Passive Acoustic Monitoring for Marine Mammals off Cape Hatteras during April 2016 – January 2017

Macey A. Rafter, Kaitlin E. Frasier, Jennifer S. Trickey, John A. Hildebrand, Ally C. Rice, Bruce J. Thayre, Sean M. Wiggins, Ana Širović, Simone Baumann-Pickering

Marine Physical Laboratory
Scripps Institution of Oceanography
University of California San Diego
La Jolla, CA 92037

Cuvier's Beaked Whale *(Ziphius cavirostris)* Photo credit: Jennifer Trickey

MPL TECHNICAL MEMORANDUM #628
July 2018

Suggested Citation:

Rafter. M.A., Frasier K.E., Trickey, J.S., Hildebrand, J.A., Rice, A.C., Thayre, B.J.,Wiggins, S.M., Baumann-Pickering, S, Širović, A. Passive Acoustic Monitoring for Marine Mammals off Cape Hatteras during April 2016 – January 2017. Final Report. Marine Physical Laboratory Technical Memorandum 628. July 2018. Submitted to Naval Facilities Engineering Command (NAVFAC) Atlantic, Norfolk, Virginia, under Contract No. N62470-15-D-8006 Subcontract #383-8476 (MSA2015-1176 Task Order 003) issued to HDR, Inc.

Additional information on previous HARP deployments and availability of all associated reports can be found on the project profile page of the U.S. Navy's Marine Species Monitoring Program web portal.

This project is funded by US Fleet Forces Command and managed by Naval Facilities Engineering Command Atlantic as part of the US Navy's Marine Species Monitoring Program.

Table of Contents

Executive Summary

A High-Frequency Acoustic Recording Package (HARP) was deployed from April 2016 to February 2017 to detect marine mammal and anthropogenic sounds in the Navy's Virginia Capes Range Complex offshore from Cape Hatteras (HAT). The HARP was located 75 nm offshore in approximately 1000 m of water. The HARP recorded sound in the frequency band 10 Hz – 100 kHz. Data analysis consisted of analyst scans of long-term spectral averages (LTSAs) and spectrograms, and automated computer algorithm detection when possible. Three frequency bands were analyzed for marine mammal vocalizations and anthropogenic sounds: (1) Low-frequency, between 10-500 Hz, (2) Mid-frequency, between 500-5,000 Hz, and (3) High-frequency, between 5-100 kHz.

Four baleen whale species were recorded: blue, fin, minke, and sei whales. No Bryde's whale, right whale, or humpback whale calls were found. Fin whales were detected throughout the monitoring period with higher activity from October 2016 to January 2017. Sei and Minke whales were detected from October 2016 to January 2017. Blue whale A calls were found in low numbers between August and October 2016.

Ambient sound levels of 80-85 dB re:$\mu Pa^2/Hz$ were observed below 60 Hz, predominantly due to basin-wide commercial shipping. Episodic high levels of noise at low frequencies (10-15 Hz) may be due to strong tidal currents that result in hydrophone cable strumming. A peak in ambient noise at 15-25 Hz is related to the seasonal presence of fin whales. Sound levels at 200-1000 Hz are higher during the fall and winter months, related to wind and wave noise associated with higher sea states.

Several known odontocete signals were detected, along with odontocete signals that cannot yet be distinguished to species. Cuvier's beaked whales were detected in high numbers throughout the monitoring period. Gervais' beaked whales as well as sperm whales were detected intermittently throughout the monitoring period. Kogia spp. echolocation clicks were also found throughout the recording period, with highest numbers of detections occurring in May and June 2016. One acoustically identifiable delphinid species was Risso's dolphins, whose echolocation clicks were observed intermittently between May and September 2016, with decreasing detections from late September through November 2015. Odontocete signals that could not be distinguished to species were common throughout the recordings. However, three distinct click types (CT) of unknown species origin were identified and designated as CT 1, CT 4, and CT 6. Unidentified odontocete whistles were detected and categorized as either above or below 5 kHz.

Seven types of anthropogenic sounds were identified. Explosions were detected in May 2016 and airguns were detected between May and July 2016. LFA, MFA and HFA sonar were detected infrequently. Echosounders were detected intermittently in low numbers. Ships were detected throughout the deployment.

Project Background

The US Navy's Virginia Capes Range Complex is located in the coastal and offshore waters of the western North Atlantic Ocean adjacent to Delaware, Maryland, Virginia, and North Carolina. The seafloor features a broad continental shelf, with an inner zone of less than 200 m water depth, and an outer zone extending to water depths of 2000 m. A diverse array of marine mammals is found in this region, including baleen and toothed whales.

In March 2012, an acoustic monitoring effort was initiated within the boundaries of the Virginia Capes Range Complex with support from US Fleet Forces under contract to HDR and Duke University. The goal of this effort was to characterize the vocalizations of marine mammal species present in the area, to determine their seasonal presence patterns, and to evaluate the potential for impact from naval operations. This report documents the analysis of data recorded by a High-Frequency Acoustic Recording Package (HARP) that was deployed within the Virginia Capes Range Complex offshore from Cape Hatteras that collected data from May 2016 to January 2017 (Figure 1).

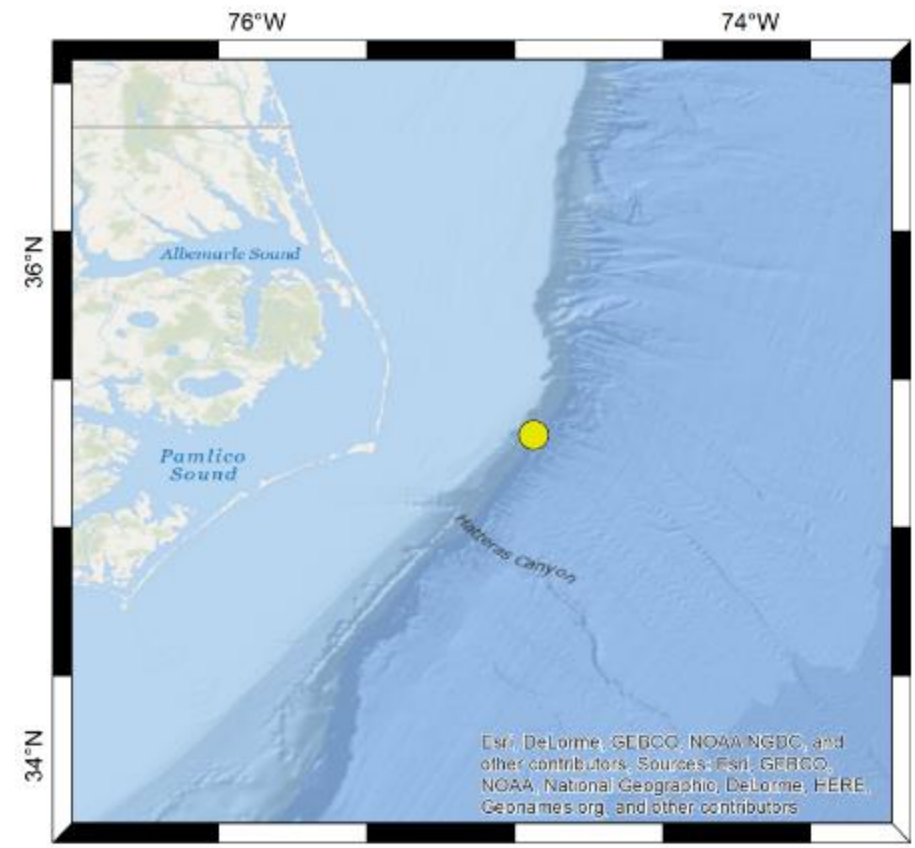

Figure 1. Location of High-Frequency Acoustic Recording Package (HARP) at HAT Site A (35° 08.110 N, 74° 52.737 W, depth 1021 m) deployed in the Cape Hatteras Complex study area from April 2016 to February 2017.

Methods

High-Frequency Acoustic Recording Package (HARP)

HARPs are autonomous underwater acoustic recording packages that can record sounds over a bandwidth from 10 Hz up to 160 kHz and are capable of approximately 300 days of continuous data storage. The HARP was deployed in a small mooring configuration with the hydrophone suspended approximately 22 m above the seafloor. Each HARP is calibrated in the laboratory to provide a quantitative analysis of the received sound field. Representative data loggers and hydrophones were also calibrated at the Navy's TRANSDEC facility to verify the laboratory calibrations (Wiggins and Hildebrand, 2007).

Data Collected

From April 2016 to February 2017 a HARP was deployed at HAT Site A (35° 08.110 N, 74° 52.737 W, depth 1021 m) configured to sample continuously at 200 kHz to provide 100 kHz of effective bandwidth. The instrument recorded 267.7 days from April 29th, 2016 to January 21st, 2017, for a total of 6,423.7 hours of data. Earlier data collection from the HAT site is documented in previous detailed reports (Frasier *et al*., 2017, Debich, et al., 2016). Intermittent data gaps appeared toward the end of the deployment due to a data logger malfunction. Recording coverage began as 100% and was 82% at the end of the recording period

Data Analysis

To visualize the acoustic data, frequency spectra were calculated for all data using a time average of 5 seconds. These data, called Long-Term Spectral Averages (LTSAs), were then examined to detect marine mammal and anthropogenic sounds. Data were analyzed by visually scanning LTSAs in source-specific frequency bands and, when appropriate, using automatic detection algorithms (described below). During visual analysis, when a sound of interest was identified in the LTSA but its origin was unclear, the waveform or spectrogram was examined to further classify the sounds to species or source. Signal classification was carried out by comparison to known species-specific spectral and temporal characteristics.

Recording over a broad frequency range of 1 – 100 kHz allows detection of toothed whales (odontocetes) and anthropogenic sounds. The presence of acoustic signals from multiple marine mammal species and anthropogenic noise was evaluated in the data. To document the data analysis process, we describe the major classes of marine mammal calls and anthropogenic sound in this band in the HAT region, and the procedures used to detect them. For effective analysis, the data were divided into three frequency bands: (1) Low-frequency, 10-500 Hz, (2) Mid-frequency, 500-5,000 Hz, and (3) High-frequency, 5-100 kHz.

Each band was analyzed for the sounds of an appropriate subset of species or sources. Blue, fin, Bryde's, sei, minke, and North Atlantic right whale sounds, as well as low frequency active sonar less than 500 Hz, were classified as low-frequency. Humpback, nearby shipping, explosions, airguns, underwater anthropogenic communications, low frequency active sonar greater than 500

Hz, and mid-frequency active sonar sounds were classified as mid-frequency. The remaining odontocete and sonar sounds were considered high-frequency. Analysis of low-frequency recordings required decimation by a factor of 100. For the analysis of the mid-frequency recordings, the data were decimated by a factor of 20.

We summarize acoustic data collected at the HAT Site A between April 2016 and January 2017. We discuss seasonal occurrence and relative abundance of calls for different species and anthropogenic sounds that were consistently identified in the acoustic data.

Low-Frequency Ambient Soundscape

Ocean ambient sound pressure levels tend to decrease as frequency increases (Wenz, 1962). While baleen whales and anthropogenic sources, such as large ships and airguns, often dominate the ambient soundscape below 100 Hz (Širović et al., 2004; McDonald et al., 2006a; Wiggins et al., 2016), wind causes increased sound pressure levels from 200 Hz to 20 kHz (Knudsen et al., 1948). To analyze the ambient soundscape, data were decimated by a factor of 100 to provide an effective bandwidth of 10 Hz to 1 kHz. LTSAs were then constructed with 1 Hz frequency and 5 s temporal resolution. To determine low-frequency ambient sound levels, daily spectra were computed by averaging five, 5 s sound pressure spectrum levels calculated from each 75 s acoustic record. System self-noise was excluded from these averages. Additionally, daily averaged sound pressure spectrum levels in 1-Hz bins were concatenated to produce long-term spectrograms for each site.

Low-Frequency Marine Mammals

The Virginia Capes Range Complex is inhabited, at least for a portion of the year, by blue whales *(Balaenoptera musculus)*, fin whales *(B. physalus)*, Bryde's whales *(B. edeni)*, sei whales *(B. borealis)*, minke whales *(B. acutorostrata)*, and North Atlantic right whales *(Eubalaena glacialis)*. For the low-frequency data analysis, the 200 kHz sampled raw data were decimated by a factor of 100 for an effective bandwidth of 1 kHz. Long-term spectral averages (LTSAs) were created using a time average of 5 seconds and frequency bins of 1 Hz. The same LTSA and spectrogram parameters were used for manual detection of all call types using the custom software program *Triton*. During manual scrutiny of the data, the LTSA frequency was set to display between 1- 300 Hz with a 1-hour plot length. To observe individual calls, the spectrogram window was typically set to display 1-250 Hz with a 60 second plot length. The FFT was generally set between 1500 and 2000 data points, yielding about 1 Hz frequency resolution, with an 85-95% overlap. When a call of interest was identified in the LTSA or spectrogram, its presence during that hour was logged.

The hourly presence of North Atlantic blue whale A calls and arch calls, fin whale 40 Hz calls, Bryde's whale Be7 and Be9 calls, sei whale downsweeps, minke whale pulse trains, and North Atlantic right whale up-calls was determined by manual scrutiny of low-frequency LTSAs and spectrograms. Detections were logged in hourly bins. Fin whale 20 Hz calls were detected automatically using an energy detection method and are reported as a daily average termed the 'fin whale acoustic index'.

Blue Whales

Blue whales produce a variety of calls worldwide (McDonald et al., 2006). Blue whale calls recorded in the western North Atlantic include the North Atlantic A call and the arch call (Mellinger and Clark, 2003).

North Atlantic Blue Whale Calls

The North Atlantic blue whale A call is an 18-19 Hz tone lasting approximately 8 s, often followed by an 18-15 Hz downsweep lasting approximately 11 seconds (Figure 2).

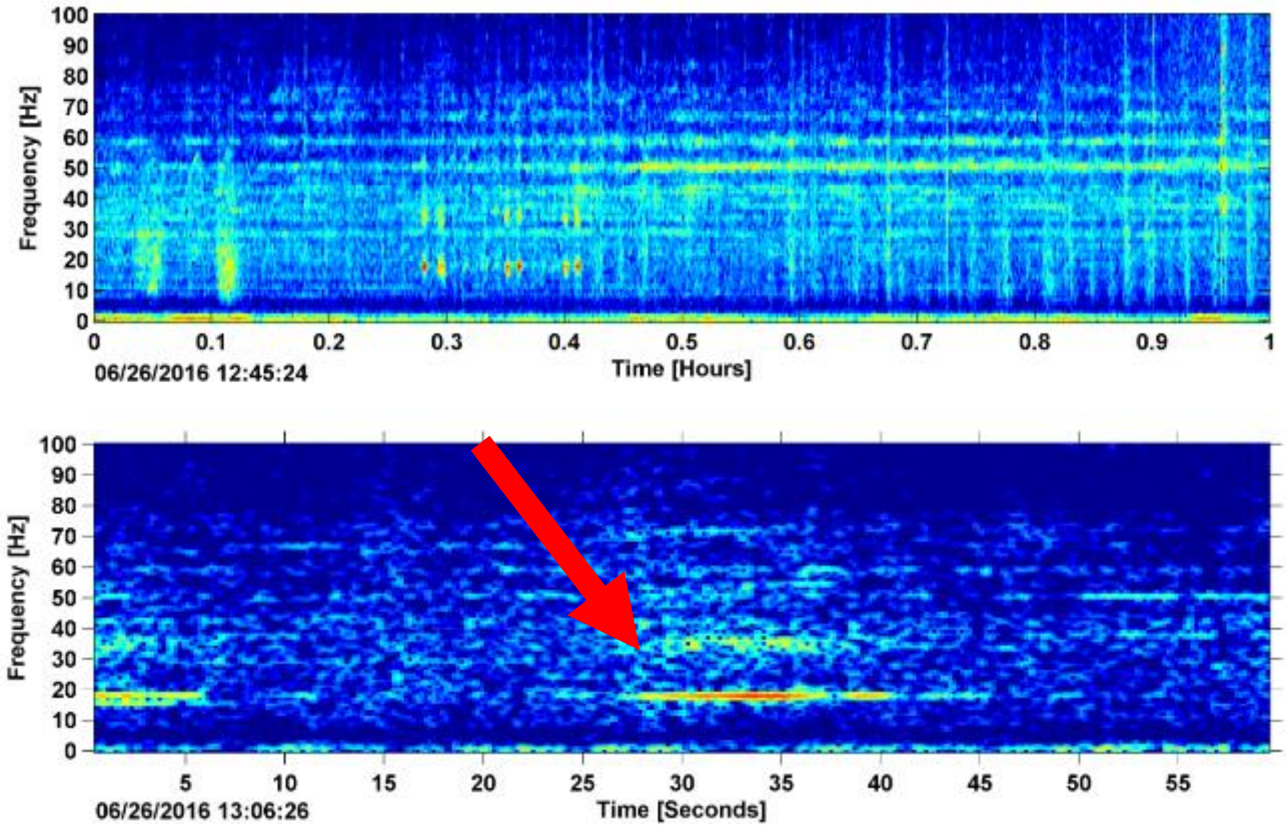

Figure 2. North Atlantic blue whale tonal calls in the LTSA (top) and spectrogram (bottom) at the Jacksonville Range Complex, June 2016.

Blue Whale Arch Calls

The blue whale arch call starts around 60 Hz, can ascend up to 70 Hz and then descends to approximately 35 Hz over a period of about 6 seconds (Figure 3). There were no detections for blue whale arch calls during the recording period.

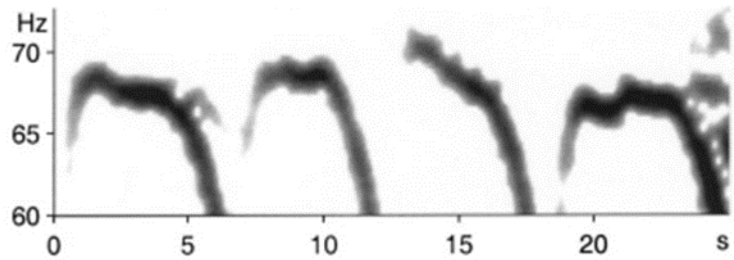

Figure 3. Spectrogram of blue whale arch calls from Mellinger and Clark (2003).

Bryde's Whales

Bryde's whales inhabit tropical and subtropical waters worldwide (Omura, 1959; Wade and Gerrodette, 1993).

Be7 Calls

The Be7 call is one of several call types in the Bryde's whale repertoire, first described in the Southern Caribbean (Oleson et al., 2003). The average Be7 call has a fundamental frequency of 44 Hz and ranges in duration from 0.8 and 2.5 s with an average intercall interval of 2.8 minutes (Figure 4). There were no detections for Bryde's whale Be7 calls during this recording period.

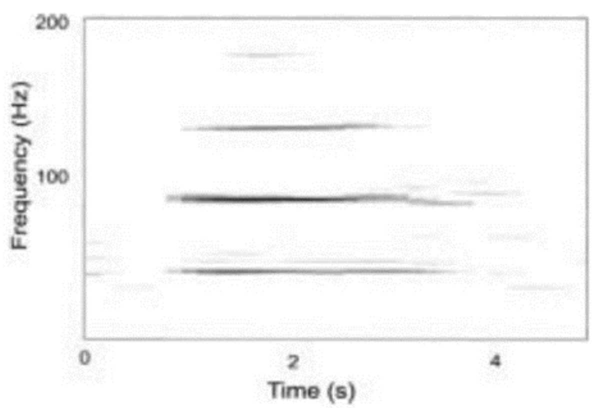

Figure 4. Spectrogram of Bryde's whale Be7 call from Oleson et al., 2003.

Be 9 Calls

The Be9 call type, described for Bryde’s whales in the Gulf of Mexico (Širović et al., 2014), is a downswept pulse ranging from 143 to 85 Hz, with each pulse approximately 0.7 s long (Figure 5). There were no detections for Bryde’s whale Be9 calls during the recording period.

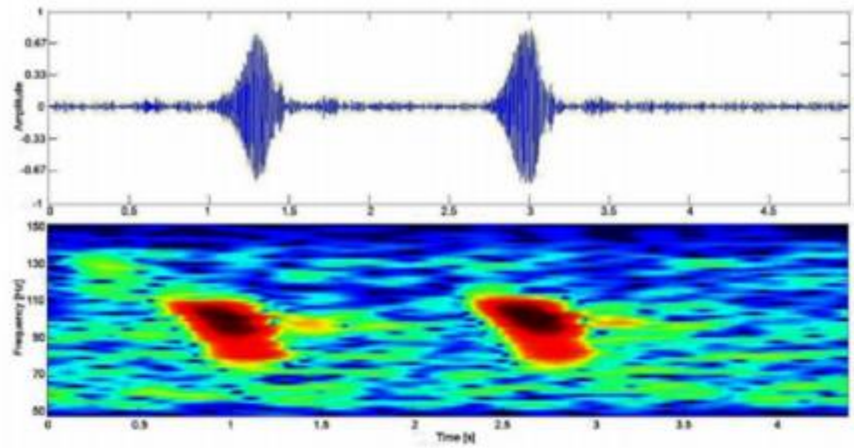

Figure 5. Waveform (top) and spectrogram (bottom) of Bryde’s whale Be9 call from the Gulf of Mexico (Širović et al., 2014).

Fin Whales

Fin whales produce two types of short (approximately 1 s duration), low-frequency calls: downsweeps in frequency from 30-15 Hz, called 20 Hz calls (Watkins, 1981; Figure 6) and downsweeps from 75-40 Hz, called 40 Hz calls (Figure 7). The 20 Hz calls can occur at regular intervals as song (Thompson et al., 1992), or irregularly as call counter-calls among multiple, traveling animals (McDonald et al., 1995). The 40 Hz calls most often occur in irregular patterns.

Fin Whale 20 Hz Calls

Fin whale 20 Hz calls (Figure 6) were detected automatically using an energy detection method (Širović et al., 2014). The method used a difference in acoustic energy between signal and noise, calculated from a 5 second LTSA with 1 Hz resolution. The frequency at 22 Hz was used as the signal frequency, while noise was calculated as the average energy between 10 and 34 Hz. The resulting ratio is termed fin whale acoustic index and is reported as a daily average. All calculations were performed on a dB scale.

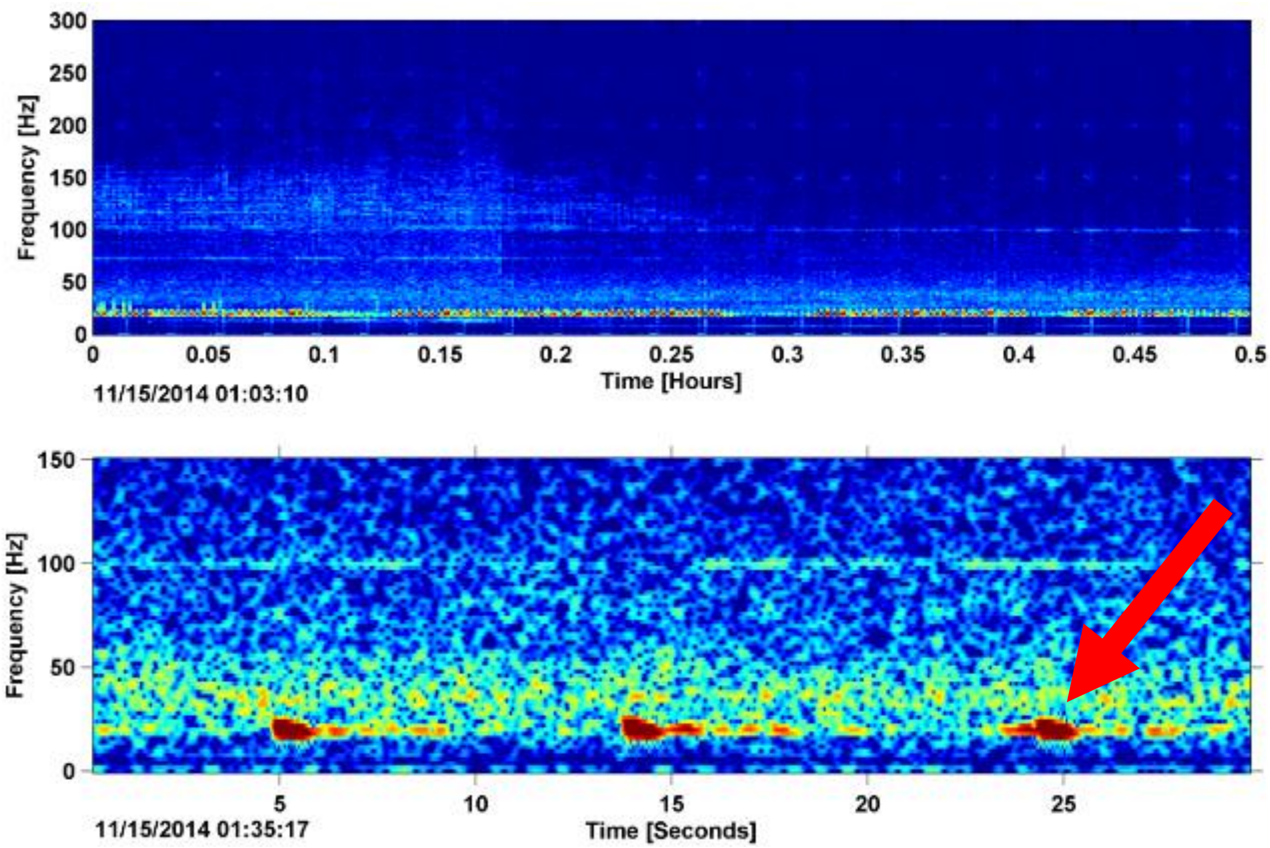

Figure 6. Fin whale 20 Hz call in LTSA (top) and spectrogram (bottom) at Norfolk Canyon Site A, November 2014.

Fin Whale 40 Hz Calls

The presence of fin whale 40 Hz calls (Figure 7) was examined via manual scanning of the LTSA and subsequent verification from a spectrogram of the frequency and temporal characteristics of the calls. There were no confirmed detections of fin whale 40 Hz calls in this recording period.

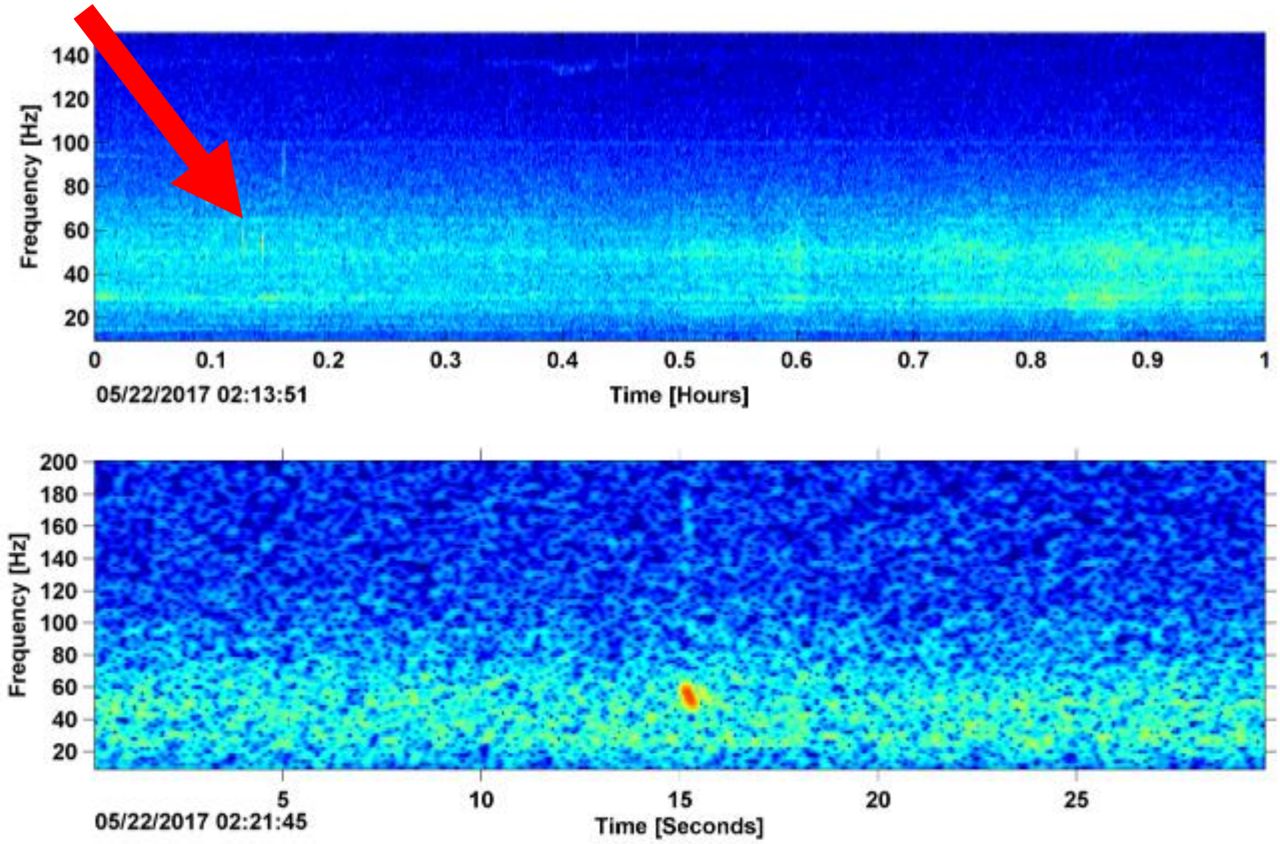

Figure 7. Fin whale 40 Hz call in LTSA (top) and spectrogram (bottom) at Norfolk Canyon Site A, May 2017.

Minke Whales

Minke whales in the North Atlantic produce long pulse trains. Mellinger et al. (2000) described minke whale pulse sequences near Puerto Rico as speed-up and slow-down pulse trains, with increasing and decreasing pulse rates respectively. Recently, these call types were detected in the North Atlantic and they were expanded to also include pulse trains with non-varying pulse rates (Risch et al., 2013) (Figure 8). The presence of pulse trains was marked but effort was not expended to denote whether they were slow-down, speed-up, or constant types.

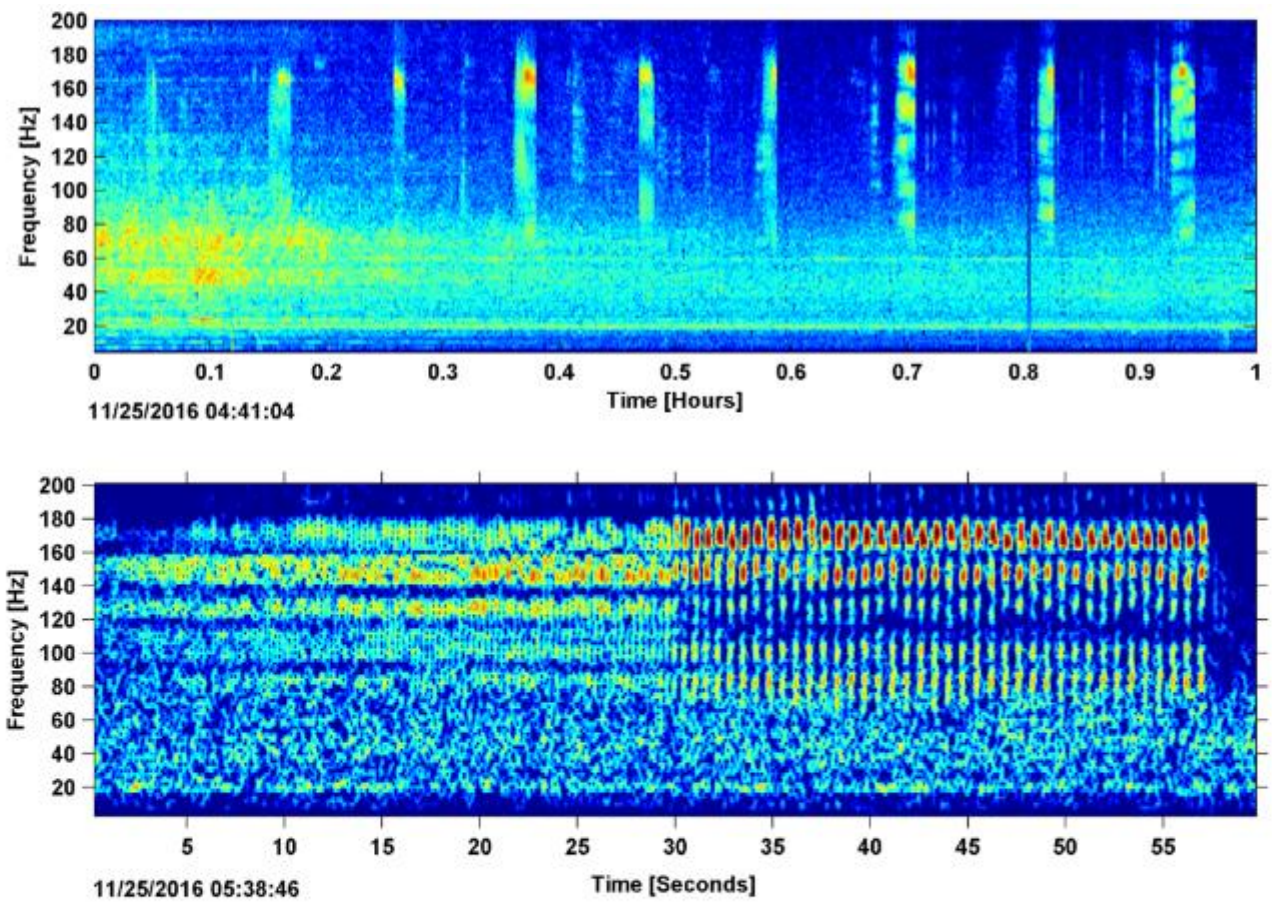

Figure 8. Minke whale pulse train in the LTSA (top) and spectrogram (bottom) recorded at HAT Site A, November 2016.

Sei Whales

Sei whales are found primarily in temperate waters and undergo annual migrations between lower latitude winter breeding grounds and higher latitude summer feeding grounds (Mizroch et al., 1984; Perry et al., 1999). Multiple sounds have been attributed to sei whales, including a low-frequency downsweep (Baumgartner and Fratantoni, 2008; Baumgartner et al., 2008). These calls typically sweep from a starting frequency around 100 Hz to an ending frequency around 40 Hz (Figure 9).

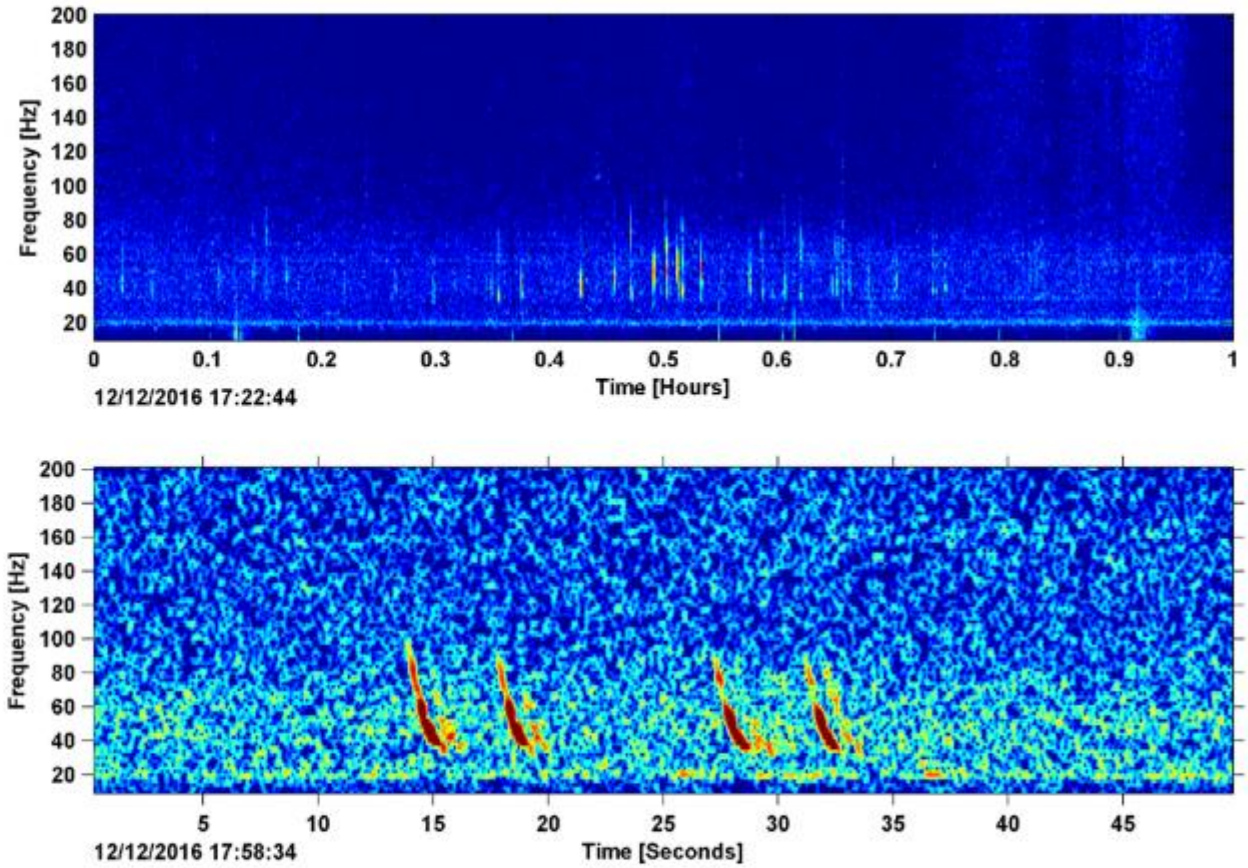

Figure 9. Downsweep calls from sei whales in the LTSA (top) and spectrogram (bottom) from HAT Site A, December 2016.

Northern Atlantic Right Whales

The critically endangered North Atlantic right whale is found in the Western North Atlantic. Several call types have been described for the North Atlantic right whale, including the scream, gunshot, blow, upcall, warble, and downcall (Parks and Tyack, 2005). For low-frequency analysis, we examined the data for upcalls, which are approximately 1 second in duration and range between 80 Hz and 200 Hz, sometimes with harmonics (Figure 10). There were no confirmed detections for North Atlantic right whale upcalls in this recording period.

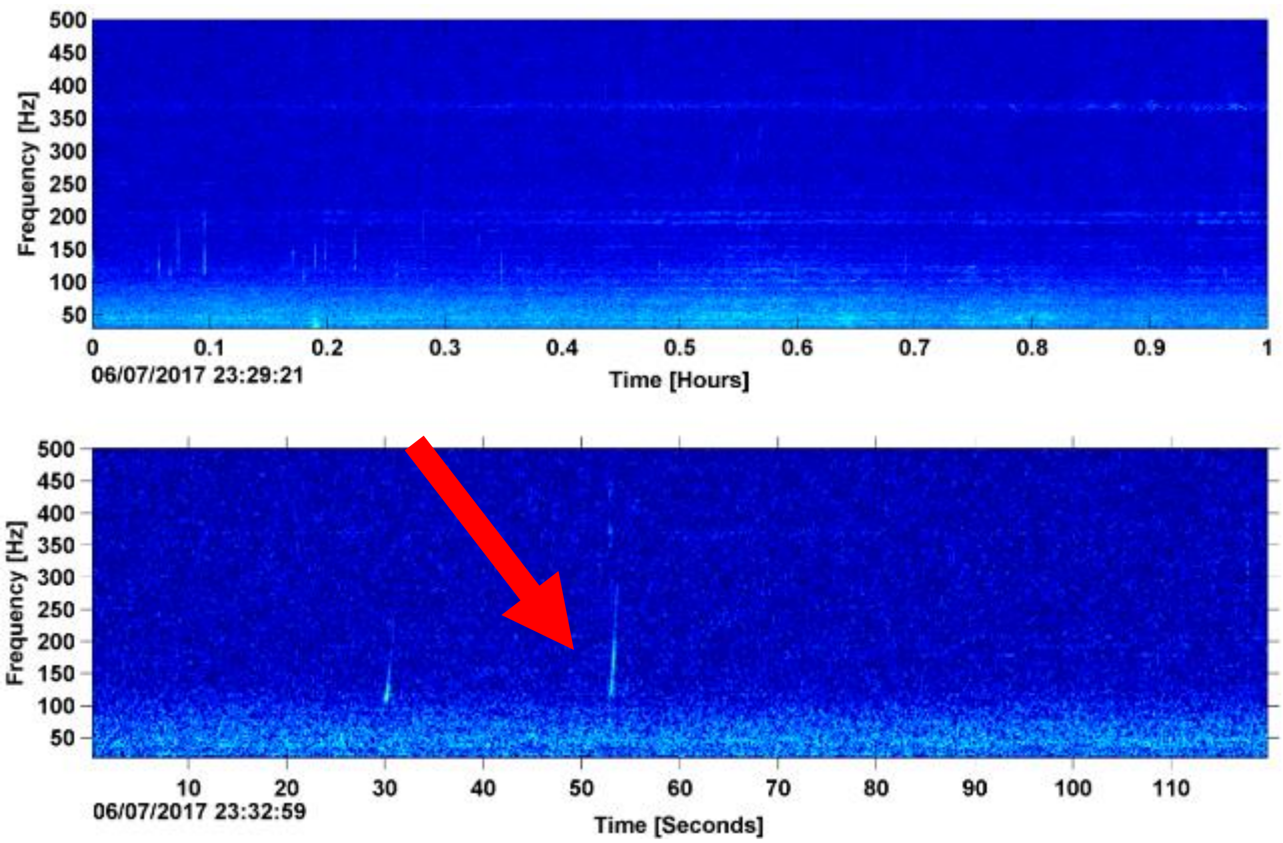

Figure 10. Right whale up-calls in the LTSA (top) and spectrogram (bottom) recorded at Norfolk Canyon Site A, June 2017.

Mid-Frequency Marine Mammals

Humpback whales *(Megaptera novaeangliae)* were the only marine mammal species in the Virginia Capes Range Complex with calls in the mid-frequency range monitored for this report. For mid-frequency data analysis, the 100 kHz data were decimated by a factor of 20 for an effective bandwidth of 5 kHz. The LTSAs for mid-frequency analysis were created using a time average of 5 seconds, and a frequency bin size of 10 Hz. Humpback whale presence was determined by manual scrutiny of LTSAs and spectrograms in the custom software program *Triton.* The LTSA frequency was set to display between 10-5,000 Hz with a 1-hour plot length. To observe individual calls, the spectrogram window was typically set to display 10-3,000 Hz with a 30 s plot length. The FFT was generally set between 1000 and 1500 data points, yielding about a 5 Hz frequency resolution, with a 90% overlap. When humpback whale calls were identified in the LTSA or spectrogram they were logged according to the start and end time of the encounter. An encounter was considered to end when there were no calls for 30 min. The encounter durations were added to estimate cumulative hourly presence.

Humpback Whales

Humpback whales produce both song and non-song calls (Payne and McVay 1971, Dunlop et al. 2007, Stimpert et al., 2011). The song is categorized by the repetition of units, phrases, and themes of a variety of calls as defined by Payne and McVay (1971). Most humpback whale vocalizations are produced between 100 - 3,000 Hz (Figure 11). There were no humpback whale detections in this deployment.

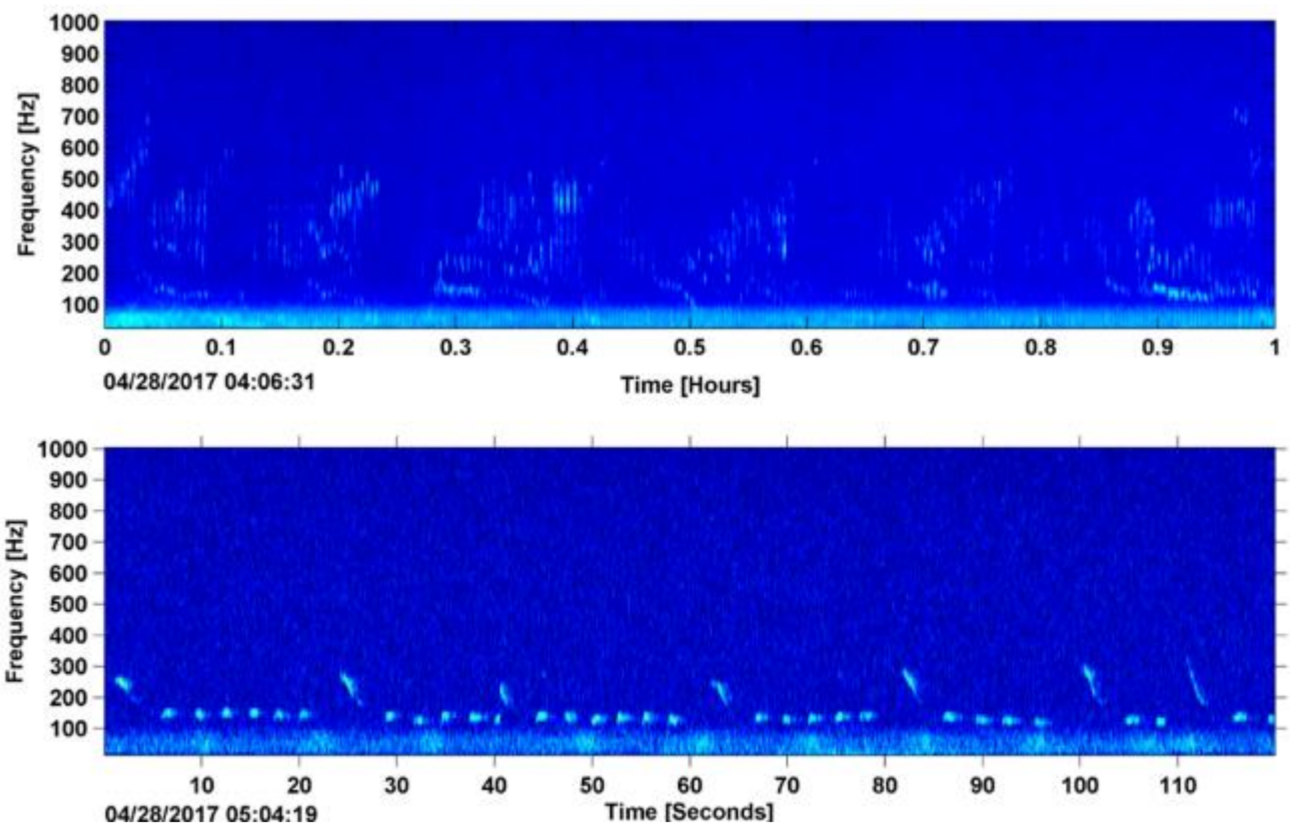

Figure 11. Humpback whale calls in the LTSA (top) and spectrogram (bottom) recorded at Norfolk Canyon Site A, April 2017.

High-Frequency Marine Mammals

Marine mammal species with sounds in the high-frequency range and possibly found in the Virginia Capes Range Complex include bottlenose dolphins (*Tursiops truncatus*), short-finned pilot whales (*Globicephala macrorhynchus*), long-finned pilot whales (*G. melas*), short-beaked common dolphins (*Delphinus delphis*), Atlantic spotted dolphins (*Stenella frontalis*), pantropical spotted dolphins (*Stenella frontalis*), spinner dolphins (*Stenella longirostris*), striped dolphins (*Stenella coeruleoalba*), Clymene dolphins (*Stenella clymene*), rough-toothed dolphins (*Steno bredanensis*), Risso's dolphins (*Grampus griseus*), Fraser's dolphins (*Lagenodelphis hosei*), killer whales (*Orcinus orca*), pygmy killer whales (*Feresa attenuata*), melon-headed whales (*Peponocephala electra*), sperm whales (*Physeter macrocephalus*), dwarf sperm whales (*Kogia sima*), pygmy sperm whales (*Kogia breviceps*), Cuvier's beaked whales (*Ziphius cavirostris*), Gervais' beaked whales (*Mesoplodon europaeus*), Blainville's beaked whales (*Mesoplodon densirostris*), True's beaked whales (*Mesoplodon mirus*) and Sowerby's beaked whales (*Mesoplodon bidens*).

High-Frequency Call Types

Odontocete sounds can be categorized as echolocation clicks, burst pulses, or whistles. Echolocation clicks are broadband impulses with peak energy between 5 and 150 kHz, dependent upon the species. Buzz or burst pulses are rapidly repeated clicks that have a creak or buzz-like sound quality; they are generally lower in frequency than echolocation clicks. Dolphin whistles are tonal calls predominantly between 1 and 20 kHz that vary in frequency content, their degree of frequency modulation, as well as duration. These signals are easily detectable in an LTSA as well as the spectrogram (Figure 12).

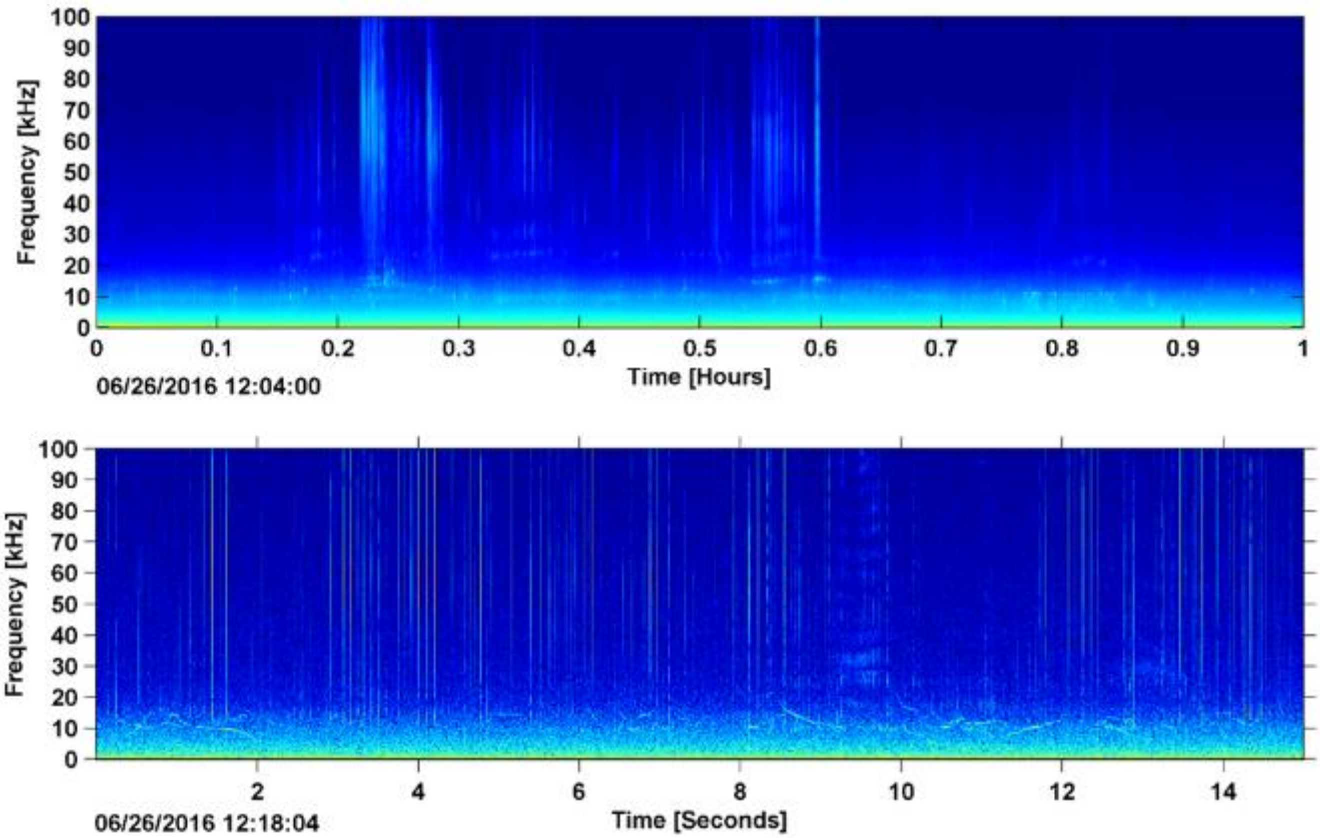

Figure 12. LTSA (top) and spectrogram (bottom) demonstrating odontocete signal types at HAT Site A, June 2016.

Beaked Whales

Beaked whales can be identified acoustically by their echolocation signals (Baumann-Pickering *et al.*, 2014). These signals are frequency-modulated (FM) upsweep pulses, which appear to be species specific and distinguishable by their spectral and temporal features. Identifiable signals are known for Gervais', Blainville's, Cuvier's, and Sowerby's beaked whales.

Beaked whale FM pulses were detected with an automated method. This automated effort was for all identifiable beaked whale signals found in the Cape Hatteras Complex. After all echolocation signals were identified with a Teager Kaiser energy detector (Soldevilla *et al.*, 2008; Roch *et al.*, 2011), an expert system discriminated between delphinid clicks and beaked whale FM pulses. A decision about presence or absence of beaked whale signals was based on detections within a 75 second segment. Only segments with more than 7 detections were used in further analysis. All echolocation signals with a peak and center frequency below 32 and 25 kHz, respectively, a duration less than 355 μs, and a sweep rate of less than 23 kHz/ms were deleted. If more than 13% of all initially detected echolocation signals remained after applying these criteria, the segment was classified to have beaked whale FM pulses. A third classification step, based on computer assisted manual decisions by a trained analyst, was used to label the automatically detected segments to pulse type level and reject false detections (Baumann-Pickering *et al.*, 2013). The rate of missed segments is approximately 5%, varying slightly across deployments.

Blainville's Beaked Whale

Blainville's beaked whale echolocation signals are, like most beaked whales' signals, polycyclic, with a characteristic frequency-modulated upsweep, peak frequency around 34 kHz and uniform inter-pulse interval (IPI) of about 280 ms (Johnson *et al.*, 2004; Baumann-Pickering *et al.*, 2013). Blainville's FM pulses are also distinguishable in the spectral domain by their sharp energy onset around 25 kHz with only a small energy peak at around 22 kHz (Figure 13).

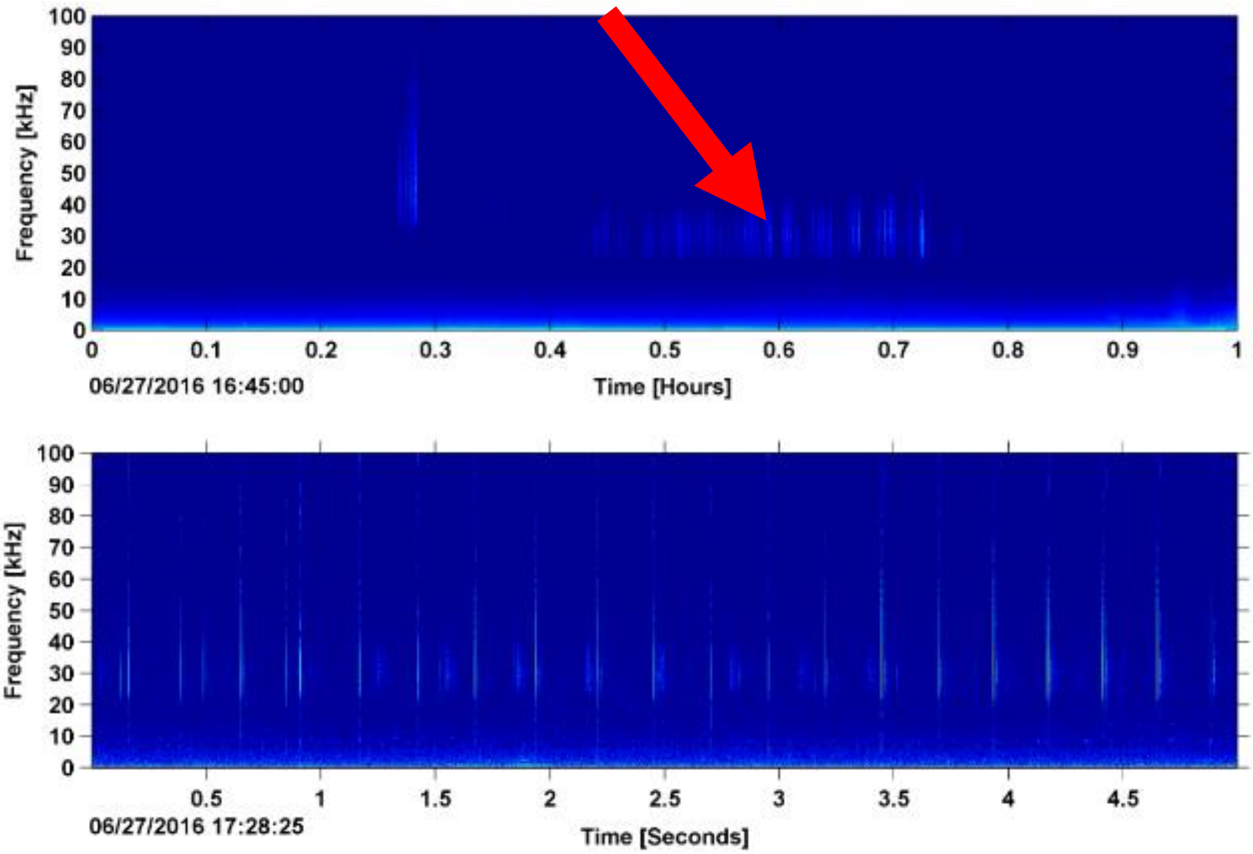

Figure 13. Blainville's beaked whale echolocation clicks in the LTSA (top) and spectrogram (bottom) from HARP recording at HAT Site A, June 2016.

Cuvier's Beaked Whales

Cuvier's echolocation signals are polycyclic, with a characteristic FM pulse upsweep, peak frequency around 40 kHz (Figure 14), and uniform inter-pulse interval of about 0.5 s (Johnson *et al.*, 2004; Zimmer *et al.*, 2005). An additional feature that helps with the identification of Cuvier's FM pulses is that they have two characteristic spectral peaks around 17 and 23 kHz.

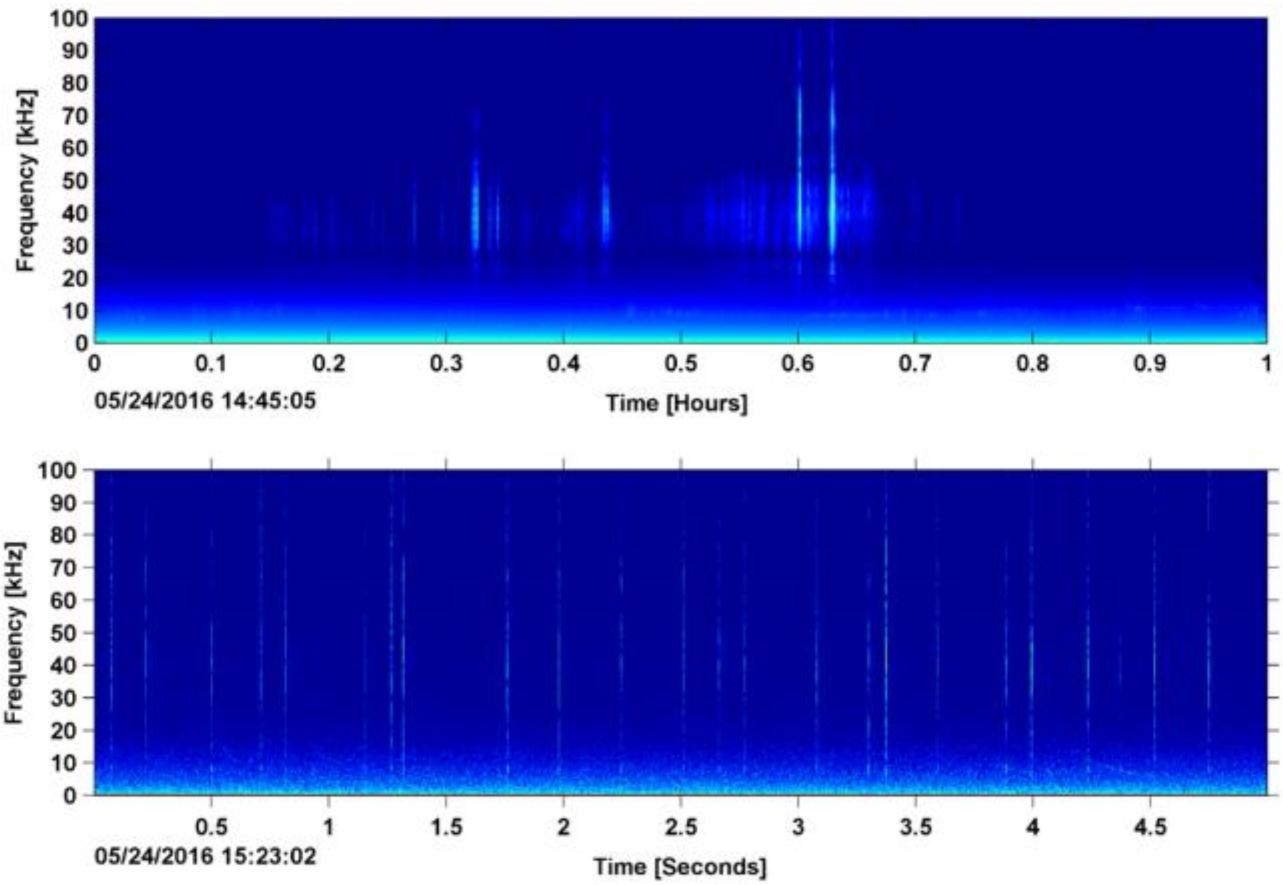

Figure 14. Cuvier's beaked whale signals in LTSA (top) and spectrogram (bottom) from HARP recording at HAT Site A, May 2016.

Gervais' Beaked Whales

Gervais' beaked whale signals have energy concentrated in the 30 – 50 kHz band (Gillespie et al., 2009), with a peak at 44 kHz (Baumann-Pickering et al., 2013). While Gervais' beaked whale signals are similar to those of Cuvier's and Blainville's beaked whales, the Gervais' beaked whale FM pulses are at a slightly higher frequency than those of the other two species. Similarly, Gervais' beaked whale FM pulses sweep up in frequency (Figure 15). The IPI for Gervais' beaked whale signals is typically around 275 ms (Baumann-Pickering et al., 2013). At this time, Gervais' and True's beaked whale signals are not distinguishable, thus encounters classified as Gervais' beaked whale may include True's beaked whale.

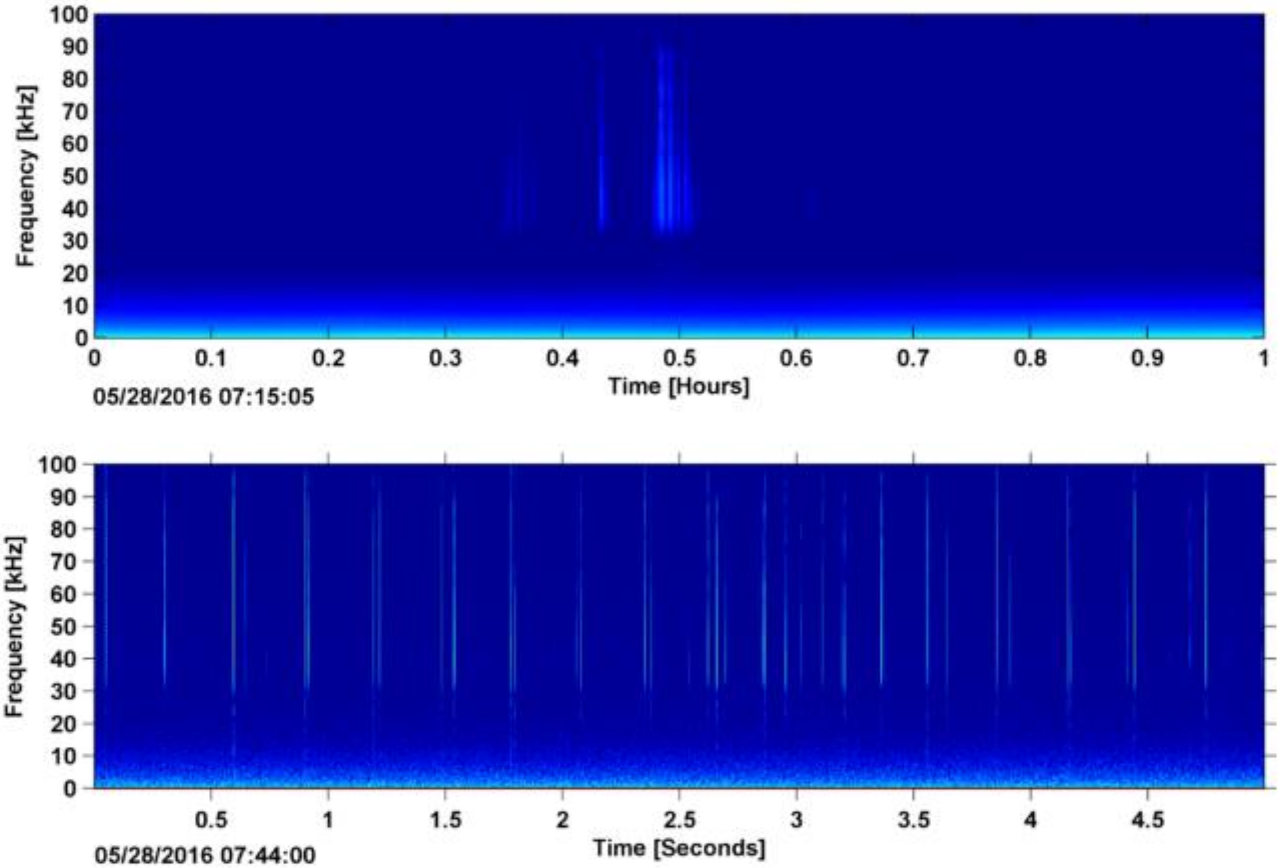

Figure 15. Gervais' beaked whale signals in LTSA (top) and spectrogram (bottom) from HARP recording at HAT Site A, May 2016.

Sowerby's Beaked Whales

Sowerby's beaked whale echolocation signals have energy concentrated in the 50 – 95 kHz band, with a peak at 67 kHz (Figure 16). Sowerby's beaked whale signals have a characteristic FM upsweep, and are distinguishable from other co-occurring beaked whale signal types by their higher frequency content and a relatively short inter-pulse interval of around 150 ms (Cholewiak et al., 2013). There were no Sowerby's beaked whale echolocation detections in this deployment.

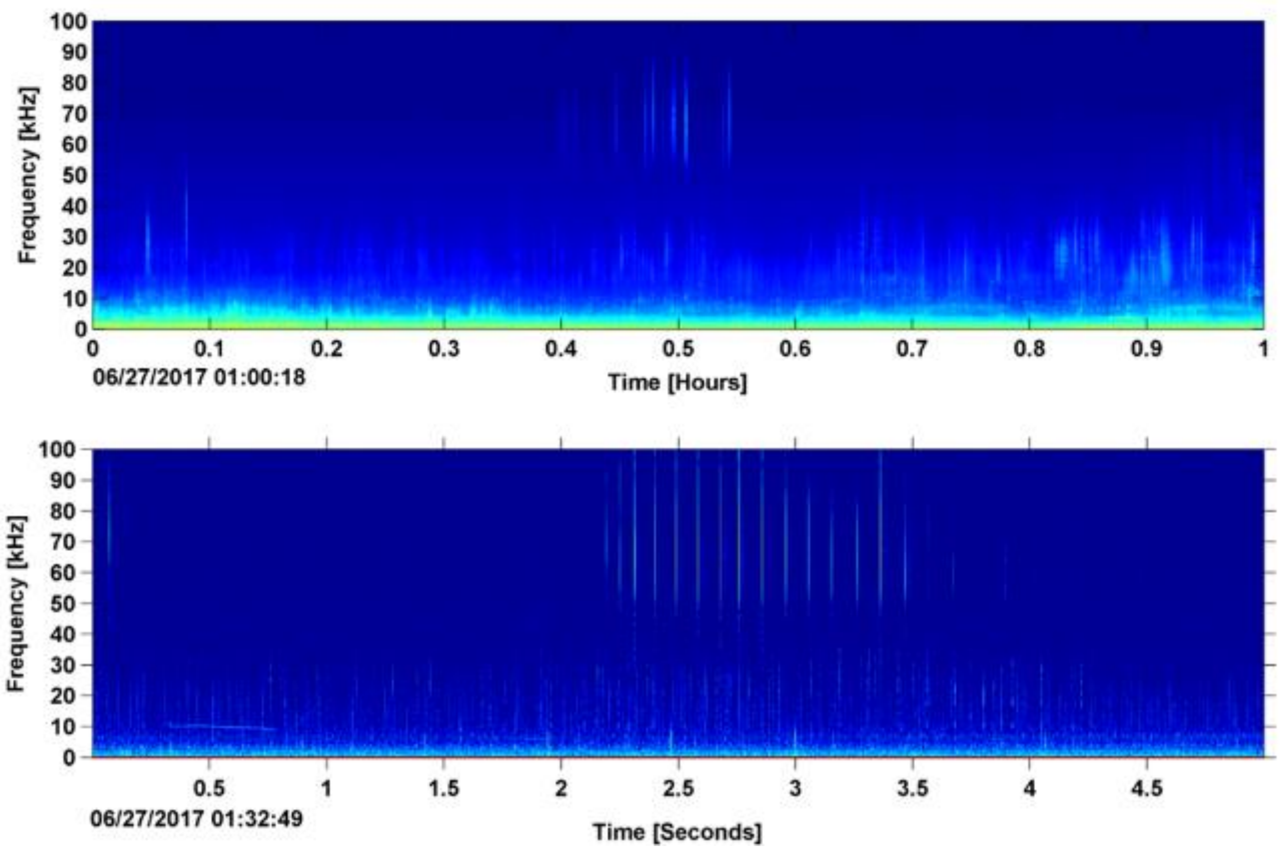

Figure 16. Sowerby's beaked whale echolocation clicks in LTSA (top) and spectrogram (bottom) from HARP recording at NFC Site A, June 2017.

Dolphins

Echolocation Clicks

Delphinid echolocation clicks were detected automatically using an energy detector with a minimum received level threshold of 120 dB_{pp} re:µPa (Roch *et al.*, 2011). Dominant click types at this site were identified automatically by dividing detections into successive five-minute windows and determining the dominant click type(s) in each window. An automated clustering algorithm was then used to identify recurrent click types as well as false positives across all windows (Frasier *et al*. 2017). Detections were automatically labeled by a classifier based on the automatically identified categories. All classifications were then verified by an analyst who reviewed LTSAs and mean spectra for each detected bout. A bout was defined as a period of clicking separated before and after by at least 15 minutes without clicking.

Whistles

Many species of delphinids produce tonal calls known as whistles. These frequency-modulated signals are predominantly found between 1 and 20 kHz. Whistles were detected manually in LTSAs and spectrograms, and characterized based on their frequency content as unidentified odontocete whistles either above or below 5 kHz.

Unidentified Odontocetes

Many Atlantic delphinid sounds are not yet distinguishable to species based on the character of their clicks, buzz or burst pulses, or whistles (Roch *et al.*, 2011; Gillespie *et al.*, 2013). For instance, common dolphin species (short-beaked and long-beaked) and bottlenose dolphins make clicks that are thus far indistinguishable from each other (Soldevilla *et al.*, 2008). Risso's dolphin clicks are distinguishable, and were identified based on known characteristics (Soldevilla *et al.*, 2008). Since delphinid signals are detectable in an LTSA as well as the spectrogram, they were monitored during this analysis effort, but were characterized as unidentified odontocete signals.

Risso's Dolphins

Risso's dolphin echolocation clicks can be identified to species by their distinctive banding patterns observable in the LTSA (Figure 17). Studies show that spectral properties of Risso's dolphin echolocation clicks vary based on geographic region (Soldevilla *et al.*, 2017), although the multiple sharp frequency peaks and average inter-click interval (ICI) found at these North-Western Atlantic sites are similar to what has been found elsewhere. Risso's dolphin clicks detected in this recording period had peaks at 23, 26, and 33 kHz (Figure 18). Modal inter-click interval (ICI) was 165 ms.

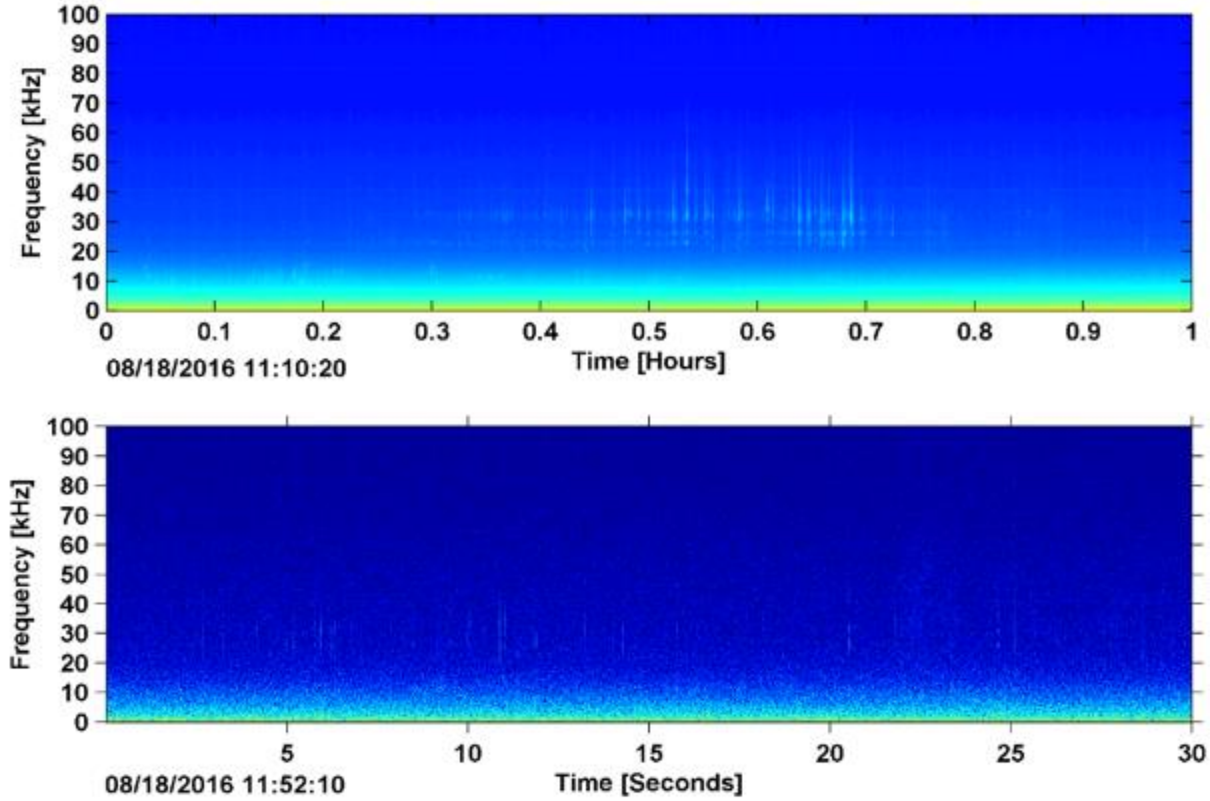

Figure 17. Risso's dolphin acoustic encounter in LTSA (top) and spectrogram (bottom) from HARP recording at HAT Site A, August 2016.

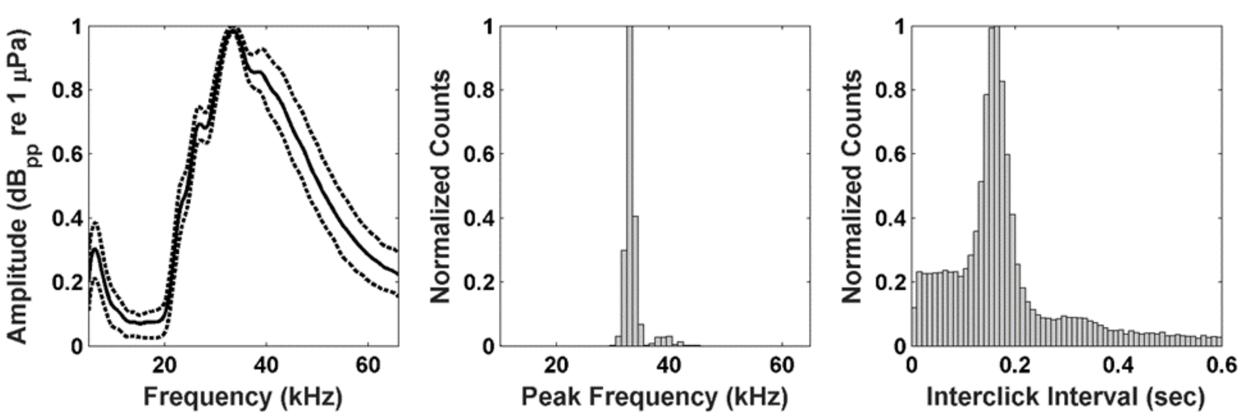

Figure 18. Risso's dolphin click type detected at HAT Site A from April 2016 to January 2017. Left: Mean frequency spectrum of click cluster (solid line) and 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies; Right: Distribution of inter-click intervals (ICI) within cluster.

Other Echolocation Click Types

An automated clustering procedure was used to identify recurrent delphinid click types (CT) in the dataset. Three click types were identified (Figures 19-24). These click types are not currently identified to species, but have consistent spectral shapes and ICI distributions, making them candidates for future identification. CT 1 has a simple spectral shape with peak frequency at approximately 32 kHz, and a modal ICI of 75 ms (Figure 19). An example encounter is shown in Figure 20.

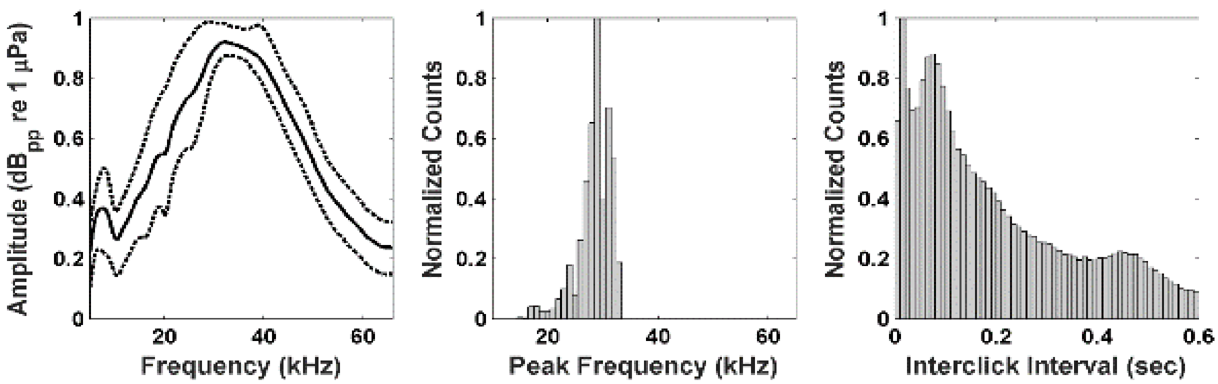

Figure 19. Click type CT 1 detected at HAT Site A from April 2016 to January 2017. Left: Mean frequency spectrum of click cluster (solid line) and 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies; Right: Distribution of inter-click intervals (ICI) within cluster.

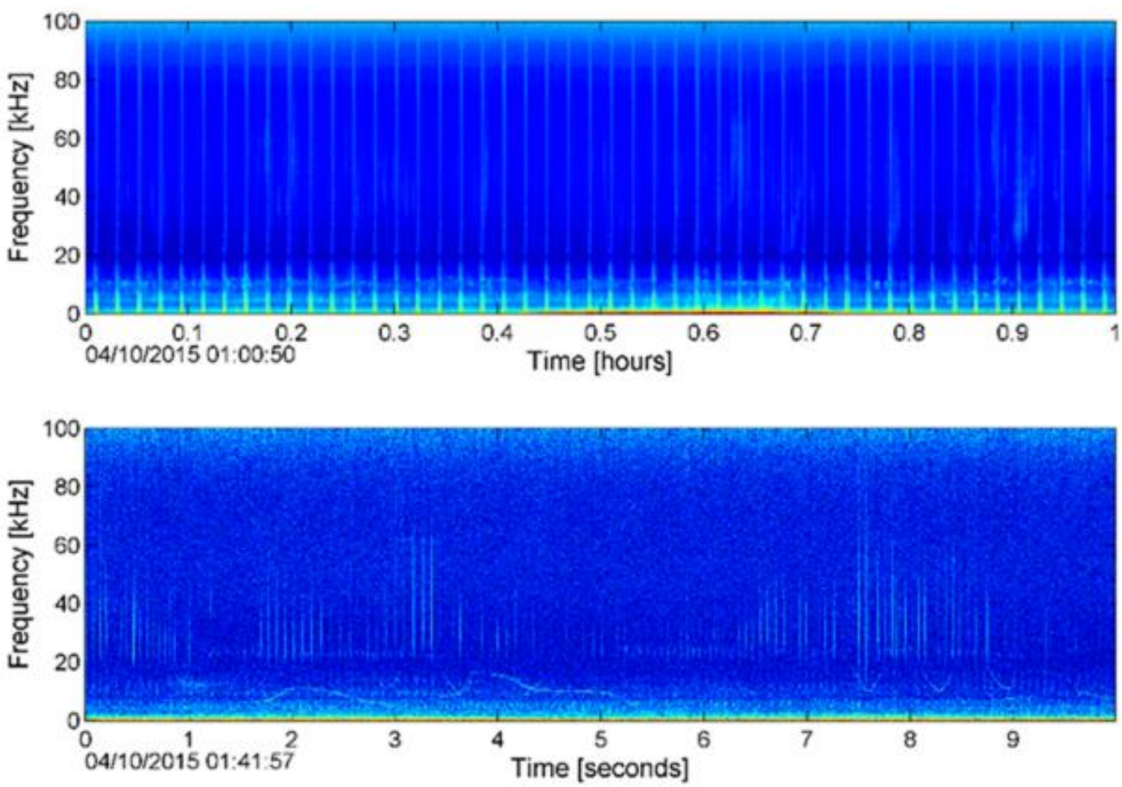

Figure 20. Click type CT 1 acoustic encounter in LTSA (top) and spectrogram (bottom) recorded at HAT Site A, April 2015.

CT 4 spectra has a complex banding pattern with peaks at 8, 21 and 28 kHz and a main peak frequency at 45 kHz (Figure 21). The modal ICI was 65 ms. An example encounter is shown in Figure 22.

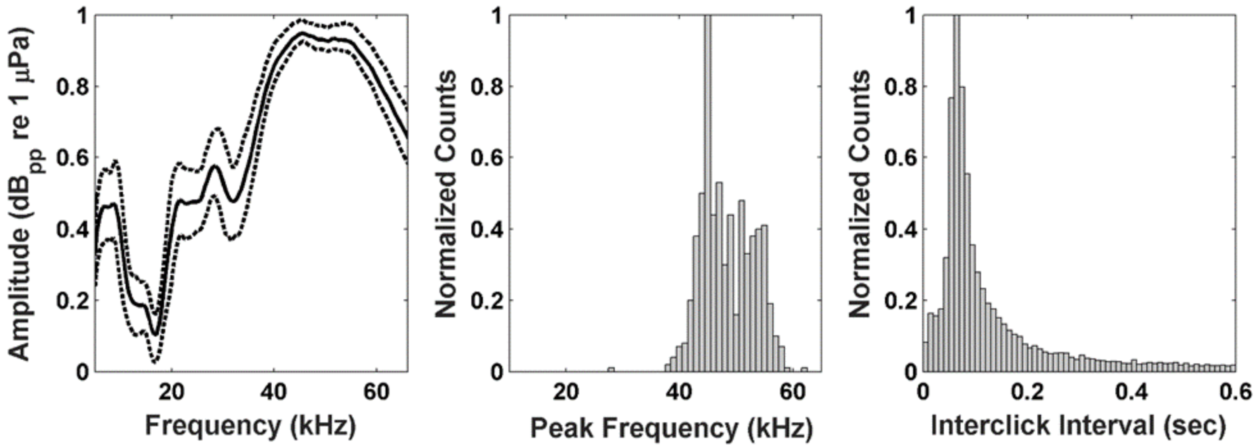

Figure 21. Click type CT 4 detected at HAT Site A from April 2016 to January 2017. Left: Mean frequency spectrum of click cluster (solid line) and 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies; Right: Distribution of inter-click intervals (ICI) within cluster.

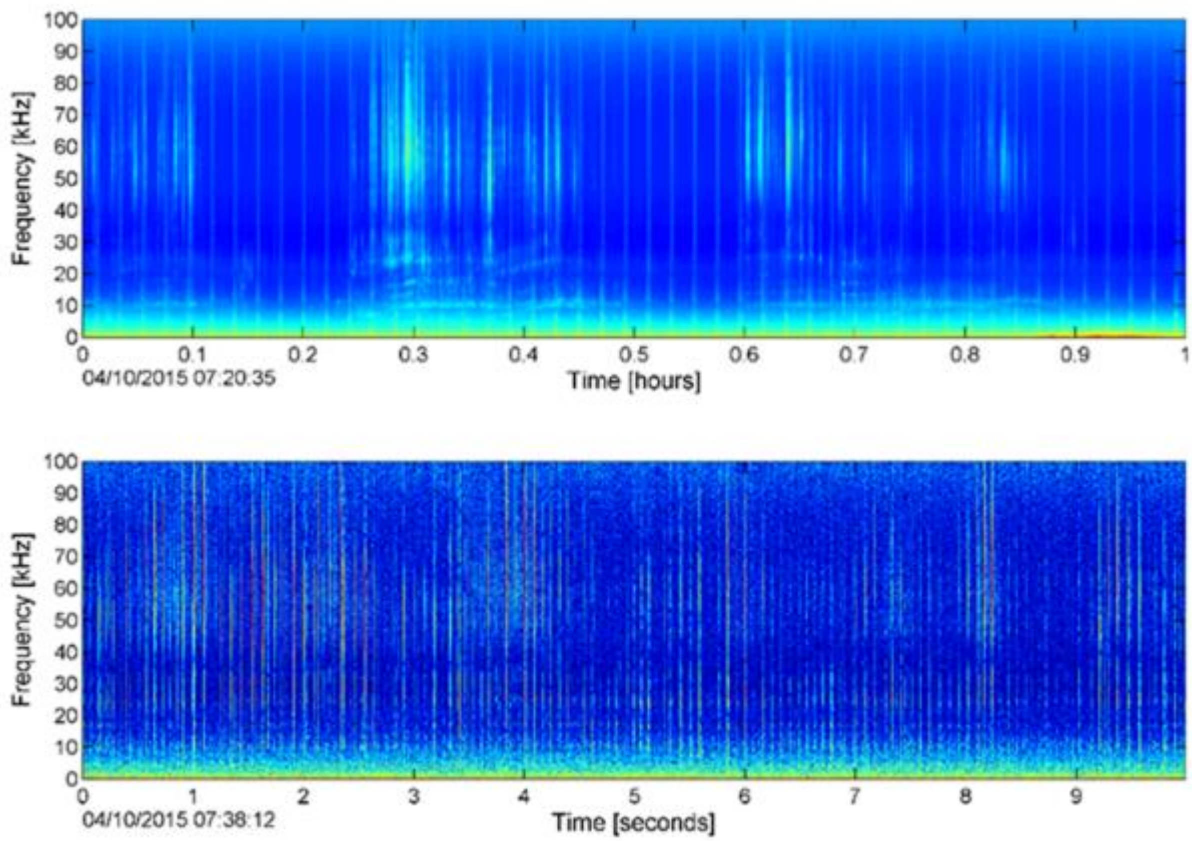

Figure 22. Click type CT 4 acoustic encounter in LTSA (top) and spectrogram (bottom) recorded at HAT Site A, April 2015.

CT 6 has a frequency distribution with a peak near 24 kHz, and a modal ICI of 165 ms (Figure 23). An example encounter is shown in Figure 24.

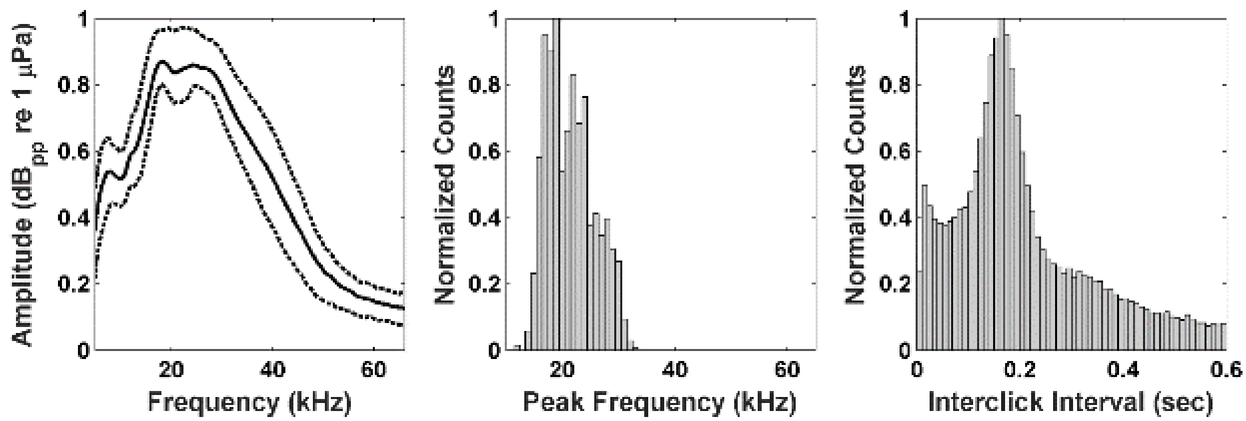

Figure 23. Click type CT 6 detected at HAT Site A from April 2016 to January 2017. Left: Mean frequency spectrum of click cluster (solid line) and 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies; Right: Distribution of inter-click intervals (ICI) within cluster.

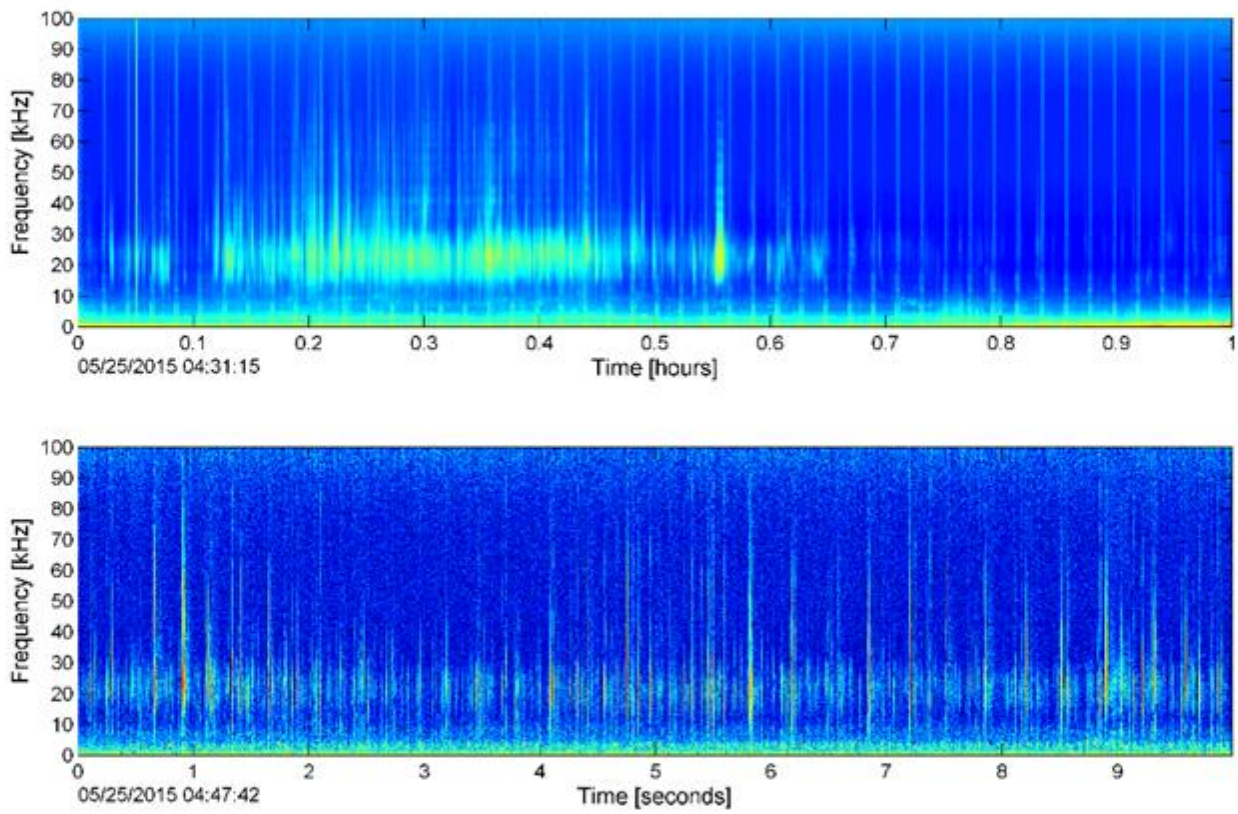

Figure 24. Click type CT 6 acoustic encounter in LTSA (top) and spectrogram (bottom) recorded at HAT Site A, July 2015.

Sperm Whales

Sperm whale clicks contain energy from 2-20 kHz, with most energy between 10-15 kHz (Møhl *et al.*, 2003) (Figure 25). Regular clicks, observed during foraging dives, demonstrate an ICI from 0.25-1 s (Goold and Jones, 1995; Madsen *et al.*, 2002a). Short bursts of closely spaced clicks called creaks are observed during foraging dives and are believed to indicate a predation attempt (Wysocki *et al.*, 2006). Slow clicks (> 1 sec ICI) are used only by males and are more intense than regular clicks with long inter-click intervals (Madsen *et al.*, 2002b). Codas are stereotyped sequences of clicks which are less intense and contain lower peak frequencies than regular clicks (Watkins and Schevill, 1977). Effort was not expended to denote whether sperm whale detections were codas or regular or slow clicks.

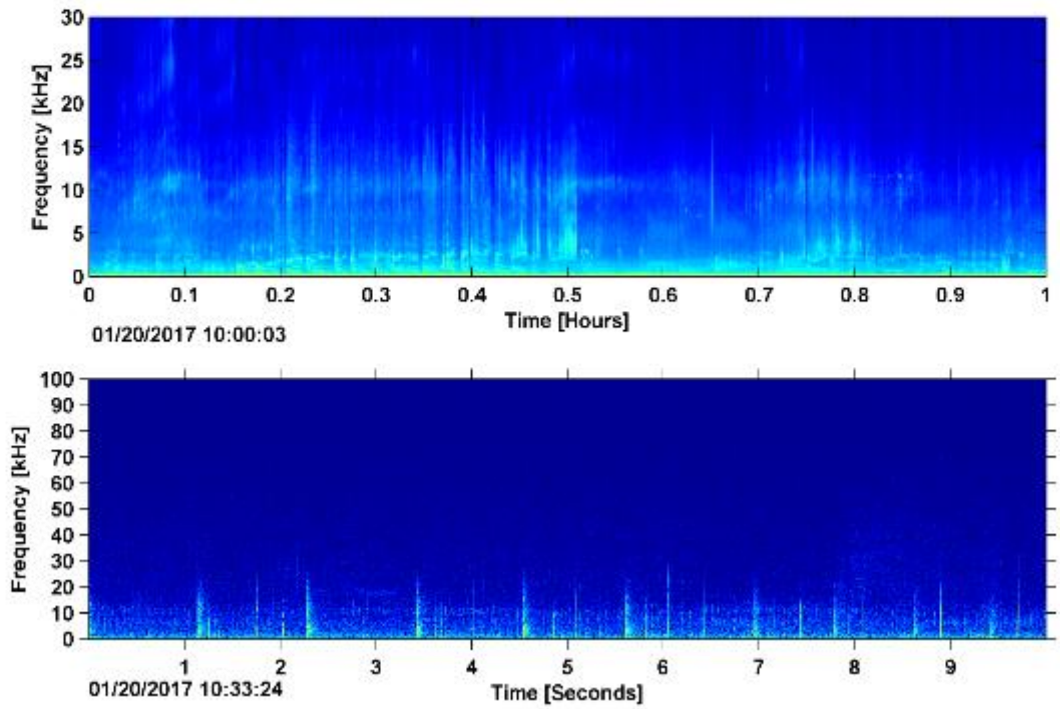

Figure 25. Sperm whale echolocation clicks in LTSA (top) and spectrogram (bottom) recorded at HAT Site A, January 2017.

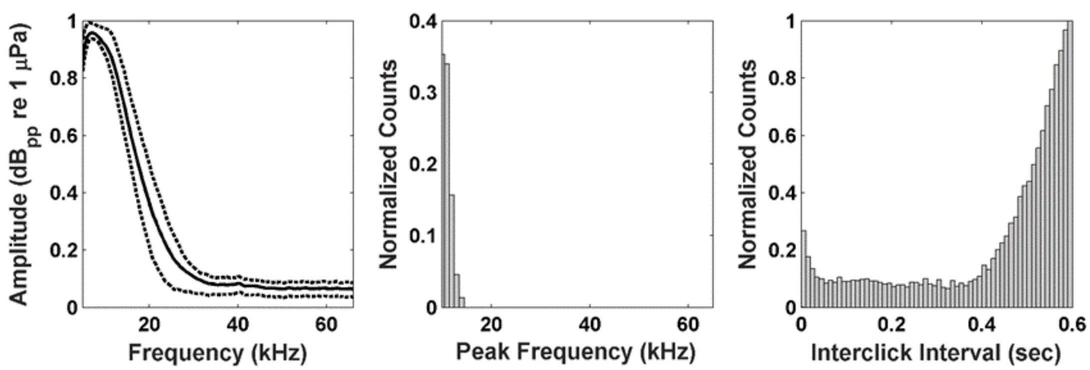

Figure 26. Sperm whale echolocation clicks detected at HAT Site A from April 2016 to January 2017. Left: Mean frequency spectrum of click cluster (solid line) and 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies; Right: Distribution of inter-click intervals (ICI).

Kogia spp.

Dwarf and pygmy sperm whales emit echolocation signals that have peak energy at frequencies near 130 kHz (Au, 1993). While this is above the frequency band recorded by the HARP, the lower portion of the *Kogia* energy spectrum is within the 100 kHz HARP bandwidth (Figure 27). The observed signal may result both from the low-frequency tail of the *Kogia* echolocation click spectra, and from aliasing of energy from above the Nyquist frequency of 100 kHz (Figure 28). *Kogia* echolocation clicks were analyzed using a multi-step detector. The first step was to identify clicks with energy in the 70-100 kHz band that simultaneously lacked energy in lower frequency bands. An expert system then classified these clicks based on spectral characteristics, and finally an analyst verified all echolocation click bouts manually.

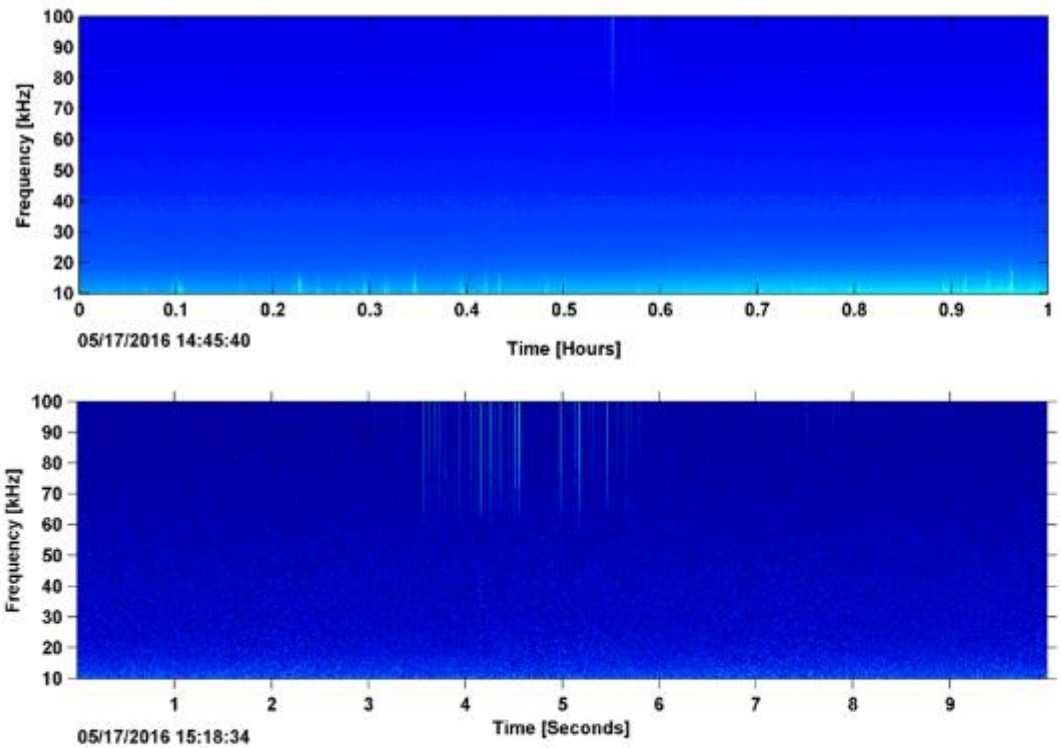

Figure 27. Kogia spp. echolocation clicks in LTSA (top) and spectrogram (bottom) recorded at HAT Site A, May 2016.

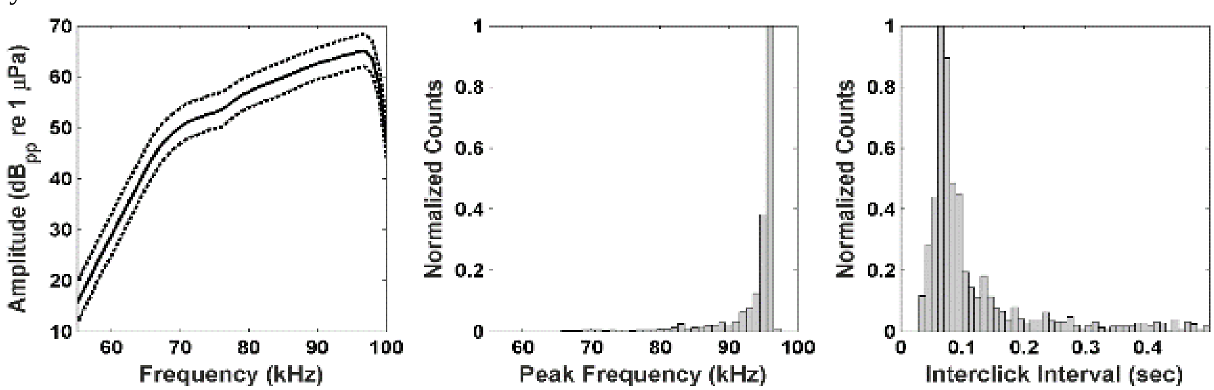

Figure 28. Kogia spp. detected at HAT Site A from April 2016 to January 2017. Left: Mean frequency spectrum of click cluster (solid line) and 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies; Right: Distribution of inter-click intervals (ICI) within cluster.

Anthropogenic Sounds

Several anthropogenic sounds including broadband ship noise, Low-Frequency Active (LFA) Sonar, Mid-Frequency Active (MFA) sonar, High Frequency Active (HFA) sonar, echosounders, underwater communications, explosions, and airguns were monitored for this report. The LTSA manual search parameters used to detect these sounds are given in Table 1.The start and end of each sound or session was logged and their durations were added to estimate cumulative hourly presence. Airguns and explosions were analyzed by using a detector, described below.

Table 1. Anthropogenic sound data manual effort analysis parameters.

Sound Type	**LTSA Search Parameters**	
	Plot Length (Hour)	**Display Frequency Range (Hz)**
Broadband Ship Noise	3	10 – 5,000
LFA Sonar	1	10 – 1,000
HFA Sonar	1	10,000 – 100,000
MFA Sonar	1	1,000 – 5,000
Echosounder	1	5,000 – 100,000

Broadband Ship Noise

Broadband ship noise occurs when a ship passes within a few kilometers of a hydrophone. Ship noise can occur for many hours at a time, but broadband ship noise typically lasts from 10 minutes up to 3 hours at a time. Ship noise has a characteristic interference pattern in the LTSA (McKenna et al., 2012). Combination of direct paths and surface reflected paths produce constructive and destructive interference (bright and dark bands) in the spectrogram that varies by frequency and distance between the broadband ship and the receiver (Figure 29). Ship noise can extend above 10 kHz, although typically falls off above a few kHz. Broadband ship analysis effort consisted of manual scans of the LTSA set at 1 hour with a frequency range of 10-5,000 Hz.

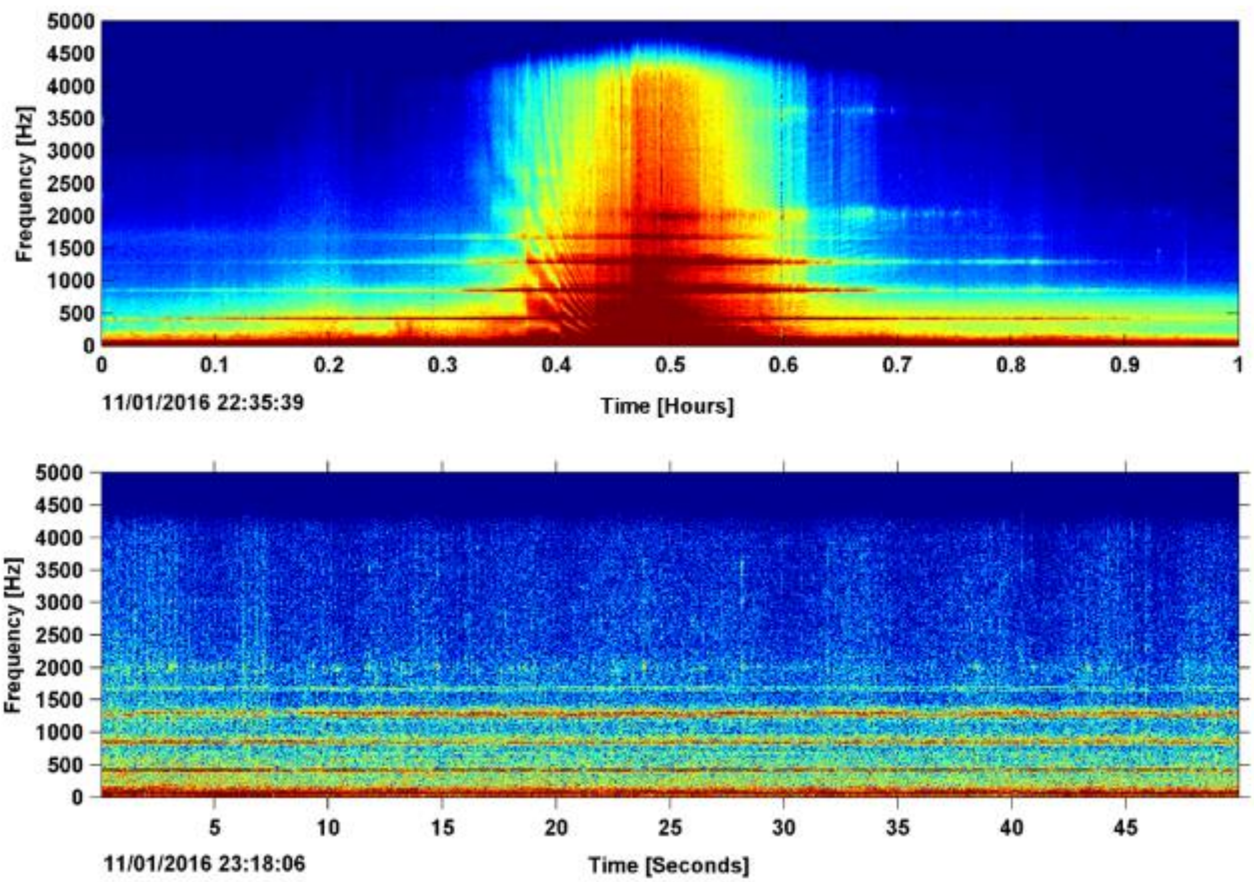

Figure 29. Broadband ships in LTSA (top) and spectrogram (bottom) recorded at HAT Site A, November 2016.

Low-Frequency Active Sonar

Low-frequency active sonar includes military sonar between 100 and 500 Hz and other sonar systems up to 1 kHz. There was effort for LFA sonar both greater than 500 Hz and less than 500 Hz but there were no detections of greater than 500 Hz (Figure 30).

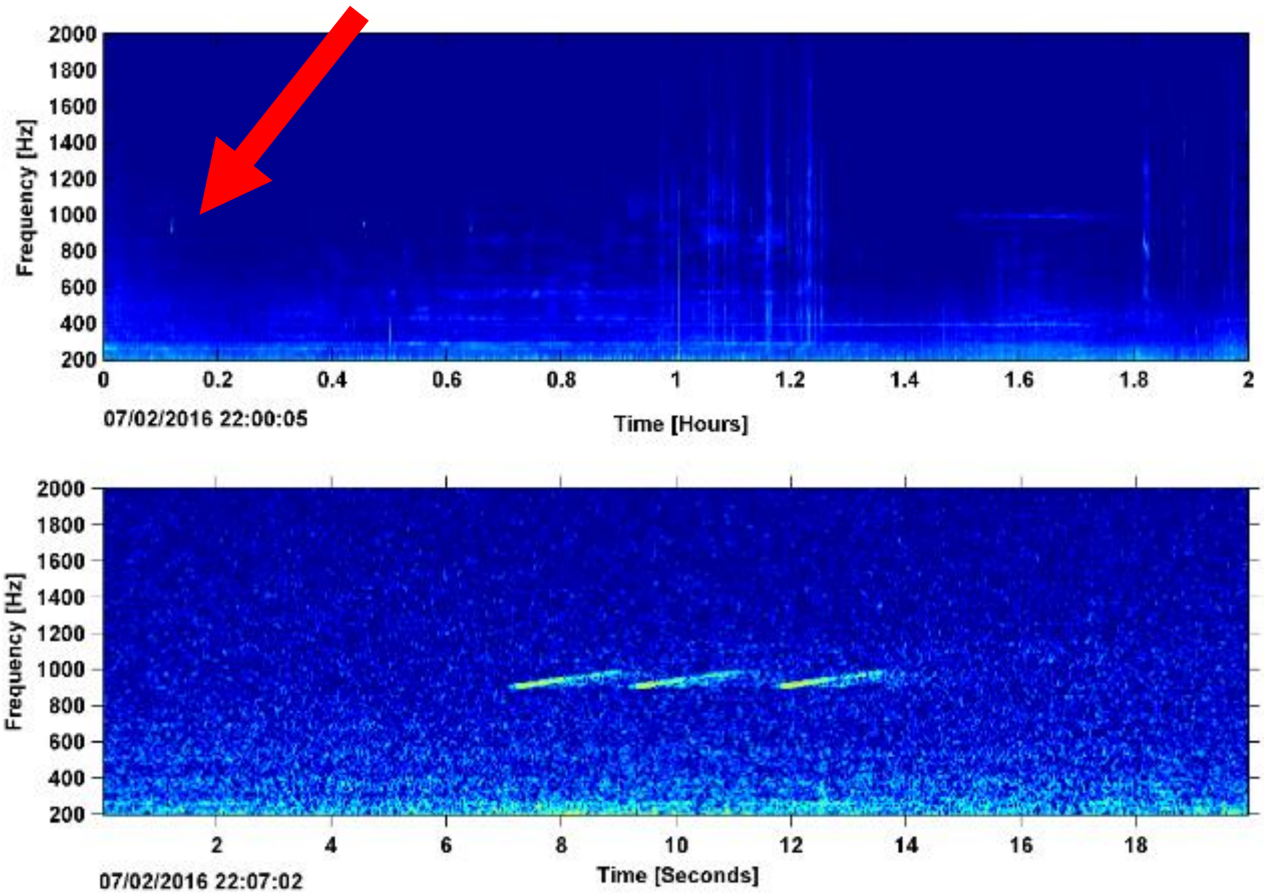

Figure 30. Low-frequency active sonar in Hz in the LTSA (top) and spectrogram (bottom) recorded at HAT Site A, July 2016.

Mid-Frequency Active Sonar

Sounds from MFA sonar vary in frequency (1 – 10 kHz) and are composed of pulses of both frequency modulated (FM) sweeps and continuous wave (CW) tones grouped in packets with durations ranging from less than 1 s to greater than 5 s. Packets can be composed of single or multiple pulses and are transmitted repetitively as wave trains with inter-packet-intervals typically greater than 20 s (Figure 31). In the Jacksonville Range Complex, the most common MFA sonar packet signals are between 2 and 5 kHz and are known more generally as '3.5 kHz' sonar. Analysts manually scanned LTSAs and logged sonar wave train event start and end times. A custom software routine was used to detect sonar pings within the analyst-defined bouts and to calculate peak-to-peak (PP) received sound pressure levels (Wiggins, 2015). For this detector, a sonar ping is defined as the presence of sonar within a 5 s window and may contain multiple individual pings. The detector calculates the average spectrum level across the frequency band from 2.4 to 4.5 kHz for each 5 s time bin. This provides a time series of the average received levels in that frequency band. Minimum values were noted for each 5 s time bin, and used as a measure of background noise level over the sonar event period. Spectral bins that contained system noise (disk writing) were eliminated to prevent contaminating the results. Each of the remaining average spectral bins was compared to the background minimum levels. If levels were more than 3 dB above the background, then a detection time was noted. These detection times were then used to index to the original time series to calculate PP levels. Received PP levels were calculated by differencing the maximum and minimum amplitude of the time series in the 5 s window. The raw 28 time series amplitudes are in units of analog-to-digital converter (ADC) counts. These units were corrected to µPa by using the calibrated transfer function for this frequency band. Since the instrument response is not flat over the 2.4 – 4.5 kHz band, a middle value at 3.3 kHz was used. For sonar pings less than this middle frequency, their levels are overestimated by up to about 5 dB and for those at higher frequency their levels are underestimated by up to about 4 dB. While all sonar was manually detected, only the sonars between 2.4 and 4.5 kHz were further analyzed in the received levels analysis.

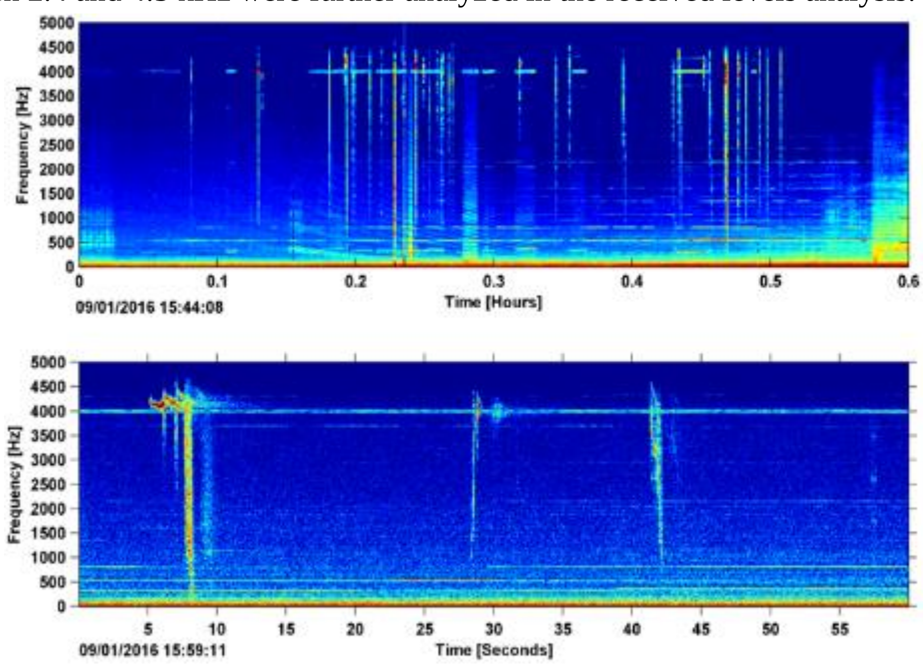

Figure 31. Mid-frequency active sonar in LTSA (top) and spectrogram (bottom) at HAT Site A, September 2016.

High-Frequency Active Sonar

HFA sonar is used for specialty military and commercial applications including high-resolution seafloor mapping, short-range communications, such as with Autonomous Underwater Vehicles (AUVs), multi-beam fathometers, and submarine navigation (Cox, 2004). HFA sonar upsweeps between 10 and 100 kHz were manually detected by analysts in LTSA plots (Figure 32) for this deployment.

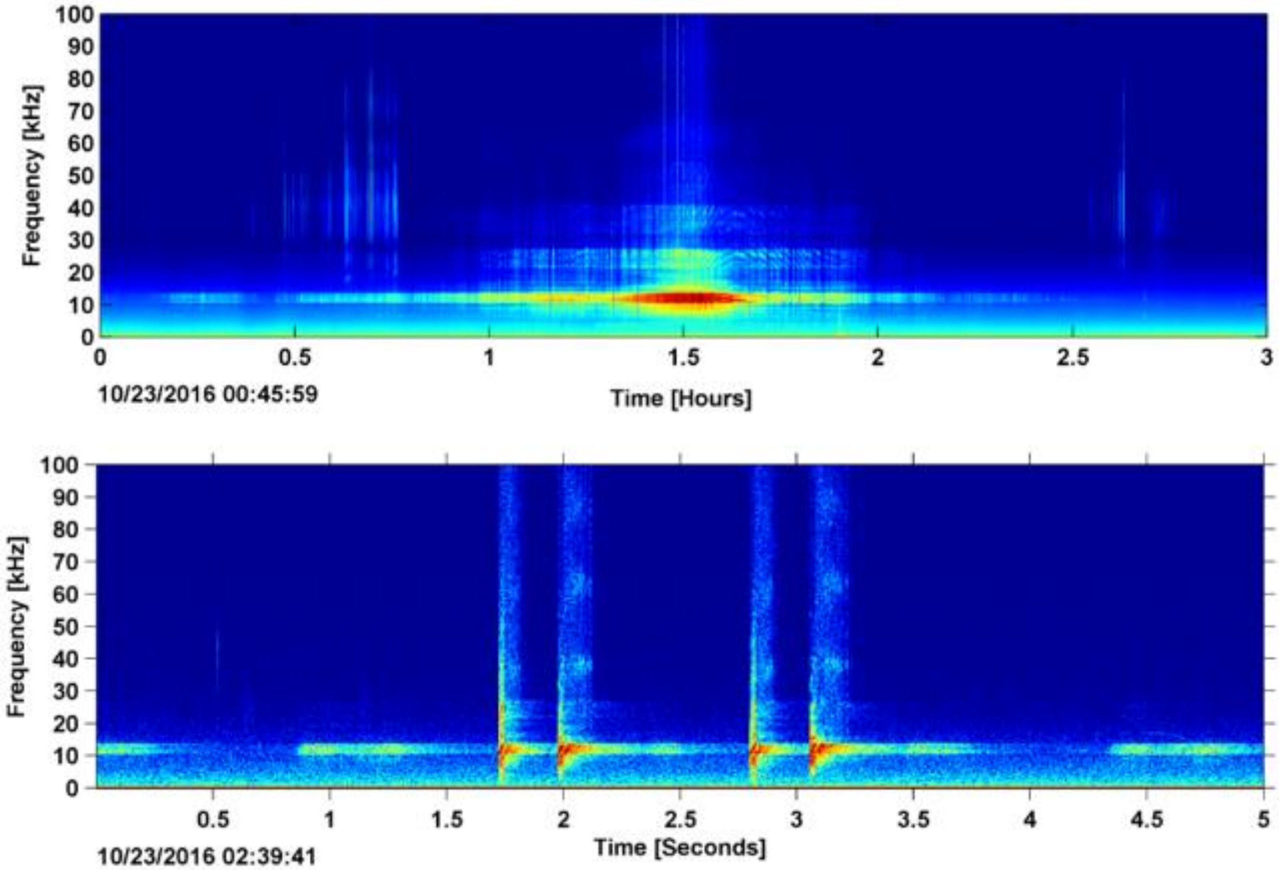

Figure 32. High-frequency active sonar in LTSA (top) and spectrogram (bottom) recorded at HAT Site A, October 2016.

Echosounders

Echosounding sonars transmit short pulses or frequency sweeps, typically in the high-frequency (above 5 kHz) band (Figure 33), though echosounders are occasionally found in the mid-frequency range (2-5 kHz). Many large and small vessels are equipped with echosounding sonar for water depth determination; typically these echosounders are operated much of the time a ship is at sea, as an aid for navigation. In addition, sonars may be used for sea bottom mapping, fish detection, or other ocean sensing. High-frequency echosounders were manually detected by analysts reviewing LTSA plots.

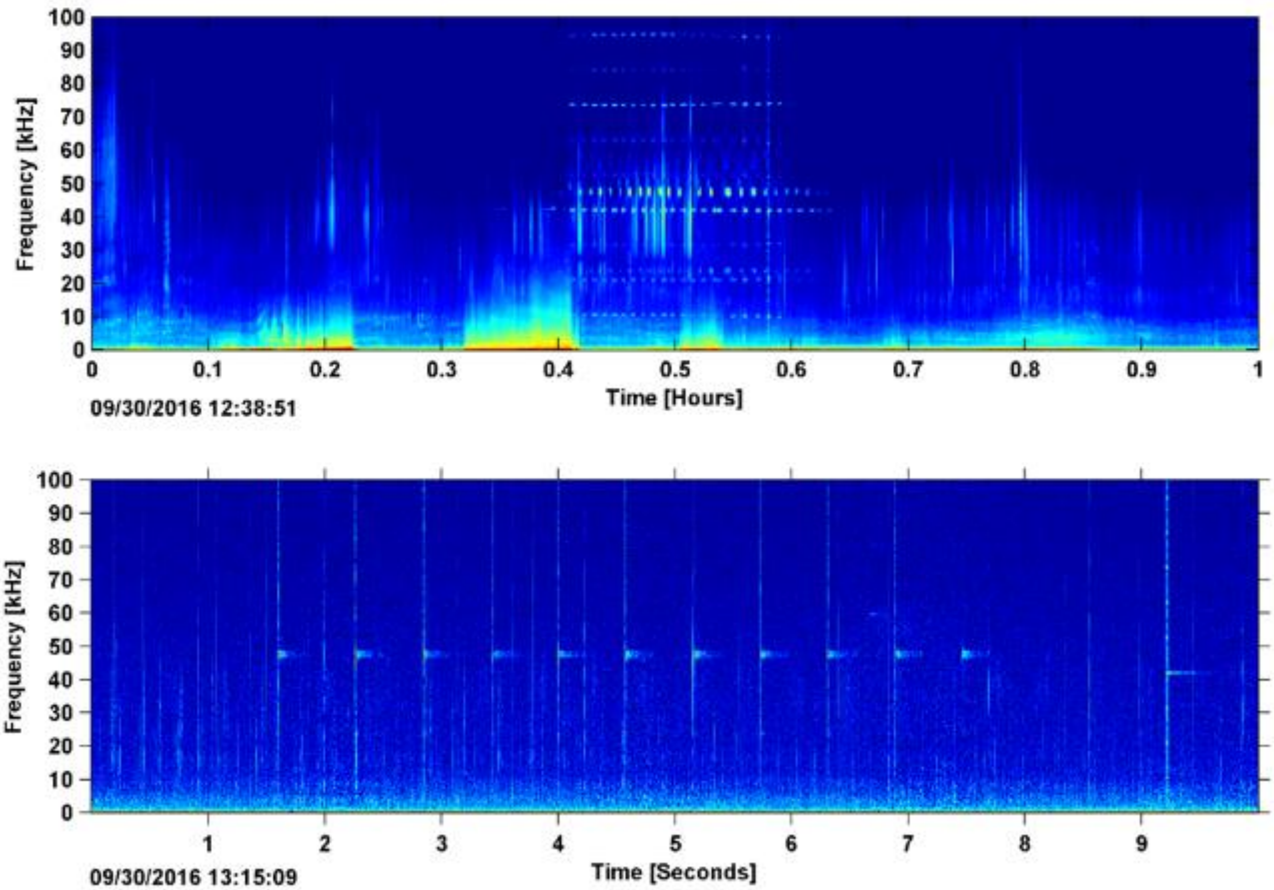

Figure 33. Echosounders in LTSA (top) and spectrogram (bottom) recorded at HAT Site A, September 2016.

Explosions

Effort was directed toward finding explosive sounds in the data including military explosions, subseafloor exploration, and seal bombs used by the fishing industry. An explosion appears as a vertical spike in the LTSA that when expanded in the spectrogram and has sharp onset reverberant decay (Figure 34). Explosions were detected automatically using a matched filter detector on data decimated to a 5 kHz bandwidth. The time series was filtered with a 10th order Butterworth bandpass filter between 200 and 2,000 Hz. Cross correlation was computed between 75 seconds of the envelope of the filtered time series and the envelope of a filtered example explosion (0.7 s, Hann windowed) as the matched filter signal. The cross correlation was squared to 'sharpen' peaks of explosion detections. A floating threshold was calculated by taking the median cross correlation value over the current 75 seconds of data to account for detecting explosions within noise, such as shipping. A cross correlation threshold above the median was set. When the correlation coefficient reached above threshold, the time series was inspected more closely. Consecutive explosions were required to have a minimum time separation of 2 seconds to be detected. A 300-point (0.03 s) floating average energy across the detection was computed. The start and end above threshold was determined when the energy rose by more than 2 dB above the median energy across the detection. Peak-to-peak (pp) and rms received levels (RL) were computed over the potential explosion period and a time series of the length of the explosion template before and after the explosion. The potential explosion was classified as false detection and deleted if: 1) the dB difference pp and rms between signal and time after the detection was less than 4 dB or 1.5 dB, respectively; 2) the dB difference pp and rms between signal and time before signal was less than 3 dB or 1 dB, respectively; and 3) the detection was shorter than 0.03 and longer than 0.55 seconds of duration. These thresholds were evaluated based on the distribution of histograms of manually verified true and false detections. A trained analyst subsequently verified the remaining potential explosions for accuracy. Explosions have energy as low as 10 Hz and may extend up to 2,000 Hz or higher, lasting for a few seconds including the reverberation. Explosions were automatically detected and then manually verified to remove false positives associated with airgun activity and fish sounds.

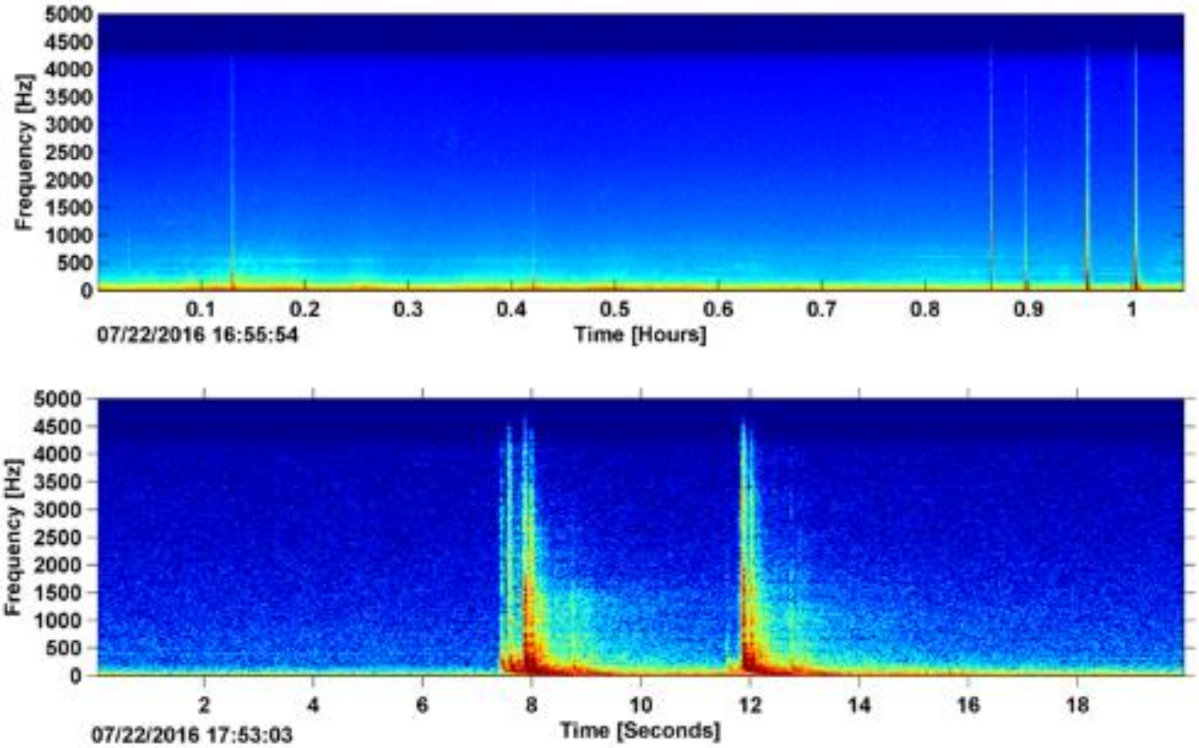

Figure 34. Explosions recorded in LTSA (top) and spectrogram (bottom) recorded at Norfolk Canyon Site A, July 2016.

Airguns

Airguns are regularly used in seismic exploration to investigate the ocean floor and what lies beneath it. A container of high-pressure air is momentarily vented to the surrounding water, producing an air-filled cavity which expands and contracts violently several times (Barger and Hamblen, 1980). While most of the energy produced by an air fun array falls below 250 Hz, airguns can produce significant energy at frequencies up to at least 1 kHz (Blackman, et al., 2004). Source levels tend to be 200 dB re 1 µPa-m (Blackman et al., 2004; Amundsen and Landro, 2010). These shots typically have an inter-pulse-interval of approximately 10 seconds and can last from several hours to days (Figure 35). Airguns were detected automatically using a matched filter detector on data decimated to 1 kHz sampling rate. The time series was filtered with a 10th order Butterworth bandpass filter between 25 and 200 Hz. Cross correlation was computed between 75 seconds of the envelope of the filtered time series and the envelope of a filtered example explosion (0.7 s, Hann windowed) as the matched filter signal. The cross correlation was squared to 'sharpen' peaks of airgun blast detections. A floating threshold was calculated by taking the median cross correlation value over the current 75 seconds of data to account for detecting airguns within noise, such as shipping. A cross correlation threshold of $3x10^{-3}$ above the median was set. When the correlation coefficient reached above this threshold, the time series was inspected more closely. Consecutive airgun shots were required to have a minimum time distance of 2 seconds to be detected. A 300-point (0.03 s) floating average energy across the detection was computed. The start and end times above the threshold were marked when the energy rose by more than 2 dB above the median energy across the detection. Peak-to-peak (pp) and root mean-square (rms) received sound pressure levels (RL) were computed over the potential signal period as well as a timeseries of the length of the airgun shot template before and after the explosion. The potential airgun shot was classified as a false detection and deleted if 1) the dB difference of pp and rms between signal and time AFTER the detection was less than 0.5 dB; 2) the dB difference of pp and rms between signal and time BEFORE the signal was less than 0.5 dB; and 3) the detection was shorter than 0.5 or longer than 10 s. The thresholds were evaluated based on the distribution of histograms of manually verified true and false detections. A regular airgun shot interpulse interval was used to discard potential airgun detections that were not part of a sequence. A trained analyst subsequently verified the remaining potential airgun detections for accuracy. Airgun shots have energy as low as 10 Hz and can extend up to 250 Hz or higher, lasting for a few seconds including the reverberation.

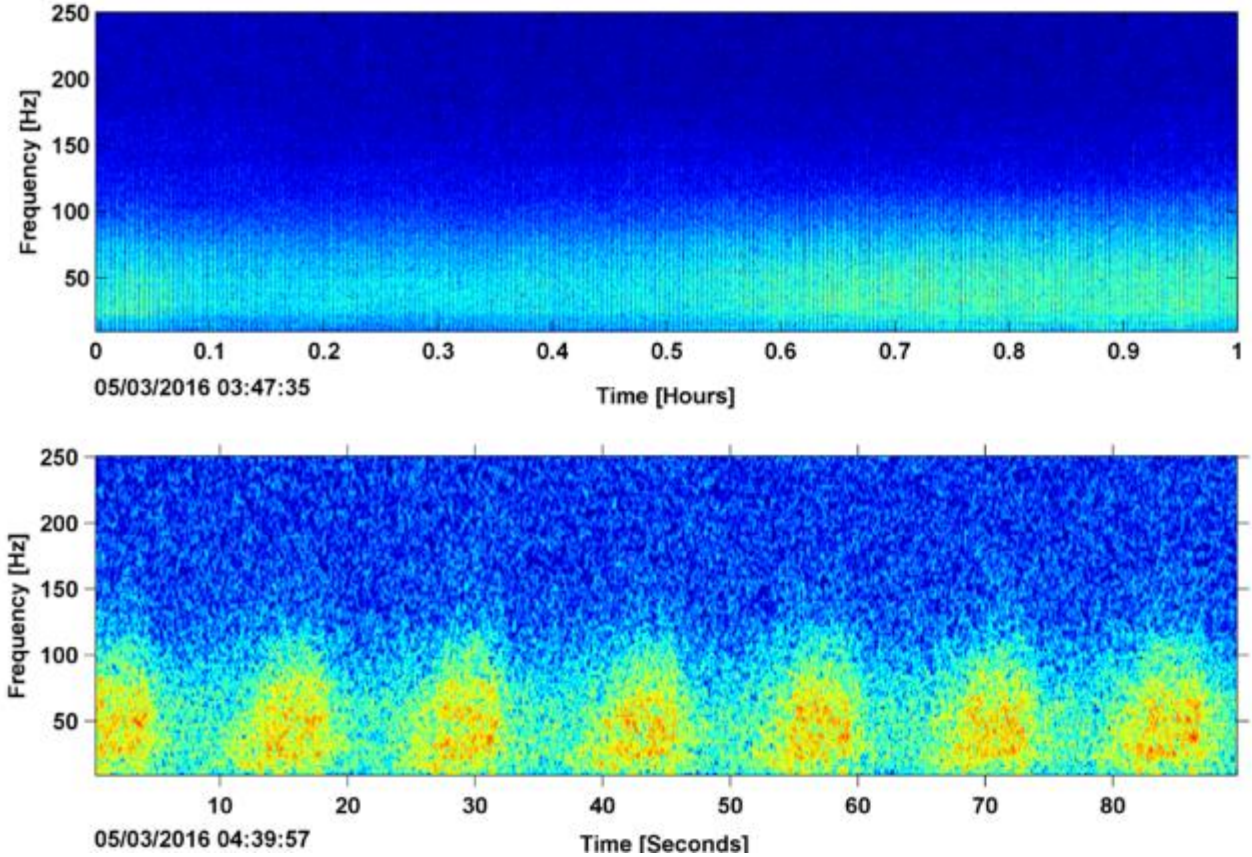

Figure 35. Airguns in LTSA (top) and spectrogram (bottom) recorded at HAT Site A, May 2016.

Results

The results of acoustic data analysis at HAT Site A from April 2016 to January 2017 are summarized, and the seasonal occurrence and relative abundance of marine mammal acoustic signals and anthropogenic sounds are documented.

Low-Frequency Ambient Soundscape

To provide a means for evaluating seasonal sound spectral variability, daily-averaged spectra were processed into monthly averages (Figure 36) and plotted so that months could be compared. Incomplete days were removed from the analysis, but incomplete months were not. Incomplete months are designated by an asterisk (*) in the color legend of Figure 36 and are detailed in Table 1. Long-term spectrograms were generated using daily-averaged spectra.

- Below 60 Hz sound levels are 80-85 dB re:μPa^2/Hz, predominantly due to basin-wide commercial shipping.
- Episodic high levels of noise at low frequencies (10-15 Hz) may be due to strong tidal currents that result in hydrophone cable strumming.
- From September 2016 - January 2017, a peak in spectrum levels from 15-25 Hz is related to the seasonal increase in fin whale 20 Hz calls.
- Sound levels at 200-1000 Hz are higher during the fall and winter months, related to wind and wave noise associated with higher sea states.

Table 2. Incomplete months included in the ambient soundscape analysis during this recording period.

Deployment	Month / Year	Days of Data / Days In Month
HAT_A_06	November 2016	9 / 30
HAT_A_06	December 2016	22 / 31
HAT_A_06	January 2016	20 / 31

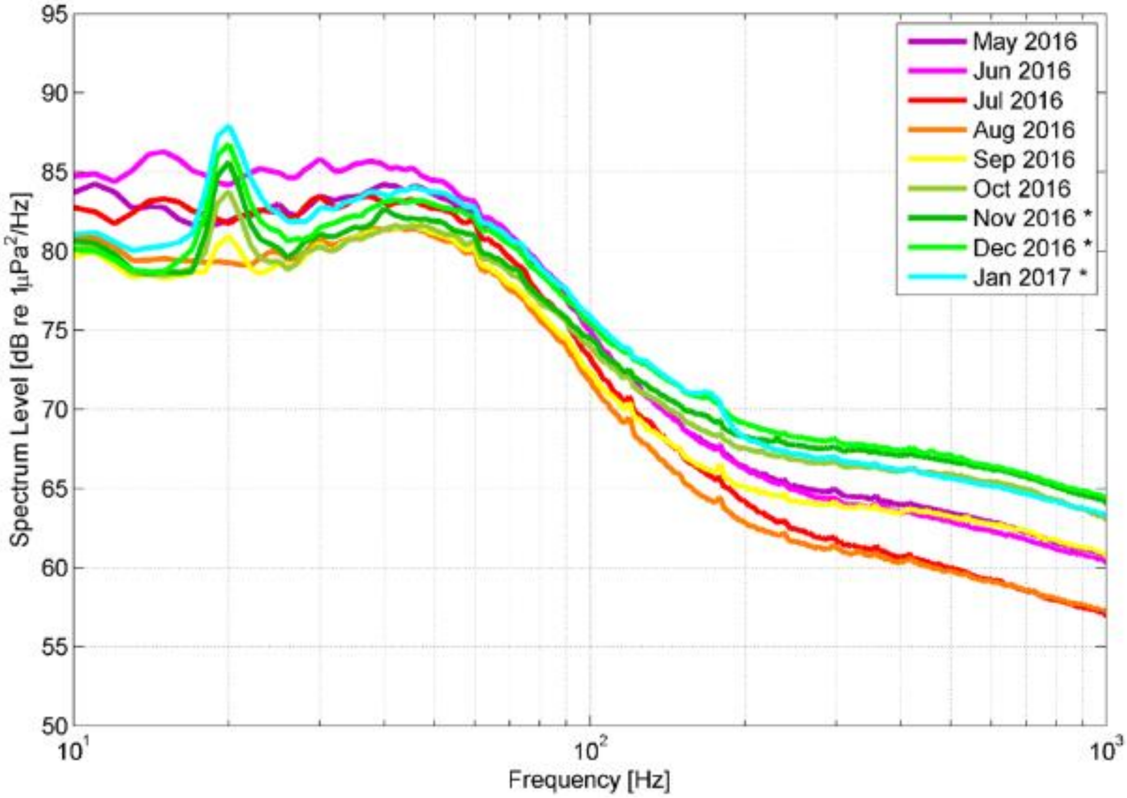

Figure 36. Monthly averages of ambient soundscape at HAT Site A for each month from May 2016 to January 2017. Legend gives color coding by month. Months with an asterisk are partial recording periods.

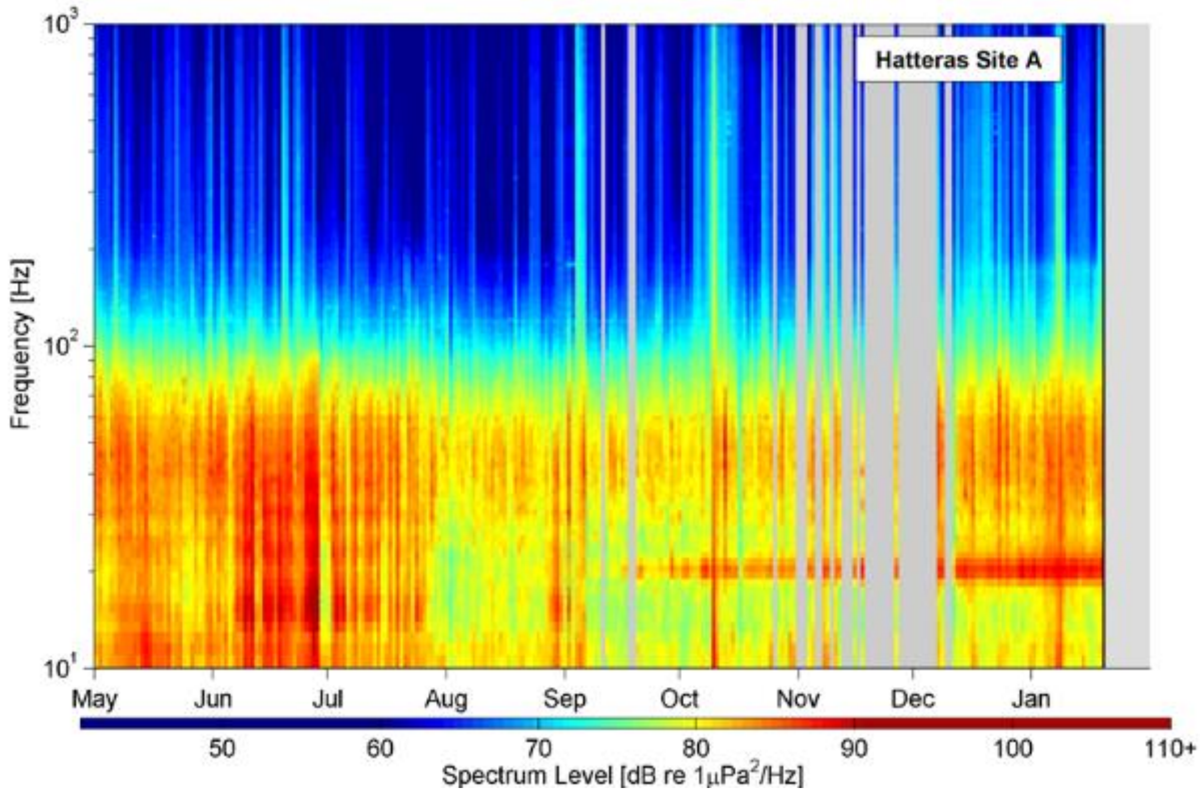

Figure 37. Long-term spectrograms using daily-averaged spectra for HAT Site A from April 2016 to January 2017.

Mysticetes

Four known baleen whale species were recorded between April 2016 and January 2017: blue whales, sei whales, fin whales, and minke whales. More details of each species' presence are given below.

Blue Whales

- Northern Atlantic blue whale tonal calls were detected in low numbers from August to October 2016 (Figure 38).
- Although there were few detections overall, there was no discernible diel pattern for Northern Atlantic blue whale tonal calls (Figure 39).
- There were no arch calls detected in this deployment.

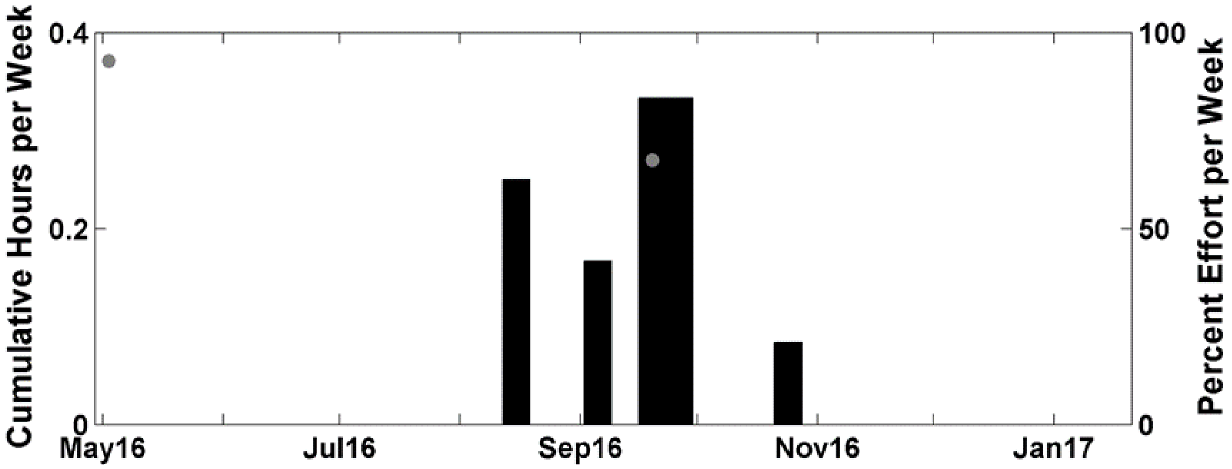

Figure 38. Weekly presence of Northern Atlantic blue whale tonal calls detected between April 2016 and January 2017 at HAT Site A. Gray dots represent percent of effort per week in weeks with less than 100% recording effort. Where gray dots are absent, full recording effort occurred for the entire week. X-axis labels refer to month and year of recording.

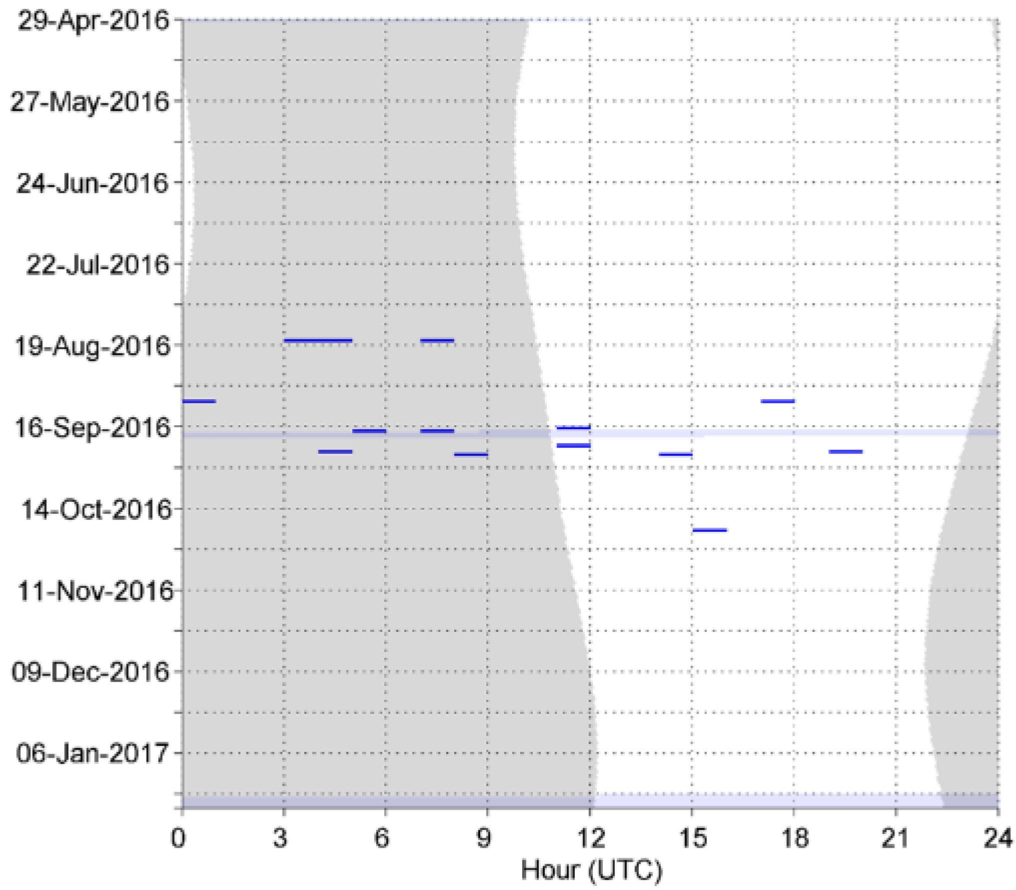

Figure 39. Northern Atlantic blue whale tonal calls in hourly bins at HAT Site A from April 2016 to January 2017. Gray vertical shading denotes nighttime.

Sei Whales

- Sei whale downsweeps were observed in low numbers between October 2016 and January 2017 (Figure 40).
- Although there were few detections overall, there was no discernible diel pattern for sei whale downsweeps (Figure 41).

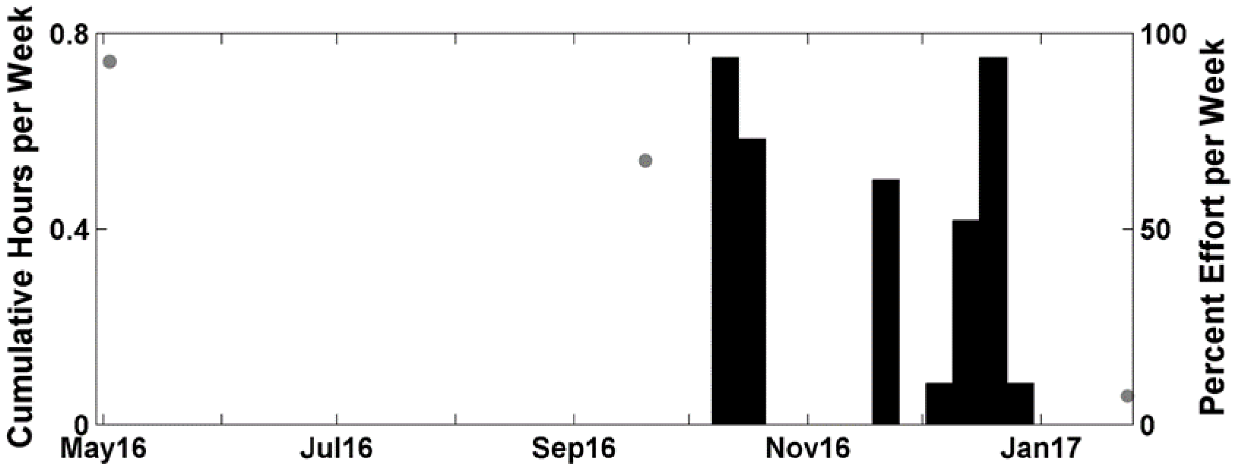

Figure 40. Weekly presence of sei whale downsweeps detected between April 2016 and January 2017 at HAT Site A. Effort markings are described in Figure 38.

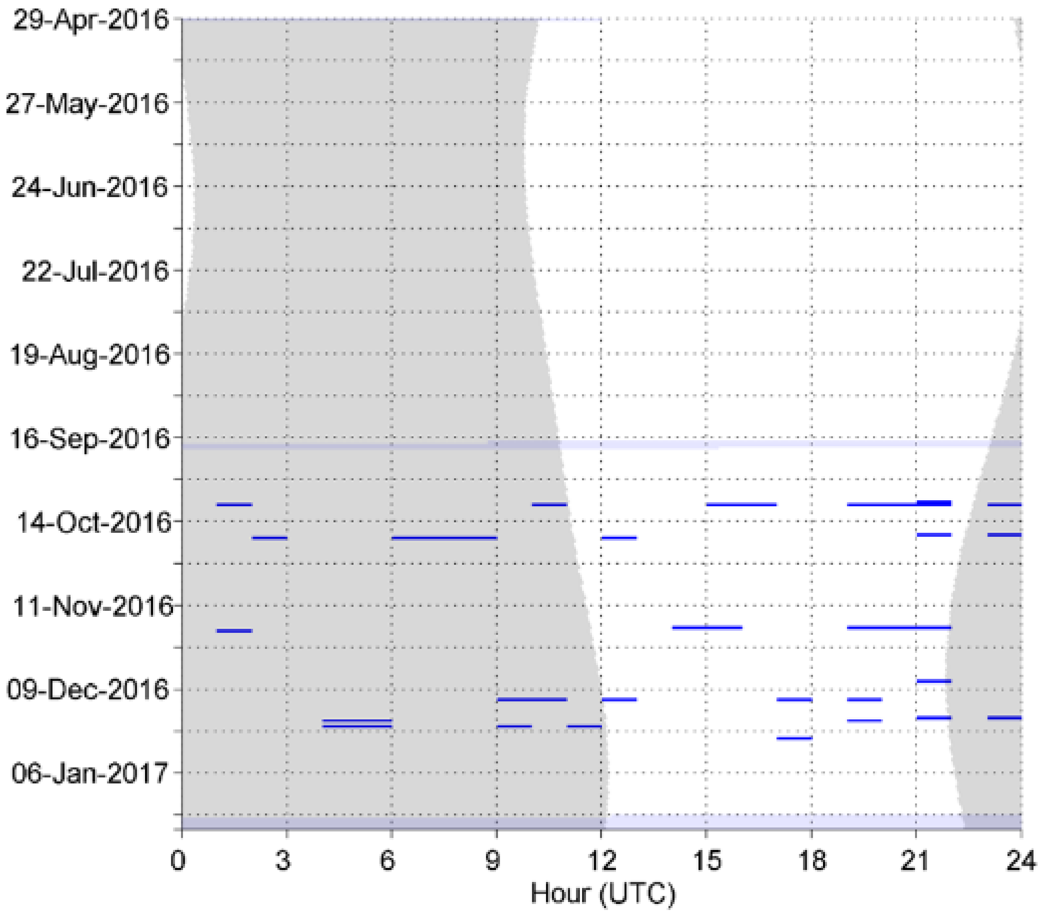

Figure 41. Sei whale downsweeps in hourly bins at HAT Site A from April 2016 to January 2017. Gray vertical shading denotes nighttime.

Fin Whales

- The fin whale acoustic index, a proxy for 20 Hz calls, was low from May through August 2016 and increased September 2016 to January 2017 (Figure 42).
- There were no fin whale 40 Hz calls detected in this deployment.

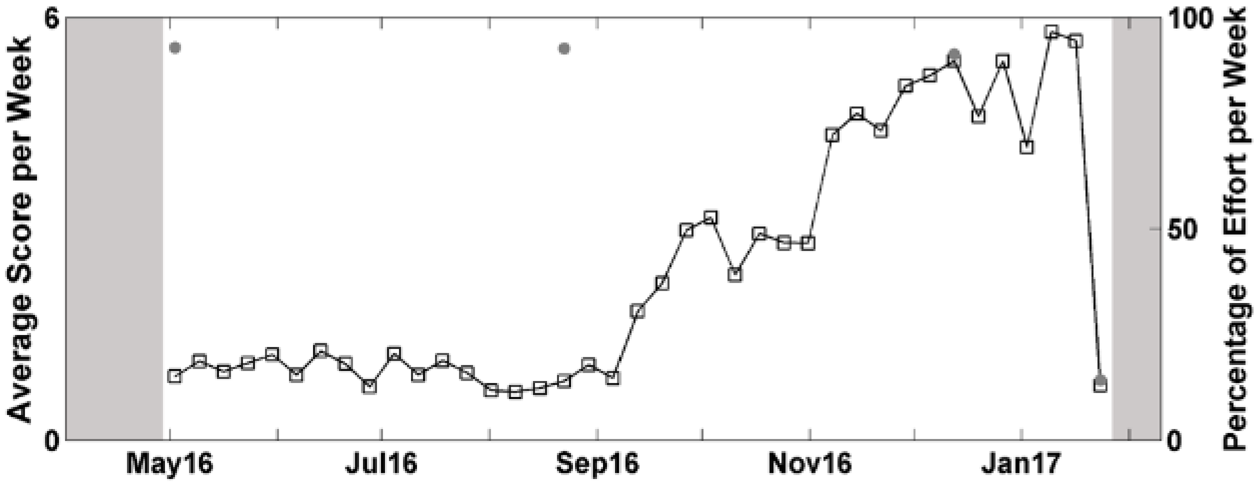

Figure 42. Weekly value of fin whale acoustic index (proxy for 20 Hz calls) detected between April 2016 and January 2017 at HAT Site A. Effort markings are described in Figure 38.

Minke Whales

- Minke whale pulse trains peaked November 2016 through January 2017.
- They were detected in low numbers in May 2016 and were not detected at all from June to September 2016 (Figure 43).
- There was no discernible diel pattern for minke pulse trains (Figure 44).

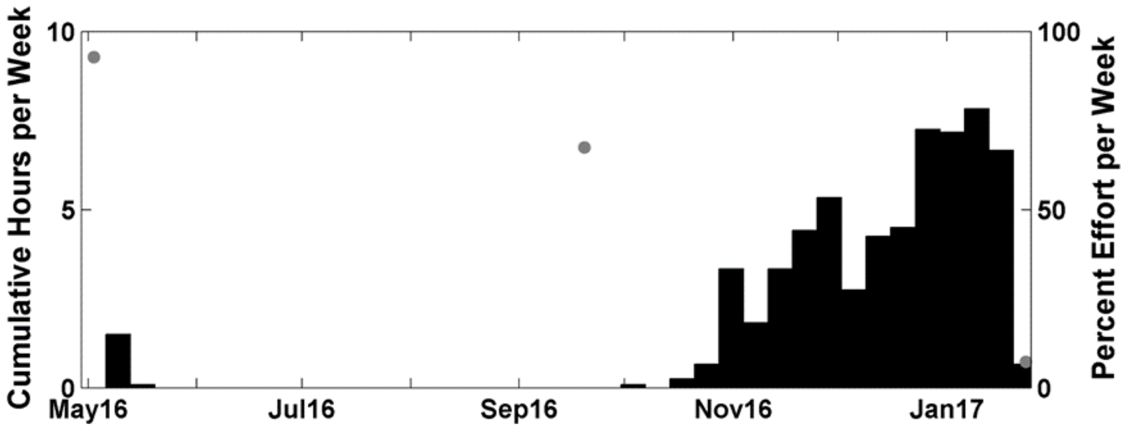

Figure 43. Weekly presence of minke whale pulse trains detected between April 2016 and January 2017 at HAT Site A. Effort markings are described in Figure 38.

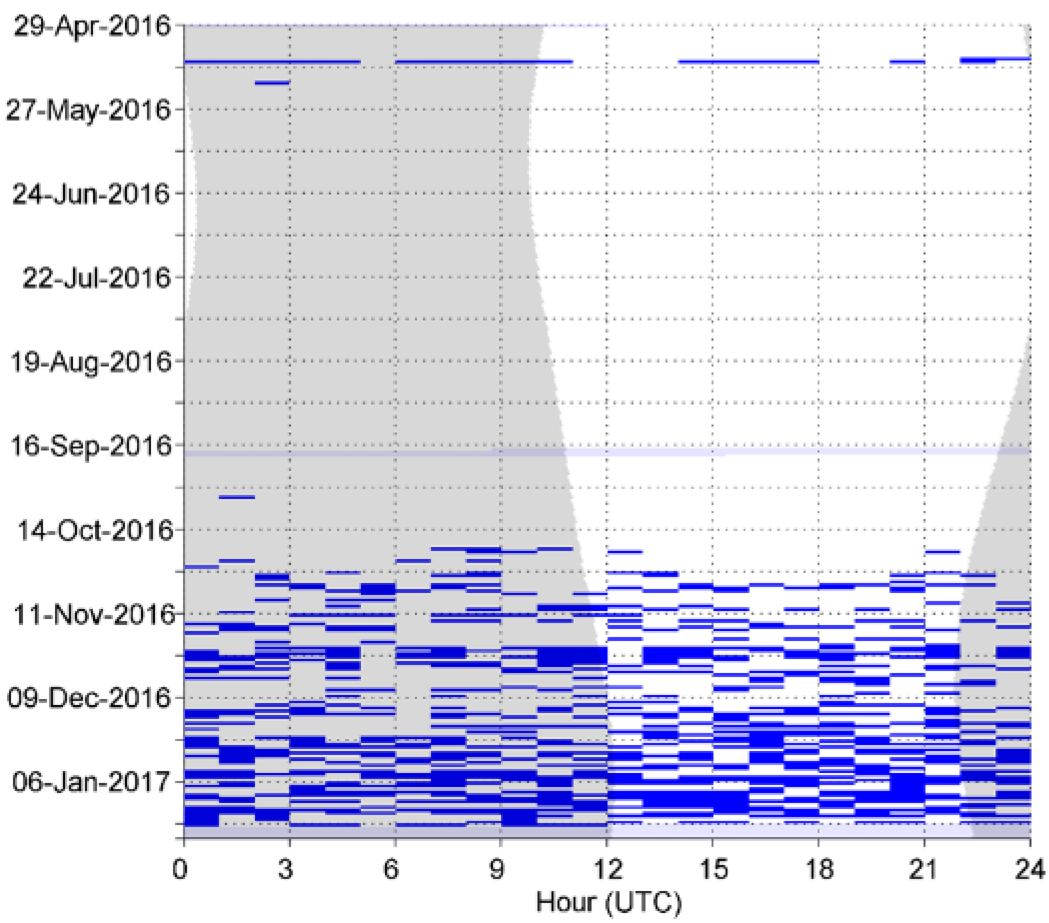

Figure 44. Minke whale pulse trains in hourly bins at HAT Site A from April 2016 to January 2017. Gray vertical shading denotes nighttime.

Odontocetes

Clicks from Blainville's beaked whale, Cuvier’s beaked whale, Gervais’ beaked whale, Risso’s dolphins, *Kogia* spp., sperm whales, three odontocete click types that are not yet assigned to a species, and clicks of unidentified odontocetes were discriminated. Whistles from unidentified odontocete species were detected both above and below 5 kHz. Details of each species’ presence at these sites are given below.

Blainville's Beaked Whale

- Blainville's beaked whale echolocation clicks were detected in low numbers throughout the deployment (Figure 45).
- There were not enough encounters to discern a diel pattern (Figure 46).

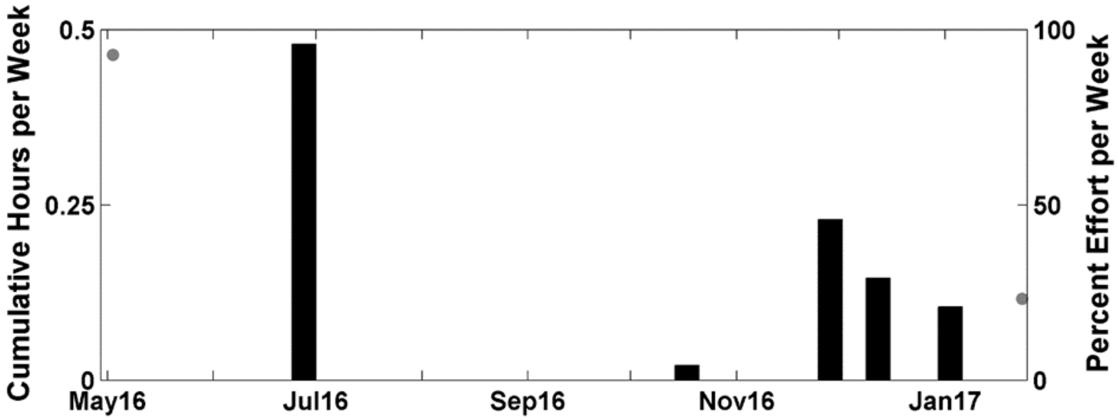

Figure 45. Weekly presence of Blainville's beaked whale echolocation clicks detected between April 2016 and January 2017 at HAT Site A. Effort markings are described in Figure 38.

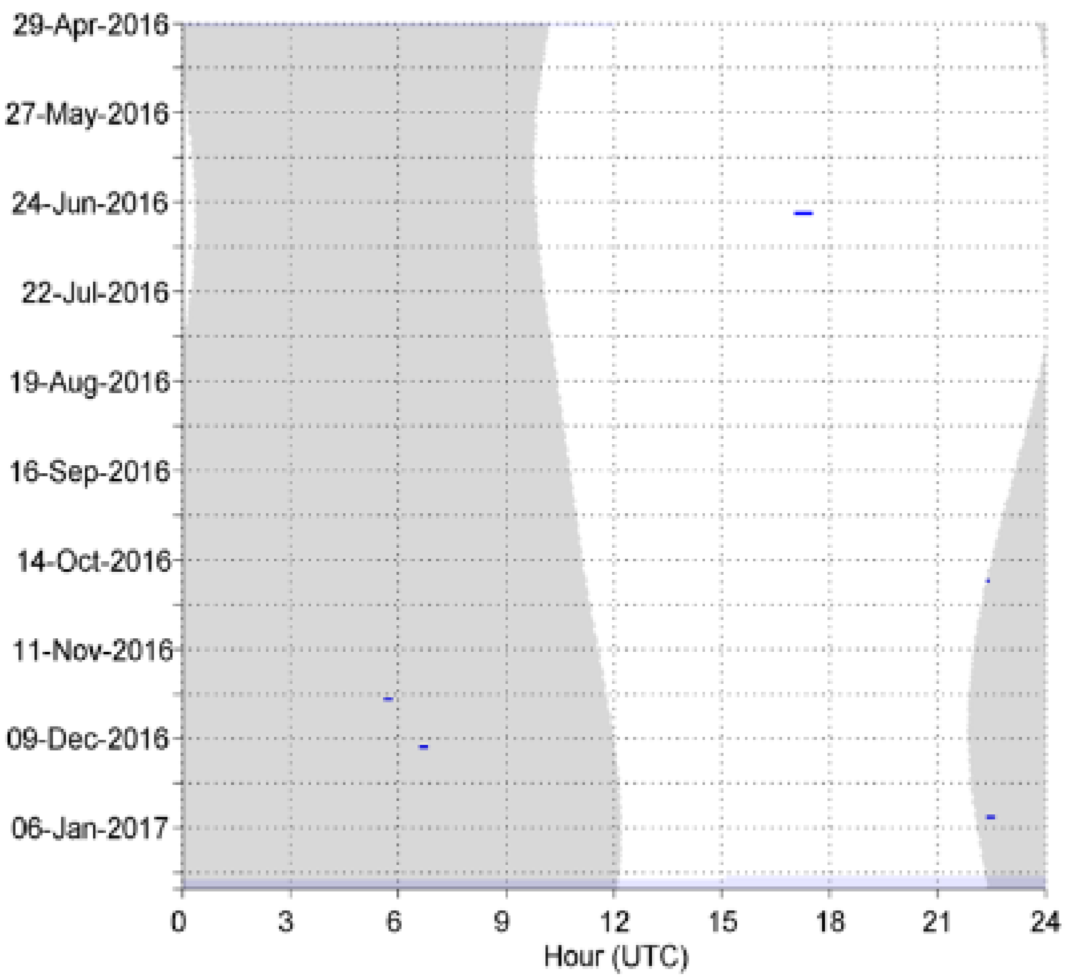

Figure 46. Blainville's beaked whale echolocation clicks in one-minute bins at HAT Site A from April 2016 to January 2017. Gray vertical shading denotes nighttime.

Cuvier's Beaked Whale

- Cuvier's beaked whale echolocation clicks were detected in high numbers throughout the recording period. Detections increased from September 2016 to January 2017 (Figure 47).
- There was no discernible diel pattern for Cuvier's beaked whale clicks (Figure 48).

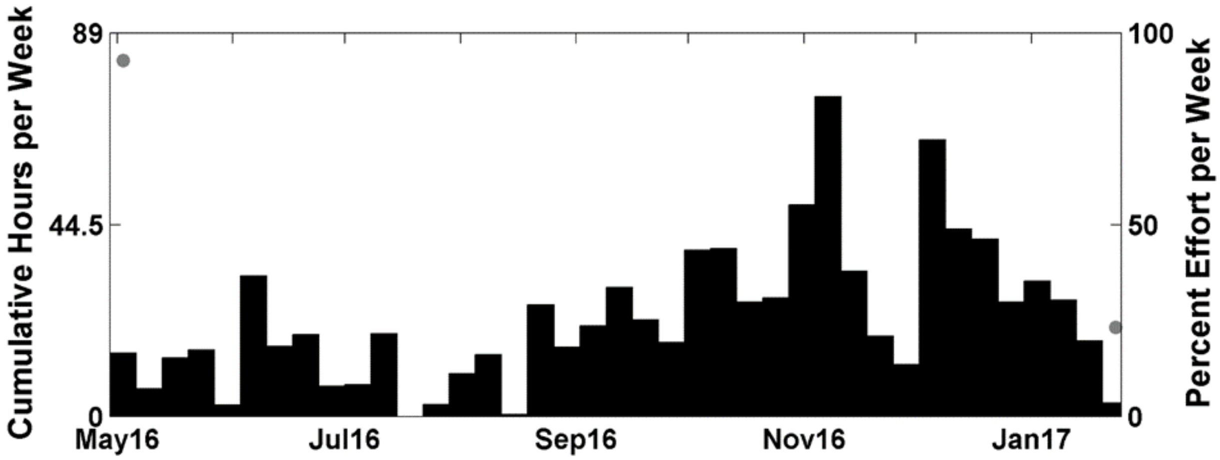

Figure 47. Weekly presence of Cuvier's beaked whale echolocation clicks detected between April 2016 and January 2017 at HAT Site A. Effort markings are described in Figure 38.

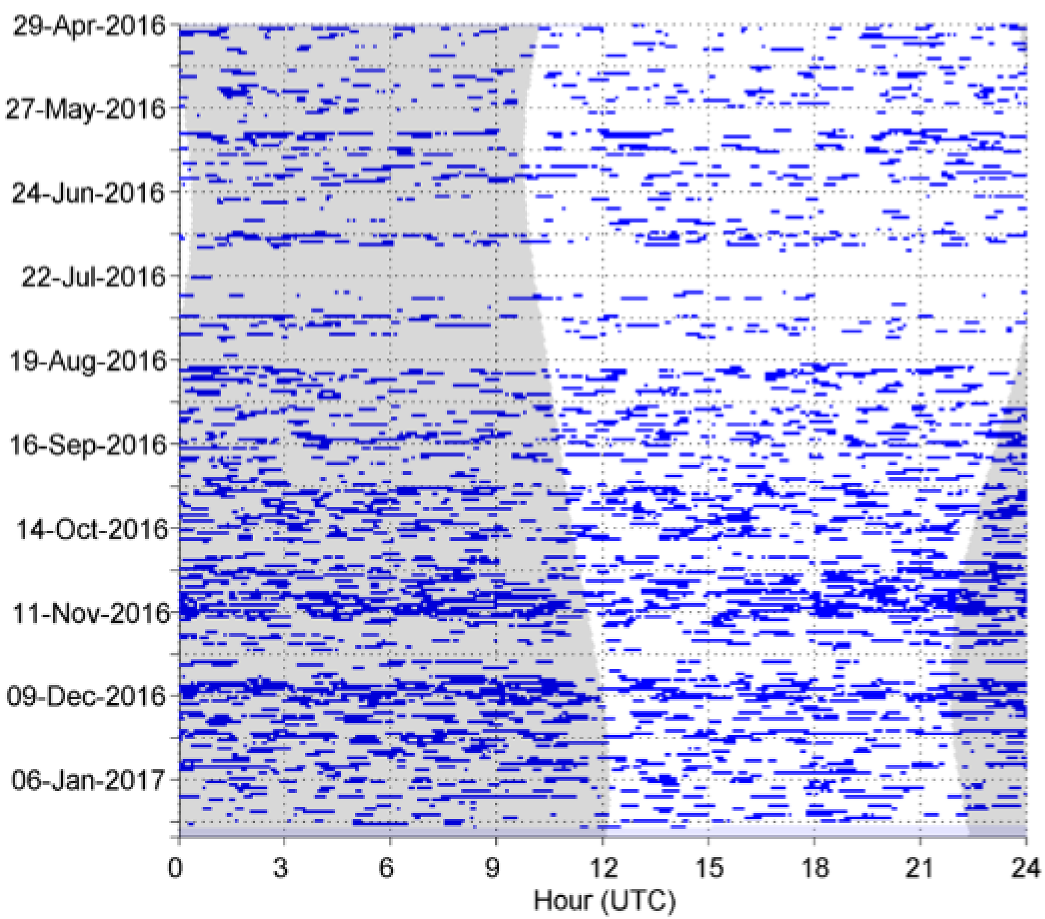

Figure 48. Cuvier's beaked whale echolocation clicks in one-minute bins at HAT Site A from April 2016 to January 2017. Gray vertical shading denotes nighttime.

Gervais' Beaked Whale

- Gervais' beaked whale echolocation clicks were detected throughout the recording period (Figure 49).
- Detections peaked in November and December 2016.
- There was no discernible diel pattern for Gervais' beaked whale clicks (Figure 50).

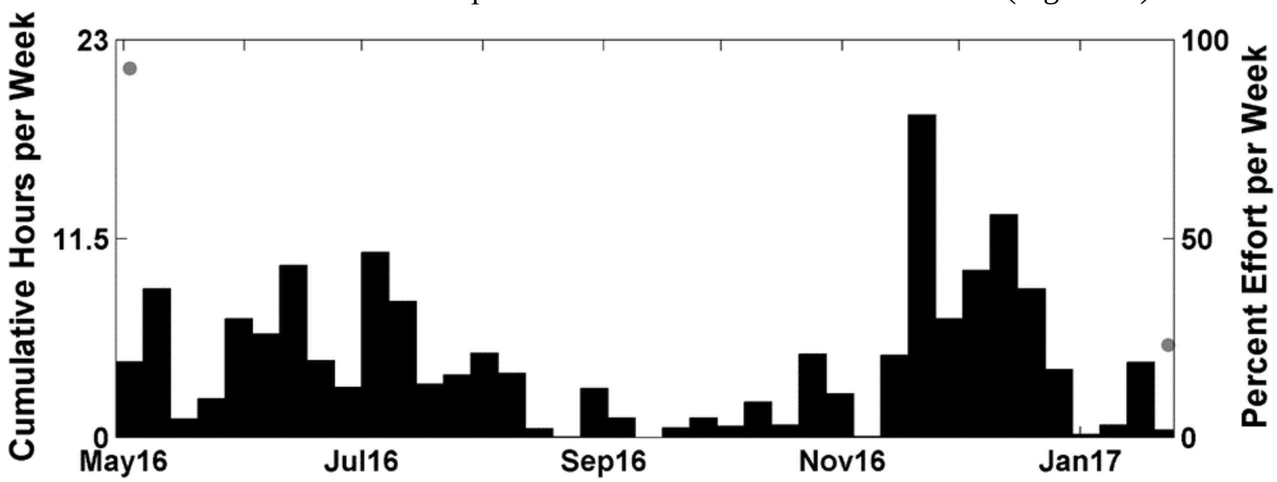

Figure 49. Weekly presence of Gervais' beaked whale echolocation clicks between April 2016 and June 2017 at HAT Site A. Effort markings are described in Figure 38.

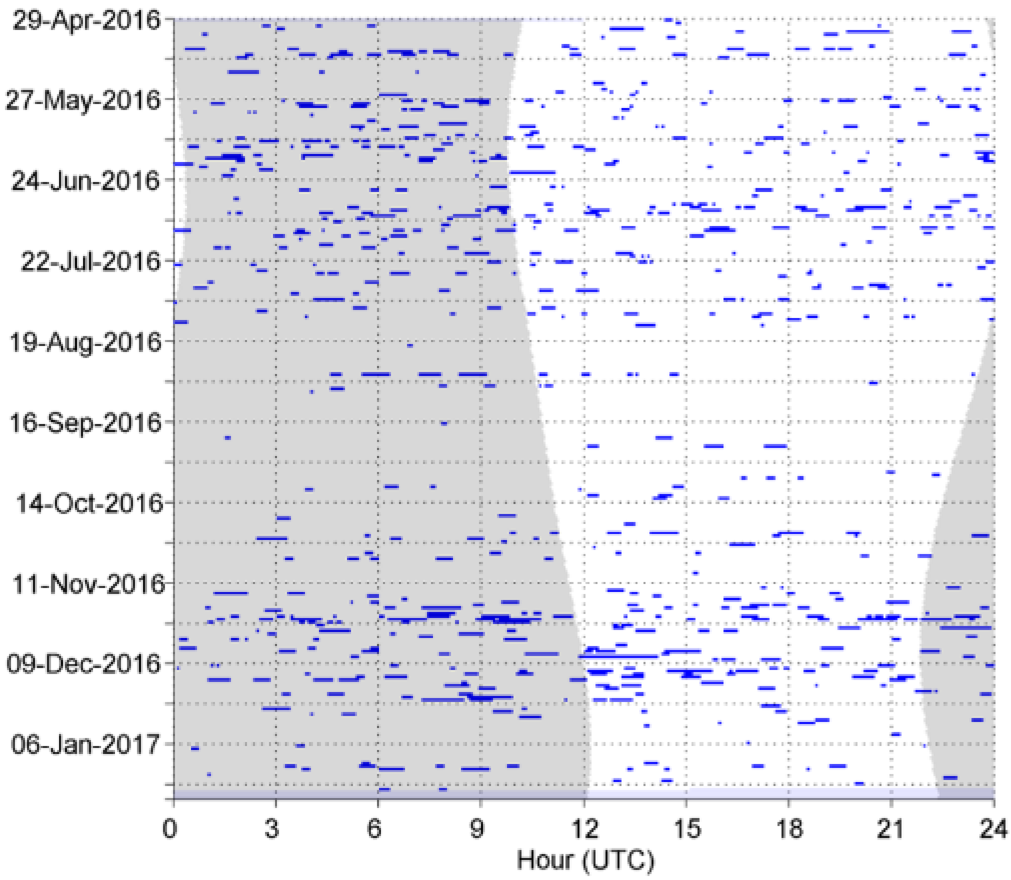

Figure 50. Gervais' beaked whale echolocation clicks in one-minute bins at HAT Site A from April 2016 to January 2017. Gray vertical shading denotes nighttime.

Risso's Dolphins

- Risso's dolphin echolocation clicks were detected between May and September 2016, and in January 2017 (Figure 51).
- There was no discernible diel pattern for Risso's dolphin echolocation clicks (Figure 52).

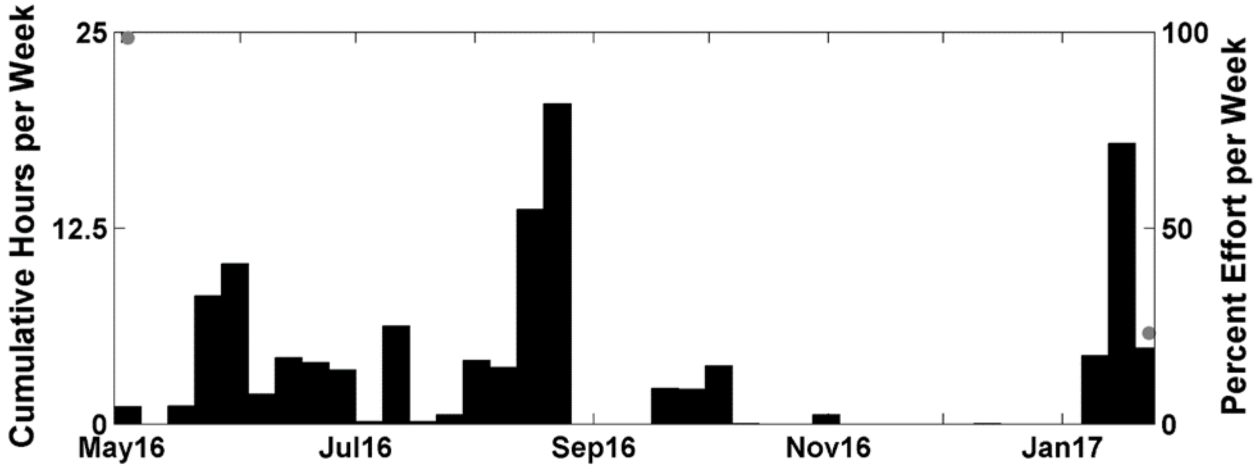

Figure 51. Weekly presence of Risso's dolphin echolocation clicks detected between April 2016 and January 2017 at HAT Site A. Effort markings are described in Figure 38.

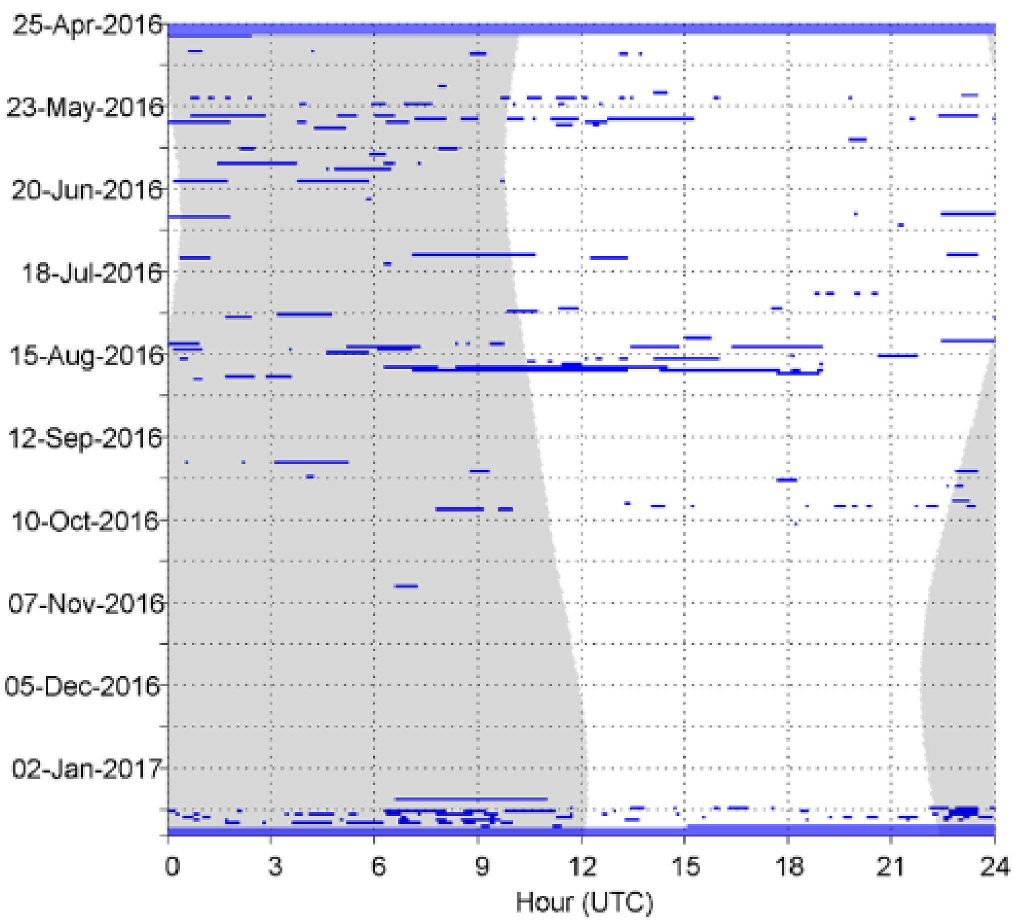

Figure 52. Risso's dolphin echolocation clicks in five-minute bins at HAT Site A from April 2016 to January 2017. Gray vertical shading denotes nighttime.

Unidentified Odontocete Clicks

Signals that had characteristics of odontocete sounds (both whistles and clicks), but could not be classified to species were labeled as unidentified odontocetes. Clicks were left unidentified if too few clicks were detected in a time bin, or if detected clicks were of poor quality (e.g. low amplitude or masked).

- Unidentified odontocete clicks were detected throughout the recording period (Figure 53).
- There was no discernible diel pattern for unidentified dolphin clicks (Figure 54).

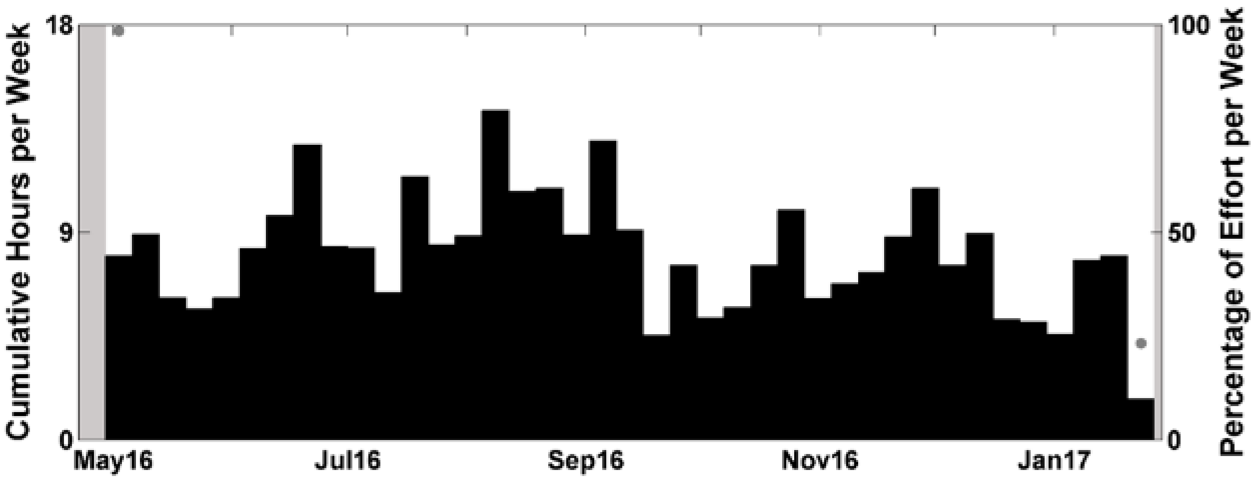

Figure 53. Weekly presence of unidentified odontocete clicks detected between April 2016 and January 2017 at HAT Site A. Effort markings are described in Figure 38.

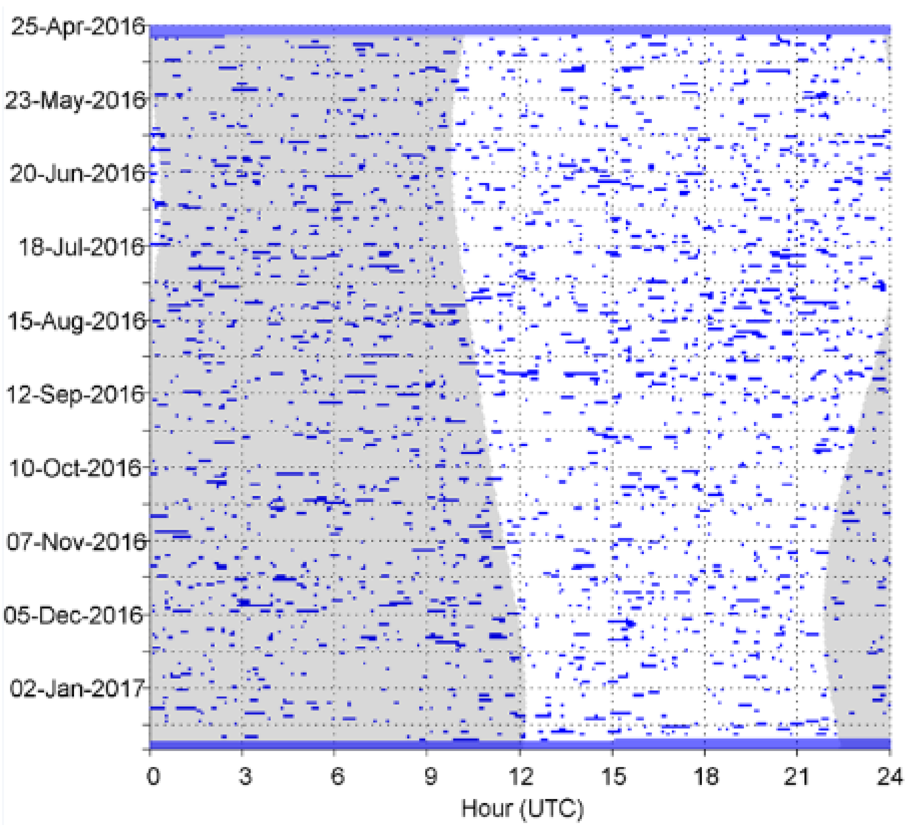

Figure 54. Unidentified odontocete clicks in five-minute bins at HAT Site A from April 2016 to January 2017. Gray vertical shading denotes nighttime.

Click Type 1

- CT 1 was detected consistently throughout the deployment (Figure 55).
- CT 1 was more often detected during nighttime (Figure 56).

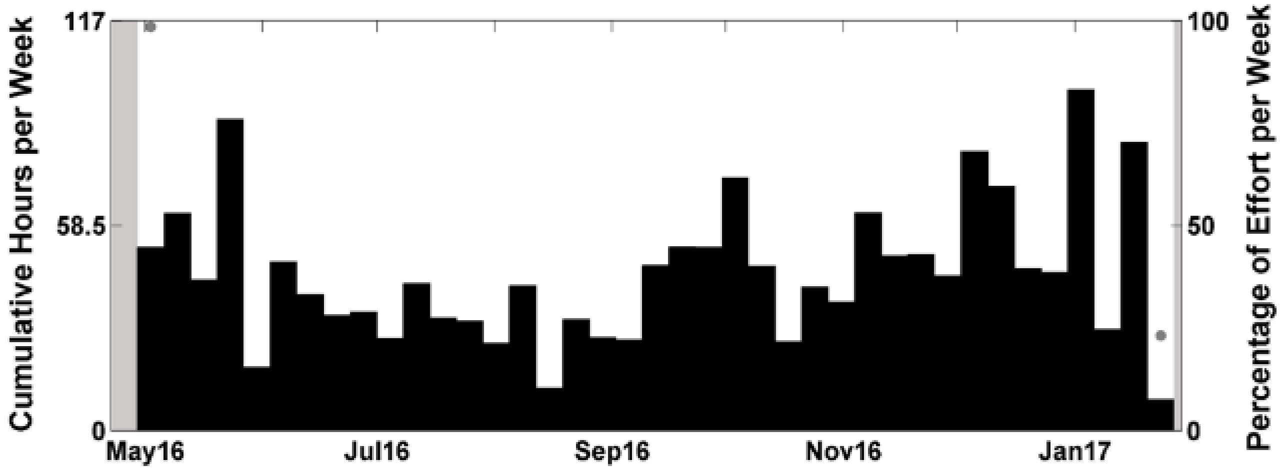

Figure 55. Weekly presence of CT J1 detected between April 2016 and February 2017 at HAT Site A. Effort markings are described in Figure 38.

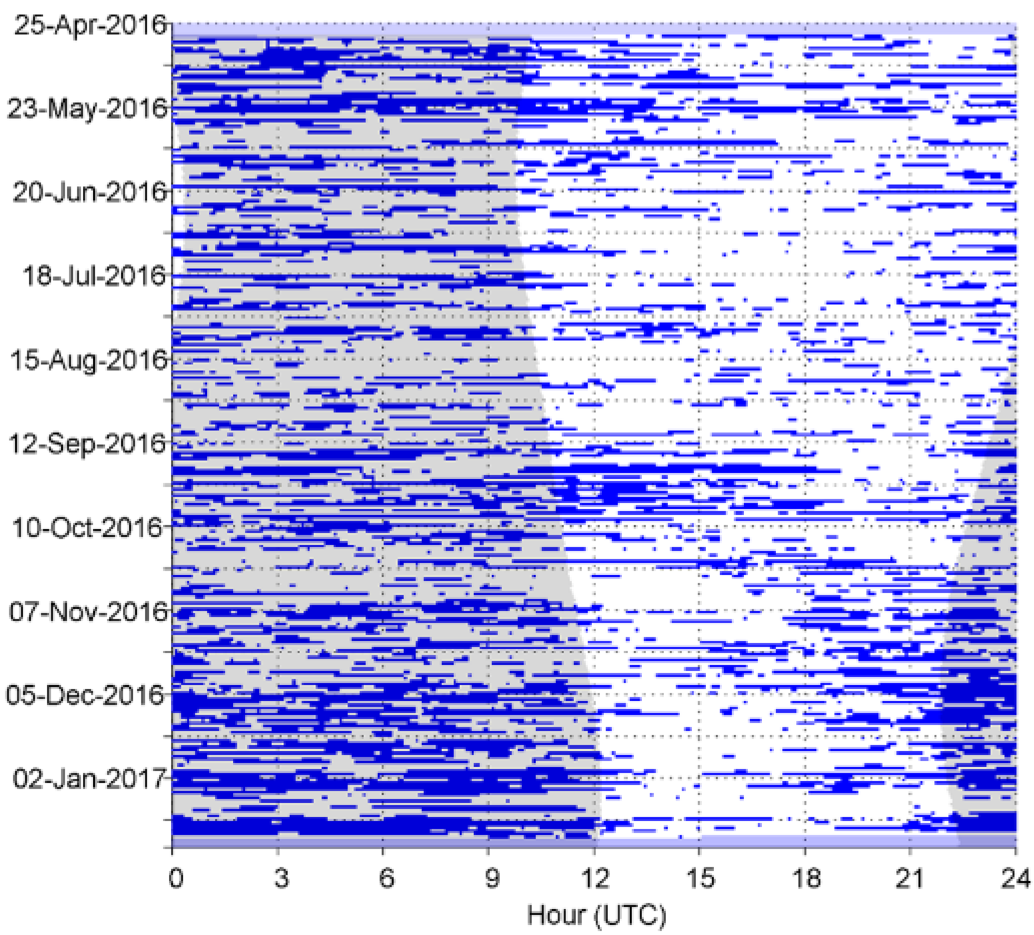

Figure 56. CT J1 in five-minute bins at HAT Site A from April 2016 to January 2017. Gray vertical shading denotes nighttime.

Click Type 4

- CT 4 was detected consistently throughout the deployment (Figure 57).
- CT 4 was detected predominantly during nighttime (Figure 58).

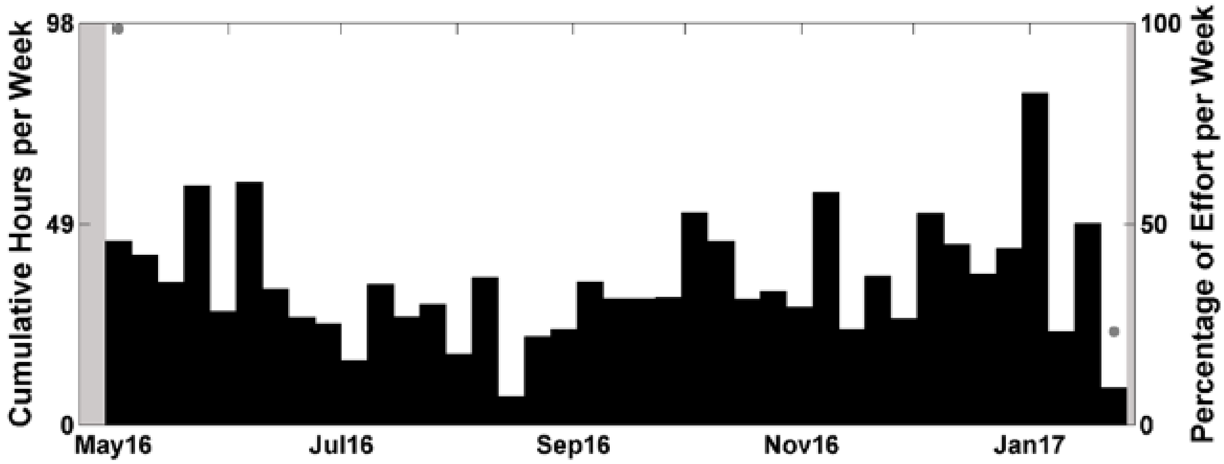

Figure 57. Weekly presence of CT J3 detected between April 2016 and January 2017 at HAT Site A. Effort markings are described in Figure 38.

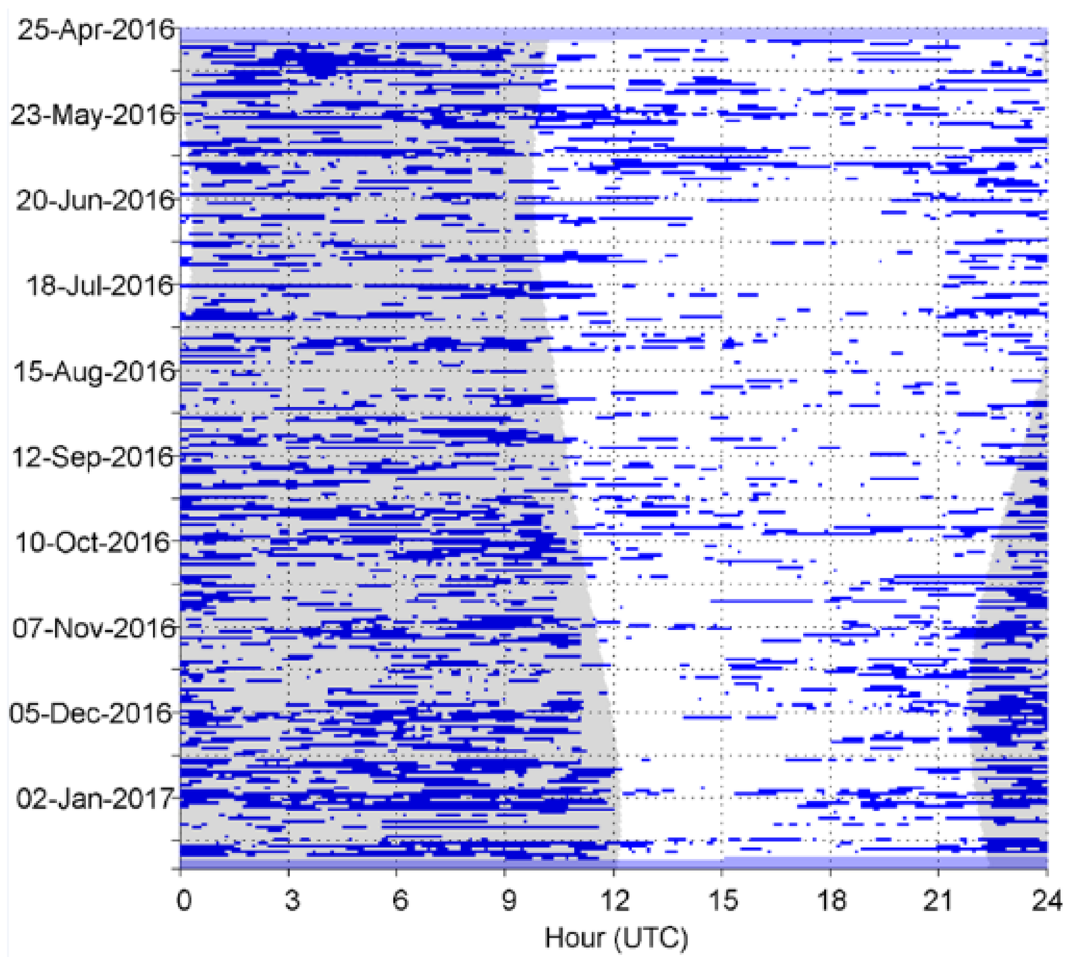

Figure 58. CT J3 in five-minute bins at HAT Site A from April 2016 to January 2017. Gray vertical shading denotes nighttime.

Click Type 6

- CT 6 detections peaked in May 2016, October 2016 and January 2-17, with fewer detections in-between (Figure 59).
- There was no discernible diel pattern for CT 6 detections (Figure 60).

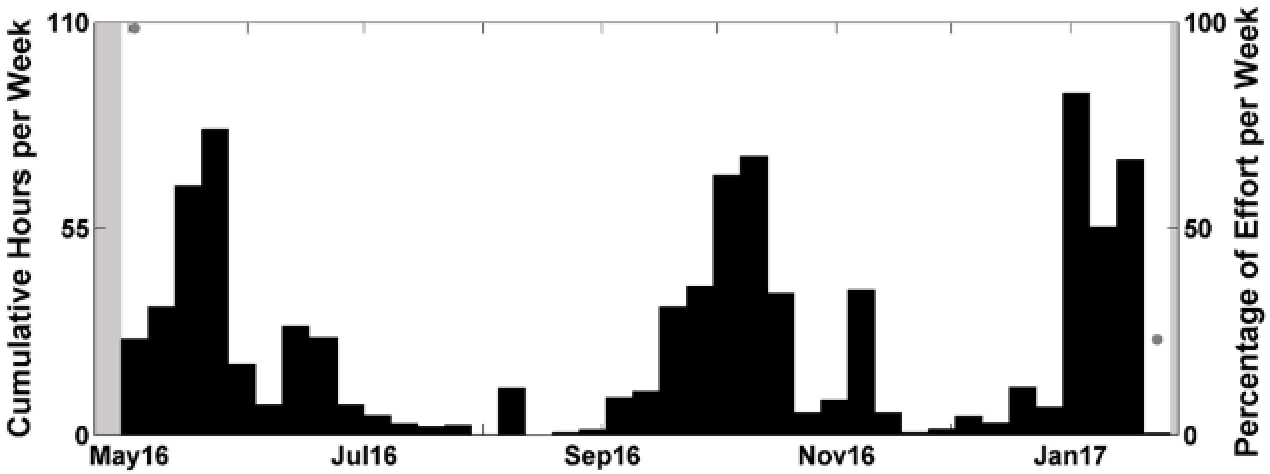

Figure 59. Weekly presence of CT 6 detected between April 2016 and January 2017 at HAT Site A. Effort markings are described in Figure 38.

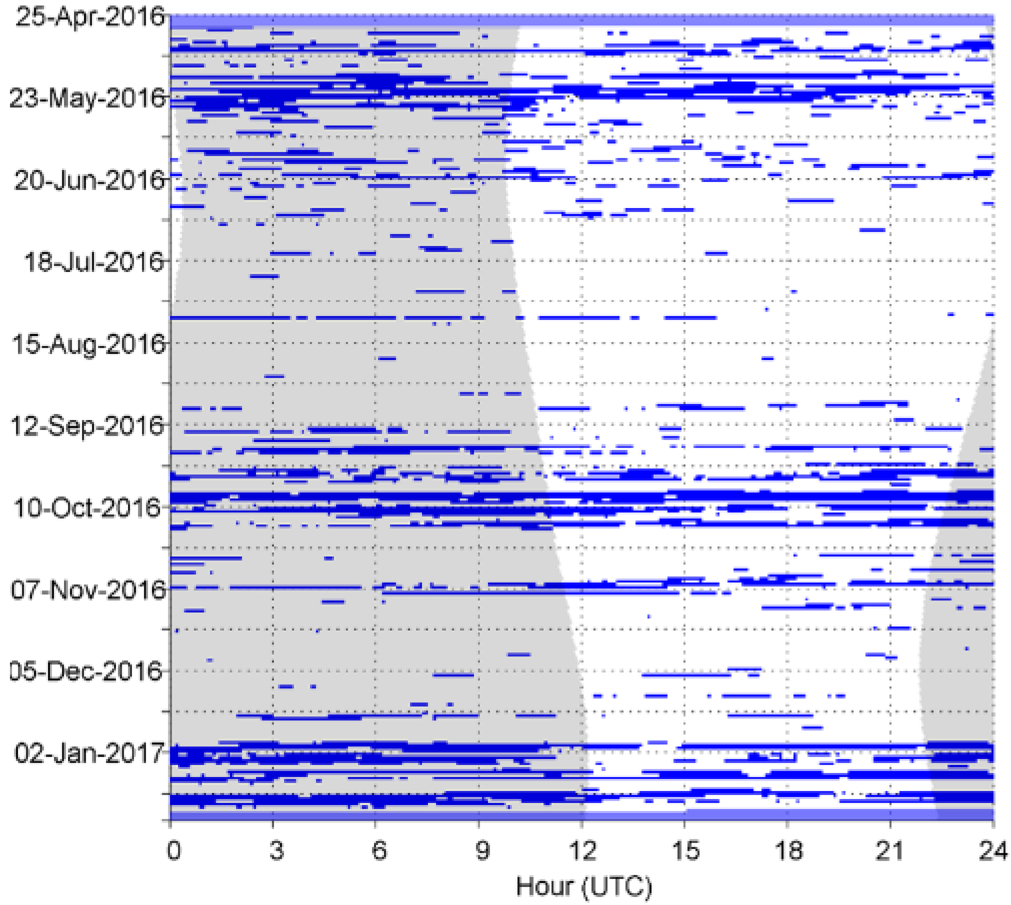

Figure 60. CT 6 in five-minute bins at HAT Site A from April 2016 to January 2017. Gray vertical shading denotes nighttime.

Unidentified Odontocete Whistles Less Than 5 kHz

- Unidentified odontocete whistles less than 5 kHz were detected in high numbers between April 2016 - June 2016, September 2016 - November 2016, and in January 2017 (Figure 61).

There was no apparent diel pattern for unidentified whistles less than 5 kHz (Figure 62).

Pilot whales most likely produced these whistles, though it is possible they are from other blackfish species that have overlapping distributions.

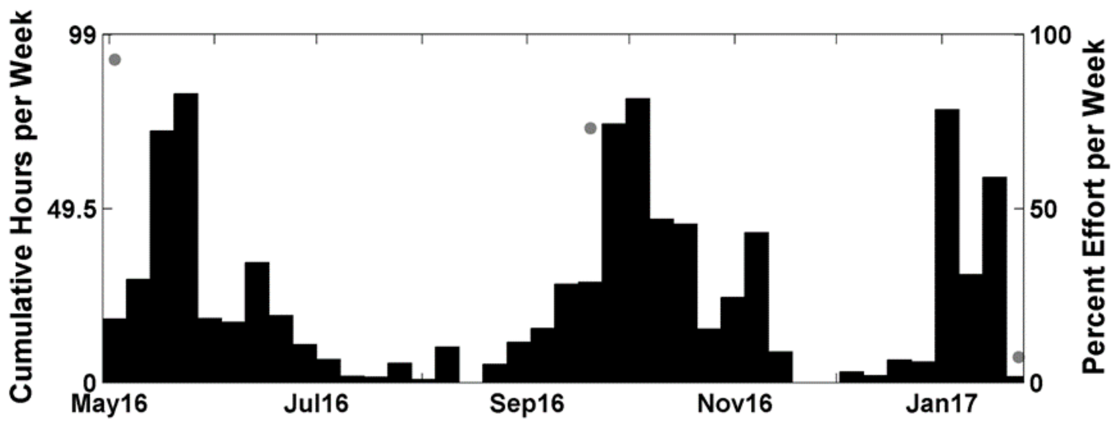

Figure 61. Weekly presence of unidentified odontocete whistles less than 5 kHz detected between April 2016 and January 2017 at HAT Site A. Effort markings are described in Figure 38.

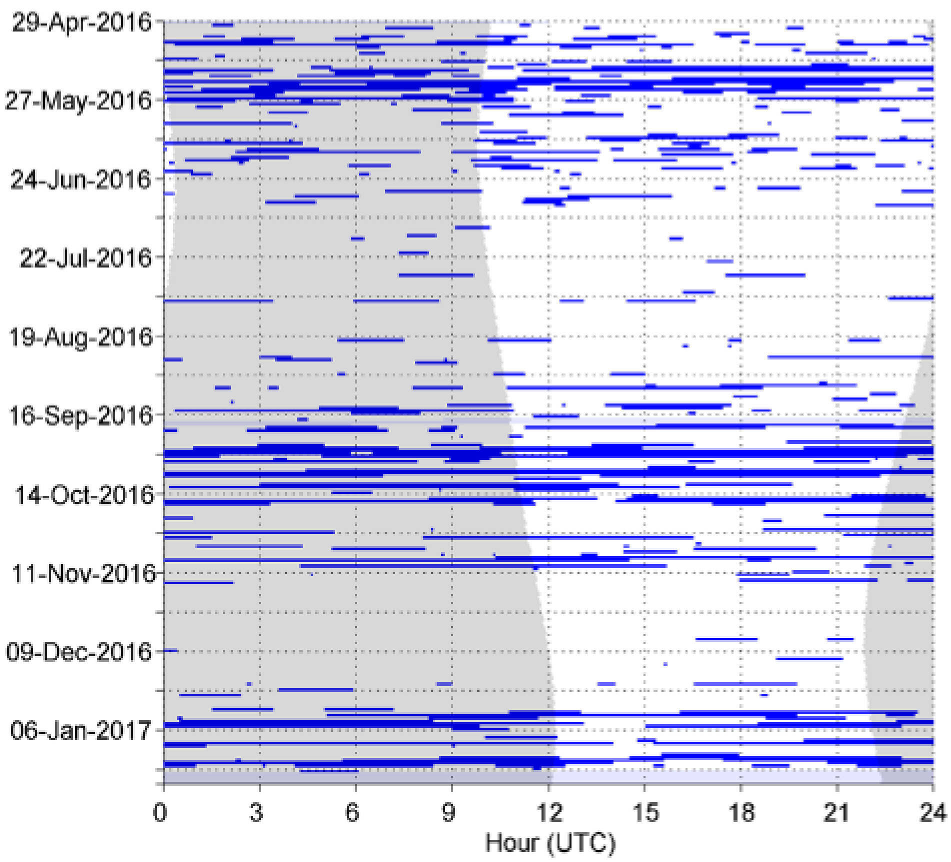

Figure 62. Unidentified odontocete whistles less than 5 kHz in five-minute bins at HAT Site A from April 2016 to January 2017. Gray vertical shading denotes nighttime.

Unidentified Odontocete Whistles Greater Than 10 kHz

- Unidentified odontocete whistles greater than 10 kHz were detected in high numbers between April 2016 and January 2017. Detections were highest in May 2016 and August through September 2016 (Figure 63).
- There was no diel pattern for whistles greater than 10 kHz (Figure 64).

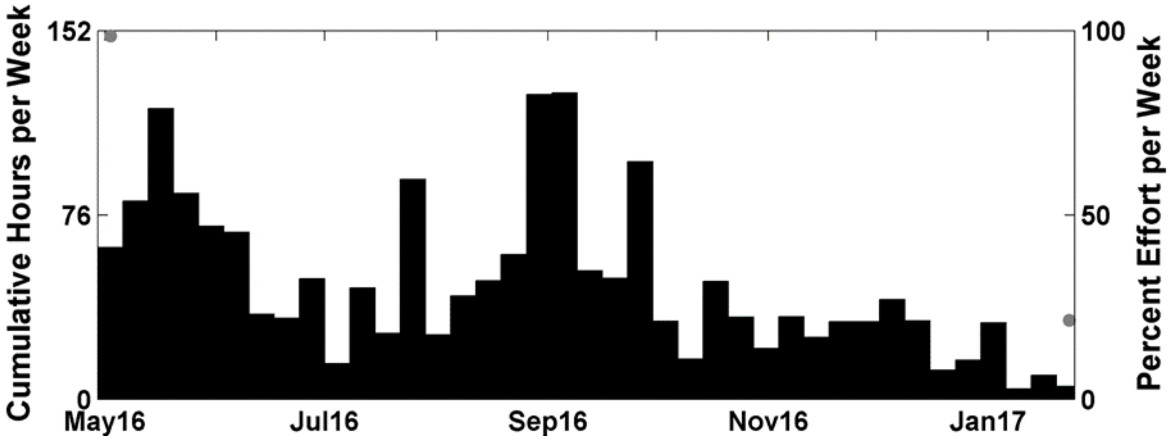

Figure 63. Weekly presence of unidentified odontocete whistles greater than 10 kHz detected between April 2016 and January 2017 at HAT Site A. Effort markings are described in Figure 38.

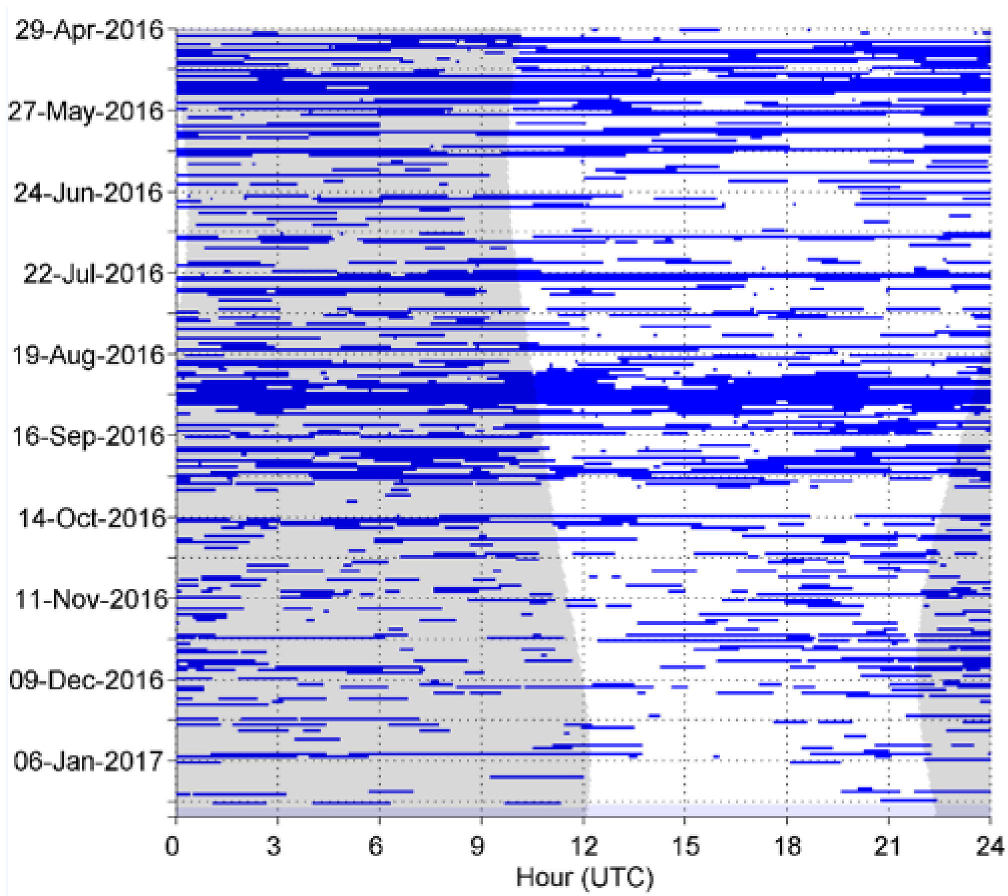

Figure 64. Unidentified odontocete whistles greater than 10 kHz in five-minute bins at HAT Site A from April 2016 to January 2017. Gray vertical shading denotes nighttime.

Sperm Whales

- Sperm whale clicks were detected between May and September 2016, and between November 2016 and January 2017 (Figure 65).
- There was no discernible diel pattern for sperm whale clicks (Figure 66).

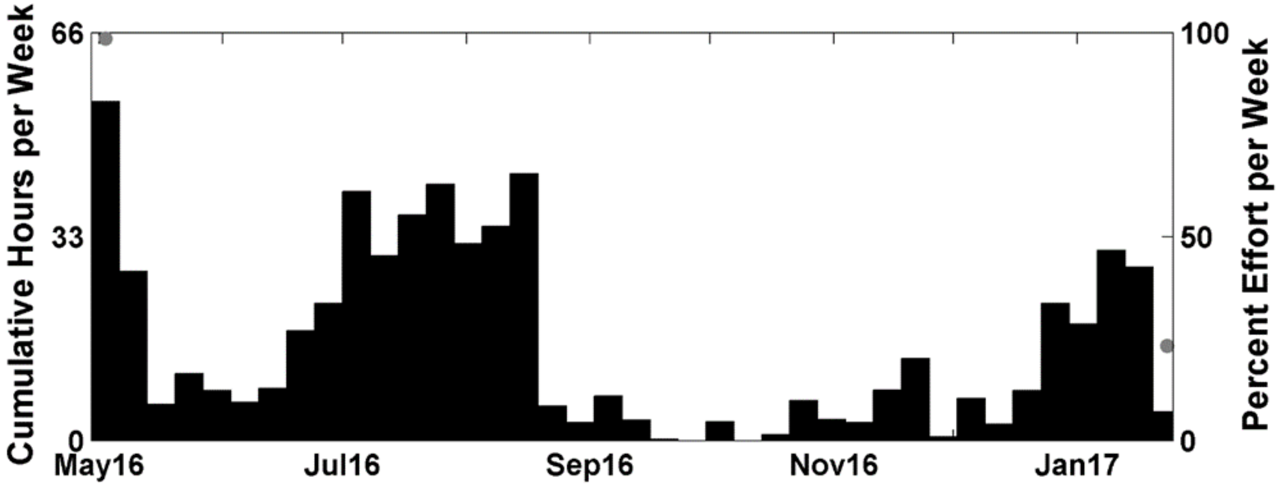

Figure 65. Weekly presence of sperm whale clicks detected between April 2016 and January 2017 at HAT Site A. Effort markings are described in Figure 38.

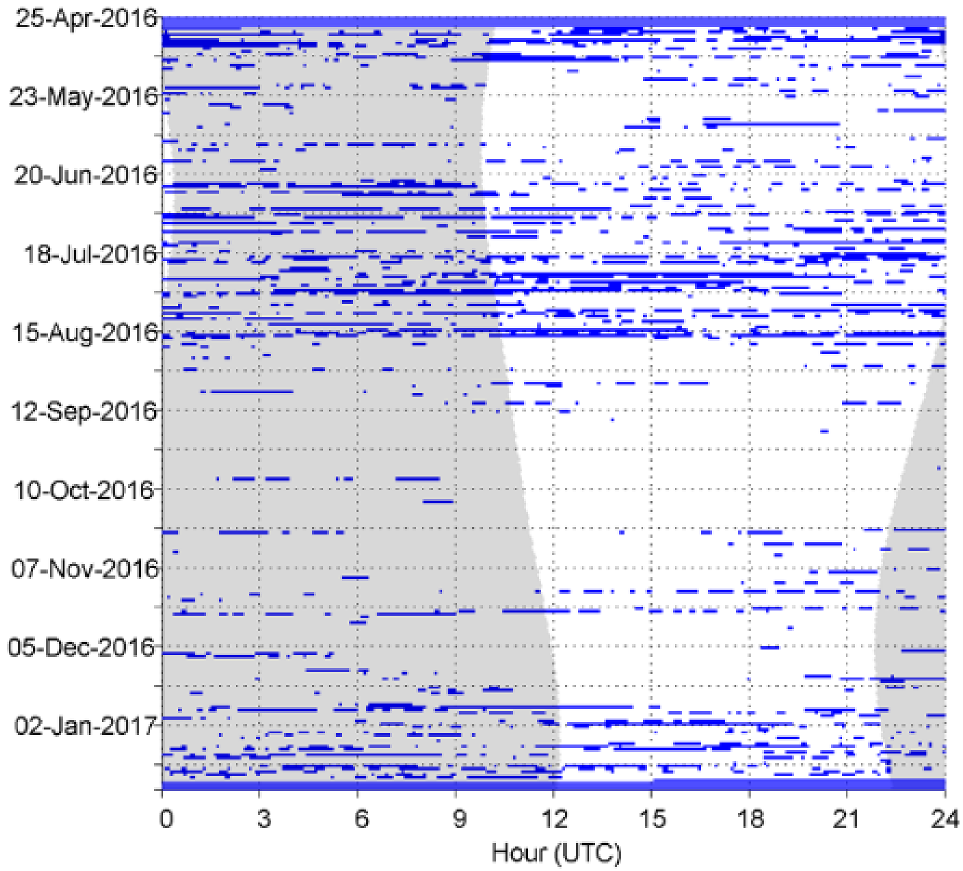

Figure 66. Sperm whale clicks in one-minute bins at HAT Site A from April 2016 to January 2017. Gray vertical shading denotes nighttime.

***Kogia* spp.**

- *Kogia* spp. echolocation clicks were detected in low numbers throughout the recording period, with most of the detections between May 2016 and June 2016 (Figure 67).

There was no discernible diel pattern for *Kogia* echolocation click (Figure 68).

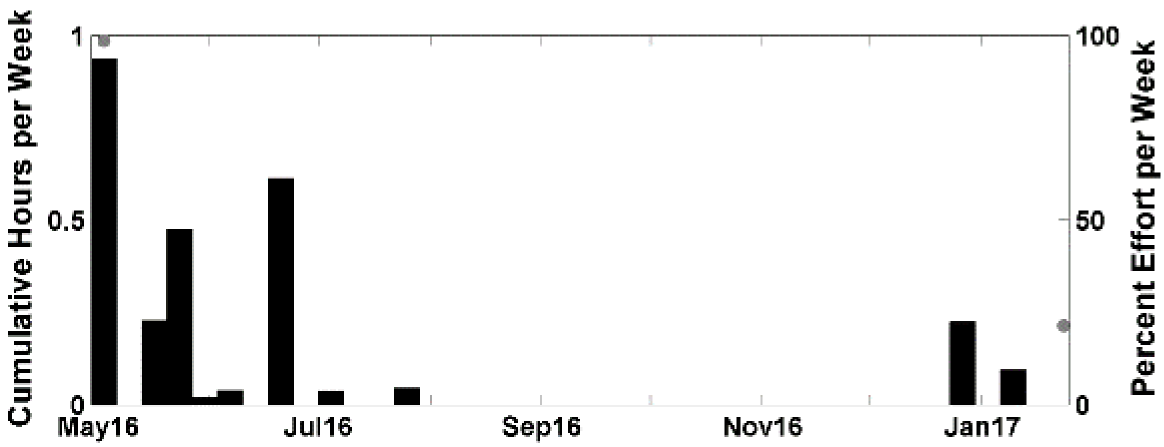

Figure 67. Weekly presence of Kogia spp. clicks detected between April 2016 and January 2017 at HAT Site A. Effort markings are described in Figure 38.

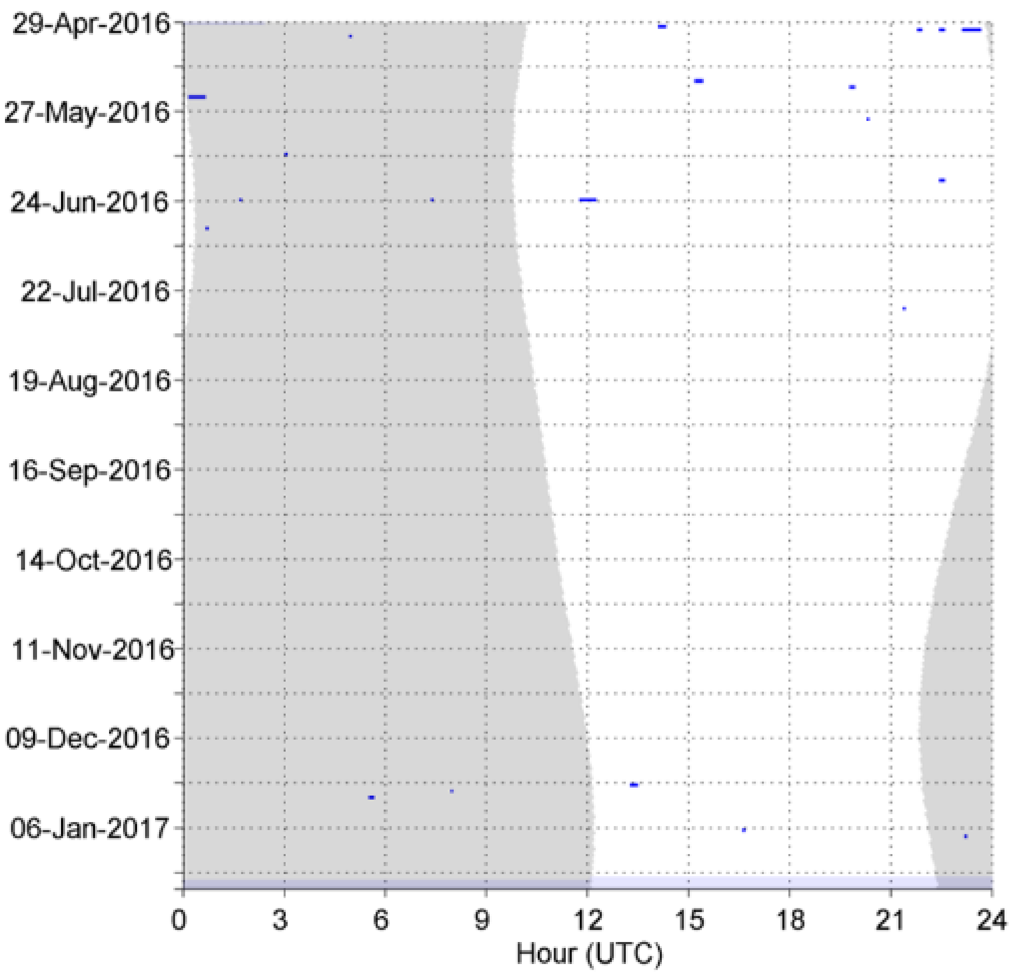

Figure 68. Kogia spp. clicks in one-minute bins at HAT Site A from April 2016 to January 2017. Gray vertical shading denotes nighttime.

Anthropogenic Sounds

Seven types of anthropogenic sounds were detected: broadband ships, LFA sonar, MFA sonar, HFA sonar, echosounders, explosions, and airguns.

Broadband Ships

- Broadband ship noise was detected regularly throughout the recording period. Detections were highest in January 2017 (Figure 69).
- There was no discernible diel pattern for broadband ships during the recording period (Figure 70).

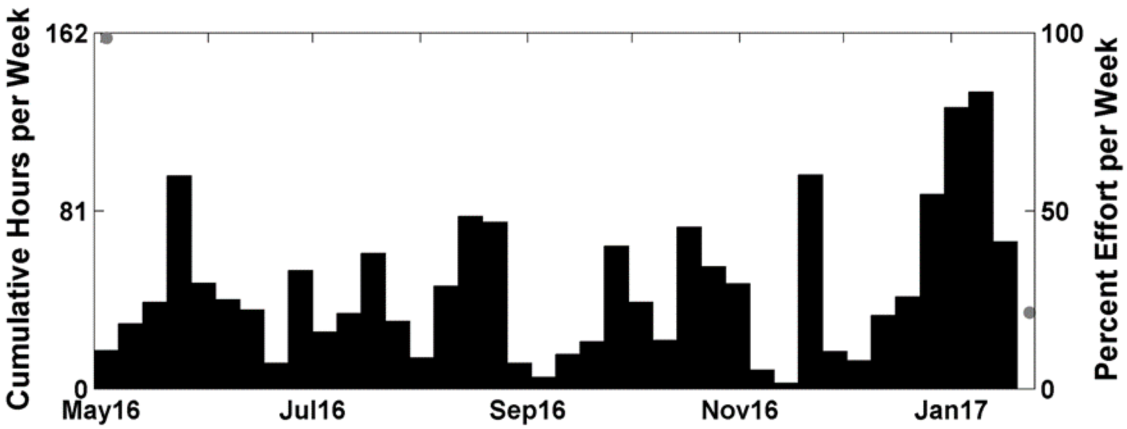

Figure 69. Weekly presence of broadband ships detected between April 2016 and January 2017 at HAT Site A. Effort markings are described in Figure 38.

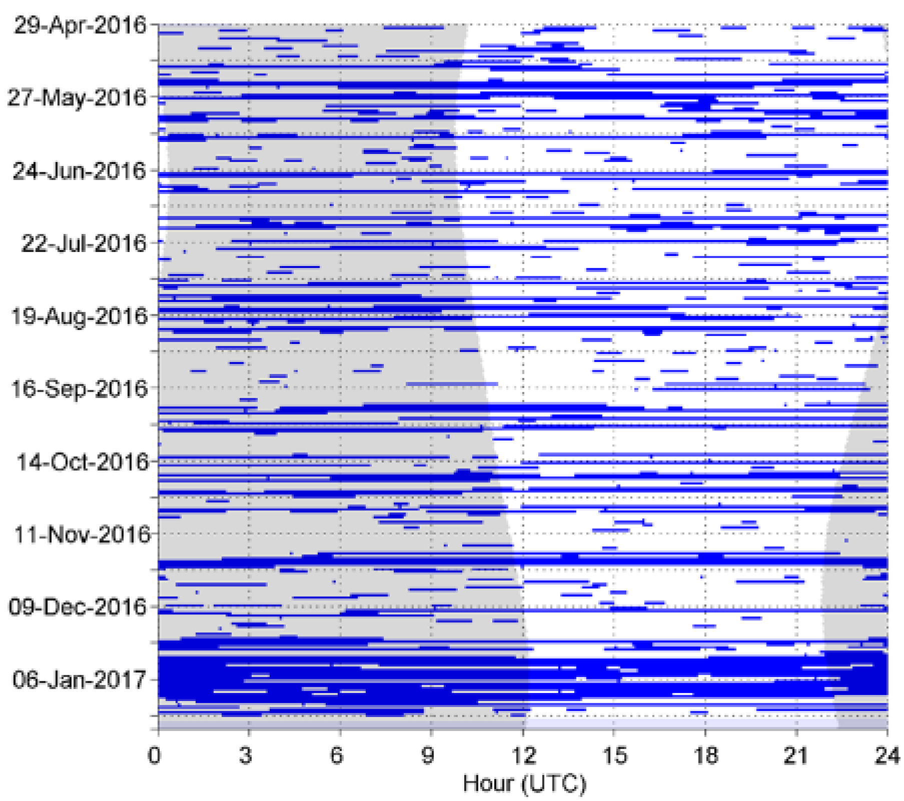

Figure 70. Broadband ship noise in one-minute bins at HAT Site A from April 2016 to January 2017. Gray vertical shading denotes nighttime.

LFA Sonar

- LFA sonar greater than 500 Hz was detected once in July 2016 (Figure 71).
- The only instance of LFA sonar occurred during daytime, but there were not enough detections to establish a diel pattern (Figure 72).

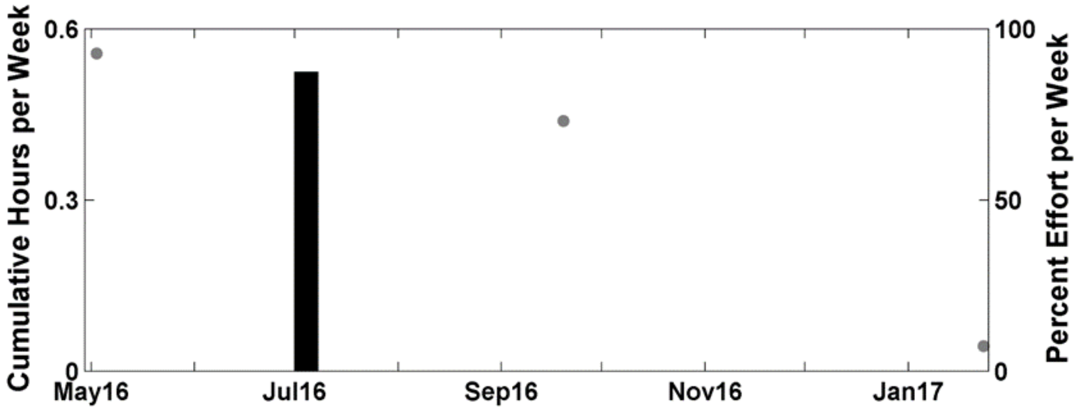

Figure 71. Weekly presence of LFA sonar detected between April 2016 and January 2017 at HAT Site A. Effort markings are described in Figure 38.

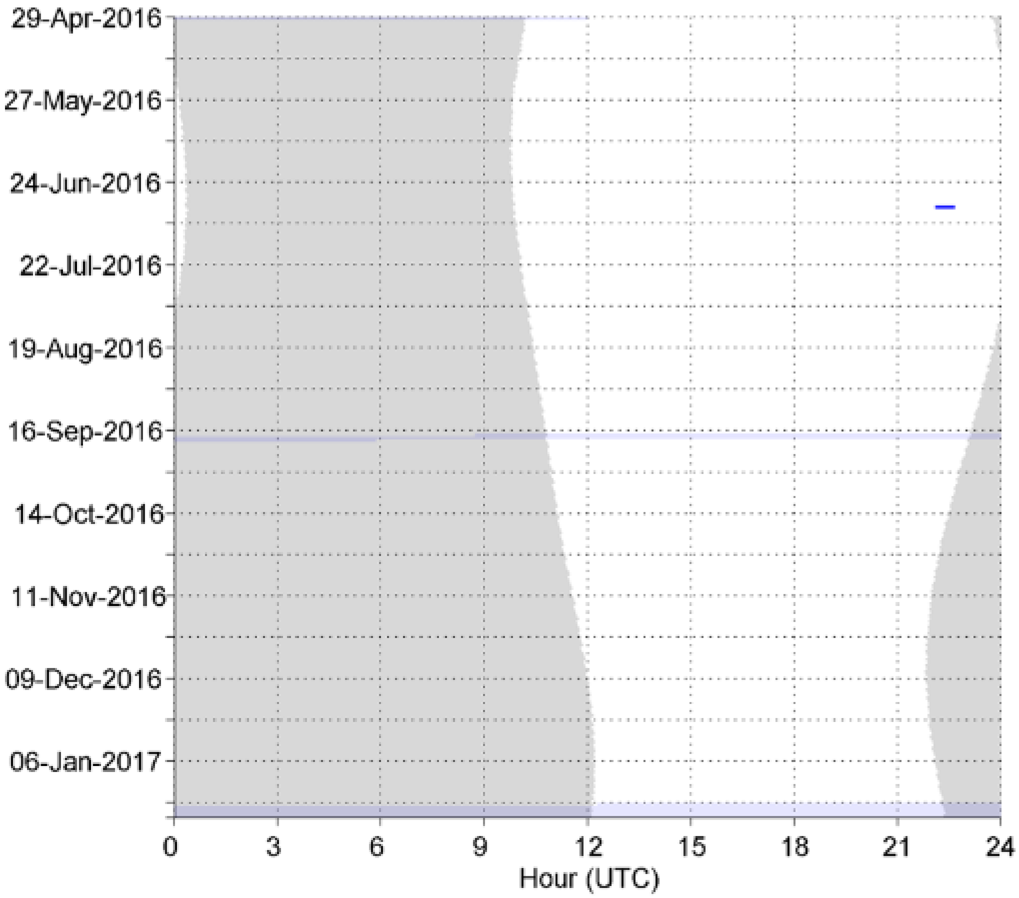

Figure 72. LFA sonar in one-minute bins at HAT Site A from April 2016 to January 2017. Gray vertical shading denotes nighttime.

MFA Sonar

- MFA sonar less than 5 kHz was detected in low numbers throughout the recording period but was highest in December 2016 (Figure 73).
- Most MFA sonar less than 5 kHz occurred during daytime during the recording period (Figure 73). About 7% of analyst-defined MFA events contained packets which exceeded the minimum thresholds required for further analysis (Table 3).
- Highest number of packets (>600) and Cumulative Sound Exposure Levels (CSEL) (> 160 dB re 1 µPa s) MFA events were detected in May 2016. The maximum peak-to-peak RL was 136 dB (Figure 75).

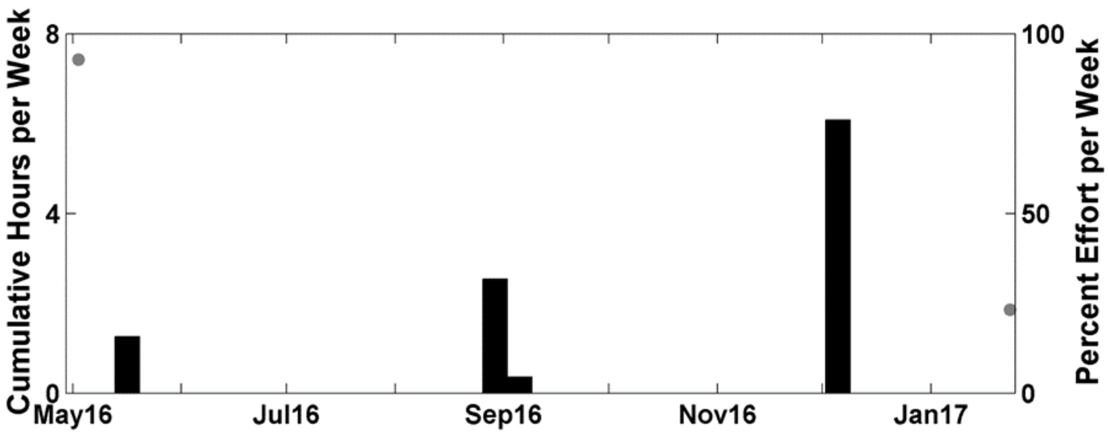

Figure 73. Weekly presence of MFA sonar less than 5 kHz detected between April 2016 and January 2017 at HAT Site A. Effort markings are described in Figure 38.

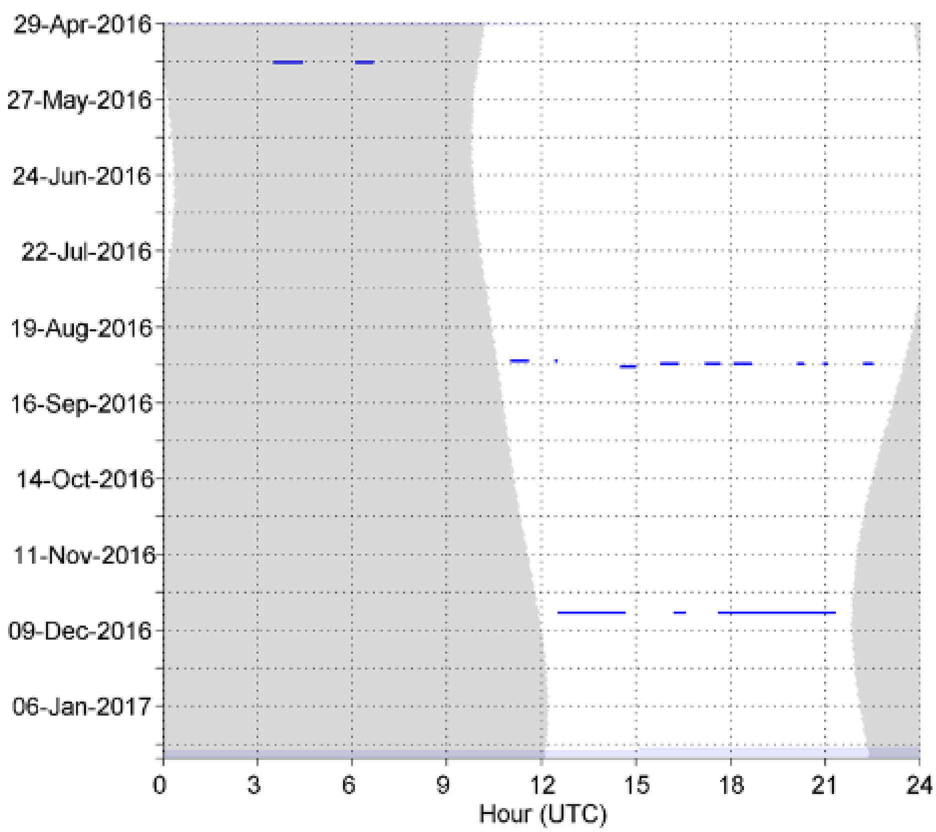

Figure 74. MFA sonar less than 5 kHz in one-minute bins at HAT Site A from April 2016 to January 2017. Gray vertical shading denotes nighttime.

Table 3. Number of analyst-defined MFA events, with wave trains and packets detected by energy detector for this recording period.

Deployment	Analyst Defined Events	Wave Trains (Filtered)	Detected Packets (Filtered)
HAT_A_06	14	1	19

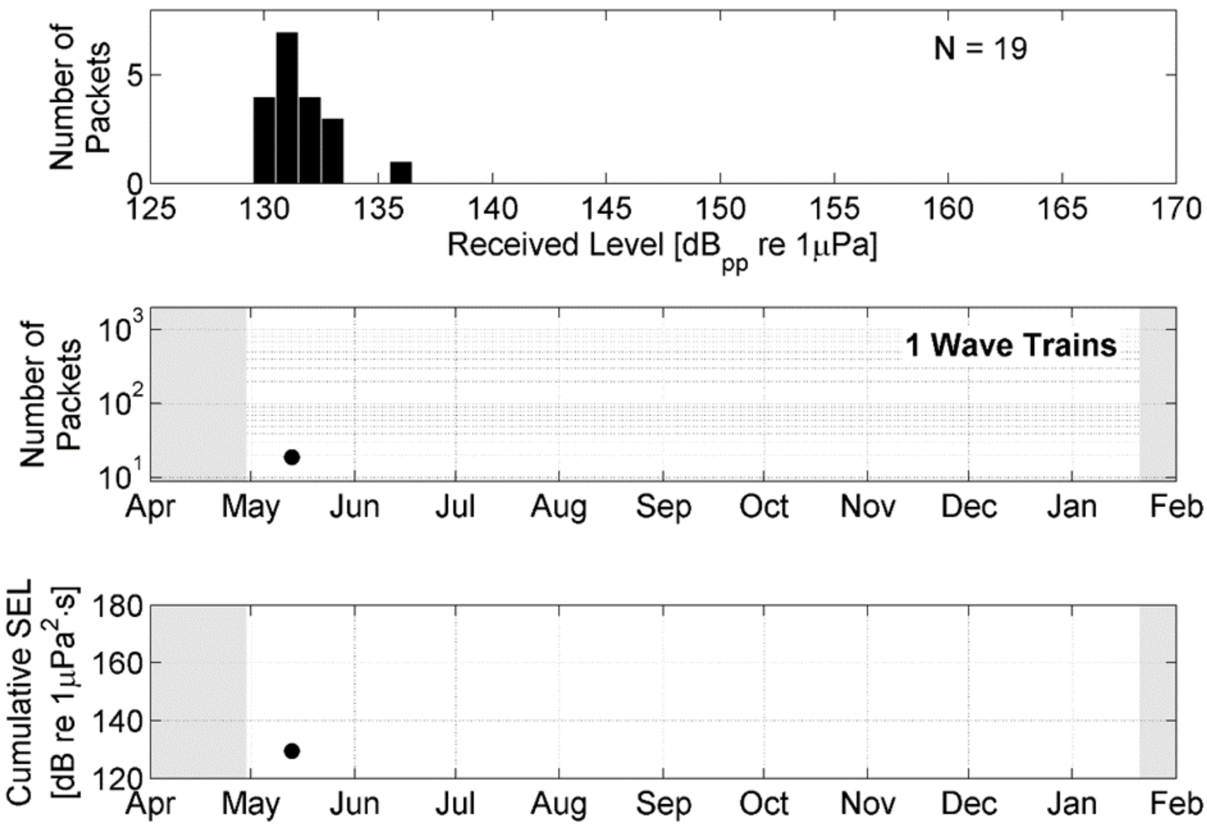

Figure 75. *Top:* Distribution of received levels (RL) of detected MFA packets. *Center:* Number of MFA packets detected in each wave train exceeding the minimum RL threshold (130 dBpp re 1μ Pa). *Bottom:* Cumulative Sound Exposure Levels (CSEL) associated with each wave train.

HFA Sonar

HFA sonar greater than 5 kHz was detected once during October 2016 (Figure 76).

The only detection of HFA sonar greater than 5 kHz occurred at night, but there were not enough detections to establish a diel pattern (Figure 77).

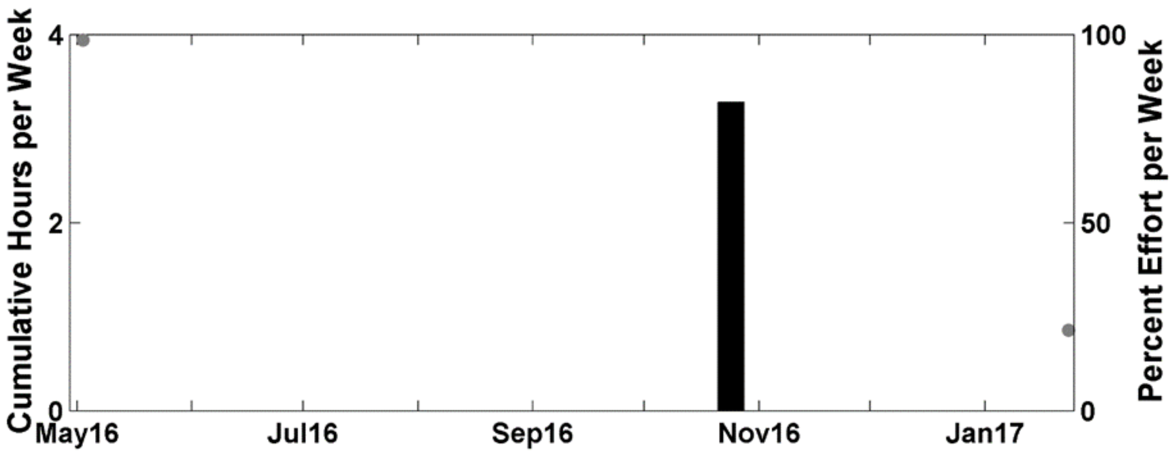

Figure 76. Weekly presence of HFA sonar greater than 5 kHz detected between April 2016 and January 2017 at HAT Site A. Effort markings are described in Figure 38.

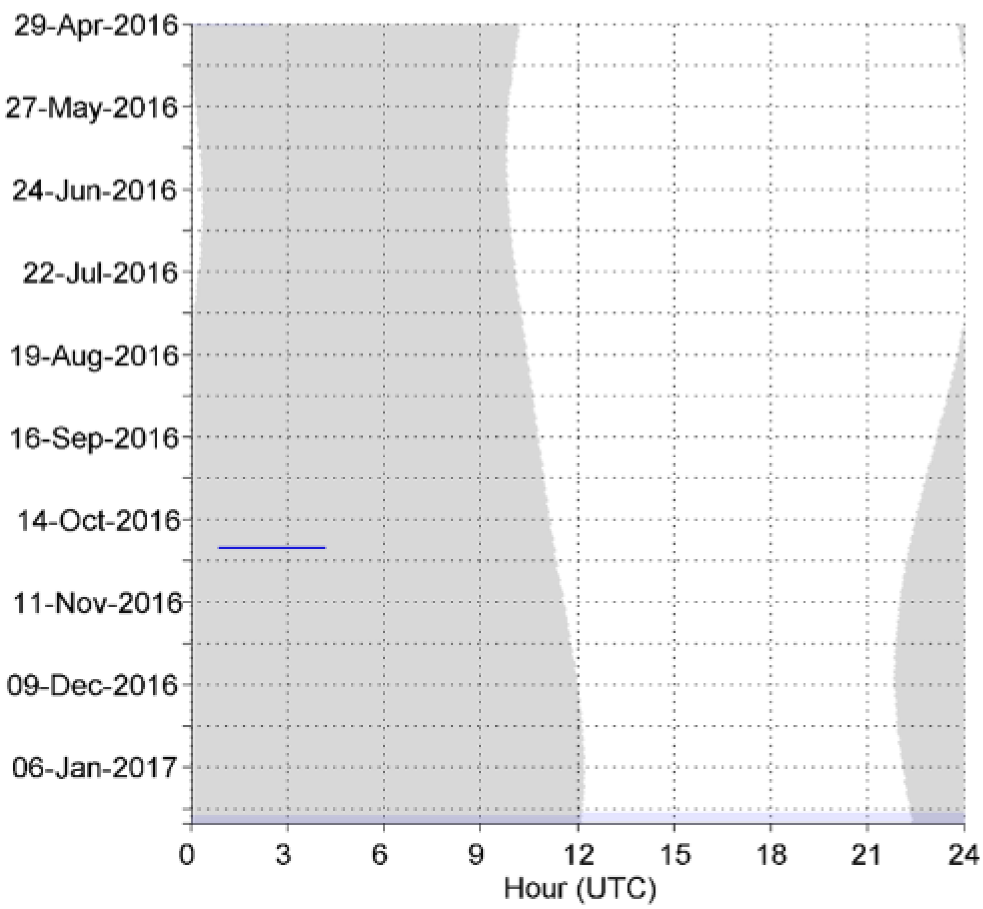

Figure 77. HFA sonar greater than 5 kHz in one-minute bins at HAT Site A from April 2016 to January 2017. Gray vertical shading denotes nighttime.

Echosounders

Echosounder detections greater than 5 kHz were highest in July and August 2016 (Figure 78).

- There was no apparent diel pattern for echosounder detections (Figure 79).

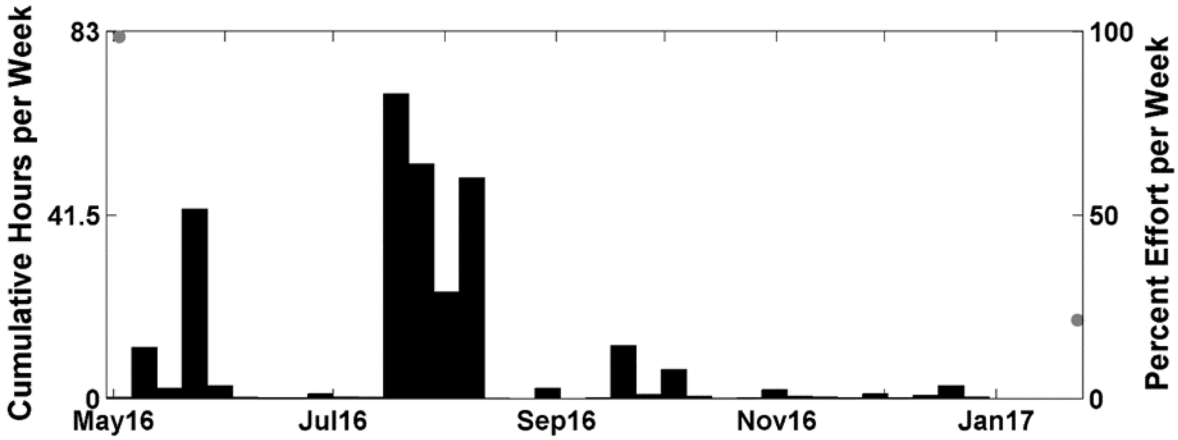

Figure 78. Weekly presence of echosounders greater than 5 kHz detected between April 2016 and January 2017 at HAT Site A. Effort markings are described in Figure 38.

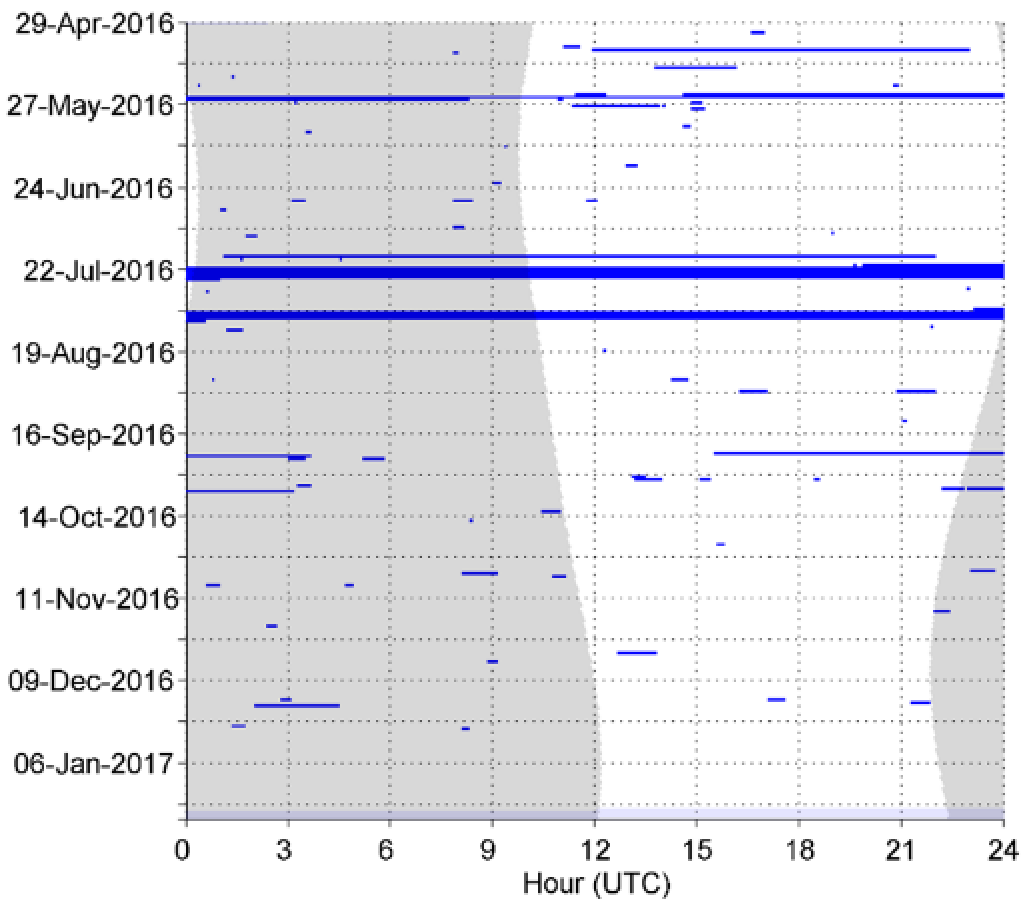

Figure 79. Echosounders greater than 5 kHz in one-minute bins at HAT Site A from April 2016 to January 2017. Gray vertical shading denotes nighttime.

Explosions

- Explosions were detected in low numbers in May 2016 (Figure 80).
- Explosions were detected evenly in the day and night during the recording period (Figure 81).

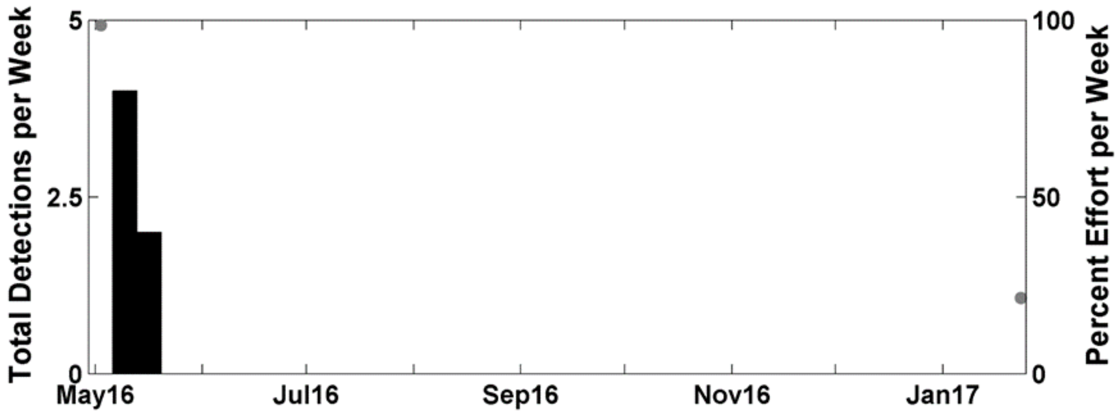

Figure 80. Weekly presence of explosions detected between April 2016 and January 2017 at HAT Site A. Effort markings are described in Figure 38.

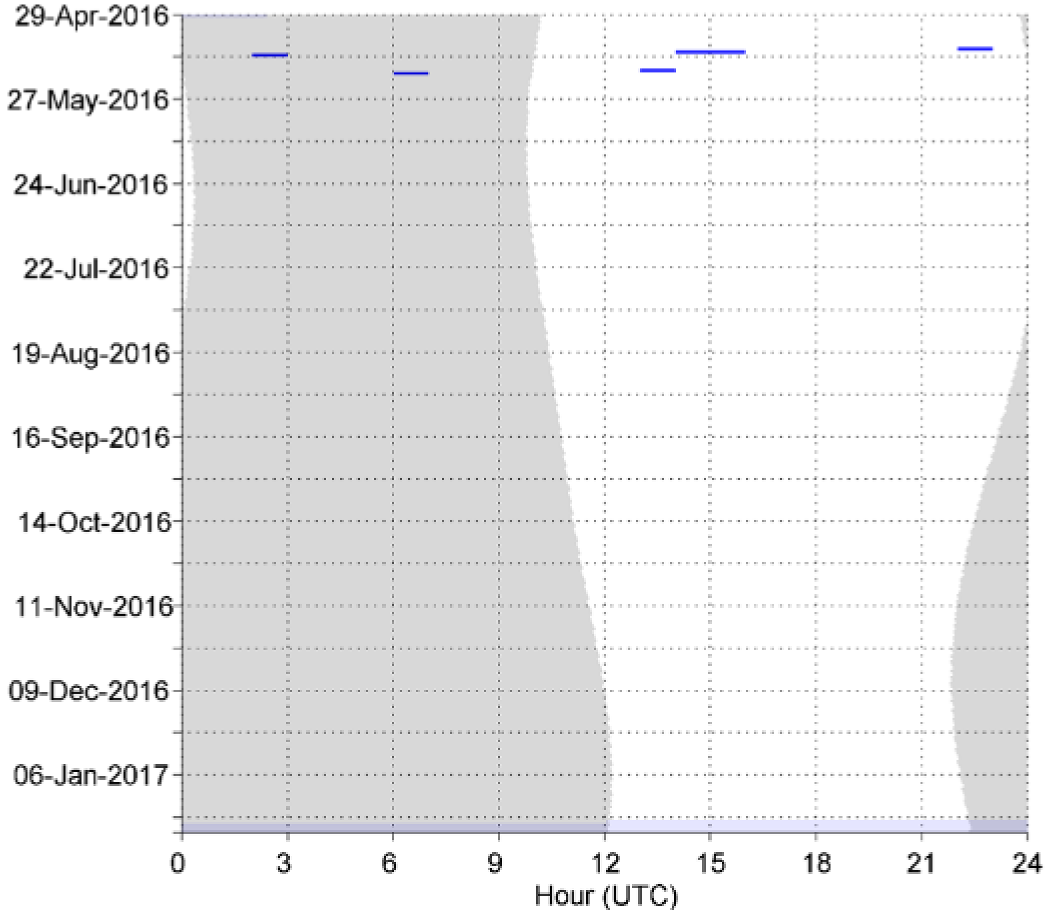

Figure 81. Explosions in one-minute bins at HAT Site A from April 2016 to January 2017. Gray vertical shading denotes nighttime.

Airguns

- Airguns were detected in low numbers between May 2016 and July 2016 (Figure 82).
- There was no apparent diel pattern for airgun detections (Figure 83).

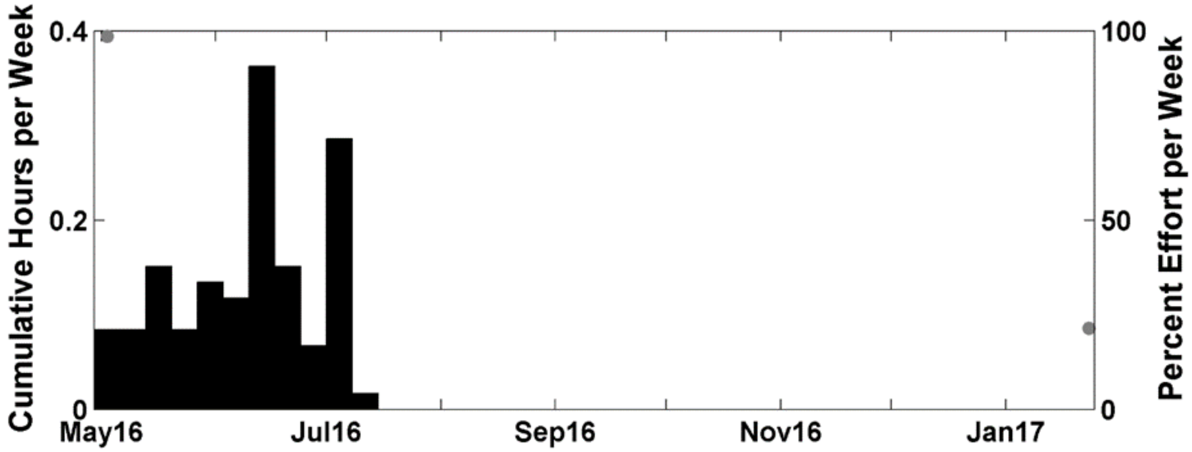

Figure 82. Weekly presence of airguns detected between April 2016 and January 2017 at HAT Site A. Effort markings are described in Figure 38.

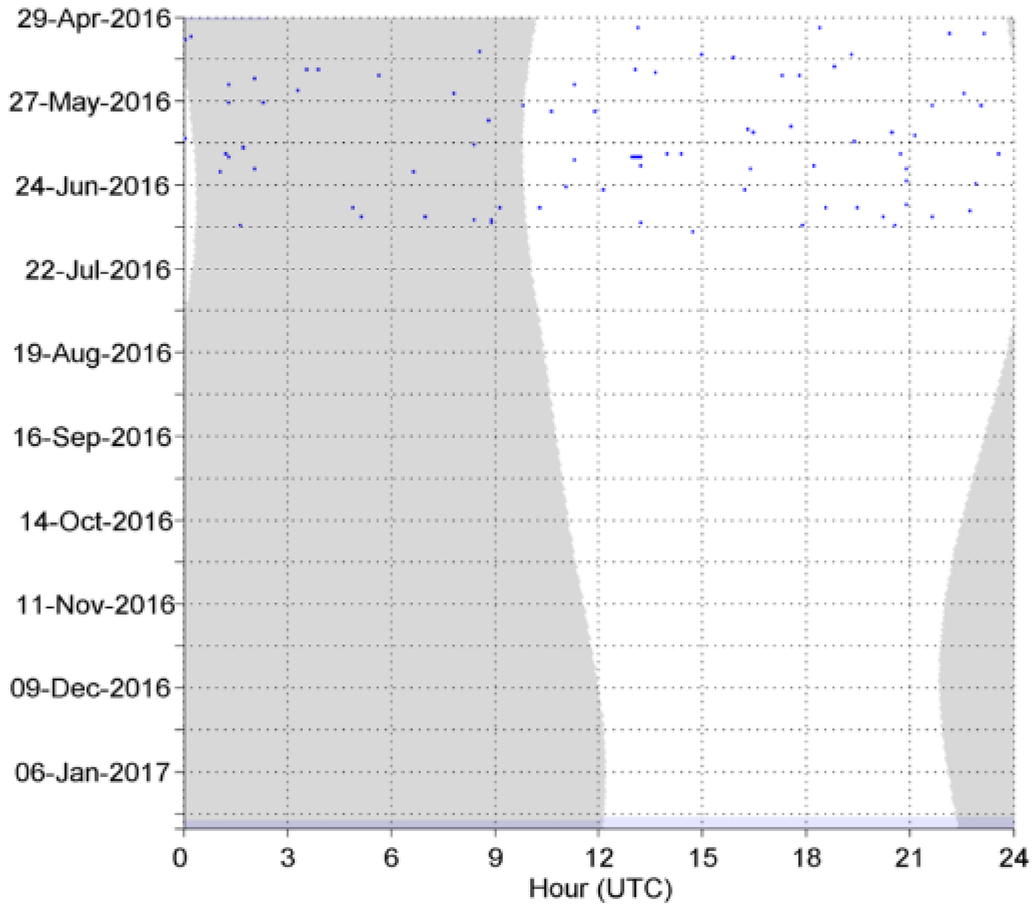

Figure 83. Airguns in one-minute bins at HAT Site A from April 2016 to January 2017. Gray vertical shading denotes nighttime.

References

Amundsen, L., and Landro, M. (2010). "Marine Seismic Sources, Part 1 - Air-guns for no experts," (Geo ExPro), pp. 32-34.

Au, W. W. L. (1993). *The Sonar of Dolphins* (Springer).

Barger, J. E., and Hamblen, W. R. (1980). "The air gun impulsive underwater transducer," The Journal of the Acoustical Society of America 68, 1038-1045.

Baumann-Pickering, S., McDonald, M. A., Simonis, A. E., Berga, A. S., Merkens, K. P. B., Oleson, E. M., Roch, M. A., Wiggins, S. M., Rankin, S., Yack, T. M., and Hildebrand, J. A. (2013). "Species-specific beaked whale echolocation signals," The Journal of the Acoustical Society of America 134, 2293-2301.

Baumann-Pickering, S., Roch, M. A., Brownell Jr, R. L., Simonis, A. E., McDonald, M. A., Solsona-Berga, A., Oleson, E. M., Wiggins, S. M., and Hildebrand, J. A. (2014). "Spatio-Temporal Patterns of Beaked Whale Echolocation Signals in the North Pacific," PLOS ONE 9, e86072.

Baumgartner, M. F., and Fratantoni, D. M. (2008). "Diel periodicity in both sei whale vocalization rates and the vertical migration of their copepod prey observed from ocean gliders," Limnology and Oceanography 53, 2197-2209.

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

Blackman, D. K., Groot-Hedlin, C. d., Harben, P., Sauter, A., and Orcutt, J. A. (2004). "Testing low/very low frequency acoustic sources for basin-wide propagation in the Indian Ocean," The Journal of the Acoustical Society of America 116, 2057-2066.

Cholewiak, D., Baumann-Pickering, S., and Parijs, S. V. (2013). "Description of sounds associated with Sowerby's beaked whales (Mesoplodon bidens) in the western North Atlantic Ocean," The Journal of the Acoustical Society of America 134, 3905-3912.

Cox, H. (2004). "Navy applications of high-frequency acoustics," High Frequency Ocean Acoustics 728, 449-455.

Debich, A. J., Baumann-Pickering, S., Širović, A., Buccowich, J. S., Gentes, Z. E., Gottlieb, R. S., Johnson, S. C., Kerosky, S. M., Roche, L. K., Thayre, B. J., Trickey, J. S., Wiggins, S. M., Hildebrand, J. A., Hodge, L. E. W., and Read, A. J. (2014). "Passive Acoustic Monitoring for Marine Mammals in the Cherry Point OPAREA 2011-2012," (Scripps Institution of Oceanography, Marine Physical Laboratory, La Jolla, CA), p. 83.

Debich, A. J., Baumann-Pickering, S., Širović, A., Hildebrand, J. A., Brewer, A. M., Frasier, K. E., Gresalfi, R. T., Herbert, S. T., Johnson, S. C., Rice, A. C., Varga, L. M., Wiggins, S. M., Hodge, L. E. W., Stanistreet, J. E., and Read, A. J. (2016). "Passive Acoustic Monitoring for Marine Mammals in the Virginia Capes Range Complex October 2012 - April 2015," (Scripps Institution of Oceanography, Marine Physical Laboratory, La Jolla, CA)

Frasier, K. E. (2015). Density estimation of delphinids using passive acoustics: A case study in the Gulf of Mexico. Doctoral dissertation, University of California San Diego, Scripps Institution of Oceanography, La Jolla, CA, USA. 321 pp.

Frasier, K. E., Debich, A. J., Hildebrand, J. A., Rice, A. C., Brewer, A. M., Herbert, S. T., Thayre, B. J., Wiggins, S. M., Baumann-Pickering, S., Sirovic, S., Hodge, L. E. W., and Read, A. J. (2016). "Passive Acoustic Monitoring for Marine Mammals in the Jacksonville Range Complex August 2014 – May 2015" in Marine Physical Laboratory Technical Memorandum 602 (Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA) p. 82.

Gillespie, D., Caillat, M., Gordon, J., and White, P. (2013). "Automatic detection and classification of odontocete whistles," The Journal of the Acoustical Society of America 134, 2427-2437.

Gillespie, D., Dunn, C., Gordon, J., Claridge, D., Embling, C., and Boyd, I. (2009). "Field recordings of Gervais' beaked whales Mesoplodon europaeus from the Bahamas," The Journal of the Acoustical Society of America 125, 3428-3433.

Goold, J. C., and Jones, S. E. (1995). "Time and frequency domain characteristics of sperm whale clicks," The Journal of the Acoustical Society of America 98, 1279-1291.

Helble, T. A., Ierley, G. R., D'Spain, G. L., Roch, M. A., and Hildebrand, J. A. (2012). "A generalized power-law detection algorithm for humpback whale vocalizations," Journal of the Acoustical Society of America 131, 2682-2699.

Johnson, M., Madsen, P. T., Zimmer, W. M. X., de Soto, N. A., and Tyack, P. L. (2004). "Beaked whales echolocate on prey," Proceedings of the Royal Society B: Biological Sciences 271, S383-S386.

Johnson, S. C., Širović, A., Buccowich, J. S., Debich, A. J., Roche, L. K., Thayre, B. J., Wiggins, S. M., Hildebrand, J. A., Hodge, L. E. W., and Read, A. J. (2014). "Passive Acoustic Monitoring for Marine Mammals in the Jacksonville Range Complex 2010," (Scripps Institution of Oceanography, Marine Physical Laboratory, La Jolla, CA), p. 26.

Madsen, P. T., Payne, R., Kristiansen, N. U., Wahlberg, M., Kerr, I., and Møhl, B. (2002a). "Sperm whale sound production studied with ultrasound time/depth-recording tags," Journal of Experimental Biology 205, 1899.

Madsen, P. T., Wahlberg, M., and Møhl, B. (2002b). "Male sperm whale (Physeter macrocephalus) acoustics in a high-latitude habitat: implications for echolocation and communication," Behavioral Ecology and Sociobiology 53, 31-41.

McDonald, M. A., Hildebrand, J. A., and Webb, S. C. (1995). "Blue and fin whales observed on a seafloor array in the Northeast Pacific," J. Acoust. Soc. Am. 98, 712-721.

McDonald, M. A., Messnick, S. L., and Hildebrand, J. A. (2006). "Biogeographic characterisation of blue whale song worldwide: using song to identify populations," Journal of Cetacean Research and Management 8, 55-65.

Mellinger, D. K., Carson, C. D., and Clark, C. W. (2000). "Characteristics of minke whale (Balaenoptera acutorostrata) pulse trains recorded near Puerto Rico," Marine Mammal Science 16, 739-756.

Mellinger, D. K., and Clark, C. W. (2003). "Blue whale (Balaenoptera musculus) sounds from the North Atlantic," Journal of the Acoustical Society of America 114, 1108-1119.

Mizroch, S. A., Rice, D. W., and Breiwick, J. M. (1984). "The sei whale, Balaenoptera borealis," Marine Fisheries Review 46, 25-29.

Møhl, B., Wahlberg, M., Madsen, P. T., Heerfordt, A., and Lund, A. (2003). "The monopulsed nature of sperm whale clicks," The Journal of the Acoustical Society of America 114, 1143-1154.

Oleson, E. M., Barlow, J., Gordon, J., Rankin, S., and Hildebrand, J. A. (2003). "Low frequency calls of Bryde's whales," Marine Mammal Science 19, 160-172.

Omura, H. (1959). "Bryde's whale from the coast of Japan," Scientific Reports of the Whales Research Institute, Tokyo 14, 1-33.

Parks, S. E., and Tyack, P. L. (2005). "Sound production by North Atlantic right whales (Eubalaena glacialis) in surface active groups," Journal of the Acoustical Society of America 117, 3297-3306.

Payne, R., and McVay, S. (1971). "Songs of humpback whales," Science 173, 585-597.

Perry, S. L., DeMaster, D. P., and Silber, G. K. (1999). "The great whales: History and status of six species listed as endangered under the US Endangered Species Act of 1973," Marine Fisheries Review 61, 1-74.

Risch, D., Clark, C. W., Dugan, P. J., Popescu, M., Siebert, U., and Van Parijs, S. M. (2013). "Minke whale acoustic behavior and multi-year seasonal and diel vocalization patterns in Massachusetts Bay, USA," Mar Ecol Prog Ser 489, 279-295.

Roch, M. A., Klinck, H., Baumann-Pickering, S., Mellinger, D. K., Qui, S., Soldevilla, M. S., and Hildebrand, J. A. (2011). "Classification of echolocation clicks from odontocetes in the Southern California Bight," The Journal of the Acoustical Society of America 129, 467-475.

Širović, A., Bassett, H. R., Johnson, S. C., Wiggins, S. M., and Hildebrand, J. A. (2014). "Bryde's whale calls recorded in the Gulf of Mexico," Marine Mammal Science 30, 399-409.

Soldevilla, M. S., Henderson, E. E., Campbell, G. S., Wiggins, S. M., Hildebrand, J. A., and Roch, M. A. (2008). "Classification of Risso's and Pacific white-sided dolphins using spectral properties of echolocation clicks," The Journal of the Acoustical Society of America 124, 609-624.

Soldevilla, M. S., Baumann-Pickering, S., Cholewiak, D., Hodge, L. E., Oleson, E. M., & Rankin, S. (2017). "Geographic variation in Risso's dolphin echolocation click spectra," The Journal of the Acoustical Society of America, 142(2), 599-617.

Thompson, P. O., Findley, L. T., and Vidal, O. (1992). "20-Hz pulses and other vocalizations of fin whales, Balaenoptera physalus, in the Gulf of California, Mexico," Journal of the Acoustical Society of America 92, 3051-3057.

Trygonis, V., Gerstein, E., Moir, J., and McCulloch, S. (2013). "Vocalization characteristics of North Atlantic right whale surface active groups in the calving habitat, southeastern United States," Journal of the Acoustical Society of America 134, 4518-4521.

Wade, P. W., and Gerrodette, T. (1993). "Estimates of cetacean abundance and distribution in the Eastern Tropical Pacific," Report of the International Whaling Commission 43, 477-494.

Watkins, W. A., and Schevill, W. E. (1977). "Sperm whale codas," The Journal of the Acoustical Society of America 62, 1485-1490.

Watkins, W. A. (1981). "Activities and underwater sounds of fin whales," Scientific Reports of the Whale Research Institute 33, 83-117.

Wiggins, S. M., and Hildebrand, J. A. (2007). "High-frequency Acoustic Recording Package (HARP) for broad-band, long-term marine mammal monitoring.," (IEEE, Tokyo, Japan, International Symposium on Underwater Technology and Workshop on Scientific Use of Submarine Cables and Related Technologies), pp. 551-557.

Wiggins, S. M. (2015). “Methods for quantifying mid-frequency active sonar in the SOCAL Range Complex," MPL TM-533. Marine Physical Laboratory, Scripps Institution of Oceanography, La Jolla, CA, p. 14.

Wysocki, L. E., Dittami, J. P., and Ladich, F. (2006). "Deep-diving behaviour of sperm whales (*Physeter macrocephalus*) Ship noise and cortisol secretion in European freshwater fishes," Biological Conservation 128, 501-508.

Zimmer, W. M. X., Johnson, M. P., Madsen, P. T., and Tyack, P. L. (2005). "Echolocation clicks of free-ranging Cuvier’s beaked whales (Ziphius cavirostris)," The Journal of the Acoustical Society of America 117, 3919-3927.