Passive Acoustic Monitoring for Marine Mammals in the SOCAL Naval Training Area 2010-2011

John A. Hildebrand, Simone Baumann-Pickering, Ana Širović, Hannah Bassett, Amanda Cummins, Sara Kerosky, Lauren Roche, Anne Simonis, and Sean M. Wiggins

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

Photo by Michael H. Smith

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Executive Summary

Passive acoustic monitoring was conducted at two sites in the Navy's Southern California Range Complex during April 2010 – April 2011. These data provide information on the presence of marine mammals and anthropogenic sound sources. High-frequency acoustic recording packages documented sounds between 10 Hz and 100 kHz with nearly continuous temporal coverage at a site near Santa Barbara Island (site M) and a site south of San Clemente Island (site N). Data analysis methods consisted of analyst scans of long-term spectral averages and spectrograms. The data were divided into three frequency bands and each band was analyzed for the sounds of marine mammal species or anthropogenic sources. Representative sounds are presented.

Six baleen whale species were recorded: blue whales, fin whales, Bryde's whales, gray whales, humpback whales, and minke whales. Site N has more calling baleen whales than site M, as blue, fin, humpback, and Bryde's whale calls were all detected during more hours at site N. However, gray whale calls were detected only at site M. Pinniped barks, presumably made by California sea lions, were recorded during just a single week and only at site M. The largest number of odontocete detections by echolocation clicks and whistles were attributed to "unidentified dolphin" which is primarily comprised of short- and long-beaked common dolphins as well as bottlenose dolphins. Unidentified dolphins were detected throughout the year with a peak acoustic activity in late summer and fall months. Overall numbers of detections were slightly higher at site N than M. There was a distinct diel acoustic activity likely due to nighttime foraging, which was more apparent for click and less for whistle detections. Risso's dolphin echolocation clicks occurred throughout the year with increased detections in winter and early spring at site M. They were generally more frequent at site M than N. Two kinds of Pacific white-sided dolphin echolocation clicks were detected: Type A were present more often at site N and with higher numbers of detections at night indicating nighttime foraging, whereas type B were overall very seldom with highest detections at site M and a higher rate of detections during daytime. Sperm whale echolocation clicks were distributed throughout the year with more frequent detections at site M. Cuvier's beaked whales were detected throughout the year at both sites with higher numbers of occurrences at site N. A few detections were made of Baird's beaked whale and Stejneger's beaked whale, as well as two unidentified beaked whales with peak echolocation signal frequencies at 43 kHz and 50 kHz.

Ship noise was the most common anthropogenic noise at both sites M and N. Both sites had Mid-Frequency Active (MFA) sonar events throughout the period April 2010 – April 2011. At site N, over 55,000 MFA sonar pings were detected ranging from 105 to 170 dB pp re 1 μPa. While site M had MFA sonar events recorded, the received levels and the number of pings were often much lower (e.g. < 120 dB pp re 1 μPa and 10's of pings/event) than at site N. Echosounder pings with a variety of primary frequencies (8 – 80 kHz) were found at both sites M and N. More echosounders were present at site M than at site N. Explosions were recorded at both sites up to 40 hours per week.

Project Background

The Navy's Southern California Offshore Range (SCORE) is located in the California Borderlands and adjacent deep water to the west (Figure 1). This region has a highly productive marine ecosystem owing to the southward flowing California Current, and associated coastal current system. A diverse array of marine mammals is found in this region, including baleen whales, beaked whales and other cetaceans and pinnipeds.

In January 2009, an acoustic monitoring effort was initiated within the boundaries of SCORE with support from the Pacific Fleet under contract to the Naval Post-Graduate School (DoN 2009). The goal of this effort was to characterize the vocalizations of marine mammal species present in the area, to determine their year-round seasonal presence, and to evaluate the potential for impact from Naval operations. This report documents the analysis of two High-frequency Acoustic Recording Packages (HARPs) that have been deployed within SCORE, one to the southwest and one to the northwest of San Clemente Island (Figure 1) during the time period April 2010 – April 2011.

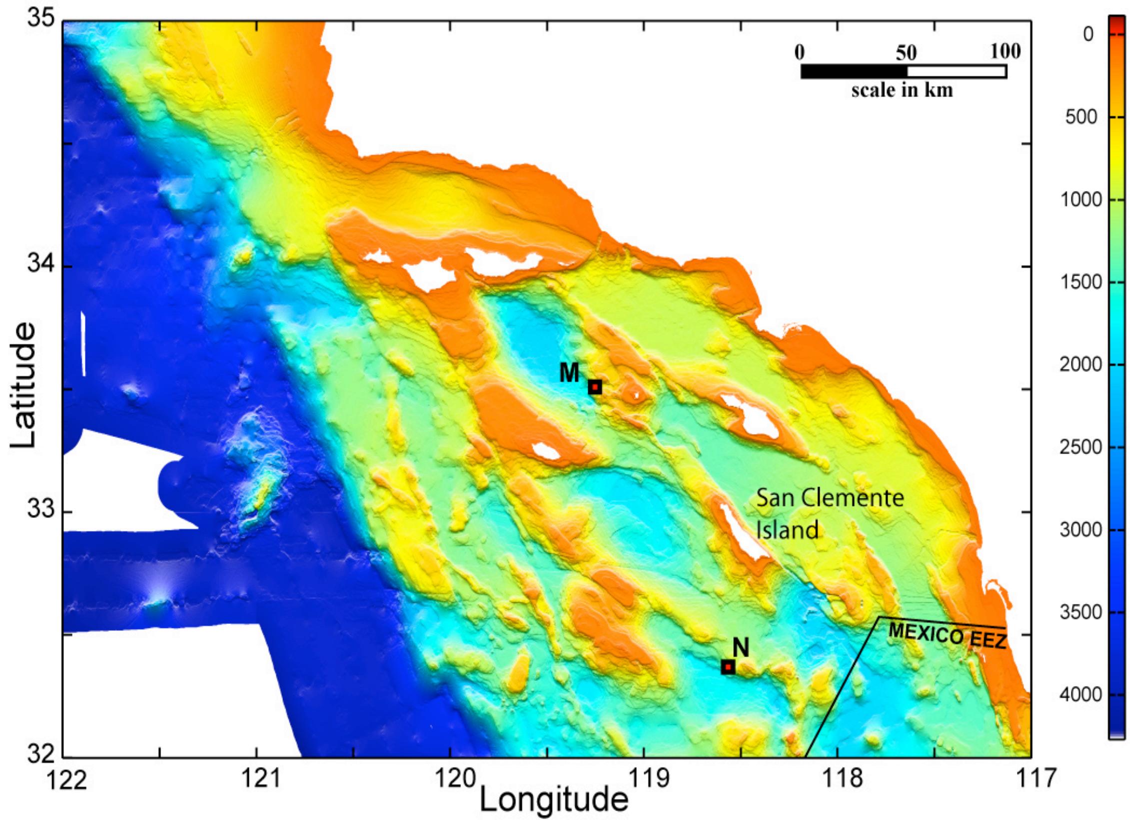

Figure 1 Locations of High-frequency Acoustic Recording Packages at sites M and N in the southern California Range Complex area. Color is bathymetric depth (scale bar at right in meters depth).

Methods

High Frequency Acoustic Recording Packages

High-frequency Acoustic Recording Packages (HARPs) were used to detect marine mammal species and characterize ambient noise in the SOCAL Naval Training area. HARPs record underwater sounds from 10 Hz to 100 kHz with approximately 110 days of continuous data storage. The HARP sensor and mooring package are described in Wiggins and Hildebrand (2007). For the SOCAL range deployments, the HARP was located on 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 have also been calibrated at the Navy's TRANSDEC facility to verify the laboratory calibrations.

Data Collected to Date

Acoustic data have been collected at two sites within SCORE using autonomous High-frequency Acoustic Recording Packages (HARPs) sampling at 200 kHz since January 2009 (Table 1). The two sites are designated site M (33° 30.92N, 119° 14.96W, depth 920 m) and site N (32° 22.18N, 118° 33.77W, depth 1250 m).

Table 1. SCORE acoustic monitoring since January 2009. Period of instrument deployment analyzed in this report is shown in bold. Results of acoustic monitoring through April 2010 are described in Hildebrand et al. (2009, 2010a and 2010b).

Deployment Designation	**Site M Deployment Period**	**Site N Deployment Period**
SOCAL 31	1/13/09 - 3/10/09	1/13/09 - 3/13/09
SOCAL 32	3/10/09 - 5/16/09	3/14/09 - 5/19/09
SOCAL 33	5/16/09 – 7/26/09	5/19/09 – 7/22/09
SOCAL 34	7/27/09 – 9/25/09	7/22/09 – 9/25/09
SOCAL 35	9/25/09 – 12/4/09	9/25/09 – 12/6/09
SOCAL 36	12/4/09 – 1/29/10	12/6/09 – 1/30/10
SOCAL 37	1/29/10 – 4/9/10	1/30/10 – 4/11/10
SOCAL 38	**4/9/10 – 7/21/10**	**4/11/10 – 7/23/10**
SOCAL 40	**7/21/10 – 12/5/10**	**7/23/10 – 12/6/10**
SOCAL 41	**12/5/10 – 5/10/11**	**12/6/10 – 5/12/11**

Data Analysis

To assess the quality of the acoustic data, frequency spectra were calculated for all the data (over one-year at each of two instruments) using a time average of 5 seconds and frequency bins of 1 Hz. These data, called Long-Term Spectral Averages (LTSA) were then examined both for characteristics of ambient noise and also as a means to discover marine mammal and anthropogenic sounds in the data set.

Recording a broad frequency range up to 100 kHz allows detection of baleen whales (mysticetes), toothed whales (odontocetes) and seal/sea lion (pinniped) species. 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 scrutinizing LTSAs in appropriate frequency bands. When a sound of interest was identified in the LTSA, we often examined the waveform or spectrogram at the time of interest to further identify particular sounds to species or source. Acoustic classification was carried out either from comparison to species-specific spectral characteristics or through analysis of the time and frequency characters of individual sounds.

To document the data analysis process, we describe the major classes of marine mammal calls and anthropogenic sounds in the SOCAL region, and the procedures used 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 are as follows: (1) low frequencies, between 10 – 1000 Hz, (2) mid frequencies, between 500 – 5000 Hz, and (3) high frequencies, between 1 – 100 kHz. Blue, fin, Brydes's, and grey whale sounds were classified as low frequency; humpback, minke, pinnipeds, shipping, explosions, and mid-frequency active sonar were classified as mid-frequency; while the remaining odontocete and sonar sounds were considered high-frequency. We describe the calls and procedures separately for each frequency band.

Low Frequency Marine Mammals

For the low frequency data analysis, the 200 kHz sampled raw-data are decimated by a factor of 100 for an effective bandwidth of 1 kHz. Long-term spectral averages (LTSAs) of these data are created using a time average of 5 seconds and frequency bins of 1 Hz. The presence or absence of each call type was determined in hourly bins for each low frequency dataset.

Blue whale A, B and D calls, fin whale 20 Hz pulses, and Bryde's whale Be4 calls were monitored for this report, in addition to gray whale calls and the "50 Hz pulse" call type of unknown origin (presumably baleen whale). A low frequency rapid pulsing sound (presumably from fish) is also described as it occasionally masked baleen whale sounds. The same LTSA and spectrogram parameters were used to detect all call types. For spectrogram scrolling, the LTSA frequency was set to display between 1-500 Hz. To observe individual calls, spectrogram parameters were typically set to 120 seconds by 200 Hz. The FFT was generally set between 1500 and 2000 data points (yielding about 1 Hz frequency resolution), with an 85-95% overlap of data in the input time series. Table 2 presents a quantitative description of each call type.

Table 2: Description of selected low frequency whale calls in SOCAL HARP data. The mean values (±one standard deviation) of measurements from 30 independent calls are presented. Measured calls were separated by a minimum of 24 hours to try to ensure calls from a single animal are not over-represented.

Species	Call Type	Start Frequency (Hz)	End Frequency (Hz)	Duration (s)
Blue whale	B	48.6 (± 0.9)	44.3 (± 0.7)	12.2 (± 1.5)
	D	72.5 (± 11.6)	32.3 (± 8.2)	3.3 (± 1.6)
Fin whale	20 Hz pulse	31.6 (± 2.3)	18.7 (± 1.4)	1.1 (± 0.2)
Unidentified	50 Hz pulse	62.6 (± 5.7)	46.5 (± 5.5)	0.6 (± 0.1)
Bryde's whale	Be4	52.9 (± 1.5)	58.1 (± 0.6)	1.9 (± 0.3)

Blue Whales

Several different calls were used to detect the presence of blue whales in the dataset. Calls of type A and B (**Figure 2**) are representative of the blue whale population found in the eastern North Pacific (McDonald et al. 2006) and are produced exclusively by males and likely associated with mating behavior (Oleson et al. 2007a). These calls have long durations (20 sec) and low frequencies (10-100 Hz) that can be produced either as repetitive sequences (song) or as singular calls. The A call is pulsed, whereas the B call has a set of harmonic tonals. Individual A and B calls are readily detected in an LTSA, owing to their long duration (**Figure 2**). For this report manual scanning of the LTSA has been the primary means for blue whale call detection.

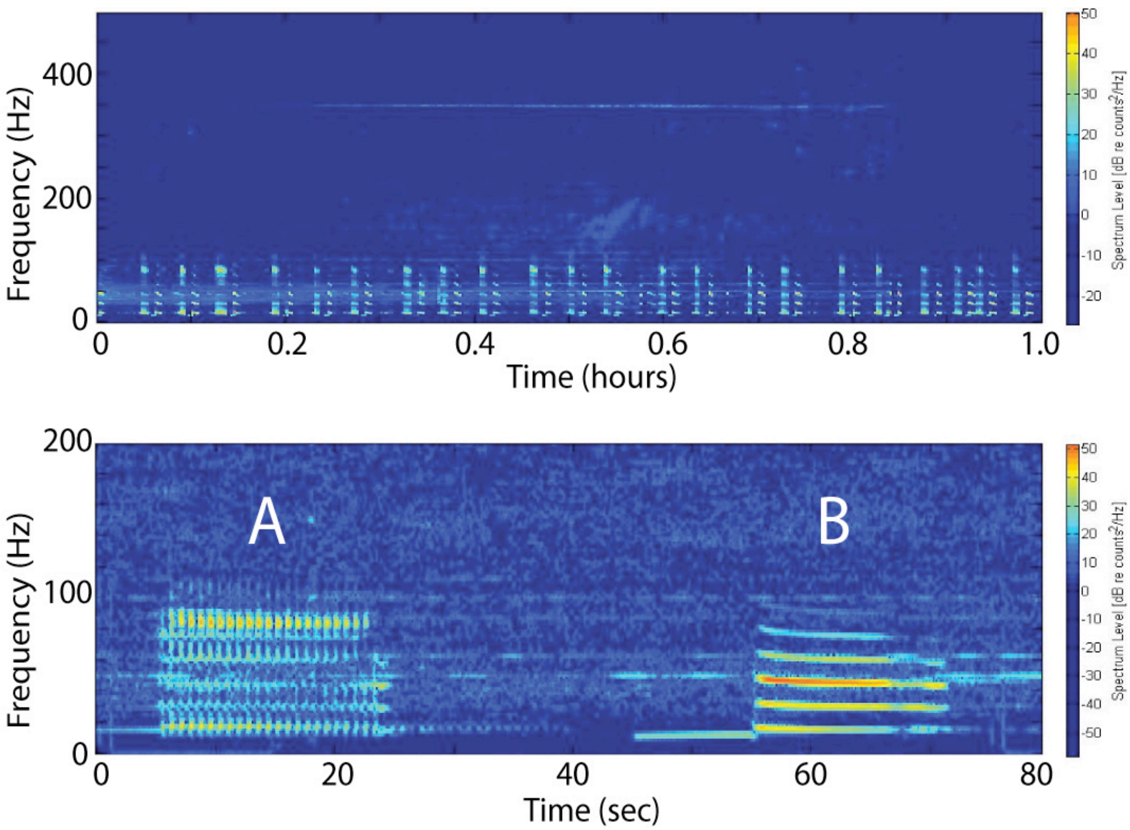

Figure 2 Long term spectral average (above) and spectrogram (below) of blue whale A and B calls (spectrogram made with 1200-point FFT and 80% overlap).

Since blue whale calls are low frequency, they occupy the same band as noise generated by shipping, as well as sounds thought to be produced by fish (Figure 3). These anthropogenic and biological sounds make it challenging to detect blue whale calls, affecting the ability of both analysts and computer algorithms to find calls imbedded in noise. Likewise, there are regular sounds introduced into the HARP data on a 75 sec interval that are associated with the noise of the mechanical spinning of the disk drive, appearing in the LTSA as a regular series of sounds.

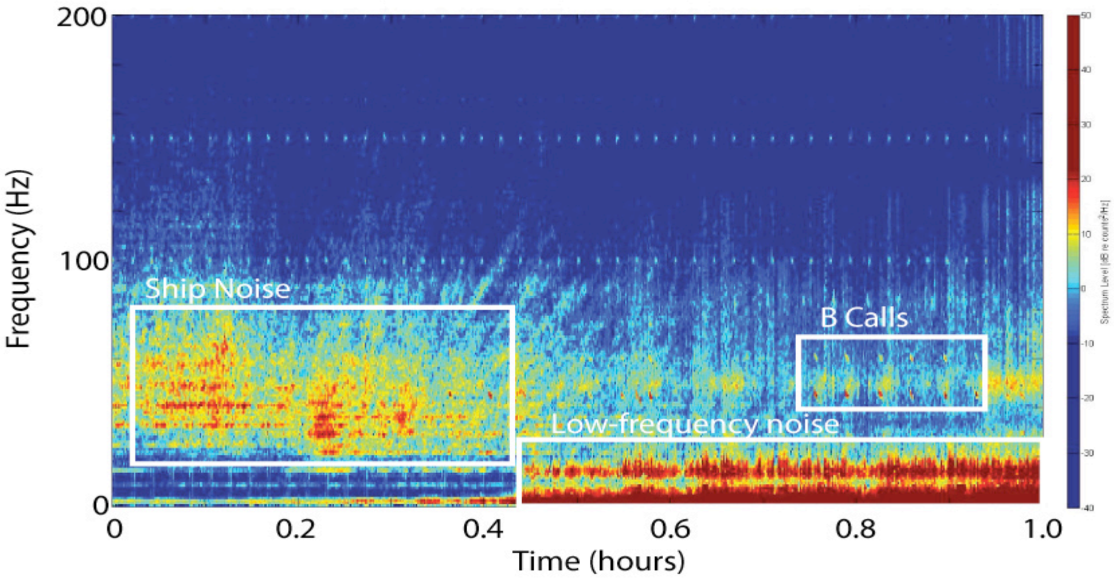

Figure 3 LTSA with blue whale B calls in the presence of ship noise and low frequency rapid-pulsing noise (thought to be produced by fish).

Blue whale B calls are long duration tonals that are harmonically related and slightly downswept in frequency. Owing to greater noise at low frequency, B calls are best identified based on the presence of their 3rd harmonic at 46 Hz, which generally has a higher signal to noise ratio (SNR) than the fundamental frequency at 15 Hz. B calls occasionally exhibit two segments, with a break or step in the frequency of the tonal in the latter portion of the call (Figure 4).

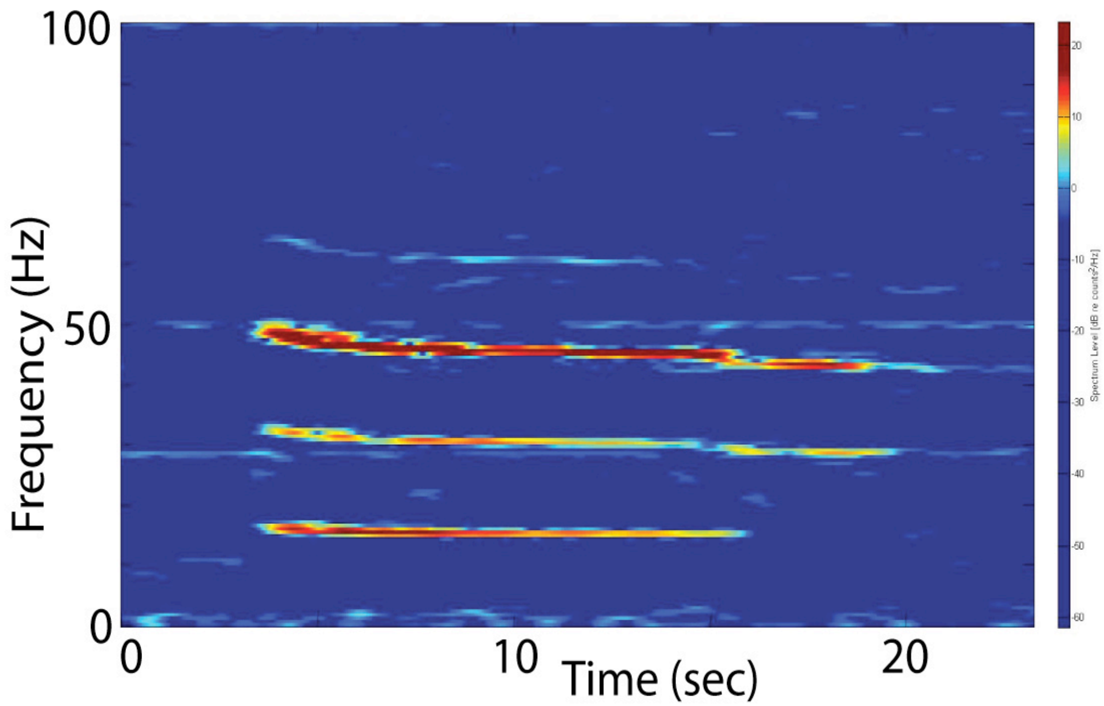

Figure 4 Blue whale B call showing harmonic tones with frequency step near the end of the call (FFT 3500 points, 98% overlap)

Blue whale D calls are down-swept in frequency (100-40 Hz) with a duration of several seconds (Figure 5). 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. 2007a). In the SOCAL region, D calls are produced in highest numbers during the late spring and early summer, and in diminished numbers during the fall, when A-B song dominates blue whale calling (Oleson et al. 2007b).

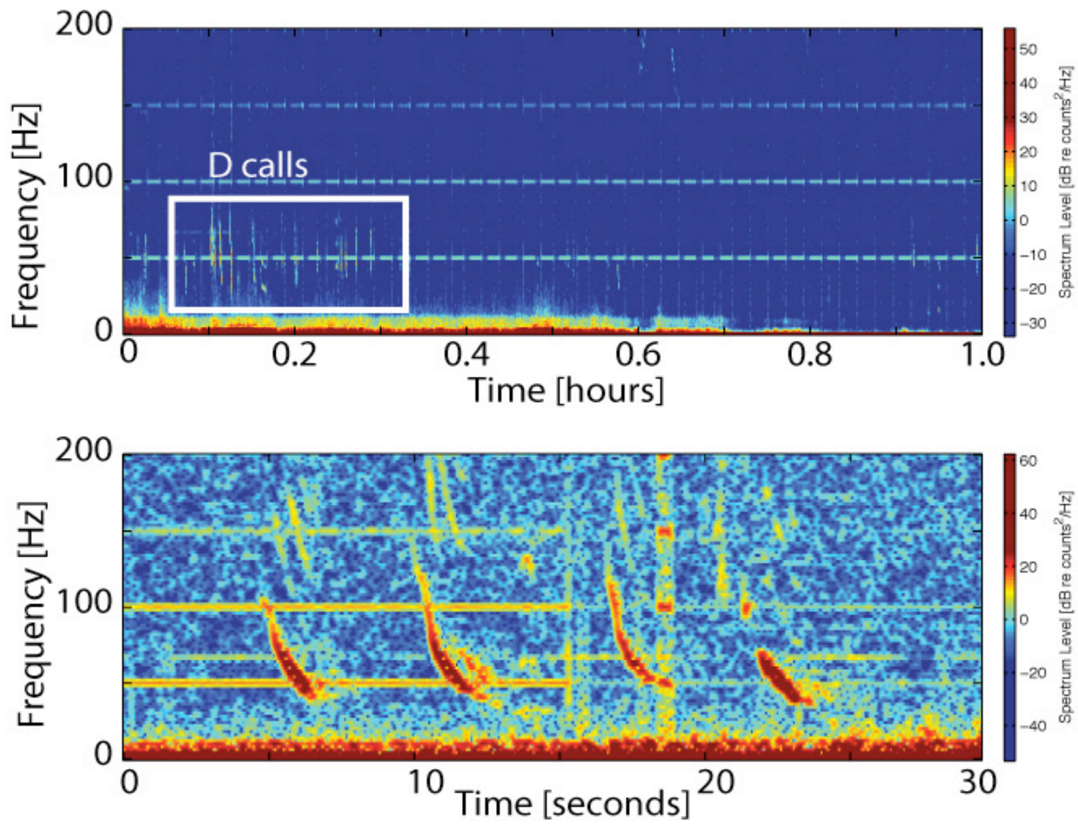

Figure 5 LTSA (above) with a red box marking the period of blue whale D calls enlarged in the spectrogram (below), (1000-point FFT and 90% overlap).

Fin Whales

Fin whales are known to produce pulsed calls with about 1 sec duration, that are downswept in the frequency band 30 - 15 Hz (Figure 6). These pulses occur both at regular intervals as song (Thompson et al. 1992), and at somewhat irregular intervals as counter-calling between multiple animals (McDonald et al. 1995). Fin whale 20 Hz pulses appear as a band of energy in the LTSA (Figure 7). For the purposes of this report we indicate the presence of 20 Hz pulses, but we do not attempt to categorize them as either song or irregular interval calls.

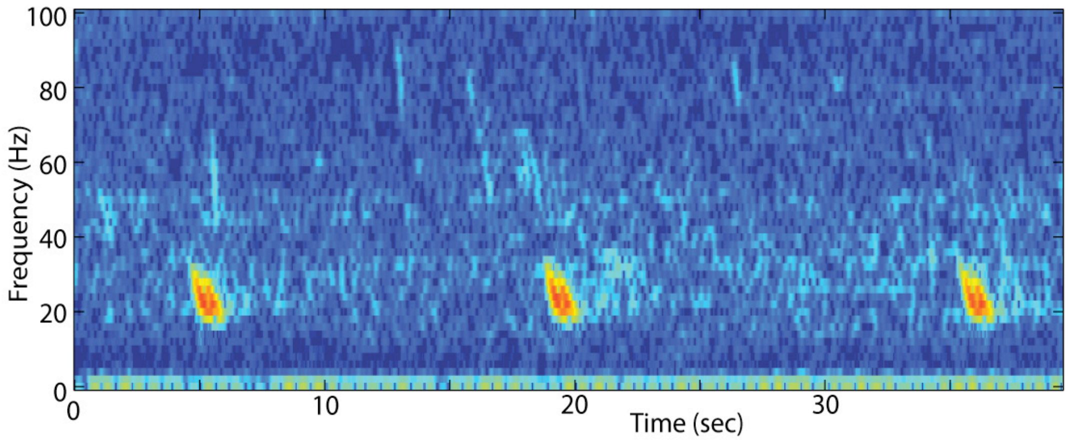

Figure 6 Fin whale 20 Hz pulsed call, created in regular pattern or song.

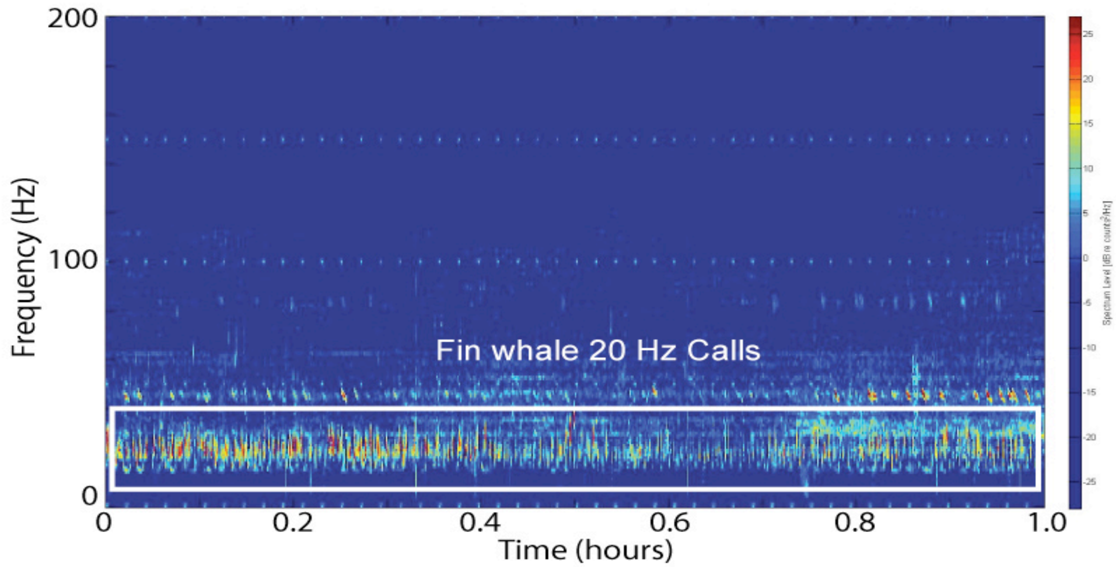

Figure 7 LTSA with fin whale 20 Hz pulsed calls (as well as blue whale B and D calls).

"50 Hz" Whales

Another low frequency call detected in the SOCAL data is a downswept pulse from 75 – 40 Hz; we will designate these as "50 Hz" calls (**Figure 8** for spectrogram and Figure 9 for LTSA). The 50 Hz calls were first described by Watkins (1981) as associated with fin whales, but they have not been reported in the literature since. For this report manual scanning of the LTSA and subsequent verification from a spectrogram have been the primary means for 50 Hz call detection.

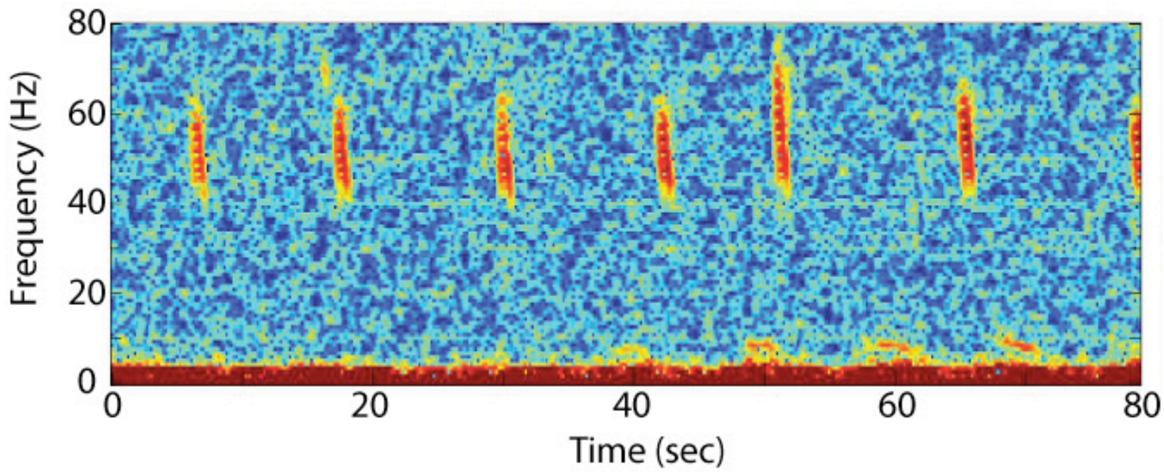

Figure 8 The 50 Hz pulse that has been associated with fin whales (Watkins 1981).

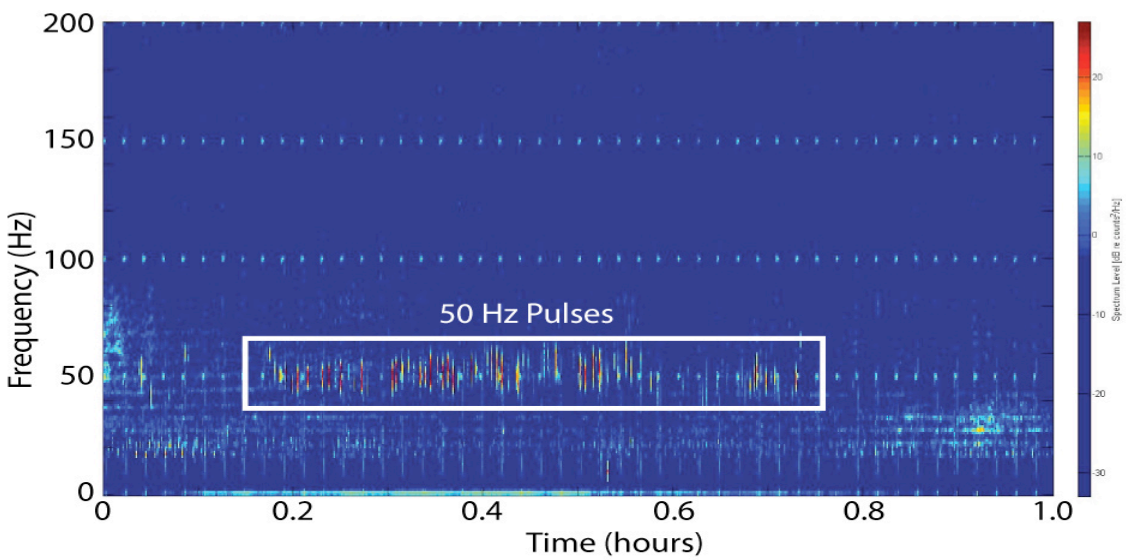

Figure 9 LTSA of the 50 Hz pulse associated with fin whales.

Bryde's Whales

Bryde's whales generally inhabit the warm waters of the eastern tropical Pacific and the Gulf of California, Mexico (Leatherwood *et al.*, 1988; Tershy *et al.*, 1991). The SOCAL region is considered their northerly range limit, although they have been sighted occasionally farther north (Barlow & Forney, 2007). The Be4 call is one of several call types (Oleson et al. 2003) in the Bryde's whale repertoire. Be4 calls are the most common Bryde's whale call observed in the SOCAL region. The Be4 call consists of a short, slightly upswept tone between 50 – 60 Hz. The call occasionally has harmonics and overtones present, along with an undertone that follows the primary tone (Figure 10 and Figure 11). The Be4 call is typically observed at regular intervals; occasionally, it is evident that multiple callers are present.

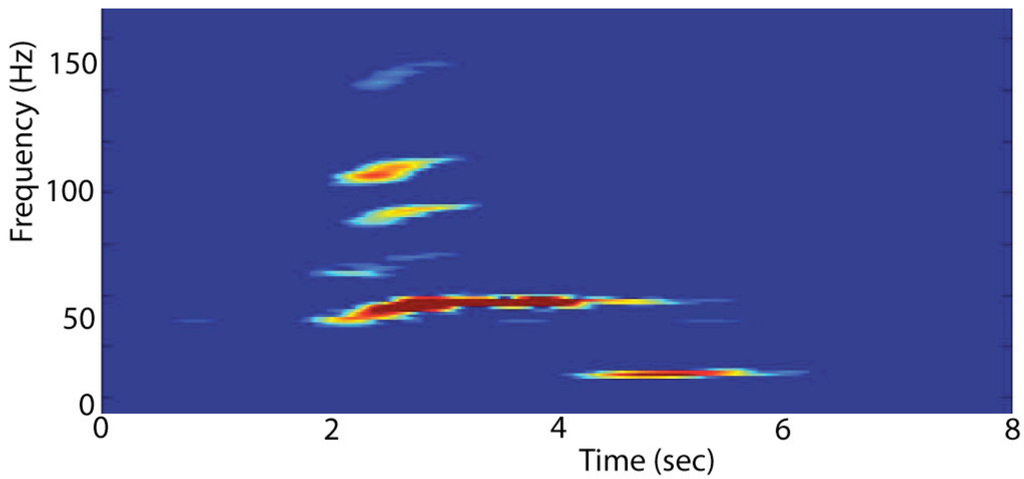

Figure 10 Spectrogram of Bryde's whale Be4 call type.

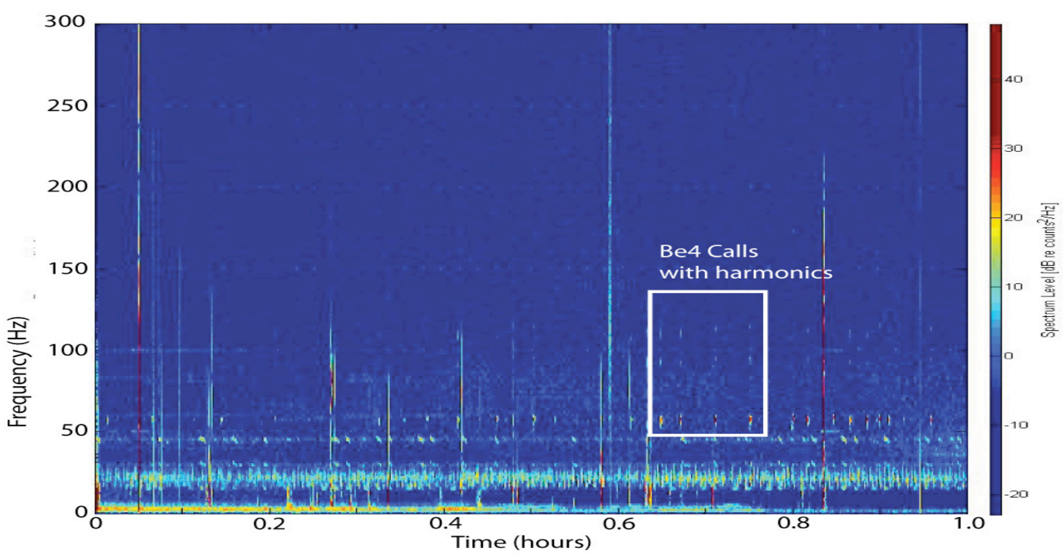

Figure 11 LTSA with Bryde's whale Be4 call type at 60 Hz with overtones.

Gray Whales

Gray whales produce low frequency sounds along their migration route between Baja California and the Bering Sea. Four types of sounds have been described (Crane and Lashkari 1996): M1 were pulses and bonging signals, M3 were low frequency moans, M4 were grunts, and M5 were subsurface exhalations. M3 signals are known to be the most common (Figure 12), followed by M1 signals (Figure 13). Both signal types can be discerned from the LTSA and are reported jointly in this report.

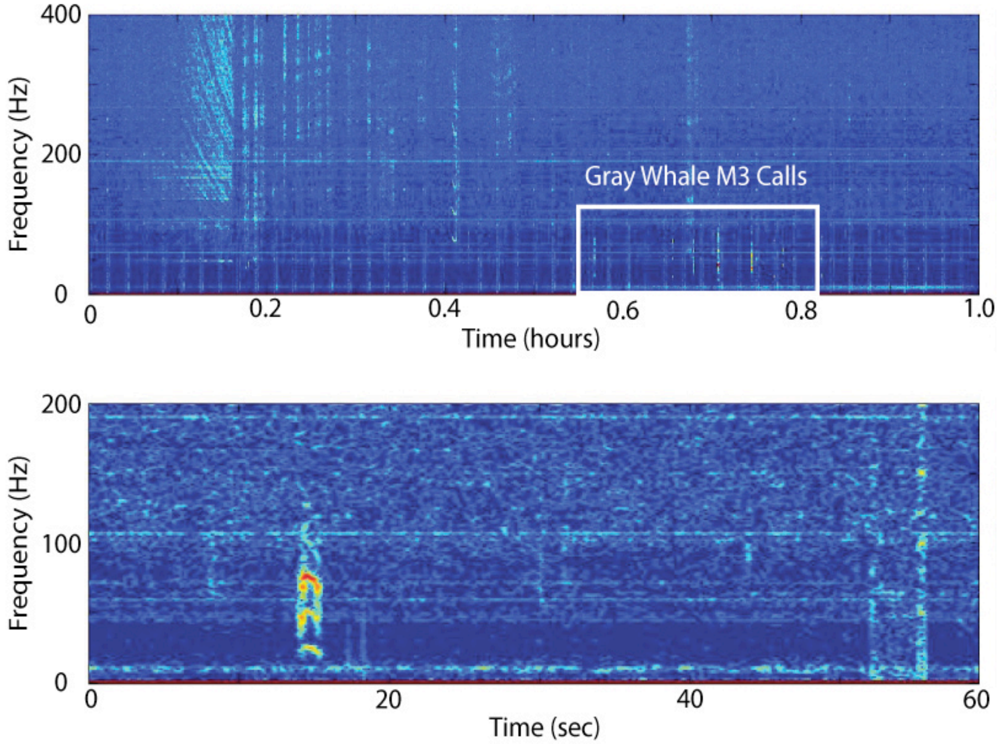

Figure 12 LTSA and spectrogram of gray whale M3 calls.

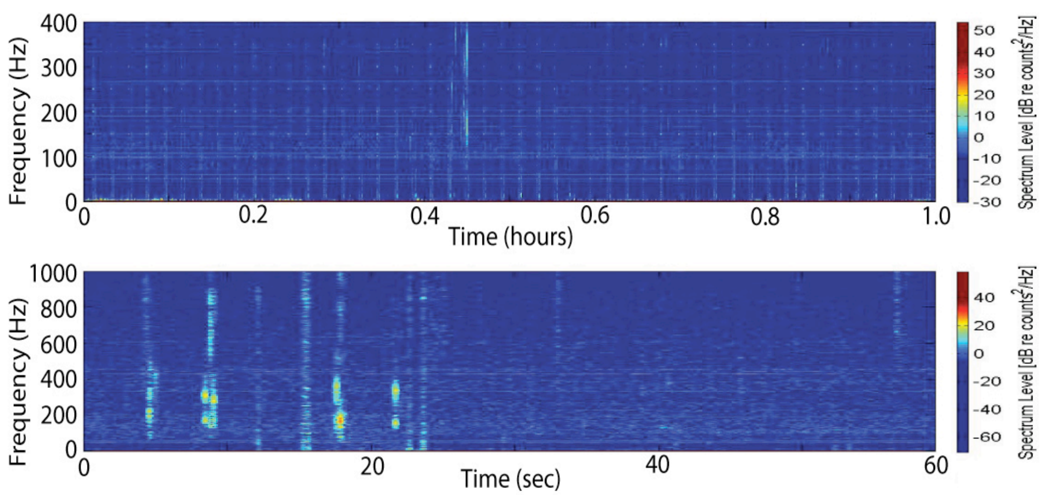

Figure 13 LTSA and spectrogram of gray whale M1 calls.

Mid-Frequency Marine Mammals

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

Mid-frequency sounds monitored in this report include: humpback whale, minke whale, pinniped, MFA (Mid-Frequency Active) sonar, explosions, and broadband ship noise. The LTSA search parameters used to detect each sound are given in Table 2.

Table 2. Mid-Frequency data analysis parameters.

	LTSA Search Parameters	
Species	Plot Length (Hr)	Frequency Range (Hz)
Humpback	0.75	150-5000
Minke	0.5	1000-2000
Pinniped	0.75	200-700
MFA Sonar	0.75	1000-5000
Broadband Ship Noise	3.0	0-5000
Explosions	0.75	0-5000

Humpback Whale

Humpback whales song is categorized by the repetition of units, phrases and themes as defined by Payne and McVay (1971). Non-song vocalizations such as social sounds and feeding sounds consist of individual units that can last from 0.15 to 2.5 seconds (see Dunlop et al 2007 and Stimpert et al 2001). Most humpback whale vocalizations are produced between 100-3000 Hz (Figure 14). For this report we detected humpback calls (both song and non-song) using a computer algorithm (Helble et al. submitted), and then verified the accuracy of the detected signals with a trained analyst.

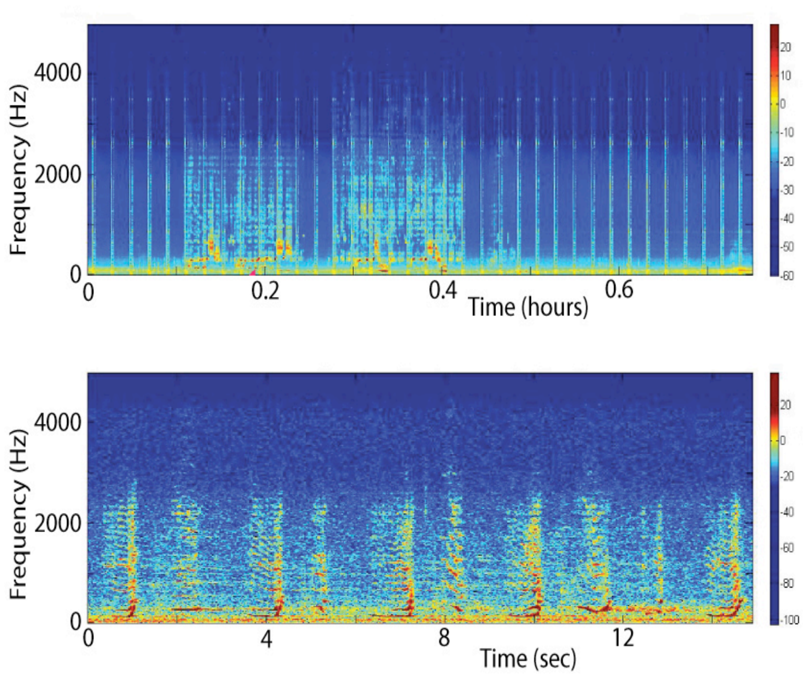

Figure 14 Humpback song in the LTSA (above) and spectrogram (below).

Minke Whale

Minke whales “boings” consist of 2 parts, beginning with a burst followed by a long buzz, with the dominant signal band just below 1400 Hz (Figure 15). A typical California minke boing has an average duration of 3.6 seconds and a pulse repetition rate of 92 s^{-1} (Rankin and Barlow 2005).

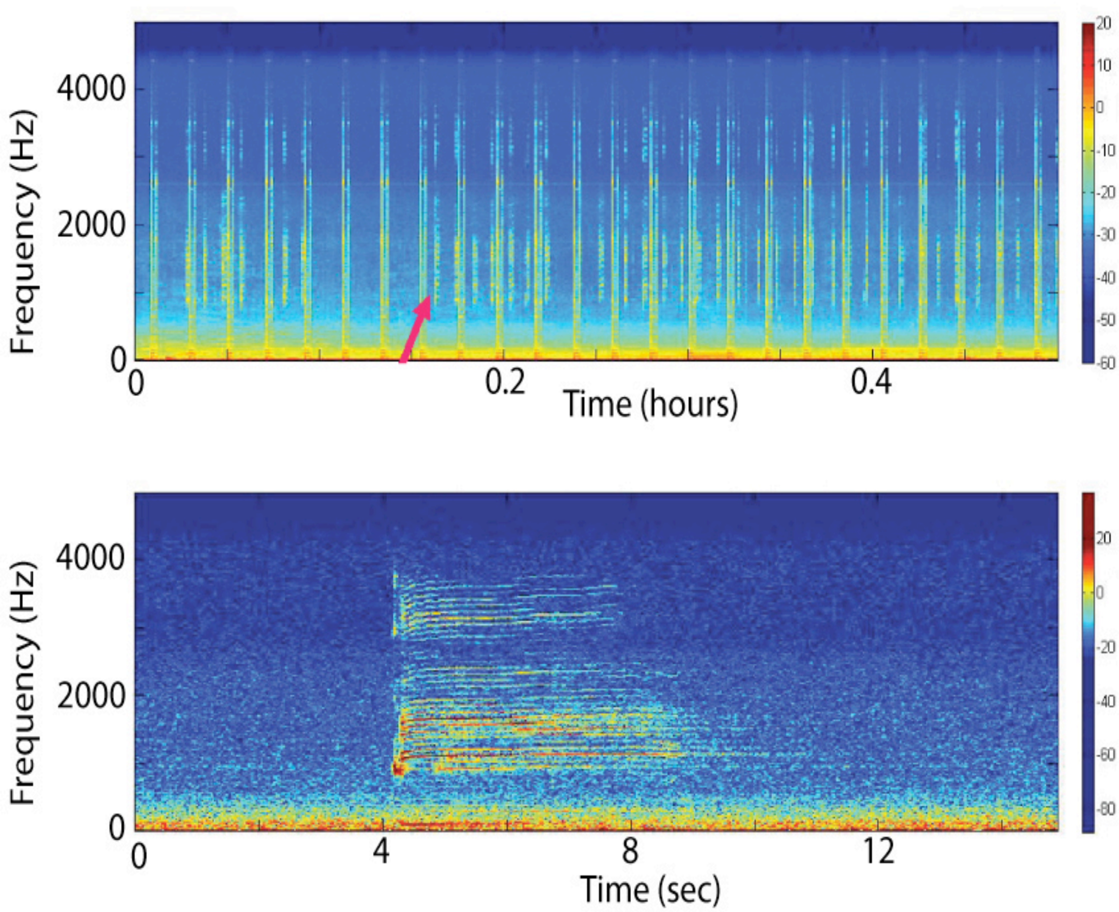

Figure 15 A series of minke boings in the LTSA (above with red arrow), with a single boing in the spectrogram (below).

Pinniped

Pinniped sounds in California consist mainly of barking California sea lions. Most of these vocalizations occur between 400 and 600 Hz, with short durations of less than 1 second. Pinniped vocalization bouts can occur up to several hours at a time. Often confused with humpback vocalizations in the LTSA, it is necessary to zoom in to the spectrogram view to confirm presence of pinnipeds in the data (Figure 16).

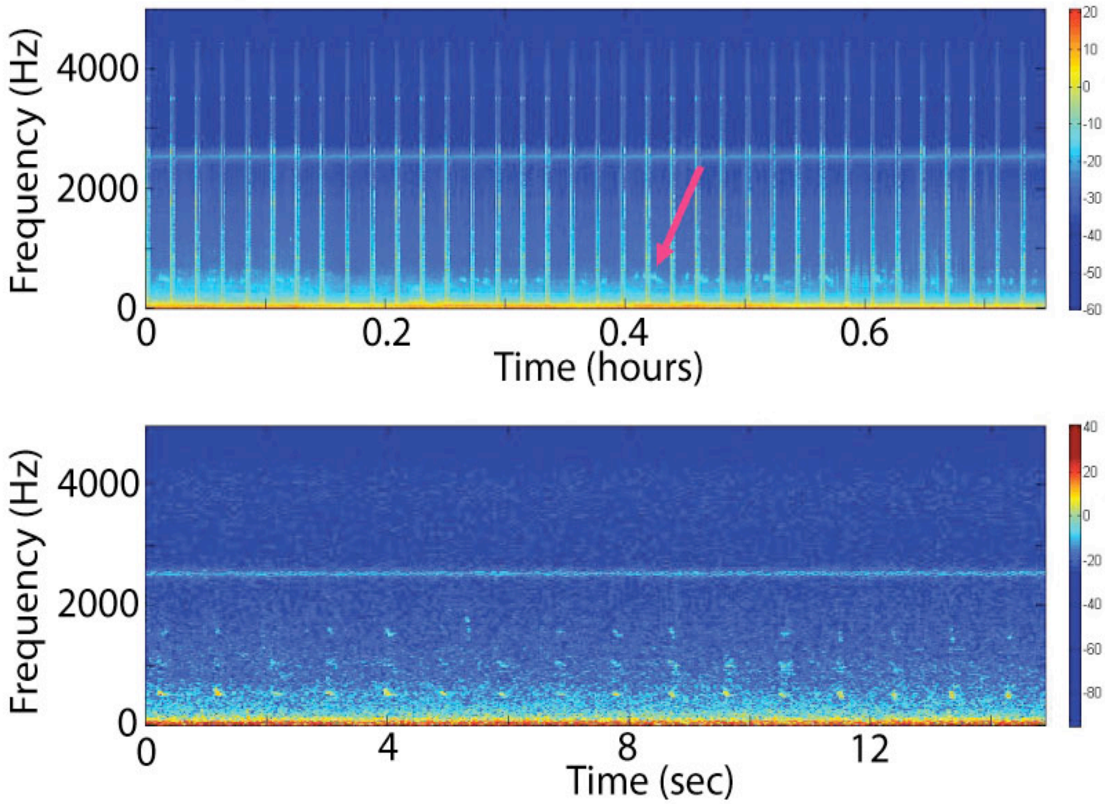

Figure 16 A bout of pinniped barks in the LTSA (red arrow in upper) and spectrogram (below).

High Frequency Marine Mammals

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

Unidentified Dolphin

Delphinid sounds can be categorized as either: (1) echolocation clicks, (2) buzz pulses, or (3) whistles. Dolphin echolocation clicks are broadband impulses with the majority of energy between 20 and 60 kHz. Buzz pulses are rapidly repeated clicks that have a creak or buzz-like sound quality; they are in approximately the same frequency band as the echolocation clicks. Dolphin whistles are tonal calls predominantly between 5 and 20 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 17).

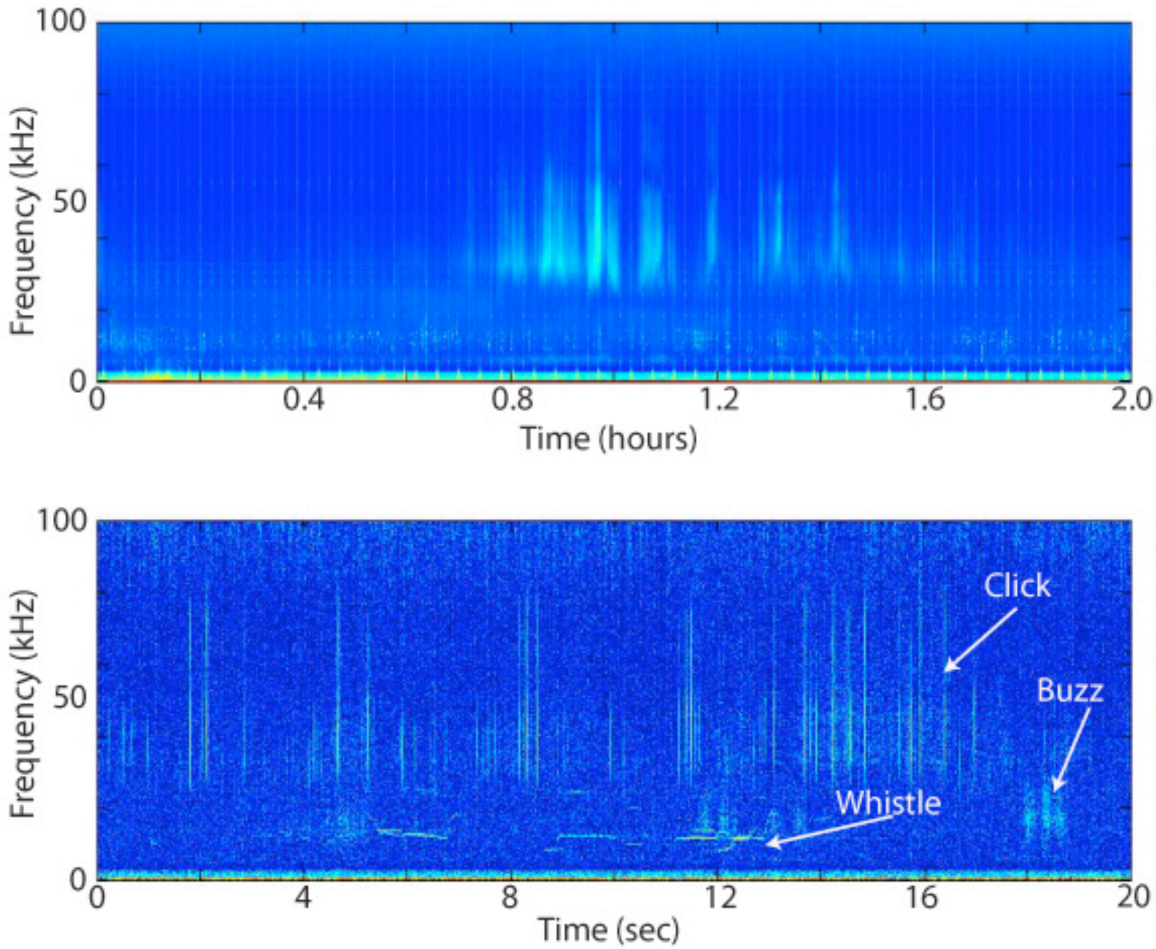

Figure 17 LTSA (top) and spectrogram of odontocete echolocation clicks and whistles (either common or bottlenose dolphins).

Some delphinid sounds are not yet distinguishable by species based on the character of their clicks, buzz pulses or whistles (Roch et al. 2007 and 2011). Both common dolphin species (short-beaked and long-beaked) and bottlenose dolphins make clicks and whistles that are thus far indistinguishable from each other (Soldevilla et al. 2008). These detections are classified as odontocete echolocation clicks in the HARP data analysis.

Risso's Dolphin

Risso's dolphin echolocation clicks can be identified to species by their distinctive banding patterns observable in the LTSA (Figure 18). Risso's dolphin echolocation clicks have energy peaks at 22, 26, 30, and 39 kHz (Soldevilla *et al*. 2008).

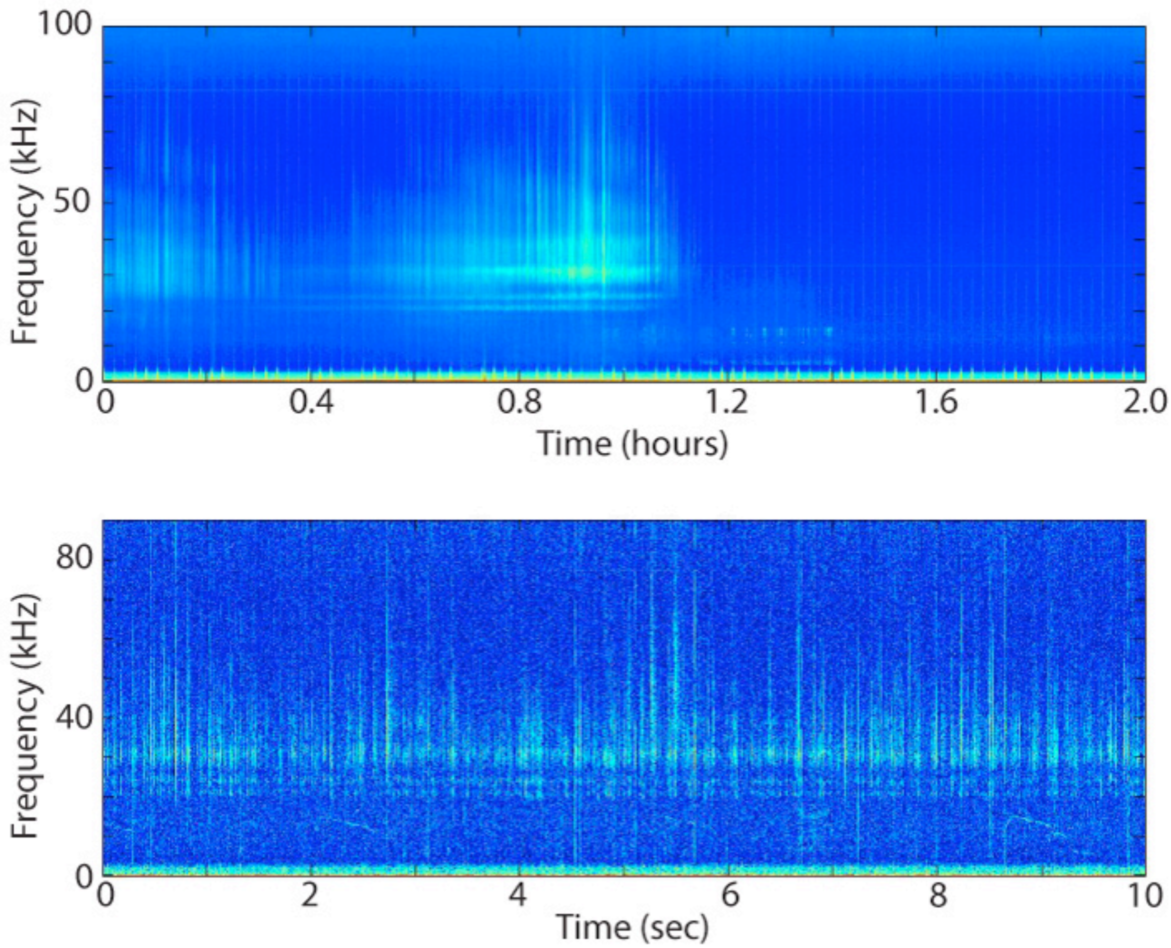

Figure 18 Risso's dolphin click bout in LTSA (above) and spectrogram (below). A distinctive banding pattern is seen in the LTSA

Pacific White-Sided Dolphin

Pacific white-sided dolphin echolocation clicks also can be identified to species by their distinctive banding patterns (**Figure 19** and **Figure 20**). Pacific white-sided dolphin echolocation clicks have energy peaks at 22, 27, 33, and 37 kHz. Soldevilla et al. (2008, 2010) were able to decipher two different click types within Pacific white-sided dolphin recordings that belong to the two populations with ranges that overlap in the Southern California Bight. The two click types are distinguished by a frequency difference in the second peak. For the HARP data analysis we have specified the Pacific white-sided clicks to be either type A (**Figure 19**) or B (**Figure 20**).

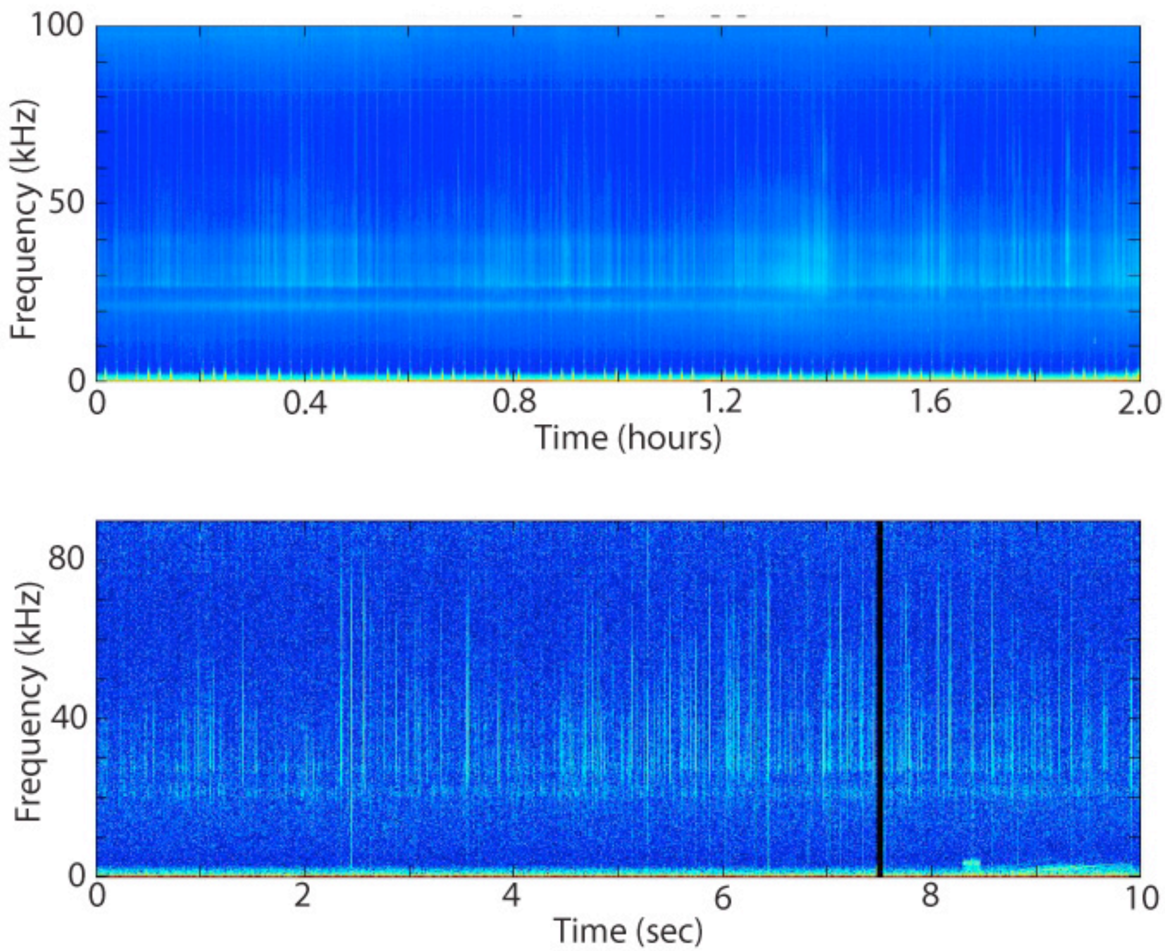

Figure 19 Pacific white-sided dolphin type A echolocation clicks in LTSA (above) and spectrogram (below).

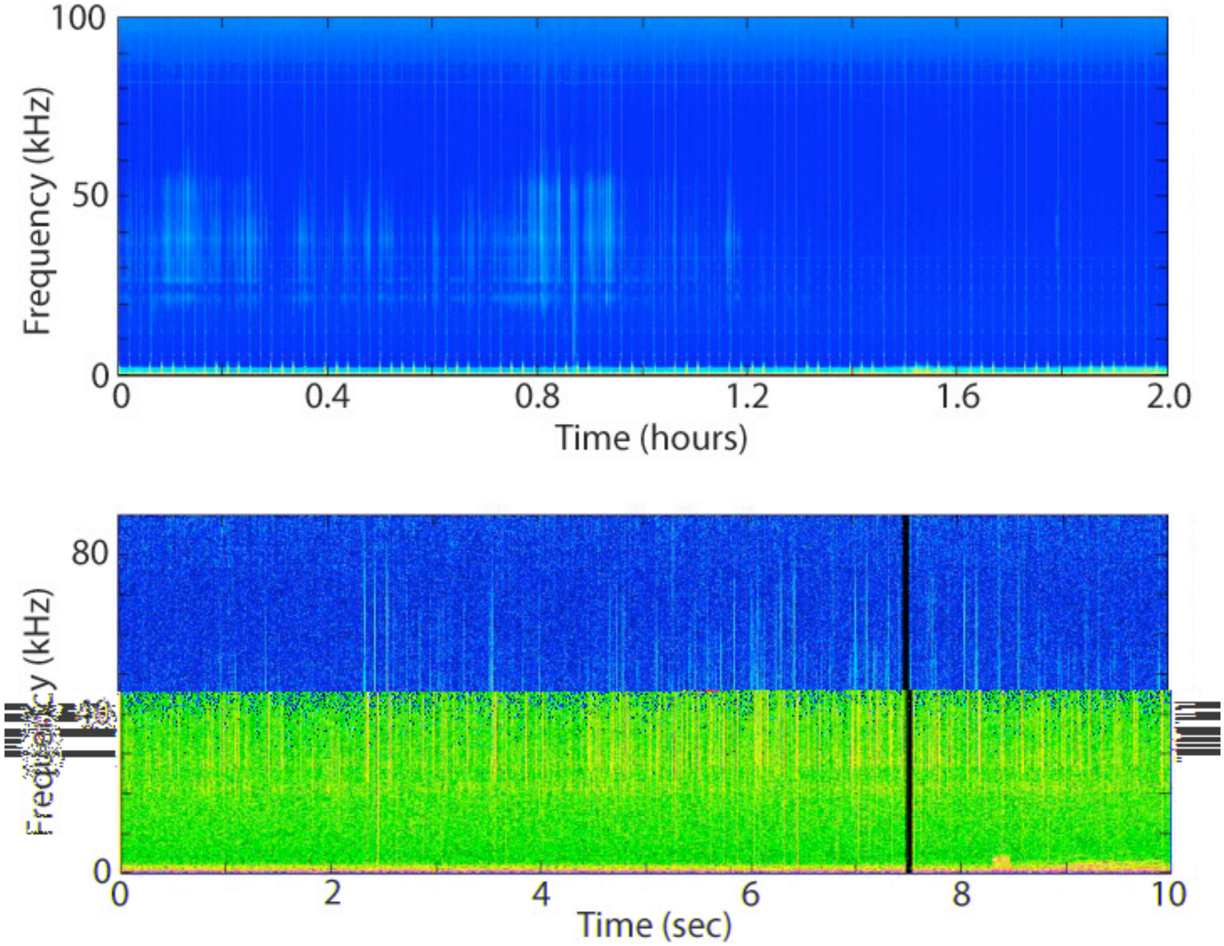

Figure 20 Pacific white-sided dolphin type B echolocation clicks in LTSA (above) and spectrogram (below).

Killer Whale

Killer whales are known to produce four call types: echolocation clicks, low frequency whistles, high-frequency (ultrasonic) whistles, and pulsed calls (Ford *et al.* 1989, Samarra et al. 2010). Killer whale pulsed calls are well documented and the best described of their 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 *et al.* 1989). Ultrasonic whistles have only recently been attributed to killer whales in both the Northeast Atlantic (Samarra *et al*. 2010) and Northeast Pacific (Simonis *et al*., in prep.). These whistles have fundamental frequencies between 17 and 75 kHz, the highest of any known delphinid whistles.

We do not use echolocation clicks or low frequency whistles to positively identify killer whale presence as these call-types are highly variable and not easily distinguished from other odontocete clicks and whistles (e.g. pilot whales). Instead we use the pulsed calls (**Figure 21**) and the ultrasonic whistles (Figure 22) for killer whale species identification. Since killer whale sightings in the SOCAL region are rare (authors' CalCOFI survey results), few acoustic detections were expected. Additionally, acoustic classification of killer whale signals is difficult due to their similarity with false killer whale and short-finned pilot whale acoustic signals.

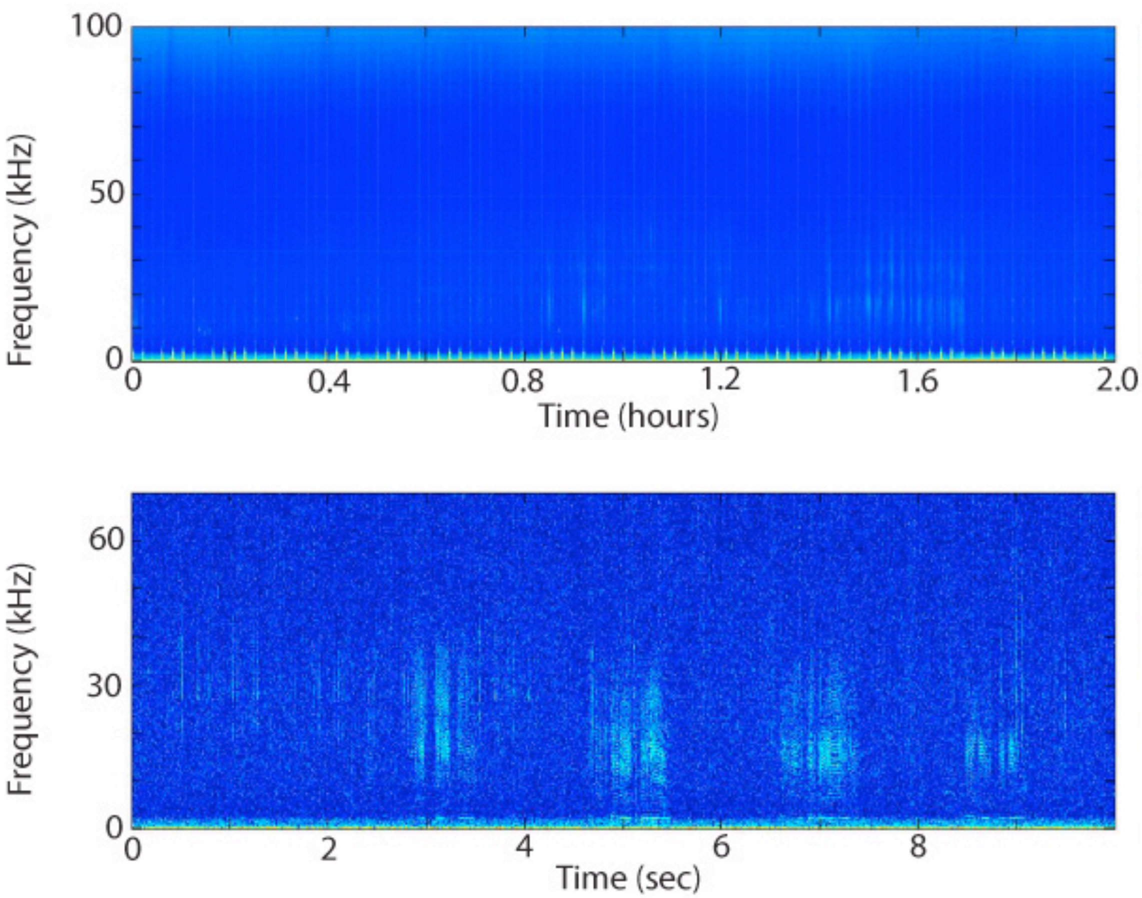

Figure 21 Killer whale pulsed calls in the LTSA (above) and spectrogram (below).

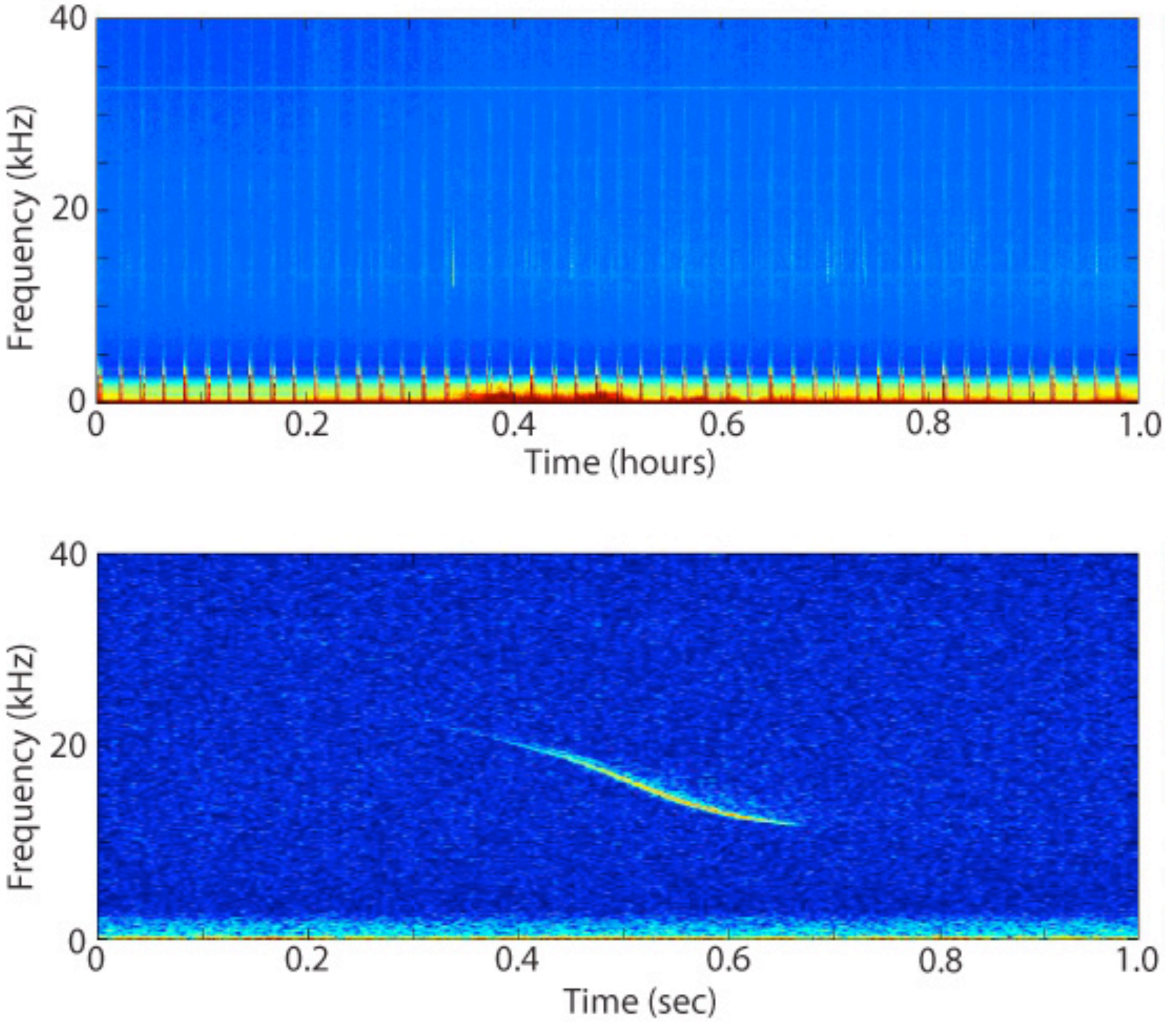

Figure 22 LTSA (above) and spectrogram (below) of killer whale ultrasonic whistle.

Sperm Whale

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 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). Sperm whales emit regular clicks and buzzes during dives typically lasting about 45 minutes, followed by a quiet period of about 9 minutes while the whales are at the surface (Watwood et al. 2006). Multiple foraging dives and rest periods are often observed over a long period of time in the LTSA (Figure 23). Although ship noise can be confused with sperm whales in the LTSA, in the finer resolution of a spectrogram, the erratic impulses from mechanical noise and prop cavitation can be easily distinguished from the continuous, regular sperm whale clicks.

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 and Schevill, 1977, Madsen et al. 2002).

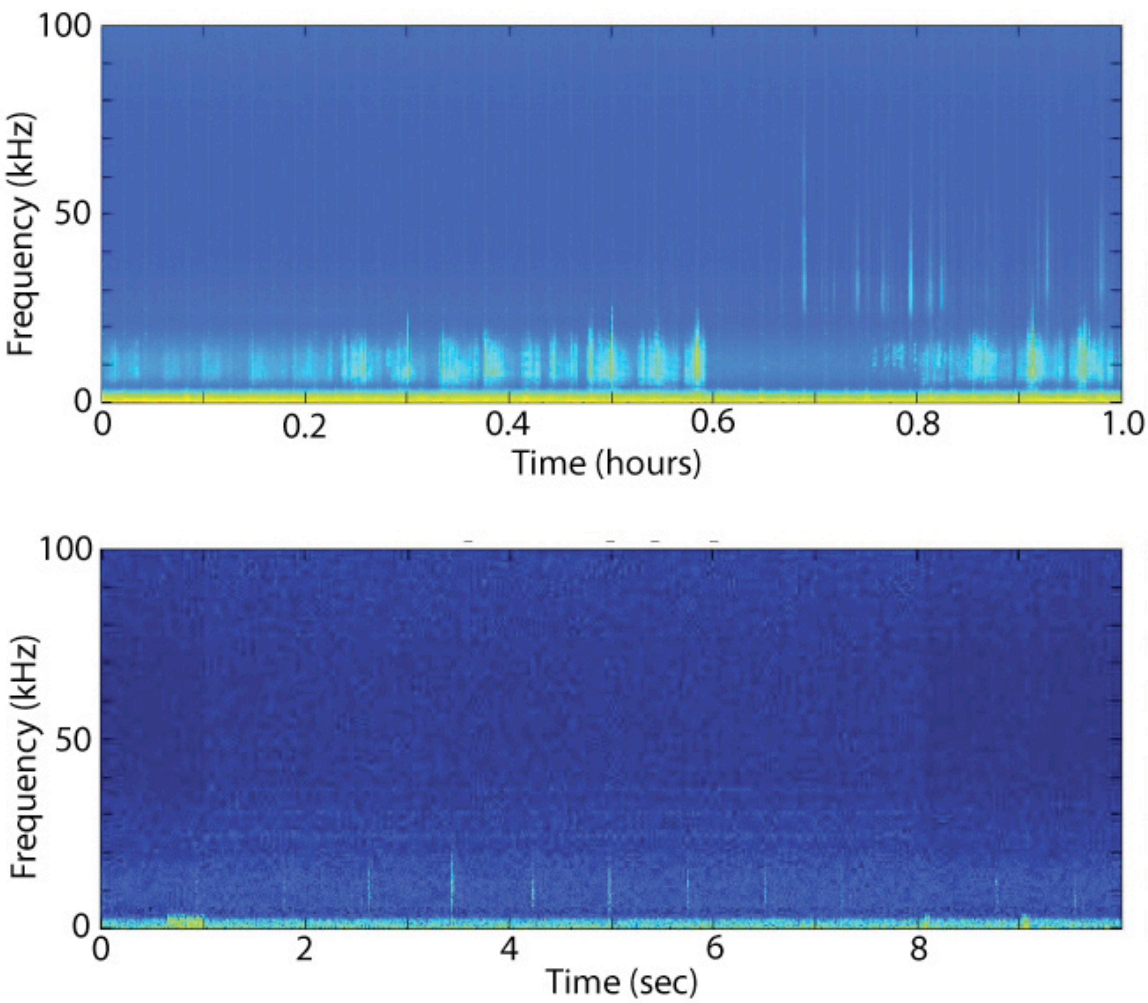

Figure 23 Echolocation clicks of sperm whale in LTSA (above) and spectrogram (below).

Cuvier's Beaked Whale

Cuvier's beaked whale is the most common beaked whale in the Southern California Bight. Cuvier's echolocation clicks are well differentiated from other species' acoustic signals. These clicks are polycyclic, with a characteristic FM upsweep, peak frequency around 40 kHz (**Figure 24**) and uniform inter-pulse interval of about 0.4s (Johnson et al. 2004, Zimmer et al. 2005).

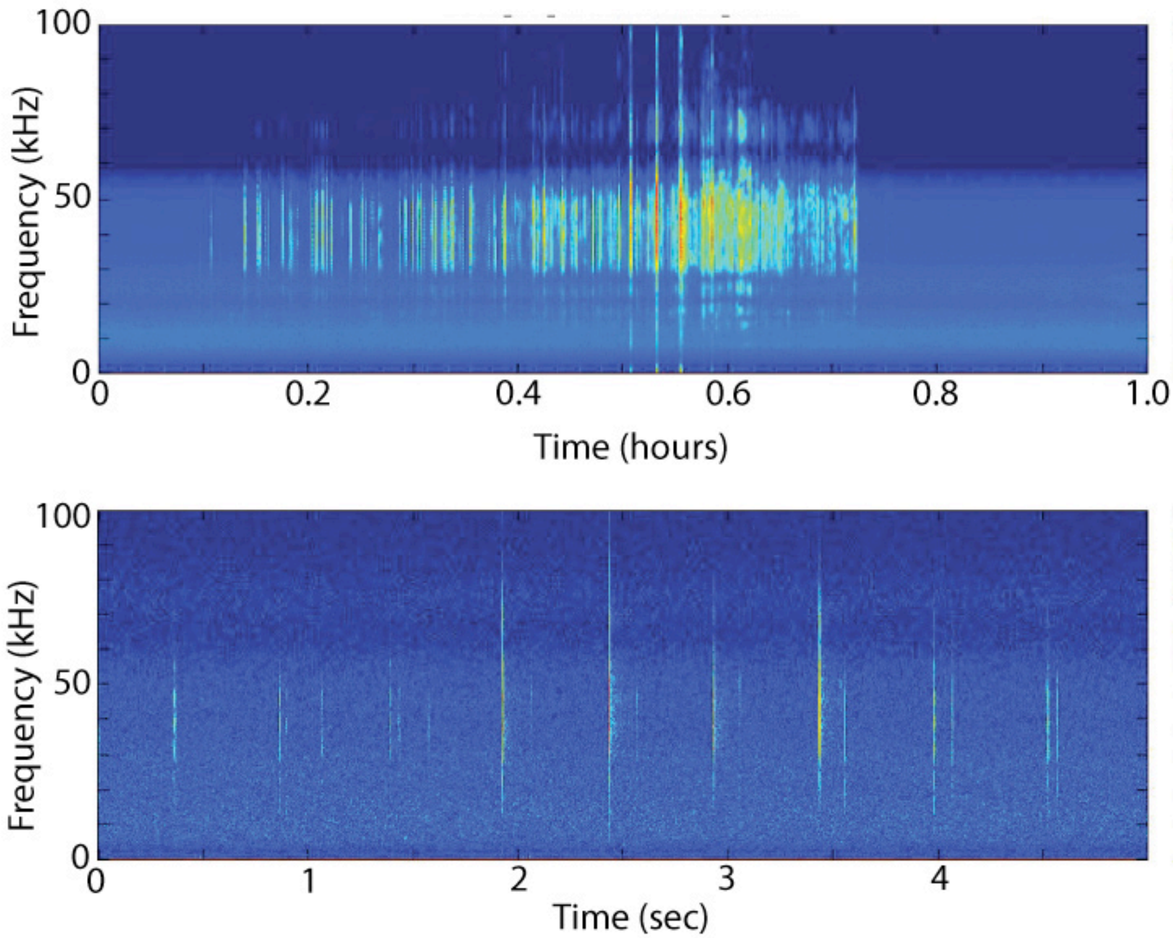

Figure 24 Cuvier's beaked whale clicks in LTSA (above) and spectrogram (below).

Baird's Beaked Whale

Baird's beaked whale is the second most common beaked whale in the Southern California Bight. Baird's echolocation clicks are easily distinguished from other species' acoustic signals and demonstrate the typical beaked whale polycyclic, FM upsweep (Dawson et al 1998). These clicks are identifiable due to the lower frequency than other beaked whale clicks. Spectral peaks are notable around 15, 30 and 50 kHz (Figure 25). Unlike other beaked whales in the area, Baird's beaked whales incorporate whistles and burst pulses into their acoustic repertoire (Dawson et al 1998, Baumann-Pickering et al., in prep).

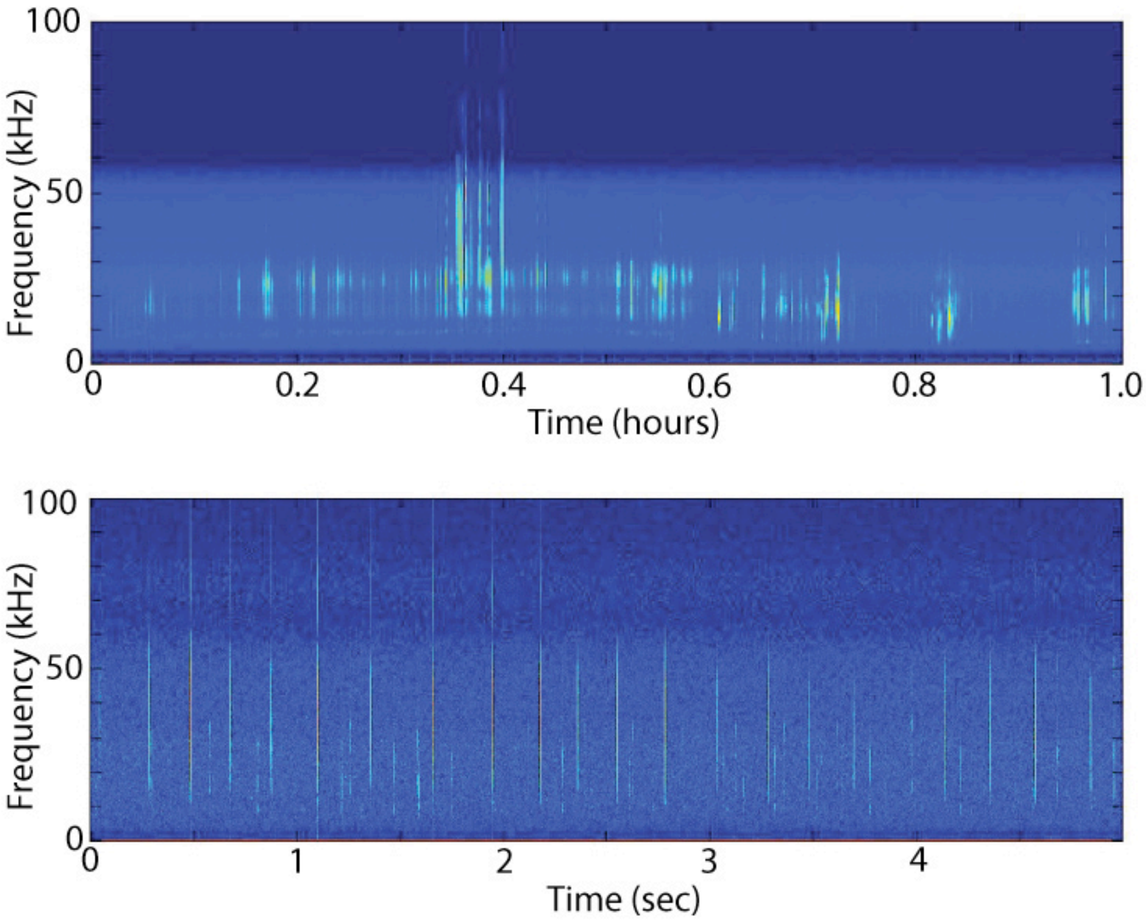

Figure 25 Baird's beaked whale clicks in LTSA (above) and spectrogram (below).

43 kHz Beaked Whale

The 43 kHz beaked whale echolocation clicks have yet to be assigned to an individual species. These clicks are easily distinguished from other species' acoustic signals and demonstrate the typical beaked whale polycyclic click structure and FM upsweep with a peak frequency around 43 kHz (Figure 26) and uniform inter-pulse interval around 0.2s (Baumann-Pickering et al., in prep).

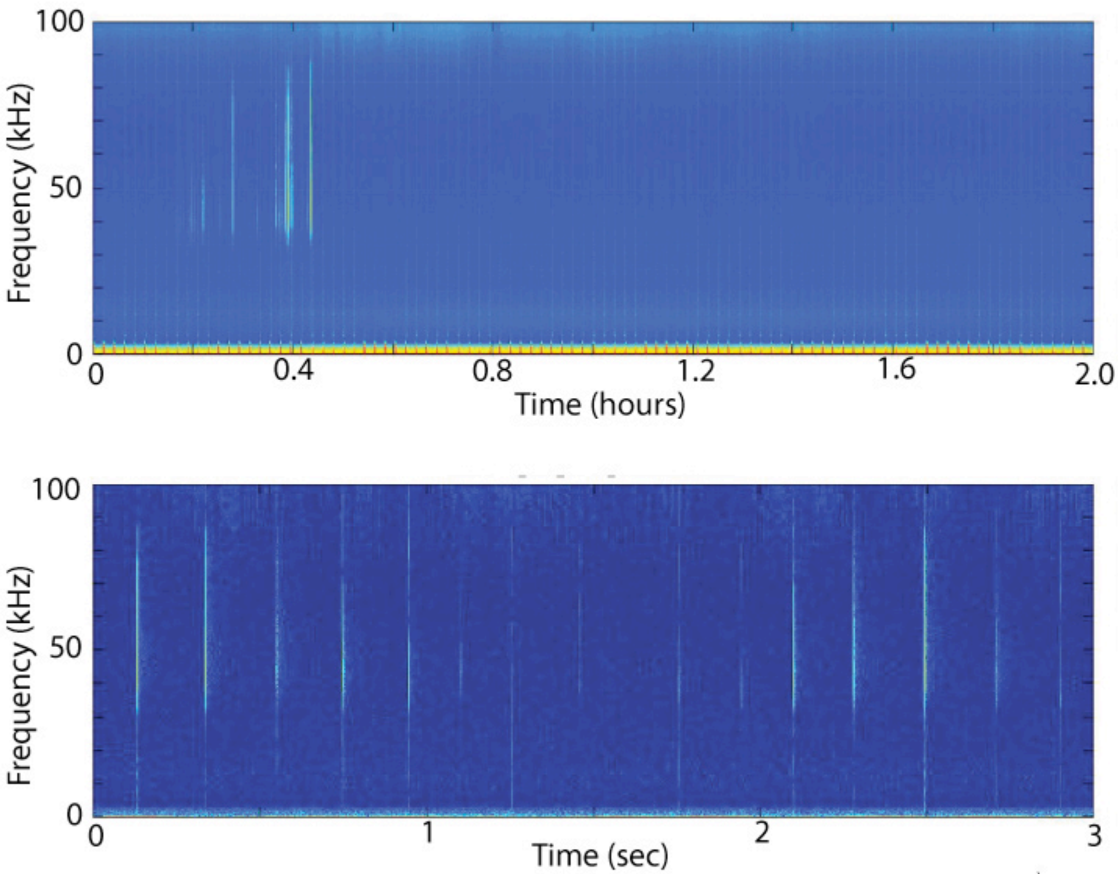

Figure 26 The 43 kHz beaked whale clicks in LTSA (above) and spectrogram (below).

50 kHz Beaked Whale

The 50 kHz beaked whale echolocation clicks have yet to be assigned to an individual species. These clicks are distinct from other species' acoustic signals and demonstrate the typical beaked whale polycyclic click structure and FM upsweep with a peak frequency around 50 kHz (Figure 27) and uniform inter-pulse interval around 0.5s (Baumann-Pickering et al., in prep).

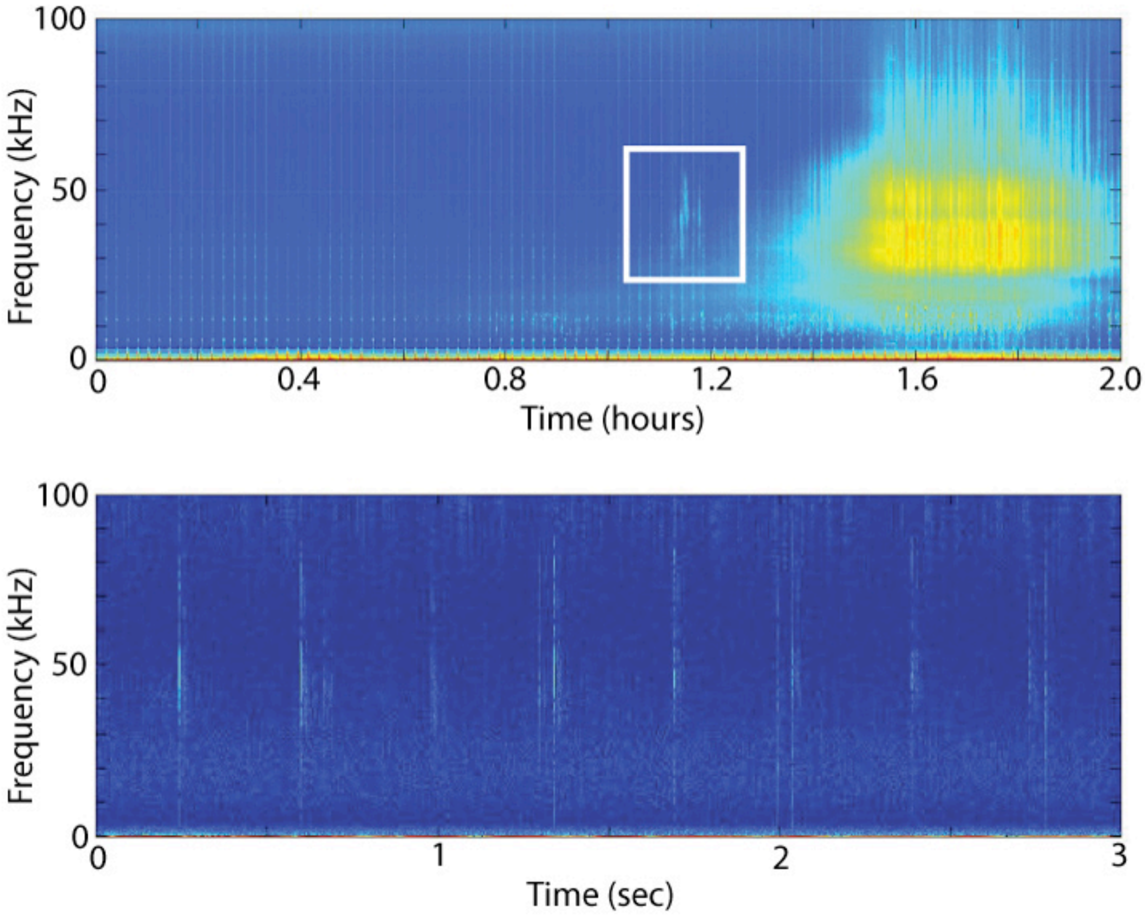

Figure 27 The 50 kHz beaked whale clicks in LTSA (above) and spectrogram (below).

Stejneger's Beaked Whale

Stejneger's beaked whale is primarily known from the north Pacific, but their echolocation clicks are also found in the SOCAL region (Figure 28). Their clicks are easily distinguished from other species' acoustic signals and demonstrate the typical beaked whale polycyclic click structure and FM upsweep with a peak frequency above 50 kHz and uniform inter-pulse interval around 0.1s (Baumann-Pickering et al., in prep).

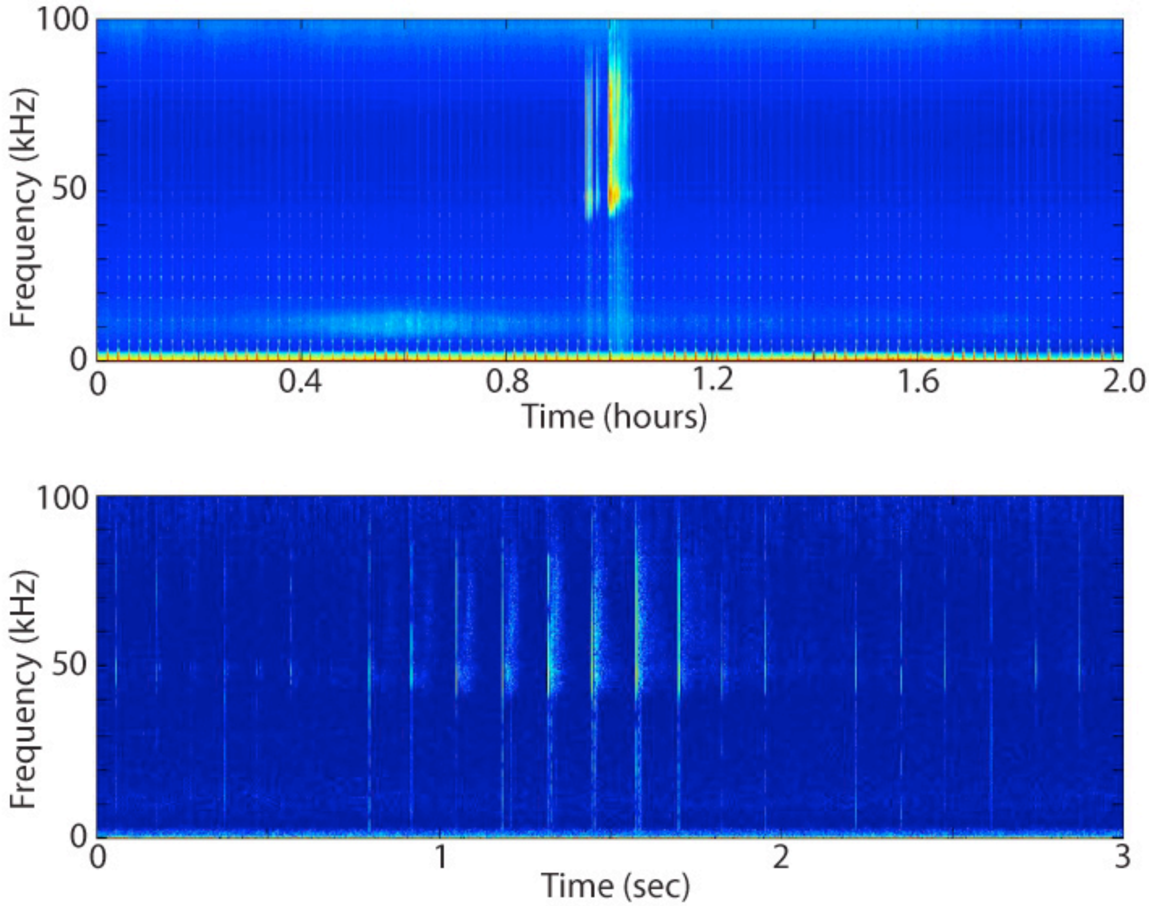

Figure 28 Stejneger's beaked whale clicks in LTSA (above) and spectrogram (below).

Anthropogenic Sounds

Broadband Ship Noise

Broadband ship noise occurs when a ship passes relatively close to the HARP. Ship noise can occur for many hours at a time, but broadband ship noise typically lasts from 10 minutes up to 3 hours. Ship noise has a characteristic interference pattern in the LTSA. Combination of direct paths and surface reflected paths produces constructive and destructive interference (bright and dark bands) in the spectrogram that vary by frequency and distance between the ship and the HARP (red arrows in Figure 29). This noise can extend to well above 10 kHz, though typically falls off above a few kHz.

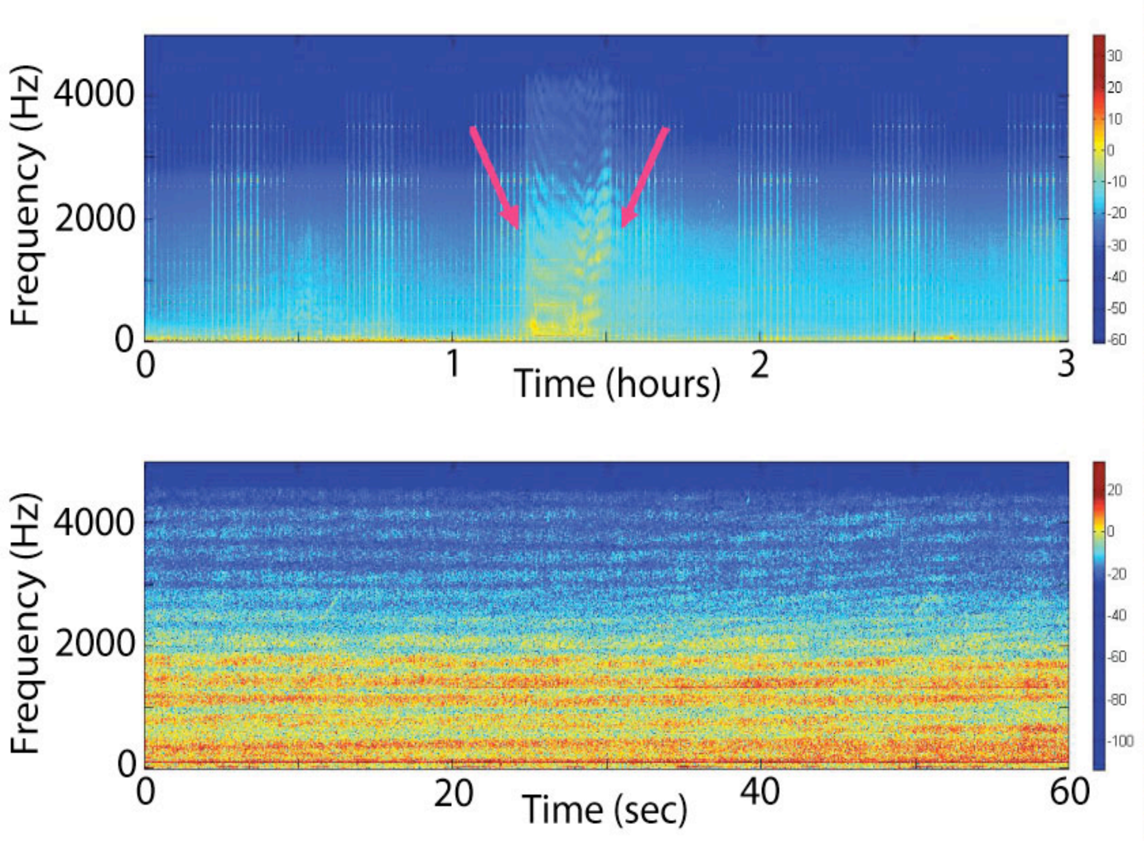

Figure 29 Broadband ship noise in the LTSA (above) and spectrogram (below).

Mid-Frequency Active Sonar

There are many types of active sonar used in the Southern California Offshore Range (SCORE). These span from about 1 kHz to over 50 kHz and include short duration pings, frequency modulated (FM) sweeps and short and long duration continuous wave (CW) tones. One common type of sonar used in SCORE is mid-frequency active (MFA) sonar for anti-submarine warfare (ASW) exercises. Sounds from MFA sonar vary in frequency and duration and can be used in a combination of FM sweeps and CW tones; however, many of these are between 2.0 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 is conducted by an analyst scanning HARP data for periods of sonar activity. Start and end times of MFA sonar events from LTSAs are noted and saved to a file to provide target periods for automatic detections. Full bandwidth (10Hz – 100kHz) data were used to calculate the spectra for the LTSAs with 100 Hz frequency bin width and 5 s time bin width. These spectra are arranged sequentially to provide a long-term spectrogram so that hours of data can be easily displayed on a computer monitor for analysis. Individual MFA sonar pings typically span 1 – 3 s, but are intense enough to show up as 'pulses' in LTSA plots (Figure 30). LTSA display parameters used by the analyst were 1 or 2 hour window length, 2 – 5 kHz window height.

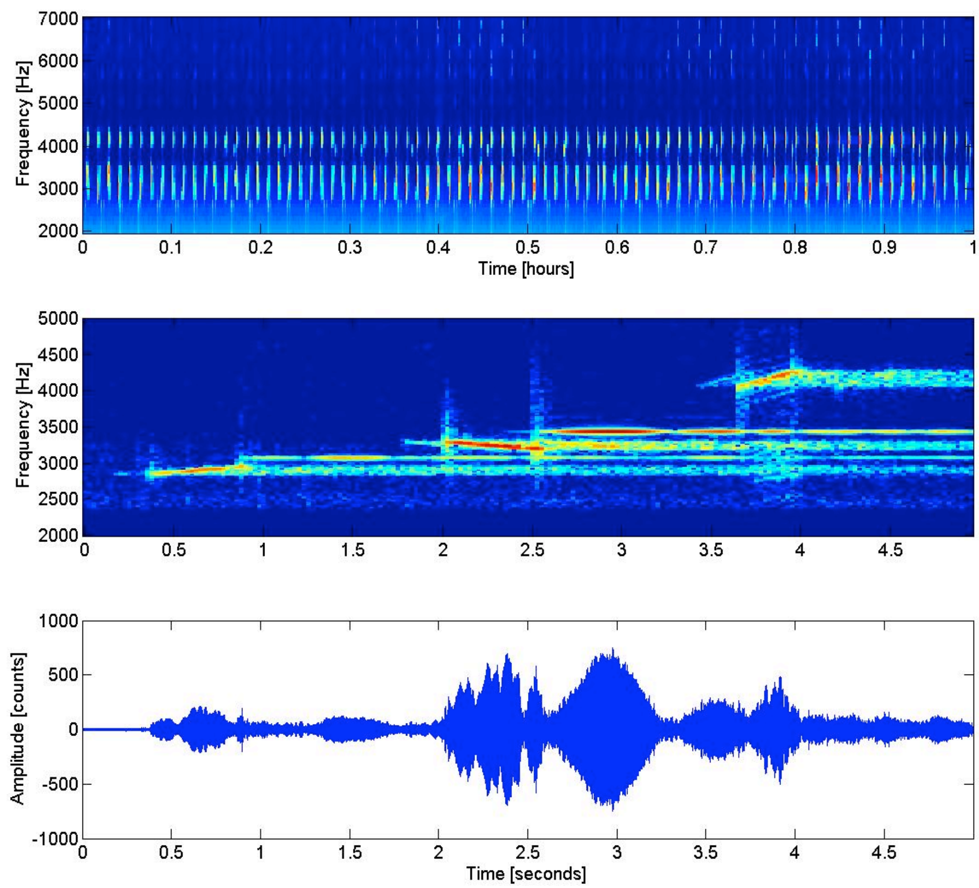

Figure 30 Mid-frequency active (MFA) sonar event. (top) Long-Term Spectral Average of one-hour of data (middle) Spectrogram and (bottom) time series of 5-seconds with multiple sonar pings.

A custom developed software routine was used to detect sonar pings and calculate peak-to-peak (PP) received sound pressure levels. For this detector, a sonar ping is defined as the presence of sonar within the 5 s and may contain multiple individual pings (Figure 30). The detector calculates the average spectrum level across the frequency band from 2.4 to 4.5 kHz for each 5 s time bin. This provides a long-term time series of the average received levels in that frequency band. Minimum values were noted for each 15 time bins, and used as a measure of background noise level over the sonar event period. Spectral bins that contained system noise (disk writing) were eliminated to prevent contaminating the results. Each of the remaining average spectral bins was compared to the background minimum levels. If levels were more than 3 dB above the background, then a detection time was noted. These detection times were then used to index to the original time series to calculate PP levels. Received PP levels were calculated by differencing the maximum and minimum amplitude of the time series in the 5 s window. The raw time series amplitudes are in units of analog-to-digital converter (ADC) counts. These units were corrected to µPa by using the 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 3.3 kHz was used. The transfer function value used was 81 dB re $\mu Pa^2/counts^2$. For sonar pings less than this middle frequency, the levels are overestimated up to about 5 dB and for higher frequency sonar the levels are underestimated up to about 4 dB.

High Frequency Active Sonar

High frequency active sonars were detected by analysts in the LTSA, and are seen as upsweeps with a frequency range from 20 to 30 kHz and an average 4 to 5 s inter-pulse interval (Figure 31).

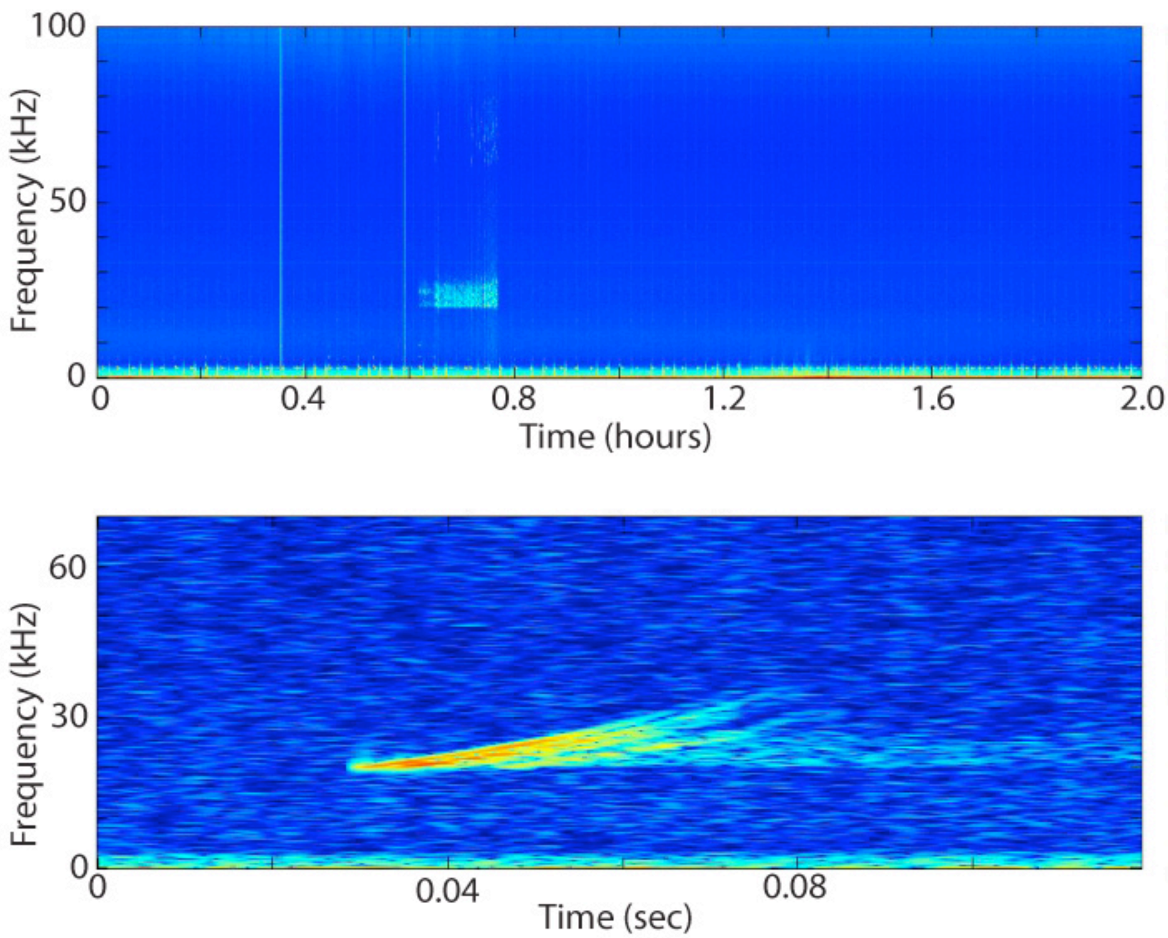

Figure 31: HFA sonar in the LTSA (top), with a single upsweep in the spectrogram (bottom).

Explosions

Explosive sounds logged in the HARP data include military explosions, shots from sub-seafloor exploration, and seal bombs used by the fishing industry. An explosion appears as a vertical spike in the LTSA that when expanded in the spectrogram has a sharp onset with a reverberant decay (Figure 32). These sounds have peak bandwidth as low as10 Hz and often extend up to 2000 Hz or higher, lasting for a few seconds including the reverberation.

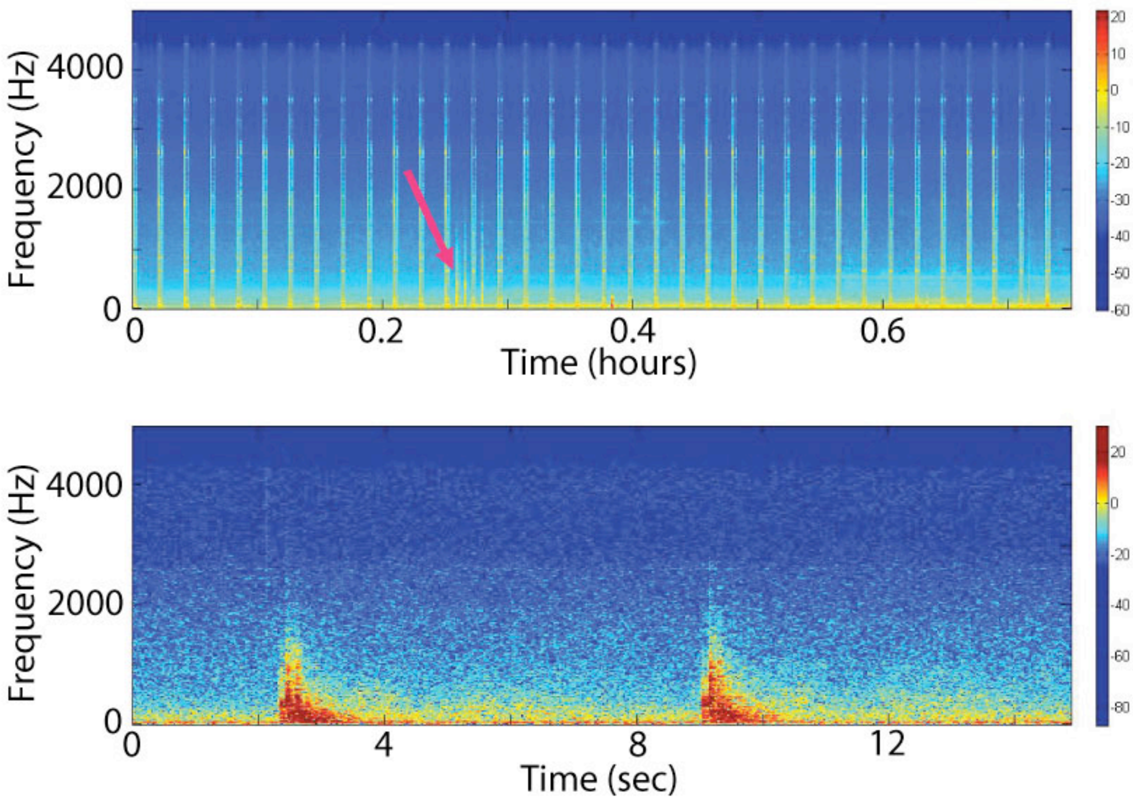

Figure 32 Three explosions are seen in the LTSA (arrow in above) and two of these are expanded in the spectrogram (below).

Results

This report summarizes the results of acoustic data collected from April 2010 - April 2011 at two sites in the SOCAL range area. We discuss ambient noise as well as the seasonal occurrence and relative abundance of marine mammal species and anthropogenic sounds.

Ambient Noise

Underwater ambient noise at sites M and N has spectral shapes with higher levels at low frequencies (Figure 33), primarily owing to the presence of ship noise with secondary contributions from local wind and waves (Hildebrand 2009). Ambient noise levels at site M are typically 5 dB higher than at site N, consistent with site M's greater exposure to commercial shipping traffic associated with the Ports of Los Angeles and Long Beach. Noise levels at both sites are 5-10 dB less in the fall relative to the spring, probably related to diminished noise from wind and waves. A prominent peak in noise is observed at 20-30 Hz and also at 47 Hz related to the presence of blue and fin whales calls.

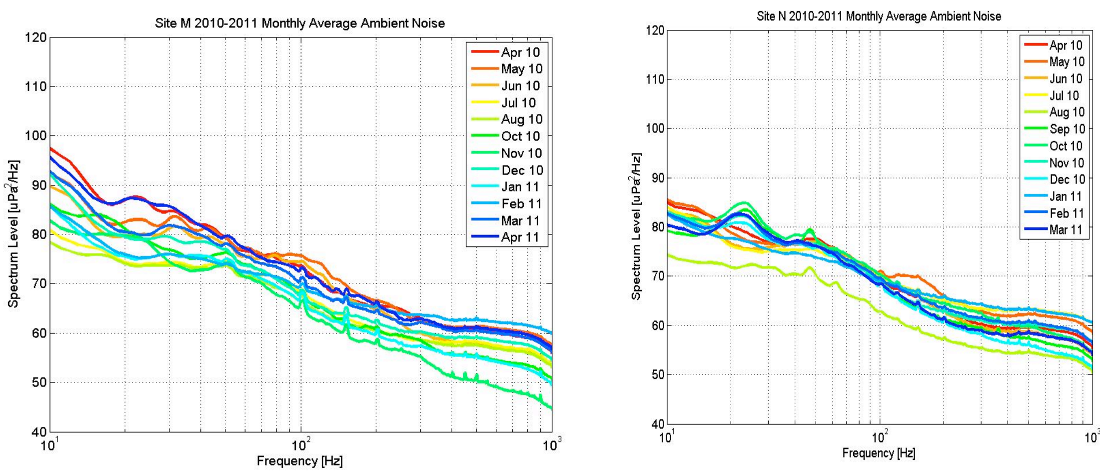

Figure 33 Monthly averages of ambient noise at site M (left) and site N (right) for the period April 2010 – April 2011. Legend gives color-coding by date.

Mysticetes

Six baleen whale species were recorded between April 2010 and April 2011 at sites M and N: blue whales, fin whales, Bryde's whales, gray whales, humpback whales, and minke whales. Generally, site N appears to be frequented by calling baleen whales more often than site M, as blue, fin, humpback, and Bryde's whale calls were all detected during more hours at site N. However, gray whale calls were detected only at site M. More details of each species' presence at these sites are given below.

Blue Whales

Blue whales were detected at both sites between April 2010 and January 2011, but consistently more hours with calls were detected at site N (Figure 34). Blue whale calls also were detected between February and April 2011, but during this period they were much less common. Peak in calling at both sites occurred between August and December 2010, which is the period with peak detection of blue whale A and B calls (Figure 35; Figure 36). Similarity in call occurrence between A and B calls is not surprising as they are often produced in a song sequence. Peaks in D call detections, in contract to A and B calls, occurred in July and October 2010 (Figure 37). During peak occurrence, almost twice as many D calls were detected weekly at site N as at site M. This seasonal difference in the occurrence of A and B versus D calls is consistent with previous passive acoustic studies of blue whales in the Southern California Bight (Oleson et al. 2007b) and likely reflects the transition in blue whale behavior from feeding during the summer, to courting or other mating behavior in the fall (Oleson et al. 2007a).

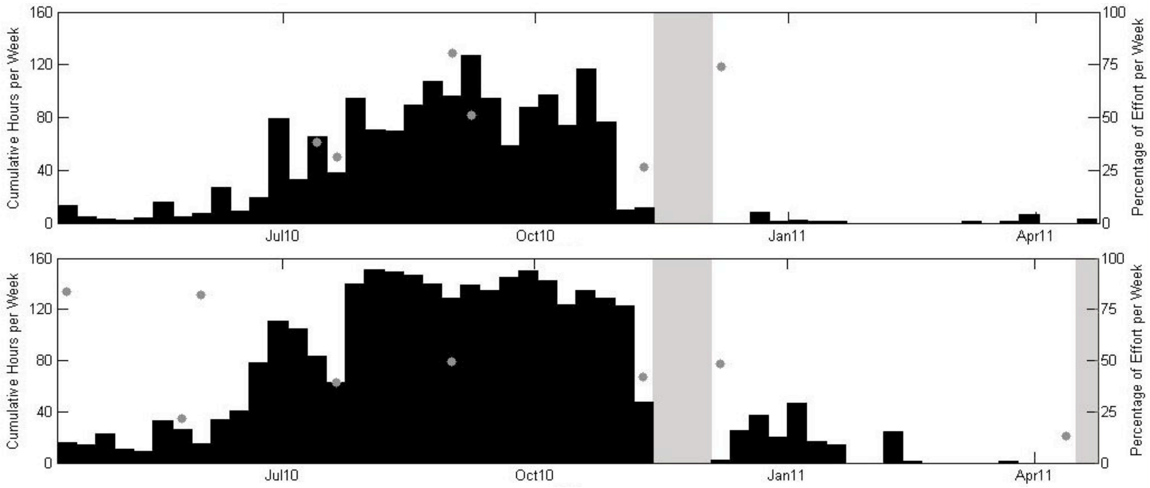

Figure 34 Weekly presence of all blue whale calls (black bars) at sites M (top) and N (bottom) between April 2010 and April 2011. Grey dots represent percent of effort per week in weeks with less than 100% recording effort and grey shading marks periods with no recording effort. Where grey dots or shading are absent, full recording effort occurred for the entire week.

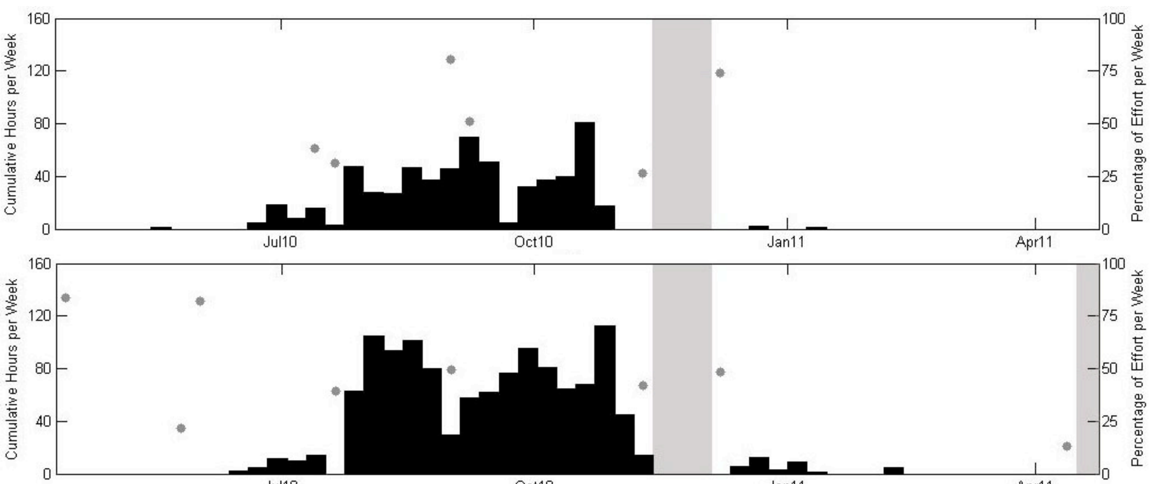

Figure 35 Weekly blue whale A call presence (black bars) at sites M (top) and N (bottom) between April 2010 and April 2011. Effort markings are as described in Figure 34.

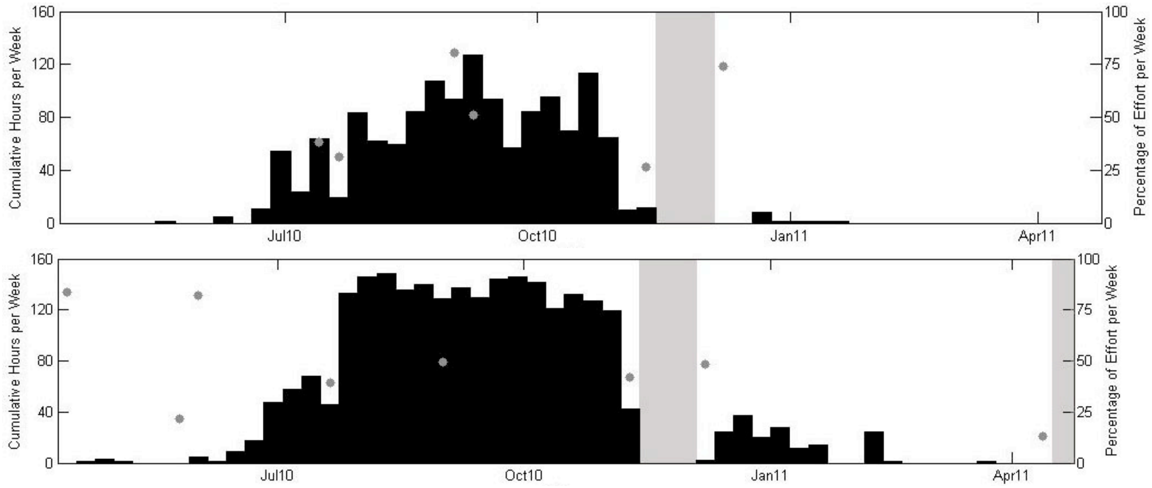

Figure 36 Weekly blue whale B call presence at sites M (top) and N (bottom) between April 2010 and April 2011. Effort markings are as described in Figure 34.

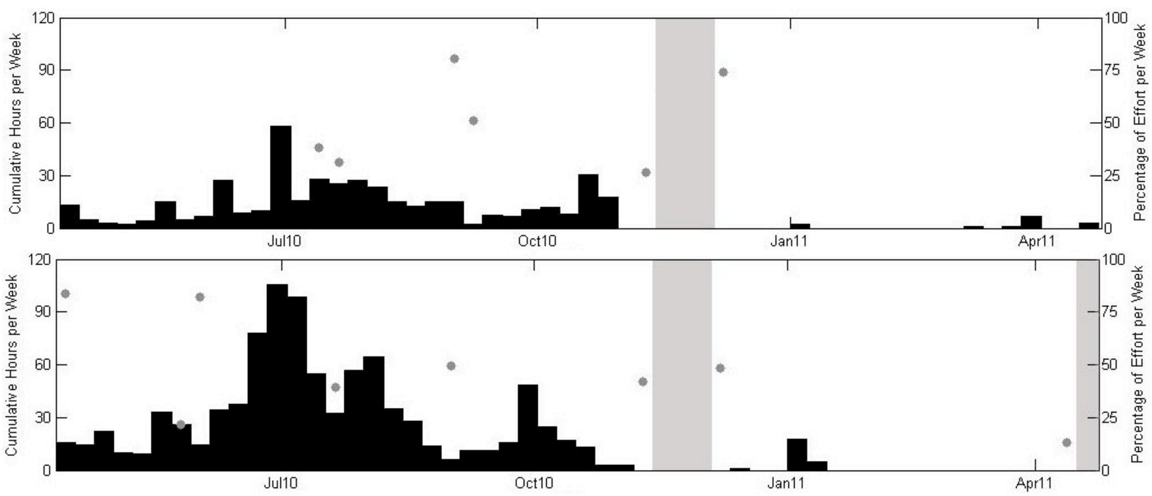

Figure 37 Weekly blue whale D call presence at sites M (top) and N (bottom) between April 2010 and April 2011. Effort markings are as described in Figure 34.

Fin Whales

Fin whales were the most common acoustically detected baleen whale at both sites. Their calls were detected at both sites year-round, but generally, their calls were present during more hours per week at site N (Figure 38). Peaks in calling occurred from August to December 2010, during which period there were eight weeks with almost 100% of hours of fin whale calls present. Secondary peak in fin whale calls were detected in April of both years. Farther offshore in the eastern North Pacific, fin whale calls have been detected from October through April (Watkins et al. 2000). Thus the decrease in calling during the winter at sites M and N may be due to the movement of some part of the population farther offshore. Alternatively, the change in the weekly number of hours with calls could be due to the differences in behavioral state of the whales that may result in different frequency of calling.

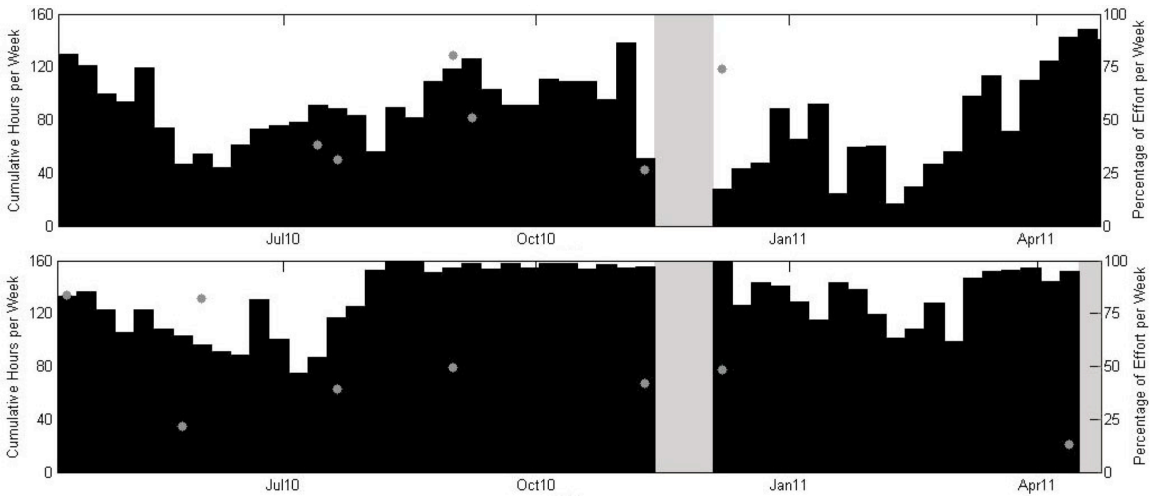

Figure 38 Weekly fin whale 20 Hz call presence at sites M (top) and N (bottom) between April 2010 and April 2011. Effort markings are as described in Figure 34.

"50 Hz" Whales

An additional baleen whale sound, 50 Hz call, was frequently recorded at both sites (Figure 39). Watkins (1981) attributed this call to fin whales although we found them to not be as common as the more typical 20 Hz fin whale pulses. Likewise, seasonality of the 50 Hz call differs from 20 Hz calls; 50 Hz calls were more prominent between April and August 2010 (Figure 39), whereas fin whale 20 Hz pulses were more prominent in the fall (Figure 38). There are three possibilities for the source of this 50 Hz call: (1) the 50 Hz calls are produced by a sub-population of fin whales (distinct from the 20z Hz producing whales), (2) the 50 Hz calls represent a distinct behavioral state for fin whales (e.g. communication between nearby animals as suggested by Watkins 1981), or (3) the 50 Hz calls are produced by a baleen whale species other than fin whales**.** Thus, we categorized the 50 Hz calls separately from 20 Hz fin whale pulses until the context of their production is better established.

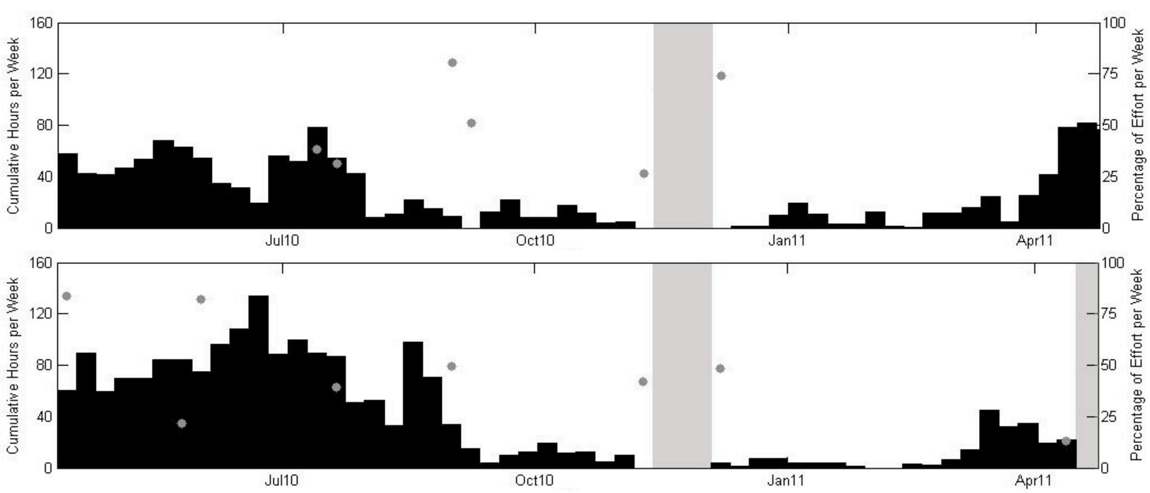

Figure 39 Weekly unknown whale 50 Hz call presence at sites M (top) and N (bottom) between April 2010 and April 2011. Effort markings are as described in Figure 34.

Bryde's Whales

Bryde's whale calls were first detected at sites M and N in August 2010 (Figure 40). The peak number of weekly hours with calls occurred in November 2010 at both sites, though, at site N, there was another peak in weekly hours with Bryde's whale calls in January 2011. The last Bryde's whale calls were detected at both sites in February 2011. This represents a later arrival to site N and a later departure of Bryde's whales from both sites than during the winter 2009/10 (*Hildebrand et al., 2010a and 2010b*).

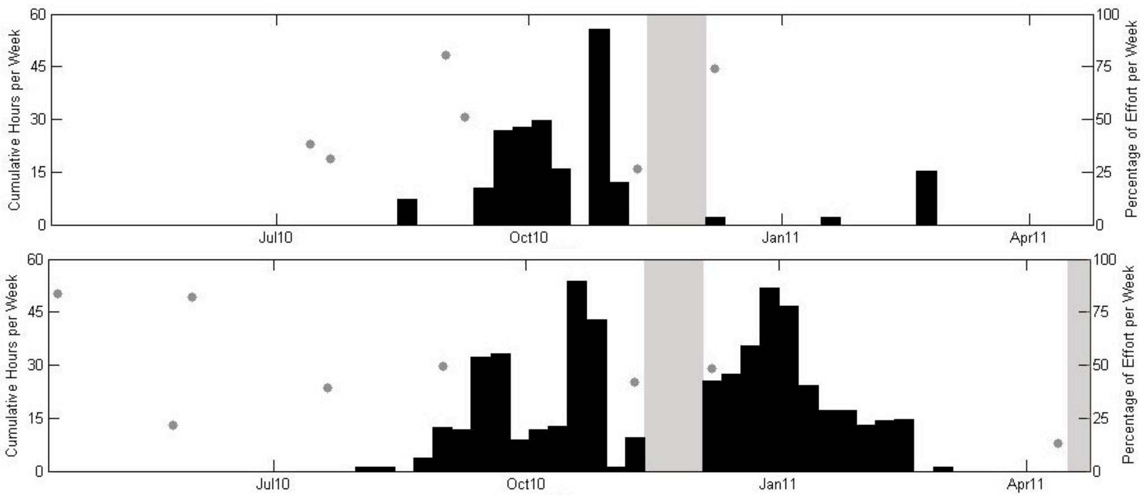

Figure 40 Weekly Bryde's whale call presence at sites M (top) and N (bottom) between April 2010 and April 2011. Effort markings are as described in Figure 34.

Gray Whales

Of the two gray whale call types found in the data (M1 and M3) M3 was the more common, which is consistent with previous studies of gray whale sounds off California (Crane and Lashkari 1996). Gray whales were only detected at one of the sites, M, during the time period reported here (Figure 41). The lack of calls at site N is likely due to the offshore location of this site, while site M is on a path between northern Channel Islands and Catalina or San Clemente islands, which the migrating gray whales likely use (Sumich and Show, 2011). The two peaks in the data probably represent the southbound migration in January/February and northbound migration in March/April.

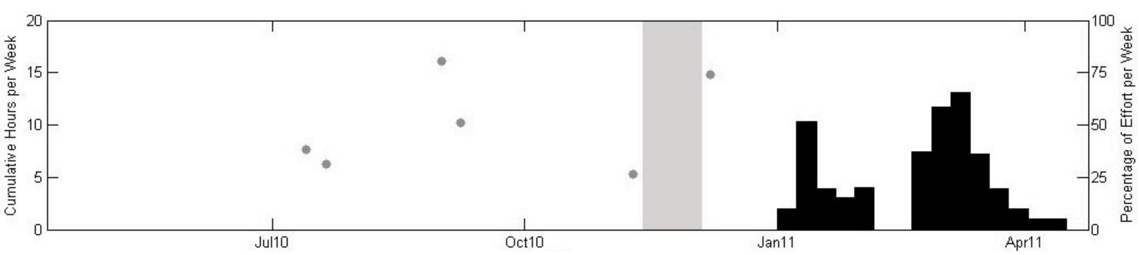

Figure 41 Weekly gray whale call presence at site M between April 2010 and April 2011. Effort markings are as described in Figure 34. No gray whales were detected at site N during this time period.

Humpback Whales

Both song and non-song call types were grouped for this analysis of humpback whale presence. Humpback whales were detected at both sites year-round, although like other baleen whales, they were more common at site N (Figure 42). While the number of weekly hours with humpback whale calls was more persistent year-round at site M, both sites had peaks in calling in November 2010, January-February 2011, and April 2011. Site N had generally higher number of hours with calls in the winter and through April 2011. Humpback whales are known to feed off California in spring, summer, and fall (Calambokidis et al. 1996) which is the time with a low number of hours with calls at site N. It is likely that vocalizing humpbacks are engaged in a behavior other than feeding and thus may not be as readily available for visual surveys during the winter period.

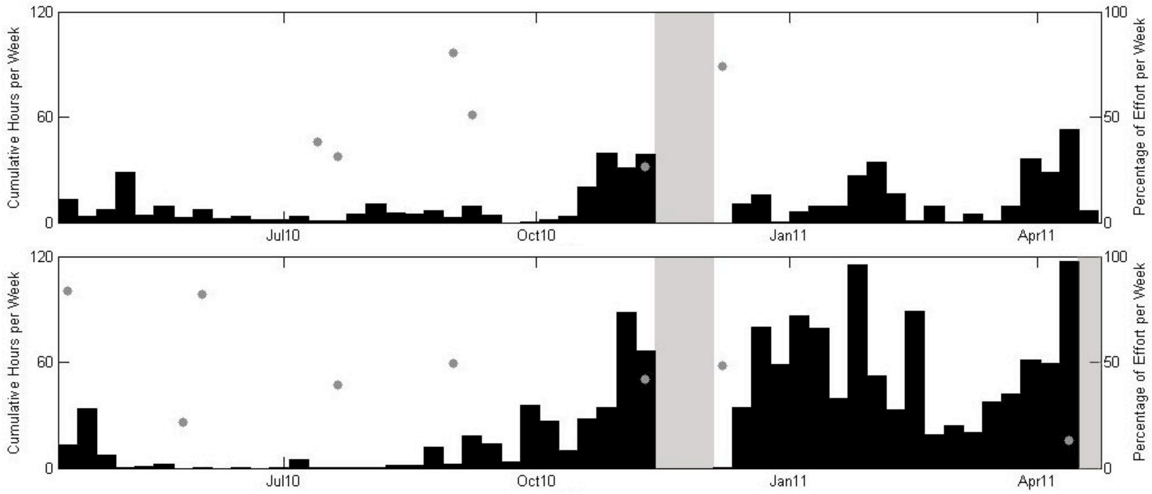

Figure 42 Weekly presence of all humpback whale calls (black bars) at sites M (top) and N (bottom) between April 2010 and April 2011. Effort markings are as described in Figure 34.

Minke Whales

Minke whale boings were the rarest baleen whale sounds recorded between April 2010 and April 2011 (Figure 43). No minke whales were recorded after November 2011 at either site. Off Hawaii, where Minke boing sounds are more common, they occur between February and June, peaking in early April, although data are lacking on other months (Oswald et al. 2008). Based on two full years of monitoring at sites M and N (Hildebrand et al. 2010a and 2010b), presence of boings is rare at these sites, but appears to be most likely to occur in the spring and fall months.

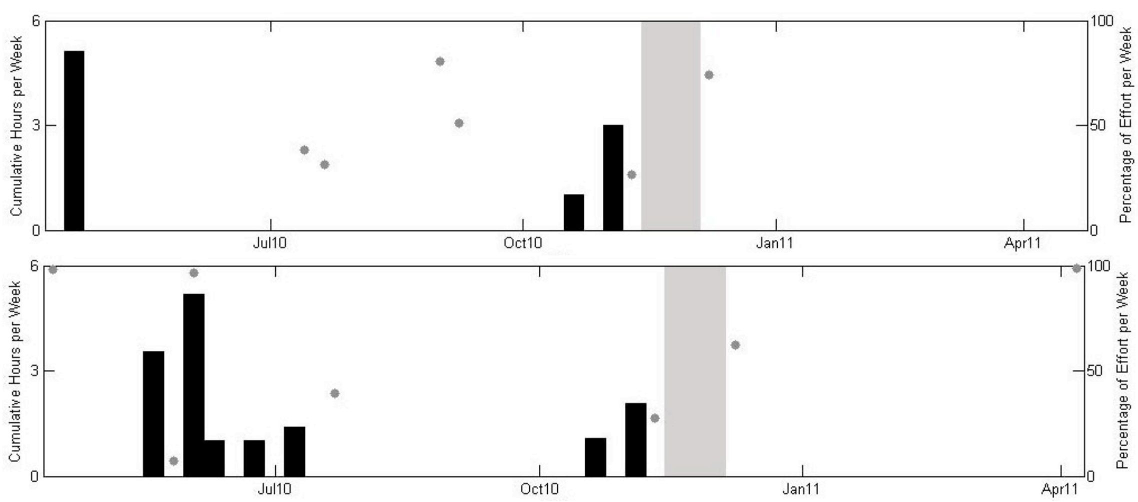

Figure 43 Weekly minke whale boing call presence at sites M (top) and N (bottom) between April 2010 and April 2011. Effort markings are as described in Figure 34.

Pinnipeds

Sea Lion

Pinniped barks, presumably made by California sea lions, were recorded a lot more frequently at site M than N, and most of them were recorded during July and August 2010 at both sites (Figure 44). Low level of barking persisted at site M until February. Site N may be too far from shore and islands to be appropriate for barking pinnipeds.

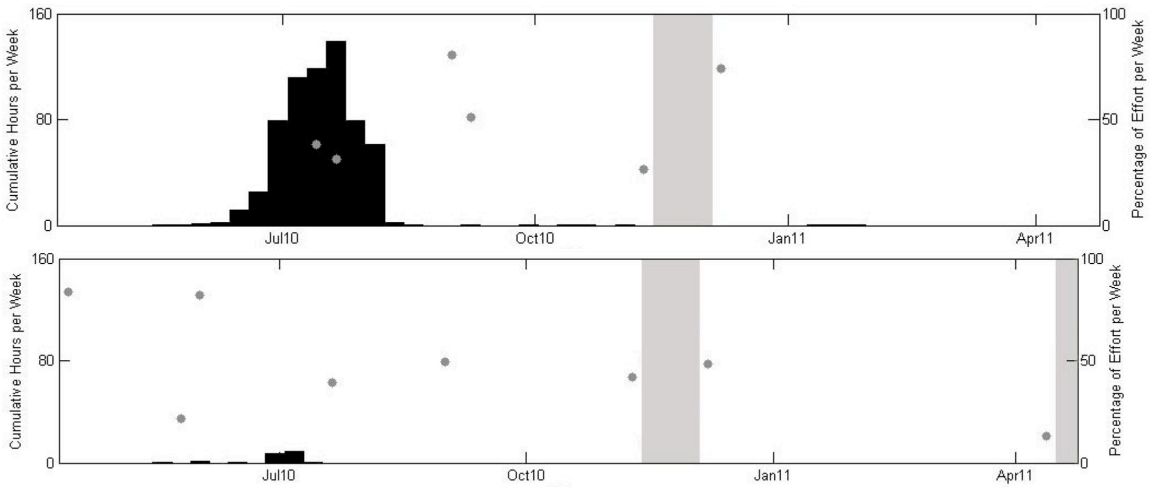

Figure 44 Weekly pinniped bark presence at sites M (top) and N (bottom) between April 2010 and April 2011. Effort markings are as described in Figure 34.

Odontocetes

Unidentified Dolphin

The largest number of odontocete detections for echolocation clicks and whistles were attributed to the category "unidentified dolphin" which is primarily comprised of short- and long-beaked common dolphins as well as bottlenose dolphins. Unidentified dolphins were detected throughout the year with a peak acoustic activity in late summer and fall months. Overall numbers of detections were slightly higher at site N than M. Number of detections declined intermittently with no apparent pattern (Figure 45, Figure 46). There was a very distinct diel acoustic activity, likely due to nighttime foraging, which was more apparent for click and less for whistle detections (see Appendix).

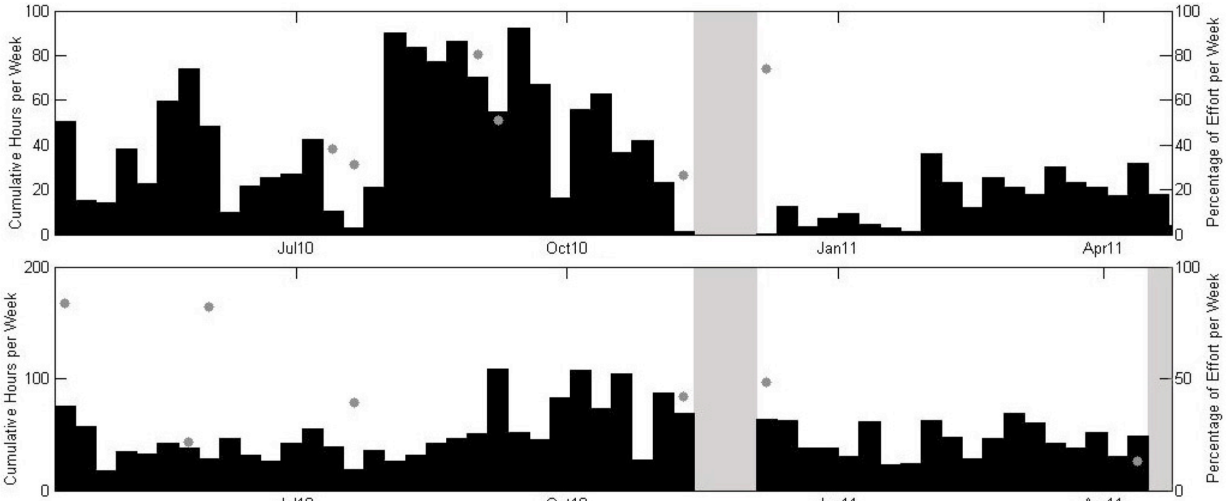

Figure 45: Weekly unidentified dolphin echolocation click presence at sites M (top) and N (bottom) between April 2010 and April 2011. Note y-axis in different scale. Effort markings are as described in Figure 34.

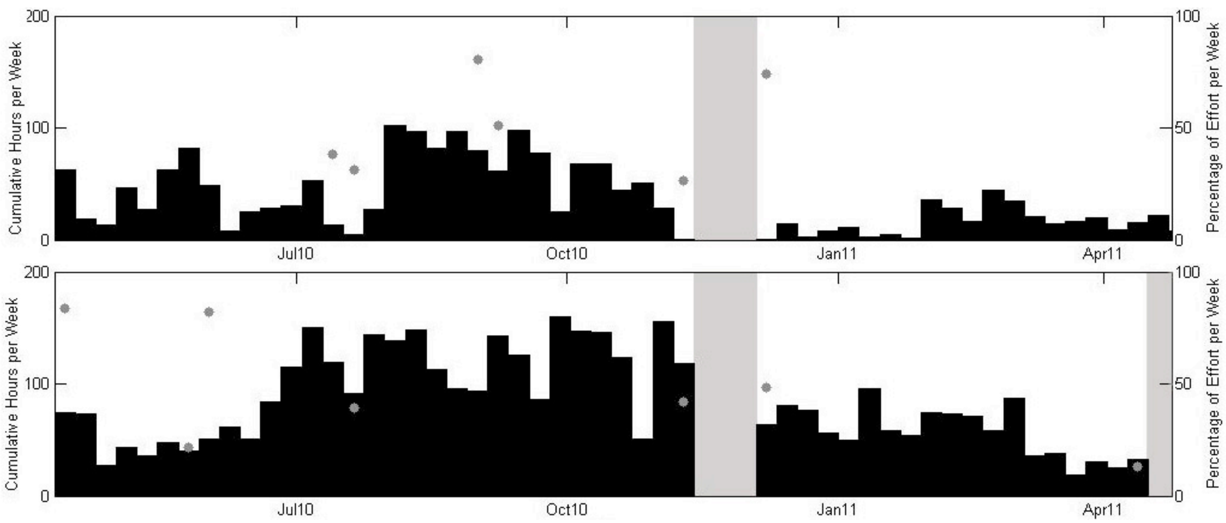

Figure 46: Weekly unidentified dolphin whistle presence at sites M (top) and N (bottom) between April 2010 and April 2011. Effort markings are as described in Figure 34.

During some echolocation click detections, clicks were broadband but with significant energy below 20 kHz. These detections were categorized as unidentified dolphin with low frequency echolocation clicks. Further investigation is needed to classify these clicks to the species level. Potential species producing these types of clicks are killer whales, false killer whales and short-finned pilot whales (Baumann-Pickering et al., unpublished data). All of these species are not common to the Southern California Bight and accordingly seldom are detections of low echolocation clicks. Due to the low number of detections, seasonality is not clearly apparent but there was a higher rate of detections towards late fall at both sites (Figure 47).

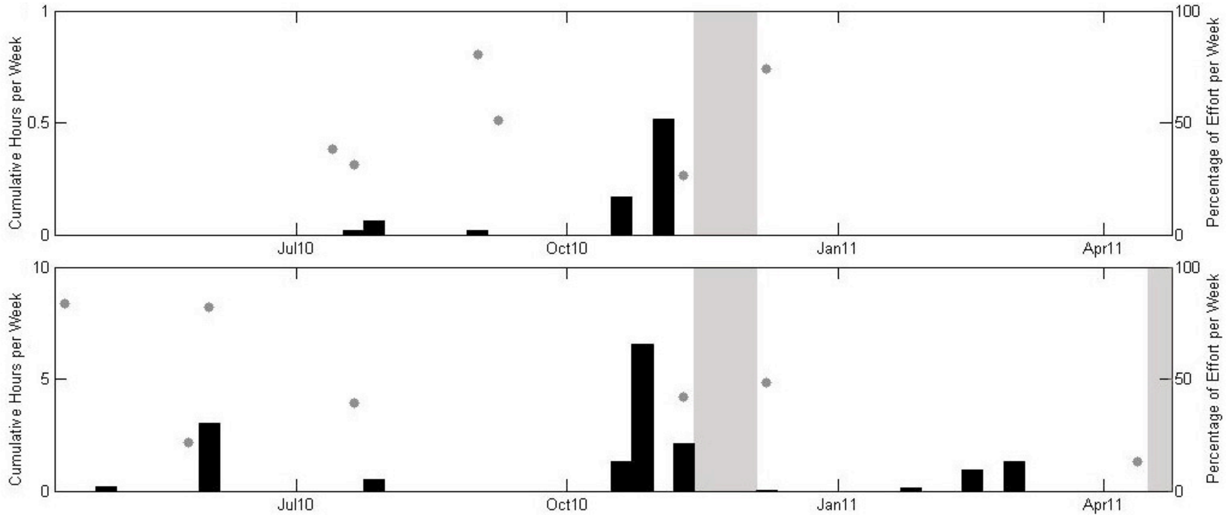

Figure 47: Weekly unidentified dolphin low frequency echolocation click presence at sites M (top) and N (bottom) between April 2010 and April 2011. Note y-axis in different scale. Effort markings are as described in Figure 34.

Risso's Dolphin

Risso's dolphin echolocation clicks occurred throughout the year with increased detections in winter and early spring months at site M in 2011 and late spring at site N in 2010. They were generally more frequent at site M than N (Figure 48). In the previous year, site M also was preferred over site N by this species while their peak occurrence was then during summer months at both sites (Hildebrand et al. 2010a and 2010b). They showed a diel pattern with higher echolocation click activity at night indicating nighttime foraging (see Appendix). This is consistent with what is reported by Soldevilla et al. (2010a).

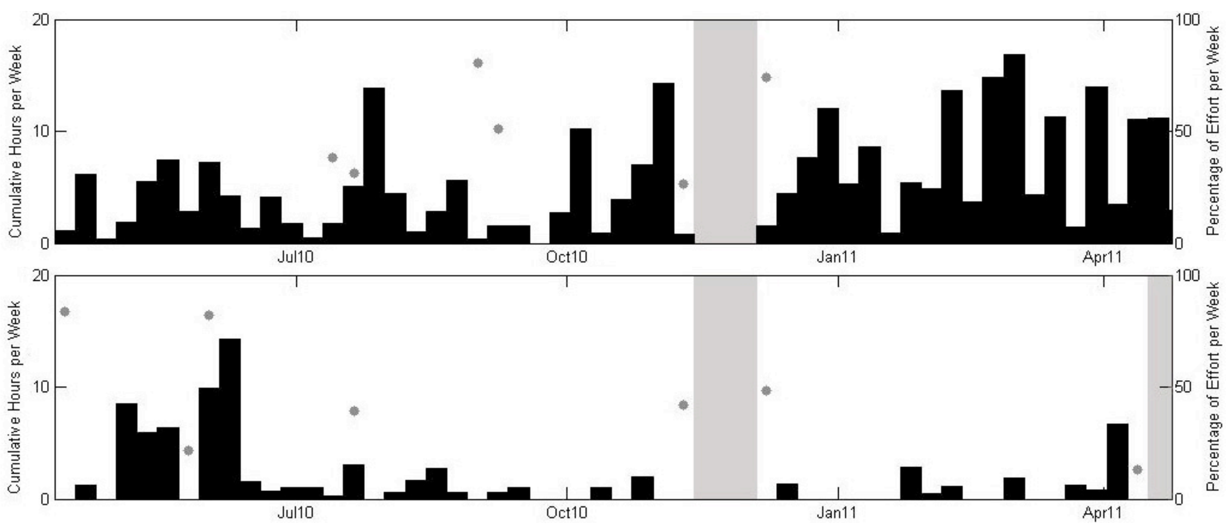

Figure 48: Weekly Risso's dolphin echolocation click presence at sites M (top) and N (bottom) between April 2010 and April 2011. Effort markings are as described in Figure 34.

Pacific White-Sided Dolphin

Pacific white-sided dolphin echolocation clicks of type A were present distinctly more often at site N than M. They had a seasonal occurrence with higher detections from November 2010 until March 2011 (Figure 49). There was a diel pattern notable with higher numbers of detections at night indicating nighttime foraging (see Appendix). Echolocation clicks of type B were overall very seldom with highest detections at site M in late spring and early summer (Figure 50). There was a higher rate of detections during daytime (see Appendix). Nighttime foraging of type A Pacific white-sided dolphins and daytime foraging of type B was observed, as described by Soldevilla et al. (2010b). The northern extent of type B, however, was reported at Santa Catalina Island. Since site M is north of Santa Catalina Island, it is currently the northernmost site with acoustic detections of this click type. A fall-winter peak was expected for both click types (Soldevilla et al. 2010b) and type A follows the expected pattern. Type B, however, had a spring occurrence.

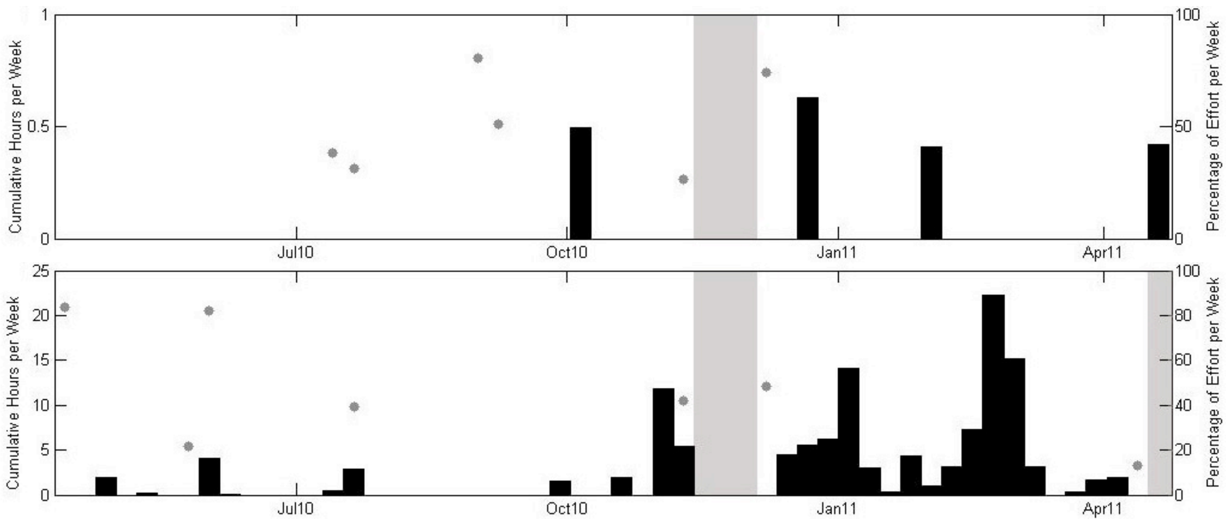

Figure 49: Weekly Pacific white-sided dolphin type A echolocation click presence at sites M (top) and N (bottom) between April 2010 and April 2011. Note y-axis in different scale. Effort markings are as described in Figure 34.

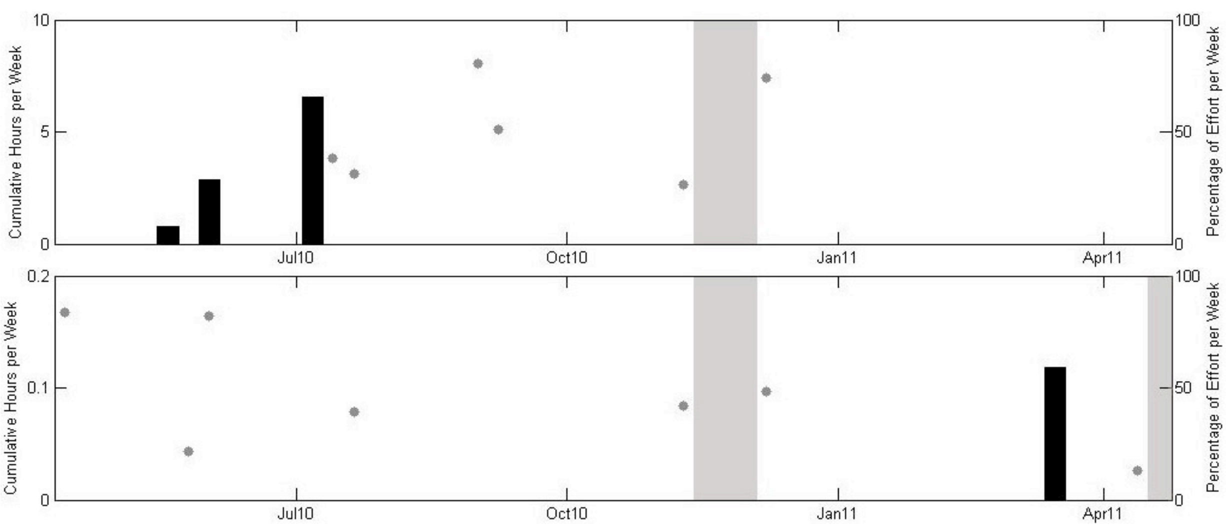

Figure 50: Weekly Pacific white-sided dolphin type B echolocation click presence at sites M (top) and N (bottom) between April 2010 and April 2011. Note y-axis in different scale. Effort markings are as described in Figure 34.

Killer Whale

Killer whale detections were overall very few and with no apparent pattern or site preference. The large number of detections in April 2011 at site N was likely artificial due to partial recording effort in that week and normalization to a full week of effort (Figure 51).

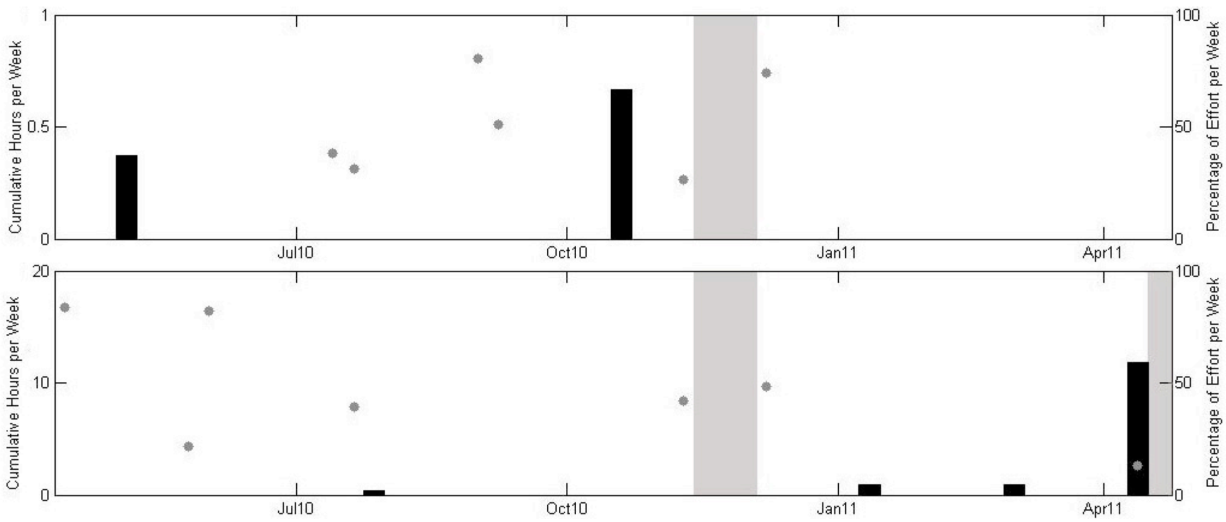

Figure 51: Weekly killer whale presence at sites M (top) and N (bottom) between April 2010 and April 2011. Note y-axis in different scale. Effort markings are as described in Figure 34.

Sperm Whale

Sperm whale echolocation clicks were detected throughout the year without apparent seasonal pattern but in general there were more frequent detections at site M (Figure 52). This is in contrast to last year's analysis that showed more hours with sperm whale echolocation clicks at site N (Hildebrand et al. 2010a and 2010b). There may be a preference for daytime acoustic activity (see Appendix).

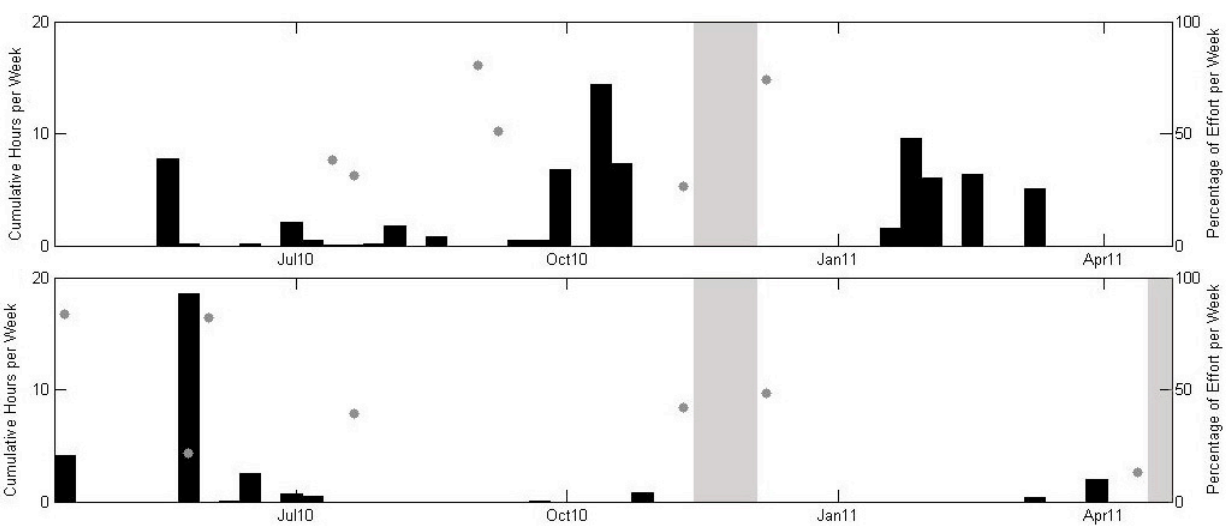

Figure 52: Weekly sperm whale echolocation click presence at sites M (top) and N (bottom) between April 2010 and April 2011. Effort markings are as described in Figure 34.

Cuvier's Beaked Whale

Cuvier's beaked whales were detected throughout the year at both sites with a higher number of occurrences at site N (Figure 53). There was no clear seasonal pattern visible but there was a period with lower detections from July to October and in April at site M as well as from September to January at site N. Highest numbers of detections were counted at the end of April in 2010. There was no preferred time of the day for echolocation click detections.

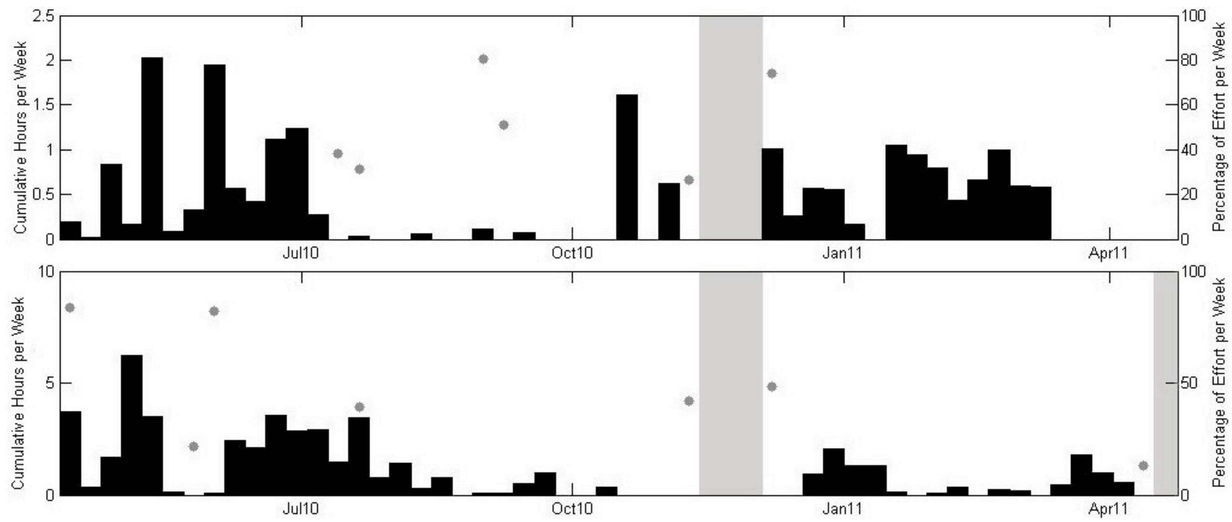

Figure 53: Weekly Cuvier's beaked whale frequency modulated pulse presence at sites M (top) and N (bottom) between April 2010 and April 2011. Note y-axis in different scale. Effort markings are as described in Figure 34.

Baird's Beaked Whale

There were only a few detections of Baird's beaked whales; they were found in December 2010 and January 2011 at sites M and in May 2010 at site N (Figure 54).

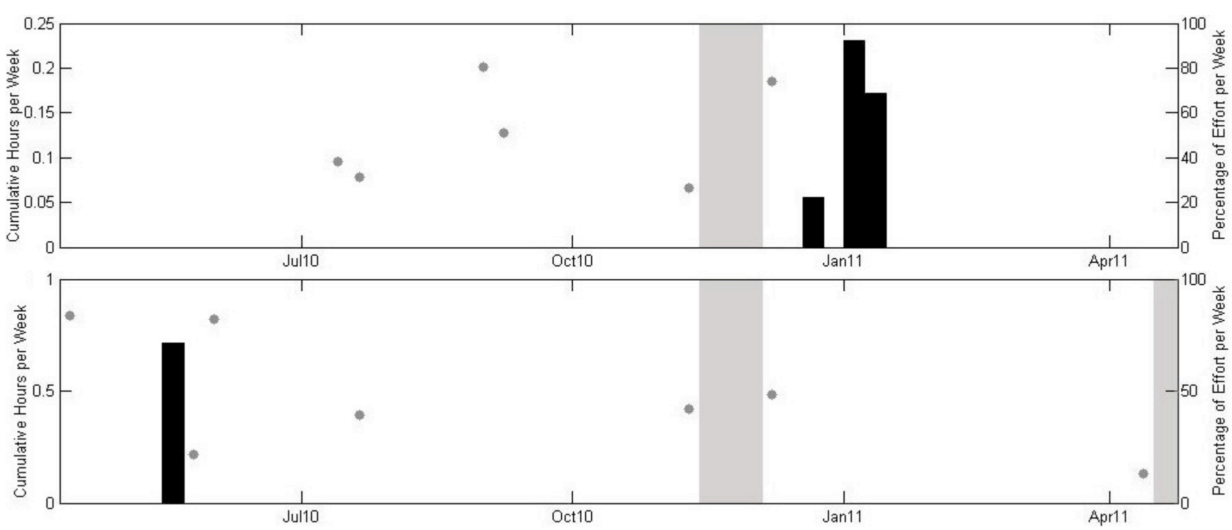

Figure 54: Weekly Baird's beaked whale frequency modulated pulse and click presence at sites M (top) and N (bottom) between April 2010 and April 2011. Note y-axis in different scale. Effort markings are as described in Figure 34.

Unidentified Beaked Whales

Detections of unidentified beaked whale frequency modulated (FM) pulses were very rare and due to the lack of data with no apparent diel or seasonal pattern. A group of possible Stejneger's beaked whales with signals reminiscent to those described from the Aleutian Islands were detected during three consecutive days in the end of July 2010 at site M (Figure 55 top). FM pulses with 50 kHz peak frequency were detected once early February 2011 at site M (Figure 55 middle) and with 43 kHz peak frequency once at site N in late January 2011 (Figure 55 bottom).

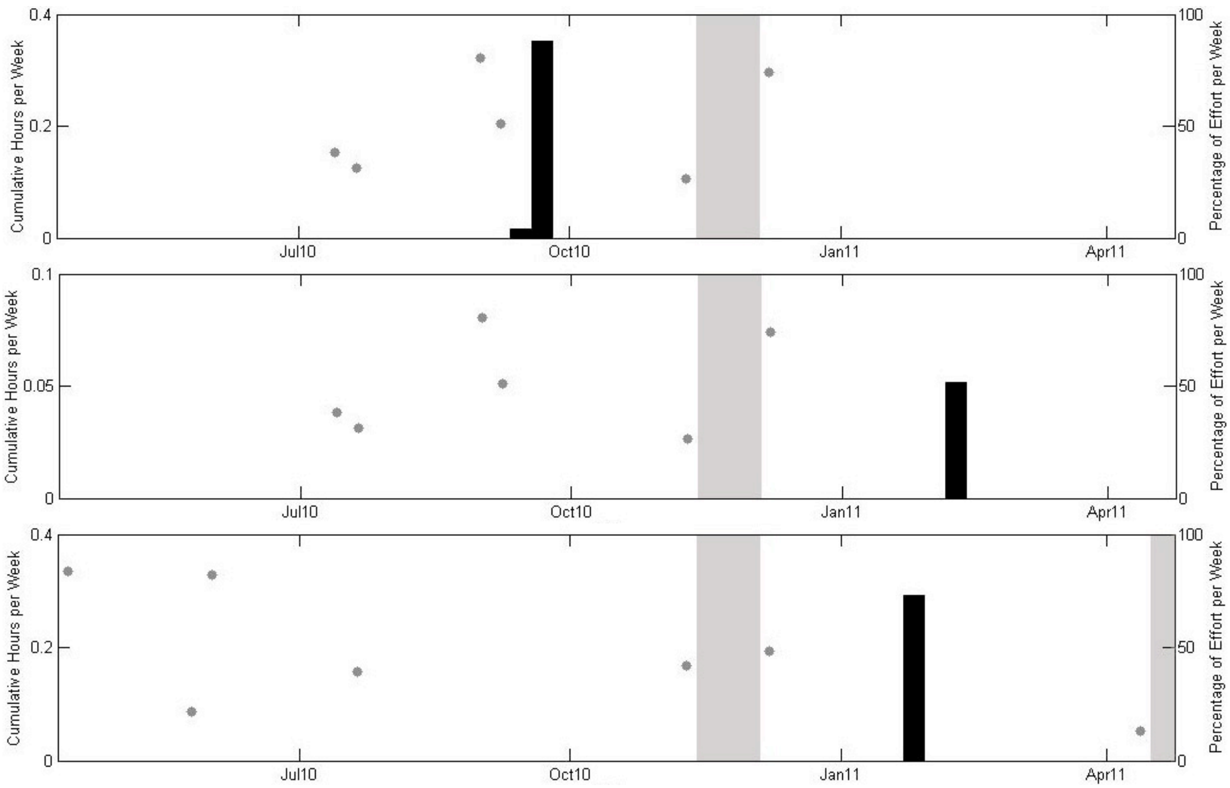

Figure 55: Weekly unidentified beaked whale frequency modulated (FM) pulse presence between April 2010 and April 2011. FM pulses reminiscent to likely Stejneger's beaked whale signals identified at the Aleutian Islands were present at site M (top). FM pulses with a peak frequency of 50 kHz were detected at site M (middle) and with a peak frequency of 43 kHz at site N (bottom). Note y-axis in different scale. Effort markings are as described in Figure 34.

Anthropogenic Sounds

Broadband Ship Noise

Ship noise was the most common anthropogenic sound at sites M and N, although it was more common at site M (Figure 56). Site M is on the south side of the northern Channel Islands, on the route for ships embarking at the Ports of Los Angeles and Long Beach. Daily patterns of ship noise with two temporal peaks (see Appendix) shows the preference in times for ship arrival and departure to port.

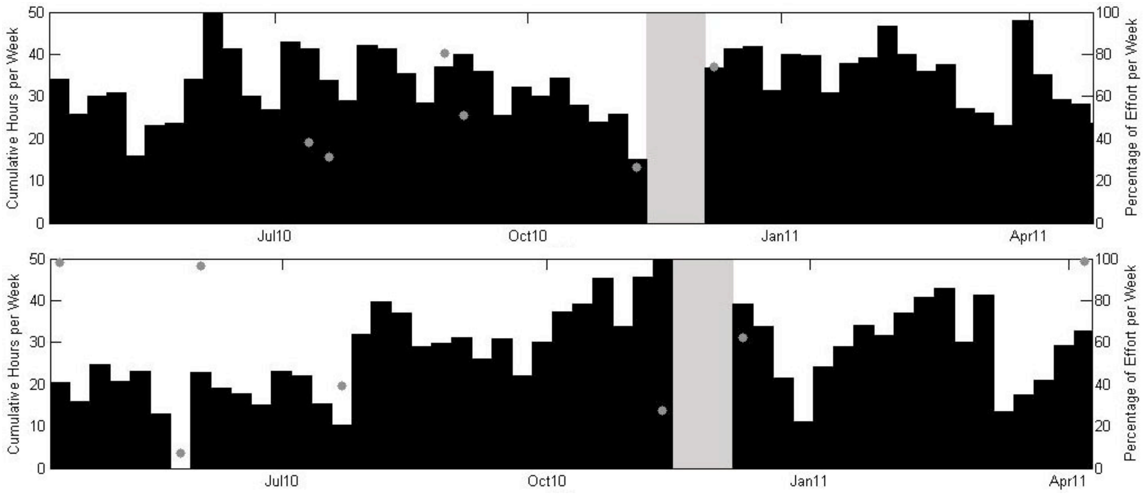

Figure 56 Weekly hours with broadband ship noise at sites M (top) and N (bottom) between April 2010 and April 2011. Effort markings are as described in Figure 34**.**

Mid-Frequency Active Sonar

Both sites M and N had MFA sonar events throughout the period April 2010 – April 2011 (Figure 57). At site N, over 55,000 MFA sonar pings were detected, ranging from 105 to 170 dB pp re 1 µPa; the maximum value is the clipping level of the HARP and the minimum value is a threshold limit based on the analysis methods used. Early December had the largest number of pings per week detected (~12,000) while some weeks did not have any detections. Distribution of ping levels from site N in 1 dB bins shows a peak around 120 dB pp re 1 µPa and is long-tailed to higher levels (**Figure 58**). Cumulative distribution of ping levels shows that half of the pings detected are above 125 dB pp re 1 µPa (Figure 59). While site M had MFA sonar events recorded, the received levels and the number of pings for these events were often much lower (e.g. < 120 dB pp re 1 µPa and 10's of pings/event) than at site N. These low levels precluded the use of the automated detection and received level routine on many of the low intensity (presumably distant) events from site M; however, one event in early August 2010 with about 800 pings was from a close source as received levels were almost up to the clipping level at 170 dB pp re 1 µPa.

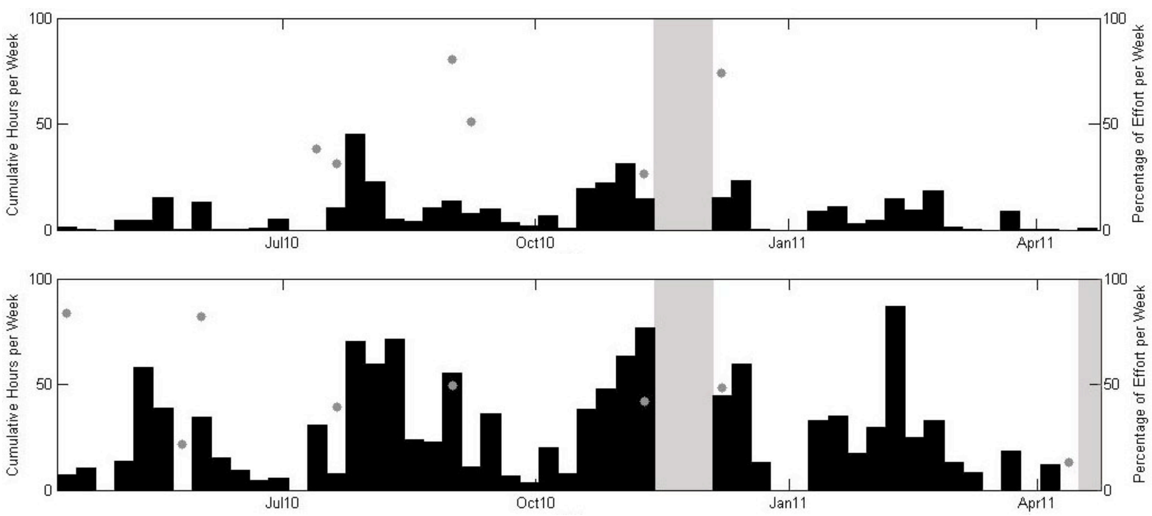

Figure 57 Weekly mid-frequency active (MFA) sonar presence at sites M (top) and N (bottom) between April 2010 and April 2011. Effort markings are as described in Figure 34.

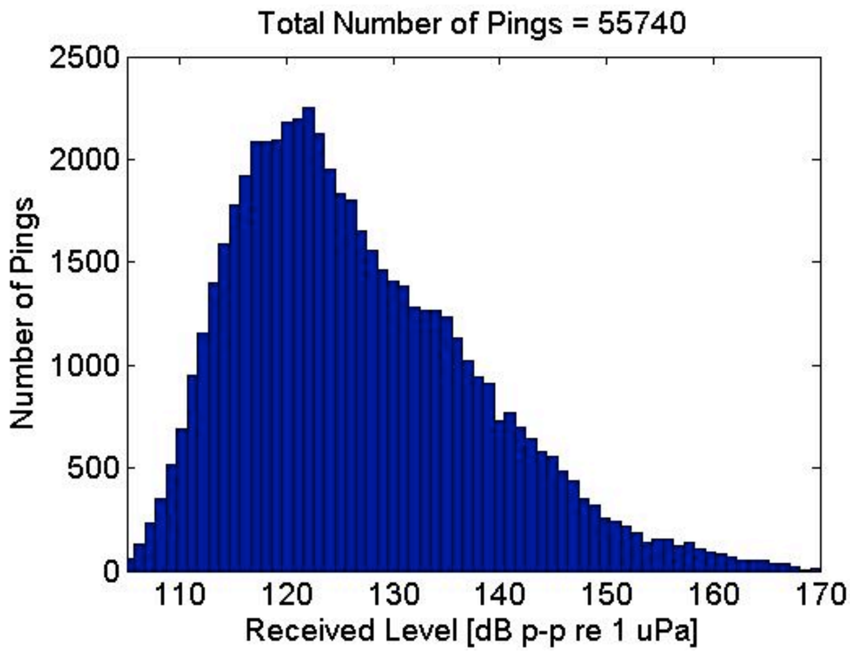

Figure 58 Distribution of number of MFA sonar pings by received levels at site N in 1 dB bins. Peak number of pings is at 120 dB pp re 1 µPa. Minimum level is 105 dB pp re 1 µPa and is related to the detection threshold and maximum level is 170 dB pp re 1 µPa which is the clipping level of the HARP. The period from early September to late November is not included in this analysis pending further data processing.

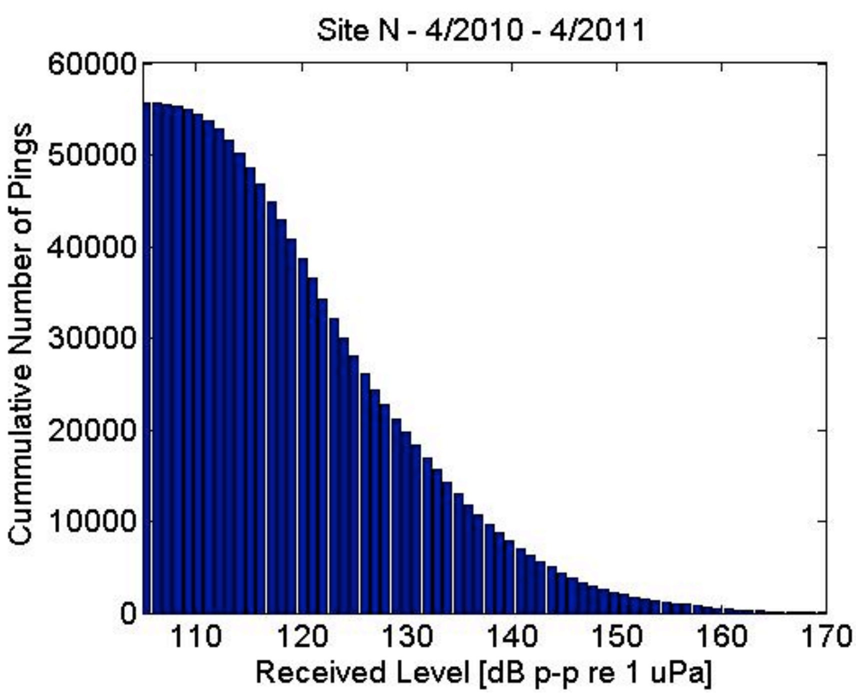

Figure 59 Cumulative distribution of the number of MFA sonar pings detected at site N by received level in 1 dB bins. One-half of the pings are above about 125 dB pp re 1 µPa.

High Frequency Active Sonar

High Frequency Active (HFA) sonar was infrequently detected at both sites M and N (Figure 60). A list of some HFA sonar events and their characteristics is given in Table 3.

Table 3: Frequency and inter-pulse interval features of HFA sonar during five detections with mean and standard deviation.

Date	Inter-pulse Interval	Start Frequency	End Frequency	Frequency Range
2/2/2011 3:37	8.2±2.7	19.7±0.2	28.0±0.9	8.4±1.0
2/5/2011 20:36	4.4±0.5	19.7±0.6	27.6±1.1	7.9±1.5
2/6/2011 0:08	4.2±0.4	19.5±0.5	28.9±0.8	9.5±0.8
2/6/2011 1:19	4.9±1.6	19.5±0.3	29.7±0.8	10.2±0.8
3/7/2011 12:37	4.2±0.4	19.8±0.2	25.2±0.6	5.4±0.6

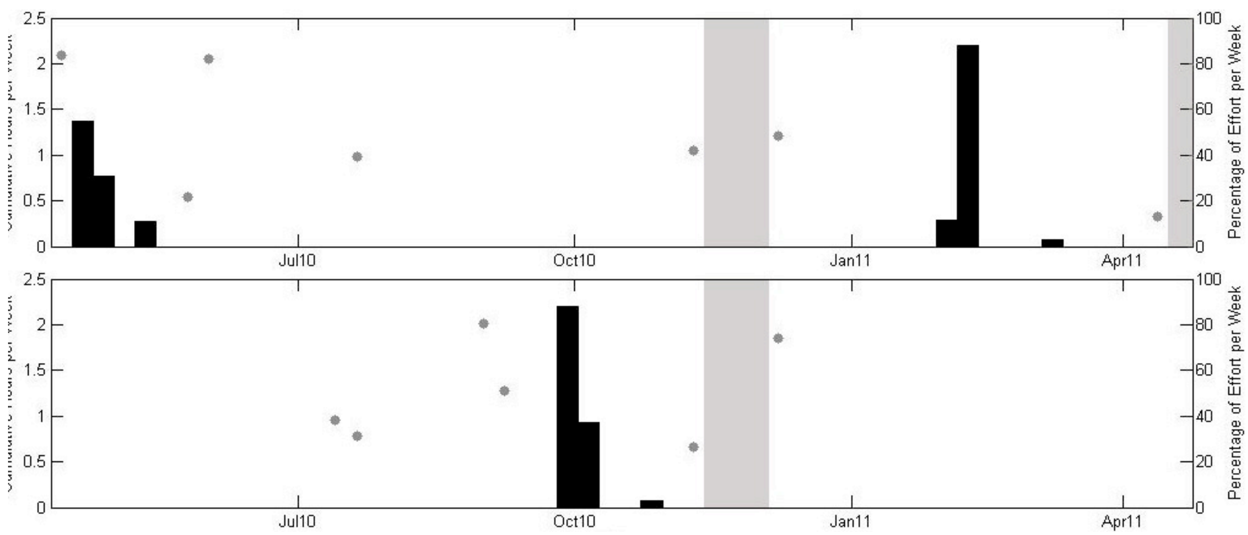

Figure 60 Weekly high frequency active sonar presence at sites M (top) and N (bottom) between April 2010 and April 2011. Effort markings are as described in Figure 34.

Echosounders

Echosounder pings with a variety of primary frequencies (8 – 80 kHz) were found at both sites M and N (Figure 61). More echosounders were present at site M than at site N, perhaps related to the presence of higher numbers of commercial vessels. The occurrence of these pings had no apparent seasonal cycle.

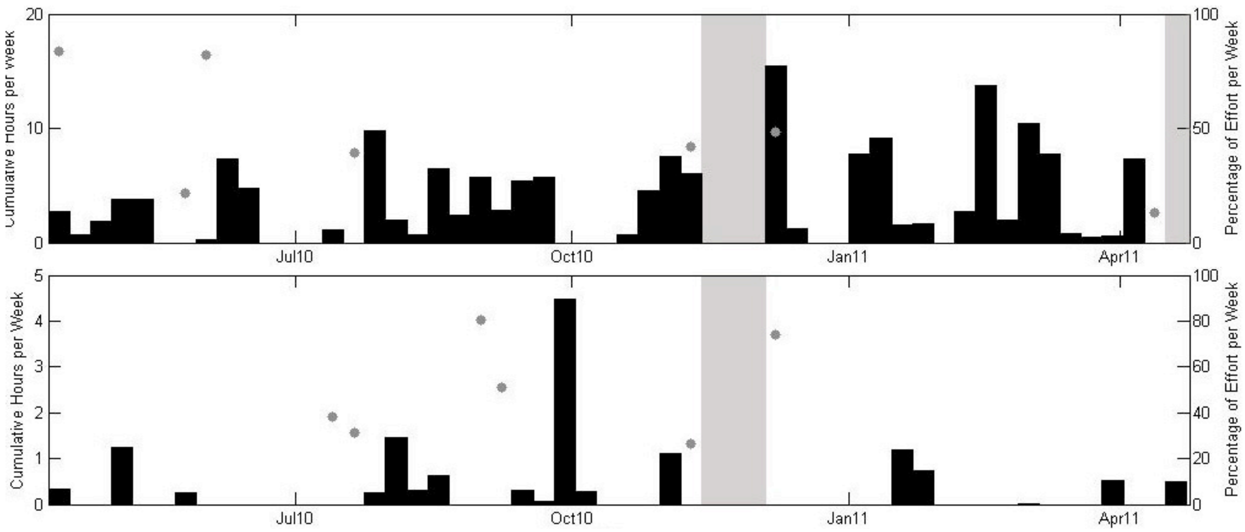

Figure 61 Weekly echosounder ping presence at sites M (top) and N (bottom) between April 2010 and April 2011. Effort markings are as described in Figure 34.

Explosions

Up to 60 and 30 hours with explosions per week were recorded at sites M and N, respectively (Figure 62). Peak in explosions at site M was recorded in December 2010, while at site N it was in October 2010. There is somewhat of a tendency for explosions to occur at night (Appendix).

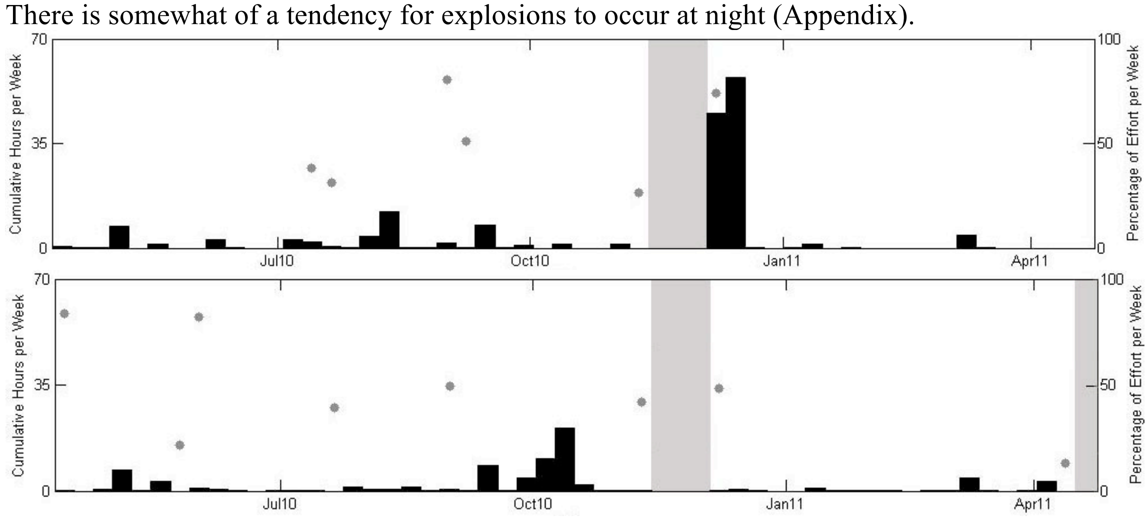

Figure 62 Weekly hours with explosions at sites M (top) and N (bottom) between April 2010 and April 2011. Effort markings are as described in Figure 34.

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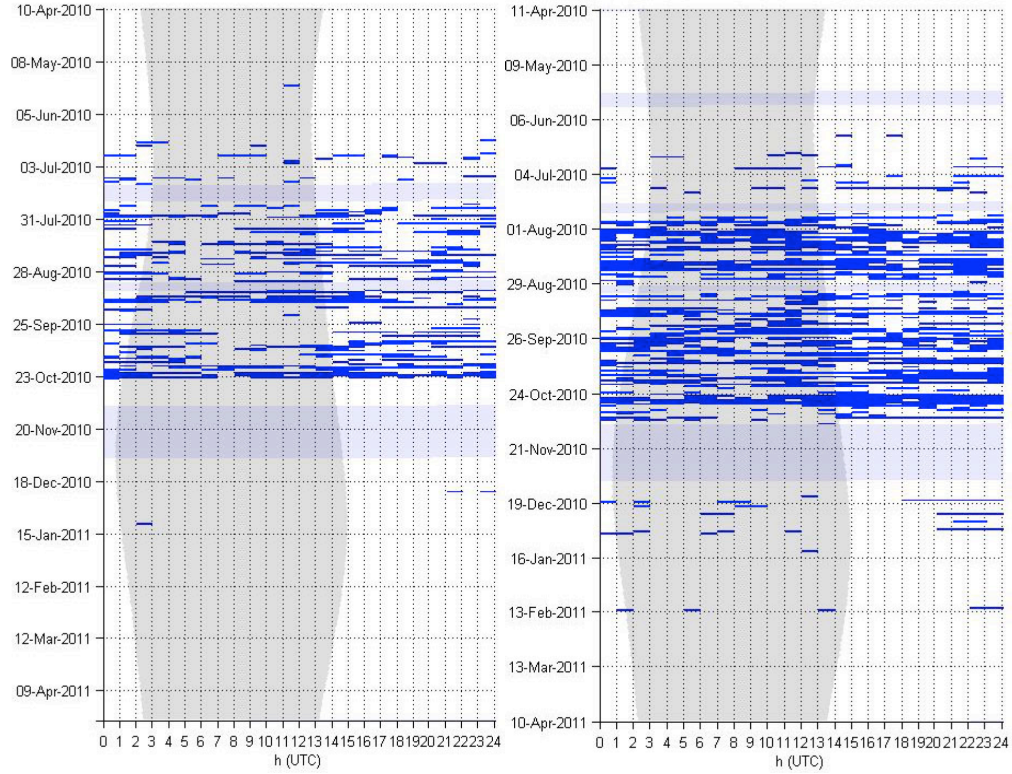
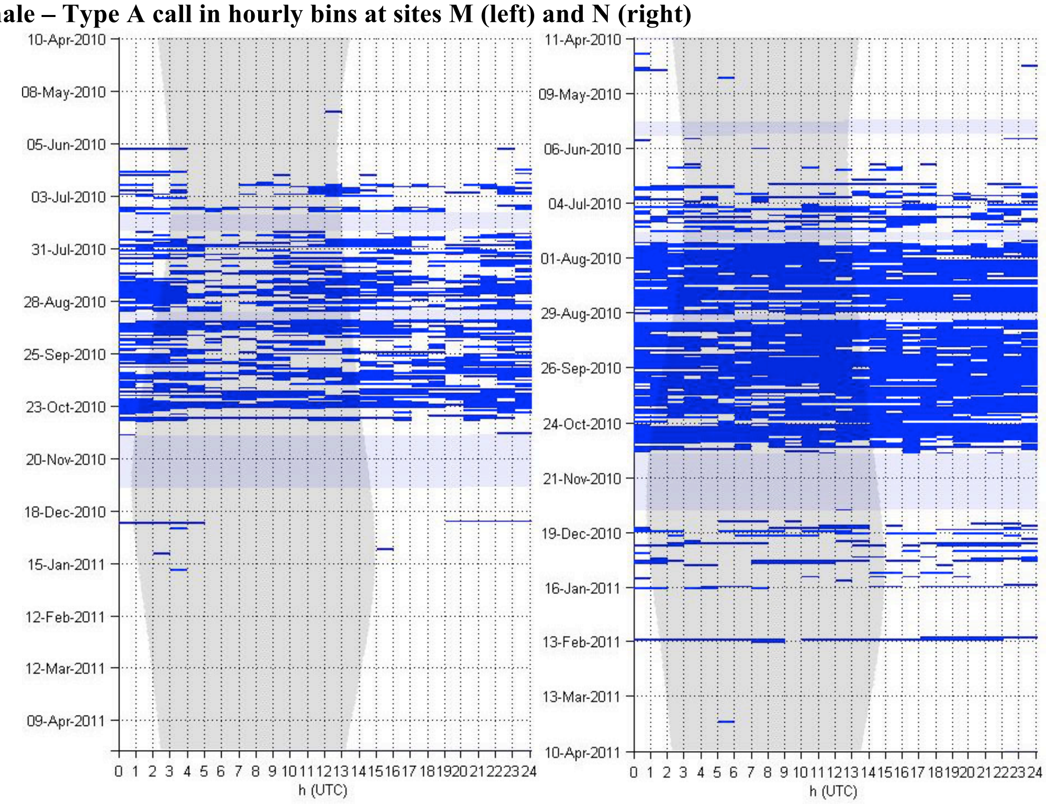
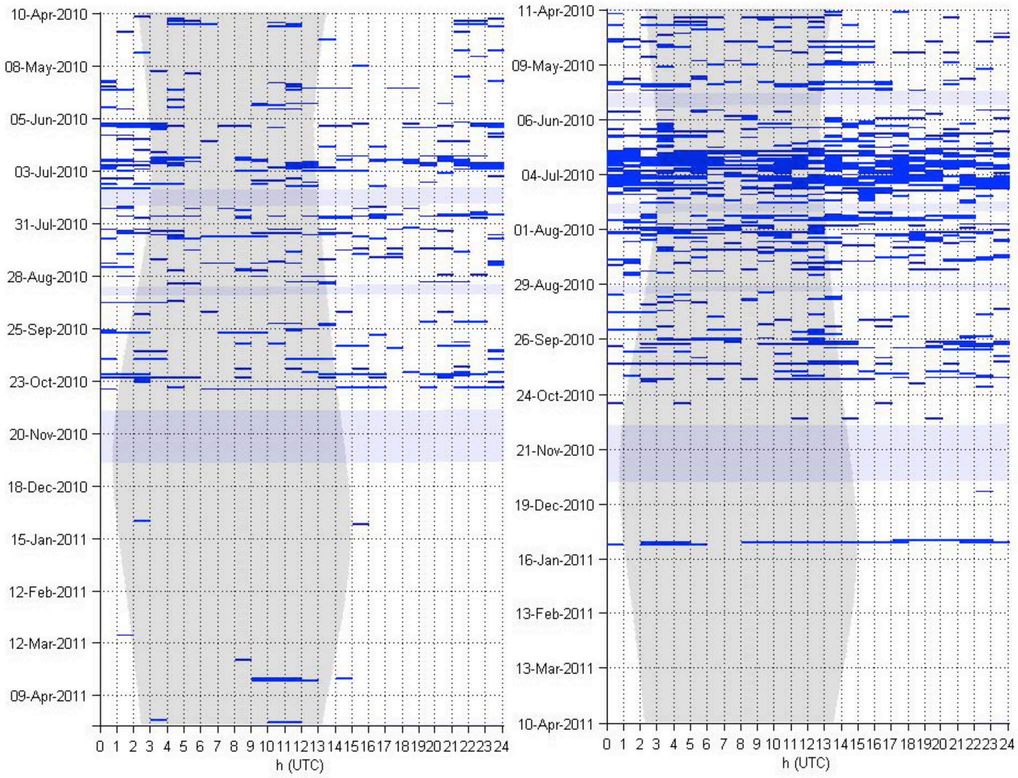
Appendix - Seasonal/Diel Occurrence Plots



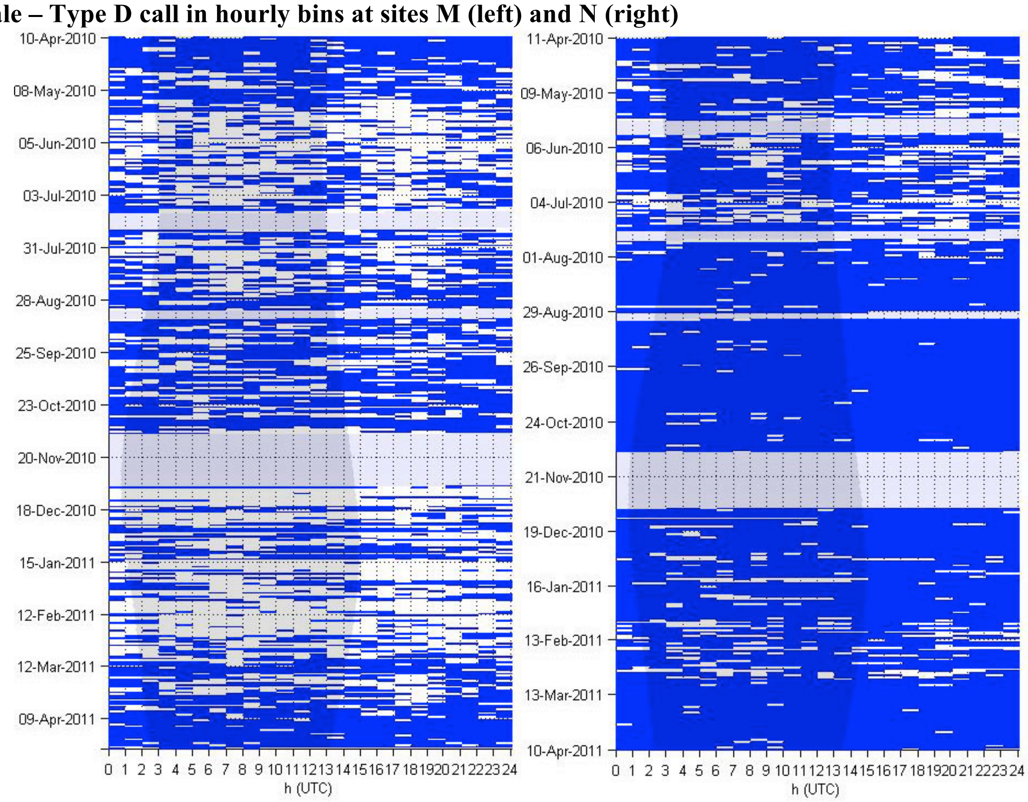
Blue whale – Type A call in hourly bins at sites M (left) and N (right)



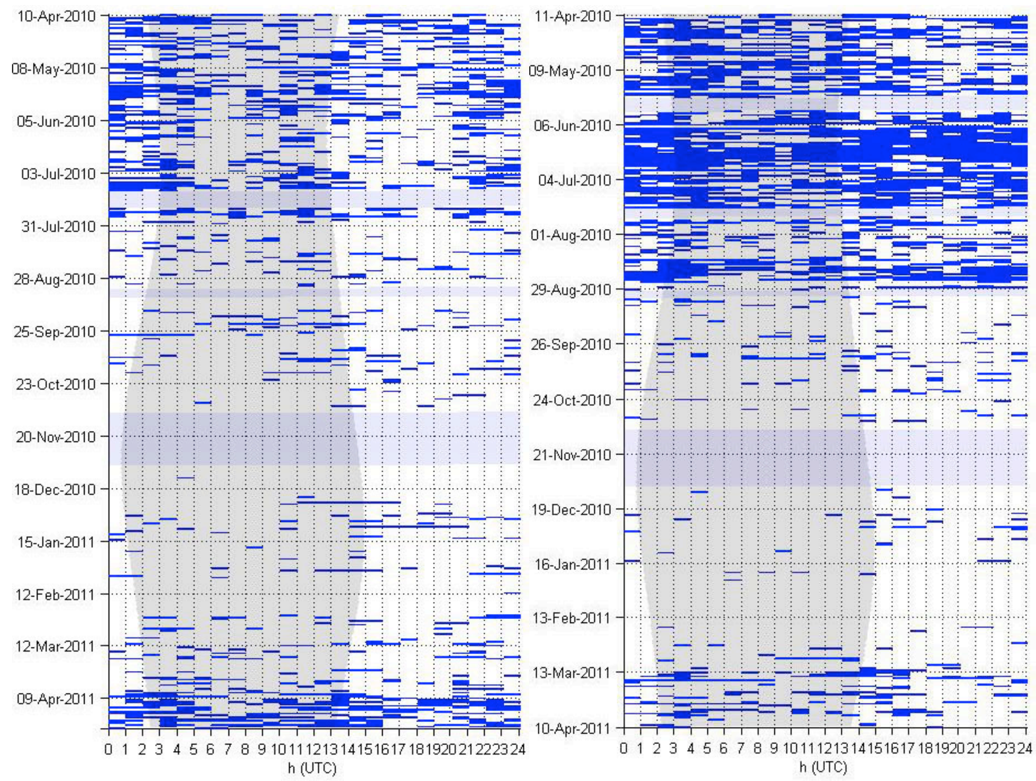
Blue whale – Type B call in hourly bins at sites M (left) and N (right)



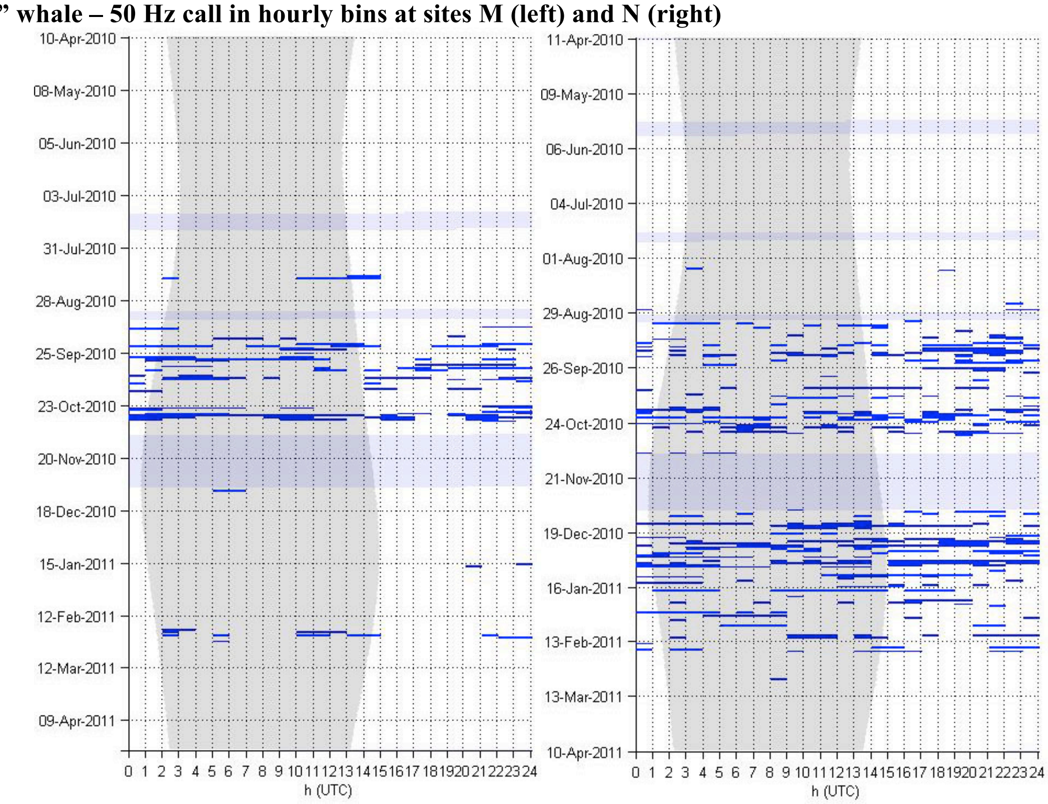
Blue whale – Type D call in hourly bins at sites M (left) and N (right)



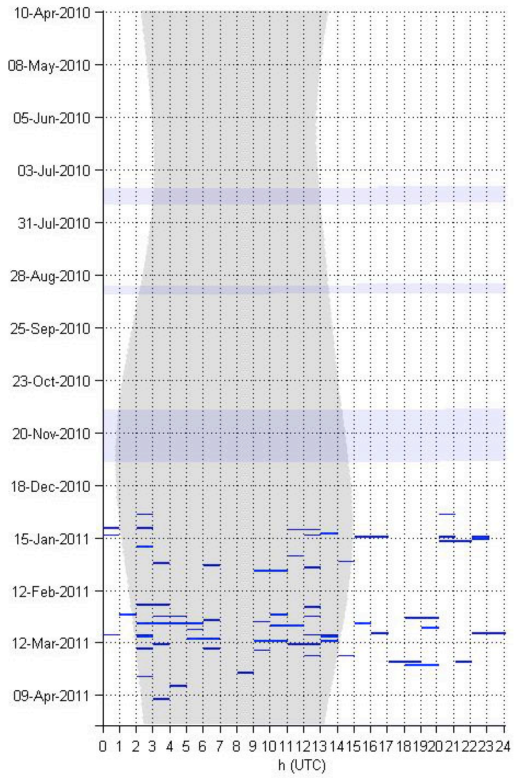
Fin whale – 20 Hz call in hourly bins at sites M (left) and N (right)



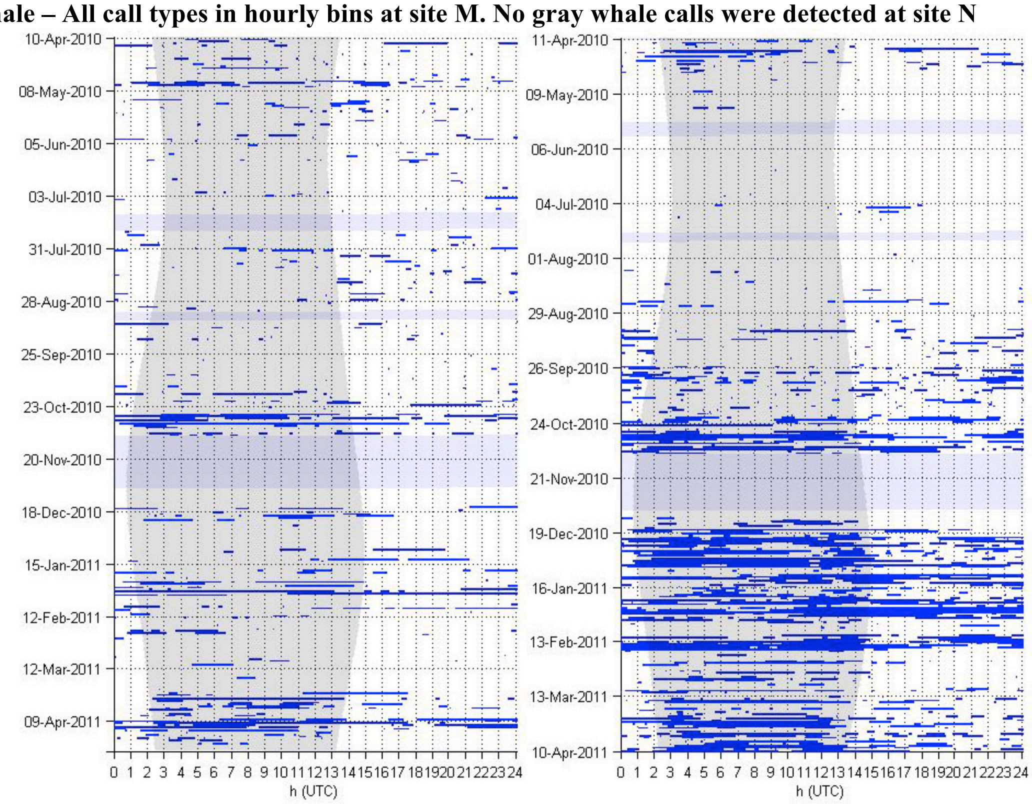
"50 Hz" whale – 50 Hz call in hourly bins at sites M (left) and N (right)



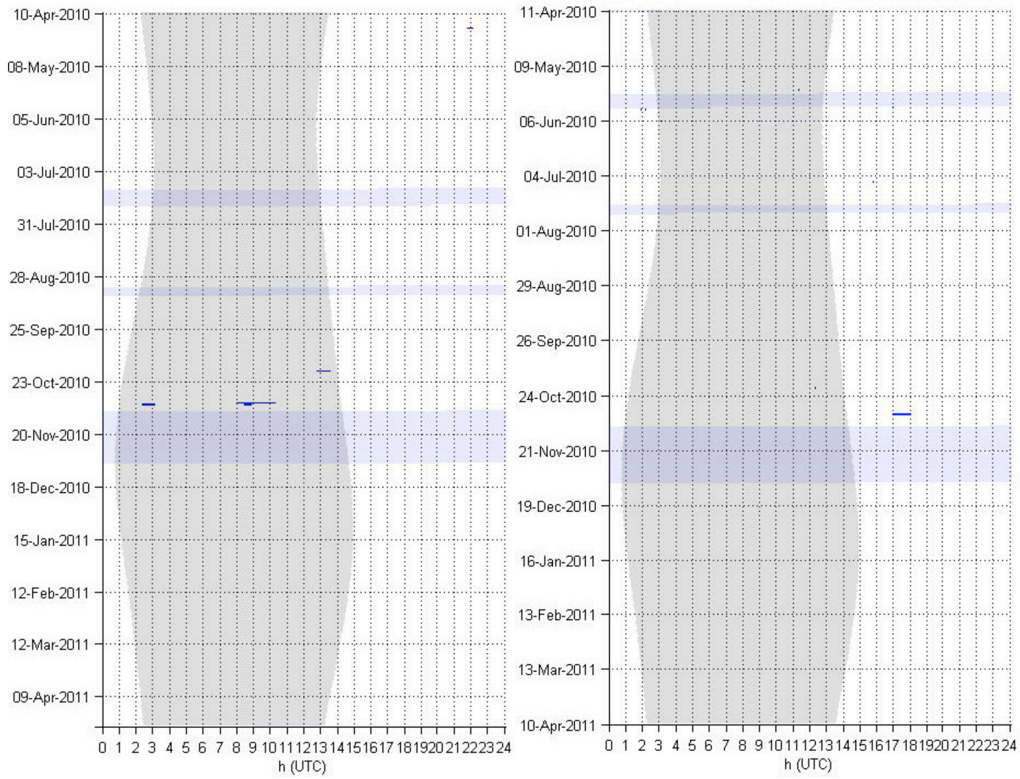
Bryde's whale – Be4 call in hourly bins at sites M (left) and N (right)



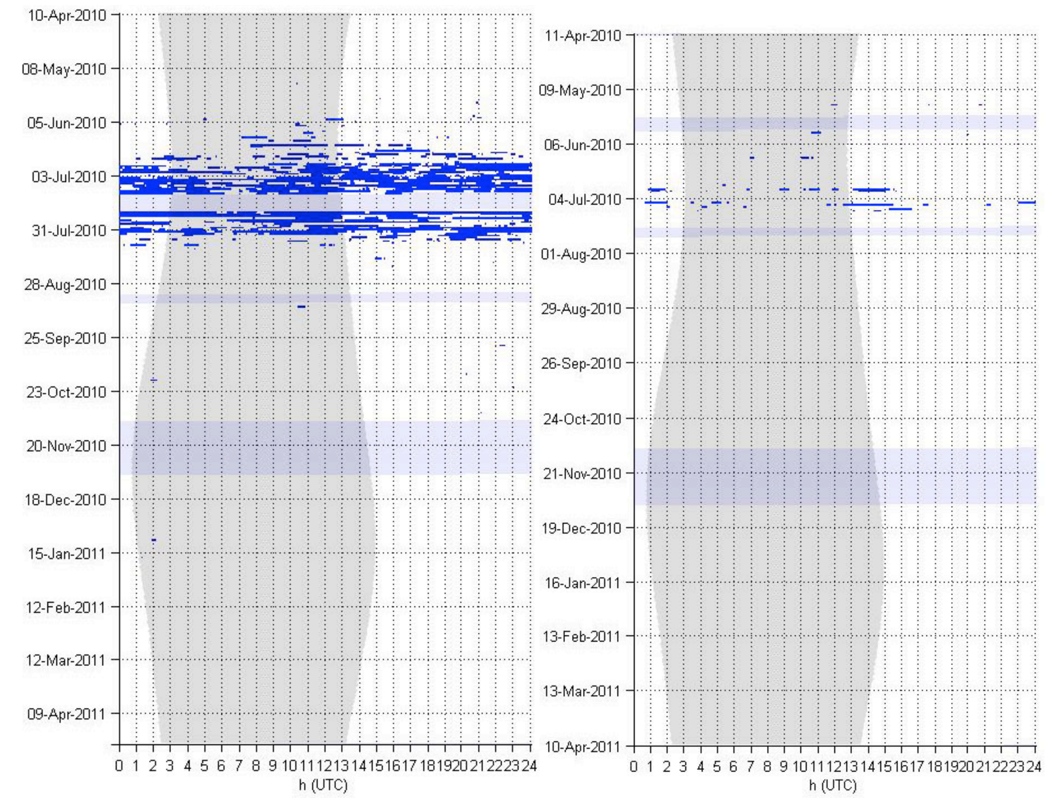
Gray whale – All call types in hourly bins at site M. No gray whale calls were detected at site N



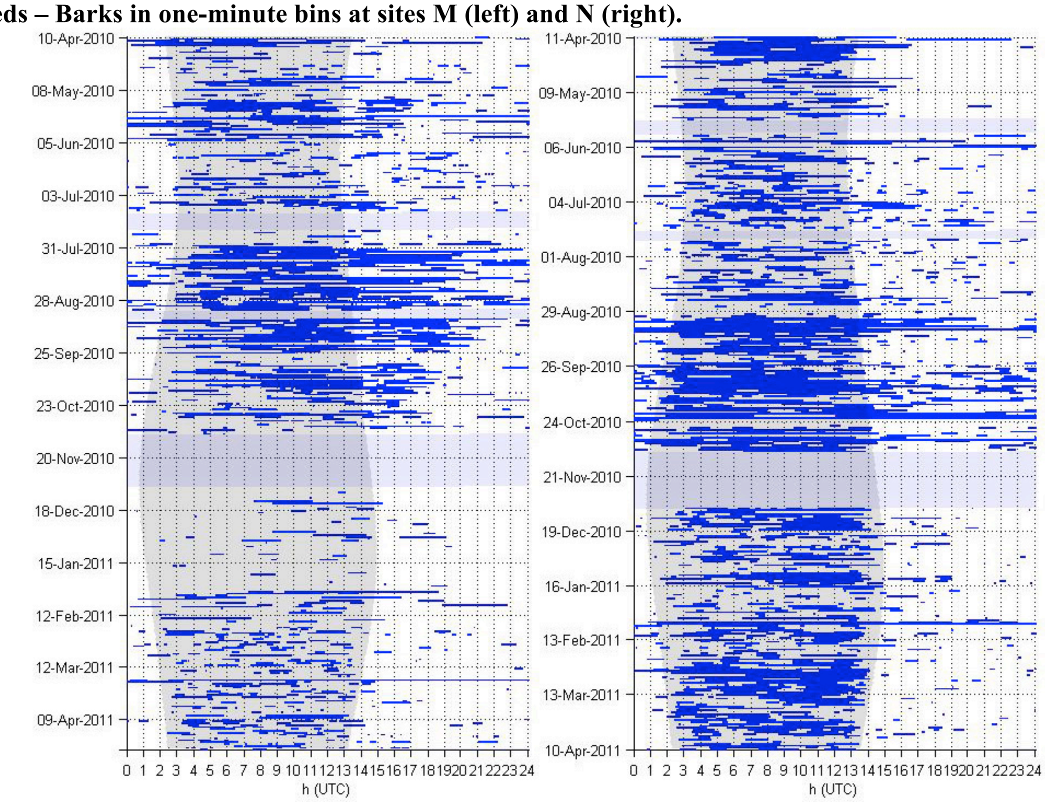
Humpback whale – Song and non-song calls in one-minute bins at sites M (left) and N (right)



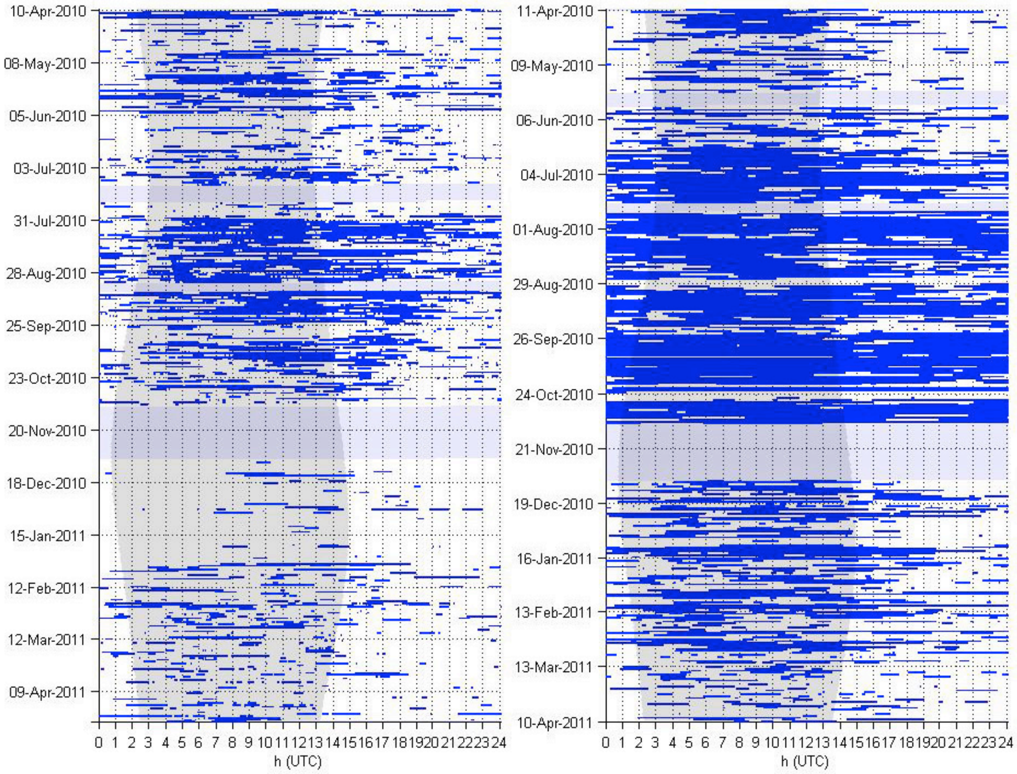
Minke whale – Boings in one-minute bins at sites M (left) and N (right)



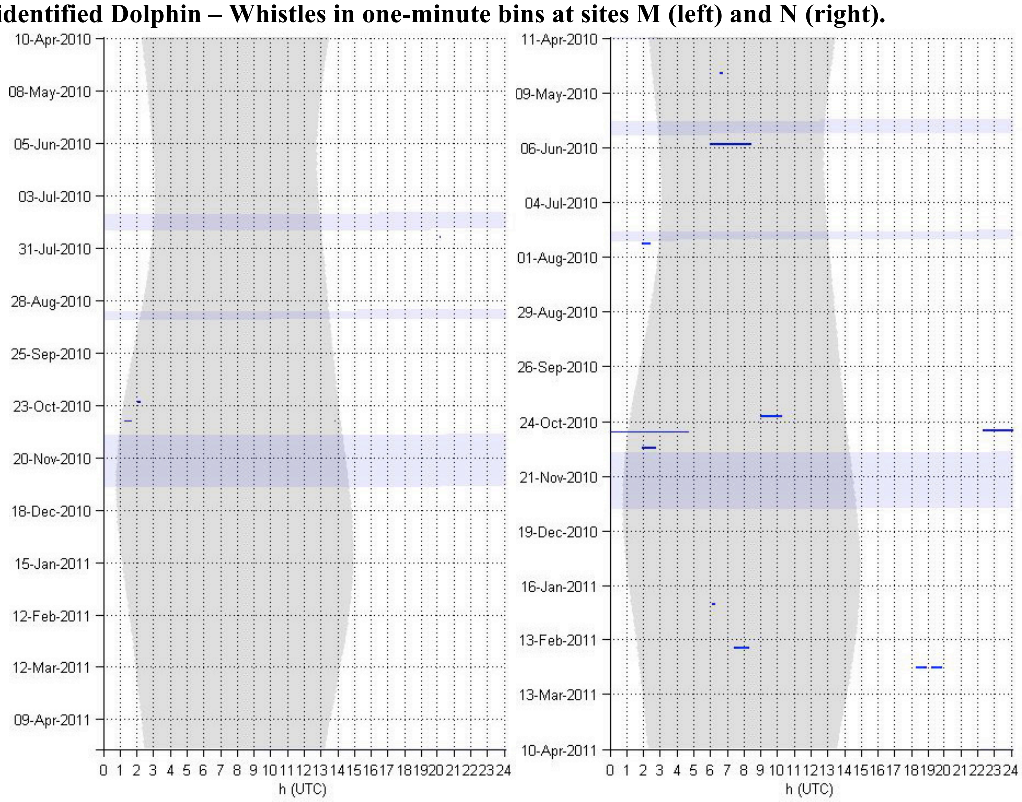
Pinnipeds – Barks in one-minute bins at sites M (left) and N (right).



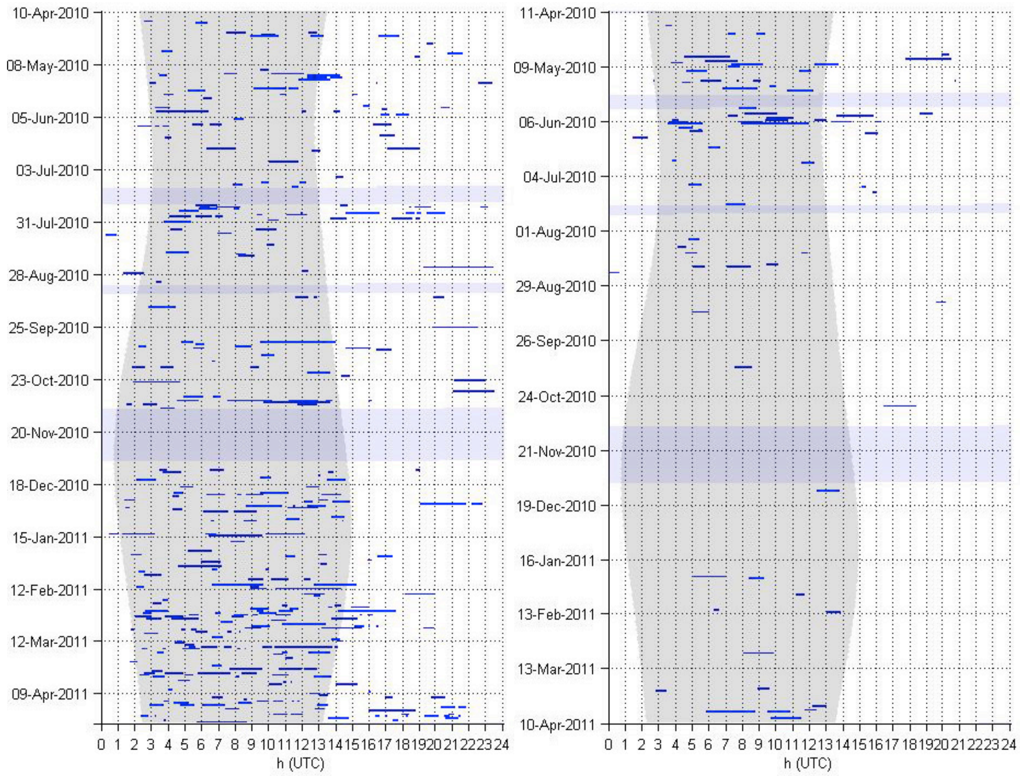
Unidentified Dolphin –Echolocation clicks in one-minute bins at sites M (left) and N (right).



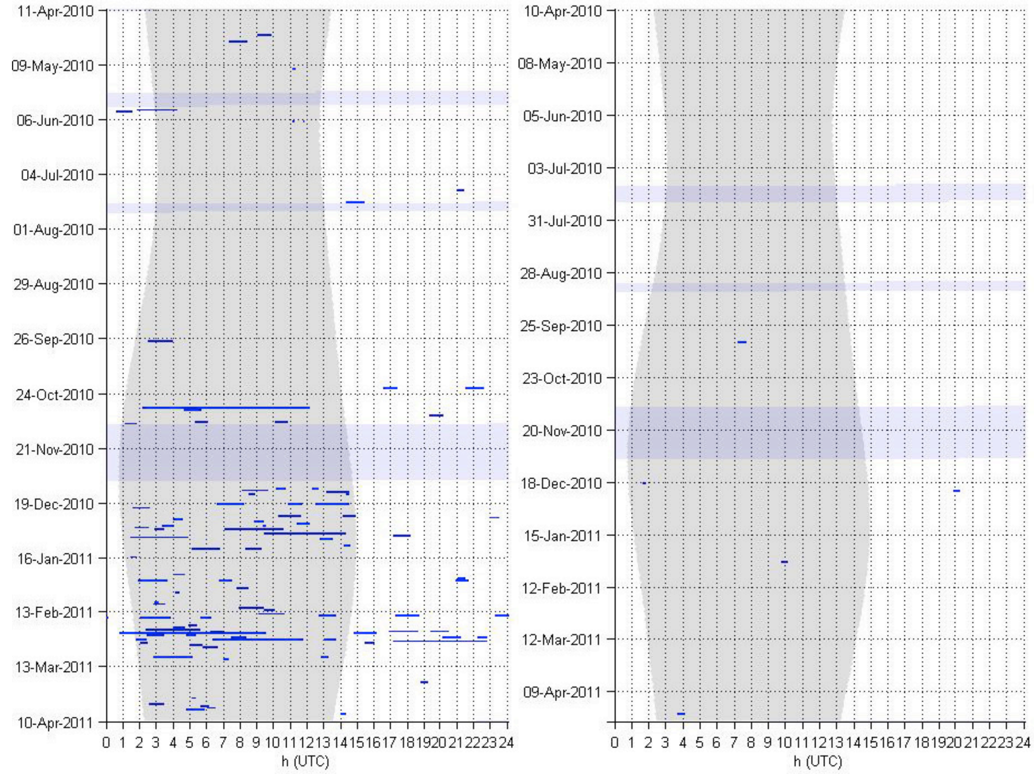
Unidentified Dolphin – Whistles in one-minute bins at sites M (left) and N (right).



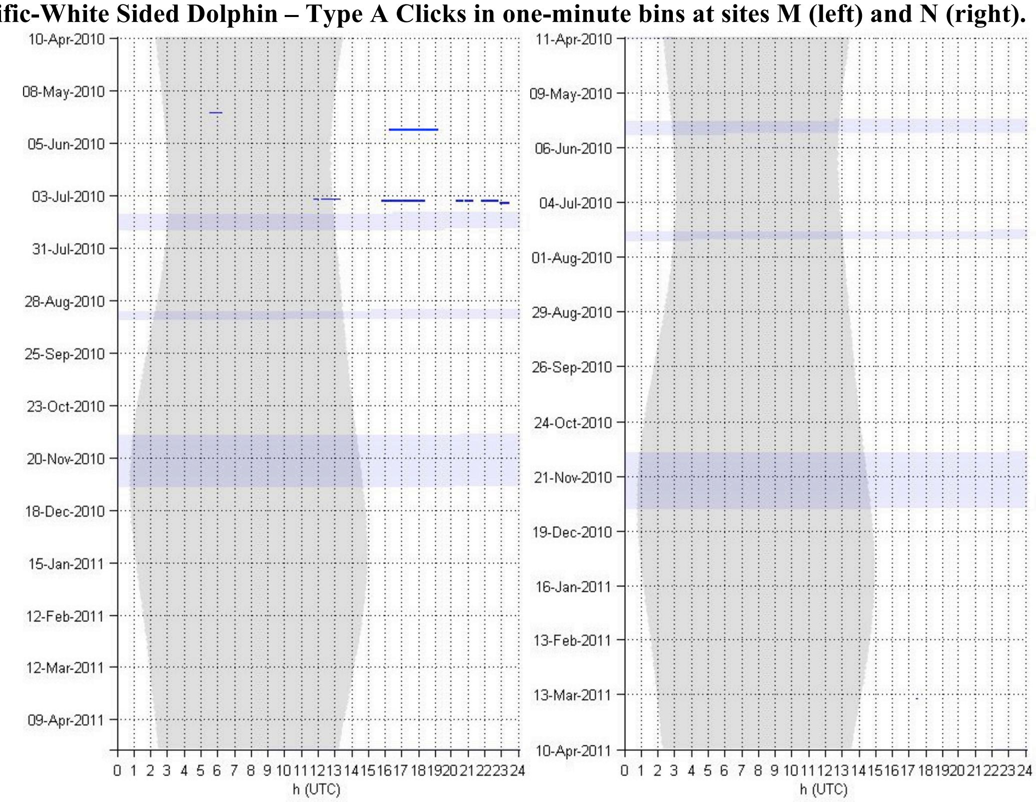
Unidentified Dolphin – Clicks at < 20 kHz in one-minute bins at sites M (left) and N (right).



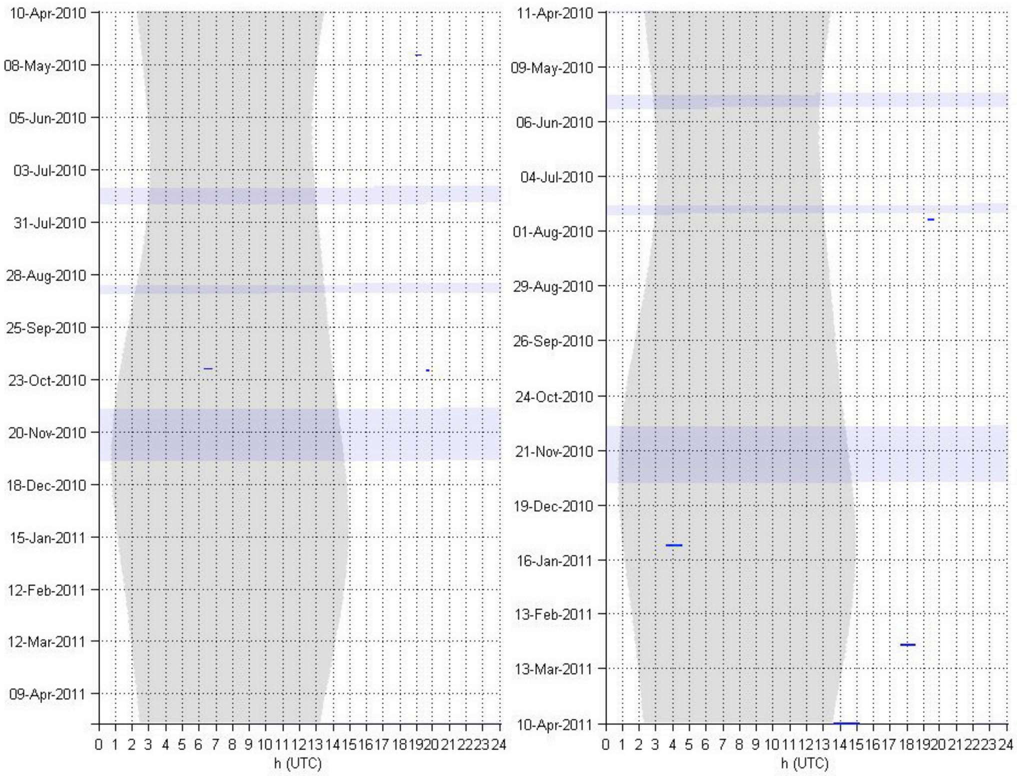
Risso's Dolphin – Echolocation Clicks in one-minute bins at sites M (left) and N (right).



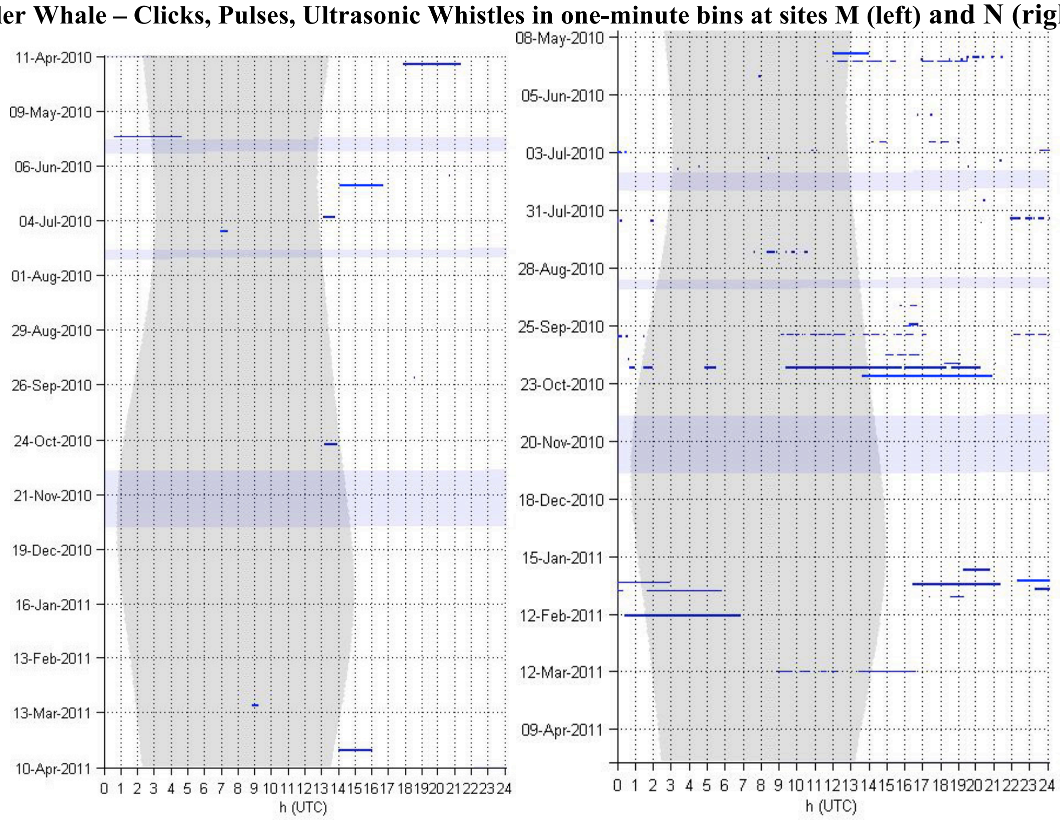
Pacific-White Sided Dolphin – Type A Clicks in one-minute bins at sites M (left) and N (right).



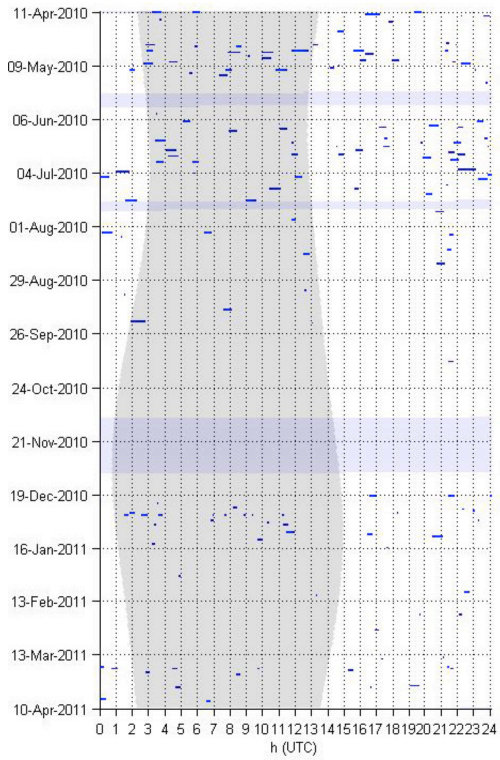
Pacific-White Sided Dolphin – Type B Clicks in one-minute bins at sites M (left) and N (right).



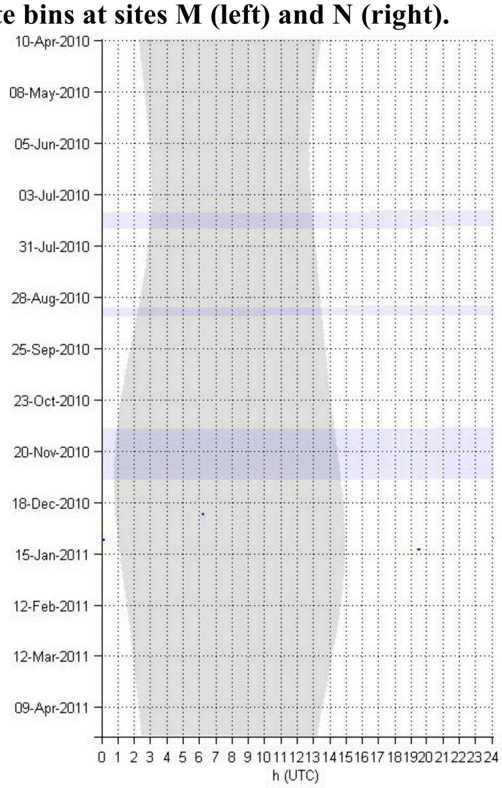
Killer Whale – Clicks, Pulses, Ultrasonic Whistles in one-minute bins at sites M (left) and N (right).



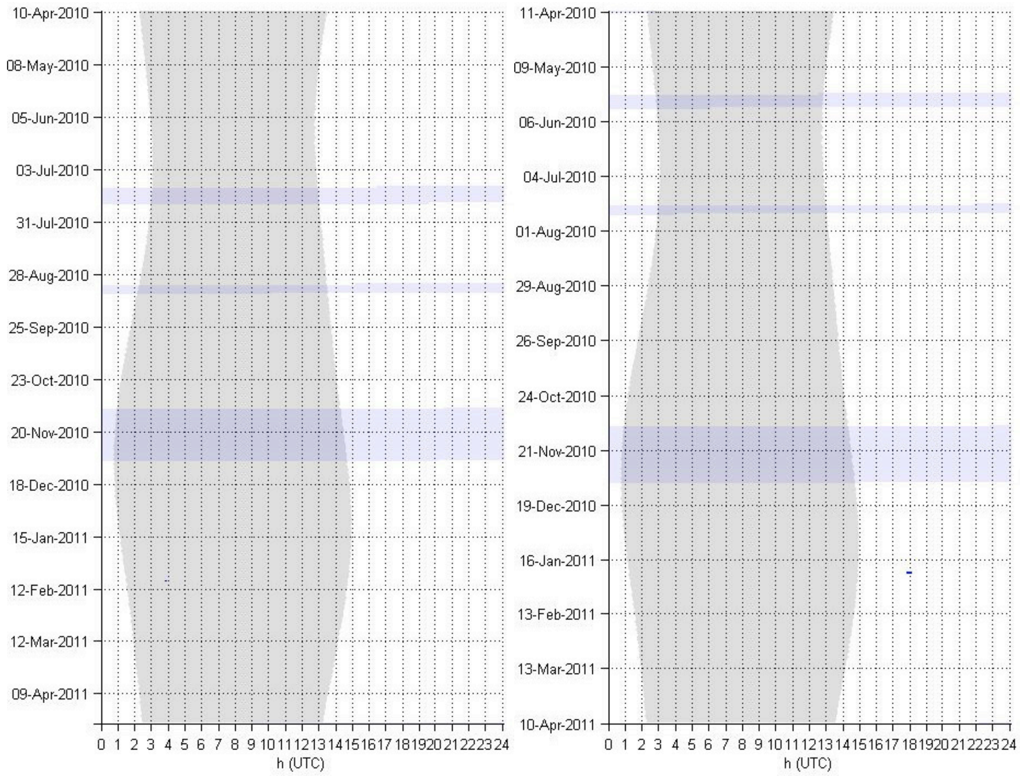
Sperm Whale – Echolocation Clicks in one-minute bins at sites M (left) and N (right).



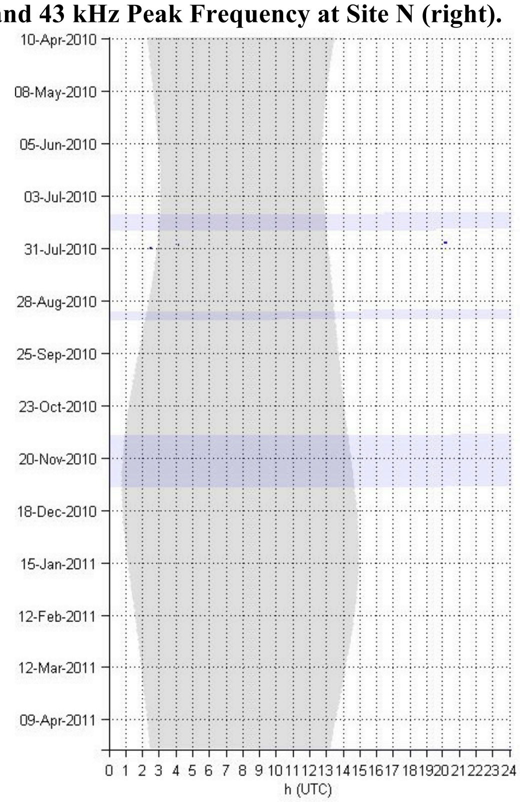
Cuvier's Beaked Whale - Frequency-Modulated Pulses (40 kHz peak frequency) in one-minute bins at sites M (left) and N (right).



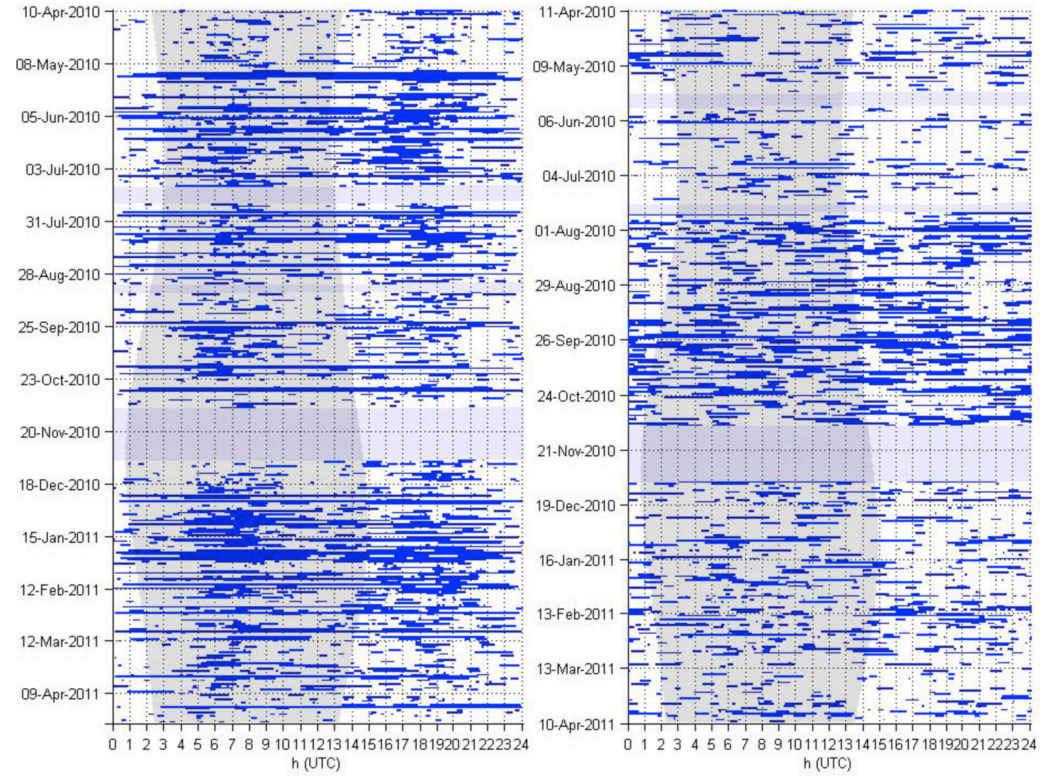
Baird's Beaked Whale – Frequency-Modulated Pulses (15 kHz Peak Frequency), Echolocation Clicks (30, 50 kHz Energy Bands) in one-minute bins at sites M (left) and N (right).



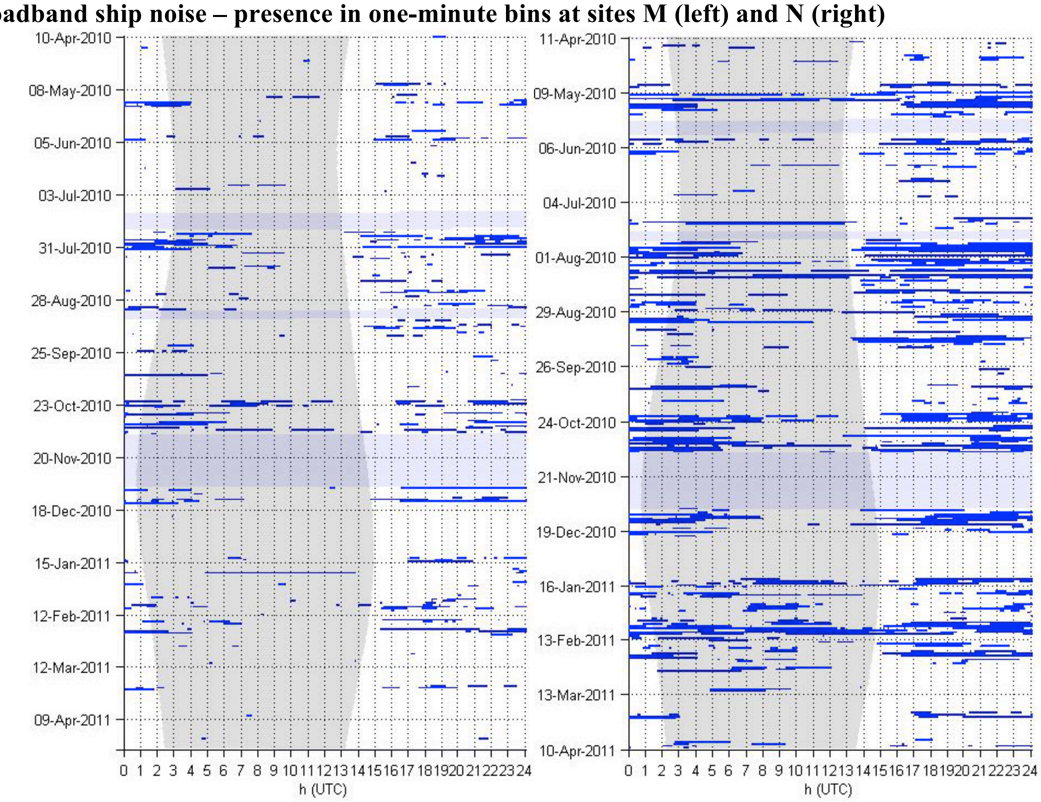
Unidentified Beaked Whale – Frequency-Modulated Pulses with 50 kHz Peak Frequency at Site M (left) and 43 kHz Peak Frequency at Site N (right).



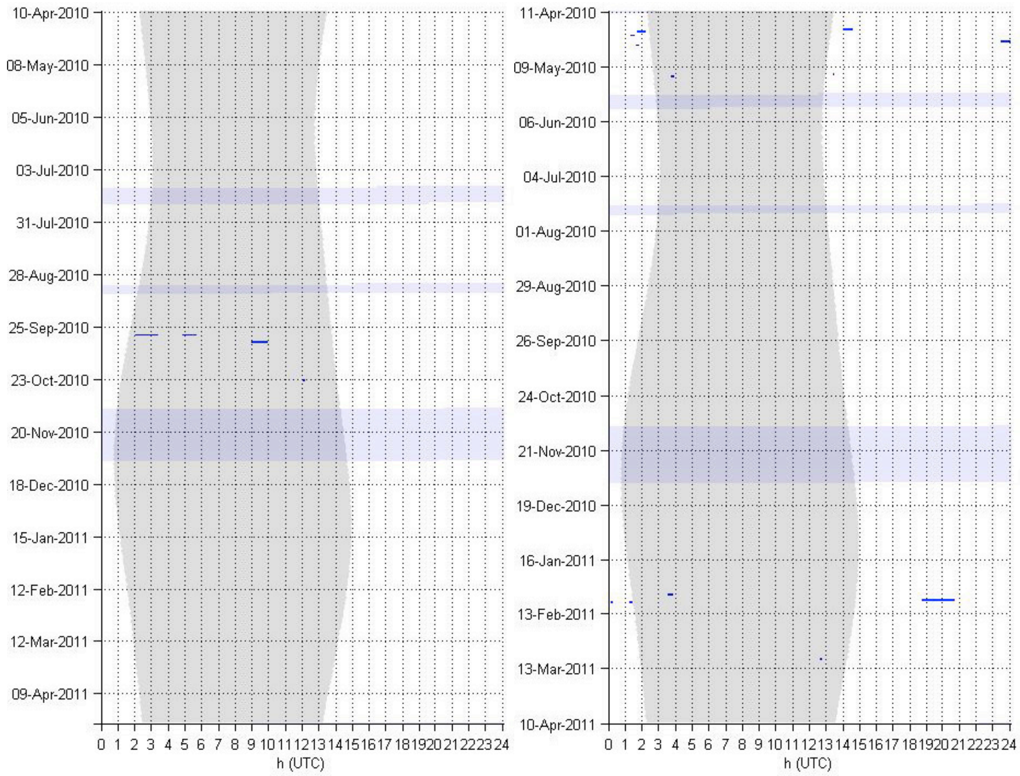
Unidentified Beaked Whale – Frequency-Modulated Pulses by Stejneger's beaked whale at Site M



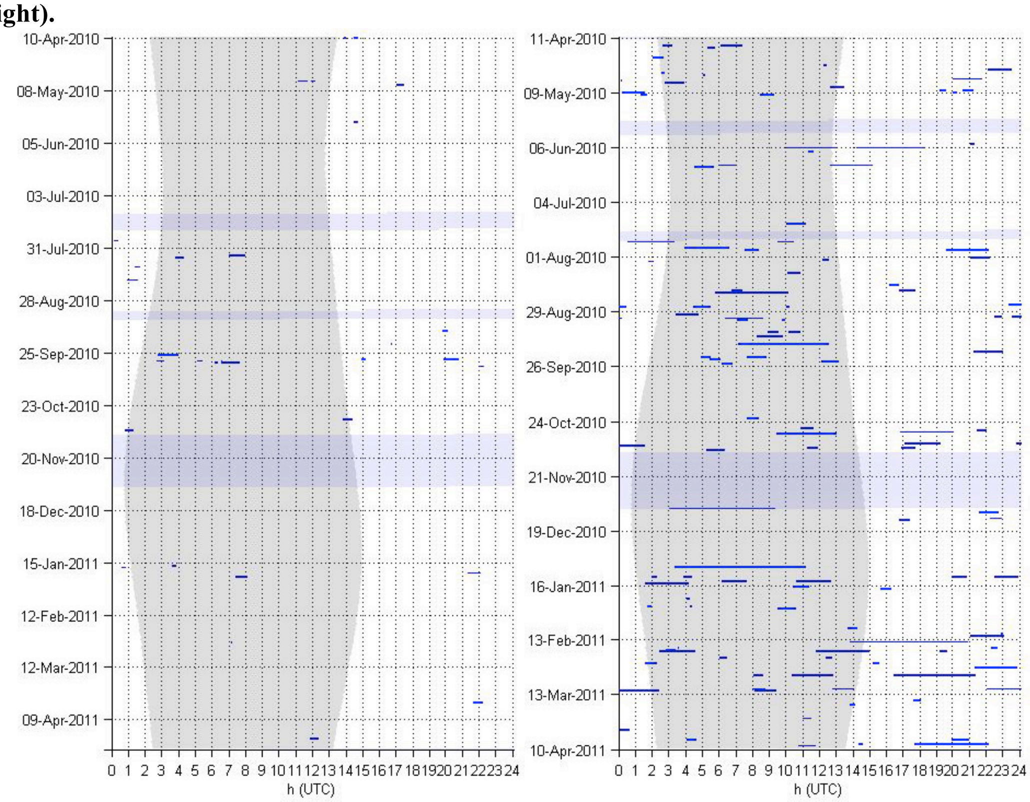
Broadband ship noise – presence in one-minute bins at sites M (left) and N (right)



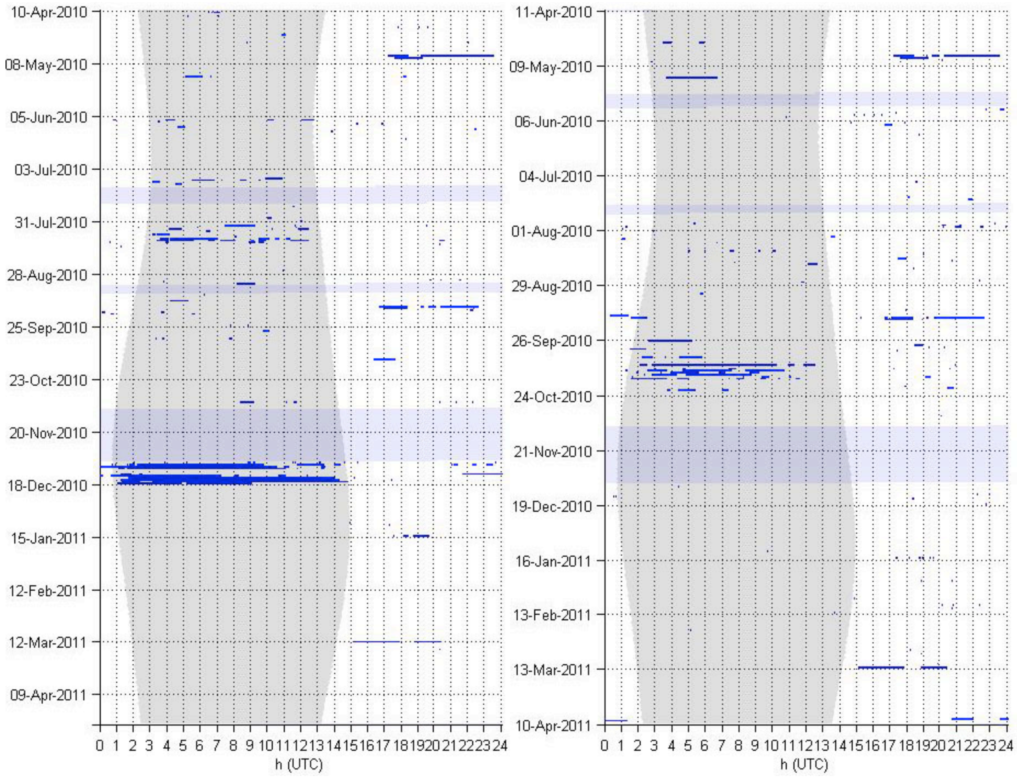
Mid-frequency active sonar – presence in one-minute bins at sites M (left) and N (right)



High Frequency Active Sonar – Upsweep Pulses (20-30 kHz) in One-Minute Bins at Sites M (left) and N (right).



Echosounder Pings – Various Frequency Pings in One-Minute Bins at Sites M (left) and N (right).



Explosions – Presence in hourly bins at sites M (left) and N (right)