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Passive Acoustic Monitoring for Marine Mammals in the SOCAL Naval Training Area 2011-2012

John A. Hildebrand, Simone Baumann-Pickering, Ana Širović, Jasmine Buccowich, Amanda Debich, Sarah Johnson, Sara Kerosky, Lauren Roche, Alba Solsona Berga, and Sean M. Wiggins

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

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MPL TECHNICAL MEMORANDUM # 537

Table of Contents

Executive Summary

Passive acoustic monitoring was conducted in the Navy's Southern California Range Complex during May 2011 – March 2012 to detect the presence of marine mammal and anthropogenic sounds. High-frequency Acoustic Recording Packages (HARPs) recorded sounds between 10 Hz and 100 kHz with nearly continuous temporal coverage at a site near Santa Barbara Island (site M) and at a site west of San Clemente Island (site H). Data analysis consisted of detection of sounds of interest by analyst scans of long-term spectral averages and spectrograms, and by automated computer algorithm detection when possible. Representative sounds are presented in this report, as well as details of the computer algorithms used to detect them.

Five baleen whale species were detected: blue whales, fin whales, Bryde's whales, gray whales, and humpback whales. No minke whale sounds were detected in these data. Site H had more calling baleen whales than site M; using a measure of species richness, there were on average 2.8 baleen whale species present daily at site M and 3.8 present at site H.

At least 11 species of odontocetes were detected. There were 6 species with known species-specific acoustic signal characteristics: Risso's dolphin, Pacific white-sided dolphin, killer whale, sperm whale, Cuvier's beaked whale, and Baird's beaked whale. The data most likely included three species whose sounds cannot yet be differentiated to species: short-beaked common dolphins, long-beaked common dolphins, and bottlenose dolphins, grouped as unidentified dolphins. There were possibly two additional species of beaked whales that were detected: the 43 kHz beaked whale and an unidentified beaked whale. Using a measure of species richness, including only those species with known sound characteristics, odontocete daily species richness at site M was 1.8 species and site H was 2.1 species.

Ship noise was a common anthropogenic sound at site M and less common at site H. Both sites had Mid-Frequency Active (MFA) sonar events throughout the monitoring period May 2011 – March 2012. Site H had 51,121 MFA sonar pings detected with a median received level of 128 dB pp re 1 μPa, and maximum received level of 177 dB pp re 1 μPa. Site M had fewer MFA sonar pings recorded with 3,777, and the received levels were lower, with a median of 123 dB pp re 1 μPa and a maximum of 167 dB pp re 1 μPa. Acoustic communications systems were detected primarily at site H, corresponding to periods of high MFA sonar usage. Echosounder pings were found primarily at site H. Explosions were also recorded primarily at site H, but their small size and nighttime pattern suggest that they may be associated with fishing activity.

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 here, 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. 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 data recorded by two High-frequency Acoustic Recording Packages (HARPs) that were deployed within SCORE, one to the west (site H) and one to the northwest (site M) of San Clemente Island (Figure 1) during the time period May 2011 – March 2012. Previous acoustic monitoring efforts for the SCORE area (Hildebrand *et al.* 2009b, Hildebrand *et al.* 2010b, Hildebrand *et al.* 2010a, Hildebrand *et al.* 2011) have analyzed data from site N (southwest of San Clemente Island, Figure 1) rather than site H. The change for this report was necessitated by a hardware (hydrophone) failure at site N during the 2011-2012 recording period. A continuation of data collection at site N would have been preferred for continuity, but we found higher levels of both marine mammal presence and anthropogenic activity (MFA sonar) at site H than previously observed at site N. Table 1 lists the time periods for occupation of these sites. Although site H has not been previously included in detailed acoustic monitoring reports, nearly continuous data for it are available for the January 2009 to present period. This provides the potential for retrospective analysis of the earlier site H data to yield a time series equivalent to that previously reported for site N.

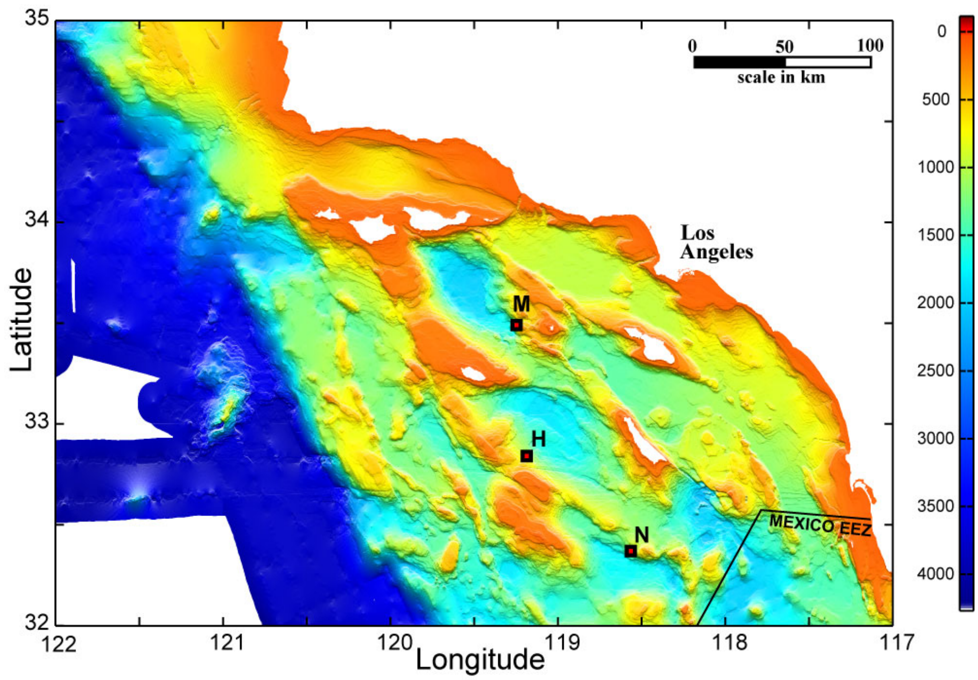

Figure 1. Locations of High-frequency Acoustic Recording Packages at sites M, H and N in the Southern California Range Complex area. Color is bathymetric depth (scale bar at right in meters depth).

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 and are capable of approximately 150 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 three sites within SCORE using autonomous High-frequency Acoustic Recording Packages (HARPs) sampling at 200 kHz since January 2009 (Table 1). The sites are designated site M (33° 30.92N, 119° 14.96W, depth 920 m), site H (32° 56.54, 119° 10.217 W, depth 1000 m) and site N (32° 22.18N, 118° 33.77W, depth 1250 m). This report will focus on data analysis from sites M and H collected between May 2011 and March 2012.

Table 1. SCORE acoustic monitoring since January 2009. Period of instrument deployment analyzed in this report is shown in bold. Results of acoustic monitoring at sites M and N through May 2011 are described in (Hildebrand et al. 2009a, Hildebrand et al. 2009b, Hildebrand et al. 2010b, Hildebrand et al. 2010a, Hildebrand et al. 2011). Data are available for site H for January 2009 – May 2011, but have not been fully analyzed.

Deployment Designation	**Site H Deployment Period**	**Site M Deployment Period**	**Site N Deployment Period**
SOCAL 31	1/12/09 - 3/13/09	1/13/09 - 3/10/09	1/13/09 - 3/13/09
SOCAL 32	3/13/09 - 5/19/09	3/10/09 - 5/16/09	3/14/09 - 5/19/09
SOCAL 33	5/19/09 – 7/22/09	5/16/09 – 7/26/09	5/19/09 – 7/22/09
SOCAL 34	7/23/09 – 9/25/09	7/27/09 – 9/25/09	7/22/09 – 9/25/09
SOCAL 35	9/25/09 – 12/5/09	9/25/09 – 12/4/09	9/25/09 – 12/6/09
SOCAL 36	12/5/09 – 1/30/10	12/4/09 – 1/29/10	12/6/09 – 1/30/10
SOCAL 37	1/30/10 – 4/10/10	1/29/10 – 4/9/10	1/30/10 – 4/11/10
SOCAL 38	4/10/10 – 7/22/10	4/9/10 – 7/21/10	4/11/10 – 7/23/10
SOCAL 40	7/22/10 – 12/6/10	7/21/10 – 12/5/10	7/23/10 – 12/6/10
SOCAL 41	12/6/10 – 5/11/11	12/5/10 – 5/10/11	12/6/10 – 5/12/11
SOCAL 44	**5/11/11 – 10/12/11**	**5/11/11 – 10/1/11**	5/12/10 – 9/23/11
SOCAL 45	**10/16/11 – 3/5/12**	**10/27/11 – 3/17/12**	10/16/11 – 2/13/12

Data Analysis

To assess the quality of the acoustic data, frequency spectra were calculated for all the data (about one-year each at site M and H) using a time average of 5 seconds and variable frequency bins (1, 10, and 100 Hz). These data, called Long-Term Spectral Averages (LTSA) were then examined both for characteristics of ambient noise and as a means to detect 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 sounds from multiple marine mammal species was analyzed, along with the presence of anthropogenic noise such as sonar, explosions, and shipping. Data were analyzed by visually scanning 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. Blue whale B calls and fin whale 20 Hz calls were detected using computer algorithms (described in detail below). Likewise, odontocete echolocation clicks were detected using a Teager energy detector (Roch *et al.* 2011).

To document the data analysis process, we describe the 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 – 500 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, pinniped, 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. We compared differences between sites by calculating the species richness, that is, the number of species present daily, at each site, averaged over the year-long data set.

Low Frequency Marine Mammals

Blue whale B and D calls, fin whale 20 Hz and 40 Hz pulses, Bryde's whale Be4 and Be2 calls, and gray whale M1 and M3 calls were the focus of the low frequency analysis. Table 2 presents a quantitative description of each call type from selection of 30 calls for each species and call type. The calls were separated by at least 24 hours to ensure that calls from a single animal were not over-represented.

Table 2: Description of low-frequency call types including their mean frequency values (one standard deviation in parentheses) of at least 30 independent calls. Measured calls were separated by a minimum of 24 hours to ensure calls from a single animal are not over-represented.

Species	Call Type	Number of Calls	Start Frequency (Hz)	End Frequency (Hz)	Duration (s)
Blue whale	B	41	48.1 (± 0.9)	43.9 (± 0.8)	12.5 (± 2.8)
	D	31	71.0 (± 8.5)	35.5 (± 5.8)	3.3 (± 1.1)
Bryde's whale	Be4	30	53.8 (± 1.3)	57.8 (± 0.5)	1.9 (± 0.7)
Fin whale	20 Hz pulse (high)	42	30.8 (± 1.8)	18.4 (± 1.0)	1.5 (± 0.5)
	20 Hz pulse (low)	42	23.4 (± 1.1)	15.3 (± 0.9)	1.3 (± 0.5)
	40 Hz pulse	32	63.4 (± 7.2)	48.7 (± 6.4)	0.8 (± 0.4)

For the low frequency data analysis, the 200 kHz sampled raw-data were decimated by a factor of 100 for an effective bandwidth of 1 kHz. Long-term spectral averages (LTSAs) of these data 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. For manual detection, 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 resolution), with an 85-95% overlap of data in the input time series.

Blue Whales

Two different call types were used to detect the presence of blue whales: type B and D. Calls of type 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 associated with mating behavior (Oleson *et al.* 2007b). These calls have long durations (20 sec) and low frequencies (10-100 Hz); they are produced either as repetitive sequences (song) or as singular calls. The B call has a set of harmonic tonals, and may be paired with a pulsed type A call. Individual type A and B calls are readily detected in an LTSA, owing to their long duration. We did not assess the presence of type A calls during this reporting period, judging them to be duplicative with type B.

Blue whale B calls were detected automatically using spectrogram correlation (Mellinger and Clark 2000). The kernel for automatic detection was made of four segments, three 1.5 s and one 5.5 s long, for a total 10 s duration. The frequency ranged over those time periods from 47.37 to 47.10; 47.10 to 46.66; 46.66 to 46.30; and 46.30 to 45.73 Hz. The kernel bandwidth was 2 Hz.

The performance of the detector was tested against nine days of manual hourly picks of blue whale B calls from both sites and different times of the year. We found that average hourly false alarm and missed detection rates were 9% and 11.5%, respectively, though they varied between the sites and across seasons. In addition, automatic detections during winter months, when blue whales are not common in this area, were manually reviewed and false alarms from this period were removed from further analysis. Detections were binned into 1-hour bins for consistent reporting.

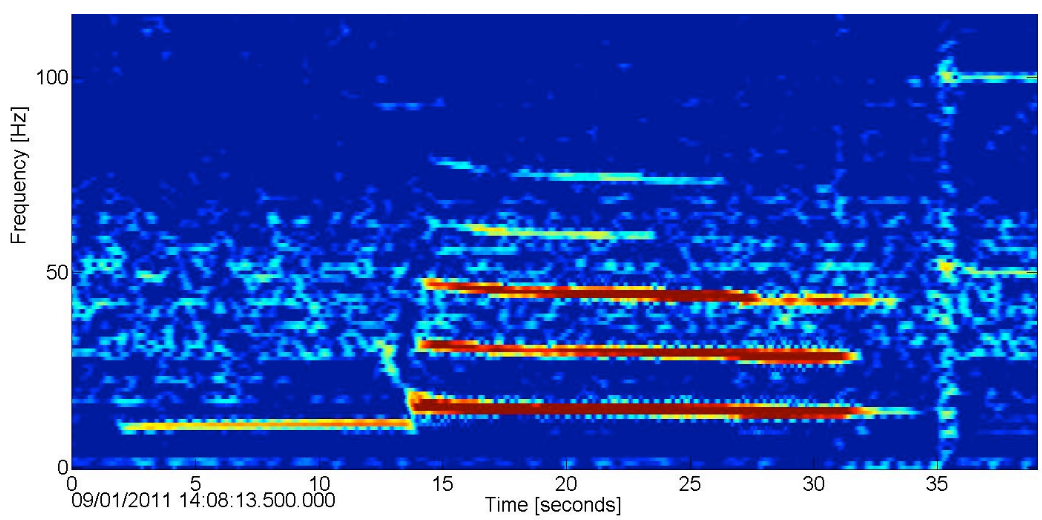

Figure 2. Blue whale B call showing harmonic tones.

Blue whale D calls are down-swept 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. 2007b). 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.* 2007c).

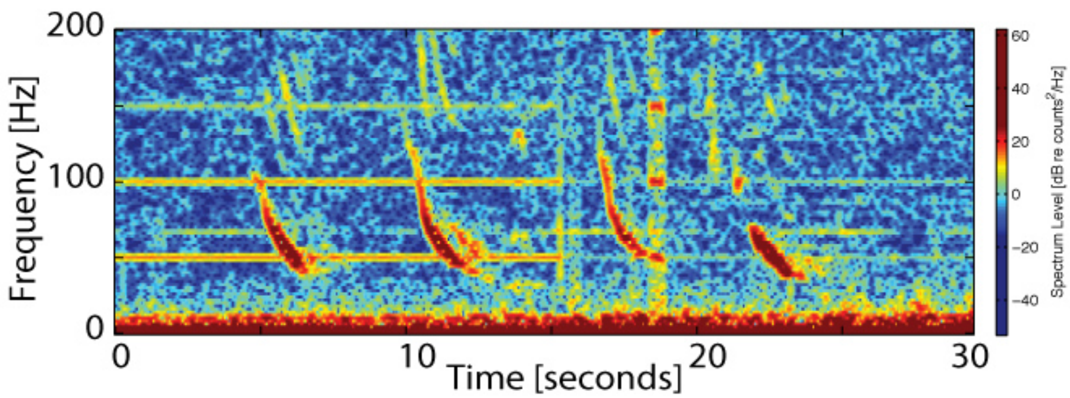

Figure 3. Blue whale D calls, downswept from 100 to 40 Hz.

Fin Whales

Fin whales are known to produce a pulsed call of about 1-sec duration, downswept in the frequency band 30 - 15 Hz (Figure 4). These pulses occur both at regular intervals as song (Thompson *et al.* 1992), and at irregular intervals as counter-calling between multiple animals (McDonald *et al.* 1995). 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.

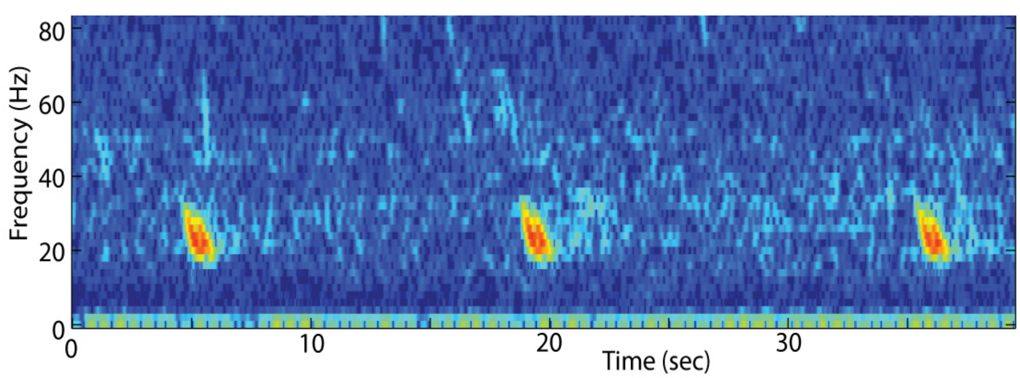

Figure 4. Fin whale 20 Hz pulsed call, created in regular pattern or song.

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 at different frequencies, 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 the acoustic energies at 10 and 34 Hz. All calculations were performed on the logarithmic scale. The performance of the detector was tested against eight days of manual hourly picks of fin whale 20 Hz calls from each site to find the optimal threshold. The average rate of false positives and missed detections were 10% and 17%, respectively, but they also varied by site. Detections were binned into 1-hour bins for consistent reporting.

Another fin whale call detected in the SOCAL data is a short duration (~ 1 sec) downswept pulse from 75 – 40 Hz; we will designate these as 40 Hz calls (Figure 5). The 40 Hz calls were first described by Watkins (1981) as associated with fin whales. Manual scanning of the LTSA and subsequent verification from a spectrogram were the primary means for 40 Hz call detection.

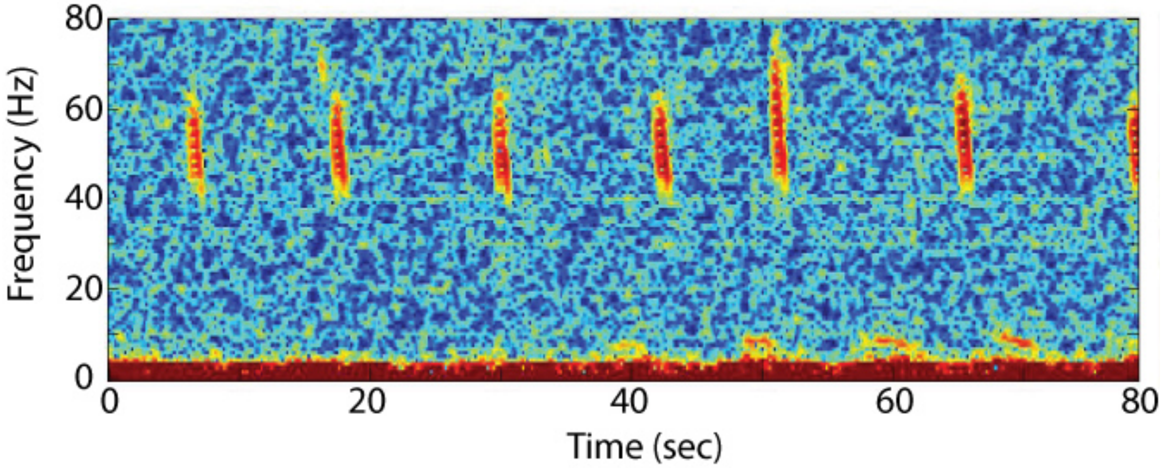

Figure 5. **Fin whale 40 Hz pulsed call.**

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.* 1982, Tershy *et al.* 1991). Acoustic detections suggest that over the last decade they have become seasonal inhabitants of the SOCAL region (Kerosky *et al.* 2012, Smultea *et al.* 2012). 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 6). The Be4 call is typically observed at regular intervals; occasionally, it is evident that multiple callers are present. Another common call detected from Bryde's whales in the Eastern Tropical Pacific is designated Be2; it has an average frequency of about 40 Hz and lasts 1-2 sec (Figure 7). The call is occasionally detected with a series of two to four harmonics up to 160 Hz.

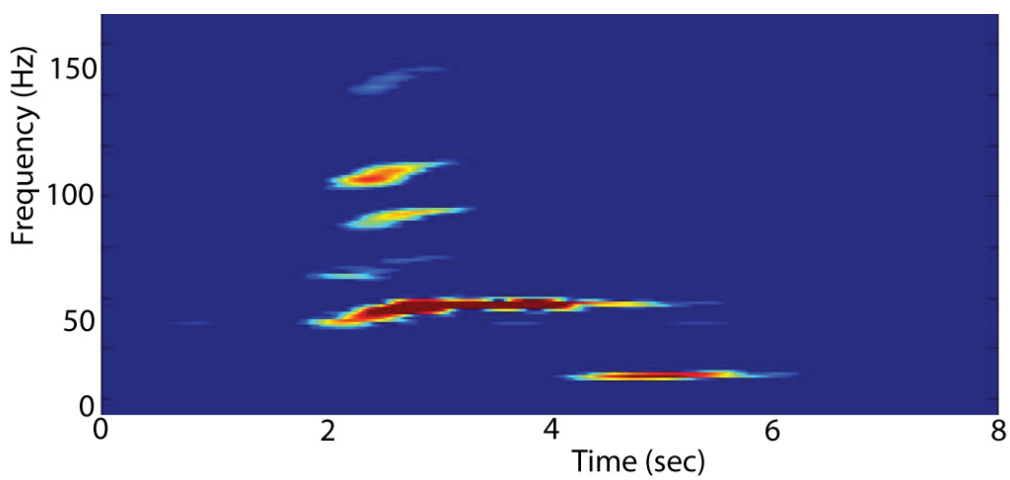

Figure 6. Bryde's whale Be4 call.

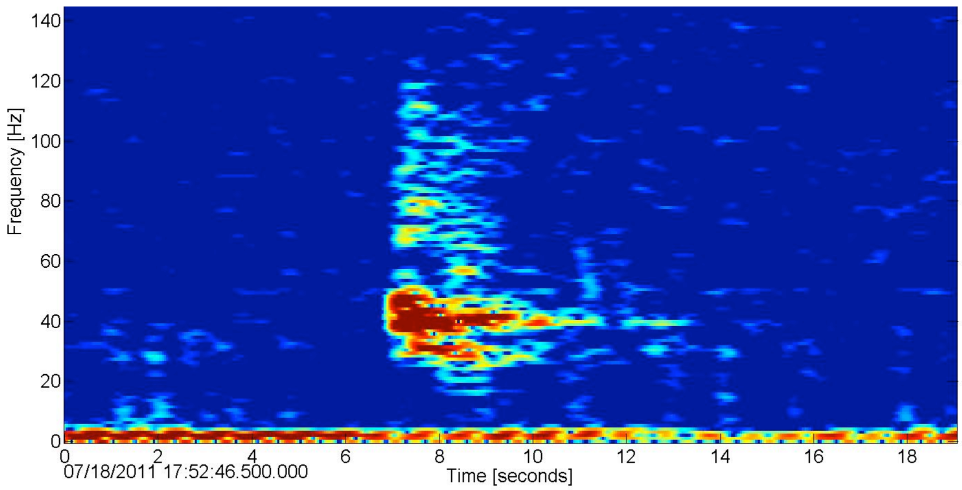

Figure 7. Bryde's whale Be2 call.

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 & Lashkari 1996). M1 were pulses and bongo signals, M3 were low frequency moans, M4 were grunts, and M5 were subsurface exhalations. M3 signals are known to be the most common (Figure 8), followed by M1 signals (Figure 9). Both signal types can be discerned from the LTSA and are reported jointly.

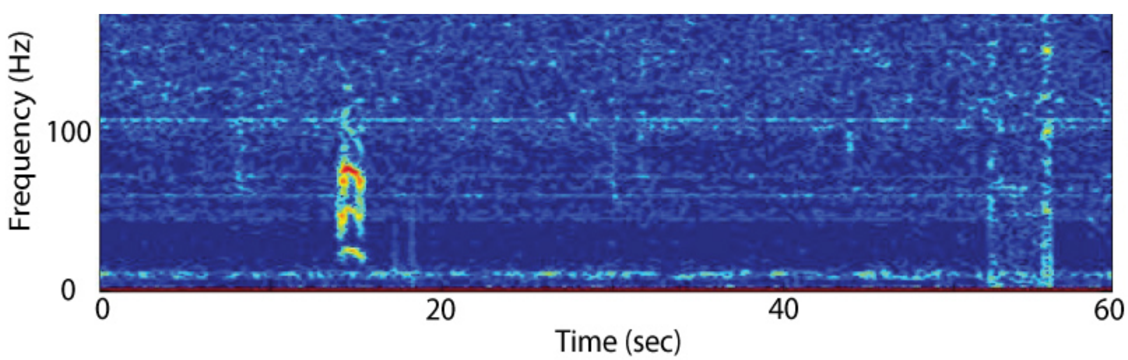

Figure 8. Gray whale M3 call.

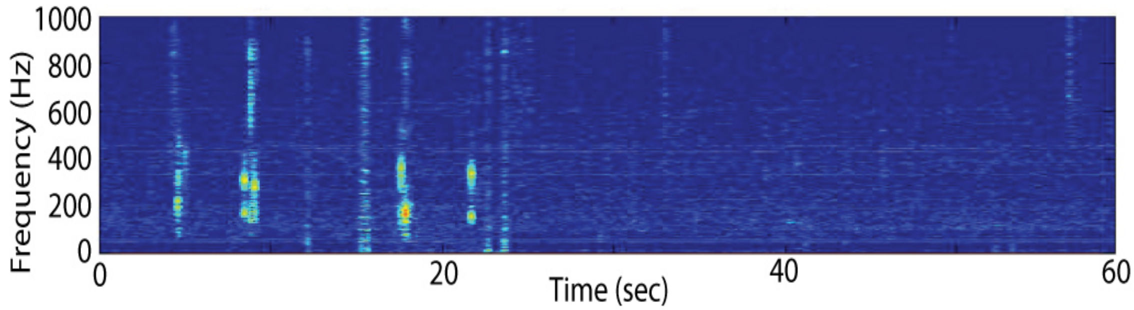

Figure 9. Gray whale M1 calls.

Mid-Frequency Marine Mammals

For mid-frequency data analysis, the 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 one-minute bins for each mid-frequency dataset.

Effort was expanded to find mid-frequency sounds including: 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 3.

Table 3. Mid-Frequency LTSA search parameters including plot length and frequency range

Species or Anthropogenic Source	LTSA Search Parameters	
	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 whale song is categorized by the repetition of units, phrases and themes 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 100-3000 Hz (Figure 10). For this report we detected humpback calls using a computer algorithm based on the generalized power law detector (Helble *et al.* 2012), and then the accuracy of the detected signals were verified by a trained analyst.

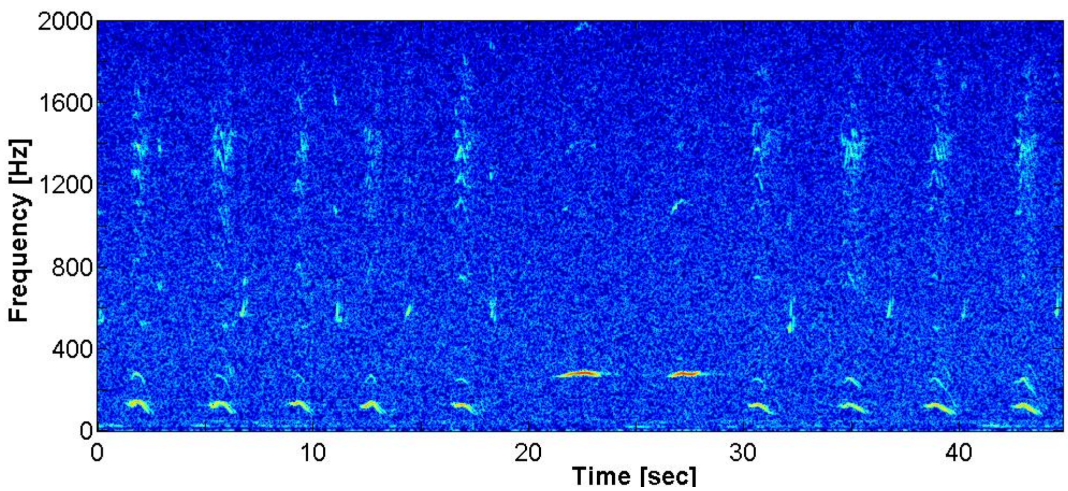

Figure 10. Humpback song spectrogram from January 2012 at Site H.

Minke Whale

Minke whales "boings" consist of 2 parts, beginning with a burst followed by a long buzz, with the dominant energy band just below 1400 Hz (Figure 11). A typical California minke boing has an average duration of 3.6 seconds and a pulse repetition rate of 92 s^{-1} (Rankin & Barlow 2005).

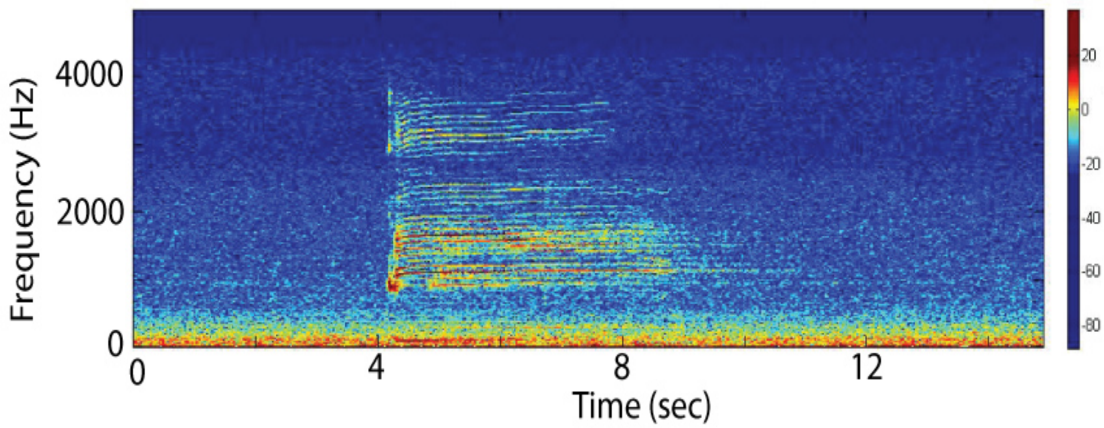

Figure 11. Spectrogram of a minke whale boing.

Pinniped

Pinniped sounds in California are produced primarily by barking California sea lions. Most of these sounds occur between 400 and 600 Hz, with durations of less than 1 second (Figure 12). Pinniped vocalization bouts can continue for up to several hours.

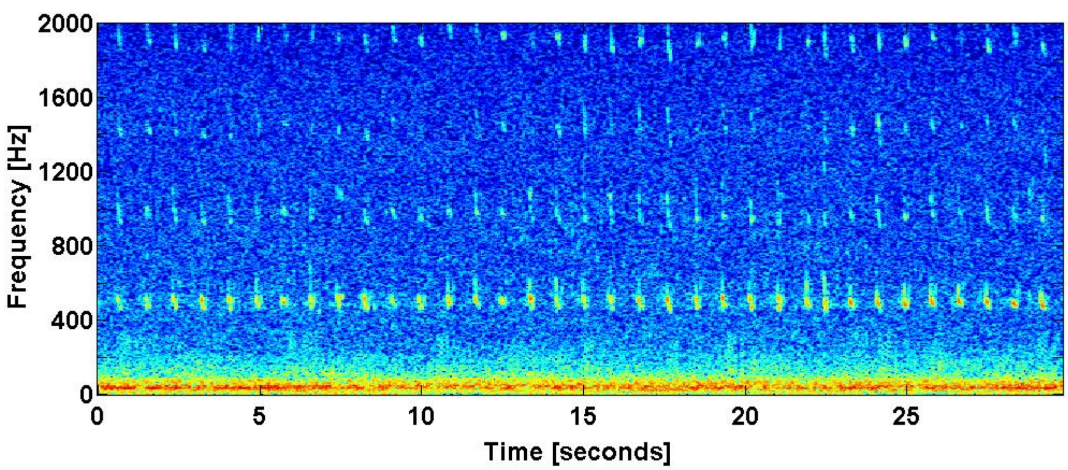

Figure 12. A bout of pinniped barks during June 2011 at site M.

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: echolocation clicks, burst pulses, or whistles. Dolphin echolocation clicks are broadband impulses with the majority of energy between 20 and 60 kHz. Burst pulses are rapidly repeated clicks that have a creak or buzz-like sound quality; they are generally lower in frequency than 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 13).

Some delphinid sounds are not yet distinguishable by species based on the character of their clicks, burst pulses or whistles (Roch *et al.* 2007, Roch et al. 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). In this report these detections are classified as unidentified dolphins.

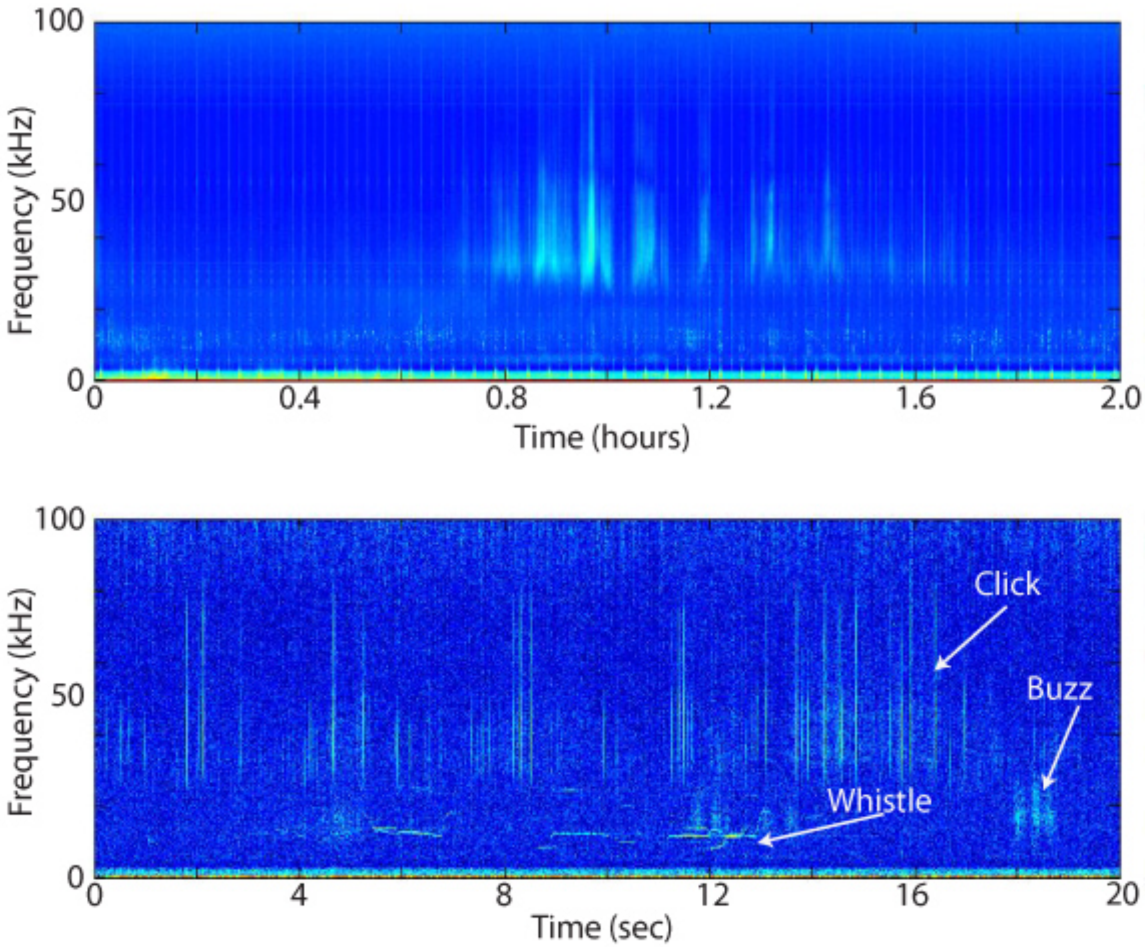

Figure 13. LTSA (above) and spectrogram (below) of unidentified dolphins (either common or bottlenose dolphins).

Risso's Dolphin

Risso's dolphin echolocation clicks can be identified to species by their distinctive banding patterns observable in the LTSA and the spectrogram (Figure 14). Risso's dolphin echolocation clicks in the SOCAL area have energy peaks at 22, 26, 30, and 39 kHz (Soldevilla et al. 2008).

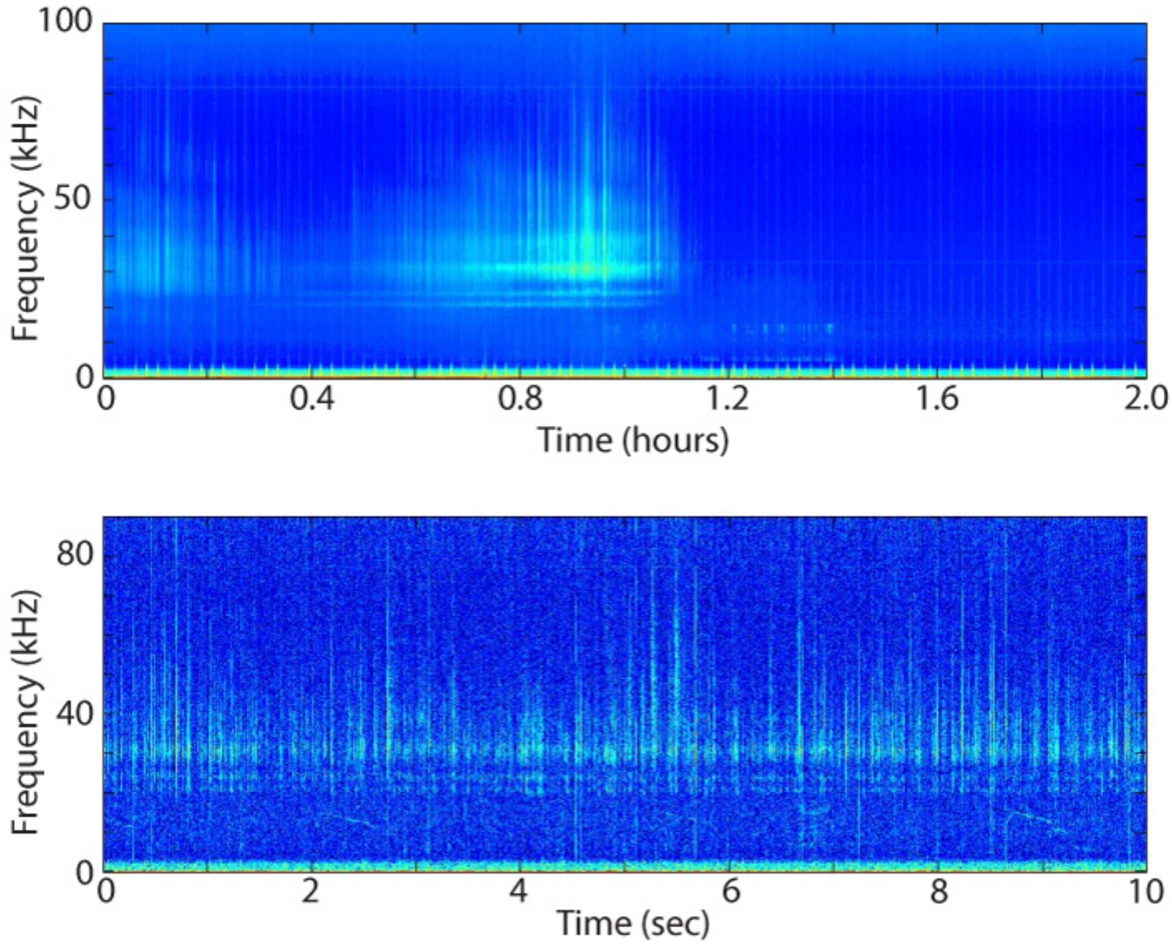

Figure 14. Risso's dolphin click bout in LTSA (above) and spectrogram (below). A distinctive banding pattern is noticeable.

Pacific White-Sided Dolphin

Pacific white-sided dolphin echolocation clicks also can be identified to species by their distinctive banding patterns (**Figure 15** and **Figure 16**). Pacific white-sided dolphin echolocation clicks have energy peaks at 22, 27, 33, and 37 kHz. Soldevilla *et al.* (2011) present two different click types within Pacific white-sided dolphin recordings, possibly belonging to 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 (type A = 26.1 kHz; type B = 27.4 kHz). For this analysis we have specified the Pacific white-sided clicks to be either type A or type B.

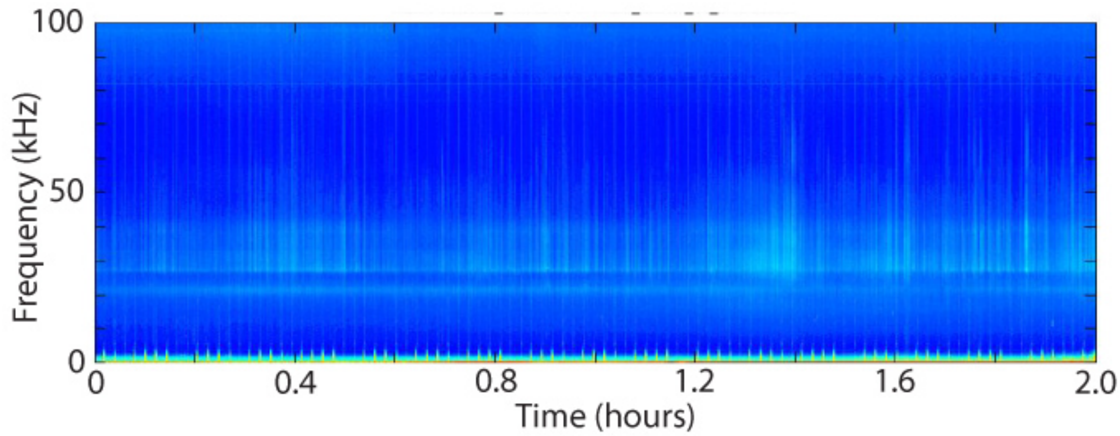

Figure 15 Pacific white-sided dolphin type A echolocation clicks in LTSA.

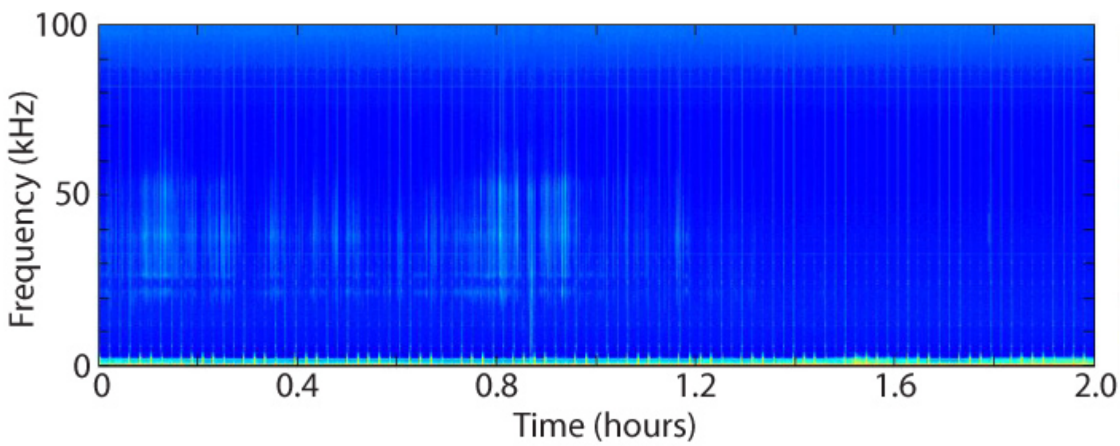

Figure 16 Pacific white-sided dolphin type B echolocation clicks in LTSA.

Killer Whale

Killer whales are known to produce four call types: echolocation clicks, low frequency whistles, high-frequency modulated (HFM) signals, and pulsed calls (Ford 1989, Samarra *et al.* 2010). 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). HFM signals have only recently been attributed to killer whales in both the Northeast Atlantic (Samarra *et al*. 2010) and Northeast Pacific (Simonis *et al.* 2012). These singals have fundamental frequencies between 17 and 75 kHz, the highest of any known delphinid tonal calls.

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 17**) and the HFM signals (Figure 18) for killer whale species identification.

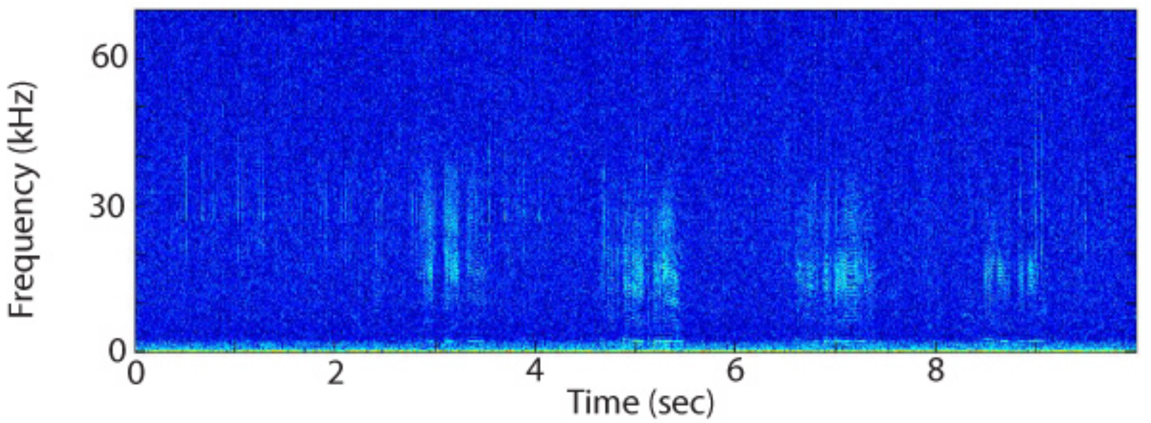

Figure 17. Killer whale pulsed calls.

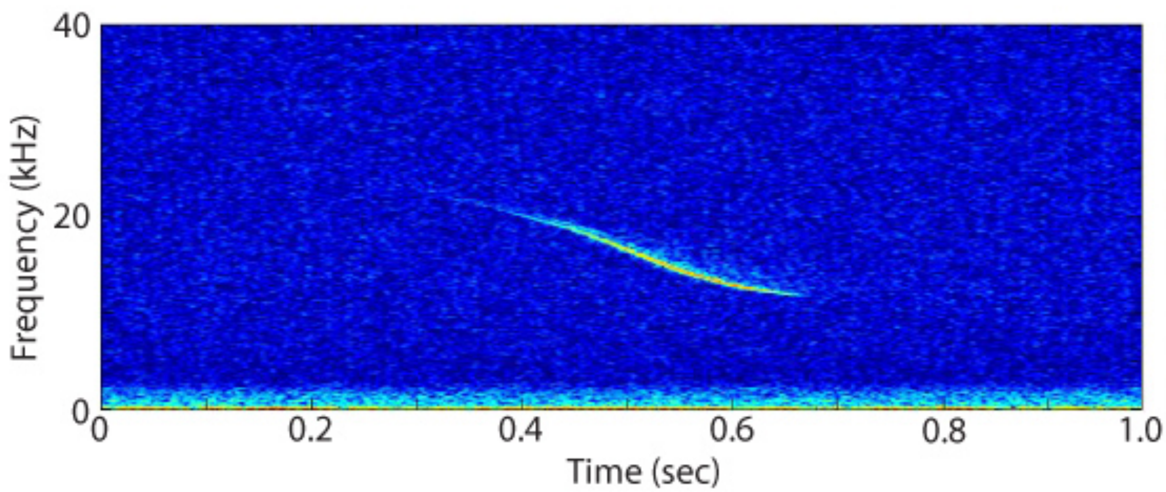

Figure 18. Killer whale high-frequency modulated (HFM) signal.

Sperm Whale

Sperm whale clicks contain energy from 2-20kHz, with peak energy between 10-15 kHz (Møhl et al. 2003). Regular clicks, observed during foraging dives, have a uniform inter-click interval of about one second (Goold & Jones 1995, Madsen *et al.* 2002a, Mohl *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 19).

Sperm whales also produce other clicks, which can be classified as slow clicks and codas. Slow clicks are produced by males and are more intense than regular clicks with longer inter-click intervals (Madsen *et al.* 2002b). Codas are stereotyped sequences of clicks which are less intense and contain lower peak frequencies than regular clicks (Madsen et al. 2002a, Watkins & Schevill 1977).

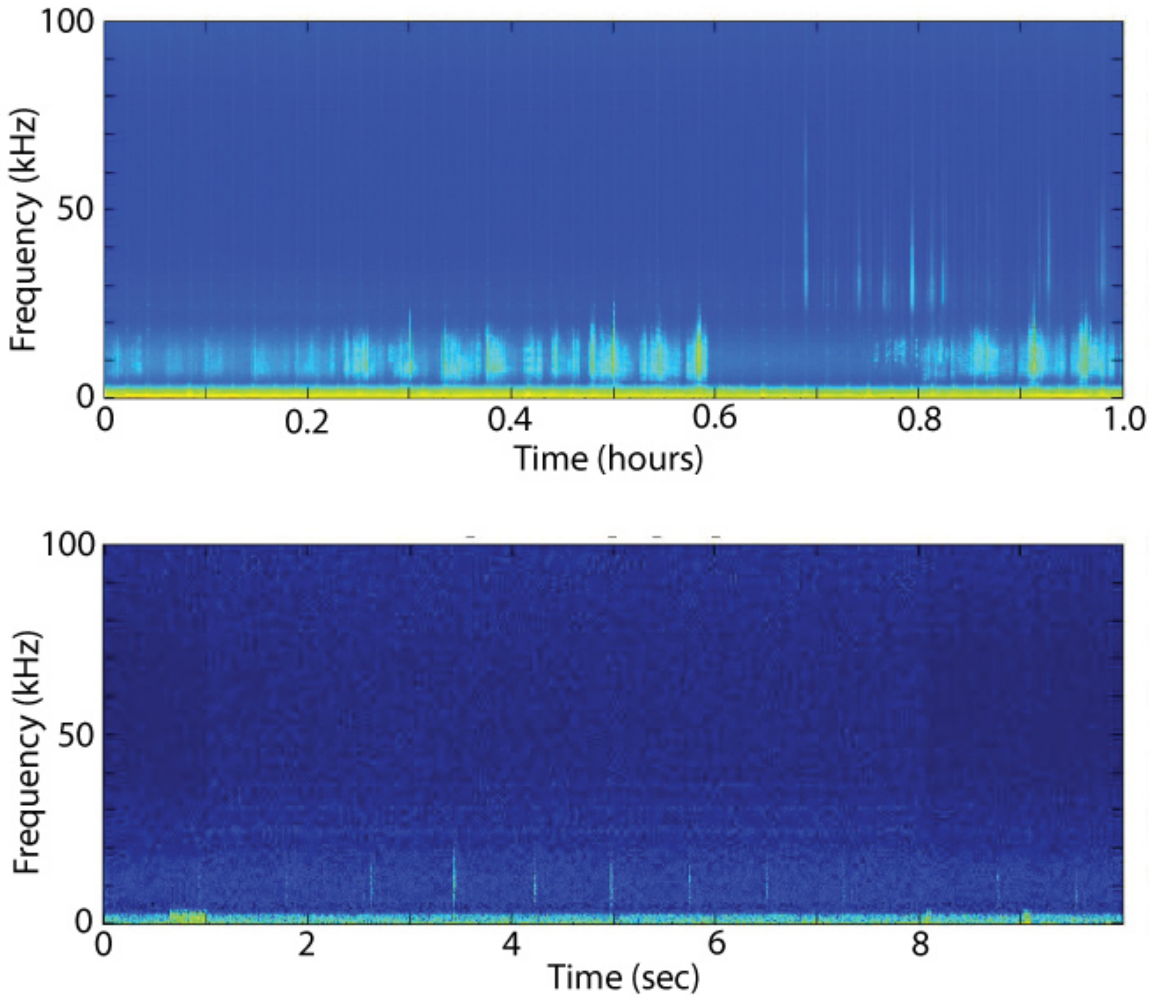

Figure 19. Echolocation clicks of sperm whale in LTSA (above) and spectrogram (below).

Beaked Whales

The north Pacific is known to be inhabited by at least ten species of beaked whales: Baird's (*Berardius bairdii*), Cuvier's (*Ziphius cavirostris*), Longman's (*Indopacetus pacificus*), Blainville's (*Mesoplodon densirostris*), Stejneger's (*M. stejnegeri*), Hubbs's (*M. carlhubbsi*), Perrin's (*M. perrini*,), Ginkgo-toothed (*M. ginkgodens*) and Pygmy beaked whale (*M. peruvianus*) (Jefferson *et al.* 2008). The tenth species is the Deraniyagala's beaked whale, *M. hotaula* (Dalebout *et al.* 2007), which is likely the beaked whale that has been visually and acoustically observed at Palmyra Atoll (Baumann-Pickering *et al.* 2010). In recent years, advances have been made in acoustically identifying beaked whales by their echolocation signals (Baumann-Pickering *et al.* 2012). These signals are frequency-modulated (FM) upsweep pulses, which appear to be species specific and distinguishable by their spectral and temporal features (Figure 20).

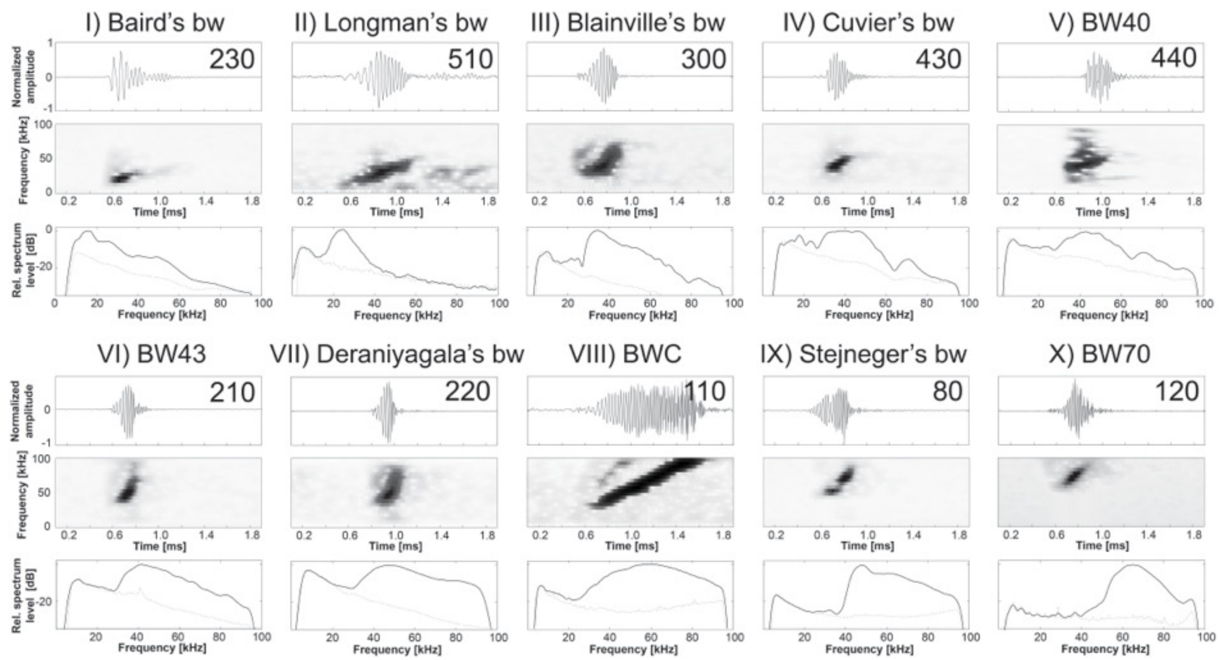

Figure 20. Beaked whale frequency-modulated (FM) upsweep pulses from known (I-IV, VII, IX) and unknown species (V, VI, VIII, X). Each FM pulse type is shown with an example pulse time series (top plot for each species) and spectrogram (middle plot), as well as a mean spectra (bottom plot, solid line) and mean noise (dotted line). Inter-pulse interval (IPI) is specified in ms (above, upper left).

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 20) and uniform inter-pulse interval of about 0.4s (Johnson *et al.* 2004, Zimmer *et al.* 2005).

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. These clicks are identifiable due to their lower frequency than other beaked whale clicks. Spectral peaks are notable around 15, 30 and 50 kHz (Figure 20). Unlike other beaked whales in the area, Baird's beaked whales incorporate whistles and burst pulses into their acoustic repertoire (Dawson *et al.* 1998).

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 20) and uniform inter-pulse interval around 0.2s.

Anthropogenic Sounds

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 produces constructive and destructive interference (bright and dark bands) in the spectrogram that varies by frequency and distance between the ship and the receiver (red arrows in Figure 21). Noise can extend to well above 10 kHz, though it typically falls off above a few kHz.

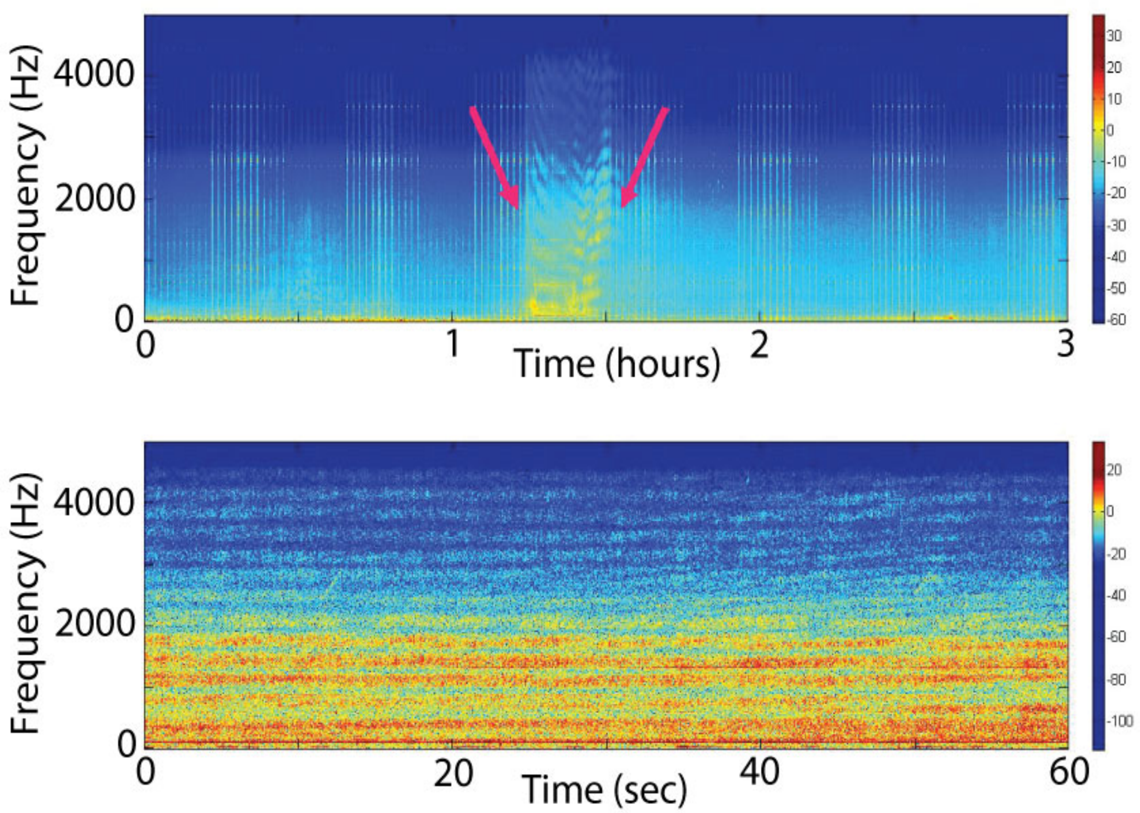

Figure 21. Broadband ship noise in the LTSA (above) and spectrogram (below).

Mid-Frequency Active Sonar

There are multiple types of active sonar used in the Southern California Offshore Range (SCORE). These span frequencies 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 and 5 kHz and are more generically known as '3.5 kHz' sonar. In this section, we describe the process for identifying MFA sonar in recordings 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 the LTSA 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. Individual MFA sonar pings typically span 1 – 3 s, but are intense enough to show up as 'pulses' in LTSA plots. LTSA display parameters used by the analyst were 1 or 2 hour window length, 2 – 5 kHz window height.

A custom software routine was used to detect sonar pings and calculate peak-to-peak (PP) received sound pressure levels. For this detector, a sonar ping is defined as the presence of sonar within a 5 s window and may contain multiple individual pings. The detector calculates the average spectrum level across the frequency band from 2.4 to 4.5 kHz for each 5 s time bin. This provides a time series of the average received levels in that frequency band. Minimum values were noted for each 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 calibrated transfer function for this frequency band. Since the instrument response is not flat over the 2.4 – 4.5 kHz band, a middle value at 3.3 kHz was used. The transfer function value used was 81 dB re $\mu Pa^2/counts^2$. For sonar pings less than this middle frequency, their levels are overestimated by up to about 5 dB and for those at higher frequency their levels are underestimated up to about 4 dB.

In addition to MFA at ~3.5 kHz, in the SOCAL region there are naval sonars that operate at higher frequencies. These higher frequency active sonars were detected by analysts using the LTSA plots, and we designate these as a separate category, naval sonar > 5kHz.

Echosounders

Echosounding sonars transmit short pulses or frequency sweeps, typically in the mid-frequency (12 kHz) or high frequency (30-100 kHz) band. These sonars may be used for seabottom mapping, fish detection or other ocean sensing. 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. Echosounders were detected by analysts using the LTSA plots at both mid- and high-frequency.

Acoustic Communications system

Acoustic telemetry is used for underwater communications, remote vehicle command and control, diver communications, underwater monitoring and data logging, trawl net monitoring and other applications requiring underwater wireless communications. Long-range systems operate over distances of up to 10 km with frequencies of 7 - 45 kHz. A key characteristic of these sonars is that they are highly modulated, to encode the communication signal. In the SOCAL region, acoustic communications systems are typically detected at 7 – 13 kHz, with the main frequency at about 10 kHz (Figure 22).

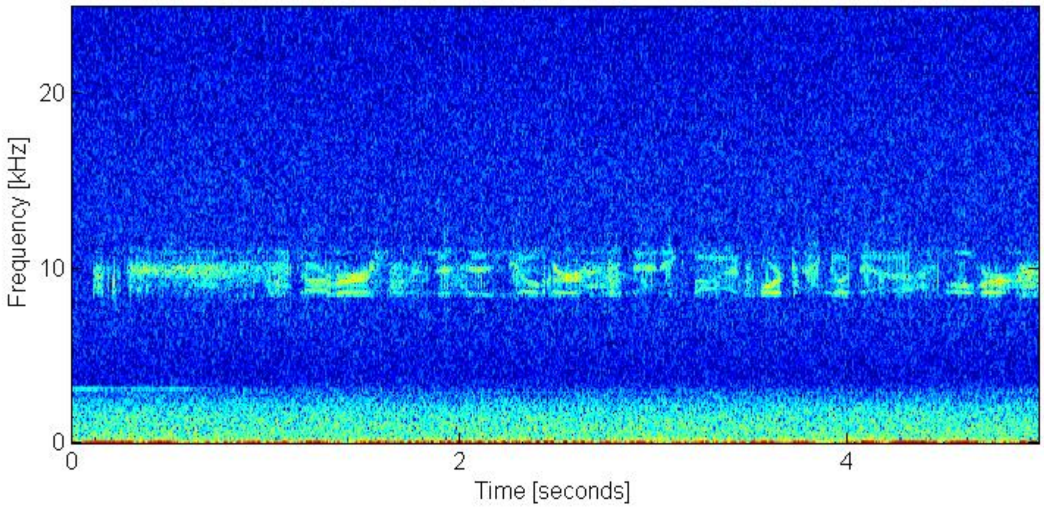

Figure 22. Acoustic communications system with highly modulated signal.

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 23). These sounds have peak energy as low as10 Hz and often extend up to 2000 Hz or higher, lasting for a few seconds including the reverberation.

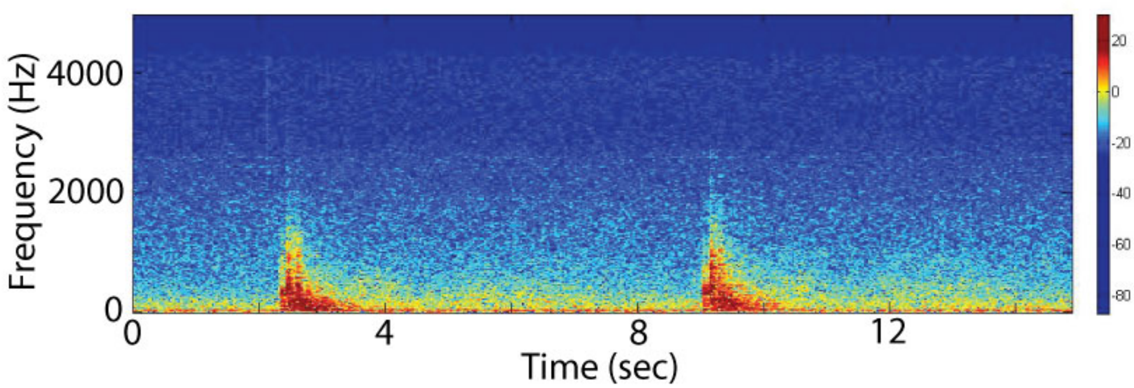

Figure 23. Two explosions are shown with rapid onset and extended reverberation.

Results

We discuss ambient noise as well as the seasonal occurrence and relative abundance of marine mammal species and anthropogenic sounds. For clarity of presentation, all marine mammal and anthropogenic sound source occurrence will be displayed as a weekly average.

Ambient Noise

Underwater ambient noise at sites M and H has spectral shapes with higher levels at low frequencies (Figure 24), owing to the dominance of ship noise at frequencies below 100 Hz and local wind and waves above 100 Hz (Hildebrand 2009). Noise levels at both sites are 5-10 dB less in the fall relative to the spring, probably due to diminished noise from wind and waves. At site H a prominent peak in noise is observed at 15-30 Hz and also at 47 Hz, related to the presence of blue and fin whales calls.

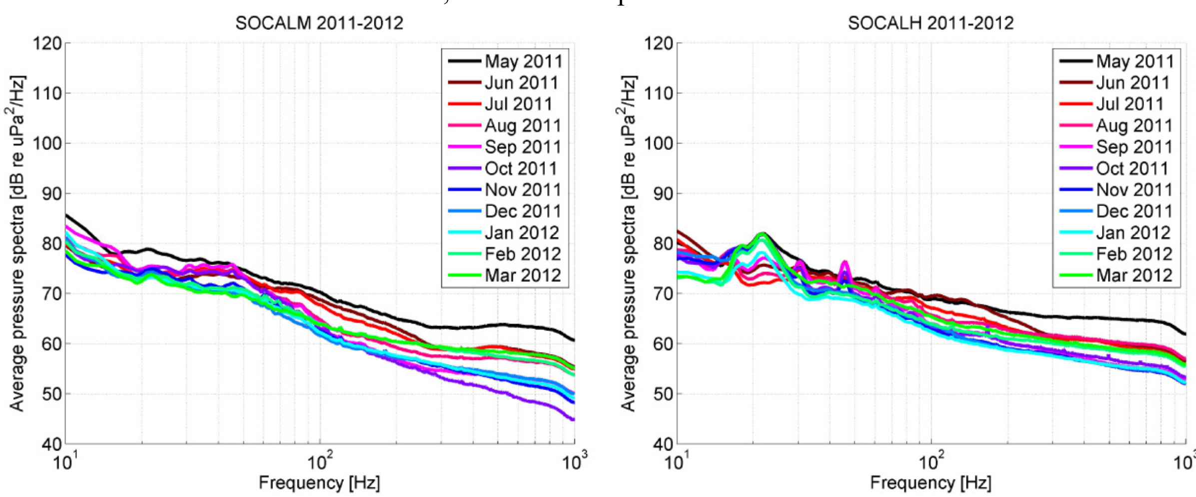

Figure 24. Monthly ambient noise at site M (left) and site H (right).

Mysticetes

Five baleen whale species were recorded between May 2011 and March 2012 at sites M and H: blue whales, fin whales, Bryde's whales, gray whales, and humpback whales. No minke whale sounds were detected. Site H 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 H. 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 whale calls of both type B and type D were detected at sites M and H, with higher numbers in the summer and fall than in the spring and winter. Generally more hours with calls were detected at site H (Figure 25). Peak in overall calling at both sites occurred between August and November 2011, which is the period with peak detection of blue whale B calls, known to occur in large numbers associated with song (Figure 26). Peaks in D call detections occurred in July (Figure 27). D calls are known to be associated with feeding behavior (Oleson et al. 2007a) and were detected at higher levels at site H than at site M. A seasonal difference in the occurrence of B versus D calls is consistent with previous studies of blue whales in the Southern California Bight (Oleson et al. 2007b) and likely reflects the transition of blue whale behavior from feeding during the summer, to pairing and mating in the fall (Oleson *et al.* 2007a).

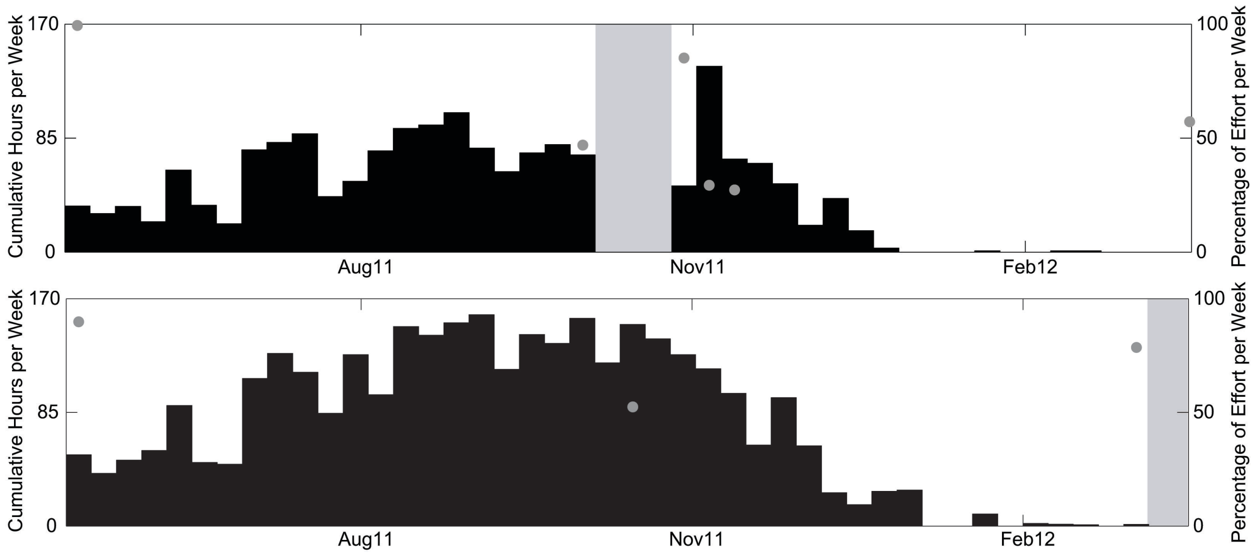

Figure 25. Presence of all blue whale calls (black bars) at sites M (above) and H (below) between May 2011 and March 2012. Grey dot represents percent of effort per week in weeks with less than 100% recording effort and grey shading shows periods with no recording effort. Where grey dots or shading are absent, full recording effort occurred for the entire week.

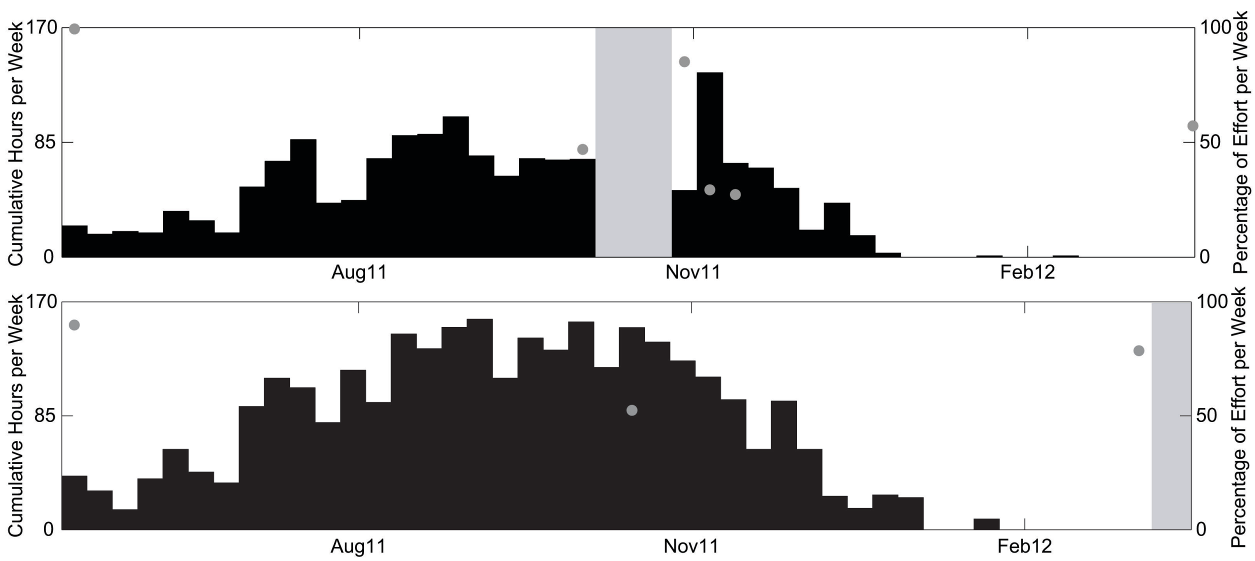

Figure 26. Presence of blue whale B calls at sites M (above) and H (below) between May 2011 and March 2012.

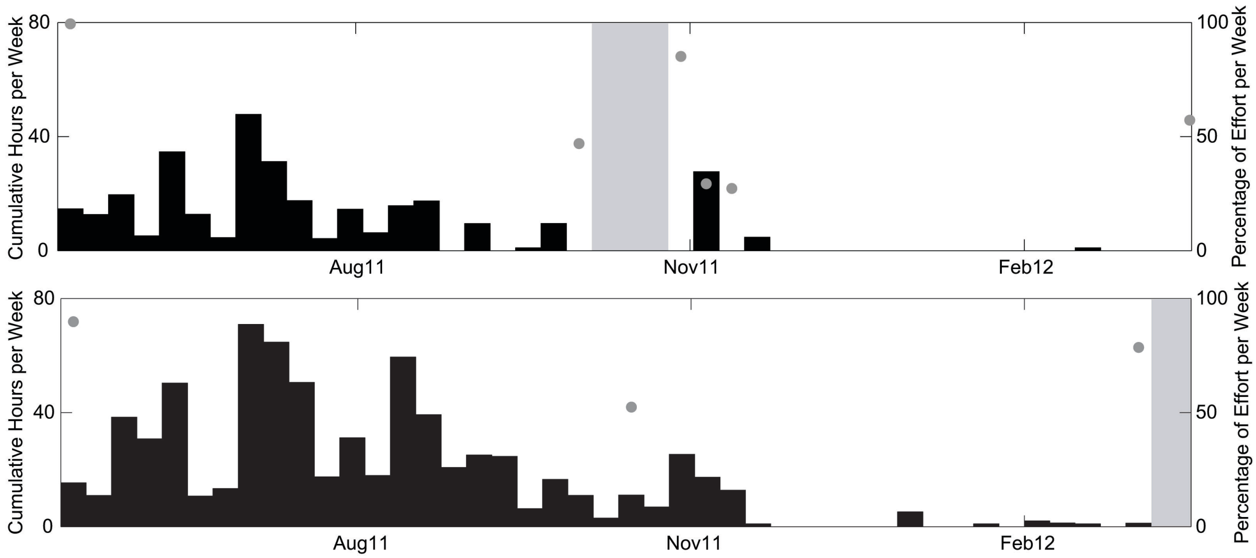

Figure 27. Presence of blue whale D calls at sites M (above) and H (below) between May 2011 and March 2012.

Fin Whales

Fin whales were acoustically detected year-round at both sites M and H, but generally with fewer calls per hour occurring in the summer and fall (Figure 28). This seasonal change in calling may be due to differences in behavioral state of the whales, rather than changes in the density of animals. Their calls were present during more hours per week at site H than site M. The 20 Hz pulses are the dominant fin whale call type (Figure 29) associated both with call-counter-call between multiple animals and with singing. An additional fin whale sound, the 40 Hz call described by Watkins (1981), was also frequently recorded at both sites (Figure 30), although these calls not as common as the 20 Hz fin whale pulses. Seasonality of the 40 Hz calls differed from the 20 Hz calls, since 40 Hz calls were more prominent in the spring, as observed at other sites across the northeast Pacific (Sirovic *et al.* 2012).

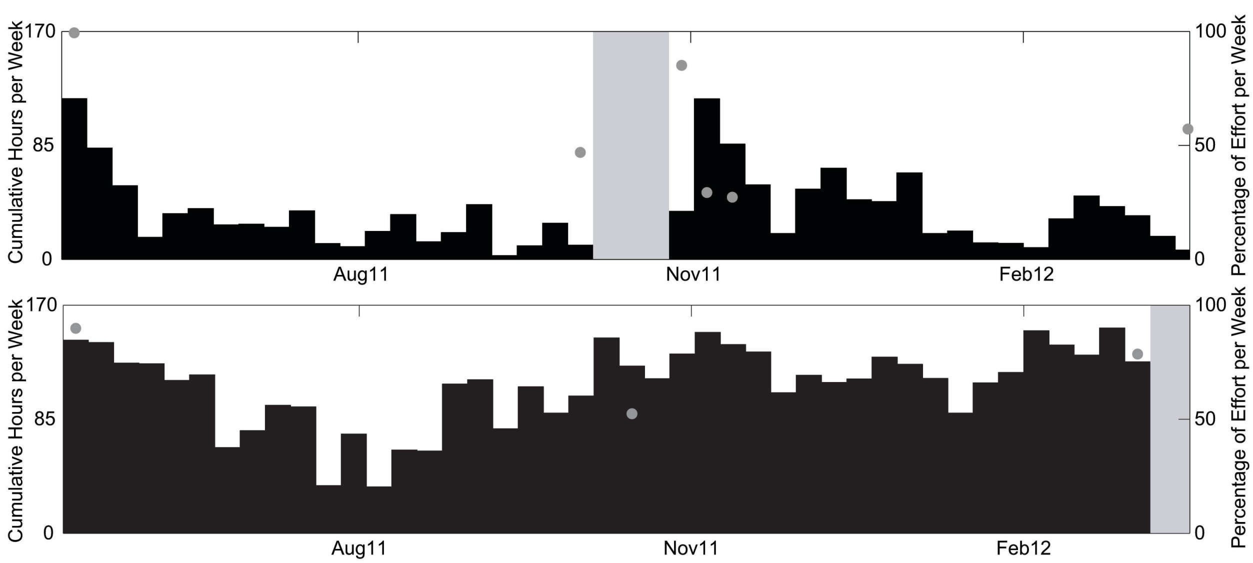

Figure 28. Presence of all fin whale calls at sites M (above) and H (below) between May 2011 and March 2012.

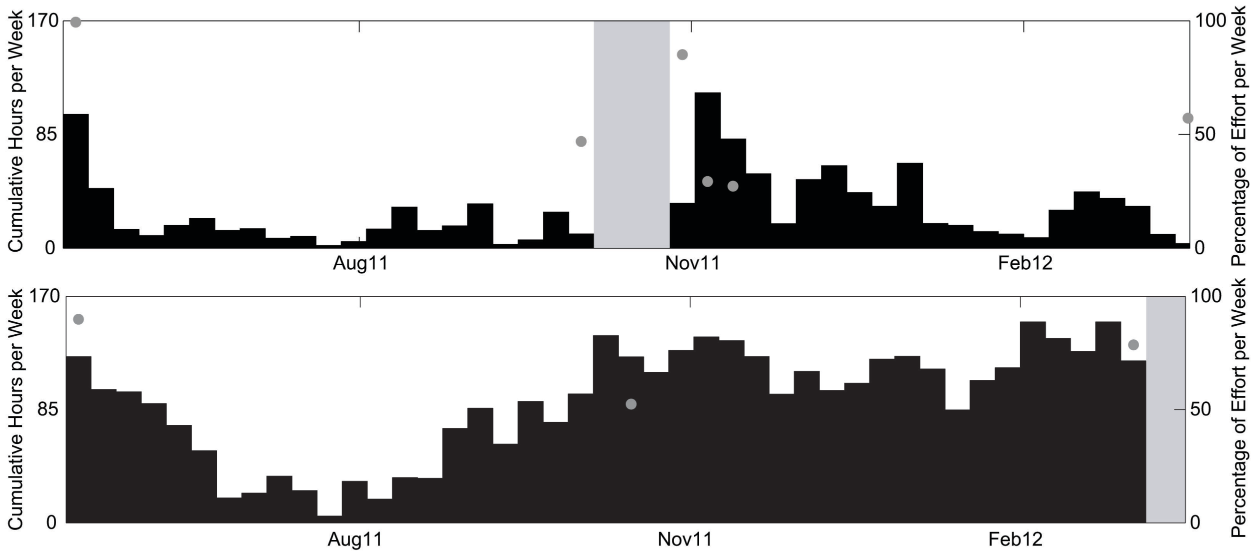

Figure 29. Presence of fin whale 20 Hz pulse calls at sites M (above) and H (below) between May 2011 and March 2012.

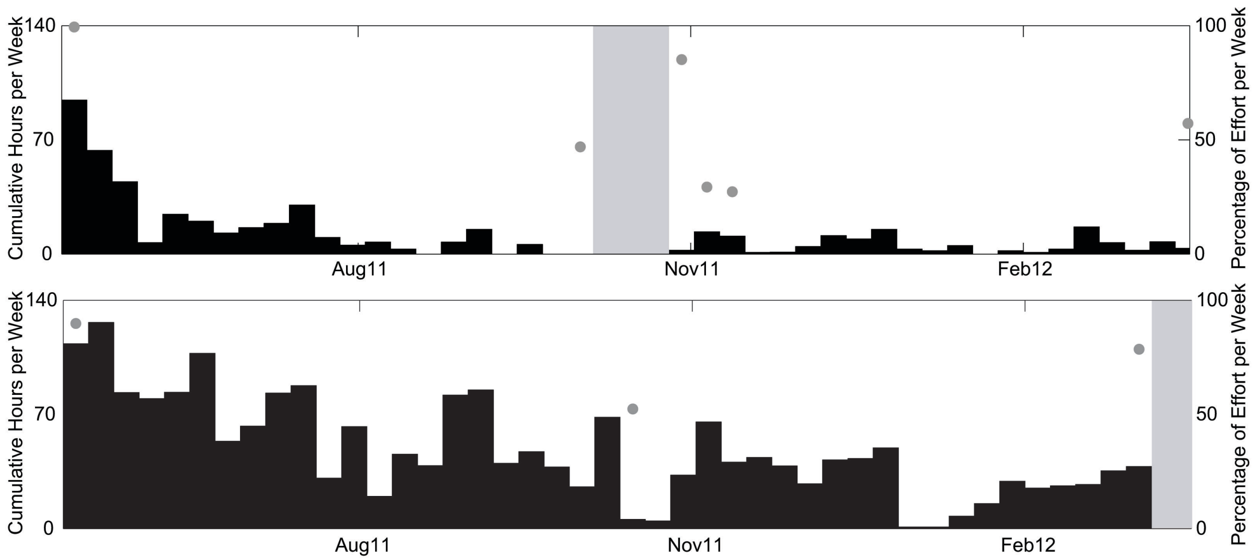

Figure 30. Presence of fin whale 40 Hz pulse calls at sites M (above) and H (below) between May 2011 and March 2012.

Bryde’s Whales

Bryde’s whale calls were detected at both sites, but they were present during more hours at site H (Figure 31). The peak numbers of calls occurred in the summer and fall. The last Bryde’s whale calls of the season were detected in January at site H. Calls of both type Be2 and Be4 were detected at site H (Figure 32), but only Be4 calls were detected at site M.

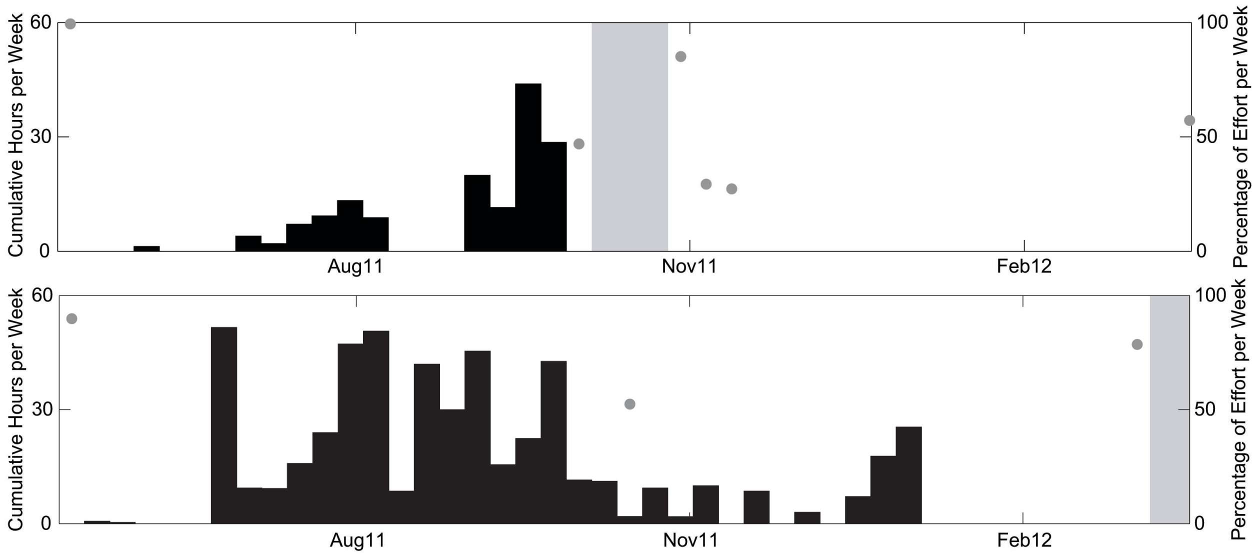

Figure 31. Presence of all Bryde’s whale calls (black bars) at sites M (above) and H (below) between May 2011 and March 2012.

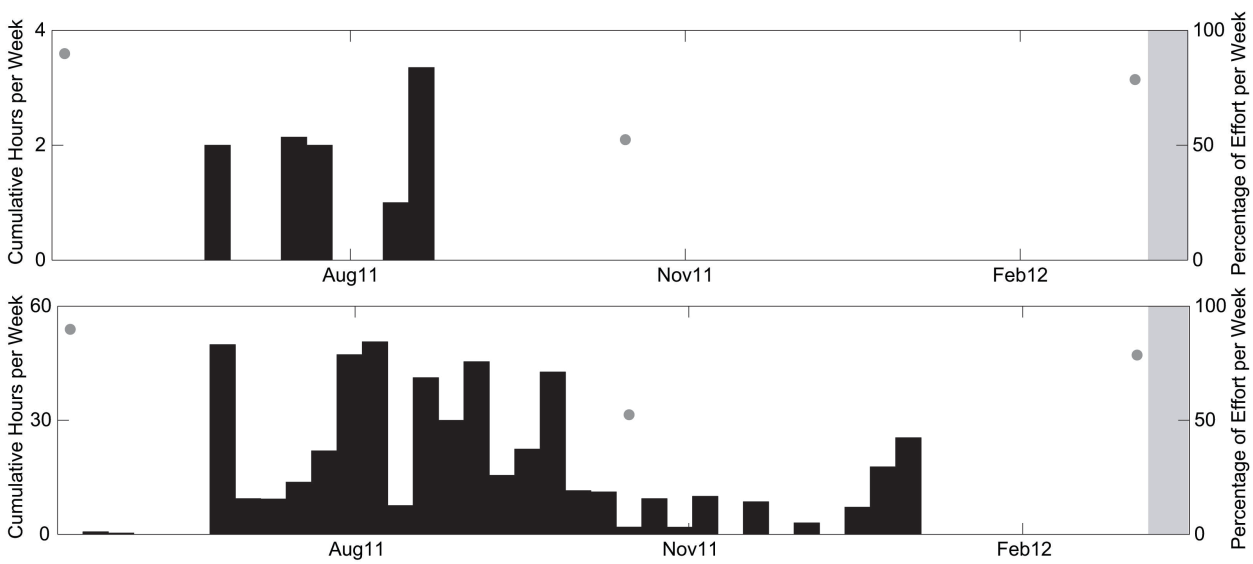

Figure 32. Presence of Bryde’s whale Be2 (above) and Be4 (below) calls at site H between May 2011 and March 2012. Note the difference in scale of the cumulative hours axis between the two plots.

Gray Whales

Gray whales were primarily detected at site M (Figure 33). The scarcity of calls at site H is likely due to the offshore location of this site, while site M is on a path between the northern Channel Islands and Catalina or San Clemente islands, which some migrating gray whales are known to use (Sumich & Show 2011). The two peaks in the site M data probably represent the southbound migration in January/February and northbound migration in March/April. Of the two gray whale call types found in the data, M3 was the more common, consistent with previous studies of gray whale sounds off California (Crane & Lashkari 1996). M1 calls were detected only at site M, and their occurrence coincided with the occurrence with M3 calls so they are not plotted separately.

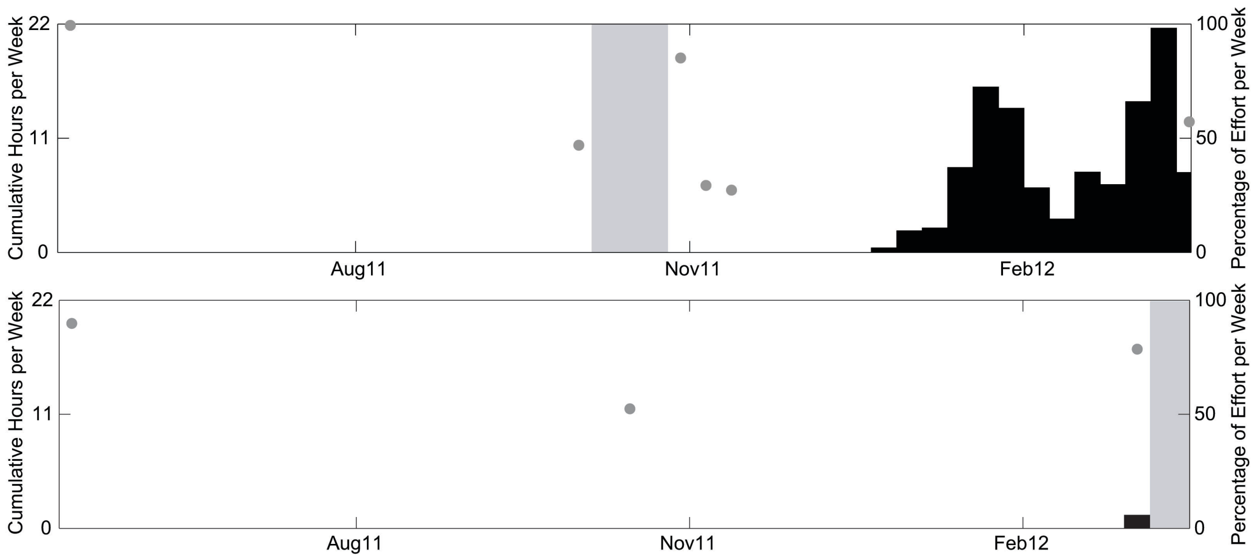

Figure 33. Presence of gray whale M3 calls at sites M (above) and H (below) between May 2011 and March 2012.

Humpback Whales

Humpback whales were detected at both sites year-round, although they were more common at site H than at site M (Figure 34). Both song and non-song call types were grouped for this analysis. Both sites had an increase in hours with calls in the fall, but at site H a high number of hours with calls persisted throughout the winter, whereas at site M there were only a low number of calls in the winter. Humpback whales are known to feed off California in spring, summer, and fall (Calambokidis *et al.* 1996) and the onset of low call hours at site H may be due to a behavioral shift (emphasis on feeding) rather than a lack of animals.

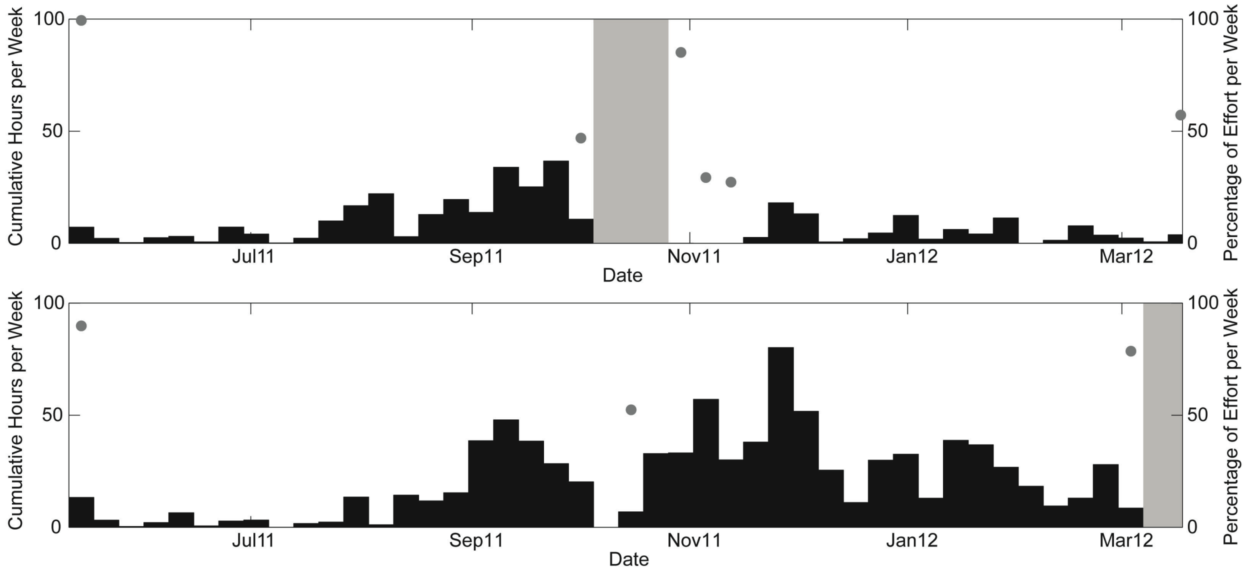

Figure 34. Presence of all humpback whale calls at sites M (above) and H (below) between May 2011 and March 2012.

Pinnipeds

Sea Lion

Pinniped barks, presumably made by California sea lions, were recorded more frequently at site M than site H. They were predominantly recorded during July and August at both sites (Figure 35). Low hourly level of barking persisted at site M into the fall. The seasonality of pinniped barks suggests that they may be associated with a mating display.

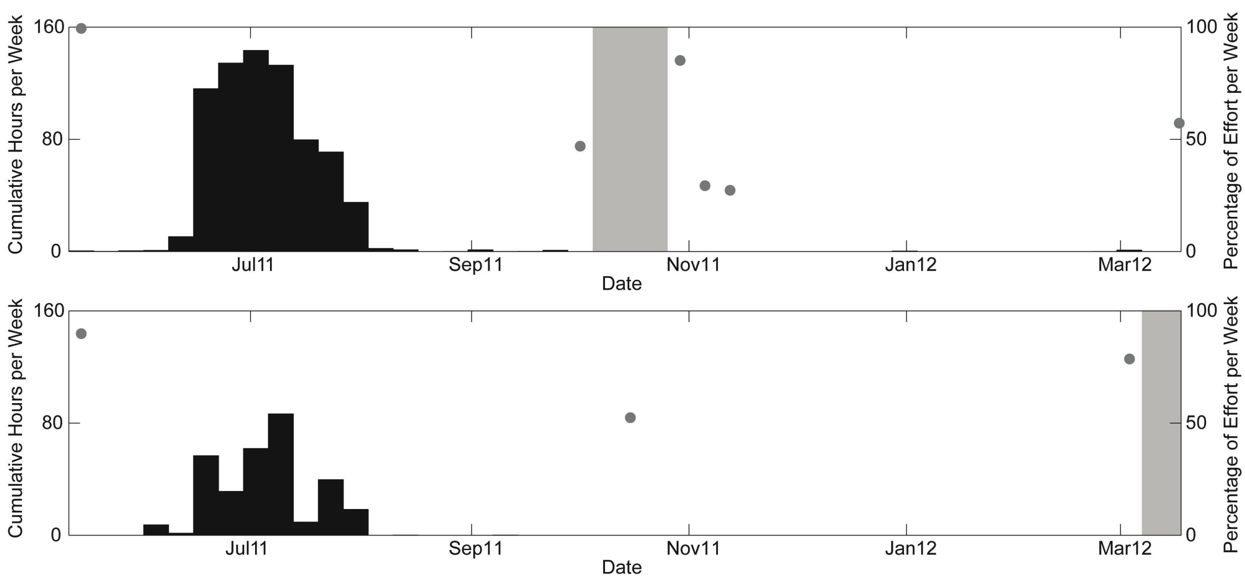

Figure 35. Pinniped bark presence at sites M (above) and H (below) between May 2011 and March 2012.

Odontocetes

Unidentified Dolphin

The largest number of detections for odontocete echolocation clicks 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 at both sites with peak acoustic activity in fall months (Figure 36). Site M had a distinct seasonal pattern (high numbers in summer/fall, low number in winter/spring), whereas site H showed only slight seasonal variations. There was a distinct diel pattern, with more activity at night, likely due to nighttime foraging (Appendix).

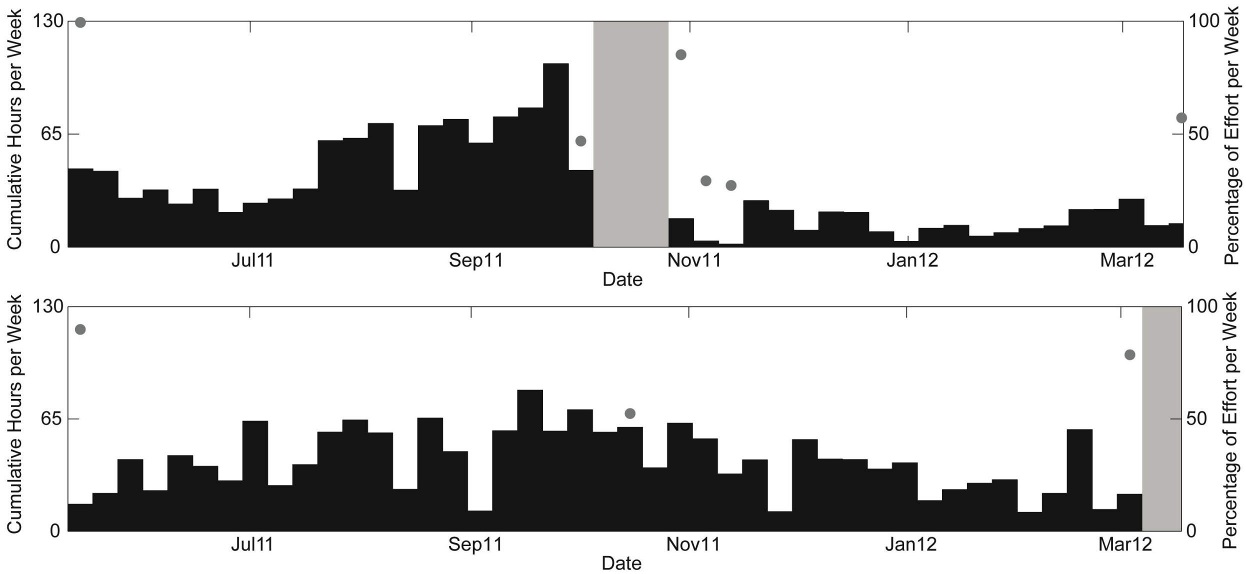

Figure 36. Unidentified dolphin echolocation click presence at sites M (above) and H (below) between May 2011 and April 2012.

Risso's Dolphin

Risso's dolphin echolocation clicks occurred throughout the year with decreased detections in fall and winter months at site M (Figure 37). They were more frequent at site M than at site H. In previous years of acoustic monitoring in SOCAL, site M also was preferred over site N (located south of San Clemente Island). It is known that Risso's dolphins are island associated, consistent with site M's proximity to the Channel Islands, and site H's more offshore setting. Risso's echolocation clicks showed a diel pattern with higher echolocation click activity at night indicating nighttime foraging (Appendix), consistent with what is reported by Soldevilla *et al.* (2010a).

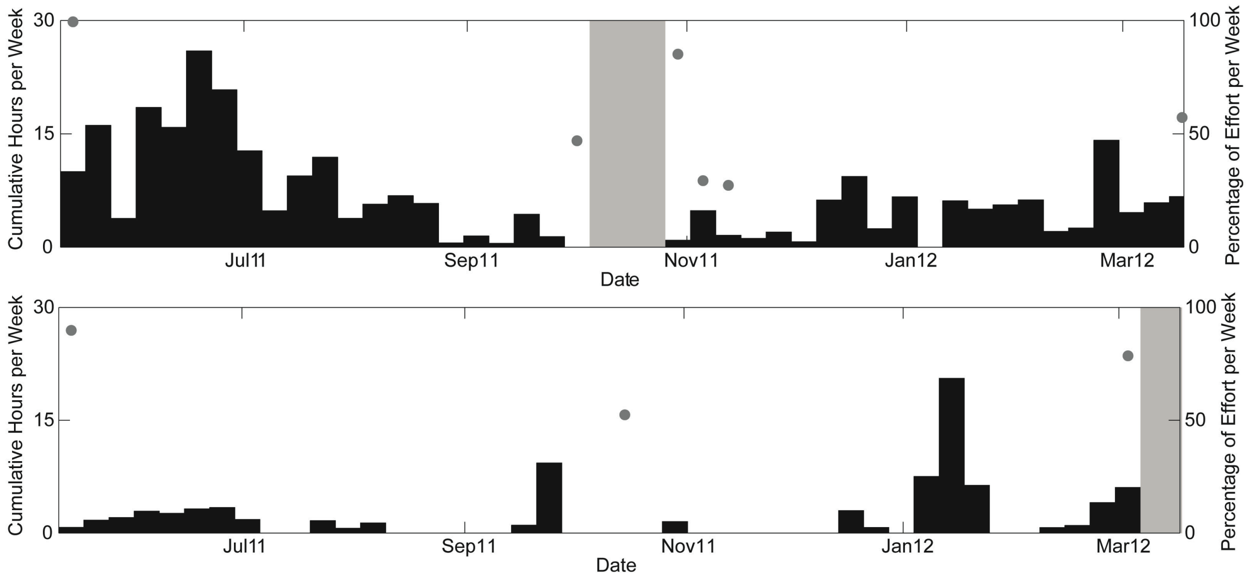

Figure 37. Risso's dolphin echolocation clicks at sites M (above) and H (below) between May 2011 and March 2012.

Pacific White-Sided Dolphin

Pacific white-sided dolphin echolocation clicks of type A were present more often at site H than at site M. They had a seasonal occurrence with higher detections in the summer and fall (Figure 38). There was a diel pattern notable with higher numbers of detections at night indicating nighttime foraging (Appendix). Echolocation clicks of type B were only detected at site H, and only in the summer (Figure 39). There were too few type B detections to determine a diel pattern (Appendix). A fall-winter peak was expected for both click types (Soldevilla *et al.* 2010b) and both types appeared in summer, somewhat earlier than the expected pattern.

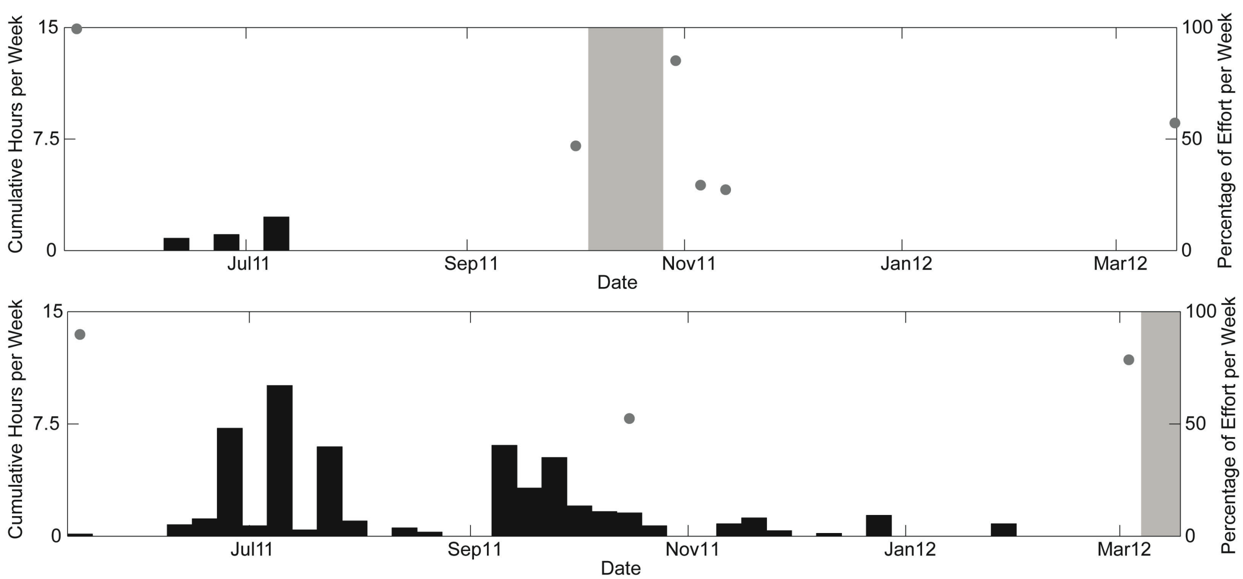

Figure 38. Pacific white-sided dolphin type A echolocation click presence at sites M (above) and H (below) between May 2011 and March 2012.

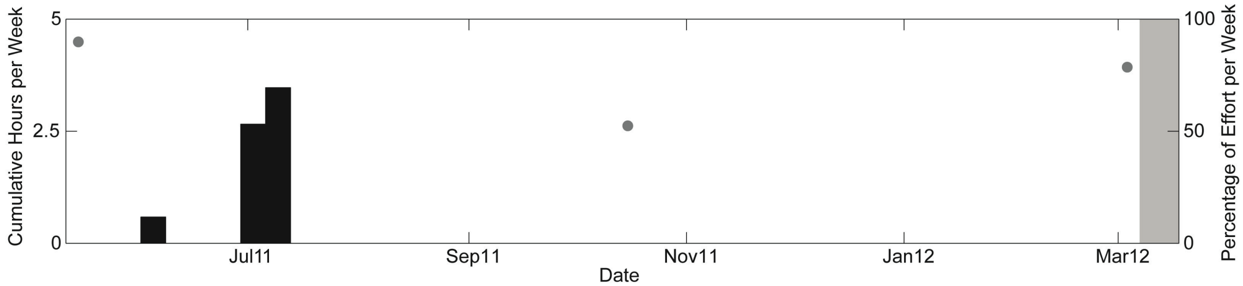

Figure 39. Pacific white-sided dolphin type B echolocation click presence at site H between May 2011 and March 2012.

Killer Whale

Killer whale detections consisted of only a single encounter at each site (Figure 40). The close timing of the occurrence at the two sites suggests that these may represent a single group of animals.

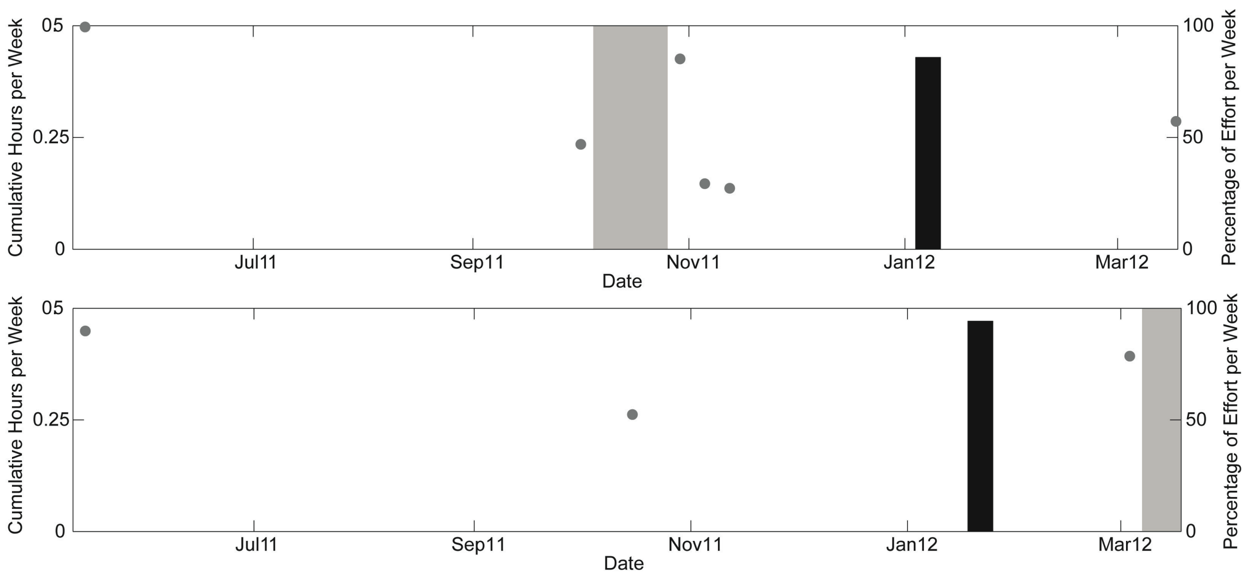

Figure 40. Weekly killer whale presence at sites M (above) and H (below) between May 2011 and March 2012.

Sperm Whale

Sperm whale echolocation clicks were detected at both sites throughout the year, without apparent seasonal pattern (Figure 41). There may be a preference for daytime acoustic activity (Appendix).

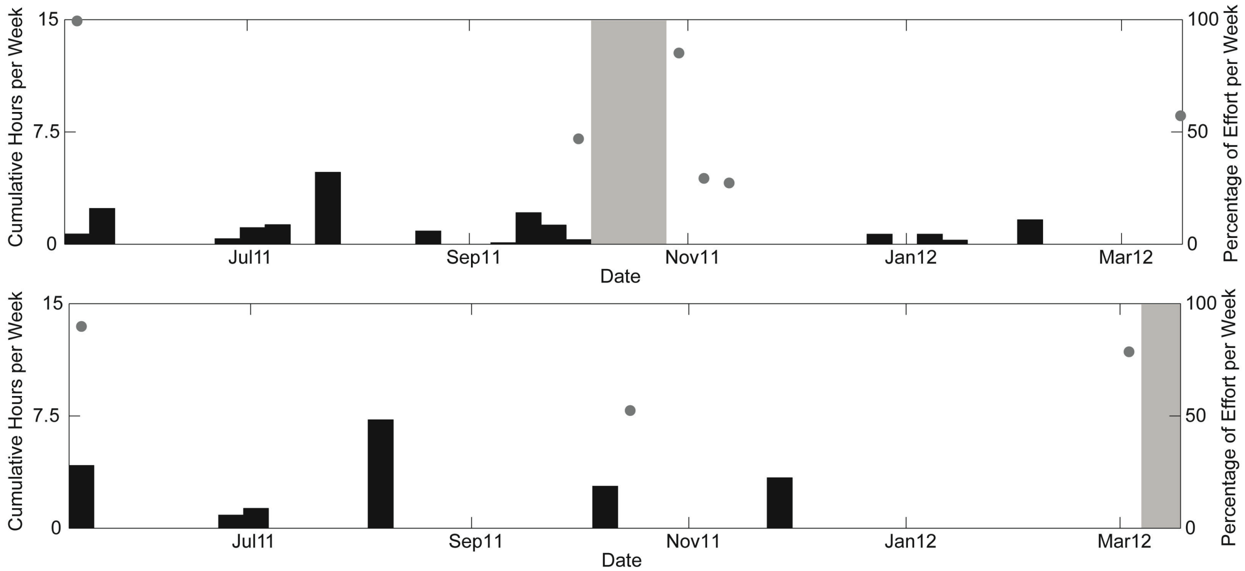

Figure 41. Weekly sperm whale echolocation click presence at sites M (above) and H (below) between May 2011 and March 2012.

Cuvier's Beaked Whale

Cuvier's beaked whales were detected throughout the year at both sites with a higher number of occurrences at site H (Figure 42). A period with lower detections occurred at site H from August to October and there were few detections at site M in the fall. There was no preferred time of the day for echolocation click detections (Appendix).

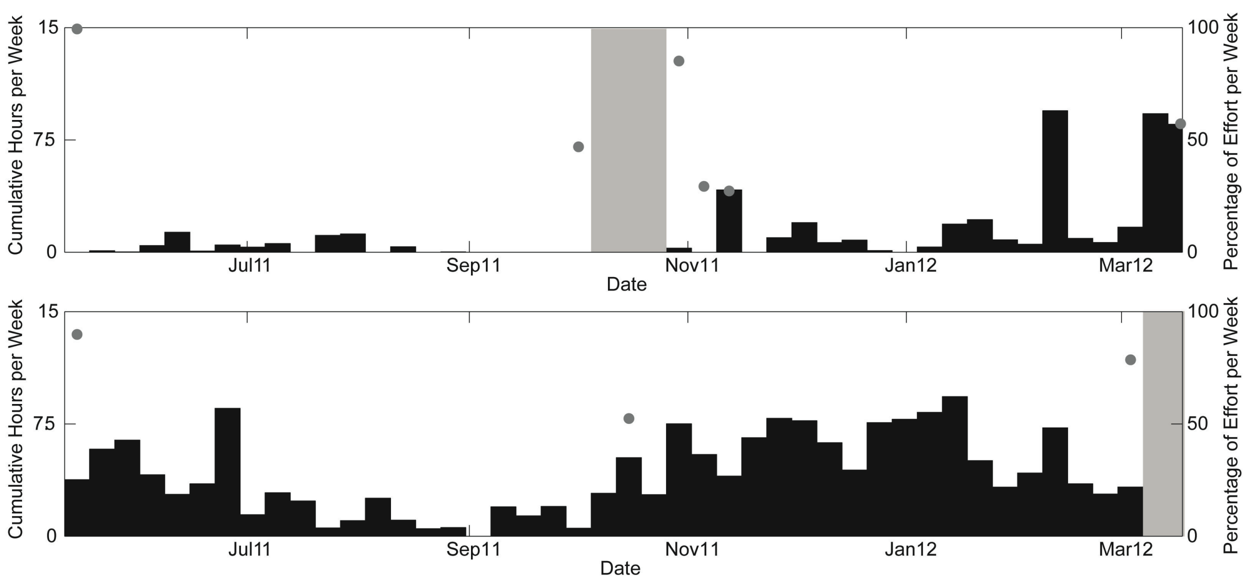

Figure 42. Weekly Cuvier's beaked whale frequency modulated pulse presence at sites M (above) and H (below) between May 2011 and March 2012.

Baird’s Beaked Whale

There were only a few acoustic encounters with Baird’s beaked whales; they were found in August and December at site M and in June/July and March at site H (Figure 43).

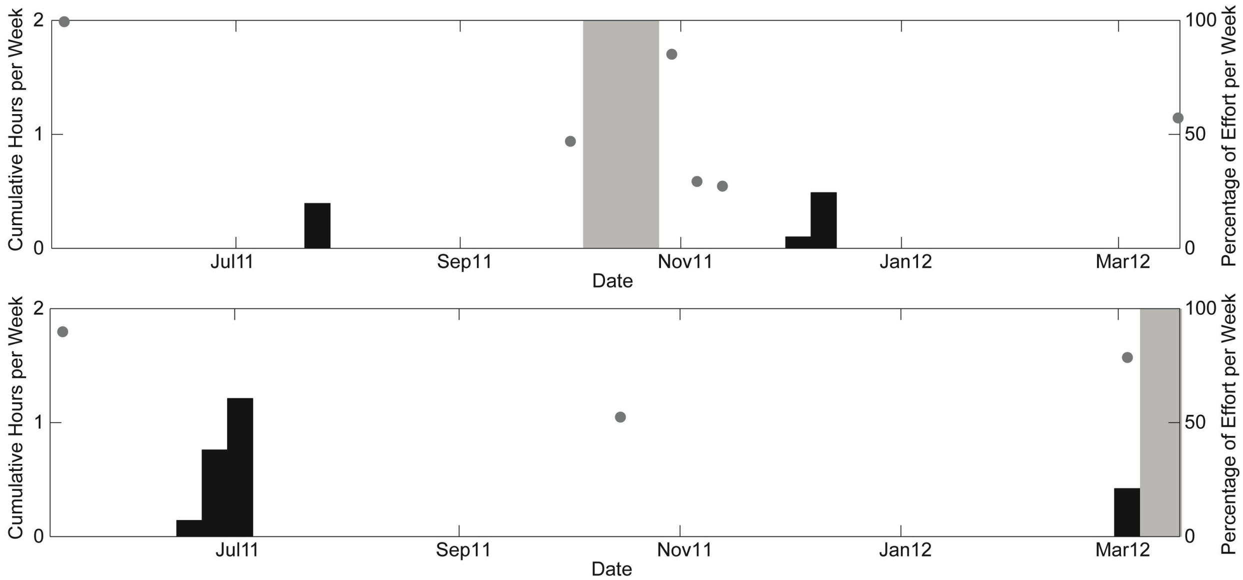

Figure 43. Weekly Baird’s beaked whale frequency modulated pulse and click presence at sites M (above) and H (below) between May 2011 and March 2012.

43 kHz Beaked Whale

There was only a single acoustic encounter with the 43 kHz beaked whale signal; it was found in March 2012 at site M (Figure 44).

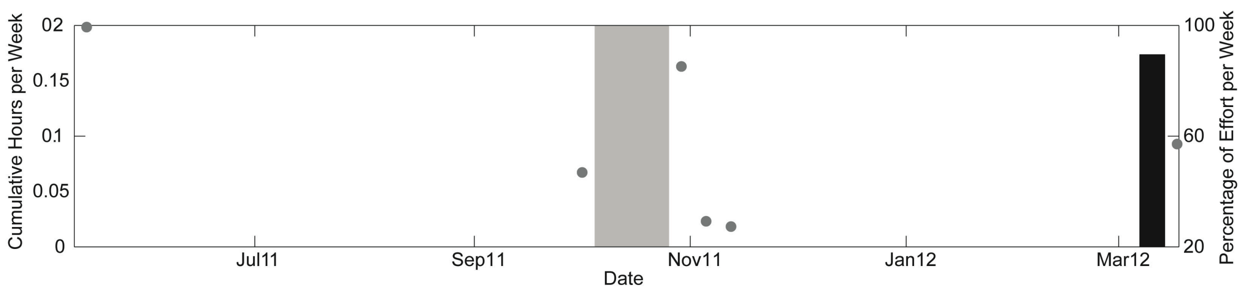

Figure 44. Weekly 43 kHz beaked whale frequency modulated pulse at site M between May 2011 and April 2012.

Unidentified Beaked Whales

Detections of unidentified beaked whale FM pulses were rare (Figure 45), and due to the lack of data there is no apparent diel or seasonal pattern. These signals had beaked whale like character but were not clearly classifiable to one of the FM pulse types of Figure 20.

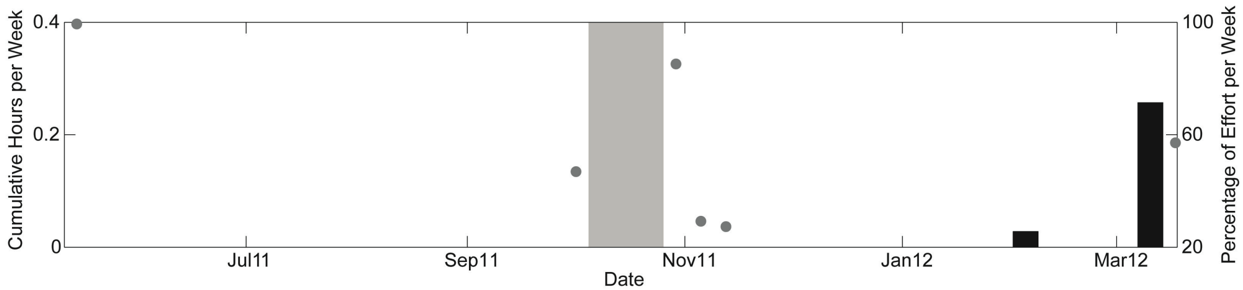

Figure 45. Unidentified beaked whale frequency modulated pulse at site M between May 2011 and March 2012.

Species Richness

Species richness is the number of different species represented in a population assessment. Species richness counts the number of species, but it does not take into account species abundance. We calculated species richness separately for mysticetes and odontocetes at site M and site H, due to their different detection radii. Past data suggest detection of up to 6 species of mysticetes and 12 species of odontocetes is possible over a yearly cycle. Note that for the odontocetes, we are not yet able to separate common dolphin and bottlenose dolphins, so these are lumped together into "unidentified dolphin" and not counted in the species richness values. The ability to separate these two species will lead to an increase in the richness values, although how this may impact individual sites has to be evaluated. Also, at this point the acoustic data do not have enough sensitivity for pinnipeds (primarily sea lion calling during the mating season) to calculate a richness number explicitly for pinnipeds.

The species richness, calculated in daily bins, is presented for mysticetes and odontocetes in `Figure 46`. The mean number of odontocetes present at site M and site H are 1.8 ±0.8 and 2.1±0.9, respectively. The mean number of mysticete species at site M and site H are somewhat higher, 2.8±0.8 and 3.8±0.9. During this monitoring period, there were significantly more odontocete and mysticete species present daily at site H than at site M (Kruskal-Wallis ANOVA= 7.86; $P = 0.005$ and Kruskal-Wallis ANOVA = 15.02; $P < 0.0001$, respectively).

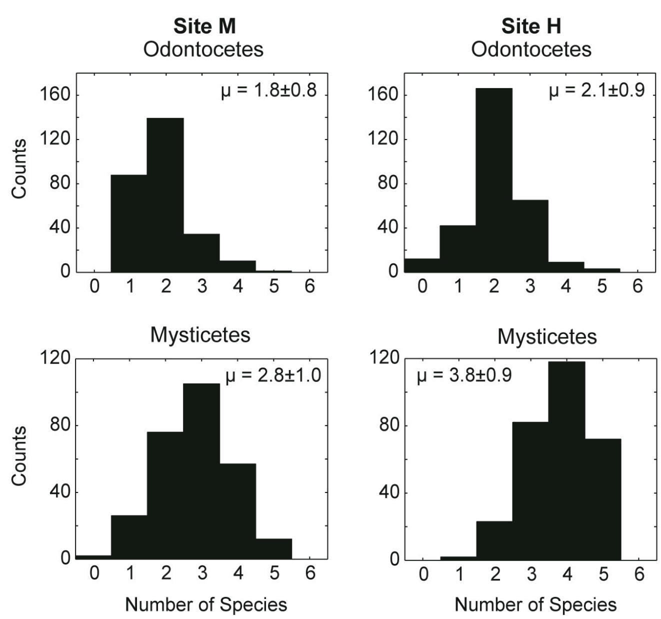

Figure 46. Species richness for mysticetes (lower) and odontocetes (upper) at site M (left) and site H (right) calculated for daily bins between May 2011 and March 2012.

Anthropogenic Sounds

Broadband Ship Noise

Ship noise was a common anthropogenic sound, although more so at site M than site H (Figure 47). 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 had two temporal peaks (Appendix) showing the preference in times for ship arrival and departure to port.

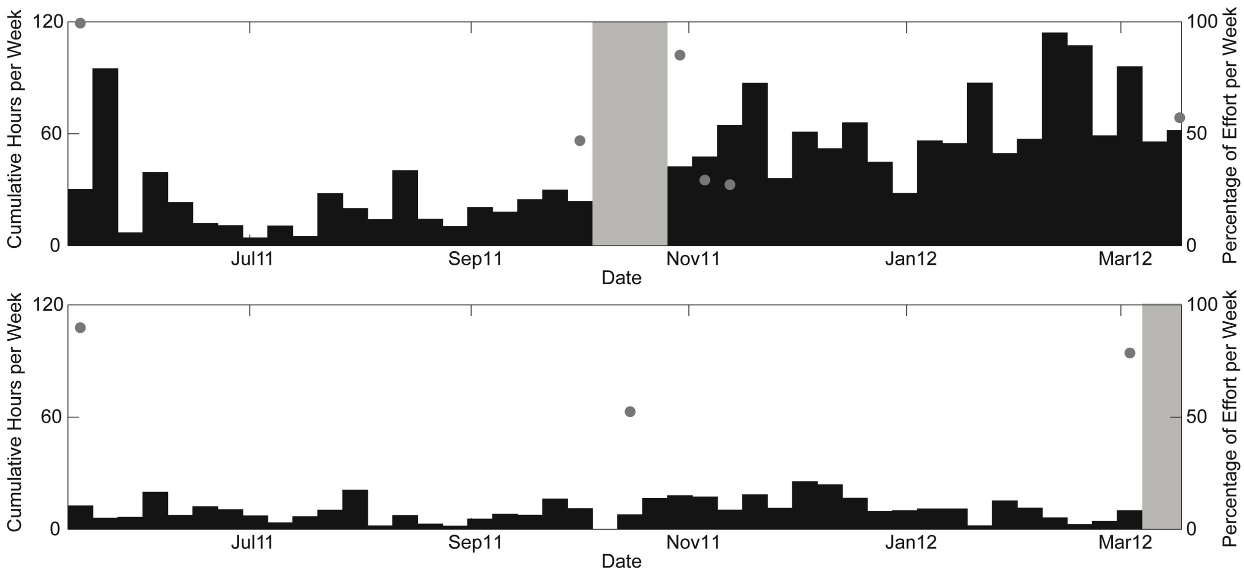

Figure 47. Weekly hours with broadband ship noise at sites M (above) and H (below) between May 2011 and March 2012.

Mid-Frequency Active Sonar

The dates for major naval training exercises that were conducted in the SOCAL region between May 2011 and March 2012 are listed in Table 4. Three distinct types of training exercises were held: (1) Sustainment Exercise (SUSTEX) are training exercises involving a Strike Group in multiple warfare areas, potentially including air events, surface events, and Anti-Submarine Warfare (ASW). Sonar usage during a SUSTEX can vary from none to some; (2) Component Training Exercise (COMPUTEX), is a major integration of at-sea training and certification. These exercises integrate an aircraft carrier and carrier air wing with surface ships and submarines in a challenging training scenario. ASW training and sonar usage is generally scripted for certain portions of time within a COMPTUEX; (3) Joint Task Force Exercise (JTFEX) is a complex scenario-driven training and certification exercise used to evaluate the Strike Group. ASW training and sonar can occur at any point during the JTFEX. In addition to the events described above, there may be unit level training that takes place outside of the time periods for major exercises.

Table 4. Major naval training events in the SOCAL region between May 2011 and March 2012.

Begin Date	End Date	Type of Exercise
May 6, 2011	May 27, 2011	COMPUTEX
June 3, 2011	June 8, 2011	JTFEX
Sept 17, 2011	Sept 29, 2011	SUSTEX
Sept 22, 2011	Oct 11, 2011	COMPUTEX
Oct 1, 2011	Oct 5, 2011	JTFEX

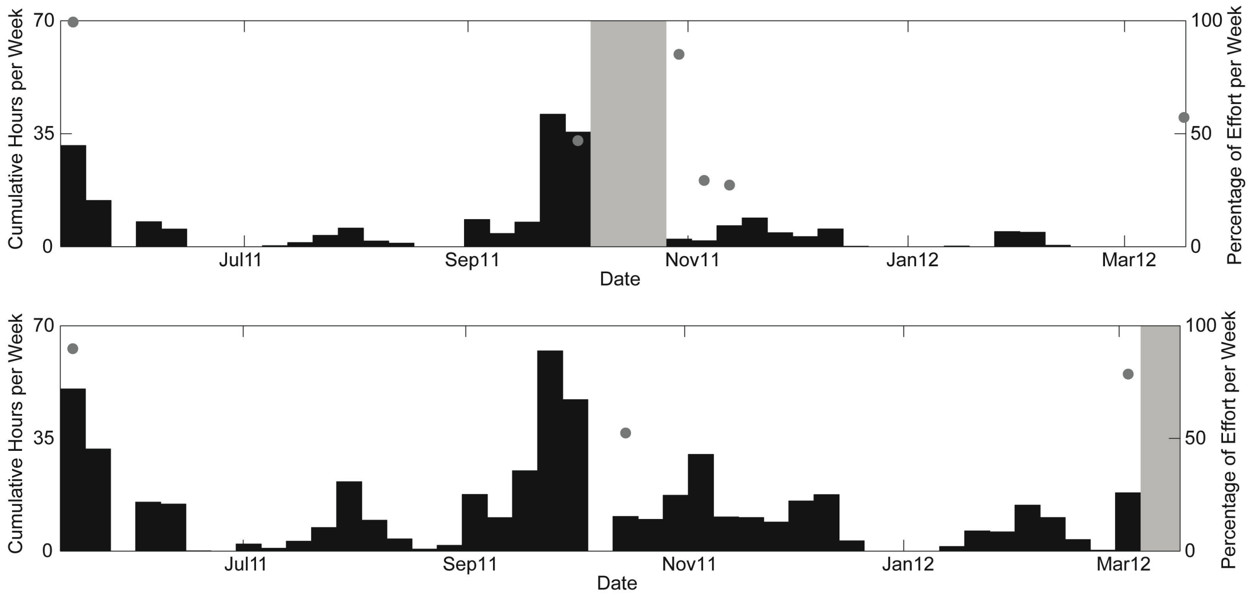

Figure 48. Weekly mid-frequency active (MFA) sonar presence at sites M (above) and H (below) between May 2011 and March 2012.

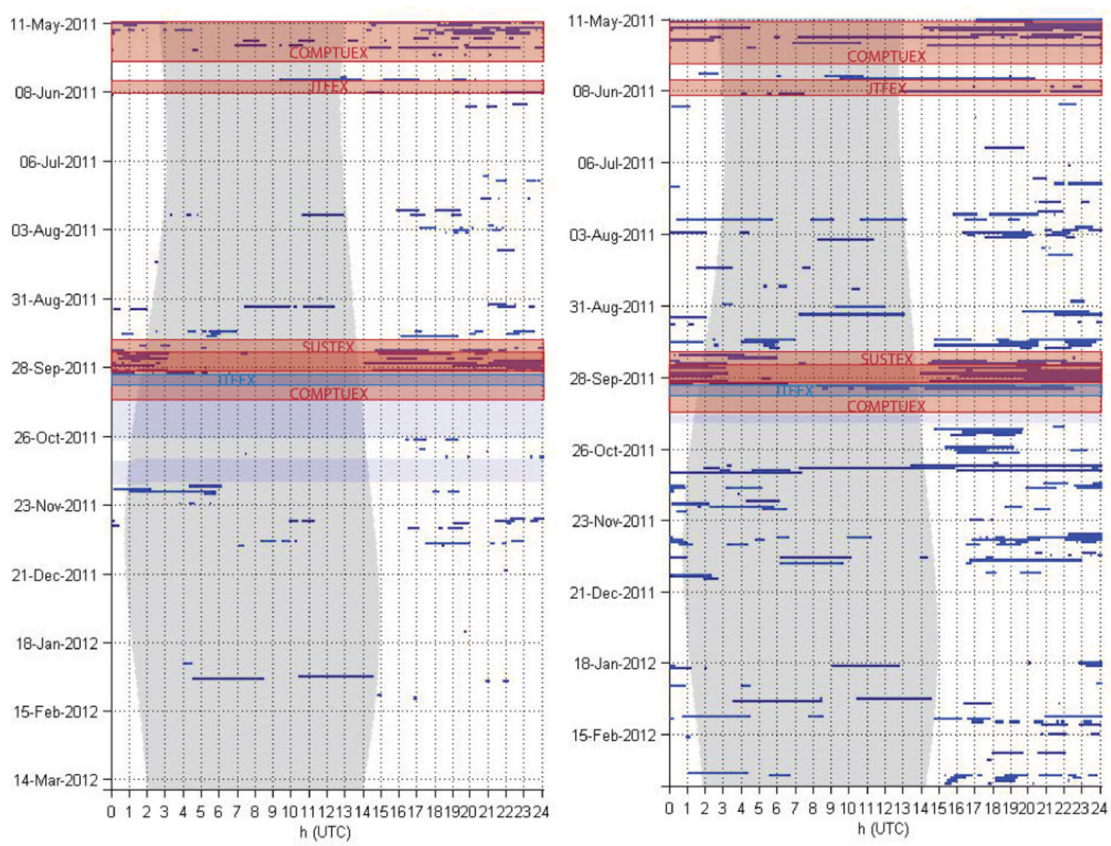

Figure 49. Major training events (shaded red) overlaid on MFA sonar detections (blue) for site M (left) and site H (right). Gray shading denotes nighttime and light purple shading denotes lack of acoustic data (no sonar detection possible).

MFA sonar events were detected at both sites M and H throughout the period May 2011 – March 2012 (Figure 48). Late September and early October had the largest number of hours of sonar pings detected, coincident with the SUSTEX, COMPUTEX and JTFEX conducted during this time period (Figure 49). Sonar usage outside of designated major exercises is probably due to unit level training.

At site H a total of 51,121 MFA sonar pings were detected in the frequency range 2.4 – 4.5 kHz (Table 5), ranging from 117 to 177 dB pp re 1 μPa received level. Likewise, at site M a total of 3,777 MFA sonar pings were detected with a maximum received level of 167 dB pp re 1 μPa. (Table 5).

Table 5. MFA sonar at 2.4 – 4.5 kHz, number of bouts, pings and maximum and median received level.

Site	# Bouts	#Pings	Max dB P-P	Median dB P-P
M	207	3777	167	123
N	261	51121	177	128

The distribution of sonar ping received levels from site H shows a peak around 128 dB pp re 1 μPa and is long-tailed to higher levels (**Figure 50**). Cumulative distribution of ping levels shows that half of the pings detected are above 128 dB pp re 1 μPa (Figure 51). MFA sonar events at site M show a peak around 122 dB pp re 1 μPa (Figure 52); at site M there were generally lower received levels and lower numbers of pings than at site H. Cumulative distribution of ping levels shows that half of the pings detected at site M are above 123 dB pp re 1 μPa (Figure 53).

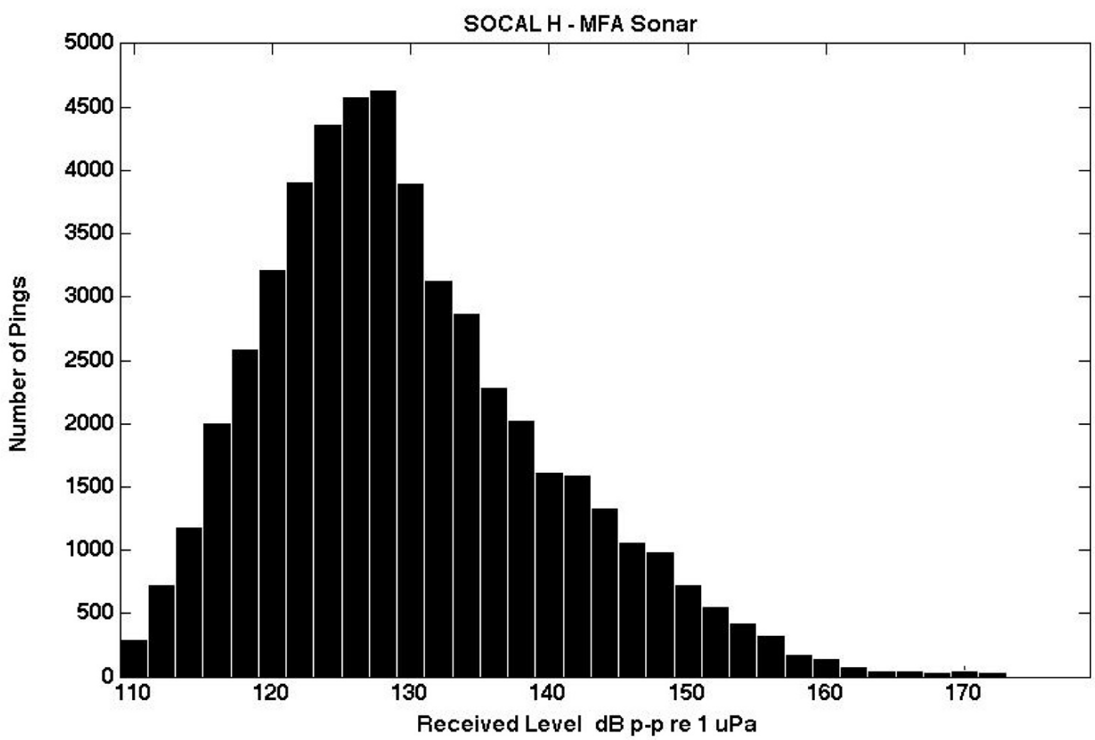

Figure 50. Distribution of number of MFA sonar pings by peak-to-peak received levels at site H.

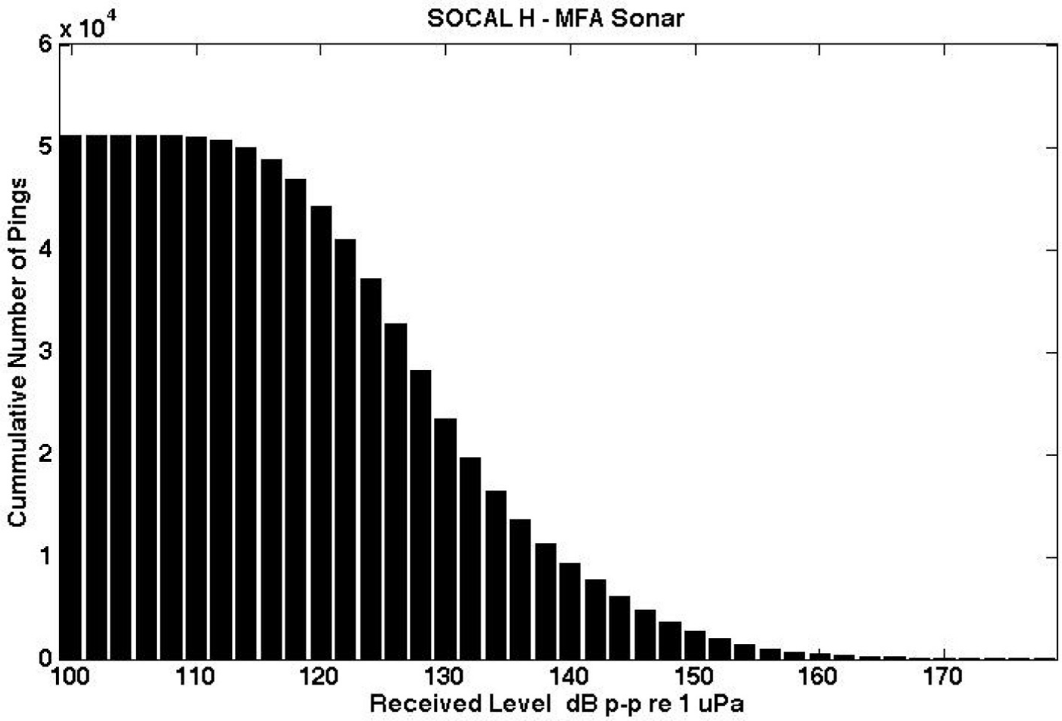

Figure 51. Cumulative distribution of MFA sonar peak-to-peak received levels at site H.

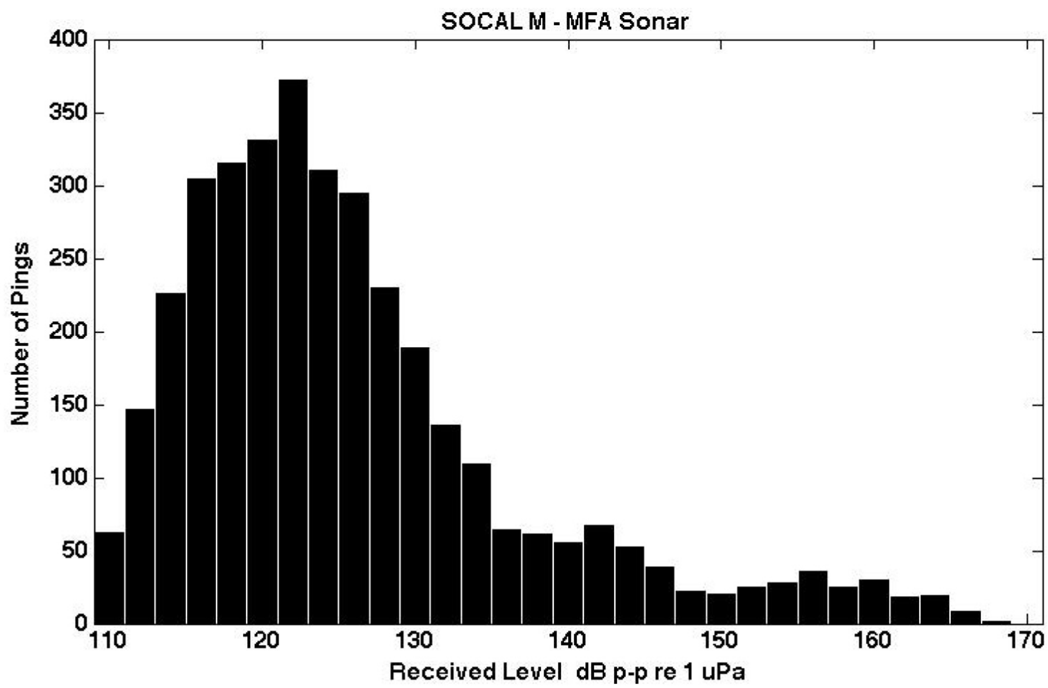

Figure 52. Distribution of number of MFA sonar pings by peak-to-peak received levels at site M.

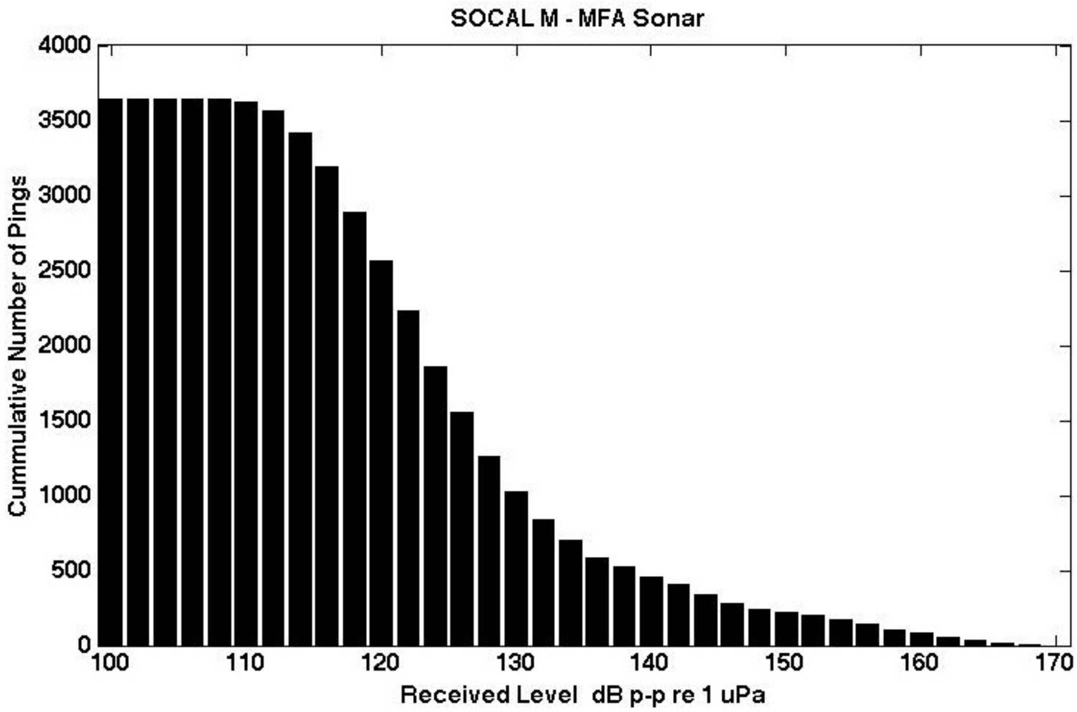

Figure 53. Cumulative distribution of MFA sonar peak-to-peak received levels at site M.

Naval Sonar > 5kHz

Sonar was also detected in the frequency band above 5 kHz (Figure 54). These sonars were heard predominantly at site H, and at lower rates than the MFA sonar at 2.4 – 4.5 kHz.

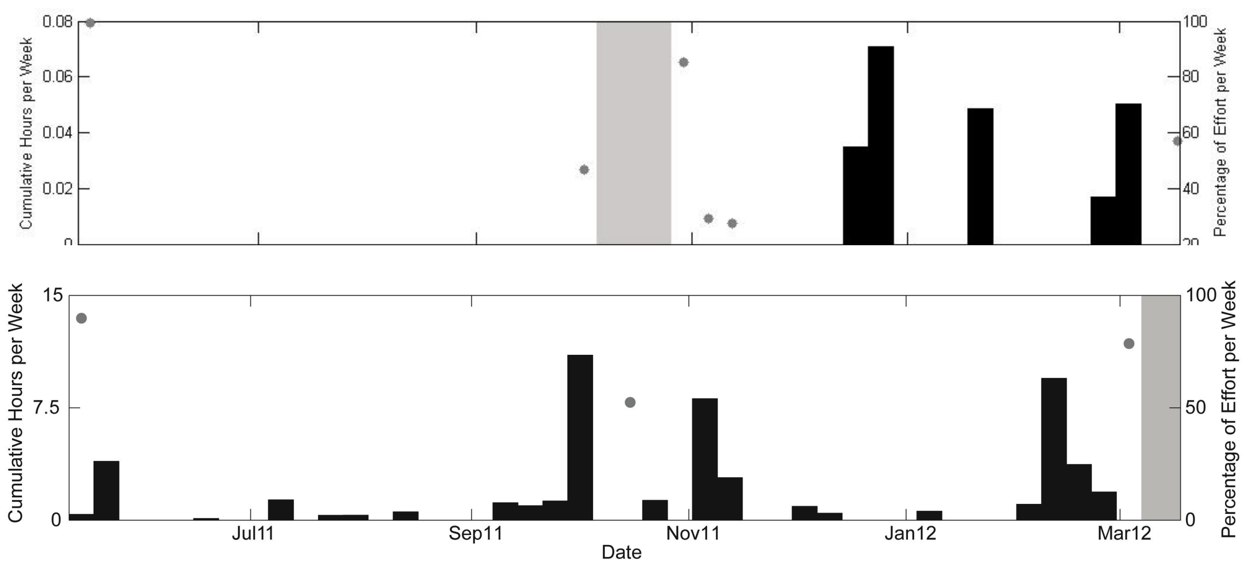

Figure 54. Weekly mid-frequency active sonar at > 5kHz at site M (above) and H (below). Note difference in the cumulative hours axis between the two plots.

Echosounders

Echosounder pings with a variety of primary frequencies (8 – 80 kHz) were found at both sites M and H (Figure 55). More echosounders were present at site H than at site M, perhaps partially related to the presence of fishing vessels. The occurrence of these pings had no apparent seasonal cycle.

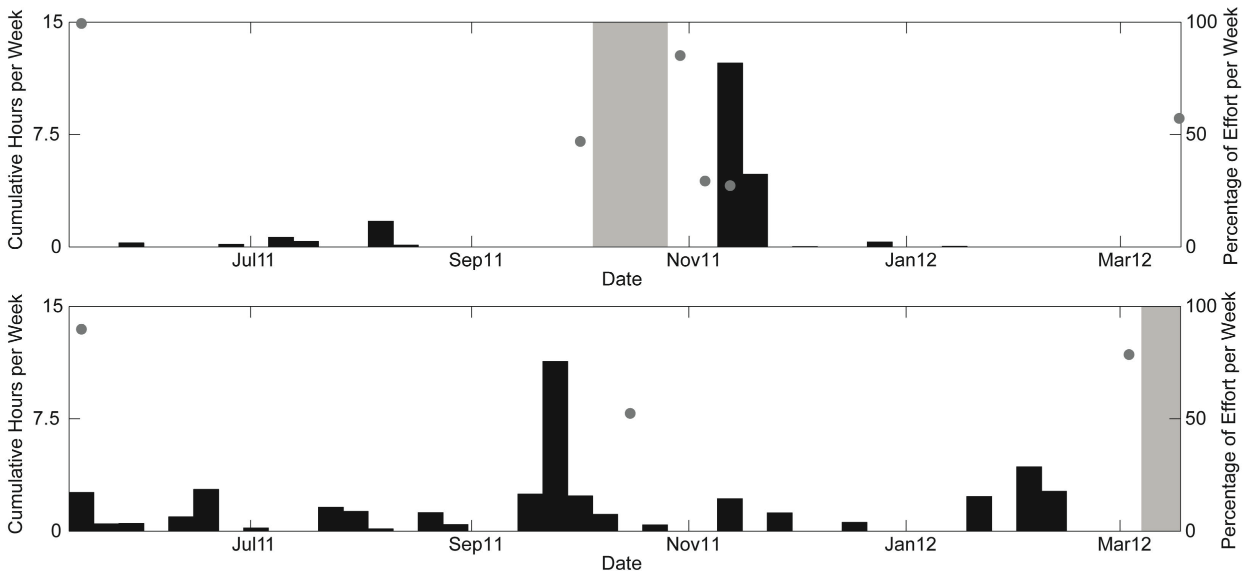

Figure 55. Weekly echosounder ping presence at sites M (above) and H (below) between May 2011 and March 2012.

Acoustic Communications Systems

Acoustic communications systems were detected primarily at site H (Figure 56). Although they were not detected a high percentage of the time, their correspondence with periods of high use of MFA sonar (September – October; Figure 48) suggests that they may have originated with naval operations.

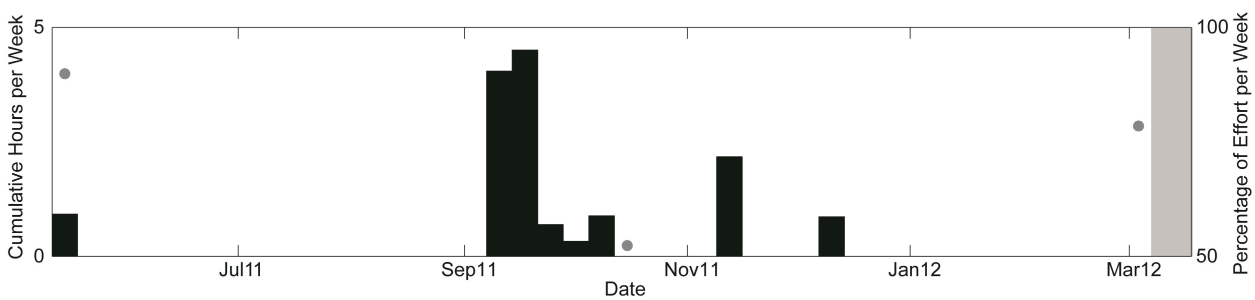

Figure 56. Weekly hours with communications system at site H between May 2011 and March 2012.

Explosions

Site H had higher numbers of hours per week with explosions than site M (Figure 57). There is a strong tendency for explosions to occur at night, and with little or no correlation to major training exercises (Appendix and Figure 58). In addition, the relatively short time duration of the explosion reverberations suggest that they are small charges (< 1 lb). These patterns together suggest that they may be primarily related to fishing activity (seal bombs) rather than naval activity, although verification requires further investigation.

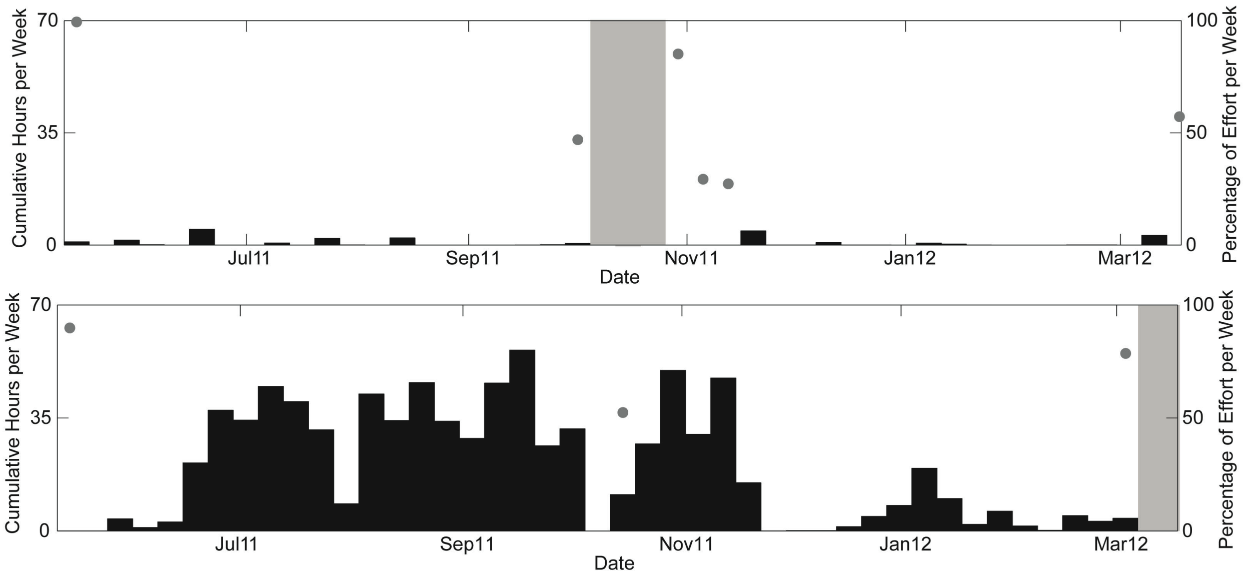

Figure 57. Weekly hours with explosions at sites M (above) and H (below) between May 2011 and March 2012.

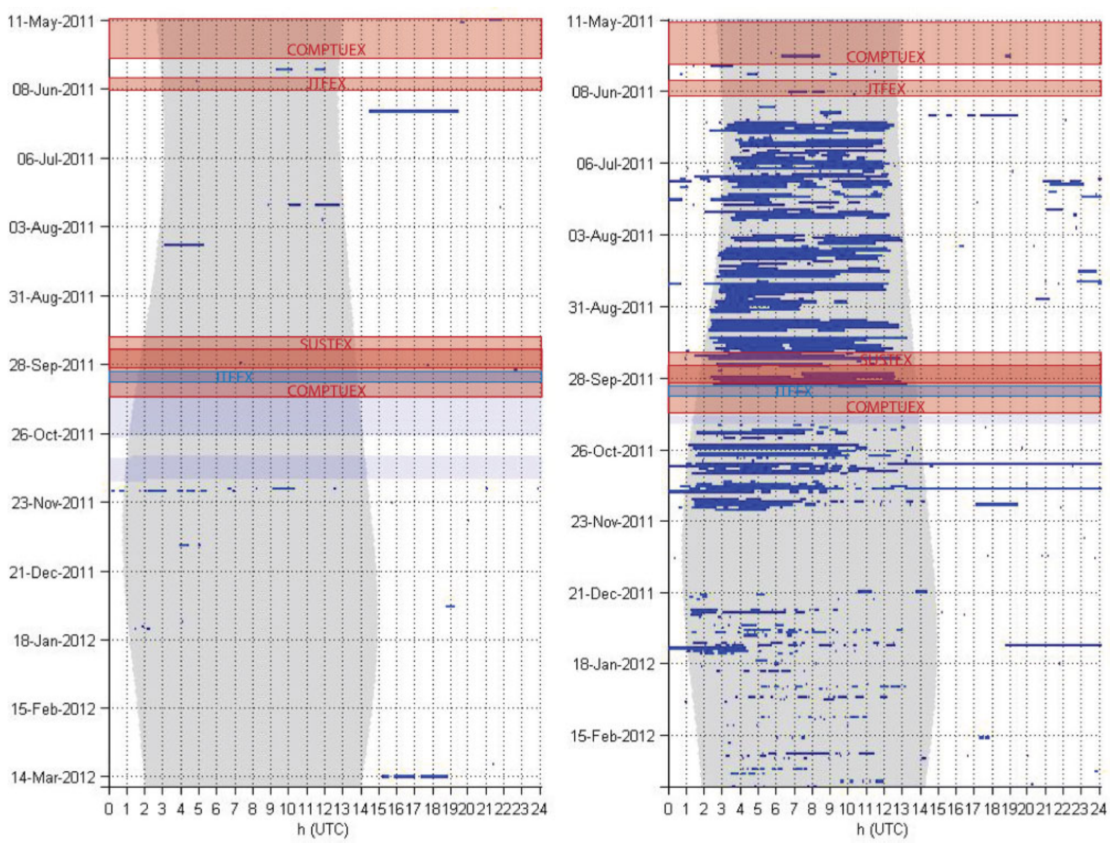

Figure 58. Major training events (shaded red) overlaid on explosions (blue) for site M (left) and site H (right). Gray shading denotes nighttime and light purple shading denotes lack of acoustic data (no sonar detection possible).

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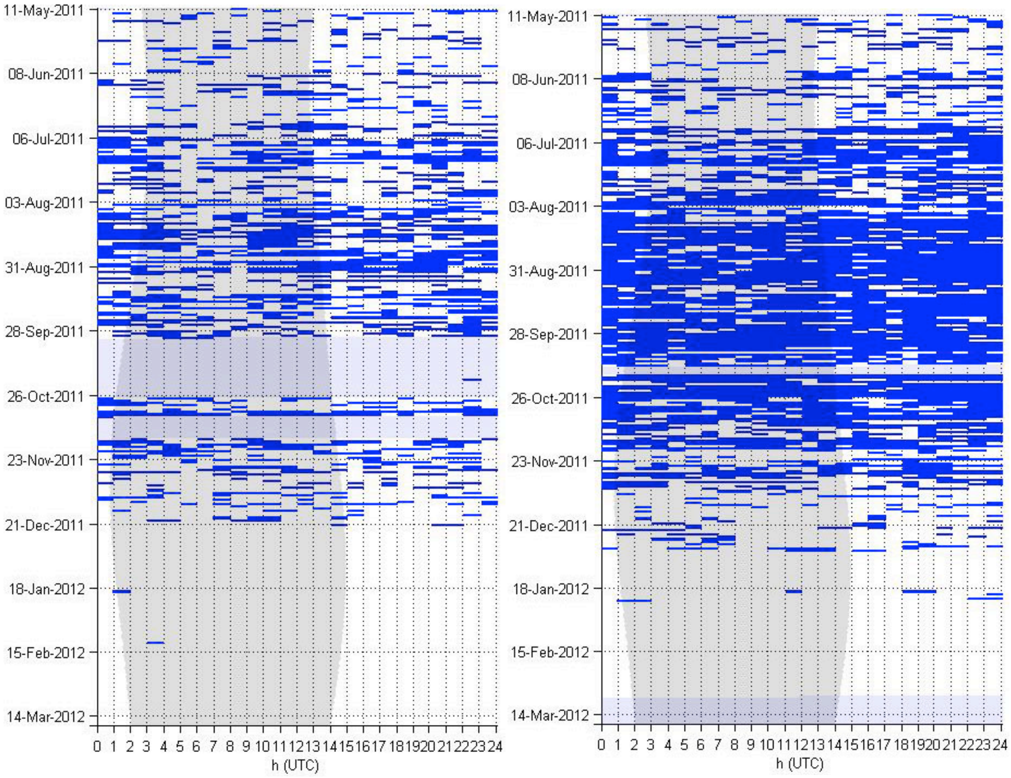
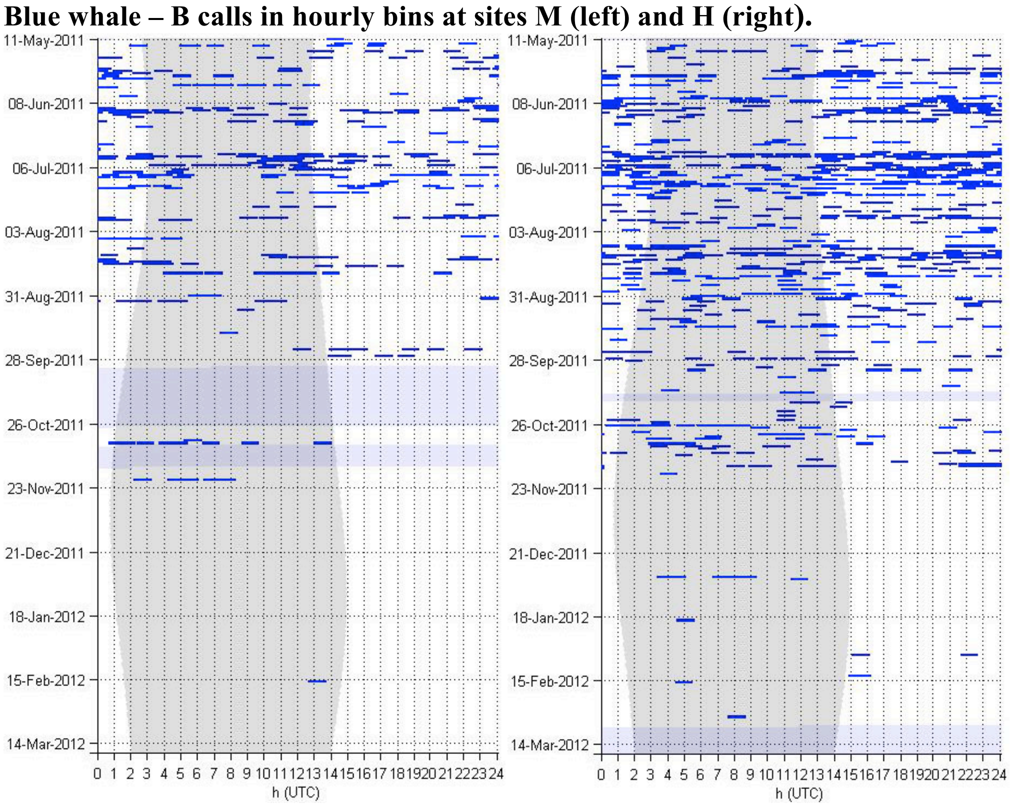
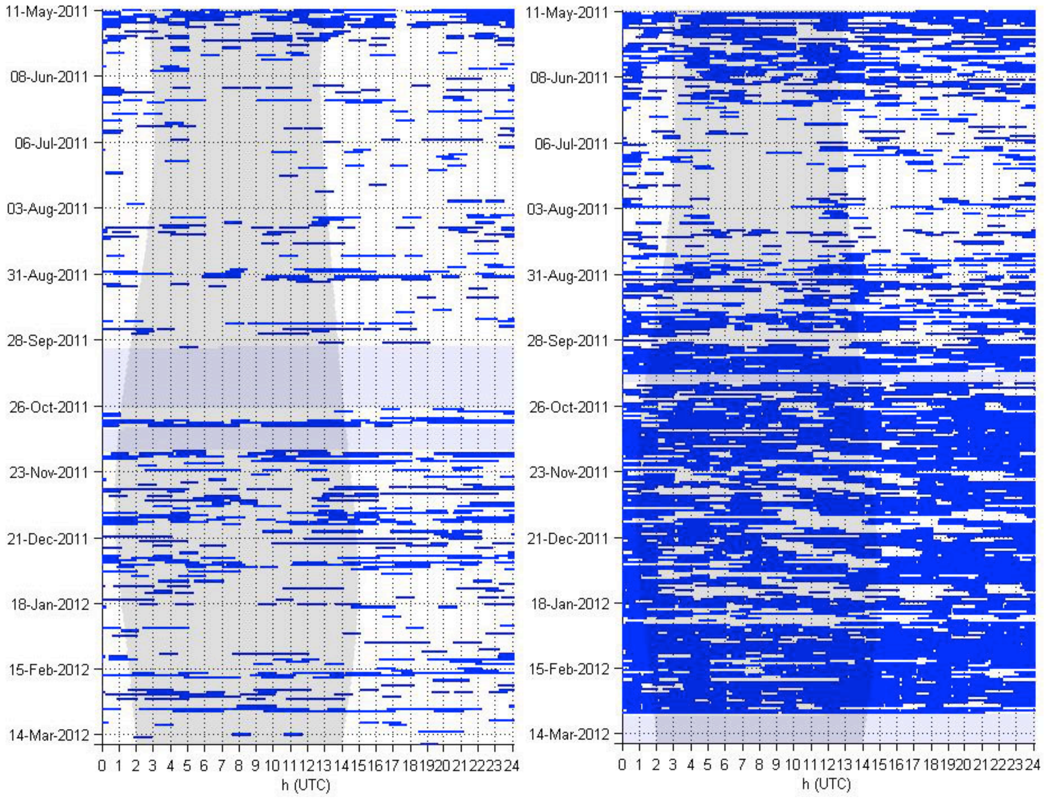
Appendix - Seasonal/Diel Occurrence Plots



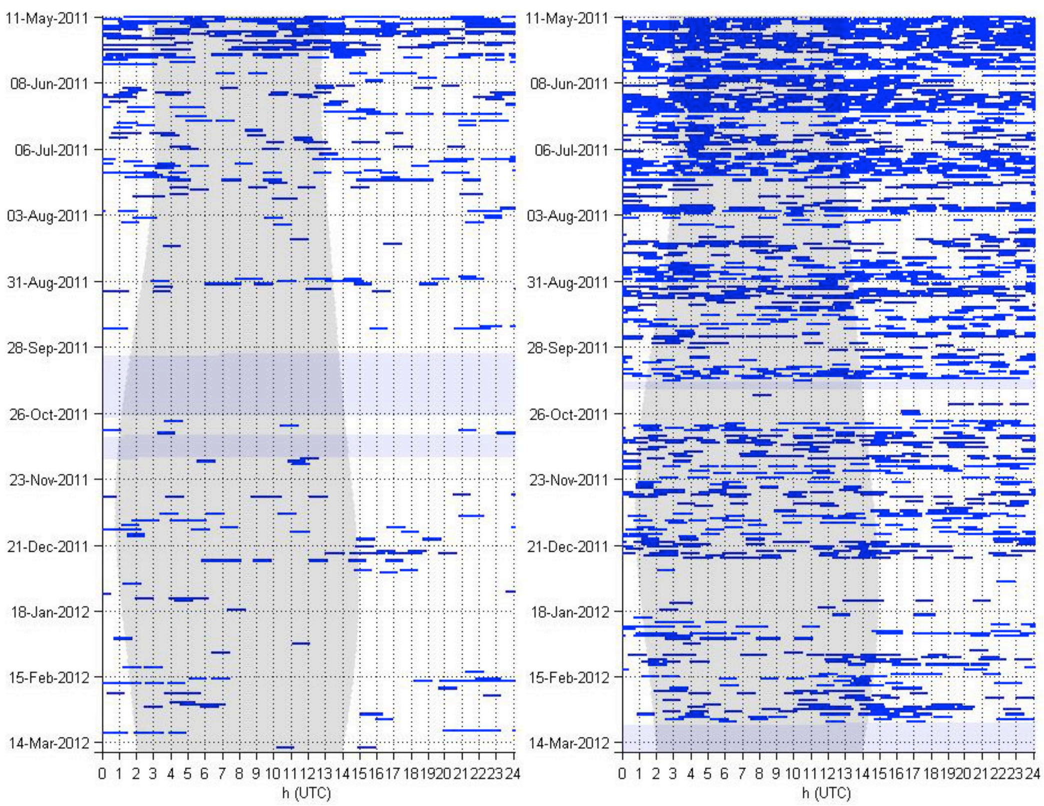
Blue whale – B calls in hourly bins at sites M (left) and H (right).



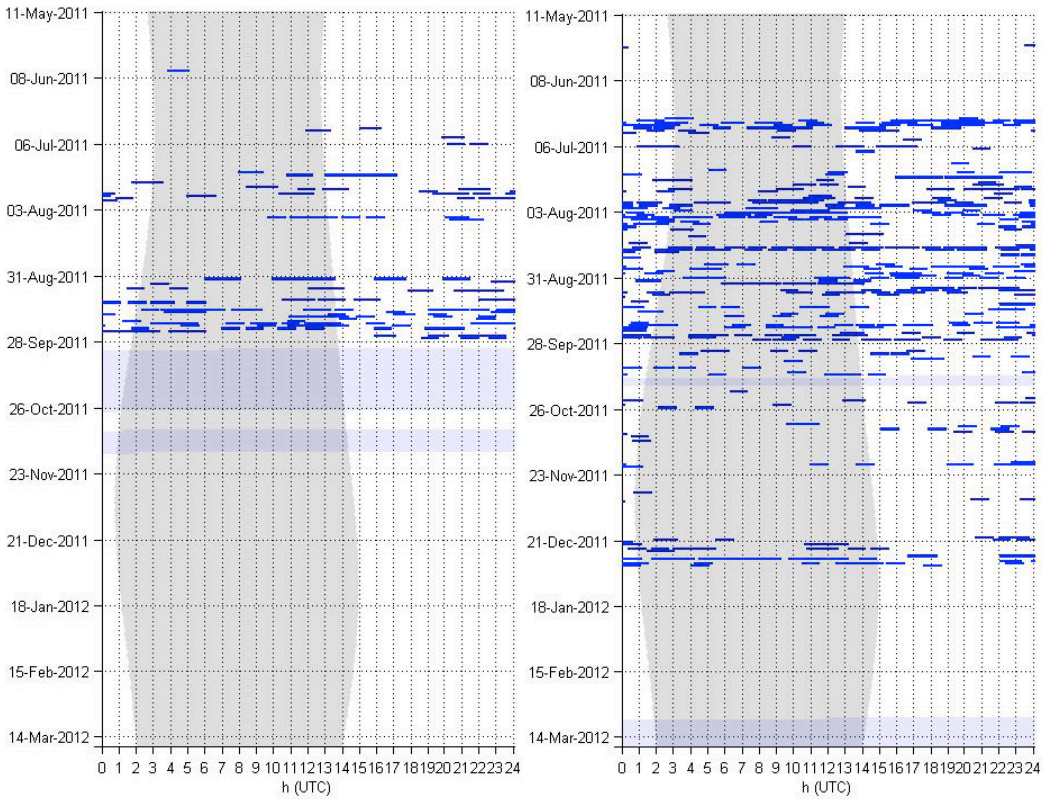
Blue whale – D calls in hourly bins at sites M (left) and H (right).



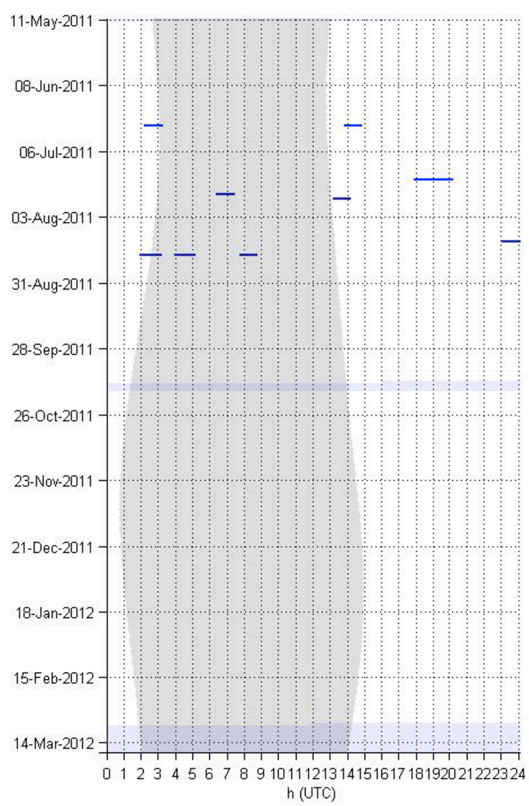
Fin whale – 20 Hz pulse calls in hourly bins at sites M (left) and H (right).



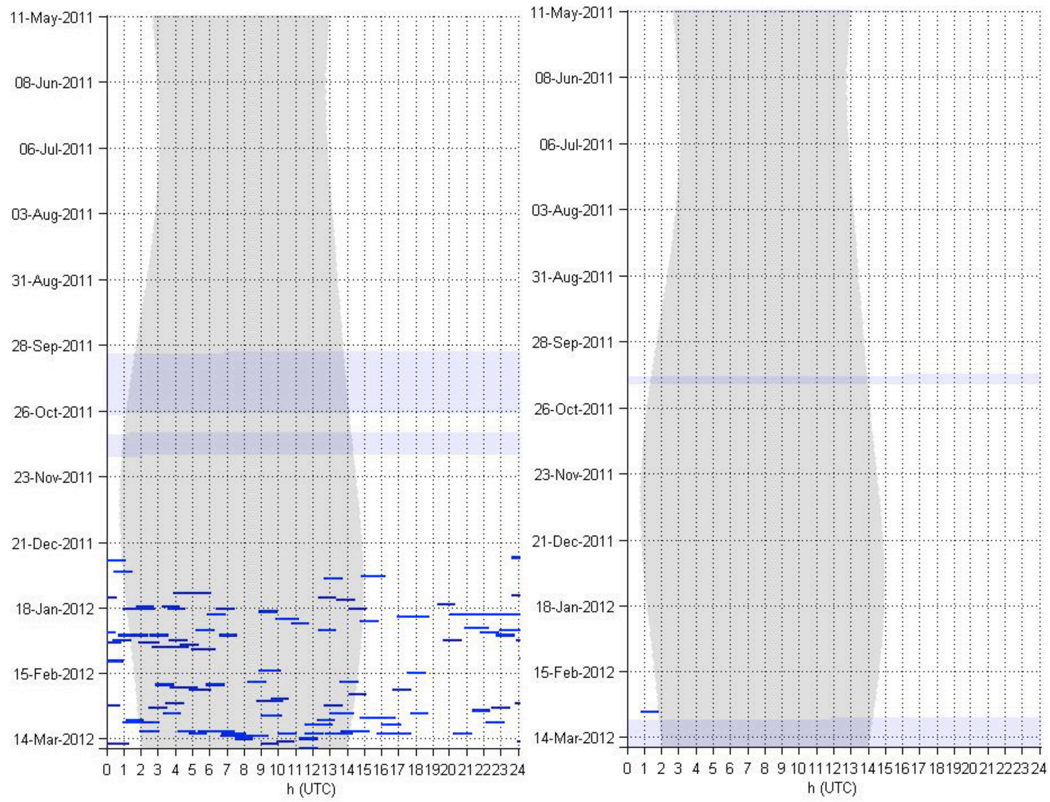
Fin whale – 40 Hz pulse calls in hourly bins at sites M (left) and H (right).



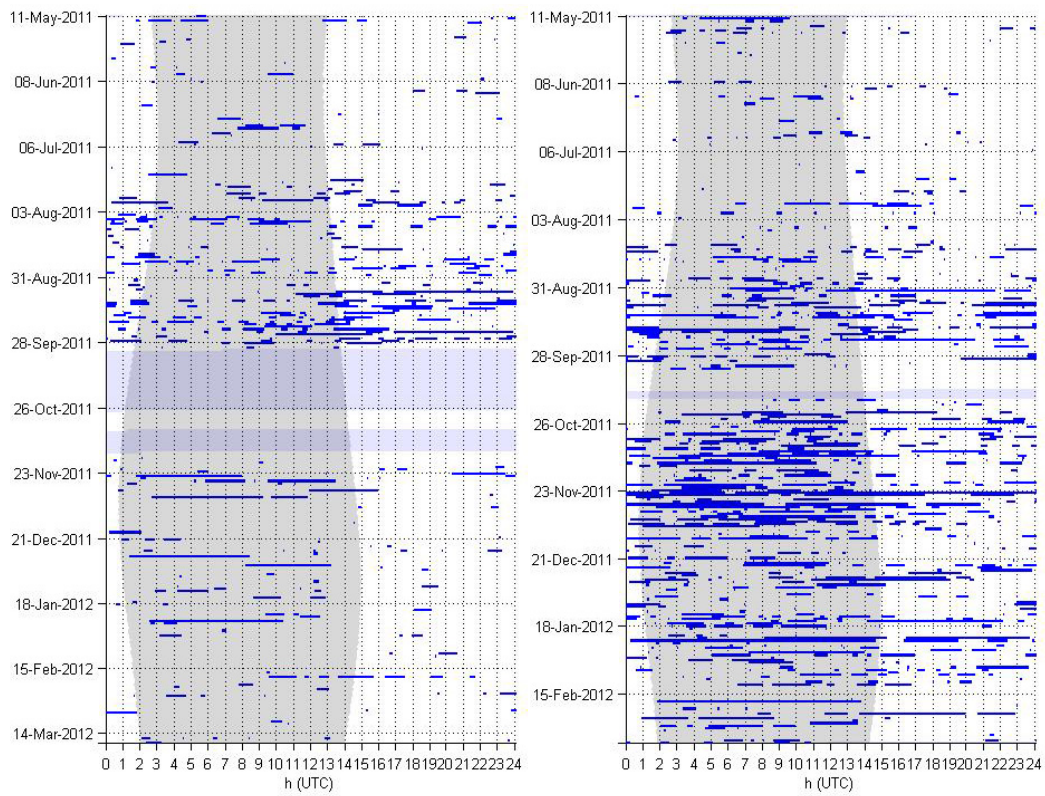
Bryde's whale – Be4 calls in hourly bins at sites M (left) and H (right).



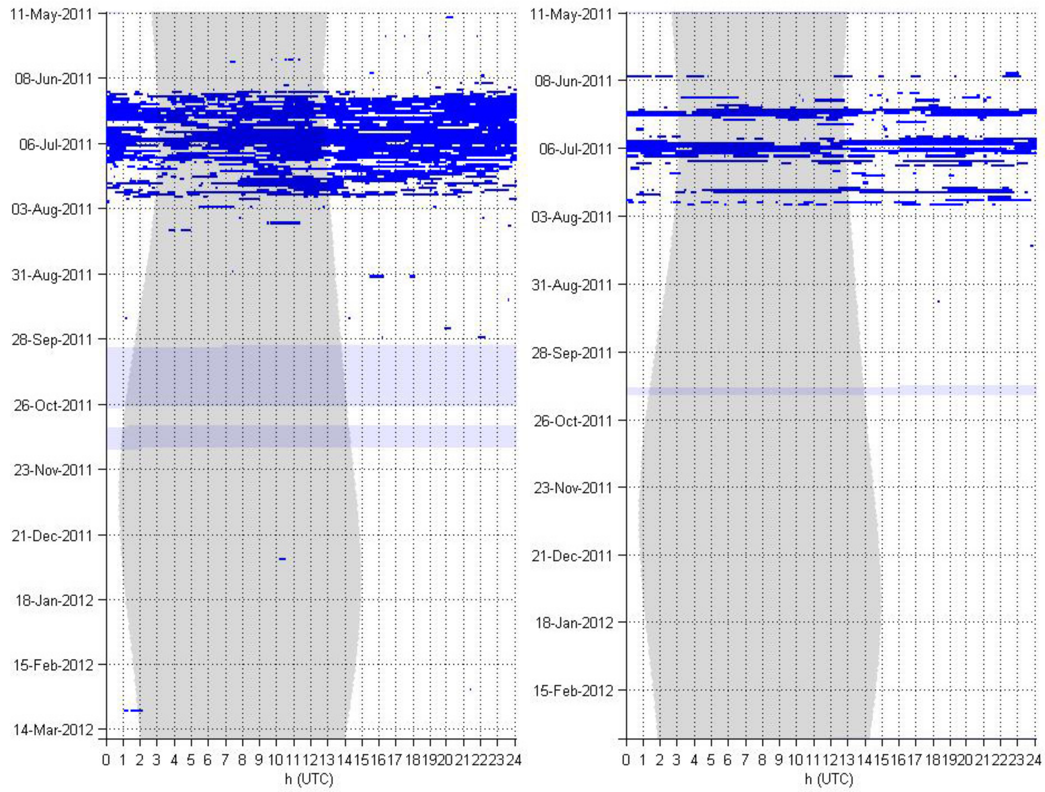
Bryde's whale – Be2 calls in hourly bins, site H. Be2 calls not detected at site M.



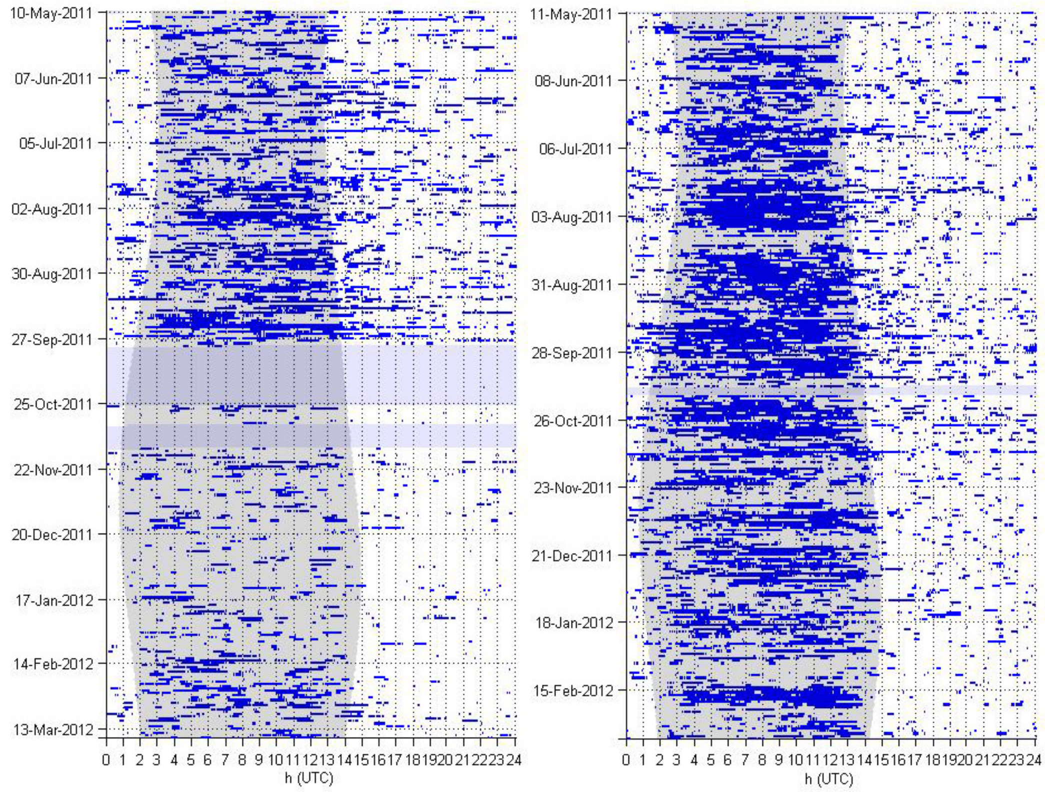
Gray whale – M3 calls in hourly bins at sites M (left) and H (right).



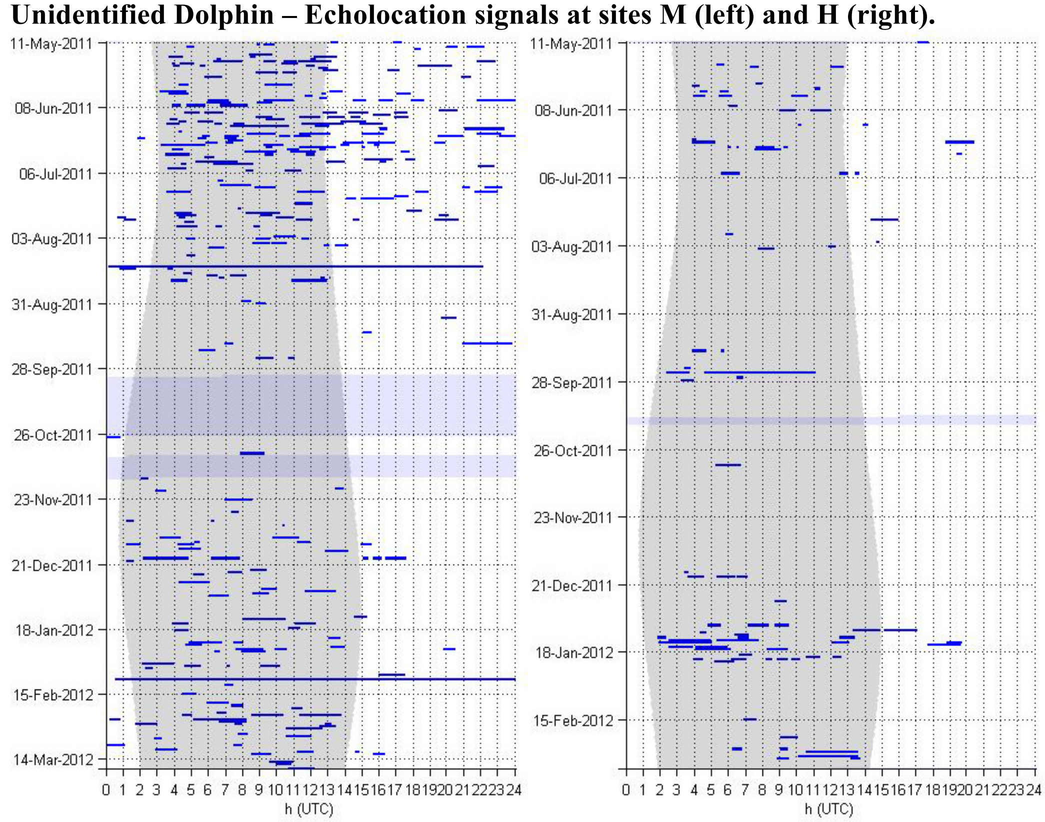
Humpback whale – All calls one-min bins, sites M (left) and H (right).



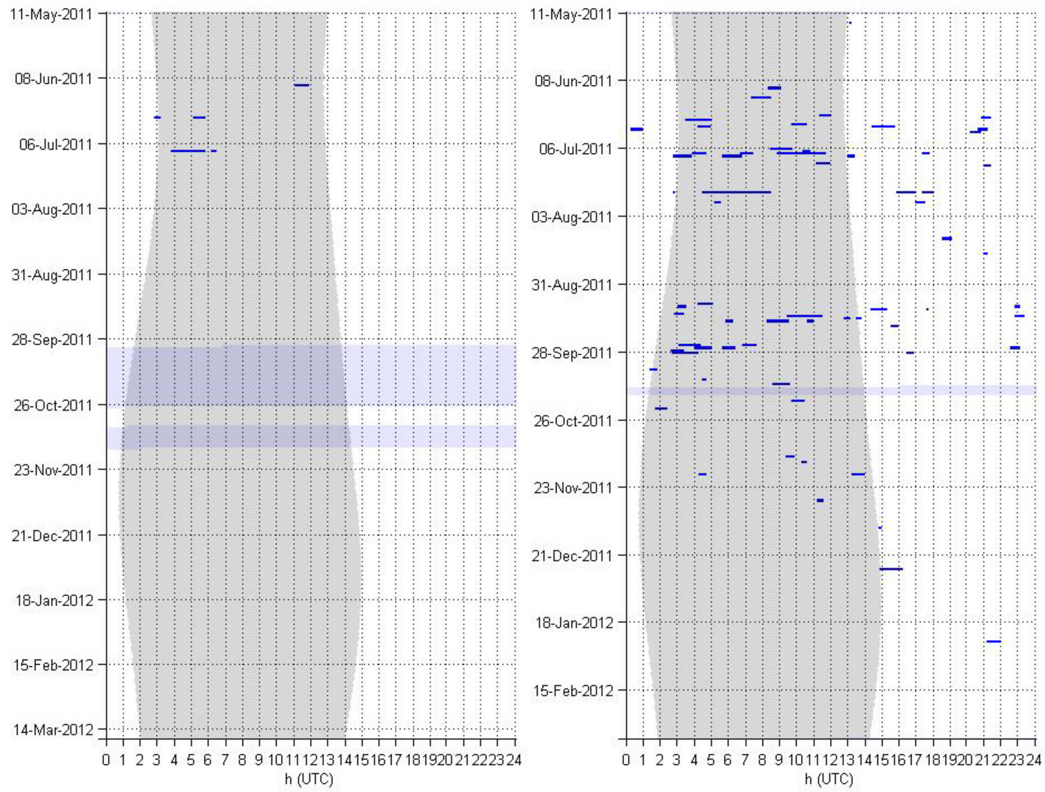
Pinnipeds – Barks in one-minute bins at sites M (left) and H (right).



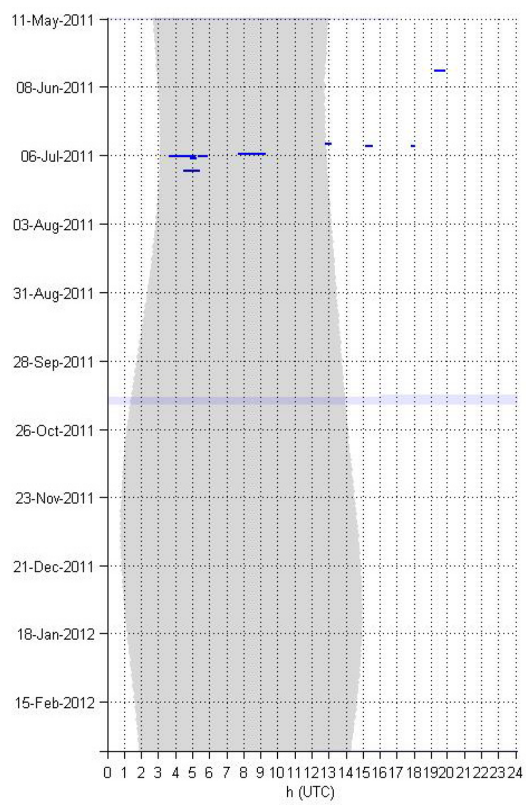
Unidentified Dolphin – Echolocation signals at sites M (left) and H (right).



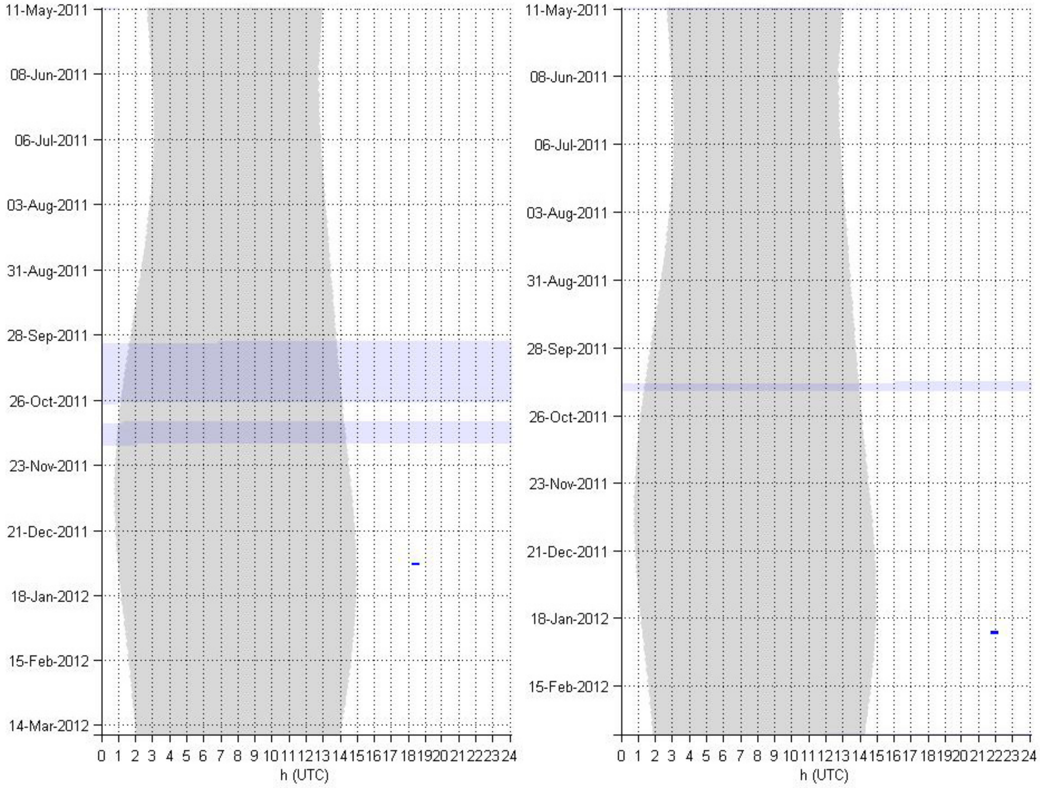
Risso's Dolphin – Echolocation Clicks in one-minute bins at sites M (left) and H (right).



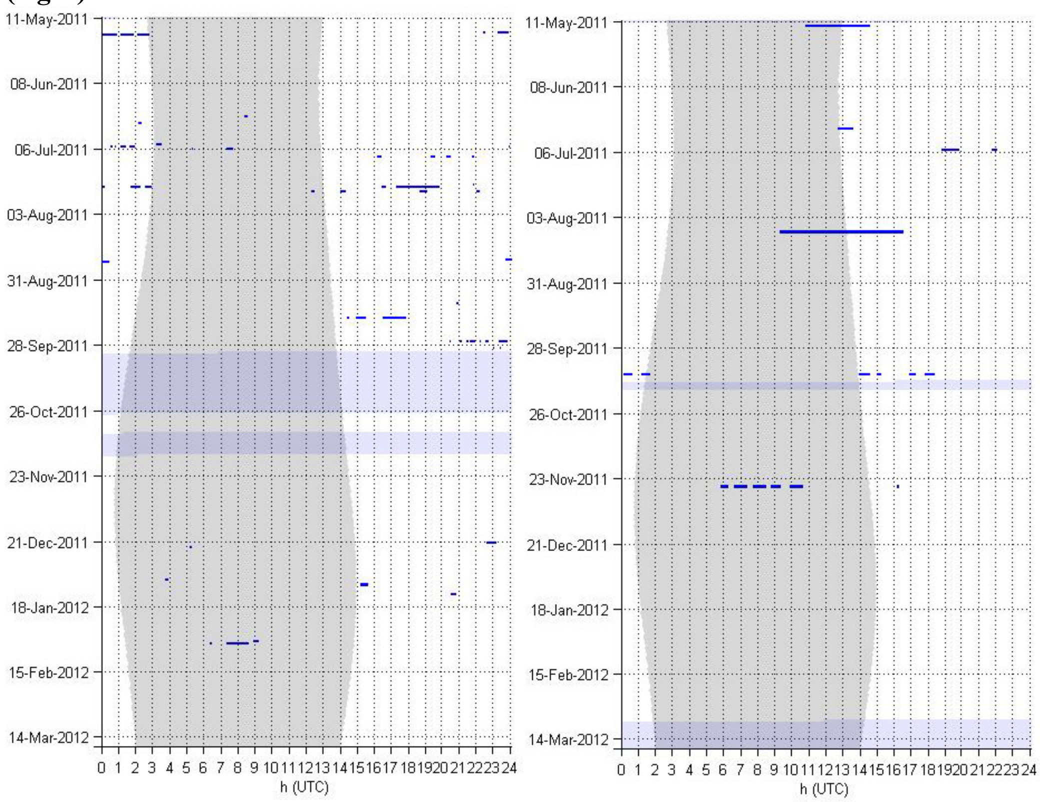
Pacific-White Sided Dolphin – Type A Clicks in one-minute bins at sites M (left) and H (right).



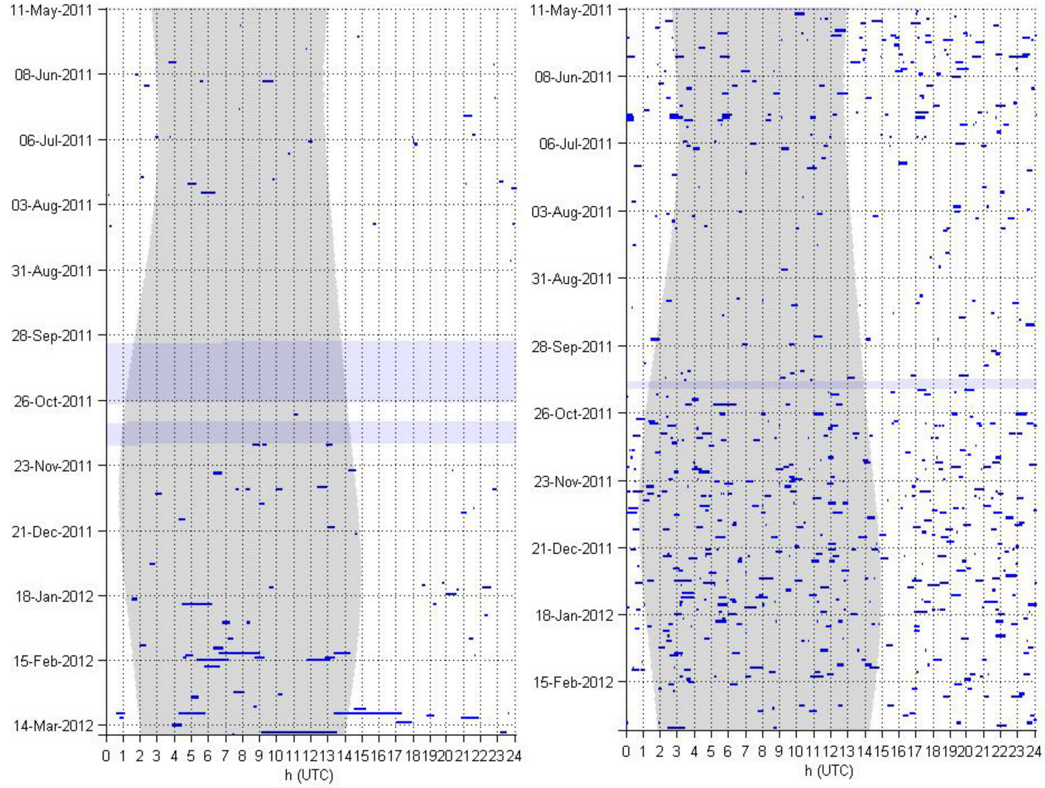
Pacific White-Sided Dolphin – Type B Clicks in one-minute bins at site H only.



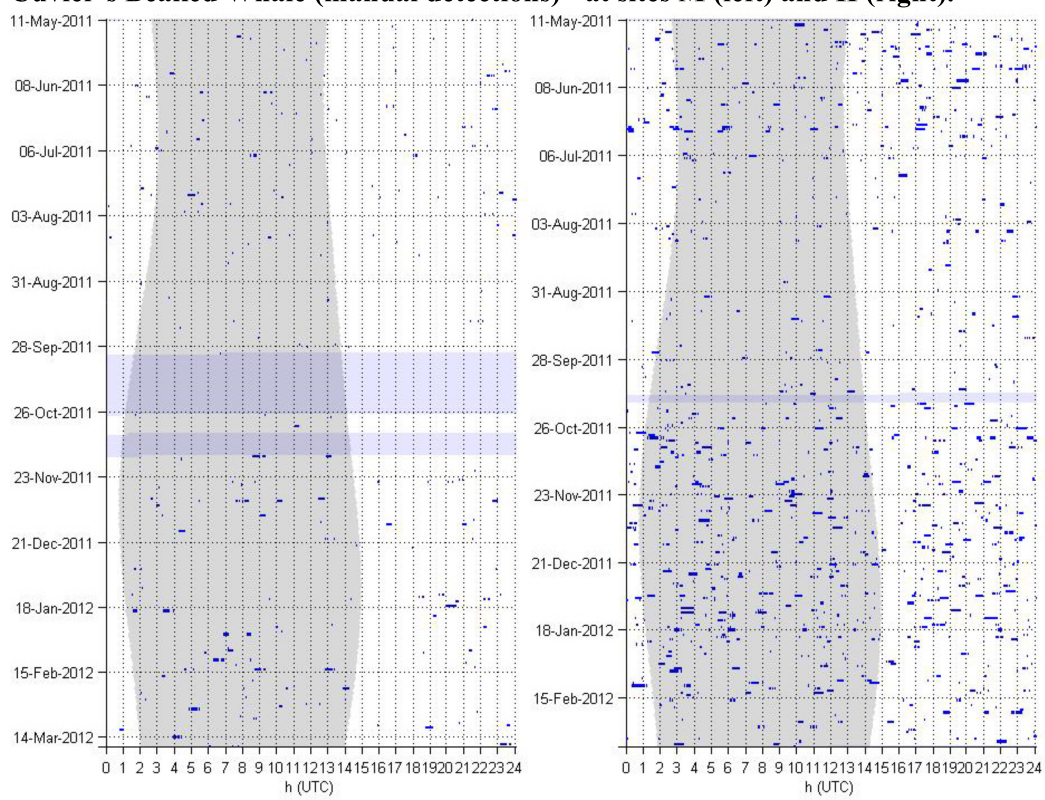
Killer Whale – Clicks, Pulses, Ultrasonic Whistles in one-minute bins, sites M (left) and H (right).



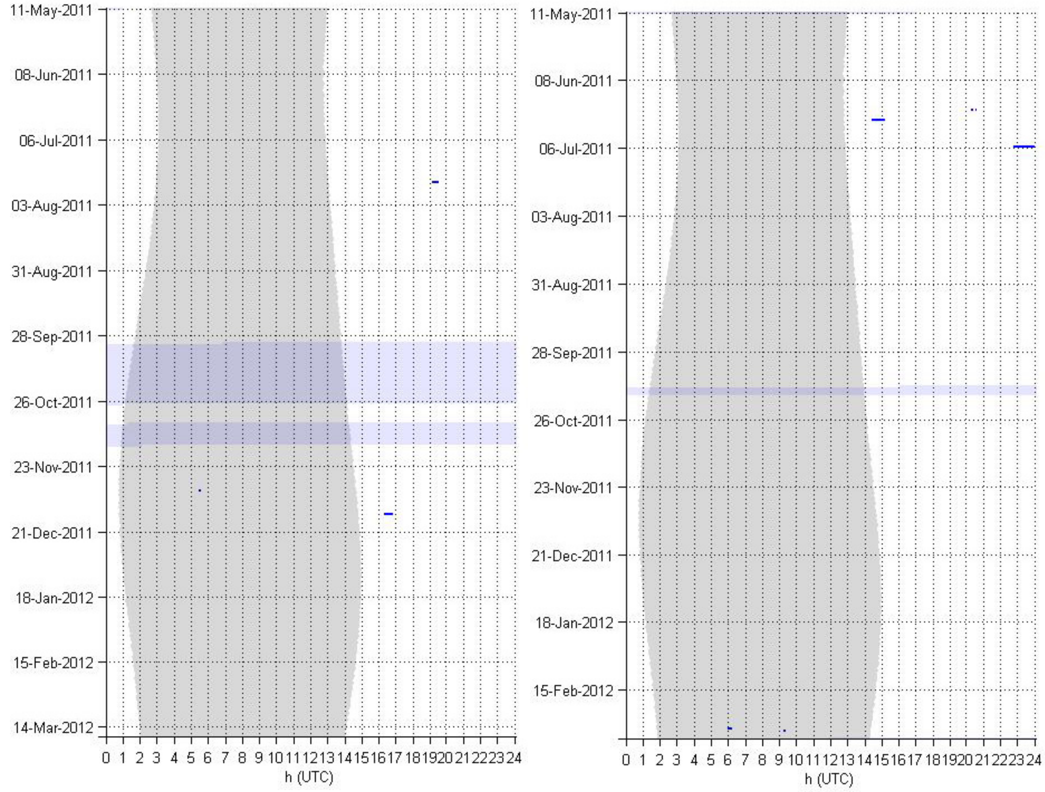
Sperm Whale – Clicks in one-minute bins at sites M (left) and H (right).



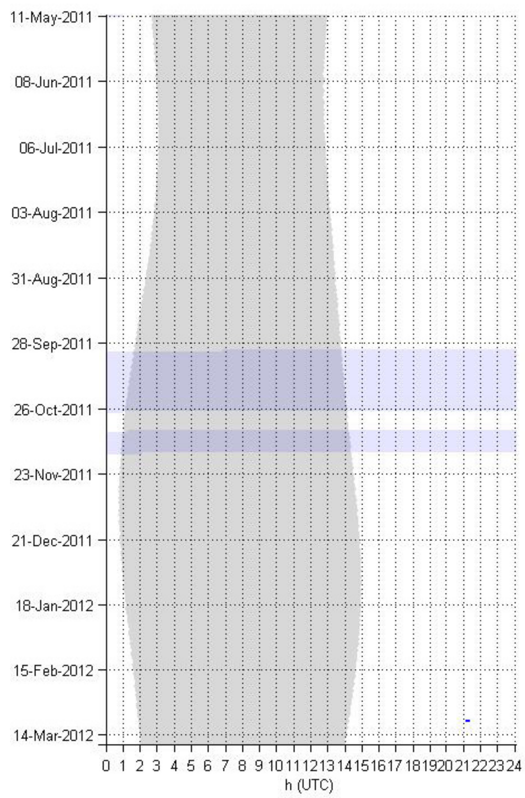
Cuvier’s Beaked Whale (manual detections) - at sites M (left) and H (right).



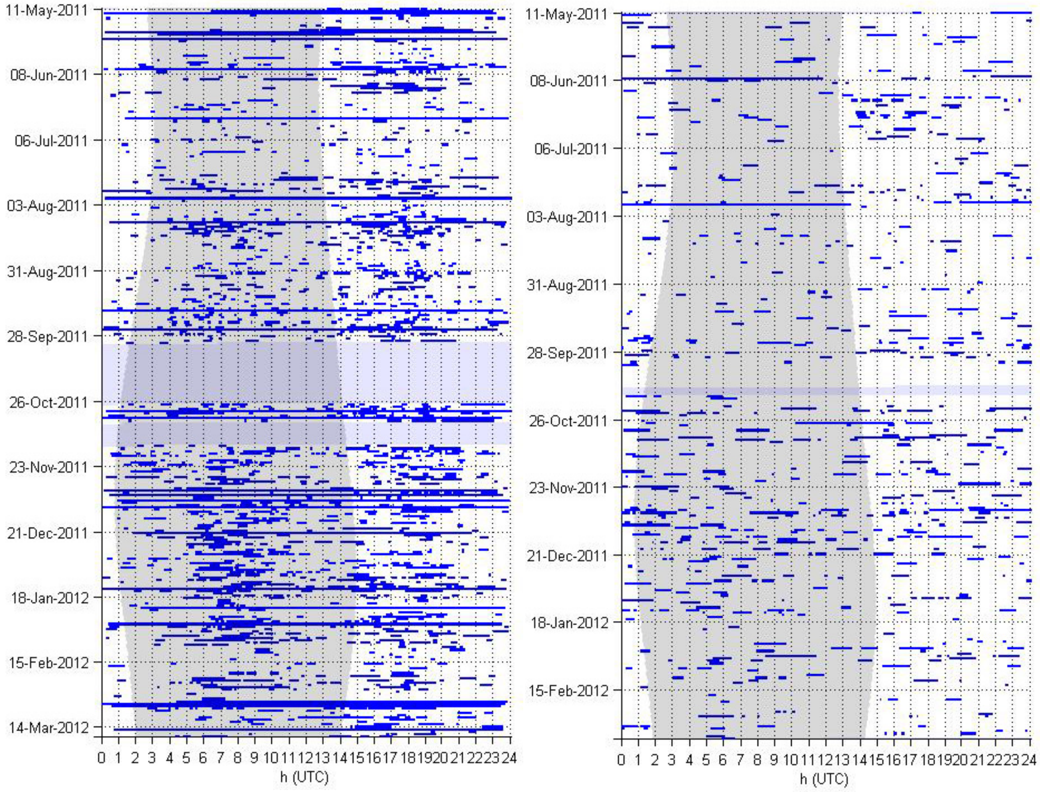
Cuvier’s Beaked Whale (automatic detections) – at sites M (left), and H (right).



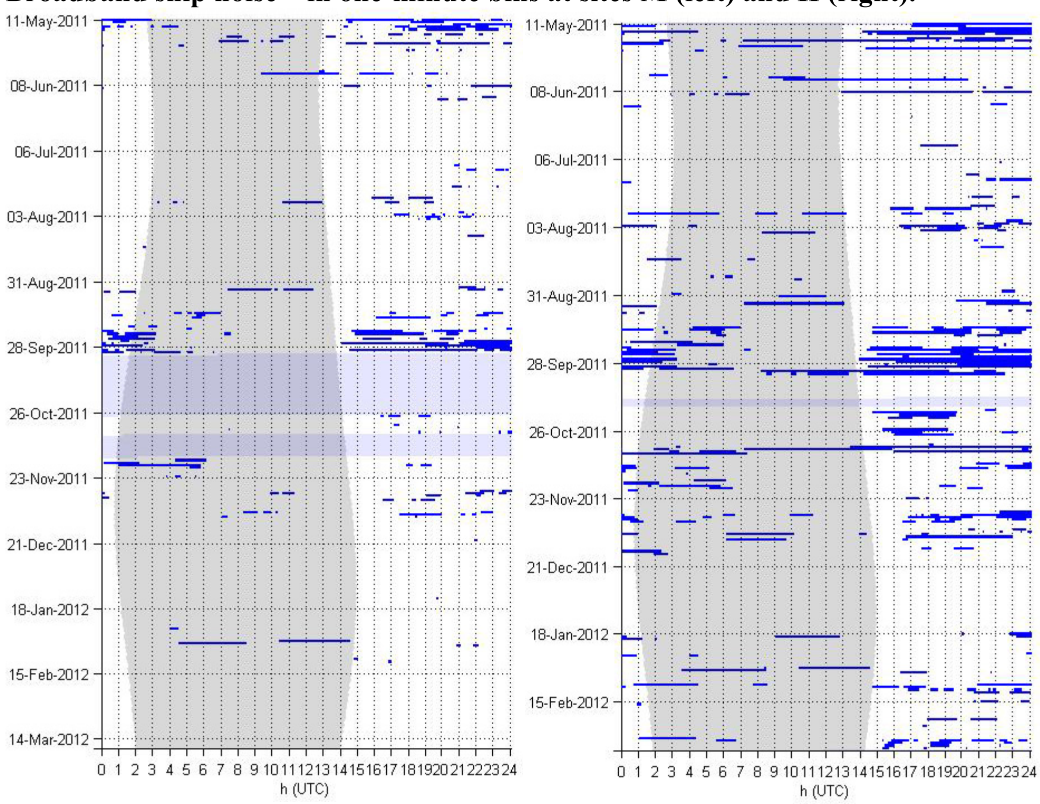
Baird's Beaked Whale – in one-minute bins at sites M (left) and H (right).



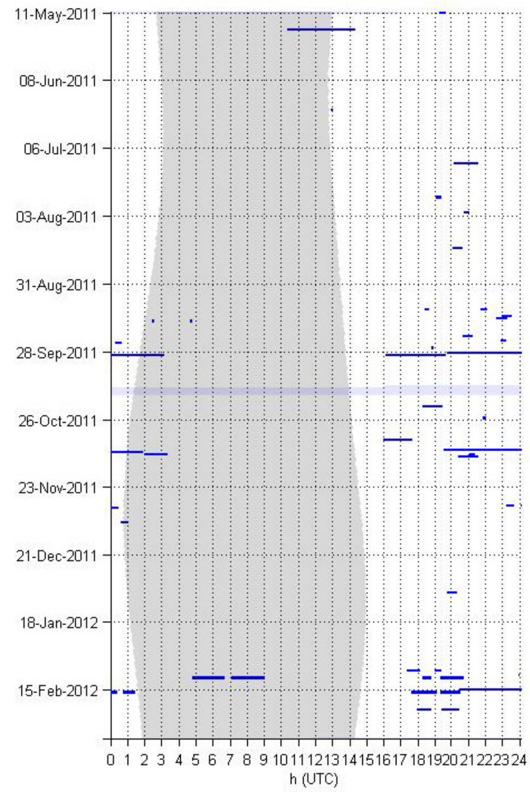
Unidentified Beaked Whale – Frequency-Modulated Pulses at Site M.



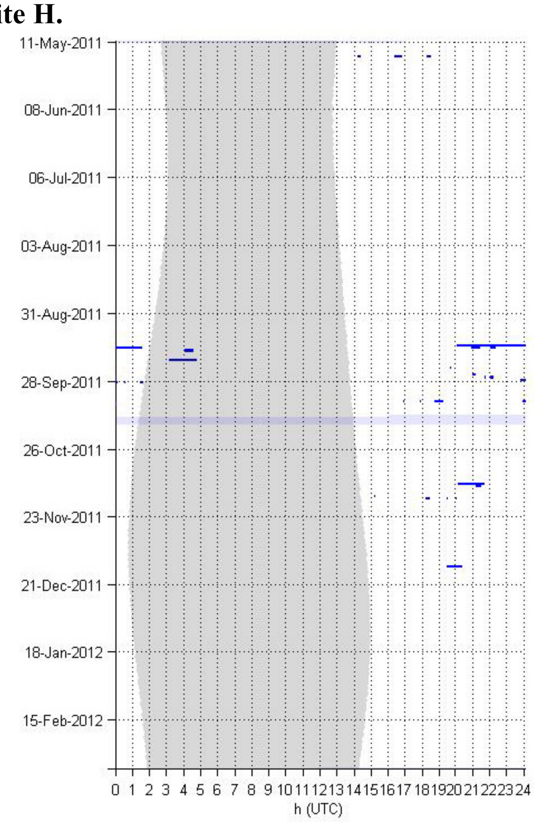
Broadband ship noise – in one-minute bins at sites M (left) and H (right).



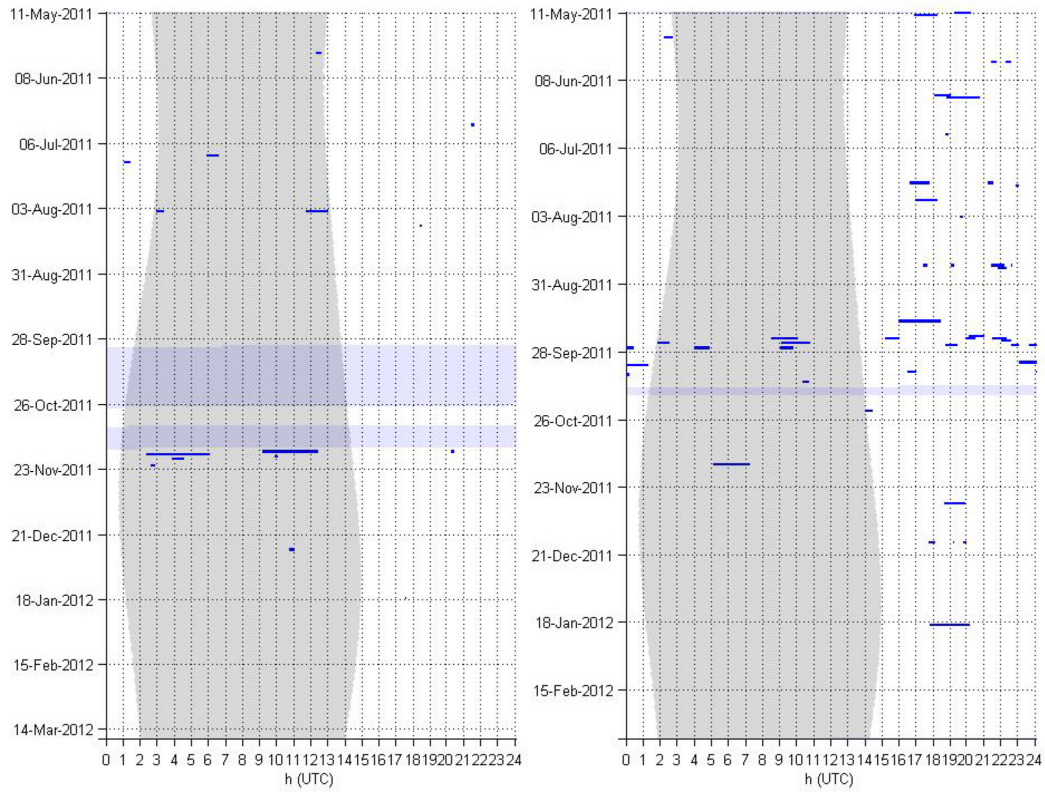
Mid-frequency active sonar – in one-minute bins at sites M (left) and H (right).



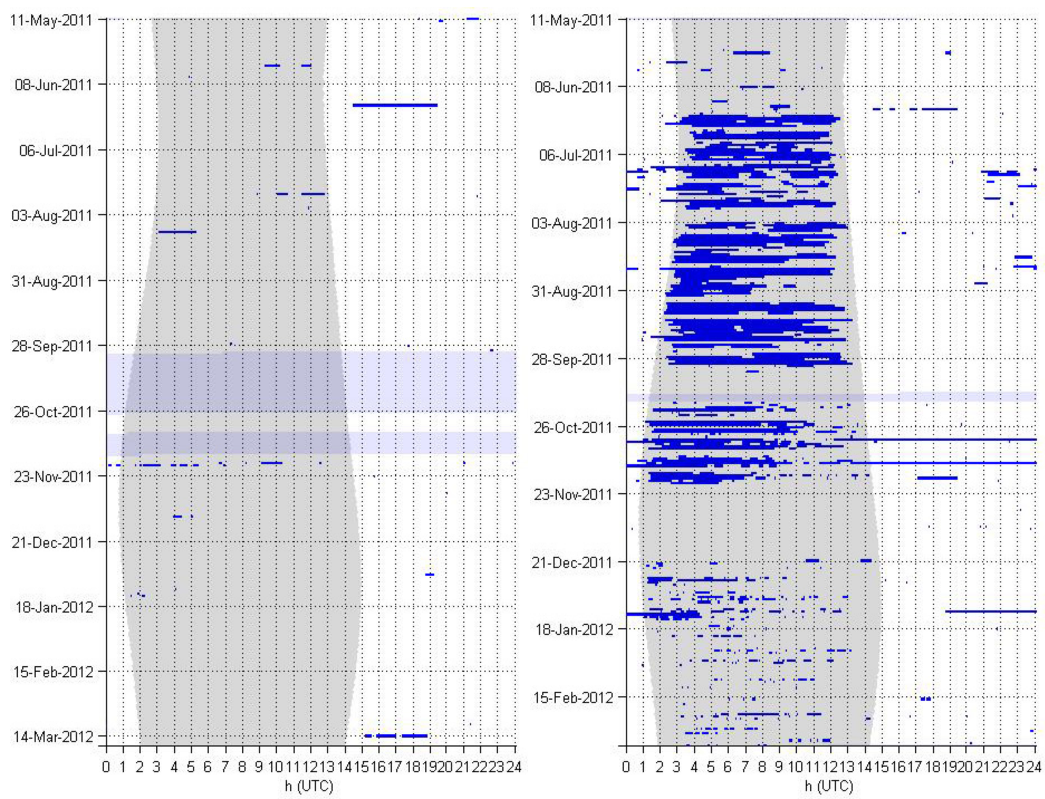
Naval sonar > 5 kHz – in one-minute bins at site H.



Communications system – Presence in one-minute bins at site H.



Echosounder Pings – in one-minute bins at sites M (left) and H (right).



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