Passive Acoustic Monitoring for Marine Mammals in the Jacksonville Range Complex August 2014 – May 2015

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Spinner Dolphin, photo by Amanda J. Debich

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Additional technical reports for HARP deployments in the Atlantic under the Navy's monitoring program are available at:
http://www.navymarinespeciesmonitoring.us/reading-room/

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Executive Summary

A High-frequency Acoustic Recording Package (HARP) was deployed from August 2014 to July 2015, with recordings made between August 2014 and May 2015, 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 10-300 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, minke whales and sei whales. Fin whales were detected January - March 2015. Minke whale pulse trains were detected October 2014 - April 2015. Sei whales were detected November 2014 - January 2015.

Several known odontocete signals were detected, along with odontocete signals that cannot yet be distinguished by species. Sperm whales were detected intermittently throughout the monitoring period. *Kogia* spp. echolocation clicks were also found throughout the recording period, with highest numbers of detections occurring October 2014 - April 2015. One acoustically identifiable delphinid species was Risso's dolphins, whose echolocation clicks were identified in low numbers between August 2014 and April 2015. Detections increased in late April through May 2015. Odontocete signals that could not be distinguished to species were common throughout the recordings. However, three distinct click types (CT) of unknown species origin were identified and designated as CT J1, J2 and J3. Beaked whale click analysis was performed by Joy Stanistreet (Duke University) and is not included in this report.

The following anthropogenic sounds were detected: broadband ship noise, Mid-Frequency Active (MFA) and High-Frequency Active (HFA) sonar, echosounders, and explosions. Broadband ships were common throughout the recordings. MFA sonar was detected intermittently with peaks in September and October 2014, as well as February and March 2015. HFA was detected on a single day in April 2015. Echosounders were detected intermittently in low numbers. Explosions were detected on a single day in January 2015.

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 sea floor 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 water 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 at a site (designated site D), within the Jacksonville Range Complex and collected data from August 2014 through May 2015 (Figure 1).

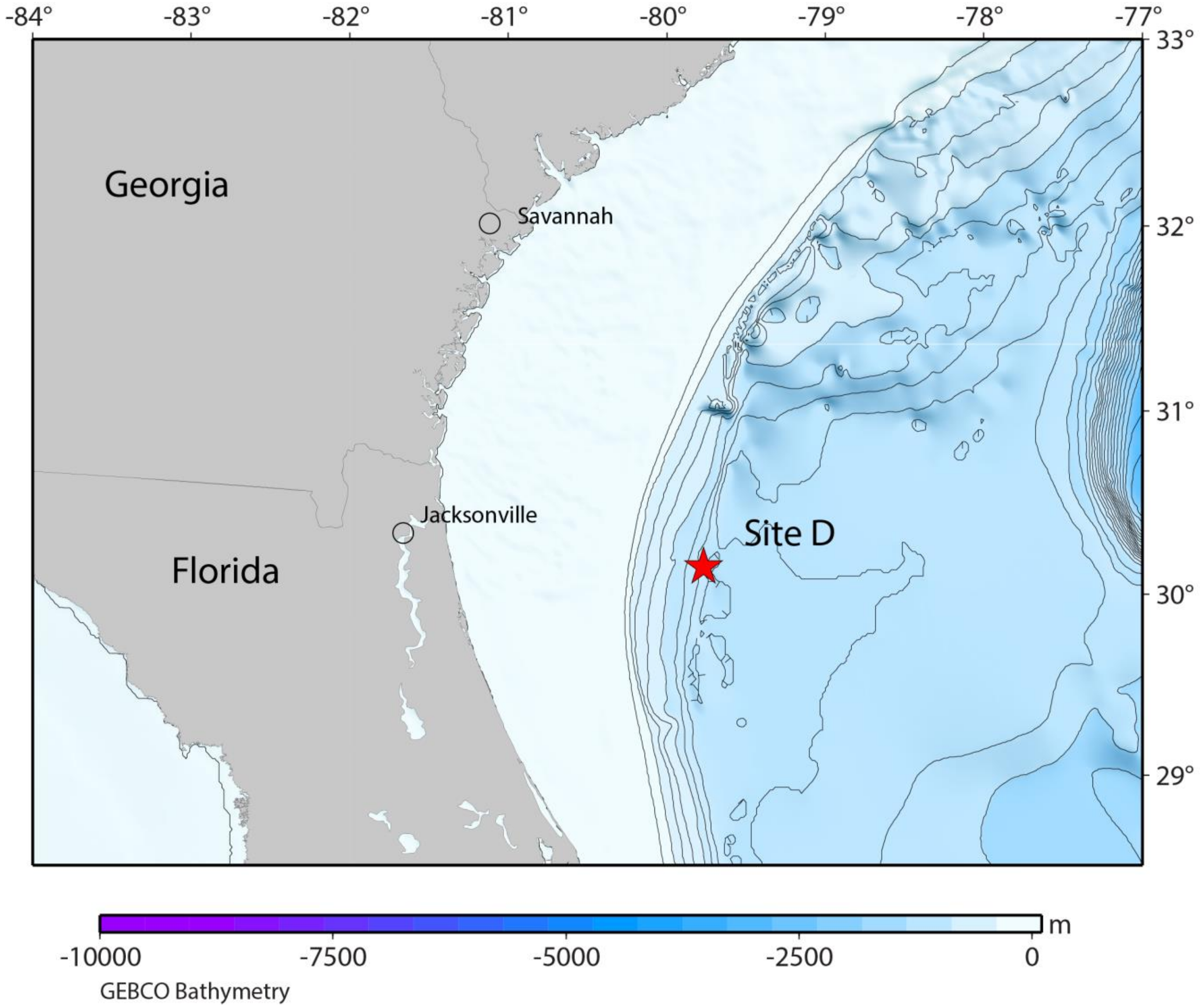

Figure 1. Location of High-frequency Acoustic Recording Package (HARP) at site D (30° 09.036 N, 79° 46.203 W, depth 800 m) deployed in the Jacksonville Range Complex study area August 2014 through July 2015.

Methods

High-frequency Acoustic Recording Package (HARP)

HARPs record underwater sounds from 10 Hz to 100 kHz and are capable of approximately 300 days of continuous data storage. The HARP was in a seafloor package 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 August 2014 to July 2015 at site D (30° 09.036 N, 79° 46.203 W, depth 800 m) and sampled continuously at 200 kHz to provide 100 kHz of effective bandwidth. The instrument recorded 279 days from August 23, 2015 to May 22, 2015, for a total of 6,697 hours of data analyzed. Earlier data collection in the Jacksonville Range Complex is documented in previous annual reports (Debich *et al*., 2013; Johnson *et al*., 2014).

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 sound in the JAX region, and the procedures used to detect them. For effective analysis, the data were divided into three frequency bands: (1) Low-frequency, between 10-300 Hz, (2) Mid-frequency, between 10-5,000 Hz, and (3) High-frequency, between 1-100 kHz.

Each band was analyzed for the sounds of an appropriate subset of species or sources. Blue, fin, Bryde's, sei, minke, North Atlantic right whale and 5-pulse sounds were classified as low-frequency. Humpback, killer whale tonal and pulsed calls, nearby shipping, explosions, underwater communications, 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. The LTSAs were created using a 5 s time average with 1 Hz resolution for low-frequency analysis, 10 Hz resolution for mid-frequency analysis, and 100 Hz frequency resolution for high-frequency analysis.

We summarize acoustic data collected between August 2014 and May 2015 at site D. 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 calls, blue whale arch sounds, fin whale 20 and 40 Hz calls, Bryde's whale Be7 and Be9 calls, minke whale pulse trains, North Atlantic right whale up-calls and 5-pulse sounds was determined by manual scrutiny of low-frequency LTSAs and spectrograms.

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–B call and the arch call (Mellinger and Clark, 2003).

Blue Whale North Atlantic Calls

The A-B call is a 18-19 Hz tone lasting approximately 8 s (A), often followed by an 18-15 Hz downsweep (B) lasting approximately 11 s (Figure 2). There were no detections of blue whale North Atlantic A-B calls during the recording period.

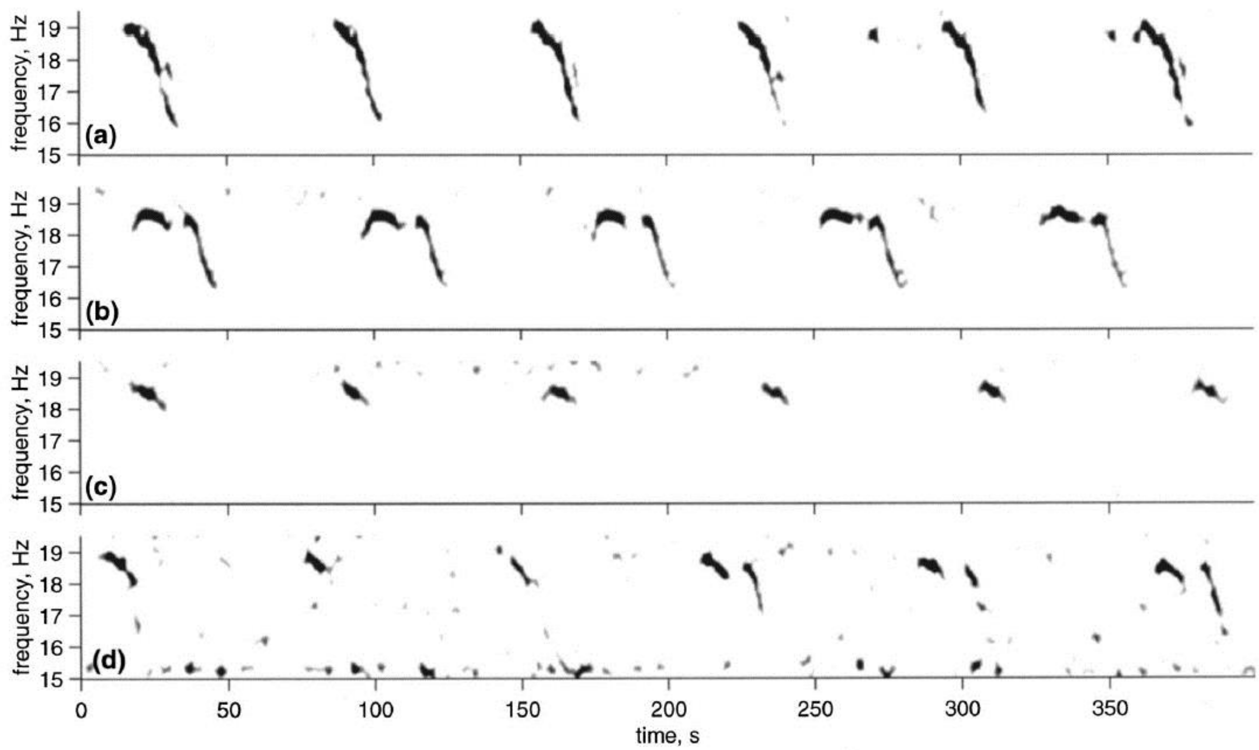

Figure 2. North Atlantic blue whale calls from Mellinger and Clark (2003).

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 s (Figure 3). There were no detections of blue whale arch calls during this deployment period.

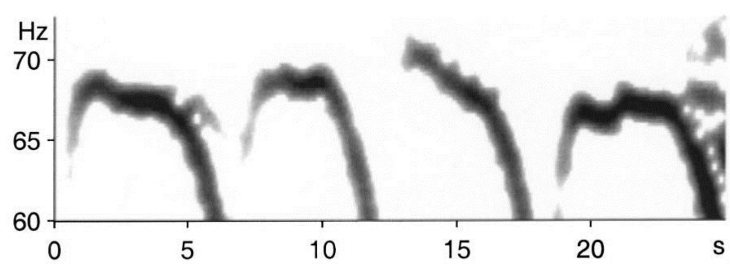

Figure 3. Blue whale arch calls from Mellinger and Clark (2003).

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, 1981) (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 via manual scanning of the LTSA and subsequent verification from a spectrogram of the frequency and temporal characteristics of the calls. An automated detection algorithm was used for previous datasets (Hatteras 02A, 03A, 04A and Norfolk Canyon 01A) to calculate an acoustic index for fin whale 20 Hz calls. The automated detector was not used in this JAX dataset due to the presence of high amounts of low frequency noise in the LTSA observed in the, which may have masked calls and made them difficult to detect automatically.

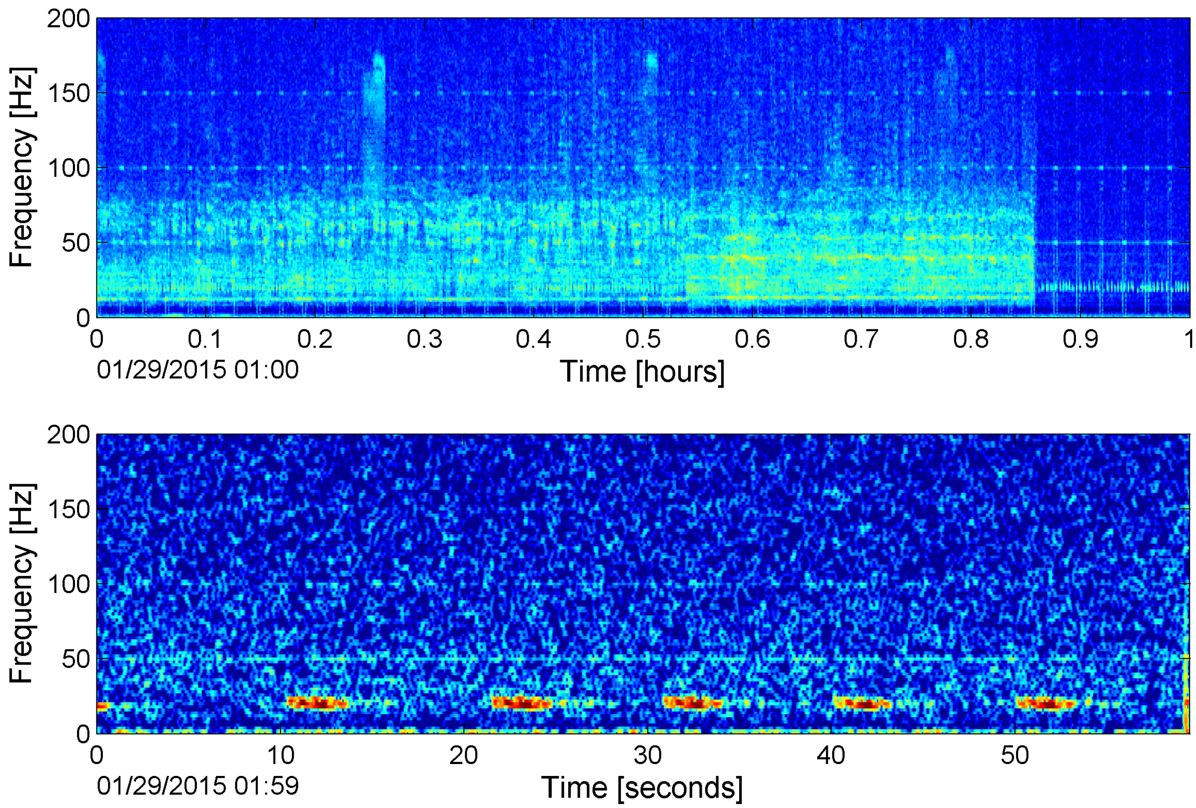

Figure 4. Fin whale 20 Hz calls in LTSA (top) and spectrogram (bottom) at JAX site D.

Fin whale 40 Hz calls

The potential 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 detections of fin whale 40 Hz calls during this recording period.

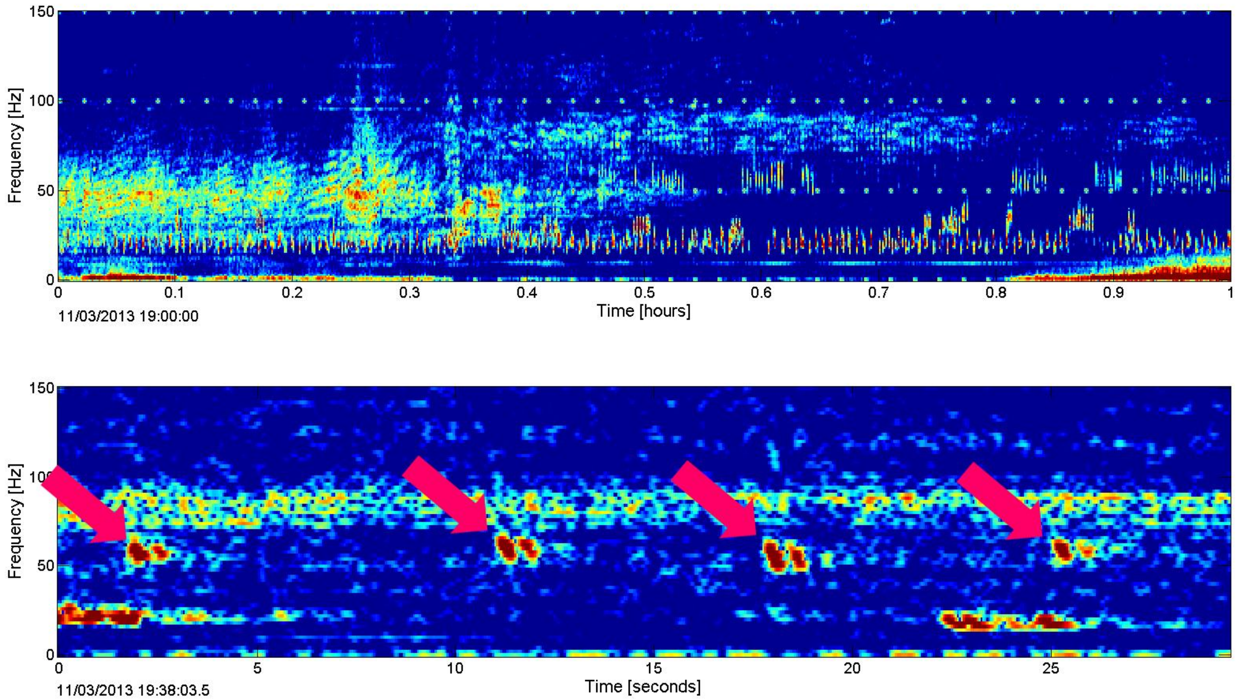

Figure 5. Fin whale 40 Hz calls in LTSA (top) and spectrogram (bottom) from southern California HARP data.

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.

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 inter-call interval of 2.8 minutes (Figure 6). There were no detections of Bryde's whale Be7 calls during this recording period.

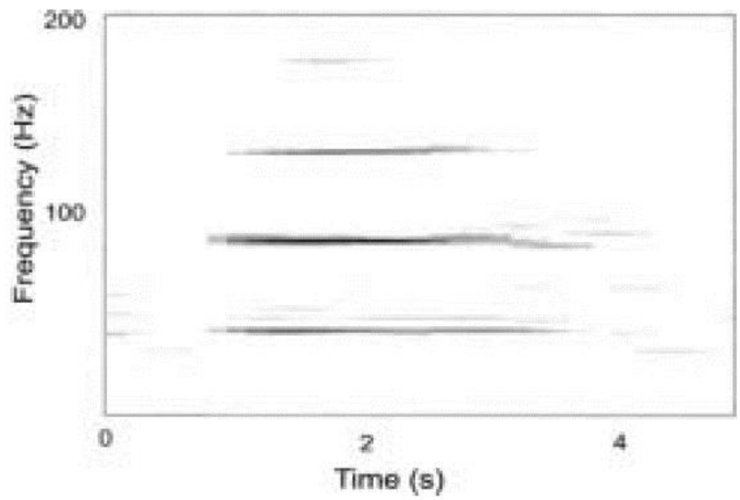

Figure 6. Bryde's whale Be7 call from Oleson *et al*., 2003.

Be9 Calls

The Be9 call type, described for the Gulf of Mexico, 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 the Bryde's whale Be9 call during this recording period.

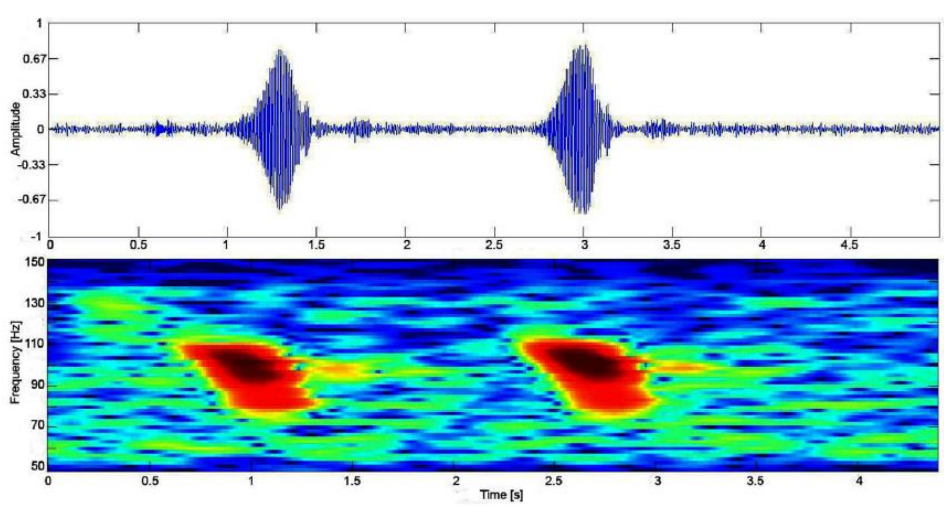

Figure 7. Bryde's whale Be9 call from the Gulf of Mexico (Širović et al., 2014).

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).

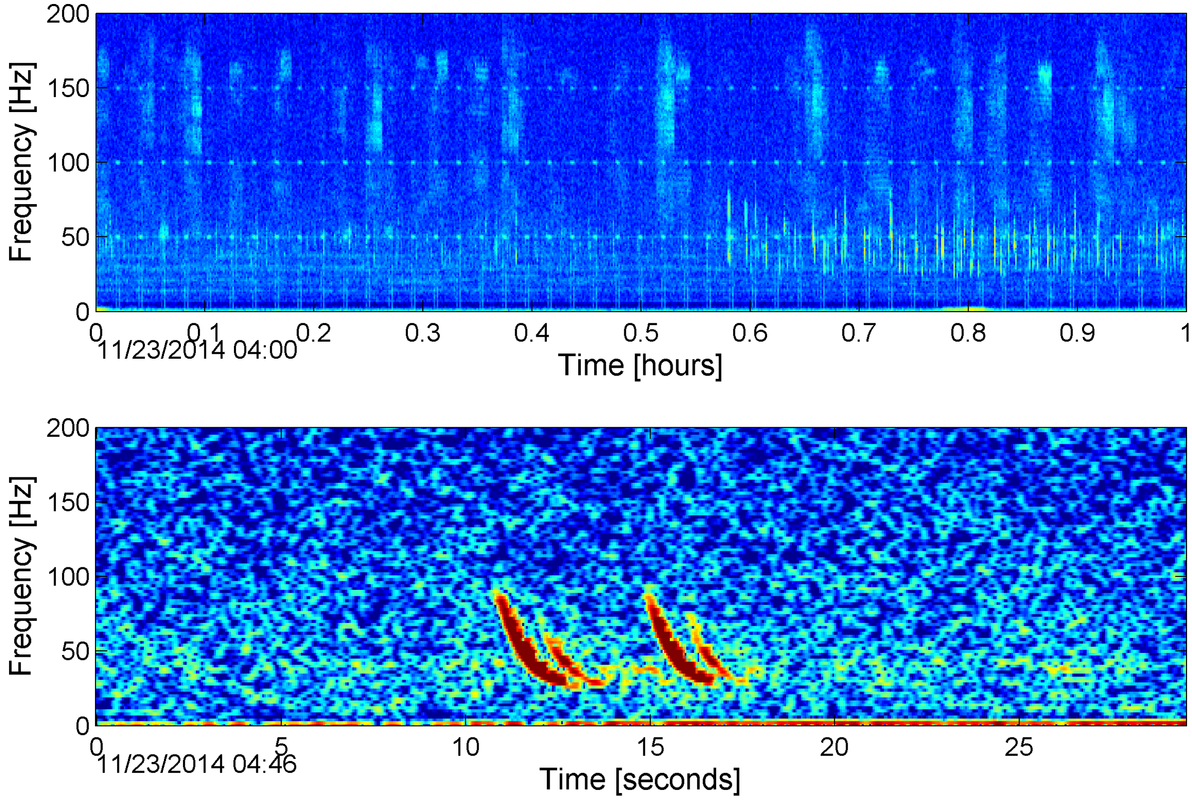

Figure 8. Downsweep calls similar to those reported to be from sei whales in the LTSA (top) and spectrogram (bottom) from JAX site D in November, 2014.

Minke Whales

Minke whales in the North Atlantic produce long pulse trains (Figure 9). Mellinger *et al*. (2000) describe 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).

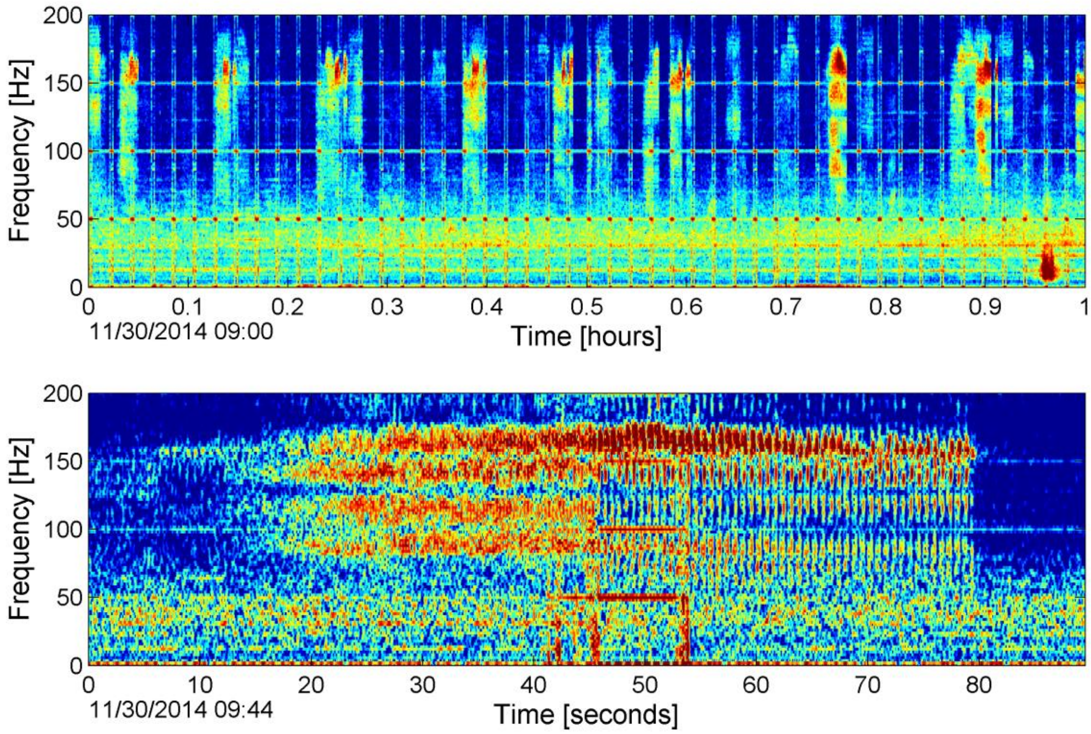

Figure 9. Minke whale pulse train in the LTSA (top) and spectrogram (bottom) recorded in November 2014 at JAX site D.

North 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 North Atlantic right whale up-call detections during this recording period.

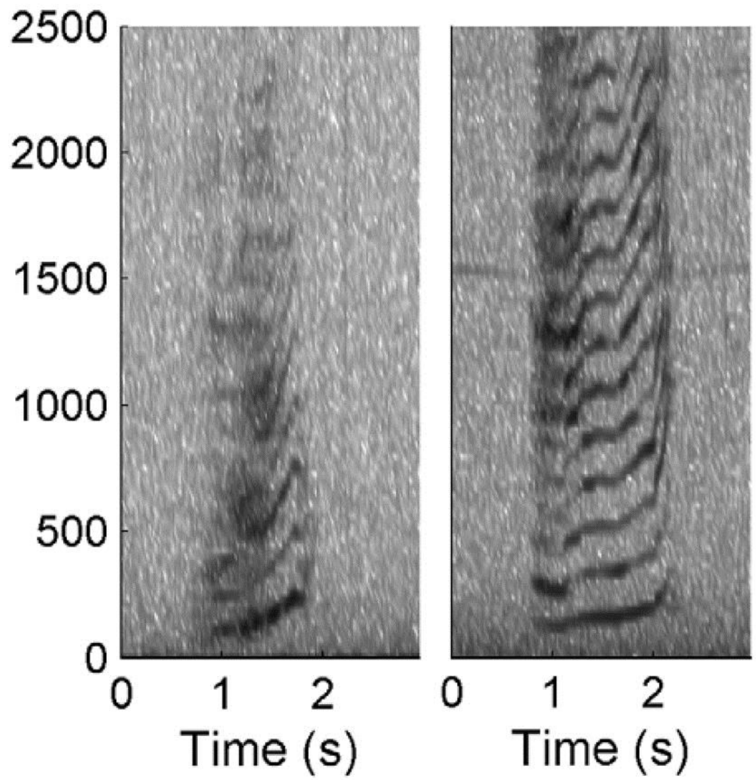

Figure 10. Right whale up-calls from Trygonis *et al*., 2013.

5-pulse signal

The 5-pulse signal consists of multiple (usually five) pulses over approximately two seconds. It has a starting frequency around 150 Hz with a very slight increase in frequency from the first to subsequent pulses. However, 5 pulses can vary in fundamental frequency from 120 – 200 Hz (Figure 11). Because of its character, prevalence, and intensity, this sound is classified as the call of a baleen whale, but of unknown species. No 5-pulse signals were detected in this deployment.

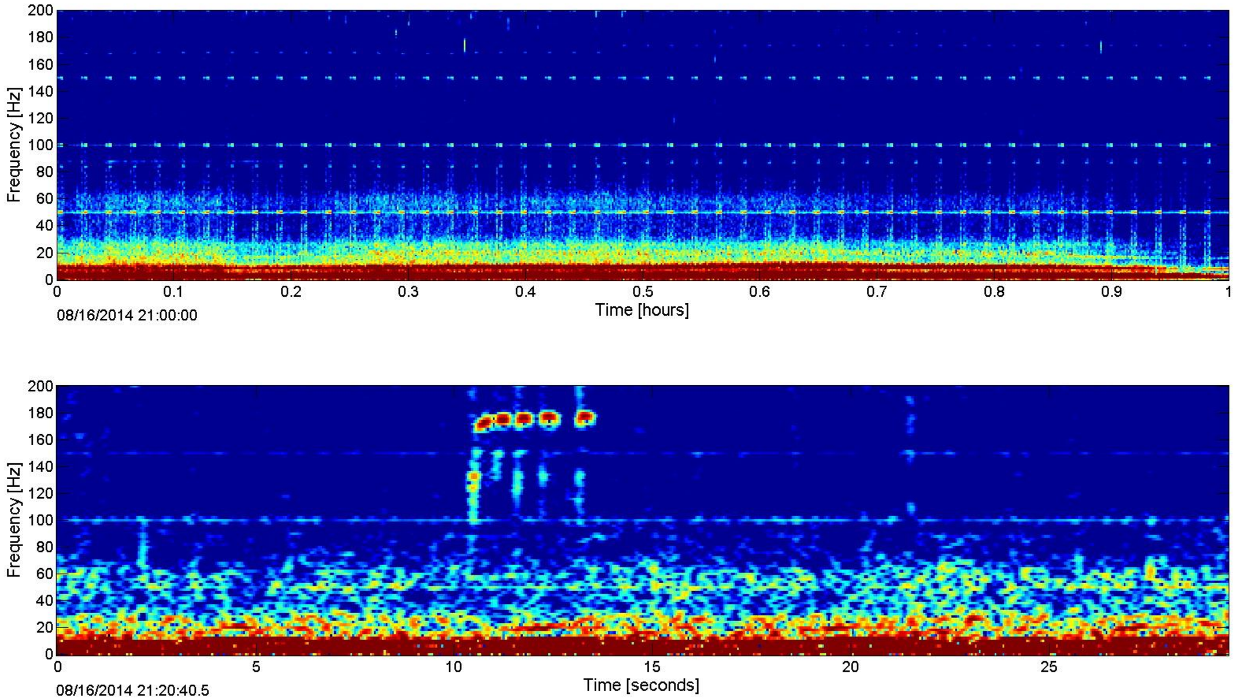

Figure 11. 5-pulse signal in the LTSA (top) and spectrogram (bottom) at JAX site C.

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. Humpback whales were detected automatically as described below. Automatic detections were subsequently verified for accuracy by a trained analyst. 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. We used an automatic humpback whale detector based on the generalized power law (Helble *et al.*, 2012). No humpback whale calls were detected in this deployment.

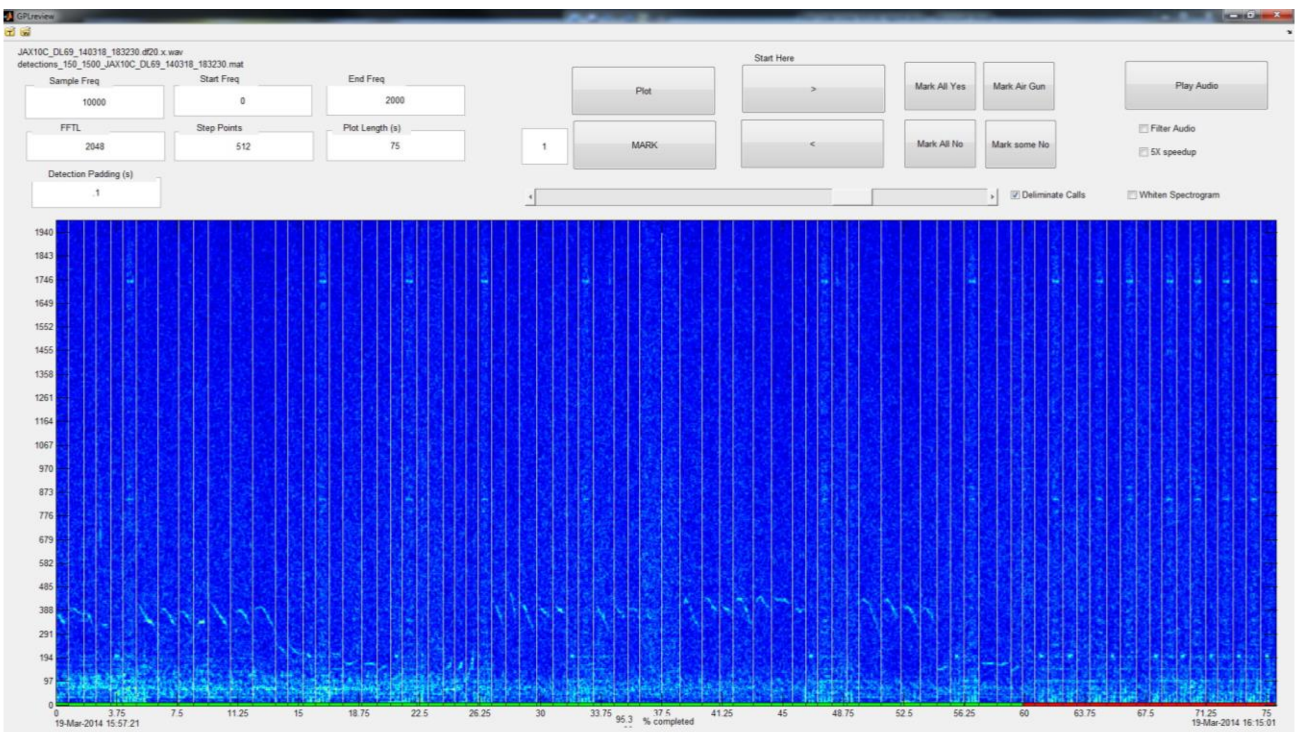

Figure 12. Humpback whale song from JAX site C in the analyst verification stage of the detector. Green in the bottom evaluation line indicates true detections.

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*), 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 13).

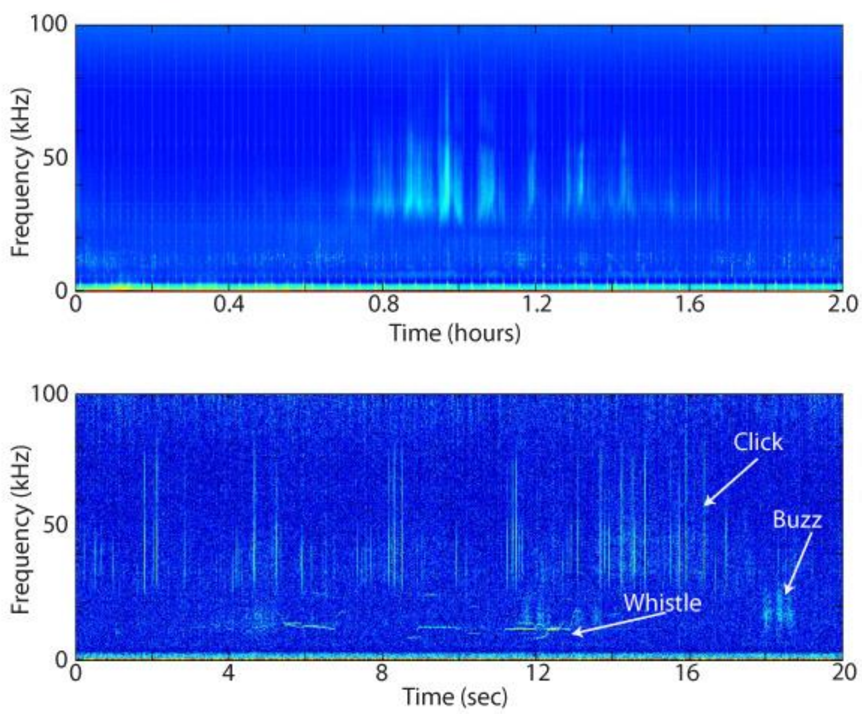

Figure 13. LTSA (top) and spectrogram (bottom) demonstrating odontocete signal types.

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.

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 and whistles 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).

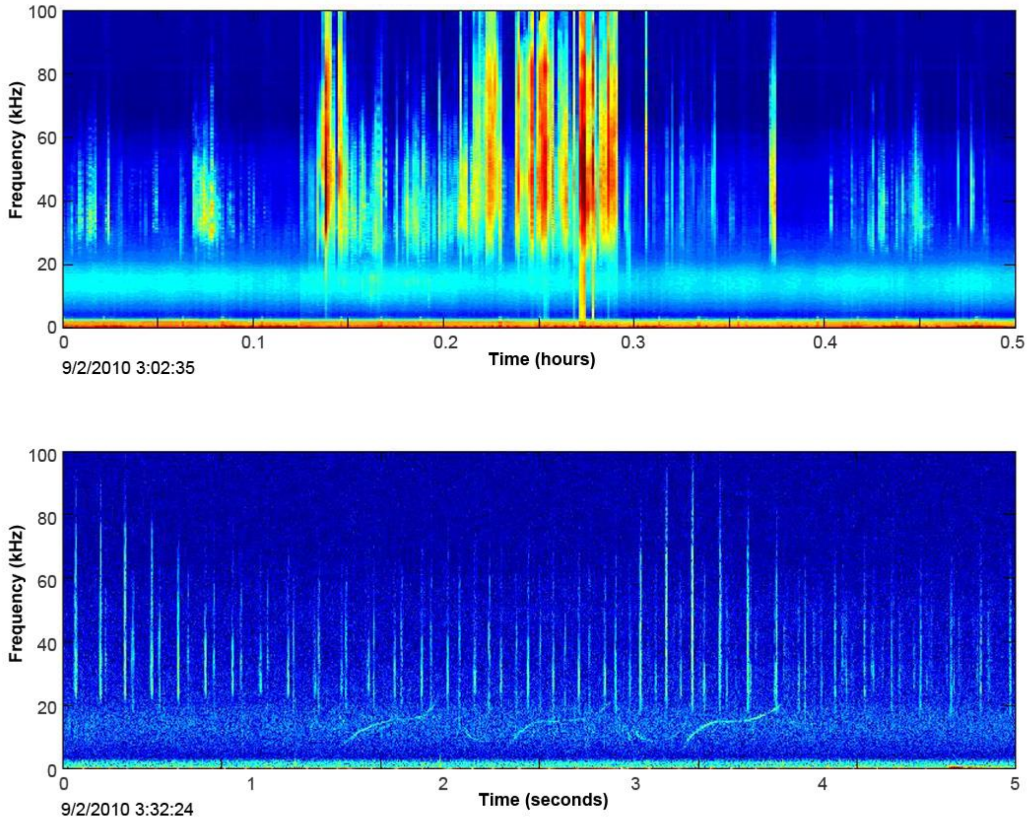

Figure 14. LTSA (top) and spectrogram (bottom) of unidentified odontocete signals from HARP recording within the Jacksonville Range Complex, September, 2010.

Risso's Dolphins

Risso's dolphin echolocation clicks can be identified to species by their distinctive banding patterns observable in the LTSA (Figure 15). Studies show that spectral properties of Risso's dolphin echolocation clicks vary based on geographic region (Soldevilla, personal communication). Risso's dolphin clicks that were detected in this recording period had peaks at 23, 26, and 33 kHz (Figure 16). Modal inter-click interval (ICI) was 170 ms, with broad variability between 100 and 200 ms across all encounters. 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).

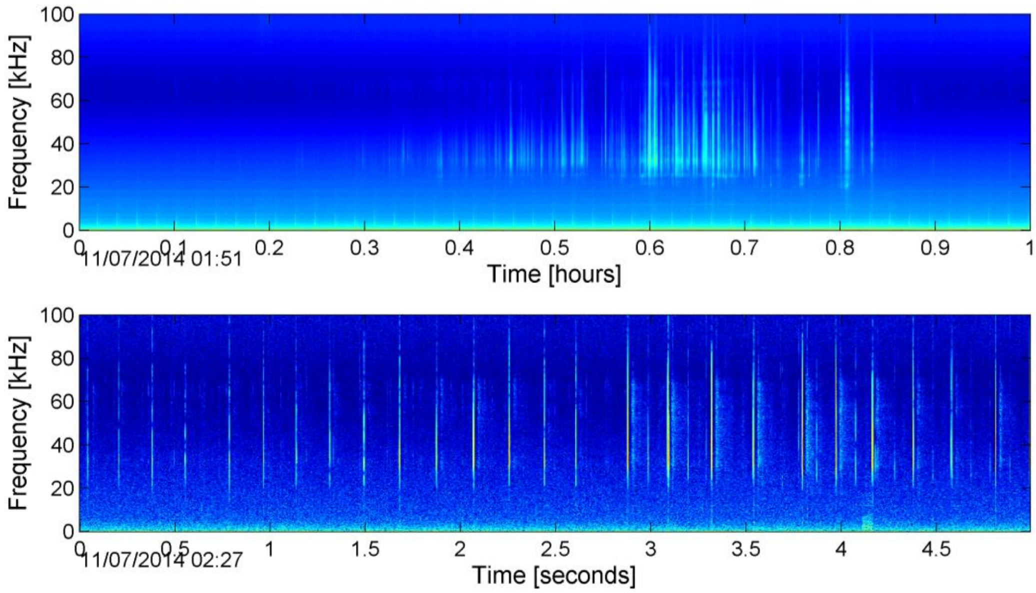

Figure 15. Risso's dolphin acoustic encounter in LTSA (top) and spectrogram (bottom) from HARP recording within the Jacksonville Range Complex, October 2010.

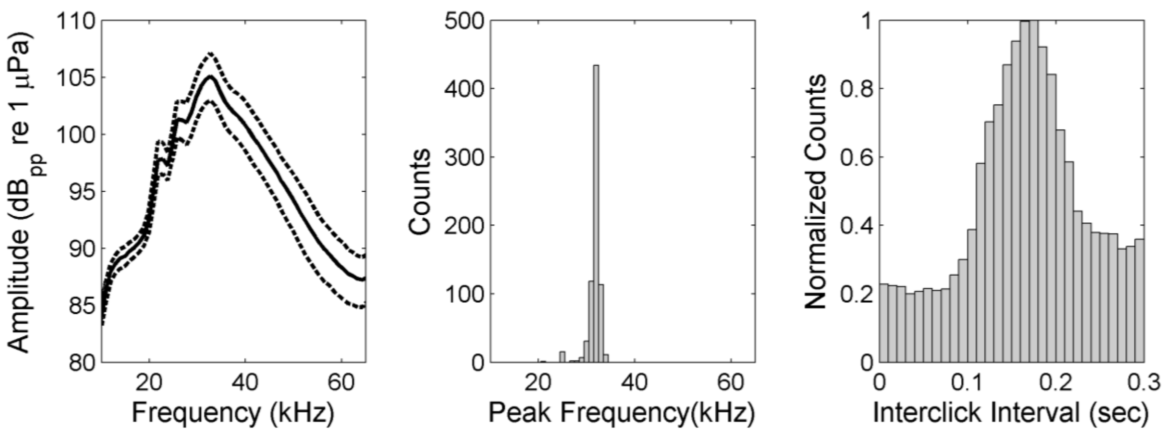

Figure 16. Risso's dolphin click type detected at site D from August 2014 to May 2015. *Left*: Mean (solid line) click spectrum with 25th and 75th percentiles (dashed lines) across click bouts. *Center*: Histogram of mean click peak frequency. *Right*: Inter-click interval (ICI) distribution across bouts.

Other Echolocation Click Types

An automated clustering procedure was used to identify recurrent delphinid click types (CT) in the dataset. Three click types were identified (Figures 15-20). These click types are not currently identified to type, but have consistent spectral shapes and ICI distributions, making them candidates for future identification.

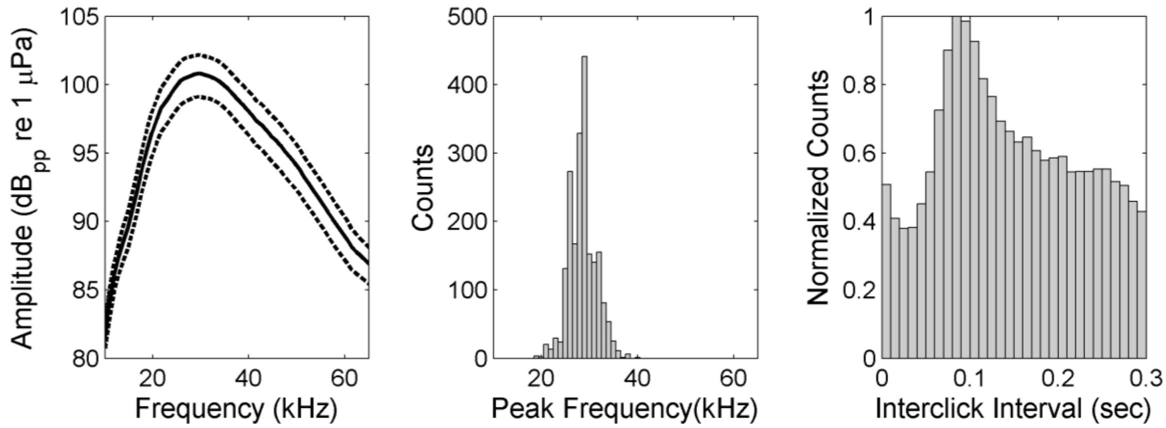

Figure 15. Click type CT J1 detected at JAX site D from August 2014 to May 2015.

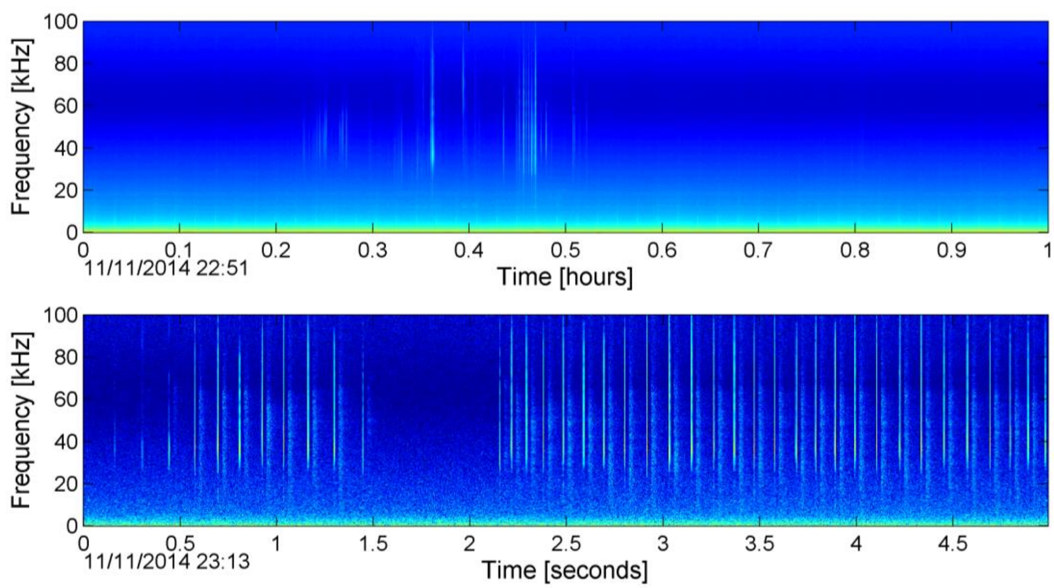

Figure 16. Click type CT J1 acoustic encounter in LTSA (top) and spectrogram (bottom) from JAX site D in November 2014.

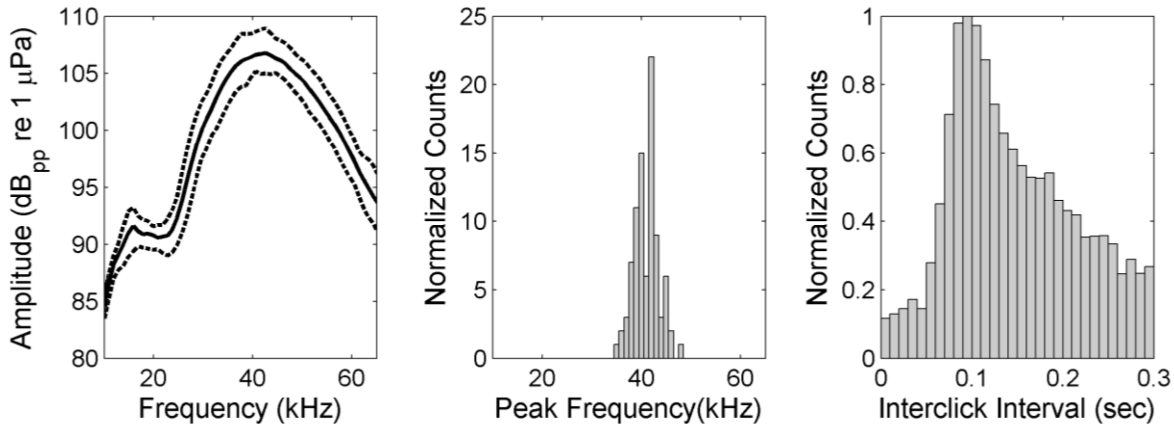

Figure 17. Click type CT J2 detected at JAX site D from August 2014 to May 2015.

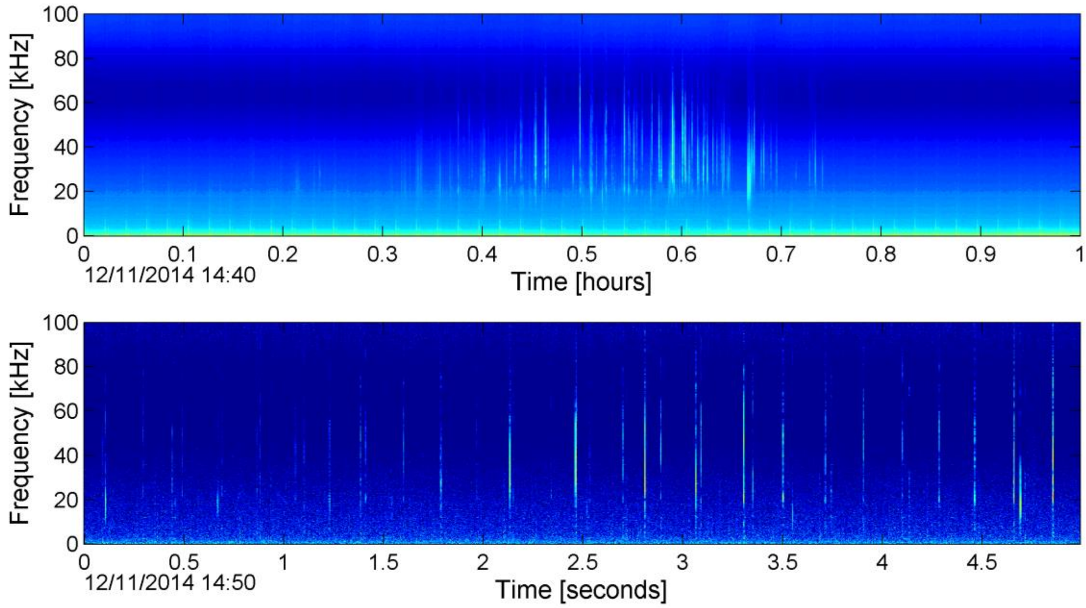

Figure 18. Click type CT J2 acoustic encounter in LTSA (top) and spectrogram (bottom) from JAX site D in December 2014.

- CT J1 had a simple spectral shape with peak frequencies between 26 and 29 kHz, and a modal ICI of 85 ms (Figure 15). An example encounter is shown in Figure 16.
- CT J2 had a low spectral peak at 16 kHz, a dominant peak between 40 and 42 kHz, and a modal ICI of 100 ms (Figure 17). An example encounter is shown in Figure 18. A similar click type has been identified at a site near Desoto Canyon in the Gulf of Mexico (site depth = 260 m) with no seasonal trend (Frasier, 2015). It has not been identified at continental slope sites in the Gulf of Mexico. CTJ2 may be associated with one of the more coastal species such as bottlenose or Atlantic spotted dolphins.
- CT J3 had a lower frequency distribution with a single peak near 22 kHz, and a modal ICI of 170 ms (Figure 19). An example encounter is shown in Figure 20. This click type may be associated with short-finned pilot whales. A similar type has been identified at continental slope sites in the northeastern Gulf of Mexico during spring and summer months (Frasier, 2015).

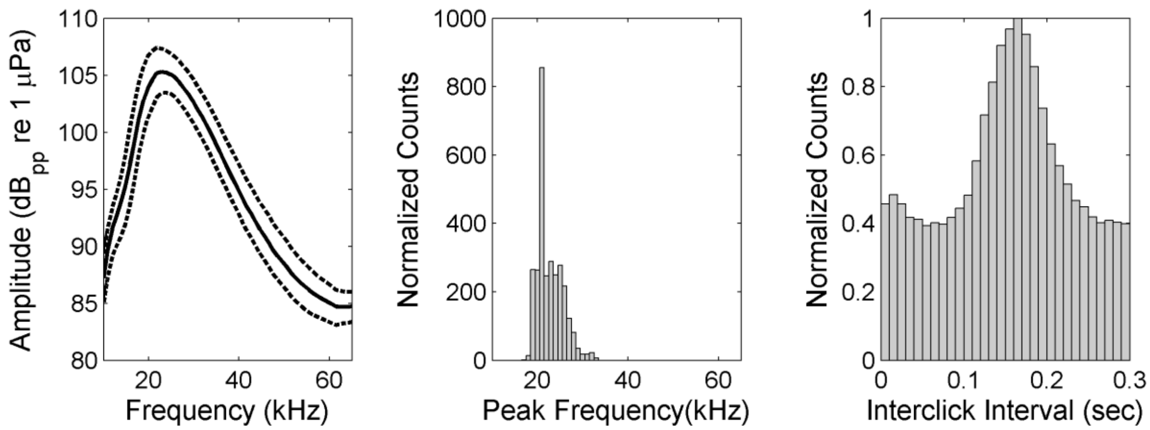

Figure 19. Click type CT J3 detected at JAX site D from August 2014 to May 2015.

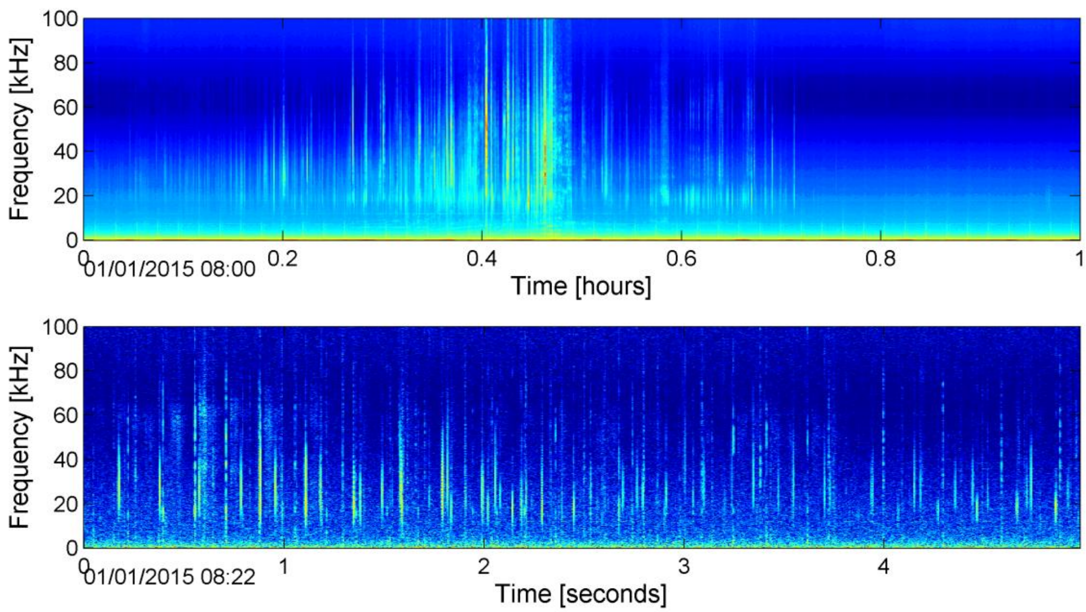

Figure 20. Click type CT J3 acoustic encounter in LTSA (top) and spectrogram (bottom) from JAX site D in January 2015.

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 21). 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 (Watwood *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.

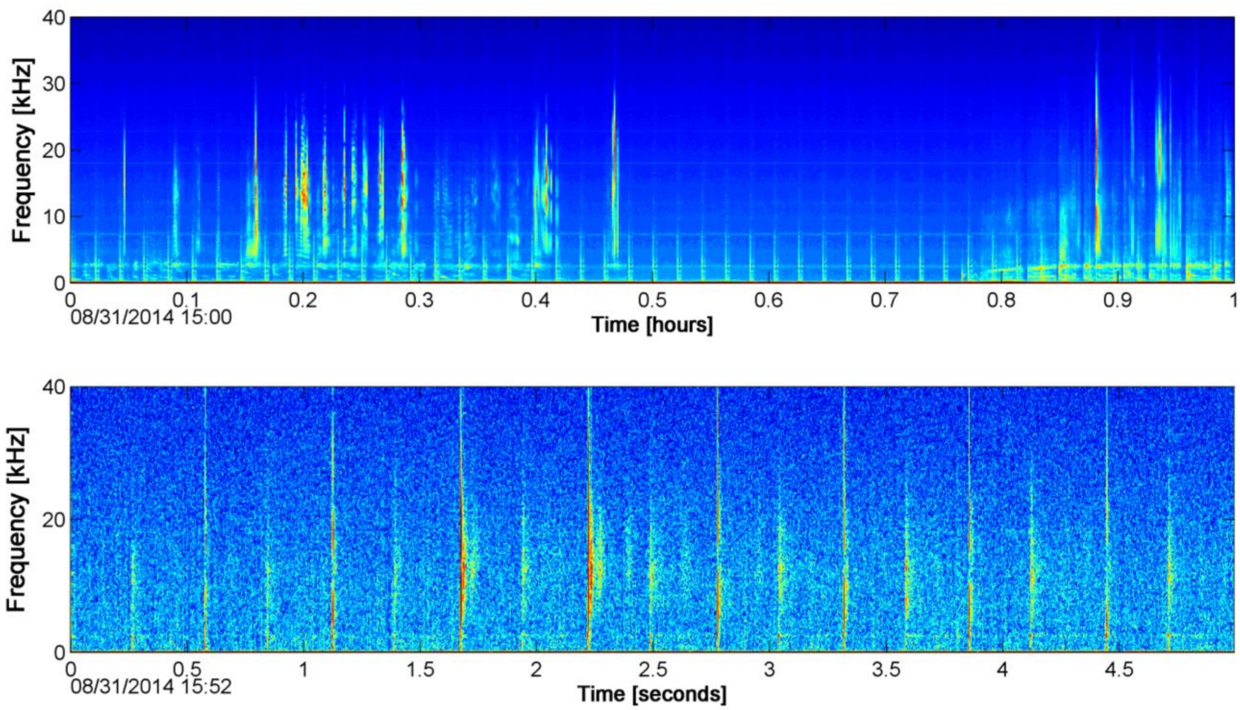

Figure 21. Sperm whale echolocation clicks in LTSA (top) and spectrogram (bottom) at JAX site D in August 2014.

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 22). 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 23). *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.

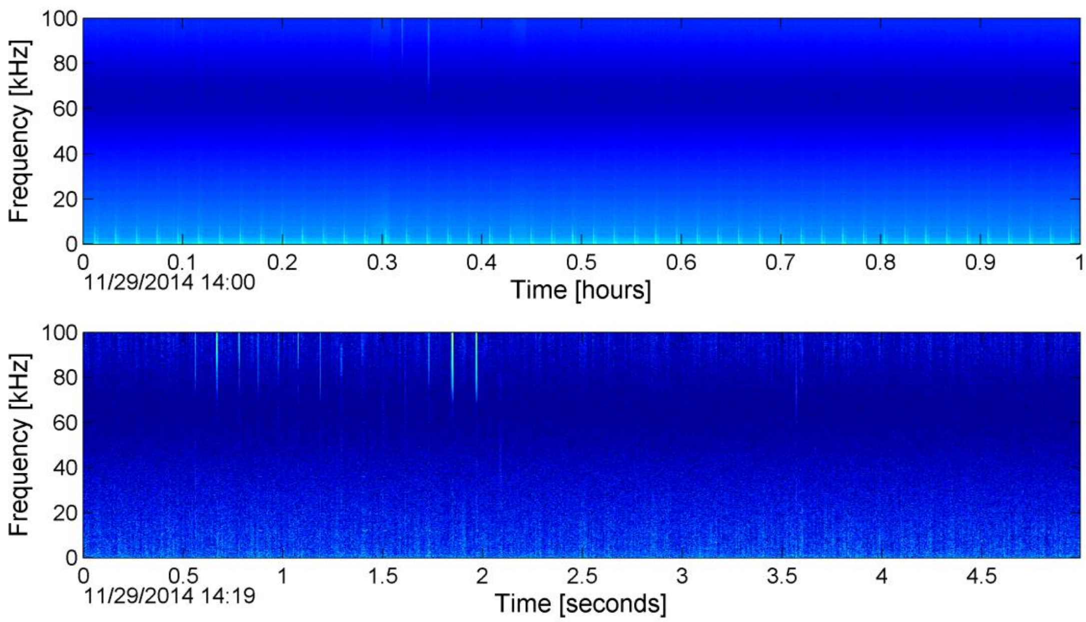

Figure 22. *Kogia* spp. echolocation clicks in the LTSA (top) and spectrogram (bottom) from site D.

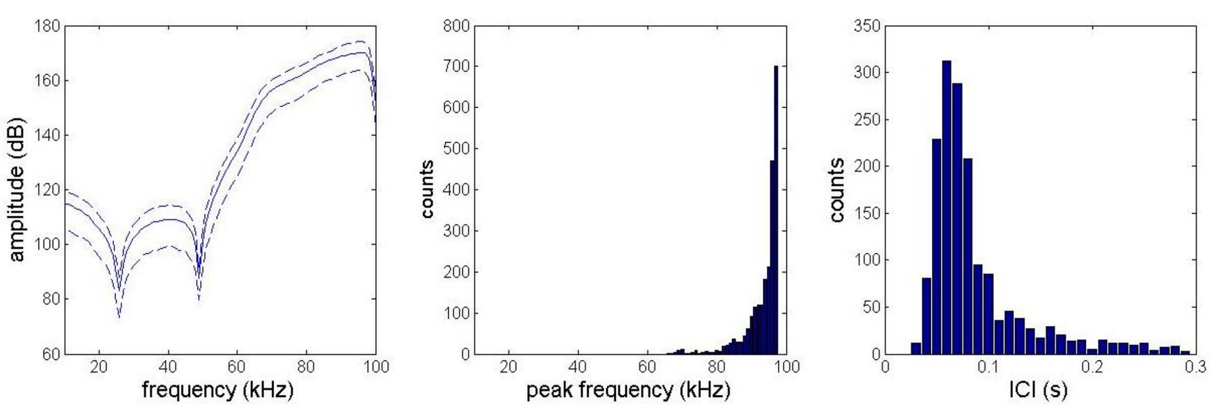

Figure 23. Left: *Kogia* spp. mean spectra computed from a HARP deployed off of Cape Hatteras (solid line) with 25th and 75th percentiles (dashed lines); Center: Distribution of click peak frequencies with peak near the Nyquist frequency (100kHz); Right: Distribution of inter-click-intervals with modal peak at 0.07 seconds.

Anthropogenic Sounds

Several anthropogenic sounds were monitored for this report: broadband ship noise, Low Frequency Active (LFA) sonar, Mid-Frequency Active (MFA) sonar, High Frequency Active (HFA) sonar, echosounders, and explosions. The LTSA search parameters used to detect each sound are given in Table 1. The start and end of each sound or session was logged and their durations were added to estimate cumulative hourly presence.

Table 1. Anthropogenic sound data analysis parameters.

Sound Type	LTSA Search Parameters	
	Plot Length (hr)	Frequency Range (Hz)
Broadband Ship Noise	3.0	10 – 5,000
LFA Sonar >500 Hz	0.75	500 - 1000
MFA Sonar	0.75	1,000 – 10,000
HFA Sonar	1	10,000 – 100,000
Echosounder	1	5,000 – 100,000
Explosions	0.75	10 – 5,000

Broadband Ship Noise

Broadband ship noise occurs when a vessel 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 24). Noise can extend above 10 kHz, though it typically falls off above a few kHz.

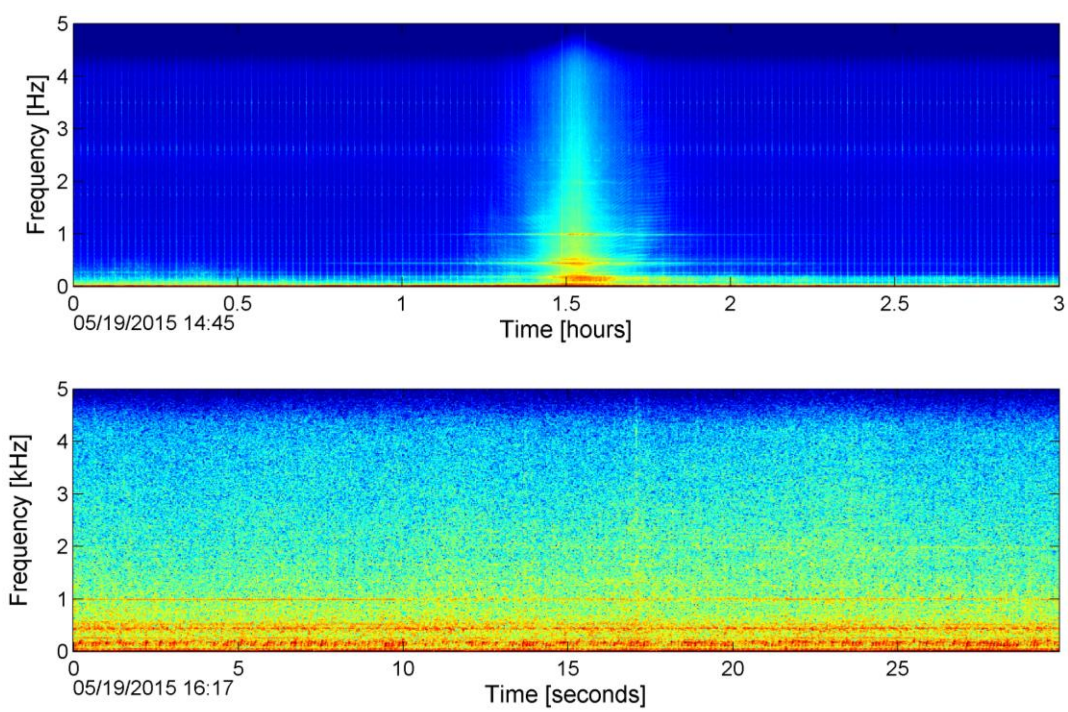

Figure 24. Broadband ship noise in LTSA (top) and spectrogram (bottom) at JAX site D.

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 25).

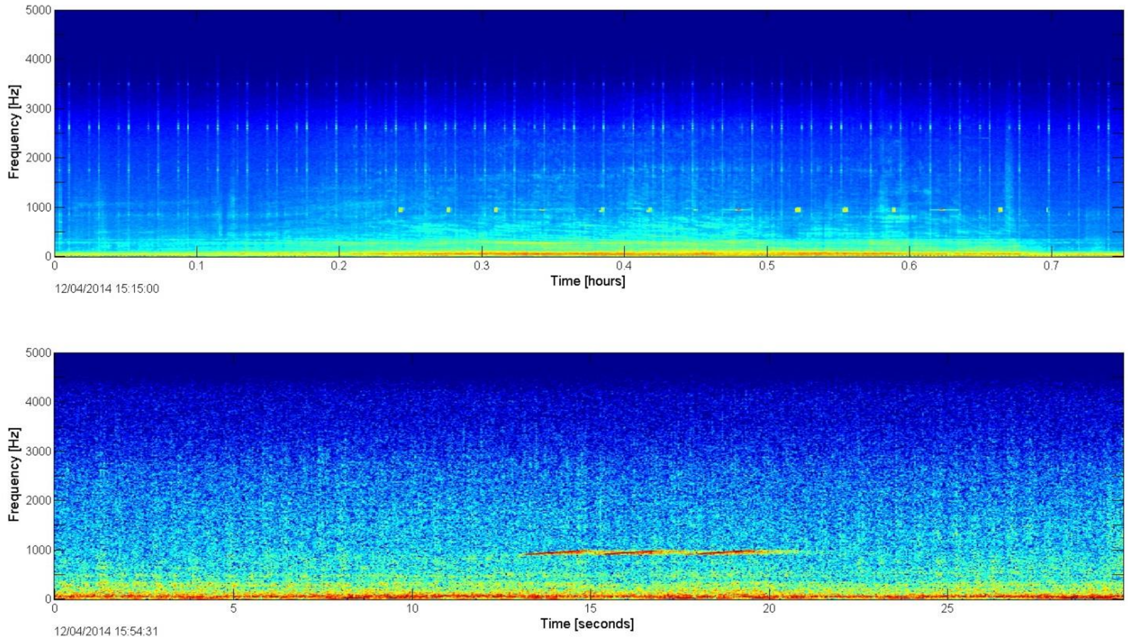

Figure 25. LFA at 950 Hz in the LTSA (top) and spectrogram (bottom) at a North Atlantic HARP site, recorded in December 2014.

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 26). 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 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.

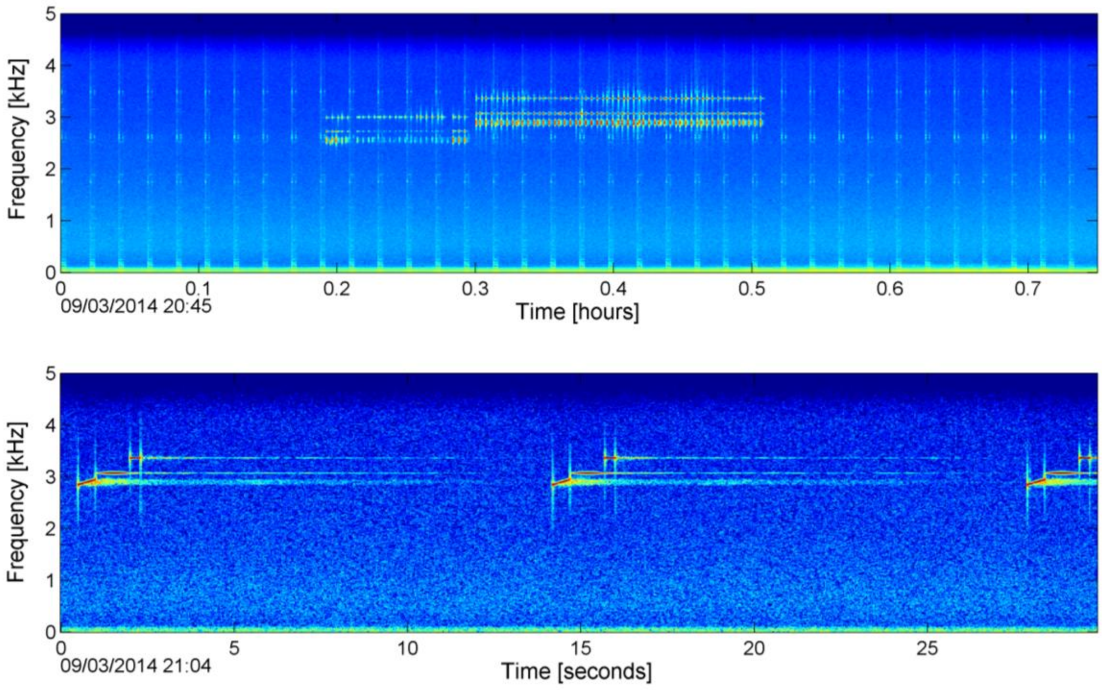

Figure 26. MFA in LTSA (top) and spectrogram (bottom) at JAX site D.

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 27).

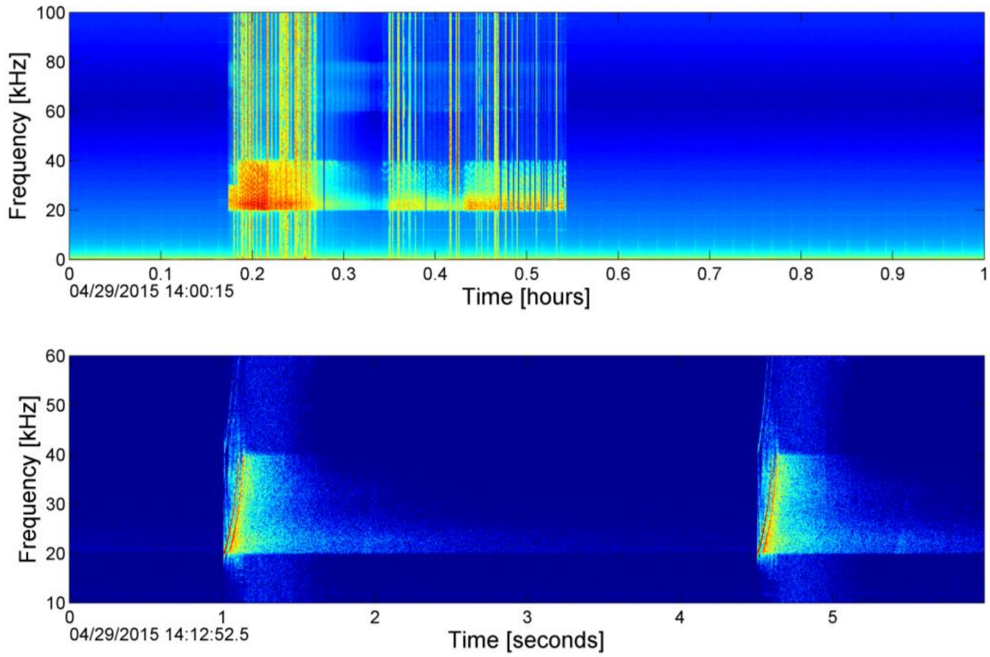

Figure 27. HFA sonar in LTSA (top) and spectrogram (bottom) at JAX site D.

Echosounders

Echosounding sonars transmit short pulses or frequency sweeps, typically in the high-frequency (above 10 kHz) band (Figure 28), though echosounders are occasionally found in the mid-frequency range (2-5 kHz). Many large and small vessels are equipped with echosounding sonar for water depth determination; typically these echosounders are operated much of the time a ship is at sea, as an aid for navigation. In addition, sonars may be used for sea bottom mapping, fish detection, or other ocean sensing. High-frequency echosounders were manually detected by analysts reviewing LTSA plots.

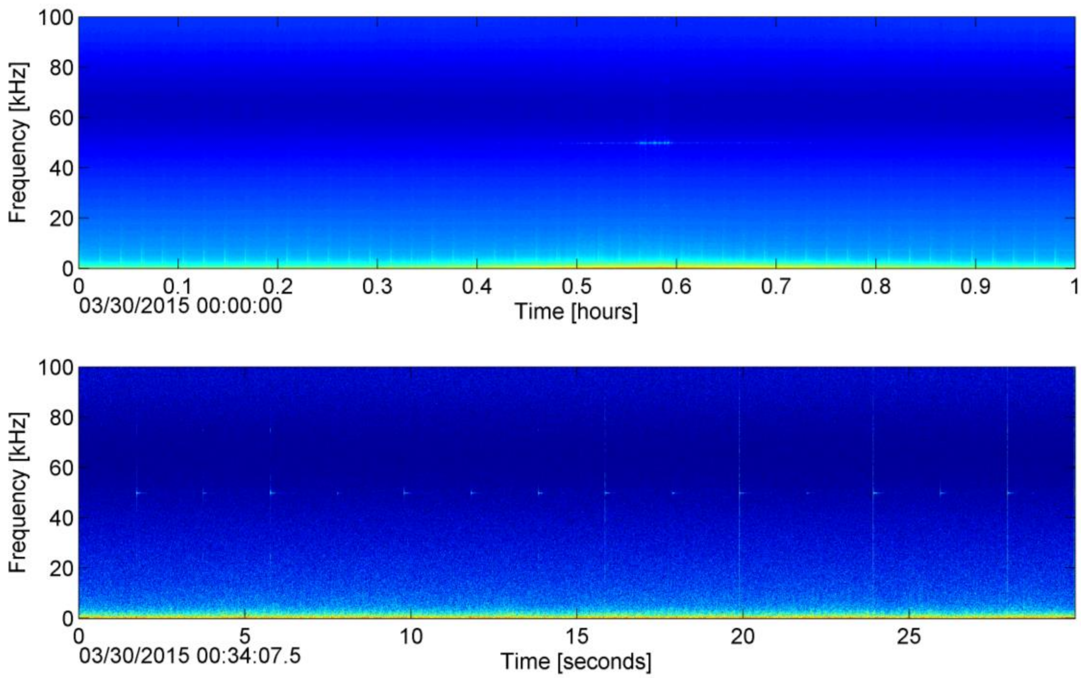

Figure 28. Echosounders in LTSA (top) and spectrogram (bottom) at JAX site D.

Explosions

Effort was directed toward finding explosive sounds in the data including military explosions, shots from 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, has a sharp onset with a reverberant decay (Figure 29). Explosions were detected automatically using a matched filter detector on data decimated to 10 kHz sampling rate. 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 distance of 0.5 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. The 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 often extend up to 2,000 Hz or higher, lasting for a few seconds including the reverberation.

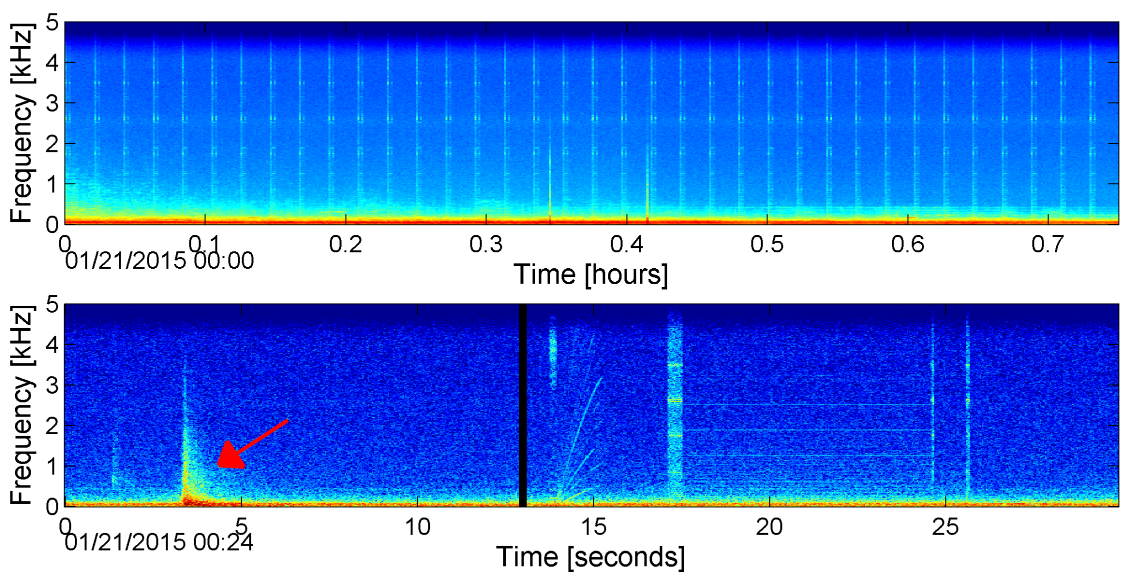

Figure 29. Explosions in the LTSA (top) and spectrogram (bottom, event indicated by red arrow) at JAX site D, recorded in January 2015.

Results

The results of acoustic data analysis at site D from August 2014 to May 2015 are summarized including ambient noise, and the seasonal occurrence and relative abundance of marine mammal acoustic signals and anthropogenic sounds.

Ambient Noise

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

- At very low frequencies (10-15 Hz) high noise levels may be due to ocean currents.
- Energy from Minke pulse train signals is visible in the ambient noise spectra between 100-200Hz from December to March (Figure 30).

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

Deployment	Month/Year	Days of Data / Days in Month
JAX11D	8/2014	8/31
JAX11D	5/2015	20/31

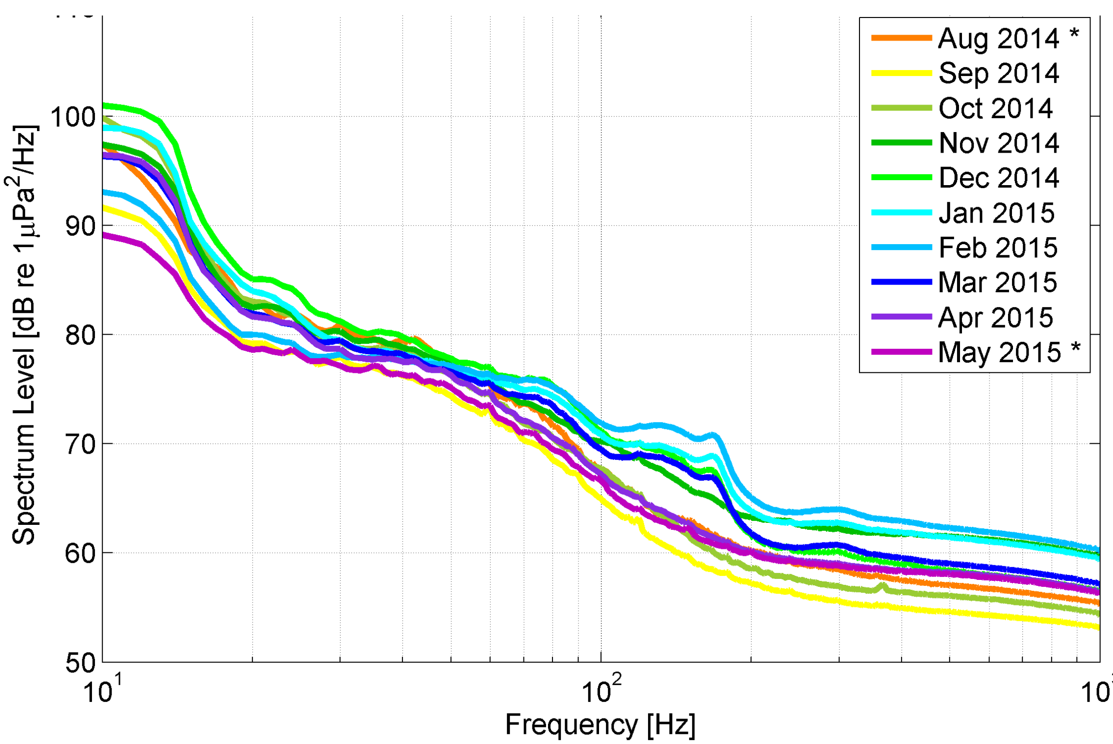

Figure 30. Monthly averages of ambient noise at site D from August 2014 to May 2015. Legend gives color-coding by month. Months with an asterisk (*) are partial recording periods.

Mysticetes

Three known baleen whale species were detected between August 2014 and May 2015: fin whales, sei whales, and minke whales. Details of each species' presence at these sites are given below.

Fin Whales

- Fin whale 20 Hz calls, associated with singing and call-counter-call among animals, were detected intermittently between January and March 2015 (Figure 31).
- There was no discernible diel pattern for fin whale 20 Hz calls (Figure 32).

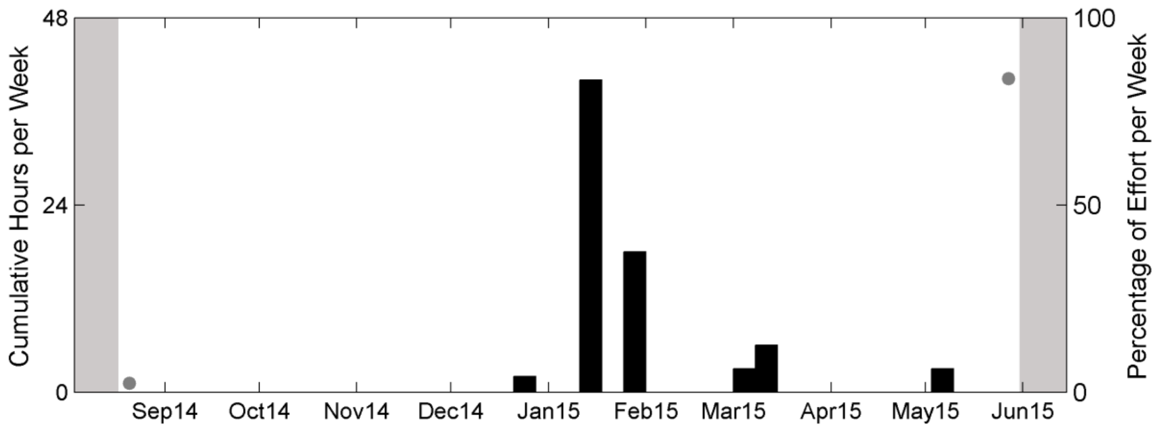

Figure 31. Weekly presence of fin whale 20 Hz calls (black bars) between August 2014 and May 2015 at site D. Gray dots represent percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods before and after the recording period. Where gray dots or shading are absent, full recording effort occurred for the entire week.

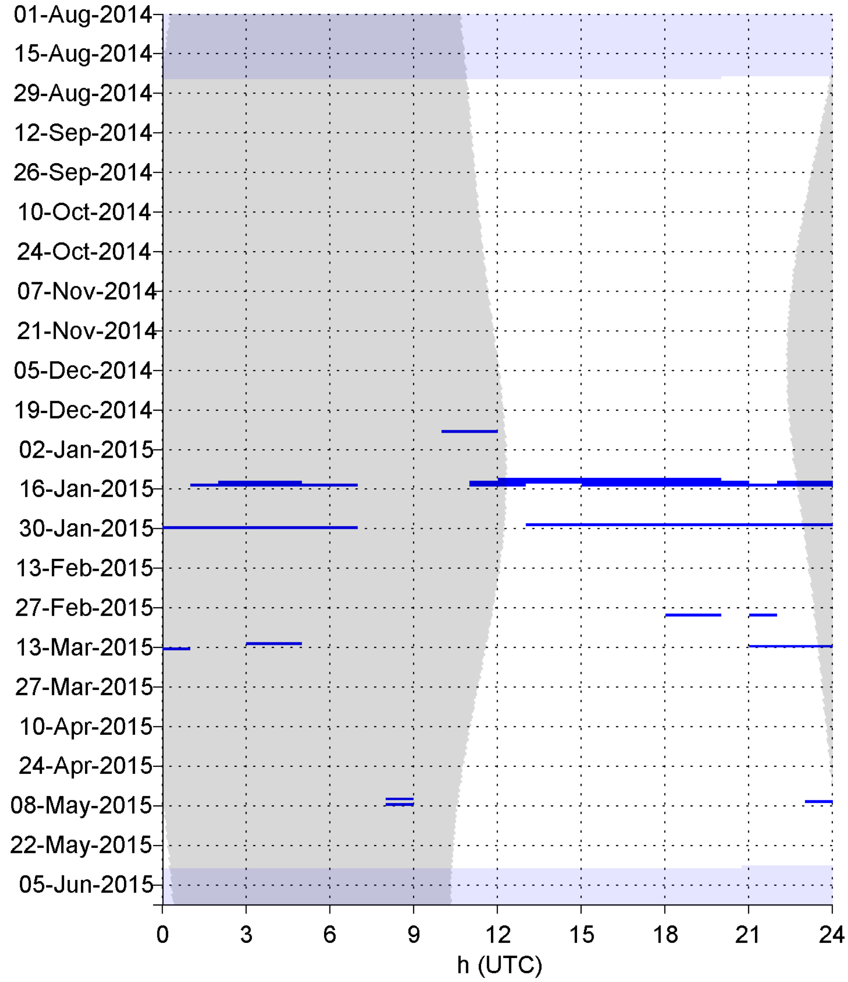

Figure 32. Fin whale 20 Hz calls in hourly bins (blue bars) at site D. Gray vertical shading denotes nighttime. Light purple horizontal shading denotes absence of acoustic data.

Sei Whales

- Sei whale downsweep calls were detected November 2014 - January 2015 (Figure 33).
- No diel pattern in detections was seen (Figure 34).

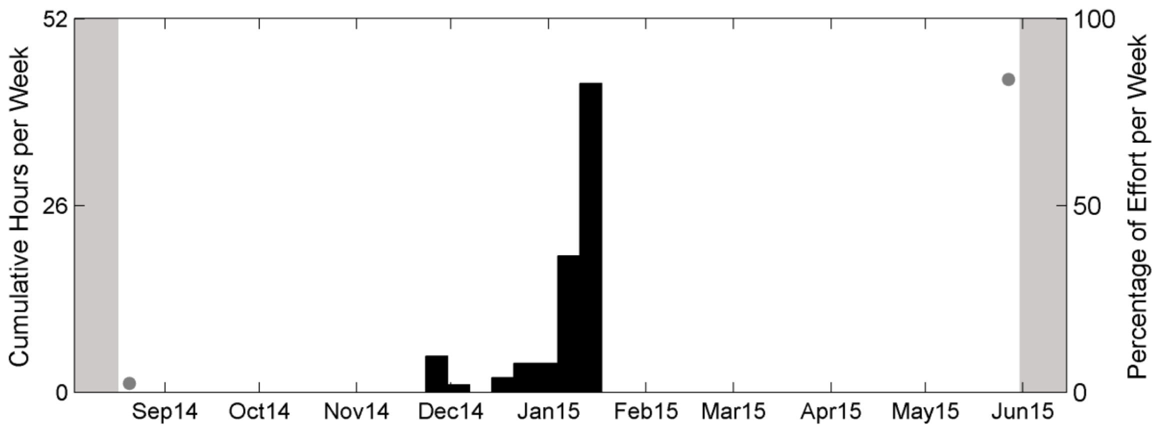

Figure 33. Weekly presence of sei whale downsweeps between August 2014 and May 2015 at site D. Effort markings are described in Figure 31.

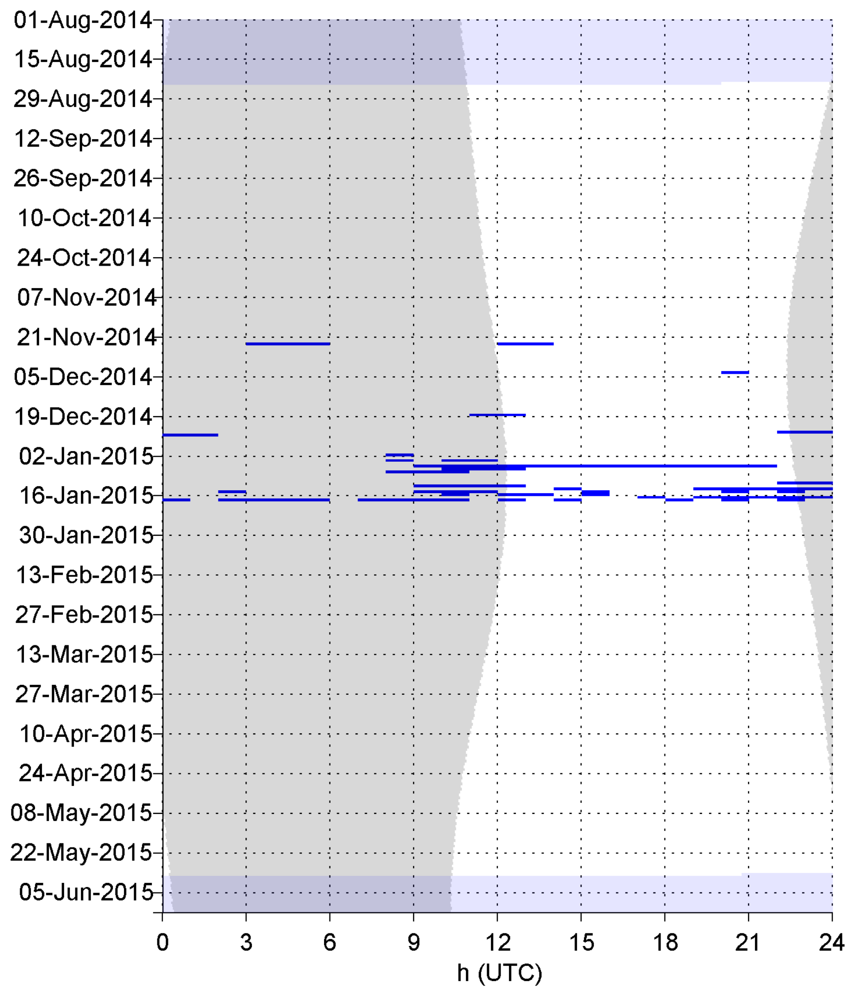

Figure 34. Sei whale downsweeps in one-hour bins at site D. Effort markings as in Figure 32.

Minke Whales

- Minke pulse trains were first detected in October 2014 (Figure 35). Detections ramped up to be nearly continuous (168 hours per week) in December, and remained elevated through March 2015. Incidence of pulse trains decreased throughout early April, and these calls were not detected after early May 2015.
- There was no discernible diel pattern for minke pulse trains (Figure 36).

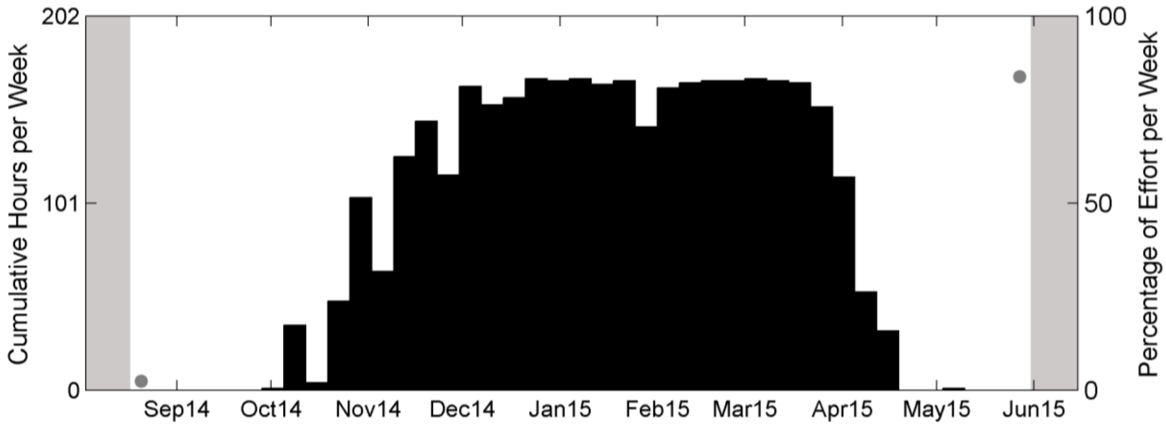

Figure 35. Weekly presence of minke whale pulse trains between August 2014 and May 2015 at site D. Effort markings are described in Figure 31.

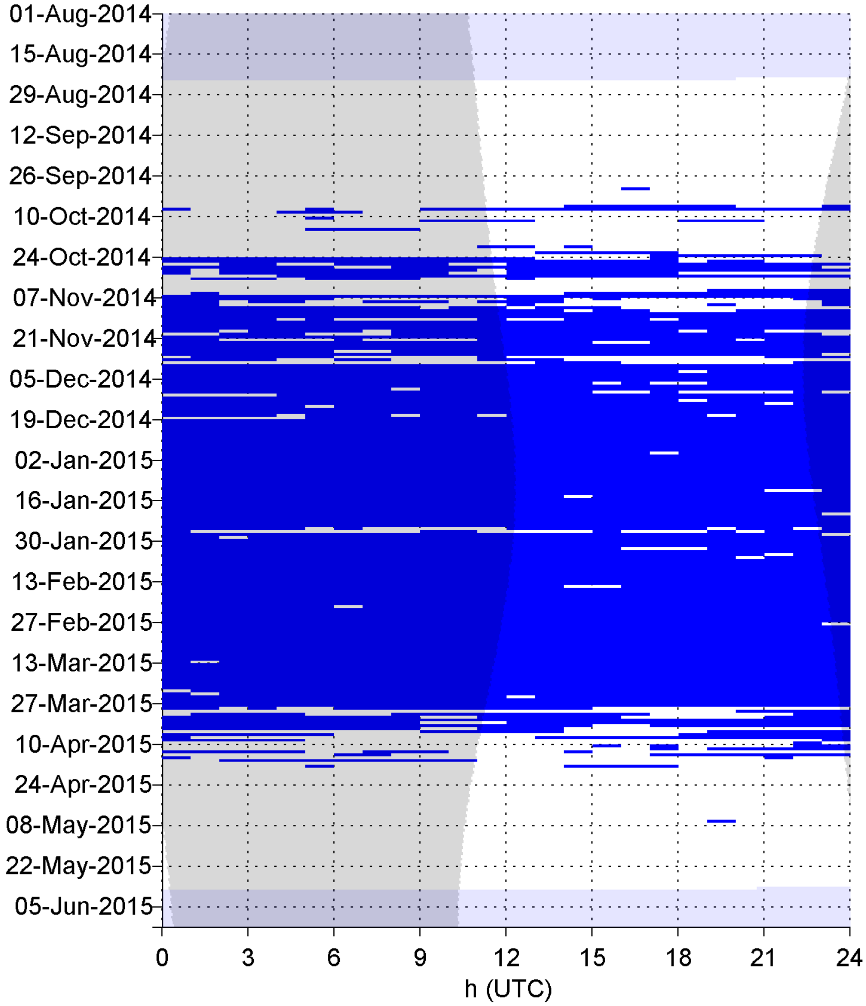

Figure 36. Minke whale pulse trains in hourly bins at site D. Effort markings as in Figure 32.

Odontocetes

Clicks from Risso's dolphins, *Kogia* spp., sperm whales, and three click types that are not yet assigned to a species were detected. Details of each species' presence at these sites are given below.

Risso's Dolphins

- Risso's dolphin echolocation clicks were detected in low numbers between August 2014 and April 2015. Detections increased in late April through May 2015 (Figure 37).
- Clicks were primarily detected during nighttime (Figure 38).

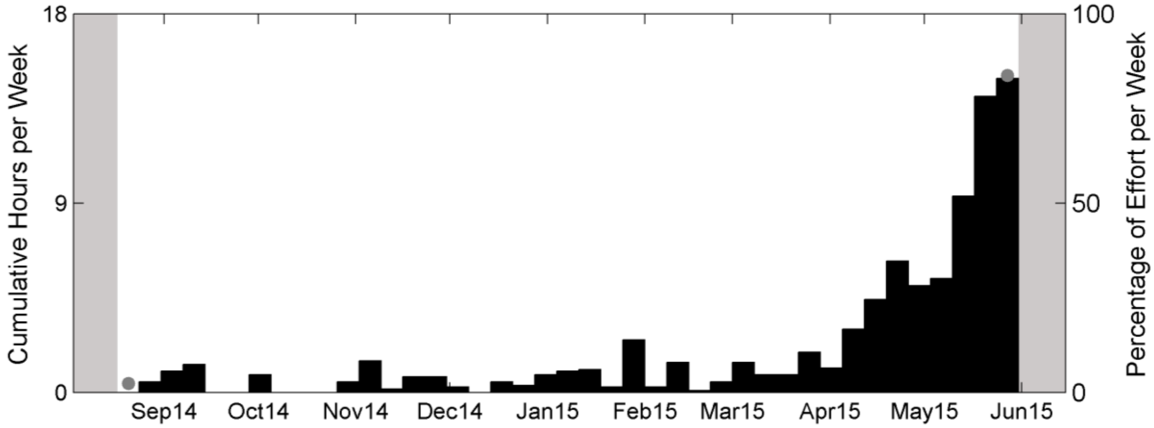

Figure 37. Weekly presence of Risso's dolphin echolocation clicks between August 2014 and May 2015 at site D. Effort markings are described in Figure 31.

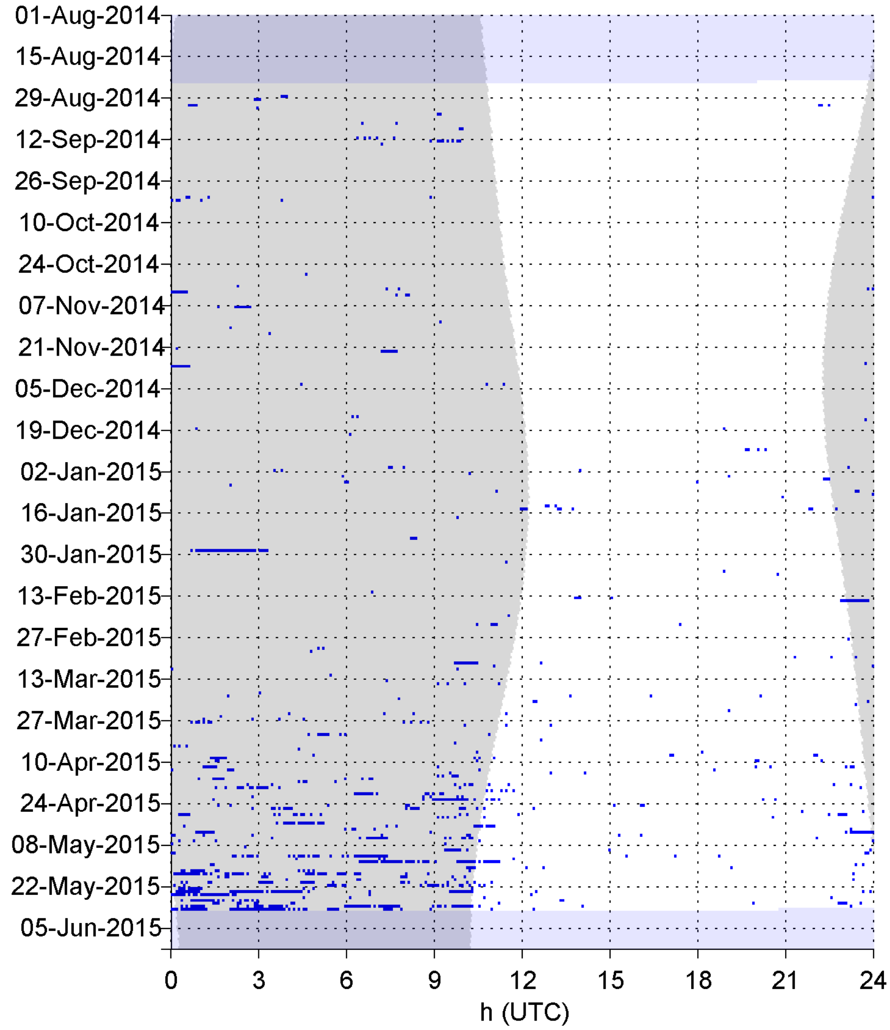

Figure 38. Risso's dolphin echolocation clicks in five-minute bins between August 2014 and May 2015 at site D. Effort markings as in Figure 32.

Unidentified Odontocetes

Signals that had characteristics of odontocete sounds (both whistles and clicks), but could not be classified to species were labeled as unidentified odontocetes.

- Clicks were left unidentified if too few clicks were detected in a time bin, or if detected clicks were of poor quality (e.g. low amplitude or masked).
- Unidentified odontocete clicks were detected throughout the recording period in low numbers. Unidentified detections increased in March 2015, and remained elevated through May 2015 (Figure 39).
- Unidentified clicks were detected primarily during nighttime (Figure 40).

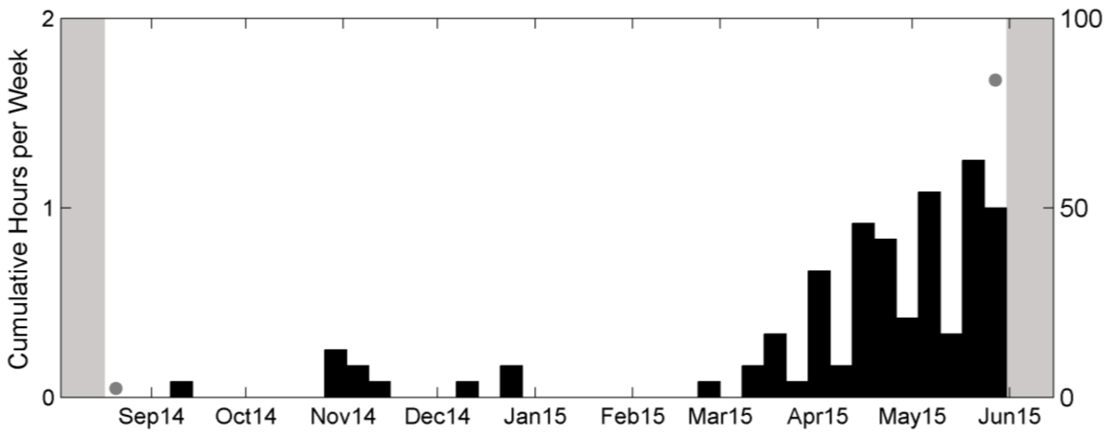

Figure 39. Weekly presence of unidentified odontocete clicks between August 2014 and May 2015 at site D. Effort markings are described in Figure 31.

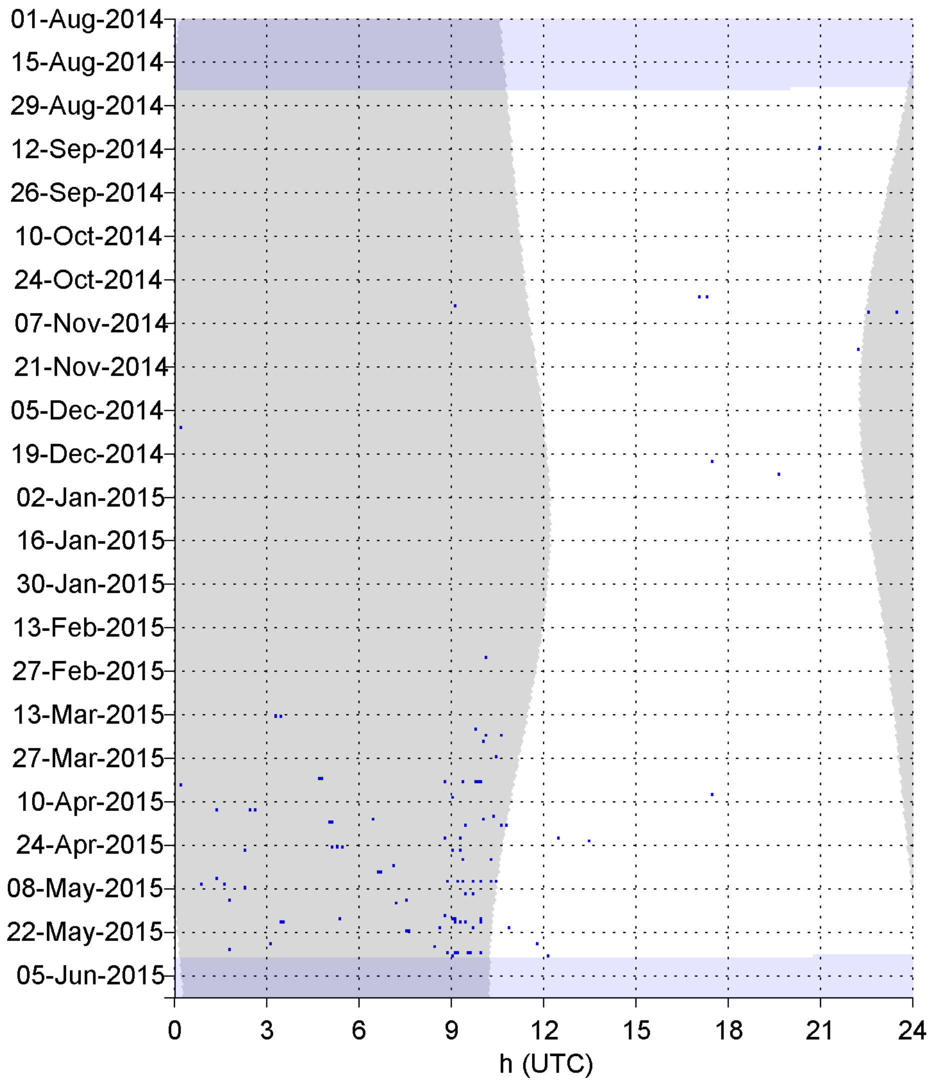

Figure 40. Unidentified odontocete clicks in five-minute bins between August 2014 and May 2015 at site D. Effort as in Figure 32.

Click Type J1

- CT J1 was detected between August 2014 and May 2015 with presence increasing steadily throughout the monitoring period (Figure 41).
- CT J1 was more often detected during nighttime (Figure 42).

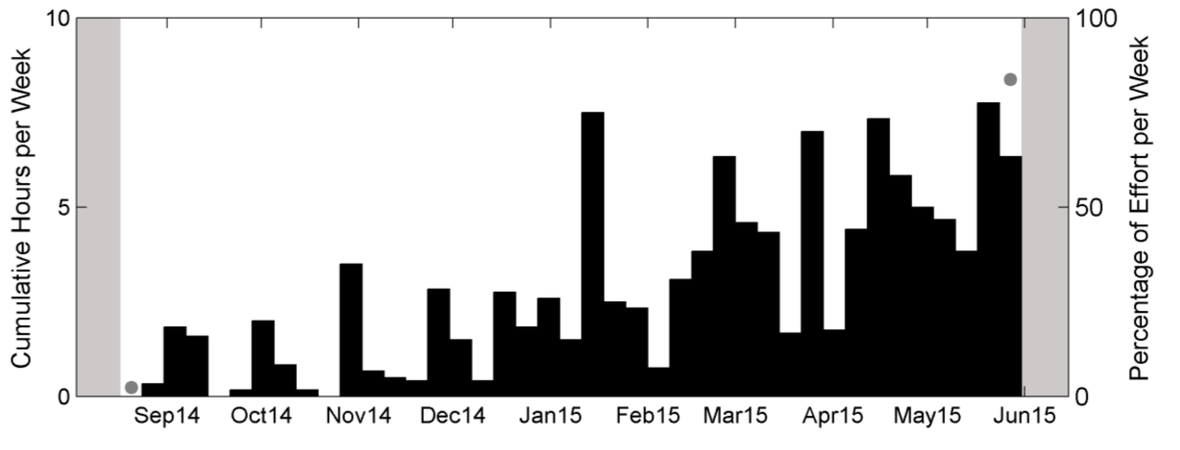

Figure 41. Weekly presence of CT J1 between August 2014 and May 2015 at site D. Effort markings are described in Figure 31.

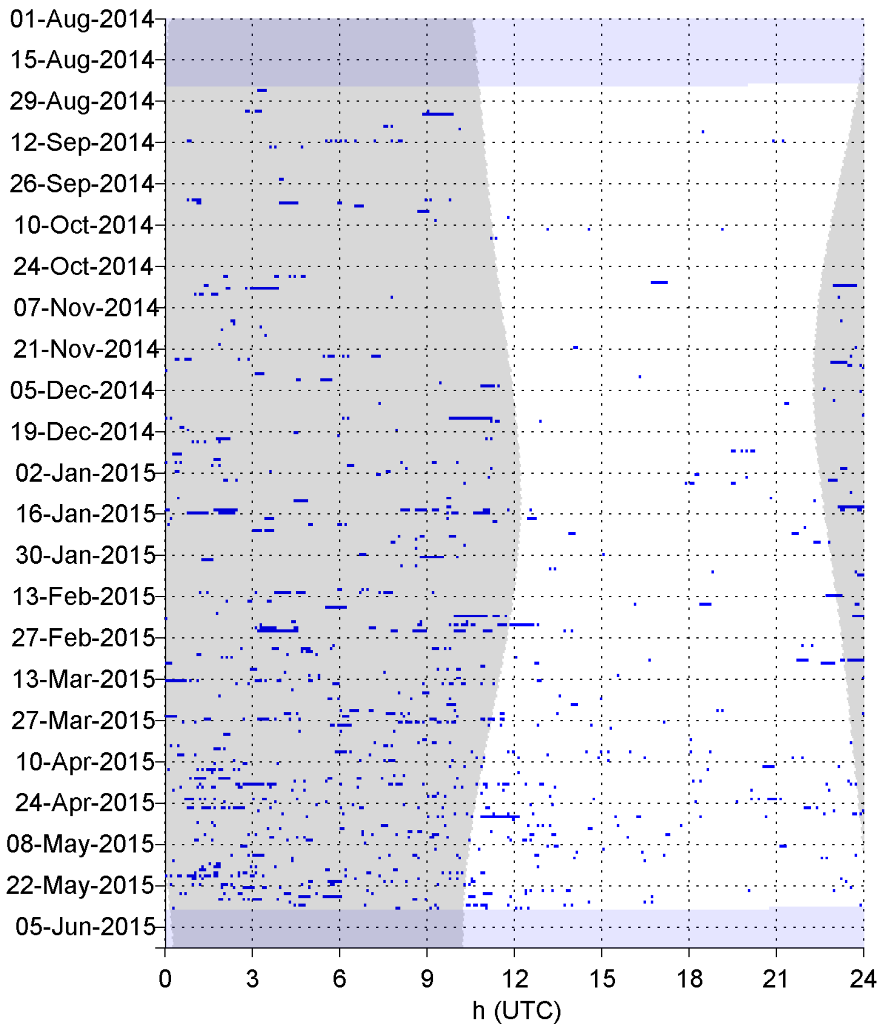

Figure 42. CT J1 in one-minute bins between August 2014 and May 2015 at site D. Effort markings as in Figure 32.

Click Type J2

- CT J2 was detected in low numbers between August 2014 and May 2015, with detections increasing toward the end of the monitoring period (Figure 43).
- This click type was more often detected during nighttime with a peak before sunrise (Figure 44).

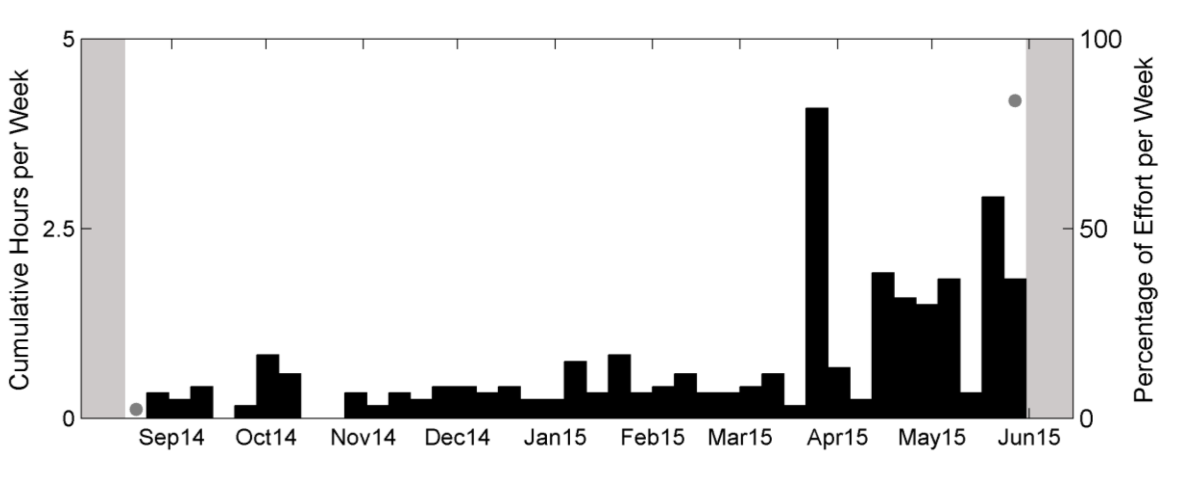

Figure 43. Weekly presence of CT J2 between August 2014 and May 2015 at site D. Effort markings are described in Figure 31.

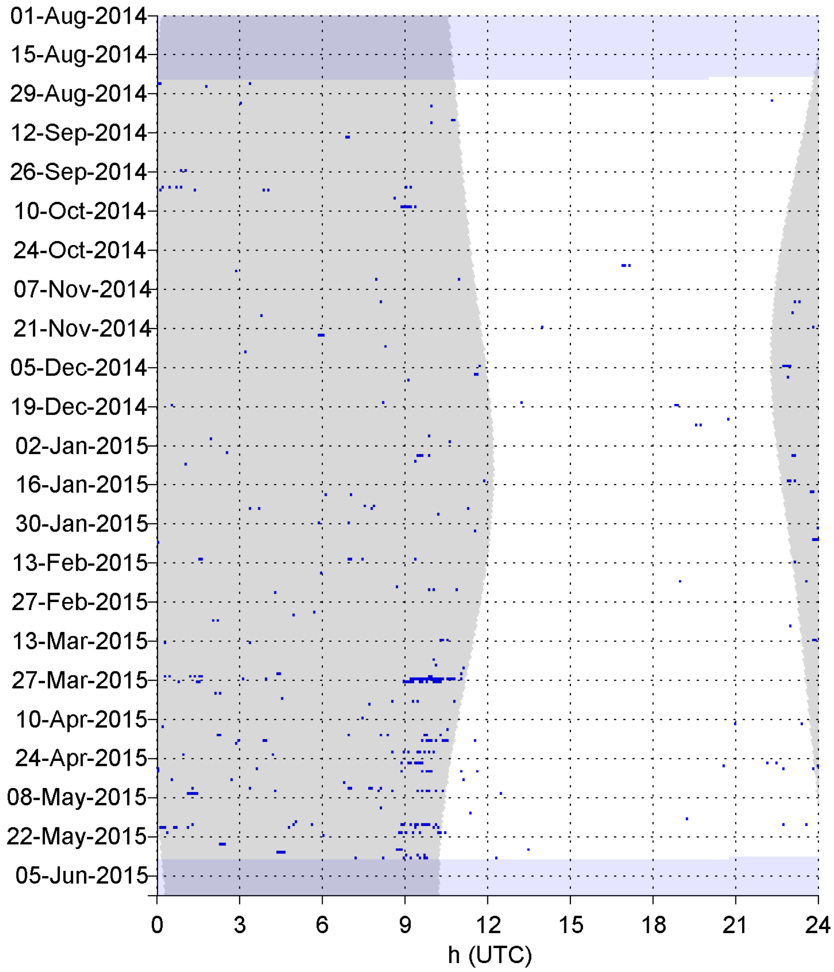

Figure 44. CT J2 in five-minute bins between August 2014 and May 2015 at site D. Effort markings as in Figure 32.

Click Type J3

- CT J3 was detected from September 2014 to May 2015, with cumulative detection durations increasing rapidly in March 2015 and remaining elevated for the remainder of the deployment (Figure 45).
- This click type may be associated with short-finned pilot whales. Increases in CTJ3 detections occurred at the same time as increases in the detection of whistles below 5kHz, which are also linked to pilot whales.
- CT J3 was detected predominantly during nighttime (Figure 46).

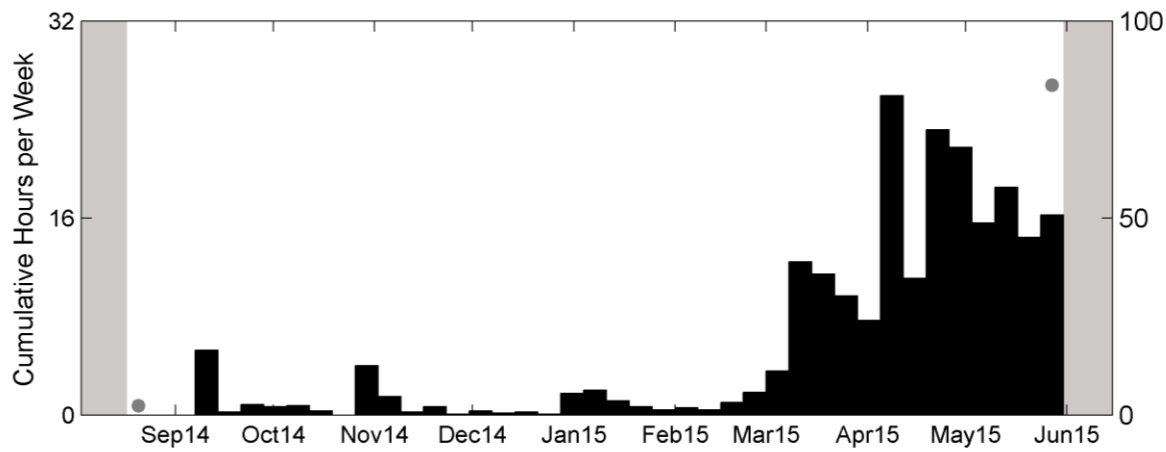

Figure 45. Weekly presence of CT J3 between August 2014 and May 2015 at site D. Effort markings are described in Figure 31.

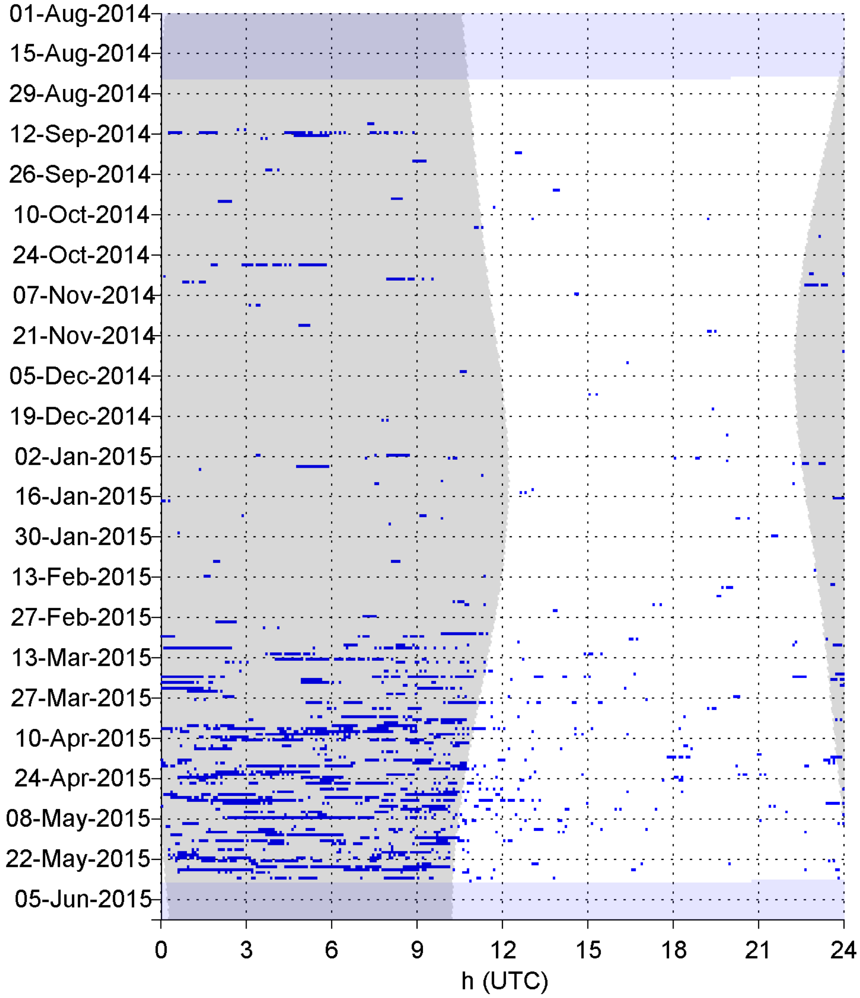

Figure 46. CT J3 in five-minute bins between August 2014 and May 2015 at site D. Effort markings as in Figure 32.

Unidentified Odontocete Whistles

- Unidentified whistles were detected between August 2014 and May 2015. Detections increased in the latter months of the recording period, between March and May 2015 (Figure 47).
- These detections were slightly more likely to occur in the hours around sunrise (Figure 48).

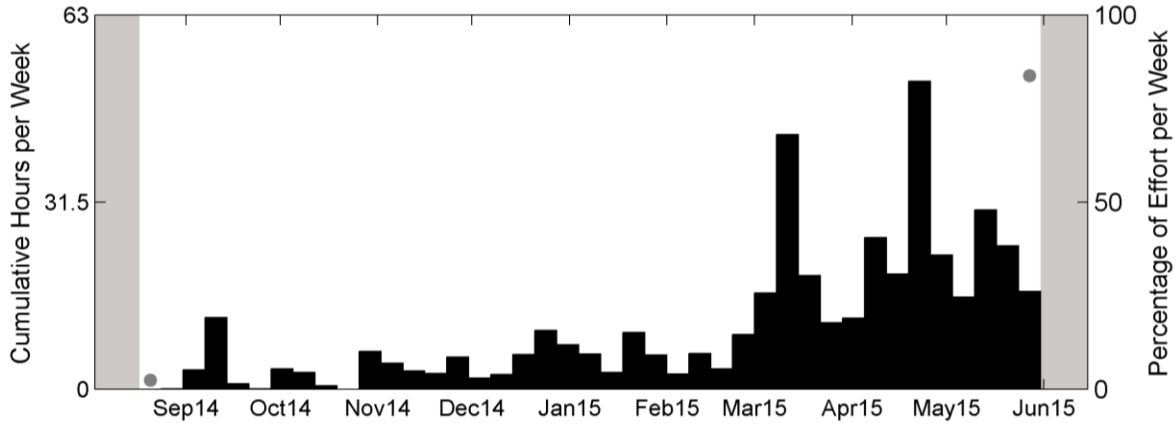

Figure 47. Unidentified odontocete whistles between August 2014 and May 2015 at site D. Effort markings as in Figure 31.

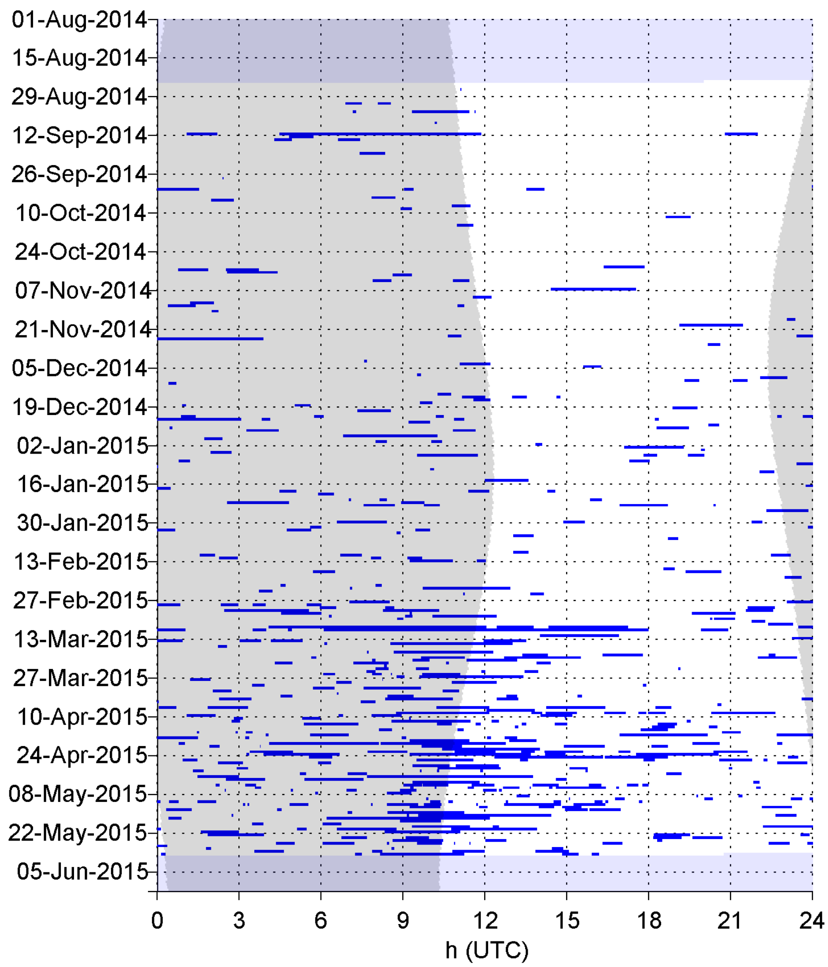

Figure 48. Unidentified odontocete whistles in one minute bins between August 2014 and May 2015 at site D. Effort markings as in Figure 32.

Whistles Less Than 5 kHz

- Unidentified whistles less than 5 kHz were detected intermittently in low numbers between August 2014 and February 2015. Detections increased in the latter months of the recording period, between March and May 2015 (Figure 49).
- These detections were slightly more likely to occur in the hours before and after sunrise (Figure 50).
- Pilot whales most likely produced these whistles, though it is possible they are from other blackfish that have overlapping distributions.

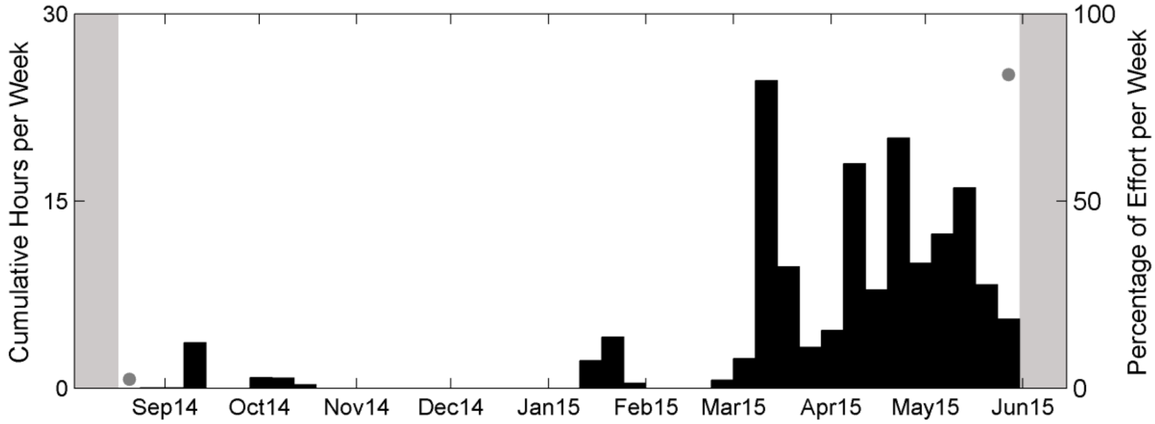

Figure 49. Weekly presence of unidentified odontocete whistles less than 5 kHz between August 2014 and May 2015 at site D. Effort markings are described in Figure 31.

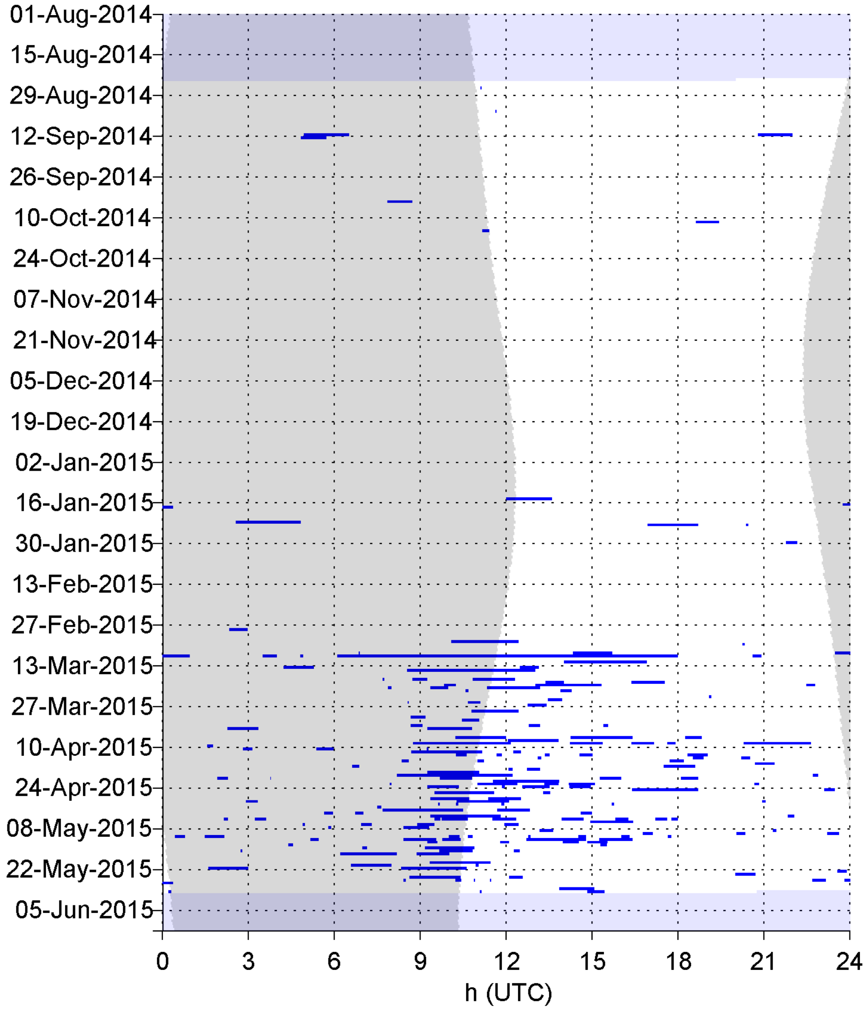

Figure 50. Unidentified odontocete whistles less than 5 kHz in one minute bins between August 2014 and May 2015 at site D. Effort markings as in Figure 32.

Sperm Whales

- Sperm whale clicks were detected intermittently between August 2014 and May 2015 (Figure 51).
- There was no discernible diel pattern for sperm whale clicks (Figure 52).

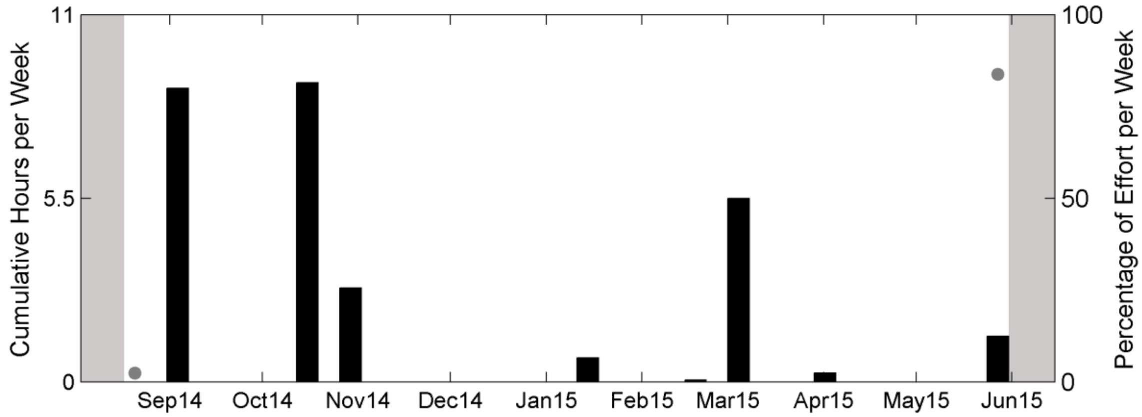

Figure 51. Sperm whale clicks between August 2014 and May 2015 at site D. Effort markings as in Figure 31.

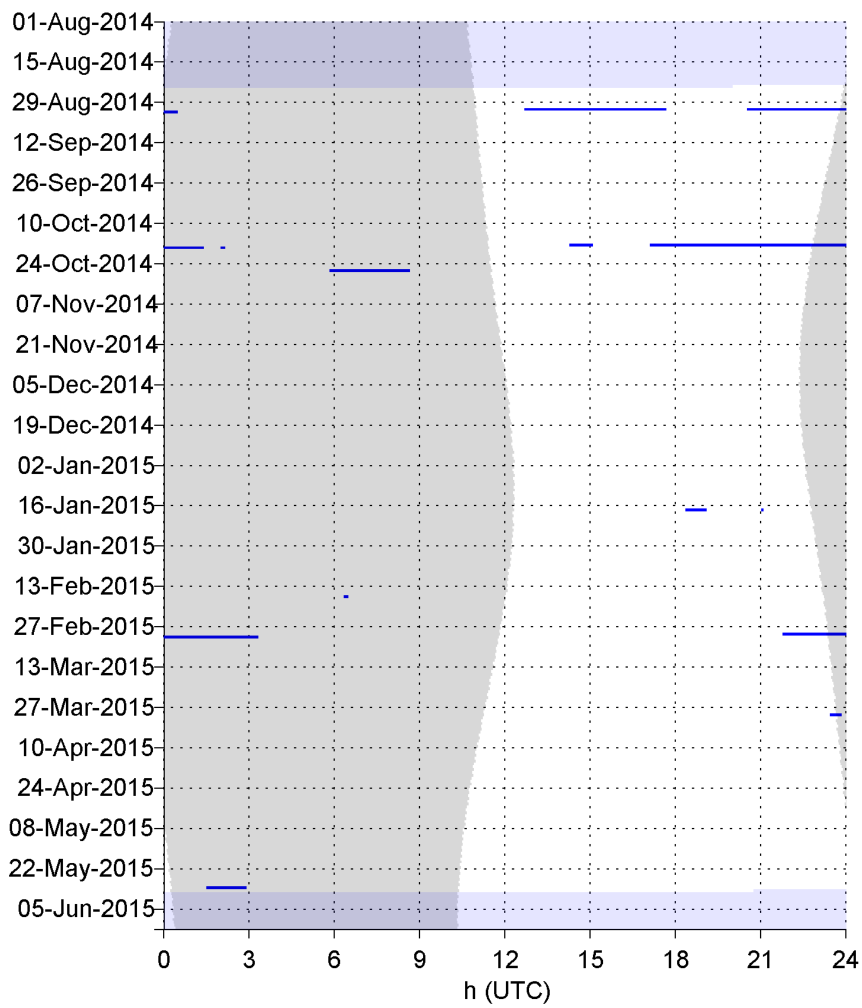

Figure 52. Sperm whale clicks in one minute bins between August 2014 and May 2015 at site D. Effort markings as in Figure 32.

***Kogia* spp.**

- *Kogia* spp. echolocation clicks were detected throughout the recording period, with highest numbers of detections occurring between October 2014 and April 2015 (Figure 53).
- There was no discernible diel pattern for *Kogia* echolocation clicks (Figure 54).

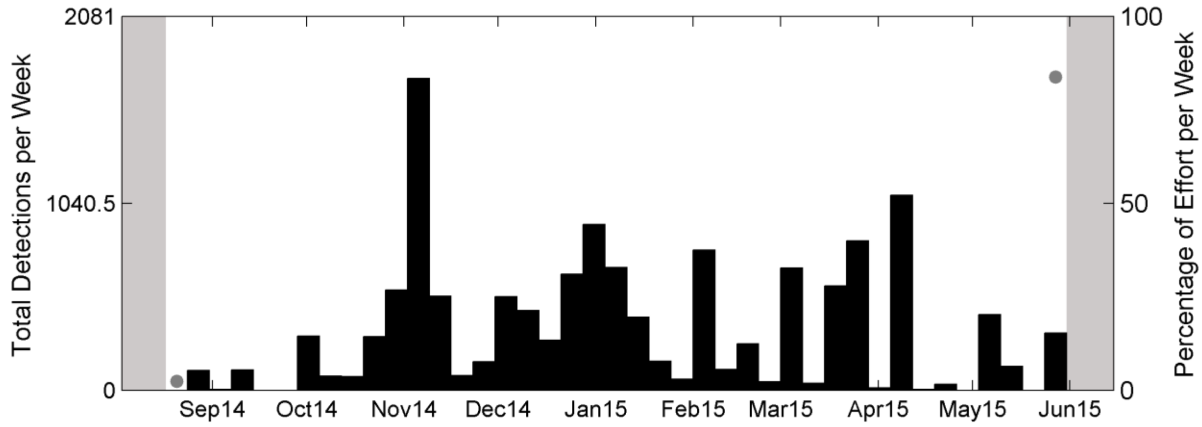

Figure 53. Kogia clicks between August 2014 and May 2015 at site D. Effort markings as in Figure 31.

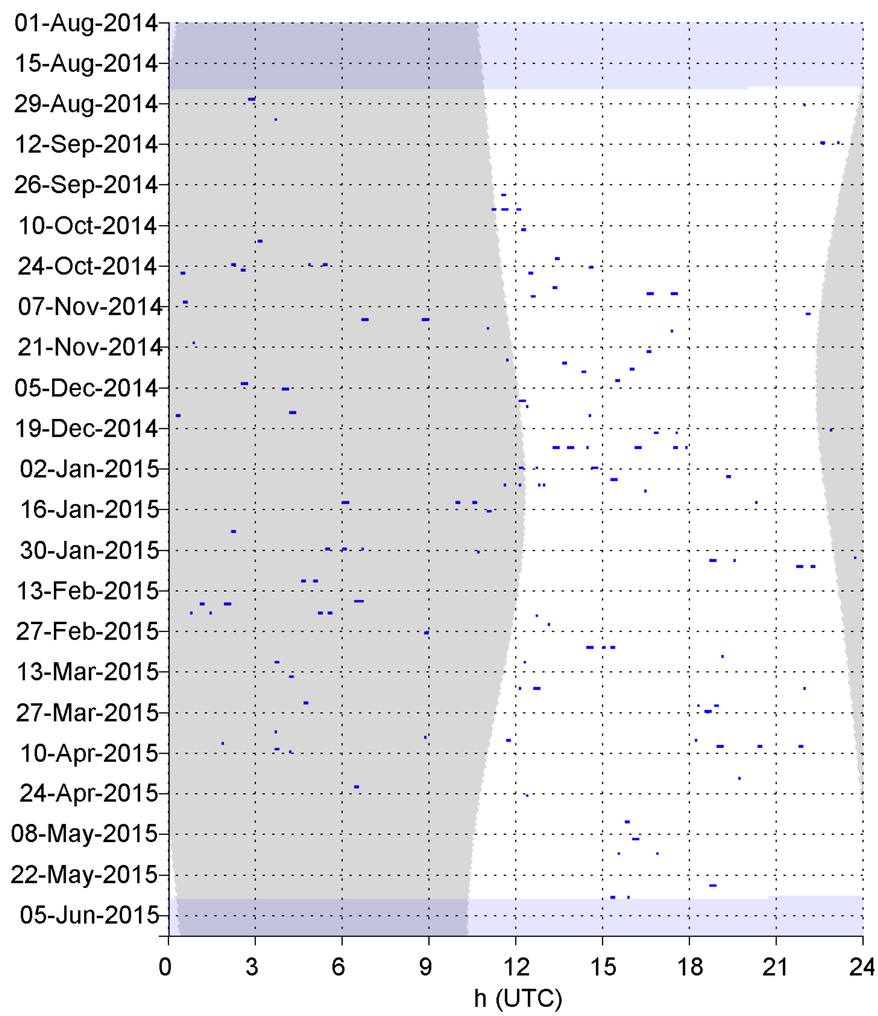

Figure 54. *Kogia* spp. clicks in one minute bins between August 2014 and May 2015 at site D. Effort markings as in Figure 32.

Anthropogenic Sounds

Five types of anthropogenic sounds were detected between August 2014 and May 2015 at site D: broadband ship noise, MFA sonar less than 5 kHz, HFA sonar, echosounders and explosions.

Broadband Ship Noise

Broadband ship noise was a common anthropogenic sound.

- Broadband ship noise was detected throughout the recording period (Figure 55).
- There was no discernible diel pattern for broadband ships (Figure 56).

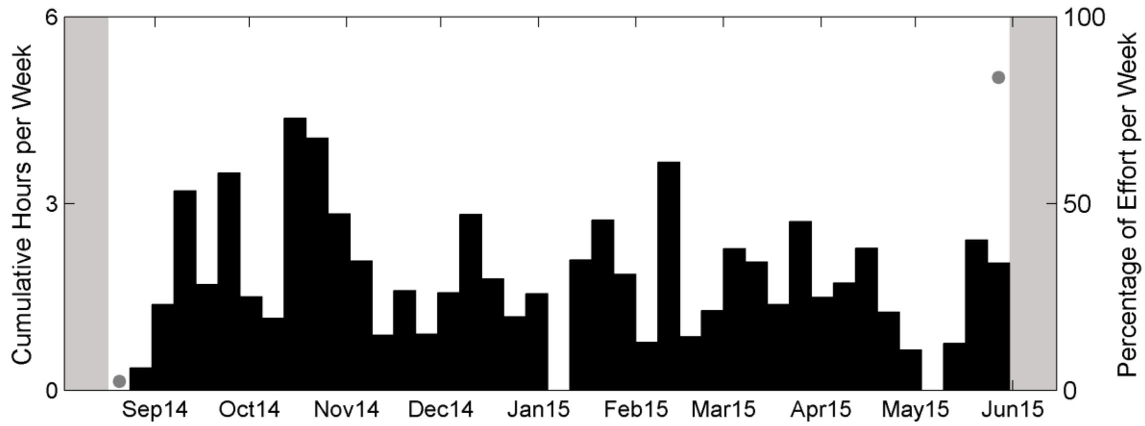

Figure 55. Weekly presence of broadband ships between August 2014 and May 2015 at site D. Effort markings are described in Figure 31.

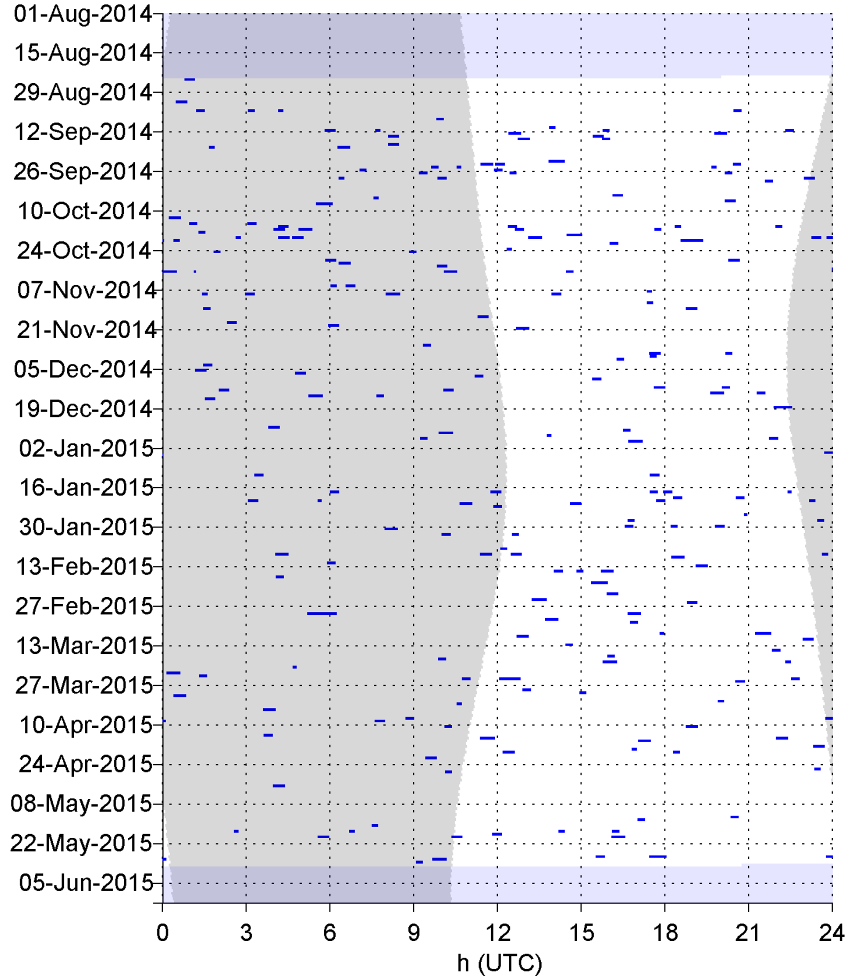

Figure 56. Broadband ship noise in one minute bins between August 2014 and May 2015 at site D. Effort markings as in Figure 32.

MFA and HFA Sonar

MFA sonar was a common anthropogenic sound detected during these deployments.

- MFA sonar less than 5 kHz was detected intermittently with peaks in September and October 2014, as well as February and March 2015 (Figure 57).
- There was no apparent diel pattern for MFA sonar detections (Figure 58).
- One HFA sonar event was detected on April 29th, 2015 (Figure 59).
- There were too few HFA sonar detections to identify a diel pattern (Figure 60)
- Nearly 30% of analyst-defined MFA events contained packets which exceeded the minimum thresholds required for further analysis (Wiggins 2015;
- Table 3).
- MFA less than 5 kHz events were detected in September and October 2014, and between January and April 2015. Highest number of packets (>600) and Cumulative Sound Exposure Levels (CSEL) (> 170 dB re 1 µPa s) MFA events were detected in September 2014 (Figure 61). An increase in the number of packets at 164-165 dB_{pp} re 1 µPa in Figure 61 (top panel) indicates that packet amplitudes occasionally exceeded the recording capability of the instrument, leading to signal clipping.

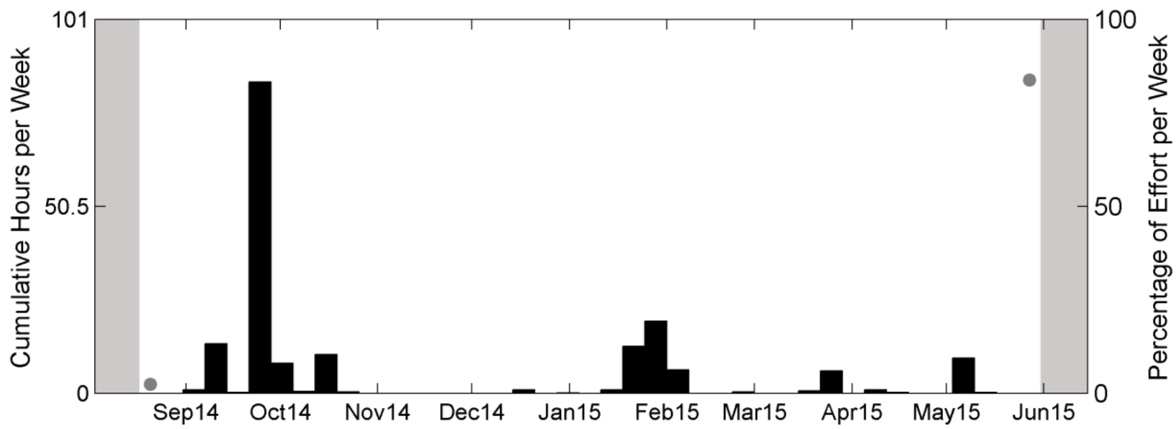

Figure 57. Weekly presence of MFA sonar less than 5 kHz between August 2014 and May 2015 at site D. Effort markings are described in Figure 31.

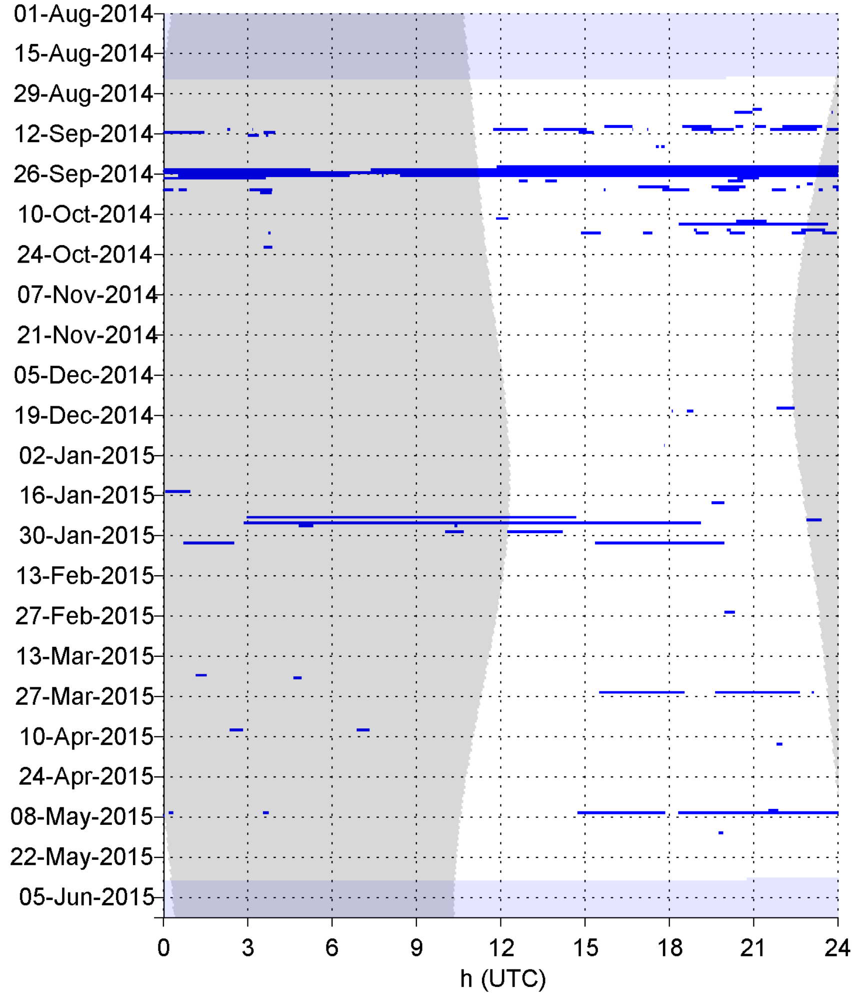

Figure 58. MFA sonar less than 5 kHz signals in one-minute bins between August 2014 and May 2015 at site D. Effort markings as in Figure 32.

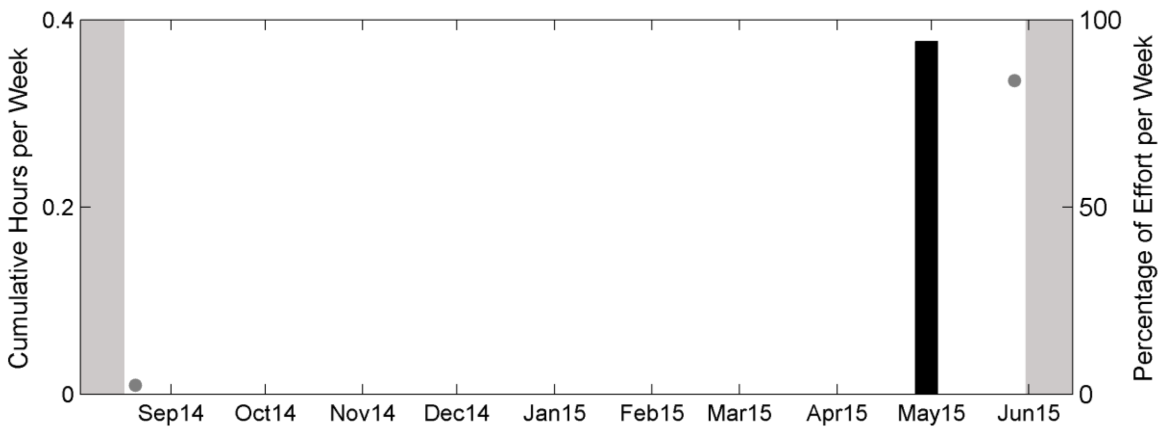

Figure 59. Weekly presence of HFA sonar greater than 5 kHz between August 2014 and May 2015 at site D. Effort markings are described in Figure 31.

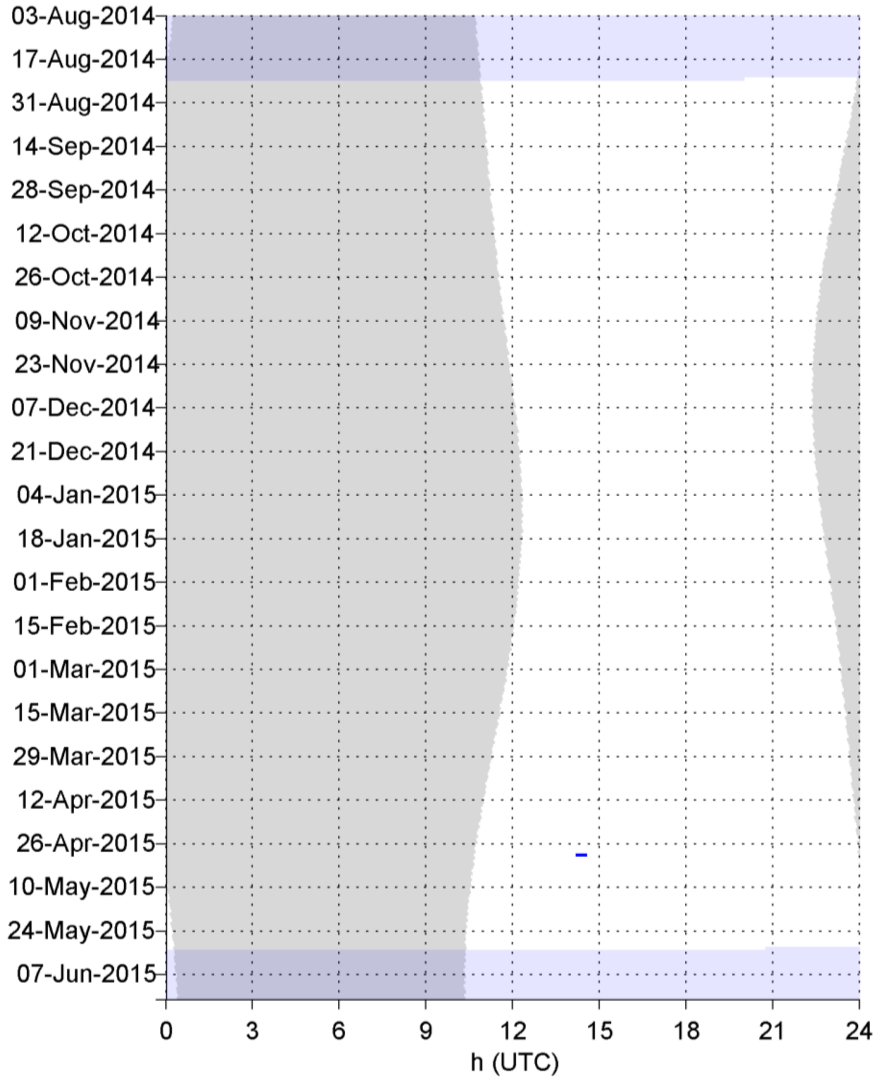

Figure 60. HFA sonar signals in one-minute bins between August 2014 and May 2015 at site D. Effort markings as in Figure 32.

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)
JAX11D	87	25	4119

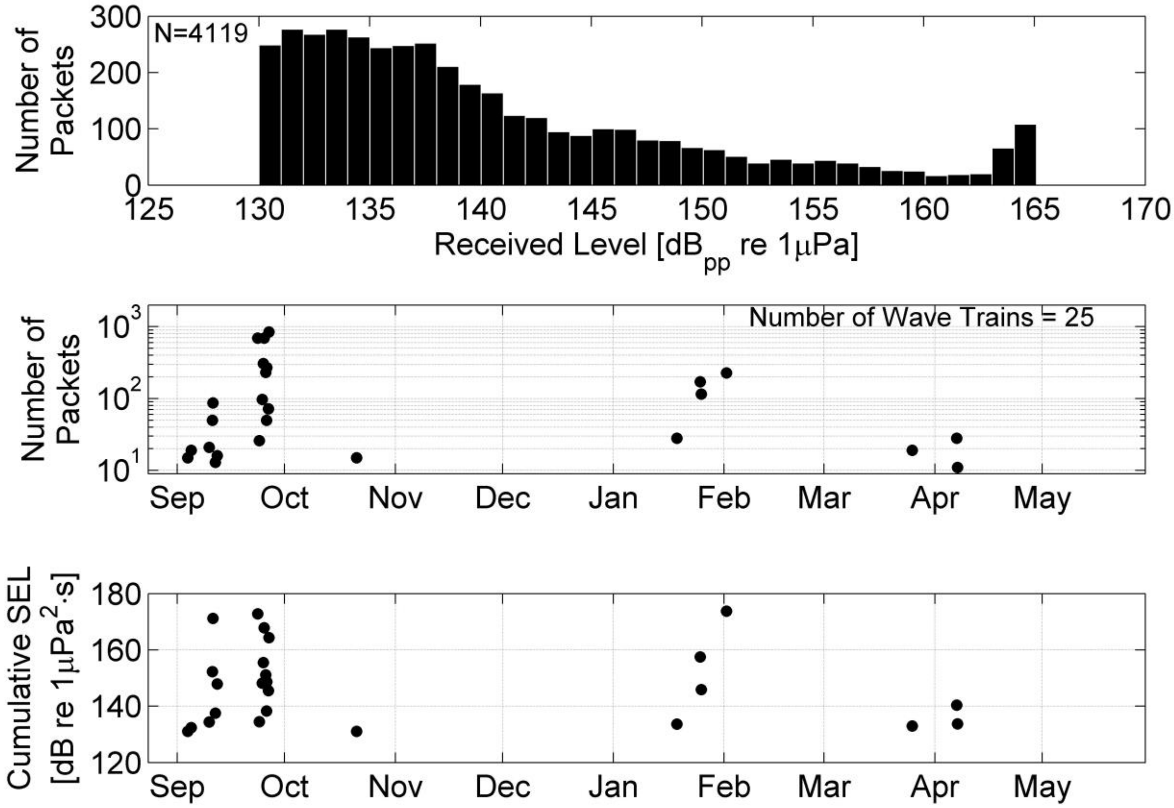

Figure 61. ***Top*: Distribution of received levels (RL) of detected MFA packets. *Center*: Number of MFA packets detected in each wave train exceeding the minimum RL threshold (130 dB$_{pp}$ re 1μ Pa). *Bottom*: Cumulative Sound Exposure Levels (CSEL) associated with each wave train.**

Echosounders

- Echosounders greater than 5 kHz were detected in low numbers throughout the monitoring period (Figure 62).
- There was no apparent diel pattern for echosounder detections (Figure 63).

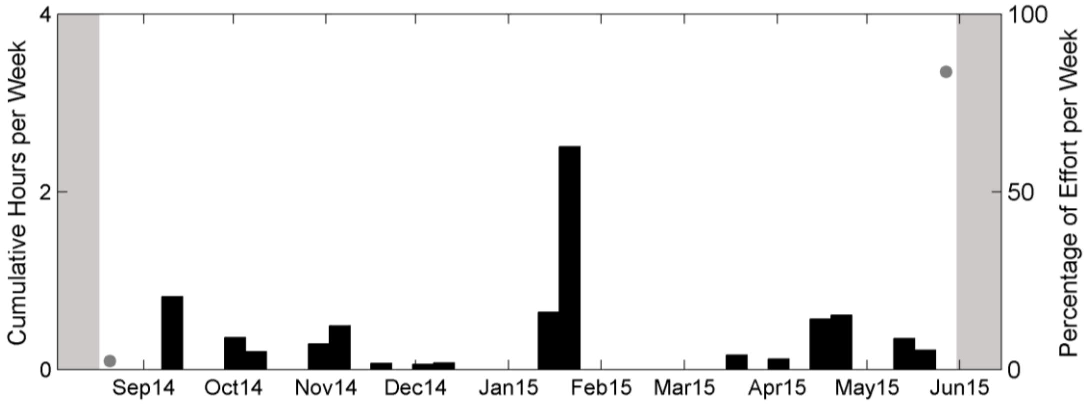

Figure 62. Weekly presence of echosounders greater than 5 kHz between August 2014 and May 2015 at site D. Effort markings are described in Figure 31.

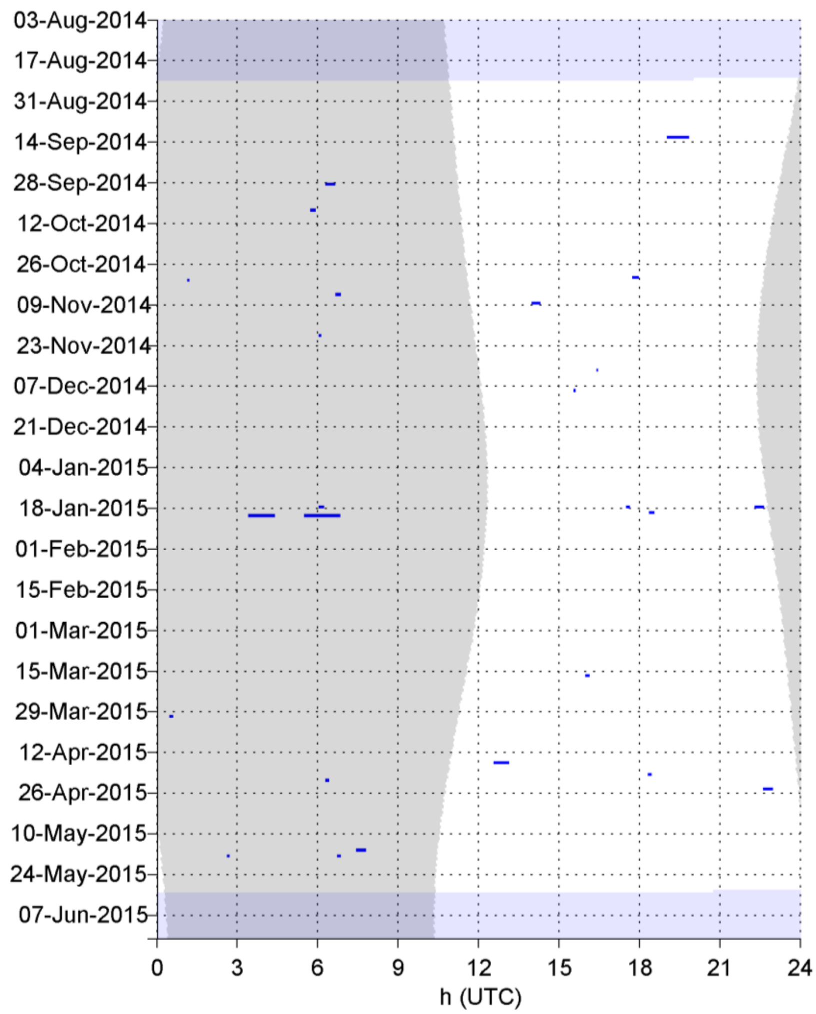

Figure 63. Echosounders greater than 5 kHz in one-minute bins between August 2014 and May 2015 at site D. Effort markings as in Figure 32.

Explosions

- Two explosions were detected in January 2015 (Figure 64). Explosions were rare in this deployment. Manual analysis was conducted to ensure that explosions were not missed by the automated detector.
- There were too few detections to determine a diel pattern (Figure 65).

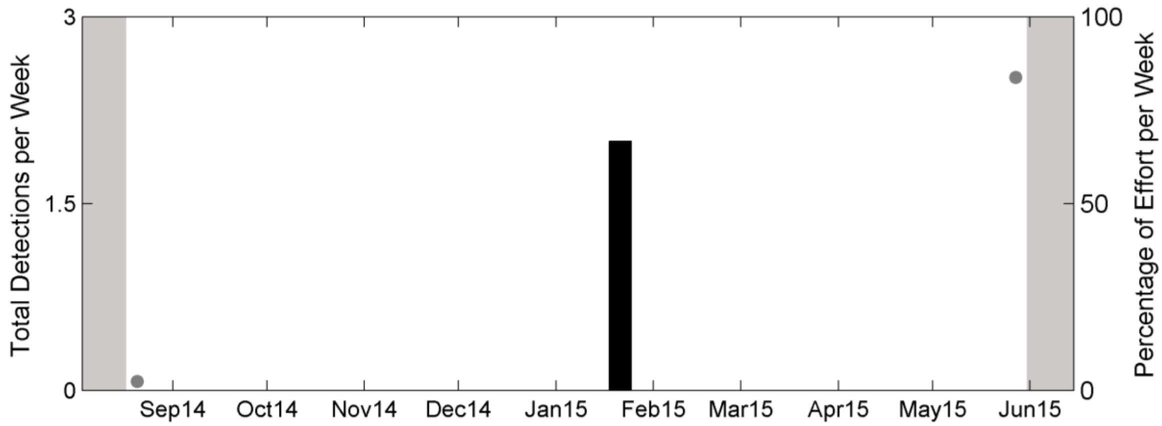

Figure 64. Weekly presence of explosions detected between August 2014 and May 2015 at site D. Effort markings as in Figure 31

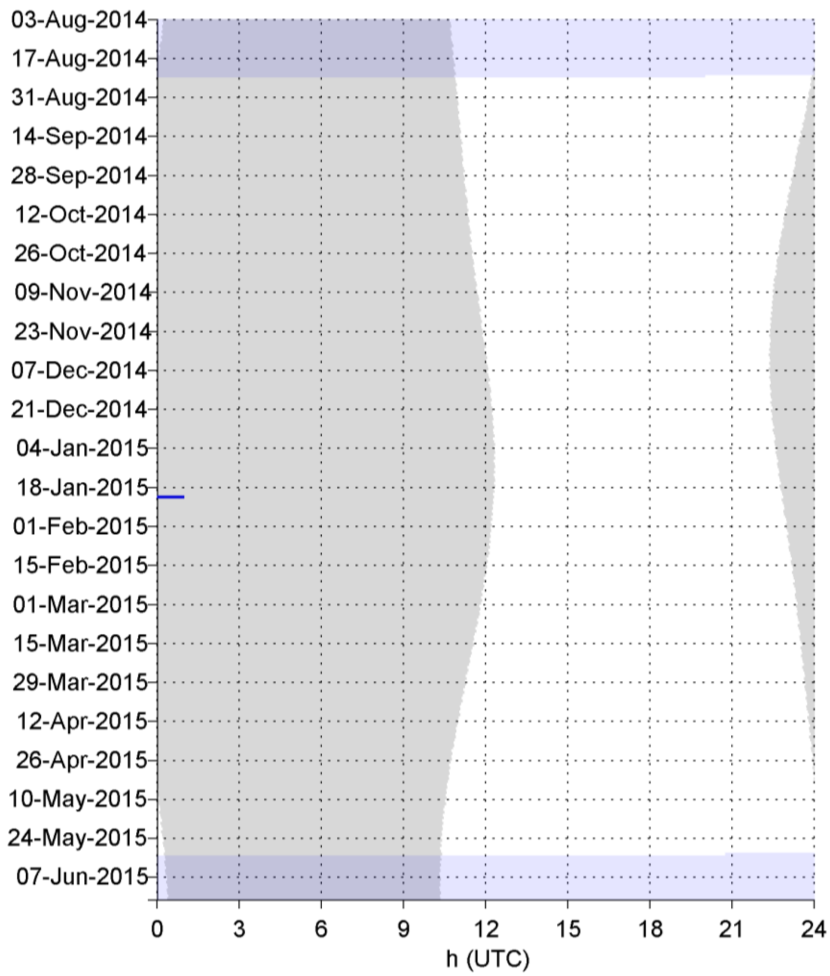

Figure 65. Explosions in one-hour bins between August 2014 and May 2015 at site D. Effort markings as in Figure 32.

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