

Passive Acoustic Monitoring for Marine Mammals in the Virginia Capes Range Complex April 2015 – January 2016

Kait E. Frasier, Amanda J. Debich, Jenny Tricky, Simone Baumann-Pickering, Ana Širović,
John A. Hildebrand, Leah M. Varga, Ally C. Rice, Bruce J. Thayre, Ariel M. Brewer,
and Sean M. Wiggins

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

Lynne E.W. Hodge and Andrew J. Read

Duke University Marine Laboratory, Nicholas School of the Environment, Beaufort, NC 28516



Short-finned pilot whales, photo by Amanda J. Debich

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

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Executive Summary

To monitor for the presence of marine mammals, a High-frequency Acoustic Recording Package (HARP) recorded within the Navy's Virginia Capes Range Complex, offshore from Cape Hatteras (HAT), between April 2015 and January 2016. The HAT site was located approximately 75 nm offshore in about 1000 m of water.

The HARP recorded underwater acoustic data between 10 Hz and 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 10-300 Hz, (2) Mid-frequency, between 10-5,000 Hz, and (3) High-frequency, between 1-100 kHz.

Three baleen whale species were detected: fin whales, sei whales, and minke whales. Fin whale calls were detected throughout the monitoring period with a peak in calling from November 2015 through early January 2016. Sei whales were detected in December 2015 and January 2016. Minke whale pulse trains were common in April 2015 and from November 2015 to January 2016.

Echolocation clicks from six known odontocete species were detected: Risso's dolphins, sperm whales, Cuvier's beaked whale, Gervais' beaked whale, Blainville's beaked whale and *Kogia* spp. Five distinct click types that are not yet assigned to a species were also detected. Risso's dolphins were detected between May and June 2015. Sperm whale detections peaked in May 2015, August 2015 and January 2016. Cuvier's and Gervais' beaked whales were detected throughout the monitoring period. A single Blainville's beaked whale encounter was detected in January 2016. *Kogia* spp. echolocation clicks were detected throughout the deployment with a peak in June 2015.

Two categories of unidentified odontocete whistles were detected; Whistles below 5 kHz and whistles above 5 kHz were detected throughout the monitoring period.

Airguns and broadband ships were the most commonly detected anthropogenic sounds. Other anthropogenic sounds detected include explosions, Low-Frequency Active (LFA) sonar above 500 Hz, Mid-Frequency Active (MFA) sonar, and echosounders. Broadband ship noise was detected throughout the recording period. Airguns were detected throughout the recording period with higher detection rates in summer months. A gap in airgun activity was observed in May and June 2015. Explosions were detected infrequently with a peak in August 2015. MFA sonar was detected sporadically throughout the deployment. LFA sonar above 500 Hz was detected on a single day in September 2015. Echosounders were detected throughout the deployment, with higher numbers in summer months.

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 shallower 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 the Atlantic Fleet under contract to HDR and Duke University. The goal of this effort was to characterize the vocalizations of marine mammal species present in the area, to determine their seasonal presence patterns, and to evaluate the potential for impact from naval operations. This report documents the analysis of data recorded by a High-frequency Acoustic Recording Package (HARP) deployed off Cape Hatteras (designated HAT) within the Virginia Capes Range Complex that collected data from April 2015 - January 2016 (Figure 1).

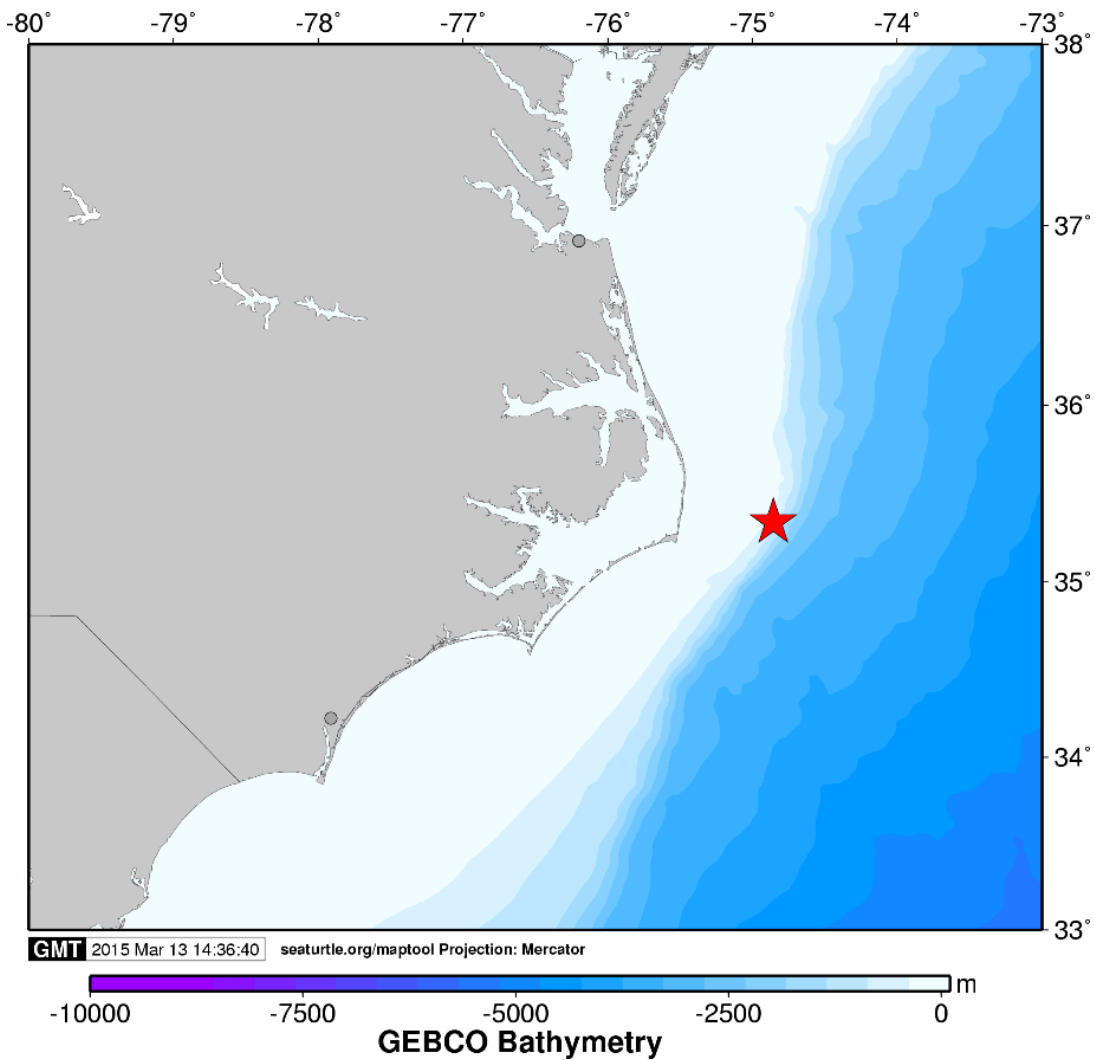


Figure 1. Location of High-frequency Acoustic Recording Package (HARP) at site HAT (35° 20.531 N, 74° 51.436 W, depth 980 m) recording from April 2015 to January 2016.

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 that are capable of approximately 300 days of continuous data storage. The HARP was deployed in a compact 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

One HARP was deployed from April 2015 to April 2016 at HAT (35° 20.531 N, 74° 51.436 W, depth 980 m) and sampled continuously at 200 kHz to provide 100 kHz of effective bandwidth. The instrument recorded 289.5 days from April 7, 2015 to January 21, 2016, for a total of 6,948 hours of data analyzed. Earlier data collection in the Virginia Capes Range Complex is documented in a previous report (Debich *et al.*, 2016).

Data Analysis

To visualize the acoustic data, frequency spectra were calculated for all data using a time average of 5 seconds and variable size frequency bins (1, 10, and 100 Hz). These data, called Long-Term Spectral Averages (LTSAs), were then examined as a means to detect marine mammal and anthropogenic sounds. Data were analyzed by visually scanning LTSAs in source-specific frequency bands and, when appropriate, using automatic detection algorithms (described below). During visual analysis, when a sound of interest was identified in the LTSA but its origin was unclear, the waveform or spectrogram was examined to further classify the sounds to species or source. Signal classification was carried out by comparison to known species-specific spectral and temporal characteristics.

Recording over a broad frequency range of 10 Hz – 100 kHz allows detection of baleen whales (mysticetes), toothed whales (odontocetes), and anthropogenic sounds. The presence of acoustic signals from multiple marine mammal species and anthropogenic noise was evaluated in the data. To document the data analysis process, we describe the major classes of marine mammal calls and anthropogenic sounds in the region, and the procedures used to detect them. For effective analysis, the data were divided into three frequency bands: (1) Low-frequency, 10-300 Hz, (2) Mid-frequency, 10-5,000 Hz, and (3) High-frequency, 1-100 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 were classified as low-frequency. Humpback whale calls, nearby shipping, explosions, airguns, underwater communications, low-frequency active sonar above 500 Hz, and mid-frequency active sonar sounds were classified as mid-frequency. The remaining odontocete and sonar sounds were considered high-frequency. For efficient analysis of low-frequency recordings, data were decimated by a factor of 100 and for the mid-frequency analysis by a factor of 20.

We summarize acoustic data collected between April 2015 and January 2016. We discuss seasonal occurrence and relative abundance of calls for different species and anthropogenic sounds that were consistently identified in the acoustic data.

Low-Frequency 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*). The hourly presence of North Atlantic blue whale calls, blue whale arch sounds, 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. For this analysis, the 200 kHz sampled raw data were decimated by a factor of 100 for an effective bandwidth of 1 kHz. LTSAs of decimated data were created using a time average of 5 seconds and frequency bins of 1 Hz. The same LTSA and spectrogram parameters were used for manual detection of all call types using the custom software program *Triton*. During manual scrutiny of the data, the LTSA was set to display frequencies between 1-300 Hz with a 1-hour plot length. To observe individual calls, the spectrogram window was typically set to display 1-250 Hz with a 60 second plot length. The spectral analysis length 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.

Fin whale 20 Hz calls were detected automatically using an energy detection method and are reported as 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 tonal call and the arch call (Mellinger and Clark, 2003).

Blue Whale North Atlantic Calls

The blue whale tonal call is an 18-19 Hz tone lasting approximately 8 s, often followed by an 18-15 Hz slightly frequency modulated component lasting approximately 11 s (Figure 2). There were no detections of blue whale tonal calls in this recording.

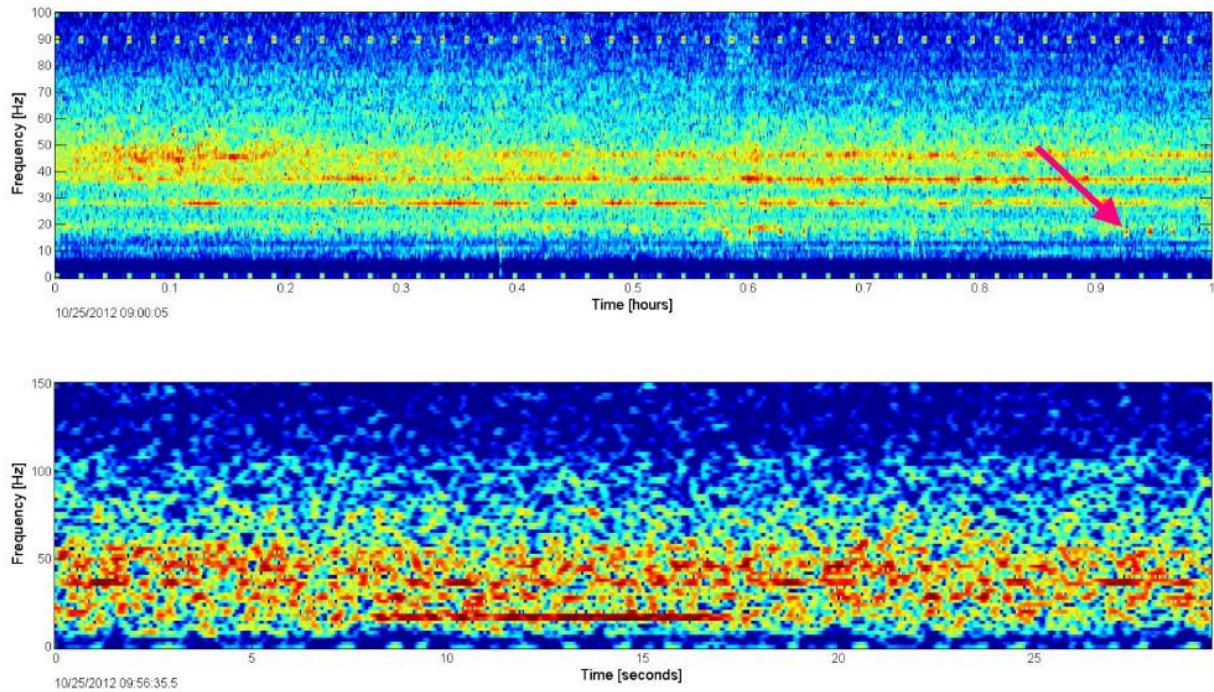


Figure 2. North Atlantic blue whale calls in the LTSA (top) and spectrogram (bottom) recorded at HAT. Red arrow indicates location of LTSA expanded in the spectrogram.

Blue Whale Arch Calls

The blue whale arch calls are variable frequency modulated calls, usually covering frequencies between approximately 70 and 35 Hz lasting up to 6 s (Figure 3). There were no detections for blue whale arch calls in this recording.

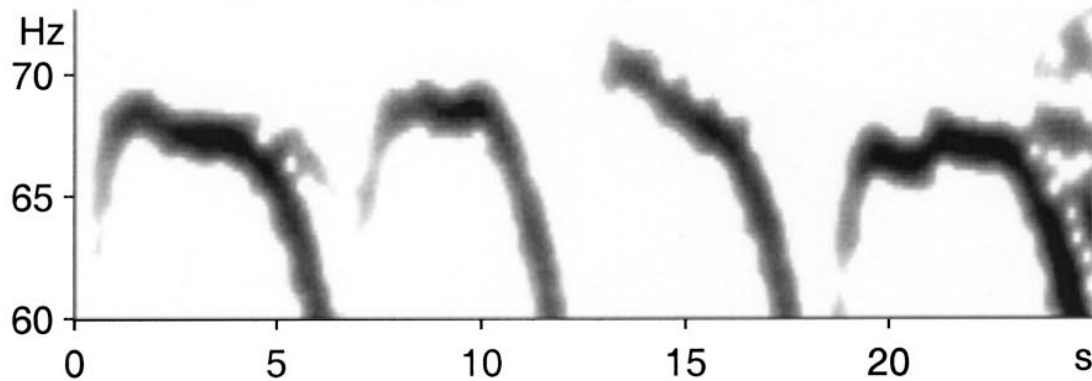


Figure 3. Blue whale arch calls from Mellinger and Clark (2003).

Fin Whales

Fin whales produce two types of short (approximately 1 s duration), low-frequency calls: downsweeps in frequency from 30-15 Hz, called 20 Hz calls (Watkins, 1980) (Figure 4) and downsweeps from 75-40 Hz, called 40 Hz calls (Figure 5). 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 4) were detected automatically using an energy detection method (Širović et al., 2014). The method used a difference in acoustic energy between signal and noise, calculated from a 5 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.

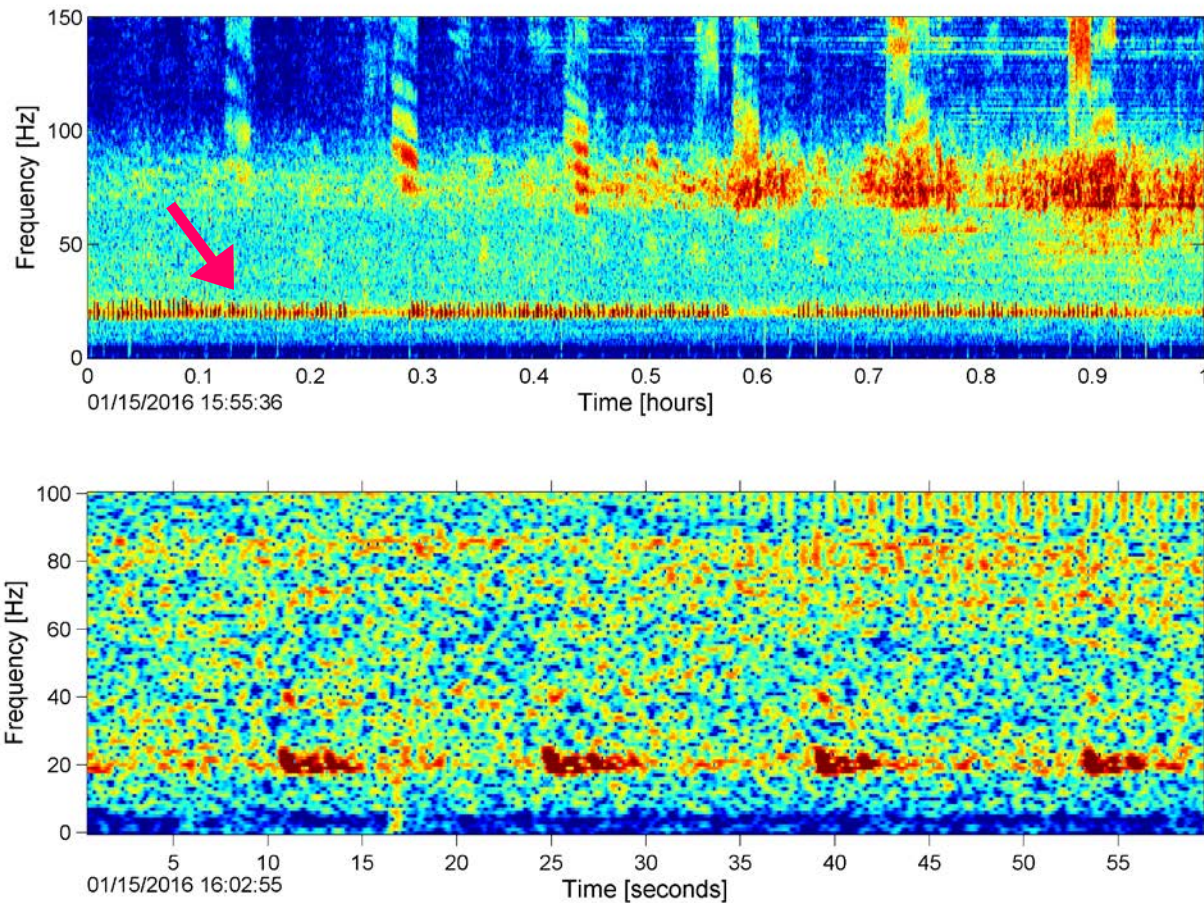


Figure 4. Fin whale 20 Hz calls in the LTSA (top) and spectrogram (bottom) recorded at HAT. Red arrow indicates location of LTSA expanded in the spectrogram.

Fin Whale 40 Hz Calls

The presence of fin whale 40 Hz calls (Figure 5) was examined via manual scanning of the LTSA and subsequent verification from a spectrogram of the frequency and temporal characteristics of the calls. There were no confirmed detections of fin whale 40 Hz calls in this recording.

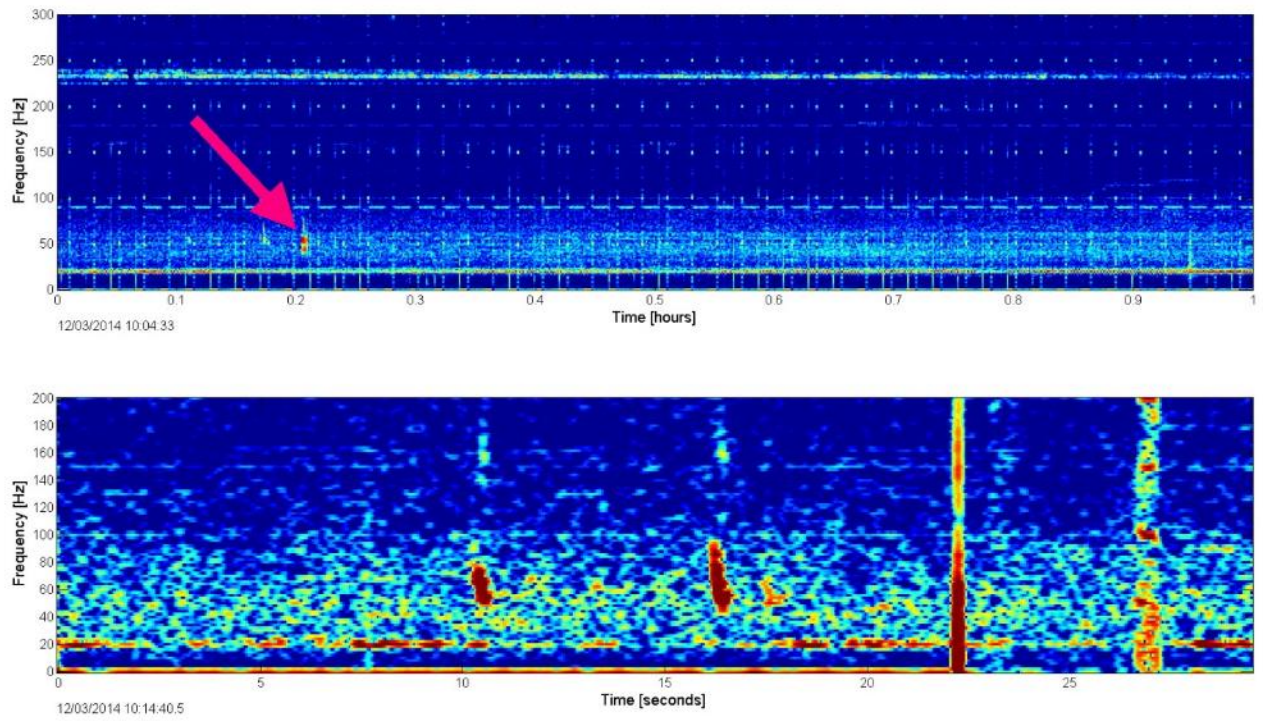


Figure 5. Fin whale 40 Hz calls in the LTSA (top) and spectrogram (bottom) recorded at HAT during previous deployments. Red arrow indicates location of LTSA expanded in the spectrogram.

Bryde's Whales

Bryde's whales inhabit tropical and subtropical waters worldwide (Omura, 1959; Wade and Gerrodette, 1993), and have been reported as far north as Chesapeake Bay in the Northwestern Atlantic (Rice, 1998).

Be 7 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 minutes (Figure 6). There were no detections of Bryde's whale Be7 calls in these recordings.

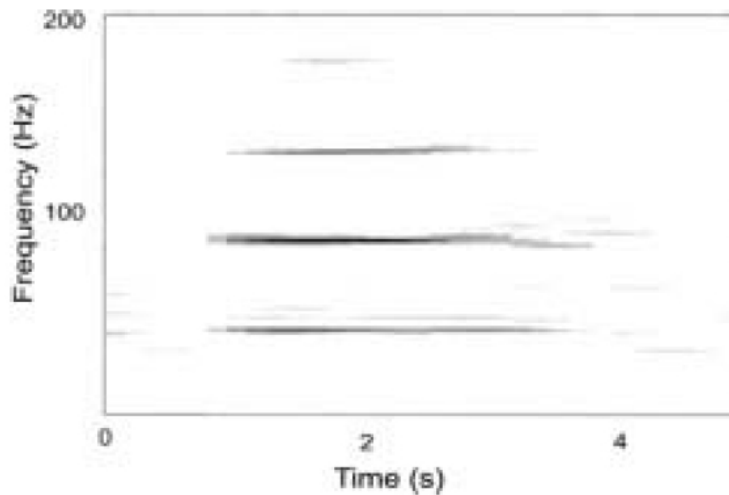


Figure 6. Bryde's whale Be7 call from Oleson *et al.* (2003).

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 7). There were no detections of Bryde's whale Be9 calls in these recordings.

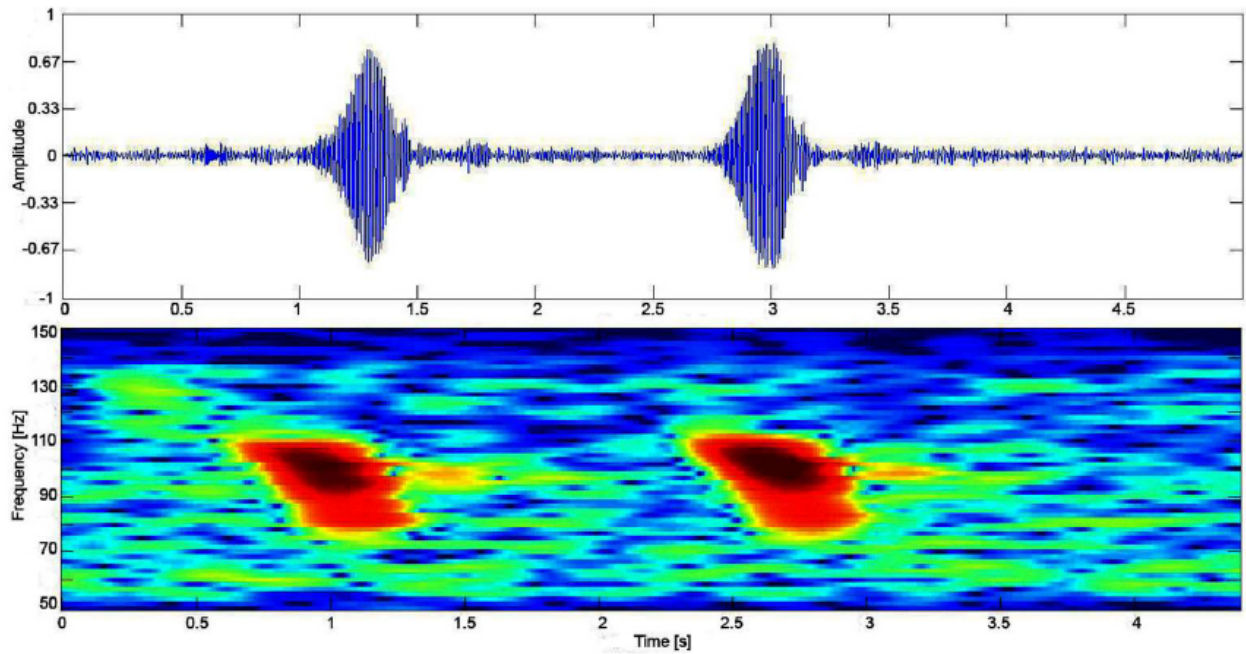


Figure 7. Bryde's whale Be9 calls from the Gulf of Mexico (Širović *et al.*, 2014).

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).

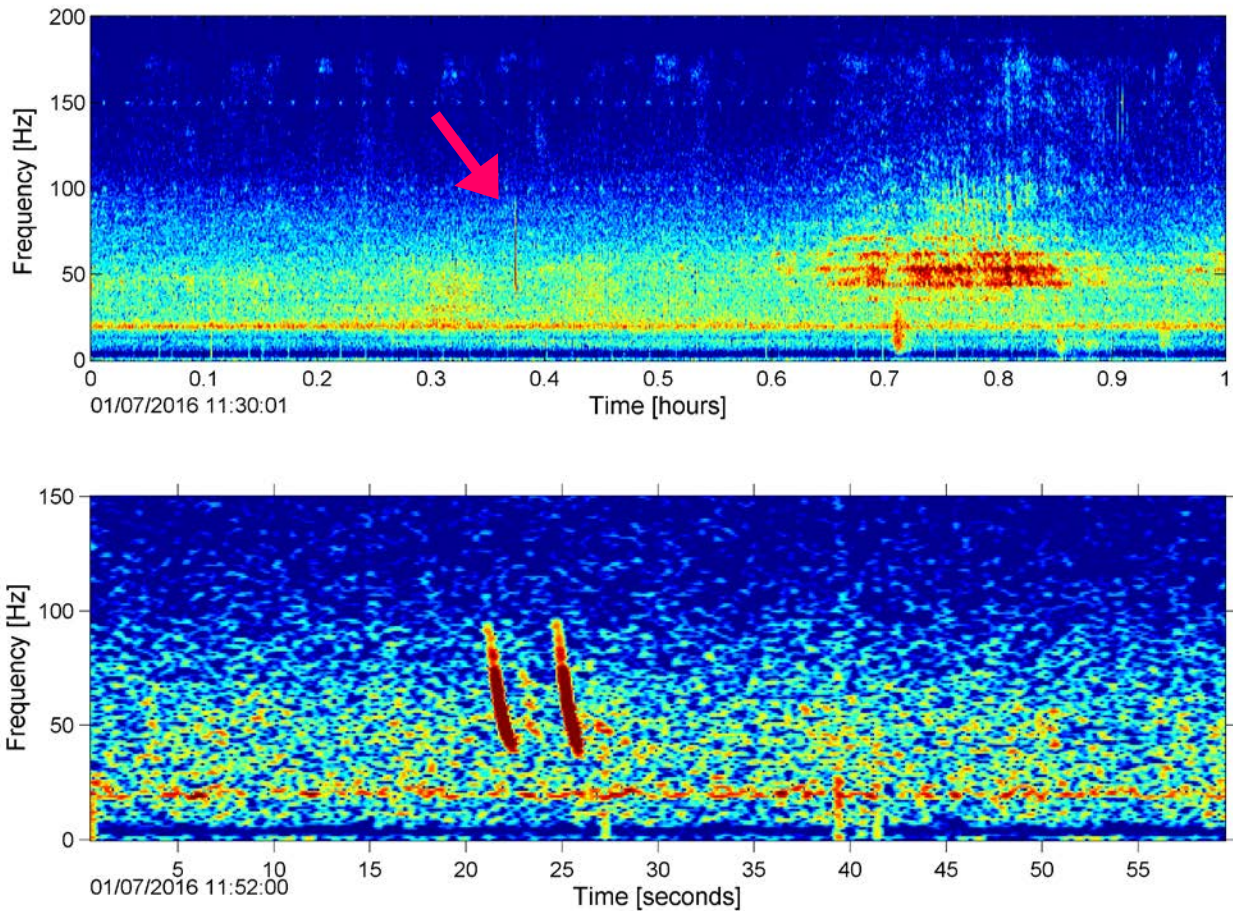


Figure 8. Sei whale downsweep calls in the LTSA (top) and spectrogram (bottom) recorded at HAT. Red arrow indicates location of LTSA expanded in the spectrogram.

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

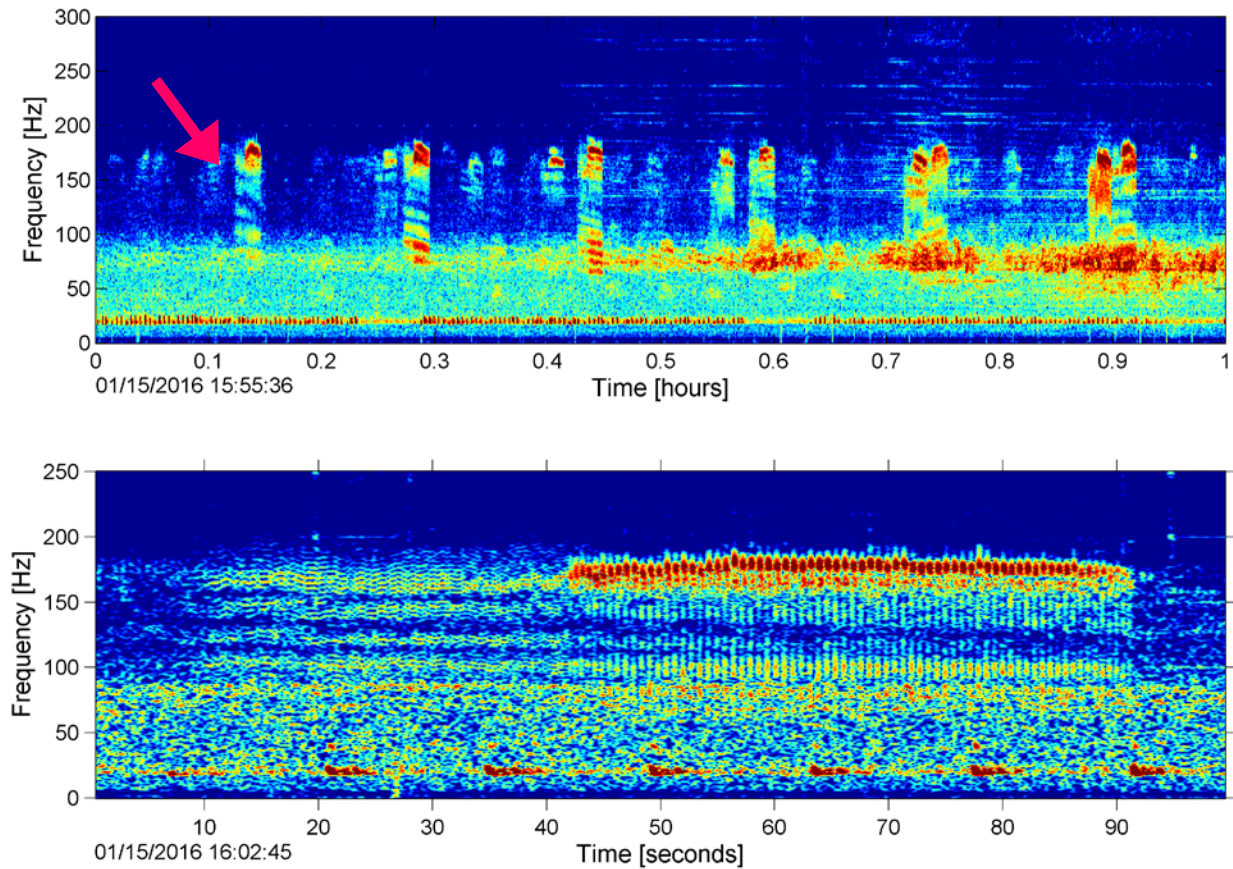


Figure 9. Minke whale pulse train in the LTSA (top) and spectrogram (bottom) recorded at HAT. Red arrow indicates location of LTSA expanded in the spectrogram.

North Atlantic Right Whales

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

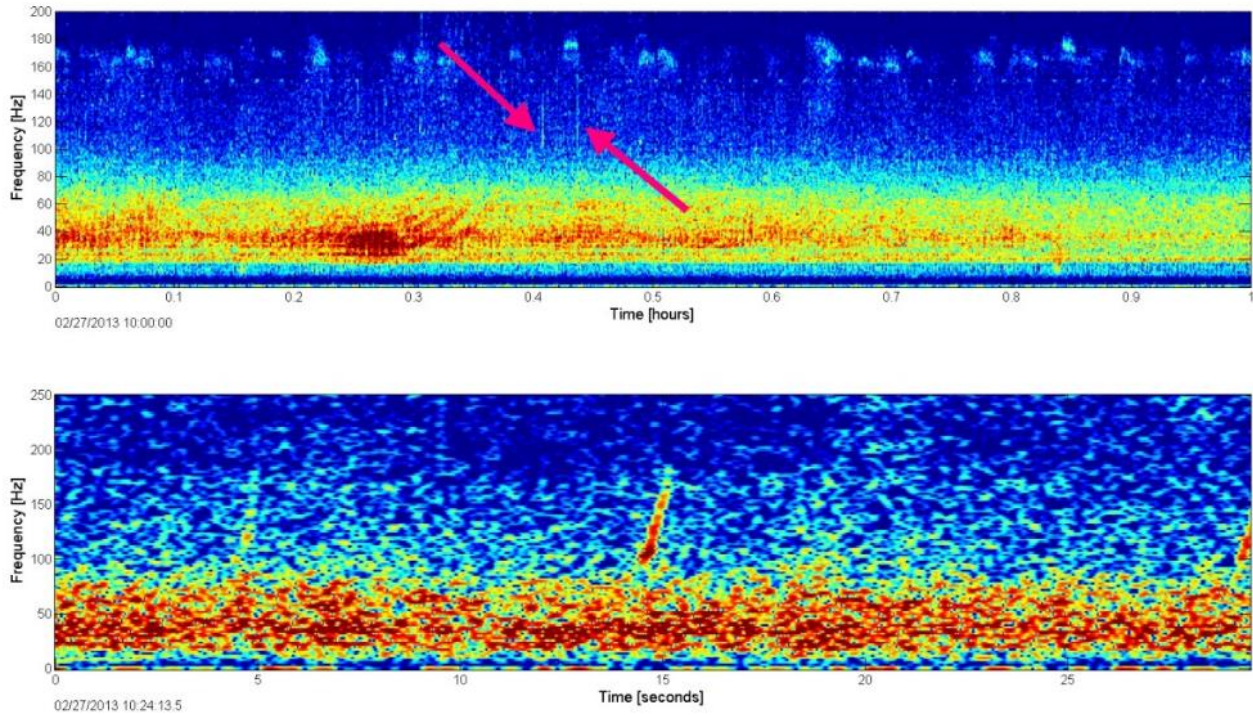


Figure 10. North Atlantic right whale up-calls in the LTSA (top) and spectrogram (bottom) recorded at HAT. Red arrow indicates location of calls in the LTSA.

Mid-Frequency Marine Mammals

Marine mammal species with sounds in the mid-frequency range expected in the Virginia Capes Range Complex include humpback whales (*Megaptera novaeangliae*). For mid-frequency data analysis, the 100 kHz data were decimated by a factor of 20 for an effective bandwidth of 5 kHz. The LTSAs for mid-frequency analysis were created using a time average of 5 seconds, and a frequency bin size of 10 Hz. Humpback whales were detected automatically as described below.

Humpback Whales

Humpback whales produce both song and non-song calls (Payne and McVay, 1971; Dunlop *et al.*, 2007; Stimpert *et al.*, 2011). Most humpback whale vocalizations are produced between 100 - 3,000 Hz. An automatic detection algorithm based on the generalized power law was used to detect humpback calls (Helble *et al.*, 2012). Potential detections were subsequently verified for accuracy by a trained analyst (Figure 11). There was no effort to separate song and non-song calls. There were no humpback whale detections in this deployment.

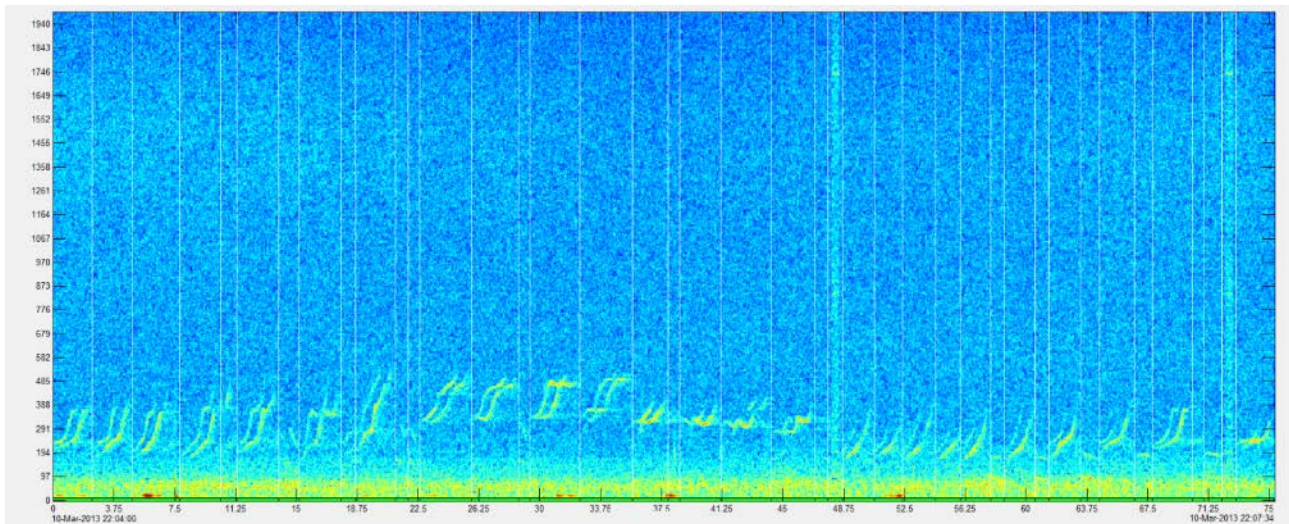


Figure 11. Humpback whale song from previous deployment at the HAT site in the analyst verification stage of the detector. Green in the bottom evaluation line indicates true detections.

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*), killer whales (*Orcinus orca*), pygmy killer whales (*Feresa attenuata*), melon-headed whales (*Peponocephala electra*), sperm whales (*Physeter macrocephalus*), dwarf sperm whales (*Kogia sima*), pygmy sperm whales (*Kogia breviceps*), Cuvier's beaked whales (*Ziphius cavirostris*), Gervais' beaked whales (*Mesoplodon europaeus*), Blainville's beaked whales (*Mesoplodon densirostris*), True's beaked whales (*Mesoplodon mirus*) and Sowerby's beaked whales (*Mesoplodon bidens*).

High-Frequency Call Types

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

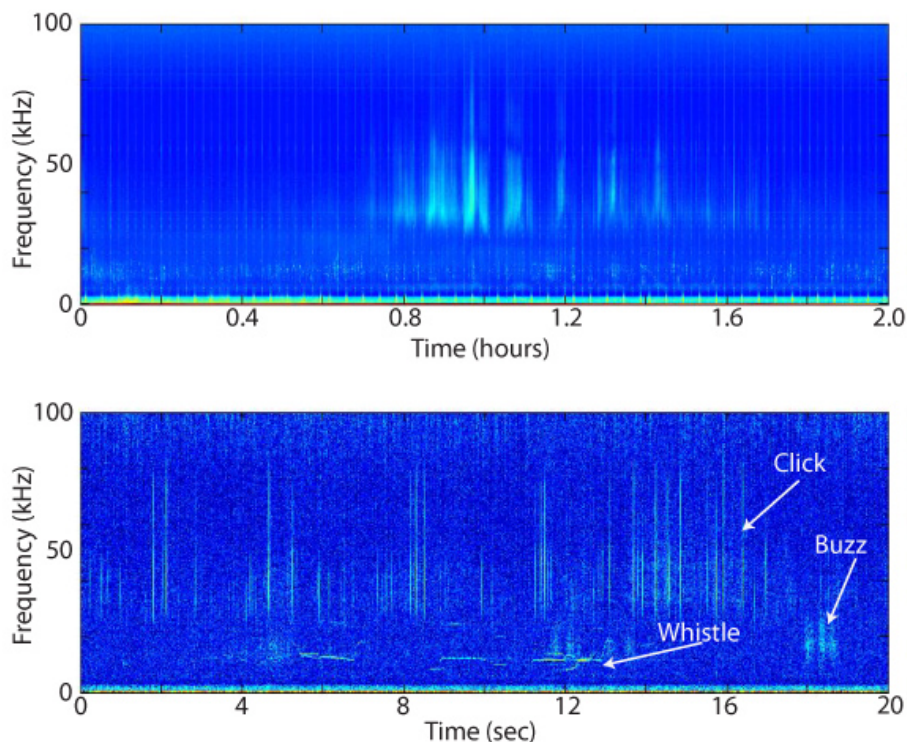


Figure 12. LTSA (top) and spectrogram (bottom) demonstrating odontocete signal types.

Sperm Whales

Sperm whale clicks contain energy from 2-20 kHz, with the majority of energy between 10-15 kHz (Møhl *et al.*, 2003) (Figure 13). Regular clicks, observed during foraging dives, demonstrate an ICI from 0.25-2 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 (Mellinger *et al.*, 2007). Slow clicks 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, regular or slow clicks.

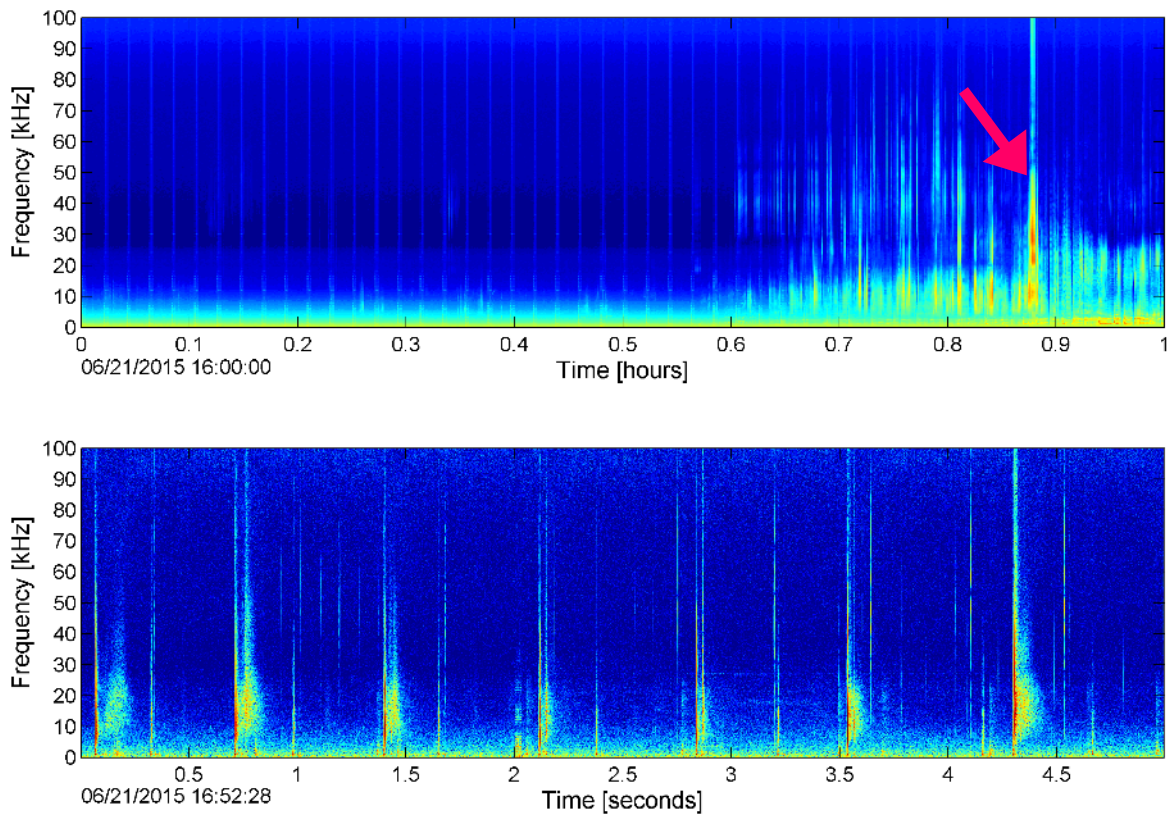


Figure 13. Sperm whale echolocation clicks in LTSA (top) and spectrogram (bottom) recorded at HAT. Red arrow indicates location of LTSA expanded in the spectrogram.

Beaked whales

Beaked whales can be identified acoustically by their echolocation signals (Baumann-Pickering *et al.*, 2014; Stanistreet *et al.*, 2016). 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. No Sowerby's beaked whales were detected in these data or in previous HAT recordings and they are not further described below.

Beaked whale FM pulses were detected with an automated method. This automated effort was for all identifiable beaked whale signals found in the Virginia Capes Range 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 μ s, 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.

Cuvier's Beaked Whales

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

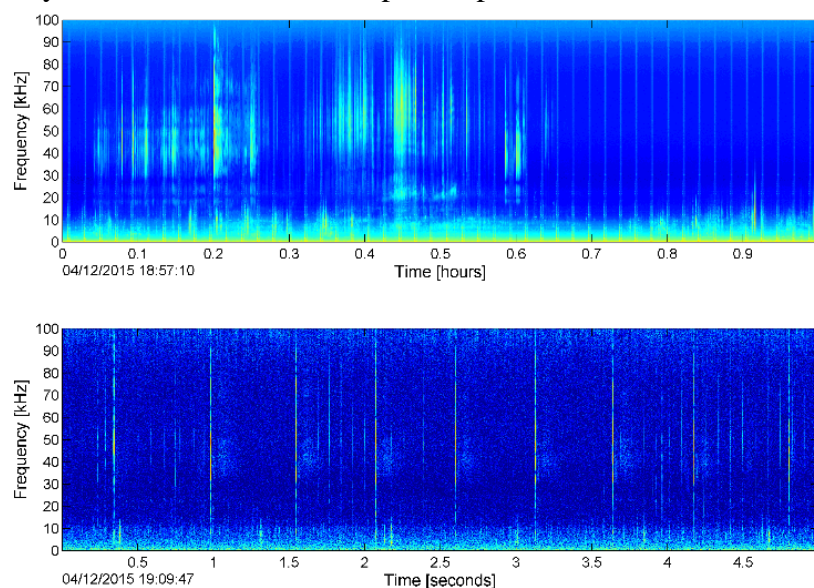


Figure 14. Cuvier's beaked whale echolocation clicks in LTSA (top) and spectrogram (bottom) recorded at HAT.

Gervais' Beaked Whales

Gervais' beaked whale signals have energy concentrated in the 30 – 50 kHz band (Gillespie *et al.*, 2009), with a peak at 44 kHz (Baumann-Pickering *et al.*, 2013). While Gervais' beaked whale signals are similar to those of Cuvier's and Blainville's beaked whales, the Gervais' beaked whale FM pulses are at a slightly higher frequency than those of the other two species. Similarly, Gervais' beaked whale FM pulses sweep up in frequency (Figure 15). The IPI for Gervais' beaked whale signals is typically around 275 ms (Baumann-Pickering *et al.* 2013).

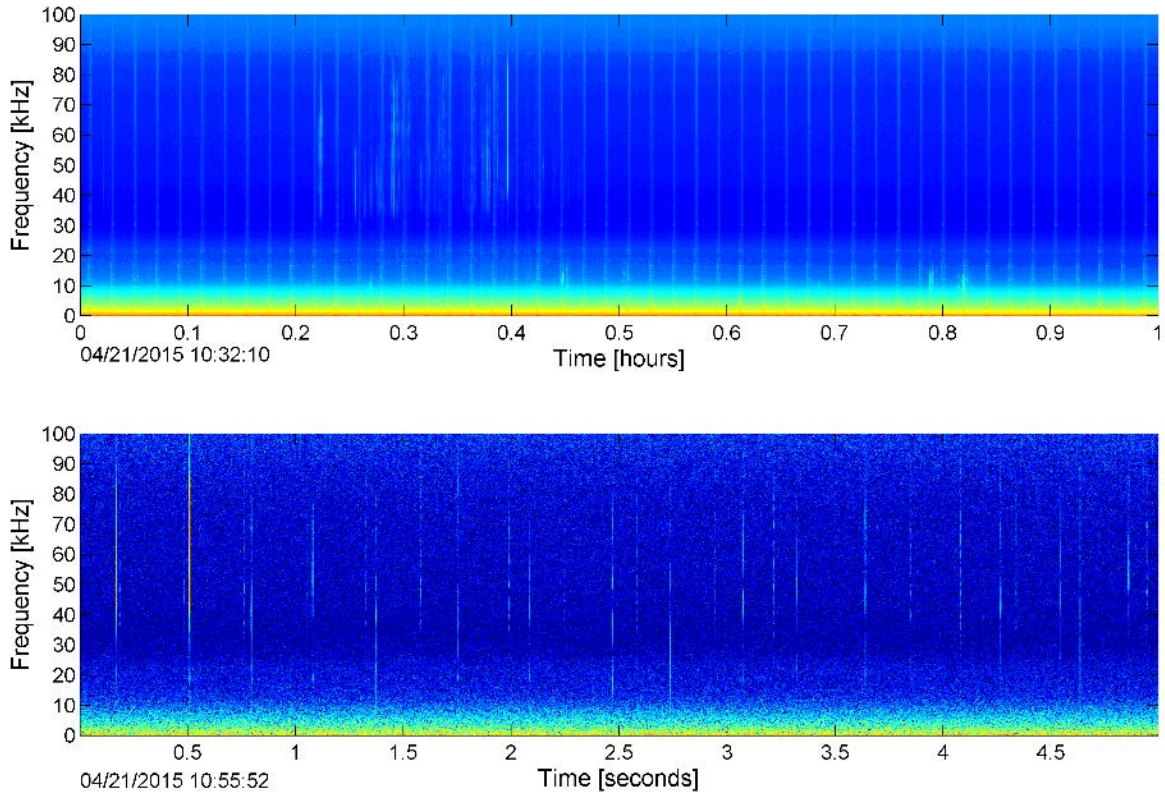


Figure 15. Gervais' beaked whale echolocation clicks in LTSA (top) and spectrogram (bottom) recorded at HAT.

Blainville's Beaked Whales

Blainville's beaked whale echolocation signals are, like most beaked whales' signals, polycyclic, with a characteristic frequency-modulated upswing, peak frequency around 34 kHz and uniform inter-pulse interval (IPI) of about 280 ms (Johnson *et al.*, 2006; 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 16).

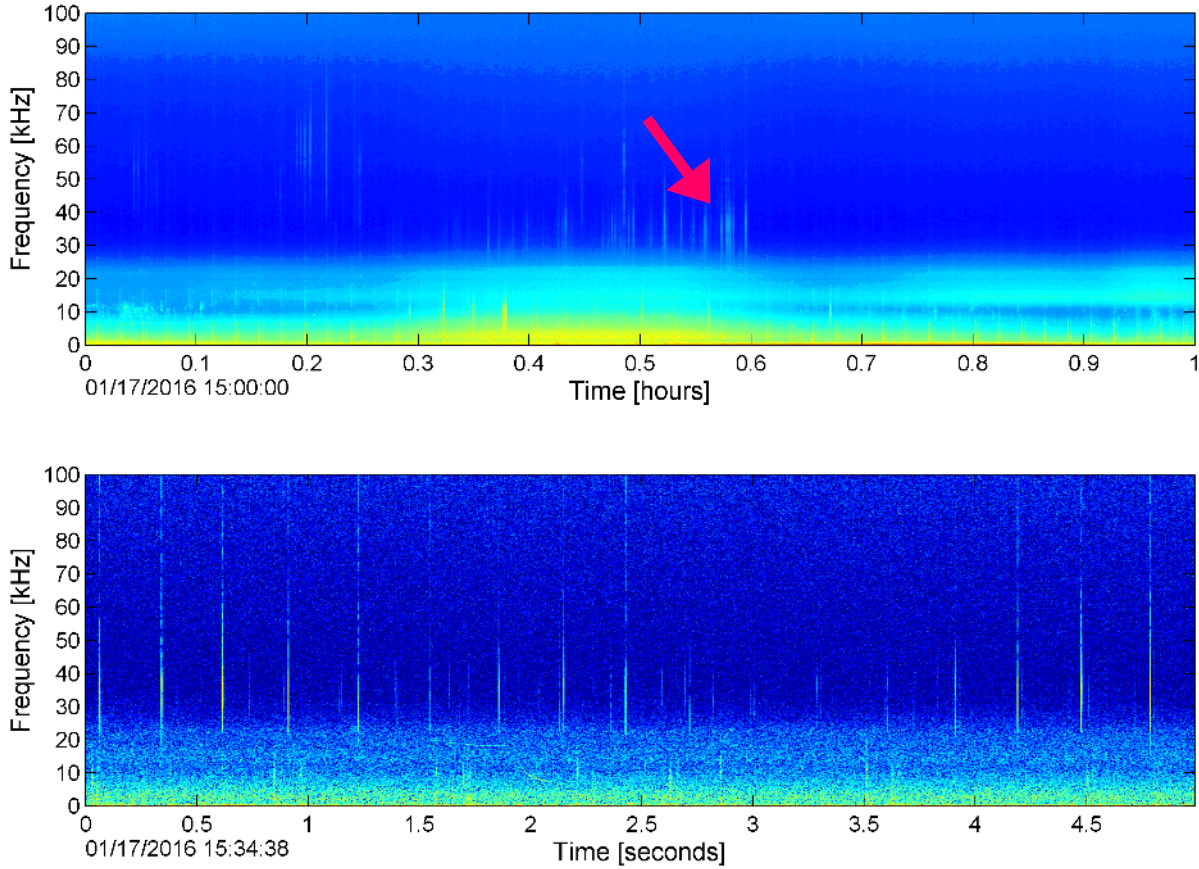


Figure 16. Blainville's beaked whale echolocation clicks in LTSA (top) and spectrogram (bottom) recorded at HAT. Red arrow indicates location of LTSA expanded in the spectrogram.

Kogia Spp.

Dwarf and pygmy sperm whales emit echolocation signals which have peak energy at frequencies near 130 kHz (Au, 1993). While this is above the upper frequency band recorded by the HARP during these deployments, the lower portion of the *Kogia* energy spectrum is within the 100 kHz HARP bandwidth (Figure 17 and Figure 18). 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. *Kogia* echolocation clicks were analyzed using a multi-step detector. The first step identified clicks with energy in the 70-100 kHz band that lacked energy in lower frequency bands. An expert system then classified these clicks based on spectral characteristics. An analyst verified all echolocation click bouts manually.

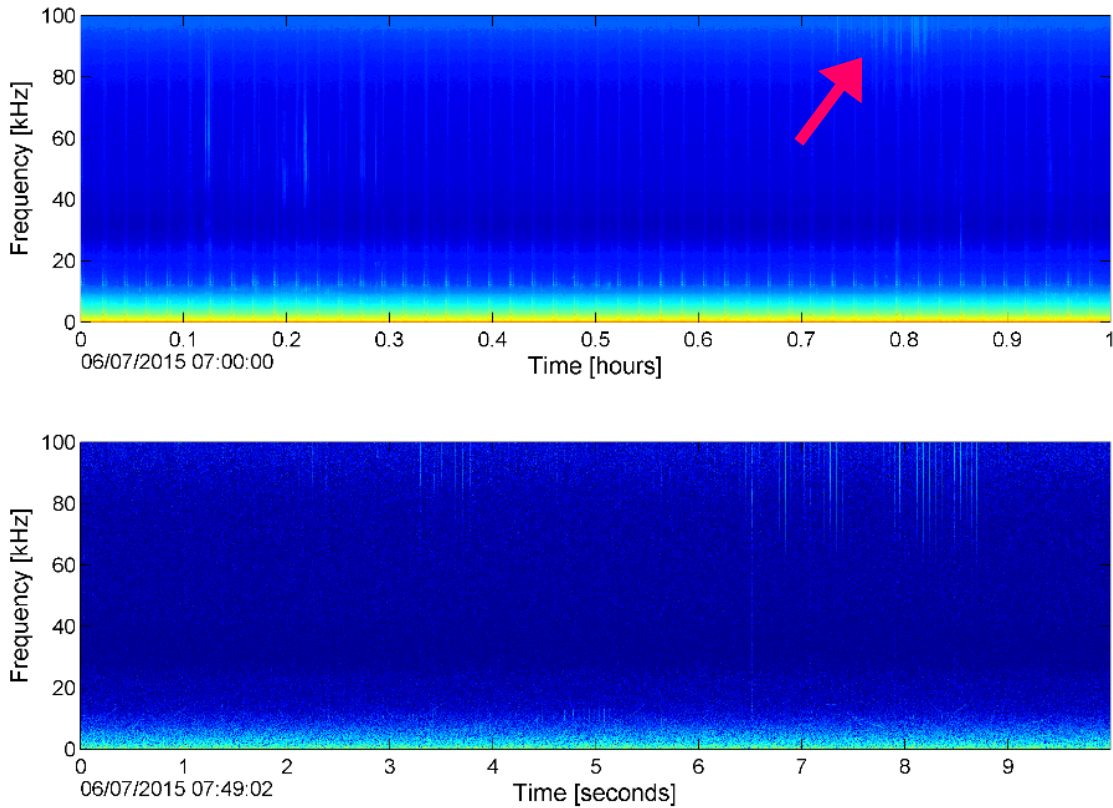


Figure 17. *Kogia spp.* echolocation clicks in the LTSA (top) and spectrogram (bottom) recorded at HAT. Red arrow indicates location of LTSA expanded in the spectrogram.

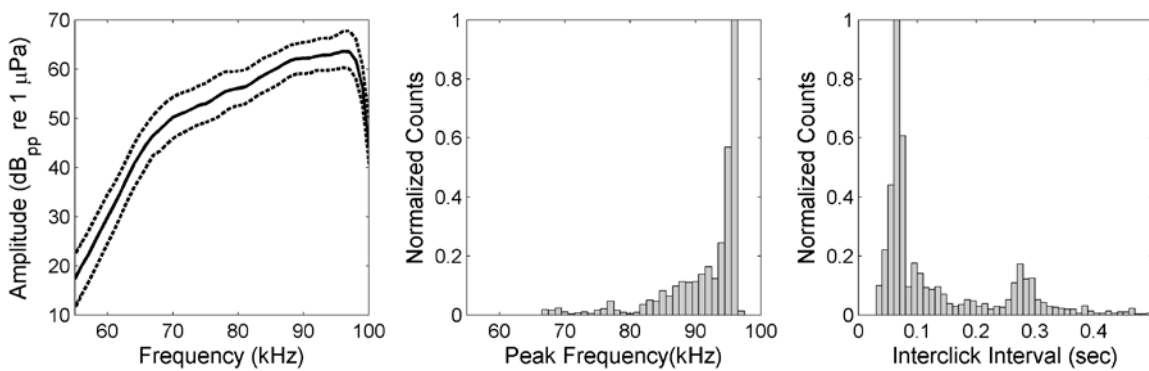


Figure 18. Left: *Kogia* mean frequency spectrum at HAT (solid line) with 25th and 75th percentiles (dashed lines); Center: Distribution of click peak frequencies with peak near the Nyquist frequency (100 kHz); Right: Distribution of inter-click-intervals with modal peak at 0.07 seconds.

Risso's Dolphin

Risso's dolphin clicks (Figure 19 and Figure 20) have frequency peaks at approximately 22, 26 and 33 kHz. These clicks have a modal inter-click interval of approximately 0.15 seconds (Figure 20). Past studies have shown that spectral properties of Risso's dolphin clicks have slight variations with geographic region (Soldevilla *et al.*, 2014), 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.

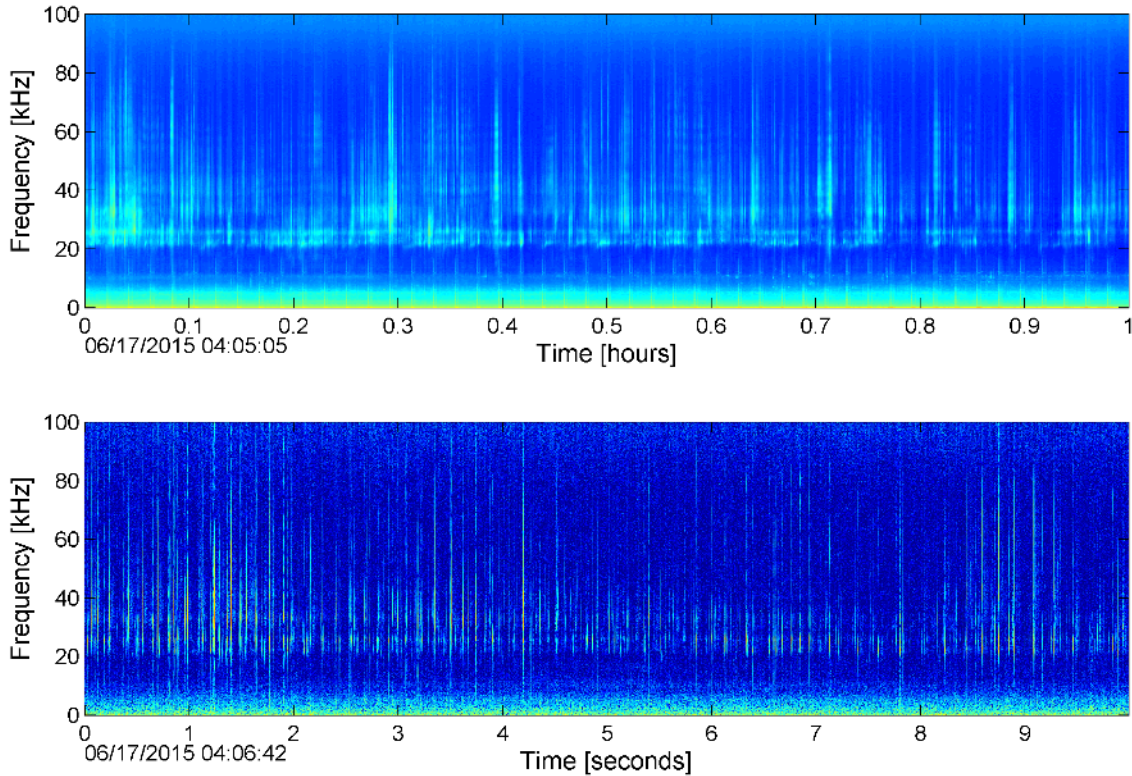


Figure 19. Risso's dolphin clicks in the LTSA (top) and spectrogram (bottom) at HAT.

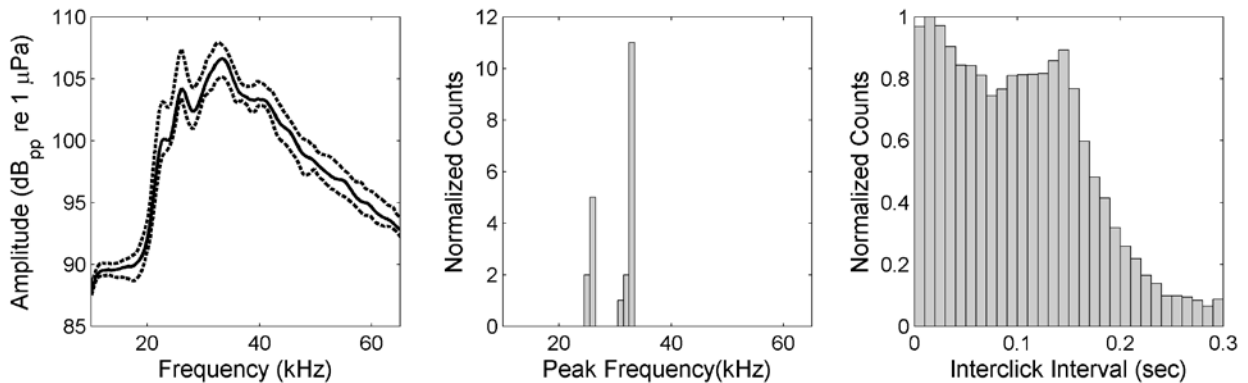


Figure 20. Left: Mean frequency spectrum of Risso's dolphin click cluster (solid line) and 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies with primary peak at 33 kHz and secondary peaks at 22 and 26 kHz; Right: Distribution of inter-click-intervals within cluster with modal peak at 0.15 seconds .

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).

Whistles

Many species of delphinids produce tonal calls known as whistles (Figure 12). 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 (Figure 21, Figure 22).

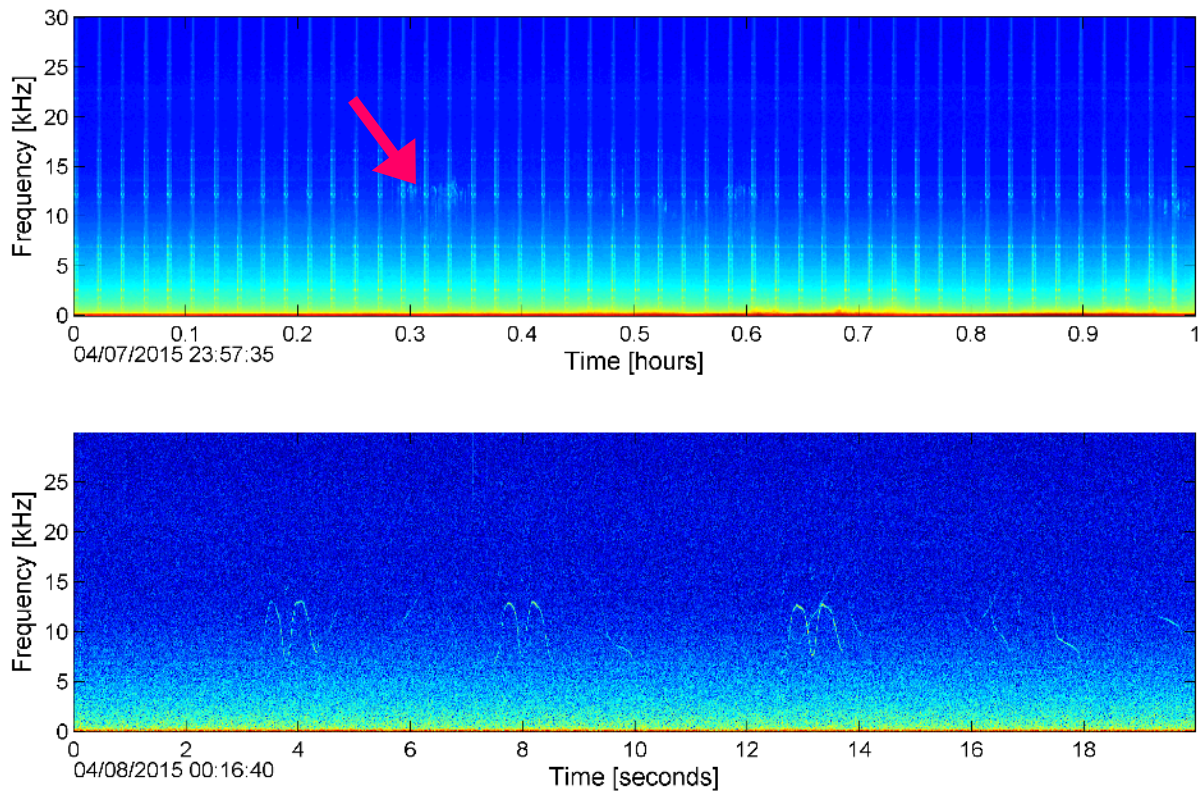


Figure 21. Unidentified odontocete whistles over 5 kHz in the LTSA (top) and spectrogram (bottom) recorded at HAT. Red arrow indicates location of LTSA expanded in the spectrogram.

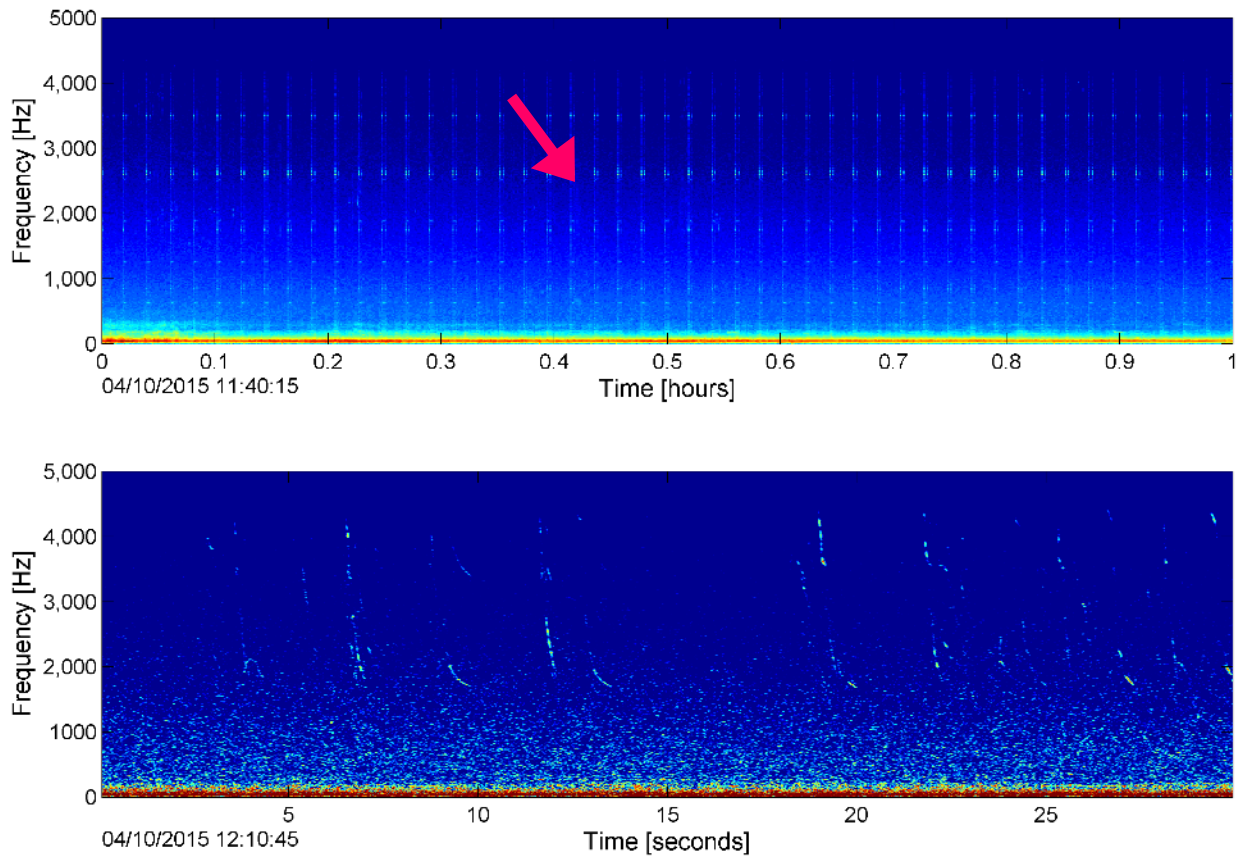


Figure 22. Unidentified odontocete whistles under 5 kHz in the LTSA (top) and spectrogram (bottom) recorded at HAT. Red arrow indicates location of LTSA expanded in the spectrogram.

Echolocation clicks

Delphinid echolocation clicks were detected automatically using an energy detector with a minimum received level threshold of 120 dB_{pp} re: 1 μPa. (Roch *et al.*, 2011, Frasier 2015). False positives were identified and removed manually 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.

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 types across all windows (Frasier *et al.* in prep). Recurrent types were used as templates. Templates were attributed to a specific species if known (e.g., Risso's dolphin) or assigned a number if species was unknown. Templates were compared with the click types in each five-minute window for matches. Click types that matched a template were classified by the matched template. Click types that did not match a template were labeled as unknown.

Click Type 1

Click type 1 (Figure 23 and Figure 24, left) has two small frequency peaks at 12 and 16 kHz with a variable main peak frequency between 32 and 45 kHz. It has a modal ICI at 0.07 seconds (Figure 24, right). The modal ICI of this echolocation click is similar to what is found in species belonging to the *Stenella* genus (Figure 24).

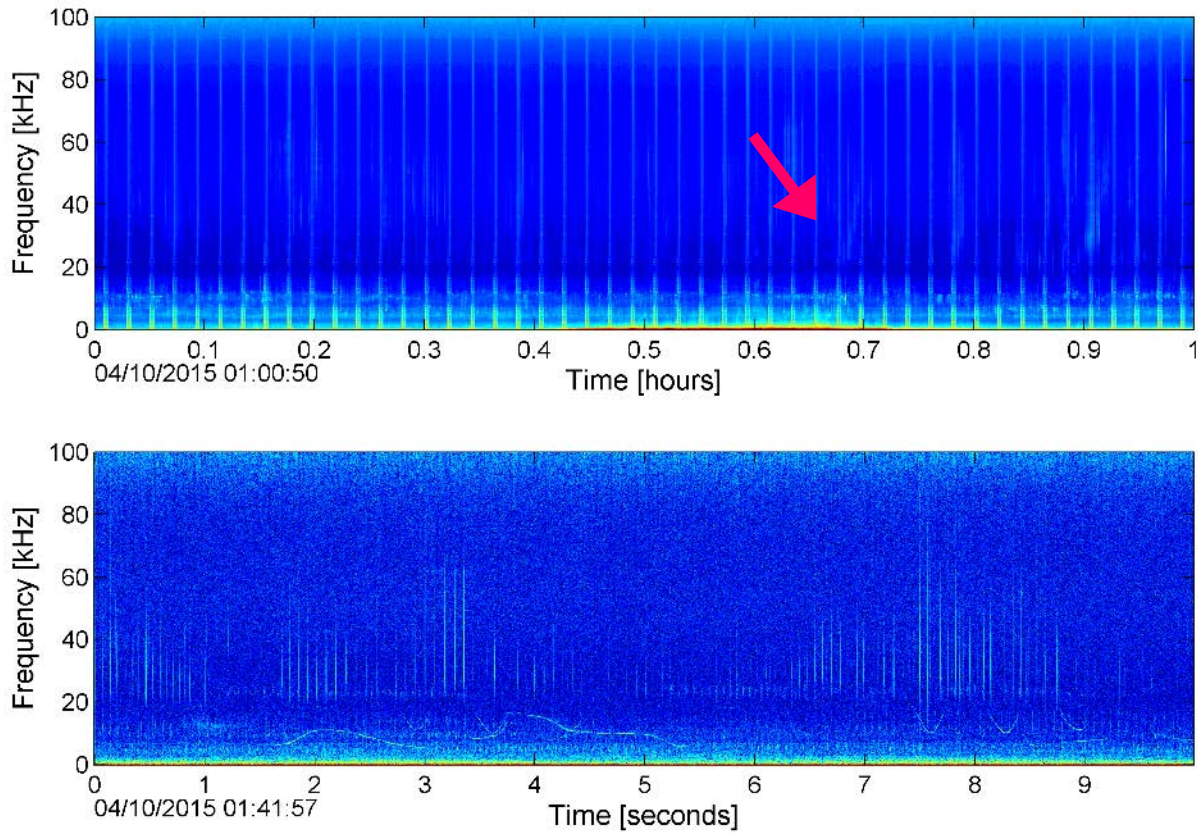


Figure 23. CT 1 in the LTSA (top) and spectrogram (bottom) recorded at HAT. Red arrow indicates location of LTSA expanded in the spectrogram.

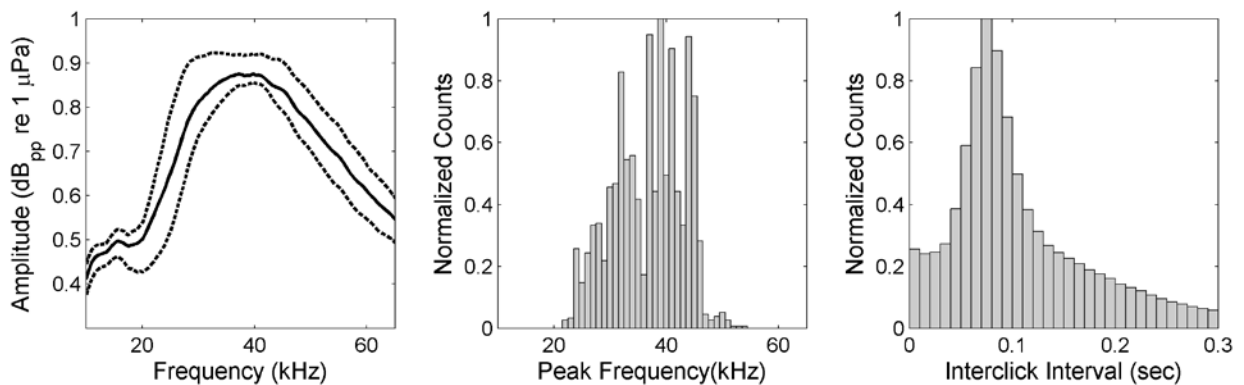


Figure 24. Left: Mean frequency spectrum of CT 1 cluster (solid line) with 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies; Right: Distribution of inter-click-intervals within cluster with modal peak at 0.07 seconds.

Click Type 2

Click type 2 (Figure 25) has two minor peaks at 12 and 19 kHz (Figure 26, left), and variable dominant peak frequency between 27 and 32 kHz (Figure 26, center) and a modal inter-click interval of 0.15 seconds (Figure 26, right).

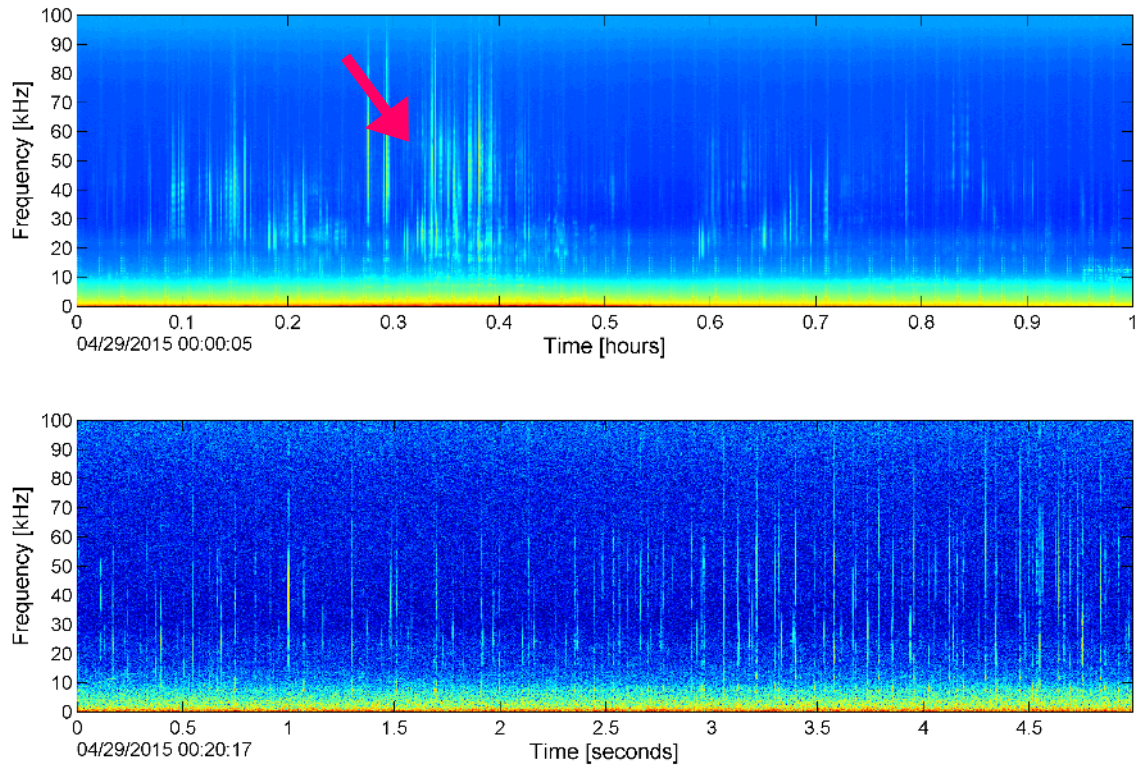


Figure 25. CT 2 in the LTSA (top) and spectrogram (bottom) recorded at HAT. Red arrow indicates location of LTSA expanded in the spectrogram.

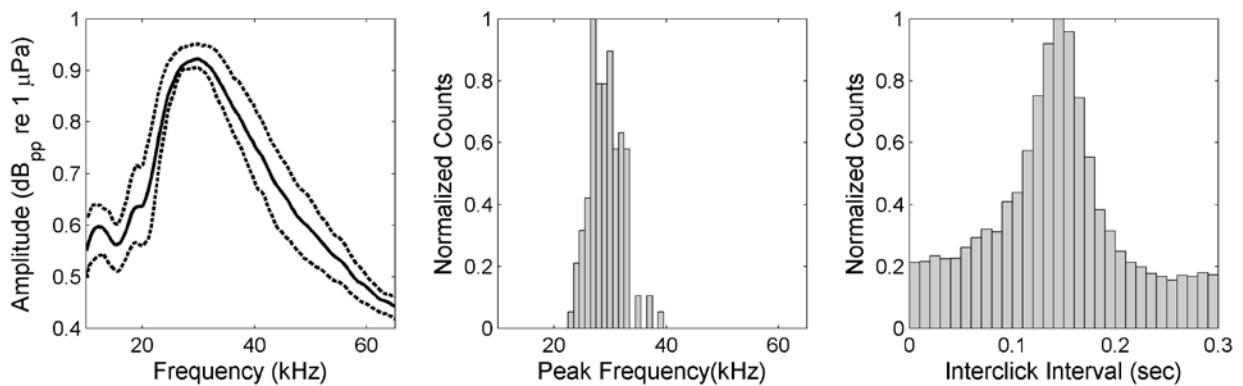


Figure 26. Left: Mean frequency spectrum of CT 2 cluster (solid line) with 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies; Right: Distribution of inter-click-intervals within cluster with modal peak at 0.15 seconds.

Click Type 4

Click type 4 (Figure 27 and Figure 28, left) has characteristic spectral peaks at 13, 21 and 27 kHz and a mean peak frequency at approximately 55 kHz (Figure 28, center). It has a modal inter-click interval of 0.7 seconds (Figure 28, right).

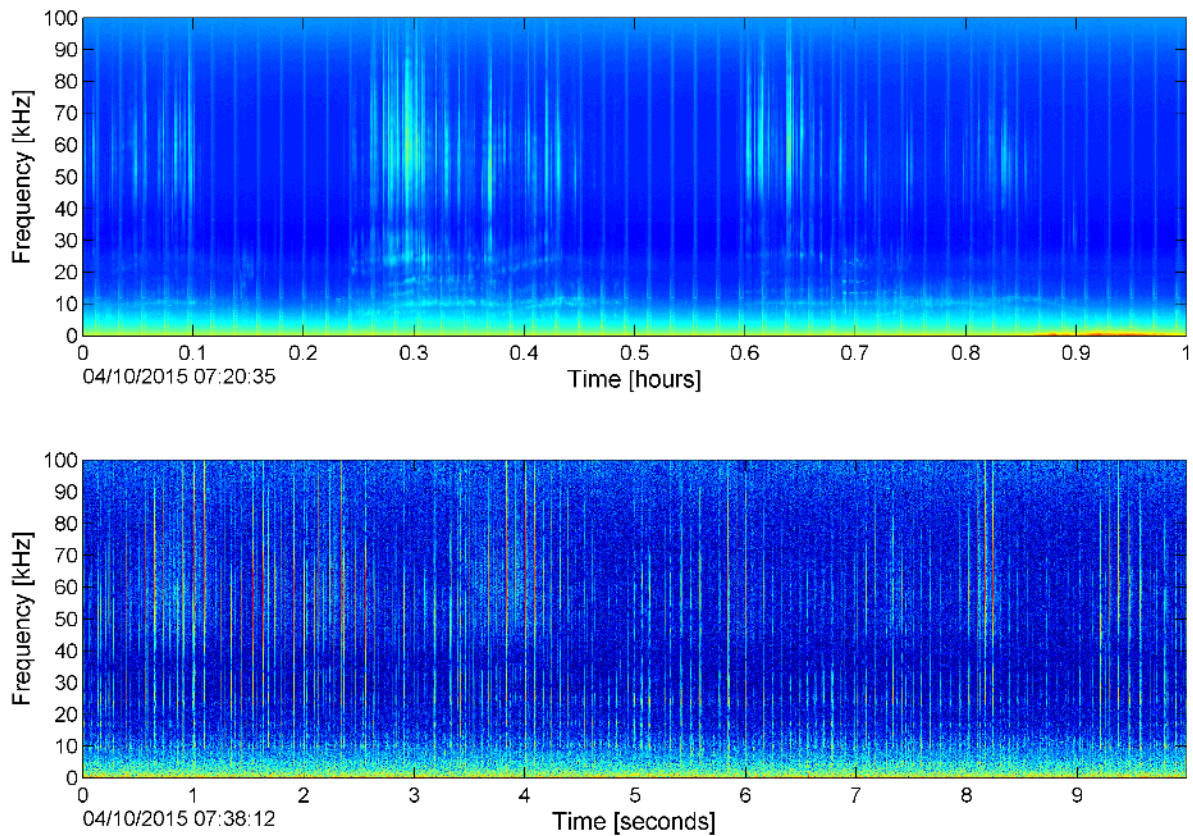


Figure 27. CT 4 in the LTSA (top) and spectrogram (bottom) recorded at HAT.

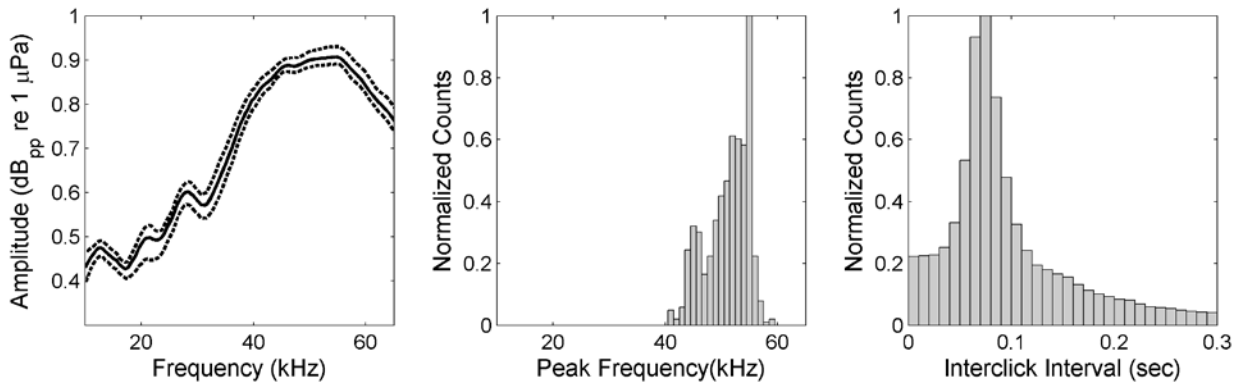


Figure 28. Left: Mean frequency spectrum of CT 4 cluster (solid line) with 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies; Right: Distribution of inter-click-intervals within cluster with modal peak at 0.07 seconds.

Click Type 6

Click type 6 (Figure 29 and Figure 30) has a mean spectral peak at 24 kHz (Figure 30, center). It has a modal inter-click interval peak at approximately 0.16 seconds (Figure 30, right). The average ICI of this click type is longer than what is commonly found in echolocation clicks of smaller dolphins, suggesting that this click might belong to one of the blackfish species (Roth *et al.*, 2013; Baumann-Pickering *et al.*, 2015).

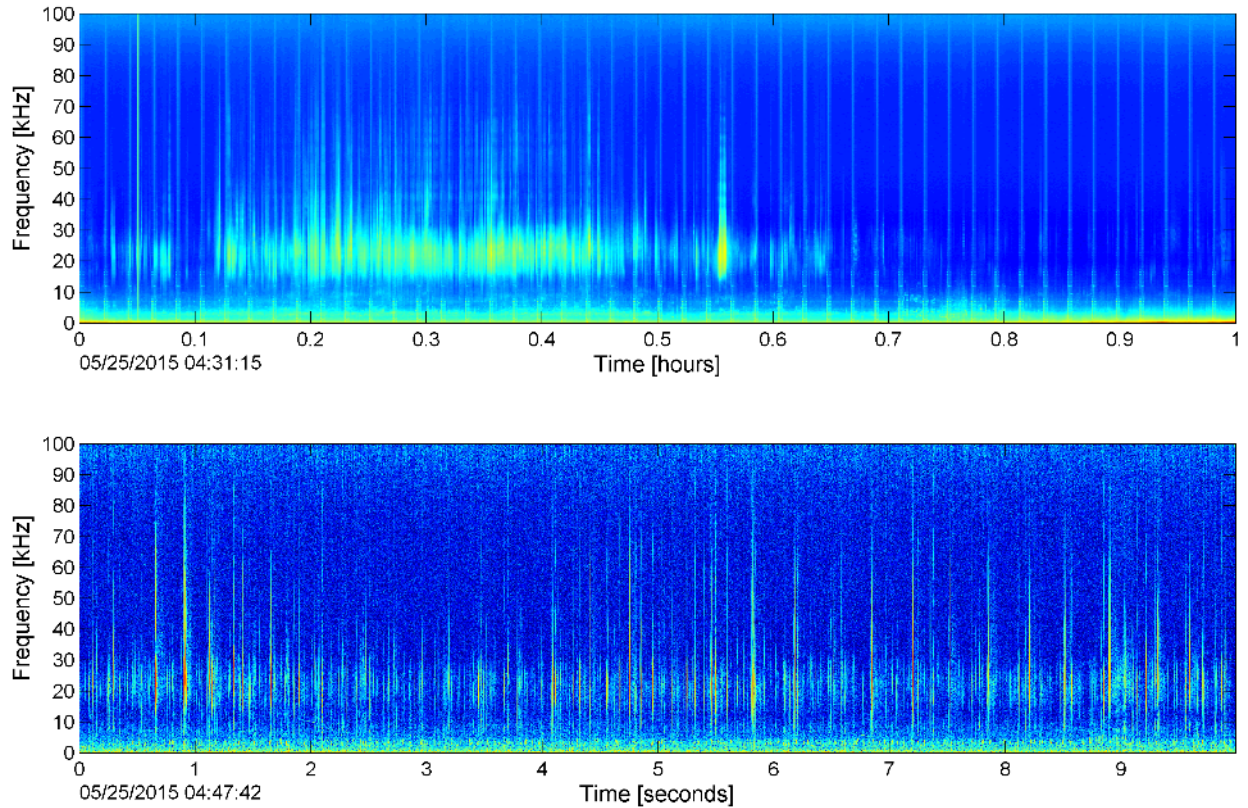


Figure 29. CT 6 in the LTSA (top) and spectrogram (bottom) recorded at HAT.

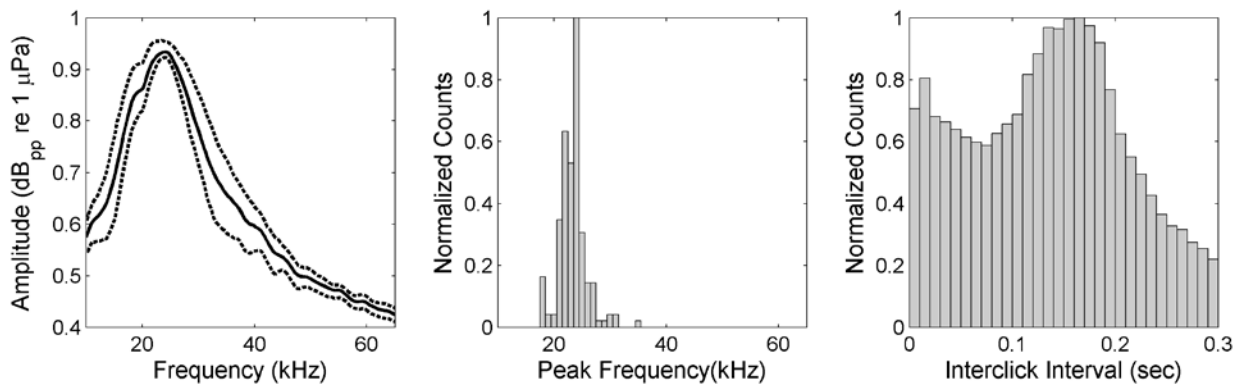


Figure 30. Left: Mean frequency spectrum of CT 6 cluster (solid line) with 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies; Right: Distribution of inter-click-intervals within cluster with modal peaks at 0.07 and 0.13 seconds.

Click Type 7

Click type 7 (Figure 31 and Figure 32) is characterized primarily by burst pulses, with a modal ICI below 0.01 seconds (Figure 32, right). Occasional regular clicks are detected, with no distinct modal ICI. Peak frequency is between 24 and 26 kHz (Figure 32, center).

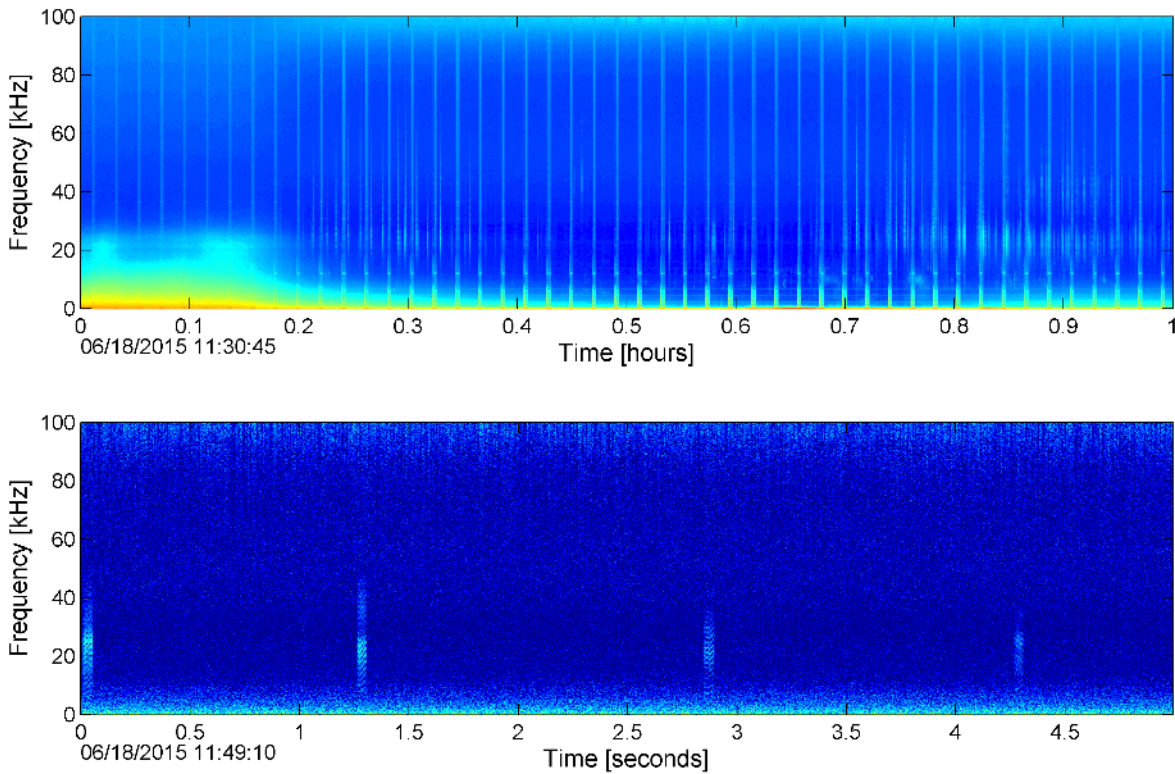


Figure 31. CT 7 in the LTSA (top) and spectrogram (bottom) recorded at HAT.

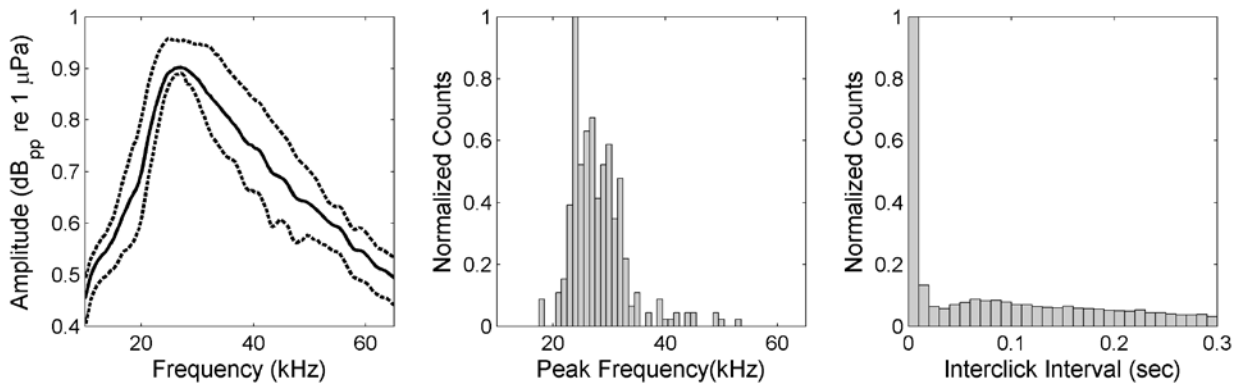


Figure 32. Left: Mean frequency spectrum of CT 7 cluster (solid line) with 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies; Right: Distribution of inter-click-intervals within cluster.

Anthropogenic Sounds

Several anthropogenic sounds were monitored for this report: broadband ship noise, airguns, explosions, LFA sonar above 500 Hz, MFA sonar, HFA sonar and echosounders. Manual effort was expended for broadband ship noise, explosions, MFA, LFA, HFA and echosounders (Table 1). The start and end of each session was logged and their durations were added to estimate cumulative hourly presence. A detector was used for airgun analysis, as described below.

Table 1. Anthropogenic sound data manual analysis parameters.

Sound Type	LTSA Search Parameters	
	Plot Length (hr)	Display Frequency Range (Hz)
Broadband Ship Noise	3	10 – 5,000
Explosions	0.75	10 – 1,000
LFA Sonar	0.75	10 – 2,000
MFA Sonar	0.75	1,000 – 5,000
HFA Sonar	1	10,000 – 100,000
Echosounder	1	5,000 – 100,000

Airguns were detected automatically and manually verified following the method used for explosion detections by Debich *et al.* (2016). This approach produces more precise airgun counts and imposes a consistent detection threshold.

Explosions were detected manually due to heavy airgun activity and numerous fish sounds, which falsely trigger the automatic detector. Because explosions were few relative to other signals, they were more readily distinguished by a trained analyst reviewing LTSAs. This differs from a previous report (Debich *et al.*, 2016) for which explosions were automatically detected.

Broadband Ship Noise

Broadband ship noise occurs when a ship passes within a few km of the hydrophone. Ship noise can occur for many hours at a time, but broadband ship noise typically lasts from 10 minutes up to 3 hours. 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 ship and the receiver (Figure 33). Noise can extend above 10 kHz, though it typically falls off above a few kHz. Broadband ship analysis effort consisted of manual scans of the LTSA set at 3 hours with a frequency range of 10 – 5,000 Hz.

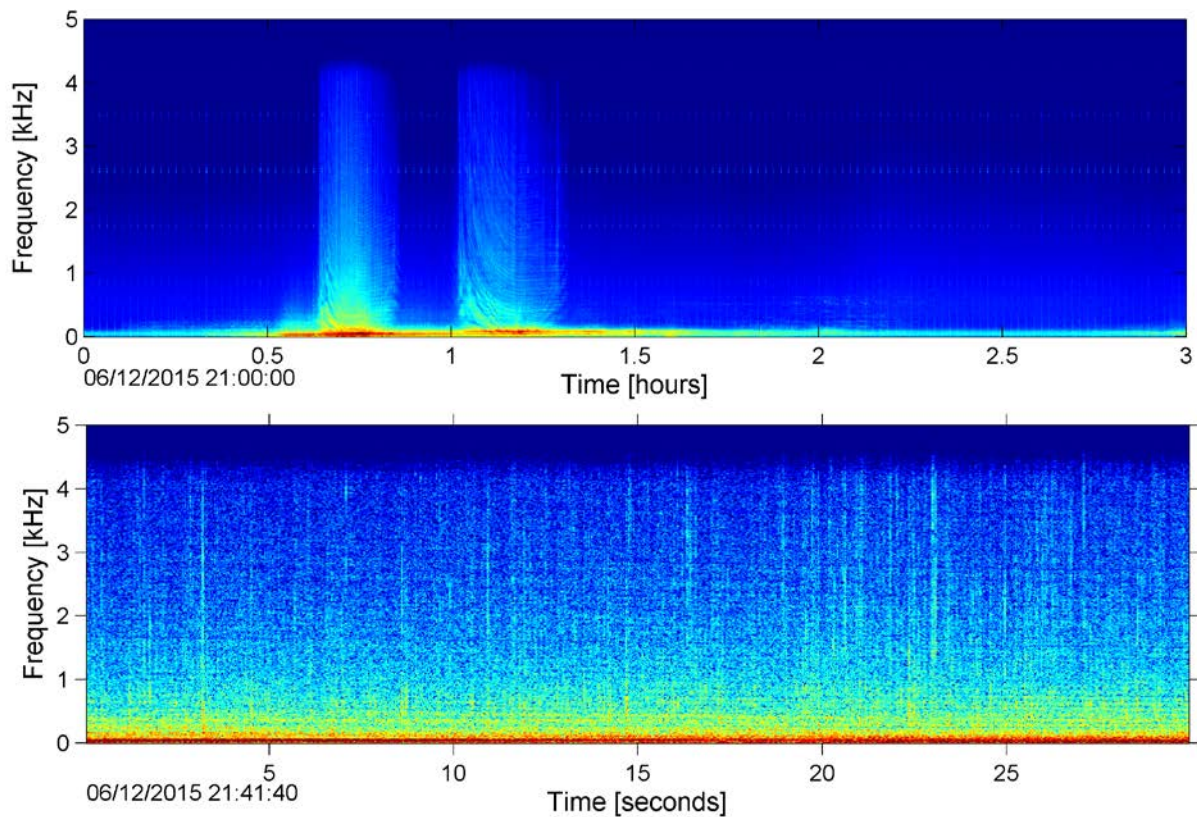


Figure 33. Broadband ship noise in the LTSA (top) and spectrogram (bottom) recorded at HAT.

Explosions

Effort was directed toward finding explosive sounds in the data including military explosions and seal bombs used by the fishing industry. An explosion appears as a vertical spike in the LTSA that, when expanded in the spectrogram, has a sharp onset with a reverberant decay (Figure 34).

Explosion analysis effort consisted of manual scans of the LTSA set at 0.75 hours with a frequency range of 10 – 1,000 Hz. Explosions were automatically detected for a previous HAT report (Debich *et al.*, 2016). Manual detections were preferred to the automated detector in this case due to high false positive rates associated with heavy airgun activity and numerous fish sounds.

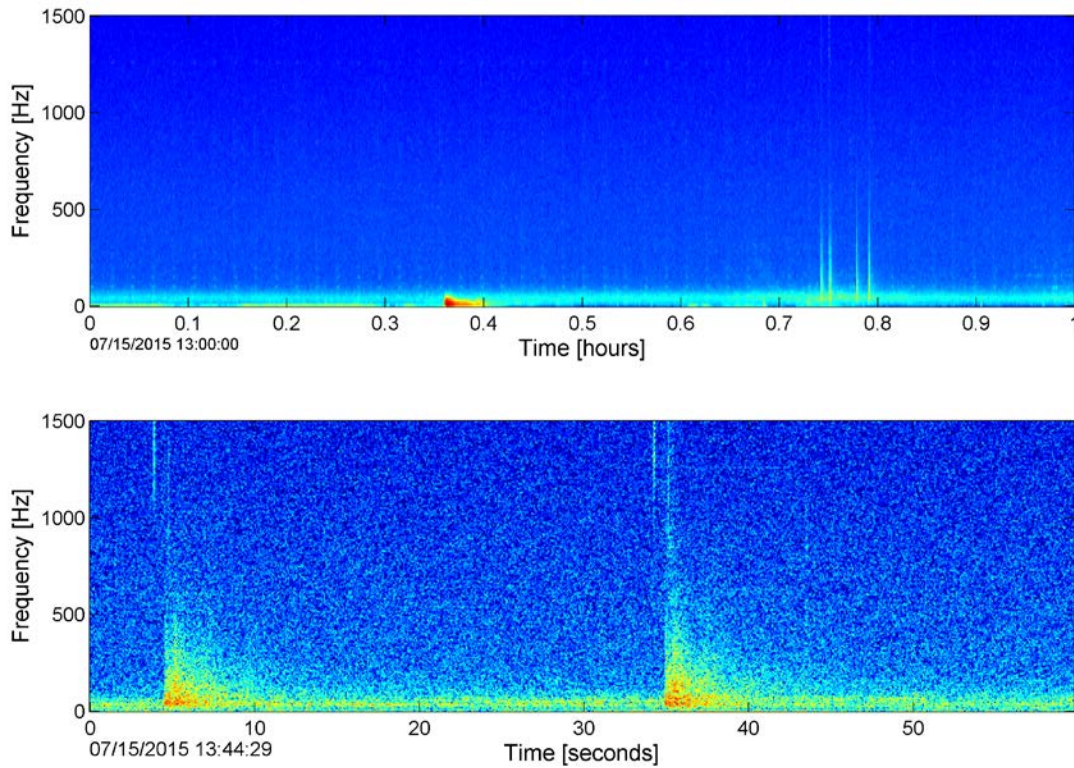


Figure 34. Explosions in the LTSA (top) and spectrogram (bottom) recorded at HAT.

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 gun 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 over 200 dB re 1 μ Pa-m (Blackman *et al.*, 2004; Amundsen and Landro, 2010). These blasts typically have an inter-pulse-interval of approximately 10 seconds and can last from several hours to days (Figure 35).

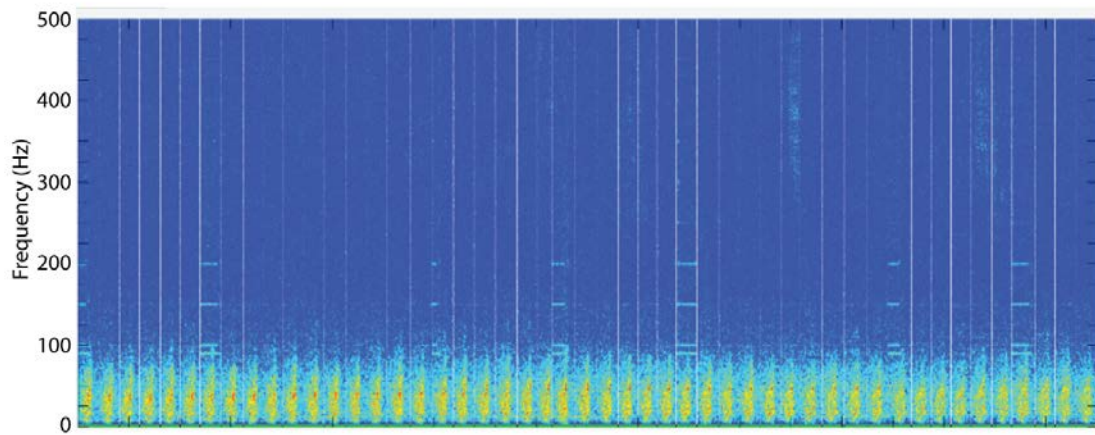


Figure 35. Airgun pulses recorded at HAT in the analyst verification stage of the detector.

Airguns were detected automatically using a matched filter detector on data decimated to 10 kHz sampling rate. The timeseries was filtered with a 10th order Butterworth bandpass filter between 25 and 200 Hz. Cross correlation was computed between 75 seconds of the envelope of the filtered timeseries and the envelope of a filtered example explosion (0.7 s, Hann windowed) as the matched filter signal. The cross correlation was squared to ‘sharpen’ peaks of airgun blast detections. A floating threshold was calculated by taking the median cross correlation value over the current 75 seconds of data to account for detecting airguns within noise, such as shipping. A cross correlation threshold of 2×10^{-6} above the median was set. When the correlation coefficient reached above this threshold, the timeseries was inspected more closely. Consecutive airgun blasts were required to have a minimum time distance of 2 seconds to be detected. A 300-point (0.03 s) floating average energy across the detection was computed. The start and end times above the threshold were marked when the energy rose by more than 2 dB above the median energy across the detection. Peak-to-peak (pp) and root-mean-square (RMS) received levels (RL) were computed over the potential blast period as well as a timeseries of the length of the airgun blast template before and after the explosion. The potential airgun blast was classified as a 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 0.5 dB, respectively; 2) the dB difference pp and rms between signal and time BEFORE the signal was less than 3 dB or 0.5 dB, respectively; and 3) the detection was shorter than 0.03 s or longer than 10 s. The thresholds were evaluated based on the distribution of histograms of manually verified true and false detections. Airgun blast interpulse intervals were 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 blasts have energy as low as 10 Hz and can extend up to 250 Hz or higher, lasting for a few seconds including the reverberation.

Low-Frequency Active Sonar

Low-frequency active sonar includes military sonar between 100 and 500 Hz and other sonar systems up to 1 kHz. Effort was expended for LFA sonar between 500 Hz and 1 kHz (Figure 36).

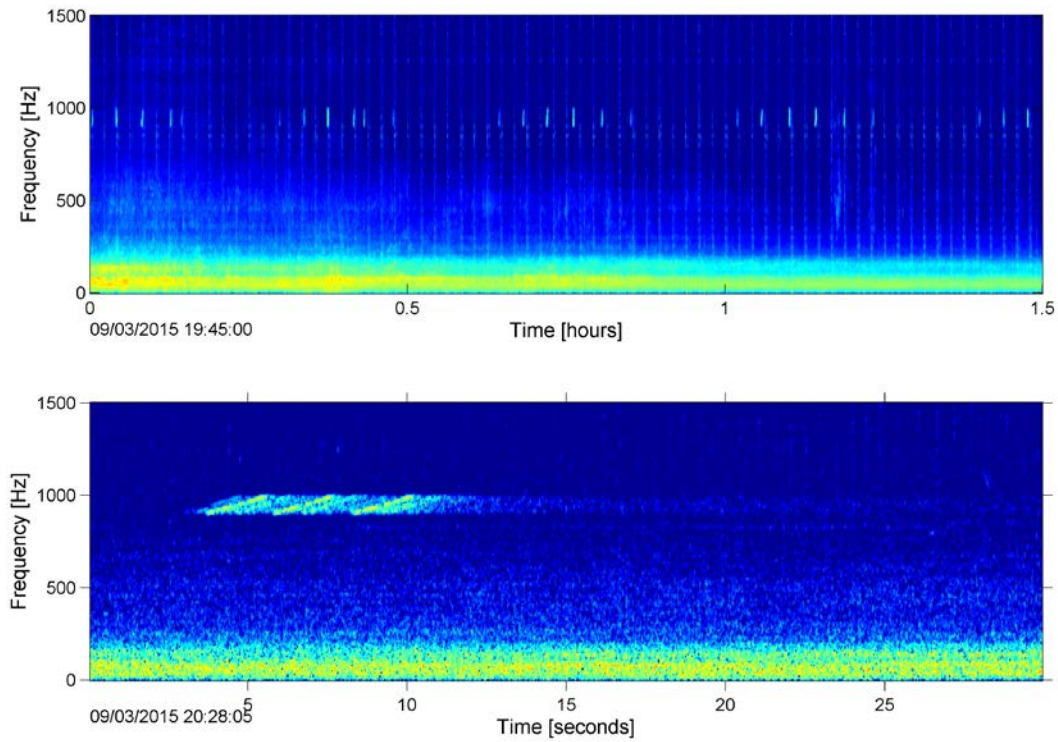


Figure 36. LFA at 950 Hz in the LTSA (top) and spectrogram (bottom) recorded at HAT.

Mid-Frequency Active Sonar

Sounds from MFA sonar vary in the frequency range (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 37). In the SOCAL 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., 2011) 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 (see Wiggins, 2015 for details). 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 duration (for RL_{pp} -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 μ Pa. Instrument maximum received level for these recordings was ~163 dB_{pp} re 1 μ Pa above which waveform clipping occurred. Packets were grouped into wave trains separated by more than 1 hour. Packet received level distribution was plotted in each wave train over the study period.

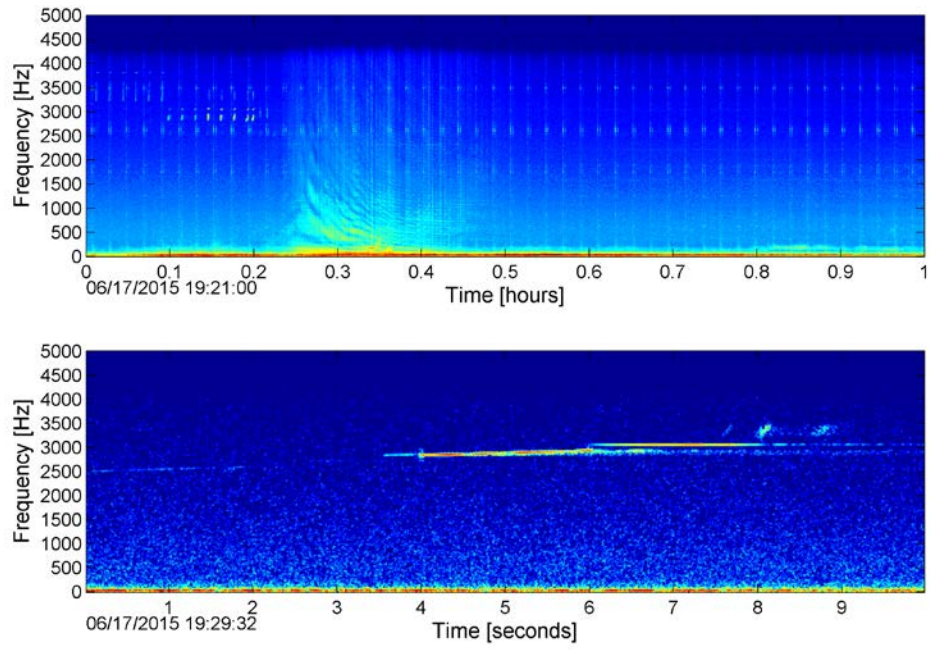


Figure 37. MFA sonar in the LTSA (top) and spectrogram (bottom) recorded at HAT.

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 38). There were no detections of HFA sonar in this deployment.

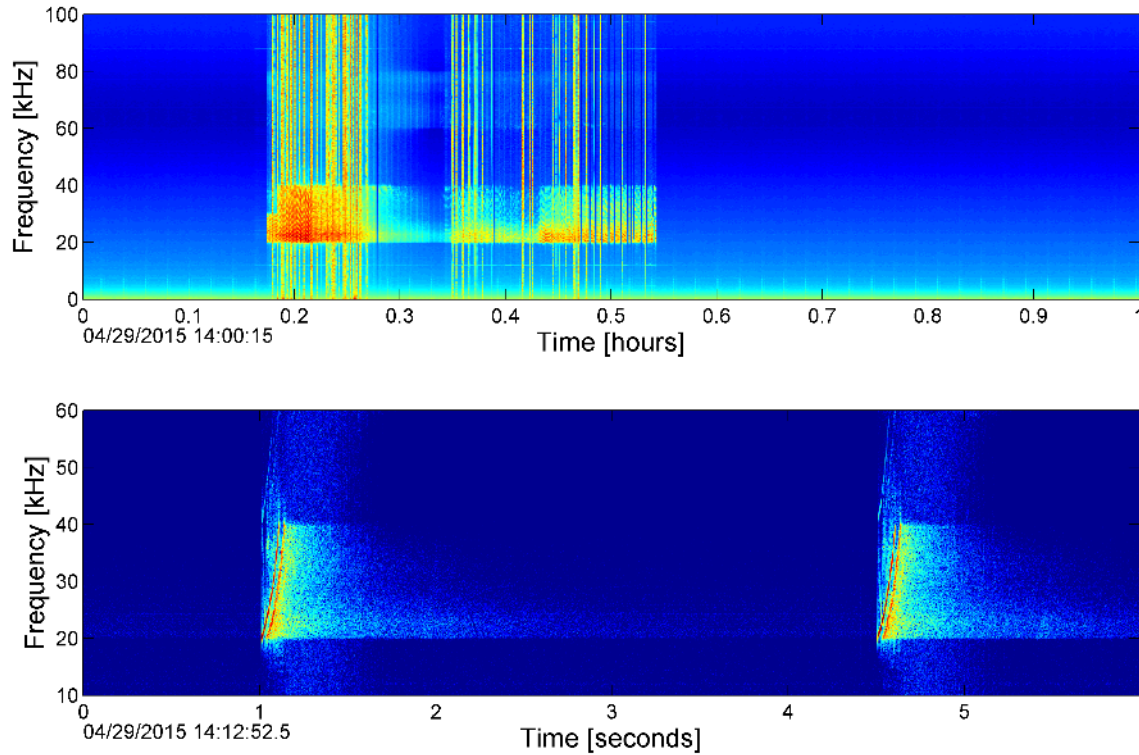


Figure 38. HFA sonar in LTSA (top) and spectrogram (bottom) recorded in the Jacksonville Range Complex.

Echosounders

Echosounding sonars transmit short pulses or frequency sweeps, typically in the high-frequency (above 10 kHz) band (Figure 39), 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. Presence of high-frequency echosounders was manually detected by analysts reviewing LTSA plots.

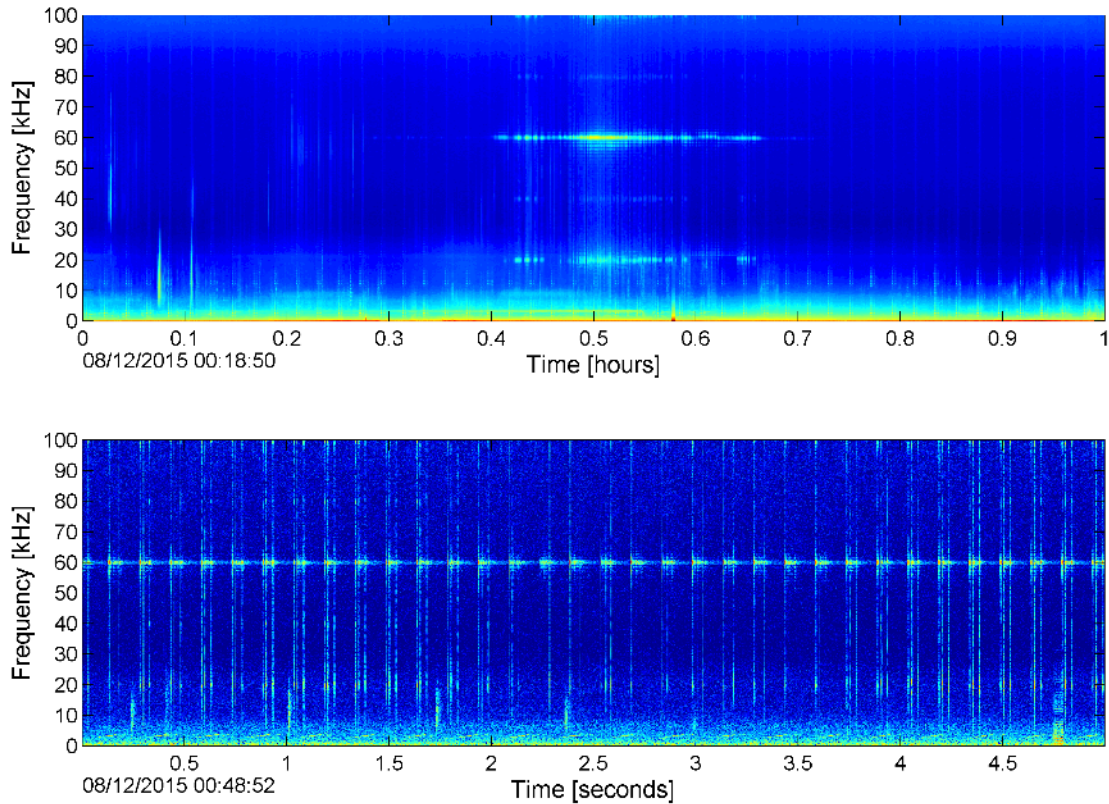


Figure 39. Echosounders in LTSA (top) and spectrogram (bottom) recorded at HAT.

Results

The results of acoustic data analysis at HAT from April 2015 to January 2016 are presented. We describe ambient noise and the seasonal occurrence and relative abundance of several marine mammal acoustic signals and anthropogenic sounds of interest.

Ambient Noise

To provide a means of evaluating seasonal spectral variability, daily-averaged spectra were processed into monthly-averages. It is important to note that while incomplete days have been removed from analysis, incomplete months were not. Partial months include an asterisk (*) in the color legend and are detailed in Table 2.

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

Deployment	Month/Year	Days of Data / Days in Month
HAT05A	4/2015	24/31
HAT05A	1/2016	21/31

- Underwater ambient noise at HAT had higher spectral levels at low frequencies, owing to the dominance of ship and airgun noise at frequencies below 100 Hz.
- Prominent peaks in noise were observed around 20 Hz during winter months and are related to seasonally increased presence of fin whale calls, with highest levels during winter months.
- Peaks observed at approximately 120 and 170 Hz are related to seasonally increased presence of minke whale pulse trains, with highest levels during winter months.
- Increased levels in July/August 2015 are observed between 12-40Hz and are related to increased presence of seismic airgun surveys. Similarly, decreased levels in that band are observed between May-June 2015 when airgun surveys were not detected. There was about 6 dB difference in levels at 20 Hz during these two periods.

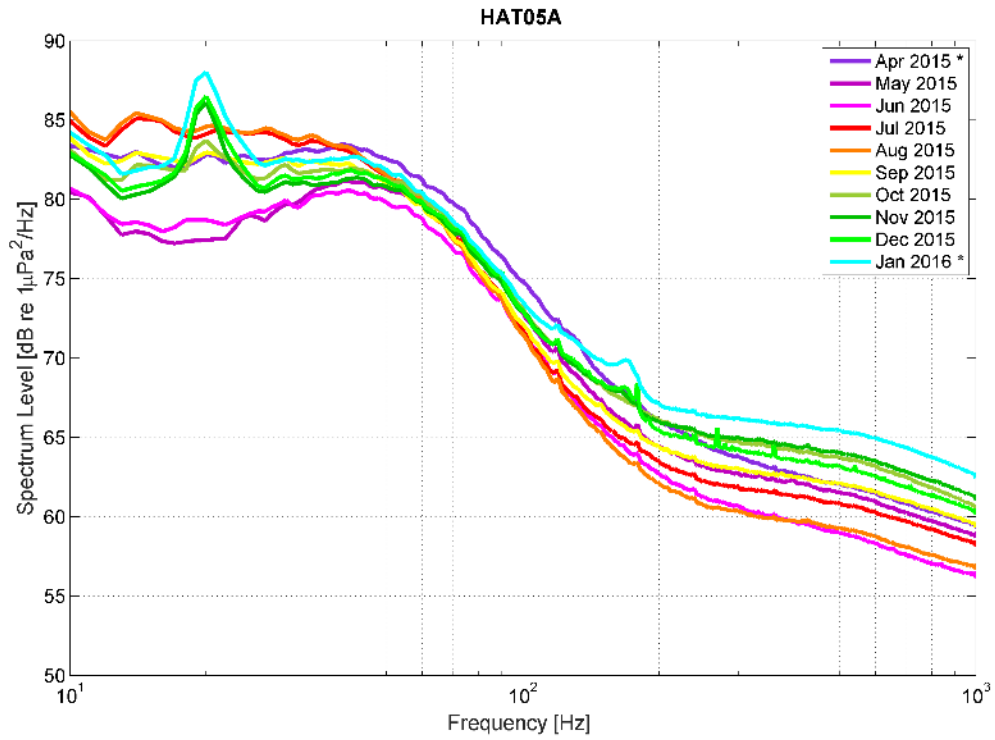


Figure 40. Monthly averages of ambient noise at HAT from April 2015 to January 2016. Legend gives color-coding by month. Months with an asterisk (*) have partial recording effort.

Mysticetes

Three known baleen whale species were recorded between April 2015 and January 2016: fin whales, sei whales, and minke whales. More details of each species' presence are given below.

Fin Whales

- Fin whale 20 Hz calls (as measured by the acoustic index (Širović *et al.*, 2015)), peaked from November 2015 through early January 2016 (Figure 41).

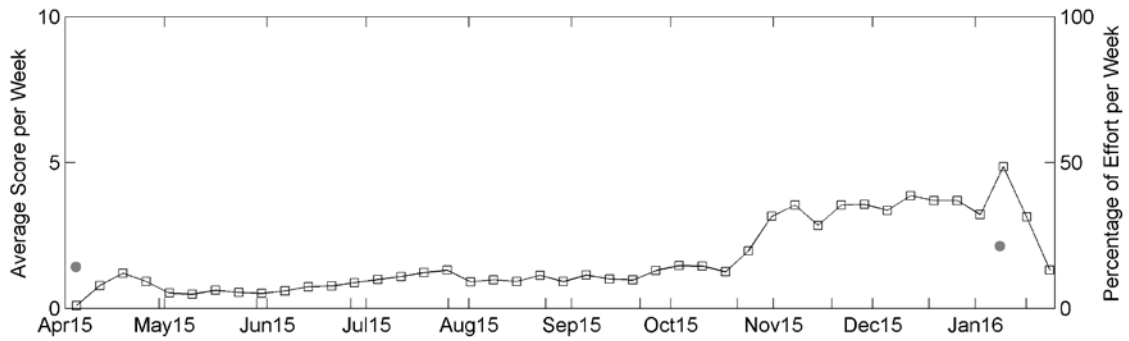


Figure 41. Weekly value of fin whale acoustic index (proxy for 20 Hz calls) from April 2015 to January 2016 at HAT. Gray dots represent percent of effort per week in weeks with less than 100% recording effort. Where gray dots are absent, full recording effort occurred for the entire week. Dates are abbreviated as month-year (mmmyy).

Sei Whales

- Sei whale downsweep calls were detected in December 2015 and January 2016 (Figure 42).
- There was no discernable diel pattern for sei whale downsweep calls (Figure 43).

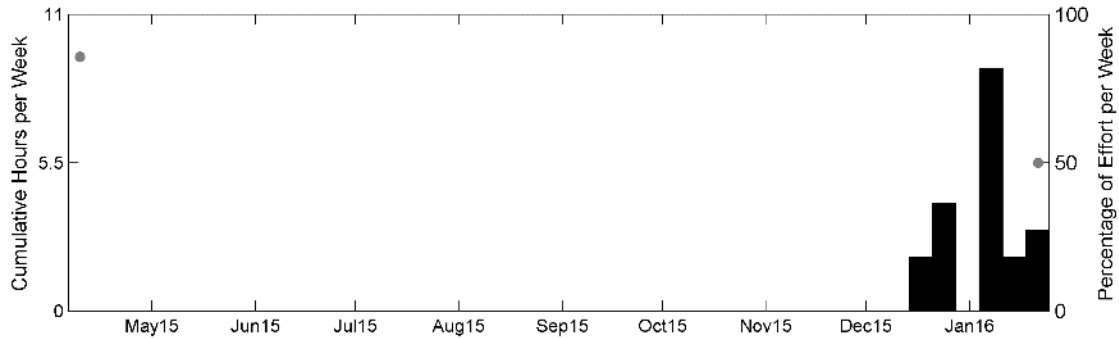


Figure 42. Weekly presence (black bars) of sei whale downsweep calls from April 2015 to January 2016. Effort markings are described in Figure 41.

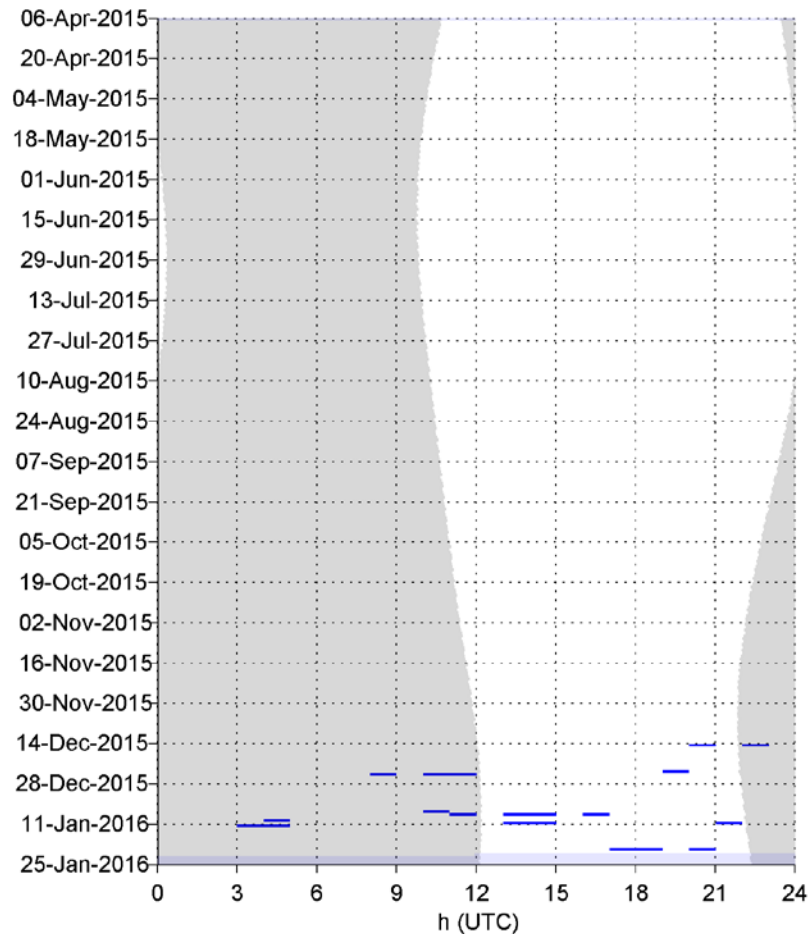


Figure 43. Sei whale downsweep calls in hourly bins (blue bars) from April 2015 to January 2016. Gray vertical shading denotes nighttime.

Minke Whales

- Minke whale pulse train detections occurred in April and May 2015 and peaked again from November 2015 to January 2016 (Figure 44).
- There was no discernable diel pattern for minke whale pulse trains (Figure 45).

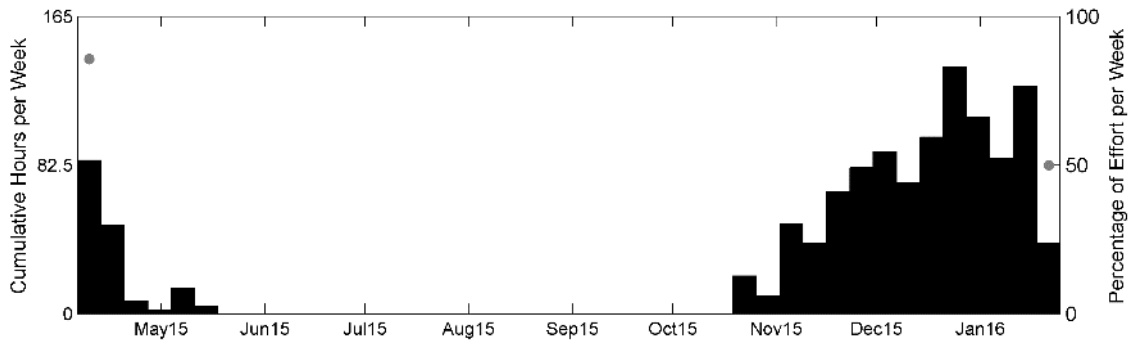


Figure 44. Weekly presence (black bars) of minke whale pulse trains from April 2015 to January 2016. Effort markings are described in Figure 41.

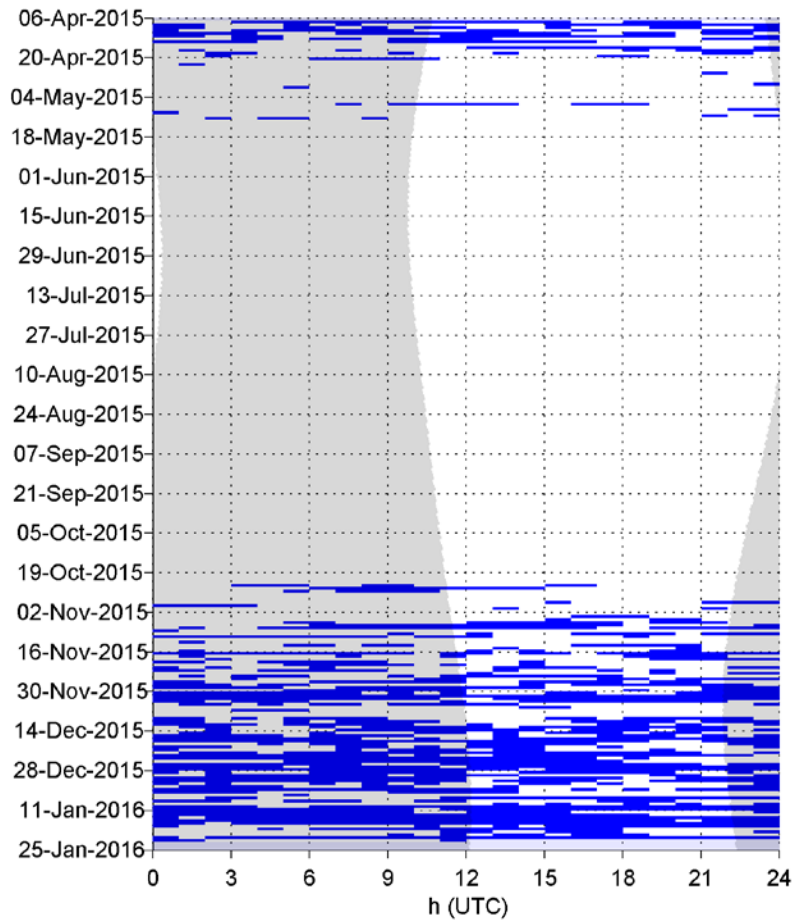


Figure 45. Minke whale pulse trains in hourly bins (blue bars) from April 2015 to January 2016. Effort markings are described in Figure 43.

Odontocetes

Unidentified odontocete whistles were detected throughout the recording. Echolocation clicks from six known odontocete species were detected: Sperm whales, Cuvier's beaked whale, Gervais' beaked whale, Blainville's beaked whale, *Kogia spp.*, and Risso's dolphins. Different click types that are not yet assigned to a species were also detected. More details of each species' presence in this dataset are given below.

Sperm Whales

- Sperm whale clicks were detected from April 2015 to January 2016, with peaks in May 2015, August 2015 and January 2016 (Figure 46).
- There was no diel pattern for sperm whale clicks (Figure 47).

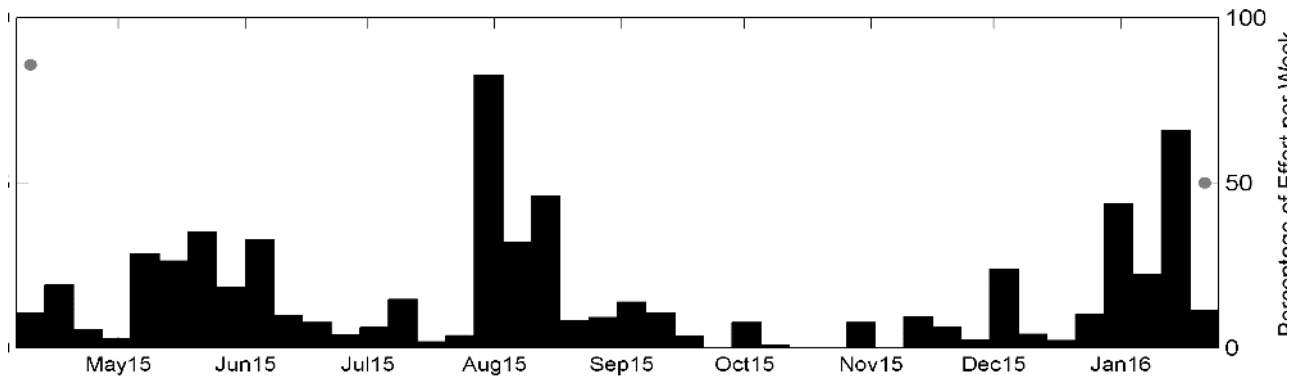


Figure 46. Weekly presence (black bars) of sperm whale clicks from April 2015 to January 2016. Effort markings are described in Figure 41.

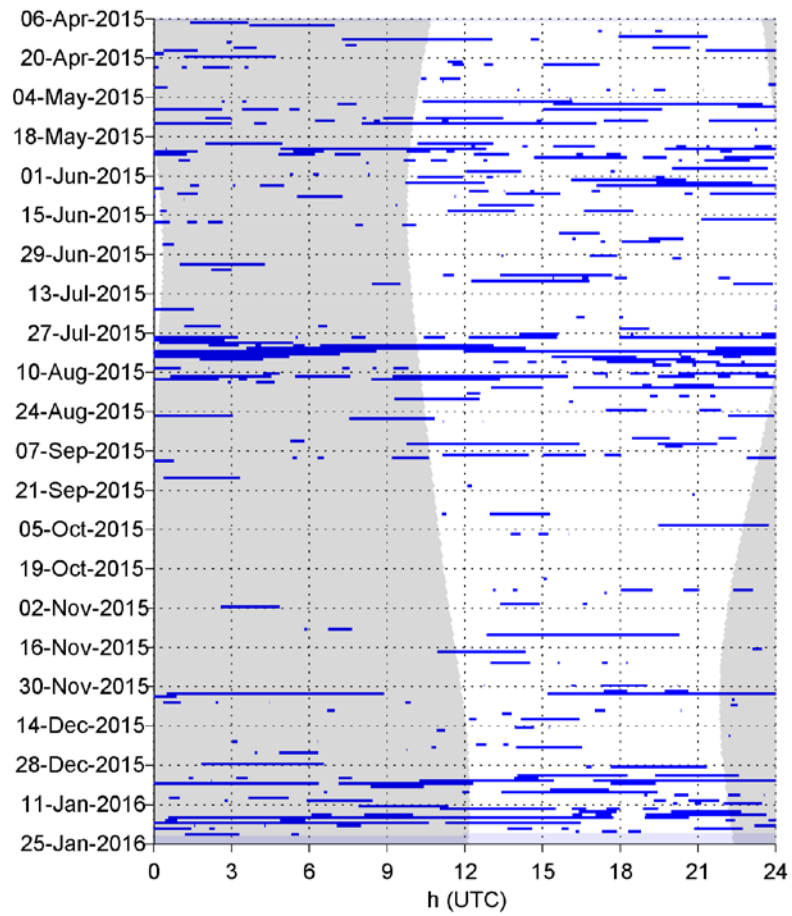


Figure 47. Sperm whale echolocation clicks in one-minute bins (blue bars) from April 2015 to January 2016. Effort markings are described in Figure 43.

Cuvier's Beaked Whale

- Cuvier's beaked whale clicks were detected from April 2015 to January 2016 (Figure 48).
- There was no diel pattern for Cuvier's beaked whale clicks (Figure 49).

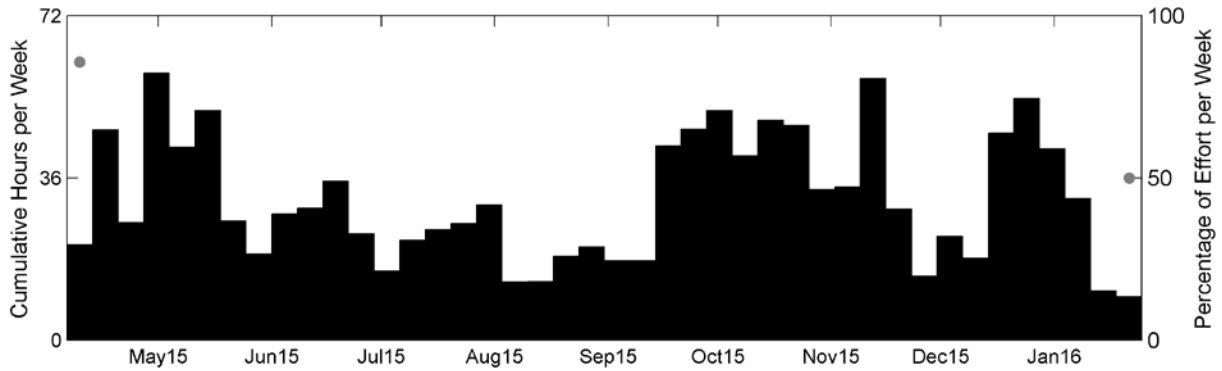


Figure 48. Weekly presence (black bars) of Cuvier's beaked whale clicks from April 2015 to January 2016. Effort markings are described in Figure 41.

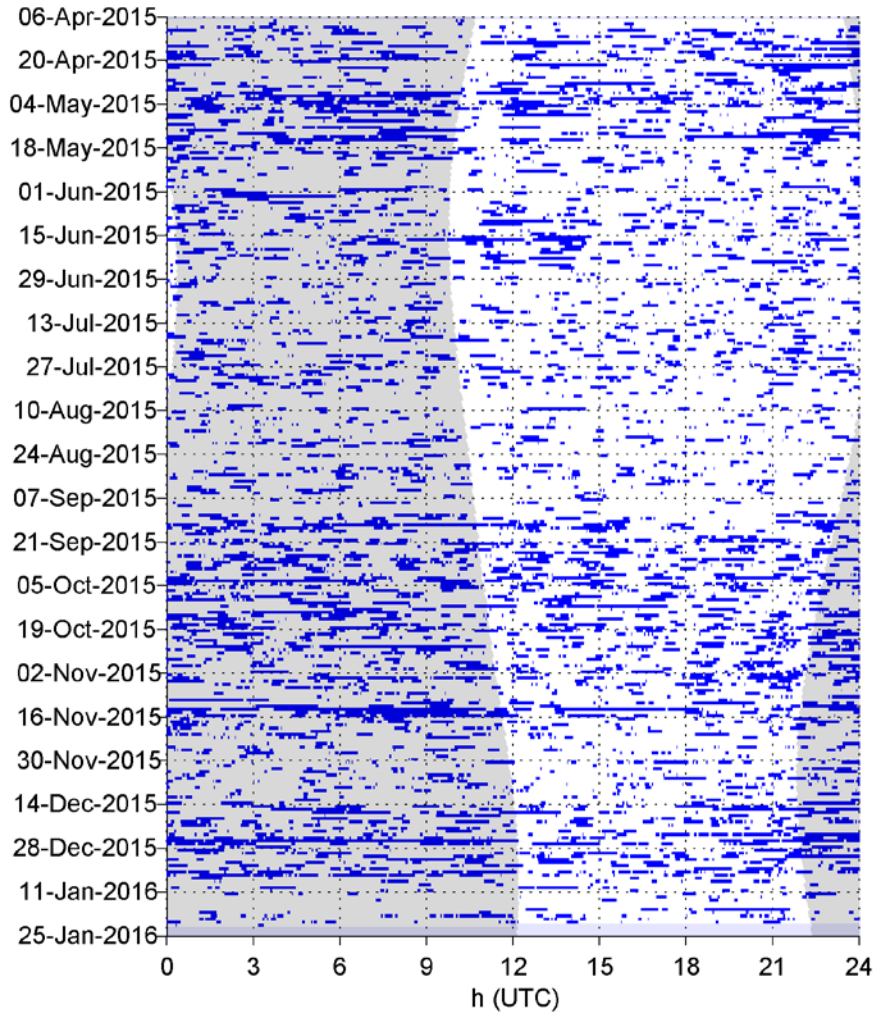


Figure 49. Cuvier's beaked whale echolocation clicks in one-minute bins (blue bars) from April 2015 to January 2016. Effort markings are described in Figure 43.

Gervais' Beaked Whale

- Gervais' beaked whale clicks were detected from April 2015 to January 2016, with fewer detections between September and November 2015 (Figure 50).
- There was no diel pattern for Gervais' beaked whale clicks (Figure 51).

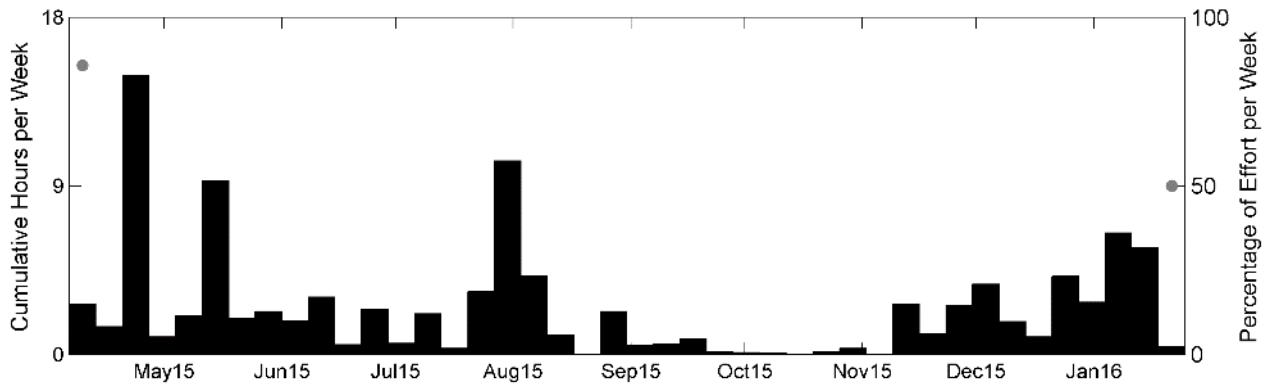


Figure 50. Weekly presence (black bars) of Gervais' beaked whale clicks from April 2015 to January 2016. Effort markings are described in Figure 41.

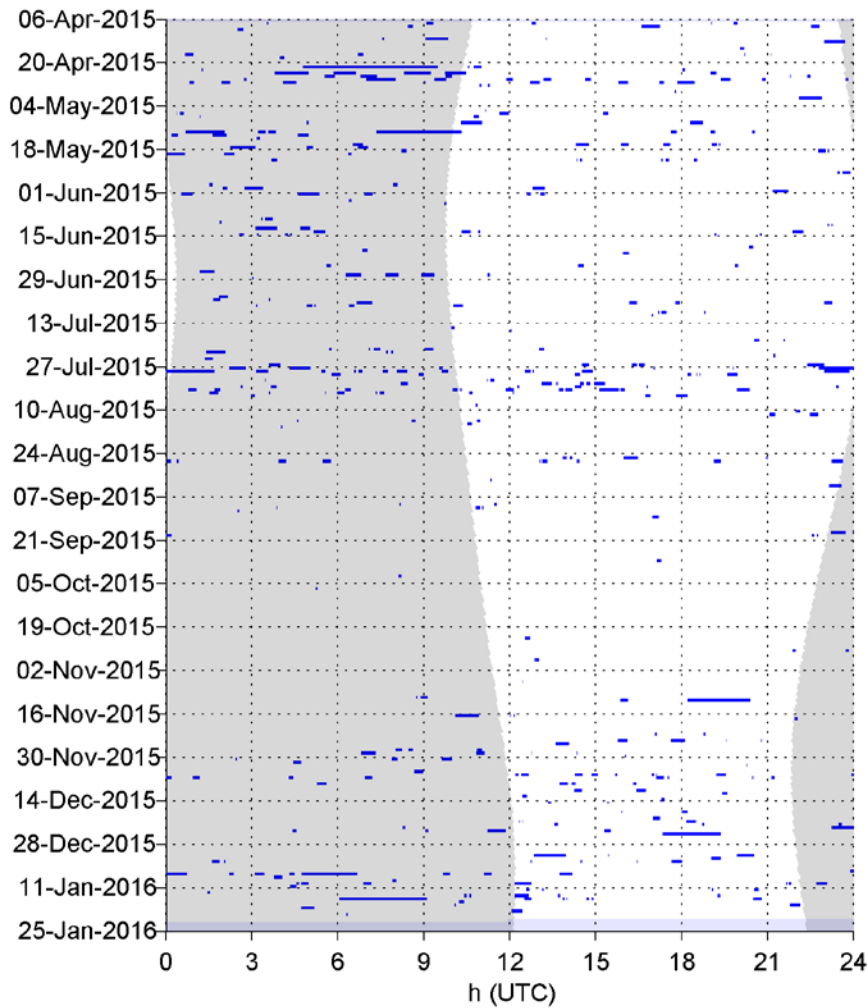


Figure 51. Gervais' beaked whale echolocation clicks in one-minute bins (blue bars) from April 2015 to January 2016. Effort markings are described in Figure 43.

Blainville's Beaked Whale

- Blainville’s beaked whale clicks were detected on a single day in January 2016. (Figure 52).
- There were too few encounters to determine a diel pattern for Blainville’s beaked whale clicks (Figure 53).

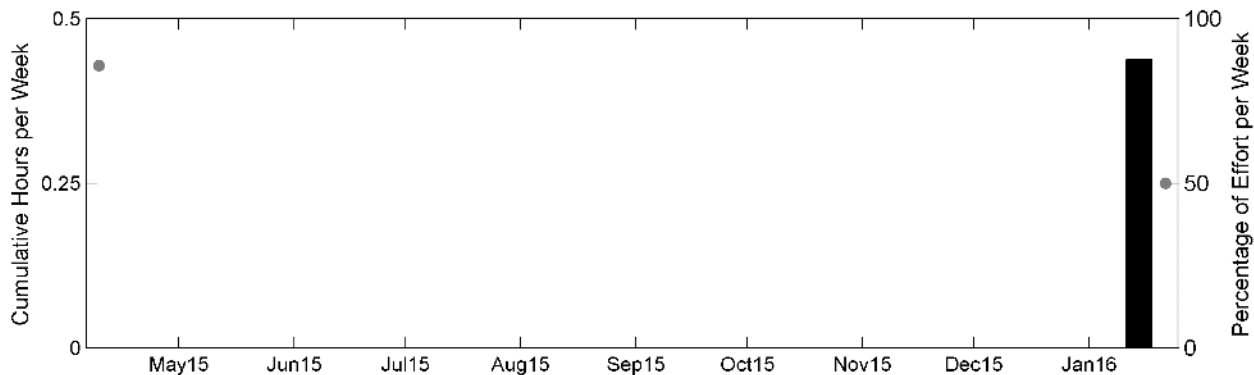


Figure 52. Weekly presence (black bar) of Blainville’s beaked whale clicks from April 2015 to January 2016. Effort markings are described in Figure 41.

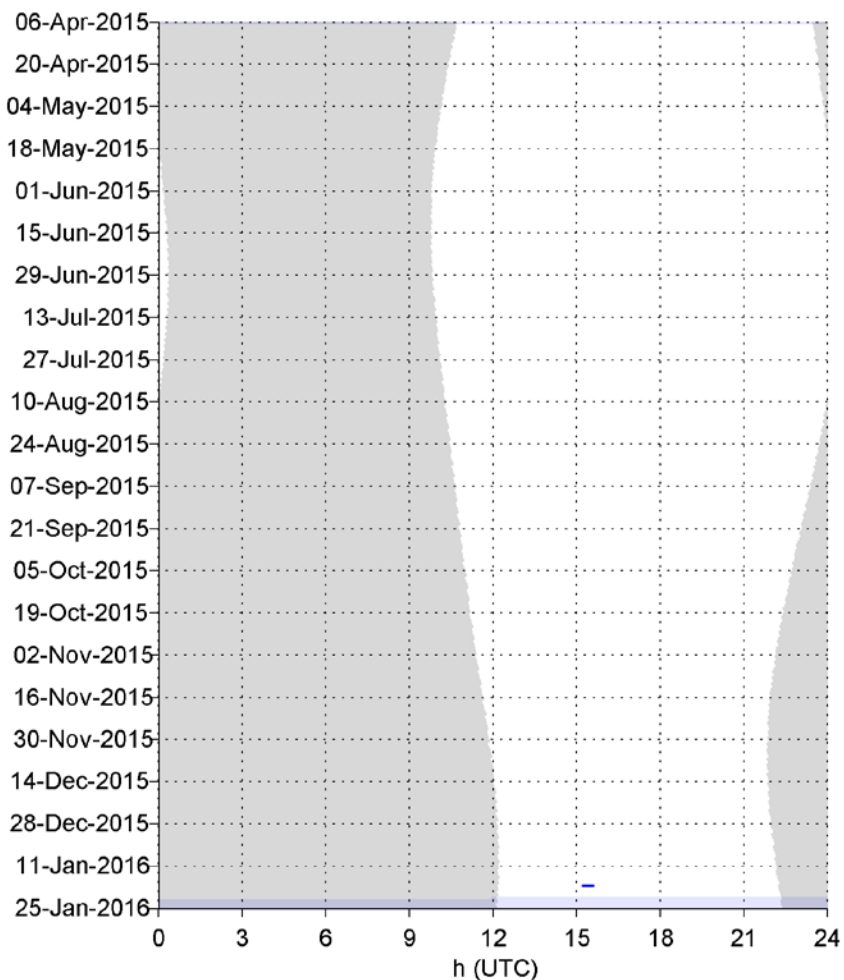


Figure 53. Blainville’s beaked whale echolocation clicks in one-minute bins (blue bar) from April 2015 to January 2016. Effort markings are described in Figure 43.

Kogia Spp.

- *Kogia* spp. echolocation clicks were detected throughout the recording period (Figure 54). Detections peaked in June 2015 (Figure 54).
- There was no discernable diel pattern for *Kogia* spp. clicks (Figure 55).

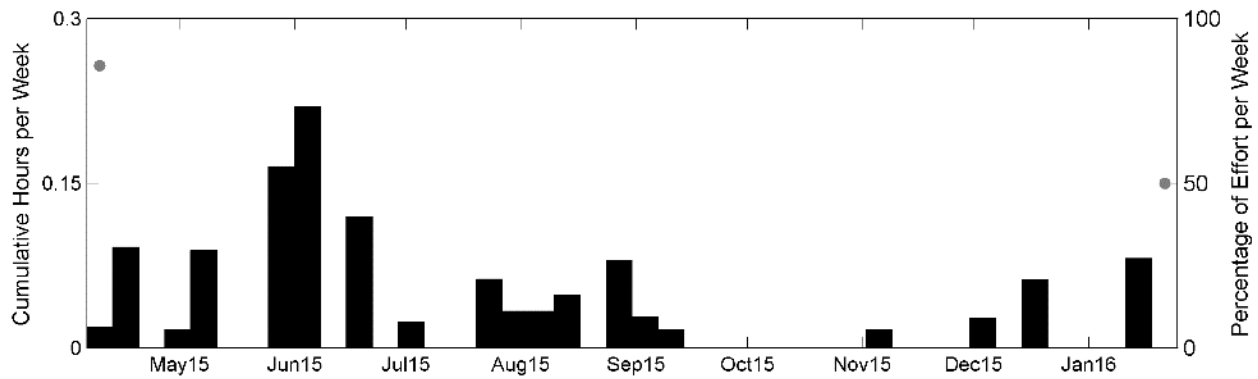


Figure 54. Weekly presence (black bars) of *Kogia* spp. clicks from April 2015 to January 2016. Effort markings are described in Figure 41.

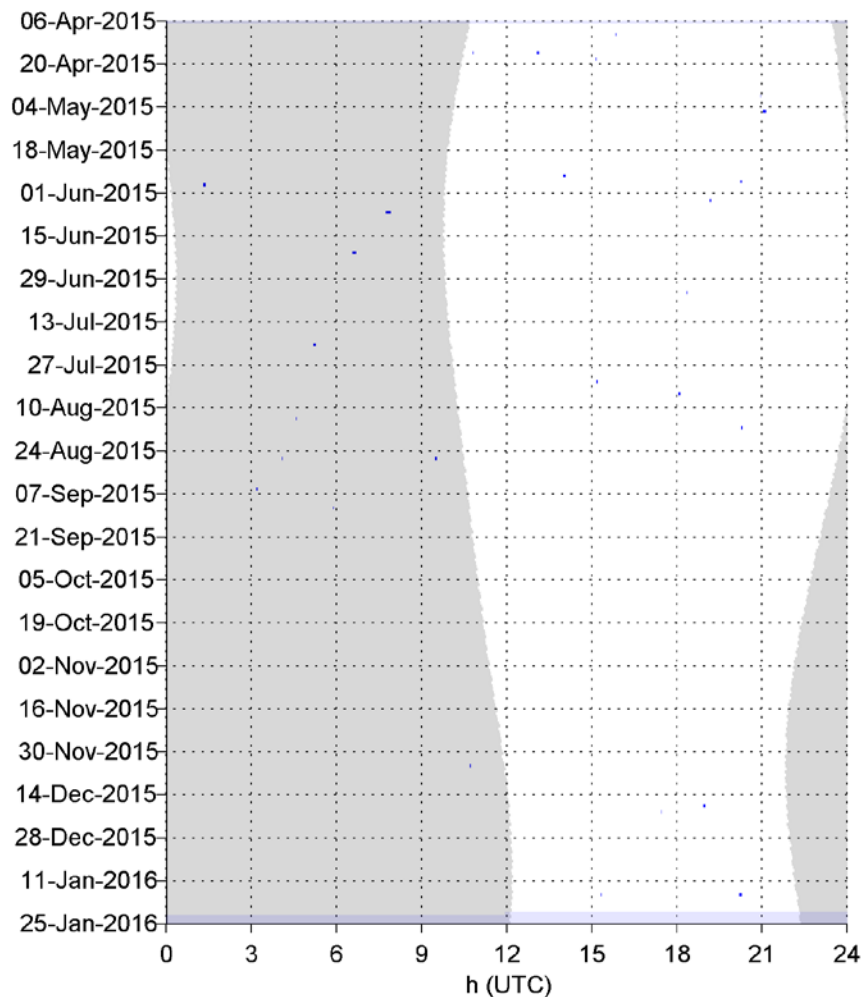


Figure 55. *Kogia* spp. clicks in one-minute bins (blue bars) from April 2015 to January 2016. Effort markings are described in Figure 43.

- Risso's dolphin clicks were detected from May to July 2015, with a peak in July 2015 (Figure 56).
- There were too few detections to determine a diel pattern for Risso's dolphin clicks (Figure 57).

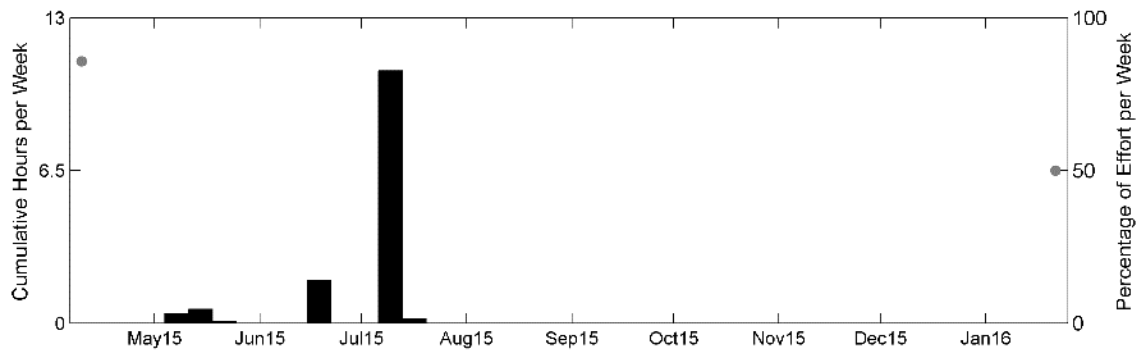


Figure 56. Weekly presence (black bars) of Risso's dolphin clicks from April 2015 to January 2016. Effort markings are described in Figure 41.

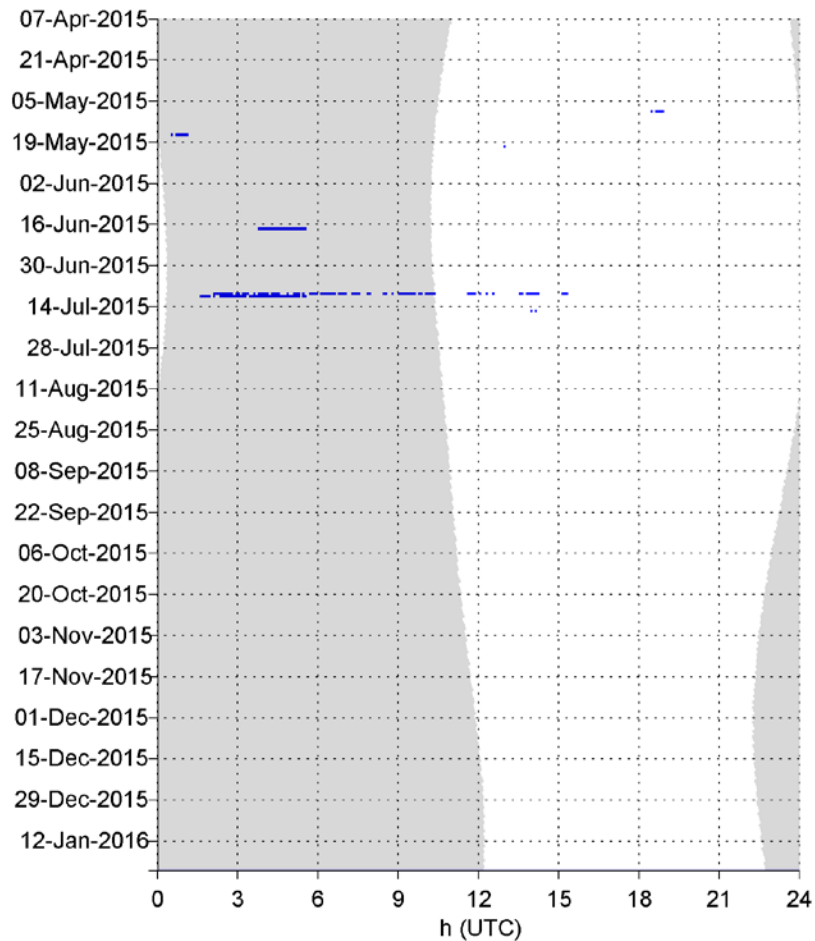


Figure 57. Risso's dolphin clicks in five-minute bins from April 2015 to January 2016. Effort markings are described in Figure 43.

Unidentified Odontocetes

Echolocation Click Types

Click Type 1

- Click type 1 was detected throughout the recording period (Figure 58).
- The majority of click type 1 detections occurred during nighttime hours, indicating foraging at night (Figure 59).

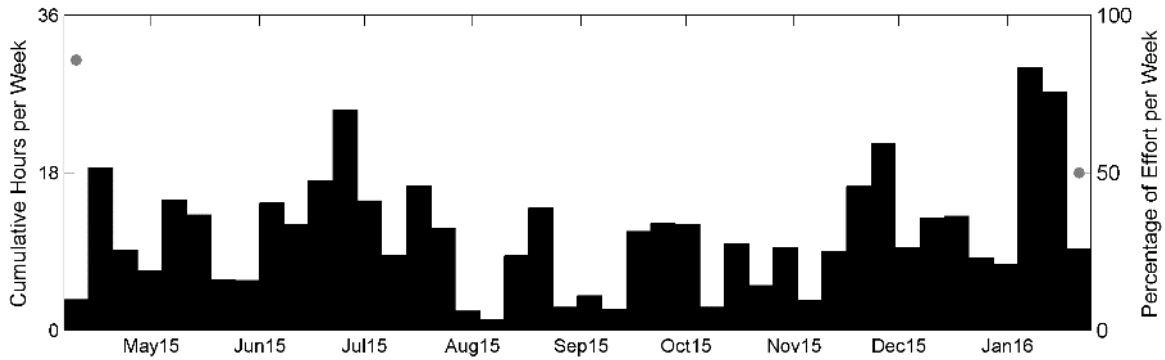


Figure 58. Weekly presence (black bars) of Click Type 1 detections from April 2015 to January 2016. Effort markings are described in Figure 41.

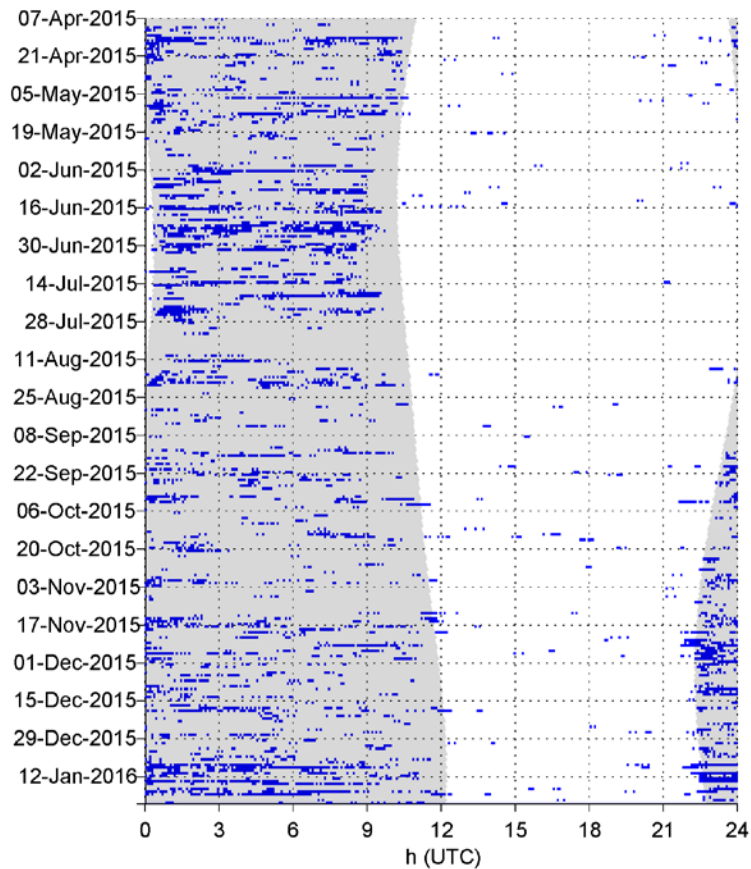


Figure 59. Click Type 1 detections in five-minute bins from April 2015 to January 2016 at HAT. Effort markings are described in Figure 43.

Click Type 2

- Click type 2 was detected sporadically throughout the deployment, with a peak in April 2015 (Figure 60).
- Click type 2 occurred during nighttime hours (Figure 61).

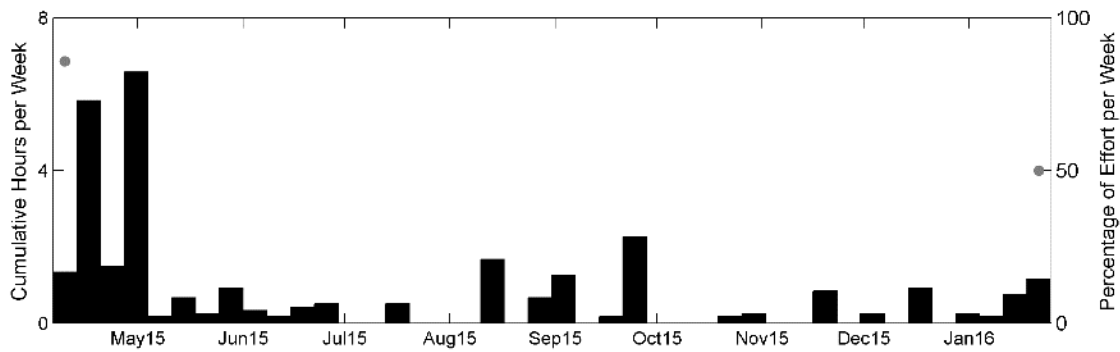


Figure 60. Weekly presence (black bars) of Click Type 2 detections from April 2015 to January 2016. Effort markings are described in Figure 41.

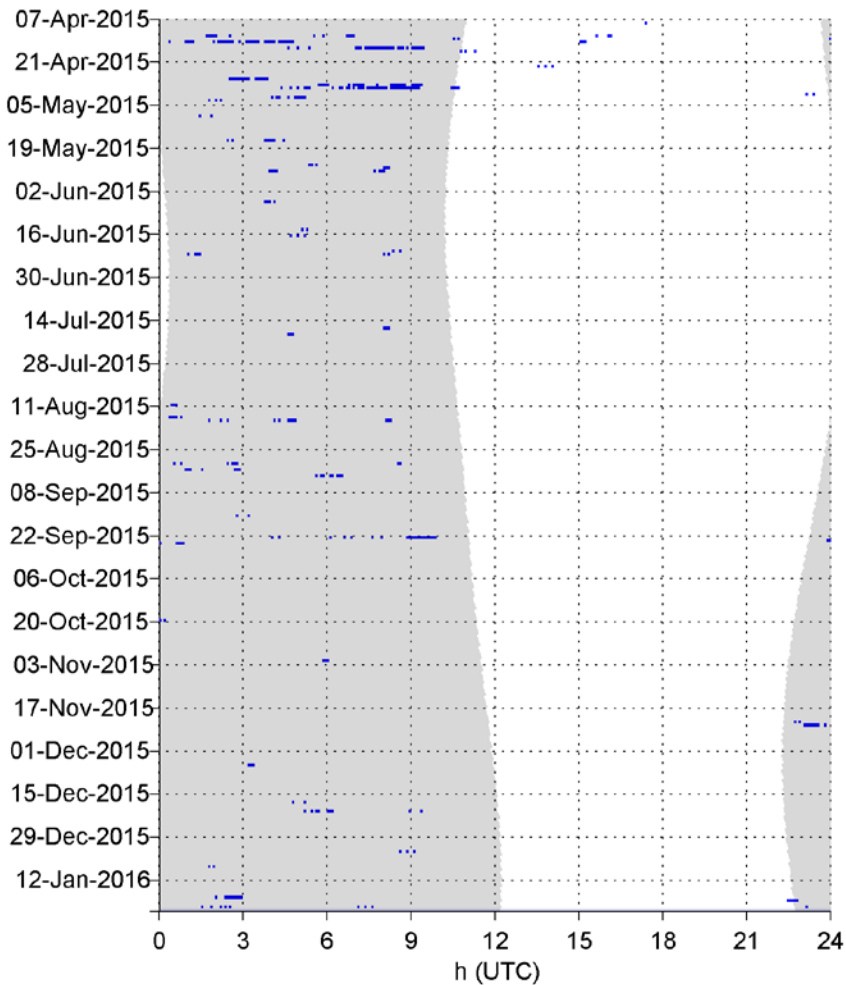


Figure 61. Click Type 2 detections in five-minute bins (blue bars) at HAT. Effort markings are described in Figure 43.

Click Type 4

- Click type 4 was detected throughout the recording period, with more detections from September 2015 to January 2016 (Figure 62).
- The diel pattern for click type 4 was less pronounced than in other click types (Figure 63).

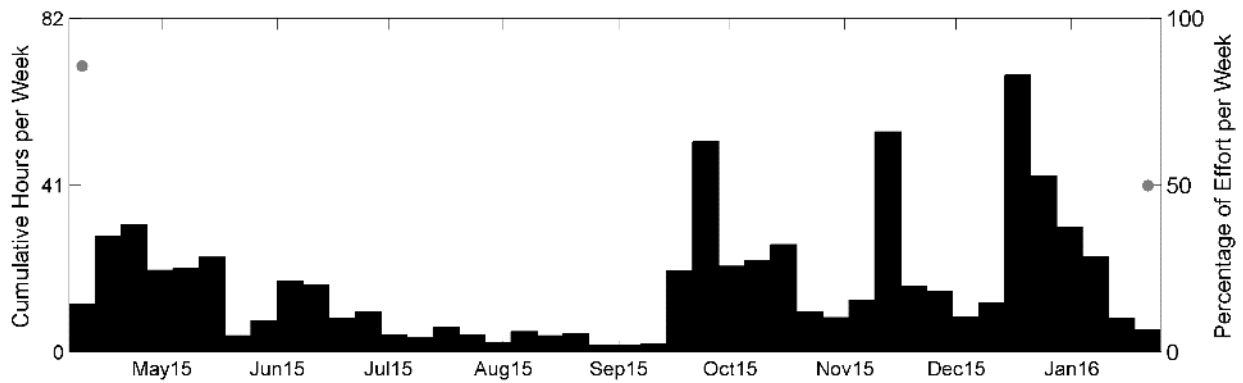


Figure 62. Weekly presence (black bars) of Click Type 4 detections from April 2015 to January 2016 at HAT. Effort markings are described in Figure 41.

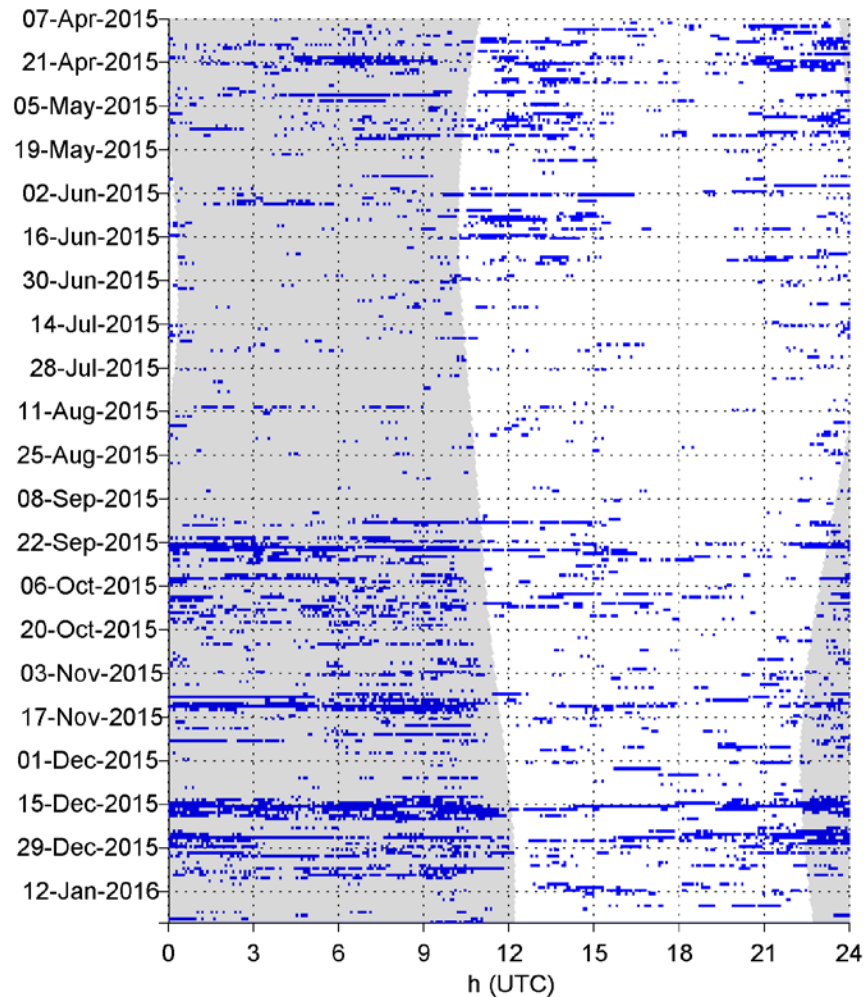


Figure 63. Click Type 4 detections in five-minute bins at HAT. Effort markings are described in Figure 43.

Click Type 6

- Click type 6 was detected throughout the recording period, with higher numbers of detections from May to September 2015 (Figure 64).
- Click type 6 was primarily detected during nighttime (Figure 65).

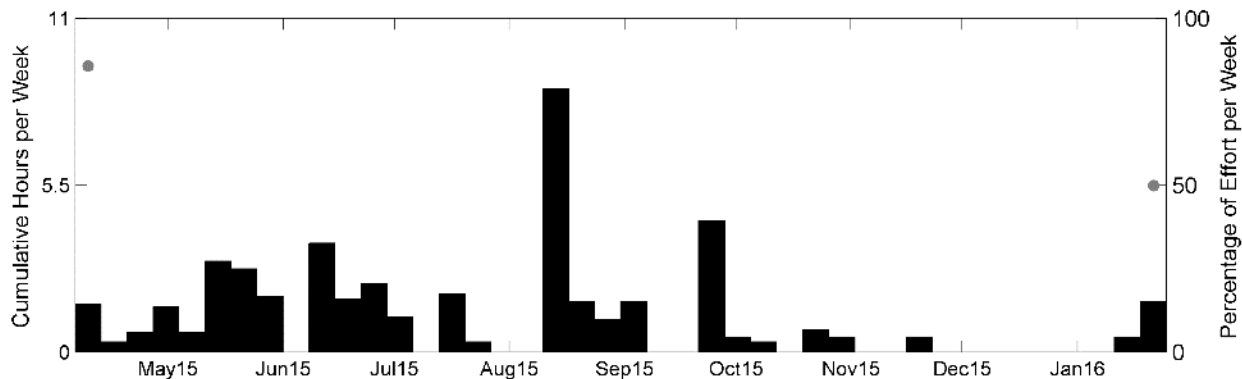


Figure 64. Weekly presence (black bars) of click type 6 detections from April 2015 to January 2016 at HAT. Effort markings are described in Figure 41.

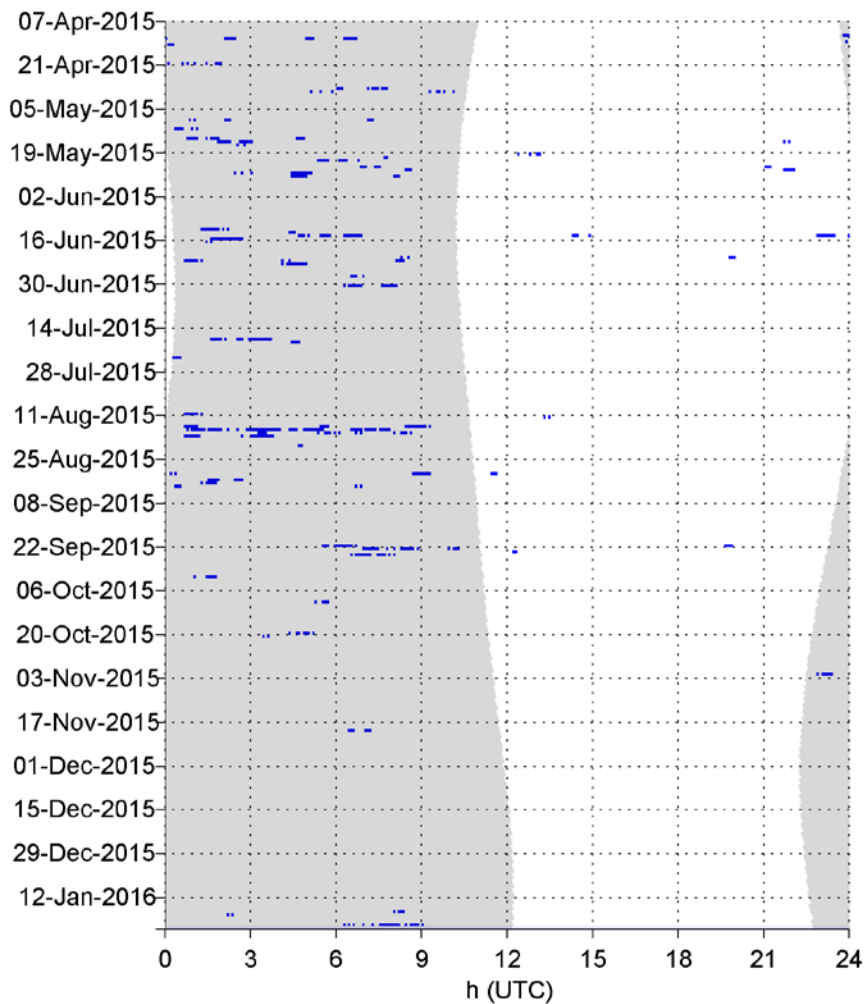


Figure 65. Click type 6 detections in five-minute bins at HAT. Effort markings are described in Figure 43.

Click Type 7

- Click type 7 was detected throughout the recording period (Figure 66).
- There was no pronounced diel pattern for click type 7 (Figure 67).

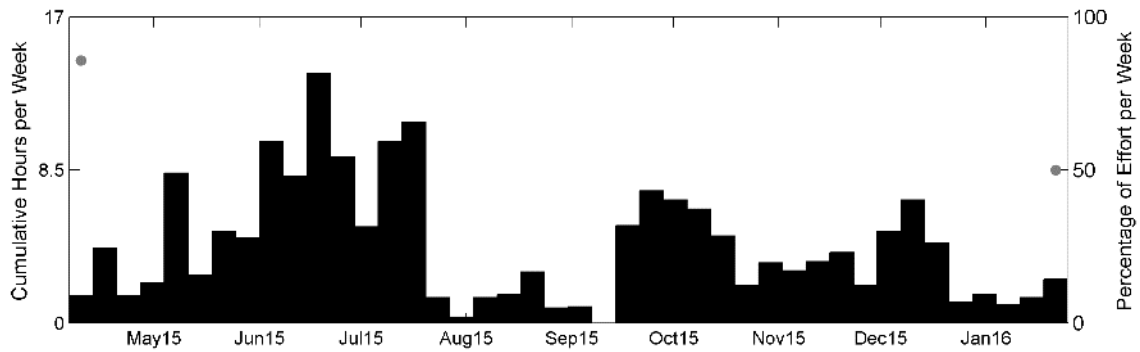


Figure 66. Weekly presence (black bars) of click type 7 detections from April 2015 to January 2016 at HAT. Effort markings are described in Figure 41.

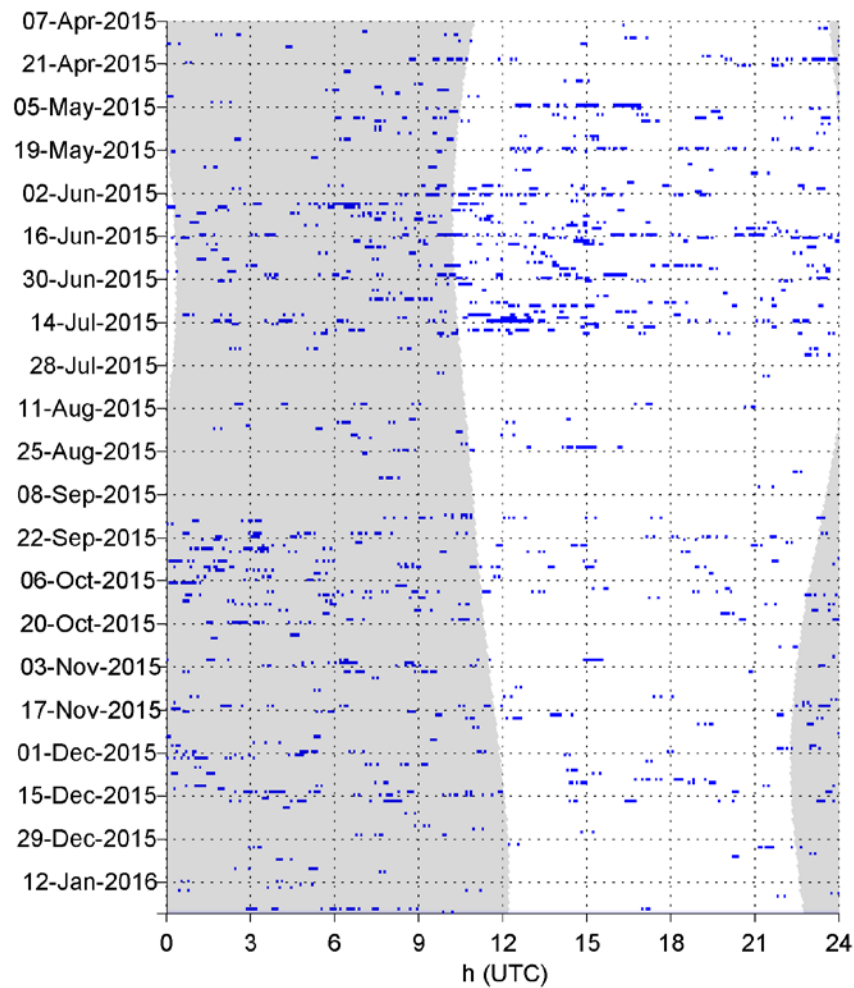


Figure 67. Click type 7 detections in five-minute bins at HAT. Effort markings are described in Figure 43.

Unidentified Odontocete Clicks

Signals that had characteristics of odontocete 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, if they did not match documented click type, 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 68).
- Unidentified odontocete clicks were predominantly detected during nighttime hours (Figure 69).

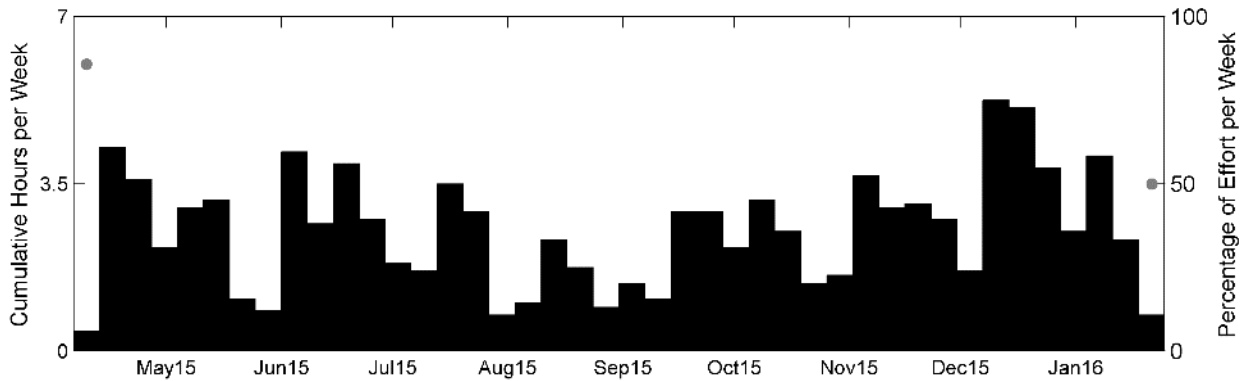


Figure 68. Weekly presence (black bars) of unidentified click detections from April 2015 to January 2016. Effort markings are described in Figure 41.

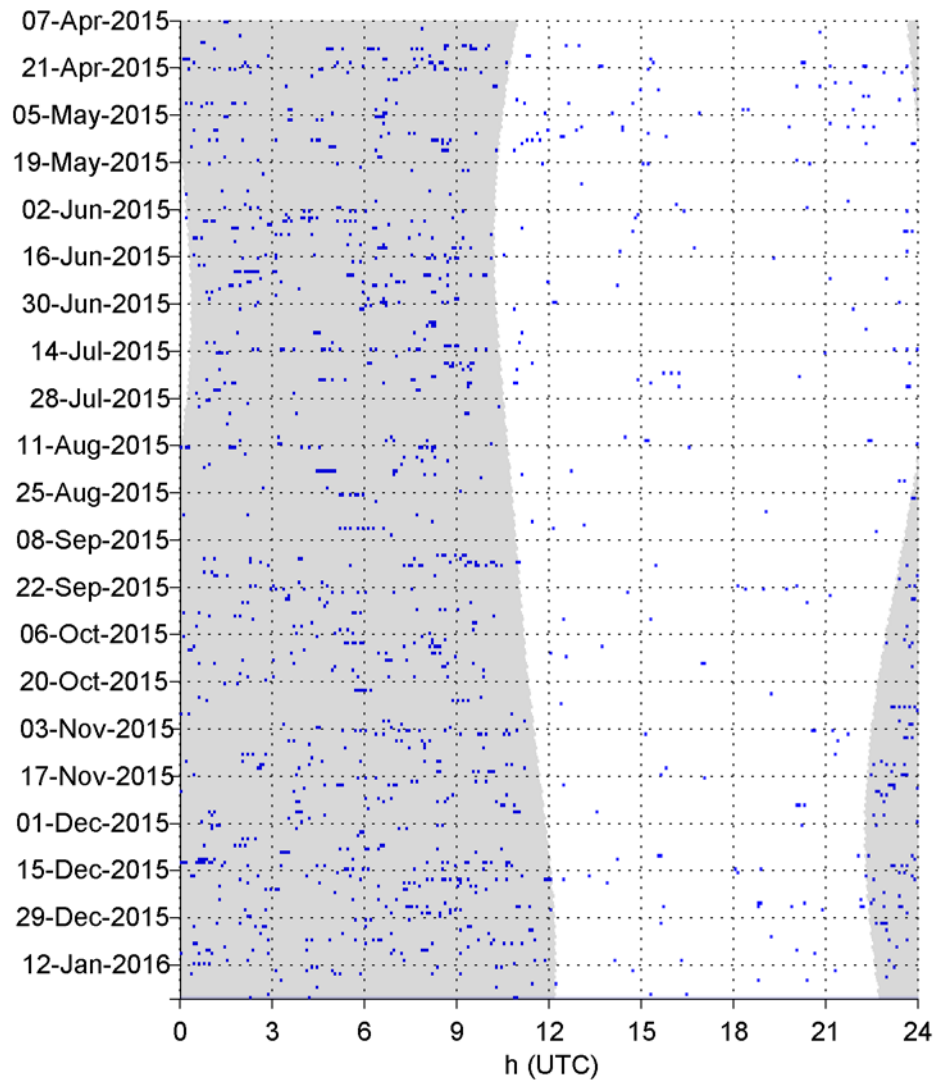


Figure 69. Unidentified odontocete clicks in five-minute bins (blue bars) from April 2015 to January 2016. Effort markings are as described in Figure 43.

Unidentified Odontocete Whistles

Unidentified odontocete whistles were detected throughout the recording.

- Whistles less than 5 kHz were detected from April 2015 to January 2016 with higher presence from April to October 2015 (Figure 70).
- Whistles above 5 kHz were detected from April 2015 to January 2016 (Figure 71).
- There was no diel pattern detected for whistles below 5 kHz or for whistles greater than 5 kHz (Figure 72, Figure 73)

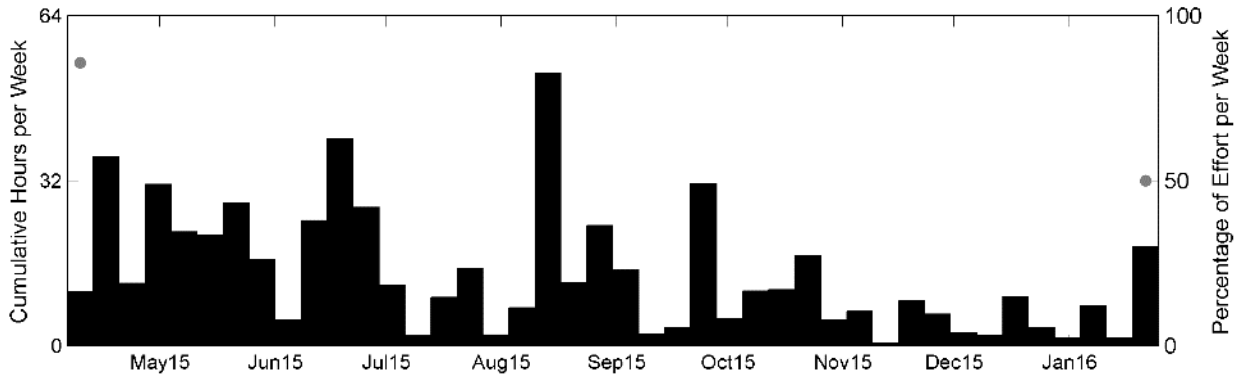


Figure 70. Weekly presence (black bars) of unidentified odontocete whistles less than 5 kHz from April 2015 to January 2016. Effort markings are described in Figure 41.

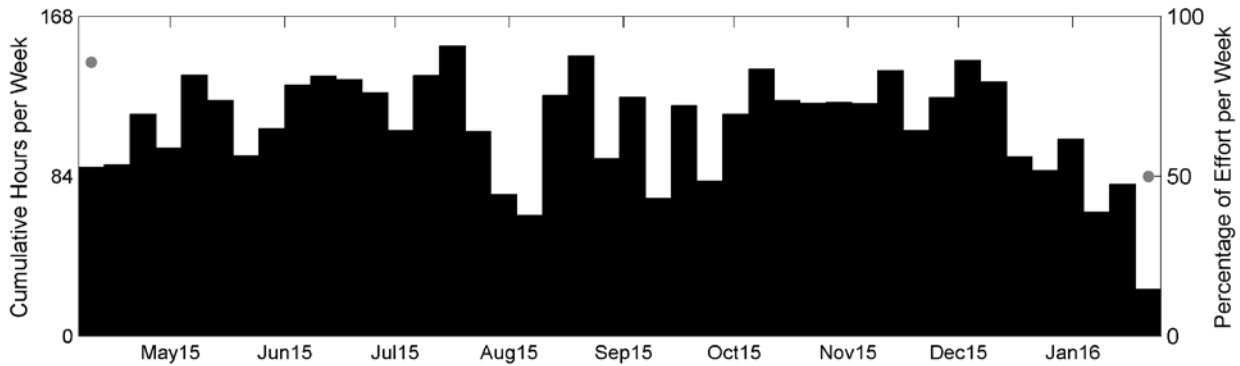


Figure 71. Weekly presence (black bars) of unidentified odontocete whistles greater than 5 kHz from April 2015 to January 2016. Effort markings are described in Figure 41.

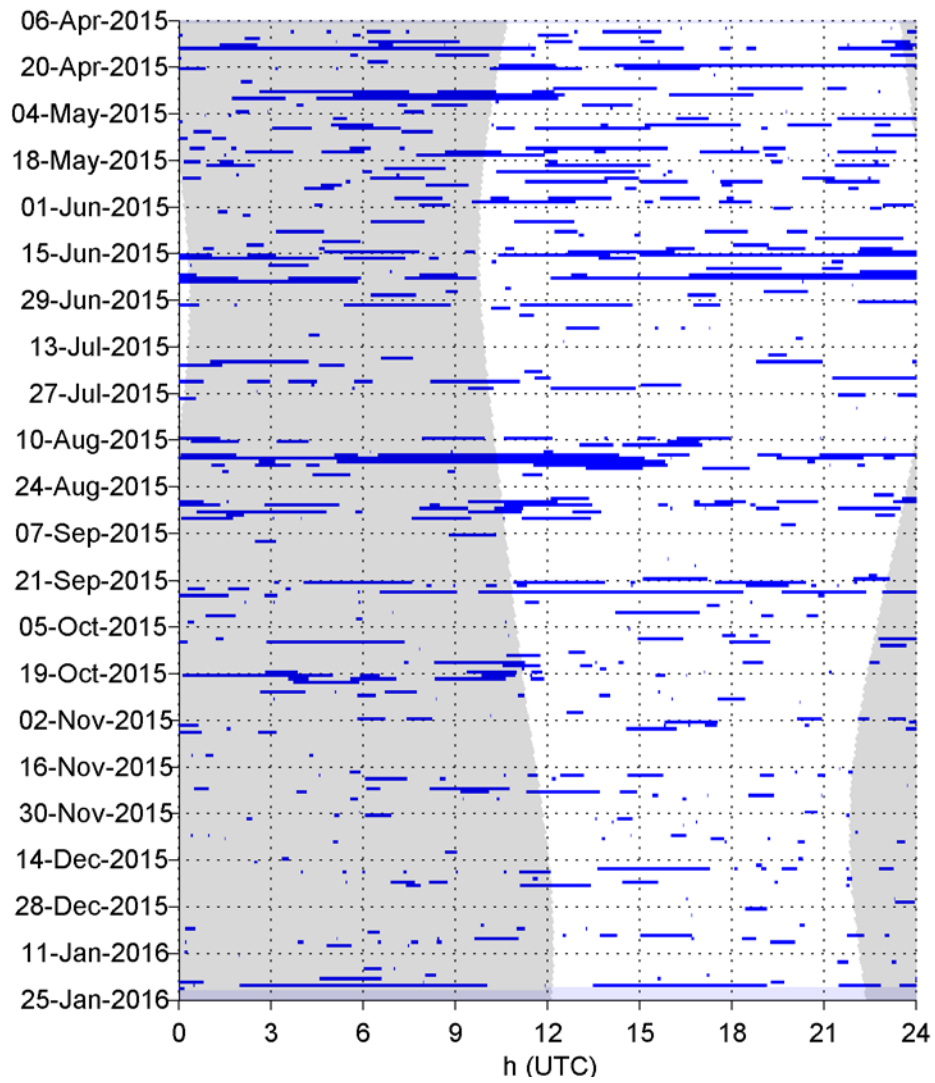


Figure 72. Unidentified odontocete whistles less than 5 kHz in one-minute bins (blue bars) from April 2015 to January 2016. Effort markings are described in Figure 43.

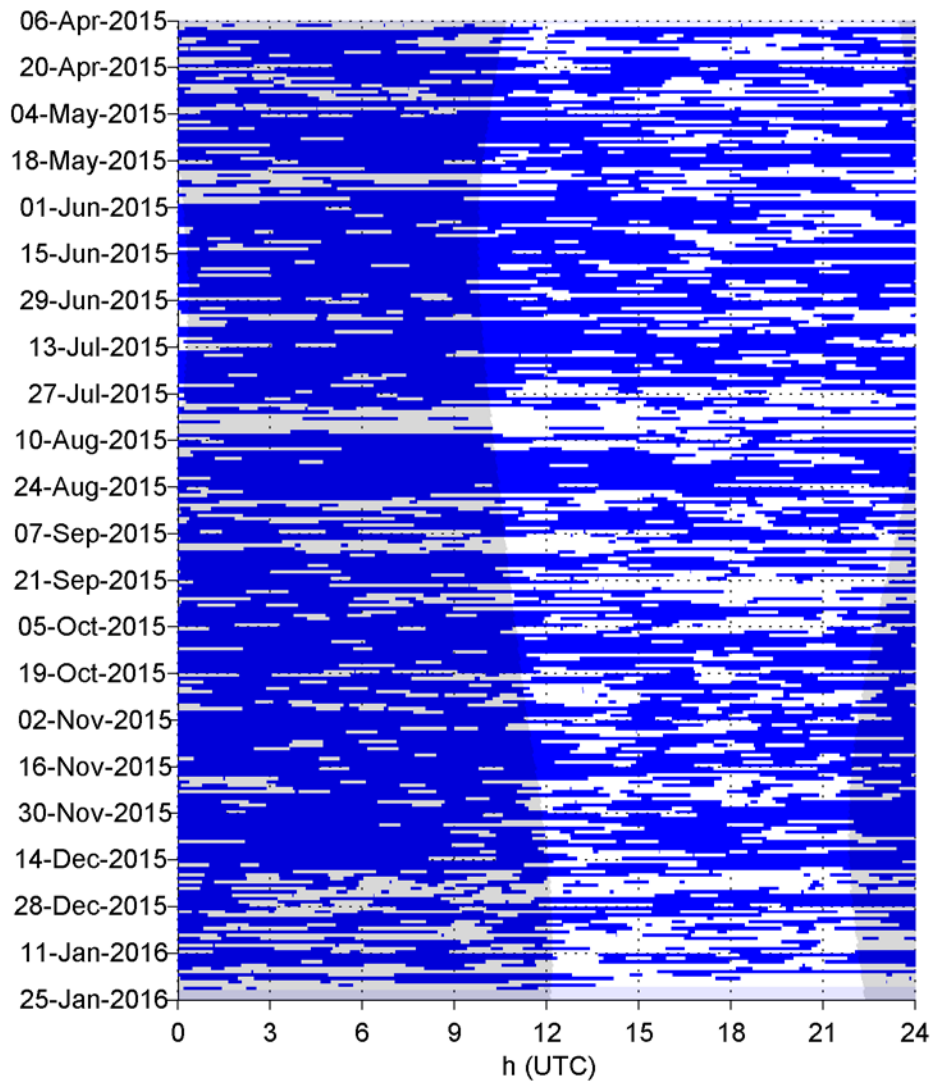


Figure 73. Unidentified odontocete whistles greater than 5 kHz in one-minute bins (blue bars) from April 2015 to January 2016. Effort markings are described in Figure 43.

Anthropogenic Sounds

Five types of anthropogenic sounds were detected: broadband ship noise, explosions, airguns, MFA sonar, and LFA sonar (500-1000 Hz).

Broadband Ship Noise

- Broadband ship noise was detected throughout the deployment from April 2015 to January 2016, with a slight decrease in late September 2015 (Figure 74).
- There was no discernable diel pattern for broadband ship noise (Figure 75).

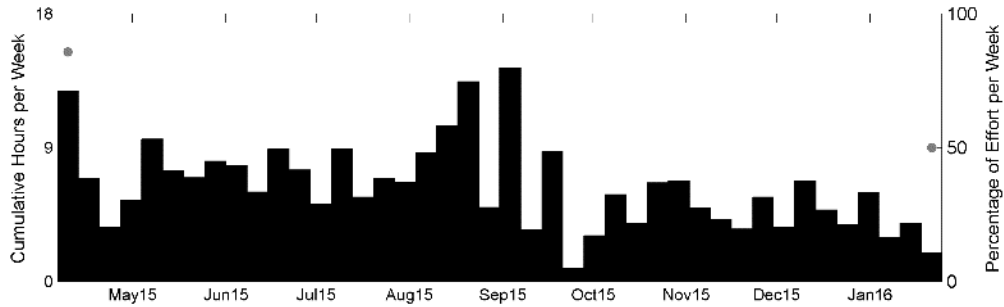


Figure 74. Weekly presence (black bars) of broadband ship noise from April 2015 to January 2016. Effort markings are described in Figure 41.

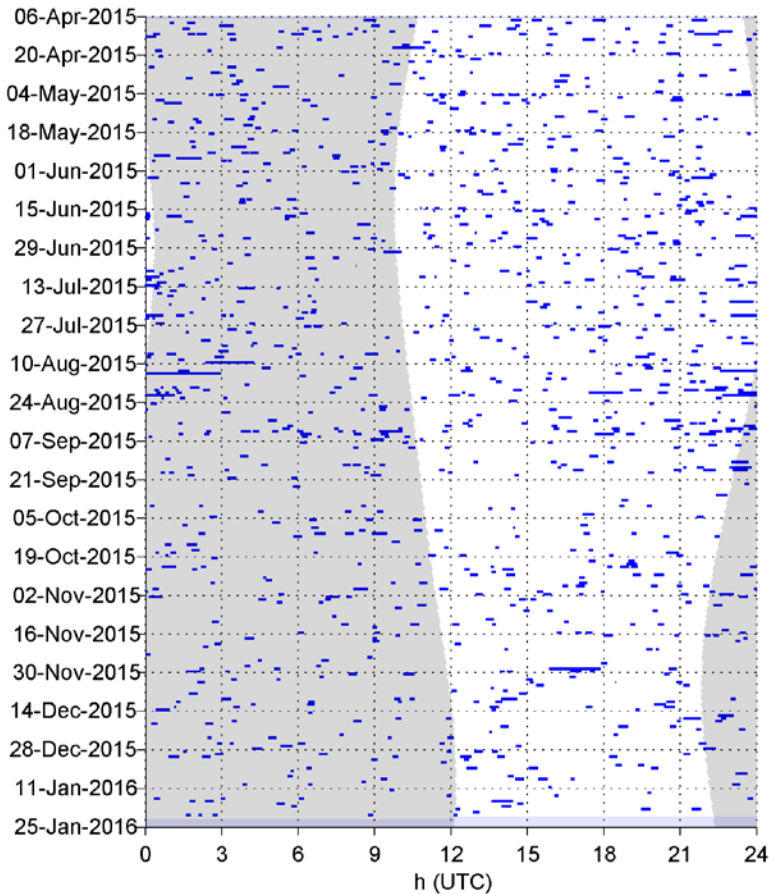


Figure 75. Broadband ship noise in one-minute bins (blue bars) from April 2015 to January 2016. Effort markings are described in Figure 43.

Explosions

- Explosions were detected sporadically in low numbers during the deployment, with a peak in August 2015 (Figure 76).
- There were too few detections to determine a diel pattern (Figure 77).

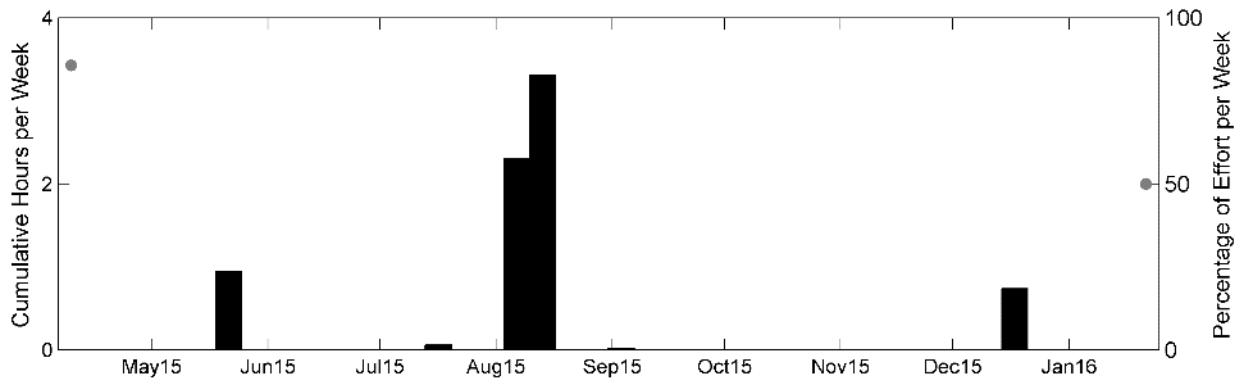


Figure 76. Weekly presence (black bars) of explosions from April 2015 to January 2016. Effort markings are described in Figure 41.

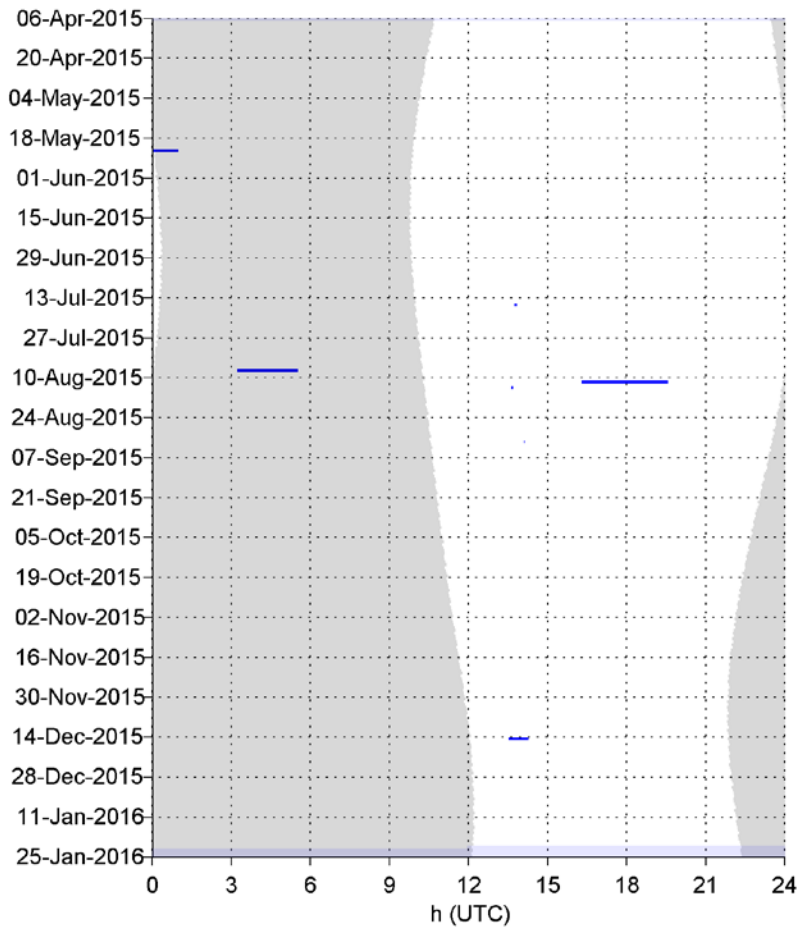


Figure 77. Explosion detections in one-minute bins (blue bars) at HAT. Effort markings are described in Figure 43.

Airguns

- Airguns were detected from April 2015 to January 2016 with a period of low activity from early May to late June 2015. Peak airgun activity occurred in April 2015 and from July to September 2015 (Figure 78).
- The majority of airgun detections were of low received level indicating distant surveys.
- There was no discernable diel pattern for airguns (Figure 79).

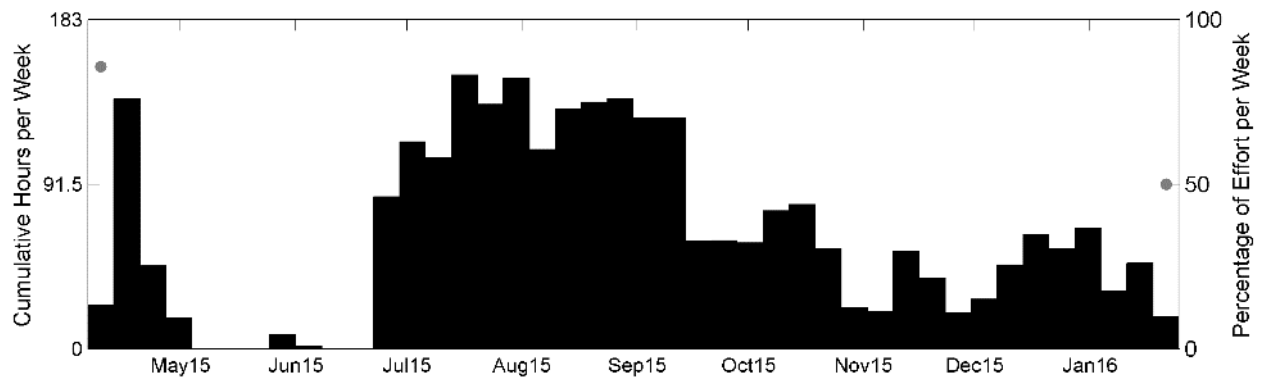


Figure 78. Weekly presence (black bars) of airguns from April 2015 to January 2016. Effort markings are described in Figure 41.

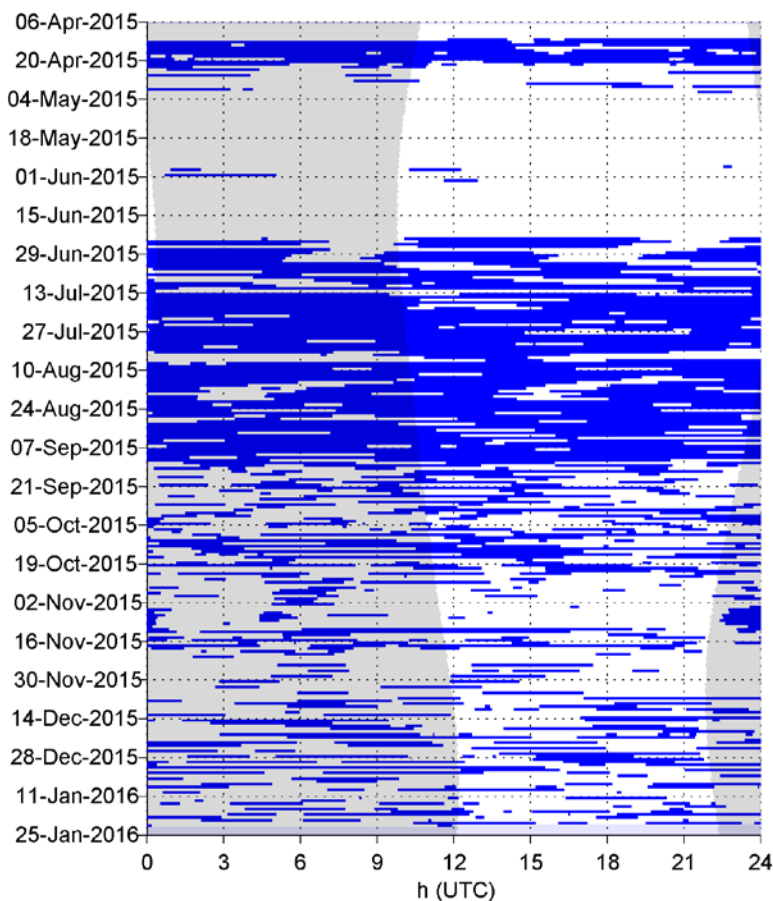


Figure 79. Airgun detections in one-minute bins from April 2015 to January 2016. Effort markings are described in Figure 43.

Low-Frequency Active Sonar

- LFA sonar at frequencies above 500 Hz was detected on a single day in September 2015 (Figure 80).
- There were too few LFA detections to determine a diel pattern (Figure 81).

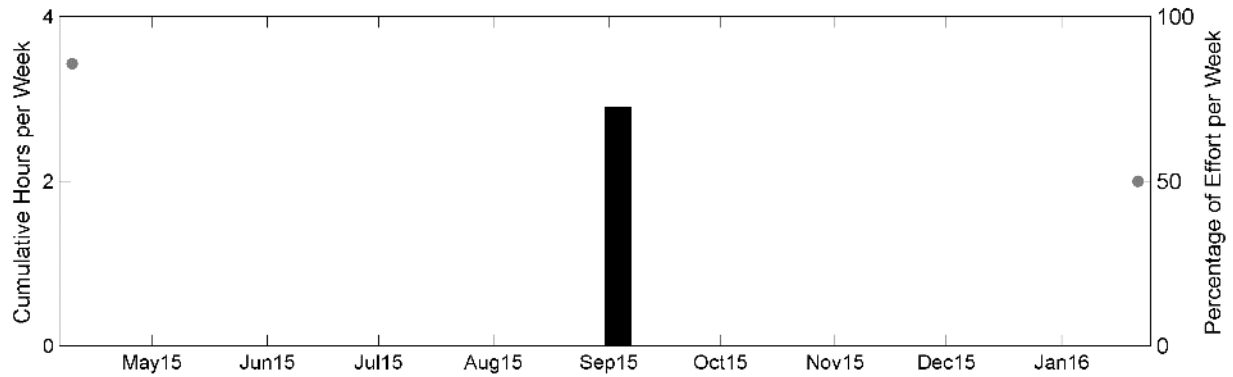


Figure 80. Weekly presence (black bar) of LFA sonar above 500 Hz from April 2015 to January 2016. Effort markings are described in Figure 41.

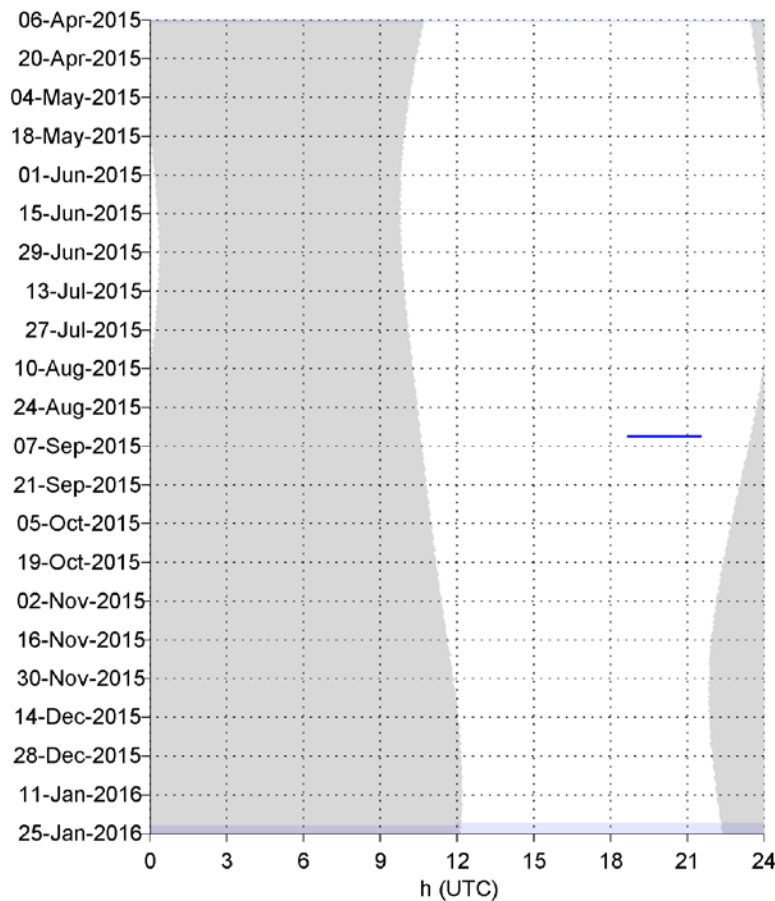


Figure 81. LFA sonar above 500 Hz in one-minute bins (blue bars) from April 2015 to January 2016. Effort markings are described Figure 43.

Mid-Frequency Active Sonar

- MFA sonar was detected sporadically between April 2015 and January 2016 (Figure 82).

- There were too few MFA detections to discern any diel pattern (Figure 83).
- After filtering, a single MFA wave train consisting of 35 packets above 130 dB pp re 1 μ Pa was detected in October 2015 (Figure 84).
- For the single wave train, a maximum peak to peak level of 143 dB pp re 1 μ Pa, and median level of 138 dB pp re 1 μ Pa was measured, with a cumulative SEL of 141 dB re 1 μ Pa²-s.
- Packets ranged in duration from 1.5 to 4 seconds. The majority of packets had a duration of approximately 4 seconds.

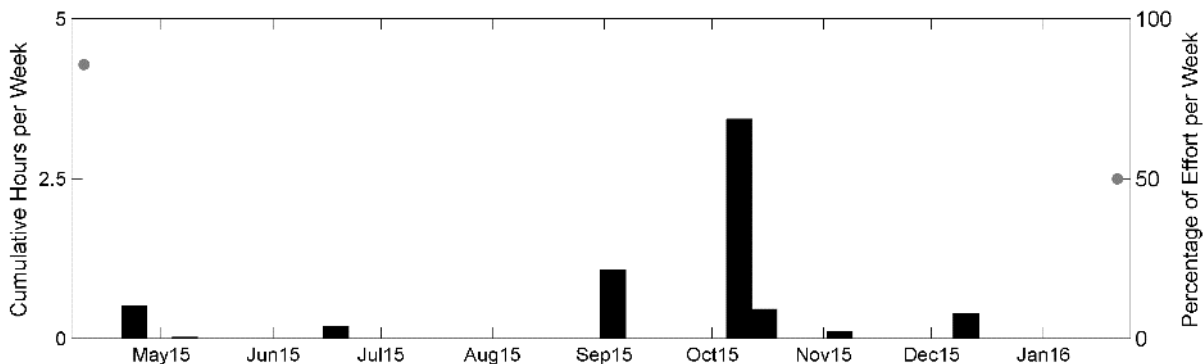


Figure 82. Weekly presence (black bars) of MFA sonar from April 2015 to January 2016. Effort markings are described in Figure 41.

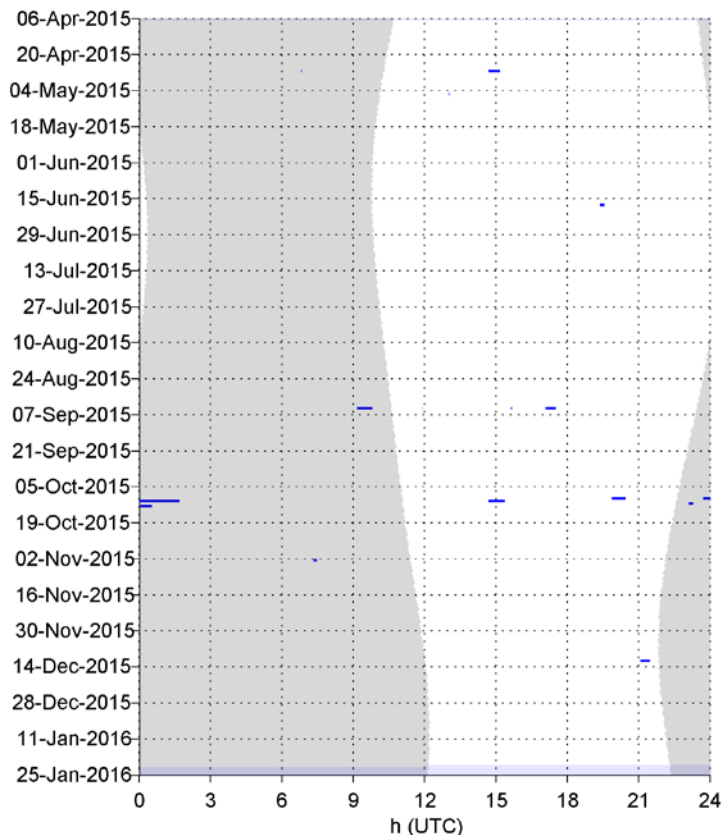


Figure 83. MFA sonar in one-minute bins (blue bars) from April 2015 to January 2016. Effort markings are described in Figure 43.

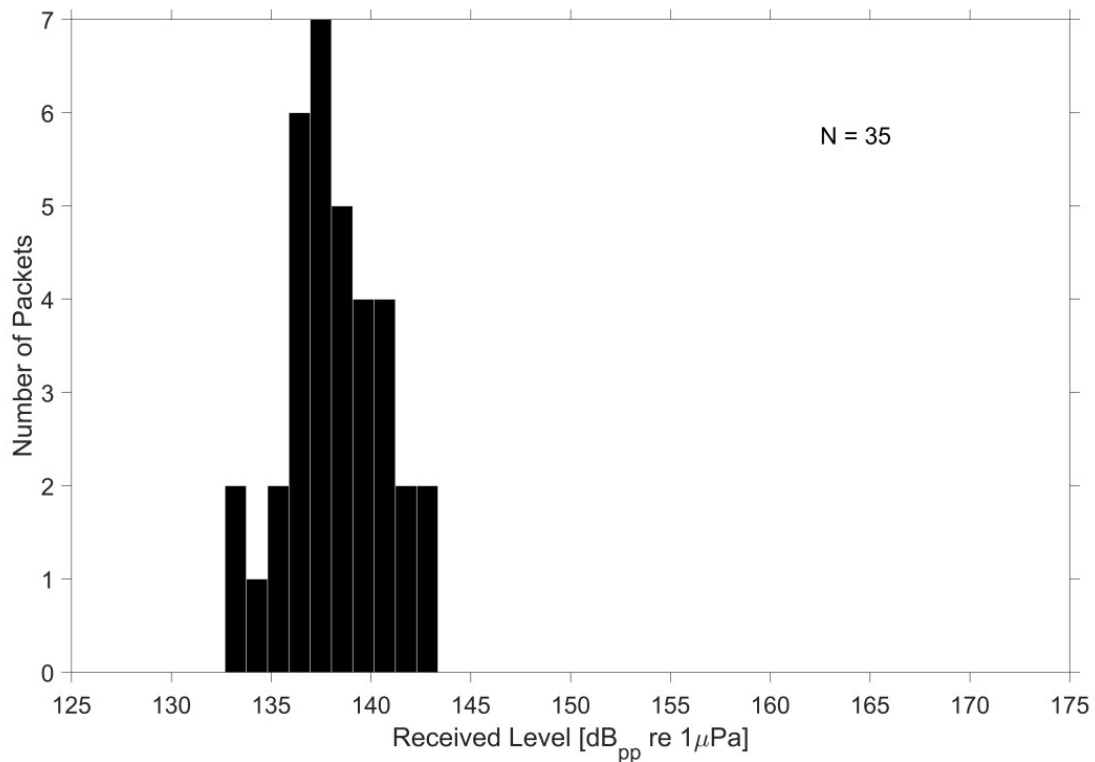


Figure 84. Distribution of received levels (dB pp re 1µPa) for MFA sonar in October 2015.

Echosounders

- Echosounders were detected sporadically from April 2015 to January 2016, with higher numbers of detections from May to October 2015 (Figure 85).
- Echosounders were observed more often during the day, or just after sunset (Figure 86).

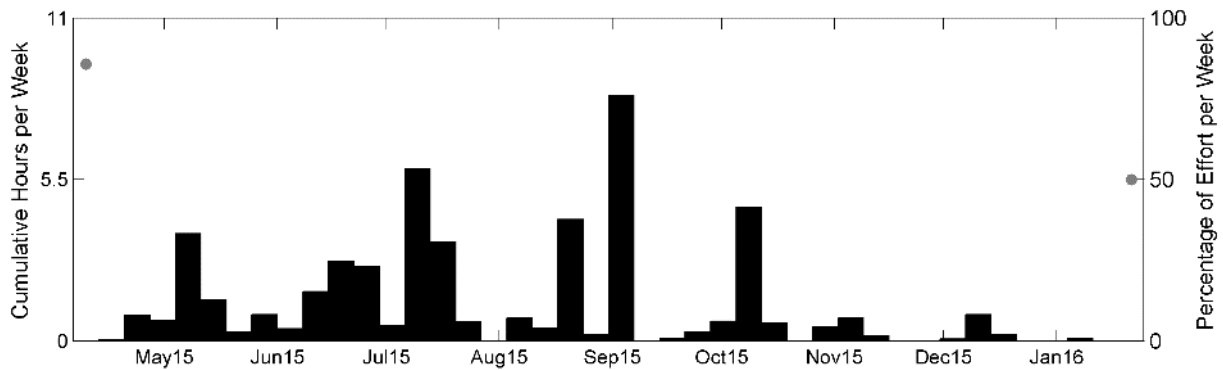


Figure 85. Weekly presence (black bars) of echosounders from April 2015 to January 2016. Effort markings are described in Figure 41.

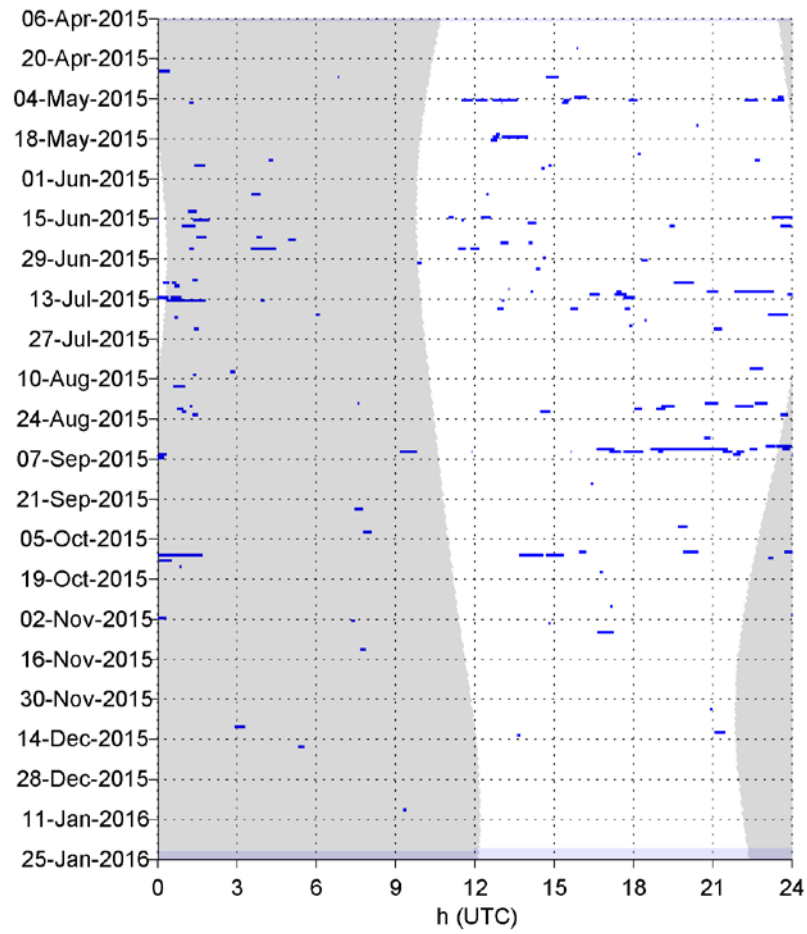


Figure 86. Echosounder detections in one-minute bins (blue bars) from April 2015 to January 2016. Effort markings are described in Figure 43.

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