Passive Acoustic Monitoring of Marine Mammals offshore of Cape Hatteras May 2017– June 2018

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

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Executive Summary

Two High-Frequency Acoustic Recording Packages (HARP) were deployed sequentially from May 2017 to June 2018 to record marine mammal and anthropogenic sounds in the Navy's Virginia Capes Range Complex offshore ~ 44 nm northeast from Cape Hatteras (HAT). Both HARPs were deployed on the seafloor at approximately 1,150 m depth. The HARPs 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.

Ambient sound levels of 80-85 dB re: 1 μPa^2/Hz were observed at 45 Hz, predominantly due to basin-wide commercial shipping. Peaks in spectrum levels at 20 Hz from September 2017 to March 2018 are related to the seasonally increased presence of fin whales. Sound levels at 200-1000 Hz were higher during January and March, related to wind and wave noise from higher sea states.

Five baleen whale species were recorded: blue, fin, minke, sei, and humpback whales. No Bryde's whale nor right whale calls were detected. Fin whales were detected throughout the monitoring period with higher activity from October 2017 to January 2018. Blue whale A calls were found in low numbers between August 2017 and February 2018. Sei and minke whales were detected primarily from January to April 2018. Humpback whale call types were primarily detected during March and April 2018.

Several known odontocete signals were detected. Blainville's and Sowerby's beaked whales were each detected once throughout the recording period. Cuvier's beaked whales were detected more than 20 hours per week throughout the monitoring period. Gervais' beaked whales and *Kogia* spp. were detected intermittently throughout the monitoring period. One acoustically identifiable delphinid species was Risso's dolphins, whose echolocation clicks occurred less than an hour per week throughout the recording period but peaked between February and May 2018. 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 intermittently between February and May 2018 and airguns were detected in June, September, and November 2017. Low-frequency active (LFA) sonar was detected infrequently between July and October 2017 and mid-frequency active (MFA) sonar was detected intermittently throughout the recording period but was highest in October 2017. High-frequency active (HFA) sonar was detected once in July 2017. Echosounder pings were continuous from October 2017 to February 2018. Ships were detected throughout the deployment. A controlled exposure experiment (CEE) was conducted using a scaled sound pressure level source and a US Navy full-scale 53C mid-frequency active sonar (MFAS) was operated in concurrence with beaked whale tracking experiments.

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 two High-Frequency Acoustic Recording Packages (HARP) that were deployed sequentially within the Virginia Capes Range Complex offshore from Cape Hatteras and collected data from May 2017 to June 2018 (Figure 1).

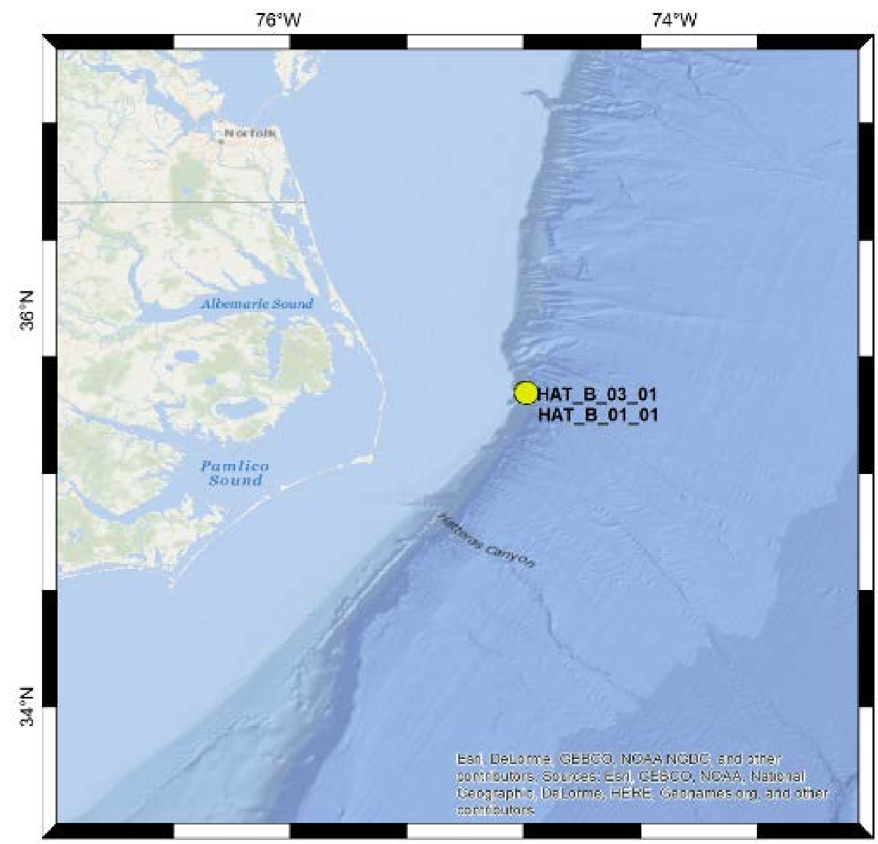

Figure 1a. Location of the two High-Frequency Acoustic Recording Packages (HARPs) at site HAT_B (HAT_B_01_01 located at 35° 35.022 N, 74° 44.947 W, depth 1,118 m, HAT_B_03_01 located at 35° 35.018 N, 74° 44.599 W, depth 1,200 m) deployed in the Cape Hatteras Complex study area from May 2017 to June 2018.

Beaked Whale Tracking Off of Cape Hatteras

An array of passive acoustic monitoring (PAM) recorders was deployed during May 2017 in the U.S. Navy's Virginia Capes Range Complex offshore of Cape Hatteras to spatially track marine mammal sounds (Wiggins *et al.*, 2018). The large (~1 km) aperture array was deployed at HAT Site B and consisted of High-Frequency Acoustic Recording Packages (HARPs), one (mentioned above) was configured as a single hydrophone sampling at 200 kHz (HAT_B_01_01) for 169 days and another two (HAT_B_01_02_C4 and HAT_B_01_03_C4) were configured as four-hydrophone small aperture (~ 1 m) arrays sampling at 100 kHz for 50 days (Figure 1b). In late June 2017, the two four-hydrophone HARPs were recovered, serviced, and redeployed; however, one instrument prematurely released from the seafloor and was lost (HAT_B_02_02_C4), whereas, the other (HAT_B_02_03_C4) recorded for 122 days until October 2017.

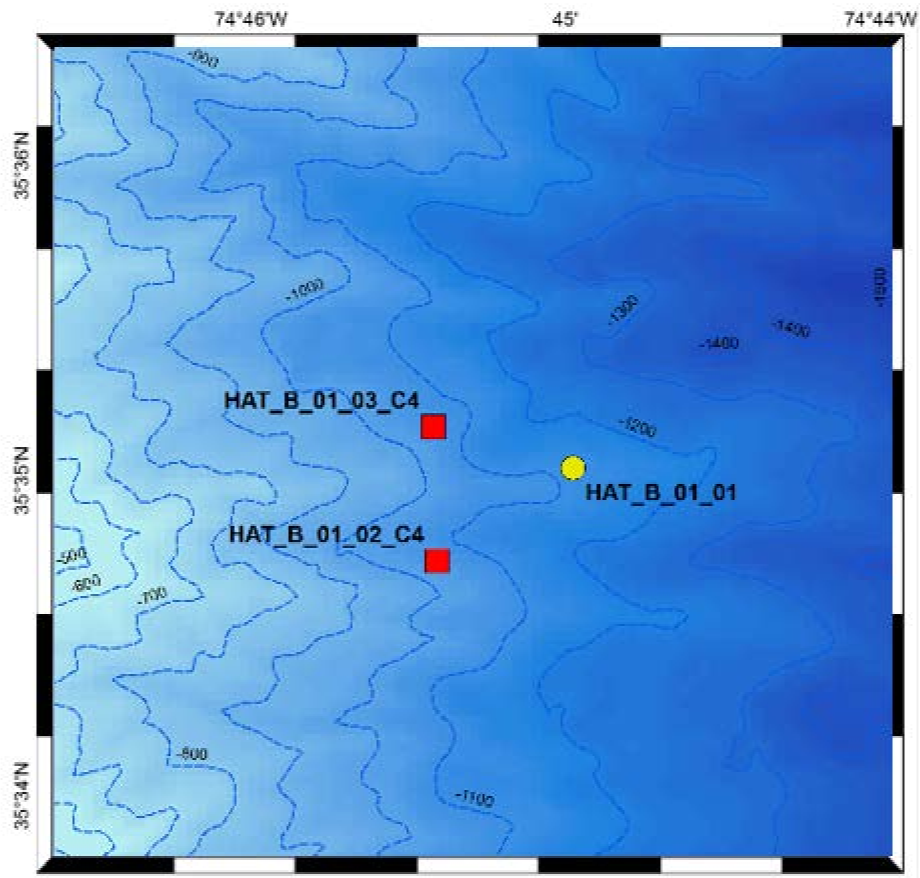

Figure 1b. Location of the three High-Frequency Acoustic Recording Packages (HARP) at HAT Site B deployed in the Cape Hatteras Complex study area in May 2017 as an array for tracking beaked whales.

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 more than a year of continuous data storage. The HARPs were 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

Two single channel HARPs recorded data sequentially from May 2017 to June 2018 at HAT Site B and sampled continuously at 200 kHz to provide 100 kHz of effective bandwidth. The first instrument (HAT_B_01_01, latitude 35° 35.022 N, longitude 74° 44.947 W, depth 1,118 m) recorded 169.1 days from May 9, 2017 to October 25, 2017. The second instrument (HAT_B_03_01, latitude 35° 35.018 N, longitude 74° 44.599 W, depth 1,200 m) recorded for 217.5 days from October 26, 2017 to June 1, 2018. Both instruments together recorded a total of 9,278 hours of data. Intermittent data gaps appeared at the end of the HAT_B_01_01 deployment due to a data logger malfunction. Recording coverage began as 100% and was 91% at the end of the recording period. For comparison, data collection earlier at HAT Site A was documented in previous reports (Rafter *et al.*, 2018, Frasier *et al.*, 2017, Debich, *et al.*, 2016).

Data Analysis

To visualize the acoustic data, frequency spectra were calculated using the Welch method (Welch, 1967) for all recorded data using a time average of 5 s. 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 associated 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 10 Hz – 100 kHz allows detection of baleen whales, toothed whales (odontocetes), and anthropogenic sounds. The presence of acoustic signals from multiple marine mammal species and anthropogenic noise was found in the recordings. 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 of the original recordings by a factor of 100. For the analysis of the mid-frequency recordings, the original recordings were decimated by a factor of 20.

We summarize acoustic data collected at HAT Site B from May 2017 to June 2018, and discuss seasonal occurrence and relative abundance of calls for different species and anthropogenic sounds that were consistently identified in the recordings.

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). In the absence of wind, ambient sound pressure levels are low and difficult to measure at frequencies above ~10 kHz. Therefore, to analyze the ambient soundscape, the recordings 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 s 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 and 300 Hz with a 1 h plot length. To observe individual calls, the spectrogram window was typically set to display 1-250 Hz with a 60 s 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 s (Figure 2).

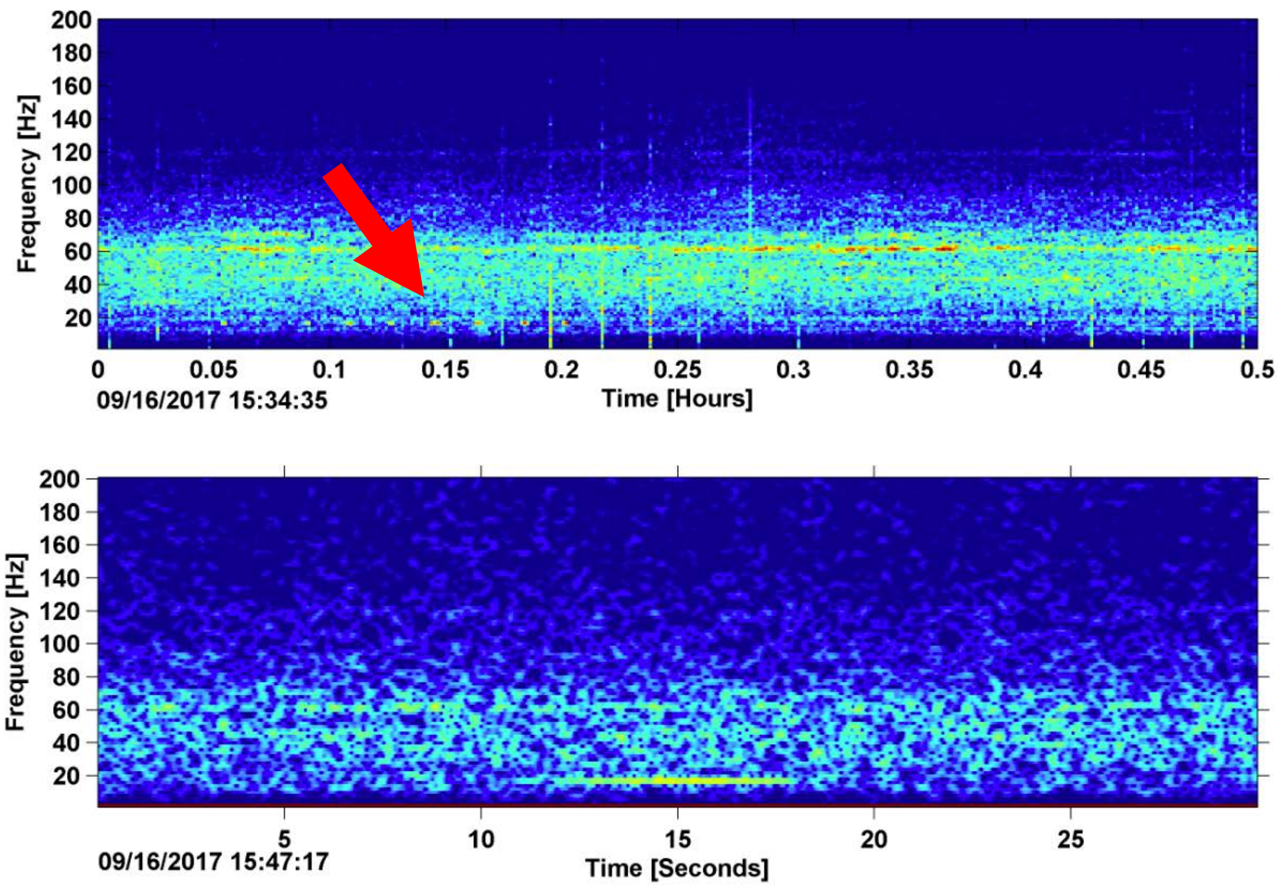

Figure 2. North Atlantic blue whale A calls in the LTSA (top) and spectrogram (bottom) at the HAT Site B, September 2017.

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 between 0.8 and 2.5 s with an average intercall interval of 2.8 min (Figure 3). There were no detections for Bryde’s whale Be7 calls during the recording period.

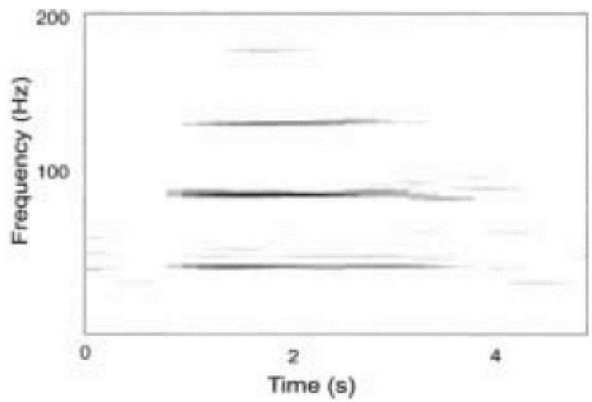

Figure 3. Spectrogram of Bryde’s whale Be7 call from Oleson et al., 2003.

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 4). There were no detections of Bryde’s whale Be9 calls during the recording period.

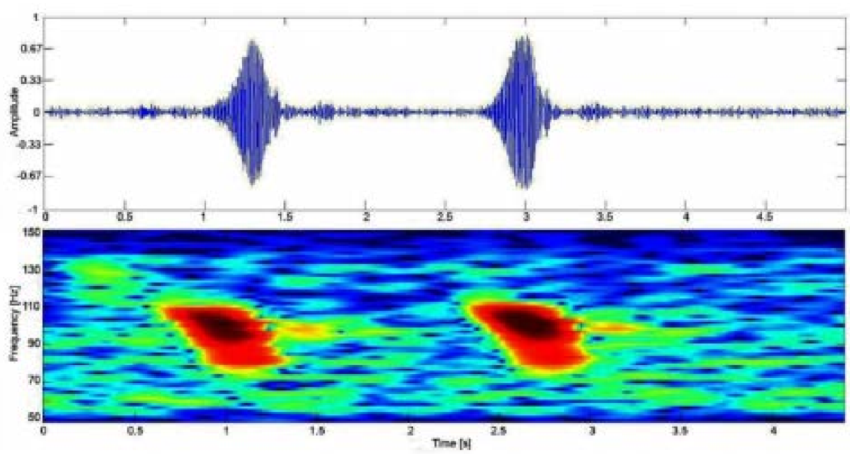

Figure 4. Timeseries (top) and spectrogram (bottom) of Bryde’s whale Be9 call from the Gulf of Mexico (Širović et al., 2014).

Fin Whales

Fin whales produce two types of short (approximately 1 s duration), low-frequency calls: downsweeps in frequency from 30 to 15 Hz, called 20 Hz calls (Watkins, 1981; Figure 5) and downsweeps from 75 to 40 Hz, called 40 Hz calls (Figure 6). 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 5) were detected automatically using an energy detection method (Širović *et al.*, 2014). The method uses a difference in acoustic energy between signal and noise, calculated from a 5 s 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.

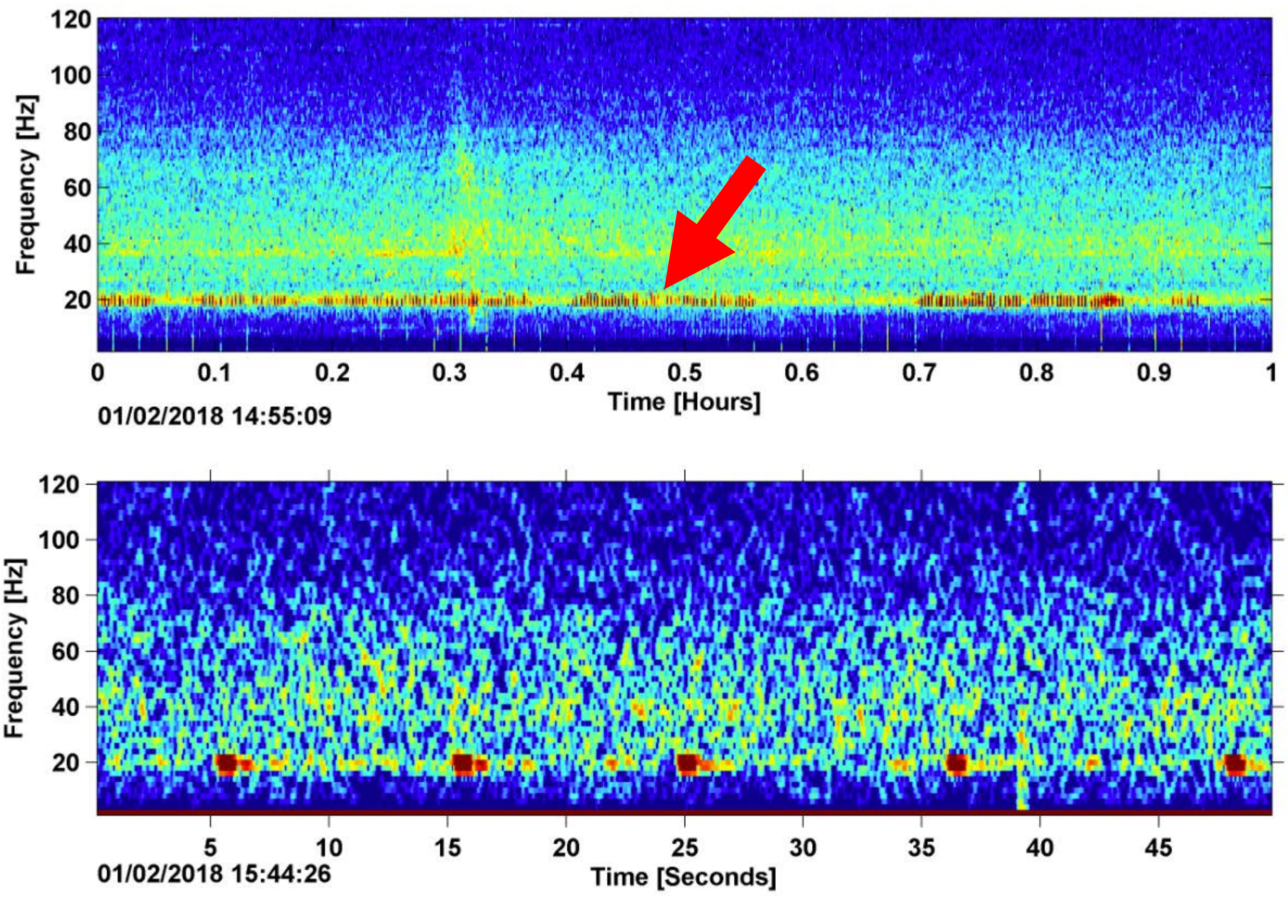

Figure 5. Fin whale 20 Hz call in LTSA (top) and spectrogram (bottom) at HAT Site B, January 2018.

Fin Whale 40 Hz Calls

The presence of fin whale 40 Hz calls (Figure 6) was examined via manual scanning of the LTSA and subsequent verification from a spectrogram of the frequency and temporal characteristics of the calls.

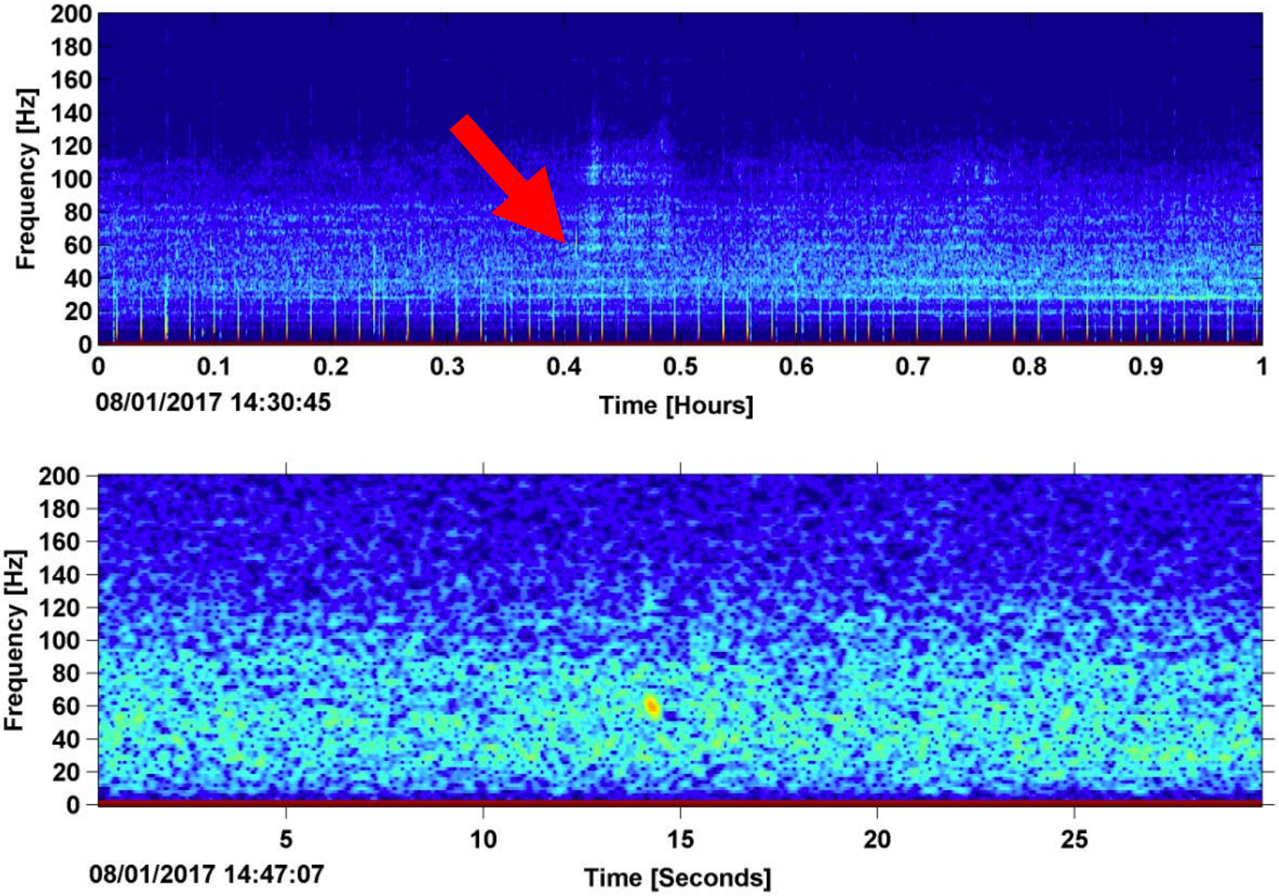

Figure 6. Fin whale 40 Hz call in LTSA (top) and spectrogram (bottom) at HAT Site B, August 2017.

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 7). The presence of pulse trains was marked but effort was not expended to denote whether they were slow-down, speed-up, or constant types.

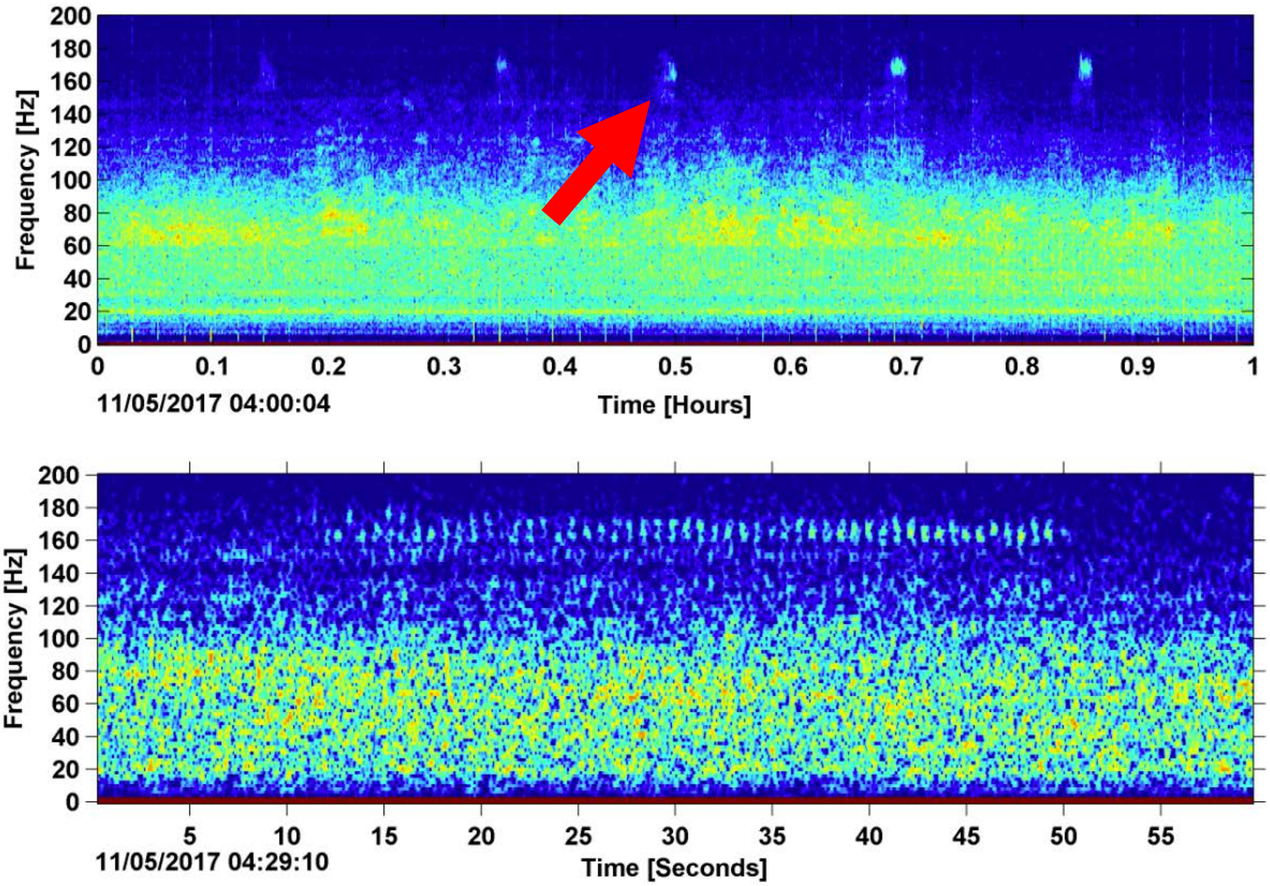

Figure 7. Minke whale pulse train in the LTSA (top) and spectrogram (bottom) recorded at HAT Site B, November 2017.

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 8).

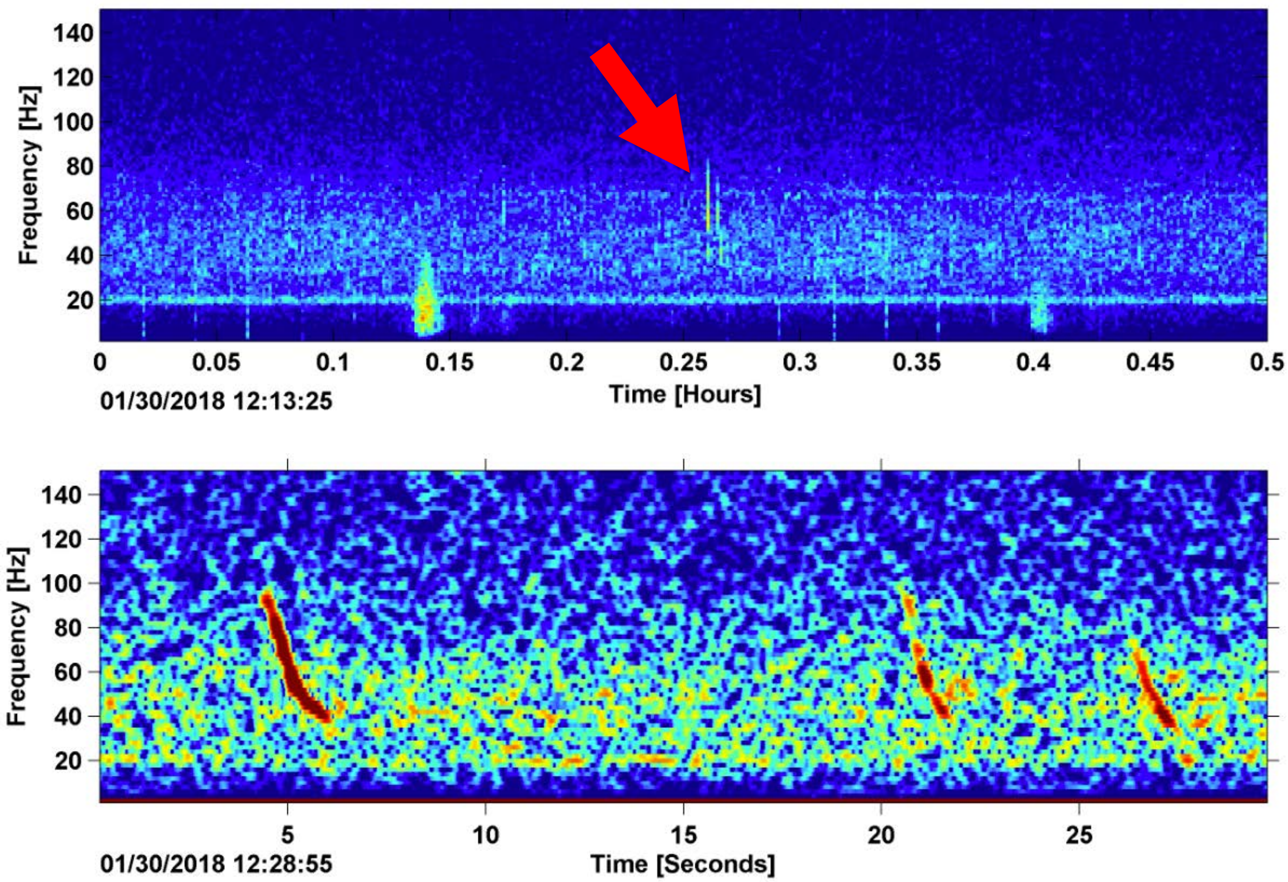

Figure 8. Downsweep calls from sei whales in the LTSA (top) and spectrogram (bottom) from HAT Site B, January 2018.

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 s in duration and range between 80 Hz and 200 Hz, sometimes with harmonics (Figure 9). There were no confirmed detections for North Atlantic right whale upcalls in this recording period.

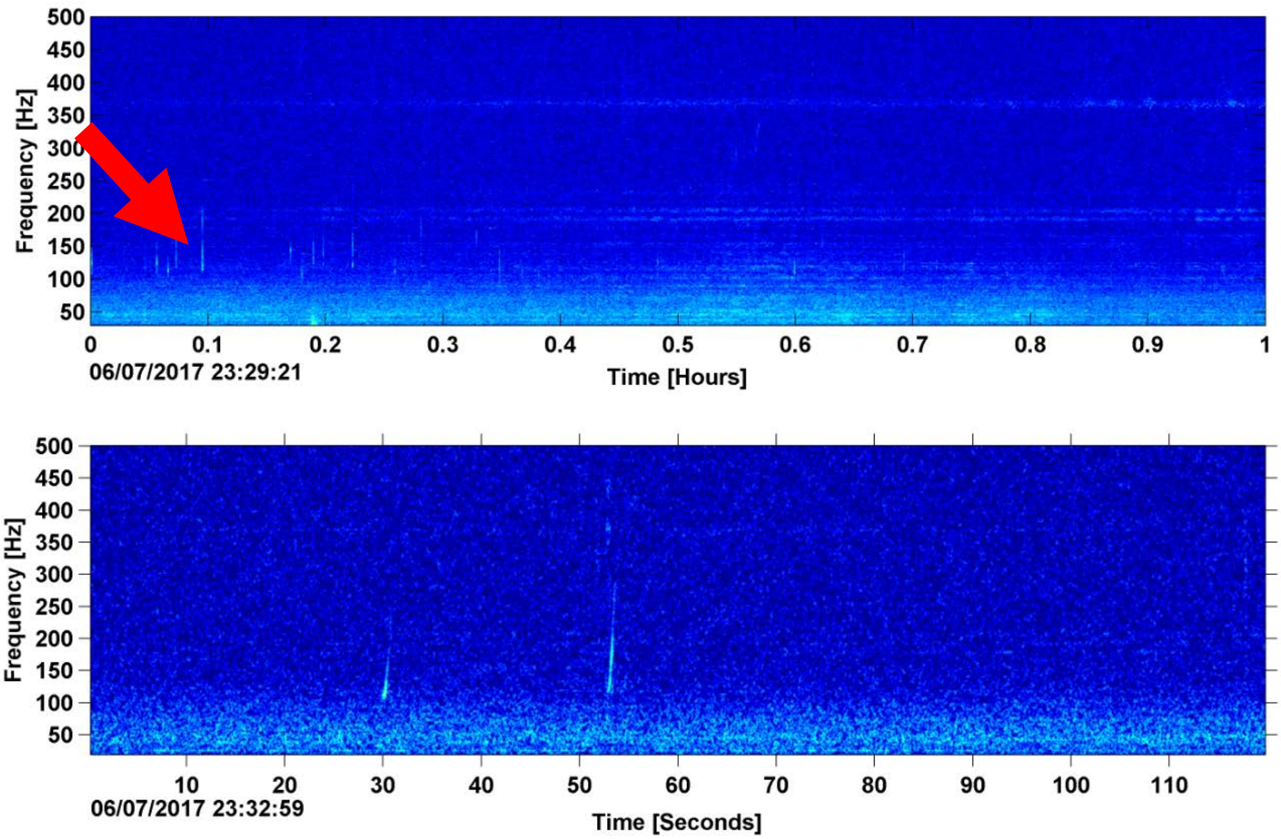

Figure 9. Right whale up-calls in the LTSA (top) and spectrogram (bottom) recorded at Norfolk Canyon Site A, June 2017.

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. We detected humpback whale calls using an automatic detection algorithm based on the generalized power law (Helble *et al.*, 2012). The detections were subsequently verified for accuracy by a trained analyst. When humpback calls were identified in the LTSA or spectrogram, they were logged according to the start time and end time of the encounter. An encounter was consider 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 and 3,000 Hz (Figure 10).

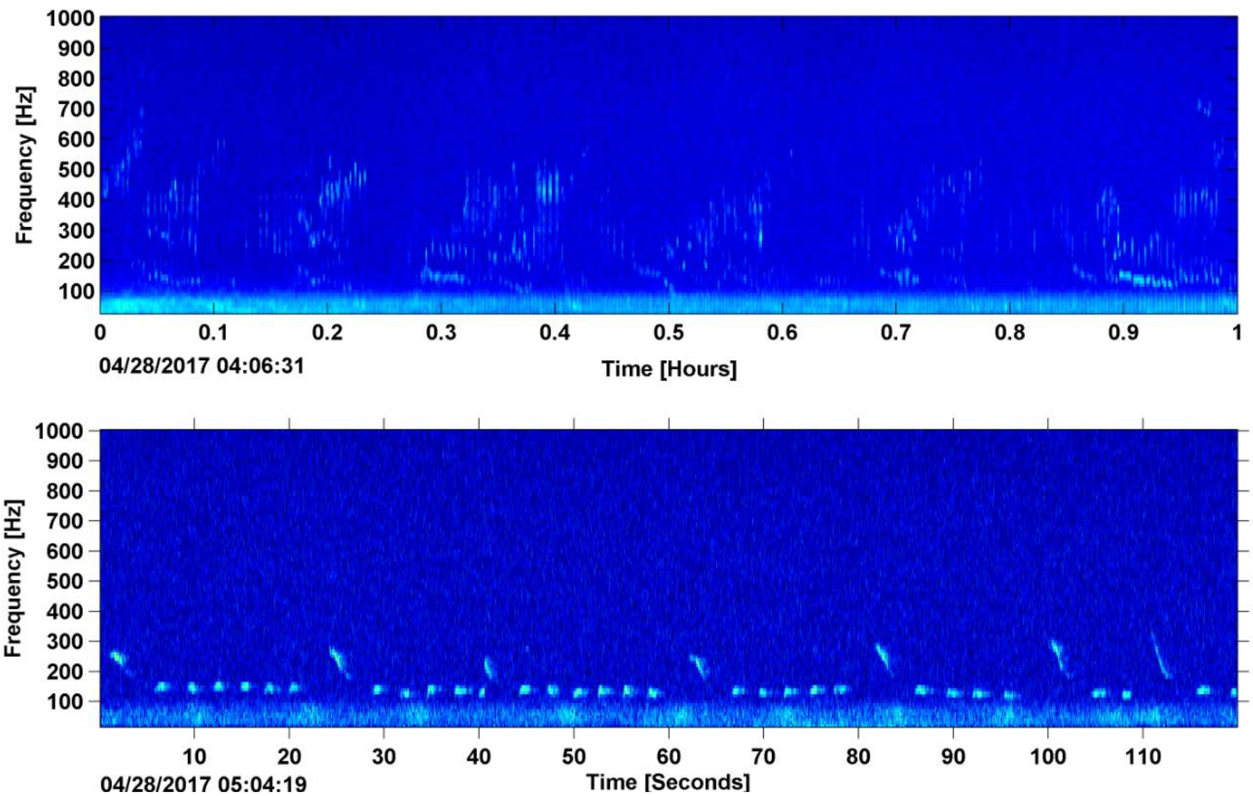

Figure 10. Humpback whale calls in the LTSA (top) and spectrogram (bottom) recorded at Norfolk Canyon Site A, April 2017.

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 11).

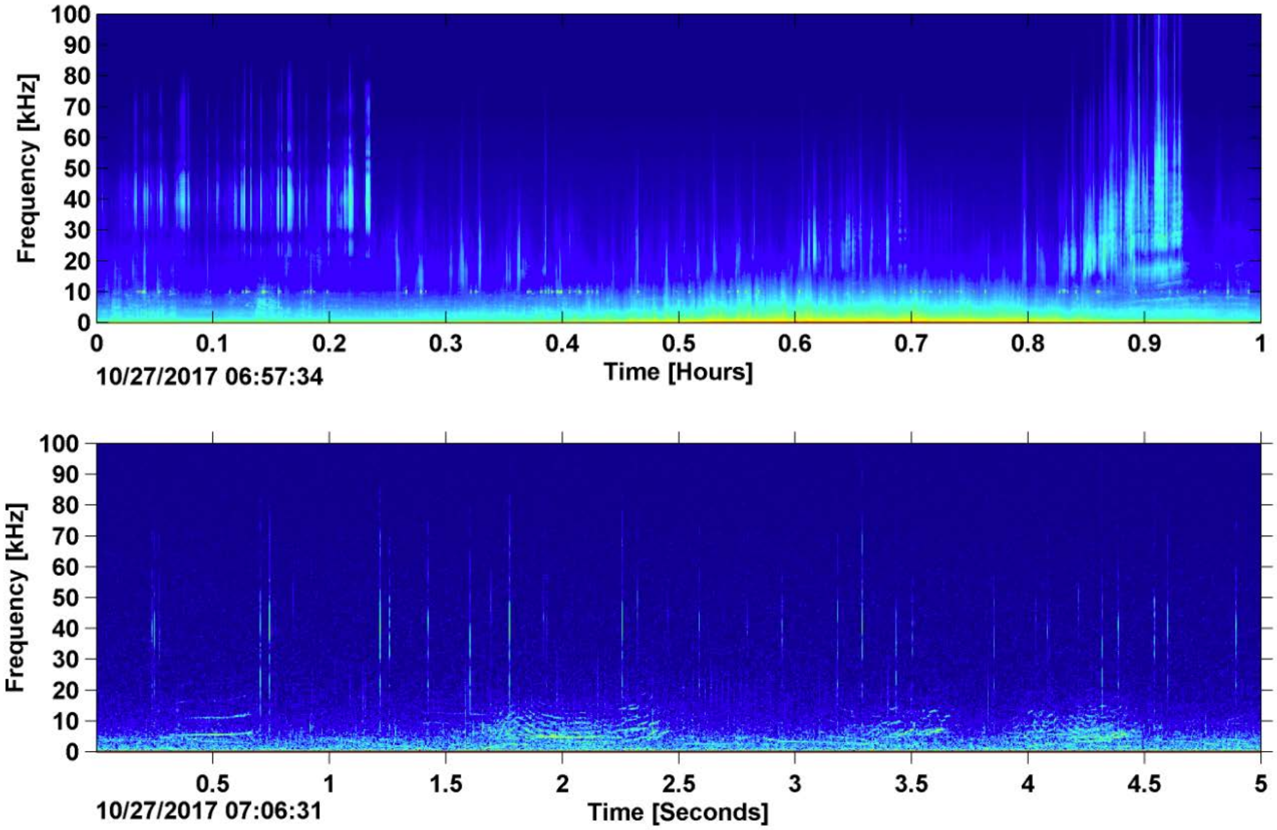

Figure 11. LTSA (top) and spectrogram (bottom) demonstrating odontocete signal types at HAT Site B, October 2017.

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 applied 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 12).

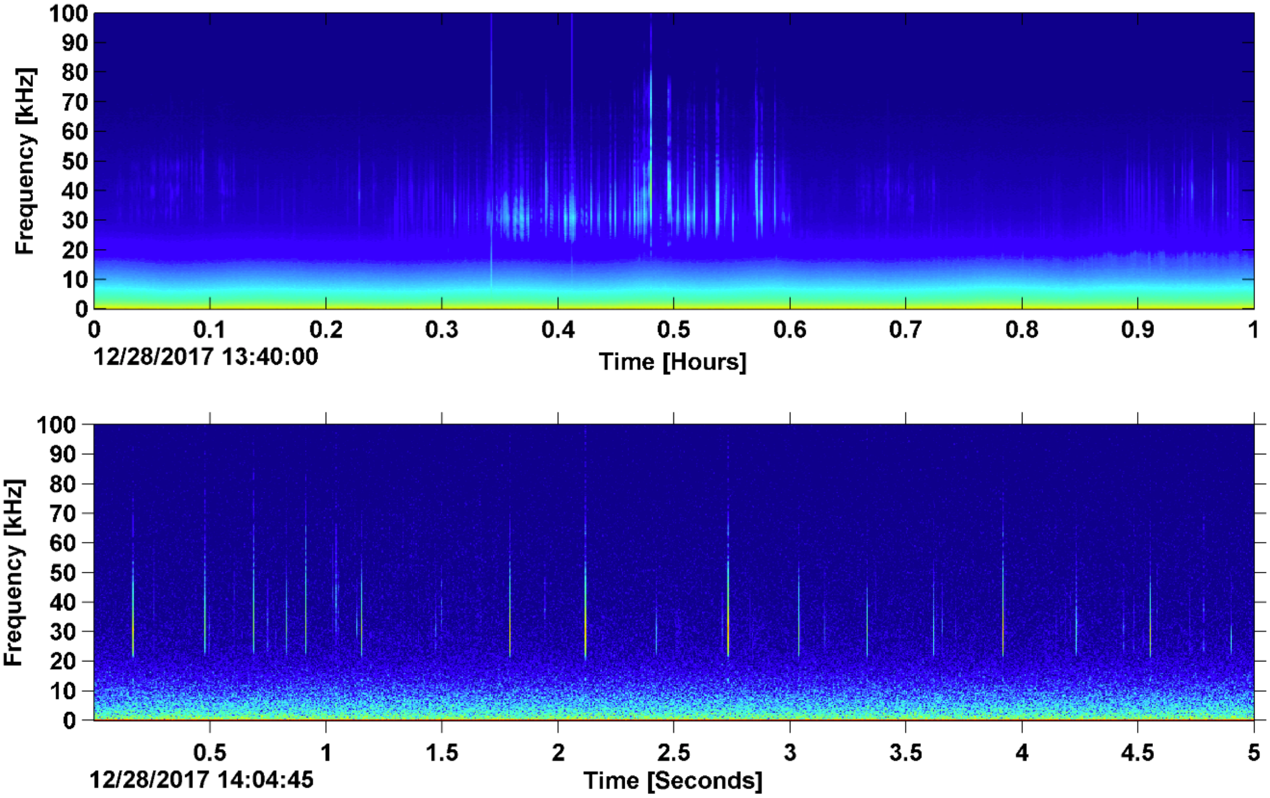

Figure 12. Blainville's beaked whale echolocation clicks in the LTSA (top) and spectrogram (bottom) from HARP recording at HAT Site B, December 2017.

Cuvier's Beaked Whales

Cuvier's echolocation signals are polycyclic, with a characteristic FM pulse upsweep, peak frequency around 40 kHz (Figure 13), 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.

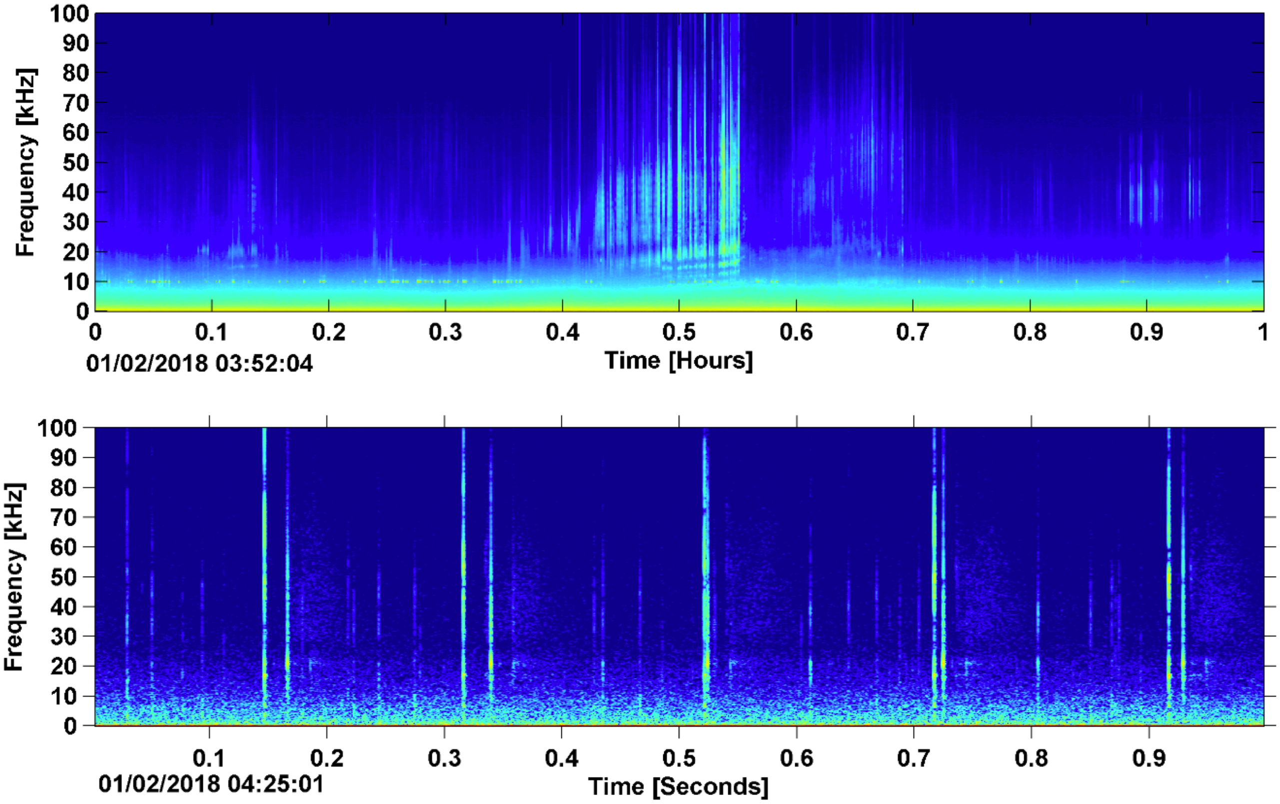

Figure 13. Cuvier's beaked whale signals in LTSA (top) and spectrogram (bottom) from HARP recording at HAT Site B, January 2018.

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 14). 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.

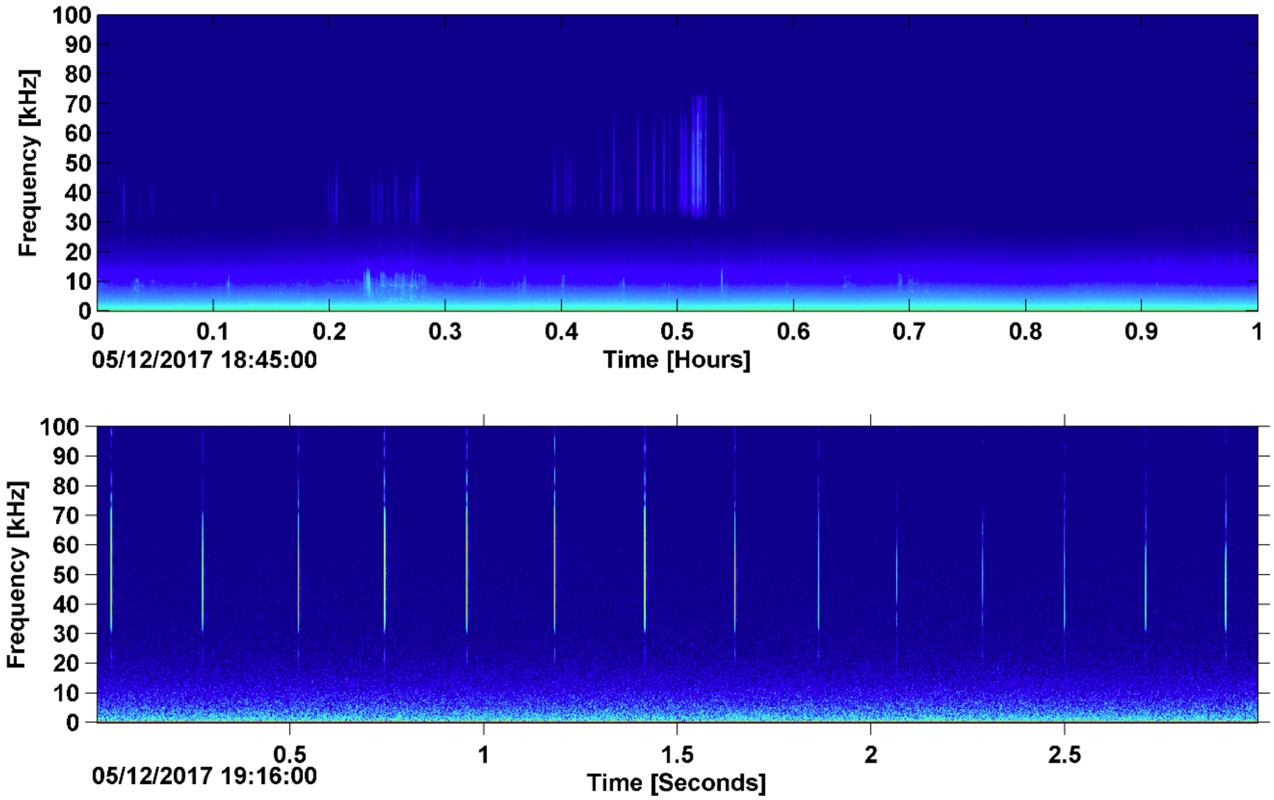

Figure 14. Gervais' beaked whale signals in LTSA (top) and spectrogram (bottom) from HARP recording at HAT Site B, May 2017.

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 15). 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).

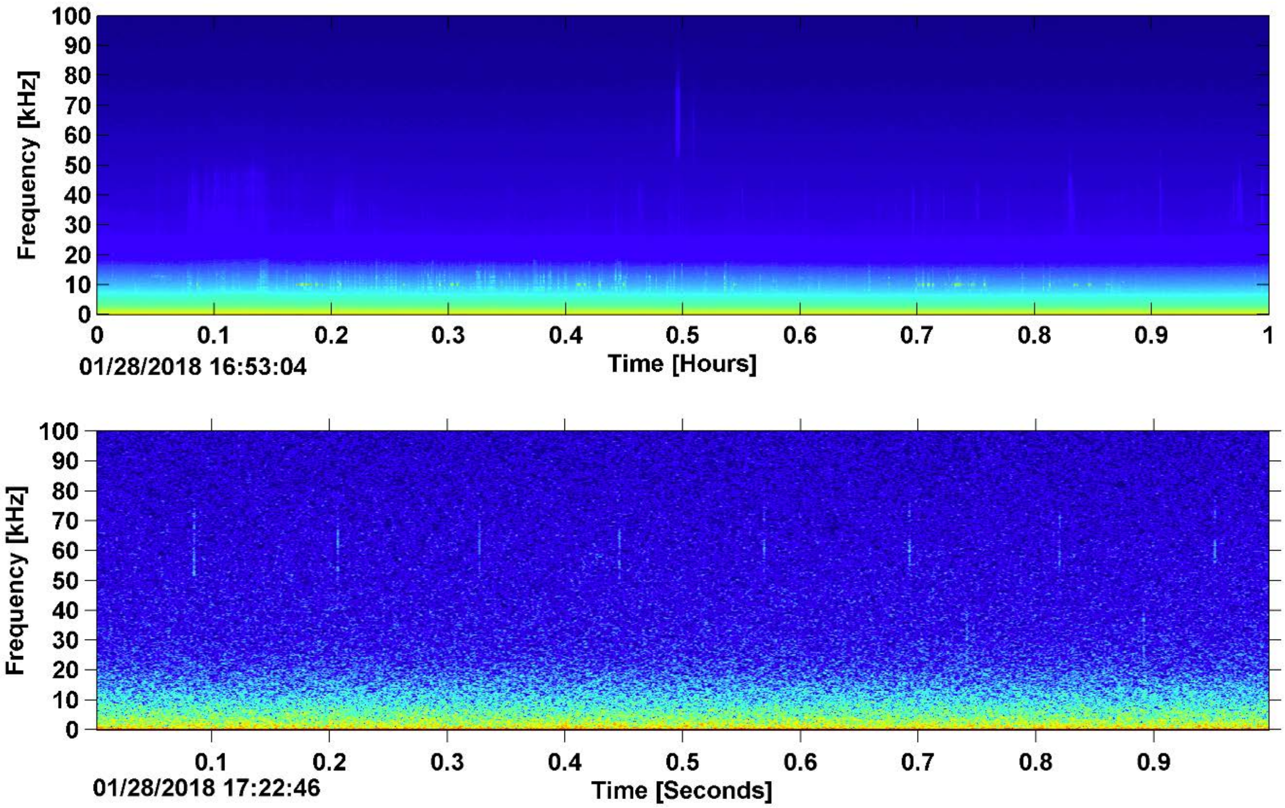

Figure 15. Sowerby's beaked whale echolocation clicks in LTSA (top) and spectrogram (bottom) from HARP recording at HAT Site B, January 2018.

Dolphins

Echolocation Clicks

Delphinid echolocation clicks were detected automatically using an energy detector with a minimum peak-to-peak received level threshold of 120 dB re: 1 µPa (Frasier *et al.*, 2015). 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 16). 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 17). Modal inter-click interval (ICI) was 165 ms.

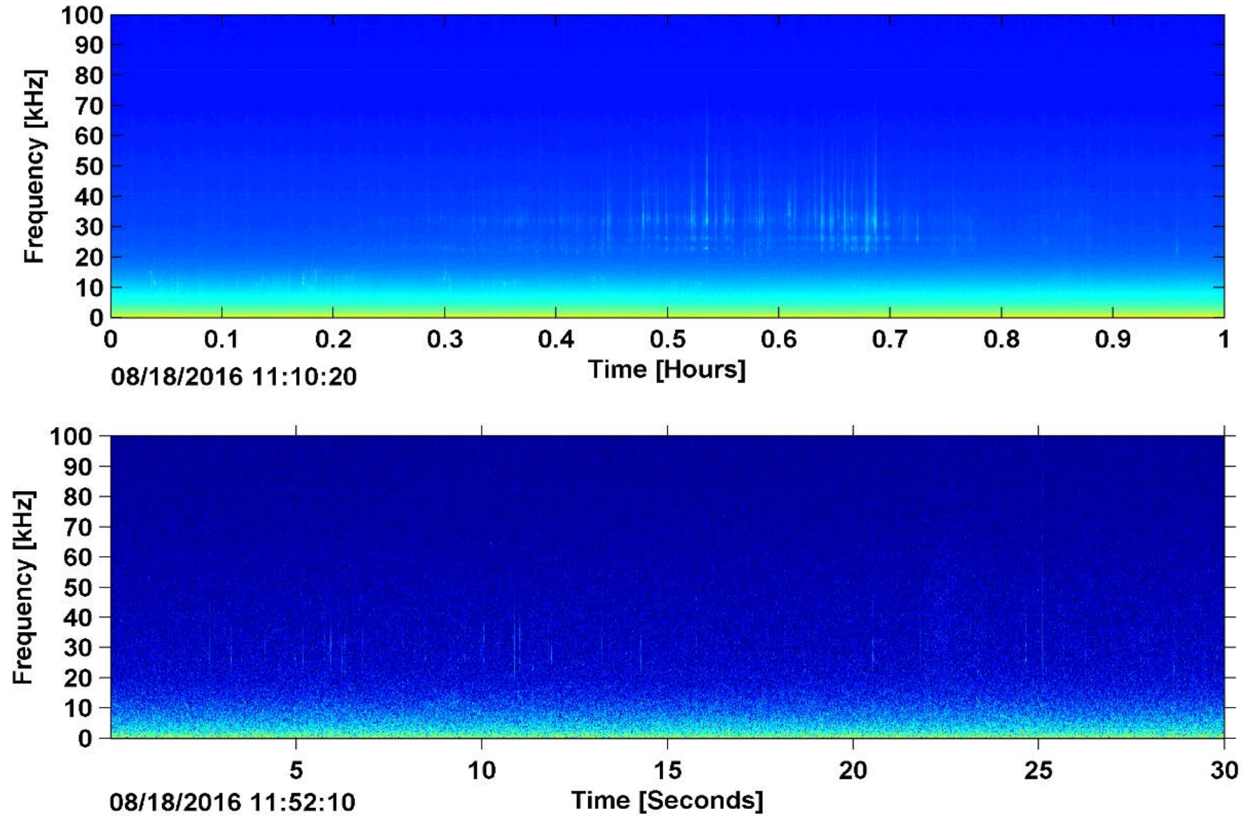

Figure 16. Risso's dolphin acoustic encounter in LTSA (top) and spectrogram (bottom) from HARP recording at HAT Site A, August 2016.

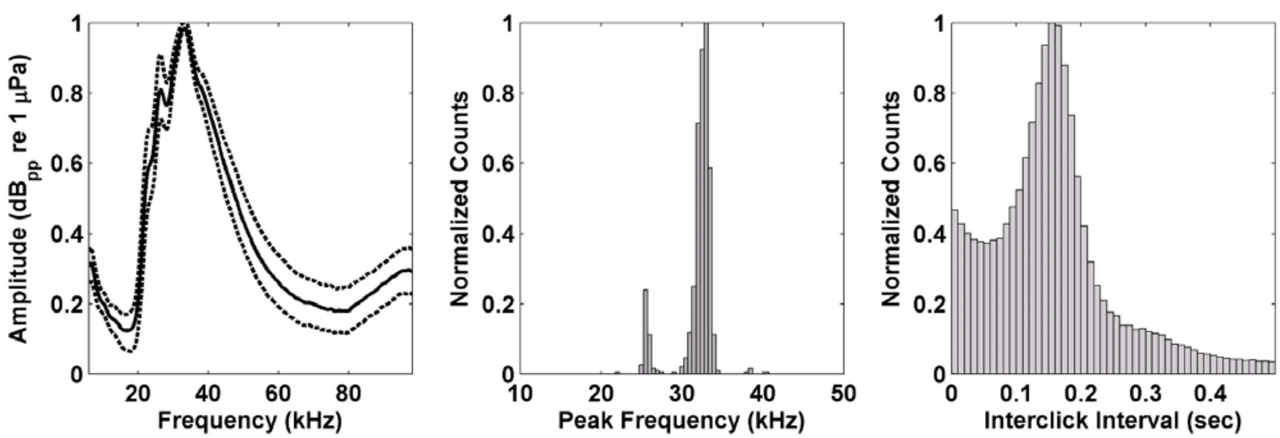

Figure 17. Risso's dolphin click type detected at HAT Site B from May 2017 to June 2018. Left: Mean frequency spectrum of click cluster (solid line) and 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies; Right: Distribution of inter-click intervals (ICI) 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.

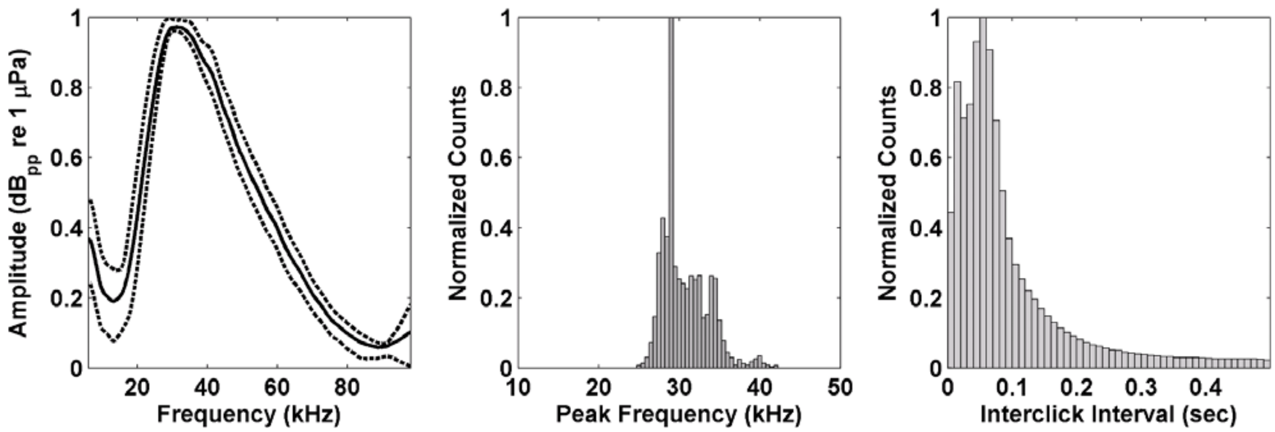

Figure 18. Click type CT 1 detected at HAT Site B from May 2017 to June 2018. Left: Mean frequency spectrum of click cluster (solid line) and 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies; Right: Distribution of inter-click intervals (ICI) within cluster.

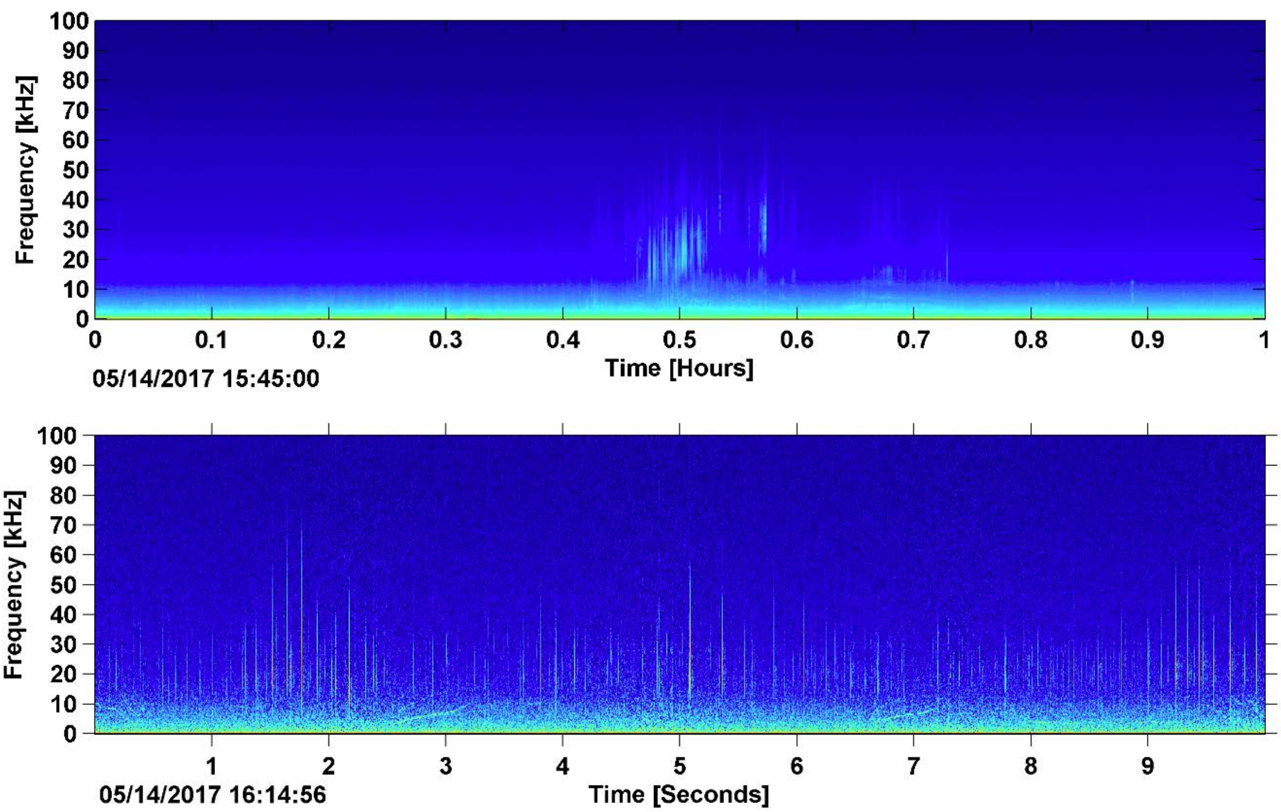

Figure 19. Click type CT 1 acoustic encounter in LTSA (top) and spectrogram (bottom) recorded at HAT Site B, May 2017.

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 20). The modal ICI was 65 ms. An example encounter is shown in Figure 21.

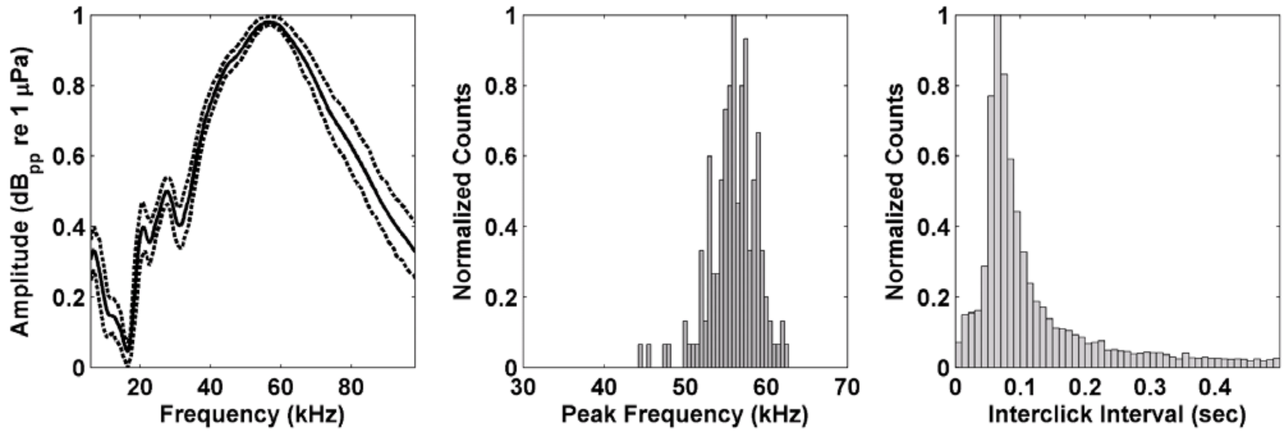

Figure 20. Click type CT 4 detected at HAT Site B from May 2017 to June 2018. Left: Mean frequency spectrum of click cluster (solid line) and 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies; Right: Distribution of inter-click intervals (ICI) within cluster.

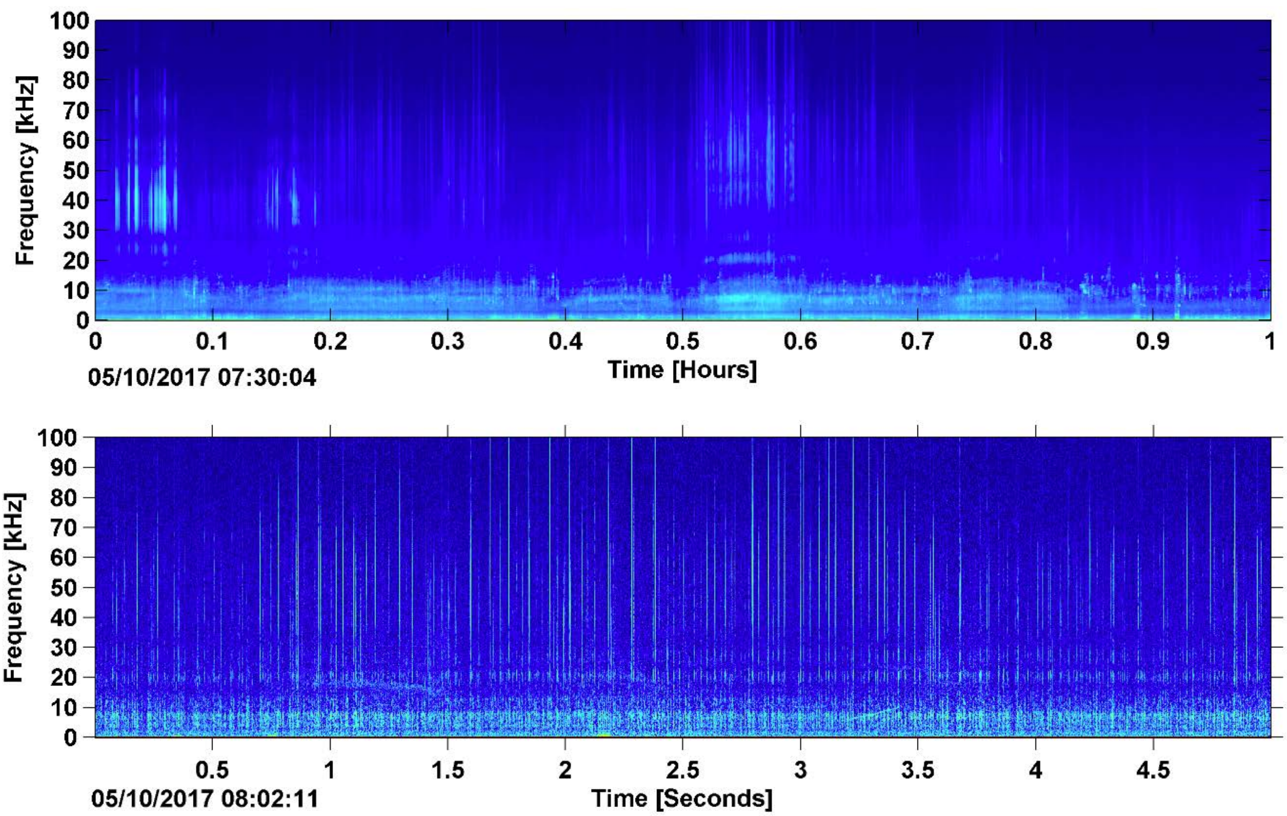

Figure 21. Click type CT 4 acoustic encounter in LTSA (top) and spectrogram (bottom) recorded at HAT Site B, May 2017.

CT 6 has a frequency distribution with a peak near 24 kHz, and a modal ICI of 165 ms (Figure 22). An example encounter is shown in Figure 23.

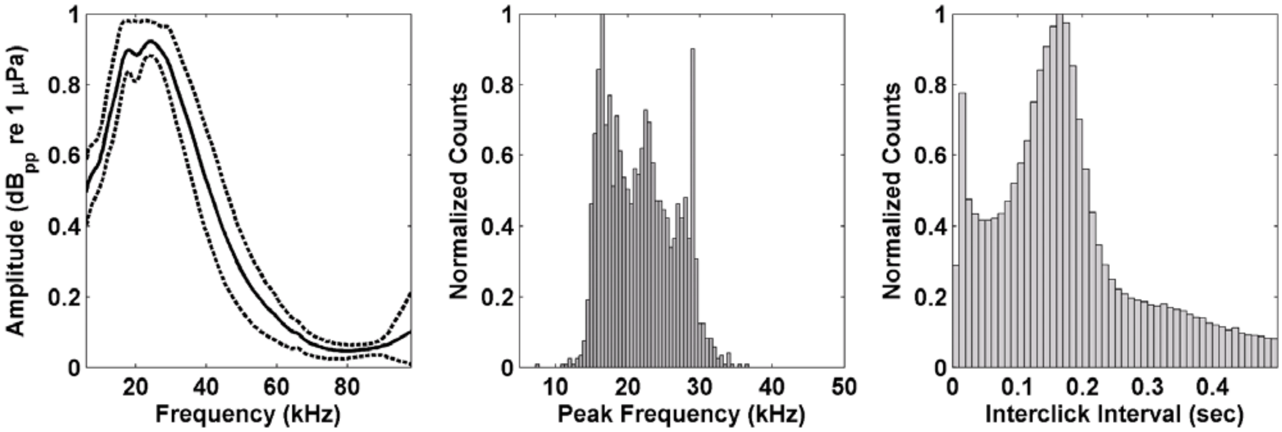

Figure 22. Click type CT 6 detected at HAT Site B from May 2017 to June 2018. Left: Mean frequency spectrum of click cluster (solid line) and 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies; Right: Distribution of inter-click intervals (ICI) within cluster.

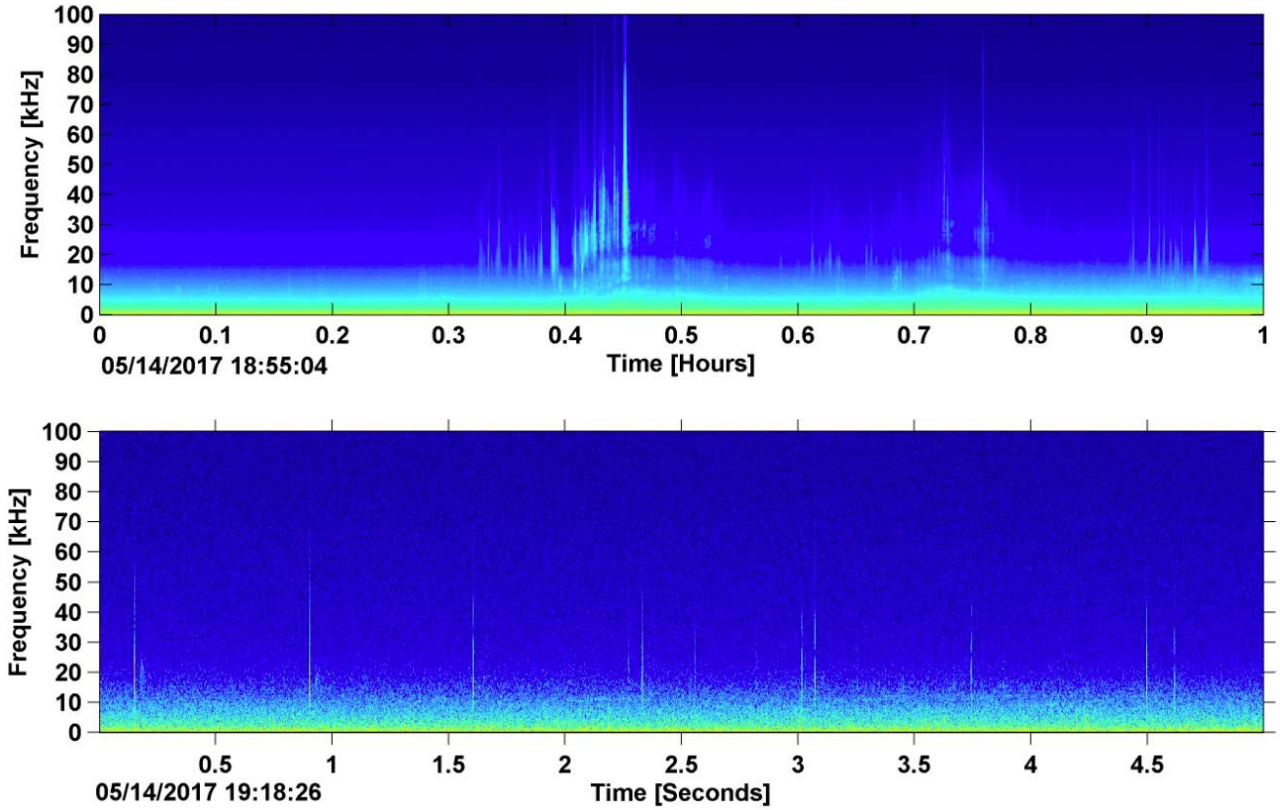

Figure 23. Click type CT 6 acoustic encounter in LTSA (top) and spectrogram (bottom) recorded at HAT Site B, May 2017.

Sperm Whales

Sperm whale clicks contain energy from 2 to 20 kHz, with most energy between 10 and 15 kHz (Møhl *et al.*, 2003) (Figure 24). Regular clicks, observed during foraging dives, demonstrate an ICI from 0.25 to 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 s 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.

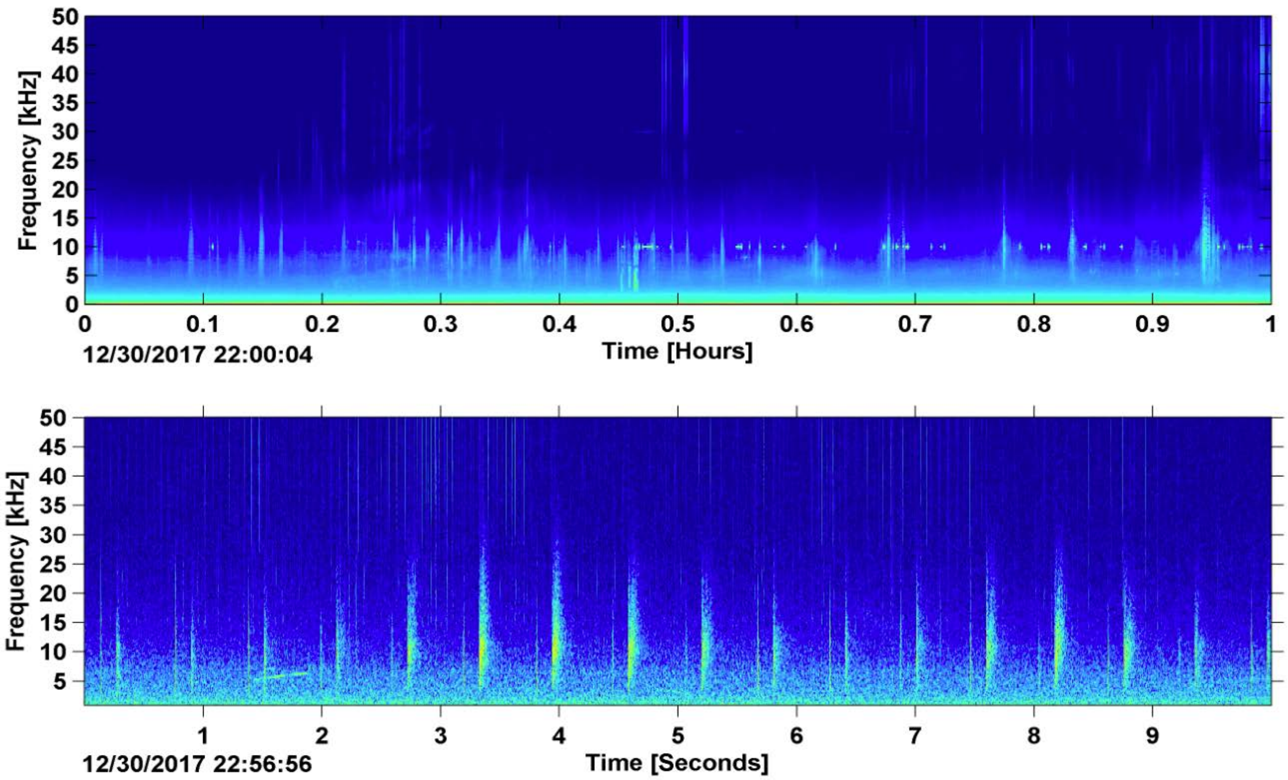

Figure 24. Sperm whale echolocation clicks in LTSA (top) and spectrogram (bottom) recorded at HAT Site A, January 2017.

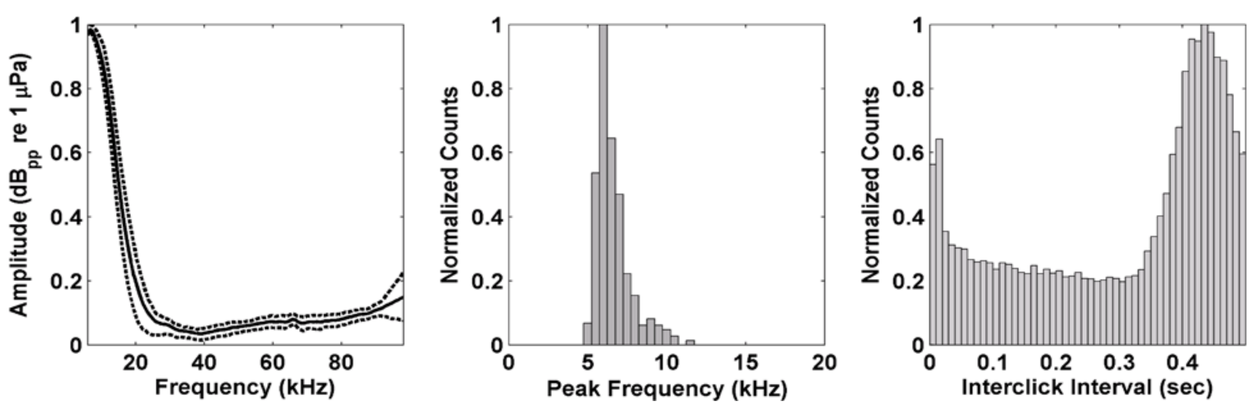

Figure 25. Sperm whale echolocation clicks detected at HAT Site B from May 2017 to June 2018. Left: Mean frequency spectrum of click cluster (solid line) and 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies; Right: Distribution of inter-click intervals (ICI) within cluster.

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 26). 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 27). *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.

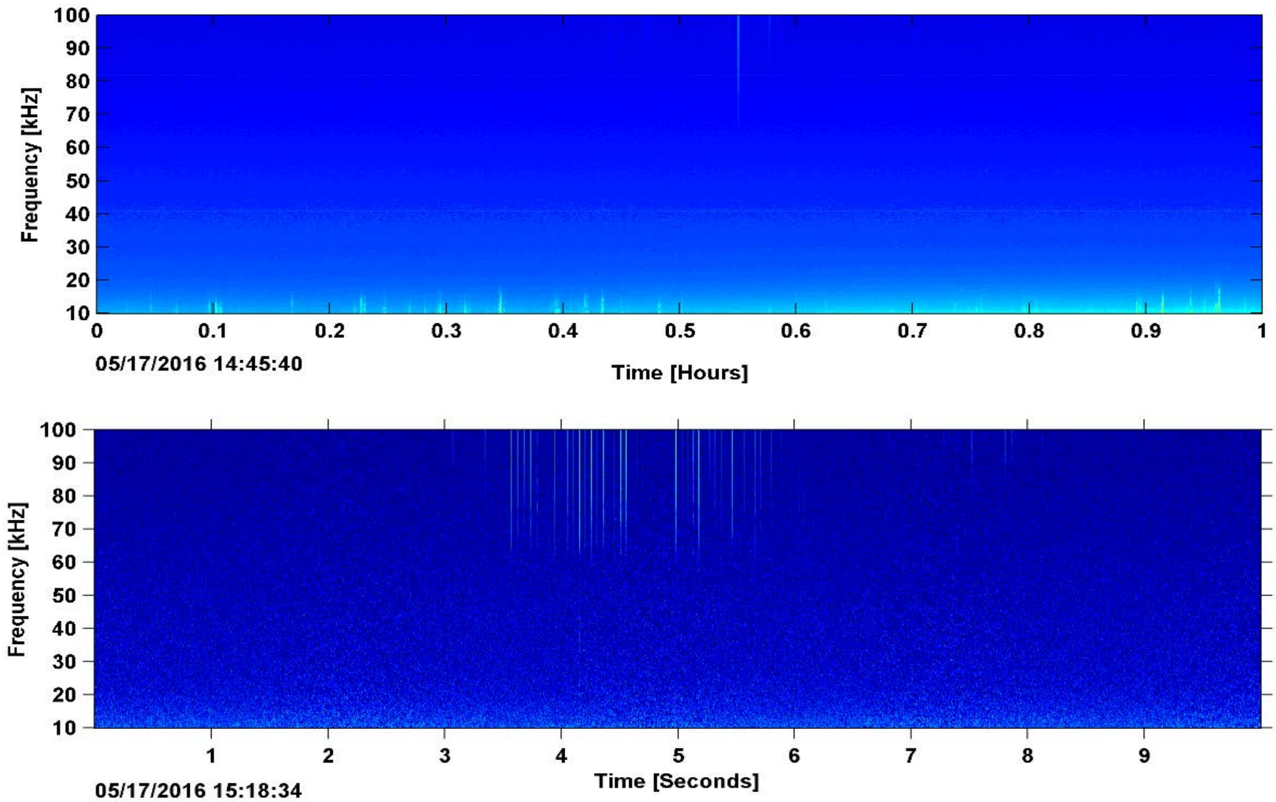

Figure 26. Kogia spp. echolocation clicks in LTSA (top) and spectrogram (bottom) recorded at HAT Site A, May 2016.

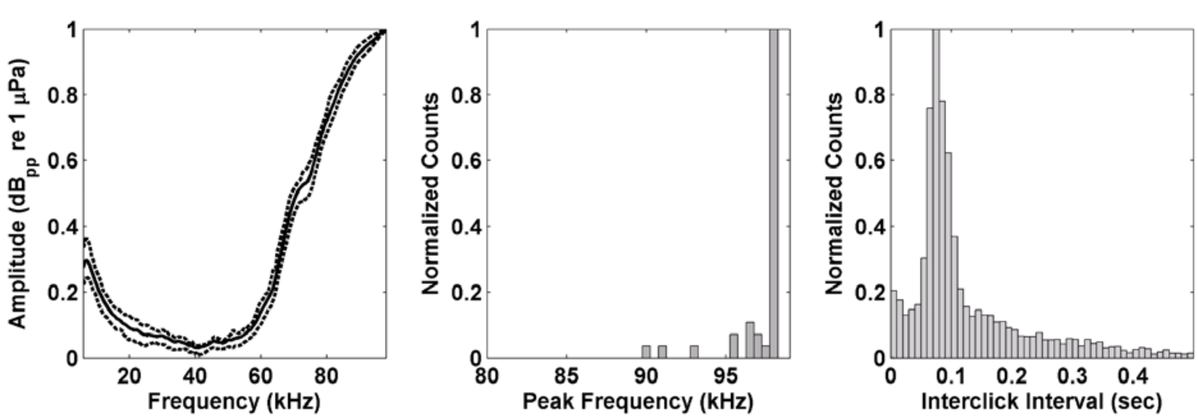

Figure 27. Kogia spp. detected at HAT Site B from May 2017 to June 2018. Left: Mean frequency spectrum of click cluster (solid line) and 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies; Right: Distribution of inter-click intervals (ICI) within cluster.

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, 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 28). 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.

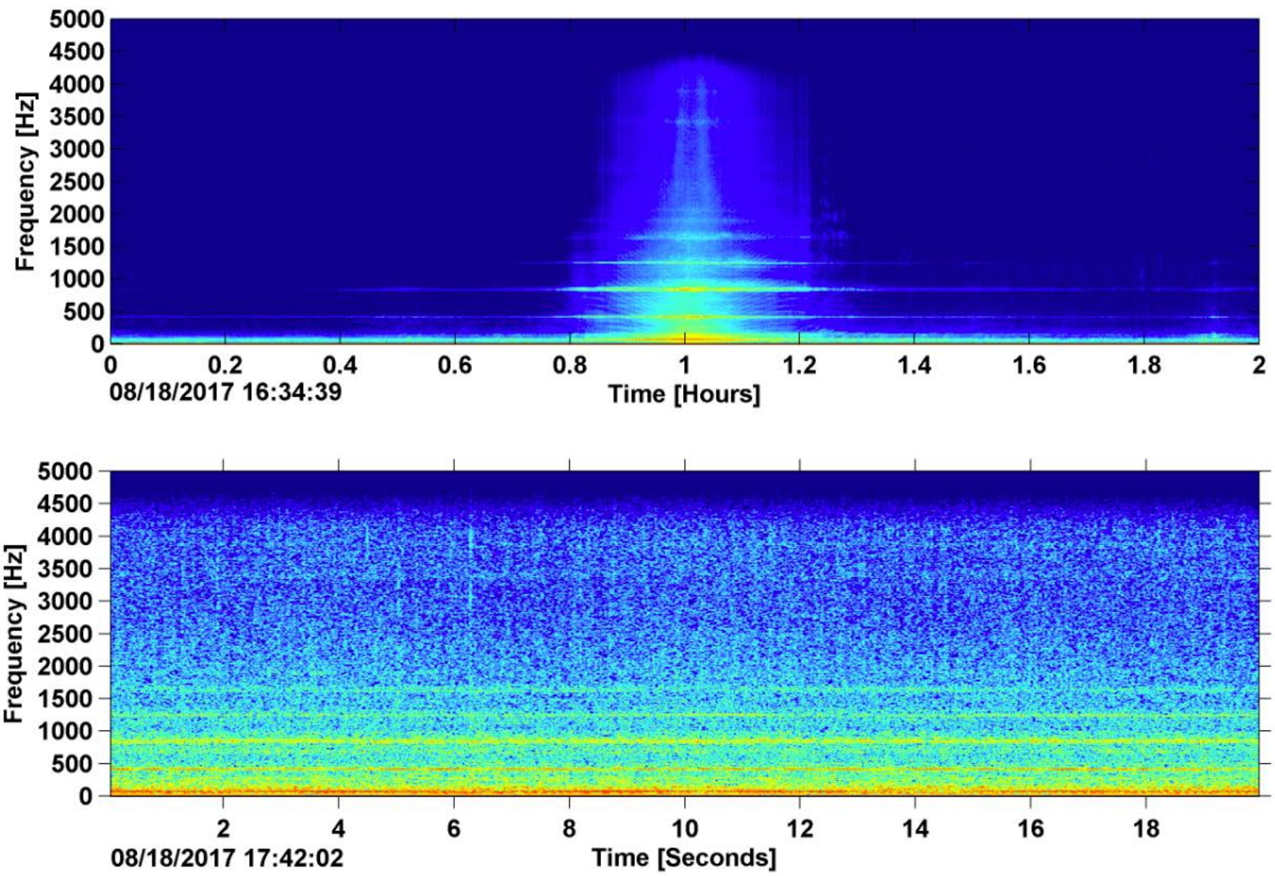

Figure 28. Broadband ships in LTSA (top) and spectrogram (bottom) recorded at HAT Site B, August 2017.

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 29).

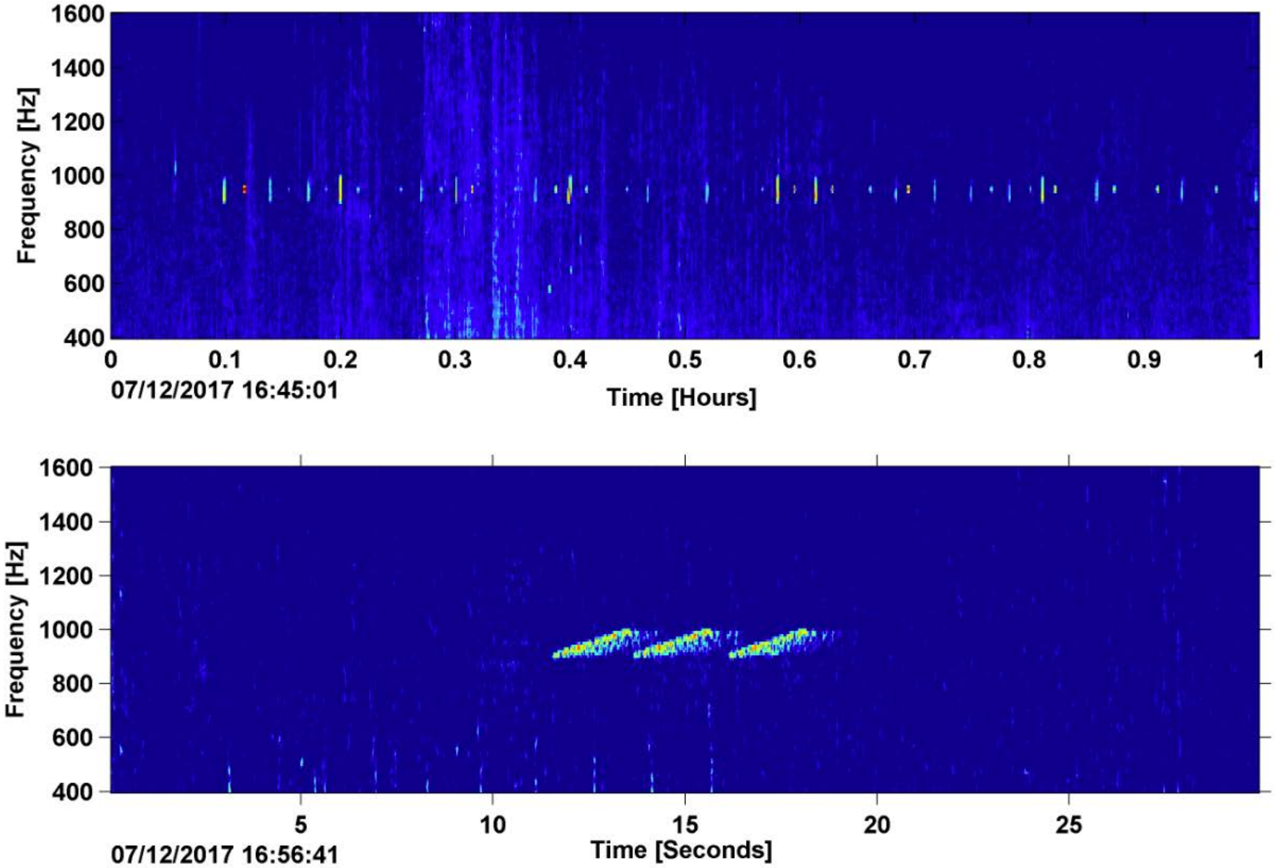

Figure 29. Low-frequency active sonar in Hz in the LTSA (top) and spectrogram (bottom) recorded at HAT Site B, August 2017.

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 Virginia Capes 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.

MFA sonar was detected using a modified version of the Silbido detection system (Roch *et al.*, 2011a) originally designed for characterizing toothed whale whistles. The algorithm identifies peaks in time-frequency distributions (e.g. spectrogram) and determines which peaks should be linked into a graph structure based on heuristic rules that include examining the trajectory of existing peaks, tracking intersections between time-frequency trajectories, and allowing for brief signal dropouts or interfering signals. Detection graphs are then examined to identify individual tonal contours looking at trajectories from both sides of time-frequency intersection points. For MFA detection, parameters were adjusted to detect tonal contours at or above 2 kHz in data decimated to a 10 kHz sample rate with time-frequency peaks with signal to noise ratios of 5 dB or above and contour durations of at least 200 ms with a frequency resolution of 100 Hz. The detector frequently triggered on noise produced by instrument disk writes that occurred at 75 s intervals.

Over periods of several months, these disk write detections dominated the number of detections and could be eliminated using an outlier detection test. Histograms of the detection start times modulo the disk write period were constructed and outliers were discarded. This removed some valid detections that occurred during disk writes, but as the disk writes and sonar signals are uncorrelated this is expected to only have a minor impact on analysis. As the detector did not distinguish between sonar and non-anthropogenic tonal signals within the operating band (e.g. humpback whales), human analysts examined detection output and accepted or rejected contiguous sets of detections. Start and end time of these cleaned sonar events were then created to be used in further processing.

These start and end times were used to read segments of waveforms upon which a 2.4 to 4.5 kHz bandpass filter and a simple time series energy detector was applied to detect and measure various packet parameters after correcting for the instrument calibrated transfer function (Wiggins, 2015). For each packet, maximum peak-to-peak (pp) received level (RL), sound exposure level (SEL), root-mean-square (RMS) RL, date/time of packet occurrence, and packet RMS duration (for RLpp 10dB) were measured and saved.

Various filters were applied to the detections to limit the MFA sonar detection range to ~20 km for off-axis signals from an AN/SQS 53C source, which resulted in a received level detection threshold of 130 dB pp re 1 µPa (Wiggins, 2015). Instrument maximum received level was ~162 dB pp re 1 µPa, above which waveform clipping occurred. Packets were grouped into wave trains separated by more than 1 hour. Packet received levels were plotted along with the number of packets and cumulative SEL (CSEL) in each wave train over the study period. Wave train duration and total packet duration were also calculated. Wave train duration is the difference between the first and last packet detections in an event. The total packet duration of for a wave train is the sum of the individual packet (i.e., group of pings) durations, which is measured as the period of the waveform that is 0 to 10 dB less than the maximum peak-to-peak received level of the ping group.

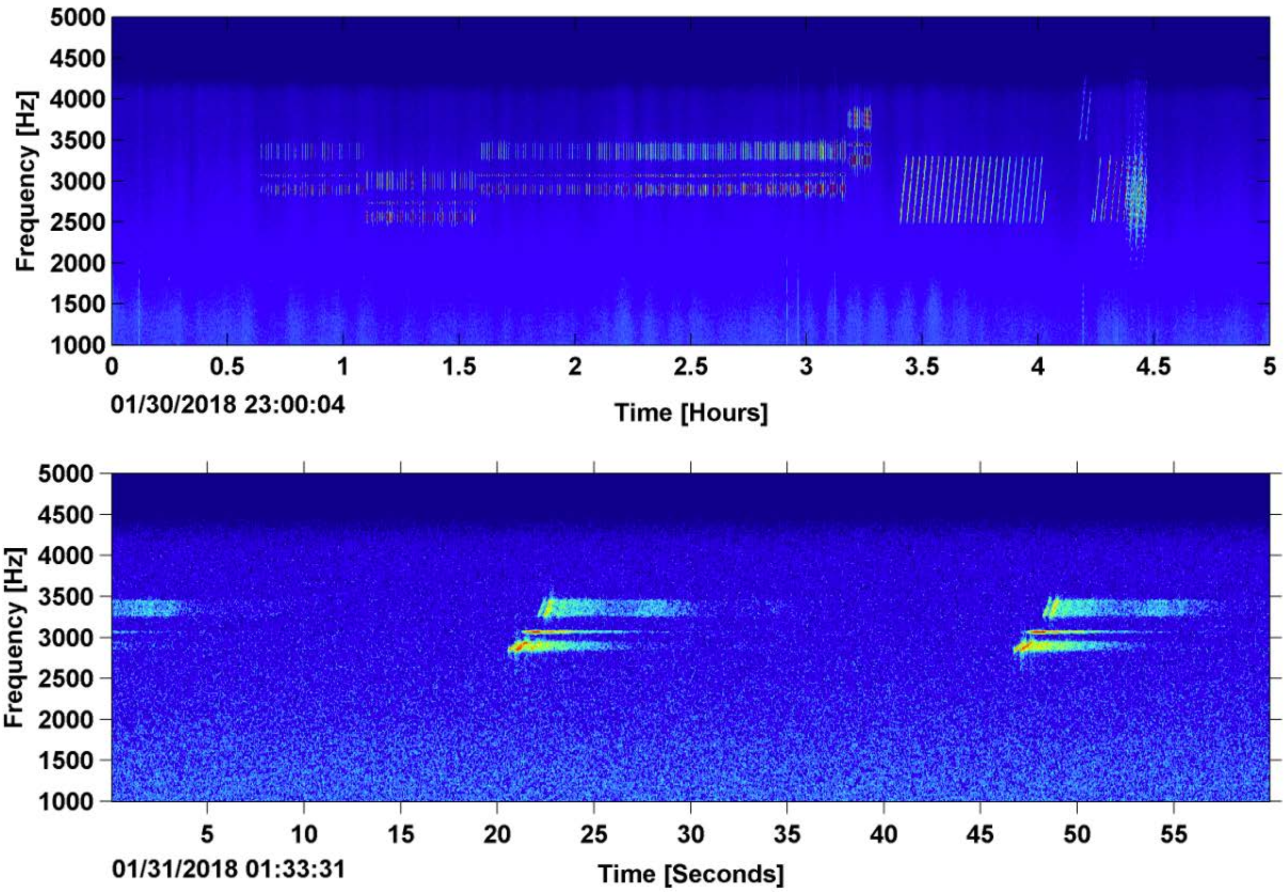

Figure 30. Mid-frequency active sonar in LTSA (top) and spectrogram (bottom) at HAT Site B, January 2018.

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 31) for this deployment.

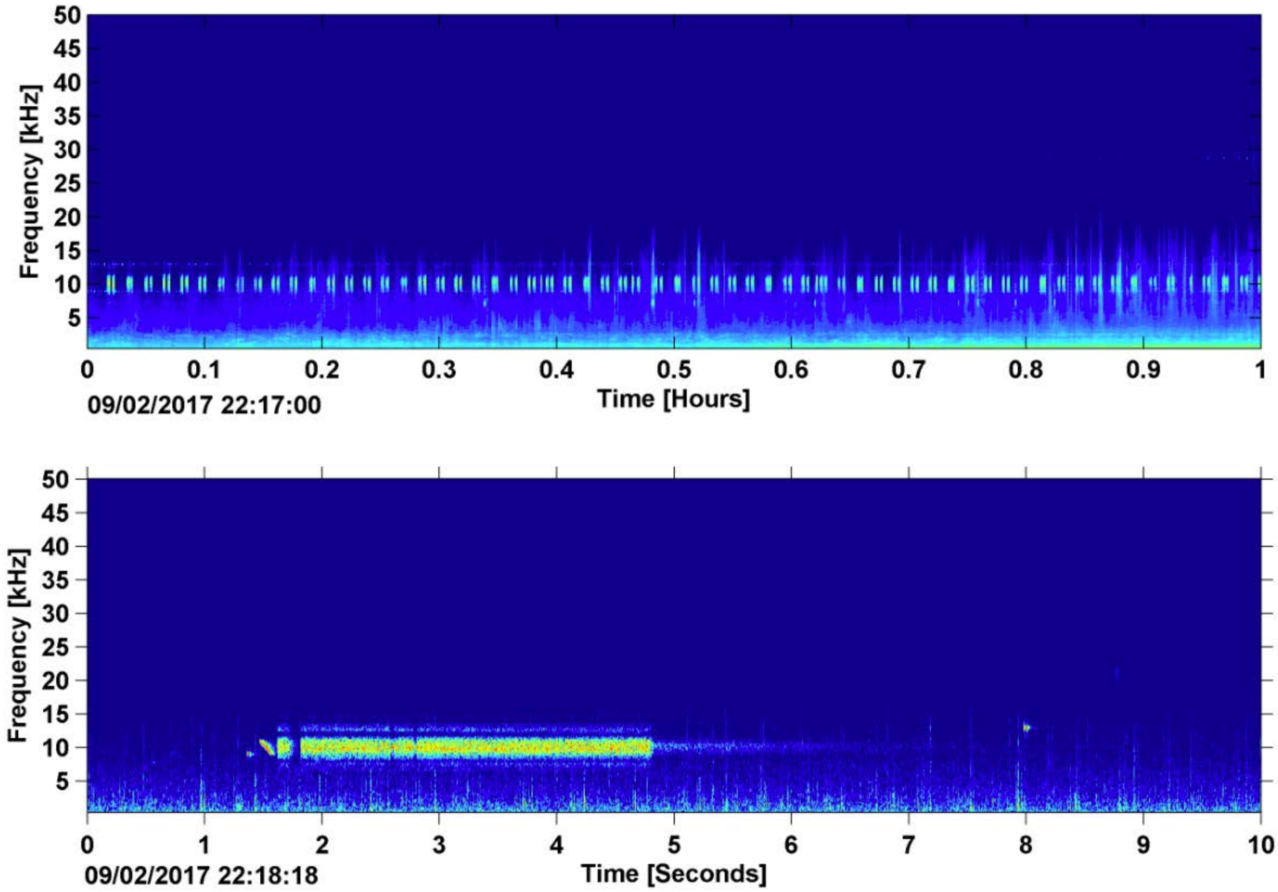

Figure 31. High-frequency active sonar in LTSA (top) and spectrogram (bottom) recorded at HAT Site B, September 2017.

Echosounders

Echosounding sonars transmit short pulses or frequency sweeps, typically in the high-frequency (above 5 kHz) band (Figure 32), 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.

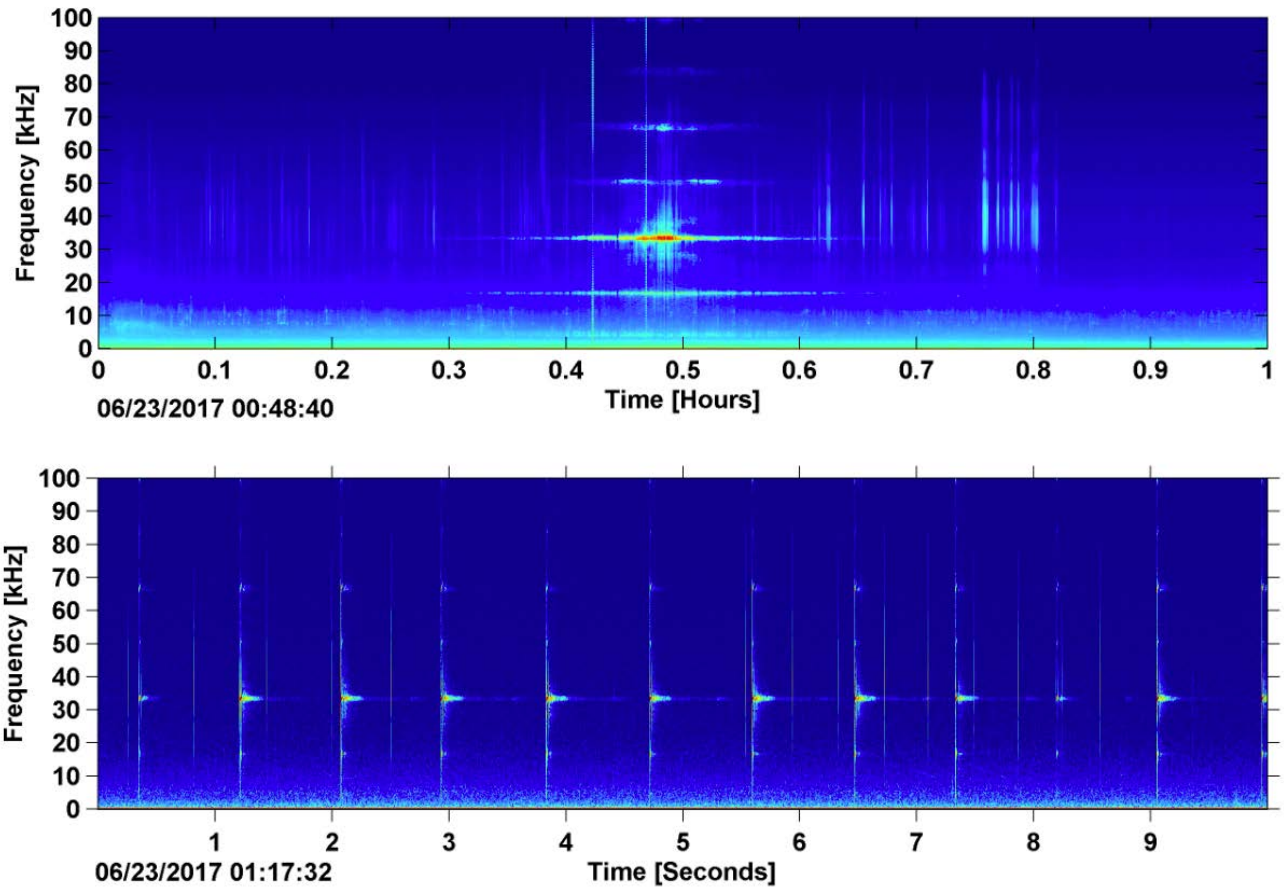

Figure 32. Echosounders in LTSA (top) and spectrogram (bottom) recorded at HAT Site B, June 2017.

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 s 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 s 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 s 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. PP and root-mean-squared (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 s 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.

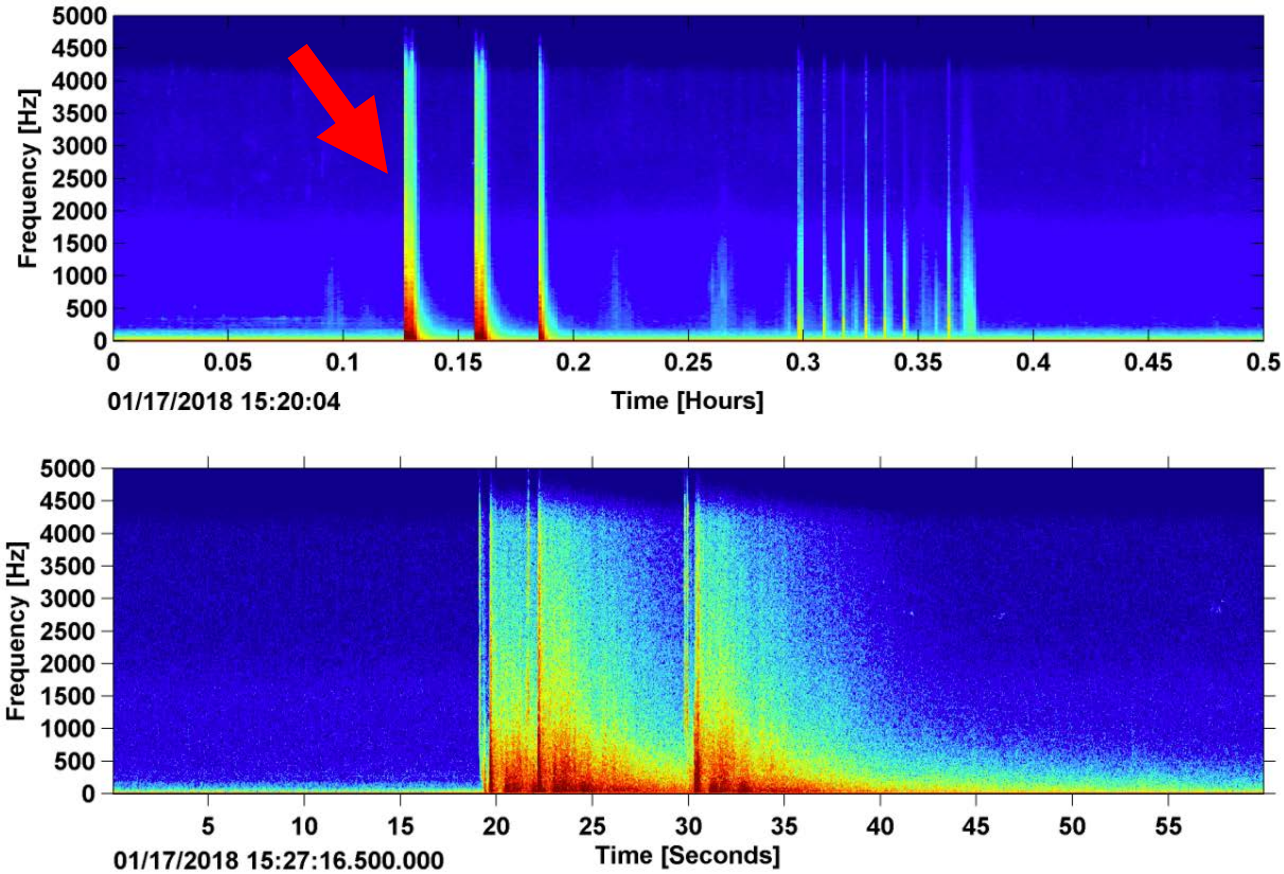

Figure 33. Explosions recorded in LTSA (top) and spectrogram (bottom) recorded at HAT Site B, January 2018.

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 s 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 s 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 s 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 s 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. PP and 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.

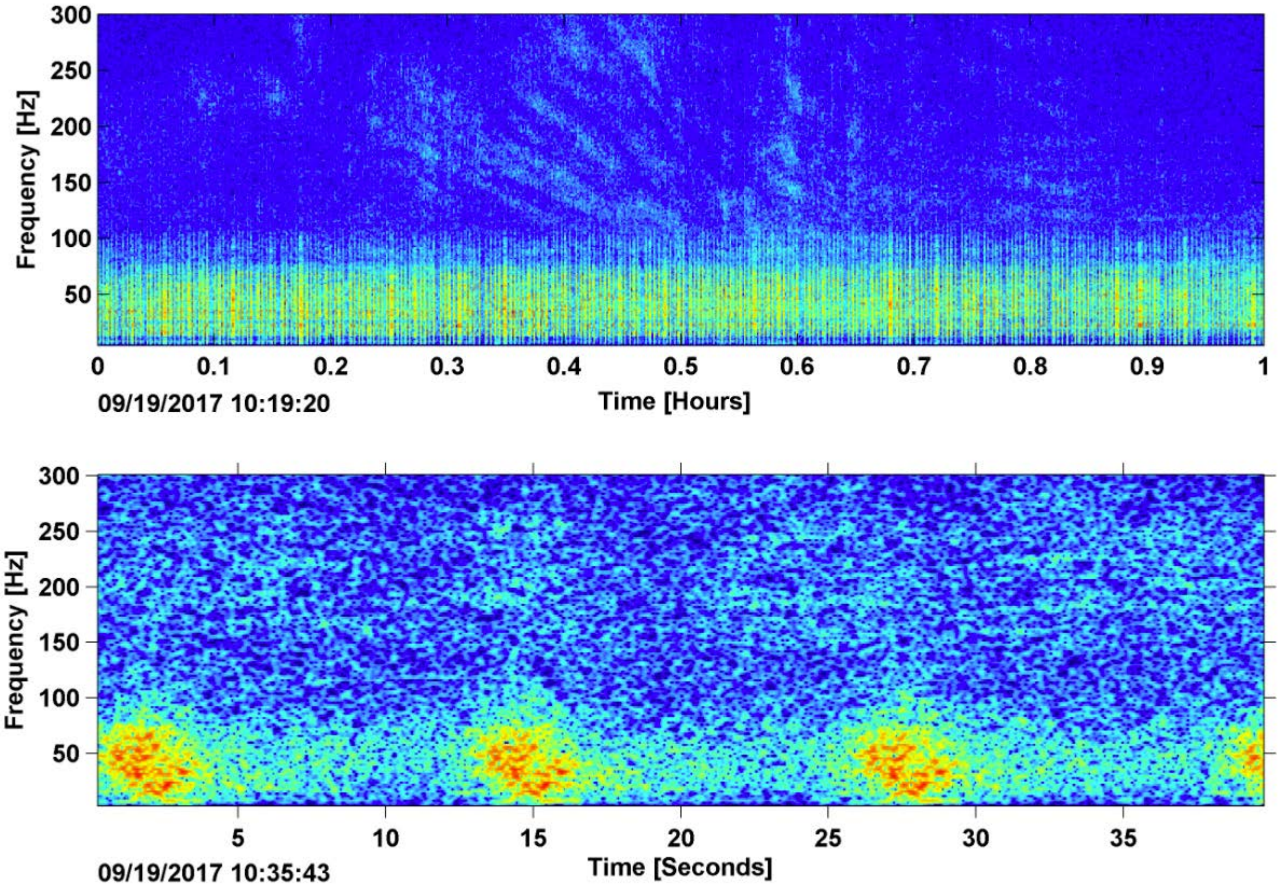

Figure 34. Airguns in LTSA (top) and spectrogram (bottom) recorded at HAT Site B, September 2017.

Results

The results of acoustic data analysis at HAT Site B from May 2017 to June 2018 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 35) and plotted so that months could be compared. Incomplete days were removed from the analysis, but incomplete months were not. Partial months are designated by an asterisk (*) in the color legend of Figure 35 and are detailed in Table 2. Incomplete months included in the ambient soundscape analysis during this recording period. Long-term spectrograms were generated using daily-averaged spectra (Figure 36).

- The broad bump peak at 45 Hz is a result of commercial shipping activity (Figure 35).
- From September 2017 to March 2018, the peak in spectrum levels from 20 Hz is related to the seasonal increase in fin whale 20 Hz calls (Figure 35 and 37).
- Sound levels at 200–1000 Hz are higher during January and March, related to wind and wave noise associated with higher sea states (Figure 35).
- Spectral peaks around 500 Hz occur during the late fall of 2017. These peaks are believed to be from a currently unidentified biological source, likely a fish chorus (Figure 35).

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

Deployment	Month / Year	Days of Data / Days In Month
HAT_B_01_01	May 2017	23 / 31

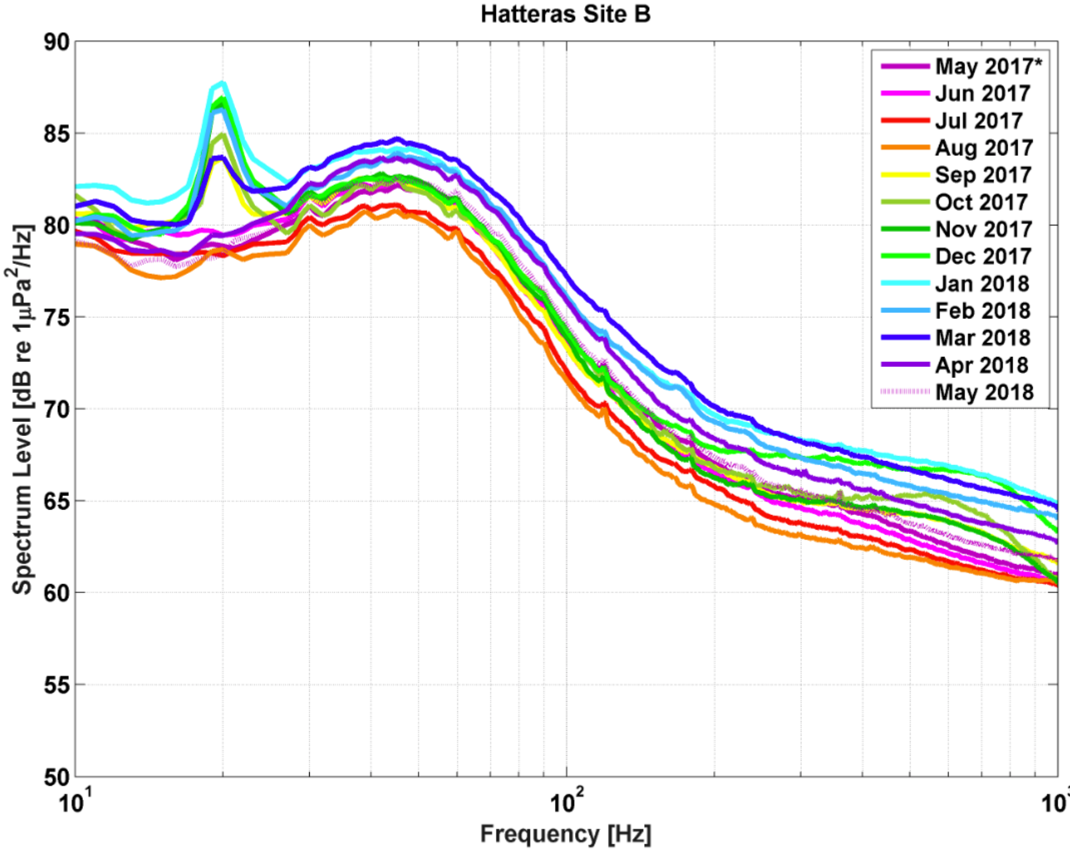

Figure 35. Monthly averages of ambient soundscape at HAT Site B for each month from May 2017 to June 2018. Legend gives color coding by month. Month with an asterisk is a partial month of recording.

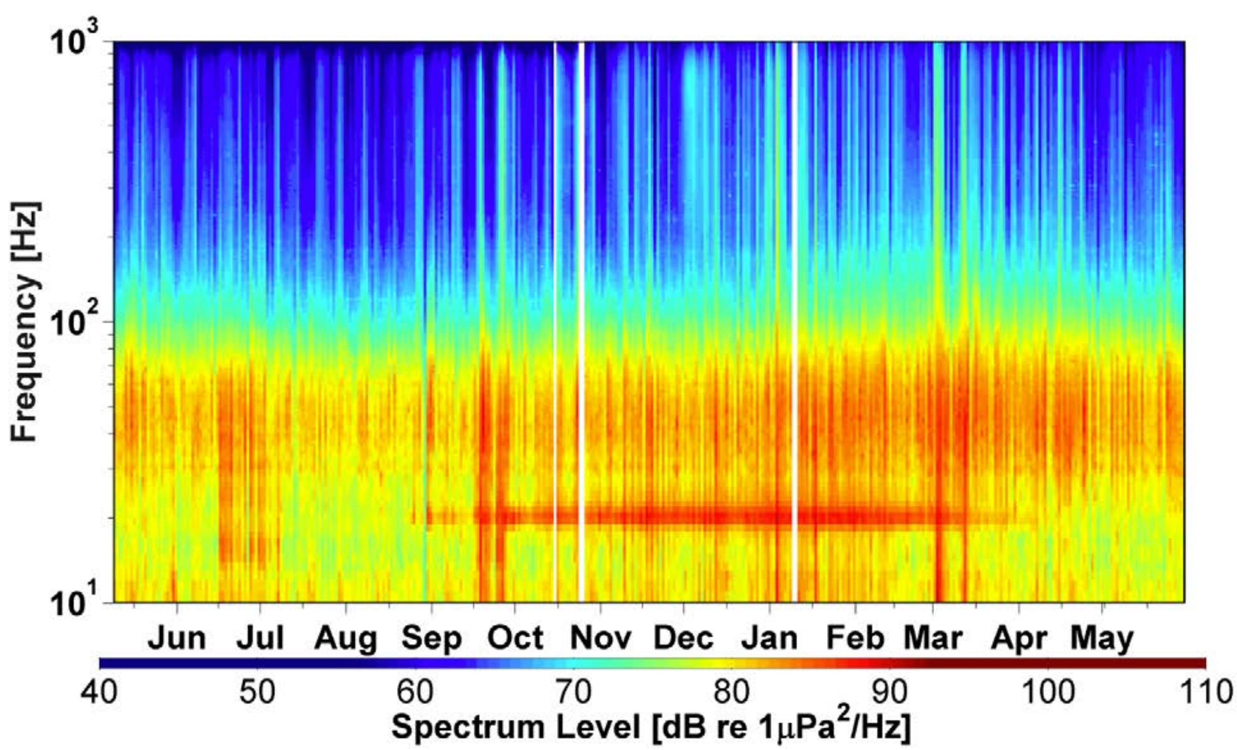

Figure 36. Long-term spectrogram using daily-averaged spectra for HAT Site B from May 2017 to June 2018.

Mysticetes

Five known baleen whale species were recorded between May 2017 and 2018: blue whales, fin whales, minke whales, sei whales, and humpback 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 2017 and in January 2018 (Figure 37).
- Although there were few detections overall, there was no discernible diel pattern for Northern Atlantic blue whale tonal calls (Figure 38).
- There were no arch calls detected in this deployment.

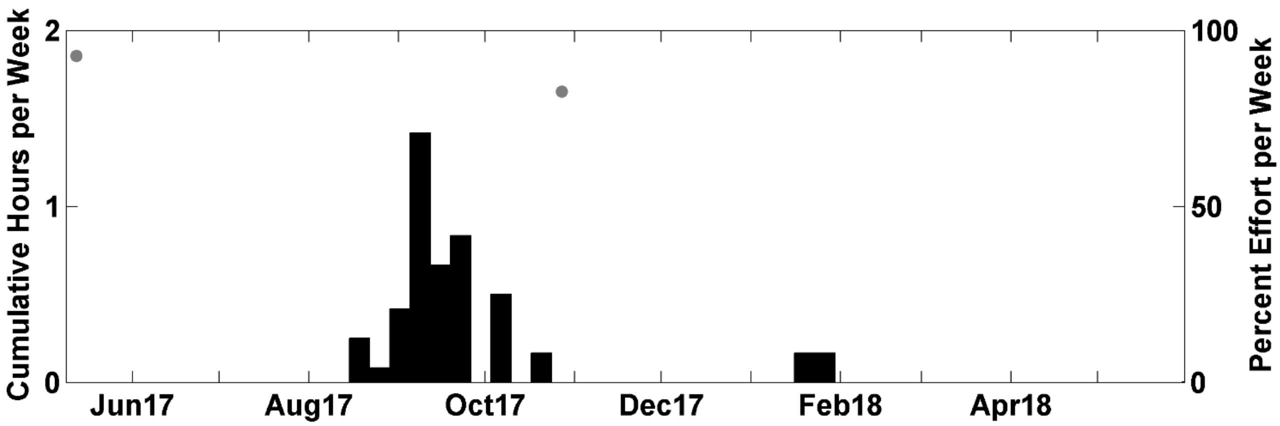

Figure 37. Weekly presence of Northern Atlantic blue whale tonal calls detected from May 2017 to June 2018 at HAT Site B. Gray dots represent percent of effort per week in weeks with less than 100% recording effort. Where gray dots are absent, full recording effort occurred for the entire week. X-axis labels refer to month and year of recording.

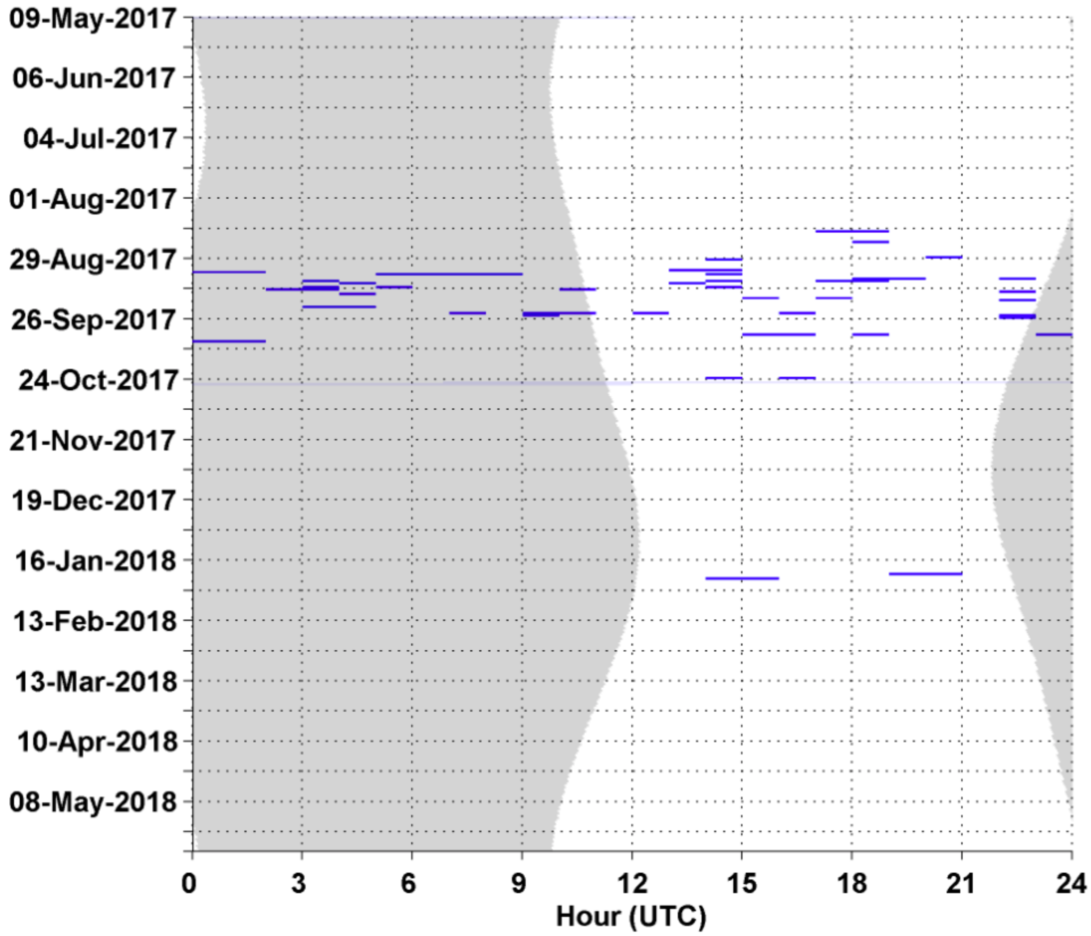

Figure 38. Northern Atlantic blue whale tonal calls in hourly bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime.

Fin Whales

- The fin whale acoustic index, a proxy for 20 Hz calls, was low from May through August 2017 and increased from October 2017 to February 2018 (Figure 39).
- Fin whale 40 Hz calls were detected in low numbers throughout the recording period (Figure 40).
- There was no discernible diel pattern for fin whale 40 Hz calls (Figure 41).

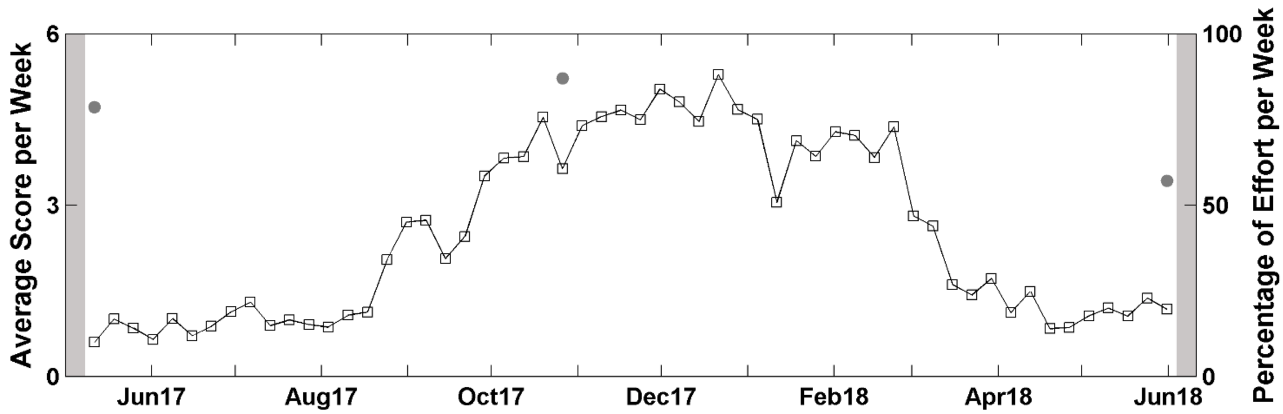

Figure 39. Weekly value of fin whale acoustic index (proxy for 20 Hz calls) detected from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

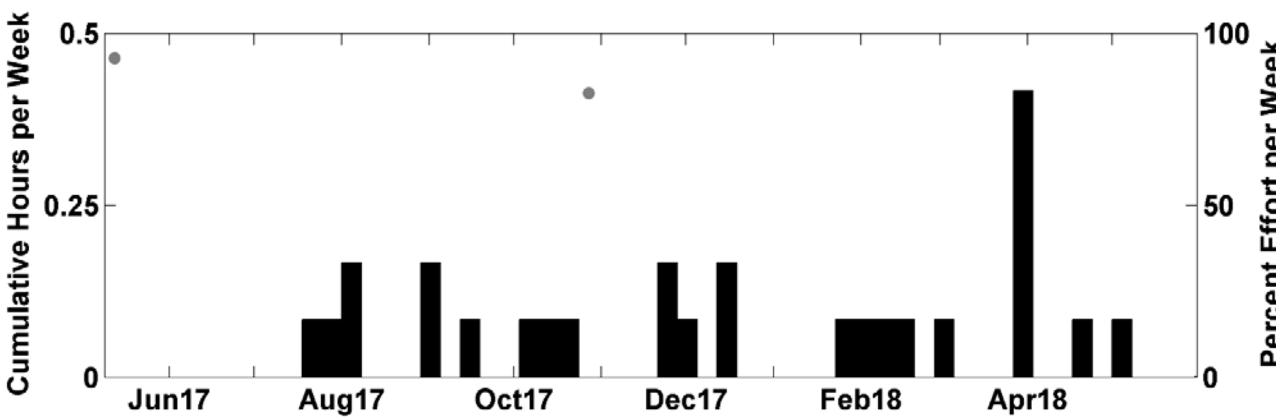

Figure 40. Fin whale 40 Hz calls detected from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

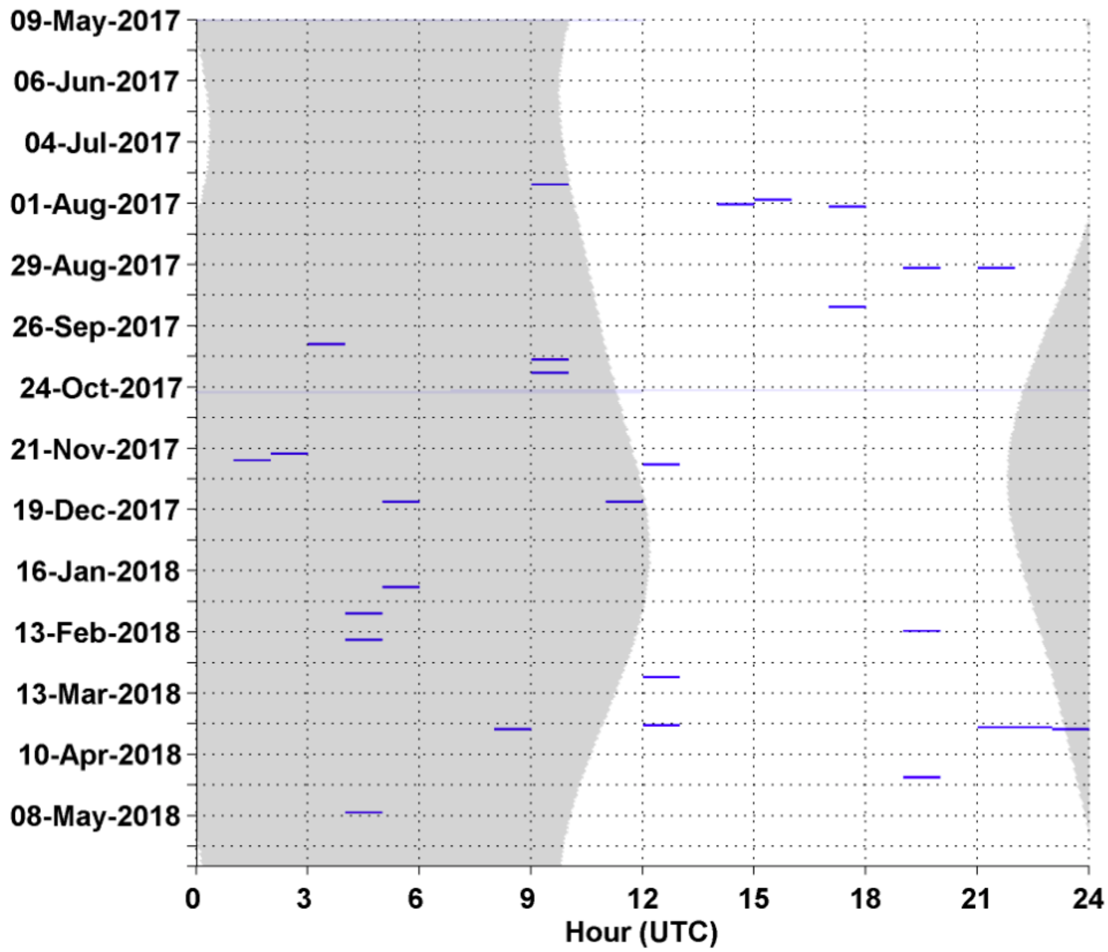

Figure 41. Fin whale 40 Hz calls in hourly bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime.

Minke Whales

- Minke whale pulse trains were detected from November 2017 through April 2018. They were detected in low numbers in October 2017 (Figure 42).
- There was no discernible diel pattern for minke pulse trains (Figure 43).

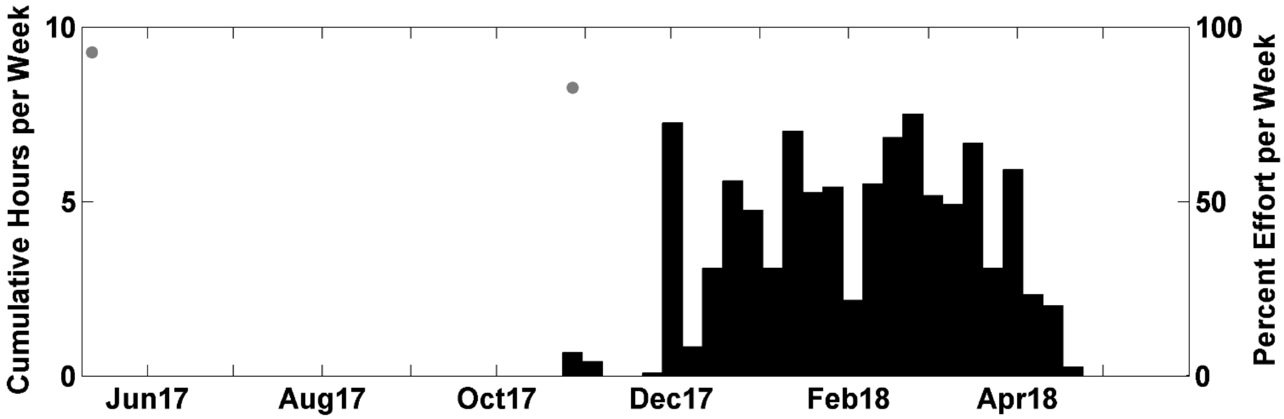

Figure 42. Weekly presence of minke whale pulse trains detected from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

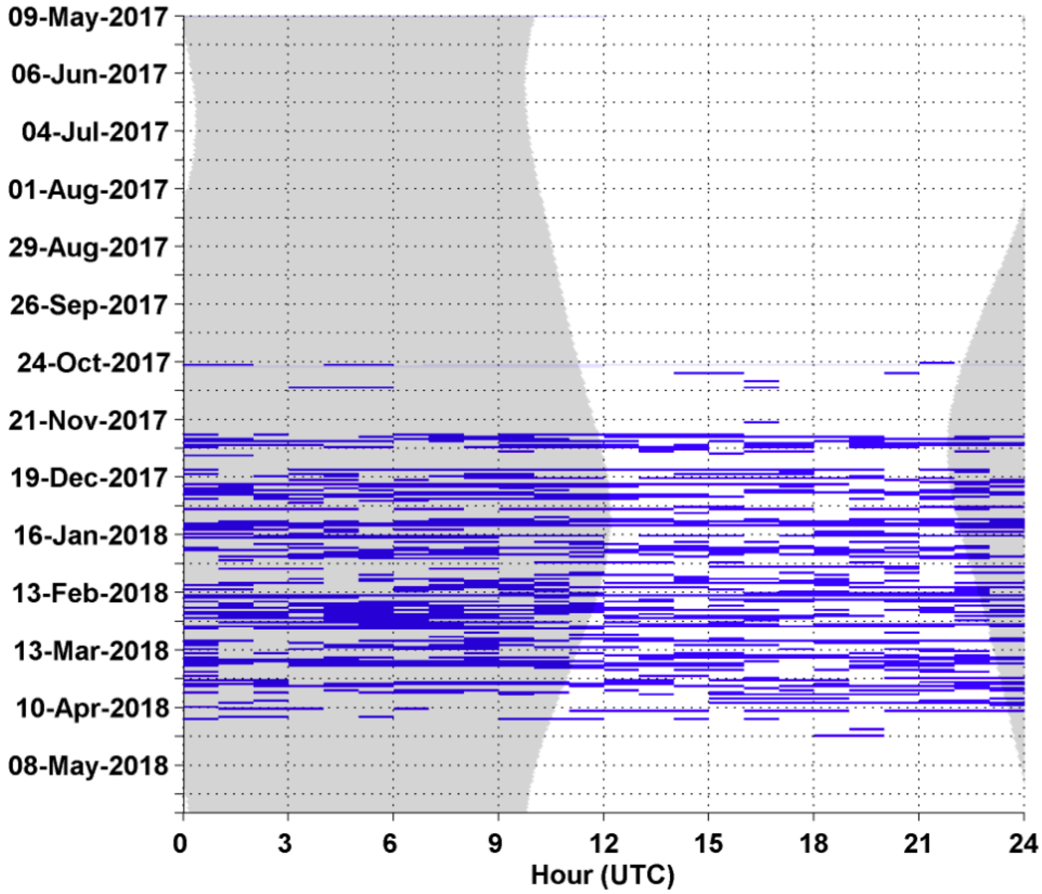

Figure 43. Minke whale pulse trains in hourly bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime.

Sei Whales

- Sei whale downsweeps were observed in low numbers between January 2018 and April 2018 (Figure 44).
- Although there were few detections overall, there was no discernible diel pattern for sei whale downsweeps (Figure 45).

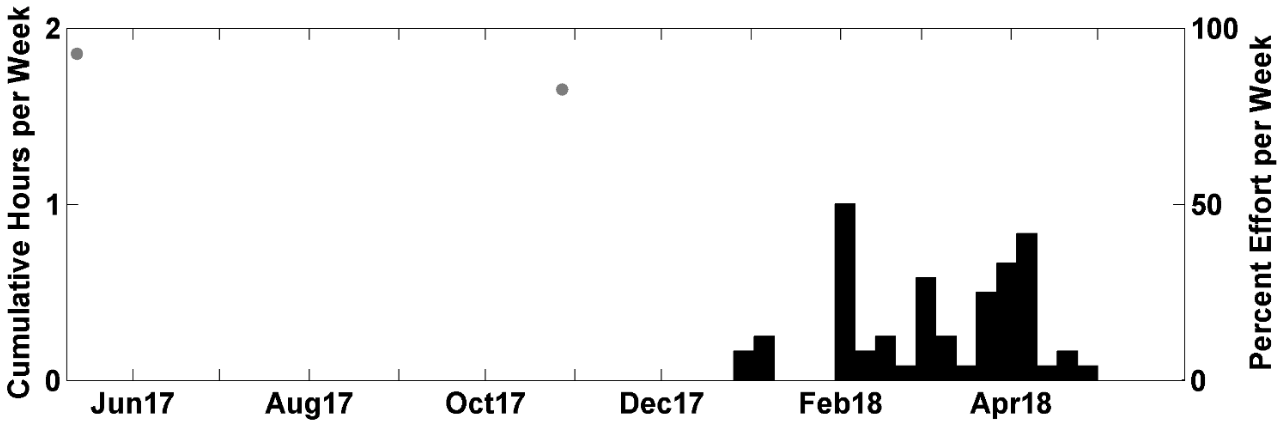

Figure 44. Weekly presence of sei whale downsweeps detected from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

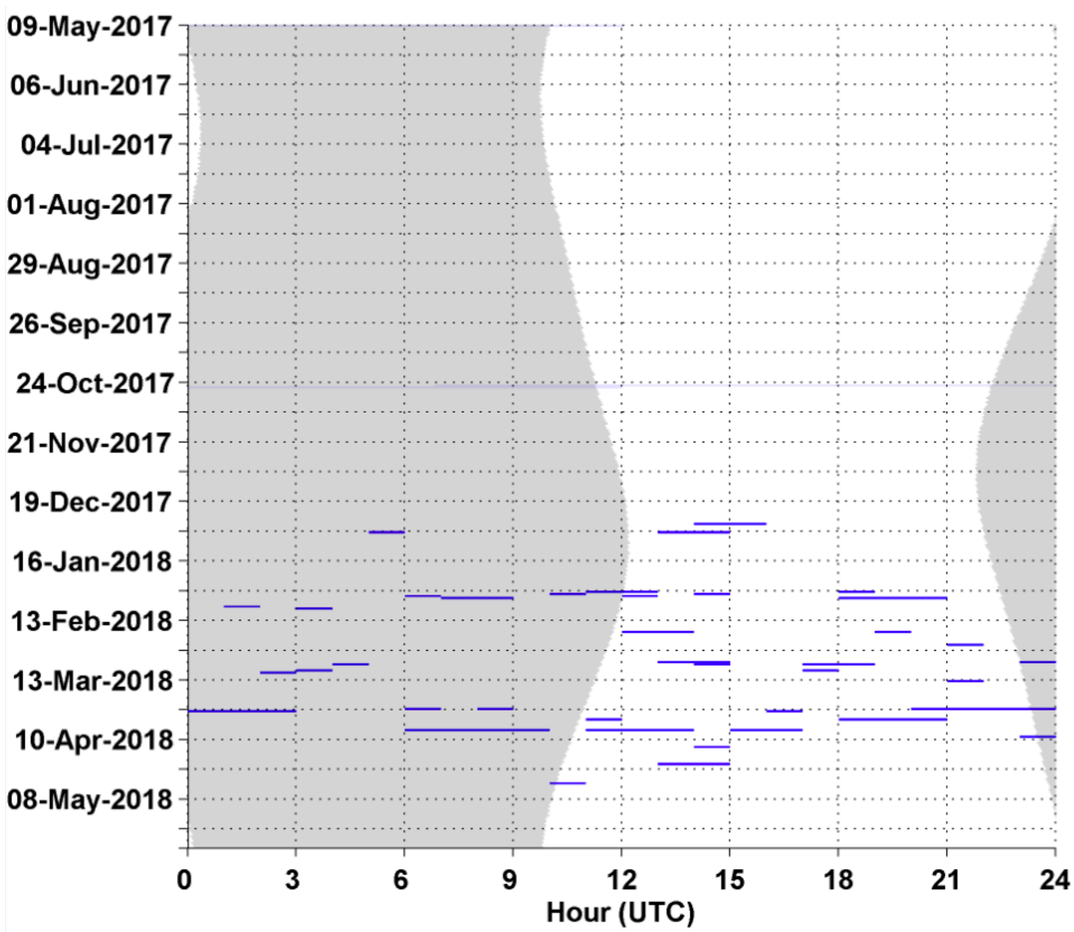

Figure 45. Sei whale downsweeps in hourly bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime.

Humpback Whales

- Humpback whale call types were observed once on December 31, 2017 and from March to April 2018 during the recording period (Figure 46).
- Humpback whale call types were found primarily during nighttime (Figure 47).

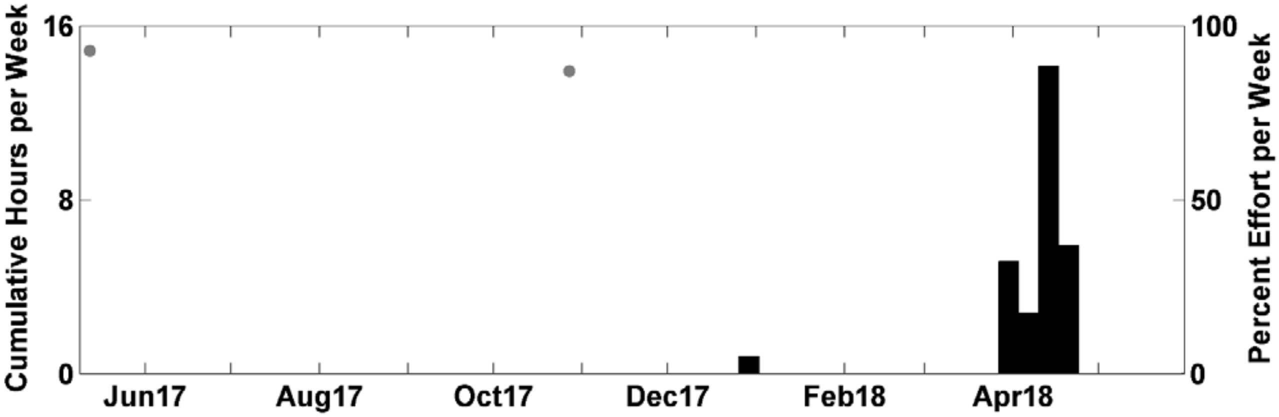

Figure 46. Weekly presence of humpback whale calls from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

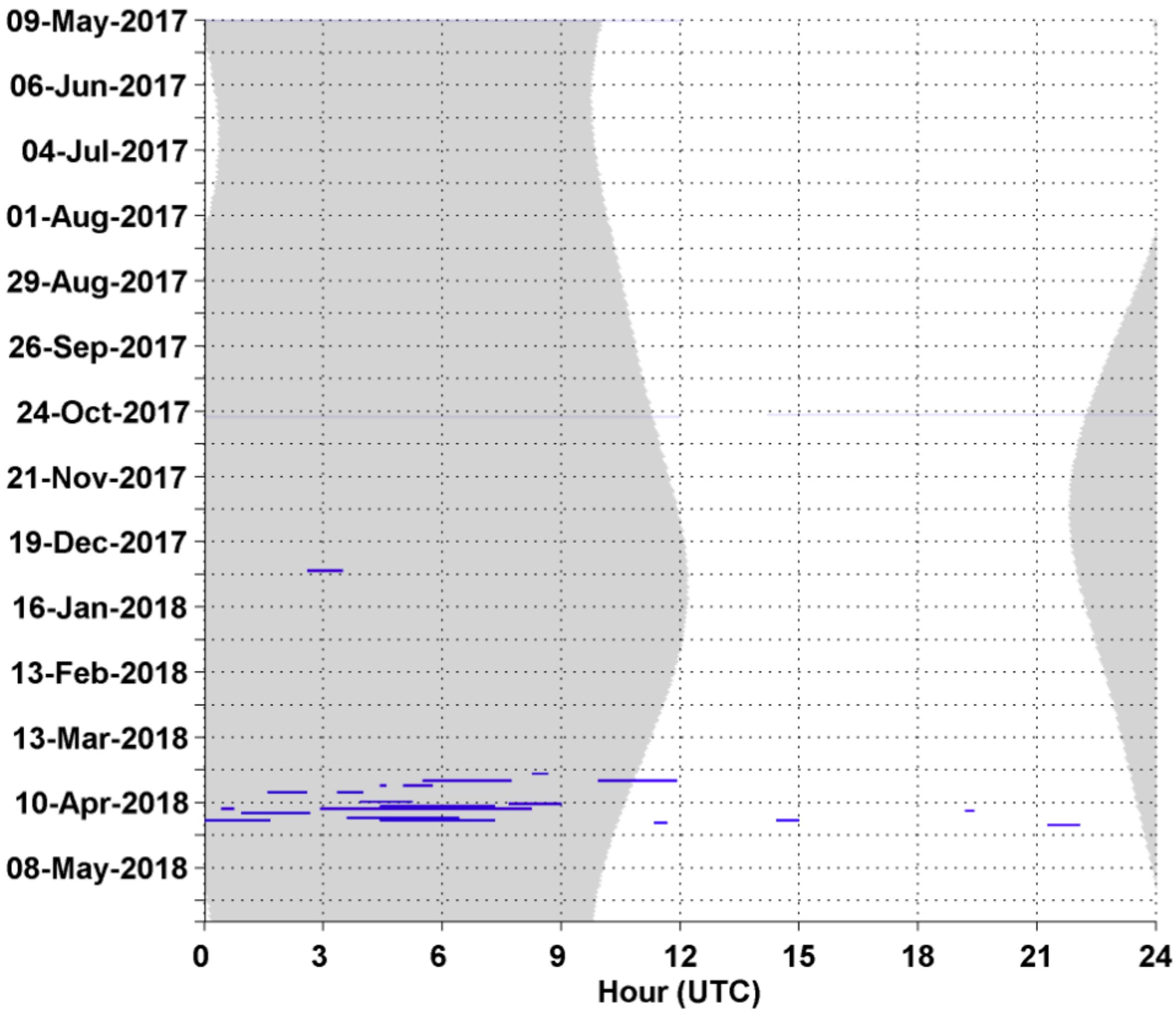

Figure 47. Humpback whale calls in hourly bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime.

Odontocetes

Clicks from Blainville's beaked whale, Cuvier’s beaked whale, Gervais’ beaked whale, Sowerby’s 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 once on December 28, 2017 (Figure 48).
- There were not enough encounters to discern a diel pattern (Figure 49).

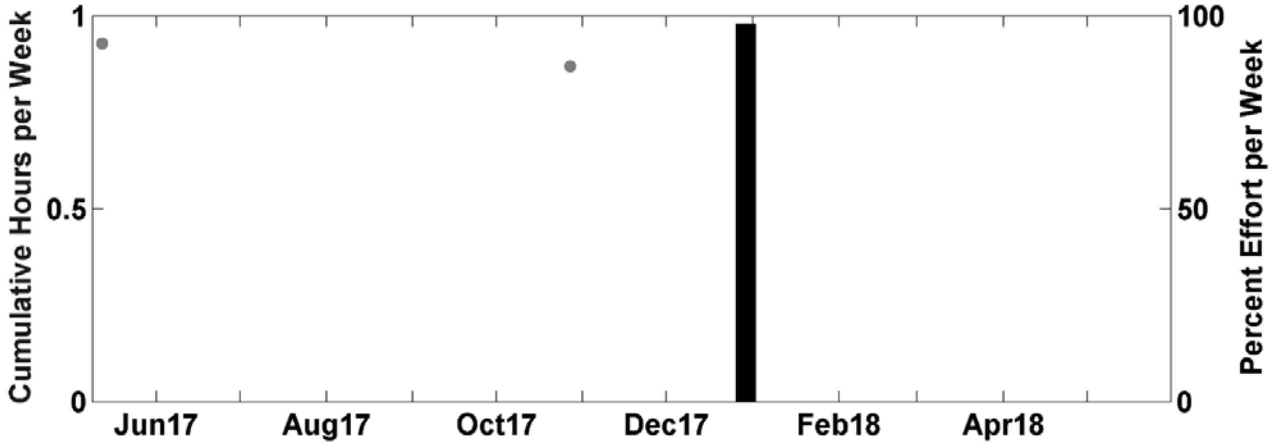

Figure 48. Weekly presence of Blainville's beaked whale echolocation clicks detected from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

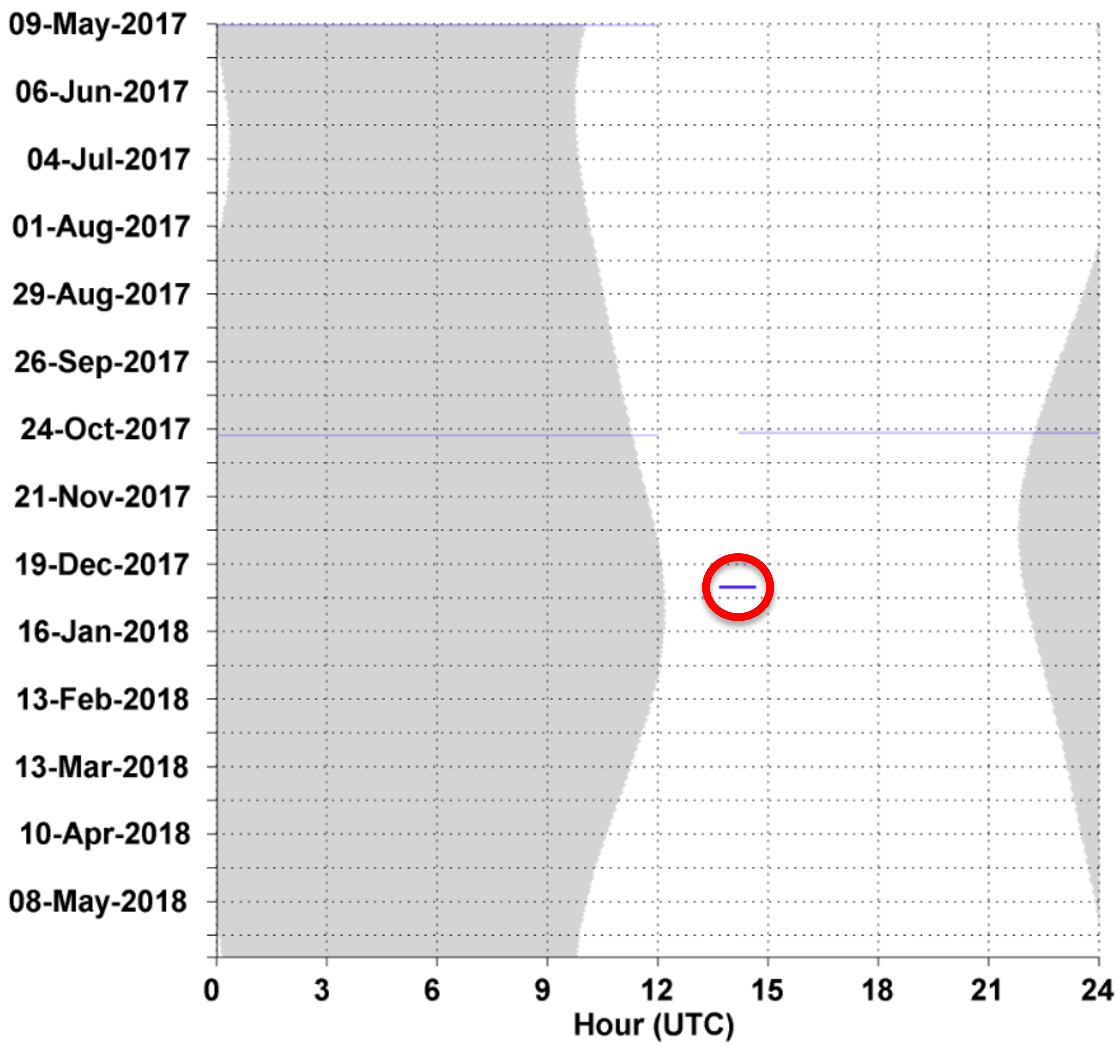

Figure 49. Blainville's beaked whale echolocation clicks in one-minute bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime.

Cuvier's Beaked Whale

- Cuvier's beaked whale echolocation clicks were detected in high numbers throughout the recording period. Detections peaked slightly in July 2017 and February 2018 (Figure 50).
- There was no discernible diel pattern for Cuvier's beaked whale echolocation clicks (Figure 51).

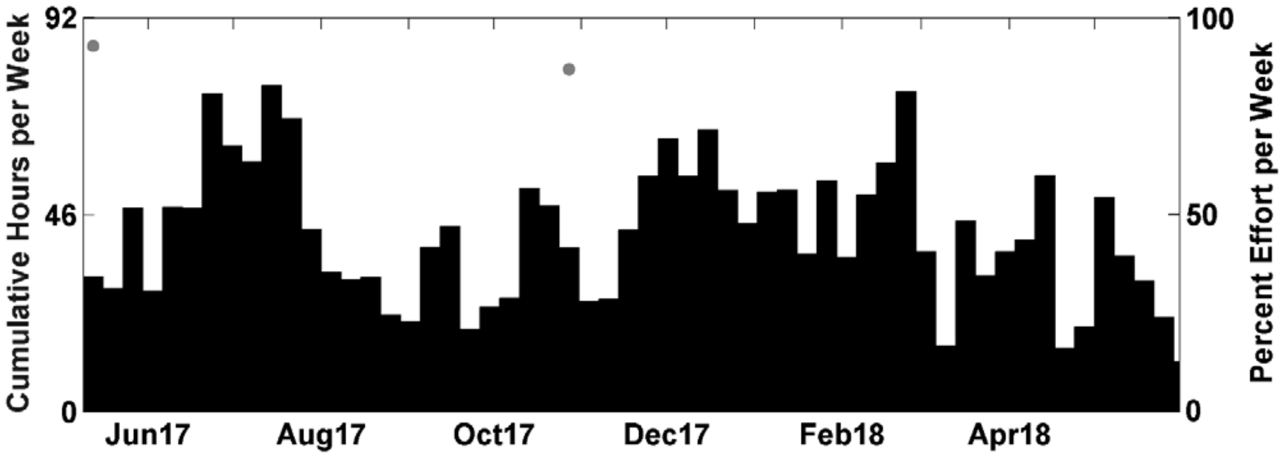

Figure 50. Weekly presence of Cuvier's beaked whale echolocation clicks detected from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

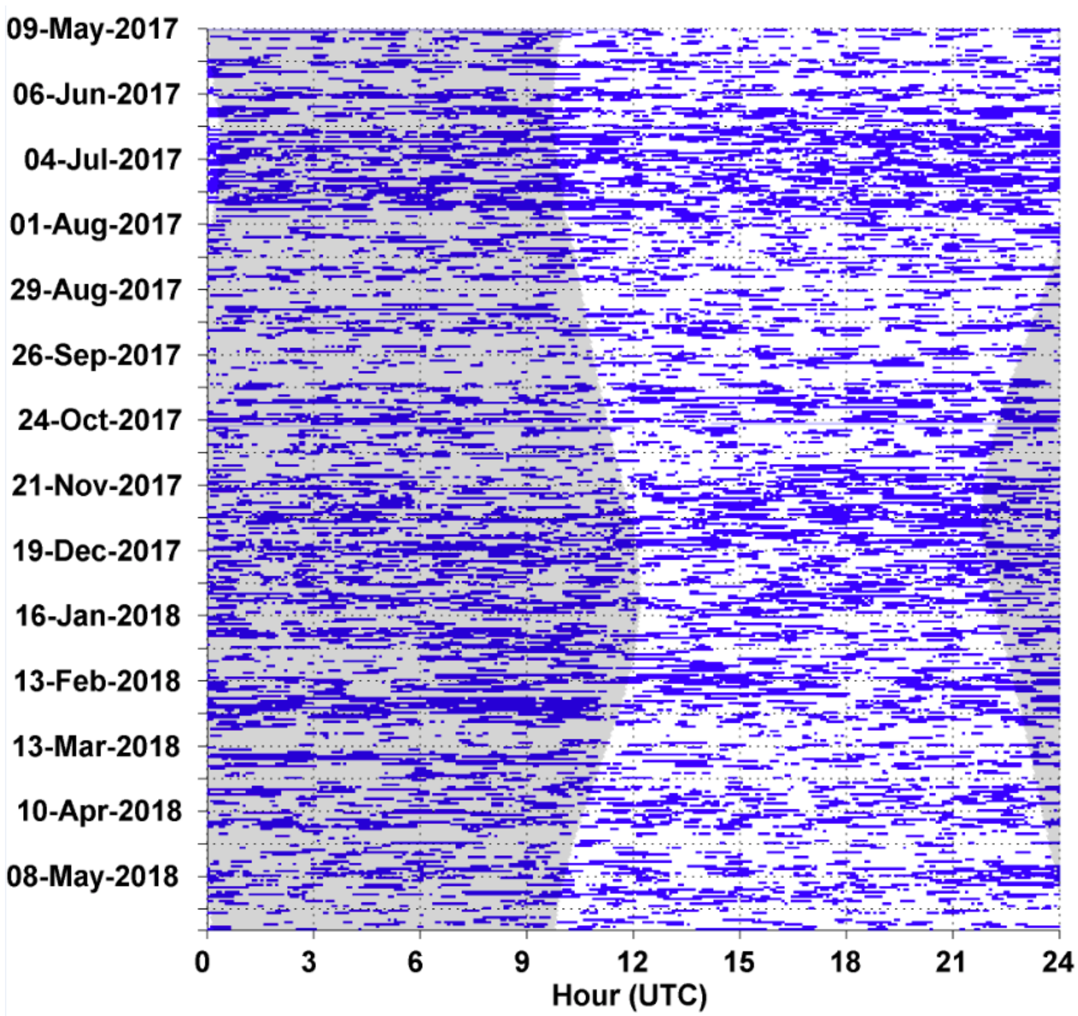

Figure 51. Cuvier's beaked whale echolocation clicks in one-minute bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime

Gervais' Beaked Whale

- Gervais' beaked whale echolocation clicks were detected intermittently from May to October 2017 and in low numbers for the remainder of the recording period (Figure 52).
- There was no discernible diel pattern for Gervais' beaked whale echolocation clicks (Figure 53).

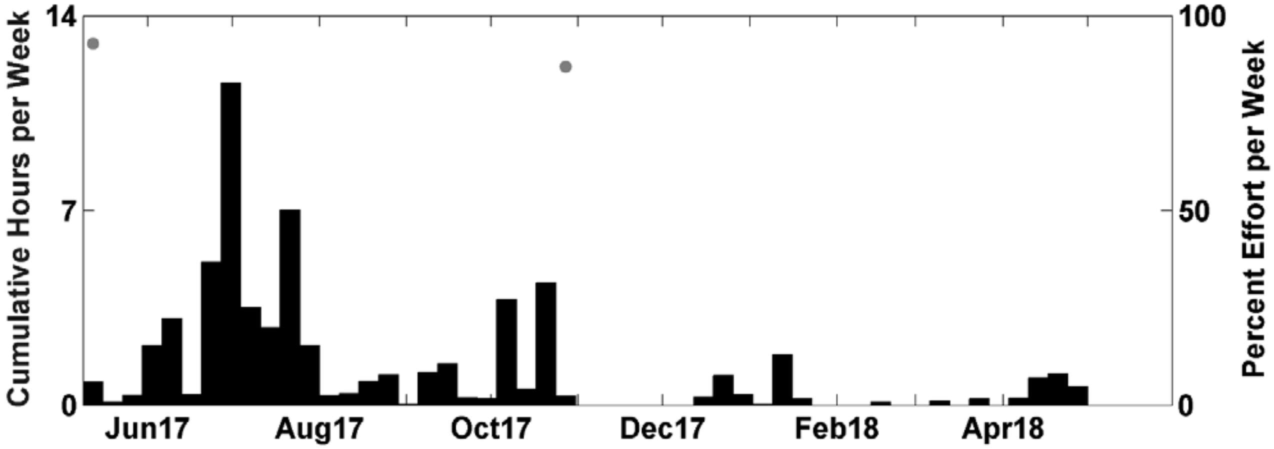

Figure 52. Weekly presence of Gervais' beaked whale echolocation clicks from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

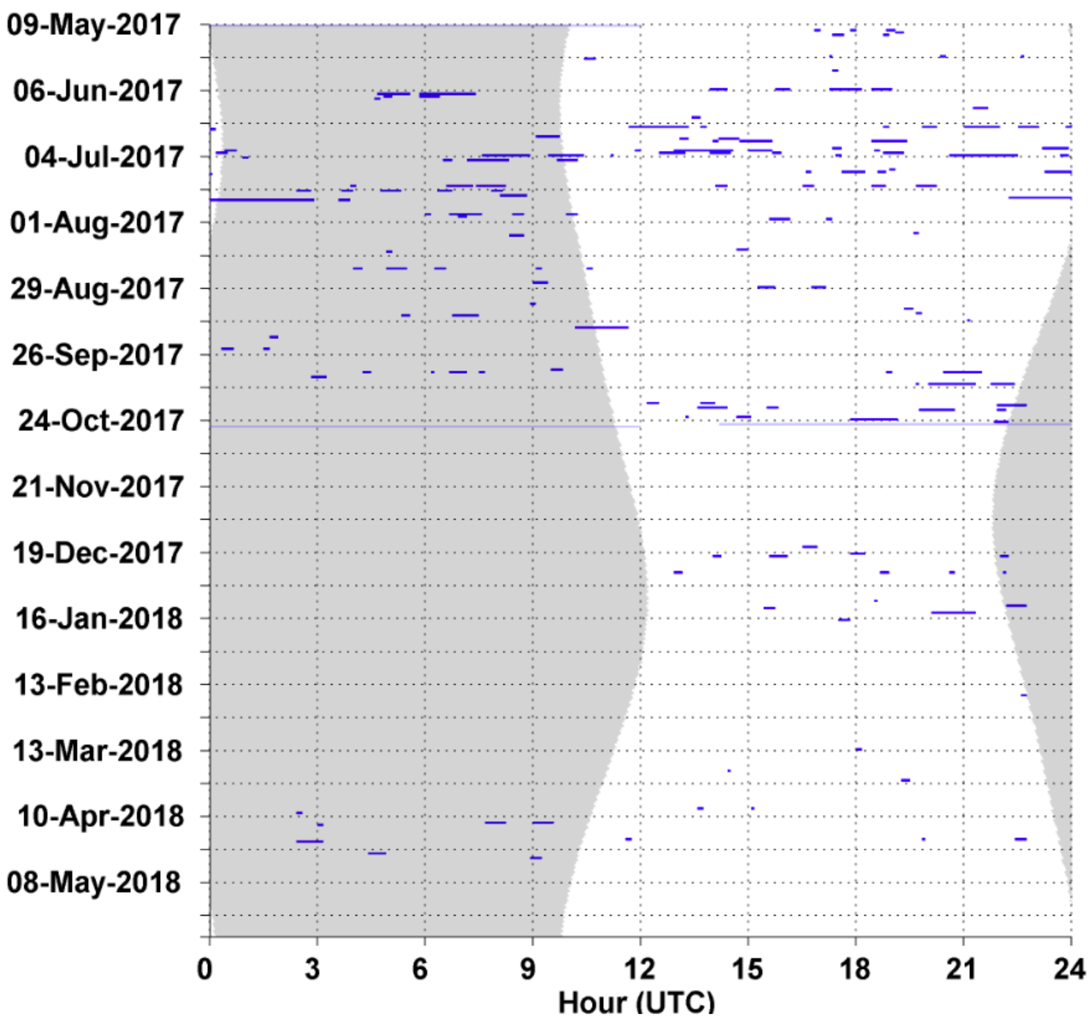

Figure 53. Gervais' beaked whale echolocation clicks in one-minute bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime.

Sowerby's Beaked Whale

- Sowerby's beaked whale echolocation clicks were detected once on January 28th, 2018 (Figure 54).
- There were not enough encounters to discern a diel pattern (Figure 55).

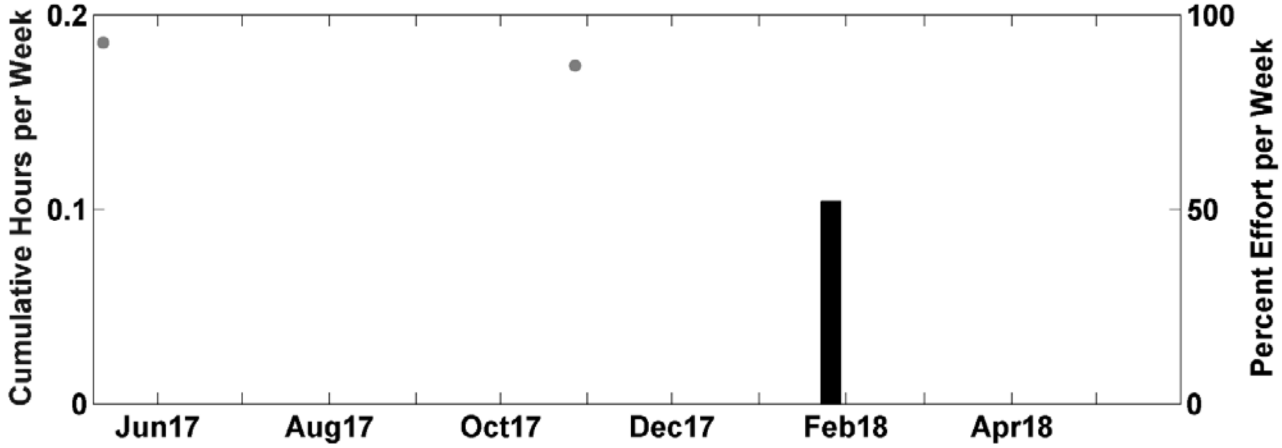

Figure 54. Weekly presence of Sowerby's beaked whale echolocation clicks from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

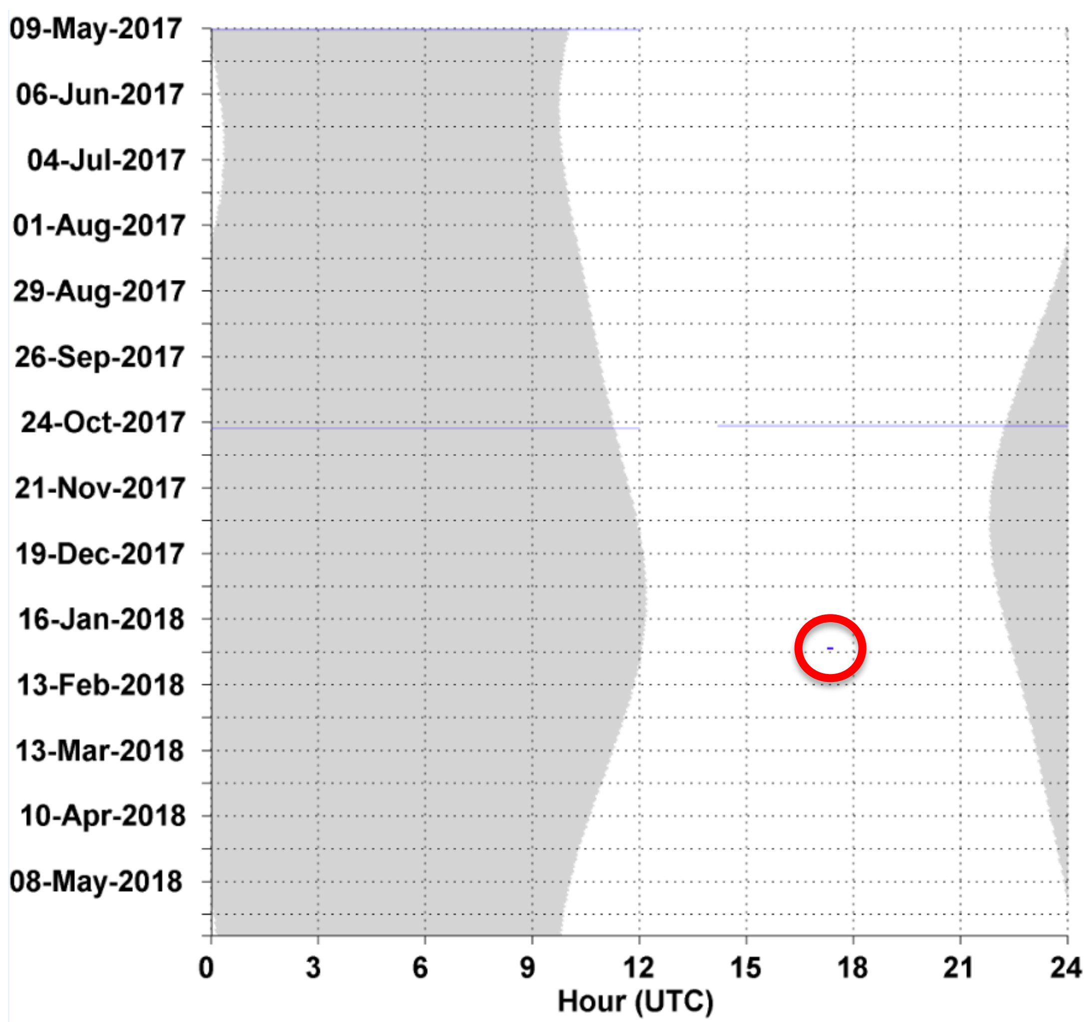

Figure 55. Sowerby's beaked whale echolocation clicks in one-minute bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime.

Risso's Dolphins

- Risso's dolphin echolocation clicks were detected in low numbers throughout the recording period (Figure 56).
- Clicks were primarily detected during nighttime (Figure 57).

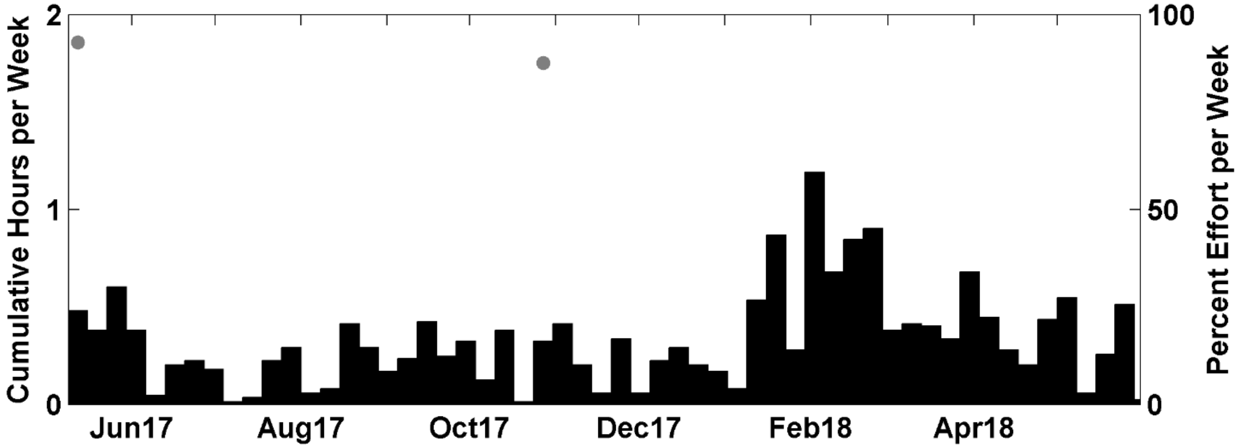

Figure 56. Weekly presence of Risso's dolphin echolocation clicks detected from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

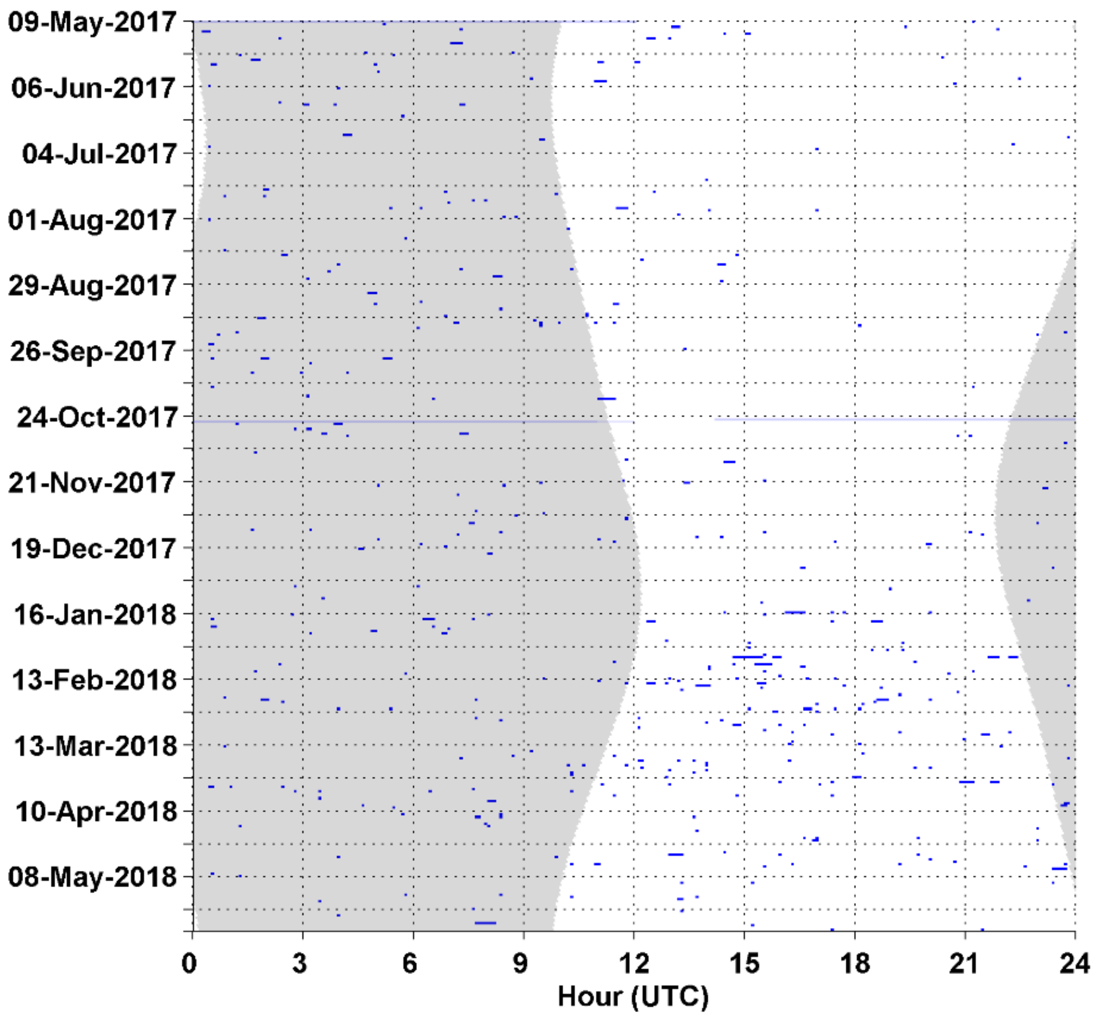

Figure 57. Risso's dolphin echolocation clicks in five-minute bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime.

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 in low numbers (Figure 58).
- There was no discernible diel pattern for unidentified odontocete clicks (Figure 59).

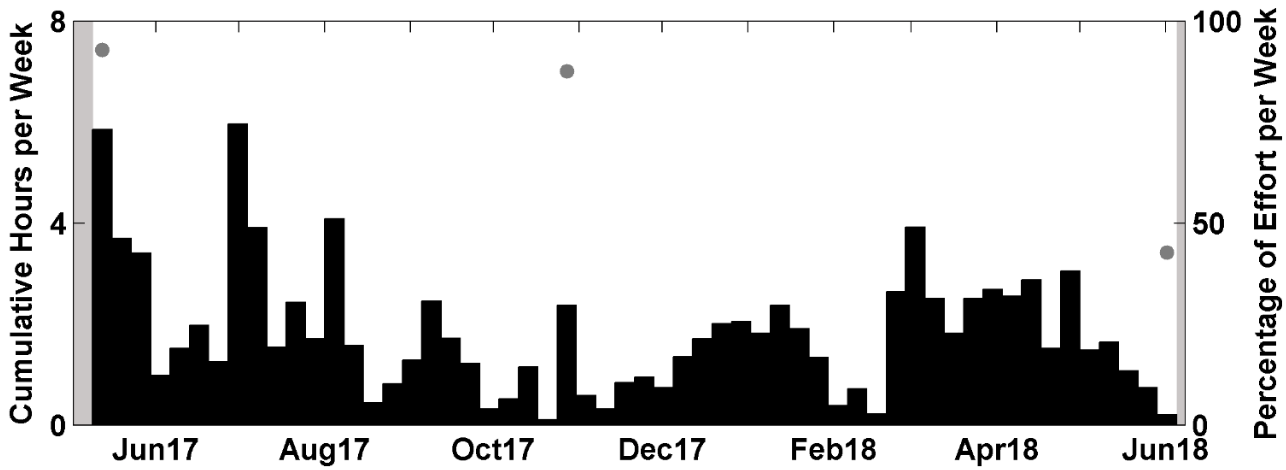

Figure 58. Weekly presence of unidentified odontocete clicks detected from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

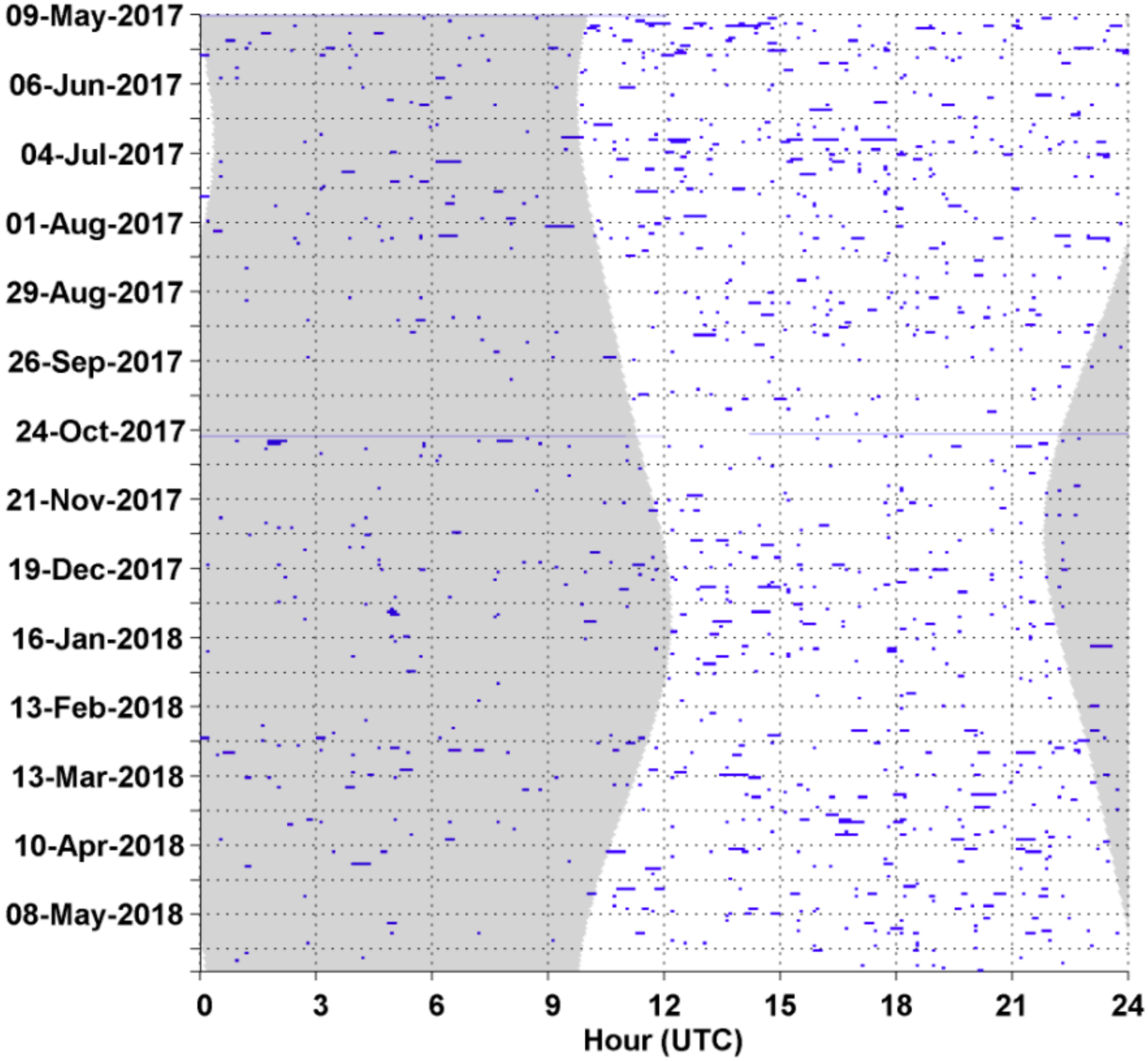

Figure 59. Unidentified odontocete clicks in five-minute bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime.

Click Type 1

- CT 1 was detected consistently throughout the deployment (Figure 60).
- CT 1 was more often detected during nighttime (Figure 61).

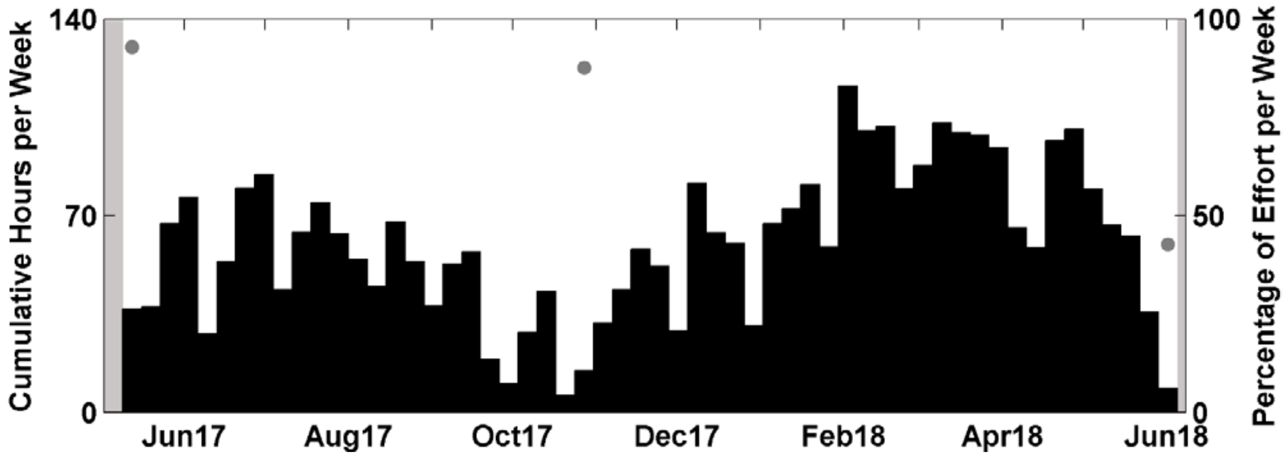

Figure 60. Weekly presence of CT 1 detected from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

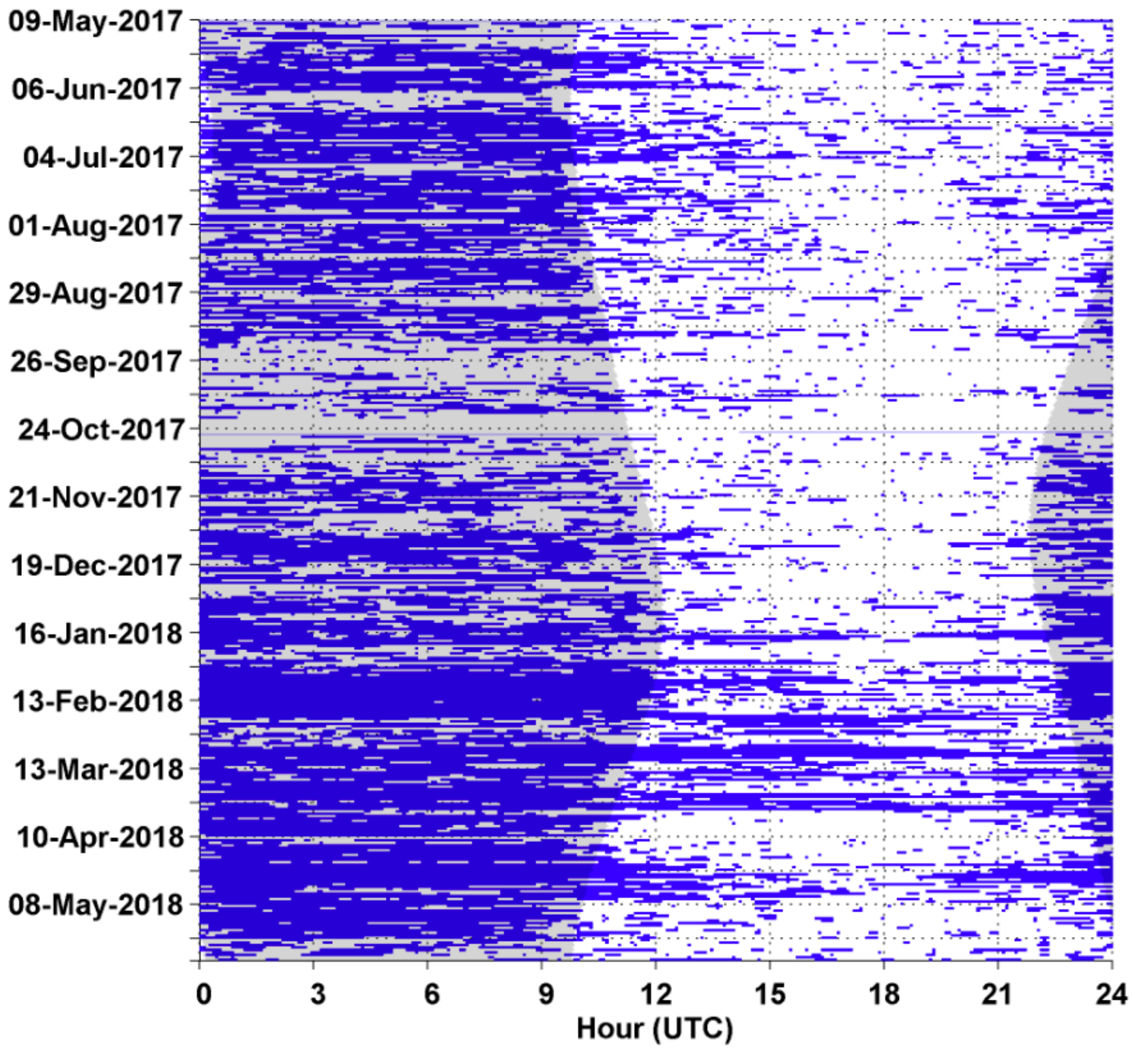

Figure 61. CT 1 in five-minute bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime.

Click Type 4

- CT 4 was detected consistently throughout the deployment, and highest from February to March 2018 (Figure 62).
- CT 4 was detected predominantly during nighttime (Figure 63).

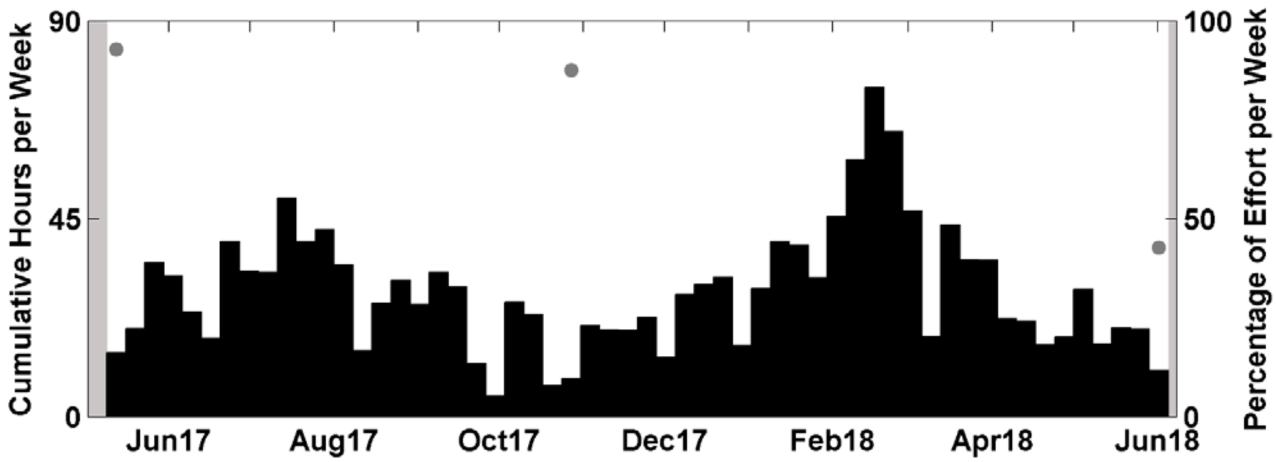

Figure 62. Weekly presence of CT 4 detected from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

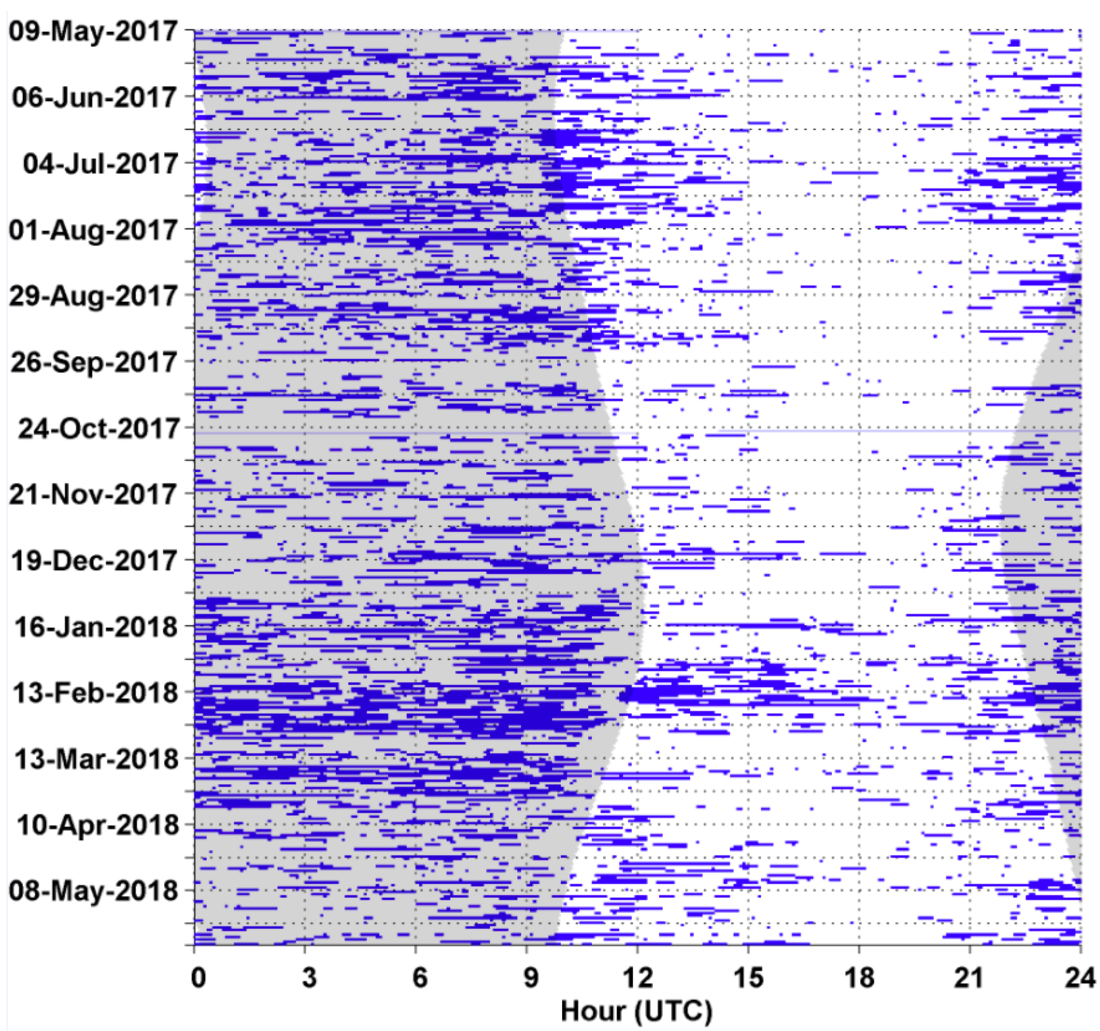

Figure 63. CT 4 in five-minute bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime.

Click Type 6

- CT 6 detections occurred consistently throughout the deployment with low points occurring from February to April 2018 (Figure 64).
- CT 6 was detected consistently in daytime and nighttime (Figure 65).

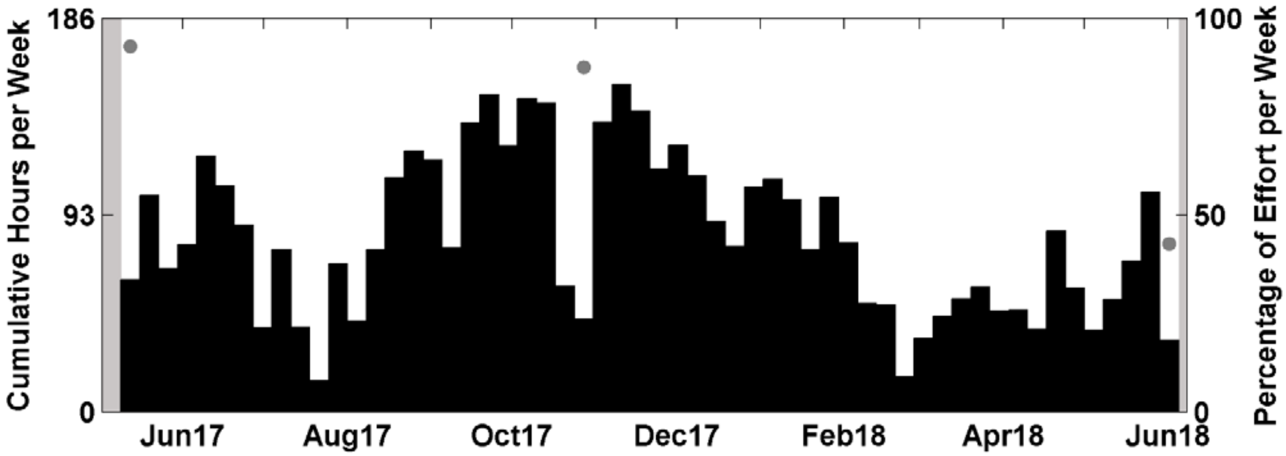

Figure 64. Weekly presence of CT 6 detected from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

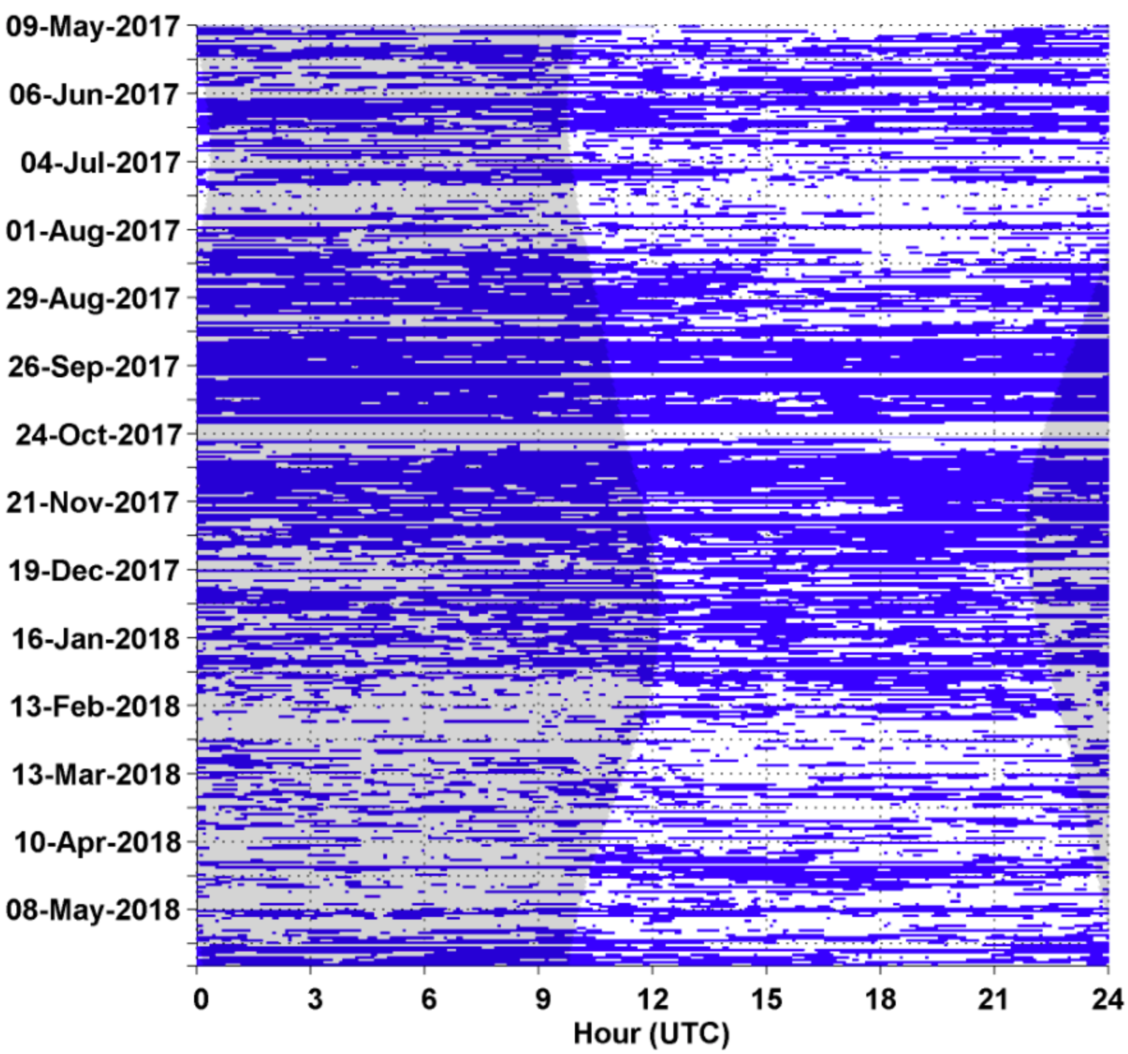

Figure 65. CT 6 in five-minute bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime.

Unidentified Odontocete Whistles Less Than 5 kHz

- Unidentified odontocete whistles less than 5 kHz were detected in high numbers throughout the recording period but were highest from August 2017 to February 2018 (Figure 66).
- There was no apparent diel pattern for unidentified whistles less than 5 kHz (Figure 67).
- Pilot whales most likely produced these whistles, though it is possible they are from other blackfish species that have overlapping distributions.

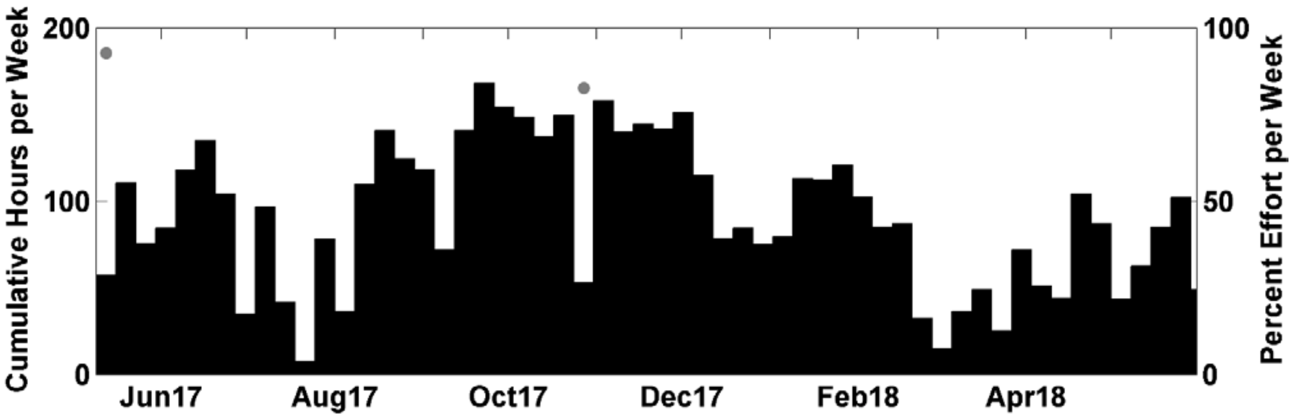

Figure 66. Weekly presence of unidentified odontocete whistles less than 5 kHz detected from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

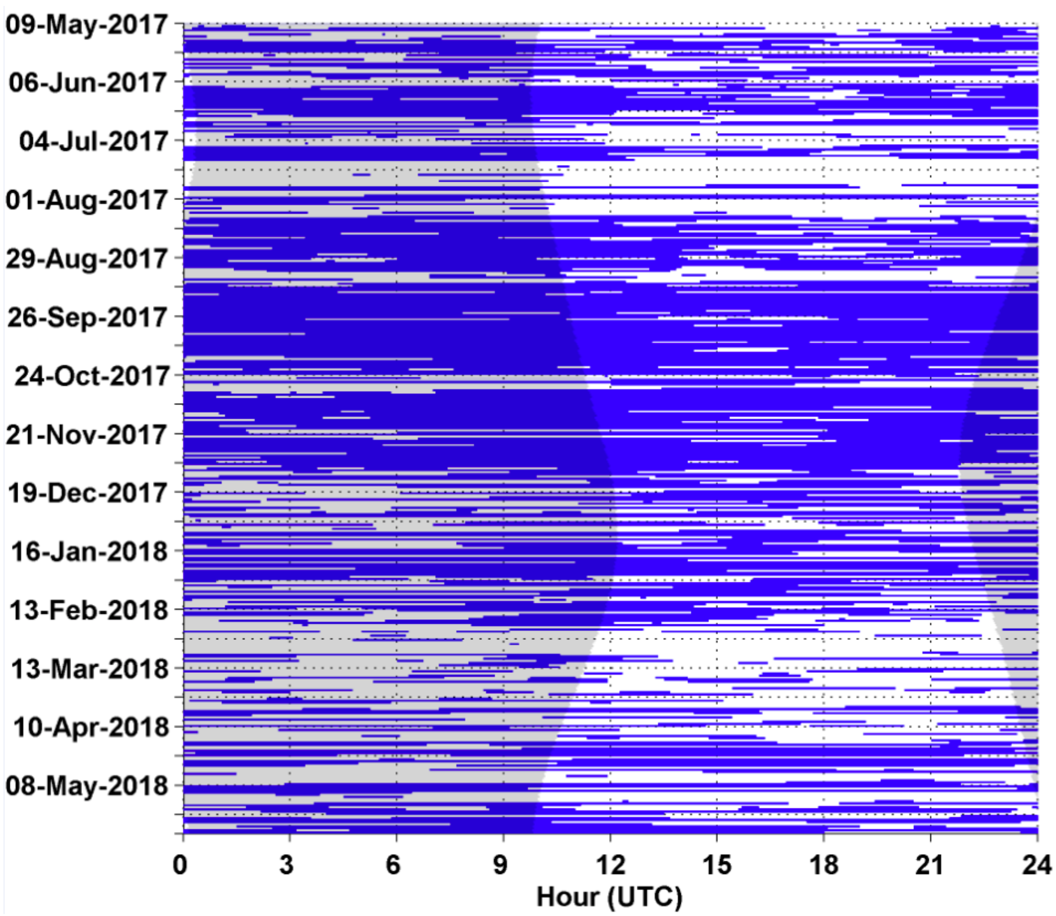

Figure 67. Unidentified odontocete whistles less than 5 kHz in one-minute bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime.

Unidentified Odontocete Whistles Greater Than 10 kHz

- Unidentified odontocete whistles greater than 10 kHz were detected throughout the recording period. Detections were highest in September 2017 and February 2018 (Figure 68).
- There was no diel pattern for whistles greater than 10 kHz (Figure 69).

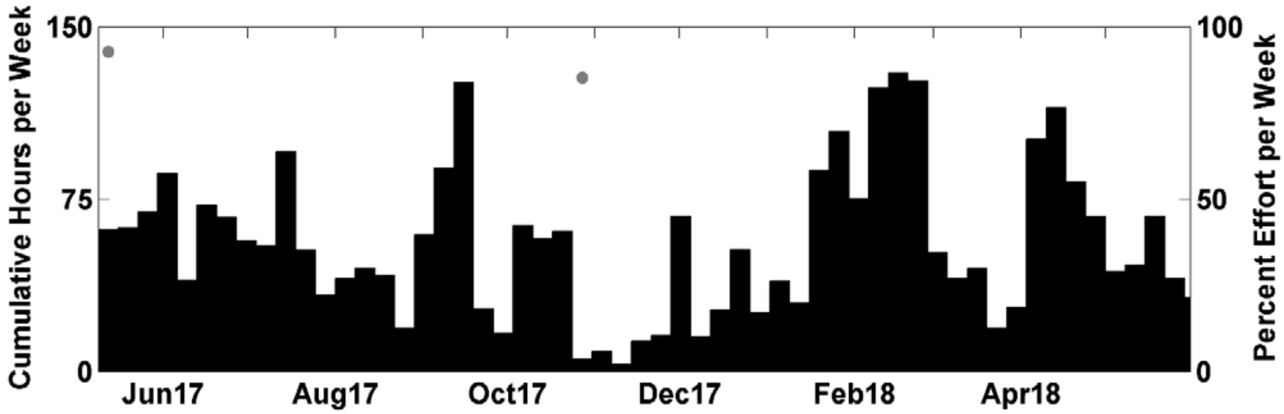

Figure 68. Weekly presence of unidentified odontocete whistles greater than 10 kHz detected from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

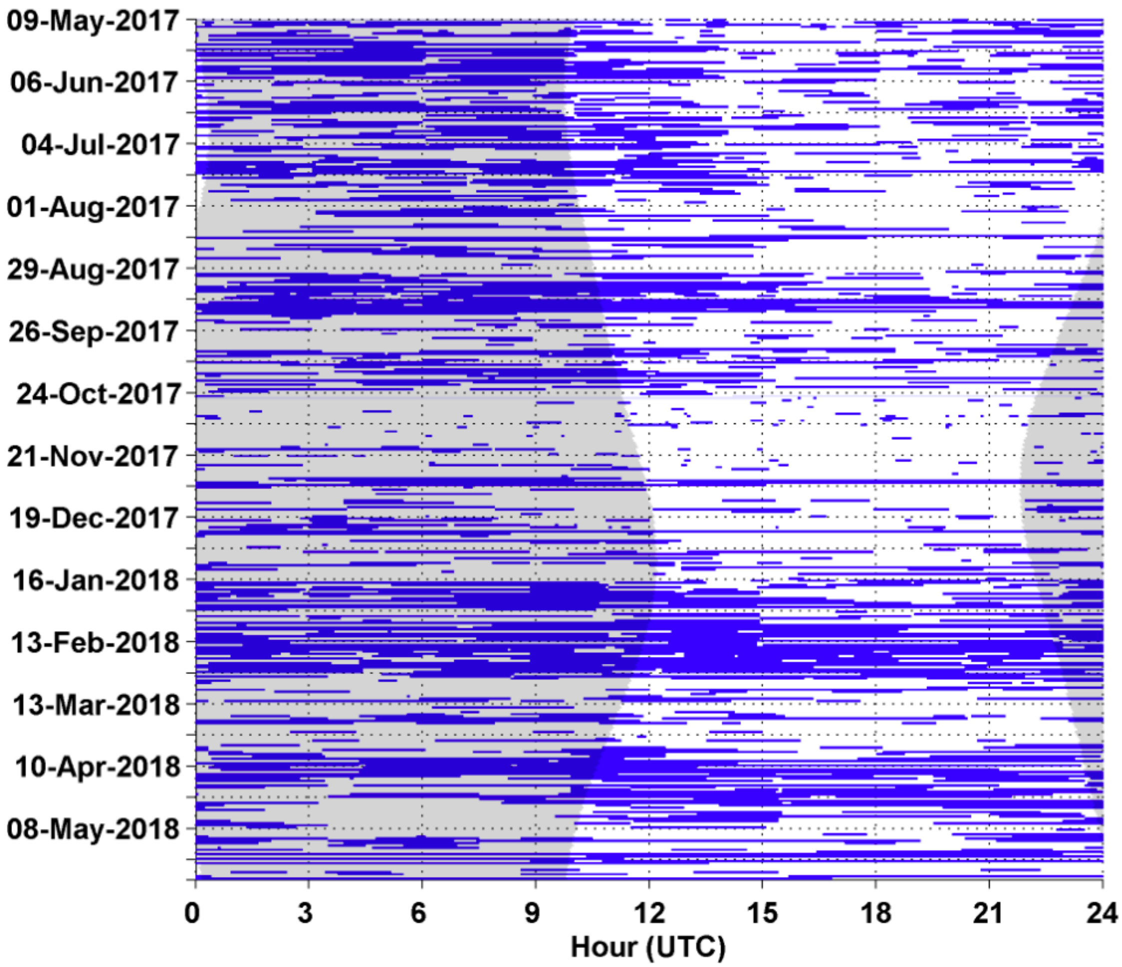

Figure 69. Unidentified odontocete whistles greater than 10 kHz in one-minute bins at HAT Site B from May 2017-2018. Gray vertical shading denotes nighttime.

Sperm Whales

- Sperm whale clicks were throughout the recording period but were highest from June to the beginning of October 2017 and from April to June 2018 (Figure 70).
- There was no discernible diel pattern for sperm whale clicks (Figure 71).

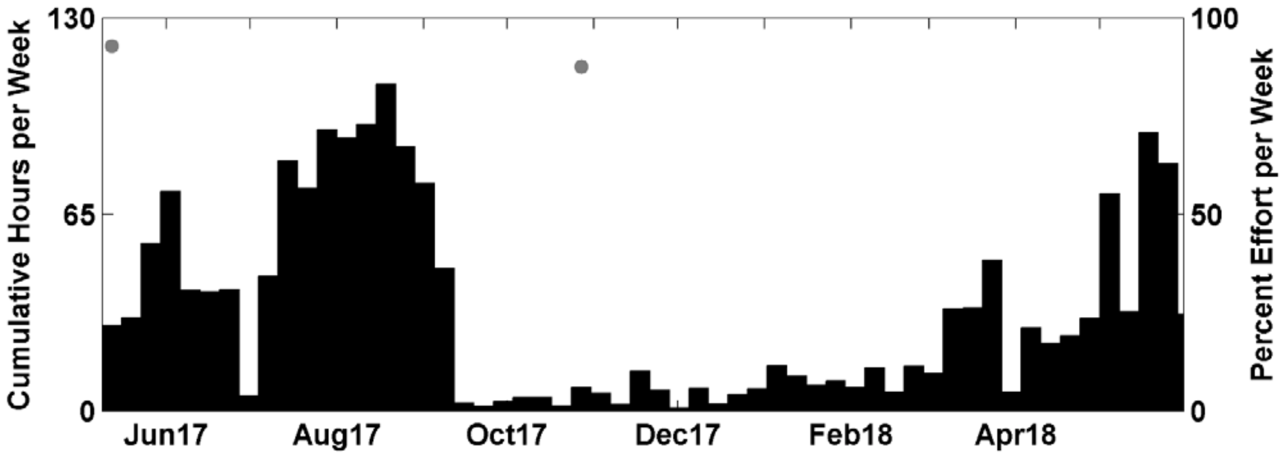

Figure 70. Weekly presence of sperm whale clicks detected from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

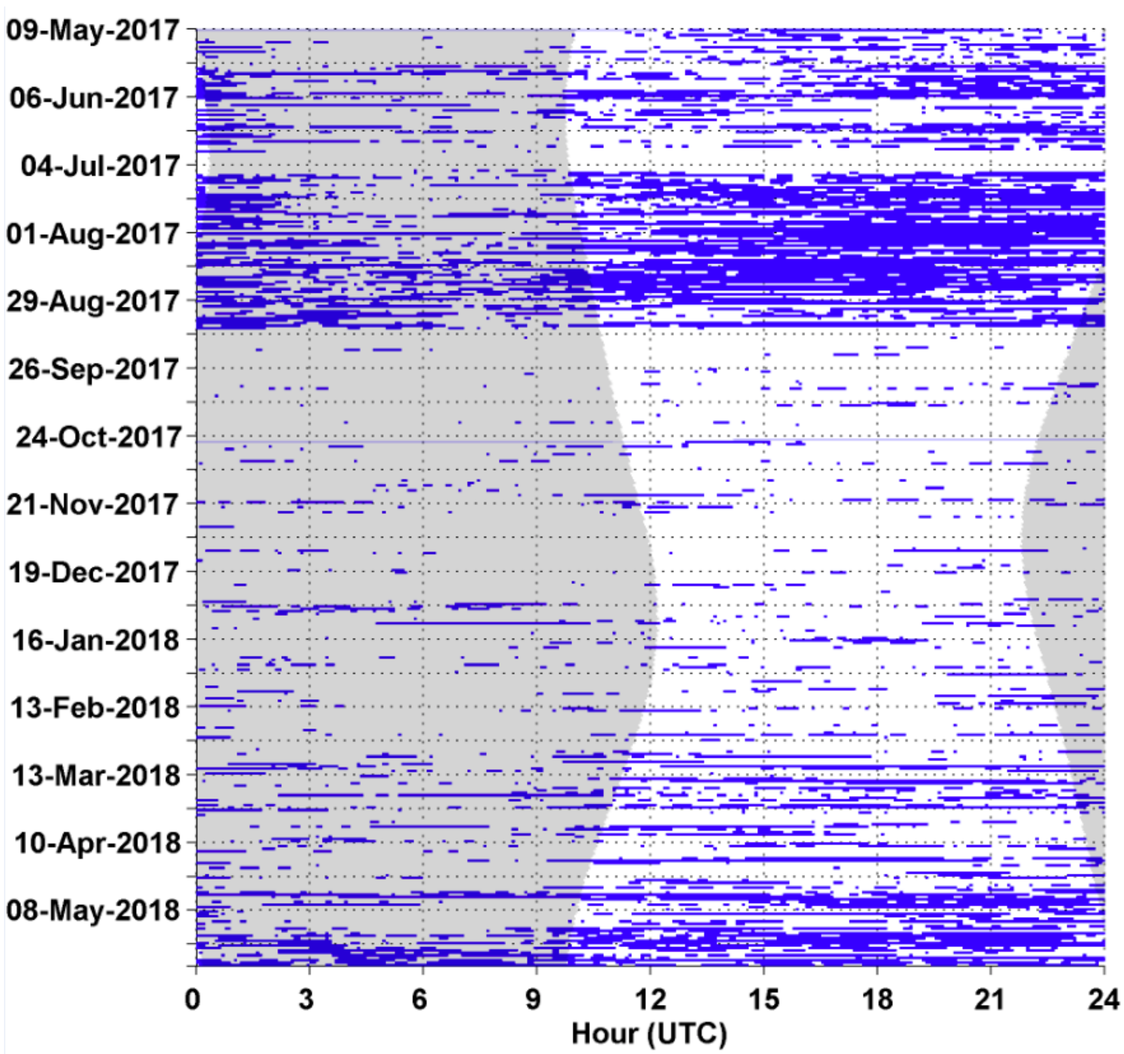

Figure 71. Sperm whale clicks in one-minute bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime.

***Kogia* spp.**

- *Kogia* spp. echolocation clicks were detected in low numbers throughout the recording period (Figure 72).
- There was no discernible diel pattern for *Kogia* echolocation clicks (Figure 73).

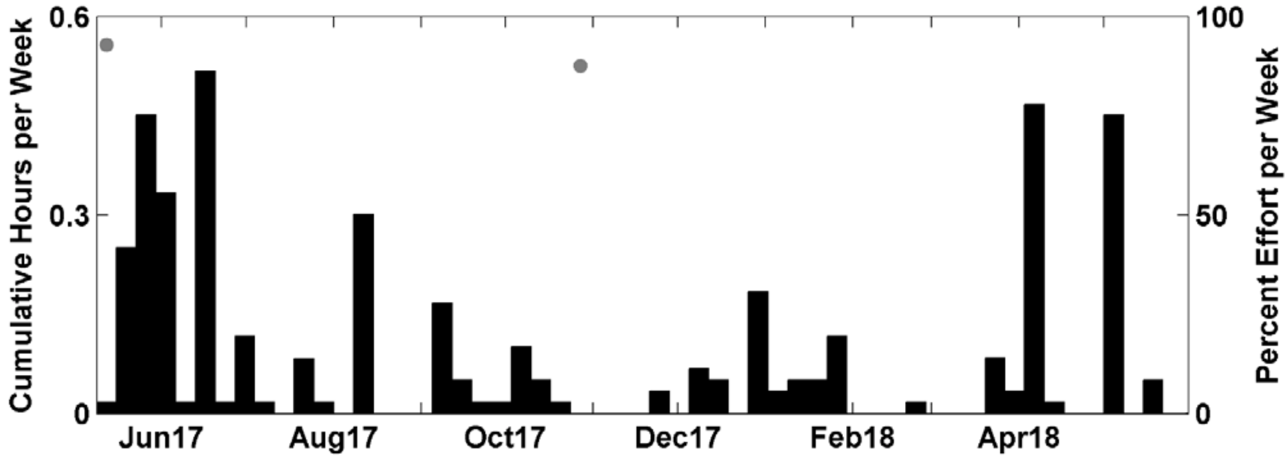

Figure 72. Weekly presence of Kogia spp. clicks detected from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

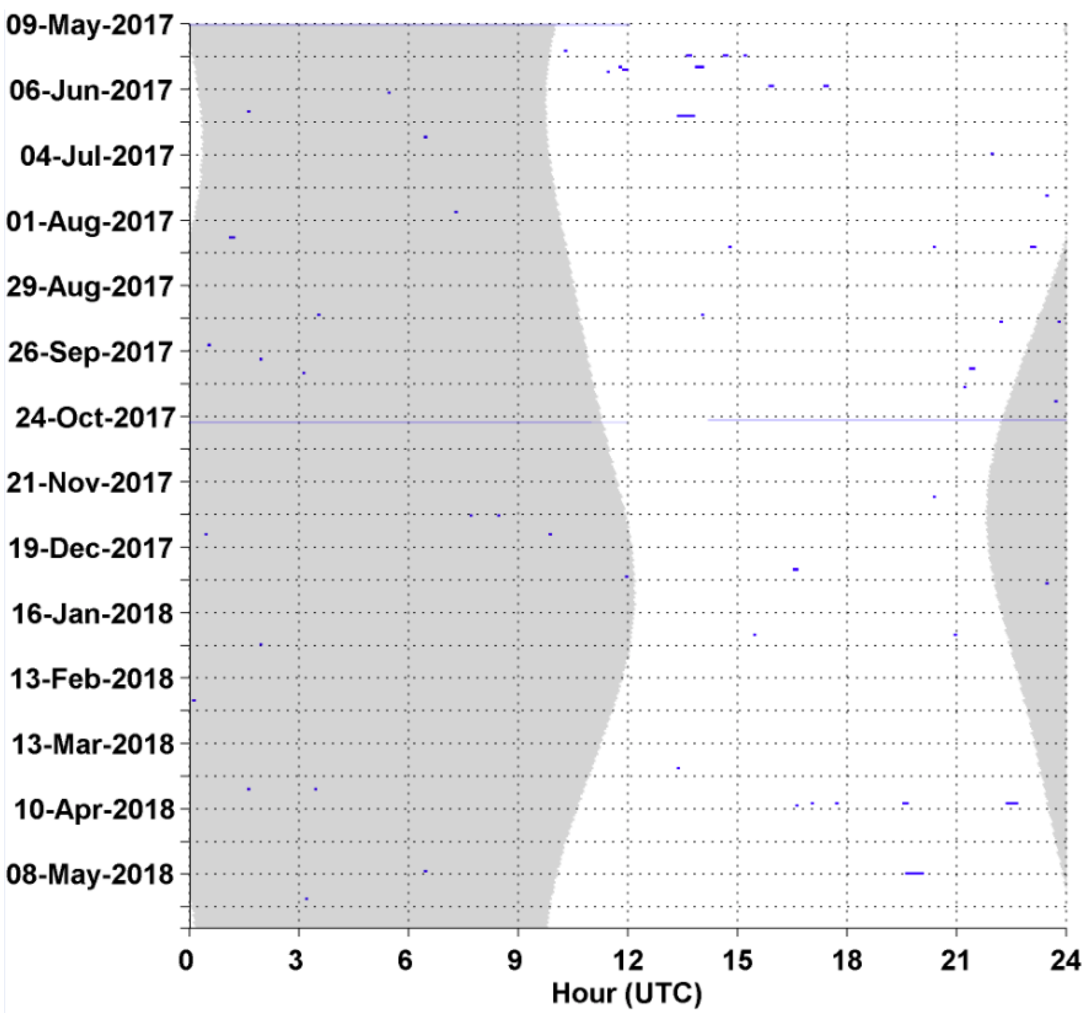

Figure 73. Kogia spp. clicks in one-minute bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime.

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 March 2018 (Figure 74).
- There was no discernible diel pattern for broadband ships during the recording period (Figure 75).

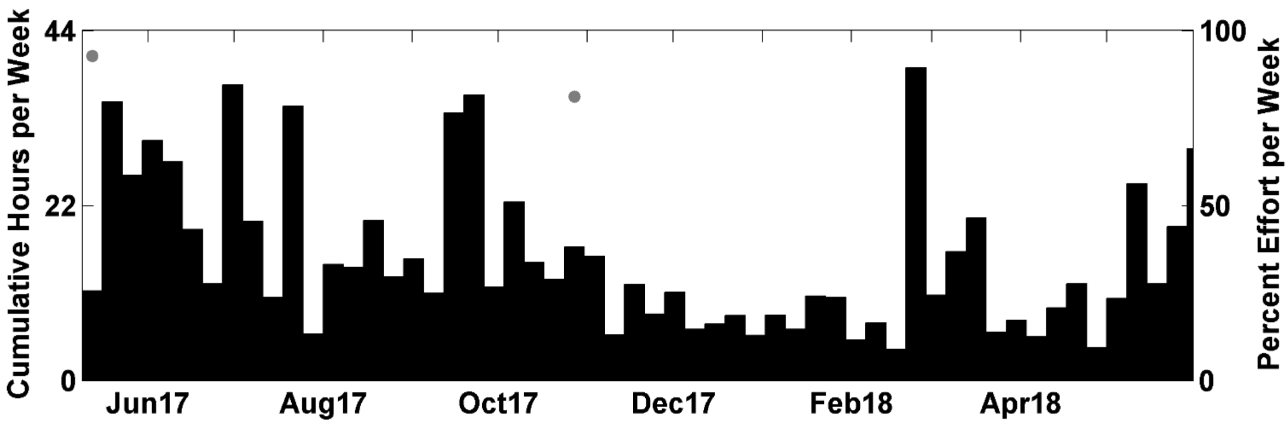

Figure 74. Weekly presence of broadband ships detected from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

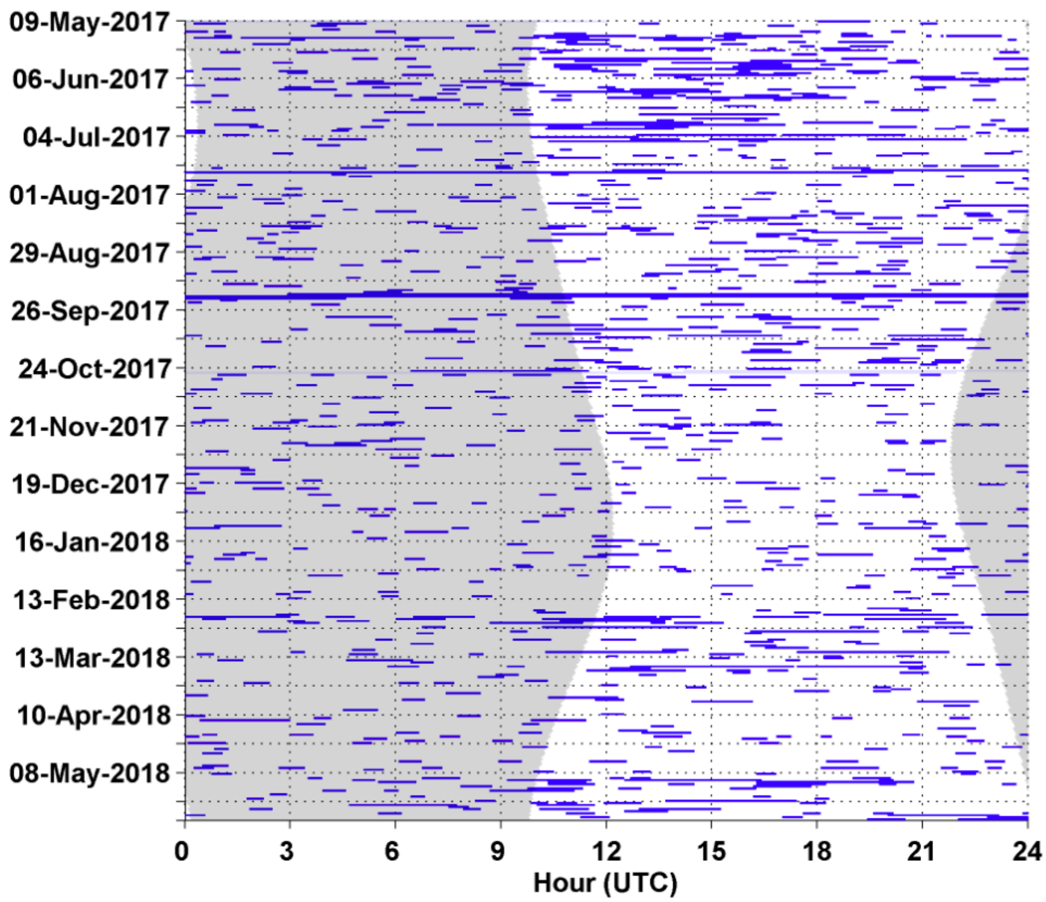

Figure 75. Broadband ship noise in one-minute bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime.

LFA Sonar

- LFA sonar greater than 500 Hz was detected once in July 2017 and once in October 2017 (Figure 76).
- The only instance of LFA sonar occurred during daytime, but there were not enough detections to establish a diel pattern (Figure 77).

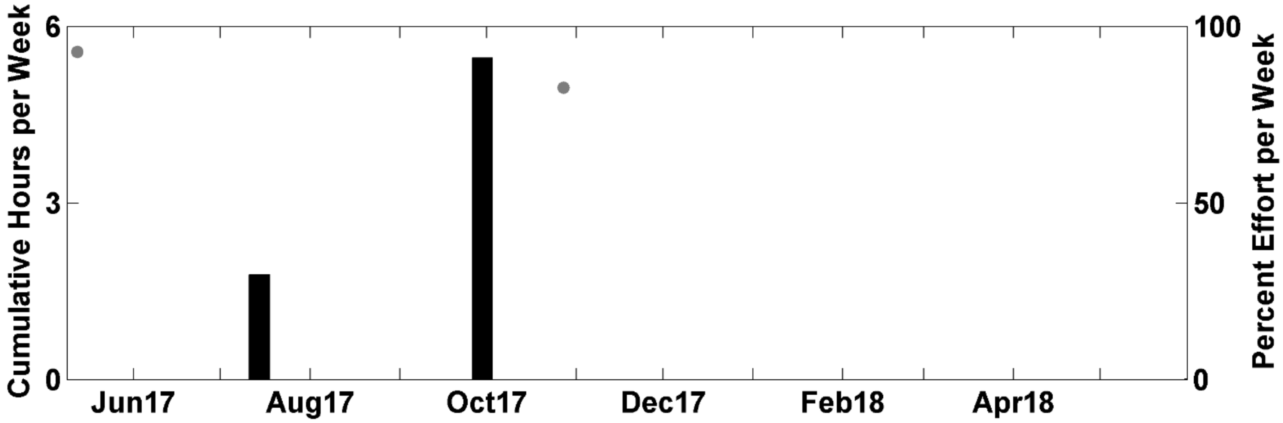

Figure 76. Weekly presence of LFA sonar detected from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

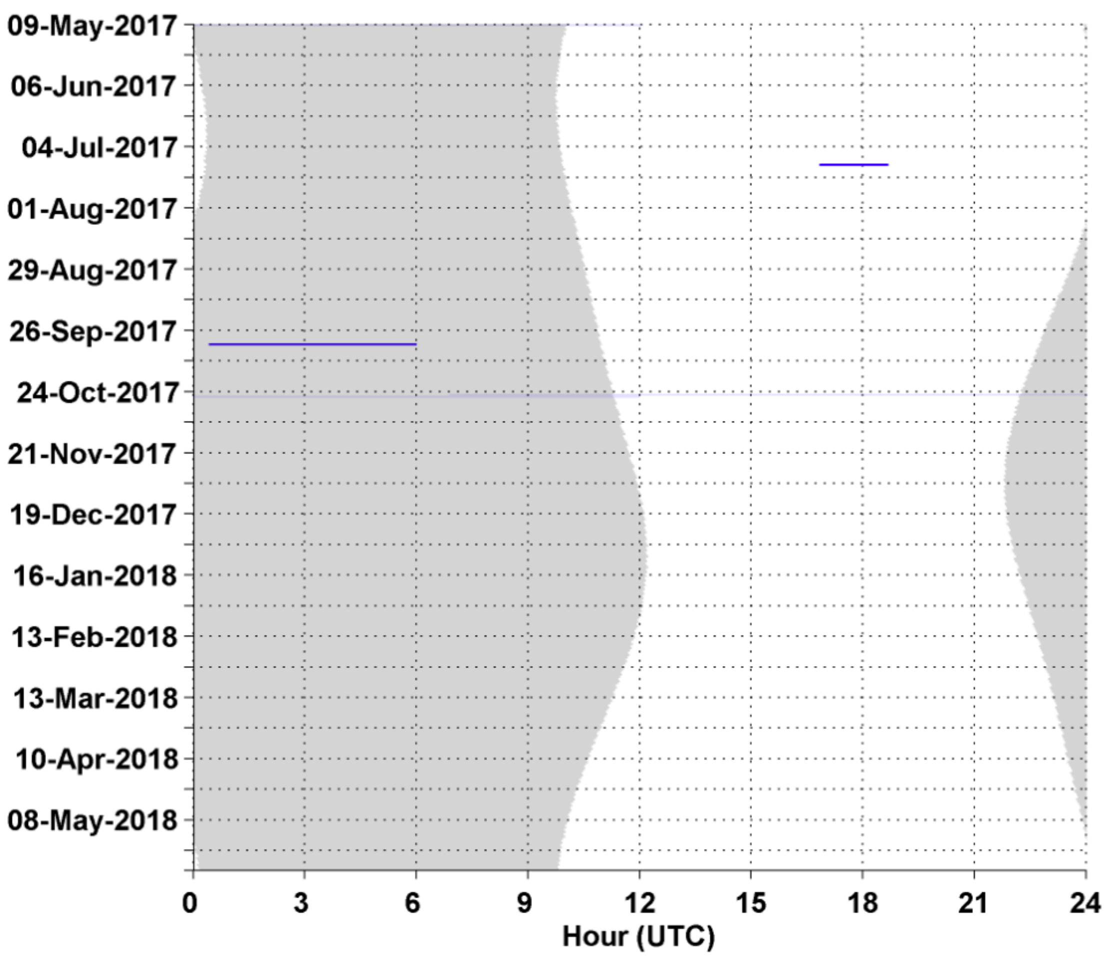

Figure 77. LFA sonar in one-minute bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime.

MFA Sonar

- MFA sonar less than 5 kHz was detected in low numbers throughout the recording period but was highest in October 2017 (Figure 78).
- There was no discernible diel pattern for MFA sonar during the recording period (Figure 79).
- Highest number of packets (> 60) and Cumulative Sound Exposure Levels (CSEL) (> 160 dB re 1 µPa s) MFA events were detected in October 2017. The maximum peak-to-peak RL was 164 dB (Figure 80).

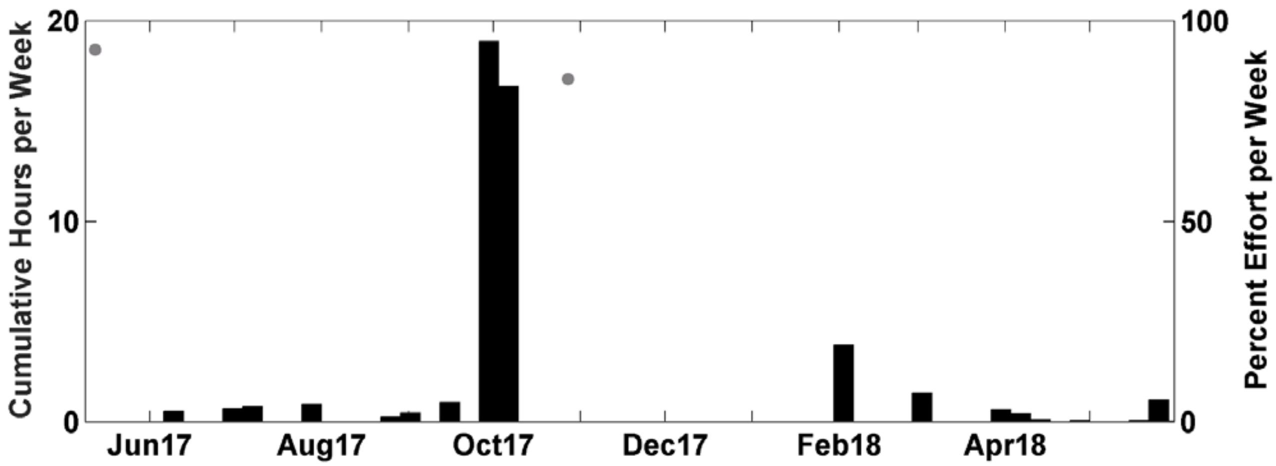

Figure 78. Weekly presence of MFA sonar less than 5 kHz detected from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

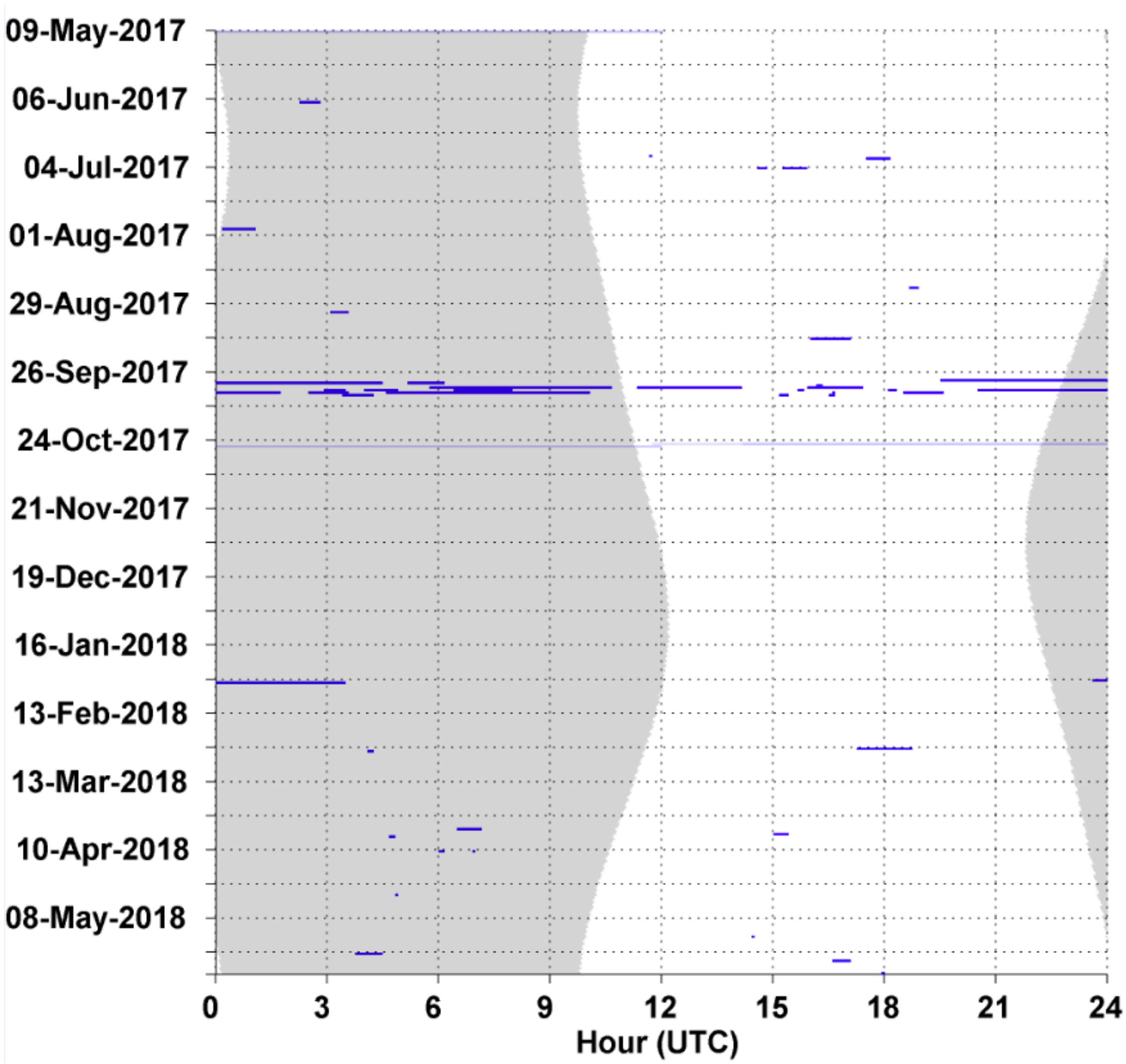

Figure 79. MFA sonar less than 5 kHz in one-minute bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime.

Table 3. Number of analyst-defined MFA events with packets detected with RL > 130 dB re 1 µPa for this recording period.

Deployment	Period Analyzed Days (Years)	Number of Wave Trains	Wave Trains per Year	Number of Packets	Packets per Year
HAT_B_01_01 HAT_B_03_01	386.5 (1.1)	8	7.3	629	571.8

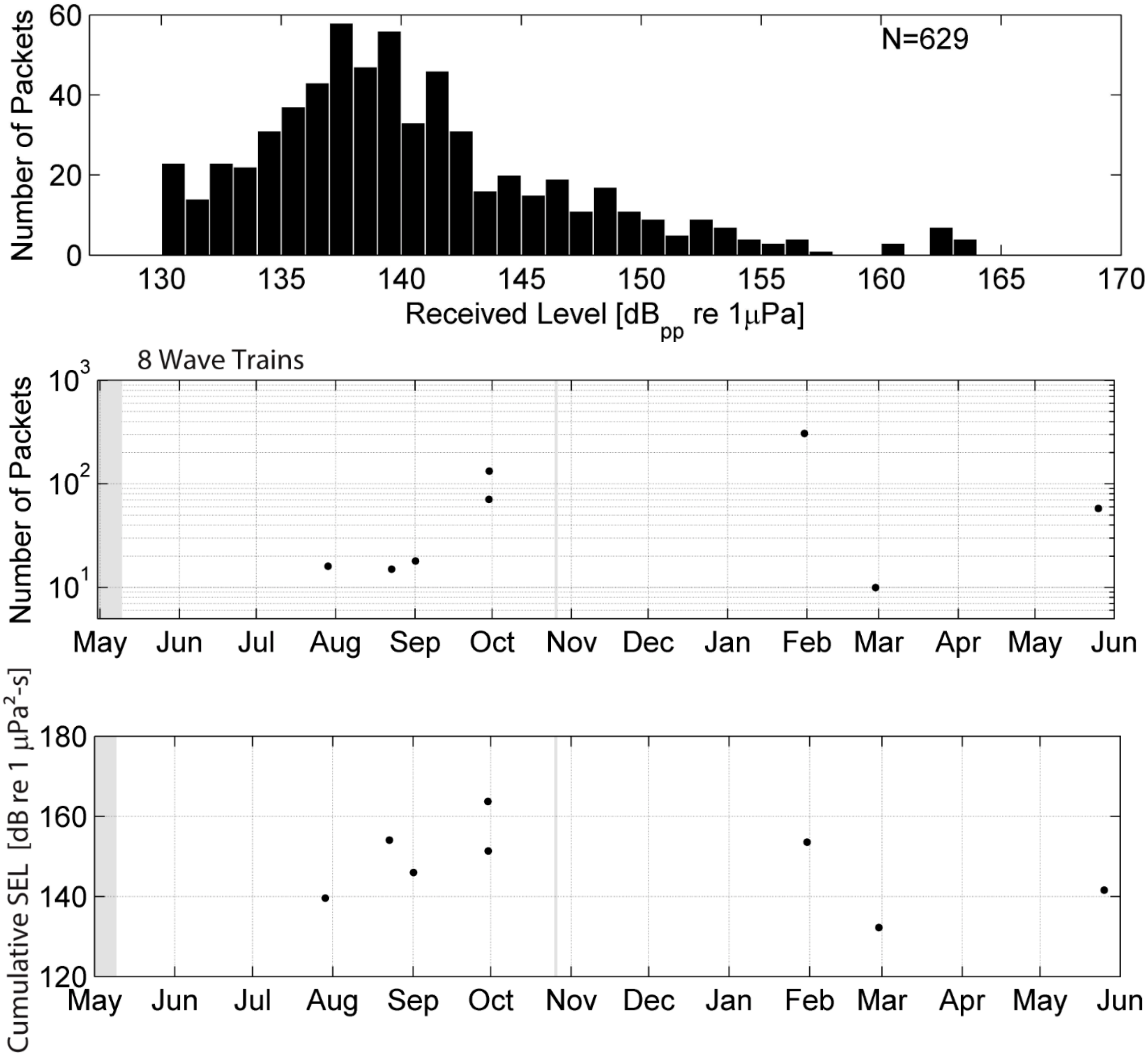

Figure 80. Top: Distribution of received levels (RL) of detected MFA packets. Center: Number of MFA packets detected in each wave train exceeding the minimum RL threshold (130 dBpp re 1µ Pa). Bottom: Cumulative Sound Exposure Levels (CSEL) associated with each wave train.

Controlled Exposure Experiment (CEE) and Mid-Frequency Active (MFA) Sonar Events

During the second recording period, a controlled exposure experiment (CEE) was conducted during August 22, 2017 using an adjustable (i.e., scaled) sound pressure level source near the hydrophone array, and in September 12, 2017 a US Navy full-scale 53C mid-frequency active sonar (MFAS) was operated northwest of the tracking array. Both events were recorded with the array as were concurrent or nearly-concurrent odontocete echolocation clicks (Figure 81–Figure 83).

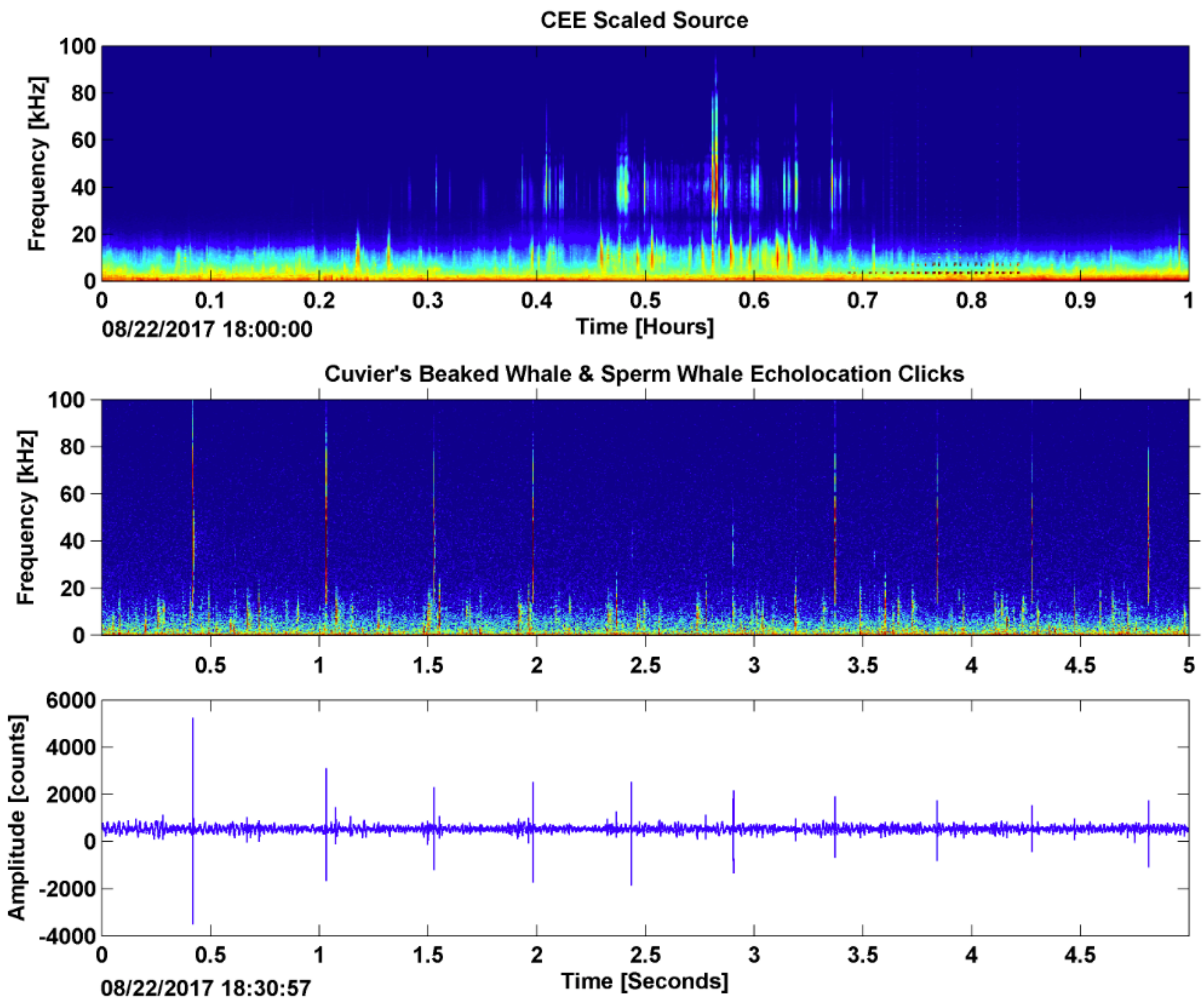

Figure 81. CEE scaled source MFA event at HAT Site B, August 2017.Top: Full band spectra displaying MFA event occurring August 22nd, 2017 from 18:41:00–18:55:00; Center: Cuvier's beaked whale and sperm whale echolocation clicks in 5 second increments; Bottom: Timeseries plot displaying amplitude of the echolocation clicks.

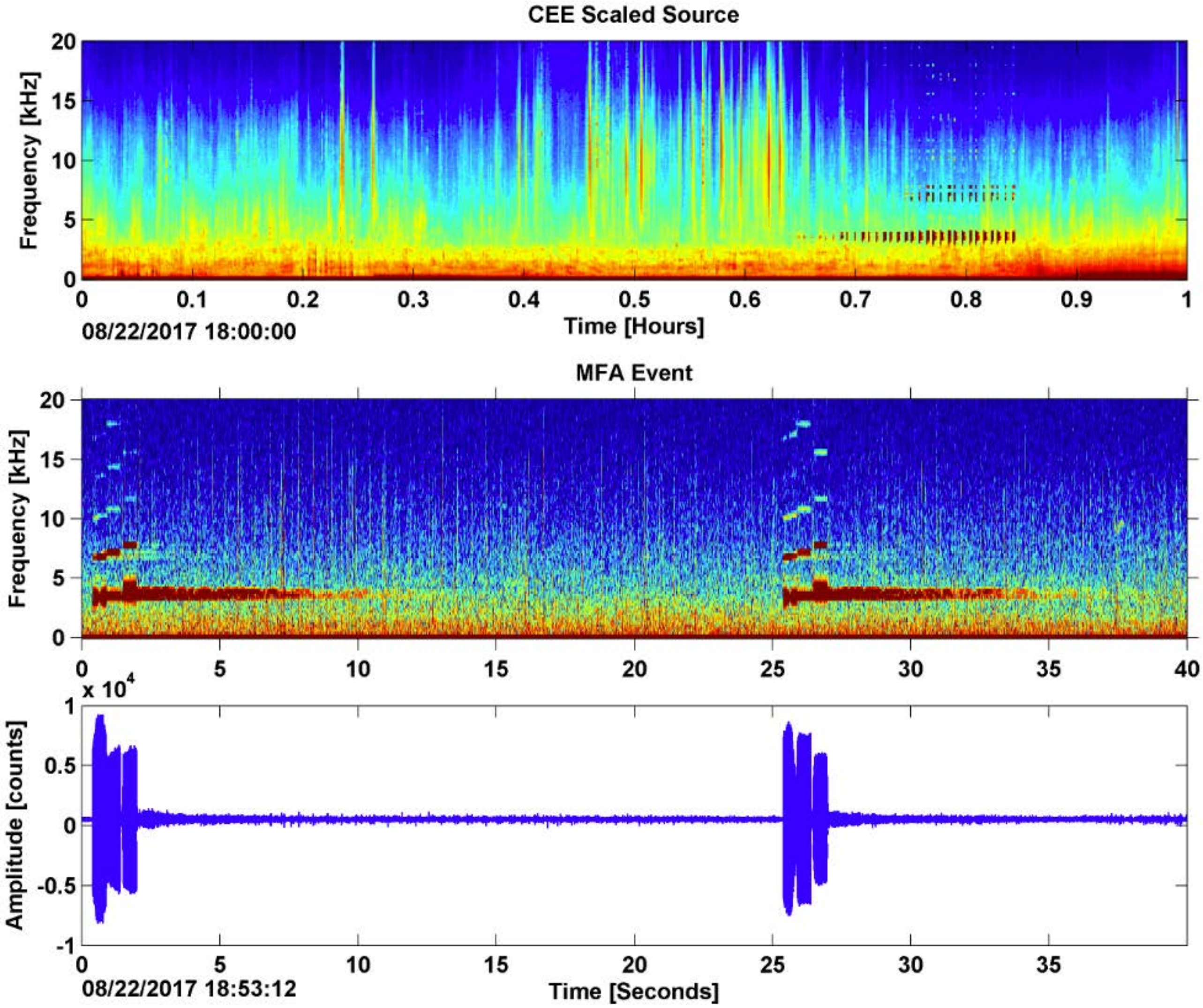

Figure 82. CEE scaled source MFA event at HAT Site B, August 2017. Top: Reduced band spectra displaying MFA event occurring August 22nd, 2017 from 18:41:00–18:55:00; Center: MFA event displaying successive pings with echolocation clicks in the background; Bottom: Timeseries plot displaying amplitude of the MFA event.

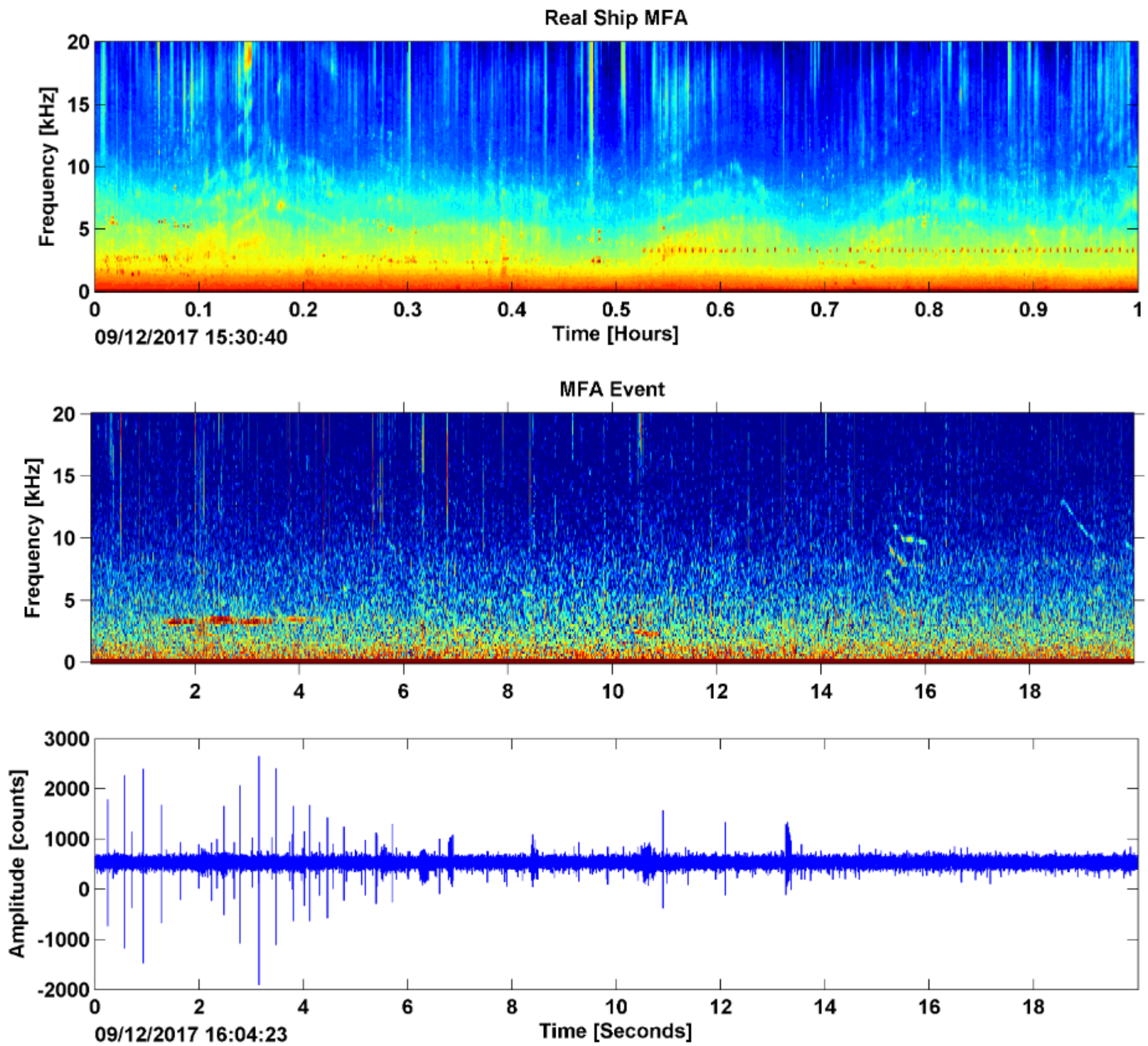

Figure 83. Real ship MFA event at HAT Site B, September 2017. Top: Reduced band spectra displaying MFA event occurring September 12th, 2017 from 16:03:46–17:02:46; Center: MFA event with delphinid clicks, buzzes, and whistles; Bottom: Timeseries plot displaying amplitude of each signal.

HFA Sonar

- HFA sonar greater than 5 kHz was detected once on September 2nd, 2017 (Figure 84).
- The only detection of HFA sonar greater than 5 kHz occurred primarily at night, but there were not enough detections to establish a diel pattern (Figure 85).

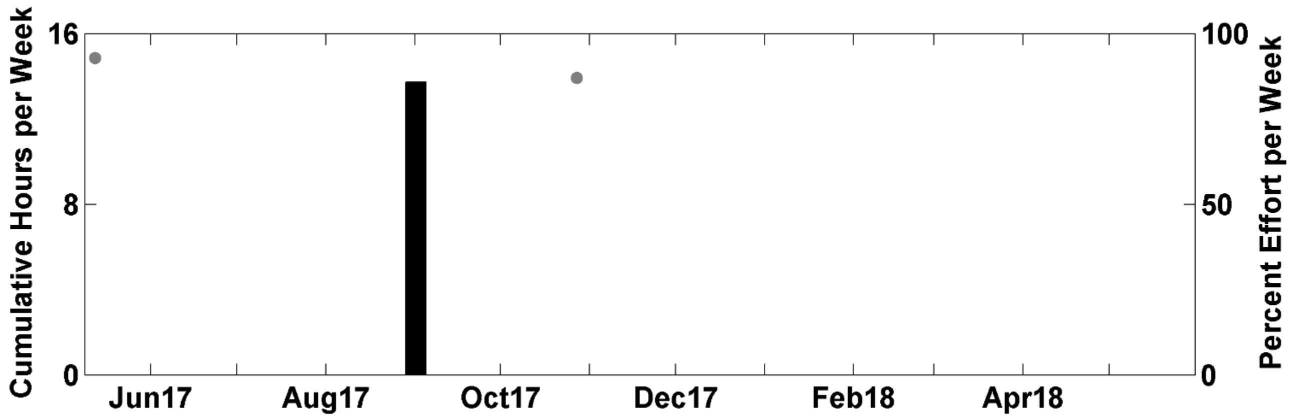

Figure 84. Weekly presence of HFA sonar greater than 5 kHz detected from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

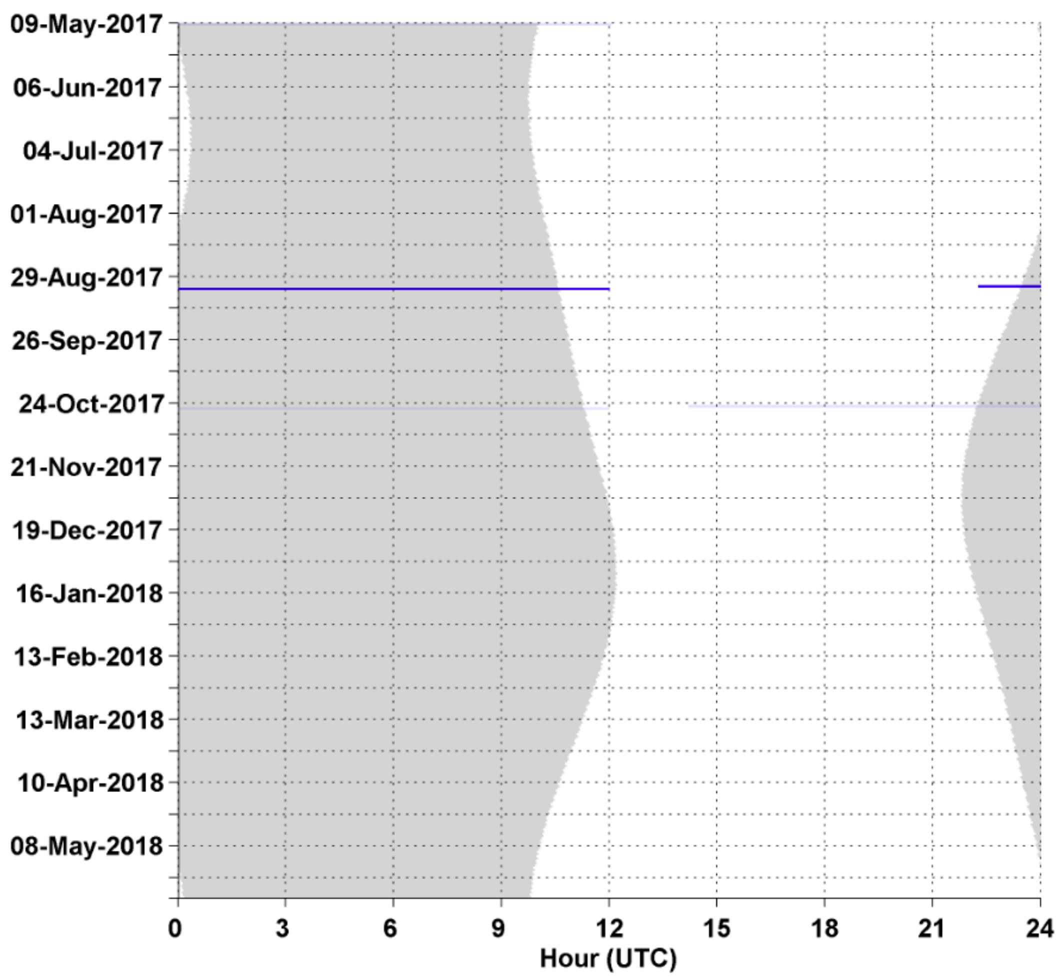

Figure 85. HFA sonar greater than 5 kHz in one-minute bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime.

Echosounders

- Echosounder detections greater than 5 kHz were highest in September 2017 and from November 2017 to March 2018 (Figure 86).
- There was no apparent diel pattern for echosounder detections (Figure 87).

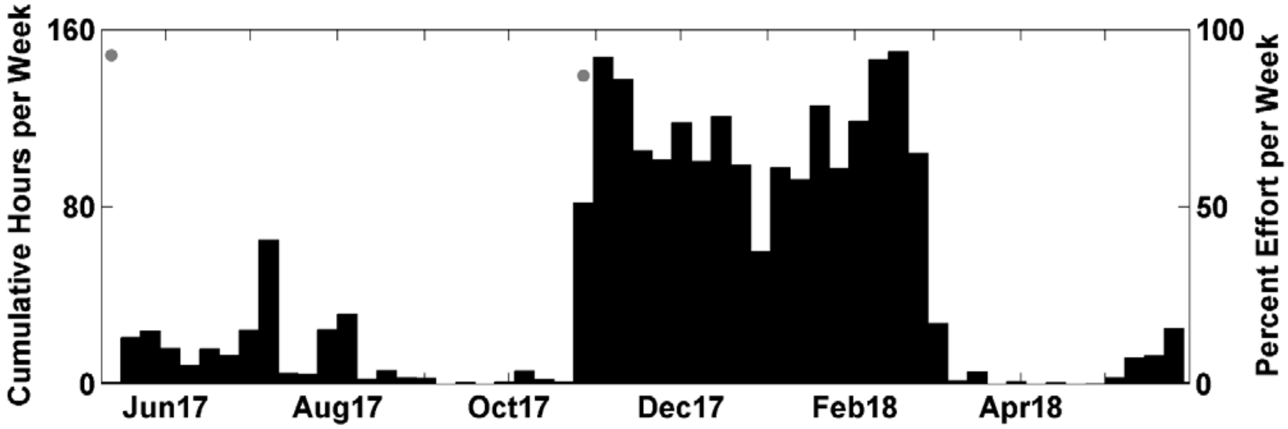

Figure 86. Weekly presence of echosounders greater than 5 kHz detected from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

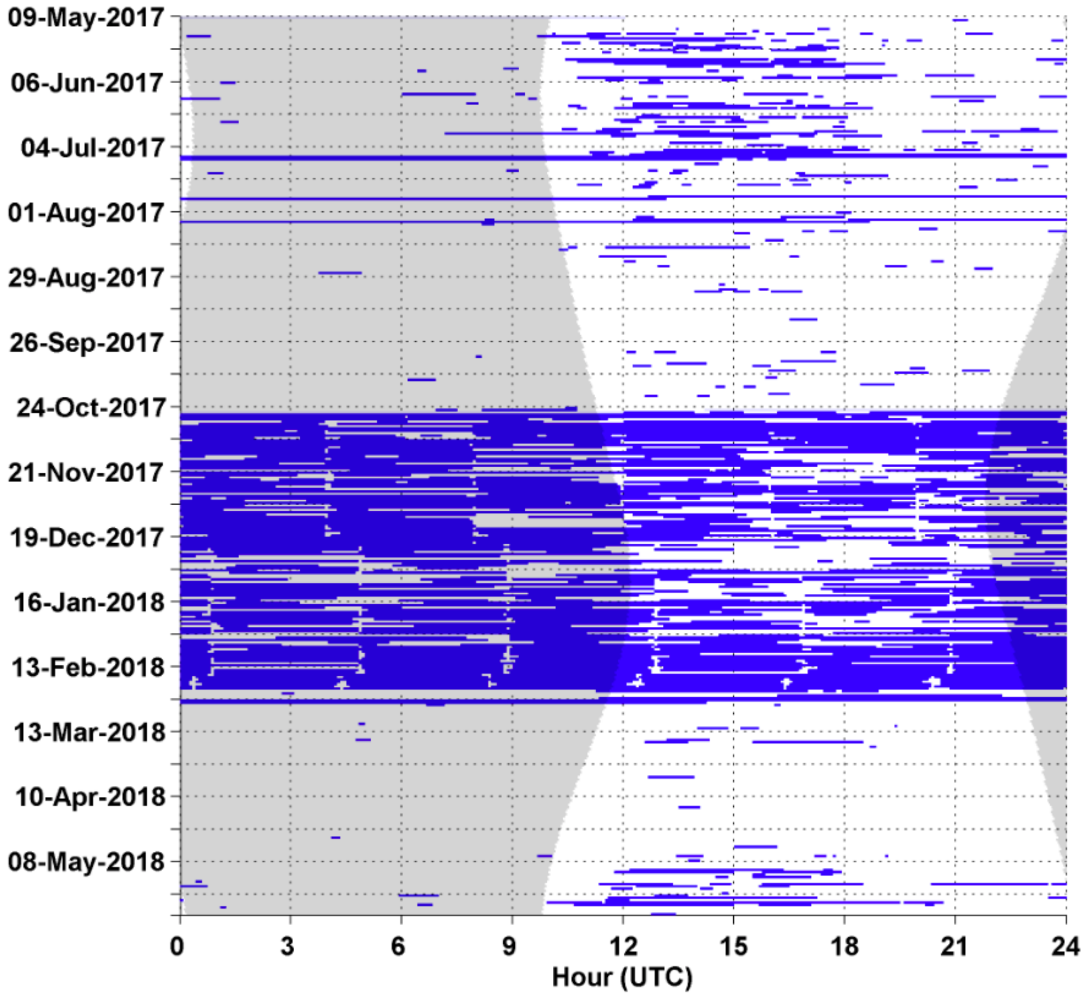

Figure 87. Echosounders greater than 5 kHz in one-minute bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime.

Explosions

- Explosions were detected in low numbers in throughout the recording period. Detections occurred in January, February, April, and May 2018 (Figure 88).
- Explosions were detected only during the day throughout the recording period (Figure 89).

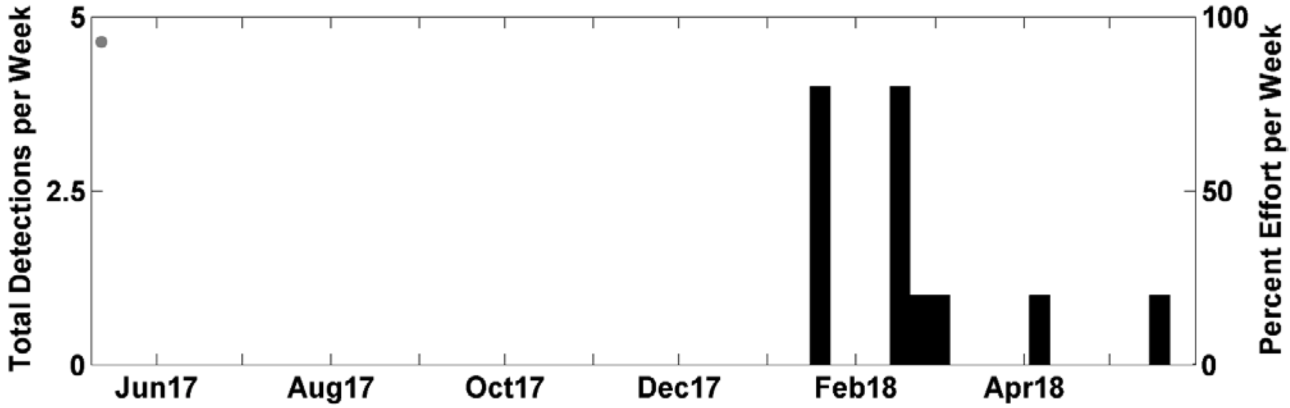

Figure 88. Weekly presence of explosions detected from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

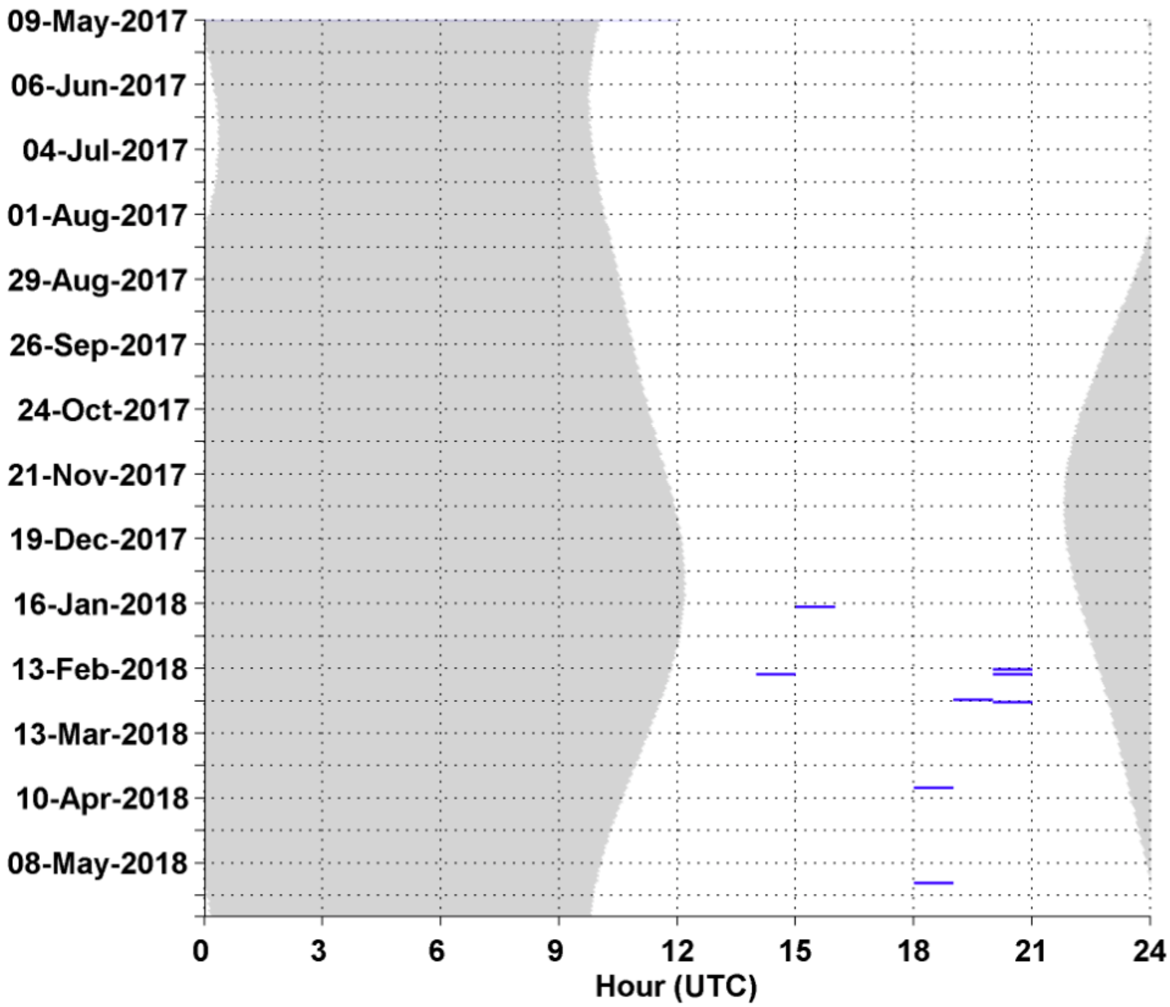

Figure 89. Explosions in one-minute bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime.

Airguns

- Airguns were detected in low numbers throughout the recording period (Figure 90).
- There was no apparent diel pattern for airgun detections (Figure 91).

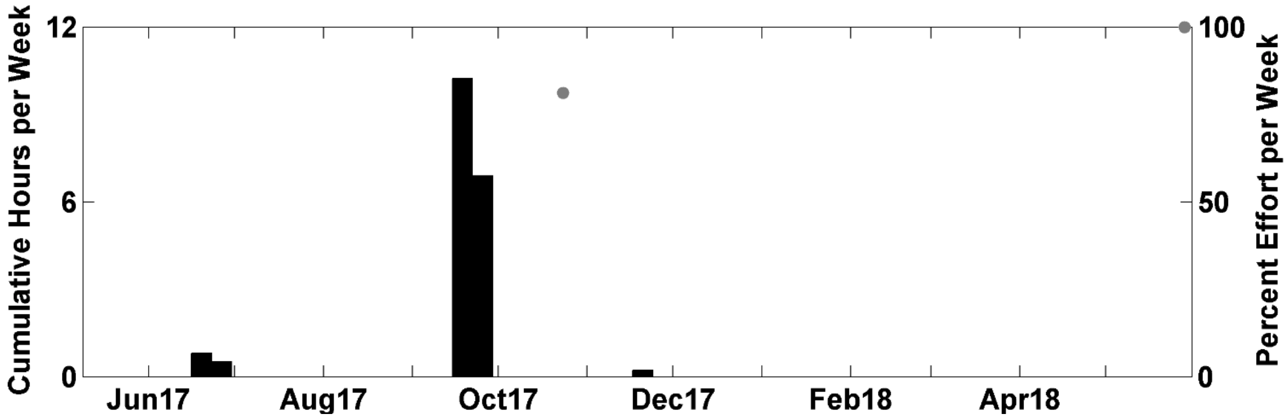

Figure 90. Weekly presence of airguns detected from May 2017 to June 2018 at HAT Site B. Effort markings are described in Figure 38.

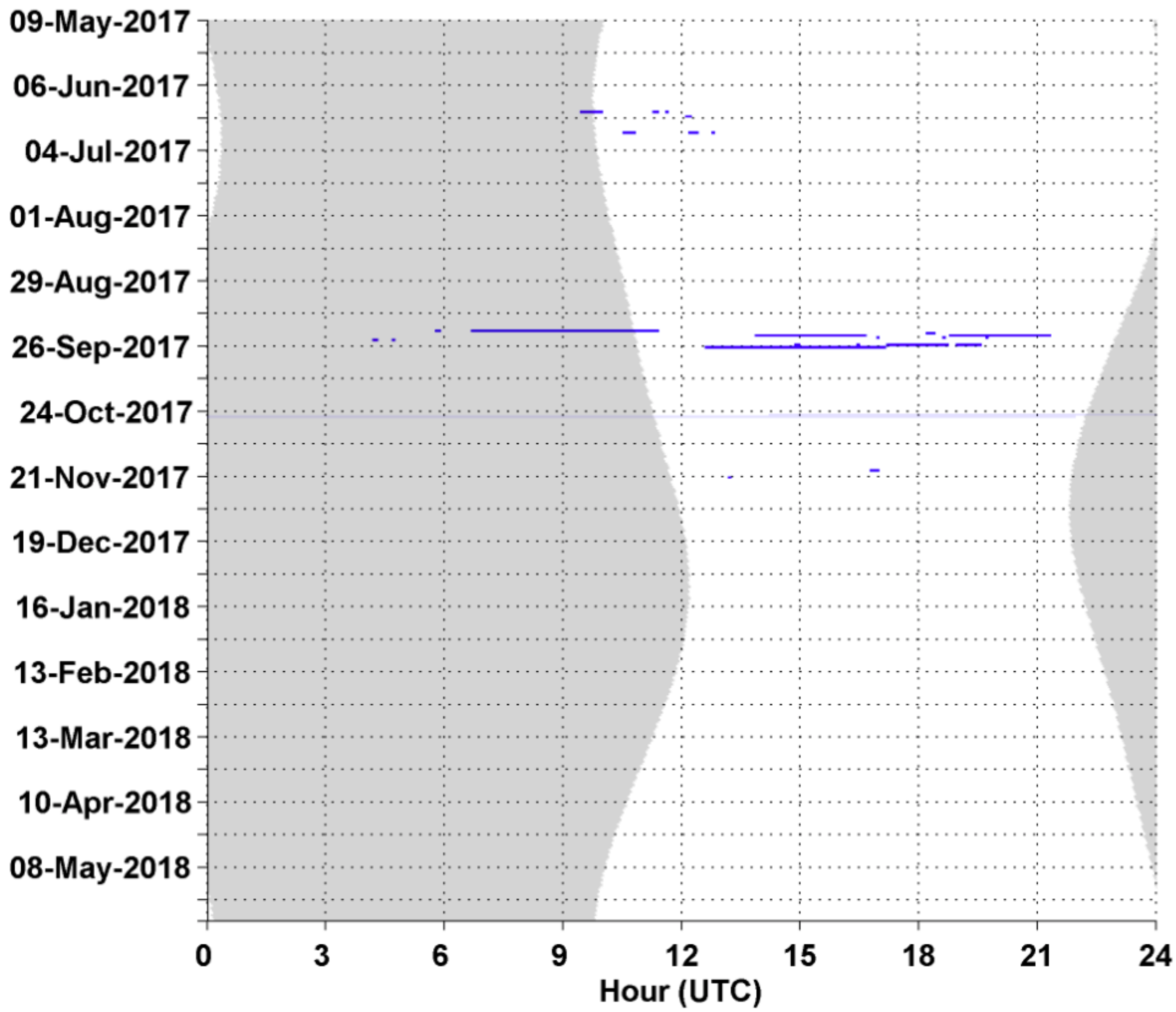

Figure 91. Airguns in one-minute bins at HAT Site B from May 2017 to June 2018. Gray vertical shading denotes nighttime.

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.

Frasier, K. E., Roch, M. A., Soldevilla, M. S., Wiggins, S. M., Garrison, L. P., and Hildebrand, J. A. (2017). Automated classification of dolphin echolocation click types from the Gulf of Mexico. PLoS Computational Biology, 13(12), e1005823.

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.

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.

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.

Roch, M. A., Brandes, T. S., Patel, B., Barkley, Y., Baumann-Pickering, S., and Soldevilla, M. S. (2011a). "Automated extraction of odontocete whistle contours," Journal of the Acoustical Society of America 130, 2212-2223.

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.

Welch, P.D., 1967. The use of fast Fourier transform for the estimation of power spectra: a method based on a time averaging over short, modified periodgrams. IEEE T Acoust. Speech 15, 70–73.

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.

Wiggins, S. M, Thayre, B. J., Trickey, J. S., Baumann-Pickering, S., Hildebrand. J. A. “Beaked Whale Passive Acoustic Tracking offshore of Cape Hatteras 2017,” Marine Physical Laboratory, Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, MPL Technical Memorandum 631 October 2018.

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.