



## **Passive Acoustic Monitoring for Marine Mammals in the SOCAL Range Complex April 2016 – June 2017**

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Humpback whale, Photo by Ally Rice

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<b>14. ABSTRACT</b> Passive acoustic monitoring was conducted in the Navy's Southern California Range Complex from April 2016 to June 2017 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). In addition, an array of 9 HARPs was deployed in the San Diego Trough, during the fall of 2017, to track baleen whale calls.  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. The low-frequency ambient soundscape and the presence of Mid-Frequency Active (MFA) sonar and explosions were also analyzed.  Ambient sound levels were highest at site P and lowest at site H, likely related to boat activity. Peaks in sound levels at all sites during the fall and winter are related to the seasonally increased presence of blue whales and fin whales, respectively.  For marine mammal and anthropogenic signals, 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 call detections and the fin whale acoustic index representative of 20 Hz calls were highest at sites H and N. Site P had the lowest call detection levels for both species. Blue whale B call detections peaked from September to December 2016 and very few B calls were detected after January 2017. Blue whale D calls peaked in May and June 2017 at sites H and N and from May to July 2016 at site P. The fin whale acoustic index was highest from October 2016 to April 2017.

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 during March and April 2017 at site H. At site N detections showed a slight increase during July 2016 and a more pronounced increase from December 2016 to March 2017. There were no detections of Cuvier's at site P. There was an additional beaked whale-like FM pulse type, BW43, possibly produced by Perrin's beaked whale (Baumann-Pickering et al., 2014), that was detected infrequently during winter, only at site N. No other beaked whale signal types were detected.

Two anthropogenic signals were detected: MFA sonar and explosions. MFA sonar was detected at all sites with a peak in fall 2016. 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 November 2016. Site H had fewer detections than site N as well as lower received and sound exposure levels. Site P had the lowest maximum received levels, and the least amount of MFA sonar packet detections.

Explosions were detected at all sites, but were highest from April to June 2016 at site P. Temporal and spectral parameters, as well as received levels of these explosive events suggest association with fishing, specifically the use of seal bombs.

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## Executive Summary

Passive acoustic monitoring was conducted in the Navy's Southern California Range Complex from April 2016 to June 2017 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). In addition, an array of 9 HARPs was deployed in the San Diego Trough, during the fall of 2017, to track baleen whale calls.

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. The low-frequency ambient soundscape and the presence of Mid-Frequency Active (MFA) sonar and explosions were also analyzed.

Ambient sound levels were highest at site P and lowest at site H, likely related to boat activity. Peaks in sound levels at all sites during the fall and winter are related to the seasonally increased presence of blue whales and fin whales, respectively.

For marine mammal and anthropogenic signals, 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 call detections and the fin whale acoustic index representative of 20 Hz calls were highest at sites H and N. Site P had the lowest call detection levels for both species. Blue whale B call detections peaked from September to December 2016 and very few B calls were detected after January 2017. Blue whale D calls peaked in May and June 2017 at sites H and N and from May to July 2016 at site P. The fin whale acoustic index was highest from October 2016 to April 2017.

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 during March and April 2017 at site H. At site N detections showed a slight increase during July 2016 and a more pronounced increase from December 2016 to March 2017. There were no detections of Cuvier's at site P. There was an additional beaked whale-like FM pulse type, BW43, possibly produced by Perrin's beaked whale (Baumann-Pickering *et al.*, 2014), that was detected infrequently during winter, only at site N. No other beaked whale signal types were detected.

Two anthropogenic signals were detected: MFA sonar and explosions. MFA sonar was detected at all sites with a peak in fall 2016. 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 November 2016. Site H had fewer detections than site N as well as lower received and sound exposure levels. Site P had the lowest maximum received levels, and the least amount of MFA sonar packet detections.



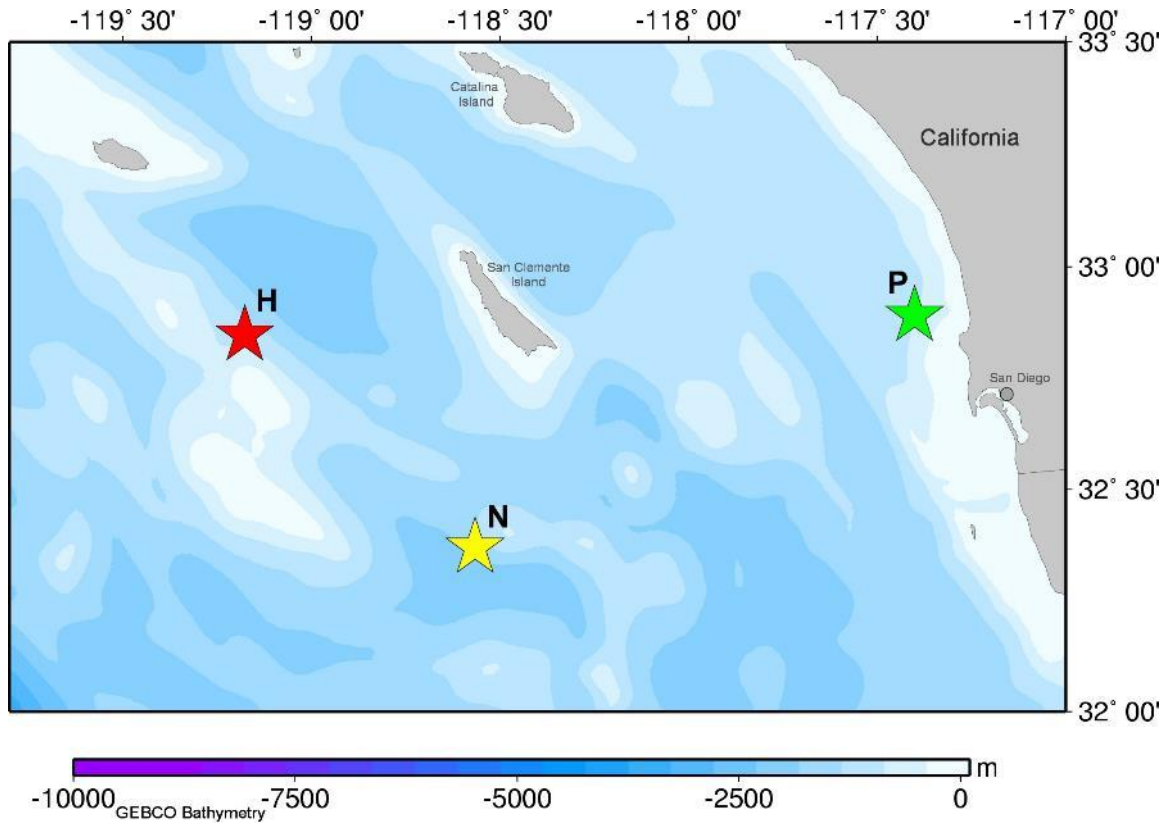
Explosions were detected at all sites, but were highest from April to June 2016 at site P. Temporal and spectral parameters, as well as received levels of these explosive events suggest association with fishing, specifically the use of seal bombs.

## **Project Background**

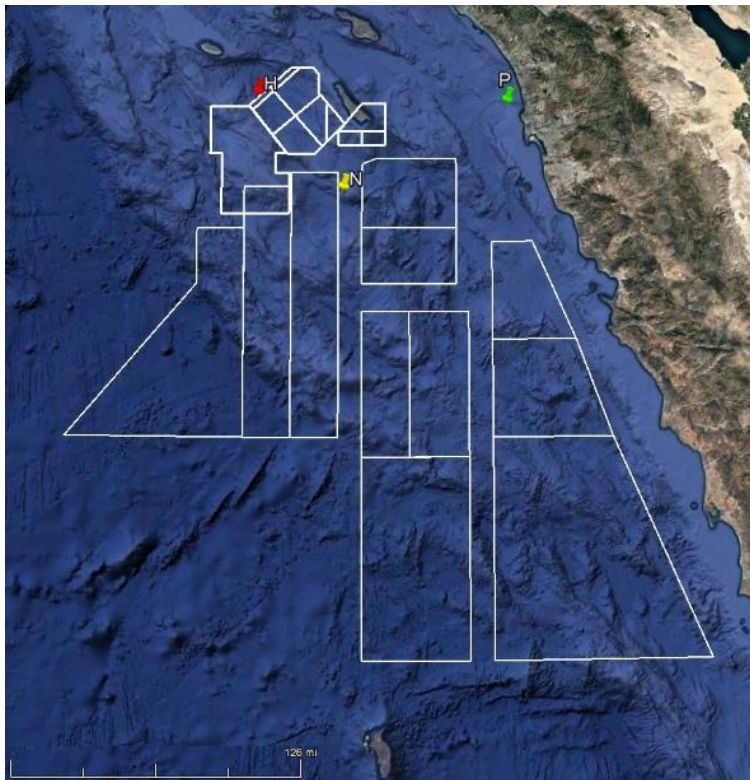
The Navy's Southern California (SOCAL) Range Complex is located in the Southern California Bight and the adjacent deep waters to the west. This region has a highly productive marine ecosystem due to the southward flowing California Current, and associated coastal current system. A diverse array of marine 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, determine their seasonal presence, and 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. In addition, the low-frequency ambient soundscape, as well as the presence of Mid-Frequency Active (MFA) sonar and explosions were analyzed.

This report documents the analysis of data recorded by High-frequency Acoustic Recording Packages (HARPs) that were deployed at three sites within the SOCAL Range Complex and collected data between April 2016 and June 2017. 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; Figure 2). Data from site H and N were analyzed for July 2016 through June 2017 (Table 1) and site P data were analyzed for April to October 2016 and again February through May 2017 (Table 2). In addition, an array of HARPs, sampling at 20 kHz (Table 3), were deployed in the San Diego Trough (Figure 3) during summer and fall 2017, to provide localization capability for baleen whale calls.

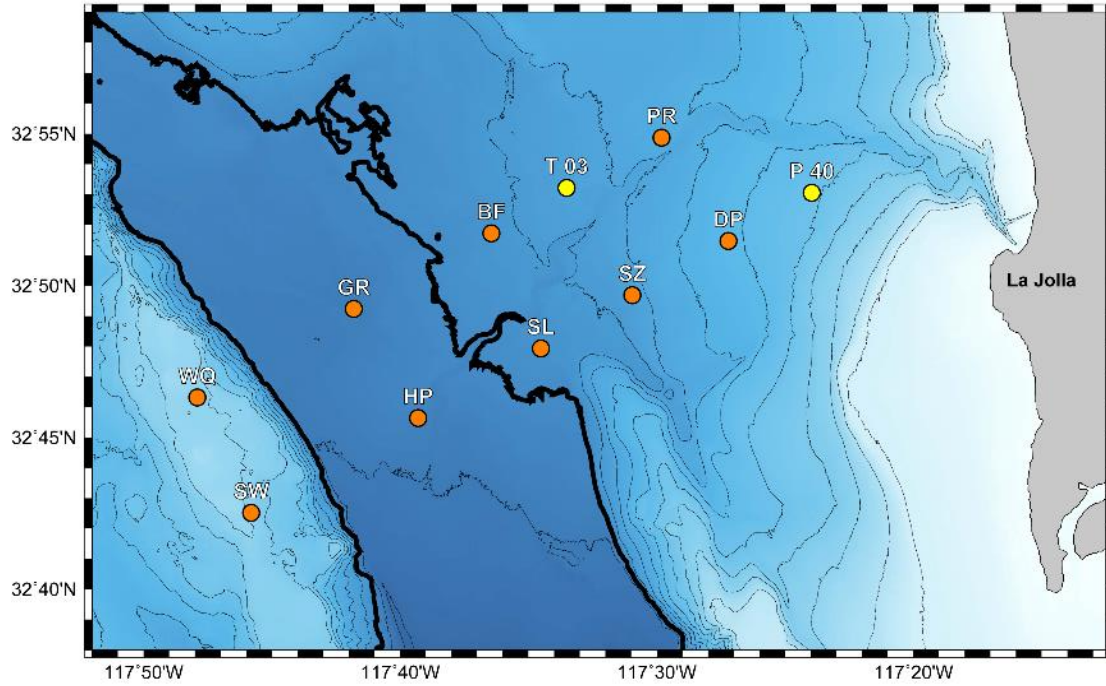


**Figure 1. Locations of High-frequency Acoustic Recording Package (HARP) deployment sites H, N, and P (stars) in the SOCAL study area from April 2016 through June 2017. Color indicates bathymetric depth.**



**Figure 2. Locations of High-frequency Acoustic Recording Package (HARP) deployments in the SOCAL study area (pins) and SCORE operating areas (white boxes).**

### SDT 2017



**Figure 3. Deployment locations of HARP array sampling at 20kHz (orange circles) and those sampling at 200kHz (yellow circles) in the San Diego Trough region. Contour lines are at 100 m intervals (thick black contour line represents 1000 m).**

**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.

<b>Deployment Name</b>	<b>Site H Monitoring Period</b>	<b># Hours</b>	<b>Site N Monitoring Period</b>	<b># Hours</b>
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
<b>SOCAL 59</b>	<b>7/6/16 – 11/9/16</b>	<b>3011</b>	<b>7/7/16 – 11/8/16</b>	<b>2999</b>
<b>SOCAL 60</b>	-	-	<b>11/9/16 – 2/21/17</b>	<b>2457</b>
<b>SOCAL 61</b>	<b>2/22/17 – 6/6/17</b>	<b>2518</b>	<b>2/21/17 – 6/7/17</b>	<b>2528</b>

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

<b>Deployment Name</b>	<b>Site P Monitoring Period</b>	<b># Hours</b>
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
<b>LJ 35-P</b>	<b>4/9/16 – 8/10/16</b>	<b>2971</b>
<b>LJ 36-P</b>	<b>8/12/16 – 10/26/16</b>	<b>1803</b>
LJ 37-P	-	-
LJ 38-P	-	-
<b>LJ 39-P</b>	<b>2/14/17 – 5/24/17</b>	<b>2377</b>

**Table 3. HARP array deployments in the San Diego Trough from May 2017 to January 2018.**

<b>Deployment Name</b>	<b>Site P Monitoring Period</b>	<b>Latitude (N)</b>	<b>Longitude (W)</b>	<b>Depth (m)</b>	<b># Hours</b>
LJ 40-P	5/30/2017 – 9/29/2017	32° 53.053	117° 23.954	517	2933
SOCAL 03-T	7/8/2017 – 1/17/2018	32° 53.199	117° 33.496	814	4632
SDT 01-BF	7/27/2017 – 11/13/2017	32° 51.721	117° 36.446	915	2636
SDT 01-DP	8/3/17 – 11/15/17	32° 51.467	117° 27.204	609	2514
SDT 01-GR	7/31/17 – 11/13/17	32° 49.231	117° 41.802	1068	2539
SDT 01-HP	7/31/17 – 11/13/17	32° 45.640	117° 39.295	1051	2535
SDT 01-PR	8/03/17 – 11/15/17	32° 54.867	117° 29.805	725	2513
SDT 01-SL	7/27/17 – 11/15/17	32° 47.930	117° 34.513	943	2667
SDT 01-SW	7/31/17 – 11/13/17	32° 42.512	117° 45.805	295	2537
SDT 01-SZ	8/3/2017 – 11/15/2017	32° 49.685	117° 30.951	823	2512
SDT 01-WQ	7/31/2017 – 11/13/2017	32° 46.317	117° 47.905	285	2537

## Methods

### High-frequency Acoustic Recording Package (HARP)

HARPs were used to record the low-frequency ambient soundscape as well as marine mammal and anthropogenic sounds 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 at least 10 m above the seafloor. Each HARP hydrophone 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 recordings have been collected within the SOCAL Range Complex near San Clemente Island since 2009 (Table 1) and off La Jolla, CA since 2014 (Table 2) using HARPs sampling at 200 kHz. The sites analyzed in this report 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 July 6, 2016 to June 6, 2017. Analysis could not be conducted on data from November 10, 2016 to February 21, 2017 because a hydrophone problem resulted in poor quality data. Site N yielded data from July 7, 2016 to June 7, 2017. Data recording occurred at site P from April 9, 2016 to May 24, 2017. However, analysis was not conducted on data from October 27, 2016 to February 13, 2017 as there was a hydrophone problem similar to what occurred at site H. For all three sites, a total of 20,664 hours, covering 861 days of acoustic data were recorded in the deployments analyzed in this report.

In addition, an array of HARPs was deployed in the San Diego Trough (SDT) during summer and fall of 2017 (Table 3). A total of 9 instruments were deployed, sampling at 20 kHz, and these were supplemented by two additional sites that sampled at 200 kHz, to yield a total array of 11 instruments. The instruments were deployed in a northeast-to-southwest trending array with dimensions of 20 nm x 5 nm. They will provide baleen whale call tracking capabilities from August 3, 2017 – November 13, 2017.

### Data Analysis

Recording over a broad frequency range of 10 Hz to 100 kHz allows detection of the low-frequency ambient soundscape, 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

a daily average, termed the '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 2016 and June 2017 at sites H and N, and between April 2016 and May 2017 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. For the SDT array, baleen whale call localization analysis is not yet complete, although data quality assessment, presented here, suggests that the array will provide a rich dataset of blue and fin whale localizations.



## **Low-frequency Ambient Soundscape**

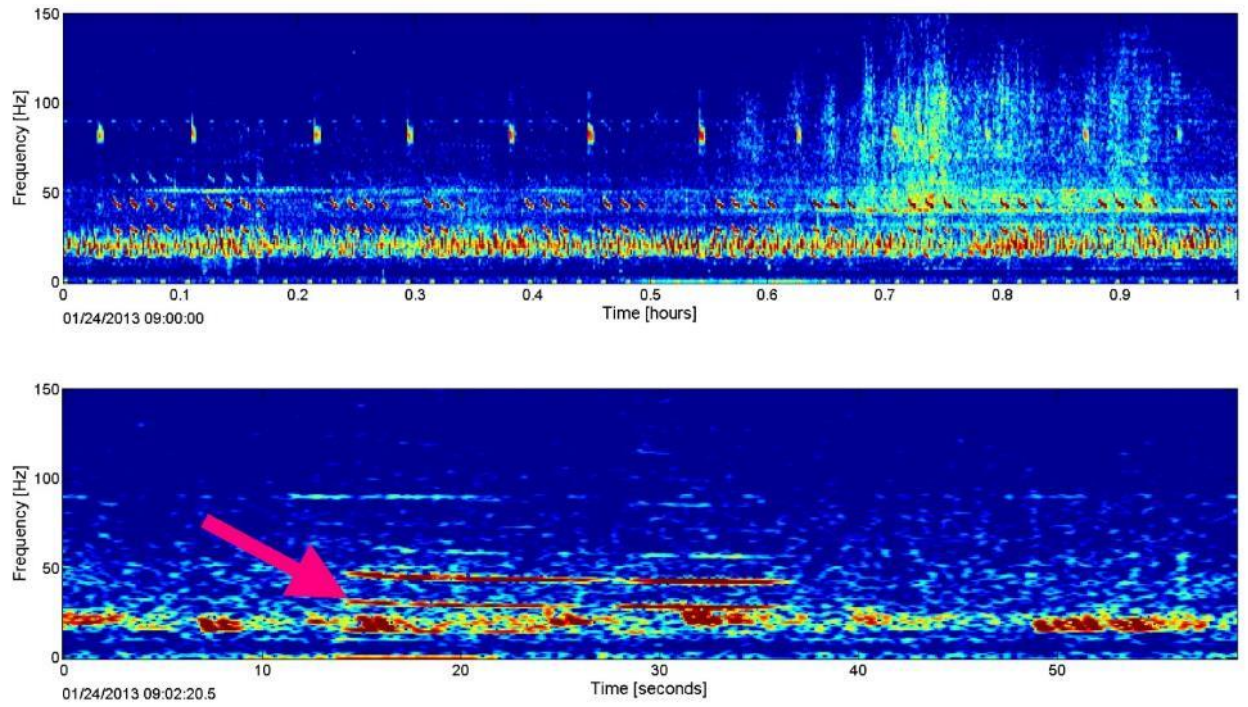
To determine ambient sound levels, HARP recordings were decimated by a factor of 100 to provide an effective bandwidth of 10 Hz to 1 kHz from which LTSAs were constructed with 1 Hz frequency and 5 s temporal resolution. Daily spectra were computed by averaging 5, 5 s sound pressure spectrum levels calculated from each 75 s acoustic record. System self-noise was excluded from these averages.

## **Blue Whales**

Blue whales produce a variety of calls worldwide (McDonald *et al.*, 2006). Calls recorded in the eastern North Pacific include the Northeast Pacific blue whale B call (Figure 4) and the D call (Figure 5). Northeast Pacific blue whale B calls are geographically distinct and potentially associated with mating functions (McDonald *et al.*, 2006; Oleson *et al.*, 2007). They are low-frequency (fundamental frequency <20 Hz), long duration (> 10 s) calls that are often regularly repeated. D calls are downswept in frequency (approximately 100-40 Hz) with a duration of several seconds. These calls are similar worldwide and are associated with feeding animals; they may be produced as call-counter call between multiple animals (Oleson *et al.*, 2007).

### ***Northeast Pacific blue whale B calls***

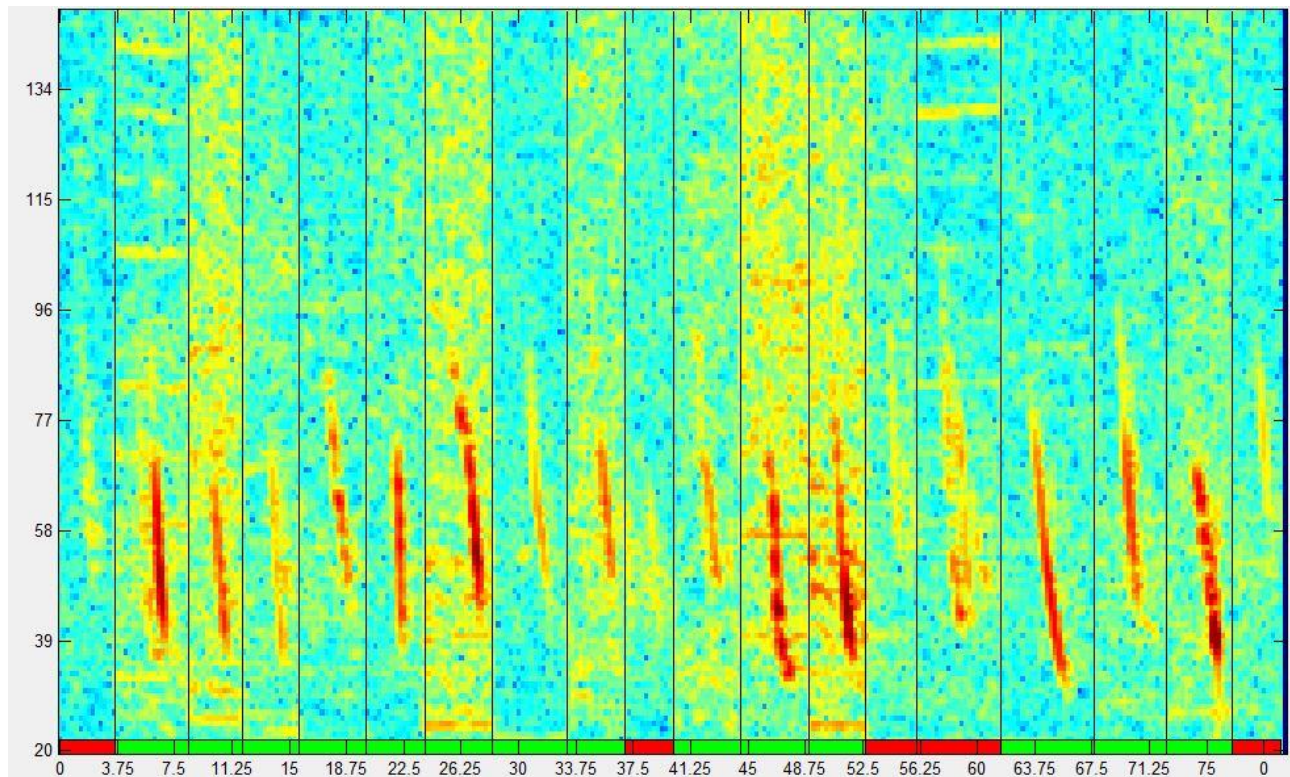
Blue whale B calls (Figure 4) were detected automatically using spectrogram correlation (Mellinger and Clark, 1997). The detection kernel was based on frequency and temporal characteristics measured from 30 calls recorded in the data set, each call separated by at least 24 hours. The kernel was comprised of four segments, three 1.5 s and one 5.5 s long, for a total duration of 10 s. Since blue whale calls change over time (McDonald *et al.*, 2009; Širović, 2016), separate kernels were measured for summer and fall periods. The summer 2016 kernel was defined as sweeping from 46 to 45.4 Hz; 45.4 to 44.7 Hz, 44.7 to 44.1 Hz, and 44.1 to 43.5 Hz during these predefined periods. The fall 2016 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 Hz. The kernel bandwidth was 2 Hz. Total numbers of detections are reported for this call type.



**Figure 4. Blue whale B calls (just below 50 Hz) in Long-term Spectral Average (LTSA; top) and an individual call shown in a spectrogram (bottom) recorded at site N.**

**Blue whale D calls**

Blue whale D calls (Figure 5) 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 that included the frequency space over which the detector operates. A trained analyst subsequently verified the detections (Figure 5).



**Figure 5. Blue whale D calls from site H in the analyst verification stage of the detector. Green along the bottom evaluation line indicates true detections and red indicates false detections.**

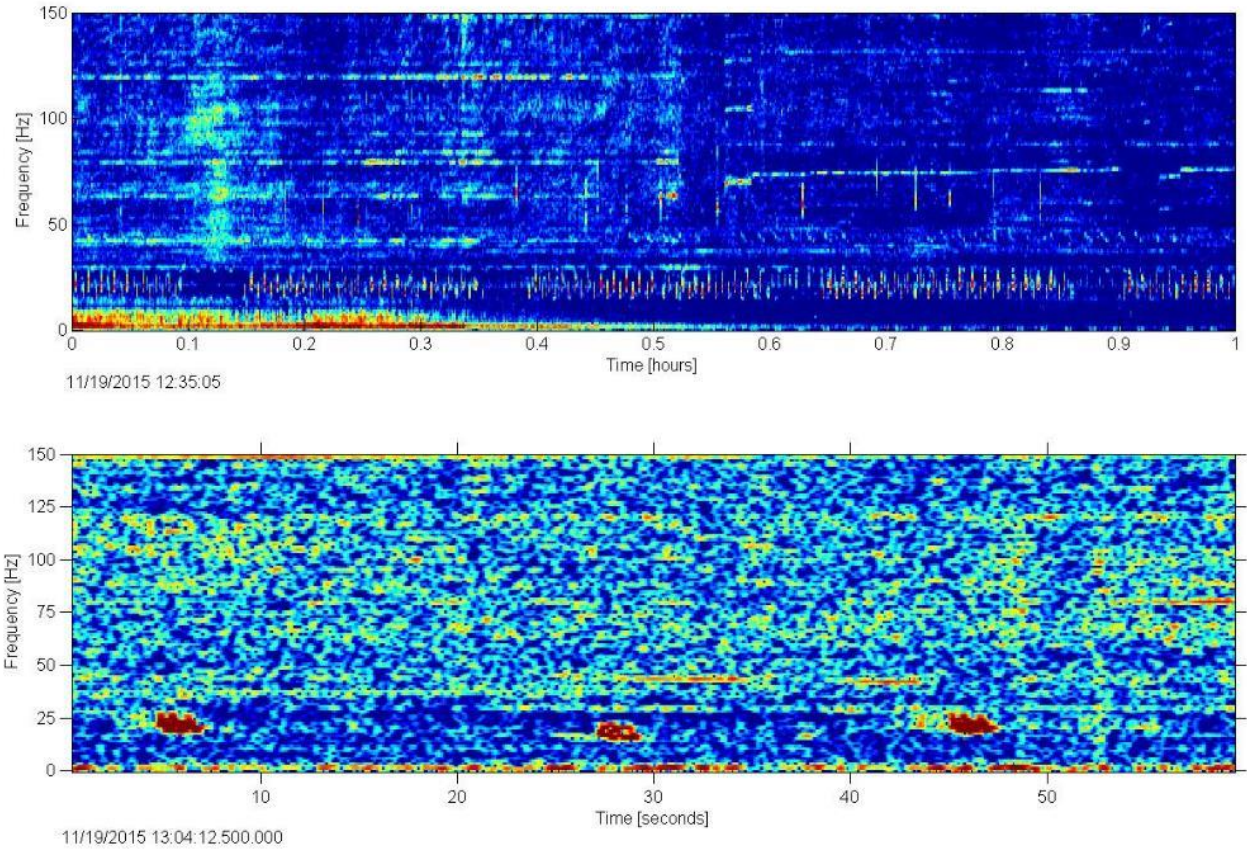
**Fin Whales**

Fin whales produce short (~ 1 s duration), low-frequency calls. The most common is a frequency downsweep from 30-15 Hz called the 20 Hz call (Watkins, 1981; Figure 6). 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**

In the SOCAL study area, fin whale 20 Hz calls are so abundant that it is often impossible to distinguish, and therefore detect, individual calls (Watkins *et al.*, 2000; Širović *et al.*, 2015). Therefore, fin whale 20 Hz calls (Figure 6) 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 a long-term spectral average (LTSA) calculated over 5 s with 1 Hz frequency resolution. The frequency at 22 Hz was used as the signal frequency (Nieukirk *et al.*, 2012; Širović *et al.*, 2015), 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 6. Fin whale 20 Hz calls in an 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 whales (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) upswept 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 likely Stejneger's beaked whales (Baumann-Pickering *et al.*, 2013b).

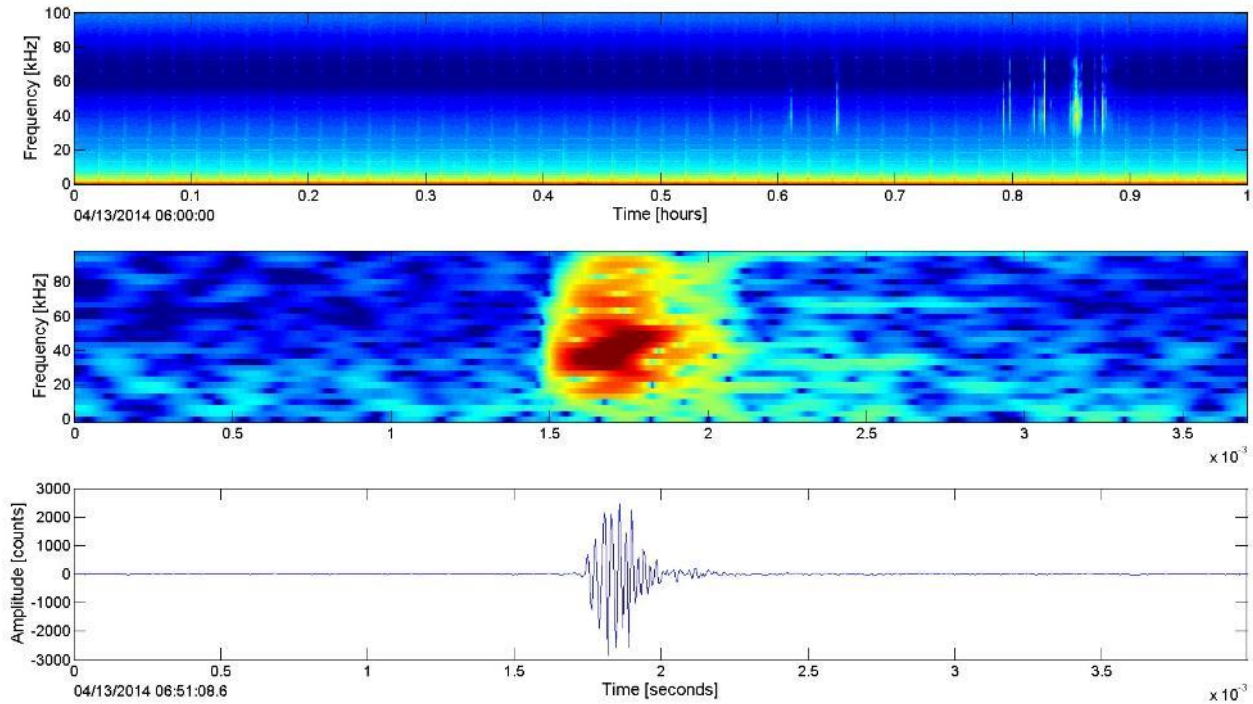
Other beaked whale signals detected in the Southern California Bight include FM pulses known as BW40, BW43, and BW70, which may belong to Hubbs', Perrin's, and pygmy beaked whales, respectively (Baumann-Pickering *et al.*, 2013a; Baumann-Pickering *et al.*, 2014). Only Cuvier's and BW43 signals were 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 than is 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 based on the parameters described below (Roch *et al.*, 2011b).

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  $\mu$ 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. 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.*, 2013a). The rate of missed segments was approximately 5%. 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*

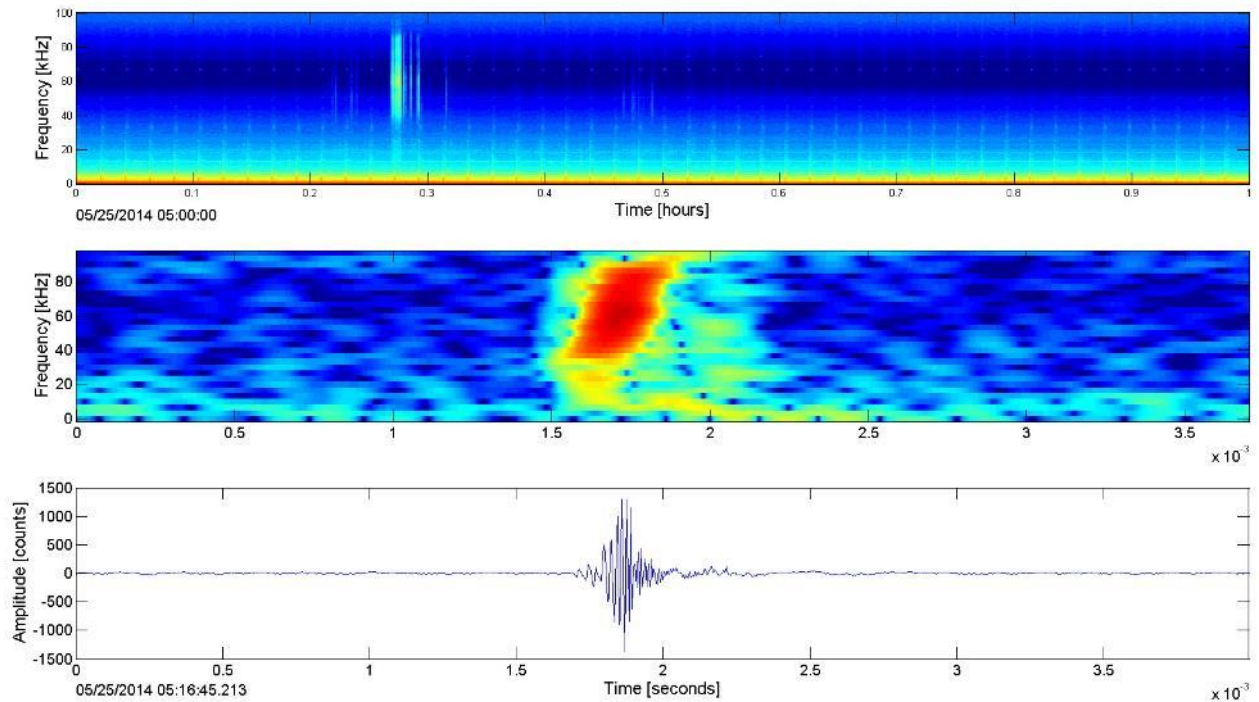
Cuvier's beaked whale echolocation signals are well differentiated from other species' acoustic signals as polycyclic, with a characteristic FM pulse upsweep, peak frequency around 40 kHz, and uniform inter-pulse interval of about 0.4 – 0.5 s (Johnson *et al.*, 2004; Zimmer *et al.*, 2005; Figure 7). 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 7. Echolocation sequence of Cuvier's beaked whale in an LTSA (top) and example FM pulse in a spectrogram (middle) and corresponding time series (bottom) recorded at site N.**

**BW43**

The BW43 FM pulse has yet to be positively 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.*, 2013a; Figure 8). A candidate species for producing this FM pulse type may be Perrin's beaked whale (Baumann-Pickering *et al.*, 2014).



**Figure 8. Echolocation sequence of BW43 in an LTSA (top) and example FM pulse in a spectrogram (middle) and corresponding 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 9). 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.

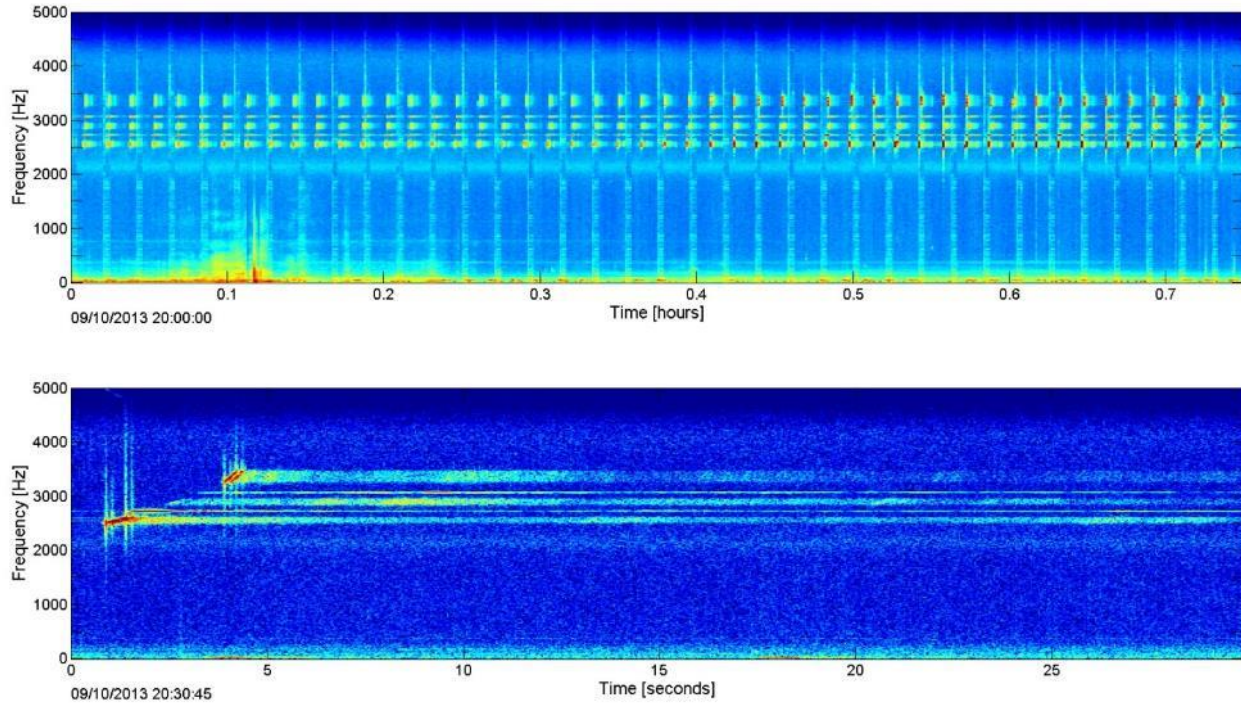
MFA sonar was detected using a modified version of the *Silbido* detection system (Roch *et al.*, 2011a) originally designed for characterizing toothed whale whistles. The algorithm identifies peaks in time- frequency distributions (e.g. spectrogram) and determines which peaks should be linked into a 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 RMS duration (for  $RL_{pp} - 10dB$ ) were measured and saved.



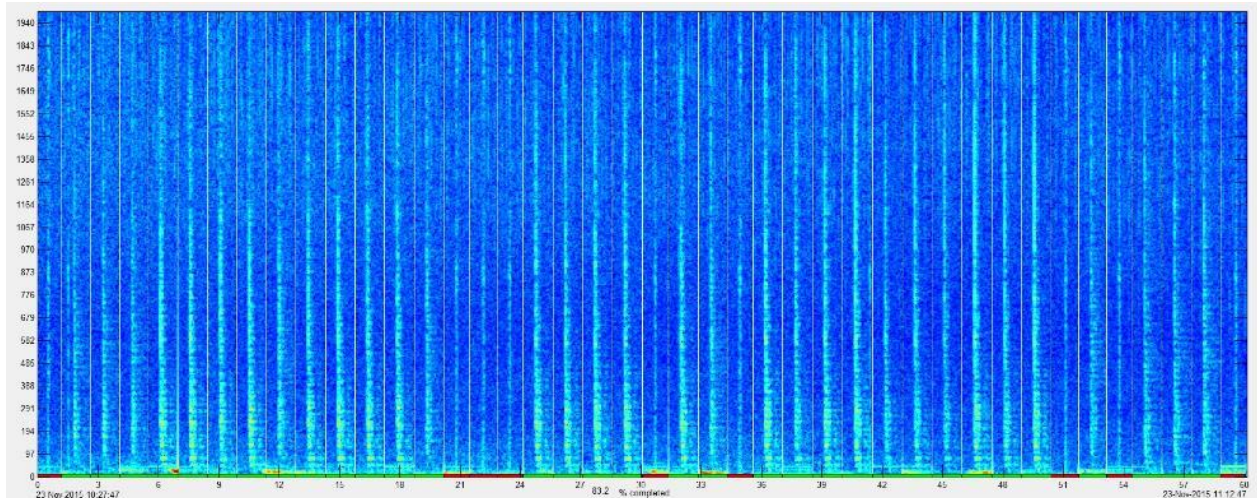
Various filters were applied to the detections to limit the MFA sonar detection range to ~20 km for off-axis signals from an AN/SQS 53C source, which resulted in a received level detection threshold of 130 dB pp re 1  $\mu$ Pa. Instrument maximum received level was ~162 dB pp re 1  $\mu$ Pa, above which 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 9. 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 recordings 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 10). 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 10<sup>th</sup> 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 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 10. Explosions from site H in the analyst verification stage where events are concatenated into a single spectrogram.**

**Green along the bottom indicates true and red indicates false detections.**

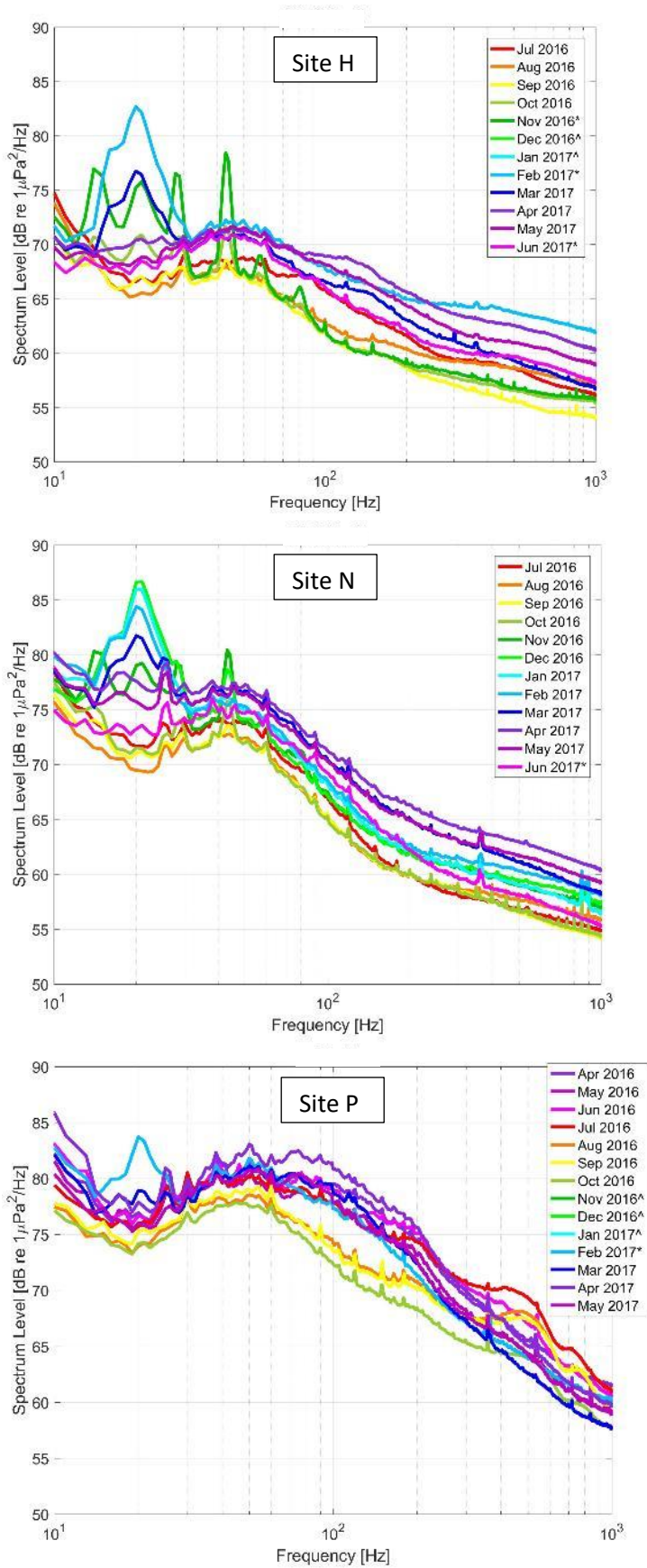
## Results

The results of acoustic data analysis at sites H, N, and P from April 2016 through June 2017 are summarized below.

We describe the low-frequency ambient soundscape, the seasonal occurrence, and relative abundance of marine mammal acoustic signals and anthropogenic sounds of interest.

### **Low-frequency Ambient Soundscape**

- The underwater ambient soundscape 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 (Hildebrand, 2009; Figure 11).
- Variability in spectra above 200 Hz is likely from higher wind during winter and spring.
- Site H had the lowest spectrum levels below 100 Hz (Figure 11). 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 (Figure 11).
- 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 (Figure 11).
- Prominent peaks in sound spectrum levels observed in the frequency band 15-30 Hz during winter at all sites are related to seasonally increased presence of fin whale calls, with highest levels at site N (Figure 11).
- October – December spectral peaks at 45-47 Hz, along with lower frequency harmonics, at sites H and N, are related to blue whale B calls (Figure 11).



**Figure 11. Monthly averages of sound spectrum levels at sites H, N, and P. Legend gives color-coding by month. \* denotes months with partial effort. ^ denotes months with no effort.**

## **Mysticetes**

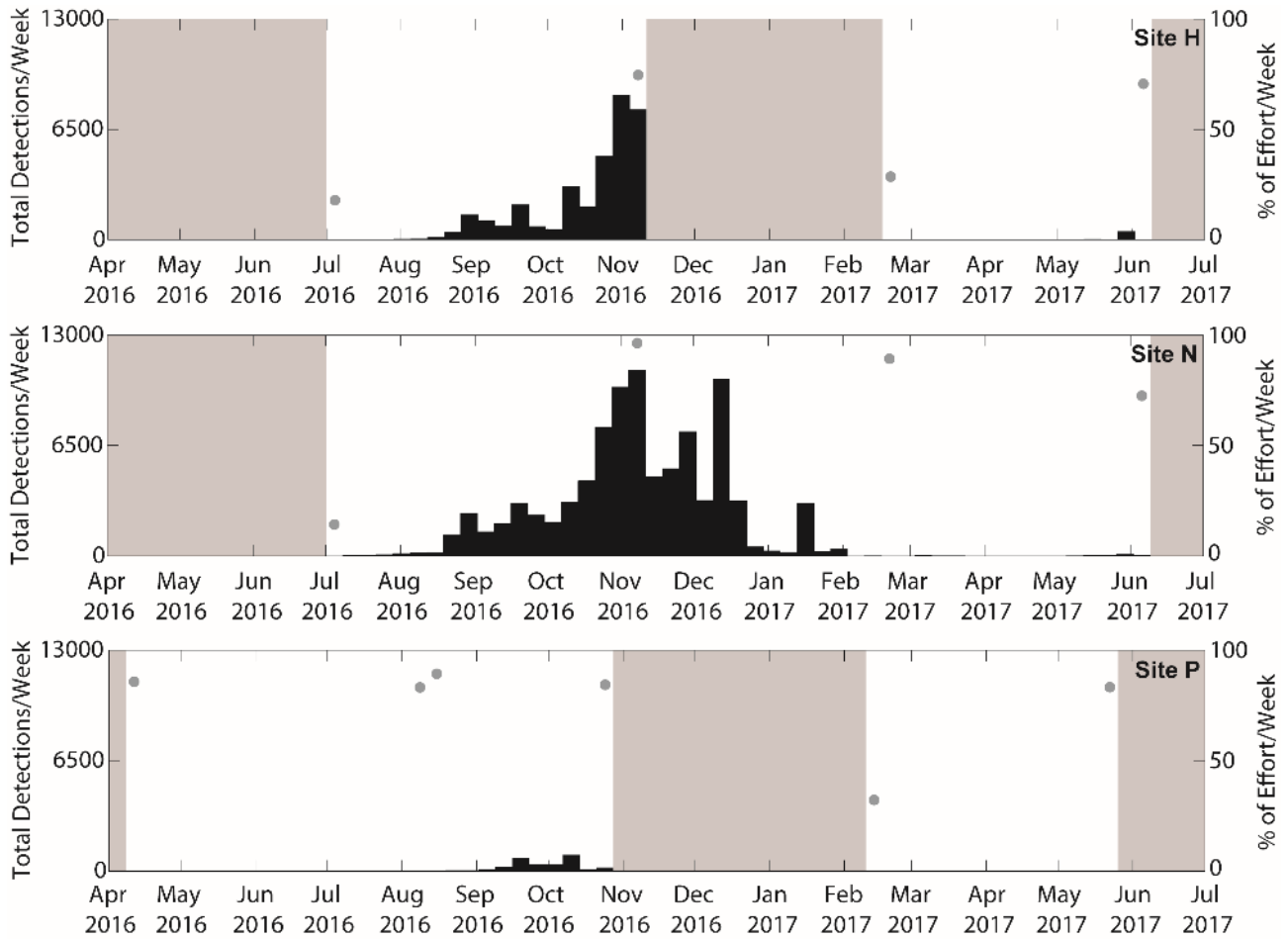
Blue and fin whales were detected using automated methods between April 2016 and June 2017. In general, fewer baleen whale vocalizations were detected at site P. More details of each species' presence are given below.

### **Blue Whales**

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

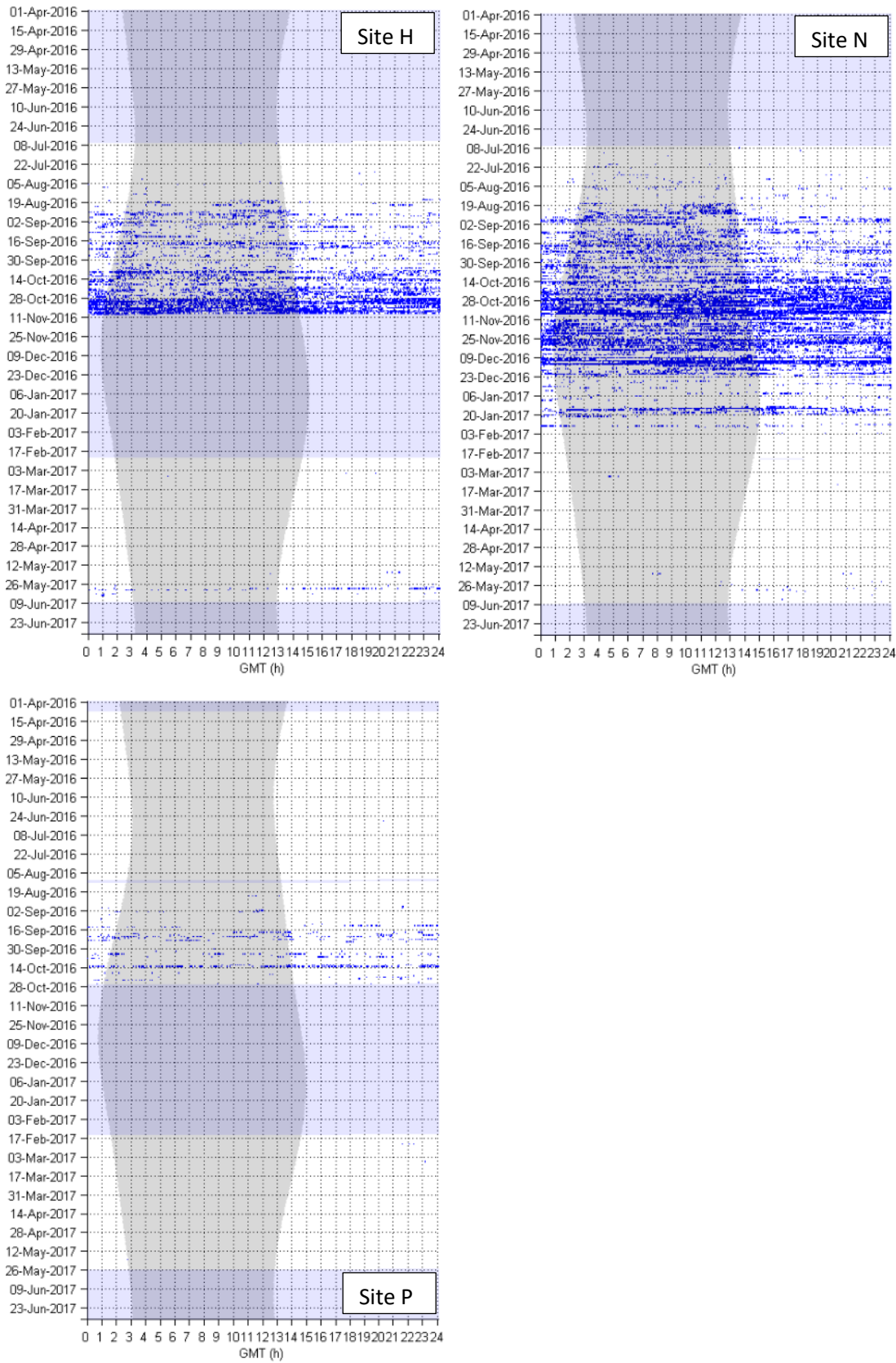
- Northeast (NE) Pacific blue whale B calls were typically detected from summer through late winter with a peak in November at sites H and N. (Figure 12).
- Site P had a substantially lower number of NE Pacific B call detections than sites H and N (Figure 12).
- There was no discernable diel pattern for the NE Pacific B calls (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.*, 2015a; Debich *et al.*, 2015b; Širović *et al.*, 2016; Rice *et al.*, 2017)
- D call detections occurred between March and December but were highest from May - June at all sites, though detections were lowest at site P (Figure 14).
- There was no clear D call diel pattern at any site (Figure 15)
- The spring/summer peak in D calls is consistent with earlier recordings at these sites (Debich *et al.*, 2015b; Rice *et al.*, 2017).



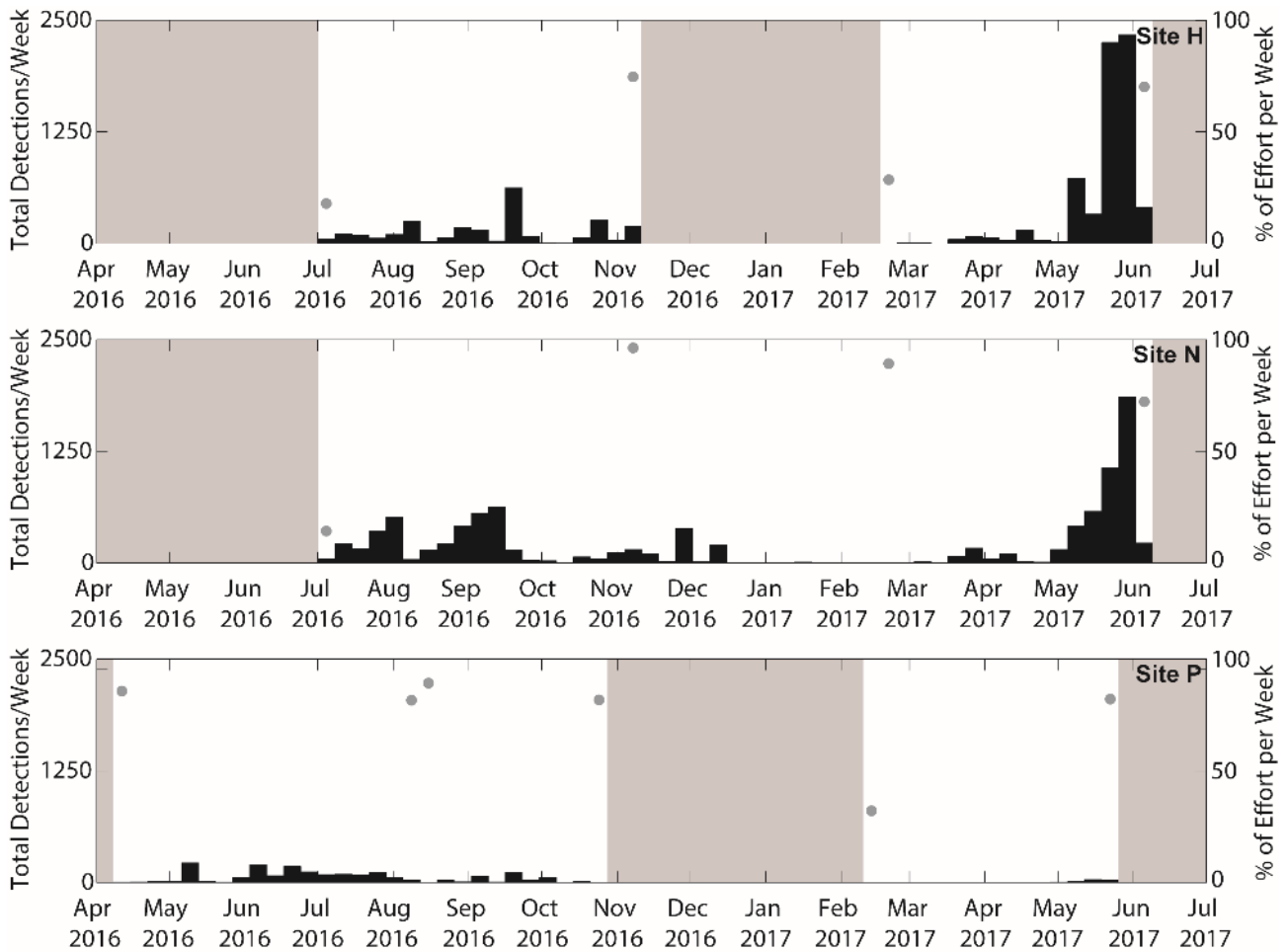


**Figure 12. Weekly presence of NE Pacific blue whale B calls between April 2016 and June 2017 at sites H, N, and P.**

**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.**

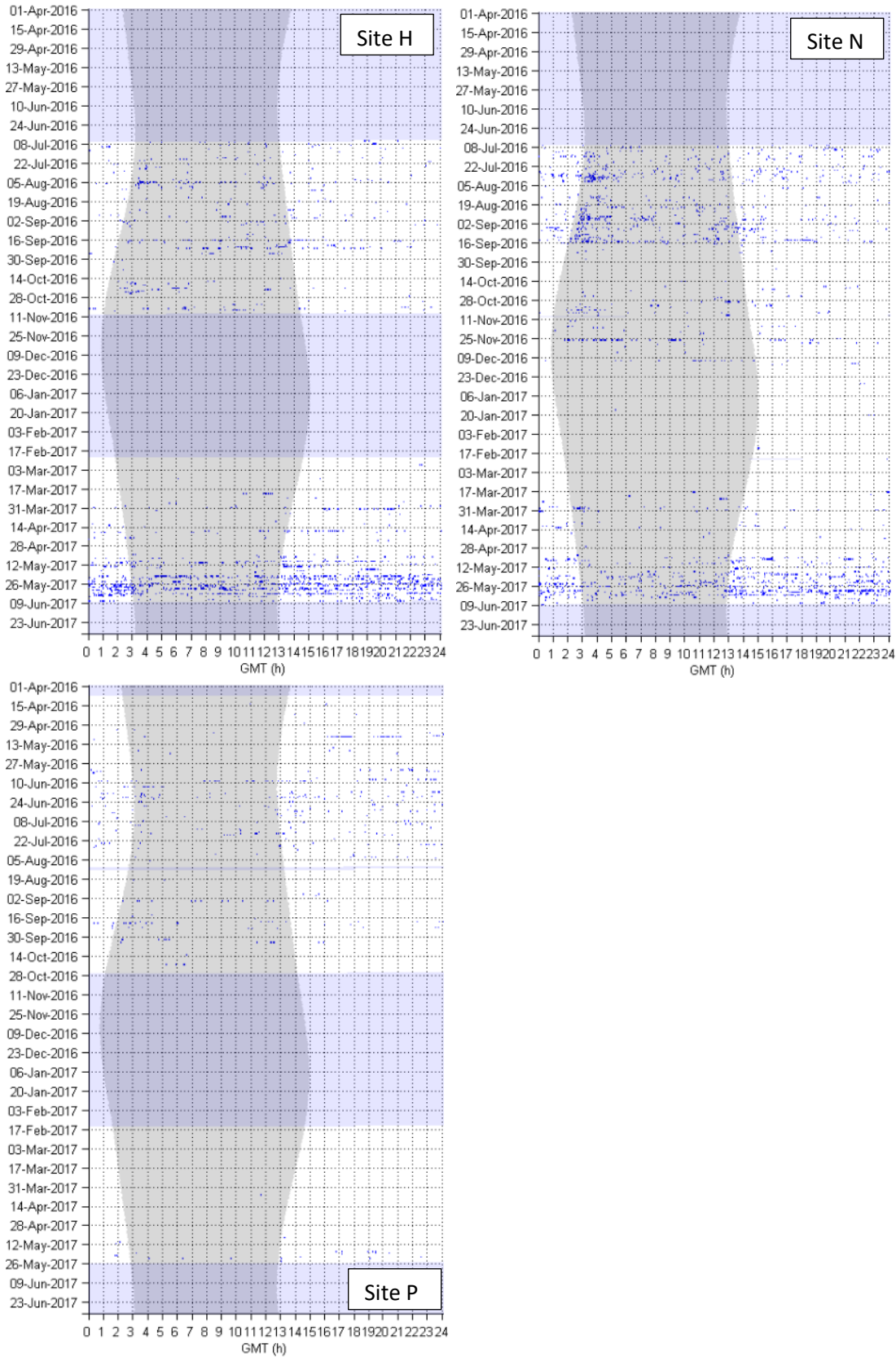


**Figure 13. Diel presence of NE Pacific blue whale B calls, indicated by blue dots, in one-minute bins at sites H, N, and P. Gray vertical shading denotes nighttime and light purple horizontal shading denotes absence of acoustic data.**



**Figure 14. Weekly presence of NE Pacific blue whale D calls between April 2016 and June 2017 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.



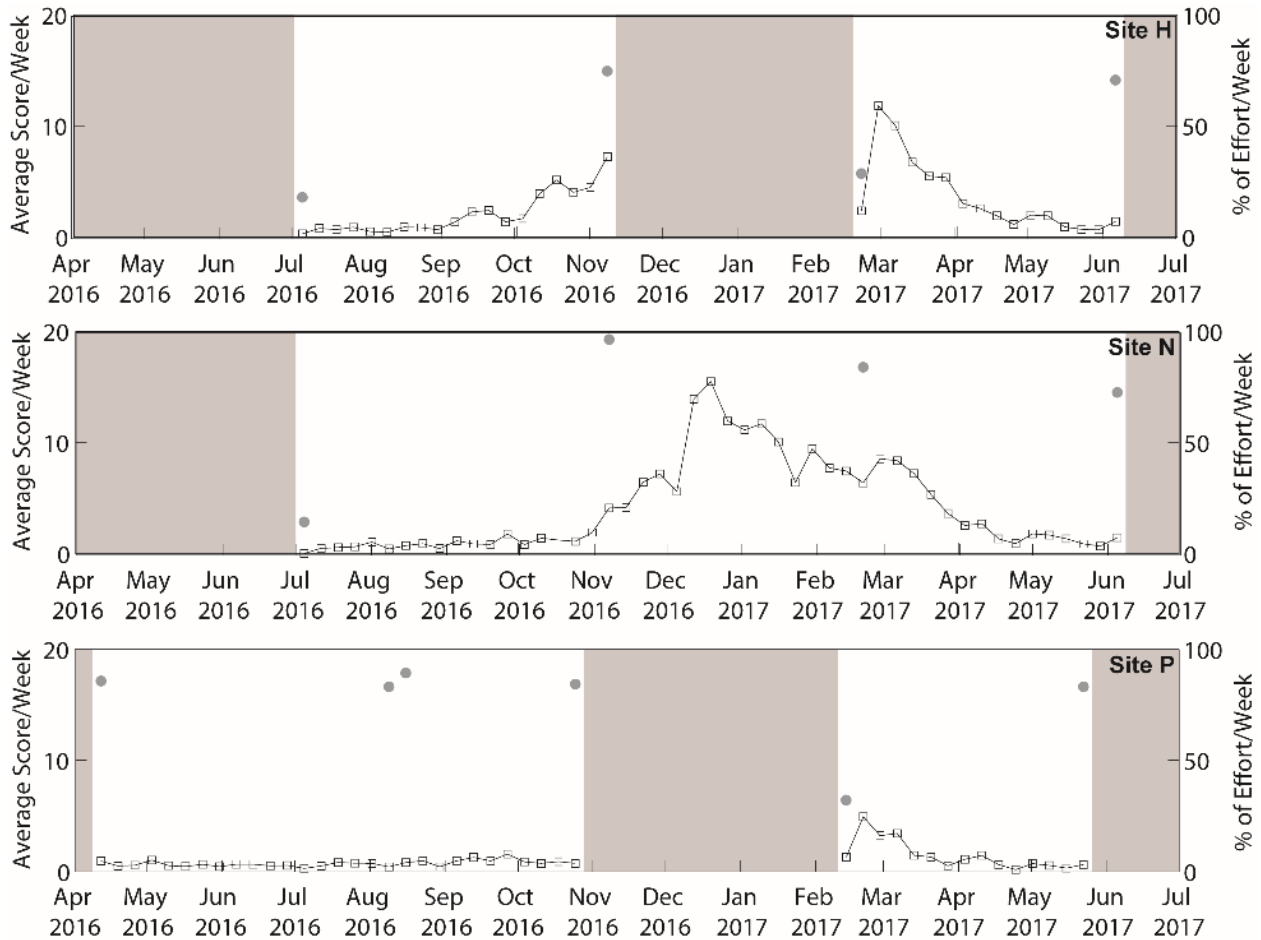


**Figure 15. Diel presence of NE Pacific blue whale D calls, indicated by blue dots, in one-minute bins at sites H, N, and P. Gray vertical shading denotes nighttime and light purple horizontal shading denotes absence of acoustic data.**

## 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 N (Figure 16).
- A peak in the fin whale acoustic index occurred in December 2016 at site N. The data gap at site H during the winter makes it impossible to determine if a similar peak was present there (Figure 16).
- The late fall or early winter peak in the fin whale acoustic index is consistent with earlier recordings (Debich *et al.*, 2015a; Debich *et al.*, 2015b; Širović *et al.*, 2016; Rice *et al.*, 2017)



**Figure 16. Weekly value of fin whale acoustic index (proxy for 20 Hz calls) between April 2016 and June 2017 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.**

## **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 only occasionally. 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**

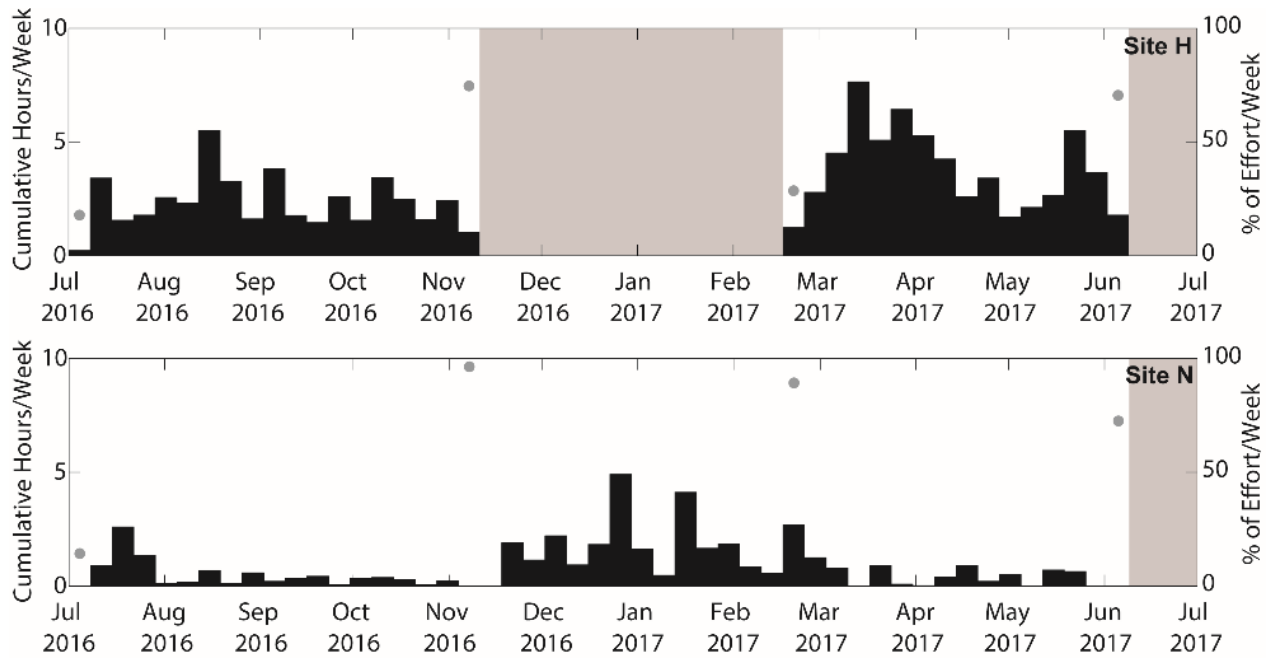
Cuvier's beaked whale was the most commonly detected beaked whale.

- Cuvier's beaked whale FM pulses were detected most commonly at site H and less commonly at site N (Figure 17). There were no detections at site P.
- Detections were highest during March and April 2017 at site H and during January and February 2017 at site N (Figure 17).
- There was no discernable diel pattern for Cuvier's beaked whale detections (Figure 18).
- The results were consistent with previous monitoring periods (Kerosky *et al.*, 2013; Debich *et al.*, 2015a; Debich *et al.*, 2015b; Širović *et al.*, 2016; Rice *et al.*, 2017).

### **BW43**

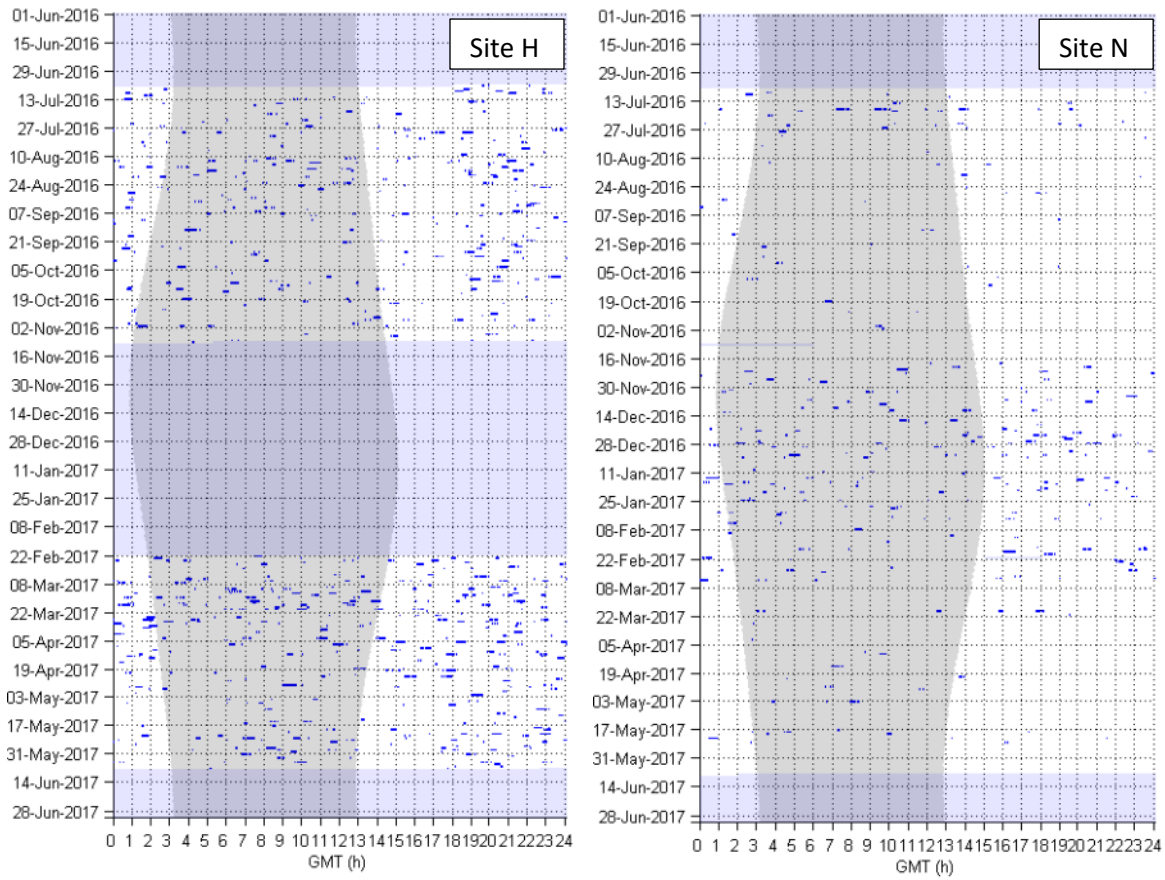
There were very few detections of BW43 FM pulses with only 10 detections on 5 days between July 2016 and June 2017.

- BW43 FM pulses were only detected at site N and all detections occurred during late fall and winter months. There were no detections at sites H or P (Figure 19).
- There was no discernable diel pattern for BW43 detections (Figure 20).
- There were no detections at site H as there were in the last two monitoring periods (Širović *et al.*, 2016; Rice *et al.*, 2017) but the overall results are consistent with previous reports (Kerosky *et al.*, 2013; Debich *et al.*, 2015a; Debich *et al.*, 2015b).

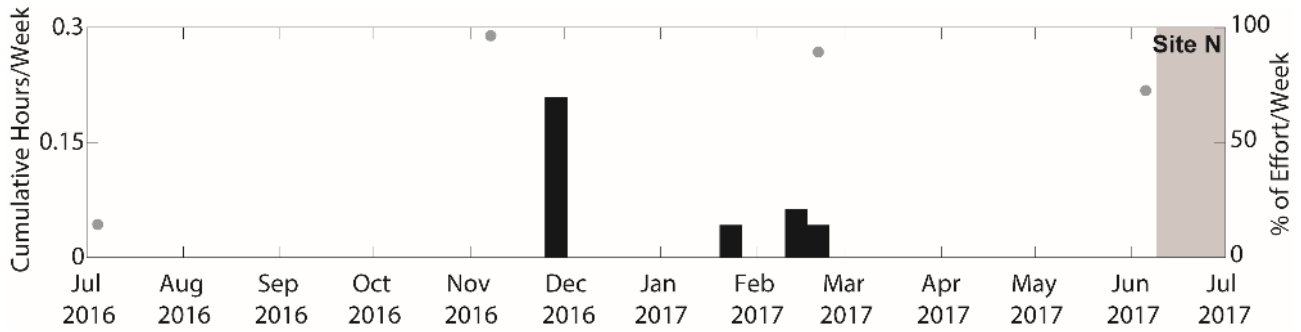


**Figure 17. Weekly presence of Cuvier's beaked whale FM pulses between July 2016 and June 2017 at sites H and N. There were no detections at site P.**

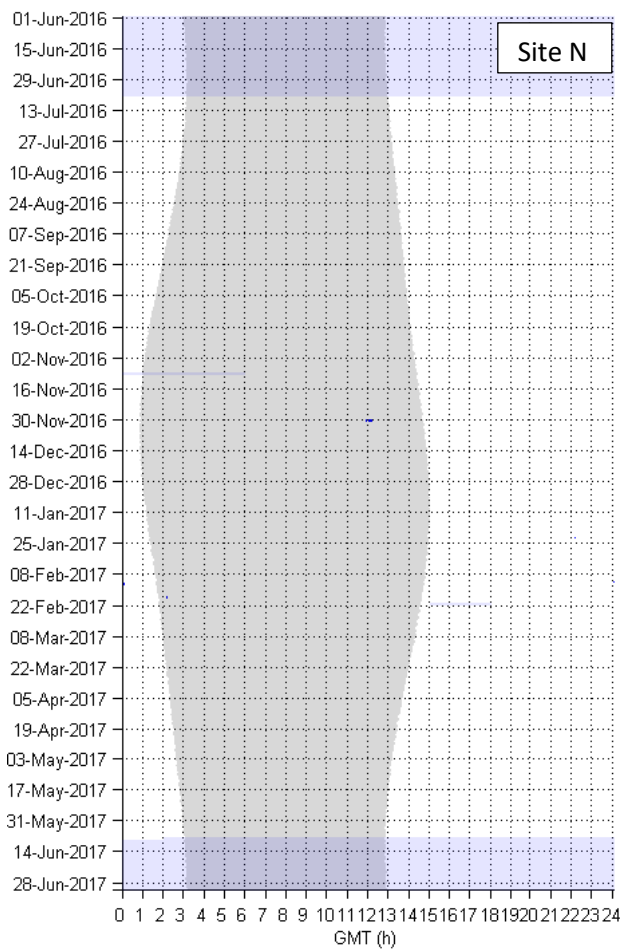
**Gray dots represent percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.**



**Figure 18. 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. Gray vertical shading denotes nighttime and light purple horizontal shading denotes absence of acoustic data.**



**Figure 19. Weekly presence of BW43 FM pulses between July 2016 and June 2017 at site N. There were no detections at sites H 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 20. BW43 FM pulses, indicated by blue dots, in one-minute bins at site N. There were no detections at sites H and P. Gray vertical shading denotes nighttime and light purple horizontal shading denotes absence of acoustic data.**

## Anthropogenic Sounds

Anthropogenic sounds from MFA sonar (2.4 – 4.5 kHz) and explosions, between April 2016 and June 2017, were analyzed for this report.

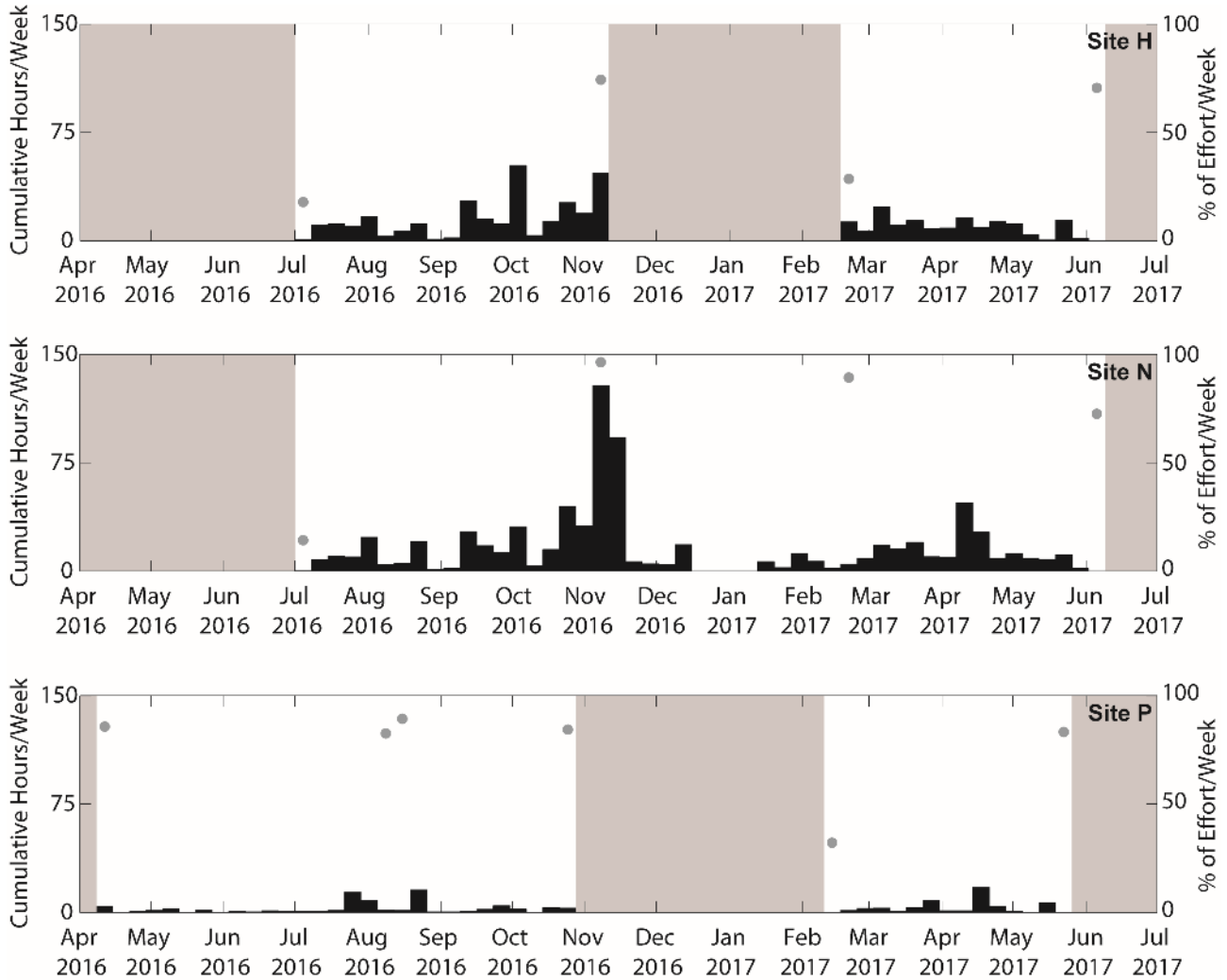
### Mid-Frequency Active Sonar

MFA sonar was a commonly detected anthropogenic sound. The dates of major naval training exercises that were conducted in the SOCAL region between April 2016 and June 2017 are listed in Table 4 (C. Johnson, personal communication). 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<sub>pp</sub> re 1  $\mu$ Pa) when normalized per year at site N, followed by site H and then site P (Table 5).

- MFA sonar was detected at all 3 sites. There was a peak in detections in September and October 2016 at site H and November at site N. Very small peaks occurred in August 2016 and April 2017 at site P, though detections at site P were much lower overall (Figure 21).
- During periods without major naval training exercises (e.g. fall 2016), bouts of MFA sonar seem to typically begin an hour or so following sunrise, but they could persist throughout the night (Figure 22).
- At site H, a total of 8,048 packets were detected, with a maximum received level of 164 dB<sub>pp</sub> re 1  $\mu$ Pa and a median received level of 139 dB<sub>pp</sub> re 1  $\mu$ Pa (Figure 23).
- At site N, a total of 16,148 packets were detected, with a maximum received level of 169 dB<sub>pp</sub> re 1  $\mu$ Pa and a median received level of 143 dB<sub>pp</sub> re 1  $\mu$ Pa (Figure 23).
- At site P, a total of 1,581 packets were detected, with a maximum received level of 155 dB<sub>pp</sub> re 1  $\mu$ Pa, and a median received level of 136 dB<sub>pp</sub> re 1  $\mu$ Pa (Figure 23).
- Most MFA sonar packets had durations up to 2 s (Figure 24).
- Maximum cumulative sound exposure levels of wave trains occurred during November 2016 at site N and were greater than 170 dB re 1  $\mu$ Pa<sup>2</sup>-s. At site H, maximum levels were around 170 dB re 1  $\mu$ Pa<sup>2</sup>-s and occurred in October 2016 and March 2017. At site P maximum levels were less than 160 dB re 1  $\mu$ Pa<sup>2</sup>-s and occurred during April 2016 (Figure 25).
- Most MFA sonar wave trains occurred at site N in November 2016 during a major training exercise (Figure 26).

**Table 4. Major naval training exercises in the SOCAL region between April 2016 and June 2017.**

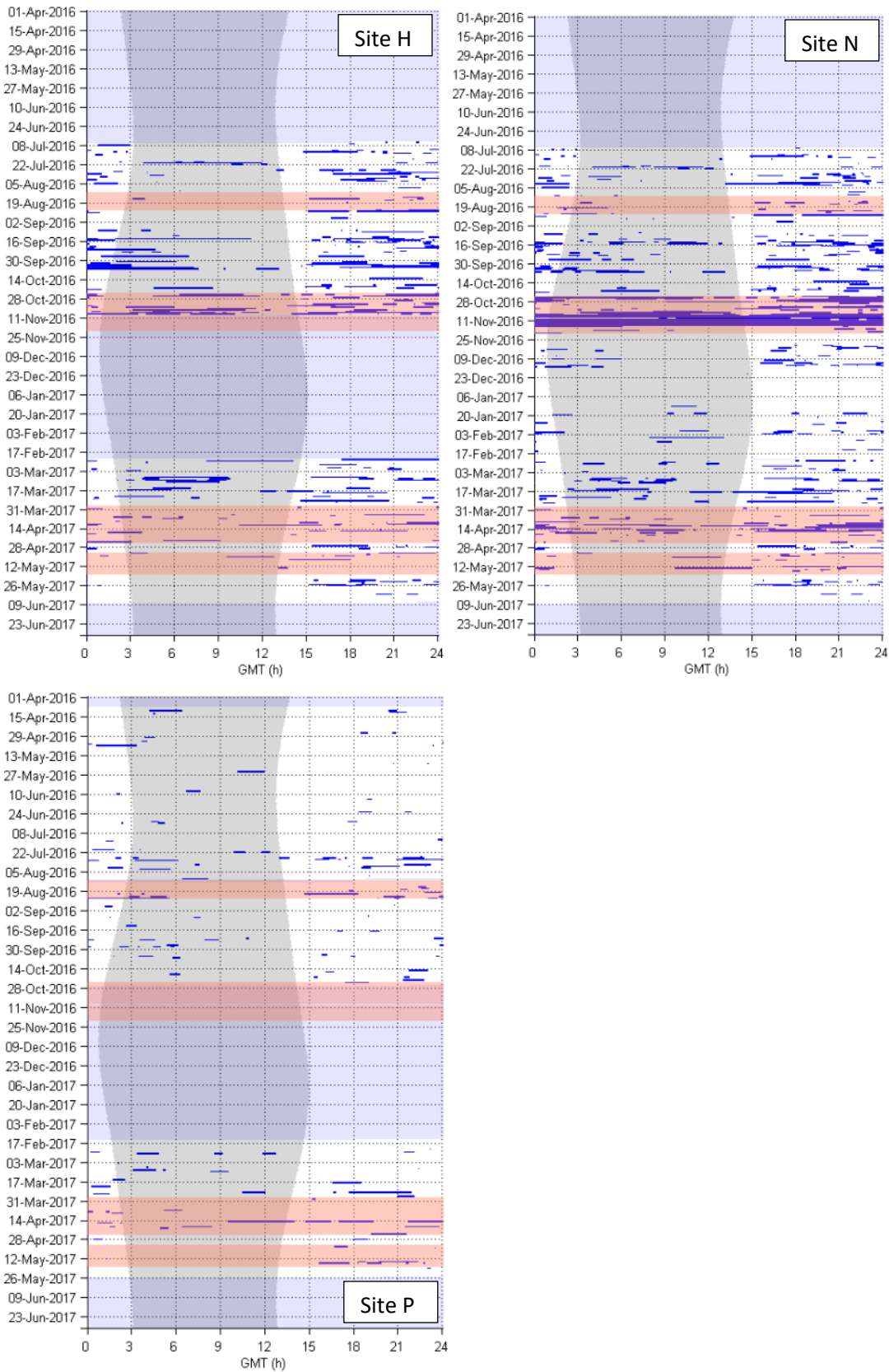
Exercise Dates	Type of Exercise
12 to 25 August 2016	C2X
24 October to 9 November 2016	C2X
10 to 21 November 2016	JTFEX
28 March to 24 April 2017	C2X
1 to 17 May 2017	C2X



**Figure 21. Weekly presence of MFA sonar <5kHz between April 2016 and June 2017 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.



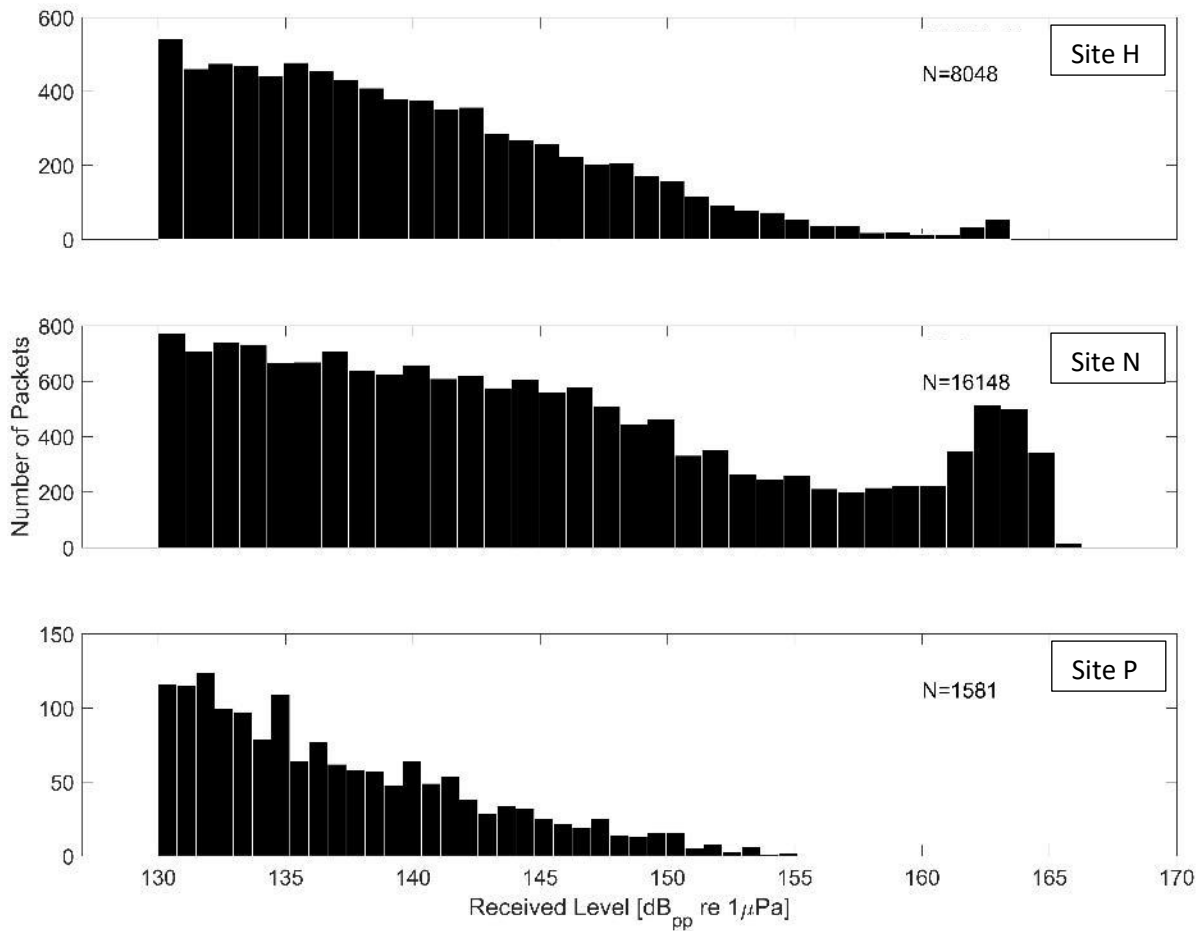


**Figure 22. Major naval training events (shaded red, from Table 4) overlaid on MFA sonar <5kHz signals, indicated by blue dots, in one-minute bins at sites H, N, and P. Gray vertical shading denotes nighttime and light purple horizontal shading denotes absence of acoustic data.**

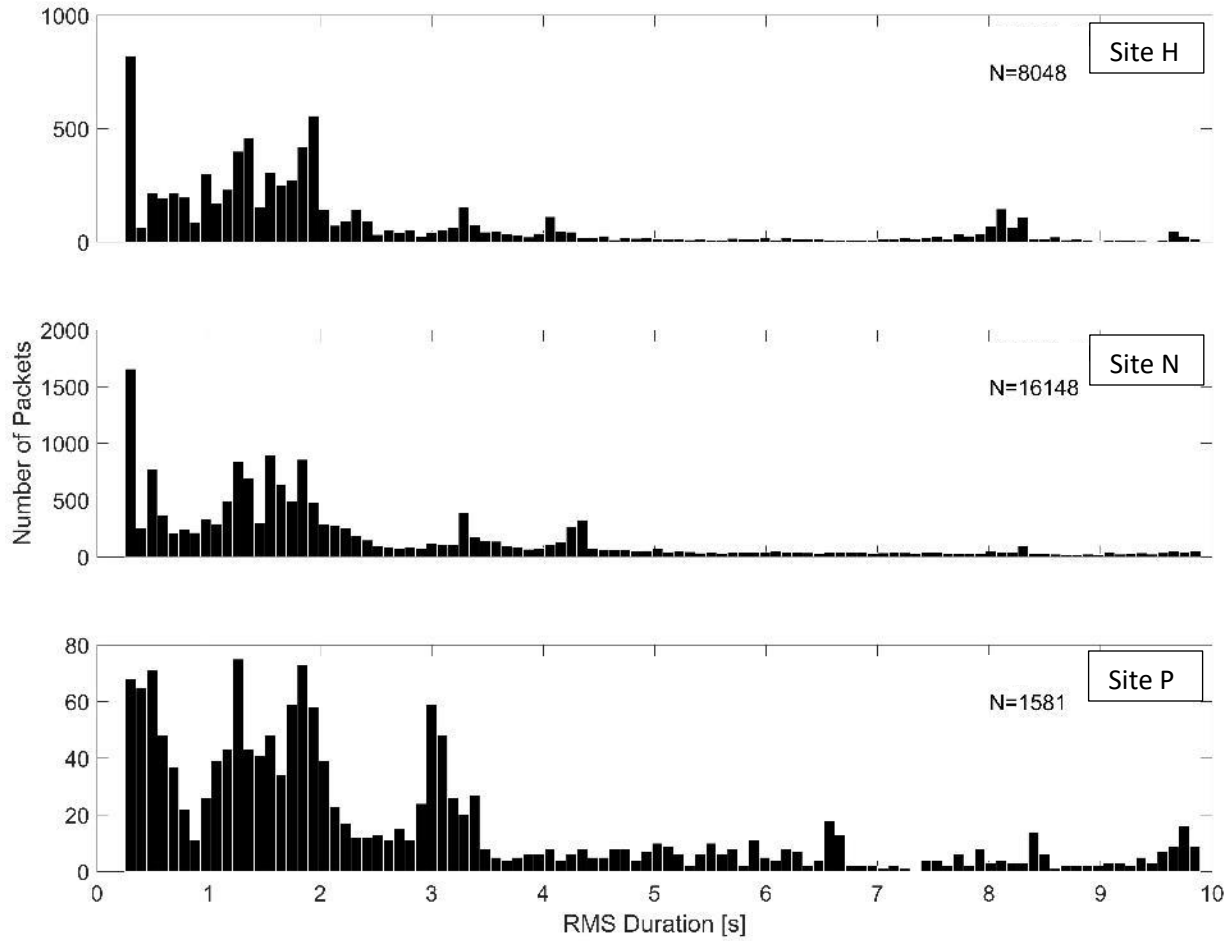
**Table 5. MFA sonar automated detector results for sites H, N, and P.**

**Total effort at each site in days (years), number of and extrapolated yearly estimates of wave trains and packets at each site (> 130 dB<sub>pp</sub> re 1 μPa).**

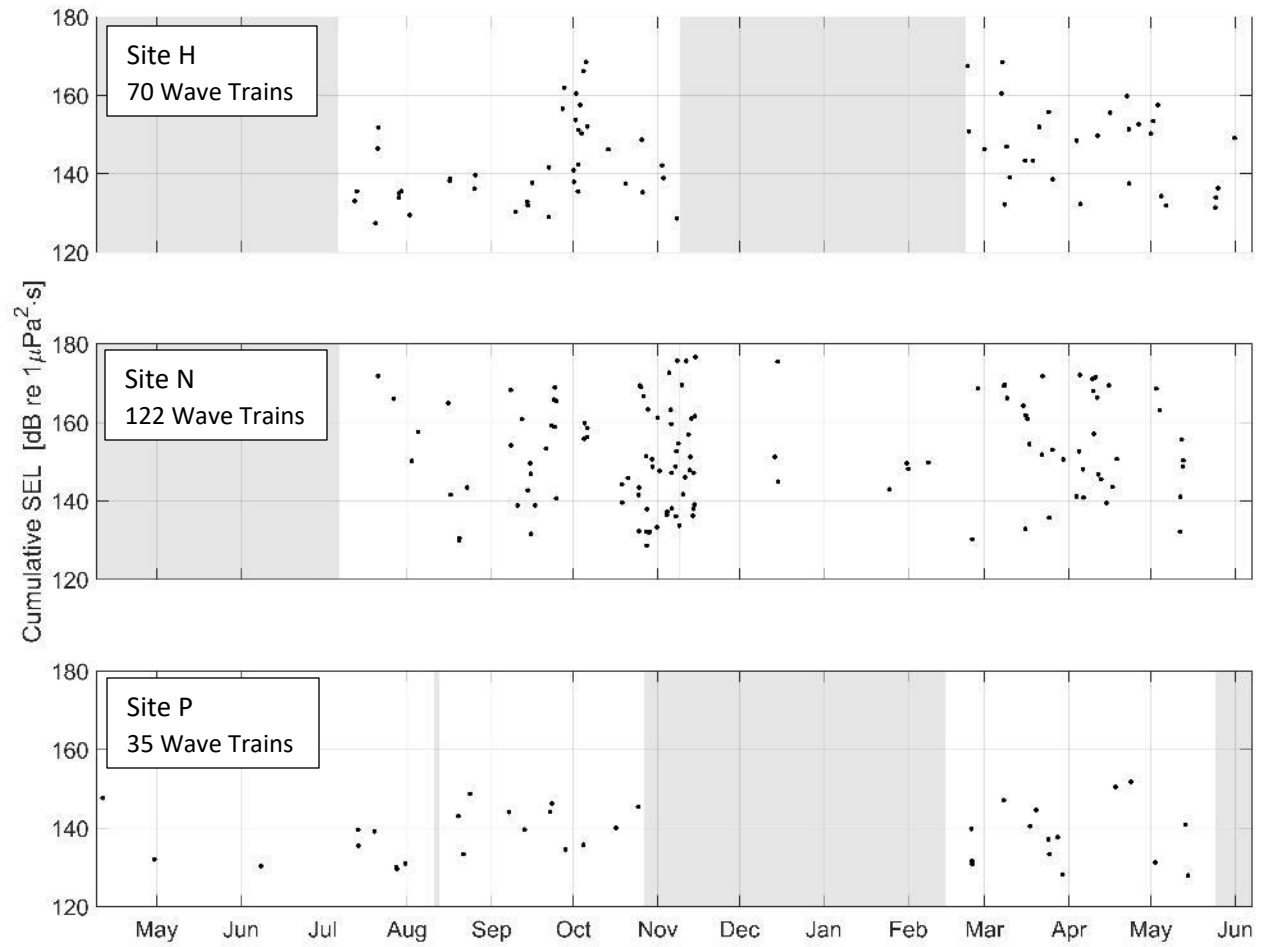
Site	Period Analyzed Days (Years)	Number of Wave Trains	Wave Trains per year	Number of Packets	Packets per year
H	230 (0.63)	70	111	8,048	12,775
N	332 (0.91)	122	134	16,148	17,745
P	296 (0.81)	35	43	1,581	1,952



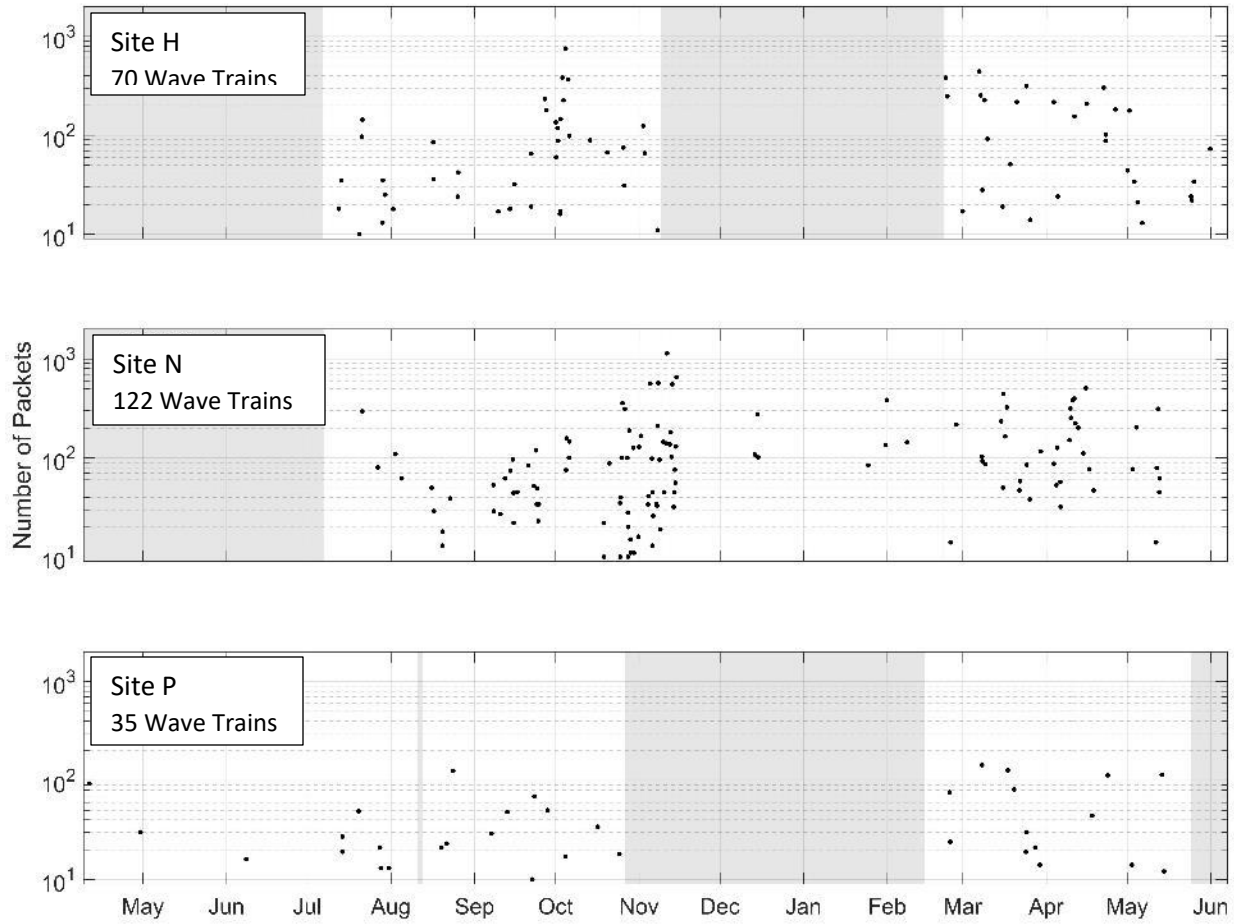
**Figure 23. MFA sonar packet peak-to-peak received level distributions for sites H, N, and P. The total number of packets detected at each site is given in the upper right corner of each panel. Instrument clipping levels are reached around 161-165 dB<sub>pp</sub> re 1 μPa, depending on hydrophone configuration. Note the vertical axes are at different scales.**



**Figure 24. 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 25. Cumulative sound exposure level for each wave train at sites H, N, and P.**



**Figure 26. Number of MFA sonar packets for each wave train at sites H, N, and P. Note the vertical axes are logarithmic base-10.**

## Explosions

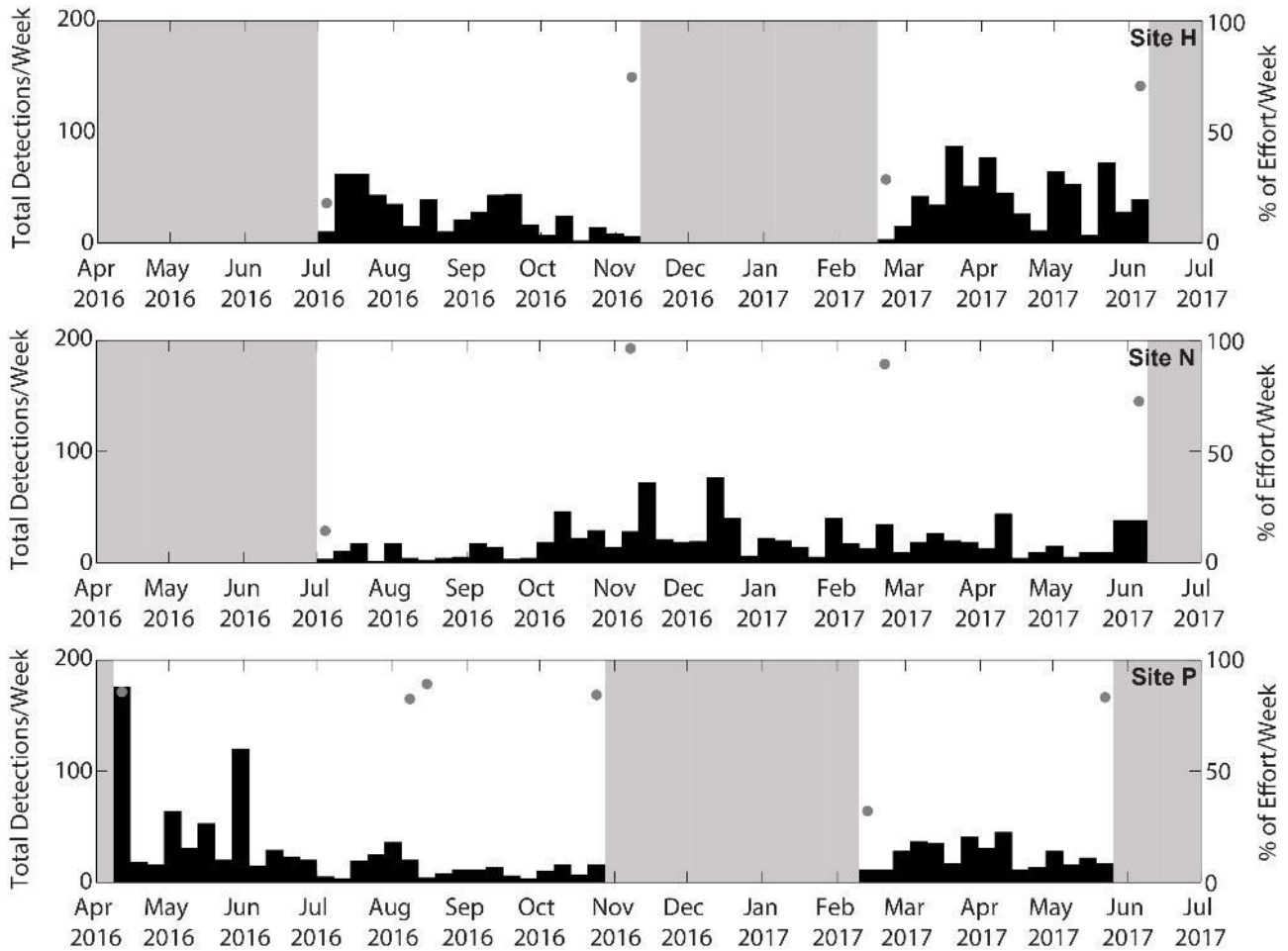
Explosions were detected at all three sites. The dates of naval training exercises that used explosions near site H from July to November 2016 and February to June 2017 are listed in Table 6 (C. Johnson, personal communication).

- Explosions occurred throughout the monitoring periods at all sites, with relatively constant numbers of explosions at sites H and N and a peak from April to June 2016 at site P (Figure 27).
- Total explosion counts at each site were as follows:
  - 1,273 at H
  - 951 at N
  - 1,163 at P
- There were more explosions at night at site H in 2016, but overall there was no clear diel pattern present at any site (Figure 28).
- As the majority of navy exercises involving explosions occurred during daylight hours, there is no clear overlap between detected explosions and navy exercises at site H (Figure 28).
- The relatively short duration of the explosion reverberations, and moderate received levels suggest these explosions may be seal bombs related to fishing activity.
- The lack of diel pattern may indicate a shift in the use of seal bombs to a fishery other than squid.
- The number of explosions at sites H are consistent with the previous report while detections at site N and P were lower (Rice *et al.*, 2017). The overall number of detections at all sites has decreased compared to earlier reports (Debich *et al.*, 2015a; Debich *et al.*, 2015b; Širović *et al.*, 2016) which could be due to a geographic shift in fishing effort.

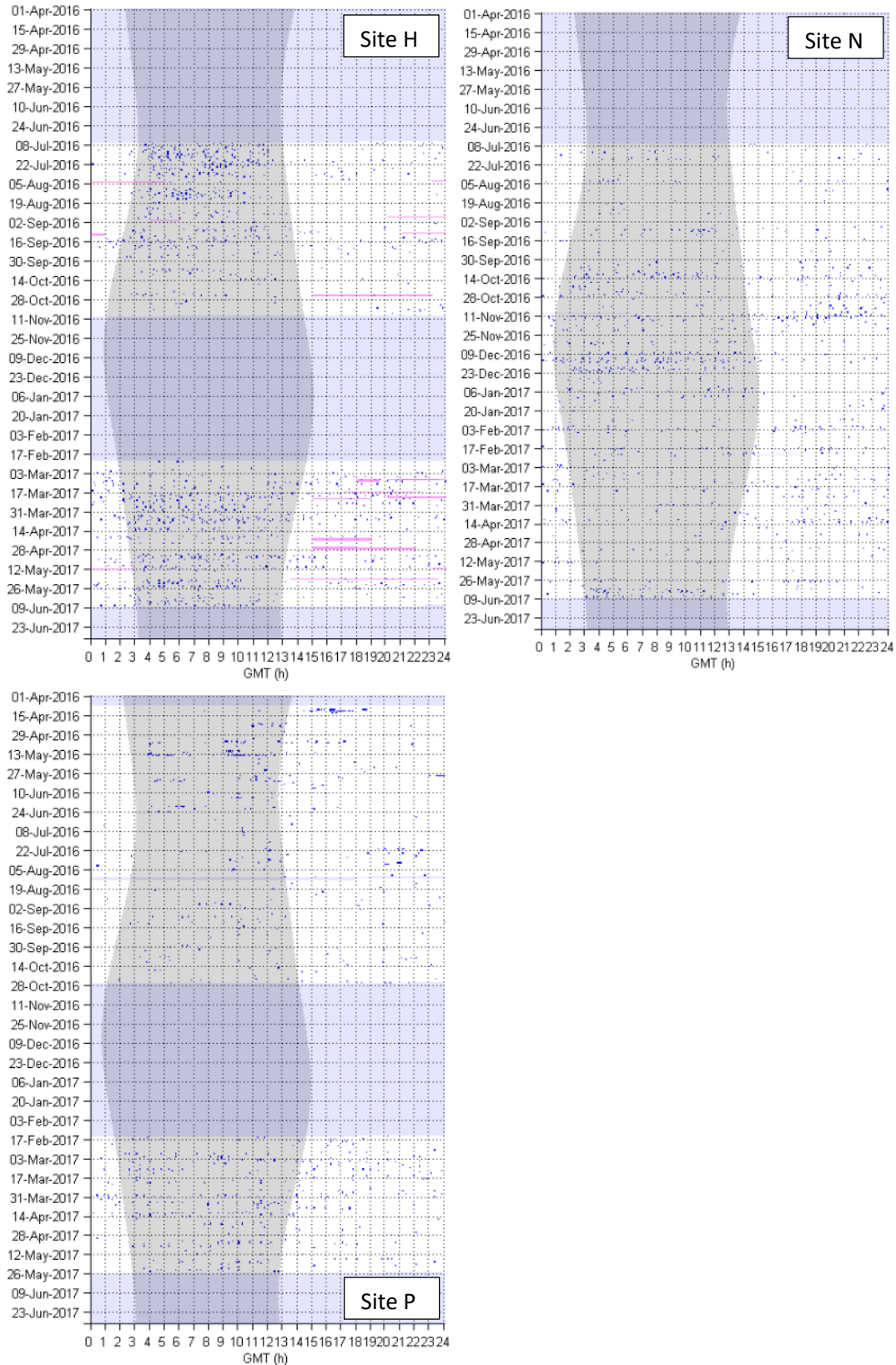
**Table 6. Naval training exercises involving explosions near site H between July to November 2016 and February to June 2017.**

<b>Exercise Start</b>	<b>Exercise End</b>
8/3/16 16:00	8/3/16 19:00
8/3/16 19:00	8/3/16 22:00
8/29/16 13:00	8/29/16 17:00
8/31/16 21:00	8/31/16 23:00
9/10/16 14:00	9/10/16 18:00
10/25/16 8:00	10/25/16 12:00
10/25/16 12:00	10/25/16 16:00
3/7/17 10:00	3/7/17 11:30
3/7/17 12:00	3/7/17 16:00
3/7/17 13:00	3/7/17 15:30
3/8/17 10:00	3/8/17 11:30
3/16/17 10:00	3/16/17 15:00
3/20/17 13:00	3/20/17 17:00
3/21/17 8:00	3/21/17 12:00
4/19/17 8:00	4/19/17 12:00
4/20/17 8:00	4/20/17 12:00
4/25/17 8:00	4/25/17 11:00
4/26/17 8:00	4/26/17 11:00
4/26/17 11:00	4/26/17 15:00
5/10/17 16:00	5/10/17 20:00
5/18/17 6:30	5/18/17 11:30
5/18/17 11:30	5/18/17 16:30





**Figure 27. Weekly presence of explosions between April 2016 and June 2017 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.**

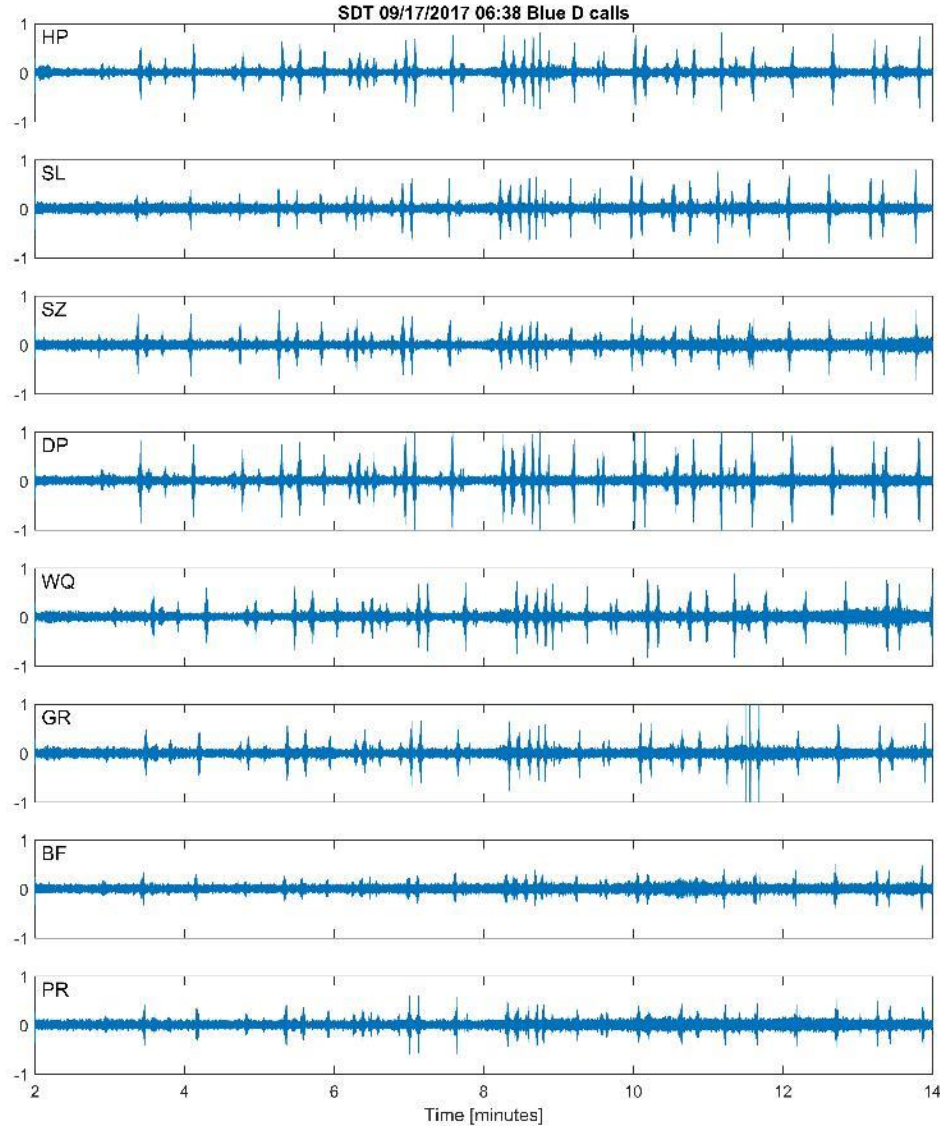


**Figure 28. Explosion detections, indicated by blue dots, in five-minute bins at sites H, N, and P. Red shading at site H indicates dates of naval training exercises that used explosions (Table 6, times converted to GMT).**

**Gray vertical shading denotes nighttime and light purple horizontal shading denotes absence of acoustic data**

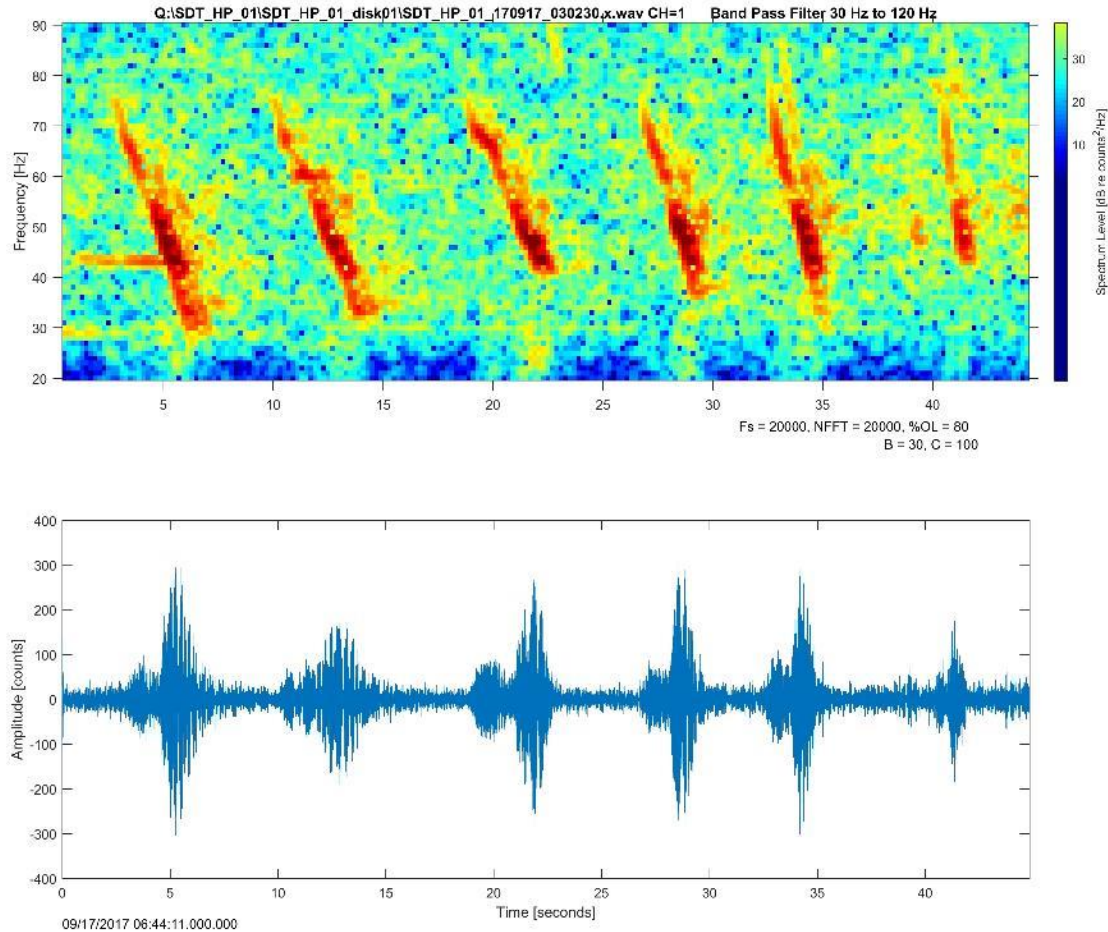
## San Diego Trough Array

A selection of time series data from 8 of the SDT array instruments is presented in Figure 29. These data reveal pulsed signals from blue whale D calls that are well detected on all instruments and have noticeable differences in arrival time at different instruments. A more detailed spectrogram and time series of 6 of these D calls are shown in Figure 30. These data suggest that the SDT array is well configured to allow localization of baleen whale calls.



**Figure 29. Time series showing a 12 minutes sequence of blue whale D calls from eight of the 20 kHz HARPs in the San Diego Trough.**

**Preliminary localization analysis from this call sequence puts the calls to the south east of site SL, near the Coronado Bank.**



**Figure 30. Spectrogram (top) and time series (bottom) showing 6 blue whale D calls in 45 s of data from site HP.**

## Conclusion

The results from this report are generally consistent with previous reports on the SOCAL region. The main differences are the lack of BW43 signals at site H and the lower number of explosions detected at all sites. However, there are typically very few BW43 signals detected overall and the decrease in explosions could signal a geographic shift in fishing effort. Monitoring will continue at these three sites in the SOCAL range in an effort to document the seasonal presence of this subset of marine mammal species and to record anthropogenic activity as well as the low-frequency ambient soundscape. Additionally, as analysis of the 9 SDT sites progresses we will be able to provide details about the localization of baleen whale calls.

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