

Passive Acoustic Monitoring for Marine Mammals in the Jacksonville Range Complex April 2016 – June 2017

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Spinner Dolphin (*Stenella longirostris*) Photo credit: Amanda 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

A High-Frequency Acoustic Recording Package (HARP) was deployed from April 2016 to June 2017 to detect marine mammal and anthropogenic sounds in the Navy's Jacksonville Range Complex. The HARP was located 83 nm off the Florida coastline on the continental slope. The HARP recorded sound in the frequency band 10 Hz – 100 kHz. Data analysis consisted of analyst scans of long-term spectral averages (LTSAs) and spectrograms, and automated computer algorithm detection when possible. Three frequency bands were analyzed for marine mammal vocalizations and anthropogenic sounds: (1) Low-frequency, between 10-500 Hz, (2) Mid-frequency, between 500-5,000 Hz, and (3) High-frequency, between 5-100 kHz.

Two baleen whale species were detected: fin whales and minke whales. Fin whales were detected intermittently throughout the monitoring period. Minke whales were detected continuously from November 2016 to April 2017.

Several known odontocete species were detected, along with odontocete signals that cannot yet be distinguished to species. *Kogia* spp. echolocation clicks were found throughout the recording period, with highest numbers of detections occurring in March 2017 and June 2017. Sperm whale echolocation clicks were detected intermittently throughout the detection period with highest numbers in September 2016 and October 2016. One acoustically identifiable delphinid species was Risso's dolphins, whose echolocation clicks were detected in high numbers between July and September 2016. Detections decreased in late September through November 2016. Odontocete signals that could not be distinguished to species were common throughout the recordings. Three distinct click types (CT) of unknown species origin were identified and designated as CT J1, J2, and J3. Unidentified odontocete whistles were detected and categorized as either above or below 5 kHz.

Anthropogenic sounds from broadband ships were detected throughout the recording period. Echosounders greater than 5 kHz were detected intermittently. LFA sonar greater than 500 Hz was detected only in February 2017, whereas other LFA sonar was detected only in April 2016. HFA sonar was detected only in June 2016. MFA sonar less than 5 kHz was detected intermittently, primarily between May 2016 and March 2017. The highest number of MFA sonar packets (>600) and Cumulative Sound Exposure Levels (CSEL) (> 160 dB re 1 μ Pa s) were detected in March 2017. The maximum peak-to-peak sound received level for MFA sonar was 164 dB. Explosions were detected from May 2016 to August 2016 and during October 2016.

Project Background

The US Navy's Jacksonville Range Complex (JAX) is located within the South Atlantic Bight that extends from Cape Hatteras, North Carolina to the Florida Straits. The seafloor is relatively smooth and features a broad continental shelf, with an inner zone of less than 200 m water depth, and an outer zone extending to depths of 2000 m. A diverse array of marine mammals are found in this region, including baleen whales, toothed whales, and manatees.

In April 2009, an acoustic monitoring effort was initiated within the boundaries of JAX with support from the Atlantic Fleet under contract to Duke University. The goal of this effort was to characterize the vocalizations of marine mammal species present in the area, to determine their seasonal presence patterns, and to evaluate the potential for impact from naval operations. This report documents the analysis of data recorded by a High-Frequency Acoustic Recording Package (HARP) that was deployed off Jacksonville, Florida (designated Site D), within the Jacksonville Range Complex and collected data from April 2016 to June 2017 (Figure 1).

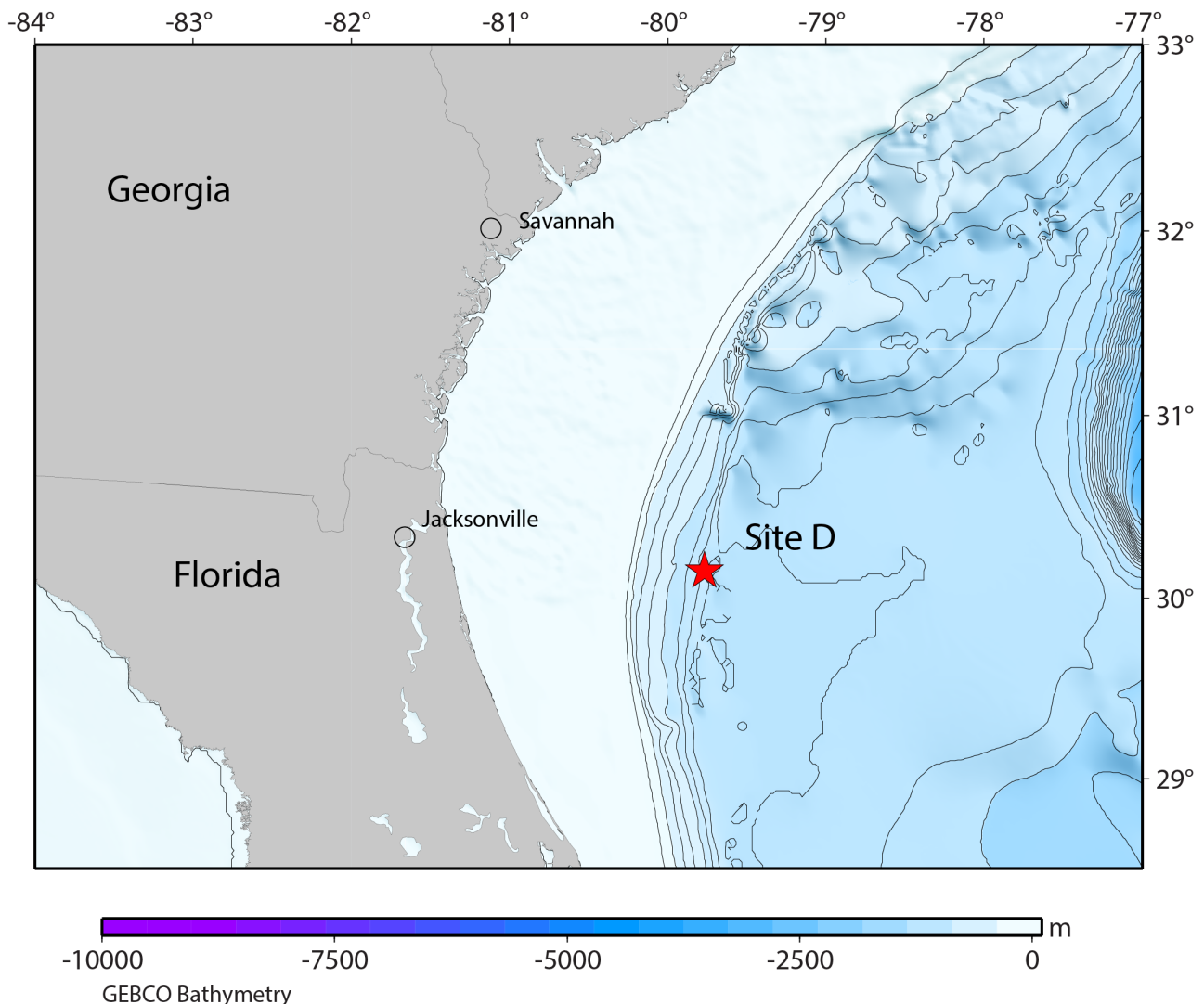


Figure 1. Location of High-Frequency Acoustic Recording Package (HARP) at Site D (30° 09.110 N, 79° 46.213 W, depth 736 m) deployed in the Jacksonville Range Complex study area from April 2016 to June 2017.

Methods

High-Frequency Acoustic Recording Package (HARP)

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

Data Collected

The HARP recorded from April 26, 2016 to June 25, 2017 at Site D (30° 09.110 N, 79° 46.213 W, depth 736 m) and sampled continuously at 200 kHz to provide 100 kHz of effective bandwidth. The instrument recorded 425.1 days for a total of 10,202.4 hours of data analyzed. Earlier data collection in the Jacksonville Range Complex is documented in previous detailed reports (Debich *et al.*, 2013; Johnson *et al.*, 2014; Frasier *et al.*, 2016).

Data Quality

During the initial 4 days of the deployment, from 04/26/2016 18:00:00 - 04/30/2016 14:08:30, a data logger malfunction reduced recorded data quality. The data logger reset successfully and produced high quality data for the remaining 421 days of deployment.

Data Analysis

To visualize the acoustic data, frequency spectra were calculated for all data using a time average of 5 seconds and 100 Hz frequency bins for high-frequency, 10 Hz for mid-frequency, and 1 Hz for low-frequency. 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 these data. To document the data analysis process, we describe the major classes of marine mammal calls and anthropogenic sound in this band in the Jacksonville region, and the procedures used to detect them. For effective analysis, the data were divided into three frequency bands: (1) Low-frequency, 10-500 Hz, (2) Mid-frequency, 500-5,000 Hz, and (3) High-frequency, 5-100 kHz.

Each band was analyzed for the sounds of an appropriate subset of species or sources. Blue, fin, Bryde's, sei, minke, and North Atlantic right whale sounds, as well as low frequency active sonar less than 500 Hz, were classified as low-frequency. Humpback, nearby shipping, explosions, airguns, underwater anthropogenic communications, low frequency active sonar greater than 500 Hz, and mid-frequency active sonar sounds were classified as mid-frequency. The remaining odontocete and sonar sounds were considered high-frequency. Analysis of low-frequency recordings required decimation by a factor of 100. For the analysis of the mid-frequency recordings, the data were decimated by a factor of 20.

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

Low-Frequency Marine Mammals

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

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

Blue Whale North Atlantic A Calls

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

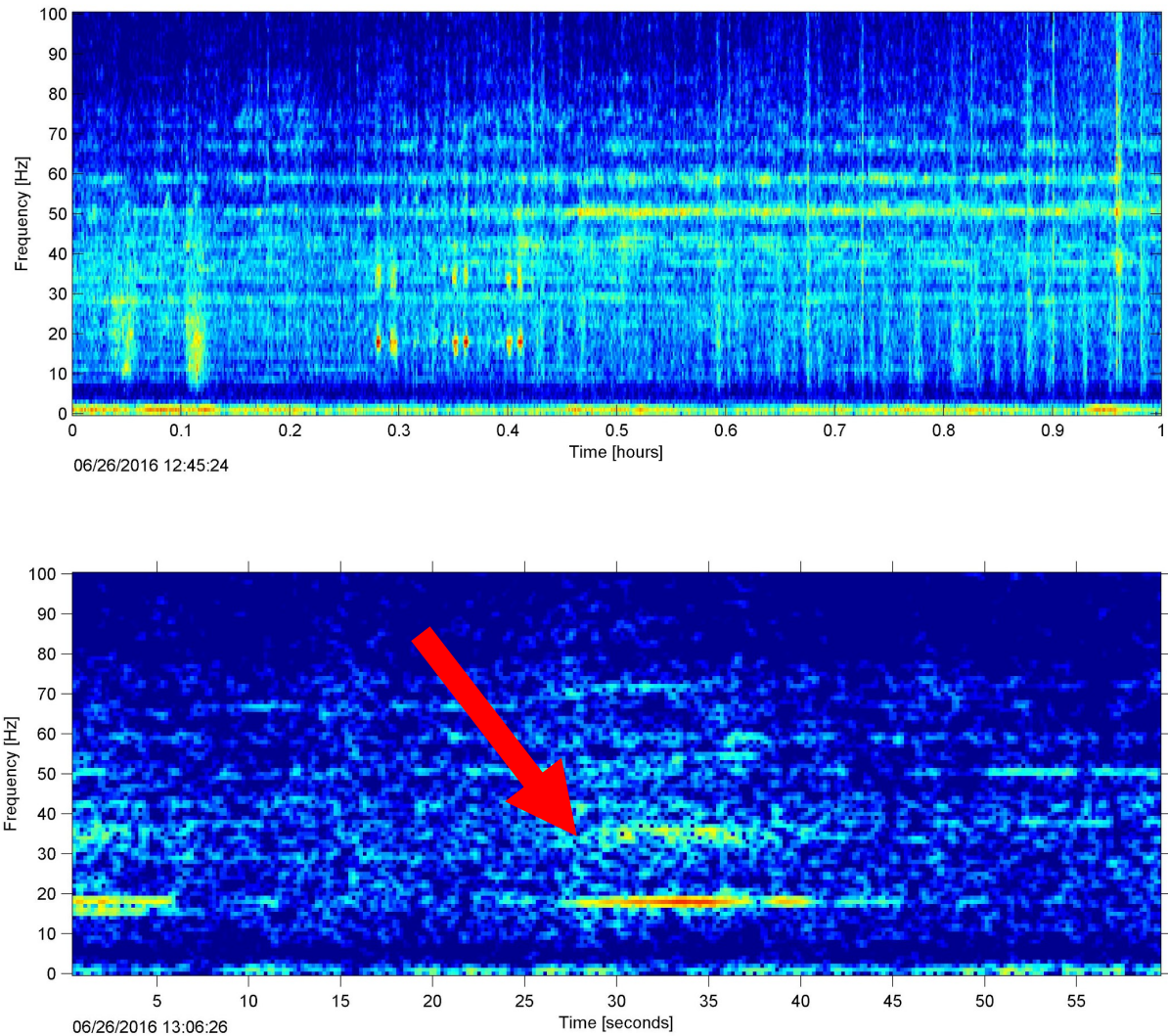


Figure 2. North Atlantic blue whale tonal calls in the LTSA (top) and spectrogram (bottom) at JAX Site D, June 2016.

Blue Whale Arch Calls

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

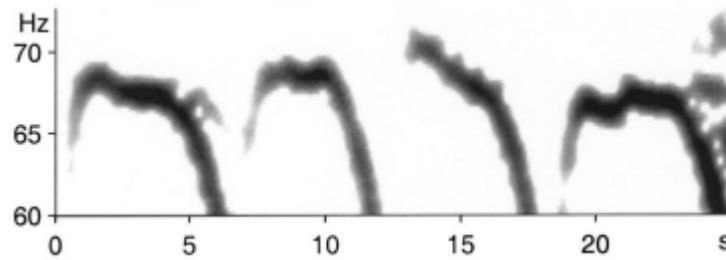


Figure 3. Blue whale arch calls from Mellinger and Clark (2003).

Bryde's Whales

Bryde's whales inhabit tropical and subtropical waters worldwide (Omura, 1959; Wade and Gerrodette, 1993), and the JAX HARP site is considered to be near their northerly range limit.

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 minutes (Figure 4). There were no detections for Bryde's whale Be7 calls during this recording period.

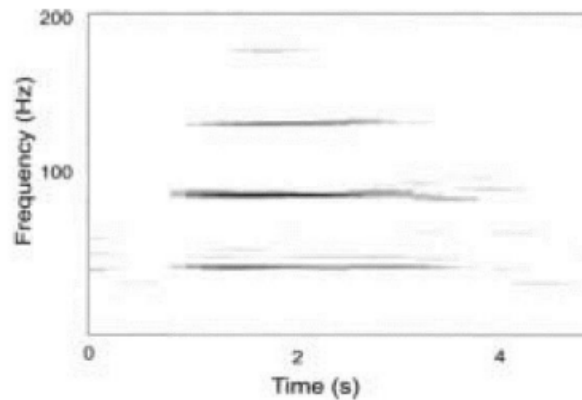


Figure 4. Bryde's whale Be7 call from Oleson et al., 2003.

Be9 Calls

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

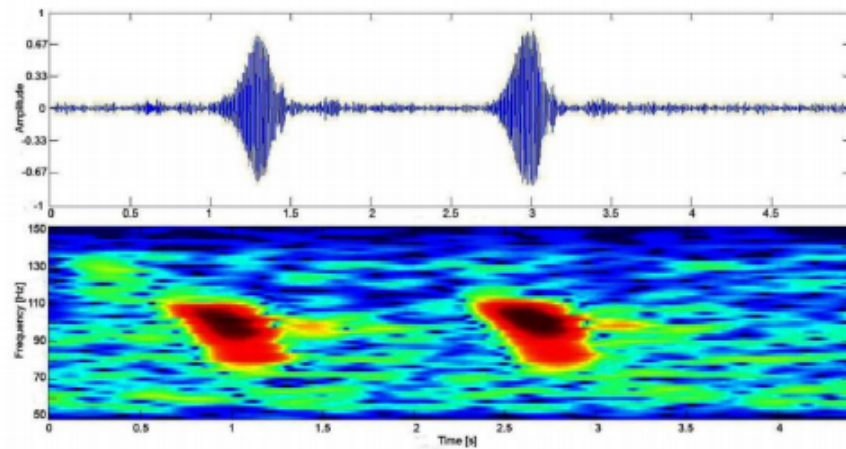


Figure 5. Bryde's whale Be9 call from the Gulf of Mexico (Širović et al., 2014).

Fin Whales

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

Fin Whale 20 Hz Calls

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

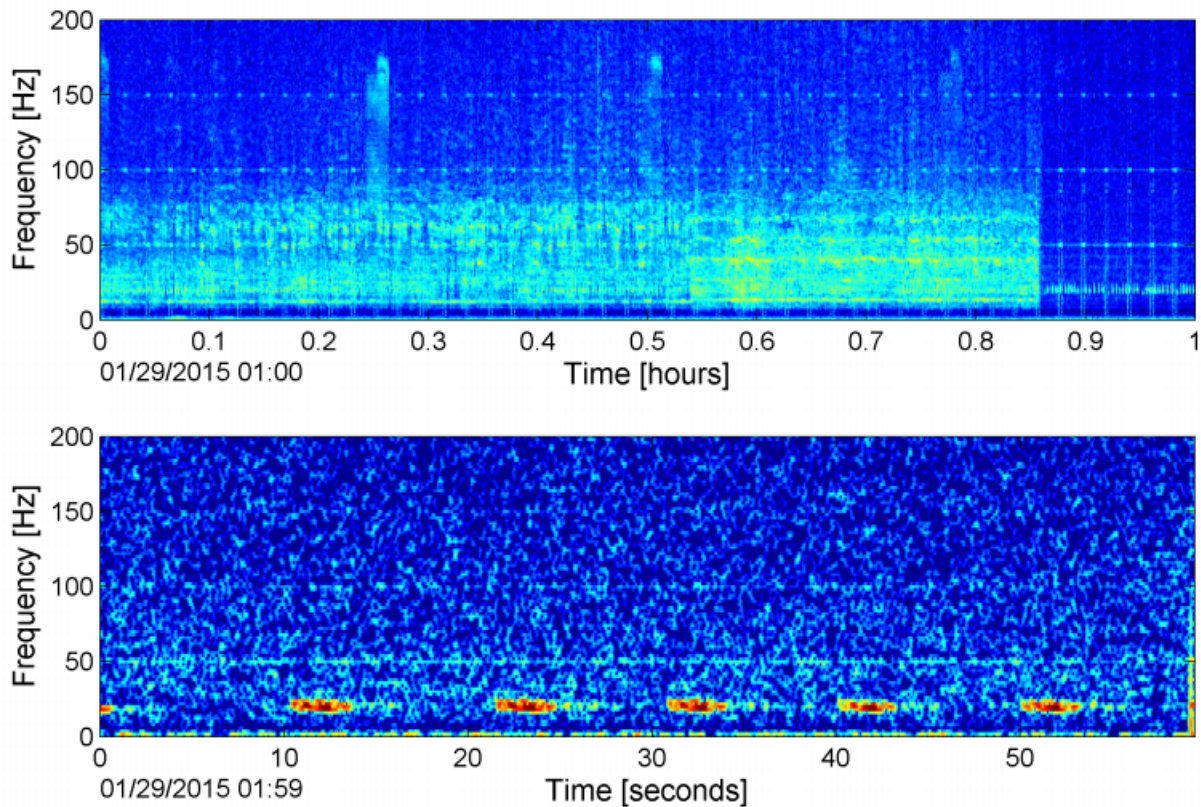


Figure 6. Fin whale 20 Hz call in LTSA (top) and spectrogram (bottom) at JAX Site D, January 2015.

Fin Whale 40 Hz Calls

The presence of fin whale 40 Hz calls (Figure 7) was examined via manual scanning of the LTSA and subsequent verification (from a spectrogram) of the frequency and temporal characteristics of the calls.

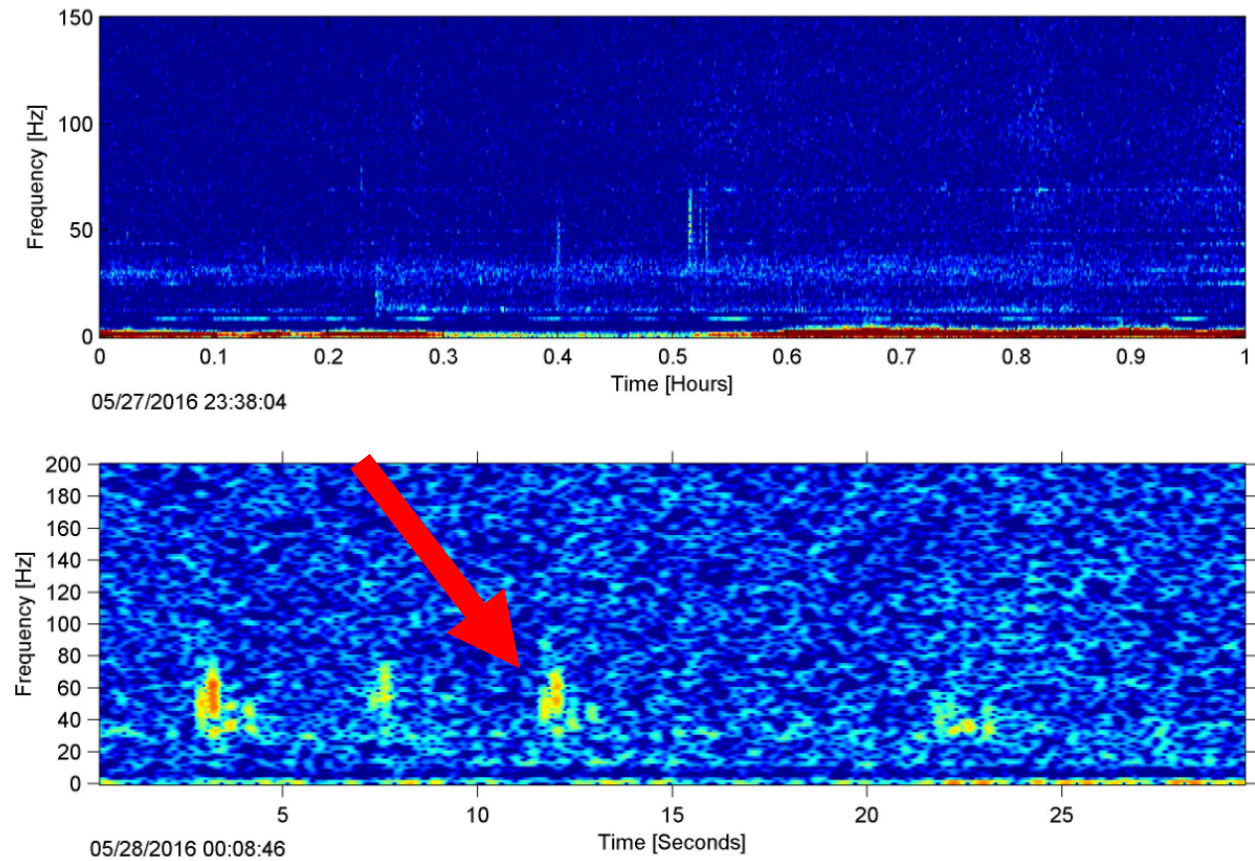


Figure 7. Fin whale 40 Hz call in LTSA (top) and spectrogram (bottom) at JAX Site D, May 2016.

Minke Whales

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

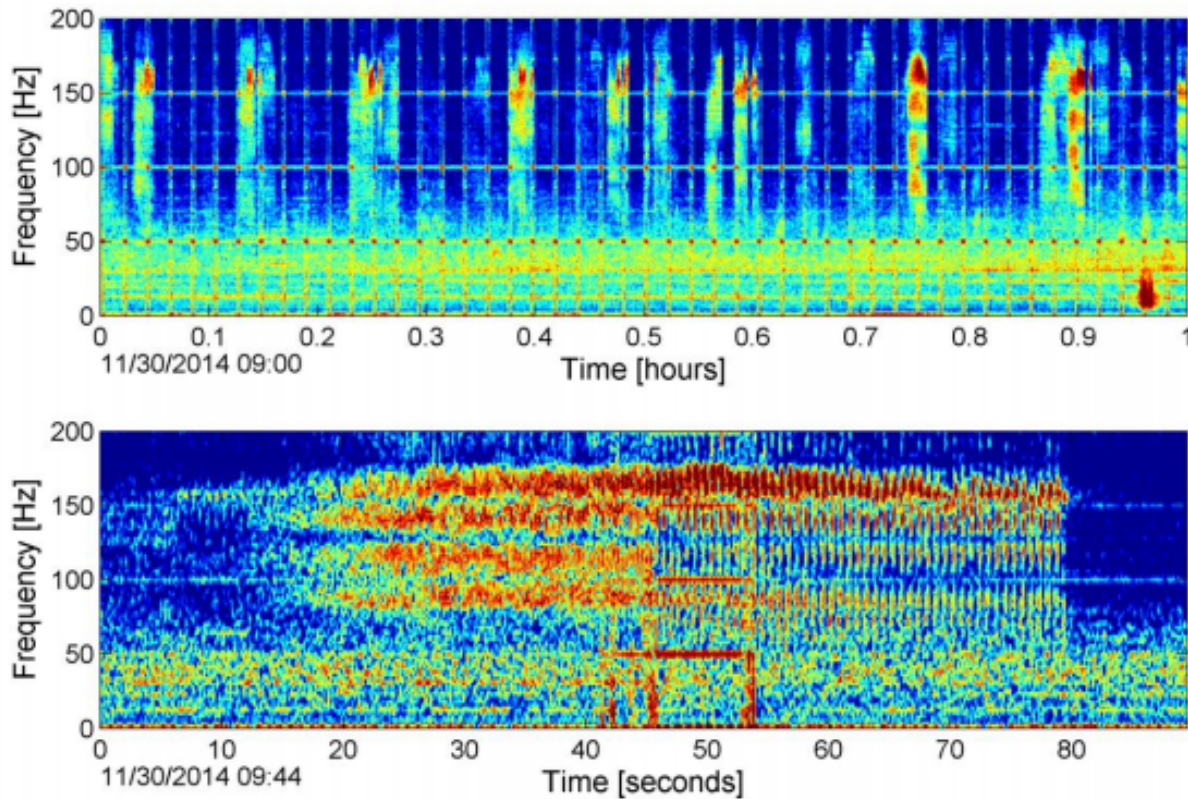


Figure 8. Minke whale pulse train in the LTSA (top) and spectrogram (bottom) recorded at JAX Site D, November 2014.

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 9).

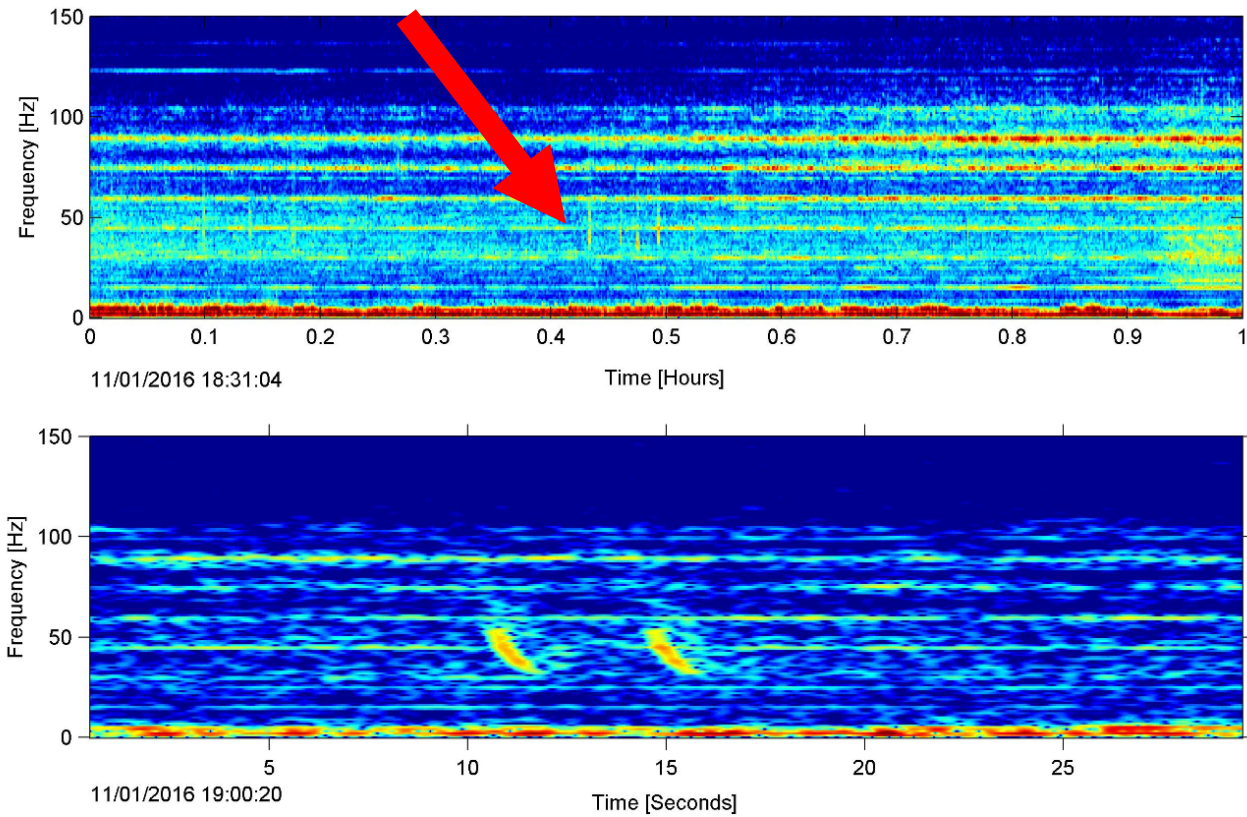


Figure 9. Downsweep calls from sei whales in the LTSA (top) and spectrogram (bottom) from JAX Site D, November 2016.

Northern Atlantic Right Whales

The critically endangered North Atlantic right whale is found in the Western North Atlantic, and the JAX region is included in their calving grounds, although typically in the shallow waters of the continental shelf. Several call types that have been described for the North Atlantic right whale include the scream, gunshot, blow, upcall, warble, and downcall (Parks and Tyack, 2005). For low-frequency analysis, we examined the data for upcalls, which are approximately 1 second in duration and range between 80 Hz and 200 Hz, sometimes with harmonics (Figure 10). There were no detections for Northern Atlantic right whale calls during the recording period.

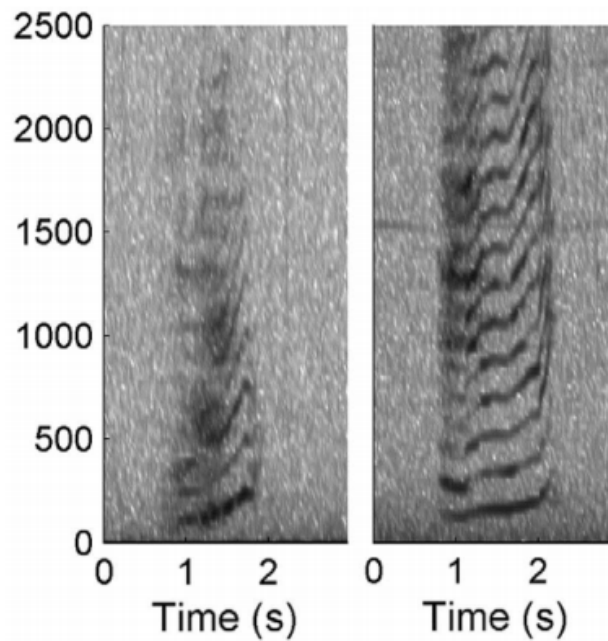


Figure 10. Right whale up-calls from Trygonis et al., 2013.

Mid-Frequency Marine Mammals

Marine mammal species with sounds in the mid-frequency range expected in the Jacksonville Range Complex include humpback whales (*Megaptera novaeangliae*) and killer whales (*Orcinus orca*). 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. The presence of each call type was determined using an encounter-granularity, to one-minute precision, for each mid-frequency dataset. Whistles resembling those of killer whales were logged as unidentified odontocete whistles <5 kHz due to overlapping distributions with other large delphinids in the area.

Humpback Whales

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

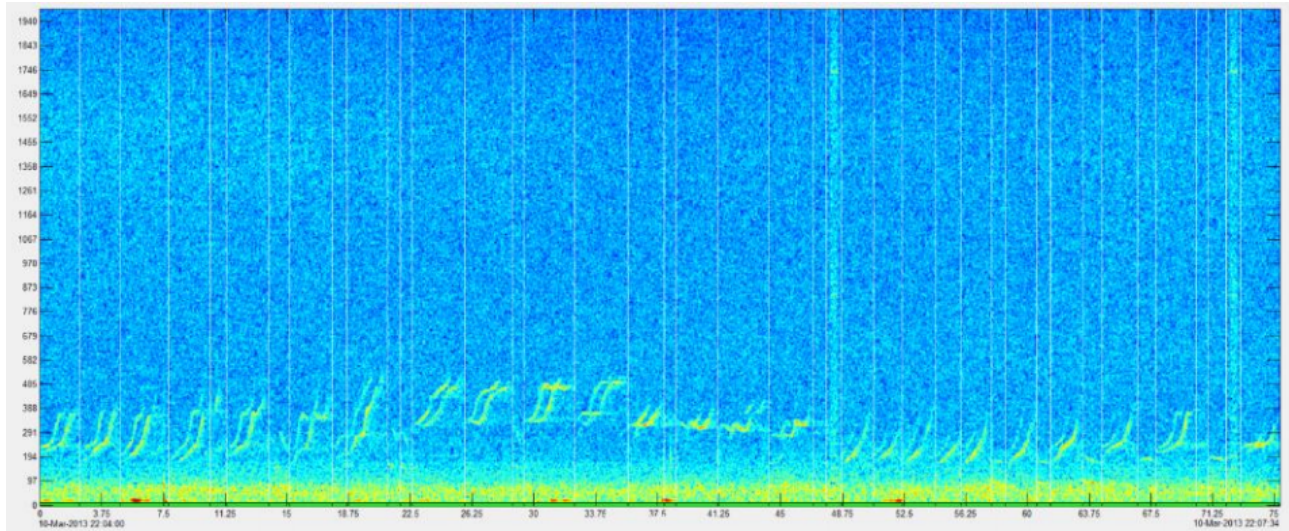


Figure 11. Humpback whale song from deployment at the Cape Hatteras site in the analyst verification stage of the detector. Green in the bottom evaluation line indicates true detections.

High-Frequency Marine Mammals

Marine mammal species with sounds in the high-frequency range and possibly found in the Jacksonville 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*), 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).

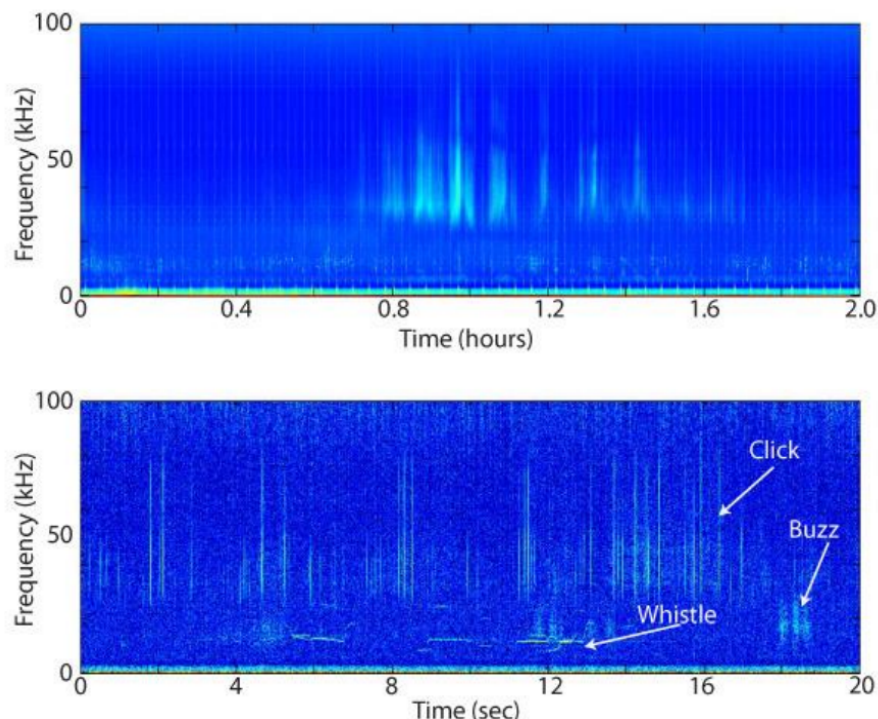


Figure 12. LTSA (top) and spectrogram (bottom) demonstrating odontocete signal types.

Beaked Whales

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

Beaked whale FM pulses were detected with an automated method. This automated effort was for all identifiable beaked whale signals found in the Jacksonville 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.

Blainville's Beaked Whale

Blainville's beaked whale echolocation signals are, like most beaked whales' signals, polycyclic, with a characteristic frequency-modulated upsweep, peak frequency around 34 kHz and uniform inter-pulse interval (IPI) of about 280 ms (Johnson et al., 2004; Baumann-Pickering et al., 2013). Blainville's FM pulses are also distinguishable in the spectral domain by their sharp energy onset around 25 kHz with only a small energy peak at around 22 kHz (Figure 13). Blainville's beaked whales were not identified at Site D during the recording period.

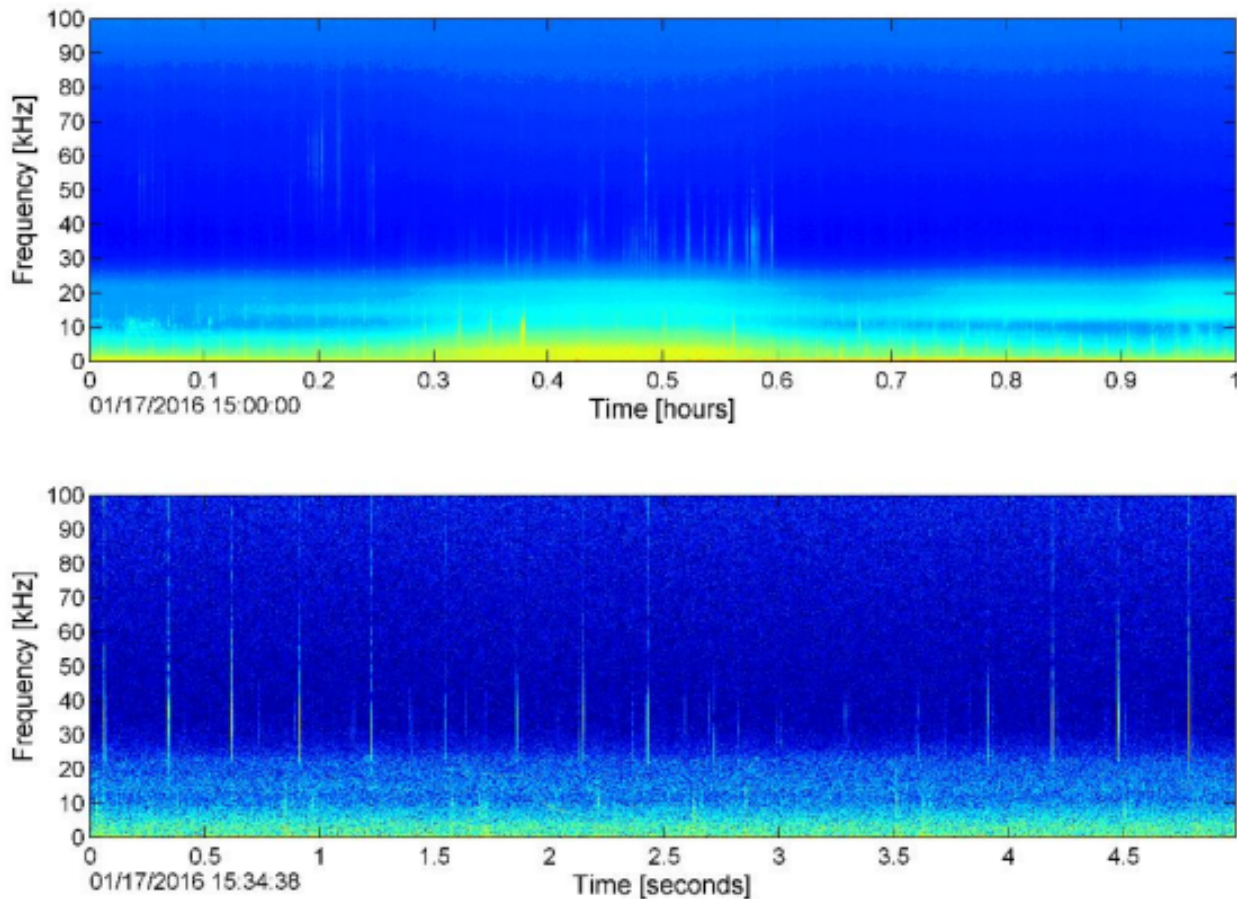


Figure 13. Blainville's beaked whale echolocation clicks in the LTSA (top) and spectrogram (bottom) from the Virginia Capes Range, January 2016.

Cuvier's Beaked Whales

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

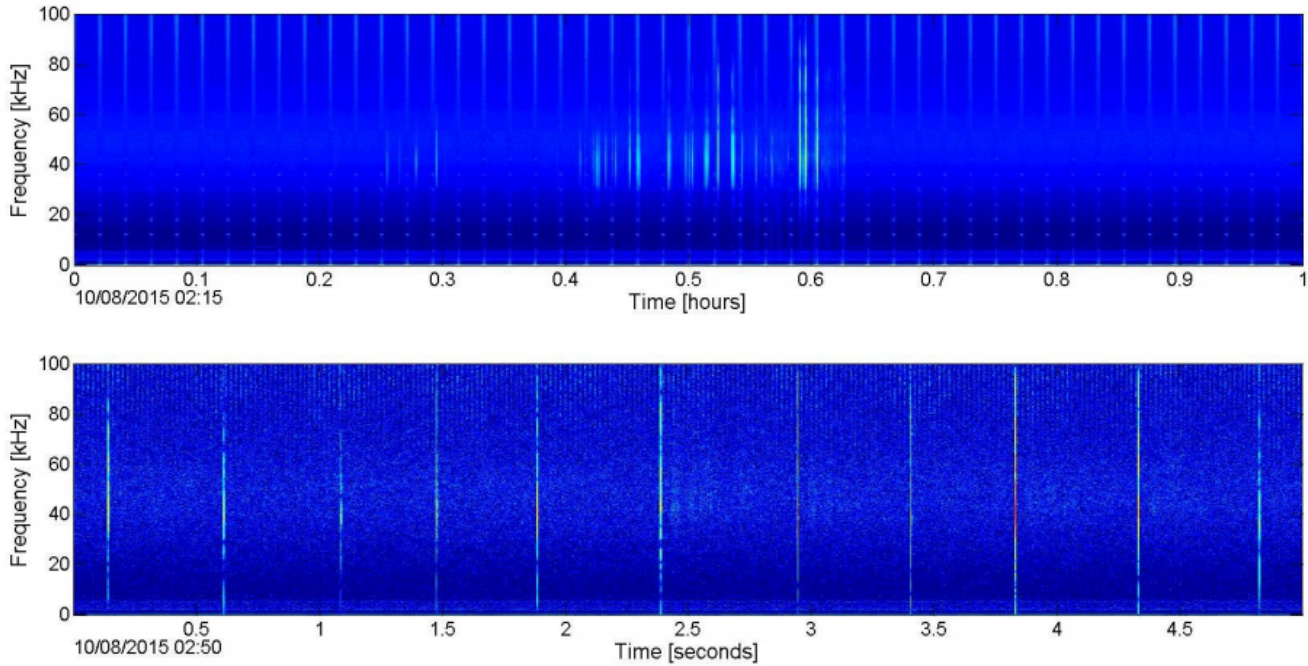


Figure 14. Cuvier's beaked whale signals in LTSA (top) and spectrogram (bottom) from HARP recording within the Jacksonville Range Complex, October 2015.

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). Gervais' beaked whales were not identified at Site D during the recording period.

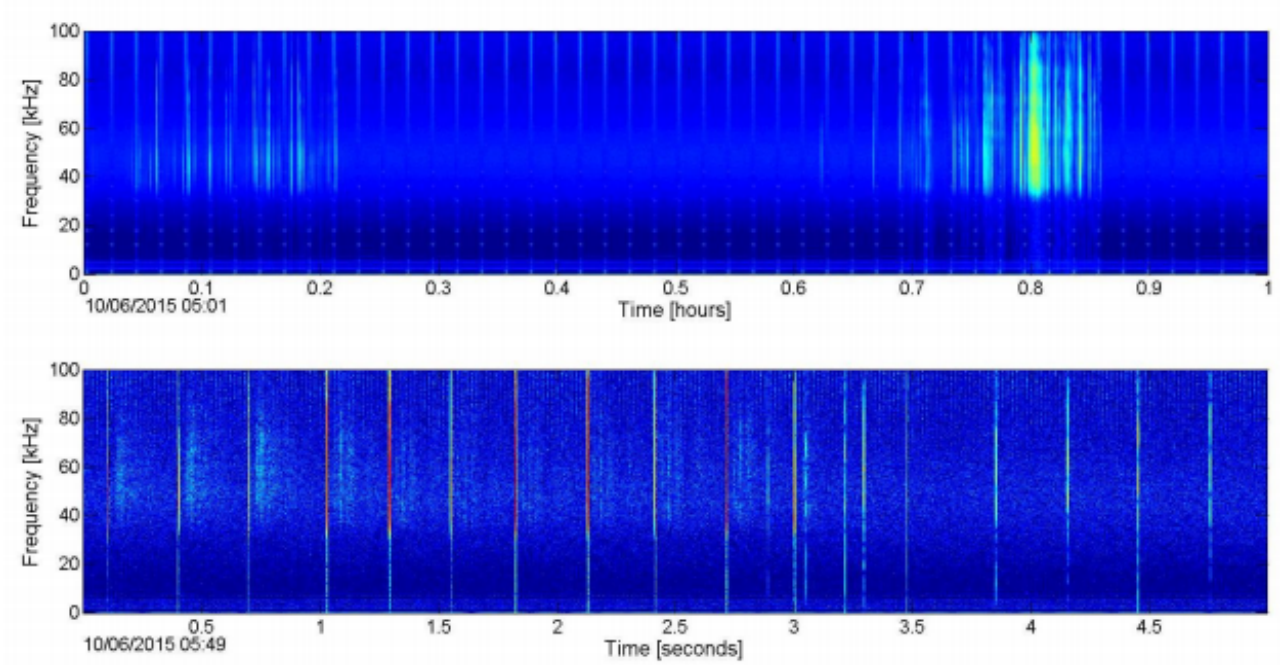


Figure 15. Gervais' beaked whale signals in LTSA (top) and spectrogram (bottom) from HARP recording within the Jacksonville Range Complex, October 2015.

Sowerby's Beaked Whales

Sowerby's beaked whale echolocation signals have energy concentrated in the 50 – 95 kHz band, with a peak at 67 kHz (Figure 16). Sowerby's beaked whale signals have a characteristic FM upsweep, and are distinguishable from other co-occurring beaked whale signal types by their higher frequency content and a relatively short inter-pulse interval of around 150 ms (Cholewiak et al., 2013).

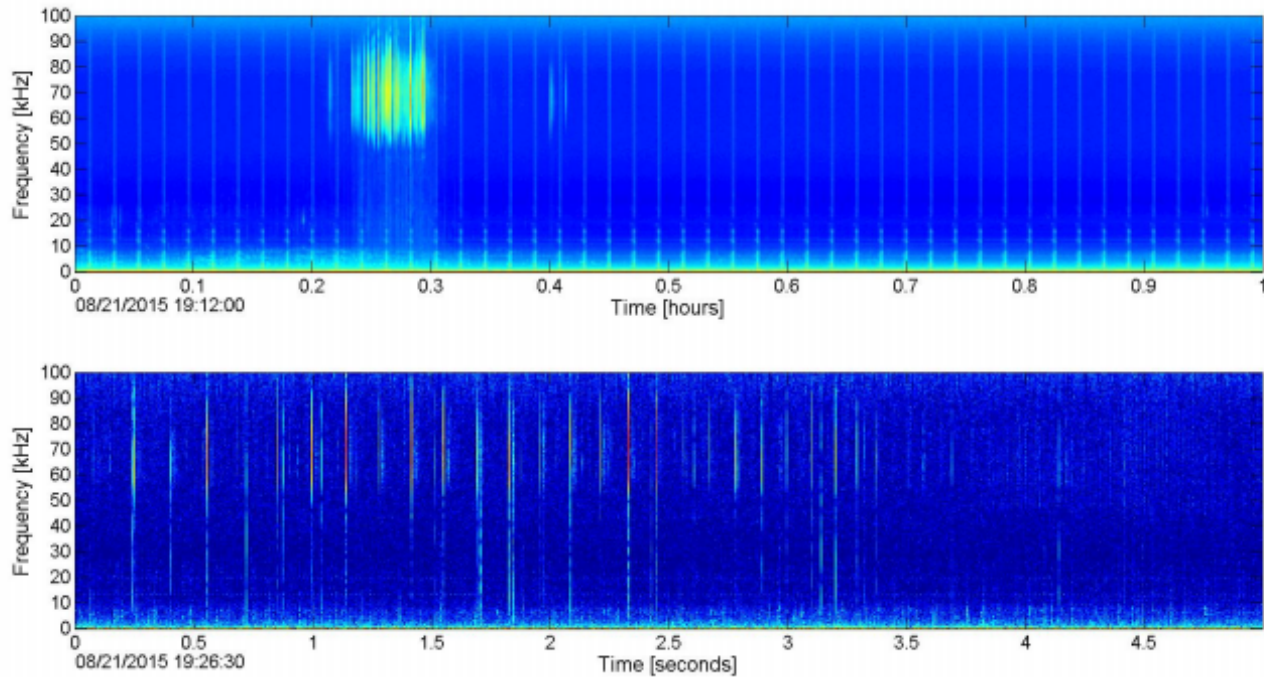


Figure 16. Sowerby's beaked whale echolocation clicks in LTSA (top) and spectrogram (bottom) recorded in the Western Atlantic, August 2015.

Dolphins

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). 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.* 2017). 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.

Whistles

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

Unidentified Odontocetes

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

Risso's Dolphins

Risso's dolphin echolocation clicks can be identified to species by their distinctive banding patterns observable in the LTSA (Figure 17). Studies show that spectral properties of Risso's dolphin echolocation clicks vary based on geographic region (Soldevilla *et al.*, 2017). Risso's dolphin clicks that were detected in this recording period had peaks at 22, 26, and 33 kHz (Figure 18). A bimodal modal inter-click interval (ICI) had peaks at 150 and 340 ms. Risso's dolphin detections in previous recordings from the Jacksonville Range complex had peaks at 23, 26, 35, and 44 kHz (Debich *et al.*, 2013), while clicks recorded in the Cherry Point OPAREA had peaks at 21, 25, 30, and 42 kHz (Debich *et al.*, 2014).

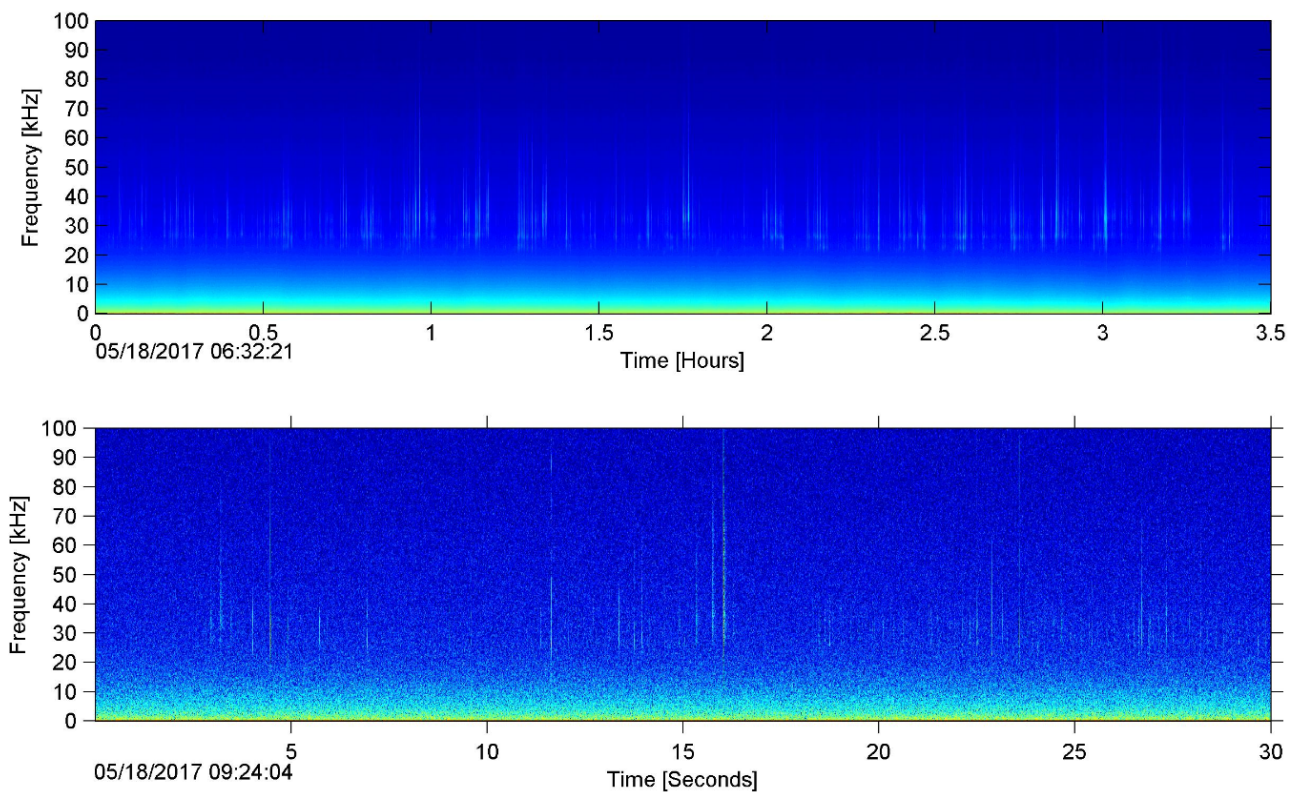


Figure 17. Risso's dolphin acoustic encounter in LTSA (top) and spectrogram (bottom) from HARP recording at JAX Site D, May 2017.

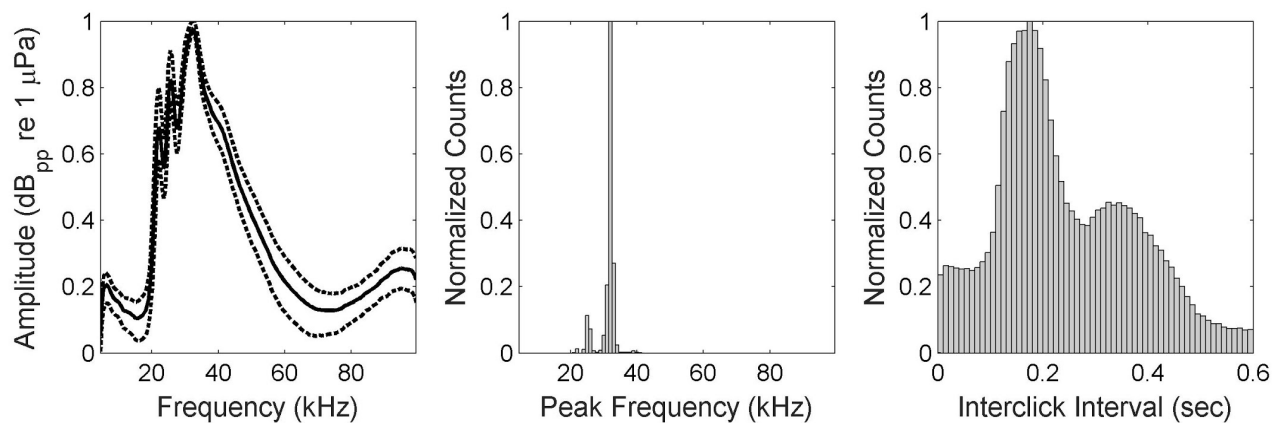


Figure 18. Risso's dolphin click type detected at JAX Site D from April 2016 to June 2017. Left: Mean frequency spectrum of click cluster (solid line) and 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies; Right: Distribution of inter-click intervals (ICI)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

Other Echolocation Click Types

An automated clustering procedure was used to identify recurrent delphinid click types (CT) in the dataset. Three click types were identified: J1 (Figure 19), J2 (Figure 21), and J3 (Figure 23). These click types are not currently identified to species, but have consistent spectral shapes and ICI distributions, making them candidates for future identification. All of these types have been identified in previous JAX deployments.

- CT J1 has a simple spectral shape with peak frequencies at approximately 30 kHz, and a modal ICI of 85 ms. An example encounter is shown in Figure 20.
- CT J2 spectra has a complex banding pattern with peaks at 7.5 and 21 kHz and a main peak frequency at 45 kHz. The modal ICI was 300 ms. An example encounter is shown in Figure 22.
- CT J3 has a frequency distribution with a single peak near 24 kHz, and a modal ICI of 175 ms (Figure 24). An example encounter is shown in Figure 24.

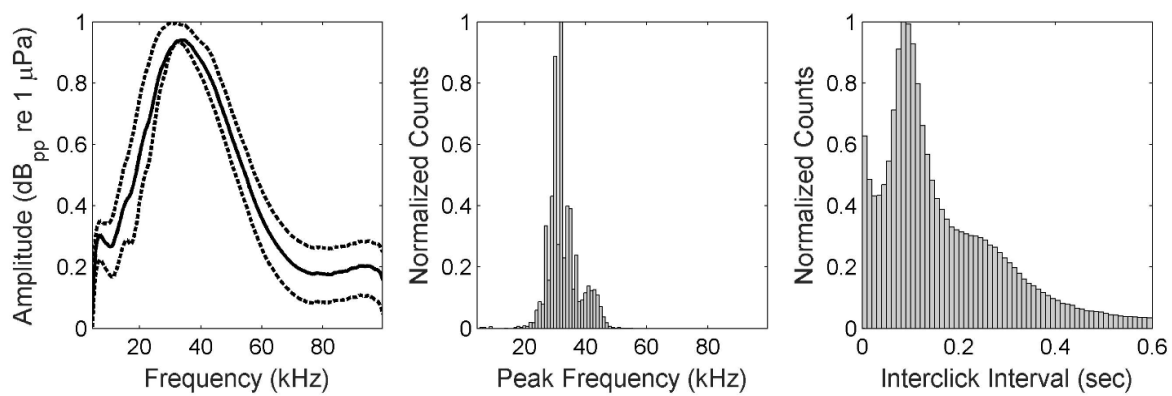


Figure 19. Click type CT J1 detected at JAX Site D. Left: Mean frequency spectrum of click cluster (solid line) and 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies; Right: Distribution of inter-click intervals (ICI) within cluster.

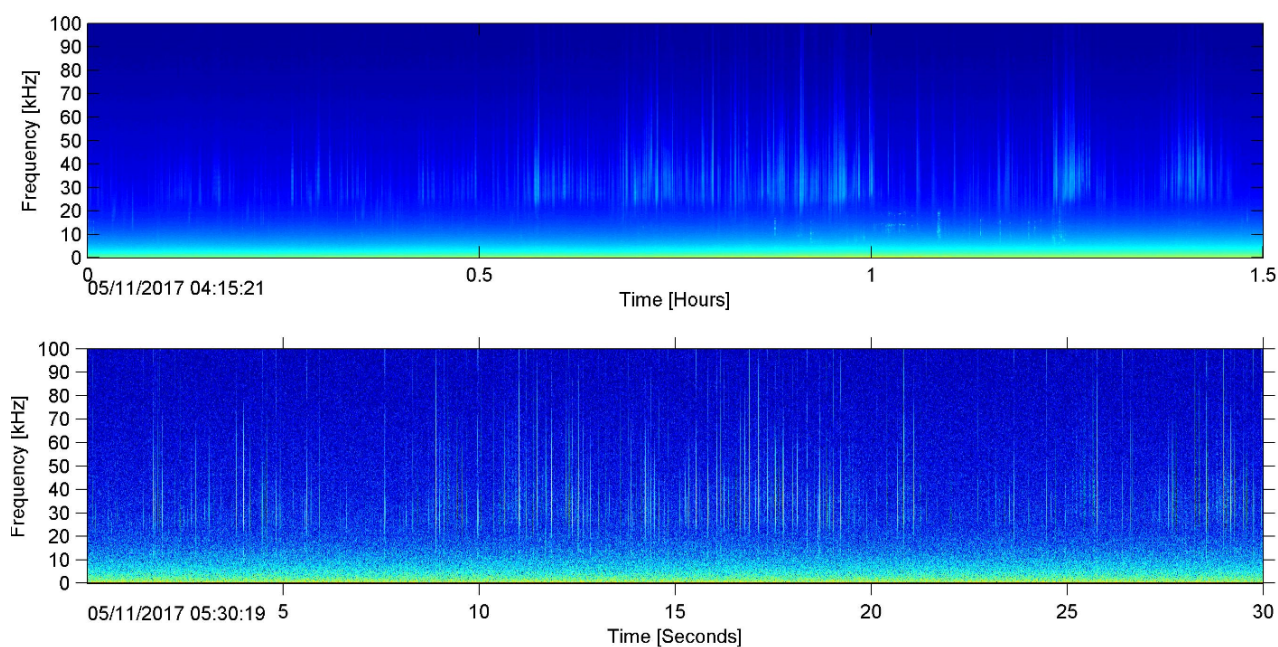


Figure 20. Click type CT J1 acoustic encounter in LTSA (top) and spectrogram (bottom) recorded at JAX Site D, May 2017.

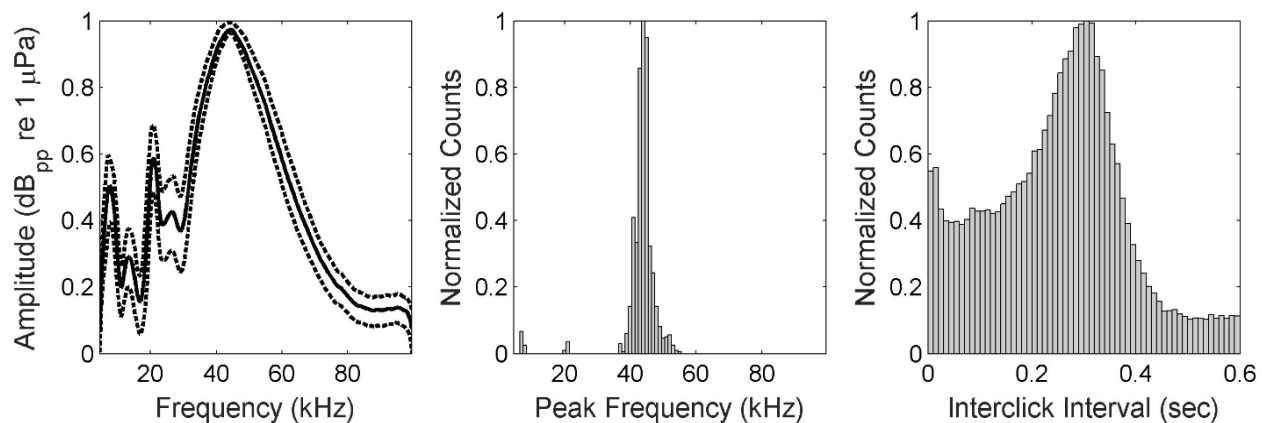


Figure 21. Click type CT J2 detected at JAX Site D. Left: Mean frequency spectrum of click cluster (solid line) and 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies; Right: Distribution of inter-click intervals (ICI) within cluster.

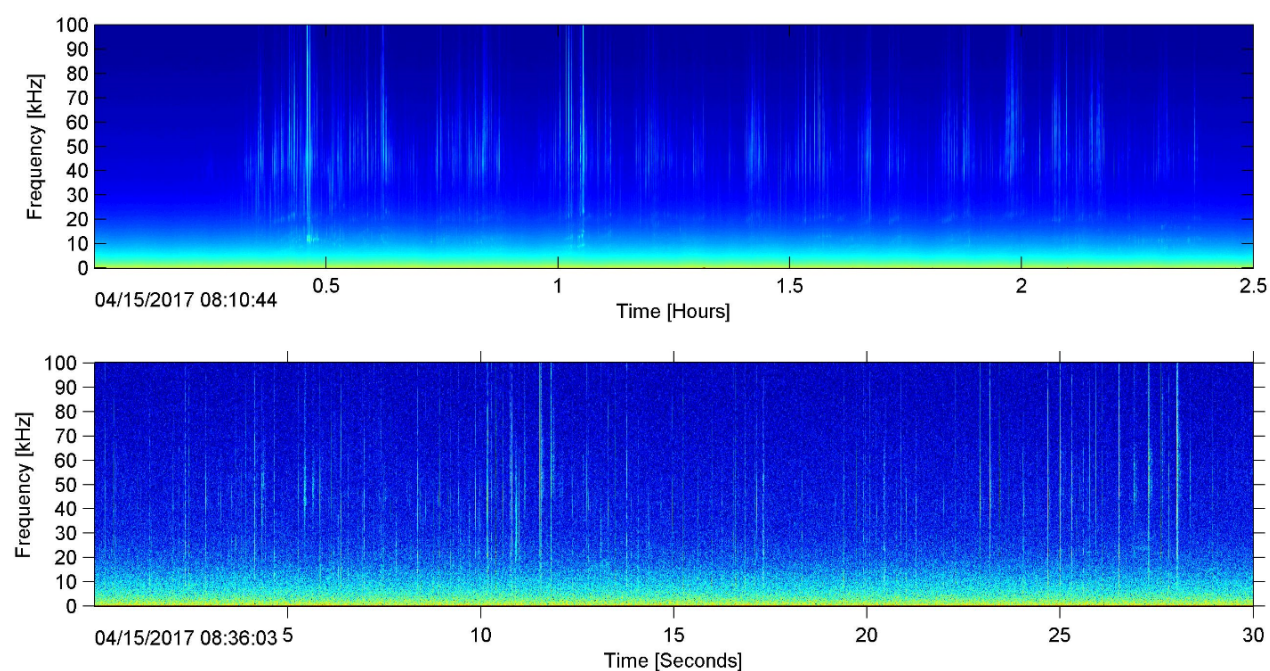


Figure 22. Click type CT J2 acoustic encounter in LTSA (top) and spectrogram (bottom) recorded at JAX Site D, April 2017.

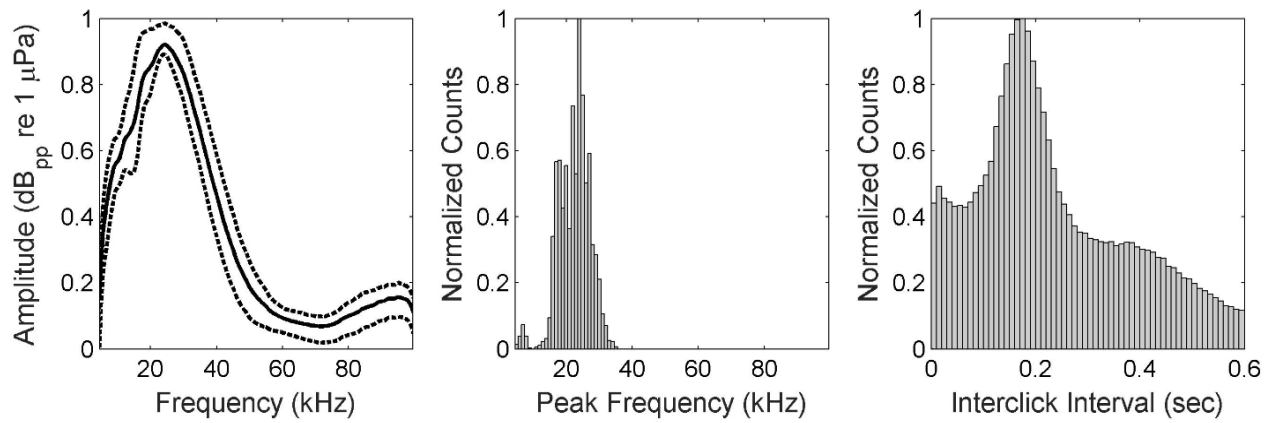


Figure 23. Click type CT J3 detected at JAX Site D. Left: Mean frequency spectrum of click cluster (solid line) and 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies; Right: Distribution of inter-click intervals (ICI) within cluster.

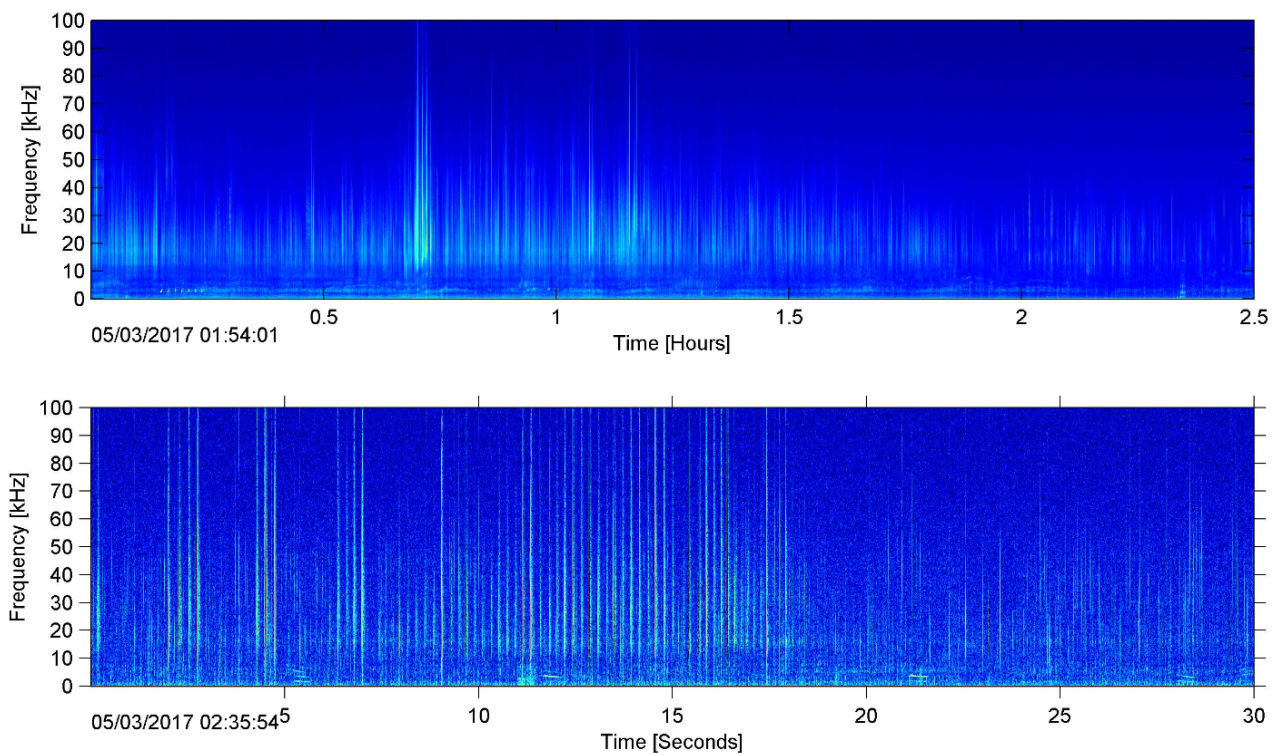


Figure 24. Click type CT J3 acoustic encounter in LTSA (top) and spectrogram (bottom) recorded at JAX Site D, May 2017.

Sperm Whales

Sperm whale clicks contain energy from 2-20 kHz, with most energy between 10-15 kHz (Møhl *et al.*, 2003) (Figure 25). Regular clicks, observed during foraging dives, demonstrate an ICI from 0.25-1 s (Goold and Jones, 1995; Madsen *et al.*, 2002a). Short bursts of closely spaced clicks called creaks are observed during foraging dives and are believed to indicate a predation attempt (Wysocki *et al.*, 2006). Slow clicks (> 1 sec ICI) are used only by males and are more intense than regular clicks with long inter-click intervals (Madsen *et al.*, 2002b). Codas are stereotyped sequences of clicks which are less intense and contain lower peak frequencies than regular clicks (Watkins and Schevill, 1977). There was no effort to divide sperm whale clicks by type.

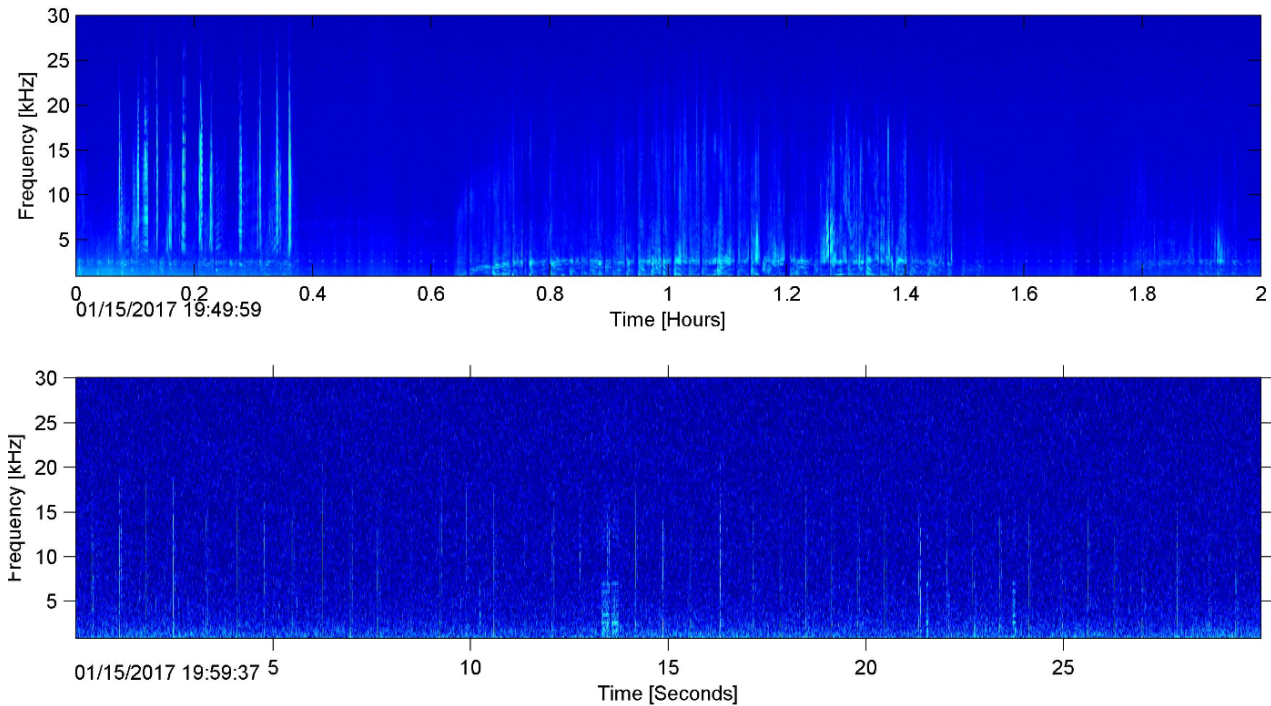


Figure 25. Sperm whale echolocation clicks in LTSA (top) and spectrogram (bottom) recorded at JAX Site D, January 2017.

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.

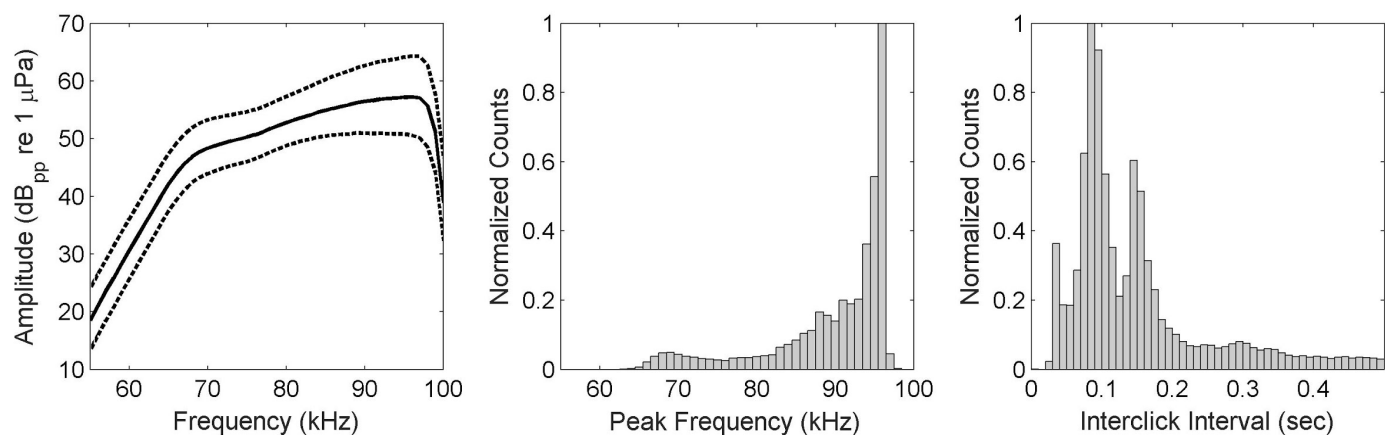


Figure 26. *Kogia* spp. detected at JAX Site D. Left: Mean frequency spectrum of click cluster (solid line) and 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies; Right: Distribution of inter-click intervals (ICI) within cluster.

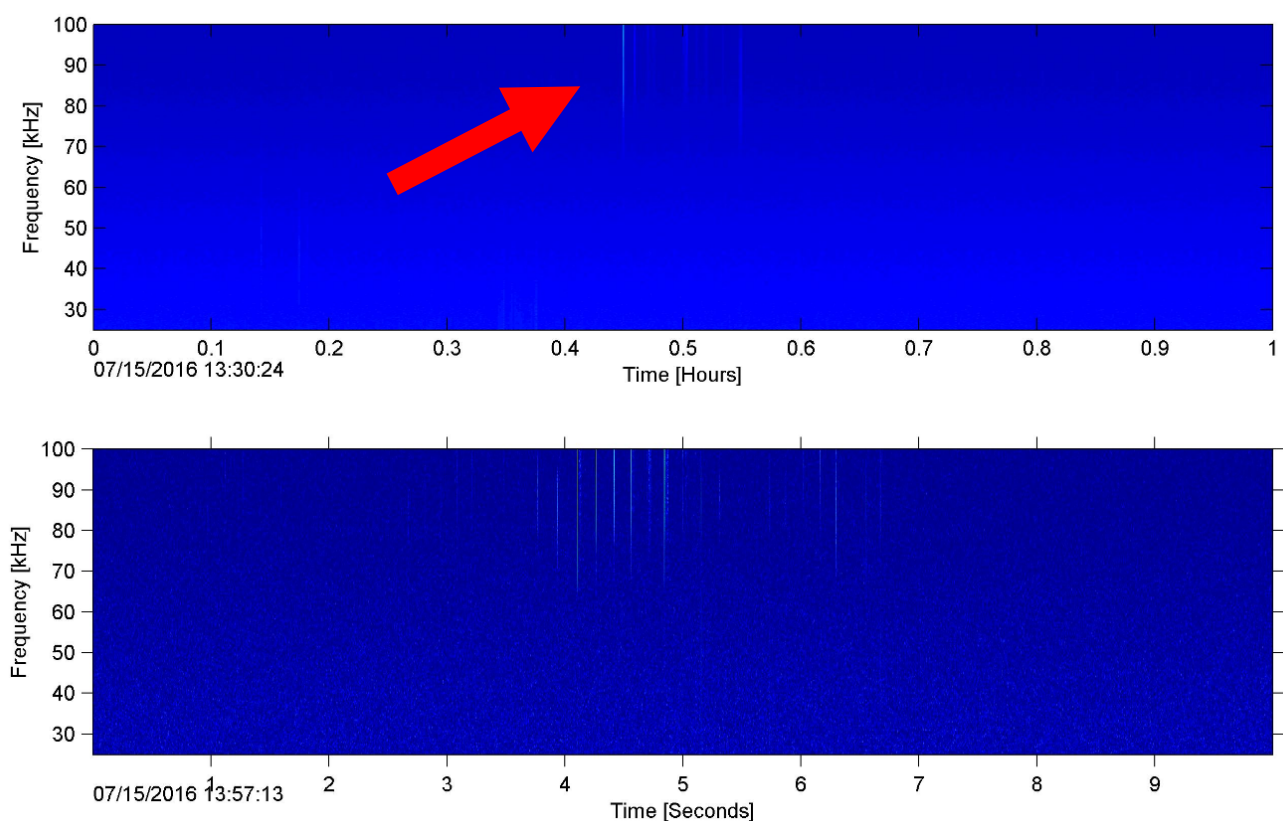


Figure 27. *Kogia* spp. echolocation clicks in LTSA (top) and spectrogram (bottom) recorded at JAX Site D, July 2016.

Anthropogenic Sounds

Several anthropogenic sounds including broadband ship noise, Low-Frequency Active (LFA) Sonar, Other 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 search parameters used to detect these sounds are given in Table 1 by manual effort. 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
Other 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 2 hours with a frequency range of 10-5,000 Hz.

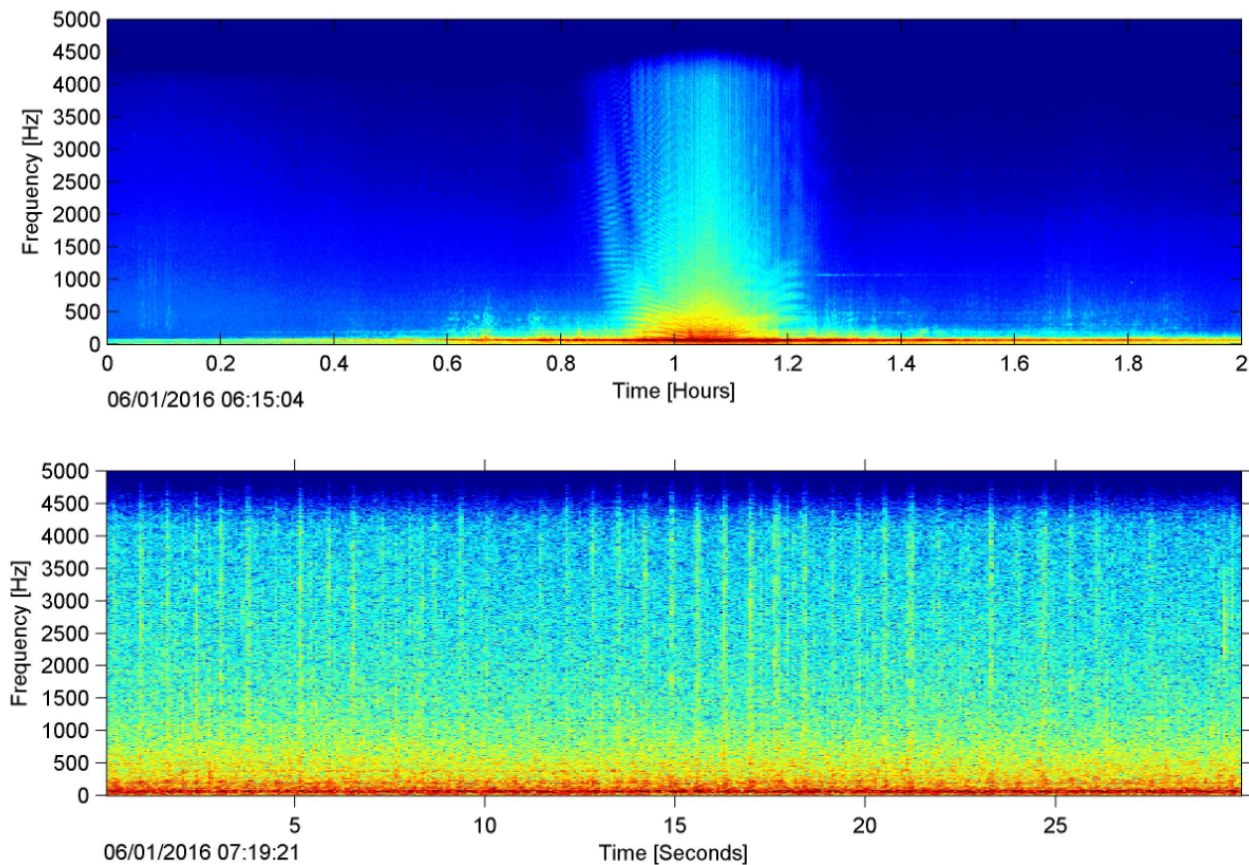


Figure 28. Broadband ships in LTSA (top) and spectrogram (bottom) recorded at JAX Site D, June 2016

Low-Frequency Active Sonar

Low-frequency active sonar includes military sonar between 100 and 500 Hz and other sonar systems up to 1 kHz. Effort was expended for LFA sonar less than 500 Hz and between 500 Hz and 1 kHz (Figure 29).

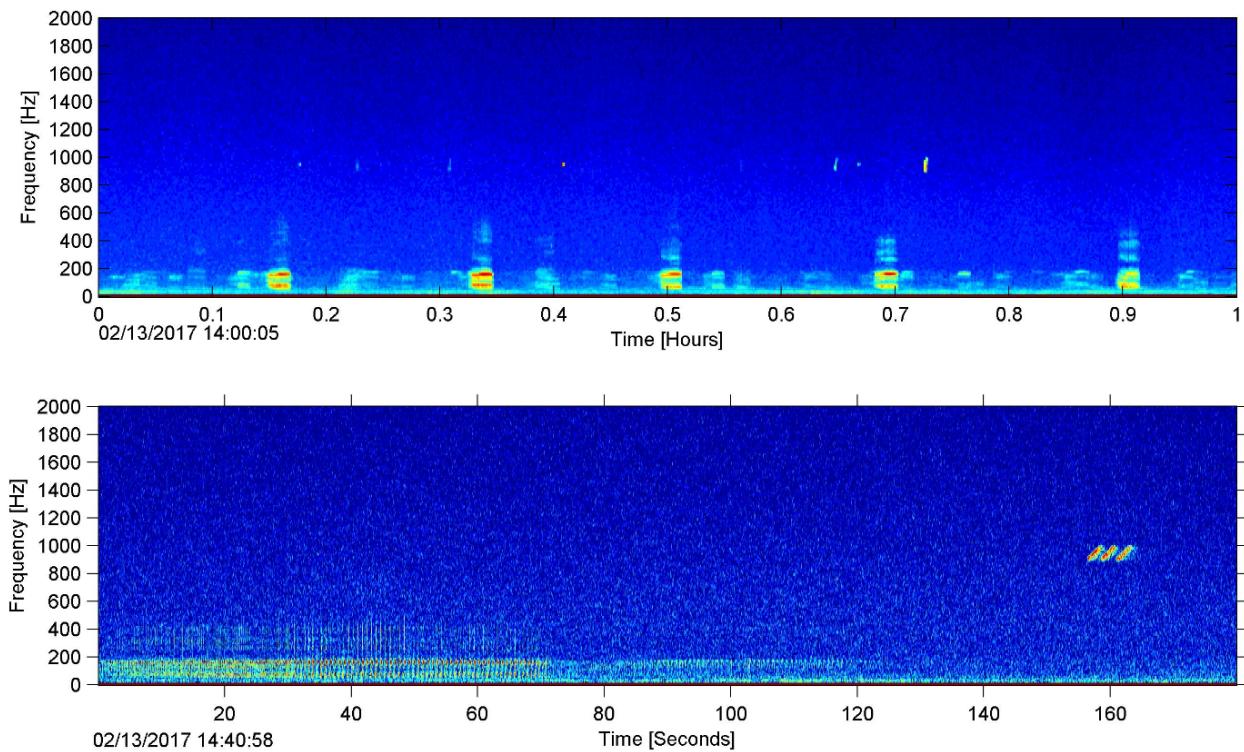


Figure 29. Low-frequency active sonar in Hz in the LTSA (top) and spectrogram (bottom) recorded at JAX Site D, February 2017.

Other Low-Frequency Active Sonar

A second type of atypical low-frequency active sonar was detected in April of 2016 at Site D (Figure 30) with frequencies below 1 kHz, but with simple pulses reminiscent of an echosounder.

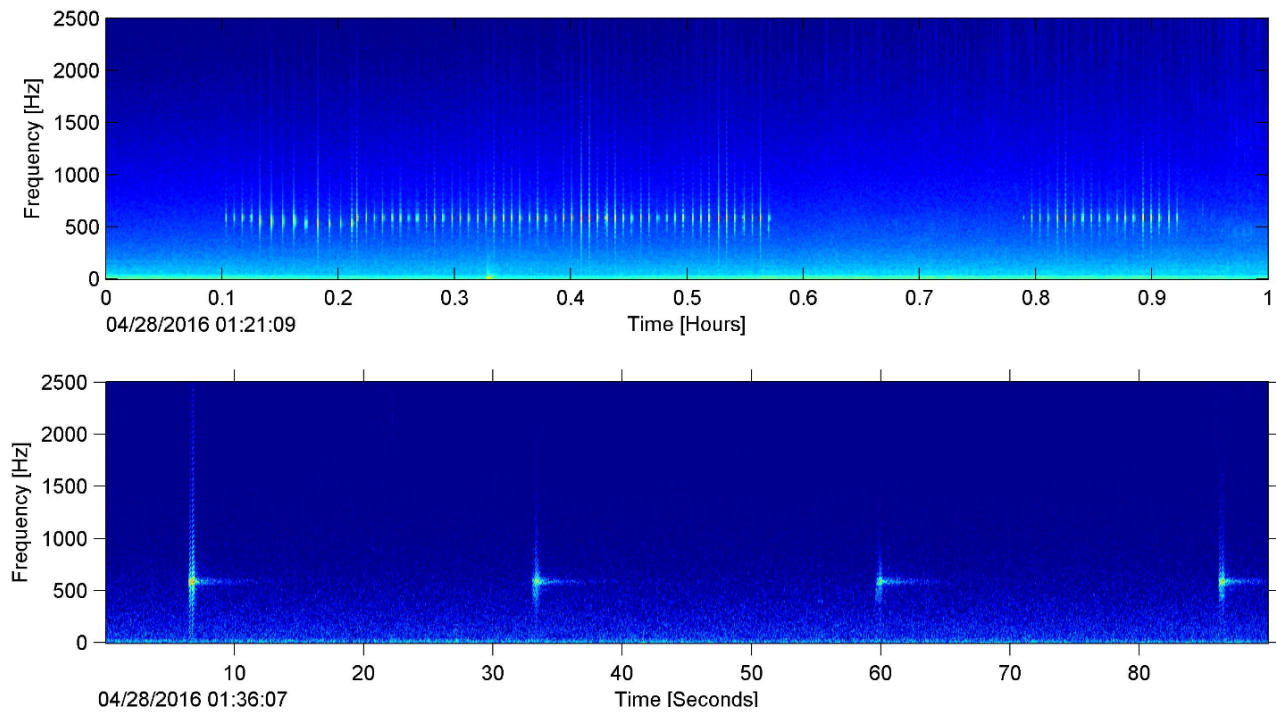


Figure 30. Other low-frequency active sonar in Hz in the LTSA (top) and spectrogram (bottom) recorded at JAX Site D, April 2016.

Mid-Frequency Active Sonar

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

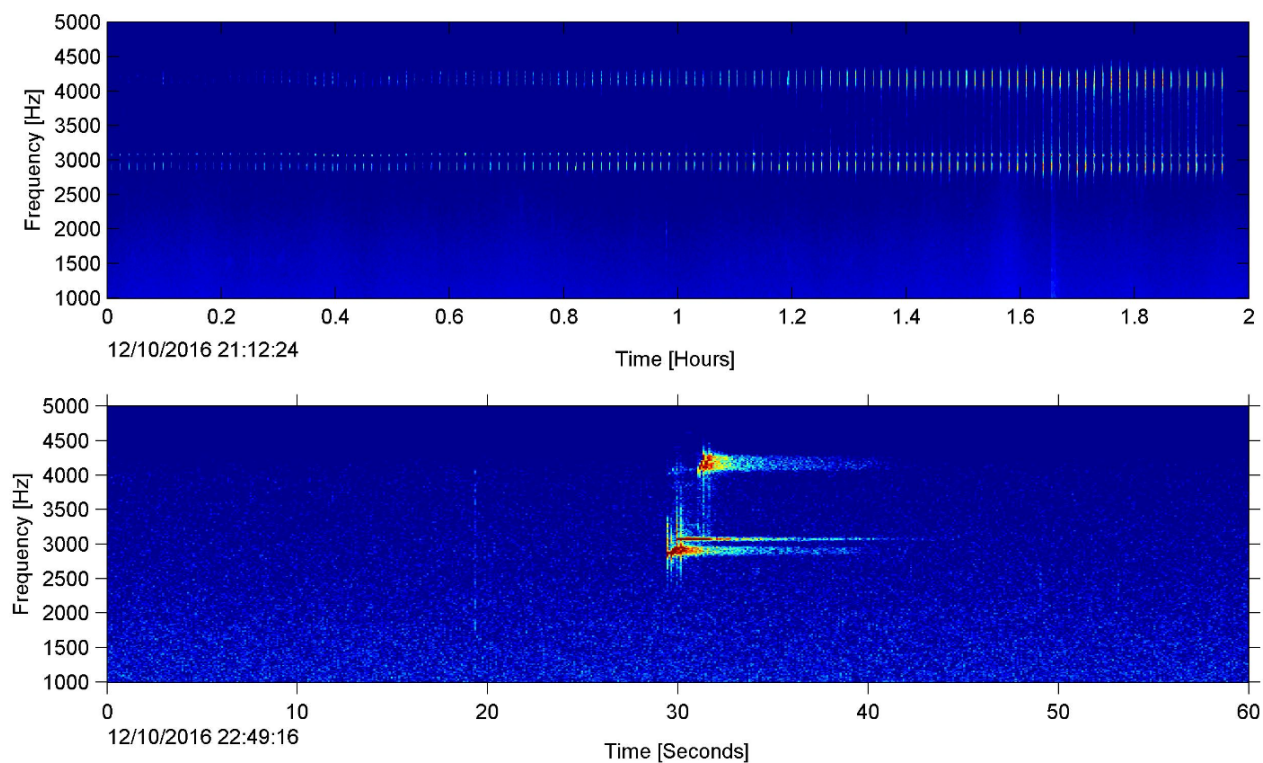


Figure 31. Mid-frequency active sonar in LTSA (top) and spectrogram (bottom) at JAX Site D, December 2016.

High-Frequency Active Sonar

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

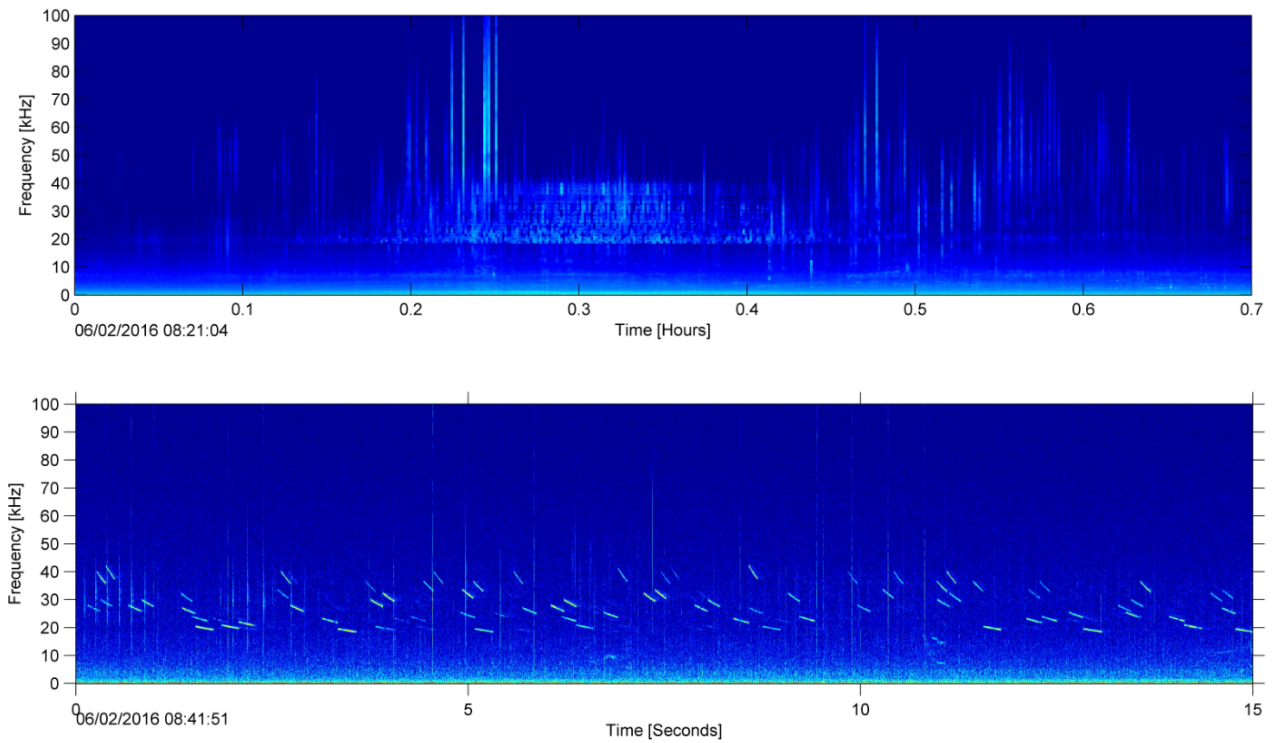


Figure 32. High-frequency active sonar in LTSA (top) and spectrogram (bottom) in JAX Site D, June 2016.

Echosounders

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

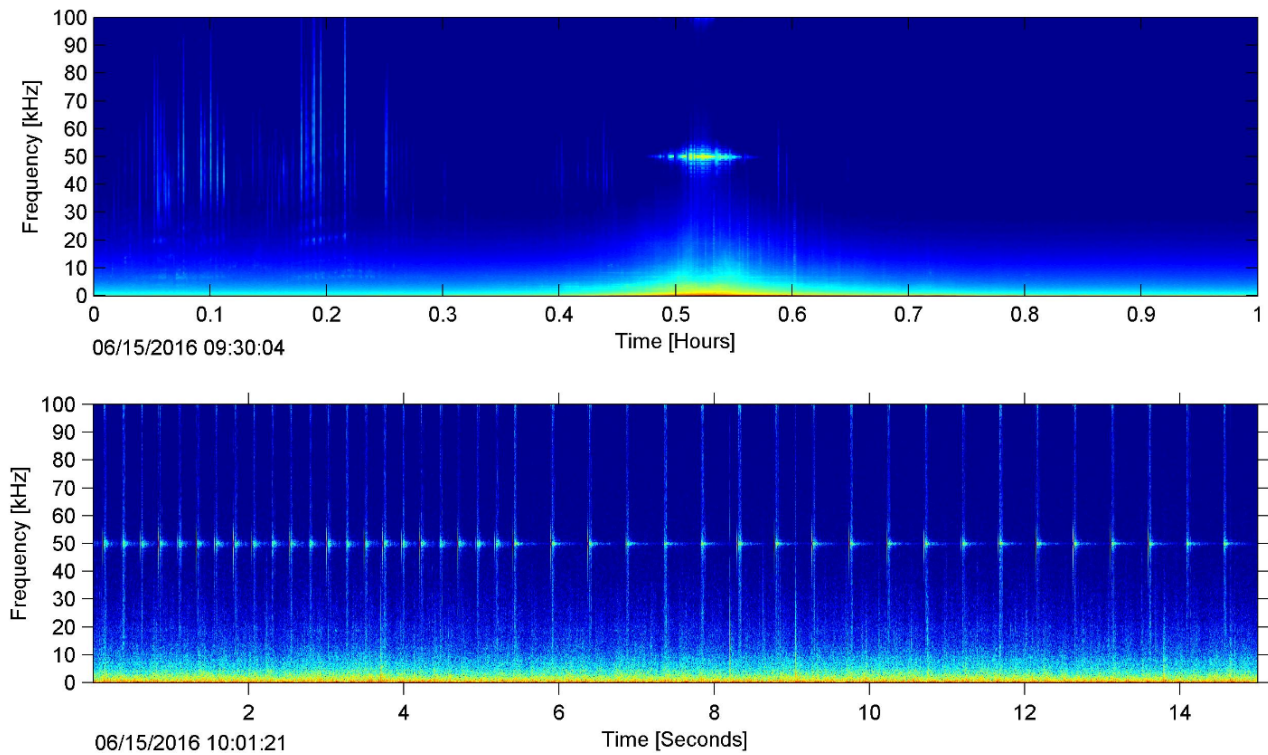


Figure 33. Echosounders in LTSA (top) and spectrogram (bottom) recorded at JAX Site D, June 2016.

Explosions

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

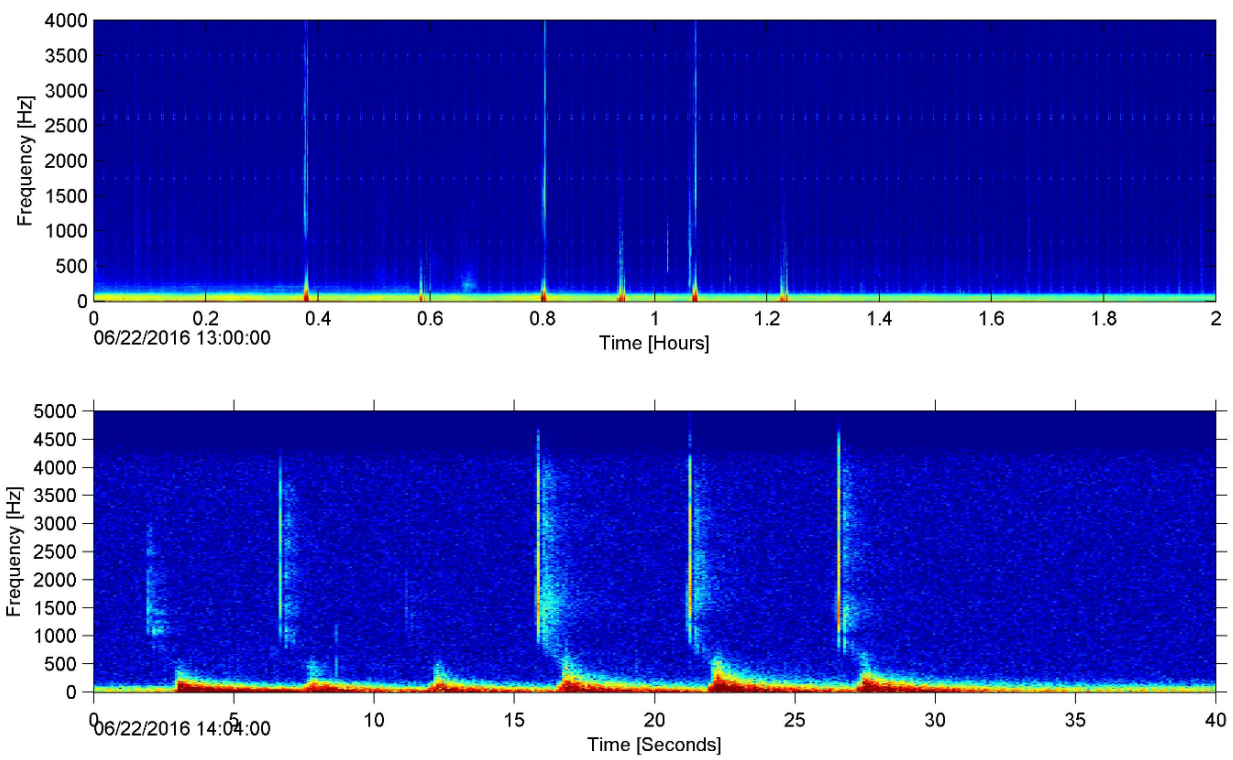


Figure 34. Explosions in LTSA (top) and spectrogram (bottom) recorded at JAX Site D, June 2016.

Airguns

Airguns are regularly used in seismic exploration to investigate the ocean floor and what lies beneath it. A container of high-pressure air is momentarily vented to the surrounding water, producing a 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 200 dB re 1 μ Pa-m (Blackman et al., 2004; Amundsen and Landro, 2010). These shots typically have an inter-pulse-interval of approximately 10 seconds and can last from several hours to days (Figure 35). Airguns were detected automatically using a matched filter detector on data decimated to 1 kHz sampling rate. The time series was filtered with a 10th order Butterworth bandpass filter between 25 and 200 Hz. Cross correlation was computed between 75 seconds of the envelope of the filtered time series and the envelope of a filtered example explosion (0.7 s, Hann windowed) as the matched filter signal. The cross correlation was squared to ‘sharpen’ peaks of airgun blast detections. A floating threshold was calculated by taking the median cross correlation value over the current 75 seconds of data to account for detecting airguns within noise, such as shipping. A cross correlation threshold of 3×10^{-3} above the median was set. When the correlation coefficient reached above this threshold, the time series was inspected more closely. Consecutive airgun shots were required to have a minimum time distance of 2 seconds to be detected. A 300-point (0.03 s) floating average energy across the detection was computed. The start and end times above the threshold were marked when the energy rose by more than 2 dB above the median energy across the detection. Peak-to-peak (pp) and root mean-square (rms) received sound pressure levels (RL) were computed over the potential signal period as well as a timeseries of the length of the airgun shot template before and after the explosion. The potential airgun shot was classified as a false detection and deleted if 1) the dB difference of pp and rms between signal and time AFTER the detection was less than 0.5 dB; 2) the dB difference of pp and rms between signal and time BEFORE the signal was less than 0.5 dB; and 3) the detection was shorter than 0.5 or longer than 10 s. The thresholds were evaluated based on the distribution of histograms of manually verified true and false detections. A regular airgun shot interpulse interval was used to discard potential airgun detections that were not part of a sequence. A trained analyst subsequently verified the remaining potential airgun detections for accuracy. Airgun shots have energy as low as 10 Hz and can extend up to 250 Hz or higher, lasting for a few seconds including the reverberation. No airguns were detected during this deployment.

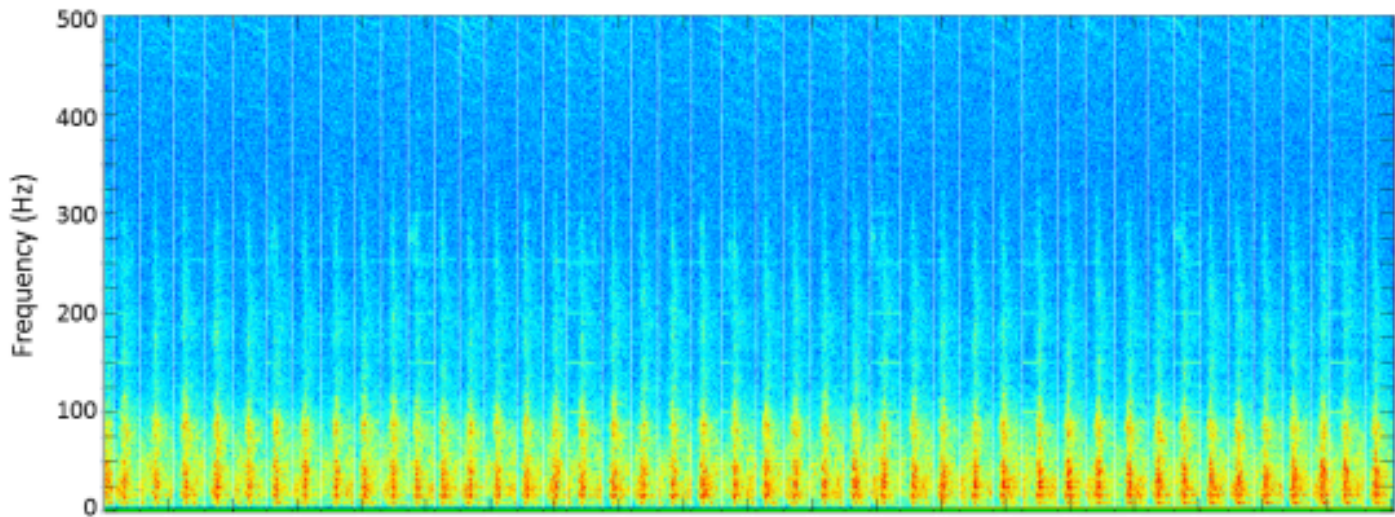


Figure 35. Airgun pulses recorded in the Western Atlantic during the analyst verification stage of the detector.

Results

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

Ambient Soundscape

To provide a means for evaluating seasonal sound spectral variability, daily-averaged spectra were processed into monthly averages (Figure 36) and plotted so that months could be compared. Incomplete days were removed from the analysis, but incomplete months were not. Partial months are designated by an asterisk (*) in the color legend of Figure 36 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 37).

- High levels of noise at low frequencies (10-15 Hz) may be due to strong tidal currents that result in hydrophone cable strumming.
- Energy from Minke pulse train signals is visible from November to March in the ambient spectra and long-term spectrogram between 100 - 200 Hz (Figure 37).

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

Deployment	Month / Year	Days of Data / Days in Month
JAX_D_13	6 / 2017	25 / 30

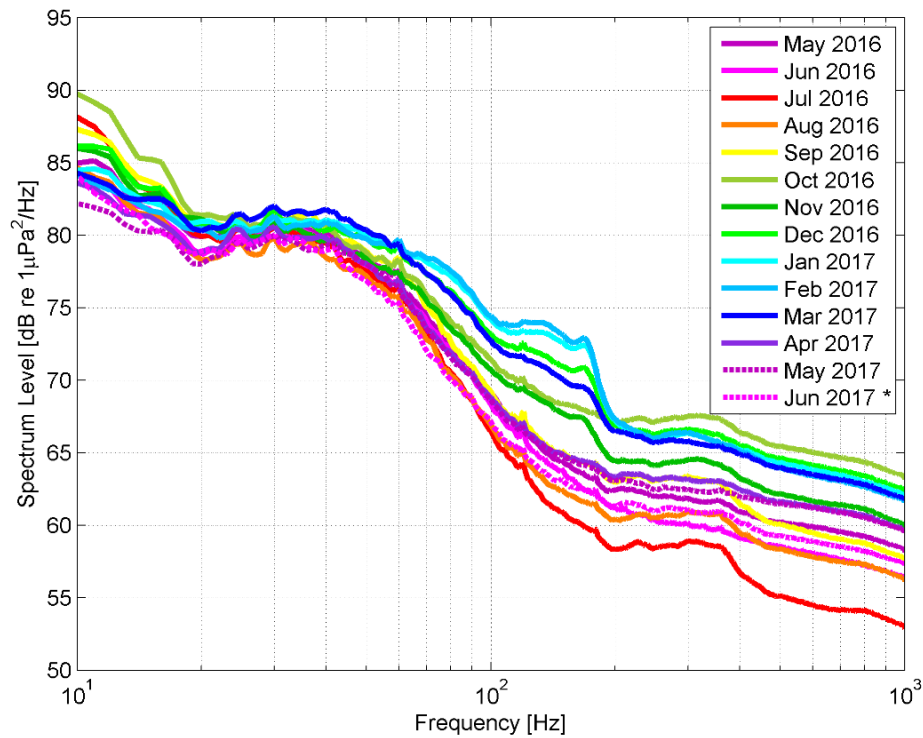


Figure 36. Monthly averages of ambient soundscape at JAX Site D for each month from May 2016 to June 2017. Legend gives color coding by month. Months with an asterisk are partial recording periods.

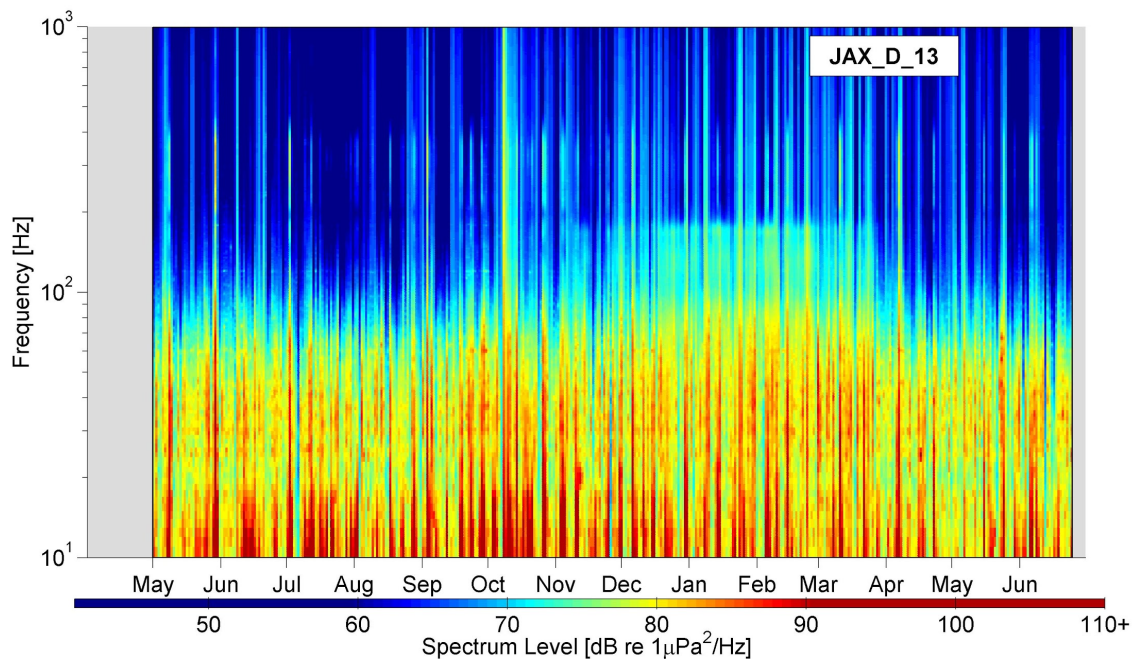


Figure 37. Long-term spectrograms using daily-averaged spectra for JAX Site D from April 2016 to June 2017.

Mysticetes

Blue Whales

- Northern Atlantic blue whale tonal calls were detected only in July 2016 (Figure 38).
- There were too few encounters to discern a diel pattern for Northern Atlantic blue whale tonal calls (Figure 39).

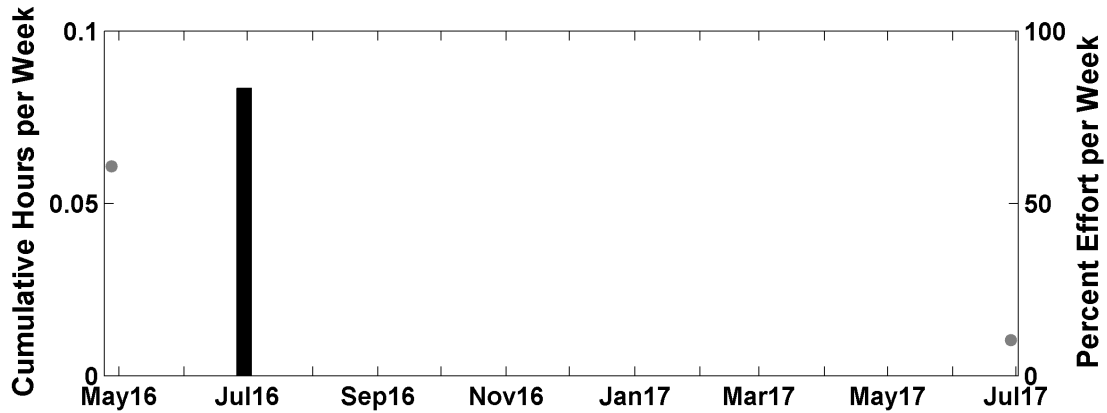


Figure 38. Weekly presence of Northern Atlantic blue whale tonal calls between April 2016 and June 2017 at JAX Site D. Black dots represent percent of effort per week in weeks with less than 100% recording effort. Where black dots are absent, full recording effort occurred for the entire week. X-axis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

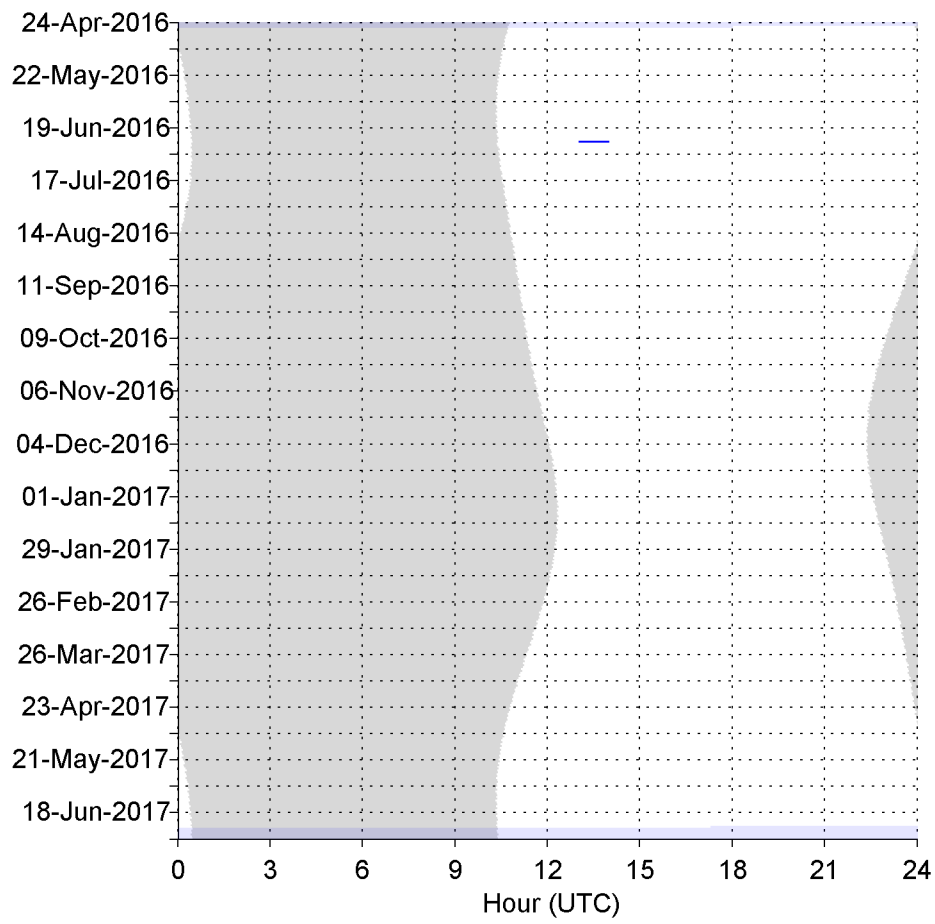


Figure 39. Northern Atlantic blue whale tonal calls in hourly bins at JAX Site D. Gray vertical shading denotes nighttime.

Sei Whales

- Sei whale downsweeps were observed in low numbers between November 2016 and January 2017 (Figure 40).
- There were too few encounters to discern a diel pattern (Figure 41).

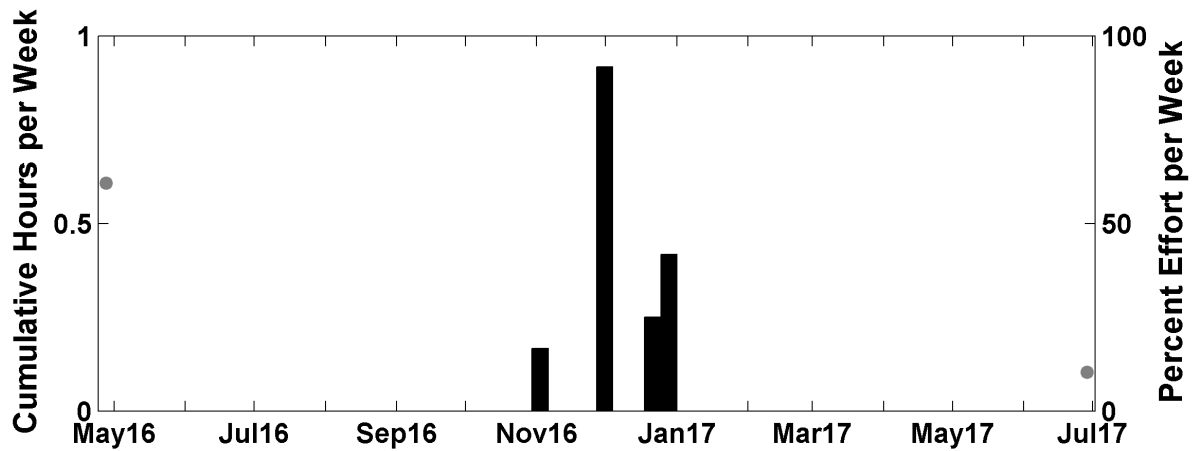


Figure 40. Weekly presence of Sei whale downsweep calls at JAX Site D. Effort markings described in Figure 38.

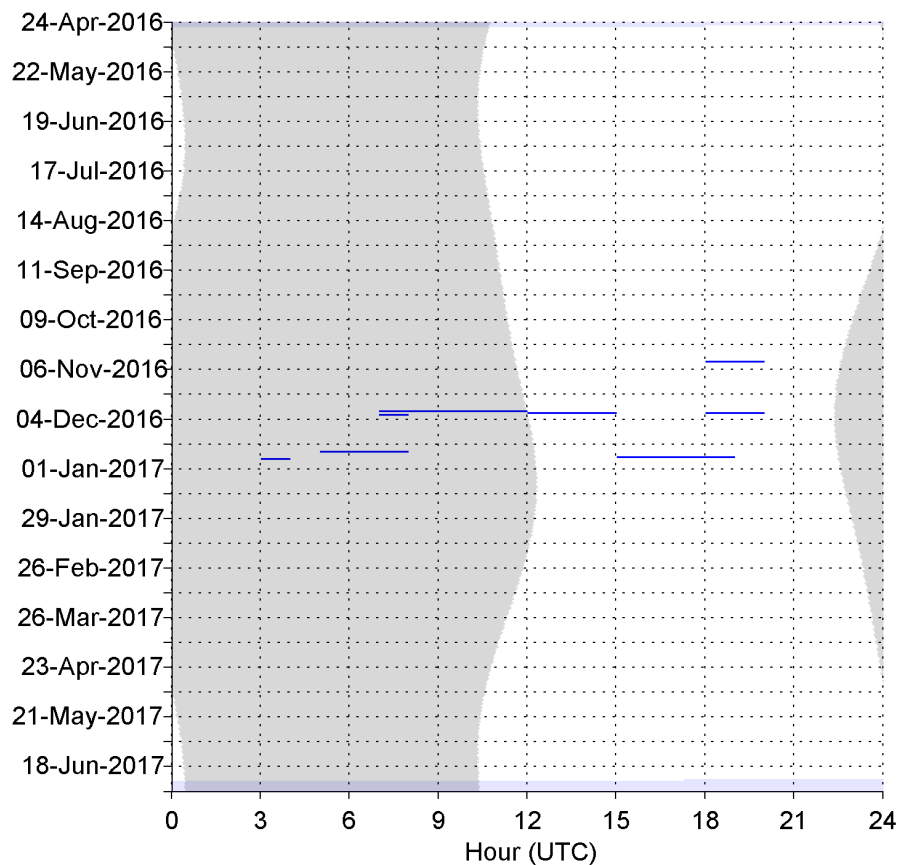


Figure 41. Sei whale downsweep calls in hourly bins at JAX Site D. Gray vertical shading denotes nighttime.

Fin Whales

- Fin whale 20 Hz calls, associated with singing and call-counter-call among animals, were detected in intermittently low numbers between April 2016 and June 2017 (Figure 42).
- Fin whale 40 Hz calls were detected occasionally at low levels (Figure 43) particularly in the summer and fall of 2016.
- There was no discernible diel pattern for fin whale 40 Hz calls (Figure 44).

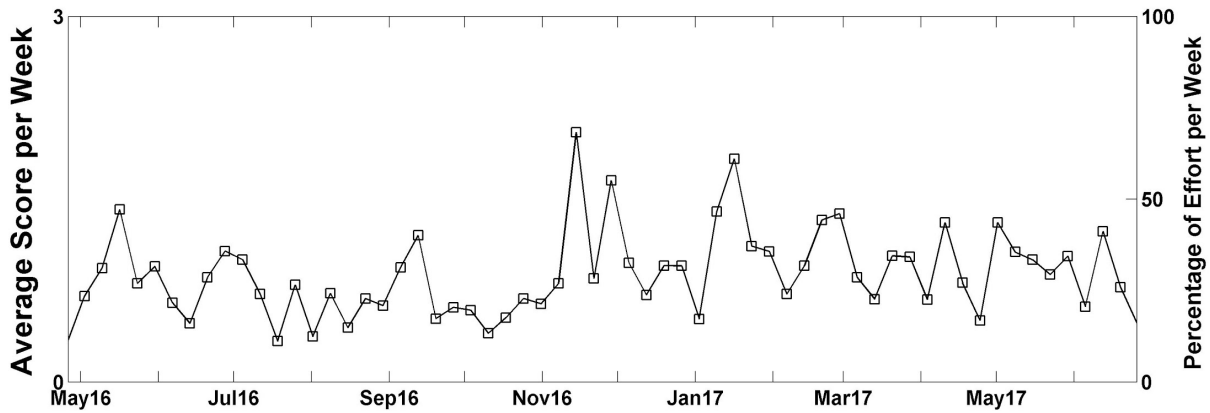


Figure 42. Weekly value of fin whale 20 Hz call index at JAX Site D.

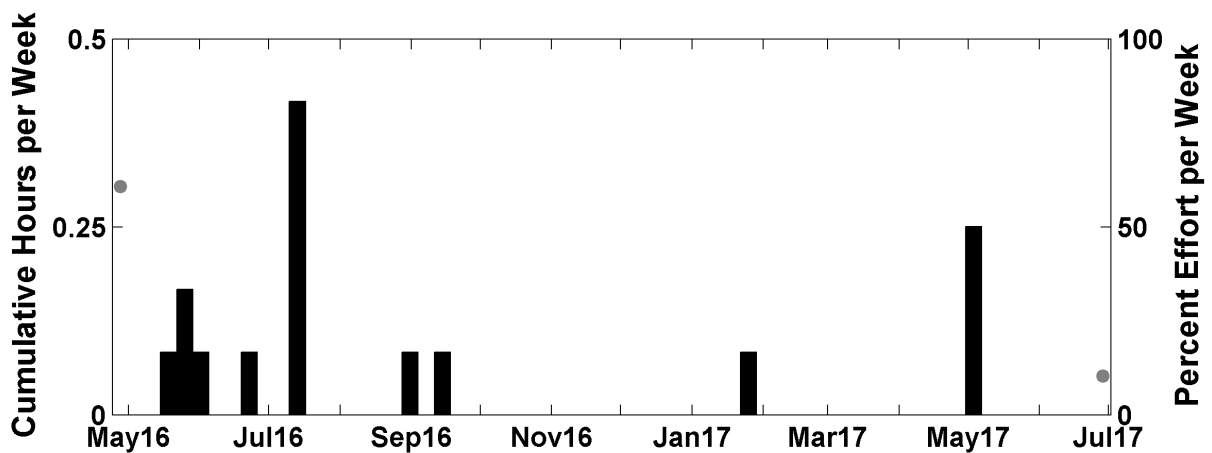


Figure 43. Fin whale 40 Hz calls detected at JAX Site D. Effort markings described in Figure 38.

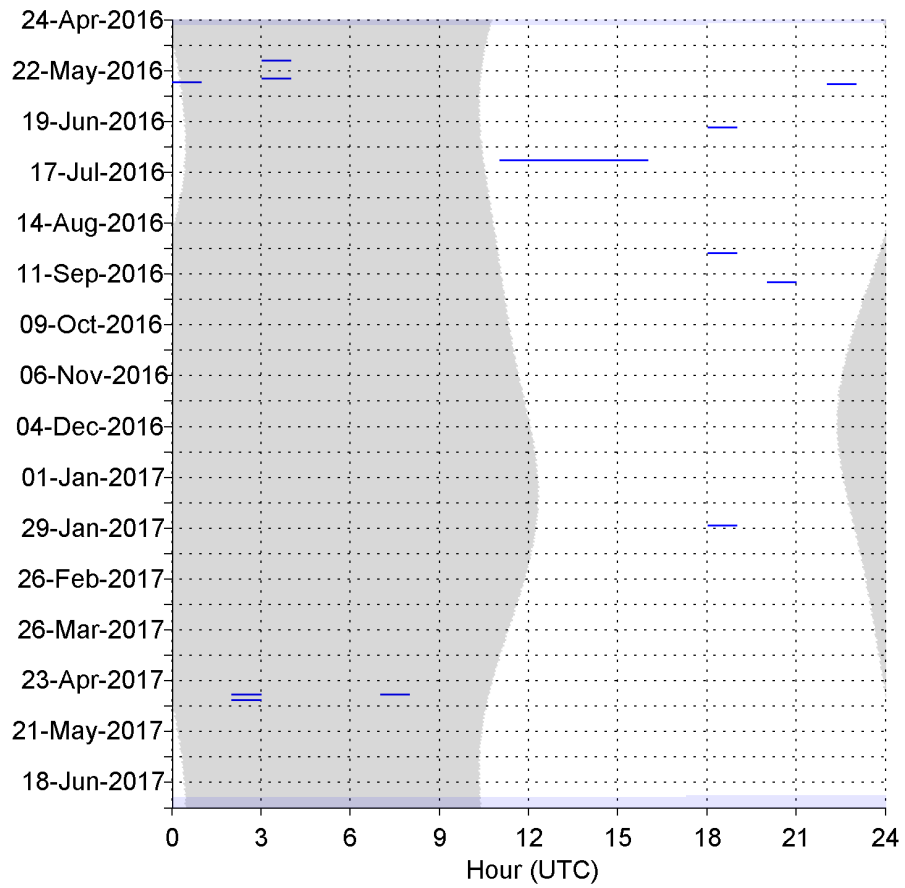


Figure 44. Fin whale 40 Hz calls in hourly bins at JAX Site D. Gray vertical shading denotes nighttime.

Minke Whales

- Minke pulse trains were detected briefly in May 2016 (Figure 45). Detections became nearly continuous in November 2016 and remained elevated through April 2017.
- There was no discernible diel pattern for minke pulse trains (Figure 46).

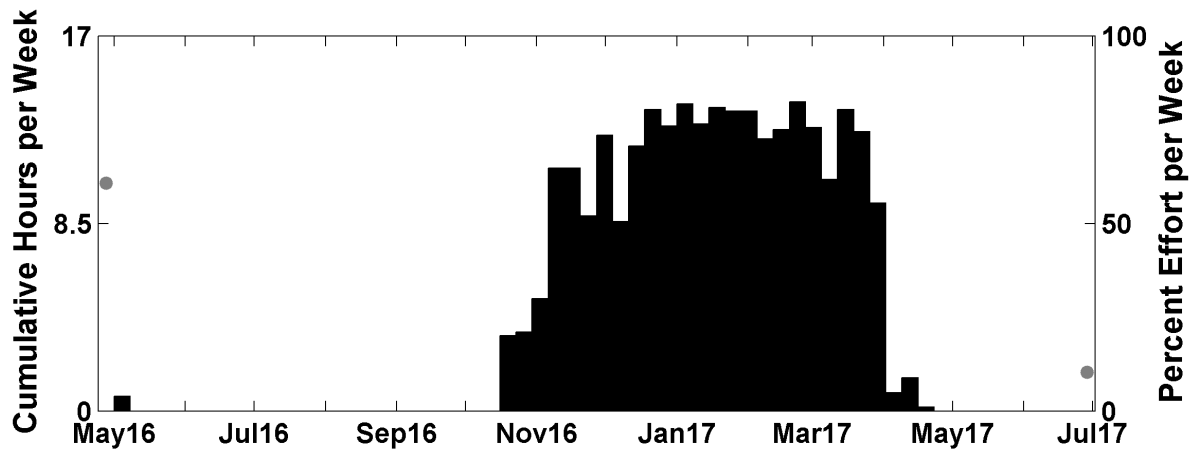


Figure 45. Weekly presence of minke whale pulse trains at JAX Site D. Effort markings described in Figure 38.

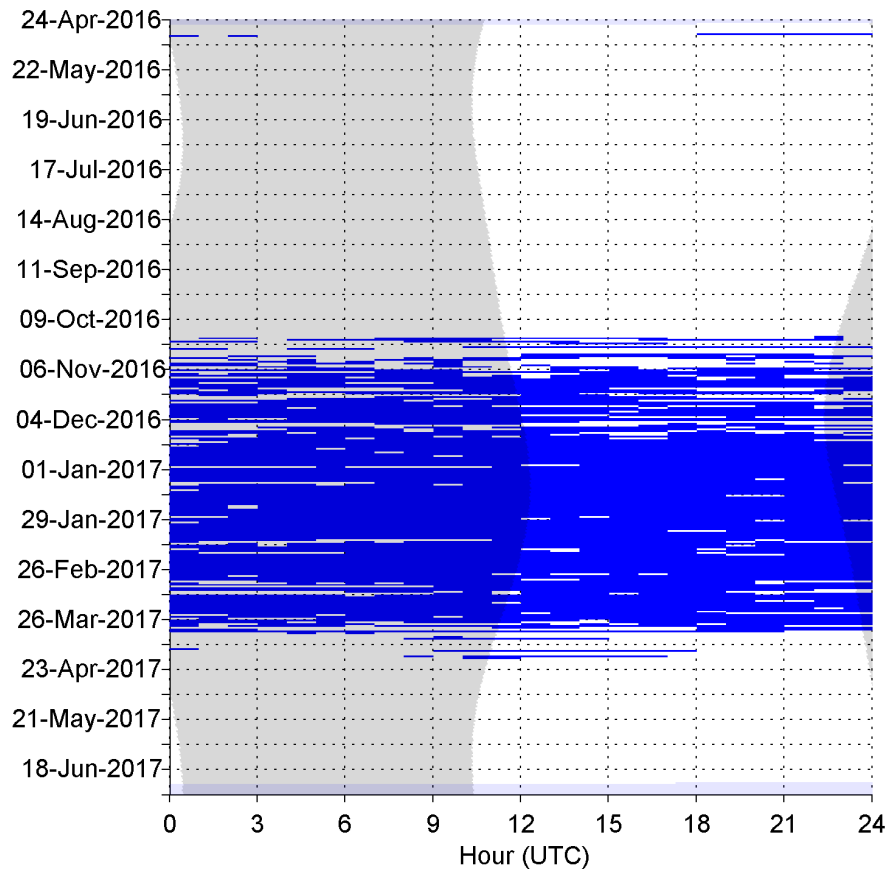


Figure 46. Minke whale pulse trains in hourly bins at JAX Site D. Gray vertical shading denotes nighttime.

Odontocetes

Clicks from Cuvier's beaked whale, Risso's dolphins, *Kogia* spp., sperm whales, three click types not yet assigned to a species, and unidentified odontocetes clicks 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.

Cuvier's Beaked Whale

- Cuvier's beaked whale echolocation clicks were detected in one week in October 2016 (Figure 47).
- There were not enough encounters to discern a diel pattern (Figure 48).

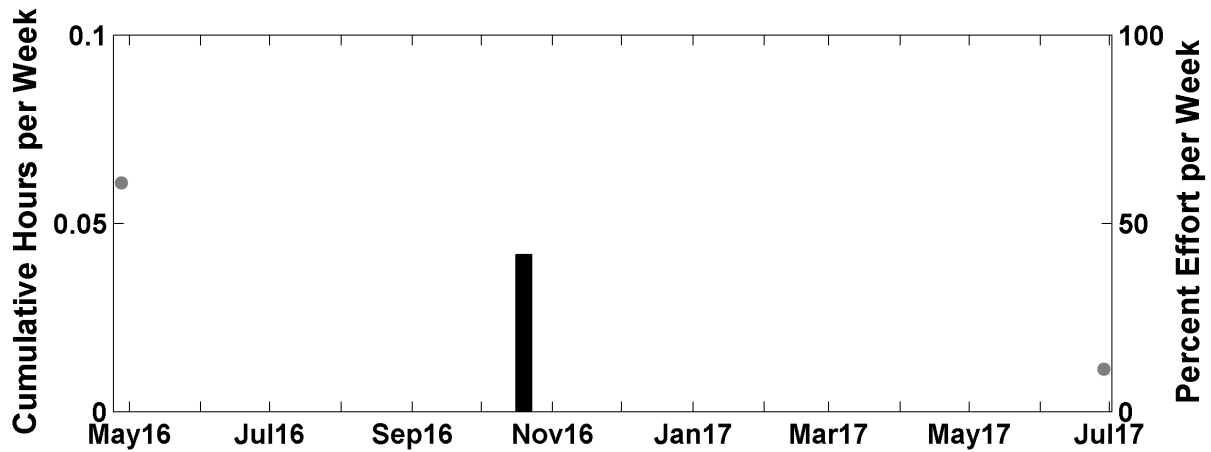


Figure 47. Weekly presence of Cuvier's beaked whale echolocation clicks at JAX Site D. Effort markings described in Figure 38.

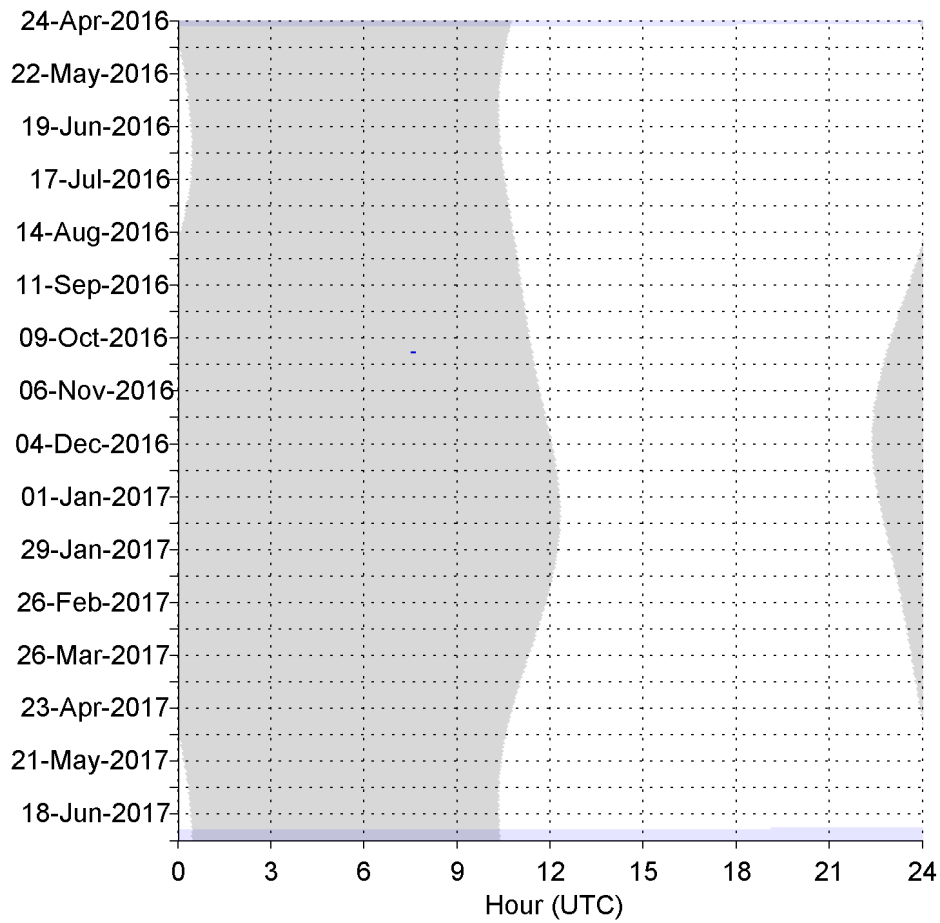


Figure 48. Cuvier's beaked whale echolocation clicks in five minute bins at JAX Site D. Gray vertical shading denotes nighttime.

Risso's Dolphins

- Risso's dolphin echolocation clicks were detected intermittently throughout the recording period but were highest from May to September 2016 (Figure 49).
- Risso's echolocation clicks were detected more often during nighttime (Figure 50).

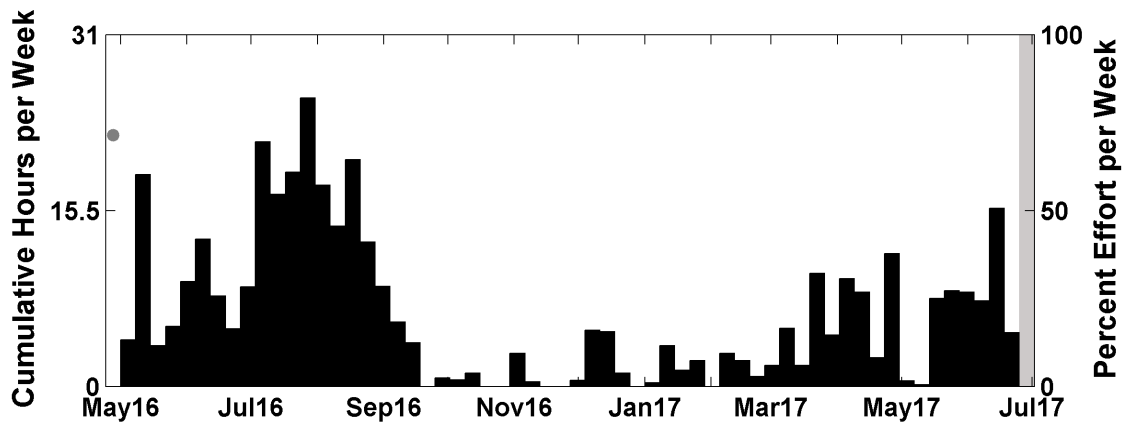


Figure 49. Weekly presence of Risso's dolphin echolocation clicks at JAX Site D. Effort markings described in Figure 38.

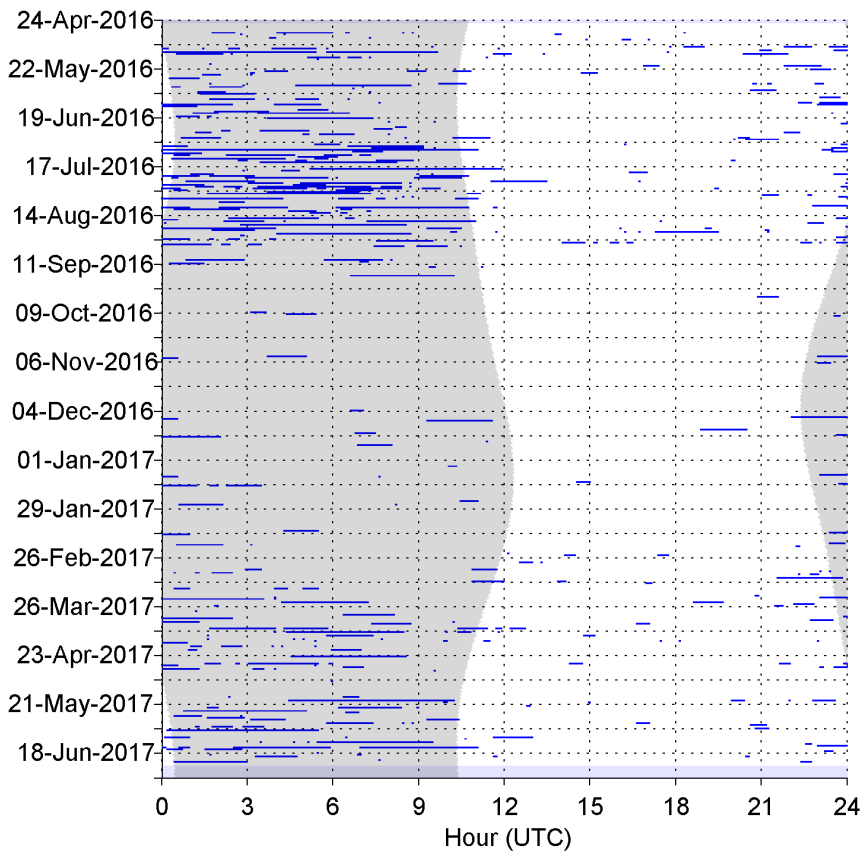


Figure 50. Risso's dolphin echolocation clicks in five minute bins at JAX Site D. Gray vertical shading denotes nighttime.

Click Type J1

- CT J1 was frequently detected from May 2016 to July 2016 and from March 2017 to July 2017. Detections decreased between September 2016 and December 2016 (Figure 51).
- CT J1 was more often detected during nighttime (Figure 52).

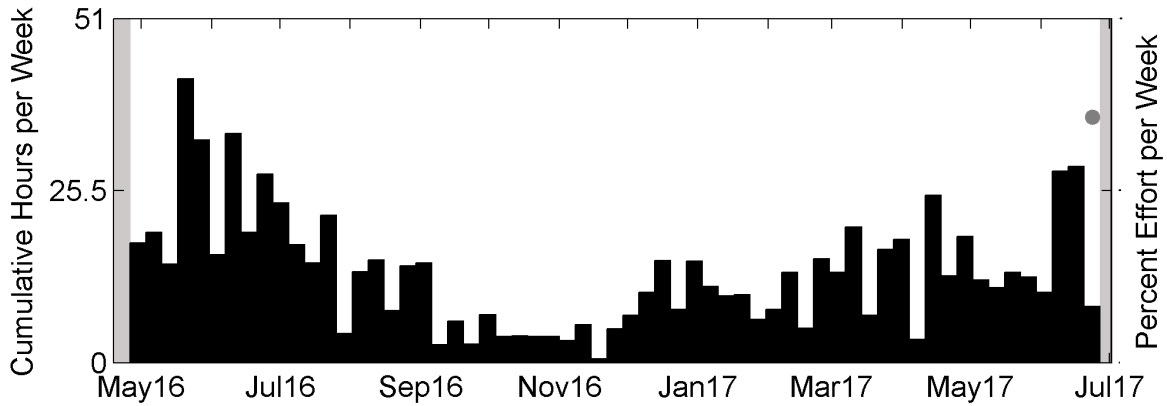


Figure 51. Weekly presence of CT J1 at JAX Site D. Effort markings described in Figure 38.

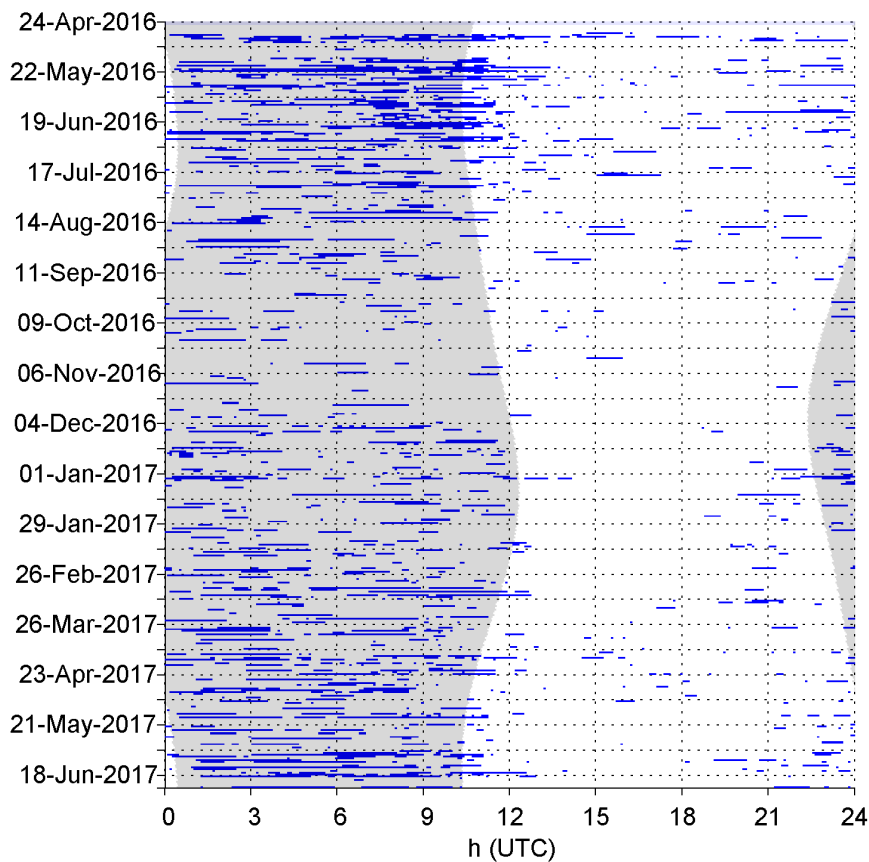


Figure 52. T J1 in five minute bins at JAX Site D. Gray vertical shading denotes nighttime.

Click Type J2

- CT J2 was frequently detected from May through July, with fewer detections from September to January (Figure 53).
- CT J2 was detected predominantly before and during sunrise (Figure 54).

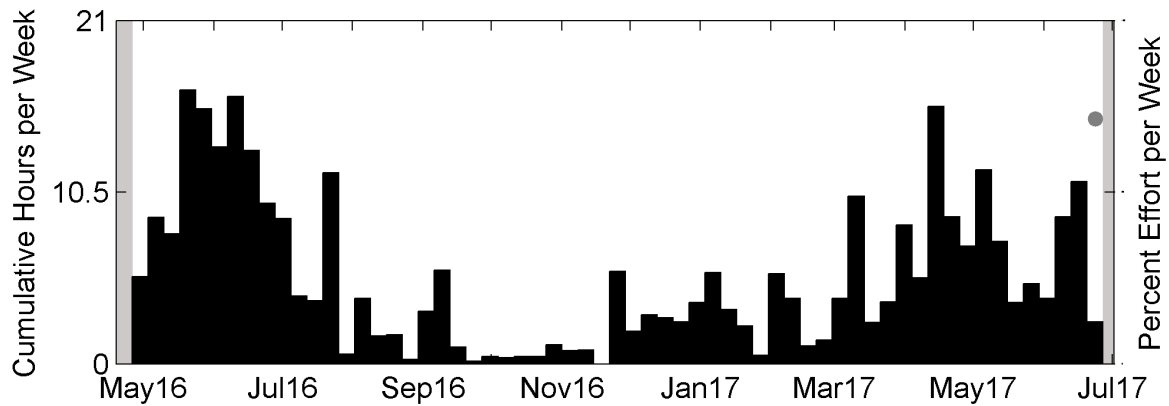


Figure 53. Weekly presence of CT J2 at JAX Site D. Effort markings described in Figure 38.

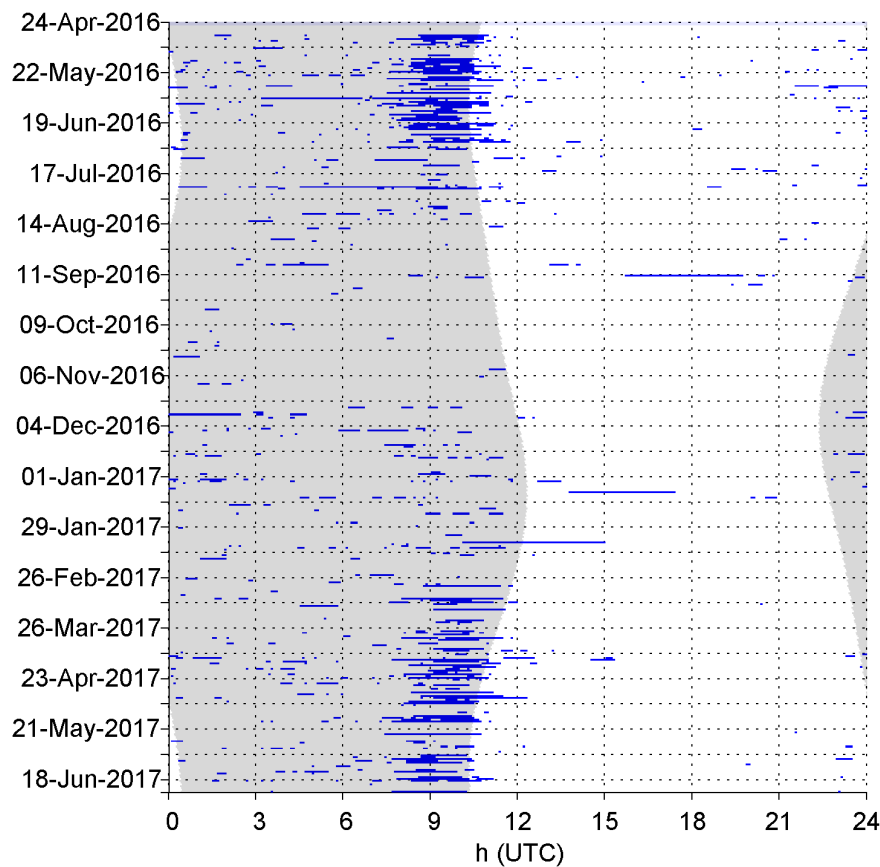


Figure 54. CT J2 in one-hour bins between April 2015 and June 2017 at JAX Site D. Gray vertical shading denotes nighttime.

Click Type J3

- CT J3 was detected from May to June 2016 and March to June 2017, with fewer detections from August 2016 to February 2017 (Figure 55).
- CT J3 was detected primarily, but not exclusively, during nighttime (Figure 56).

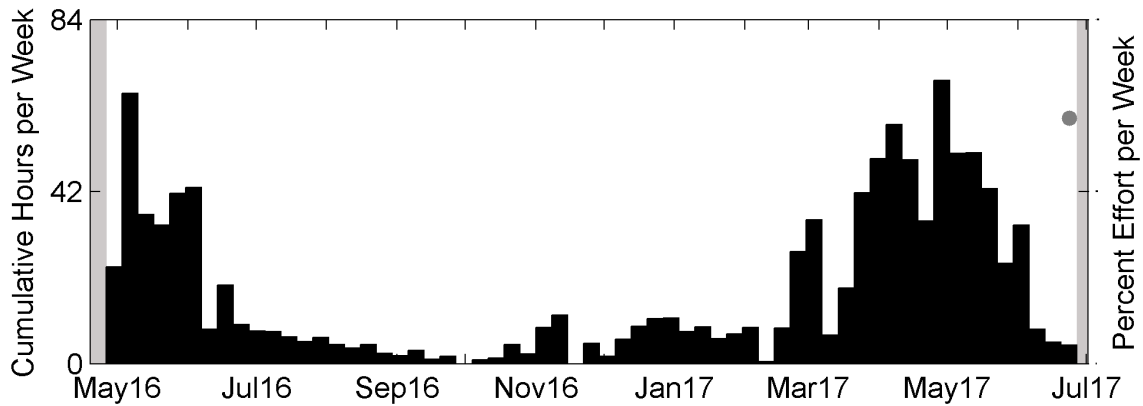


Figure 55. Weekly presence of CT J3 at JAX Site D. Effort markings described in Figure 38.

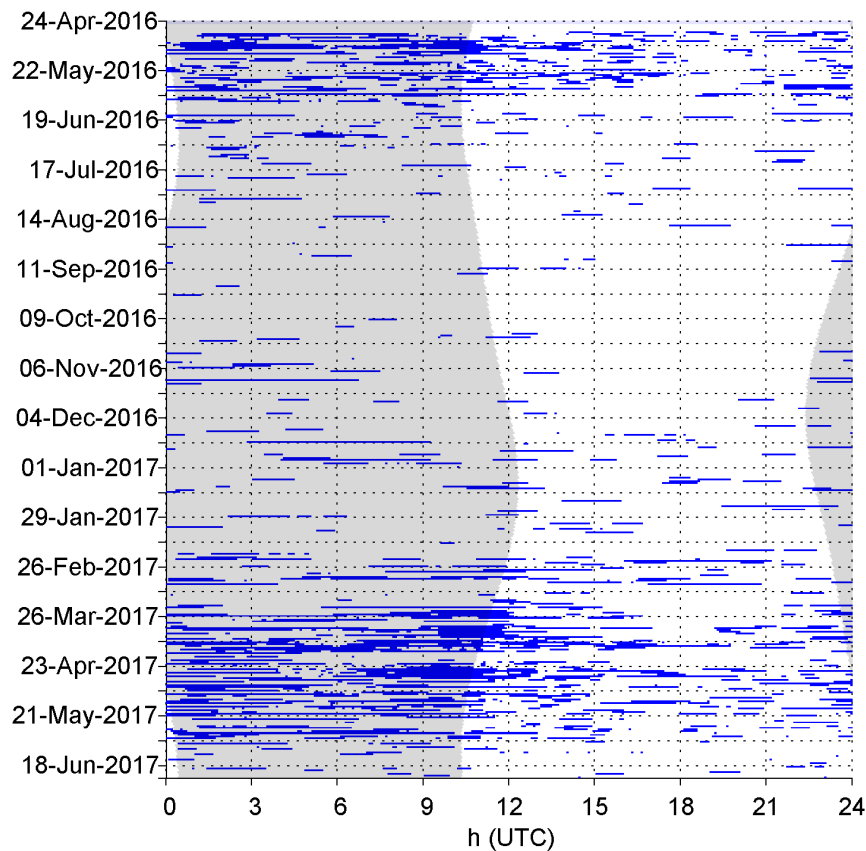


Figure 56. CT J3 in one-hour bins between April 2015 and June 2017 at JAX Site D. Gray vertical shading denotes nighttime.

Unidentified Odontocete Clicks

Signals that had characteristics of odontocete echolocation clicks, but could not be classified to species or click type 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. Unidentified detections decreased from September to December 2016 (Figure 57).
- There was no discernable diel pattern for unidentified odontocete clicks (Figure 58).

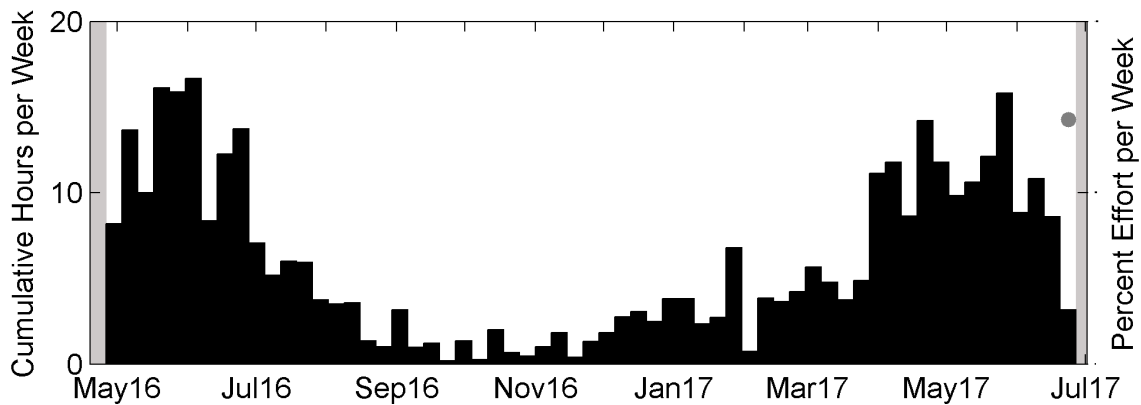


Figure 57. Weekly presence of unidentified odontocete clicks at JAX Site D. Effort markings described in Figure 38.

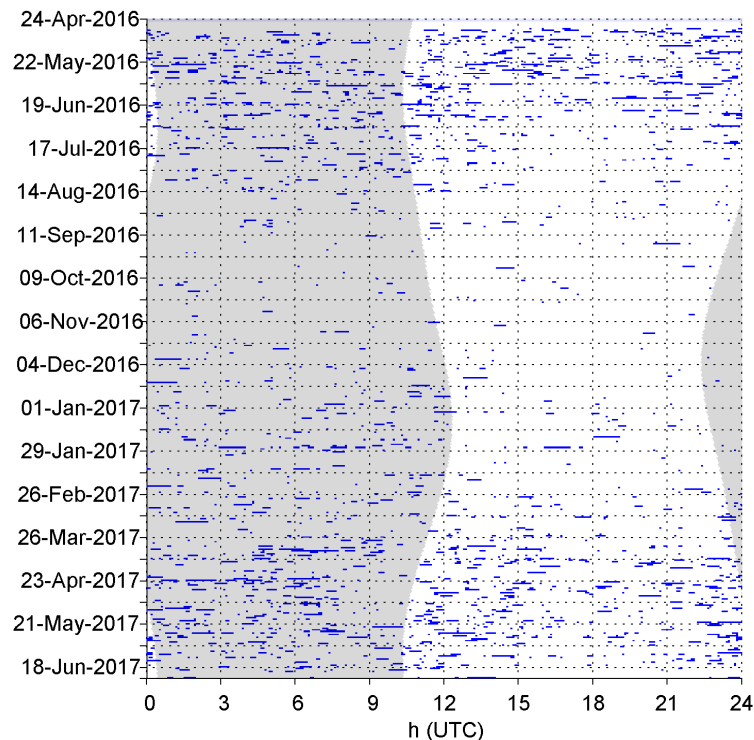


Figure 58. Unidentified odontocete clicks in five minute bins at JAX Site D. Gray vertical shading denotes nighttime.

Unidentified Odontocete Whistles Less Than 5 kHz

- Unidentified odontocete whistles less than 5 kHz were detected frequently between April 2016 and June 2017. Most detections were in between May 2016 and June 2016 and between April 2017 and June 2017 (Figure 59).
- There was a slight crepuscular pattern for unidentified whistles less than 5 kHz (Figure 60).
- Pilot whales most likely produced these whistles, though it is possible they are from other blackfish species that have overlapping distributions.

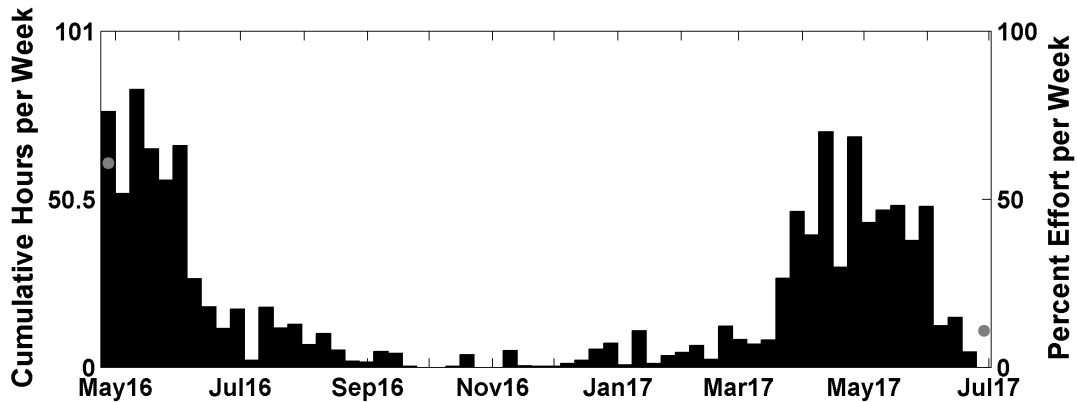


Figure 59. Weekly presence of unidentified odontocete whistles less than 5 kHz at JAX Site D. Effort markings described in Figure 38.

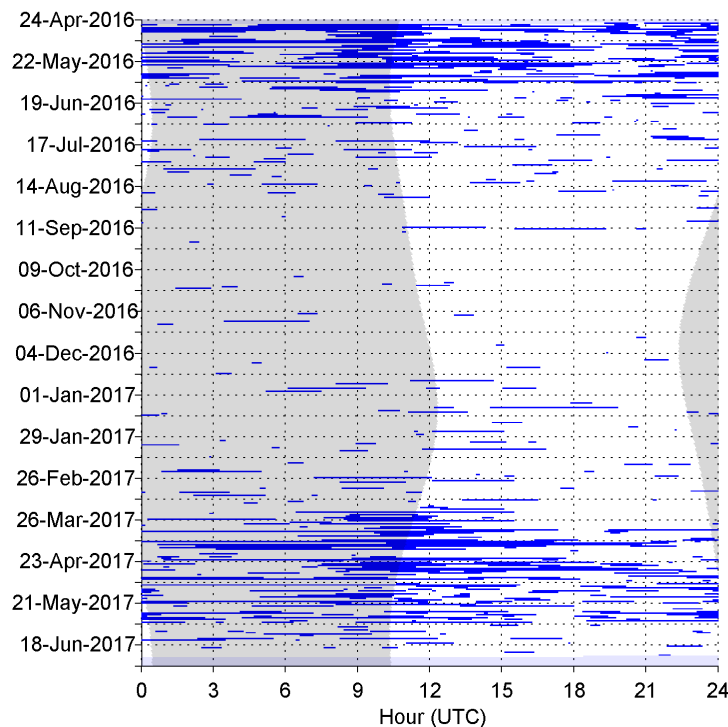


Figure 60. Unidentified odontocete whistles less than 5 kHz in one-minute bins between April 2016 and June 2017 at JAX Site D. Gray vertical shading denotes nighttime.

Unidentified Odontocete Whistles Greater Than 10 kHz

- Unidentified odontocete whistles greater than 10 kHz were detected frequently between April 2016 and June 2016, as well as between January 2017 to May 2017 (Figure 61).
- There was somewhat of a crepuscular diel pattern for whistles greater than 5 kHz (Figure 62), although they were also detected at other times of day.

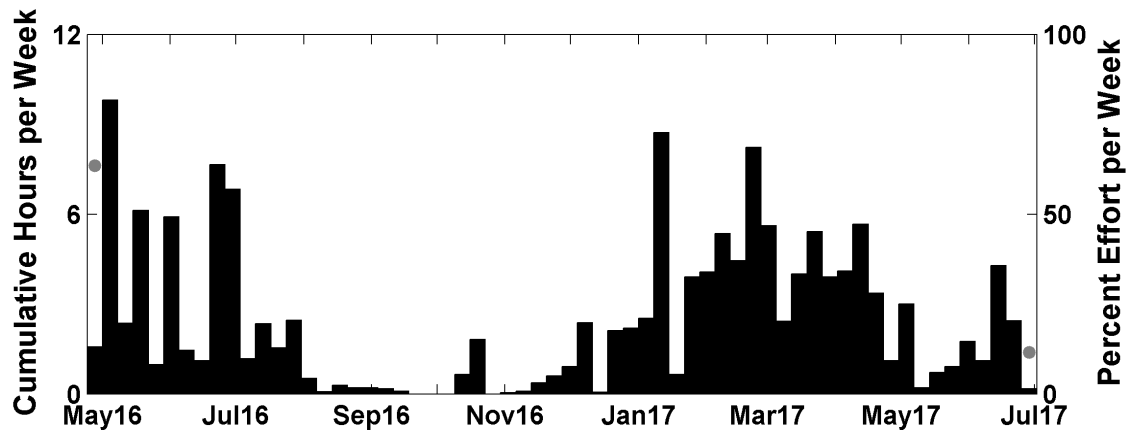


Figure 61. Weekly presence of unidentified odontocete whistles greater than 10 kHz at JAX Site D. Effort markings described in Figure 38.

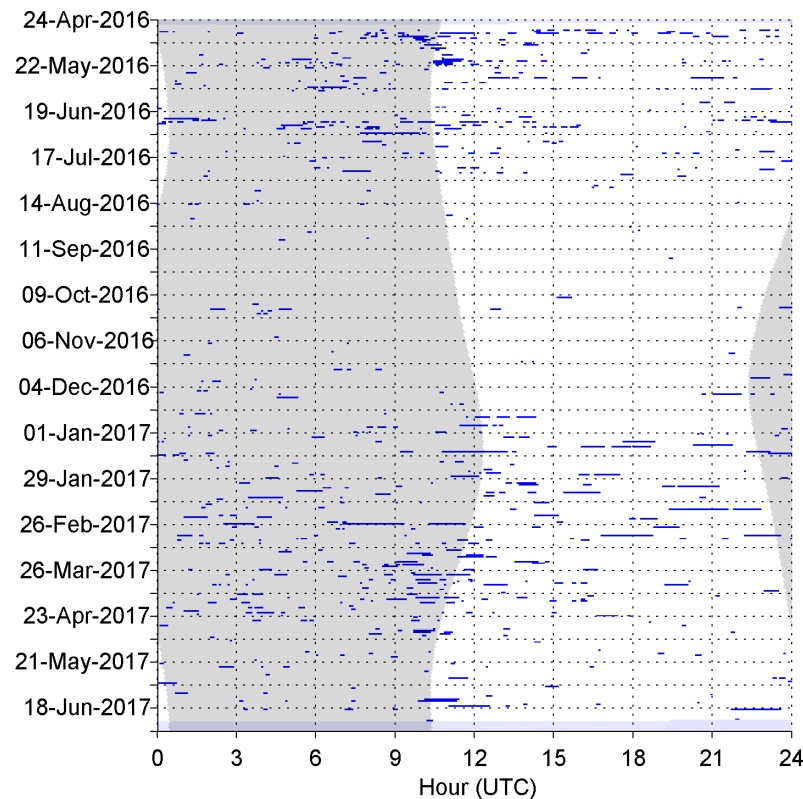


Figure 62. Unidentified odontocete whistles greater than 10 kHz in one-hour bins at JAX Site D. Gray vertical shading denotes nighttime.

Sperm Whales

- Sperm whale clicks were detected intermittently throughout the detection period but were highest in September 2016 and October 2016 (Figure 63).
- There was no discernible diel pattern for sperm whale clicks (Figure 64).

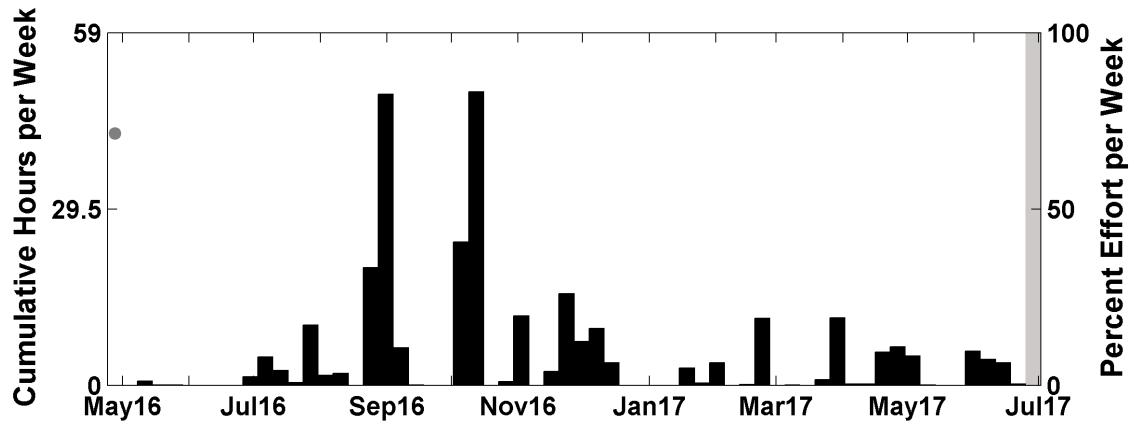


Figure 63. Weekly presence of sperm whale clicks at JAX Site D. Effort markings described in Figure 38.

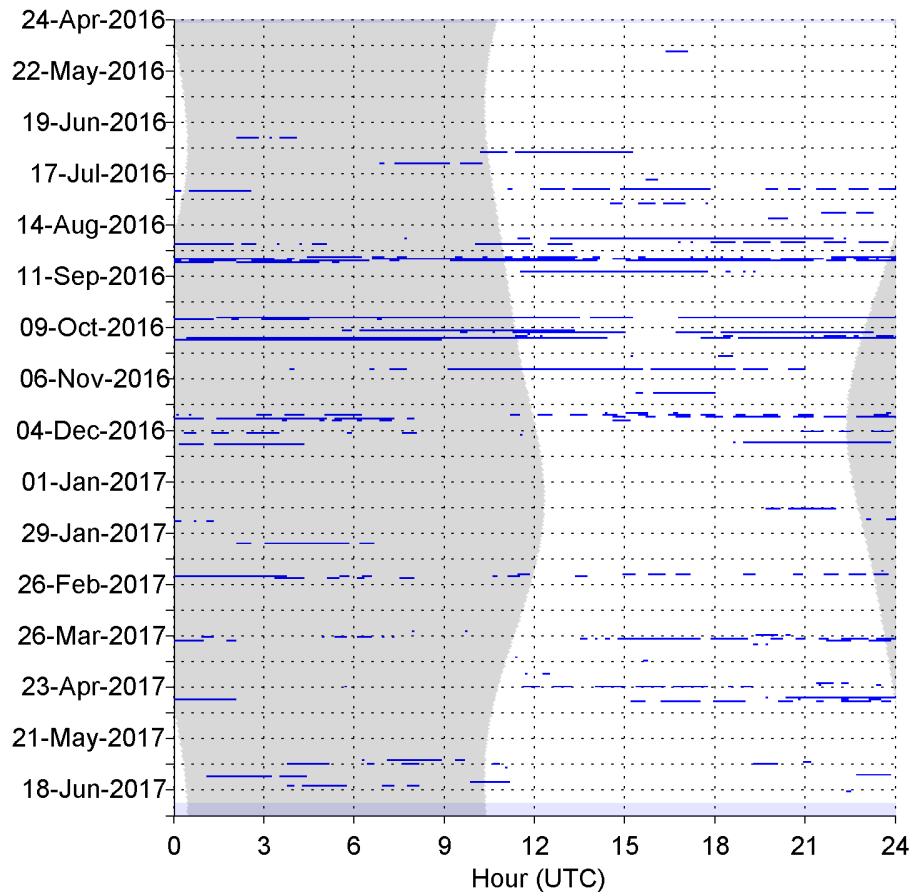


Figure 64. Sperm whale clicks in one-hour bins at JAX Site D. Gray vertical shading denotes nighttime.

***Kogia* spp.**

- *Kogia* spp. echolocation clicks were detected intermittently throughout the deployment (Figure 65).
- There was no discernible diel pattern for *Kogia* echolocation clicks (Figure 66).

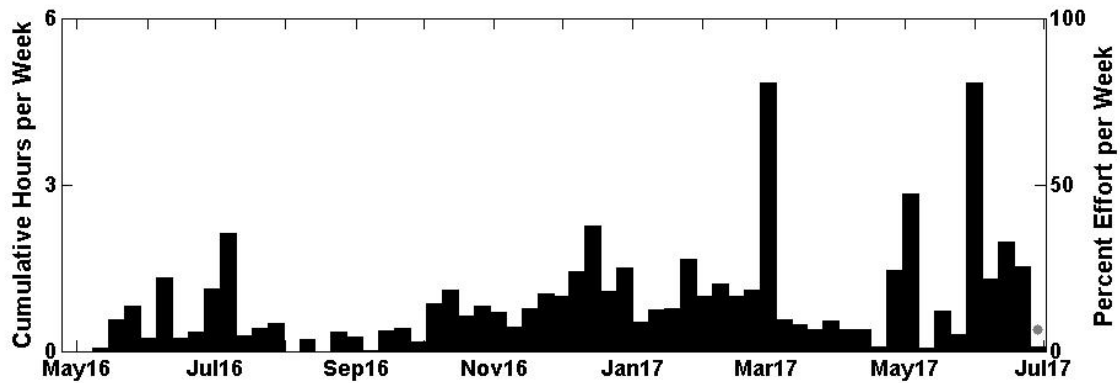


Figure 65. Weekly presence of *Kogia* spp. clicks at JAX Site D. Effort markings described in Figure 38.

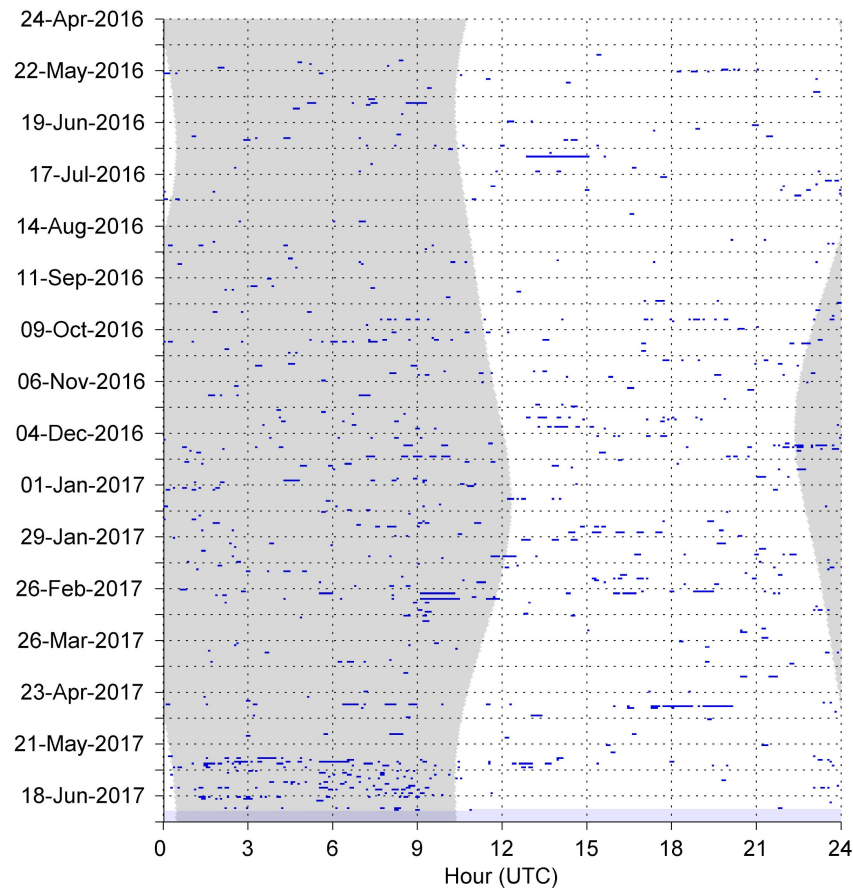


Figure 66. *Kogia* spp. clicks in one-hour bins at JAX Site D. Gray vertical shading denotes nighttime.

Anthropogenic Sounds

Seven categories of anthropogenic sounds were detected: broadband ships, LFA sonar, other low-frequency sonar, MFA sonar, HFA sonar, echosounders and explosions.

Broadband Ships

- Broadband ship noise was detected regularly throughout the recording period (Figure 67), with a drop in detections during November 2016.
- There was no discernible diel pattern for broadband ships during the recording period (Figure 68).

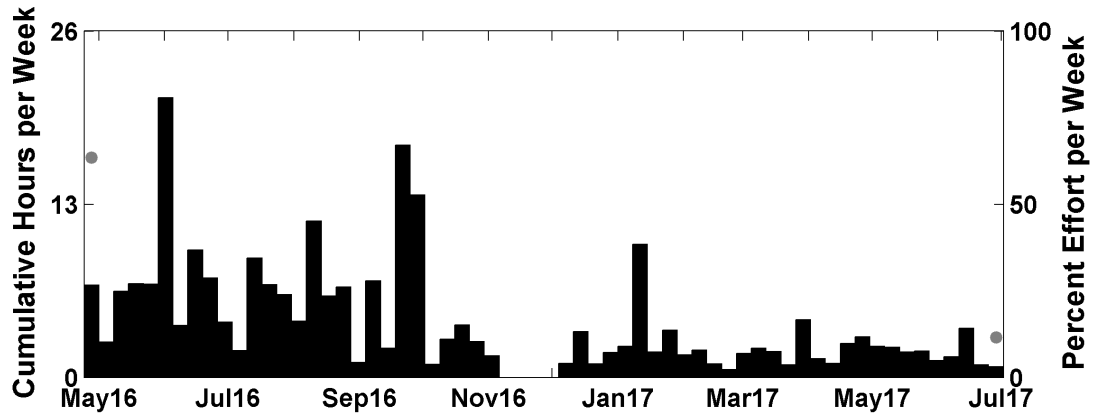


Figure 67. Weekly presence of broadband ships at JAX Site D. Effort markings described in Figure 38.

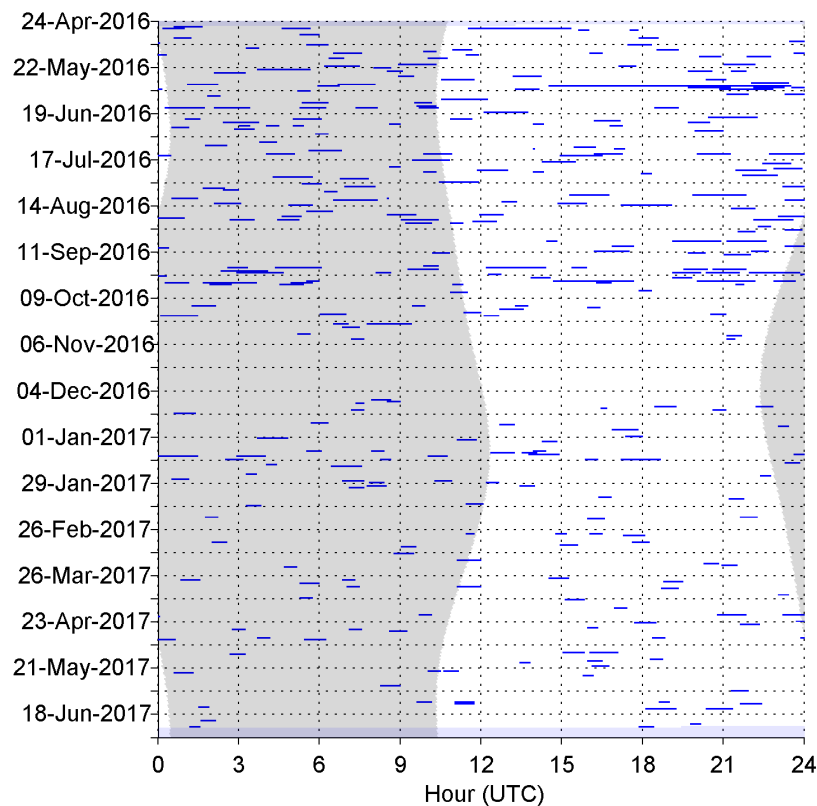


Figure 68. Broadband ship noise in one-minute bins at JAX Site D. Gray vertical shading denotes nighttime.

LFA Sonar

- LFA sonar greater than 500 Hz was detected only in February 2017 (Figure 69).
- There were not enough encounters of LFA to determine a diel pattern during the recording period (Figure 70).

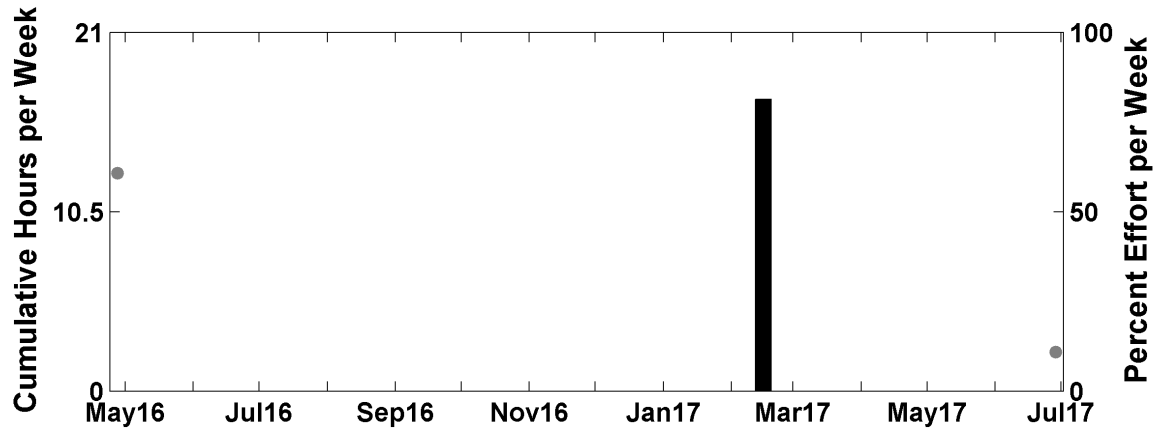


Figure 69. Weekly presence of LFA sonar at JAX Site D. Effort markings described in Figure 38.

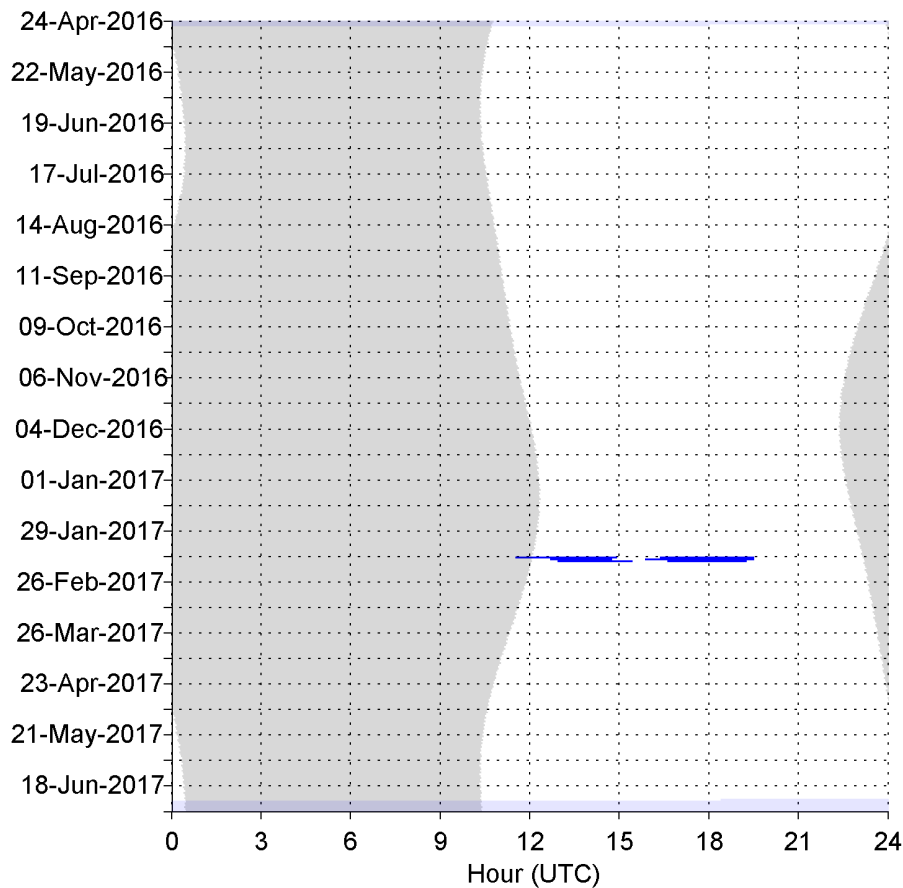


Figure 70. LFA sonar in one-hour bins at JAX Site D. Gray vertical shading denotes nighttime.

Other LFA Sonar

- Other LFA sonar was detected only in April 2016 (Figure 71).
- There were not enough encounters of other LFA to determine a diel pattern during the recording period (Figure 72).

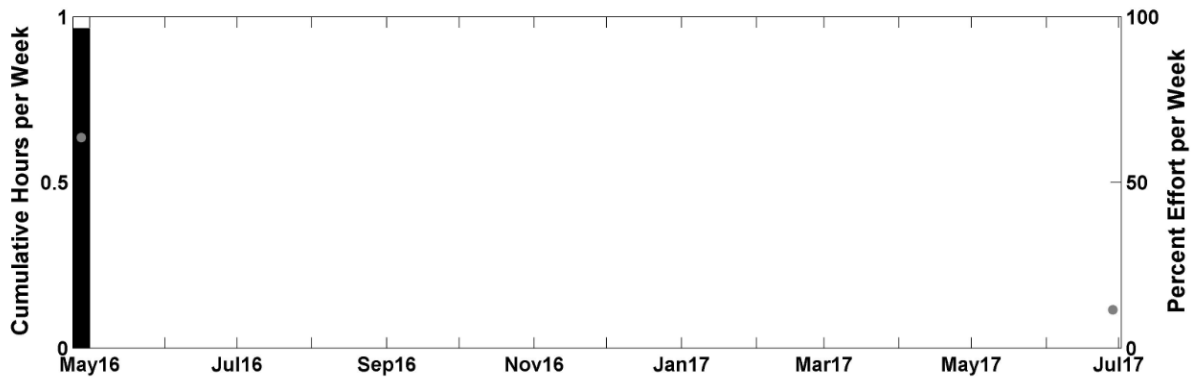


Figure 71. Weekly presence of Other LFA sonar at JAX Site D. Effort markings described in Figure 38.

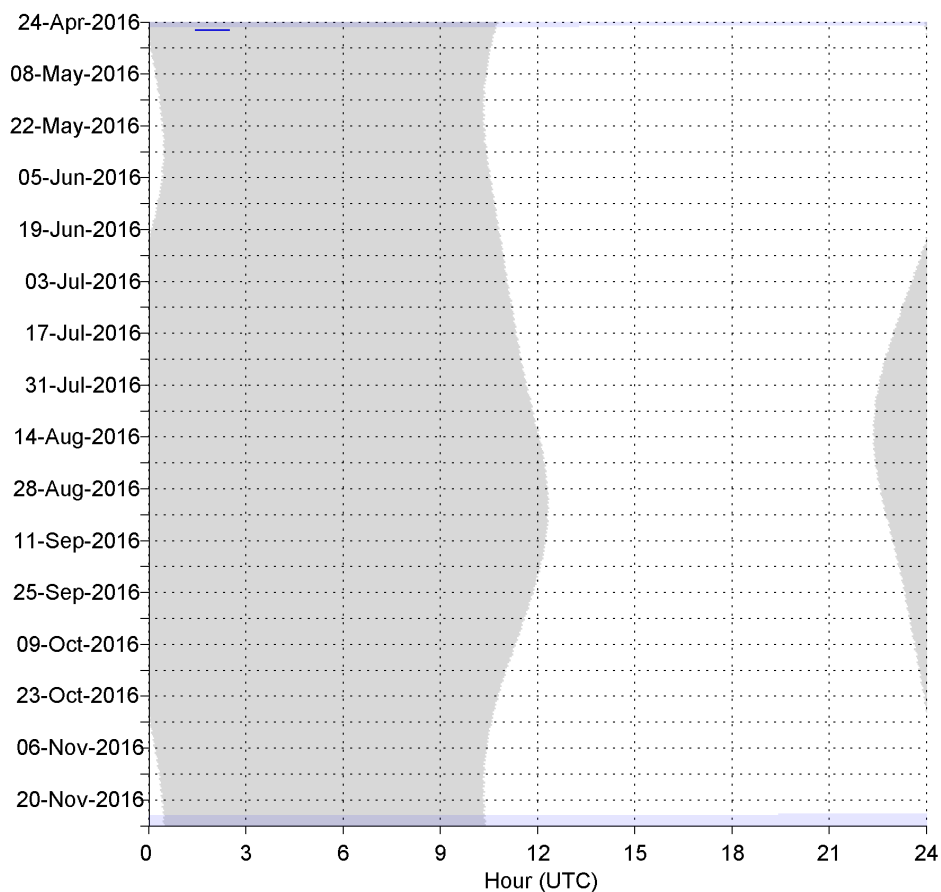


Figure 72. Other LFA sonar in one-hour bins at JAX Site D. Gray vertical shading denotes nighttime.

MFA Sonar

- MFA sonar less than 5 kHz was detected intermittently, primarily between May 2016 and March 2017 (Figure 73).
- There was no discernible diel pattern for MFA sonar less than 5 kHz during the recording period (Figure 74).
- About 20% of analyst-defined MFA events contained packets which exceeded the minimum thresholds required for further analysis (Table 3).
- Highest number of packets (>600) and Cumulative Sound Exposure Levels (CSEL) (> 160 dB re 1 μ Pa s) MFA events were detected in March 2017. The maximum peak-to-peak RL was 164 dB (Figure 75).

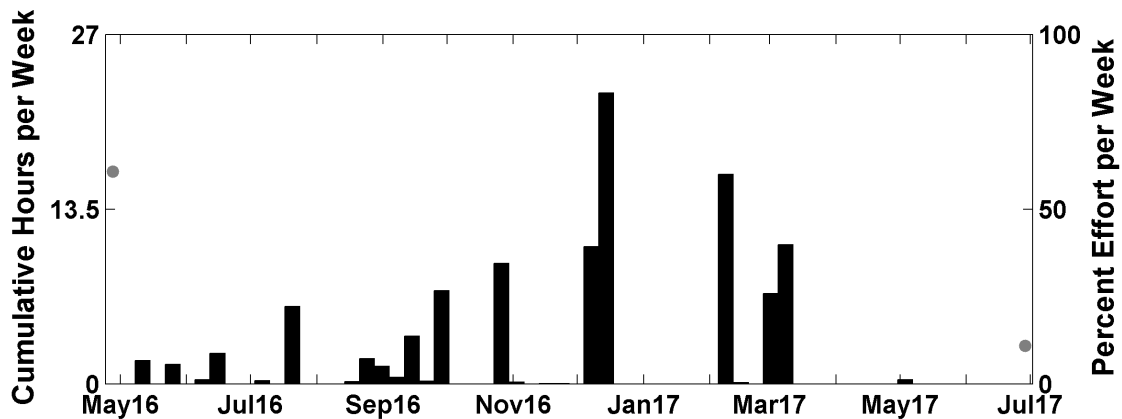


Figure 73. Weekly presence of MFA sonar less than 5 kHz at JAX Site D. Effort markings described in Figure 38.

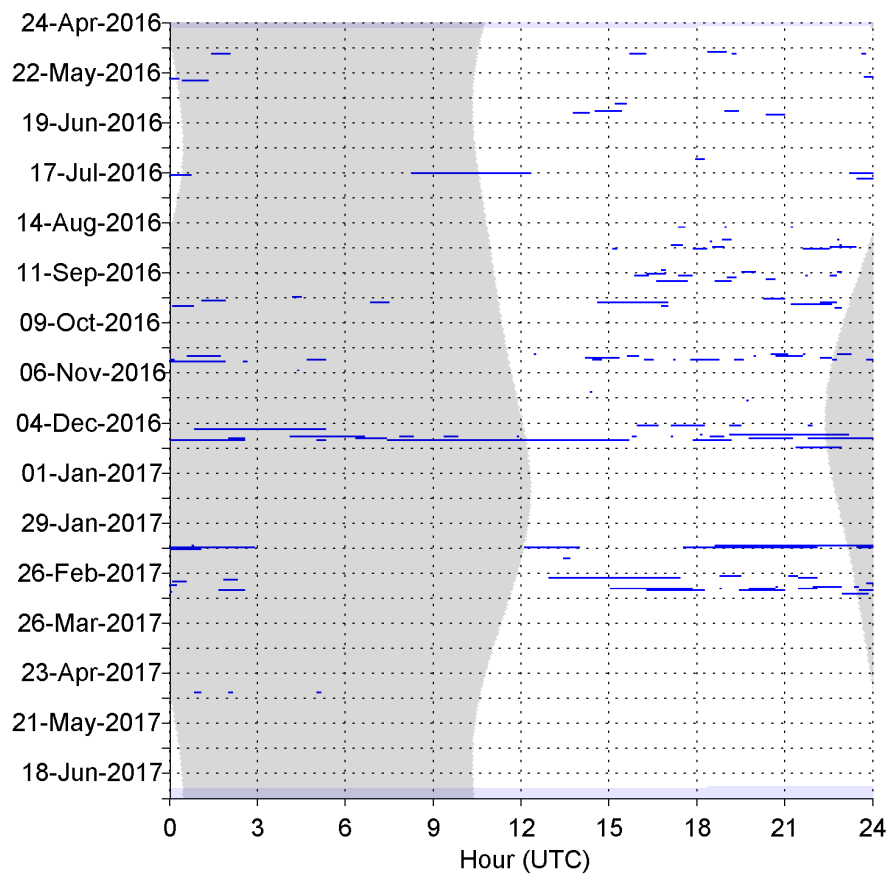


Figure 74. MFA sonar less than 5 kHz in five minute bins at JAX Site D. Gray vertical shading denotes nighttime.

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

Deployment	Analyst Defined Events	Wave Trains (Filtered)	Detected Packets (Filtered)
JAX_D_13	125	27	1212

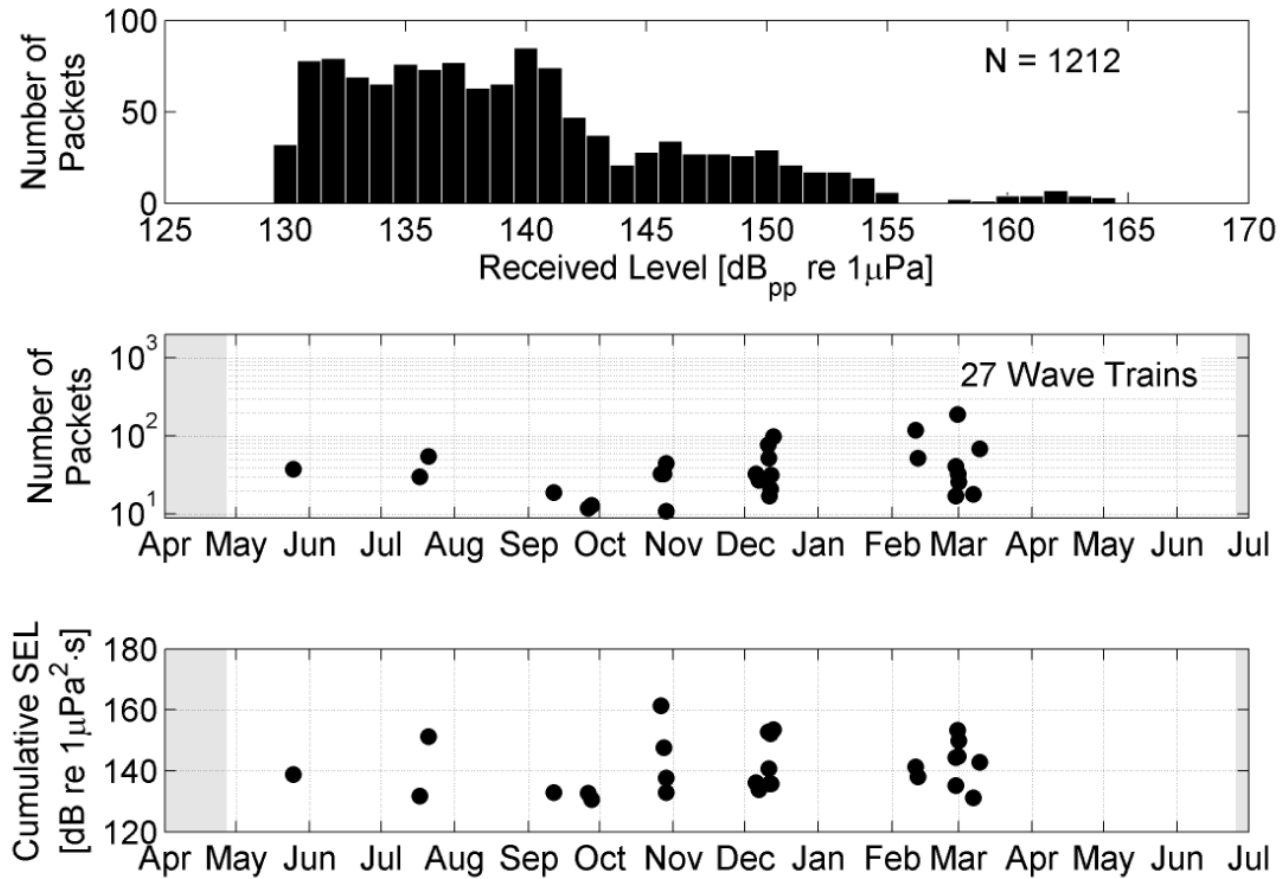


Figure 75. *Top:* Distribution of received levels (RL) of detected MFA packets. *Center:* Number of MFA packets detected in each wave train exceeding the minimum RL threshold (130 dB_{pp} re 1μ Pa). *Bottom:* Cumulative Sound Exposure Levels (CSEL) associated with each wave train.

HFA Sonar

- HFA sonar was detected only in June 2016 (Figure 76).
- There was no apparent diel pattern for HFA sonar during the recording period (Figure 77) .

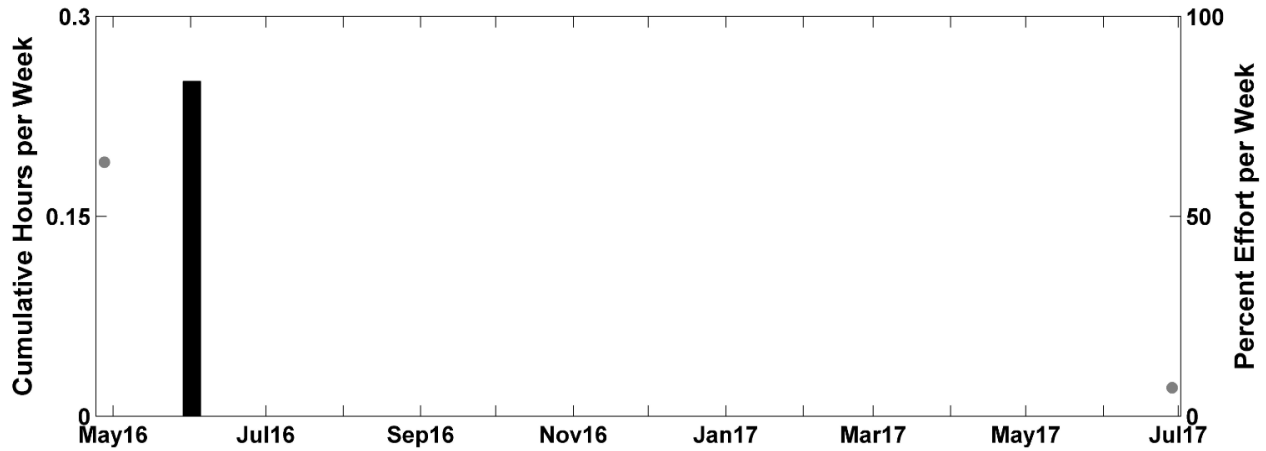


Figure 76. Weekly presence of HFA sonar greater than 5 kHz at JAX Site D. Effort markings described in Figure 38.

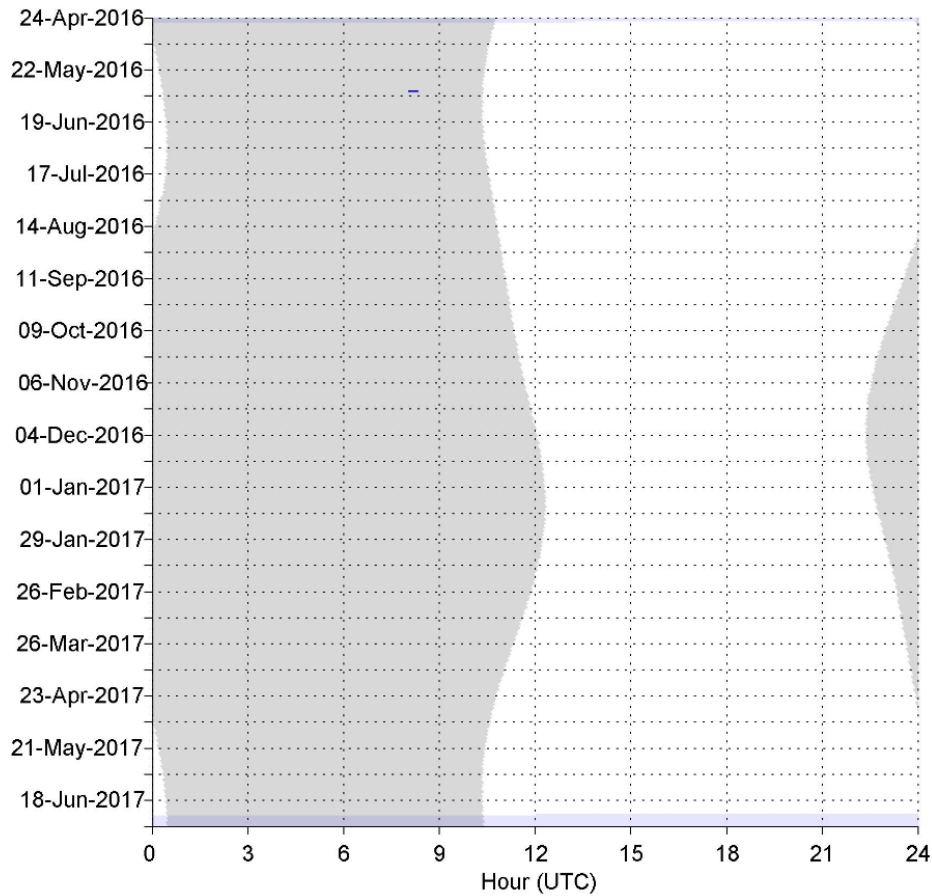


Figure 77. HFA sonar greater than 5 kHz in one-hour bins at JAX Site D. Gray vertical shading denotes nighttime.

Echosounders

- Echosounders greater than 5 kHz were detected intermittently throughout the monitoring period (Figure 78).
- There was no apparent diel pattern for echosounder detections (Figure 79).

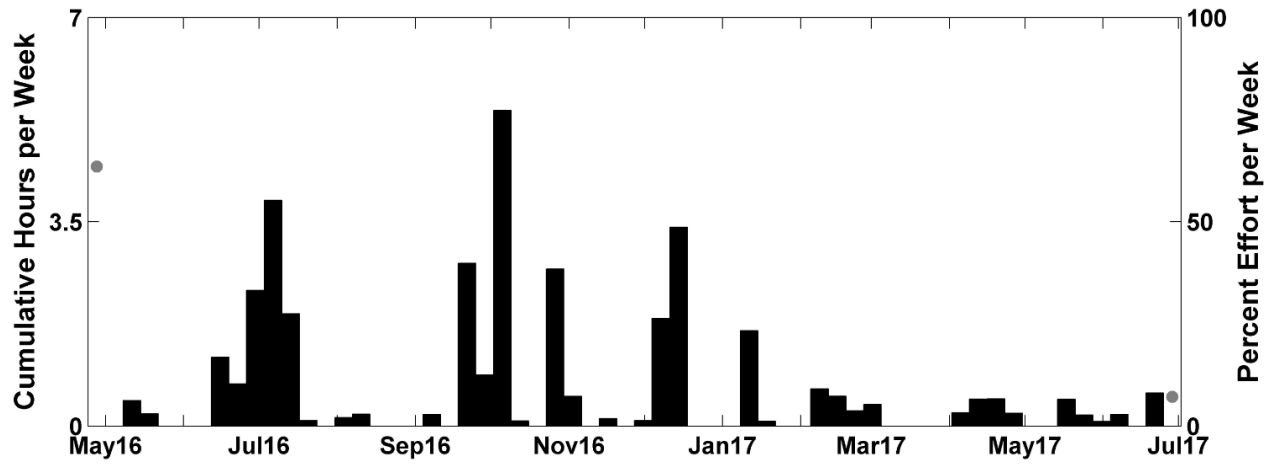


Figure 78. Weekly presence of echosounders greater than 5 kHz at JAX Site D. Effort markings described in Figure 38.

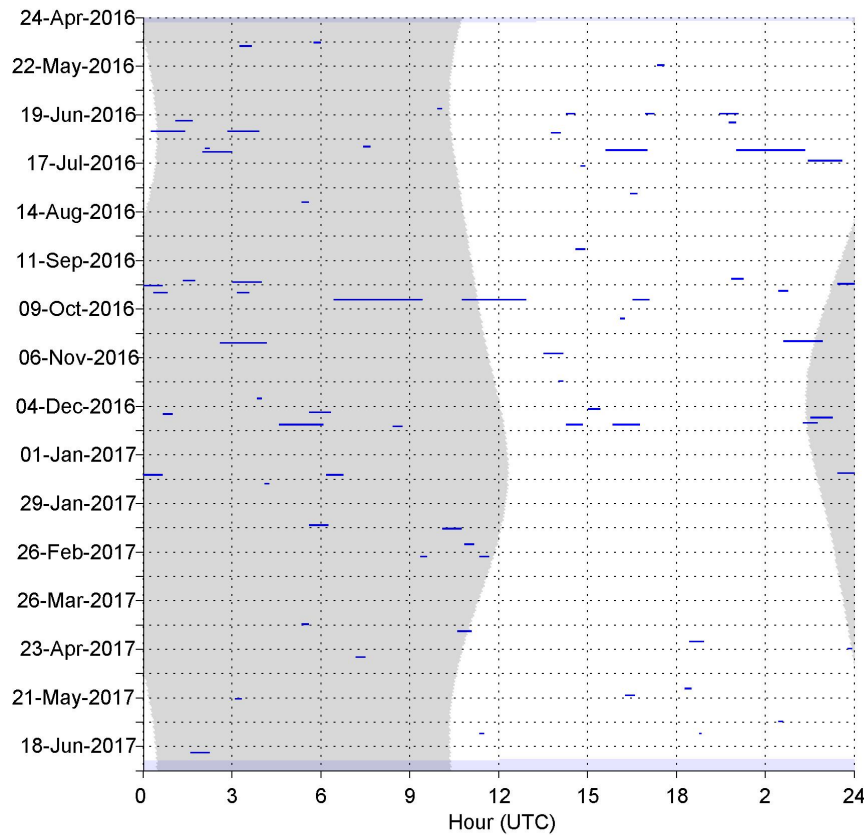


Figure 79. Echosounders greater than 5 kHz in one-minute bins at JAX Site D. Gray vertical shading denotes nighttime.

Explosions

- Explosions were detected from May 2016 to August 2016 and during October 2016 (Figure 80).
- There was no discernable diel pattern for explosions during the recording period (Figure 81).

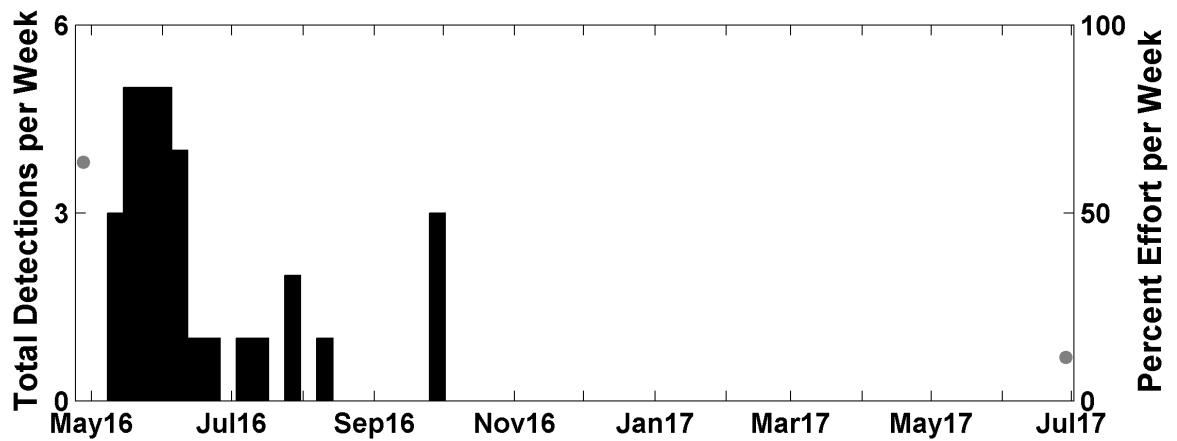


Figure 80. Weekly presence of explosions detected at JAX Site D. Effort markings described in Figure 38.

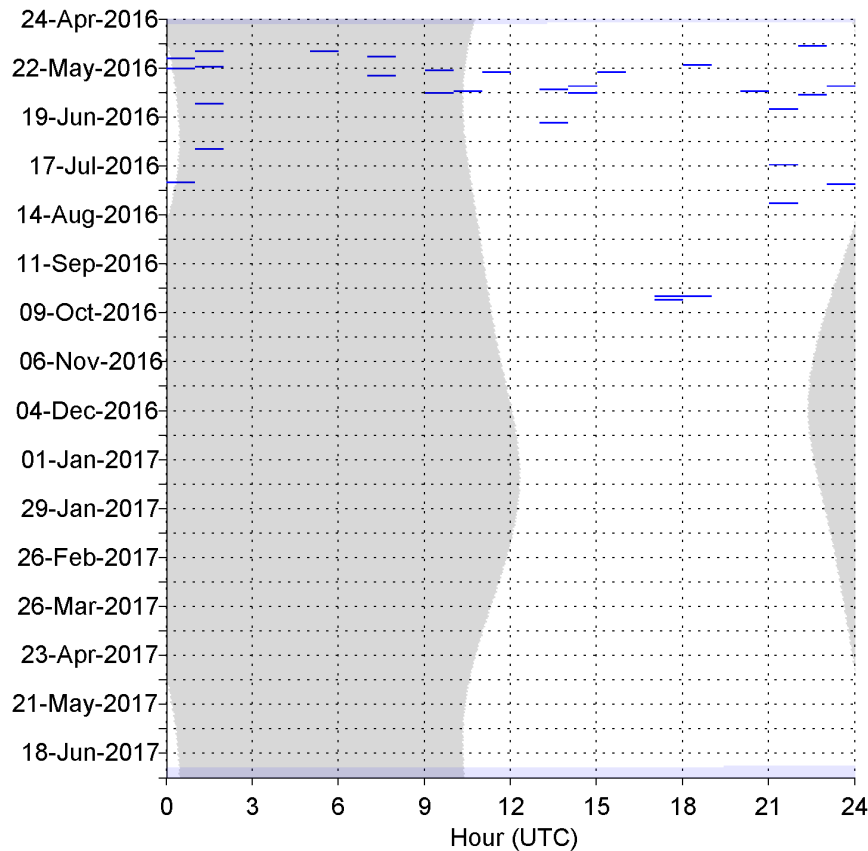


Figure 81. Explosions in five-minute bins at JAX Site D. Gray vertical shading denotes nighttime.

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