HDR Cape Hatteras Localization Trial

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1. Introduction

HDR contracted JASCO Applied Sciences to collect data from a cluster of four recorders off Cape Hatteras NC and demonstrate our ability to quantify ambient, anthropogenic, and biologic activity in the data. For three sets of detected click-trains from beaked whales or dolphins JASCO is required to localize the clicks and determine the tracks of the animals.

Four acoustic recorders were deployed off Cape Hatteras (Figure 1) for 34 days (16 Nov 2013–19 Dec 2013). This report describes the methods used and the results generated from the data.

![Figure 1. AMAR cluster deployment location at the edge of the Albemarle Shelf.](image-url)
2. Methods

2.1. Acoustic Data Acquisition

Acoustic data were acquired with four Autonomous Multi-Channel Acoustic Recorders (AMARs, JASCO Applied Sciences). Acoustic data were recorded continuously into 1.024 TB of internal solid-state memory. Each AMAR (Figure 2) was fitted with an M8E calibrated omnidirectional hydrophone (GeoSpectrum Technologies Inc.; $-165 \pm 5$ dB re 1 V/µPa nominal sensitivity) and set for a gain of 0 dB. Data were recorded on a 24-bit AMAR channel sampling at 128 ksps. The spectral density of the electronic background noise of the AMARs on the 24-bit channel was $\sim 16$ dB re 1 µPa²/Hz, and the broadband noise floor was 63 dB re 1 µPa.

![Autonomous Multichannel Acoustic Recorder](image)

The recorders were deployed in an equilateral triangle near 35° 45’ N, 74° 49’ W (Figure 1) from the vessel R/V Cape Fear (Figure 3). The center mooring (P1) had an AMAR recorder approximately 400 feet off the ocean bottom, and a deep rated acoustic pinger located $\sim 25^\circ$ off the ocean bottom (Figure 4). Moorings A1, A2 and A3 had an AMAR recorder located $\sim 15^\circ$ off the ocean bottom (Figure 5) and were at the apexes of an equilateral triangle with 1000 m sides (Figure 1, Table 1). The pinger emitted a stepped-FM pulse every 12 hours to synchronize so the AMAR clocks for time delay of arrival localization of the detected clicks. All moorings include dual acoustic releases, an Iridium satellite beacon, and a visual / radio-frequency beacon. Dual releases were provided as a redundant retrieval mechanism. The Iridium beacon and visual / radio-frequency beacon assisted the team to retrieve the moorings. See Appendix B for details of the deployment and retrieval procedures.
Figure 3. R/V Cape Fear was used to deploy and retrieve the AMARs.

Figure 4. Autonomous Multichannel Acoustic Recorder (AMAR) Mooring with tandem acoustic release and syntactic floats for array P1.
The deployment occurred on 16 Nov 2013, and the recorders were retrieved 9 Jan 2014 (Table 1). All recorders operated from deployment to 19 Dec 2013. During the deployment and the retrieval the ‘ranging’ mode of the acoustic releases provided the distance from the deployment vessel to the bottom of the moorings. These measurements ‘boxed-in’ the recorder positions for more accurate localizations (Appendix A).

Table 1. AMAR locations (see Figure 1) and recording durations for the deployment. The AMARs recorded continuously from deployment to 19 Dec 2013.

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude (°N)</th>
<th>Longitude (°W)</th>
<th>Water Depth (m)</th>
<th>Deployment</th>
<th>Retrieval</th>
<th>Recording days</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>35° 45.1020</td>
<td>74° 49.0680’</td>
<td>542</td>
<td>16 Nov</td>
<td>09 Jan</td>
<td>34</td>
</tr>
<tr>
<td>A1</td>
<td>35° 45.4140</td>
<td>74° 49.0800</td>
<td>558</td>
<td>16 Nov</td>
<td>09 Jan</td>
<td>34</td>
</tr>
<tr>
<td>A2</td>
<td>35° 44.9280’</td>
<td>74° 49.3920’</td>
<td>427</td>
<td>16 Nov</td>
<td>09 Jan</td>
<td>34</td>
</tr>
<tr>
<td>A3</td>
<td>35° 44.9520</td>
<td>074° 48.7560</td>
<td>626</td>
<td>16 Nov</td>
<td>09 Jan</td>
<td>34</td>
</tr>
</tbody>
</table>
2.2. Data Analysis

This section describes the marine mammal and vessel noise detection algorithms employed in addition to how the total sound levels were quantified.

2.2.1. Automated Detection of Clicks

Clicks from sperm, killer, pilot and beaked whales and dolphins were detected automatically based on the energy ratios between several frequency bands.

The steps below describe the detection process:

1. The spectrogram (short-time Fourier transform) of the acoustic signal was calculated using 256 sample Hamming-weighted windows overlapped by 50 percent.
2. The spectrogram was normalized with a split-window normalizer using a 2 ms frame and a 0.5 ms notch (Struzinski and Lowe 1984). Frequency bins in the normalized spectrogram that had normalized energy less than the threshold $T_{\text{norm}} = 2$ were set to zero.
3. To create a detection function, the ratio of the number of positive bins over the number of null bins in the frequency band of interest was defined for each time step of the spectrogram. Parts of the detection function that exceeded the empirically chosen threshold $T_{\text{dect}} = 0.3$ defined the times of potential click detections.
4. The normalized spectrogram for each of the potential click detection was used to calculate ratio $R$ of the energy in the frequency bands of the species of interest and a band below the species band which would not contain energy. We attributed a detection to a click only if the energy ratio $R$ exceeded the decision threshold $T_{\text{ER}} = 4.9$.

Figure 6 illustrates the click detection process.

![Click Detection Schematic](image-url)
2.2.2. Moan and Whistle Marine Mammal Vocalization Detection

A simple moan and whistle detector identified time periods that were likely to contain marine mammal moans and whistles. The moan and whistle detector was performed in four steps:

1. Calculation and binarization of the spectrogram,
2. Definition of time-frequency objects,
3. Feature extraction, and
4. Classification.

2.2.2.1. Spectrogram Processing

The first step of the detection process was the calculation of the spectrogram. The spectrogram parameters used are in the Table 1. To attenuate long spectral rays in the spectrogram due to vessel noise and to enhance weaker transient biological sounds, the spectrogram was normalized in each frequency band (i.e., each row of the spectrogram) with a median normalizer. The size of the window used by the normalizer is indicated in Table 1. The normalized spectrogram was binarized by setting all the time-frequency bins exceeding a normalized amplitude of 4 (no unit) to 1 and the other bins to 0.

<table>
<thead>
<tr>
<th>Table 1. Spectrogram parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Analysis frame size (samples)</td>
</tr>
<tr>
<td>Blue Whale</td>
</tr>
<tr>
<td>Right Whale</td>
</tr>
<tr>
<td>Moans</td>
</tr>
<tr>
<td>Whistles</td>
</tr>
<tr>
<td>Overlap between frames (samples)</td>
</tr>
<tr>
<td>FFT size (sample)</td>
</tr>
<tr>
<td>Window function</td>
</tr>
<tr>
<td>Normalizer window size (s)</td>
</tr>
<tr>
<td>Binarization threshold (no unit)</td>
</tr>
</tbody>
</table>

2.2.2.2. Definition of Time-Frequency Objects

The second step of the detection process consisted of defining time-frequency objects (or events) by associating contiguous bins in the binary spectrogram. The algorithm implemented is a variation of the flood-fill algorithm (Nosal 2008). Every spectrogram bin that equals 1 and is separated by less than 3 bins in both time and frequency are connected together. Figure 1 illustrates the search area used to connect a spectrogram bin to another one. The bin connection process moves from oldest data to newest and from lowest frequency to highest. Also, a spectrogram bin can only belong to a single time-frequency object. Each group of connected bins is referred to as a time-frequency object.
2.2.2.3. Feature extraction

The third step consists of representing each of the time-frequency objects extracted in the previous step by a set of features. Features of the time-frequency objects were defined by:

- **Start time**: (date),
- **Duration** (s),
- **Minimum frequency** (Hz),
- **Maximum frequency** (Hz), and
- **Bandwidth** (Hz).

2.2.2.4. Classification

The final step consisted of classifying the time-frequency objects by comparing their features against a dictionary that defines the features of the vocalizations present in the Chukchi Sea based on the literature and on analysts’ observations. In the present study, only bearded seal calls were represented in the dictionary (Error! Reference source not found.). Notice that the classification process can handle vocalizations made of several time-frequency objects such as vocalizations with harmonics (“MultiFrequencyComponents”) and vocalizations made of a succession of time-frequency objects such as seal trills and groups of beluga, dolphin, or beaked whale whistles (“MultiTimeComponents”).

Vocalizations in the dictionary are defined by the following features:

- **Minimum frequency**: the minimum frequency of the expected call type, or that of the data, whichever is higher.
- **Maximum frequency**: either that expected for the call type, or that of the data, whichever is lower.
- **Minimum duration**: minimum duration of the expected call. This should be at least one spectrogram time slice.
- **Maximum duration**: The maximum duration of the expected call type.
- **Minimum bandwidth**: The minimum frequency bandwidth of the expected call type.
- **Maximum bandwidth**: The maximum frequency bandwidth of the expected call type. Can not be more than (maximum frequency – minimum frequency).
- **MultiFrequencyComponent** (Boolean): for call types where contours should be grouped in frequency with some time overlap before applying the frequency, duration, and bandwidth constraints. Each contour that is added to the multi-component contour has the following constraints applied:
  - **minComponentDuration**: minimum duration for a contour to be added to the multi-component contour.
  - **minComponentBW**: minimum bandwidth for a contour to be added to the multi-component contour.
  - **Minimum and maximum frequencies**: as per the global definition.

- **MultiTimeComponent** (Boolean): for call types where contours should be grouped in time before applying the frequency, duration, and bandwidth constraints. Each contour that is added to the multi-time-component contour has the following constraints applied:
  - **minTimeComponentDuration**: minimum duration for a contour to be added to the multi-time-component contour.
  - **minTimeComponentBW**: minimum bandwidth for a contour to be added to the multi-time-component contour.
  - **Minimum and maximum frequencies**: as per the global definition.

### 2.2.3. Localization

The localization processing approach assumes that cetacean vocalizations are detected on several hydrophones simultaneously. Because underwater sound travels at a finite speed, the vocalizations arrive sooner at nearby hydrophones than at more distant hydrophones. Under certain conditions the differences in arrival times of calls among three or more hydrophones can be used to determine the position of the calling animal.

The analysis uses a 3D localization processor using multiple hydrophones previously designed and tested in MATLAB, and implemented for processing of large data sets with JASCO’s Acoustic Analysis software suite (AA). The methodology consisted of four main stages: (3) Recorder clock synchronization; (2) Data extraction; (3) Event association; and (4) Event localization.

1) **TDOA Synchronization**. The synchronization stage determined the clock drift between a reference recorder (P1) and each of the other recorder’s clocks using a ping from known location at the center of the cluster as the synchronization event (Figure 2). The relative arrival time of this signal at each recorder (relative to the central “reference” recorder P1) was computed using a cross-correlation. These time offsets were then adjusted to account for the difference in distance from the projector to each recorder using the speed of sound at the time of the measurement. The temperature recorded by the AMAR and an assumed salinity of 35 parts-per-million were used to compute the speed of sound. This automated process produces an intermediate record of both the time drift factors and the acoustic data segments used to compute the cross-correlations. An analyst uses the record to audit the accuracy of the drift factors, as any issues with consistency or the presence of outliers are immediately apparent. The manual factors were substituted for the automatic ones for the remainder of the process.
Figure 2. Sample of the synchronization signal. The signal was a stepped sequence of tones each lasting 5 seconds, spaced 50 Hz apart (5800-6200 Hz). The signal was replayed every 12 hours at approximately 02:07 and 14:07 (UTC) daily.

2) **Data Identification and extraction.** The automatic localization technique occurred when an operator selected the automatically detected clicks for localization analysis. For each detected click the start time, duration, start frequency and bandwidth were extracted.

3) **Event association.** To avoid misleading information, an event association method eliminated redundant information from the rest of the hydrophones and discriminated false TDOAs that would generate false source locations. This procedure also lessened the algorithms computing time. The aim was to find detections of the same vocalization event recorded by various hydrophones with different delay times. The association stage identified events across multiple hydrophones that were in the same frequency bands and occurred at approximately the same time. All call detection events were sorted and classified by frequency band, date and an elapsed delay time. An event association was a candidate for potential localization if the call was detected by at least three hydrophones.

4) **Event localization.** The event localization approach produced a candidate source location based on a linear equation approach. For valid localizations, a combination of multiple hydrophone-pair TDOAs produced approximate locations and from these, localization polygon zones were generated. The centroid, or geometric center, of the polygon is often a good approximation of the 3D localization.

The linear equation approach describes the algebraic relation between the TDOA and the locations of the source and the receivers. Defining one of the receivers as the origin, the source location \( s \) from a three-receiver array is obtained as:

\[
s = \frac{1}{2} R^{-1} b - c^2 \delta \tau_1 R^{-1}
\]  

(1)

where \( c \) is sound velocity, \( \delta \) is the TDOA vector, \( \delta = [\delta_{12}, \delta_{13}]^T \), \( b \) is given by

\[
b_i = r_{i(i)}^2 + r_{y(i)}^2 - c^2 \delta_{i(i)}^2,
\]

\( \tau_1 \) is time of arrival from source to receiver reference, and \( R \) represents the receiver matrix:

\[
R = \begin{bmatrix}
r_{x(2)} & r_{y(2)} \\
r_{x(3)} & r_{y(3)}
\end{bmatrix}
\]

Solving for \( \tau_1 \):

\[
\tau_1 = \frac{ca_2 \pm \sqrt{c^2a_2^2 - (c^2a_3 - 1)a_1}}{2c(c^2a_3 - 1)}
\]

(2)

where \( a_2 = (R^{-1} \tau)^T (R^{-1} b) \), \( a_3 = (R^{-1} \tau)^T (R^{-1} \tau) \).
Substituting equation 2 into equation 1, the source location \( s \) is obtained. Two positive solutions correspond to two possible source positions. Negative and complex solutions are discarded as they have no physical solution or meaning (Wahlberg et al. 2001, Vallarta 2009).

### 2.2.4. Total Ocean Sound Level Analysis

All recordings were analyzed with the Acoustic Analysis tool-suite (which includes SpectroPlotter, JASCO Applied Sciences) Ocean sound levels were quantified using a 1 Hz resolution frequency domain analysis; results were averaged to produce spectral density values for each minute of recording. These values directly compare to the Wenz curves (Figure 3), which represent typical sound levels in the ocean. The ambient analysis also yields 1/3-octave-band and decade-band sound pressure levels for each minute of data. The peak amplitudes, peak-to-peak amplitudes, and root-mean-square (rms) amplitudes of the time series were computed and stored for each minute and each second of data.

Sound level statistics quantify the observed distribution of recorded sound levels. Following standard acoustical practice, the \( n \)th percentile level (\( L_n \)) is the spectral density, SPL or SEL exceeded by \( n \)% of the data. \( L_{\text{max}} \) is the maximum recorded sound level. \( L_{\text{mean}} \) is the linear arithmetic mean of the sound power, which can be significantly different from the median sound level (\( L_{50} \)). In this report, we use the median level to compare the most typical sound level between stations since the median is not as affected by high outliers as the mean sound level. \( L_5 \), the level exceeded by only 5% of the data, generally represents the highest typical sound levels measured. Sound levels between \( L_5 \) and \( L_{\text{max}} \) are due to very close passes of vessels, very intense weather, or other abnormal conditions. \( L_{95} \) represents the quietest typical conditions.

These acoustic metrics describe levels of ambient noise:

- **Sound Pressure Level (SPL):** A hydrophone measures the pressure level caused by underwater sound. Three SPLs are reported:
  - **root-mean-square (rms):** the mean pressure value averaged over some time period. It is measured in decibels re 1 µPa. SPL can represent the total pressure over any band of frequencies, but 1/3-octave-bands, decade-bands and total broadband are what we used in this study. rms SPLs are highly dependent on the time over which they are summed. In this report we provide the one-minute rms SPLs and the maximum one-second rms SPLs that have been either IEC or ANSI fast-time weighted. All of these values are reported for the full bandwidth, and for the 1/3-octave-bands and decade bands.
  - **peak:** the maximum sampled value over the reporting period (one minute for this report)
  - **peak-to-peak:** the maximum–minimum sampled values over the reporting period (one minute for this report)

- **Power Spectrum Density (PSD):** This describes how the power density is distributed over different frequencies within a spectrum. It is measured in dB re 1 µPa²/Hz.

- **Sound Exposure Level (SEL):** The metric describes the total sound energy flux density over a period; this measure is commonly used as surrogate for the received energy.
Cumulative Sound Exposure Levels (cSELs): Cumulative SELs consider the noise level as well as the duration over which the noise accumulates. Its unit of measure is decibels re 1 µPa²·s. We used 24-hour cSELs in to quantify anthropogenic noise that occurred in one day.

Figure 3. Wenz curves (NRC 2003), adapted from Wenz (1962) describing pressure spectral density levels of marine ambient noise from weather, wind, geologic activity, and commercial shipping.

2.2.5. Comparison of Sound Levels to Thresholds for Acoustic Impacts

In December 2013, the US National Oceanographic and Atmospheric Administration (NOAA) posted a Draft Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammals (2013) on its website for public review. The Draft Guidelines are largely based on Southall et al. (2007), with some adaptations to noise weighting based on Finneran and Jenkins (2012). The Draft Guidelines recommend dual criteria for assessing possible effects: SEL_{24h} and the peak SPL. The impact thresholds depend on the type of sound, either impulsive or non-impulsive, and the potentially affected species, which are in one of the five functional hearing groups (LF-, MF-, HF-cetaceans, phocids, or otariids).

All sounds recorded during this study were non-impulsive. Animals from all species groups were present in the study area.

To account for the expected hearing abilities of different marine mammal groups, we used the revised noise weighting approach outlined in the Draft Guidelines to reference the total sound
levels in the study area against specific functional hearing groups of cetaceans and pinnipeds. This proposed weighting scheme reduces the influence of frequencies outside the most sensitive hearing range of marine mammals.

Species are divided into five functional hearing groups based on their estimated auditory bandwidth. A-weighting factor W(f), which is a function of frequency, was applied to modify sound levels according to the hearing groups. Figure 4 shows the revised M+EQL-weighting function curves for the five groups. Because little is known about the detailed auditory characteristics of individual species within these bands, the specific auditory response of each species was not considered.

The Draft Guidelines provide thresholds for the onset of auditory temporary threshold shift (TTS, Level B harassment) and onset of auditory permanent threshold shift (PTS, Level A harassment). The minimum peak SPL threshold for TTS is 195 dB re 1 μPa (high-frequency cetaceans), a level well above the AMAR’s maximum of 171 dB re 1 μPa; therefore, in this study only the SEL_{24h} thresholds are considered for possible auditory impact. Table 2 lists TTS and PTS onset thresholds as proposed by NOAA (2013) for non-impulsive sources.

Figure 4. Revised acoustic M+EQL-weighting functions for different functional hearing groups as proposed by NOAA (2013).
Table 2. PTS and TTS onset threshold levels for cetaceans and underwater pinnipeds exposed to non-impulsive sound sources.

<table>
<thead>
<tr>
<th>Functional hearing group</th>
<th>TTS</th>
<th>PTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cumulative SEL (dB re 1 μPa²·s)</td>
<td></td>
</tr>
<tr>
<td>High frequency cetaceans</td>
<td>160</td>
<td>180</td>
</tr>
<tr>
<td>Mid frequency cetaceans</td>
<td>178</td>
<td>198</td>
</tr>
<tr>
<td>Low frequency cetaceans</td>
<td>178</td>
<td>198</td>
</tr>
<tr>
<td>Phocid pinnipeds (true seals)</td>
<td>183</td>
<td>197</td>
</tr>
<tr>
<td>Otariid pinnipeds (earless seals)</td>
<td>206</td>
<td>220</td>
</tr>
</tbody>
</table>

The NOAA 2013 Draft Guidelines only addressed the potential for auditory damage to marine mammals by anthropogenic sound, not thresholds for behavioral disturbance or masking marine mammal communications. The Draft Guidelines do not offer any thresholds for impacts to fish, which can indirectly affect marine mammals if the affected fishes are a prey species. A commonly used threshold for behavioral disturbance of marine mammals by non-impulsive noise is 120 dB re 1 μPa rms SPL (Southall et al. 2007). For fish the current recommend threshold for behavioral disturbance is 150 dB re 1 μPa rms SPL ([FHWG] Fisheries Hydroacoustic Working Group 2008).

2.2.6. Vessel Detection

Vessel detection is performed in two steps. First, narrowband sinusoidal tones (tonals) produced by the ship’s propulsion and other rotating machinery (Arveson and Venditis 2000) are detected in each 7-minute data file. Second, the results of all the 7-min files are combined to detect ship passages.

The tonal detector is based on overlapping FFTs. The number of seconds of data input to the FFT determines its spectral resolution. Arveson and Venditis (2000) used both 0.5 and 0.125 Hz resolutions. For the current study, we performed spectral analysis at 0.125 Hz resolution by using 8 s of real data with a 2 s advance. This frequency resolution separates the tones from each other for easy detection, and the 2 s advance provides suitable temporal resolution. Higher frequency resolutions can reduce shipping tone detections, which are often unstable within 1/16 Hz for long periods. A 120 s long spectrogram is created with 0.125 Hz frequency resolution and 2 s time resolution (524288-point FFTs, 512000 real data points, 128000-point advance, Hamming window). A split-window normalizer (Struzinski and Lowe 1984) selects the tonal peaks from the background (2 Hz window, 0.75 Hz notch, and detection threshold of 4 times the median). The peaks are joined with a 3 × 3 kernel to create contours. Associations in frequency are made if contours occur at the same time. The event time and number of tones for any event at least 20 s long and 40 Hz in bandwidth are recorded for further analysis.

The shipping detection is performed on the combined results from each WAV file. A “shipping band” of 40–315 Hz is defined and an rms SPL for the band is obtained once per minute.
Background estimates of the shipping band rms SPL and the total rms SPL are compared to their median values over the 12-hour window centered on the current time. The total per-minute rms SPL is attributed to shipping when these conditions are true: the rms SPL in the shipping band is at least 3 dB above the median, at least 5 shipping tonals are present, and the rms SPL in the shipping band is within 8 dB of the total rms SPL (Figure 5).

![Graph showing broadband and in-band rms sound pressure level (SPL) and the number of 0.125 Hz wide tonals detected per minute as a ship approached the recorder, stopped to perform a task, and then departed. The shaded area is the period of shipping detection. All tonals are from the same vessel. Fewer tonals are detected at the ship’s closest points of approach (CPA, at 22:59) because of the broadband cavitation noise at CPA and the Doppler shift of the tonals.](image)

**Figure 5.** Example of the broadband and in-band rms sound pressure level (SPL) and the number of 0.125 Hz wide tonals detected per minute as a ship approached the recorder, stopped to perform a task, and then departed. The shaded area is the period of shipping detection. All tonals are from the same vessel. Fewer tonals are detected at the ship’s closest points of approach (CPA, at 22:59) because of the broadband cavitation noise at CPA and the Doppler shift of the tonals.

### 2.2.7. Total, Ambient, and Anthropogenic Sound Levels

The shipping detections (described above) allow the analysis to divide the total sound level into an ambient and anthropogenic contribution. Each minute with a shipping detection is declared anthropogenic. Each minute that does not have a shipping detection within 15 minutes is declared ambient data. The 15-minute shoulder means that when a vessel is approaching a recorder, but is not yet detectable, the energy is still attributed to the vessel. For each class, the daily cumulative sound exposure level, histograms of the sound levels, and sound levels statistics are computed and plotted for comparison.
3. Results

Results in this section are expressed in local time (Eastern Standard Time, EST, UTC-4), except when specified in the text (for example: Coordinated Universal Time, UTC).

3.1. Click Detections

3.2. Moan and Whistle Marine Mammal Detections

3.3. Localizations

3.3.1. Recorder Synchronization

It was obvious from the audit records that there were problems with the drift factors computed for two of the synchronized recorders. Upon inspection of the acoustic data, it was determined that multipath interference (most likely from bottom reflection) was confounding the cross-correlation calculation. The drift factors for all 66 synchronization instances were therefore manually corrected using the generated intermediate acoustic segments (multi-channel WAV files containing solely the synchronization points for the reference and comparison recorders). The automatically computed drift factors had a mean linear correlation coefficient of $r=0.95503$ whereas the manually corrected ones had a mean linear correlation coefficient of $r=0.99999$ (Figure 6).

Figure 6. Automatic and manually corrected drift factors for the P1-A3 synchronization. One synchronization instance occurred every 12 hours.
3.3.2. Mammal Tracks

3.4. Received Sound Levels

This section provides an overview of the variability in the total received sound levels throughout the study period, as well as a discussion of notable acoustic events (beside marine mammals). Error! Reference source not found. contains detailed spectrogram and statistical sound levels measured at each station and each deployment.

3.4.1. Total Received Sound Levels and Shipping Noise Contribution

3.4.2. Comparison of Measured Sound Levels to Acoustic Impact Thresholds

3.4.3. Notable Acoustic Events
4. Discussion

4.1. Synchronization Signal

4.2. Marine Mammal Vocalization Detections

4.3. Marine Mammal Localizations

4.4. Total Sound Levels and Anthropogenic Activity
Acknowledgements

JASCO Applied Sciences thanks the captain and crew of the R/V Cape Fear for assistance with deployments, retrievals, and shipping.
Literature Cited


Martin, B. 2013. Computing cumulative sound exposure levels from anthropogenic sources in large data sets. Proceedings of Meetings on Acoustics 19(1): -.


Appendix A. Position Data Processing

During Deployment and Recovery the JASCO team preformed acoustic ranging of the arrays on the bottom using a topside acoustic signal box communicating with the acoustic releases. This data was logged (Tables C-3 and C-4), and entered into a proprietary spreadsheet based program called Puglist. Puglist takes an original estimated position and compares it to the slant range for two to eight other marked positions resulting in a calculated “on bottom” position of the deployed equipment. A comparison of calculate positions and the original deployment position can be seen in tables C-1(deployment) and C-2(retrieval).

Table A-1. Comparison of original positions and calculated positions from 16 Nov 2013 (deployment).

<table>
<thead>
<tr>
<th>Array</th>
<th>Water Depth (M)</th>
<th>Original Latitude (N)</th>
<th>Original Longitude (W)</th>
<th>Calculated Latitude (N)</th>
<th>Calculated Longitude (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>542</td>
<td>35° 45.0242’</td>
<td>74° 49.0032’</td>
<td>35° 45.1020’</td>
<td>74° 49.0680’</td>
</tr>
<tr>
<td>A1</td>
<td>558</td>
<td>35° 45.3338’</td>
<td>74° 49.0112’</td>
<td>35° 45.4140’</td>
<td>74° 49.0800’</td>
</tr>
<tr>
<td>A2</td>
<td>427</td>
<td>35° 44.8526’</td>
<td>74° 49.3287’</td>
<td>35° 44.9280’</td>
<td>74° 49.392’</td>
</tr>
<tr>
<td>A3</td>
<td>626</td>
<td>35° 44.8711’</td>
<td>74° 48.6698’</td>
<td>35° 44.9520’</td>
<td>74° 48.7560’</td>
</tr>
</tbody>
</table>

Table A-2. Comparison of original positions and calculated positions from 09 Jan 2014 (retrieval).

<table>
<thead>
<tr>
<th>Array</th>
<th>Water Depth (M)</th>
<th>Original Latitude (N)</th>
<th>Original Longitude (W)</th>
<th>Calculated Latitude (N)</th>
<th>Calculated Longitude (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>542</td>
<td>35° 45.0242’</td>
<td>74° 49.0032’</td>
<td>35° 45.1020’</td>
<td>74° 49.0680’</td>
</tr>
<tr>
<td>A1</td>
<td>558</td>
<td>35° 45.3338’</td>
<td>74° 49.0112’</td>
<td>35° 45.4140’</td>
<td>74° 49.0800’</td>
</tr>
<tr>
<td>A2</td>
<td>427</td>
<td>35° 44.8526’</td>
<td>74° 49.3287’</td>
<td>35° 44.9280’</td>
<td>74° 49.392’</td>
</tr>
<tr>
<td>A3</td>
<td>626</td>
<td>35° 44.8711’</td>
<td>74° 48.6698’</td>
<td>35° 44.9520’</td>
<td>74° 48.7380’</td>
</tr>
</tbody>
</table>

Table A-3. Ranging log from 16 Nov 2013 (deployment)

<table>
<thead>
<tr>
<th>AMAR</th>
<th>Latitude (N)</th>
<th>Longitude (W)</th>
<th>Range (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>187/A1</td>
<td>35° 45.3939’</td>
<td>74° 49.1464’</td>
<td>608</td>
</tr>
</tbody>
</table>
Table C-3. Ranging log from 09 Jan 2014 (retrieval)

<table>
<thead>
<tr>
<th>AMAR</th>
<th>Latitude (N)</th>
<th>Longitude (W)</th>
<th>Range (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>187/A1</td>
<td>35° 45.3896'</td>
<td>74° 49.0751'</td>
<td>585</td>
</tr>
<tr>
<td>187/A1</td>
<td>35° 45.3113'</td>
<td>74° 49.0975'</td>
<td>598</td>
</tr>
<tr>
<td>187/A1</td>
<td>35° 45.2445'</td>
<td>74° 49.0390'</td>
<td>602</td>
</tr>
<tr>
<td>187/A1</td>
<td>35° 45.1182'</td>
<td>74° 49.1380'</td>
<td>689</td>
</tr>
<tr>
<td>188/A2</td>
<td>35° 44.8732'</td>
<td>74° 49.2161'</td>
<td>447</td>
</tr>
<tr>
<td>188/A2</td>
<td>35° 44.7786'</td>
<td>74° 49.4540'</td>
<td>472</td>
</tr>
<tr>
<td>188/A2</td>
<td>35° 44.9677'</td>
<td>74° 49.4032'</td>
<td>468</td>
</tr>
<tr>
<td>188/A2</td>
<td>35° 45.1187'</td>
<td>74° 49.1386'</td>
<td>704</td>
</tr>
<tr>
<td>189/A3</td>
<td>35° 45.2247'</td>
<td>74° 48.9978'</td>
<td>1046</td>
</tr>
<tr>
<td>189/A3</td>
<td>35° 44.9678'</td>
<td>74° 48.6433'</td>
<td>680</td>
</tr>
<tr>
<td>189/A3</td>
<td>35° 44.7726'</td>
<td>74° 48.7173'</td>
<td>687</td>
</tr>
<tr>
<td>189/A3</td>
<td>35° 44.9309'</td>
<td>74° 48.7900'</td>
<td>696</td>
</tr>
<tr>
<td>190/P1</td>
<td>35° 45.2315'</td>
<td>74° 49.0236'</td>
<td>639</td>
</tr>
<tr>
<td>190/P1</td>
<td>35° 44.9661'</td>
<td>74° 48.6406'</td>
<td>781</td>
</tr>
<tr>
<td>190/P1</td>
<td>35° 44.8388'</td>
<td>74° 49.2208'</td>
<td>711</td>
</tr>
<tr>
<td>190/P1</td>
<td>35° 45.1112'</td>
<td>74° 49.1420'</td>
<td>580</td>
</tr>
</tbody>
</table>
Appendix B. Deployment/Retrieval Procedures

This Appendix contains a copy of the Deployment and Retrieval Procedures originally provided to HDR before the deployment.

B.1. Deployment Procedure

The following steps outline the procedure for deploying the four moorings from the vessel. The moorings will be lifted over the side using the vessel’s boom and hydraulic winch. The floating elements will be deployed first, and the anchor last. The anchor will free-fall to the bottom as the last step of the deployment procedure. This procedure is subject to change based on weather conditions and consultation with the vessel master and crew.

Each AMAR will be deployed as follows:

1. Job Safety Analysis meeting with JASCO crew, ship’s crew, crane operator, and vessel master.

2. Prepare the equipment for deployment:
   a. Move the mooring weight to the vessel stern, close to the railing, and secure it appropriately.
   b. Connect all the mooring components together as per the mooring diagram.
   c. Connect the boom winch to the off-load release.
   d. Attach off-load release hook to the upper-float’s lifting ring.

3. Deploy the upper float and AMAR:
a. Ensure the lower float is secured on deck.
b. Lift the upper float over the railing using the boom winch and lower it into the water.
c. Once the mooring wire is under tension and the load of the upper float is transferred to the lower float still secured on deck, then release the hook.

4. **Deploy the lower float:**
   a. Attach the BOSS off-load release hook to the bottom float with soft slings, such that the sling will stay attached to the winch after release.
   b. Ensure the releases are attached securely to the anchor wire, and the anchor is secured on deck.
   c. Lift the lower float over the side with the boom winch and lower to the water.
   d. Once the anchor wire is under tension and holding the releases, then release the BOSS off-load release to release the lower float.
   e. Remove the off-load release hook from the boom winch wire.

5. **Deploy the anchor weight:**
   a. Attach the on-load release to the boom winch wire.
   b. Attach the on-load release to the anchor lifting point.
   c. Tighten the boom winch wire until it is under tension and taking the load of the mooring.
   d. Release ropes securing the mooring weight to the vessel.
   e. Lift the weight with the crane, move it over the side at the stern of the vessel and lower it to the water line to minimize swinging. While doing so, one person holds the SeaCatch quick release trigger line.
   f. Once at the deployment location, the vessel slows down, the mooring weight is lowered at the surface of the water. One person is holding the SeaCatch quick release trigger line.
g. Trigger the SeaCatch quick release and let the mooring sink. JASCO Crew 1 marks the GPS location of the drop.

6. Debriefing meeting to capture lessons learned.

B.2. Retrieval Procedure

The following steps outline the procedure for retrieving all four moorings. The moorings will be retrieved using the hydraulic boom winch on the vessel. This procedure is subject to change based on weather conditions and consultation with the vessel master and crew.

The AMARs will be retrieved as follows:

1. Job Safety Analysis meeting with JASCO crew, ship’s crew, crane operator, and vessel master.

2. Position the vessel:
   a. Heading abeam the wind, the vessel approaches the location to within 100 m and maintains position. Ship’s crew are positioned around the vessel to act as spotters. The crane is ready, with tag lines attached to the crane hook.
   b. The Command Unit transducer is lowered into the water and held steady.
   c. The field team will check the distance to the mooring using the command unit ranging feature.
   d. If needed, JASCO Crew 1 brings the transducer back onboard, and return to Step 1. OR, if the distance is okay for retrieval, continue to Step 3.

3. Release the mooring:
   a. The field team will trigger the acoustic release let go of the anchor weight so the mooring can float to the surface.
   b. The ship’s crew observe the waters to spot the yellow floats on the surface.
   c. Once the floats are spotted, the field team will bring the Command Unit transducer back onboard.

4. Retrieve the mooring:
   a. The vessel proceeds slowly and positions the mooring on the vessel’s windward side.
b. The ship’s crew use a boat hook to bring the mooring alongside and attach the crane hook to the lifting ring on the upper float.

c. The crane lifts the upper float onboard, taking care to not damage the hydrophone or the AMAR.

d. Once the upper float is on deck, secure it to the deck.

e. Once the upper float is secure, release the boom hook.

f. Attach the mooring hook to the boom winch hook.

g. Attach the mooring hook to the lower float still over the side.

h. Lift the lower float and tandem release on deck.

5. Debriefing meeting to capture lessons learned.