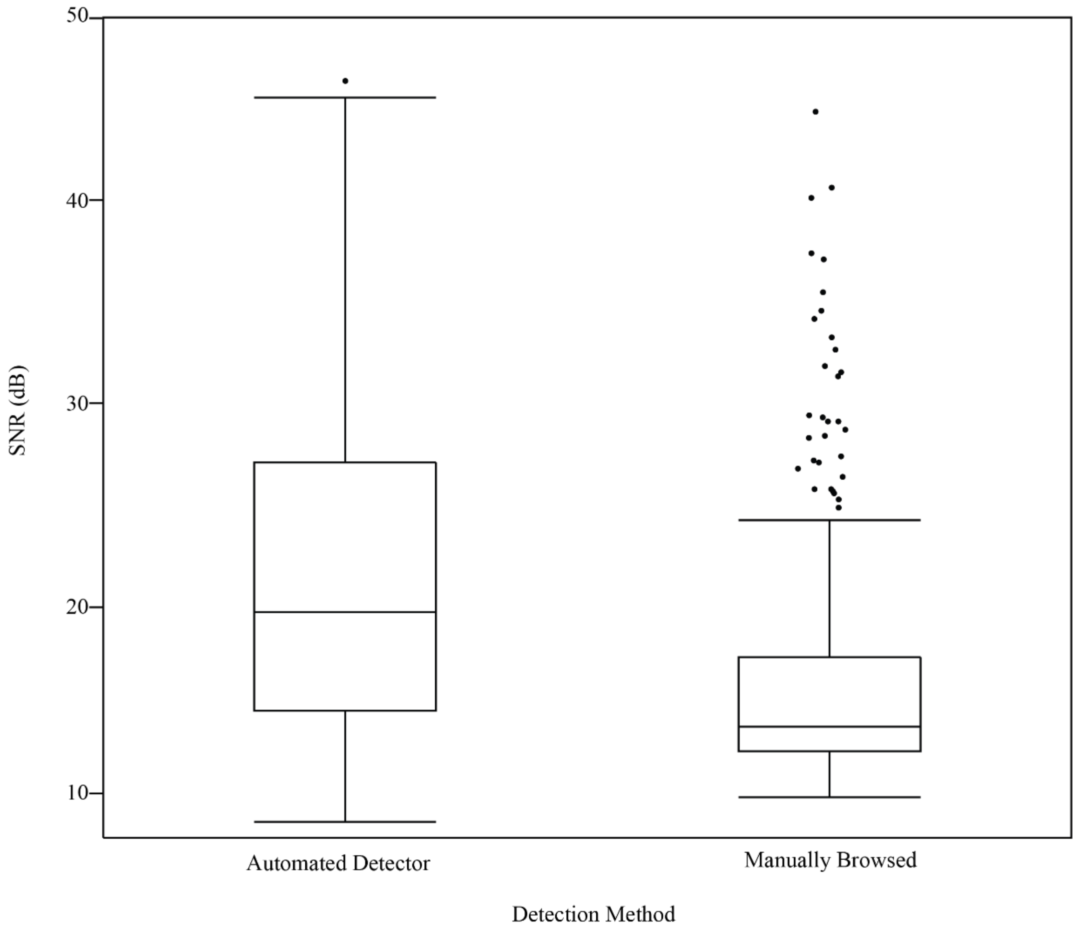


Figure 4.6 SNR of Manual versus Automated Detector calls
A boxplot comparing the mean SNR of whale calls found with automated detectors and manual browsing.

4.3.2 Seasonal trends

Right whales showed distinct periods of seasonality. When comparing percent monthly presence across the Historical Transect and Transect datasets, we saw a recurring cyclical pattern of presence (Figure 4.7). Peak periods of whale presence occurred from November through April, with variability depending on the year. Whale presence during the rest of the year from May through October was relatively lower than the peak season with some periods of time with no whale presence, however some years showed higher levels of offseason presence than others, especially May through July 2017. Average monthly presence was 9.95% (standard deviation=18.69).

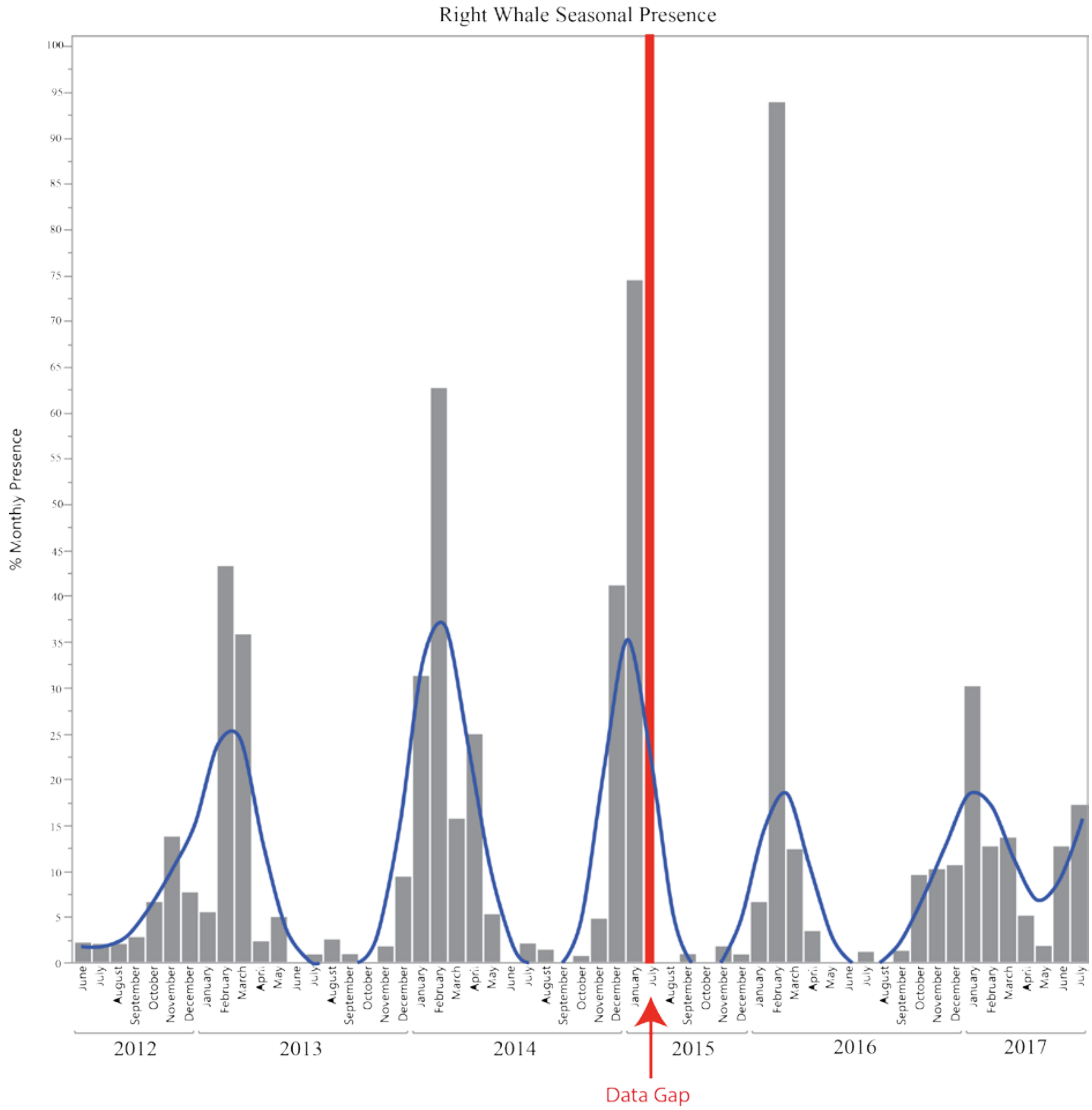


Figure 4.7 Percent Monthly Presence of Right Whales
Data from all 5.5 years of Historical Transect and Transect recording units combined. The solid red line shows the cutoff from the Historical Transect configuration and the Transect configuration. There is a 6 month gap in data here from January 2015 through June 2015 where no data was collected. A blue smoothing line was fit to the data to correct for outliers.

Minke whale presence was very low throughout the entire study period, however the low presence did show periods of seasonality with higher frequency of presence found in two distinct periods in the autumn and late winter or early spring. Compared across years, 2013 showed the highest levels of minke whale presence and 2014/2015 the lowest (Figure 4.8). Average monthly presence was 1.30% (standard deviation=5.45).

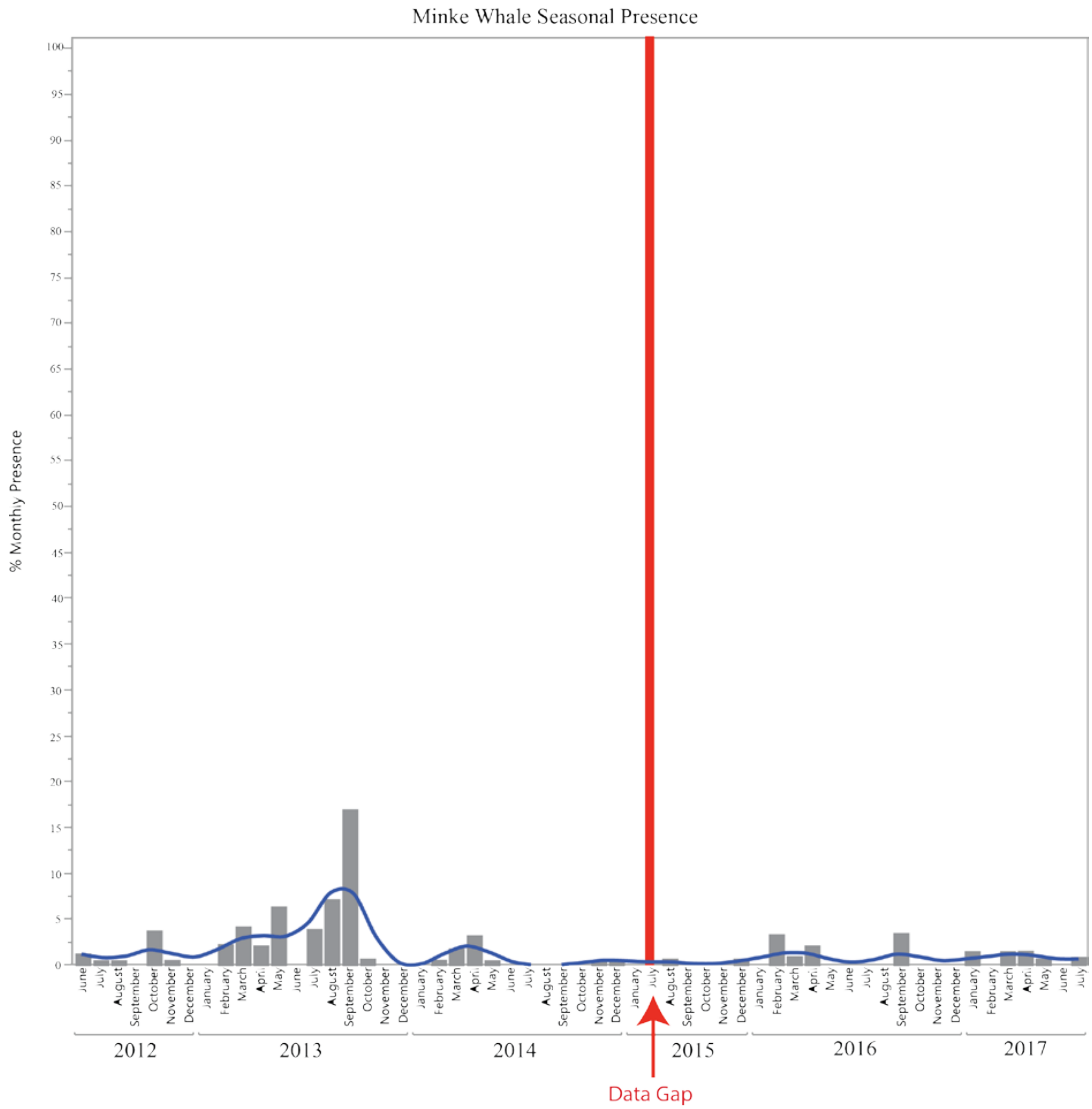


Figure 4.8 Percent Monthly Presence of Minke Whales
Data from all 5.5 years of Historical Transect and Transect recording units combined. The solid red line shows the cutoff from the Historical Transect configuration and the Transect configuration. There is a 6 month gap in data here from January 2015 through June 2015 where no data was collected. A blue smoothing line was fit to the data to correct for outliers.

Fin whales showed the highest levels of monthly presence of the four focal species with seasonal trends of peak months of presence in October through February. Lowest periods of presence occurred during the summer in the months of June through August, but the whales were often still detected in relatively high numbers compared to the other species (Figure 4.9). Average monthly presence was 38.96% (standard deviation=34.39).

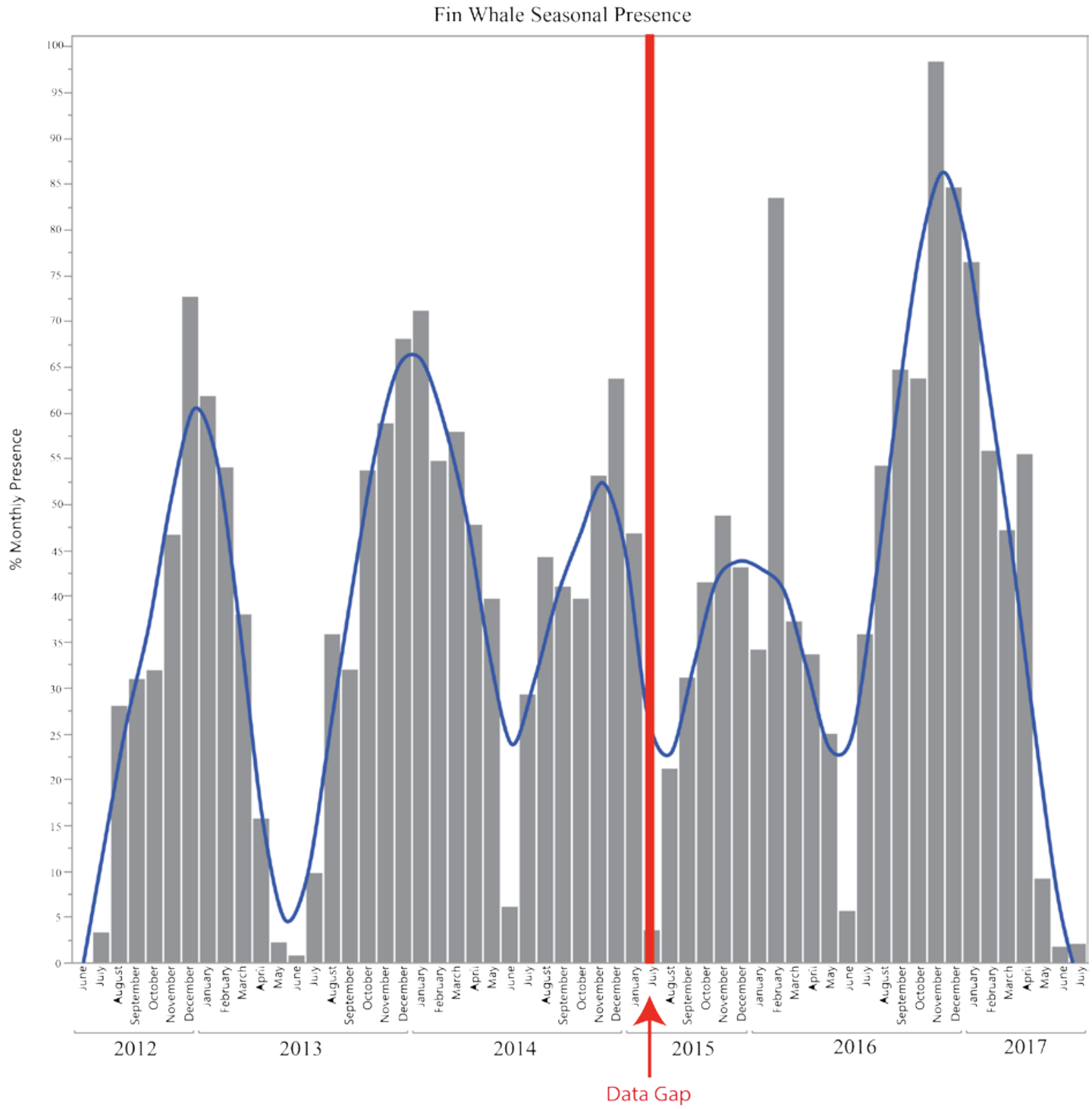


Figure 4.9 Percent Monthly Presence of Fin Whales
Data from all 5.5 years of Historical Transect and Transect recording units combined. The solid red line shows the cutoff from the Historical Transect configuration and the Transect configuration. There is a 6 month gap in data here from January 2015 through June 2015 where no data was collected. A blue smoothing line was fit to the data to correct for outliers.

Humpback whales showed similar seasonal trends compared to right whales, but with the peak period of presence shifted slightly later in the year, from February through April. Monthly presence was lower in the summer months of June through August with a notable exception in 2012, where whales were present in the summer months with a higher level of frequency (Figure 4.10). Average monthly presence was 7.91% (standard deviation=15.31).

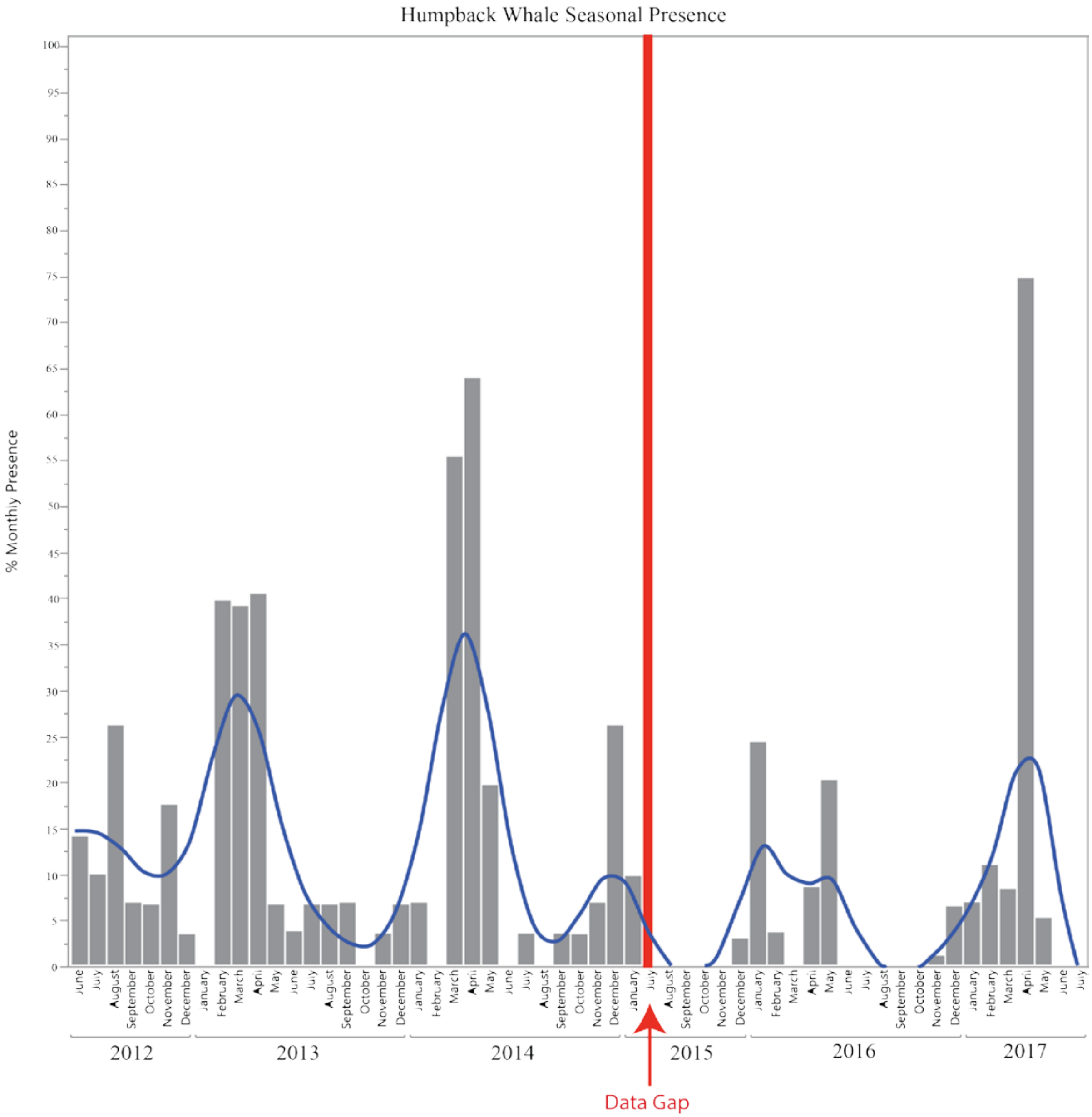


Figure 4.10 Percent Monthly Presence of Humpback Whales
Data from all 5.5 years of Historical Transect and Transect recording units combined. The solid red line shows the cutoff from the Historical Transect configuration and the Transect configuration. There is a 6 month gap in data here from January 2015 through June 2015 where no data was collected. A blue smoothing line was fit to the data to correct for outliers.

We combined the smoothing curves for the percent monthly presence for each species and overlay histograms of mean monthly SST to show possible correlations between the two. Seasonal trends in mean monthly SST were fairly consistent among years, with notable exceptions to the minimum temperature in 2016 and 2017, which were higher than previous years by 2.5-4 °C. Peak right whale presence was found on average during the lowest temperature periods and humpback whale peak presence was found during slightly warmer periods after the right whale peak presence. Fin whale peak presence was found during times of the year when SST was decreasing from the warmest seasonal peaks (Figure 4.11).

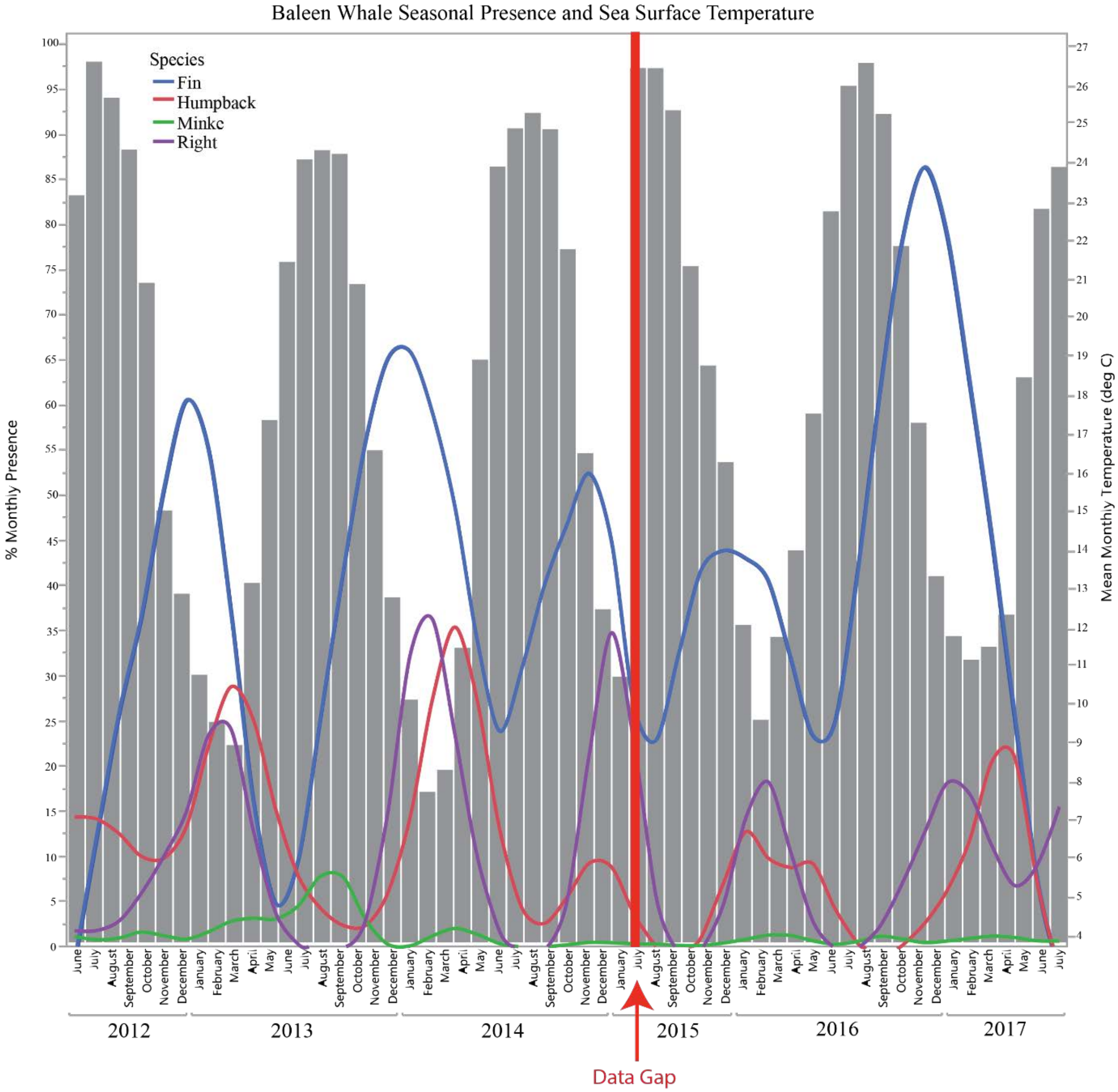


Figure 4.11 Baleen Whale Monthly Presence and Sea Surface Temperature
Data from all 5.5 years of Historical Transect and Transect recording units combined. The solid red line shows the cutoff from the Historical Transect configuration and the Transect configuration. There is a 6 month gap in data here from January 2015 through June 2015 where no data was collected. Colored smoothing lines were fit to the data to correct for outliers. Grey histograms show mean monthly SST.

Variability in species presence existed within each month. We plotted weekly presence from daily presence results for transect data from 2012 – 2017, where 100% denotes that a species of whale was present on all 7 days during that week and where ~14% denotes that a species of whale was present for only one day during that week. Right whales had seasonal blocks of weeks with high levels of presence, whereas minke whales had weeks with mostly low presence volume. Fin whales had the highest levels of weekly presence throughout the 5 year period and humpbacks had mostly low levels of weekly presence. Of note, the subsampling methods for obtaining humpback presence skews the weekly results to the lower end (Figure 4.12).

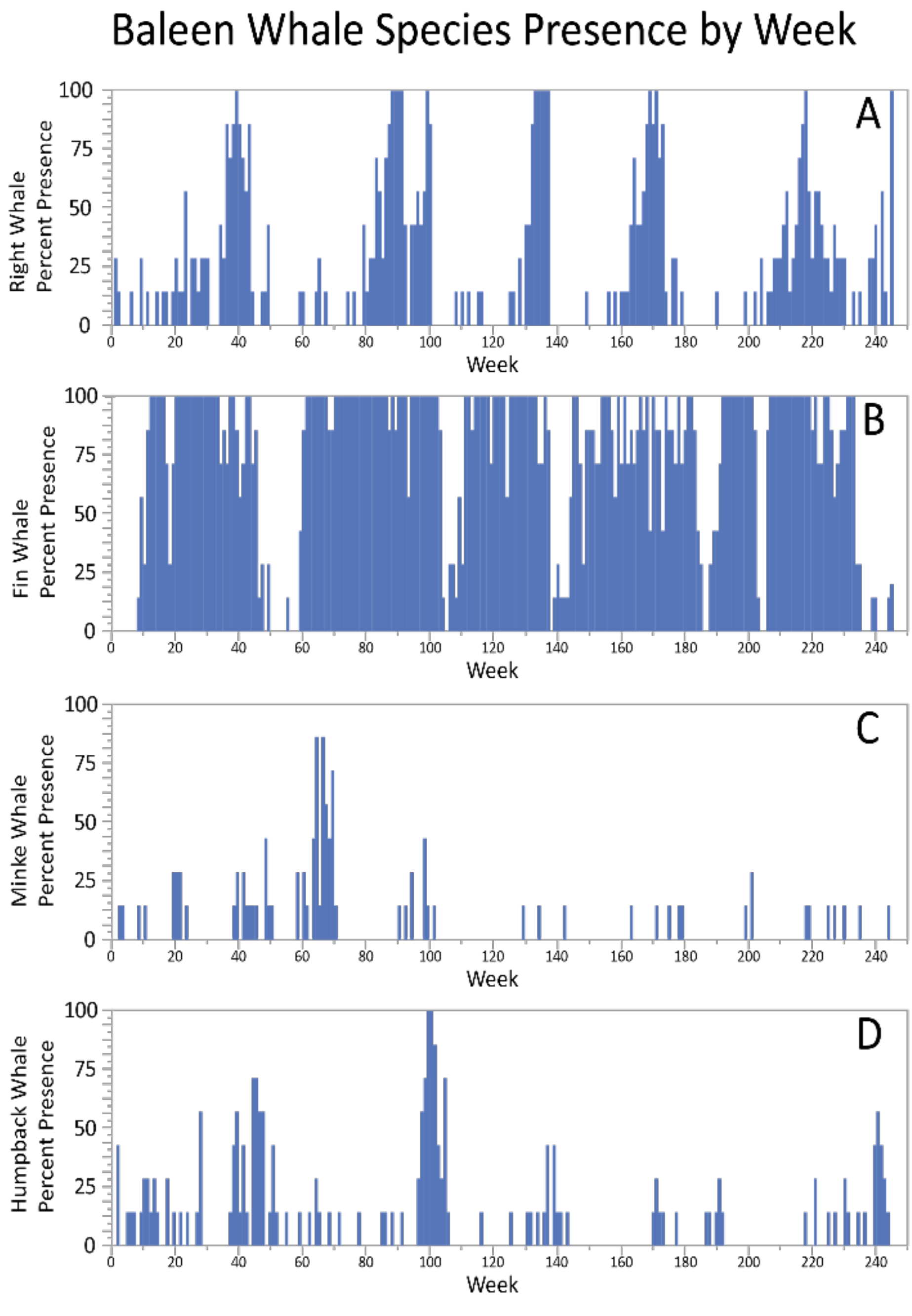


Figure 4.12 Weekly Presence for Baleen Whale Species
Data from all 5.5 years of Historical Transect and Transect recording units combined. A) North Atlantic right whale weekly presence B) Fin whale weekly presence. C) Minke whale weekly presence. D) Humpback whale weekly presence.

4.3.3 Inter-annual Variation Analysis Results

Variation existed between different sets of years for different species of whales. For right whales, 2014 and 2017 were statistically similar, but statistically different from 2012, 2013, 2015 and 2016. Minke whales however, did not show any statistical variation between years, with 2013 showing only a small increase in average monthly presence. Fin whales showed higher variation, with 2012, 2014 and 2016 all statistically different from each other, as well as from 2013, 2015 and 2017, which were all similar to each other. Humpback whales had similar monthly averages in 2012, 2013, 2014 and 2017, but both 2015 and 2016 were significantly different from each other and the years 2012, 2013, 2014 and 2017 (Figure 4.13).

Averaging presence across seasons, instead of months for all five years of the transect data set showed similar patterns compared to the monthly presence results. Variation existed between years for all four species and seasons (Figure 4.14).

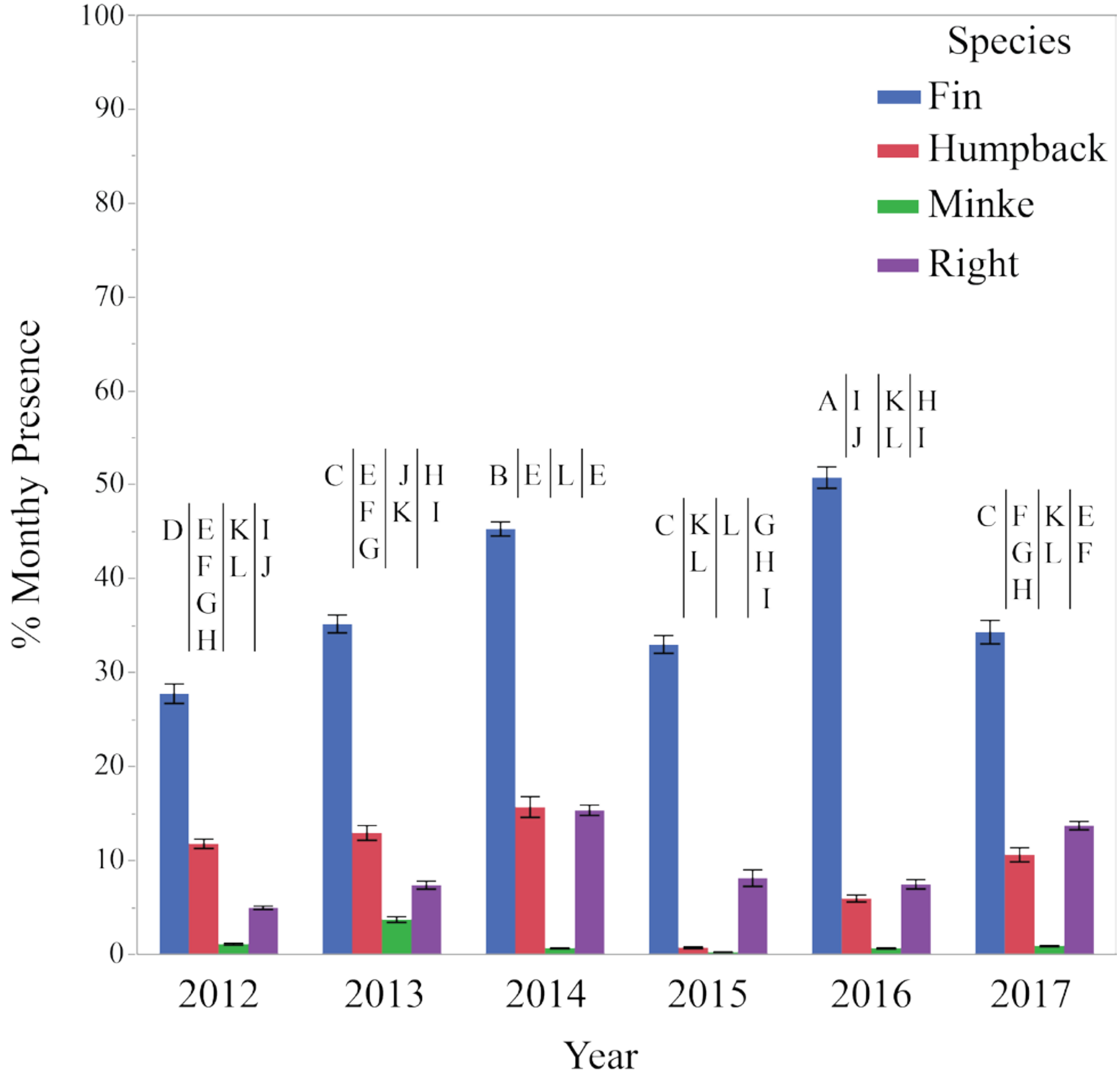


Figure 4.13 Mean Monthly Percent Presence per year for baleen whale species.
Letters above each bar indicate statistical differences between year and species (from two-way ANOVA and Tukey's HSD post hoc test); groups that do not share the same letter are significantly different from each other.

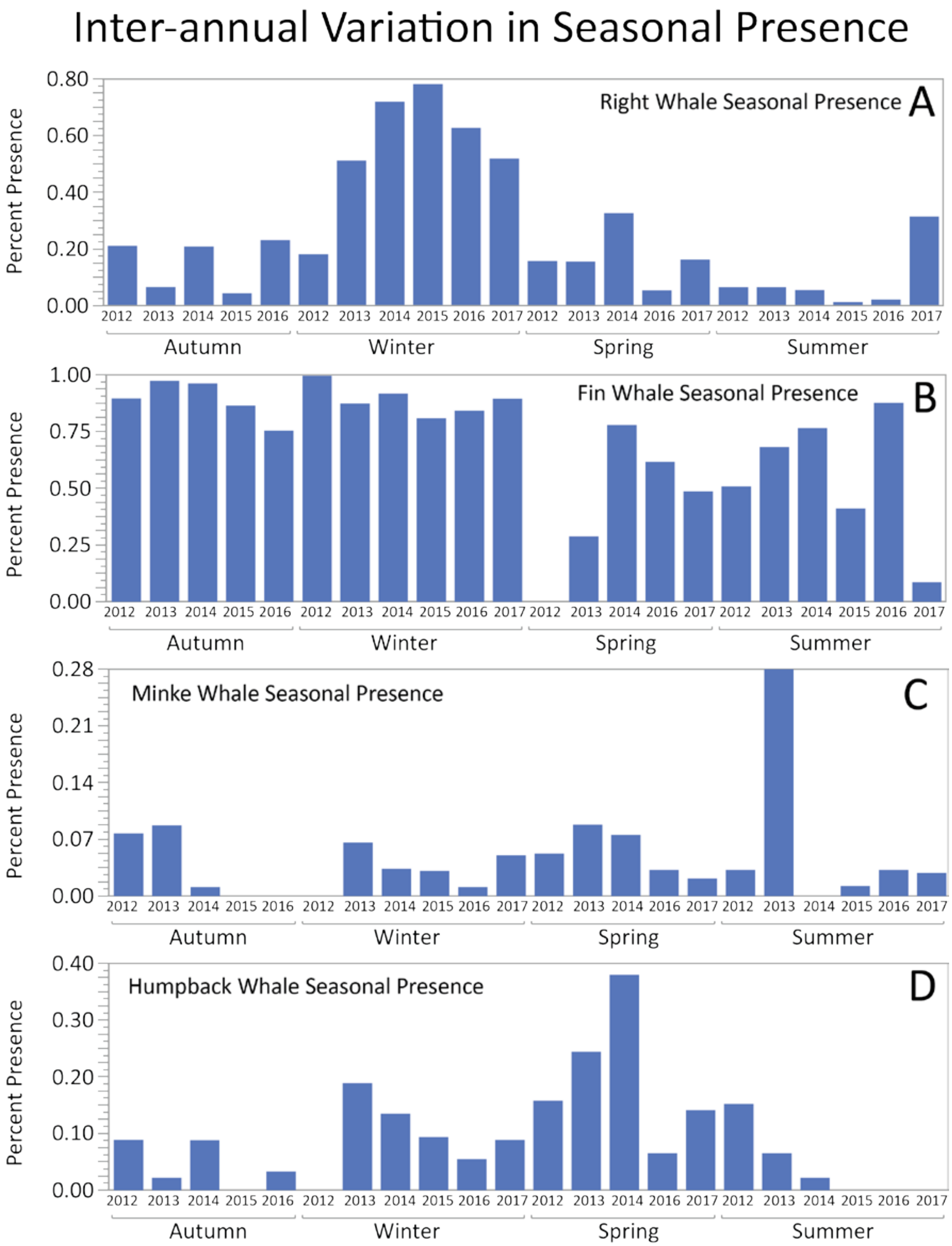


Figure 4.14 Mean Percent Presence per year per season for baleen whale species.
Presence per season per year plotted for each of the four baleen whale species. A) North Atlantic right whale. B) Fin Whale. C) Minke Whale. D) Humpback whale. Note that the Percent Presence Y-Axis scale is different and optimized for each panel.

4.4 Discussion

Seasonal changes in species presence was best shown by plotting the percentage of monthly presence over time, for all four focal species of baleen whales. The results showed distinct periods of time where fin, humpback and right whales had the highest presence levels. While some of these time periods overlap, each peak was different. Fin whales were more likely to be detected in November through January, while humpbacks were more common in March and April. Right whales had highest presence levels in January, which agrees with data from shipboard surveys on whale watching boats (Ambler 2011). Minke whales were the rarest of the four focal species and determining seasonal patterns is difficult given the small sample size of detections, but even those low numbers showed consistent peaks in February through May. Monthly presence was consistently lowest during the summer months for all four species, which suggests that any potential high-risk activity during wind farm construction may be mitigated by scheduling during the low-presence seasons. However, for each species, seldom was there a month where zero whales were detected. Weekly presence for low-presence seasons were low as well, suggesting whales did not spend much time in the area as opposed to high-presence seasons when weekly presence was much higher. These results are consistent with previous density models for baleen whales that predict low-level presence in July and peak presence in January (Roberts et al. 2016). With near year-round presence at some level, the risk of human interactions cannot be completely removed through temporal considerations.

Understanding the inter-annual variation of these seasonal trends is important to effectively mitigating risks in that it highlights the need for long-term studies. Right whale distributional changes in the last few years have shown a higher proportion of the population occurring throughout their entire habitat range throughout the year, shifting from the previously assumed migration pattern (Davis et al. 2017). This shift in distribution can have critical impacts to the species, such as the example with the recent increase in right whales in the northern ranges of the Gulf of St. Lawrence, which is linked to 10 right whale deaths in 2017 alone (Davis et al. 2017). Our study supports these findings in annual variation, with the historical transect results showing higher levels of whales from 2012-2014 than the AMAR transect that recorded from 2015-2017. Right whales and humpback whales showed similarity in their annual presence patterns, however, fin whales diverged from that pattern in 2017, showing the highest percent of monthly presence out of all five study years. Correlating environmental variables to predict inter-annual variation is a complicated process, as many variables exist that might explain why whales choose to be at a certain place at a certain time. Noise conditions, oceanographic conditions, bottom-type, hydrology, food-availability, and temperature all can play a role. While the mean monthly sea surface temperature at the highest end of its range in the summer was fairly consistent, the lowest temperature averages showed an increase by two to three degrees Celsius in 2016 and 2017, compared to 2012-2014. Both right whale and humpback whales had lower levels of presence during the warmer winter months of 2016 and 2017, suggesting that perhaps SST could be a factor in driving whale distribution patterns, but more data is needed to explore whether this observation holds merit.

4.4.1 Study Limitations

When analyzing the temporal presence results, several variables existed that had the potential to influence the interpretation of the results. Overall, due to the limitations of PAM, whale presence is considered a conservative estimate. Potential masking from noise conditions, difficulties in detecting signals in high noise conditions, variation in the acoustic behavior of different species (call rates and detection range of each species), a lack of an automated humpback detector all affect detection range and probability of detection (See section 5). Therefore, care needs to be taken when comparing presence trends between species, as certain species may vocalize louder and more often, which would then result in more detections than less vocal species. Absence of whale vocalizations is not a confirmation that whales are not present in the study area.

By having analysts conduct a manual browsing of a subset of the data, we attempted to improve on the performance of the detectors, and found that on average human analysts were more likely to detect faint whale calls than the detector. Likewise, manually verifying all detected events reduced the likelihood that a false positive was accidentally scored as a true whale detection. So, while the chance of a type I error is low, incorrectly identifying whale presence as occurring when it did not, there is a higher chance of type II error, not identifying whale presence when it in fact, does exist.

In addition, the presence of data gaps throughout the study period potentially reduce our estimates of whale presence, especially when those gaps exist during seasons of historically high activity such as the data gap during February of 2016. While we corrected our monthly percent values to take into account days and months where we did not record data, the overall whale presence may be higher than reported.

Finally, the hydrophone malfunction in the first deployment of AMARs at the transect site potentially reduced our ability to detect whales during that time period. While the increase in visible internal noise from the units resulted in a potential measurable increase to the background noise environment (see section 7), there is a possibility that it reduced the performance of our automated detectors due to interfering with the spectrogram cross-correlation algorithms. Whale presence was low in 2015 and while this may suggest that the hydrophone malfunction played a role, the fact that whale presence was low for all four species suggests that in fact, it may not. The internal noise affected each whale frequency band differently and if it had been a driving factor in detection probability, we could have seen different results among species. Similar presence trends between the detectors and the analyst browsed data sets also suggest that the hydrophone malfunction had a negligible effect on the study results.

5 Baleen Whale Spatial Patterns

5.1 Introduction

In addition to studying when the whales are in the area, where they are detected is equally as important. In developing plans for minimizing risks to baleen whale species, from WEA construction and operations, understanding what spatial features are important to whales helps provide context for making these plans.

There are many spatial features important to baleen whale distribution. Density models predicted that baleen whales aggregate in productive northern waters, concentrated near the continental shelf and near on-shelf areas of bathymetric relief such as banks and ledges (Roberts et al. 2016). While these density models are useful in areas with known presence, they become less robust in low survey areas such as Virginia. Besides bathymetry, sea surface temperature, chlorophyll concentration and thermal fronts can all affect prey availability and whale distribution (Ambler 2011). In coastal Virginia waters, the hydrography of the mouth of the Chesapeake Bay can create conditions favorable to opportunistically feeding whales and increased zooplankton aggregations, while eddies from the Gulf Stream can form additional offshore frontal areas that support increased food availability (Ambler 2011).

Current protection zones for baleen whales in coastal Virginia waters, specifically designed for the critically endangered right whale extend out approximately 37 km offshore. These seasonal management areas are applied from November to April and regulate speeds on all vessels 19.8 m (65 ft) or greater in overall length to a maximum of 18.5 km/hr (10 knots)(Merrick et al. 2001). However, previous acoustic surveys found right whales present at recording sites ranging from inshore to the continental shelf edge (Salisbury et al. 2016). Studying the spatial patterns of baleen whales within and around the WEA will prove useful for mitigating potential risks to the animals.

5.1.1 Localization Process

The use of multiple recording units deployed in an area with overlapping detection ranges allows for the ability to localize signals that are recorded on multiple units. There are two primary methods used to calculate the source of a call, available in Raven Pro (Bioacoustics Research Program 2015), spectrogram cross-correlation and time delay of arrivals (TDOA). The TDOA method measures the delay in time between the arrivals of signals on different units and calculates the range and bearing of the source by triangulating the arrival times, assuming the locations of the recorders and speed of sound in the water column are known. Spectrogram cross-correlation uses similar assumptions about the location of the recording units and sound speed of the water, but instead of arrival times between user-identified calls, calculates a correlation score for each arrival and searches for a range and bearing that has the highest probability of highest correlation score. Spectrogram cross-correlation is less susceptible to errors in clock drift alignment, and since our study requires alignment of non-cabled arrays, we found it to be more accurate, consistent and reliable than the TDOA method.

The process of localizing baleen whale calls has several requirements. The array of recorders must be properly aligned and synchronized using a GPS clock. Sound speed profiles are required to estimate signal transmission in the water column and accurate positions of the recording units are required. In some areas with high currents and depths, the recording unit may drift in location from the drop location until it is anchored on the seafloor. For accurate locations, high quality signal to noise ratios are very important as are distance from the circumference of the array. As the estimated location moves farther from the array, the accuracy of the tool decreases as errors in clock drift expand exponentially (Shiu et al. 2016). Finally, while locating whales can provide data on where they are, it is difficult to extrapolate where the whales are absent. Absence of locatable calls does not mean absence of whales, since the successful location of a call depends on signal and alignment quality. Calling rates and behavior of the species itself can also have an effect on spatial data. If the whales do not vocalize in certain noise conditions or during certain behavior states, it may skew the spatial dataset.

When the limitations of the localization process are understood and controlled for, the tool provides us with insight into spatial patterns that can be useful for understanding habitat usage and spatial features important to each species of whale. Correlating species spatial patterns to bathymetric features such as depth, or predicting habitat preferences may help mitigate risks of ship-strikes or other whale/human conflict.

5.2 Methods

Analysis of spatial patterns of baleen whale distribution throughout the Virginia study area was accomplished by using all three acoustic datasets (historical transect, transect and array). For the historical transect and transect datasets, the presence of a species' call at a recording site conveys some relative spatial information, primarily that the whale is located within the detection range of the recording unit. Percent distribution of calls per site were calculated for the Transect dataset. Sites were also combined to show distribution of inshore calls (site T1 and site T2) and offshore calls (site T3 and T4).

For the array dataset, we used the same methods and parameters described in section 4 to find potentially locatable species specific vocalizations, that is, any calls that were received by 3 or more recording units in the array. For right whales and minke whales, we identified every potentially locatable up-call and pulse-train, but due to the high call rate and repetitive nature of fin whale 20 Hz pulse song and humpback whale song and social calls, where an individual may have hundreds of signals in their call sequences, we identified one potentially locatable call per hour.

For right whale calls, we measured the SNR of all the potentially locatable calls and processed the highest 20% of calls per deployment through the Raven Pro Locator tool to obtain spatial data within the WEA. During exploratory work, we found that as SNR decreased, the success rate of the locator tool decreased significantly. For minke, humpback and fin whale calls, we attempted to locate at least one call successfully per 60 minute bin. We also calculated the percent distribution of all potentially locatable calls per recording site in the array to obtain relative spatial data for calls that were not processed through the locator tool due to a low SNR. We used the site where the first arrival of the call was detected to show the distribution of calls across the array.

5.2.1 Detection Range Model

Acoustic detection ranges for right whales, humpback whales, fin whales, and minke whales, were modeled using the Acoustic Ecology Toolbox (Bioacoustics Research Program 2017), a MATLAB-based algorithm. In order to choose the appropriate spreading loss model for this shelf region, we referred to empirical data from playback signals that were transmitted in a similar habitat off the coast of Maryland during June 2017. Those data comprised 17 sequences of playbacks along two transects, each sequence comprised eight sweep (300 – 600 Hz) signals. We determined the playback system source level to be approximately 166 dB re 1µPa@1m within the 300 – 600 Hz frequency band. We then measured the received level for each recorded signal and measured the distance from the source (a Lubell speaker) to the receiver. From that, a regression was used to estimate the relationship between received level and range for each site (Figure 5.1), from which we determined the overall spreading loss model that best fit the empirical data (Equation 5.1). The model that best fit the empirical data was compared against the spherical spreading loss model ($20\log_{10}R$), cylindrical spreading loss model ($10\log_{10}R$), and a semiempirical model which comprises the spherical spreading loss model, to account for near-source spreading, with an intermediate model based on the best fit to the empirical data (Richardson et al. 1995). The model that best fit the empirical data was an intermediate 16.1$\log_{10}$(R) model.

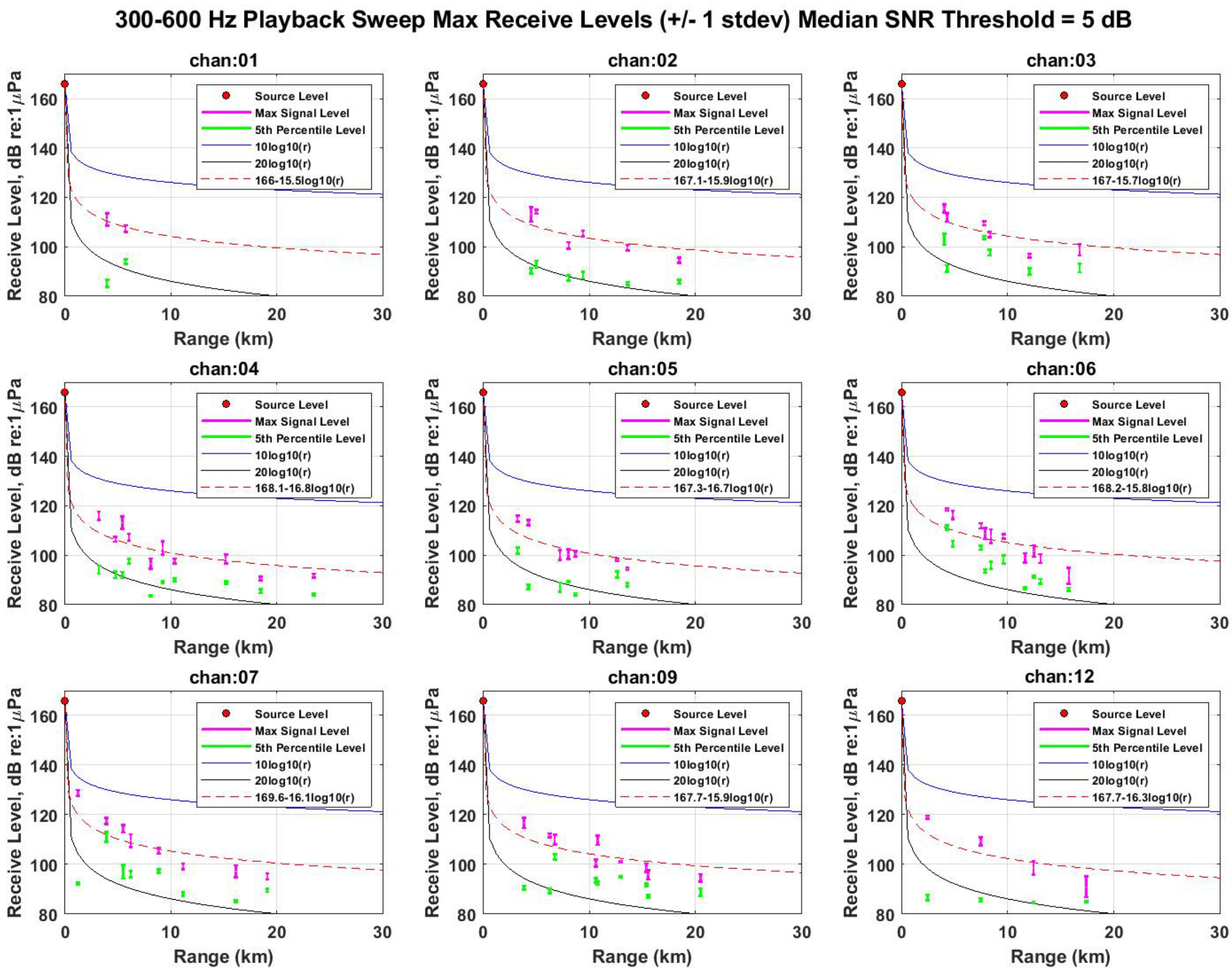


Figure 5.1. Regression of modeled receive levels.
For each playback sweep, (300 – 500 Hz) at each site given range from the source, a regression for modeled receive levels was plotted. The dashed red line represents the model that best fits the empirical data, which typically had a spreading coefficient of 16. The blue line represents the 10log10(r) model and the black line represents the 20log10(r) model for comparison. The best-fit lines for each site were average to determine the spreading loss model to use.

Detection range estimates for the Virginia sites were subsequently derived from the intermediate spreading loss model below:

$$RL = SL - 16.1 \log_{10}(R) \quad \textbf{(5. 1)}$$

where *RL* is the receive level, *SL* is the source level, and *R* represents the range of the signal from the source to the receiver. These calculations take into account source level and measured local ambient noise levels at each location. Source levels for each whale were estimated using values documented in the peer-reviewed scientific literature (**Error! Reference source not found.**). Ambient noise measurements from species-specific bandwidths (**Error! Reference source not found.**) were calculated within each deployment. Using the intermediate $16.1\log_{10}R$ spreading loss model, we estimated and averaged the detection range of the four whale species from each site locations, during high (95^{th} percentile), median (50^{th} percentile), and quiet (5^{th} percentile) noise conditions.

Table 5.1. Species-specific source levels and bandwidth used in the detection range calculations for four whale species.

Species	Source Levels	Species Specific Bandwidth
North Atlantic right whale	172 dB (Hatch et al. 2012)	71 – 224 Hz (Hatch et al. 2012; Urazghildiiev et al. 2009)
Minke whale	168 dB (Risch et al. 2014)	50 – 300 Hz (Risch et al. 2014)
Fin whale	189 dB (Weirathmueller et al. 2013)	15 – 25 Hz (Weirathmueller et al. 2013)
Humpback whale	169 dB (Au et al. 2006)	20 – 600 Hz (Thompson et al. 1986))

5.2.2 Locator Tool

We used the localization toolbox in Raven Pro 2.0 (Bioacoustics Research Program 2018)to estimate positions of vocalizing whales within the WEA. The locator tool uses spectrogram cross-correlation to identify arrivals of the detected call on multiple recording units and estimates the bearing and range of the call. We defined the search radius for the tool as ± 25 km based on a conservative estimate of our detection range model estimates. Sound speed was calculated using data from temperature and salinity measurements made by Star Oddi CTD dataloggers that were attached to the MARU at site M6 in the center of the array and recording measurements every 12 hours for the duration of each deployment. For each potentially locatable call, we ran the tool and accepted any calls where the tool successfully identified the proper call arrivals on three or more recording units and rejected any call where the locator tool failed to properly identify the arrivals (Figures 5.2).

We assessed the accuracy of the locator tool by running it on the artificial tones we played at known positions throughout the project that were used for time synchronization of the array and comparing the locator tool's output coordinates to the actual coordinates.

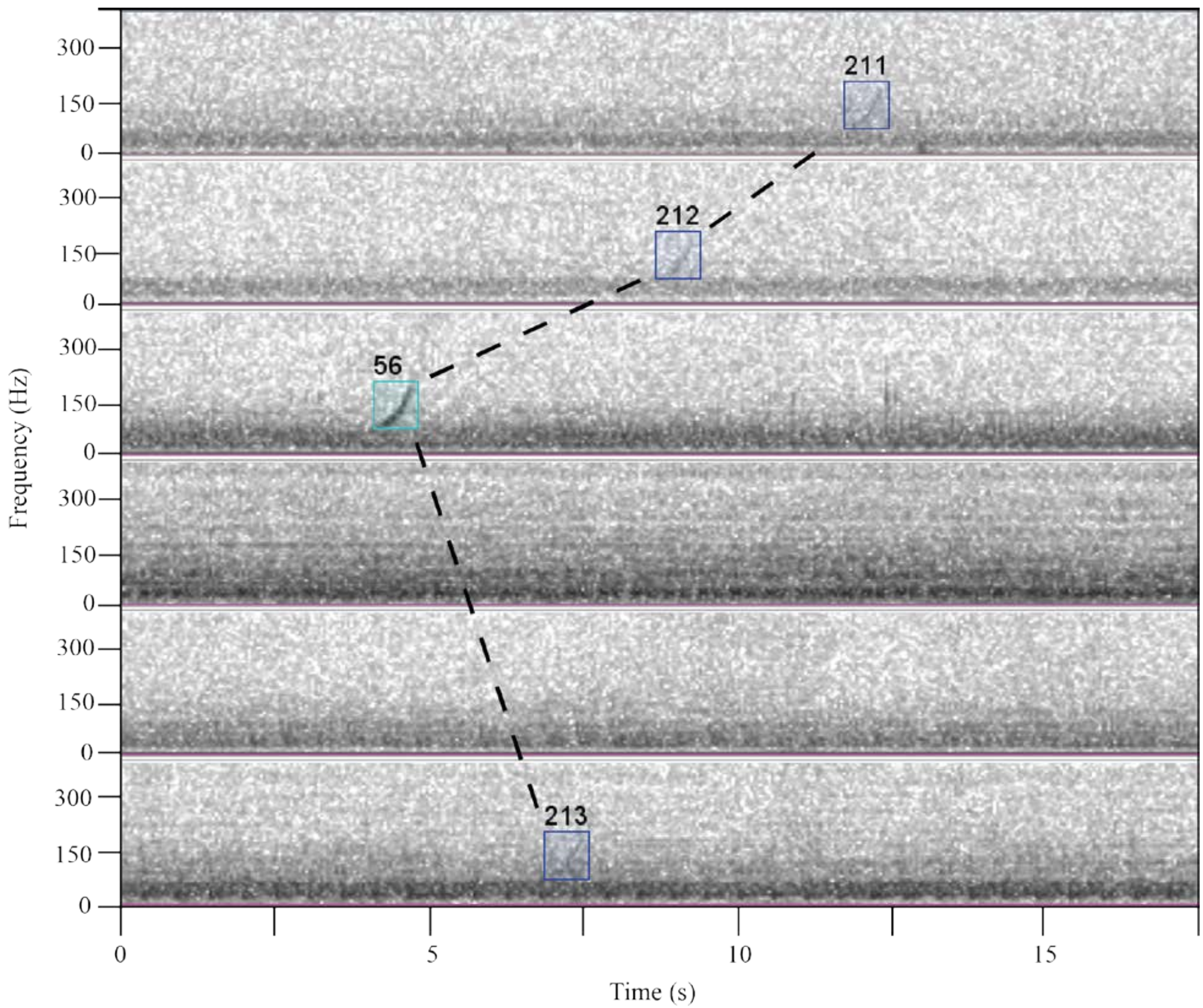


Figure 5.2. Image of a right whale up-call properly boxed and located.
The first arrival of the up-call is boxed in light blue on channel 3. The locator correctly boxes the arrivals of the same call on channels 1, 2 and 6.

5.3 Results

5.3.1 Detection Range Model

Depending on the noise conditions, detection range estimates varied from very large during the quietest periods of time (>150 km for fin whales) to very small during the loudest periods of time (0.4 km for minke whales). On average, minke whale calls had the smallest detection range, while fin whale calls had the highest detection range. Humpbacks and right whales shared similar ranges (Figure 5.3, Figure 5.4, Figure 5.5, Figure 5.6). Each percentile represents the estimated detection range for the corresponding percentile of noise. That is, the 5% percentile detection range represents the average estimated detection range for the quietest 5% of time throughout the study period and is a good proxy for maximum likely detection range. Whereas the 95% percentile detection range represents the average estimated detection range for the loudest 5% of the time throughout the study period and is a good proxy for minimum detection range. Of the four focal species, only fin whales showed detection range overlap between all sites at the 50% median detection range. Both right whales and humpback whales showed minimal overlap in 50% median detection range at the offshore recording sites (T3, T4). Detection range estimates had small variation between sites due to differences in noise conditions at each site, but were averaged across all sites and bearings to make comparisons between species easier (Table 5.2).

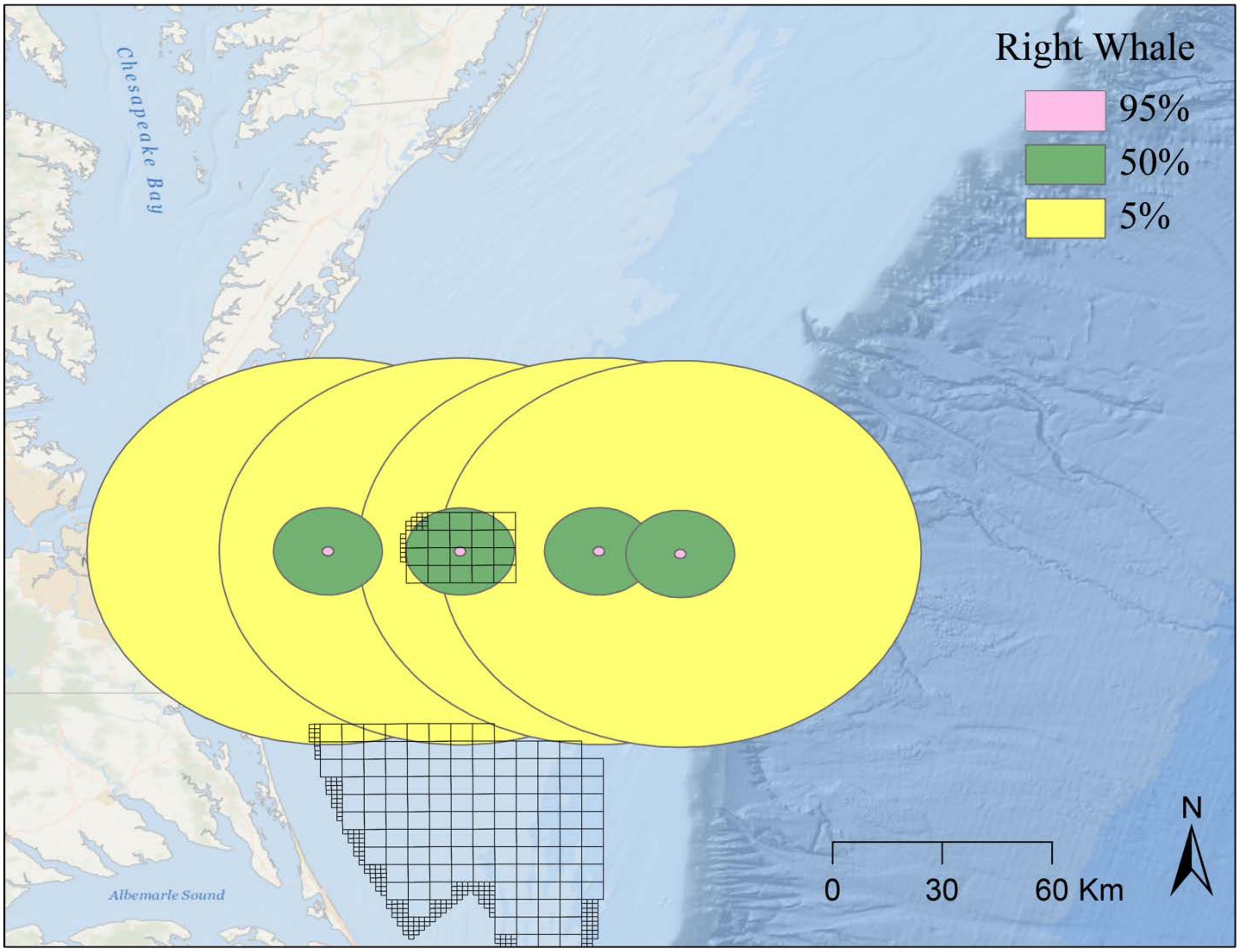


Figure 5.3. Map of study area with right whale detection ranges overlaid.
Estimated detection ranges for the quietest and loudest 5% of noise conditions (5% and 95%) and the median noise conditions (50%).

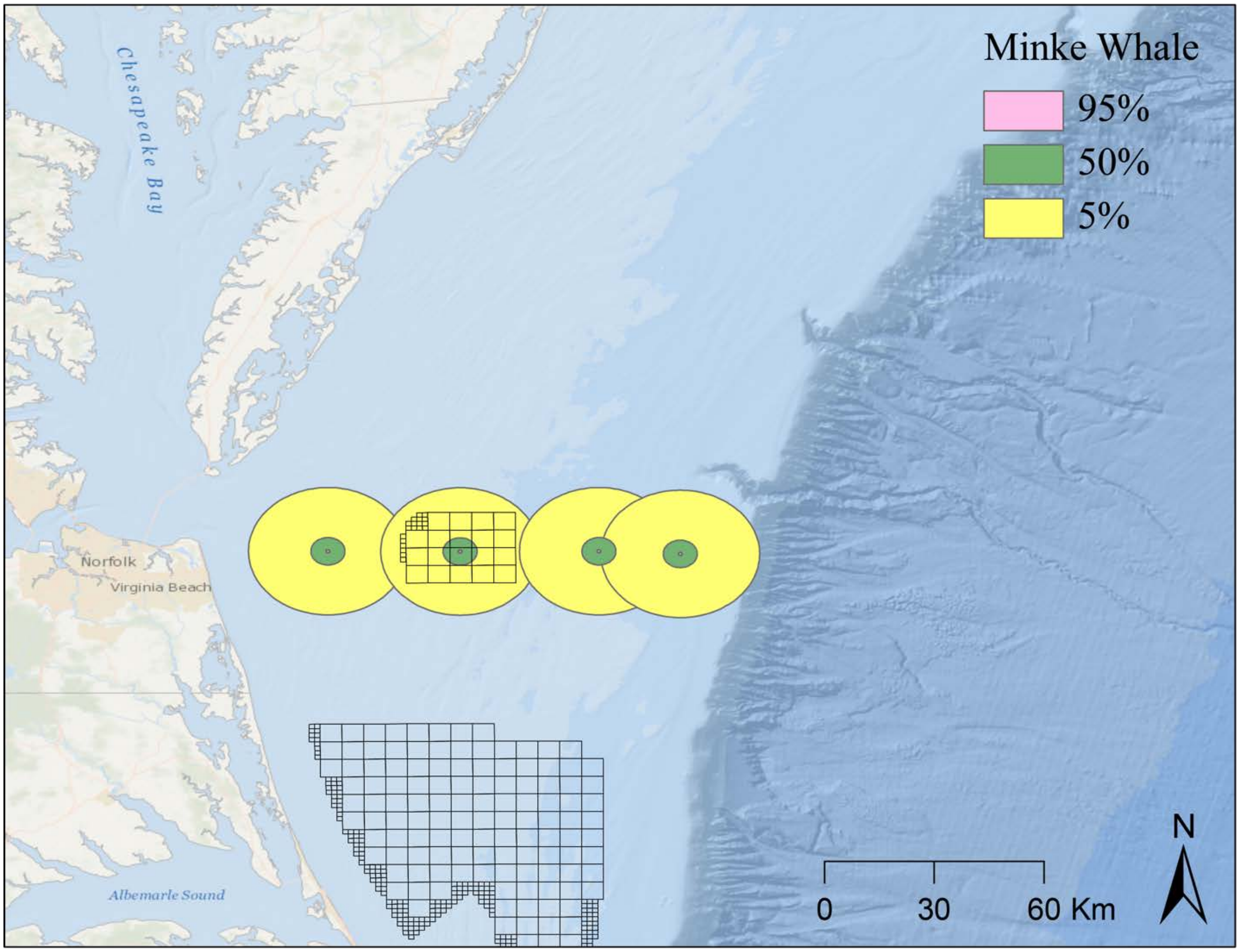


Figure 5.4. Map of study area with minke whale detection ranges overlaid.
Estimated detection ranges for the quietest and loudest 5% of noise conditions (5% and 95%) and the median noise conditions (50%). The 95% detection range (0.40 km) is too small to be viewed at this scale.

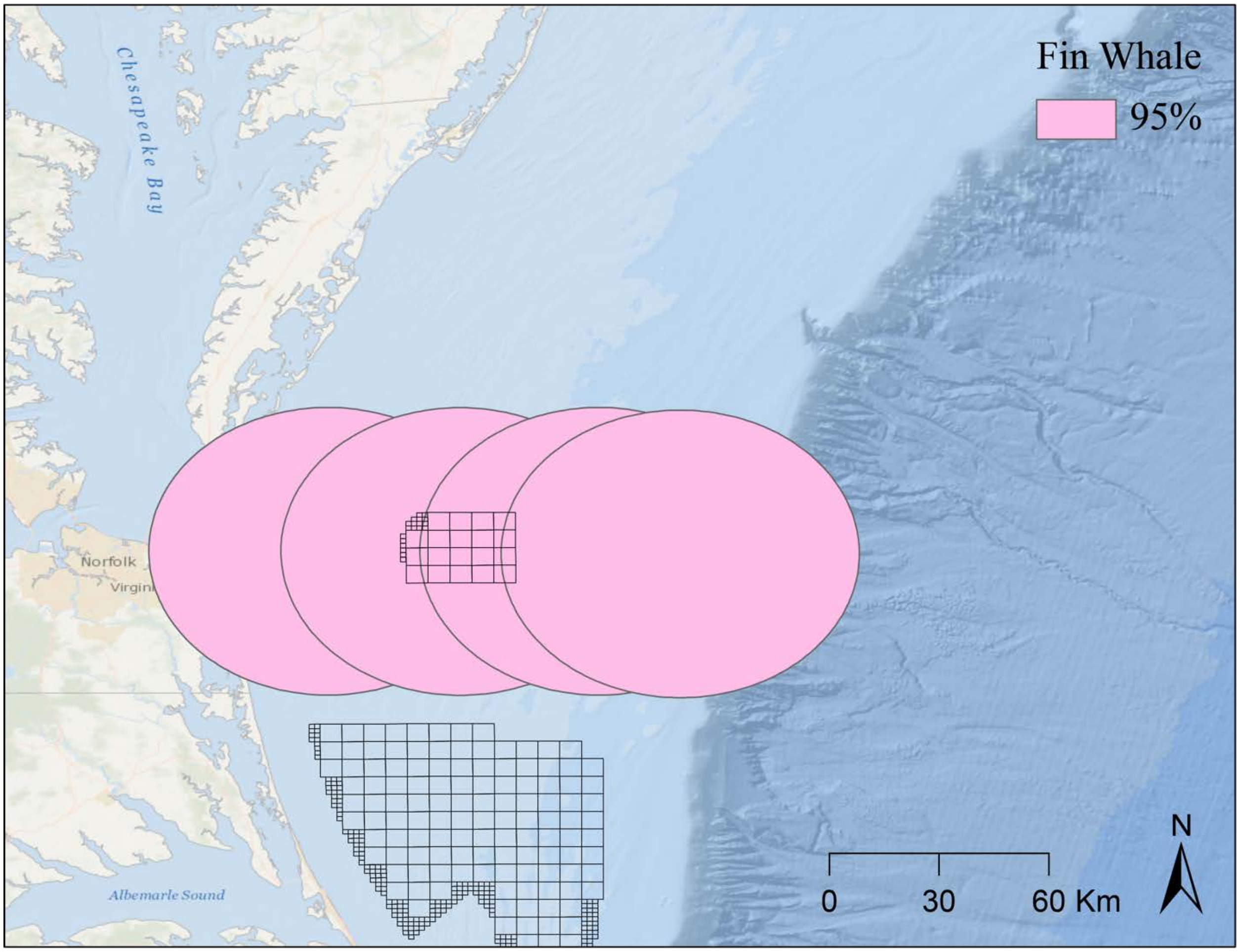


Figure 5.5. Map of study area with fin whale detection ranges overlaid.
Estimated detection ranges for the quietest 5% of noise conditions (95%). The estimated detection ranges for the 50% and 5% (118.6 km and >150 km) were too large to display at this scale.

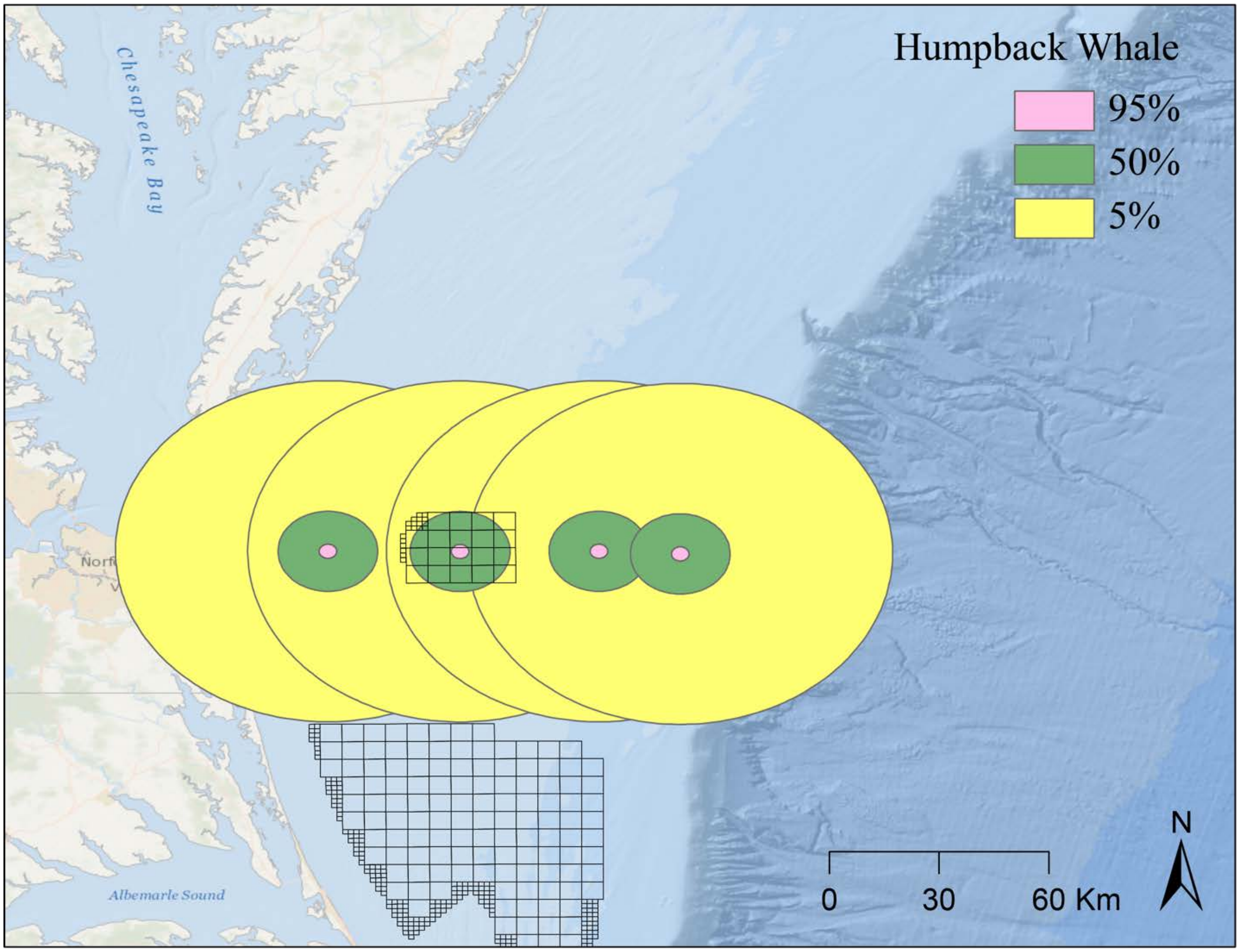


Figure 5.6. Map of study area with humpback whale detection ranges overlaid.
Estimated detection ranges for the quietest and loudest 5% of noise conditions (5% and 95%) and the median noise conditions (50%).

Table 5.2 Detection Range Model Results

Species	Site	5th Percentile (km)	50th Percentile (km)	95th Percentile (km)
Right whale	T1	25.43	6.12	1.04
Right whale	T2	67.02	12.57	1.04
Right whale	T3	61.75	15.43	1.51
Right whale	T4	56.90	13.45	1.37
Minke whale	T1	9.13	2.07	0.32
Minke whale	T2	22.46	3.83	0.31
Minke whale	T3	19.89	4.70	0.52
Minke whale	T4	18.10	4.31	0.45
Fin whale	T1	>150	118.60	49.29
Fin whale	T2	>150	131.20	53.09
Fin whale	T3	>150	135.13	28.25
Fin whale	T4	>150	130.68	26.36
Humpback whale	T1	24.38	5.58	0.70
Humpback whale	T2	46.13	10.37	1.29
Humpback whale	T3	58.00	12.91	2.80
Humpback whale	T4	57.65	14.88	2.97
Right whale	Average	52.77	11.89	1.24
Minke whale	Average	17.40	3.73	0.40
Fin whale	Average	>150	128.90	39.25
Humpback whale	Average	46.54	10.93	1.94

5.3.2 Locator Tool Performance

We tested a set of five synchronization sweep tones which contain energy in the 50-1000 Hz frequency range with the locator tool, all played within the WEA at known times and coordinates. Two sweep tones were tested outside of the outer circumference of the array, while three tones were tested inside the array circumference. All five sweeps were successfully located with the Raven Pro Locator tool and the mean location error was ± 719.6 m, but the average was high because one sweep located within the array circumference had an error of ± 3060m. If this outlier is removed, the mean location error drops to +/- 134.5 m (range=31-280m).

Out of the 3,845 potentially locatable calls among all four focal species, we processed 983 calls and successfully located 540 calls for an overall success rate of 55%. Different species had different success rates with the Locator tool performing best on the minke whale calls and worst on the fin whale calls (Table 5.3).

Table 5.3 Locator Tool Success Rate

Species	# of Potentially Locatable Calls	# of Calls Processed through Locator Tool	# of Successfully located calls.	Locator Tool Success Rate %
Right whale	2995	600	342	57%
Minke whale	21	12	9	75%
Fin whale	395	215	86	40%
Humpback whale	434	156	103	66%

5.3.3 Spatial Results from Transect Data

For each of the four focal whale species, the distribution of calls across each recording site in the Transect configuration was calculated and plotted (Figure 5.7). Right whales had the highest distribution (>50%) of calls at site T2, centered in the WEA, with similar levels of distribution at the remaining three sites. Minke whale presence was significantly higher at site T4 (75%), the farthest offshore site. No minke whales were detected at site T1, the site nearest to shore. Fin whales showed higher levels of offshore presence at sites T3 and T4, with the lowest level of presence inshore at site T1. Humpback whales also showed higher offshore presence at site T4, but also had a high distribution of presence at site T2, in the WEA (Figure 5.7). Data was combined from sites T3 and T4 (offshore) and T1 and T2 (inshore) and fin, minke and humpback whales had higher percentages of offshore presence than inshore presence. Right whales had slightly higher levels of inshore presence (Figure 5.8).

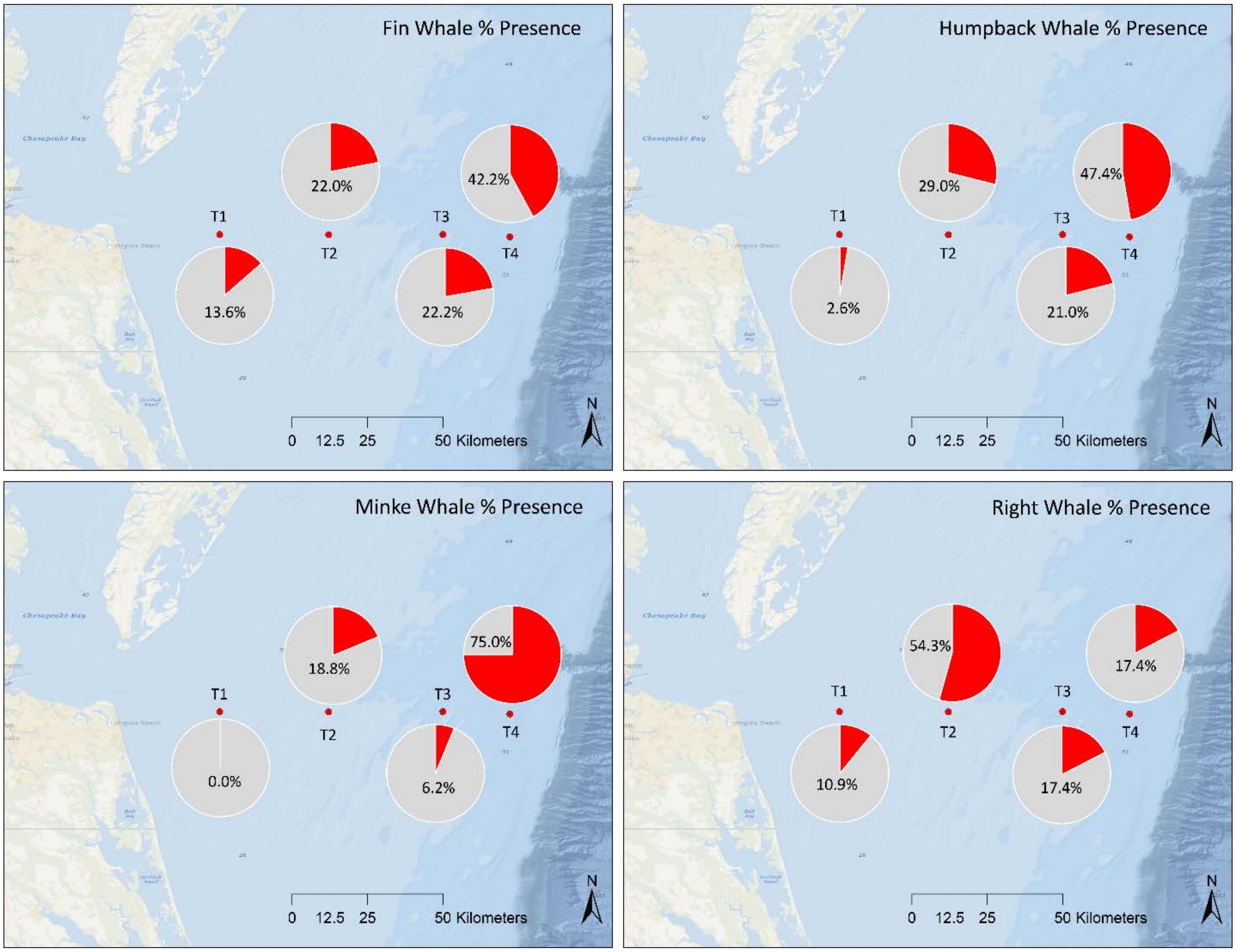


Figure 5.7. Percent distributions of calls per species per recording site.
Proportion of calls received per species per site from the transect dataset.

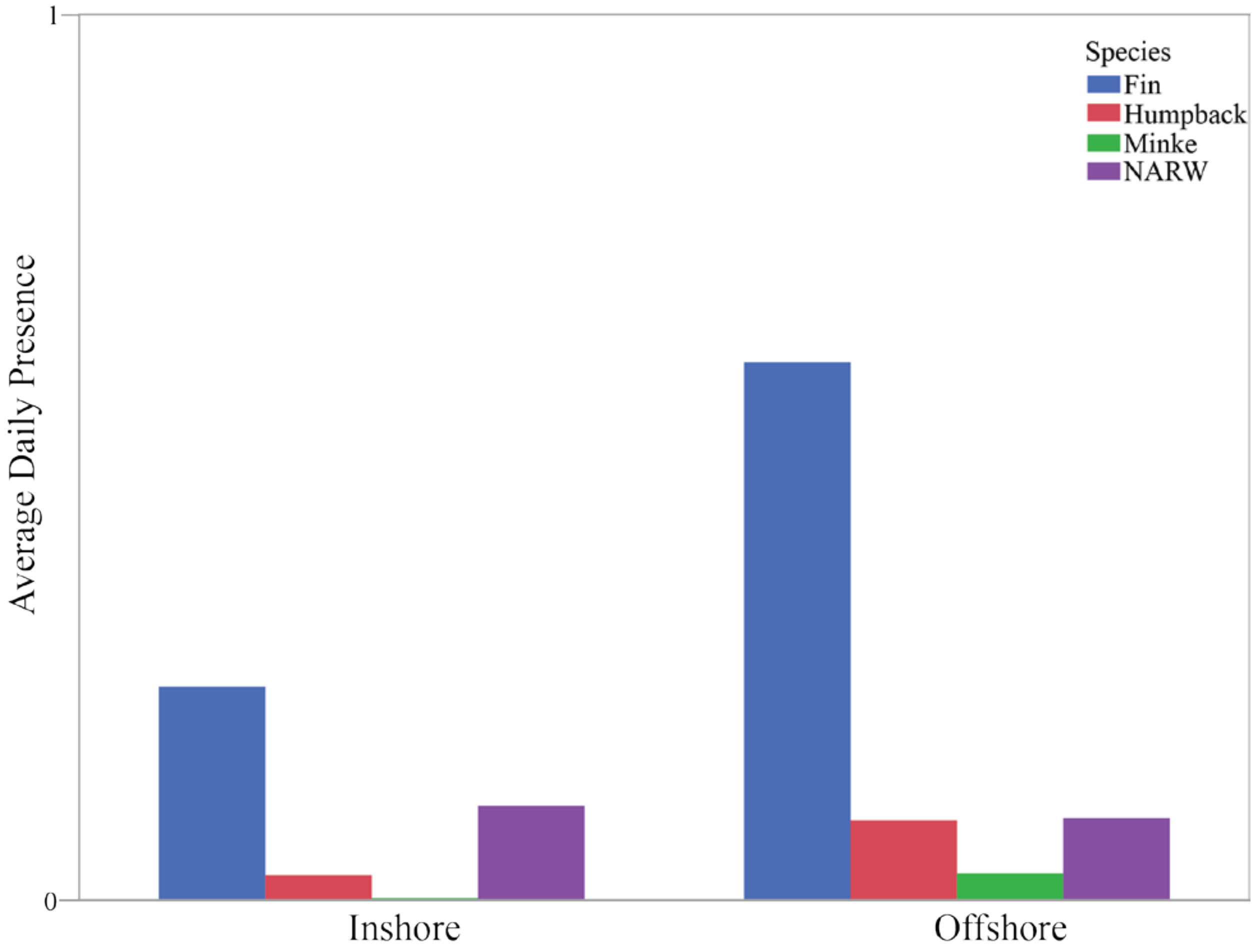


Figure 5.8. Average daily presence of calls detected on offshore (Sites T3,T4) vs inshore (Sites T1, T2) per species.

5.3.4 Spatial Results from Array Data

The distribution of potentially locatable calls across the array varied per species. Right whales showed a higher proportion of first arrival calls in the north and northwest array sites. The lowest proportion of calls were found on the southern sites (A2, A3). Minke whales had a relatively even distribution of calls across the array, with the highest recorded at the western-most site A1 and the lowest at the south-west site A2. However, the sample size of potentially locatable minke whale calls was low. Similar to minke whales, fin whales had a relatively even distribution of potentially locatable calls throughout the array. There was a higher percentage of calls detected on the northern sites (A1, A5, A4) compared to the southern sites (A2, A3). Humpback whales had a higher distribution of calls to the eastern part of the array, with the highest concentration at site A4. The two western-most sites (A1, A2) and the central site (A6) received the lowest proportion of calls (Figure 5.9).

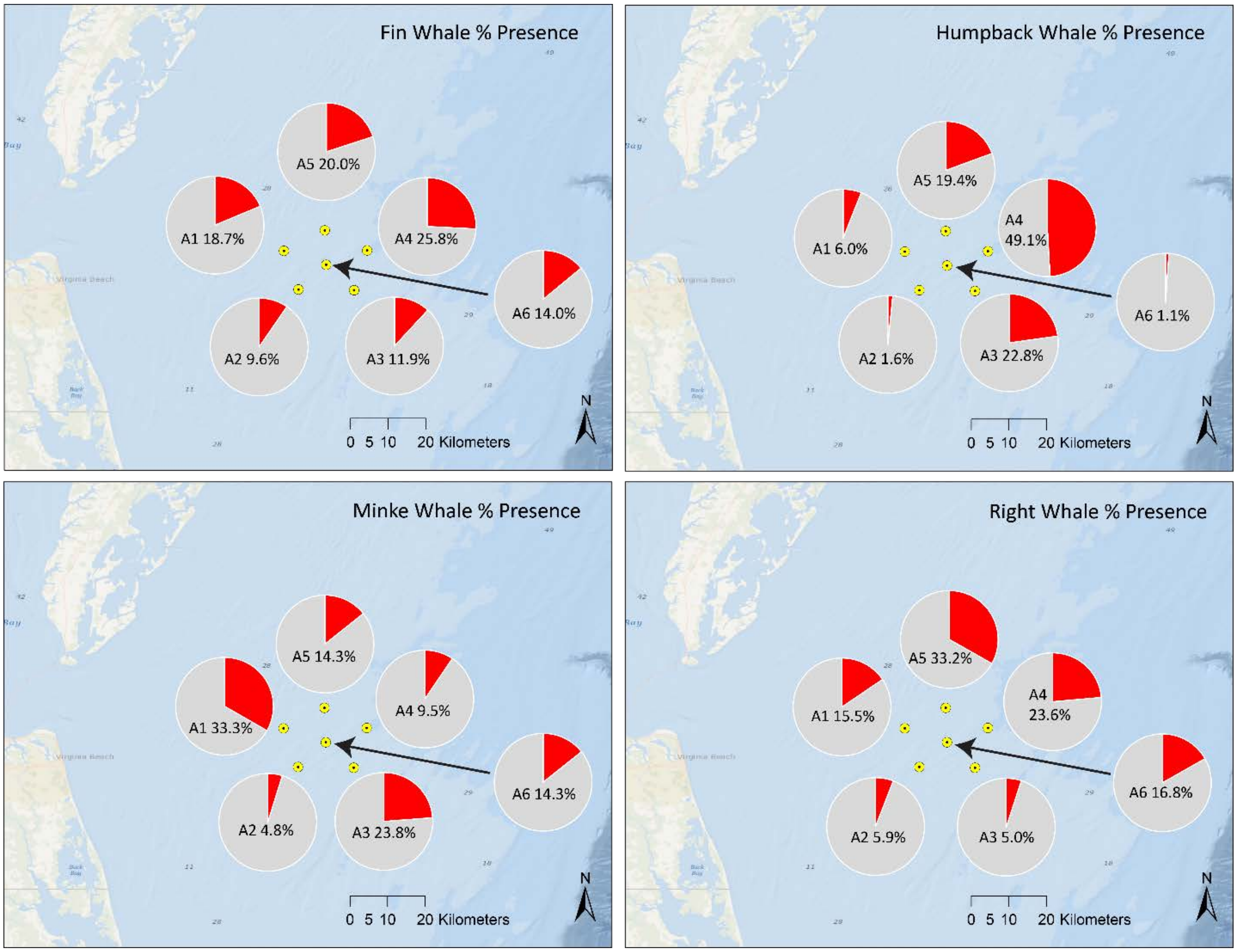


Figure 5.9. Percent distributions of calls per species per recording site.
The yellow circles below the pie graphs show the array geometry and site identification as a reference.

In addition to first-arrival distribution, the resolution of the spatial patterns of the four focal whale species can be improved by analyzing the distribution of bearings from calls that were successfully located with the Raven Pro Locator tool. Located right whale calls show a distribution skewed slightly towards the north and northwest portions of the array (Figure 5.10). Minke whale locatable calls are all distributed in the northwest part of the array (Figure 5.11). Fin whales have a more even distribution with the highest proportion of call bearings found in the northwest and southeast directions (Figure 5.12). Humpback whales have the highest proportion of call bearings in the northeast and east directions (Figure 5.13).

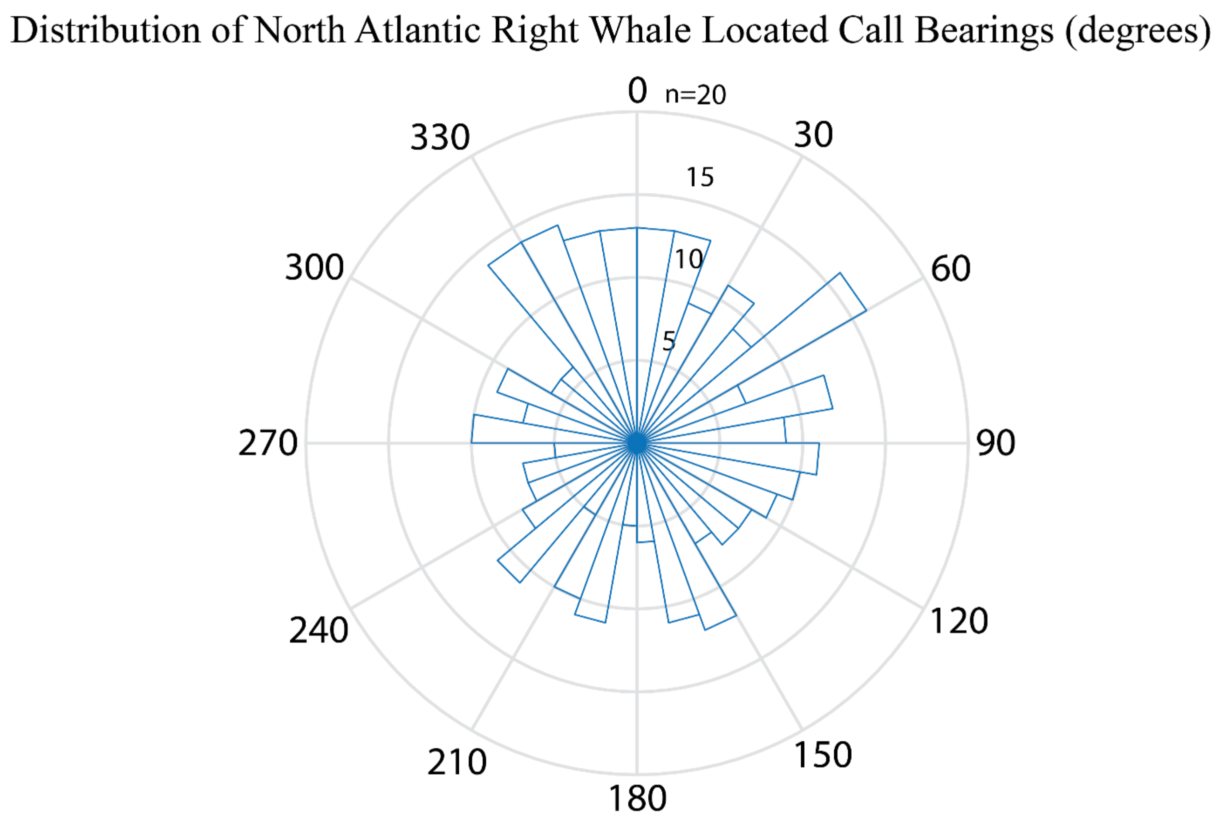


Figure 5.10. Bearings from located right whale calls relative to the recording array.
The histograms represent number of calls found in each bearing direction in degrees where north is represented by 0. The width of each circle diameter represents the labeled number of calls.

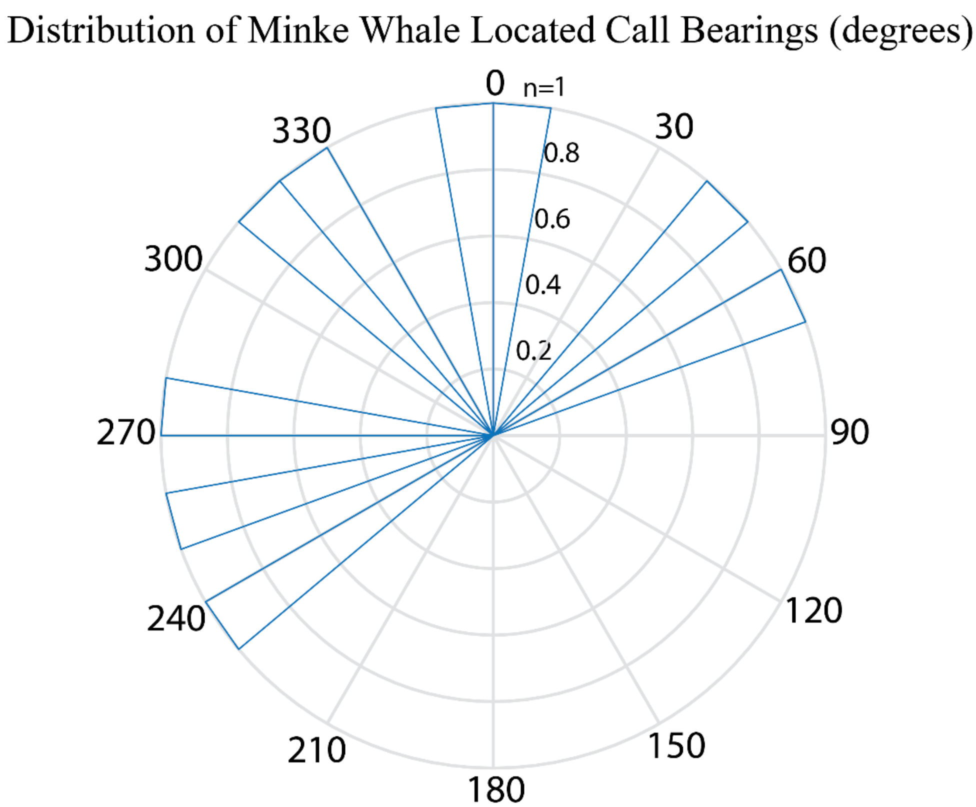


Figure 5.11. Bearings from located minke whale calls relative to the recording array.
The histograms represent number of calls found in each bearing direction in degrees where north is represented by 0. The width of each circle diameter represents the labeled number of calls.

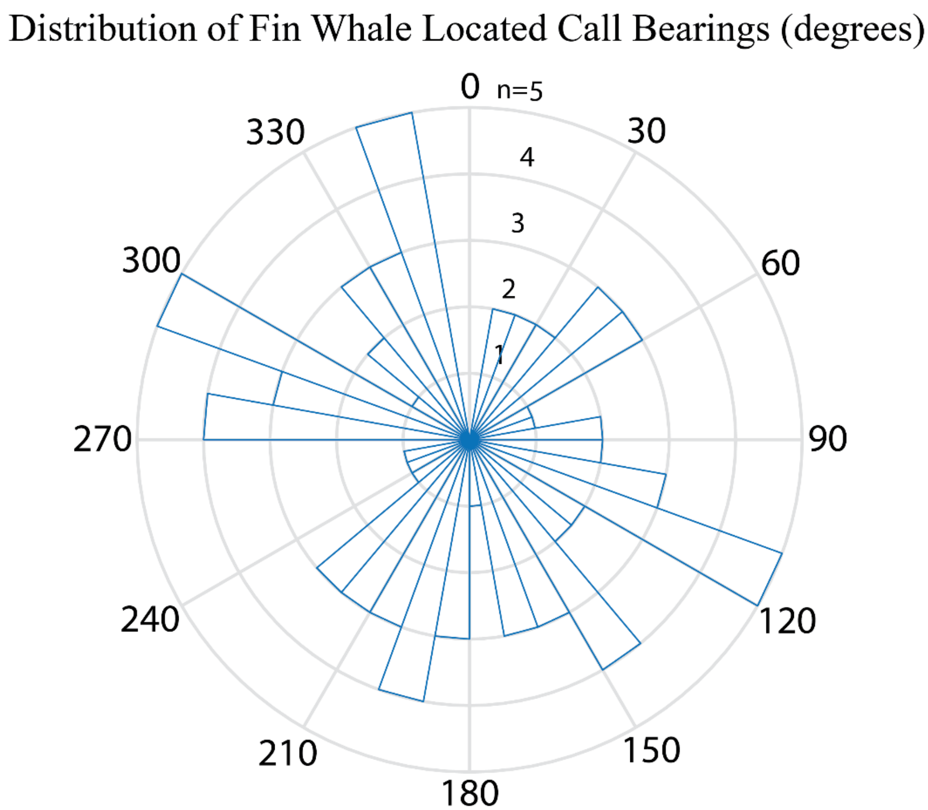


Figure 5.12. Bearings from located fin whale calls relative to the recording array.
The histograms represent number of calls found in each bearing direction in degrees where north is represented by 0. The width of each circle diameter represents the labeled number of calls.

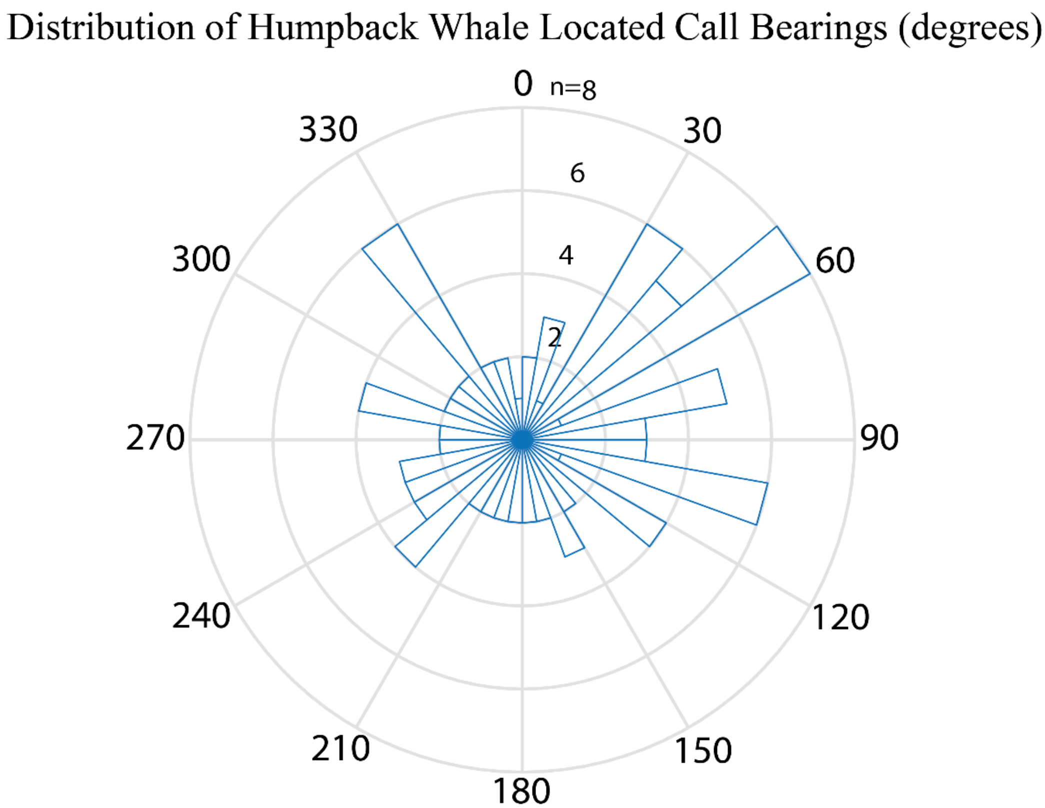


Figure 5.13. Bearings from located humpback whale calls relative to the recording array.
The histograms represent number of calls found in each bearing direction in degrees where north is represented by 0. The width of each circle diameter represents the labeled number of calls.

Adding range estimates to the bearing information allows us to map successfully locatable calls for each species. Mapping all locatable calls for each species shows total distribution of calls throughout the WEA, however, mapping small durations of time can also be useful in exploring potential patterns in whale movements over the course of days or even hours. Right whale call locations were mapped for the entire array dataset with a distribution of calls throughout the WEA and surrounding area (Figure 5.14). Right whales had a more concentrated distribution during sample periods of three days in February, 2016 (Figure 5.16) and for a single day in January, 2017 (Figure 5.17), with the smallest range of calls found for a four hour period in January, 2017 (Figure 5.18).

Minke whale call locations were mapped for the entire array dataset (Figure 5.19.) and for a sample period of one day on January 14, 2017 (Figure 5.21). The number of locatable minke whale calls was very low compared to the other species, but did show presence within and around the WEA. Fin whale call locations were mapped for the entire array dataset (Figure 5.22.) and for a sample period of one day on October 28, 2017 (Figure 5.24), with a large percentage of calls clustered in the western in-shore portion of the WEA. Humpback whale call locations however, were mapped for the entire array dataset (Figure

5.25.) and for a sample period of one day on April 8, 2017 (Figure 5.27) with clusters of calls distributed towards the eastern offshore portion of the array.

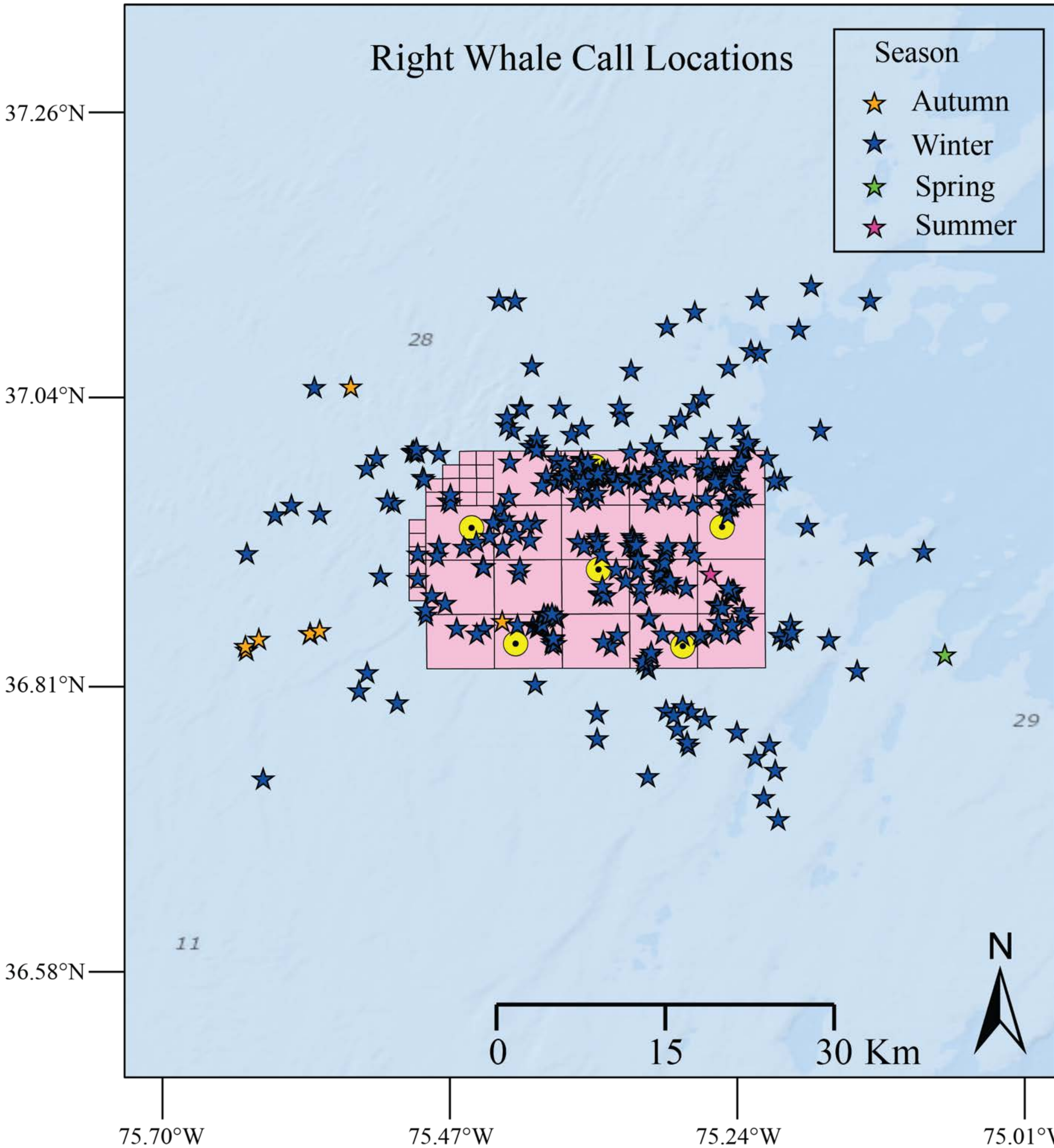


Figure 5.14. Map of located right whale calls from July 2015 through May 2017.
Stars denote estimated location of each call. Different colors code to distinguish locations made during Autumn (September 21 – December 20), Winter (December 21 – March 20), Spring (March 21 – June 20), Summer (June 21 – September 20).

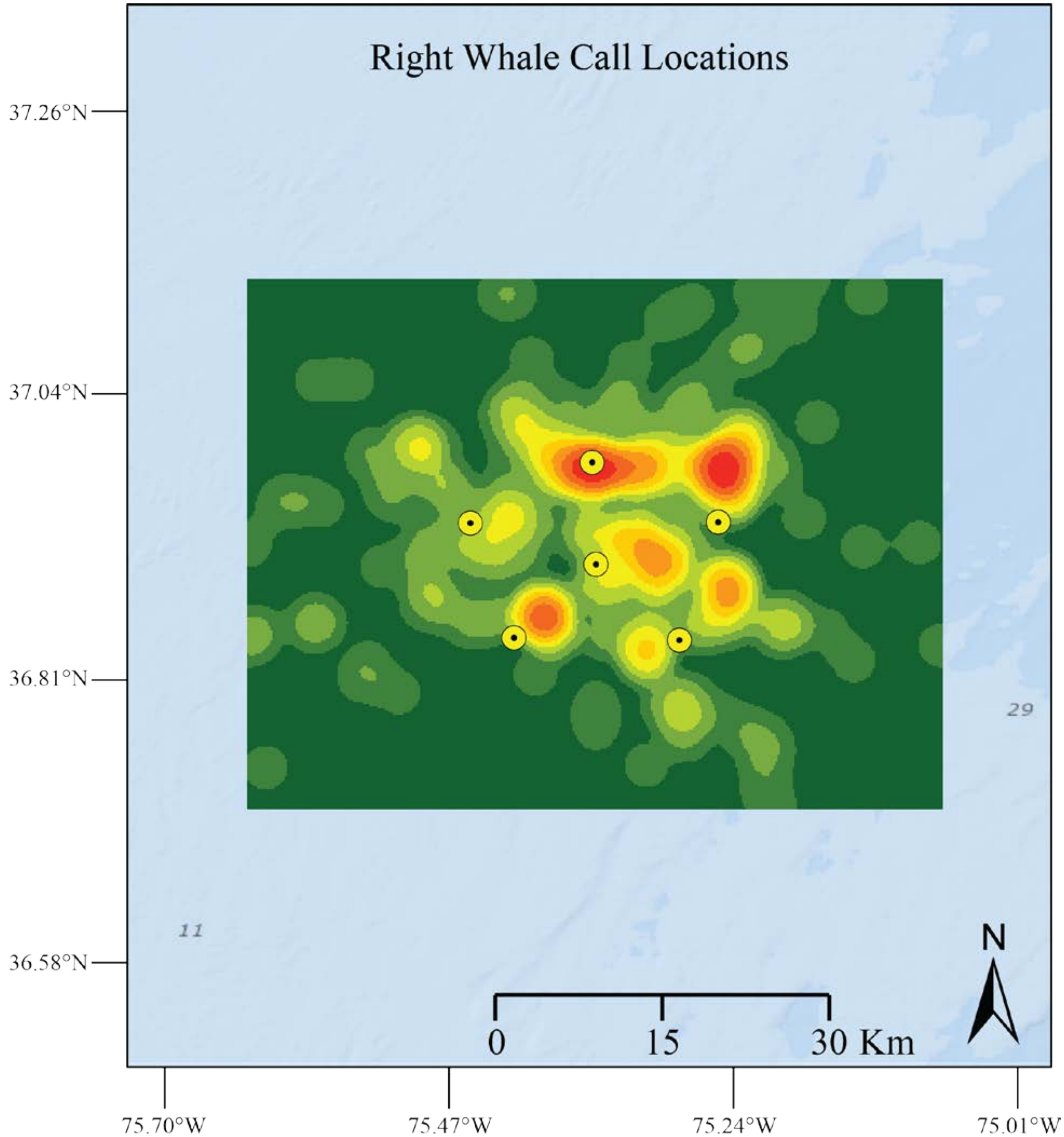


Figure 5.15. Map of located right whale calls from July 2015 through May 2017.
Kernel density map showing higher (red) and lower density (green) of located calls.

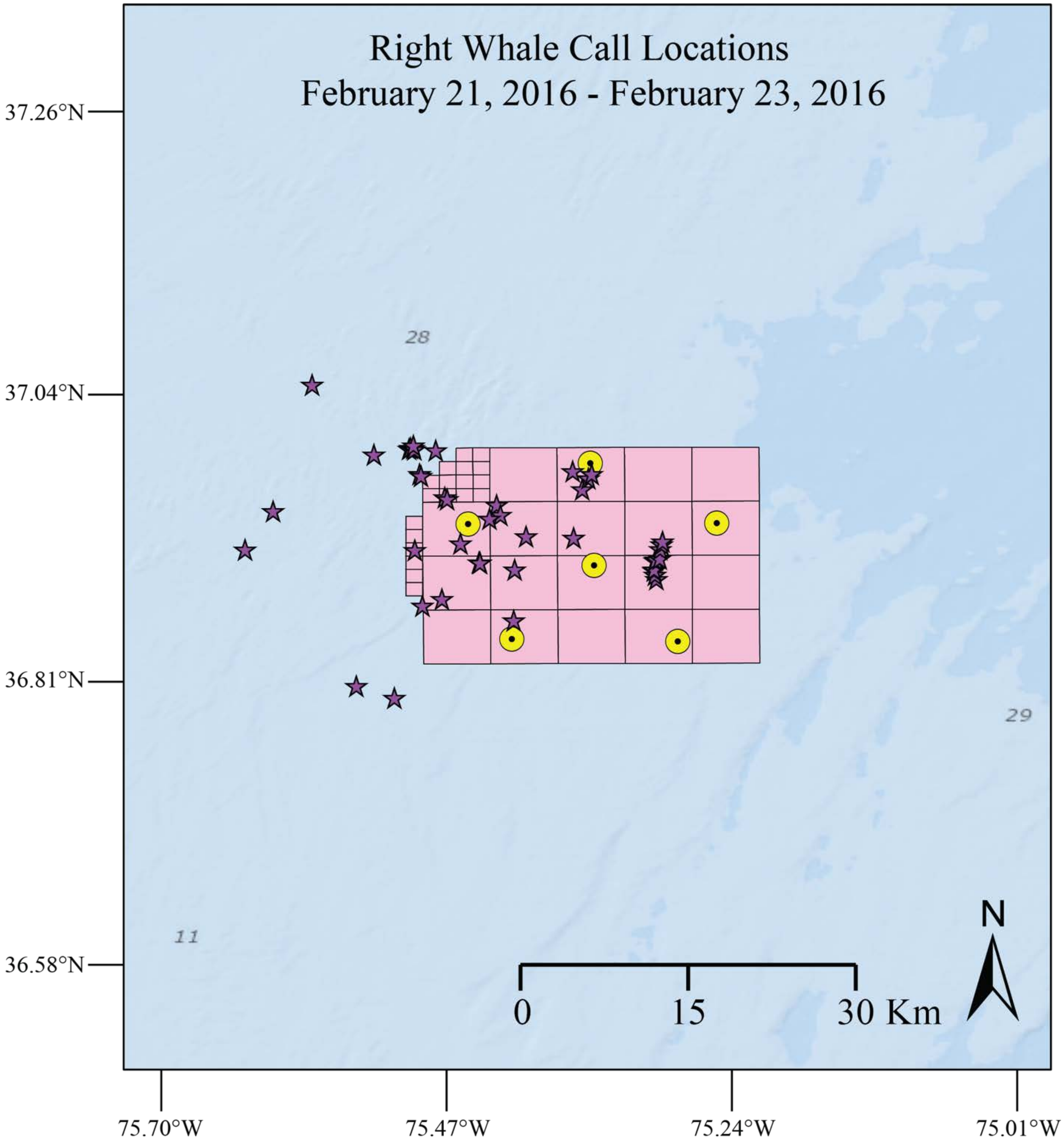


Figure 5.16. Map of located right whale calls from February 21-23, 2016.
Stars denote estimated location of each call.

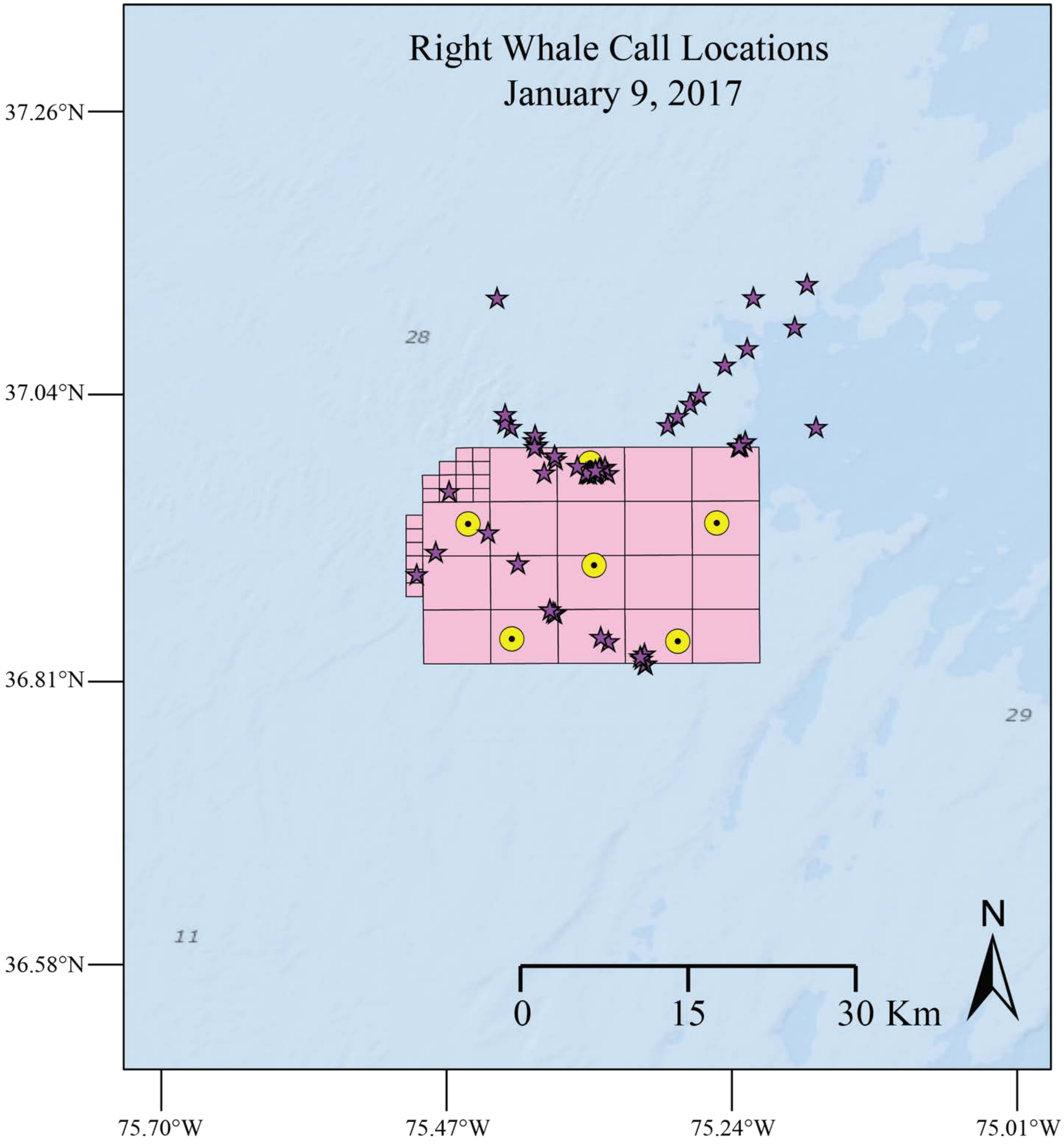


Figure 5.17. Map of located right whale calls from January 9, 2017.
Stars denote estimated location of each call.

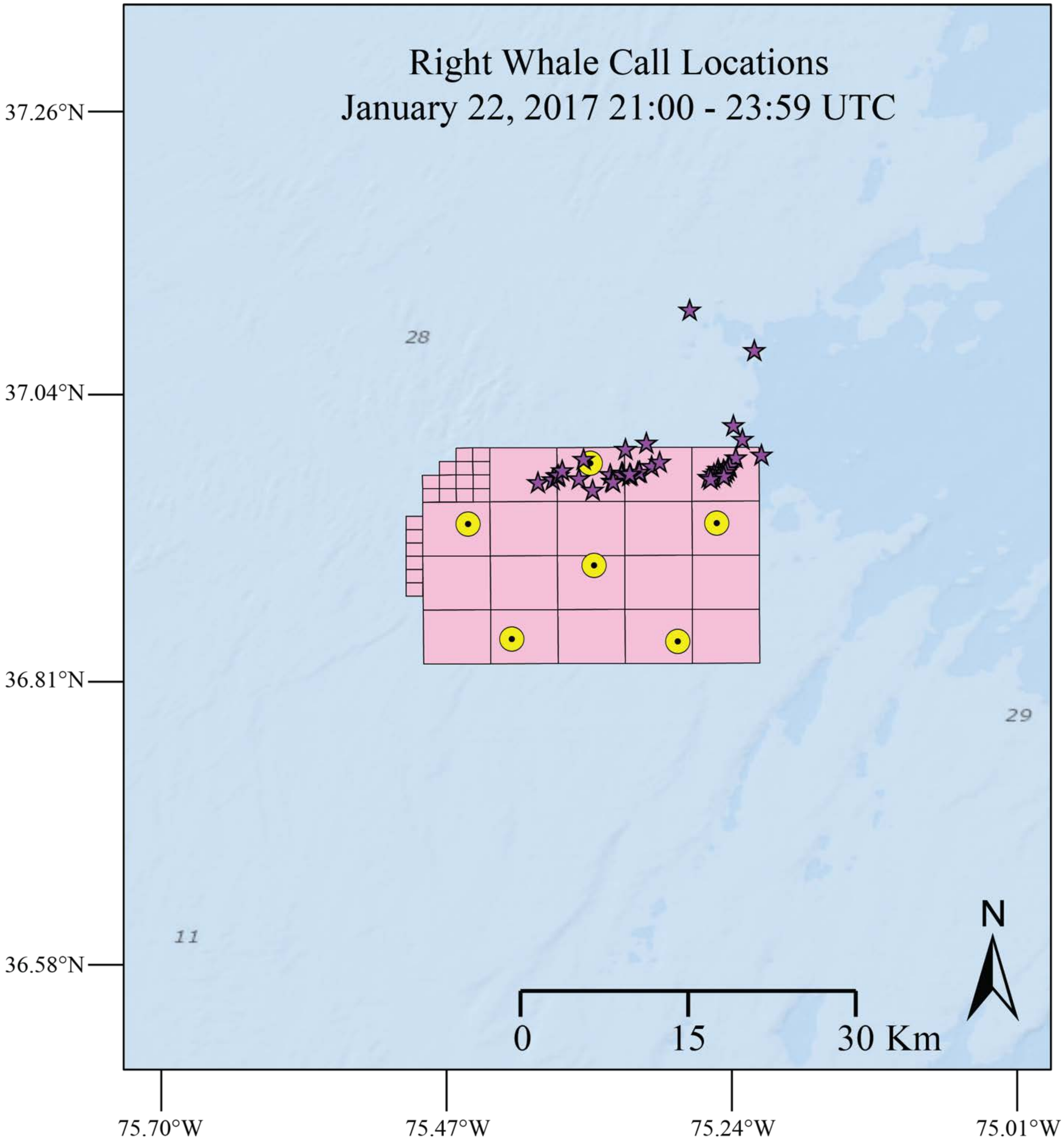


Figure 5.18. Map of located right whale calls from January 22, 2017 21:00-23:59 UTC. Stars denote estimated location of each call.

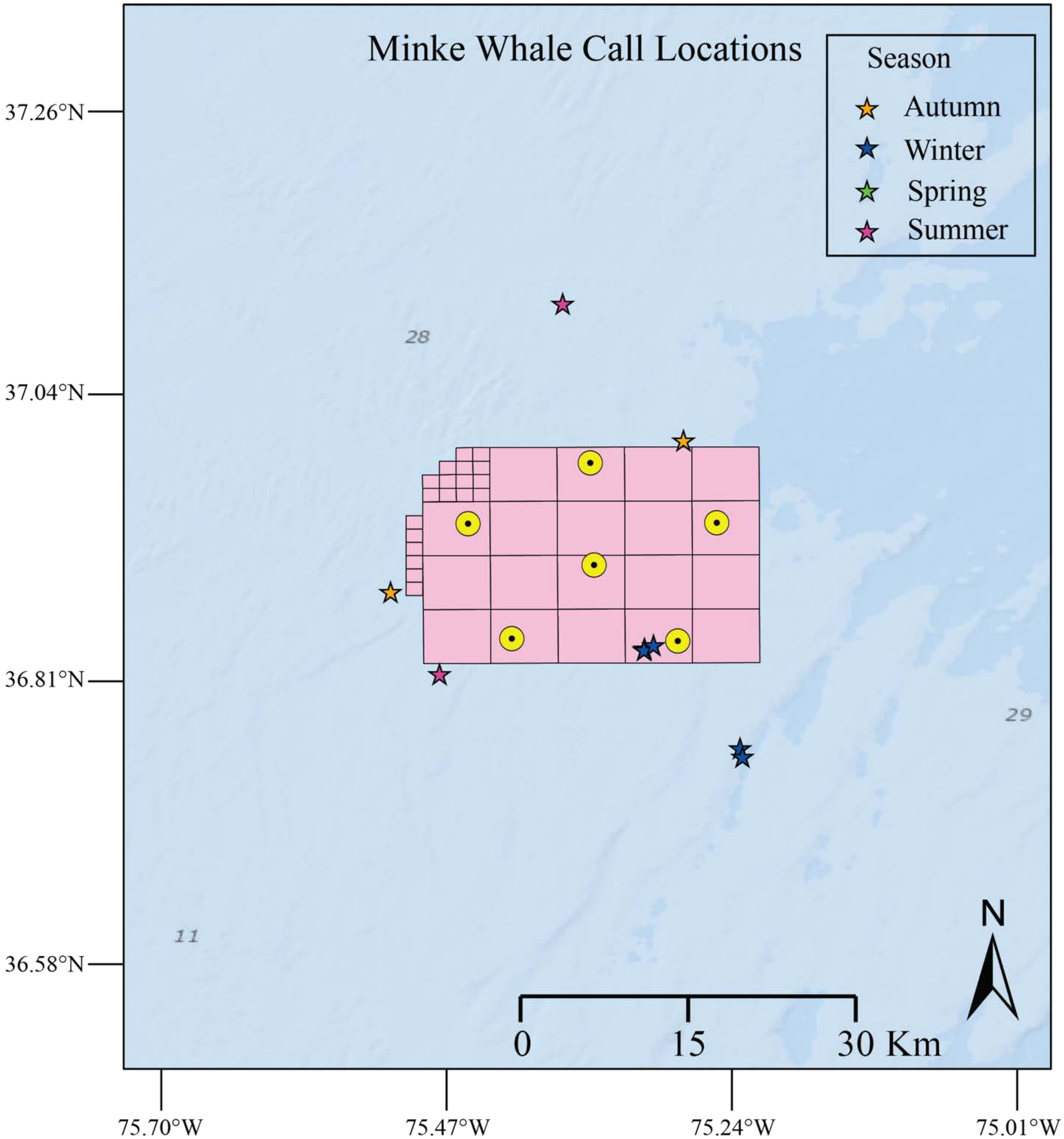


Figure 5.19. Map of located minke whale calls from July 2015 through May 2017.
Stars denote estimated location of each call. Different colors code to distinguish locations made during Autumn (September 21 – December 20), Winter (December 21 – March 20), Spring (March 21 – June 20), Summer (June 21 – September 20).

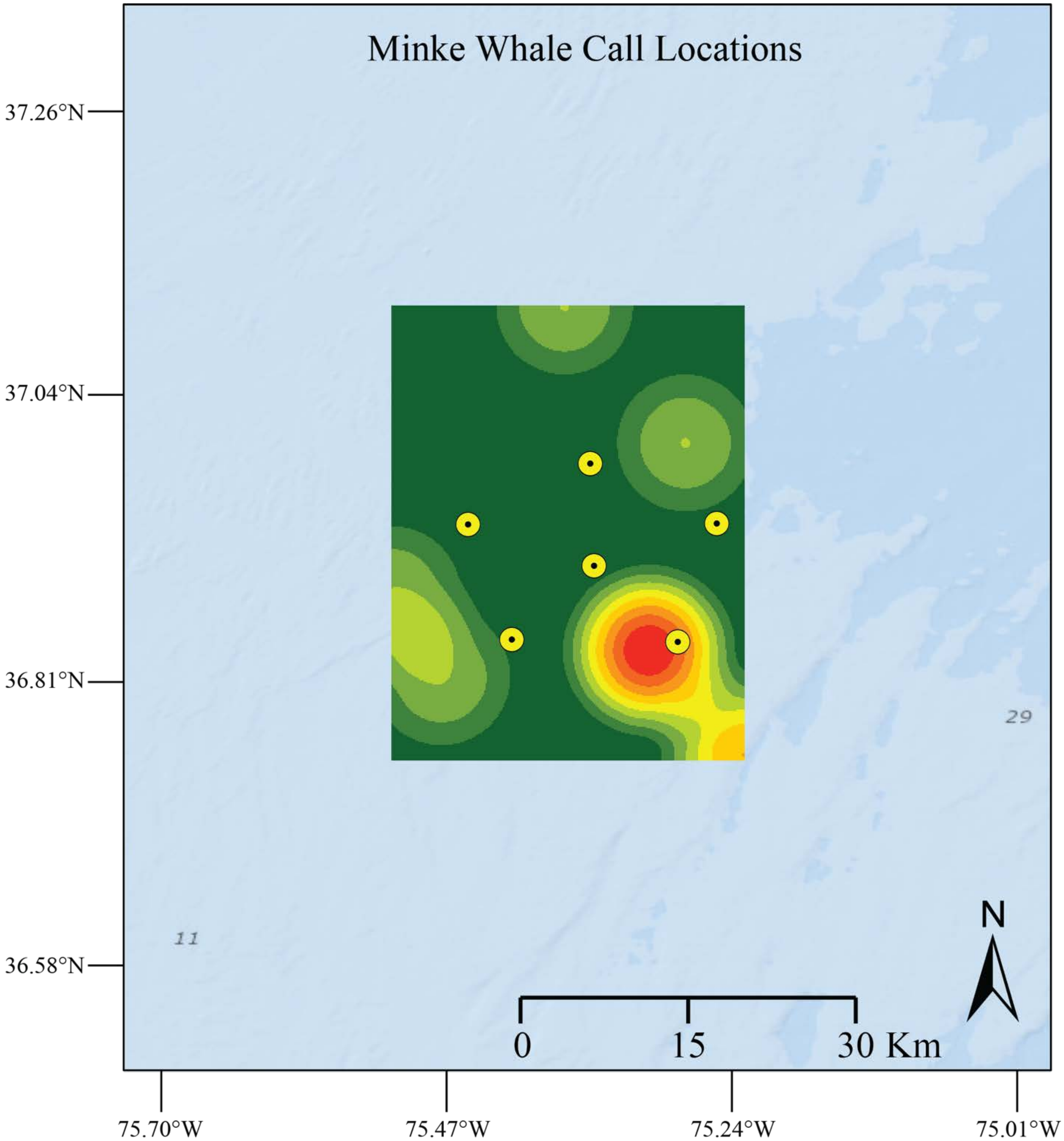


Figure 5.20. Map of located minke whale calls from July 2015 through May 2017.
Kernel density map showing higher (red) and lower density (green) of located calls.

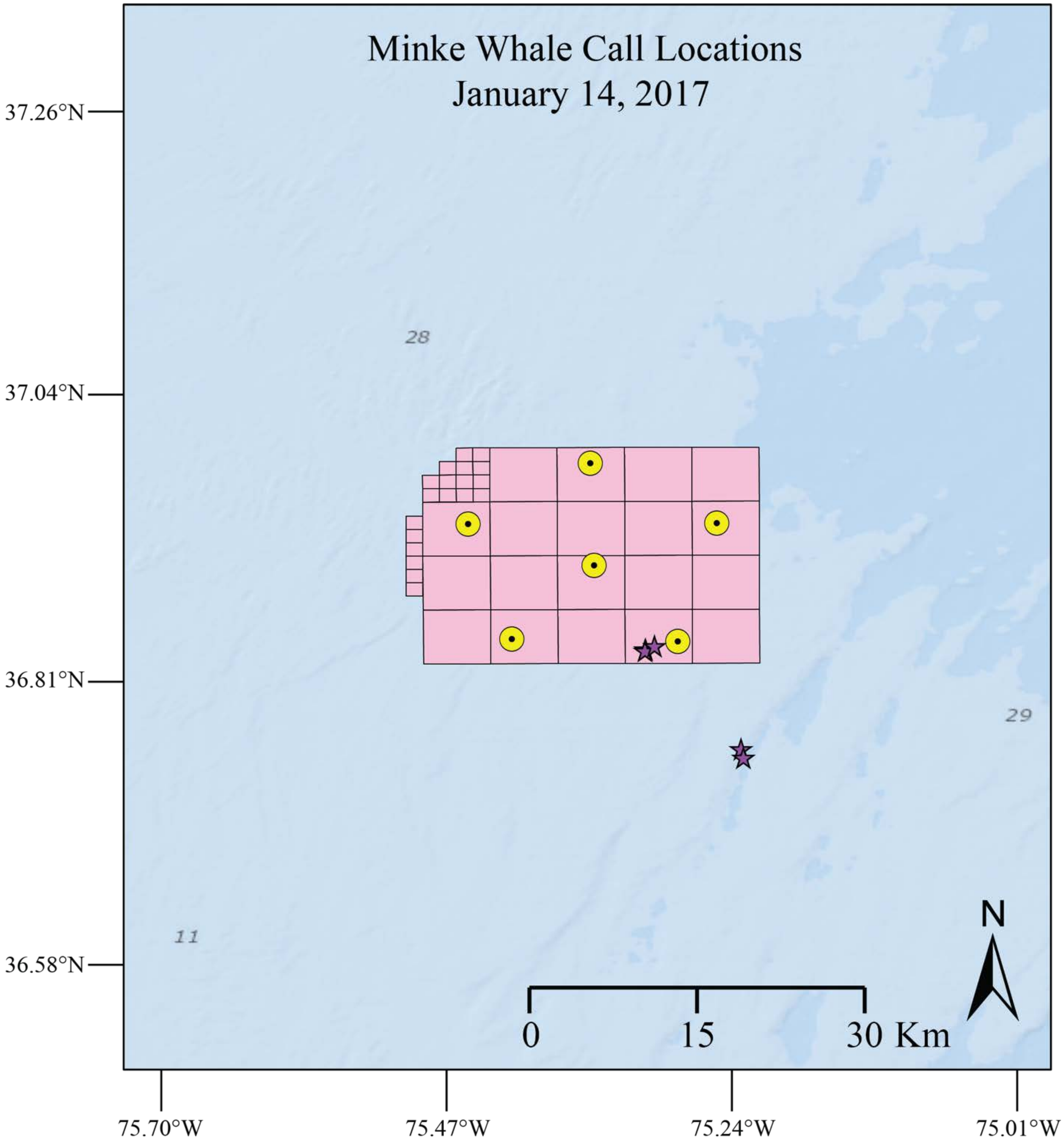


Figure 5.21. Map of located minke whale calls from January 14, 2017.
Stars denote estimated location of each call.

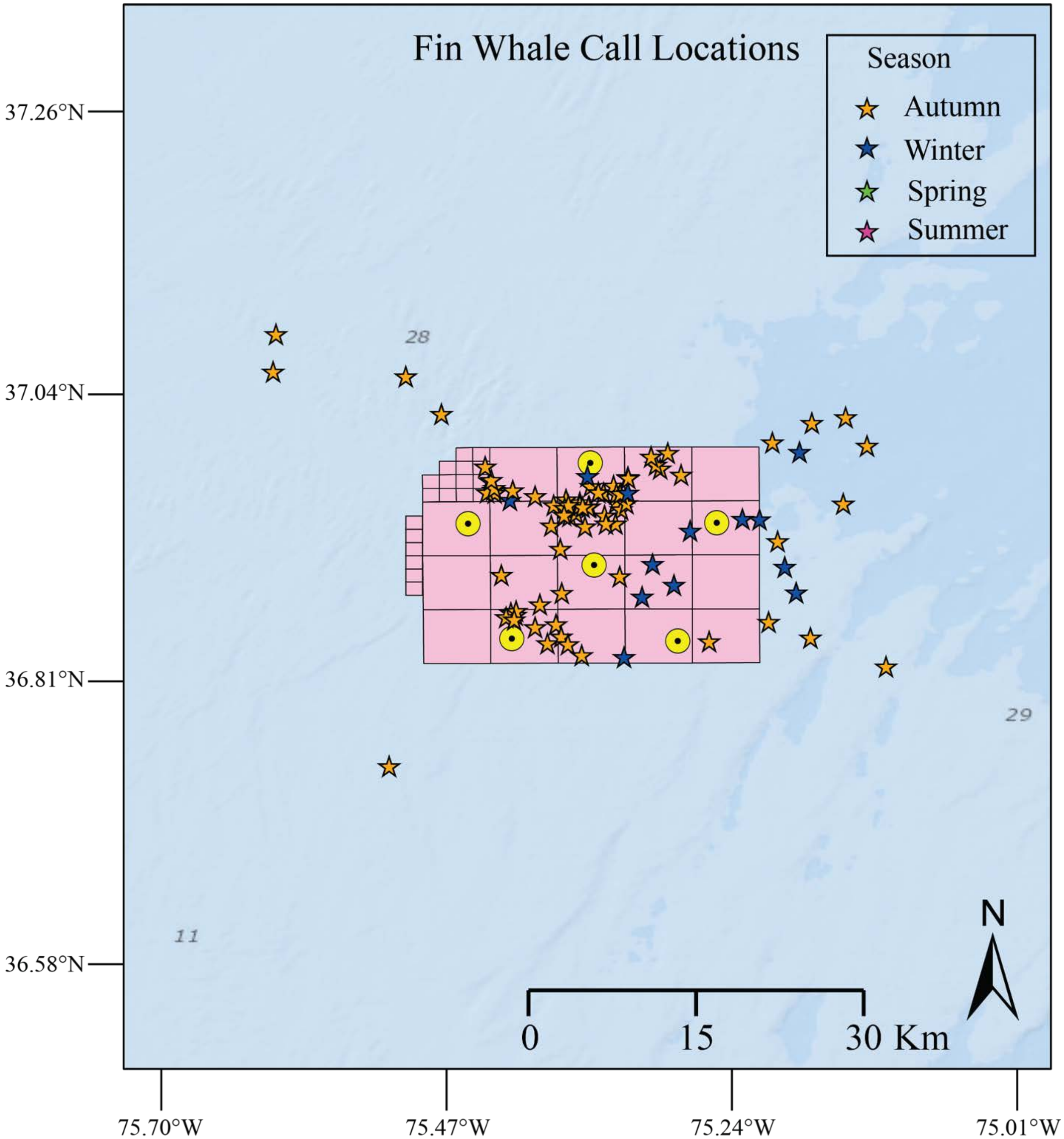


Figure 5.22. Map of located fin whale calls from July 2015 through May 2017.
Stars denote estimated location of each call. Different colors code to distinguish locations made during Autumn (September 21 – December 20), Winter (December 21 – March 20), Spring (March 21 – June 20), Summer (June 21 – September 20).

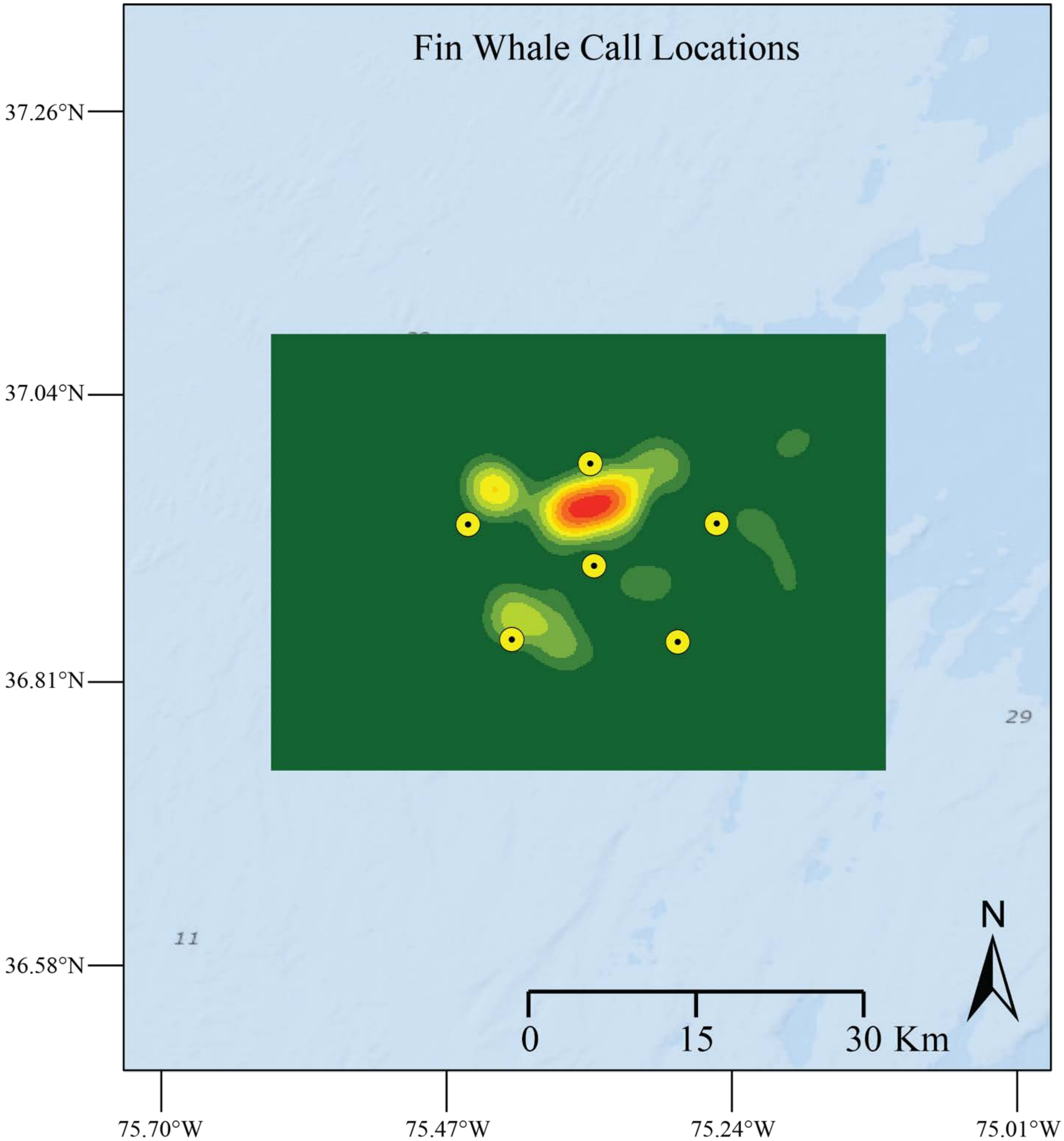


Figure 5.23. Map of located fin whale calls from July 2015 through May 2017.
Kernel density map showing higher (red) and lower density (green) of located calls.

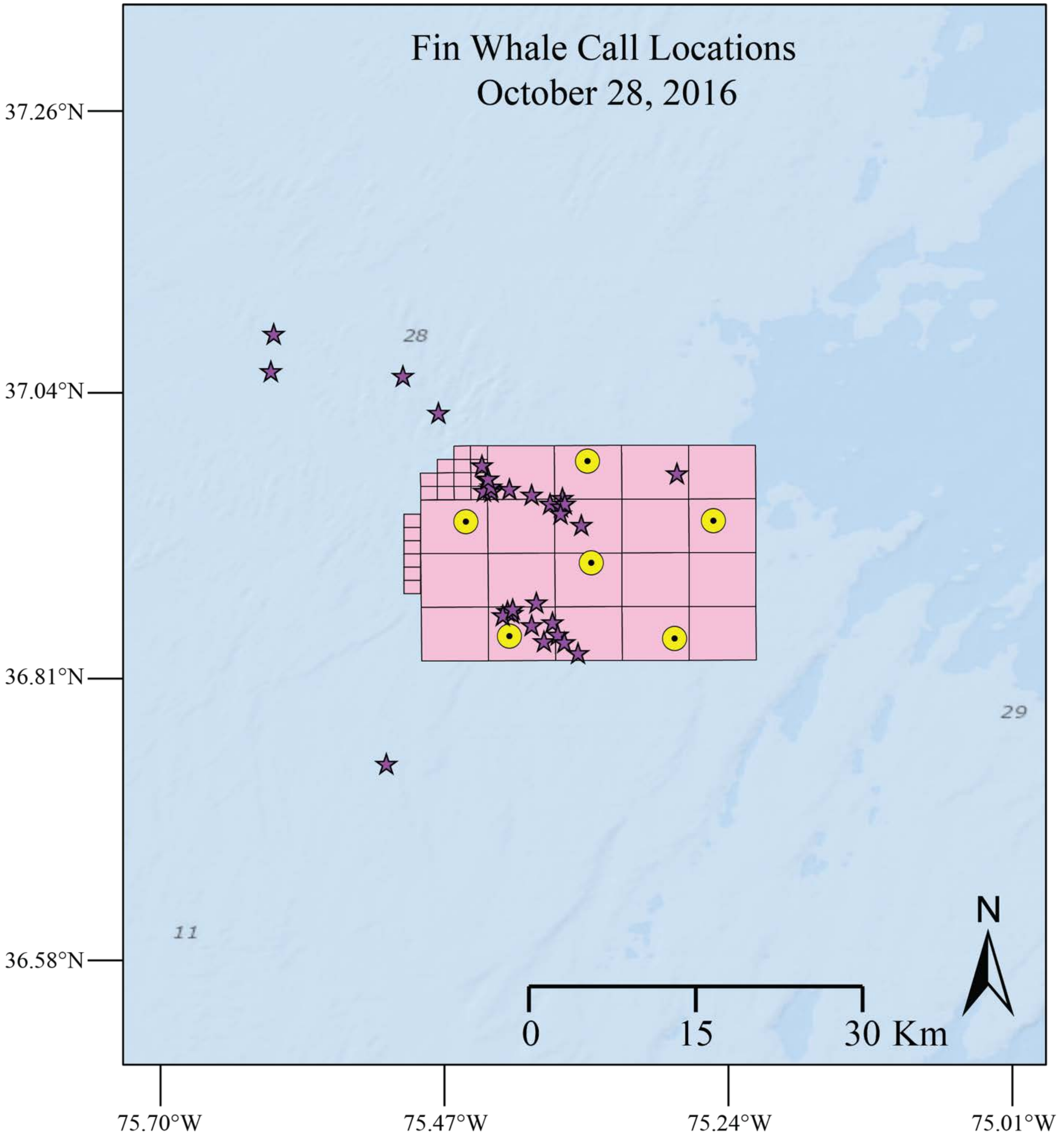


Figure 5.24. Map of located fin whale calls from October 28, 2016.
Stars denote estimated location of each call.

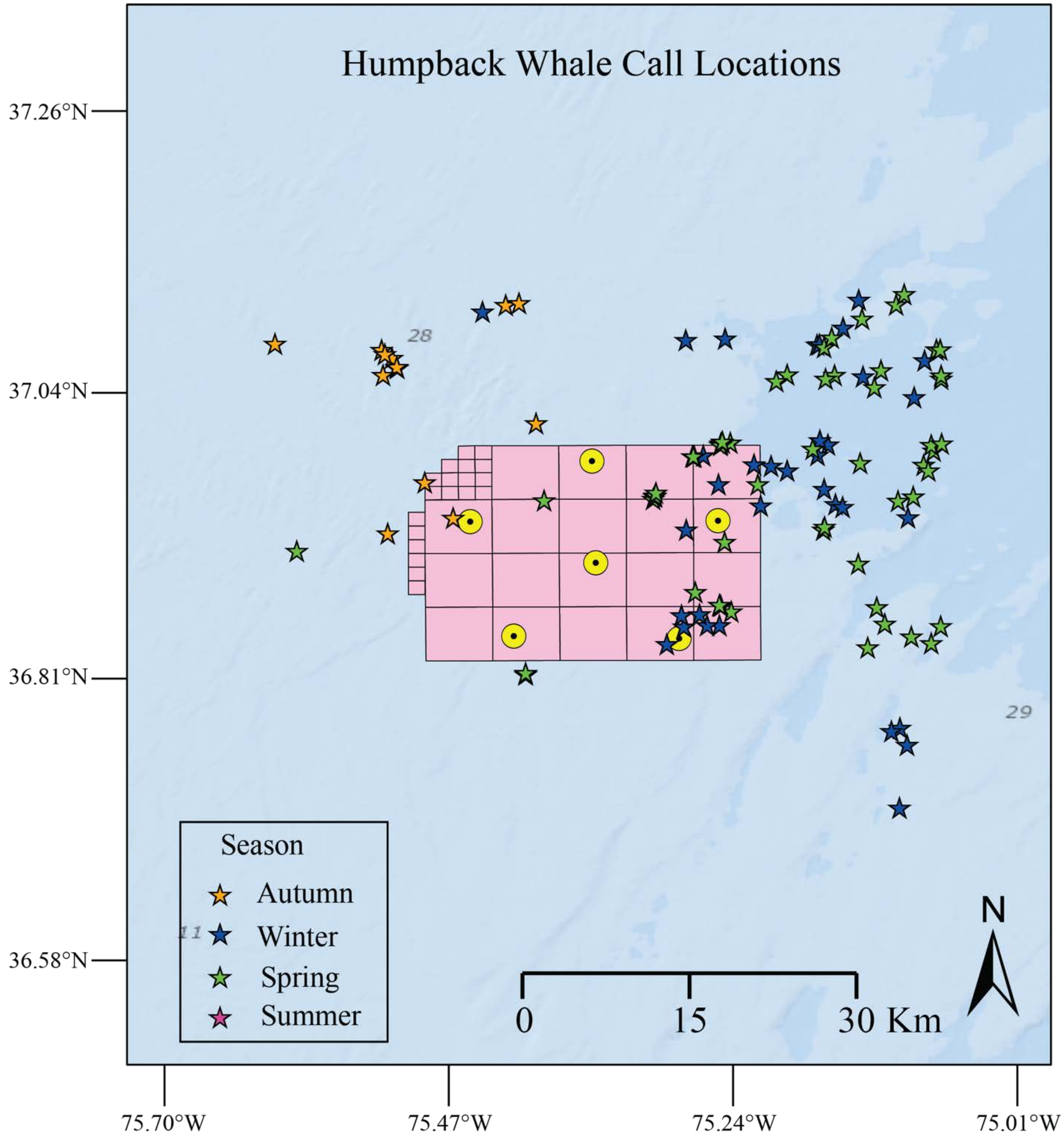


Figure 5.25. Map of located humpback whale calls from July 2015 through May 2017.
Stars denote estimated location of each call. Different colors code to distinguish locations made during Autumn (September 21 – December 20), Winter (December 21 – March 20), Spring (March 21 – June 20), Summer (June 21 – September 20).

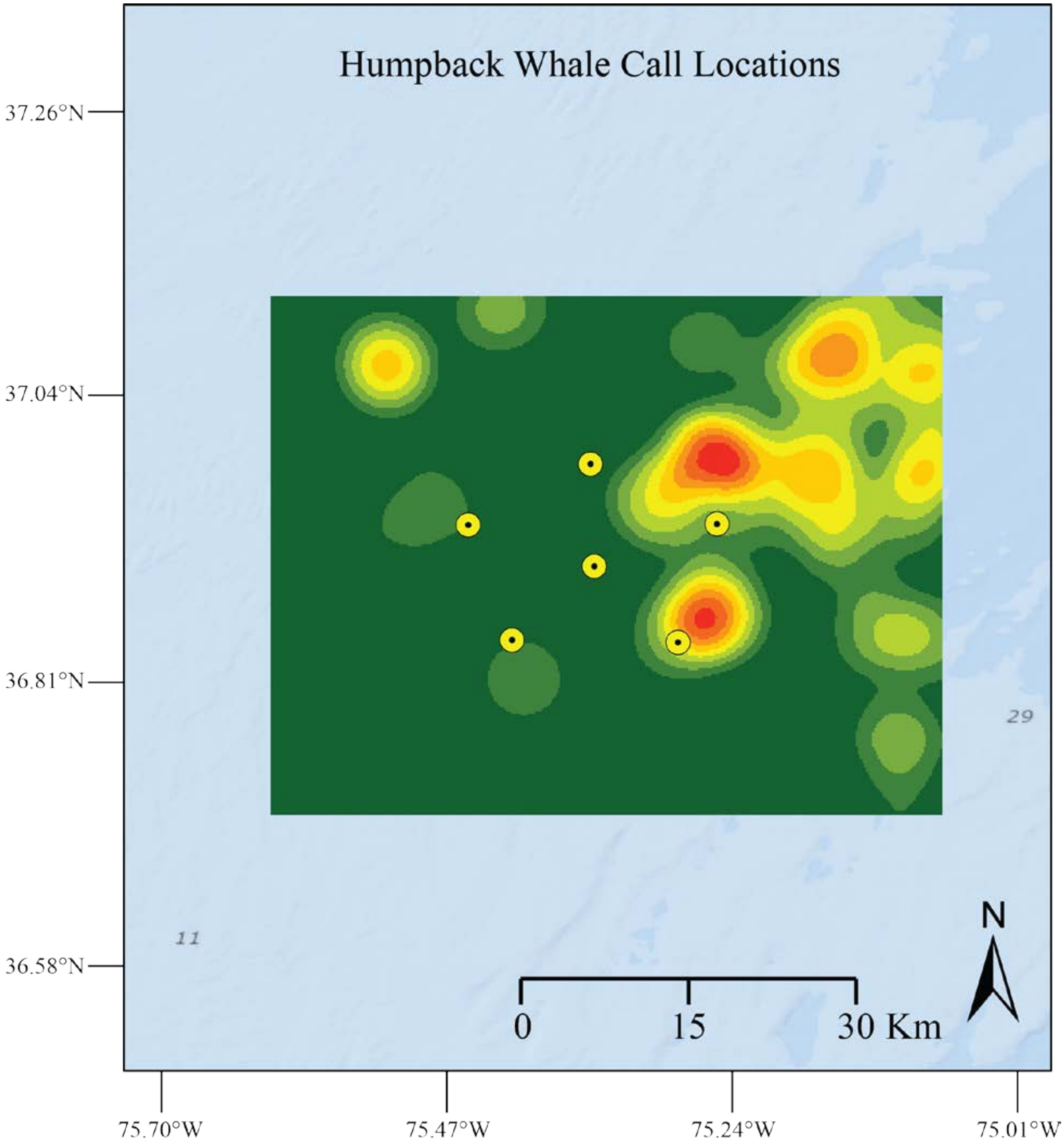


Figure 5.26. Map of located humpback whale calls from July 2015 through May 2017.
Kernel density map showing higher (red) and lower density (green) of located calls.

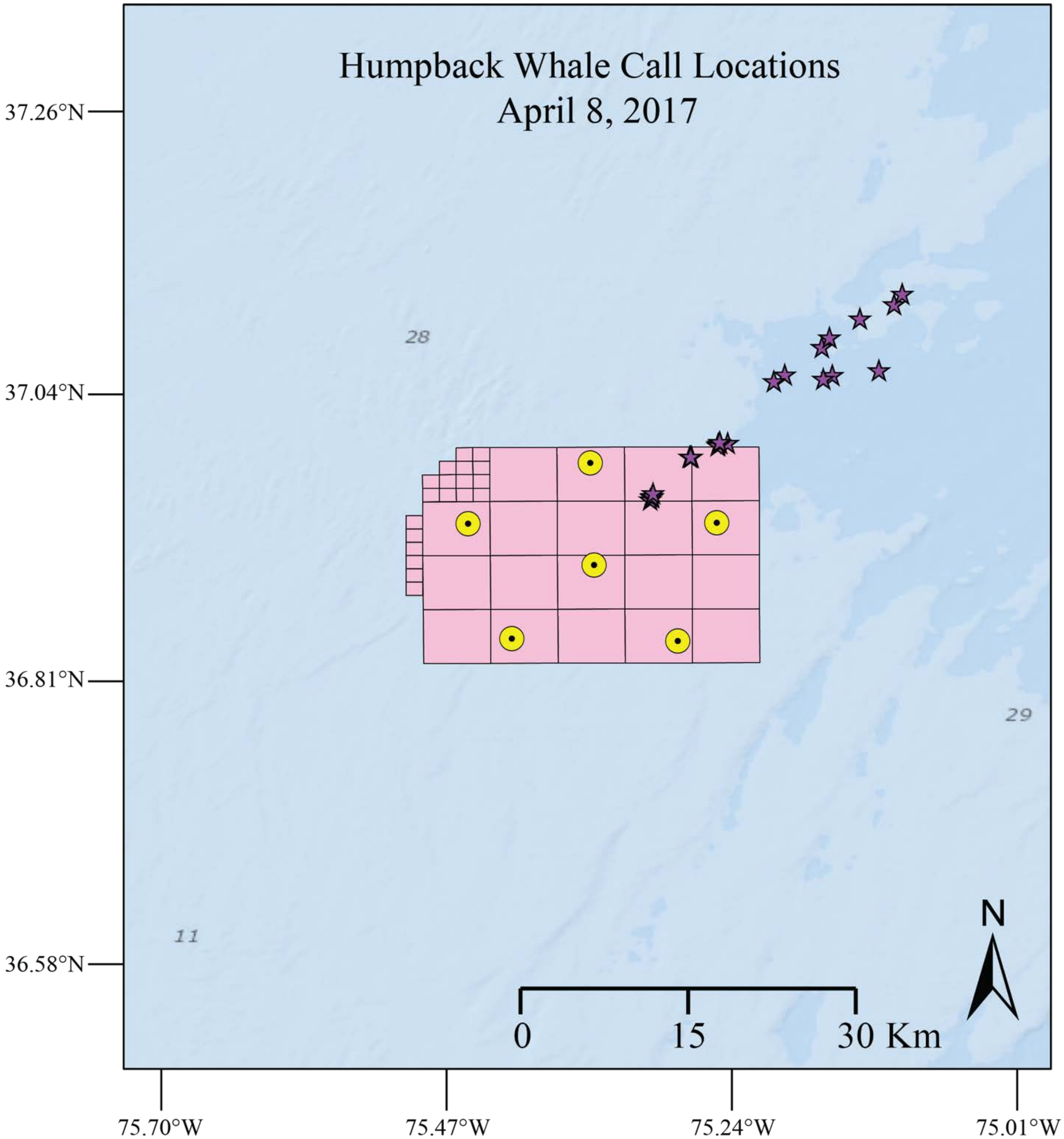


Figure 5.27. Map of located humpback whale calls from April 8, 2017.
Stars denote estimated location of each call.

5.4 Discussion

Spatial data derived from percentages of arrivals at different transect units showed that fin and minke whales primarily were present offshore, with no detected minke whales from the furthest inshore site T1, whereas fin whales were detected on both inshore units for roughly a third of the percentage of total calls. Right whales were the only species that had a majority of detections at site T2, within the WEA lease blocks. Contrary to previous studies, that suggested humpback whales were most common near shore (Ambler 2011), our data found the majority of humpback whales at the farthest offshore site T4.

The plots of bearings and the locations maps for each species narrow the scope of the spatial analysis to the extent of the WEA lease blocks and surrounding area based on the detection range of each species. All four species had presence in the WEA, with right whales having the highest numbers of calls and the most even distribution. When looking at locations for small durations of time, such as a period of days or hours, the distribution in the WEA of located calls gets smaller and more concentrated in specific areas. These periods of time with many locatable calls, followed by periods of time with little or no calls, may suggest the whales are spending relatively little time in the WEA, however, it could also be due to noise conditions or the calling behavior of the whale itself, and thus is difficult to prove either way through acoustics alone. While the number of calls does not directly correlate to the number of whales, large amounts of calls in multiple areas during similar time periods can suggest the presence of multiple whales. The presence of a high concentration of calls from a critically endangered species like the North Atlantic right whale, as well as the highest proportion of right whale calls being detected within the WEA at site T-2, should be considered for risk management plans.

In addition to right whales, both fin and humpback whales had a large number of calls successfully localized. Humpbacks were distributed more offshore on the western edge of the WEA, whereas fin whales were more concentrated on the eastern side. The very small numbers of minke whales located within the WEA, along with the low number and distribution of overall detected calls suggest that minke whales either do not commonly frequent the coastal waters of Virginia, are too far offshore to be reliably detected, or are being acoustically masked by the high ambient noise levels (see section 7). Interestingly, the modeled detection range estimates for minke whales was the lowest of all four species. None of these possible explanations of minke whale presence data are mutually exclusive.

For all species, the lowest proportion of calls were located at the nearshore site T1. Whether this is an artifact of lower detection probability due to higher noise conditions (see section 7) or whether whales are avoiding the area is unknown at this time. If whales are avoiding the in-shore areas, understanding the characteristics of those sites (noise conditions, temperature, prey availability) could be useful in predicting effects from introducing wind farm construction and operation and this study provides a good basis from which to compare pre-construction whale spatial patterns to those during and post construction and operation of wind farms in the WEA.

5.4.1 Study Limitations

In addition to the limitations of the location process (section 5.1.1), the estimates of detection range are critical to understanding and interpreting our location results. There was ample evidence to support our model's results. First, both the right whale and humpback median detection ranges show little overlap between transect sites, and no overlap between in shore and off shore sites. This was observed in the data, where in many days, presence of humpbacks or right whales were only detected at a single site. This also supports our comparisons between percentages of detections at each site since they would not be biased by calls that are recorded by multiple sites. These detection ranges are also validated by our empirical results when browsing for locatable calls. Calls, regardless of species, that had arrivals on many, or all of the array recording units were located within the array, whereas calls with only a few units recording arrivals were located further outside the array. If our detection range estimates were significantly underestimated, we would not have cases of located calls where some sites did not record an arrival. Fin whales had the largest detection ranges of the four species, with ranges overlapping recording sites. Many of the locatable calls in the array for fin whales were not received on all six of the array units, when they are all within the estimated minimum detection range. This suggests that the model may be overestimating the fin whale detection range, or it may be a propagation artifact due to the low frequency of the call and shallow water of the environment. Overall, the results from the detection range model were supported by the data and while more extensive field testing may result in improved accuracy, using the model to obtain spatial data from the transect units, and to set the framework for looking at the minimum and maximum spatial scale of the study area, it proves useful.

6 Odontocete Analysis

The Western North Atlantic is home to various odontocete species, many of which inhabit the continental shelf waters off the Virginia coast and deeper waters off the shelf (Roberts et al. 2016). Many odontocete species have the potential to be present in this survey area, including bottlenose dolphin (*Tursiops truncatus*), Atlantic spotted dolphin (*Stenella frontalis*), pantropical spotted dolphin (*Stenella attenuata*), striped dolphin (*Stenella coeruleoalba*), common dolphin (*Delphinus delphis*), Risso's dolphin (*Grampus griseus*), pilot whale (*Globicephala spp.)*, rough-toothed dolphin (*Steno bredanensis*), Spinner dolphin (*Stenella longirostris*), Fraser's dolphin (*Lagenodelphis hosei*), Clymene dolphin (*Stenella clymene*), harbor porpoise (*Phocoena phocoena*), false killer whale (*Pseudorca crassidens*), killer whale (*Orcinus orca*), melon-headed whale (*Peponocephala electra*), and sperm whale (*Physeter macrocephalus*), and beaked whale (*Family Ziphiidae*).

Odontocetes utilize high-frequency acoustic signals, which primarily comprise broadband clicks and whistles to communicate, hunt, and navigate (for examples, see Figure 6.1, Figure 6.2, Figure 6.3). Echolocation clicks are broadband pulses that typically function in navigation, and localization and discrimination of a target (Au 1993). Buzzes comprise rapid sequences of echolocation clicks that are utilized to detect and locate prey. Whistles are tonal signals that can last between a fraction of a second and several seconds, with fundamental frequencies typically below 20 kHz (Lammers et al. 2003; Richardson et al. 1995), and are utilized in social contexts. Whistles here are further defined as high-frequency (>10 kHz) and low-frequency (<10 kHz).

The frequency band of most odontocete signals commonly overlaps with mid-frequency active (MFA) sonar, which raises concern for the potential of negative impacts that sonar activity may have on their hearing, communication, health, and navigation. Here, we analyzed data from the four AMAR sites between 2015 July and 2017 May for the acoustic occurrence of odontocetes.

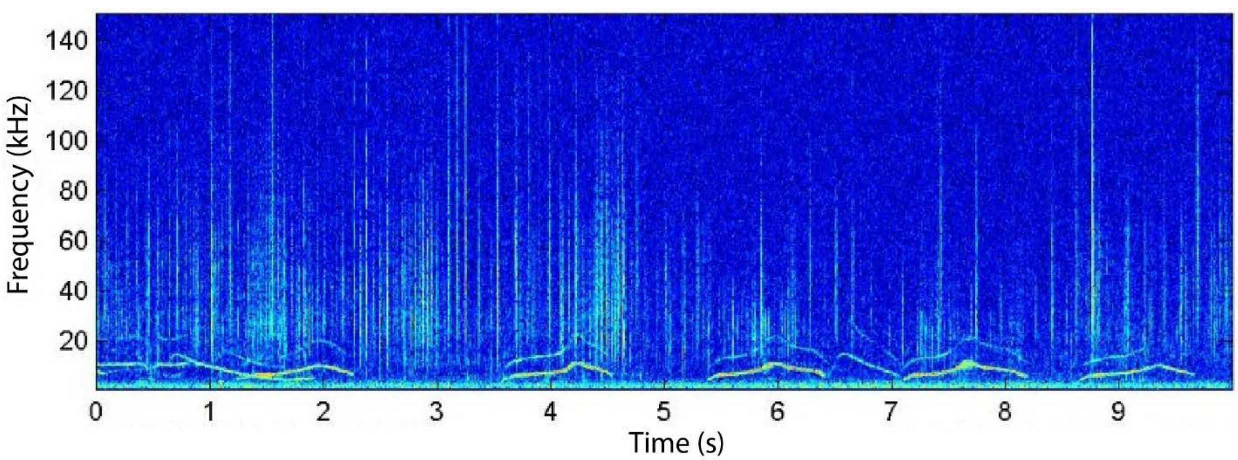


Figure 6.1. Odontocete whistles and clicks from site T1 on 16 August 2015 at 08:38:21 (UTC)

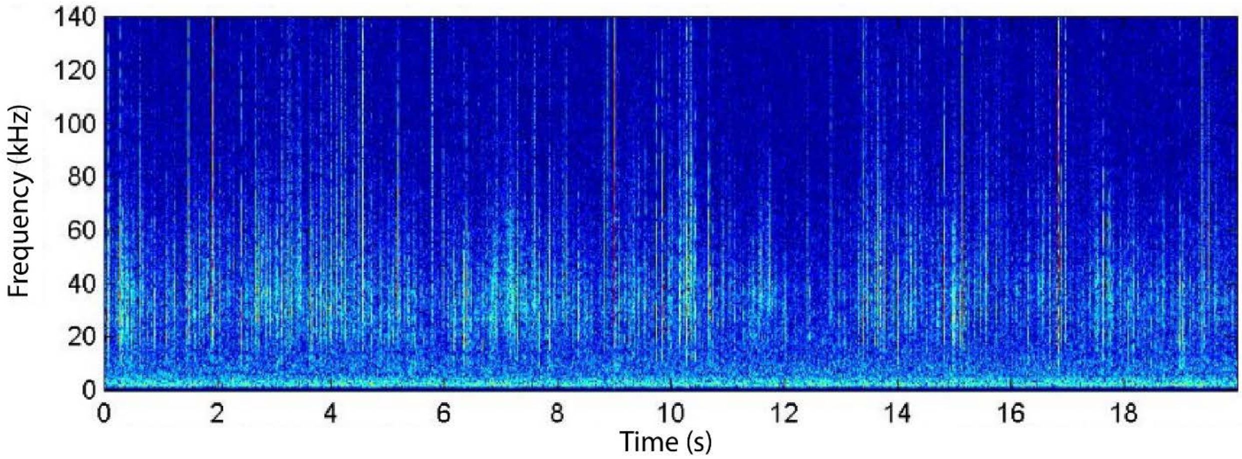


Figure 6.2. Odontocete echolocation clicks from site T4 on 5 August 2015 at 13:21:00 (UTC)

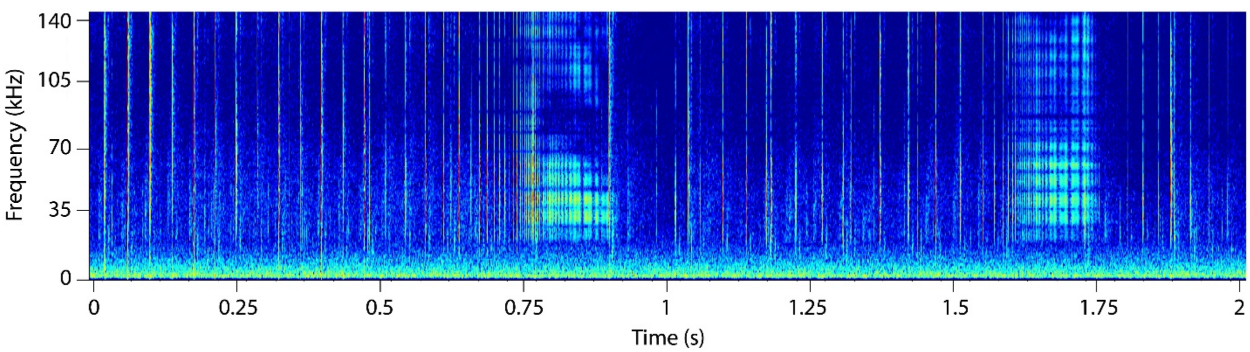


Figure 6.3. Odontocete clicks and burst pulses from site T4 on 2 March 2017 at 16:43:46 (UTC)

6.1 Methods

To quantify odontocete spatiotemporal occurrence, we manually reviewed 2,019 days of sound data from the four AMAR sites. For this, only the 375 kHz sound files were reviewed, since the 8 kHz recordings would not encompass the frequency ranges of the target signals. The Triton Software Package (Wiggins et al. 2010) was used to manually review all sound data of 30-minute spectral averages at a time, with a temporal resolution of 5s and a frequency resolution of 200 Hz. Each instance of an odontocete encounter was marked. A single *encounter* is defined by periods of acoustic activity (click, buzz, or whistle) separated by at least 30 minutes of silence. A single encounter is not distinguished by a single signal-type; therefore one encounter may contain multiple signal-types.

Odontocete click and whistle encounters were then classified using the Real-time Odontocete Call Classification Algorithm (ROCCA; Oswald et al. 2007) to test the efficacy of the algorithm for odontocete species encounters in this region. The ROCCA measures distinct features (e.g., duration, frequency, slope, and shape) from an extracted whistle contour or click, and then uses Random Forest-based classifier models to classify the signal to a species. The output from ROCCA include the probability of identification for each of the nine species. From there, we applied a minimum probability threshold of 0.5 for each encounter to exclude encounters where all species received a low-probability of being the source.

6.2 Results

Spatial variation in odontocete occurrence was observed (Table .1), where acoustic occurrence was highest near the shelf break at site T4 (n = 1,422), yet lowest at the neighboring site T3 (n = 422). Site T1, the near-shore site, also had relatively high odontocete occurrence (n = 1,145). Signal-type varied marginally by location (

Table), including a decreasing trend in click occurrence from nearshore to offshore, and an increase in high-frequency whistles from nearshore sites to offshore. Click occurrence was highest at site T1 (98% of encounters) and lowest at site T4 (91%). Buzzes occurred most at site T2 (41%) and least at site T4 (23%). High-frequency whistles had the highest encounter rate at site T4 (26%) and least at site T1 (18%), while low-frequency whistles were more spatially variable, with most occurring at site T1 (37%) and the least encounters at site T3 (19%). From July 2015 through May 2017, odontocete encounter occurrence varied by site (Figure .4). Encounter occurrence decreased at site T1 and increased at site T2, while occurrence at site T4 did not follow a clear temporal trend. Sites T1 and T4 expressed strong diel trends in occurrence, where encounters were lowest during the day and highest at night (Figure 6.5).

Table 6.1. Spatial occurrence of odontocete encounters

Site	Total Encounters	Days with Encounters	Mean Encounters per Day
T1	1,145	548	2.1
T2	742	577	1.3
T3	422	317	1.3
T4	1,422	577	2.5

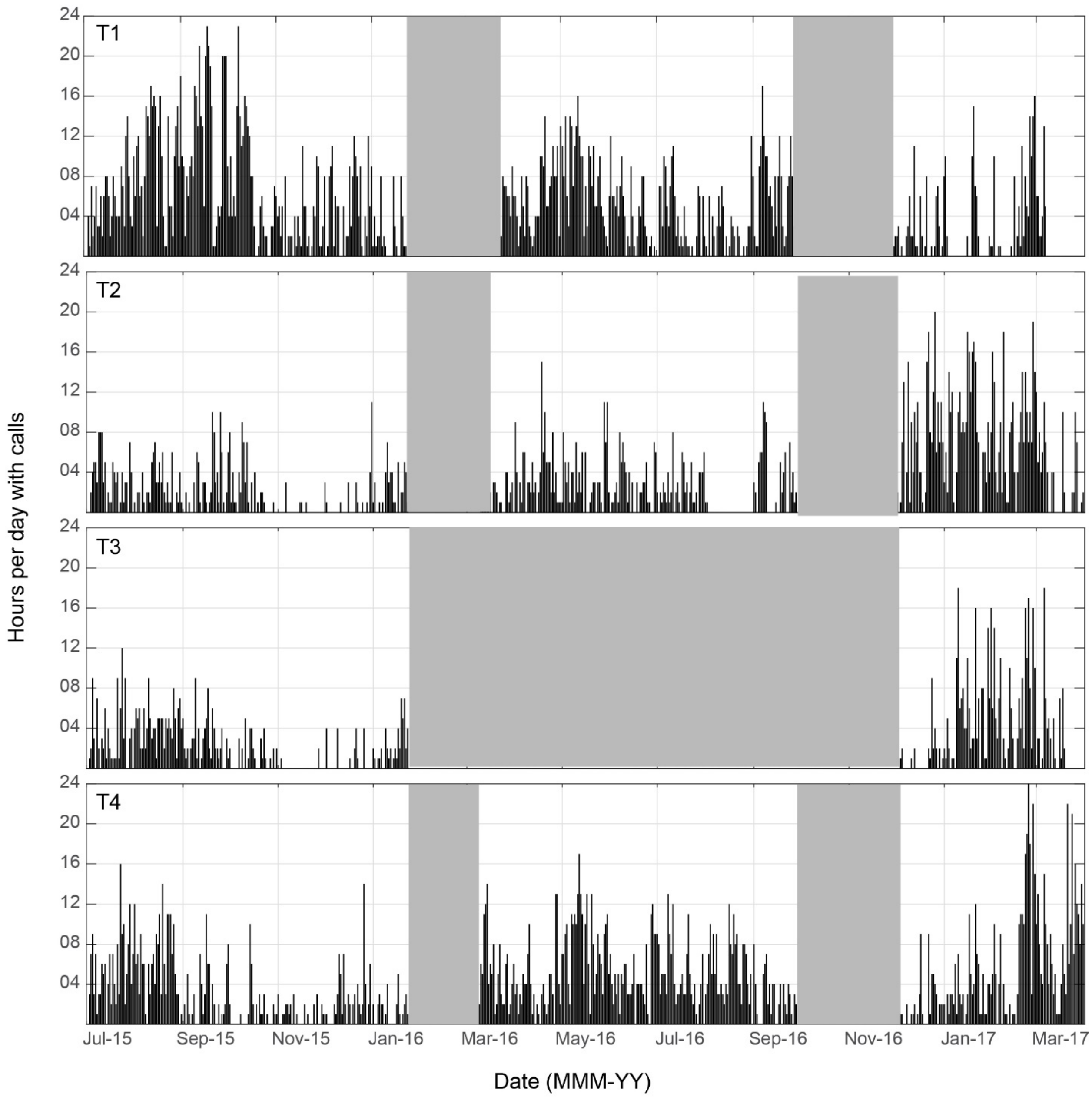


Figure 6.4. Time series of odontocete acoustic occurrence at four AMAR sites.
The grey bars represent time periods when the AMAR was not recording.

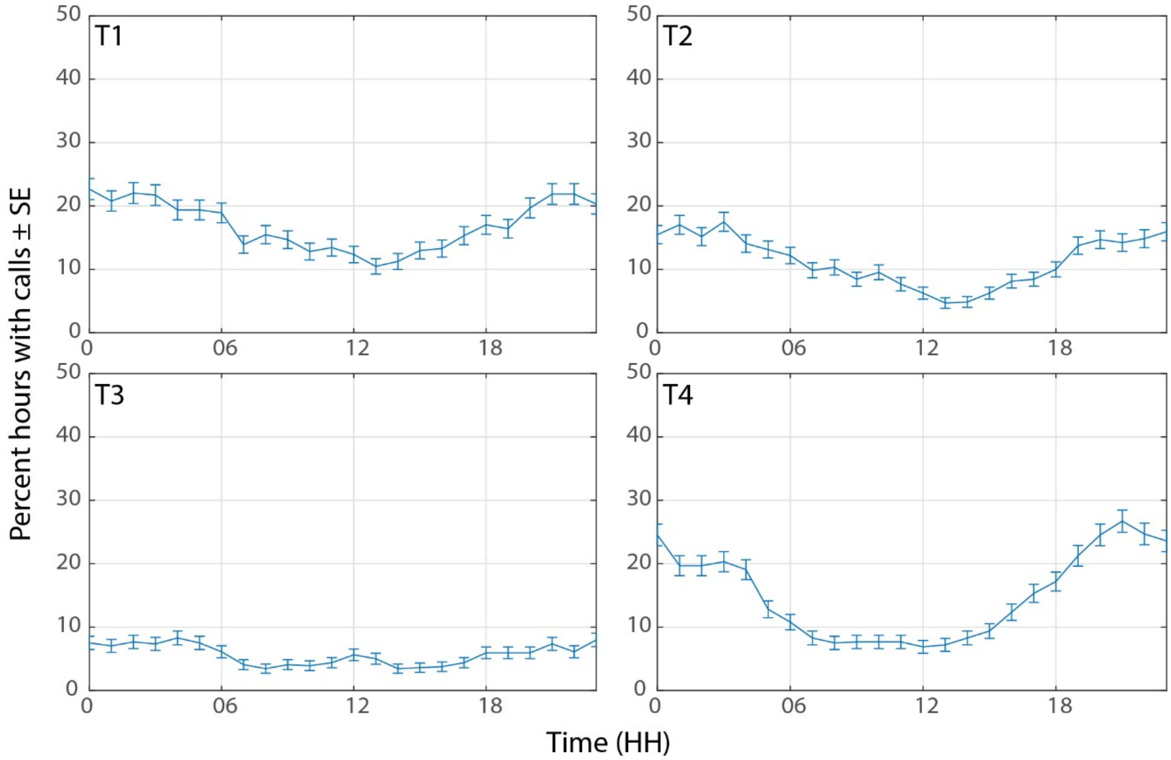


Figure 6.5. Odontocete diel occurrence per AMAR site between July 2015 and May 2017

Table 6.2. Percentage of encounters per site by signal type

Site	Percent Encounters per Signal Type			
	Click	Buzz	HF Whistle	LF Whistles
T1	98.3	31.9	17.9	37.4
T2	93.7	40.6	21.6	23.5
T3	94.3	33.4	23.5	19.0
T4	90.9	22.6	26.2	33.5
Average	94.3	32.1	22.3	28.3

The ROCCA identified eight odontocete species from the dataset (Risso's dolphin [Gg]; common dolphin [Dd]; bottlenose dolphin [Tt]; pan-tropical spotted dolphin [Sf]; Clymene dolphin [Scl]; striped dolphin [Sc]; Atlantic spotted dolphin [Sa]; and pilot whale [Gm]) based on the clicks and whistles recorded in this survey area. Striped dolphins are estimated to be the dominant source of echolocation clicks at all 4 sites, followed by Risso's dolphin. Striped dolphins comprised > 60% of the clicks at offshore sites, and about 50% at sites T1 and T2. Whistles appear to be mainly produced by Clymene, pantropical, and bottlenose dolphins, with bottlenose dolphins being the dominant source of whistles at sites T1 and T2, and Clymene dolphins being the dominant species at sites T3 and T4 (Figure 6.6).

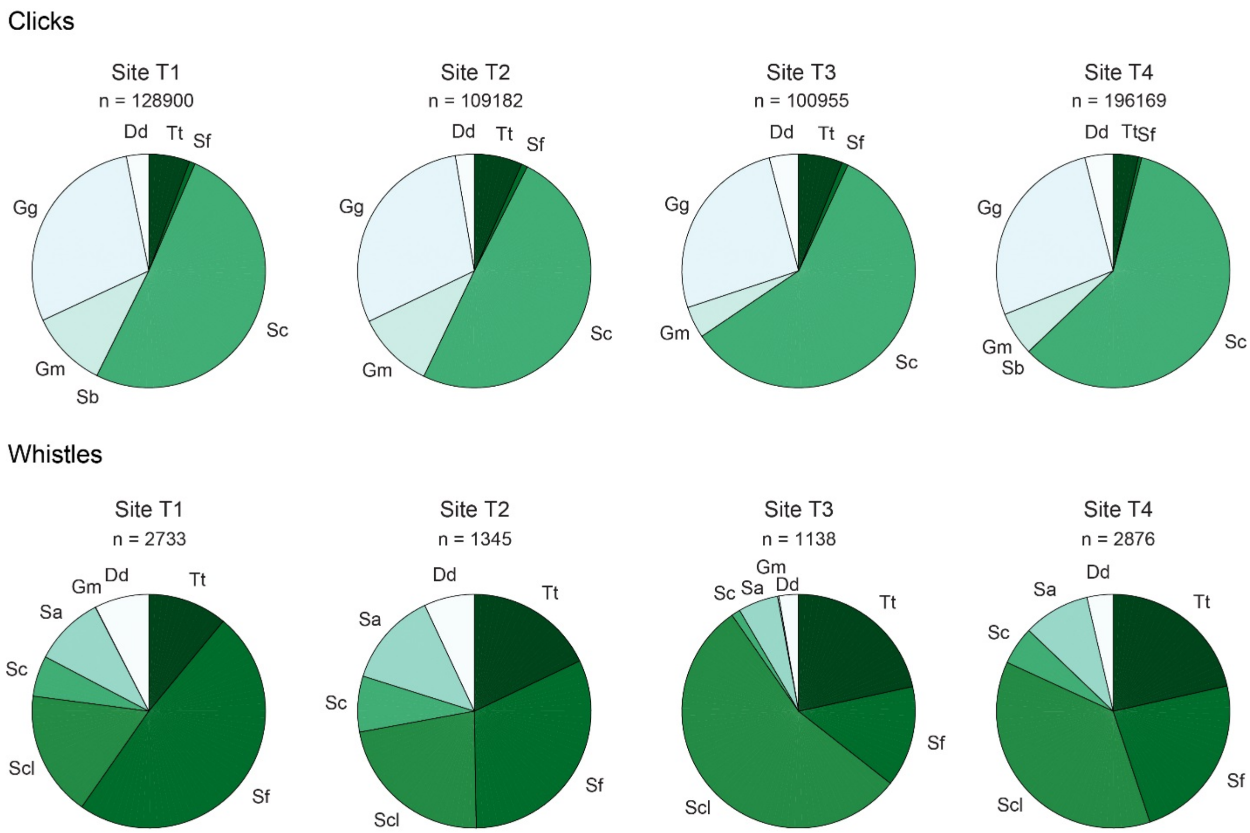


Figure 6.6. ROCCA click and whistle classification for each site from odontocete species.
Each slice of a pie chart represents the percentage of total encounters for each species per site. Risso's dolphin [Gg]; common dolphin [Dd]; bottlenose dolphin [Tt]; pan-tropical spotted dolphin [Sf]; Clymene dolphin [Scl]; striped dolphin [Sc]; Atlantic spotted dolphin [Sa]; and pilot whale [Gm]

6.3 Conclusions

Odontocete signals were recorded throughout the recording period at all sites. More calls were identified at the site nearest to shore (T1) and the site farthest from shore (T4). Clicks were the dominant signal-type across all site locations, but most commonly occurred near-shore. High-frequency whistles were more common farther offshore. The variation in signal composition across sites may be associated with the mixture of species across the shelf.

The most commonly observed dolphin species along the Virginia shelf are bottlenose dolphins (Roberts et al. 2016) however, the ROCCA classified the Clymene, pantropical spotted, and striped dolphin species' far more frequently. It is important to note that the ROCCA was developed and trained using data from offshore towed-arrays, which our data do you represent. Our results suggest that the ROCCA species-level classification did not perform well in this situation and that the ROCCA results should be supervised when applied to datasets from the Atlantic continental shelf region.

A harbor porpoise signal detector (Klinck and Mellinger 2012) was also applied to this dataset, however there were only a few detections. We suspect that the sensitivity of the sensors was not high enough to detect the species more than a few hundred meters away.

7 Ambient Noise

7.1 Introduction

Sound is a critical component of the marine environment, and many, if not most, marine animals use sound in different aspects of their life history. Measurements of ocean ambient noise have long been used to characterize different geographic areas from an oceanographic or physical perspective (Hildebrand 2009; Urick 1967; 1986; Wenz 1962; 1972); these measurements are now being calculated in different ecosystems to evaluate how marine animals may be influenced by sound from environmental and anthropogenic processes (Clark et al. 2009; Samuel et al. 2005; Simard et al. 2010). Analysis of the ambient noise environment over large spatial and temporal scales provides a broad, quantitative perspective on ecosystem function.

The term "ocean ambient noise" includes the combination of biological, environmental, and anthropogenic sounds occurring within a particular region (Hildebrand 2009; Urick 1986; Wenz 1962). In temperate marine environments, major contributors to the overall acoustic ambient noise environment include the combination of surface wave action (generated by wind), weather events such as rain, lightning, earthquakes, marine organisms, and anthropogenic sound sources such as ships, geophysical seismic surveys, and construction (Hildebrand 2009). These different sound sources are detectable over different orders of magnitude in both temporal and spatial scales; in the case of sounds from commercial shipping vessels, this acoustic signature is detectable in the low frequency bandwidth thousands of kilometers from the actual ship (Hildebrand 2009). Anthropogenic noise between the 20-150 Hz frequency range is usually due to shipping and mining operations (Jobst and Adams 1977), and environmental noise above 150 Hz in the deep ocean is surface-generated (Jobst and Adams 1977; Urick 1986; Wenz 1972). Ambient noise analysis characterizes the acoustic environment and is a mechanism to evaluate acoustic activity and other stimuli of both focal and non-focal species.

One of the fundamental characteristics of the ambient noise environment is its variability (Wenz 1962), and thus, long term studies are needed to statistically characterize the ambient noise variability (Wenz 1972). In these long-term data collection efforts, analysis of ambient noise allows for the opportunity to broadly evaluate the periodicity of physical environmental processes, vocally active biological constituents of an acoustic environment, and the contribution of anthropogenic sounds to the ambient noise environment. The combined analysis of biological acoustic activity in relation to different anthropogenic or environmental sound levels offers the opportunity to examine how increases in noise levels may impact behavior of vocal and non-vocal species. Specific to the waters off the coast of Virginia, we provide opportunities to assess the possible future impacts of wind farm construction operation noise by characterizing the baseline ambient noise environment, and highlight potential species that are susceptible to increased risk or impact from anthropogenic noise.

Baleen whales are susceptible to adverse effects from acute noise exposure (Nowacek et al. 2007), as well as possible poorly understood chronic effects over ecologically relevant spatial and temporal scales (Ellison et al. 2012). Increased anthropogenic noise can reduce the area in which a whale can communicate (Clark et al. 2009) and thus trends in spatial and temporal noise patterns contribute to the acoustic ecology of each species. With regards to wind farm construction and operation, increased noise from ship traffic and pile driving have the potential to impact whales. Pile driving during wind farm construction has been demonstrated to be detectable up to 70 km away (Bailey et al. 2010) and while data suggests that no form of injury or hearing impairment should have occurred at ranges greater than 100 m from the pile driving operation, whales could be susceptible to increased stress or behavioral changes due to the increased noise levels (Bailey et al. 2010) and lack of data for many species indicates that acute noise exposure could still pose a threat in the WEA.

7.1.1 Geophysical Survey Impacts

Marine geophysical survey data was collected by Fugro (https://www.fugro.com/) during the summer of 2013 within the WEA, which overlapped deployment 3 of the historical transect dataset. This presents an opportunity to attempt to assess the noise impacts from the survey and document the potential impacts on spatial movements of any whales that were potentially exposed to the survey effort.

7.2 Methods

Acoustic data from each AMAR and MARU in the transect dataset were processed using the Noise Analysis tools within the Raven-X toolbox for Matlab (Dugan et al. 2018), using a Hann window, FFT size of 8000 samples, time resolution at 1 s, and frequency resolution at 1 Hz. To evaluate the ambient noise conditions, two different representations of sound were used: frequency vs. time (spectrogram) and power vs. frequency (power spectra). Spectrograms of acoustic data were created using 1-hr integration time slices for each AMAR, and a FFT of 8000 samples. Two different frequency scales were used to represent the data, a linear scale with frequencies between 0-4 kHz, and a scale based on 1/3rd octave frequency bands between 10-2500 Hz. For MARU datasets, noise data was only collected from the 0-1 kHz frequency scale and 10-650 Hz 1/3rd octave frequency bands. Traditional signal processing methods divide the acoustic signal into smaller frequency bands (based on octaves), to reduce the amount of data being analyzed for greater ease in processing and interpretation (Peterson and Gross 1978). These bands effectively filter the data into smaller subsets. For sound analysis in a biological context, 1/3rd octave bands are commonly used for two principal reasons: use of these bands cover a 10-to-1 frequency range (Peterson and Gross 1978) and the function of the mammalian ear can be approximated as a set of bandpass filters with a sensitivity of approximately 1/3rd of an octave (Madsen et al. 2006; Richardson et al. 1995). With these 1/3rd octave bands, the bandwidth is approximately 23% of the center frequency (Peterson and Gross 1978). This spectrographic representation also provides a good illustration of energy in lower frequency ranges, which are difficult to see with a full-bandwidth linear scale spectrogram. The power spectral density represents the amount of power in the signal as a function of frequency. We calculated power spectral densities and represented them as statistical percentiles of total data (Roth et al. 2012; Samuel et al. 2005). Data were represented using the lower 01st, 25th, 50th (= median), 75th, and upper 99th percentiles.

In addition, we examined the noise data in the specific whale frequency bands that were used to model detection range of the recording units. These broadband noise files were calculated using periods of time from the three deployments of AMARs where all four recording sites had viable data. This provided us with a direct comparison of noise in species-specific frequency bands between transect sites. We omitted the fourth deployment of MARUs at the transect sites from this dataset since the frequency range of the noise data was not the same as the AMAR. We plotted both cumulative percent distribution and normal percent distribution.

7.2.1 Geophysical Survey Analysis

Fugro conducted three survey tracklines in and around the WEA from May 28 – July 3, 2013. Acoustic survey equipment included an R2 Sonic 2024 multibeam echosounder, Edgetech Model 4125 side scan sonar system, Edgetech 3200 spread spectrum sub-bottom profiler (CHIRP) system and an Applied Acoustic Engineers CSP Seismic Energy Source and Subsea System's double-plate "Boomer" system (Figure 7.1).

Whale presence was examined for the months of May, June and July for sites H2 and H3, located within the WEA and geophysical survey. To assess noise conditions, we compared the 1st, 50th and 99th percentile sound level equivalent values (dB) for a period of time equal to the duration of the survey before and after. Time periods were defined as Before Survey: April 22-May 27, 2013, During Survey May 28 – July 3, and After Survey July 4 – August 9, 2013. Data gaps existed for a portion of these periods for both H2 and H3, but H2 had the large gaps before and during the survey effort, so it was excluded from the analysis (see Section 2).

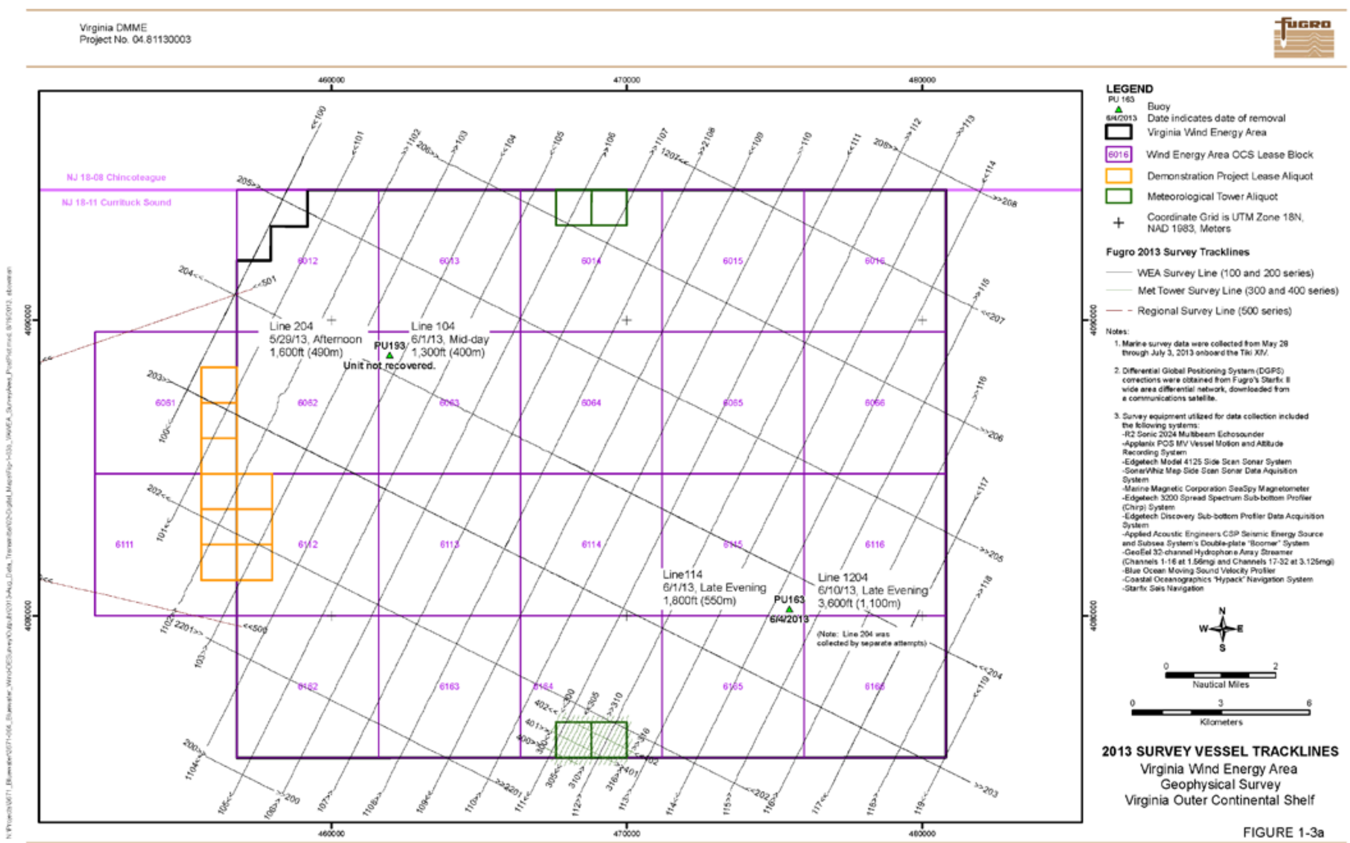


Figure 7.1. Map of the Fugro survey site.
Map showing the transect lines within the WEA of the Fugro geophysical surveys. Map provided by BOEM.

7.3 Results

Long-term spectrograms for each transect site from July 2015 through July 2017 show a qualitative overview of baseline ambient noise in the WEA and allow for quick visual comparisons of noise levels between sites. At a broad level, ambient noise levels appear to be similar across all four transect sites.

Noise does vary between deployments, of note with deployment 2 (March – September 2016) appearing to have decreased noise levels compared to deployment 1 (July 2015 – January 2016) and deployment 3 (October 2016 – May 2017) (Figure 7.2, Figure 7.3, Figure 7.4, Figure 7.5). Power spectral density plots were generated to show percentiles (01^{st}, 25^{th}, 50^{th}, 75^{th}, 99^{th}) of noise at different frequencies to provide a quantitative approach to comparing ambient noise values across sites and time periods (Figure 7.6, Figure 7.7, Figure 7.8, Figure 7.9). For any given frequency, the percentile line plots the amount of noise that occurs for that percent of the time period. Ambient noise levels were relatively consistent among sites and deployments. On average, noise levels did not occur higher than 115 dB, and did not occur lower than 40 dB for any period of time at the spectral or $1/3^{rd}$ octave level. The loudest concentration of noise was found in the low frequency range from 0-100 Hz with the quietest frequencies at the high end of the recording spectrum (3-4 kHz).

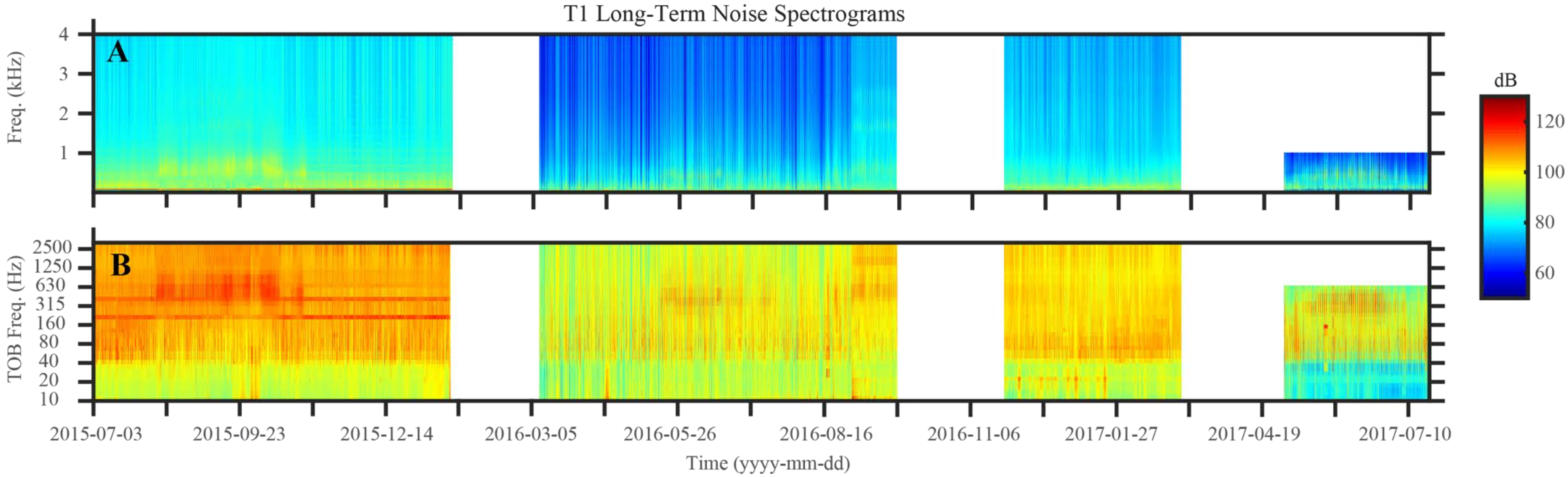


Figure 7.2. Long-term spectrogram for site T1 for all four transect deployments.
A. 0-4 kHz frequency scale. B. 1/3rd octave frequency scale. White periods of time correspond to data coverage gaps where no noise data was collected.

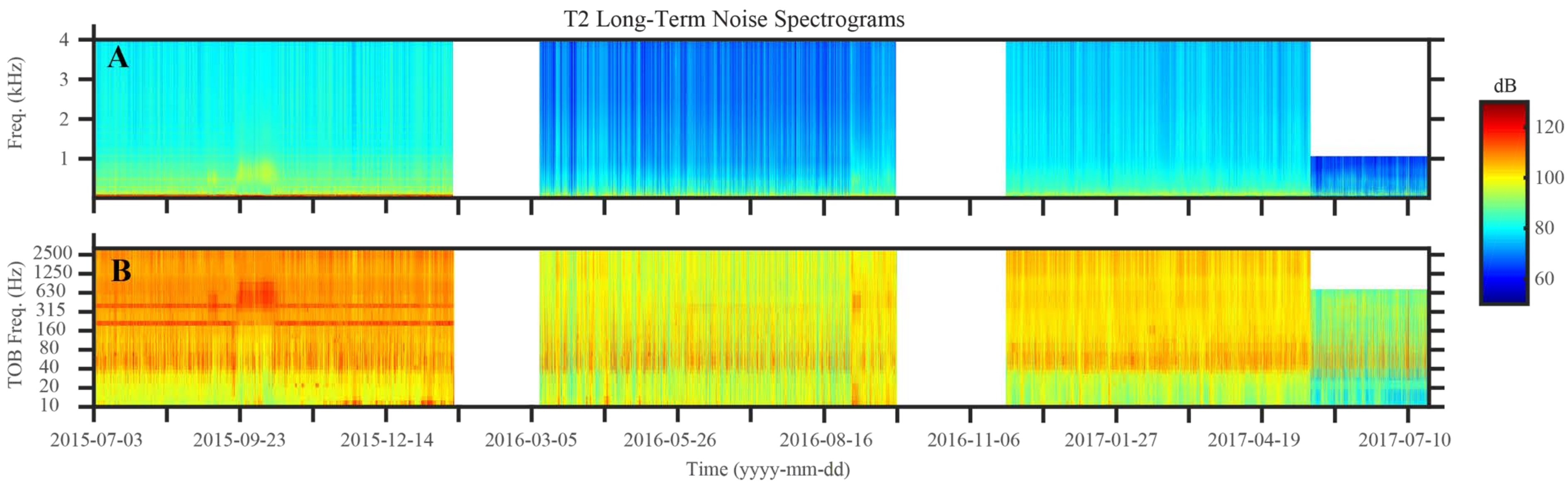


Figure 7.3. Long-term spectrogram for site T2 for all four transect deployments.
A. 0-4 kHz frequency scale. B. 1/3rd octave frequency scale. White periods of time correspond to data coverage gaps where no noise data was collected.

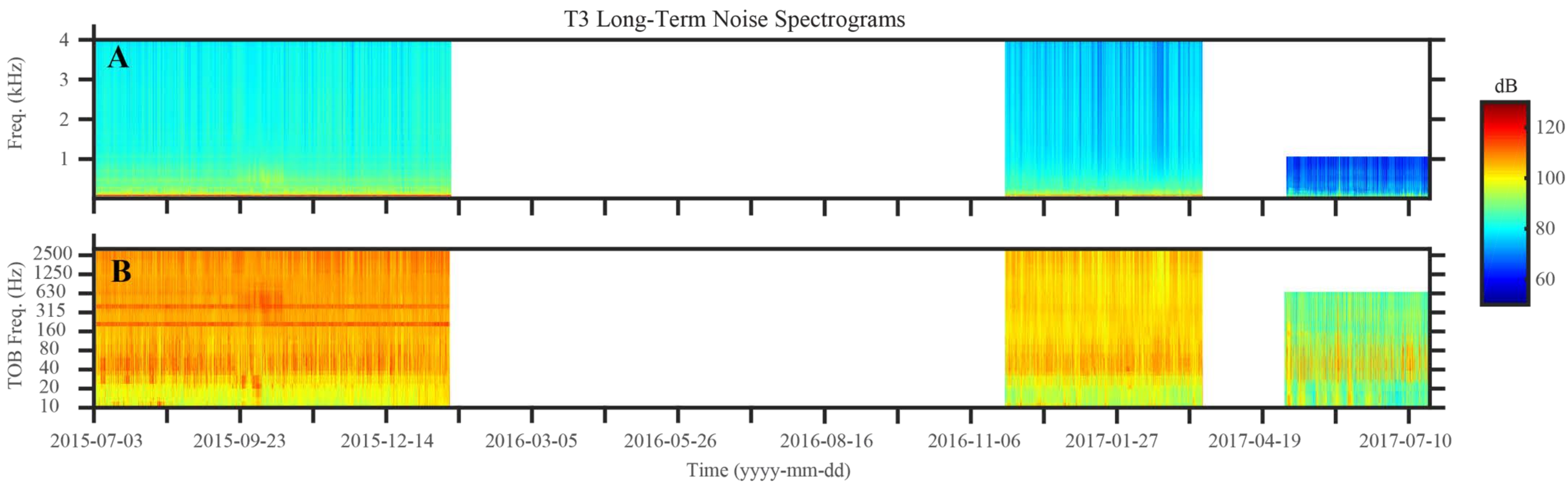


Figure 7.4. Long-term spectrogram for site T3 for all four transect deployments.
A. 0-4 kHz frequency scale. B. 1/3rd octave frequency scale. White periods of time correspond to data coverage gaps where no noise data was collected.

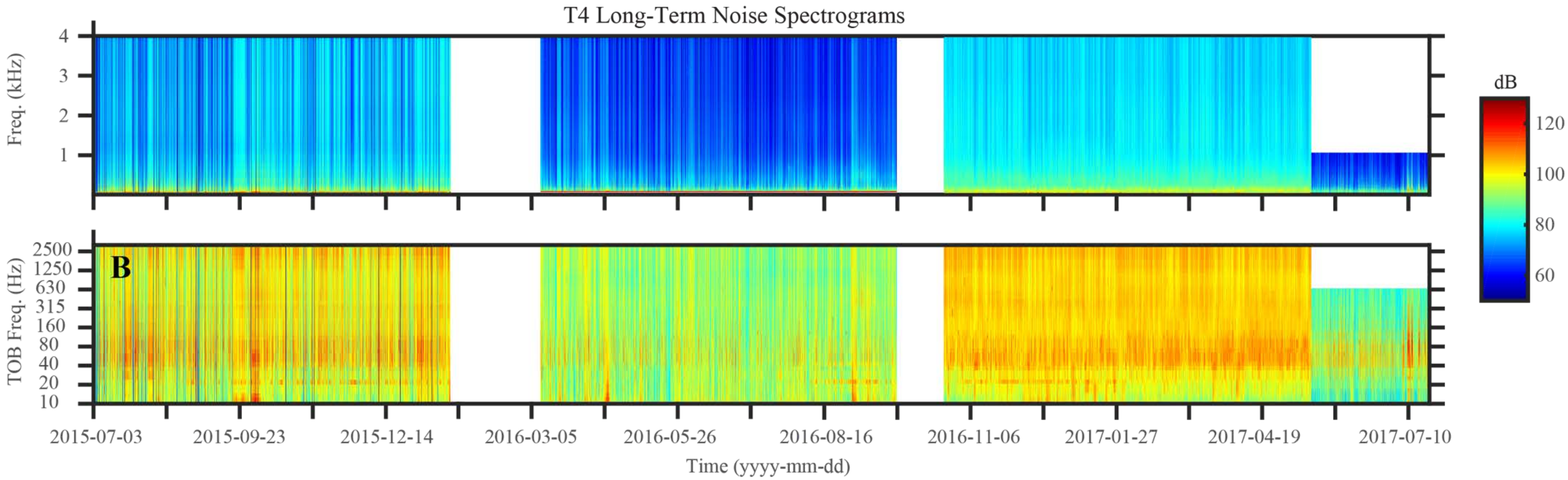


Figure 7.5. Long-term spectrogram for site T4 for all four transect deployments.
A. 0-4 kHz frequency scale. B. 1/3rd octave frequency scale. White periods of time correspond to data coverage gaps where no noise data was collected.

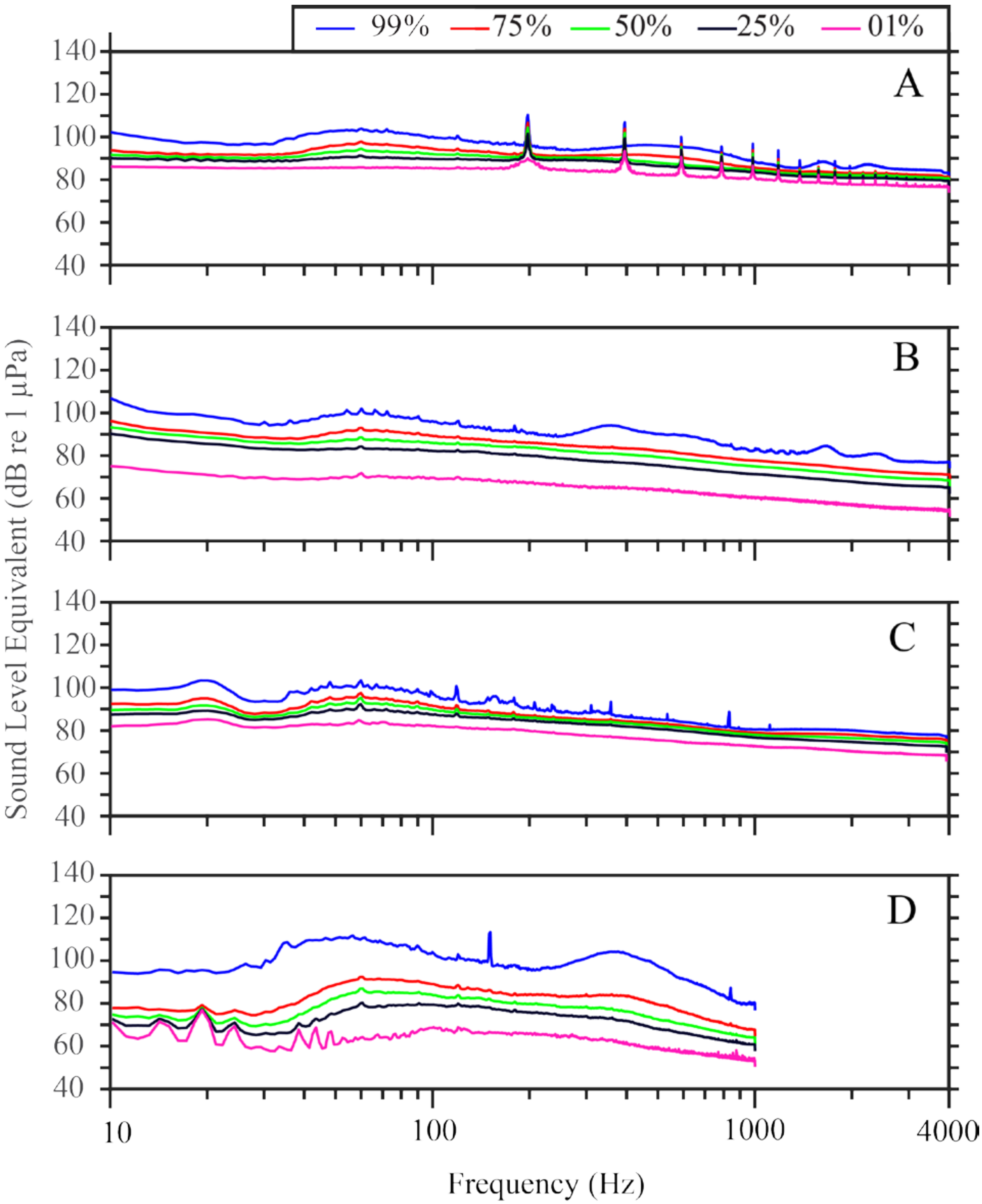


Figure 7.6. Power Spectral Density Plots for T1

A. Noise data from deployment 01. B. Noise data from deployment 02. C. Noise data from deployment 03. D. Noise data from deployment 04. Each line represents the percentile of noise conditions from 1 hour averages across the entire recording period. For example, in plot A, at 100 Hz, noise conditions are below 89 dB 50% of the time.

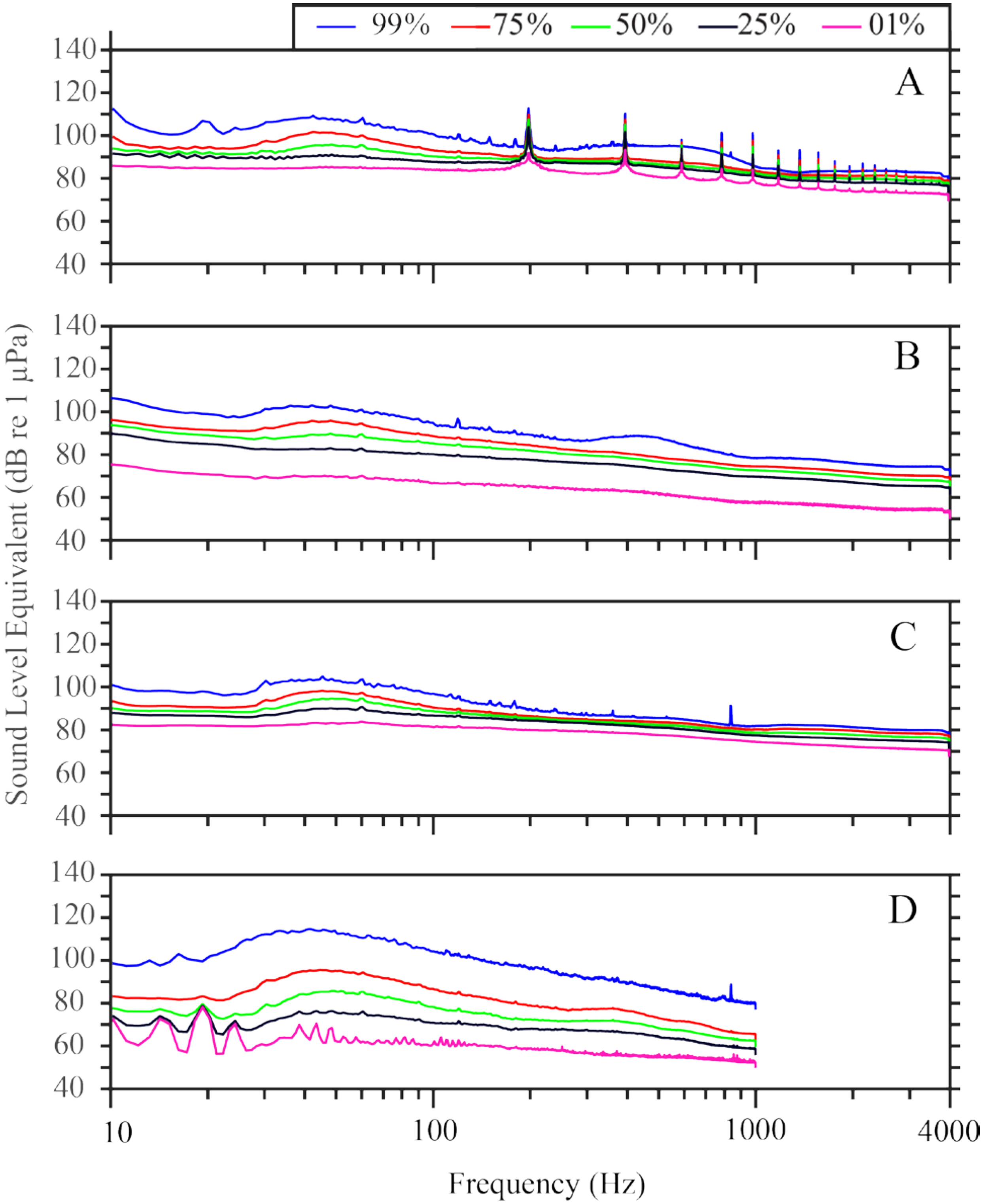


Figure 7.7. Power Spectral Density Plots for T2
A. Noise data from deployment 01. B. Noise data from deployment 02. C. Noise data from deployment 03. D. Noise data from deployment 04. Each line represents the percentile of noise conditions from 1 hour averages across the entire recording period. For example, in plot B, 99% of the time, noise at 10 Hz is below 133 dB.

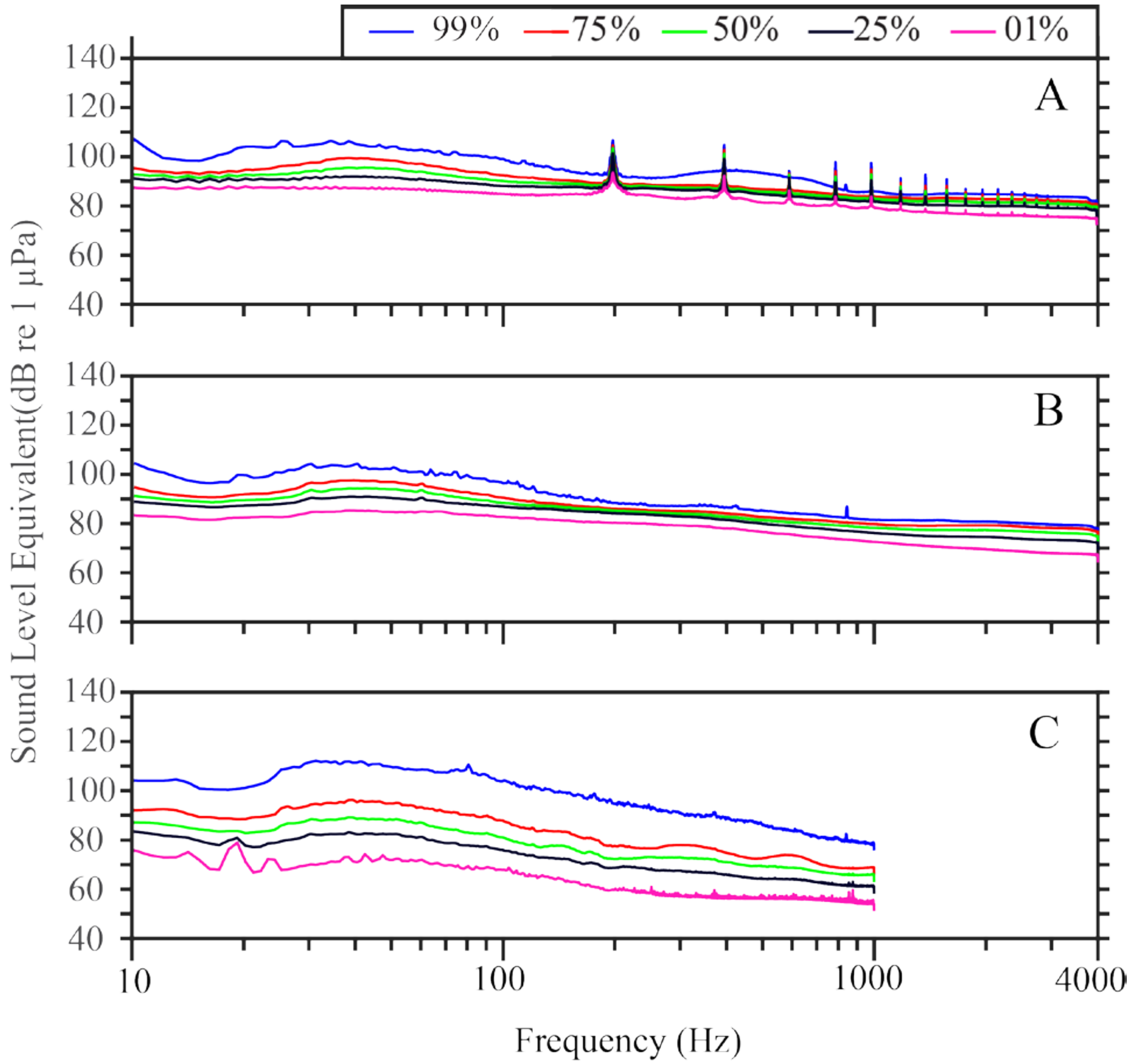


Figure 7.8. Power Spectral Density Plots for T3

A. Noise data from deployment 01. B. Noise data from deployment 02. C. Noise data from deployment 03. D. Noise data from deployment 04. Each line represents the percentile of noise conditions from 1 hour averages across the entire recording period. For example, in plot C, 75% of the time at 1000 Hz, noise conditions measure below 70 dB.

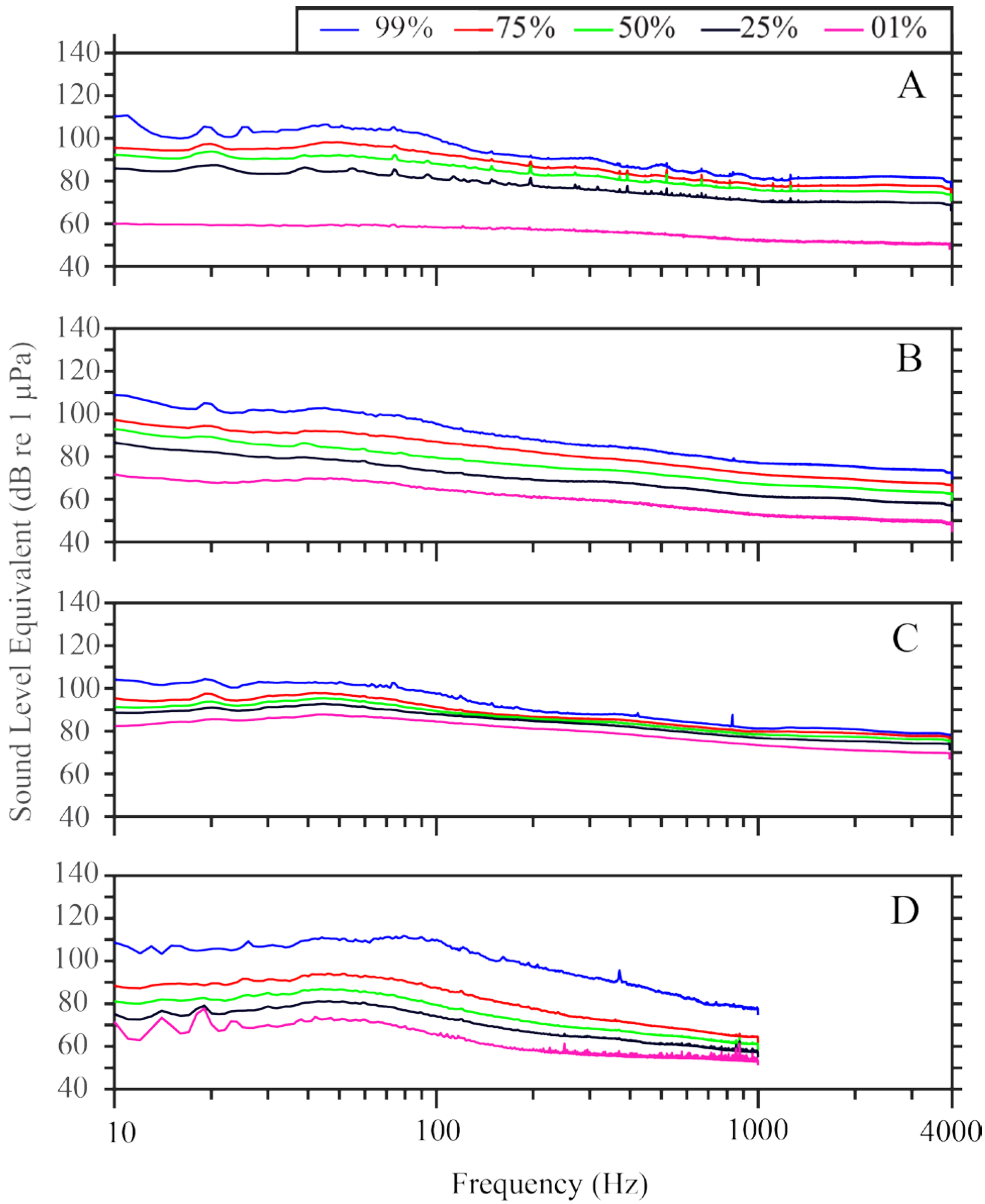


Figure 7.9. Power Spectral Density Plots for T4

A. Noise data from deployment 01. B. Noise data from deployment 02. C. Noise data from deployment 03. D. Noise data from deployment 04. Each line represents the percentile of noise conditions from 1 hour averages across the entire recording period. For example, in plot A, 1% of the time at 4000 Hz, the noise is lower than 40dB.

Broadband noise files were aggregated from all three AMAR deployments in the species-specific frequency bands to allow comparisons of noise between sites. Cumulative distribution of noise (Figure 7.10) combines all 1 hour averaged time slices of noise from the entire recording period and plots the result, so that sites with lines plotted further to the right of the dB scale were on average, noisier in that species frequency range. Normal percent distribution plots the noise levels occurring as a percentage of the time period along the dB scale. For the right whale frequency band of 71-224 Hz, site T3 was on average, the loudest site, with noise exceeding 110 dB, 50% of the time. T2, located in the WEA, was the next loudest site. The normal percent distribution shows that noise levels on T3 measured 115 dB for 14% of the time period (Figure 7.10). The minke whale frequency band of 45-355 Hz showed similar patterns to the right whale results, with T3 and T2, being the loudest sites. Compared to the right whale results, 50% of the time, minke whale frequency noise levels exceeded a higher level, at 115 dB for site T3. At the low end of the scale, the noise levels at site T4 were rarely measured below 105 dB (Figure 7.11). Noise levels in the fin whale frequency band (18-28 Hz) were lower than the other whale species, with site T3 being the loudest site. 50% of the time, noise levels at T3 exceeded 100 dB. For site T2, sound levels were measured at 100 dB for over 12.5% of the time period (Figure 7.12). In the humpback whale band (224-708 Hz) were more similar to the minke and right whale bands, with site T3, T2 and T1 measuring louder noise values than site T4 (Figure 7.13).

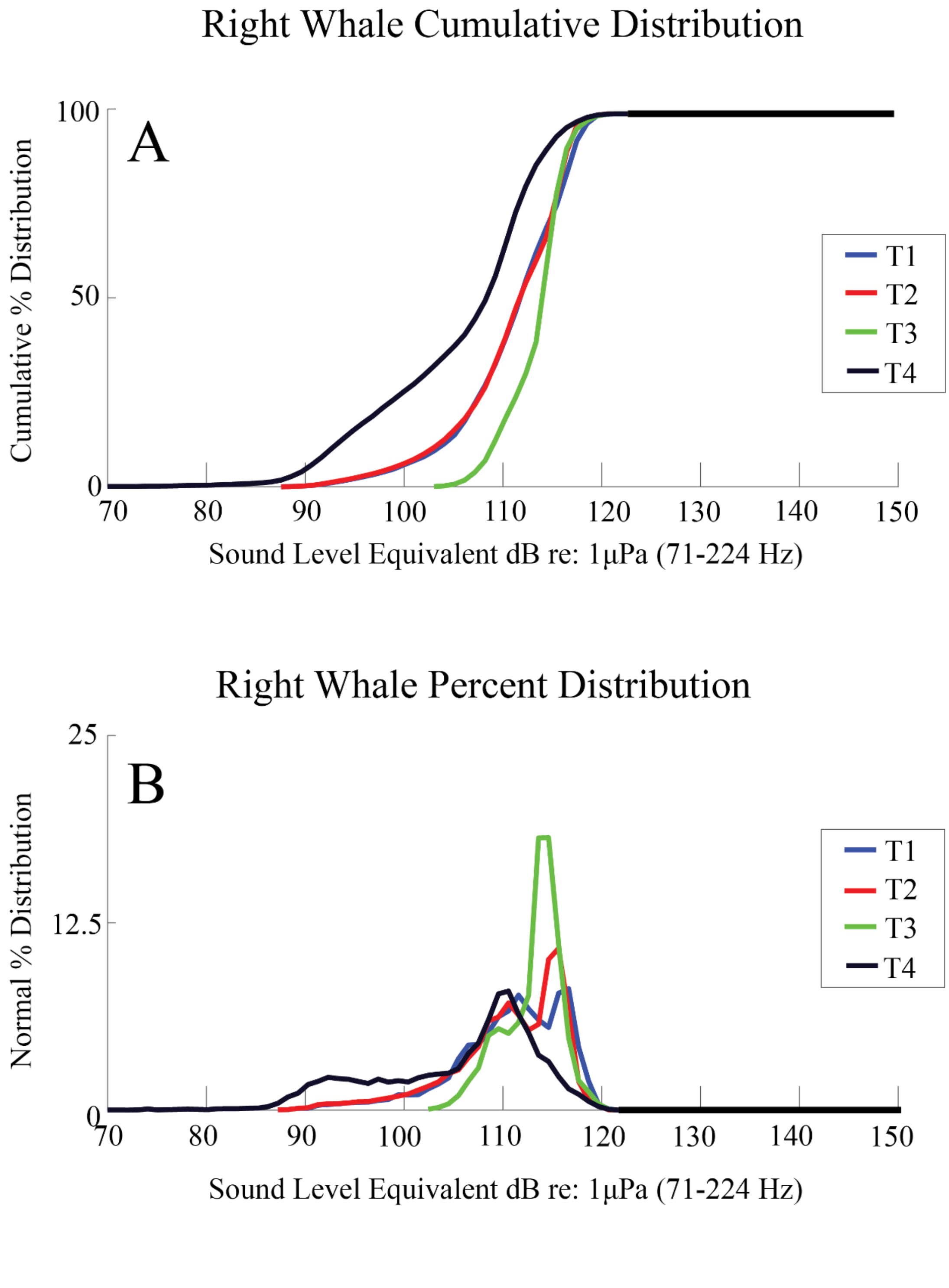


Figure 7.10. Cumulative and percent distribution for right whales.
A. Cumulative percent distribution of noise in the right whale frequency band (71-224 Hz) for 4 transect sites. B. Normal percent distribution of noise in the right whale frequency band for 4 transect sites.

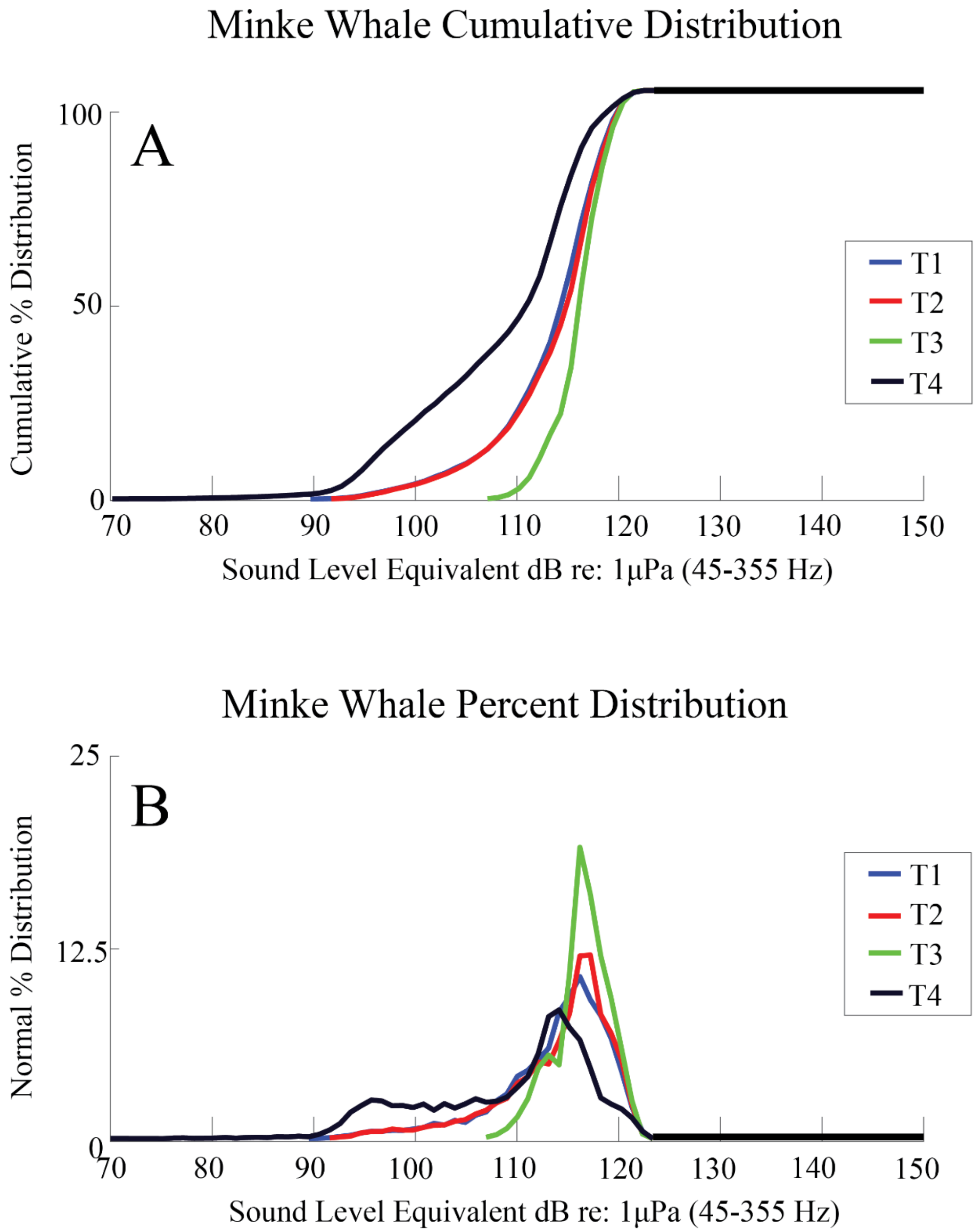
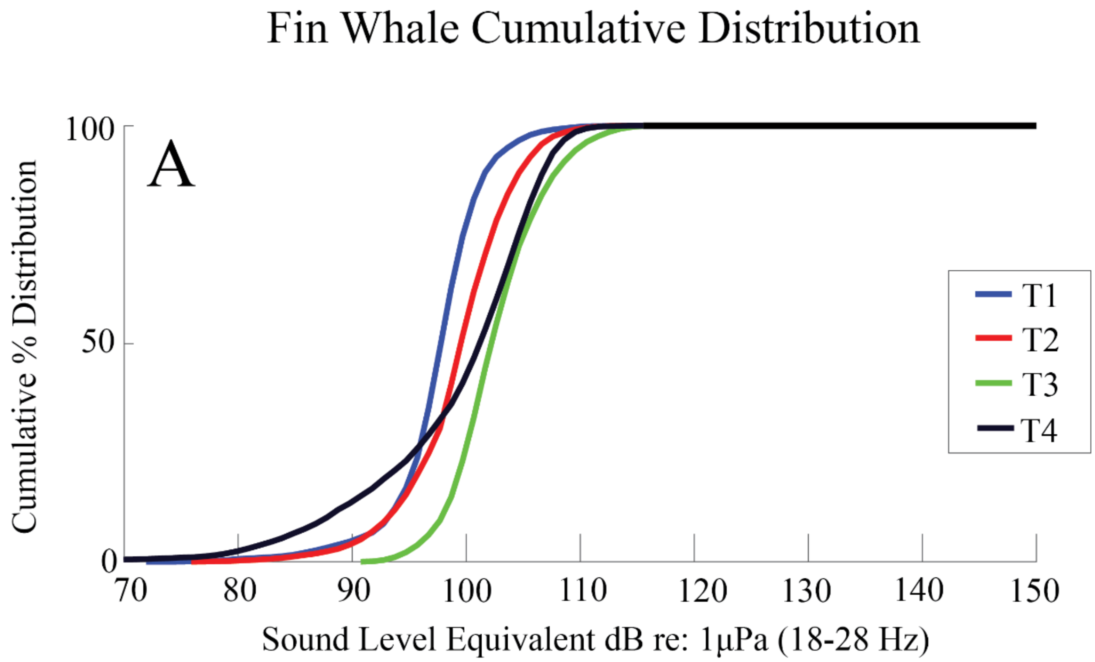


Figure 7.11. Cumulative and percent distribution for minke whales.
A. Cumulative percent distribution of noise in the minke whale frequency band (45-355 Hz) for 4 transect sites. B. Normal percent distribution of noise in the minke whale frequency band for 4 transect sites.



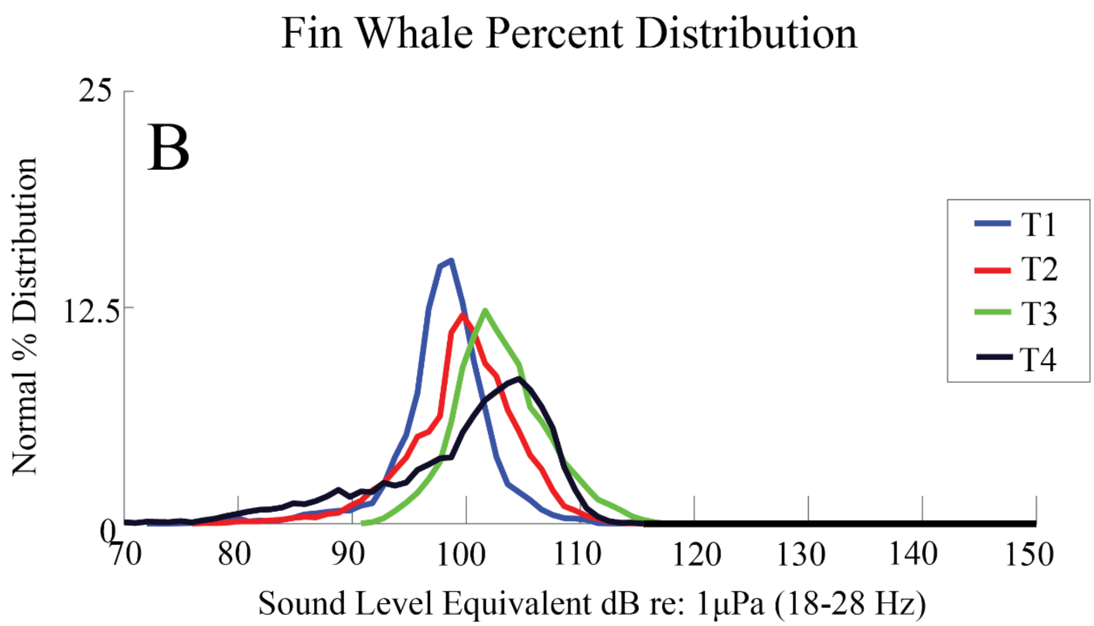


Figure 7.12. Cumulative and percent distribution for fin whales.
A. Cumulative percent distribution of noise in the fin whale frequency band (18-28 Hz) for 4 transect sites. B. Normal percent distribution of noise in the fin whale frequency band for 4 transect sites.

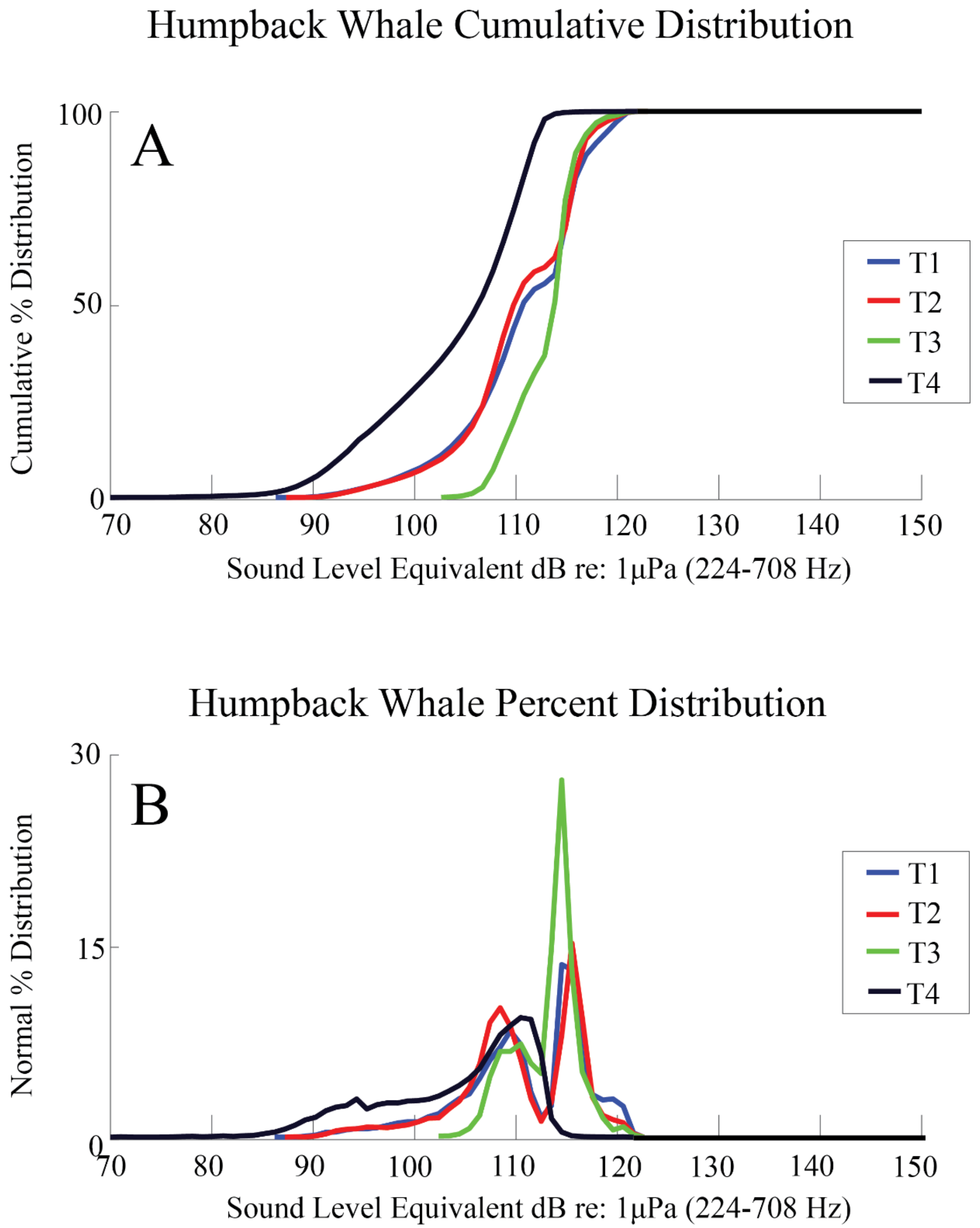


Figure 7.13. Cumulative and percent distribution for humpback whales.
A. Cumulative percent distribution of noise in the humpback whale frequency band (224-708 Hz) for 4 transect sites.
B. Normal percent distribution of noise in the humpback whale frequency band for 4 transect sites.

7.3.1 Geophysical Survey Analysis Results

Whale presence for the months of May, June and July 2013 were very low, with no presence of minke whales or right whales detected in the WEA, and only 1 day of humpback and fin whale presence, both detected on offshore sites east of the WEA. Noise conditions calculated from 1 hour averages for before (April 22-May 27, 2013), during (May 28 – July 3) and after (July 4 – August 9, 2013) the survey effort were very similar across all frequency bands (Figure 7.14).

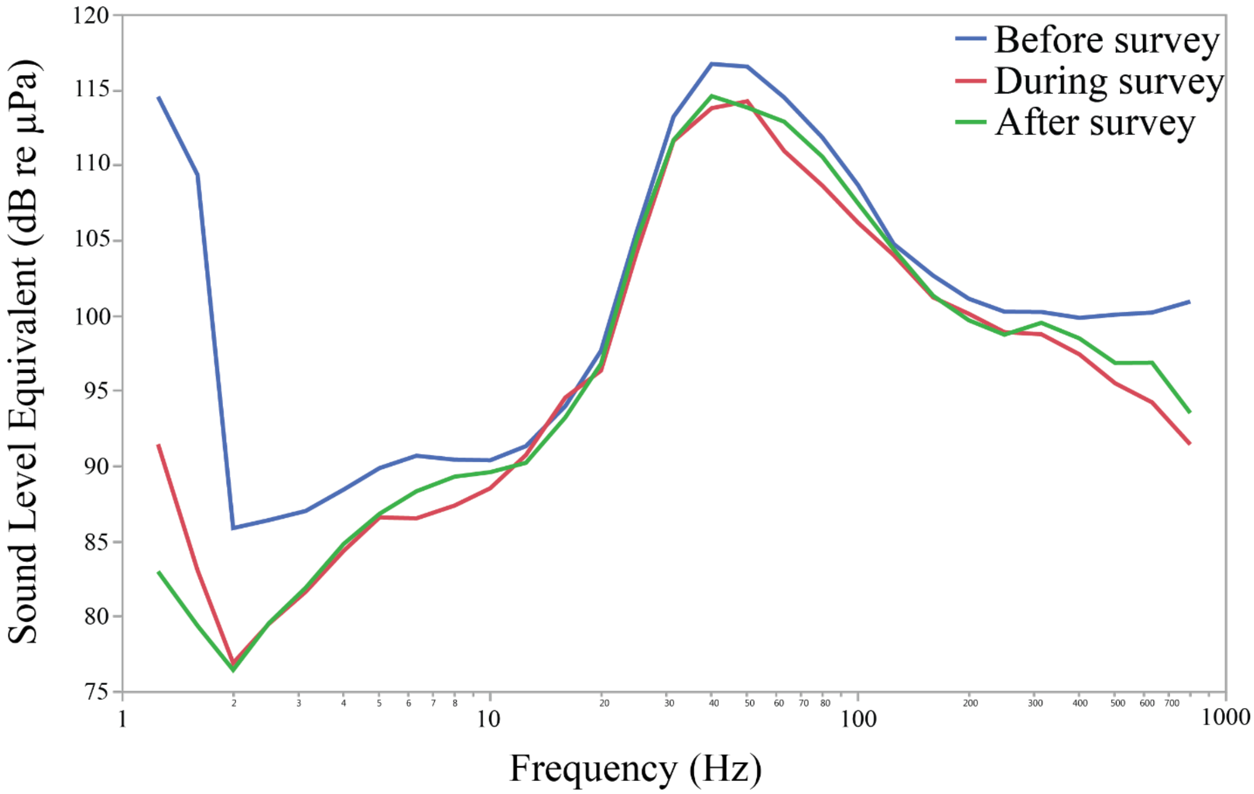


Figure 7.14. Average Noise conditions for Fugro survey effort.
Average noise conditions in dB for 1/3rd band octave levels 1-800 (Hz) for periods of time before, during and after survey effort. Before Survey: April 22-May 27, 2013, During Survey May 28 – July 3, and After Survey July 4 – August 9, 2013

7.4 Discussion

Qualitatively, the long term noise spectrograms for each site are a quick visual way to characterize the ambient noise conditions in the study area. The loudest periods of noise for all sites and periods of time were found below 1000 Hz in the 40-160 Hz frequency band range. Visual inspection of loud or quiet events show a range of noise conditions which could be biological, weather-related, or human induced, but these noise events were generally consistent across recording sites.

Quantitatively, the power spectral density plots (Figures 7.6-7.9) verify the visual observations of noise conditions from the long-term spectrograms. Median 50% noise values across all sites and deployments were in the 70-100 dB range from 10-1000 Hz, with the most energy contained in the lowest frequencies (50% median noise values at 10 Hz ranged from 80-100 dB and 50% median noise values at 1000 Hz were approximately 70-80 dB). While deployments 1-3 showed little temporal variation, noise values were lowest for deployment two at all sites (recorded March 2016 – September 2016). Sound levels were similar in deployment 04 (recorded May 2017 – July 2017), as opposed to louder periods of recording from deployments 1 (recorded July 2015 – January 2016) and 3 (recorded October 2016 – May 2017). These results do not support a seasonal trend as a driving factor in noise, but rather some other variable or combination of variables. Deployment 1 hydrophones did have elevated levels of external noise, but they were similar to levels of noise from deployment 3, so it is uncertain how much of an impact the hydrophone malfunctions made in the overall noise measurements.

While noise conditions across all frequencies, sites and deployments were fairly consistent, the cumulative and percent distribution plots (Figures 7.10-7.13) for the species-specific frequency bands combined all deployments to look at noise per site for the entire study period and did show some variation among sites. The frequency bands corresponding to vocalizations of right whales (71-224 Hz), humpback (224-708 Hz) and minke whales (45-355 Hz) had similar patterns of cumulative distribution of noise, which is consistent with the similar frequency bands they share. Sites T1, T2 and T3 were the loudest with 50% of the noise exceeding 105-115 dB depending on site and species. The furthest off-shore site T4 was consistently quieter for all species. Compared to a study of noise conditions in the right whale frequency band across multiple sites in the Western North Atlantic, these data from Virginia are louder than any of the other 10 sites sampled (Rice et al. 2014b). Noise data recorded from New Jersey and New York were closest in comparison with 50% distribution of cumulative noise in the 100-105 dB range, with many of the northern feeding ground sites much quieter in the 90-95 dB range (Rice et al. 2014b). The frequency band of fin whales was the only one that showed consistent noise distribution across all sites, with site T3 having a slightly higher 50% median cumulative distribution of noise. This most likely is due to the much lower frequency band range for fin whales (18-28 Hz), which was below the frequency of the majority of shipping noise present in the data. When comparing noise levels across different frequency bandwidths that are used by different species to communicate, the narrower or wider the band has consequences on how much variable noise from different sources is included in the noise measurements. These acoustic niches used by different species are affected disproportionate to the sources of noise, so that fin whales communicating in a narrow band, may be less affected by lower levels of noise than humpback whales, that communicate in a wide bandwidth that coexists with many other sources of noise.

Predicting the potential impact of constructing and operating a wind energy farm based on these data suggests that while noise levels will increase from increased ship traffic, pile driving, and operations activity, chronic noise exposure for whales in an environment with already high levels of background noise may have less of an impact than for whales in a much quieter environment. However, increased noise levels would decrease the already small acoustic space of the four baleen whale species and would most likely impact the right whale, minke and humpback whale more than the fin whale. Right whales may experience the most exposure to chronic noise increases, as they were present in the WEA the most frequently out of the four species. While whales have continued to use the habitat off the coast of Virginia despite the current loud noise conditions, compared to other areas along the U.S. East Coast, we do not fully understand whether these conditions affect their survival and reproductive rates due to constant stress from the environment, or whether increased presence in the Mid-Atlantic (Davis et al. 2017) suggests that whales may have acclimated to the noise conditions. Further long term acoustic monitoring during construction and operation periods would be valuable in determining how/if whales respond.

Evaluating the potential impact of the Fugro geophysical surveys presented challenges due to the nature of our recording units and the design of the study. Insufficient whale presence data for that time period did not allow us to qualify potential changes in whale distribution in response to survey activity. In terms of noise impact, our instruments did not detect any noticeable increase in baseline ambient noise during the survey effort, but the low frequency of our recorders (sample rate 2 kHz) may have omitted much of the noise generated by the survey from our measurements.

8 Summary

8.1 Spatial and Temporal Occurrence of Baleen Whales

The four focal species of baleen whales studied included right whales, minke whales, fin whales and humpback whales. All species showed patterns of seasonality over the 5.5 year study period, with minke whales being the lowest detected species and fin whales being the highest detected species. Peak whale presence occurred during the November through April months, but low levels of presence were detected at periods of time throughout the year. Seasonal patterns were variable across years and species in both the amount of calls detected as well as the timing of the period of peak presence.

Except for right whales, the three other focal species showed a higher proportion of calls detected on the offshore recording units at sites T3 and T4. Right whales had the highest levels of presence detected on site T2, in the WEA. Some level of presence was detected on every recording site for every species, with the exception of no minke whale calls detected on the near shore recording site T1. Calls of all four species were located within and around the WEA, with right whales having the highest number and distribution of calls within the WEA. Humpback whales had a higher proportion of locatable calls in the surrounding water east of the WEA, while fin whales had more calls located on the western portion of the WEA. Located calls from minke whales in the WEA were very rare, with under 10 calls for the entire study period.

Estimates of the detection range of the recording units, probability of detection from our automated detectors and accuracy of our locator tool support the spatial and temporal trends reflected in the data.

8.2 Ambient Noise Environment

Noise patterns from long-term noise spectrograms at the full 0-4 kHz and 1/3rd octave frequency scales suggest relatively consistent baseline ambient noise levels among sites and deployments. Louder periods of noise were concentrated in the lower range of frequencies (below 1 kHz), with the quietest periods of noise in the highest frequencies (3-4 kHz). Measurements from power spectral density plots confirm that 50% median noise values for all deployments and recording sites fall within a 75-100 dB range across all frequencies. In the species-specific frequency bands, noise levels were very high compared to other areas of the Western North Atlantic, with right whales, minke whales and humpback whales experiencing the highest levels of noise at the inshore sites T1 and T2, where average noise measurements were between 100-115 dB in their specific frequency ranges. The fin whale frequency band measured the lowest noise of the four species, with the offshore sites T3 and T4 measuring louder than the inshore sites at approximately a median noise value of 105 dB.

8.3 Odontocetes

Odontocete acoustic signals were recorded across the continental shelf at all four high-frequency AMAR sites, totaling 3,731 encounters. Clicks, whistles, and buzzes were recorded at all sites, though there was spatial variability for occurrence of each signal type, where clicks were most dominant at site T1 and buzzes were most dominant at site T2. High-frequency whistles occurred mostly at site T4 while the low-frequency whistles occurred most at site T1. Given visually observed occurrence of odontocete species in this region, we determined the ROCCA was not appropriate for signal classification on the species-level in this region. The ROCCA classified most signals as species that are less common, and infrequently classified the more common species in this region.

8.4 Conclusions and Recommendations

This study found ample evidence of vocally active right whales, humpback whales and fin whales and the abundance of detected calls showed patterns of seasonality and inter-annual variation. While, minke whales were not detected at the frequency level of the other species, their presence was confirmed in the study area, especially in waters further offshore. Peak presence in the winter months was contrasted by low periods of presence in the summer months, and while periods of time existed when no whales were detected, the variability between seasons and years, as well as the conservative approach to our study design supports a conclusion that for any given time, there is a chance of baleen whale presence in the area. Within the study area, whales were found across the recording transect, with different species having different distributions. Only the right whale had the largest proportion of detected presence within the WEA, but all four species did have some minimum level of presence inside the WEA.

Our recommendations from these temporal and spatial results are that potential impacts from wind energy development pose the highest risks to right whales during their peak seasonal presence from November through April. Humpback, fin and minke whales are also at highest risk during their peak seasonal occurrence in the area, however that risk is somewhat lessened by their probability of being detected further offshore from the WEA. We caution that the variability between years makes defining peak seasonal presence difficult, and the potential environmental, anthropogenic or biological drivers of this variability are poorly understood. Based on the variable low-level monthly presence during the summer offseason months, we conclude that any risk posed by wind energy development cannot be completely mitigated through seasonal planning of activities.

Baseline ambient noise for the study area revealed a very high level of background noise at low frequencies, especially in the communication bandwidth of the right whale, minke whale and humpback whales. While we still do not fully understand how the current chronic noise conditions affect the whales on a population level, we can conclude that the addition of turbine construction and operation would not represent a large increase in ambient noise levels, due to the current high levels of noise. We recommend measures that would mitigate risks to whales from pile driving and acute noise events and caution that even modest increases in ambient noise levels within the WEA may elicit behavioral responses from whales. Therefore, the risks of noise increases are highest for right whales that have the largest distribution in the WEA, and that further studies or analyses may be warranted to understand the potential impacts from these risks. Adding additional protections such as extending speed-restricted seasonal management areas boundaries to the WEA may mitigate some of the risks.

9 References

Ambler JB. 2011. Whales and the people who watch them: Baleen Whales in Virginia's near-shore waters and the educational and conservation potential of whale watching [Ph.D. Dissertation]. [Fairfax, VA]: George Mason University.

Au WWL. 1993. The Sonar of Dolphins. New York, NY: Springer.

Au WWL, Pack AA, Lammers MO, Herman LM, Deakos MH, Andrews K. 2006. Acoustic properties of humpback whale songs. J Acoust Soc Am 120(2):1103-1110.

Bailey H, Senior B, Simmons D, Rusin J, Picken G, Thompson PM. 2010. Assessing underwater noise levels during pile-driving at an offshore windfarm and its potential effects on marine mammals. Mar Pollut Bull 60(6):888-897.

Barker DJ, Herrera C, West MO. 2014. Automated detection of 50-kHz ultrasonic vocalizations using template matching in XBAT. J Neurosci Meth 236:68-75.

Bioacoustics Research Program. 2012. XBAT R6: Extensible Bioacoustics Tool. Ithaca, NY: Cornell Lab of Ornithology.

Bioacoustics Research Program. 2015. Raven Pro 1.5: Interactive Sound Analysis Software. Ithaca, NY: Cornell Lab of Ornithology. Available at: http://www.birds.cornell.edu/brp/raven/RavenOverview.html.

Bioacoustics Research Program. 2017. Acoustic Ecology Toolbox. Ithaca, NY: Cornell Laboratory of Ornithology.

Bioacoustics Research Program. 2018. Raven Pro 2.0: Interactive Sound Analysis Software. Ithaca, NY: Cornell Lab of Ornithology. Available at: http://www.birds.cornell.edu/brp/raven/RavenOverview.html.

Blaylock RA. 1985. The marine mammals of Virginia with notes on identification and natural history. VIMS Education Series No. 35 (VSG-85-05). Gloucester Point, VA: Virginia Sea Grant, Virginia Institute of Marine Science.

Blaylock RA. 1988. Distribution and abundance of the bottlenose dolphin, *Tursiops truncatus* (Montagu, 1821), in Virginia. Fish Bull 86(4):797-805.

Bort J, Van Parijs SM, Stevick PT, Summers E, Todd S. 2015. North Atlantic right whale *Eubalaena glacialis* vocalization patterns in the central Gulf of Maine from October 2009 through October 2010. Endang Species Res 26(3):271-280.

Calupca TA, Fristrup KM, Clark CW. 2000. A compact digital recording system for autonomous bioacoustic monitoring. J Acoust Soc Am 108(5):2582.

Chabot D. 1988. A quantiative technique to compare and classify humpback whale (*Megaptera novaeangliae*) sounds. Ethology 77(2):89-102.

Clark CW, Brown MW, Corkeron PJ. 2010. Visual and acoustic surveys for North Atlantic right whales, *Eubalaena glacialis*, in Cape Cod Bay, Massachusetts, 2001-2005: management implications. Mar Mamm Sci 26(4):837-854.

Clark CW, Ellison WT, Southall BL, Hatch L, Van Parijs SM, Frankel A, Ponirakis D. 2009. Acoustic masking in marine ecosystems: intuitions, analysis, and implication. Mar Ecol Prog Ser 395:201-222.

Clark CW, Gagnon GJ. 2002. Low-frequency vocal behaviors of baleen whales in the North Atlantic: insights from integrated undersea surveillance system detections, locations, and tracking from 1992 to 1996. US Navy J Underw Acoust 52(3):609-640.

Cole TVN, Hamilton P, Henry AG, Duley P, Iii RMP, White BN, Frasier T. 2013. Evidence of a North Atlantic right whale *Eubalaena glacialis* mating ground. Endang Species Res 21(1):55-64.

Davis GE, Baumgartner MF, Gurnee J, Bell J, Berchok C, Bort Thornton J, Brault S, Buchanan G, Charif RA, Cholewiak D, Clark CW, Corkeron P, Delarue J, Dudzinski K, Hatch L, Hildebrand J, Hodge L, Klinck H, Kraus S, Martin B, Mellinger DK, Moors-Murphy H, Nieukirk S, Nowacek D, Parks S, Read A, Rice AN, Risch D, Širović A, Soldevilla M, Stafford K, Stanistreet J, Summers E, Todd S, Warde A, Parijs SMV. 2017. Long-term passive acoustic recordings track the changing distribution of North Atlantic right whales (*Eubalaena glacialis*) from 2004 to 2014. Sci Rep 7:13460.

Delarue J, Todd SK, Van Parijs SM, Di Iorio L. 2009. Geographic variation in Northwest Atlantic fin whale (*Balaenoptera physalus*) song: Implications for stock structure assessment. J Acoust Soc Am 125(3):1774-1782.

Department of the Navy. 2009. Virginia Capes Range Complex Final Environmental Impact Statement/ Overseas Environmental Impact Statement (EIS/OEIS), Volume 1. Norfolk, VA: NAVFAC Atlantic.

Dugan P, Pourhomayoun M, Shiu Y, Paradis R, Rice A, Clark C. 2013. Using high performance computing to explore large complex bioacoustic soundscapes: case study for right whale acoustics. Procedia Comput Sci 20:156-162.

Dugan PJ, Zollweg J, Roch MA, Helble T, Pitzrick MS, Clark CW, Klinck H. Forthcoming 2018. The Raven-X Software Package: A scalable high-performance computing framework in Matlab for the analysis of large bioacoustic sound archives. Ithaca, NY: Bioacoustics Research Program. DOI: 10.5281/zenodo.1221417

Dunlop RA, Cato DH, Noad MJ. 2008. Non-song acoustic communication in migrating humpback whales (*Megaptera novaeangliae*). Mar Mamm Sci 24(3):613-629.

Dunlop RA, Noad MJ, Cato DH, Stokes D. 2007. The social vocalization repertoire of east Australian migrating humpback whales (*Megaptera novaeangliae*). J Acoust Soc Am 122(5):2893-2905.

Ellison WT, Southall BL, Clark CW, Frankel AS. 2012. A new context-based approach to assess marine mammal behavioral responses to anthropogenic sounds. Conserv Biol 26(1):21-28.

Foley MM, Halpern BS, Micheli F, Armsby MH, Caldwell MR, Crain CM, Prahler E, Rohr N, Sivas D, Beck MW, Carr MH, Crowder LB, Emmett Duffy J, Hacker SD, McLeod KL, Palumbi SR, Peterson CH, Regan HM, Ruckelshaus MH, Sandifer PA, Steneck RS. 2010. Guiding ecological principles for marine spatial planning. Mar Policy 34(5):955-966.

Hain JHW, Ratnaswamy MJ, Kenney RD, Winn HE. 1992. The fin whale, *Balaenoptera physalus*, in waters of the northeastern United States continental shelf. Rep Int Whale Comm 42:653-669.

Hatch LT, Clark CW, Van Parijs SM, Frankel AS, Ponirakis DW. 2012. Quantifying loss of acoustic communication space for right whales in and around a US National Marine Sanctuary. Conserv Biol 26(6):983-994.

Hildebrand JA. 2009. Anthropogenic and natural sources of ambient noise in the ocean. Mar Ecol Prog Ser 395:5-20.

Hodge KB, Muirhead CA, Morano JL, Clark CW, Rice AN. 2015. North Atlantic right whale occurrence in two wind planning areas along the mid-Atlantic U.S. coast: implications for management. Endang Species Res 28:225-234.

Jobst WJ, Adams SL. 1977. Statistical analysis of ambient noise. J Acoust Soc Am 62(1):63-71.

Klinck H, Mellinger DK. 2012. The energy ratio mapping algorithm: A tool to improve the energy-based detection of odontocete echolocation clicks. J Acoust Soc Am 131(5):4203-4203.

Kraus SD, Brown MW, Caswell H, Clark CW, Fujiwara M, Hamilton PK, Kenney RD, Knowlton AR, Landry S, Mayo CA. 2005. North Atlantic right whales in crisis. Science 309(5734):561.

Kraus SD, Leiter S, Stone K, Wikgren B, Mayo C, Nughes P, Kenney RD, Clark CW, Rice AN, Estabrook B, Tielens J. 2016. Northeast large pelagic survey collaborative aerial and acoustic surveys for large whales and sea turtles. OCS Study BOEM 2016-054. Herndon, VA: U.S. Department of Interior, Bureau of Ocean Energy Management, Office of Renewable Energy Programs.

Kraus SD, Prescott JH, Knowlton AR, Stone GS. 1986. Migration and calving of right whales (*Eubalaena glacialis*) in the Western North Atlantic. Rep Int Whale Comm 10:139-144.

LaBrecque E, Courtice C, Harrison J, Van Parijs SM, Halpin PN. 2015. Biologically important areas for cetaceans within U.S. waters – East Coast region. Aquat Mamm 41(1):17-29.

Lammers MO, Au WWL, Herzing DL. 2003. The broadband social acoustic signaling behavior of spinner and spotted dolphins. J Acoust Soc Am 114(3):1629-1639.

Lammers MO, Howe M, Zang E, McElligott M, Engelhaupt A, Munger L. 2017. Acoustic monitoring of coastal dolphins and their response to naval mine neutralization exercises. R Soc Open Sci 4(12):16.

Madsen PT, Wahlberg M, Tougaard J, Lucke K, Tyack P. 2006. Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs. Mar Ecol Prog Ser 309:279-295.

Marchetto P, Strickhart A, Mack R, Cheyne H, Ieee. 2012. Temperature compensation of a Quartz tuning-fork clock crystal via post-processing. IEEE Int Freq Control Symp:1-4.

McDonald MA, Hildebrand JA, Webb SC. 1995. Blue and fin whales observed on a seafloor array in the Northeast Pacific. J Acoust Soc Am 98(2):712-721.

Mellinger DK, Nieukirk SL, Matsumoto H, Heimlich SL, Dziak RP, Haxel J, Fowler M, Meinig C, Miller HV. 2007. Seasonal occurrence of North Atlantic right whale (*Eubalaena glacialis*) vocalizations at two sites on the Scotian Shelf. Mar Mamm Sci 23(4):856-867.

Merrick RL, Clapham PJ, Cole TVN, Gerrior P, Pace RM. 2001. Identification of seasonal area management zones for North Atlantic right whale conservation. Woods Hole, MA: Northeast Fisheries Science Center Reference Document 01-14.

Morano JL, Rice AN, Tielens JT, Estabrook BJ, Murray A, Roberts B, Clark CW. 2012a. Acoustically detected year-round presence of right whales in an urbanized migration corridor. Conserv Biol 26:698-707.

Morano JL, Salisbury DP, Rice AN, Conklin KL, Falk KL, Clark CW. 2012b. Seasonal changes in fin whale song in the Western North Atlantic Ocean. J Acoust Soc Am 132(2):1207-1212.

Mussoline SE, Risch D, Hatch LT, Weinrich MT, Wiley DN, Thompson MA, Corkeron PJ, Van Parijs SM. 2012. Seasonal and diel variation in North Atlantic right whale up-calls: implications for management and conservation in the northwestern Atlantic Ocean. Endang Species Res 17(1):17-26.

National Marine Fisheries Service. 2018. Taking and importing marine mammals; Taking marine mammals incidental to the U.S. Navy training and testing activities in the Atlantic Fleet Training and Testing Study Area. Fed Reg 83(49):10954-11096.

Nowacek DP, Thorne LH, Johnston DW, Tyack PL. 2007. Responses of cetaceans to anthropogenic noise. Mamm Rev 37(2):81-115.

Oswald JN, Rankin S, Barlow J, Lammers MO. 2007. A tool for real-time acoustic species identification of delphinid whistles. J Acoust Soc Am 122(1):587-595.

Parks SE, Clark CW. 2007. Acoustic communication: social sounds and the potential impacts of noise. In: Kraus SD, Rolland RM, editors. The Urban Whale: North Atlantic Right Whales at the Crossroads. Cambridge, MA: Harvard University Press. p. 310-332.

Payne RS, McVay S. 1971. Songs of humpback whales. Science 173(3997):585-597.

Peterson APG, Gross EE. 1978. Handbook of noise measurement, 8th ed. Concord, MA: GenRad.

Popescu M, Dugan PJ, Pourhomayoun M, Risch D, Lewis HW, Clark CW. 2013. Bioacoustical periodic pulse train signal detection and classification using spectrogram intensity binarization and energy projection. ICML 2013 Workshop on Machine Learning for Bioacoustics arXiv:1305.3250.

Punt MJ, Groeneveld RA, van Ierland EC, Stel JH. 2009. Spatial planning of offshore wind farms: A windfall to marine environmental protection? Ecol Econom 69(1):93-103.

Rice AN, Morano JL, Hodge KB, Salisbury DP, Muirhead CA, Clark CW. 2014a. Baseline bioacoustic characterization for offshore alternative energy development in North Carolina and Georgia wind planning areas, Final Technical Report. U.S. Department of Interior, Bureau of Ocean Energy Management, New Orleans, LA. BOEM Atlantic OCS Study 2014-006.

Rice AN, Tielens JT, Estabrook BJ, Muirhead CA, Rahaman A, Guerra M, Clark CW. 2014b. Variation of ocean acoustic environments along the western North Atlantic coast: a case study in context of the right whale migration route. Ecol Informat 21:89-99.

Richardson WJ, Greene CR, Malme CI, Thomson DH. 1995. Marine Mammals and Noise, 1st ed. San Diego: Academic Press.

Risch D, Castellote M, Clark CW, Davis GE, Dugan PJ, Hodge LE, Kumar A, Lucke K, Mellinger DK, Nieukirk SL, Popescu CM, Ramp C, Read AJ, Rice AN, Silva MA, Siebert U, Stafford KM, Verdaat H, Van Parijs SM. 2014. Seasonal migrations of North Atlantic minke whales: novel insights from large-scale passive acoustic monitoring networks. Mov Ecol 2(1):24.

Risch D, Clark CW, Dugan PJ, Popescu M, Siebert U, Van Parijs SM. 2013. Minke whale acoustic behavior and multi-year seasonal and diel vocalization patterns in Massachusetts Bay, USA. Mar Ecol Prog Ser 489:279-295.

Roberts JJ, Best BD, Mannocci L, Fujioka E, Halpin PN, Palka DL, Garrison LP, Mullin KD, Cole TVN, Khan CB, McLellan WA, Pabst DA, Lockhart GG. 2016. Habitat-based cetacean density models for the U.S. Atlantic and Gulf of Mexico. Sci Rep 6:22615.

Robinson SP, Lepper PA, Ablitt J. 2007. The measurement of the underwater radiated noise from marine piling including characterisation of a "soft start" period. OCEANS 2007 - Europe:1-6.

Roth EH, Hildebrand JA, Wiggins SM, Ross D. 2012. Underwater ambient noise on the Chukchi Sea continental slope from 2006--2009. J Acoust Soc Am 131(1):104-110.

Salisbury DP, Clark CW, Rice AN. 2016. Right whale occurrence in the coastal waters of Virginia, U.S.A.: implications of endangered species presence in a rapidly developing energy market. Mar Mamm Sci 32(2):509-519.

Samuel Y, Morreale SJ, Clark CW, Greene CH, Richmond ME. 2005. Underwater, low-frequency noise in a coastal sea turtle habitat. J Acoust Soc Am 117(3):1465-1472.

Shiu Y, Greene E, Morano JL, Billings AC, Hawthorne DL, Clark CW. 2016. A practical guide for designing acoustic recording arrays in terrestrial environments: best practices for maximizing location accuracy and precision. Presented at the Ecoacoustics Congress June 5-7, 2016, East Lansing, Michgan, United States.

Silber GK. 1986. The relationship of social vocalizations to surface behavior and aggression in the Hawaiian humpback whale (*Megaptera novaeangliae*). Can J Zool 64(10):2075-2080.

Simard Y, Lepage R, Gervaise C. 2010. Anthropogenic sound exposure of marine mammals from seaways: Estimates for Lower St. Lawrence Seaway, eastern Canada. Appl Acoust 71(11):1093-1098.

Thompson PM, Lusseau D, Barton T, Simmons D, Rusin J, Bailey H. 2010. Assessing the responses of coastal cetaceans to the construction of offshore wind turbines. Mar Pollut Bull 60(8):1200-1208.

Thompson PO, Cummings WC, Ha SJ. 1986. Sounds, source levels, and associated behavior of humpback whales, southeast Alaska. J Acoust Soc Am 80(3):735-740.

Tougaard J, Carstensen J, Teilmann J, Skov H, Rasmussen P. 2009. Pile driving zone of responsiveness extends beyond 20 km for harbor porpoises (*Phocoena phocoena* (L.)). J Acoust Soc Am 126(1):11-14.

U.S. Department of Transportation Maritime Administration (MARAD). 2013. 2011 US Water Transportation Statistical Snapshot. Washington, D.C.: Office of Policy and Plans, Maratime Administration, US Department of Transportation.

Urazghildiiev IR, Clark CW, Krein TP, Parks SE. 2009. Detection and recognition of North Atlantic right whale contact calls in the presence of ambient noise. IEEE J Ocean Eng 34(3):358-368.

Urick RJ. 1967. Principles of underwater sound for engineers. New York: McGraw-Hill Book Company.

Urick RJ. 1986. Ambient noise in the sea. Los Altos Hills, CA: Peninsula Publishing.

Waring GT, Josephson E, Maze-Foley K, Rosel PE. 2014. U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments - 2013. NOAA Tech Memo NMFS-NE-228. Woods Hole, MA: National Marine Fisheries Service, National Oceanic and Atmospheric Administration.

Watkins WA, Tyack P, Moore KE, Bird JE. 1987. The 20-Hz signals of finback whales (*Balaenoptera physalus*). J Acoust Soc Am 82(6):1901-1912.

Weirathmueller MJ, Wilcock WSD, Soule DC. 2013. Source levels of fin whale 20 Hz pulses measured in the Northeast Pacific Ocean. J Acoust Soc Am 133(2):741-749.

Wenz GM. 1962. Acoustic ambient noise in the ocean: spectra and sources. J Acoust Soc Am 34(12):1936-1956.

Wenz GM. 1972. Review of underwater acoustics research: noise. J Acoust Soc Am 51(3):1010-1024.

Whitt AD, Dudzinski K, Laliberté JR. 2013. North Atlantic right whale distribution and seasonal occurrence in nearshore waters off New Jersey, USA, and implications for management. Endang Species Res 20(1):59-69.

Wiggins SM, Roch MA, Hildebrand JA. 2010. TRITON sotware package: Analyzing large passive acoustic monitoring data sets using MATLAB. J Acoust Soc Am 128(4):2299-2299.

Wingfield JE, O'Brien M, Lyubchich V, Roberts JJ, Halpin PN, Rice AN, Bailey H. 2017. Year-round spatiotemporal distribution of harbour porpoises within and around the Maryland Wind Energy Area. PLoS ONE 12(5):e0176653.

Winn HE, Price CA, Sorensen PW. 1986. The distributional biology of the right whale (*Eubalaena glacialis*) in the western North Atlantic. Rep Int Whale Comm Special Issue (10):129-138.

Department of the Interior (DOI)

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

Bureau of Ocean Energy Management (BOEM)

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

BOEM Environmental Studies Program

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