Passive Acoustic Monitoring for Marine Mammals in the Cherry Point OPAREA 2011-2012

Amanda J. Debich, Simone Baumann-Pickering, Ana Širović, Jasmine S. Buccowich, Zoe E. Gentes, Rachel S. Gottlieb, Sarah C. Johnson, Sara M. Kerosky, Lauren K. Roche, Bruce Thayre, Jennifer T. Trickey, Sean M. Wiggins, John A. Hildebrand, Lynne E. W. Hodge and Andrew J. Read

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

Minke Whale, Photo by Amanda J. Debich

MPL TECHNICAL MEMORANDUM # 545
February 2014

Prepared for US Fleet Forces Command and submitted to Naval Facilities Engineering Command (NAVFAC) Atlantic, under Contract No. N62470-10D-3011 issued to HDR, Inc.

Suggested Citation:

Debich AJ, S Baumann-Pickering, A Širović, JS Buccowich, ZE Gentes, RS Gottlieb, SC Johnson, SM Kerosky, LK Roche, B Thayre, JT Trickey, SM Wiggins, JA Hildebrand, LEW Hodge, and AJ Read. 2014. Passive Acoustic Monitoring for Marine Mammals in the Cherry Point OPAREA 2011-2012. Final Report. Submitted to Naval Facilities Engineering Command (NAVFAC) Atlantic, Norfolk, Virginia, under Contract No. N62470-10D-3011 issued to HDR, Inc.

Individual technical reports of the HARP deployments are available at:
http://www.navymarinespeciesmonitoring.us/reading-room/

Table of Contents

Executive Summary

Passive acoustic monitoring was conducted within the Navy's Cherry Point OPAREA during August – December 2011 and July – October 2012 for a total of 105 and 81 days respectively. This site is located approximately 100 miles from the North Carolina coastline on the shelf break. The 2011 deployment was at a water depth of 952 m and the 2012 deployment was at a water depth of 914 m. Acoustic data collected at this site provide information on the presence of marine mammals and anthropogenic sound sources. High-frequency Acoustic Recording Packages (HARPs) recorded sounds between 10 Hz and 100 kHz with recording cycles of 5 minutes every 10 minutes. The data were divided into three frequency bands and data were analyzed by scans of long-term spectral averages and spectrograms.

Four baleen whale species were recorded: blue, fin, minke, and sei whales. The detections of their calls were made between late August and early December 2011. Blue whale calls were the only baleen whale call type detected in the 2012 deployment. No Bryde's, humpback, or North Atlantic right whale calls were detected in either deployment.

Several different toothed whale species were recorded: Blainville's, Cuvier's, and Gervais' beaked whales, killer whales, pygmy or dwarf sperm whales (*Kogia* spp.), Risso's dolphins, sperm whales, and unidentified odontocetes. All species except killer whales were recorded in 2011 and 2012. Killer whales were detected only in 2011.

Ship noise was the most common anthropogenic sound in both deployments. MFA was noted during both deployments. A total of 391 pings were detected in 2011 with a maximum peak-to-peak received level of 156 dB re 1 µPa. In 2012, a total of 492 pings were detected with a maximum peak-to-peak received level of 167 dB re 1 µPa. Few echosounder pings over a variety of frequencies (4-80 kHz) were detected during both deployments. Explosions were detected in both deployments, though they were more prevalent in 2011 than 2012. High noise levels, possibly caused by instrument strumming and fluid flow at the sensor, occurred intermittently in both deployments and likely decreased the detection range for low-frequency sounds. This strumming was most prevalent in 2012.

Project Background

The US Navy's Cherry Point OPAREA is located within the South Atlantic Bight that extends from Cape Hatteras, North Carolina to the Florida Straits. The broad continental shelf varies from 40 to 140 km wide, with an inner zone of less than 200 m water depth, and an outer zone extending to water depths of 2000 m. A diverse array of marine mammals is found in this region, including baleen and toothed whales, and manatees.

In October 2007, an acoustic monitoring effort was initiated 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 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 at one site, designated USWTR site E, during the time period August – December 2011 and July – October 2012 at depths of 952 m and 914 m, respectively. The HARP deployments from this area were named "USWTR" when the USWTR area was originally planned to be north of its current location. The HARP location is approximately 100 miles east of the North Carolina coastline (Figure 1).

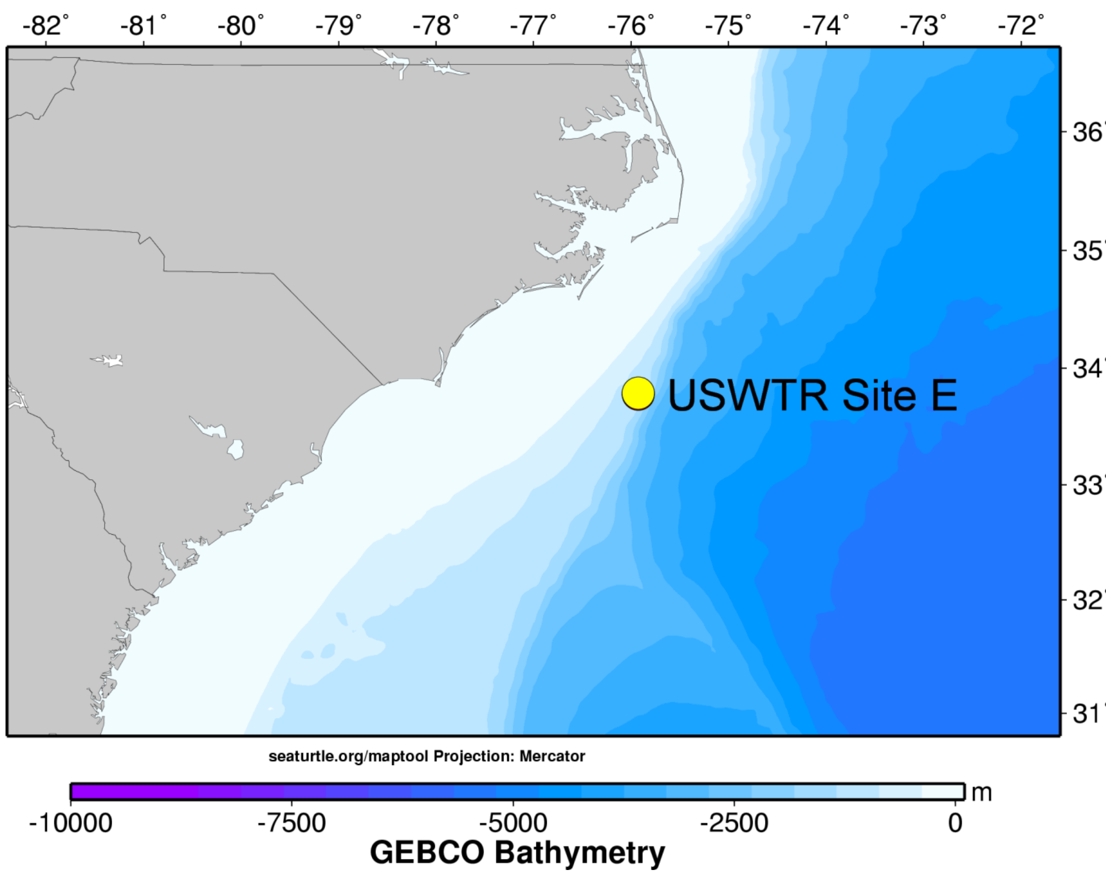


Figure 1. Deployment location of the High-frequency Acoustic Recording Package.

Methods

High-frequency Acoustic Recording Packages

High-frequency Acoustic Recording Packages (HARPs) were used to record marine mammal species, anthropogenic noise, and ambient noise in the Cherry Point OPAREA. 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 Cherry Point OPAREA 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 five sites in the Cherry Point OPAREA since October 2007 (Table 1). The two deployments analyzed in this report are from Site E (33° 46.7 N, 75° 55.6 W, depth 952 m during deployment 06, and 33° 47.2N, 75° 55.7W, depth 914 m during deployment 07).

Table 1. Cherry Point OPAREA HARP deployments. Periods of deployment analyzed in this report are shown in bold.

Deployment Designation	Site A Deployment Period	Site B Deployment Period	Site C Deployment Period	Site D Deployment Period	Site E Deployment Period
USWTR 01	10/10/2007 – 1/16/2008				
USWTR 02		5/31/2008 – 9/11/2008			
USWTR 04	11/8/2009 – 2/24/2010		11/8/2009 – 4/20/2010		
USWTR 05	7/30/2010 – 3/3/2011			7/30/2010 – 2/4/2011	
USWTR 06					**8/19/2011 – 12/1/2011**
USWTR 07					**7/14/2012 – 10/2/2012**

Data Analysis

To assess the quality of the acoustic data, frequency spectra were calculated for all the data using a time average of 5 seconds and variable frequency bins (1, 10, and 100 Hz). These data, called Long-Term Spectral Averages (LTSAs) were examined both for characteristics of ambient noise and also as a means to discover marine mammal and anthropogenic sounds.

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 Cherry Point OPAREA, 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 1 – 1000 Hz, (2) mid frequencies, between 500 – 5000 Hz, and (3) high frequencies, between 1 – 100 kHz. Blue, Bryde's, fin, minke, North Atlantic right, and sei whale sounds were classified as low frequency; humpback whale, shipping, explosions, and mid-frequency active sonar sounds 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 sample raw data were decimated by a factor of 100 for an effective bandwidth of 1 kHz. Long-term spectral averages 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.

Whale calls for which low-frequency effort was expended include: blue whale A, B, and arch calls (Mellinger & Clark 2003), Bryde's whale Be7 and Be9 calls (Oleson et al. 2003), fin whale 20 Hz and 40 Hz pulses, minke whale pulse trains, North Atlantic right whale up-calls, and sei whale calls. The same LTSA and spectrogram parameters were used to detect all call types. For spectrogram scrolling, the LTSA frequency was set to display up to 500 Hz. To observe individual calls, spectrogram parameters were typically set to 120 seconds and 200 Hz. The DFT was generally set between 1500 and 2000 data points (yielding about 1 Hz frequency resolution), and an 85-95% overlap of data in the input time series.

Blue Whales

Several different calls were used to detect the presence of blue whales. Detection effort included call types A, B, and arch sensu Mellinger & Clark (2003) (Figure 2). The North Atlantic A call is a constant 18-19 Hz tone lasting approximately 8 seconds while the North Atlantic B call is an 18-15 Hz downsweep lasting approximately 11 seconds (Figure 3). Individual calls are readily detected in an LTSA, owing to their long duration. The third call, the arch call, on average starts at a frequency of 56 Hz, ascends to a peak frequency of 69 Hz, and then descends to 35 Hz over a period of 6.3 seconds (Figure 4). Manual scanning of the LTSA was the primary means to search for blue whale calls.

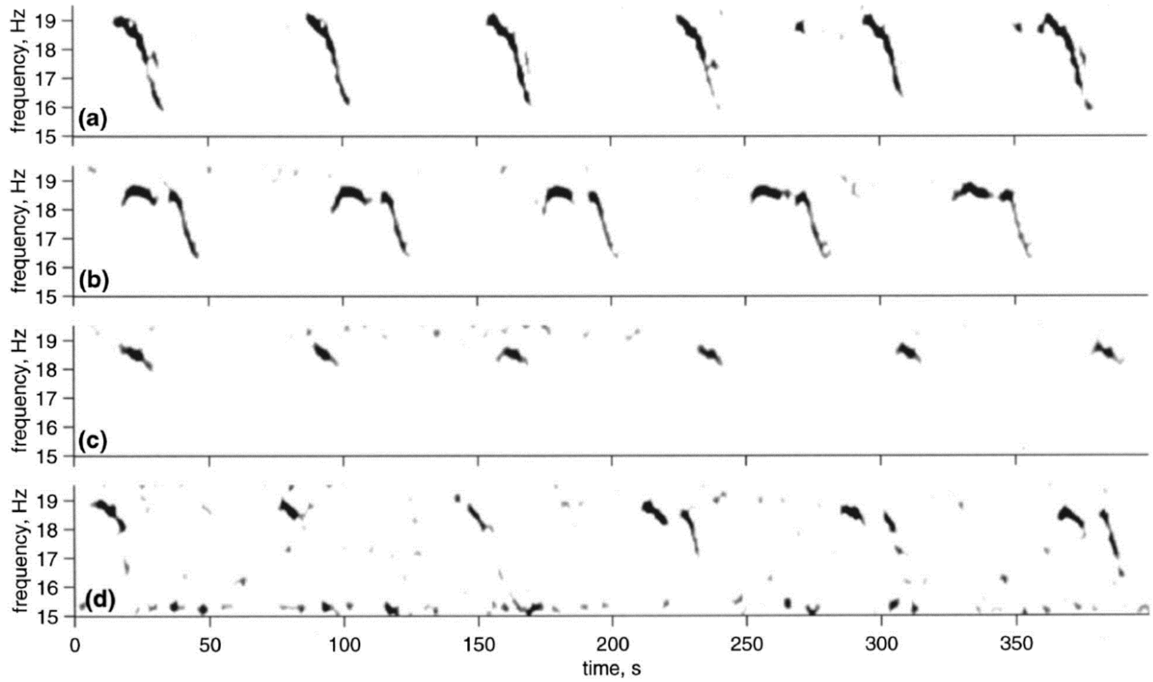


Figure 2. North Atlantic blue whale A and B calls from Mellinger and Clark (2003). (a) Series of the most common blue whale phrase type in which part B follows part A without a gap. (b) Another common phrase type in which part A is followed by a short silent gap before part B, and the start of part A sweeps up slightly in frequency. (c) A sequence consisting of only part A sounds. (d) A sequence consisting of a mixture of A-only phrases and A-B phrases.

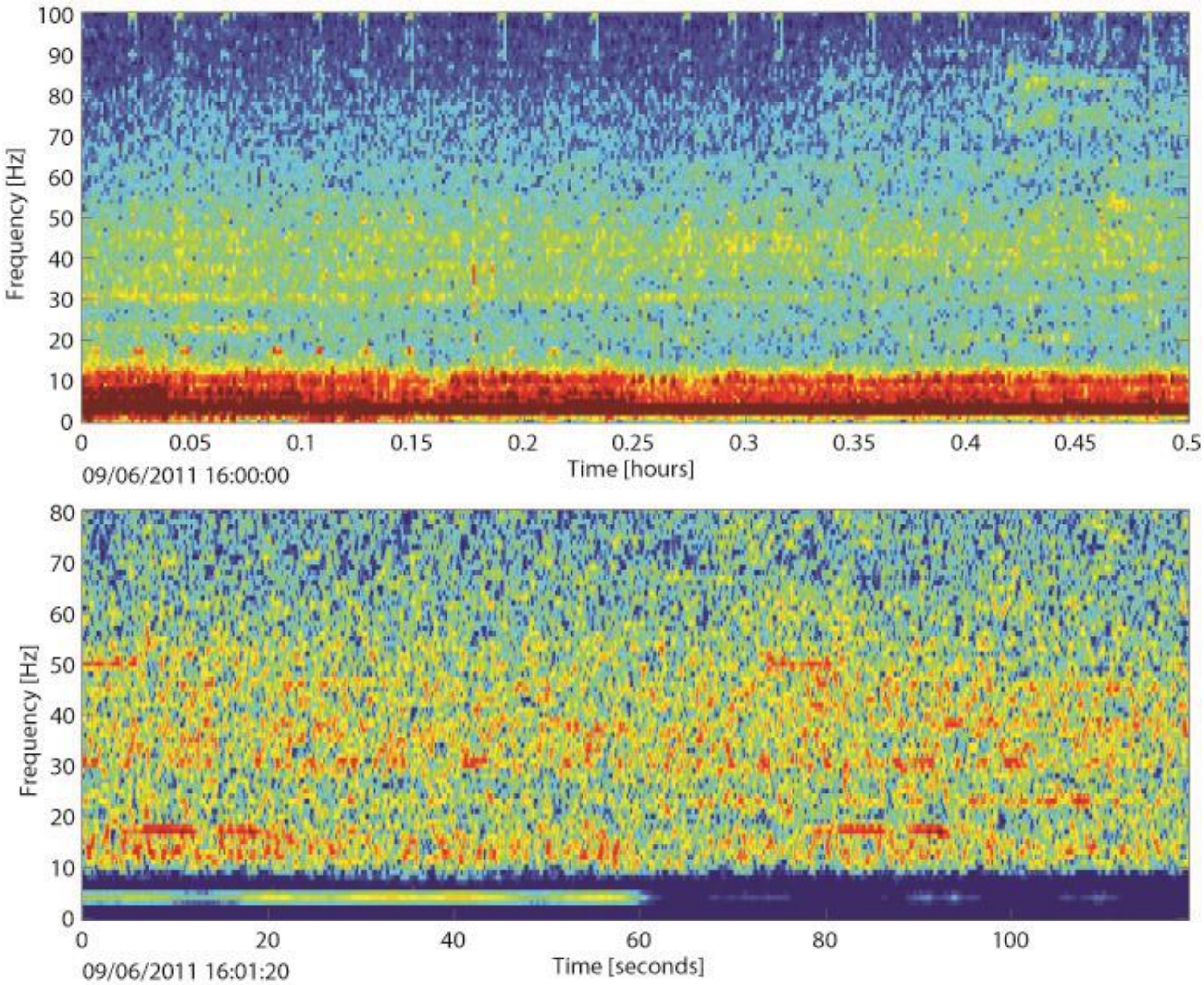


Figure 3. Blue whale calls in the LTSA (top) and spectrogram (bottom) from the USWTR data.

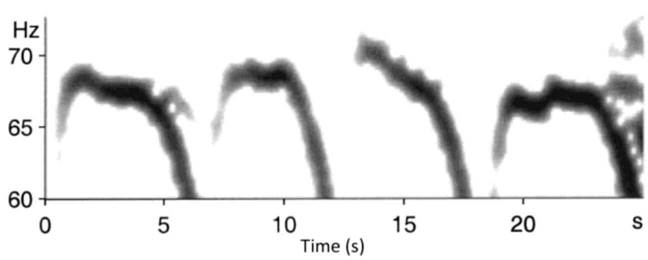


Figure 4. Blue whale arch calls from Mellinger and Clark (2003).

Bryde's Whales

Bryde's whales inhabit tropical and subtropical waters worldwide (Omura 1959, Wade and Gerrodette 1993), and the Cherry Point OPAREA HARP site 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 average 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 5). The Be9 call type, described for the Gulf of Mexico (Širović et al. 2013a), is a downswept pulse ranging from 143 to 85 Hz, with each pulse approximately 0.7 seconds long (Figure 6).

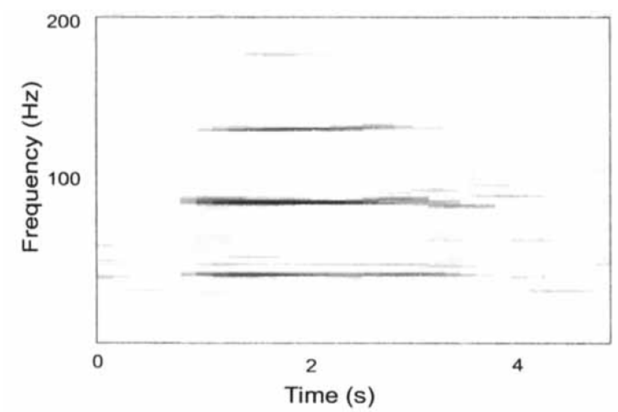


Figure 5. Spectrogram of Bryde's whale Be7 call type from the Southern Caribbean, from Oleson et al. (2003).

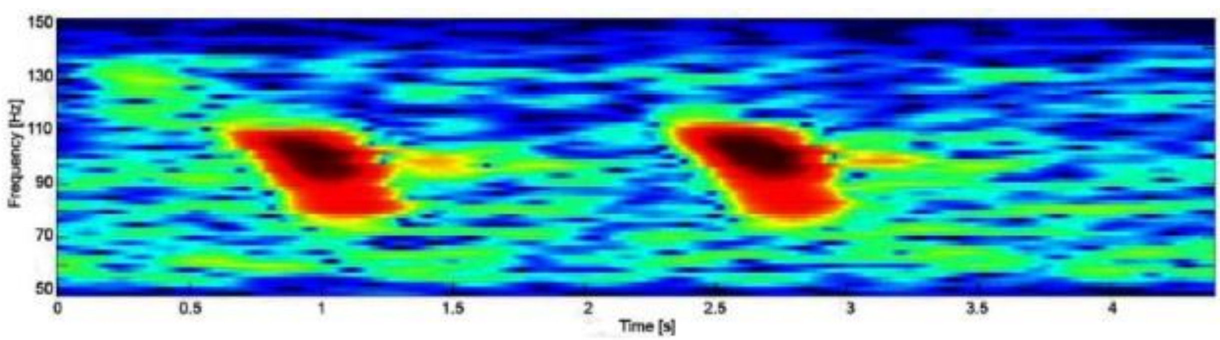


Figure 6. Bryde's whale Be9 call type from the Gulf of Mexico, from Širović et al. (2013a).

Fin Whales

Fin whales produce a variety of calls. Most have frequency lower than 100 Hz, are short in duration, and frequency-modulated. The best-known fin whale call is the 20 Hz pulse, downswept from 30 – 15 Hz (Figure 7). These pulses occur at regular intervals as song (Thompson et al. 1992). In this report we indicate the presence of 20 Hz pulses, but do not categorize them as either song or irregular calls. Fin whale 40 Hz pulses (Watkins 1981; Širović et al. 2013b), sweep down in frequency from 75 to 40 Hz and are typically produced in irregular sequences (Figure 8).

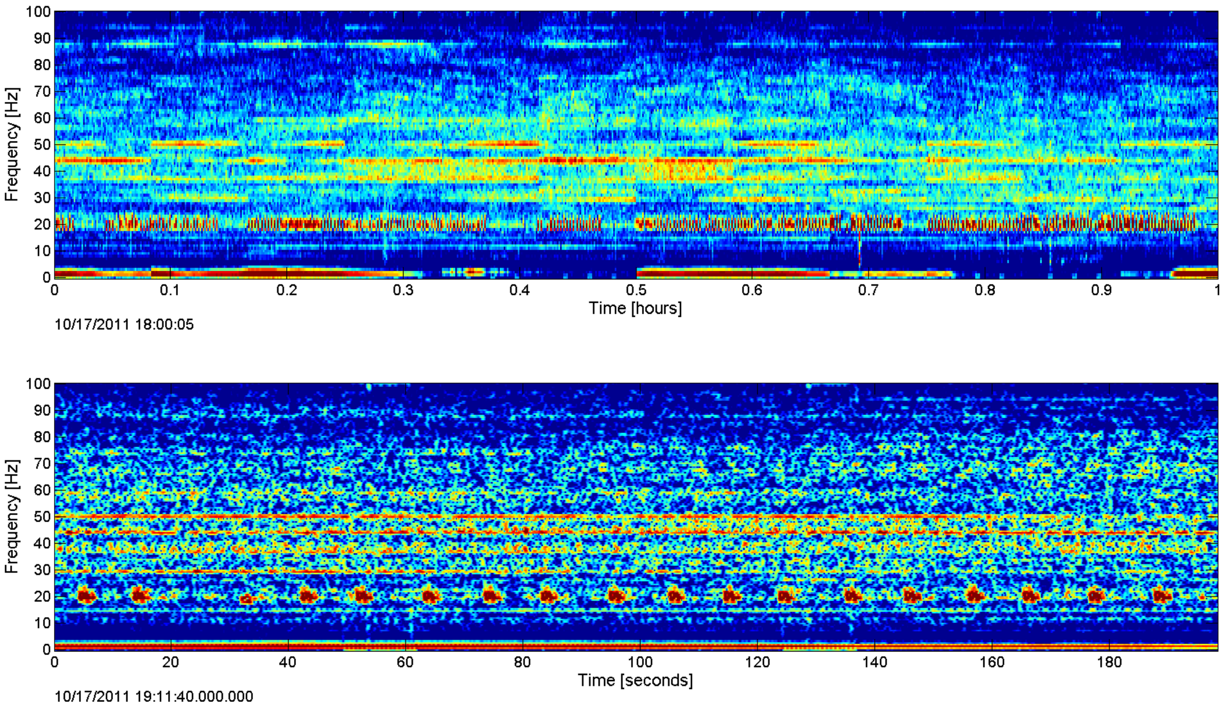


Figure 7. 20 Hz fin whale calls in the LTSA (top) and spectrogram (bottom) from USWTR06E.

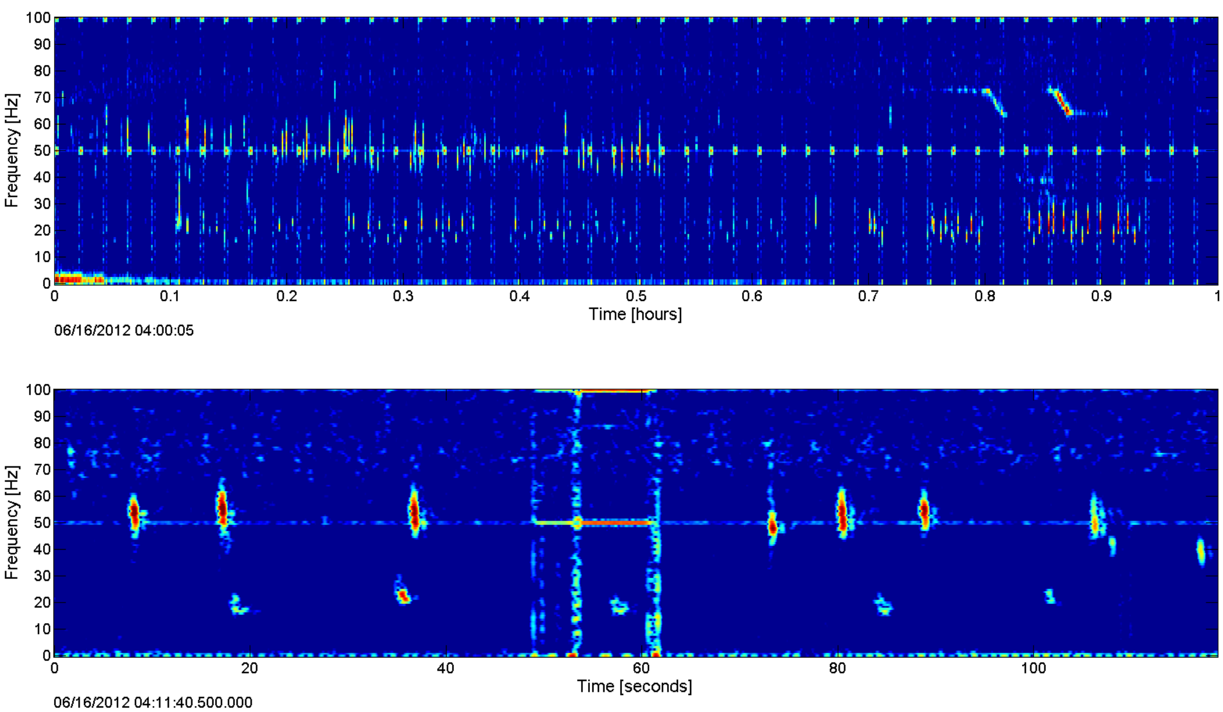


Figure 8. 40 Hz fin calls in the LTSA (circled, top) and spectrogram (bottom) from southern California HARP data.

Minke Whales

Minke whales in the North Atlantic produce long pulse trains. Mellinger et al. (2000) described minke whale pulse sequences near Puerto Rico as speed-up and slow-down pulse trains, with increasing and decreasing pulse rate respectively. Recently, those call types were detected in the North Atlantic and were expanded to include pulse trains with non-varying pulse rate (Risch et al. 2012) (Figure 9).

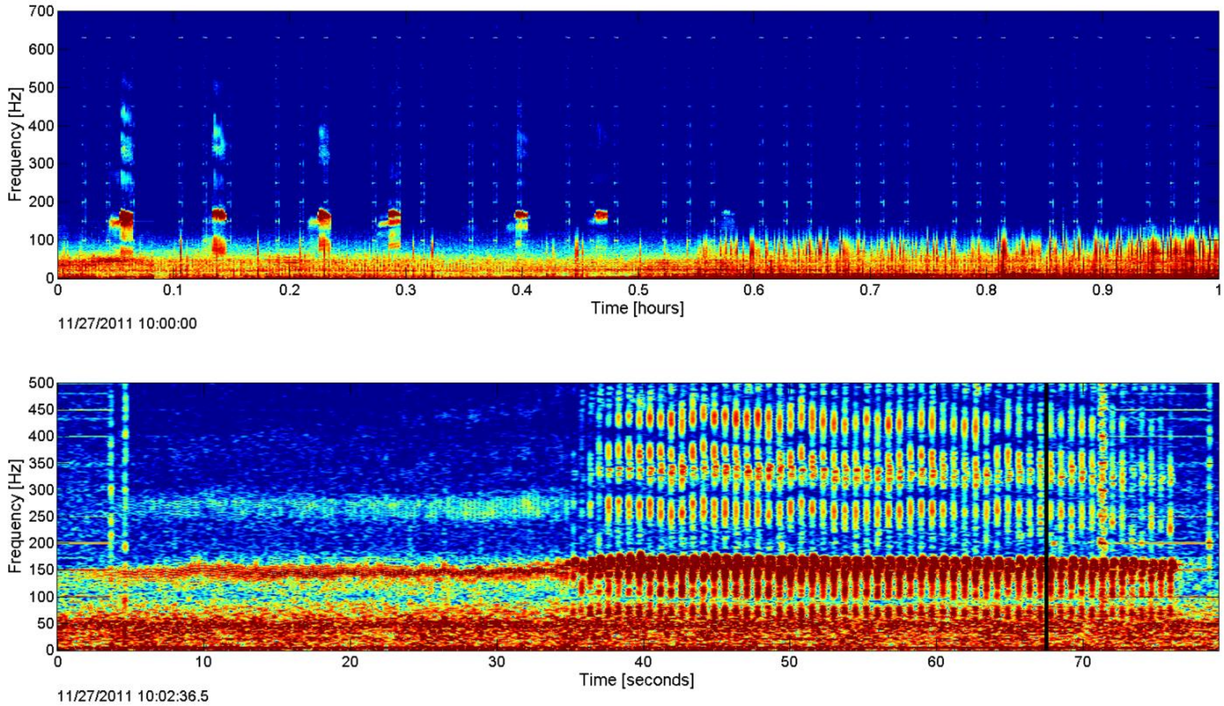


Figure 9. Minke whale pulse train in the LTSA (top) and spectrogram (bottom) from USWTR06E.

North Atlantic Right Whales

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 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). No right whale upcalls were detected.

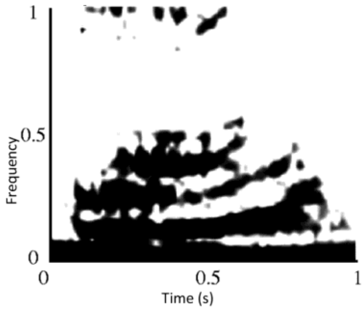


Figure 10. Right whale upcall call from Parks and Tyack (2005).

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, but we report on a low frequency downsweep call similar to those Baumgartner et al. (2008) reported as sei whale calls. These calls typically sweep from a starting frequency around 100 Hz to an ending frequency around 40 Hz (Figure 11).

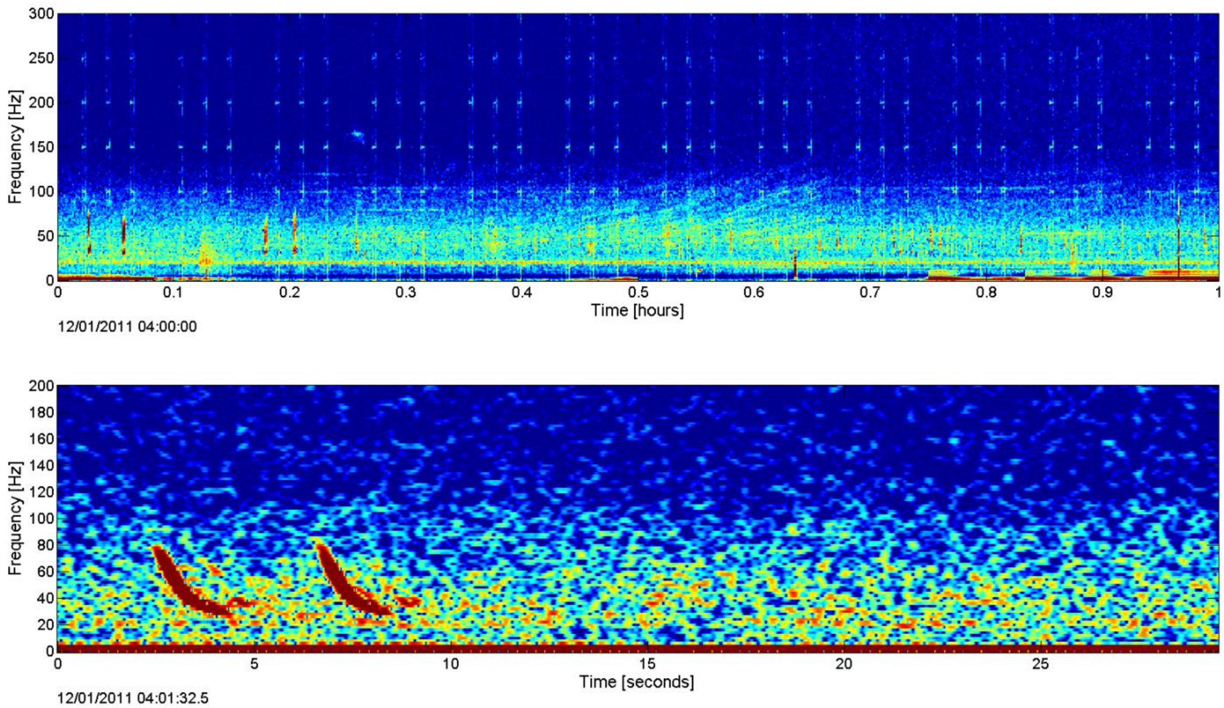


Figure 11. Downsweep calls reported to be from sei whales in the LTSA (top) and spectrogram (bottom) from USWTR06E.

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 10 Hz frequency bin. The presence of each call type was determined in one-minute bins.

Mid-frequency sounds monitored in this report include: humpback whale, unidentified odontocete whistles less than 5 kHz, and North Atlantic right whale gunshot calls. LTSA search parameters used to search for each sound are given in Table 2. Humpback whale call detection effort was automated using a power-law detector (Helble et al. 2012).

Table 2. Mid-frequency data analysis search parameters.

	LTSA Search Parameters	
Species	**Plot Length (Hr)**	**Frequency Range (Hz)**
N Atlantic Right Whale (gunshot calls)	0.75	0 – 2000
Unidentified Odontocete (whistles <5 kHz)	0.75	0 – 5000

Humpback Whales

Humpback whale song is categorized by the repetition of units, phrases and themes (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. For this report, we examined the data for humpback calls (both song and non-song) using the generalized power-law algorithm (Helble et al. 2012), and then a trained analyst verified the accuracy of the detected signals (Figure 12). No humpback calls were detected.

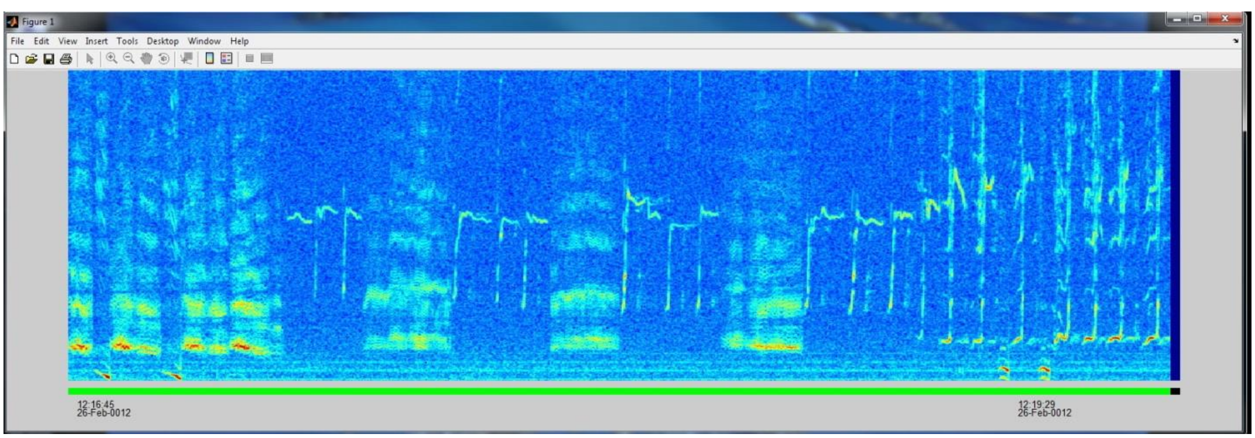


Figure 12. Example of humpback whale song from southern California in analyst verification stage of detector.

Unidentified Odontocete Whistles <5 kHz

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 occurred on the shelf (Katona et al. 1988). Acoustic parameters from known Western Atlantic killer whale calls were used to search for killer whale acoustic signals (Figure 13). Killer whale pulsed calls are well documented with primary energy between 1 and 6 kHz and duration primarily between 0.5 and 1.5 seconds (Ford 1989). While most of the whistles detected are likely produced by killer whales, we report these as unidentified odontocete whistles <5 kHz as these call types are not as easily distinguishable from other odontocete whistles such as those produced by pilot whales or false killer whales.

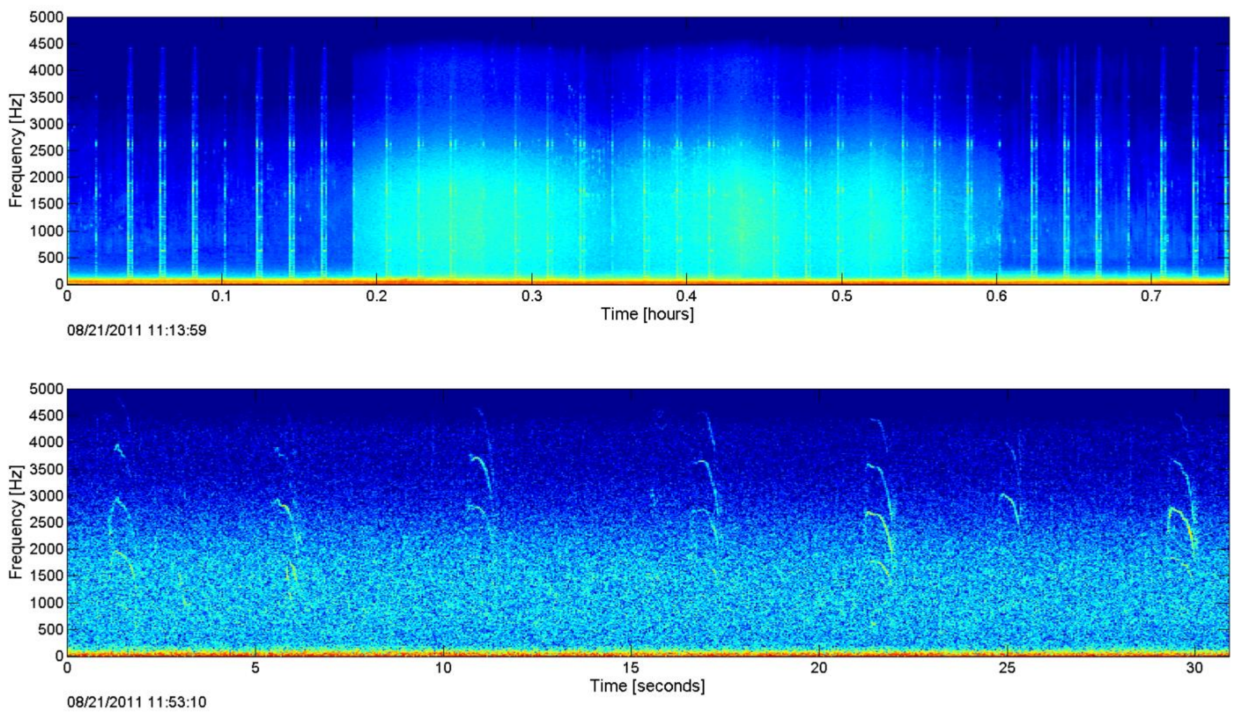


Figure 13. Unidentified odontocete whistles <5 kHz from USWTR06E.

North Atlantic Right Whales

North Atlantic right whale gunshot calls are high intensity (~196 dB re 1 μPa) and broadband (20 Hz – 20 kHz) (Parks et al. 2005) and were therefore included in mid-frequency analysis. Gunshot calls consist of a short initial signal followed by prolonged reverberation (Figure 14). Although these calls are capable of being detected at a range of several miles, no right whale gunshot calls were detected in the data.

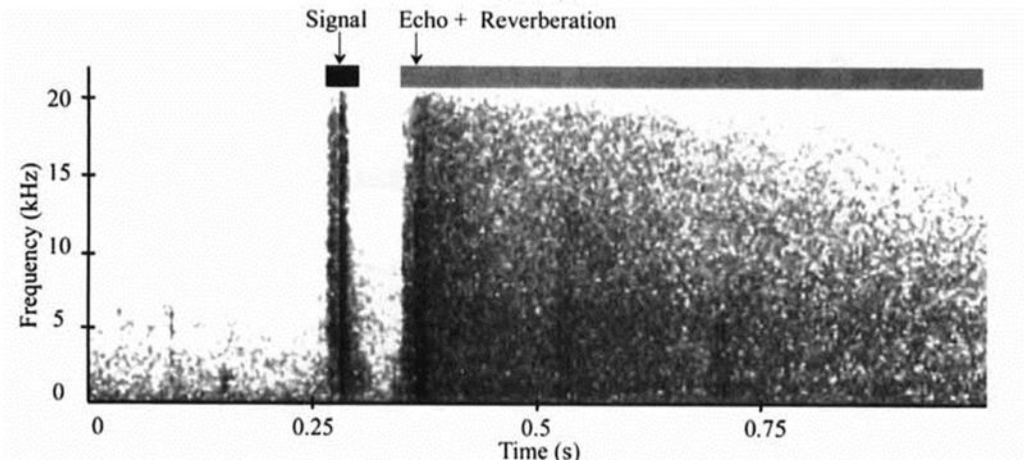


Figure 14. North Atlantic right whale gunshot call from Parks et al. (2005).

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.

Whale calls for which high-frequency effort was expended include: beaked whales, killer whales, pygmy and dwarf sperm whales (referred to as *Kogia* spp.), Risso's dolphins, sperm whales, and unidentified odontocetes. The same LTSA and spectrogram parameters were used to detect all call types. For spectrogram scrolling, the LTSA frequency was set to display up to 100 kHz. To observe individual calls, spectrogram parameters were typically set to 5 seconds and 100 kHz. The DFT was generally set to 1000 data points (yielding about 400 Hz frequency resolution), and a 50% overlap of data in the input time series.

Beaked Whales

Frequency modulated (FM) pulses from Blainville's, Cuvier's, Gervais', and one other unidentified beaked whale were detected with an automated method. After all echolocation signals were identified with a Teager Kaiser energy detector (Soldevilla et al. 2008, Roch et al. 2011), an expert system discriminated between delphinid clicks and beaked whale FM pulses. A decision about presence or absence of beaked whale signals was based on detections within a 75 second segment. Only segments with more than 7 detections were used in further analysis. All echolocation signals with a peak and center frequency below 32 and 25 kHz, respectively, a duration less than 355 µs, and a sweep rate of less than 23 kHz/ms were removed from the analysis. If more than 13% of all initially detected echolocation signals remained after applying these criteria, the segment was classified to have beaked whale FM pulses. This method detected beaked whale signals that are expected to be found in the area. A third classification step, based on computer assisted manual decisions by a trained analyst, labeled the automatically detected segments to pulse type level and rejected false detections (Baumann-Pickering et al. 2013). The rate of missed segments, based on Southern California HARP data tests, was approximately 5%, varying slightly between deployments. The performance of the detector was spot checked for the USWTR data sets.

Blainville's Beaked Whales

Blainville's beaked whale echolocation signals are, like most beaked whales' signals, polycyclic, with a characteristic frequency-modulated upsweep, peak frequency around 34 kHz and uniform inter-pulse interval (IPI) of about 280 ms (Johnson et al. 2004, Baumann-Pickering et al. 2013). Blainville's FM pulses are also distinguishable in the spectral domain by their sharp energy onset around 25 kHz with only a small energy peak at around 22 kHz (Figure 15).

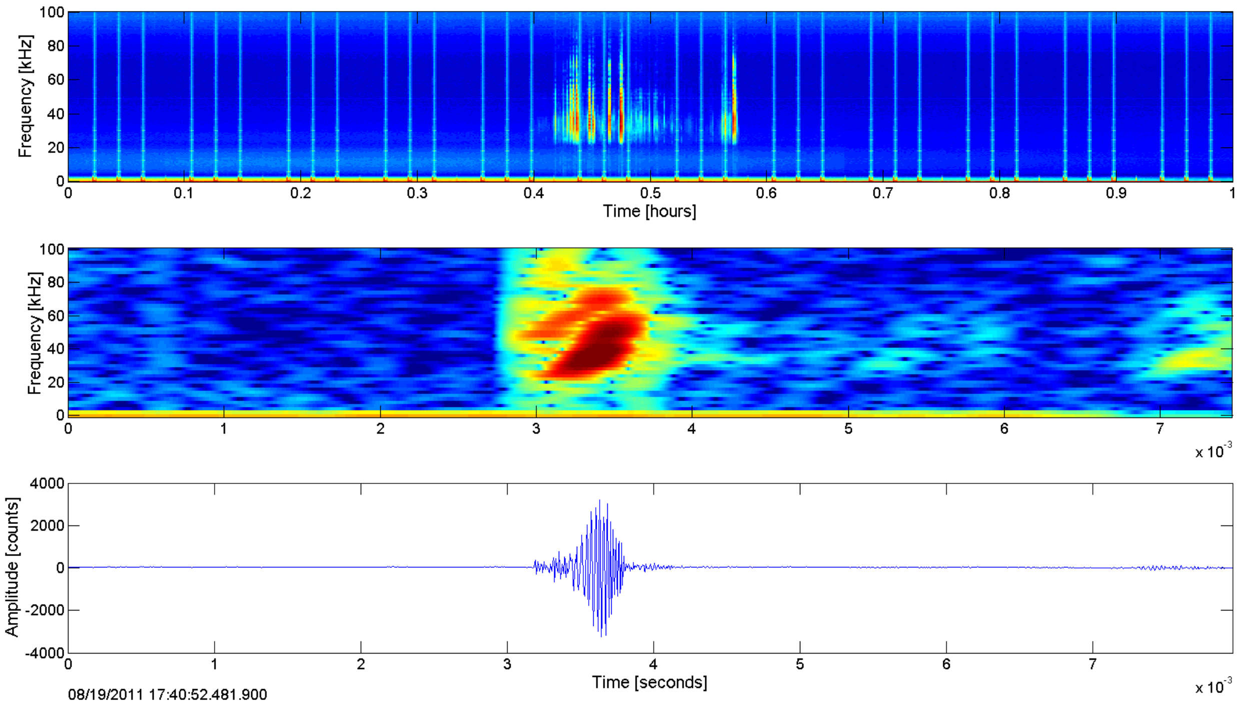


Figure 15. Blainville's beaked whale FM pules in the LTSA (top) and spectrogram (bottom) from USWTR06E.

Unidentified Beaked Whale (BW38)

A beaked whale-like FM pulse was detected and its origin classified as unidentified beaked whale. It had a peak frequency around 38 kHz and is subsequently referred to as BW38. The BW38 signal type is similar to the FM pulse type produced by Blainville's beaked whale. The spectral content of the BW38 signal type is shifted about 5 kHz higher in comparison to Blainville's signal. This FM pulse type has been observed before on long-term recordings collected in the central Pacific (Baumann-Pickering unpublished data). The BW38 inter-pulse-interval (IPI) is about 310 ms longer than that of Blainville's and shorter than that of Cuvier's beaked whale. It also has on average the shortest duration of all encountered FM pulse types (440 µs, in comparison to 580 and 590 µs, respectively) (Figure 16,and Figure 17). We are treating it as a new signal type, however, it is uncertain whether this is a new unknown signal originating from a yet to be determined species or if Blainville's beaked whales may change their signal spectrum dependent on e.g. behavior, sex, or age.

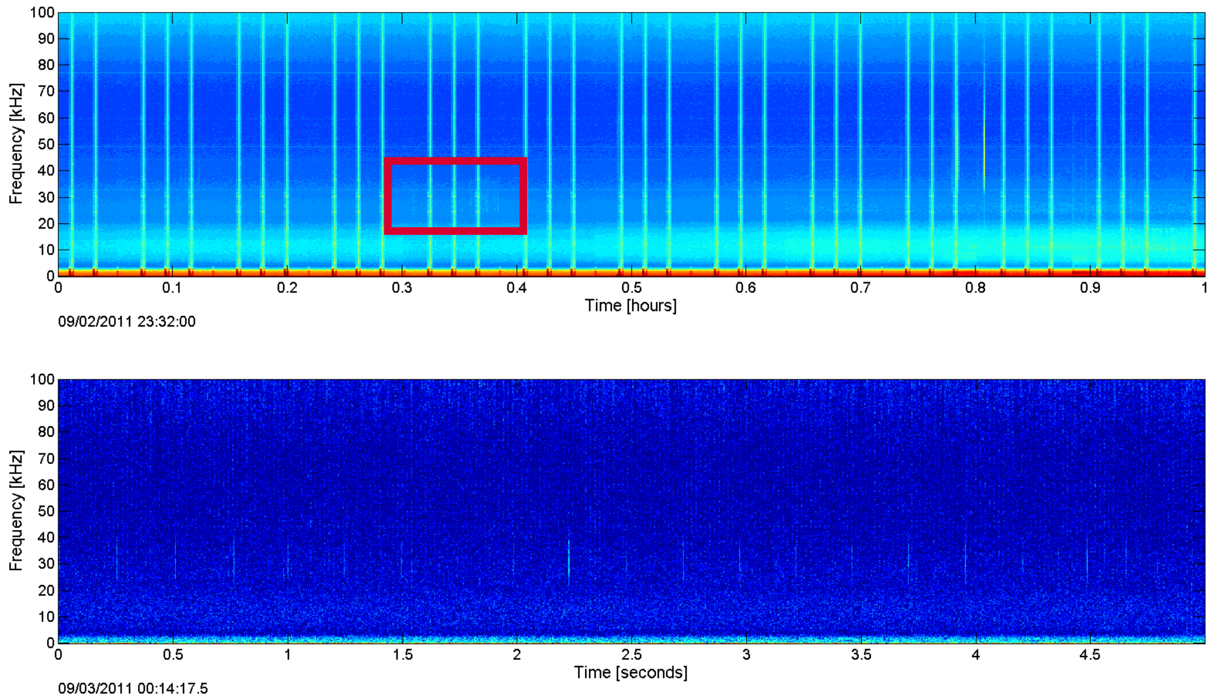


Figure 16. LTSA (top) and spectrogram (bottom) of a BW38 signal from USWTR06E.

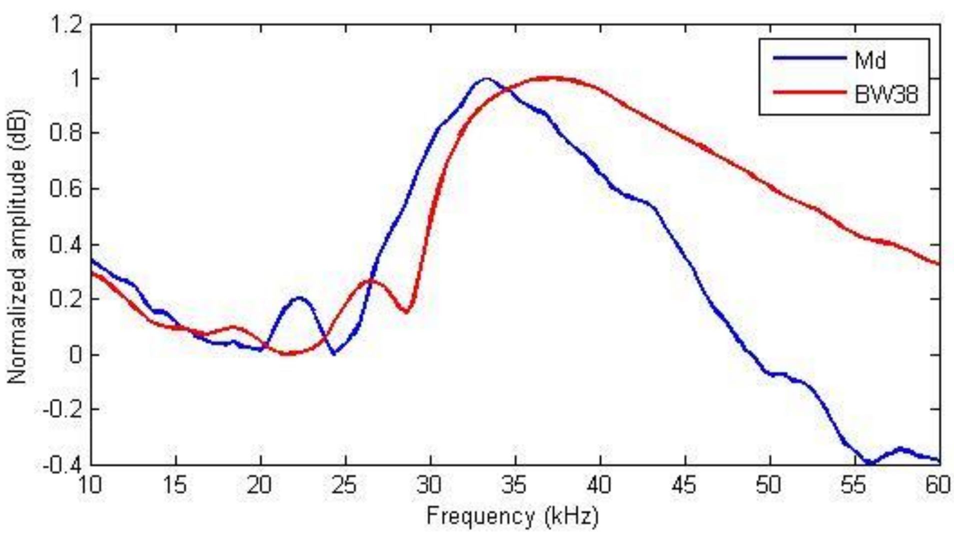


Figure 17. Mean spectra of Blainville's beaked whale (Md, blue) and the new signal type BW38 (red). The signals have very similar properties; however, BW38 is shifted to higher frequencies by approximately 5 kHz.

Cuvier's Beaked Whales

Cuvier's beaked whale echolocation signals are well differentiated from other species' acoustic signals. These signals are polycyclic, with a characteristic frequency-modulated upsweep, peak frequency around 40 kHz and uniform IPI of about 340 ms (Johnson et al. 2004, Zimmer et al. 2005, Baumann-Pickering et al. 2013). Cuvier's FM pulses are also distinct in that they have two characteristic spectral peaks around 17 and 23 kHz (Figure 18).

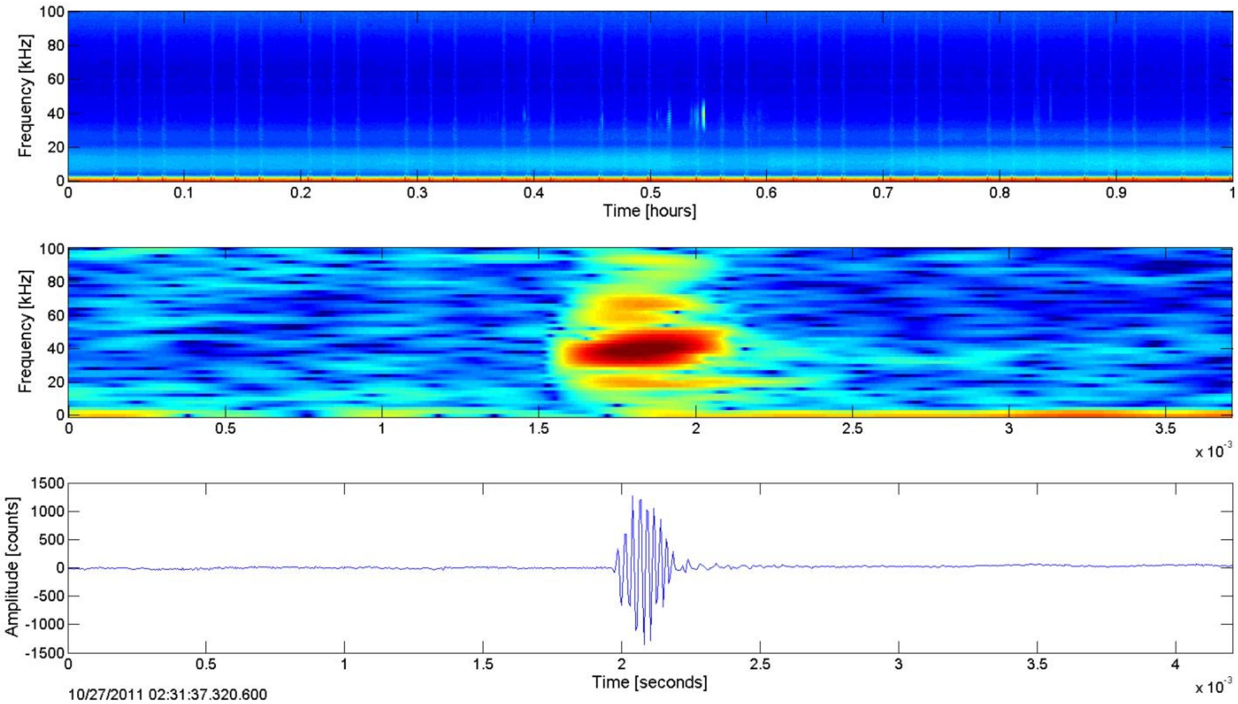


Figure 18. Cuvier's beaked whale echolocation FM pulses in the LTSA (top), spectrogram (middle), and timeseries (bottom) from USWTR06E.

Gervais' Beaked Whales

Gervais' beaked whale signals have energy concentrated in the 30 – 50 kHz band (Gillespie et al. 2009), with a peak at 44 kHz (Baumann-Pickering et al 2013). While Gervais' beaked whale signals are similar to those of Cuvier's and Blainville's beaked whales, the Gervais' beaked whale FM pulses are at a slightly higher frequency than those of the other two species. Similarly, Gervais' beaked whale FM pulses sweep up in frequency (Figure 19). The IPI for Gervais' beaked whale signals is typically around 275 ms (Baumann-Pickering et al. 2013).

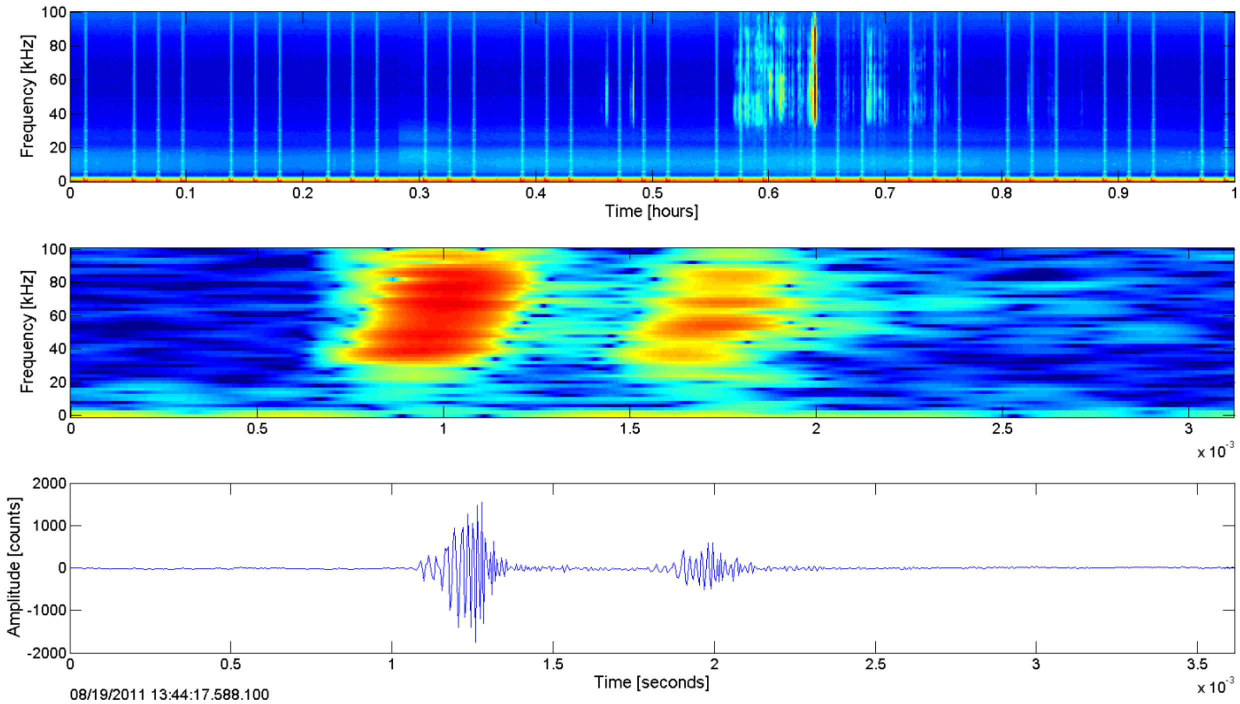


Figure 19. LTSA (top), spectrogram (middle), and timeseries (bottom) of a Gervais' beaked whale FM pulse from USWTR06E.

Unidentified Odontocetes

Delphinid sounds can be categorized as either: (1) echolocation clicks, (2) burst pulses/buzzes, or (3) whistles. Dolphin echolocation clicks are broadband impulses with the majority of energy between 20 and 80 kHz. Burst pulses and buzzes 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. They are used in a communication context (Lammers et al 2003). 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 20). Only some delphinid sounds are distinguishable by species based on the character of their clicks, buzz pulses, or whistles (e.g. Roch et al. 2011).

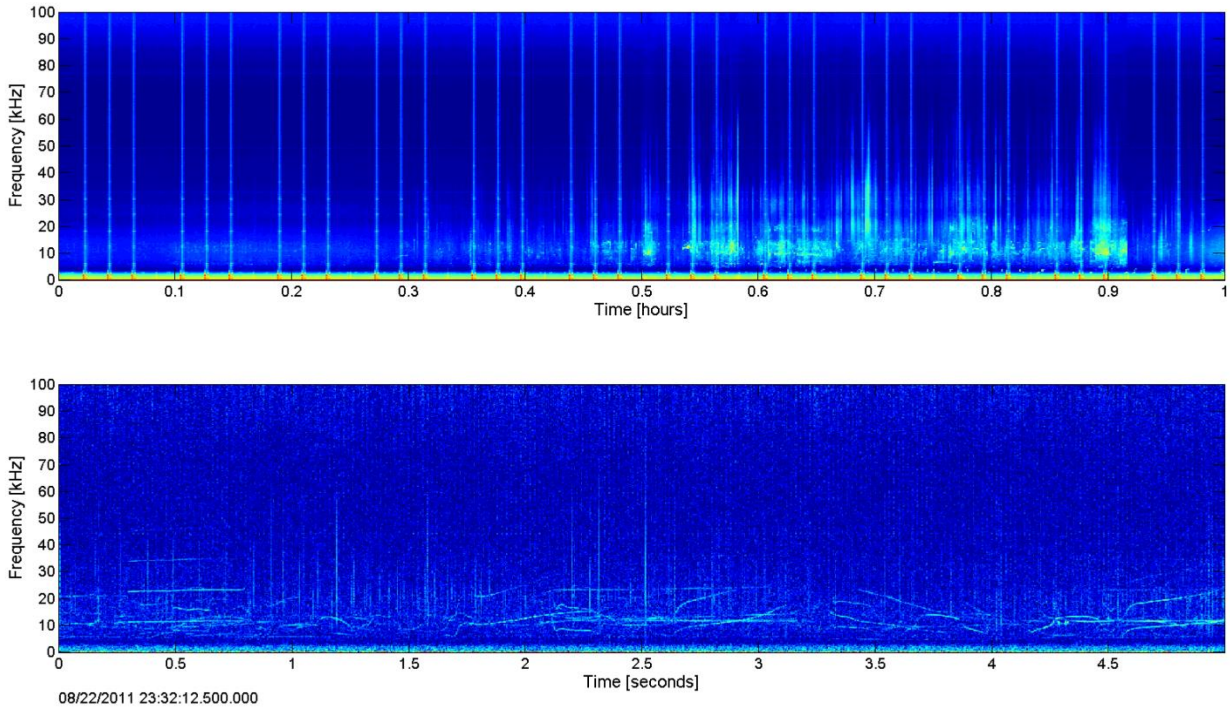


Figure 20. LTSA (top) and spectrogram (bottom) of odontocete echolocation clicks and whistles from USWTR06E.

Killer Whales

Killer whales are known to produce four call types: echolocation clicks, low frequency whistles, high frequency modulated (HFM) signals and pulsed calls (Ford 1989, Samarra et al. 2010). While we primarily use pulsed calls and HFM signals for killer whale species identification, echolocation clicks (Figure 21) are used to a lesser extent for the classification of killer whale signals as these call types are not as easily distinguishable from other odontocete clicks and whistles (e.g. pilot whales).

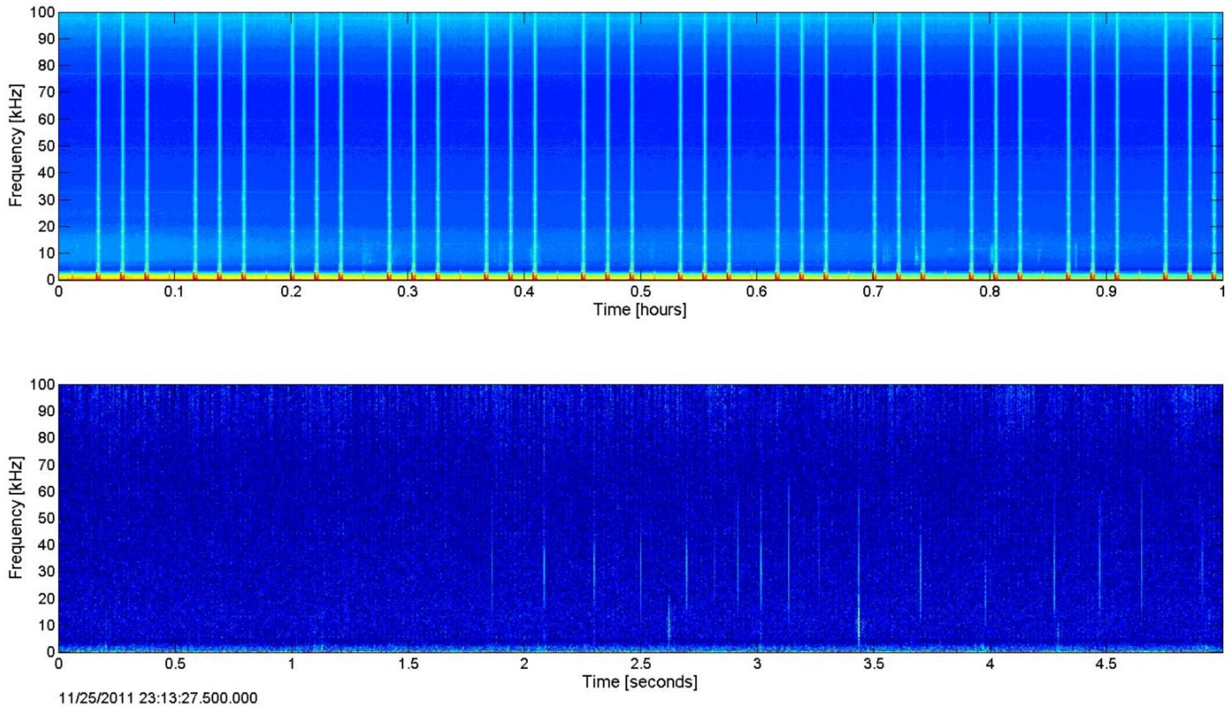


Figure 21. Killer whale echolocation clicks in the LTSA (top) and spectrogram (bottom) from USTR06E.

Kogia spp.

Dwarf and pygmy sperm whales emit echolocation signals which have peak energy at frequencies near 130 kHz (Au 1993). While this is above the upper frequency band recorded by the HARP, the lower portion of the *Kogia* energy spectrum is within the 100 kHz HARP bandwidth (Figure 22). All Kogia detections were found by manual scanning of the HARP data.

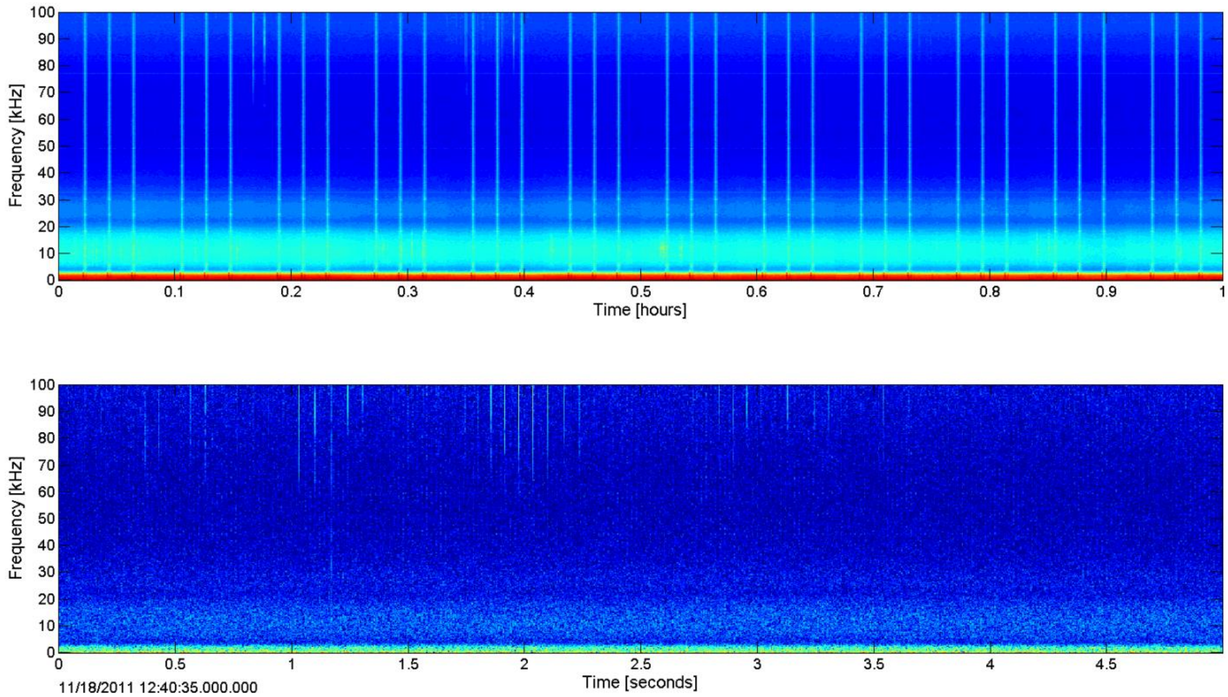


Figure 22. *Kogia* spp. echolocation clicks in the LTSA (top) and spectrogram (bottom) from USWTR06E.

Risso's Dolphins

Risso's dolphin echolocation clicks can be identified to species by their distinctive banding patterns in the LTSA (Figure 23). 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). In our analysis, we found Risso's dolphin energy peaks at 21, 25, 30, and 42 kHz, only slightly different to those previously reported for the JAX area (Debich et al. 2013)

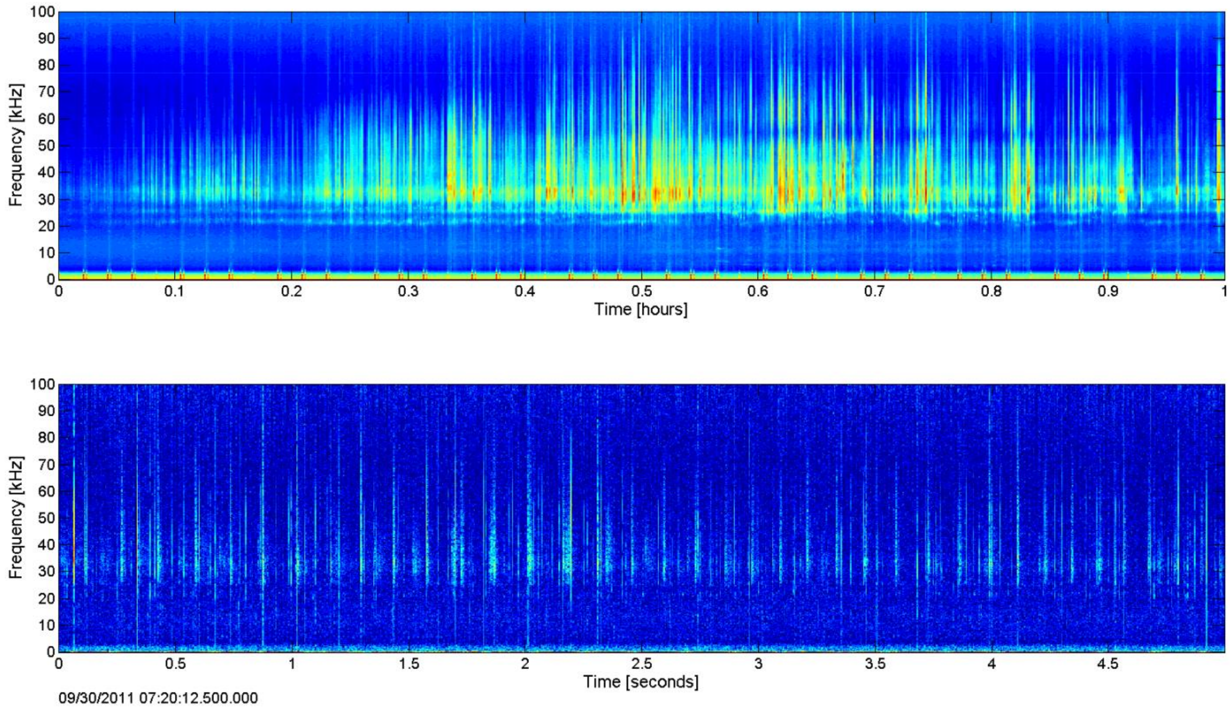


Figure 23. Risso's dolphin click bout in LTSA (top) and spectrogram (bottom). A distinctive banding pattern is seen in the LTSA from USWTR06E.

Sperm Whales

Sperm whales produce echolocation clicks in the frequency range 5 – 20 kHz with peak energy between 10 – 15 kHz (Møhl et al. 2003). Regular clicks, observed during foraging dives, have a uniform inter-click interval of about one second (Goold and Jones 1995, Madsen et al. 2002, Møhl, et al. 2003). Short bursts of closely spaced clicks called buzzes are observed during foraging dives and are believed to indicate a predation attempt (Watwood et al. 2006). Multiple foraging dives and rest periods are often observed over a long period of time in the LTSA (Figure 24). Care must be taken not to misclassify impulsive anthropogenic sounds (particularly cavitation sounds of ship propellers) that maintain a similar frequency to sperm whales.

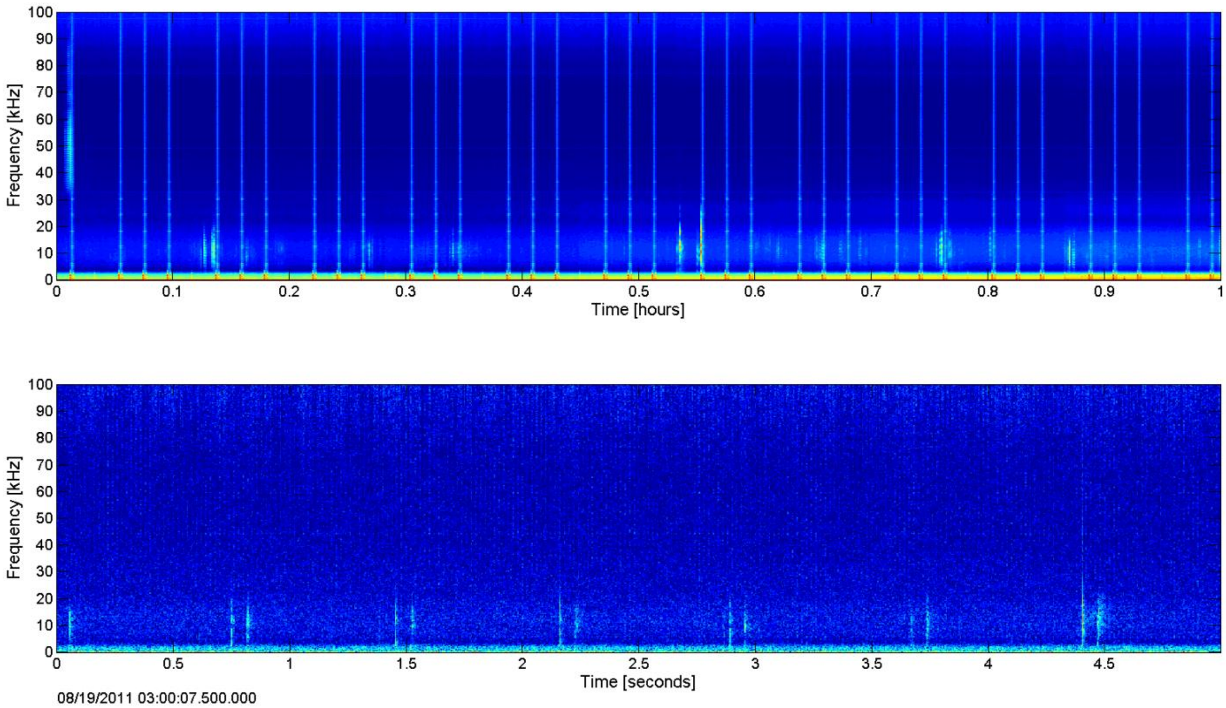


Figure 24. Sperm whale echolocation clicks in the LTSA (top) and spectrogram (bottom) from USWTR06E.

Echolocation Click Types

A manual 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 Hodge, were used as templates. These previous analyses were combined and provided thirteen distinct mean click spectra (Debich et al. 2013). 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 mean spectra of manually detected acoustic encounters in the data. 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, four CT (Figure 25) were identified within each deployment and are described below. CT were then assigned names based on the frequency at which their spectra reached 50% of maximum energy (e.g. CT30 = 30 kHz for the 50% energy level).

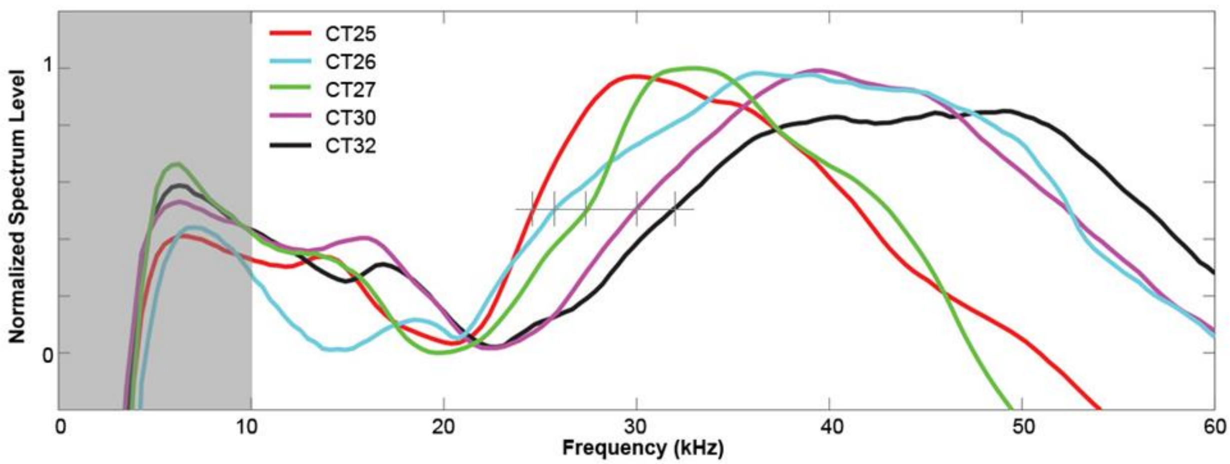


Figure 25. Echolocation click types (CT) that occurred in the Cherry Point OPAREA repeatedly. Numerical values (e.g. CT25 = 25 kHz) refer to low end of 50% energy bandwidth. CT 27 was not detected in the Cherry Point OPAREA, but was included in this figure for comparison since it occurs in a nearby HARP site in the Jacksonville Range Complex.

Click Type 25

CT 25 (Figure 26) 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 27).

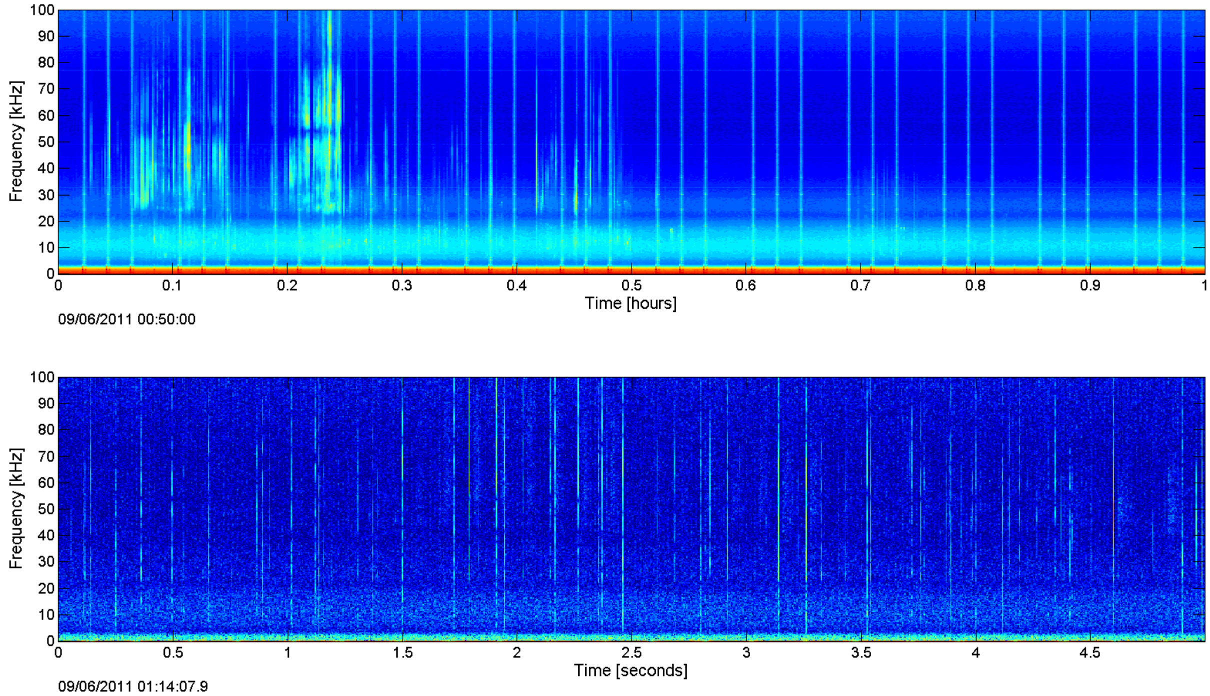


Figure 26. CT 25 in the LTSA (top) and spectrogram (bottom).

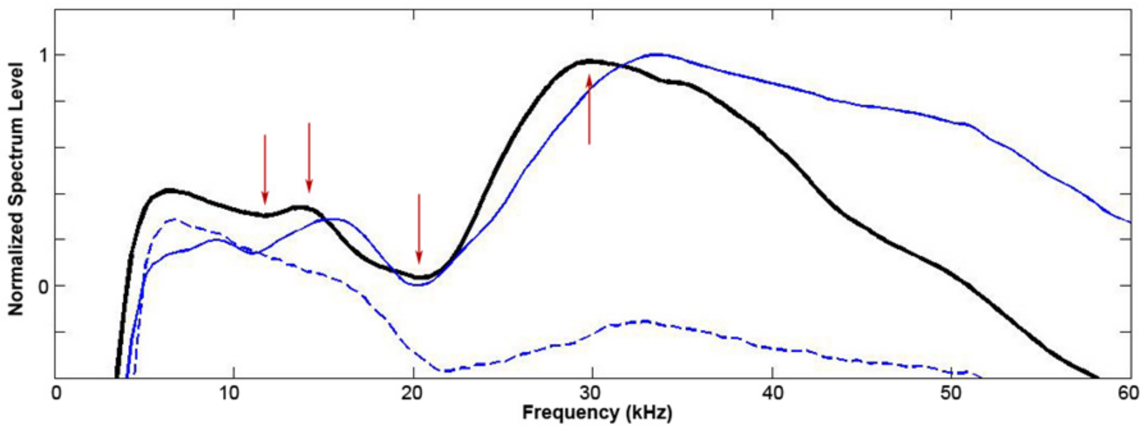


Figure 27. Mean spectra of CT25. Example encounter (black line), template for CT (blue line; from Gulf of Mexico and/or North Carolina), and noise floor (dotted line). Arrows denote spectral peaks or troughs.

Click Type 26

CT 26 (Figure 28) 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 29).

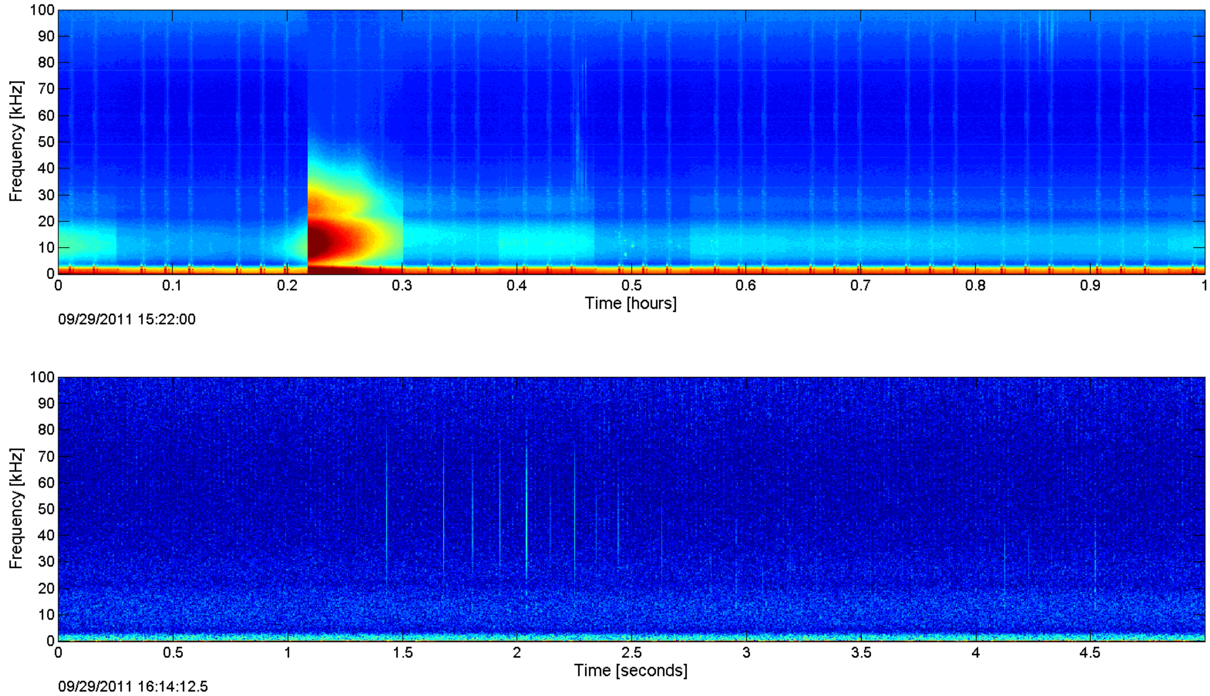


Figure 28. CT 26 in the LTSA (top) and spectrogram (bottom).

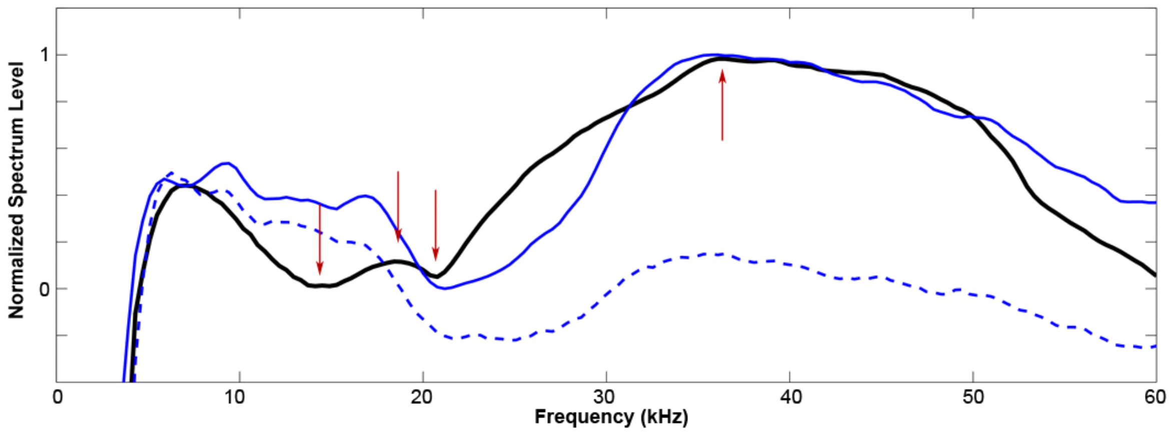


Figure 29. Mean spectra of clicks for CT26. Example (black line), template (blue line), and noise floor (dotted line). Arrows denote spectral peaks or troughs.

Click Type 30

CT 30 (Figure 30) 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 31).

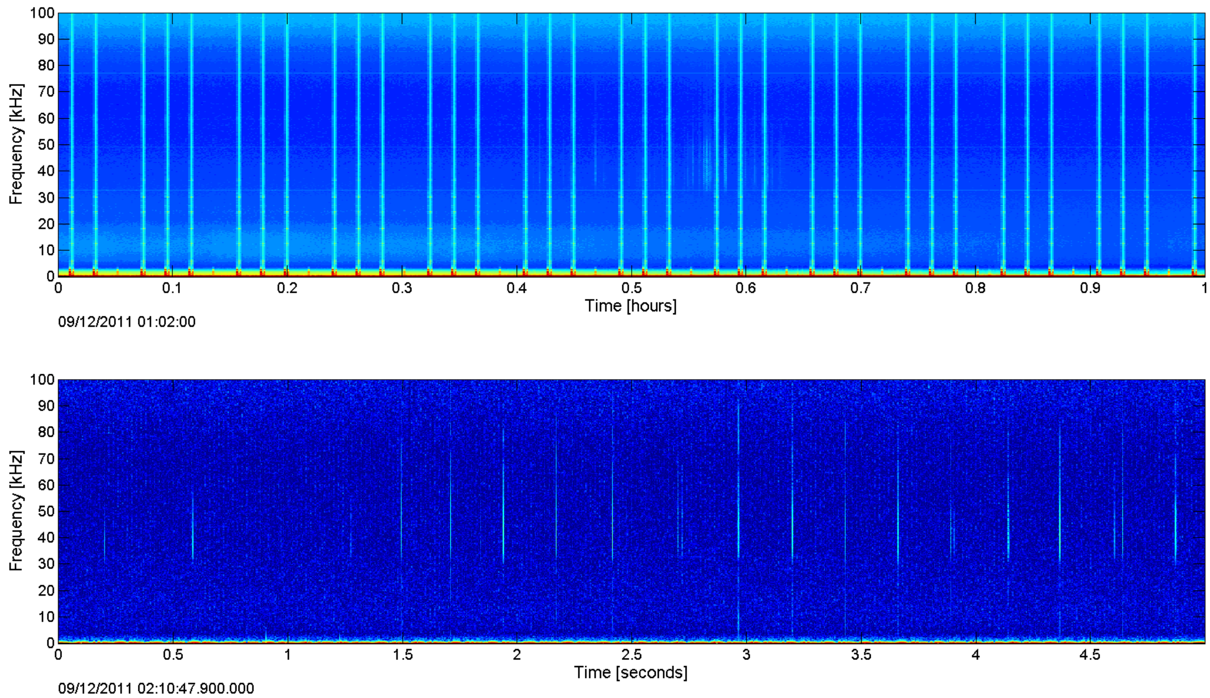


Figure 30. CT30 in the LTSA (top) and spectrogram (bottom).

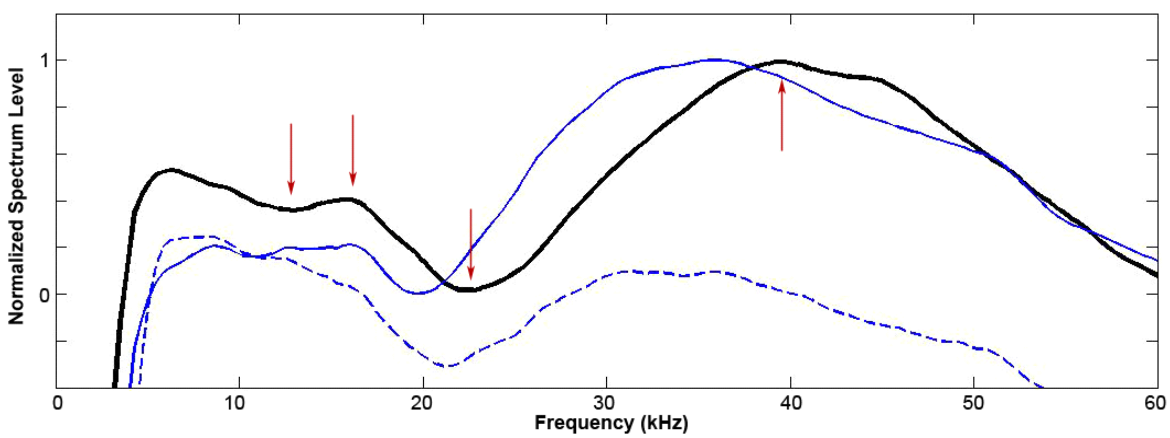


Figure 31. Mean spectra of CT30. Example (black line), template (blue line), and noise floor (dotted line). Arrows denote spectral peaks or troughs.

Click Type 32

CT32 (Figure 32) 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 33). This low peak becomes apparent in LTSAs but a high pass filter cuts it out in the mean spectra.

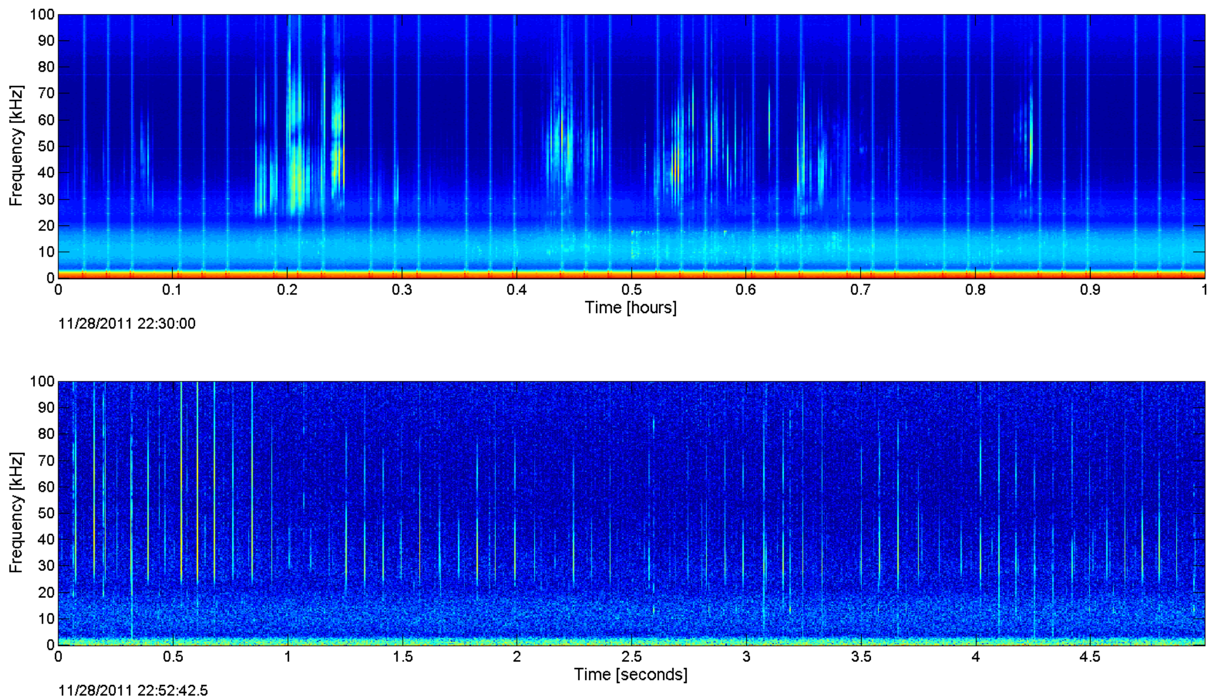


Figure 32. CT32 in the LTSA (top) and spectrogram (bottom).

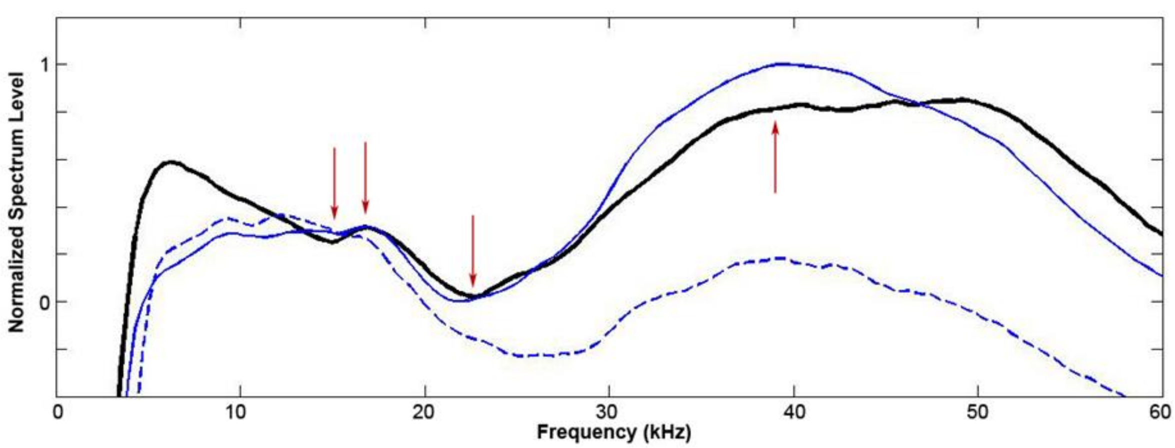


Figure 33. Mean spectra of CT32. Example (black line), template (blue line), and noise floor (dotted line). Arrows denote spectral peaks or troughs.

Anthropogenic Sounds

For anthropogenic sound analysis, the raw 200 kHz HARP data were decimated by a factor of 20 for an effective bandwidth of 5 kHz to find broadband ship noise, explosions, and mid-frequency active sonar. The LTSAs for mid-frequency data 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 in one-minute bins. The full effective bandwidth of 100 kHz was used for echosounder analysis.

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 (McKenna et al. 2012). Combination of direct paths and surface reflected paths produces constructive and destructive interference (bright and dark bands) in the spectrogram that varies by frequency and distance between the ship and the HARP (Figure 34). This noise can extend to well above 10 kHz, though typically falls off above a few kHz.

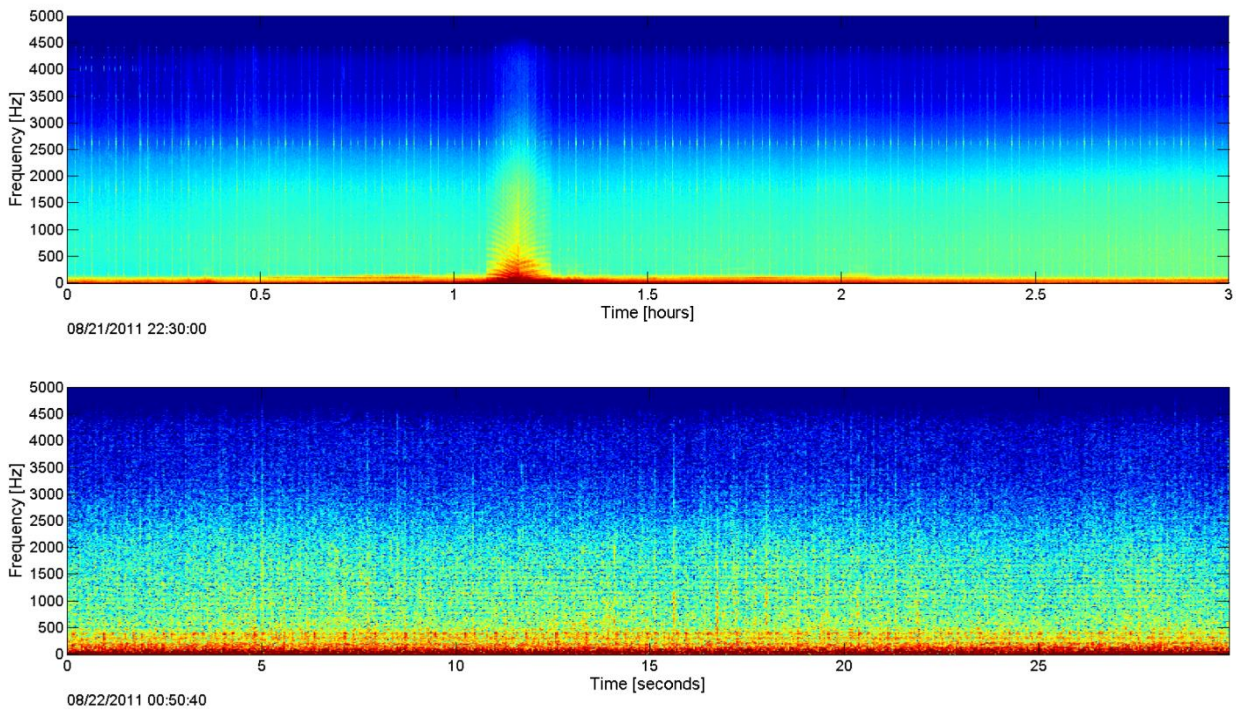


Figure 34. Broadband ship noise in the LTSA (top) and spectrogram (bottom) from USWTR06E.

Echosounders

Echosounding sonars transmit short pulses or frequency sweeps, typically in the mid-frequency (8-12 kHz) or high frequency (30 – 100 kHz) band. These sonars may be used for sea bottom mapping, fish detection, or other ocean sensing. Many large and small vessels are equipped with echosounding sonar for water depth determination, and typically these echosounders are operated much of the time a ship is at sea, as an aid for navigation. Echosounders were detected by analysts using the LTSA plots at both mid- and high-frequency. Echosounder pings were detected at a variety of frequencies (8-80 kHz). They are easily identified as dotted lines in the LTSA (Figure 35).

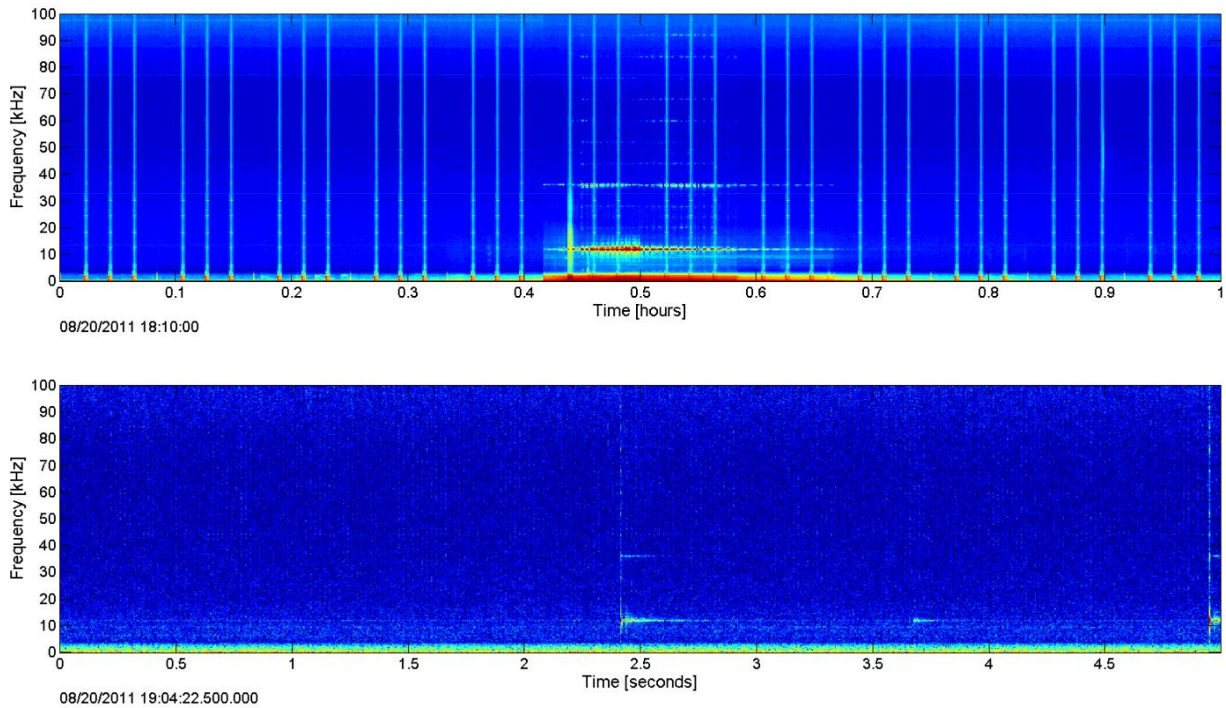


Figure 35. Echosounder pings in the LTSA (top) and spectrogram (bottom) from USWTR06E.

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 36). These sounds have peak energy as low as 10 Hz and often extend up to 2000 Hz or higher, lasting a few seconds including the reverberation.

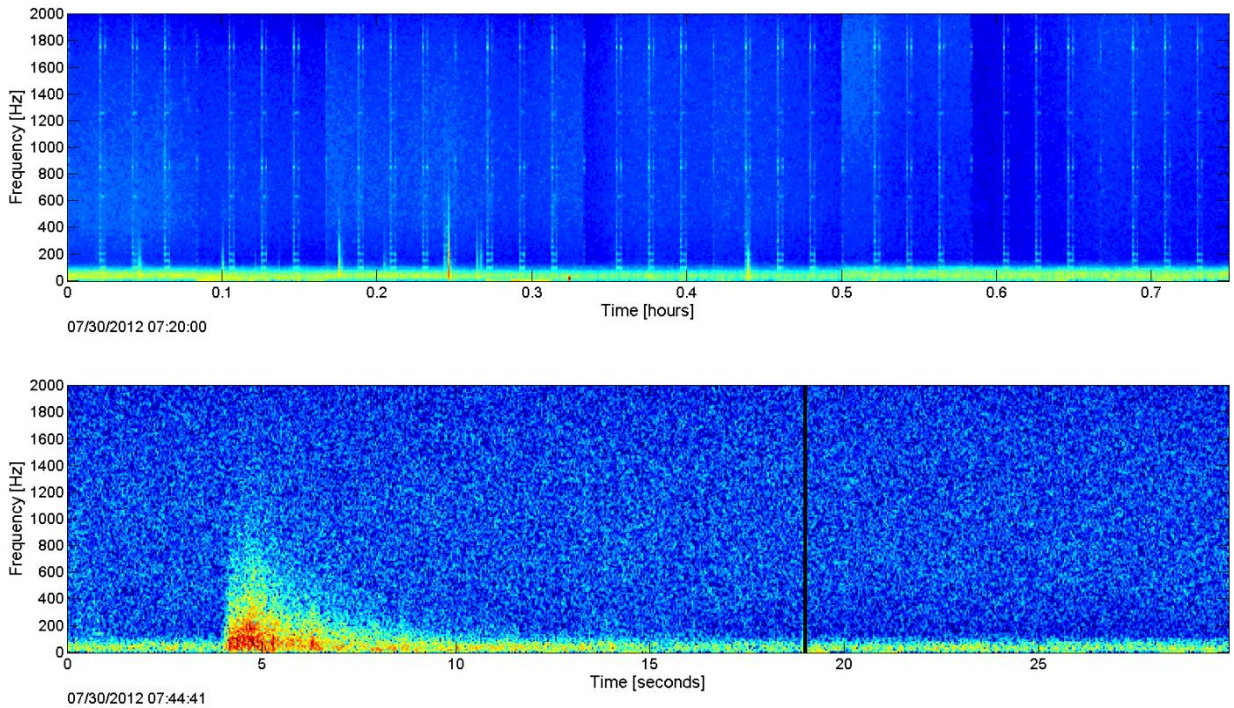


Figure 36. An explosion in the LTSA (top) and spectrogram (bottom) from USWTR07E.

Mid-Frequency Active Sonar

Many types of sonar are used in the Cherry Point OPAREA. 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. Sounds from mid-frequency active (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.

The first step in analyzing MFA sonar was conducted by a trained analyst who scanned for periods of sonar activity. Start and end times of MFA sonar events from LTSAs were noted to provide target periods for automatic detections. Decimated data (10 Hz – 5 kHz) data were used to calculate the spectra for the LTSAs with 10 Hz frequency bins and 5 s time bins. Individual MFA sonar pings typically span 1 – 3 s, but are intense enough to appear as "pulses" in LTSA plots (Figure 37). LTSA display parameters used by the analyst were 0.75 hour window length and 2 – 5 kHz bandwidth.

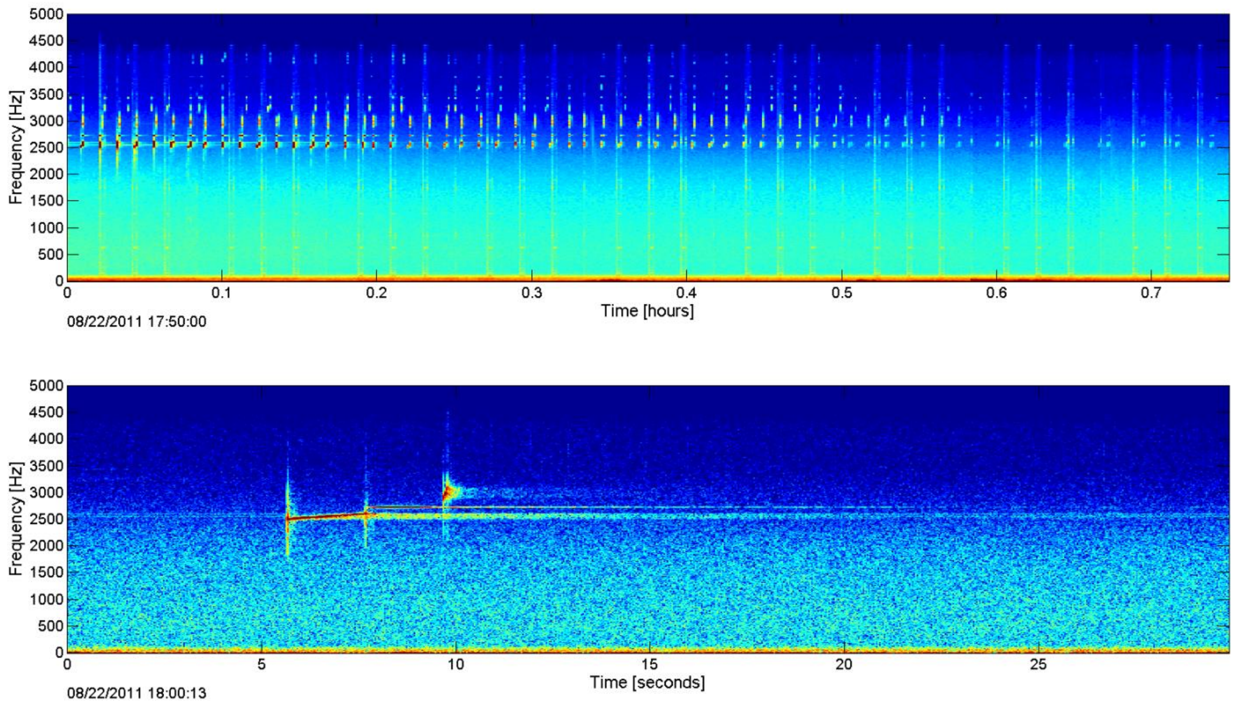


Figure 37. MFA in the LTSA (top) and spectrogram (bottom) from USWTR06E.

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 37). 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 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. 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 (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 3.5 kHz was used to approximate the entire band. The transfer function value for the 2011 deployment was 84.2 dB re $\mu Pa^2/counts^2$ while the transfer function value for the 2012 deployment was 82.5 dB re $\mu Pa^2/counts^2$. MFA events were detected in both deployments.

Results

This report summarizes the analysis of acoustic data collected from August – December 2011 and July – October 2012 at one site in the Cherry Point OPAREA. We discuss ambient noise as well as the seasonal occurrence and relative abundance of marine mammal species and anthropogenic sounds. For clarity of presentation, all marine mammal and anthropogenic sound source occurrences will be displayed as weekly averages. More precise occurrence plots, depicting each day and indicating exact hour of the day of detection, are included in the Appendix.

Ambient Noise

Underwater ambient noise in 2011 and 2012 has spectral shapes with higher levels at low frequencies (Figure 38), owing to the dominance of ship noise at frequencies below 100 Hz and local wind and waves above 100 Hz (Hildebrand 2009). A prominent peak in noise is observed at 15-20 Hz in 2011, related to the presence of fin whale calls.

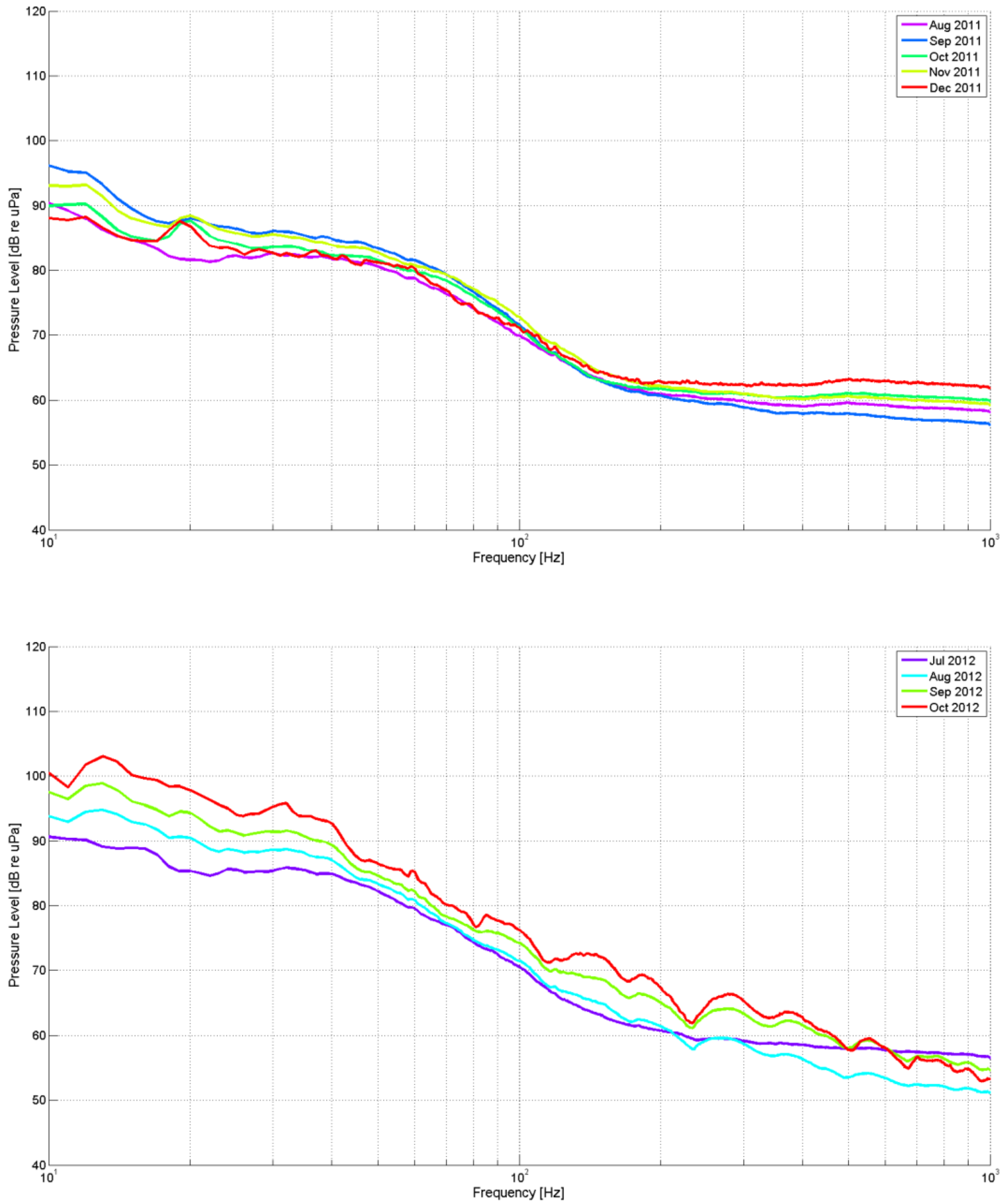


Figure 38. Monthly ambient noise in 2011 (top) and 2012 (bottom).

Masking

Masking was noted when hydrophone strumming, likely caused by tidal flow, obscured the lower frequencies in the LTSA (Figure 39 and Appendix). This likely reduced the detection probability for baleen whales in the lower frequencies during those times.

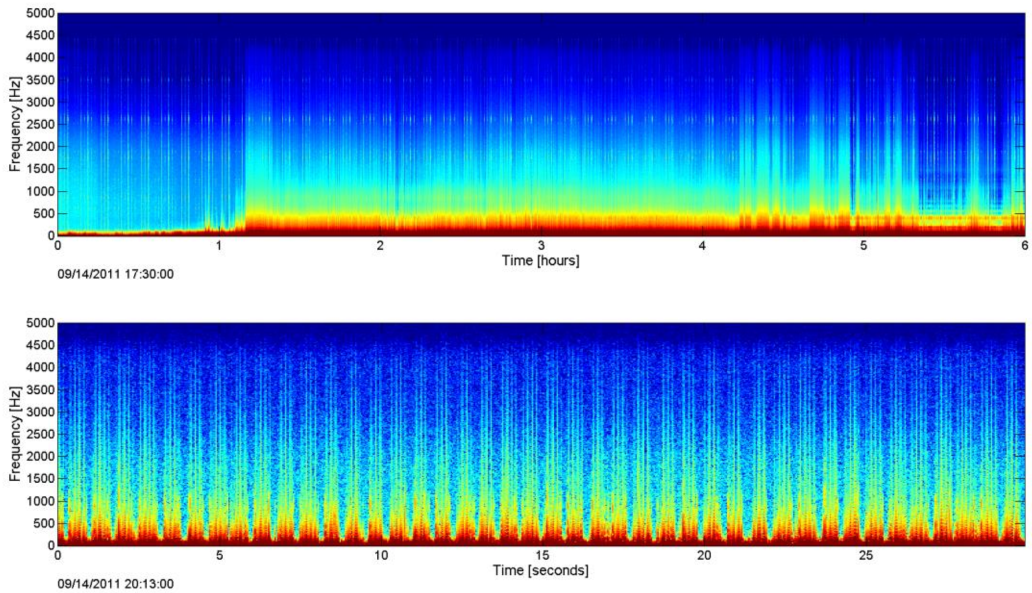


Figure 39. Masking from USWTR06E in the LTSA (top) and spectrogram (bottom).

Mysticetes

Four species of mysticetes whales were recorded between late August and early December 2011: blue, fin, minke, and sei whales. No Bryde's whale Be7 and Be9, humpback, or North Atlantic right whale up calls were detected during this time period. Blue whale calls were the only baleen whale call detected in the 2012 deployment.

Blue Whales

North Atlantic blue whale calls were detected from early September through late October in 2011 (Figure 40) and from late August through late September in 2012 (Figure 41). This timing is similar to that of other recordings at similar latitudes near the mid-Atlantic ridge (Nieukirk, et al. 2004).

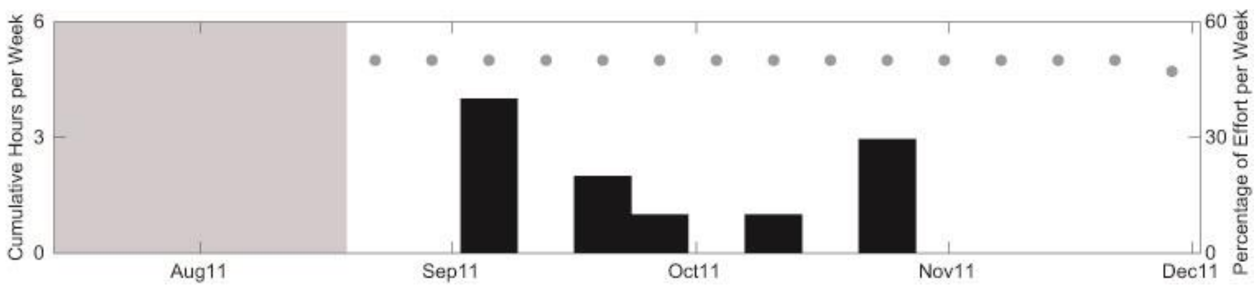


Figure 40. Weekly blue whale call presence in 2011. The area shaded in gray represents the section of data where there were no recordings. The light gray dots represent weekly recording effort.

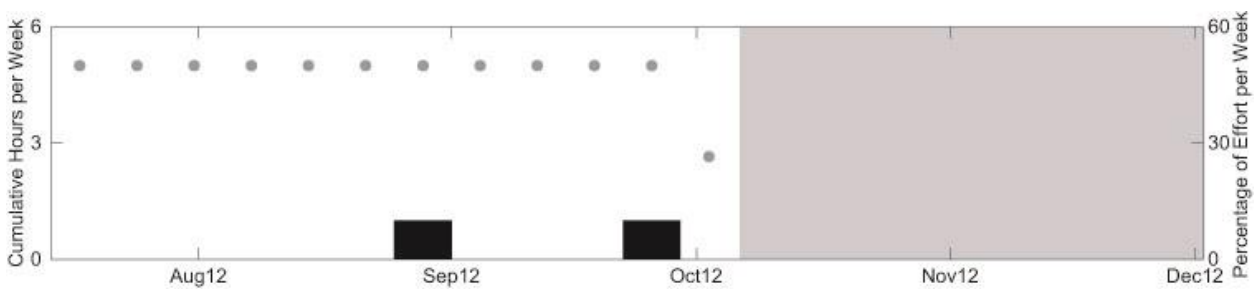


Figure 41. Weekly blue whale call presence in 2012. Effort is as described in Figure 40.

Fin Whales

Fin whale 20 Hz calls were detected from late August, through November 2011, with peak calling in October (Figure 42). Fin whale 40 Hz calls were not detected in either deployment, nor did daily presence of fin whale calls have any temporal patterns (Appendix). No fin whales were recorded at this site between July and October 2012.

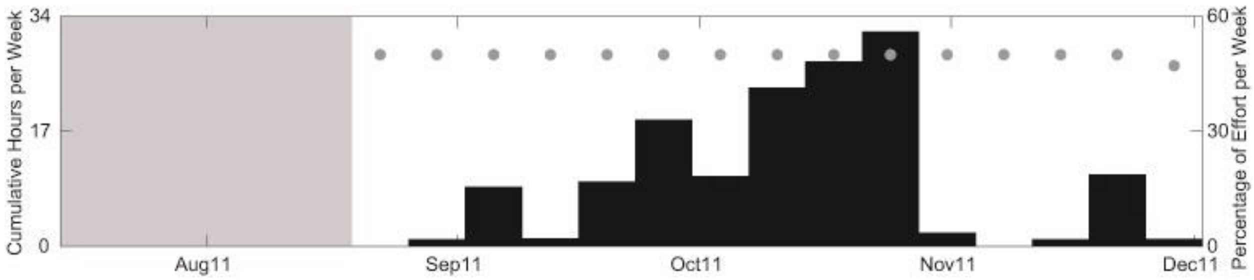


Figure 42. Weekly fin whale 20 Hz call presence in 2011. Effort is as described in Figure 40.

Minke Whales

Minke whale pulse trains were recorded only in 2011 (Figure 43). The pulse trains were detected between late September and early December, peaking towards the end of deployment, indicating there may be a seasonal variation in this call type (or presence of minkes) in this area. Daily presence of minke whale calls had no temporal patterns (Appendix). No minke whales were recorded at this site in 2012.

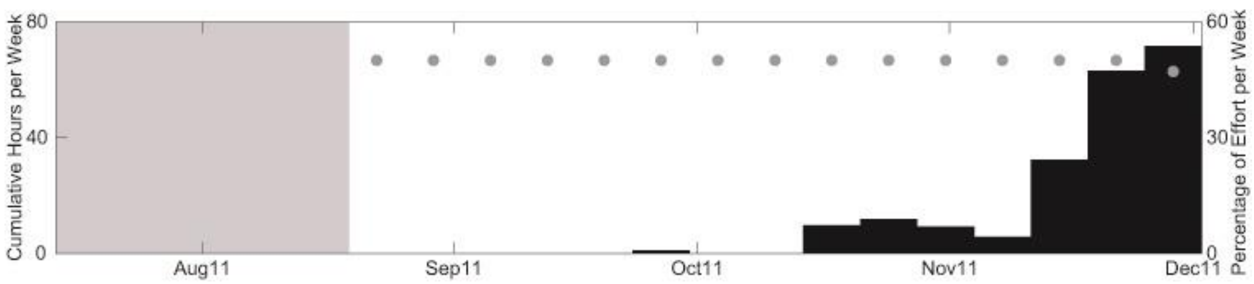


Figure 43. Weekly minke whale call presence in 2011. Effort is as described in Figure 42.

Sei Whales

Downsweep calls, reported as being from sei whales, were detected in October, November, and early December 2011 (Figure 44). However, these calls were not very common. Daily presence of sei whale calls had no temporal patterns (Appendix). No sei whale calls were detected in 2012.

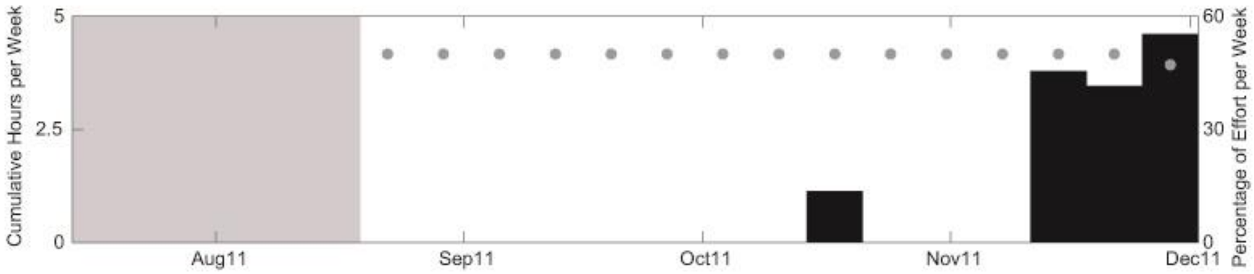


Figure 44. Weekly occurrence of downsweep calls in 2011. Effort as described in Figure 42.

Odontocetes

Most odontocete species were detected in both 2011 and 2012.

Unidentified Beaked Whale (BW38)

There were only a few BW38 detections in 2011 (Figure 45) and no detections in 2012.

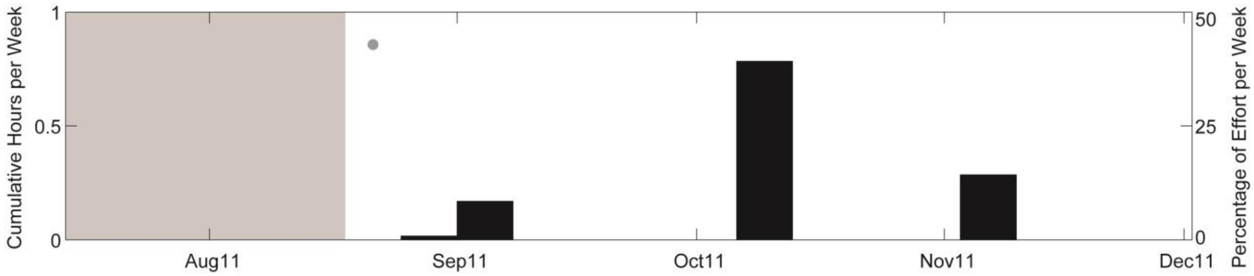


Figure 45. Weekly occurrence of BW38 calls in 2011. The area shaded in gray represents the section of data where there were no recordings. Recording effort was at 50% (5 minutes every 10 minutes). The light gray dots represent recording effort during partial weeks.

Blainville's Beaked Whales

Blainville's beaked whale echolocation signals were detected in 2011 and 2012 (Figure 46). Their presence was consistent in 2011, while all detections occurred in July and August in 2012.

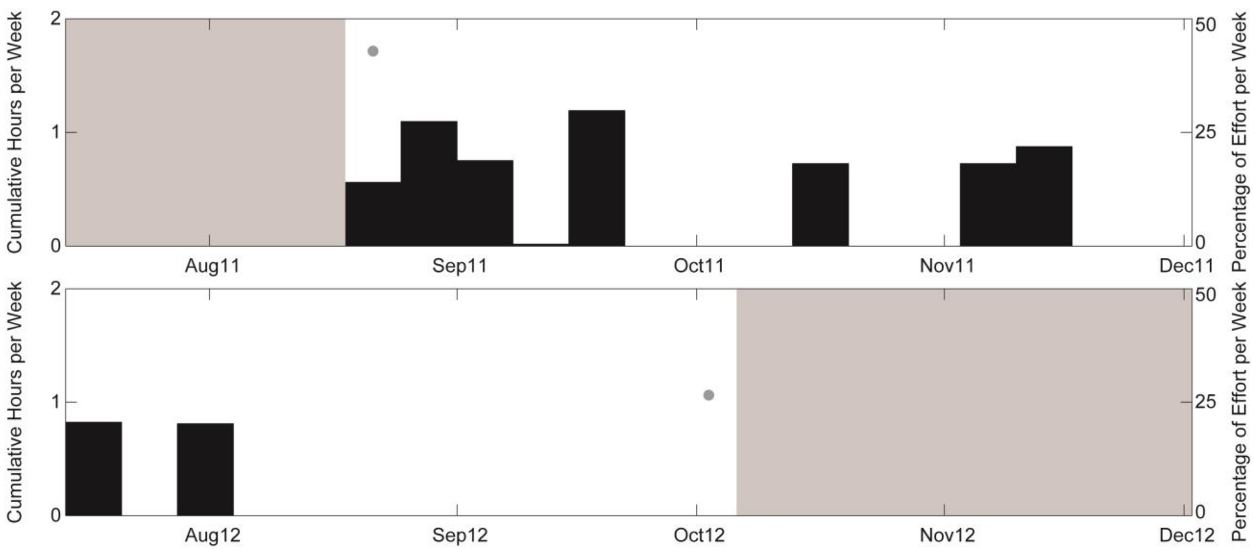


Figure 46. Weekly Blainville's beaked whale presence in 2011 (top) and 2012 (bottom). Effort as described in Figure 45.

Cuvier's Beaked Whales

There were few Cuvier's beaked whale detections in these deployments (Figure 47). There was a slight peak in detections in November 2011.

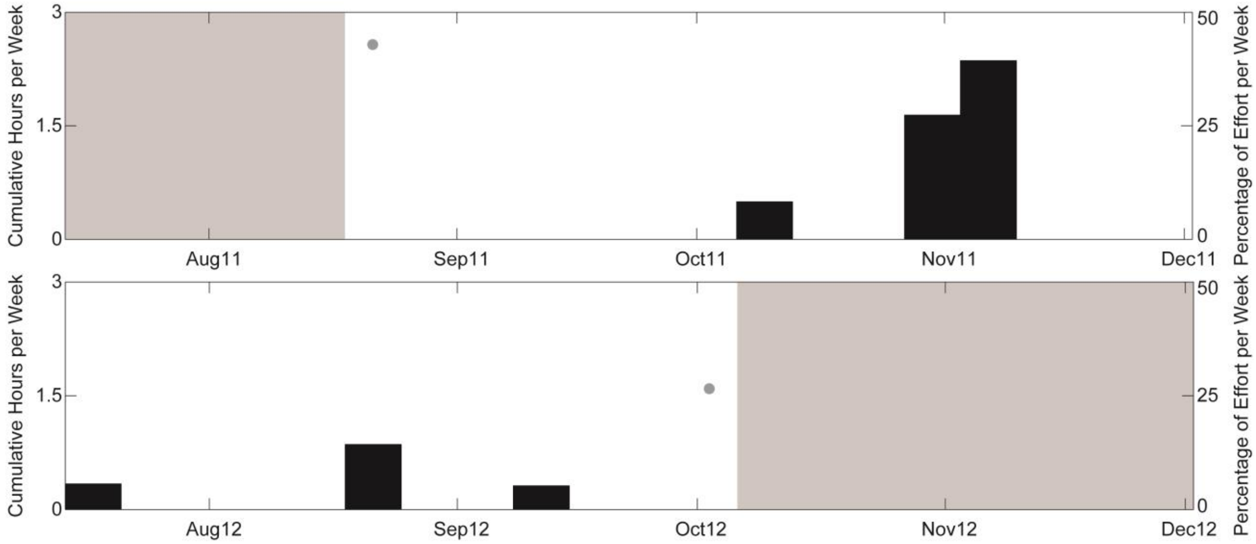


Figure 47. Weekly Cuvier's beaked whale presence in 2011 (top) and 2012 (bottom). Effort as described in Figure 45.

Gervais' Beaked Whales

There were significantly more Gervais' beaked whale detections than any other beaked whale. Detections peaked in November 2011 and in mid-late September in 2012 (Figure 48). Compared to other sites recorded in the Gulf of Mexico or the North Pacific, this site was highly frequented by this species of beaked whale.

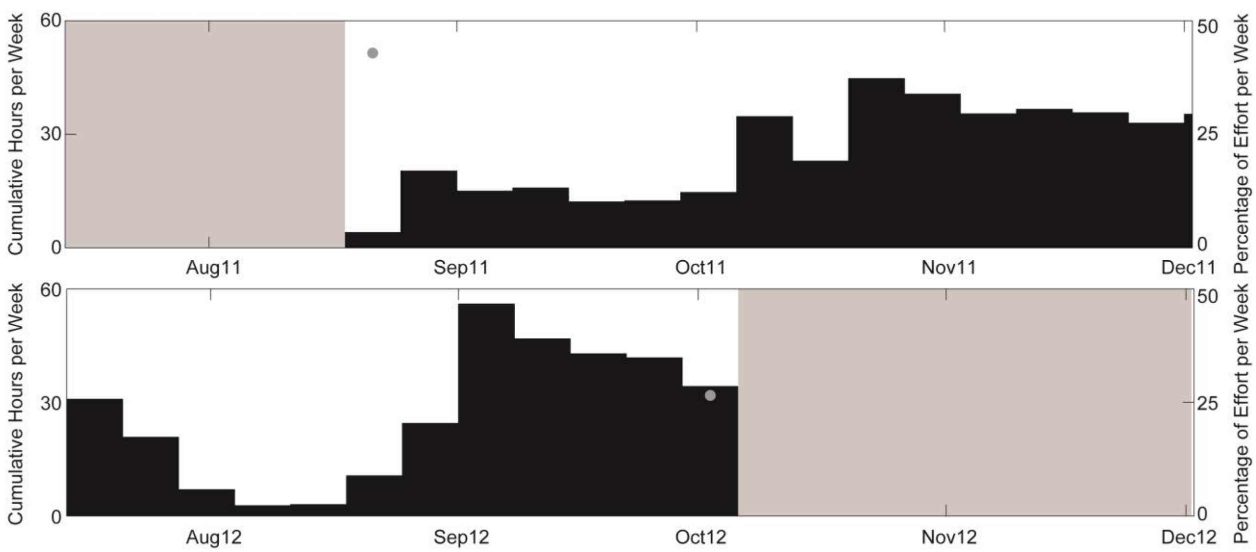


Figure 48. Weekly Gervais' beaked whale presence in 2011 (top) and 2012 (bottom). Effort as described in Figure 45.

Unidentified Odontocetes

Unidentified odontocete clicks and whistles were detected in both 2011 and 2012. There are no obvious peaks in click detections in 2011 while October had the most detections in 2012 (Figure 49).Whistle detections peaked in late September and early October in 2011 and 2012 (Figure 50).

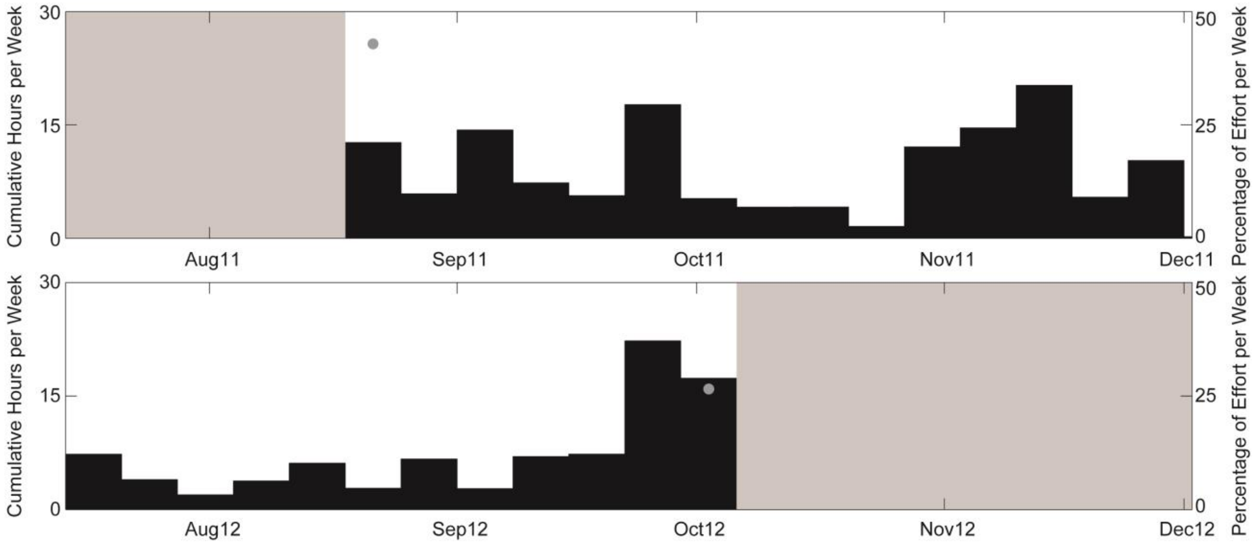


Figure 49. Weekly unidentified odontocete click presence in 2011 (top) and 2012 (bottom). Effort as described in Figure 45.

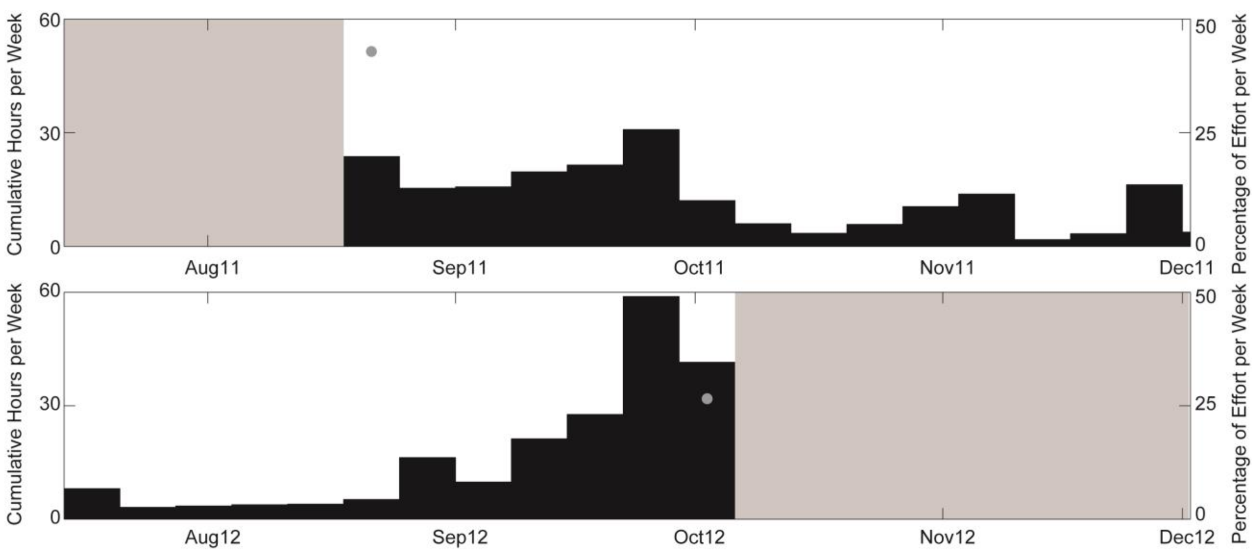


Figure 50. Weekly unidentified odontocete whistle presence in 2011 (top) and 2012 (bottom). Effort as described in Figure 45.

Unidentified Odontocete Whistles <5 kHz

Unidentified odontocete whistles <5 kHz were detected in both 2011 and 2012 (Figure 51). There was a peak in detections in mid-November 2011 while there were no obvious peaks in detections in 2012. These detections are possibly related to killer whale occurrence.

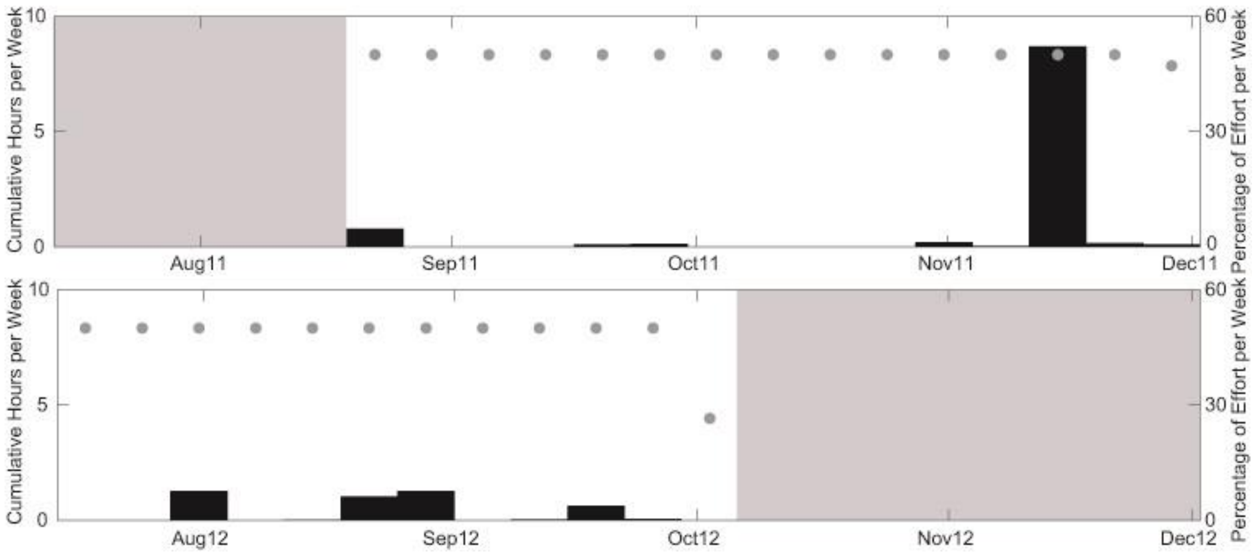


Figure 51. Weekly unidentified odontocete whistles <5 kHz presence in 2011 (top) and 2012 (bottom). Effort as described in Figure 45.

Killer Whales

Killer whale echolocation clicks were only detected in late November 2011 (Figure 52). No killer whale echolocation clicks were detected in 2012.

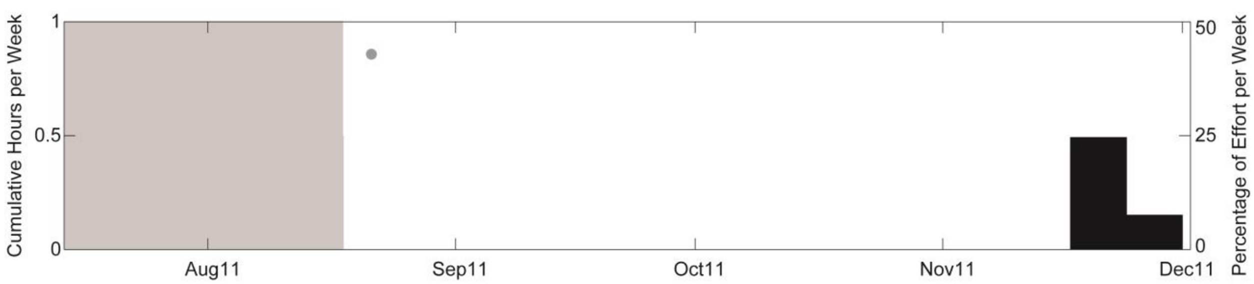


Figure 52. Weekly presence of killer whale echolocation clicks in 2011. Effort as described in Figure 45.

Kogia spp.

Kogia spp. were detected in 2011 and 2012. There was a peak in detections in late November 2011 while there was no obvious peak in detections in 2012 (Figure 53).

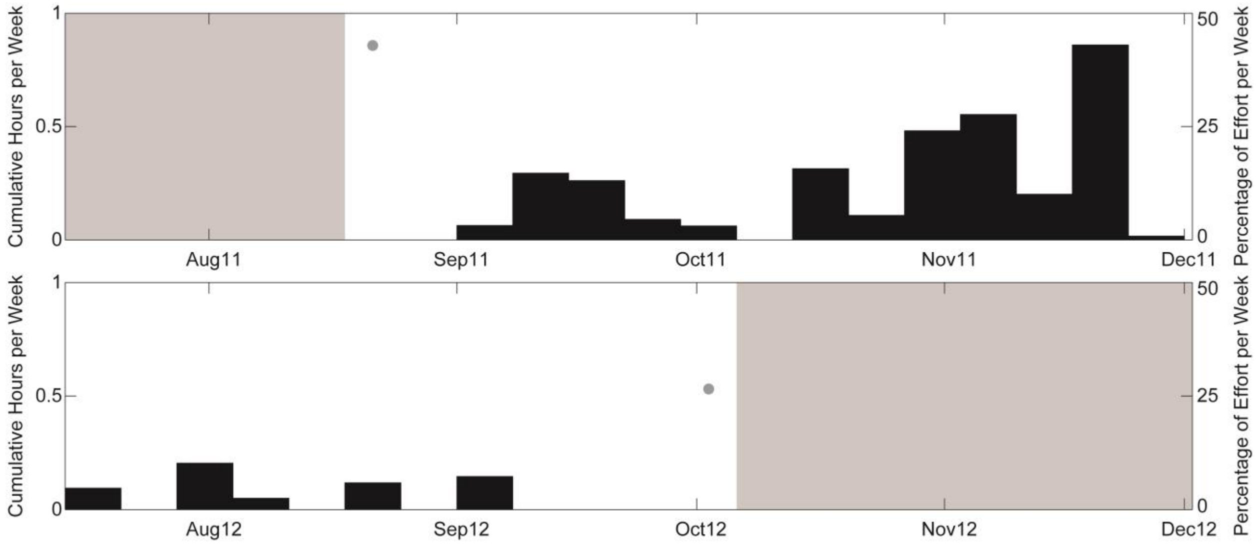


Figure 53. Weekly *Kogia* spp. presence in 2011 (top) and 2012 (bottom). Effort as described in Figure 45.

Risso's Dolphins

Risso's dolphins were only detected in October in 2011 while there were more detections in August and September in 2012 (Figure 54).

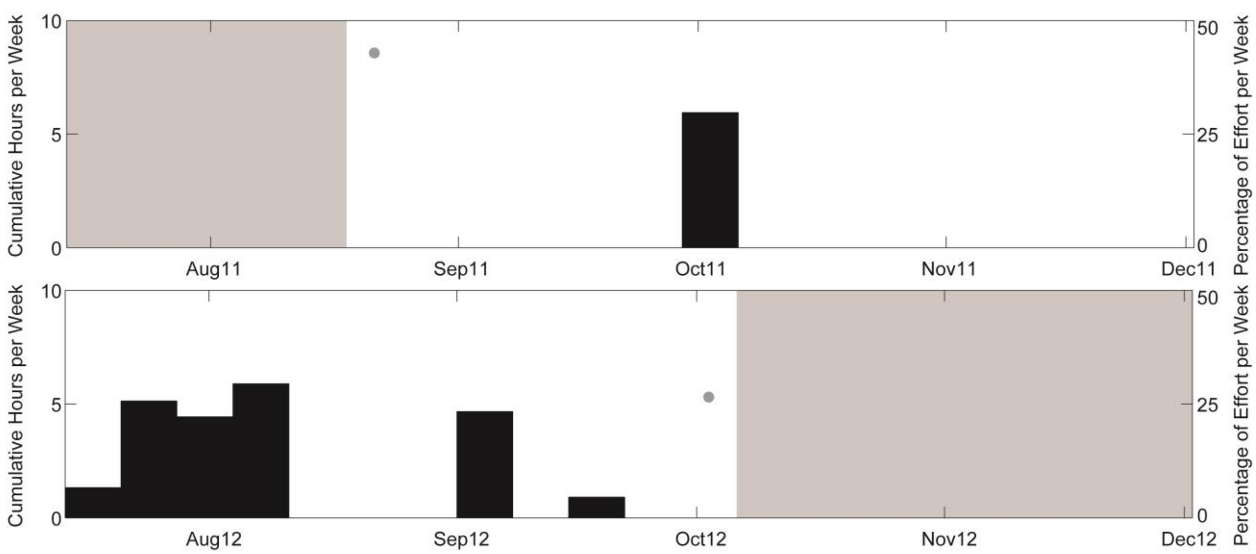


Figure 54. Weekly Risso's dolphin presence in 2011 (top) and 2012 (bottom). Effort as described in Figure 45.

Sperm Whales

Sperm whales were detected throughout 2011 and 2012 (Figure 55). There were more cumulative hours per week detected in 2011 than in 2012.

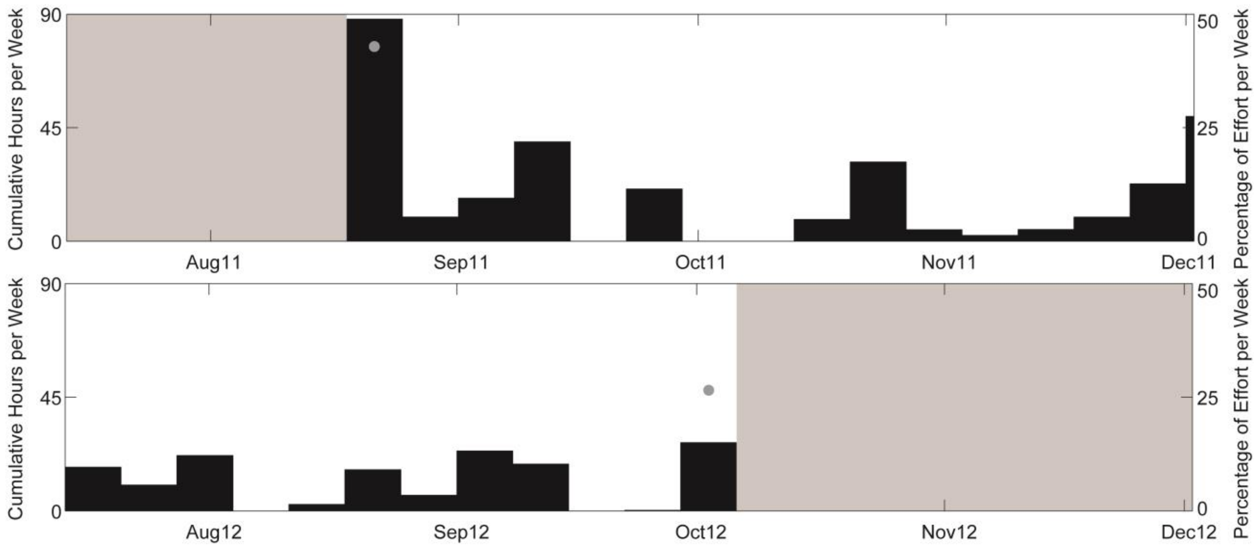


Figure 55. Weekly sperm whale presence in 2011 (top) and 2012 (bottom). Effort as described in Figure 45.

Echolocation Click Types

CT25

CT 25 was only detected in 2011 (Figure 56). Most detections were made in September, with a few detections in November.

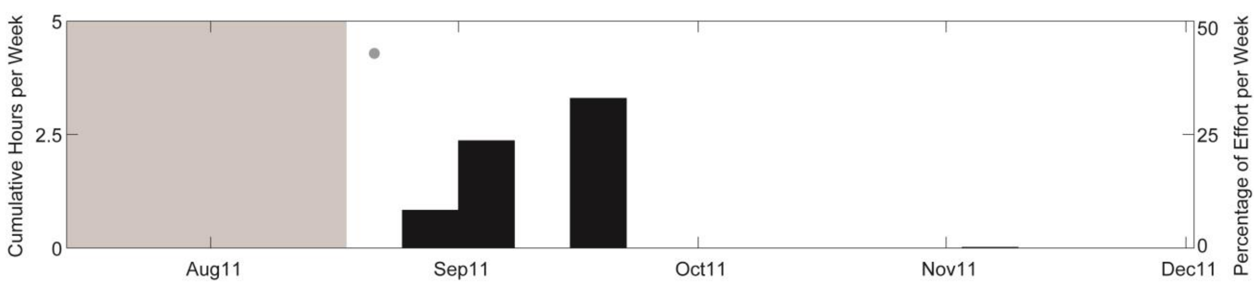


Figure 56. Weekly CT25 presence in 2011. Effort as described in Figure 45.

CT26

There were few detections of CT26 throughout both deployments (Figure 57). In 2012, there was only one detection in September and one detection in early October.

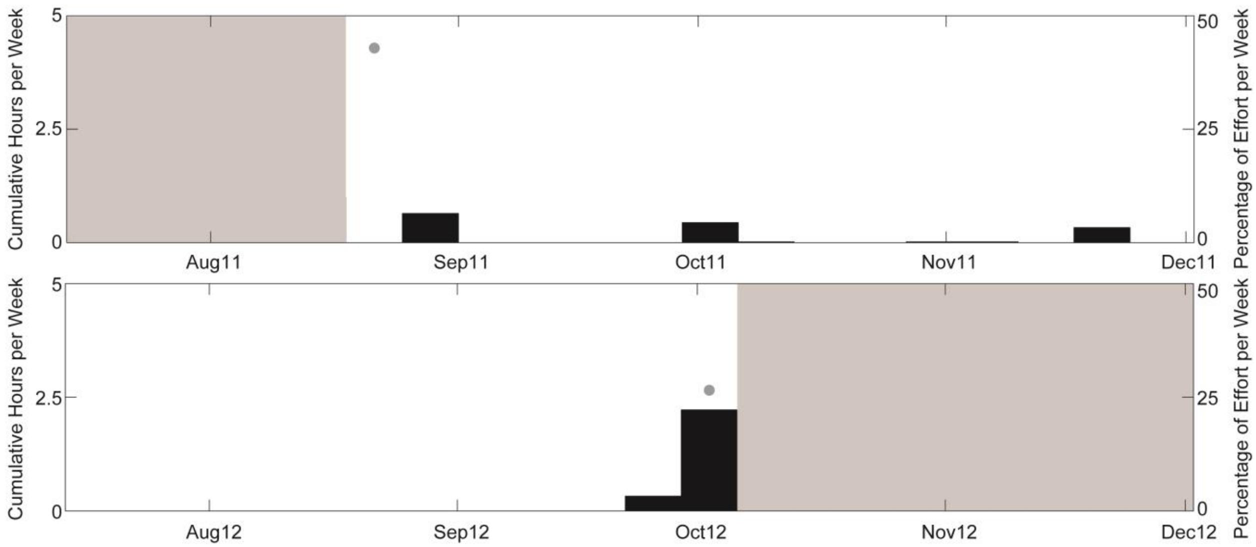


Figure 57. Weekly CT26 presence in 2011 (top) and 2012 (bottom). Effort as described in Figure 45.

CT30

CT30 was prevalent in 2011 and 2012 (Figure 58). While there were no obvious peaks in detections in 2011, most CT30 detections occurred in October in 2012.

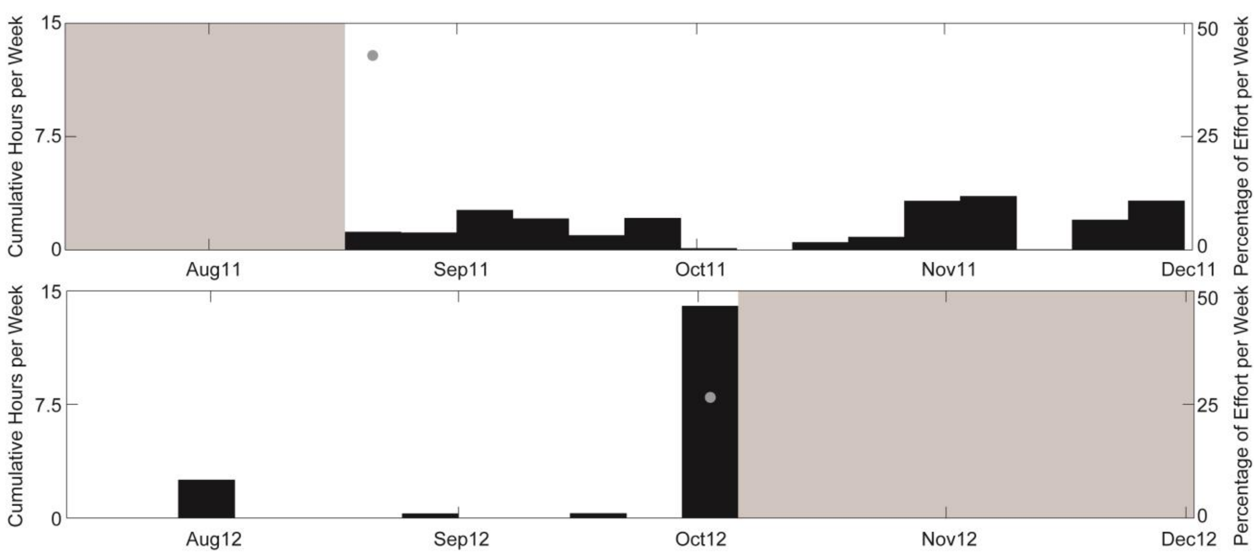


Figure 58. Weekly CT30 presence in 2011 (top) and 2012 (bottom). Effort as described in Figure 45.

CT32

CT32 showed similar detection pattern as CT30. There were no obvious peaks in detections in 2011. In 2012, CT32 detections peaked in late August (Figure 59).

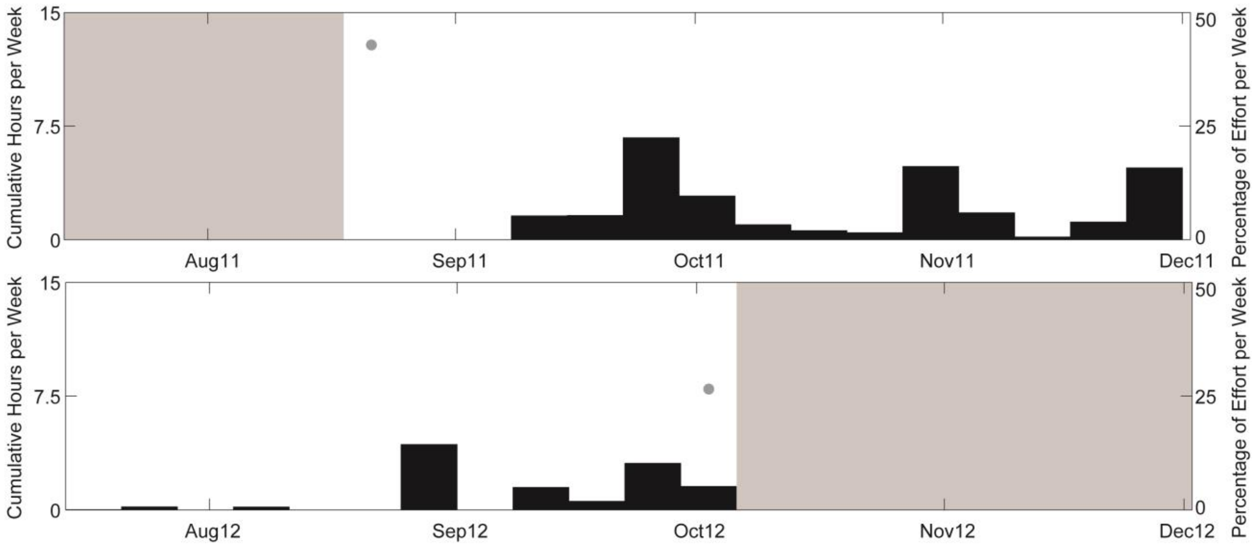


Figure 59. Weekly CT32 presence in 2011 (top) and 2012 (bottom). Effort as described in Figure 45.

Anthropogenic Sounds

Anthropogenic sounds detected in these data include broadband ship noise, echosounders, explosions, and mid-frequency active sonar.

Broadband Ship Noise

Ship noise was common in 2011 and 2012 throughout the deployments (Figure 60).

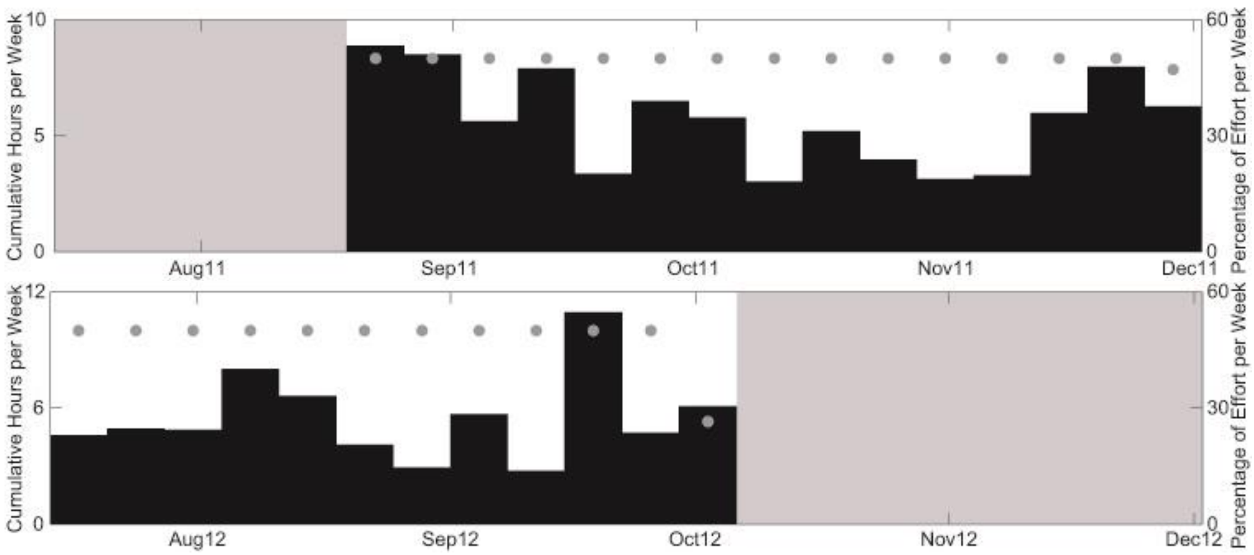


Figure 60. Weekly broadband ship noise in 2011 (top) and 2012 (bottom). The area shaded in gray represents where there were no recordings. The light gray dots represent weekly recording effort.

Echosounders

Very few echosounders were detected in these data (Figure 61).

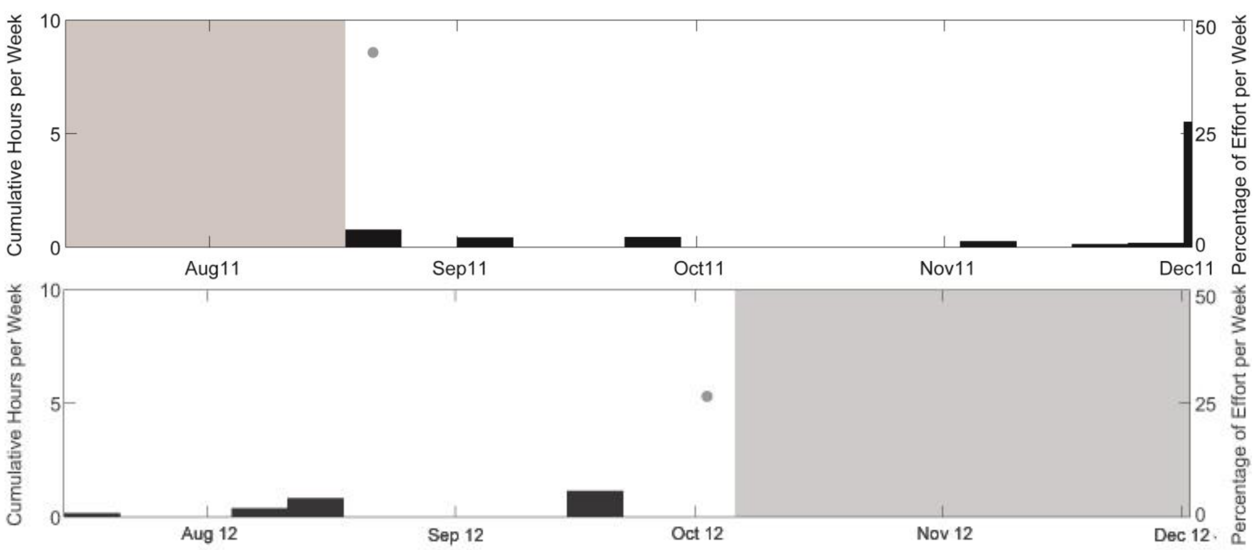


Figure 61. Weekly echosounder presence in 2011 (top) and 2012 (bottom). Recording effort was at 50% (5 minutes every 10 minutes). The light gray dots represent recording effort during partial weeks.

Explosions

Few explosions were recorded at either site during these deployments (Figure 62).

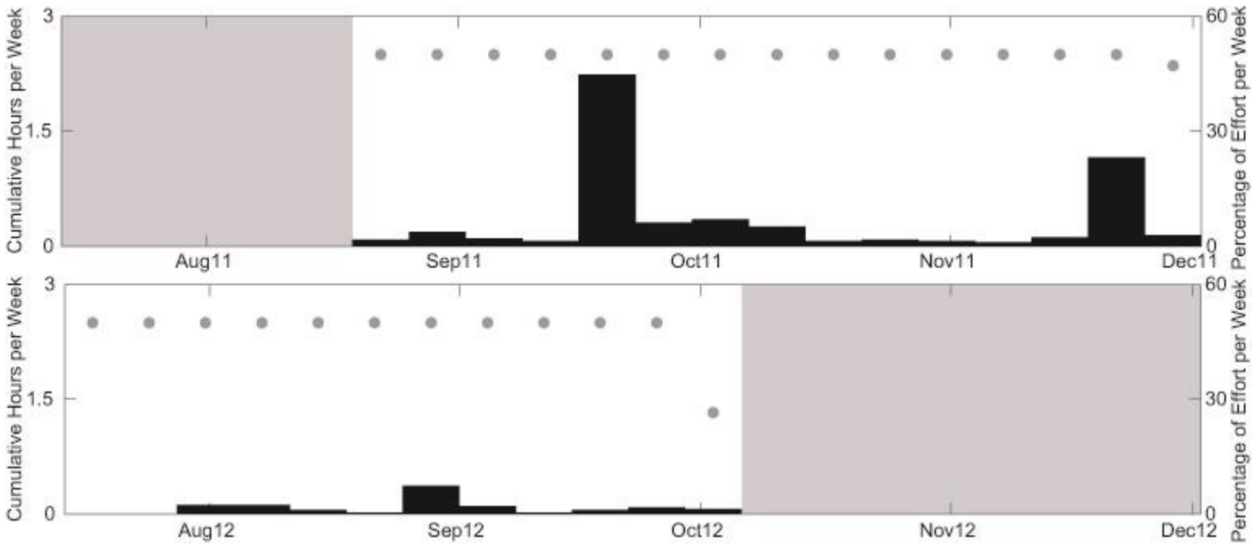


Figure 62. Weekly explosion presence in 2011 (top) and 2012 (bottom). Effort as described in Figure 60.

Mid-Frequency Active Sonar

Both deployments had MFA sonar events (Figure 63). In 2011, a total of 391 pings were detected, ranging from 100 – 156 dB pp re 1 µPa. Mid- to late August had the highest number of pings detected per week in 2011. A total of 492 pings were detected in the 2012 deployment ranging from 100 – 167 dB pp re 1 µPa. Mid-August had the largest number of pings detected per week in 2012 while some weeks did not have any sonar detections. Distribution of ping levels from 2011 show a peak around 118 dB pp re 1 µPa and 130 dB pp re 1 µPa in 2012 (Figure 64). Cumulative distribution of ping levels shows that less than half of the pings detected were above 125 dB pp re 1 µPa in both deployments (Figure 65).

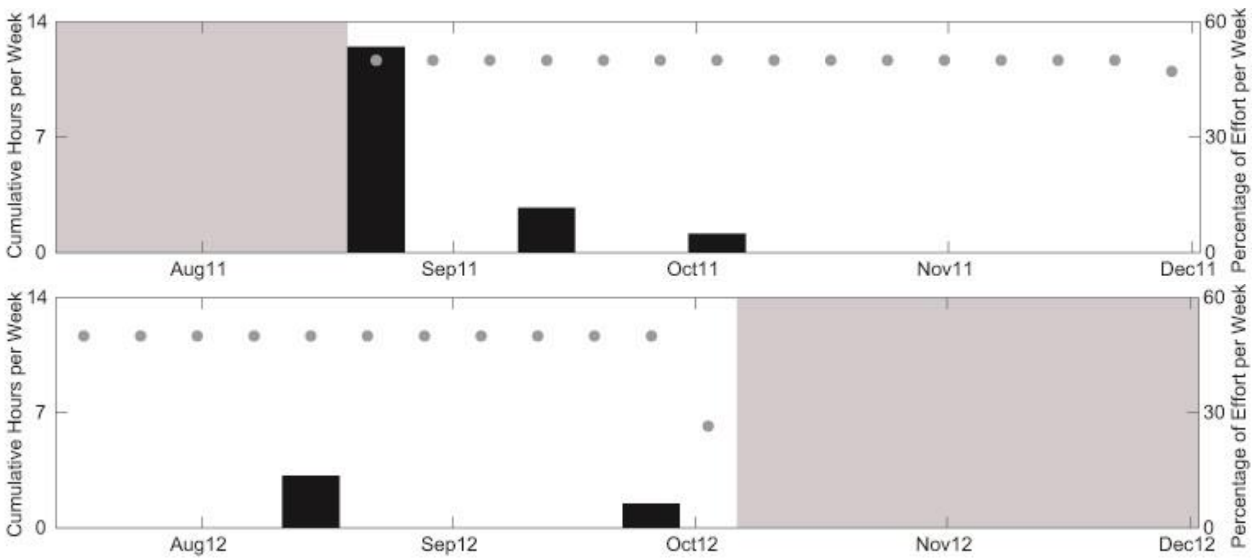


Figure 63. Weekly MFA presence in 2011 (top) and 2012 (bottom). Effort markings are as described in Figure 60.

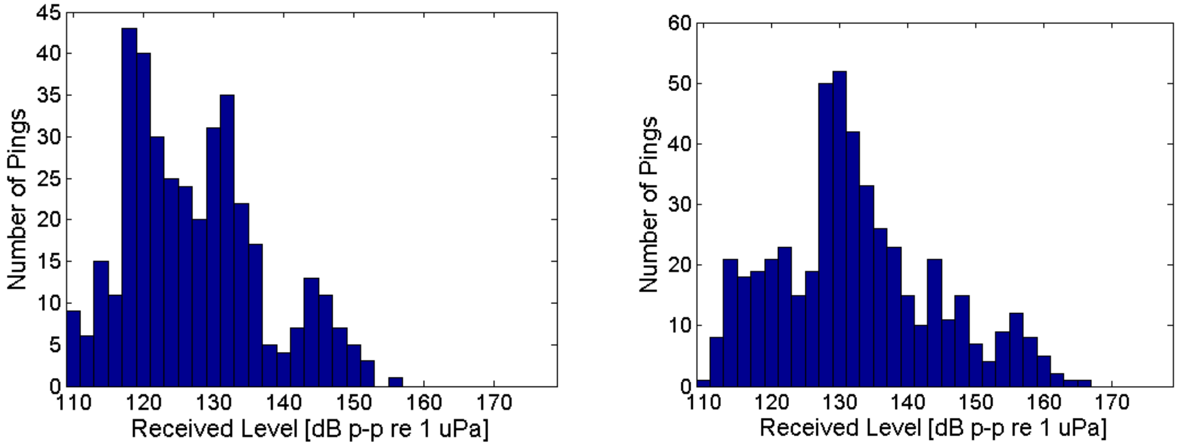


Figure 64. Distribution of MFA sonar pings by received level in 2011 (left) and 2012 (right) in 2 dB bins. Median received level is 118 dB pp re 1 µPa in 2011 and 130 dB pp re 1 µPa in 2012. Maximum level is 156 dB pp re 1 µPa for 2011 and 167 dB pp re 1 µPa for 2012.

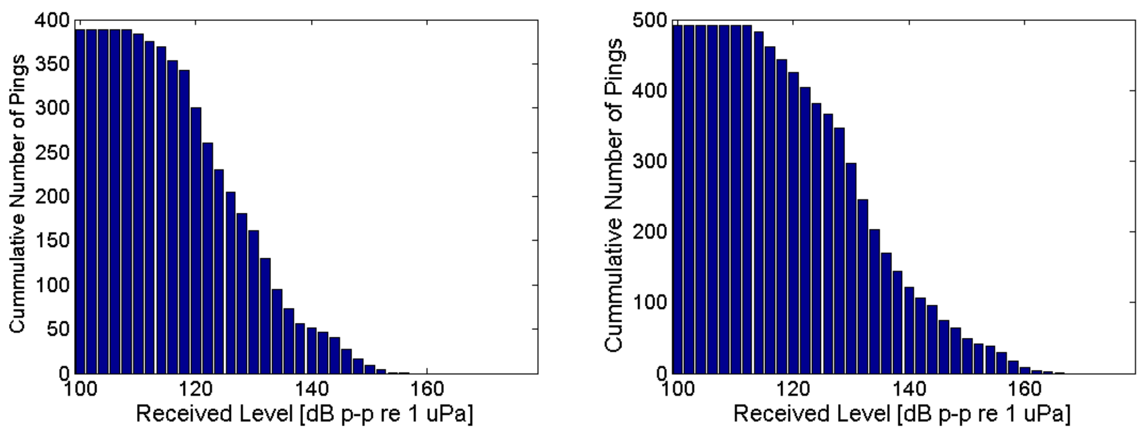


Figure 65. Cumulative distribution for the number of MFA sonar pings detected at a given received level or higher in 2011 (left) and 2012 (right) in 2 dB bins.

References

Au, Whitlow W. L. *The Sonar of Dolphins.* New York: Springer-Verlag, 1993.

Baumann-Pickering, Simone, et al. "Species-specific beaked whale echolocation signals." *Journal of the Acoustical Society of America* 134, no. 3 (2013): 2293-2301.

Baumgartner, Mark F., Sofie M. Van Parijs, and Frederick W. Wenzel. "Low frequency vocalizations attributed to sei whales (Balaenoptera borealis)." *Journal of the Acoustical Society of America* 124, no. 2 (2008): 1339-1349.

Debich, Amanda J., et al. "Passive acoustic monitoring for marine mammals in the Jacksonville Range Complex 2010-2011." Marine Physical Laboratory Technical Memorandum 541, La Jolla, 2013, 57.

Dunlop, Rebecca A., Michael J. Noad, Douglas H. Cato, and Dale Stokes. "The social vocalization repertoire of east Australian migrating humpback whales (Megaptera novaeangliae)." *Journal of the Acoustical Society of America* 122, no. 5 (2007): 2983-2905.

Ford, John K.B. "Acoustic behaviour of resident killer whales (Orcinus orca) off Vancouver Island, British Columbia." *Canadian Journal of Zoology* 67 (1989): 727-745.

Gillespie, Douglas, Charlotte Dunn, Jonathan Gordon, Diane Claridge, Clare Embling, and Ian Body. "Field recordings of Gervais' beaked whales Mesoplodon eruopaeus from the Bahamas." *Journal of the Acoustical Society of America* 125, no. 5 (2009): 3428-3433.

Goold, John C., and Sarah E. Jones. "Time and frequency domain characteristics of sperm whale clicks." *Journal of the Acoustical Society of America* 98, no. 3 (1995): 1279-1291.

Gormley, Gerard. *Orcas of the Gulf: A natural history.* San Francisco: Sierra Club Books, 2000.

Helble, Tyler A., Glenn R. Ierley, Gerald L. D'Spain, Marie A. Roch, and John A. Hildebrand. "A generalized power-law detection algorithm for humpback whale vocalizations." *Journal of the Acoustical society of America* 131, no. 4 (2012): 2682-2699.

Hildebrand, John A. "Anthropogenic and natural sources of ambient noise in the ocean." *Marine Ecology Progress Series* 395 (2009): 5-20.

Johnson, Mark, Peter T. Madsen, Walter M. Zimmer, Natacha Agullar de Soto, and Peter L. Tyack. "Beaked whales echolocate on prey." *Proceedings of the Royal Society of London. Series B: Biological Sciences* 271 (2004): S383-S386.

Katona, Steven K., Judith A. Beard, Phillip E. Girton, and Frederick Wenzel. "Killer whales (Orcinus orca) from the Bay of Fundy to the Equator, including the Gulf of Mexico." *Rit Fiskideldar* 11 (1988): 205-225.

Lammers, Marc O., Whitlow W. L. Au, and Denise L. Herzing. "The broadband social acoustic signaling behavior of spinner and spotted dolphins." *Journal of the Acoustical Society of America* 114, no. 3 (2003): 1629-1639.

Madsen, P. T., R. Payne, N. U. Kristiansen, M. Wahlberg, I. Kerr, and B. Møhl. "Sperm whale sound production studied with ultrasound time/depth-recording tags." *The Journal of Experimental Biology* 205 (2002): 1899-1906.

McKenna, Megan F., Donald Ross, Sean M. Wiggins, and John A. Hildebrand. "Underwater radiated noise from modern commercial ships." *Journal of the Acoustical Society of America* 131, no. 1 (2012): 92-103.

Mellinger, David K., and Christopher W. Clark. "Blue whale (Balaenoptera musculus) sounds from the North Atlantic." *Journal of the Acoustical Society of America* 114, no. 2 (2003): 1108-1119.

Mellinger, David K., Carol D. Carson, and Christopher W. Clark. "Characteristics of minke whale (Balaenoptera acutorostrata) pulse trains recorded near Puerto Rico." *Marine Mammal Science* 16, no. 4 (2000): 739-756.

Mizroch, Sally A., Dale W. Rice, and Jeffrey M. Breiwick. "The sei whale, Balaenoptera borealis." *Marine Fisheries Review* 46, no. 4 (1984): 25-29.

Møhl, Bertel, Magnus Wahlberg, Peter T. Madsen, Anders Heerfordt, and Anders Lund. "The monopulsed nature of sperm whale clicks." *Journal of the Acoustical Society of America* 114, no. 2 (2003): 1143-1154.

Nieukirk, Shannon L., Kathleen M. Stafford, David K. Mellinger, Robert P. Dziak, and Christopher G. Fox. "Low-frequency whale and seismic airgun sounds recorded in the mid-Atlantic Ocean." *Journal of the Acoustical Society of America* 115, no. 4 (2004): 1832-1843.

Oleson, Erin M., Jay Barlow, Jonathan Gordon, Shannon Rankin, and John A. Hildebrand. "Low frequency calls of Bryde's whales." *Marine Mammal Science* 19, no. 2 (2003): 160-172.

Omura, Hideo. "Bryde's whale from the coast of Japan." *The Scientific Reports of the Whale Research Institute*, 1959: 1-39.

Parks, Susan E., and Peter L. Tyack. "Sound production by North Atlantic right whales (Eubalaena glacialis) in surface active groups." *Journal of the Acoustical Society of America* 117, no. 5 (2005): 3297-3306.

Parks, Susan E., Philip K. Hamilton, Scott D. Kraus, and Peter L. Tyack. "The gunshot sound produced by male North Atlantic right whales (Eubalaena glacialis) and its potential function in reproductive advertisement." *Marine Mammal Science* 21, no. 3 (2005): 458-475.

Payne, Roger S., and Scott McVay. "Songs of humpback whales." *Science* 173, no. 3997 (1971): 585-597.

Perry, Simona L., Douglas P. DeMaster, and Gregory K. Silber. "The great whales: history and status of six species listed as endangered under the U.S. Endangered Species Act of 1973." *Marine Fisheries Review* 61, no. 1 (1999): 1-74.

Risch, Denise, Christopher W. Clark, Peter J. Dugan, Marian Pospescu, Ursula Siebert, and Sofie M. Van Parijs. "Minke whale acoustic behavior and multi-year seasonal and diel vocalization patterns in Massachusetts Bay, USA." *Marine Ecology Progress Series* 489 (2012): 279-295.

Roch, Marie A, Melissa S. Soldevilla, Jessica C. Burtenshaw, E. Elizabeth Henderson, and John A. Hildebrand. "Gaussian mixture model classification of odontocetes in the Southern California Bight and the Gulf of California." *Journal of the Acoustical Society of America* 121, no. 3 (2007): 1737-1748.

Roch, Marie A., et al. "Classification of echolocation clicks fom odontocetes in the Southern California Bight." *Journal of the Acoustical Society of America* 129, no. 1 (2011): 467-475.

Samarra, Filipa I. P., Volker B. Deecke, Katja Vinding, Marianne H. Rasmussen, René J. Swift, and Patrick J. O. Miller. "Killer Whales (Orcinus orca) produce ultrasonic whistles." *Journal of the Acoustical Society of America* 128, no. 5 (2010).

Širović, Ana, Hannah R. Bassett, Sarah C. Johnson, Sean M. Wiggins, and John A. Hildebrand. "Bryde's whale calls recorded in the Gulf of Mexico." *Marine Mammal Science*, 2013: Accepted.

Širović, Ana, Lauren N. Williams, Sara M. Kerosky, Sean M. Wiggins, and John A. Hildebrand. "Temporal separation of two fin whale call types across the eastern North Pacific." *Marine Biology* 160 (2013): 47-57.

Soldevilla, Melissa S., E. Elizabeth Henderson, Gregory S. Campbell, Sean M. Wiggins, and Marie A. Roch. "Classification of Risso's and Pacific white-sided dolphins using spectral properties of echolocation clicks." *Journal of the Acoustical Society of America* 124, no. 1 (2008): 609-624.

Soldevilla, Melissa S., Sean M. Wiggins, John A. Hildebrand, Erin M. Oleson, and Megan C. Ferguson. "Risso's and Pacific white-sided dolphin habitat modeling from passive acoustic monitoring." *Marine Ecology Progress Series* 423 (2011): 247-260.

Stimpert, Alison K., Whitlow L. Au, Susan E. Parks, Thomas Hurst, and David N. Wiley. "Common humpback whale (Megaptera novaeangliae) sound types for passive acoustic monitoring." *Journal of the Acoustical Society of America* 129, no. 1 (2011): 476-482.

Thompson, Paul O., Lloyd T. Findley, and Omar Vidal. "20-Hz pulses and other vocalizations of fin whales, Balaaenoptera physalus, in the Gulf of California, Mexico." *Journal of the Acoustical Society of America* 92, no. 6 (1992): 3051-3057.

Wade, Paul R., and Tim Gerrodette. "Estimates of cetacean abundance and distribution in the Eastern Tropical Pacific." *Report of the International Whaling Commission* 43 (1993): 477-493.

Watkins, William A. "Activities and underwater sounds of fin whales." *Scientific Reports of the Whales research Institute* 33 (1981): 83-117.

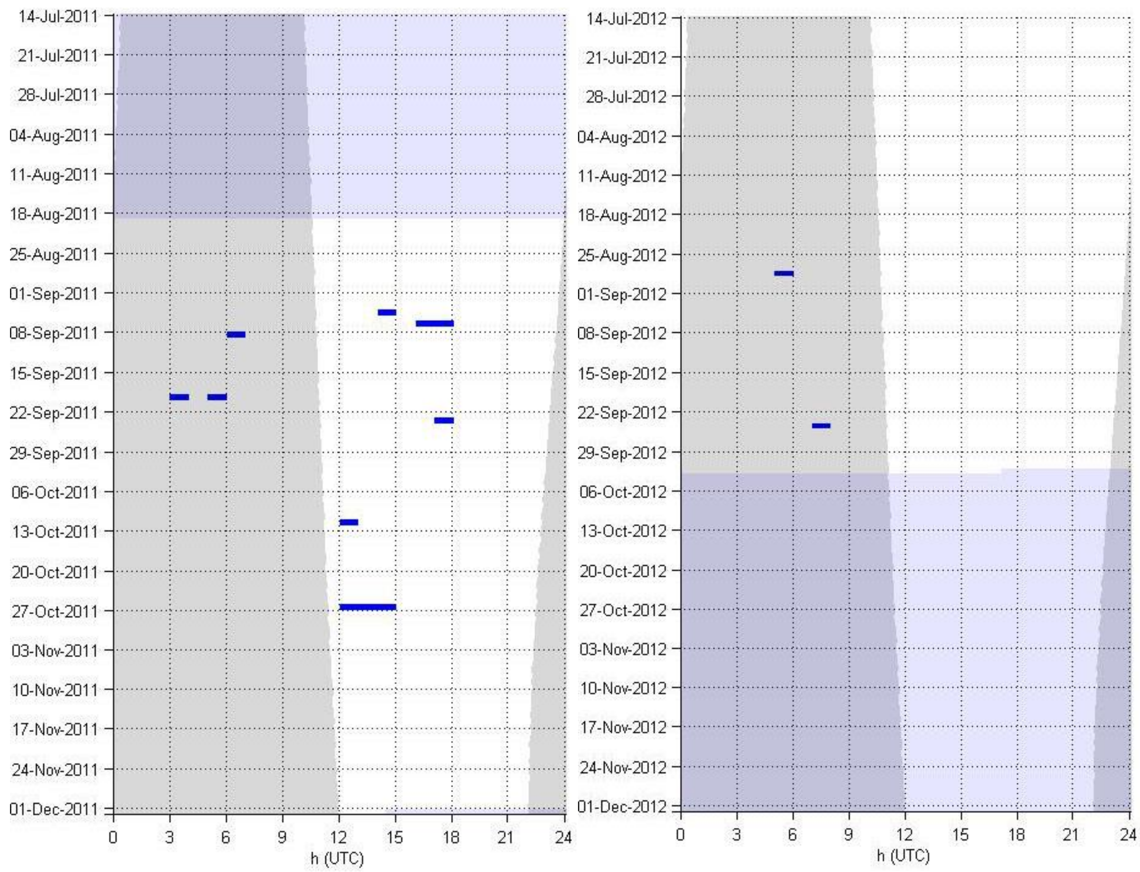
Watwood, Stephanie L., Patrick J. O. Miller, Mark Johnson, Peter T. Madsen, and Peter L. Tyack. "Deep-diving foraging behaviour of sperm whales." *Journal of Animal Ecology* 75 (2006): 814-825.

Wiggins, Sean M., and John A. Hildebrand. "High-frequency acoustic recording package (HARP) for broad-band, long-term marine mammal monitoring." *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*, 2000: 551-557.

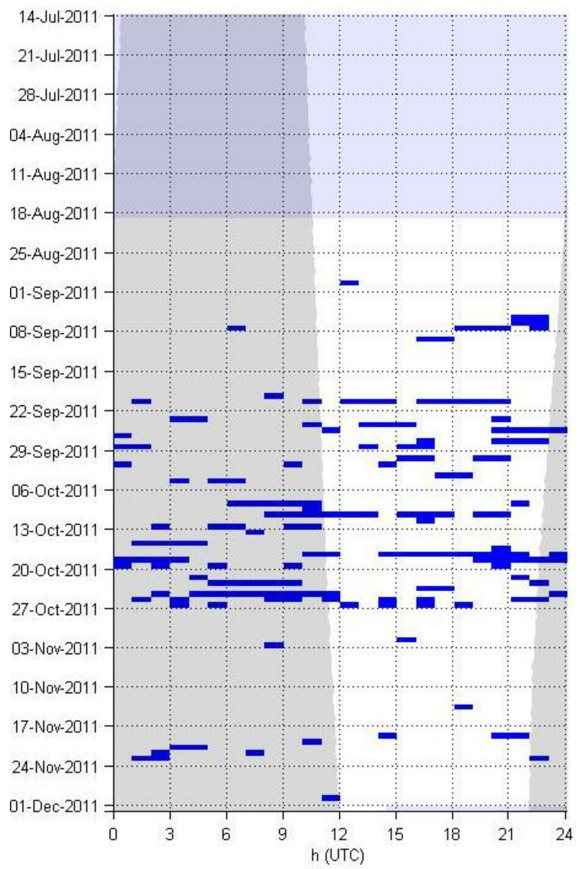
—. "High-frequency Acoustic Recording Package (HARP) for broad-band, long-term marine mammal monitoring." *Institute of Electrical and Electronics Engineers.* Tokyo: Institute of Electrical and Electronics Engineers, 2007. 551-557.

Zimmer, Walter M. X., Mark P. Johnson, Peter T. Madsen, and Peter L. Tyack. "Echolocation cilcks of free-ranging Cuvier's beaked whales (Ziphius cavirostris)." *Journal of the Acoustical Society of America* 117, no. 6 (2005): 3919-3927.

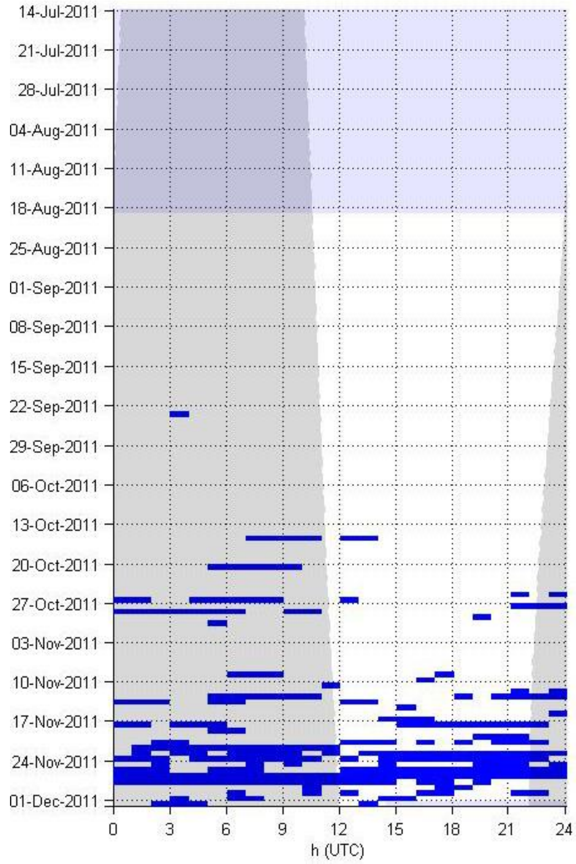
Appendix – Seasonal/Diel Occurrence Plots



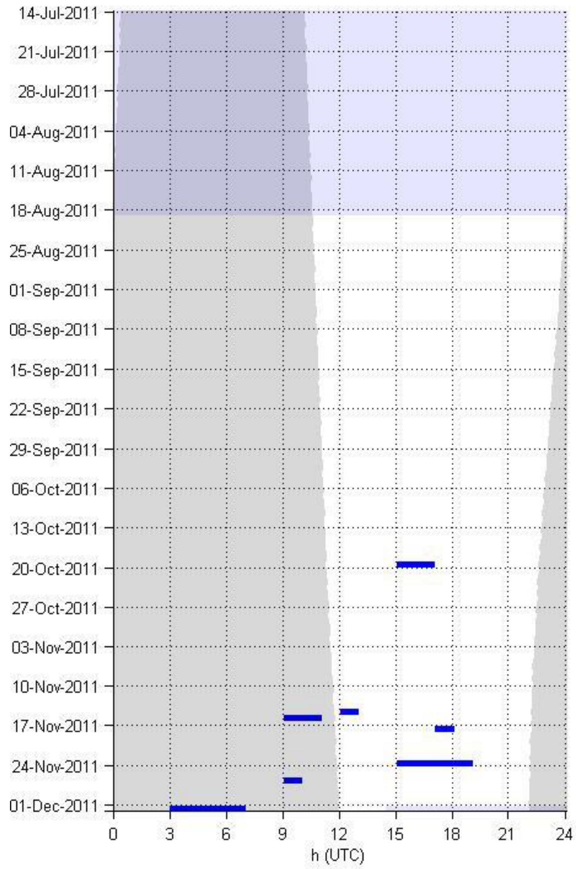
Blue whale – North Atlantic blue whale calls in hourly bins in 2011 (left) and 2012 (right).



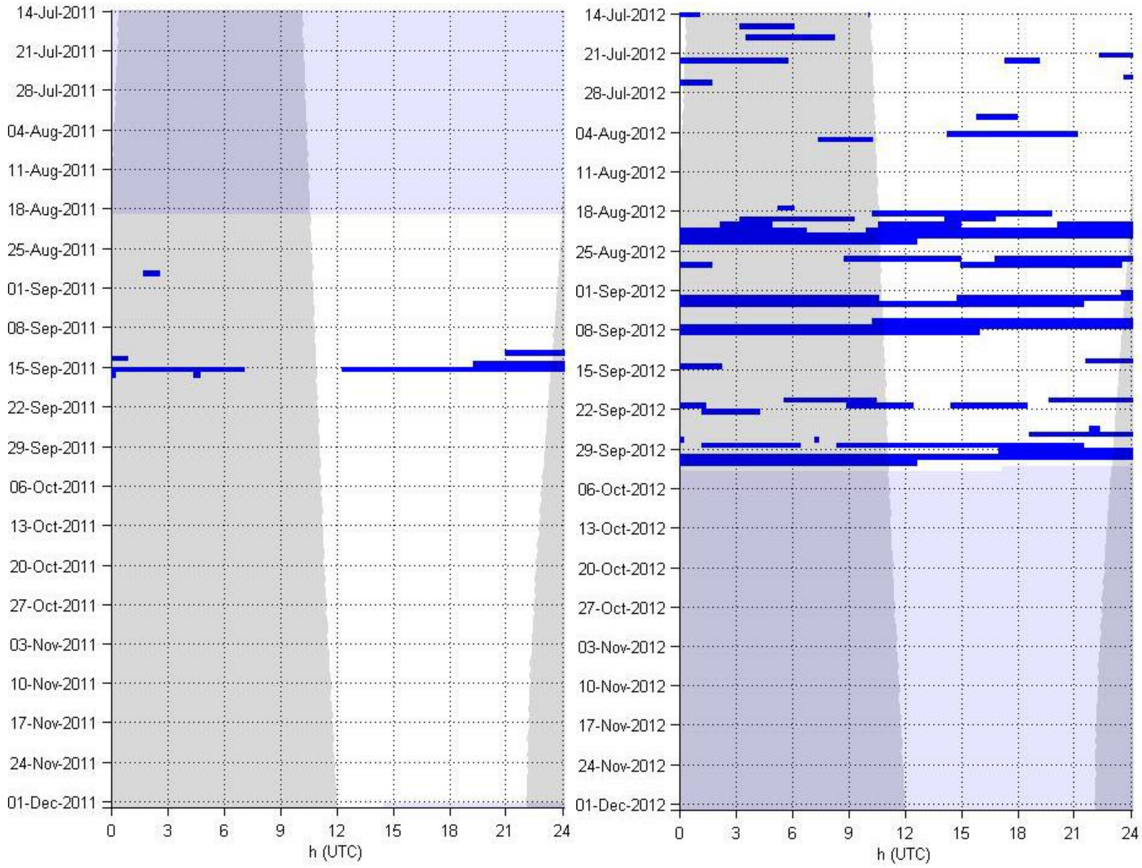
Fin whale – 20 Hz calls in hourly bins in 2011. No 20 Hz fin whale calls were detected in 2012. No 40 Hz calls were detected in 2011 or 2012.



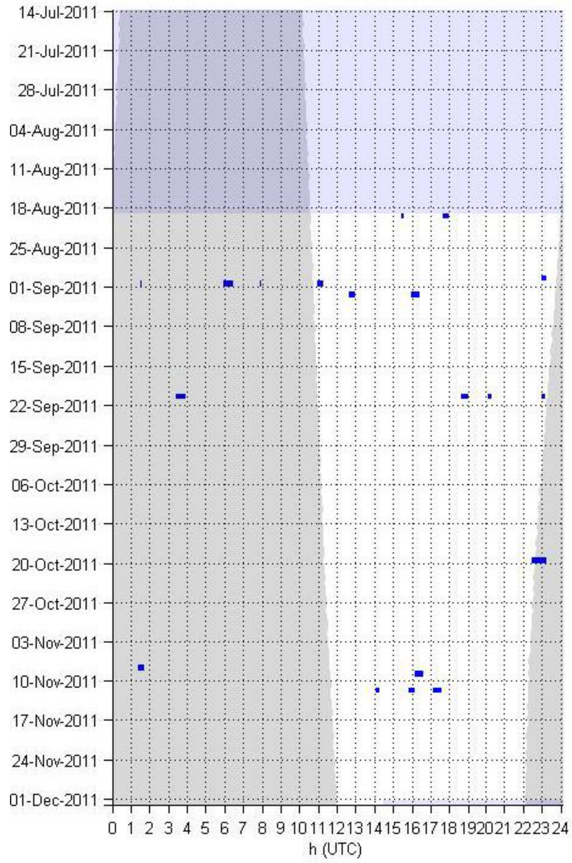
Minke whale – 160 Hz and 60 Hz pulse trains in hourly bins in 2011. No minke whales were detected in 2012.



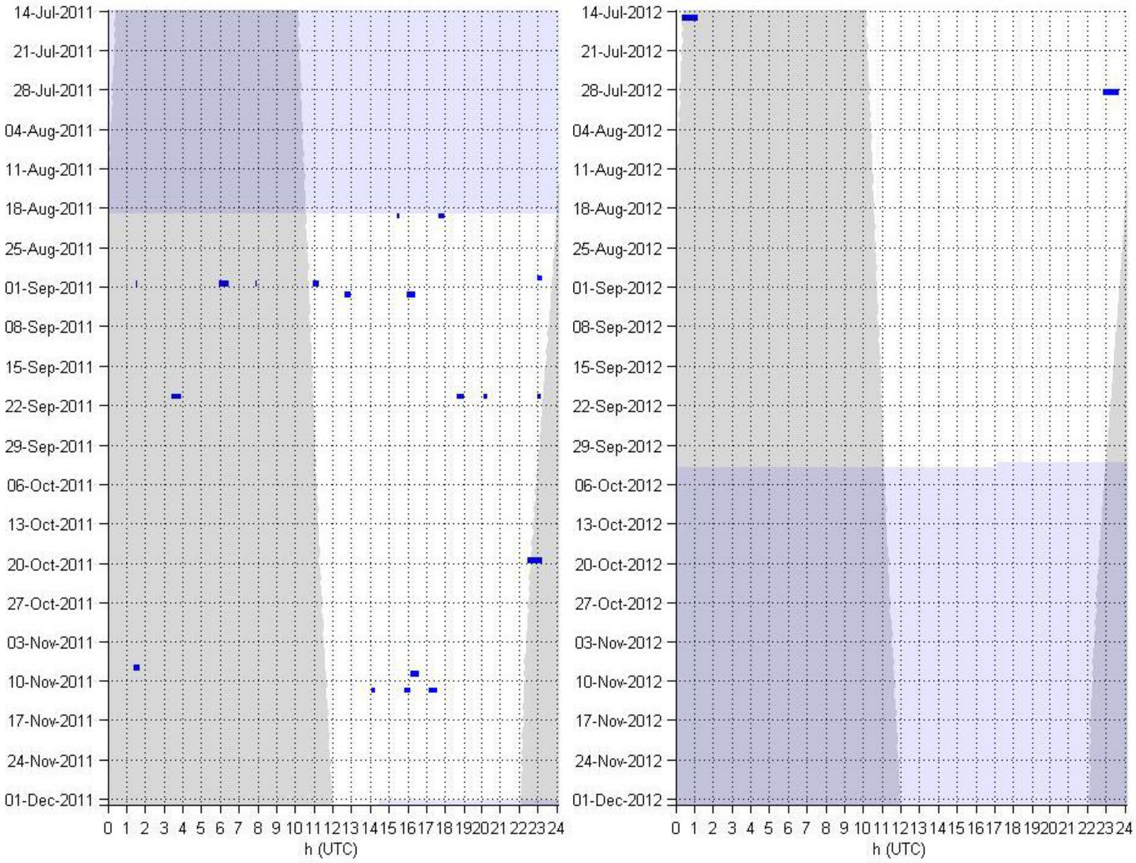
Sei whale – Downsweeps in hourly bins in 2011. No sei whale calls were detected in 2012.



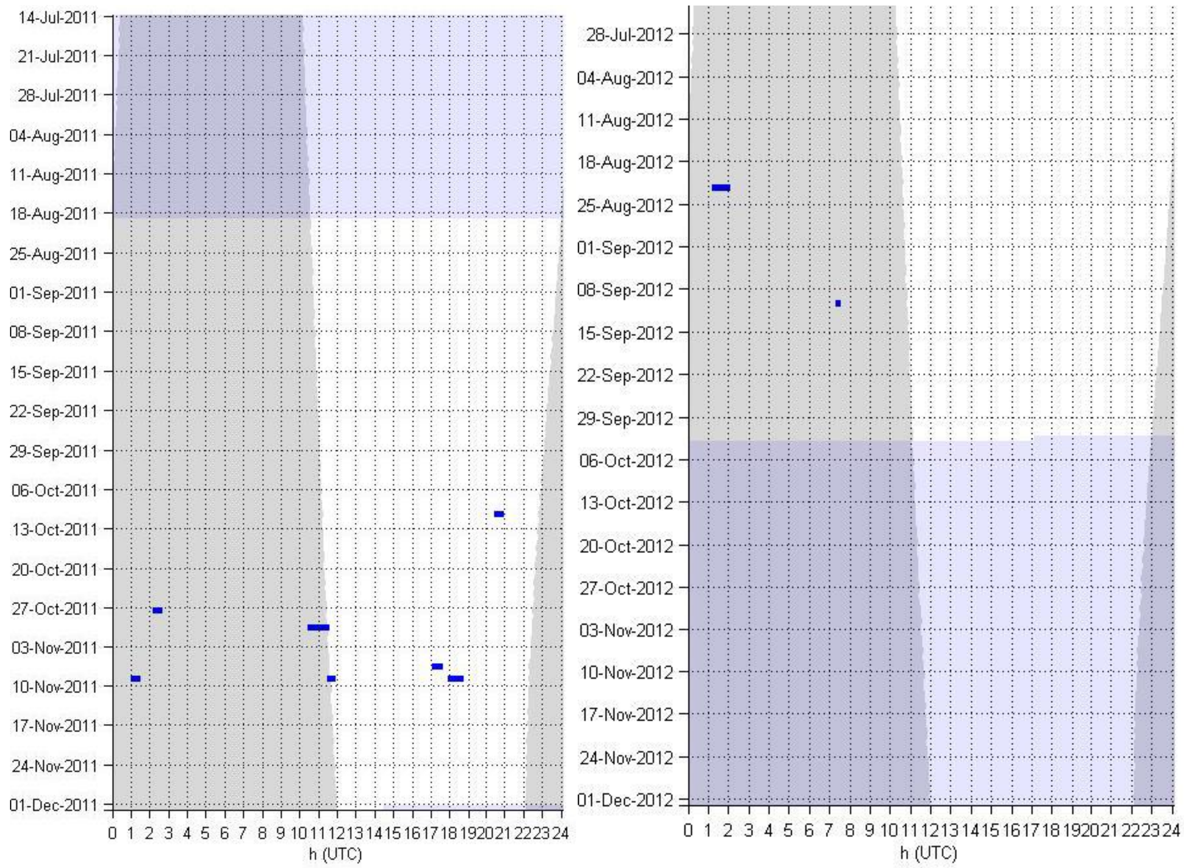
Low-frequency noise causing masking of baleen whale calls – Occurrence in 1 minute bins in 2011 (left) and 2012 (right).



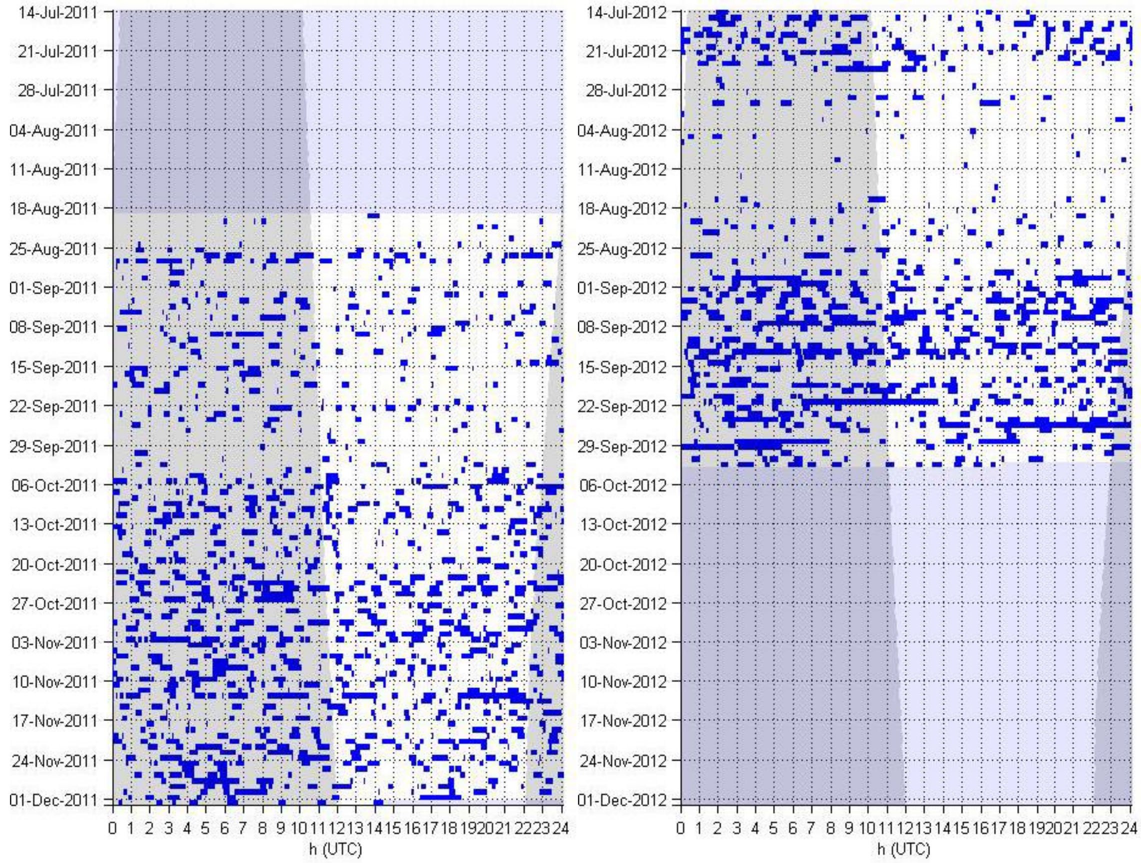
BW38 - Occurrence in 1 minute bins in 2011.



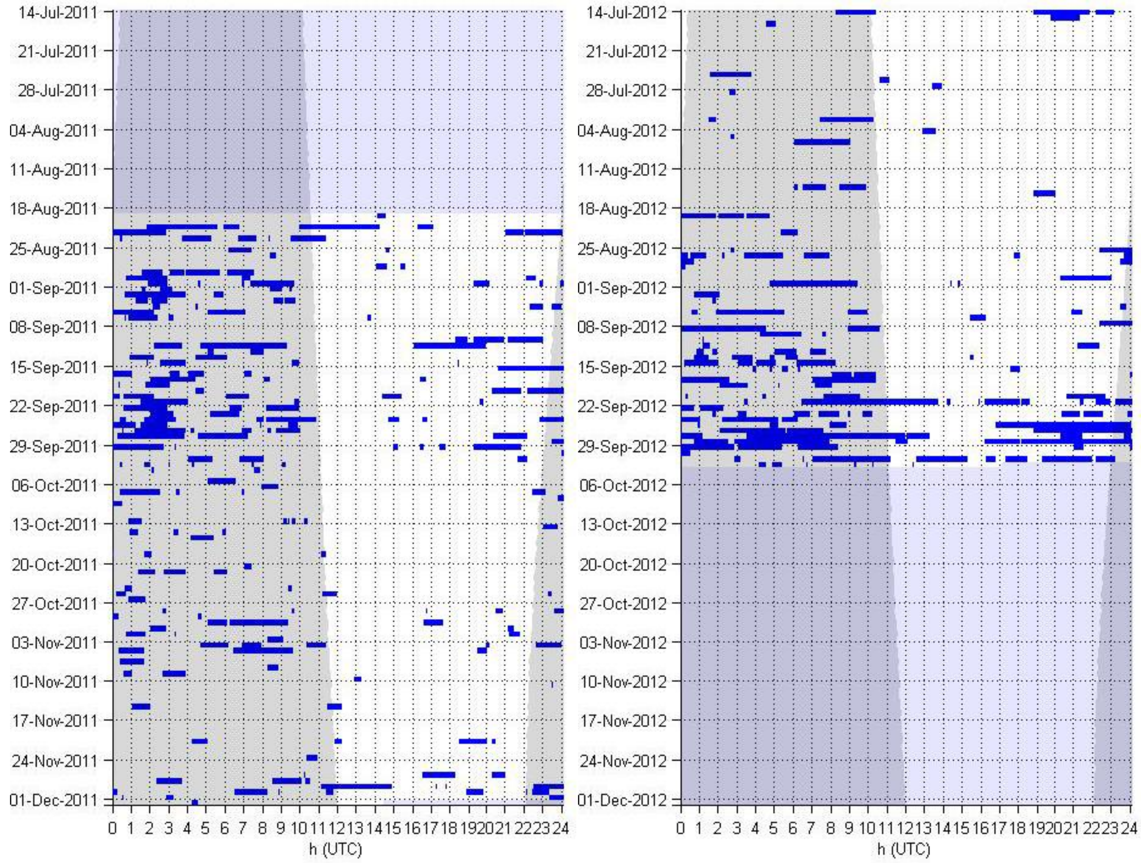
Blainville’s beaked whales - Occurrence in 1 minute bins in 2011 (left) and 2012 (right).



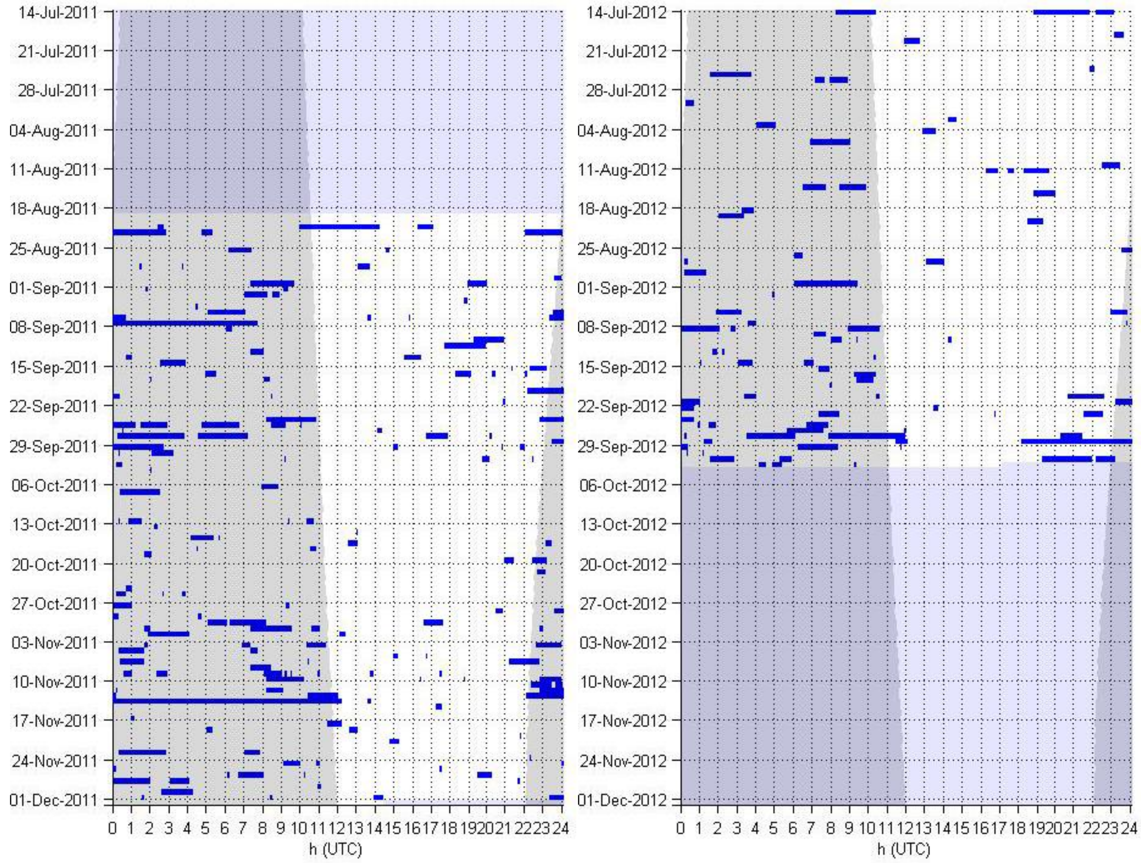
Cuvier's beaked whales - Occurrence in 1 minute bins in 2011 (left) and 2012 (right).



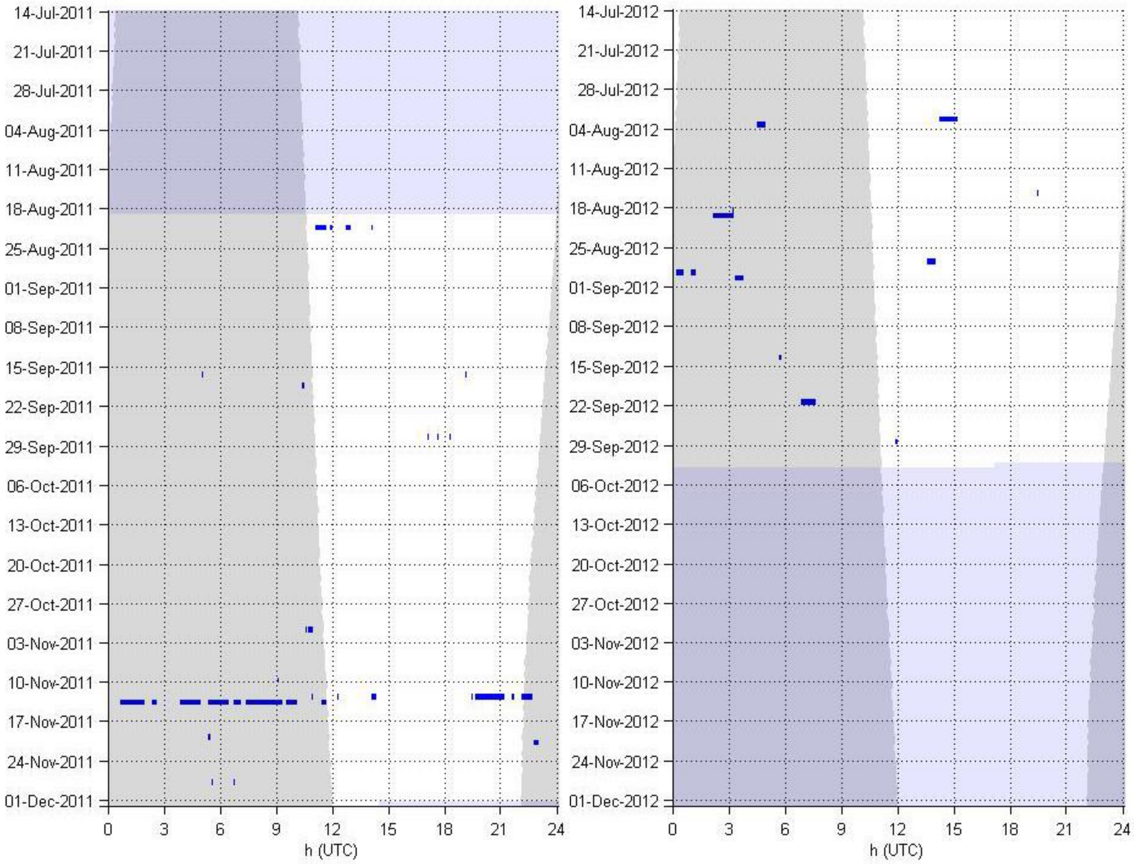
Gervais’ beaked whales - Occurrence in 1 minute bins in 2011 (left) and 2012 (right).



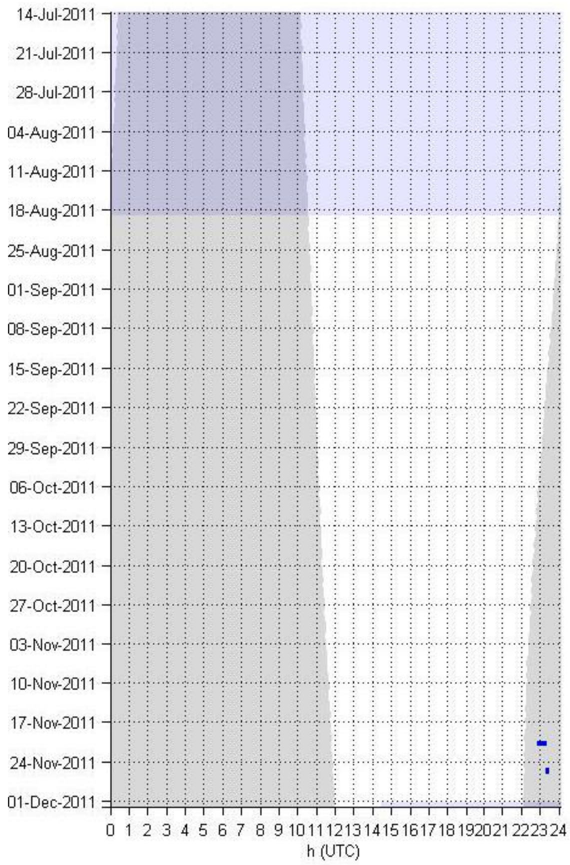
Unidentified odontocete whistles – Occurrence in 1 minute bins in 2011 (left) and 2012 (right).



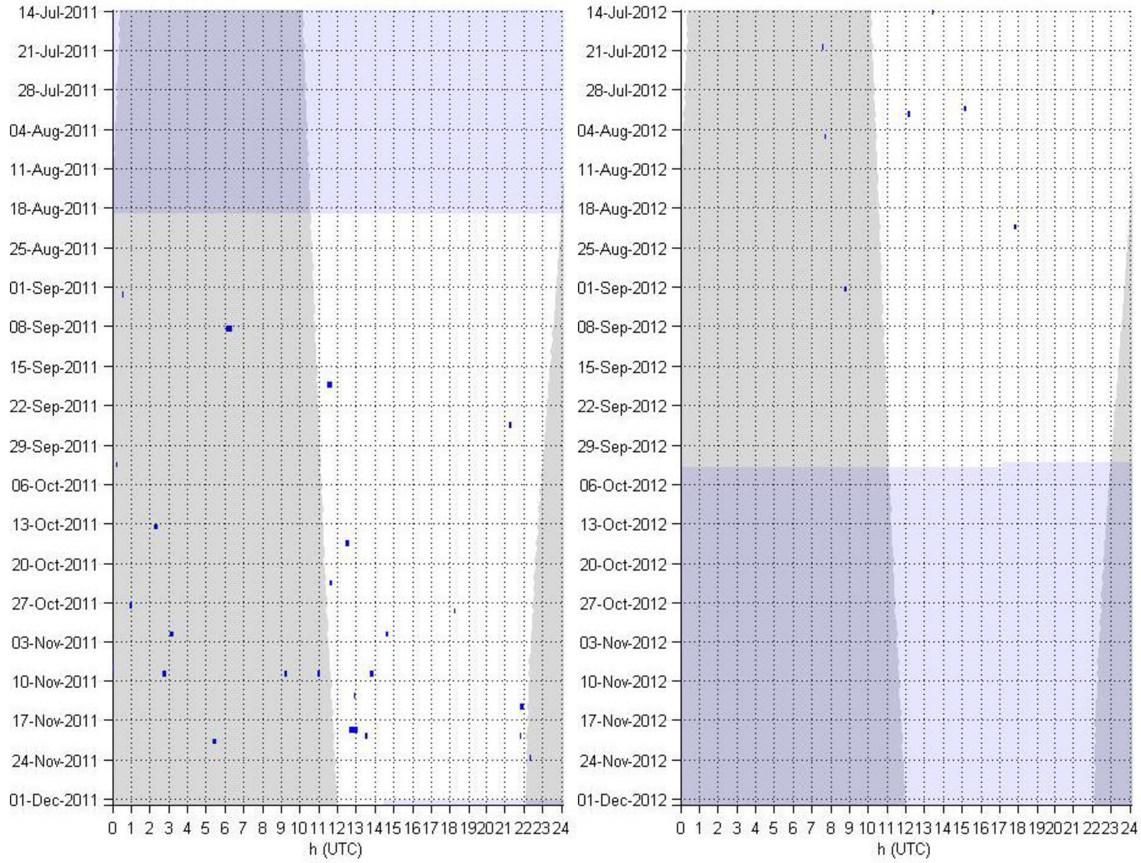
Unidentified odontocete clicks - Occurrence in 1 minute bins in 2011 (left) and 2012 (right).



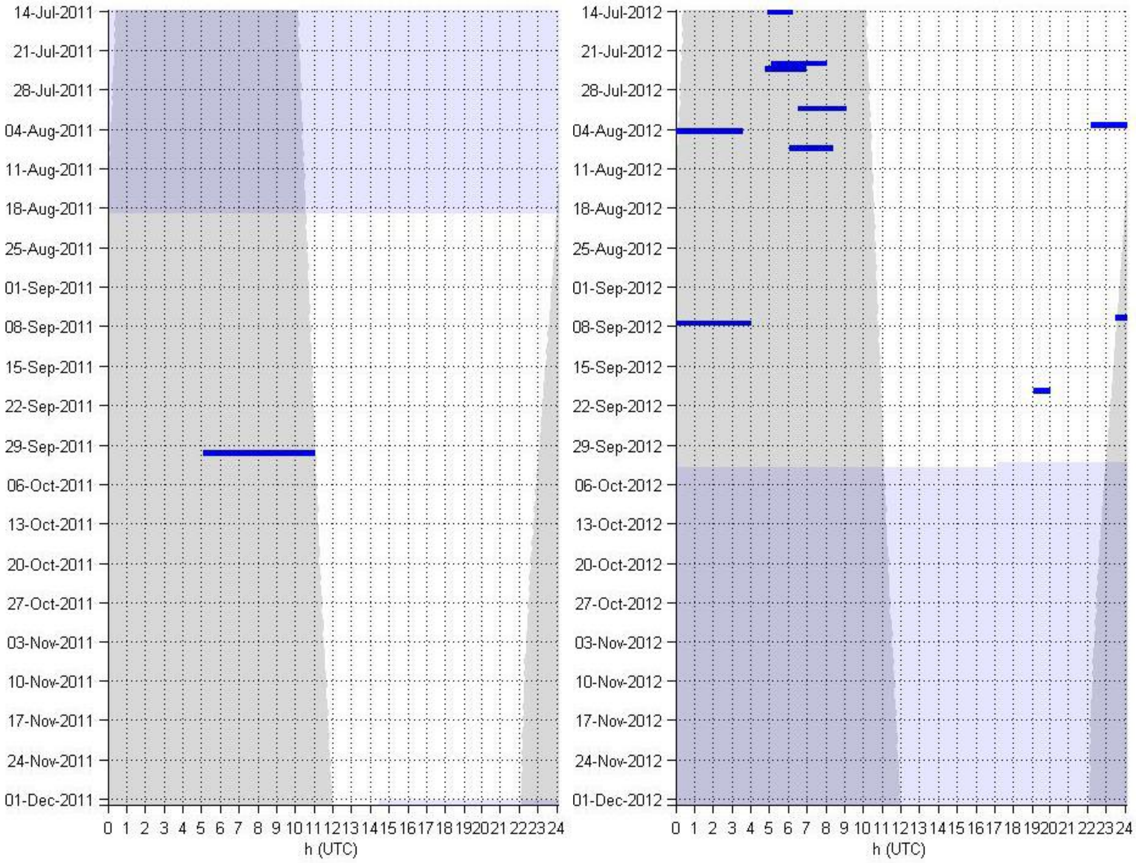
Unidentified odontocete whistles <5 kHz (presumably killer whales) – Occurrence in 1 minute bins in 2011 (left) and 2012 (right).



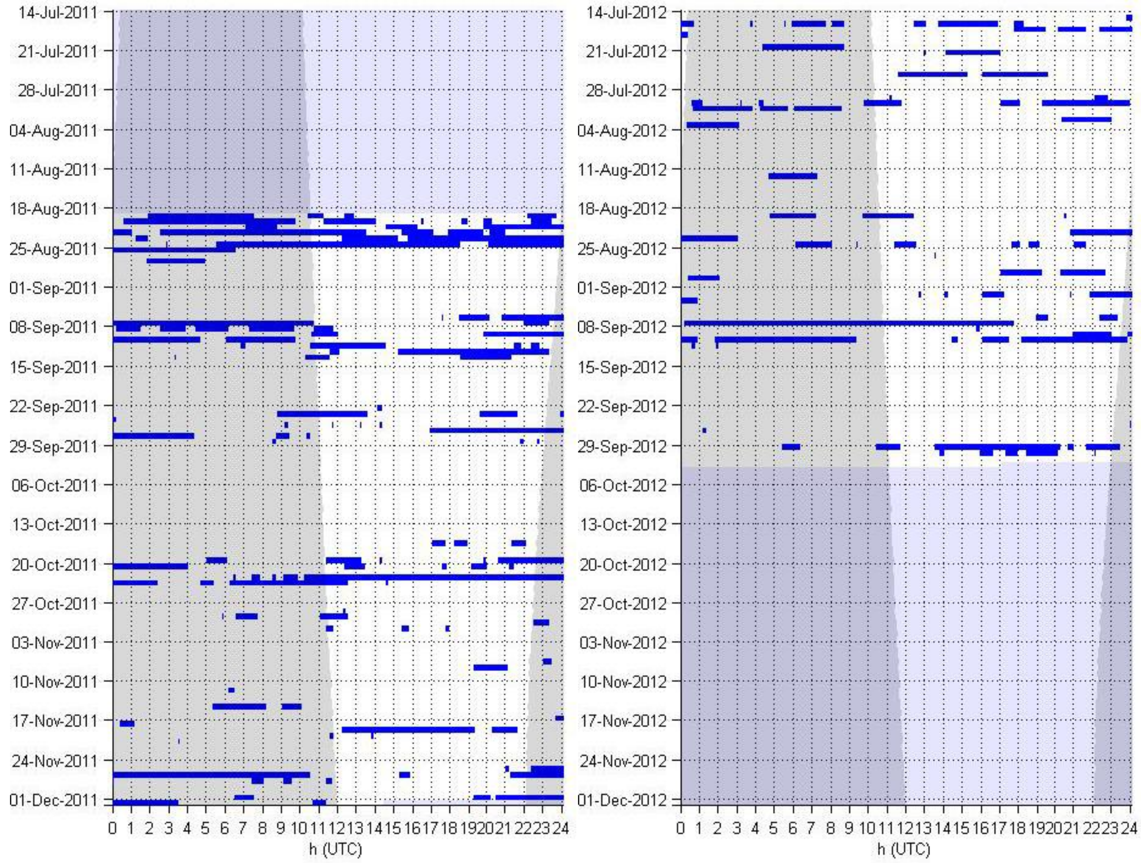
Killer whale clicks - Occurrence in 1 minute bins in 2011 (left). There were no detections in 2012.



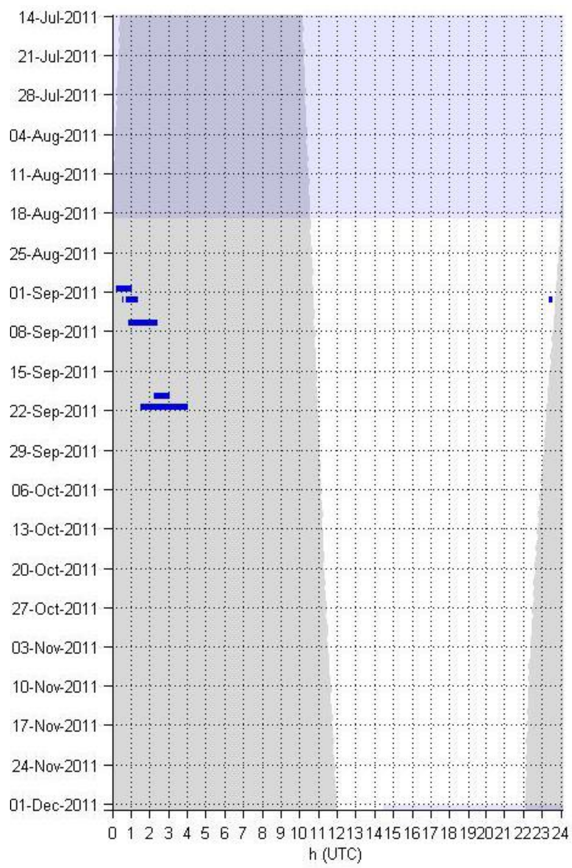
Kogia spp. - Occurrence in 1 minute bins in 2011 (left) and 2012 (right).



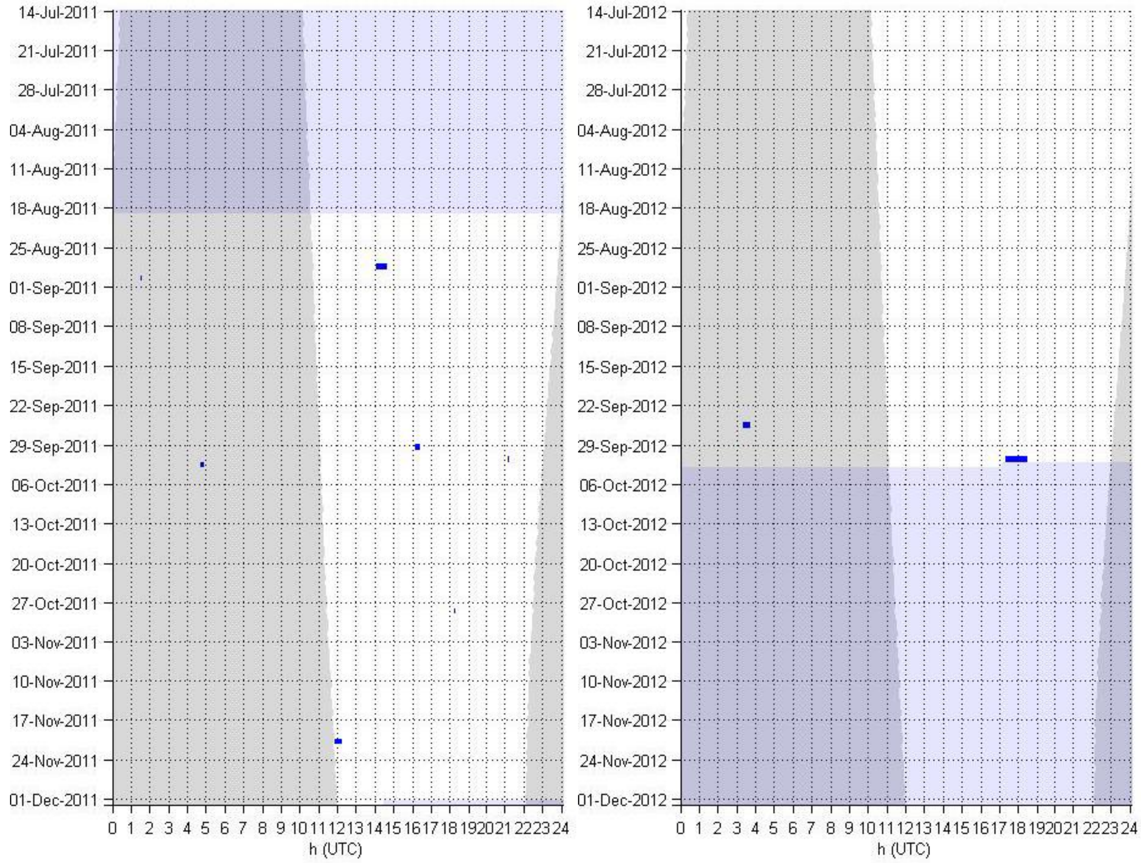
Risso's dolphins - Occurrence in 1 minute bins in 2011 (left) and 2012 (right).



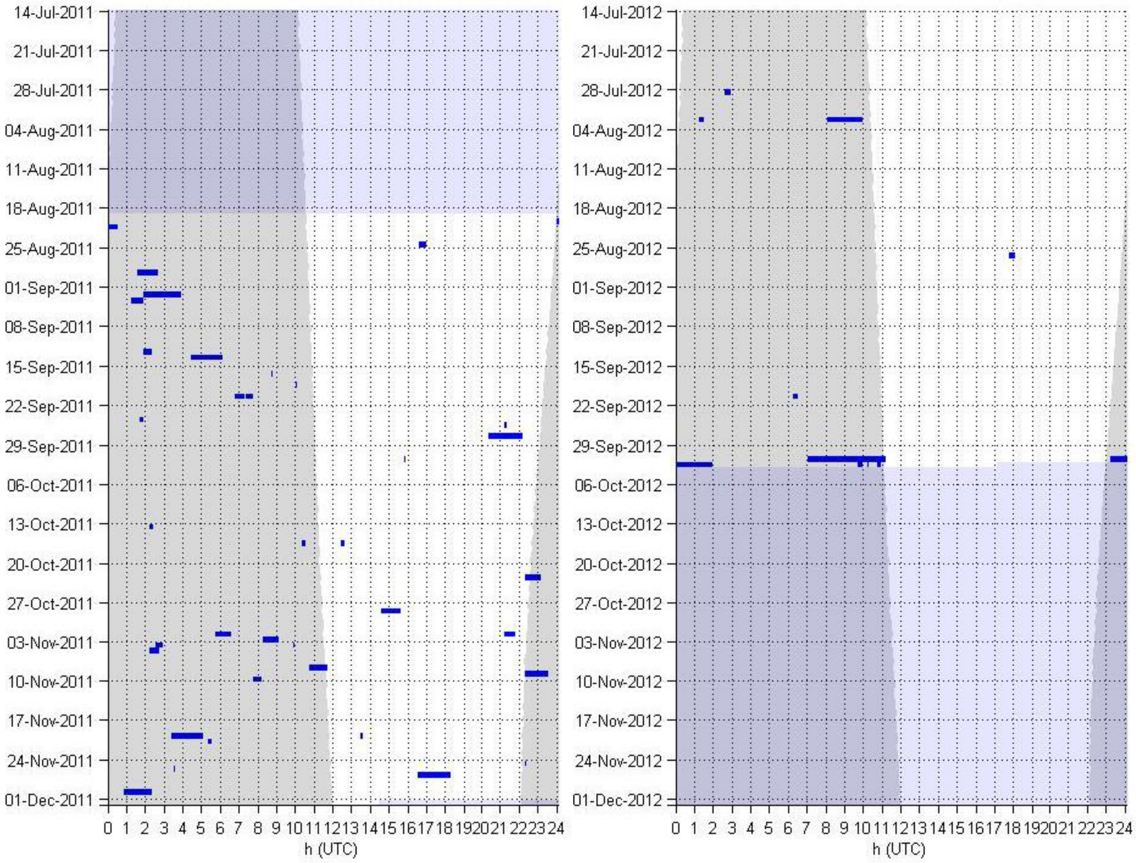
Sperm whales - Occurrence in 1 minute bins in 2011 (left) and 2012 (right).



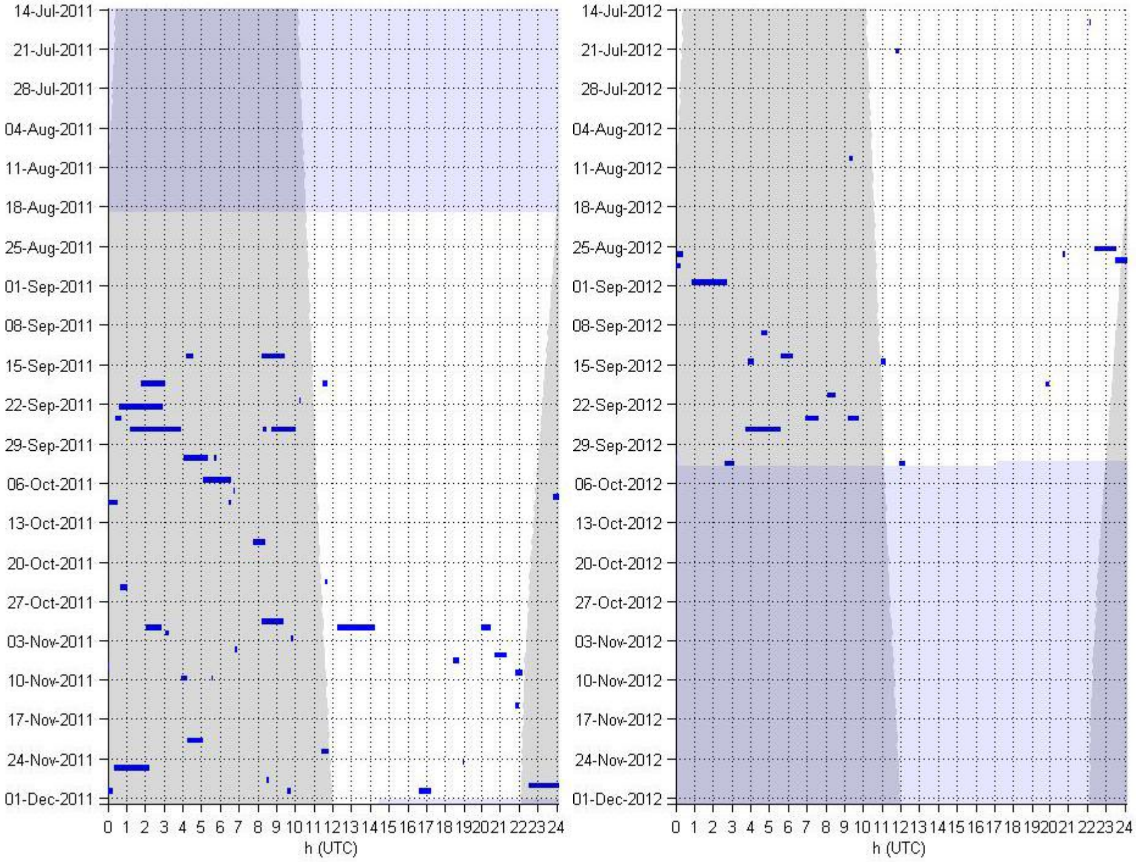
CT25 – Occurrence in 1 minute bins in 2011.



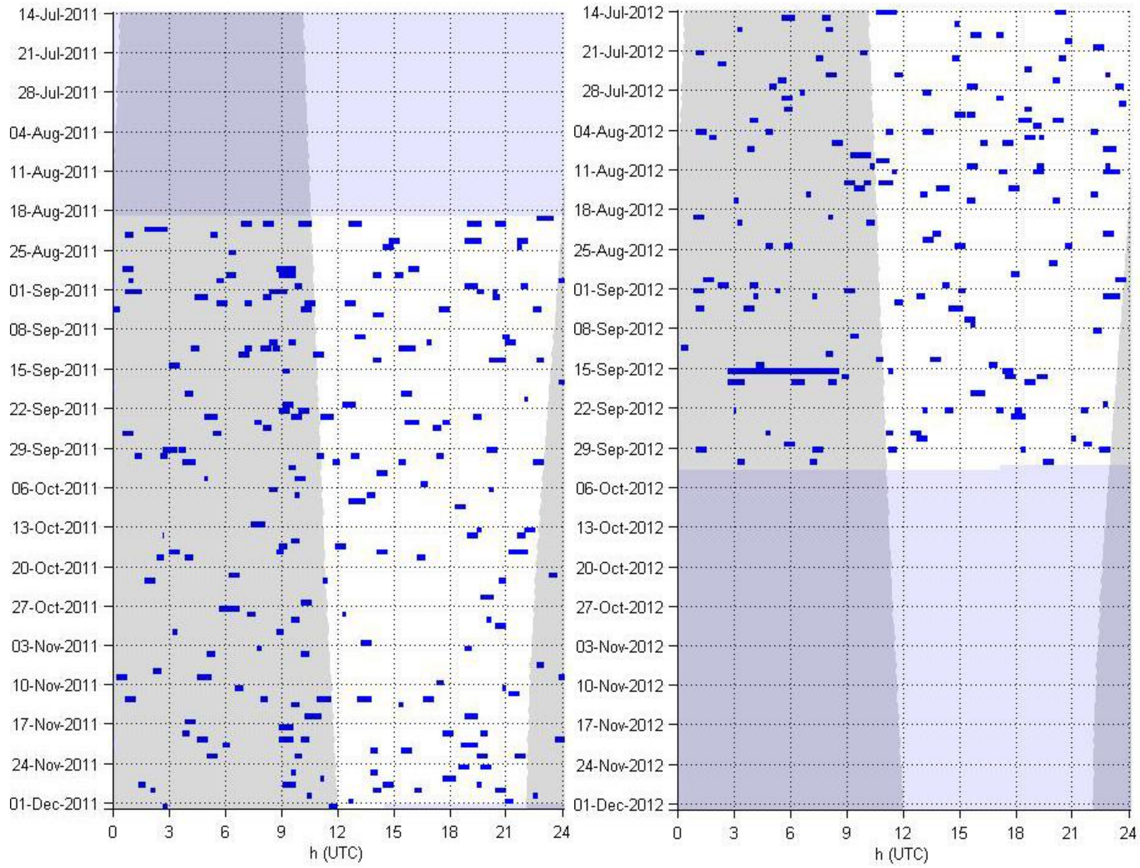
CT 26 – Occurrence in 1 minute bins in 2011 (left) and 2012 (right).



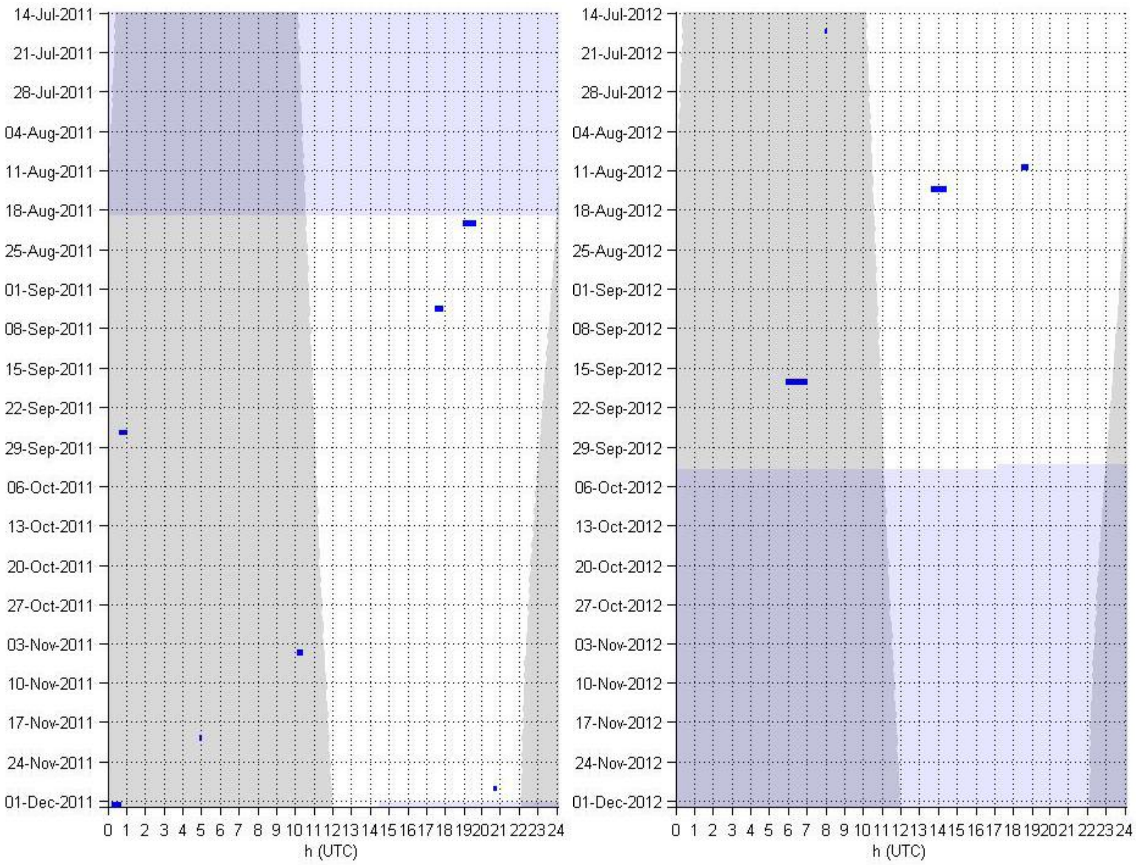
CT 30 – Occurrence in 1 minute bins in 2011 (left) and 2012 (right).



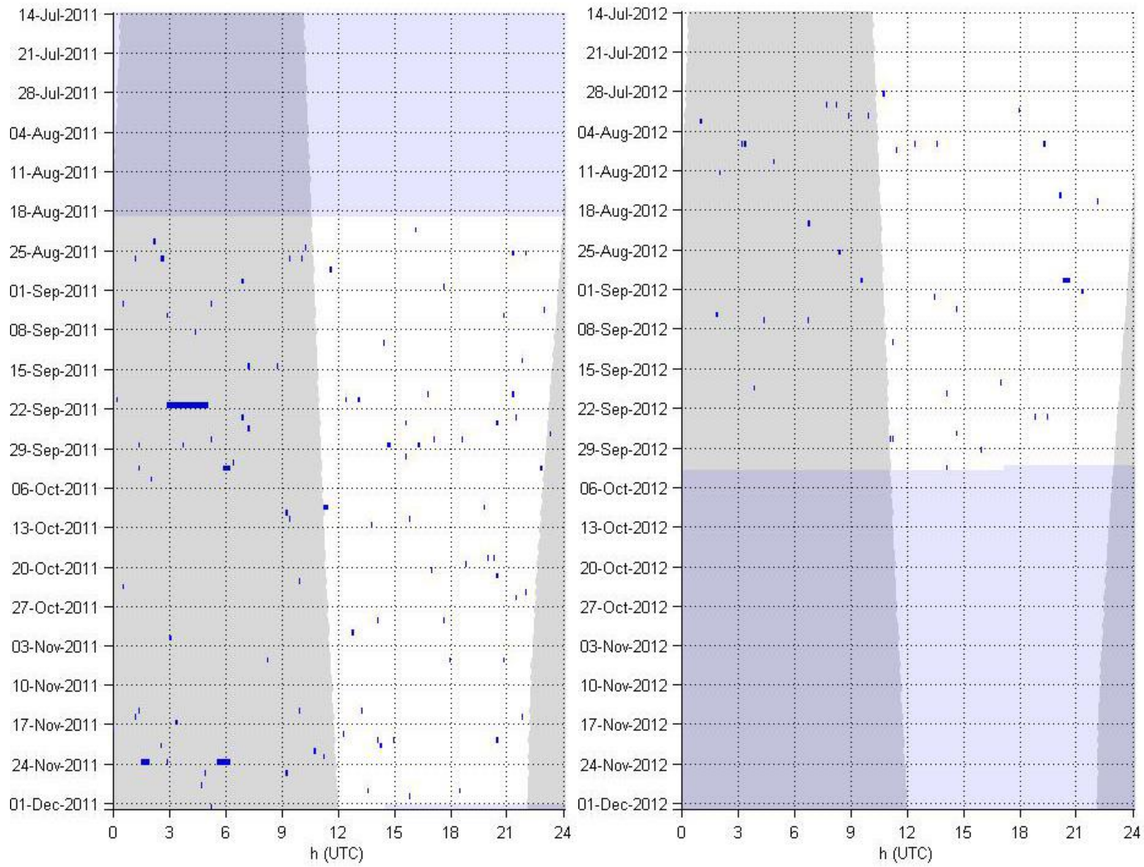
CT 32 – Occurrence in 1 minute bins in 2011 (left) and 2012 (right).



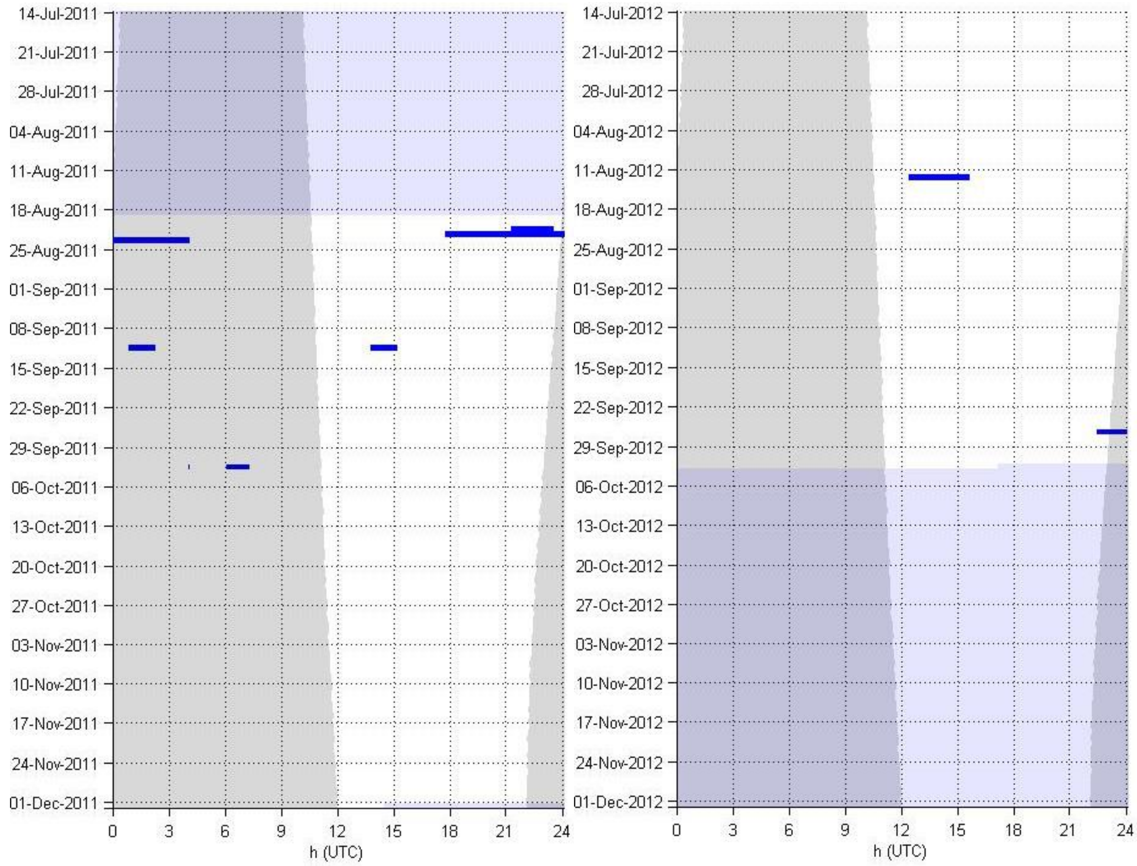
Broadband ship noise – Occurrence in 1 minute bins in 2011 (left) and 2012 (right).



Echosounders – Occurrence in 1 minute bins in 2011 (left) and 2012 (right).



Explosions – Occurrence in 1 minute bins in 2011 (left) and 2012 (right).



Mid-frequency active sonar – Occurrence in 1 minute bins in 2011 (left) and 2012 (right).