Acoustic and Visual Surveys for Baleen Whales in Virginia’s Coastal Waters

Final Report
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# Table of Contents

**Executive Summary** .................................................................................................................. 5  
**Background** ............................................................................................................................... 5  
  Importance of Virginia Waters ........................................................................................................ 5  
  Visual and Acoustic Surveys ........................................................................................................... 6  
  Study Objectives ............................................................................................................................ 6  
**Methods** .................................................................................................................................... 7  
  Acoustic Data Collection ................................................................................................................ 7  
  Aerial Observation Data Collection ............................................................................................... 9  
  Acoustic Analysis of Multiple Species during 10 days of Acoustic and Aerial Surveys .......... 10  
    Right Whale Acoustic Analysis .................................................................................................... 11  
    Minke Whale Acoustic Analysis .................................................................................................. 12  
    Sei Whale Acoustic Analysis ....................................................................................................... 13  
    Humpback Whale Acoustic Analysis ............................................................................................ 14  
    Fin Whale Acoustic Analysis ....................................................................................................... 15  
**Objectives** .................................................................................................................................. 16  
  Objective 1: Compare the number of visual sightings with the number of acoustic detections during 10 days of acoustic and aerial surveys. .............................................................................. 16  
  Objective 2: Determine the detection overlap of the two survey methods for each species within set timeframes. .................................................................................................................................................. 16  
  Objective 3: Quantify the effect of ambient noise on the acoustic detectability of each species using the aerial survey results as a baseline for presence. .............................................................................. 17  
  Objective 4: Quantify the effect of sea state and visibility on the visual detectability of each species using the PAM results as a baseline for presence. .............................................................. 17  
  Objective 5: Where applicable, investigate whether call type and call rate are correlated to group size for each species. ......................................................................................................................... 17  
  Objective 6: Where applicable, investigate whether call type and call rate are correlated to behavioral state for each species. ......................................................................................................................... 18  
**Additional Work:** Describe right whale acoustic presence throughout the study site during the first year of recordings. .................................................................................................................. 18  

**Results** ....................................................................................................................................... 18  
  Objective 1: Compare the number of visual sightings with the number of acoustic detections during 10 days of acoustic and aerial surveys. .............................................................................. 18  
  Objective 2: Determine the detection overlap of the two survey methods for each species within set timeframes. .................................................................................................................................................. 20  
  Objective 3: Quantify the effect of ambient noise on the acoustic detectability of each species using the aerial survey results as a baseline for presence. .............................................................................. 25  
  Objective 4: Quantify the effect of sea state and visibility on the visual detectability of each species using the PAM results as a baseline for presence. .............................................................................. 25  
  Objective 5: Where applicable, investigate whether call type and call rate are correlated to group size for each species. ......................................................................................................................... 26  
  Objective 6: Where applicable, investigate whether call type and call rate are correlated to behavioral state for each species. ......................................................................................................................... 26
Additional Results: Right whale acoustic presence throughout the study site during the first year of recordings........................................................................................................................................26

Discussion........................................................................................................................................28
Detecting and identifying species acoustically ......................................................................................28
Comparing the number of visual sightings with the number of acoustic detections...............................29
Detection overlap between aerial and acoustic surveys ............................................................................29
Quantifying the effect of ambient noise on species’ detectability ..........................................................29
Quantifying the effect of sea state and visibility on the visual detectability of each species using the PAM results as a baseline for presence..................................................................................30
Right whale acoustic presence in Virginia...............................................................................................30
Significance of Virginia to cetaceans and directions for future research..................................................30

Literature Cited ......................................................................................................................................31
Executive Summary

The Bioacoustics Research Program (BRP) at Cornell University collected acoustic data from June 2012 through January 2014 off the coast of Virginia to determine whale presence through passive acoustic monitoring (PAM). Data were collected at five sites in an east-west transect across the outer continental shelf. The location and period of this monitoring effort coincided with aerial over flight whale surveys conducted by the Virginia Aquarium between 26 November 2012 and 29 October 2013. The focus of this report is to 1) document the seasonal occurrence of the endangered North Atlantic right whale off the Virginia coast, and 2) compare the effectiveness of aerial and acoustic surveys for determining the presence of five baleen whale species in an area where wind energy development is planned to occur. The five species of interest for this project are: North Atlantic right (*Eubalaena glacialis*), minke (*Balaenoptera acutorostrata*), sei (*Balaenoptera borealis*), humpback (*Megaptera novaeangliae*), and fin (*Balaenoptera physalus*) whales. All of these species are protected under the Marine Mammal Protection Act, and four of them (right, sei, humpback, and fin) under the Endangered Species Act. The North Atlantic right whale is one of the principal species of concern, and its occurrence influences human activities in the Atlantic. Even though much of the literature suggests either low-degrees of occurrence of many of these whale species, or no data at all, we found that North Atlantic right whales were present off the coast of Virginia nearly year-round. This effort is the first study demonstrating right whale presence during all seasons in these waters. We observed several of the other focal species throughout the year as well. In comparing the two survey methods to evaluate their effectiveness for wildlife monitoring, the acoustic survey detected daily presence of the five focal species approximately three times as often as did the aerial surveys. These findings demonstrate the importance of this particular habitat to the five focal species and the utility of PAM for characterizing long term species distribution patterns in areas with limited historical data and increasing amounts of anthropogenic activity. These data can be used to guide wind energy development in the Virginia wind lease area, reduce risks to development, and suggest future cost-effective strategies for wildlife monitoring and environmental risk mitigation.

Background

Importance of Virginia Waters

The shelf waters off Virginia, which are a current focus for offshore wind energy development, comprise a habitat that supports a number of cetacean species. Understanding the occurrence and seasonality of marine protected species can resolve information gaps, thus substantially reducing potential industry risk in wind development due to possible environmental impacts. Minke, sei, and fin whales occupy this area to various extents (Mead 1977; Ambler 2011; Waring et al. 2013), as do North Atlantic right and humpback whales travelling between southern calving grounds and northern feeding grounds (Wiley & Asmutis 1995; Kenney et al. 2001). While it has long been established that female and juvenile right whales use mid-Atlantic shelf waters as a migratory corridor (Winn et al. 1986), Swingle (1993) and Wiley (1995) suggest that the area is becoming an increasingly important habitat for juvenile humpback whales. An increasing number of recent studies document previously unobserved trends in whale distribution along the mid-Atlantic (Whitt et al. 2013; Hodge, et al. In prep; Salisbury et al. In review). Historically, the majority of survey efforts for these species have focused on areas where they are expected to occur and during seasons of peak presence (i.e. waters north of Delaware during spring, summer, and fall) (Waring et al. 2013) while surveys of migratory corridors and sporadically occupied
areas have received less attention. Long-term systematic surveys of these large geographic areas have, to a great extent, been cost prohibitive until the introduction of lower cost PAM methods.

Here, we focus on a habitat which lacks historical baseline data. Ship strikes, construction, and the introduction of anthropogenic noise have been identified as threats associated with these energy development activities (Bureau of Ocean Energy Management (BOEM) 2012). Therefore, an understanding of protected species’ habitat use in the area can help reduce risk to offshore wildlife and quantify impacts that may arise throughout the construction and operation phases of planned wind energy installations.

**Visual and Acoustic Surveys**

Mitigation of impacts to protected species first requires establishing when and where the species occur. Yet surveying for whales to answer these fundamental questions continues to present a challenge to researchers and regulators. Whale migratory ranges cover vast areas, often requiring survey efforts at remote locations under adverse environmental conditions. Strategies to accomplish this, which rely on either visual identification of surfacing whales or acoustic detection of vocalizing whales, each have different associated advantages and disadvantages. Visual surveys offer the ability to determine individual identity, group size and composition, direction of travel, behavioral state, and in the case of ship strikes or line entanglements, the physical condition of individuals. However, they are limited by available daylight, weather, sea state, species’ surface time, and the high cost of operation. Alternatively, passive acoustic monitoring surveys offer the ability to monitor relatively large areas continually, for long periods of time, in remote locations regardless of weather, daylight, or sea state, and at relatively low cost; yet lack the ability to identify specific individuals, detect silent individuals, and apart from synchronized arrays, locate individuals, determine group size, or direction of travel (Mellinger et al. 2007; Van Parijs et al. 2009).

Inquiries of behavior, movement patterns, habitat use, and population size have historically relied on either visual or acoustic surveys (Watkins & Schevill 1979; Clark et al. 1996; Hain et al. 1999; Pollock et al. 2006; Mellinger et al. 2007) and more rarely have used both in a complementary manner (Ko et al. 1986; George et al. 2004; Barlow & Taylor 2005). Utilizing the complementary value of both survey types may allow for an evaluation of survey effectiveness for monitoring requirements, as well as provide insights that could not be made using either method alone, such as establishing relationships between group size and call rate (Clark et al. 2010) or social behavior and call type (Parks & Tyack 2005).

**Study Objectives**

In this study, we aim to compare the effectiveness of aerial and acoustic surveys for determining the presence of five baleen whale species: North Atlantic right, minke, sei, humpback, and fin whales. Understanding the difference in information coming from these two different marine mammal survey methods may help guide further wildlife monitoring and mitigation strategies for the Commonwealth of Virginia as offshore wind development proceeds. Our specific objectives are as follows.

1) Compare the number of visual sightings with the number of acoustic detections during 10 days of acoustic and aerial surveys.
2) Determine the detection overlap of the two survey methods for each species within set timeframes.
3) Quantify the effect of ambient noise on the acoustic detectability of each species using the aerial survey results as a baseline for presence.
4) Quantify the effect of sea state and visibility on the visual detectability of each species using the PAM results as a baseline for presence.

5) Where applicable, investigate whether call type and call rate are correlated to group size for each species.

6) Where applicable, investigate whether call type and call rate are correlated to behavioral state for each species.

Methods

Acoustic Data Collection

Five marine autonomous recording units (MARUs; described in (Calupca et al. 2000; Morano et al. 2012) were deployed on the seafloor in an east-west transect off the Virginia coast, extending to the edge of the continental shelf (Figure 1). All five units were deployed in shallow water, ranging in depth from 21 m (Site 1) to 50 m (Site 5). While initially deployed under the scope of a separate project, the recorded data were incorporated for this present study. Each MARU was equipped with a HTI-94-SSQ hydrophone, had a flat frequency response of -151.2 dB (re: 1 V/µPa) between 15 and 585 Hz (Parks et al. 2009), and recorded continuously at a 2 kHz sampling rate. Each MARU had a 10 Hz high-pass filter to reduce electrical interference from the recording unit and an anti-aliasing low-pass filter at 800 Hz.

Three consecutive, six-month MARU deployments recorded data from 2 June 2012 through 9 January 2014 with two days of missing coverage on 10 November 2012 and 12 June 2013 when the MARUs were recovered and redeployed. During the third deployment, an extra MARU was deployed in the middle of the transect for additional acoustic coverage (Site 6). Several of the MARUs experienced hardware issues that resulted in data coverage gaps. Site 2 was not recovered during the second deployment whereas Site 1 and Site 3 stopped recording early. Site 4 had a hardware malfunction that resulted in a loss of data during the first half of the second deployment. During the third deployment, Sites 1,2,3,5 and 6 stopped recording early due to an internal hardware malfunction. The date ranges of the recording periods for each site are listed for comparison (Table 1).
**Figure 1.** Map of acoustic and aerial survey study area off the coast of Virginia. MARU sites are represented by yellow circles. Aerial survey transects flown throughout the study are labeled as Line 1-12. The BOEM wind energy lease block for this area is shown in pink (data from http://www.marinecadastre.gov).
Table 1. Locations, times, and depths of MARU deployments

<table>
<thead>
<tr>
<th>MARU Site</th>
<th>Latitude (°)</th>
<th>Longitude (°)</th>
<th>Depth (m)</th>
<th>Recording Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36.8640</td>
<td>-75.6652</td>
<td>21</td>
<td>6/2/2012 - 5/26/2013</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6/11/2013 - 12/30/2013</td>
</tr>
<tr>
<td>2</td>
<td>36.9341</td>
<td>-75.4249</td>
<td>28</td>
<td>6/2/2012 - 11/9/2012</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6/11/2013 - 12/13/2013</td>
</tr>
<tr>
<td>3</td>
<td>36.8679</td>
<td>-75.2750</td>
<td>31</td>
<td>6/2/2012 - 6/4/2013</td>
</tr>
<tr>
<td>4</td>
<td>36.9214</td>
<td>-75.1037</td>
<td>35</td>
<td>5/31/2013 - 6/8/2013</td>
</tr>
<tr>
<td>5</td>
<td>36.9185</td>
<td>-74.8384</td>
<td>50</td>
<td>6/2/2012 - 1/9/2014</td>
</tr>
<tr>
<td>6</td>
<td>36.9651</td>
<td>-75.2979</td>
<td>33</td>
<td>6/11/2013 - 9/12/2013</td>
</tr>
</tbody>
</table>

Aerial Observation Data Collection

Aerial surveys were carried out from 26 November 2012 through 29 October 2013 by the Virginia Aquarium Foundation (VAQF) and the University of North Carolina Wilmington (UNCW) in over-wing, twin-engine, Cessna 337 aircraft (Table 2). The survey team included two observers and a coordinator. Surveys were flown only in safe operating conditions according to NOAA Aircraft Operations Center (AOC) standards and under visual flight regulations (VFR) flight conditions.

Survey track-lines, oriented perpendicular to shore, began at 36.60° N, and ran at 6 km intervals to 37.25°N, off the eastern shore of Virginia. Each track-line began at the beach and extended to 30-50 nmi (55-92 km) offshore (Figure 1). Surveys were flown at 1,000 feet altitude at operational airspeeds of 100 mph. The two observers, positioned on each side of the aircraft (left and right), carried out the surveys. The plane was equipped with a Global Navigation System (GPS) to permit precise track-line fidelity. Each observer used an independent GPS to record precise time and geographic position of all marine mammal sightings. Binoculars were used only if an observer saw a sighting cue from a distance, or saw a possible marine mammal that was too far away to confirm with the naked eye. When a sighting occurred, the initial location on the track-line was recorded and the plane broke from the track-line. Over the actual sighting, the GPS location, species identification, and group size was collected. Observers also recorded sea state, visibility conditions, and all large vessel locations.

The probability of visually detecting a whale was highly dependent on visibility, glare, sea state, and whether a marine mammal was identified by visually detecting a body part versus a surface blow or breach. Conservatively, this range was estimated at 0.5-1.5 km, so for any given transect flown, the area sampled from both the left and right observer was estimated at 1-3 km (S. Barco, personal communication).
Table 2. Aerial Survey Dates and Transects Flown

<table>
<thead>
<tr>
<th>Date of Aerial Survey Flight</th>
<th>Transect # Flown</th>
</tr>
</thead>
<tbody>
<tr>
<td>11/26/2012</td>
<td>5,6,7,8</td>
</tr>
<tr>
<td>11/27/2012</td>
<td>5,6,7,8</td>
</tr>
<tr>
<td>2/22/2013</td>
<td>3,4,5,6,7,8,9,10</td>
</tr>
<tr>
<td>3/20/2013</td>
<td>1,2,5,6</td>
</tr>
<tr>
<td>3/29/2013</td>
<td>3,4,5,6,7,8,9,10,11,12</td>
</tr>
<tr>
<td>4/10/2013</td>
<td>1,2,3,4,5,6,7,8</td>
</tr>
<tr>
<td>4/11/2013</td>
<td>7,8,9,10,11,12</td>
</tr>
<tr>
<td>5/29/2013</td>
<td>1,2,3,4,5,6,7,8,9,10</td>
</tr>
<tr>
<td>5/30/2013</td>
<td>6,7,11,12</td>
</tr>
<tr>
<td>10/29/2013</td>
<td>5,6,7,8,9,10,11,12</td>
</tr>
</tbody>
</table>

Acoustic Analysis of Multiple Species during 10 days of Acoustic and Aerial Surveys

For each of the 10 days when aerial surveys were conducted, acoustic analysis was performed on the MARU data. 24 hour spectrograms (Hann window, 512 FFT, 90 s page duration, 0-600 Hz frequency range) were manually browsed by human analysts using a MATLAB-based program, XBAT (Bioacoustics Research Program 2012; Figueroa and Robbins 2008) to identify species-specific vocalizations from 5 species of whales: North Atlantic right, minke, sei, humpback and fin.
Right Whale Acoustic Analysis

The right whale up-call is the most commonly produced right whale call (Parks & Tyack 2005; Parks et al. 2007). Up-calls have a fundamental frequency of 100-300 Hz with the majority of energy occurring between 71 – 224 Hz (Hatch et al. 2012) and an average duration of approximately 2 s (Urazghildiiie  et al. 2009). See Figure 2 for an example of a right whale up-call. Acoustic occurrence of right whales on an hourly basis was determined using an automated detection algorithm (Urazghildiiie et al. 2009), followed by human verification of their contact up-calls (sensu Morano et al. 2012). Analysts visually identified and marked every up-call and the results were verified by a second analyst to minimize error.

![Spectrogram showing an example of a right whale contact call (up-call) occurring on 22 February 2013 at Site 3.](image)

**Figure 2.** Spectrogram showing an example of a right whale contact call (up-call) occurring on 22 February 2013 at Site 3.
Minke Whale Acoustic Analysis

Minke whales produce a series of rapid pulses with energy in the 50-400 Hz band (Mellinger et al. 2000; Risch et al. 2014), with individual pulses lasting 40-60 ms (Figure 3). These pulse trains can speed up or slow down and are 40-60 seconds in duration (Mellinger et al. 2000). To determine presence, analysts counted every pulse train and the results were checked for accuracy by a second analyst.

Figure 3. Spectrogram showing an example of a minke whale pulse train occurring on 22 February 2013 at Site 5.
Sei Whale Acoustic Analysis

The occurrence of sei whale downsweep vocalizations was used to determine sei whale presence. Sei whale downsweep vocalizations can occur as single calls, or as sets of double or triple calls, and have a bandwidth of 30-85 Hz lasting approximately 1.5 s (Figure 4; Rankin & Barlow 2007; Baumgartner et al. 2008). For each day analyzed, all downsweeps were marked and counted as separate events.

Figure 4. Example of two sei whale downsweeps occurring on 22 February 2013 at Site 3.
Humpback Whale Acoustic Analysis

We used both song sequences and social calls to determine humpback whale presence, which represent a wide and varied repertoire of upsweep, downsweep, and tonal vocalizations with fundamental frequencies often concentrated in the 100-600 Hz band (Figure 5; Payne & McVay 1971; Silber 1986; Chabot 1988). Since humpback song sequences and periods of calling activity can include a high number of individual calls, we did not count individual signals. Rather, we divided each hour quarterly and marked the presence of song or calls in each 15 minute segment for all 24 hours of the day.

Figure 5. Spectrogram showing characteristic social calls in a repeated sound pattern which can make up a segment of humpback whale song, occurring on 29 March 2013 at Site 3.
Fin Whale Acoustic Analysis

The occurrence of 20 Hz pulse fin whale song was used to determine fin whale presence. Fin whale song consists of a series of downsweeps centered at 20 Hz, lasting approximately 1 s per downsweep with regular pulse intervals of 7-26 seconds (Figure 6; Watkins et al. 1987; McDonald et al. 1995; Clark et al. 2002). Since a bout of fin whale song can contain hundreds of pulses and last for hours at a time (Watkins et al. 1987), we did not count individual signals. We divided each hour into quarters and marked the presence of fin whale song in each 15 minute segment for all 24 hours of the day.

Figure 6. Example of a segment of fin whale song occurring on 27 November 2012 at Site 1.
Objectives

Objective 1: Compare the number of visual sightings with the number of acoustic detections during 10 days of acoustic and aerial surveys.

To compare the effectiveness of each survey method at determining species presence, we compared whether acoustic detections and visual sightings occurred during each day when aerial surveys were flown. See Table 2 for aerial survey dates. For comparison at a higher spatiotemporal resolution, we reviewed the acoustic data from the geographically closest recording MARU during the hour prior to, and the hour after reported aerial sightings (Table 3).

Table 3. Aerial Survey and Acoustic Data Comparison Analysis Dates and Times. All reported times are in local EST/EDT time (UTC-5/4).

<table>
<thead>
<tr>
<th>Date of Aerial Survey</th>
<th>Time of Whale Observation*</th>
<th>Species Observed</th>
<th>Nearest Recording MARU Site</th>
<th>Period of MARU Data Browsed*</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/22/2013</td>
<td>13:54</td>
<td>Humpback whale</td>
<td>1</td>
<td>12:54-14:54</td>
</tr>
<tr>
<td>3/29/2013</td>
<td>15:06</td>
<td>Humpback whale</td>
<td>3</td>
<td>14:06-16:06</td>
</tr>
<tr>
<td>3/29/2013</td>
<td>15:11</td>
<td>Fin whale</td>
<td>3</td>
<td>14:11-16:11</td>
</tr>
<tr>
<td>3/29/2013</td>
<td>15:14</td>
<td>Fin whale</td>
<td>5</td>
<td>14:14-16:14</td>
</tr>
<tr>
<td>4/10/2013</td>
<td>10:41</td>
<td>Humpback whale</td>
<td>1</td>
<td>9:41-11:41</td>
</tr>
<tr>
<td>4/10/2013</td>
<td>15:53</td>
<td>Fin whale</td>
<td>5</td>
<td>14:53-16:53</td>
</tr>
<tr>
<td>4/11/2013</td>
<td>9:10</td>
<td>Fin whale</td>
<td>5</td>
<td>8:10-10:10</td>
</tr>
<tr>
<td>4/11/2013</td>
<td>9:26</td>
<td>Fin whale</td>
<td>5</td>
<td>8:26-10:26</td>
</tr>
<tr>
<td>4/11/2013</td>
<td>9:29</td>
<td>Fin whale</td>
<td>5</td>
<td>8:29-10:29</td>
</tr>
<tr>
<td>4/11/2013</td>
<td>9:31</td>
<td>Humpback whale</td>
<td>5</td>
<td>8:31-10:31</td>
</tr>
<tr>
<td>4/11/2013</td>
<td>9:47</td>
<td>Humpback whale</td>
<td>5</td>
<td>8:47-10:47</td>
</tr>
<tr>
<td>4/11/2013</td>
<td>9:51</td>
<td>Fin whale</td>
<td>5</td>
<td>8:51-10:51</td>
</tr>
<tr>
<td>4/11/2013</td>
<td>10:04</td>
<td>Fin whale</td>
<td>5</td>
<td>9:04-11:04</td>
</tr>
</tbody>
</table>

Objective 2: Determine the detection overlap of the two survey methods for each species within set timeframes.

To determine the detection overlap of the two survey methods, we mapped the acoustic detection ranges of each species (see Objective 3) and superimposed the aerial survey flight transects and locations of sighted species using ARC GIS mapping software (https://www.arcgis.com/). We examined the proximity of sighted species to their respective acoustic detection ranges surrounding each MARU.
Objective 3: Quantify the effect of ambient noise on the acoustic detectability of each species using the aerial survey results as a baseline for presence.

There was only one instance in which a species was visually sighted on a day and not acoustically detected (minke whale sighted; 29 March 2013). Consequently, we could not use aerial survey results as a baseline for presence. To determine the effect of increased ambient noise on the acoustic detectability of each species, we quantified the ambient noise levels in the MARU recordings by calculating the root mean square (RMS) values of 10 second time slices within the frequency band of each species’ call type. We modeled transmission loss (assuming spherical spreading) using Marine Acoustic Inc.’s Acoustic Integration Model (AIM) (Ellison et al. 1999; Frankel et al. 2002). Estimates of species’ source levels and frequency bands were based on previous studies (McDonald et al. 2005; Au et al. 2006; Širović et al. 2007; Hatch et al. 2012; Weirathmueller et al. 2013; Risch et al. 2014). Average temperature, salinity, bathymetry, and bottom type were factored in using AIM’s parameter database which consists of empirical oceanographic data. The effect of ambient noise on the acoustic detectability of each species was evaluated through this process by estimating the acoustic detection ranges at which species’ signals exceeded ambient noise levels 90% ($L_{10}$), 50% ($L_{50}$), and 10% ($L_{90}$) of the time.

Objective 4: Quantify the effect of sea state and visibility on the visual detectability of each species using the PAM results as a baseline for presence.

Because data on visibility conditions were only compiled for times when whales were sighted and not for the duration of aerial surveys, it was not feasible to assess the impact of visibility on sighting success. We were, however, provided the sea state data for each aerial survey track, regardless of whether whales were sighted or not. Sea state was estimated visually by aerial survey observers and quantified using the Beaufort scale which relates wind speed to wave height, rating sea surface conditions numerically from 0 – 12. The calmest condition has a rating of 0 and is therefore most conducive to visual detection of whales. As Beaufort sea state increases, the visibility of surfacing whales decreases.

To determine the extent of this effect on the performance of aerial surveys, we used daily presence results from the acoustic survey as a baseline, or truth set. We ran a regression analysis to examine daily aerial survey ‘false negative rate’ vs. daily average Beaufort sea state; where ‘false negative rate’ was the proportion of the truth set (acoustically determined daily presence of species) that was not detected by the aerial surveys. Because acoustic detections were treated as a ‘truth set’ in this analysis, we omitted the single instance when a whale was visually sighted but not acoustically detected (Minke whale; 29 March 2013).

Objective 5: Where applicable, investigate whether call type and call rate are correlated to group size for each species.

The acoustic analysis of two hour periods surrounding aerial sightings only yielded one matching species detection (fin whale; 10 April 2013). In order to determine whether group size was correlated to call types and call rates, we needed a much more extensive set of data containing matched visual sightings and acoustic detections within 2 hour time periods. The 10 days of aerial and acoustic data we analyzed did not provide a sufficient sample size for statistical analysis. With additional data points, an analysis of changes in call rate as a function of group size could be examined following methods described in Clark et al. (2010).
Objective 6: Where applicable, investigate whether call type and call rate are correlated to behavioral state for each species.

In order to determine if behavioral state was correlated with call types and rates, we needed a higher sample size of visual data to compare with the acoustic detections within 2 hour time periods. The 10 days of aerial and acoustic data we analyzed did not provide a sufficient sample size for statistical analysis. A more robust dataset would provide the ability to examine relationships between behaviors and call types (Parks & Tyack 2005).

Additional Work: Describe right whale acoustic presence throughout the study site during the first year of recordings.

The first year of recordings (two deployments; 2 June 2012 – 12 June 2013) were analyzed for patterns of right whale acoustic activity (as described above). Detection analysis was performed on a total of 34,464 hours of MARU data recorded from 5 sites during a 375-day period. Every detection event was visually confirmed or rejected, resulting in no false positives. A performance test of the detector algorithm found that it accurately detected 75% of up-calls (Dugan et al. 2010), indicating a low false negative rate for up-calls.

Results

Objective 1: Compare the number of visual sightings with the number of acoustic detections during 10 days of acoustic and aerial surveys.

Whales were acoustically detected on all 10 days and visually detected on 4 days. To examine daily presence on a per species basis, we termed the presence of a specific species during a specific day as a “species-day”. For example, all 5 species were present on 22 February 2013, amounting to 5 species-days. Alternatively, right whales were present on 22 February 2013, 20 March 2013, and 29 March 2013, amounting to 3 species-days. There were 16 species-days for which acoustic detections occurred and visual detections did not. Only one species-day occurred for which an aerial detection occurred and an acoustic detection did not (Tables 4, 5). When analyzing the two hours surrounding each visual sighting, only one acoustic detection of a sighted species occurred; a fin whale was sighted at 36.9729° N, 74.9369° W at 16:53 EST on 10 April 2013 and a fin whale was acoustically detected at 16:49 EST on 10 April 2013 by the closest MARU (Site 5, 10.75 km from the sighting location).
**Table 4.** Daily presence of each species determined by aerial sightings and acoustic detections. All species were present during this analysis. There were 16 species-days for which acoustic detections occurred and visual detections did not. Only one species-day occurred for which an aerial detection occurred and an acoustic detection did not. The acoustic survey detected approximately 3 times as many species-days as did the aerial survey.

<table>
<thead>
<tr>
<th>Species</th>
<th>Right</th>
<th>Humpback</th>
<th>Fin</th>
<th>Sei</th>
<th>Minke</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>Aerial</td>
<td>Acoustic</td>
<td>Aerial</td>
<td>Acoustic</td>
<td>Aerial</td>
</tr>
<tr>
<td>11/26/2012</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>11/27/2012</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2/22/2013</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3/20/2013</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3/29/2013</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4/10/2013</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4/11/2013</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>5/29/2013</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>5/30/2013</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>10/29/2013</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>8</td>
<td>3</td>
</tr>
</tbody>
</table>

**Table 5.** Acoustic detections for all 5 species of whales on days when aerial surveys were flown. Total number of calls detected is shown for right, minke and sei whales. Percent of 15 minute segments with calling activity is shown for humpback and fin whales. There were distinct temporal peaks in acoustic presence of Right, Minke, and Sei whales. Humpback and fin whales occurred more regularly.

<table>
<thead>
<tr>
<th>Date</th>
<th>Right</th>
<th>Minke</th>
<th>Sei</th>
<th>Percentage of 15 min segments with calling activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>11/26/2012</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>11/27/2012</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>2/22/2013</td>
<td>288</td>
<td>4</td>
<td>19</td>
<td>4.2</td>
</tr>
<tr>
<td>3/20/2013</td>
<td>211</td>
<td>0</td>
<td>0</td>
<td>15.6</td>
</tr>
<tr>
<td>3/29/2013</td>
<td>6</td>
<td>0</td>
<td>17</td>
<td>22.9</td>
</tr>
<tr>
<td>4/10/2013</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>14.6</td>
</tr>
<tr>
<td>4/11/2013</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12.5</td>
</tr>
<tr>
<td>5/29/2013</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2.1</td>
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<tr>
<td>5/30/2013</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.0</td>
</tr>
<tr>
<td>10/29/2013</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2.1</td>
</tr>
</tbody>
</table>
Objective 2: Determine the detection overlap of the two survey methods for each species within set timeframes.

During the 4 days when whales were sighted via aerial surveys (Figures 7-10), there were 3 instances when sighted species were located within their estimated $L_{90}$ acoustic detection ranges; Humpback on 22 February 2013, Fin on 10 April 2013, and Humpback on 11 April 2013. The remaining 17 sighting locations occurred outside of the species’ estimated $L_{90}$ acoustic detection ranges. Despite this, the species were acoustically detected within the 24 h period of each day. This is most likely due to movement of sighted individuals or the presence of additional individuals that were not sighted. Without acoustic localization analysis, we were unable to determine whether sightings and acoustic detections were of the same individuals.
Figure 7. Aerial survey results for 22 February 2013. MARU’s that were recovered and yielded data for this day are shown with estimated acoustic detection ranges (Table 4 $L_{90}$ Range) in yellow. Flight transects that were covered on this day are shown as horizontal lines. Locations of visually observed whales are shown as stars. The BOEM wind energy lease block is shown in pink (data from http://www.marinecadastre.gov). Right, minke, sei, humpback and fin whales were acoustically detected on this day (Table 5). Note: some of the acoustically detected whales may have been beyond the estimated detection range, but it is difficult to confirm with the present recording configuration.
Figure 8. Aerial survey results for 29 March 2013. MARU’s that were recovered and yielded data for this day are shown with estimated acoustic detection ranges (Table 6 L₉₀ Range) in yellow. Flight transects that were covered on this day are shown as horizontal lines. Locations of visually observed whales are shown as stars. The BOEM wind energy lease block is shown in pink (data from http://www.marinecadastre.gov). Right, sei, humpback and fin whales were acoustically detected on this day (Table 5). Note: some of the acoustically detected whales may have been beyond the estimated detection range, but it is difficult to confirm with the present recording configuration.
Figure 9. Aerial survey results for 10 April 2013. MARU’s that were recovered and yielded data for this day are shown with estimated acoustic detection ranges (Table 6, L_{90} Range) in yellow. Flight transects that were covered on this day are shown as horizontal lines. Locations of visually observed whales are shown as stars. The BOEM wind energy lease block is shown in pink (data from http://www.marinecadastre.gov). Minke, humpback and fin whales were acoustically detected on this day (Table 5). Note: the acoustically detected whales may have been beyond the estimated detection range, but it is difficult to confirm with the present recording configuration.
Figure 10. Aerial survey results for 11 April 2013. MARU’s that were recovered and yielded data for this day are shown with estimated acoustic detection ranges (Table 6, $L_{90}$ Range) in yellow. Flight transects that were covered on this day are shown as horizontal lines. Locations of visually observed whales are shown as stars. The BOEM wind energy lease block is shown in pink (data from http://www.marinecadastre.gov). Humpback and fin whales were acoustically detected on this day (Table 5). Note: some of the acoustically detected whales may have been beyond the estimated detection range, but it is difficult to confirm with the present recording configuration.
Objective 3: Quantify the effect of ambient noise on the acoustic detectability of each species using the aerial survey results as a baseline for presence.

The estimated 90% (L_{10}), 50% (L_{50}), and 10% (L_{90}) acoustic detection ranges varied among species (Table 6). Humpback and right whales had the largest detection ranges due to the relatively high source levels and broad frequency bands of their vocalizations. The 10% (L_{90}) detection range of fin whales was less than that of humpback and right whales even though fin whale source levels were the highest of the five species. This may be due to the narrow bandwidth of the 20 Hz notes targeted for detection and the prevalence of ambient noise within that bandwidth. Minke whale detection ranges were central among the values, while sei whales had the lowest detection ranges.

**Table 6.** Ranges at which species could be acoustically detected 90% (L_{10}), 50% (L_{50}), and 10% (L_{90}) of the time.

<table>
<thead>
<tr>
<th>Species</th>
<th>SL (dB)</th>
<th>Frequency Band (Hz)</th>
<th>L_{10} Range (km)</th>
<th>L_{50} Range (km)</th>
<th>L_{90} Range (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right</td>
<td>172</td>
<td>71 - 224 Hz</td>
<td>0.7</td>
<td>5.1</td>
<td>19</td>
</tr>
<tr>
<td>Minke</td>
<td>166</td>
<td>50 - 300Hz</td>
<td>0.4</td>
<td>2.9</td>
<td>11.3</td>
</tr>
<tr>
<td>Sei</td>
<td>156</td>
<td>44 - 100Hz</td>
<td>0.1</td>
<td>0.5</td>
<td>2.2</td>
</tr>
<tr>
<td>Fin</td>
<td>189</td>
<td>15 - 28 Hz</td>
<td>3.7</td>
<td>11.1</td>
<td>14</td>
</tr>
<tr>
<td>Humpback</td>
<td>173</td>
<td>20 - 600 Hz</td>
<td>0.7</td>
<td>5.3</td>
<td>18.8</td>
</tr>
</tbody>
</table>

Objective 4: Quantify the effect of sea state and visibility on the visual detectability of each species using the PAM results as a baseline for presence.

Daily average Beaufort sea state ranged from a minimum of 1.89 to a maximum of 3.05, which occurred on 26 November 2012 and 29 May 2013 respectively. We found no relationship between Beaufort sea state and the rate at which aerial surveys missed acoustically detected species (Figure 11).
Figure 11. Scatter plot of aerial survey daily false negative rate vs. Beaufort sea state. False negative rate is the proportion of the truth set (acoustically determined daily presence of species) that was not detected by the aerial surveys, where a rate of 1 means none of the acoustically detected whales were visually sighted and a rate of 0 means all acoustically detected whales were sighted.

Objective 5: Where applicable, investigate whether call type and call rate are correlated to group size for each species.

There were not sufficient data available from the aerial survey results to complete this objective. To establish a statistically significant correlation, additional data points are required.

Objective 6: Where applicable, investigate whether call type and call rate are correlated to behavioral state for each species.

There were not sufficient data available from the aerial survey results to complete this objective. To establish a statistically significant correlation, additional data points are required.

Additional Results: Right whale acoustic presence throughout the study site during the first year of recordings

Of the 375 days sampled there were 86 days on which right whale up-calls were detected on at least one recording site. Of the total 9,000 hours collectively sampled within this 375-day period, at least one right whale up-call was detected on 485 hours (Figure 12). Right whale contact calls were detected at all five sites nearly throughout the year, with the exception of June, 2013, during which there were only 12 days of acoustic recording effort at Site 5. Site 3 had the greatest number of days sampled with detections (367 days sampled, 58 days [15.8%] with detections), while Site 2 and Site 4 had the fewest days (161 days sampled, 7 days [4.3%] with detections, and 175 days sampled, 6 days [3.4%] with detections, respectively). The low number of detection days at Site 2 and Site 4 is explained by the MARUs’ failure to record properly during the second half of the recording period, so data on acoustic occurrence during the spring northward migration season were not available (Table 1).
There were two seasonal peaks of occurrence: a broad, relatively sparse peak during the fall period (October – December) and a contracted, relatively dense peak during the late winter-early spring period (February - March) (Figure 12). Overall, right whales were detected at one or more recording sites on 22% of the days during the October – December period (5 sites, 91 day period, average 70.6 days per site, range 40-91 days per site), and on 80% of the days during the February – March period (3 sites, 59 day period, average 59 days per site, range 59 days per site). In contrast, during the other 225 days of the year right whales were only detected on 8.4% of those days (3-5 sites, average 181.2 days per site, range 121-225 days per site).

During the February - March seasonal peak there was a substantial number of hours per day with acoustic detections (6.4 hours per day, 59 days) compared to the rest of the year (0.33 hours per day, 316 days) (Figure 12). The total number of detections throughout the deployment, for each hour of the day, reveals a diel pattern of right whale contact calling activity, with an increase in calls during dusk and evening periods (16:00 – 21:00h, EST, Fig 13). Over the course of the year and all sites, 61% of all detected up-calls occurred between 16:00-21:00 (Fig 13).

**Figure 12.** Total number of hours per day with right whale acoustic detections based on detection analysis for all five recording sites throughout the entire recording period from 2 June 2012 through 12 June 2013.
Figure 13. Total number of up-calls in each hour across all five recording sites throughout the entire recording period of 2 June 2012 through 12 June 2013. Hour of the day is represented as local standard time (Eastern Standard Time, UTC-5 hours), with no correction for daylight savings time.

Discussion

Detecting and identifying species acoustically

While the environmental and biological variables that affect acoustic survey performance are different from those of visual surveys, they have a similar influence in that they affect the maximum range, probability, and accuracy of detections. Therefore, even though PAM provides a means for continuous survey effort over large areas, the efficacy of this effort changes with environmental conditions, and species behavior.

Not all of the acoustic signals that we detected could be attributed to specific species. While previous research has demonstrated that the whales in this study produce readily identifiable species-specific sounds, there are call parameters that overlap. Indeed, many of the vocalizations we detected were not easily discernable; specifically, downsweeps occurring between 30 - 100 Hz over 1.5 s have been attributed to sei, fin, and humpback whales (Watkins 1981; Au et al. 2006; Rankin & Barlow 2007). Upsweeps occurring between 70 - 350 Hz have been attributed to both right and humpback whales (Payne & McVay 1971; Parks & Tyack 2005). And low frequency modulated tonal calls (< 300 Hz) have been attributed to all species in this study except minke whales (Payne & McVay 1971; Clark 1982; Cummings et al. 1986; McDonald et al. 2005). To distinguish between species with some level of confidence, we applied specific signal criteria, thereby removing overlapping signal parameters. For example, presence of fin whales was based solely on the detection of 20 Hz pulses while higher frequency downsweeps which may have been either fin or humpback whales were ignored. In doing so, our confidence that the signals were attributed to the correct species increased, but the portion of recorded signals used to quantify...
presence in the survey decreased. Our estimates of the presence of detected whales are therefore conservative.

Comparing the number of visual sightings with the number of acoustic detections

In this study, the acoustic survey method was more effective than the aerial survey method in determining the daily presence of each species. Previous studies have shown the same to be true in other geographic regions and for different focal species (Mellinger et al. 2007; Clark et al. 2010). There are factors that may affect this relative performance (e.g. infrequently vocalizing whales in noisy environments are less likely to be acoustically detected while infrequently surfacing whales in low visibility conditions are less likely to be visually detected). As such, the relative performance of each survey method will vary with species, time of day, season, and geographic area. On a broad scale however, this study, Clark et al. (2010) and Mellinger (2007) demonstrated that acoustic surveys have a higher probability of detecting the presence of their respective focal species. This is most likely due to the greater spatiotemporal coverage achieved with acoustics.

Detection overlap between aerial and acoustic surveys

The spatiotemporal coverage of aerial and acoustic surveys is different for each method. While acoustic surveys continuously cover areas with stationary centers and varying detection ranges, aerial surveys cover areas with moving central points and very limited time spent surveying any single location. Without defining spatiotemporal boundaries, quantitative comparisons of results from the two methods are to a certain extent arbitrary. Because the acoustic survey was not designed to localize calling animals, we could not verify if acoustically detected signals came from the same individuals that were visually sighted. The minimum area we could compare in this study was the full acoustic coverage area of a single MARU. Signals detected from one end of the MARU’s detection range may have occurred while the aerial overflight was occurring on the opposite end.

The majority of aerial sightings occurred outside of the estimated acoustic detection ranges. Despite this, we acoustically detected the presence of each species that was sighted on each day (except for the minke whale sighted on 29 March 2013). This sighting/detection overlap was either due to the movement of individuals throughout each day or the presence of additional conspecifics. When looking at the two hours surrounding aerial sightings on the closest MARU, the detection overlap was greatly diminished. We only detected one matching vocalizing species (fin whale; 10 April 2013 at Site 5). Overlap between the two surveys was expected to be higher for daily presence than for the 2 hours surrounding each siting, as there is a higher probability of acoustically detecting whales in a 24 h period than in a 2 h period.

Quantifying the effect of ambient noise on species’ detectability

As signal masking increases and decreases with ambient noise levels, the effective detection range of recorders may change by orders of magnitude over short periods of time. Moreover, signal propagation changes dynamically as a consequence of the sound level, frequency, and relative position of the signal source and varying oceanographic characteristics including temperature, salinity, stratification, and sea state. Consequently, the survey area of stationary recorders is not static.

An absence of detections by a recorder may be the result of diminished detection range as opposed to an absence of vocalizing whales thereby biasing sampling efforts that occur in areas of differing ambient noise and oceanographic characteristics. It is therefore necessary to consider the limitations of defining acoustic survey areas when investigating a given question. Passive acoustic monitoring without the
capacity for localization is limited to monitoring presence in generalized areas to determine broad scale distribution and movement patterns and comparisons of relative presence should account for differences in ambient noise and sound propagation factors.

**Quantifying the effect of sea state and visibility on the visual detectability of each species using the PAM results as a baseline for presence**

While it is known that increased sea state negatively impacts the visual detectability of species, our results did not reflect this. Very few data points were available in this study to quantify such an effect. For a more robust analysis, additional data points are required.

**Right whale acoustic presence in Virginia**

Year-round acoustic presence of right whales off the coast of Virginia is contrary to what was previously suspected as a late winter and early spring occurrence only phenomenon (Ambler 2011; Northeast Fisheries Science Center 2012). The increase in acoustic detections in the October - December period occurred during the season when right whales are expected to be migrating southward through the area, while presence in the February - March period occurred in the season when right whales are expected to be migrating northward through the area. A critical finding from this study is that right whales were in the area throughout the rest of the year, outside of these seasonal migration periods (i.e. fall and spring; Kraus et al. 1986; Winn et al. 1986). The increase in number of hours per day with detections during the migration period may be due to a greater number of whales, greater individual calling rates per whale during that period, or a combination of both, perhaps through a form of social facilitation.

The occurrence of right whales along the entire east-west expanse of the Virginia continental shelf, as clearly demonstrated here, does not necessarily preclude development, but certainly warrants a re-evaluation of effective monitoring and mitigation measures. In addition to using year-round acoustic monitoring to understand long-term seasonal patterns, as demonstrated here with archival recorders, another proven mechanism by which to mitigate potential risk to right whales, is to implement a 24-h, real-time monitoring system similar to what is now operating in the shipping lanes off Boston (Clark et al. 2005; Clark et al. 2009a; Spaulding et al. 2010). Such a system allows for near-real-time notification to vessels that right whales are in an area, and that operations need to be modified to account for right whale presence (http://stellwagen.noaa.gov/protect/whalealert.html). A similar approach could be useful for minimizing exposure of protected marine species to pile-driving sounds or noise from seismic air gun surveys. Live feedback as to when whales are detected in an area of concern could be used to develop a dynamic management process that would be flexible enough to account for non-seasonal right whale occurrence. NOAA has considered mandatory and voluntary dynamic management areas based on aerial sightings (National Marine Fisheries Service 2008), but concerns over how long to maintain a protected area and how to communicate the information on protected species occurrence to the maritime community could be resolved or improved with the high-resolution temporal and spatial coverage provided by passive acoustic surveys.

**Significance of Virginia to cetaceans and directions for future research**

The whale presence detected on all ten days indicates that this area is of importance to all five species and appropriate mitigation strategies should be devised before energy installation activities begin. To date, large data gaps in whale distribution exist along the coastal mid-Atlantic states. This paucity of data poses a risk to endangered whale species occurring within these habitats as well as to industries charged with impact mitigation. The most comprehensive assessments of whale presence along the Atlantic include the
Bureau of Land Management (BLM) Cetacean and Turtle Assessment Program (CETAP), which was conducted between 1978 and 1982, and the National Marine Fisheries Service (NMFS) Marine Mammal Stock Assessment which primarily focuses on north-Atlantic states. These visually-based assessments produced very few data points along the mid-Atlantic in comparison to acoustic surveys occurring in the same areas (Whitt et al. 2013; Hodge et al. In Prep; Salisbury et al. In review). Moreover, the visual surveys did not occur continuously to allow for analysis of seasonal changes in species distribution.

While the presence of these species has not been described in Virginia waters as extensively as in northern summer feeding grounds, the detections observed here fall within previously documented ranges. All five species occupy the Gulf of Maine during summer months (Waring et al. 2013) and show varying extents of southward migration during the winter (Winn et al. 1986; Wiley & Asmutis 1995; Reeves et al. 1998; Clark & Gagnon 2002; Waring et al. 2013). This southward migration may be demographically segregated as in the case of right whales (Kraus et al. 1986; Kenney et al. 2001), with pregnant females and mother calf pairs using the migratory corridor more often than males, and in the case of humpbacks (Swingle et al. 1993; Wiley & Asmutis 1995) with juveniles occurring over the shelf of the mid-Atlantic more often than sexually mature adults. Specifically for right whales, protection of sexually mature females is critical to the recovery of an exceedingly small population (Caswell et al. 1999; Fujiwara & Caswell 2001; Kraus et al. 2005).

The results presented here demonstrate the utility of acoustics for long-term continuous surveys of species presence. In this study, we systematically examined right whale occurrence the first year only of a two-year acoustic survey. Potential multiyear variability in seasonal distribution can be achieved through analysis of additional data. This ability to identify seasonal peaks and lulls in species presence through continuous acoustic surveys offers an important perspective from which mitigation strategies can be devised. Determining time periods of least potential impact by development activities is a fundamental step in the sustainable use of areas occupied by protected species. Moreover, the multiyear continuous datasets attainable through acoustic surveys offer a robust baseline, against which the potential impacts of energy development can be measured.

**Literature Cited**


Reeves, R. R., G. K. Silber, and P. M. Payne. 1998. Draft Recovery Plan for the Fin Whale *Balaenoptera physalus* and Sei Whale *Balaenoptera borealis*. Silver Spring, MD: USDOC, NOAA, NMFS, Office of Protected Resources:


