

Passive Acoustic Monitoring for Marine Mammals in the SOCAL Range Complex January – July 2014

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Blue whale, photo by Amanda J. Debich

MPL TECHNICAL MEMORANDUM # 554
February 26, 2015

REPORT DOCUMENTATION PAGE			<i>Form Approved</i> OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Service, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.				
1. REPORT DATE (DD-MM-YYYY) 01-2015	2. REPORT TYPE Monitoring report		3. DATES COVERED (From - To) Jan- Jul 2014	
4. TITLE AND SUBTITLE Passive Acoustic Monitoring for Marine Mammals in the SOCAL Naval Training Area Dec Jan- Jul 2014			5a. CONTRACT NUMBER	
			5b. GRANT NUMBER W9126G-14-2-0040	
			5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Amanda J. Debich, Simone Baumann-Pickering, Ana Širović, John A. Hildebrand, Sean T. Herbert, Sarah C. Johnson, Ally C. Rice, Jenny S. Trickey, Sean M. Wiggins			5d. PROJECT NUMBER	
			5e. TASK NUMBER	
			5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Whale Acoustics Laboratory, Marine Physical Laboratory, Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA 92037			8. PERFORMING ORGANIZATION REPORT NUMBER MPL TECHNICAL MEMORANDUM # 554	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Commander, U.S.Pacific Fleet, 250 Makalapa Dr., Pearl Harbor, HI			10. SPONSOR/MONITOR'S ACRONYM(S)	
			11. SPONSORING/MONITORING AGENCY REPORT NUMBER	
12. DISTRIBUTION AVAILABILITY STATEMENT Approved for public release; distribution is unlimited				
13. SUPPLEMENTARY NOTES				
14. ABSTRACT Passive acoustic monitoring was conducted in the Navy's Southern California Range Complex from January to July 2014 to detect marine mammal and anthropogenic sounds. High-frequency Acoustic Recording Packages (HARPs) recorded sounds between 10 Hz and 100 kHz at three locations: west of San Clemente Island (1,000 m depth, site H), southwest of San Clemente Island (1,200 m depth, site N), and west of La Jolla, California (550 m depth, site P). Sites H and N are located offshore, whereas, site P is located nearer to the coast.				
15. SUBJECT TERMS Monitoring, marine mammal, passive acoustic, Southern California Range Complex, Hawaii-Southern California Training and Testing				
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified	UU	43
			19a. NAME OF RESPONSIBLE PERSON Department of the Navy	
			19b. TELEPHONE NUMBER (Include area code) (619) 767-1567	

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Executive Summary

Passive acoustic monitoring was conducted in the Navy's Southern California Range Complex from January to July 2014 to detect marine mammal and anthropogenic sounds. High-frequency Acoustic Recording Packages (HARPs) recorded sounds between 10 Hz and 100 kHz at three locations: west of San Clemente Island (1,000 m depth, site H), southwest of San Clemente Island (1,200 m depth, site N), and west of La Jolla, California (550 m depth, site P). Sites H and N are located offshore, whereas, site P is located nearer to the coast.

Data analysis was performed using automated computer algorithms, augmented with analyst scans of long-term spectral averages (LTSAs) and spectrograms. Calls of three baleen whale species were detected using automatic algorithms: blue whale B calls, fin whale 20 Hz calls, and humpback whale calls. All three species were present at all sites, but least common at site P. Blue whale B calls increased in June and July, but were detected during all months. Fin whale acoustic index, representative of 20 Hz calls, was high during January – April. Humpback whale calling peaked in March – April at site H and in January at site P.

Frequency modulated (FM) echolocation pulses from Cuvier's beaked whales were regularly detected at sites H and N, but not at site P. These detections peaked in April and June. There was an additional beaked whale-like FM pulse type, BW43, possibly produced by Perrin's beaked whales (Baumann-Pickering *et al.*, 2014), that was detected infrequently and only at site N. No other beaked whale signal types were detected.

Mid-Frequency Active (MFA) sonar was found at all sites. Sites P and N had the highest maximum received levels, but site P had the fewest number of MFA sonar packets. Site N had the most MFA sonar packet detections and highest cumulative sound exposure levels concurrent with major naval exercises during May-June, while site H had the lowest maximum received and sound exposure levels. Low Frequency Active (LFA) sonar with frequency between 500 Hz and 1,000 Hz was detected intermittently at sites H and P. LFA sonar detections at site N were limited to July. Explosions were detected at all sites, but were most prevalent at site H. Explosion detections peaked in June across sites. Temporal and spectral parameters, received levels, and the nighttime pattern of these explosive events suggest association with fishing, specifically the use of seal bombs.

Project Background

The Navy's Southern California (SOCAL) Range Complex is located in the Southern California Bight and adjacent deep waters to the west. 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 near the SOCAL Range Complex with support from the Pacific Fleet under contract to the Naval Postgraduate School. The goal of this effort was to characterize the vocalizations of marine mammal species present in the area, to determine their seasonal presence patterns, and to evaluate the potential for impact from naval operations. In this current effort, the goal was focused on exploring the seasonal presence of a subset of species of particular interest, including blue, fin, and humpback whales, as well as beaked whales.

This report documents the analysis of data recorded by three High-frequency Acoustic Recording Packages (HARPs) that were deployed within the SOCAL Range Complex in January 2014 and collected data through July 2014. The three recording sites include one to the west (site H), and one to the southwest (site N) of San Clemente Island, and one west of La Jolla, California (site P) (Figure 1). Data from site H were analyzed for the January through July 2014 time period; site N data were analyzed for the January through February 2014 and April through July 2014 time periods; site P data were analyzed January through June 2014 (Table 1 and Table 2).

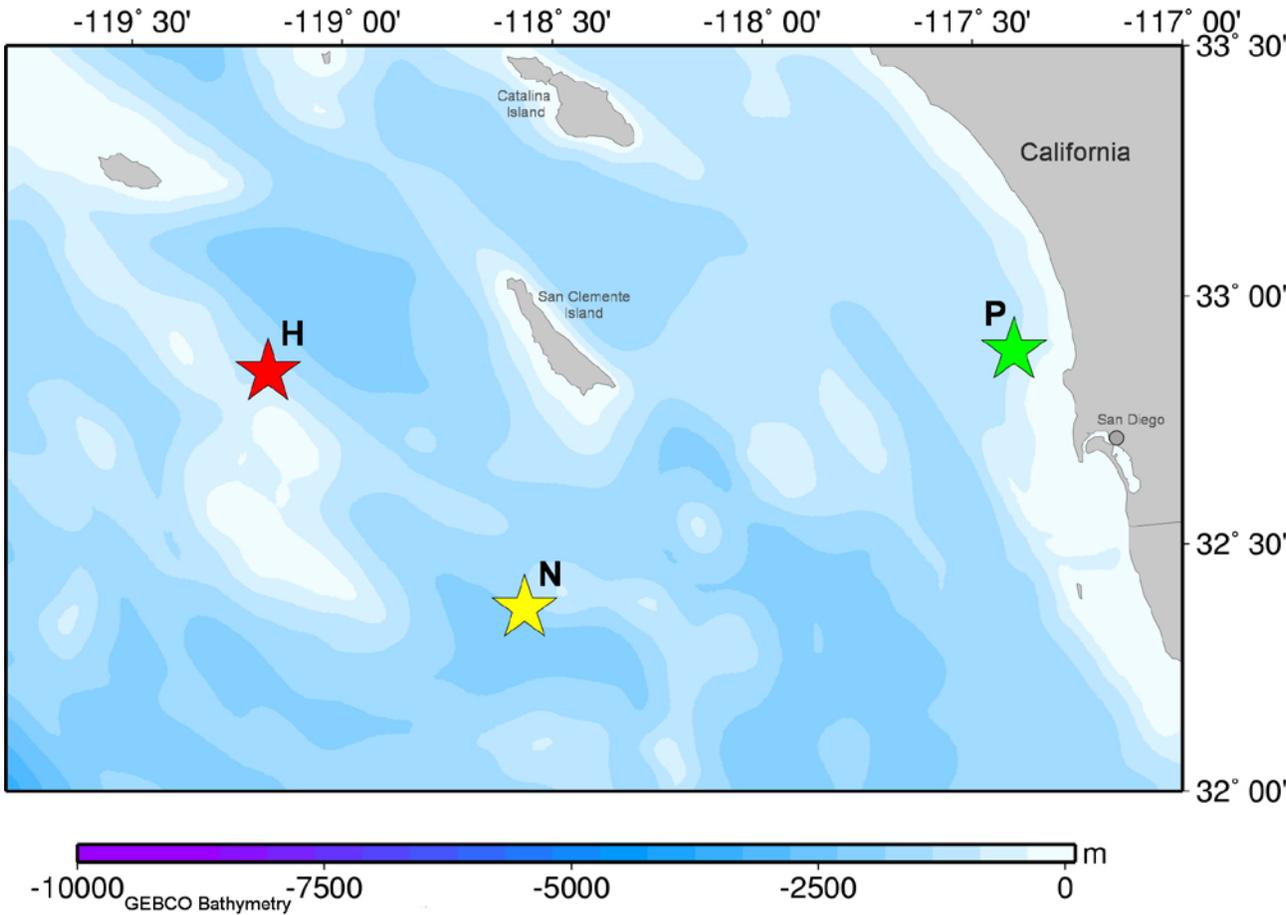


Figure 1. Locations of High-frequency Acoustic Recording Packages (HARPs) at sites H, N, and P deployed in the SOCAL study area January through July 2014. Color is bathymetric depth.

Table 1. SOCAL Range Complex acoustic monitoring since January 2009. Periods of instrument deployment analyzed in this report are shown in bold.

Deployment Name	Site H Monitoring Period	# Hours	Site N Monitoring Period	# Hours
SOCAL 31	1/13/09 – 3/08/09	1320	1/14/09 – 3/09/09	1296
SOCAL 32	3/14/09 – 5/07/09	1320	3/14/09 – 5/07/09	1320
SOCAL 33	5/19/09 – 6/13/09	600	5/19/09 – 7/12/09	1296
SOCAL 34	7/23/09 – 9/15/09	1296	7/22/09 – 9/15/09	1320
SOCAL 35	9/25/09 – 11/18/09	1320	9/26/09 – 11/19/09	1296
SOCAL 36	12/6/09 – 1/29/10	1296	12/6/09 – 1/26/10	1224
SOCAL 37	1/30/10 – 3/22/10	1248	1/31/10 – 3/26/10	1296
SOCAL 38	4/10/10 – 7/22/10	2472	4/11/10 – 7/18/10	2352
SOCAL 40	7/23/10 – 11/8/10	2592	7/23/10 – 11/8/10	2592
SOCAL 41	12/6/10 – 4/17/11	3192	12/7/10 – 4/09/11	2952
SOCAL 44	5/11/11 – 10/12/11	2952	5/12/10 – 9/23/11	3216
SOCAL 45	10/16/11 – 3/5/12	3024	10/16/11 – 2/13/12	2904
SOCAL 46	3/25/12 – 7/21/12	2856	3/25/12 – 8/5/12	3216
SOCAL 47	8/10/12 – 12/20/12	3192	8/10/12 – 12/6/12	2856
SOCAL 48	12/21/2012 – 4/30/2013	3140	12/20/2012 – 5/1/2013	3155
SOCAL 49	-	-	5/2/2013 – 9/11/2013	3156
SOCAL 50	9/10/2013 – 1/6/2014	2843	-	-
SOCAL 51	1/7/2014 – 4/3/2014	2082	1/7/2014 – 2/16/2014	956
SOCAL 52	4/4/2014 – 7/30/2014	2814	4/4/2014 – 7/30/2014	2817

Table 2. Site P acoustic monitoring since 2014. Periods of instrument deployment analyzed in this report are shown in bold.

Deployment Name	Site P Monitoring Period	# Hours
LJ 23-P	1/25/2014 – 3/4/2014	936
LJ 26-P	3/6/2014 – 6/27/2014	2711

Methods

High-frequency Acoustic Recording Package

HARPs were used to record marine mammal sounds and characterize anthropogenic sounds and ambient noise in the SOCAL area. HARPs can record underwater sounds from 10 Hz up to 160 kHz and are capable of approximately 300 days of continuous data storage. The HARPs were in a seafloor package configuration with the hydrophones suspended 10 m above the seafloor. Each HARP is calibrated in the laboratory to provide a quantitative analysis of the received sound field. Representative data loggers and hydrophones were also calibrated at the Navy's TRANSDEC facility to verify the laboratory calibrations (Wiggins and Hildebrand, 2007).

Data Collected

Acoustic data have been collected at three sites within the SOCAL Range Complex using autonomous HARPs sampling at 200 kHz (Table 1 and 2). The sites are designated site H (32° 56.54'N, 119° 10.22' W, depth 1,000 m), site N (32° 22.18'N, 118° 33.77'W, depth 1,200 m), and site P (32° 53.42'N, 117° 24.06'W, depth 550 m). Each HARP sampled continuously at 200 kHz. At each site there were two instrument deployments. Site H yielded data from January 7 to July 30 with a gap on April 3-4 for instrument recovery and redeployment. Likewise site P yielded data from January 25 to June 27 with a gap for recovery and redeployment on March 3-6. Site N had data from January 7 to February 16, and a data gap of 47 days occurred between instrument deployments, with data again collected from April 4 to July 30. A total of 12,312 hours, covering 513 days of acoustic data were recorded in the deployments analyzed in this report.

Data Analysis

Most analyses were conducted using automated detectors for whale or anthropogenic sound sources. Analysis was focused on the following species: blue whales (*Balaenoptera musculus*), fin whales (*B. physalus*), humpback whales (*Megaptera novaeangliae*), and Cuvier's beaked whales (*Ziphius cavirostris*). Individual blue whale B calls, humpback whale calls, and beaked whale echolocation clicks, as well as explosions, were detected automatically using computer algorithms. Fin whale 20 Hz calls were detected automatically using an energy detection method and are reported as fin whale acoustic index. Details of all automatic detection methods are described below.

Mid-frequency active (MFA) and low-frequency active (LFA) sonars were detected using a combination of manual and automatic methods. In both cases, the start and end times of sonar events were logged manually by examining the acoustic data as power spectra with 5 second time averages and 10 Hz frequency bins (Long-Term Spectral Averages - LTSAs). During manual analysis, when a sound of interest was identified in the LTSA but its origin was unclear, the waveform and spectrogram were examined to further classify the sound to source type. Signal classification was carried out by comparison to known signal spectral and temporal characteristics. Subsequently, an automatic detector was used between the start and end times of MFA sonar events to quantify its occurrence and levels. Details of this method are described in Wiggins (2015) and summarized below.

We summarize results of the acoustic analysis on data collected between January and July 2014 at sites H, N, and P. We discuss seasonal occurrence and relative abundance of calls for different species and anthropogenic sounds that were consistently identified in the data, as well as the characteristics of low-frequency (<1,000 Hz) ambient noise at these sites.

Blue Whales

Blue whales produce a variety of calls worldwide (McDonald *et al.*, 2006). Blue whale calls recorded in the eastern North Pacific include the Northeast Pacific blue whale B call (Figure 2), which is a geographically distinct call potentially associated with mating functions (McDonald *et al.*, 2006; Oleson *et al.*, 2007). B calls are low-frequency (fundamental frequency < 20 Hz), have long duration (> 10 s), and often are regularly repeated.

Northeast Pacific blue whale B calls

Blue whale B calls were detected automatically using the spectrogram correlation method (Mellinger and Clark, 1997). The detection kernel was based on frequency and temporal characteristics measured from 30 calls recorded in the data set, each call separated by at least 24 hours. The kernel was comprised of four segments, three 1.5 s and one 5.5 s long, for a total duration of 10 s. Separate kernels were used for the periods January through April 2014, and May through July 2014. The kernel for data recorded January through April 2014 was defined as sweeping from 46.4 to 45.7 Hz, 45.7 to 45.0 Hz, 45.0 to 44.6 Hz, and 44.6 to 43.7 Hz. The kernel for data recorded from April through July 2014 was defined as sweeping from 46.4 to 45.8 Hz, 45.8 to 45.1 Hz, 45.1 to 44.6 Hz, and 44.6 to 43.7 Hz. The bandwidth for all kernels was 2 Hz.

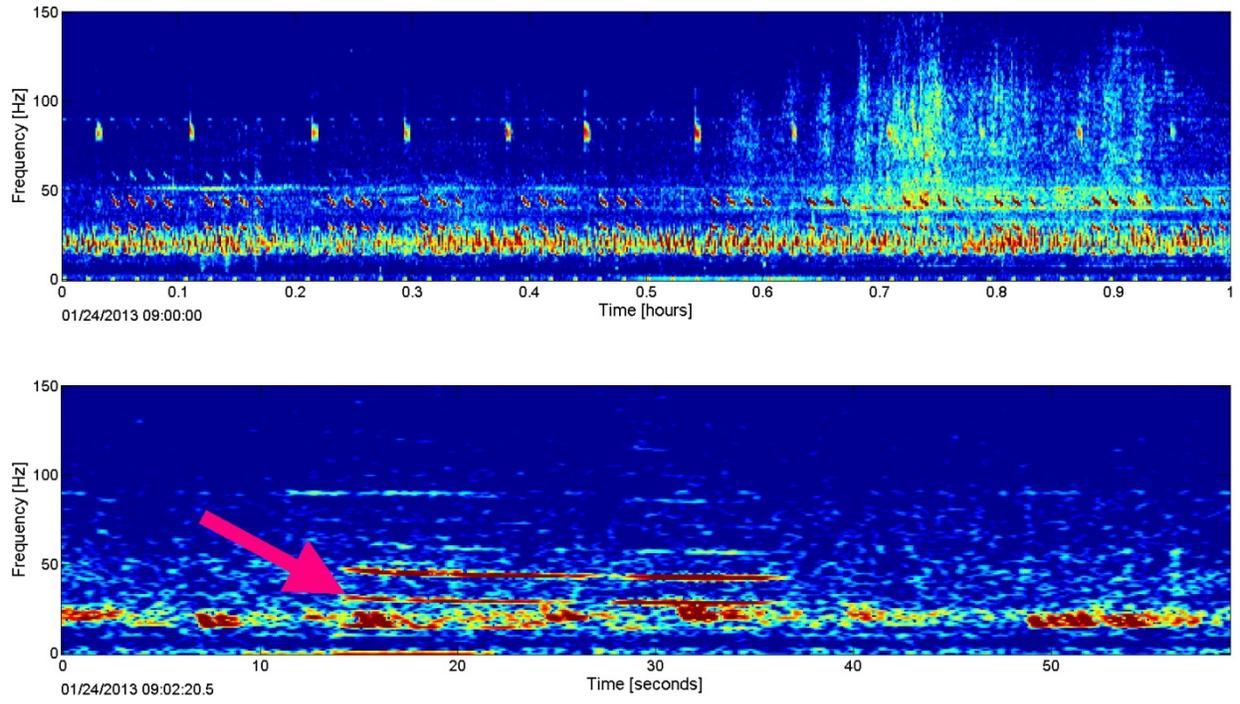


Figure 2. Blue whale B call in LTSA (top) and spectrogram (bottom) at site N.

Fin Whales

Fin whales produce short (~ 1 s duration), low-frequency calls that downsweep in frequency from 30-15 Hz, called 20 Hz calls (Watkins, 1981) (Figure 3). The 20 Hz calls can occur at regular intervals as song (Thompson *et al.*, 1992), or irregularly as call counter-calls among multiple, traveling animals (McDonald *et al.*, 1995).

Fin whale 20 Hz calls

Fin whale 20 Hz calls (Figure 3) were detected automatically using an energy detection method. The method used a difference in acoustic energy between signal and noise, calculated from 5 s LTSA with 1 Hz resolution. The frequency at 22 Hz was used as the signal frequency, while noise was calculated as the average energy between 10 and 34 Hz. The resulting ratio is termed fin whale acoustic index and is reported as a daily average. All calculations were performed on a logarithmic scale.

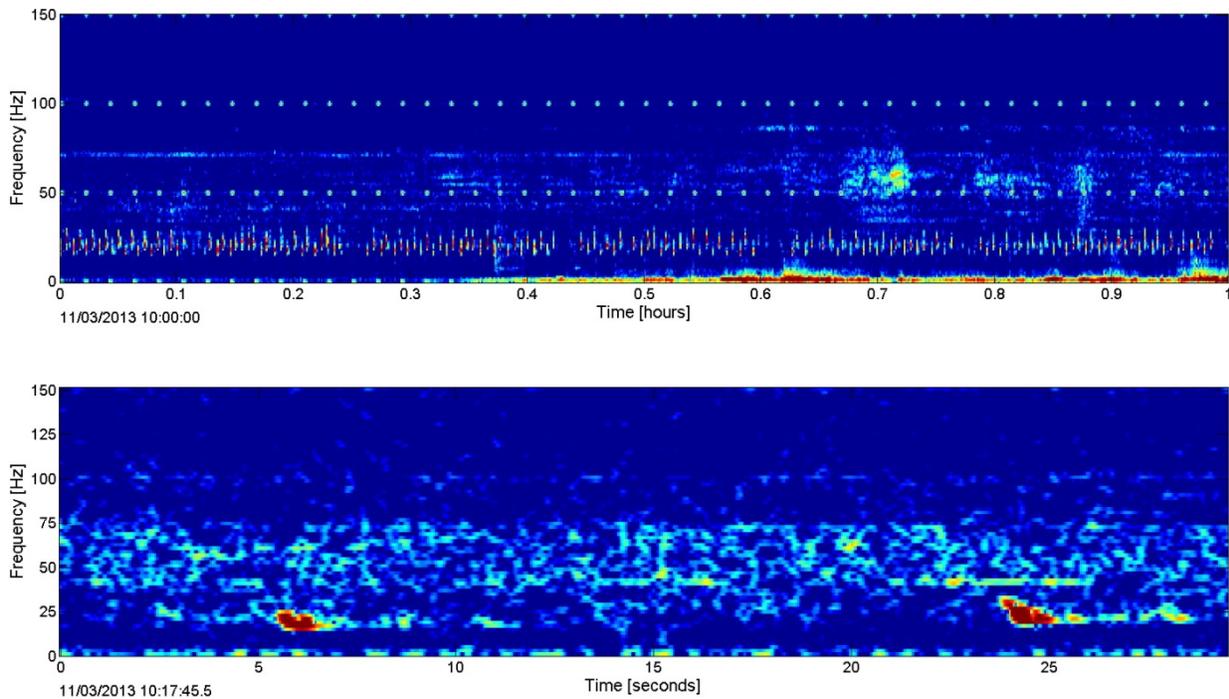


Figure 3. Fin whale 20 Hz calls in LTSA (top) and spectrogram (bottom) at site M.

Humpback Whales

Humpback whales produce both song and non-song calls (Payne & McVay 1971, Dunlop et al. 2007, Stimpert et al., 2011). The song is categorized by the repetition of units, phrases, and themes of a variety of calls as defined by Payne & McVay (1971). Most humpback whale vocalizations are produced between 100 - 3,000 Hz. We detected humpback whale calls using an automatic algorithm based on the generalized power law (Helble *et al.*, 2012). A trained analyst subsequently verified the detections (Figure 4). There was no effort to separate song and non-song calls.

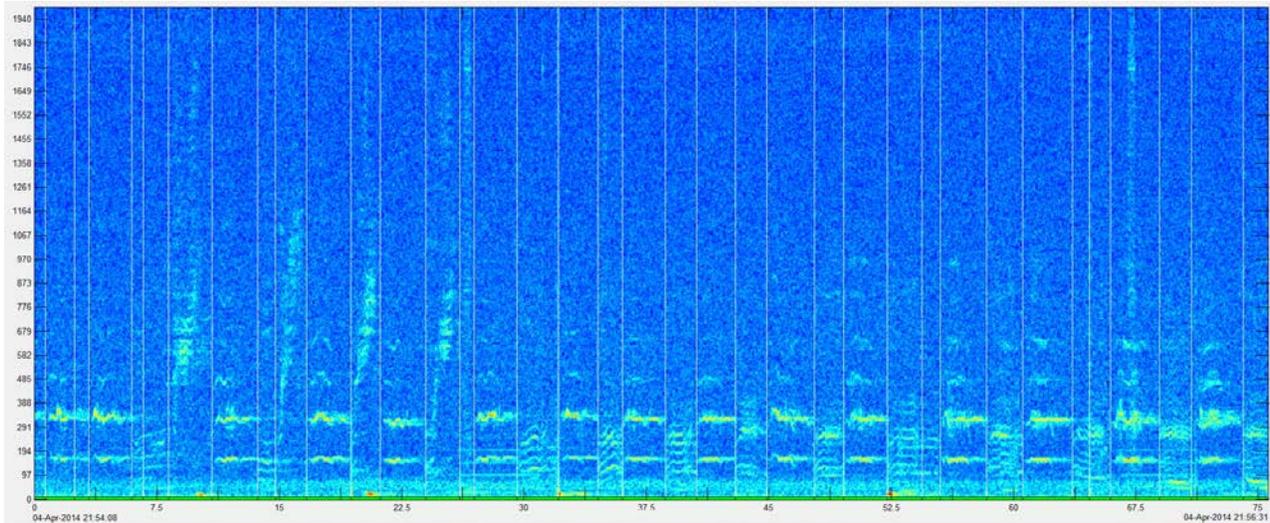


Figure 4. Humpback whale song from site N in the analyst verification stage of the detector. Green in the bottom evaluation line indicates true detections.

Beaked Whales

Beaked whales found in the Southern California Bight include Baird's (*Berardius bairdii*), Cuvier's (*Ziphius cavirostris*), Blainville's (*Mesoplodon densirostris*), Stejneger's (*M. stejnegeri*), Hubbs' (*M. carlhubbsi*), Perrin's (*M. perrini*), and Pygmy beaked whale (*M. peruvianus*) (Jefferson *et al.*, 2008).

Recently, advances have been made in acoustically identifying beaked whales by their echolocation signals (Baumann-Pickering *et al.*, 2014). These signals are frequency-modulated (FM) upswEEP pulses, which appear to be species specific and distinguishable by their spectral and temporal features. Identifiable signals are known for Baird's, Blainville's, Cuvier's, and Stejneger's beaked whales. Other beaked whale signals detected in the Southern California Bight include FM pulses known as BW40, BW43, and BW70, which may belong to Hubbs', Perrin's, and Pygmy beaked whales (Baumann-Pickering *et al.*, 2014).

Beaked whale FM pulses, except for those produced by Baird's beaked whales, 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 μ s, 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. A third classification step, based on computer assisted manual decisions by a trained analyst, labeled the automatically detected segments to pulse type level and rejected false detections (Baumann-Pickering *et al.*, 2013). The rate of missed segments was approximately 5%, varying slightly between deployments.

Cuvier's Beaked Whales

Cuvier's echolocation signals are polycyclic, with a characteristic FM pulse upsweep, peak frequency around 40 kHz, and uniform inter-pulse interval of about 0.5 s (Johnson *et al.*, 2004; Zimmer *et al.*, 2005). An additional feature that helps with the identification of Cuvier's FM pulses is that they have two characteristic spectral peaks around 17 and 23 kHz (Figure 5).

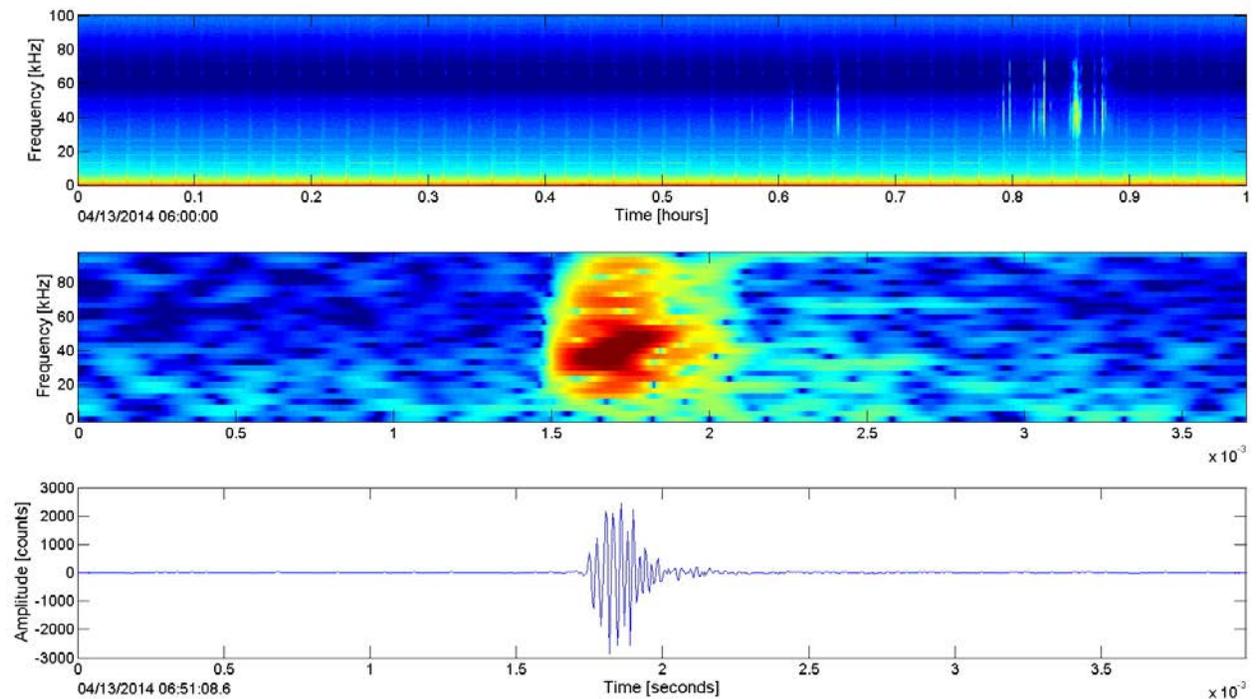


Figure 5. Echolocation sequence of Cuvier's beaked whale in LTSA (top) and example FM pulse in spectrogram (middle) and time series (bottom) at site N.

BW43

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 and uniform inter-pulse interval around 0.2 s (Figure 6) (Baumann-Pickering *et al.*, 2013). A candidate species for producing this FM pulse type may be Perrin's beaked whale (Baumann-Pickering *et al.*, 2014).

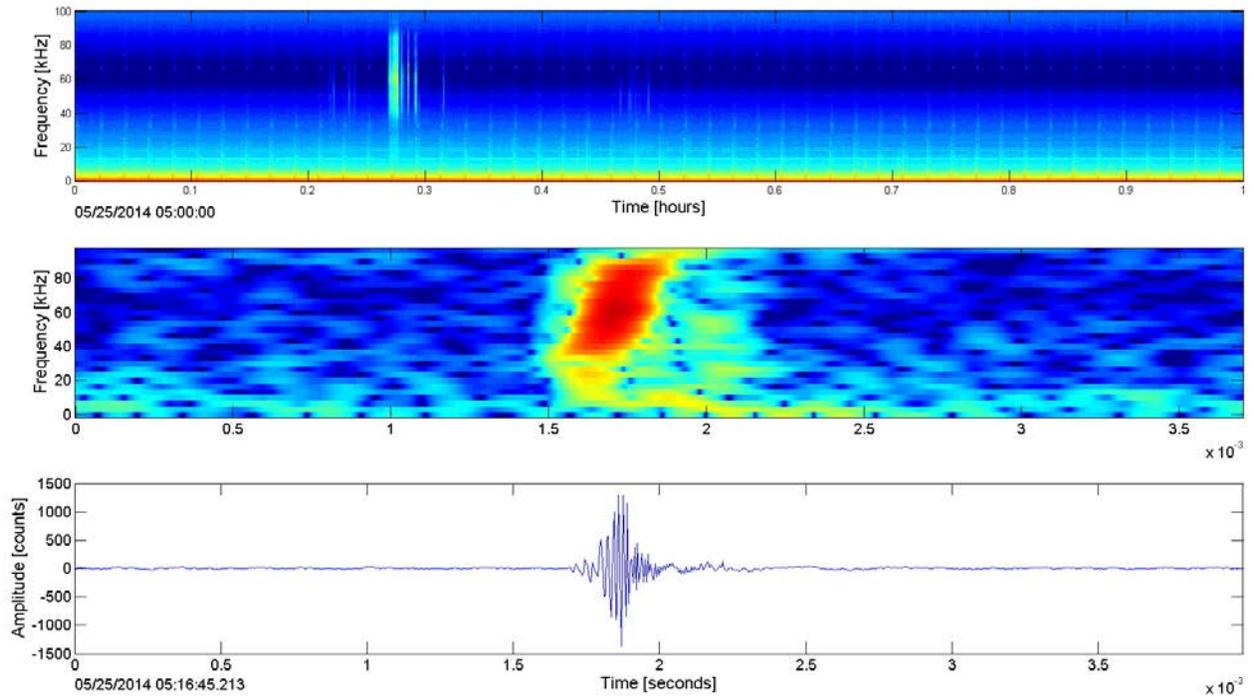


Figure 6. Echolocation sequence of BW43 in LTSA (top) and example FM pulse in spectrogram (middle) and time series (bottom) at site N.

Anthropogenic Sounds

Three anthropogenic sounds were monitored for this report: Mid-Frequency Active (MFA) sonar, Low-Frequency Active (LFA) sonar, and explosions. MFA and LFA sonars were detected by manually scanning the data, whereas, explosions were detected by a computer algorithm. During manual examination of the data, the LTSA frequency was set to display between 1-5,000 Hz with a 0.75 hour plot length. To observe individual signals, the spectrogram window was typically set to display 1-5,000 Hz with a 30 second plot length. The start and end of each sound or session was logged and their durations were added to estimate cumulative hourly presence.

Mid-Frequency Active Sonar

Sounds from MFA sonar vary in frequency (1 – 10 kHz) and are composed of pulses of both frequency modulated (FM) sweeps and continuous wave (CW) tones grouped in packets with durations ranging from less than 1 s to greater than 5 s. Packets can be composed of single or multiple pulses and are transmitted repetitively as wave trains with inter-packet-intervals typically greater than 20 s (Figure 7). In the SOCAL Range Complex, the most common MFA sonar packet signals are between 2 and 5 kHz and are known more generally as ‘3.5 kHz’ sonar. Analysts manually scanned LTSAs and logged sonar wave train event start and end times where inter-event-intervals were typically greater than 1 hour. The start and end times were used to read segments of waveforms upon which a 2.4 to 4.5 kHz bandpass filter and a simple time series energy detector was applied to detect and measure various packet parameters after correcting for the instrument calibrated transfer function (see Wiggins (2015) for details). For each packet, maximum peak-to-peak (pp) received level (RL), sound exposure level (SEL), root-mean-square (RMS) RL, date/time of packet occurrence, and packet duration (for $RL_{pp} - 10\text{dB}$) were measured and saved. Various filters were applied to the detections to reduce false detections and to limit the MFA sonar detection range to ~20 km for off-axis signals from an AN/SQS 53C source, which resulted in a received level detection threshold of 130 dB_{pp} re 1 μPa . Instrument maximum received level for these recordings was ~161 dB_{pp} re 1 μPa above which waveform clipping occurred. Packets were grouped into wave trains separated by more than 1 hour. Packet received level and duration distributions were plotted along with the number of packets and cumulative SEL (CSEL) in each wave train over the study period.

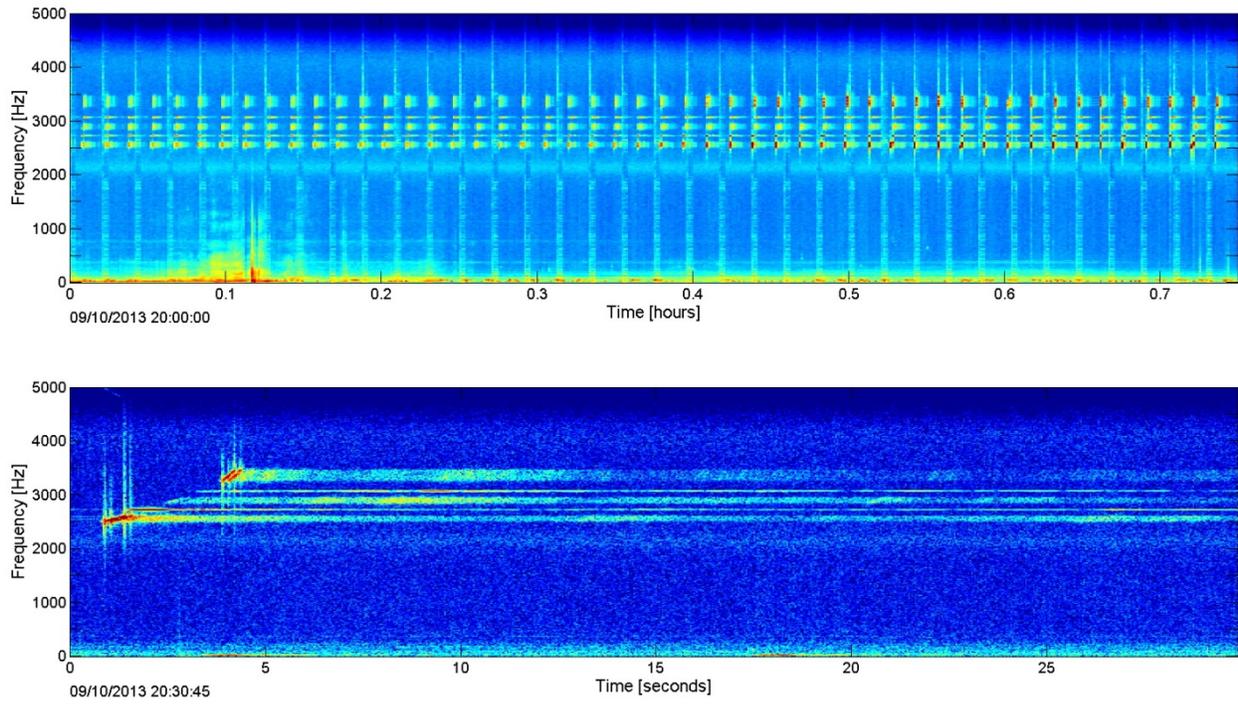


Figure 7. MFA sonar recorded at site H and shown as a wave train event in a 45 minute LTSA (top) and as a single packet with multiple pulses in a 30 second spectrogram (bottom).

Low-Frequency Active Sonar 500 Hz – 1 kHz

Effort to detect low-frequency active (LFA) sonar between 500 Hz and 1 kHz was expended on these data (Figure 8). Analysts manually scanned LTSAs for LFA sonar bout start and end times.

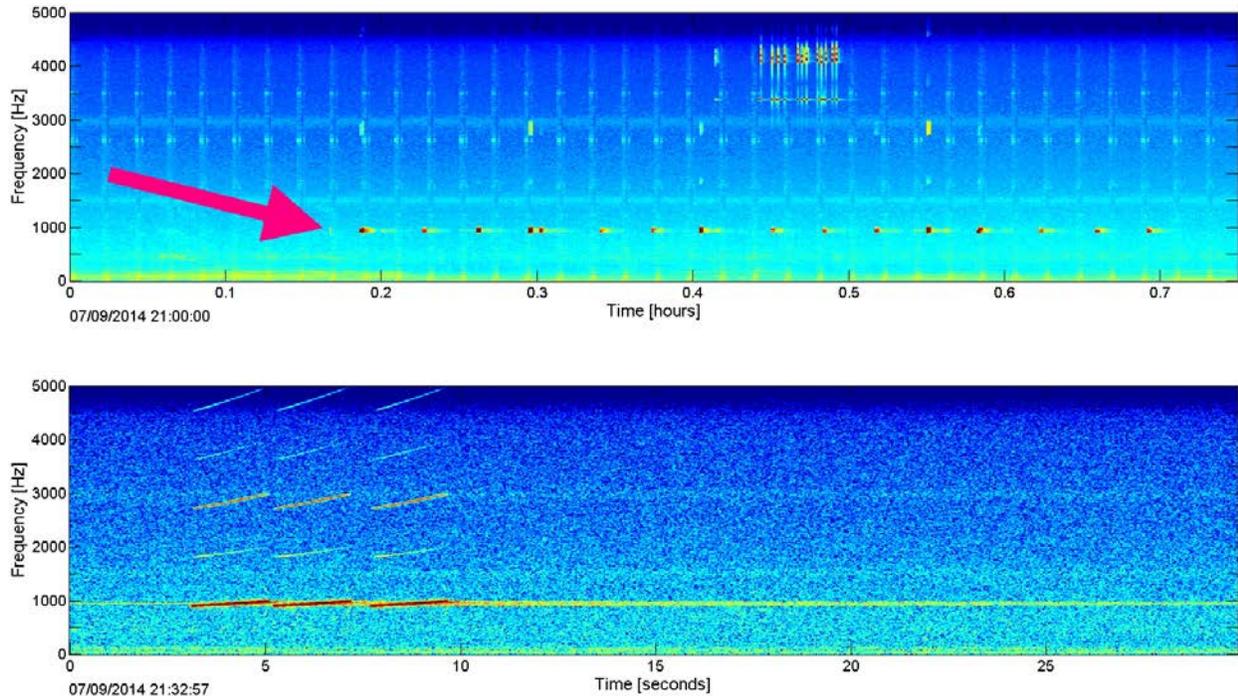


Figure 8. LFA at 950 Hz in the LTSA (top) and spectrogram (bottom) at site H.

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 9). Explosions were detected automatically using a matched filter detector on data decimated to 10 kHz sampling rate. The time series was filtered with a 10th order Butterworth bandpass filter between 200 and 2,000 Hz. Cross correlation was computed between 75 seconds of the envelope of the filtered time series and the envelope of a filtered example explosion (0.7 s, Hann windowed) as the matched filter signal. The cross correlation was squared to 'sharpen' peaks of explosion detections. A floating threshold was calculated by taking the median cross correlation value over the current 75 seconds of data to account for detecting explosions within noise, such as shipping. A cross correlation threshold above the median was set. When the correlation coefficient reached above threshold, the time series was inspected more closely. Consecutive explosions were required to be separated by at least 0.5 seconds to be detected. A 300-point (0.03 s) floating average energy across the detection was computed. The start and end above threshold was determined when the energy rose by more than 2 dB above the median energy across the detection. Peak-to-peak (pp) and rms received levels (RL) were computed over the potential explosion period and a time series of the length of the explosion template before and after the explosion. The potential explosion was classified as false detection and deleted if: 1) the dB difference pp and rms between signal and time AFTER the detection was less than 4 dB or 1.5 dB, respectively; 2) the dB difference pp and rms between signal and time BEFORE signal was less than 3 dB or 1 dB, respectively; and 3) the detection was shorter than 0.03 or longer than 0.55 seconds. The thresholds were evaluated based on the distribution of histograms of manually verified true and false detections. A trained analyst subsequently verified the remaining potential explosions for accuracy. Explosions have energy as low as 10 Hz and often extend up to 2,000 Hz or higher, lasting for a few seconds including the reverberation.

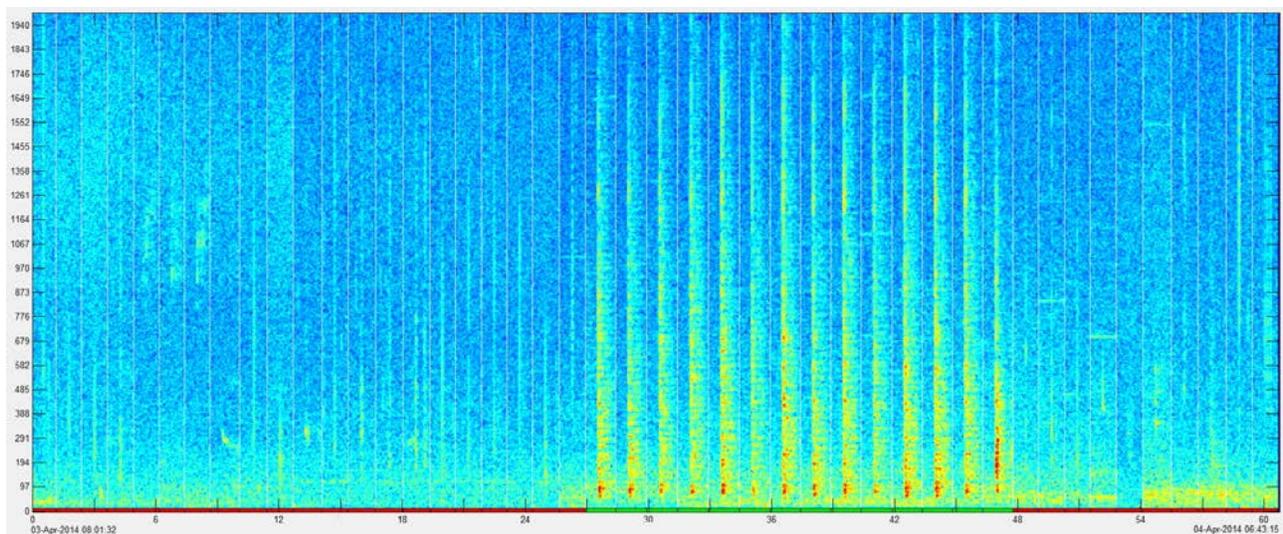


Figure 9. Explosions from site P in the analyst verification stage of the detector. Green in the bottom evaluation line indicates true and red indicates false detections.

Results

The results of acoustic data analysis at sites H, N, and P from January through July 2014 are summarized. We describe ambient noise, and the seasonal occurrence and relative abundance of marine mammal acoustic signals and anthropogenic sounds of interest.

Ambient Noise

- Underwater ambient noise at sites H, N, and P had spectral shapes with higher levels at low frequencies, owing to the dominance of ship noise at frequencies below 100 Hz and local wind and waves above 100 Hz (Figure 10, Figure 11, and Figure 12 respectively) (Hildebrand, 2009).
- Site H had the lowest spectrum levels for both ship and wind bands. This is expected owing to the fact that site H is away from shipping routes and is located in a basin shielded from the deep ocean (McDonald *et al.*, 2008).
- Site N had spectrum levels about 5-10 dB higher than site H at 10 – 200 Hz, owing to greater exposure to shipping noise.
- Site P had overall elevated spectrum levels in comparison to sites H and N, particularly in frequencies above 30 Hz, likely due to its more shallow depth and increased local small boat activity.
- All sites had higher noise levels in the spring (April) than in the winter (January) or summer (July), due to increased storm activity.
- Prominent peaks in noise observed at the frequency band 15-30 Hz during the winter and early spring at all sites are related to seasonally increased presence of fin whale calls, with highest levels at site H.
- July spectral peaks at 45-47 Hz, along with lower frequency harmonics, at sites H and N are related to blue whale B calls.

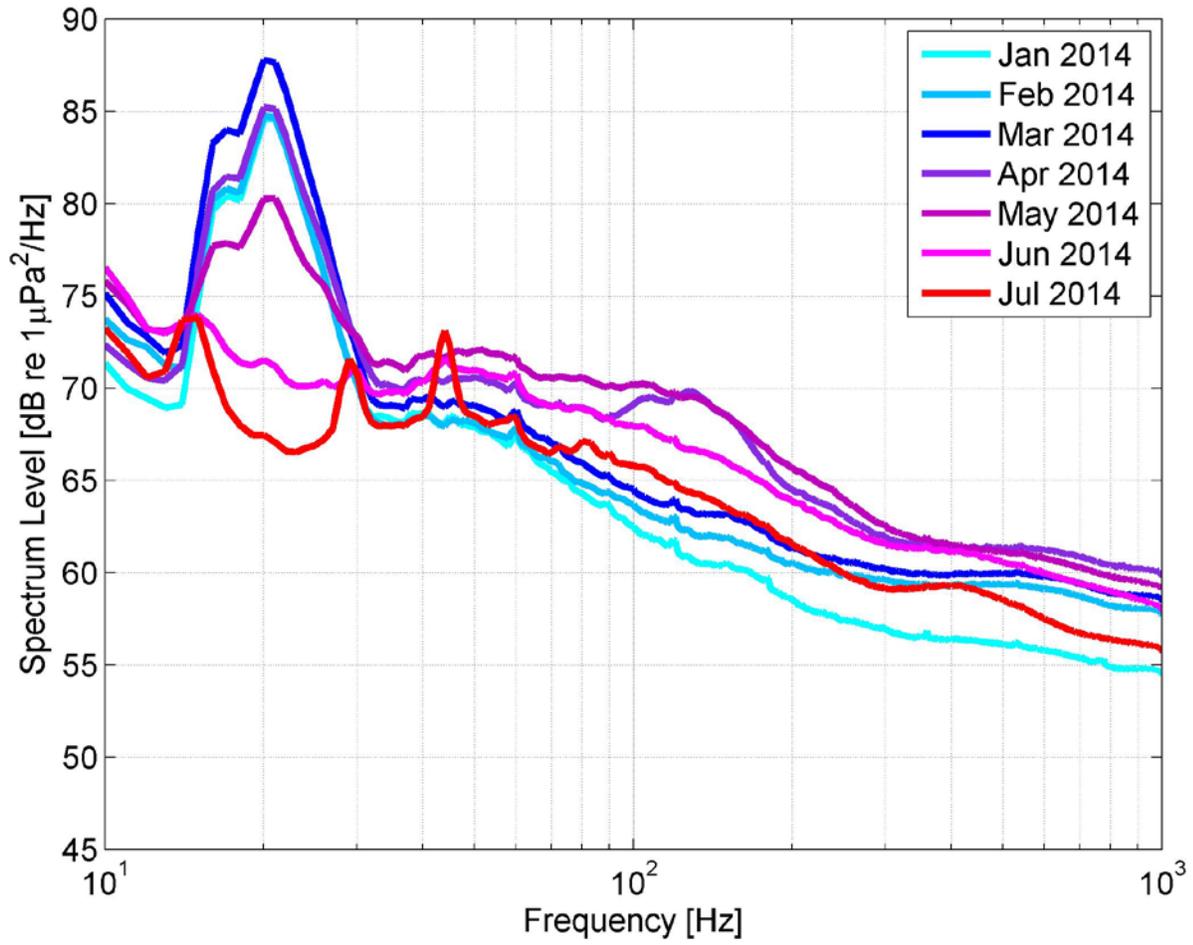


Figure 10. Monthly averages of ambient noise at site H. Legend gives color-coding by month.

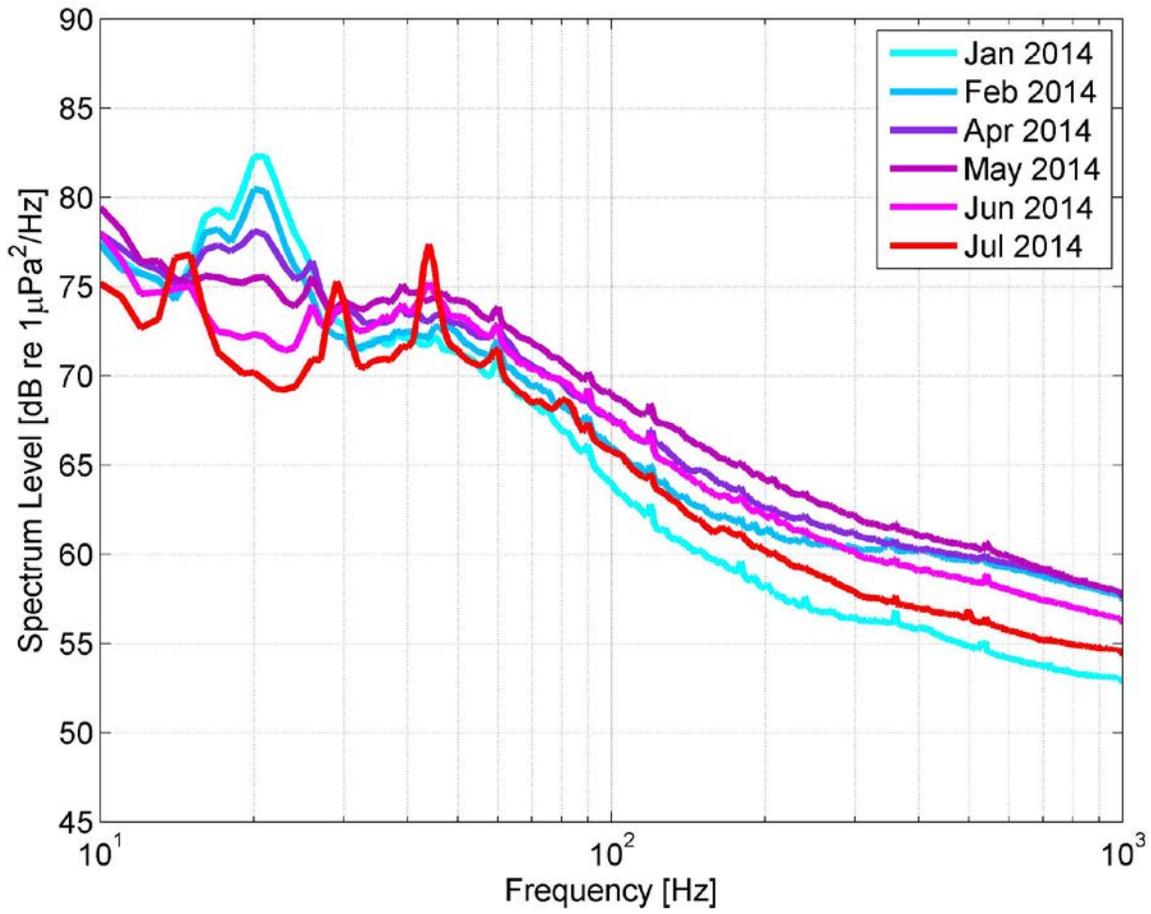


Figure 11. Monthly averages of ambient noise at site N. Legend gives color-coding by month.

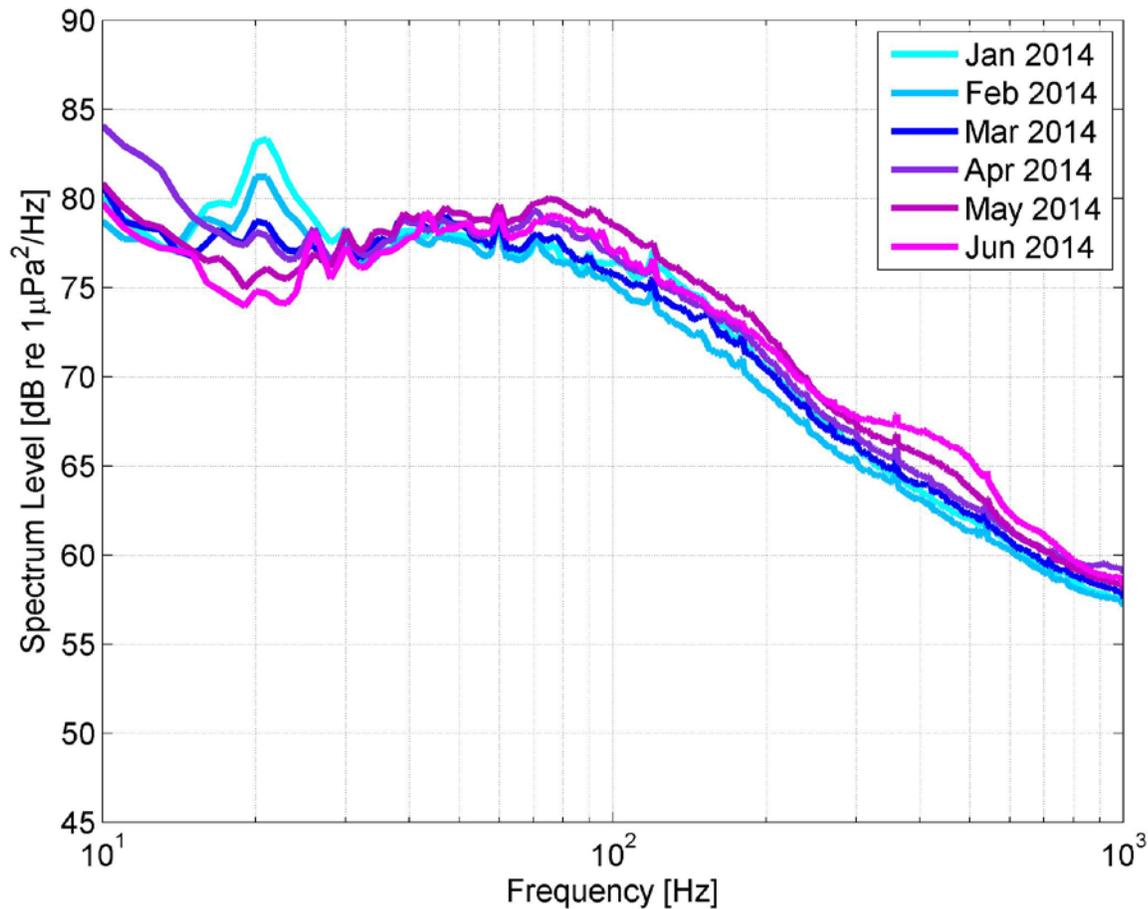


Figure 12. Monthly averages of ambient noise at site P. Legend gives color-coding by month.

Mysticetes

Three baleen whale species were detected using automated methods between January and July 2014: blue whales, fin whales, and humpback whales. In general, fewer baleen whale vocalizations were detected at site P than at sites H and N. More details of each species’ presence at these sites are given below.

Blue Whales

Blue whale B calls were detected at all three sites.

- Blue whale Northeast (NE) Pacific B calls were detected most commonly at sites N and H. Few calls were detected at site P during the monitoring period (Figure 13).
- Few NE Pacific B calls were detected between January and May, and call detections increased substantially in June and July (Figure 13).
- There was no diel pattern in the NE Pacific blue whale B calls (Figure 14).
- Detection of blue whale B calls during the spring is unusual for this area (Debich et al. 2015; Kerosky et al. 2013).

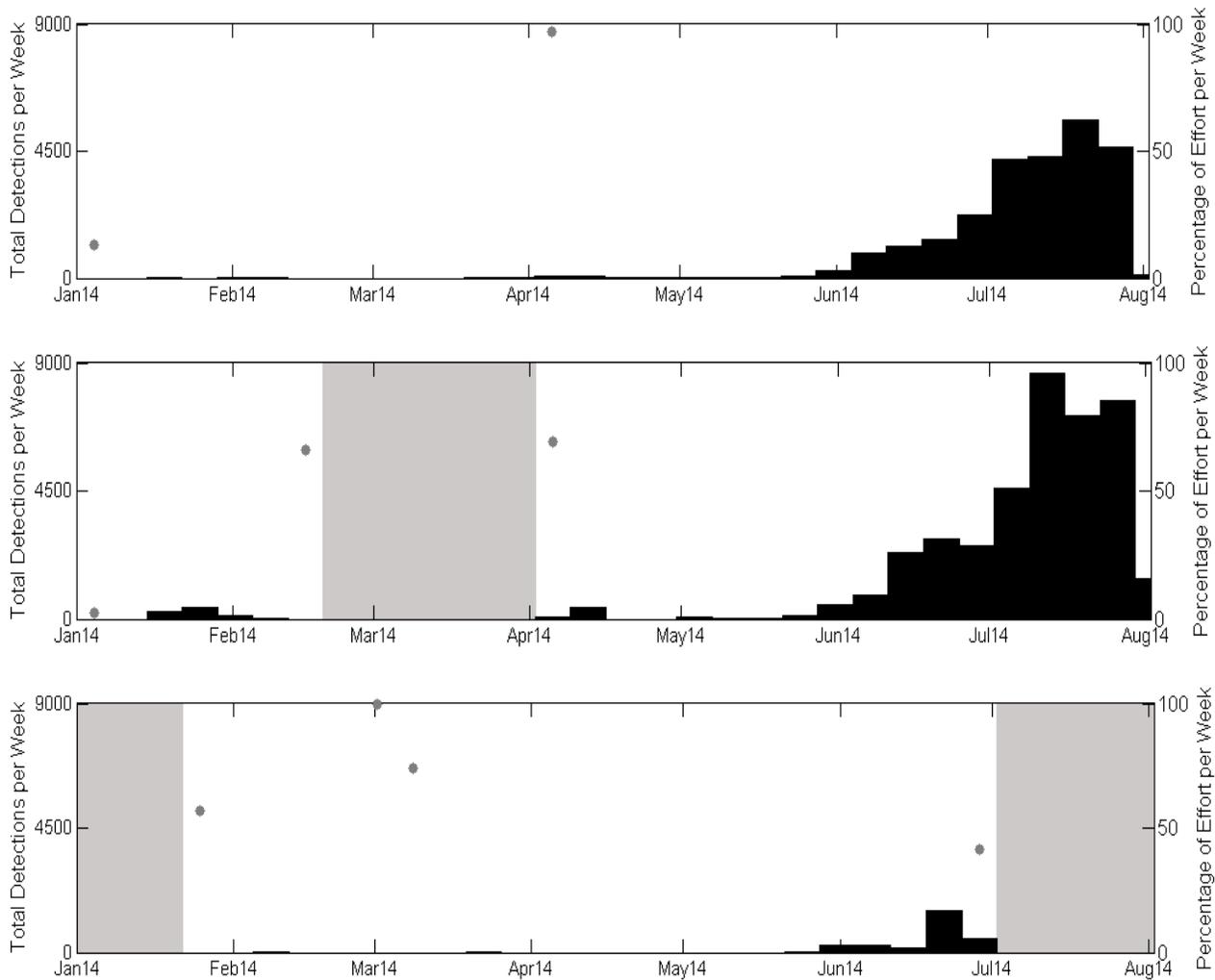


Figure 13. Weekly presence of NE Pacific blue whale B calls between January and July 2014 at sites H (top), N (middle), and P (bottom). Gray dots represent percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

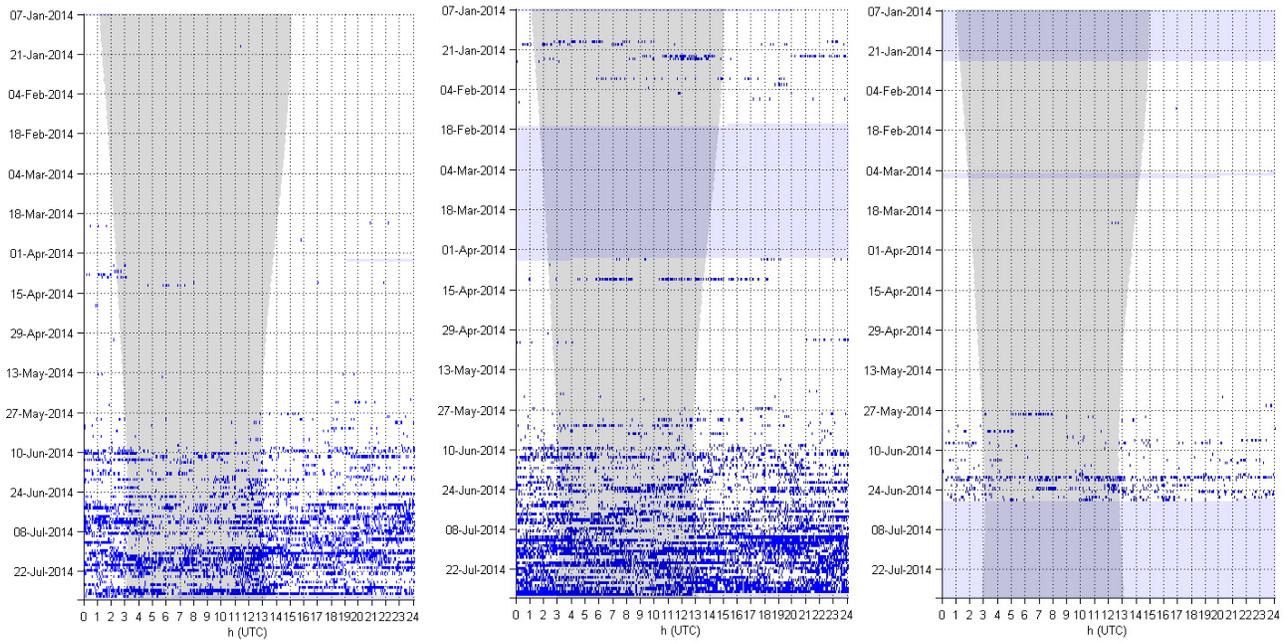


Figure 14. NE Pacific blue whale B calls in one-minute bins at sites H (left), N (middle), and P (right). Gray vertical shading denotes nighttime, and light purple horizontal shading denotes absence of acoustic data.

Fin Whales

Fin whales were one of the most commonly detected baleen whale throughout the recordings.

- The highest level of the fin whale acoustic index (representative of 20 Hz calls) was measured at site H (Figure 15).
- Peaks in the fin whale acoustic index occurred January – April 2014 at site H. A smaller peak occurred in January 2014 at site N (Figure 15).
- Site P had the lowest values of fin whale acoustic index with a small peak in February 2014 (Figure 15).
- These results are consistent with earlier findings for site H and N (Kerosky *et al.*, 2013; Debich *et al.*, 2015).

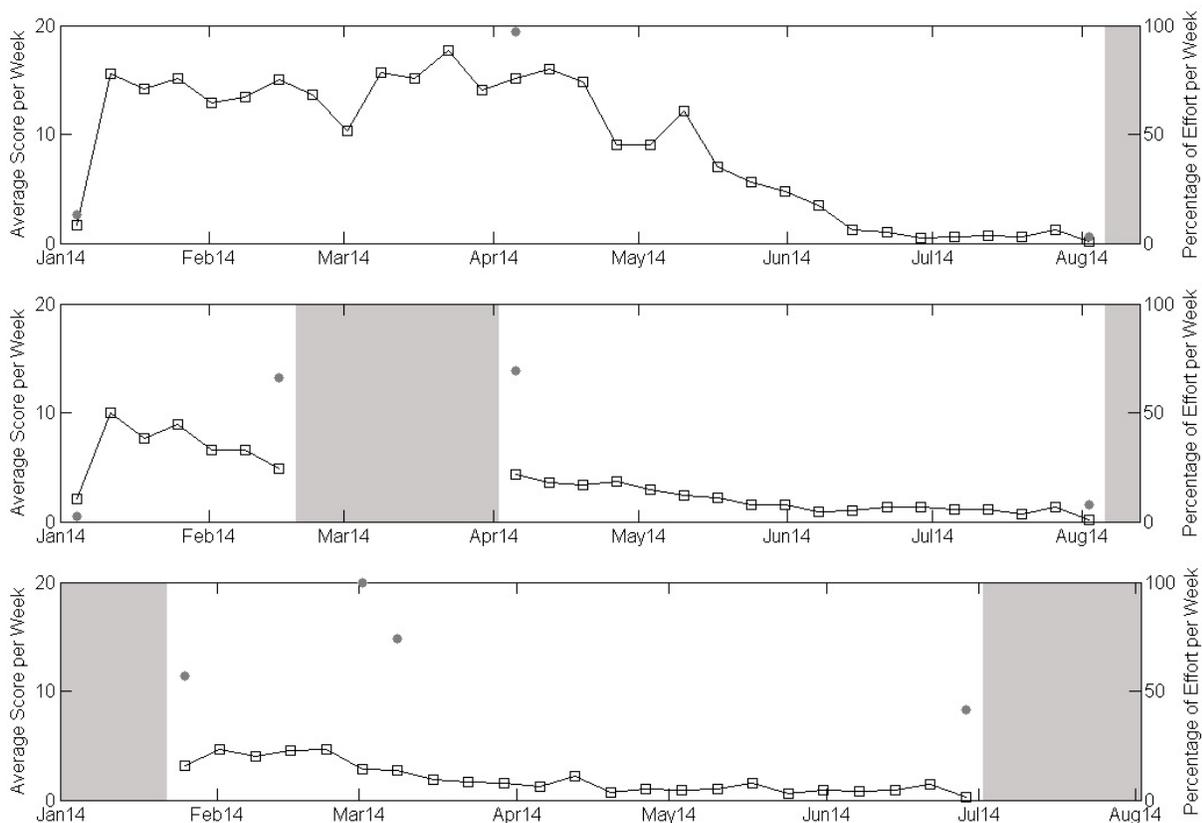


Figure 15. Weekly value of fin whale acoustic index (proxy for 20 Hz calls) between January and July 2014 at sites H (top), N (middle), and P (bottom). Effort markings are described in Figure 13.

Humpback Whales

Humpback whales were detected throughout the recordings.

- Humpbacks whales were detected throughout the recordings and were the most common at site N (Figure 16).
- Detections peaked in January at site N and in early March at site H. A decrease in detections occurred late-May through June 2014 at each site (Figure 16).
- Detections were low at site P throughout the recording period (Figure 16).
- There was no discernable diel pattern at any of the sites (Figure 17).
- 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.
- These results are similar to earlier reports for sites H and N (Kerosky *et al.*, 2013; Debich *et al.*, 2015).

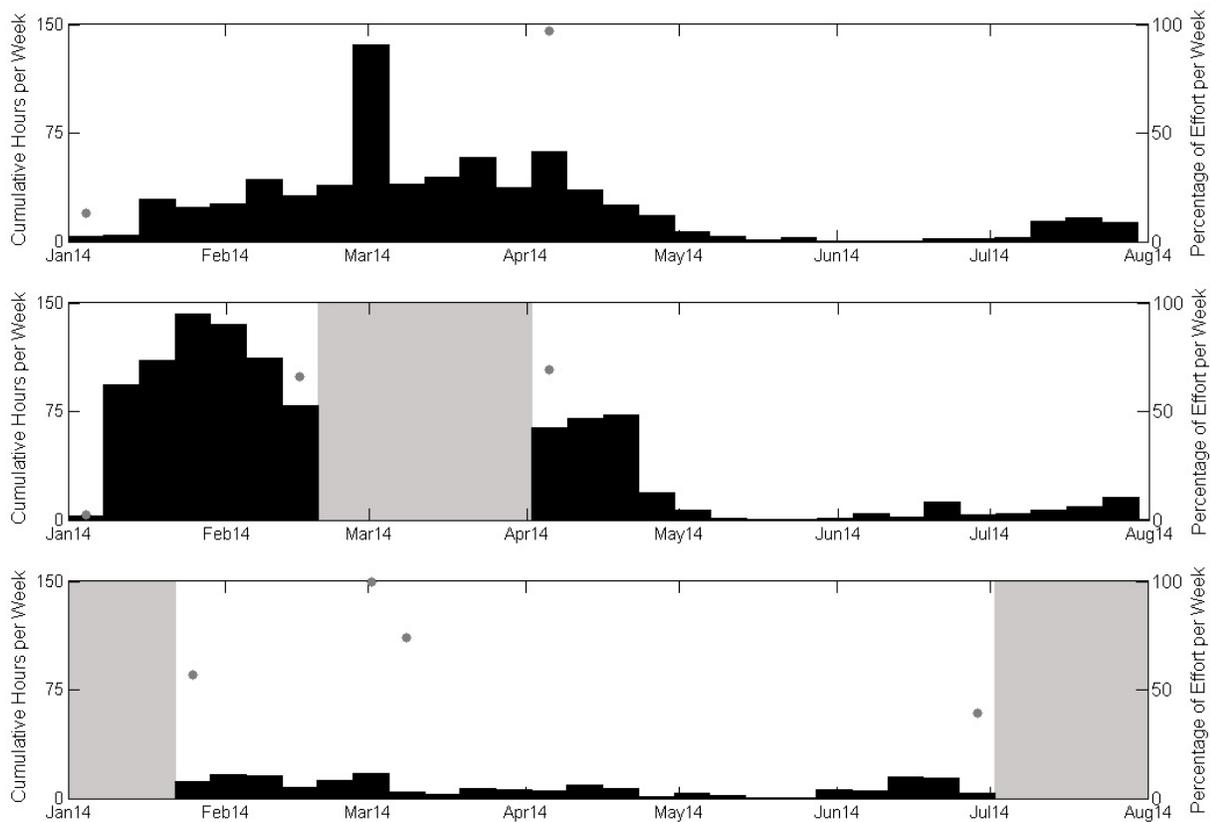


Figure 16. Weekly presence of humpback whale calls between January and July 2014 at sites H (top), N (middle), and P (bottom). Effort markings are described in Figure 13.

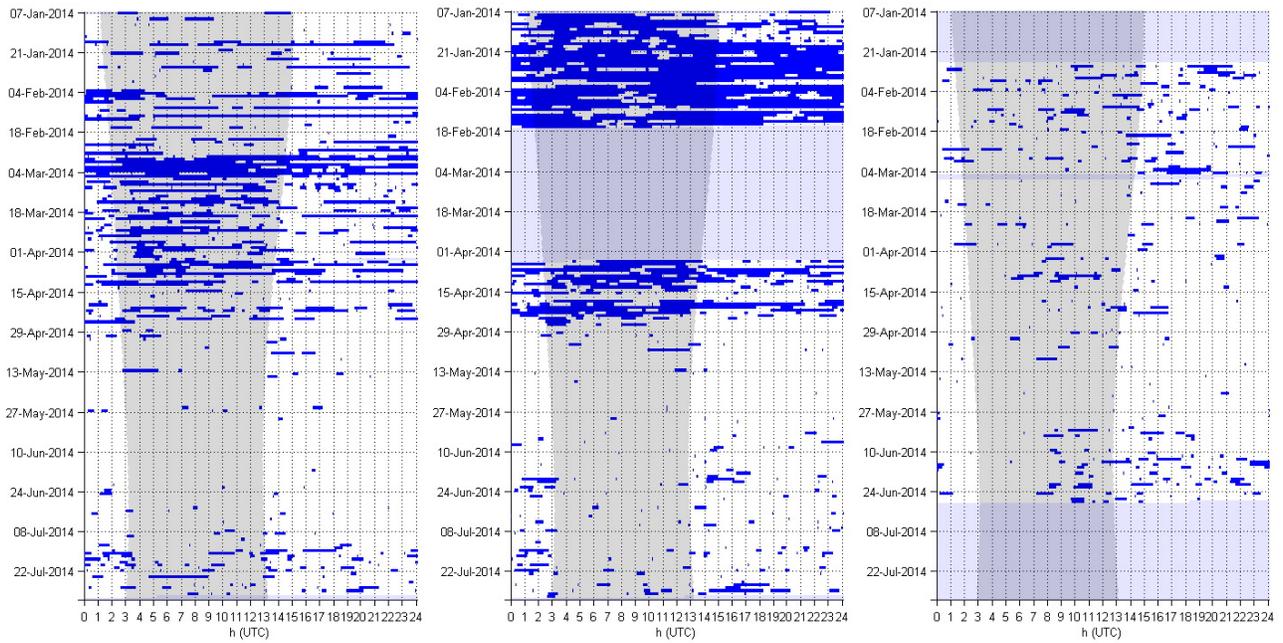


Figure 17. Humpback whale calls in one-minute bins at sites H (left), N (middle), and P (right). Effort markings are described in Figure 14.

Beaked Whales

Cuvier's beaked whales were detected between January and July 2014. The FM pulse type, BW43, possibly produced by Perrin's beaked whales (Baumann-Pickering *et al.*, 2014) were seen sporadically. More details of each species' presence at these sites are given below.

Cuvier's Beaked Whales

Cuvier's beaked whale was the most commonly detected beaked whale.

- Cuvier's beaked whale FM pulses were detected at sites H and N. There were no Cuvier's beaked whale detections at site P (Figure 18).
- Detections at sites H and N peaked in April and again in June-July, although detection levels were much higher at site H (Figure 18).
- There was no discernable diel pattern for Cuvier's beaked whale FM pulses (Figure 19).
- These results are similar to previous reports for sites H and N (Kerosky *et al.*, 2013; Debich *et al.*, 2015).

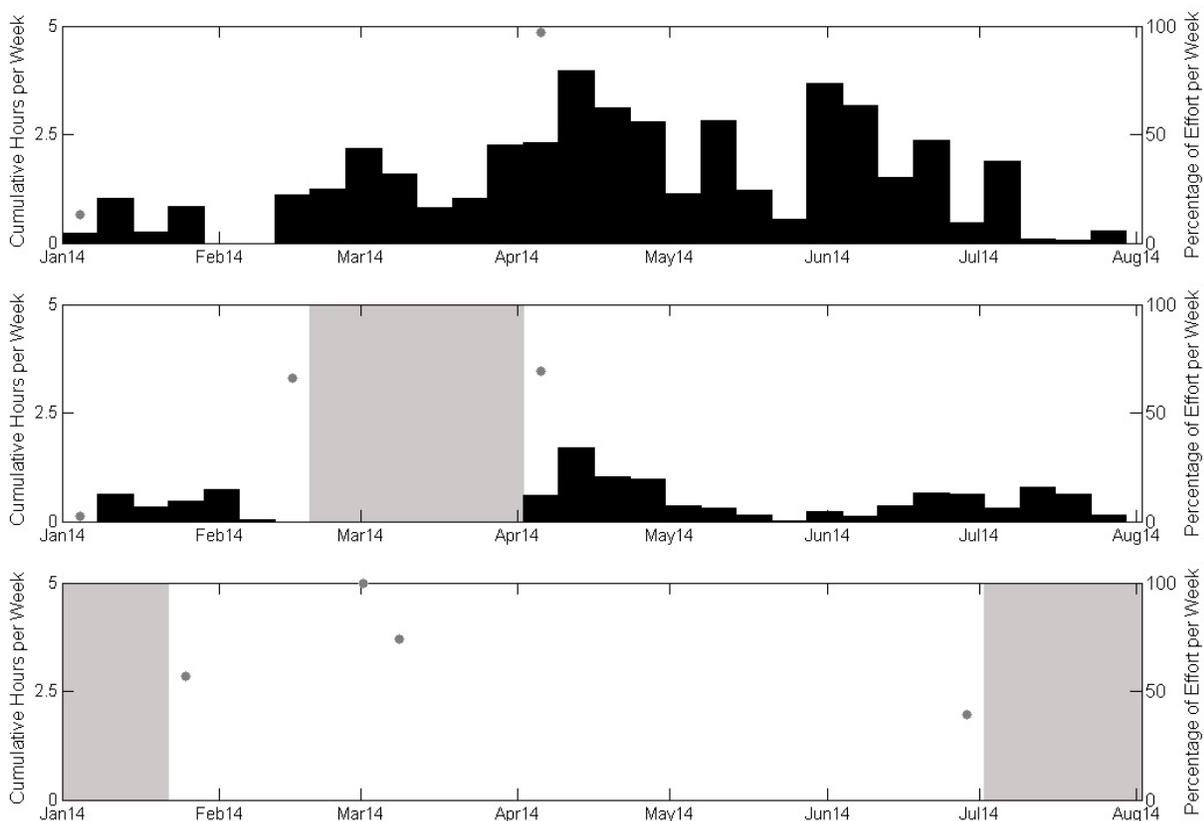


Figure 18. Weekly presence of Cuvier's beaked whale FM pulses between January and July 2014 at sites H (top), N (middle), and P (bottom). Effort markings are described in Figure 13.

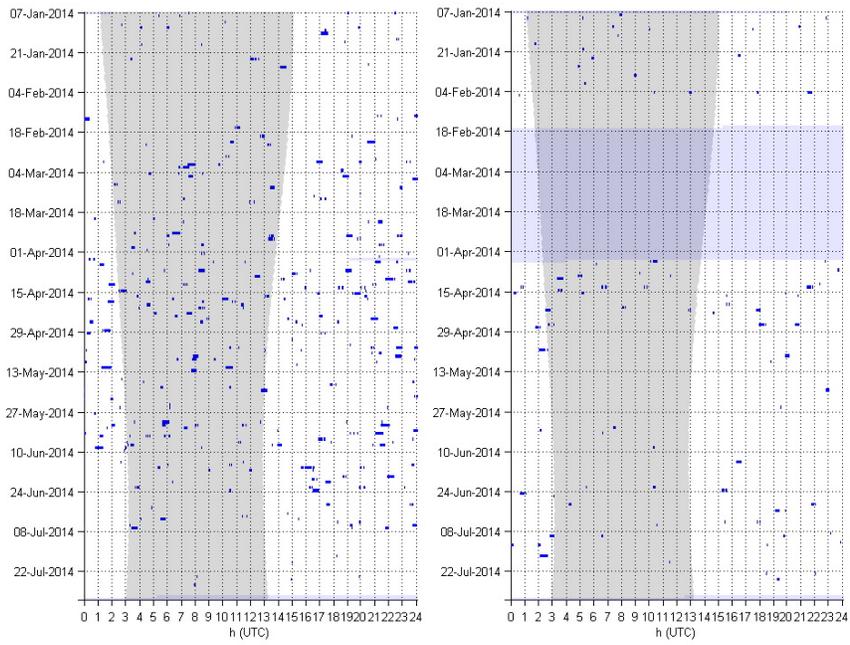


Figure 19. Cuvier's beaked whale FM pulses in one-minute bins at sites H (left) and N (right). No Cuvier's beaked whale FM pulses were detected at site P. Effort markings are described in Figure 14.

BW43

There were very few detections of BW43 FM pulses.

- BW43 FM pulses were detected in low numbers only at site N, with most detections occurring in July. There were no BW43 detections at sites H or P (Figure 20)
- There were too few detections to determine a diel pattern for BW43 (Figure 21).
- These results are similar to previous recordings (Kerosky *et al.*, 2013; Debich *et al.*, 2015).

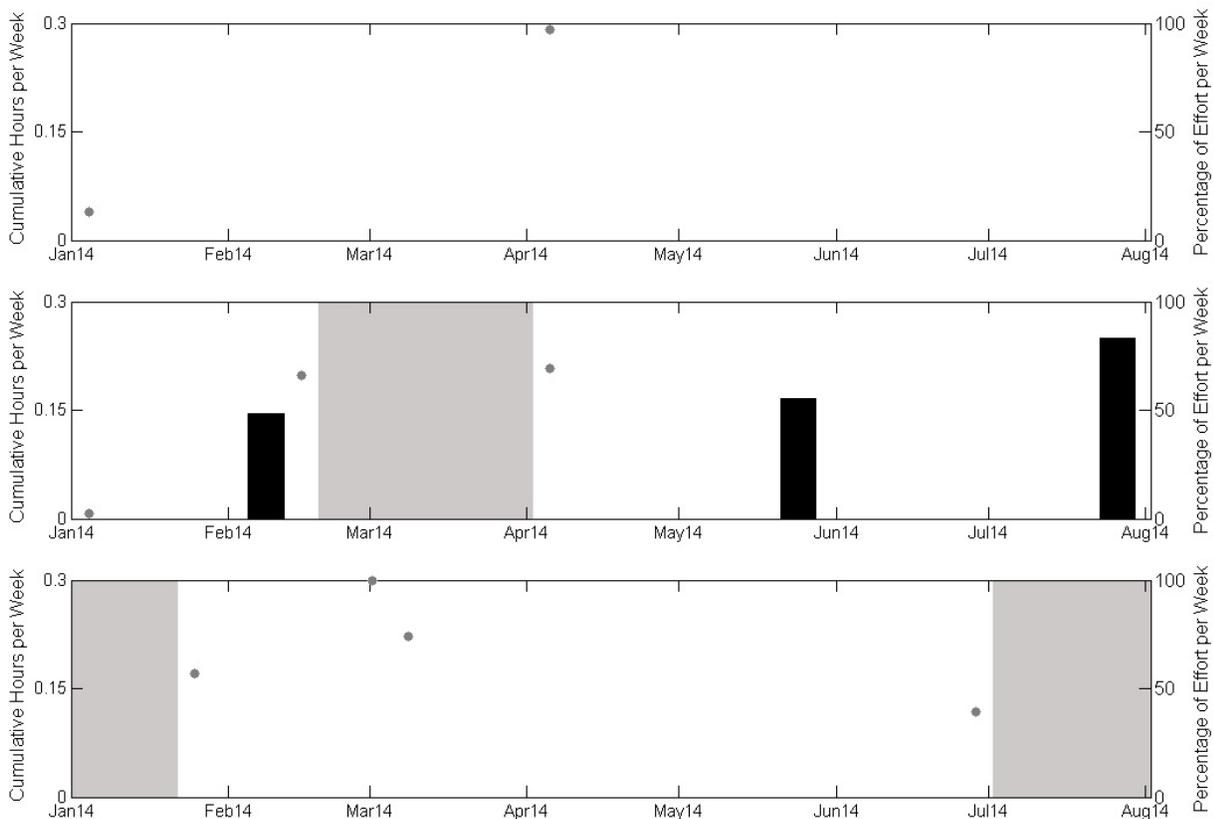


Figure 20. Weekly presence of BW43 FM pulses between January and July 2014 at sites H (top), N (middle), and P (bottom). Effort markings are described in Figure 13.

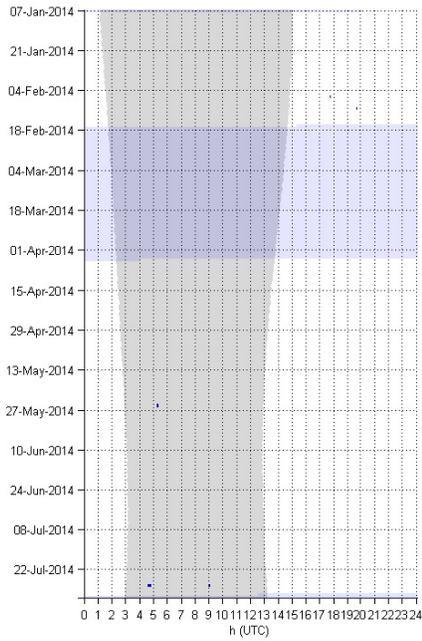


Figure 21. BW43 FM pulses in one-minute bins at site N. No BW 43 FM pulses were detected at sites H or P. Effort markings are described in Figure 14.

Anthropogenic Sounds

Three types of anthropogenic sounds were detected between January and July 2014: MFA sonar (2.4 – 4.5 kHz), LFA sonar (500 – 1000 Hz), and explosions.

Mid-Frequency Active Sonar

MFA sonar was a common anthropogenic sound. The dates for major naval training exercises that were conducted in the SOCAL region between January and July 2014 are listed in Table 3 with all three major exercises occurring between early-May and early-June. Sonar usage outside of designated major exercises is likely attributable to unit-level training. The automatically detected packets and wave trains show the highest level of MFA sonar activity (>130 dB_{pp} re 1 μPa) at site N, followed by site H and then site P (Table 4). The following bullets relate to MFA sonar less than 5 kHz:

- MFA sonar was detected at each site. There was a slight peak in analyst-defined bouts in May 2014 at site H, while bouts at site N peaked in May – June 2014 (Figure 22). The peak in May – June 2014 at site N is coincident with the three major exercises.
- Bouts of MFA sonar less than 5 kHz are somewhat more likely to begin following sunrise (Figure 23).
- At site H, a total of 4,533 packets were detected, with a maximum received level of 158 dB_{pp} re 1 μPa (Figure 24), and a median received level of 138 dB pp re 1 μPa.
- At site N, a total of 8,692 packets were detected, with a maximum received level of 163 dB_{pp} re 1 μPa (Figure 24), and a median received level of 141 dB pp re 1 μPa.
- At site P, a total of 1,936 packets were detected, with a maximum received level of 162 dB_{pp} re 1 μPa (Figure 24), and a median received level of 140 dB pp re 1 μPa.
- Most MFA sonar packets had durations less than 2 s (Figure 25).
- Maximum cumulative sound exposure levels occurred at site N during May-June and were greater than 170 dB re 1 μPa-s; whereas, at site H, maximum levels were 15-20 dB less and occurred in July. Site P had one wave train with CSEL ~170 dB re 1 μPa-s in May (Figure 26).
- Most MFA sonar wave trains occurred in May-June during the major exercises at site N, while wave trains occurred more consistently throughout the study period at sites H and P (Figure 27).

Table 3. Major naval training exercises in the SOCAL region between January and July 2014.

Exercise Dates	Type of Exercise
6 May to 2 June 2014	COMPTUEX
17 to 22 May 2014	IACII
3 to 9 June 2014	JTFEX

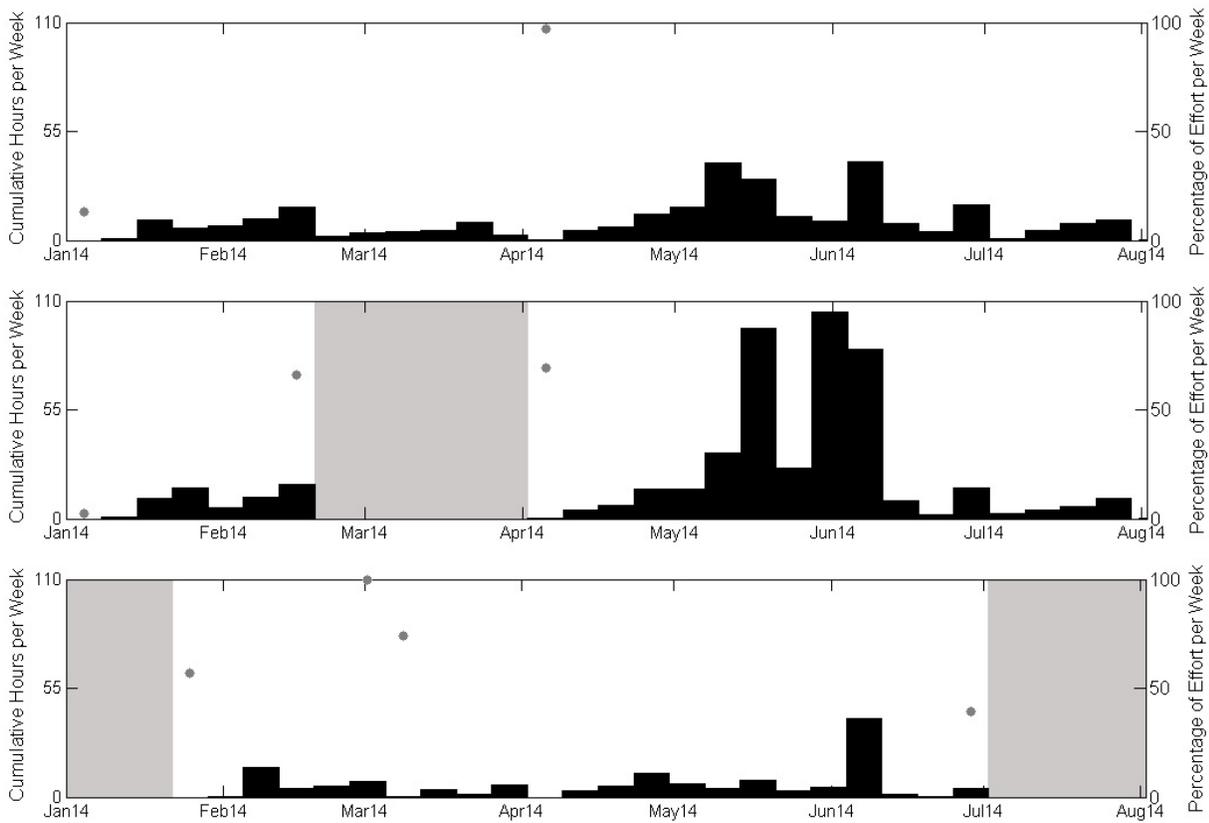


Figure 22. Weekly presence of MFA less than 5 kHz between January and July 2014 at sites H (top), N (middle), and P (bottom). Effort markings are described in Figure 13.

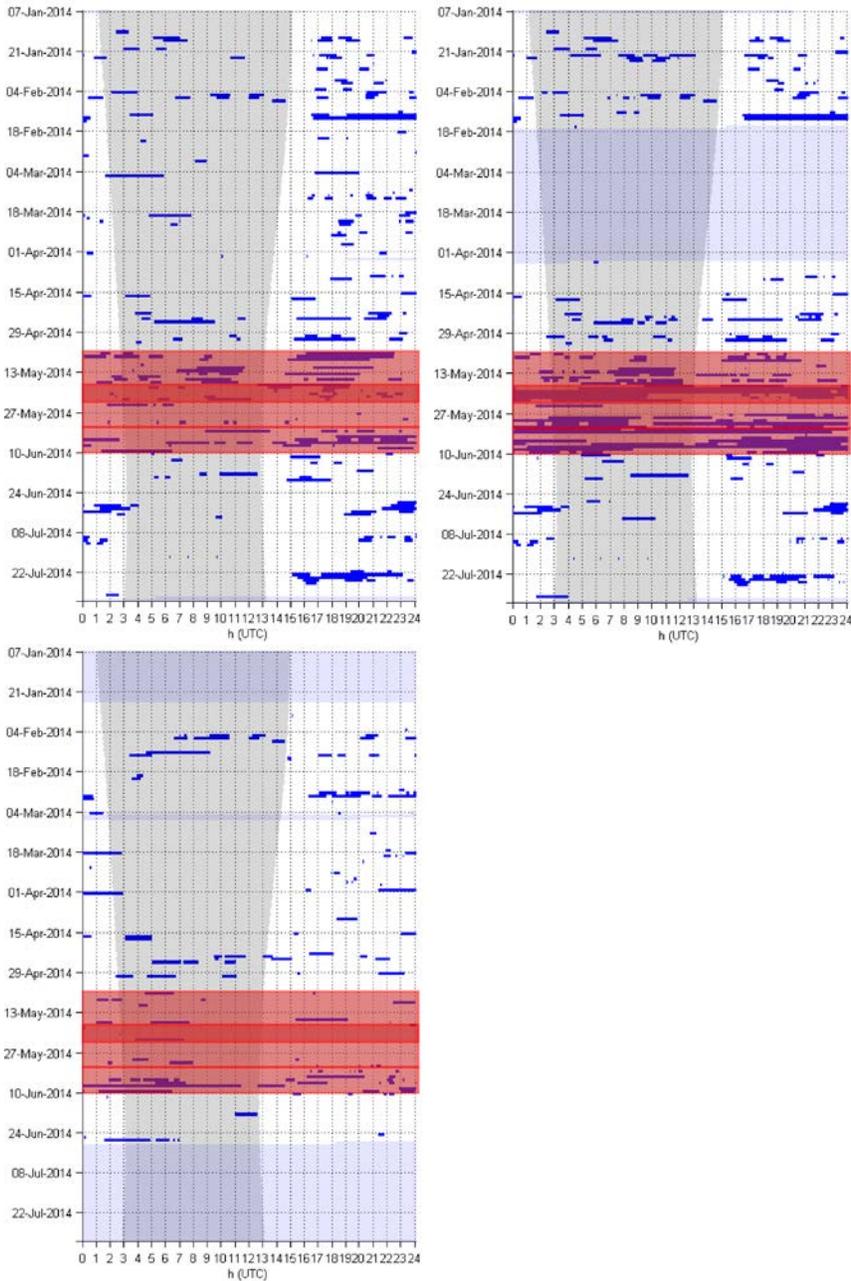


Figure 23. Major naval training events (shaded red) overlaid on MFA less than 5 kHz signals in one-minute bins at sites H (left), N (middle), and P (right). Effort markings are described in Figure 14.

Table 4. MFA sonar automated detector results for sites H, N and P. Total effort at each site in days (years), number of and extrapolated yearly estimates of wave trains and packets at each site.

Site	Period Analyzed Days (Years)	Number of Wave Trains	Wave Trains per year	Number of Packets	Packets per year
H	203 (0.56)	50	89.2	4533	8,095
N	157 (0.43)	73	169.8	8692	20,214
P	152 (0.42)	31	73.8	1936	4,610

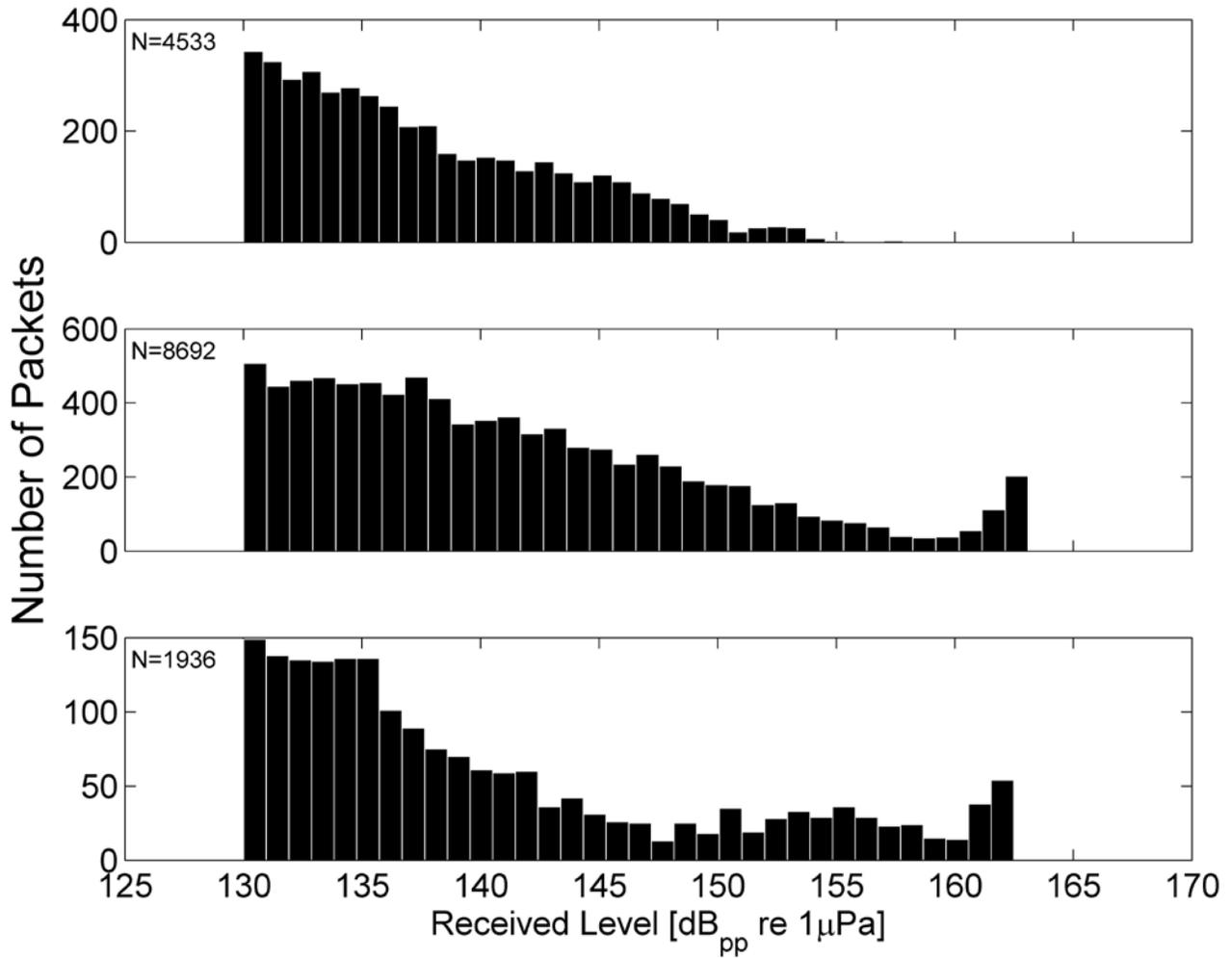


Figure 24. MFA sonar packet peak-to-peak received level distributions for sites H (top), N (middle), and P (bottom). The total number of packets detected at each site is given in the upper left corner of each panel. Note the vertical axes are at different scales.

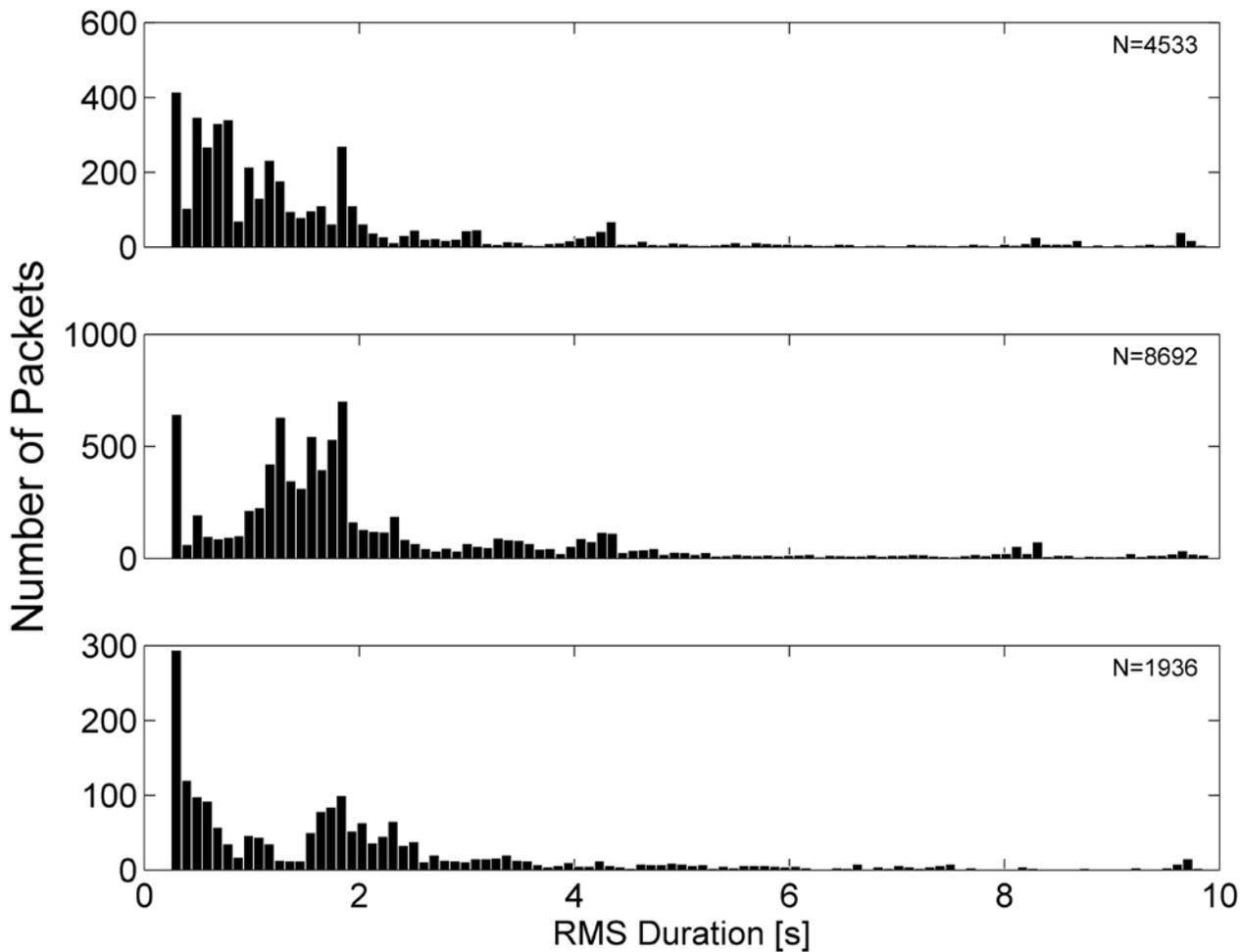


Figure 25. MFA sonar packet RMS duration distributions for sites H (top), N (middle), and P (bottom). The total number of packets detected is given in upper right corner of each panel. Note the vertical axes are at different scales.

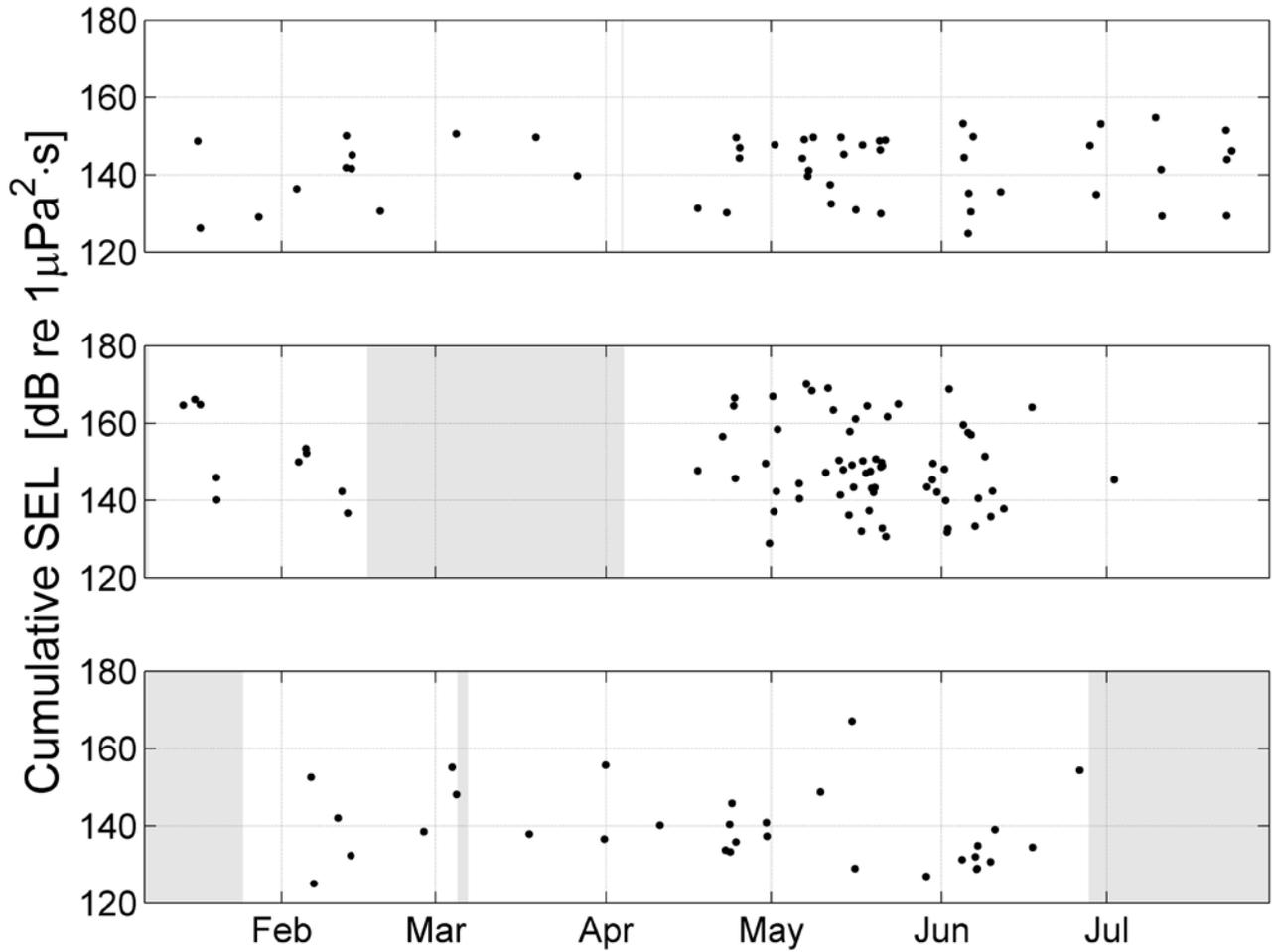


Figure 26. Cumulative sound exposure level for each wave train at sites H (top), N (middle), and P (bottom).

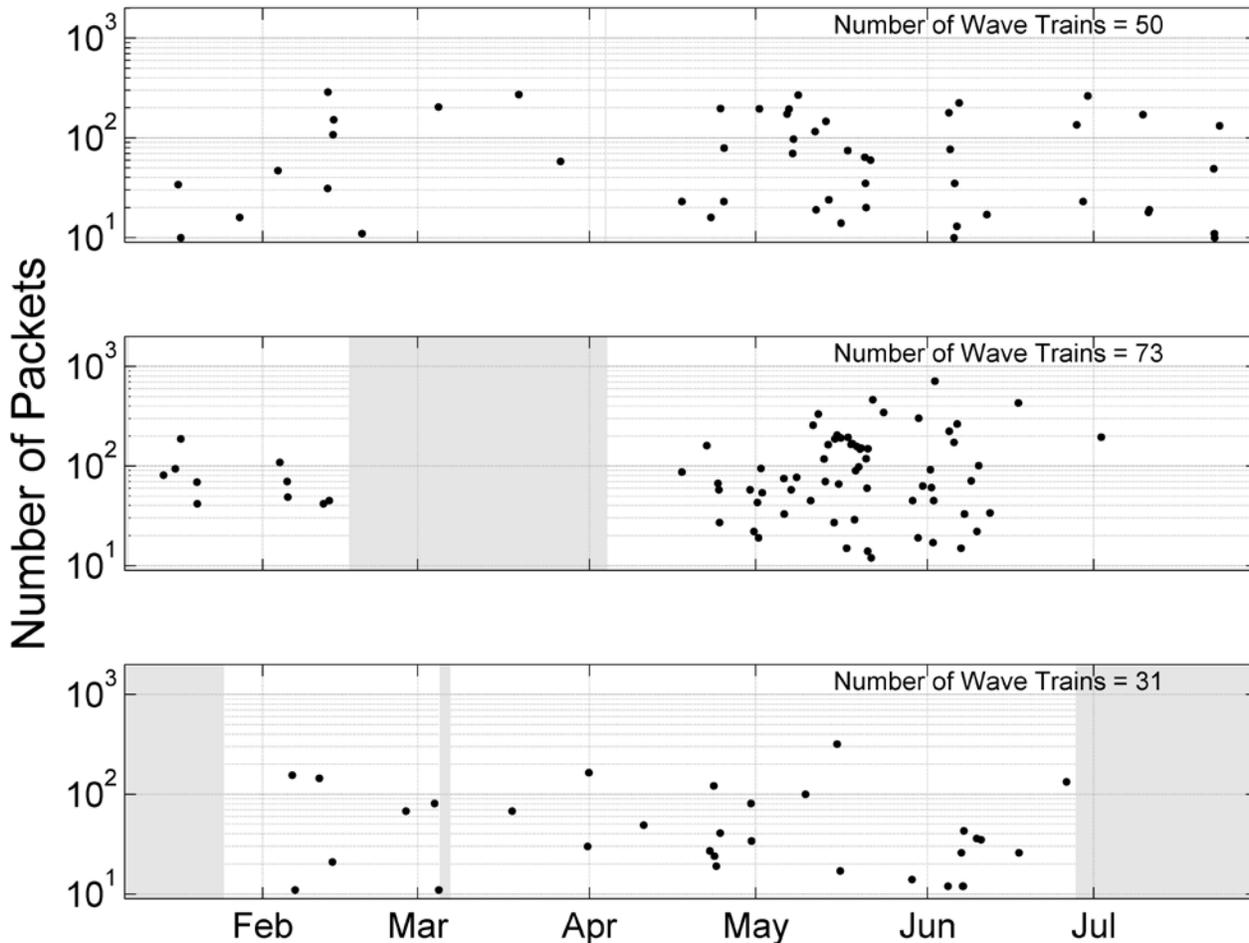


Figure 27. Number of MFA sonar packets for each wave train at sites H (top), N (middle), and P (bottom). Note the vertical axes are logarithmic base-10.

Low-Frequency Active Sonar

LFA sonar between 500 Hz and 1 kHz was detected at each site.

- LFA sonar between 500 Hz and 1 kHz was detected intermittently at sites H and P while detections at site N were limited to July 2014 (Figure 28).
- All detections occurred during daytime hours (Figure 29).

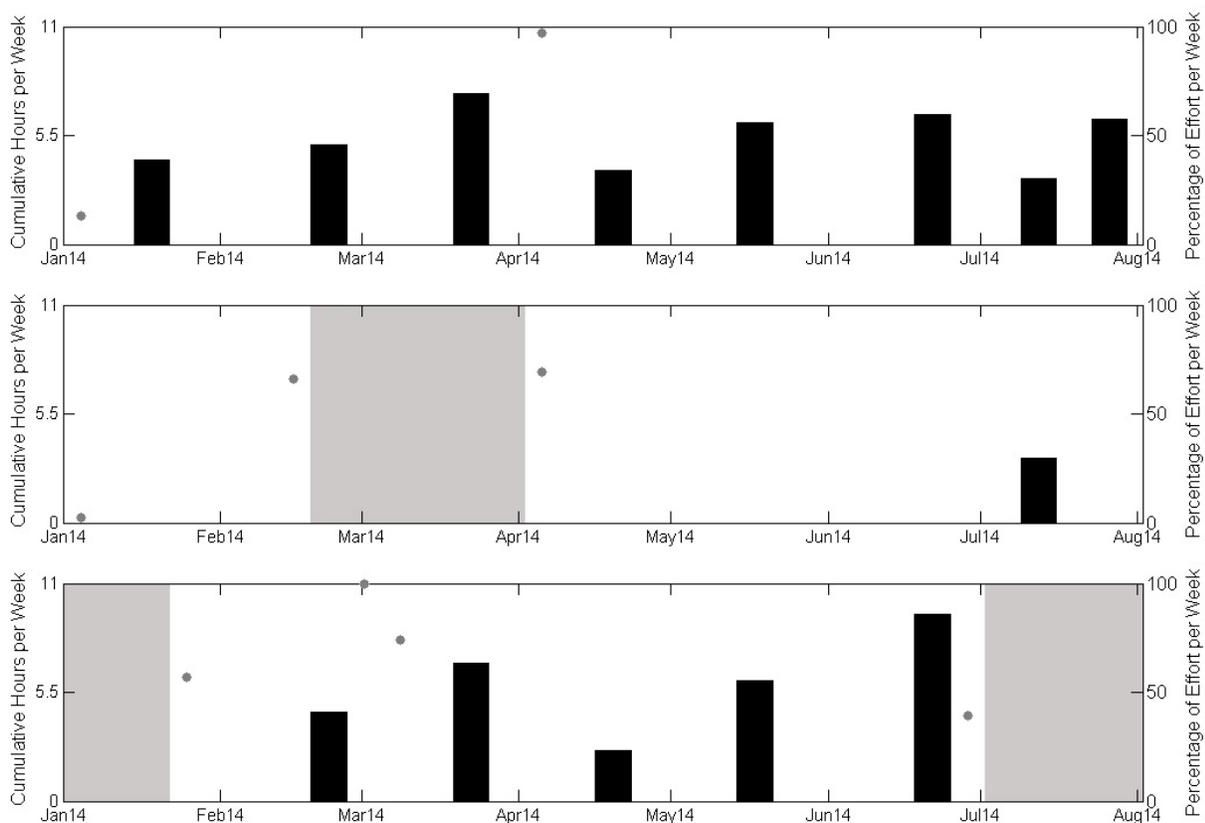


Figure 28. Weekly presence of LFA greater than 500 Hz between January and July 2014 at sites H (top), N (middle), and P (bottom). Effort markings are described in Figure 13.

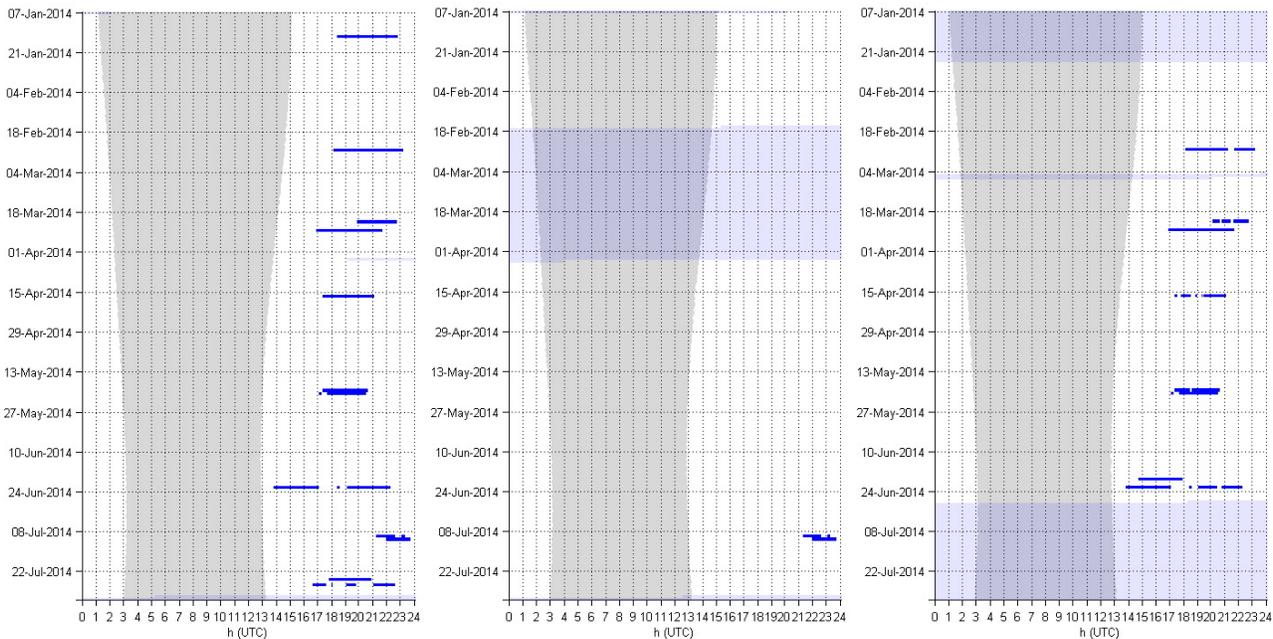


Figure 29. LFA signals between 500 Hz and 1 kHz in one-minute bins at sites H (left), N (middle), and P (right). Effort markings are described in Figure 14.

Explosions

Explosions were detected at all three sites.

- Explosion detections peaked in June 2014 at each site. Explosions were most prevalent at site H (Figure 30).
- 9,592 explosions were detected at site H, 2,296 at site N, and 2,760 at site P.
- Most explosions occurred during nighttime hours (Figure 31).
- The nighttime occurrence, relatively short duration of the explosion reverberations, and moderate received levels suggest these explosions may be seal bombs related to fishing activity.
- A decrease in detections occurred approximately on a weekly basis at each site, showing a short break in fishing activity over the weekend (Figure 31). These results differ from 2013 recordings where explosion detections were distinctly less common at site H (Debich *et al.*, 2015); however, these results are similar to those from 2012 (Kerosky *et al.*, 2013).

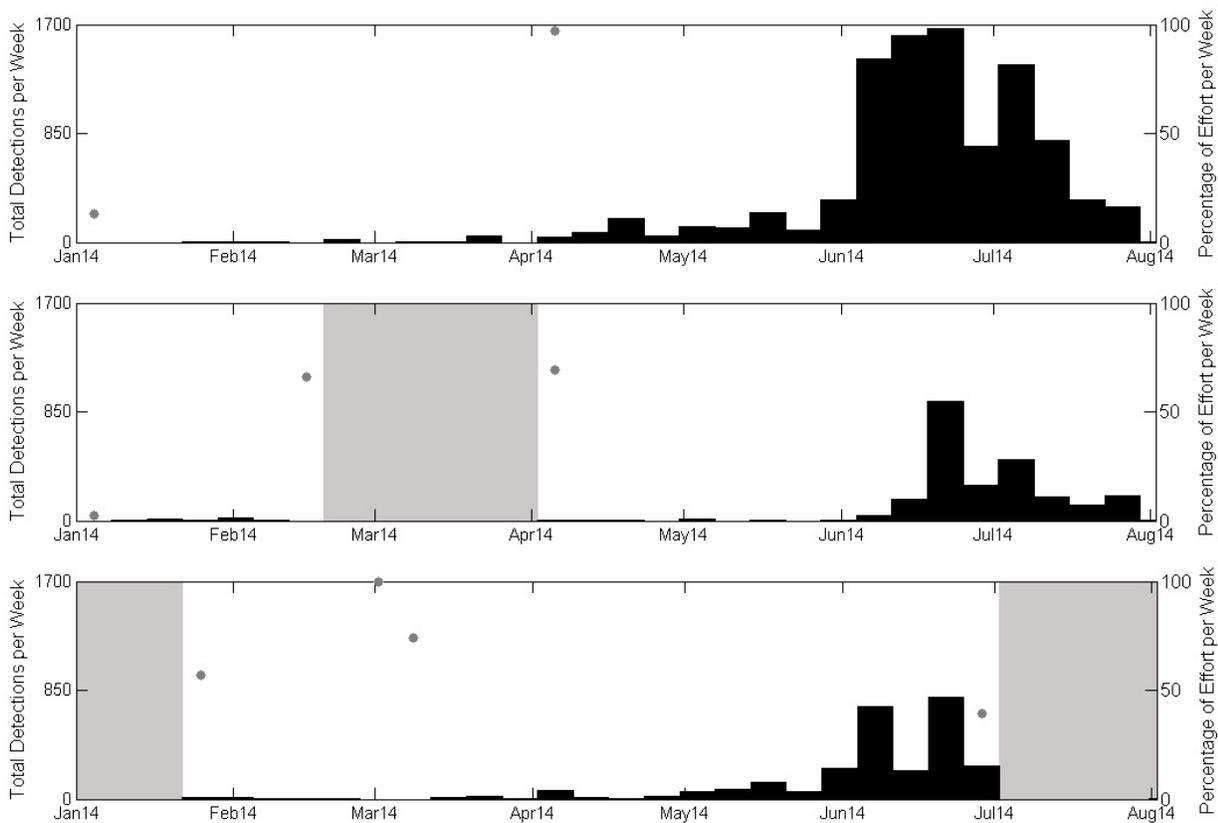


Figure 30. Weekly presence of explosions between January and July 2014 at sites H (top), N (middle), and P (bottom). Effort markings are described in Figure 13.

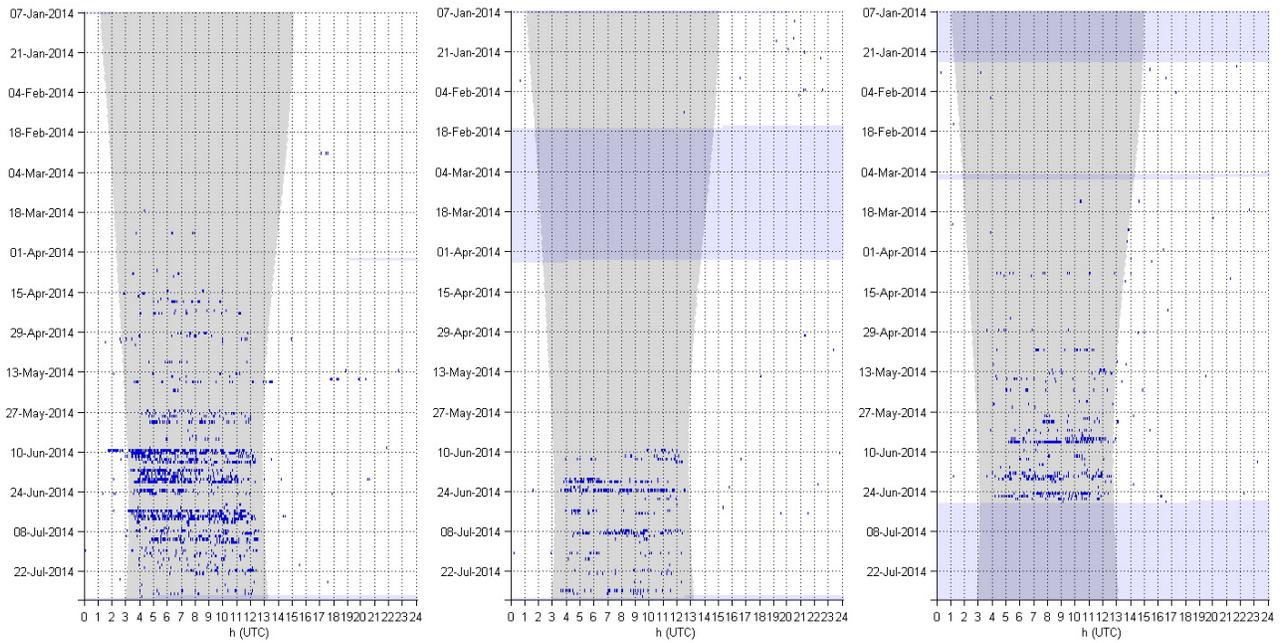


Figure 31. Explosion detections in one-minute bins at sites H (left), N (middle), and P (right). Effort markings are described in Figure 14.

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