Passive Acoustic Monitoring for Marine Mammals in the SOCAL Range Complex July 2018 – May 2019

Ally C. Rice, Macey Rafter, Jennifer S. Trickey, Sean M. Wiggins, Simone Baumann-Pickering, John A. Hildebrand

Marine Physical Laboratory
Scripps Institution of Oceanography
University of California San Diego
La Jolla, CA 92037

Cuvier's beaked whale, Photo by Jennifer Trickey

MPL TECHNICAL MEMORANDUM #643
January 2020

Suggested Citation:

Rice, A.C., Rafter, M., Trickey, J.S., Wiggins, S.M., Baumann-Pickering, S., and Hildebrand, J.A. (2019) “Passive Acoustic Monitoring for Marine Mammals in the SOCAL Range Complex July 2018 – May 2019,” Marine Physical Laboratory, Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, MPL Technical Memorandum #643 under Cooperative Ecosystems Study Unit Cooperative Agreement N62473-18-2-0016 for U.S. Navy, U.S. Pacific Fleet, Pearl Harbor, HI.

Author contributions:

A.C.R. complied, wrote, and edited report, conducted ambient soundscape analysis, as well as all low-frequency marine mammal analysis, and produced all plots. M.A.R. conducted explosion analysis. J.S.T. conducted beaked whale and MFA sonar analysis. S.M.W. contributed to algorithm development. S.B. and J.A.H. developed and managed the project.

Table of Contents

List of Tables

List of Figures

Executive Summary

Passive acoustic monitoring was conducted in the Navy's Southern California Range Complex from July 2018 to May 2019 to detect marine mammal and anthropogenic sounds. High-frequency Acoustic Recording Packages (HARPs) recorded sounds between 10 Hz and 100 kHz at three locations: two west of San Clemente Island (1,300 m depth, site E and 1,000 m depth, site H) and one southwest of San Clemente Island (1,250 m depth, site N).

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 and fin whales, listed as "Endangered," and beaked whales were analyzed for this report. The low-frequency ambient soundscape and the presence of Mid-Frequency Active (MFA) sonar and explosions are also reported.

Ambient sound levels were highest for frequencies greater than ~200 Hz at site E and lowest at site H, likely related to local wind. Peaks in sound levels at sites E, H, and N during the fall and winter are related to the seasonally increased presence of blue whales and fin whales, respectively.

For marine mammal and anthropogenic sounds, 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: blue whale B and D calls occurred in high numbers at all sites and the fin whale acoustic index, representative of 20 Hz calls, was high at sites E and H. Blue whale B call detections peaked in September 2018 and again in October and November 2018 at all sites. Very few blue whale B calls were detected after January 2019. Blue whale D calls peaked in August 2018 at site E and in July 2018 at sites H and N. The fin whale acoustic index was highest from October 2018 to February 2019.

Frequency modulated (FM) echolocation pulses from Cuvier's beaked whales were regularly detected at all sites, but were detected in much higher numbers at sites E and H. At both site E and H, detections were lowest in late summer/early fall 2018. At site E, detections were highest in late fall 2018, while at site H they peaked in spring 2019. A new beaked whale FM pulse type, BW35, thought to be produced by Hubbs' beaked whale (Griffiths *et al.*, 2018), was detected only in January 2019, on multiple occasions at site E and on only one day at site H. The FM pulse type, BW43, thought to be produced by Perrin's beaked whale (Baumann-Pickering *et al.*, 2014), was detected only in July 2018 at site E and intermittently throughout the recording period at site N. No other beaked whale signal types were detected.

Two anthropogenic pulsed signals were detected: MFA sonar and explosions. MFA sonar was detected at all sites with a peak in August and September 2018. Site N had the most MFA sonar packet detections normalized per year and the highest cumulative sound exposure levels, including events concurrent with a major naval exercise during August 2018. Site E had the lowest number of sonar packet detections, as well as the lowest cumulative sound exposure level.

Explosions were detected at all sites, but were highest in August 2018 and January 2019 at site H. Temporal and spectral parameters suggest primarily association with fishing, specifically with 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 whales, fin whales, and 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 July 2018 and May 2019 (Table 2; Table 2; Table 3). The three recording sites include two to the west (sites E and H) and one to the south (site N) of San Clemente Island (Figure 1; Figure 2). Recordings from site N were not analyzed for about 15 h from January 23 to 24, 2019 due to a hydrophone malfunction.

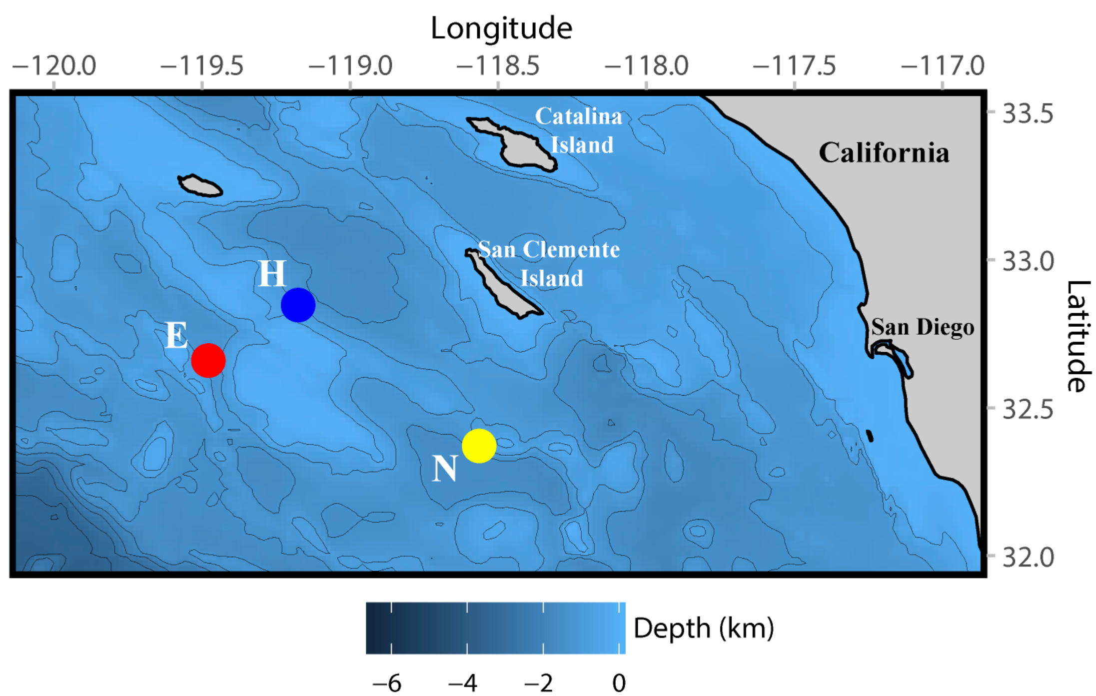

Figure 1. Locations of High-frequency Acoustic Recording Package (HARP) deployment sites E, H, and N (circles) in the SOCAL study area from July 2018 through May 2019.
Color indicates bathymetric depth. Contour lines represent 500 m depth increments.

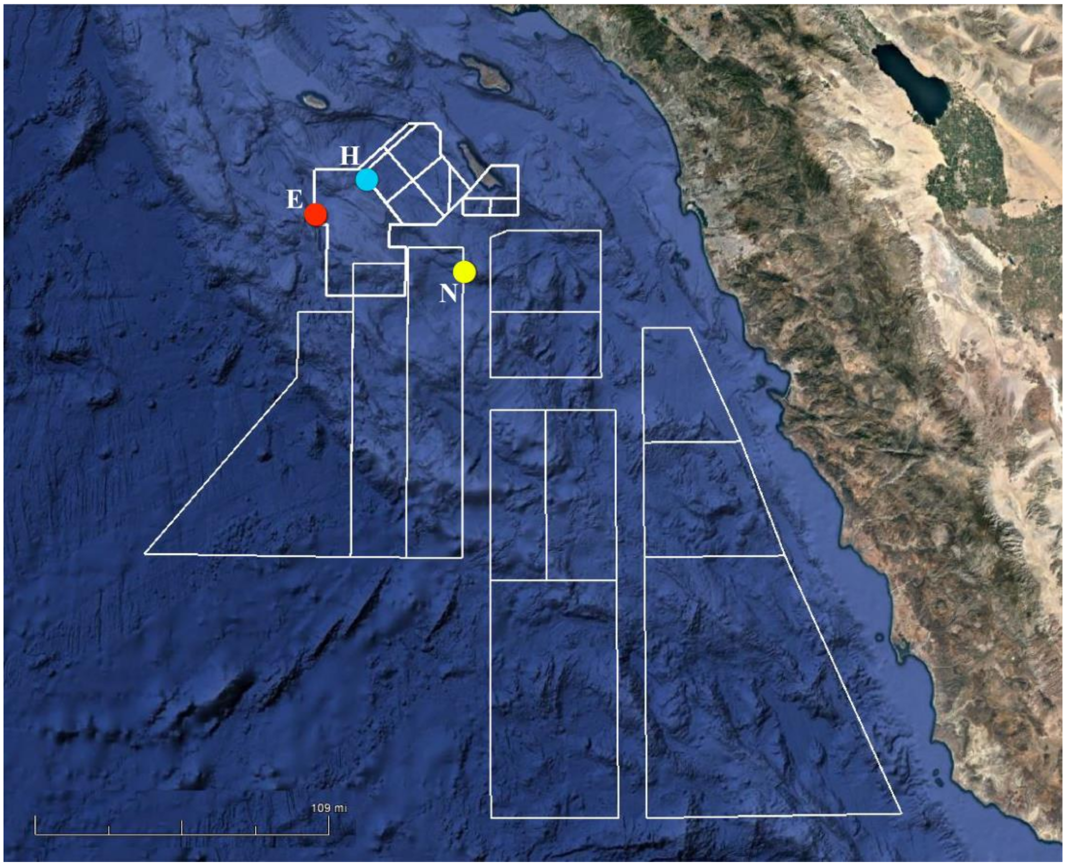

Figure 2. Locations of High-frequency Acoustic Recording Package (HARP) deployments in the SOCAL study area (colored circles) and US Naval Operation Areas (white boxes).

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

Deployment #	Monitoring Period	# Hours
31	1/13/09 – 3/09/09	1302
32	3/13/09 – 5/07/09	1302
33	5/19/09 – 7/12/09	1302
34	7/24/09 – 9/16/09	1302
61	3/5/17 – 7/10/17	3063
62	7/11/17 – 2/10/18	5148
63	3/15/18 – 7/11/18	2843
64	**7/12/18 – 11/28/18**	**3356**
65	**11/29/18 – 5/7/19**	**3838**

Table 2. SOCAL Range Complex acoustic monitoring at site H since January 2009. Periods of instrument deployment analyzed in this report are shown in bold.

Deployment #	Monitoring Period	# Hours
31	1/13/09 – 3/08/09	1320
32	3/14/09 – 5/07/09	1320
33	5/19/09 – 6/13/09	600
34	7/23/09 – 9/15/09	1296
35	9/25/09 – 11/18/09	1320
36	12/6/09 – 1/29/10	1296
37	1/30/10 – 3/22/10	1248
38	4/10/10 – 7/22/10	2472
40	7/23/10 – 11/8/10	2592
41	12/6/10 – 4/17/11	3192
44	5/11/11 – 10/12/11	2952
45	10/16/11 – 3/5/12	3024
46	3/25/12 – 7/21/12	2856
47	8/10/12 – 12/20/12	3192
48	12/21/12 – 4/30/13	3140
49	-	-
50	9/10/13 – 1/6/14	2843
51	1/7/14 – 4/3/14	2082
52	4/4/14 – 7/30/14	2814
53	7/30/14 – 11/5/14	2340
54	11/5/14 – 2/4/15	2198
55	2/5/15 – 6/1/15	2800
56	6/2/15 – 10/3/15	2952
57	-	-
58	11/21/15 – 4/25/16	3734
59	7/6/16 – 11/9/16	3011
60	-	-
61	2/22/17 – 6/6/17	2518
62	6/7/17 – 10/4/17	2879
63	10/5/17 – 11/3/17	707
65	**7/9/18 – 11/28/18**	**3413**
66	**11/29/18 – 5/5/19**	**3784**

Table 3. SOCAL Range Complex acoustic monitoring at site N 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 #	Monitoring Period	# Hours
31	1/14/09 – 3/09/09	1296
32	3/14/09 – 5/07/09	1320
33	5/19/09 – 7/12/09	1296
34	7/22/09 – 9/15/09	1320
35	9/26/09 – 11/19/09	1296
36	12/6/09 – 1/26/10	1224
37	1/31/10 – 3/26/10	1296
38	4/11/10 – 7/18/10	2352
40	7/23/10 – 11/8/10	2592
41	12/7/10 – 4/09/11	2952
44	5/12/10 – 9/23/11	3216
45	10/16/11 – 2/13/12	2904
46	3/25/12 – 8/5/12	3216
47	8/10/12 – 12/6/12	2856
48	12/20/12 – 5/1/13	3155
49	5/2/13 – 9/11/13	3156
50	-	-
51	1/7/14 – 2/16/14	956
52	4/4/14 – 7/30/14	2817
53	7/30/14 – 11/5/14	2342
54	11/4/14 -2/5/15	2196
55	2/5/15 – 2/23/15	433
56	6/2/15 – 10/3/15	2966
57	10/3/15 – 11/21/15	1168
58	*11/21/15 – 4/18/16*	*3578*
59	7/7/16 – 11/8/16	2999
60	11/9/16 – 2/21/17	2457
61	2/21/17 – 6/7/17	2528
62	6/7/17 – 12/21/17	4723
63	2/4/18 – 7/9/18	3722
64	**7/9/18 – 11/28/18**	**3417**
65	**11/29/18 – 5/5/19**	**3768**

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 up to approximately one year 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 2; Table 2; Table 3) using HARPs sampling at 200 kHz. The sites analyzed in this report are designated site E (32° 39.54' N, 119° 28.71' W, depth 1,300 m), site H (32° 50.76'N, 119° 10.57' W, depth 1,000 m), and site N (32° 22.21' N, 118° 33.85' W, depth 1,250 m).

Site E recorded from July 12, 2018 to May 7, 2019, site H recorded from July 9, 2018 to May 5, 2019, and site N recorded from July 9, 2018 to May 5, 2019; although, site N had a gap of about 15 h from January 23 to 24, 2019 due to a low-frequency channel hydrophone malfunction (analysis was still performed on this deployment as the hydrophone malfunction did not significantly impact overall data quality). For all three sites, a total of 21,576 h, covering 899 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 quantification of the low-frequency ambient soundscape, detection of baleen whales (mysticetes), toothed whales (odontocetes), and anthropogenic sounds. When possible, 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, the data were screened for signals from Blainville's (*Mesoplodon densirostris*) and Stejneger's (*M. stejnegeri*) beaked whales, as well as for FM pulse types known as BW43 and BW70, which may belong to Perrin's (*M. perrini*) and pygmy beaked whales (*M.peruvianus*), respectively (Baumann-Pickering *et al.*, 2014). A recently identified beaked whale signal type (Griffiths *et al.*, 2018), possibly belonging to Hubbs' beaked whale (*M. carlhubbsi*), was found at some sites during this reporting period and is referred to as BW35. A description of this signal type can be found below. Individual blue whale B calls, D calls, and beaked whale echolocation clicks, as well as MFA sonar and explosion occurrence and levels were detected automatically using computer algorithms. MFA sonar was logged manually for deployment 65 at site N, as the hydrophone malfunction interfered with running the MFA detector. 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 and manual detection methods are described below.

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 five, 5 s sound pressure spectrum levels calculated from the middle of each 75 s acoustic record (in order to avoid including a disk write). System self-noise (hard drive disk writes) 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 3) and D call (Figure 4). 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 3) 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 are measured for summer and fall periods. For this recording period only a fall kernel was needed. The fall 2018 kernel was defined as sweeping from 45 to 44.5 Hz; 44.5 to 44 Hz, 44 to 43.5 Hz, and 43.5 to 42.7 Hz during these predefined periods. The kernel bandwidth was 2 Hz. The total number of detections are reported for this call type.

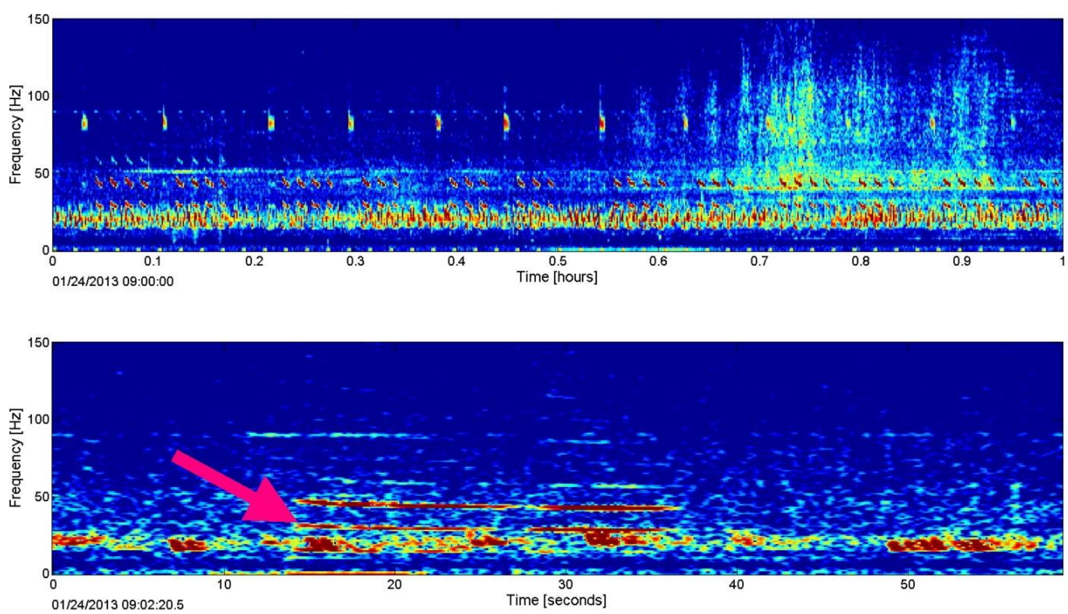

Figure 3. Blue whale B calls (just below 50 Hz) in Long-Term Spectral Average (LTSA; top) and an individual call shown in a spectrogram (bottom) recorded at site N.

Blue whale D calls

Blue whale D calls (Figure 4) were detected using an automatic algorithm based on a 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 4).

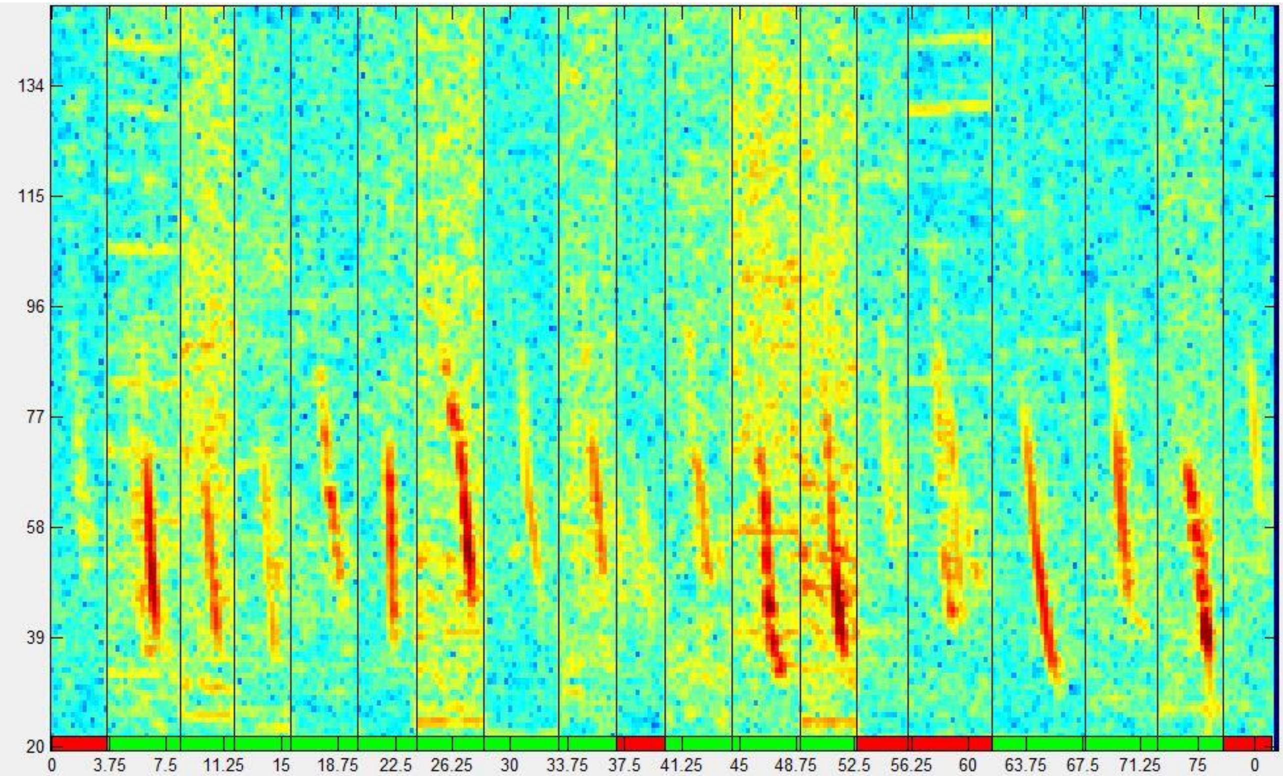

Figure 4. Blue whale D calls from site H in the analyst verification stage of the detector. Green along the bottom evaluation line indicates true detections and red indicates false detections.

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). 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 5) 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.

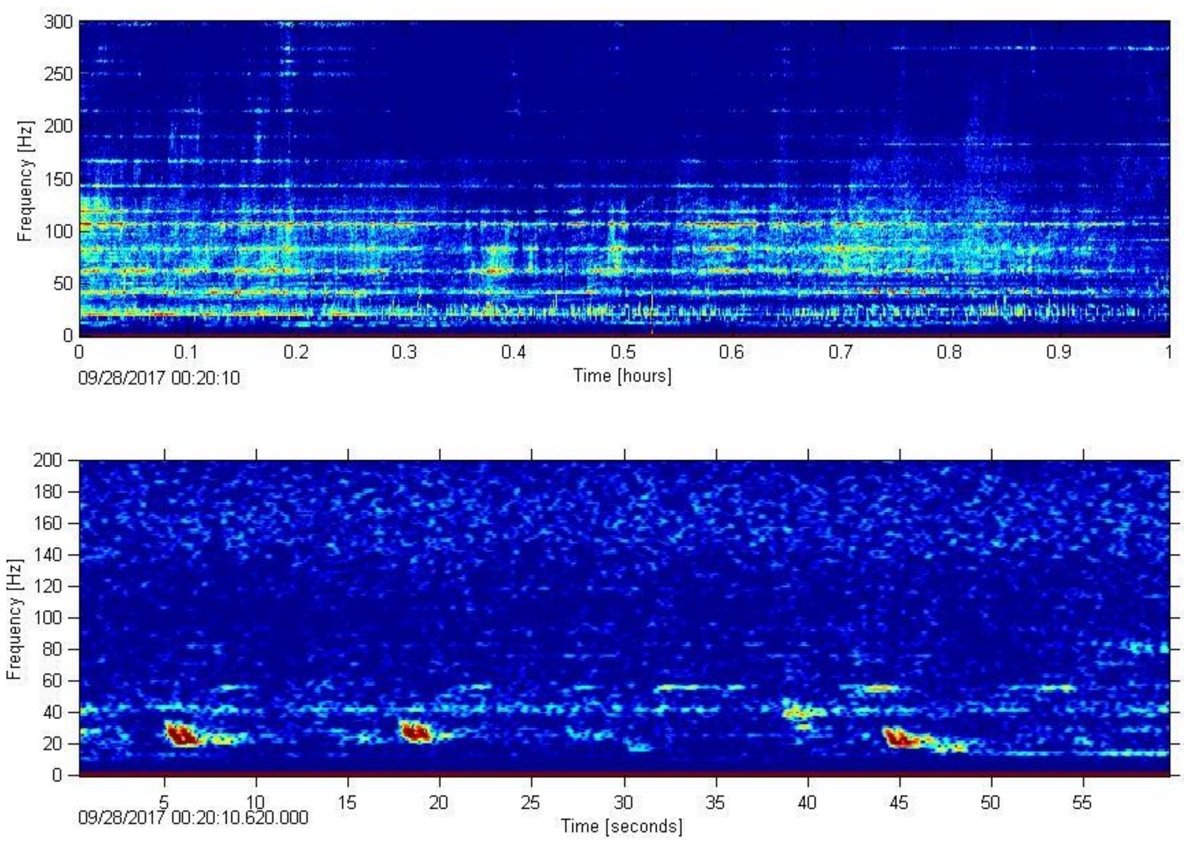

Figure 5. Fin whale 20 Hz calls in an LTSA (top) and spectrogram (bottom) recorded at site H.

Beaked Whales

Beaked whales potentially 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 BW43 and BW70, which may belong to Perrin's and pygmy beaked whales, respectively (Baumann-Pickering *et al.*, 2013a; Baumann-Pickering *et al.*, 2014). A new signal type, BW35, possibly belonging to Hubbs' beaked whales (Griffiths *et al.*, 2018), was also searched for. Only Cuvier's, BW35, and BW43 signals were detected during this recording period. These 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 for those produced by Baird's beaked whales because they produce a signal with a lower frequency content than is typical of other beaked whales and therefore are 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.

A decision about presence or absence of beaked whale signals was based on detections within a 75 s 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.*, 2013a). The rate of missed segments for this approach is typically 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 (Figure 6) 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). An additional feature that helps with the identification of Cuvier's beaked whale FM pulses is that they have characteristic spectral peaks around 17 and 23 kHz.

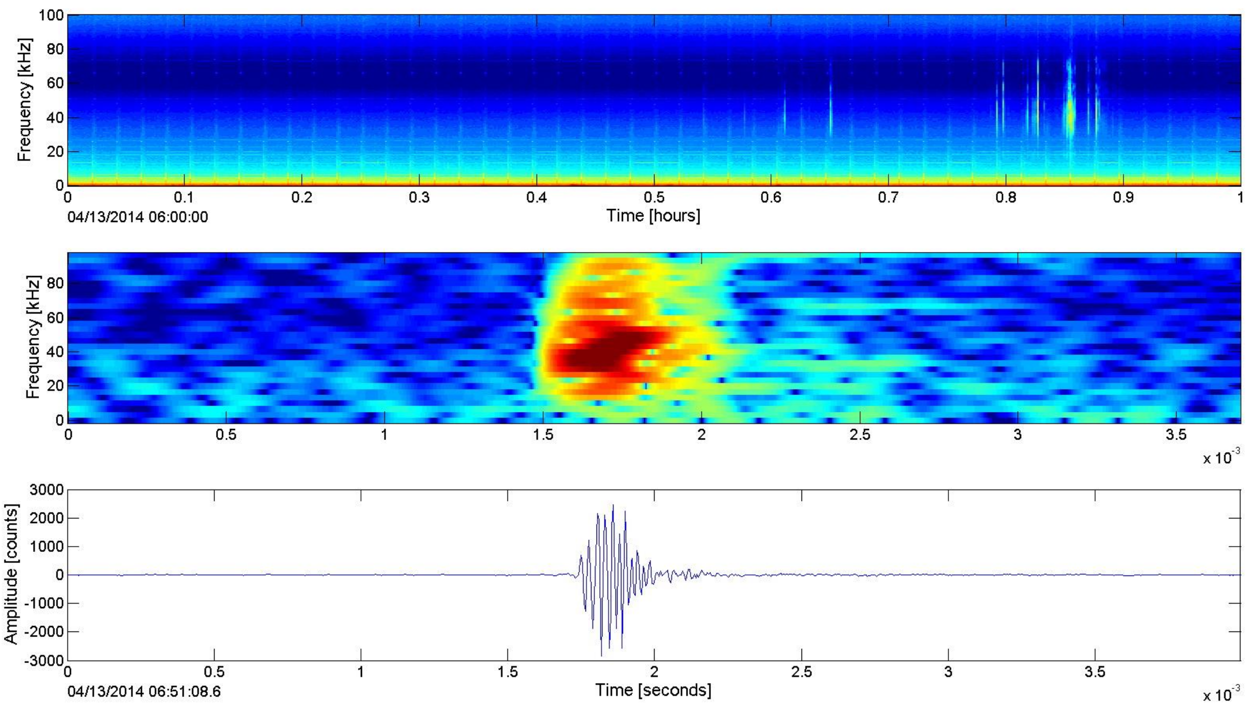

Figure 6. Echolocation sequence of Cuvier's beaked whale in an LTSA (top) and example FM pulse in a spectrogram (middle) and corresponding time series (bottom) recorded at site N.

BW35

The BW35 FM pulse type (Figure 7) has yet to be positively linked to a specific species. These FM pulses are distinct from other beaked whale species' signals in their bimodal frequency distribution, which shows a prominent spectral peak around 35 kHz, a spectral notch at 37 kHz, and an upper peak at 48 kHz (Griffiths *et al.*, 2018). This signal type has a stable inter-pulse interval of approximately 0.13 s. A candidate species for producing this FM pulse type may be Hubbs' beaked whale (Griffiths *et al.*, 2018).

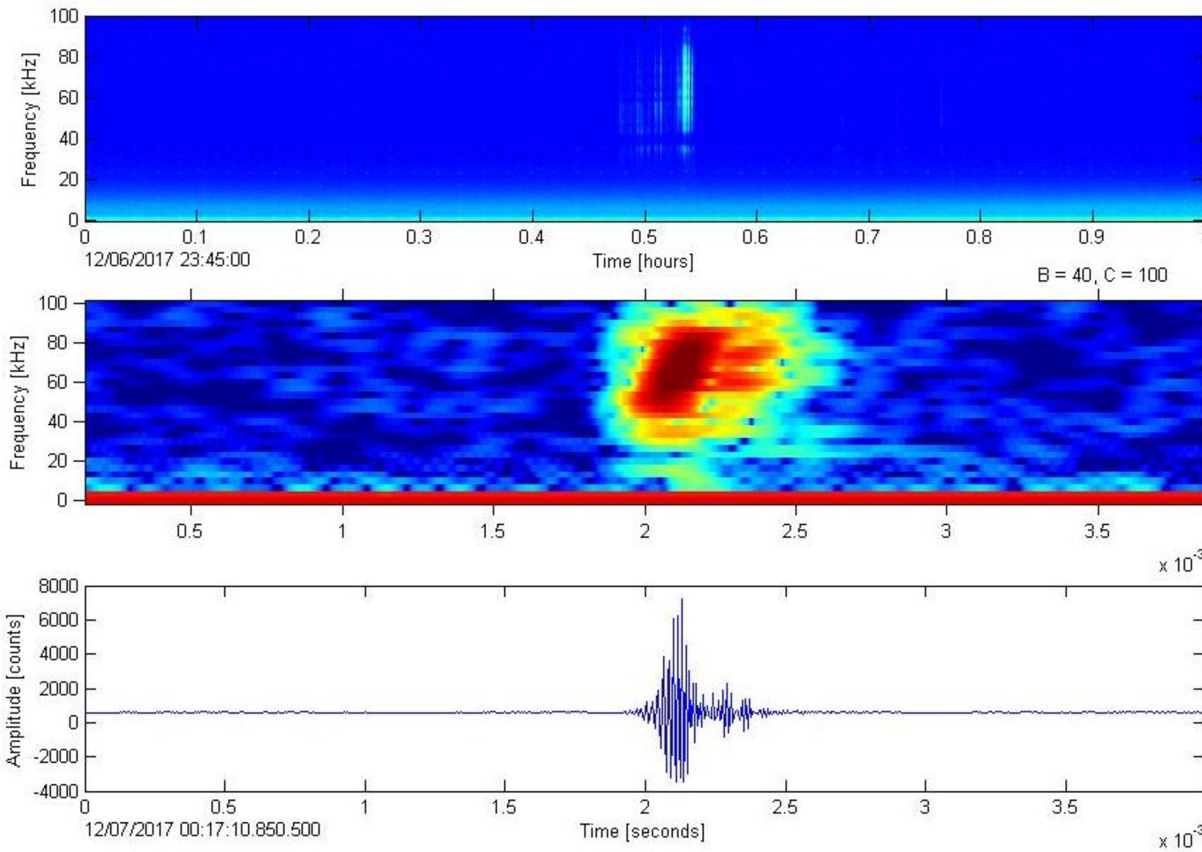

Figure 7. Echolocation sequence of BW35 in an LTSA (top) and example FM pulse in a spectrogram (middle) and corresponding time series (bottom) recorded at site E.

BW43

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

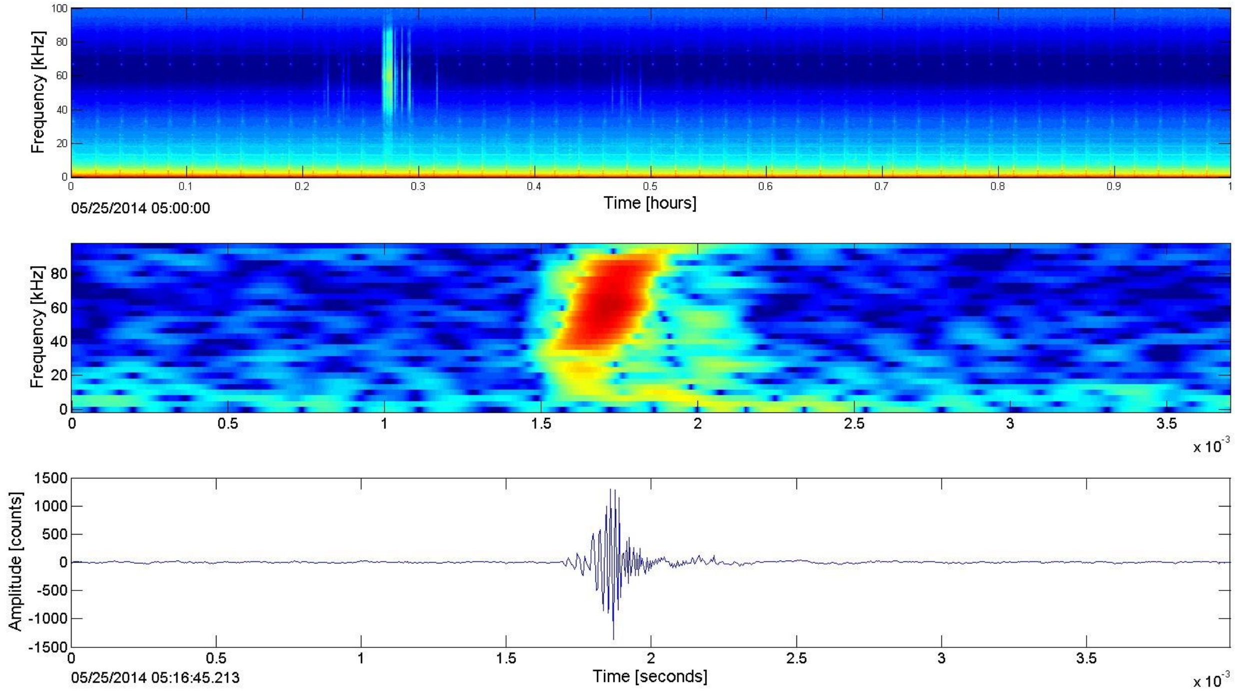

Figure 8. Echolocation sequence of BW43 in an LTSA (top) and example FM pulse in a spectrogram (middle) and corresponding time series (bottom) recorded at site N.

Anthropogenic Sounds

Two anthropogenic sounds were monitored for this report: Mid-Frequency Active (MFA) sonar and explosions. Both sounds were detected by computer algorithms, except for MFA sonar detections from deployment 65 at site N, which were analyzed manually for the first stage of analysis. For MFA sonar, the start and end of each sound or session was logged and their durations were added to estimate cumulative weekly presence. For explosions, individual explosions were detected and so weekly totals are reported.

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 that have durations ranging from less than 1 s to greater than 5 s. Groups of pulses, or pings, constitute a packet while a wave train, or an event, is a group of packets that are separated from other MFA sonar packets by at least 1 h. Packets 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.

In the first stage of MFA sonar detection, we used 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 sonar 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 that remained once disk write periods were removed 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 times of these cleaned sonar events were then created to be used in further processing.

For deployment 65 at site N it was not possible to use the MFA sonar detector due to gaps resulting from a hydrophone malfunction. Therefore, MFA sonar was logged manually for this deployment. Data were decimated by a factor of 20 for an effective bandwidth of 5 kHz. Long-term spectral averages (LTSAs) were created using a time average of 5 s and a frequency bin size of 10 Hz. During manual scrutiny of the data, using the custom MATLAB software program *Triton*, the LTSA was set to display between 1,000 and 5,000 Hz with a 0.75 h plot length. The presence of MFA sonar was logged using encounter granularity, where start and end time of an MFA event are logged and events are separated by at least 30 min where no MFA is present.

In the second stage of MFA sonar detection, these start and end times of MFA events from both methods were then 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 µPa (Wiggins, 2015). Instrument maximum received level was ~167 dB pp re 1 µPa, above which waveform clipping occurred. Packets were grouped into wave trains separated by more than 1 h. Packet received levels were plotted along with the number of packets and cumulative SEL (CSEL) in each wave train over the study period. Wave train duration and total packet duration were also calculated. Wave train duration is the difference between the first and last packet detections in an event. The total packet duration of a wave train is the sum of the individual packet (i.e., group of pings) durations, which is measured as the period of the waveform that is 0 to 10 dB less than the maximum peak-to-peak received level of the ping group.

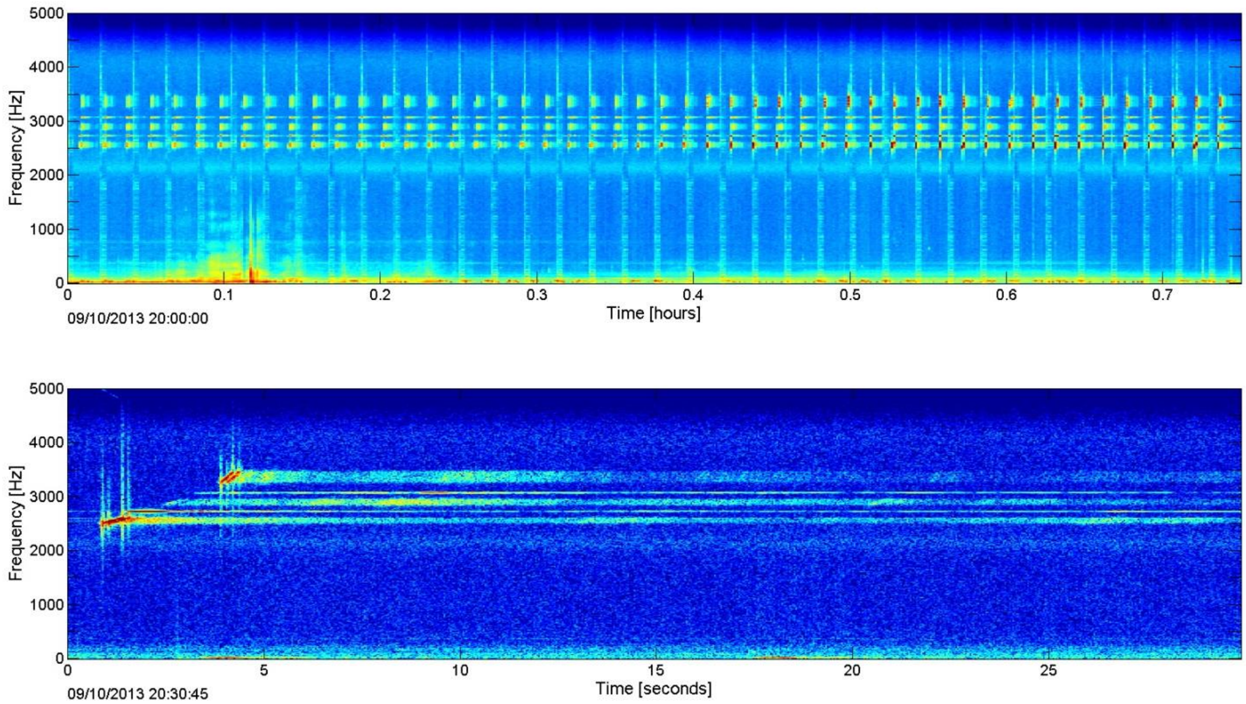

Figure 9. MFA sonar recorded at site H and shown as a wave train event in a 45 minute LTSA (top) and as a single packet with multiple pulses in a 30 second spectrogram (bottom).

Explosions
Effort was directed toward finding explosive sounds in the recordings including military explosions, shots from geophysical 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 explosion detector starts by filtering the time series with a 10^{th} order Butterworth bandpass filter between 200 and 2,000 Hz. Next, cross-correlation was computed between 75 s of the envelope (i.e., Hilbert transform low pass filter) of the filtered time series and the envelope of a filtered example explosion (0.7 s, Hann windowed) as the matched filter signal. The cross correlation was squared to 'sharpen' peaks of explosion detections. A floating threshold was calculated by taking the median cross correlation value over the current 75 s of data to account for detecting explosions within noise, such as shipping. A cross-correlation threshold of above the median was set. When the correlation coefficient reached above the threshold, the time series was inspected more closely.

Consecutive explosions were required to have a minimum time distance of 0.5 s 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 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 confirmed or rejected 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.

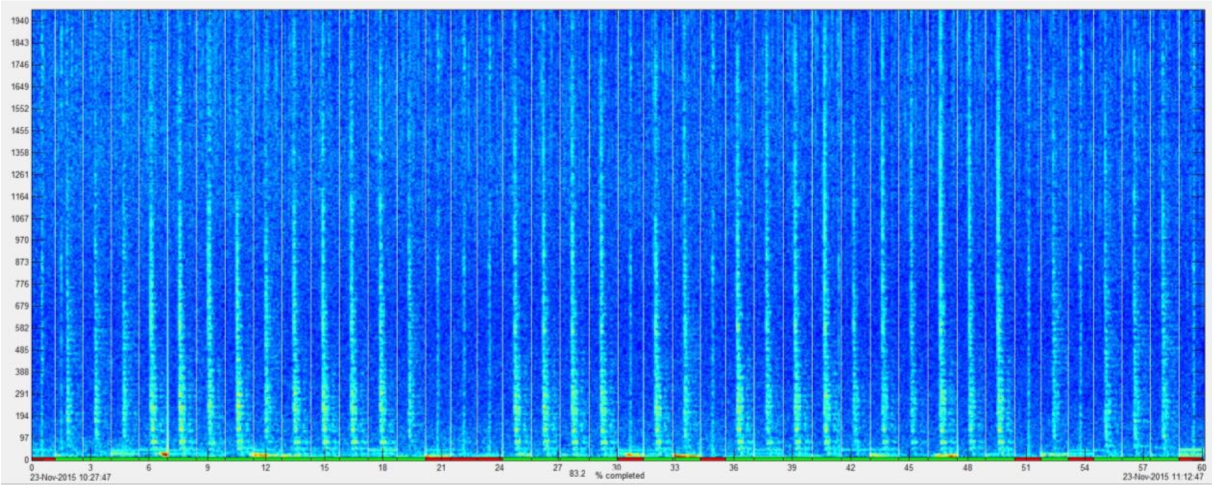

Figure 10. Explosions from site H in the analyst verification stage where events are concatenated into a single spectrogram.
Green along the bottom indicates true and red indicates false detections.

Results

The results of acoustic data analysis at sites E, H, and N from July 2018 to May 2019 are summarized below.

We describe the low-frequency ambient soundscape and 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 all sites had spectral shapes with higher levels at low frequencies (Figure 11), owing to the dominance of ship noise at frequencies below 100 Hz and local wind and waves above 100 Hz (Hildebrand, 2009).
- 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).
- Sites E and N had spectrum levels about 5 dB higher than site H at 10–100 Hz, owing to greater exposure to open-ocean shipping noise (Figure 11).
- Prominent peaks in sound spectrum levels observed in the frequency band 15–30 Hz during fall and winter at sites E, H, and N are related to the seasonally increased presence of fin whale calls. The highest levels during this period occurred at site E (Figure 11).
- Spectral peaks around 45–47 Hz from July to December at sites E, H, and N are related to blue whale B calls. The highest levels during this period occurred at site N (Figure 11).

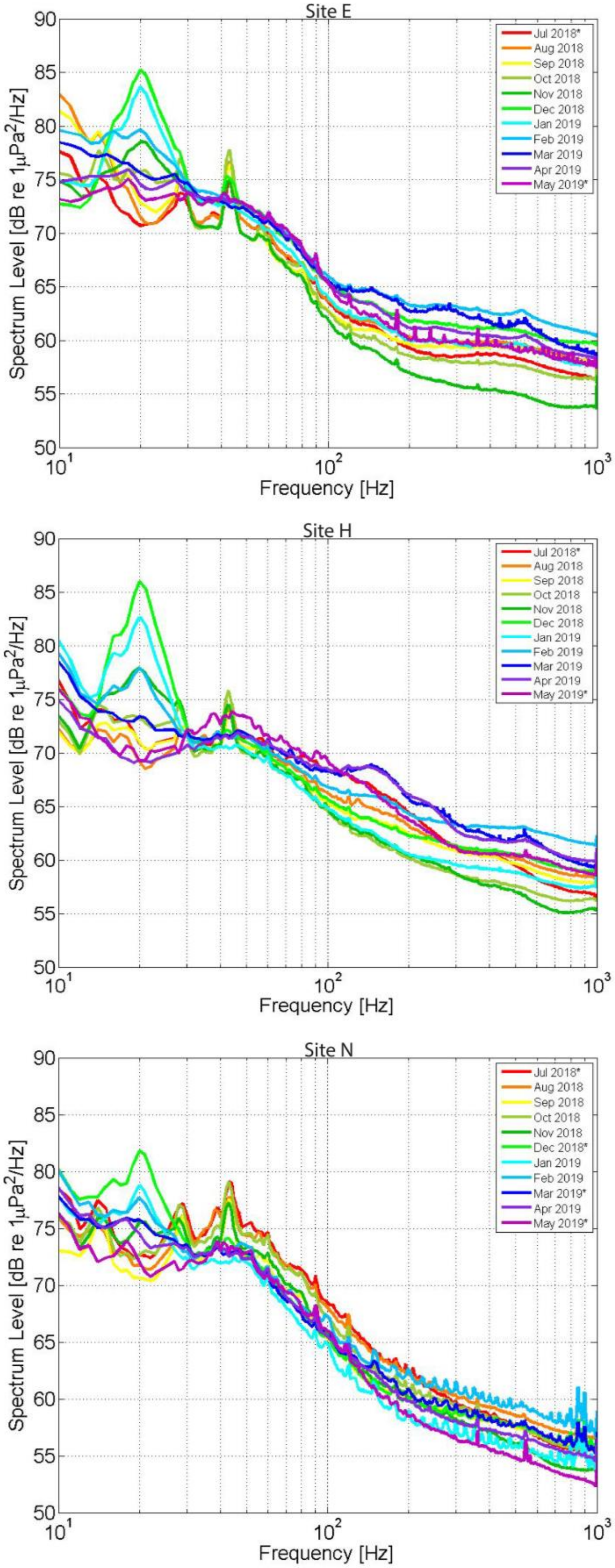

Figure 11. Monthly averages of sound spectrum levels at sites E, H, and N. Legend gives color-coding by month. * denotes months with partial (< 90%) effort.

Mysticetes

Blue and fin whales were detected using automated methods between July 2018 and May 2019. 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 early winter, with a peak in September and again from October through November at all sites (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; Rice *et al.*, 2018; Rice *et al.*, 2019)
- D call detections occurred throughout the recording period at all sites but were highest during August at site E, and during July at sites H and N (Figure 14).
- There was no clear diel pattern for D calls at any site (Figure 15).
- The summer peak in D calls is consistent with earlier recordings at these sites (Debich *et al.*, 2015b; Rice *et al.*, 2017; Rice *et al.*, 2018; Rice *et al.*, 2019).

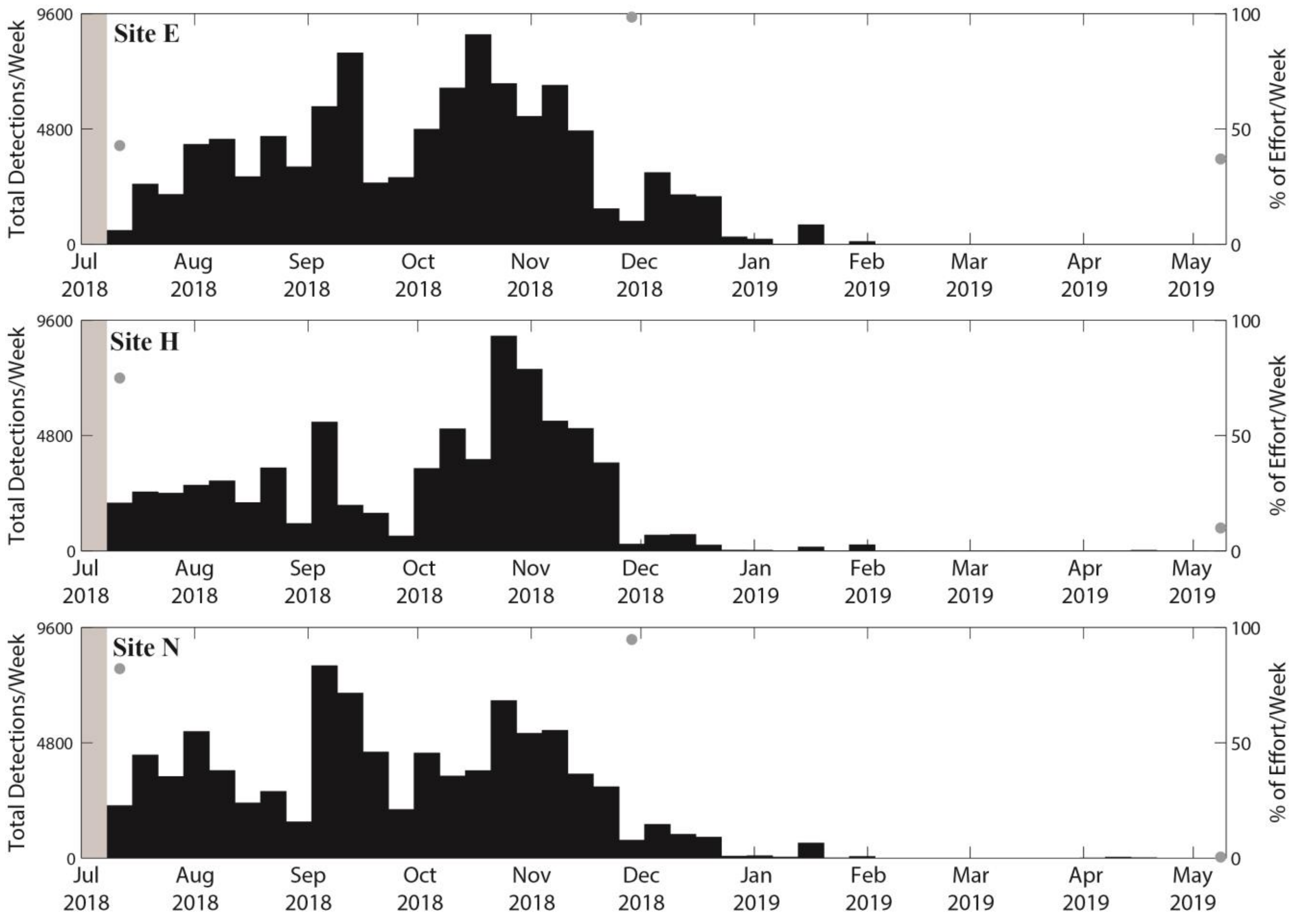

Figure 12. Weekly presence of NE Pacific blue whale B calls between July 2018 and May 2019 at sites E, H, and N.
Gray dots represent percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

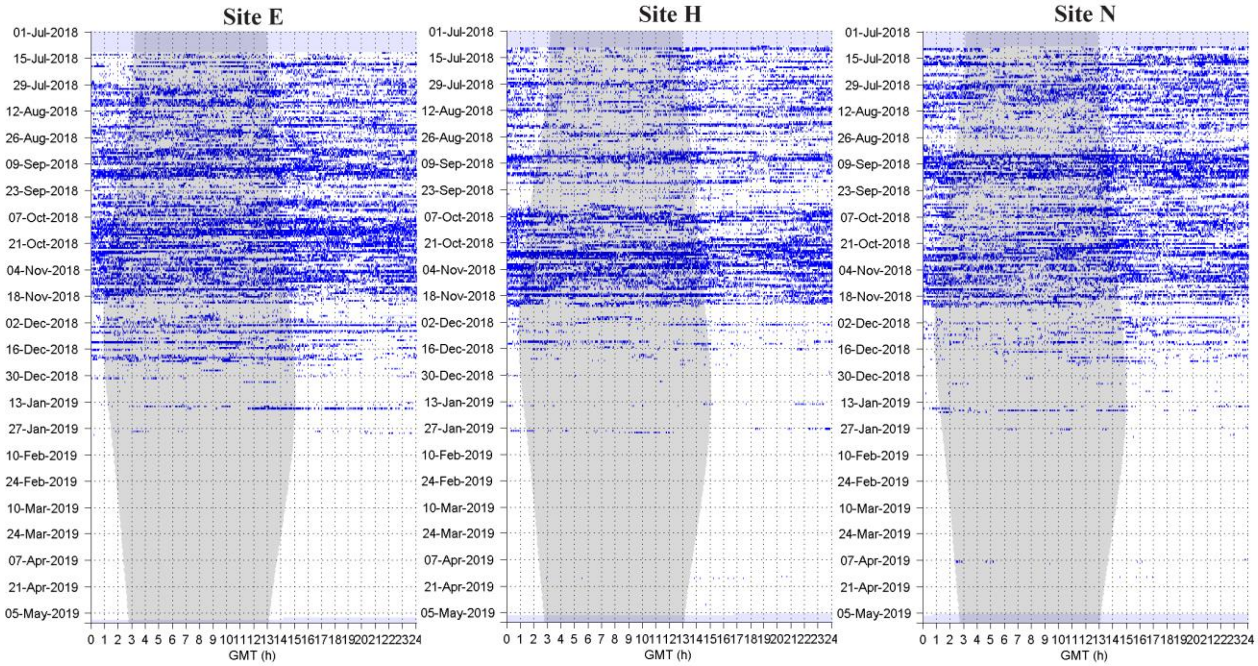

Figure 13. Diel presence of NE Pacific blue whale B calls, indicated by blue dots, in one-minute bins at sites E, H, and N.
Gray vertical shading denotes nighttime and light purple horizontal shading denotes absence of acoustic data.

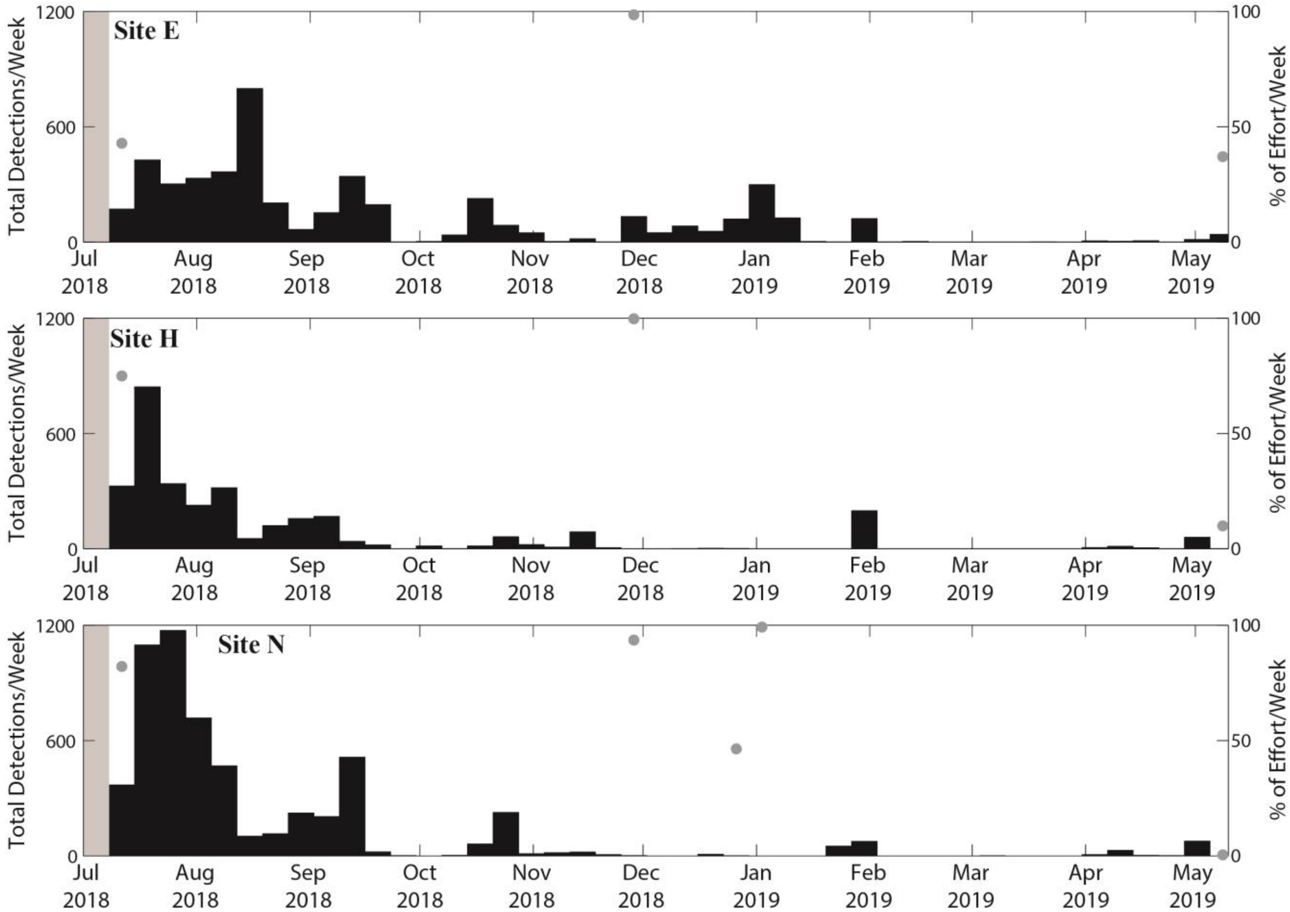

Figure 14. Weekly presence of blue whale D calls between July 2018 and May 2019 at sites E, H, and N.
Gray dots represent percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

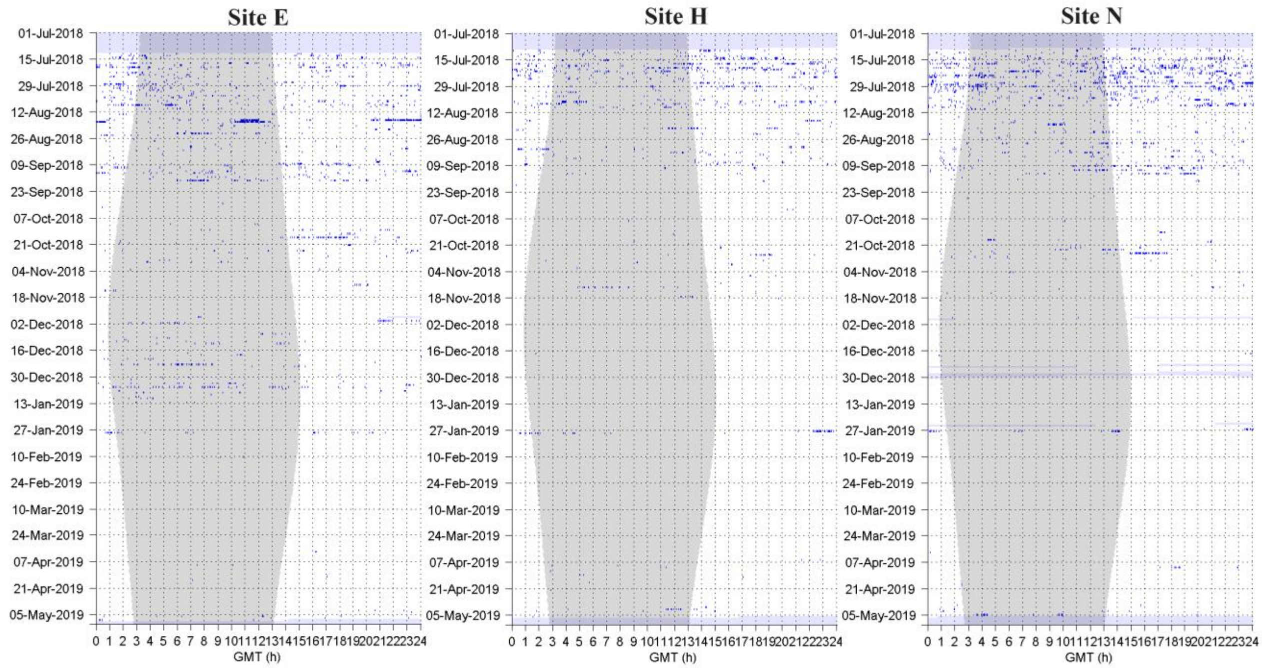

Figure 15. Diel presence of blue whale D calls, indicated by blue dots, in one-minute bins at sites E, H, and N.
Gray vertical shading denotes nighttime and light purple horizontal shading denotes absence of acoustic data.

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 sites E and H. Site N had low acoustic index values overall (Figure 16).
- A peak in the fin whale acoustic index occurred from October to February at all sites (Figure 16).
- The 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; Rice *et al.*, 2018; Rice *et al.*, 2019)

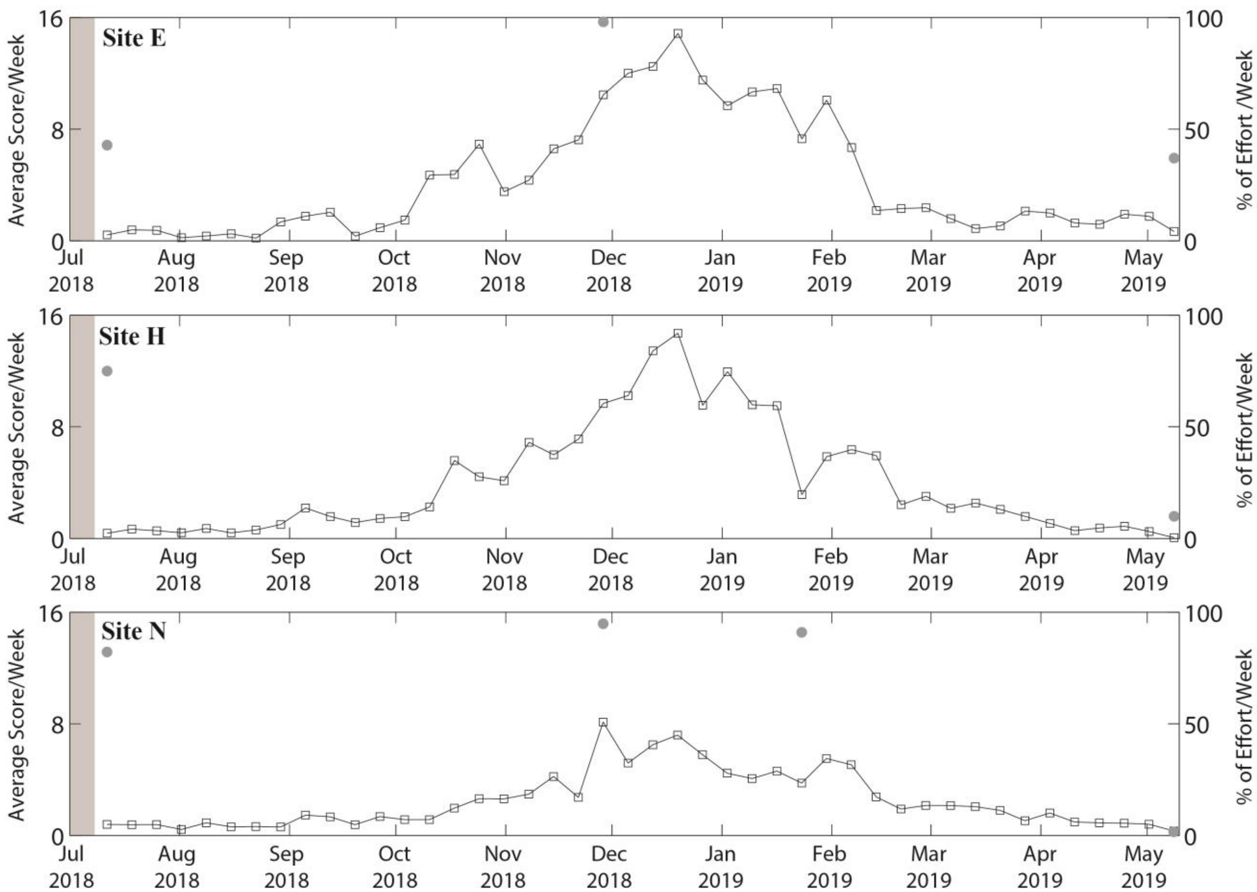

Figure 16. Weekly value of fin whale acoustic index (proxy for 20 Hz calls) between July 2018 and May 2019 at sites E, H, and N.
Gray dots represent percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots 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, BW35, possibly produced by Hubbs' beaked whales (Griffiths *et al.*, 2018), was detected only during January at site E and on only one day at site H. The FM pulse type, BW43, possibly produced by Perrin's beaked whales (Baumann-Pickering *et al.*, 2014), was detected on two occasions at site E and occasionally throughout the recording period at site N. 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 at sites E and H and least at site N (Figure 17).
- Detections were high most of the recording period at site E and only decreased during September and October 2018. At site H, detections were highest from March to May 2019. At site N, detections were low throughout the recording period and showed a small peak in December 2018 and January 2019 (Figure 17).
- There was no discernable diel pattern for Cuvier's beaked whale detections (Figure 18).
- Overall the results were consistent with pervious monitoring periods (Kerosky *et al.*, 2013; Debich *et al.*, 2015a; Debich *et al.*, 2015b; Širović *et al.*, 2016; Rice *et al.*, 2017; Rice *et al.*, 2018), though there were fewer detections at site E and more detections at site H than during the previous monitoring period (Rice *et al.*, 2019).

BW35

BW35 FM pulses were detected in low numbers at site E and on only one day at site H.

- BW35 FM pulses were only detected at site E in January, and only on January 14 at site H. There were no detections at site N (Figure 19).
- There were not enough BW35 detections to determine if there was a diel pattern (Figure 20).
- This is only the second time this FM pulse type has been recorded during a SOCAL monitoring period. Detections occurred on more days at site E than during the previous monitoring period (Rice *et al.*, 2019).

BW43

BW43 FM pulses were detected on two days at site E and intermittently throughout the recording period at site N.

- BW43 FM pulses were detected at sites E and N. At site E, the only detections occurred on July 12 and 13. Detections occurred intermittently throughout the year at site N but the majority of detections occurred during February (Figure 21). There were no detections at site H.
- There was no discernable diel pattern for BW43 detections (Figure 22).
- There were no detections at site H as there were during some previous monitoring periods (Širović *et al.*, 2016; Rice *et al.*, 2017) and there were no detections at site E during the last monitoring period (Rice *et al.*, 2019), but the overall results are consistent with previous reports (Kerosky *et al.*, 2013; Debich *et al.*, 2015a; Debich *et al.*, 2015b; Rice *et al.*, 2018; Rice *et al.*, 2019).

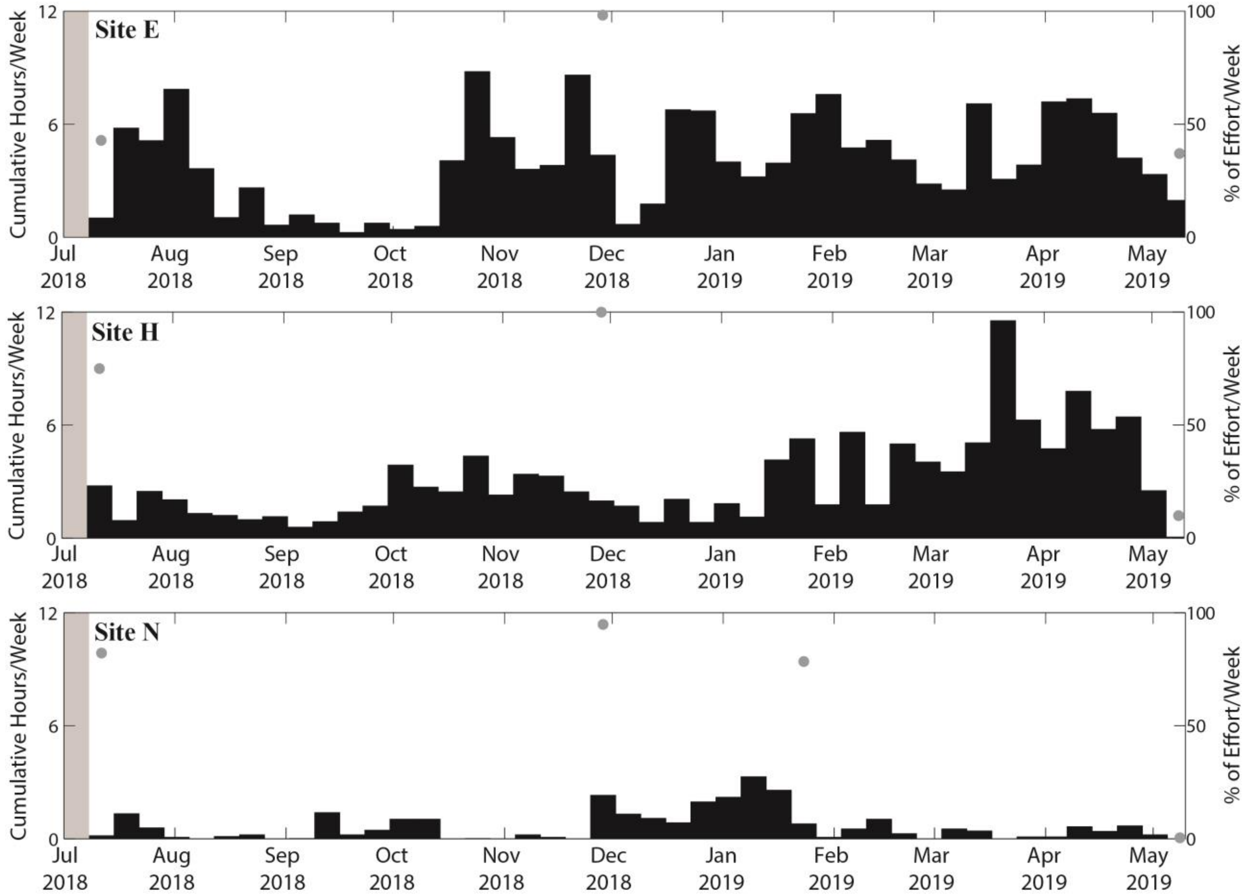

Figure 17. Weekly presence of Cuvier's beaked whale FM pulses between July 2018 and May 2019 at sites E, H, and N.
Gray dots represent percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

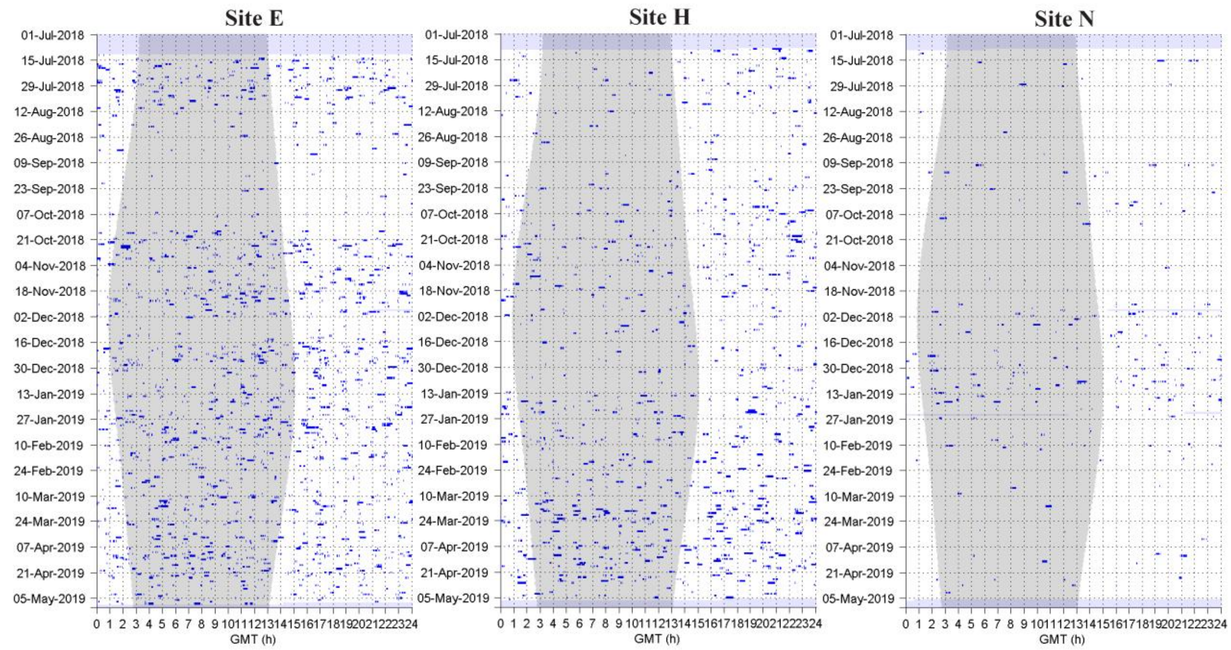

Figure 18. Cuvier's beaked whale FM pulses, indicated by blue dots, in one-minute bins at sites E, H, and N.
Gray vertical shading denotes nighttime and light purple horizontal shading denotes absence of acoustic data.

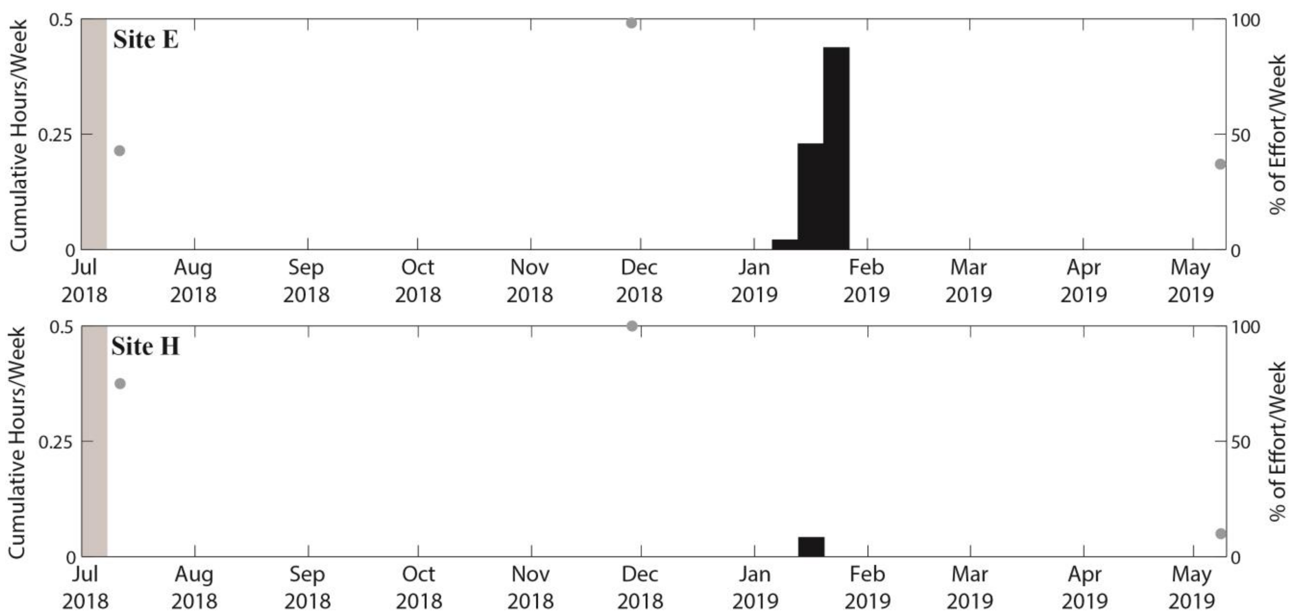

Figure 19. Weekly presence of BW35 FM pulses between July 2018 and May 2019 at sites E, H, and N. There were no detections at site N.
Gray dots represent percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

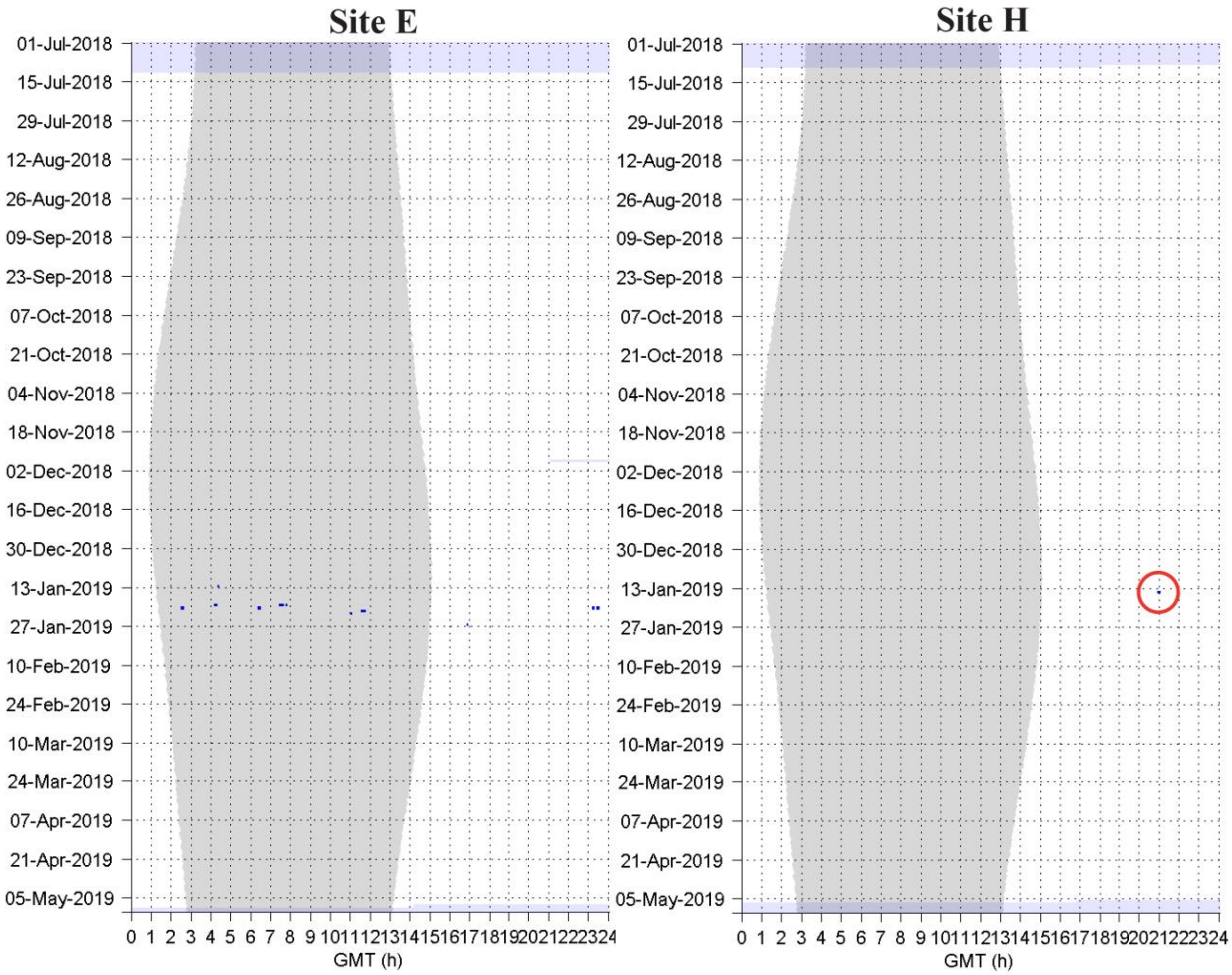

Figure 20. BW35 FM pulses, indicated by blue dots, in five-minute bins at sites E, H, and N. There were no detections at sites N.
Gray vertical shading denotes nighttime and light purple horizontal shading denotes absence of acoustic data. Red circle highlights only time where detections occurred at site H.

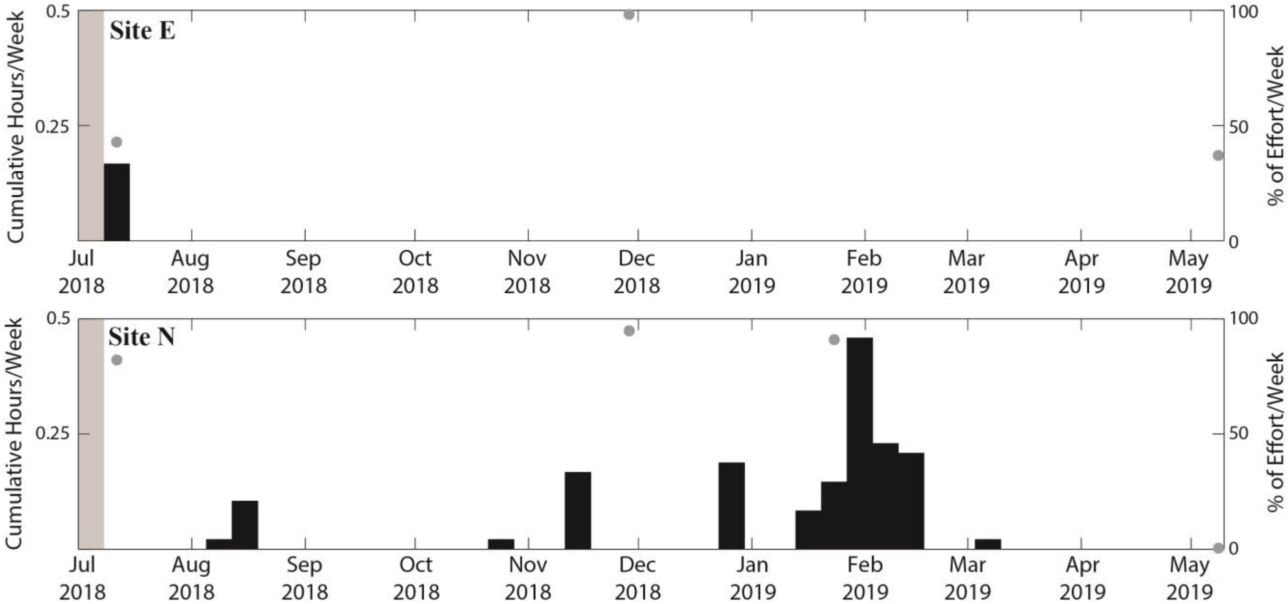

Figure 21. Weekly presence of BW43 FM pulses between July 2018 and May 2019 at sites E, H, and N. There were no detections at site H.
Gray dots represent percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

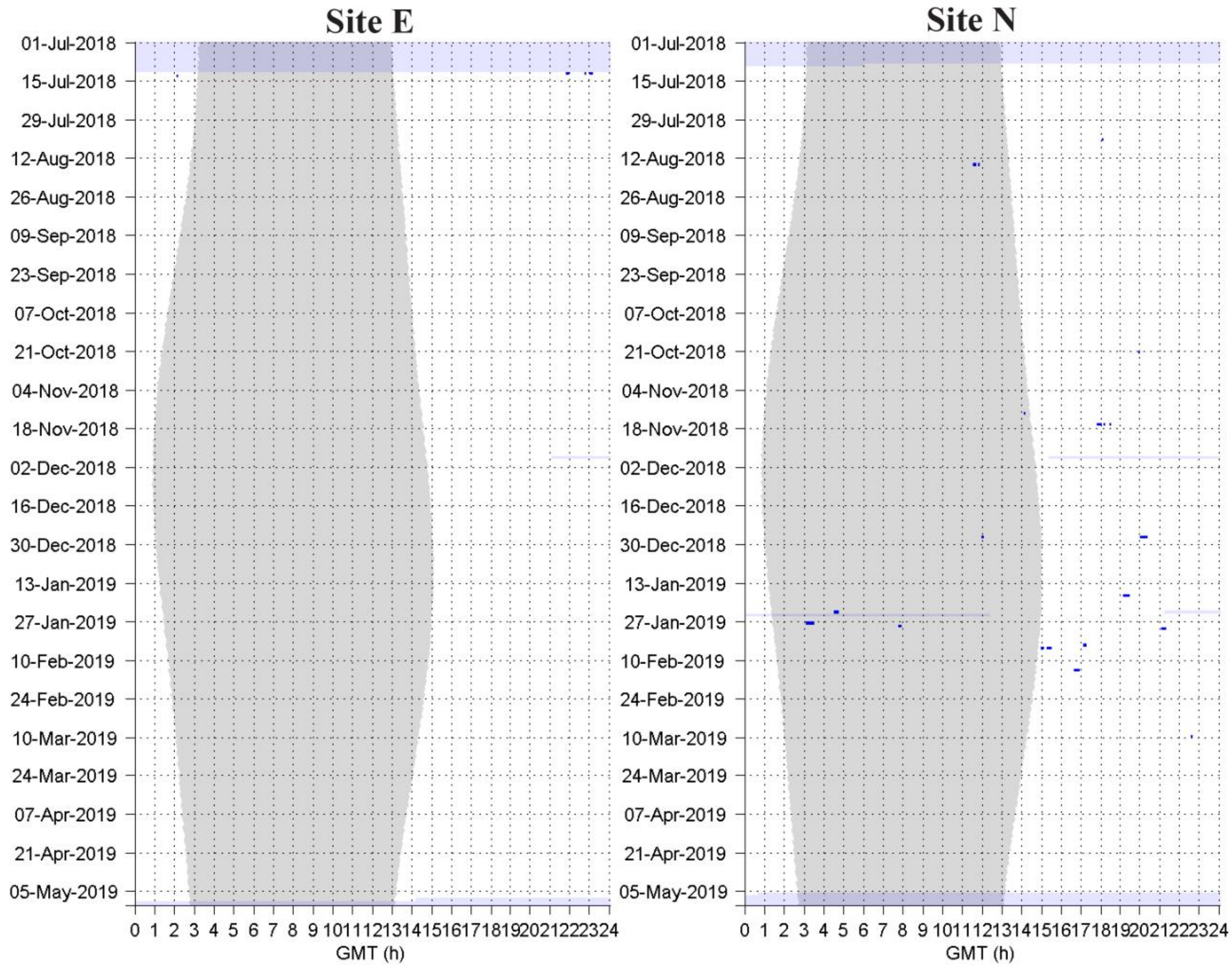

Figure 22. BW43 FM pulses, indicated by blue dots, in five-minute bins at site E, H, and N. There were no detections at site H.
Gray vertical shading denotes nighttime and light purple horizontal shading denotes absence of acoustic data.

Anthropogenic Sounds

Anthropogenic sounds from MFA sonar (2.4–4.5 kHz) and explosions, between July 2018 and May 2019, 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 July 2018 and May 2019 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_{pp} re 1 µPa) when normalized per year at site N, followed by site H, and then site E (Table 5).

- MFA sonar was detected at all three sites. Detections occurred throughout the recording period at all sites, with a peak in August and September 2018. There was an additional peak in October 2018 at site N (Figure 23).
- During July 2018, there seems to be more MFA sonar during the day. Although this overlaps with when a Navy training exercise was taking place, no MFA sonar was used during this Navy exercise and so the MFA sonar must be from a different source (Figure 24). However, overall, bouts of MFA sonar showed no clear diel pattern at any site (Figure 24).
- At site E, a total of 1,367 packets were detected, with a maximum received level of 166 dB_{pp} re 1 µPa (Figure 25). Total wave train duration was almost 29 h (Figure 28), but the total packet duration was only about 1.2 h (4,170.6 s; Table 5; Figure 29).
- At site H, a total of 11,349 packets were detected, with a maximum received level of 167 dB_{pp} re 1 µPa (Figure 25). Total wave train duration was almost 224 h (Figure 28), but the total packet duration was only about 6.3 h (22,704.8 s; Table 5; Figure 29).
- At site N, a total of 15,616 packets were detected, with a maximum received level of 168 dB_{pp} re 1 µPa (Figure 25). Total wave train duration was 293 h (Figure 28), but the total packet duration was only about 11.5 h (41,571.5 s; Table 5; Figure 29).
- Maximum cumulative sound exposure levels of wave trains occurred during December 2018 at site N and were greater than 170 dB re 1 μPa^2-s. Cumulative sound exposure levels above 170 dB re 1 μPa^2-s also occurred at site N from August to December 2018. At site E, maximum levels were around 170 dB re 1 μPa^2-s and occurred in February 2019. At site H, maximum levels were above 170 dB re 1 μPa^2-s and also occurred in February and March 2019 (Figure 26).
- Most MFA sonar wave trains occurred at site N in August 2018 during a major training exercise (Figure 27).

Table 4. Major naval training exercises in the SOCAL region between July 2018 and May 2019.

Exercise Dates
6 to 27 July 2018*
7 August to 7 September 2018
9 to 23 October 2018

*no mid-frequency active sonar was used during this exercise.

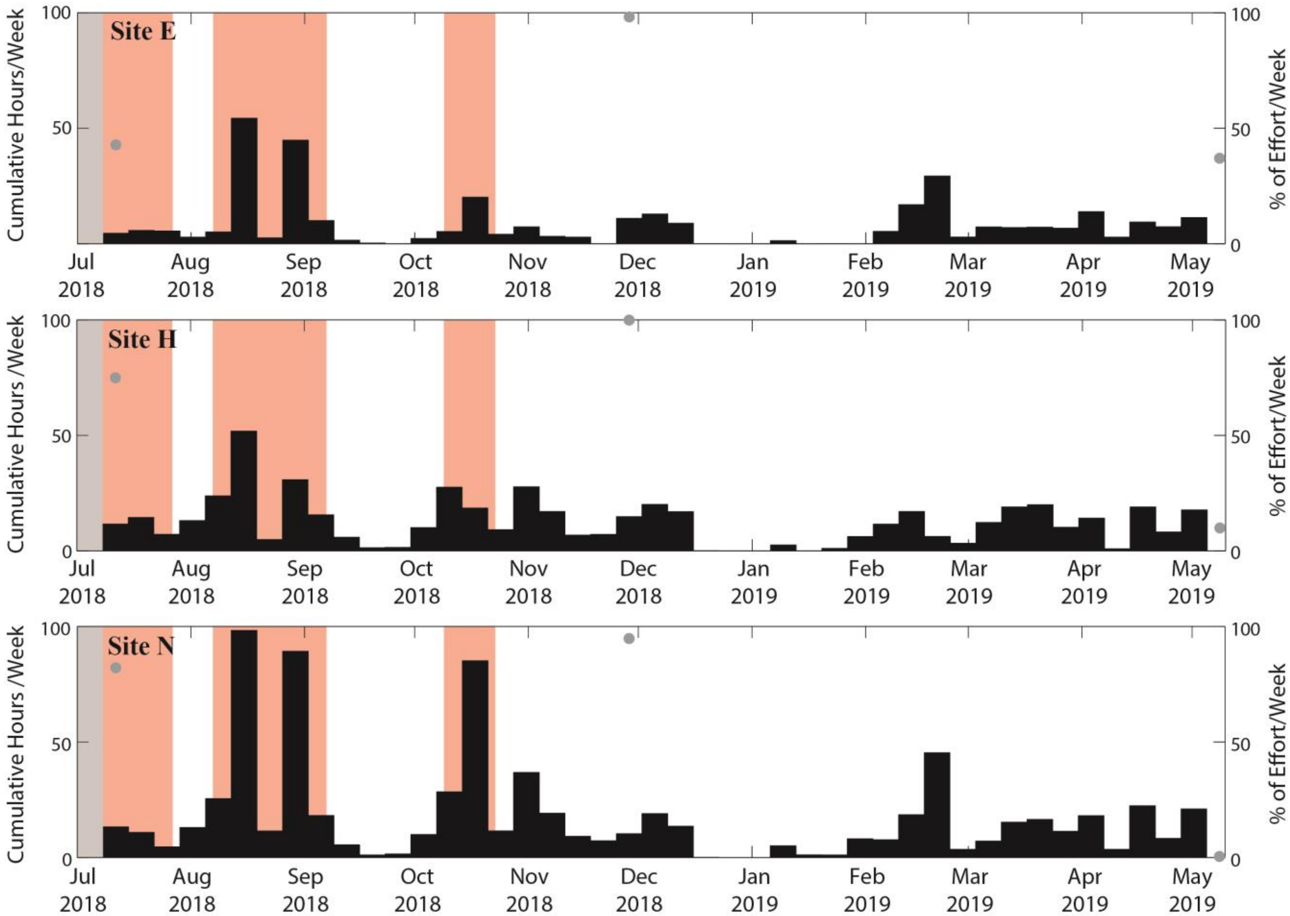

Figure 23. Major naval training events (shaded light red, from Table 4) overlaid on weekly presence of MFA sonar < 5kHz from the *Silbido* detector between July 2018 and May 2019 at sites E, H, and N. Gray dots represent percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

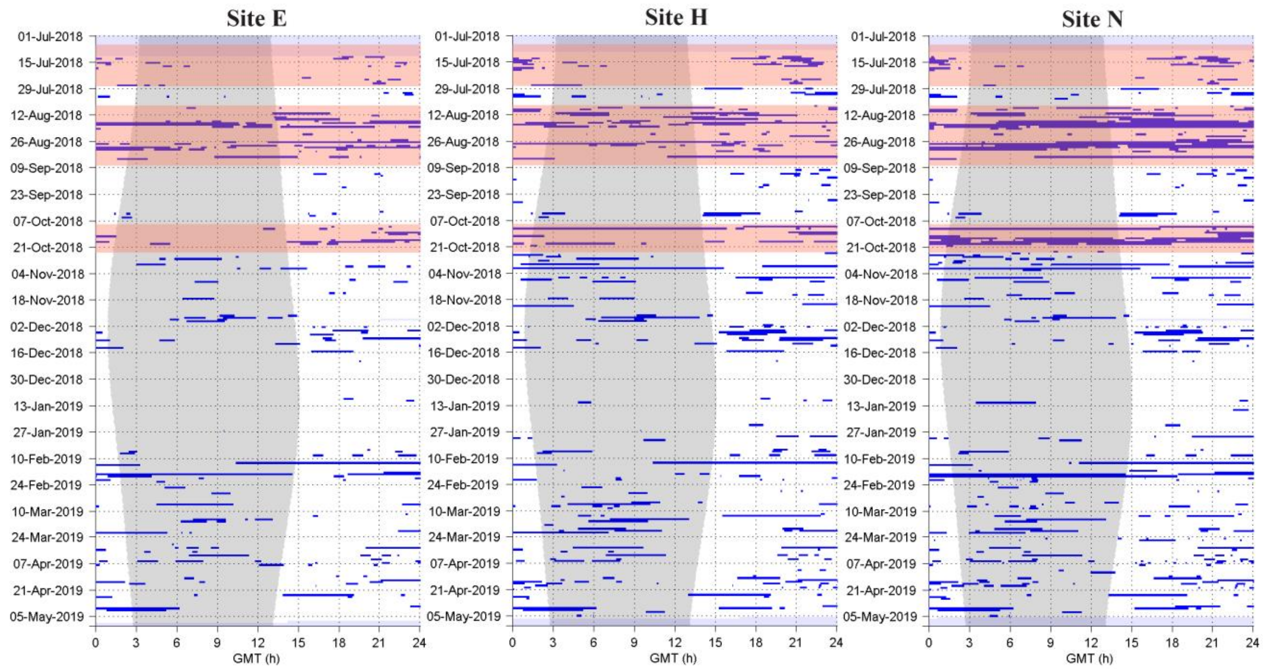

Figure 24. Major naval training events (shaded light red, from Table 4) overlaid on MFA sonar < 5kHz signals from the *Silbido* detector, indicated by blue dots, in one-hour bins at sites E, H, and N. Gray vertical shading denotes nighttime and light purple horizontal shading denotes absence of acoustic data.

Table 5. MFA sonar automated detector results for sites E, H, and N.
Total effort at each site in days (years), number of and extrapolated yearly estimates of wave trains and packets at each site (> 130 dB_{pp} re 1 μPa), total wave train duration, and total packet duration.

Site	Period Analyzed Days (Years)	Number of Wave Trains	Wave Trains per year	Number of Packets	Packets per year	Total Wave Train Duration (h)	Total Packet Duration (s)
E	300 (0.82)	14	17	1,367	1,667	28.6	4,170.6
H	300 (0.82)	101	123	11,349	13,840	223.9	22,704.8
N	299 (0.82)	107	130	15,616	19,044	293	41,571.5

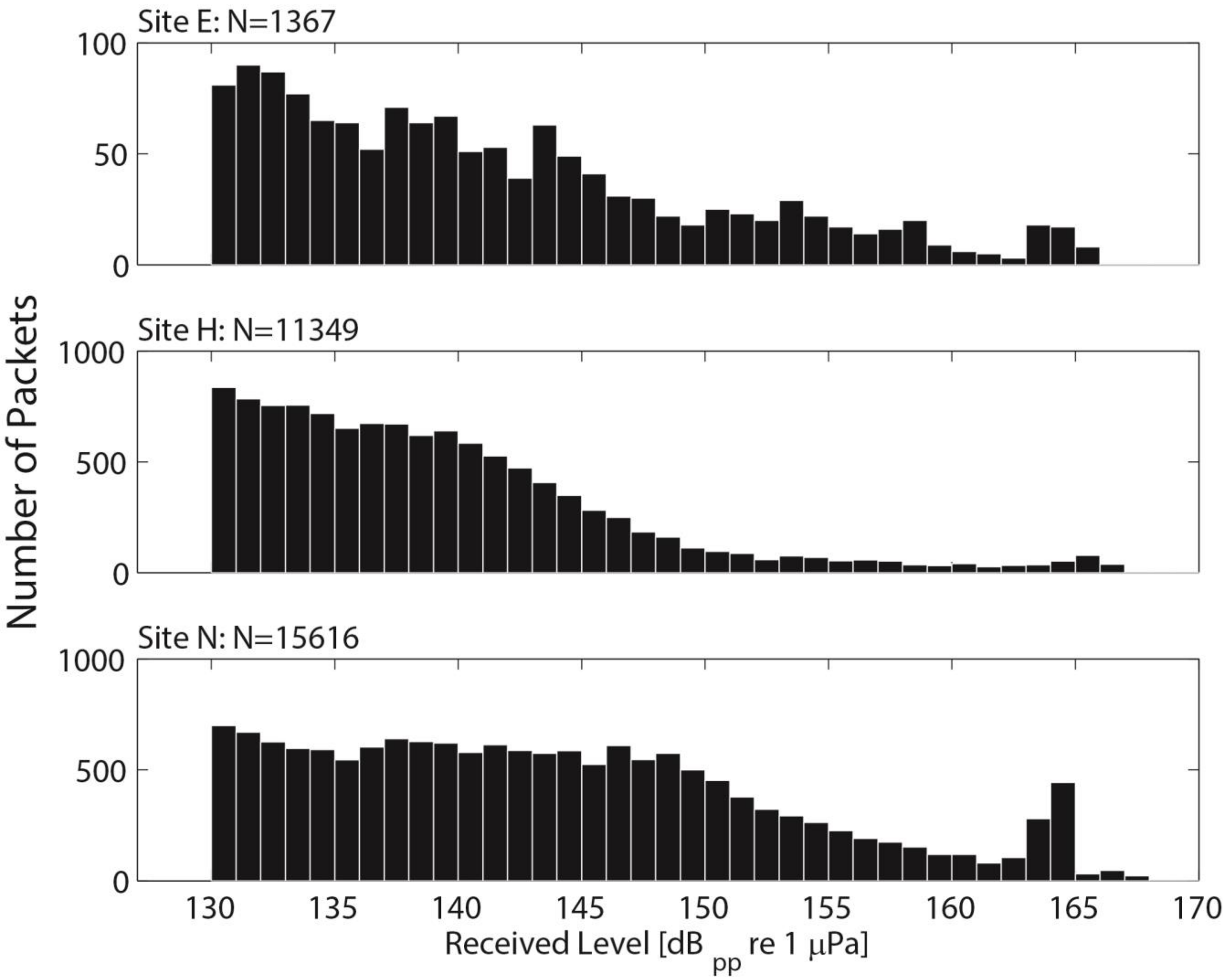

Figure 25. MFA sonar packet peak-to-peak received level distributions for sites E, H, and N. The total number of packets detected at each site is given in the upper left corner of each panel. Instrument clipping levels are reached around 166–168 dBpp re 1 μPa, depending on hydrophone configuration. Note the vetical axes are at different scales with site E being smaller.

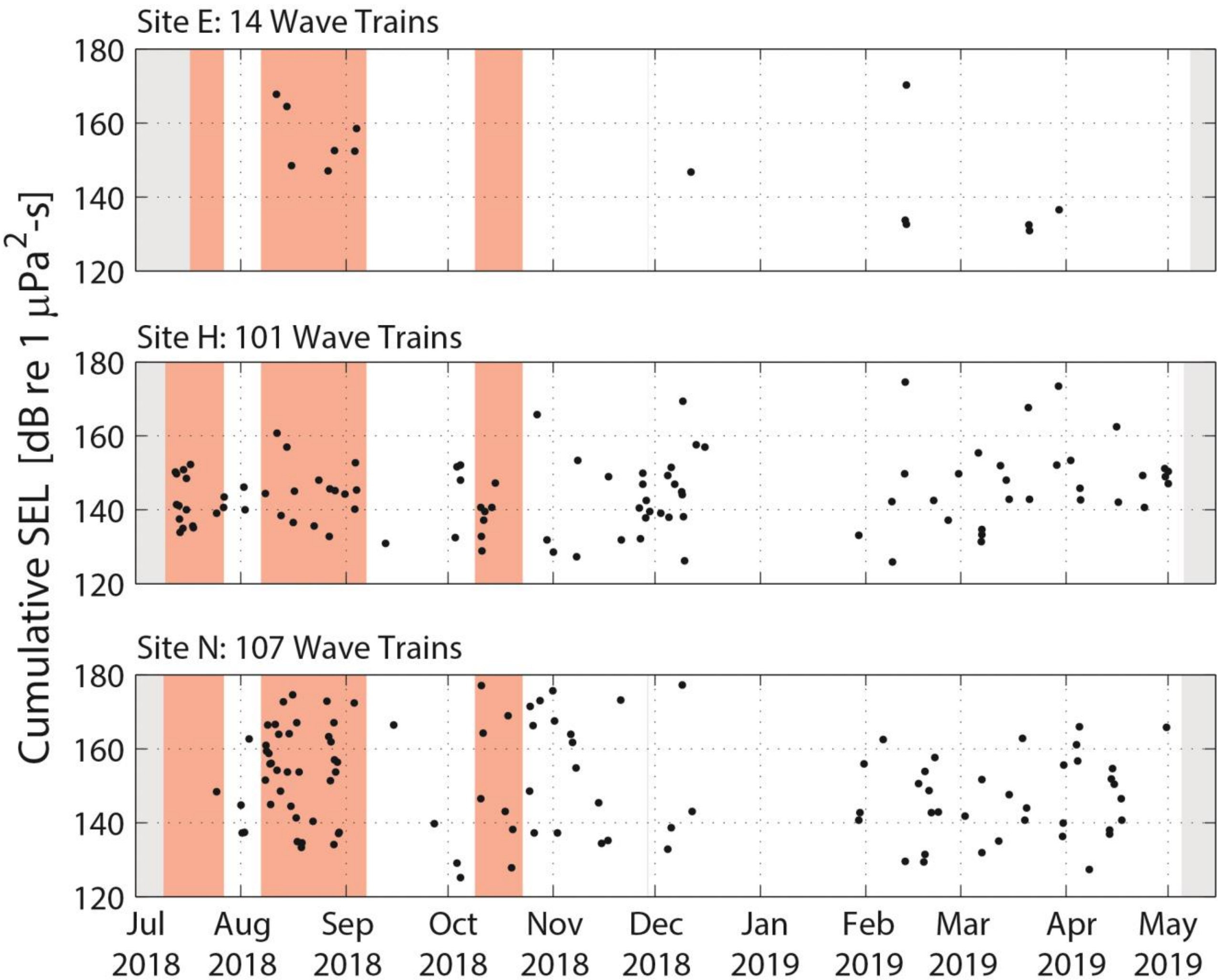

Figure 26. Cumulative sound exposure level for each wave train at sites E, H, and N.

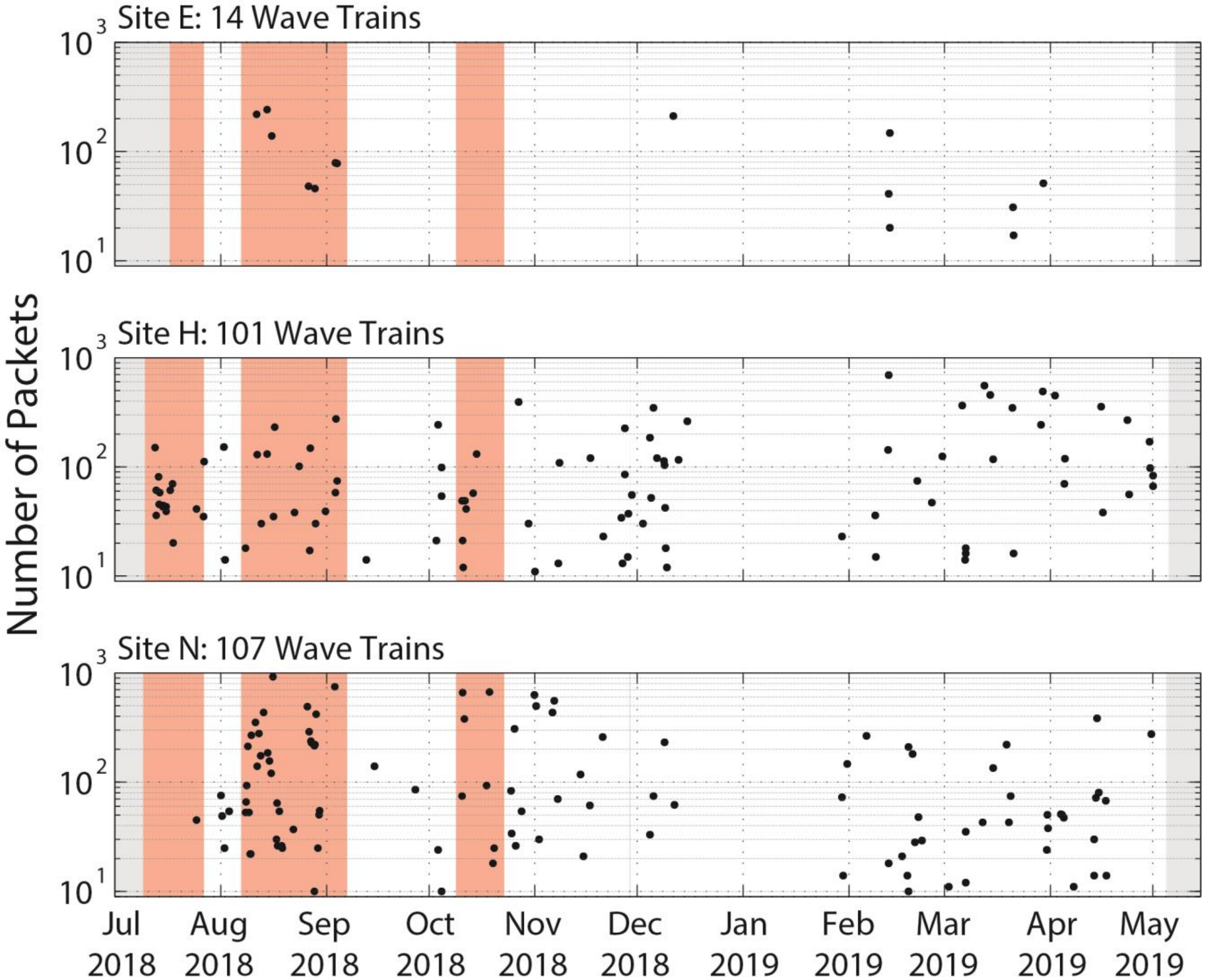

Figure 27. Number of MFA sonar packets for each wave train at sites E, H, and N. Note the vertical axes are logarithmic base-10.

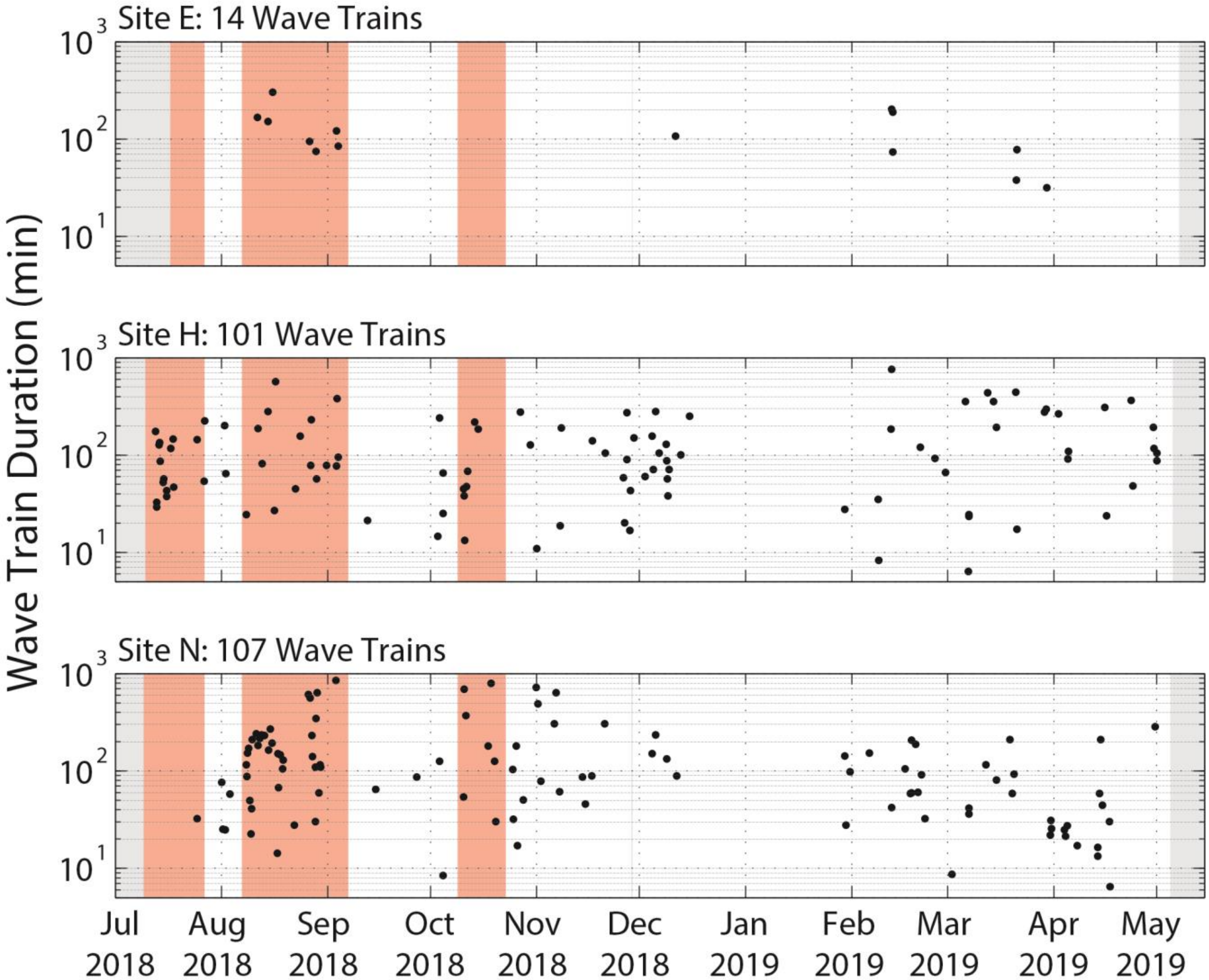

Figure 28. Wave train duration at sites E, H, and N. Note the vertical axes are logarithmic base-10.

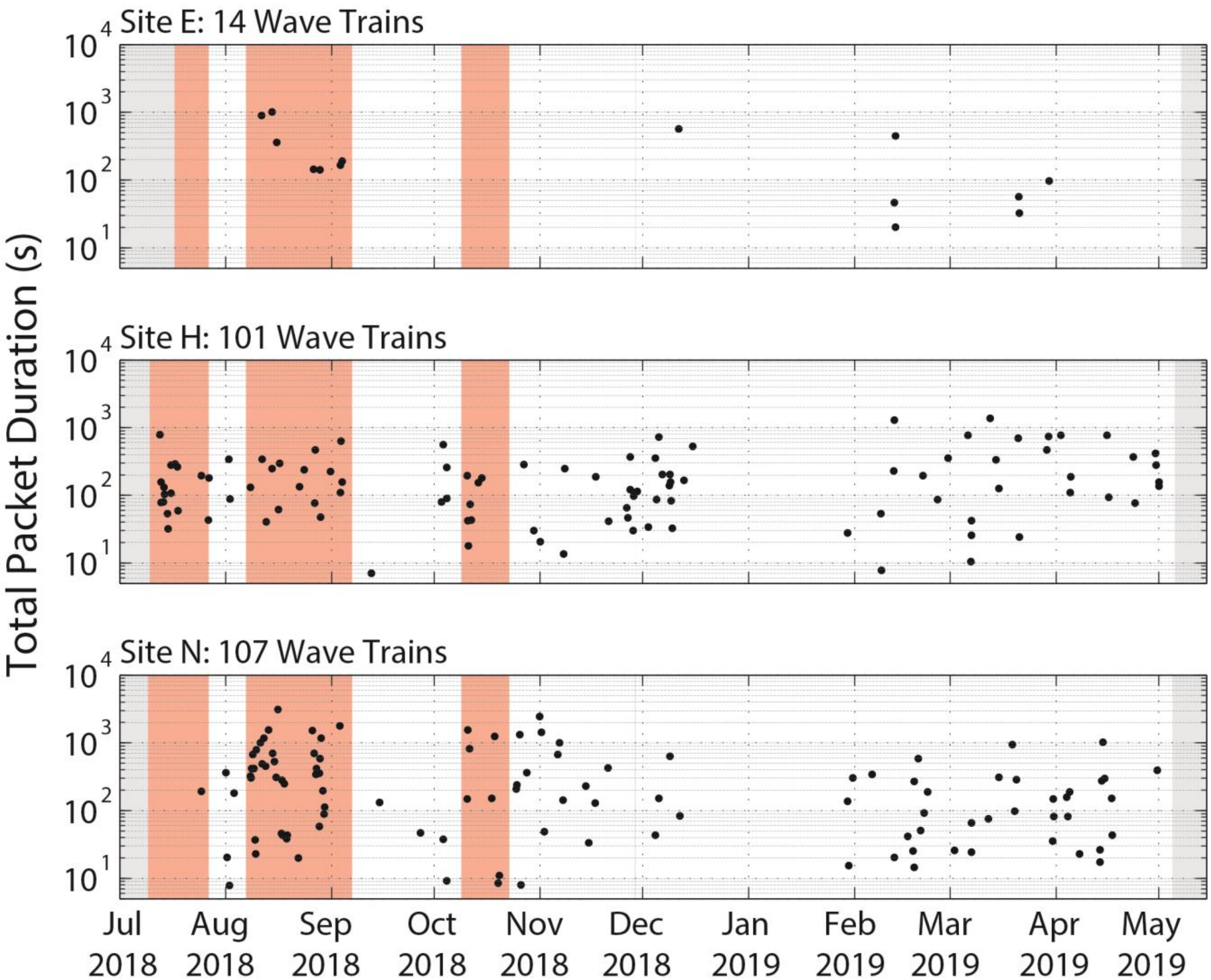

Figure 29. Total packet duration for each wave train at sites E, H, and N. Note the vertical axes are logarithmic base-10.

Explosions

Explosions were detected at all three sites.

- Explosions occurred throughout the monitoring period at all sites. The highest number of explosions occurred at site H, with a peak in July and August 2018 and again in January 2019. The lowest number of detections occurred at site E (Figure 30).
- Total explosion counts at each site were as follows:
  - 393 at site E
  - 2,651 at site H
  - 890 at site N
- There was no clear diel pattern at sites E or N, but there were more explosions for about the first six hours after sunset at site H, mainly in August 2018 and January 2019 (Figure 31).
- The diel pattern at site H indicates potential use of seal bombs by the squid fishery.
- The overall number of detections at site H has decreased compared to earlier reports (Debich *et al.*, 2015a; Debich *et al.*, 2015b; Širović *et al.*, 2016; Rice *et al.*, 2017; Rice *et al.*, 2018; Rice *et al.*, 2019) which could be due to a geographic or other shifts in fishing effort. Detections at site N have also decreased over the long term, but are increased compared to the previous reporting period (Rice *et al.*, 2019), as are detections at site E.

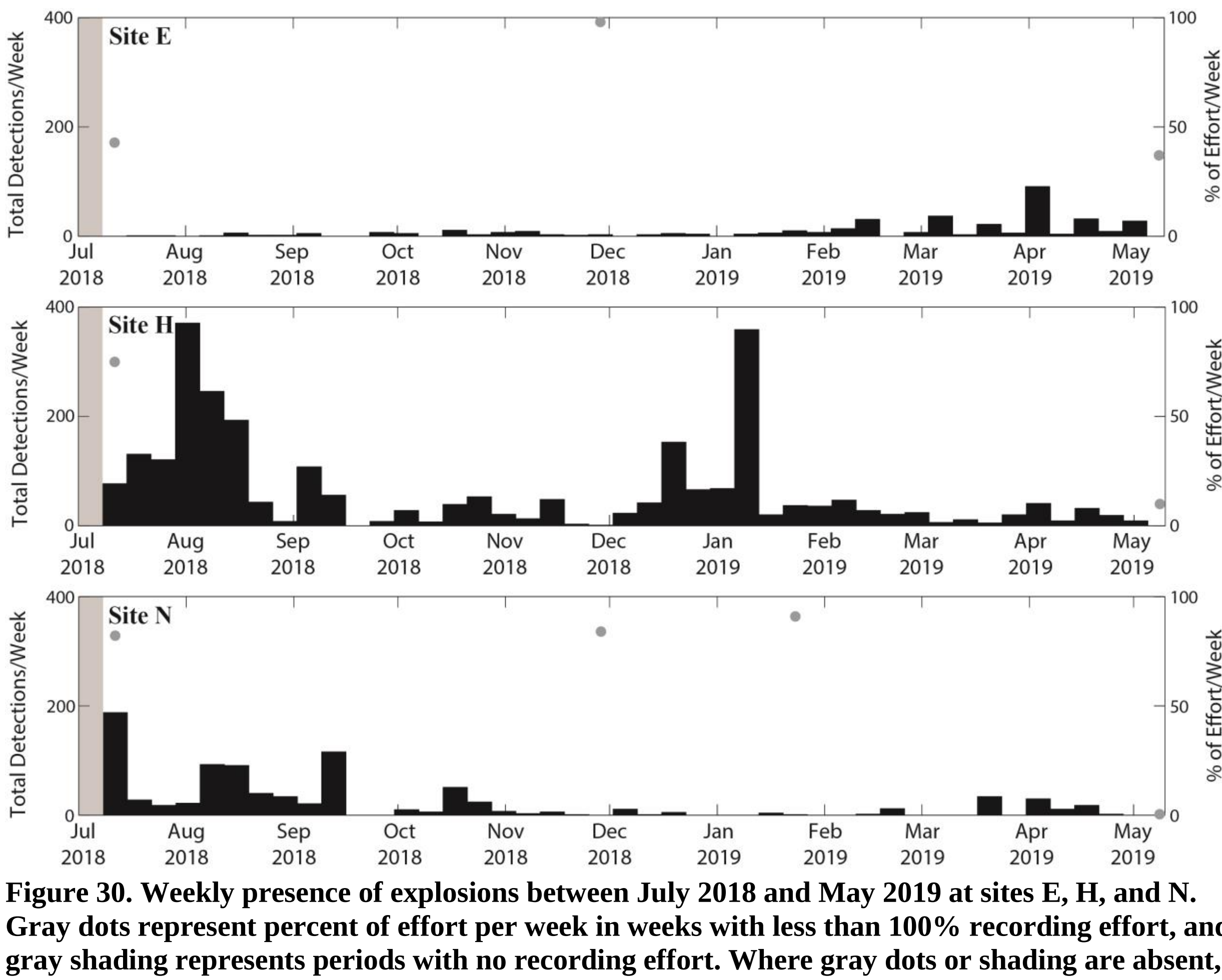

Figure 30. Weekly presence of explosions between July 2018 and May 2019 at sites E, H, and N. Gray dots represent percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

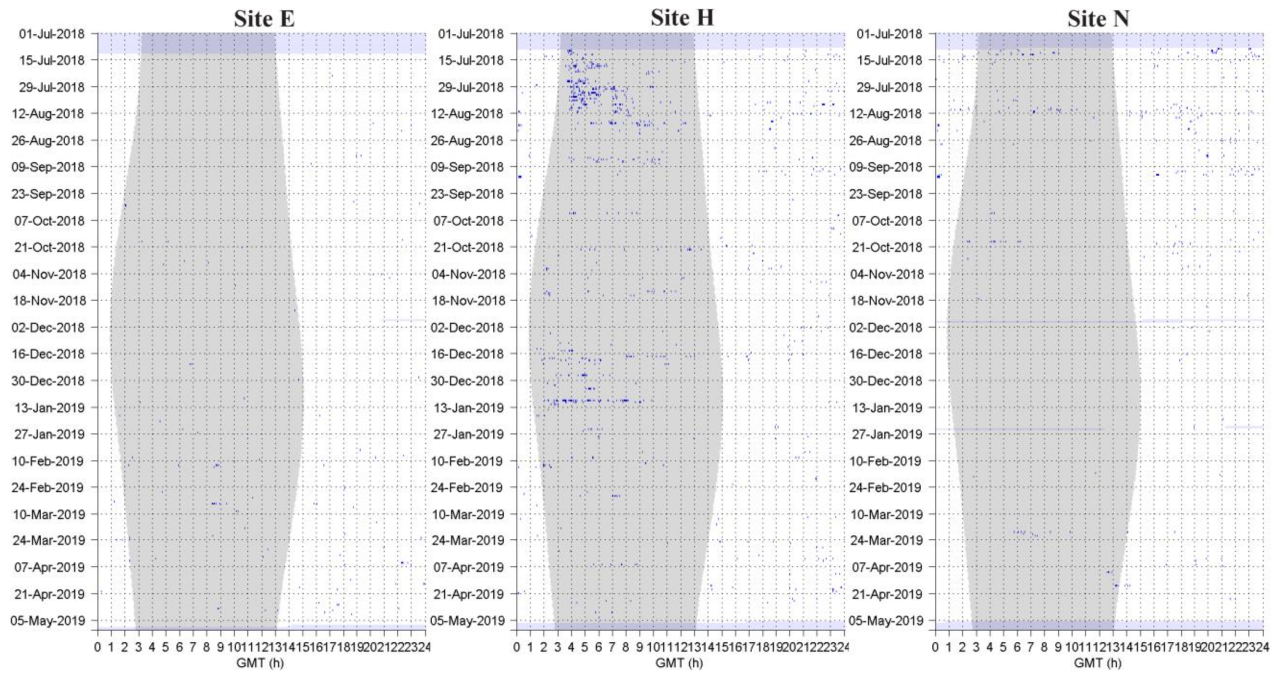

Figure 31. Explosion detections, indicated by blue dots, in one-minute bins at sites E, H, and N. Gray vertical shading denotes nighttime and light purple horizontal shading denotes absence of acoustic data.

Conclusion

The results from this report are generally consistent with previous reports on the SOCAL region. The main differences during this reporting period were the presence of the new BW35 signal at site E, which was detected more frequently than during the previous monitoring period, and the presence of the BW43 signal at site E for the first time. Additionally, the changing numbers of explosions detected at all sites potentially indicate a connection with fisheries and a geographic shift in fishing effort. Monitoring will continue 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.

References

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

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

Baumann-Pickering, S., Simonis, A. E., Wiggins, S. M., Brownell, R. L. J., and Hildebrand, J. A. (**2013b**). "Aleutian Islands beaked whale echolocation signals," Marine Mammal Science **29**, 221-227.

Debich, A. J., Baumann-Pickering, A., Širović, A., Hildebrand, J. A., Herbert, S. T., Johnson, S. C., Rice, A. C., Trickey, J. S., and Wiggins, S. M. (**2015a**). "Passive Acoustic Monitoring for Marine Mammals in the SOCAL Range Complex January - July 2014," (Marine Physical Laboratory, Scripps Institution of Oceanography, La Jolla, CA), p. 43.

Debich, A. J., Baumann-Pickering, S., Širović, A., Hildebrand, J. A., Alldredge, A. L., Gottlieb, R. S., Herbert, S. T., Johnson, S. C., Rice, A. C., Roche, L. K., Theyre, B. J., Trickey, J. S., Varga, L. M., and Wiggins, S. M. (**2015b**). "Passive Acoustic Monitoring for Marine Mammals in the SOCAL Naval Training Area Dec 2012 - Jan 2014," (Marine Physical Laboratory, Scripps Institution of Oceanography, La Jolla, CA), p. 96.

Griffiths, E. T., Keating, J. L., Barlow, J., and Moore, J. E. (**2018**). "Description of a new beaked whale echolocation pulse type in the California Current," Marine Mammal Science.

Helble, T. A., Ierley, G. R., D'Spain, G. L., Roch, M. A., and Hildebrand, J. A. (**2012**). "A generalized power-law detection algorithm for humpback whale vocalizations," Journal of the Acoustical Society of America **131**, 2682-2699.

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

Hildebrand, J. A., Baumann-Pcikering, S., Širović, A., Buccowich, J., Debich, A., Johnson, S., Kerosky, S., Roche, L., Berga, A. S., and Wiggins, S. M. (**2012**). "Passive Acoustic

Monitoring for Marine Mammals in the SOCAL Naval Training Area 2011-2012," (Marine Physical Laboratory, Scripps Institution of Oceanography, La Jolla, CA).
Jefferson, T. A., Webber, M. A., and Pitman, L. (**2015**). "*Marine Mammals of the World: A Comprehensive Guide to their Identification* (2nd Ed). (Academic Press)."
Jefferson, T. A., Webber, M. A., and Pitman, R. L. (**2008**). "*Marine Mammals of the World: A Comprehensive Guide to their Identification* (Academic Press)."
Johnson, M., Madsen, P. T., Zimmer, W. M. X., Aguilar de Soto, N., and Tyack, P. L. (**2004**). "Beaked whales echolocate on prey," Proceedings of the Royal Society B: Biological Sciences **271**, S383-S386.
Kerosky, S. M., Baumann-Pickering, S., Širović, A., Buccowich, J. S., Debich, A. J., Gentes, Z., Gottlieb, R. S., Johnson, S. C., Roche, L. K., Thayre, B., Wakefield, L., Wiggins, S. M., and Hildebrand, J. A. (**2013**). "Passive Acoustic Monitoring for Marine Mammals in the SOCAL Range Complex during 2012," (Marine Physical Laboratory, Scripps Institution of Oceanography, La Jolla, CA), p. 72.
McDonald, M. A., Hildebrand, J. A., and Mesnick, S. (**2009**). "Worldwide decline in tonal frequencies of blue whale song," Endangered Species Research **9**, 13-21.
McDonald, M. A., Hildebrand, J. A., and Webb, S. C. (**1995**). "Blue and fin whales observed on a seafloor array in the Northeast Pacific," Journal of the Acoustical Society of America **98**, 712-721.
McDonald, M. A., Hildebrand, J. A., Wiggins, S. M., and Ross, D. (**2008**). "A 50 year comparison of ambient noises near San Clemente Island: A bathymetrically complex coastal region off Southern California," Journal of the Acoustical Society of America **124**, 1985-1992.
McDonald, M. A., Mesnick, S. L., and Hildebrand, J. A. (**2006**). "Biogeographic characterisation of blue whale song worldwide: using song to identify populations," Journal of Cetacean Research and Management **8**, 55-65.
Mellinger, D. K., and Clark, C. W. (**1997**). "Methods of automatic detection of mysticete sounds," Marine and Freshwater Behaviour and Physiology **29**, 163-181.
Nieukirk, S. L., Mellinger, D. K., Moore, S. E., Klinck, K., Dzlak, R. P., and Goslin, J. (**2012**). "Sounds from airguns and fin whales recorded in the mid-Atlantic Ocean, 1999-2009," Journal of the Acoustical Society of America **131**, 1102-1112.
Oleson, E. M., Calambokidis, J., Burgess, W. C., McDonald, M. A., LeDuc, C. A., and Hildebrand, J. A. (**2007**). "Behavioral context of call production by eastern North Pacific blue whales," Marine Ecology Progress Series **330**, 269-284.
Rice, A. C., Baumann-Pickering, S., Hildebrand, J. A., Rafter, M., Reagan, E., Trickey, J. A., and Wiggins, S. M. (**2019**). "Passive Acoustic Monitoring for Marine Mammals in the SOCAL Range Complex March 2017 - July 2018," (Marine Physical Laboratory, Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, MPL Technical Memorandum #636 under Cooperative Ecosystems Study Unit Cooperative Agreement N62473-18-2-0016 for U.S. Navy Pacific Fleet, Pearl Harbor, HI).
Rice, A. C., Baumann-Pickering, S., Širović, A., Hildebrand, J. A., Debich, A. J., Meyer-Lobbecke, A., Thayre, B. J., Trickey, J. A., and Wiggins, S. M. (**2017**). "Passive Acoustic Monitoring for Marine Mammals in the SOCAL Range Complex June 2015 - April 2016," (Marine Physical Laboratory, Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, MPL Technical Memorandum #610 under

Cooperative Ecosystems Study Unit Cooperative Agreement N62473-16-2-0012 for U.S. Navy Pacific Fleet, Pearl Harbor, HI), p. 36.
Rice, A. C., Baumann-Pickering, S., Širović, A., Hildebrand, J. A., Rafter, M., Thayre, B. J., Trickey, J. A., and Wiggins, S. M. (**2018**). "Passive Acoustic Monitoring for Marine Mammals in the SOCAL Range Complex April 2016 - June 2017," (Marine Physical Laboratory, Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, MPL Technical Memorandum #618 under Cooperative Ecosystems Study Unit Cooperative Agreement N62473-17-2-0014 for U.S. Navy Pacific Fleet, Pearl Harbor, HI), p. 47.
Roch, M. A., Brandes, T. S., Patel, B., Barkley, Y., Baumann-Pickering, S., and Soldevilla, M. S. (**2011a**). "Automated extraction of odontocete whistle contours," Journal of the Acoustical Society of America **130**, 2212-2223.
Roch, M. A., Klinch, H., Baumann-Pickering, S., Mellinger, D. K., Qui, S., Soldevilla, M. S., and Hildebrand, J. A. (**2011b**). "Classification of echolocation clicks from odontocetes in the Southern California Bight," Journal of the Acoustical Society of America **129**, 467-475.
Širović, A. (**2016**). "Variability in the performance of the spectrogram correlation detector for North-east Pacific blue whale calls," Bioacoustics **25**, 145-160.
Širović, A., Baumann-Pickering, S., Hildebrand, J. A., Debich, A. J., Herbert, S. T., Meyer-Lobbecke, A., Rice, A., Thayre, B., Trickey, J. S., Wiggins, S. M., and Roch, M. A. (**2016**). "Passive acoustic monitoring for marine mammals int he SOCAL Range Complex July 2014 - May 2015," (Marine Physical Laboratory, Scripps Institution of Oceanography, La Jolla, CA), p. 39.
Širović, A., Rice, A., Chou, E., Hildebrand, J. A., Wiggins, S. M., and Roch, M. A. (**2015**). "Seven years of blue and fin whale call abundance in the Southern California Bight," Endangered Species Research **28**, 61-76.
Soldevilla, M. S., Henderson, E. E., Campbell, G. S., Wiggins, S. M., Hildebrand, J. A., and Roch, M. (**2008**). "Classification of Risso's and Pacific white-sided dolphins using spectral properties of echolocation clicks," Journal of the Acoustical Society of America **124**, 609-624.
Thompson, P. O., Findley, L. T., and Vidal, O. (**1992**). "20-Hz pulses and other vocalizations of fin whales, *Balaenoptera physalus*, in the Gulf of California, Mexico," Journal of the Acoustical Society of America **92**, 3051-3057.
Watkins, W. A. (**1981**). "Activities and underwater sounds of fin whales," Scientific Reports of the Whale Research Institute **33**, 83-117.
Watkins, W. A., Daher, M. A., Reppucci, G. M., George, J. E., Martin, D. M., DiMarzio, N. A., and Gannon, D. P. (**2000**). "Seasonality and distribution of whale calls in the North Pacific," Oceanography **13**, 62-67.
Wiggins, S. M. (**2015**). "Methods for quantifying mid-frequency active sonar in the SOCAL Range Complex," (Marine Physical Laboratory Technical Memorandum 553, Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA).
Wiggins, S. M., and Hildebrand, J. A. (**2007**). "High-frequency acoustic recording package (HARP) for broadband, long-term marine mammal monitoring," in *International Symposium on Underwater Technology 2007 and International Workshop on Scientific Use of Submarine Cables and Related Technologies 2007* (Institute of Electrical and Electronics Engineers, Tokyo, Japan), pp. 551-557.

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