Passive Acoustic Monitoring for Marine Mammals in the Northwest Training Range Complex 2012-2013

Amanda J. Debich, Simone Baumann-Pickering, Ana Širović, John A. Hildebrand, Alexa L. Alldredge, Rachel S. Gottlieb, Sean Herbert, Sarah C. Johnson, Lauren K. Roche, Bruce Thayre, Jenny S. Trickey, and Sean M. Wiggins

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

MPL TECHNICAL MEMORANDUM: MPL-TM 550
June 2014

Table of Contents

Executive Summary

Passive acoustic monitoring was conducted to detect the presence of marine mammal and anthropogenic sounds in the Navy's Northwest Training Range Complex (NWTRC) from September 14, 2012 until June 30, 2013. High-frequency Acoustic Recording Packages (HARPs) recorded sounds between 10 Hz and 100 kHz at the shelf slope near Quinault Canyon.

Data analysis methods consisted of detection of sounds by analyst scans of long-term spectral averages (LTSAs) and spectrograms, and by automated computer algorithms when possible. The data were divided into three frequency bands for analysis of marine mammal vocalizations and anthropogenic sounds.

Five baleen whale species were recorded off Washington between 2012 and 2013: blue whales, fin whales, North Pacific right whales, humpback whales, and minke whales. Seasonal patterns for blue whale B Northeast Pacific calls, fin whale 20 Hz calls, and humpback whale calls were similar with peaks during the winter months. Blue whale D calls peaked in late-March, while fin whale 40 Hz calls peaked in late-spring and early-summer. The North Pacific right whale upcalls were detected for the first time in the NWTRC in June 2013. Likewise, we report the first minke whale boings recorded at this location, which occurred in November 2012 and April 2013.

Signals from at least six known odontocete species were recorded: Risso's dolphins, killer whales, sperm whales, Stejneger's beaked whales, Cuvier's beaked whales, and Baird's beaked whales. Stejneger's beaked whale detections were more common than any other beaked whale signal recorded in this monitoring period. Stejneger's beaked whale and Cuvier's beaked whale detections peaked in December 2012 while Baird's beaked whale detections peaked in May 2013. Risso's dolphin clicks peaked in September 2012 and almost always occurred at night. Killer whale detections peaked in late-March and early-April 2013. Sperm whale echolocation clicks were detected from November 2012 through June 2013 and peaked in late-February and April 2013. Unidentified odontocete clicks and whistles were also detected throughout the monitoring period.

Several anthropogenic sounds were detected in the recordings: broadband ship noise, mid-frequency active (MFA) sonar, echosounders, underwater communications, and explosions. Ship noise was the most common anthropogenic sound at this site. Ship detections peaked in September 2012 and decreased throughout the recording. Mid-frequency active (MFA) sonar events were rare, with one event in 2012 and three months with occurrences in 2013, while echosounder pings occurred throughout the recording. Two types of underwater communications were recorded including an electronic transmission sound that had not been previously detected. These electronic sounds occurred primarily during daytime hours, beginning just before sunrise and ending just before sunset. Explosions, most likely predominantly from fishery-related seal bombs but also some naval explosives, were detected throughout the deployment with peaks in detections in September 2012 and late-March and early-April 2013.

Project Background

The Navy's Northwest Training Range Complex (NWTRC) contains an offshore area that extends west 250 nautical miles beyond the coasts of Washington, Oregon, and Northern California. This area is a productive ecosystem inhabited by many species of marine mammals. The area includes deep water habitats, utilized by beaked and sperm whales, as well as continental shelf waters frequented by coastal cetaceans, pinnipeds, and porpoises. Endangered species known to occupy this area include blue whale, fin whale, North Pacific right whale, sperm whale, humpback whale, and killer whale.

An acoustic and visual monitoring effort for marine mammals was initiated within the boundaries of the NWTRC with a focus on the Quinault Underwater Tracking Range (QUTR), off the coast of Washington, beginning in July 2004. Two High-frequency Acoustic Recording Packages (HARPs) have been deployed near the QUTR, one in deeper waters on the shelf slope within Quinault Canyon (QC) and a second on the continental shelf off Cape Elizabeth (CE) intermittently since 2004. In 2013, support for continuation of acoustic monitoring in the NWTRC was provided by the Pacific Fleet to Scripps Institution of Oceanography under the Californian Cooperative Ecosystems Studies Unit 08-09a administered by the US Army Corps of Engineers. The goal of this monitoring effort was to characterize the vocalizations of marine mammal species present in the area, determine their presence between September 2012 and June 2013, and evaluate the potential for impact from naval operations. This report documents the analysis of data collected using a HARP that was deployed within the NWTRC at site QC in September 2012 and collected data through June 2013 (Figure 1).

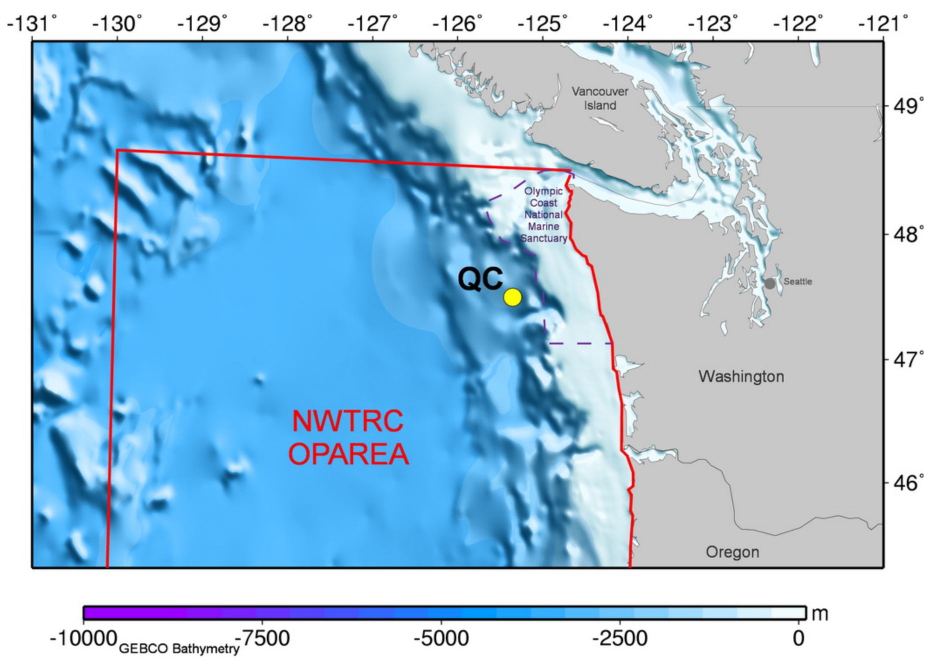

Figure 1. Location of High-frequency Acoustic Recording Package (yellow circle) deployed in the NWTRC (red outline) September 2012 through June 2013. The purple dotted line represents the Olympic Coast National Marine Sanctuary boundary.

Methods

High-frequency Acoustic Recording Package (HARP)

A HARP (Wiggins & Hildebrand, 2007) was used to detect marine mammal species and characterize noise in the NWTRC. HARPs record underwater sounds from 10 Hz to 100 kHz and are capable of approximately 300 days of continuous data storage. For the NWTRC deployment, the HARP was located on the seafloor with the hydrophone suspended 10 m above. The HARP was calibrated in the laboratory to allow a quantitative analysis of the received sound field. Representative data loggers and hydrophones were calibrated at the Navy's TANSDEC facility to verify the laboratory calibrations.

Table 1. NWTRC acoustic monitoring since 2004. Periods of instrument deployment analyzed in this report are shown in bold. Results of acoustic monitoring through 2012 are described in Oleson *et al.* (2009), Širović *et al.* (2011), Širović *et al.* (2012), and Kerosky *et al.* (2013).

Acoustic Monitoring Period	**Sample Rate & Duty Cycle (on/off, in min)**	**QC: Slope**	**CE: Shelf**
OCNMS01: July – October 2004	80 kHz Continuous	Yes	Lost
OCNMS02: October 2004 – January 2005	80 kHz 10/20	Yes	--
OCNMS03: July 2005 – February 2006	80 kHz 6/12	Yes	--
OCNMS04: August 2006 – February 2007	80 kHz 6/12	Yes	Yes
OCNMS05: April – July 2007	80 kHz Continuous	Yes	Yes
OCNMS06: July 2007 – June 2008	200 kHz 5/35	Yes	--
OCNMS07: October 2007 – June 2008	200 kHz 5/30	--	Yes
OCNMS08: June 2008 – June 2009	200 kHz 5/35	Lost	Yes
OCNMS09: December 2009 – January 2011	200 kHz 5/30	--	Lost
OCNMS12: January – October 2011	200 kHz Continuous	Yes	--
OCNMS13: May – November 2011	200 kHz Continuous	--	Yes
OCNMS14: December 2011 – July 2012	200 kHz Continuous	Yes	Yes
OCNMS 15: September 2012 – June 2013	**200 kHz Continuous**	**Yes**	Yes

Data Collected

Acoustic data have been collected at two sites within the NWTRC using HARPs since July 2004 (Table 1). Site QC (47° 30.03N, 125° 21.22W) is located on the continental slope at 1394 m water depth, and site CE (47° 21.17N, 124° 42.47W) is located at 121 m water depth on the continental shelf. Although acoustic recorders were deployed at both sites QC and CE during

September 2012 – June 2013, only site QC returned acoustic data. A computer malfunction within the acoustic recorder at site CE prevented it from collecting any data. The remainder of this report will focus on data analysis from site QC.

Data Analysis

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

Recording over a broad frequency range up to 100 kHz allows detection of baleen whales (mysticetes), toothed whales (odontocetes), and seal and sea lion (pinniped) species. The presence of acoustic signals from multiple marine mammal species was evaluated in the data. To document the data analysis process, we describe the major classes of marine mammal calls and anthropogenic sound in the NWTRC, and the procedures to detect them 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 were as follows:

(1) Low-frequency, between 10-500 Hz
(2) Mid-frequency, between 500-5,000 Hz
(3) High-frequency, between 1-100 kHz

Blue, fin, Bryde's, gray, and North Pacific right whale sounds were classified as low-frequency. Humpback, minke, pinniped, nearby shipping, explosions, and mid-frequency active sonar sounds were classified as mid-frequency. The remaining odontocete and sonar sounds were considered high-frequency. For the analysis of the mid-frequency recordings, data were decimated by a factor of 20. Analysis of low-frequency recordings required decimation by a factor of 100. The LTSAs were created using a 5s time average with 100 Hz frequency resolution for high-frequency analysis, 10 Hz resolution for mid-frequency analysis, and 1 Hz resolution for low-frequency analysis.

In this report, we summarize acoustic data collected between September 2012 and June 2013 at site QC. We discuss seasonal occurrence and relative abundance of calls for different species that were consistently identified in the acoustic data.

Low-Frequency Marine Mammals

The hourly presence of blue whale D, fin whale 40 Hz, Bryde's whale Be4, gray whale M3, and North Pacific right whale up calls was determined by manual scrutiny of low-frequency LTSAs using the custom software program *Triton*. The same LTSA and spectrogram parameters were used for manual detection of all call types. During scrutiny of the data, the LTSA frequency was set to display between 1-500 Hz. To observe individual calls, spectrogram windows 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. When a call of interest was identified in the LTSA or spectrogram, its presence during that hour was logged using *Triton*. Blue whale B calls and fin whale 20 Hz pulses were detected automatically using computer algorithms described below.

Blue Whales

Blue whales produce a variety of calls worldwide (McDonald *et al*., 2006), but B calls (Figure 2) are their most commonly recorded call in the eastern North Pacific (Oleson *et al*., 2007). These low-frequency (15-50 Hz), long duration (20 s) calls can be produced as repetitive sequences (song) or as singular calls and are produces exclusively by males, likely in association with mating behavior (Oleson*et al*., 2007). The call generally contains multiple harmonically-related tonals and, owing to greater noise at low frequency, is best identified based on the presence of the 3rd harmonic.

For this report, blue whale B calls were detected automatically from September 14, 2012 through April 19, 2013 using the spectrogram correlation method (Mellinger & Clark, 1997). The kernel was based on frequency and temporal characteristics measured from 30 calls recorded in the data set, each call separated by at least 24 hours. The kernel was comprised of four segments, three 1.5 s and one 5.5 s long, for a total duration of 10 s. The frequency ranged over those time periods from 46.60 to 46.00; 46.00 to 45.55, 45.55 to 45.07, 45.07 to 44.53 Hz. The kernel bandwidth was 2 Hz. A similar detector has been used by (Oleson *et al*., 2007), but the frequency characteristics were adjusted to account for the annual shift in frequency of blue whale B calls (McDonald *et al*., 2009). Data from April 19 through June 30, 2013 were scanned manually for individual B calls since there were not enough calls to develop the kernel for the new season.

Blue whales also produce D calls, which are downswept in frequency (100-40 Hz) with duration of several seconds (Figure 3). These calls are similar worldwide and are associated with feeding animals; they may be produced as call-counter call between multiple animals (Oleson *et al*., 2007). Blue whale D calls were detected manually by human analysts.

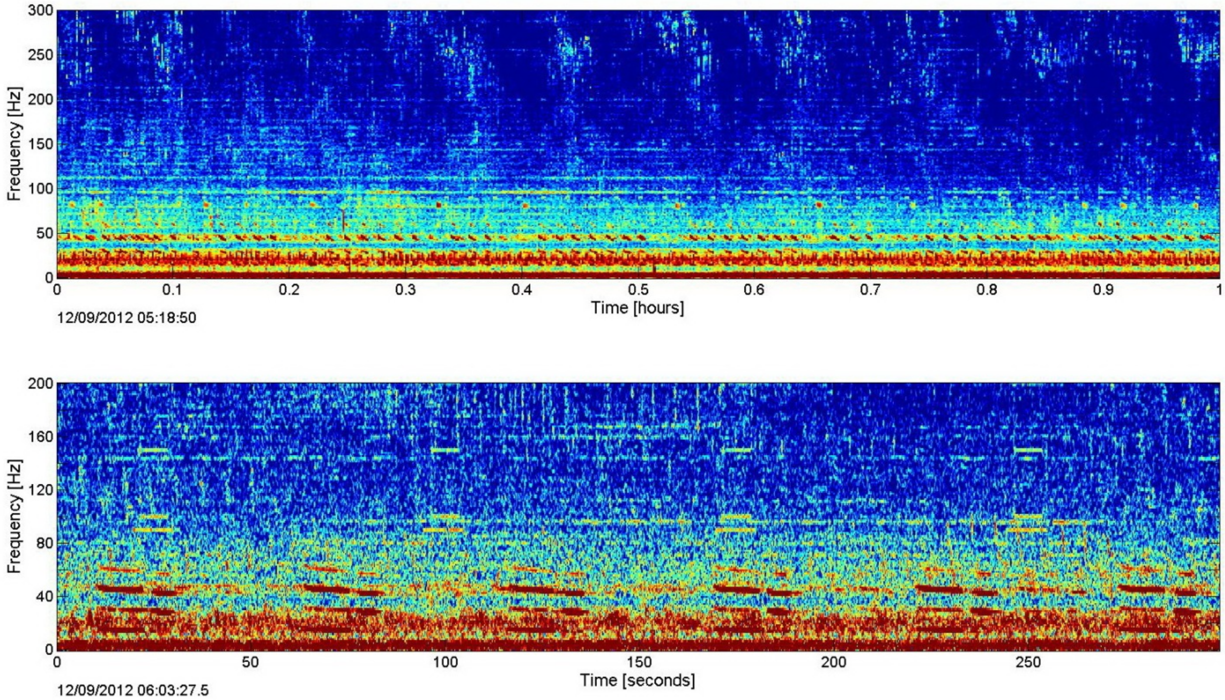

Figure 2. Blue whale B calls in the LTSA (top) and spectrogram (bottom) showing harmonic tones, most visible at about 45 Hz with a frequency step near the end of the call.

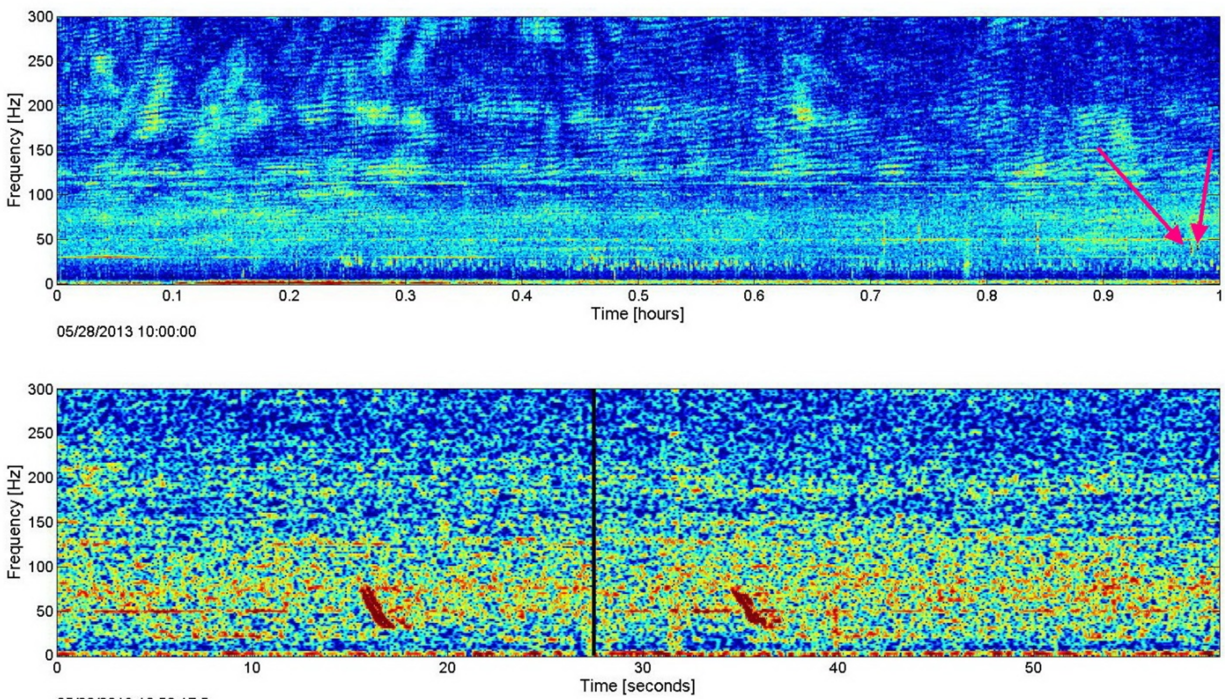

Figure 3. Blue whale D calls in the LTSA (top) and spectrogram (bottom).

Fin Whales

Fin whales produce two types of short (approximately 1 s duration), low-frequency downswept calls: downsweeps in frequency from 30-15 Hz, called 20 Hz calls (Watkins, 1981) (Figure 4), and downsweeps from 75-40 Hz, called 40 Hz calls (Širović *et al*., 2013) (Figure 5). The 20 Hz calls can occur at regular intervals as song (Thompson *et al*., 1992), or irregularly as call counter-calls among multiple, traveling animals (McDonald *et al*., 1995). The 40 Hz calls most occur in irregular patterns.

Fin whale 20 Hz calls were detected automatically using an energy detection method. The method used a difference in acoustic energy between signal and noise, calculated from 5 s LTSA with 1 Hz resolution. The frequency at 22 Hz was used as the signal frequency, while noise was calculated as the average energy between 10 and 34 Hz. All calculations were performed on a logarithmic scale.

Fin whale 40 Hz calls (Figure 5) were detected via manual scanning of the LTSA and subsequent verification from a spectrogram of the frequency and temporal characteristics of the calls.

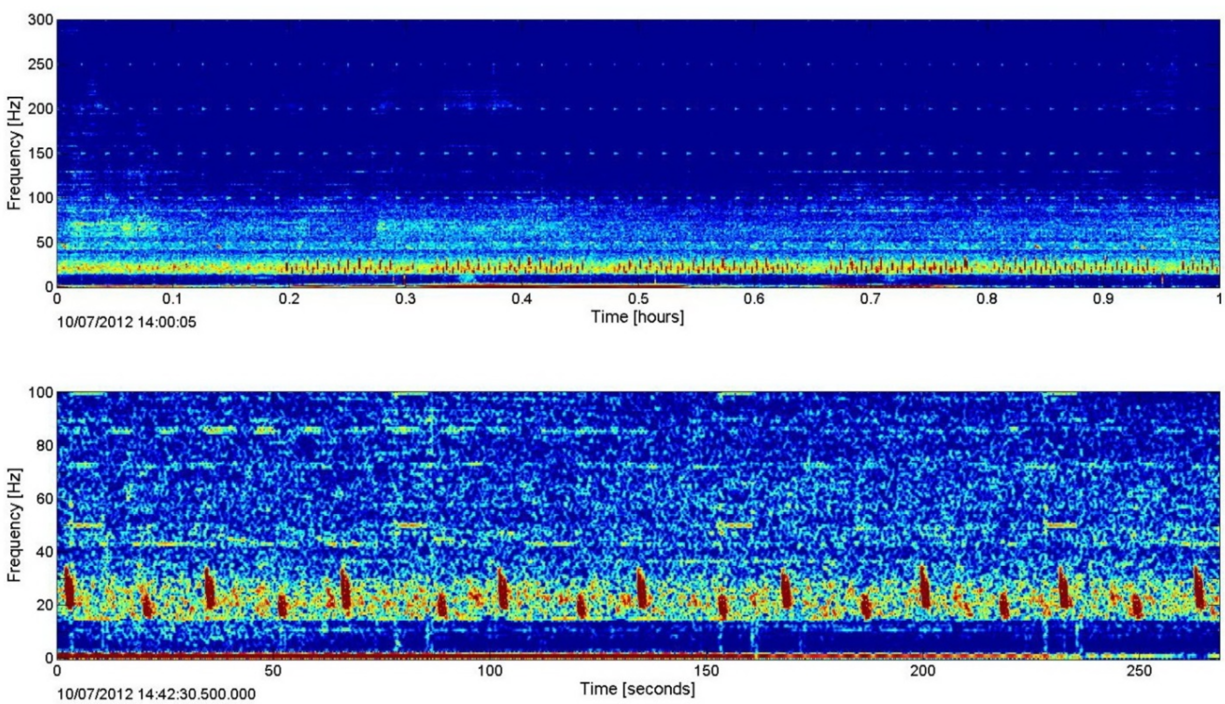

Figure 4. Fin whale 20 Hz pulsed calls in the LTSA (top) and spectrogram (bottom).

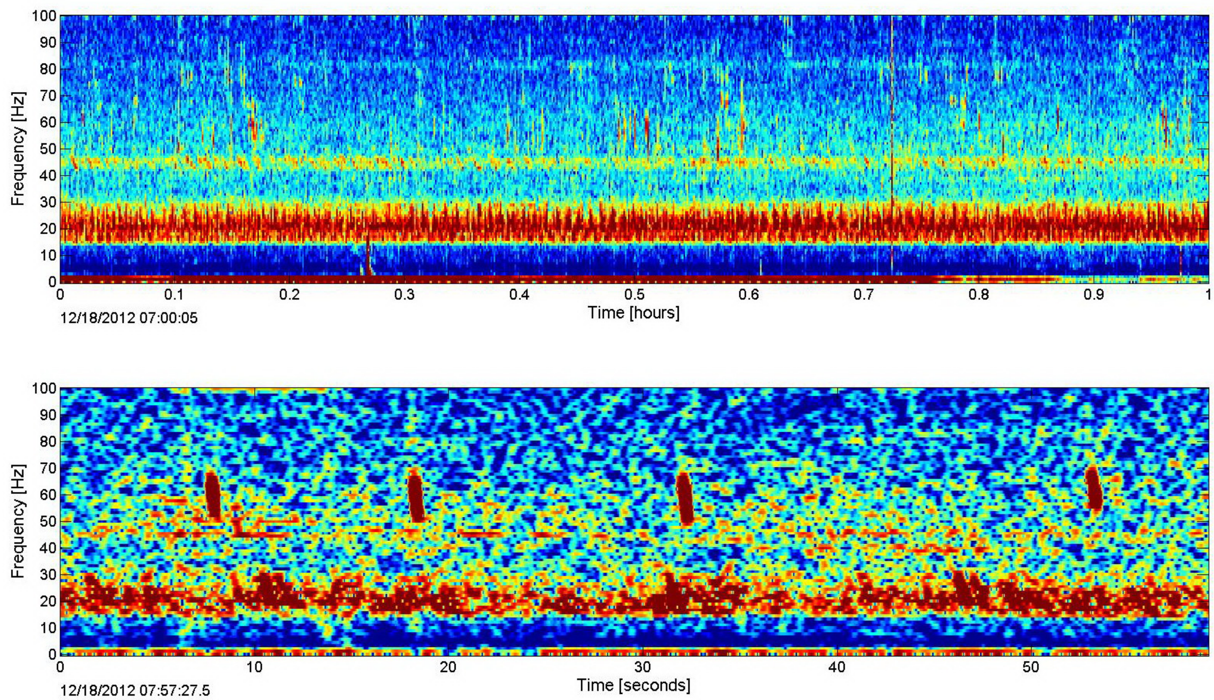

Figure 5. Fin whale 40 Hz calls in the LTSA (top) and spectrogram (bottom).

Bryde's Whales

Bryde's whales generally inhabit the warm waters of the eastern tropical Pacific and the Gulf of California (Leatherwood *et al*., 1988; Tershy *et al*., 1991). The Be4 call is one of several call types in the Bryde's whale repertoire and it is commonly recorded in the eastern North Pacific (Kerosky *et al*., 2012; Oleson *et al*., 2003). The Be4 call consists of a short, slightly upswept tone between 50 and 60 Hz. While there have been stranding reports of Bryde's whales off Washington (J. Calambokidis, pers. comm), this area is generally beyond their traditional range (Kerosky *et al*., 2012). No Bryde's whale Be4 calls were detected in this recording.

Gray Whales

Gray whales also produce low frequency sounds and four types have been described along their migration route between Baja California and the Bering Sea (Crane & Lashkari, 1996). The M1 call consists of pulses and bonging signals. M3, the most commonly recorded call on the migration route, consists of low frequency moans (Figure 6). M4 are grunts and M5 are subsurface exhalations. Presence of gray whale M3 calls was monitored in the data. Classification of gray whale vocalizations is made more complex when humpback whale song and social calls are present, owing to the overlap in call frequencies and the large volume of calls associated with humpback call production versus few sounds produced by migrating gray whales. No gray whale M3 calls were detected in this recording.

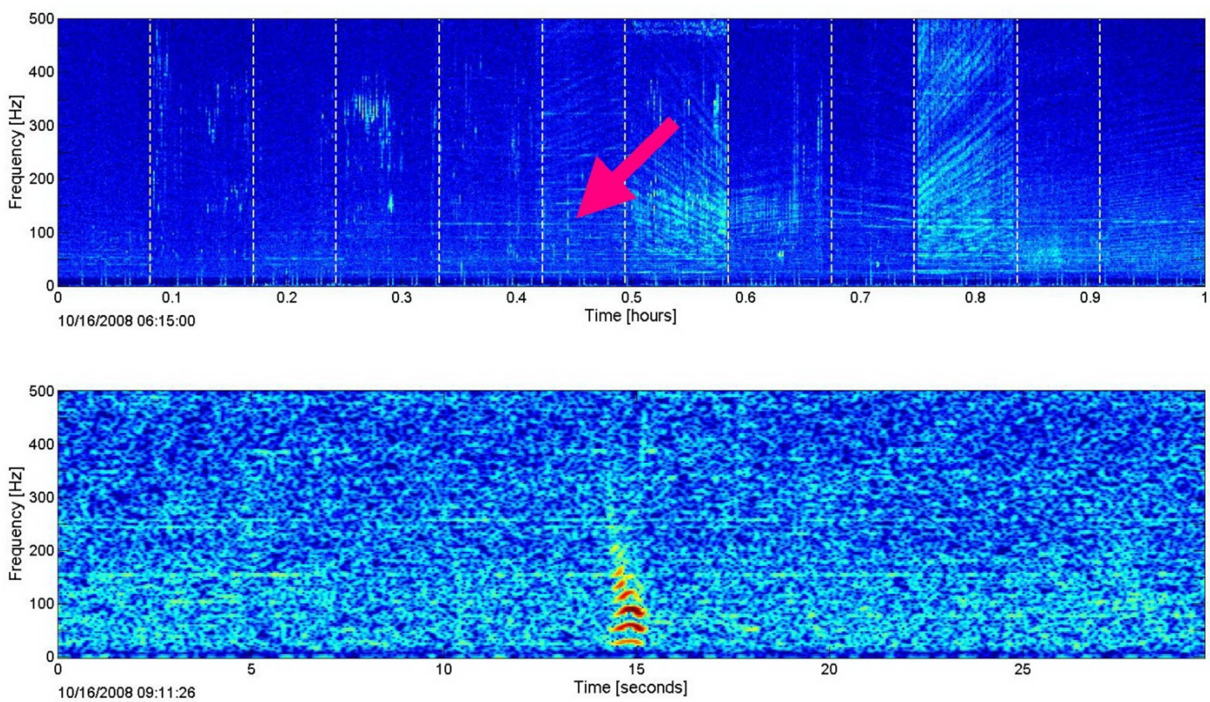

Figure 6. Gray whale M3 call recorded in NWTRC in October 2008 in the LTSA (top) and spectrogram (bottom).

North Pacific Right Whales

North Pacific right whales are a highly endangered cetacean species that was plentiful in the Gulf of Alaska prior to intense commercial whaling (Brownell *et al*., 2001; Scarff, 1986). These whales make a variety of sounds, of which the most common is the "up-call" (Figure 7). The "up-call" typically sweeps from about 90 to 150 Hz or as high as 200 Hz, and has a duration of approximately one second (McDonald & Moore, 2002).

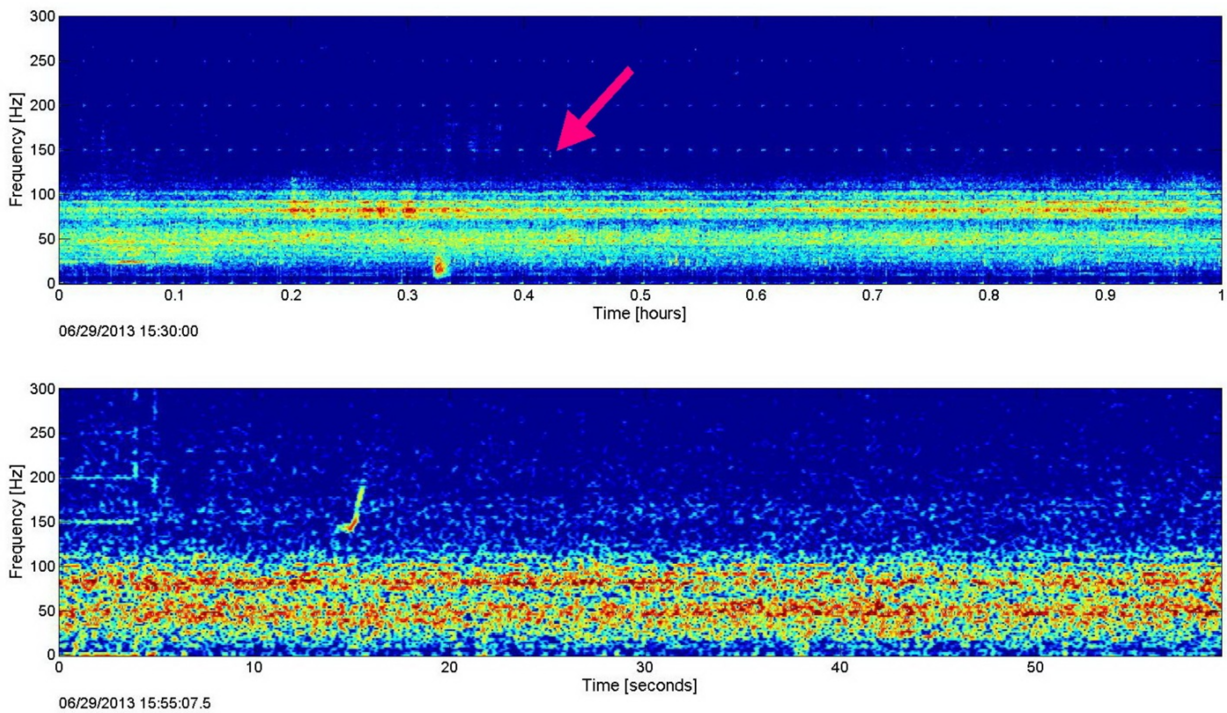

Figure 7. North Pacific right whale "up-call" example in the LTSA (top) and spectrogram (bottom) from the QC site on June 29 at 15:55 UTC.

Mid-Frequency Marine Mammals

Marine mammal species with sounds in the mid-frequency range expected off Washington include humpback whales, minke whales, killer whales, and a number of pinnipeds. For mid-frequency data analysis, the 100 kHz HARP data were decimated by a factor of 20 for an effective bandwidth of 5 kHz. The LTSAs for mid-frequency analysis were created using a time average of 5 seconds, and a frequency bin size of 10 Hz. The presence of each call type was determined in one-minute bins for each mid-frequency dataset. Minke whale boings, killer whale whistles and pulsed calls, and pinniped calls were logged manually. The LTSA search parameters used to detect each sound are given in Table 2. Humpback whale calls were detected automatically, as described below.

Table 2. Mid-frequency data analysis parameters.

Species / Sound Type	LTSA Search Parameters	
	Plot Length (hr)	Frequency Range (Hz)
Minke whale boing	0.5	1,000 – 2,000
Killer whale whistles & pulsed calls	0.75	10-5,000
Pinniped	0.75	200-800

Humpback Whales

Humpback whales produce song and non-song calls. The song is categorized by the repetition of units, phrases, and themes of a variety of calls as defined by Payne and McVay (1971). Non-song vocalizations such as social 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 are produced between 100-3,000 Hz. For this report we detected humpback calls (both song and non-song) using an automatic detection algorithm based on the power law (Helble *et al*., 2012). The detections were subsequently verified for accuracy by a trained analyst (Figure 8).

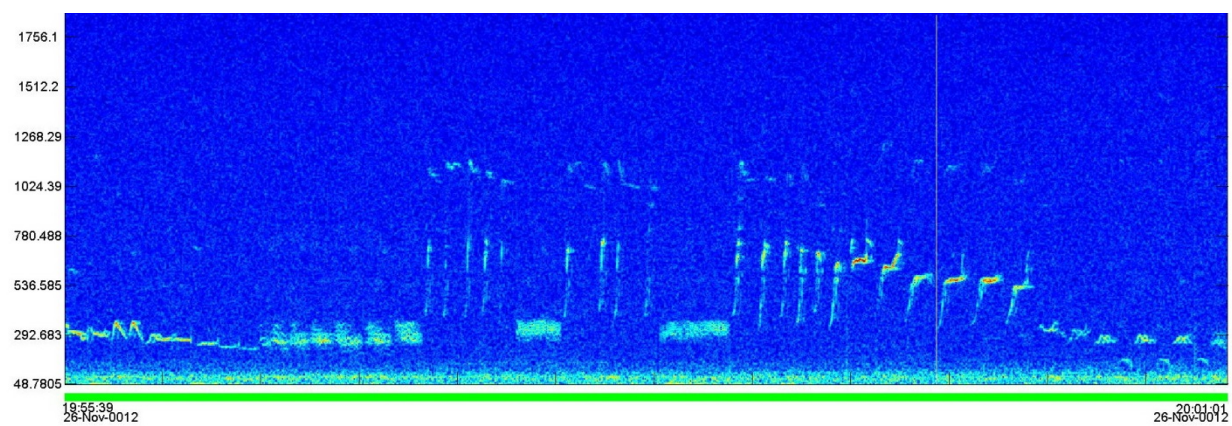

Figure 8. Humpback whale song in the analyst verification stage of the detector.

Minke Whales

Minke whale "boings" consist of 2 parts, beginning with a burst followed by a long buzz, with the dominant energy band just below 1,400 Hz (Figure 9). Boings are divided geographically into an eastern and a central Pacific variant, with a dividing line at about 135°W. Eastern boings have an average duration of 3.6 seconds and a pulse repetition rate of 92 s^{-1} (Rankin & Barlow, 2005). Boing sounds were recently reported from the Chukchi Sea, and seem to match the central Pacific boings (Delarue & Martin, 2013).

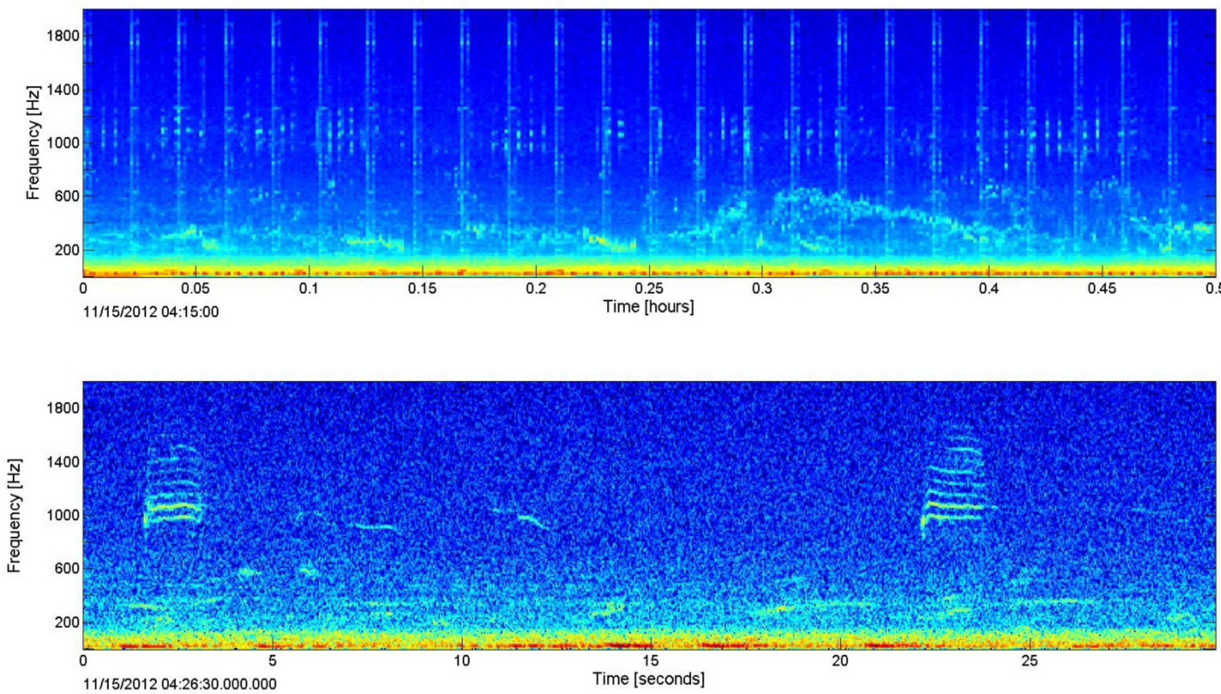

Figure 9. Minke whale boings in the LTSA (top) and spectrogram (bottom) from site QC.

Pinnipeds

Most pinniped sounds off Washington are barking vocalizations, occurring between 400 and 600 Hz, and of short duration (<1 s) (Figure 10). However, pinniped barking bouts can last several hours at a time. As they are easily confused with humpback vocalizations in the LTSA, it was necessary to examine a short-term spectrogram view to confirm presence of pinnipeds in the data. No pinniped calls were detected.

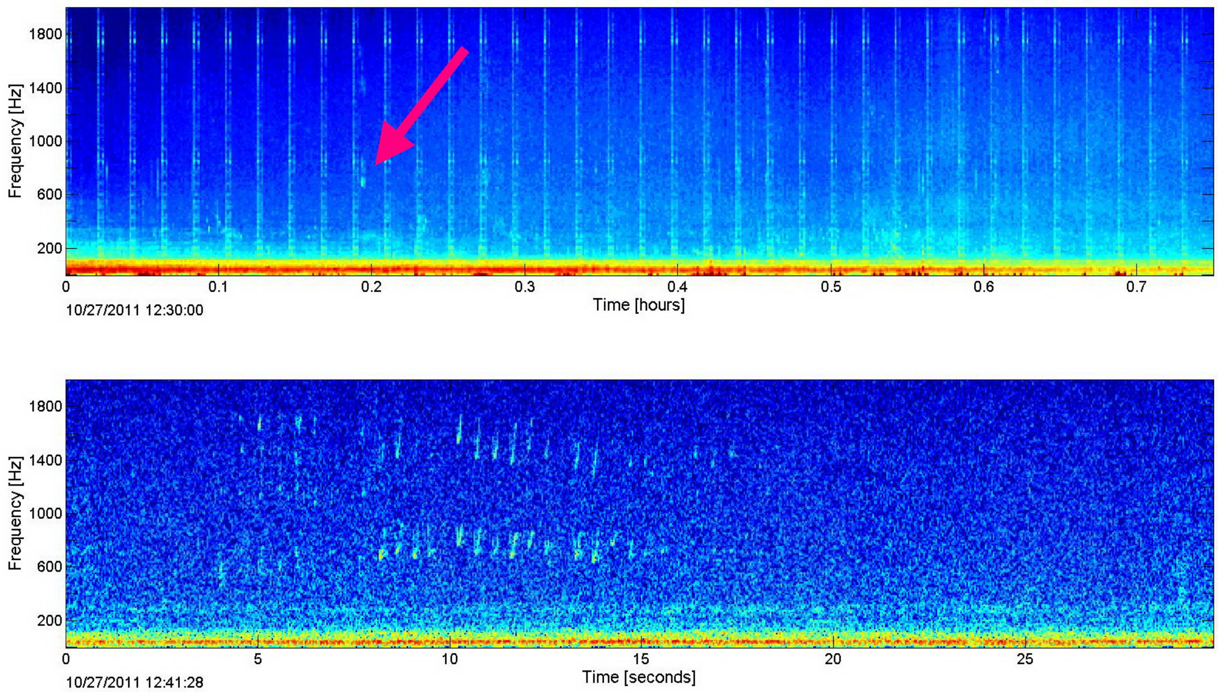

Figure 10. Pinniped vocalizations recorded in October 2011 at site CE in the LTSA (top) and spectrogram (bottom).

High-Frequency Marine Mammals

High-frequency, species-specific sounds monitored in this report include: Risso's and Pacific white-sided dolphins, killer whales, sperm whales, Stejneger's beaked whales, Baird's beaked whales, Cuvier's beaked whales, and Blainville's beaked whales. Also monitored were two frequency-modulated pulses reminiscent of beaked whale signals, called BW40 and BW43, and narrow-banded high frequency clicks from unidentified porpoise, as well as other whistles and echolocation clicks that cannot be attributed to a single species at this time. The start and end of each acoustic encounter was logged and their durations were added to estimate cumulative hourly presence of each high-frequency sound source in the two datasets.

High-Frequency Call Types

Odontocete sounds can be categorized as echolocation clicks, burst pulses, or whistles. Echolocation clicks are broadband impulses with peak energy between 5 and 150 kHz, dependent on species. Buzz or burst pulses are rapidly repeated clicks that have a creak or buzz-like sound quality; they are generally lower in frequency than echolocation clicks. Dolphin whistles are tonal calls predominantly between 1 and 20 kHz that vary in frequency content, their degree of frequency modulation, as well as duration. These signals are easily detectable in an LTSA as well as the spectrogram (Figure 11).

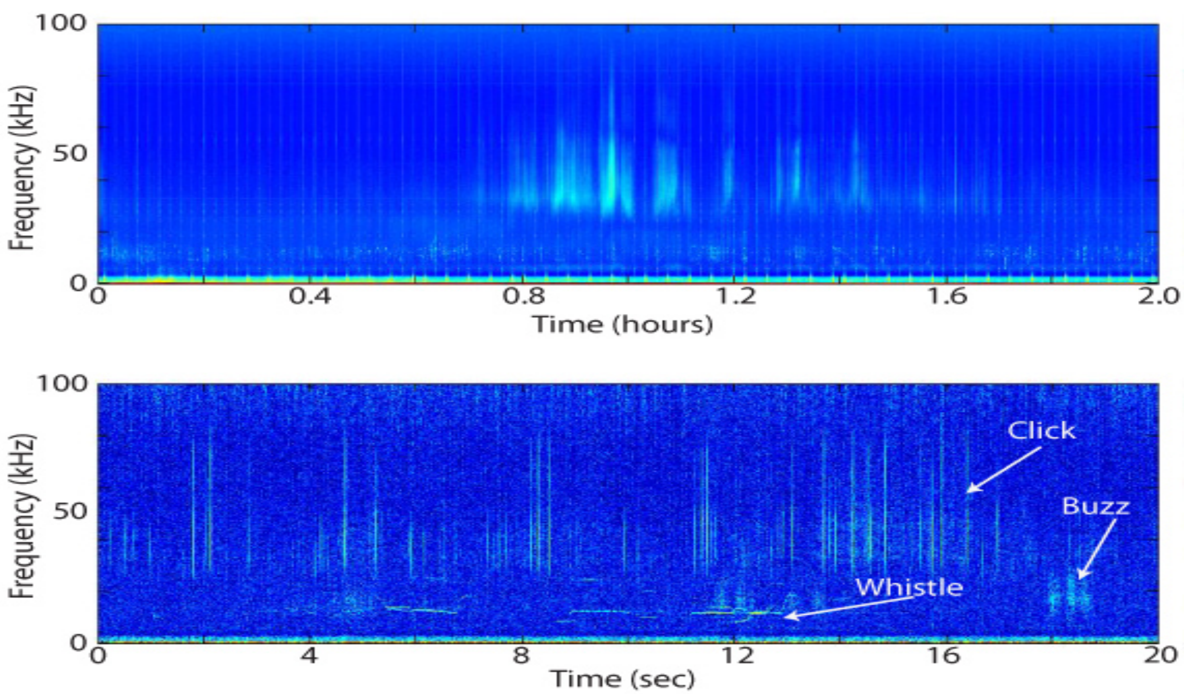

Figure 11. LTSA (top) and spectrogram (bottom) demonstrating the odontocete signal types.

Unidentified Odontocetes

Some delphinid sounds are not yet distinguishable to species based on the character of their clicks, buzz or burst pulses or whistles (Roch *et al*., 2011; Gillespie *et al*., 2013). Northern right whale dolphins (*Lissodelphis borealis*), short-beaked common dolphin (*Delphinus delphis*), bottlenose dolphins (*Tursiops truncatus*), and striped dolphins (*Stenella coeruleoalba*) make clicks and whistles that are thus far not definitively classifiable to species level and may all be encountered in this area (Jefferson *et al*., 2008), although only northern right whale dolphin sightings have been confirmed (Oleson *et al*., 2009). Since these signals are easily detectable in an LTSA as well as the spectrogram (Figure 12), they were monitored during this analysis effort and are characterized as unidentified odontocete signals.

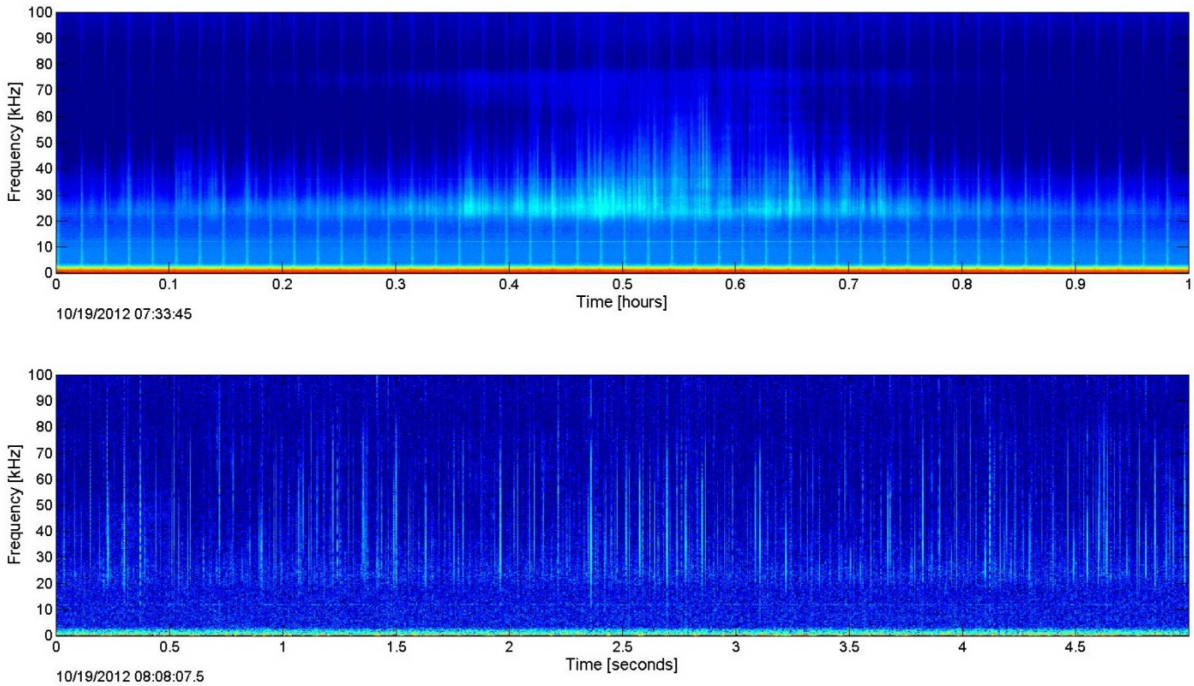

Figure 12. LTSA (top) and spectrogram (bottom) of unidentified odontocete signals.

Risso's Dolphins

Risso's dolphin echolocation clicks can be identified to species by their distinctive banding patterns observable in the LTSA (Figure 13). Risso's dolphin echolocation clicks recorded offshore southern California have energy peaks at 22, 26, 30, and 39 kHz (Soldevilla *et al*., 2008), and it is expected that their energy peaks will be similar in the NWTRC area.

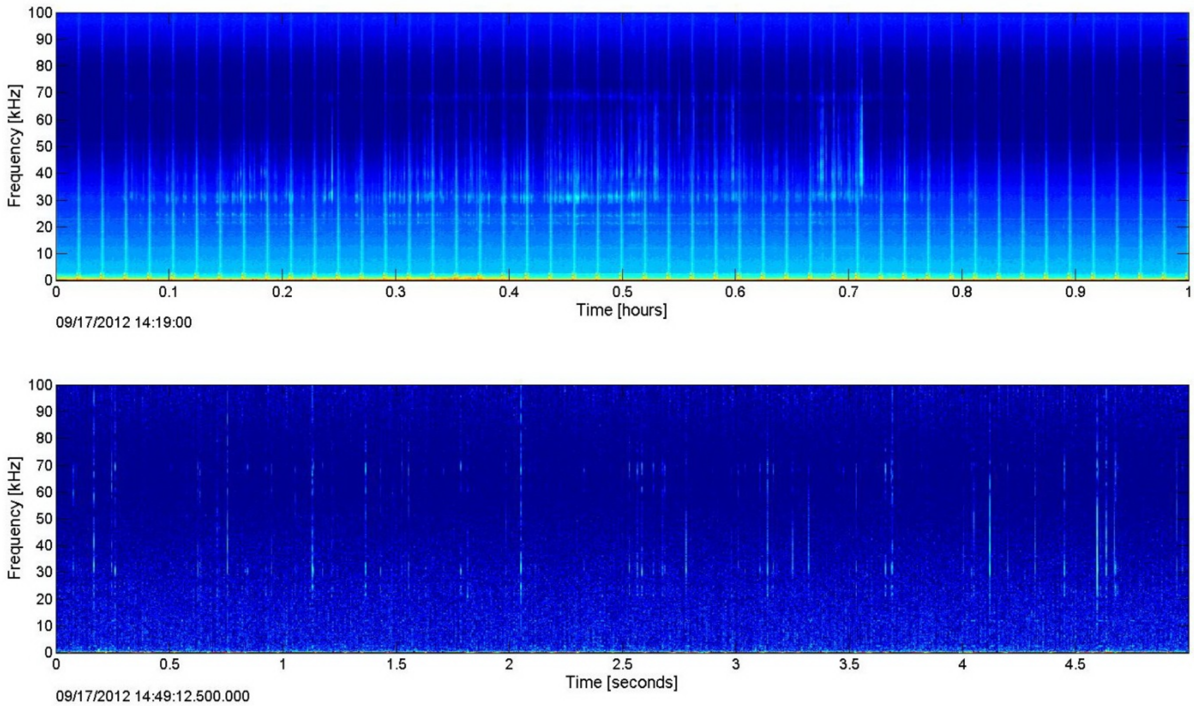

Figure 13. Risso's dolphin acoustic encounter in the LTSA (top) and spectrogram (bottom). Note a distinctive banding pattern.

Pacific White-Sided Dolphins

Pacific white-sided dolphin echolocation clicks also can be identified to species by their distinctive banding patterns (Figure 14). Pacific white-sided dolphin echolocation clicks recorded offshore southern California have two distinctive patterns of energy peaks, designated type A and type B (Soldevilla *et al*., 2010). The type A group occupies the northern portion of the southern California Bight, whereas both groups are known from the southern portion of the Bight. Soldevilla *et al*. (2010) hypothesized that type A signals may be produced by the California/Oregon/Washington population while type B signals may originate from a southern Baja California population. Since these Pacific white-sided dolphin populations are thought to seasonally migrate, the type A group is more likely to be found within the NWTRC. The type A dolphins' echolocation clicks have energy peaks at 22, 27, 33, and 37 kHz (Soldevilla *et al*., 2008).

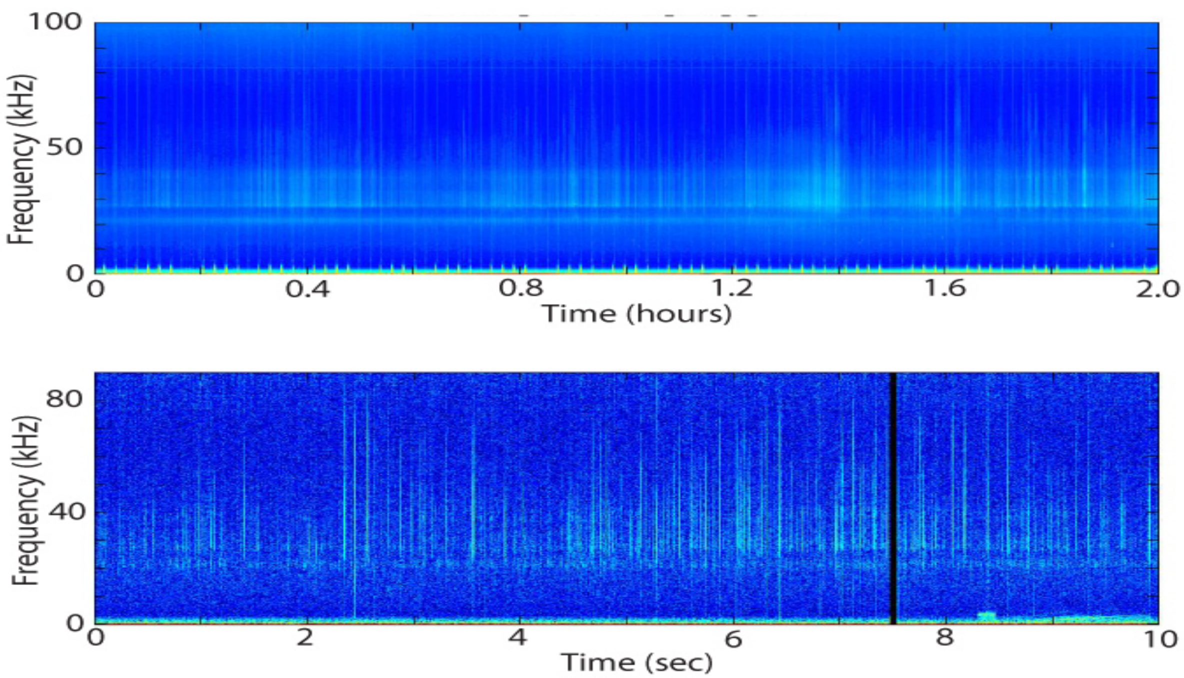

Figure 14. Pacific white-sided dolphin echolocation clicks in the LTSA (top) and spectrogram (bottom).

Killer Whales

Killer whales are known to produce four call types: echolocation clicks, low frequency whistles, high-frequency modulated signals (HFM), and pulsed calls (Ford, 1989; Samarra *et al*., 2010; Simonis *et al*., 2012). Killer whale pulsed calls are well documented and are the best described of all killer whale call types. Pulsed calls' primary energy is between 1 and 6 kHz, with high frequency components occasionally >30 kHz and duration primarily between 0.5 and 1.5 seconds (Ford, 1989). HFM signals have only recently been attributed to killer whales in both the Northeast Atlantic (Samarra *et al*., 2010) and the Northeast Pacific (Simonis *et al*., 2012). These signals have fundamental frequencies between 17 and 75 kHz, the highest of any known delphinid tonal calls. Pulsed calls (Figure 15) and the HFM signals (Figure 16) were used for killer whale species identification in this analysis.

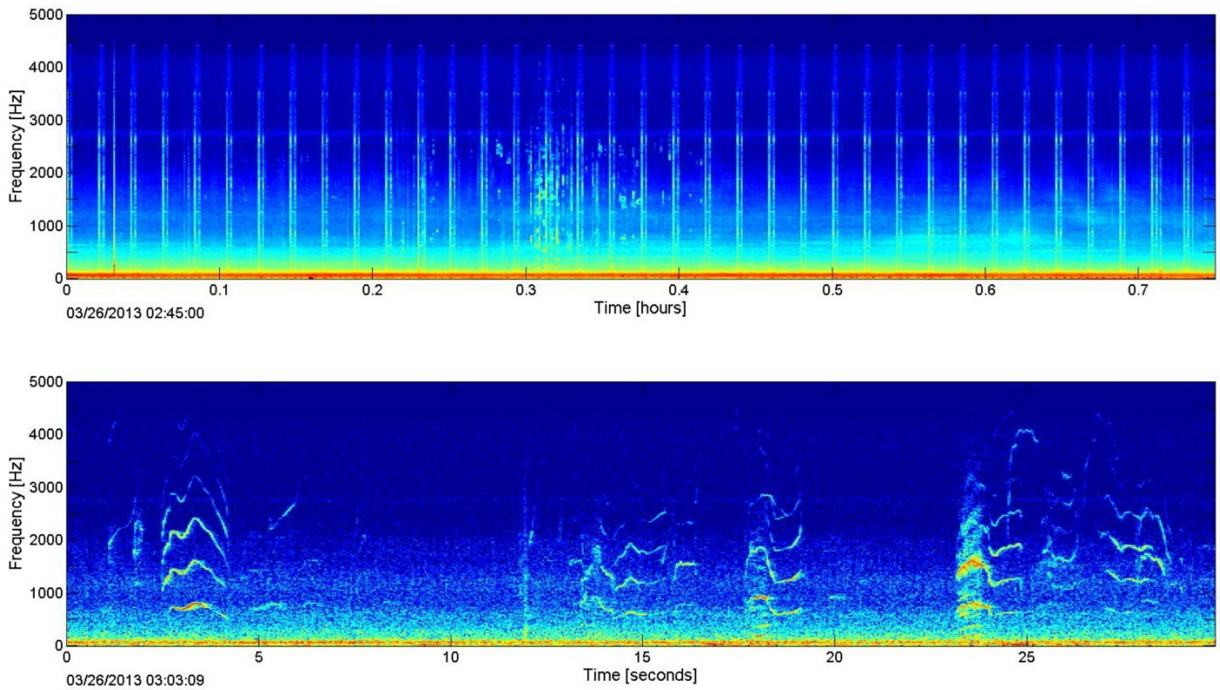

Figure 15. Killer whale whistles and pulsed calls in the LTSA (top) and spectrogram (bottom).

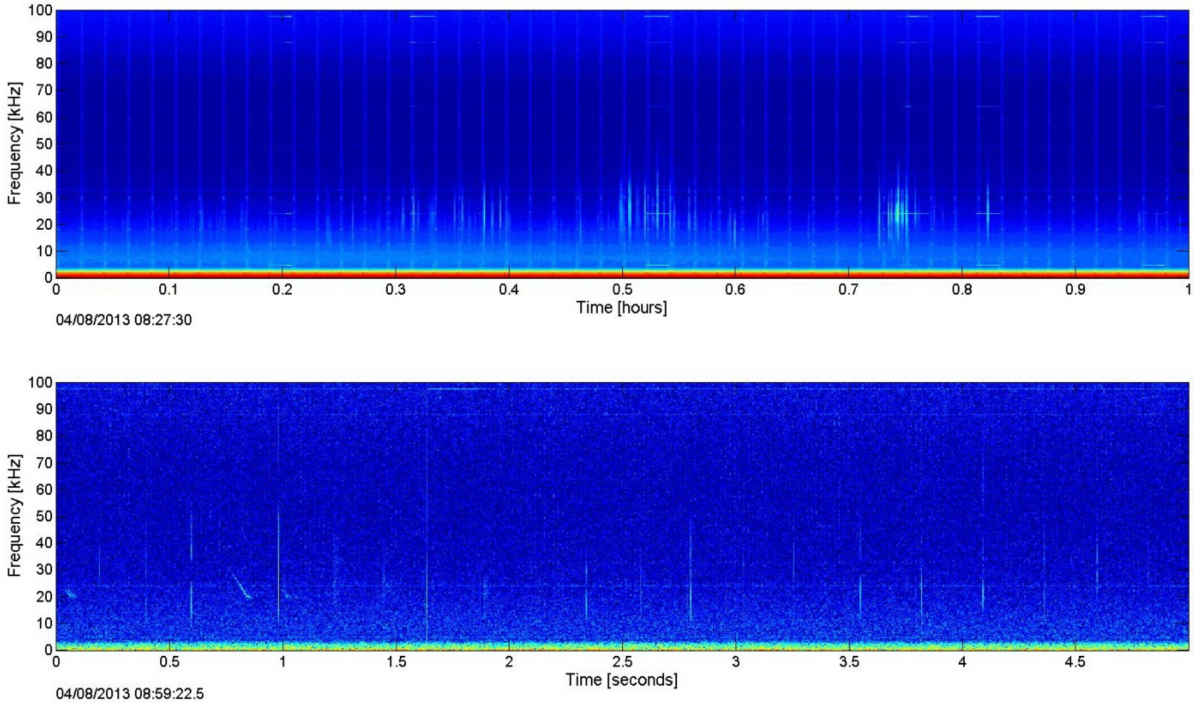

Figure 16. Killer whale echolocation clicks and HFM signals in the LTSA (top) and spectrogram (bottom).

Sperm Whales

Sperm whale clicks generally contain energy from 2-20kHz, with the majority of energy between 10-15 kHz (Møhl *et al*., 2003). Regular clicks, observed during foraging dives, demonstrate a uniform inter-click interval from 0.25-2 seconds (Goold & Jones, 1995; Madsen *et al*., 2002; Møhl *et al*., 2003). Short bursts of closely spaced clicks called creaks are observed during foraging dives and are believed to indicate a predation attempt (Watwood *et al*., 2006). Sperm whales also produce other clicks, which can be classified as slow clicks and codas. Slow clicks are used only by males and are more intense than regular clicks with long inter-click intervals (Madsen *et al*., 2002). Codas are stereotyped sequences of clicks which are less intense and contain lower peak frequencies than regular clicks (Watkins & Schevill, 1977). Multiple foraging dives and rest periods are often observed over a long period of time in the LTSA (Figure 17).

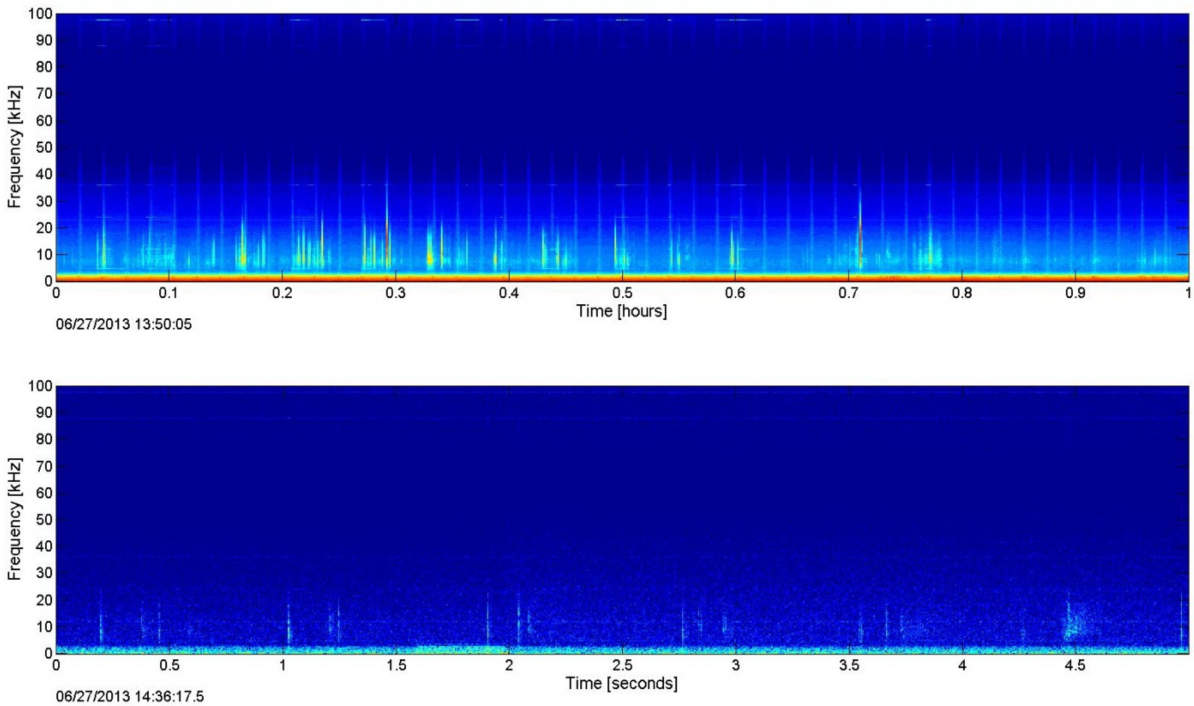

Figure 17. Sperm whale echolocation clicks in the LTSA (top) and spectrogram (bottom).

Stejneger's Beaked Whales

Stejneger's beaked whales are known to occur with some regularity in the northern Pacific Ocean. Their echolocation signals are easily distinguished from other species' acoustic signals; they have the typical beaked whale polycyclic structure and frequency-modulated (FM) pulse upsweep with a peak frequency around 50 kHz and uniform inter-pulse interval around 90 ms (Figure 18) (Baumann-Pickering *et al*., 2013a; Baumann-Pickering *et al*., 2013b).

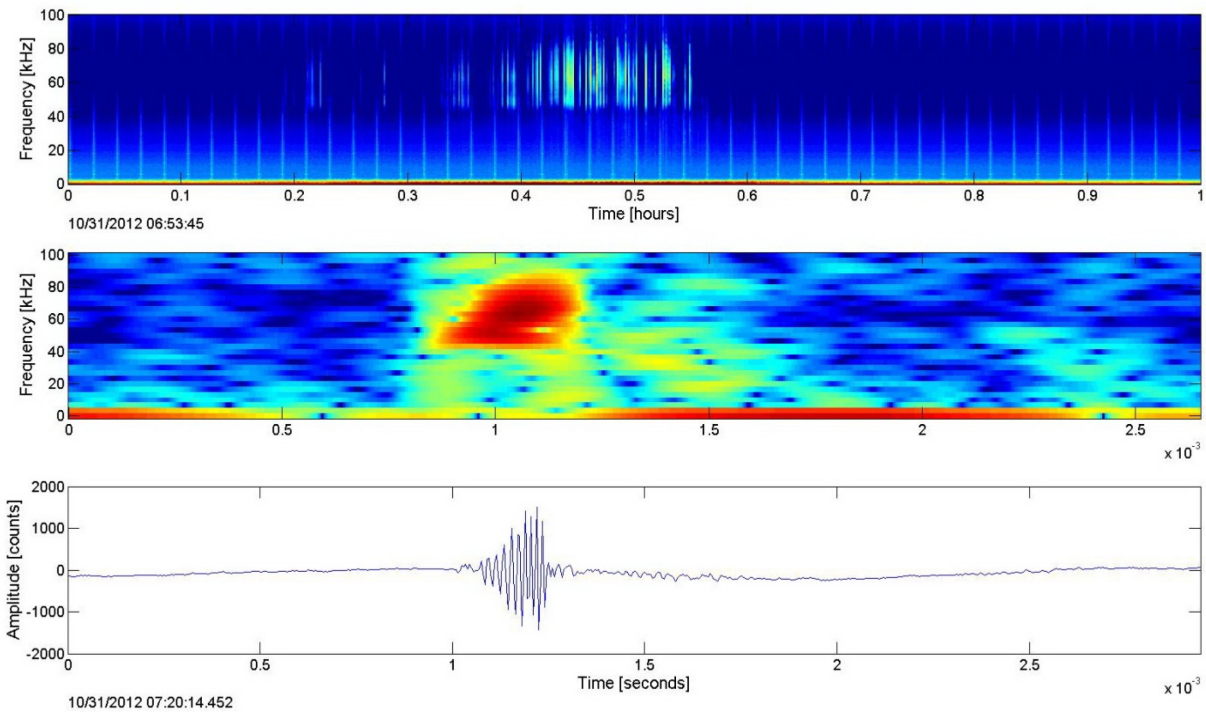

Figure 18. Echolocation sequence of Stejneger's beaked whale in the LTSA (top) and single FM pulse in the spectrogram (middle) and timeseries (bottom).

Cuvier's Beaked Whales

Cuvier's echolocation signals are also well differentiated from other species' acoustic signals as polycyclic, with a characteristic FM pulse upsweep, peak frequency around 40 kHz, and uniform inter-pulse interval of about 0.4 s (Johnson *et al*., 2004; Zimmer *et al*., 2005). An additional feature that helps with the identification of Cuvier's FM pulses is that they have two characteristic spectral peaks around 17 and 23 kHz (Figure 19).

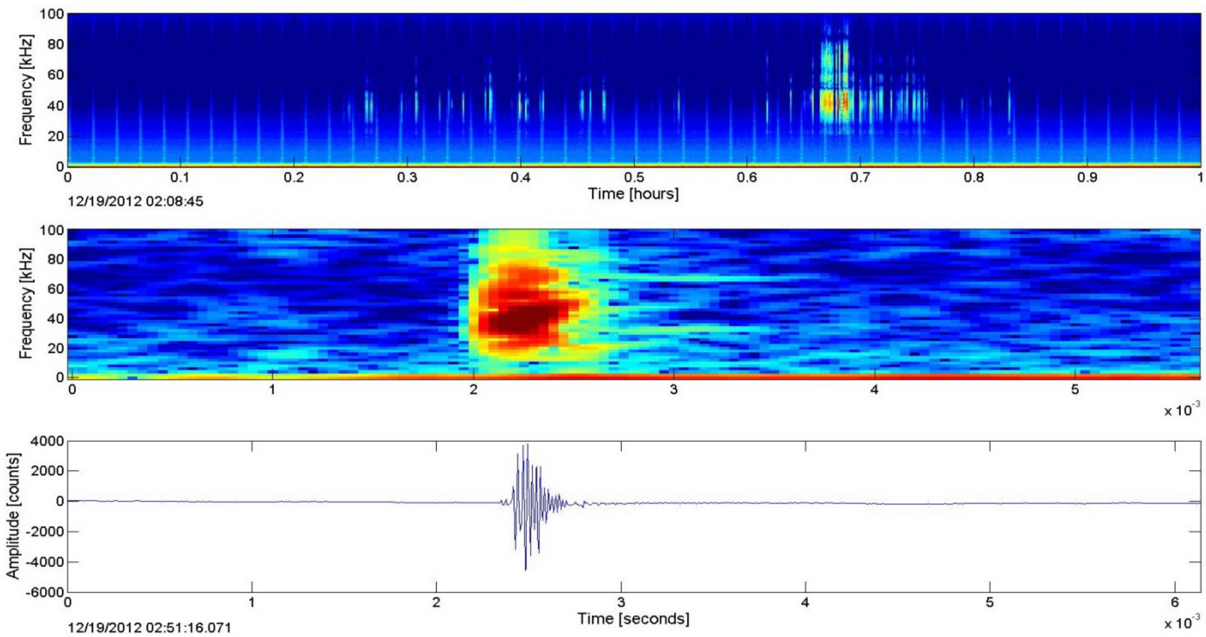

Figure 19. Echolocation sequence of Cuvier's beaked whale in the LTSA (top) and example FM pulse in the spectrogram (middle) and timeseries (bottom).

Blainville's Beaked Whales

Blainville's beaked whales produce a distinctive echolocation signal with a typical FM pulse upsweep with a -10 dB bandwidth from 26-51 kHz, a well-differentiated sharp cut-off below 25 kHz, and a peak frequency around 30 kHz (Figure 20) (Johnson *et al*., 2006).

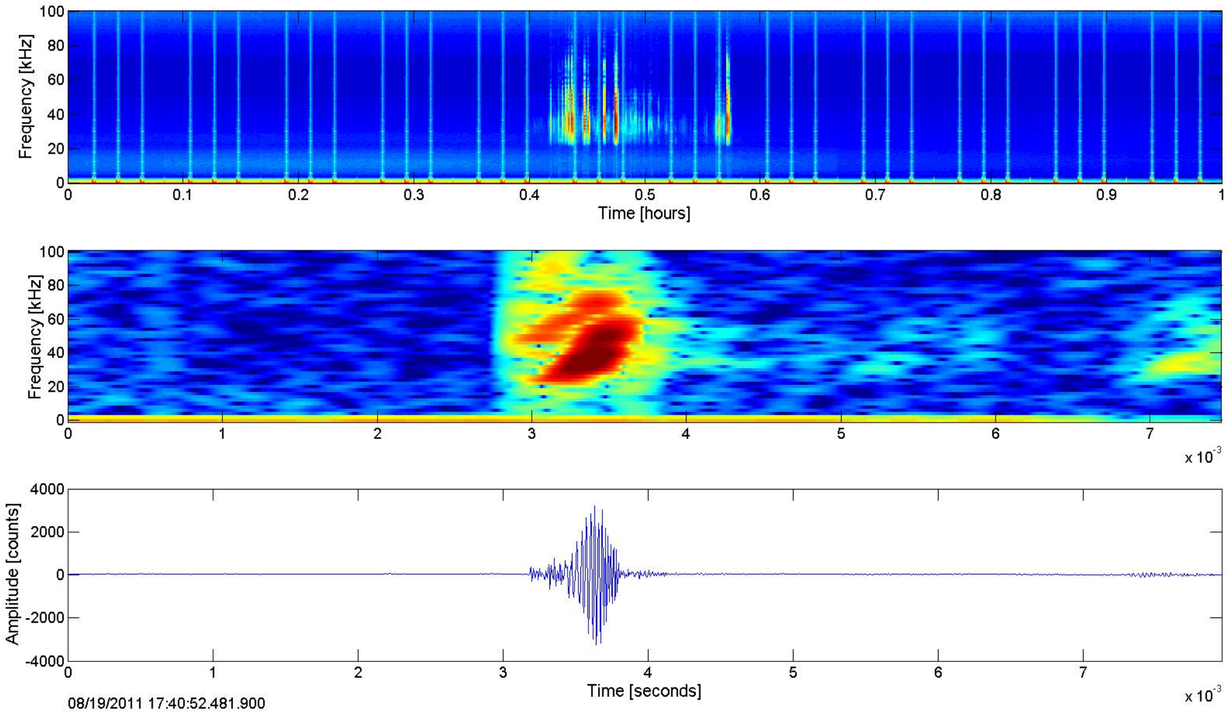

Figure 20. Echolocation sequence of Blainville's beaked whale in the LTSA (top) and example FM pulse in the spectrogram (middle) and timeseries (bottom).

Baird's Beaked Whales

Baird's beaked whale echolocation signals are distinguishable from other species' acoustic signals and one of their signal types demonstrates the typical beaked whale polycyclic, FM pulse upsweep (Dawson *et al*., 1998). These FM pulses and clicks are identifiable due to their comparably low-frequency content. Spectral peaks are notable around 15, 30, and 50-60 kHz (Baumann-Pickering *et al*., 2013a; Baumann-Pickering *et al*., 2013c) (Figure 21).

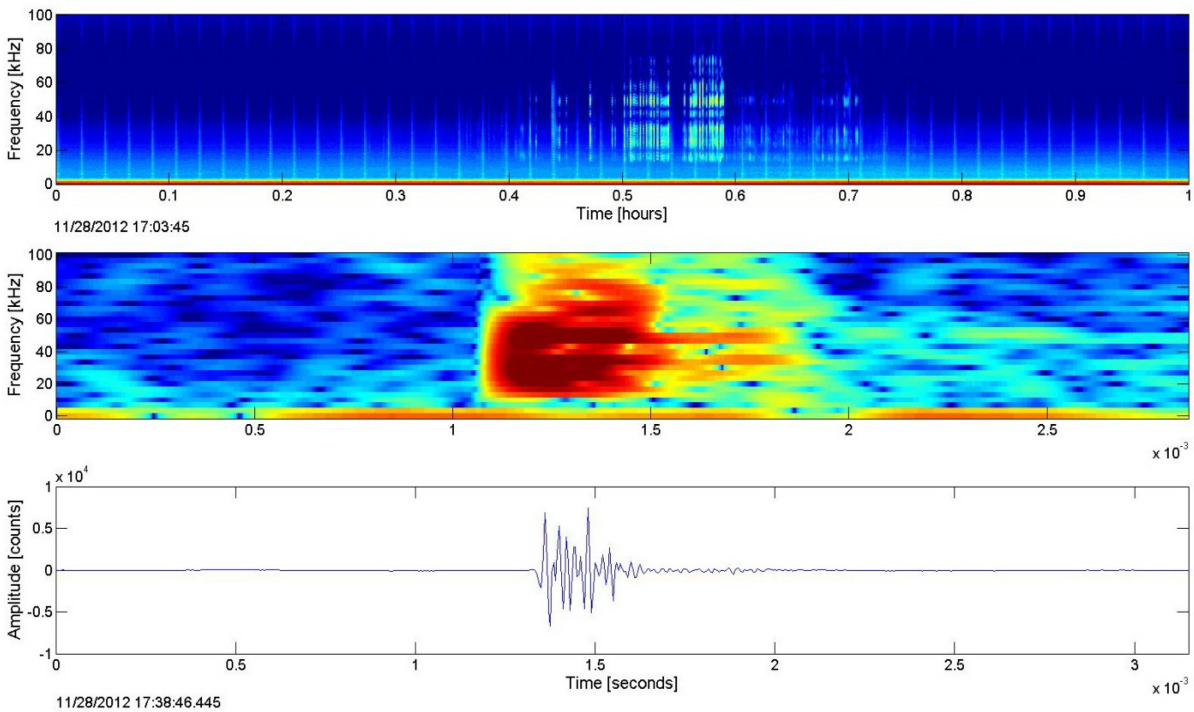

Figure 21. Echolocation sequence of Baird's beaked whale in the LTSA (top) and example FM pulse in the spectrogram (middle) and timeseries (bottom). Note the typical banding pattern of spectral peaks at about 15, 30, and 50-60 kHz.

BW40

Signal type BW40 is likely produced by a beaked whale. It is a frequency-modulated pulse (Figure 22) with a peak frequency at 43 kHz and center frequency at 40 kHz, 575 µs long with an inter-pulse interval of 0.4 s (Baumann-Pickering *et al*., 2013b). An additional signal type (**Figure 23**) similar to dolphin clicks has been observed during regular echolocation trains.

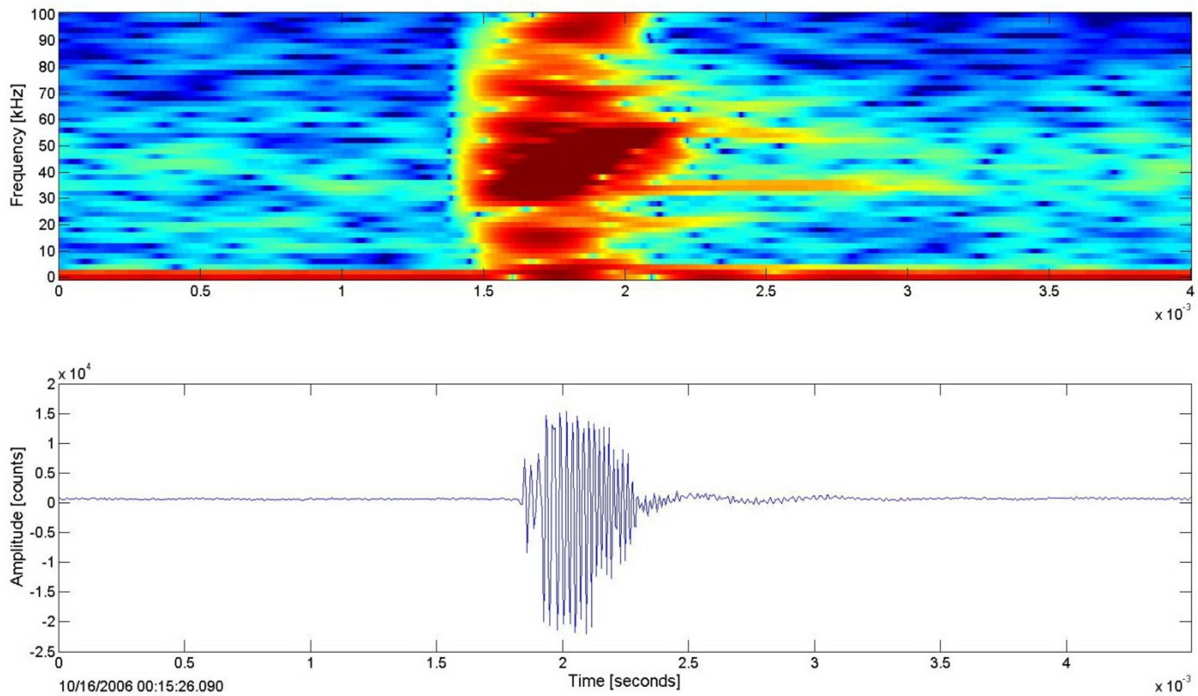

Figure 22. BW40 FM pulse in the spectrogram (top) and timeseries (bottom).

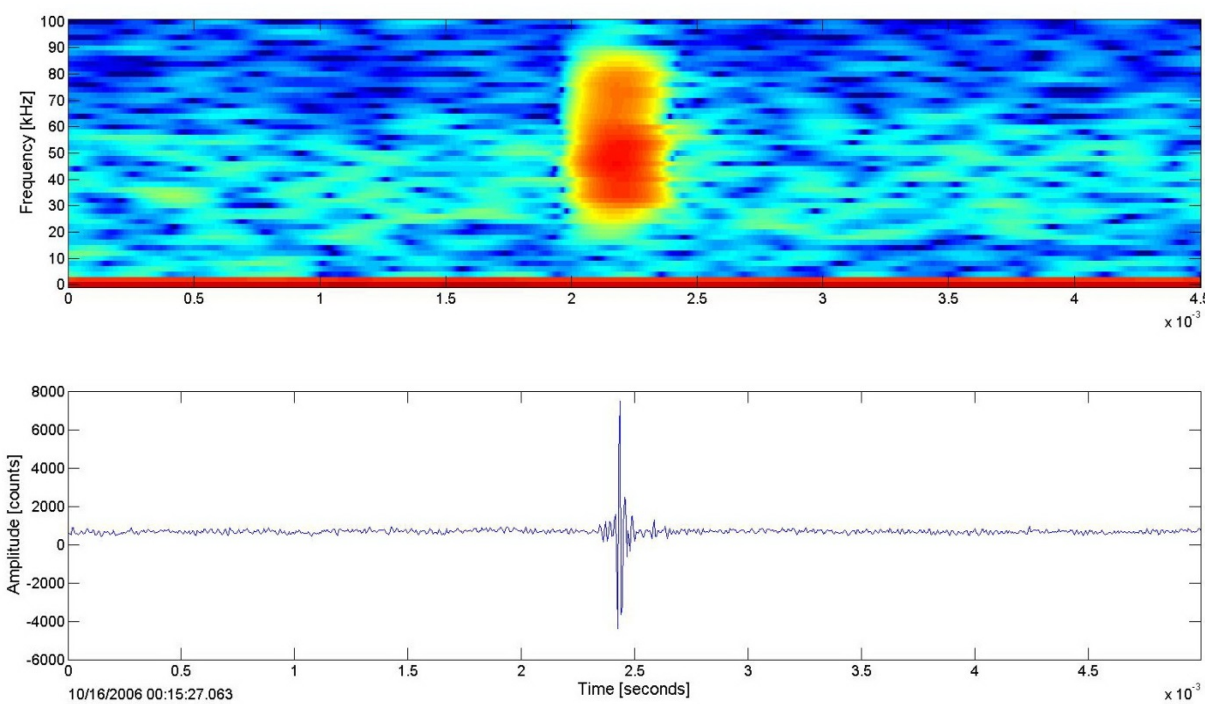

Figure 23. BW40 click in in the spectrogram (top) and timeseries (bottom).

BW43

Signal type BW43 is likely produced by a beaked whale. It is a frequency-modulated pulse (Figure 24) with a center frequency of 45 kHz and a peak frequency of 43 kHz, with a duration of 395 μs and an inter-pulse interval of 0.2 s (Baumann-Pickering *et al*., 2013b).

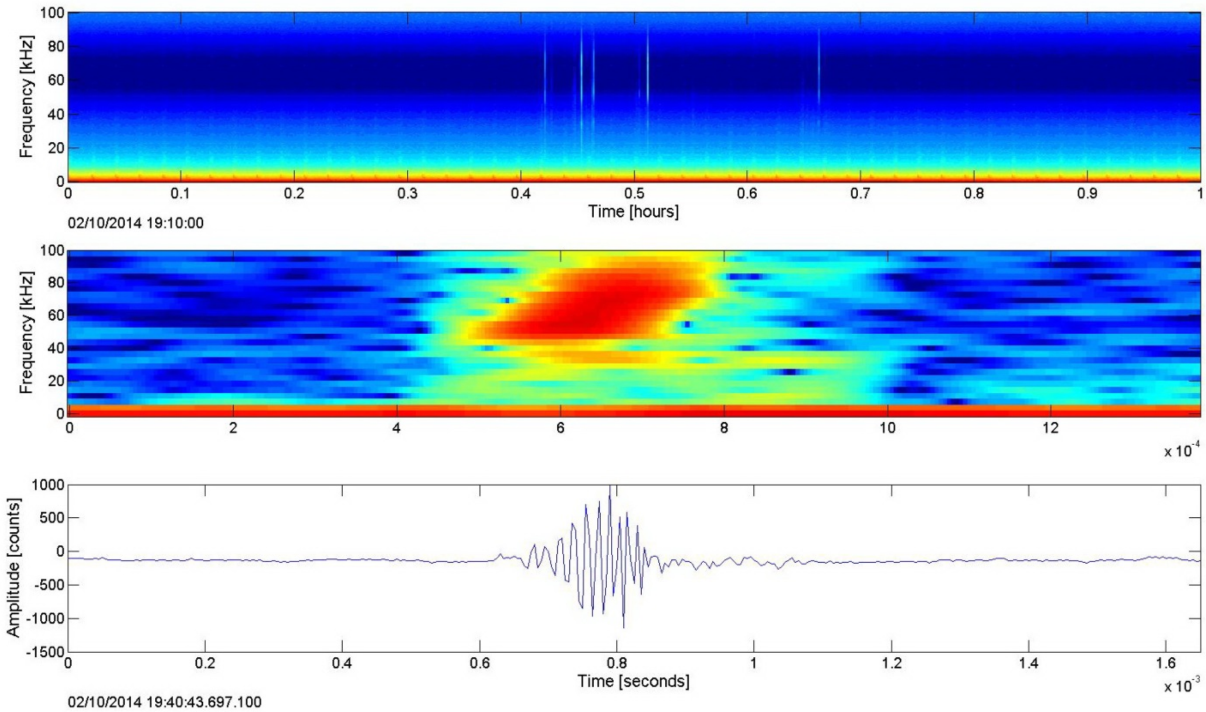

Figure 24. Echolocation sequence of BW43 in the LTSA (top) and example FM pulse in the spectrogram (middle) and timeseries (bottom).

Unidentified Porpoises

Harbour porpoises (*Phocoena phocoena*) and Dall's porpoises (*Phocoenoides dalli*) were the most frequently sighted marine mammals during visual surveys in the area (Oleson *et al*., 2010; Oleson *et al*., 2009). Both Dall's and harbour porpoises produce clicks that contain energy from 115-150 kHz (Verboom & Kastelein, 1995). The HARP only records acoustic energy up to 100 kHz, so the peak energy of the porpoise clicks is above the upper frequency band recorded by the HARPs. However, the HARP anti-alias filter will allow some spectral leakage from energy above 100 kHz, resulting in 120-140 kHz energy appearing at 60-80 kHz (Figure 25). Detection of porpoise clicks is therefore possible when the animals are close to the HARP (< ~1 km) and their received levels are high. No porpoise clicks were recorded in this deployment.

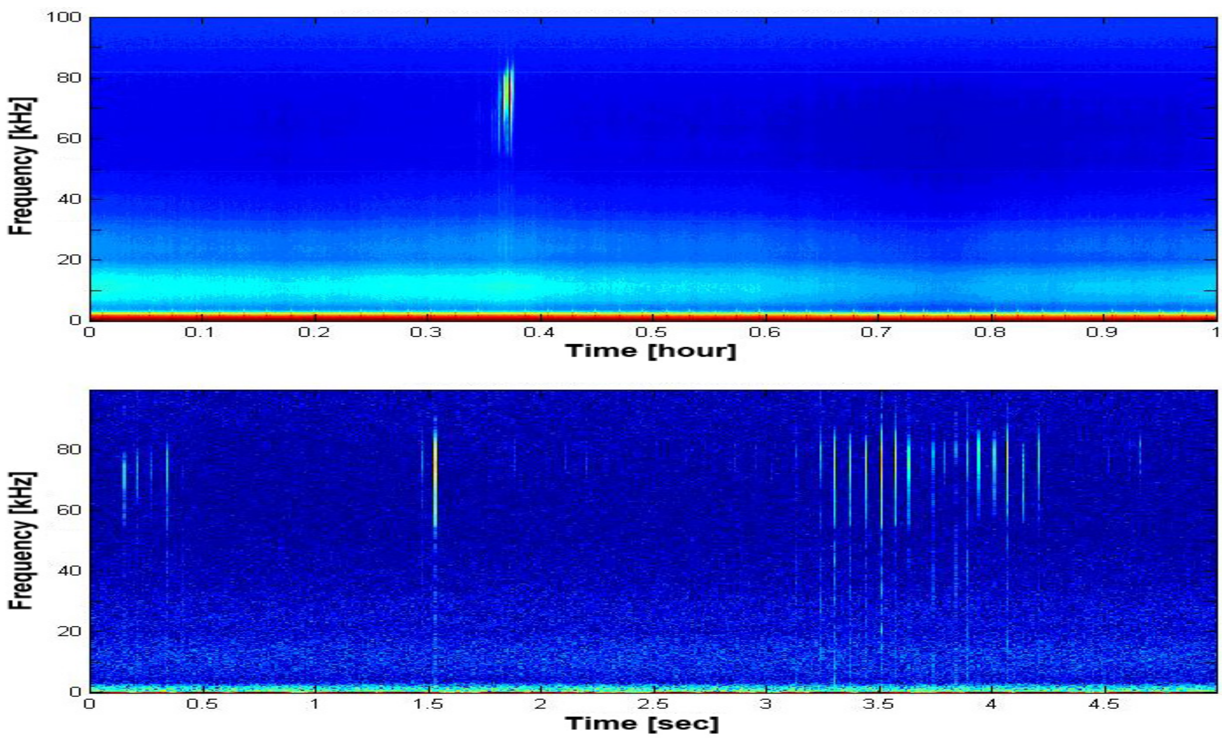

Figure 25. Example LTSA (top) and spectrogram (bottom), presumably produced by spectral aliasing of porpoise clicks (120-150 kHz frequency content), from the Gulf of Alaska.

Anthropogenic Sounds

Several anthropogenic sounds occurring at mid-frequency ranges (<5 kHz) were also monitored for this report: broadband ship noise, mid- frequency active (MFA) sonar, echosounders, underwater communications, and explosions. The LTSA search parameters used to detect each sound are given in Table 3. The start and end of each sound or session was logged and their durations were added to estimate cumulative hourly presence of each mid-frequency sound source in the dataset.

Table 3. Mid-frequency anthropogenic sound data analysis parameters.

Sound Type	LTSA Search Parameters	
	Plot Length (hr)	Frequency Range (Hz)
Broadband Ship Noise	3.0	10-5,000
MFA Sonar	0.75	1,000-5,000
Echosounders	0.75	10-5,000
Underwater Communications	0.74	10-5,000
Explosions	0.75	10-5,000

Broadband Ship Noise

Broadband ship noise occurs when a ship passes relatively close to the hydrophone. Ship noise can occur for many hours at a time, but broadband ship noise typically lasts from 10 minutes up to 3 hours. Ship noise has a characteristic interference pattern in the LTSA (McKenna *et al*., 2012). Combination of direct paths and surface reflected paths produce constructive and destructive interference (bright and dark bands) in the spectrogram that varies by frequency and distance between the ship and the receiver (Figure 26). Noise can extend above 10 kHz, though it typically falls off above a few kHz.

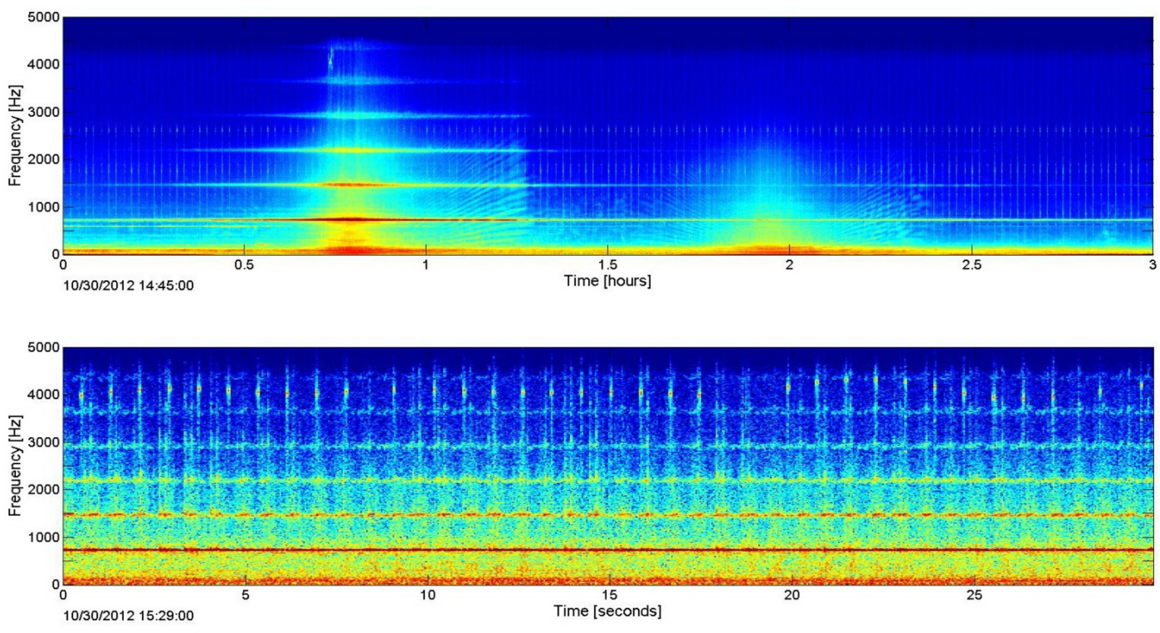

Figure 26. Broadband ship noise in the LTSA (top) and spectrogram (bottom).

Mid-Frequency Active (MFA) Sonar

Sounds from MFA sonar vary in frequency and duration and are a combination of frequency modulated (FM) sweeps and continuous wave (CW) tones. While they can span frequencies from about 1 kHz to over 50 kHz, many are between 2.0 and 5.0 kHz and are more generically known as '3.5 kHz' sonar. In this section, we describe the process for identifying sessions or events of MFA sonar in recordings from HARPs and how pings from these sessions were analyzed, including counts and distributions of sonar levels.

The first step in analyzing MFA sonar was conducted by visual screen of LTSAs for periods of sonar activity. Individual MFA sonar pings typically span 1 - 3 s, but are intense enough to show up as 'pulses' in LTSA plots (Figure 27). Start and end times of MFA sonar events were logged manually to provide target periods for automatic detections. A custom-developed MATLAB routine was used to detect sonar pings and calculate peak-to-peak (PP) received sound pressure levels using manually-picked target periods. For this detector, a sonar ping was defined as the presence of sonar within 5 s. The average spectrum level across the frequency band from 2.4 to 4.5 kHz for each 5 s time bin was calculated. This provides a 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 to prevent contamination in the results. Each of the remaining average spectral bins was compared to the background minimum levels. If levels were more than 3 dB above the background, then a detection time was noted. These detection times were used to index to the original time series to calculate peak-to-peak (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, so a middle value at 3.5 kHz was used, which was 84.4 dB re µPa2/counts2. For sonar pings less than this middle frequency, the levels are overestimated up to about 7 dB and for higher frequency sonar the levels are underestimated up to about 1 dB.

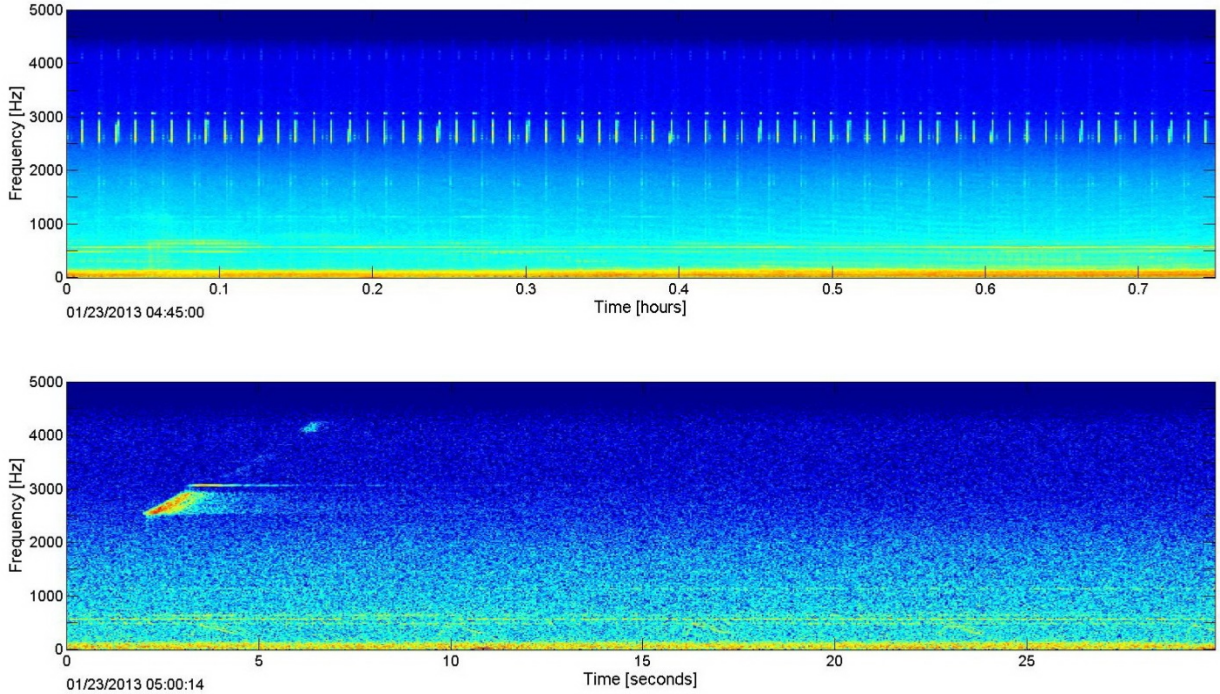

Figure 27. Mid-frequency active (MFA) sonar event in the LTSA (top) with a more detailed look in the spectrogram (bottom).

Echosounders

Echosounding sonars transmit short pulses or frequency sweeps, typically in the mid-to-high-frequency (8-12 kHz) or very high-frequency (30-100 kHz) band (Figure 28). Echosounders are occasionally found in the mid-frequency range (2-5 kHz). Many large and small vessels are equipped with echosounding sonar for water depth determination; typically these echosounders are operated much of the time a ship is at sea, as an aid for navigation. In addition, sonars may be used for sea bottom mapping, fish detection, or other ocean sensing. Echosounders were detected by analysts using the LTSA plots at both mid- and high-frequency.

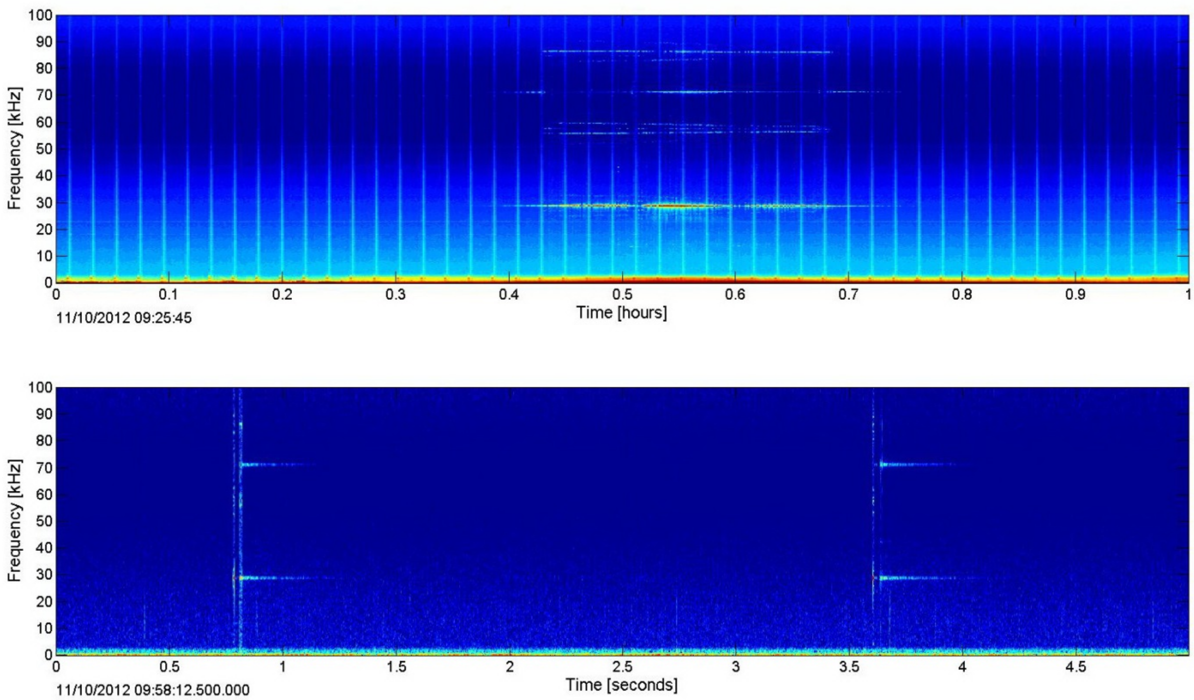

Figure 28. Example of an echosounder in the LTSA (top) and spectrogram (bottom).

Underwater Communications

Underwater communications are used to transmit information. They can sound like distorted voices underwater (Figure 29) or electronic transmissions (Figure 30).

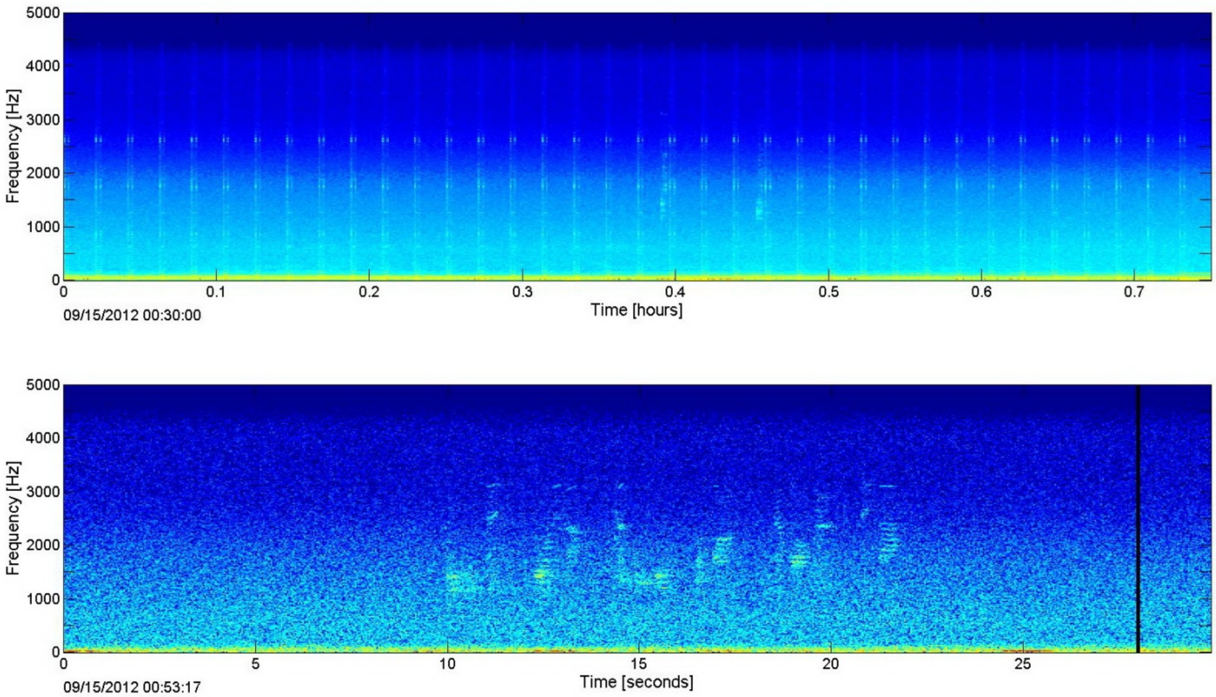

Figure 29. Underwater communications in the LTSA (top) and spectrogram (bottom).

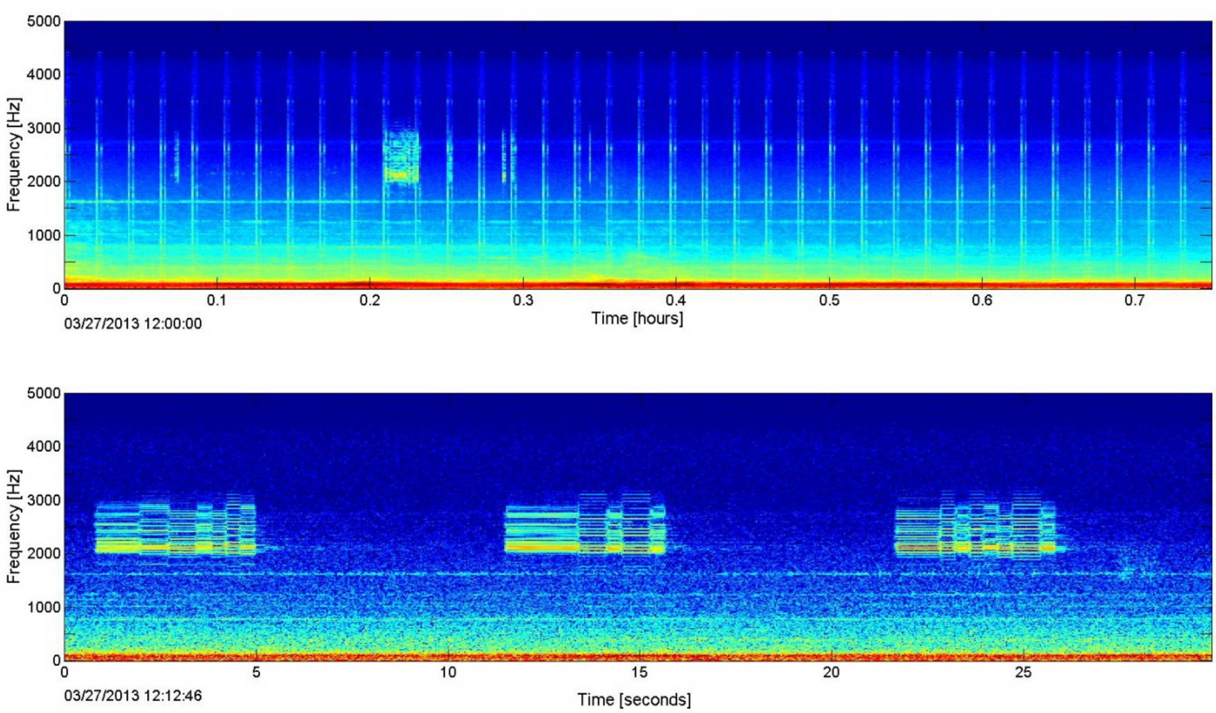

Figure 30. Electronic underwater communications in the LTSA (top) and spectrogram (bottom).

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 31). These sounds have peak energy as low as 10 Hz and often extend up to 2,000 Hz or higher, lasting for a few seconds including the reverberation.

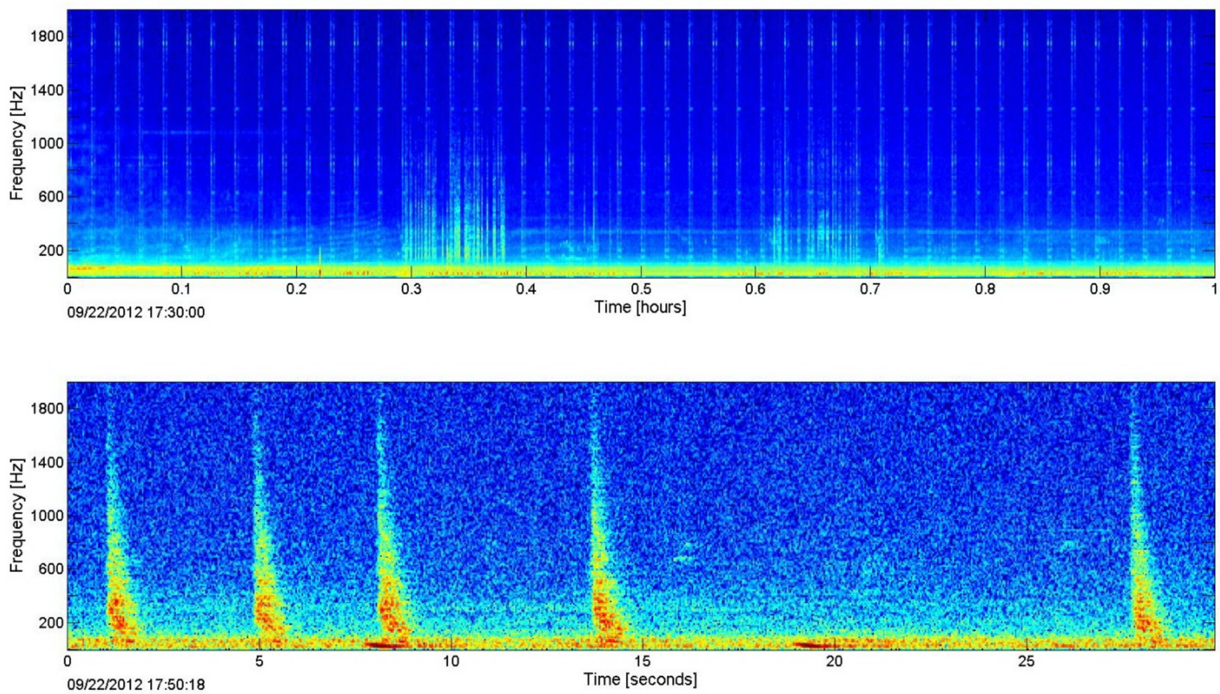

Figure 31. Multiple explosions are seen in the LTSA (top) and five individual events of these are expanded in the spectrogram (bottom).

Results

The results of acoustic data collection in the NWTRC at site QC from September 2012 through June 2013 are summarized. We describe ambient noise, the seasonal occurrence and relative abundance of marine mammal species, and anthropogenic sounds.

Ambient Noise

Underwater ambient noise at site QC has spectral shapes with higher levels at low frequencies (Figure 32). There is a prominent seasonal peak at 15-30 Hz and also at 44-47 Hz during the winter, indicative of fin and blue whale calls. At frequencies above 200 Hz, local wind and waves dominate the noise (Hildebrand, 2009) and are generally lower during the summer.

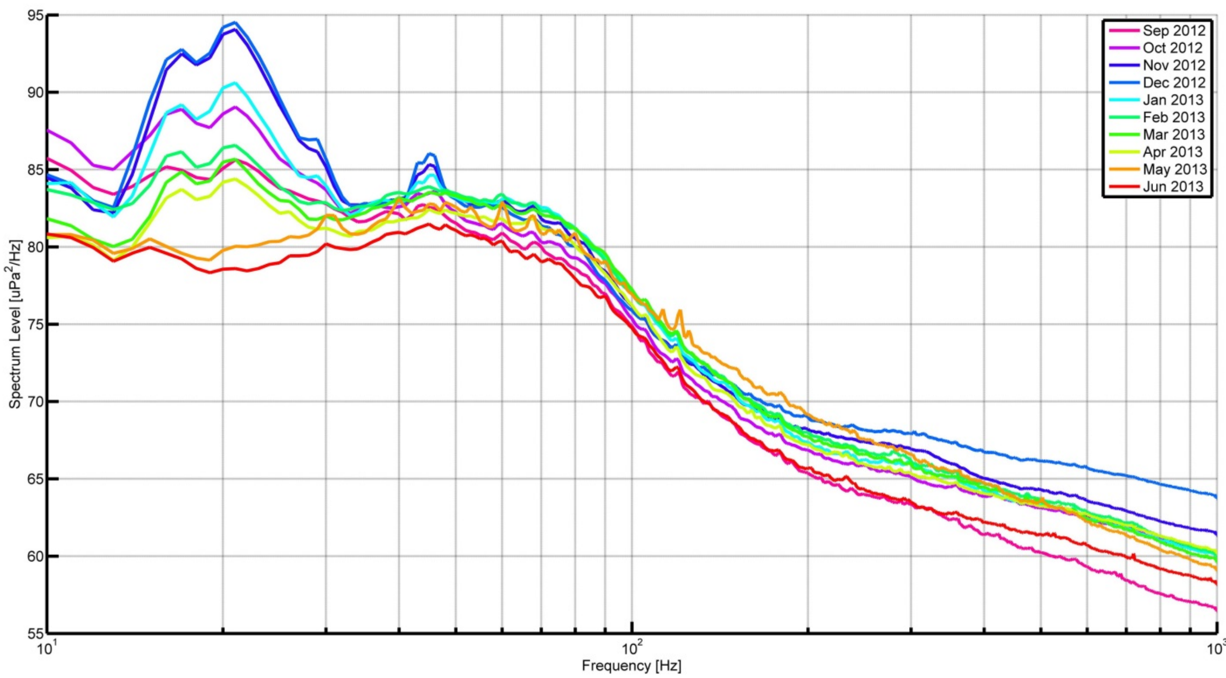

Figure 32. Monthly averages of ambient noise at site QC. Legend gives color-coding by month.

Mysticetes

Five baleen whale species were detected between September 2012 and June 2013: blue whales, fin whales, North Pacific right whales, humpback whales, and minke whales. Relative hourly calling abundance varied among species. More details of each species' presence are given below. No calls were detected for Bryde's whales (Be4 calls) or gray whales (M3 calls).

Blue Whales

Blue whale calls were recorded throughout the monitoring period.

- Blue whale Northeast (NE) Pacific B calls were detected from September 2012 through June 2013, albeit at low levels after February 2013 (Figure 33). NE Pacific B calls were the most abundant blue whale call detected with the highest number of hours with calls November 2012 through January 2013. This is consistent with earlier recordings from this site (Kerosky *et al*., 2013) and suggests evidence of year-round presence of blue whales in this area over the last few years.
- Blue whale D calls were detected from November 2012 through June 2013 (Figure 34). D call detections peaked in late March and early April 2013. Overall, this seasonal presence is consistent with previously reported seasonal occurrence of blue whale calls off Washington (Burtenshaw *et al*., 2004; Watkins *et al*., 2000; Širović *et al*., 2012; Širović *et al*., 2011).
- No diel pattern was noticeable in NE Pacific B calls, but there may have been a slight preference for D calls to occur more during nighttime hours, especially just after sunset (Figure 35 and Figure 36).

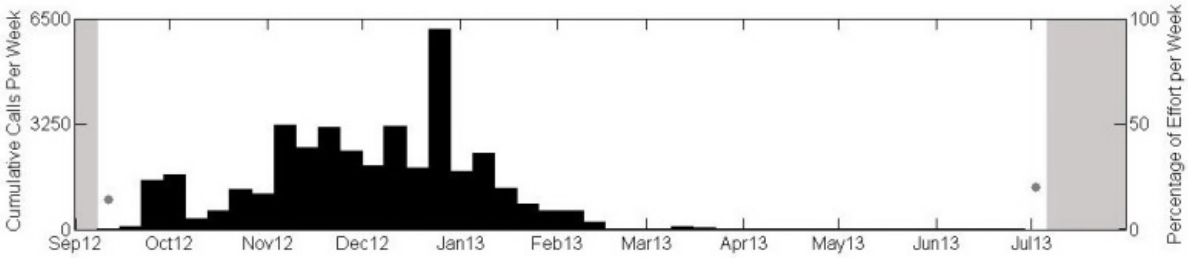

Figure 33. Weekly presence of blue whale NE Pacific B calls between September 2012 and June 2013. Gray dots represent percent of effort per week in weeks with less than 100% recording effort and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

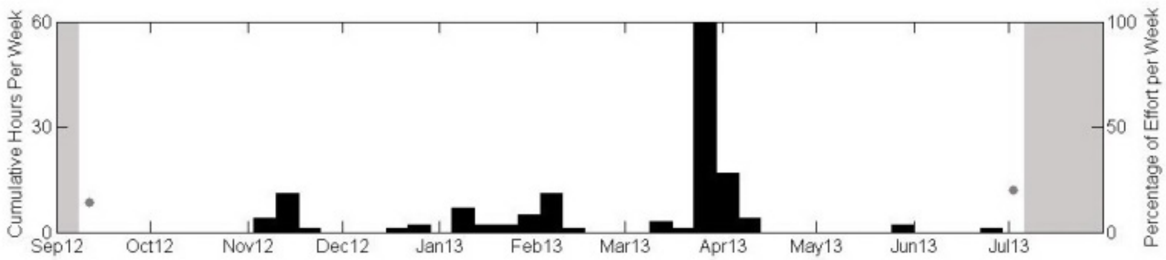

Figure 34. Weekly presence of blue whale D calls between September 2012 and June 2013. Effort markings are described in Figure 33.

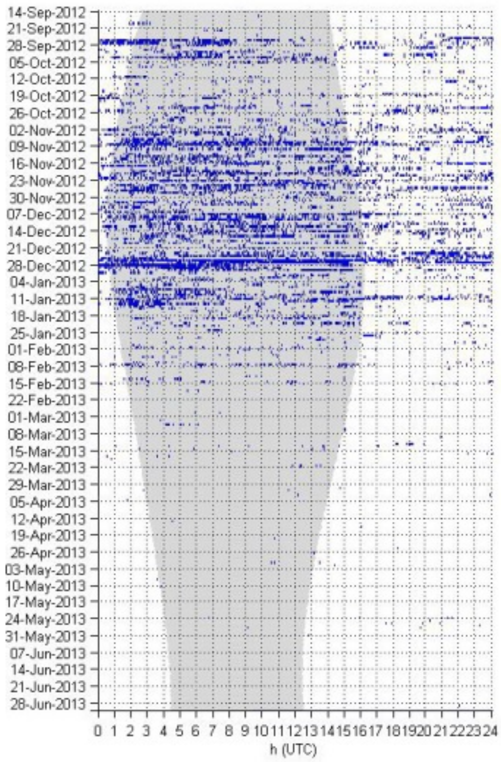

Figure 35. Blue whale NE Pacific B calls in one-minute bins. Gray shading denotes nighttime.

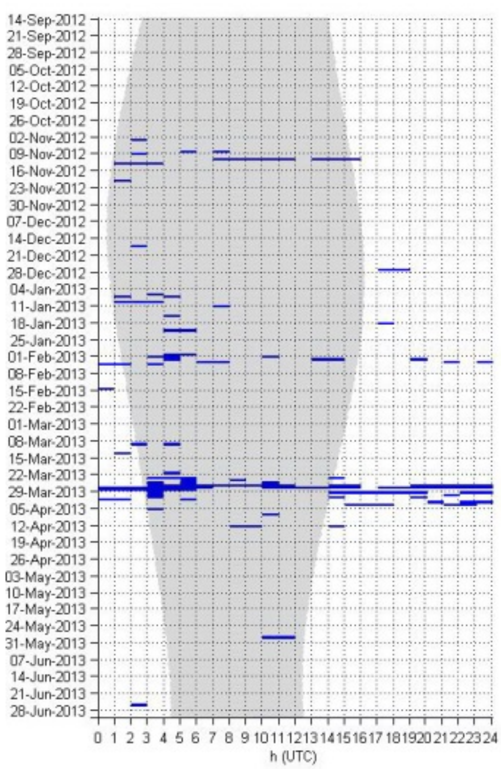

Figure 36. Blue whale D calls in hourly bins. Gray shading denotes nighttime.

Fin Whales

Fin whales were the most common acoustically detected baleen whale throughout the recording. Farther offshore in the eastern North Pacific, fin whale calls are generally detected from October through April (Watkins *et al*., 2000), corresponding to the pattern we observed at our site. Differences in the timing of peak calling presence per call type may indicate distinct behavioral functions associated with these call types (Širović *et al*., 2013).

- Fin whale 20 Hz calls, associated with singing and call-countercall among animals, were the dominant fin whale call type (Figure 37). Peaks in call index representative of 20 Hz calls occurred November 2012 through January 2013, and again in April 2013.
- Fin whale 40 Hz calls were also frequently recorded from September 2012 through June 2013 (Figure 38). Peaks in 40 Hz calls occurred in December 2012 and again in May through June 2013.
- There was no clear diel pattern in 40 Hz calls (Figure 39).

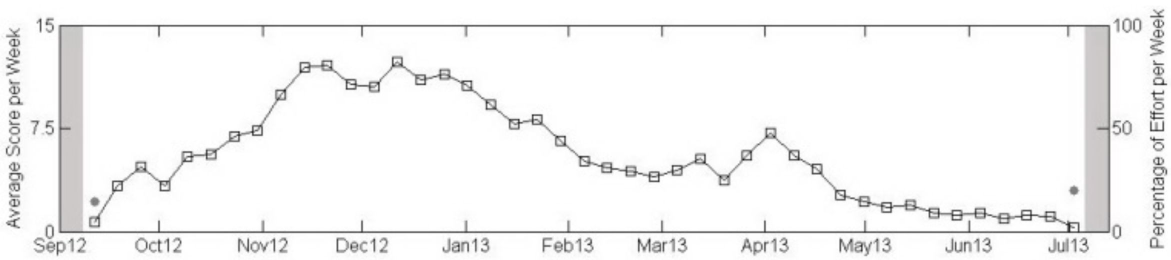

Figure 37. Weekly value of fin whale call index (proxy for 20 Hz calls) between September 2012 and June 2013. Effort markings are described in Figure 33.

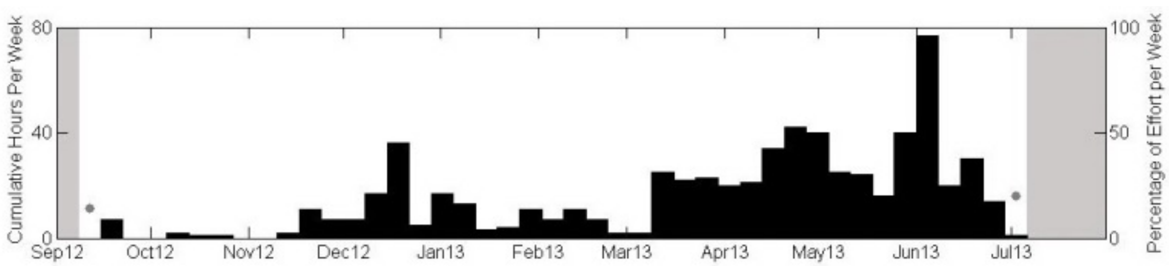

Figure 38. Weekly presence of fin whale 40 Hz calls between September 2012 and June 2013. Effort markings are described in Figure 33.

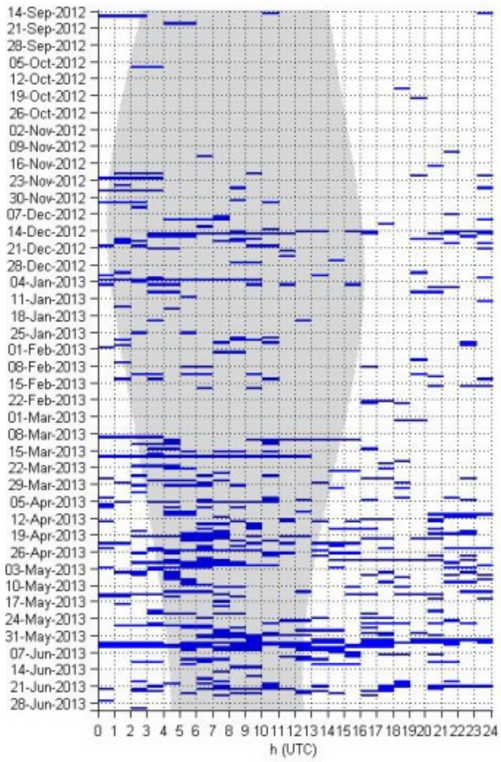

Figure 39. Fin whale 40 Hz calls in hourly bins. Gray shading denotes nighttime.

North Pacific Right Whales
These calls represent the first North Pacific right whale calls recorded in the NWTRC.

- Two North Pacific right whale upcalls were detected on June 29, 2013 at 13:42 and 15:55 UTC (Figure 40).
- The right whale calls occurred a few hours after sunrise (Figure 41).
- The calls occurred twenty days after a North Pacific right whale was sighted on June 9th off Haida Gwaii, British Colombia, the first such sighting in more than 60 years. A different North Pacific right whale was sighted on October 26th off the entrance of the Juan de Fuca Strait near Victoria. It was unclear whether the North Pacific right whale heard at the QC site is one of the same or is a different individual than those involved in the two sightings.

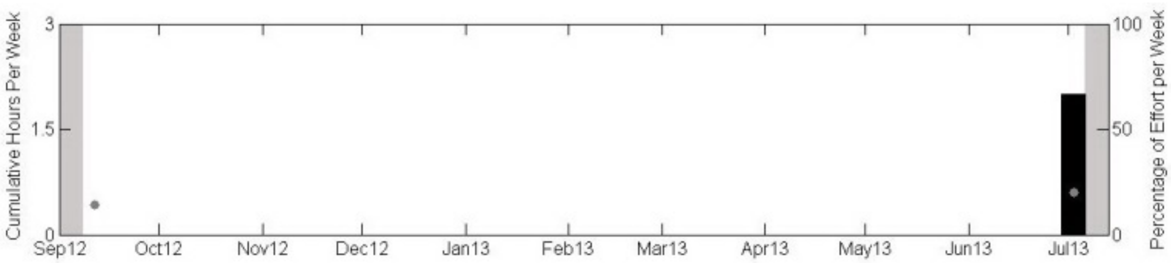

Figure 40. Weekly presence of north Pacific right whale upcalls between September 2012 and June 2013. Effort markings are described in Figure 33.

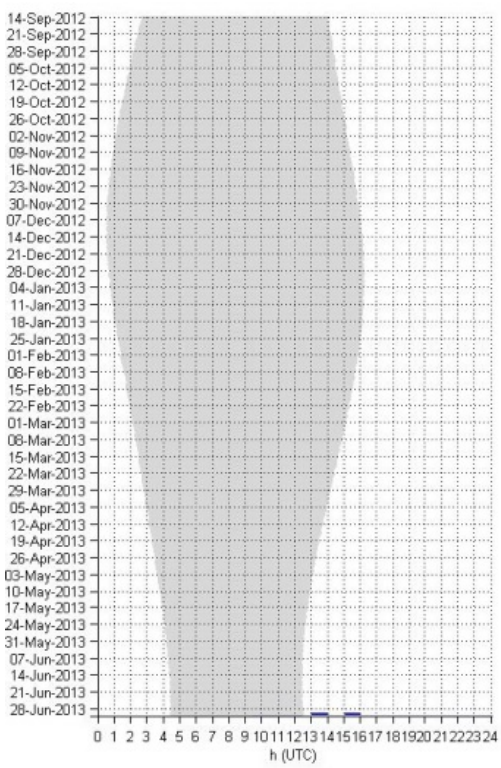

Figure 41. Right whale upcalls in hourly bins. Gray shading denotes nighttime.

Humpback Whales

Both song and non-song call types were grouped for this analysis of humpback whale presence. Humpbacks were recorded from September 2012 to June 2013. These detections are consistent with previous recordings showing overwintering presence at this site (Oleson *et al*., 2009; Širović *et al*., 2012; Širović *et al*., 2011). The substantial presence of humpback whales during the winter does not fit models of whale migration to subtropical or tropical waters. These data instead suggest that some whales remain in temperate waters during the winter.

- Humpback whale calls were detected at high rates from September 2012 through February 2013 (Figure 42). The lower level of calling from late March through June is also consistent with previous findings (Kerosky *et al*., 2013; Oleson *et al*., 2009; Širović *et al*., 2012; Širović *et al*., 2011).
- There was no clear diel pattern in humpback whale calls (Figure 43).

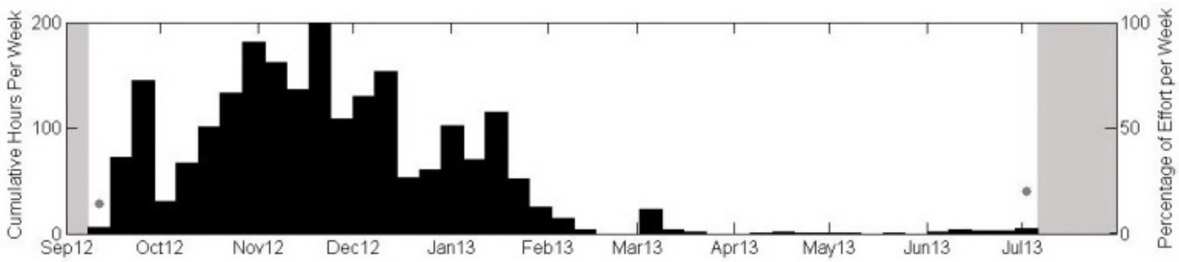

Figure 42. Weekly presence of humpback whale calls between September 2012 and June 2013. Effort markings are described in Figure 33.

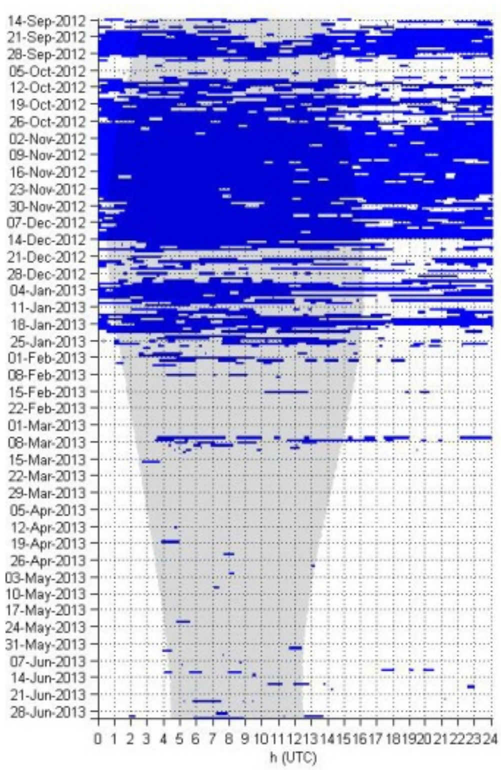

Figure 43. Humpback whale calls in one-minute bins. Gray shading denotes nighttime.

Minke Whales
These data represent the first minke whale boing detections in NWTRC HARP data.

- Minke whale boings were detected in mid-November 2012 and late-April 2013 (Figure 44).
- The data are too limited to establish a diel pattern (Figure 45).
- Compared to boings from other regions in the North Pacific, these boings most closely resemble boings from the eastern North Pacific (Figure 46).

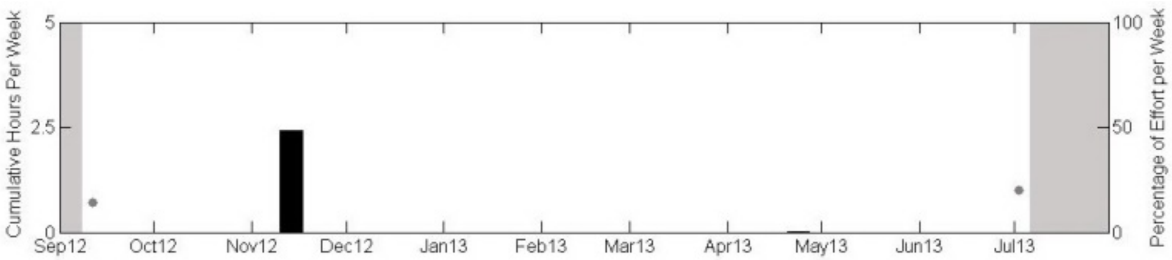

Figure 44. Weekly presence of minke whale boings between September 2012 and June 2013. Effort markings are described in Figure 33.

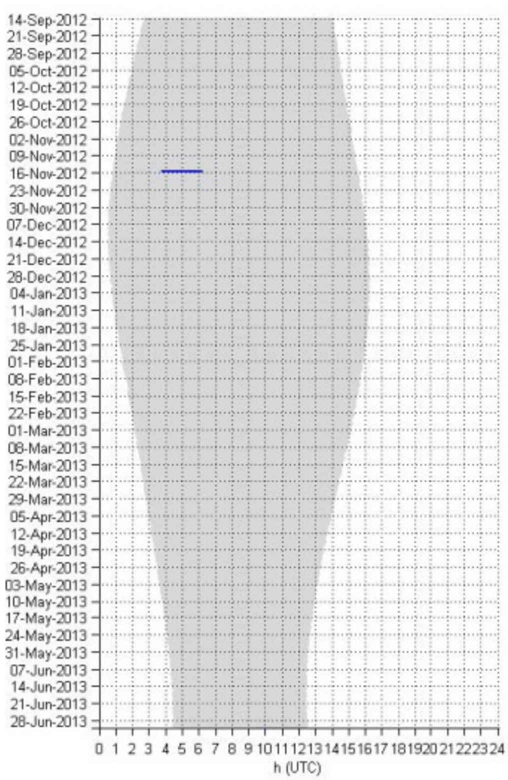

Figure 45. Minke whale boings in one-minute bins. Gray shading denotes nighttime.

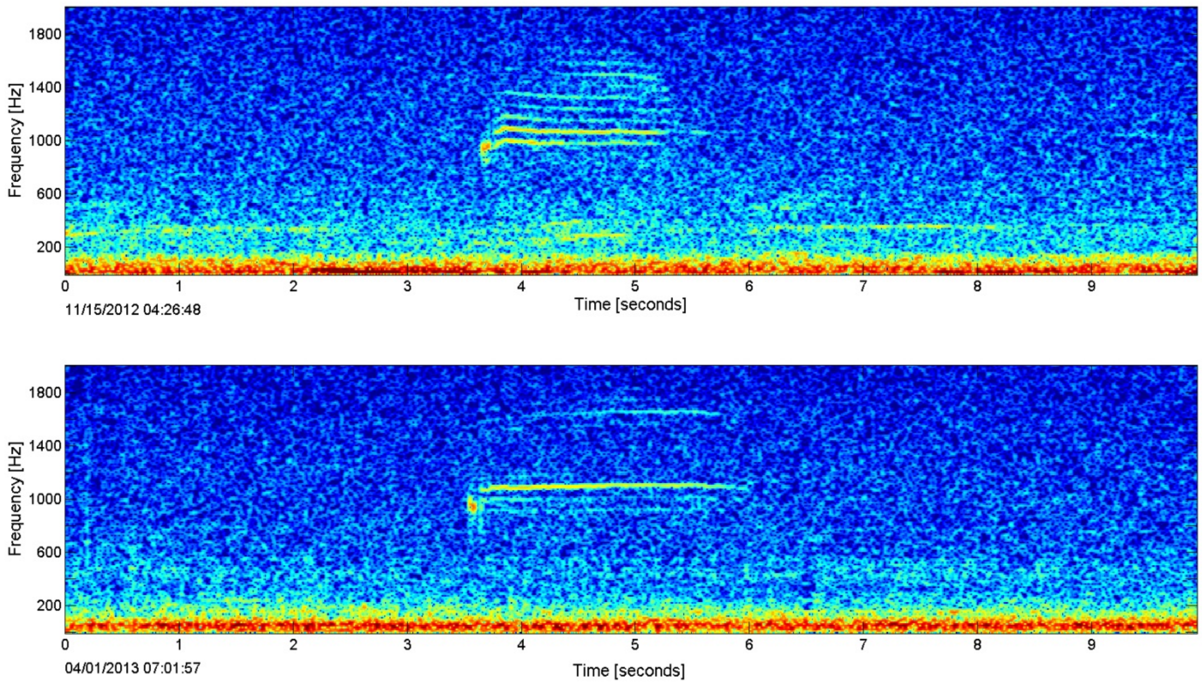

Figure 46. Minke boing spectrograms from the QC site (top) and southern California (bottom).

Odontocetes

At least six odontocete species were detected between September 2012 and June 2013: Risso's dolphins, killer whales, sperm whales, Stejneger's beaked whales, Cuvier's beaked whales, and Baird's beaked whales. More details of each species' presence at these sites are given below. No calls were detected for Pacific white-sided dolphins, Blainville's beaked whales, BW40, BW43, Dall's porpoises, or harbor porpoises.

Unidentified Odontocetes

Odontocete sounds that could not be classified to species were grouped together as unidentified. Unidentified odontocetes were detected from September 2012 through June 2013. These detections were most likely short-beaked common dolphins or northern right whale dolphins.

- Unidentified odontocete clicks with all energy above 20 kHz were the most common call type. Their detections peaked in November 2012 and June 2013 (Figure 47).
- Unidentified odontocete clicks that extended below 20 kHz peaked in February 2013 (Figure 48).
- There were few detections of unidentified odontocete whistles (Figure 49).
- Most clicks with energy above 20 kHz occurred at night (Figure 50).
- There were too few detections to establish a diel pattern for clicks with energy below 20 kHz (Figure 51).
- There were too few whistle detections to establish a diel pattern for this call type (Figure 52).

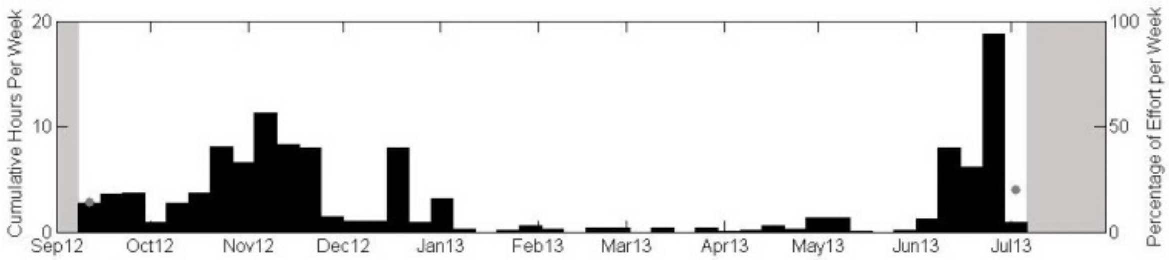

Figure 47. Weekly presence of unidentified odontocete clicks greater than 20 kHz between September 2012 and June 2013. Effort markings are described in Figure 33.

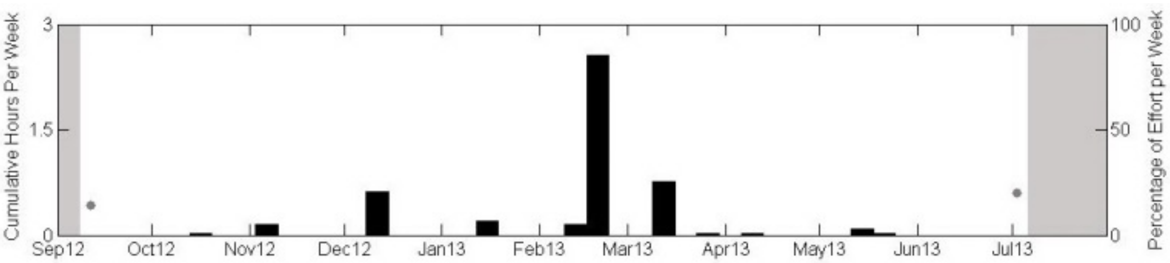

Figure 48. Weekly presence of unidentified odontocete clicks less than 20 kHz between September 2012 and June 2013. Effort markings are described in Figure 33.

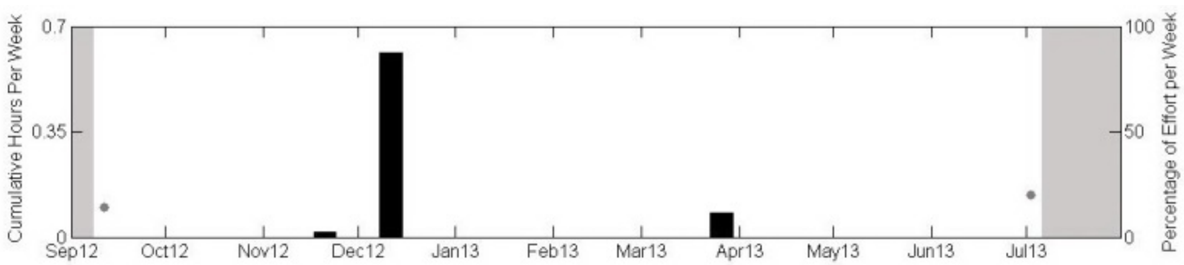

Figure 49. Weekly presence of unidentified odontocete whistles greater than 10 kHz between September 2012 and June 2013. Effort markings are described in Figure 33.

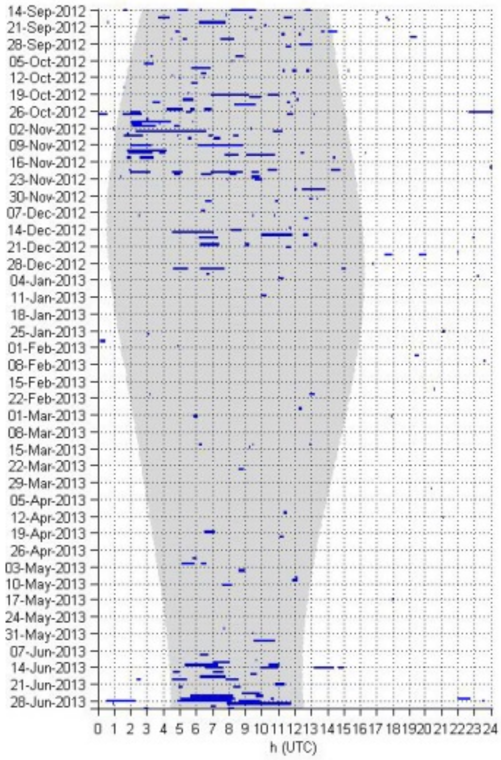

Figure 50. Unidentified odontocete clicks greater than 20 kHz in one-minute bins. Gray shading denotes nighttime.

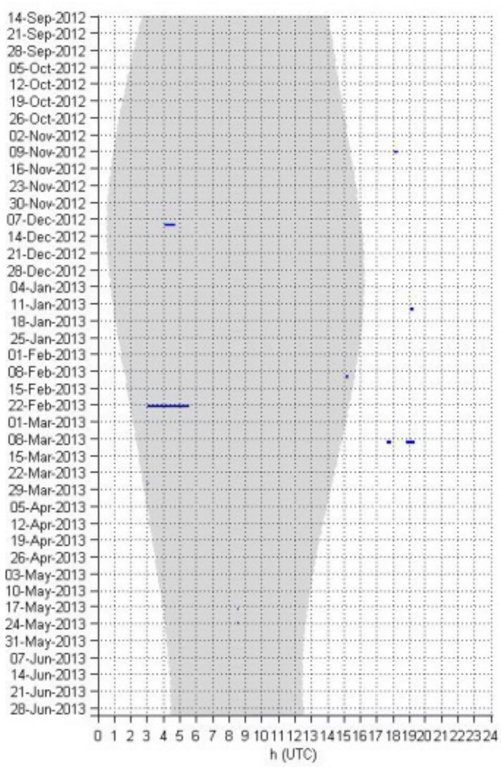

Figure 51. Unidentified odontocete clicks less than 20 kHz in one-minute bins. Gray shading denotes nighttime.

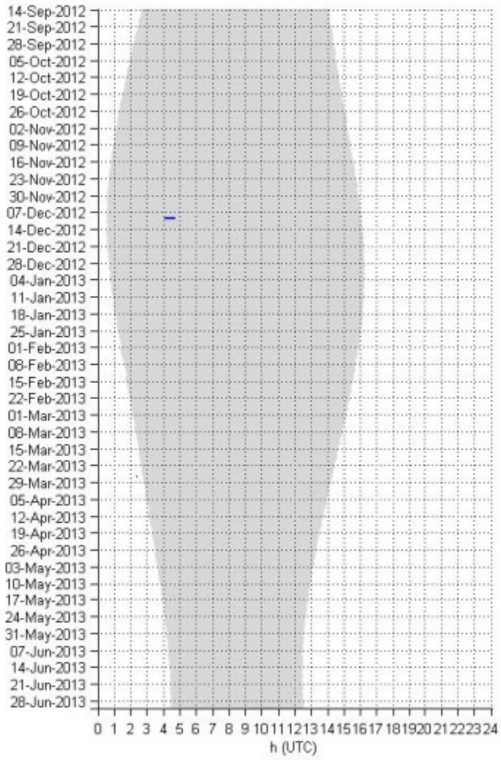

Figure 52. Unidentified odontocete whistles greater than 10 kHz in one-minute bins. Gray shading denotes nighttime.

Risso's Dolphins

Risso's dolphin echolocation clicks were detected throughout the recording.

- Peaks in detections occurred in September 2012 and again in June 2013 (Figure 53).
- A diel pattern for Risso's echolocation clicks existed, with higher activity at night indicating nighttime foraging (Figure 54). This is consistent with previous findings (Kerosky *et al*., 2013) and with previous reports in other areas (Soldevilla *et al*., 2010).

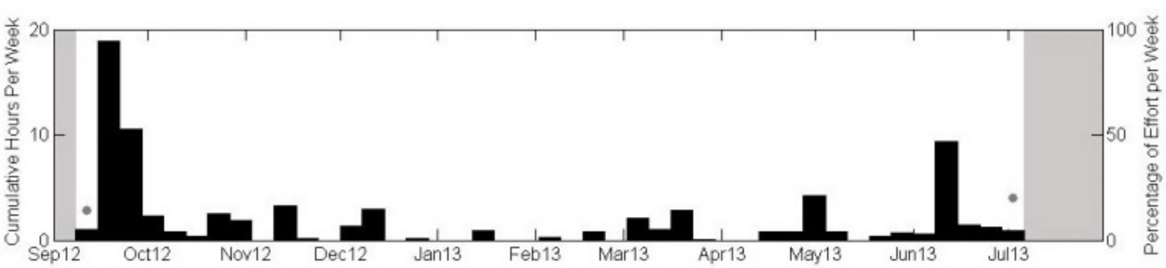

Figure 53. Weekly presence of Risso's dolphin clicks between September 2012 and June 2013. Effort markings are described in Figure 33.

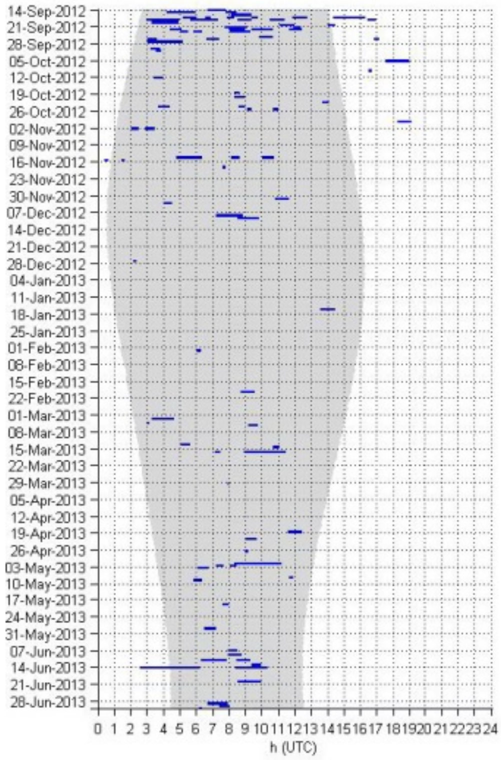

Figure 54. Risso's dolphin clicks in one-minute bins. Gray shading denotes nighttime.

Killer Whales

Killer whale vocalizations were detected intermittently throughout the recording.

- Killer whale click detections peaked in late-March and early-April 2013 (Figure 55).
- HFM signals were only detected in early-April 2013 (Figure 56).
- Killer whale whistles and pulsed calls were more common than clicks and HFM signals. Detections peaked in December 2012 and late-March 2013 (Figure 57).
- There were too few detections to determine a diel pattern for killer whale click (Figure 58) or HFM signal (Figure 59) detections; however most whistle and pulsed call detections occurred during nighttime hours (Figure 60).

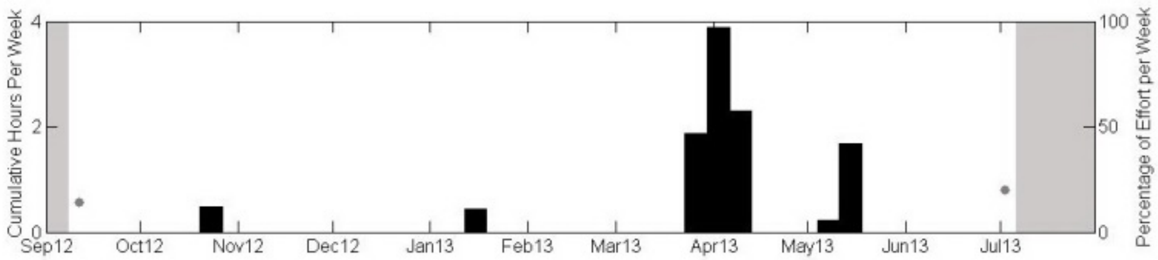

Figure 55. Weekly presence of killer whale clicks between September 2012 and June, 2013. Effort markings are described in Figure 33.

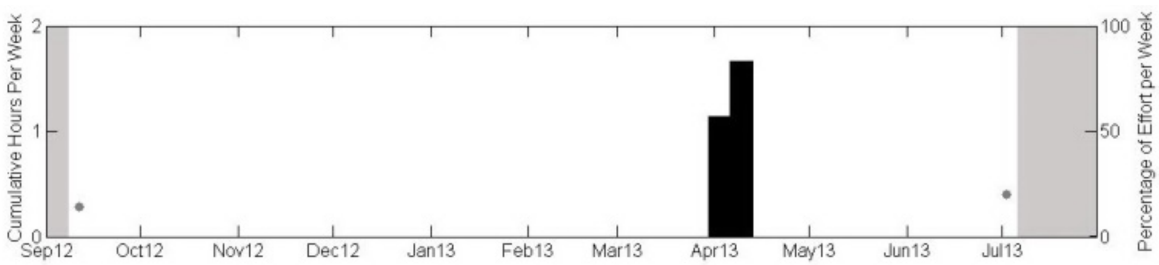

Figure 56. Weekly presence of killer whale high-frequency modulated signals between September 2012 and June 2013. Effort markings are described in Figure 33.

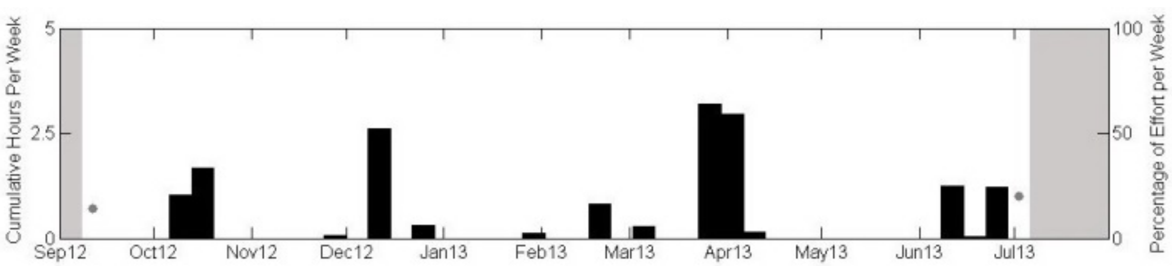

Figure 57. Weekly presence of killer whale whistles and pulsed calls between September 2012 and June 2013. Effort markings are described in Figure 33.

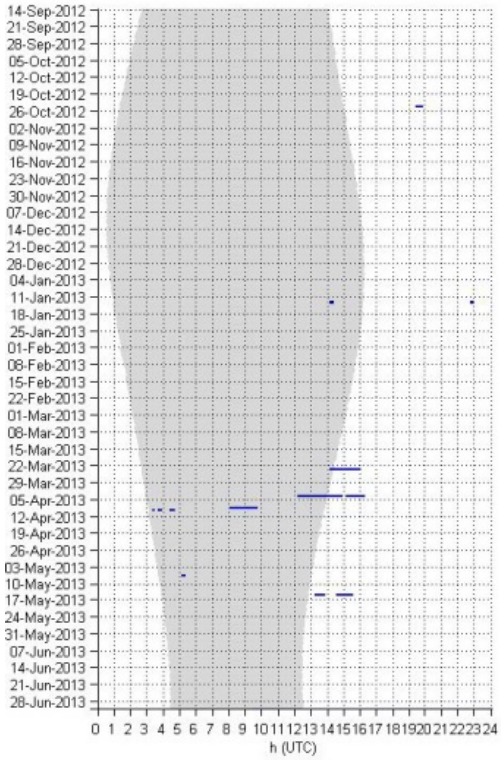

Figure 58. Killer whale clicks in one-minute bins. Gray shading denotes nighttime.

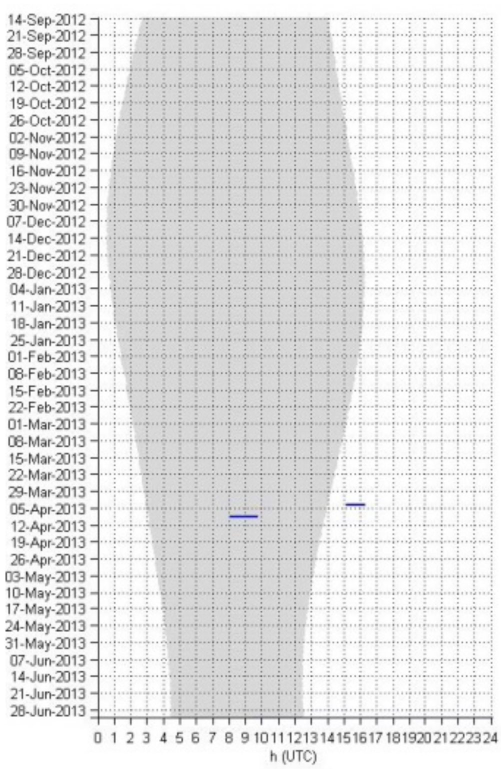

Figure 59. Killer whale high-frequency modulated signals in one-minute bins. Gray shading denotes nighttime.

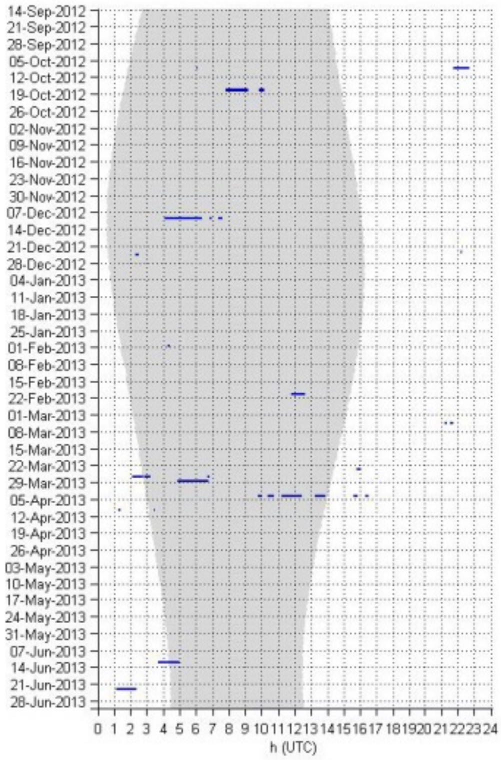

Figure 60. Killer whale whistles in one-minute bins. Gray shading denotes nighttime.

Sperm Whales

Sperm whale clicks were detected November 2012 through June 2013.

- Detections peaked in February and March 2013 (Figure 61).
- Sperm whale echolocation clicks occurred throughout the day and nighttime hours (Figure 62). Previous reports from this area have suggested the possibility of a diel preference in sperm whale echolocation clicks (Širović *et al*., 2011); more recently, however, no clear pattern has been discerned (Kerosky *et al*., 2013; Širović *et al*., 2012).

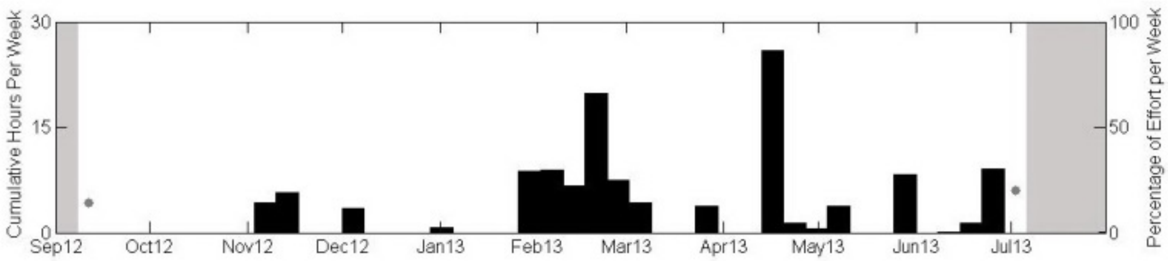

Figure 61. Weekly presence of sperm whale echolocation clicks between September 2012 and June 2013. Effort markings are described in Figure 33.

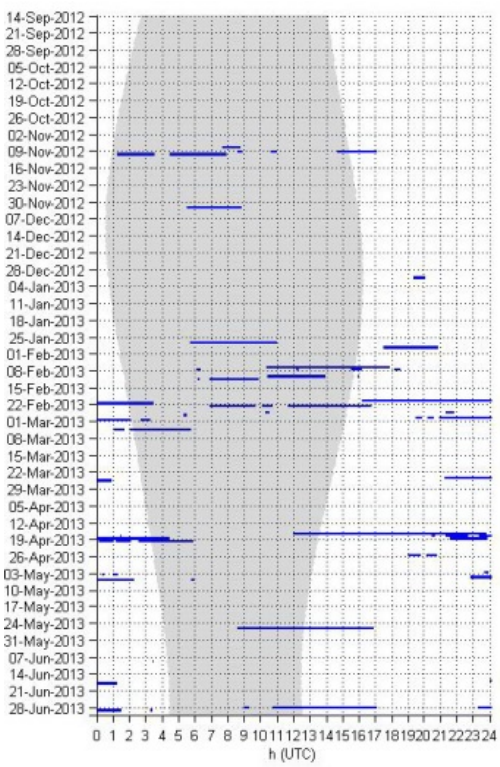

Figure 62. Sperm whale echolocation clicks in one-minute bins. Gray shading denotes nighttime.

Stejneger’s Beaked Whales

Stejneger’s beaked whales were the most consistently detected beaked whale off Washington.

- Calls were detected October 2012 through June 2013 (Figure 63), consistent with previously reported detections for this species at this site (Kerosky *et al*., 2013; Širović *et al*., 2012). Stejneger’s beaked whale FM pulse detections peaked in December 2012 and March 2013.
- There was no clear diel pattern of occurrence in Stejneger’s beaked whale FM pulses (Figure 64).

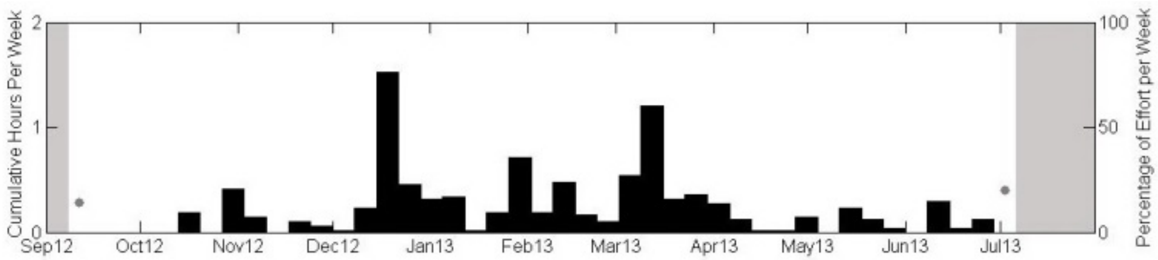

Figure 63. Weekly presence of Stejneger's beaked whale frequency-modulated pulses between September 2012 and June 2013. Effort markings are described in Figure 33.

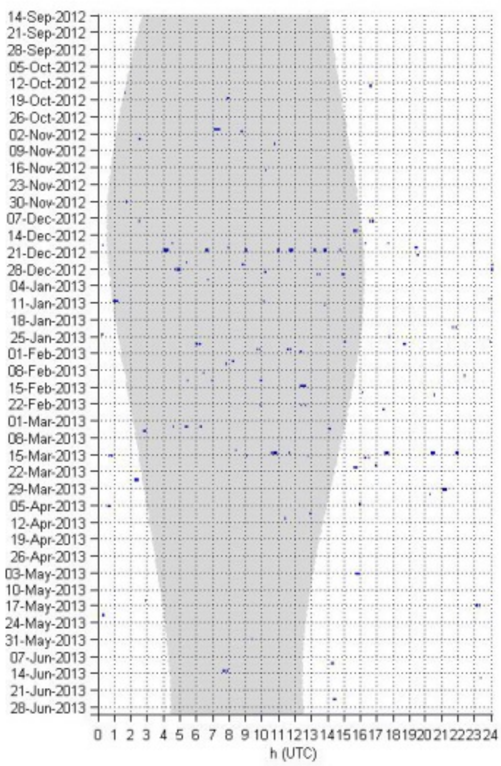

Figure 64. Stejneger's beaked whale frequency-modulated pulses in one-minute bins. Gray shading denotes nighttime.

Cuvier's Beaked Whales

Cuvier's beaked whale FM pulses were detected at low levels mid-November 2012 through mid-February 2013.

- Cuvier's beaked whale FM pulse detections peaked in December 2012 (Figure 65).
- Most Cuvier's detections occurred at night (Figure 66).

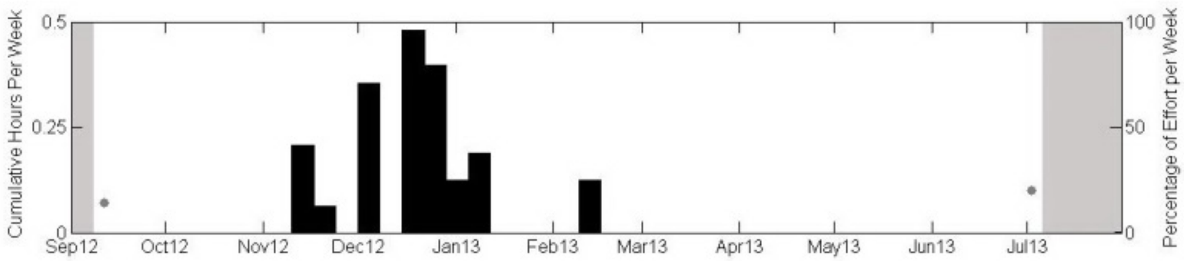

Figure 65. Weekly presence of Cuvier's beaked whale frequency-modulated pulses between September 2012 and June 2013. Effort markings are described in Figure 33.

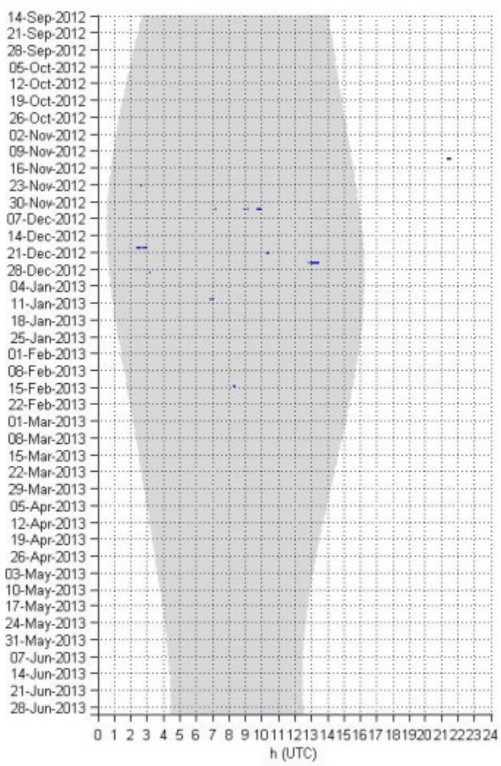

Figure 66. Cuvier's beaked whale frequency-modulated pulses in one-minute bins. Gray shading denotes nighttime.

Baird's Beaked Whales

Baird's beaked whale FM pulses were detected in low numbers sporadically at this site.

- Baird's beaked whale FM pulses were detected in October through December 2012 and again in May 2013 (Figure 67), consistent with previously reported acoustic presence (Kerosky *et al*., 2013; Širović *et al*., 2012).
- There was no apparent diel pattern in Baird's beaked whale FM pulses during this period (Figure 68).

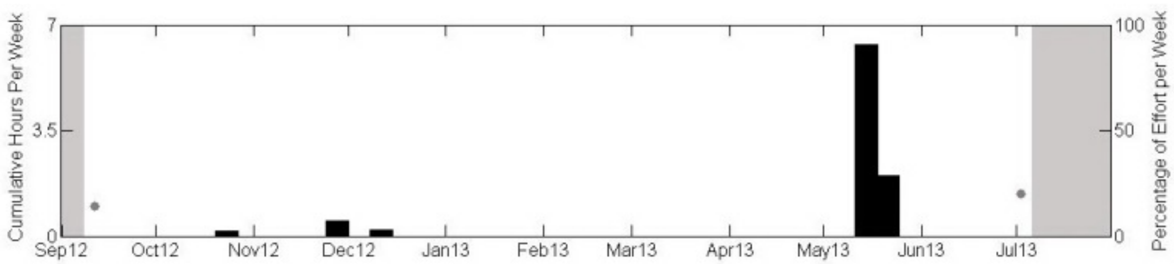

Figure 67. Weekly presence of Baird's beaked whale frequency-modulated pulses between September 2012 and June 2013. Effort markings are described in Figure 33.

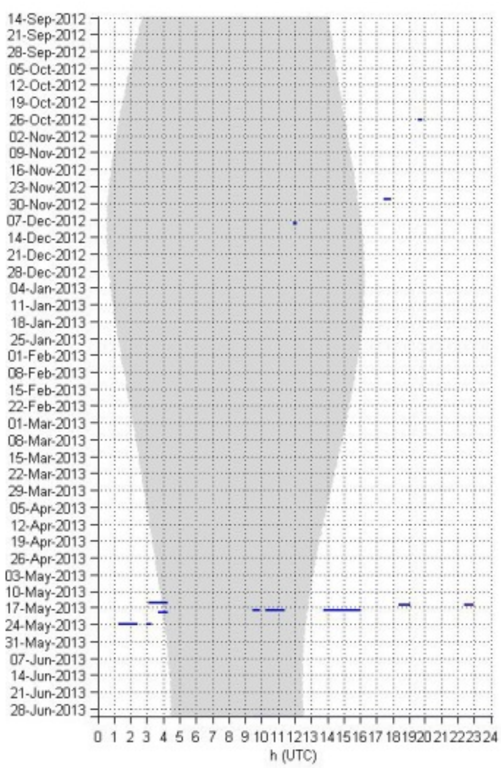

Figure 68. Baird's beaked whale frequency-modulated pulses in one-minute bins. Gray shading denotes nighttime.

Anthropogenic Sounds

Five types of anthropogenic sounds were detected between September 2012 and June 2013: broadband ship noise, mid-frequency active (MFA) sonar, echosounders, underwater communications, and explosions.

Broadband Ship Noise

Broadband ship noise was detected at high rates throughout the recording.

- Ship noise was highest in September 2012 and experienced a dip in December 2012 (Figure 69).
- There was a peak in detections at or slightly before sunrise throughout most of the recording (Figure 70).

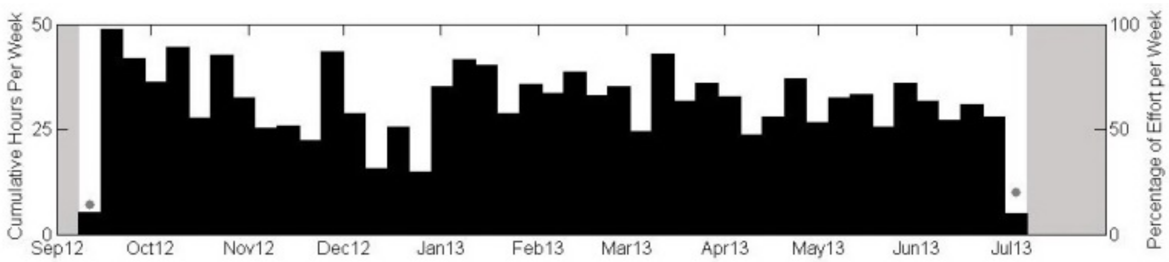

Figure 69. Weekly presence of broadband ship noise between September 2012 and June 2013. Effort markings are described in Figure 33.

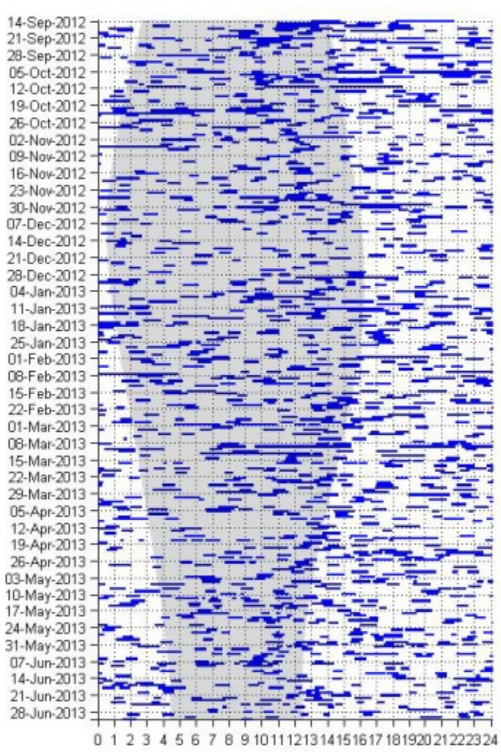

Figure 70. Broadband ship noise in one-minute bins. Gray shading denotes nighttime.

Mid-Frequency Active (MFA) Sonar

MFA occurred occasionally throughout the deployment.

- There were four days on which MFA greater than 5 kHz was detected (Figure 71) and three days on which MFA less than 5 kHz was detected (Figure 72).
- There was no obvious diel pattern in MFA occurrence (Figure 73 and Figure 74).
- A total of 101 pings less than 5 kHz were detected, ranging from 2400 to 4500 Hz. The maximum received level was 127.36 dB pp re: 1 µPa (Figure 75). Most pings detected were below 120 dB pp re: 1 µPa (Figure 76).

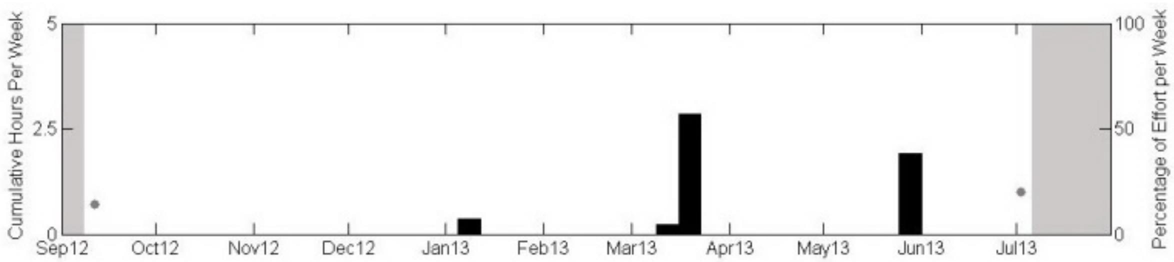

Figure 71. Weekly presence of MFA greater than 5 kHz between September 2012 and June 2013. Effort markings are described in Figure 33.

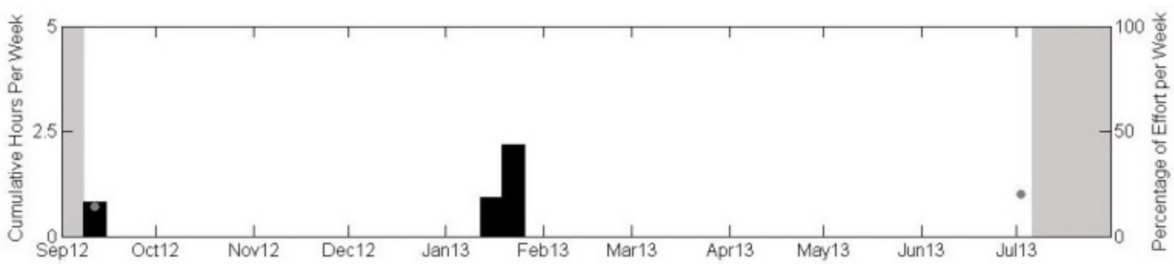

Figure 72. Weekly presence of MFA less than 5 kHz between September 2012 and June 2013. Effort markings are described in Figure 33.

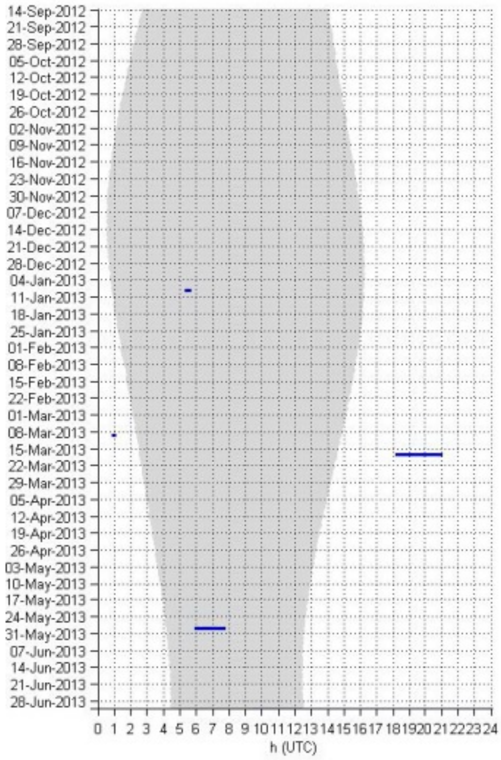

Figure 73. MFA greater than 5 kHz in one-minute bins. Gray shading denotes nighttime.

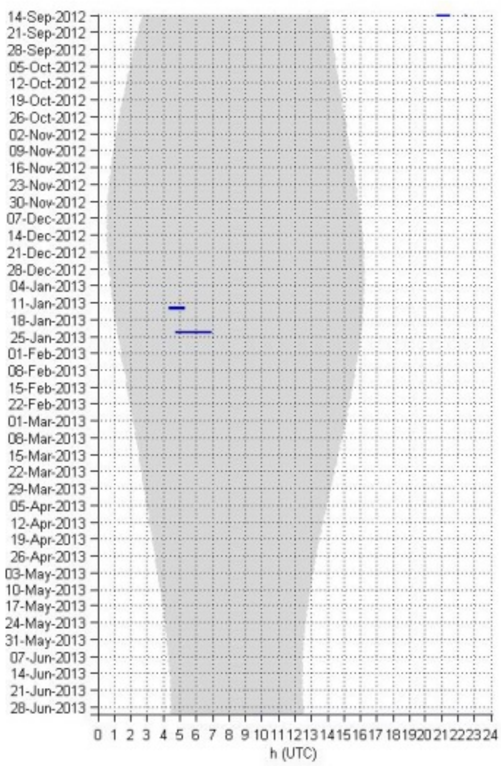

Figure 74. MFA less than 5 kHz in one-minute bins. Gray shading denotes nighttime.

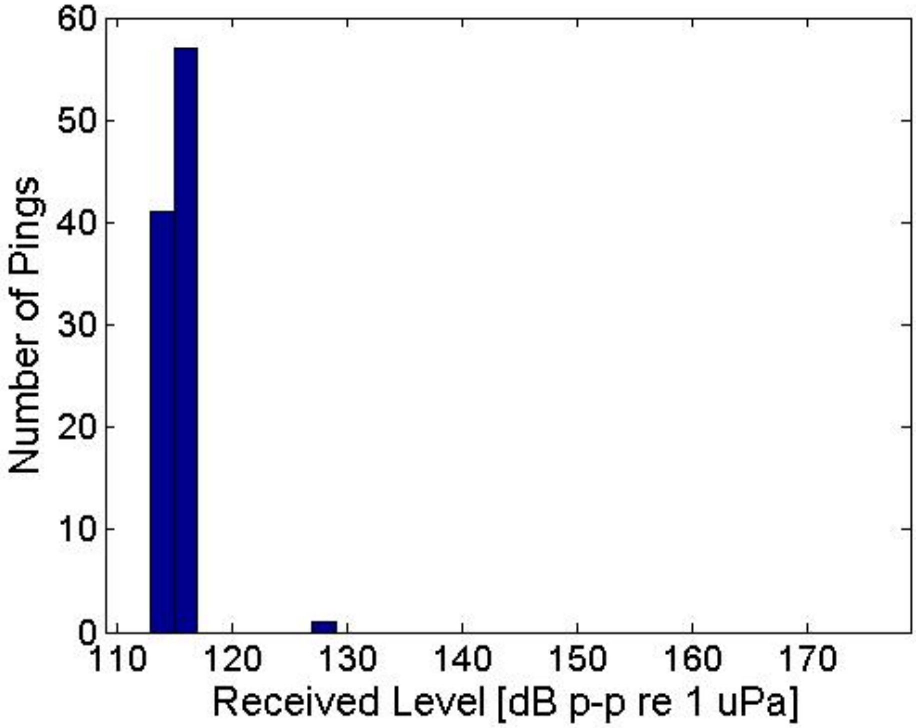

Figure 75. Distribution of the number of MFA sonar pings below 5 kHz by received levels in 1 dB bins.

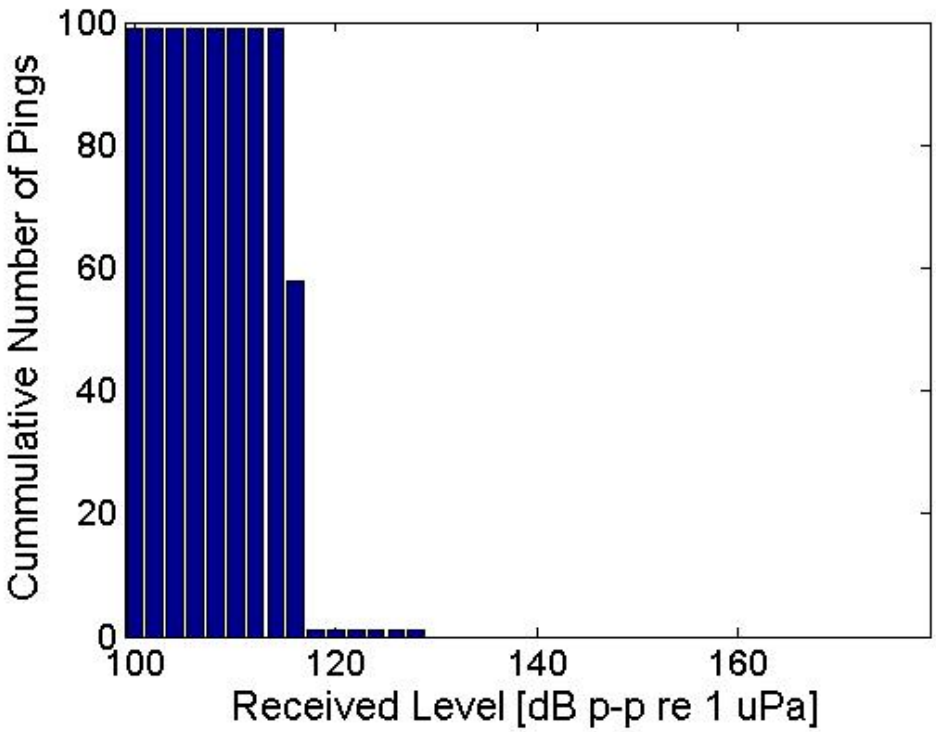

Figure 76. Cumulative distribution of the number of MFA sonar pings below 5 kHz detected by received levels in 1 dB bins.

Echosounders

Echosounder pings from a variety of frequencies were detected throughout the deployment.

- Peaks in echosounder occurrence were in October 2012 and March 2013 (Figure 77).
- There was no discernable diel pattern to echosounder pings (Figure 78).
- The majority of pings were over 20 kHz.

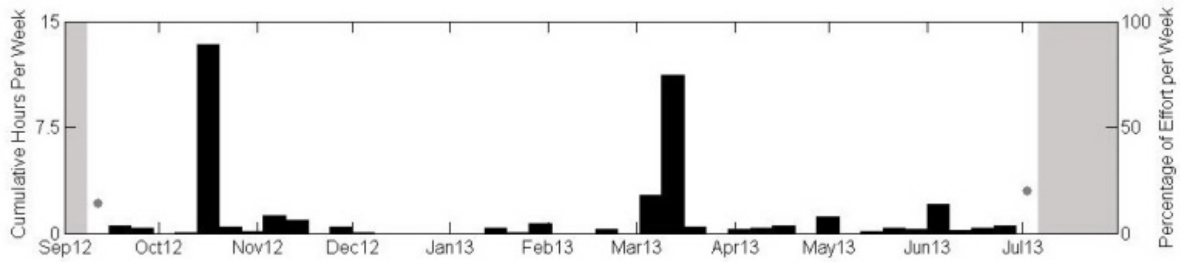

Figure 77. Weekly presence of echosounder pings between September 2012 and June 2013. Effort markings are described in Figure 33.

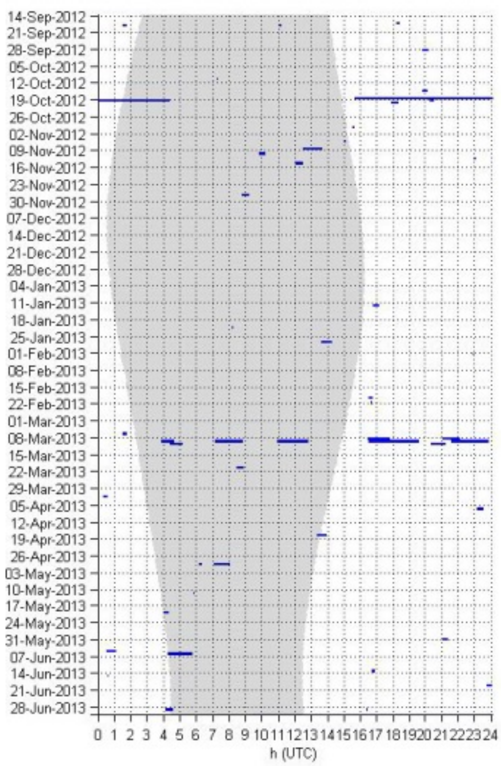

Figure 78. Echosounder ping detections in one-minute bins. Gray shading denotes nighttime.

Underwater Communications

Underwater communications were detected episodically throughout the recording.

- Noticeable peaks in detections occurred in late March and late May 2013 (Figure 79).
- Underwater communications occurred primarily during daytime hours, beginning just before sunrise (Figure 80).
- The majority of underwater communication detections were of the electronic transmission type (Figure 30).

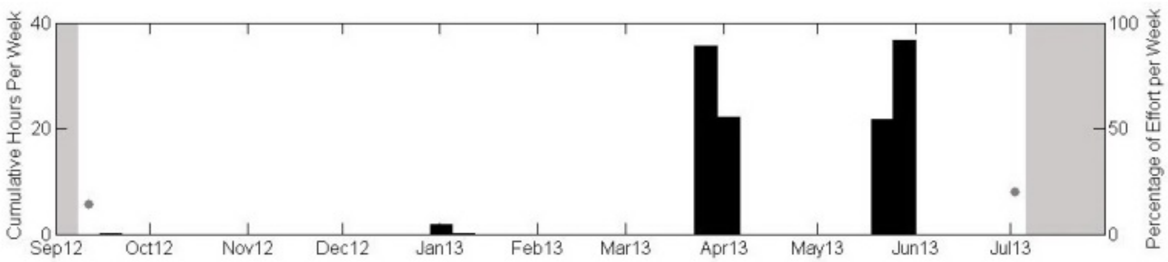

Figure 79. Weekly presence of underwater communications between September 2012 and June 2013. Effort markings are described in Figure 33.

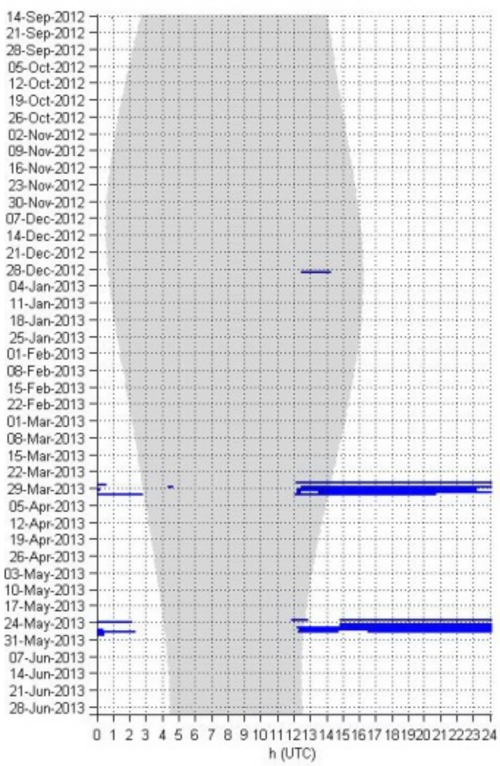

Figure 80. Communications in one-minute bins. Gray shading denotes nighttime.

Explosions

Explosions were detected throughout the recording.

- Peaks in explosion detections occurred in September 2012 and late-March and early-April 2013 (Figure 81). The peaks in September coincide with Coho and Chinook salmon season, suggesting that the explosions are likely fishery-related seal bombs.
- Most explosions occurred during daytime hours (Figure 82).
- The peaks in explosions in late-March coincide with many of the electronic communications detections (Figure 83). These explosions occur in rapid succession over the course of many minutes. Their appearance is also concurrent with the appearance of killer whale clicks, whistles, and HFM pulses.

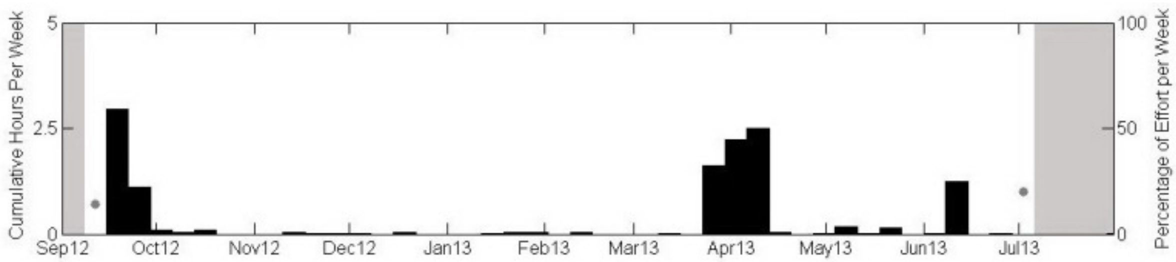

Figure 81. Weekly presence of explosions between September 2012 and June 2013. Effort markings are described in Figure 33.

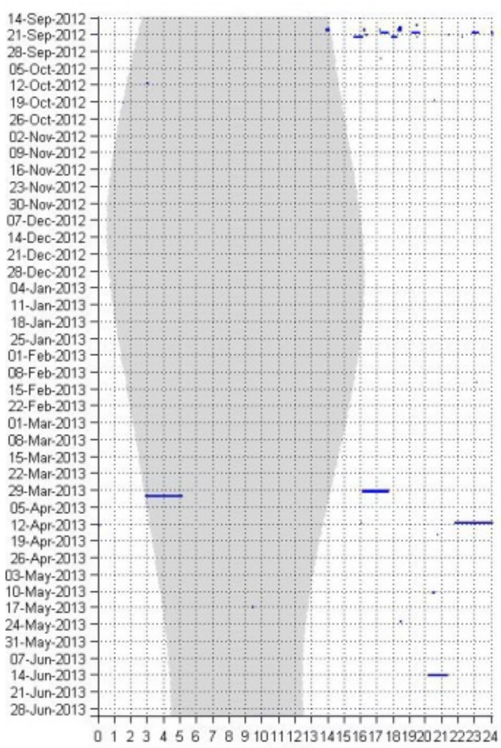

Figure 82. Explosions in one-minute bins. Gray shading denotes nighttime.

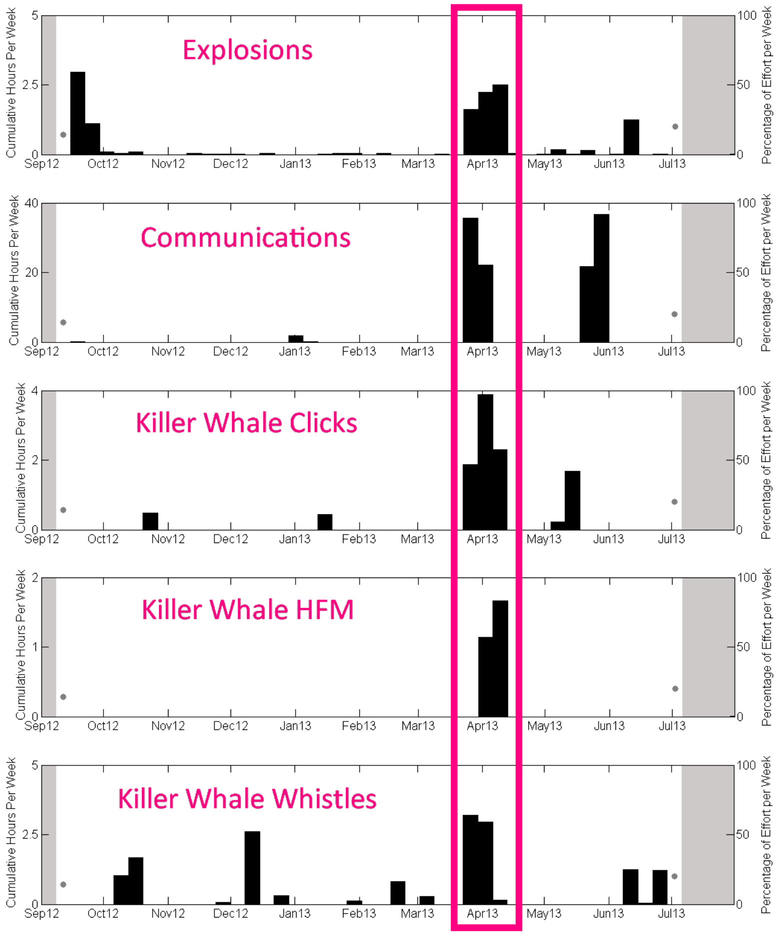

Figure 83. Weekly presence of anthropogenic events and killer whale vocalizations. Detections in late-March and early-April are highlighted in the pink box.

Acknowledgements

We thank Chip Johnson of PACFLEET for providing support for this program. In addition, we thank Liam Antrim of the Olympic Coast National Marine Sanctuary for assistance with research permit OCNMS-2010-010. This work also benefitted from members of the Scripps Whale Acoustics Laboratory who assisted with logistics support for instrument preparation, deployment and recovery including: Beve Kennedy, Ryan Griswold, John Hurwitz, and Sam Wagner. We also thank the Captain and crew of the R/V Centennial operated by the University of Washington for assistance with instrument deployment and recovery.

References

Baumann-Pickering, S., McDonald, M. A., Simonis, A. E., Solsona Berga, A., Merkens, K. P. B., Oleson, E. Roch, M., Wiggins, S., Rankin, S., Yack, T. & Hildebrand, J. A. (2013)a. Species-specific beaked whale echolocation signals. *Journal of the Acoustical Society of America 134*(3), 2293-2301. doi: 10.1121/1.4817832

Baumann-Pickering, S., Simonis, A. E., Wiggins, S. M., Brownell, R. L. J., & Hildebrand, J. A. (2013)b. Aleutian Islands beaked whale echolocation signals. *Marine Mammal Science, 29*(1), 221-227. doi: 10.1111/j.1748-7692.2011.00550.x

Baumann-Pickering, S., Yack, T. M., Barlow, J., Wiggins, S. M., & Hildebrand, J. A. (2013)c. Baird's beaked whale echolocation signals. *Journal of the Acoustical Society of America, 133*(6), 4321-4331. doi: 10.1121/1.4804316

Brownell, R. L., Clapham, P. J., Miyashita, T., & Kasuya, T. (2001). Conservation status of North Pacific right whales. *Journal of Cetacean Research and Management, Special Issue 2*, 269-286.

Burtenshaw, J. C., Oleson, E. M., Hildebrand, J. A., McDonald, M. A., Andrew, R. K., Howe, B., M., & Mercer, J. A. (2004). Acoustic and satellite remote sensing of blue whale seasonality and habitat in the Northeast Pacific. *Deep-Sea Research Part II, 51*, 967-986. doi: 10.1016/j.dsr2.2004.06.020

Crane, N. L., & Lashkari, K. (1996). Sound production of gray whales, *Eschrichtius robustus*, along the migration route: A new approach to signal analysis. *Journal of the Acoustical Society of America, 100*(3), 1878-1886.

Dawson, S., Barlow, J., & Ljungblad, D. (1998). Sounds recorded from Baird's beaked whale, *Berardius bardii*. *Marine Mammal Science, 14*(2), 335-334.

Delarue, J., & Martin, B. (2013). Minke whale boing sound detections in the northeastern Chukchi Sea. *Marine Mammal Science, 29*(3), E333-341. doi: 10.1111/j.1748-7692.2012.00611.x

Dunlop, R., Noad, M. J., Cato, D., & Stokes, D. (2007). The social vocalization repertoire of east Australian migrating humpback whales (*Megaptera novaeangliae)*. *Journal of the Acoustical Society of America, 122*(5), 2893-2905. doi: 10.1121/1.2783115

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

Goold, J. C., & Jones, S. E. (1995). Time and frequency domain characteristics of sperm whale clicks. *Journal of the Acoustical Society of America, 98*(3), 1279-1291.

Helble, T. A., Ierley, G. R., D'Spain, G. L., Roch, M. A., & Hildebrand, J. A. (2012). A generalized power-law detection algorithm for humpback whale vocalizations. *Journal of the Acoustical Society of America, 131*(4), 2682-2699. doi: 10.1121/1.3685790

Hildebrand, J. A. (2009). Anthropogenic and natural sources of ambient noise in the ocean. *Marine Ecology Progress Series, 395*, 5-20. doi: 10.3354/meps08353

Jefferson, T. A., Webber, M. A., & Pitman, R. L. (2008). *Marine mammals of the world - A comprehensive guide to their identification*. London, UK: Elsevier.

Johnson, M., Madsen, P., M., Zimmer, W. M. X., Aguilar de Soto, N., & Tyack, P. L. (2006). Foraging Blainville's beaked whales (*Mesoplodon densirostris*) produce distinct click types matched to different phases of echolocation. *Journal of Experimental Biology, 209*, 5038-5050. doi: 10.1242/jeb.02596

Johnson, M., Madsen, P. T., Zimmer, W. M. X., Aguilar de Soto, N., & Tyack, P. L. (2004). Beaked whales echolocate on prey. *Proceedings of the Royal Society B: Biological Sciences, 271*, S383-S386. doi: 10.1098/rsbl.2004.0208

Kerosky, S. M., Baumann-Pickering, S., Širović, A., Buccowich, J., S., Debich, A. J., Gentes, Z., . . . Hildebrand, J. A. (2013). Passive Acoustic Monitoring for Marine Mammals in the Northwest Training Range Complex 2011-2012. La Jolla, CA: Scripps Institution of Oceanography.

Kerosky, S. M., Širović, A., Roche, L. K., Baumann-Pickering, S., Wiggins, S. M., & Hildebrand, J. A. (2012). Bryde's whale seasonal range expansion and increasing presence in the Southern California Bight from 2000-2010. *Deep-Sea Research I, 65*, 125-132. doi: 10.1016/j.dsr.2012.03.013

Leatherwood, S., Reeves, R. R., Perrin, W. F., & Evans, W. E. (1988). *Whales, dolphins, and porpoises of the eastern North Pacific and adjacent Arctic waters: A guide to their identification*. New York, NY: Dover Publishing.

Madsen, P. T., Wahlberg, M., & Møhl, B. (2002). Male sperm whale (*Physete macrocephalus*) acoustics in a high-latitude habitat: implications for echolocation and communication. *Behavioral Ecology and Sociobiology, 53*(31-41). doi: 10.1007/s00265-002-0548-1

McDonald, M. A., Hildebrand, J. A., & Mesnick, S. (2009). Worldwide decline in tonal frequencies of blue whale songs. *Endangered Species Research, 9*, 13-21. doi: 10.3354-esr00217

McDonald, M. A., Hildebrand, J. A., & Webb, S. C. (1995). Blue and fin whales observed on a seafloor array in the Northeast Pacific. *Journal of the Acoustical Society of America, 98*(2), 712-721.

McDonald, M. A., Mesnick, S. L., & Hildebrand, J. A. (2006). Biogeographic characterisation of blue whale song worldwide: using song to identify populations. *Journal of Cetacean Research and Management, 8*, 55-65.

McDonald, M. A., & Moore, S. E. (2002). Calls recorded from North Pacific right whales (*Eubalaena japonica*) in the eastern Bering Sea. *Journal of Cetacean Research and Management, 4*(3), 261-266.

McKenna, M. F., Ross, D., Wiggins, S. M., & Hildebrand, J. A. (2012). Underwater radiated noise from modern commercial ships. *Journal of the Acoustical Society of America, 131*(1), 92-103. doi: 10.1121/1.3664100

Mellinger, D. K., & Clark, C. W. (1997). Methods of automatic detection of mysticete sounds. *Marine and Freshwater Behaviour and Physiology, 29*, 163-181.

Møhl, B., Wahlberg, M., & Madsen, P. T. (2003). The monopulsed nature of sperm whale clicks. *Journal of the Acoustical Society of America, 114*(2), 1143-1154. doi: 10.1121/1.1586258

Oleson, E. M., Barlow, J., Gordon, J., Rankin, S., & Hildebrand, J. A. (2003). Low frequency calls of Bryde's whales. *Marine Mammal Science, 19*(2), 160-172.

Oleson, E. M., Calambokidis, J., Baird, R., Falcone, E., Schorr, G., Douglas, A., Webster, D., McSweeney, D. & Hildebrand, J. A. (2010). Marine mammal demographics off the outer Washington coast and near Hawaii (pp. 21).

Oleson, E. M., Calambokidis, J., Burgess, W. C., McDonald, M. A., LeDuc, C. A., & Hildebrand, J. A. (2007). Behavioral context of call production by eastern North Pacific blue whales. *Marine Ecology Progress Series, 330*, 269-284.

Oleson, E. M., Calambokidis, J., Falcone, E., Schorr, G., & Hildebrand, J. A. (2009). Acoustic and visual monitoring of cetaceans along the outer Washington Coast. Technical report for grant N000240 WX12527. Report #NPS-OC-09-001 issued by Naval Postgraduate School, Monterey, CA. (pp. 45).

Oleson, E. M., Wiggins, S. M., & Hildebrand, J. A. (2007). Temporal separation of blue whale call types on a southern California feeding ground. *Animal Behaviour, 74*, 881-894.

Payne, R., & McVay, S. (1971). Songs of humpback whales. *Science, 173*(3997), 585-597.

Rankin, S., & Barlow, J. (2005). Source of the North Pacific "boing" sound attributed to minke whales. *Journal of the Acoustical Society of America, 118*(5), 3346-3351. doi: 10.1121/1.2046747

Roch, M. A., Klinch, H., Baumann-Pickering, S., Mellinger, D. K., Qui, S., Soldevilla, M. S., & Hildebrand, J. A. (2011). Classification of echolocation clicks from odontocetes in the Southern California Bight. *Journal of the Acoustical Society of America, 129*(1), 467-475. doi: 10.1121/1.3514383

Roch, M. A., Soldevilla, M. S., Burtenshaw, J. C., Henderson, E. E., & Hildebrand, J. A. (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*(3), 1737-1748. doi: 10.1121/1.2400663

Samarra, F. I. P., Deecke, V. B., Vinding, K., Rasmussen, M. H., Swift, R. J., & Miller, P. J. O. (2010). Killer whales (*Orciuns orca*) produce ultrasonic whistles. *Journal of the Acoustical Society of America Express Letters, 128*(5), EL205-210. doi: 10.1121/1.3462235

Scarff, J. E. (1986). Historic and present distribution of the right whale (*Eubalaena glacialis*) in the eastern North Pacific south of 50N and east of 180W. *Report of the International Whaling Commission*(Special Issue 10), 43-63.

Simonis, A. E., Baumann-Pickering, S., Oleson, E. M., Melcon, M. L., Gassman, M., Wiggins, S. M., & Hildebrand, J. A. (2012). High-frequency modulated signals of killer whales (*Orcinus orca*) in the North Pacific. *Journal of the Acoustical Society of America Express Letters, 131*(4), EL295-301. doi: 10.1121/1.3690963

Širović, A., Hildebrand, J. A., Baumann-Pickering, S., Buccowich, J., Cummins, A. J., Kerosky, S. M., . Roche, L., Solsona Berga, A., & Wiggins, S. M. (2012). Passive Acoustic Monitoring for Marine Mammals in the Northwest Training Range Complex 2011 (Vol. Marine Physical Lab Technical Memorandum 535). Scripps Institution of Oceanography, La Jolla, CA.

Širović, A., Oleson, E. M., Calambokidis, J., Baumann-Pickering, S., Cummins, A. J., Kerosky, S. M., . . . Hildebrand, J. A. (2011). Marine Mammal Demographics of the Outer Washington Coast during 2008-2009 (Vol. Technical report #NPS-OC-11-004CR). Monterey, CA: Naval Postgraduate School.

Širović, A., Williams, L., Kerosky, S. M., Wiggins, S. M., & Hildebrand, J. A. (2013). Temporal separation of two fin whale call types across the eastern North Pacific. *Marine Biology, 160*, 47-57.

Soldevilla, M. S., Henderson, E. E., Campbell, G. S., Wiggins, S. M., Hildebrand, J. A., & Roch, M. (2008). Classification of Risso's and Pacific white-sided dolphins using spectral properties of echolocation clicks. *Journal of the Acoustical Society of America, 124*(1), 609-624. doi: 10.1121/1.2932059

Soldevilla, M. S., Wiggins, S. M., & Hildebrand, J. A. (2010). Spatio-temporal comparison of Pacific white-sided dolphin echolocation click types. *Aquatic Biology, 9*, 49-62. doi: 10.3354/ab00224

Stimpert, A. K., Au, W. W. L., Parks, S. E., Hurst, T., & Wiley, D. N. (2011). Common humpback whale (*Megaptera novaeangliae*) sound types for passive acoustic monitoring. *Journal of the Acoustical Society of America, 129*(1), 476-482. doi: 10.1121/1.3504708

Tershy, B. R., Breese, D., & Alvarez-Borrego, S. (1991). Increase in cetacean and seabird numbers in the Canal de Ballenas during an El Niño-Southern Oscillation event. *Marine Ecology Progress Series, 69*, 299-302.

Thompson, P. O., Findley, L. T., & Vidal, O. (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*(6), 3051-3057.

Verboom, W. C., & Kastelein, R. A. (1995). Acoustic signals by Harbour porpoises (*Phocoena phocoena*). In P. E. Nachtigall, L. J., W. A. W. L. Au & A. J. Read (Eds.), *Harbour Porpoises, Laboratory Studies to Reduce Bycatch*. De Spil, Woerden, The Netherlands.

Watkins, W. A. (1981). Activities and underwater sounds of fin whales. *Scientific Reports of the Whale Research Institute, 33*, 83-117.

Watkins, W. A., Daher, M. A., Reppucci, G. M., George, J. E., Martin, D. M., DiMarzio, N. A., & Gannon, D. P. (2000). Seasonality and distribution of whale calls in the North Pacific. *Oceanography, 13*(1), 62-67.

Watkins, W. A., & Schevill, W. E. (1977). Sperm whale codas. *Journal of the Acoustical Society of America, 62*(6), 1485-1490.

Watwood, S., Miller, P. J. O., Johnson, M., Madsen, P. T., & Tyack, P. L. (2006). Deep-diving behaviour of sperm whales (*Physeter macrocephalus*). *Journal of Animal Ecology, 75*, 814-825. doi: 10.1111/j.1365-2656.2006.01101.x

Wiggins, S. M., & Hildebrand, J. A. (2007). High-frequency Acoustic Recording Package (HARP) for broadband, long-term marine mammal monitoring. *International Symposium on Underwater Technology 2007 and International Workshop on Scientific Use of Submarine Cables and Related Technologies 2007*, 551-557.

Zimmer, W. M. X., Johnson, M. P., Madsen, P. T., & Tyack, P. L. (2005). Echolocation clicks of free-ranging Cuvier's beaked whales (*Ziphius cavirostris*). *Journal of the Acoustical Society of America, 117*(6), 3919-3927. doi: 10.1121/1.1910225