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Passive Acoustic Monitoring for Marine Mammals in the SOCAL Range Complex July 2014 – May 2015

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Fin whale, photo by Michael H. Smith

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14. ABSTRACT
Passive acoustic monitoring was conducted in the Navy's Southern California Range Complex from July 2014 to May 2015 to detect marine mammal and anthropogenic sounds. Highfrequency Acoustic Recording Packages (HARPs) recorded sounds between 10 Hz and 100 kHz at three offshore locations: west of San Clemente Island (1,000 m depth, site H), west of Catalina Island (900 m depth, site M), and southwest of San Clemente Island (1,200 m depth, site N).

Data analysis was performed using automated computer algorithms. Calls of two baleen whale species were detected: blue whale B calls and fin whale 20 Hz calls. Both species were present at all sites, but blue whale B calls were most common at site N and fin whale acoustic index representative of 20 Hz calls was highest at site H. Both call types were least common at site M. Blue whale B call detections peaked in August and November 2014, with an unusual decrease in September and October 2014. Some B calls were also detected in March and May 2015, but mostly stopped being detected after January 2015. Fin whale acoustic index was high from October 2014 to January 2015.

Frequency modulated (FM) echolocation pulses from Cuvier's beaked whales were regularly detected at site H, they were less common at site N, and the least common at site M. These detections peaked in November 2014 and again in April-May 2015. 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 at sites H and N, mostly between November 2014 and January 2015. No other beaked whale signal types were detected.

Mid-Frequency Active (MFA) sonar was detected at all sites. Sites H and N had the highest maximum received levels; whereas, site M had the lowest. Site N had the most MFA sonar packet detections normalized per year and highest cumulative sound exposure levels, including events concurrent with a major naval exercise during late October. There were fewer detections at site H and they had lower received and sound exposure levels. Explosions were detected at all sites, but were most prevalent at site H. Explosion detections peaked in August and November 2014 across sites, albeit at lower numbers than in previous years. Temporal and spectral parameters, received levels, and the nighttime pattern of these explosive events suggest association with fishing, specifically the use of seal bombs.

15. SUBJECT TERMS
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Executive Summary

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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 toothed whales and pinnipeds.

In January 2009, an acoustic monitoring effort was initiated near the SOCAL Range Complex with support from the U.S. 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 training. In this current effort, the goal was focused on exploring the seasonal presence of a subset of species of particular interest, including blue and fin 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 July 2014 and collected data through May 2015. The three recording sites include one west of Catalina Island, (site M), as well as one to the west (site H) and one to the southwest (site N) of San Clemente Island (Figure 1). Data from site H were analyzed for the July 2014 through May 2015 time period; site M and N data were analyzed for the July 2014 through February 2015 time period (Table 1).

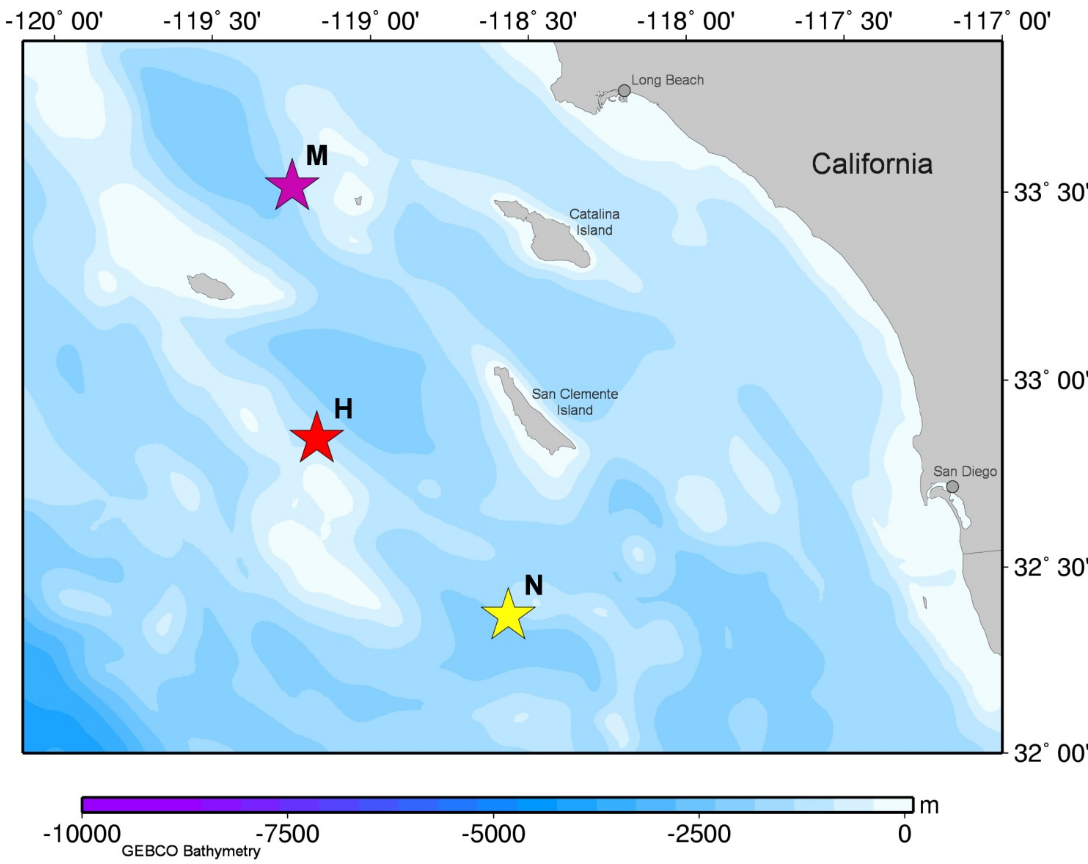

Figure 1. Locations of High-frequency Acoustic Recording Packages (HARPs) at sites H, M, and N deployed in the SOCAL study area July 2014 through May 2015. Color is bathymetric depth.

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 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
SOCAL 48	12/21/12 – 4/30/13	3140	-	-	12/20/12 – 5/1/13	3155
SOCAL 49	-	-	4/30/13 – 9/5/13	3057	5/2/13 – 9/11/13	3156
SOCAL 50	9/10/13 – 1/6/14	2843	9/9/13 – 1/6/14	2852	-	-
SOCAL 51	1/7/14 – 4/3/14	2082	-	-	1/7/14 – 2/16/14	956
SOCAL 52	4/4/14 – 7/30/14	2814	-	-	4/4/14 – 7/30/14	2817
SOCAL 53	**7/30/14 – 11/5/14**	**2340**	**7/30/14 – 11/3/15**	**2319**	**7/30/14 – 11/5/14**	**2342**
SOCAL 54	**11/5/14 – 2/4/15**	**2198**	**11/4/14 – 2/5/15**	**2233**	**11/4/14 -2/5/15**	**2196**
SOCAL 55	**2/5/15 – 6/1/15**	**2800**	**-**	**-**	**2/5/15 – 2/23/15**	**433**

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 (Table 1). The sites are designated site H (32° 56.54'N, 119° 10.22' W, depth 1,000 m), site M (33° 30.84'N 119° 14.94'W, depth 900 m), and site N (32° 22.18'N, 118° 33.77'W, depth 1,200 m). Each HARP sampled continuously at 200 kHz. Two sites (H and N) had three instrument deployments while site M had only two deployments. Site H yielded data from July 30, 2014 to the end of May 2015. Site M yielded data from July 30, 2014 to February 5, 2015. Site N had data from July 30, 2014 to February 23, 2015, when the hydrophone on the recorder started failing and resulted in lower quality data that were not analyzed further for the report to maintain a constant threshold of analysis. A total of 16,861 hours, covering 703 days of acoustic data were recorded in the deployments analyzed in this report.

Data Analysis

All 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*), and Cuvier's beaked whales (*Ziphius cavirostris*). Individual blue whale B calls and beaked whale echolocation clicks, as well as MFA and explosions occurrence and levels 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 (Širović *et al.*, 2015). Details of all automatic detection methods are described below.

We summarize results of the acoustic analysis on data collected between July 2014 and May 2015 at sites H, M, and N. 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. A single kernel was used for all deployments and it was based on the calls that were recorded in October 2014. It was defined as sweeping from 46.4 to 45.7 Hz, 45.7 to 45.1 Hz, 45.1 to 44.5 Hz, and 44.5 to 43.7 Hz. Kernel bandwidth was 2 Hz. Total numbers of detections are reported for this call type.

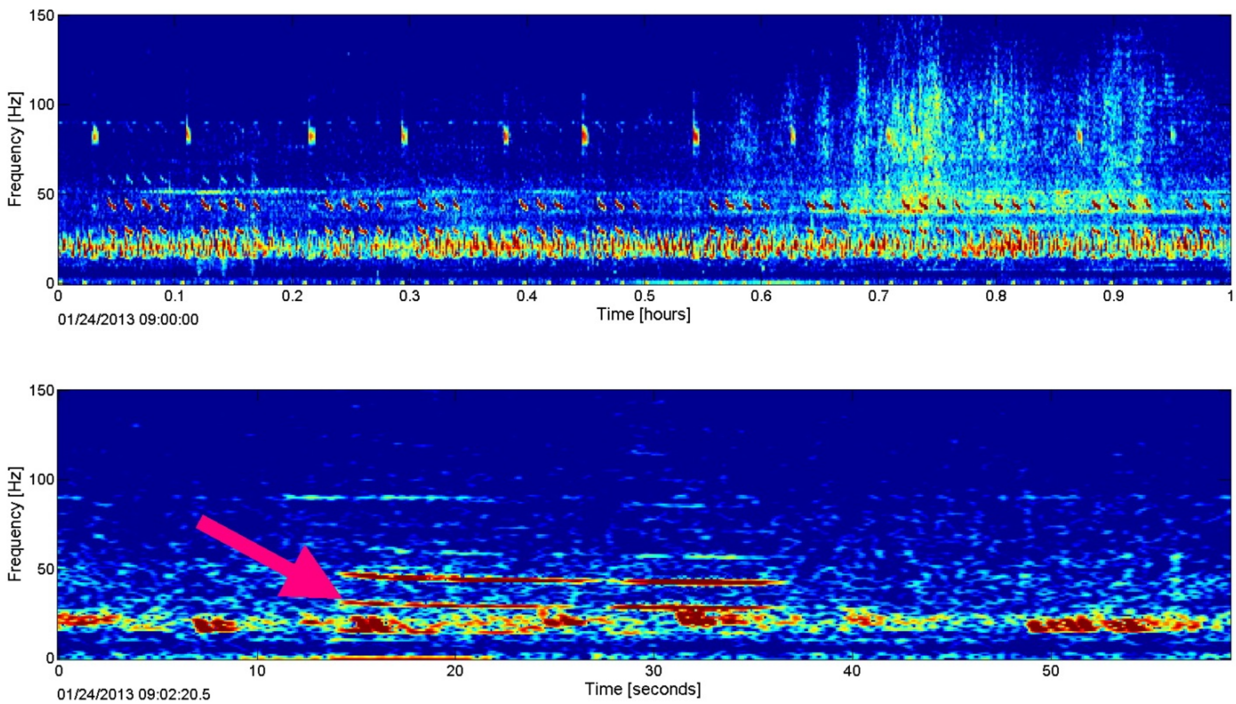

Figure 2. Blue whale B call in Long-term Spectral Average (LTSA; top) and spectrogram (bottom) at site N.

Fin Whales

Fin whales also produce multiple short duration (~ 1 s), low-frequency calls, the most ubiquitous of which are downsweeps 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.

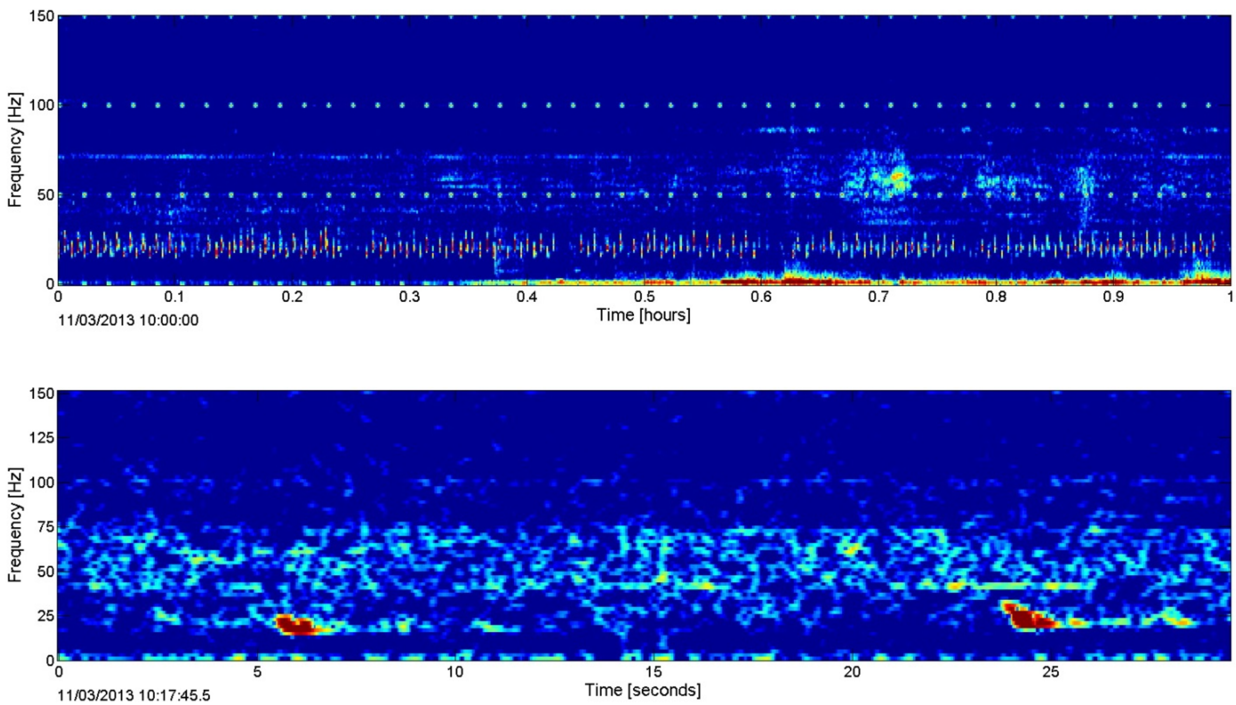

Figure 3. Fin whale 20 Hz calls in LTSA (top) and spectrogram (bottom) at site M.

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).

Beaked whales can be identified acoustically 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 were detected with an automated method. This automated effort was for all identifiable signals found in Southern California except Baird's beaked whales. 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. A third classification step, based on computer assisted manual decisions by a trained analyst, was used to label 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 across deployments.

Cuvier's Beaked Whales

Cuvier's echolocation signals are polycyclic, with a characteristic FM pulse upsweep, peak frequency around 40 kHz (Figure 4), 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.

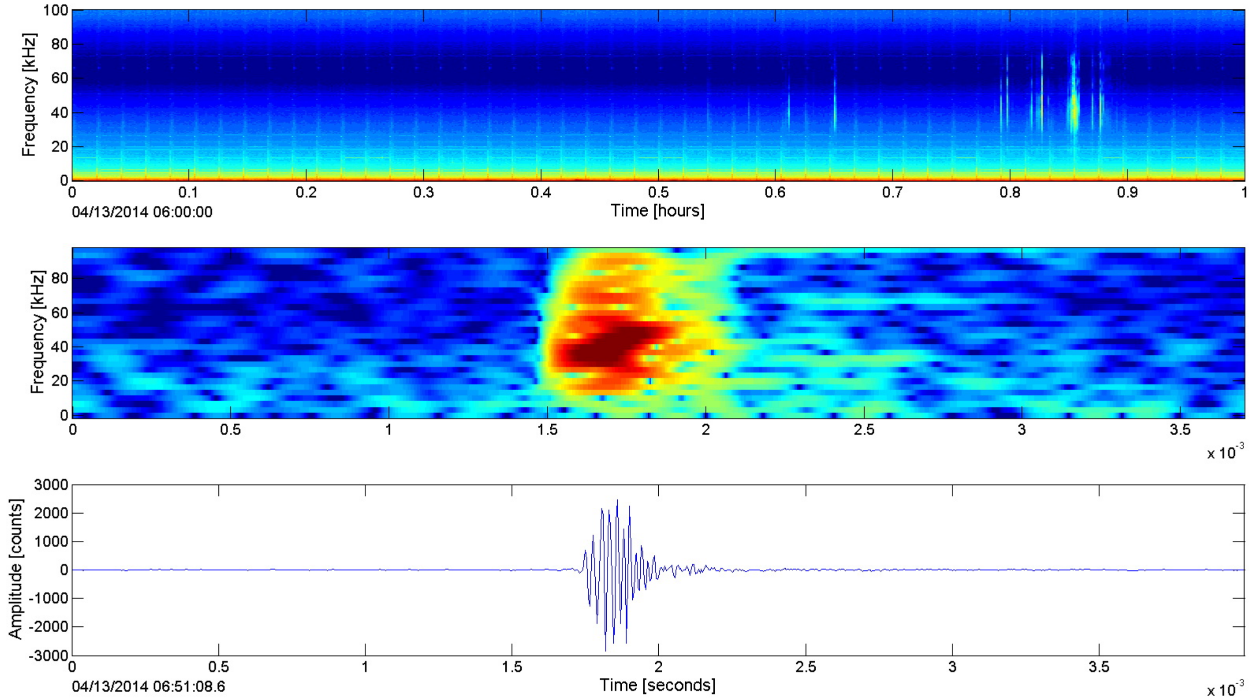

Figure 4. Echolocation sequence of Cuvier's beaked whale in LTSA (top) and example FM pulse in spectrogram (middle) and time series (bottom) at site N.

BW43

The BW43 FM pulse has yet to be linked to a specific species. These FM pulses are distinguishable from other species' signals by their peak frequency around 43 kHz and uniform inter-pulse interval around 0.2 s (Figure 5) (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).

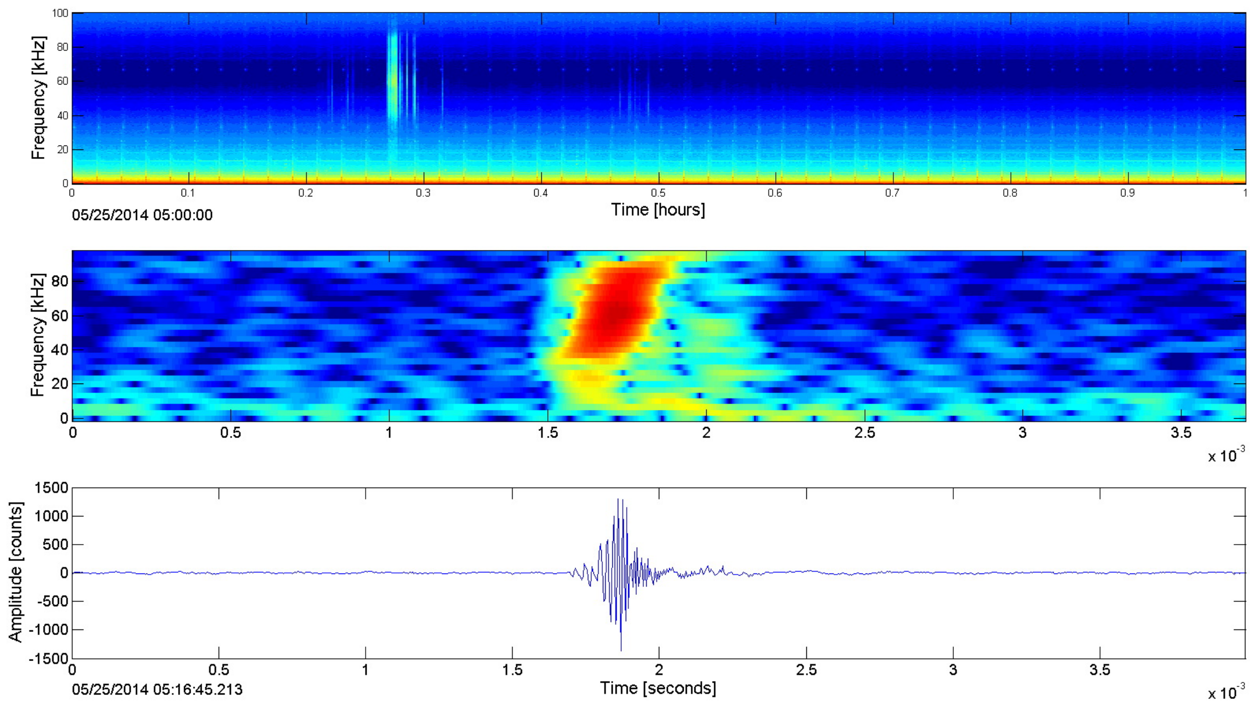

Figure 5. Echolocation sequence of BW43 in LTSA (top) and example FM pulse in spectrogram (middle) and time series (bottom) at site N.

Anthropogenic Sounds

Two anthropogenic sounds were monitored for this report: Mid-Frequency Active (MFA) sonar and explosions. Both sounds were detected by a computer algorithm. The start and end of each sound or encounter was logged and their durations were added to estimate cumulative hourly presence.

Mid-Frequency Active Sonar

Sounds from MFA sonar vary in the frequency range (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 6). 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.

MFA sonar was detected using a modified version of the *Silbido* detection system (Roch *et al.*, 2011) designed for characterizing toothed whale whistles. The algorithm identifies peaks in time-frequency distributions (e.g. spectrogram) and determines which peaks should be linked into a graph structure based on heuristic rules that include examining the trajectory of existing peaks, tracking intersections between time-frequency trajectories, and allowing for brief signal dropouts or interfering signals. Detection graphs are then examined to identify individual tonal contours looking at trajectories from both sides of time-frequency intersection points. For MFA detection, parameters were adjusted to detect tonal contours at or above 2 kHz in data decimated to a 10 kHz sample rate with time-frequency peaks with signal to noise ratios of 5 dB or above and contour durations of at least 200 ms with a frequency resolution of 100 Hz. The detector frequently triggered on noise produced by instrument disk writes that occurred at 75 s intervals. Over periods of several months, these disk write detections dominated the number of detections and could be eliminated using an outlier detection test. Histograms of the detection start times modulo the disk write period were constructed and outliers were discarded. This removed some valid detections that occurred during disk writes, but as the disk writes and sonar signals are uncorrelated this is expected to only have a minor impact on analysis. As the detector did not distinguish between sonar and non-anthropogenic tonal signals within the operating band (e.g. humpback whales), human analysts examined detection output and accepted or rejected contiguous sets of detections. Start and end time of these cleaned sonar events were then created to be used in further processing.

These 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} -10dB) were measured and saved. Various filters were applied to the detections 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 ~163 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.

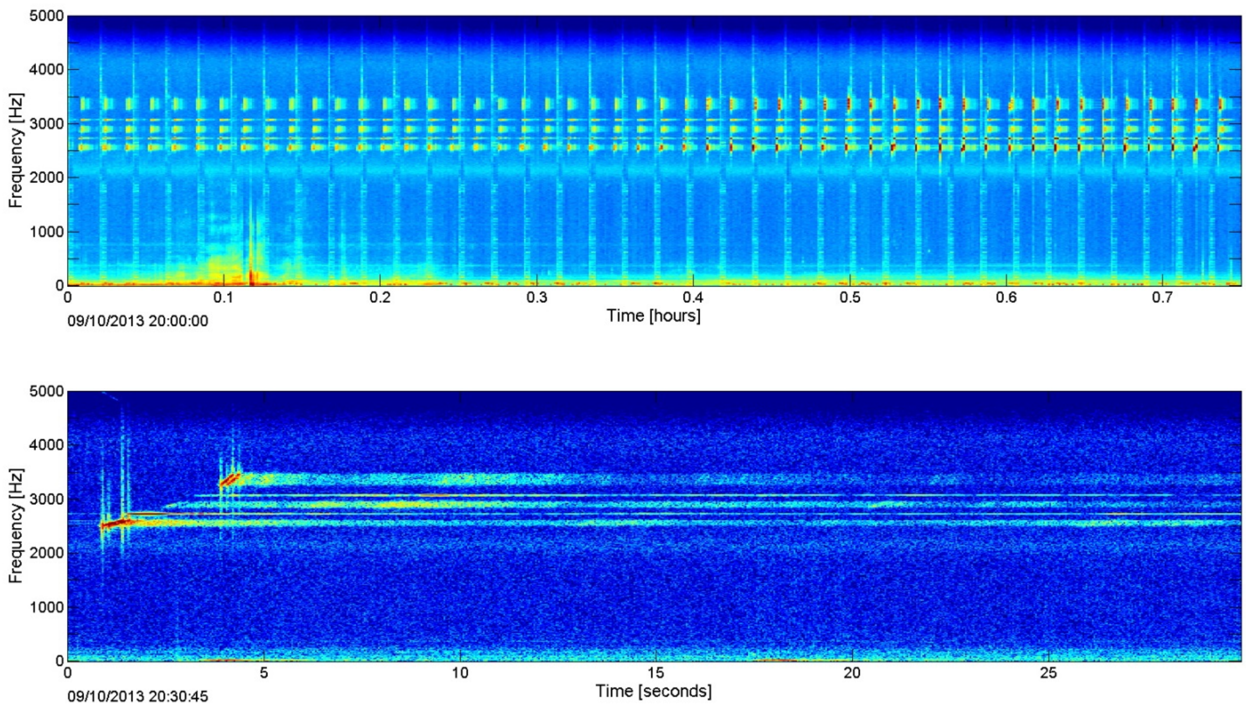

Figure 6. MFA sonar recorded at site H and shown as a wave train event in a 45 minute LTSA (top) and as a single packet with multiple pulses in a 30 second spectrogram (bottom).

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 7). 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 s 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 s 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 exceeded the threshold, the time series was inspected more closely. Consecutive explosions were required to be separated by at least 0.5 s 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 a few seconds including the reverberation.

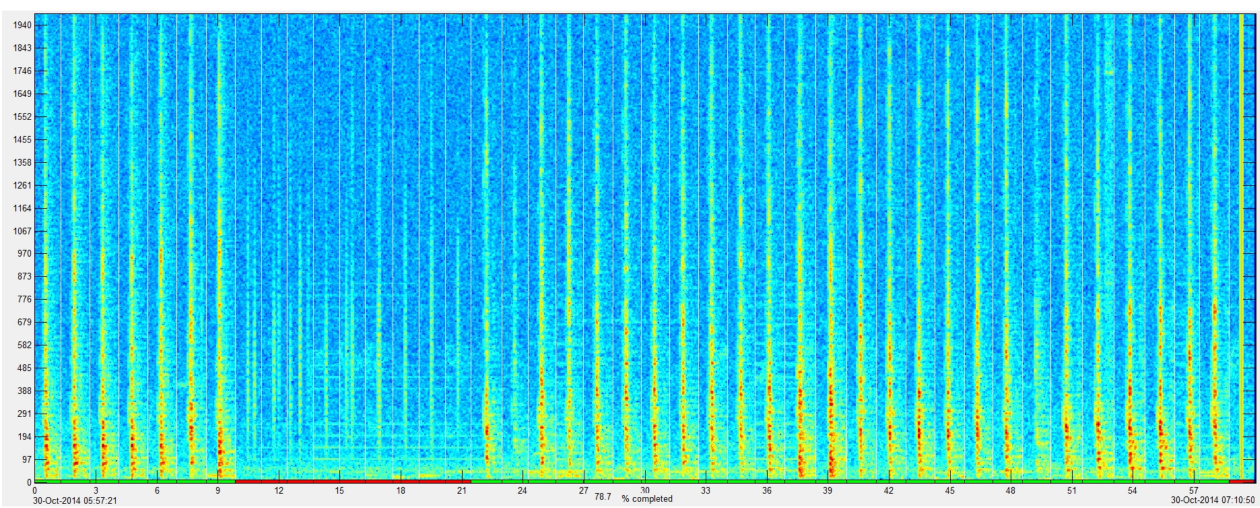

Figure 7. Explosions from site H in the analyst verification stage where events are concatenated into a single spectrogram. In the bottom line green indicates true and red indicates false detections.

Results

The results of acoustic data analysis at sites H, M, and N from July 2014 through May 2015 are summarized. We describe ambient noise, and the seasonal occurrence and relative abundance of marine mammal acoustic signals and anthropogenic sounds of interest in the following pages.

Ambient Noise

- Underwater ambient noise at sites H, M, and N 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 8, Figure 9, and Figure 10 respectively) (Hildebrand, 2009).
- Site M had lower spectrum levels at frequencies >200 Hz indicating less action from wind and waves, likely as a result of its relatively sheltered location in the vicinity of the Channel Islands. However its increased levels <30 Hz are likely due to tidal strum.
- Higher spectrum levels at frequencies >100 Hz at all sites in July are due to only one day of data having been available for analysis, so it does not represent true average for the month.
- Sites M and N showed higher noise levels at frequencies >200 Hz in summer and fall, while they were highest at site H in the spring.
- 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.
- Summer and fall month spectral peaks at 44 Hz, along with lower frequency harmonics (~15 and ~30 Hz), at all sites are related to blue whale B calls, but they were highest at site N.

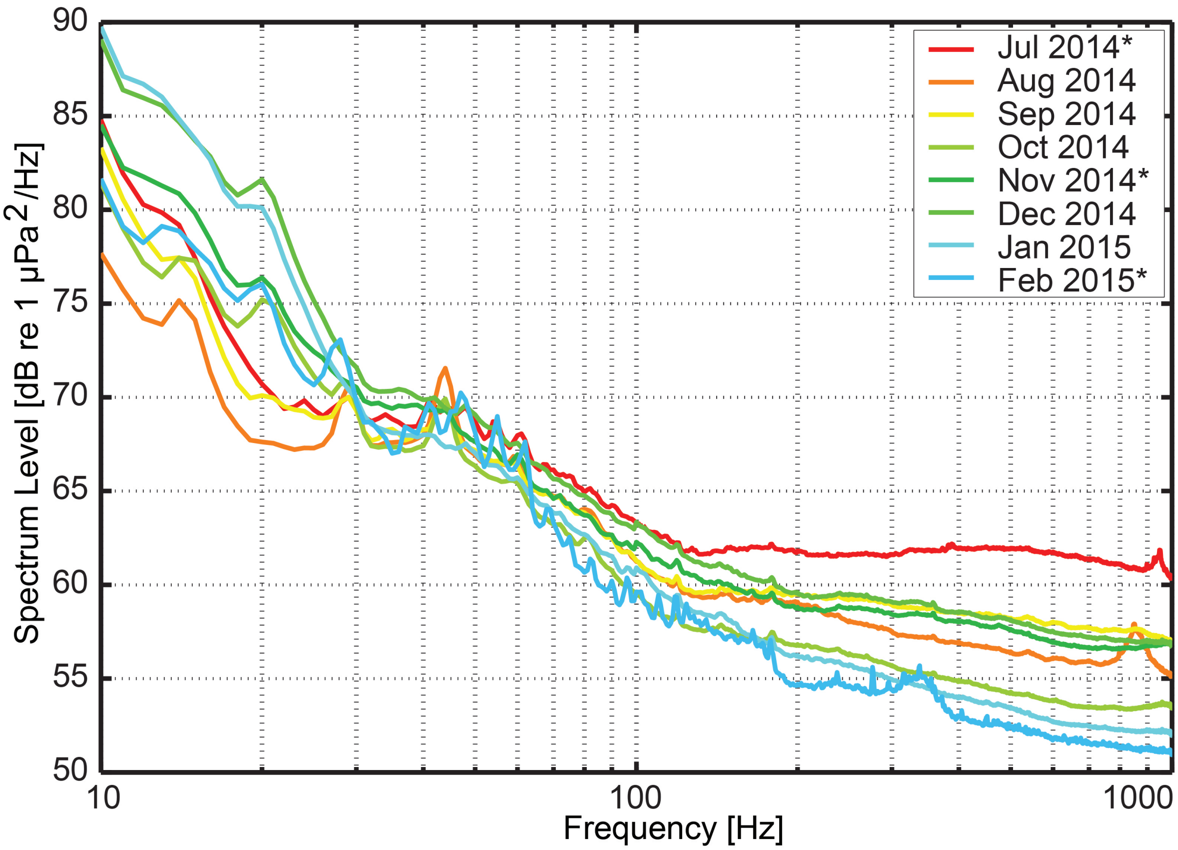

Figure 8. Monthly averages of ambient noise at site M. Legend gives color-coding by month. Asterisk denotes month with partial data.

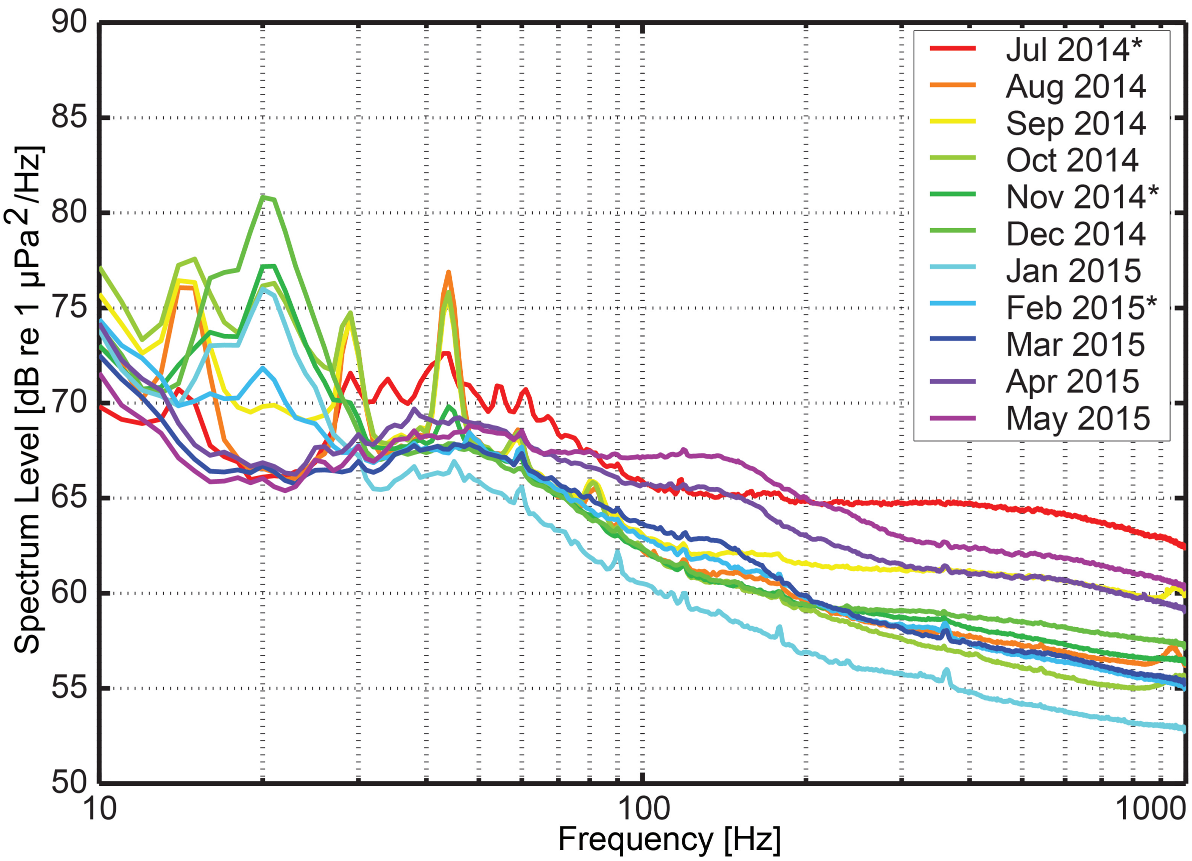

Figure 9. Monthly averages of ambient noise at site H. Legend gives color-coding by month. Asterisk denotes month with partial data.

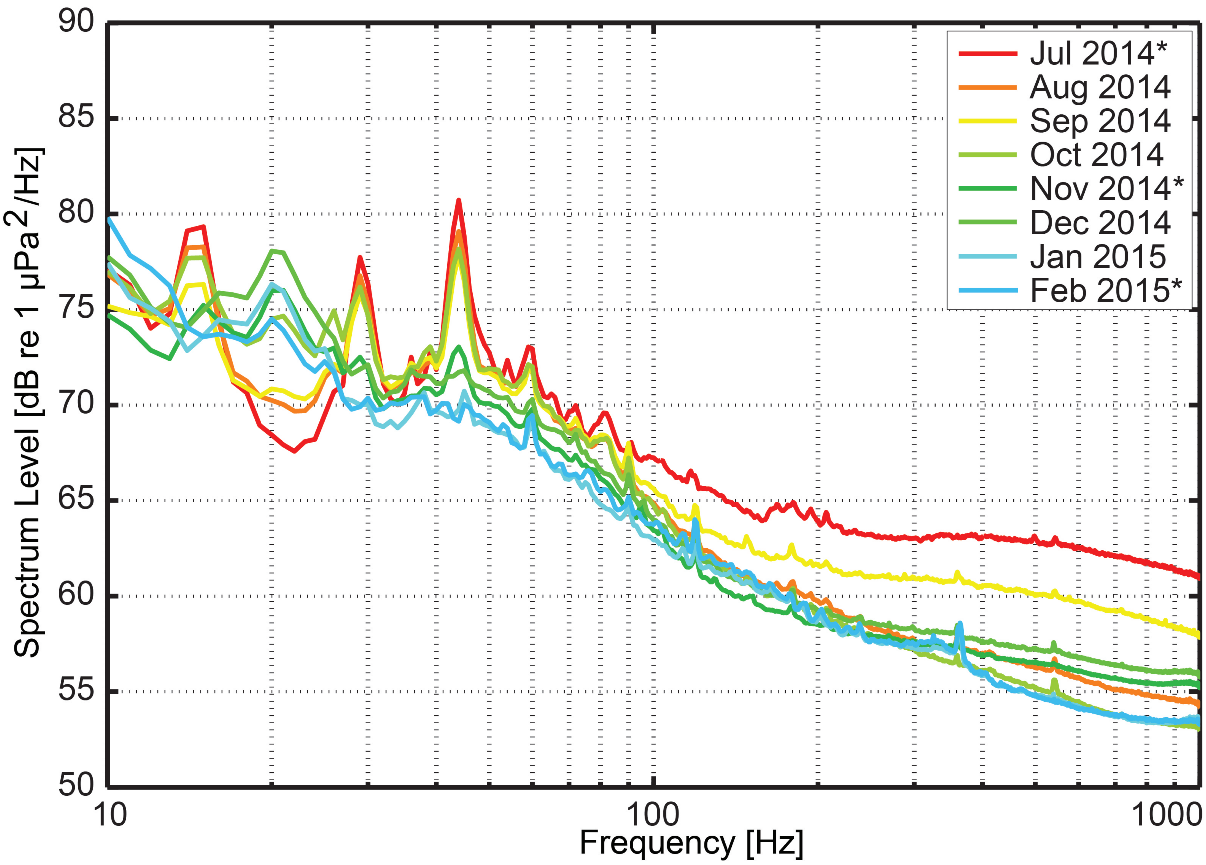

Figure 10. Monthly averages of ambient noise at site N. Legend gives color-coding by month. Asterisk denotes month with partial data.

Mysticetes

Two baleen whale species were detected using automated methods between July 2014 and May 2015, blue whales and fin whales. In general, fewer baleen whale vocalizations were detected at site M and the highest level of detections was at site H. 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. Fewer calls were detected at site M during the monitoring period (Figure 11).
- Most calls were detected between August and December, with bimodal peaks in August and November. Number of detections dropped down after February, but some detections also occurred in March and May at site H (Figure 11).
- There was no diel pattern in the NE Pacific blue whale B calls (Figure 12).

- The decrease in blue whale B call detections in September and October, as well as detections during the spring are unusual for this area (Debich et al. 2015; Kerosky et al. 2013).

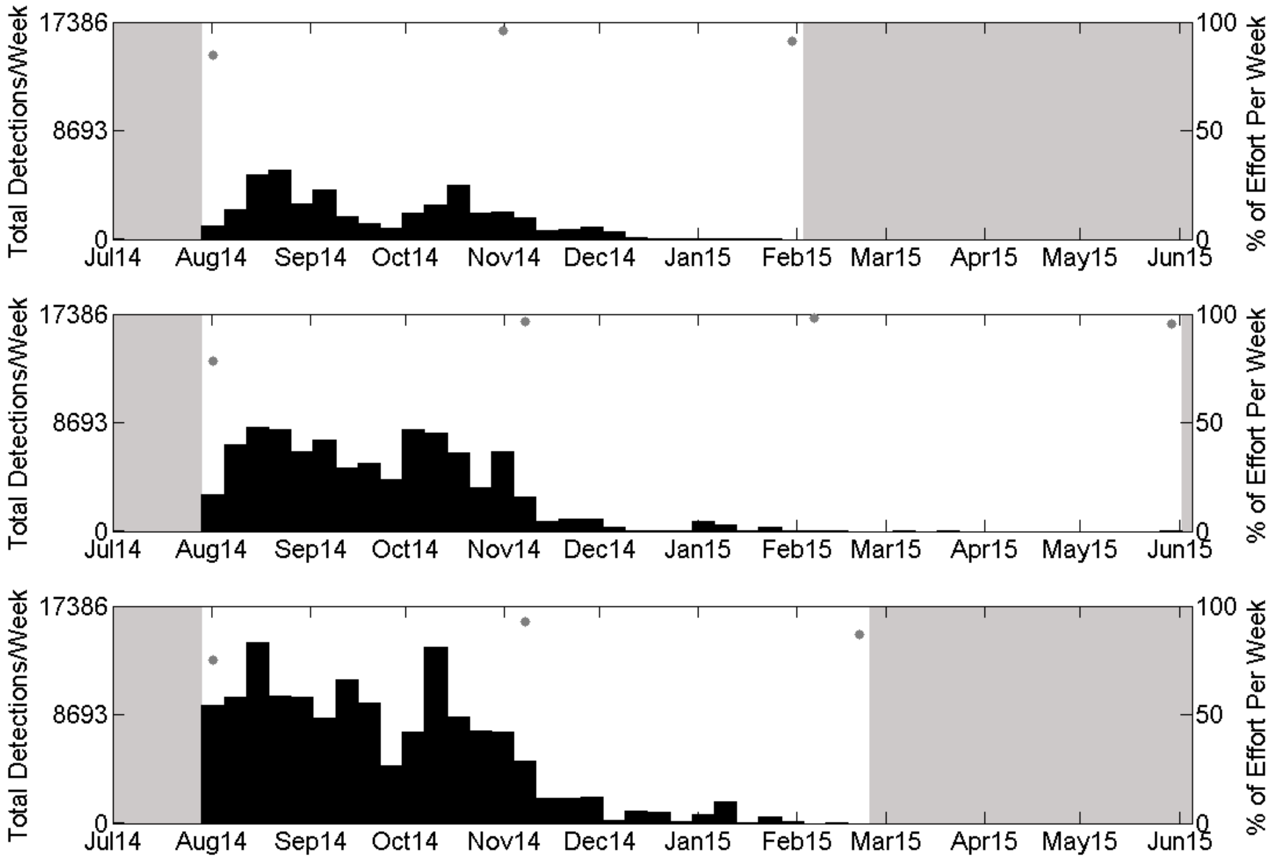

Figure 11. Weekly presence of NE Pacific blue whale B calls between July 2014 and May 2015 at sites M (top), H (middle), and N (bottom). Gray dots represent percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

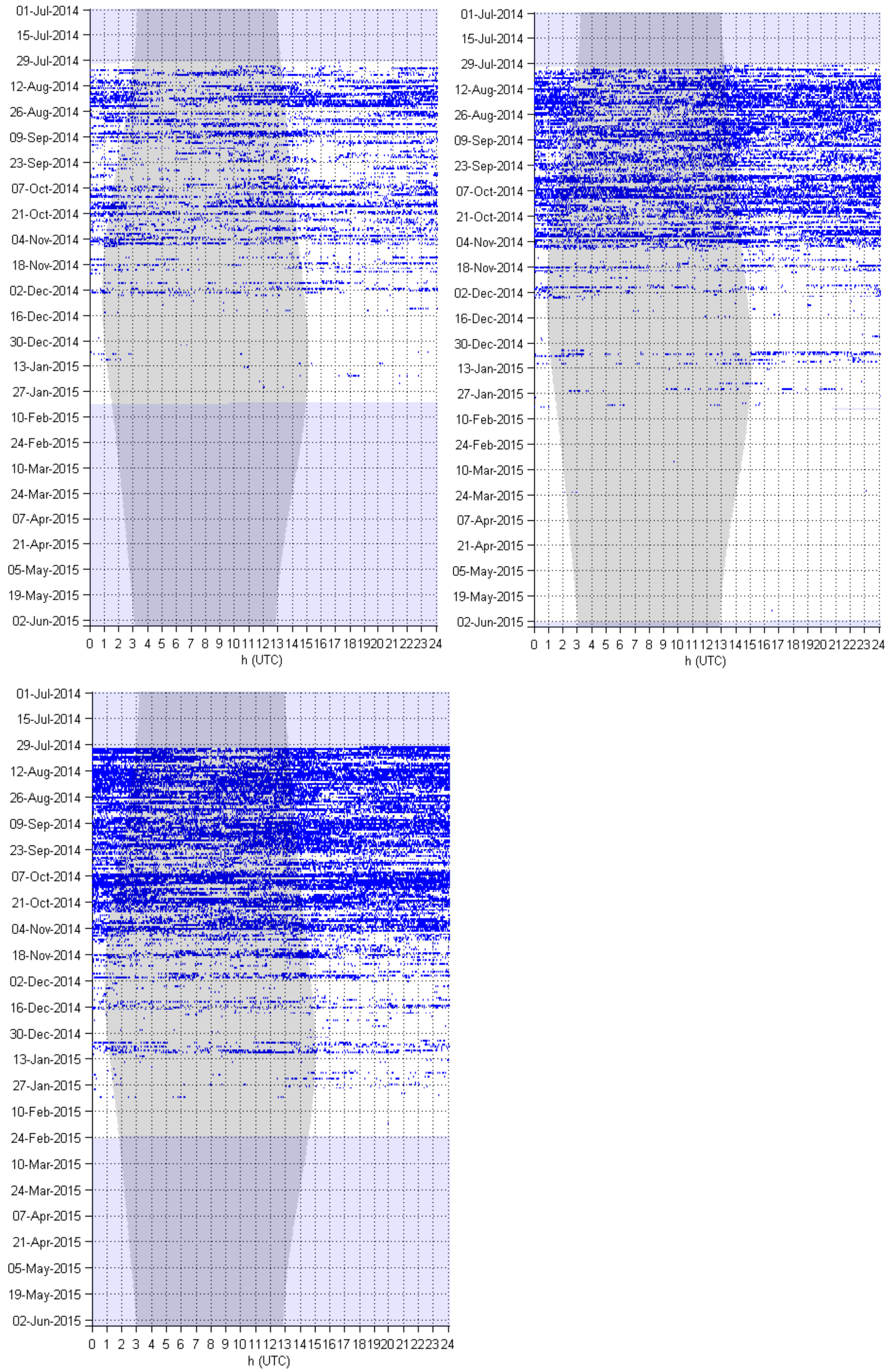

Figure 12. NE Pacific blue whale B calls in one-minute bins at sites M (top left), H (top right), and N (bottom). Gray vertical shading denotes nighttime, and light purple horizontal shading denotes absence of acoustic data.

Fin Whales

Fin whales were a commonly detected baleen whale throughout the recordings.

- The highest levels of the fin whale acoustic index (representative of 20 Hz calls) were measured at site H (Figure 13).
- Peaks in the fin whale acoustic index occurred in December 2014 and January 2015 at site H, although they were elevated from October through February (Figure 13).
- Sites M and N had lower values of fin whale acoustic index, with increased levels between October 2014 and January 2015 (Figure 13).
- These results are consistent with earlier findings (Kerosky *et al.*, 2013; Debich *et al.*, 2015).

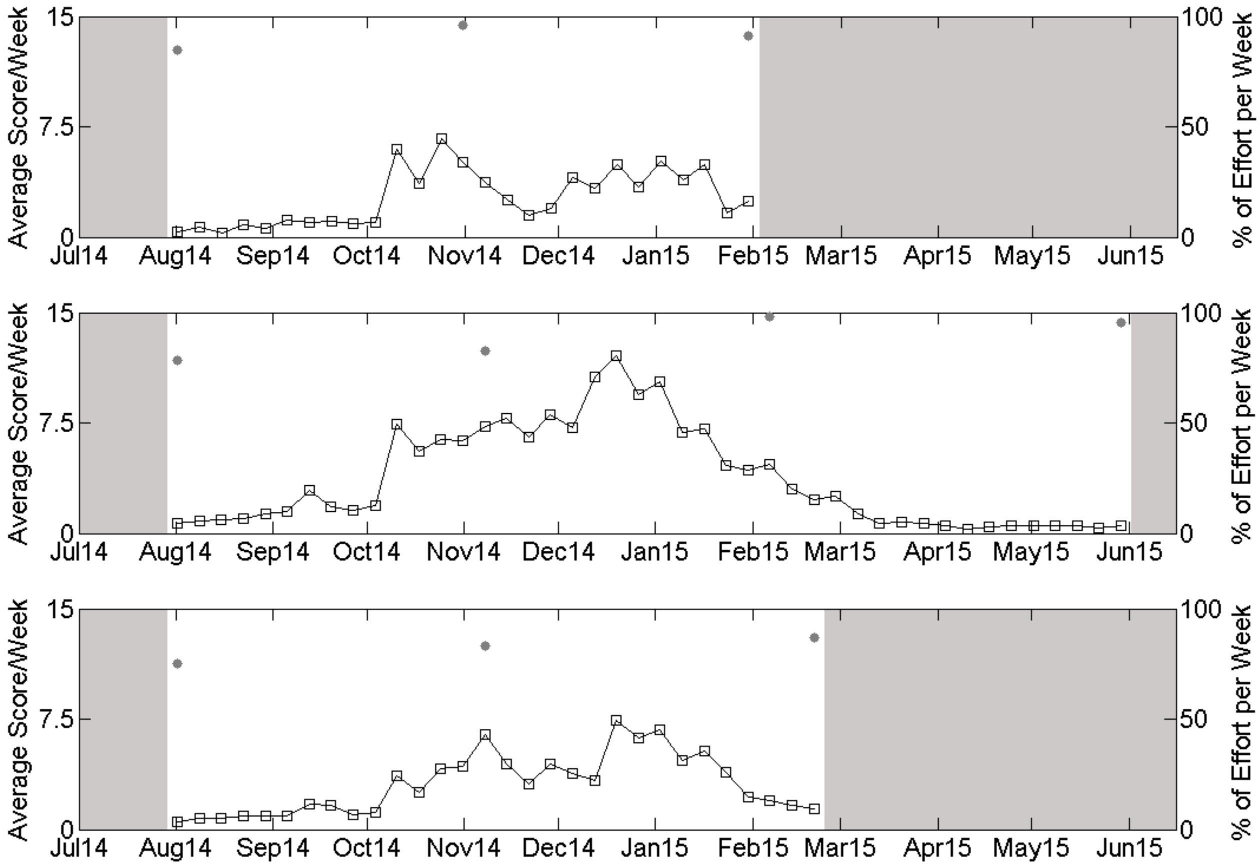

Figure 13. Weekly value of fin whale acoustic index (proxy for 20 Hz calls) between July 2014 and May 2015 at sites M (top), H (middle), and N (bottom). Effort markings are described in Figure 11.

Beaked Whales

Cuvier's beaked whales were detected during most of the deployment period. The FM pulse type, BW43, possibly produced by Perrin's beaked whales (Baumann-Pickering *et al.*, 2014) was detected sporadically. More details of each species' presence at the three 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 all sites, with most detection at site H and fewest at site M (Figure 14).
- Detections at sites H and N peaked in November and again at site H in April-May. Few detections occurred in August and September (Figure 14).
- There was a diel pattern, with more Cuvier's beaked whale FM pulses detected at night, at site M, but there was no discernable diel pattern in FM pulses at the other two sites with substantially more detections (Figure 15).
- These results are similar to previous reports for these sites (Kerosky *et al.*, 2013; Debich *et al.*, 2015).

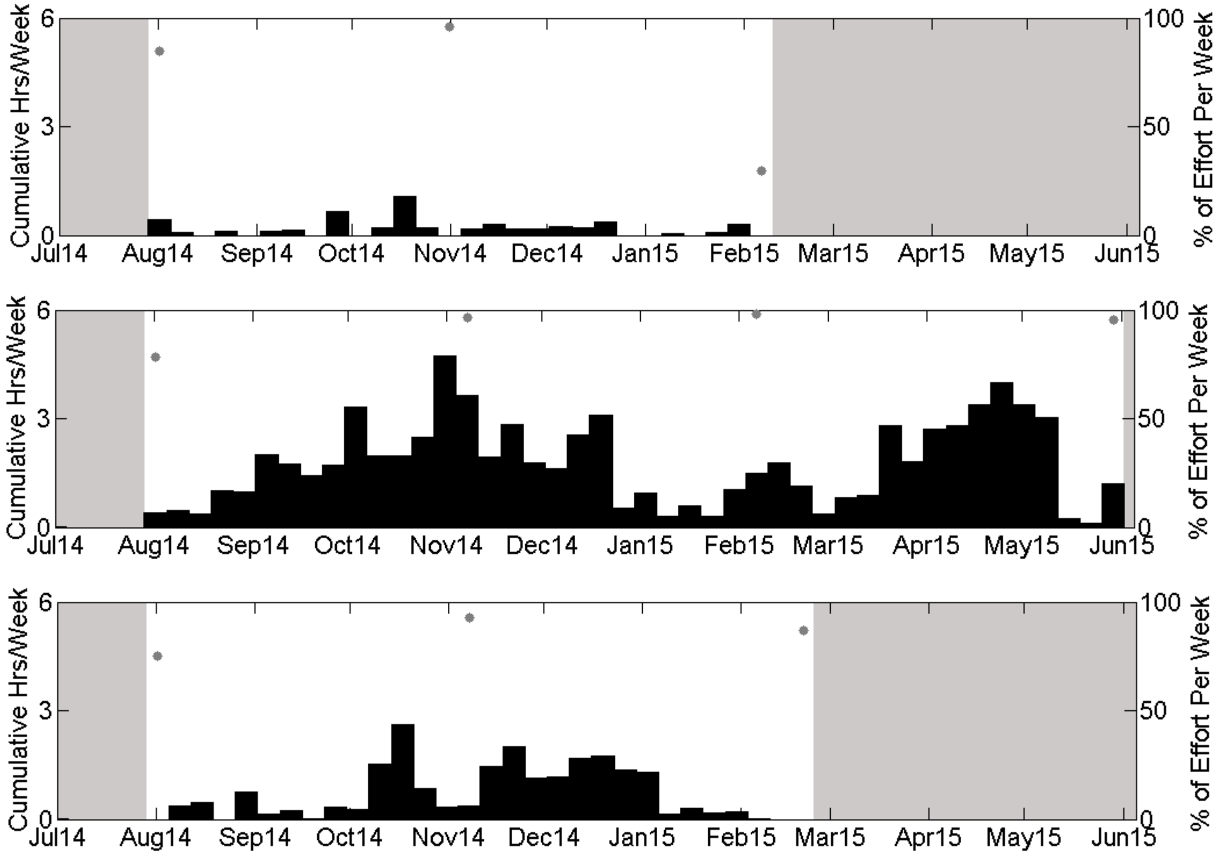

Figure 14. Weekly presence of Cuvier's beaked whale FM pulses between July 2014 and May 2015 at sites M (top), H (middle), and N (bottom). Effort markings are described in Figure 11.

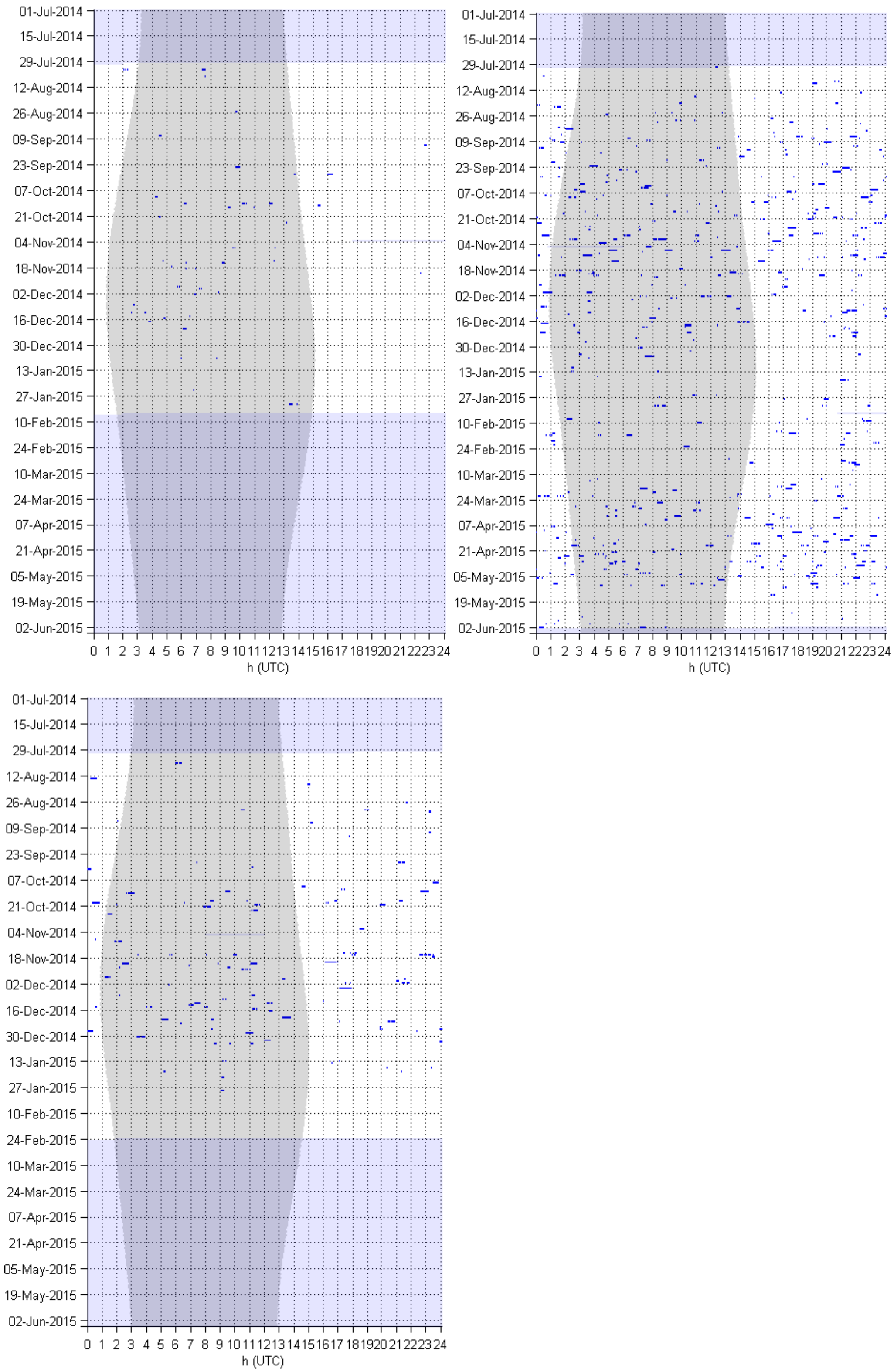

Figure 15. Cuvier's beaked whale FM pulses in one-minute bins at sites M (top left), H (top right), and N (bottom). Effort markings are described in Figure 12.

BW43

There were very few detections of BW43 FM pulses.

- BW43 FM pulses were detected in low numbers at sites N and H, with all detections occurring from November to January. There were no BW43 detections at site M (Figure 16).
- There may be a weak diel pattern in BW43 detections, with more detections at night, but more acoustic encounters are needed to confirm if this is a persistent pattern (Figure 17).
- While the total number of encounters is a bit larger than usual, especially for site N, these results are quite similar to previous recordings (Kerosky *et al.*, 2013; Debich *et al.*, 2015).

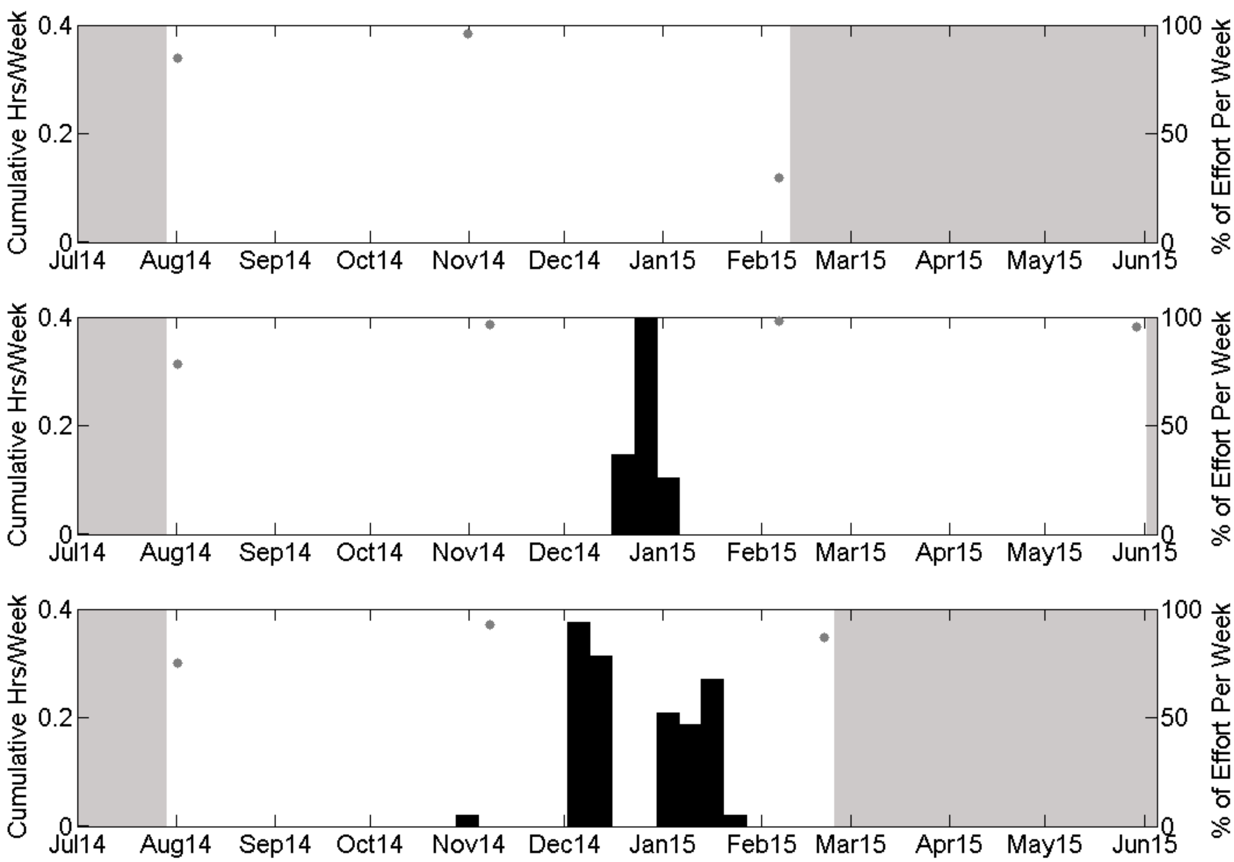

Figure 16. Weekly presence of BW43 FM pulses between July 2014 and May 2015 at sites M (top), H (middle), and N (bottom). Effort markings are described in Figure 11.

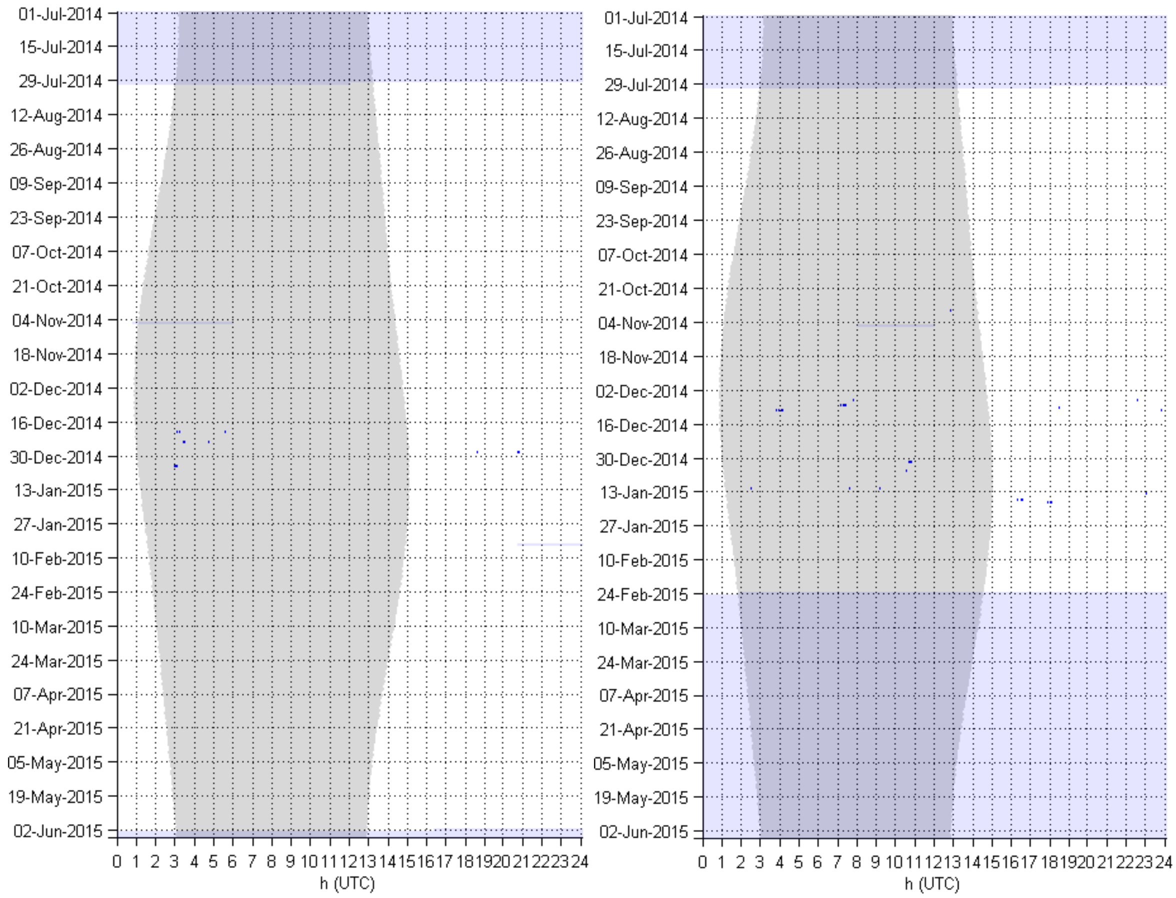

Figure 17. BW43 FM pulses in one-minute bins at site H (left) and N (right). No BW 43 FM pulses were detected at site M. Effort markings are described in Figure 12.

Anthropogenic Sounds

Two types of anthropogenic sounds were examined in these recordings between July 2014 and May 2015: MFA sonar (2.4 – 4.5 kHz) and explosions.

Mid-Frequency Active Sonar

MFA sonar was a common anthropogenic sound. The dates of major naval training exercises that were conducted in the SOCAL region between July 2014 and May 2015 are listed in Table 2. 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 when normalized per year (>130 dB_{pp} re 1 μPa) at site N, followed by site H (Table 3). No detected packets at site M had received level >130 dB_{pp} re 1 μPa. The following bullets relate to MFA sonar <5 kHz:

- MFA sonar was detected at all three sites. There was a peak in detections in November 2014 at site N, while bouts at site H were relatively abundant, but with a slight increase in March – early May 2015. Detection numbers at site M were generally low (Figure 18).
- Bouts of MFA sonar <5 kHz were somewhat more likely to begin an hour or two following sunrise, but they could persist through the night (Figure 19).
- At site H, a total of 6,767 packets were detected, with a maximum received level of 163 dB_{pp} re 1 μPa (instrument clipping level), and a median received level of 138 dB pp re 1 μPa (Figure 20).
- At site N, a total of 6,599 packets were detected, with a maximum received level of 163 dB_{pp} re 1 μPa (instrument clipping level), and a median received level of 144 dB pp re 1 μPa (Figure 20).
- Most MFA sonar packets had durations less than 2 s (Figure 21).
- Maximum cumulative sound exposure levels occurred during October, December and January at site N and were greater than 170 dB re 1 μPa-s; whereas, at site H, maximum levels were less than 170 dB and occurred in February, April, and May (Figure 22).
- Most MFA sonar wave trains occurred at site N in late October during a major training exercise (Table 2; Figure 23), and late May-early June at site H (Figure 23).

Table 2. Major naval training exercises in the SOCAL region between July 2014 and May 2015.

Exercise Dates	Type of Exercise
20 to 31 October 2014	IAC (Integrated Anti-submarine Warfare Course)
16 March to 1 April 2015	C2X (Composite Training Exercise; may or may not have involved sonar-equipped ships)
25 to 28 April 2015	IAC

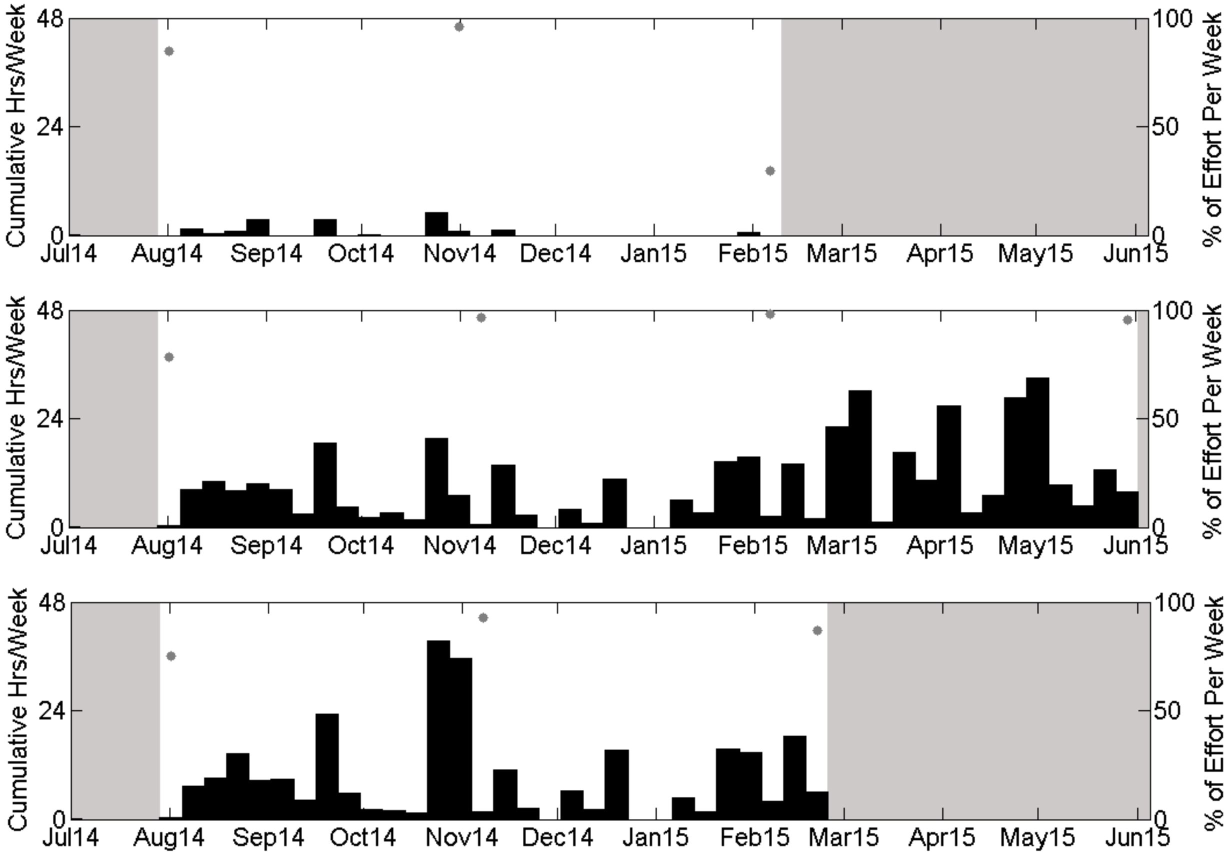

Figure 18. Weekly presence of MFA <5 kHz between July 2014 and May 2015 at sites M (top), H (middle), and N (bottom). Effort markings are described in Figure 11.

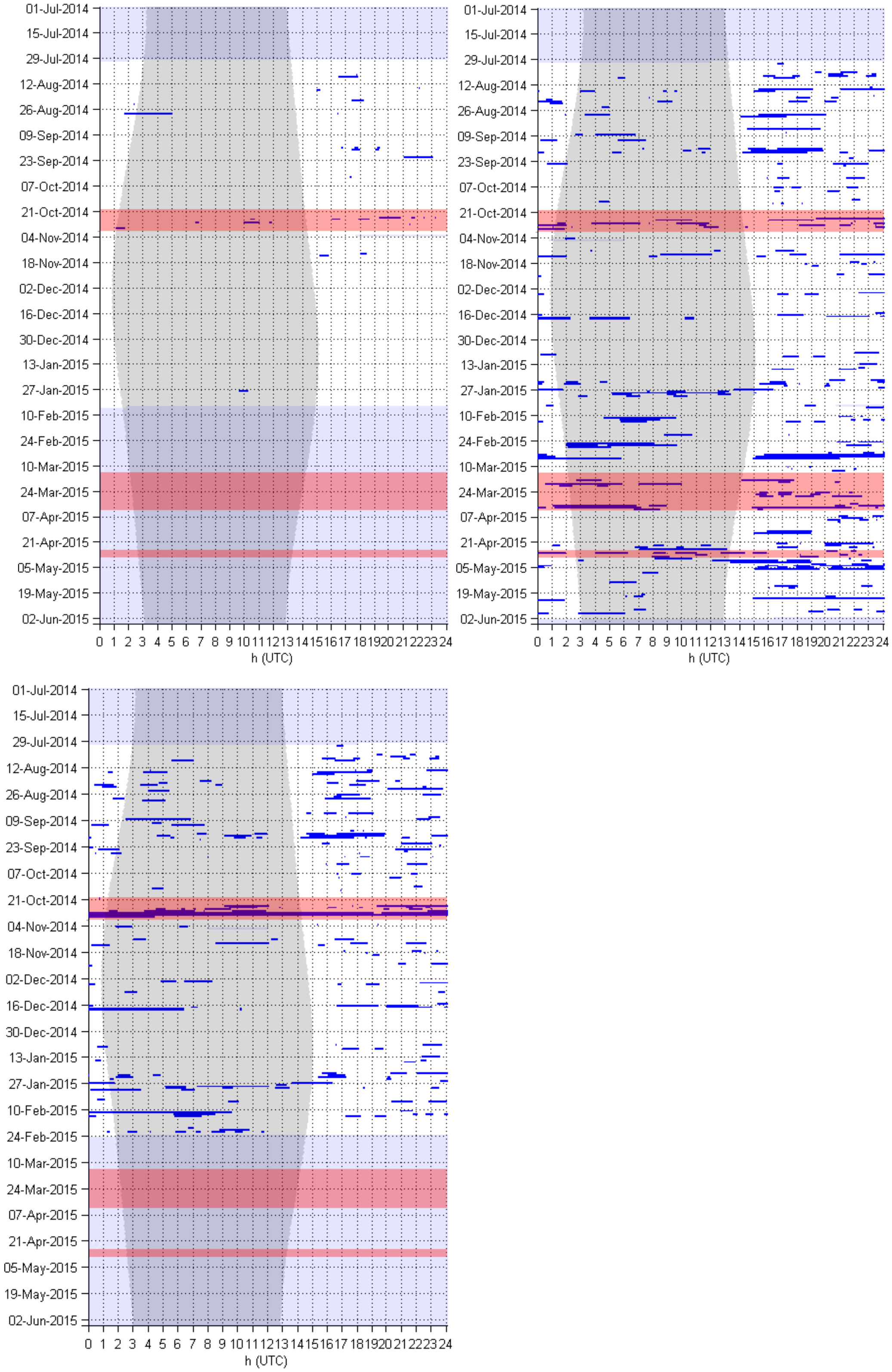

Figure 19. Major naval training events (shaded red, from Table 2) overlaid on MFA <5 kHz signals in one-minute bins at sites M (top left), H (top right), and N (bottom). Effort markings are described in Figure 12.

Table 3. MFA sonar automated detector results for sites H, M, and N. Total effort at each site in days (years), number of and extrapolated yearly estimates of wave trains and packets at each site (> 130 dB_{pp} re 1 µPa).

Site	Period Analyzed Days (Years)	Number of Wave Trains	Wave Trains per year	Number of Packets	Packets per year
H	306 (0.84)	80	95.2	6767	8,055
M	190 (0.52)	0	0	0	0
N	207 (0.57)	59	103.5	6599	11,577

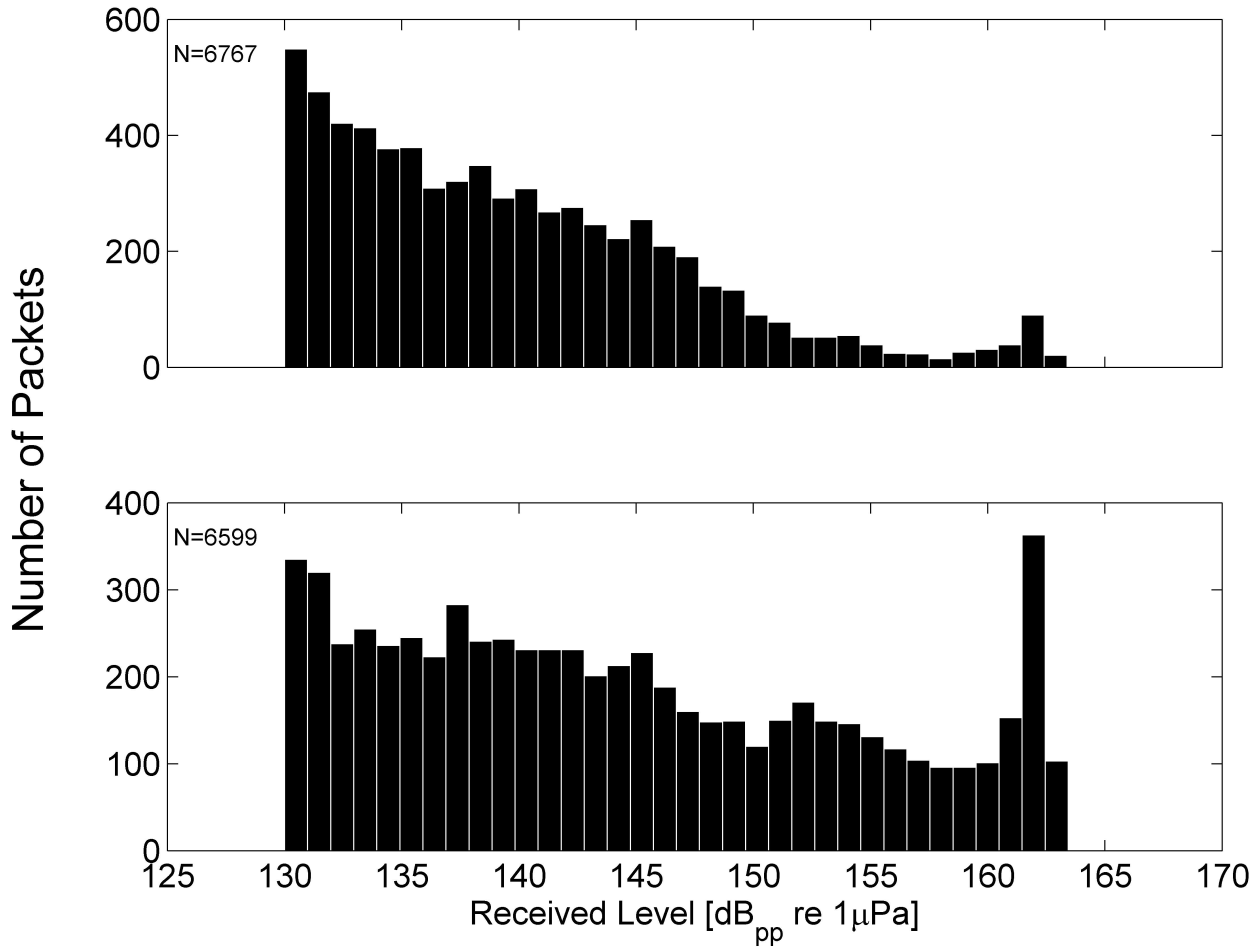

Figure 20. MFA sonar packet peak-to-peak received level distributions for sites H (top) and N (bottom). The total number of packets detected at each site is given in the upper left corner of each panel. No detected packets at site M had received level >130 dB$_{pp}$ re 1 μPa and were thus not included in this analysis. Instrument clipping levels are reached at 161-163 dB$_{pp}$ re 1 μPa (range due to signal filtering). Note the vertical axes are at different scales.

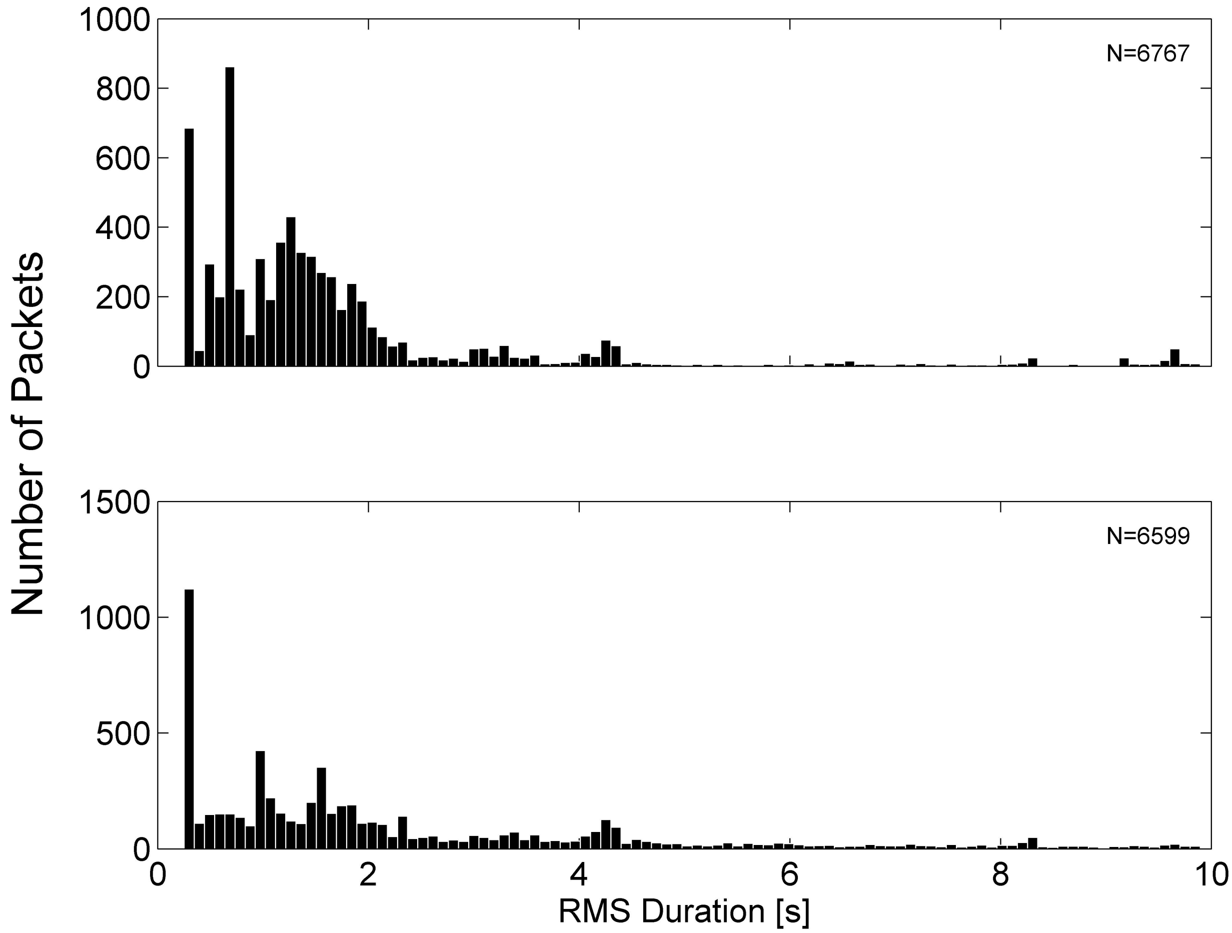

Figure 21. MFA sonar packet RMS duration distributions for sites H (top) and N (bottom). The total number of packets detected is given in upper right corner of each panel. No detected packets at site M had received level >130 dB_{pp} re 1 µPa and were thus not included in this analysis. Note the vertical axes are at different scales.

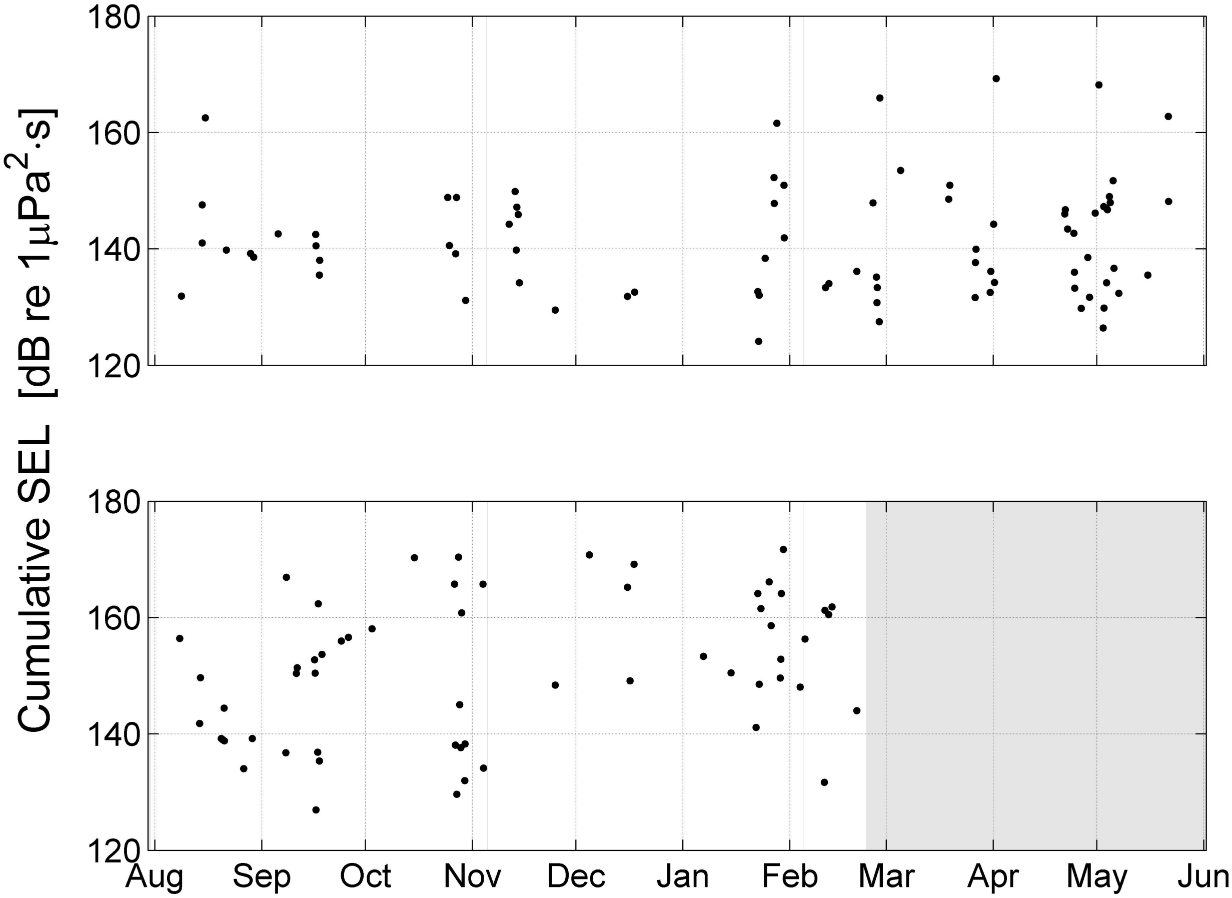

Figure 22. Cumulative sound exposure level for each wave train at sites H (top) and N (bottom). No detected packets at site M had received level >130 dB_{pp} re 1 μPa and were thus not included in this analysis.

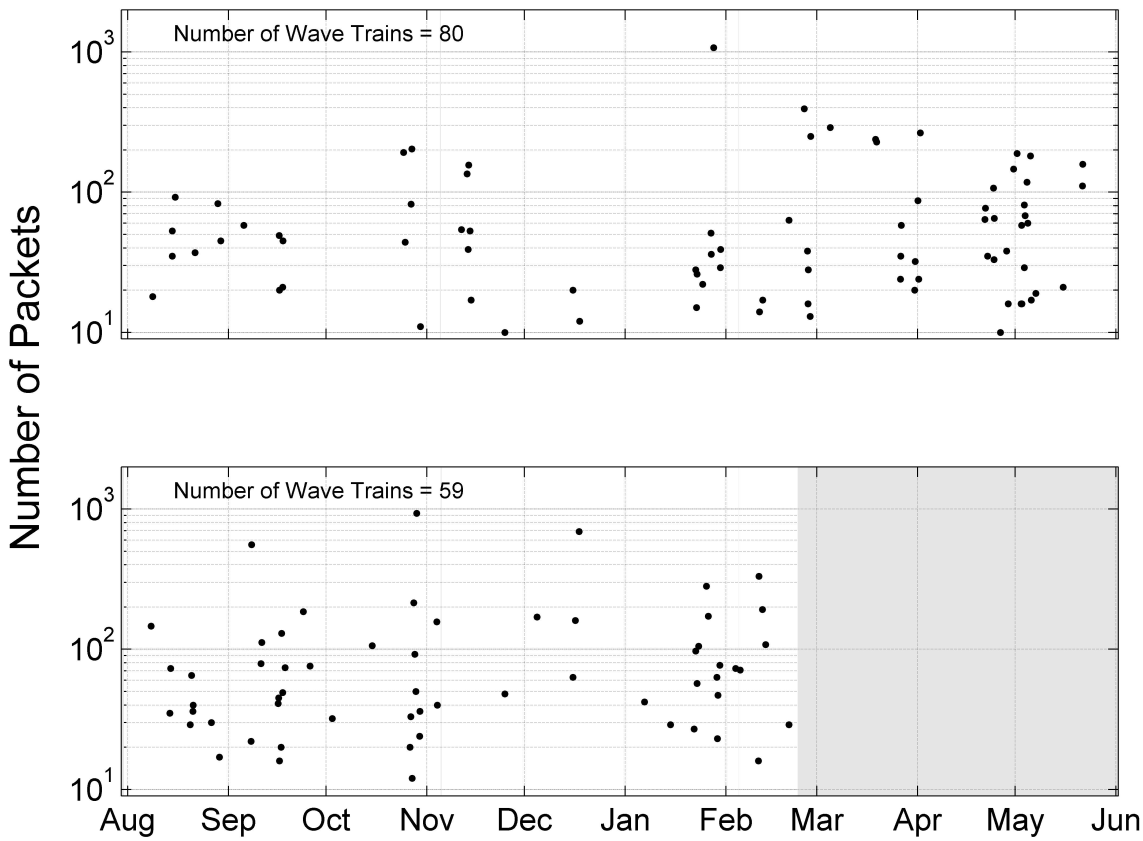

Figure 23. Number of MFA sonar packets for each wave train at sites H (top) and N (bottom). Note the vertical axes are logarithmic base-10. No detected packets at site M had received level >130 dB_{pp} re 1 µPa and were thus not included in this analysis.

Explosions

Explosions were detected at all three sites.

- Explosion detections peaked in August and November 2014 at all sites. Explosions were most prevalent at site H (Figure 24).
- Low level of explosions persisted at site H through April and May 2015 (Figure 24).
- 2,308 explosions were detected at site M, 3,949 at site H, and 1,207 at site N.
- Nearly all explosions occurred during nighttime hours (Figure 25).
- 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. Likewise, low numbers at site N indicate the source is not likely from military activities.
- There was an overall decrease in number of explosions in this region in comparison to previous years (Kerosky *et al.*, 2013; Debich *et al.*, 2015), which could be due to a geographic shift in fishing effort.

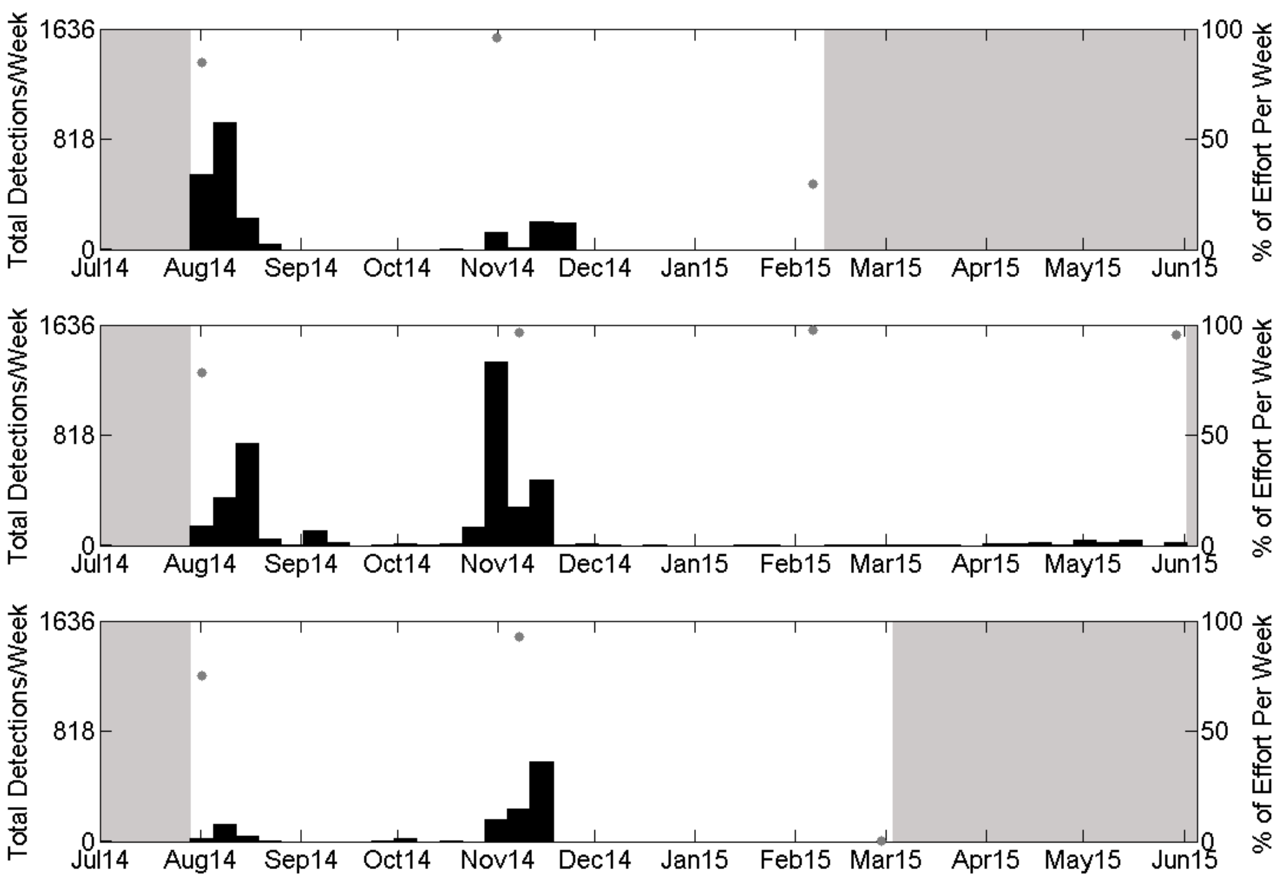

Figure 24. Weekly presence of explosions between July 2014 and May 2015 at sites M (top), H (middle), and N (bottom). Effort markings are described in Figure 11.

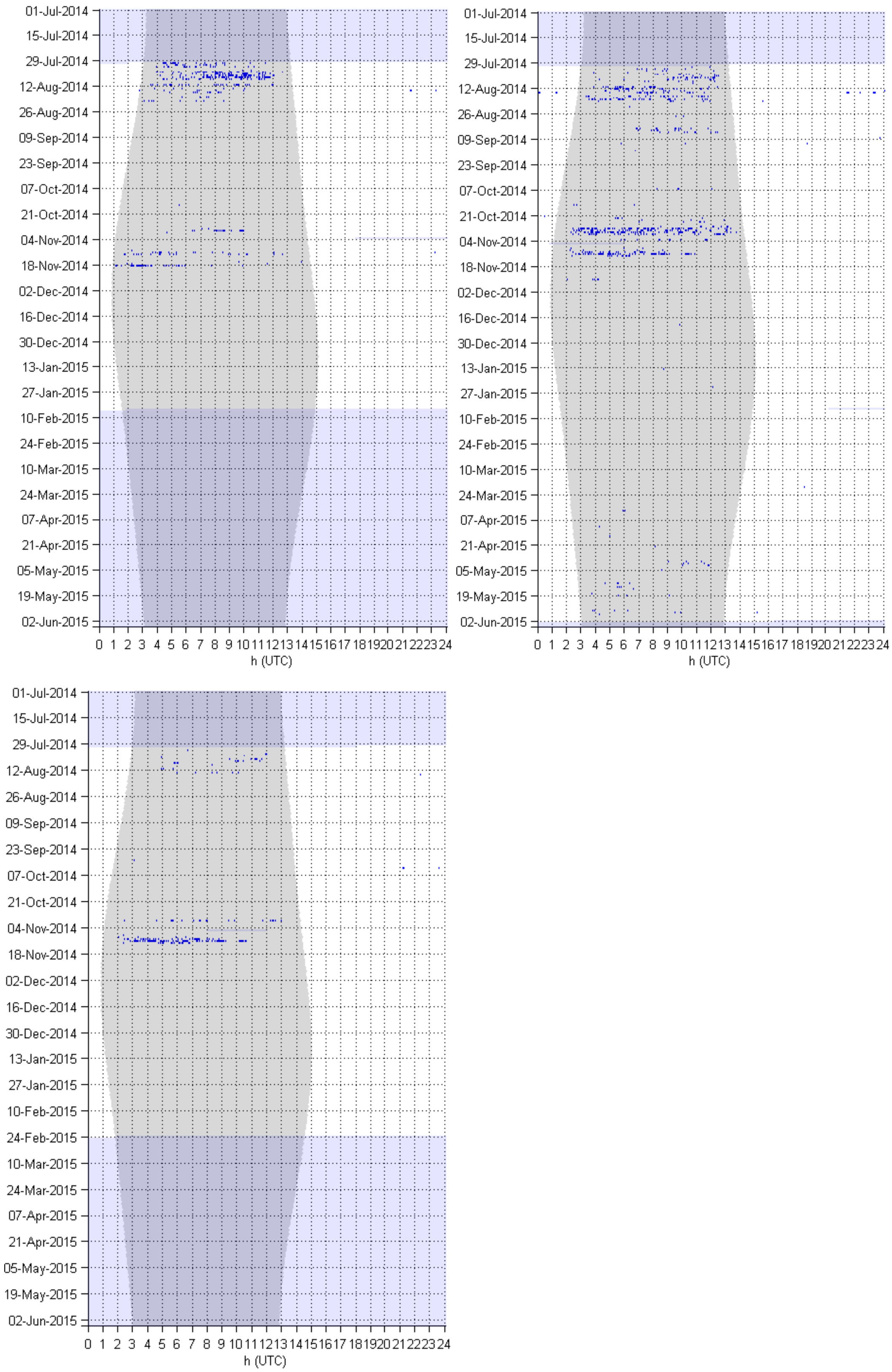

Figure 25. Explosion detections in one-minute bins at sites M (top left), H (top right), and N (bottom). Effort markings are described in Figure 12.

References

Baumann-Pickering, S., McDonald, M. A., Simonis, A. E., Solsona Berga, A., Merkens, K. P. B., Oleson, E. M., Roch, M. A., Wiggins, S. M., Rankin, S., Yack, T. M., and Hildebrand, J. A. (**2013**). "Species-specific beaked whale echolocation signals," J. Acoust. Soc. Am. **134**, 2293-2301.

Baumann-Pickering, S., Simonis, A. E., Roch, M. A., McDonald, M. A., Solsona-Berga, A., Oleson, E. M., Wiggins, S. M., Brownell, J., Robert L., and Hildebrand, J. A. (**2014**). "Spatio-temporal patterns of beaked whale echolocation signals in the North Pacific," PLOS One **9**, e86072.

Debich, A. J., Baumann-Pickering, S., Širović, A., Hildebrand, J. A., Alldredge, A. L., Gottlieb, R. S., Herbert, S. T., Johnson, S. C., Rice, A. C., Roche, L. K., Thayre, B. J., Trickey, J. S., Varga, L. M., and Wiggins, S. M. (**2015**). "Passive Acoustic Monitoring for Marine Mammals in the SOCAL Naval Training Area Dec 2012 - Jan 2014," (Scripps Institution of Oceanography, Marine Physical Laboratory, La Jolla, CA).

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

Jefferson, T. A., Webber, M. A., and Pitman, R. L. (**2008**). *Marine Mammals of the World: A Comprehensive Guide to their Identification* (Academic Press).

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

Kerosky, S. M., Baumann-Pickering, S., Širović, A., Buccowich, J. S., Debich, A. J., Gentes, Z., Gottlieb, R. S., Johnson, S. C., Roche, L. K., Thayre, B. J., Wakefield, L., Wiggins, S. M., and Hildebrand, J. A. (**2013**). "Passive Acoustic Montoring for Marine Mammals in the SOCAL Range Complex during 2012," (Marine Physical Laboratory, Scripps Institution of Oceanography, La Jolla, CA), p. 74.

McDonald, M. A., Hildebrand, J. A., and Webb, S. C. (**1995**). "Blue and fin whales observed on a seafloor array in the Northeast Pacific," J. Acoust. Soc. Am. **98**, 712-721.

McDonald, M. A., Hildebrand, J. A., Wiggins, S. M., and Ross, D. (**2008**). "A 50 year comparison of ambient noises near San Clemente Island: A bathymetrically complex coastal region off Southern California," Journal of the Acoustical Society of America **124**, 1985-1992.

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

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

Oleson, E. M., Calambokidis, J., Burgess, W. C., McDonald, M. A., LeDuc, C. A., and Hildebrand, J. A. (**2007**). "Behavioral context of call production by eastern North Pacific blue whales," Mar. Ecol. Prog. Ser. **330**, 269-284.

Roch, M. A., Brandes, T. S., Patel, B., Barkley, Y., Baumann-Pickering, S., and Soldevilla, M. S. (**2011**). "Automated extraction of odontocete whistle contours," Journal of the Acoustical Society of America **130**, 2212-2223.

Širović, A., Rice, A., Chou, E., Hildebrand, J. A., Wiggins, S. M., and Roch, M. A. (**2015**). "Seven years of blue and fin whale call abundance in the Southern California Bight," Endangered Species Research **28**, 61-76.

Thompson, P. O., Findley, L. T., and Vidal, O. (**1992**). "20-Hz pulses and other vocalizations of fin whales, *Balaenoptera physalus*, in the Gulf of California, Mexico," Journal of the Acoustical Society of America **92**, 3051-3057.

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

Wiggins, S. M. (**2015**). "Methods for quantifying mid-frequency active sonar in the SOCAL Range Complex," (Marine Physical Laboratory Technical Memorandum 553. Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA).

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

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

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