Passive Acoustic Monitoring for Marine Mammals in the SOCAL Range Complex June 2015 – April 2016

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Common Dolphins, Photo by Amanda J. Debich

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Executive Summary

Passive acoustic monitoring was conducted in the Navy's Southern California Range Complex from June 2015 to April 2016 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 (1200 m depth, site N), and west of La Jolla, California (500 m depth, site P).

While a typical southern California marine mammal assemblage is consistently detected in these recordings (Hildebrand *et al.*, 2012), only a select sub-set of species including blue whales, fin whales, and beaked whales were analyzed for this report.

Data analysis was performed using automated computer algorithms. Calls of two baleen whale species were detected: blue whale B calls and D calls, and fin whale 20 Hz calls. Both species were present at all sites, but at site H blue whale B calls were most common and the fin whale acoustic index representative of 20 Hz calls was highest. Blue whale D calls were highest at site P, whereas B calls were least common at site P. The fin whale acoustic index was lowest at site N. Blue whale B call detections peaked from August to November 2015 and very few B calls were detected after January 2016. Blue whale D calls peaked from June to July 2015. Fin whale acoustic index was highest from November 2015 to January 2016.

Frequency modulated (FM) echolocation pulses from Cuvier's beaked whales were regularly detected at sites H and N but were more common at site H. Detections were highest from December 2015 to April 2016 at site H and showed a slight increase during July and August 2015 and again in December 2015 and January 2016 at site N. 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. No other beaked whale signal types were detected.

Two anthropogenic signals were detected: Mid-frequency Active (MFA) sonar and explosions. MFA sonar was detected at all sites with a peak in August 2015. 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 August. Site H had fewer detections than site N as well as lower received and sound exposure levels. Site P had the highest maximum received levels, though the least amount of MFA sonar packet detections.

Explosions were detected at all sites, but were most prevalent at site P. The number of explosion detections peaked in June and November 2015 at site H and in September 2015 at site N. 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 toothed whales and pinnipeds.

In January 2009, an acoustic monitoring effort was initiated within the SOCAL Range Complex with support from the U.S. Pacific Fleet. 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 to explore 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 June 2015 and collected data through April 2016. The three recording sites include one to the west (site H) and one to the southwest (site N) of San Clemente Island, as well as one west of La Jolla, California (site P; Figure 1). Data from site H and N were analyzed for June 2015 through April 2016 (Table 1) and site P data were analyzed for June 2015 through March 2016 (Table 2).
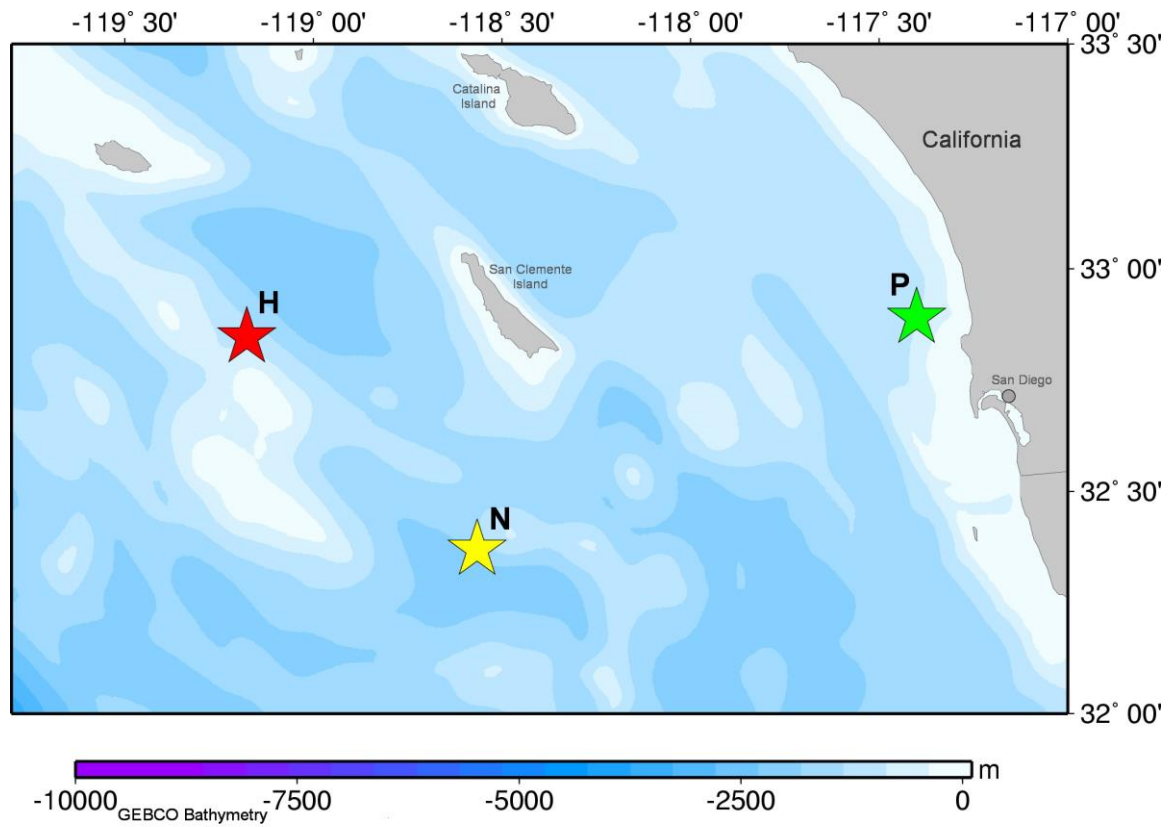
Figure 1. Locations of High-frequency Acoustic Recording Packages (HARPs) at sites H, N, and P deployed in the SOCAL study area from June 2015 through April 2016. Color indicates bathymetric depth.

Table 1. SOCAL Range Complex acoustic monitoring since January 2009.
Periods of instrument deployment analyzed in this report are shown in bold. Dates in italics were only used for high frequency analysis.

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	12/21/12 – 4/30/13	3140	12/20/12 – 5/1/13	3155
SOCAL 49	-	-	5/2/13 – 9/11/13	3156
SOCAL 50	9/10/13 – 1/6/14	2843	-	-
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 – 11/5/14	2342
SOCAL 54	11/5/14 – 2/4/15	2198	11/4/14 -2/5/15	2196
SOCAL 55	2/5/15 – 6/1/15	2800	2/5/15 – 2/23/15	433
SOCAL 56	**6/2/15 – 10/3/15**	**2952**	**6/2/15 – 10/3/15**	**2966**
SOCAL 57	**-**	**-**	**10/3/15 – 11/21/15**	**1168**
SOCAL 58	**11/21/15 – 4/25/16**	**3734**	*11/21/15 – 4/18/16*	*3578*

Table 2. Site P acoustic monitoring since January 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
LJ 31-P	**6/2/15 – 9/18/15**	**2593**
LJ 32-P	**9/25/15 – 10/19/15**	**574**
LJ 33-P	**10/20/15 – 11/20/15**	**747**
LJ 34-P	**11/20/15 – 3/1/16**	**2448**

Methods

High-frequency Acoustic Recording Package (HARP)

HARPs were used to detect marine mammal sounds and characterize anthropogenic sounds and ambient noise in the SOCAL area. HARPs can autonomously record underwater sounds from 10 Hz up to 160 kHz and are capable of approximately 300 days of continuous data storage. The HARPs were deployed in a seafloor mooring 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 Transducer Evaluation Center facility to verify the laboratory calibrations (Wiggins and Hildebrand, 2007).

Data Collected

Acoustic data have been collected at two sites within the SOCAL Range Complex since January 2009 (Table 1) and one site off La Jolla, CA since January 2014 (Table 2) using HARPs sampling at 200 kHz. The sites are designated site H (32° 56.76N, 119° 10.57W, depth 1,000 m), site N (32° 22.21N, 118° 33.85W, depth 1,200 m) and site P (32° 53.40N, 117° 24.006W, depth 500 m).

Site H yielded data from June 2, 2015 to April 25, 2016. Analysis was not conducted on data from October 3, 2015 to November 21, 2015 due to a hydrophone failure that resulted in numerous gaps in the data. Site N yielded data from June 2, 2015 to April 18, 2016 but the data from November 21, 2015 to April 18, 2016 was only suitable for high frequency analysis due to an A/D board malfunction that resulted in intermittent broadband noise that prevented analysis of low frequency data (up to 5 kHz). Site P had data from June 2, 2015 to March 1, 2016. For all three HARPs, a total of 20,760 hours, covering 865 days of acoustic data were recorded in the deployments analyzed in this report.

Data Analysis

Recording over a broad frequency range of 10 Hz to 100 kHz allows detection of baleen whales (mysticetes), toothed whales (odontocetes), and anthropogenic sounds. All analyses were conducted using appropriate automated detectors for whale and 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*). In addition, signals from Blainville's (*Mesoplodon densirostris*) and Stejneger's (*M. stejnegeri*) beaked whales were also analyzed. Other beaked whale signals screened for include FM pulses known as BW40, BW43, and BW70, which may belong to Hubbs' (*M. carlhubbsi*), Perrin's (*M. perrini*), and pygmy beaked whales (*M.peruvianus*), respectively (Baumann-Pickering *et al.*, 2014). Individual blue whale B calls, D calls, and beaked whale echolocation clicks, as well as MFA and explosion occurrence and levels were detected automatically using computer algorithms. Presence of fin whale 20 Hz calls was detected using an energy detection method and is 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 June 2015 and April 2016 at sites H and N, and between June 2015 and March 2016 at site P. We discuss seasonal occurrence and relative abundance of calls for different species and anthropogenic sounds that were consistently identified in the data.

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. Also detected were blue whale D calls, which are downswept in frequency (approximately 100-40 Hz) with duration of several seconds (Figure 3). These calls are similar worldwide and are assocaited with feeding animals; they may be produced as call-counter call between multiple animals (Oleson *et al.*, 2007).

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 measured for summer and fall periods. The summer 2015 kernel was defined as sweeping from 46.6 to 46 Hz, 46 to 45.3 Hz, 45.3 to 44.7 Hz, and 44.7 to 43.7 Hz during these predefined periods. The fall 2015 kernel was defined as 46 to 45.4 Hz; 45.4 to 44.7 Hz, 44.7 to 44.1 Hz, and 44.1 to 43.5 Hz. The kernel bandwidth was 2 Hz. Total numbers of detections are reported for this call type.
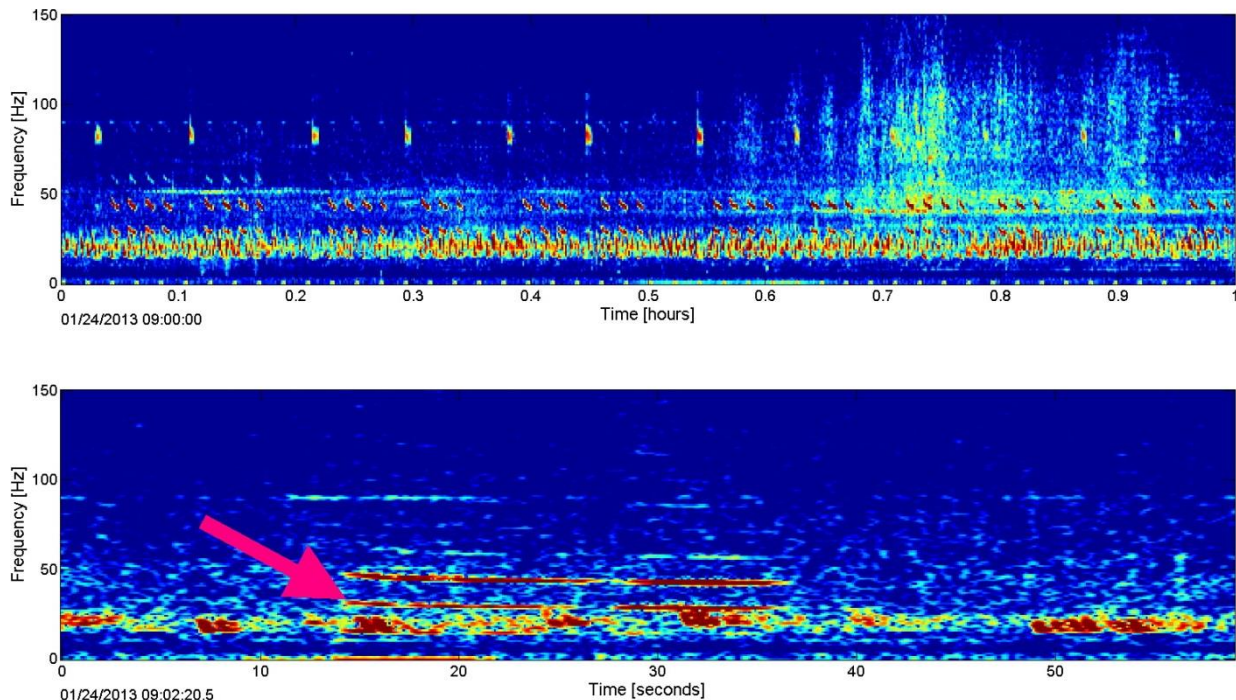

 Figure 2. Blue whale B call in Long-term Spectral Average (LTSA; top) and spectrogram (bottom) recorded at site N.

Blue whale D calls

Blue whale D calls (Figure 3) were detected using an automatic algorithm based on the generalized power law (Helble *et al.*, 2012). This algorithm was adapted for the detection of D calls by modifying detection parameters, including the frequency space over which the detector operates. A trained analyst subsequently verified the detections (Figure 3).
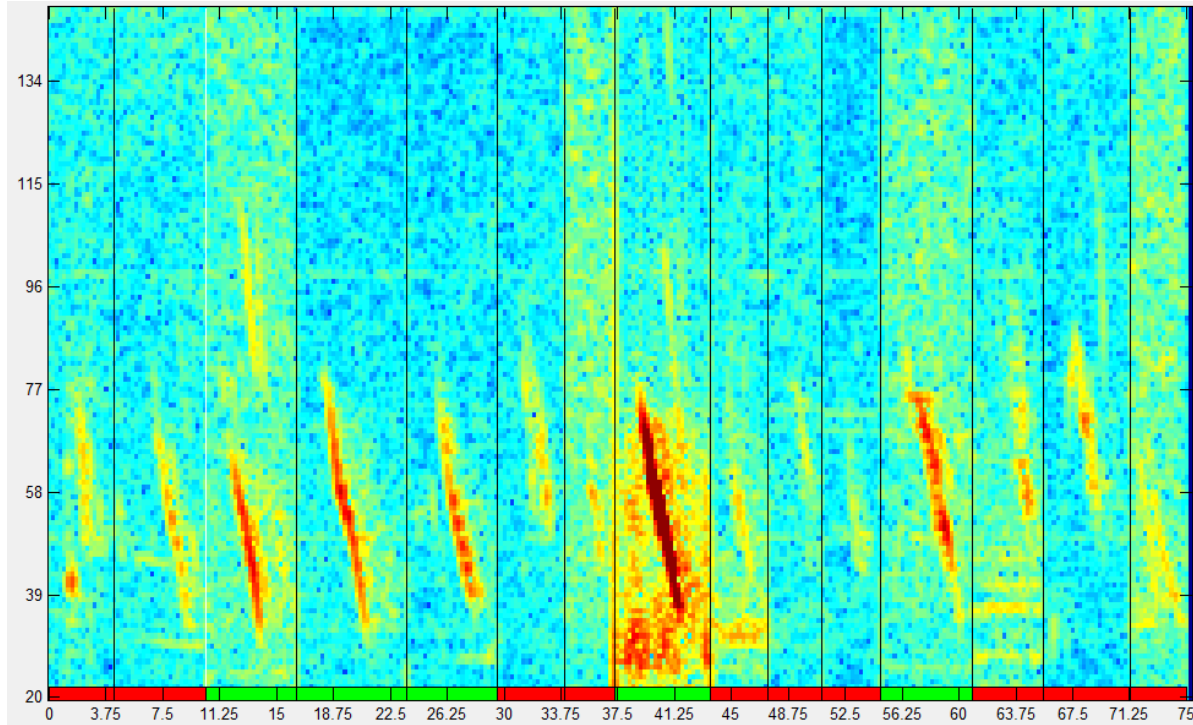
Figure 3. Blue whale D calls from site H in the analyst verification stage of the detector. Green in the bottom evaluation line indicates true detections.

Fin Whales

Fin whales produce short (~ 1 s duration), low-frequency calls, the most common of which are downsweeps in frequency from 30-15 Hz, called 20 Hz calls (Watkins, 1981) (Figure 4). 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 20Hz calls (Figure 4) were detected automatically using an energy detection method (Širović *et al.*, 2015). The method uses 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.

11/19/2015 12:35:05

11/19/2015 13:04:12.500.000

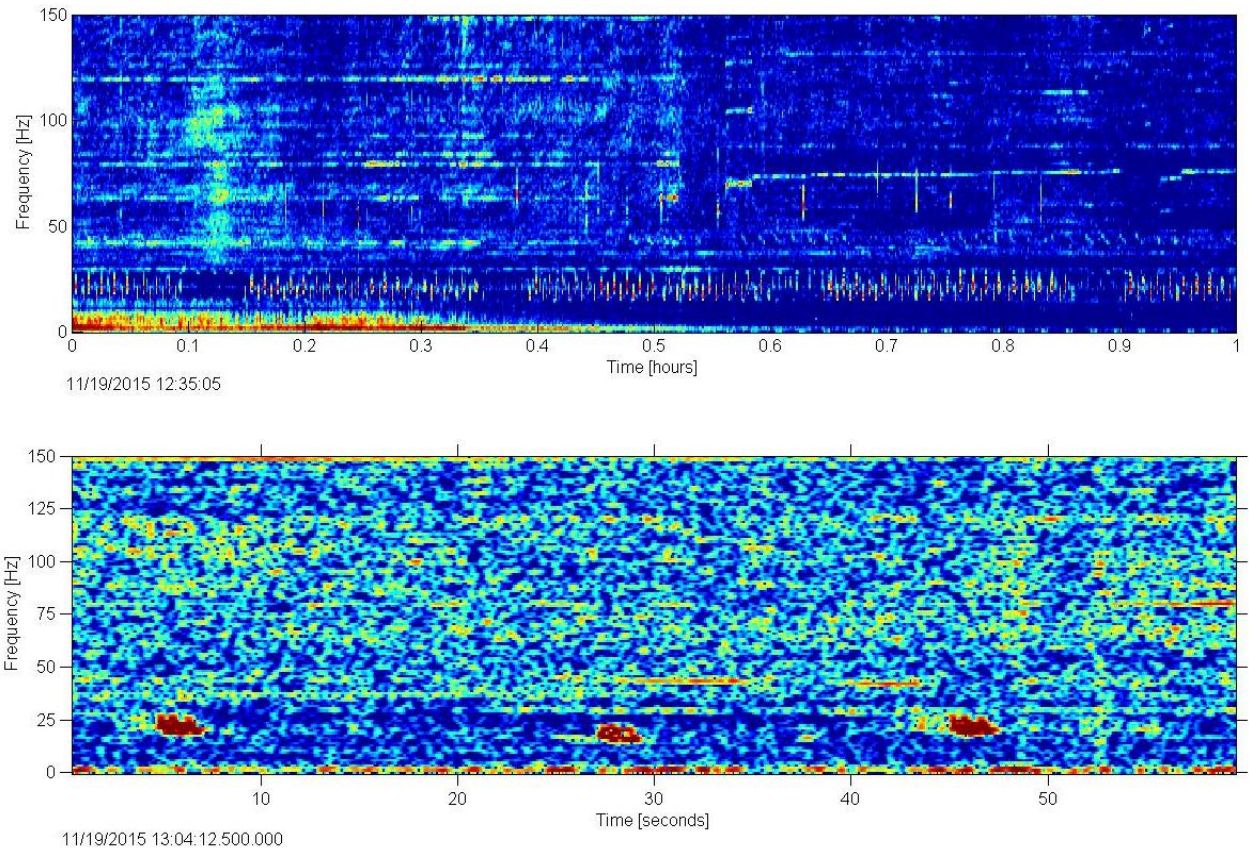**Figure 4. Fin whale 20 Hz calls in the LTSA (top) and spectrogram (bottom) recorded at site P.**

Beaked Whales
Beaked whales found in the Southern California Bight include Baird's (*Berardius bairdii*),
Cuvier's, Blainville's, Stejneger's, Hubbs', Perrin's, and pygmy beaked whale (Jefferson *et al.*,
2008; Jefferson *et al.*, 2015).

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 are 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,
respectively (Baumann-Pickering *et al.*, 2013; Baumann-Pickering *et al.*, 2014). Only Cuvier's and
BW43 signals were detected during this recording period and their signals are described below in
more detail.

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 since they
produce a signal with a lower frequency content that is not typical of other beaked whales and
therefore is not reliably identified by the detector used. After all echolocation signals were
identified with a Teager Kaiser energy detector (Soldevilla *et al.*, 2008; Roch *et al.*, 2011b), 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 seven 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 threshold was chosen to obtain the best balance
between missed and false detections. A third classification step, based on computer assisted manual
decisions by a trained analyst, labeled the automatically detected segments to pulse type and
rejected false detections (Baumann-Pickering *et al.*, 2013). The rate of missed segments was
approximately 5%, varying slightly between deployments. The start and end of each segment
containing beaked whale signals was logged and their durations were added to estimate cumulative
weekly presence.

Cuvier's Beaked Whales

Cuvier's beaked whale echolocation signals are well differentiated from other species' acoustic signals as polycyclic, with a characteristic FM pulse upsweep, peak frequency around 40 kHz, and uniform inter-pulse interval of about 0.4 – 0.5 s (Johnson *et al.*, 2004; Zimmer *et al.*, 2005) (Figure 5). An additional feature that helps with the identification of Cuvier's FM pulses is that they have characteristic spectral peaks around 17 and 23 kHz.

Figure 5. Echolocation sequence of Cuvier's beaked whale in the LTSA (top) and example FM pulse in the spectrogram (middle) and timeseries (bottom) recorded 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 (Baumann-Pickering *et al.*, 2013) (Figure 6). A candidate species for producing this FM pulse type may be Perrin's beaked whale (Baumann-Pickering *et al.*, 2014).

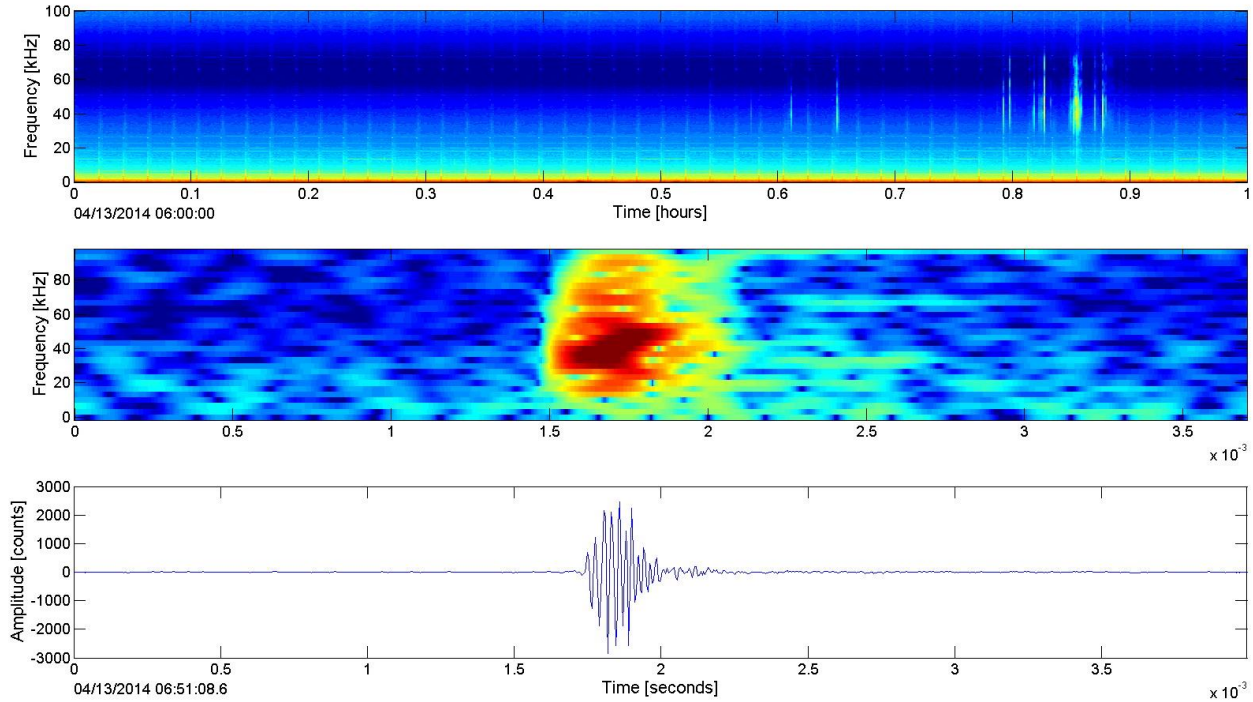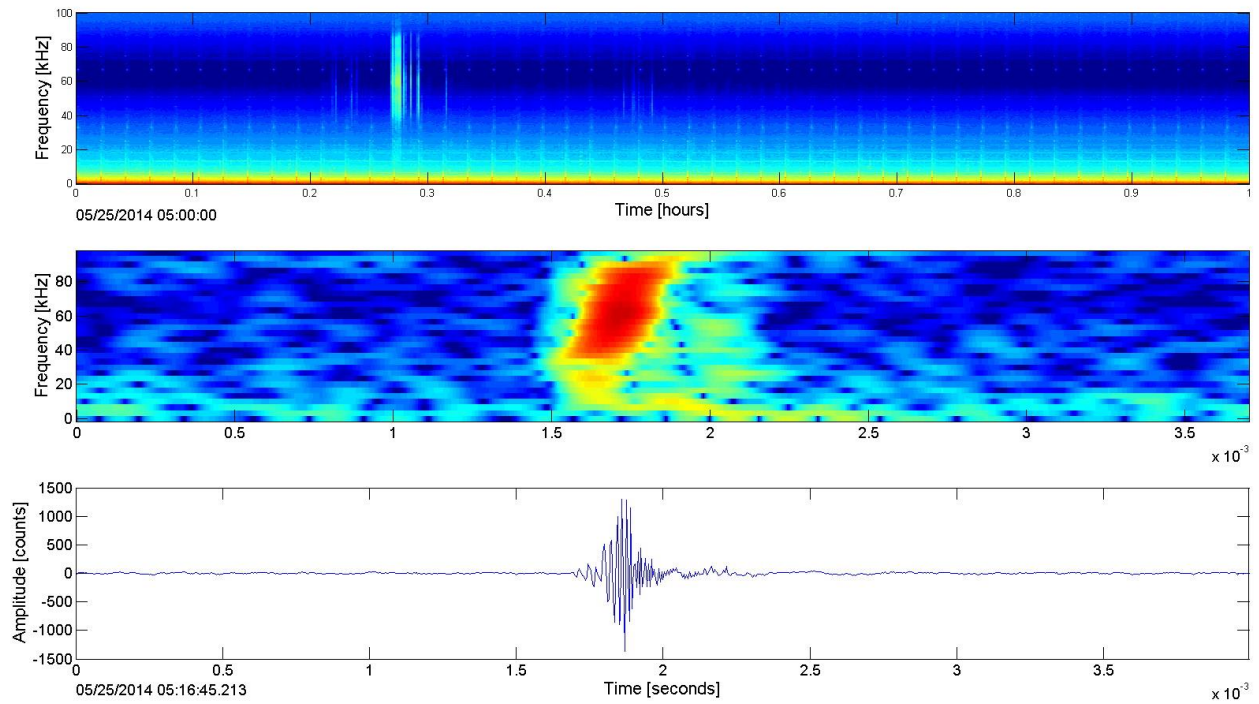**Figure 6. Echolocation sequence of BW43 in LTSA (top) and example FM pulse in spectrogram (middle) and time series (bottom) recorded at site N.**

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 session was logged and their durations were added to estimate cumulative weekly 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 signals are between 2 and 5 kHz and are more generically known as '3.5 kHz' sonar.

MFA sonar was detected using a modified version of the *Silbido* detection system (Roch *et al.*, 2011a) originally 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 (Wiggins, 2015). 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 14 of 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.
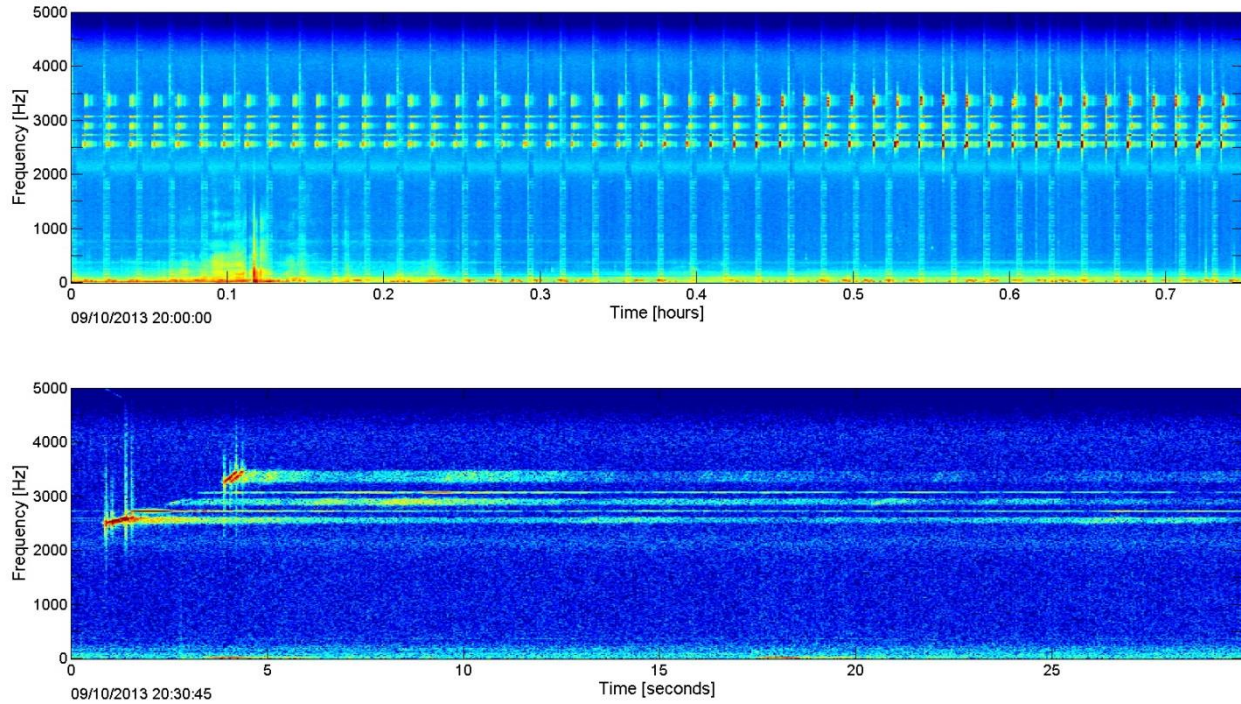

Figure 7. MFA sonar recorded at site H and shown as a wave train event in a 45 minute LTSA (top) and as a single packet with multiple pulses in a 30 second spectrogram (bottom).

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 8). Explosions were detected automatically for all deployments using a matched filter detector on data decimated to a 10 kHz sampling rate. The time series was filtered with a 10th order Butterworth bandpass filter between 200 and 2000 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 of above the median was set. When the correlation coefficient reached above threshold, the time series was inspected more closely. Consecutive explosions were required to have a minimum time distance of 0.5 seconds to be detected. A 300-point (0.03 s) floating average energy across the detection was computed. The start and end of the detection 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 RL were computed over the potential detection period and a time series of the length of the explosion template before and after the detection. The potential detection was classified as false 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 detections 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.
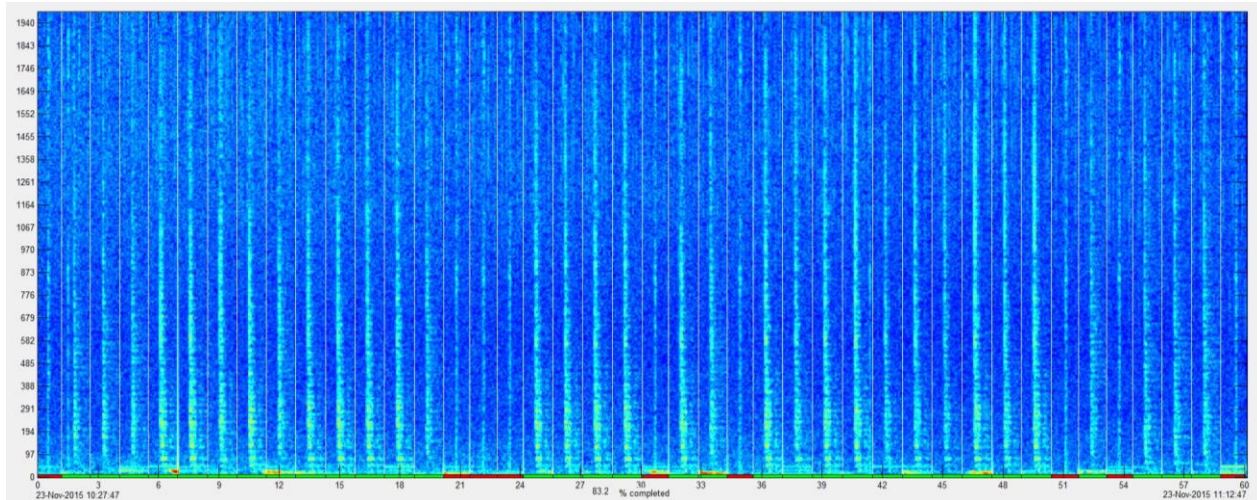

Figure 8. Explosions from site H in the analyst verification stage where events are concatenated into a single spectrogram.
In the bottom line green indicates true and red indicates false detections.

Results

The results of acoustic data analysis at sites H, N, and P from June 2015 through April 2016 are summarized.

We describe ambient noise, 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 9) (Hildebrand, 2009).
- Site H had the lowest spectrum levels for the ship band. 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 3-5 dB higher than site H at 10-100 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 shallower depth and increased local small boat activity.
- Prominent peaks in noise observed at the frequency band 15-30 Hz during the fall and winter at all sites are related to seasonally increased presence of fin whale calls. This peak is not as strong as in previous reports which may be due to an increase in lower frequency strumming noise (around 10 Hz) across all sites (Kerosky *et al.*, 2013; Debich *et al.*, 2015a; Debich *et al.*, 2015b; Širović *et al.*, 2016).
- September – November spectral peaks at 45-47 Hz, along with lower frequency harmonics, at sites H and N, and lesser peaks in summer months at site P, are related to blue whale B calls.
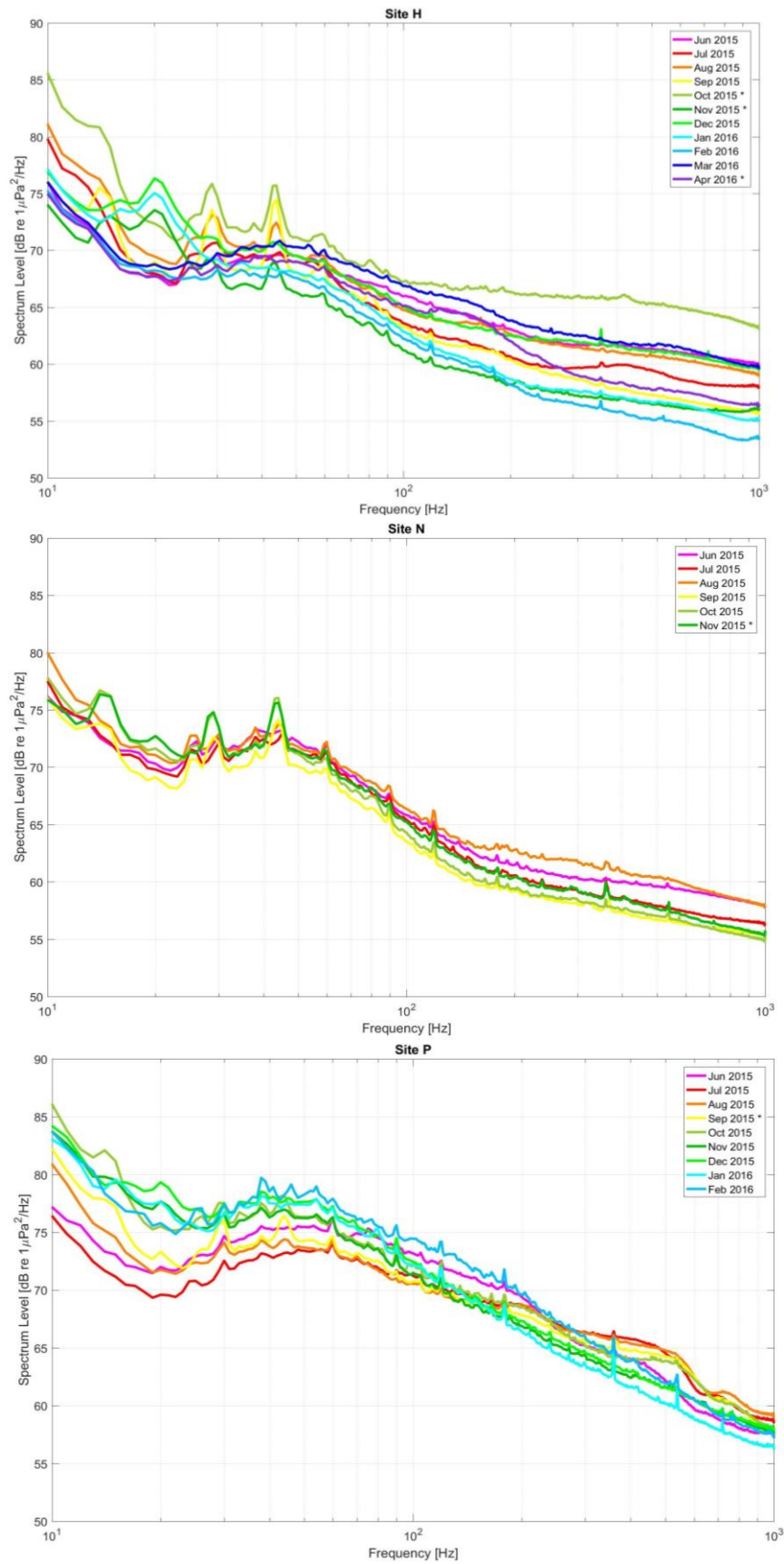
Figure 9. Monthly averages of ambient noise levels at sites H, N, and P.
Legend gives color-coding by month. Asterisk denotes months with partial effort.

Mysticetes

Blue and fin whales were detected using automated methods between June 2015 and April 2016. In general, fewer baleen whale vocalizations were detected at site P and the highest level of detections was at site H. More details of each species' presence are given below.

Blue Whales

Blue whale calls were detected at all sites and were most prevalent during the summer and fall.

- Northeast (NE) Pacific blue whale B calls were detected from June 2015 through January 2016 with a peak in September 2015. (Figure 10).
- Site P had a lower number of NE Pacific B call detections than sites H and N (Figure 10).
- There was no discernable diel pattern for the NE Pacific B calls (Figure 11).
- D call detections were highest from June - July 2015 at all sites, though detections were highest at site P (Figure 12).
- There was no clear D call diel pattern at sites H and N. Visual inspection of site P data suggests there may be a slight increase in D calls in the hours after sunset (Figure 13)
- The fall peak in NE Pacific B calls is consistent with earlier recordings at these sites (Kerosky *et al.*, 2013; Debich *et al.*, 2015b; Širović *et al.*, 2016).
- The summer peak in D calls is consistent with earlier recordings at these sites (Debich *et al.*, 2015b)
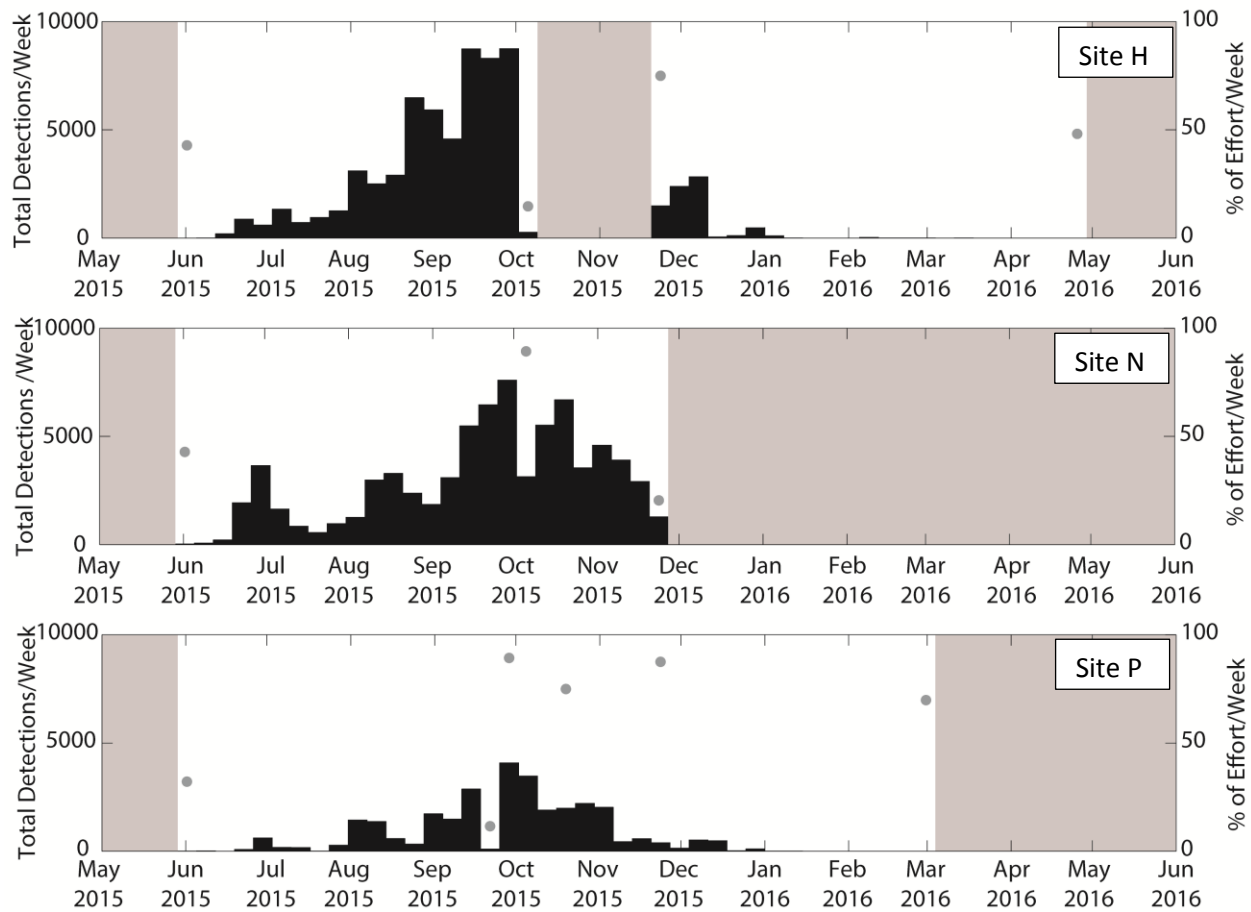
Figure 10. Weekly presence of NE Pacific blue whale B calls between June 2015 and April 2016 at sites H, N, and P.
Gray dots represent percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.
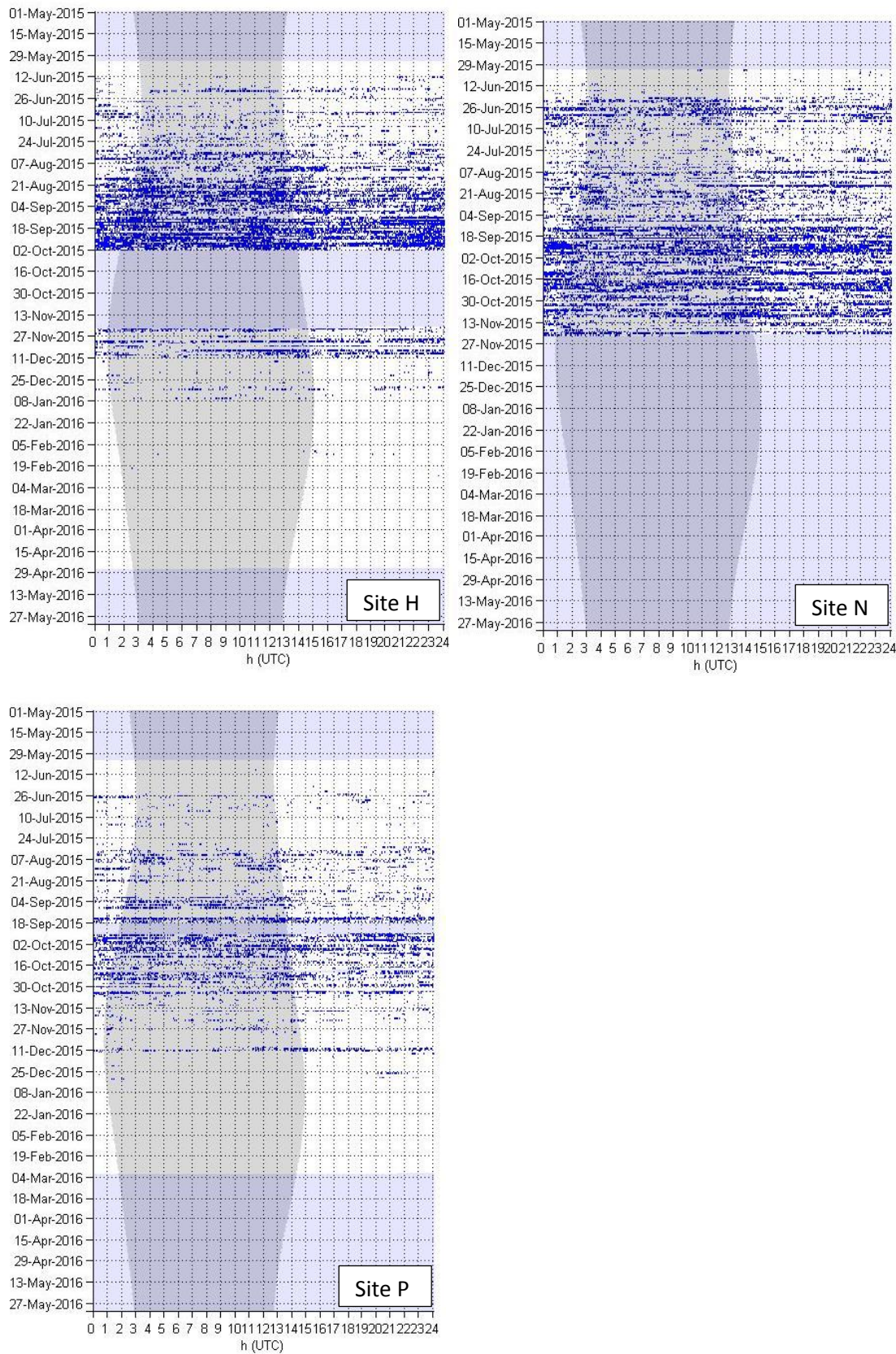
Figure 11. Diel presence of NE Pacific blue whale B calls, indicated by blue dots, in one-minute bins at sites H, N, and P.
Gray vertical shading denotes nighttime and light purple horizontal shading denotes absence of acoustic data.
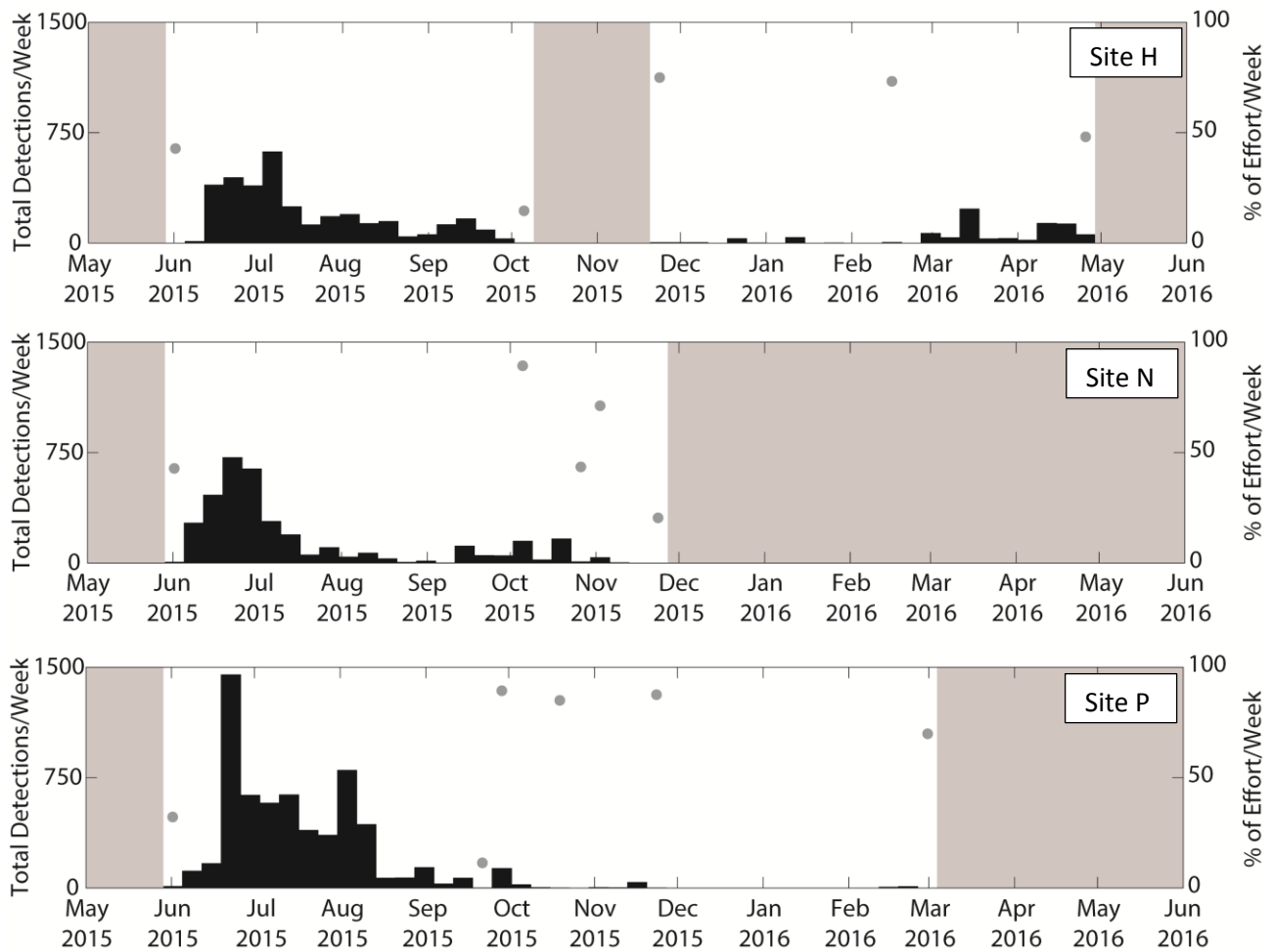
Figure 12. Weekly presence of NE Pacific blue whale D calls between June 2015 and April 2016 at sites H, N, and P.
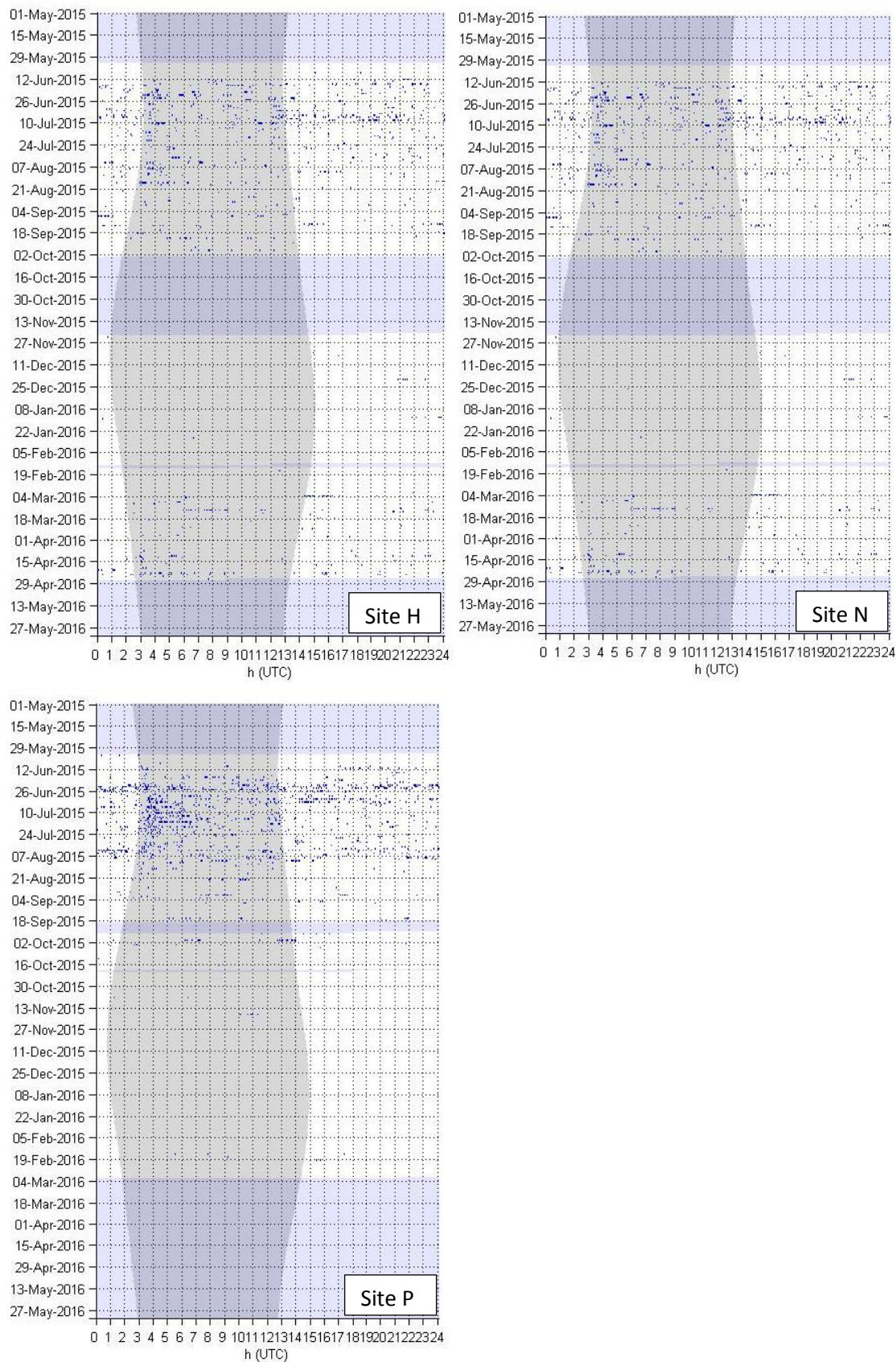**Effort markings are described in Figure 10.**

Figure 13. Diel presence of NE Pacific blue whale D calls, indicated by blue dots, in one-minute bins at sites H, N, and P.
Effort markings are described in Figure 11.

Fin Whales

Fin whales were detected throughout the recordings at all sites.

- The highest values of the fin whale acoustic index (representative of 20 Hz calls) were measured at site H (Figure 14).
- A peak in the fin whale acoustic index occurred from November 2015 – January 2016 (Figure 14).
- While the peak in the fin whale acoustic index is consistent with earlier recordings, index levels are overall lower than reported for previous monitoring periods (Debich *et al.*, 2015a; Debich *et al.*, 2015b; Širović *et al.*, 2016).
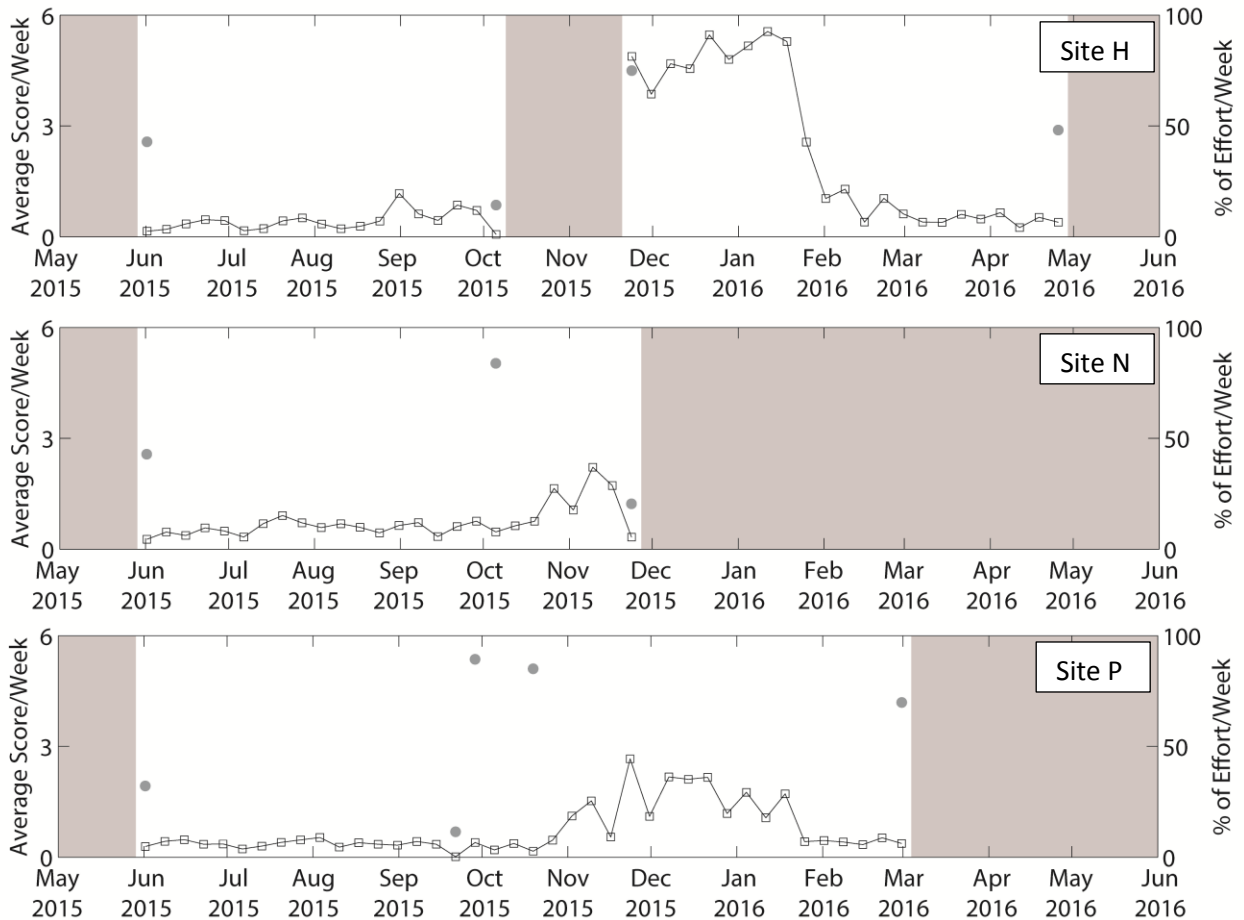

Figure 14. Weekly value of fin whale acoustic index (proxy for 20 Hz calls) between June 2015 and April 2016 at sites H, N, and P.
Effort markings are described in Figure 10.

Beaked Whales
Cuvier's beaked whales were detected throughout the deployment period. The FM pulse type, BW43, possibly produced by Perrin's beaked whales (Baumann-Pickering *et al.*, 2014) was detected sporadically. No other beaked whale species were detected during this recording period. 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 most commonly at site H and less commonly at site N (Figure 15). There were no detections at site P.
- Detections were highest from November 2015 to April 2016 at site H (Figure 15).
- There was no discernable diel pattern for Cuvier's beaked whale detections (Figure 16).
- There were more detections at site H than previously reported but the results at site N were similar to those in previous monitoring periods (Kerosky *et al.*, 2013; Debich *et al.*, 2015a; Debich *et al.*, 2015b; Širović *et al.*, 2016).

BW43
There were very few detections of BW43 FM pulses with only 21 detections on 9 days between June 2015 and April 2016.

- BW43 FM pulses were more prevalent at site N. They were only detected once in June 2015 at site H, but occurred intermittently at site N between September 2015 and April 2016. There were no detections at site P (Figure 17).
- There was no discernable diel pattern for BW43 detections (Figure 18).
- There were slightly fewer detections than in the previous monitoring period (Širović *et al.*, 2016) but the results are consistent with other reports (Kerosky *et al.*, 2013; Debich *et al.*, 2015a; Debich *et al.*, 2015b).
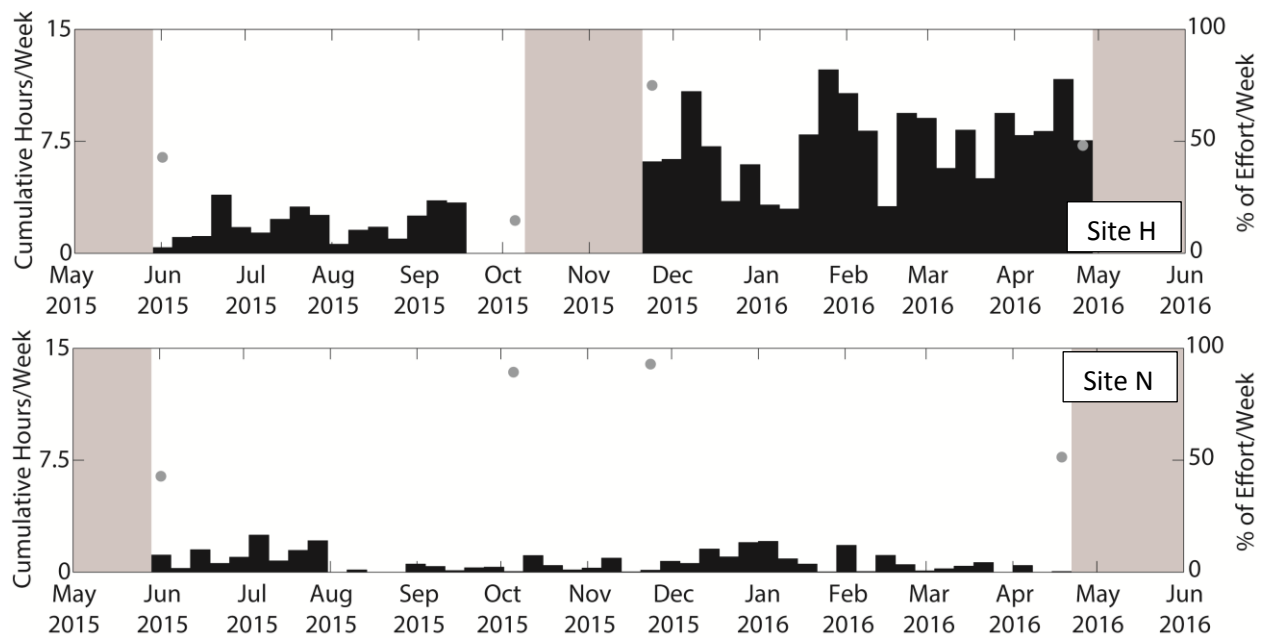
Figure 15. Weekly presence of Cuvier's beaked whale FM pulses between June 2015 and April 2016 at sites H and N. There were no detections at site P.
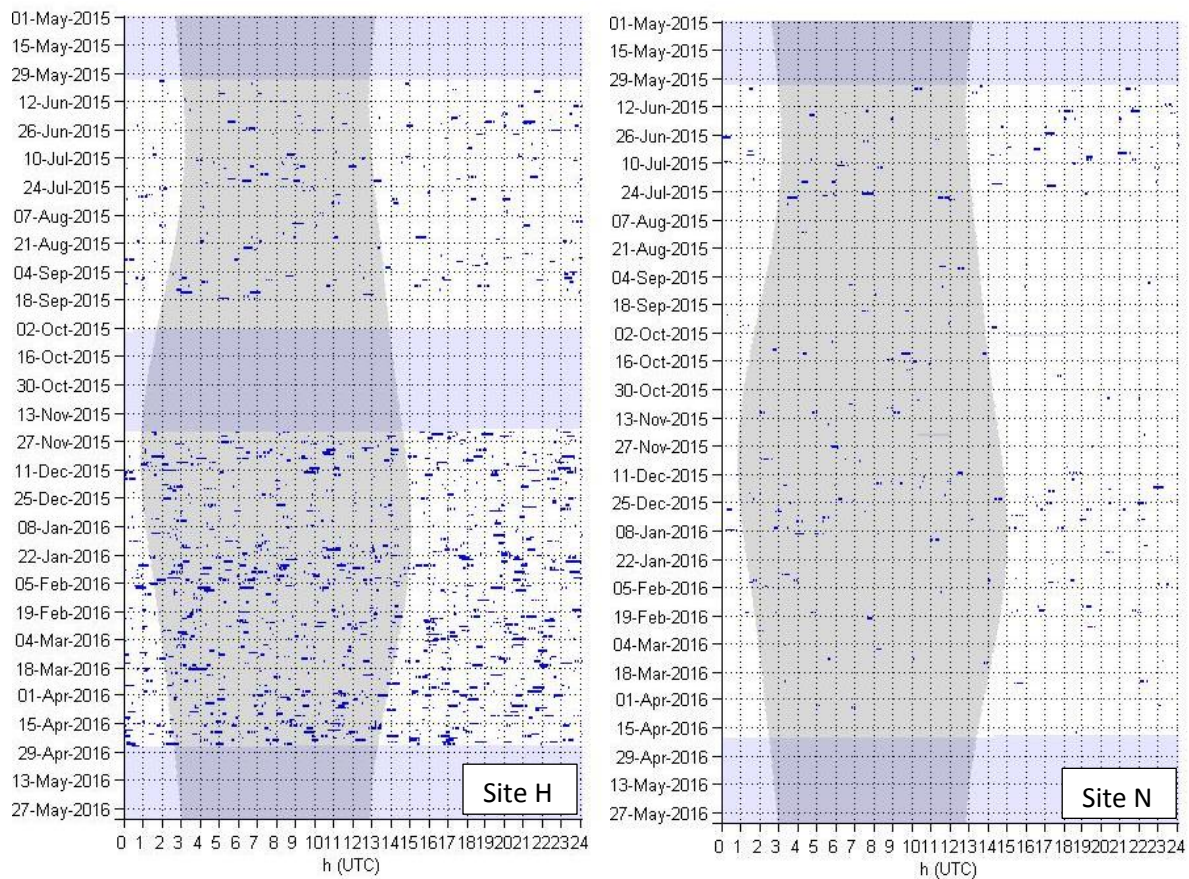**Effort markings are described in Figure 10.**

Figure 16. Cuvier's beaked whale FM pulses, indicated by blue dots, in one-minute bins at sites H and N. There were no detections at site P.
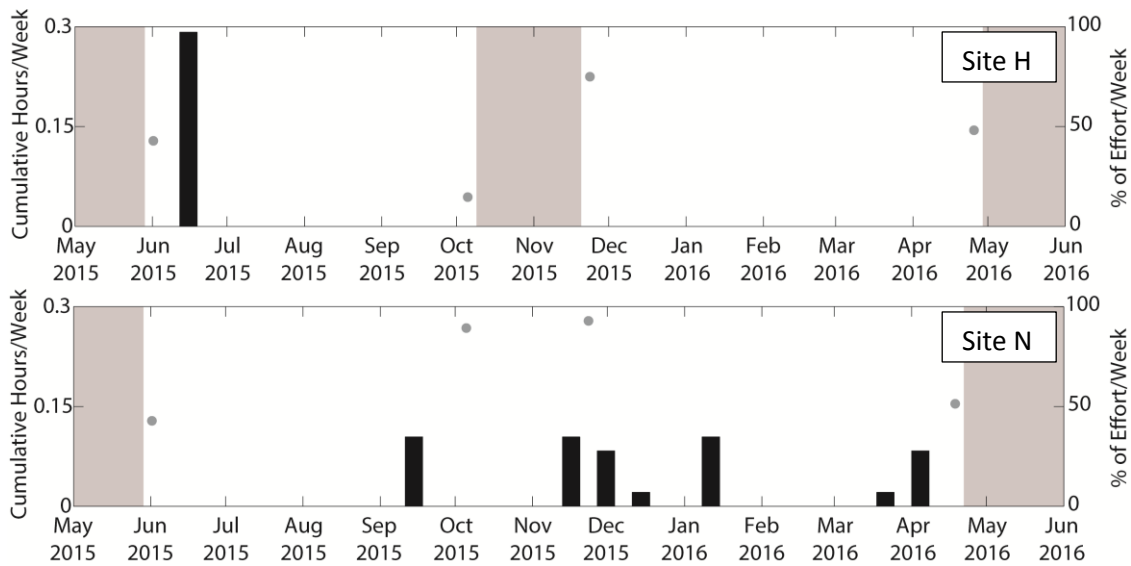**Effort markings are described in Figure 11.**

Figure 17. Weekly presence of BW43 FM pulses between June 2015 and April 2016 at sites H and N. There were no detections at site P.
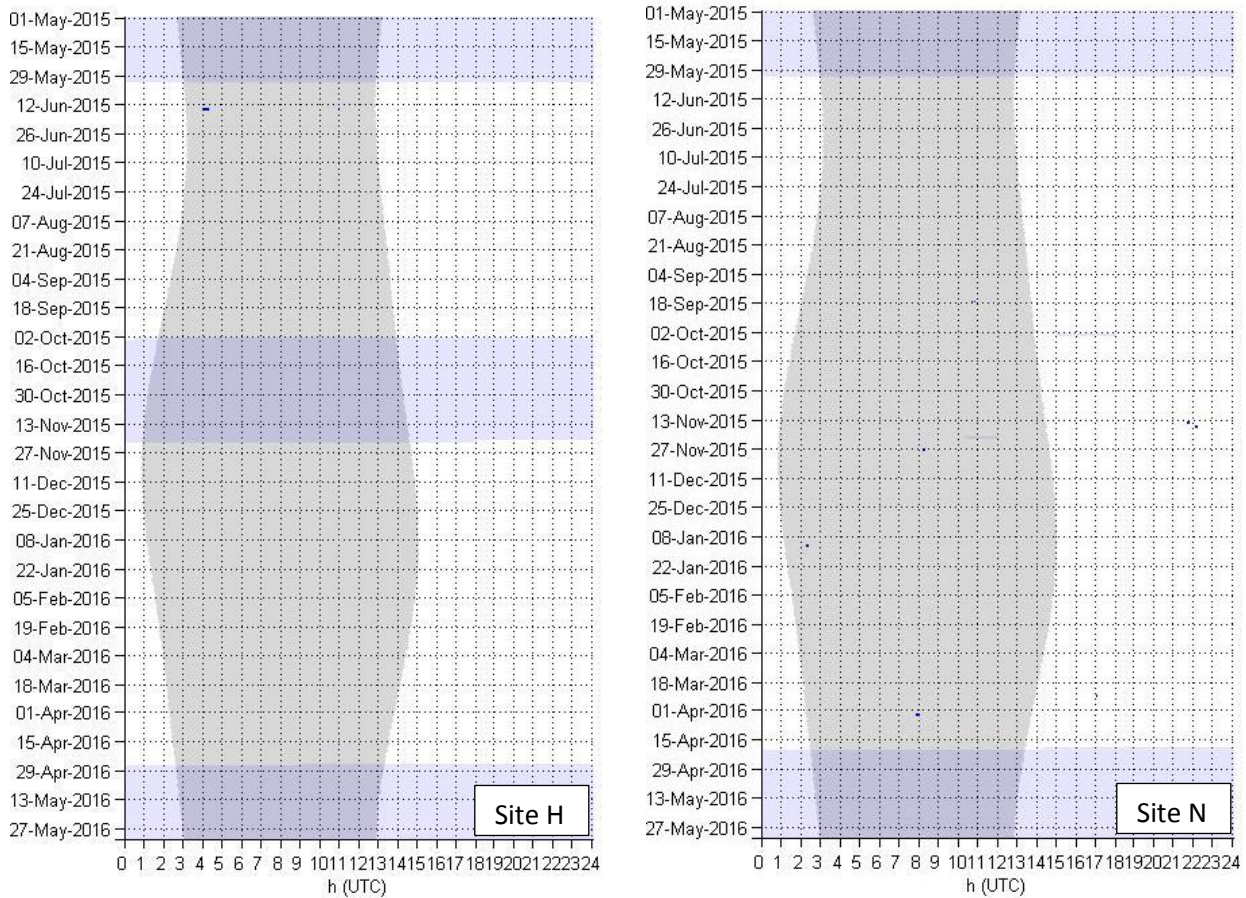**Effort markings are described in Figure 10.**

Figure 18. BW43 FM pulses, indicated by blue dots, in one-minute bins at sites H and N. There were no detections at site P.
Effort markings are described in Figure 11.

Anthropogenic Sounds

Anthropogenic sounds from MFA sonar (2.4 – 4.5 kHz) and explosions, between June 2015 and April 2016, were analyzed for this report.

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 June 2015 and June 2016 are listed in (Table 3). 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) when normalized per year at site N, followed by site H and then site P (Table 4).

- MFA sonar was detected at all 3 sites. There was a peak in detections in August 2015 at sites H and N. A much smaller peak occurred at the same time at site P, though detections at site P were much lower overall (Figure 19).
- Bouts of MFA sonar seem to typically begin an hour or so following sunrise, but they could persist throughout the night (Figure 20).
- At site H, a total of 5,237 packets were detected, with a maximum received level of 163 dB_{pp} re 1 µPa (instrument clipping level), and a median received level of 136 dB_{pp} re 1 µPa (Figure 21).
- At site N, a total of 11,118 packets were detected, with a maximum received level of 163 dB_{pp} re 1 µPa (instrument clipping level), and a median received level of 142 dB_{pp} re 1 µPa (Figure 21).
- At site P, a total of 2,365 packets were detected, with a maximum received level of 167 dB_{pp} re 1 µPa (instrument clipping level), and a median received level of 138 dB_{pp} re 1 µPa (Figure 21).
- Most MFA sonar packets had durations up to 2 s (Figure 22).
- Maximum cumulative sound exposure levels occurred during late-July, August, and November at site N and were greater than 170 dB_{pp} re 1 $µPa^2$-s. At site H, maximum levels were less than 170 dB_{pp} re 1 $µPa^2$-s and occurred in August 2015 and February 2016. At site P maximum levels were less than 170 dB_{pp} re 1 $µPa^2$-s and occurred during late July (Figure 23).
- Most MFA sonar wave trains occurred at site N in August 2015 during a major training exercise (Figure 24).

Table 3. Major naval training exercises in the SOCAL region between June 2015 and April 2016.

Exercise Dates	Type of Exercise
27 July to 20 August 2015	C2X
14 to 18 August 2015	IAC
21 to 27 August 2015	JTFEX
19 October to 5 November 2015	*C2X * *
5 to 16 November 2015	SUSTEX
19 to 22 January 2016	*SUSTEX * *
26 February to 6 March 2016	CERTEX

* Exercises by non-sonar equipped ships with no sonar usage associated with this event planned. Any sonar detections during this period would be from individual ships not affiliated with the exercise and conducting small scale unit level training.
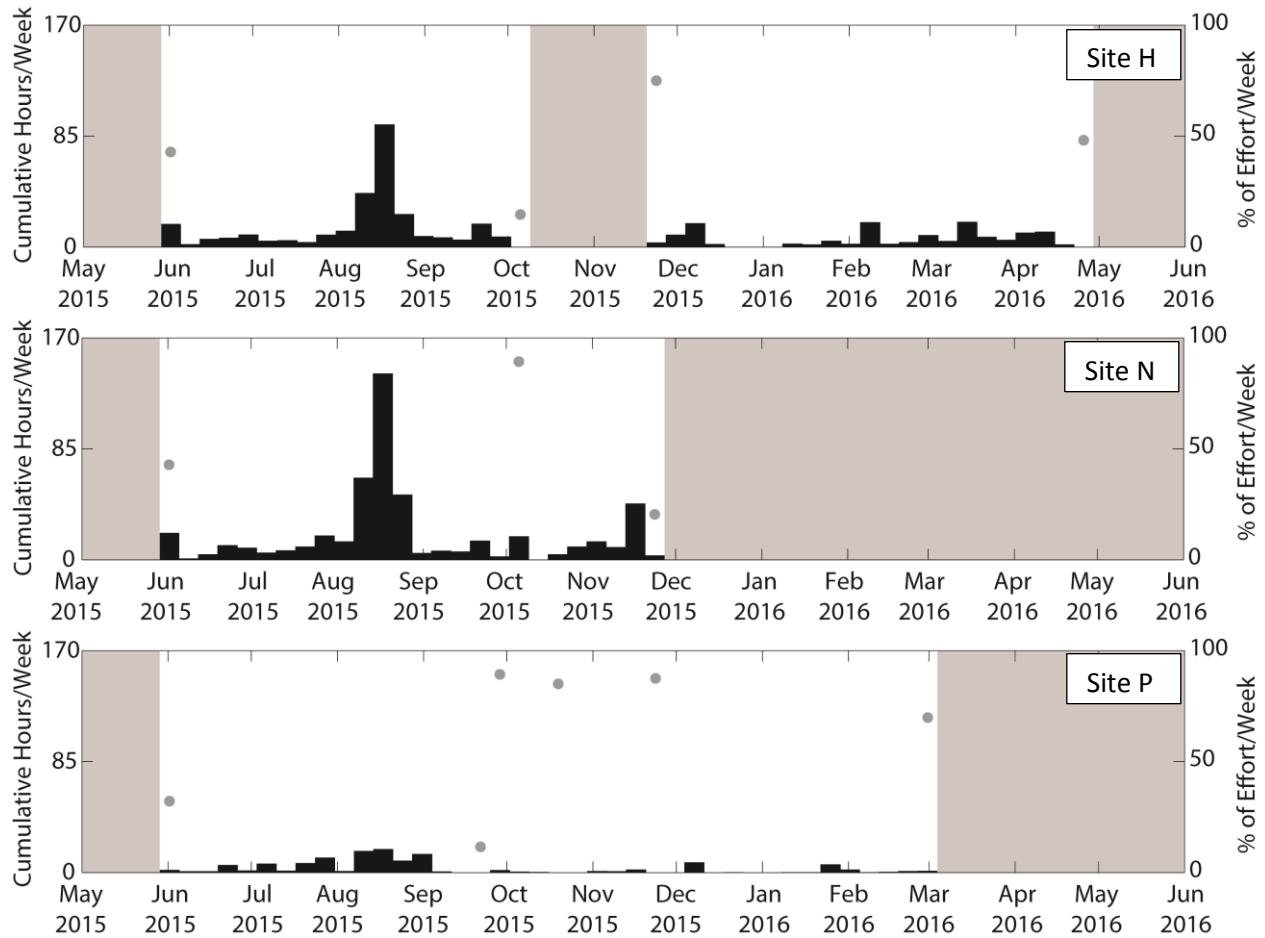

Figure 19. Weekly presence of MFA sonar <5kHz between June 2015 and April 2016 at sites H, N, and P.
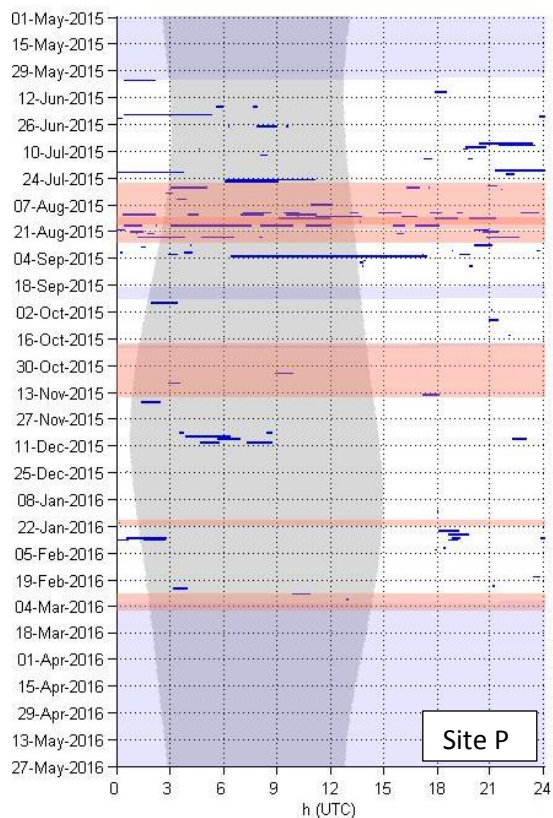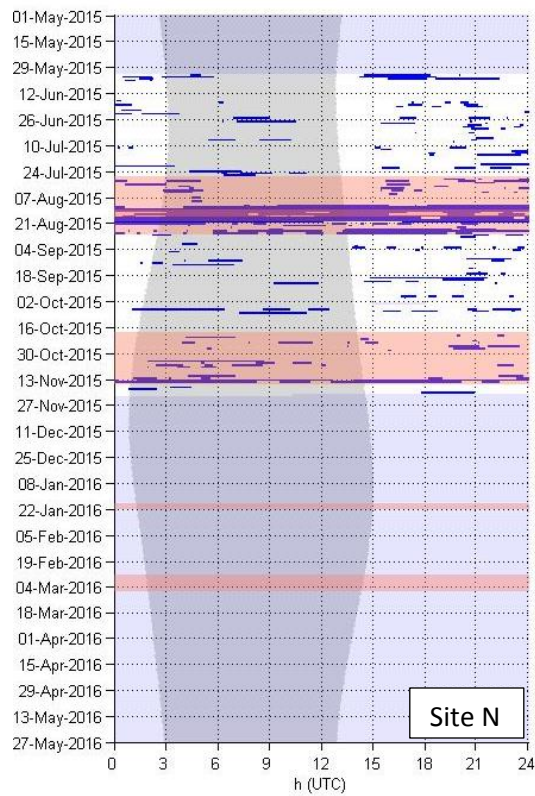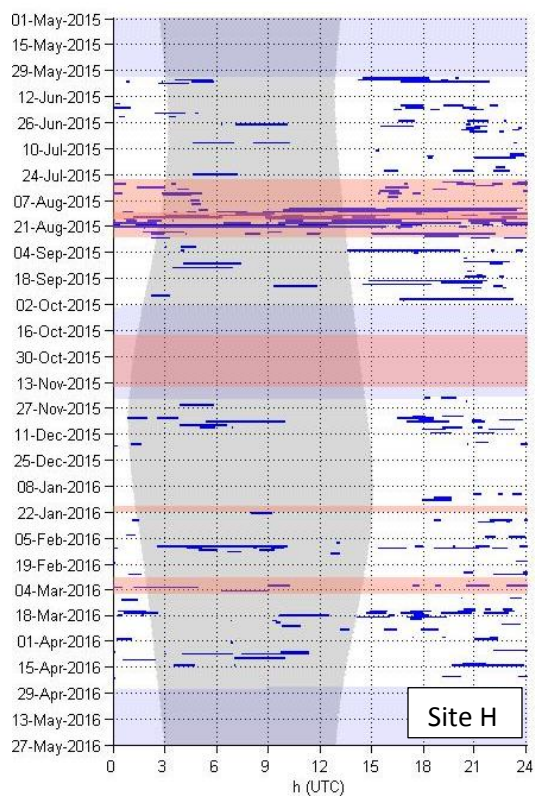**Effort markings are described in Figure 10.**

Figure 20. Major naval training events (shaded red, from Table 3) overlaid on MFA sonar <5kHz signals, indicated by blue dots, in one-minute bins at sites H, N, and P. Effort markings are described in Figure 11.

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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 (> 130 dB$_{pp}$ re 1 μPa).

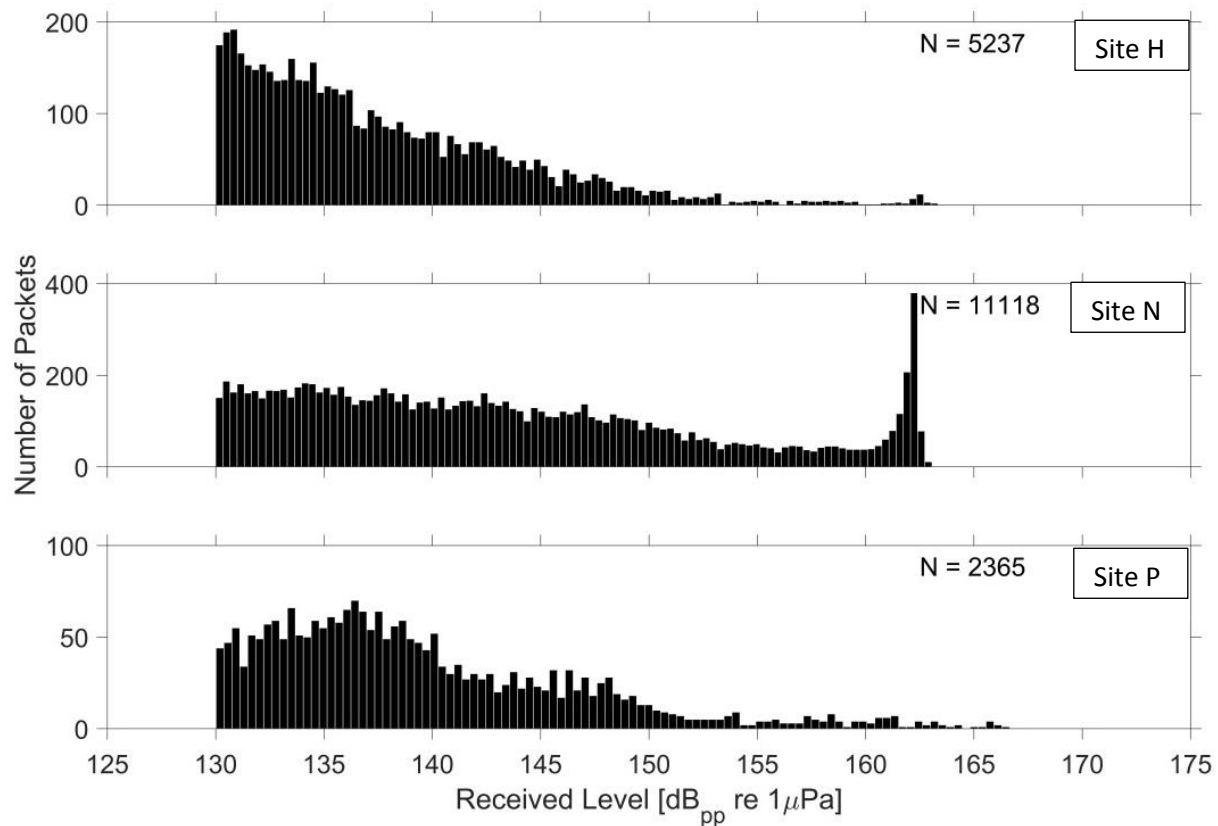| Site	Period Analyzed Days (Years)	Number of Wave Trains	Wave Trains per year	Number of Packets	Packets per year
H	279 (0.76)	77	101	5,237	6,851
N	172 (0.47)	76	161	11,118	23,593
P	265 (0.73)	28	39	2,365	3,257

Figure 21. MFA sonar packet peak-to-peak received level distributions for sites H, N, and P.
The total number of packets detected at each site is given in the upper right corner of each panel. Instrument clipping levels are reached at 161-163 dBpp re 1 μPa (range due to signal filtering). Note the vertical axes are at different scales.

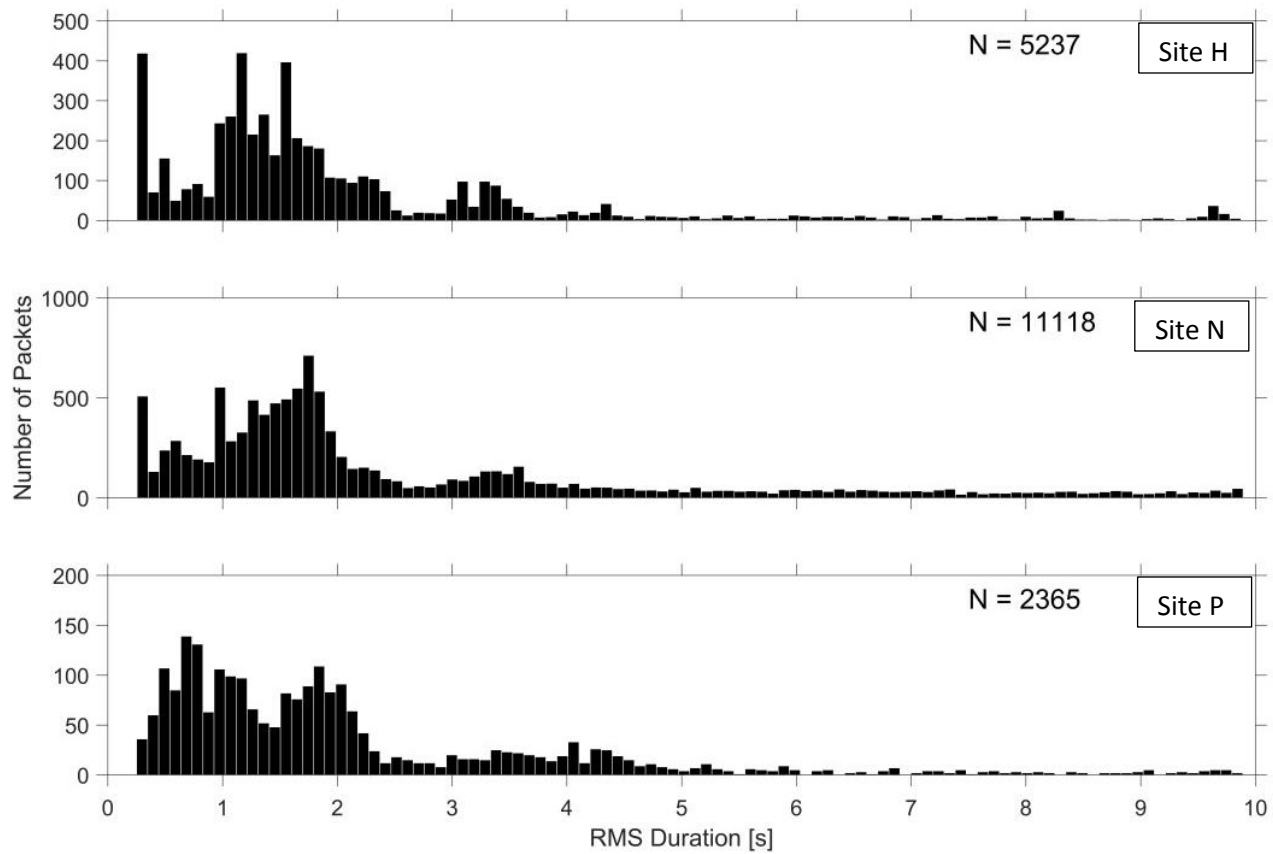**Figure 22. MFA sonar packet RMS duration distributions for sites H, N, and P.**
The total number of packets detected is given in the top right corner of each panel. Note the vertical axes are at different scales.
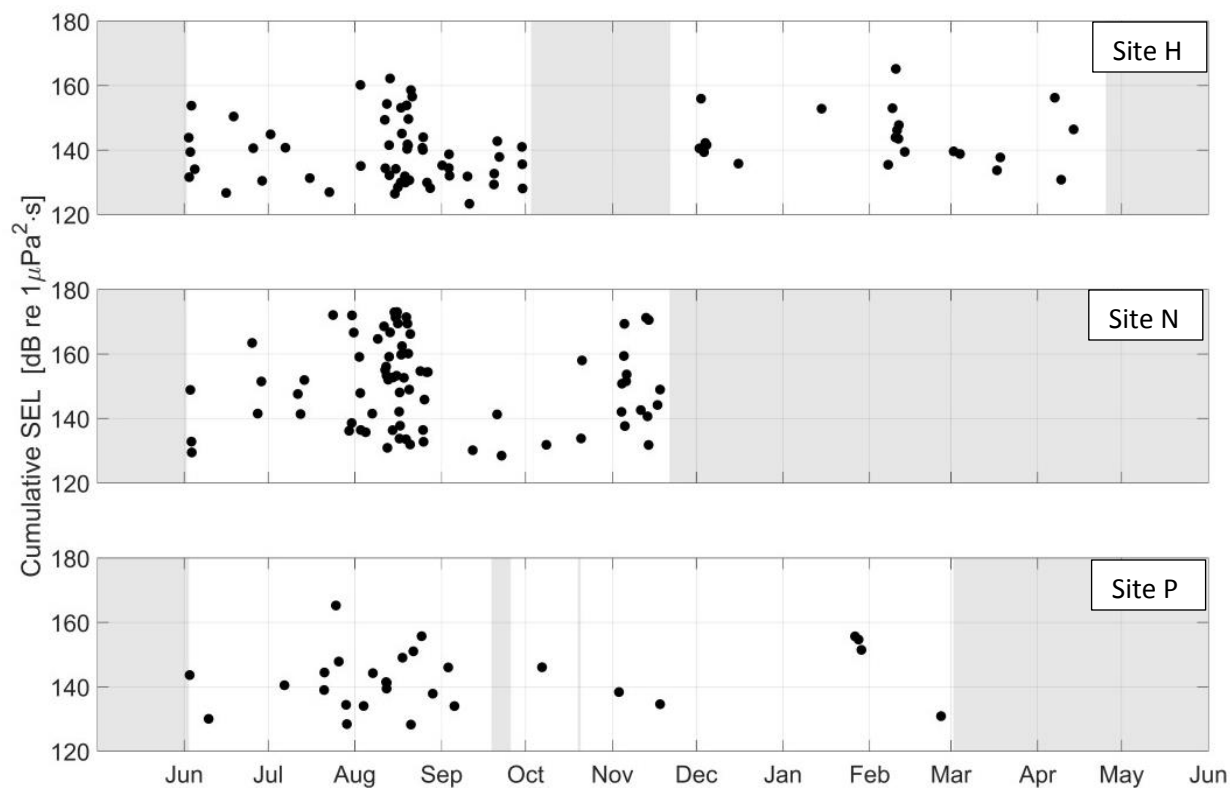
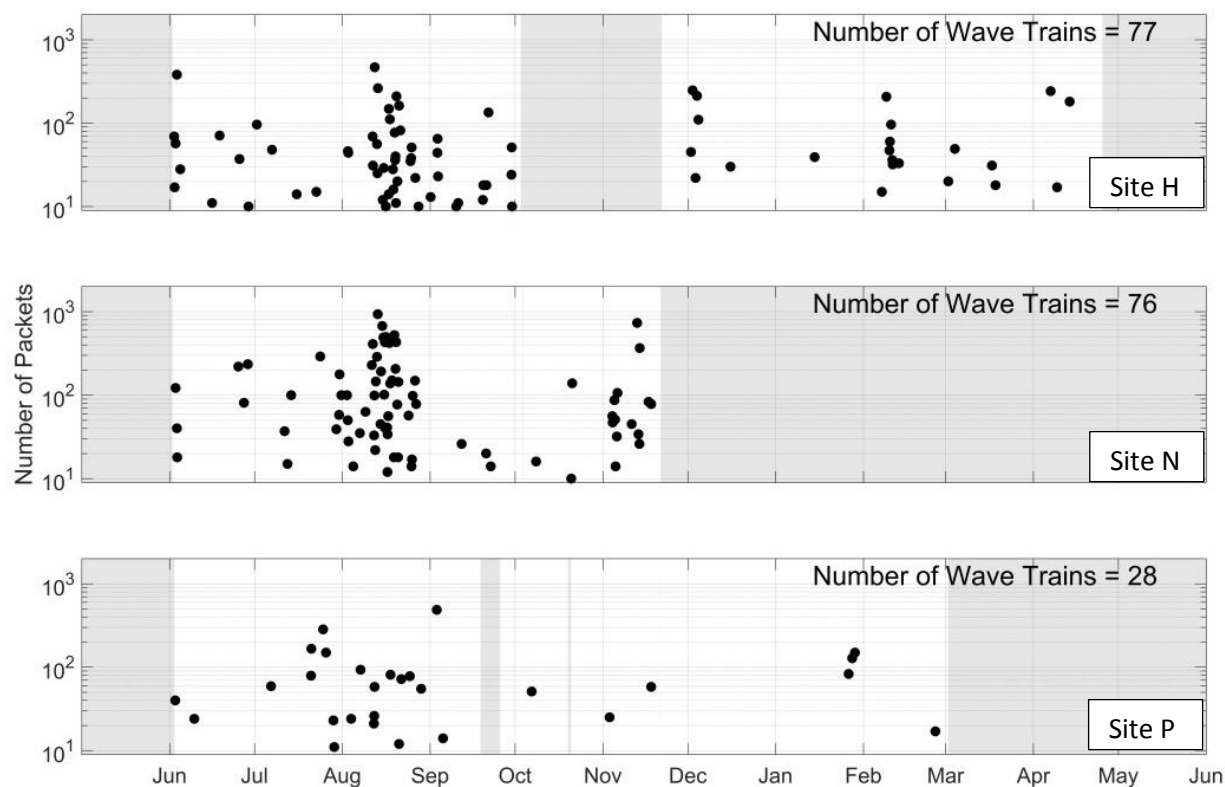**Figure 23. Cumulative sound exposure level for each wave train at sites H, N, and P.**

Figure 24. Number of MFA sonar packets for each wave train at sites H, N, and P.
Note the vertical axes are logarithmic base-10.

Explosions
Explosions were detected at all three sites.

- Explosions were prevalent throughout the monitoring periods at sites H and P, with peaks in June and December 2015 at site H and relatively constant numbers of explosions at site P (Figure 25).
- Explosions detected at site N occurred in a strong peak in September 2015, with a few additional explosions occurring in October 2015 (Figure 25).
- Total explosion counts at each site were as follows:
  - 1,233 at H
  - 1,723 at N
  - 2,438 at P
- Most explosions occurred during nighttime hours, although there was more variability in daytime occurrence of explosions at site P than at other sites (Figure 26).
- 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.
- There was an overall decrease in number of explosions in this region in comparison to previous years for sites H and P, but a slight increase at site N compared to 2014 (Debich *et al.*, 2015a; Debich *et al.*, 2015b; Širović *et al.*, 2016) which could be due to a geographic shift in fishing effort.
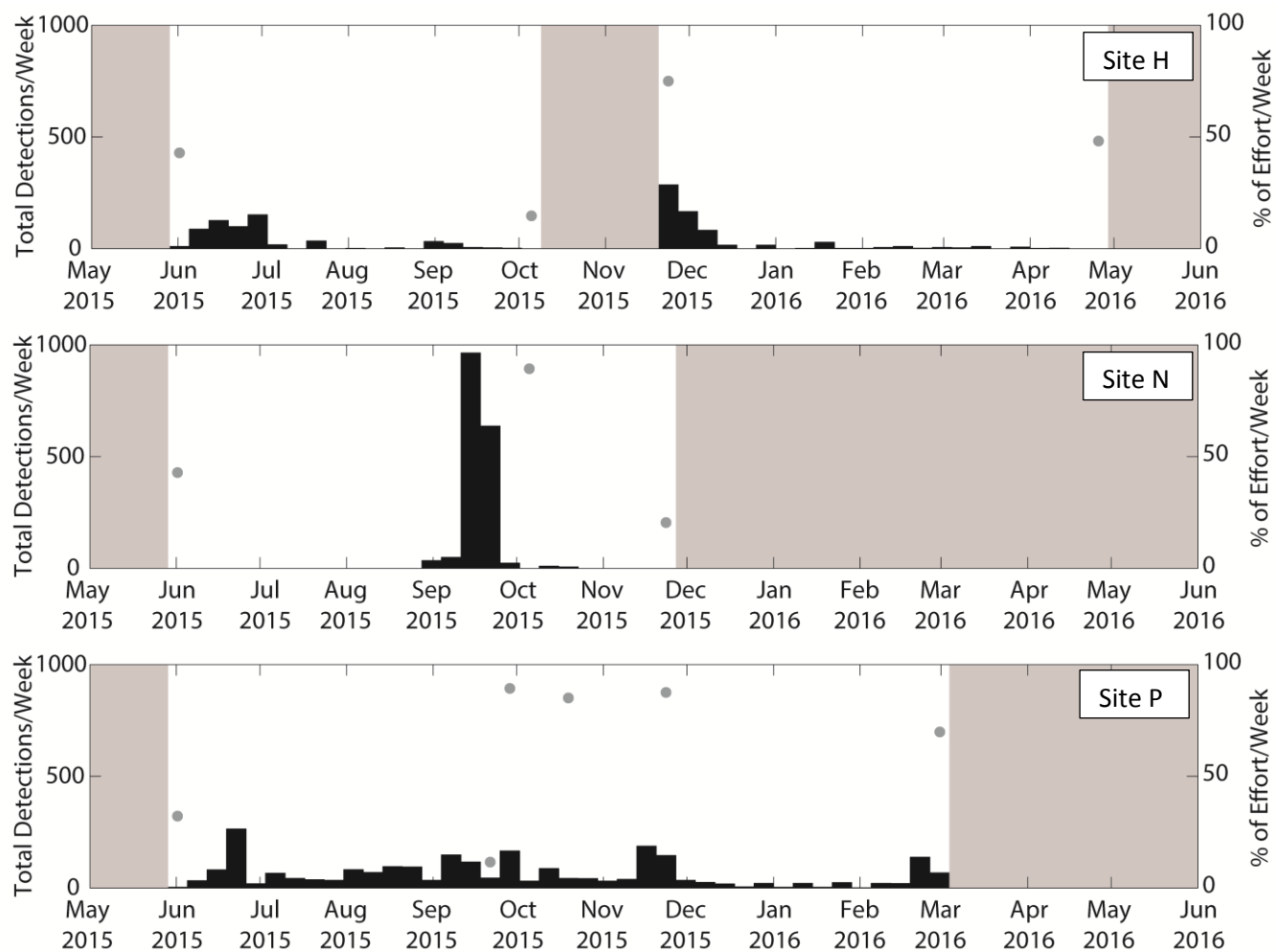
Figure 25. Weekly presence of explosions between June 2015 and April 2016 at sites H, N, and P. Effort markings are described in Figure 10.
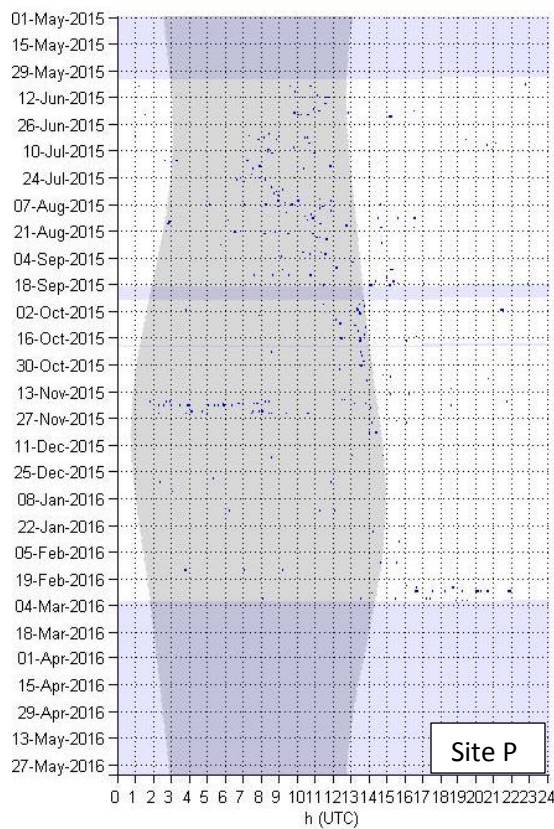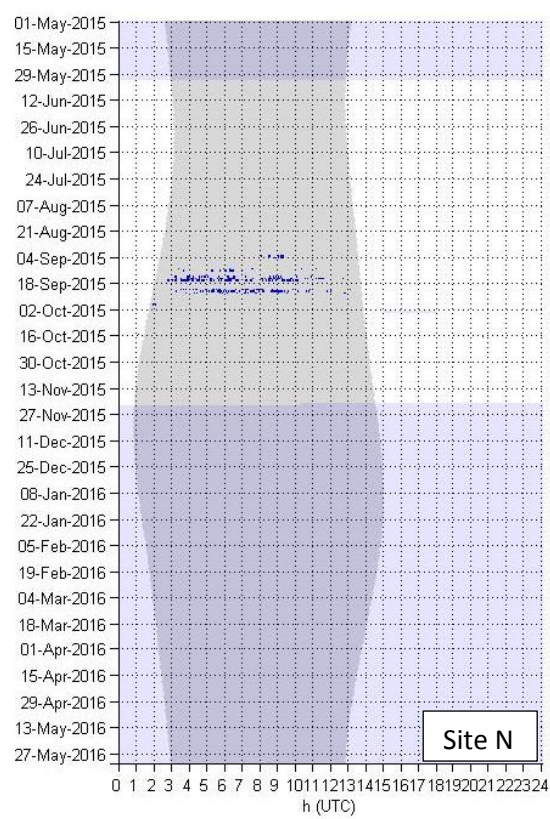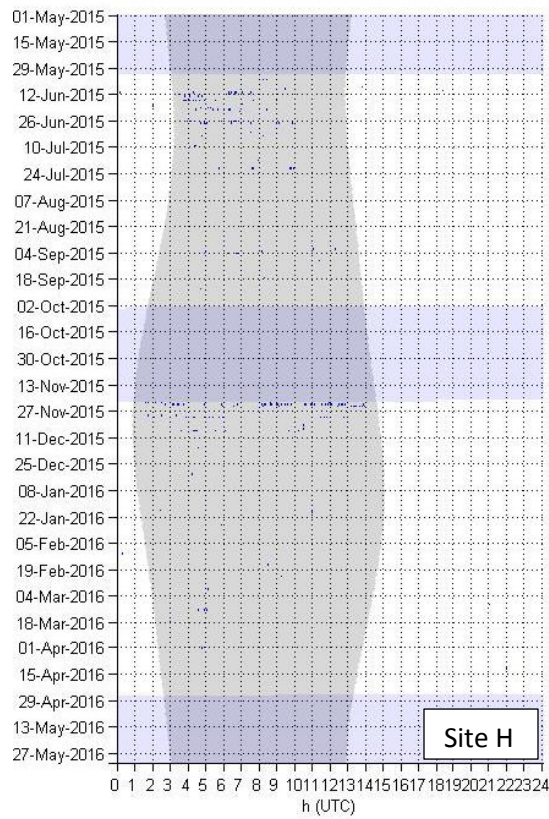
Figure 26. Explosion detections, indicated by blue dots, in one-minute bins at sites H, N, and P. Effort markings are described in Figure 11.

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