Passive Acoustic Monitoring for Marine Mammals in the Jacksonville Range Complex 2010-2011

Amanda J. Debich, Simone Baumann-Pickering, Ana Širović,
Sara M. Kerosky, Lauren K. Roche, Sarah C. Johnson,
Rachel S. Gottlieb, Zoe E. Gentes, Sean M. Wiggins, and John A. Hildebrand

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

Photo by Amanda J. Debich

MPL TECHNICAL MEMORANDUM 541

March 2013

Table of Contents

Executive Summary

Passive acoustic monitoring was conducted at two sites in the US Navy's Jacksonville Range Complex during August 2010 – July 2011. These sites are located 50 and 61 nm east of the Florida coastline on the shelf and shelf break at water depths of 40 m – 300 m. Acoustic data collected at these sites provide information on the presence of marine mammals and anthropogenic sound sources. High-frequency Acoustic Recording Packages (HARPs) documented sounds between 10 Hz and 100 kHz with recording cycles of 5 minutes every 15 minutes. The data were divided into three frequency bands and data analysis was conducted with analyst scans of long-term spectral averages and spectrograms.

Four mysticete whale species were recorded: fin, minke, sei, and humpback. No blue whale, North Atlantic right whale, or Bryde's whale calls detected. A new call, designated the "5-pulse" was detected and is presumed to be produced by a mysticete whale due to its character, prevalence and intensity. Site A has more hours with calling mysticete whales than site B. However, humpback whale calls were detected only at site B, though these detections were few.

The largest number of odontocete detections were attributed to unidentified odontocetes, thought to be primarily bottlenose and Atlantic spotted dolphins. Unidentified odontocetes were detected throughout the year. Overall numbers of detections were higher at site A than site B. There was a diel acoustic activity pattern with greater numbers of echolocation clicks produced at night, likely due to nighttime foraging. Risso's dolphin echolocation clicks were only detected at site A and only occurred August through March. Five click types, yet to be associated to an odontocete species, were characterized and their seasonal and diel occurrence described.

Ship noise was the most common anthropogenic sound at both sites A and B. Both sites had Mid-Frequency Active (MFA) sonar events throughout the period of data collection. At site A, a total of 2,437 MFA sonar pings were detected with a maximum peak-to-peak received level of 173 dB re 1 µPa. Similarly, a total of 2,496 MFA sonar pings were detected at site B, reaching a maximum peak-to-peak level of 166 dB re 1 µPa. Echosounder pings with a variety of primary frequencies (4 – 80 kHz) were found at both sites A and B. Explosions were recorded at both sites, though were more prevalent at site B. A low-frequency tone, referred to as the 130 Hz tone, was recorded at site A. High noise levels, possibly caused by instrument strumming and fluid flow at the sensor, occurred intermittently at both sites and likely decreased the detection range for low-frequency sounds.

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 mysticete whales, dolphins and other 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 year-round seasonal presence, and to evaluate the potential for impact from Naval operations. This report documents the analysis of two High-frequency Acoustic Recording Packages (HARPs) that have been deployed within JAX during the time period August 2010 – July 2011. The JAX-B HARP site is 50 miles east of the Florida coastline and the JAX-A HARP site is approximately 11 nm further offshore (Figure **1**).

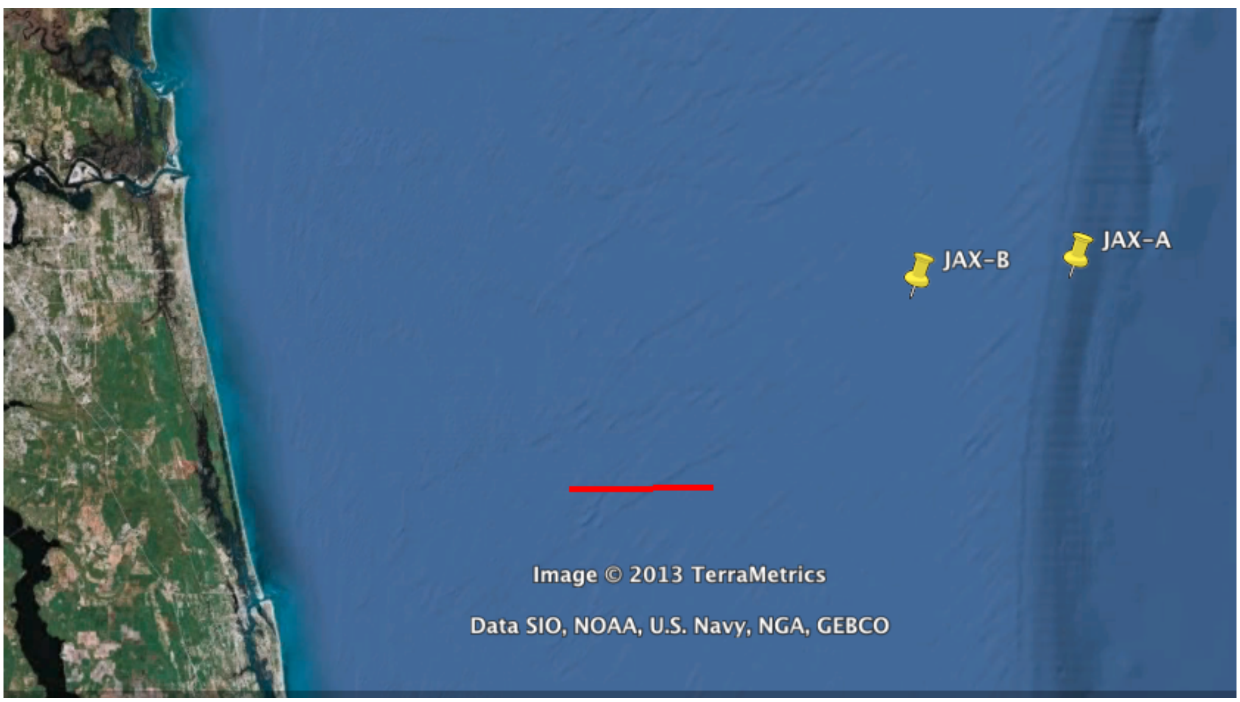


Figure 1. Locations of High-frequency Acoustic Recording Packages (yellow pins) at sites A and B in the Jacksonville Range Complex. The red bar represents 10 nm.

Methods

High Frequency Acoustic Recording Packages

High-frequency Acoustic Recording Packages (HARPs) were used to detect marine mammal species, anthropogenic noise, and ambient noise in the JAX Range Complex. HARPs record underwater sounds from 10 Hz to 100 kHz with approximately 110 days of continuous data storage. Recording a broad frequency range of 10 Hz - 100 kHz is required to detect both baleen whale (mysticetes), and toothed whale (odontocetes) species. The HARP sensor and mooring package are described in Wiggins and Hildebrand (2007). For the JAX range deployments, the HARP electronics package was located near the seafloor with the hydrophone suspended 10 m above. Each HARP is calibrated in the laboratory to provide a quantitative analysis of the received sound field. Representative data loggers and hydrophones are calibrated at the Navy's TRANSDEC facility to verify the laboratory calibrations.

Data Collected to Date

Acoustic data have been collected at two sites since April 2009 (Table 1). The two sites are designated site A (30° 27.7 N, 80° 21.6 W, depth 90 m during deployments 1-5; 30° 16.7 N, 80° 13.3 W, depth 300 m during deployment 6) and site B (30° 25.8 N, 80° 42.8 W, depth 40 m). Site A was placed at the shelf break, site B was on the shelf, approximately 11 nm apart.

Table 1. JAX HARP deployments. Periods of deployment analyzed in this report are shown in bold.

Deployment Designation	Site A Deployment Period	Site B Deployment Period
JAX 01	4/2/2009-5/25/2009	4/2/2009-9/5/2009
JAX 02	9/16/2009-12/27/2009	--
JAX 03	2/22/2010-7/30/2010	--
JAX 04	--	3/9/2010-5/29/2010
JAX 05	**8/26/2010-1/25/2011**	**8/27/2010-2/1/2011**
JAX 06	**2/1/2011-7/14/2011**	**2/2/2011-7/14/2011**

Data Analysis

To assess the quality of the acoustic data, frequency spectra were calculated for all the data (over one-year at each of the two instruments) using a time average of 5 seconds and frequency bins of 1 Hz. These data, called Long-Term Spectral Averages (LTSA) were examined both for characteristics of ambient noise and also as a means to discover marine mammal and anthropogenic sounds. As a first pass for data analysis, segments of data that did not allow for further analysis due to disk malfunctions or strumming noise were identified (Table 2).

Table 2. Periods when acoustic data were not available or amenable to analysis.

Deployment Name	Gaps In Data for High-Frequency Analysis	Too Much Noise for High-Frequency Analysis	Gaps in Data for Mid- and Low-Frequency Analysis
JAX 05A	11/23/2010 22:48 – 11/24/2010 8:09		
JAX 05B		9/1/2010 23:49 – 9/3/2010 5:49 9/17/2010 20:17 – 9/21/2010 17:17 9/30/2010 18:30 – 10/1/2010 12:30 11/12/2010 17:15 – 11/15/2010 11:15	entire deployment
JAX 06A	2/12/2011 7:02 – 2/22/2011 5:16		2/12/2011 9:16 – end
JAX 06B	2/9/2011 7:00 – 2/12/2011 5:02		2/2/2011 14:20 – 2/12 5:02

The presence of acoustic signals from multiple marine mammal species was analyzed, along with the presence of anthropogenic noise such as sonar, explosions, and shipping. All data were analyzed by visually scanning LTSAs in appropriate frequency bands. When a sound of interest was identified in the LTSA, the waveform or spectrogram at the time of interest was examined to further classify particular sounds to species or source. Acoustic classification was carried out either by comparison to species-specific spectral characteristics or by analysis of the time and frequency character of individual sounds.

To document the data analysis process, we describe the major classes of marine mammal calls and anthropogenic sounds in the JAX region, and the procedures used to test for their presence in the HARP data. For effective analysis, the data were divided into three frequency bands and each band was analyzed for the sounds of an appropriate subset of species or sources. The three frequency bands are as follows: (1) low frequencies, between 10 – 1000 Hz, (2) mid frequencies, between 500 – 5000 Hz, and (3) high frequencies, between 1 – 100 kHz. Blue, fin, sei, Bryde's, and North Atlantic right whale and a subset of minke sounds were classified as low frequency; humpback, minke, shipping, explosions, and mid-frequency active sonar were classified as mid-frequency; while the remaining odontocete and sonar sounds were considered high-frequency. We describe the calls and procedures separately for each frequency band.

Low Frequency Marine Mammals

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) of these data were created using a time average of 5 seconds and frequency bins of 1 Hz. The presence of each call type was determined in hourly bins. A subset of each call type was measured for start and end frequencies and duration (**Table 3**).

Table 3. Low-frequency whale calls in JAX data. Mean values (± one standard deviation) are presented. Calls for the 5-pulse were separated by a minimum of 24 hours to obtain calls from multiple animals. Other call types occurred in clusters and therefore measurements may represent an individual animal more than once.

Species/Call	Call Type	Start Frequency (Hz)	End Frequency (Hz)	Duration (s)
Fin whale	20 Hz pulse *(n=30)*	27.2 ± 2.0	16.4 ± 0.6	1.6 ± 0.3
Minke whale	50 Hz pulse *(n=2)*	56.5 ± 2.1	54.5 ± 2.1	64.5 ± 14.8
	150 Hz speed-up/ slow-down *(n=18)*	166.2 ± 5.0	163.6 ± 5.2	36.6 ± 7.9
Sei whale	Downsweep *(n=23)*	120.8 ± 14.6	46.2 ± 4.4	1.5 ± 0.2
5-pulse	5-pulse *(n=30)*	178.5 ± 22.3	185.9 ± 22.2	2.7 ± 0.5

Whale calls for which low frequency effort was expended include: blue whale A, B and arch calls, fin whale 20 and 40 Hz pulses, Bryde's whale Be7 and Be9 calls, North Atlantic right whale upcall, in addition to sei whale calls, and the "5- pulse" call type of unknown origin (presumably baleen whale). The same LTSA and spectrogram parameters were used to detect all call types. For spectrogram scrolling, the LTSA frequency was set to display between 1-500 Hz. To observe individual calls, spectrogram parameters were typically set to 120 seconds by 200 Hz. The FFT was generally set between 1500 and 2000 data points (yielding about 1 Hz frequency resolution), with an 85-95% overlap of data in the input time series. **Table 3** presents measurements of frequency and duration for each recorded call type.

Blue Whales

Several different calls were used to test for the presence of blue whales. Detection effort included call types A, B, and arch from Mellinger and Clark (2003) (Figure **2**). The A call is a constant 18-19 Hz tone lasting approximately 8 seconds while the B call is an 18-15 Hz downsweep lasting approximately 11 seconds. Individual A and B calls are readily detected in an LTSA, owing to their long duration. The third call, the arch call, starts at a frequency of 56 Hz, ascends to a peak frequency of 69 Hz, then descends to 35 Hz over a period of 6.3 seconds (Figure **3**). Manual scanning of the LTSA was the primary means to search for blue whale calls, however, no blue whale calls of any type were detected in the JAX data.

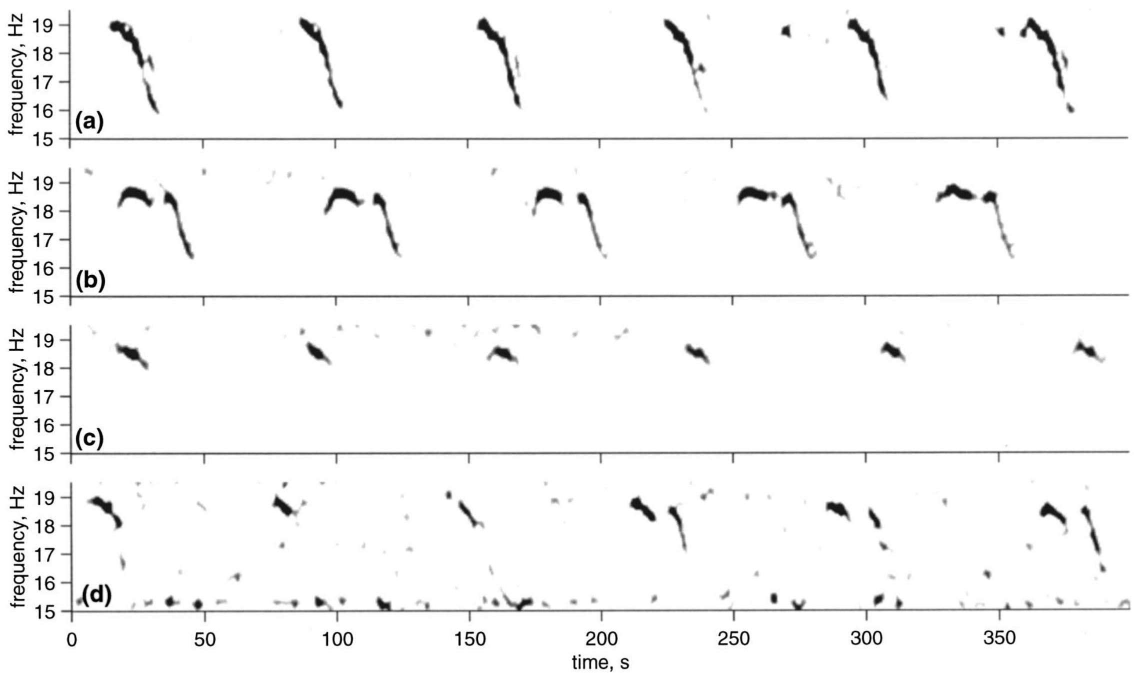


Figure 2. Blue whale A and B calls from Mellinger and Clark (2003).

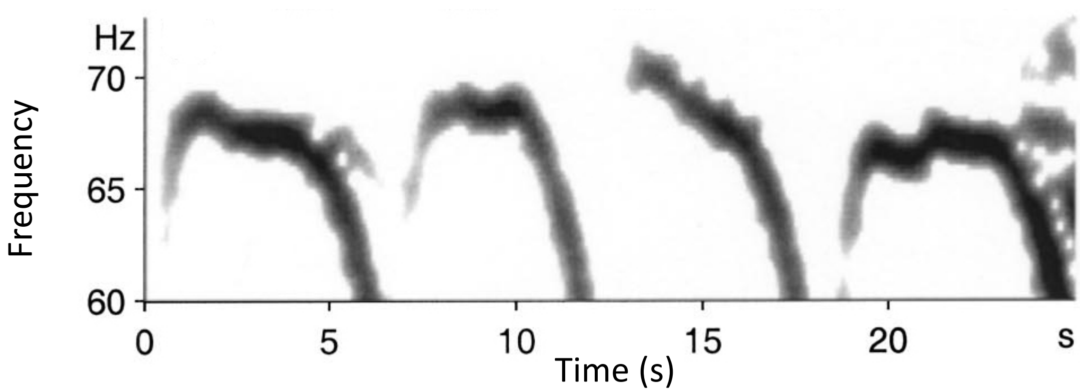


Figure 3. Blue whale arch calls from Mellinger and Clark (2003).

Fin Whales

Fin whales produce a variety of calls, most are less than 100 Hz, short in duration, and frequency-modulated. The best known fin whale call is the 20 Hz pulse, downswept at 30 - 15 Hz (Figure 4). These pulses occur at regular intervals as song (Thompson *et al.* 1992), and at irregular intervals as counter-calling between multiple animals (McDonald *et al.* 1995). In this report we indicate the presence of 20 Hz pulses, but do not categorize them as either song or irregular interval calls. Watkins (1981) and Širović *et al.* (2012) also report a fin whale 40 Hz pulse which sweeps down in frequency from 75 to 40 Hz (Figure 5). While there was logging effort for these calls, however, no 40 Hz pulses were detected in the JAX acoustic data.

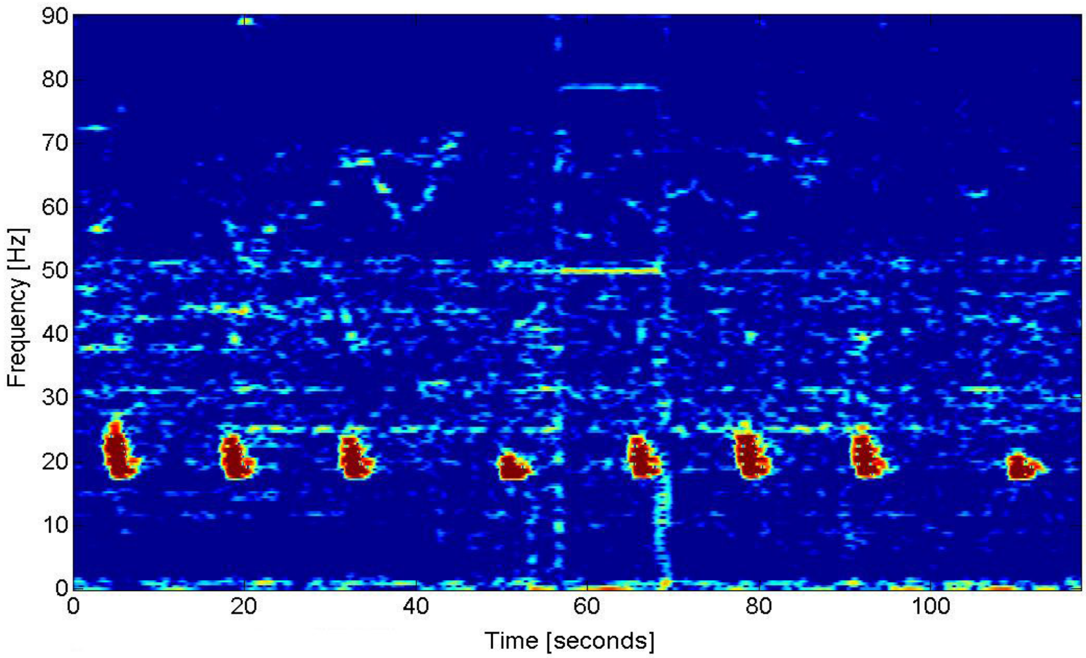


Figure 4. Fin whale 20 Hz pulse, created in regular pattern or song. Site A on January 24, 2011.

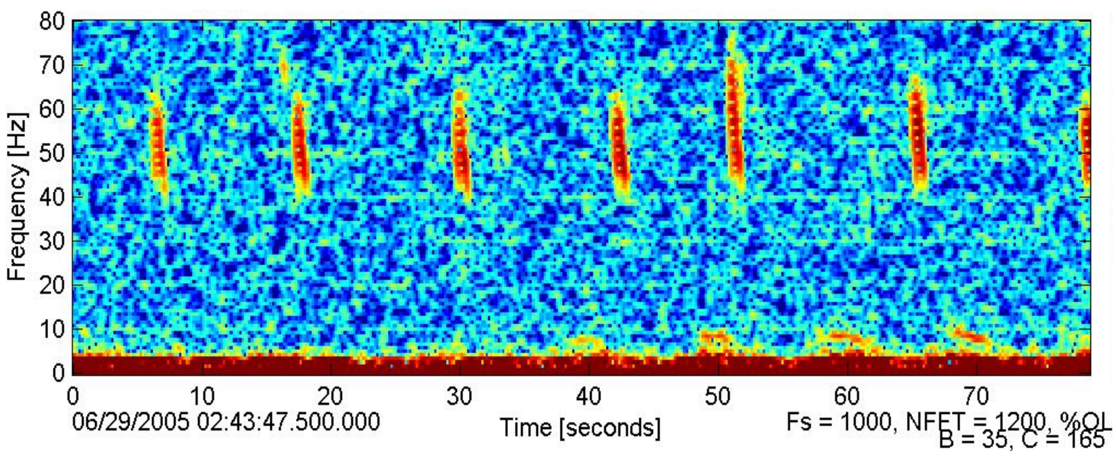


Figure 5. Fin whale 40 Hz pulse, from Bering Sea HARP data.

Minke Whales

Minke whales in the North Atlantic produce long pulse trains. Mellinger *et al.* (2000) describe minke whale pulse sequences as speed-up and slow-down pulse trains (increasing and decreasing pulse rate), centered around 150 Hz (Figure **6**). Another type of pulse train centered around 50 Hz (50 Hz pulse) has also recently been found in the North Atlantic (Figure **7**).

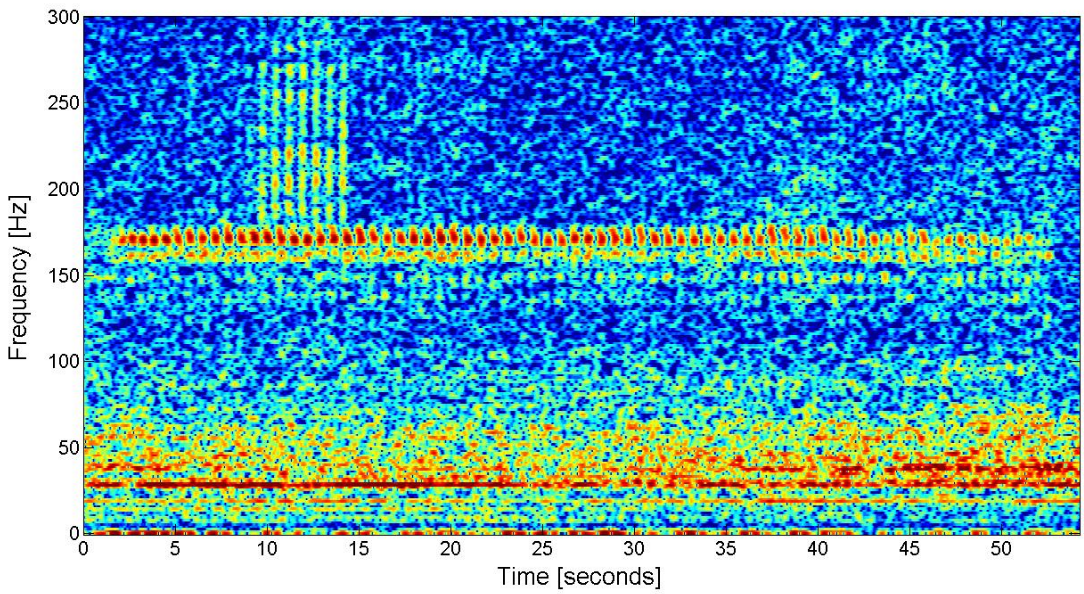


Figure 6. Minke whale speed-up/slow-down pulse train. Site A on February 10, 2011.

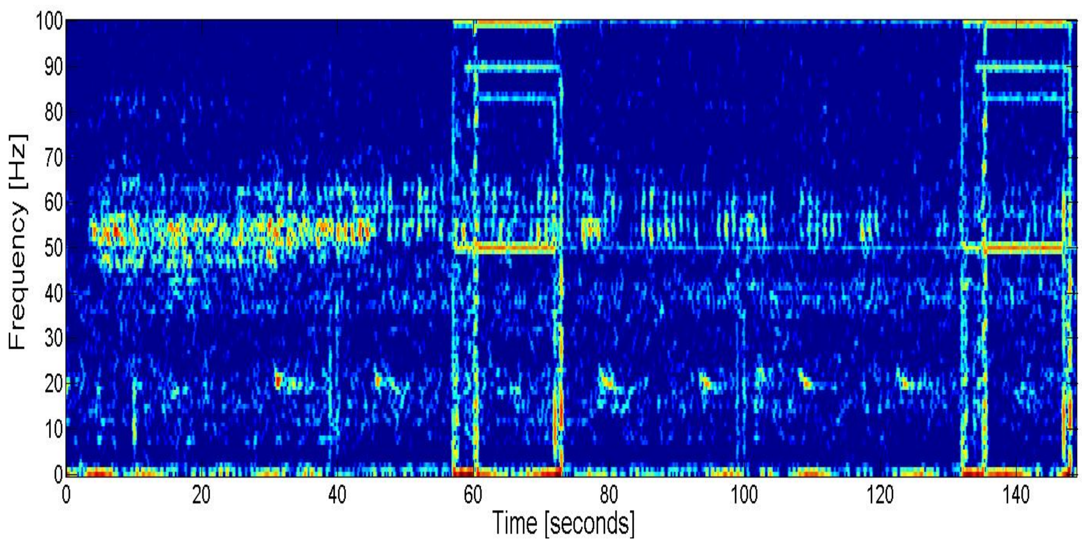


Figure 7. Minke whale 50 Hz pulses. Site A on January 17, 2011.

Bryde's Whales

Bryde's whales inhabit tropical and subtropical waters worldwide (Omura 1959, Wade & Gerrodette 1993), and the JAX region is considered their northerly range limit. 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 Be7 call has a fundamental frequency of 44 Hz and ranges in duration between 0.8 and 2.5 seconds with an average intercall interval of 2.8 minutes (Figure **8**). The Be9 call type, described for the Gulf of Mexico (Sirovic *et al.* 2013), is a downswept pulse ranging from 143 to 85 Hz, with each pulse approximately 0.7 seconds long (Figure **9**). Neither Bryde's whale call type was detected in the JAX data.

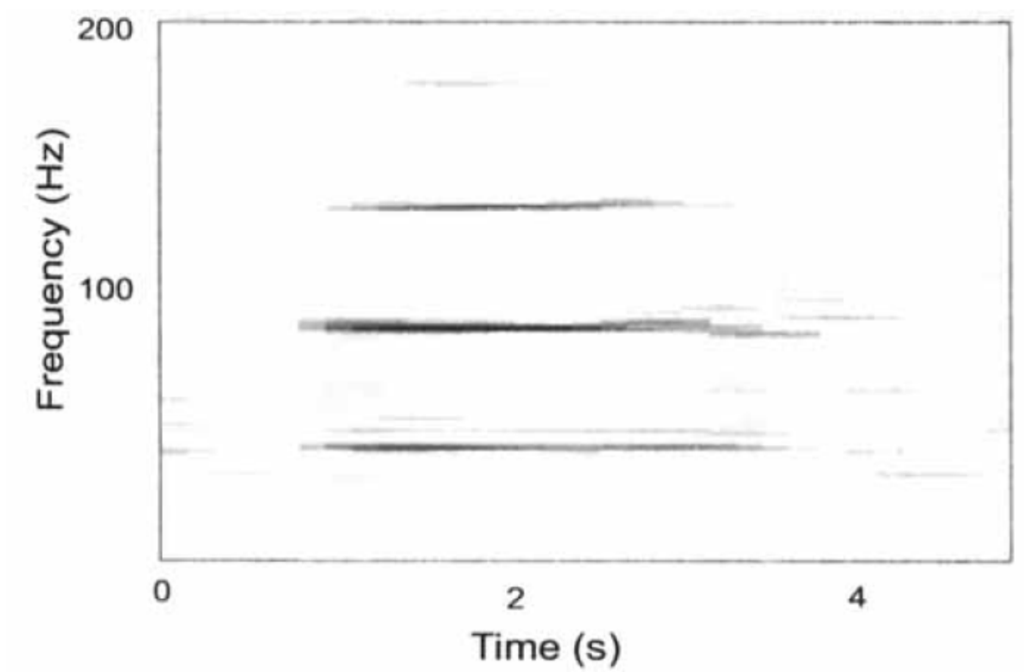


Figure 8. Spectrogram of Bryde's whale Be7 call type, from Oleson et al. (2003).

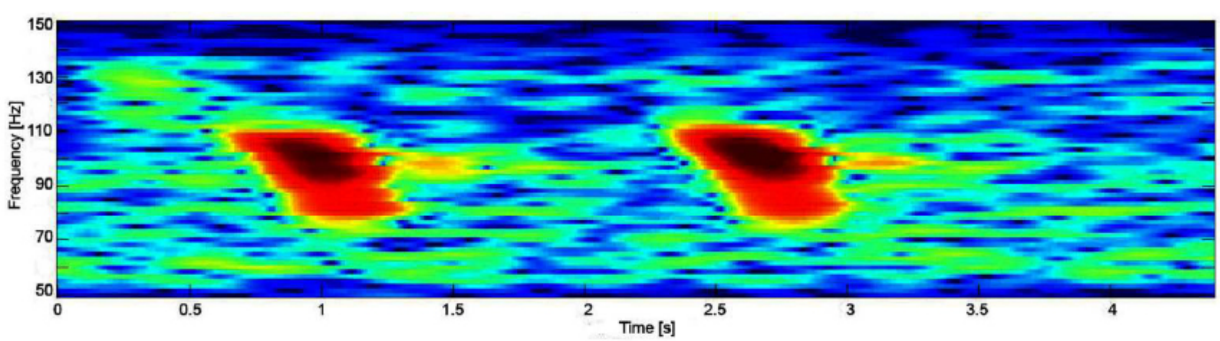


Figure 9. Bryde's whale Be9 call type from Sirovic et al. (2013).

Sei Whale

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). While several sounds have been attributed to sei whales, we report on a low frequency downsweep call similar to those Baumgartner reports as sei whale calls (Baumgartner *et al.* 2008). These calls typically sweep from a starting frequency around 100 Hz to an ending frequency around 40 Hz (Figure **10**).

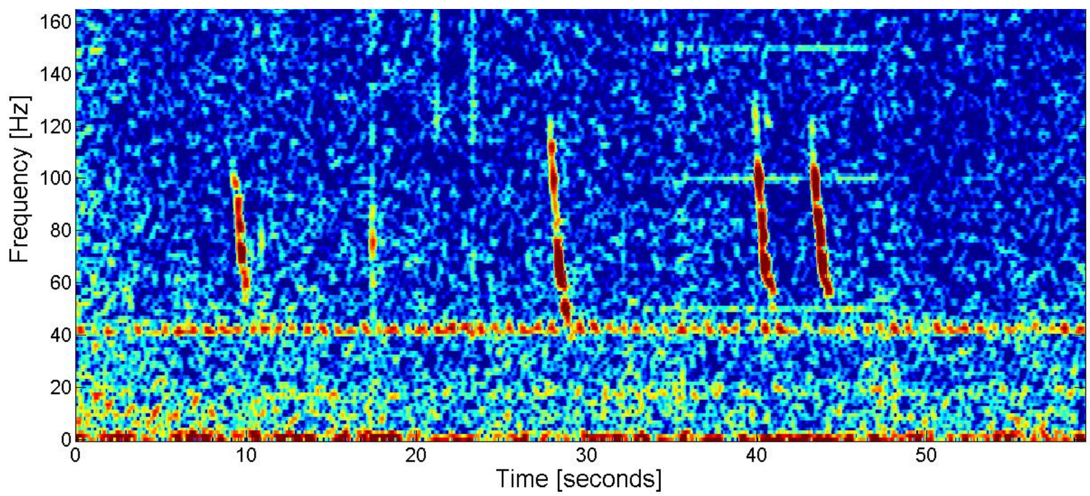


Figure 10. Downsweep calls believed to be from Sei whales. Site A on December 26, 2010.

North Atlantic Right Whale

The North Atlantic right whale is a critically endangered whale found in the Western North Atlantic. Several call types that have been described for the North Atlantic right whale including the scream, gunshot, blow, upcall, warble, and downcall (Parks & 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 3 kHz (Figure 11). No right whale upcalls were detected.

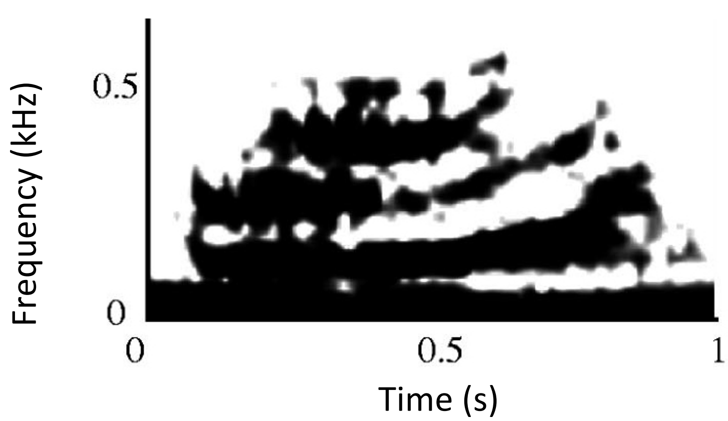


Figure 11. Right whale upcall call from Parks and Tyack (2005).

Mid-Frequency Marine Mammals

For mid-frequency data analysis, the raw 200 kHz HARP data were decimated by a factor of 20 for an effective bandwidth of 5 kHz. The LTSAs for mid-frequency data analysis are created using a time average of 5 seconds, and a frequency bin size of 10 Hz. The presence or absence of each call type was determined in hourly bins.

Mid-frequency sounds monitored in this report include: humpback whale, minke whale speed-up/slow-down pulses, North Atlantic right whale gunshot calls, and killer whale whistles. LTSA search parameters used to search for each sound are given in Table 4.

Table 4. Mid-frequency data analysis search parameters.

	LTSA Search Parameters	
Species	Plot Length (Hr)	Frequency Range (Hz)
N Atlantic Right Whale (gunshot calls)	0.75	1000-5000
Killer Whale (whistles)	3.0	0-5000

Humpback Whale

Humpback whales song is categorized by the repetition of units, phrases and themes as defined by Payne and McVay (1971). Non-song vocalizations such as social sounds and feeding sounds consist of individual units that can last from 0.15 to 2.5 seconds (Dunlop *et al.* 2007, Stimpert *et al.* 2011). Most humpback whale vocalizations have acoustic energy between 100-3000 Hz (Figure **12**). For this report we detected humpback calls (both song and non-song) using the generalized power-law algorithm (Helble *et al.* 2012), and then used a trained analyst to verify the accuracy of the detected signals.

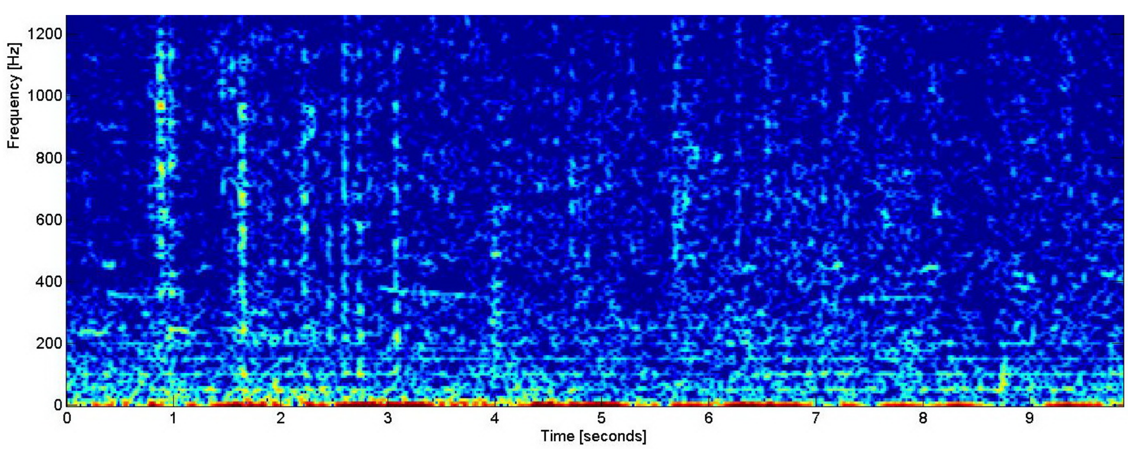


Figure 12. Humpback whale calls recorded at site A on April 13, 2011.

North Atlantic Right Whale

North Atlantic right whale gunshot calls are high intensity (~196 dB pp re 1 µPa) and broadband (20 Hz – 20 kHz) (Parks *et al.* 2005) and were therefore included in mid-frequency analysis. Gunshot calls exhibit an initial signal followed by prolonged reverberation (Figure **13**). Although these calls are capable of being detected at a several miles range, no right whale gunshot calls were detected in the JAX data.

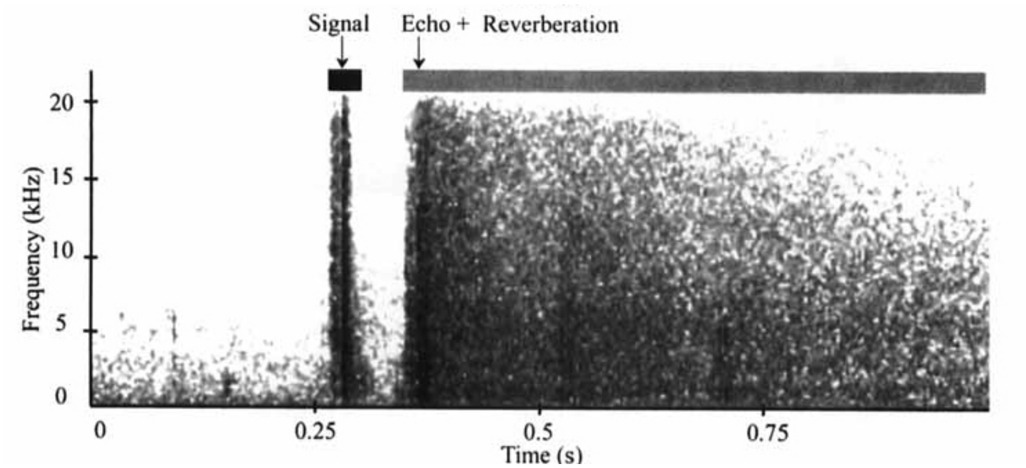


Figure 13. North Atlantic Right whale gunshot call from Parks et al, 2005.

Killer Whale

Killer whales are a cosmopolitan species, though little is known about killer whales off the east coast of the United States (Gormley 2000). Few sightings of killer whales have ocurred on the shelf (Katona *et al.* 1988). Acoustic parameters from known Western Atlantic killer whale calls were used to search for killer whale calls (Figure **14**). Neither killer whale whistles, calls nor clicks were detected in the JAX data.

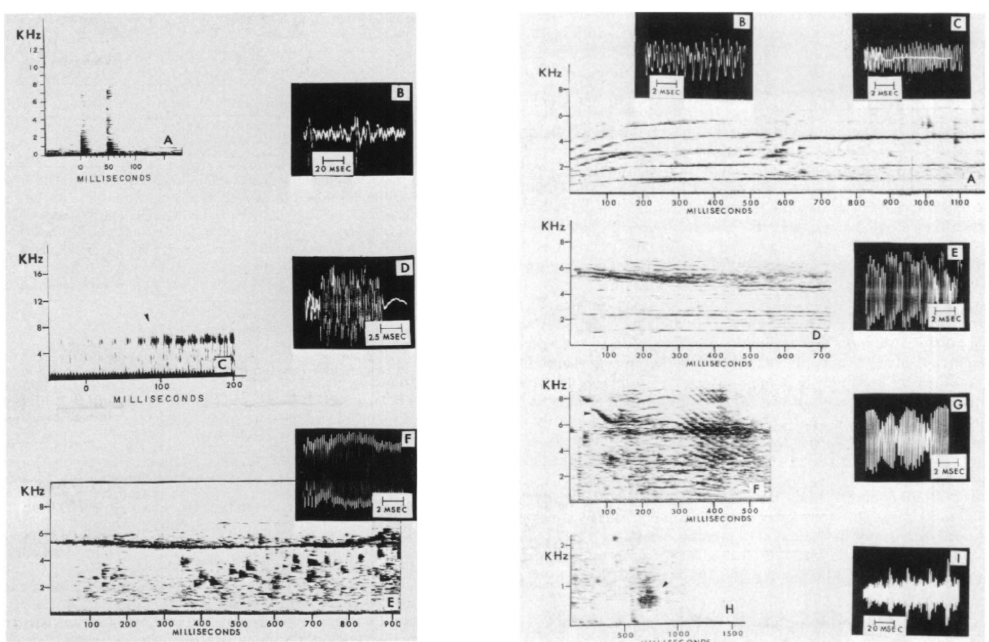


Figure 14. Killer whale vocalizations from Steiner *et al.* (1979).

High-Frequency Marine Mammals

For the high frequency data analysis, spectra were calculated for the full effective bandwidth of 100 kHz. The LTSAs were created using a time average of 5 seconds and a frequency bin size of 100 Hz. The presence of call types was determined in one-minute bins.

Unidentified Dolphin

Delphinid sounds can be categorized as either: (1) echolocation clicks, (2) buzz pulses, or (3) whistles. Dolphin echolocation clicks are broadband impulses with the majority of energy between 20 and 80 kHz. Buzz pulses are rapidly repeated clicks that have a creak or buzz-like sound quality; they are in approximately the same frequency band as the echolocation clicks. Dolphin whistles are tonal calls predominantly between 5 and 25 kHz that vary in their degree of frequency modulation as well as duration. These signals are easily detectable in an LTSA as well as the spectrogram (Figure 15). Only some delphinid sounds are distinguishable by species based on the character of their clicks, buzz pulses or whistles (Roch *et al.* 2011, Roch *et al.* 2007).

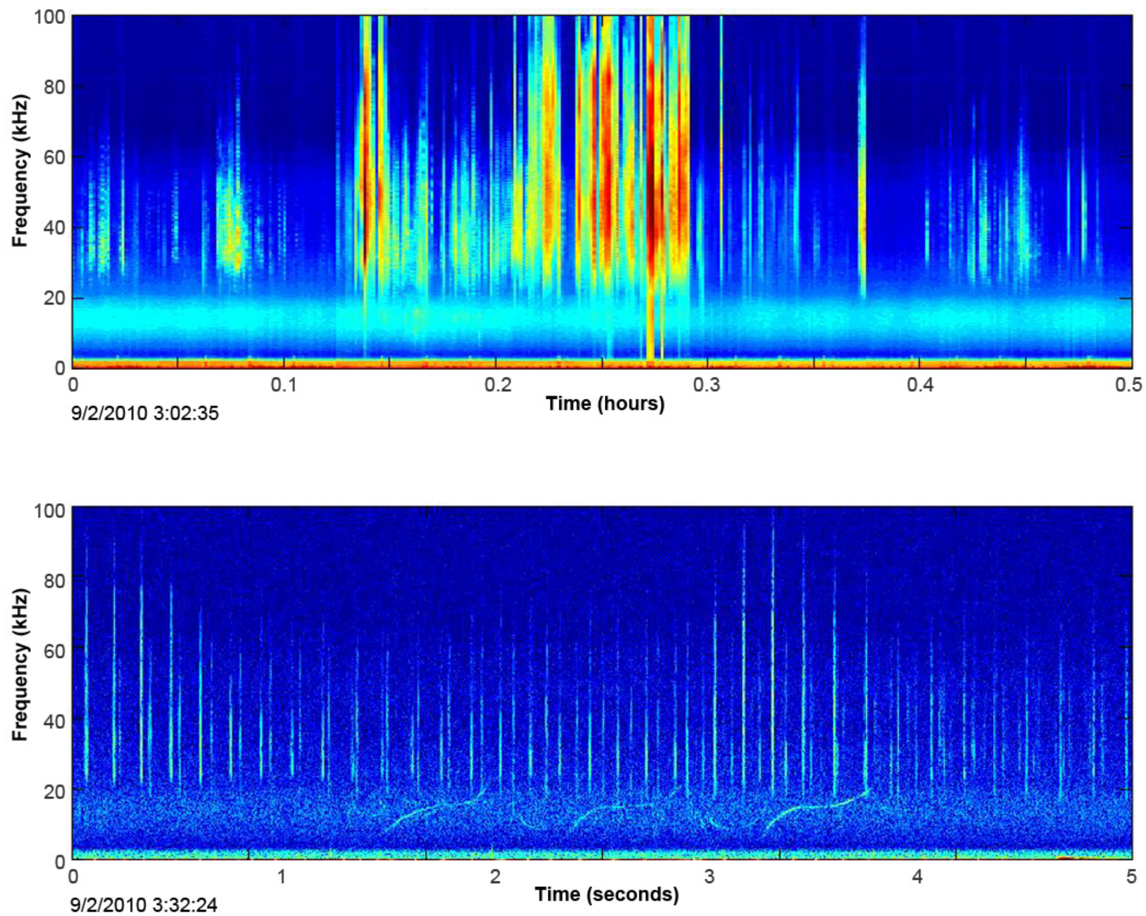


Figure 15. LTSA (top) and spectrogram (bottom) of odontocete echolocation clicks and whistles.

Risso's Dolphin

Risso's dolphin echolocation clicks can be identified to species by their distinctive banding patterns in the LTSA (Figure 16). Risso's dolphin echolocation clicks in southern California are known to have energy peaks at 22, 26, 30, and 39 kHz (Soldevilla *et al.* 2008). Our analysis found Risso's dolphin energy peaks at 23, 26, 35, 44 kHz, similar to that previously reported for the JAX area (Soldevilla et al. 2011).

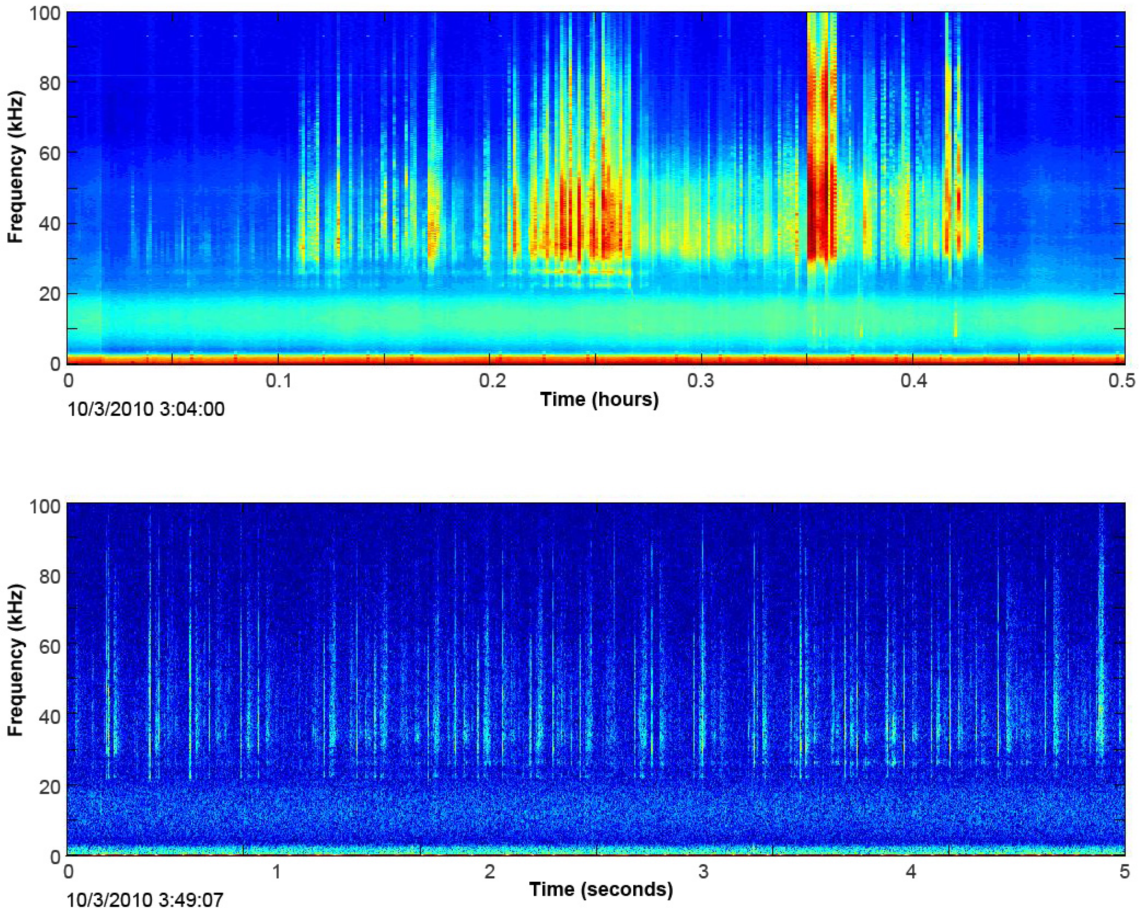


Figure 16. Risso's dolphin click bout in LTSA (above) and spectrogram (below). A distinctive banding pattern is seen in the LTSA.

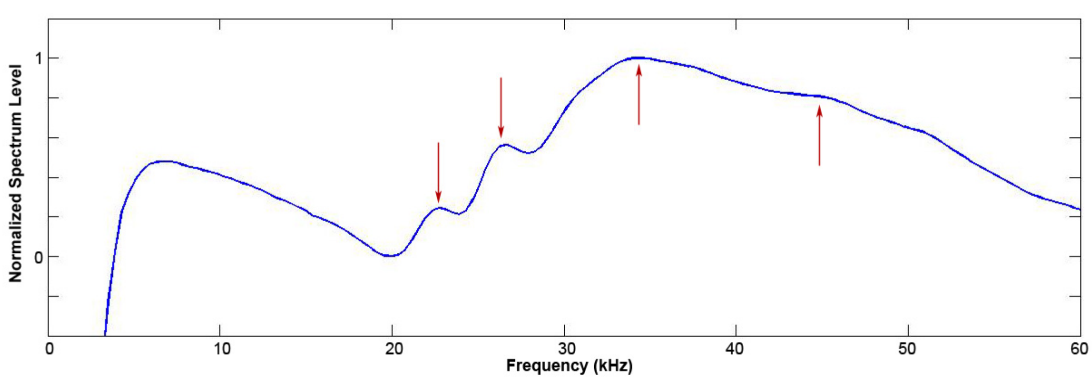


Figure 17. Risso's dolphin echolocation click mean spectra. Arrows show locate spectral peaks.

Echolocation Click Types

An analysis was conducted to describe echolocation clicks from unidentified odontocetes (UO). Click type (CT) mean spectra from HARP recordings in the Gulf of Mexico, analyzed and defined by Kait Frasier, and off the coast of North Carolina, analyzed and defined by Lynne Williams, were used as templates. These previous analyses were combined and provided thirteen distinct mean click spectra. All click types had dominant energy above 20 kHz. They differed in the prominence of spectral peaks below 20 kHz, and in the slope and onset of the lower frequency bound in their main spectral energy band. A custom software routine displayed mean click templates and overlaid novel spectra of manually detected acoustic encounters in JAX. A trained analyst determined, based on spectral content, whether an acoustic encounter remained UO or was classified as a CT. Based on a complete analysis of all deployments reported here, five CT (Figure **18**) were identified at least ten times within one deployment and will be described below. CT were then assigned names based on the frequency at which their spectra reached 50% of maximum energy (e.g CT25 = 25 kHz for the 50% energy level).

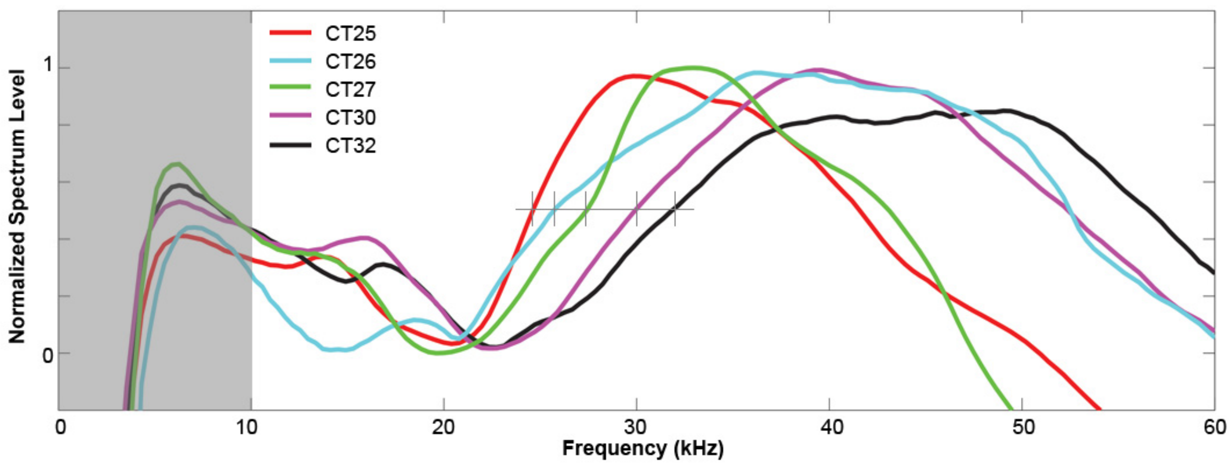


Figure 18. Echolocation click types (CT) that occurred in JAX recordings repeatedly. Numerical values (e.g. CT25 = 25 kHz) refers to low end of 50% energy bandwidth.

Click Type 25

CT 25 (Figure **19**) reaches its 50% maximum energy at approximately 25 kHz and has a peak frequency of about 33 kHz. It has a smaller peak at 15 kHz with troughs at 12 and 20 kHz (Figure **20**).

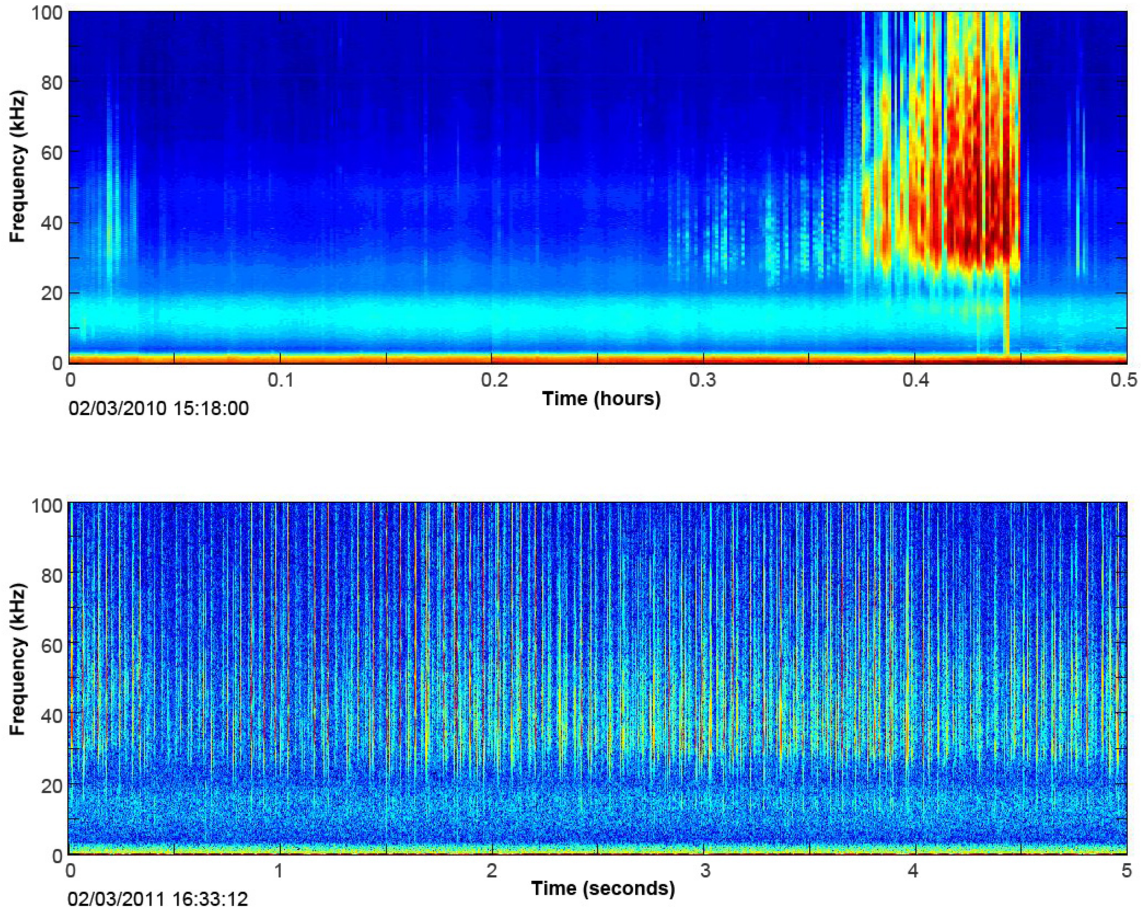


Figure 19. CT25 in the LTSA (above) and spectrogram (below).

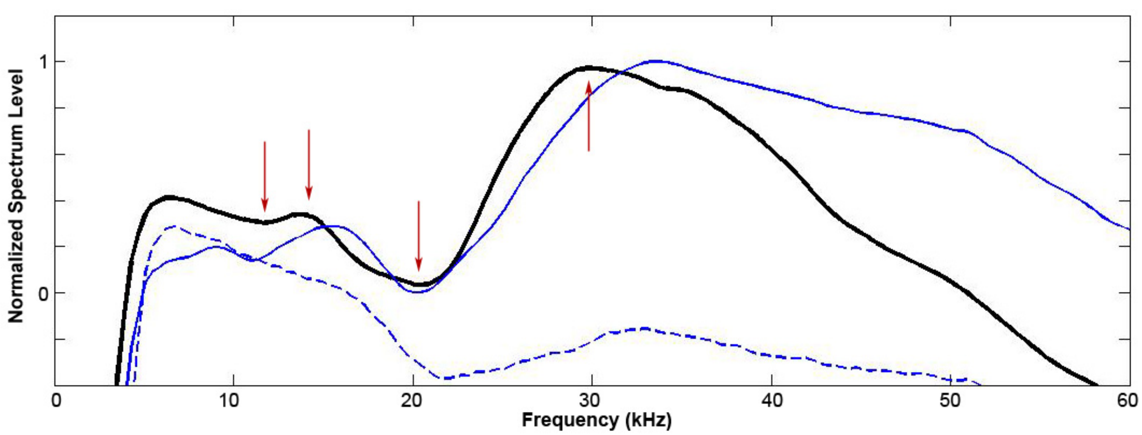


Figure 20. Mean Spectra of clicks for CT25. Example encounter (black line), template for CT (blue line; from G of Mex and/or North Carolina), noise floor (dotted line). Arrows are spectral peaks or troughs.

Click Type 26

CT 26 (Figure **21**) reaches its 50% maximum energy at approximately 26 kHz and has a peak frequency of about 35 kHz. It has a smaller peak at 18 kHz with troughs at 15 and 21 kHz (Figure **22**).

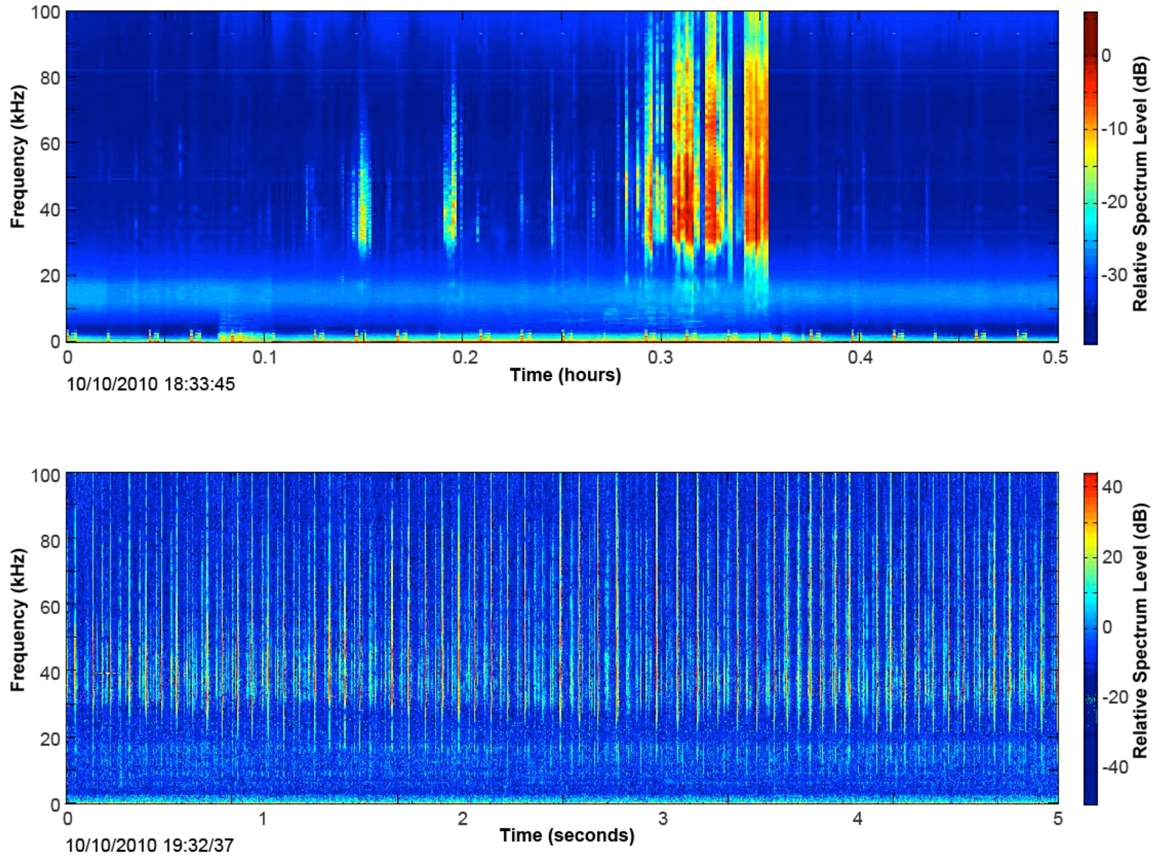


Figure 21. CT26 in the LTSA (above) and spectrogram (below).

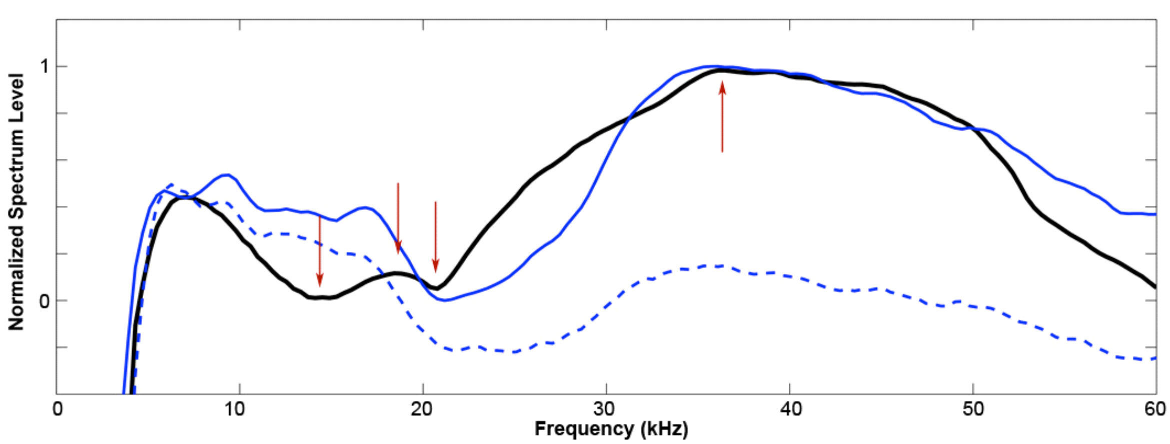


Figure 22. Mean Spectra of clicks for CT26. Example (black line), template (blue line), and noise floor (dotted line). Arrows are spectral peaks or troughs.

Click Type 27

CT 27 (Figure **23**) reaches its 50% maximum energy at approximately 27 kHz and has a peak frequency of about 35 kHz. It has a smaller peak at 16 kHz ranging with troughs at 11 and 20 kHz (Figure **24**).

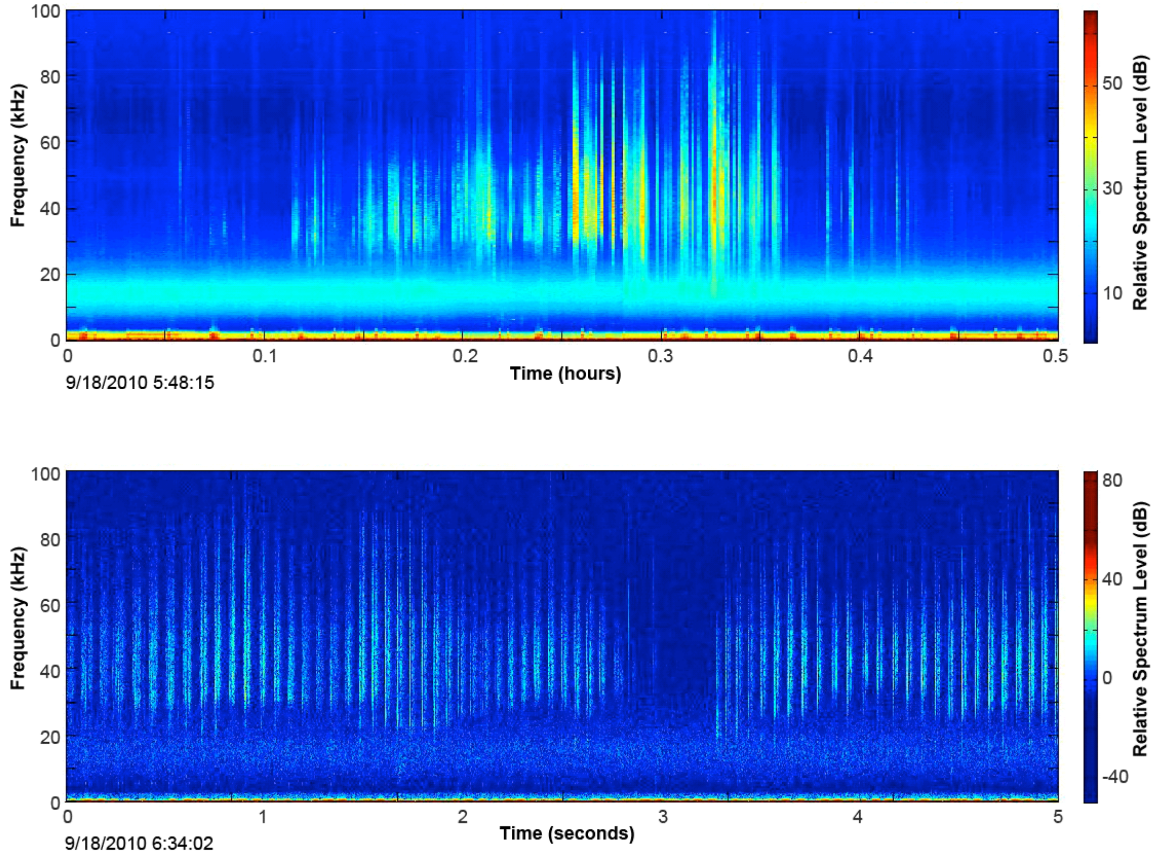


Figure 23. CT27 in the LTSA (above) and spectrogram (below).

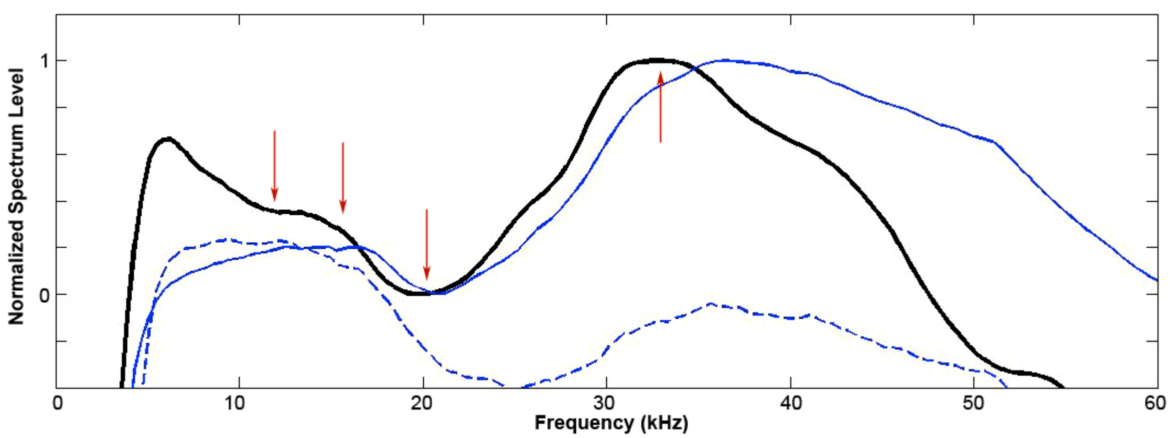


Figure 24. Mean spectra of CT27. Example (black line), template (blue line), and noise floor (dotted line). Arrows are spectral peaks or troughs.

Click Type 30

CT 30 (Figure **25**) reaches its 50% maximum energy at approximately 30 kHz and has a peak frequency of about 37 kHz. It has a smaller peak at 16 kHz with troughs at 12 and 22 kHz (Figure **26**).

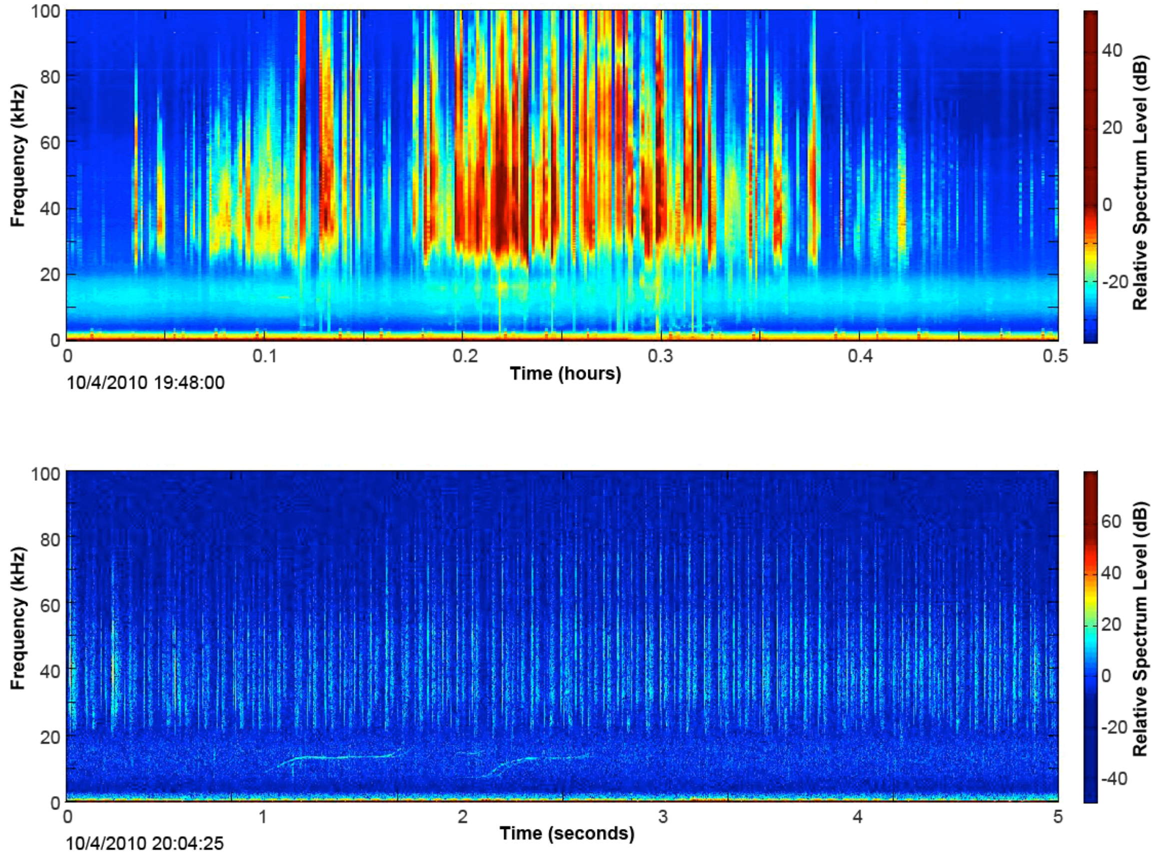


Figure 25. CT30 in the LTSA (above) and spectrogram (below).

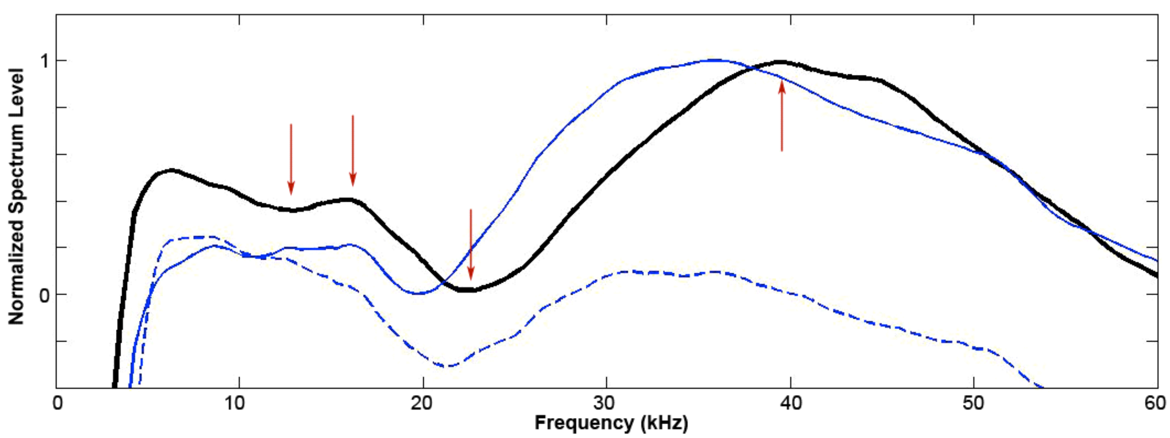


Figure 26. Mean Spectra of CT30. Example (black line), template (blue line), and noise floor (dotted line). Arrows are spectral peaks or troughs.

Click Type 32

CT 32 (Figure 27) reaches its 50% maximum energy at approximately 32 kHz and has a peak frequency of about 39 kHz. It has a smaller peak at 17 kHz with troughs at 15 and 22 kHz (Figure 28). Clicks with high received level (Figure **29**) show a peak between 4-6 kHz (Figure **30**). This low peak becomes apparent in LTSAs but a high pass filter cuts it out in the mean spectra.

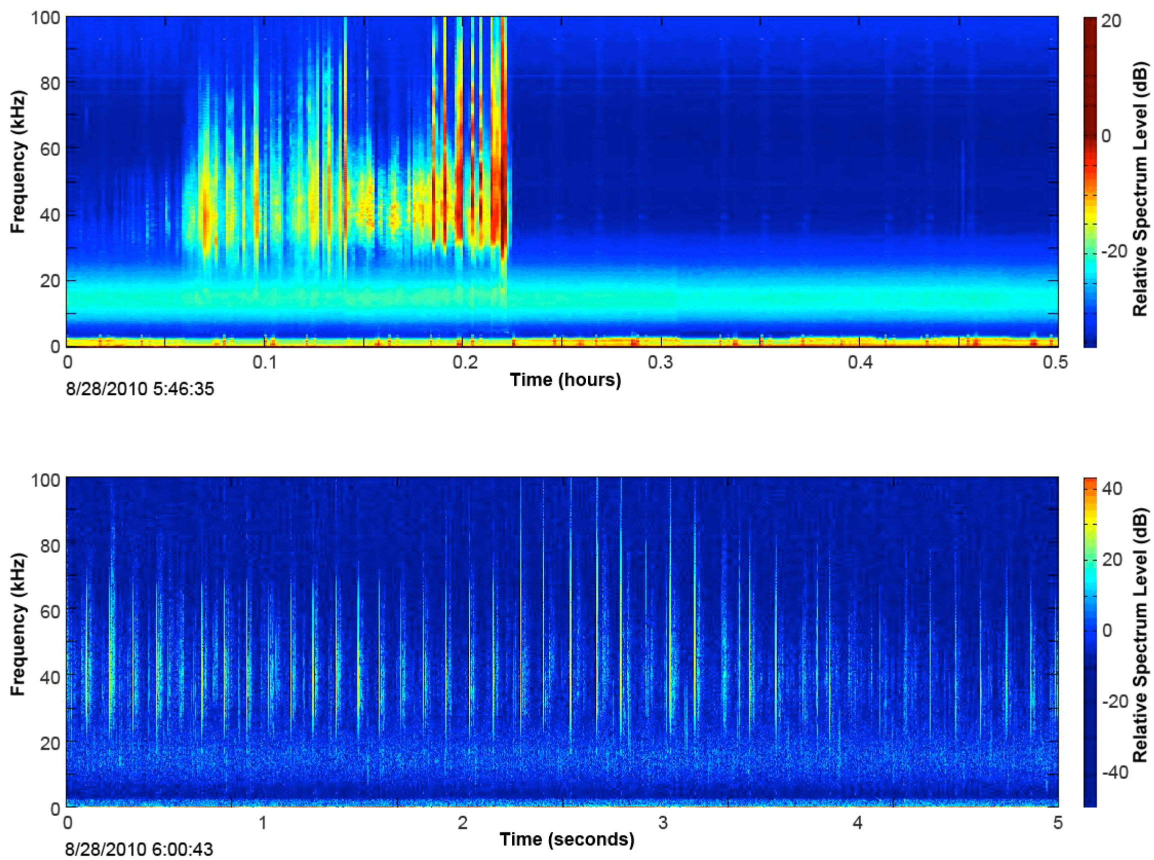


Figure 27. CT32 in the LTS A (above) and spectrogram (below).

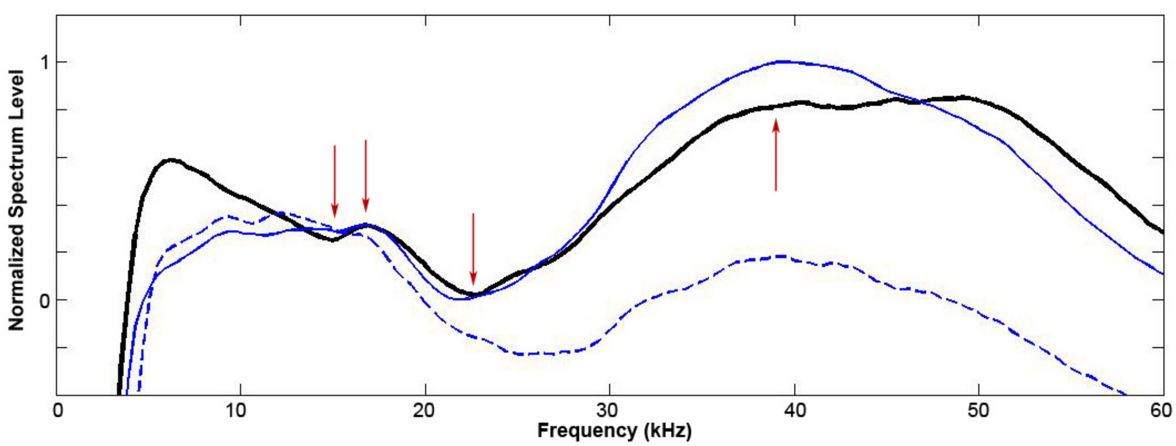


Figure 28. Mean Spectra of CT32. Example (black line), template (blue line), and noise floor (dotted line). Arrows are spectral peaks or troughs.

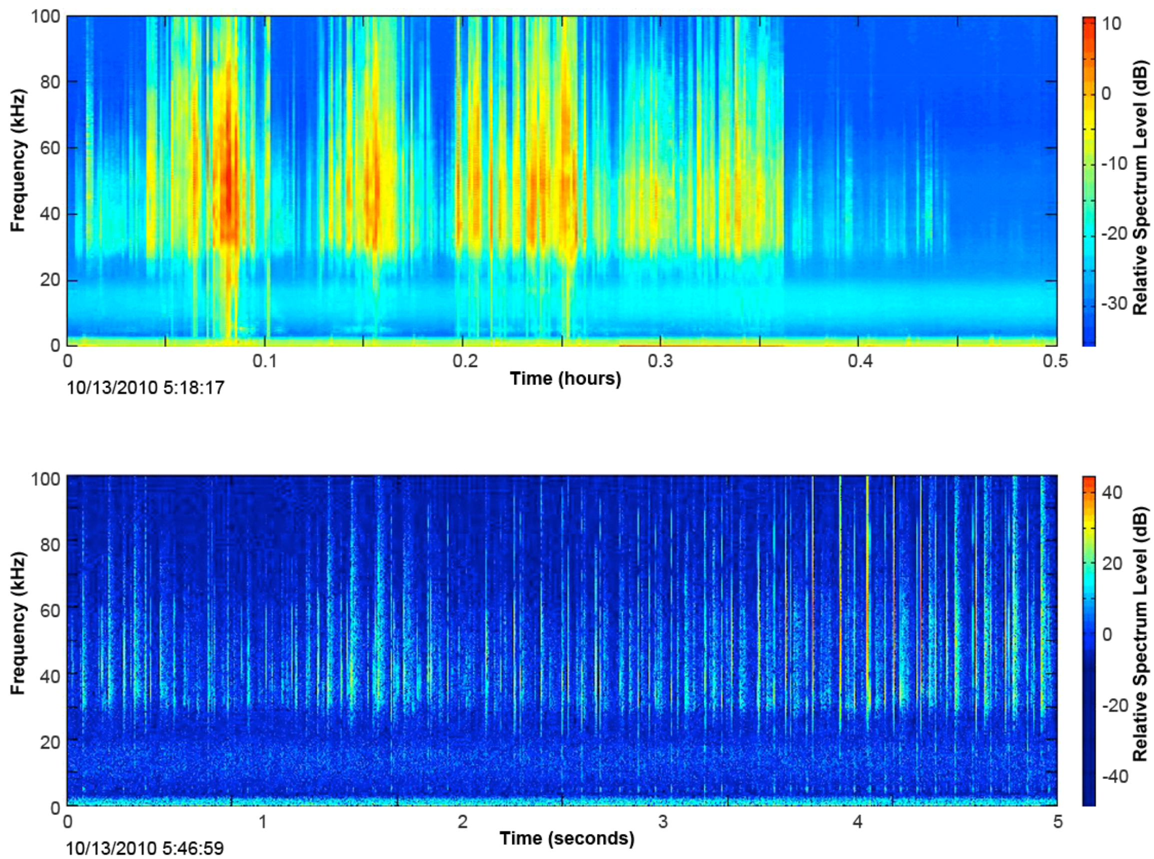


Figure 29. CT32 (emphasizing 4-6 peak) in the LTSA (above) and spectrogram (below).

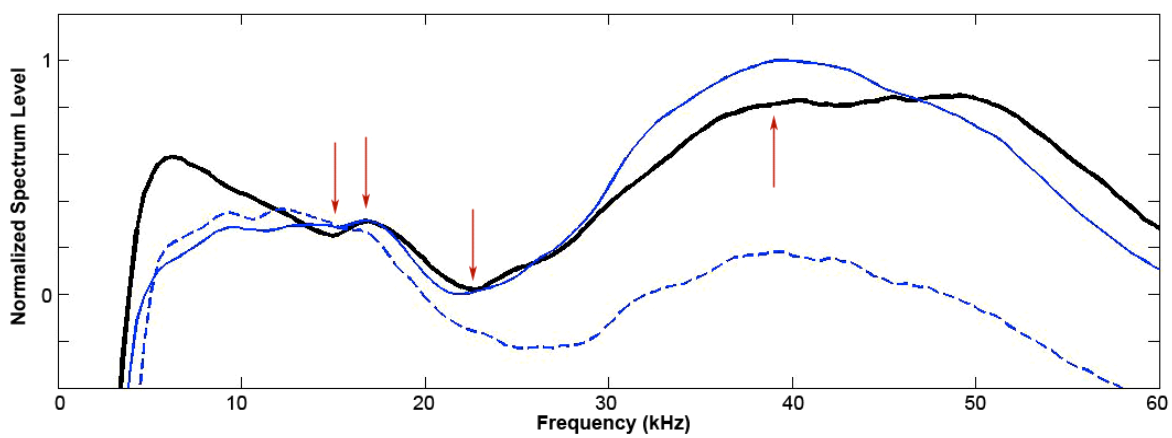


Figure 30. Mean Spectra of CT32. Example (black line), template (blue line), and noise floor (dotted line). Arrows are spectral peaks or troughs.

Sperm Whale

Sperm whales produce echolocation clicks in the frequency range 5 – 20 kHz. Care must be taken not to misclassify impulsive anthropogenic sounds that maintain a similar frequency to sperm whales. No definitive sperm whale encounters were found in the JAX data. Similar findings were reported by Soldevilla et al. (2011).

Anthropogenic Sounds

Broadband Ship Noise

Broadband ship noise occurs when a ship passes relatively close to the HARP. 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. Combination of direct paths and surface reflected paths produce constructive and destructive interference (bright and dark bands) in the spectrogram that vary by frequency and distance between the ship and the HARP (Figure **31**). This noise can extend to well above 10 kHz, though typically falls off above a few kHz.

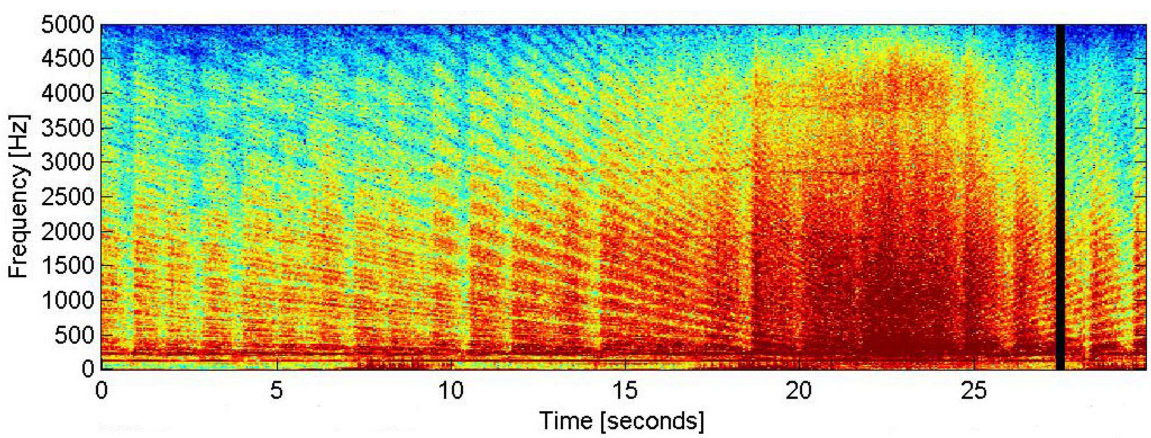


Figure 31. Broadband ship noise in the LTSA (above) and spectrogram (below).

Mid-Frequency Active Sonar

Many types of active sonar are used in the Jacksonville Range Complex. Their frequencies span 1 kHz to over 50 kHz and include short duration pings, frequency modulated (FM) sweeps and short and long duration continuous wave (CW) tones. One common type of sonar used in JAX is mid-frequency active (MFA) sonar. Sounds from MFA sonar vary in frequency and duration and can be used in a combination of FM sweeps and CW tones; however, many of these are between 2 and 5 kHz and are generically known as '3.5 kHz' sonar. We describe the process for identifying MFA sonar and how pings from these events were analyzed, including counts and distributions of sonar levels.

The first step in analyzing MFA sonar was conducted by an analyst scanning for periods of sonar activity. Start and end times of MFA sonar events from LTSAs were noted to provide target periods for automatic detections. Full bandwidth (10Hz – 100kHz) data were used to calculate the spectra for the LTSAs with 100 Hz frequency bin-width and 5 s time bin width. These spectra were arranged sequentially to provide a long-term spectrogram so that hours of data can be easily displayed for analysis. Individual MFA sonar pings typically span 1 – 3 s, but are intense enough to show up as 'pulses' in LTSA plots (Figure **32**). LTSA display parameters used by the analyst were 1 or 2 hour window length, and 2 – 5 kHz bandwidth.

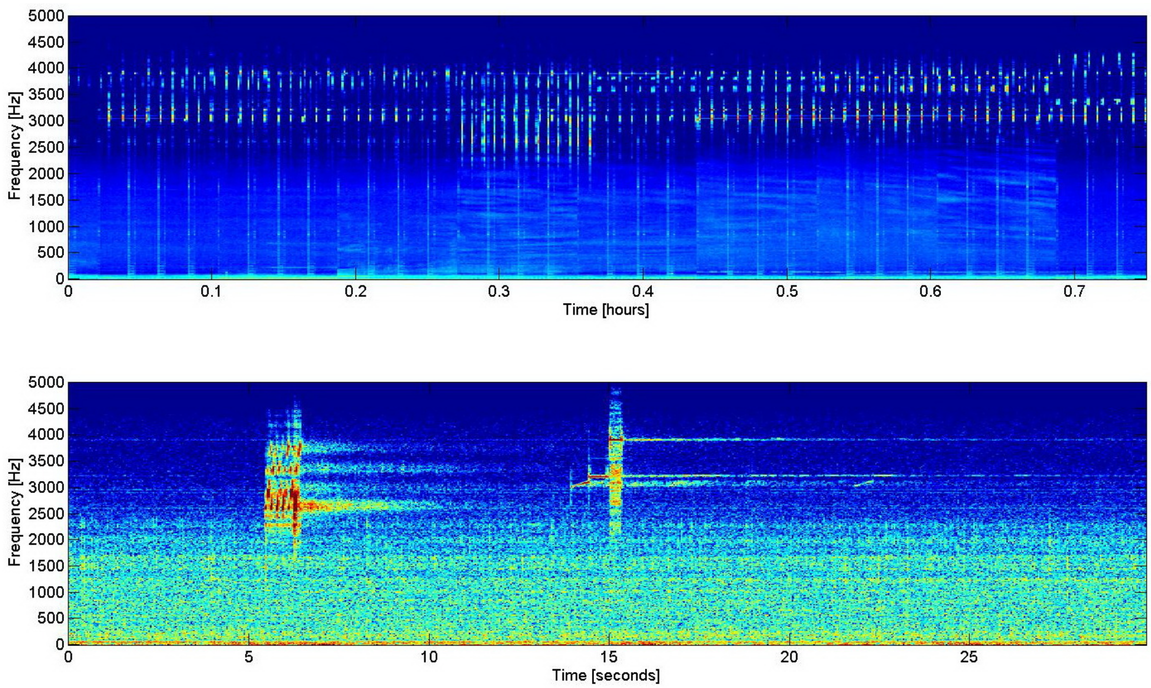


Figure 32. Mid-frequency active (MFA) sonar event. (Top) Long-Term Spectral Average of 45 minutes of data. (Bottom) Spectrogram of with multiple sonar pings.

A custom developed software routine was used to detect sonar pings and calculate peak-to-peak (PP) received sound pressure levels. For this detector, a sonar ping is defined as the presence of sonar within a 5 s window and may contain multiple individual pings (Figure 32. The detector calculates the average spectral level across the frequency band from 2.4 to 4.5 kHz for each 5 s window. This provides a long-term time series of the average received levels in that frequency band. Minimum values were noted for each 15 time bins, and used as a measure of background noise level over the sonar event period. Spectral bins that contained system noise (disk writing) were eliminated. 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 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 HARP calibrated transfer function for this frequency band. The HARP response is not flat over the 2.4 – 4.5 kHz band, and the value at 3.3 kHz was used to approximate the entire band. The transfer function value for site 5A was 83.1 dB re $\mu Pa^2/counts^2$ while the transfer function value for site 6A was 82.3 dB re $\mu Pa^2/counts^2$. The transfer function value used for site 5B was 62.8 dB re $\mu Pa^2/counts^2$. There were no MFA ping events in site 6B. For sonar pings less than this 3.3 kHz, the levels are overestimated up to about 5 dB and for higher frequency sonar the levels are underestimated up to about 4 dB.

Echosounder

Echosounder pings were detected in a variety of frequencies (8-80 kHz); they are easily identified as lines in the LTSA (Figure **33**).

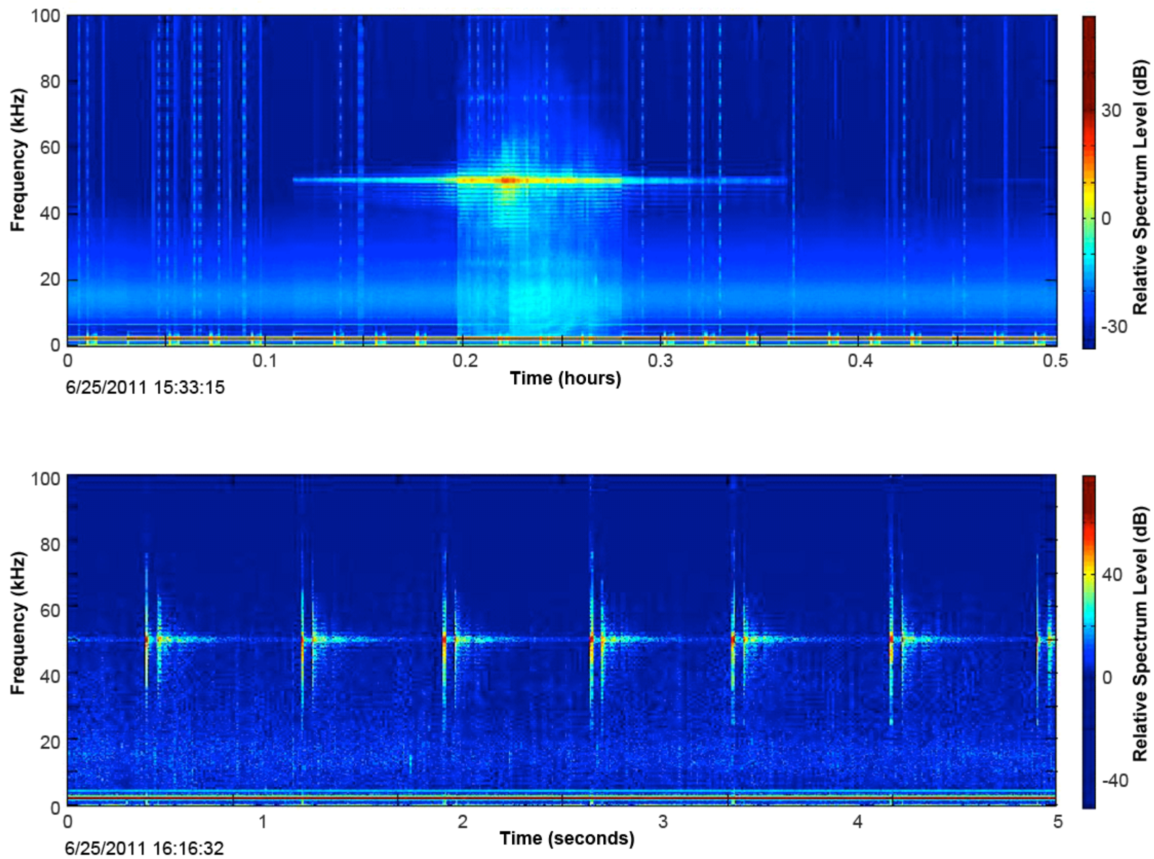


Figure 33. Echosounder in the LTSA (above) and spectrogram (below).

Explosions

Explosive sounds logged in the HARP data include 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, and when expanded in the spectrogram has a sharp onset with a reverberant decay (Figure 34). These sounds have peak bandwidth as low as 10 Hz and often extend up to 2000 Hz or higher, lasting for several seconds including the reverberation.

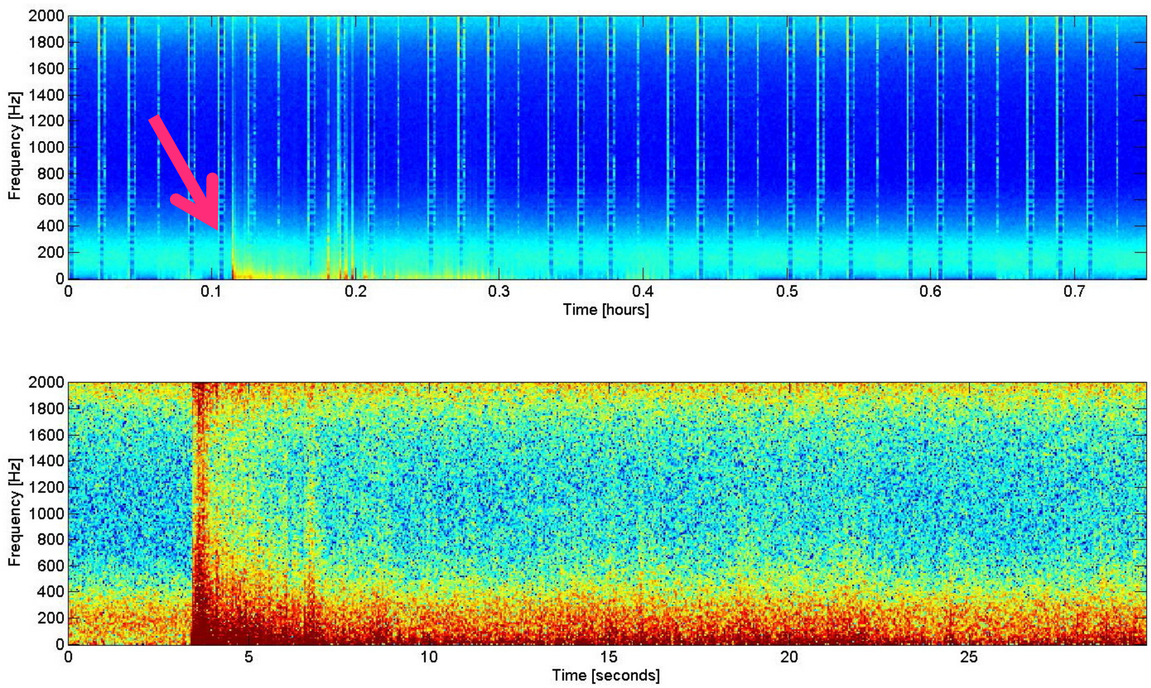


Figure 34. Five explosions are seen in the LTSA (arrow above) and one is expanded in the spectrogram (below). Site A on April 8, 2011.

Results

This report summarizes analysis of acoustic data collected from August 2010 - July 2011 at two sites in the Jacksonville Range Complex. We discuss ambient noise as well as the seasonal occurrence and relative abundance of marine mammal species and anthropogenic sounds.

Ambient Noise

Underwater ambient noise at sites A and B has spectral shapes with higher levels at low frequencies (Figure 35), owing to the presence of ship noise with secondary contributions from local wind and waves (Hildebrand 2009). An additional component of noise in the JAX data was due to mooring strum and fluid motion near the hydrophone sensor. These instrumental noise sources may have contributed to ambient noise levels at both sites that varied by as much as 20 dB at low frequency between monthly averages (Figure **35**). The months of February and March 2011 had very high noise levels at Site B.

Periods with high ambient noise at low frequency will result in lowered detection range for mysticetes calls. We attempted to quantify when high noise levels impacted the ability to detect low frequency calls (Appendix).

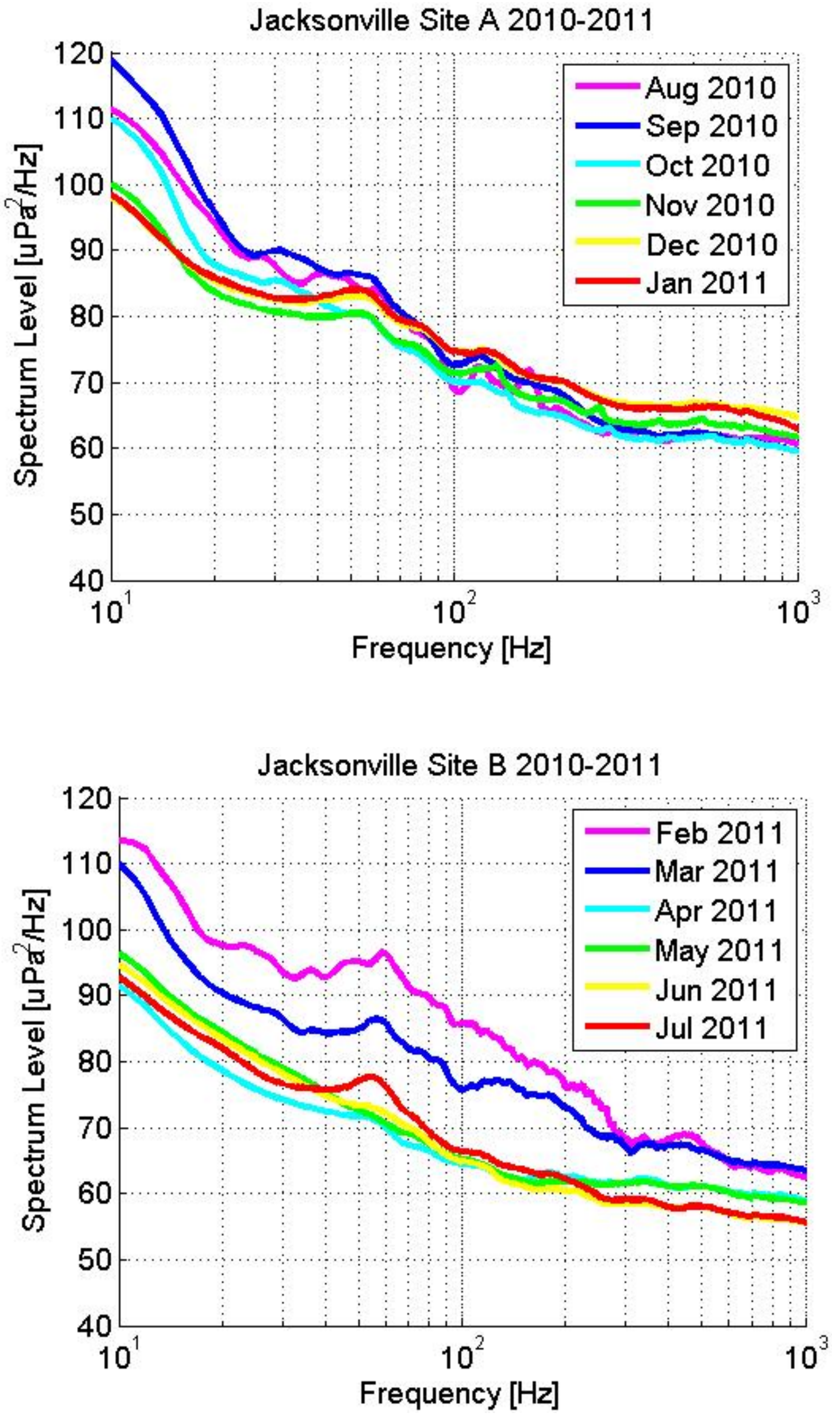


Figure 35. Monthly averages of ambient noise at site A (above) and site B (below) for the period August 2010 – July 2011. Legend gives color-coding by date.

Mysticetes

Four species of mysticete whales were recorded between August 2010 and July 2011 at sites A and B: fin, minke, sei, and humpback. In addition, the 5-pulse sound was detected, which we believe to be produced by a mysticete whale. No known blue or Bryde's whales sounds were detected at either site, nor were North Atlantic right whale upcalls or gunshot calls.

Site A was frequented by calling mysticete whales more often than site B. Fin, minke, and sei whale calls were all detected during more hours at site A, although this may be partially due to the higher ambient noise levels at site B during certain seasons, decreasing call detection ranges (Figure **35**).

Fin Whales

Fin whale 20 Hz calls were detected at site A in late January and early February (Figure **36**). Fin whale 40 Hz calls were not detected at either site, nor were there any 20 Hz calls at site B.

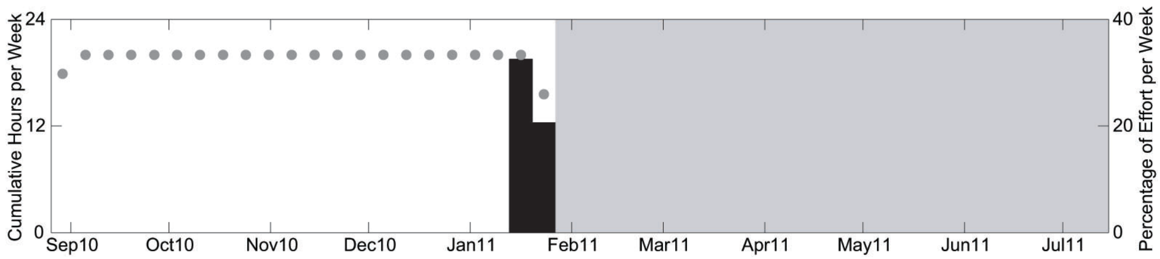


Figure 36. Weekly fin whale 20 Hz call presence at site A between August 2010 and February 2011. The area shaded in gray represents the section of data that were missing or corrupt. The light gray dots represent weekly recording effort.

Minke Whales

Two minke whale call types were recorded. 50 Hz pulses were recorded at site A, while no 50 Hz pulses were recorded at site B (Figure **37**). Minke whale pulse trains were recorded at both sites (Figure 38).

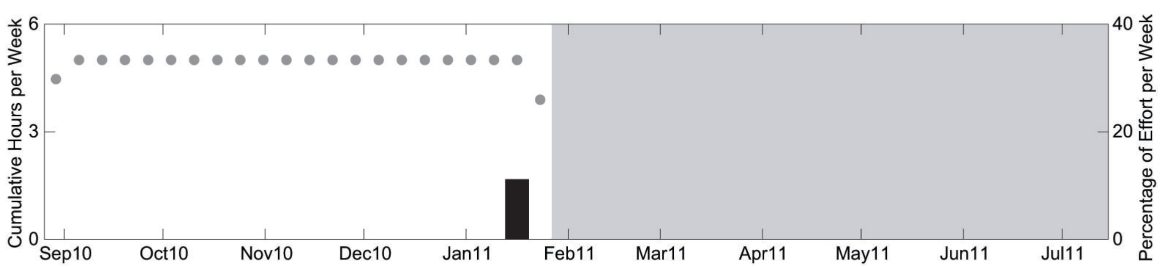


Figure 37. Occurrence of minke whale 50 Hz pulses at site A. Effort as described in Figure 36

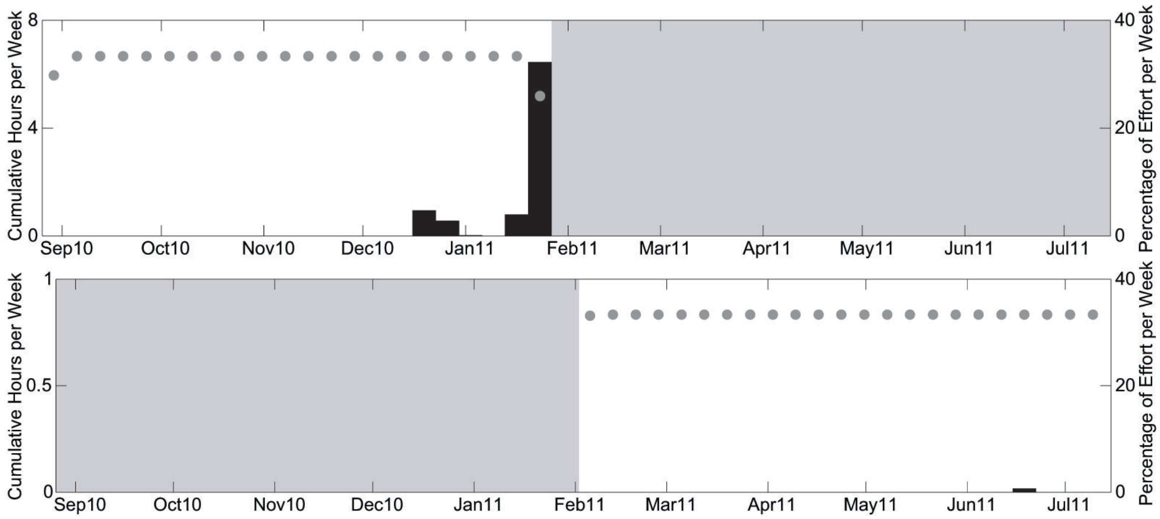


Figure 38. Weekly occurrence of minke speed-up/slow-down whale pulse trains at 150 Hz at site A (top) and site B (bottom). Effort as described in Figure 36

Sei Whales

Downsweep calls reported as being from sei whales were detected at site A, with detections occurring in November and December (Figure 39). No downsweep calls were detected at site B.

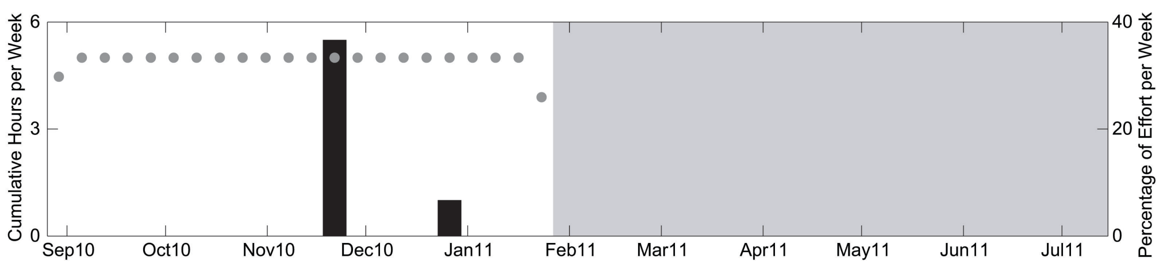


Figure 39. Weekly occurrence of downsweep calls in site A. Effort as described in Figure 36

5-Pulse Call

The 5-pulse call was detected late-October through early December in site A (Figure **40**). No 5-pulse calls were recorded at site B.

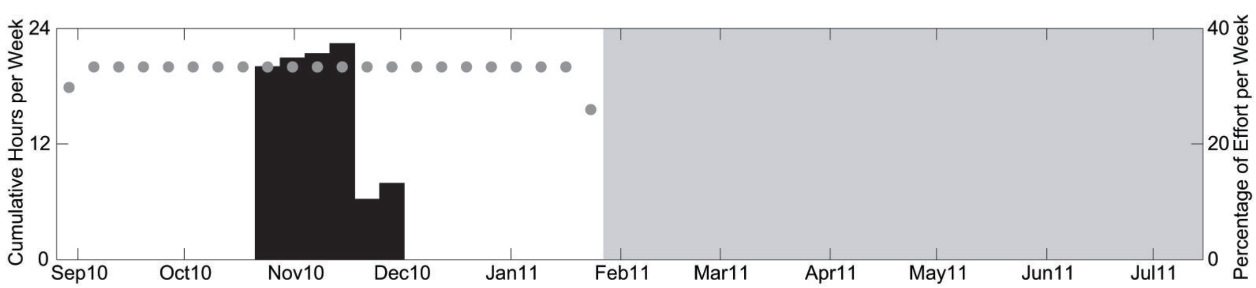


Figure 40. Weekly occurrence of 5-pulse calls at site A. Effort as described in Figure 36

Humpback Whales

Humpback whales were only detected on site B (Figure 41). The detections were few, likely owing to the fact that the migratory path of western North Atlantic humpbacks generally does not include the southeast US coastline as they migrate from their high-latitude feeding areas off the northeast coast of the US to the Barents Sea (Katona & Beard 1990, Smith *et al.* 1999) to a common breeding area in the West Indies to mate and calve (Katona & Beard 1990, Stevick *et al.* 1998).

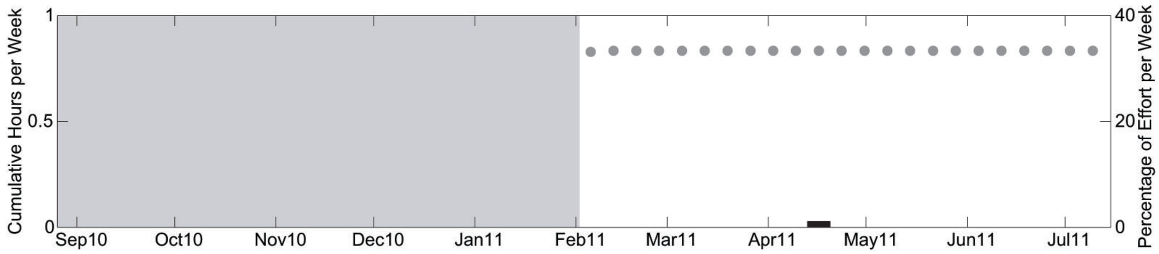


Figure 41. Weekly presence of all humpback whale calls (black bars) at site B between February and July 2011. No humpback calls were recorded at site A. Effort as described in Figure 36

Odontocetes

Clicks from Risso's dolphin and five click types that are not yet associated to a species were detected at sites A and B. Neither killer whale nor sperm whale sounds were detected at either site.

Unidentified Odontocete

The greatest number of odontocete click and whistle detections were attributed to the category unidentified odontocete (UO). Overall rates of UO detections were higher at site A than B (Figure 42). There was a distinct diel acoustic activity at site A, likely due to nighttime foraging. Nighttime clicking is more common at site B as well, but the diel pattern is not as distinct as at site A.

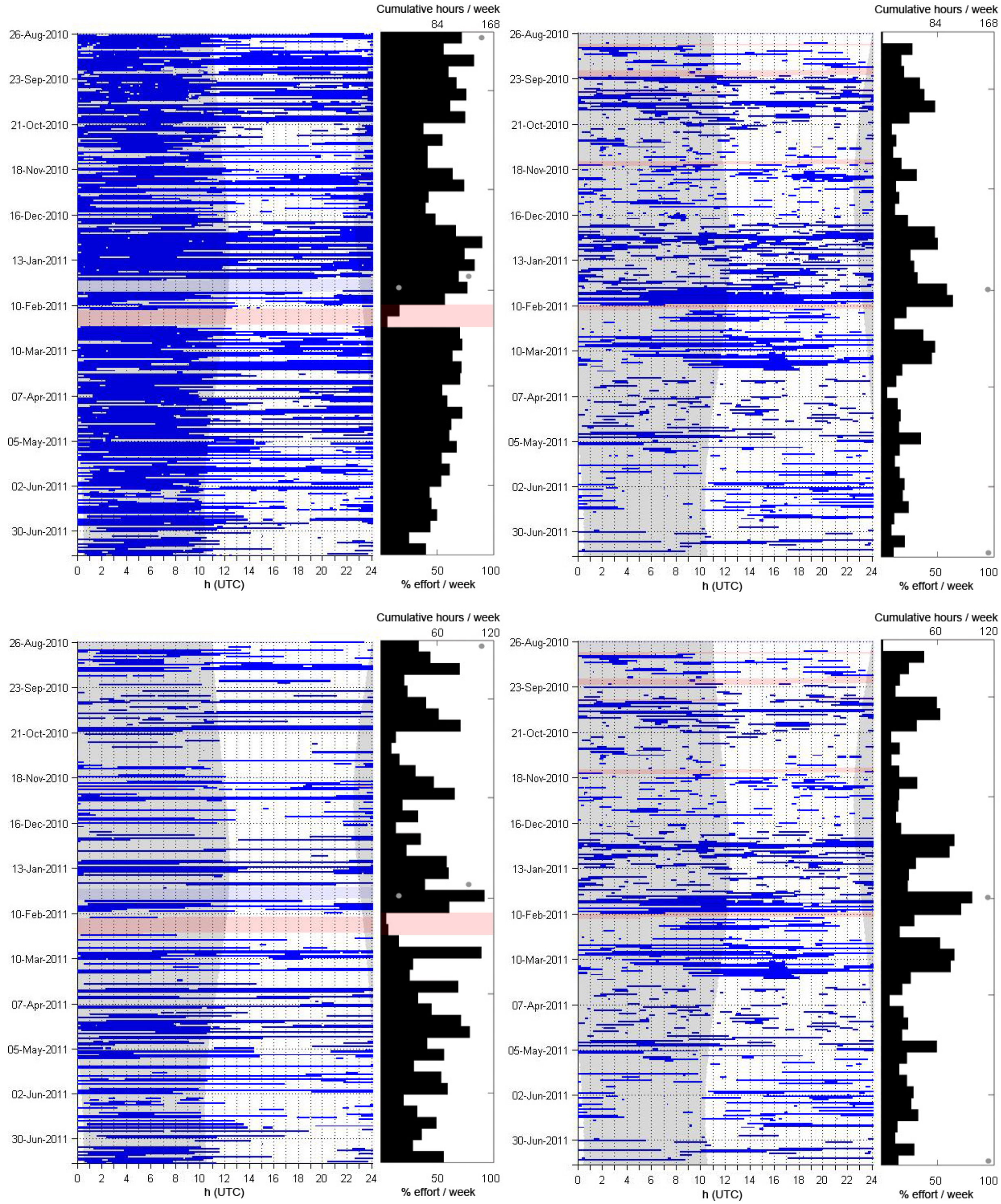


Figure 42. Odontocete echolocation clicks in one-minute bins (blue) and weekly presence (black) at site A (left) and site B (right) between August 2010 and July 2011. Top: all echolocation clicks of all species, Bottom: UO after all others were extracted. Red shading indicates data gaps. Gray shading is nighttime.

Risso's Dolphin

Risso's dolphin echolocation clicks were only detected at site A (Figure 43). Clicks were detected from the end of August until the end of November with two additional click segments: one in the middle of January and another at the beginning of March. A nighttime diel pattern is suggested.

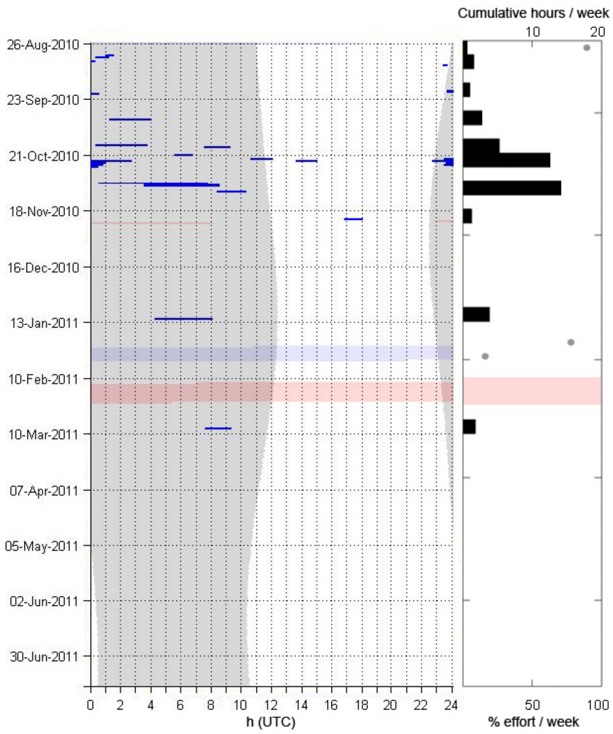


Figure 43. Risso's dolphin echolocation clicks in one-minute bins (blue) and weekly presence (black) at site A between August 2010 and July 2011. No Risso's dolphin were detected at site B. Red shading indicates data gaps. Gray shading is nighttime.

Click Type 25

Click Type 25 was detected intermittently between the end of August and the beginning of June with most of the clicks occurring at night (Figure 44). Out of the five specified click types, CT25 was the least prevalent click type.

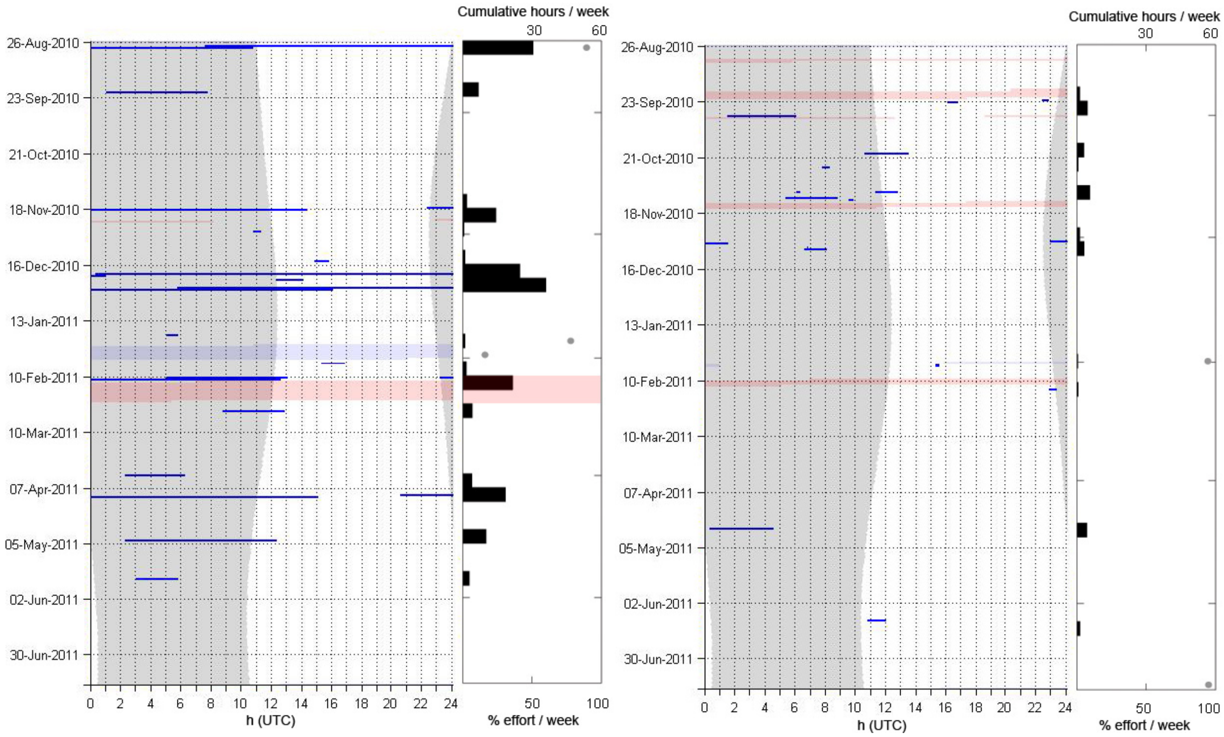


Figure 44. CT25 echolocation clicks in one-minute bins (blue) and weekly presence (black) at site A (left) and site B (right) between August 2010 and July 2011. Red shading indicates data gaps. Gray shading is nighttime.

Click Type 26

Click Type 26 was the most prevalent of the five click types detected in the JAX data set. This click type appeared throughout the duration for site A, but only occurred between the beginning of October and the middle of April at site B. A nighttime diel pattern is suggested at site A, but not at site B (Figure 45).

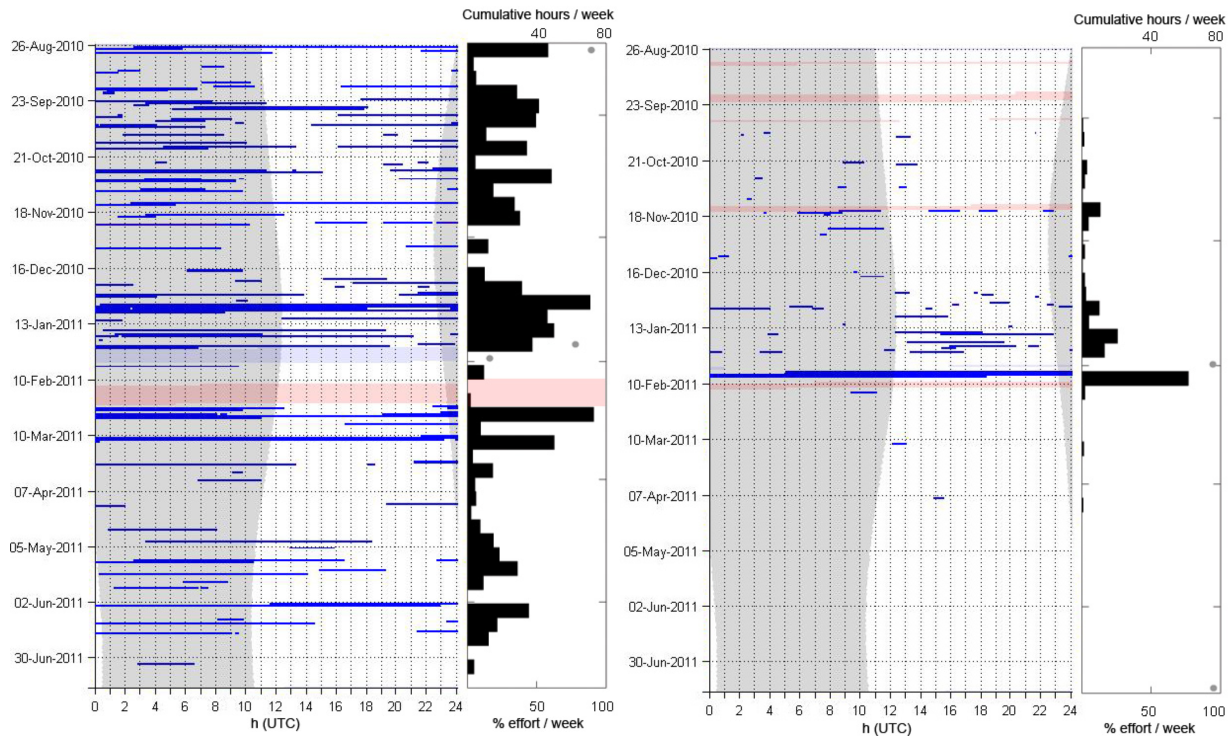


Figure 45. CT26 echolocation clicks in one-minute bins (blue) and weekly (black) at site A (left) and site B (right) between August 2010 and July 2011. Red shading indicates data gaps. Gray shading is nighttime.

Click Type 27

Click Type 27 encounters were detected throughout the entire time period at site A, but were only present at site B during the end of September and the end of November. More clicks appear to be present at night at site A (Figure 46).

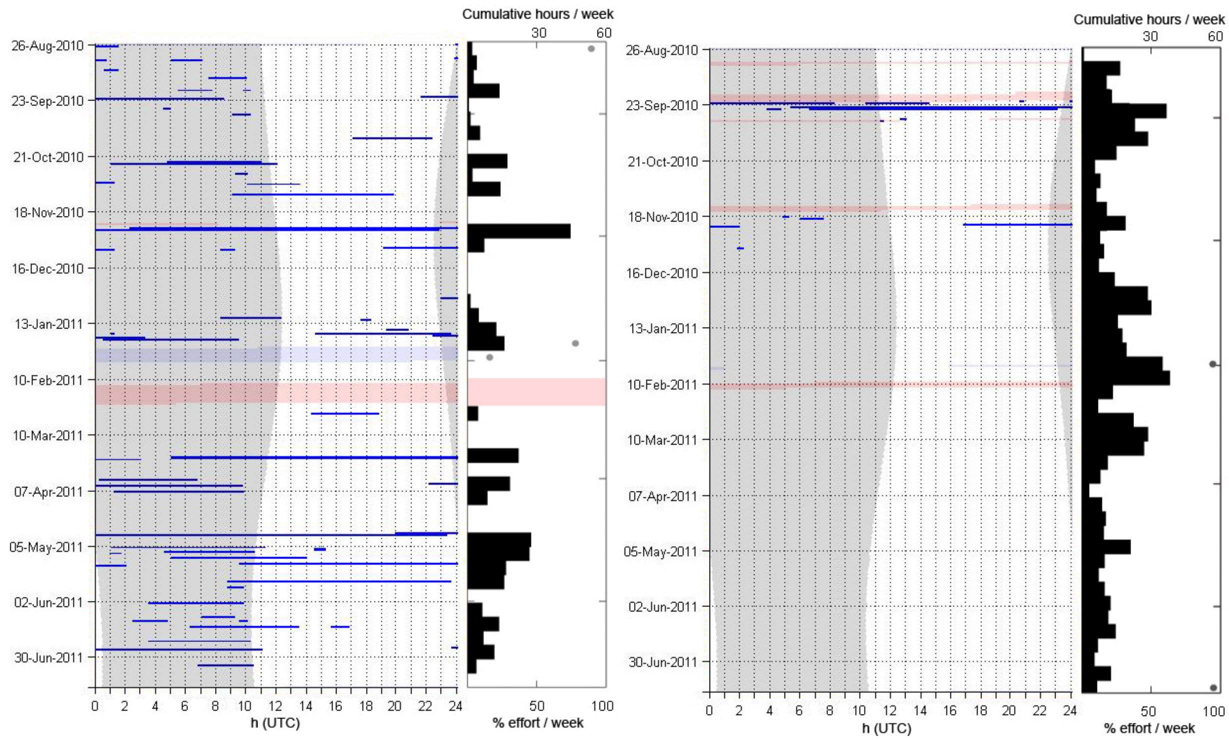


Figure 46. CT27 echolocation clicks in one-minute bins (blue) and weekly presence (black) at site A (left) and site B (right) between August 2010 and July 2011. Red shading indicates data gaps. Gray shading is nighttime.

Click Type 30

Click Type 30 was present during both day and night, but were more prevalent during the night. At site A, clicks occurred from late August to the end of December and then reoccurred at the beginning of March through the end of June (Figure 47). At site B, clicks were only present from the beginning of October to the beginning of February, with one occurrence in the middle of June. This pattern could be due to seasonal preference or based on excessive noise and the ability to identify a definitive click type.

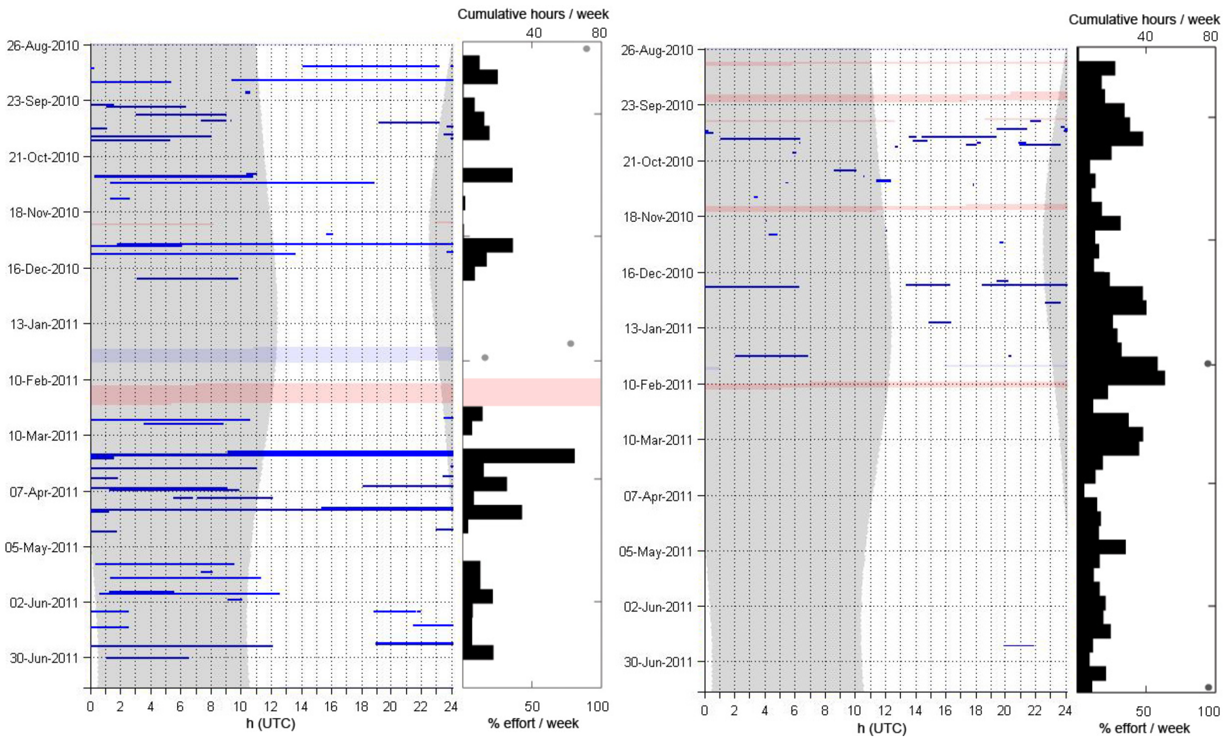


Figure 47. CT30 echolocation clicks in one-minute bins and weekly presence at site A (left) and site B (right) between August 2010 and July 2011. Red shading indicates data gaps. Gray shading is nighttime.

Click Type 32

Click Type 32 was detected from the end of August until the end of May. Site B had very few acoustic encounters. There was one encounter at the end of September, while the other encounters occurred from the end of November until the end of January. No specific diel pattern was seen (Figure 48).

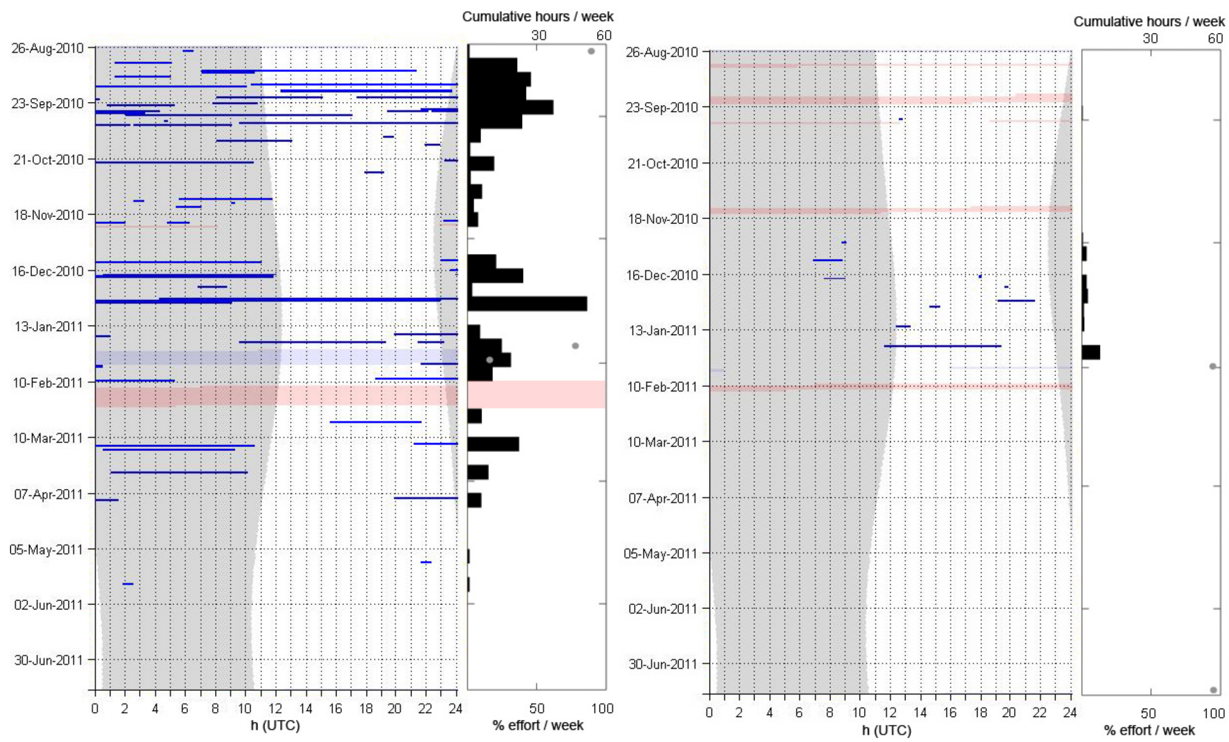


Figure 48. CT32 echolocation clicks in one-minute bins and weekly presence at site A (left) and site B (right) between August 2010 and July 2011. Red shading indicates data gaps. Gray shading is nighttime.

Anthropogenic Sounds

Broadband Ship Noise

Ship noise was common at sites A and B (Figure 49). Daily presence of ship noise had no temporal patterns (Appendix).

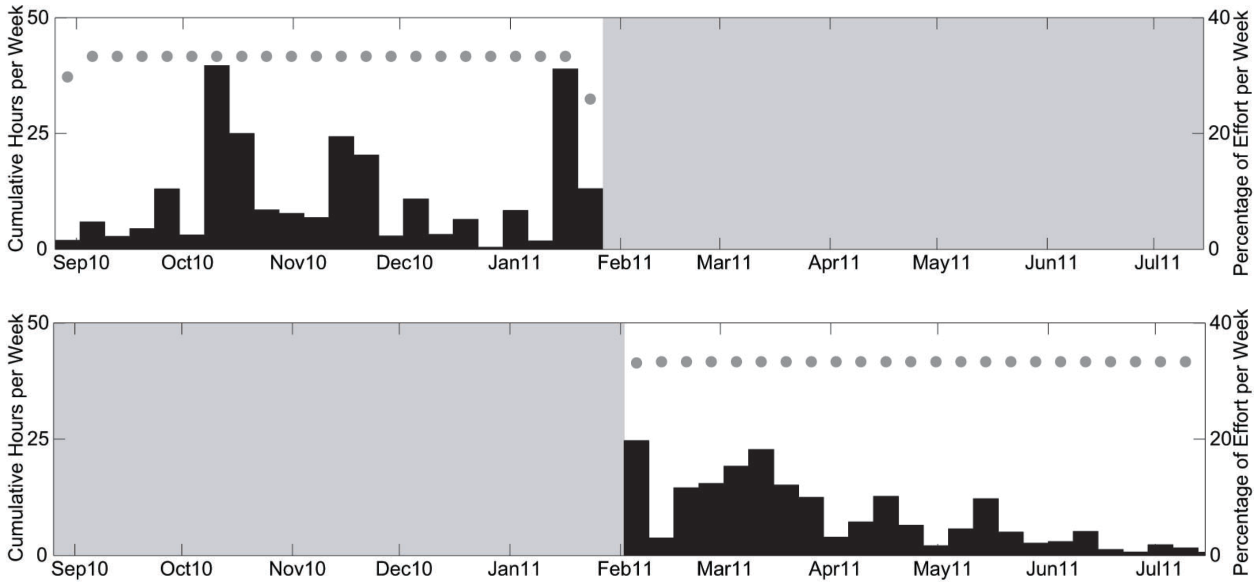


Figure 49. Broadband ship noise weekly hours at site A (top) and B (bottom) between August 2010 and July 2011. Effort markings are as described in Figure 35.

Mid-Frequency Active Sonar

Both sites A and B had MFA sonar events throughout the period August 2010 – July 2011 (Figure 50). At site A, a total of 2,437 MFA sonar pings were detected, ranging from 100 to 173 dB pp re 1 µPa; the maximum value is the clipping level of the HARP and the minimum value is a threshold limit based on the analysis methods used. 2,496 pings were detected at site B. Mid-October had the largest number of pings per week detected at both sites while some weeks did not have any sonar detections. Distribution of ping levels from site A shows a peak around 124 dB pp re 1 µPa and is long-tailed to higher levels while site B shows a peak around 134 dB pp re 1 µPa (Figure 51). Cumulative distribution of ping levels shows that half of the pings detected are above 125 dB pp re 1 µPa in both sites (Figure 52).

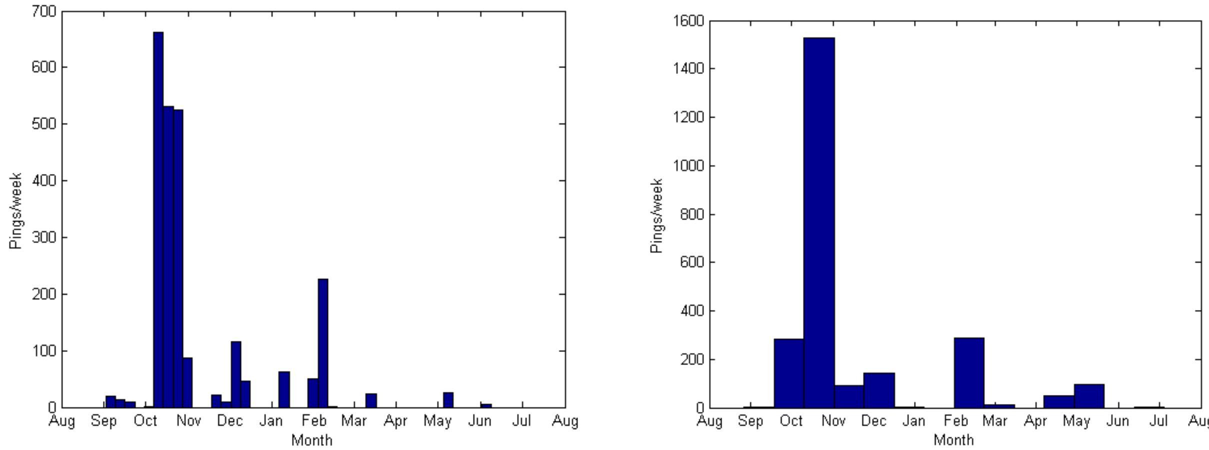


Figure 50. Mid-Frequency Active (MFA) sonar presence in weekly bins at site A (left panel) and site B (right panel) between August 2010 and July 2011.

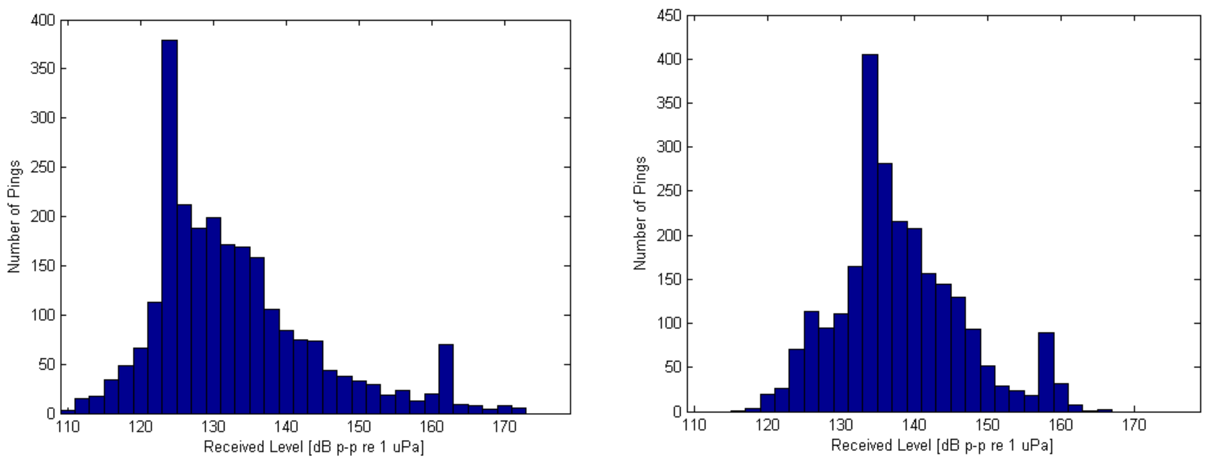


Figure 51. Distribution of MFA sonar pings by received level at site A (left) and site B (right) in 2 dB bins. Peak number of pings is 124 dB pp re 1 µPa for site A and 134 dB pp re 1 µPa for site B. Minimum level is 110 dB pp re 1 µPa and is related to the detection threshold. Maximum level is 173dB pp re 1 µPa for site A and 166 dB pp re 1 µPa for site B, set by the clipping level of the HARP.

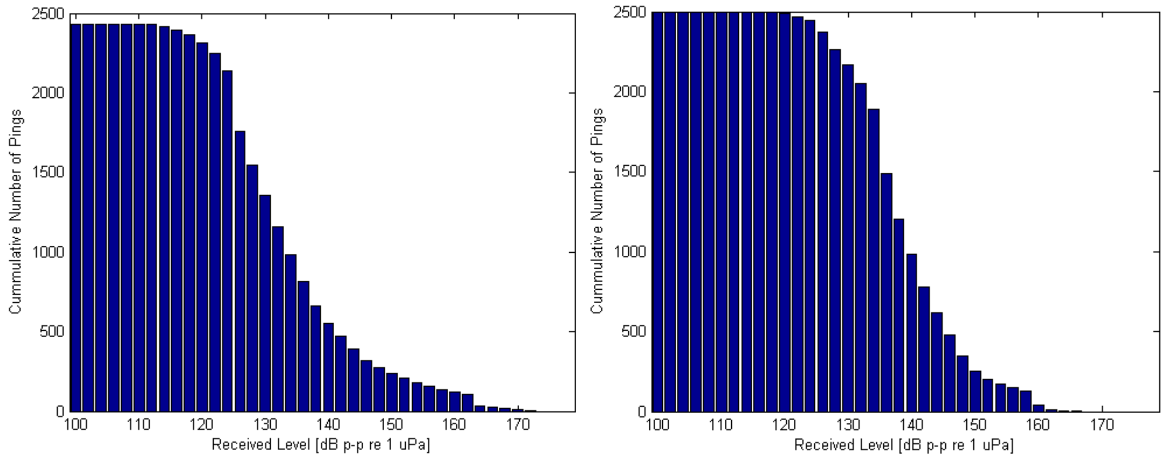


Figure 52. Cumulative distribution for the number of MFA sonar pings detected at a given received level or higher, at site A (left) and site B (right) in 2 dB bins.

Echosounders

Echosounder pings with a variety of primary frequencies (8 – 80 kHz) were found at both sites A and B (Figure 53). More echosounders were present at site A than site B, perhaps related to the greater depth at site A. Echosounder pings at both sites A and B occurred during similar times of the month. Pings were detected from the end of August to the middle of March and reoccurring at the beginning of April until the beginning of July. For site B, the pings occurred mostly at night while site A pings occurred more during the day.

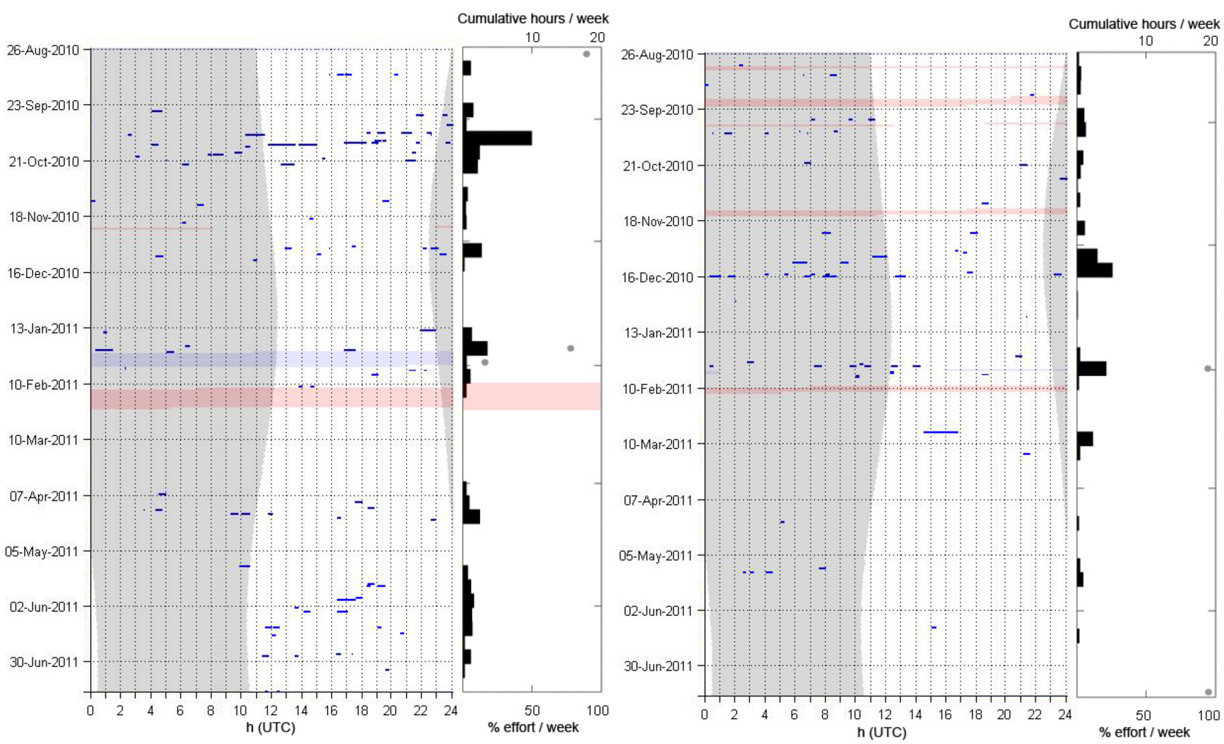


Figure 53. Echosounder pings in one-minute bins (blue) and weekly echosounder presence (black) at site A (left) and site B (right) between August 2010 and July 2011.

Explosions

Few explosions were recorded at either site (Figure 54). A peak in explosions was recorded in early July 2011 at site B.

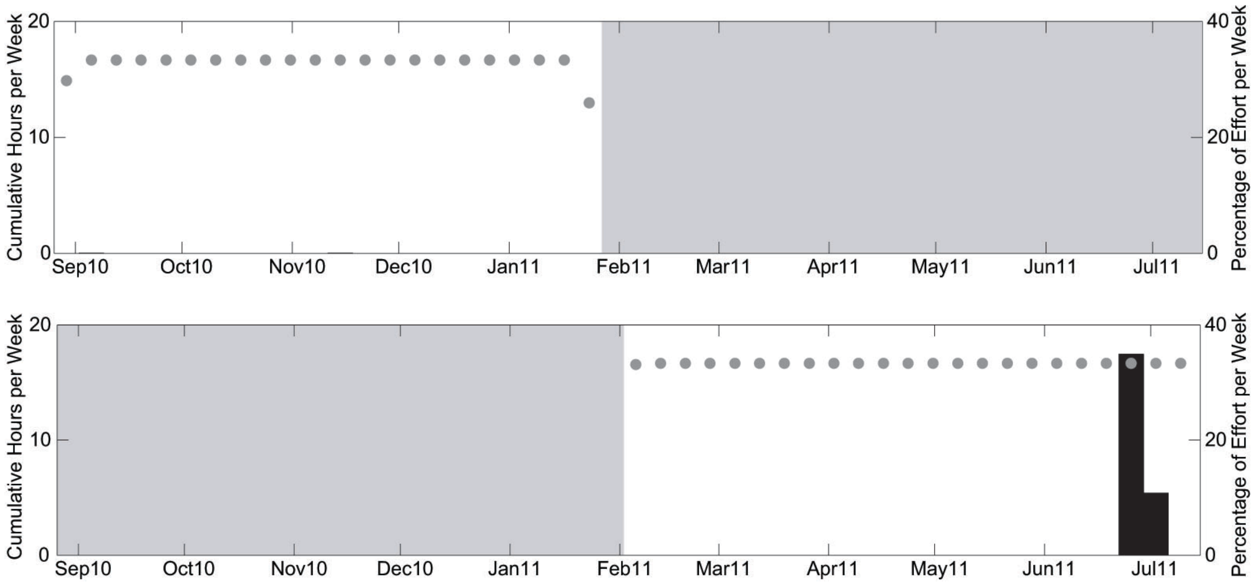


Figure 54. Weekly hours with explosions at sites A (top) and B (bottom) between August 2010 and July 2011. Effort markings are as described in Figure 36.

130-Hz Tone

The 130-Hz tone was detected at site A, with peaks in detections mid- to late November and mid-December (Figure 55). The tone was produced exclusively at night (Appendix). This tone was not detected at site B.

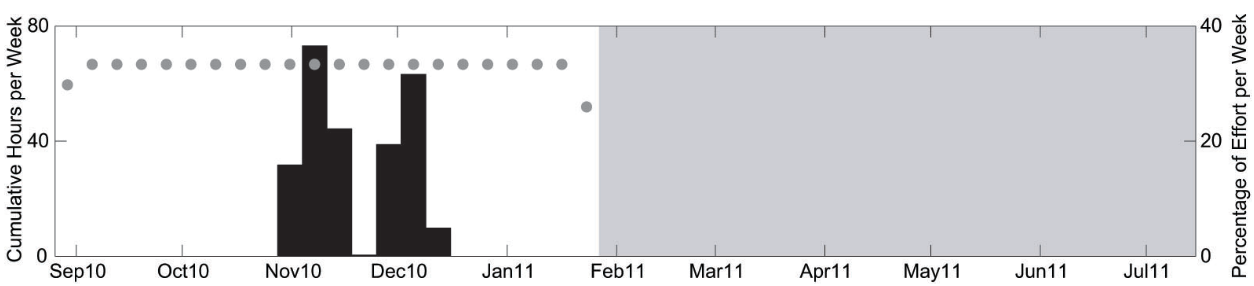


Figure 55. Weekly hours with 130-Hz tone detections at site A. Effort markings are as described in Figure 36.

References:

BAUMGARTNER, M. F., S. M. VAN PARIJS, F. W. WENZEL, C. J. TREMBLAY, H. C. ESCH and A. M. WARDE. 2008. Low frequency vocalizations attributed to sei whales (balaenoptera borealis). *The Journal of the Acoustical Society of America* **124:** 1339-1349

DUNLOP, R. A., M. J. NOAD, D. H. CATO and D. STOKES. 2007. The social vocalization repertoire of east australian migrating humpback whales (megaptera novaeangliae). *Journal of the Acoustical Society of America* **122:** 2893-2905.10.1121/1.2783115

GORMLEY, G. 2000. *Orcas of the gulf: A natural history*. Authors Choice Press.

HELBLE, T. A., G. R. IERLEY, G. L. D'SPAIN, M. A. ROCH and J. A. HILDEBRAND. 2012. A generalized power-law detection algorithm for humpback whale vocalizations. *The Journal of the Acoustical Society of America* **131:** 2682-2699

HILDEBRAND, J. A. 2009. Anthropogenic and natural sources of ambient noise in the ocean. *Marine Ecology-Progress Series* **395:** 5-20.10.3354/meps08353

KATONA, S. K. and J. A. BEARD. 1990. Population size, migrations and feeding aggregations of the humpback whale (*megaptera novaeangliae*) in the western north atlantic ocean. *Report of the International Whaling Commission* **12:** 295-305

KATONA, S. K., J. A. BEARD, P. E. GIRTON and F. WENZEL. 1988. Killer whales (orcinus orca) from the bay of fundy to the equator, including the gulf of mexico. . *Rit Fiskideild* **11:** 205-224

MCDONALD, M. A., J. A. HILDEBRAND and S. C. WEBB. 1995. Blue and fin whales observed on a sea-floor array in the northeast pacific. *Journal of the Acoustical Society of America* **98:** 712-721

MELLINGER, D. K., C. D. CARSON and C. W. CLARK. 2000. Characteristics of minke whale (balaenoptera acutorostrata) pulse trains recorded near puerto rico. *Marine Mammal Science* **16:** 739-756.10.1111/j.1748-7692.2000.tb00969.x

MELLINGER, D. K. and C. W. CLARK. 2003. Blue whale (balaenoptera musculus) sounds from the north atlantic. *Journal of the Acoustical Society of America* **114:** 1108-1119.10.1121/1.1593066

MIZROCH, S. A., D. W. RICE and J. M. BREIWICK. 1984. The sei whale, *balaenoptera borealis*. *Marine Fisheries Review* **46:** 25-29

OLESON, E. M., J. BARLOW, J. GORDON, S. RANKIN and J. A. HILDEBRAND. 2003. Low frequency calls of bryde's whales. *Marine Mammal Science* **19:** 407-419

OMURA, H. 1959. Bryde's whale from the coast of japan. *Sci. Rep. Whales Res. Inst* **14:** 1-33

PARKS, S. E., P. K. HAMILTON, S. D. KRAUS and P. L. TYACK. 2005. The gunshot sound produced by male north atlantic right whales (*eubalaena glacialis*) and its potential function in reproductive advertisement. *Marine Mammal Science* **21:** 458-475

PARKS, S. E. and P. L. TYACK. 2005. Sound production by north atlantic right whales (eubalaena glacialis) in surface active groups. *Journal of the Acoustical Society of America* **117:** 3297-3306.10.1121/1.1882946

PAYNE, R. S. and S. MCVAY. 1971. Songs of humpback whales. *Science* **173:** 585-597

PERRY, S. L., D. P. DEMASTER and G. K. SILBER. 1999. The great whales: History and status of six species listed as endangered under the us endangered species act of 1973. *Marine Fisheries Review* **61:** 1-74

ROCH, M. A., H. KLINCK, S. BAUMANN-PICKERING, D. K. MELLINGER, S. QUI, M. S. SOLDEVILLA and J. A. HILDEBRAND. 2011. Classification of echolocation clicks from odontocetes in the southern california bight. *Journal of the Acoustical Society of America* **129:** 467-475.10.1121/1.3514383

ROCH, M. A., M. S. SOLDEVILLA, J. C. BURTENSHAW, E. E. HENDERSON and J. A. HILDEBRAND. 2007. Gaussian mixture model classification of odontocetes in the southern california bight and the gulf of california. *Journal of the Acoustical Society of America* **121:** 1737-1748

SIROVIC, A., H. BASSETT, S. C. JOHNSON, S. M. WIGGINS and J. A. HILDEBRAND. 2013. Bryde's whale calls recorded in the gulf of mexico *Marine Mammal Science* **Accepted**

ŠIROVIĆ, A., L. N. WILLIAMS, S. M. KEROSKY, S. M. WIGGINS and J. A. HILDEBRAND. 2012. Temporal separation of two fin whale call types across the eastern north pacific. *Marine Biology*: 1-11.DOI 10.1007/s00227-012-2061-z.

SMITH, T. D., J. ALLEN, P. J. CLAPHAM, P. S. HAMMOND, S. KATONA, F. LARSEN, J. LIEN, D. MATTILA, P. J. PALSBOLL, J. SIGURJONSSON, P. T. STEVICK and N. OIEN. 1999. An ocean-basin-wide mark-recapture study of the north atlantic humpback whale (megaptera novaeangliae). *Marine Mammal Science* **15:** 1-32.10.1111/j.1748-7692.1999.tb00779.x

SOLDEVILLA, M. S., E. E. HENDERSON, G. S. CAMPBELL, S. M. WIGGINS, J. A. HILDEBRAND and M. A. ROCH. 2008. Classification of risso's and pacific white-sided dolphins using spectral properties of echolocation clicks. *The Journal of the Acoustical Society of America* **124:** 609-624

STEINER, W. W., J. H. HAIN, H. E. WINN and P. J. PERKINS. 1979. Vocalizations and feeding-behavior of the killer whale (orcinus-orca). *Journal of Mammalogy* **60:** 823-827.10.2307/1380199

STEVICK, P. T., N. OIEN and D. K. MATTILA. 1998. Migration of a humpback whale (megaptera novaeangliae) between norway and the west indies. *Marine Mammal Science* **14:** 162-166

STIMPERT, A. K., W. W. L. AU, S. E. PARKS, T. HURST and D. N. WILEY. 2011. Common humpback whale (megaptera novaeangliae) sound types for passive acoustic monitoring. *Journal of the Acoustical Society of America* **129:** 476-482.10.1121/1.3504708

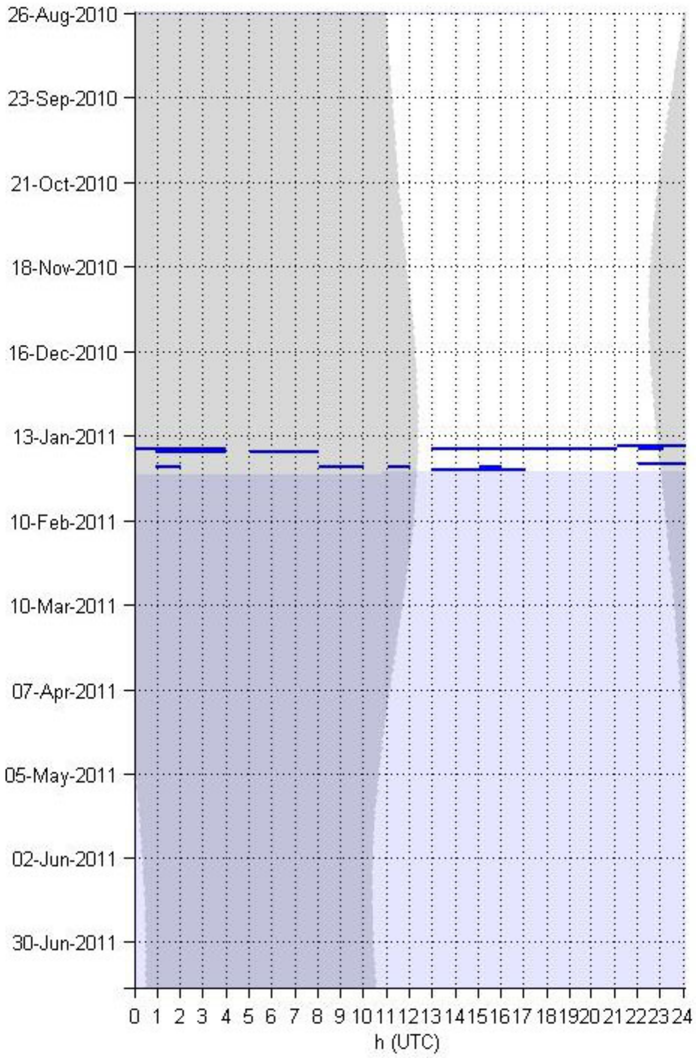
THOMPSON, P. O., L. T. FINDLEY and O. VIDAL. 1992. 20-hz pulses and other vocalizations of fin whales, balaenoptera-physalus, in the gulf-of-california, mexico. *Journal of the Acoustical Society of America* **92:** 3051-3057.10.1121/1.404201

WADE, P. R. and T. GERRODETTE. 1993. Estimates of cetacean abundance and distribution in the eastern tropical pacific. *Report of the International Whaling Commission* **43:** 477-493

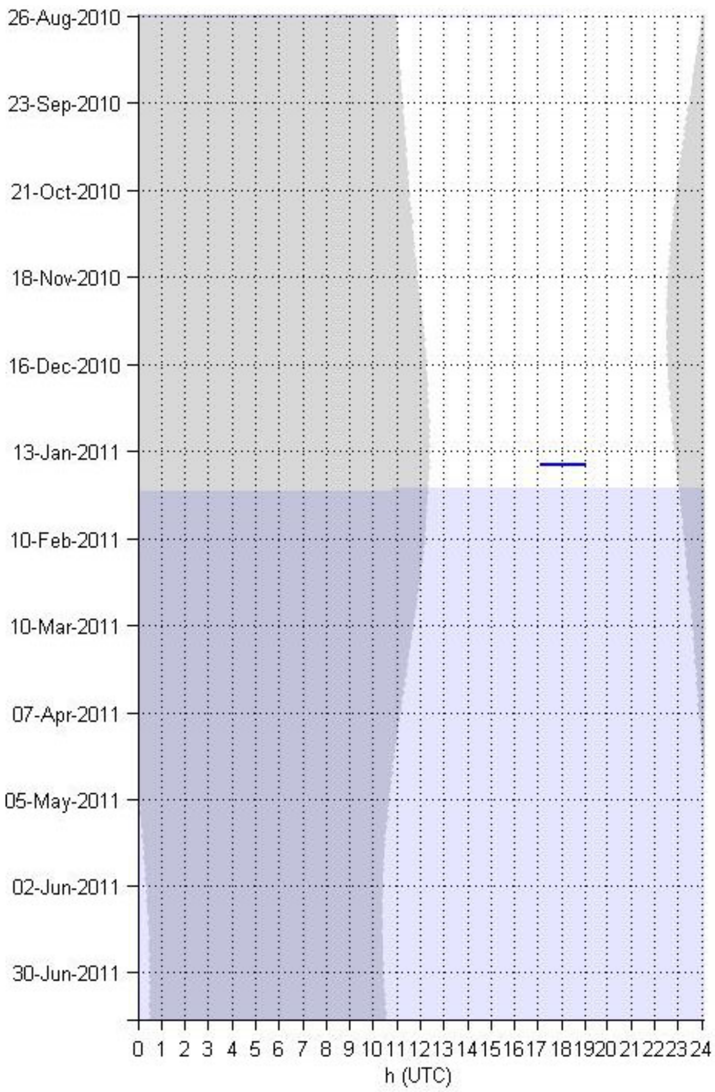
WATKINS, W. A. 1981. Activities and underwater sounds of fin whales. *Scientific reports of the Whales Research Institute* **33:** 83-117

WIGGINS, S. M. and J. A. HILDEBRAND. 2007. High-frequency acoustic recording package (harp) for broad-band, long-term marine mammal monitoring. Pages 551-557 *International Symposium on Underwater Technology 2007 and International Workshop on Scientific Use of Submarine Cables & Related Technologies 2007.* Institute of Electrical and Electronics Engineers, Tokyo, Japan.

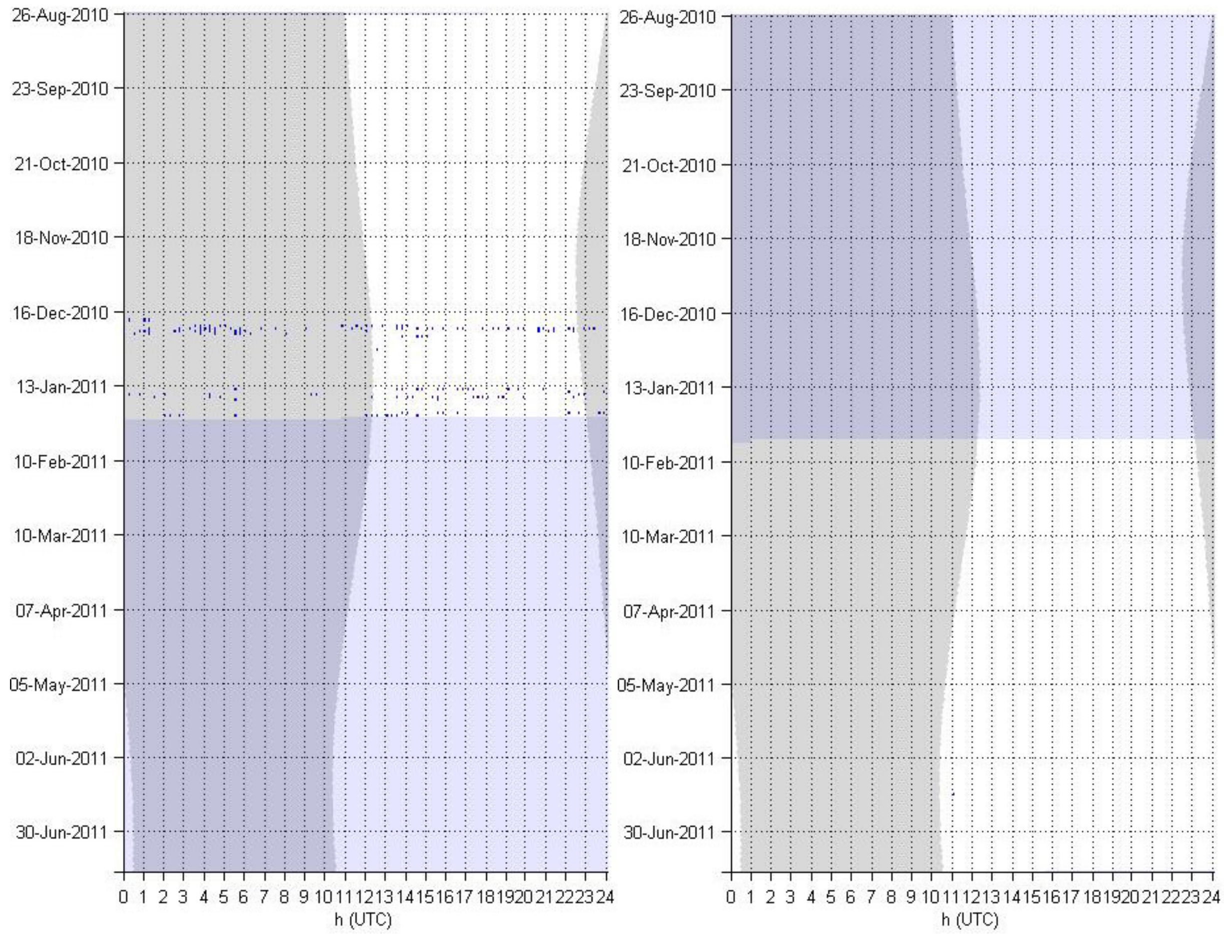
Appendix



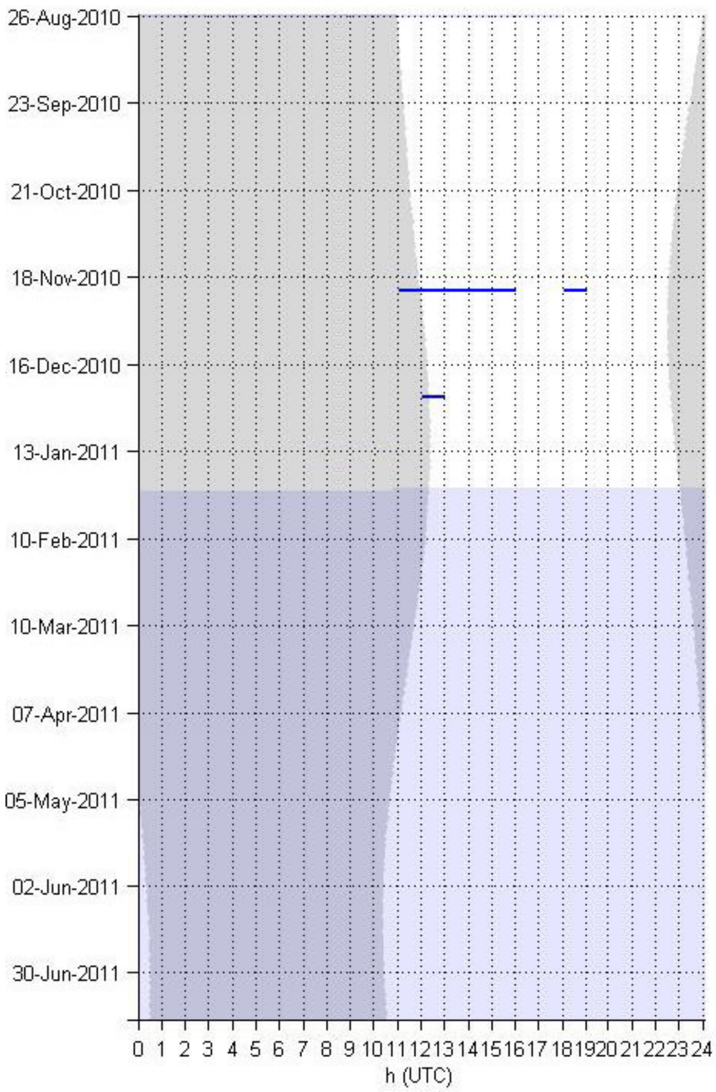
Fin whale – 20 Hz calls in hourly bins at site A. No calls were detected at site B.



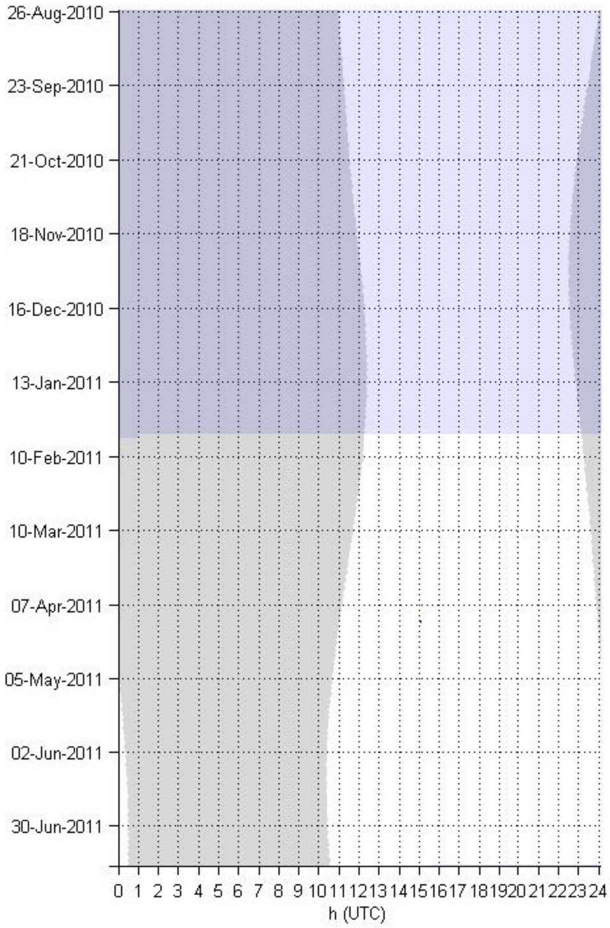
Minke whale – 50 Hz pulses in hourly bins at site A. No calls were detected at site B.



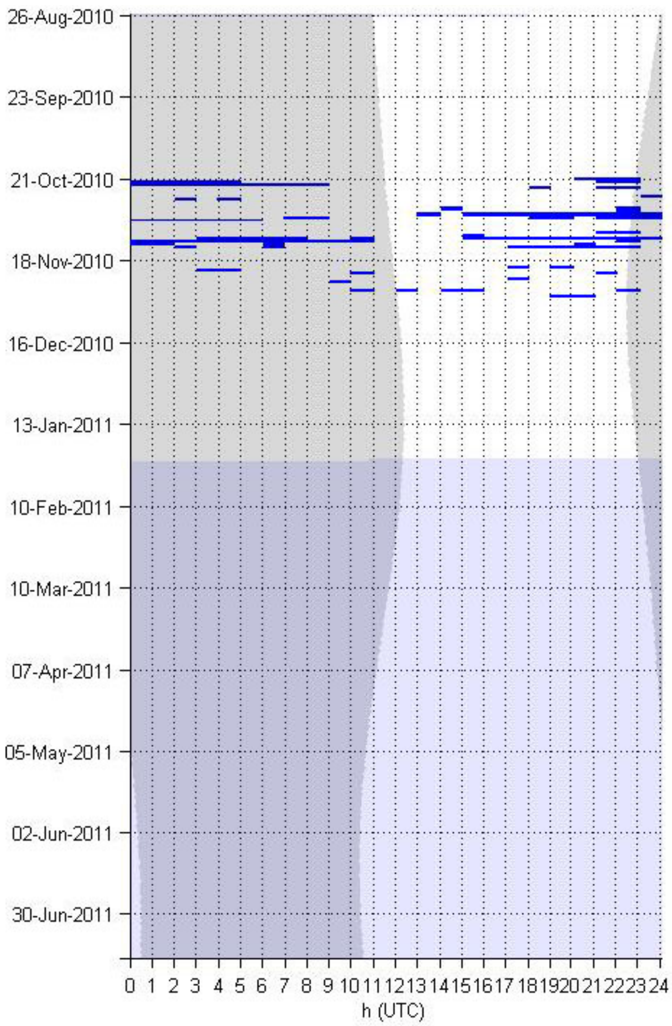
Minke whale – Speed-up/slow down pulse trains in hourly bins at sites A (left) and B (right).



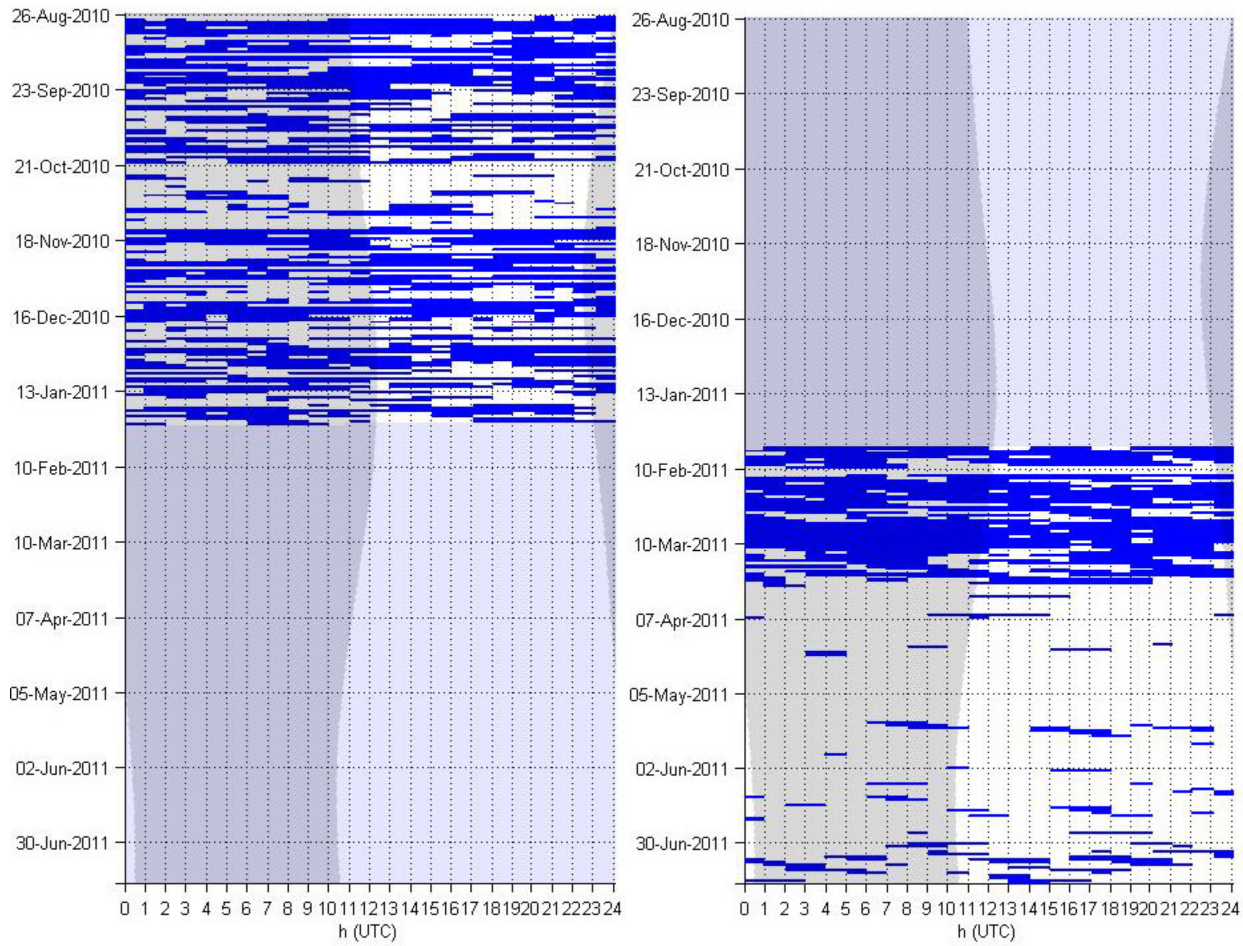
Sei whale – Downsweeps in hourly bins at site A. No calls were detected at site B.



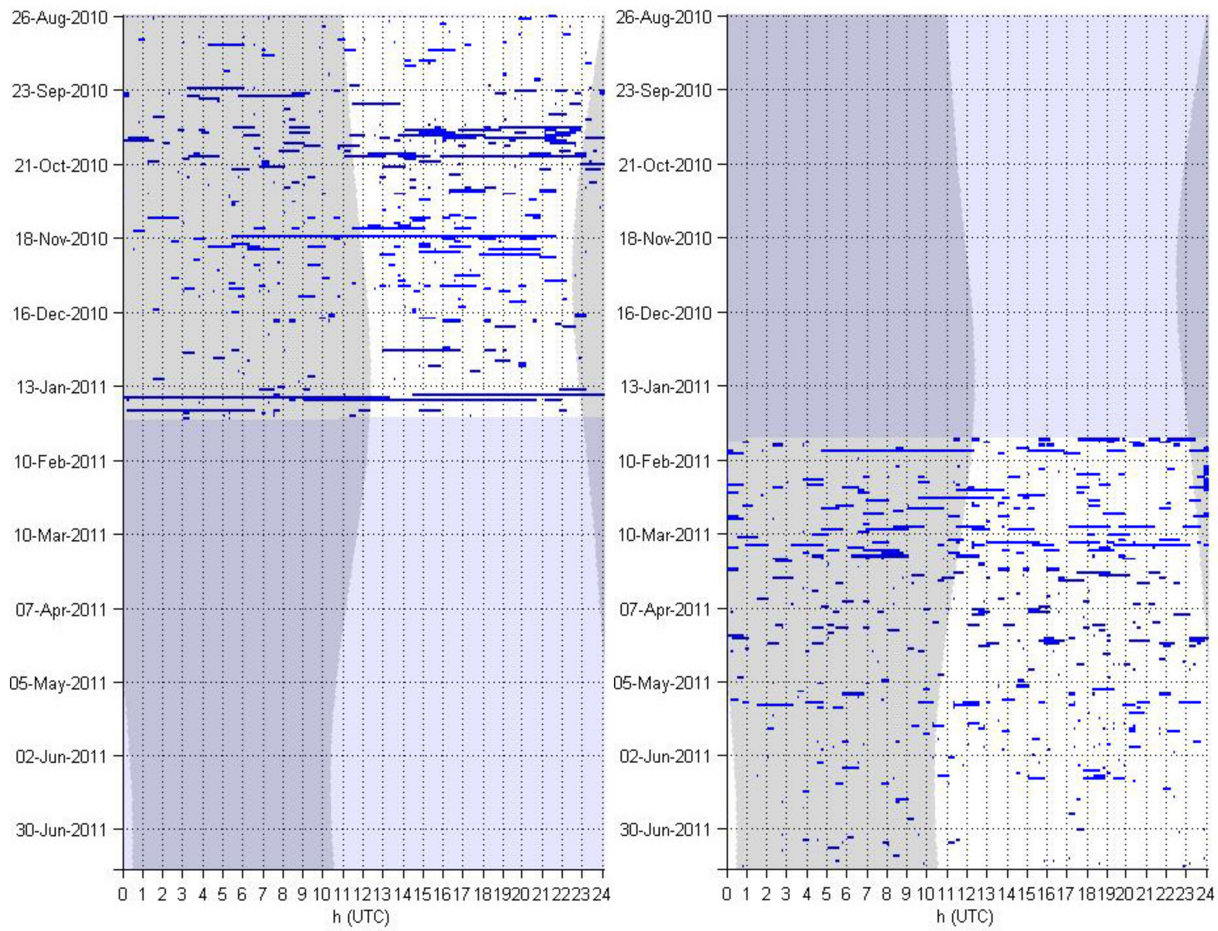
Humpback whale – Song and non-song calls detected in hourly bins at site B. No calls were detected at site A.



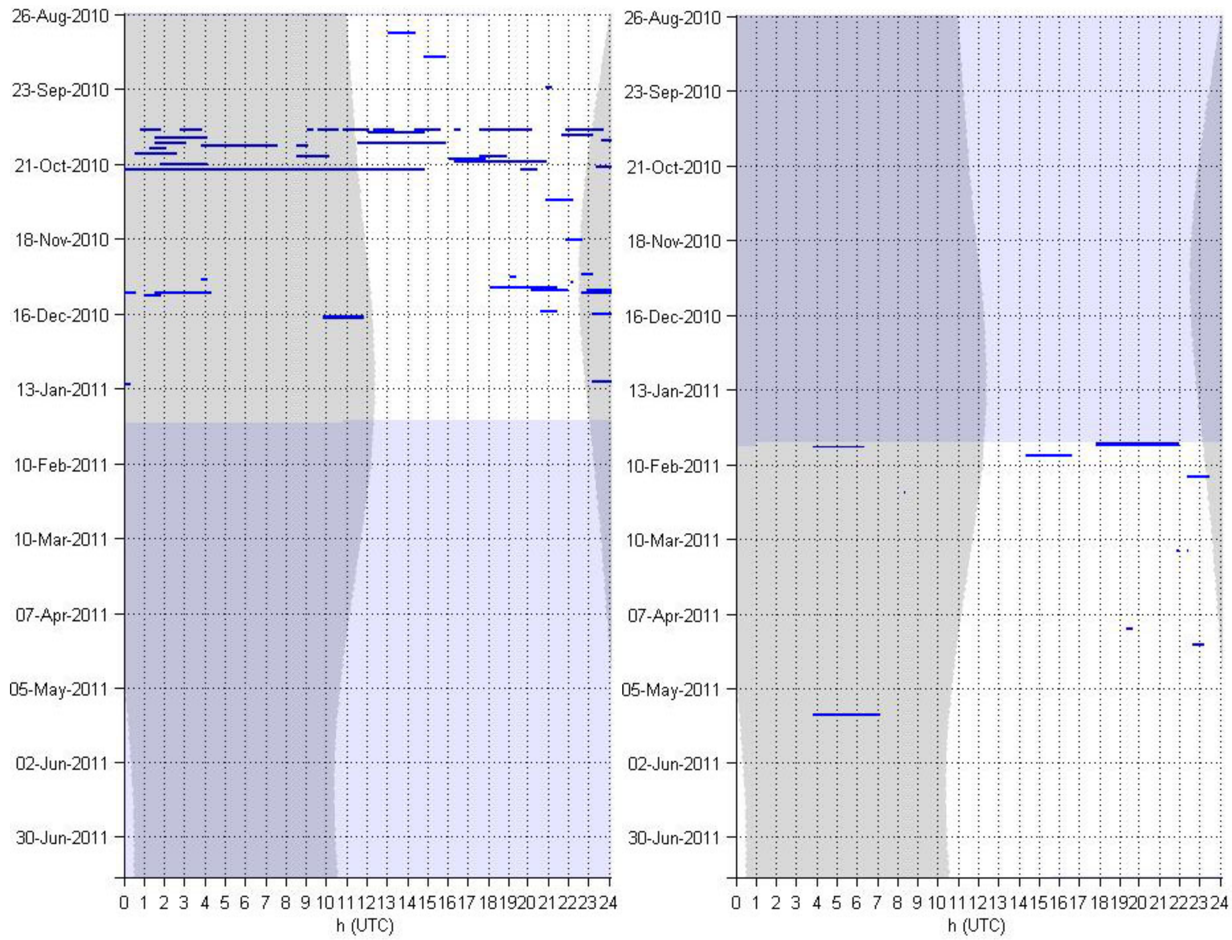
Unknown whale – 5-pulse calls in hourly bins at site A. No calls were detected at site B.



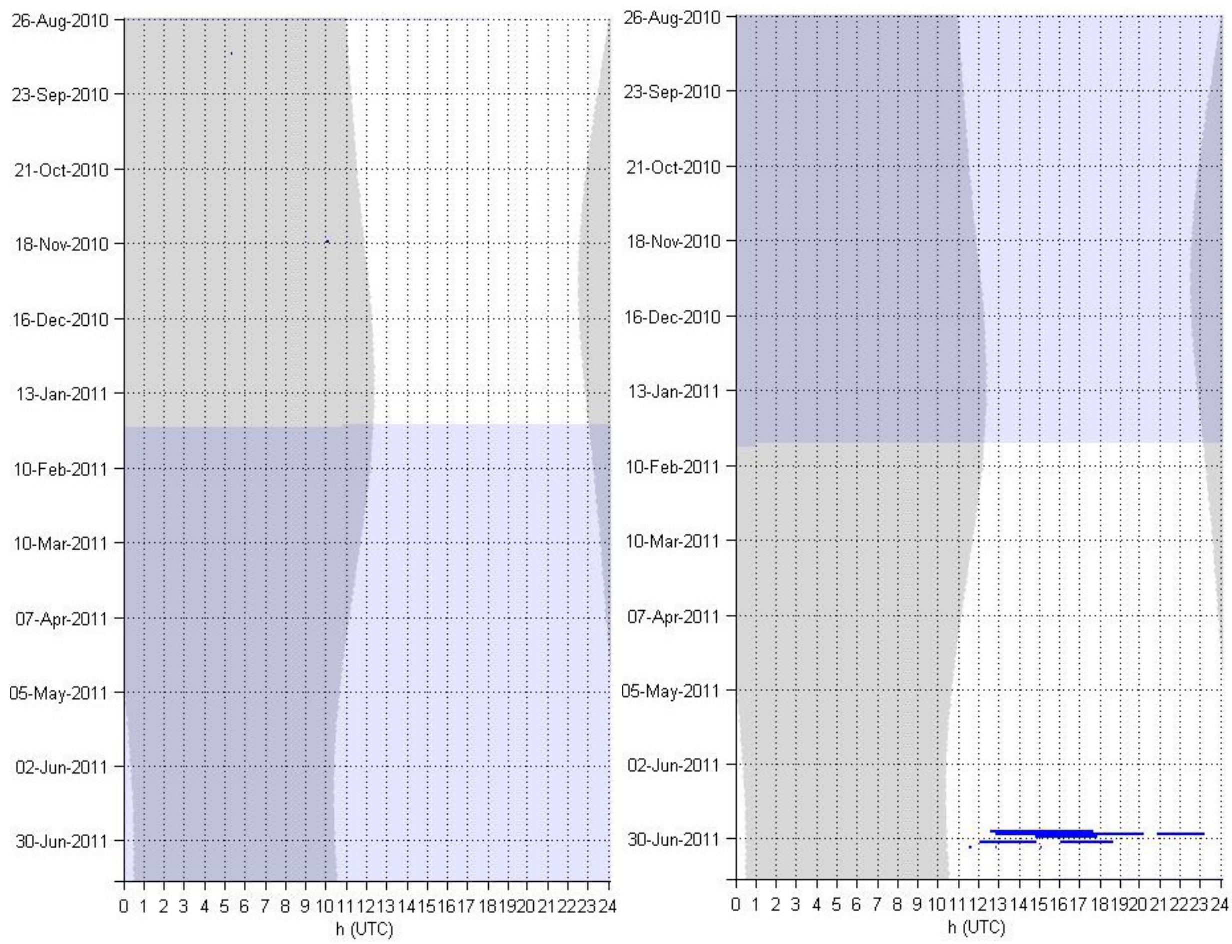
Low-frequency noise causing call masking – Occurrence in hourly bins at sites A (left) and B (right).



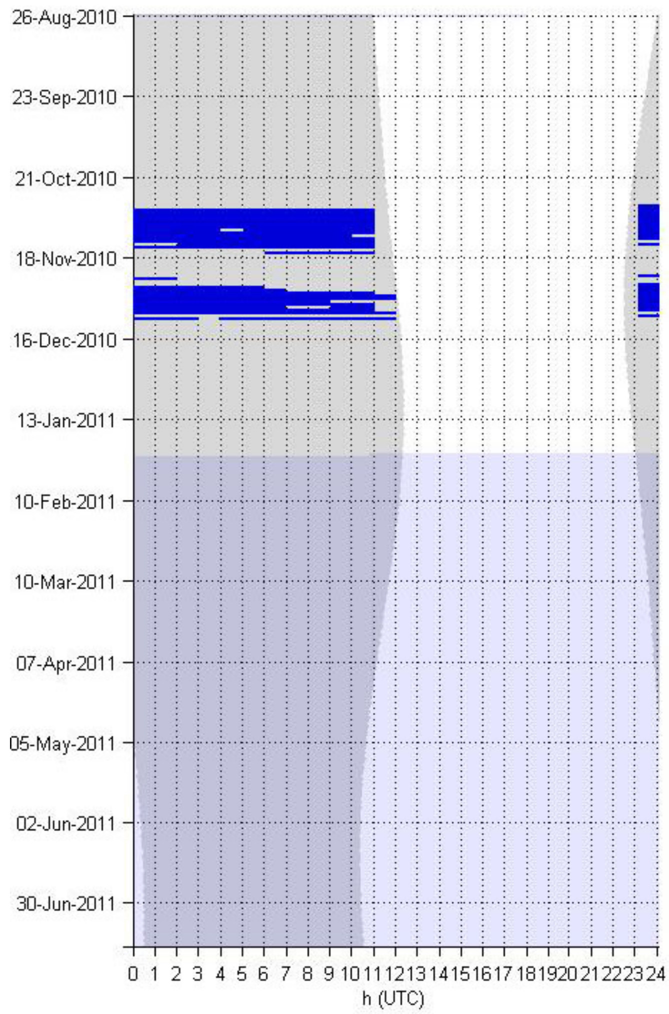
Broadband shipping – Occurrence in hourly bins at sites A (left panel) and B (right panel).



Mid-frequency active sonar – Occurrence in hourly bins at sites A (left panel) and B (right panel).



Explosions – Occurrence in hourly bins at sites A (left panel) and B (right panel).



130-Hz tone – Sounds recorded in hourly bins at site A.