# Passive Acoustic Monitoring for Marine Mammals in the SOCAL Range Complex April 2021–May 2022

Ally C. Rice, Jennifer S. Trickey, Macey A. Rafter, Sean M. Wiggins, Kaitlin E. Frasier, 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 S. Trickey, taken under SEMARNAT permit SGPA/DVGS/00451/18

MPL TECHNICAL MEMORANDUM #663
January 2023

Suggested Citation:

Rice, A.C., Trickey, J.S., Rafter, M.A., Wiggins, S.M., Frasier, K.E., Baumann-Pickering, S., and Hildebrand, J.A. (2023) "Passive Acoustic Monitoring for Marine Mammals in the SOCAL Range Complex April 2021–May 2022," Marine Physical Laboratory, Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, MPL Technical Memorandum #663 under Cooperative Ecosystems Study Unit Cooperative Agreement N62473-21-2-0012 for U.S. Navy, U.S. Pacific Fleet, Pearl Harbor, HI.

Author contributions:

A.C.R. wrote and edited report, produced all plots of acoustic results, and conducted ambient soundscape and sonar metric analysis. J.S.T. conducted beaked whale and MFA sonar analysis. M.A.R. conducted explosion analysis. S.M.W. contributed to algorithm development. K.E.F., S.B.P., 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 April 2021 to May 2022 to detect marine mammal and anthropogenic sounds. High-frequency Acoustic Recording Packages (HARPs) recorded sounds between 10 Hz and 100 kHz at four locations: one site west of San Nicolas Island (1,100 m depth, site SN), two sites west of San Clemente Island (1,300 m depth, site E and 1,200 m depth, site H), and one site southwest of San Clemente Island (1,300 m depth, site N). With the offshore expansion of the SOCAL range, site SN was added into the monitoring effort for this reporting period to improve noise monitoring for the region.

While a typical southern California marine mammal assemblage is consistently detected in these recordings (Hildebrand *et al.*, 2012), only 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 for frequencies greater than ~200 Hz at sites SN and E and lowest at site H, likely related to local wind. 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 sounds, data analysis was performed using automated computer algorithms. Frequency modulated (FM) echolocation pulses from Cuvier's beaked whales were regularly detected at all sites, but were detected in much higher numbers at site E. At site E, detections were highest from December to May, while at site H they peaked in early summer 2021. Hubbs' beaked whale FM pulses (previously referred to as BW37V; Rice *et al.*, 2021) were only detected at site SN in January and April 2022. The FM pulse type, BW43, thought to be produced by Perrin's beaked whale (Baumann-Pickering *et al.*, 2014), was detected intermittently. 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 the majority of detections occurring during summer 2021. Site H had the most MFA sonar packet detections normalized per year, while site N had the highest cumulative sound exposure levels. Site E had the lowest number of sonar packet detections and the lowest maximum cumulative sound exposure level. Explosions were detected at all sites, but the number of explosions was highest at site H and lowest at site SN. A peak in number of explosions occurred in January at sites E, H, and N. At sites E and H, temporal and spectral parameters suggest 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 beaked whales. In addition, the low-frequency ambient soundscape, as well as the presence of Mid-Frequency Active (MFA) sonar and explosions, was analyzed.

This report documents the analysis of data recorded by High-frequency Acoustic Recording Packages (HARPs) that were deployed at four sites within the SOCAL Range Complex and collected data between April 2021 and May 2022 (Table 1; Table 2; Table 3; Table 4). The four recording sites include one to the west of San Nicolas Island (site SN), two to the west of San Clemente Island (sites E and H), and one to the southwest of San Clemente Island (site N; Figure 1; Figure 2).

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

| Deployment # | Monitoring Period | # Hours |
|---|---|---|
| 33 | 5/19/09 – 6/2/10 | 9096 |
| 40 | 7/22/10 – 11/6/10 | 2568 |
| 53 | 7/29/14 – 8/8/14 | 233 |
| 56 | 6/11/15 – 10/2/15 | 2710 |
| 57 | 3/17/16 – 1/7/17 | 7104 |
| 58 | 3/5/17 – 9/10/17 | 4553 |
| 59 | 10/4/17 – 8/2/18 | 7234 |
| **60** | **11/20/21 – 5/28/22** | **4544** |

**Table 2. SOCAL Range Complex acoustic monitoring at site E since January 2009. Periods of instrument deployment analyzed in this report are shown in bold. Deployment 66 did not record due to implosion of instrument floats during deployment.**

| Deployment # | Monitoring Period | # Hours |
|---|---|---|
| 31 | 1/13/09 – 3/9/09 | 1302 |
| 32 | 3/13/09 – 5/7/09 | 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 |
| 66 | - | - |
| 67 | 11/9/19 – 5/8/20 | 4362 |
| 68 | 5/9/20–10/29/20 | 4170 |
| 69 | 10/29/20–4/24/21 | 4247 |
| **70** | **4/25/21 – 10/28/21** | **4474** |
| **71** | **11/19/21 – 5/24/22** | **4435** |

**Table 3. SOCAL Range Complex acoustic monitoring at site H since January 2009. Periods of instrument deployment analyzed in this report are shown in bold. Missing deployments are the result of hydrophone failures.**

| Deployment # | Monitoring Period | # Hours |
|---|---|---|
| 31 | 1/13/09 – 3/8/09 | 1320 |
| 32 | 3/14/09 – 5/7/09 | 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 |
| 67 | 6/1/19 – 12/8/19 | 4557 |
| 68 | 12/8/19 – 5/8/20 | 3644 |
| 69 | 5/9/20–10/29/20 | 4172 |
| 70 | 10/29/20–4/24/21 | 4245 |
| **71** | **4/25/21 – 7/30/21** | **2321** |
| **72** | **7/30/21 – 12/18/21** | **3387** |
| **73** | **12/21/21 – 5/22/22** | **3667** |

**Table 4. 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 50 yielded no usable data due to flooding of the instrument from a hardware failure.**

| Deployment # | Monitoring Period | # Hours |
|---|---|---|
| 31 | 1/14/09 – 3/9/09 | 1296 |
| 32 | 3/14/09 – 5/7/09 | 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 – 4/9/11 | 2952 |
| 44 | 5/12/11 – 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 |
| 66 | 5/5/19 – 11/7/19 | 4481 |
| 67 | 11/8/19 – 4/29/20 | 4148 |
| 68 | 4/29/20–10/15/20 | 4058 |
| 69 | 11/6/20–4/15/21 | 3861 |
| **70** | **4/16/21 – 10/13/21** | **4337** |
| **71** | **11/19/21 – 5/13/22** | **4215** |

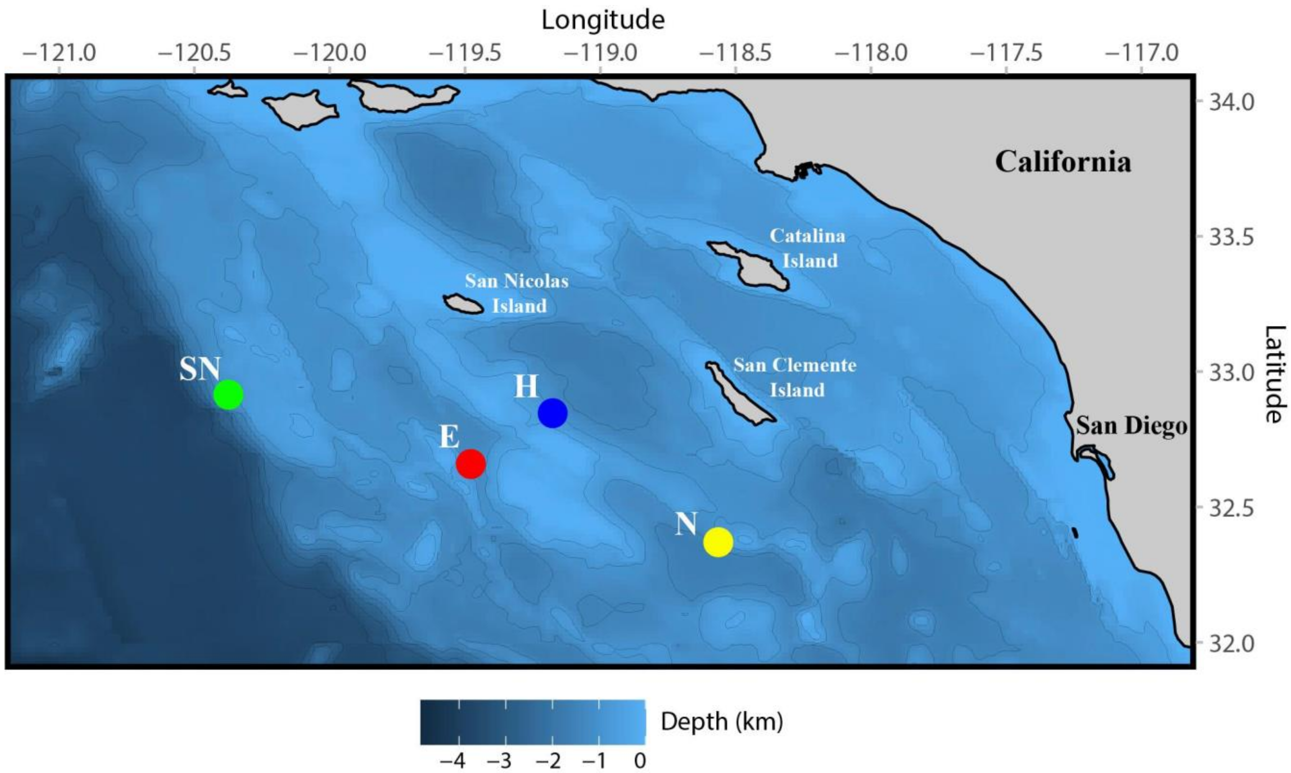


**Figure 1. Locations of High-frequency Acoustic Recording Package (HARP) deployment sites SN, E, H, and N (circles) in the SOCAL study area from April 2021 through May 2022. Color indicates bathymetric depth. Contour lines represent 500 m depth increments.**

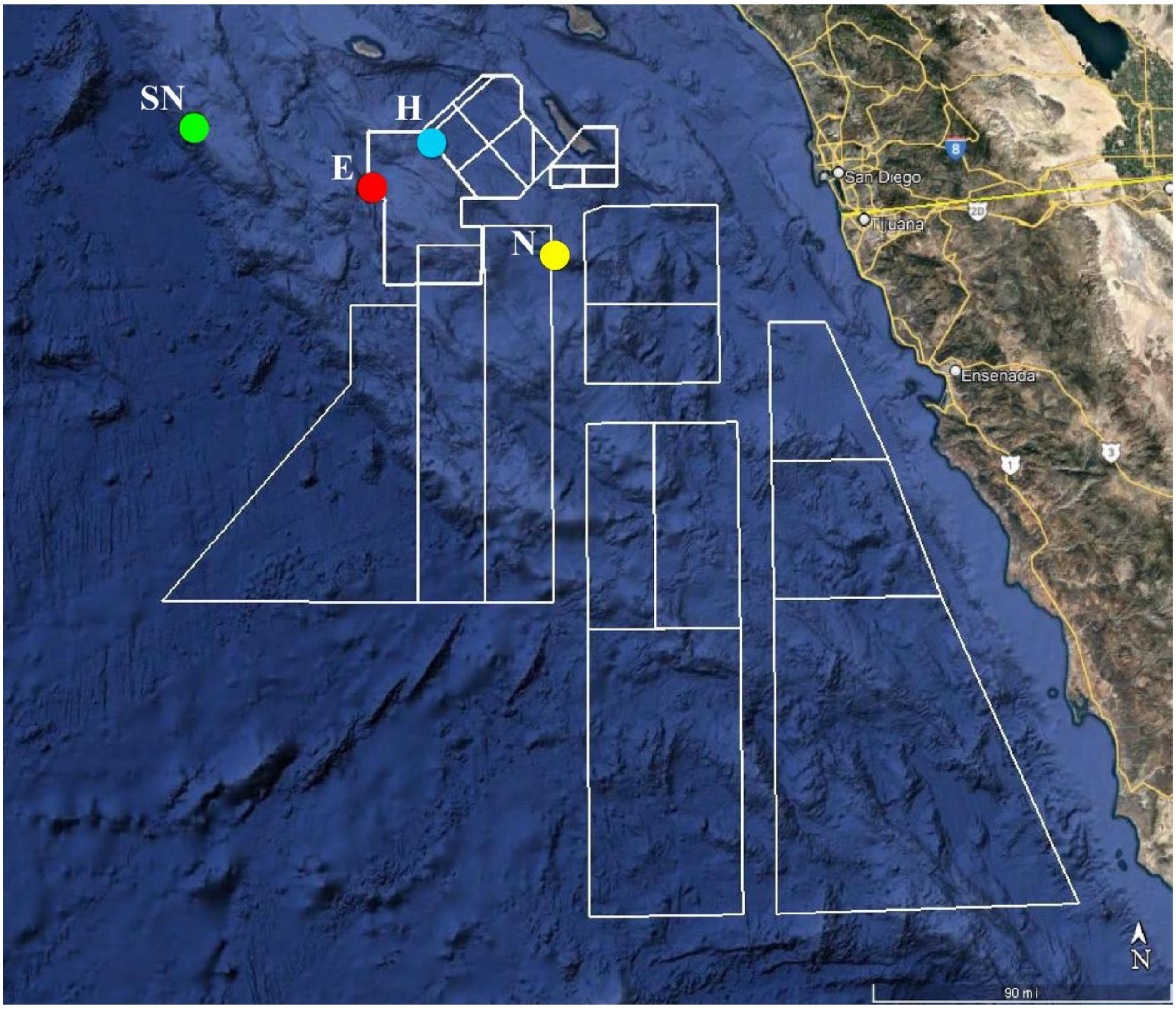

**Figure 2. Locations of High-frequency Acoustic Recording Package (HARP) deployments in the SOCAL study area (colored circles) and US Naval Operation Areas (white boxes).**

# Methods

## Passive Acoustic Monitoring

### 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 before initial deployment 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; Table 2; Table 3; Table 4) using HARPs sampling at 200 kHz. The sites analyzed in this report are designated site SN (32° 54.92' N, 120° 22.50' W, depth 1,100 m), site E (32° 39.56' N, 119° 28.76' W, depth 1,300 m), site H (32° 51.27'N, 119° 08.95' W, depth 1,200 m), and site N (32° 22.18' N, 118° 33.90' W, depth 1,300 m).

Site SN recorded from November 20, 2021 to May 28, 2022. Site E recorded from April 24, 2021 to October 28, 2021 and again from November 19, 2021 to May 24, 2022. Site H recorded from April 25, 2021 to May 22, 2022, with a short break between deployments from December 18 to 21, 2021. Site N recorded from April 16, 2021 to October 13, 2021 and again from November 19, 2021 to May 13, 2022. For all four sites, a total of 31,380 h (1,308 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. Analyses were conducted using appropriate automated detectors for whale and anthropogenic sound sources. Analysis was focused on 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 frequency-modulated (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), which has now been confirmed to belong to Hubbs' beaked whale (*M. carlhubbsi*; Ballance *et al.*, In Review), was found during this reporting period. This signal type was referred to as BW37V in previous reports (Rice *et al.*, 2021). A description of relevant signal types can be found below. Individual beaked whale echolocation clicks, as well as MFA sonar and explosion occurrence and levels were detected automatically using computer algorithms. For analysis of the low-frequency ambient soundscape, data were decimated by a factor of 100 for an effective bandwidth of 10 Hz to 1 kHz and long-term spectral averages (LTSAs) were created using a time average of 5 seconds and frequency bins of 1 Hz. For analysis of MFA sonar, data were decimated by a factor of 20 for an effective bandwidth of 10 Hz to 5 kHz and LTSAs were created using a time average of 5 seconds and frequency bins of 10 Hz. Full bandwidth data were used for the analysis of beaked whale signals and LTSAs were created using a time average of 5 seconds and a frequency bin size of 100 Hz. Details of all detection methods are described below.

**Low-frequency Ambient Soundscape**

HARPs write sequential 75-s acoustic records, from which sound pressure levels were calculated. Five, 5-s, 1-Hz sound pressure spectrum levels from the middle of each 75-s acoustic record were averaged to avoid system self-noise (specifically hard drive disk writes). Spectra from each day were subsequently combined as daily spectral averages.

**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; 2015).

Beaked whales can be identified acoustically by their echolocation signals (Baumann-Pickering *et al.*, 2014). These signals are 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, Hubbs', and likely Stejneger's beaked whales (Baumann-Pickering *et al.*, 2013b; Griffiths *et al.*, 2018; Ballance *et al.*, In Review).

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). During this reporting period, only Cuvier's, Hubbs', and BW43 signals were detected. 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, as they have a signal with lower frequency content than is typical of other beaked whales and therefore are not reliably identified by the detector used. Therefore, there was no detection effort for Baird's beaked whales. 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 3) 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.

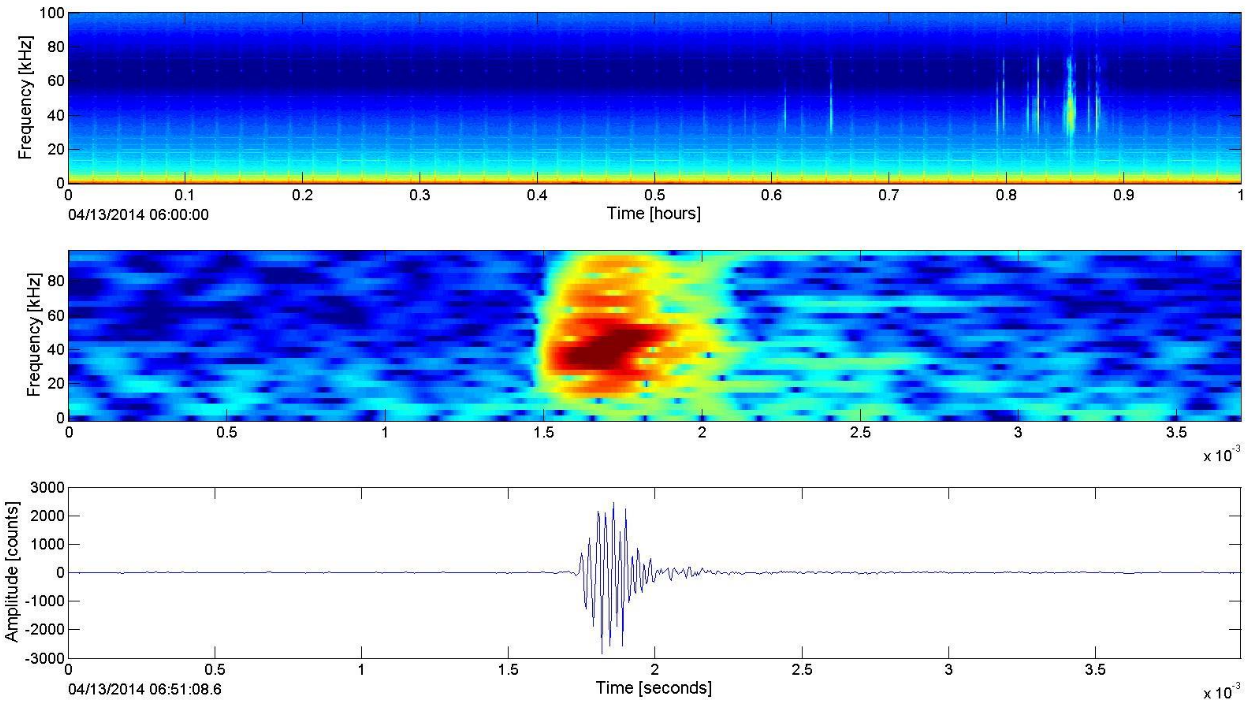


**Figure 3. Echolocation sequence of Cuvier’s beaked whale in an LTSA (top) and example FM pulse in a spectrogram (middle) and corresponding time series (bottom) previously recorded at site N.**

***Hubbs' Beaked Whales***

Hubbs' beaked whale echolocation signals (Figure 4) 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. This pulse type was previously referred to as BW37V (Griffiths *et al.*, 2018), but has recently been confirmed to be produced by Hubbs' beaked whale (Ballance *et al.*, In Review).

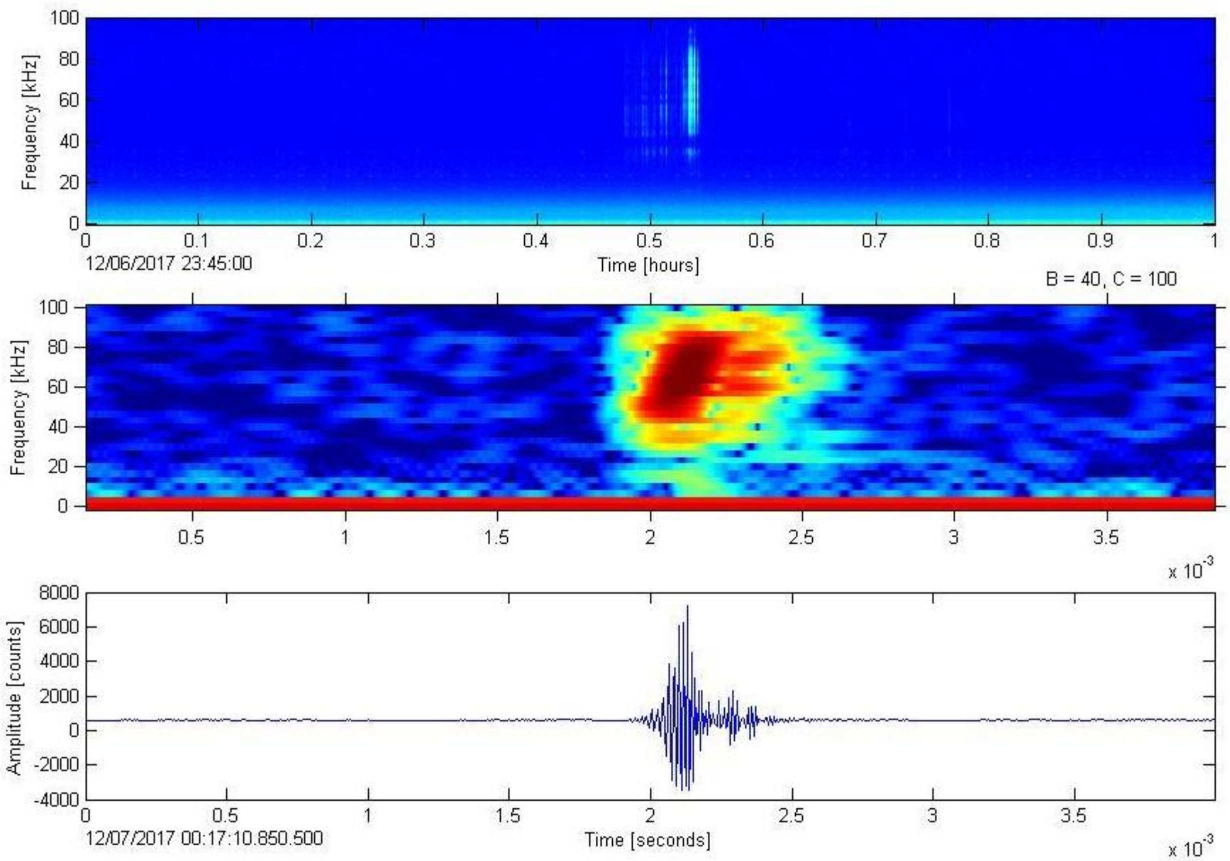


**Figure 4. Echolocation sequence of Hubbs' beaked whale in an LTSA (top) and example FM pulse in a spectrogram (middle) and corresponding time series (bottom) previously recorded at site E.**

### *BW43*

The BW43 FM pulse type (Figure 5) 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).

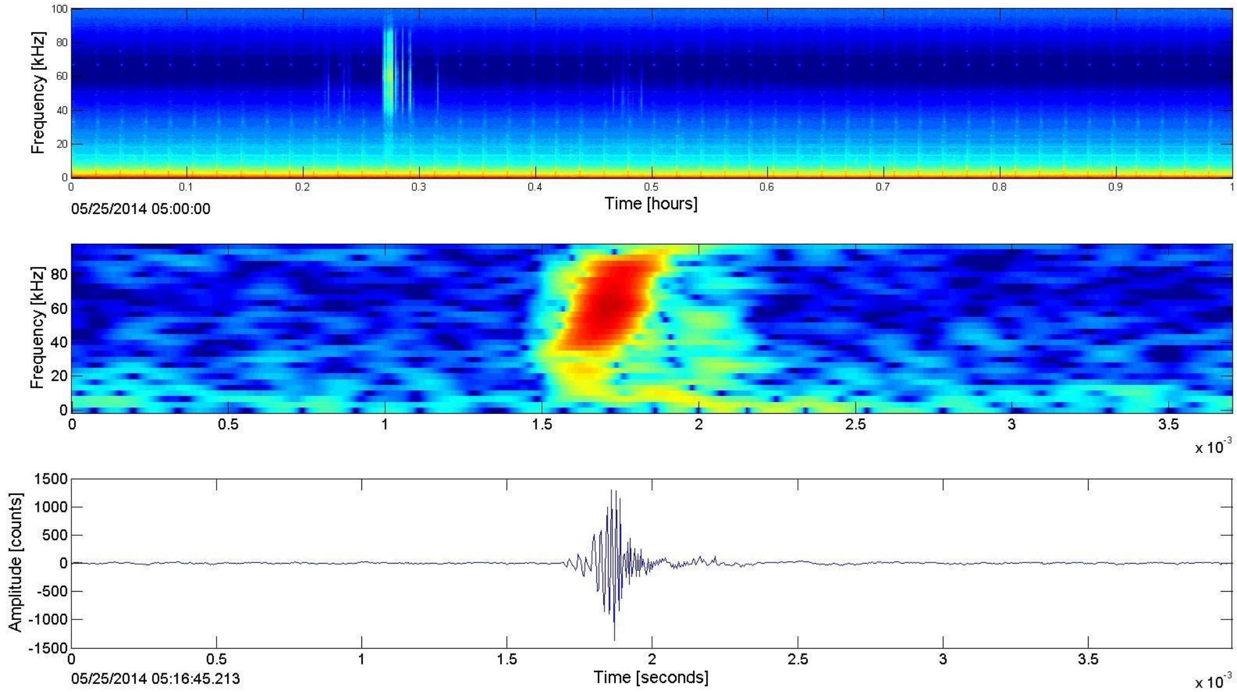


**Figure 5. Echolocation sequence of BW43 in an LTSA (top) and example FM pulse in a spectrogram (middle) and corresponding time series (bottom) previously recorded at site N.**

## Anthropogenic Sounds

Two anthropogenic sounds were monitored for this report: Mid-Frequency Active (MFA) sonar and explosions. Both sounds were detected by computer algorithms. 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 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. Packets are transmitted repetitively with inter-packet-intervals typically greater than 20 s (Figure 6). Groups of packets constitute a wave train (sometimes called an event). A 1-h separation between packets is used to delineate between wave trains. 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, thereby removing any false detections. Start and end times of these cleaned sonar events were then used in further processing.

In the second stage of MFA sonar detection, the 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 waveform amplitude 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 RL detection threshold of 130 dB pp re 1 µPa (Wiggins, 2015). Instrument maximum received level was ~165 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.

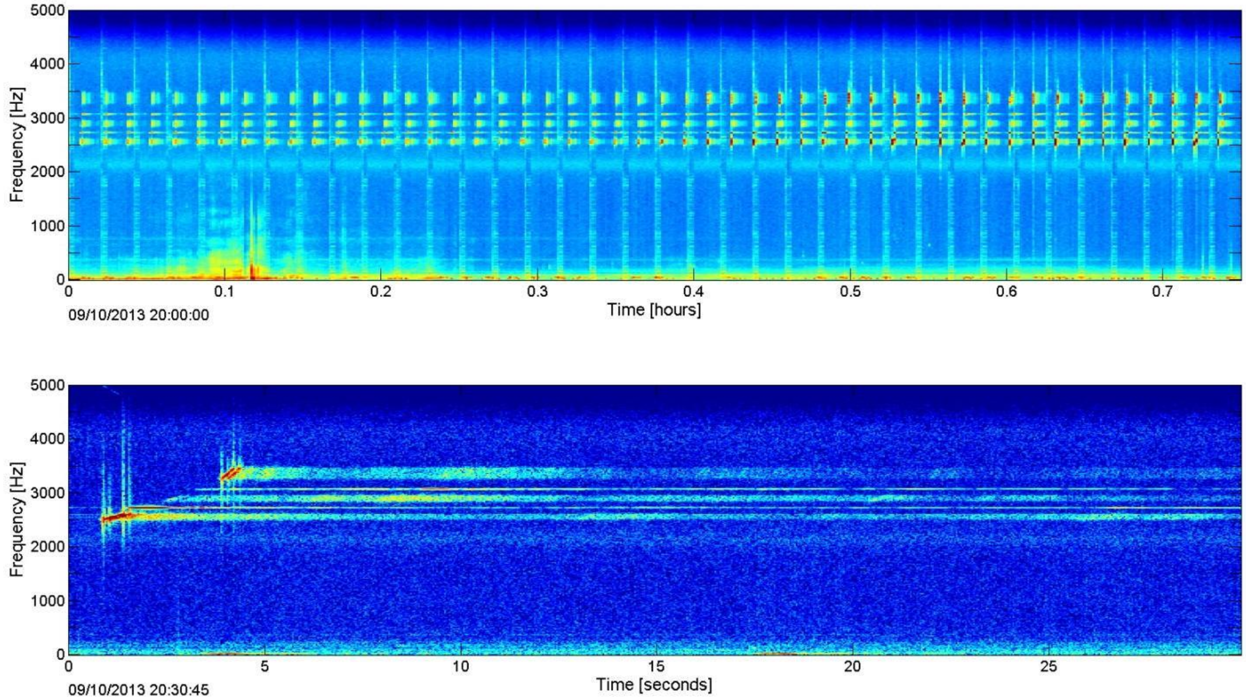


**Figure 6. MFA sonar previously recorded at site H and shown as a wave train event in a 45-minute LTSA (top) and as a single packet with multiple pulses in a 30 second spectrogram (bottom).**

***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. 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. An explosion appears as a vertical spike in the LTSA that, when expanded in the spectrogram, has a sharp onset with a reverberant decay (Figure 7). Explosions were detected automatically 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 temporal envelope (i.e., Hilbert transform lowpass filter) of the filtered time series and the temporal 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 RLs 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. By design, this detector produces a low number of false-negative detections but a high number of false-positive detections (>85%). To reduce the number of false-positive detections, each automated detection was manually reviewed and verified by a trained analyst.

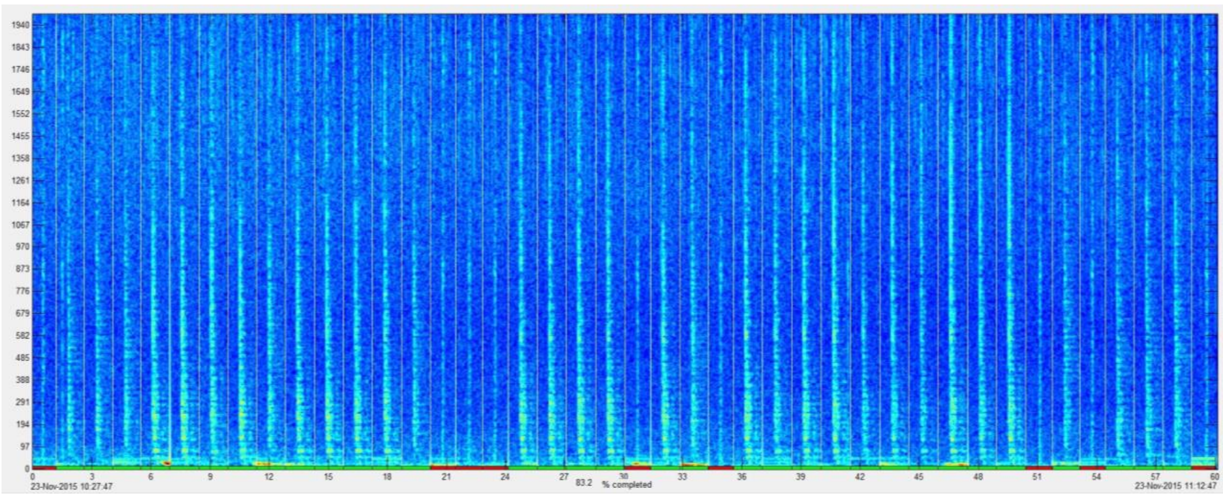

**Figure 7. Explosions previously detected at site H in the analyst verification stage where events are concatenated into a single spectrogram.**
**Green along the bottom indicates true and red indicates false detections.**

# Results

## Passive Acoustic Monitoring

The results of acoustic data analysis at sites SN, E, H, and N from April 2021 to May 2022 are summarized below.

We describe the low-frequency ambient soundscape and the seasonal occurrence of beaked whale 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 8) owing to the dominance of ship noise and whale calls at frequencies below 100 Hz and local wind and waves above 100 Hz (Hildebrand, 2009).
- Site H generally had lower spectrum levels (dB re 1 $\mu Pa^2$ /Hz), compared to the other sites, below 100 Hz (Figure 8). This is expected because site H is away from shipping routes and is located in a basin shielded from the deep ocean (McDonald *et al.*, 2008).
- Prominent peaks in sound spectrum levels observed in the frequency band 15–30 Hz during fall and winter at all sites were related to the seasonally increased presence of fin whale calls. The highest levels during this period occurred at site E (Figure 8).
- Spectral peaks around 45 Hz from July to December at all sites were related to blue whale B calls. The highest levels during this period occurred at site N. The peaks at 15 and 30 Hz at sites H and N were also a result of blue whale B calls (Figure 8).

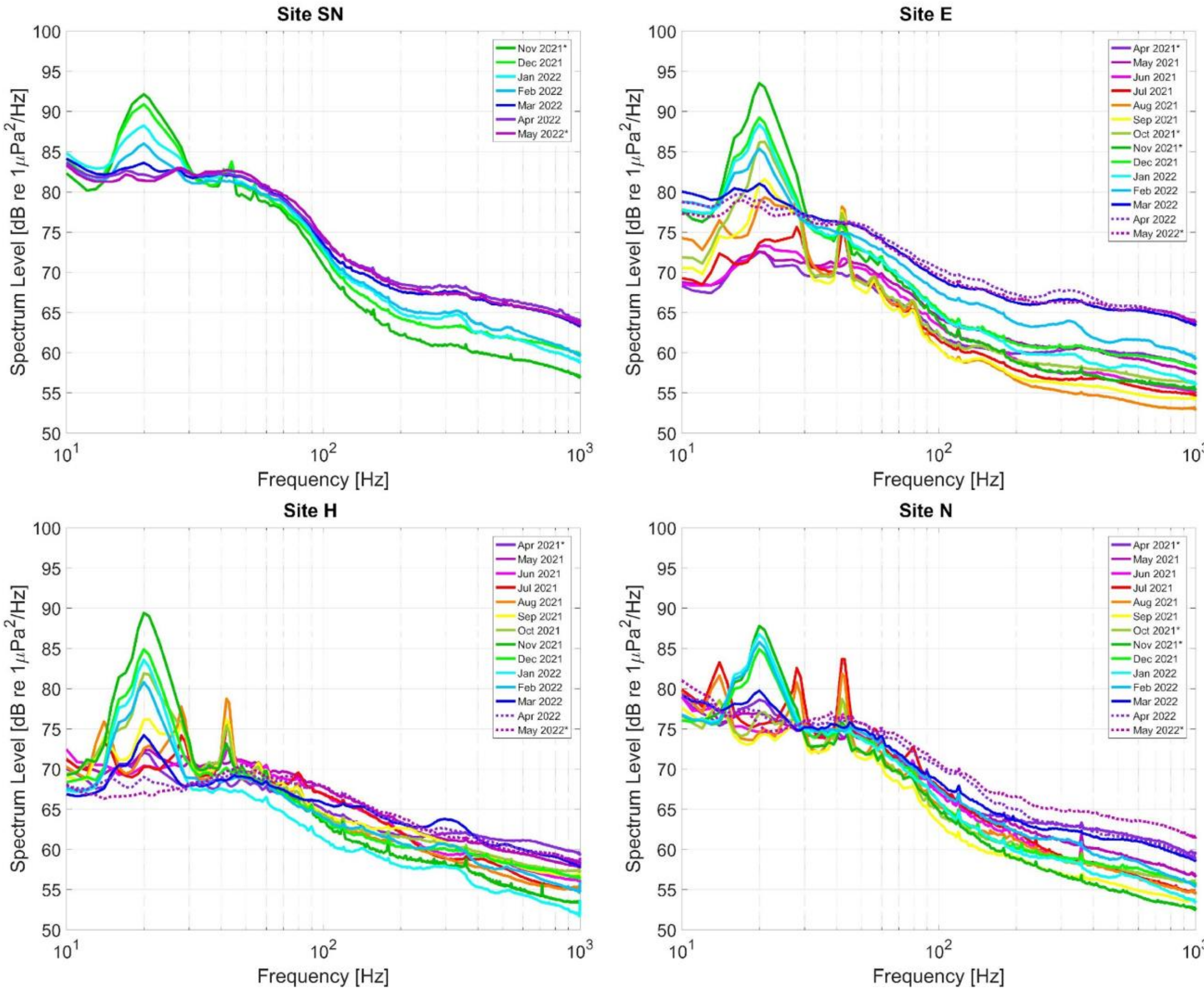


**Figure 8. Monthly averages of sound spectrum levels at sites SN, E, H, and N. Legend gives color-coding by month. * denotes months with partial (< 90%) effort.**

**Beaked Whales**

Three beaked whale species were detected during this reporting period. Cuvier's beaked whales were detected throughout the monitoring period at all four sites. Hubbs' beaked whales were detected during January and April, for < 2 hours on three separate days, only at site SN. The FM pulse type, BW43, possibly produced by Perrin's beaked whales (Baumann-Pickering *et al.*, 2014), was detected intermittently in low numbers for < 2 hours on three separate days between September and February, only at site N. More details of each species' presence at the four 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 site E and least at site N (Figure 9).
- At site SN, detections peaked in spring. At site E, detections were low August through October and highest December to May. At site H, detections peaked during early summer. Detections were low throughout the monitoring period at site N, with a slight increase in January (Figure 9).
- There was no discernable diel pattern for Cuvier's beaked whale detections (Figure 10).
- Detections were generally consistent with previous reports (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; Rice *et al.*, 2020; Rice *et al.*, 2021; Rice *et al.*, 2022).

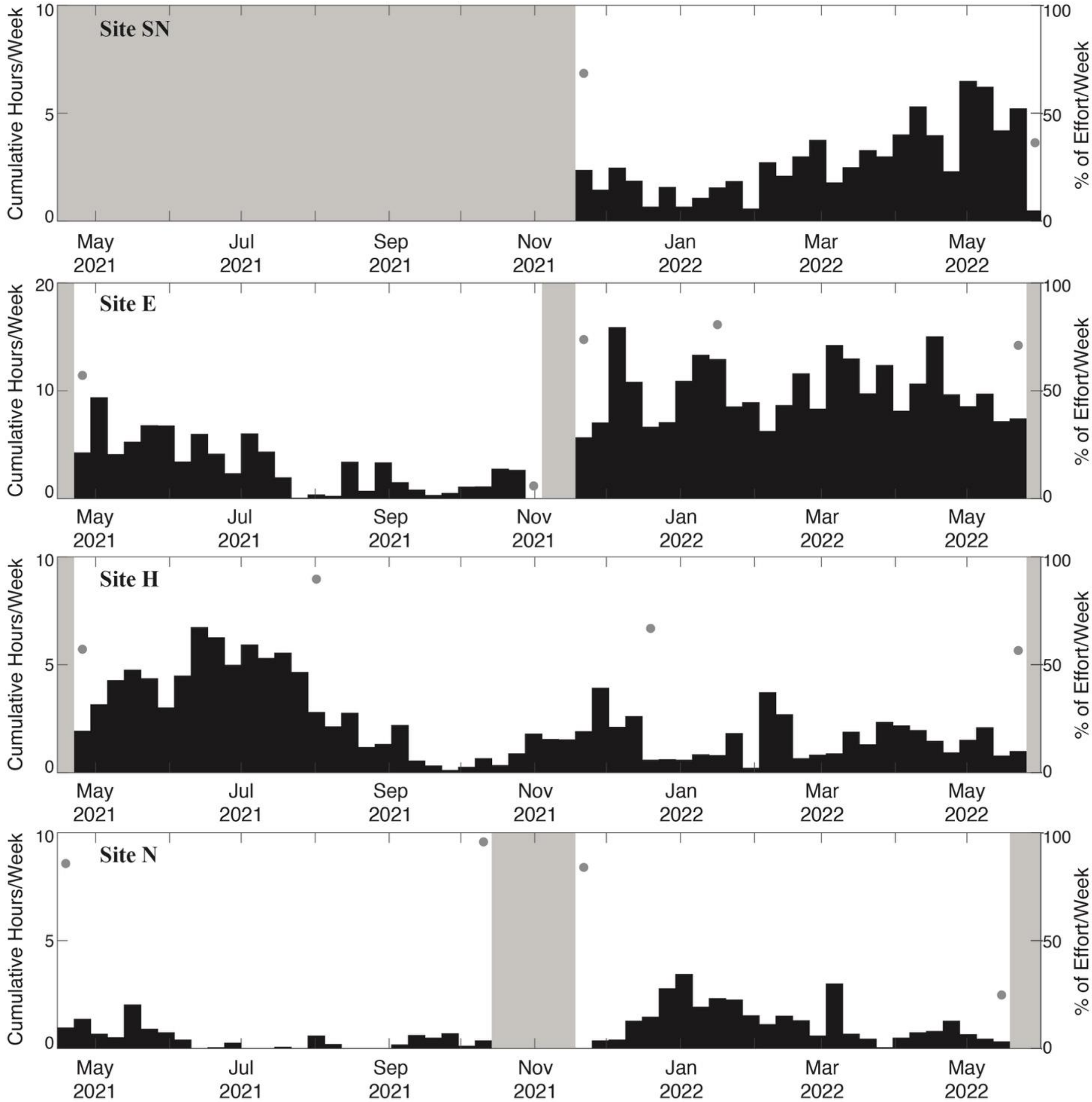


**Figure 9. Weekly presence of Cuvier's beaked whale FM pulses between April 2021 and May 2022 at sites SN, E, H, and N.**
**Gray dots represent percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week. Note the higher y-axis value for site E.**

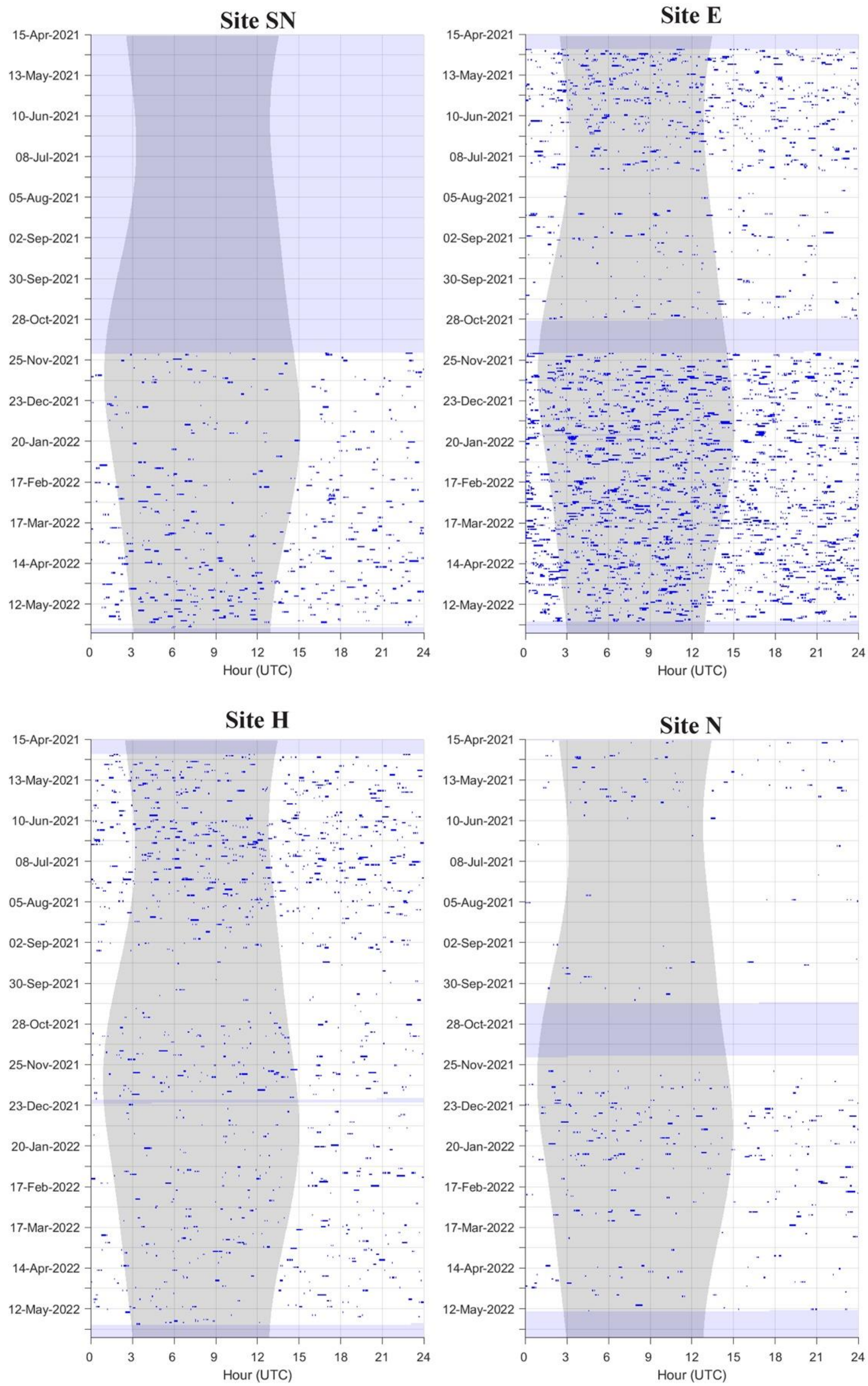


**Figure 10. Cuvier's beaked whale FM pulses, indicated by blue dots, in one-minute bins at sites SN, E, H, and N.**
**Gray vertical shading denotes nighttime and light purple horizontal shading denotes absence of acoustic data.**

### *Hubbs' Beaked Whales*

Hubbs' beaked whale FM pulses, previously referred to as BW37V FM pulses, were detected in low numbers at site SN.

- Hubbs' beaked whale FM pulses were detected at site SN on two days in January and on only one day in April. There were no detections at sites E, H, or N (Figure 11).
- All Hubbs' beaked whale detections occurred at night (Figure 12). Although there were not enough detections to determine if there was a diel pattern, almost all previous Hubbs' beaked whale detections occurred at night (Rice *et al.*, 2021; Rice *et al.*, 2022) or shortly before sunset (Rice *et al.*, 2019; Rice *et al.*, 2020).
- The number of detections is consistent with previous monitoring periods. However, there were no detections at sites E or H, as has occurred previously (Rice *et al.*, 2019; Rice *et al.*, 2020; Rice *et al.*, 2021; Rice *et al.*, 2022).

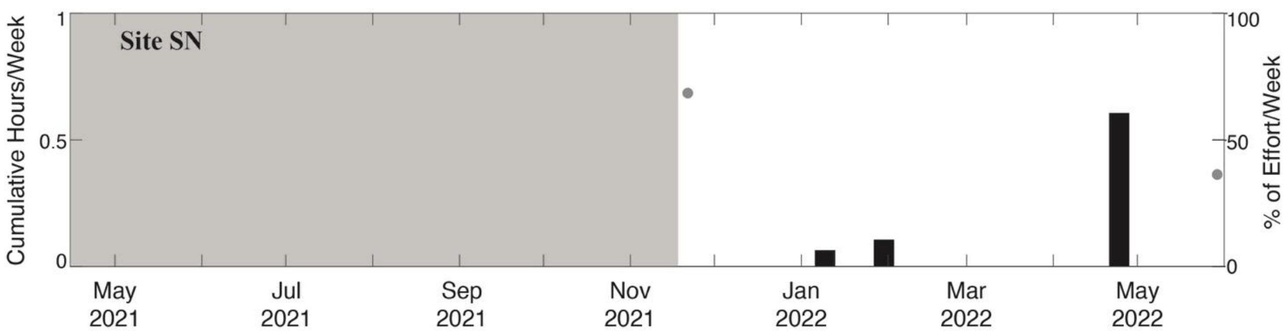


**Figure 11. Weekly presence of Hubbs' beaked whale FM pulses between April 2021 and May 2022 at site SN.**
**Gray dots represent percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.**

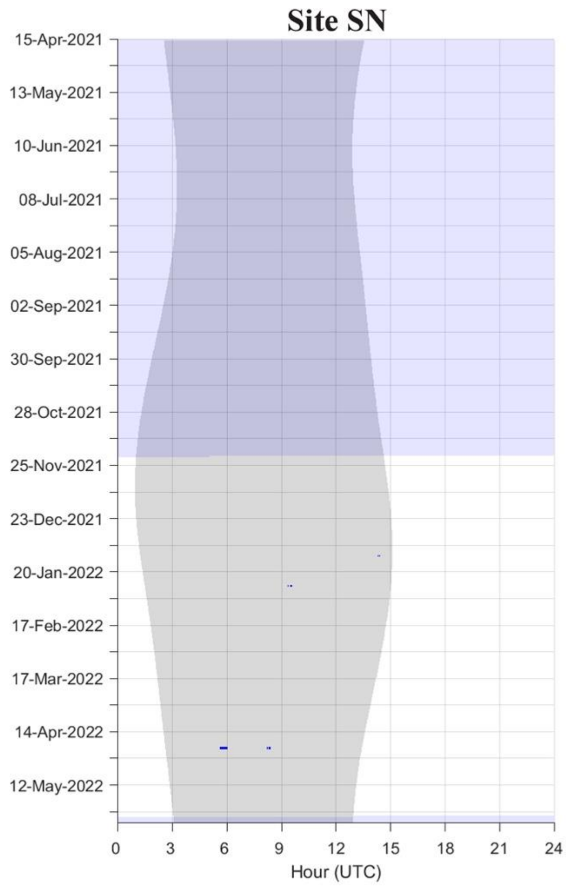


**Figure 12. Hubbs' beaked whale FM pulses, indicated by blue dots, in one-minute bins at site SN. Gray vertical shading denotes nighttime and light purple horizontal shading denotes absence of acoustic data.**

### *BW43*

BW43 FM pulses were detected in low numbers at site N. There were no detections at sites SN, H, or E.

- Detections occurred on one day each in September, December, and February (Figure 13).
- There was no discernable diel pattern for BW43 detections (Figure 14).
- The overall number of detections is generally consistent with previous reports (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; Rice *et al.*, 2020; Rice *et al.*, 2021; Rice *et al.*, 2022).

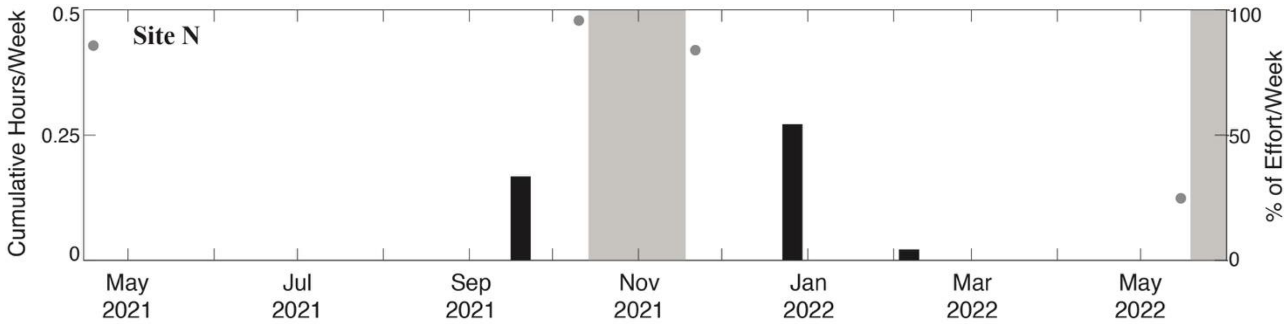


**Figure 13. Weekly presence of BW43 FM pulses between April 2021 and May 2022 at site N.**
**Gray dots represent percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.**

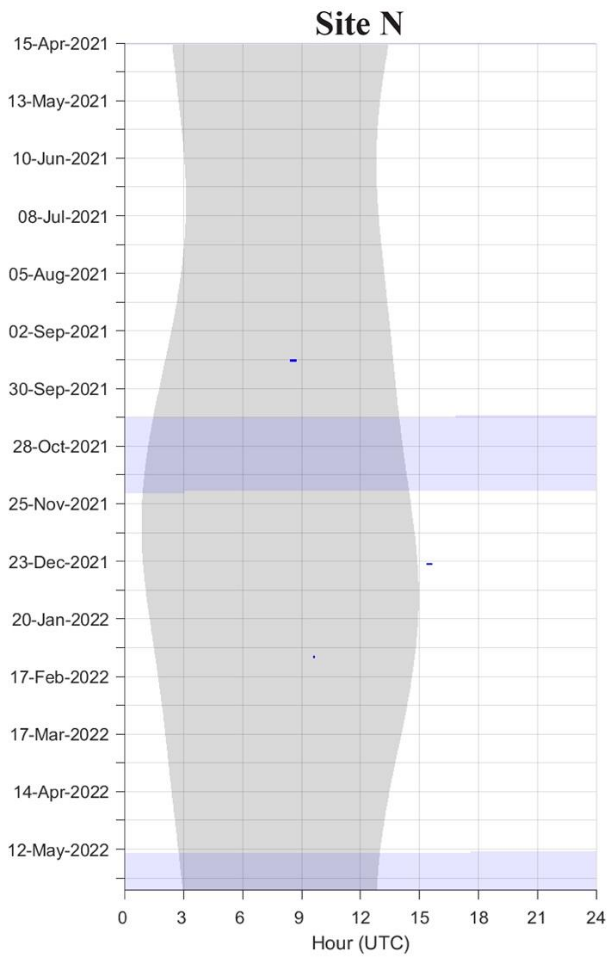


**Figure 14. BW43 FM pulses, indicated by blue dots, in five-minute bins at site N.**
**Gray vertical shading denotes nighttime and light purple horizontal shading denotes absence of acoustic data.**

## Anthropogenic Sounds

Anthropogenic sounds from MFA sonar (2.4–4.5 kHz) and explosions, between April 2021 and May 2022, 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 2021 and May 2022 are listed in Table 5 (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 H, while site E showed the lowest levels (Table 6).

- MFA sonar was detected throughout the recording period at sites E, H, and N. At these sites, detections were generally highest in summer. At site SN, MFA sonar primarily occurred in November 2021 and May 2022; however, none of the analyst-defined encounters remained after filtering, indicating that these MFA detections like had low received levels (Figure 15).
- There was no consistent diel pattern to MFA sonar detections, but at sites H and N there was a general decrease in detections in the hours before sunrise when training exercises were occurring (Figure 16).
- At site E, a total of 1,139 packets were detected, with a maximum received level of 145 $dB_{pp}$ re 1 µPa (Figure 17). Total wave train duration was 26.9 h (Figure 20), but the total packet duration was only about 1.2 h (4,306.5 s; Table 6; Figure 21).
- At site H, a total of 6,921 packets were detected, with a maximum received level of 164 $dB_{pp}$ re 1 µPa (Figure 17). Total wave train duration was 136.1 h (Figure 20), but the total packet duration was only about 4.8 h (17,351.9 s; Table 6; Figure 21).
- At site N, a total of 5,146 packets were detected, with a maximum received level of 165 $dB_{pp}$ re 1 µPa (Figure 17). Total wave train duration was 113.1 h (Figure 20), but the total packet duration was only 5.4 h (19,317 s; Table 6; Figure 21).
- Maximum cumulative sound exposure levels of wave trains were highest at site N, reaching a level of 173.8 dB re 1 $\mu Pa^2 s$ during April 2022. At site H, maximum levels of 168.4 dB re 1 $\mu Pa^2 s$ occurred in November 2021 and at site E, maximum levels of 142.8 dB re 1 $\mu Pa^2 s$ occurred in August 2021 (Figure 18).
- The majority of MFA sonar was detected outside of periods when training exercises occurred (Table 5; Figure 15).

**Table 5. Major naval training exercises in the SOCAL region between April 2021 and May 2022.**

| Exercise Dates |
|---|
| July 2 to 26, 2021 |
| November 4 to December 3, 2021 |

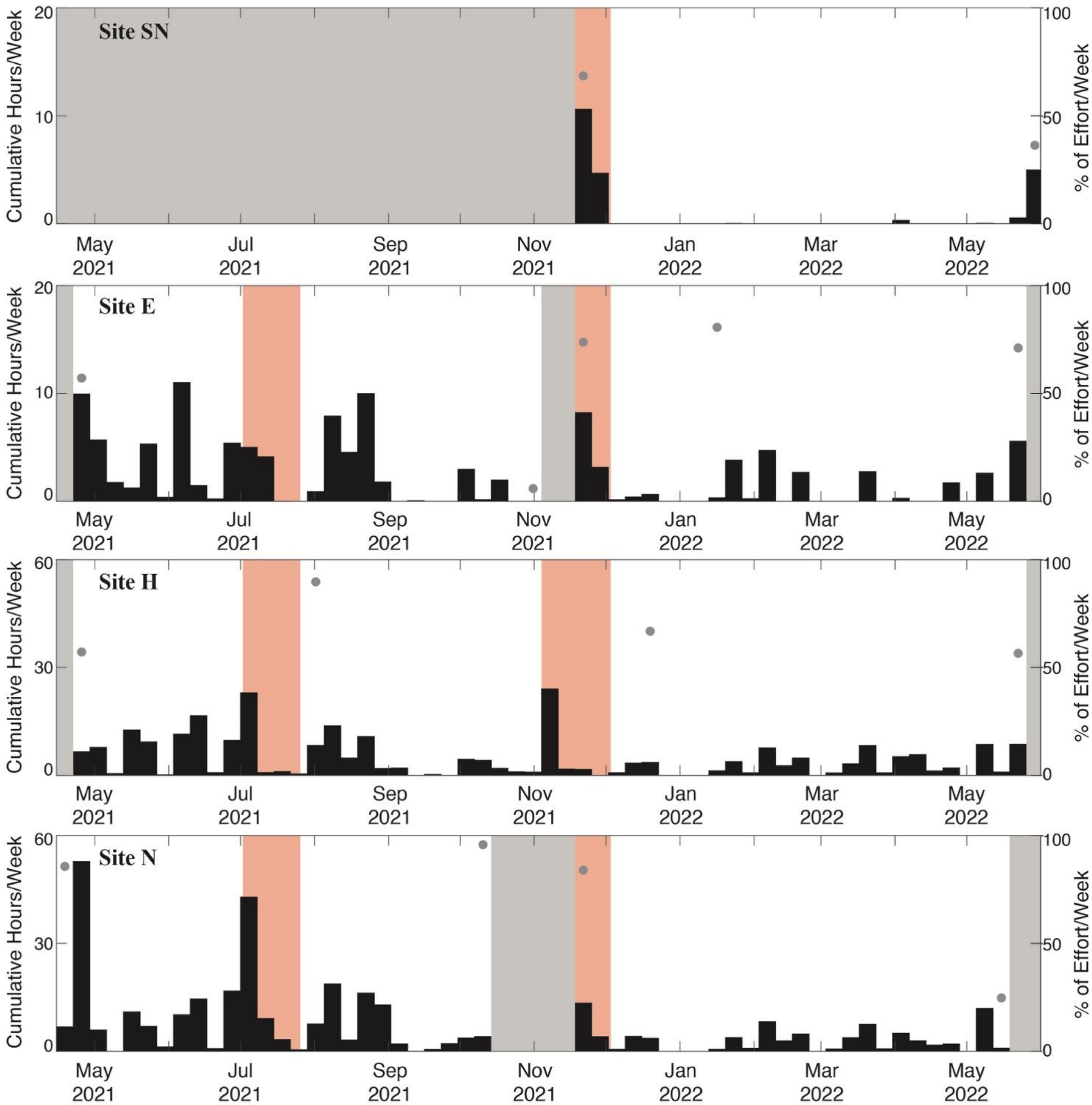


**Figure 15. Major naval training events (shaded light red, from Table 5) overlaid on weekly presence of MFA sonar < 5kHz from the *Silbido* detector between April 2021 and May 2022 at sites SN, E, H, and N.**
**Gray dots represent percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week. Note the higher y-axis values for sites H and N.**

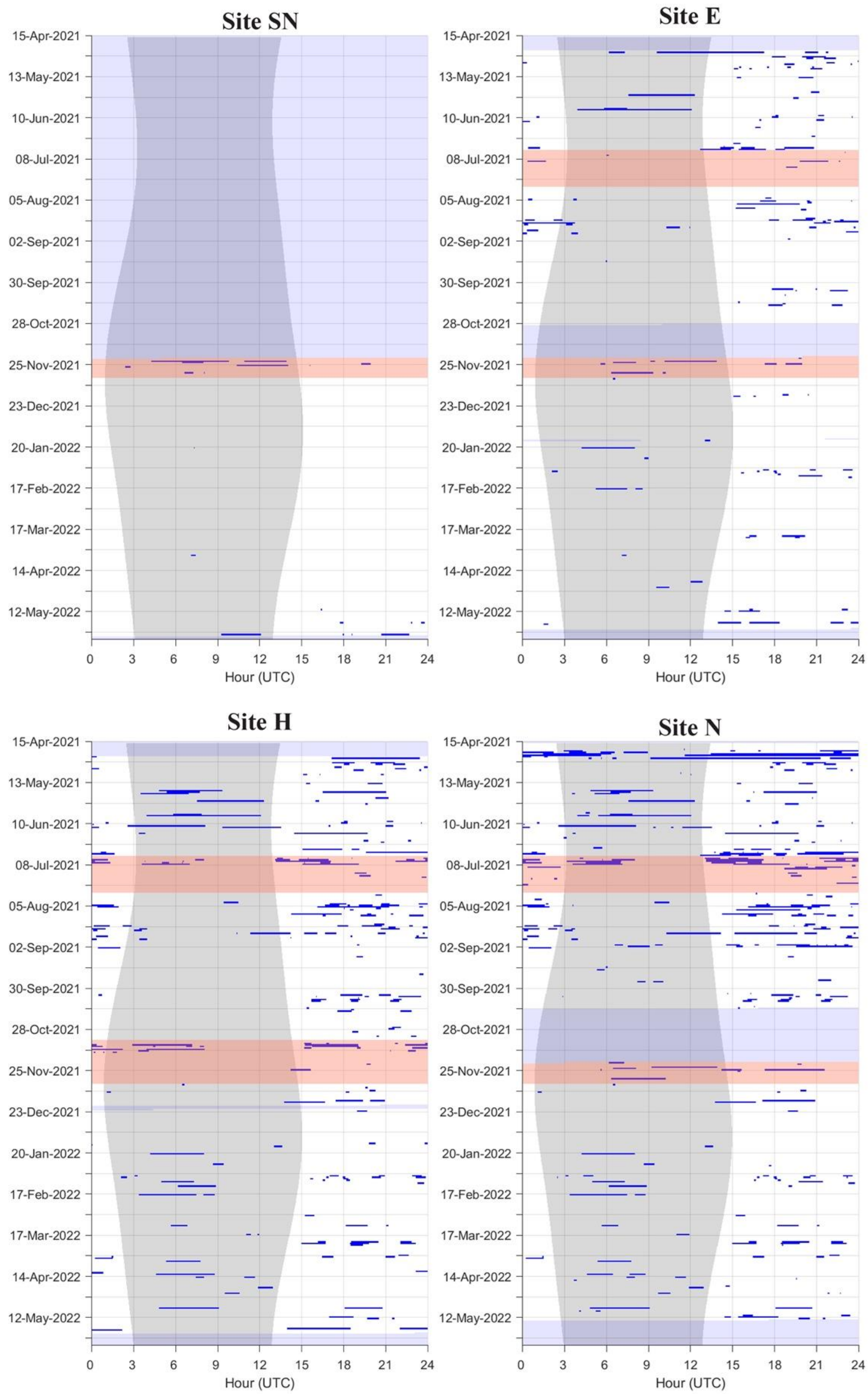


**Figure 16. Major naval training events (shaded light red, from Table 5) overlaid on MFA sonar < 5 kHz signals from the *Silbido* detector, indicated by blue dots, in one-minute bins at sites SN, E, H, and N.**
**Gray vertical shading denotes nighttime and light purple horizontal shading denotes absence of acoustic data.**

**Table 6. 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 | 371 (1.02) | 28 | 27 | 1,139 | 1,117 | 26.9 | 4,306.5 |
| H | 391 (1.07) | 91 | 85 | 6,921 | 6,468 | 136.1 | 17,351.9 |
| N | 356 (0.96) | 54 | 56 | 5,146 | 5,360 | 113.1 | 19,317 |

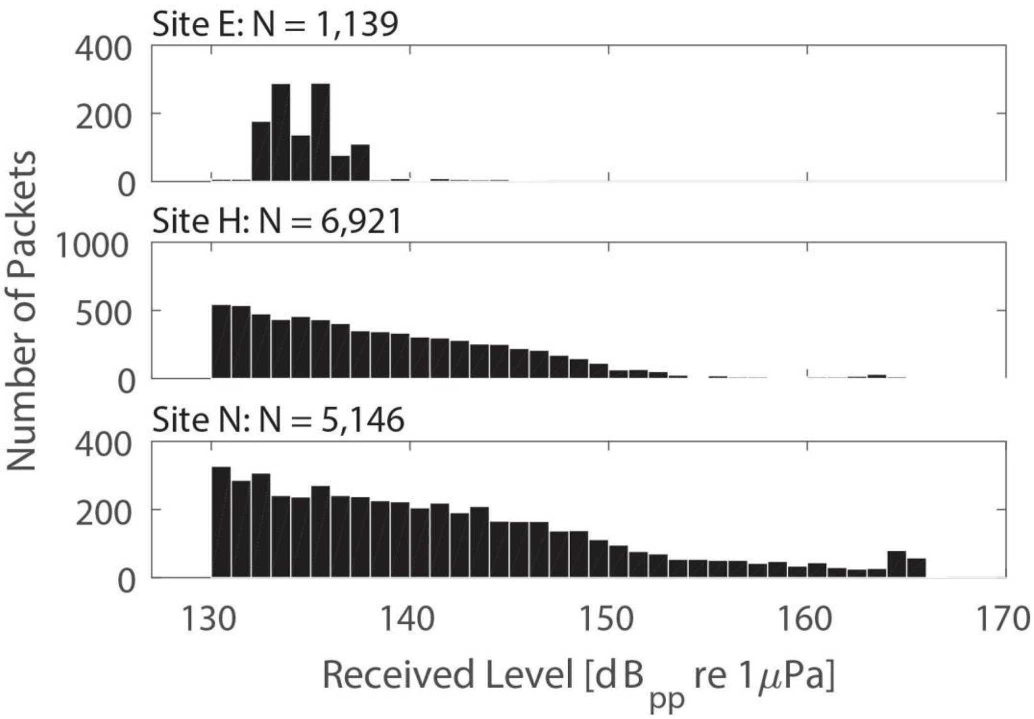


**Figure 17. MFA sonar packet peak-to-peak received level distributions for sites E, H, and N. The total number of packets detected at each site is given in the upper left corner of each panel. Instrument clipping levels typically occur around 165 $dB_{pp}$ re 1 µPa. Note the vertical axes are at different scales.**

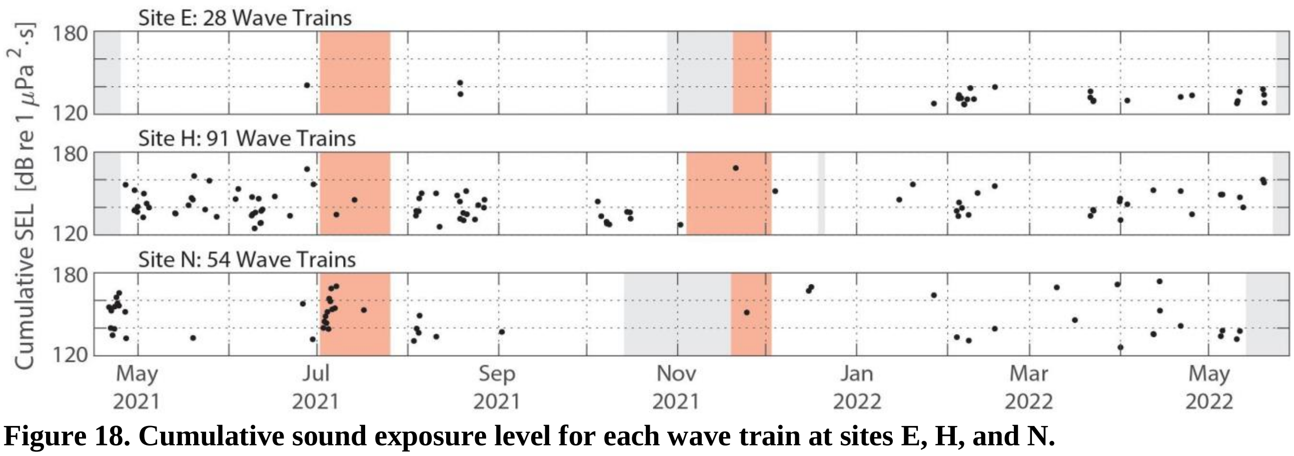


**Figure 18. Cumulative sound exposure level for each wave train at sites E, H, and N. Light red shading indicates major naval training events (Table 5).**

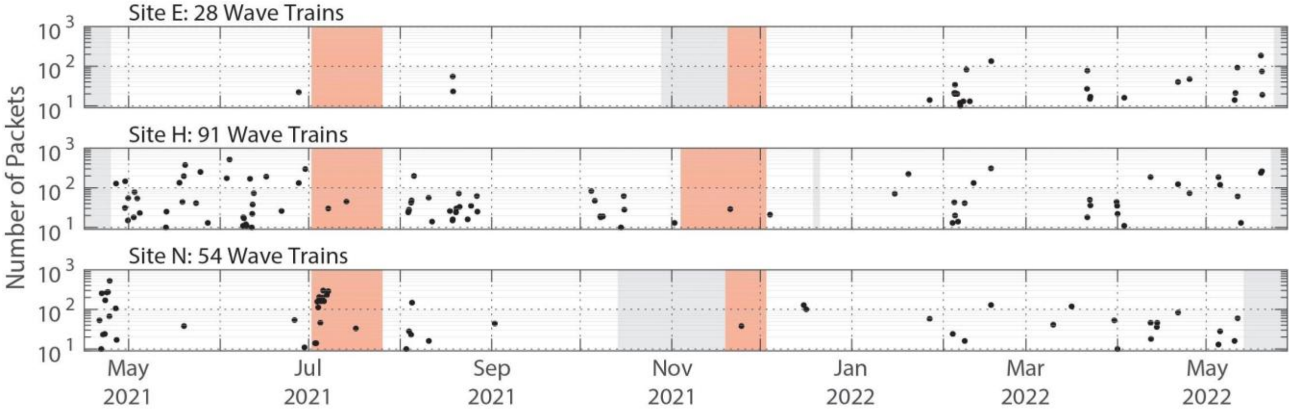


**Figure 19. Number of MFA sonar packets for each wave train at sites E, H, and N.**
**Light red shading indicates major naval training events (Table 5). Note the vertical axes are logarithmic base-10.**

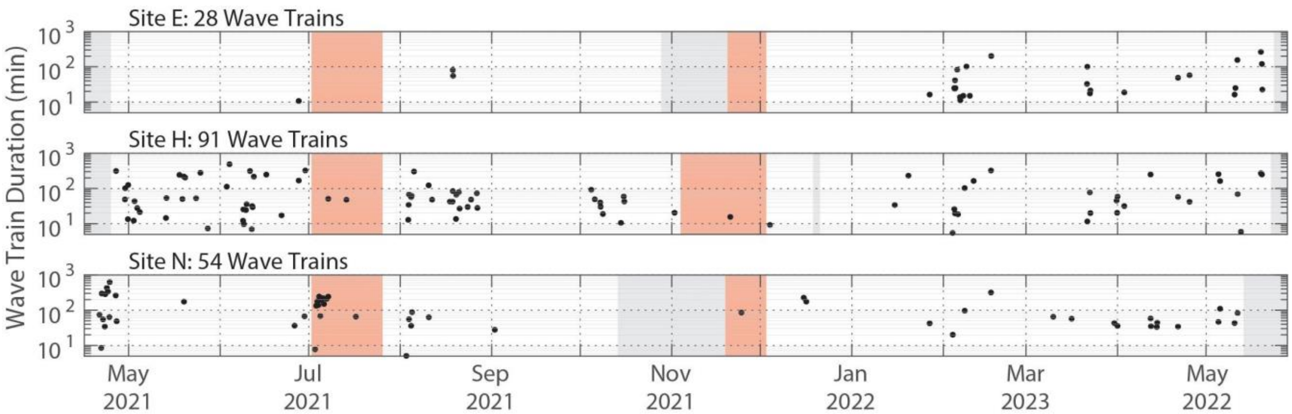


**Figure 20. Wave train duration at sites E, H, and N.**
**Light red shading indicates major naval training events (Table 5). Note the vertical axes are logarithmic base-10.**

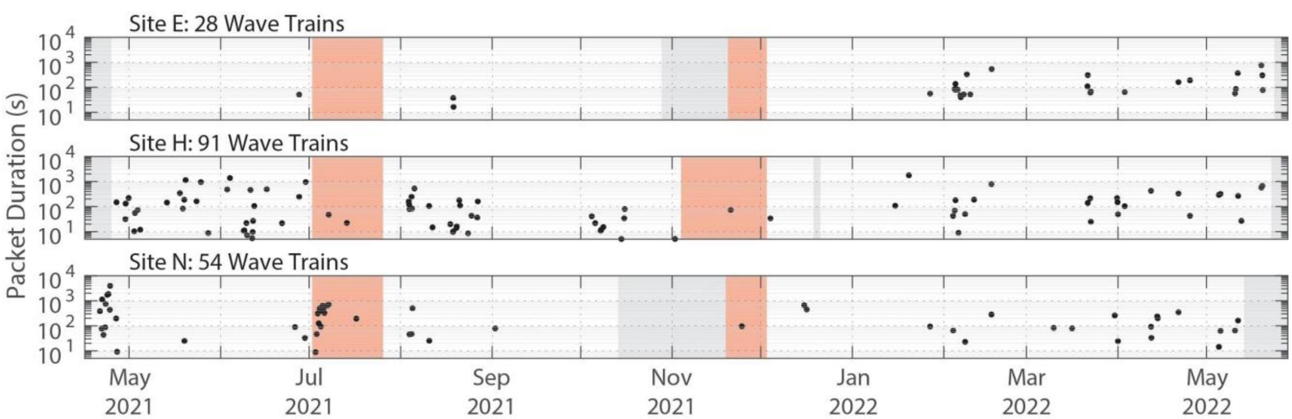


**Figure 21. Total packet duration for each wave train at sites E, H, and N.**
**Light red shading indicates major naval training events (Table 5). Note the vertical axes are logarithmic base-10.**

***Explosions***
Explosions were detected at all four sites.

- Explosions occurred throughout the monitoring periods at all sites. The highest number of explosions occurred at site H, with peaks in July and October 2021 and again in January 2022. This January peak was also present at sites E and N, where detections were otherwise low. The lowest number of detections occurred at site SN (Figure 22).
- Cumulative, 11,745 explosive events were detected during this reporting period. Total explosion counts at each site were as follows:
    - 46 at site SN
    - 2,186 at site E
    - 8,789 at site H
    - 724 at site N
- There was no clear diel pattern at sites SN or N. At sites E and H, there were more explosions at night (Figure 23). The predominant nighttime pattern at these sites suggests potential use of seal bombs by the squid fishery. The squid fishery in Southern California operates from October through March. However, daytime use at all sites may indicate another fishery using seal bombs. Additionally, the squid fishery has historically shifted effort among coastal pelagic finfish species (i.e., Pacific sardine, Pacific and jack mackerel, and northern anchovy) as a means of dealing with changes in resource availability (Pomeroy *et al.*, 2002; Aguilera *et al.*, 2015; Powell *et al.*, 2022).
- The overall number of detections at site H was <u>higher</u> than during more recent reporting periods (Rice *et al.*, 2017; Rice *et al.*, 2018; Rice *et al.*, 2019; Rice *et al.*, 2020; Rice *et al.*, 2021; Rice *et al.*, 2022). The overall number of detections at site E was also higher than in previous reporting periods, due to the peak in detections in January (Debich *et al.*, 2015a; Debich *et al.*, 2015b; Širović *et al.*, 2016; Rice *et al.*, 2017; Rice *et al.*, 2018; Rice *et al.*, 2019; Rice *et al.*, 2020; Rice *et al.*, 2021; Rice *et al.*, 2022).

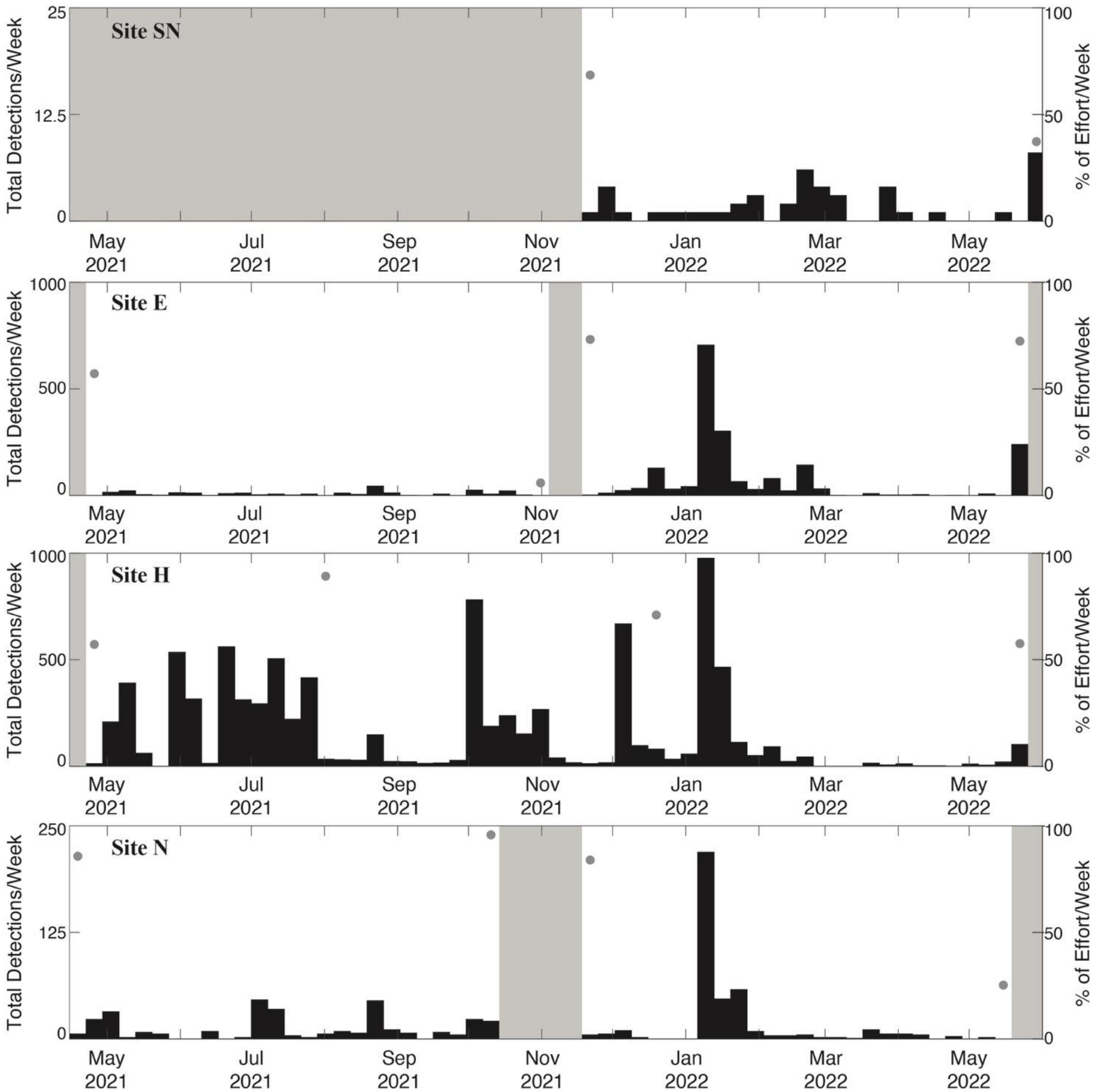


**Figure 22. Weekly presence of explosions between April 2021 and May 2022 at sites SN, E, H, and N. Gray dots represent percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week. Note the different y-axis values across sites.**

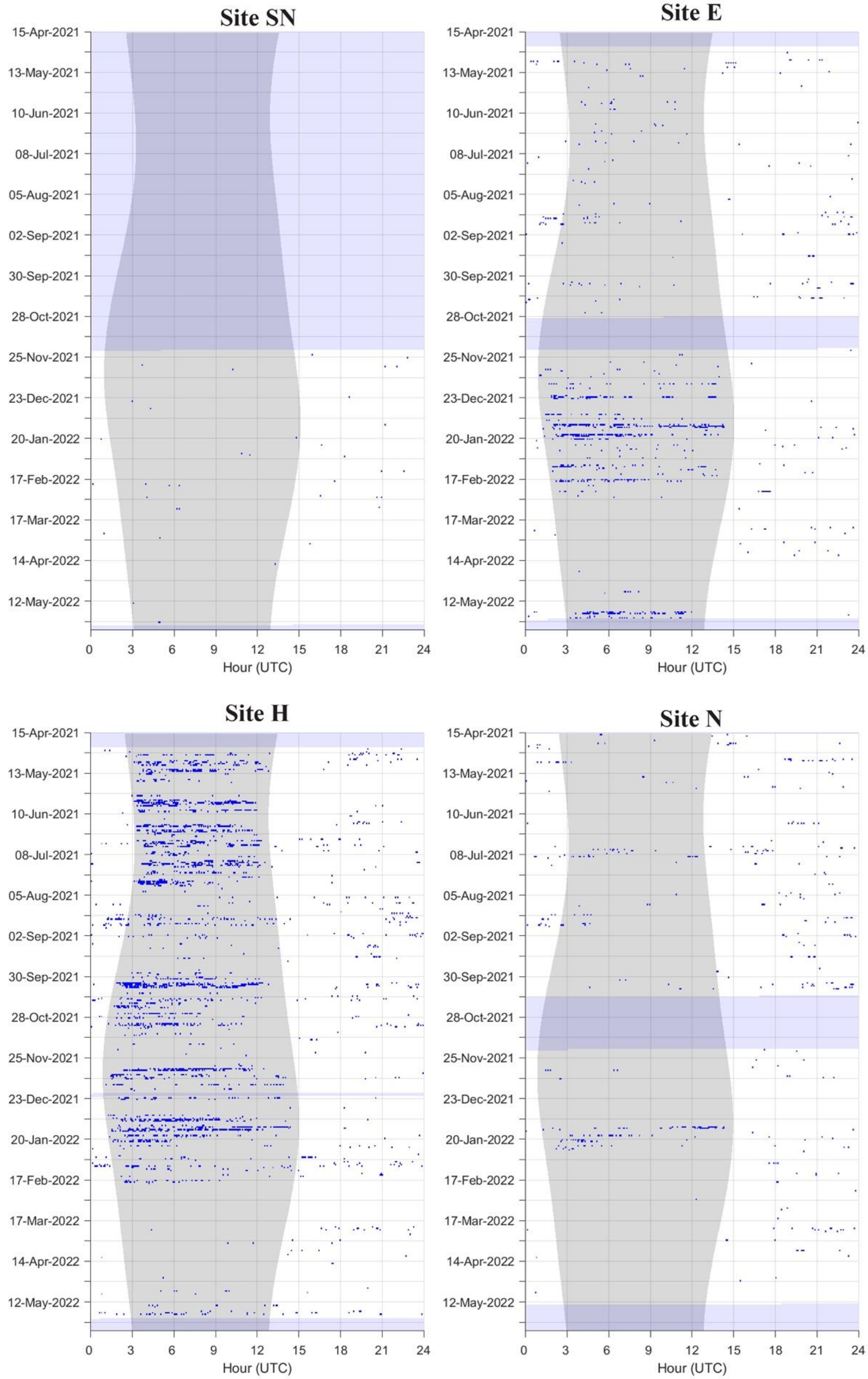


**Figure 23. Explosion detections, indicated by blue dots, in five-minute bins at sites SN, E, H, and N. Gray vertical shading denotes nighttime and light purple horizontal shading denotes absence of acoustic data.**

## Conclusions

The passive acoustic monitoring results from this report are generally consistent with previous reports for the SOCAL region. However, as noted during more recent reporting periods, site N again had fewer MFA wave trains and packets normalized per year than in past monitoring periods. Detections of explosions were also higher at site H and site E than during past reporting periods. Passive acoustic 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


Aguilera, S. E., Cole, J., Finkbeiner, E. M., Le Cornu, E., Ban, N. C., Carr, M. H., Cinner, J. E., Crowder, L. B., Gelcich, S., Hicks, C. C., Kittinger, J. N., Martone, R., Malone, D., Pomeroy, C., Starr, R. M., Seram, S., Zuercher, R., and Broad, K. (**2015**). "Managing small-scale commercial fisheries for adaptive capacity: insights from dynamic social-ecological drivers of change in Monterey Bay," PLoS One **10**, 22.

Ballance, L. T., Pitman, R. L., Barlow, J., Pusser, T., DeAngelis, A., Hayslip, C., Irvine, L., Steel, D., Baker, S., Gillies, D., Baumann-Pickering, S., Trickey, J. S., and Gisborne, B. (**In Review**). "Acoustic recordings, biological observations and genetic identification of a rare (?) beaked whale in the North Pacific: *Mesoplodon carlhubbsi*," Mar. Mamm. Sci.

Baumann-Pickering, S., McDonald, M. A., Simonis, A. E., Berga, A. S., 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," J. Acoust. Soc. Am. **134**, 2293-2301.

Baumann-Pickering, S., Roch, M. A., Brownell, R. L., Simonis, A. E., McDonald, M. A., Solsona-Berga, A., Oleson, E. M., Wiggins, S. M., and Hildebrand, J. A. (**2014**). "Spatio-temporal patterns of beaked whale echolocation signals in the North Pacific," PLoS ONE **9**, 17.

Baumann-Pickering, S., Simonis, A. E., Wiggins, S. M., Brownell, R. L., and Hildebrand, J. A. (**2013b**). "Aleutian Islands beaked whale echolocation signals," Mar. Mamm. Sci. **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," Mar. Mamm. Sci. **35**, 1058-1069.

Hildebrand, J. A. (**2009**). "Anthropogenic and natural sources of ambient noise in the ocean," Mar. Ecol. Prog. Ser. **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, R. L. (**2008**). *Marine mammals of the world: a comprehensive guide to their identification*.

Jefferson, T. A., Webber, M. A., and Pitman, R. L. (**2015**). *Marine mammals of the world: a comprehensive guide to their identification. Second edition*.

Johnson, M., Madsen, P. T., Zimmer, W. M. X., de Soto, N. A., and Tyack, P. L. (**2004**). "Beaked whales echolocate on prey," Proc. R. Soc. B-Biol. Sci. **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., Wiggins, S. M., and Ross, D. (**2008**). "A 50 Year comparison of ambient ocean noise near San Clemente Island: A bathymetrically complex coastal region off Southern California," J. Acoust. Soc. Am. **124**, 1985-1992.

Pomeroy, C., Hunter, M. S., and Los Huertos, M. (**2002**). *Socio-economic profile of the California wetfish industry* (California Seafood Council, Santa Barbara, CA).

Powell, F., Levine, A., and Ordonez-Gauger, L. (**2022**). "Climate adaptation in the market squid fishery: fishermen responses to past variability associated with El Nino Southern Oscillation cycles inform our understanding of adaptive capacity in the face of future climate change," Clim. Change **173**, 21.

Rice, A. C., Baumann-Pickering, S., Hildebrand, J. A., Rafter, M., Reagan, E., Trickey, J. S., 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.

Rice, A. C., Rafter, M., Trickey, J. A., Wiggins, S. M., Baumann-Pickering, S., and Hildebrand, J. A. (**2020**). "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 Pacific Fleet, Pearl Harbor, HI).

Rice, A. C., Rafter, M., Trickey, J. S., Wiggins, S. M., Baumann-Pickering, S., and Hildebrand, J. A. (**2021**). "Passive Acoustic Monitoring for Marine Mammals in the SOCAL Range Complex November 2018-May 2020," (Marine Physical Laboratory, Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, MPL Technical Memorandum #650 under Cooperative Ecosystems Study Unit Cooperative Agreement N62473-19-2-0028 for U.S. Navy Pacific Fleet, Pearl Harbor, HI).

Rice, A. C., Trickey, J. S., Giddings, A., Rafter, M. A., Wiggins, S. M., Frasier, K. E., Baumann-Pickering, S., and Hildebrand, J. A. (**2022**). "Passive Acoustic Monitoring for Marine Mammals in the SOCAL Range Complex April 2020-2021 and Abundance and Density Estimates from CalCOFI Visual Surveys 2004-2021," (Marine Physical Laboratory, Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, MPL Technical Memorandum #657 under Cooperative Ecosystems Study Unit Cooperative Agreement N62473-21-2-0012 for U.S. Navy Pacific Fleet, Pearl Harbor, HI).

Roch, M. A., Brandes, T. S., Patel, B., Barkley, Y., Baumann-Pickering, S., and Soldevilla, M. S. (**2011a**). "Automated extraction of odontocete whistle contours," J. Acoust. Soc. Am. **130**, 2212-2223.

Roch, M. A., Klinck, 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," J. Acoust. Soc. Am. **129**, 467-475.

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 in the SOCAL Range Complex July 2014 - May 2015," (Marine Physical Laboratory, Scripps Institution of Oceanography, La Jolla, CA), p. 39.

Soldevilla, M. S., Henderson, E. E., Campbell, G. S., Wiggins, S. M., Hildebrand, J. A., and Roch, M. A. (**2008**). "Classification of Risso's and Pacific white-sided dolphins using spectral properties of echolocation clicks," J. Acoust. Soc. Am. **124**, 609-624.

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 broad-band, long-term marine mammal monitoring," Symposium on Underwater Technology and Workshop on Scientific Use of Submarine Cables and Related Technologies, Vols 1 and 2, 594.

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*)," J. Acoust. Soc. Am. **117**, 3919-3927.