Passive Acoustic Monitoring for Marine Mammals in the SOCAL Range Complex during 2012

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MPL TECHNICAL MEMORANDUM # 544

August 18, 2013

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Executive Summary

Passive acoustic monitoring was conducted in the Navy's Southern California Range Complex during March 2012 through December 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 continuous temporal coverage at a site near Santa Barbara Island (site M), at a site west of San Clemente Island (site H), and a site southwest of San Clemente Island (site N).

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.

Six baleen whale species were detected: blue whales, fin whales, Bryde's whales, gray whales, humpback whales, and minke whales. Of the baleen whales, fin whales were the most commonly detected and minke whales were the least commonly detected. In general, site H and N appeared to have more calling baleen whales than site M, with the exception of gray whales, which were only detected at site M. Pinniped barks were also recorded, primarily at site M.

At least 10 species of odontocetes were recorded. 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 dolphin species whose sounds cannot yet be differentiated to species: short-beaked common dolphins, long-beaked common dolphins, and bottlenose dolphins. There was also an additional beaked whale signal type detected that cannot yet be assigned to a species: type BW43.

Ship noise was most common at site N, somewhat less common at site M, and least common at site H.

All three sites had Mid-Frequency Active (MFA) sonar events, typically between 2.5 and 5 kHz, throughout the monitoring period. Site M had the fewest MFA sonar pings recorded, with 321 pings detected, and the lowest received levels, with a median of 123 dB pp re 1 µPa, and maximum received level of 139 dB pp re 1 µPa. Site H had 18,919 MFA sonar pings recorded with a median received level of 125 dB pp re 1 µPa and with some ping received levels above the instrument's maximum of 177 dB pp re 1 µPa. Site N, which had the longest recording length during this monitoring period, had 57,851 sonar pings with a median of 128 dB pp re 1 µPa and with some ping received levels above the instrument's maximum of 176 dB pp re 1 µPa.

MFA sonar > 5kHz, High Frequency Active sonar, and acoustic communication systems, were also detected, though primarily at site N and very infrequently. Echosounder pings were detected at all three sites, but were predominant at site N with a notable peak in the fall. Explosive events were also recorded at all three sites, but were predominant at site H; temporal and spectral parameters, received levels, and nighttime pattern of these explosive events suggest that they may be associated with fishing activity.

Project Background

The Navy's Southern California (SOCAL) Range Complex is located in the California Borderlands and adjacent deep water (). 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 the SOCAL Range Complex with support from the Navy 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 three High-frequency Acoustic Recording Packages (HARPs) that were deployed within the SOCAL Range Complex, one to the west (site H), one to the northwest (site M), and one to the southwest (site N) of San Clemente Island () during the time period March 2012 – December 2012.

Previous acoustic monitoring for the SOCAL area (Hildebrand *et al.* 2009b, Hildebrand *et al.* 2010b, Hildebrand *et al.* 2010a, Hildebrand *et al.* 2011) have analyzed data primarily from site M and site N.

A hardware (hydrophone) problem at site N during the 2011-2012 recording period necessitated a shift in data analysis from site N to site H (Hildebrand *et al.* 2012); a similar problem at site M during the period August 2012 – December 2012 necessitated a shift in data analysis from site M to site H for this report. Table 1 lists the time periods for occupation of each of these sites.

Table 1. SOCAL 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, and Hildebrand et al. 2011. Results of acoustic monitoring at sites M and H from May 2011 through March 2012 are described in Hildebrand et al. 2012.

Deployment Name	**Site H Monitoring Period**	**# Hours**	**Site M Monitoring Period**	**# Hours**	**Site N Monitoring Period**	**# Hours**
SOCAL 31	1/13/09 – 3/08/09	1320	1/13/09 – 3/08/09	1320	1/14/09 – 3/09/09	1296
SOCAL 32	3/14/09 – 5/07/09	1320	3/11/09 – 5/04/09	1296	3/14/09 – 5/07/09	1320
SOCAL 33	5/19/09 – 6/13/09	600	5/17/09 – 7/08/09	1248	5/19/09 – 7/12/09	1296
SOCAL 34	7/23/09 – 9/15/09	1296	7/27/09 – 9/16/09	1224	7/22/09 – 9/15/09	1320
SOCAL 35	9/25/09 – 11/18/09	1320	9/25/09 – 11/17/09	1272	9/26/09 – 11/19/09	1296
SOCAL 36	12/6/09 – 1/29/10	1296	12/5/09 – 1/24/10	1200	12/6/09 – 1/26/10	1224
SOCAL 37	1/30/10 – 3/22/10	1248	1/30/10 – 3/25/10	1296	1/31/10 – 3/26/10	1296
SOCAL 38	4/10/10 – 7/22/10	2472	4/10/10 – 7/12/10	2232	4/11/10 – 7/18/10	2352
SOCAL 40	7/23/10 – 11/8/10	2592	7/22/10 – 11/7/10	2592	7/23/10 – 11/8/10	2592
SOCAL 41	12/6/10 – 4/17/11	3192	12/5/10 – 4/24/11	3360	12/7/10 – 4/09/11	2952
SOCAL 44	5/11/11 – 10/12/11	2952	5/11/11 – 10/2/11	2712	5/12/10 – 9/23/11	3216
SOCAL 45	10/16/11 – 3/5/12	3024	10/27/11 – 3/18/12	3432	10/16/11 – 2/13/12	2904
SOCAL 46	3/25/12 – 7/21/12	2856	**3/24/12 – 7/22/12**	**2904**	**3/25/12 – 8/5/12**	**3216**
SOCAL 47	**8/10/12 – 12/20/12**	**3192**	8/10/12 –12/19/12	3168	**8/10/12 – 12/6/12**	**2856**

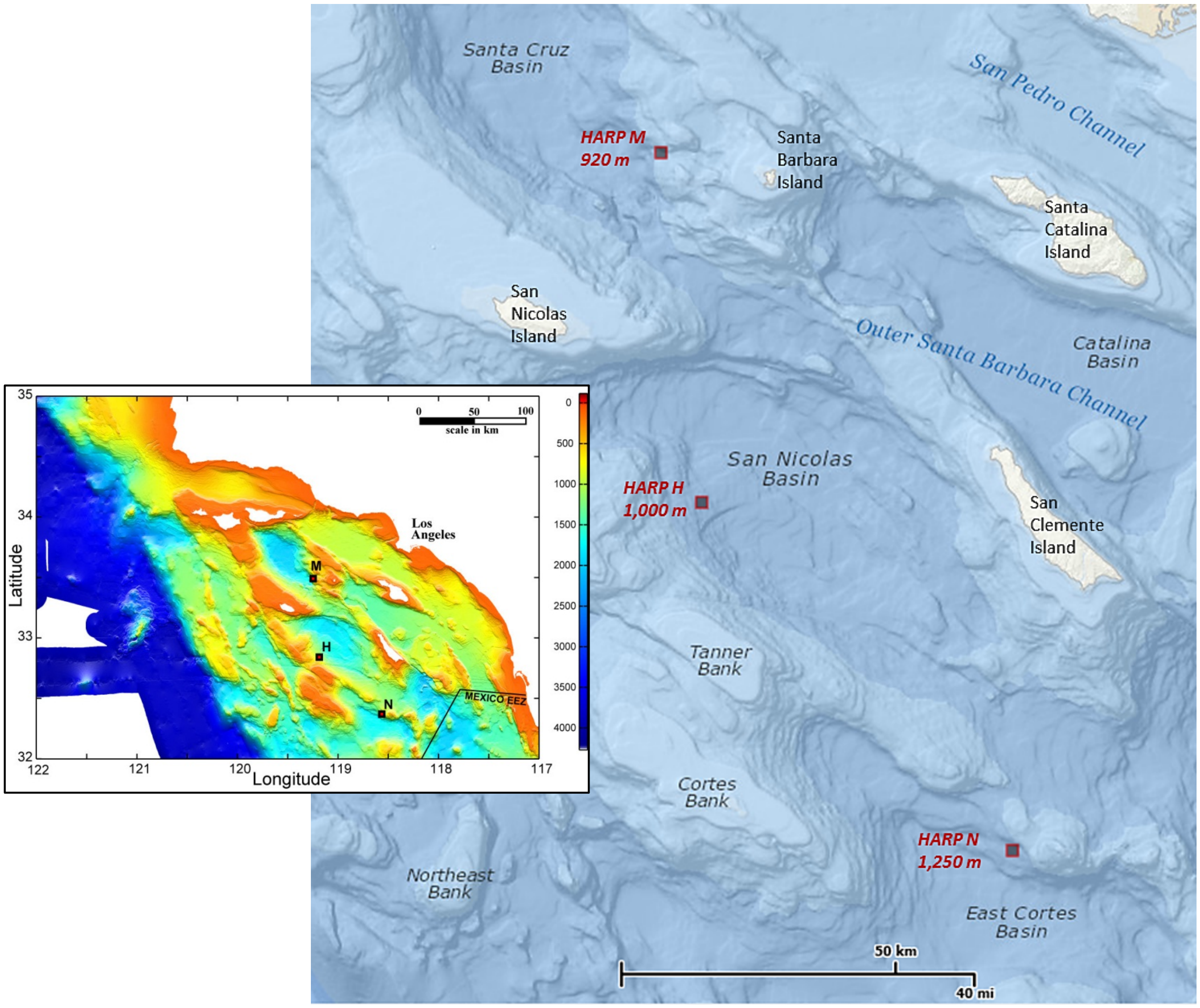


Figure 1. **Locations of High-frequency Acoustic Recording Packages at sites M, H, and N in the Southern California Range Complex area. (Left panel) Color is bathymetric depth with scale bar at right in meters depth.**

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 Range Complex.

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 SOCAL using autonomous 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 N collected between March 2012 and August 2012, and sites H and N collected between August 2012 and December

Data Analysis

To assess the quality of the acoustic data, frequency spectra were calculated for all data 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, the waveform or spectrogram at the time of interest was examined 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). Cuvier's beaked whale and BW43 FM pulses were both manually and automatically detected and compared (see detailed description below).

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, Bryde's, and gray whale sounds were classified as low frequency; humpback whale, minke whale, pinniped, shipping, explosions, and mid-frequency active sonar sounds were classified as mid-frequency; while the remaining toothed whale and sonar sounds were considered high frequency. We describe the calls and procedures separately for each frequency band.

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 M3 calls were the focus of the low frequency analysis.

For 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. Type B calls (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 (15 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 long and one 5.5 s long, for a total 10 s duration. The frequency ranged over those time periods from 47.42 to 46.83; 46.83 to 46.34; 46.34 to 46.03; and 46.03 to 45.41 Hz. The kernel bandwidth was 2 Hz.

The performance of the detector was tested against a groundtruth of blue whale B calls picked manually from ten-day periods of low, medium, and high calling rates. Automatic detections during winter months, when blue whales are not common in this area, were manually reviewed and false detections from this period were removed from further analysis. When compared to the groundtruth, we found that average hourly false alarm and missed detection rates were 4.3% and 4.6%, respectively. Detections were binned into 1-hour bins for consistent reporting.

Blue whale D calls are down-swept in frequency (100-30 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).

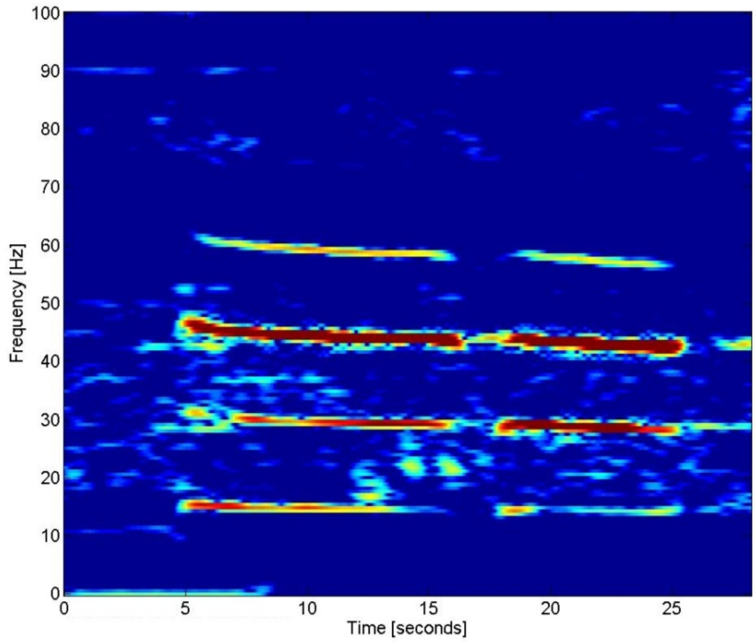


Figure 2. Blue whale B call showing harmonic tones.

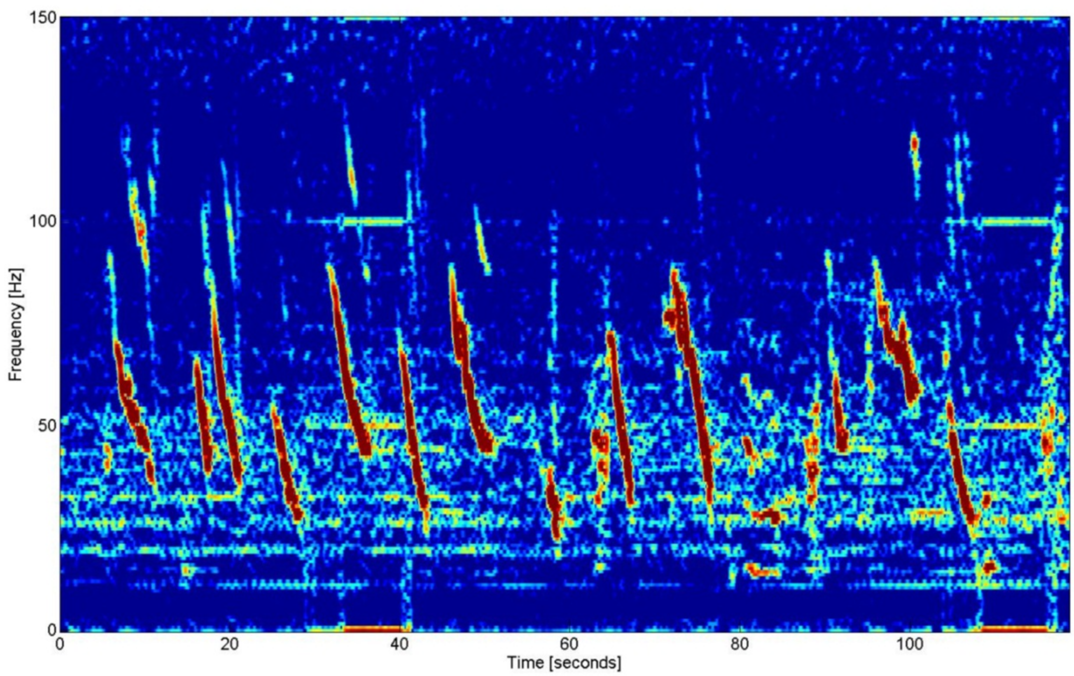


Figure 3. Blue whale D calls, downswept from 100 to 30 Hz

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.

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 1.6% and 2.0%, respectively, but these rates varied by site.

Detections were binned into 1-hour bins for consistent reporting.

Fin whale 40 Hz calls, short duration (~ 1 sec) downswept pulses from 75 – 40 Hz, were also detected in the SOCAL data (Figure 5). 40 Hz calls were attributed to fin whales by Watkins (1981); seasonality of the 40 Hz call type suggests a possible association with foraging behavior (Širović *et al.* 2013). Manual scanning of the LTSA and subsequent verification from a spectrogram were the primary means for 40 Hz call detection.

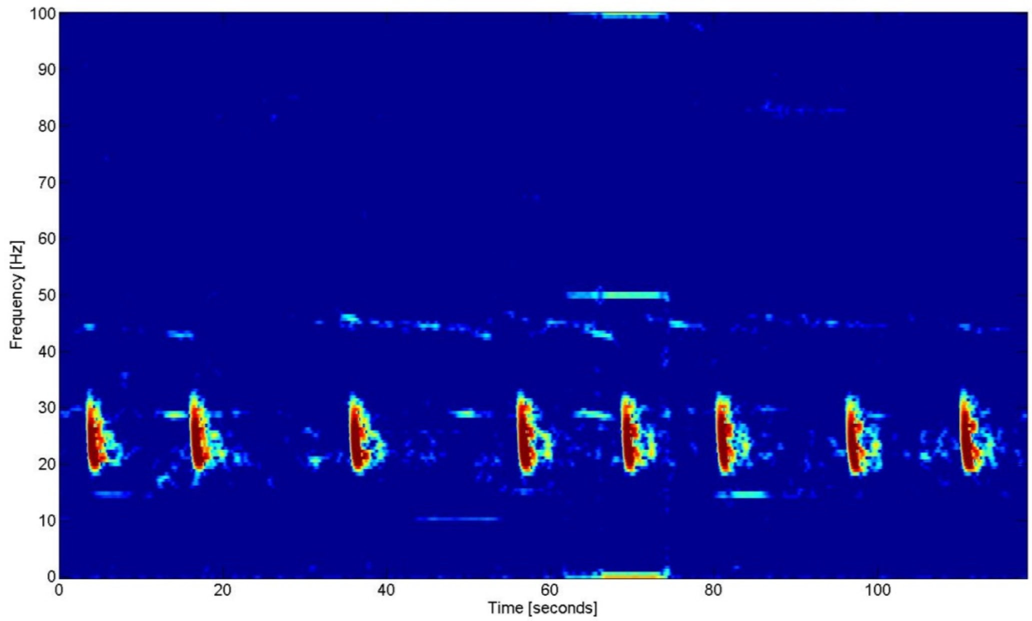


Figure 4. Fin whale 20 Hz pulsed call, created in regular pattern or song.

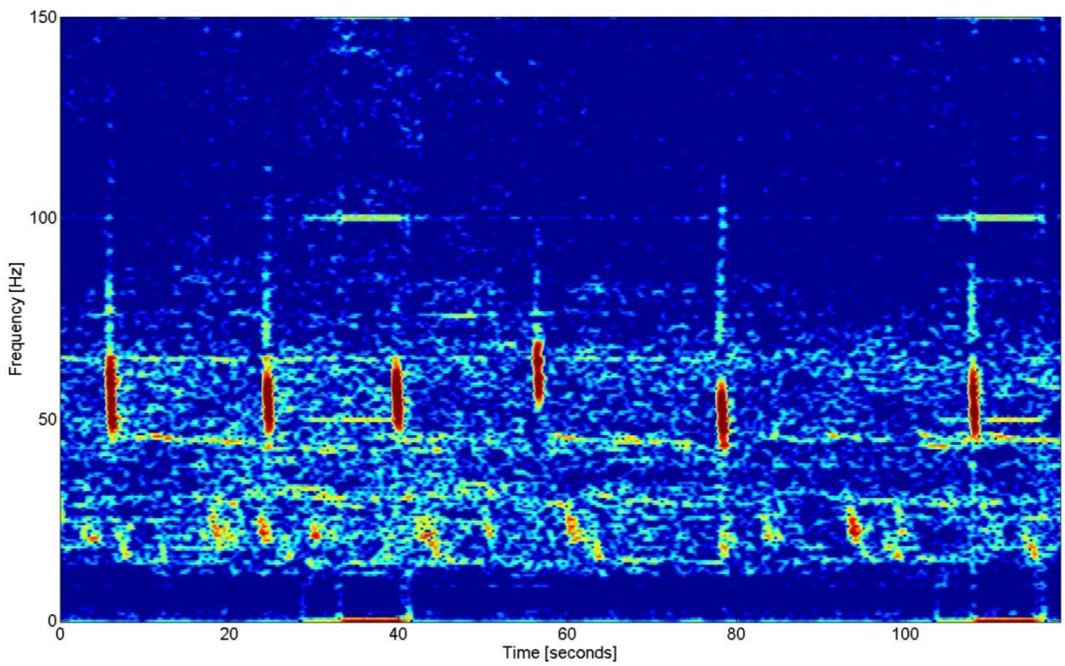


Figure 5. **Fin whale 40 Hz pulsed calls.**

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 and visual sightings over the last decade suggest 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, and 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 so that, occasionally, it is evident that multiple callers are present. Another Bryde's whale call, less commonly observed in the SOCAL region, is the Be2 call type; it is a short, 1-2 s, burst with peak acoustic energy around 40 Hz(Figure 7).

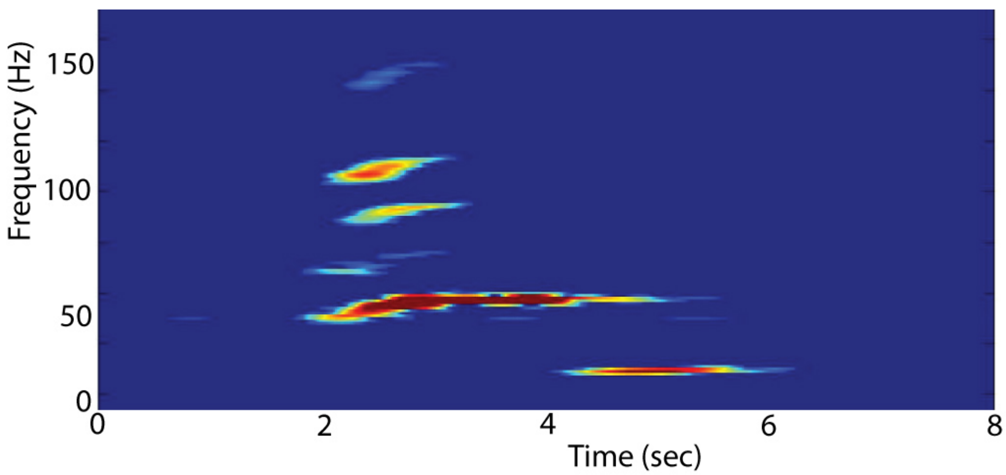


Figure 6. Bryde’s whale Be4 call.

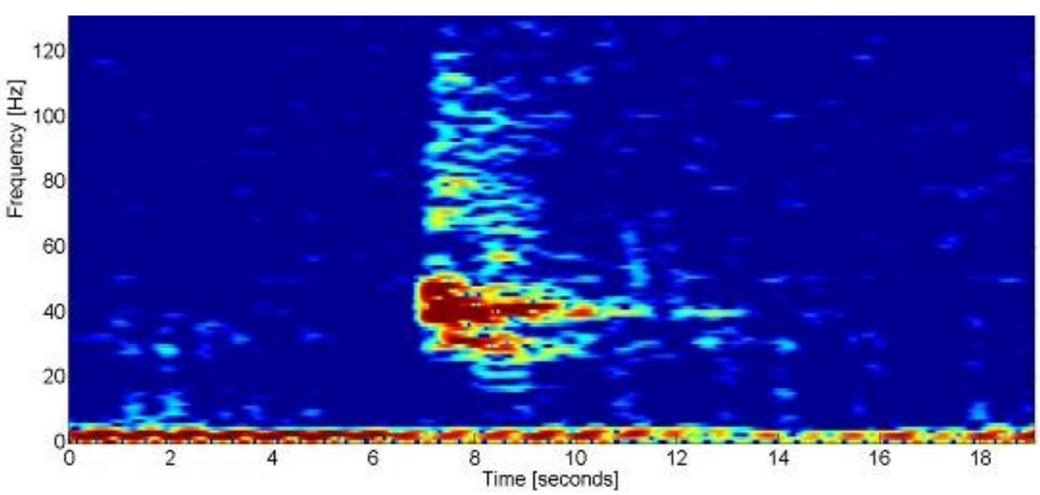


Figure 7. Bryde’s whale Be2 call.

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 recorded and 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 the most commonly detected in the SOCAL region (Figure 8).

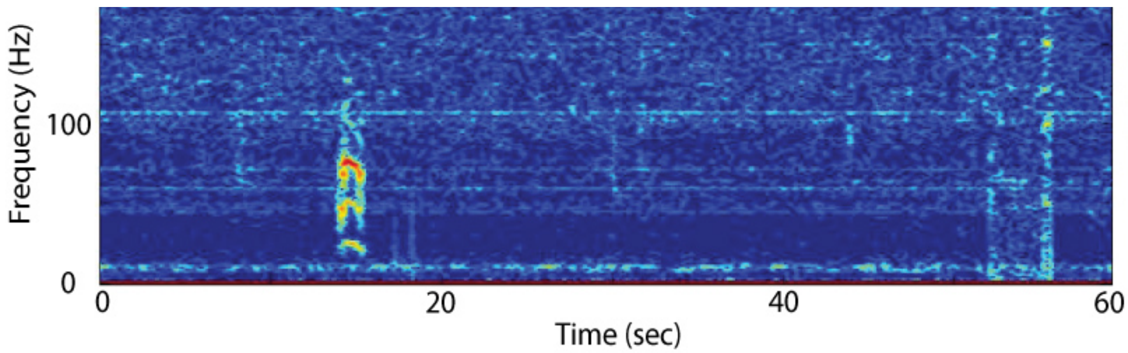


Figure 8. Gray whale M3 call.

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 were 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.

Mid-frequency effort was expanded to find both biological and anthropogenic 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 2.

Table 2. 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.

For this report we detected humpback calls using a computer algorithm based on the generalized power law detector (Helble *et al.* 2012); the accuracy of the detected signals were verified by a trained analyst. Figure 9 shows an example of the output of the detector, with call spectrograms displayed sequentially.

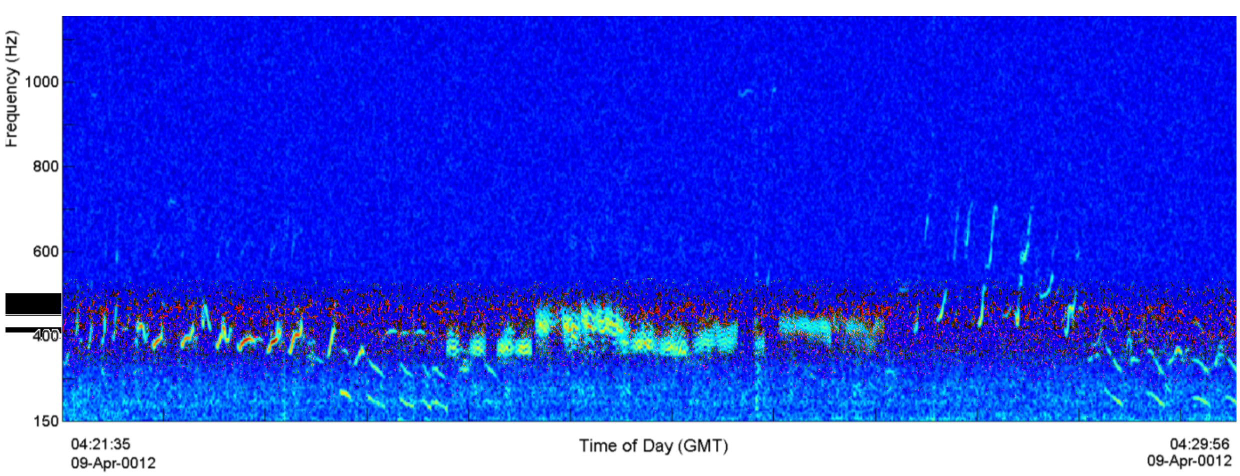


Figure 9. Humpback whale call spectrograms consolidated for manual verification by analyst.

Minke Whale

Minke whale “boings” consist of 2 parts, beginning with a burst followed by a long buzz, with the dominant energy band just below 1400 Hz (Figure 10). 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).

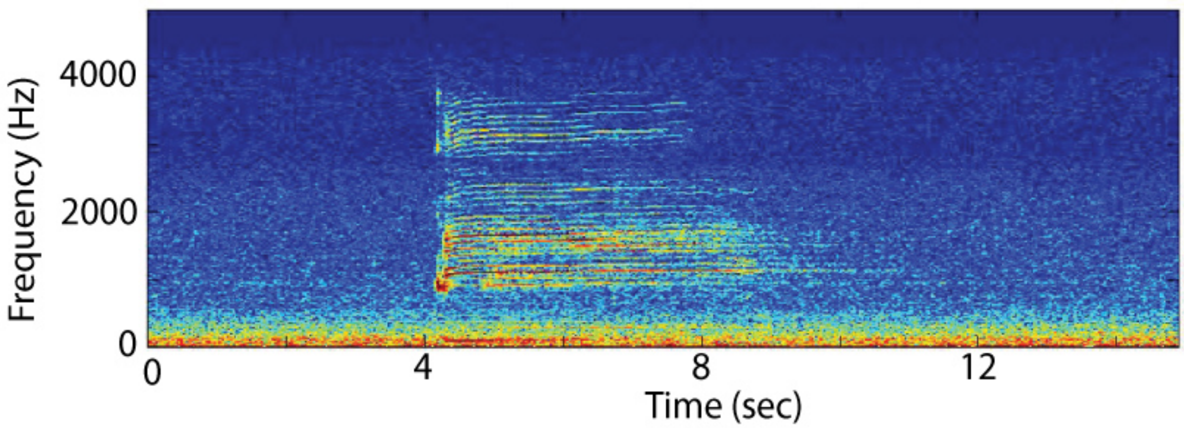


Figure 10. Minke whale boing spectrogram.

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 11).

Pinniped vocalization bouts can continue for up to several hours.

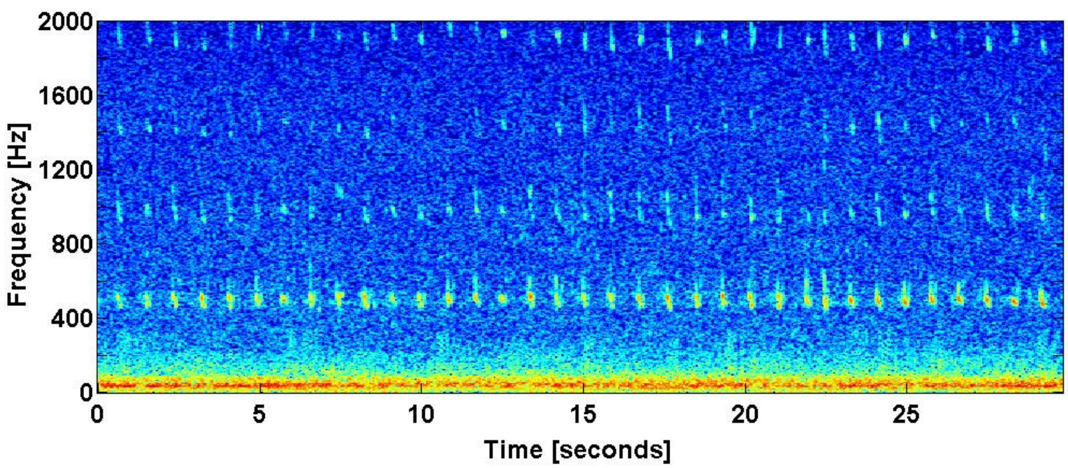


Figure 11. Series of pinniped barks, probably California sea lions.

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 12).

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). These detections are classified as unidentified dolphins in this report.

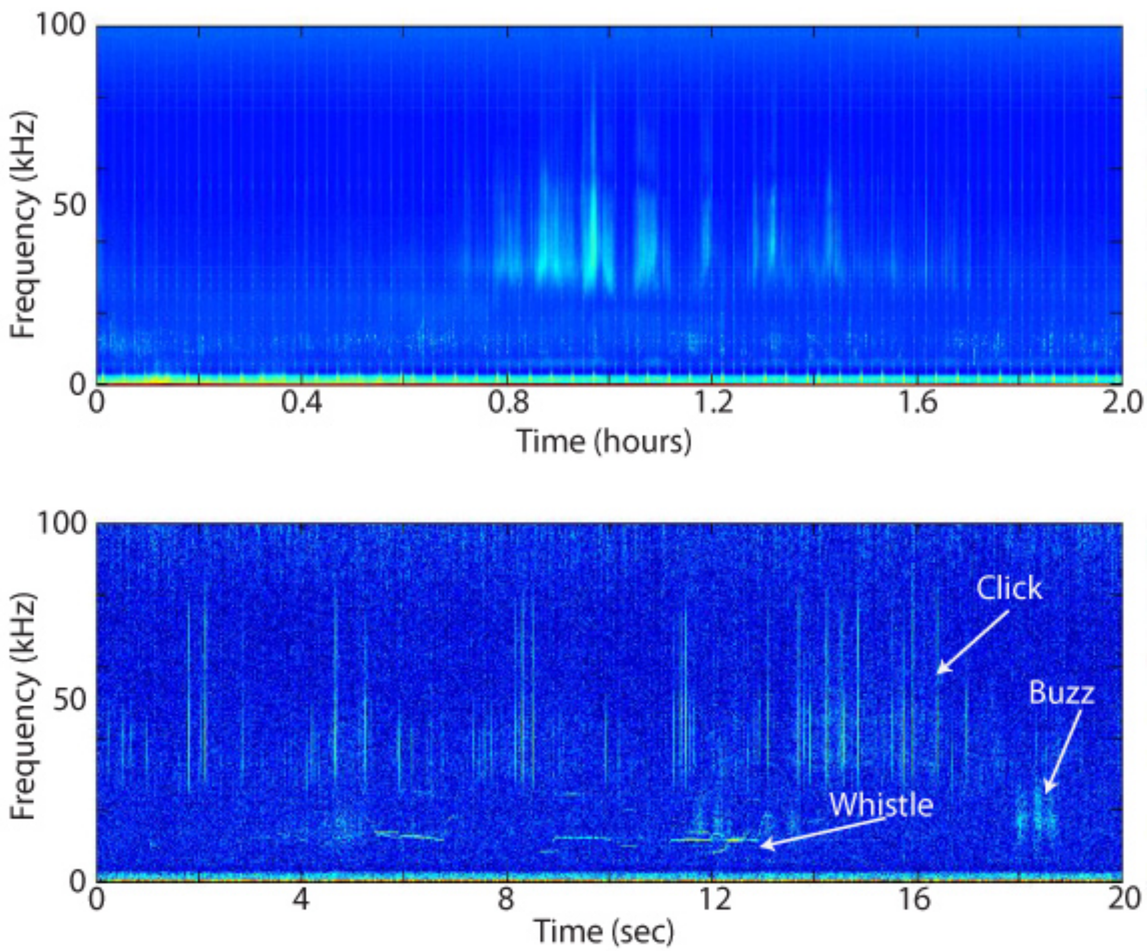


Figure 12. LTSA (above) and spectrogram (below) of unidentified dolphin (either common dolphin or bottlenose dolphin).

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 13).

Risso's dolphin echolocation clicks in the SOCAL area have energy peaks at 22, 26, 30, and 39 kHz (Soldevilla et al. 2008).

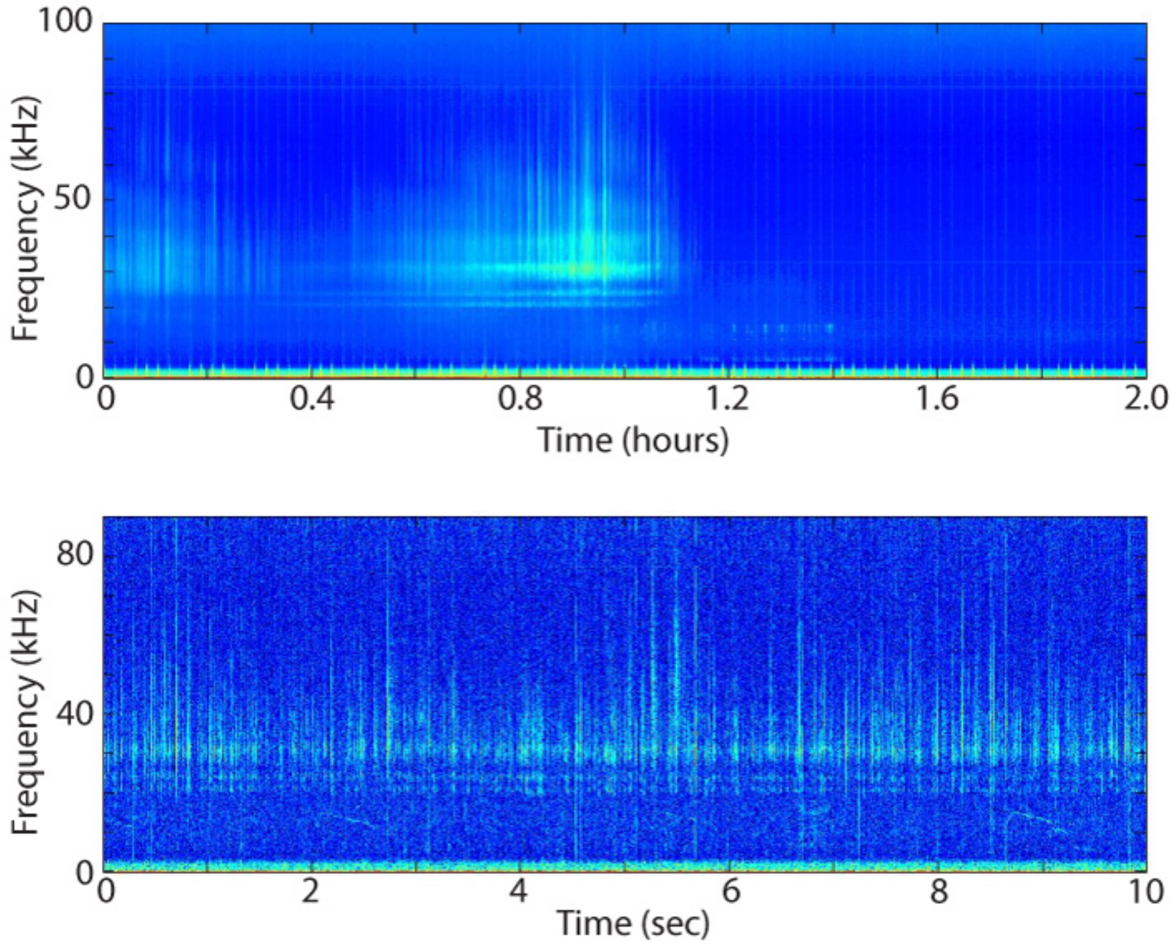


Figure 13. Risso's dolphin click bout in LTSA (above) and spectrogram (below). A distinctive banding pattern is noticeable.

Pacific White-Sided Dolphin

Pacific white-sided dolphin echolocation clicks also can be identified to species by their distinctive banding patterns (Figure 14 and Figure 15). Pacific white-sided dolphin echolocation clicks have energy peaks at 22, 27, 33, and 37 kHz.

Soldevilla *et al.* (2011) characterize 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.

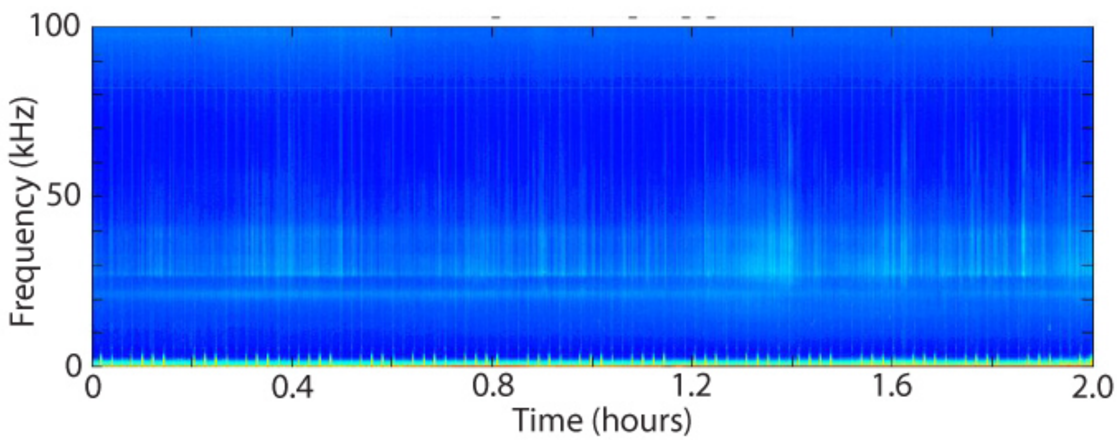


Figure 14 Pacific white-sided dolphin type A echolocation clicks in LTSA.

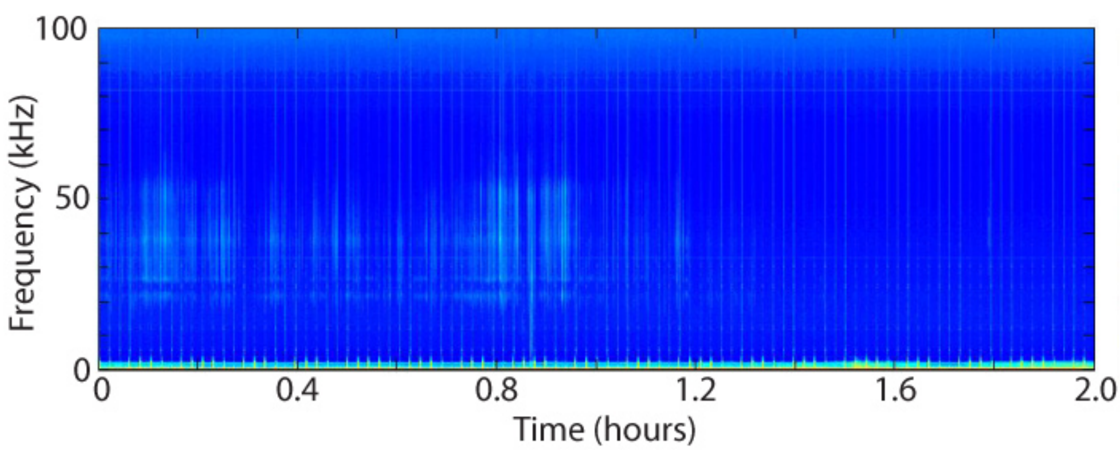


Figure 15 Pacific white-sided dolphin type B echolocation clicks in LTSA.

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 signals 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 alone 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 additional presence of pulsed calls (Figure 16) and/or the HFM signals (Figure 17) for killer whale species identification.

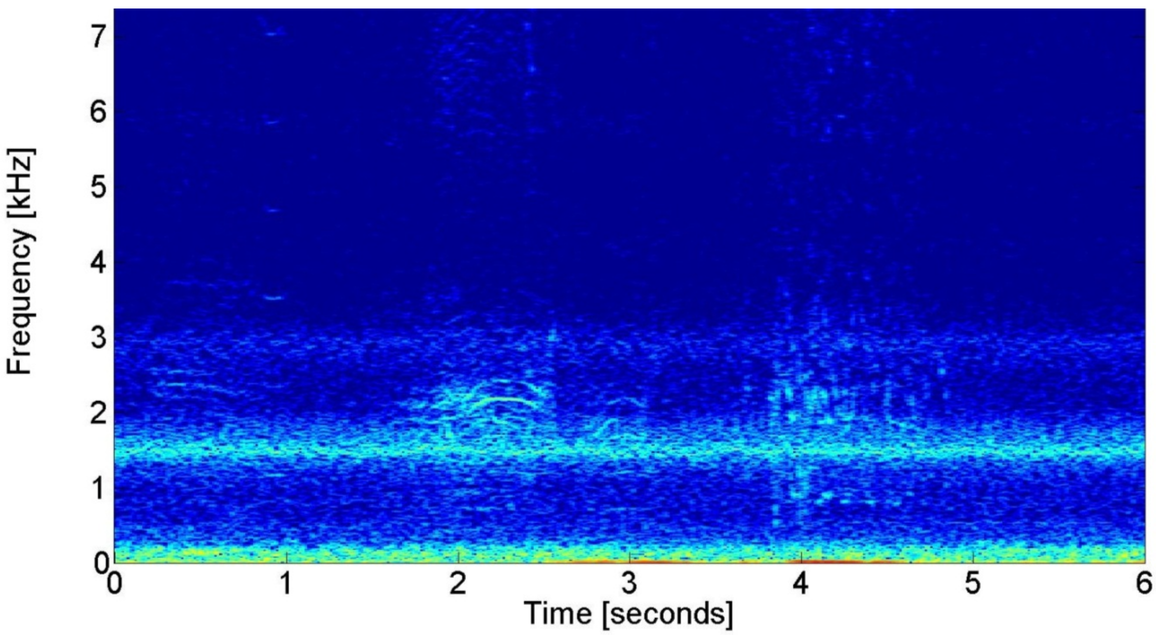


Figure 16. Killer whale pulsed calls in spectrogram.

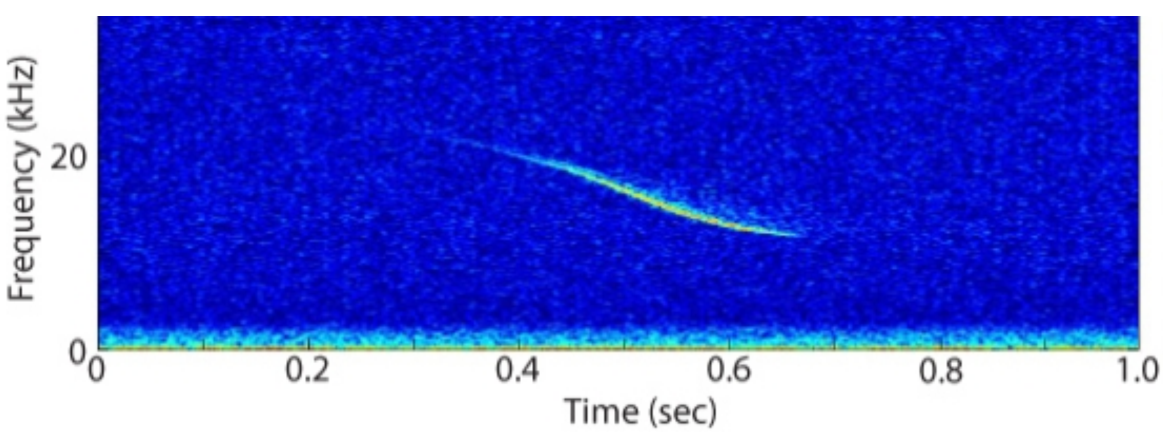


Figure 17. Killer whale high frequency modulated (HFM) signal in spectrogram.

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 18).

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).

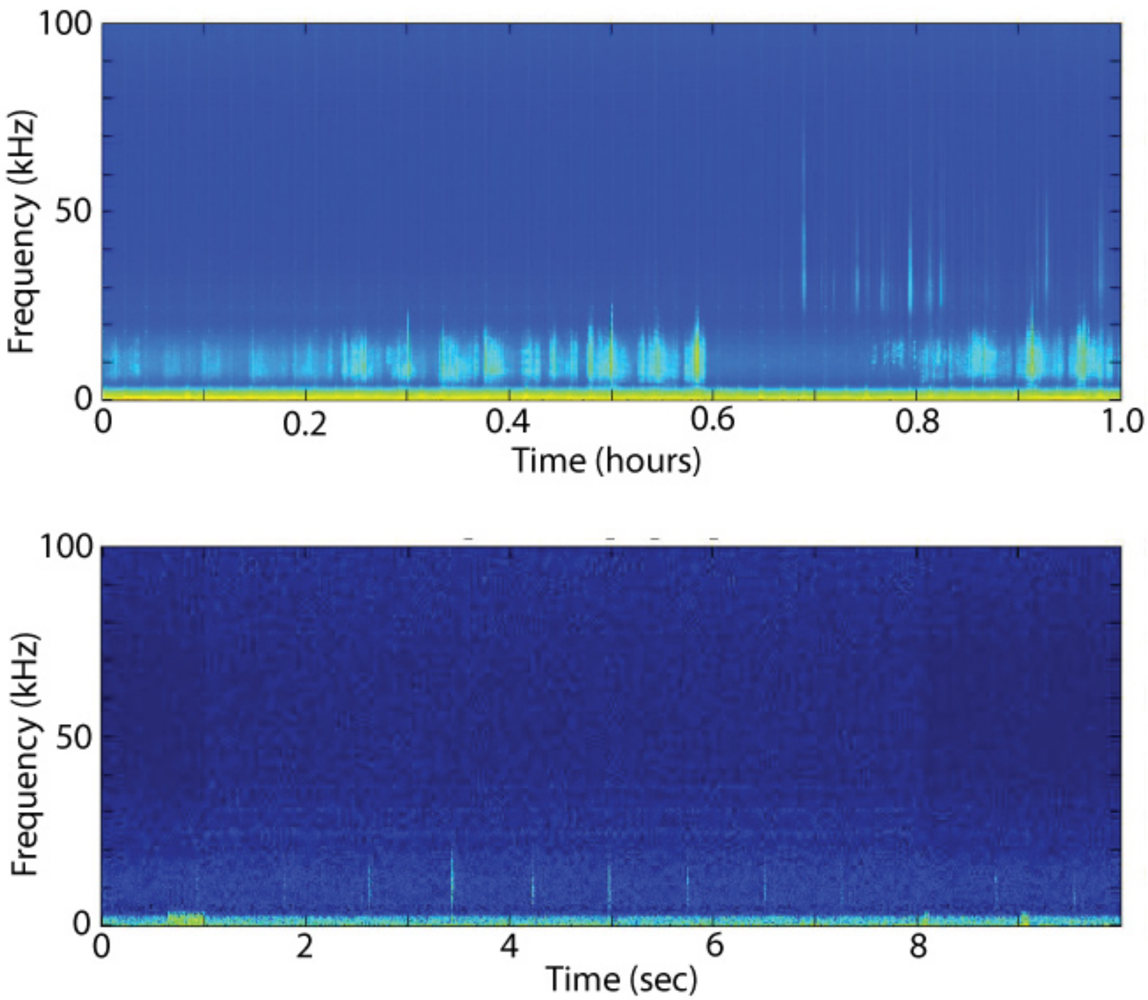


Figure 18. Echolocation clicks of sperm whale (above) LTSA and (below) spectrogram. Note regular click interval of about 0.8 sec.

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' (*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* or *M. ginkgodens hotaula* (Dalebout *et al.* 2007, Dalebout *et al.* 2012), which is likely the species to have been 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.* 2013a, Baumann-Pickering *et al.* in press). These signals are frequency-modulated (FM) upsweep pulses, which appear to be species specific and distinguishable by their spectral and temporal features (Figure 19).

Cuvier's beaked whale is the most common beaked whale in the Southern California Bight. Cuvier's beaked whale echolocation signals are well differentiated from other species' acoustic signals. These signals are polycyclic, with a characteristic FM upsweep, peak frequency around 40 kHz (Figure 19) 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 signals are easily distinguished from other species' acoustic signals and demonstrate the typical beaked whale polycyclic, FM upsweep (Baumann-Pickering *et al.* 2013b). These FM pulses are identifiable due to their lower frequency than other beaked whale pulse types. Spectral peaks are notable around 15, 30 and 50 kHz (Figure 19).

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.* 2013b).

The BW43 FM pulse has yet to be linked with a specific species. These FM pulses are distinguishable from other species' signals with a peak frequency around 43 kHz (Figure 19) and uniform inter-pulse interval around 0.2s.

Cuvier's beaked whale and BW43 FM pulses were detected with an automated method. After all echolocation signals were identified with a Teager Kaiser energy detector (Soldevilla *et al.* 2008, Roch *et al.* 2011), an expert system discriminated between delphinid clicks and beaked whale FM pulses. A decision about presence or absence of beaked whale signals was based on detections within a 75 second segment. Only segments with more than 7 detections were used in further analysis. All echolocation signals with a peak and center frequency below 32 and 25 kHz, respectively, a duration less than 355 μs, and a sweep rate of less than 23 kHz/ms were deleted. If more than 13% of all initially detected echolocation signals remained after applying these criteria, the segment was classified to have beaked whale FM pulses. This method would detect Blainville's, Cuvier's, Deraniyagala's beaked whale, BW40, and BW43 FM pulse types. A third classification step, based on computer assisted manual decisions by a trained analyst, labeled the automatically detected segments to pulse type level and rejected false detections (Baumann-Pickering *et al.* in press). The rate of missed segments was approximately 5%, varying slightly between deployments.

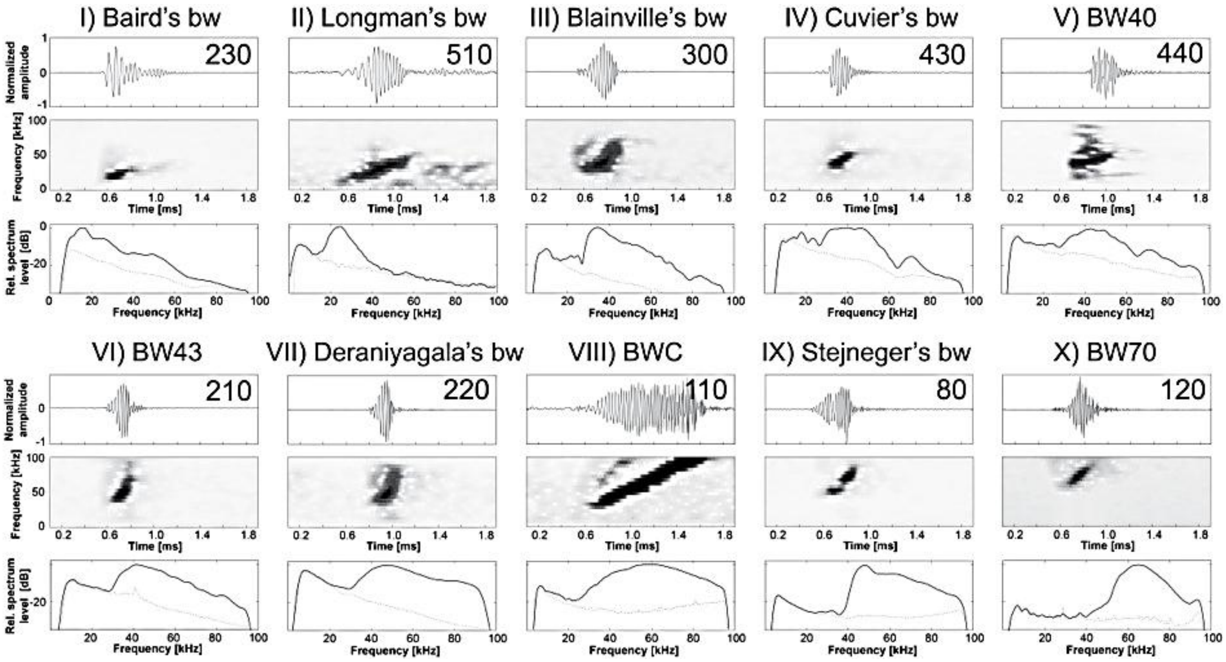


Figure 19. Beaked whale frequency-modulated (FM) upsweep pulses from known (I-IV, VII, IX) and unknown species (V, VI, VIII, X). Each FM pulse type is shown with an example pulse time series (top plot for each species) and spectrogram (middle plot), as well as a mean spectra (bottom plot, solid line) and mean noise (dotted line). Inter-pulse interval (IPI) is specified in ms (above, upper left).

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 20). Noise can extend to well above 10 kHz, though it typically falls off above a few kHz.

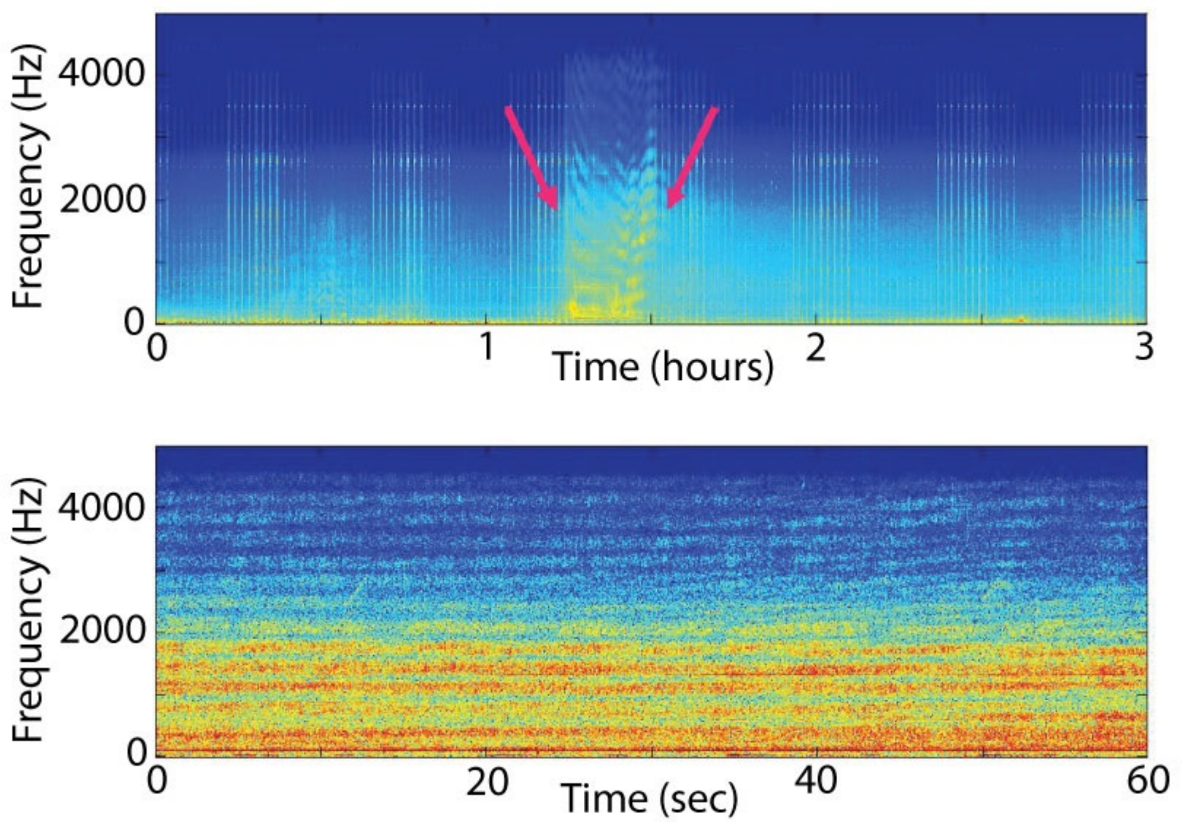


Figure 20. Broadband ship noise in the LTSA (above) and spectrogram (below).

Naval Sonar

There are multiple types of active sonar used in the SOCAL Range Complex, including Mid-Frequency Active sonar (MFA) between 2.5 and 5 kHz, MFA > 5kHz, and High Frequency Active sonar (HFA) between 20 and 30 kHz. Collectively, these sonars 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. Commonly used in anti-submarine warfare (ASW) exercises, these sonars vary in frequency and duration and can be used in a combination of FM sweeps and CW tones.

The most common of these sonars is MFA between 2 and 5 kHz, more generically known as '3.5 kHz' sonar. 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, there are naval sonars that operate at higher frequencies in the SOCAL region. These higher frequency active sonars were detected by analysts using the LTSA plots, and designated into two categories: 1) MFA sonar > 5kHz, and 2) HFA between 20 and 30 kHz, with an average 4 to 5 second inter-pulse interval.

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 Systems

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.

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 21). 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.

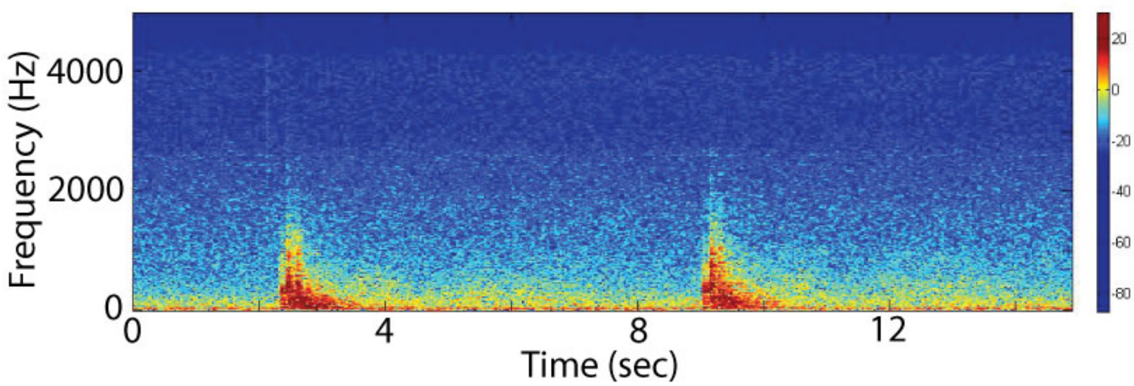


Figure 21. Two explosions are shown with rapid onset and extended reverberation.

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 occurrences will be displayed as weekly averages. More precise occurrence plots, depicting each day and indicating exact hour of the day, are also included.

Ambient Noise

Underwater ambient noise at sites M, H, and N had spectral shapes with higher levels at low frequencies (Figure **22**), owing to the dominance of ship noise at frequencies below 100 Hz and local wind and waves above 100 Hz (Hildebrand 2009). Prominent peaks in noise were observed seasonally at 15-30 Hz and also at 46 Hz, related to the presence of fin and blue whale calls, respectively, at each site. Spectral plots reveal approximately 5-10 dB lower ambient noise levels at site H relative to sites M and N, in the band below 100 Hz, coinciding with the distribution of broadband ship noise at these sites (see Broadband Ship Noise).

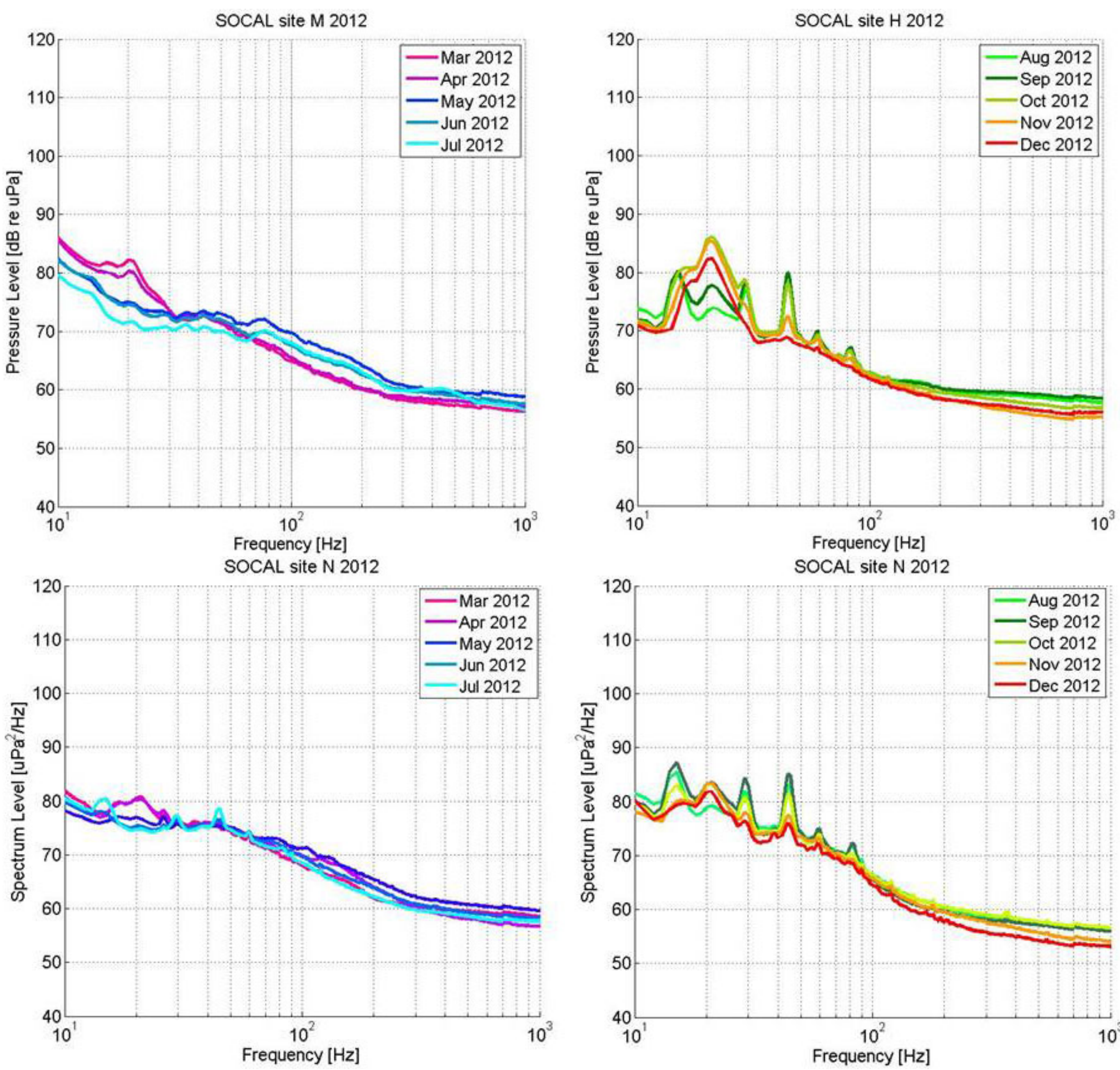


Figure 22. Monthly ambient noise at site M (top left), site H (top right), and site N (bottom).

Mysticetes

Six baleen whale species were recorded between March 2012 and December 2012 at sites M, H, and N: blue whales, fin whales, Bryde's whales, gray whales, humpback whales, and minke whales.

In general, fewer baleen whale vocalizations were detected at site M than at sites H or N, with the exception of gray whale calls, which were only detected 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, H, and N with higher numbers in the summer and fall than in the spring. Generally more hours with calls were detected at site H and N (Figure 23).

- Peak in overall calling occurred between August and November 2012, which is the period with peak detection of blue whale B calls, known to occur in large numbers associated with song (Figure 24).

- Peaks in D call detections occurred in June at site M, and in August and September at sites H and N (Figure 25). D calls are known to be associated with foraging behavior (Oleson *et al.* 2007a) and were detected at higher levels at site H and N than at site M.

- While the peak in D calls occurred a bit later than previously found in this area, the 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).

- Both blue whale B calls (Figure 26) and D calls (Figure 27) occurred during daylight and nighttime.

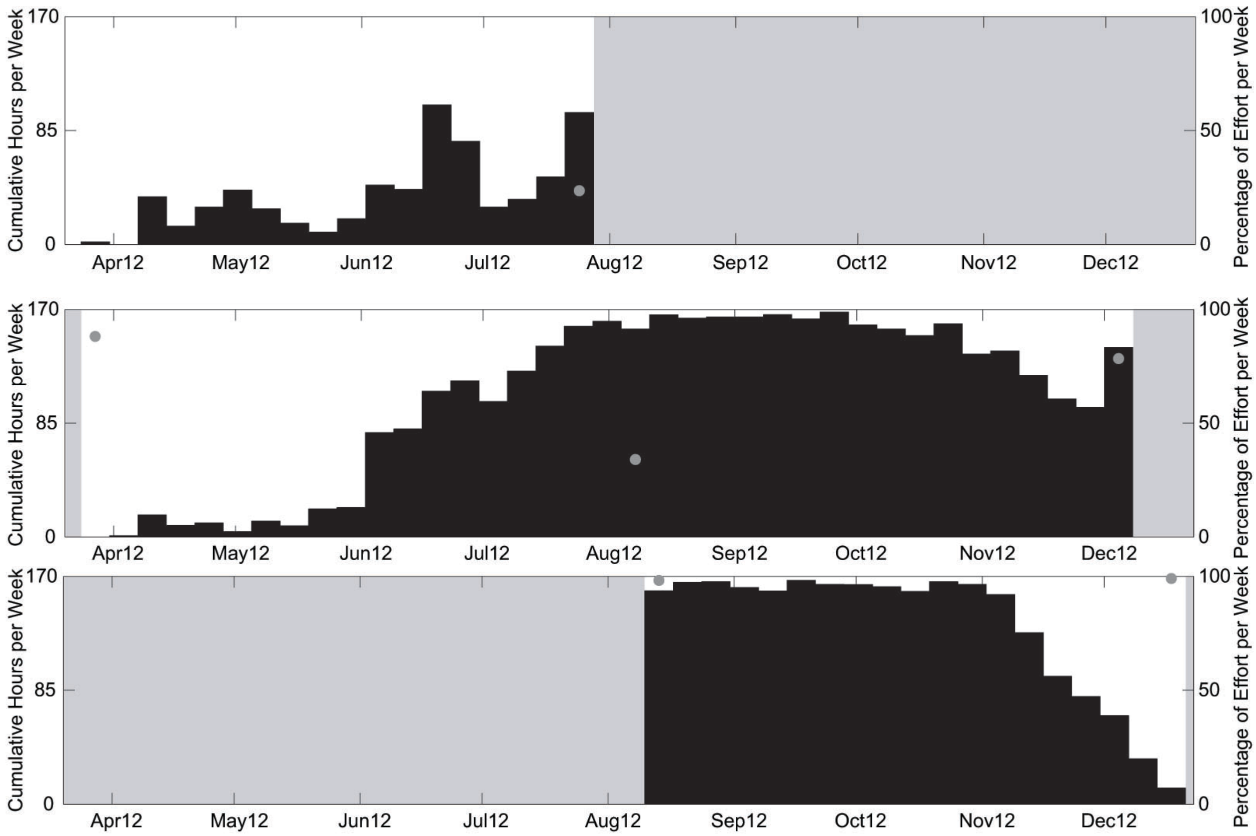


Figure 23. Presence of all blue whale calls (black bars) at sites M (top), H (middle), and N (bottom) between March 2012 and December 2012. Gray dot represents percent of effort per week in weeks with less than 100% recording effort and gray shading shows periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

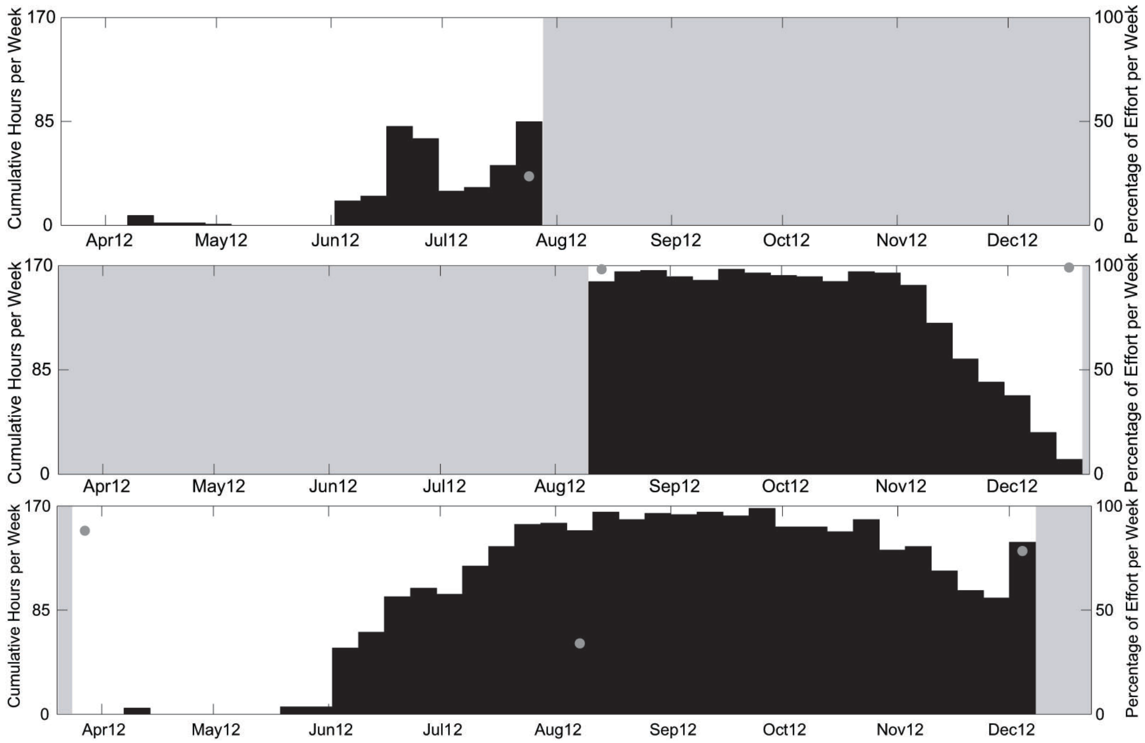


Figure 24. Presence of blue whale B calls at sites M (top), H (middle), and N (bottom) between March 2012 and December 2012.

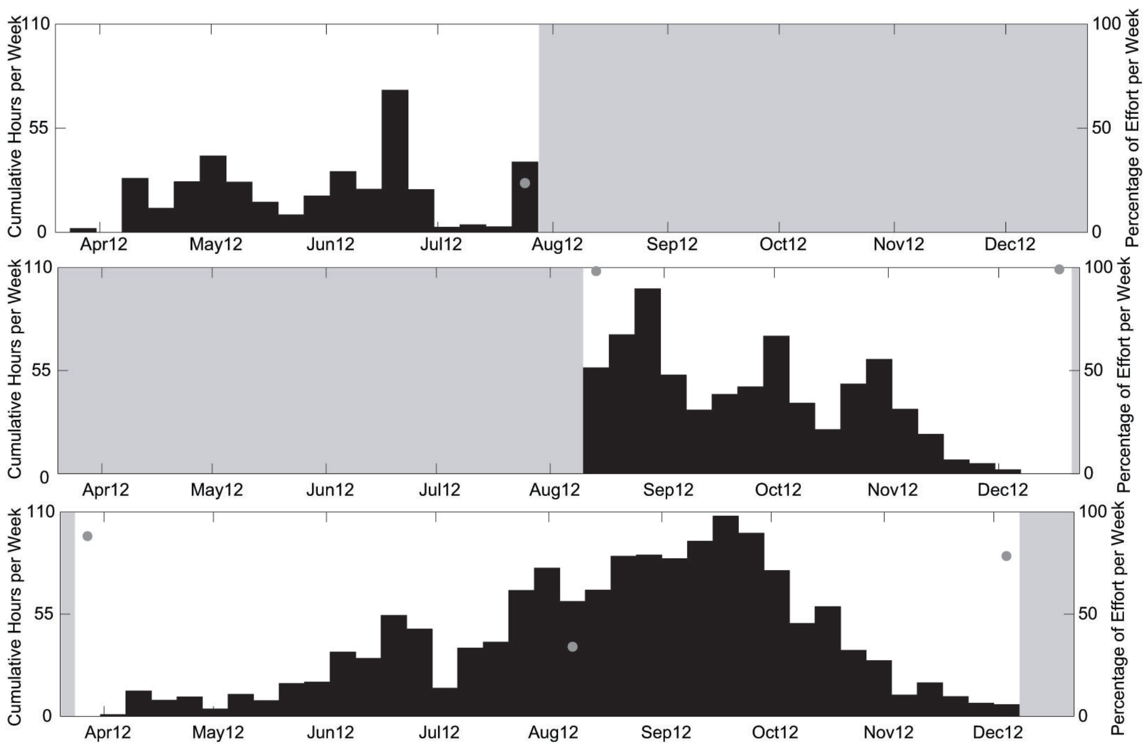


Figure 25. Presence of blue whale D calls at sites M (top), H (middle), and N (bottom) between March 2012 and December 2012.

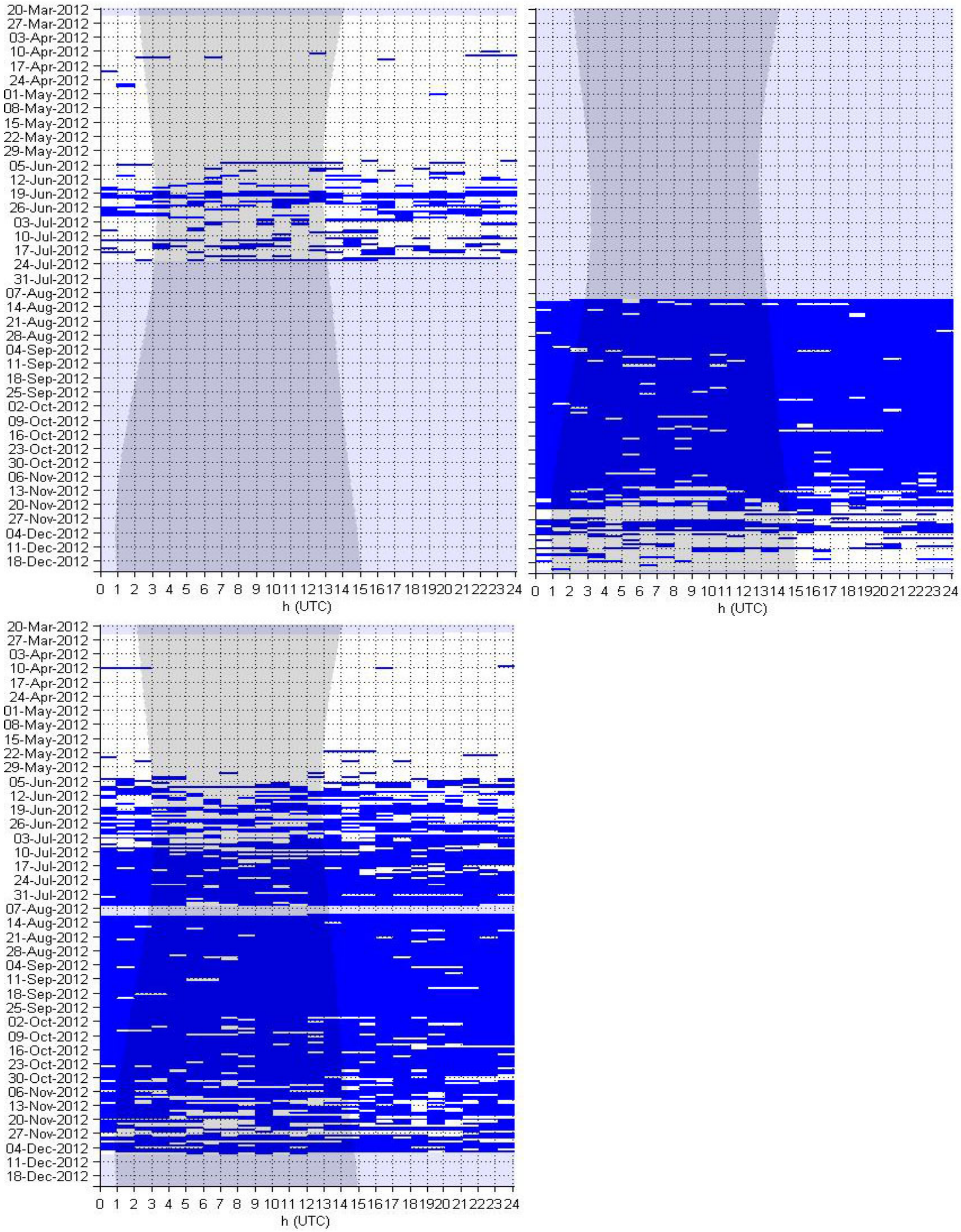


Figure 26. Blue whale B calls in hourly bins at sites M (top left), H (top right), and N (bottom). Gray shading denotes nighttime and light purple shading denotes lack of acoustic data.

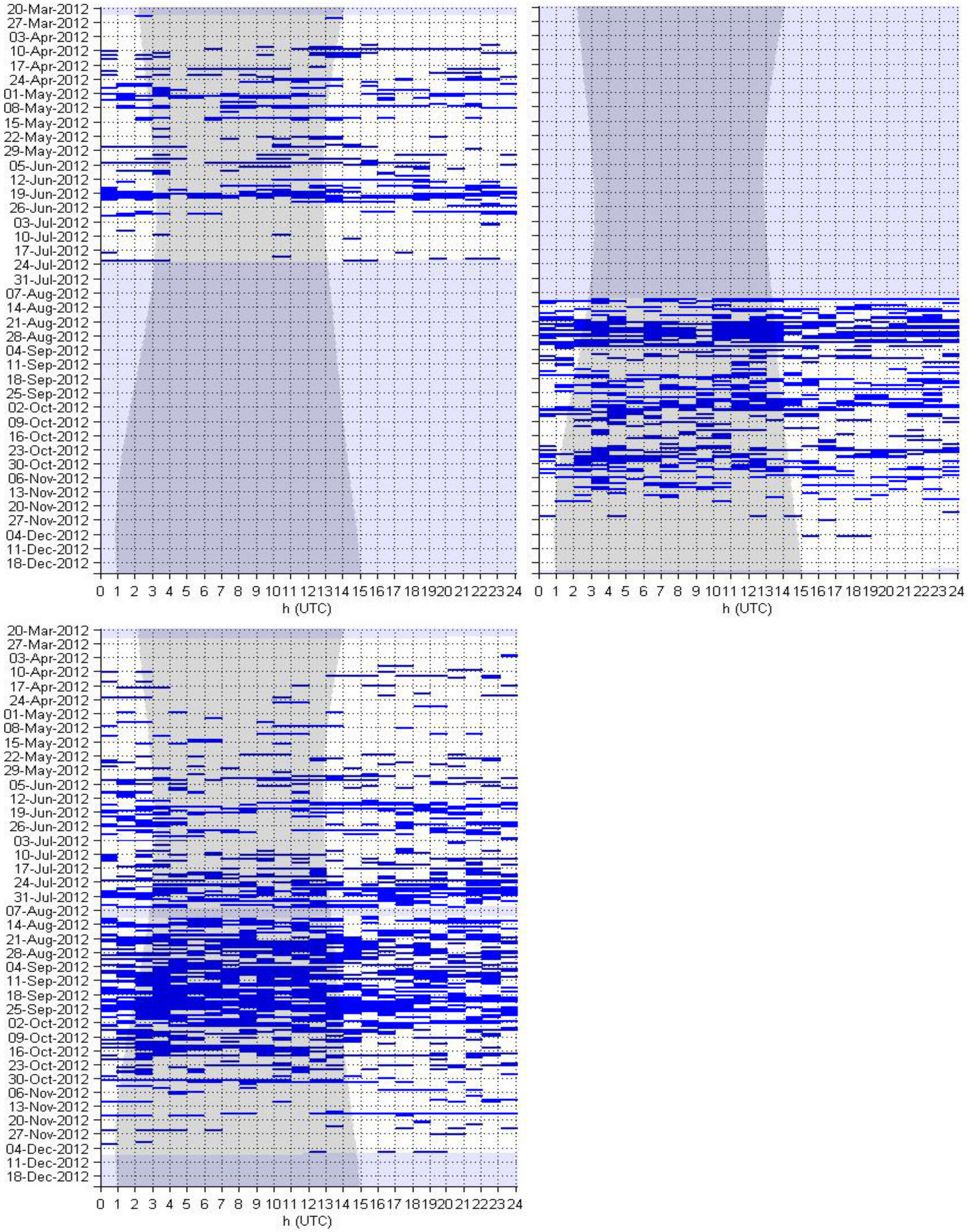


Figure 27. Blue whale D calls in hourly bins at sites M (top left), H (top right), and N (bottom). Gray shading denotes nighttime and light purple shading denotes lack of acoustic data.

Fin Whales

Fin whales were acoustically detected throughout the recording period at all sites, M, H, and N, though calls were present during more hours per week at sites H and N than at site M (Figure 28).

- 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. This call type was present at a near constant rate, with only a slight dip in presence between May and August.
- 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 are not as common as the 20 Hz fin whale pulses. The 40 Hz calls were slightly more prominent in early and late summer, but their relatively constant levels throughout the year differed from more strongly seasonal patterns observed at other sites across the northeast Pacific (Širović *et al.* 2013).
- Plotted in hourly-bins, fin whale 20 Hz (Figure 31) and 40 Hz (Figure 32) calls are detected both during daylight and nighttime.

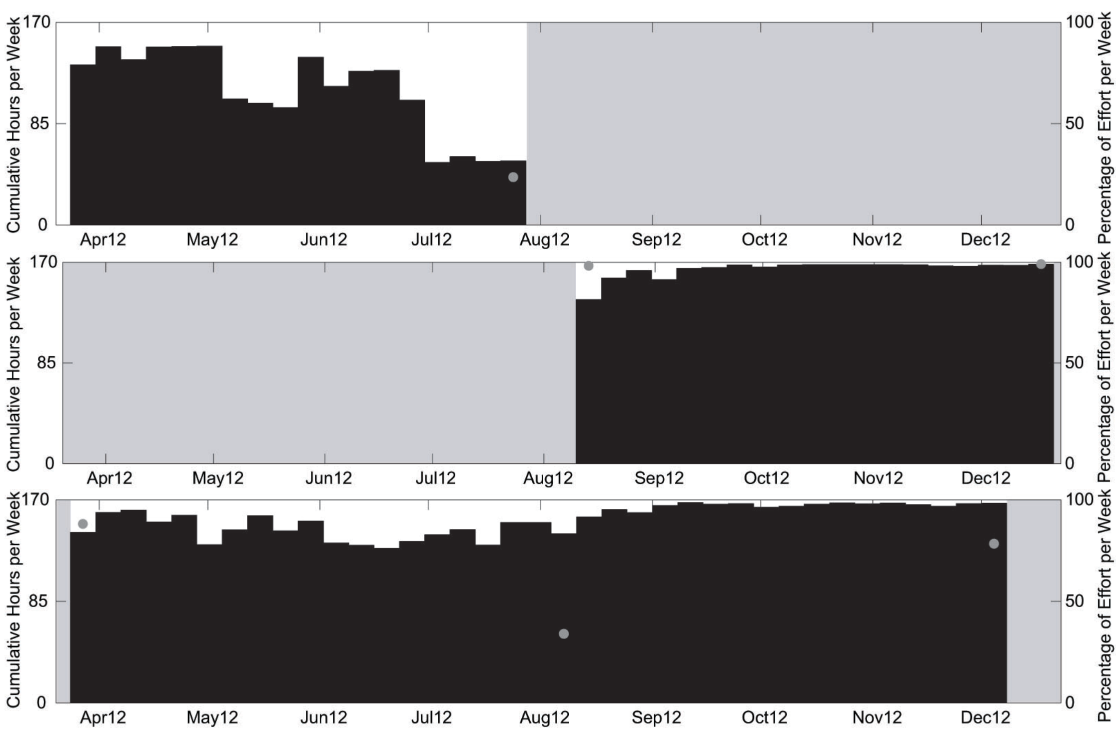


Figure 28. Presence of all fin whale calls at sites M (top), H (middle), and N (bottom) between March 2012 and December 2012.

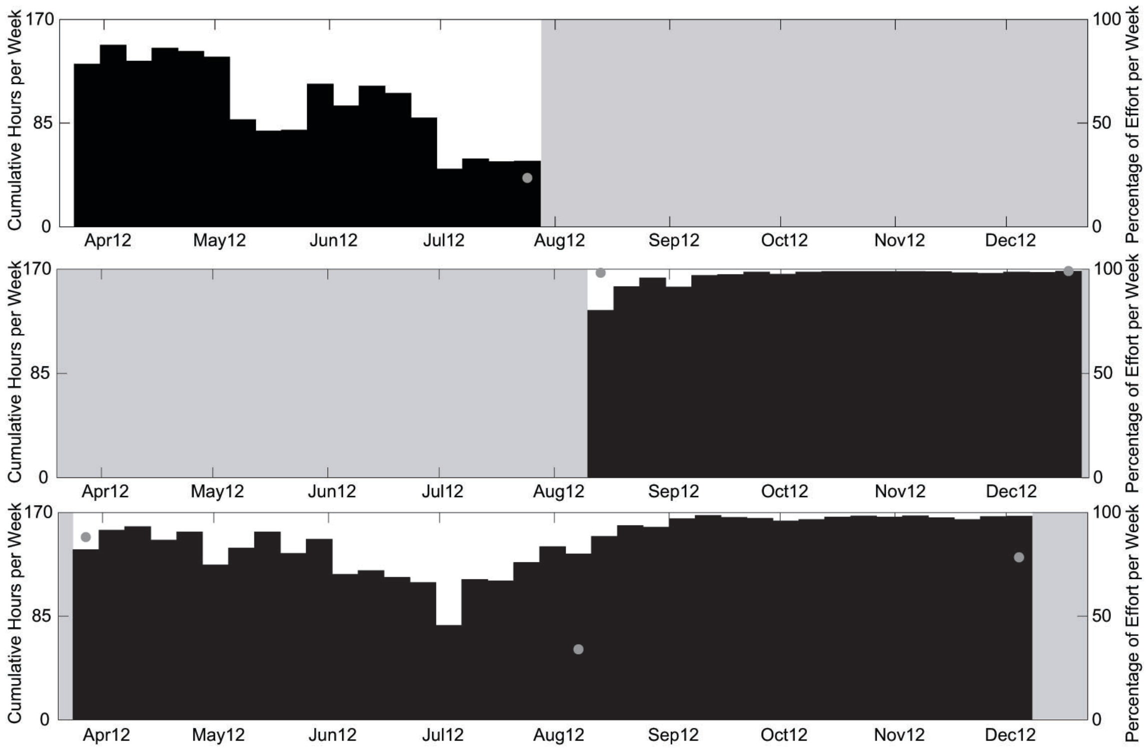


Figure 29. Presence of fin whale 20 Hz pulse calls at sites M (top), H (middle), and N (bottom) between March 2012 and December 2012.

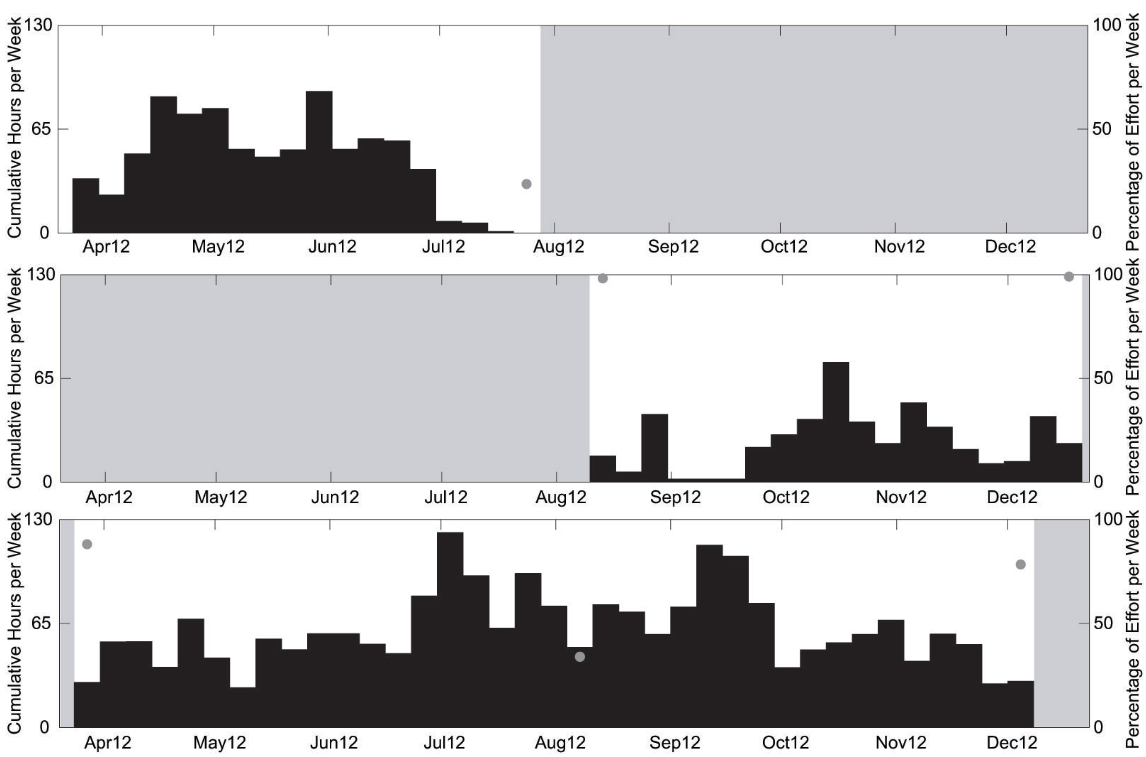


Figure 30. Presence of fin whale 40 Hz pulse calls at sites M (top), H (middle), and N (bottom) between March 2012 and December 2012.

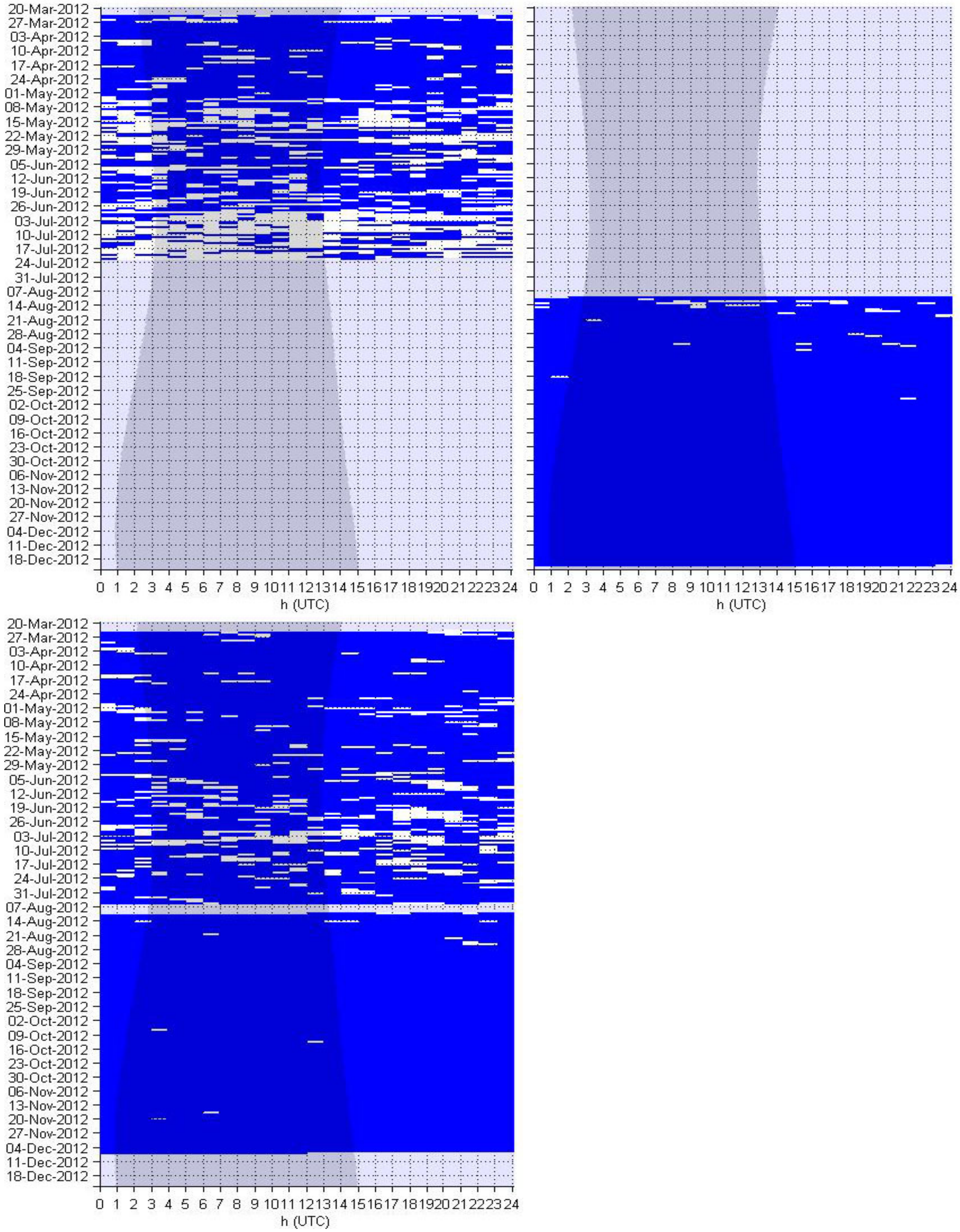


Figure 31. Fin whale 20 Hz pulse calls in hourly bins at sites M (top left), H (top right), and N (bottom). Gray shading denotes nighttime and light purple shading denotes lack of acoustic data.

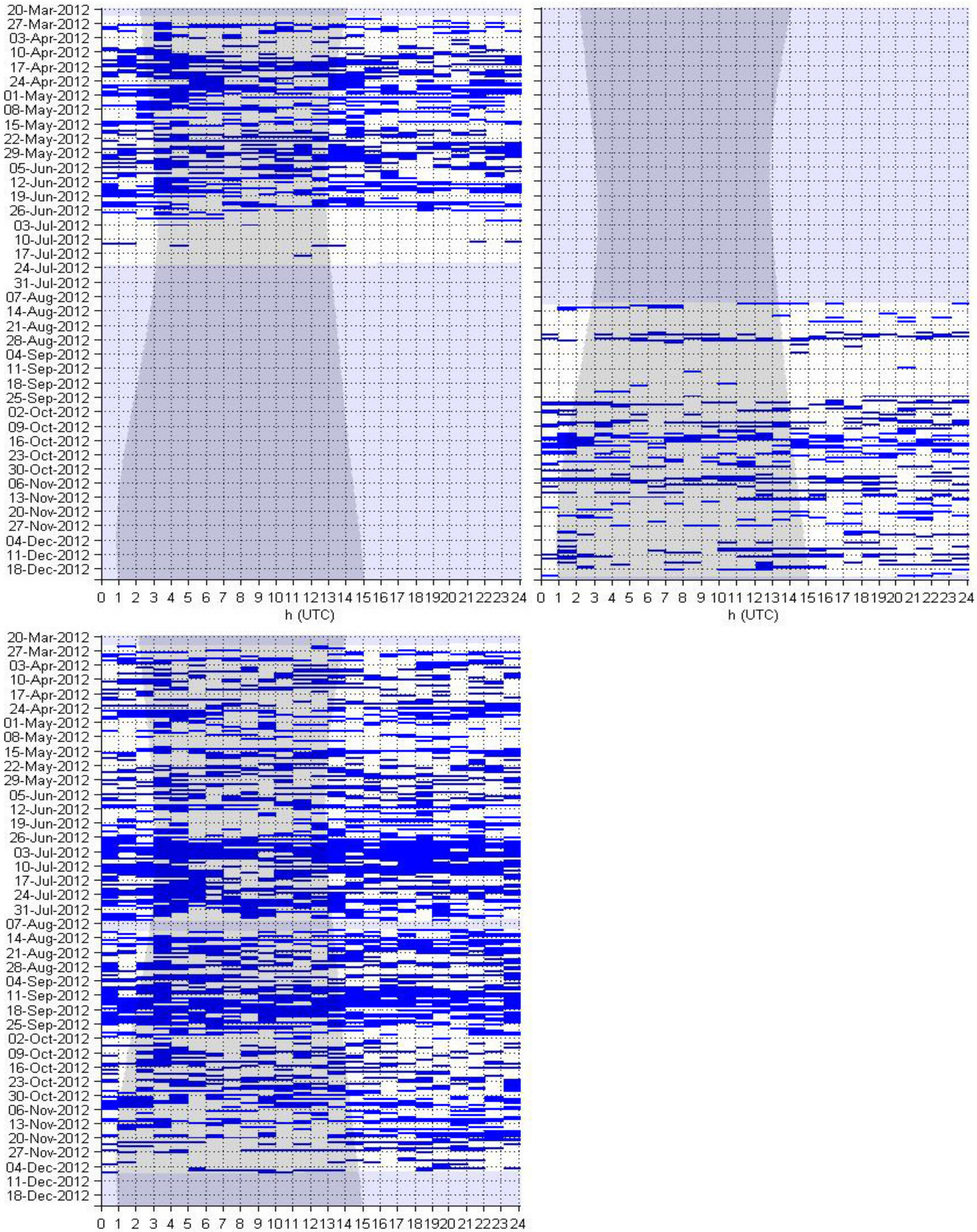


Figure 32. Fin whale 40 Hz pulse calls in hourly bins at sites M (top left), H (top right), and N (bottom). Gray shading denotes nighttime and light purple shading denotes lack of acoustic data.

Bryde's Whales

Bryde's whale calls were detected at all three sites (Figure 33).

- Peaks in calling occurred in the summer: in July at sites M and N, and in September at site H.
- Only a few occurrences of call type Be2 were detected, and only at site N (Figure 34).
- No clear diel pattern is seen in the production of Bryde's whale calls (Figure 35).

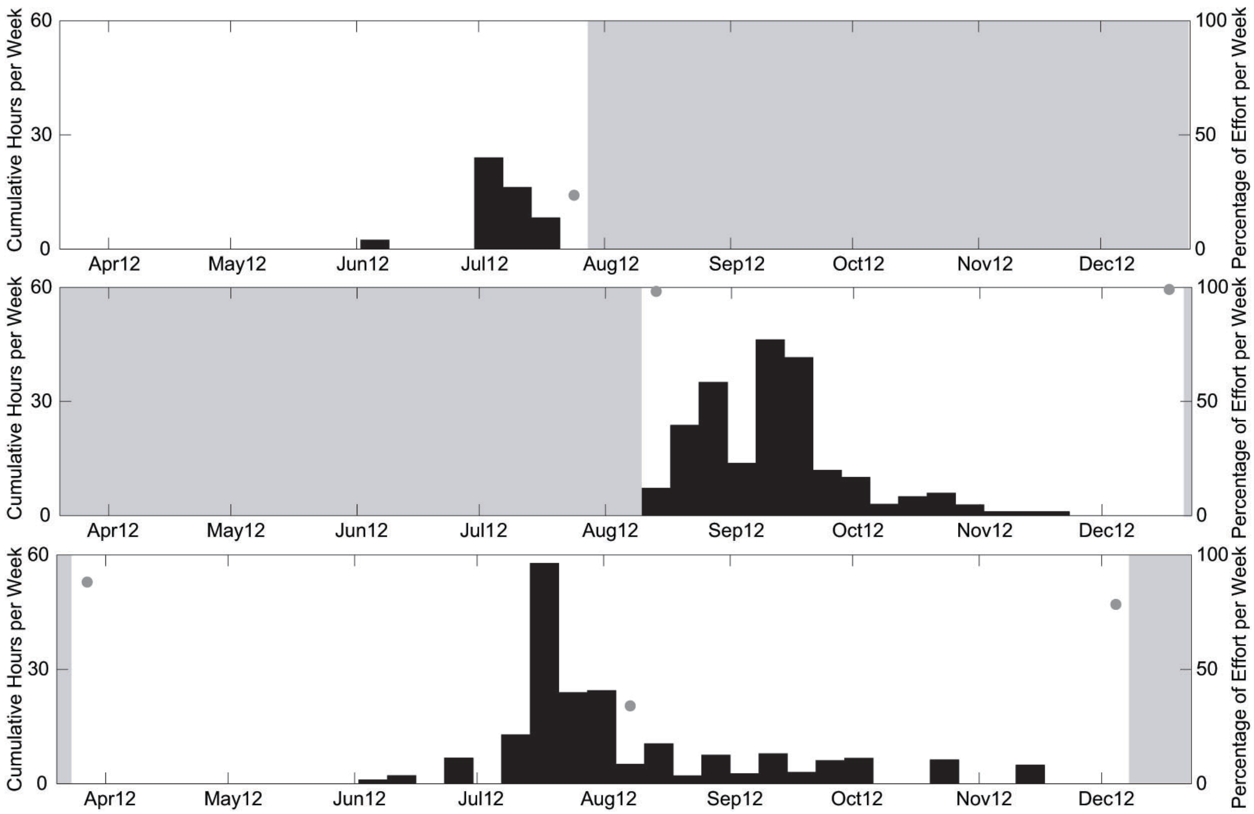


Figure 33. Presence of Bryde's whale Be4 calls at sites M (top), H (middle), and N (bottom) between March 2012 and December 2012.

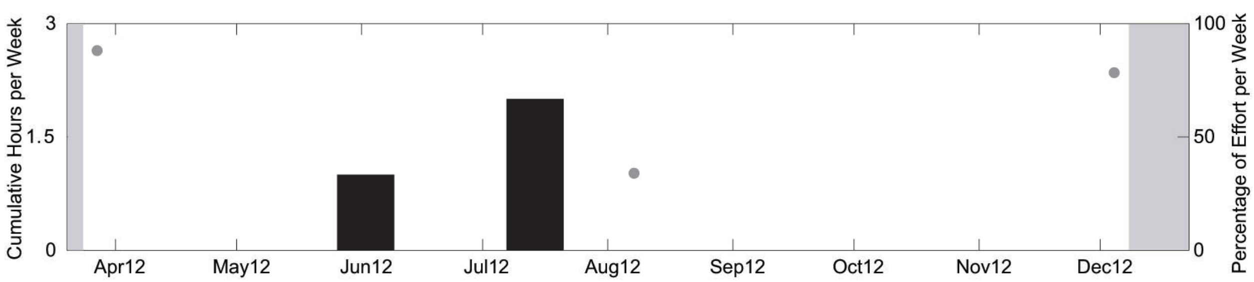


Figure 34. Presence of Bryde's whale Be2 calls at site N between March 2012 and December 2012.

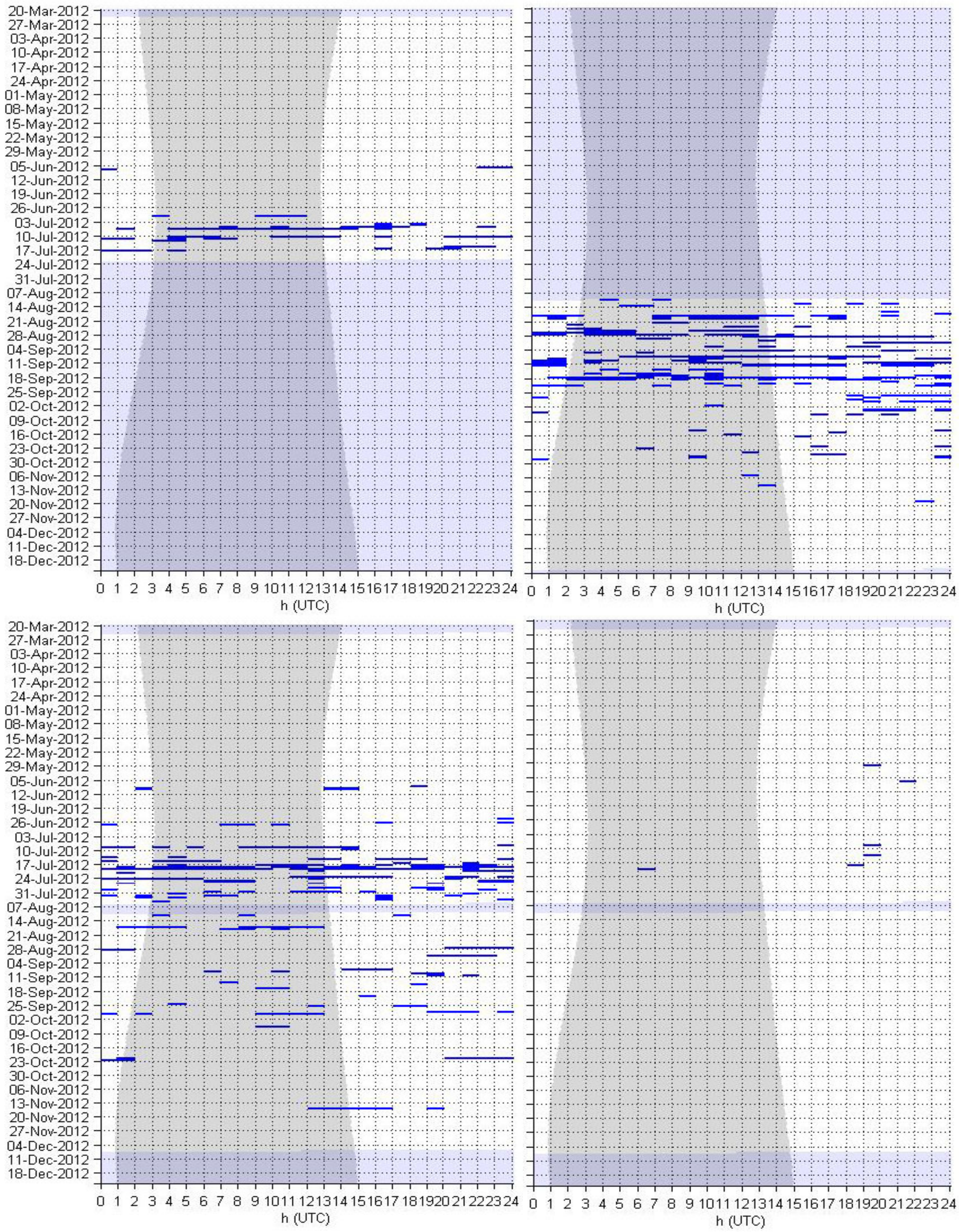


Figure 35. Bryde's whale Be4 calls in hourly bins at sites M (top left), H (top right), and N (bottom left). Bryde's whale Be2 calls in hourly bins, site N (bottom right). Be2 calls not detected at sites M or H. Gray shading denotes nighttime and light purple shading denotes lack of acoustic data.

Humpback Whales

Humpback whales were detected year-round, although they were more common at sites H and N than at site M (Figure 36).

- There were peaks in calling hours in the spring (at sites M and N) and in winter (at sites H and N), though calls were also detected throughout the summer at all sites. Humpback whales are known to feed off California in spring, summer, and fall (Calambokidis *et al.* 1996).

- While song and non-song call types were grouped together for this analysis, peaks in calling during the winter months are likely due to song, reflecting a possible shift in primary behavior from foraging to pairing and mating.

- Humpback whale calls are produced somewhat more at night than during the day during the fall and winter (Figure 37).

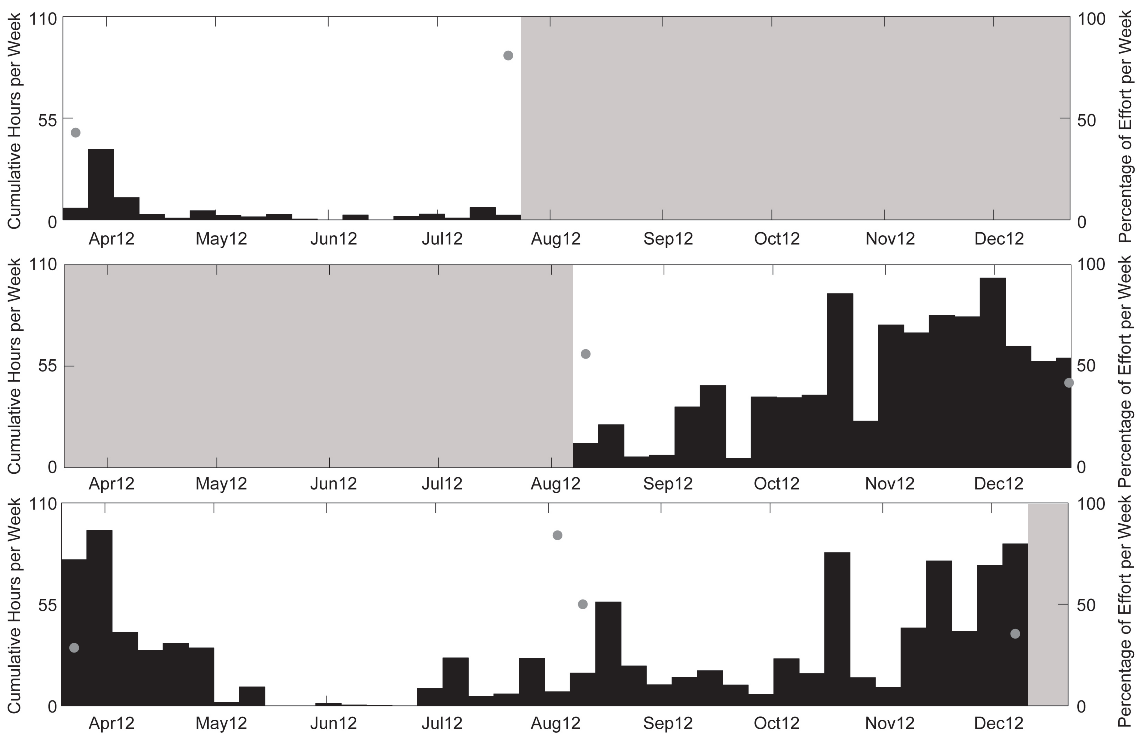


Figure 36. Presence of all humpback whale calls at sites M (top), H (middle), and N (bottom) between March 2012 and December 2012.

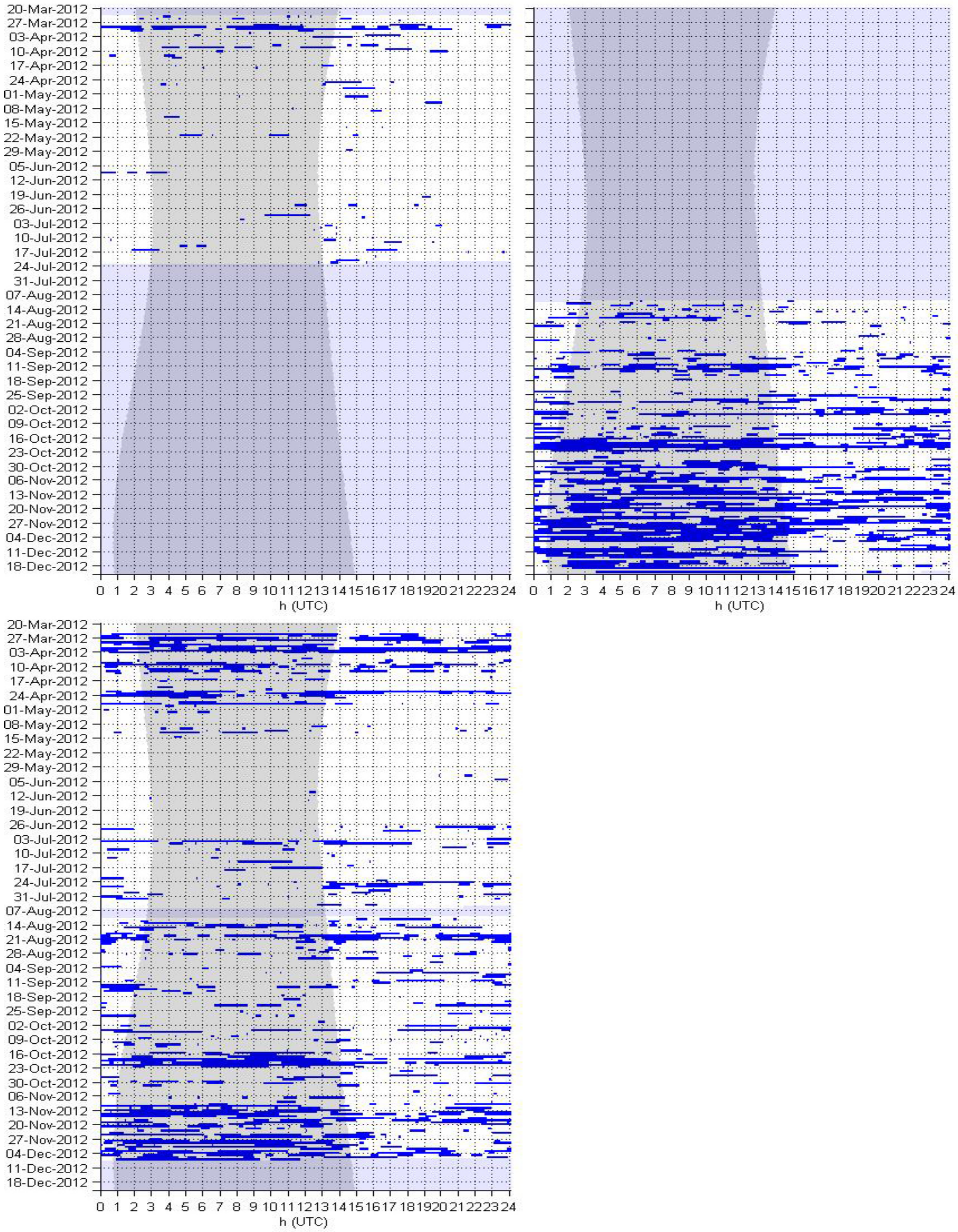


Figure 37. Humpback whale calls in one-minute bins at sites M (top left), H (top right), and N (bottom). Gray shading denotes nighttime and light purple shading denotes lack of acoustic data.

Gray Whales

Gray whales were detected only at site M (Figure 38). The scarcity of calls at sites H and N is likely due to the offshore location of these sites, 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 peak in calling presence in April at site M probably represents the northbound migration.
- Too few gray whale calls were detected to discern any diel pattern of call production (Figure 39).

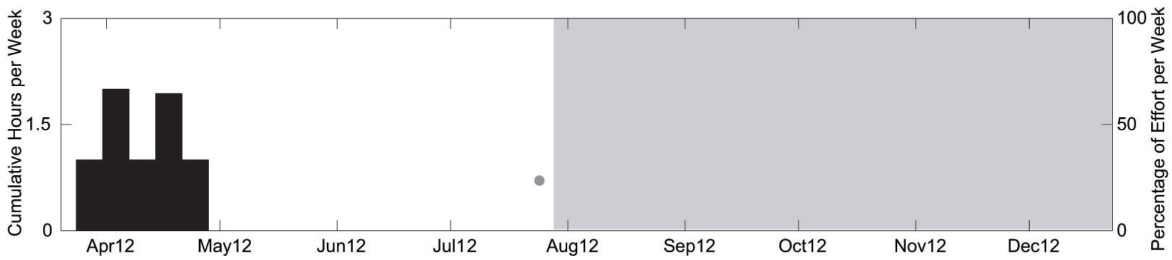


Figure 38. Presence of gray whale M3 calls at sites M between March 2012 and December 2012.

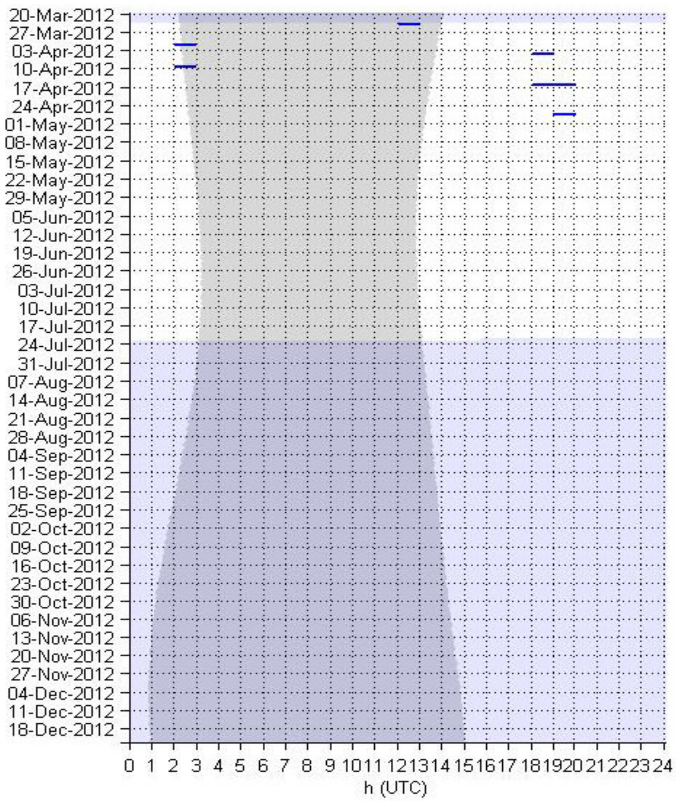


Figure 39. Gray whale M3 calls in hourly bins at site M. M3 calls not detected at sites H or N. Gray shading denotes nighttime and light purple shading denotes lack of acoustic data.

Minke Whales

Minke whale boings were rarely detected in the SOCAL region between March and December 2012. There were no detections at site M, and only one encounter was observed at site H in November. At site N, there were several encounters detected in the spring (Figure 40). These instances are consistent with previous reports showing only occasional minke boing presence, particularly in spring and fall months (Hildebrand *et al.* 2010a, Hildebrand *et al.* 2010b)

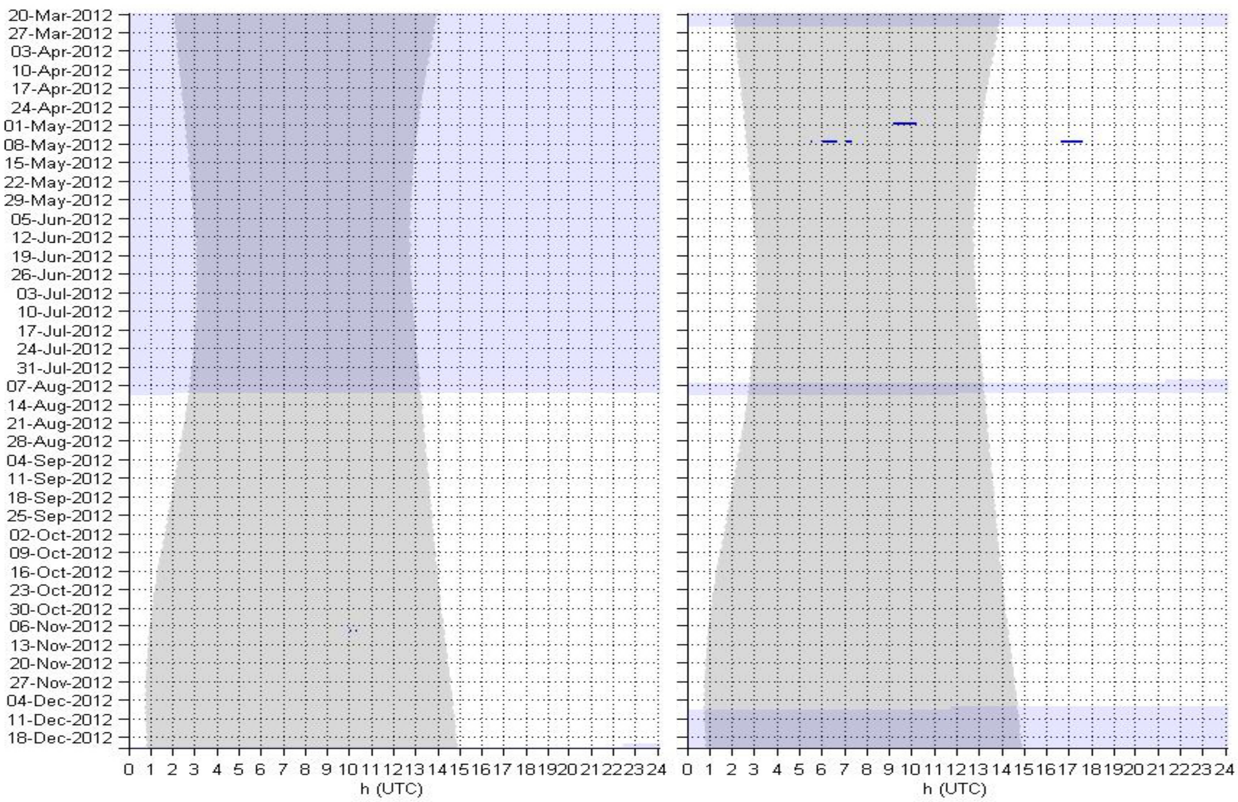


Figure 40. Minke whales boings in one-minute bins at sites H (left) and N (right). Gray shading denotes nighttime and light purple shading denotes lack of acoustic data.

Pinnipeds

Sea Lion

Pinniped barks, presumably made by California sea lions, were recorded more frequently at site M than site N (**Error! Reference source not found.**). Pinnipeds were predominantly recorded in July at both sites. The seasonality of pinniped barks suggests that they may be associated with a mating display. Only three brief pinniped encounters were detected at site H (Figure 42). There was no discernable diel pattern in bark production at any of the recording sites (Figure 42).

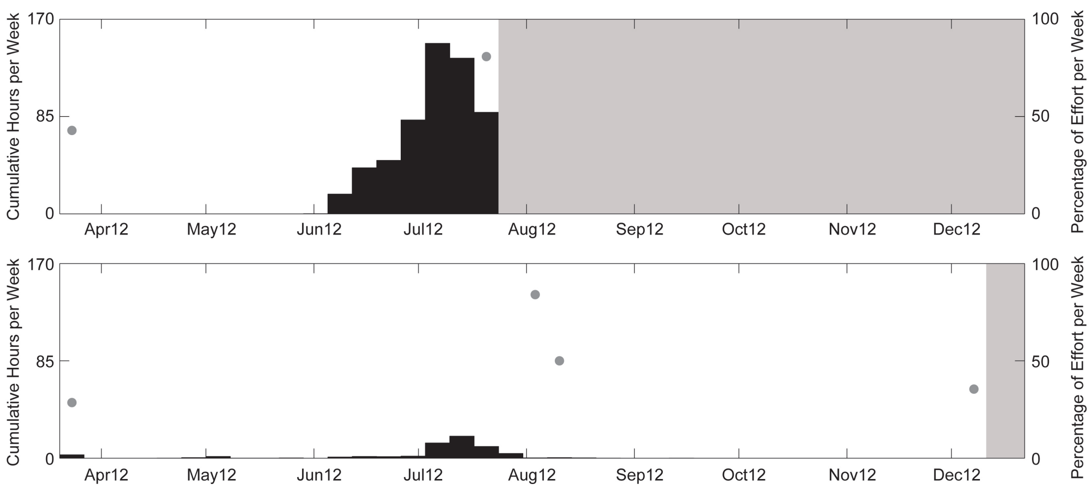


Figure 41. Pinniped bark presence at sites M (top) and N (bottom) between March 2012 and December 2012.

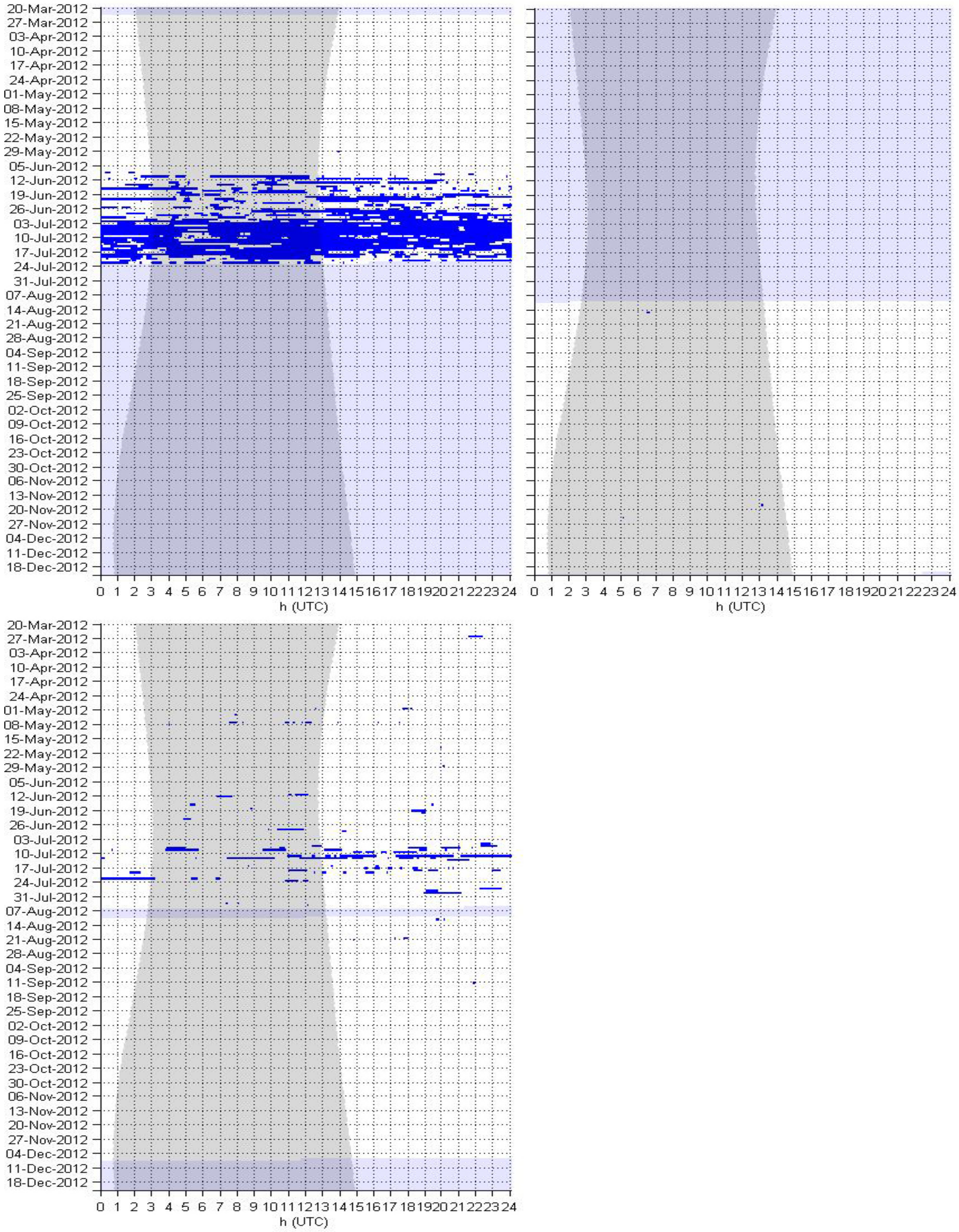


Figure 42. Pinnipeds barks in one-minute bins at sites M (top left), H (top right), and N (bottom). Gray shading denotes nighttime and light purple shading denotes lack of acoustic data.

Odontocetes

At least 10 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.

Three dolphin species were grouped as unidentified dolphins: short-beaked common dolphins, long-beaked common dolphins, and bottlenose dolphins.

There was also an additional beaked whale-like FM pulse type, BW43, of unknown origin.

Unidentified Dolphin

The largest number of detections for odontocete signals 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 the summer and fall months (Figure 43).
- Whistle presence often coincided with echolocation click presence (Figure 44).
- Data from site N suggest a seasonal pattern (higher numbers in summer/fall, lower number in winter/spring).
- There was a distinct diel pattern (Figure 45), with more echolocation activity at night and more whistling activity during the day, likely due to nighttime foraging and daytime socializing.

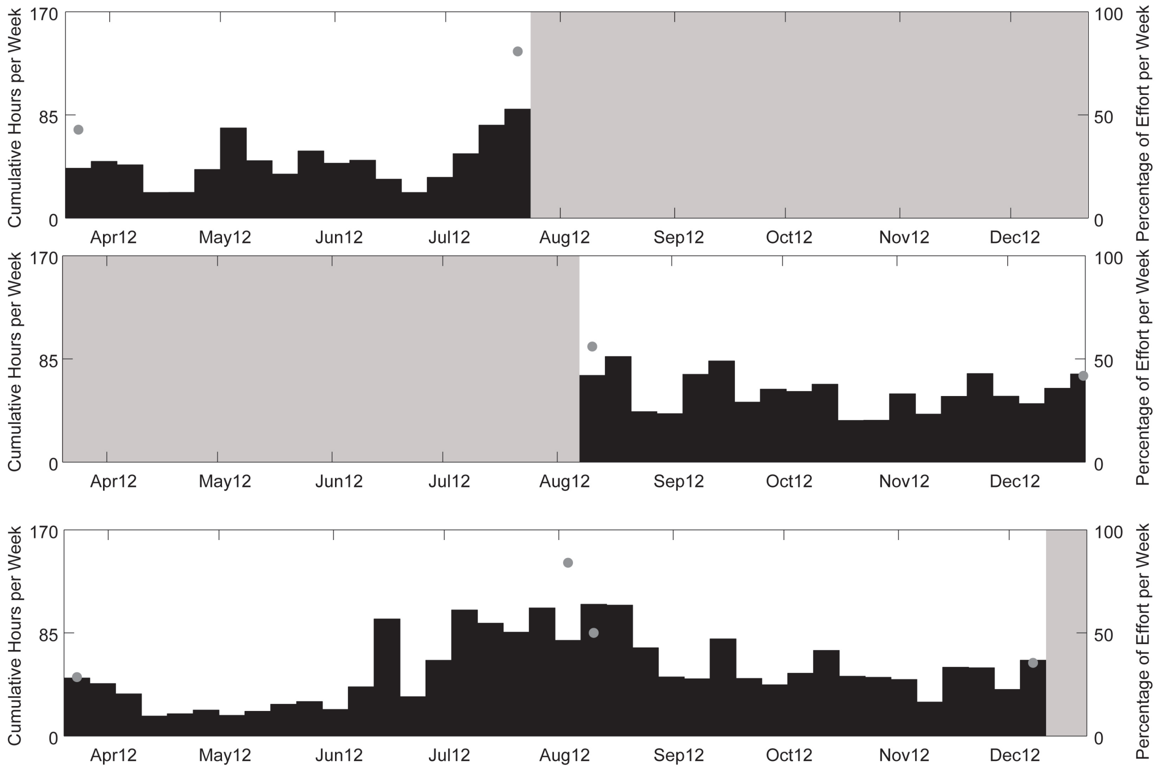


Figure 43. Unidentified dolphin echolocation click presence at sites M (top), H (middle), and N (bottom) between March 2012 and December 2012.

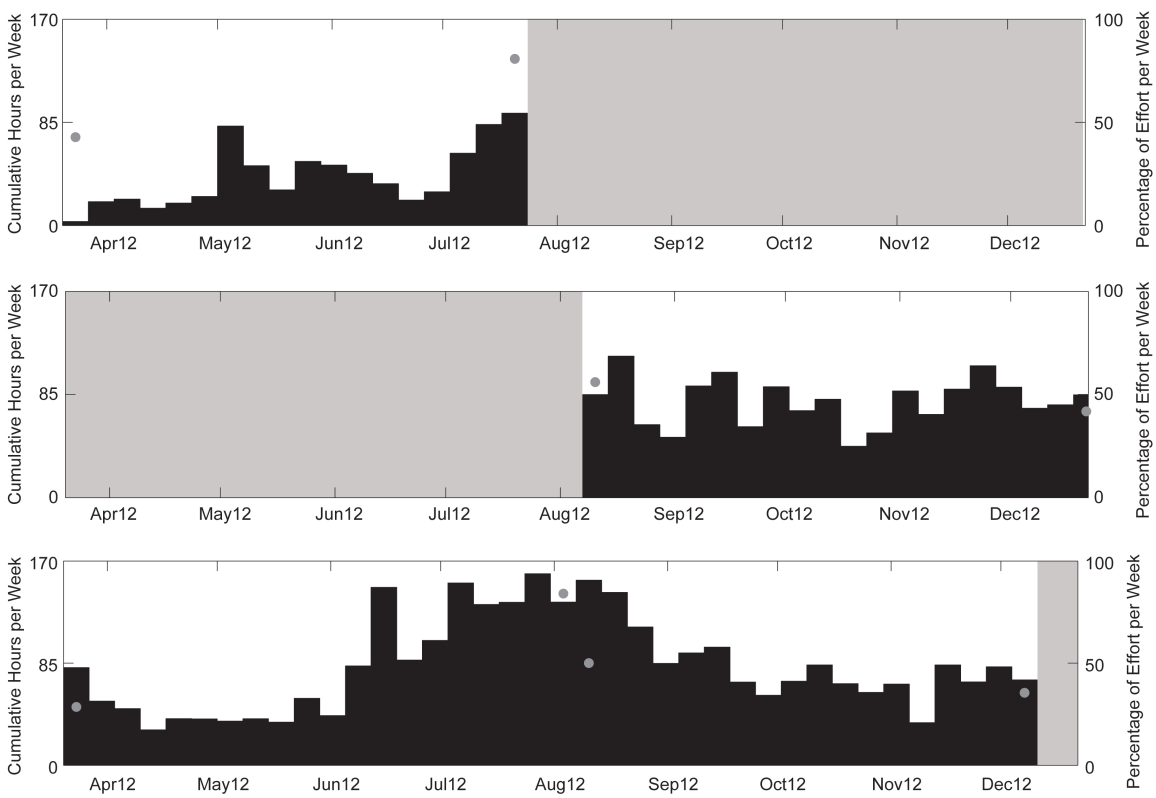
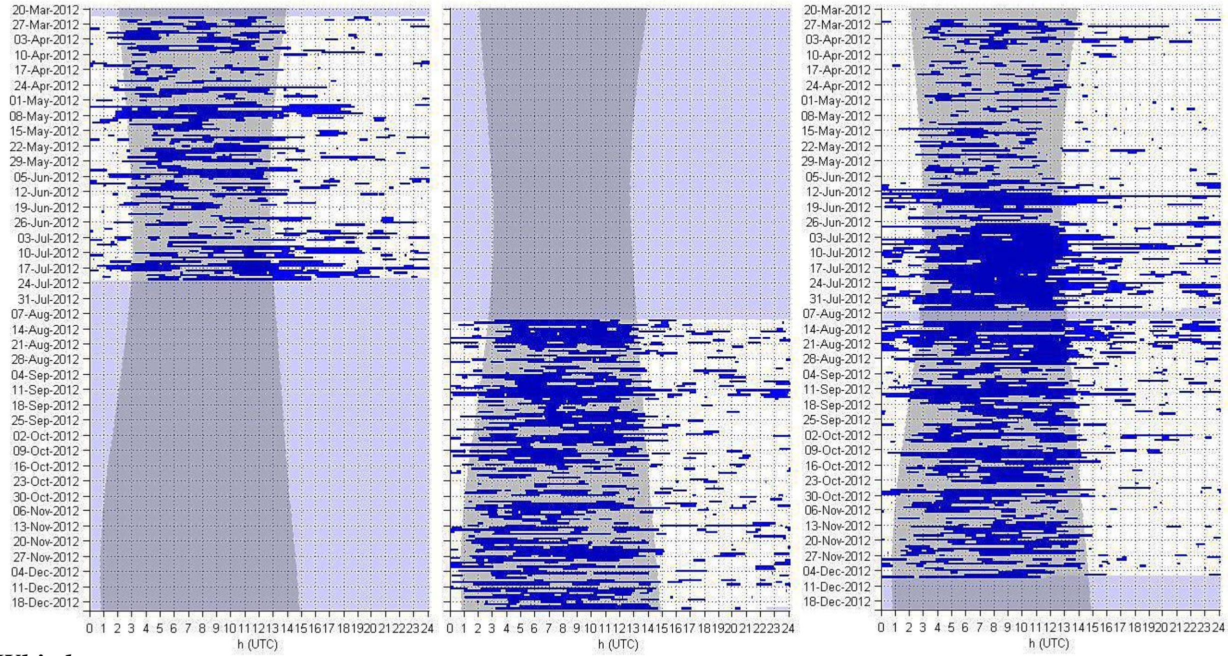


Figure 44. Unidentified dolphin whistle presence at sites M (top), H (middle), and N (bottom) between March 2012 and December 2012.

Echolocation clicks



Whistles

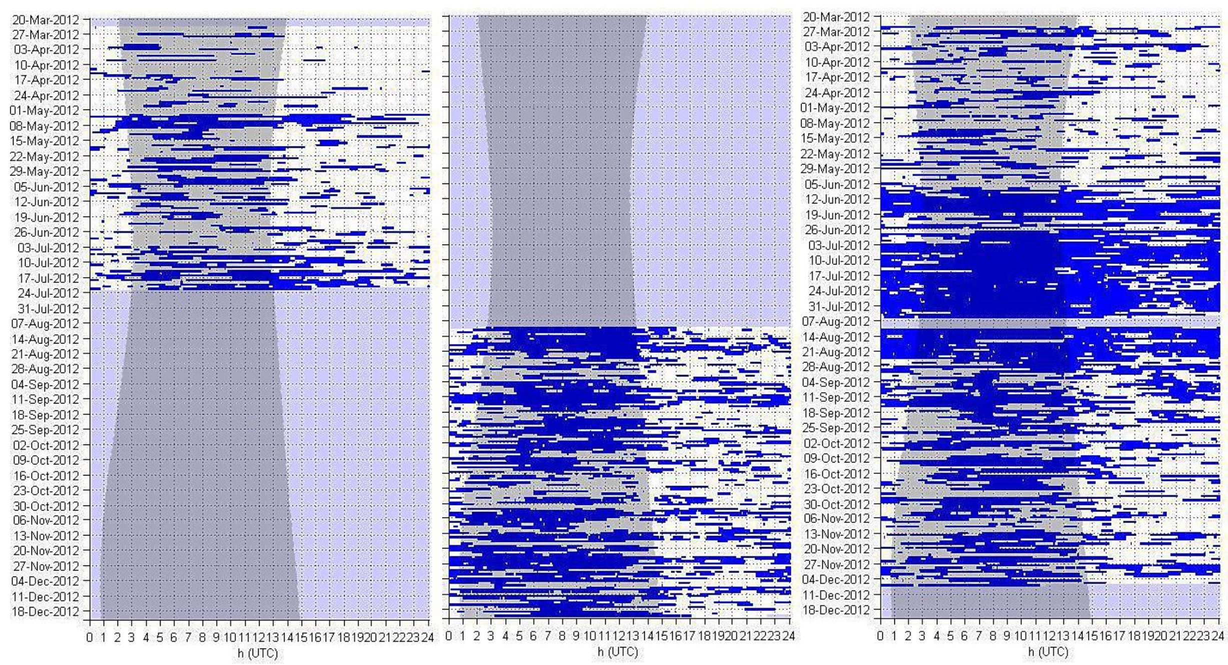


Figure 45. Unidentified dolphin [TOP] Echolocation signals in one-minute bins at sites M (top left), H (top middle), and N (top right); [BOTTOM] Whistles in one-minute bins at sites M (bottom left), H (bottom middle), and N (bottom right). Gray shading denotes nighttime and light purple shading denotes lack of acoustic data.

Risso's Dolphin

Risso's dolphin echolocation clicks were recorded at all three sites (Figure 46), though they were much more common at site M than at sites H or N.

- Peaks in calling occurred in spring and early summer. In previous years of acoustic monitoring in SOCAL, site M also was preferred over site N. These results are consistent with this species' known island-association, as site M is closer in proximity to the Channel Islands while site H and site N are located more offshore.
- Risso's echolocation clicks at site N showed a diel pattern with higher echolocation click activity at night indicating nighttime foraging, consistent with Soldevilla *et al.* (2010a), whereas those at site M did not show a clear diel pattern (Figure 47).

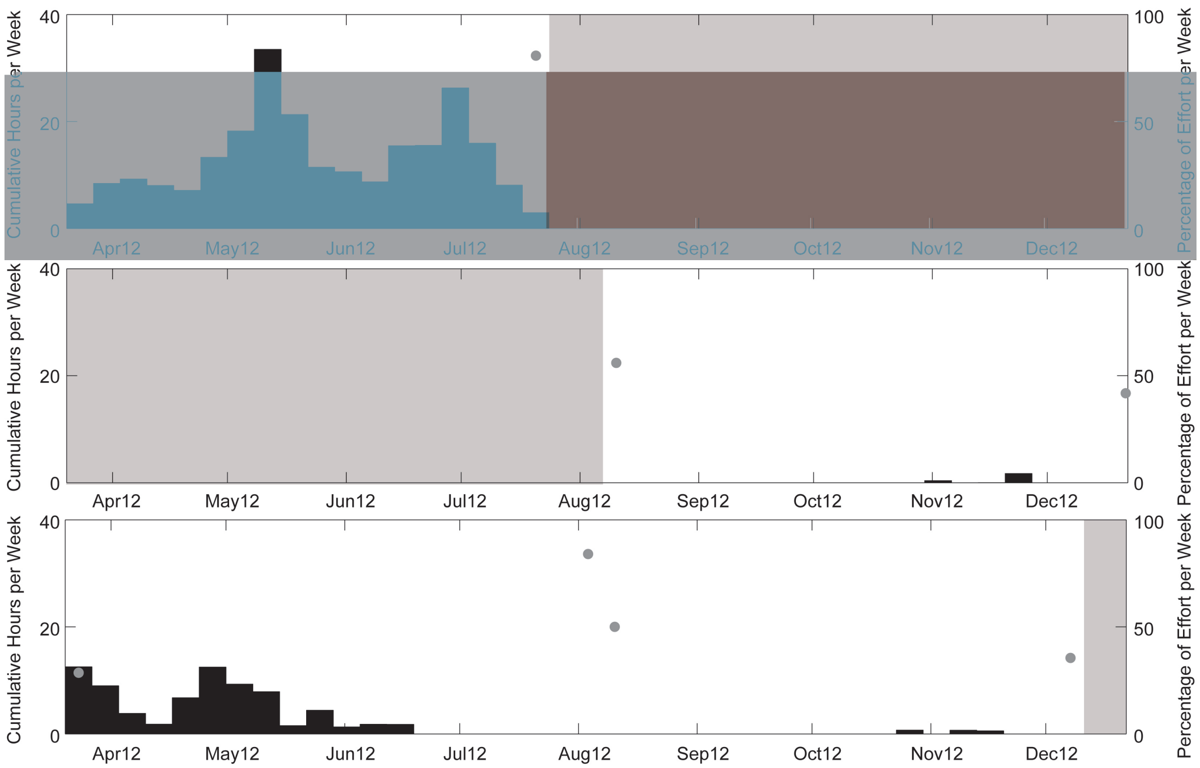


Figure 46. Risso's dolphin echolocation clicks at sites M (top), H (middle), and N (bottom) between March 2012 and December 2012.

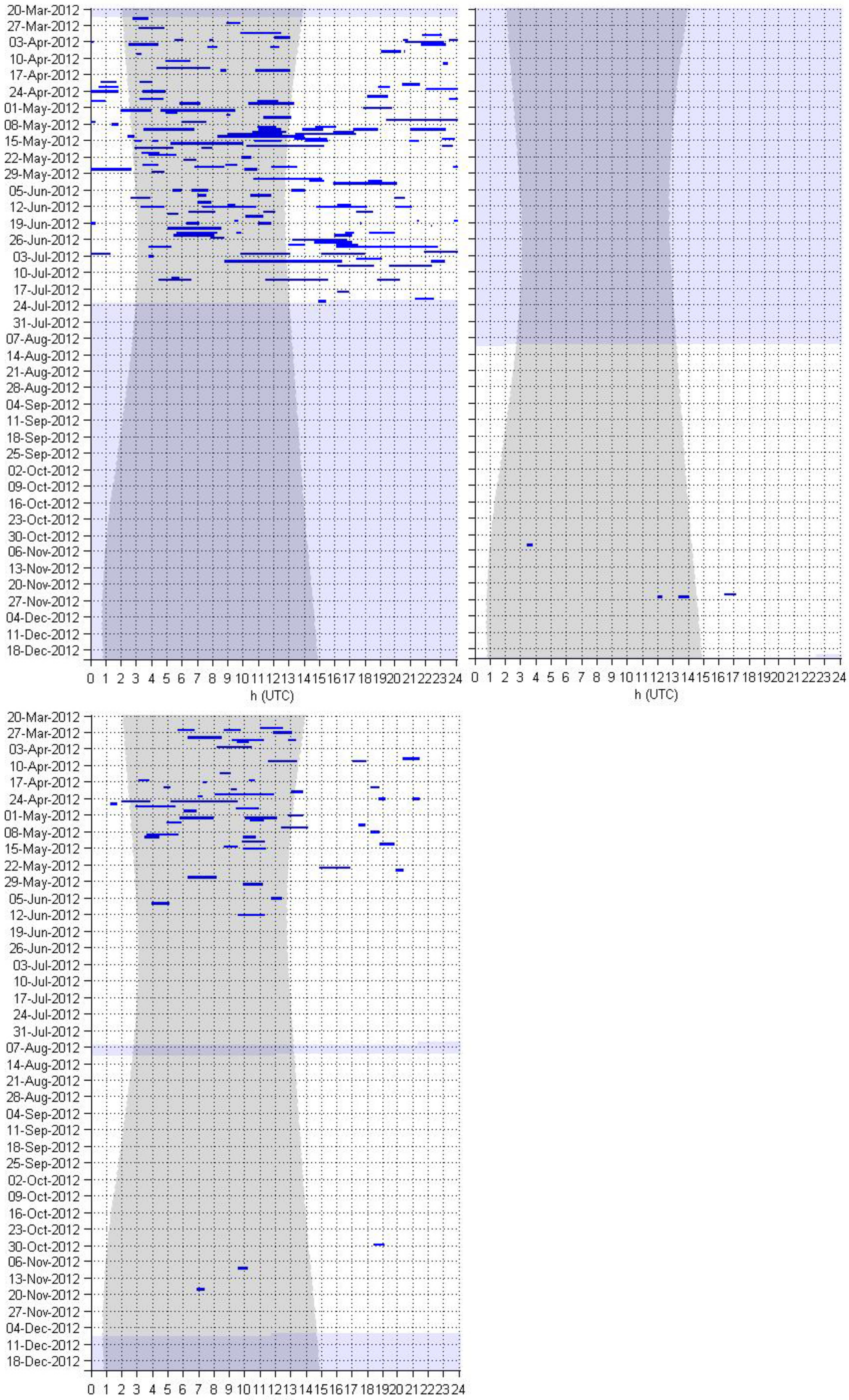


Figure 47. Risso's dolphin echolocation clicks in one-minute bins at sites M (top left), H (top right), and N (bottom). Gray shading denotes nighttime and light purple shading lack of acoustic data.

Pacific White-Sided Dolphin

Pacific white-sided dolphins were acoustically present at all three sites throughout the year (Figure 48, Figure 49).

- Pacific white-sided dolphin echolocation clicks were most commonly observed at site H, where both type A and type B clicks were detected.

- A fall-winter peak was observed at this site for both click types, as expected (Soldevilla *et al.* 2010b). At site M, the northernmost of the three sites, type A clicks were predominant, with only one occurrence of type B clicks. Only a few brief detections of type A clicks were observed at site N, with no detected presence of type B clicks.

- In general, for both click types, there was a higher instance of click detection at night (Figure 50), suggesting nighttime foraging.

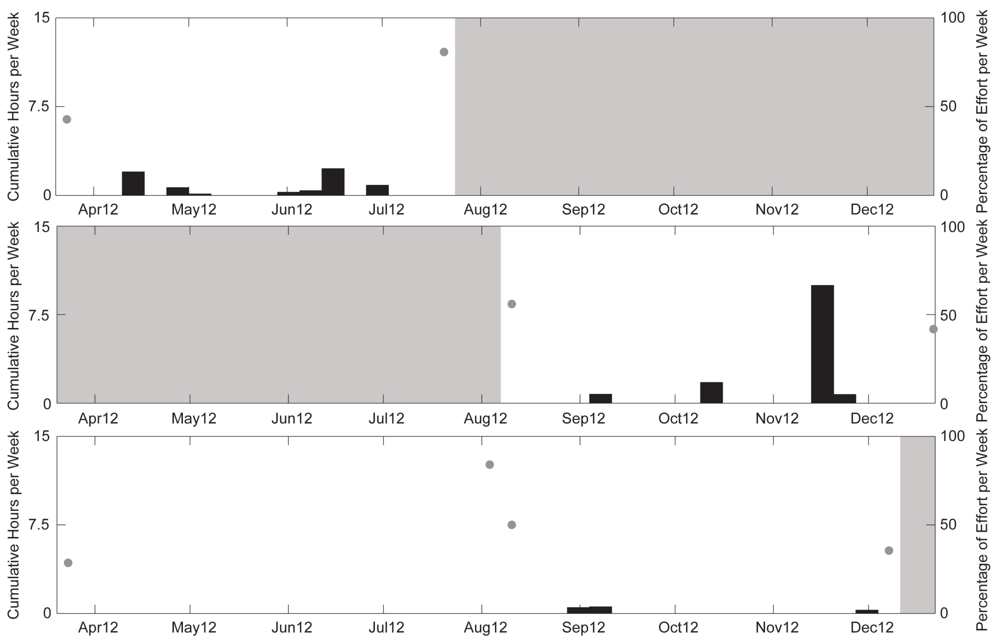


Figure 48. Pacific white-sided dolphin echolocation click type A presence at sites M (top), H (middle), and N (bottom) between March 2012 and December 2012.

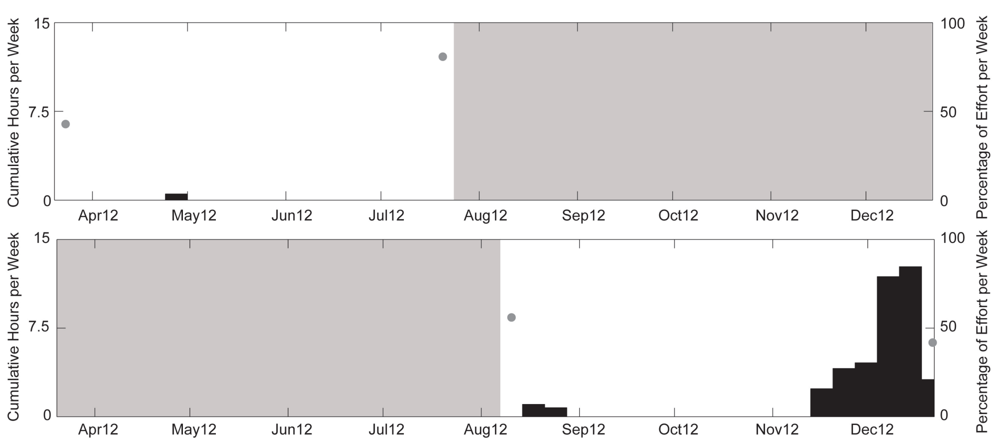
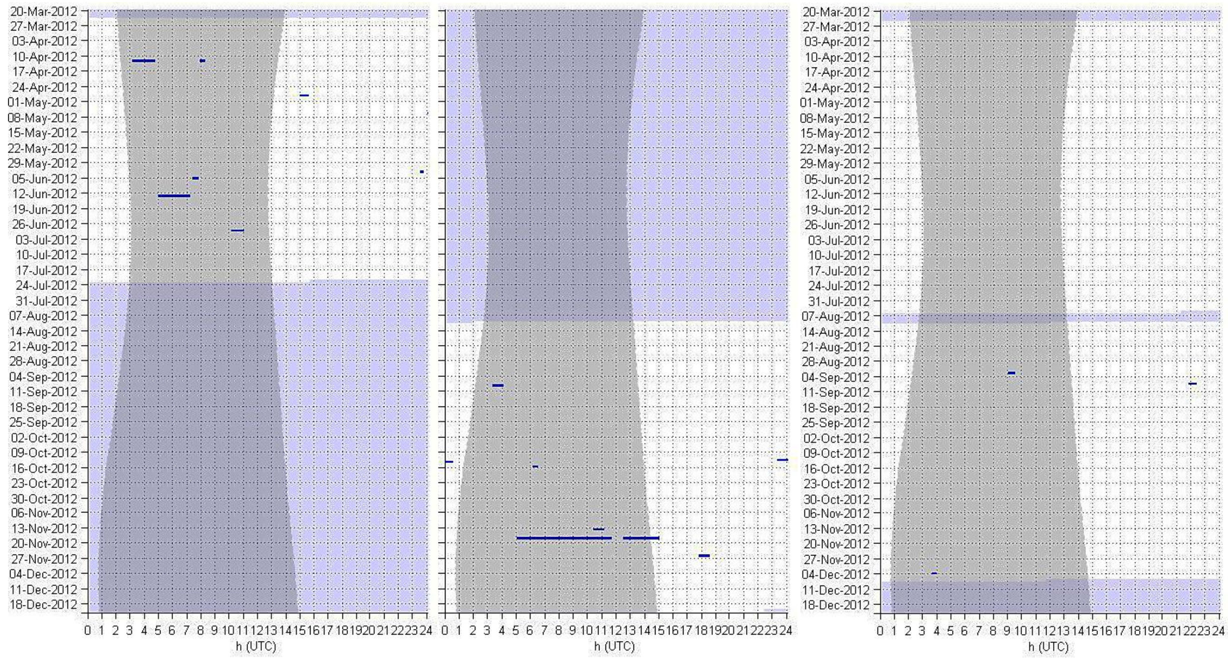


Figure 49. Pacific white-sided dolphin echolocation click type B presence at sites M (top) and H (bottom) between March 2012 and December 2012.

Type A Echolocation clicks



Type B Echolocation clicks

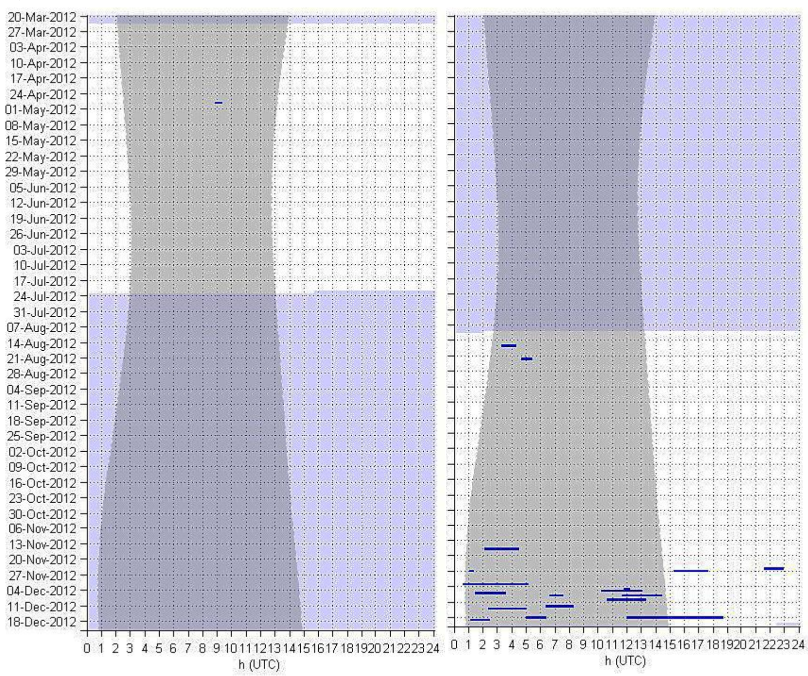


Figure 50. Pacific white-sided dolphin [TOP] Type A echolocation clicks in one-minute bins at sites M (top left), H (top middle), and N (top right); [BOTTOM] Type B echolocation clicks in one-minute bins at sites M (bottom left) and H (bottom right). Gray shading denotes nighttime and light purple shading denotes lack of acoustic data.

Killer Whale

Killer whale detections consisted of only a few encounters at each site (Figure 51).

- Detections occurred sporadically in late spring/early summer and in the fall.
- In some instances, the close timing of killer whale presence at two sites (at sites M and N in April and June, and at sites H and N in December) suggests that these may represent a single group of animals.
- Too few killer whale calls were detected to discern a diel pattern of call production (Figure 52).

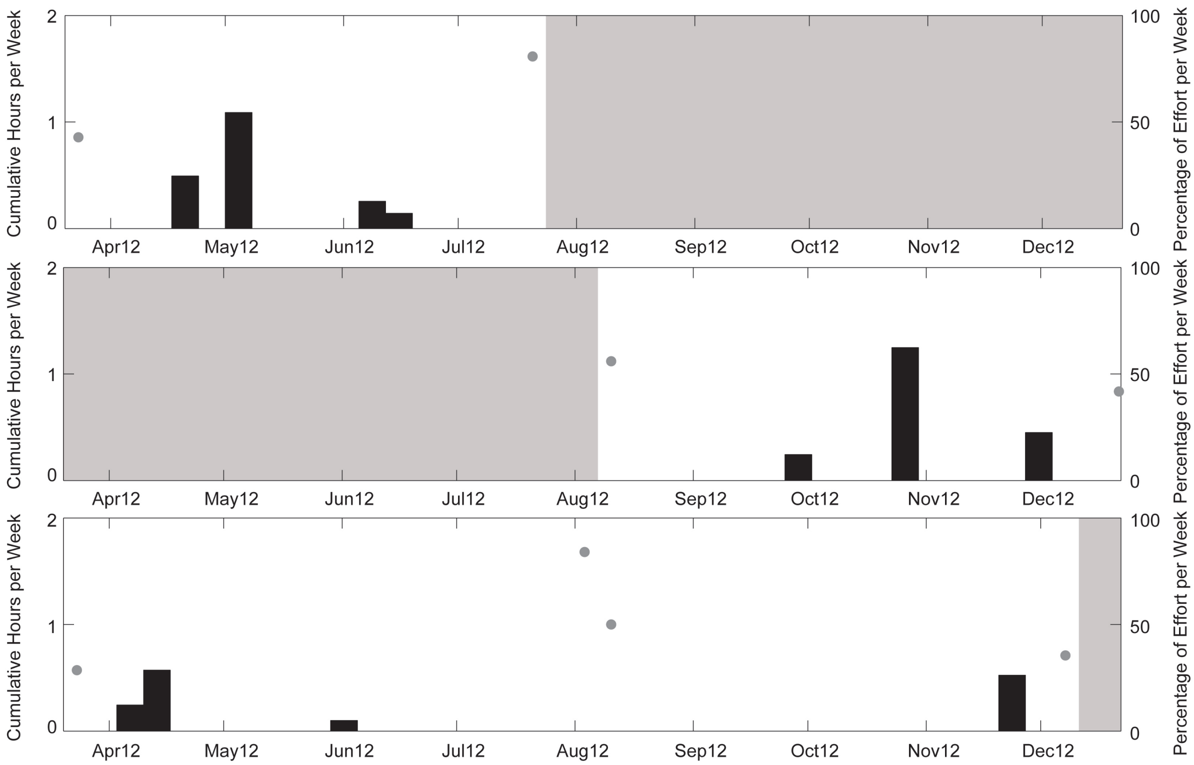


Figure 51. Weekly killer whale presence at sites M (top), H (middle), and N (bottom) between March 2012 and December 2012.

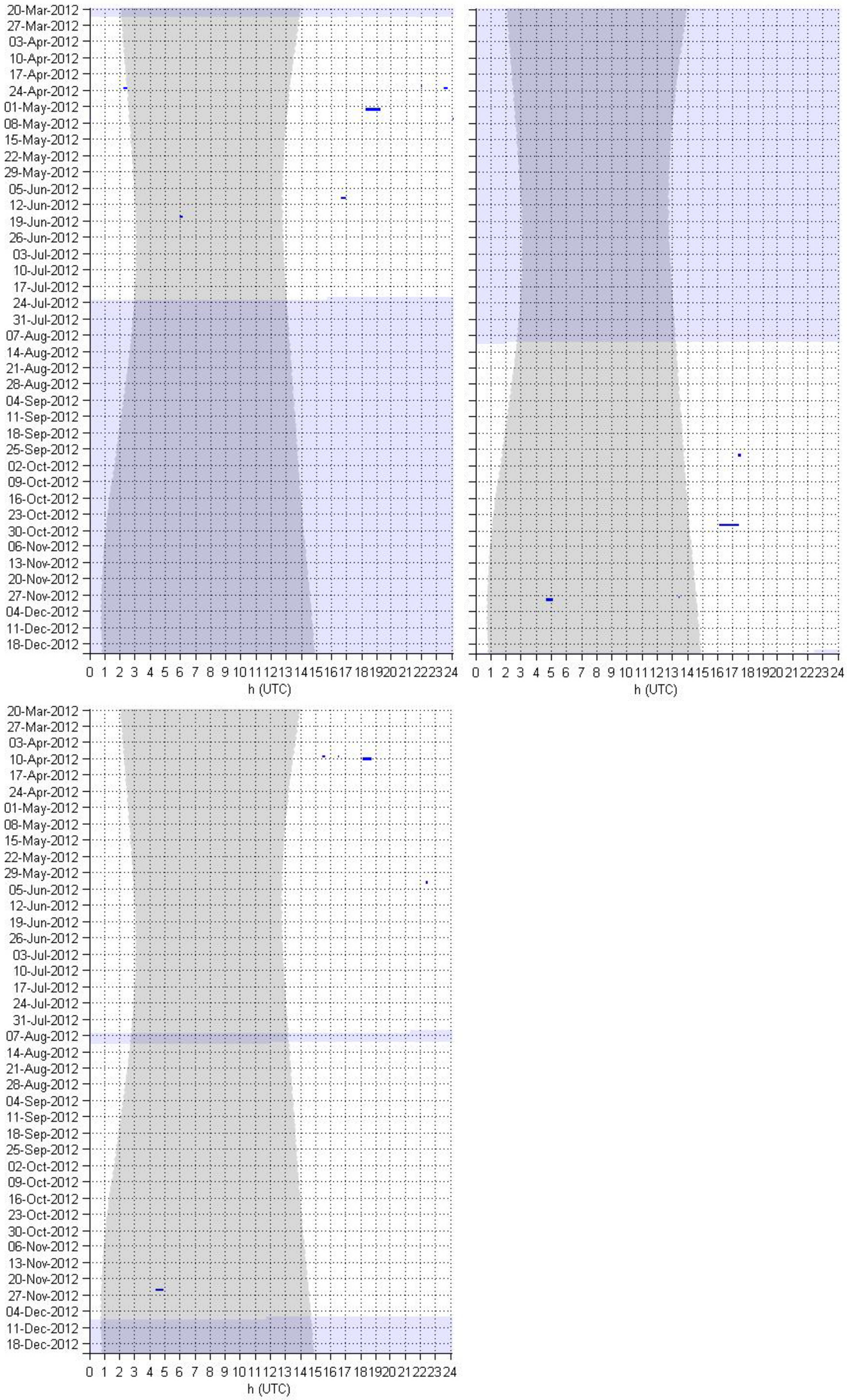


Figure 52. Killer Whale clicks, pulses, whistles in one-minute bins at sites M (top left), H (top right), and N (bottom). Gray shading denotes nighttime and light purple shading lack of acoustic data.

Sperm Whale

Sperm whale echolocation clicks were only detected at site N between August and December (Figure 53). Too few calls sperm whale calls were encountered to discern a diel pattern (Figure 54).

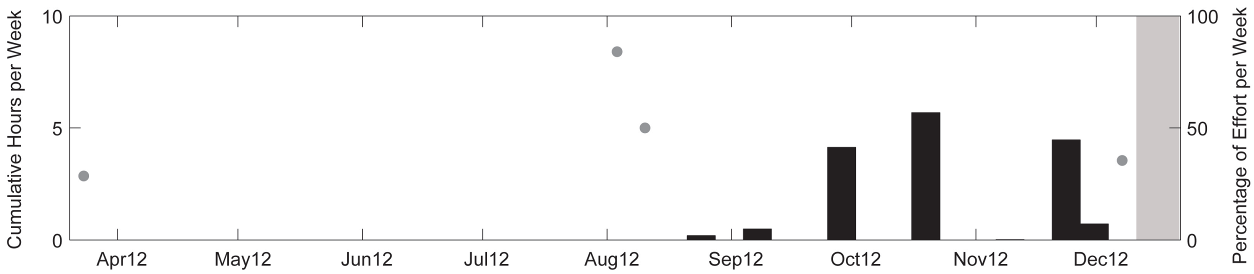


Figure 53. Weekly sperm whale echolocation click presence at site N between March 2012 and December 2012.

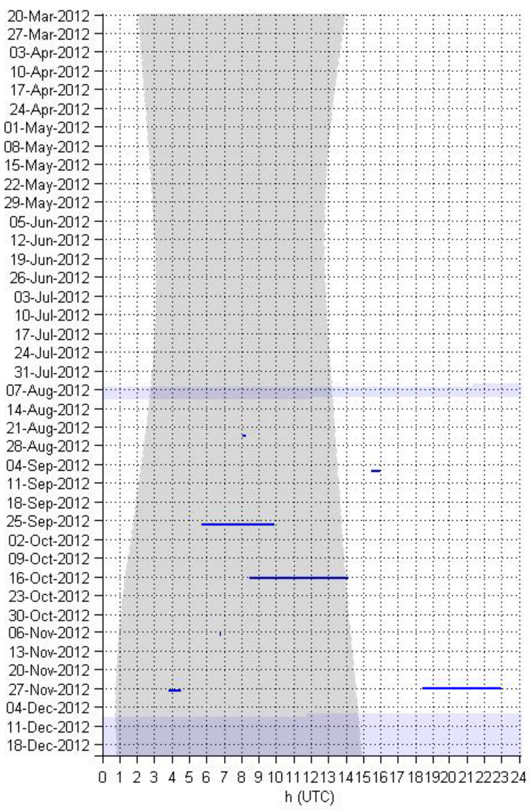


Figure 54. Sperm whale echolocation clicks in one-minute bins at site N. Gray shading denotes nighttime and light purple shading denotes lack of acoustic data.

Cuvier’s Beaked Whale

Cuvier’s beaked whales were detected throughout the year at all sites with the highest number of occurrences at site H (Figure 55 and Figure 56). There were differences in manual versus automated detection rates (Figure 57), although manual detections were overall less precise than automated detection.

- There was a peak in calling hours in October at both sites H and N.
- There was no preferred time of the day for echolocation click detections (Figure 57).

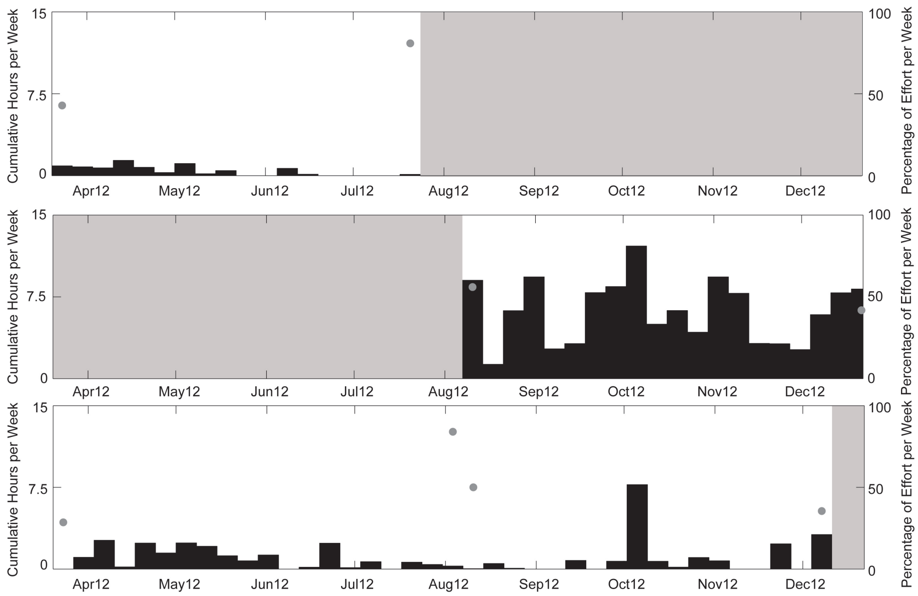


Figure 55. Weekly Cuvier’s beaked whale frequency modulated pulse presence, manually picked, at sites M (top), H (middle), and N (bottom) between March 2012 and December 2012.

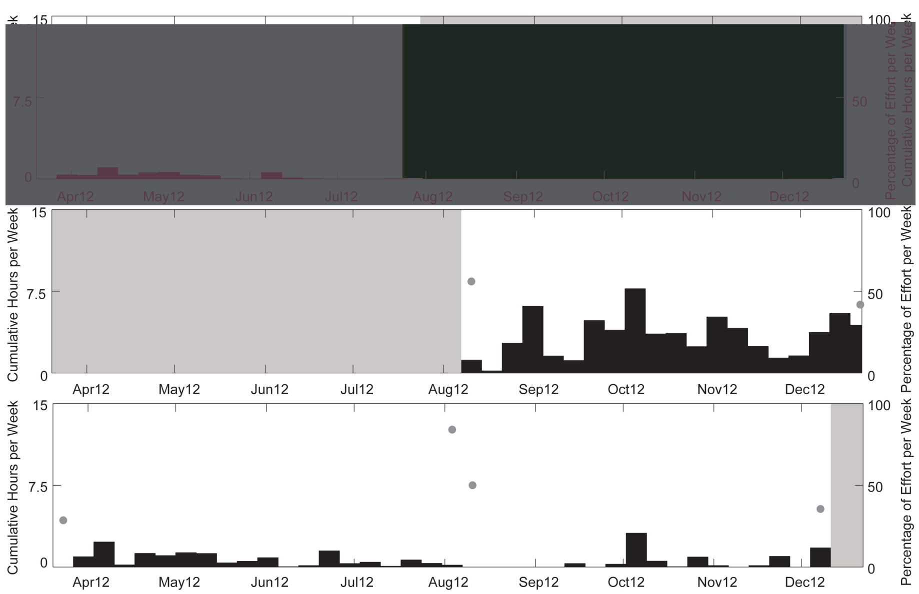


Figure 56. Weekly Cuvier’s beaked whale frequency modulated pulse presence, automatically detected, at sites M (top), H (middle), and N (bottom) between March 2012 and December 2012.

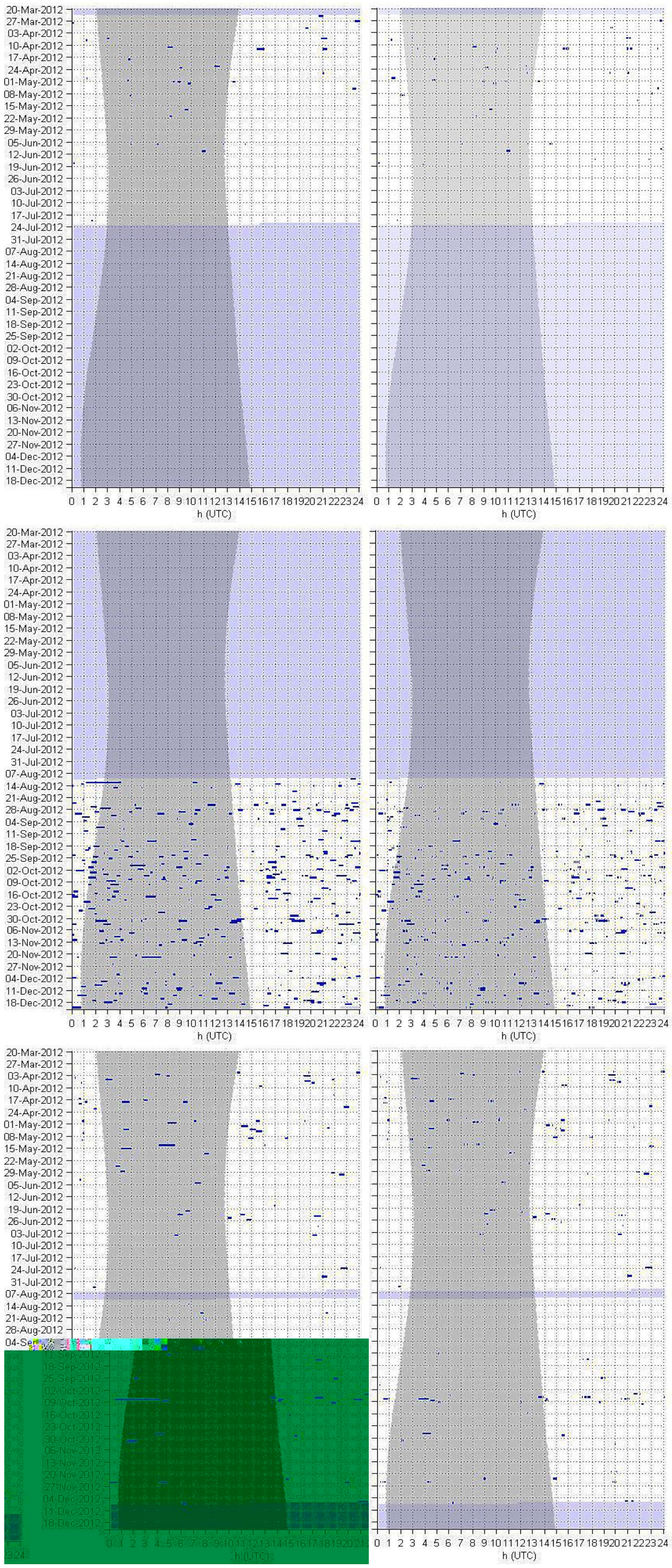


Figure 57. Cuvier's beaked whale at [TOP] site M, [MIDDLE] site H, and [BOTTOM] site N, manual picks (left) and automatic detection (right). Gray shading denotes nighttime and light purple shading denotes lack of acoustic data.

Baird's Beaked Whale

Baird's beaked whales were detected at sites M and N at various points throughout the year, with more prominent encounters in late June and July (Figure 58). More Baird's beaked whale detections occurred at night (Figure 59), although there may be too few detections to verify the significance of this pattern.

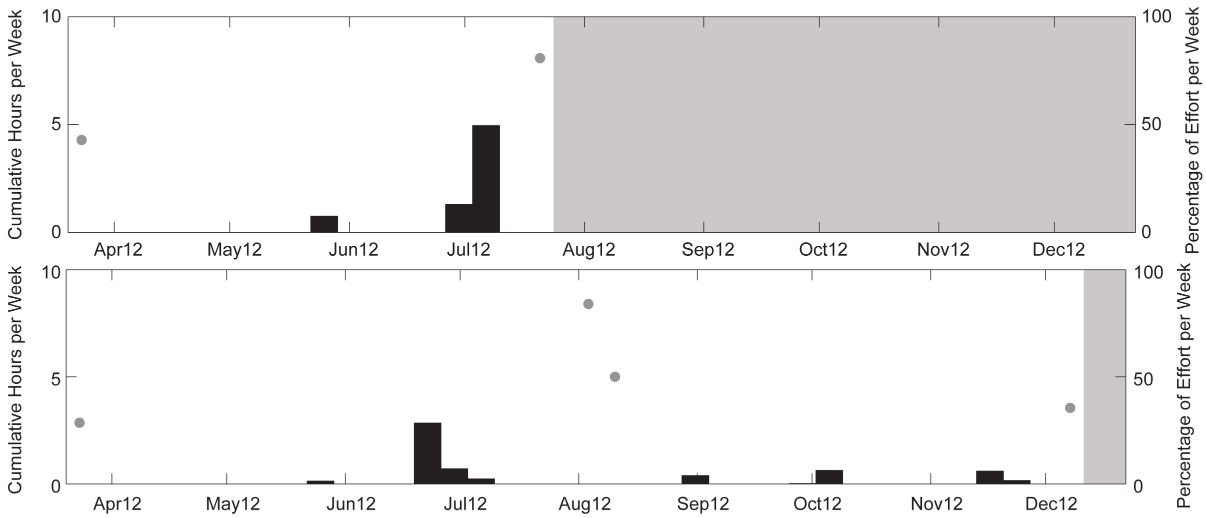


Figure 58. Weekly Baird's beaked whale frequency modulated pulse and click presence at sites M (top) and N (bottom) between March 2012 and December 2012.

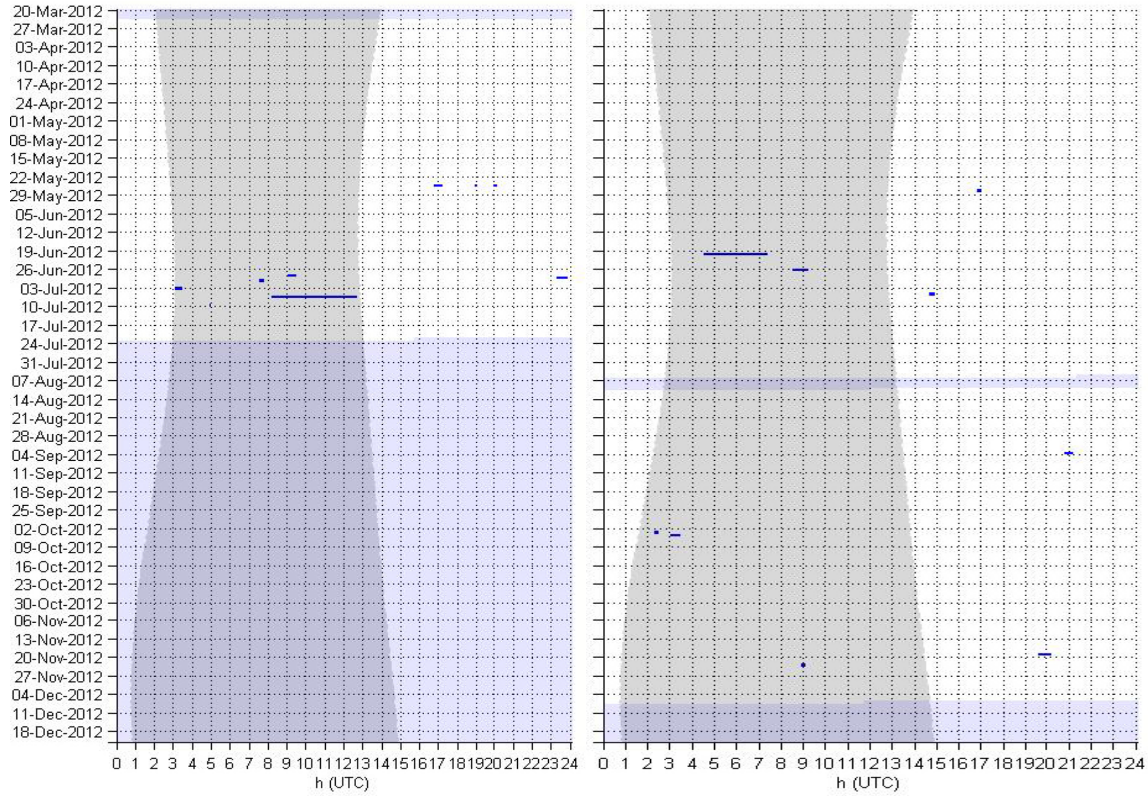


Figure 59. Baird's beaked whale echolocation signals in one-minute bins at sites M (left) and N (right). Gray shading denotes nighttime and light purple shading denotes lack of acoustic data.

BW43 FM Pulse Type

There were a few sporadic acoustic encounters of the BW43 FM pulse type; it was found in April, June, and October at site N (Figure 60). This signal type is possibly produced by Perrin's beaked whale (Baumann-Pickering *et al.* 2013a), a species that has only been known from five dead strandings along the southern California coast (Jefferson *et al.* 2008).

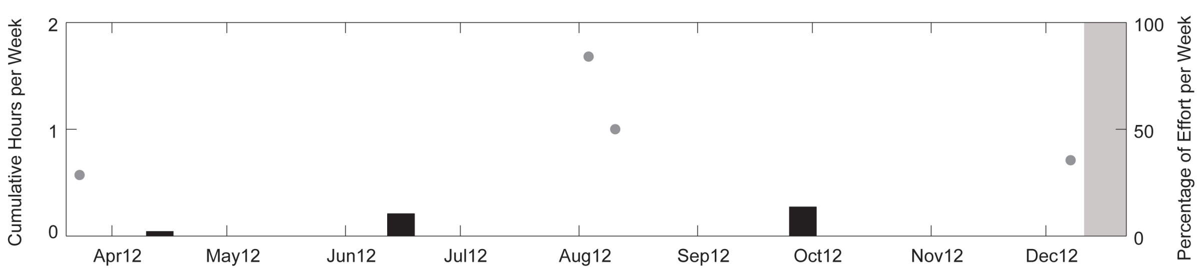


Figure 60. Weekly 43 kHz beaked whale frequency modulated pulse at site N between March 2012 and December 2012.

Anthropogenic Sounds

Broadband Ship Noise

Ship noise was a common anthropogenic sound, although more so at site N than at sites M or H (Figure 61). Site M is on the south side of the Channel Islands, on the route for ships embarking at the Ports of Los Angeles and Long Beach. Daily patterns of ship noise may show preference for times for ship arrival and departure to port (Figure 62).

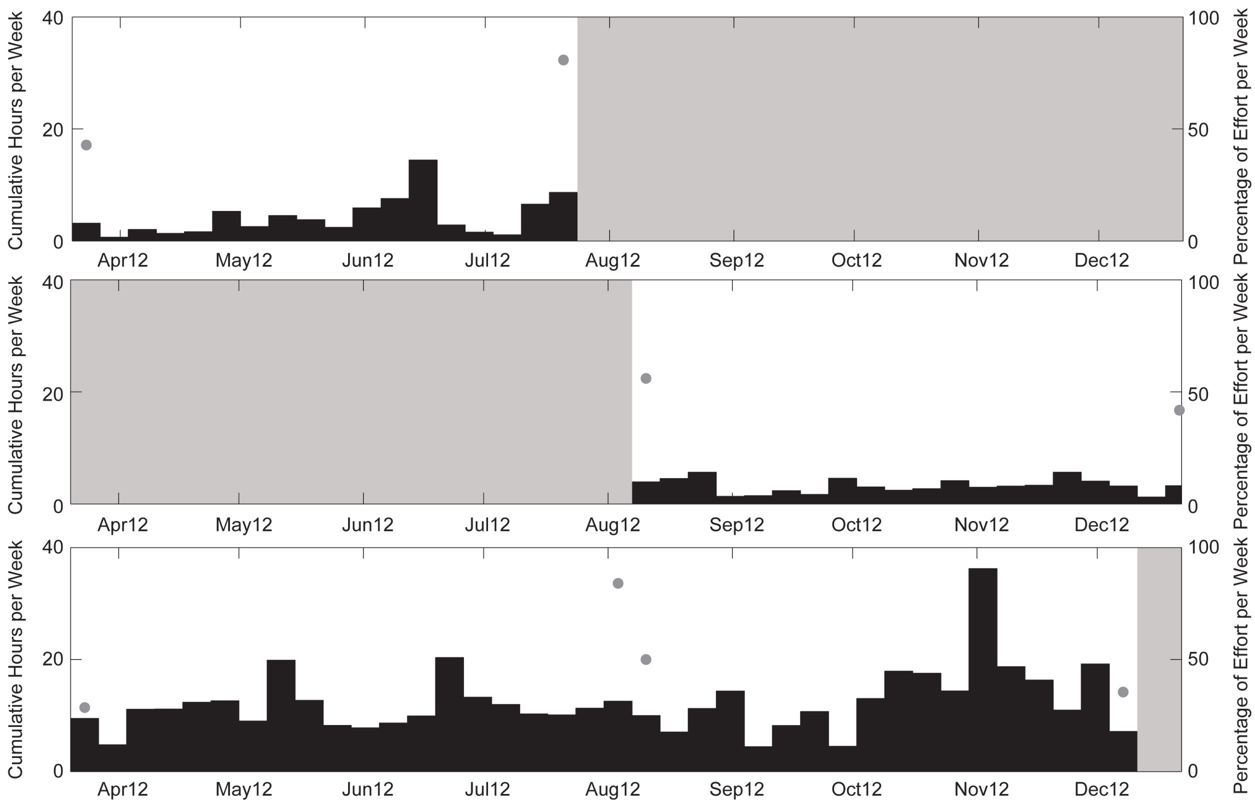


Figure 61. Weekly hours with broadband ship noise at sites M (top), H (middle), and N (bottom) between March 2012 and December 2012.

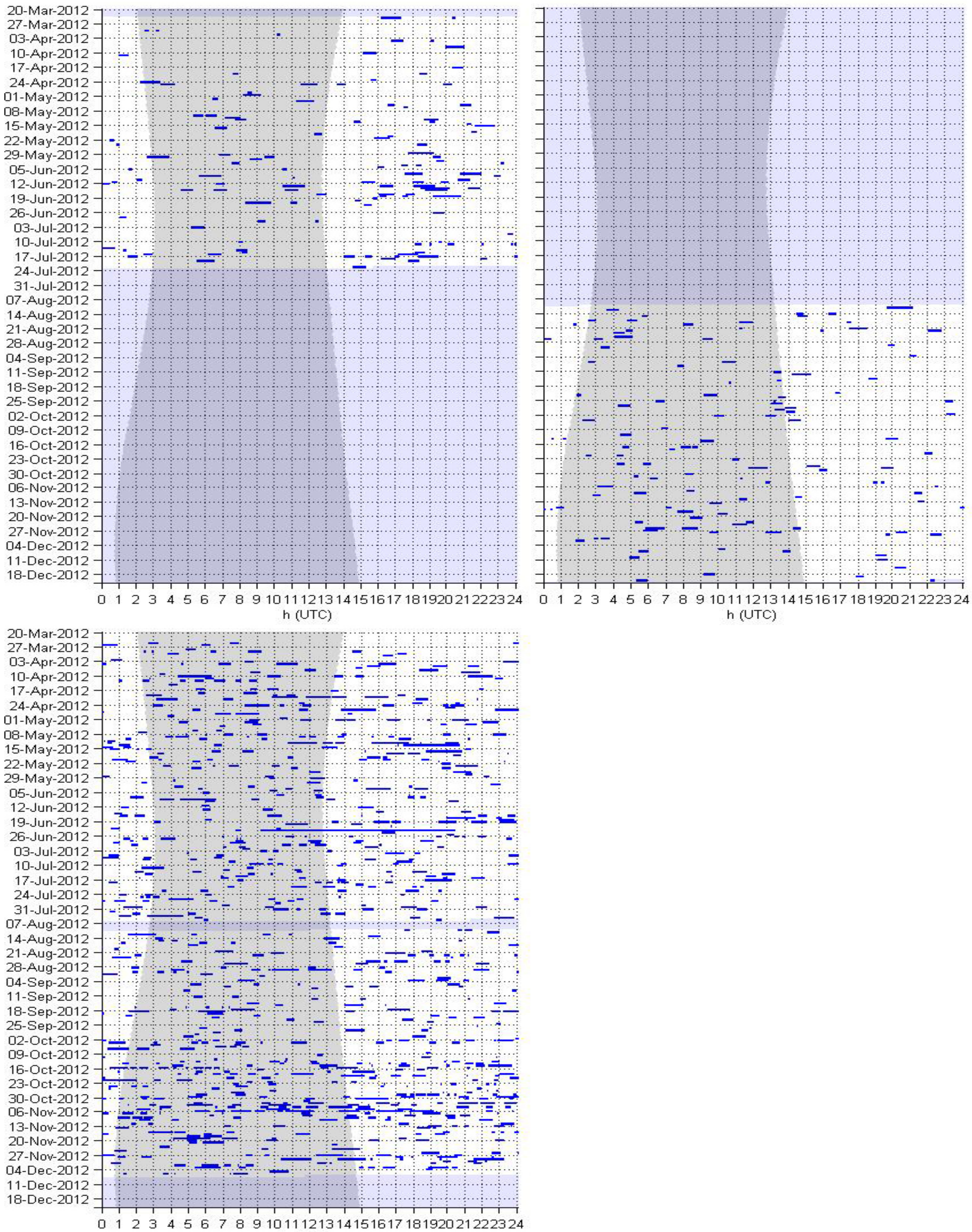


Figure 62. Broadband ship noise presence in one-minute bins at sites M (top left), H (top right), and N (bottom). Gray shading denotes nighttime and light purple shading denotes lack of acoustic data.

Mid-Frequency Active (MFA) Sonar

The dates for major naval training exercises that were conducted in the SOCAL region between March 2012 and December 2012 are listed in Table 3. Several distinct types of training exercises were held: Sustainment Exercise (SUSTEX), Integrated Anti-submarine Warfare Course II (IAC II), Composite Training Unit Exercise (COMPTUEX), and Joint Task Force Exercise (JTFEX).

In addition to the events above, unit level training took place outside of these time periods for major exercises.

- MFA sonar events were detected at all three sites throughout the period March 2012 – December 2012 (Figure 63).
- October and November had the largest number of hours of sonar pings detected, coincident with the COMPTUEX, IAC II, and JTFEX conducted during this time period (Table 3, Figure 64).
- Sonar usage outside of designated major exercises is likely attributable to unit level training.
- Fewer sonar pings and lower received levels were detected at site M than at sites H and N (Table 4). At site M a total of 321 MFA sonar pings were detected in the frequency range 2.4 – 4.5 kHz over a period of 120 days analyzed, with a maximum 139 dB pp re 1 µPa received level. The distribution of sonar ping received levels from site M shows a peak around 128 dB pp re 1 µPa (Figure 65, cumulative distribution in Figure 66).
- At site H a total of 18,919 MFA sonar pings were detected over a period of 132 days with some ping received levels above the instrument's maximum of 177 dB pp re 1 µPa. Distribution of sonar ping received levels at site H shows a peak around 122 dB pp re 1 µPa, and is long-tailed to higher levels (Figure 67, cumulative distribution Figure 68).
- A total of 57,851 MFA sonar pings were detected at site N over a period of 256 days with some ping received levels above the instrument's maximum of 176 dB pp re 1 µPa. At site N, distribution of sonar ping received levels shows a peak at about 125 dB pp re 1 µPa, and the distribution is long-tailed to higher levels (Figure 69, cumulative distribution Figure 70).

Table 3. Major naval training events in the SOCAL region between March 2012 and December 2012.

Begin Date	End Date	Type of Exercise
Jul 5, 2012	Jul 18, 2012	SUSTEX
Jul 12, 2012	Jul 14, 2012	IAC II
Oct 17, 2012	Nov 5, 2012	COMPTUEX
Oct 29, 2012	Nov 4, 2012	IAC II
Nov 6, 2012	Nov 12, 2012	JTFEX

Table 4. MFA sonar at 2.4 – 4.5 kHz, number of days analyzed, bouts, pings and maximum and median received level.

Site	# Days Analyzed	# Bouts	# Pings	Max dB P-P	Median dB P-P
M	120	88	321	139	123
H	132	128	18,919	177	125
N	256	305	57,851	176	128

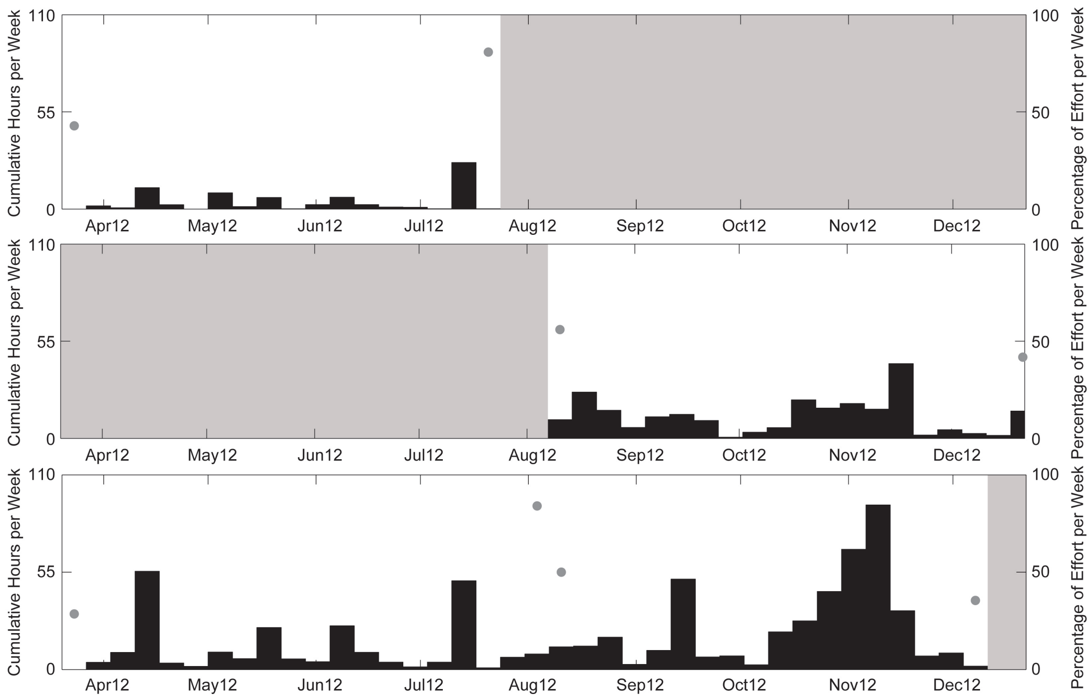


Figure 63. Weekly mid-frequency active (MFA) sonar presence at sites M (top), H (middle), and N (bottom) between March 2012 and December 2012.

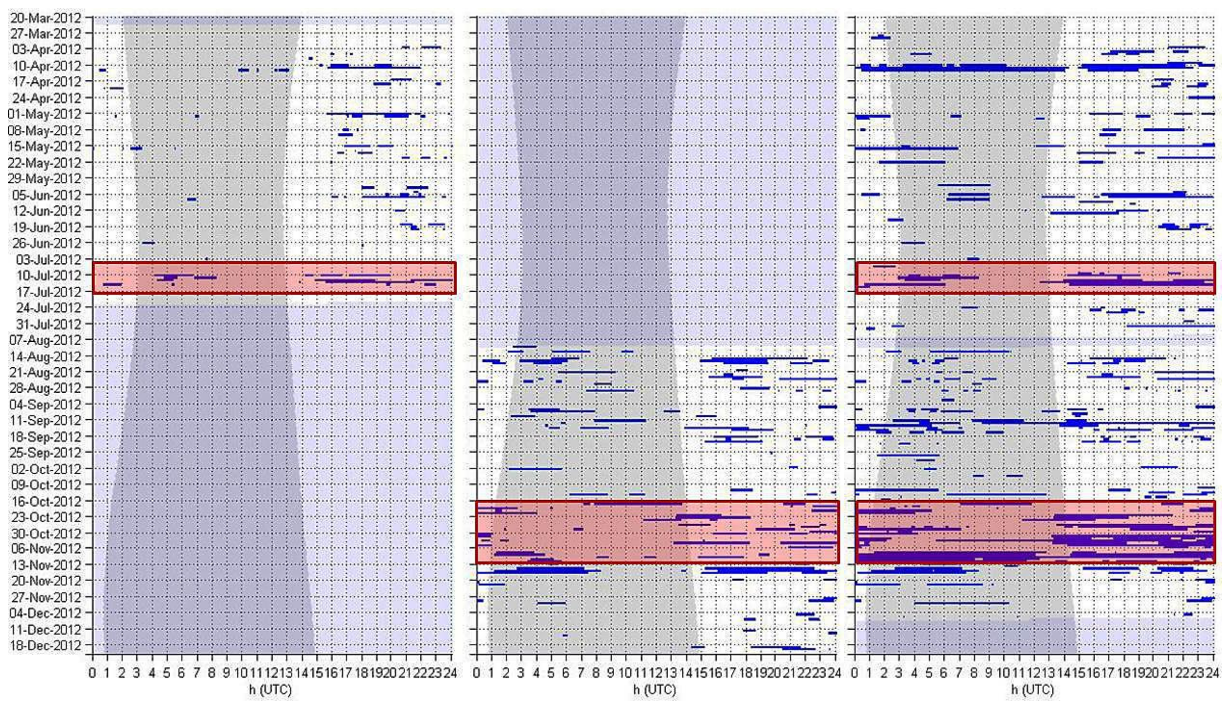


Figure 64. Major training events (shaded red) overlaid on MFA sonar detections (blue) for site M (left), site H (middle), and site N (right). Gray shading denotes nighttime and light purple shading denotes lack of acoustic data (no sonar detection possible).

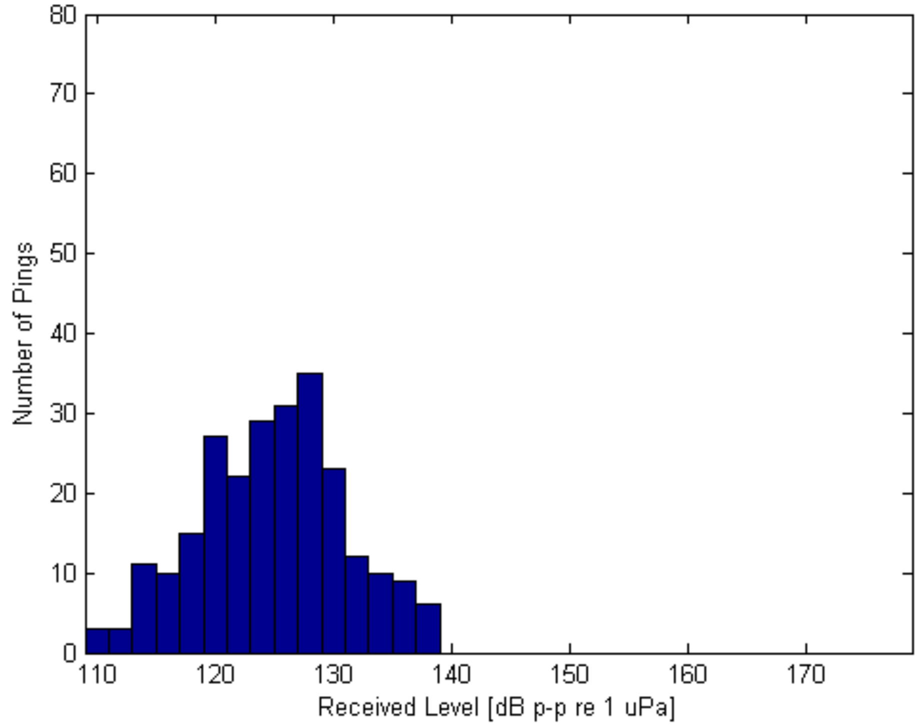


Figure 65. Distribution of number of MFA sonar pings by peak-to-peak received levels at site M.

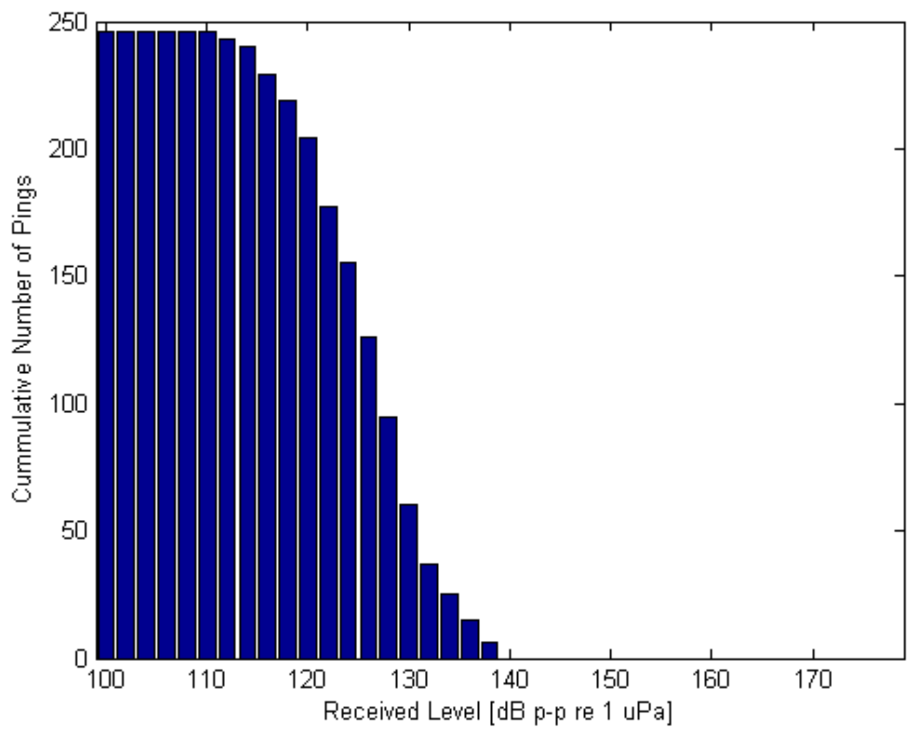


Figure 66. Cumulative distribution of MFA sonar peak-to-peak received levels at site M.

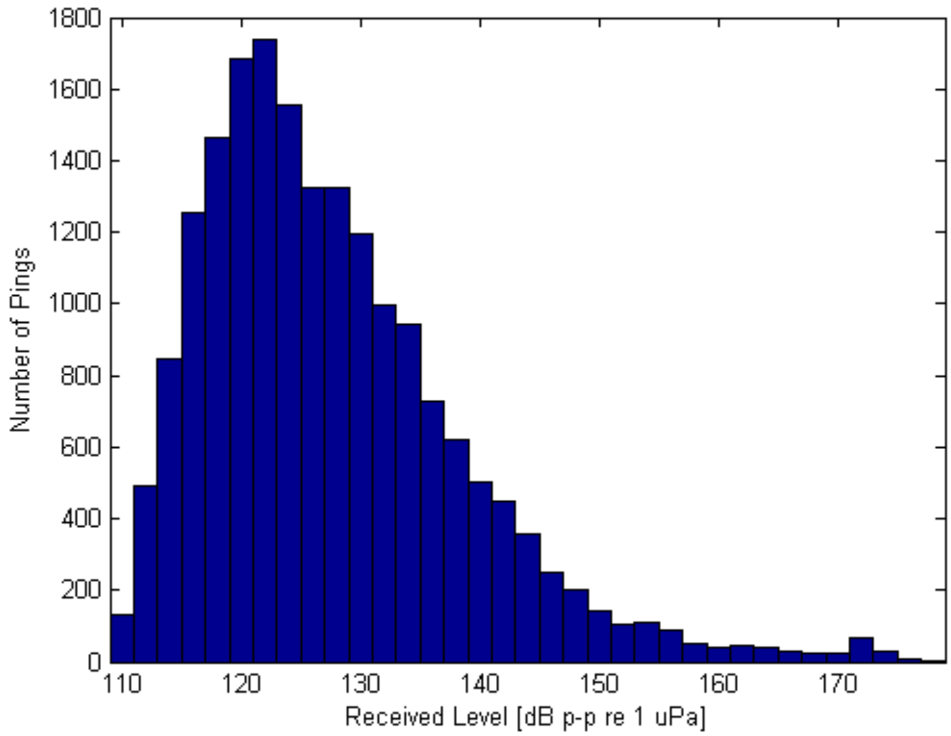


Figure 67. Distribution of number of MFA sonar pings by peak-to-peak received levels at site H.

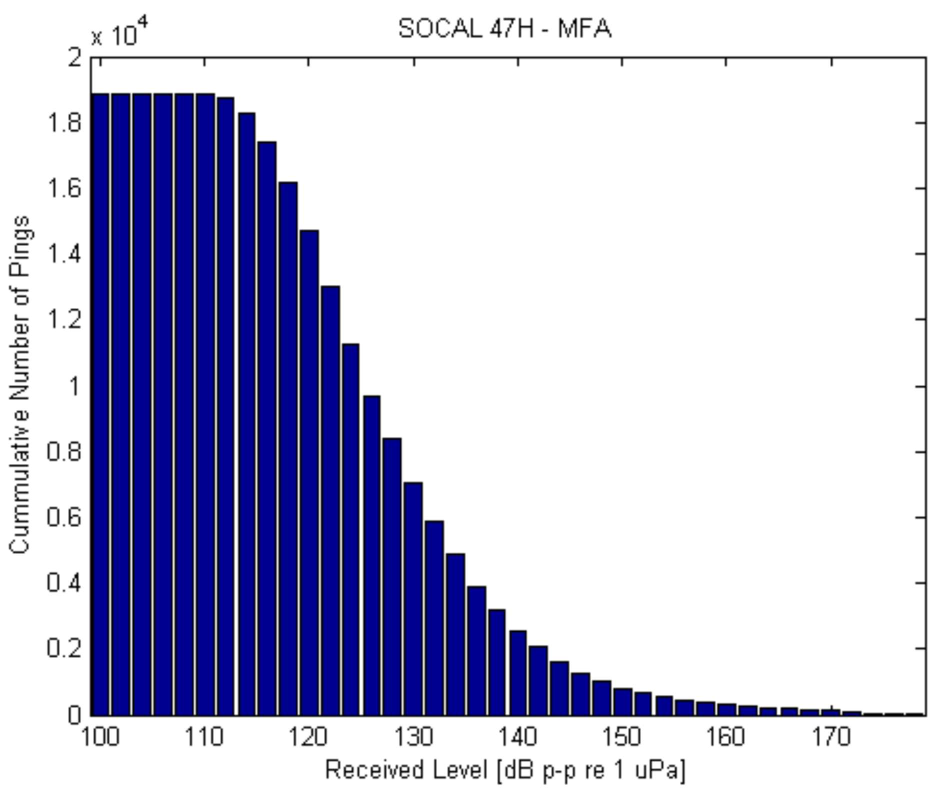


Figure 68. Cumulative distribution of MFA sonar peak-to-peak received levels at site H.

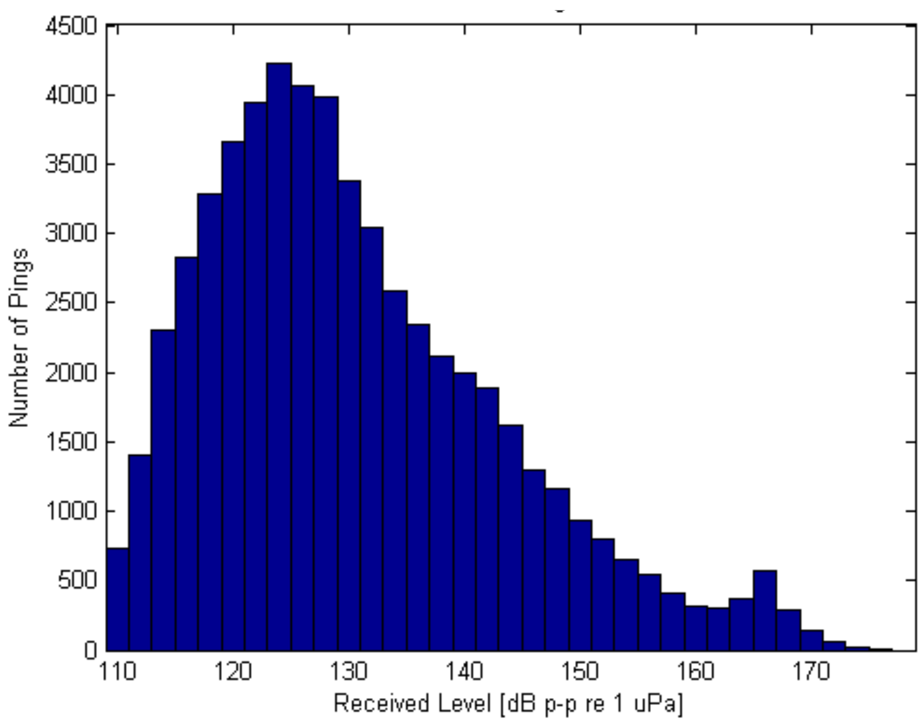


Figure 69. Cumulative distribution of MFA sonar peak-to-peak received levels at site N.

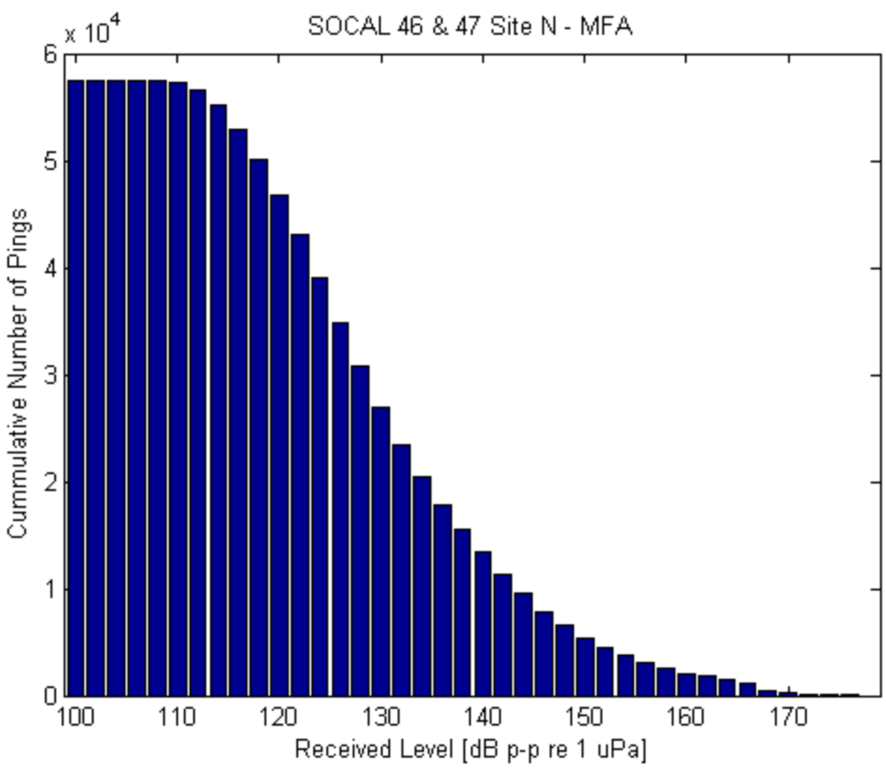


Figure 70. Cumulative distribution of MFA sonar peak-to-peak received levels at site N.

Naval Sonar > 5kHz

Sonar was also detected in the frequency band above 5 kHz (Figure 71). These sonars were detected at sites H and N, and at much lower rates than the MFA sonar at 2.4 – 4.5 kHz. A 26-hour continuous occurrence of this sonar type was observed in May at site N (Figure 72).

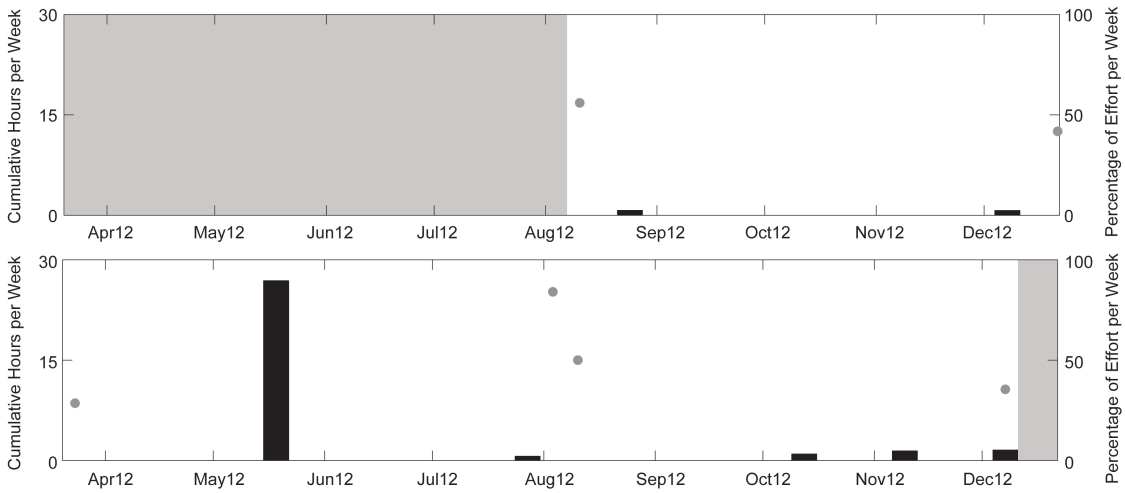


Figure 71. Weekly mid-frequency active sonar > 5kHz at sites H (top) and N (bottom) between March 2012 and December 2012.

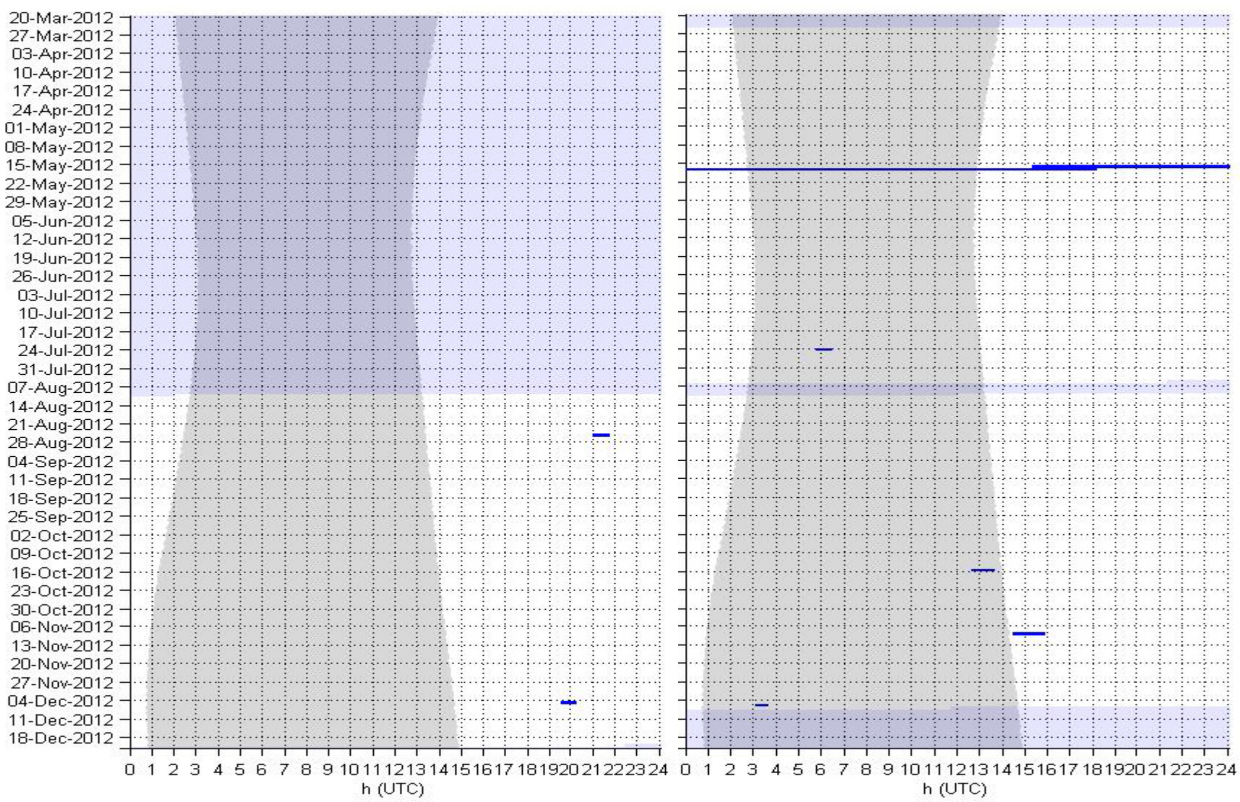


Figure 72. Naval sonar > 5 kHz in one-minute bins at sites H (left) and N (right). Gray shading denotes nighttime and light purple shading denotes lack of acoustic data.

High Frequency Active Sonar

High Frequency Active sonar was infrequently detected throughout the recording period, only at site N (Figure 73). There were a few clusters of presence in August and December; no discernible diel pattern was detected (Figure 74).

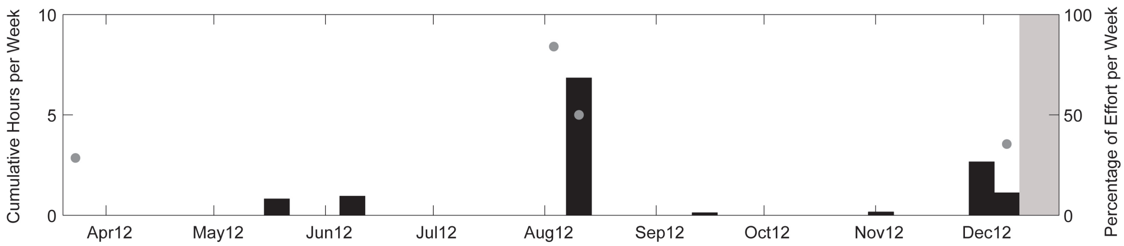


Figure 73. Weekly High Frequency Active sonar at site N between March 2012 and December 2012.

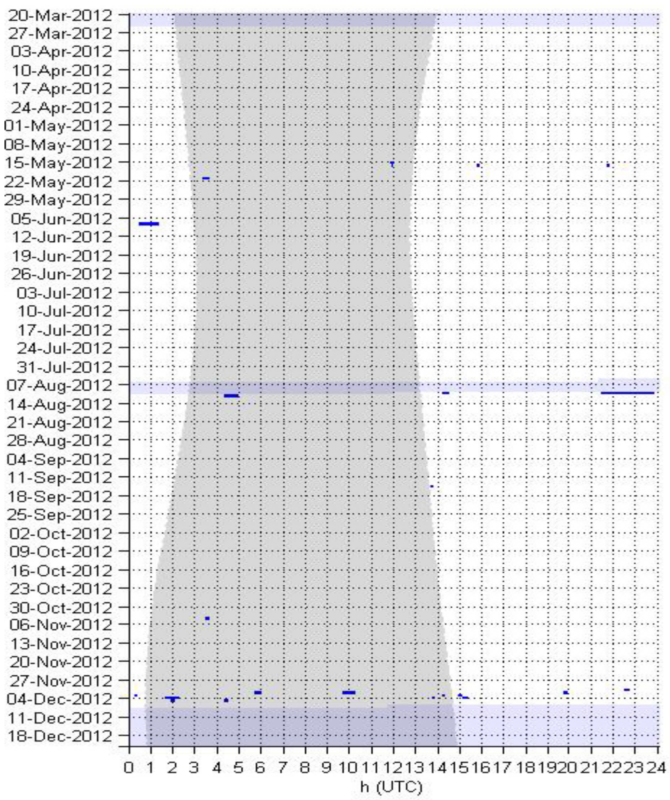


Figure 74. High Frequency Active sonar in one-minute bins at site N. Gray shading denotes nighttime and light purple shading denotes lack of acoustic data.

Acoustic Communication Systems

Acoustic communication systems were encountered exclusively at site N and only twice during the monitoring period (Figure 75). Too few acoustic communication systems were encountered to discern any diel pattern (Figure 76).

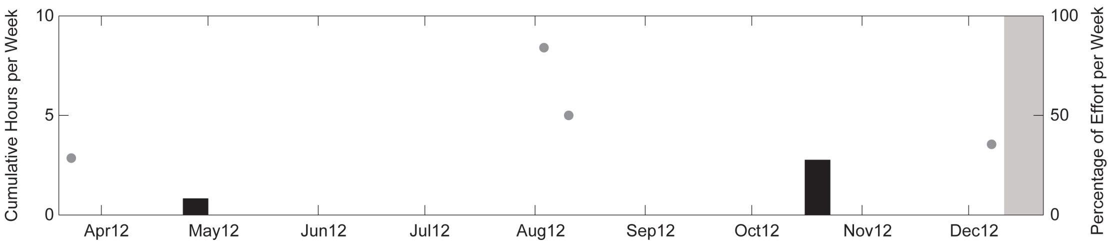


Figure 75. Weekly presence of acoustic communication at site N between March 2012 and December 2012.

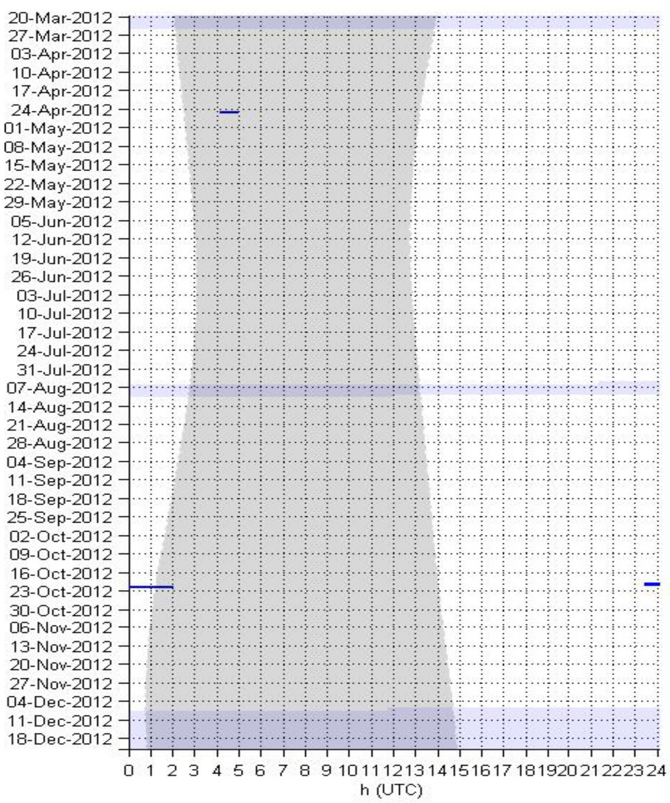


Figure 76. Acoustic communication systems detections in one-minute bins at site N. Gray shading denotes nighttime and light purple shading denotes lack of acoustic data.

Echosounders

Echosounder pings with a variety of primary frequencies (8 – 80 kHz) were found at all three sites (Figure 77).

- More echosounders were present at site N than at sites H and M.
- A notable peak in presence of echosounders occurred in October and November at site N and may correlate with naval exercises occurring at that time (Table 3).
- There may be diel patterns of echosounder use that vary by site and season (Figure 78).

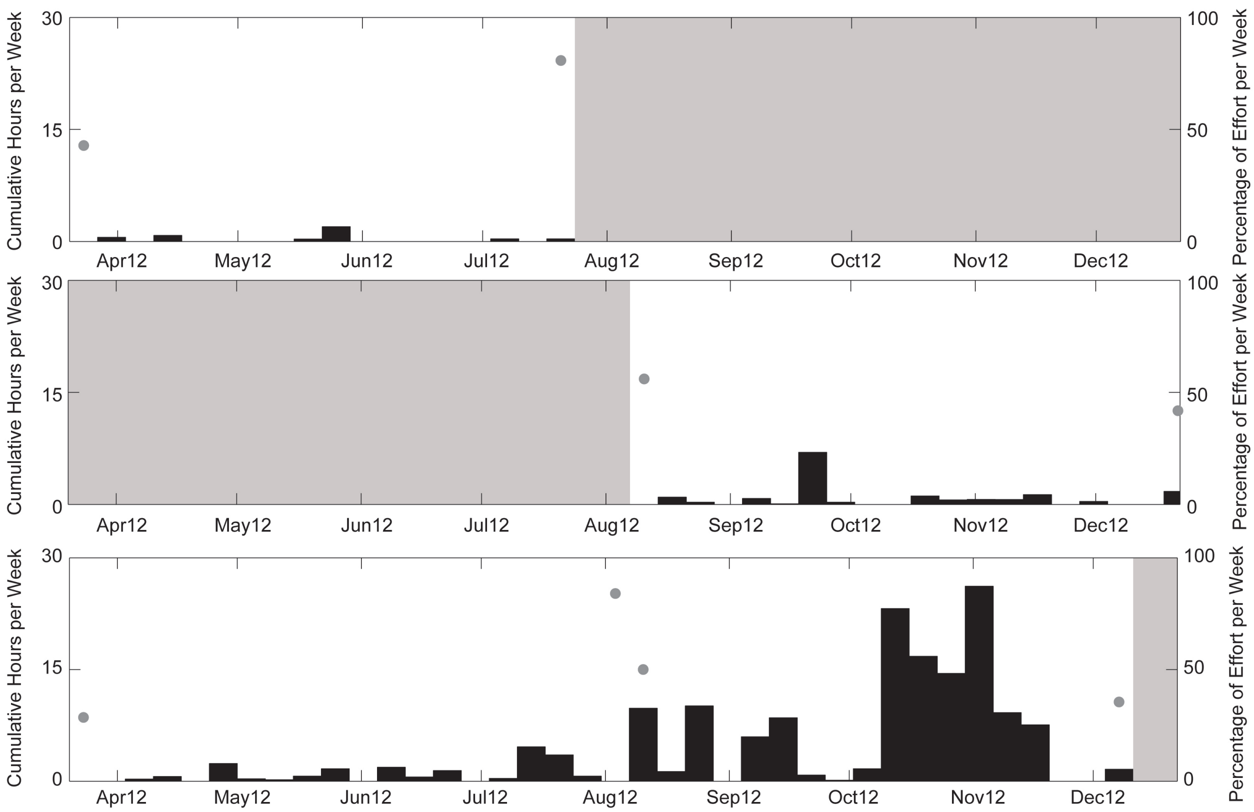


Figure 77. Weekly echosounder ping presence at sites M (top), H (middle), and N (bottom) between March 2012 and December 2012.

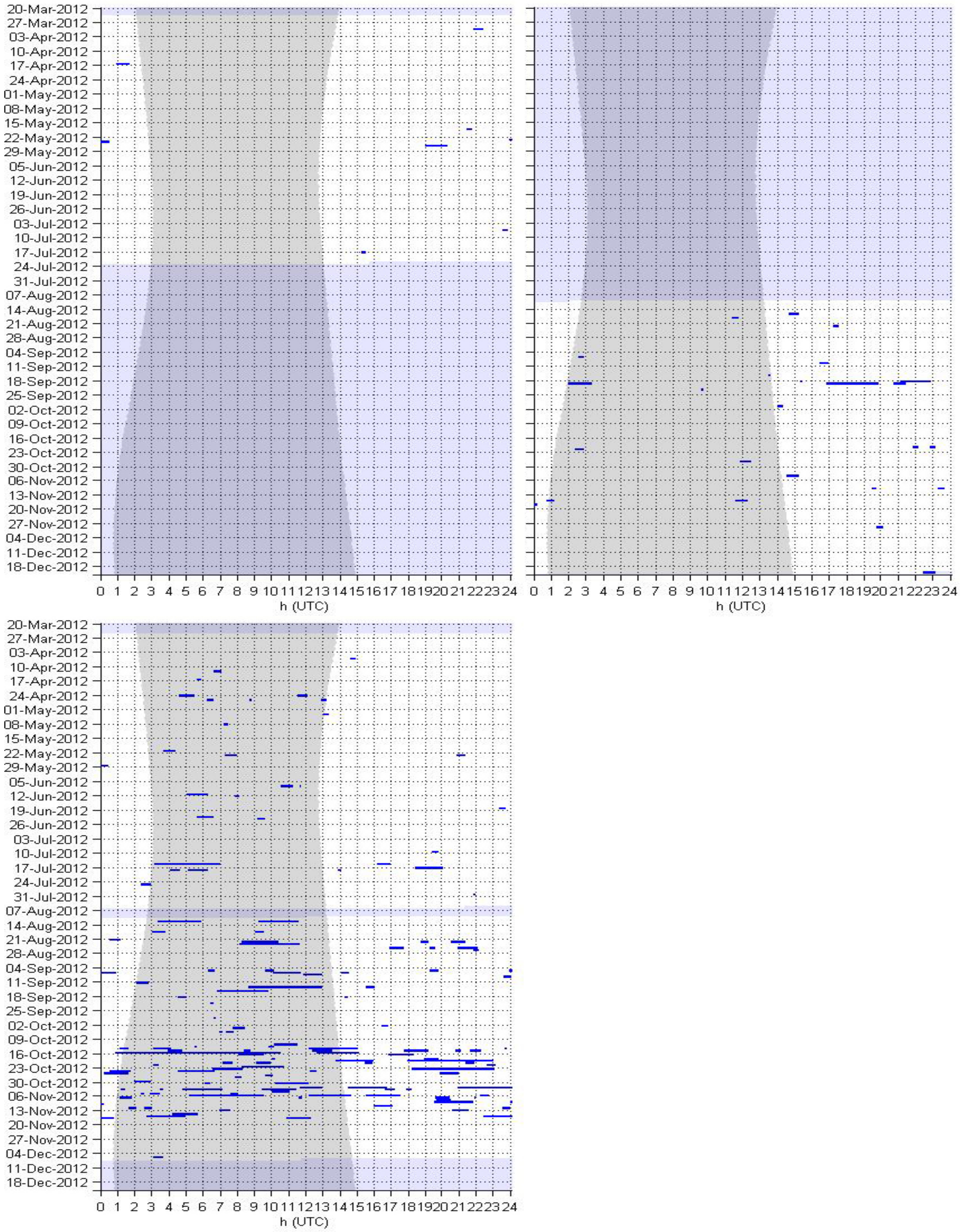


Figure 78. Echosounder ping detections in one-minute bins at sites M (top left), H (top right), and N (bottom). Gray shading denotes nighttime and light purple shading denotes lack of acoustic data.

Explosions

Sites H and N had higher numbers of hours per week with explosions than site M (Figure 79).

- There was a strong tendency toward nighttime occurrence, with little or no correlation to major training exercises (Figure 80).
- In addition, the relatively short time duration of the explosion reverberations suggests 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 further investigation is needed to verify this.
- Note that during a lull in nighttime explosions at site H in September, nighttime explosion presence increased at site N (Figure 80), indicating a possible geographic shift of fishing activity.

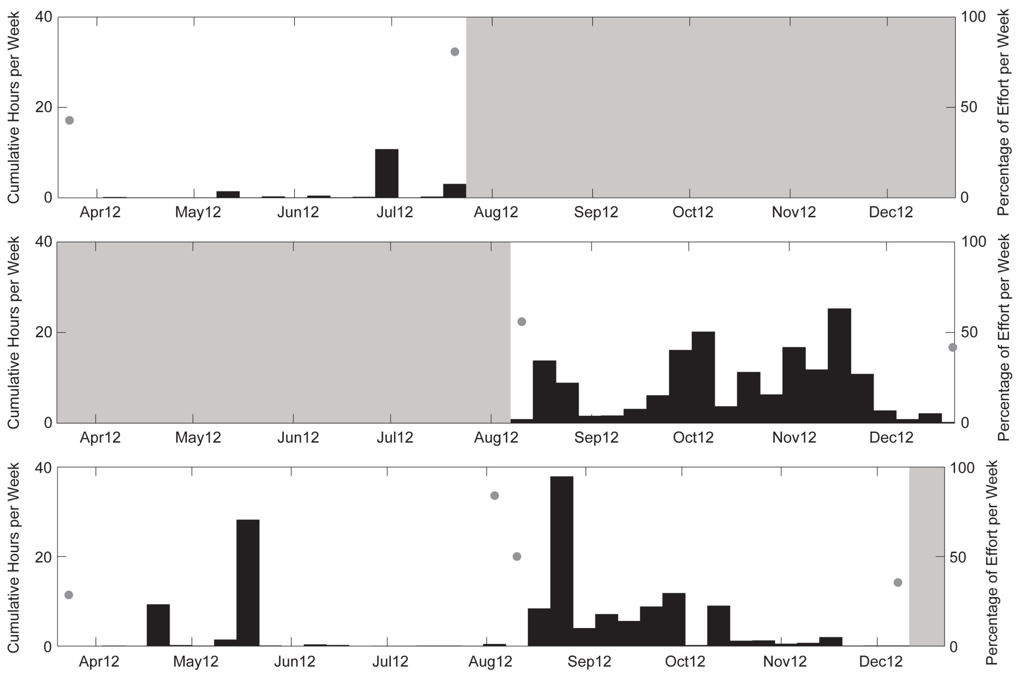


Figure 79. Weekly hours with explosions at sites M (top), H (middle), and N (bottom) between March 2012 and December 2012.

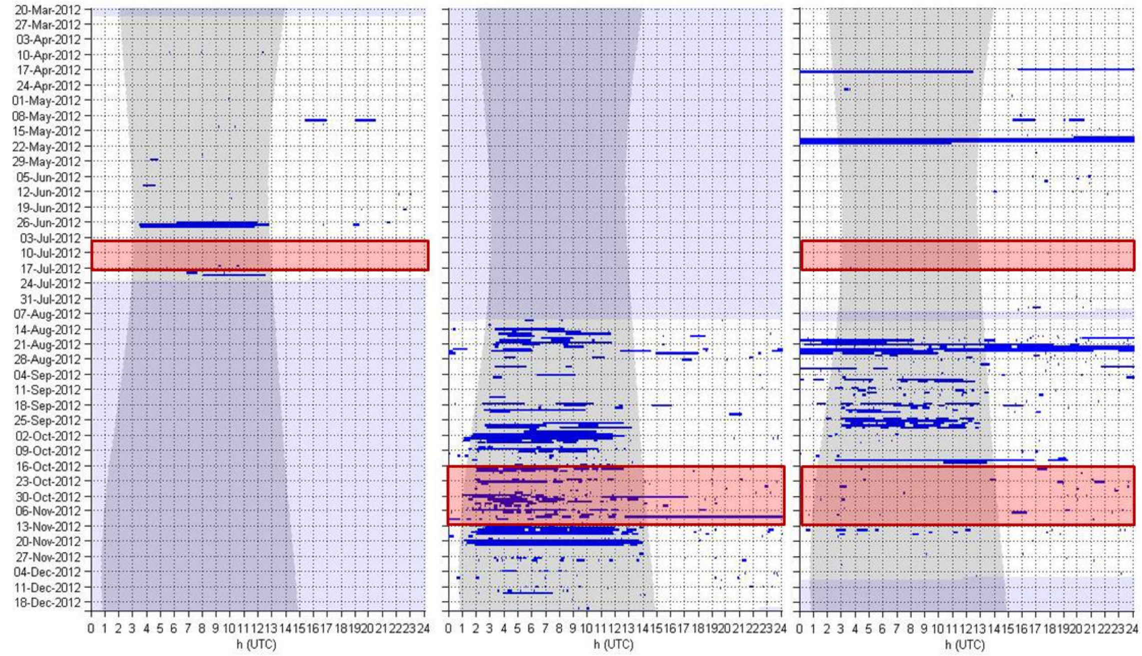


Figure 80. Major training events (shaded red) overlaid on explosions (blue) for site M (left), H (middle), and site N (right). Gray shading denotes nighttime and light purple shading denotes lack of acoustic data.

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