Passive Acoustic Monitoring for Marine Mammals in the Gulf of Alaska Temporary Maritime Activities Area May to September 2015 and April to September 2017

Ally C. Rice, Alba Solsona Berga, Natalie Posdaljian, Macey Rafter, Bruce J. Thayre, Jennifer S. Trickey, Sean M. Wiggins, Simone Baumann-Pickering, Ana Širović, John A. Hildebrand.

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

Sperm whale, Photo by Jennifer Trickey

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Executive Summary

Passive acoustic monitoring was conducted in the Gulf of Alaska Temporary Maritime Activities Area (GATMAA) from May to September 2015 and from April to September 2017 to record the low-frequency ambient soundscape and detect marine mammal and anthropogenic sounds during times of naval exercises in the area. High-frequency Acoustic Recording Packages (HARPs) recorded sounds between 10 Hz and 100 kHz at three locations: a continental slope site in deep water (900 m depth, site CB), a deep water site (hydrophone was placed at 1200 m at a location where depth was approximately 4000 m, site AB), and a deep offshore site at Quinn Seamount (900 m depth, site QN).

Ambient sound levels were highest at site CB in 2015, likely due to strumming of the hydrophone support cable. Peaks in spectrum levels occurred at all sites during September and are related to the seasonally increased presence of blue and fin whales, though peaks were higher overall in 2017.

For marine mammal and anthropogenic sounds, data analysis consisted of detecting sounds by analyst visual scans of long-term spectral averages (LTSAs) and spectrograms, and by automated computer algorithm detection when possible. The data were divided into three frequency bands and each band was analyzed for marine mammal and anthropogenic sounds.

Four baleen whale species were recorded: blue, fin, gray, and humpback whales. No North Pacific right whale up calls were noted. Blue whales and fin whales were the most commonly detected baleen whales in these recordings. Blue whale B calls were the most common blue whale call type detected and peaked in August and September 2017 at all sites. Blue whale D calls were highest at site QN and lowest at site CB. Central Pacific tonal calls were the least common blue whale call type but were detected at all three sites, peaking in August. The fin whale acoustic index (representative of 20 Hz calls) was low throughout the summer and began to increase in August at all sites. Meanwhile, fin whale 40 Hz calls were seen throughout the recordings at all sites, with highest calling in June 2017 at site QN and lowest calling at site AB. Humpback whales were detected at sites CB and QN, with peaks in calling during spring 2015 at site QN and spring 2017 at site CB. Gray whale M3 calls were detected in low numbers and occurred only at sites CB and QN in 2015.

Signals from three known odontocete species were recorded: sperm whales, Cuvier’s beaked whales, and presumable Stejneger’s beaked whales. Sperm whale clicks occurred throughout the summer at all sites, but were most common at site CB in 2015 and sites CB and QN in 2017. Cuvier’s beaked whales were detected most commonly at site AB in spring 2017, were detected only once in 2015 at site QN, and were never detected at site CB. Stejneger’s beaked whales were detected at all three sites with the most detections occurring at site CB and the least at site QN.

Three anthropogenic signals were detected: mid-frequency active (MFA) sonar, low-frequency active (LFA) sonar, and explosions. MFA sonar was detected in June 2015 and in May 2017 at all sites, while LFA sonar was only detected in June 2015. These detections corresponded with known naval training exercises. Site CB had the most MFA sonar packet detections normalized per year in 2015 and, along with site AB, had the highest cumulative sound exposure levels. In 2017, site QN had the lowest maximum received levels, cumulative sound exposure levels, and the least amount of MFA sonar packet detections. Explosions were detected in low numbers at all sites, although there were no detections at site CB in 2017. Explosion detections peaked in early spring in 2015 and occurred more sporadically in 2017.

Project Background

The Navy's Gulf of Alaska Temporary Maritime Activities Area (GATMAA) is an area approximately 300 nautical miles (nm) long by 150 nm wide, situated south of Prince William Sound and east of Kodiak Island (Figure 1). It extends from the shallow shelf region, over the shelf break and into deep offshore waters. The region has a subarctic climate and is a highly productive marine ecosystem as a result of upwelling linked to the counterclockwise gyre of the Alaska current.

A diverse array of marine mammals is found here, including baleen whales, beaked whale, other toothed whales, and pinnipeds. Endangered marine mammals that are known to inhabit this area are blue (*Balaenoptera musculus*), fin (*B. physalus*), humpback (*Megaptera novaeangliae*), North Pacific right (*Eubalaena japonica*), and sperm whales (*Physeter macrocephalus*). North Pacific right whales are of particular interest as their current abundance estimate is only a few tens of animals, making them the most endangered marine mammal species in U.S. waters. Based on visual sightings in 2004-2006, a North Pacific Right Whale Critical Habitat was defined on the shelf along the southeastern coast of Kodiak Island, bordering the GATMAA.

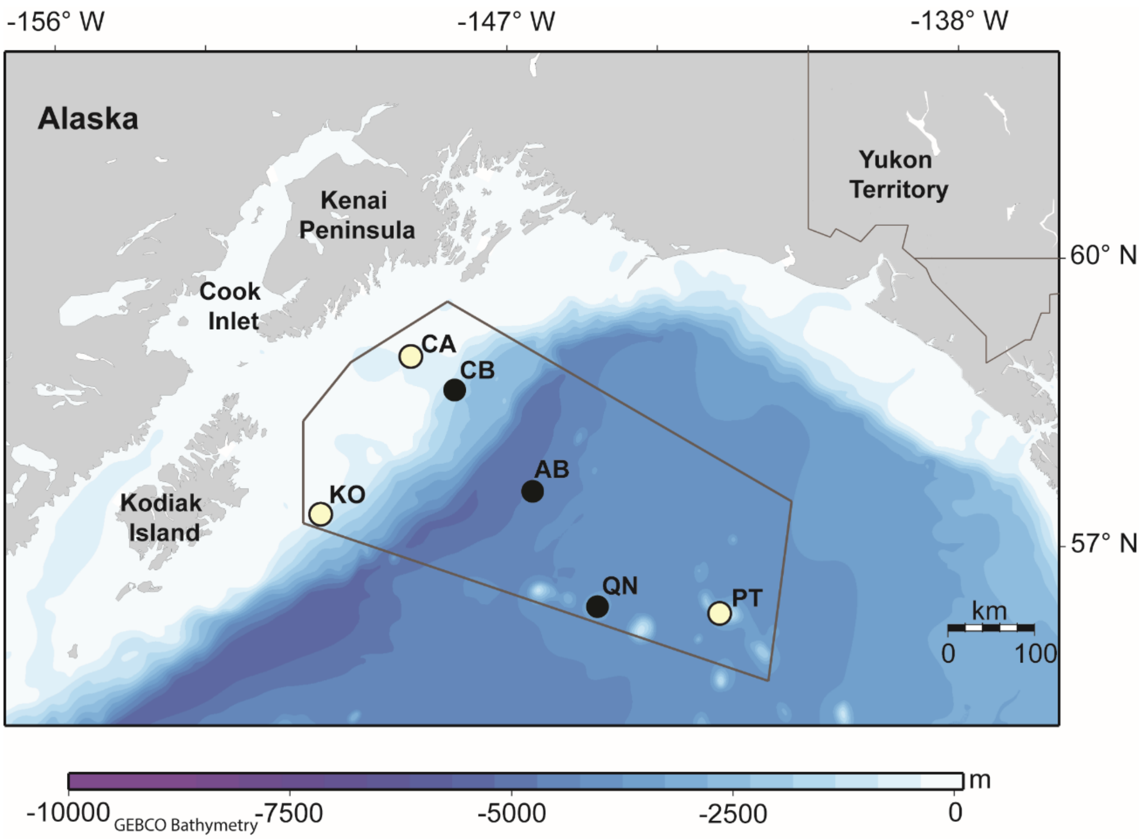

Figure 1. Locations of current (black circles) and previous (white circles) High-frequency Acoustic Recording Package (HARP) deployment sites in the GATMAA (gray line). Only sites CB and QN were monitored from May to September 2015; whereas CB, AB, and QN were monitored from April to September 2017.
Darker color indicates deeper depth.

In July 2011, an acoustic monitoring effort was initiated at two sites (CA and CB; Table 1) within the boundaries of the GATMAA with support from the Pacific Fleet under contract to the Naval Postgraduate School. The goal of this effort was to characterize the sounds produced by marine mammal species present in the area, determine their seasonal patterns, and evaluate the potential for impact from naval operations. The low-frequency ambient soundscape and anthropogenic sounds were also analyzed. Additional monitoring sites were added to this effort with PT in 2012, KO and QN in 2013, and AB in 2017 (Table 1). This report will cover only sites CB, AB, and QN, as monitoring effort was suspended for sites CA, KO, and PT in 2014. In 2017 site AB was added to examine a deep-water site that is not located at a seamount.

Table 1. Locations for HARP deployment sites in GATMAA.

Site	Latitude	Longitude	Depth (m)	Years Monitored
CA	59° 0.5 N	148° 54.1 W	200	2011 - 2014
CB	58° 40.26 N	148° 01.45 W	900	2011 – 2017
PT	56° 14.6 N	142° 45.46 W	1000	2012 – 2014
KO	57° 20.0 N	150° 40.1 W	200	2013 – 2014
QN	56° 20.48 N	145° 10.99 W	900	2013 - 2017
AB	57° 30.82 N	146° 30.05 W	1200	2017

This report documents the analysis of data recorded by three High-frequency Acoustic Recording Packages (HARPs) that were deployed within the GATMAA in May 2015 and April 2017 (Figure 1). The three sites include a continental slope site in deep water (site CB), a deep offshore site at Quinn Seamount (site QN), and a deep water site between sites CB and QN (site AB) (Table 1). Data from site CB was analyzed for May to September 2015 and again from April to September 2017 (Table 2). Data from site AB were analyzed from April to September 2017 (Table 2). Data from site QN were analyzed for May to August 2015 and again from April to September 2017 (Table 2).

Table 2. GATMAA acoustic monitoring since July 2011. Deployment periods analyzed in this report are shown in bold.
Results through early 2015 are described in Baumann-Pickering et al. (2012), Debich et al. (2013), Debich et al. (2014), and Rice et al. (2015).

Deployment Name	Deployment Period	Duration (days)	Duration (hrs)	Sample Rate (kHz)
CA01	7/13/2011 – 12/17/2011	157.97	3791.3	200
CB01	7/13/2011 – 2/19/2011	221.83	5323.97	200
CA02	5/3/2012 – 1/16/2013	343.94	8254.45	200
CB02	5/3/2012 – 2/12/2013	285.98	6863.63	200
PT01	9/9/2012 – 6/10/2013	274.63	6591.08	200
CA03	6/6/2013 – 6/17/2013	11.43	274.45	320
CB03	6/6/2013 – 9/5/2013	90.37	2168.85	200
KO01	6/9/2013 – 6/26/2013	18.09	434.05	200
PT02	6/11/2013 – 8/20/2013	70.02	1680.52	200
QN01	6/10/2013 – 9/11/2013	93.28	2238.80	320
CA04	9/6/2013 – 4/28/2014	234.74	5633.85	200
CB04	9/5/2013 – 4/28/2014	235.59	5654.27	200
KO02	9/8/2013 – 5/1/2014	234.91	5637.85	200
PT03	9/3/2013 – 3/21/2014	198.95	4774.73	200
QN02	9/11/2013 – 4/16/2014	217.03	5208.85	200
QN03	4/30/2014 – 5/24/2014	23.74	569.69	200
CA05	4/29/2014 – 9/9/2014	133.05	3193.18	200
CB05	4/29/2014 – 9/9/2014	133.19	3196.61	200
KO03	5/1/2014 – 9/11/2014	133.34	3200.07	200
PT04	4/30/2014 – 9/10/2014	133.27	3198.41	200
CB06	9/9/2014 – 5/1/2015	233.64	5607.44	200
QN04	9/10/2014 – 5/2/2015	233.37	5600.99	200
CB07	**5/1/2015 – 9/6/2015**	**128.18**	**3076.35**	**200**
QN05	**5/2/2015 – 8/18/2015**	**108.51**	**2604.29**	**200**
AB01	**4/29/2017 – 9/13/2017**	**136.6**	**3278.36**	**200**
CB08	**4/30/2017 – 9/12/2017**	**135.13**	**3243**	**200**
QN06	**4/30/2017 – 9/13/2017**	**136.64**	**3279.39**	**200**

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 GATMAA. HARPs can autonomously record underwater sounds from 10 Hz up to 160 kHz and are capable of approximately 300 days of continuous data storage. The HARPs were deployed in a seafloor mooring configuration with the hydrophones suspended at least 10 m above the seafloor. Each HARP hydrophone is calibrated in the laboratory to provide a quantitative analysis of the received sound field. Representative data loggers and hydrophones were also calibrated at the Navy’s Transducer Evaluation Center facility to verify the laboratory calibrations (Wiggins and Hildebrand, 2007).

Data Collected

Acoustic data have been collected within the GATMAA using autonomous HARPs since July 2011 (Table 2). Each HARP sampled continuously at 200 kHz except for deployments CA03 and QN01, which were sampled at 320 kHz (Table 2). The sites analyzed in this report are designated site CB, AB, and QN (Table 1). A total of 15,481 hours, covering 645 days, of acoustic data were recorded in the deployments analyzed in this report. Data from site CB was analyzed for May 1 to September 6, 2015, with a gap from ~July 20 – August 10 in the low and mid-frequency due to hard drive failures, and again from April 30 to September 12, 2017 (Table 2). Data from site AB were analyzed from April 29 to September 13, 2017 (Table 2). Data from site QN were analyzed for May 2 to August 18, 2015 and again from April 30 to September 13, 2017 (Table 2).

Data Analysis

Long-Term Spectral Averages (LTSAs) were examined for marine mammal and anthropogenic sounds. Data were analyzed by visually scanning LTSAs in source-specific frequency bands and, when appropriate, using automatic detection algorithms (described below). During visual analysis, when a sound of interest was identified in the LTSA but its origin was unclear, the waveform and/or spectrogram were examined to further classify the sounds to species or source. Signal classifications were carried out by comparison to known species-specific spectral and temporal characteristics.

Recording over a broad frequency range of 10 Hz – 100 kHz allows monitoring of the low-frequency ambient soundscape and detection of baleen whales (mysticetes), toothed whales (odontocetes), and anthropogenic sounds. The presence of acoustic signals from multiple marine mammal species and anthropogenic sources was evaluated in the recordings. To document the data analysis process, we describe the major classes of marine mammal calls and anthropogenic sound in the GATMAA, and the procedures used to detect them. For effective analysis, the data were divided into three frequency bands:

(1) Low-frequency, between 10 – 500 Hz
(2) Mid-frequency, between 10 – 5,000 Hz
(3) High-frequency, between 1 – 100 kHz

Each band was analyzed for the sounds of an appropriate subset of species or sources. Blue, fin, gray, and North Pacific right whales, as well as low-frequency active sonar sounds, were classified as low-frequency. Humpback whales, explosions, and mid-frequency active sonar sounds were classified as mid-frequency. Beaked whale and sperm whales were classified as high-frequency. For the analysis of mid-frequency recordings, data were decimated by a factor of 20. Analysis of low-frequency recordings required decimation by a factor of 100. The LTSAs were created using a 5 s time average with 100 Hz frequency resolution for high-frequency analysis, 10 Hz resolution for mid-frequency analysis, and 1 Hz resolution for low-frequency analysis.

We summarize results of the acoustic analysis on recordings between May 2015 and September 2015 at sites CB and QN, and between April and September 2017 at sites CB, AB, and QN. We discuss seasonal occurrence and relative abundance of calls for species and anthropogenic sounds that were consistently identified in the data.

Low-Frequency Ambient Soundscape

Ocean ambient sound pressure levels tend to decrease as frequency increases (Wenz, 1962). While baleen whales and anthropogenic sources, such as large ships and airguns, often dominate the ambient soundscape below 100 Hz (Širović *et al.*, 2004; McDonald *et al.*, 2006a; Wiggins *et al.*, 2016), wind causes increased sound pressure levels from 200 Hz to 20 kHz (Knudsen *et al.*, 1948). In the absence of wind, ambient sound pressure levels are low and difficult to measure at frequencies above ~10 kHz. Therefore, to analyze the ambient soundscape, data were decimated by a factor of 100 to provide an effective bandwidth of 10 Hz to 1 kHz. LTSAs were then constructed with 1 Hz frequency and 5 s temporal resolution. To determine low-frequency ambient sound levels, daily spectra were computed by averaging five, 5 s sound pressure spectrum levels calculated from each 75 s acoustic record. System self-noise was excluded from these averages. Additionally, daily averaged sound pressure spectrum levels in 1-Hz bins were concatenated to produce long-term spectrograms for each site.

Low-Frequency Marine Mammals

The Gulf of Alaska is inhabited, for at least a portion of the year, by blue whales, fin whales, gray whales, and North Pacific right whales. The hourly presence of Northeast Pacific blue whale B calls and D calls, Central Pacific tonal blue whale calls, fin whale 40 Hz calls, gray whale M3 calls, and North Pacific right whale up calls was determined by manual scrutiny of low-frequency LTSAs and spectrograms in the custom software program *Triton*. The same LTSA and spectrogram parameters were used for the manual detection of all calls types. The LTSA frequency was set to display between 1-300 Hz with a 1-hour plot length. To observe individual calls, the spectrogram window was typically set to display 1-200 Hz with a 60 s plot length. The FFT was generally set between 1500 and 2000 data points, yielding about a 1 Hz frequency resolution, with a 90% overlap. When a call of interest was identified in the LTSA or spectrogram, it's presence during that hour was logged. Fin whale 20 Hz pulses were detected automatically using the energy detection method described below for all deployments and are reported as a daily average, termed the 'fin whale acoustic index' (Širović *et al.*, 2015).

Blue Whales

Blue whales produce a variety of calls worldwide (McDonald *et al.*, 2006b). Blue whale calls recorded in the Gulf of Alaska include the Northeast Pacific blue whale B call (Figure 2) and the Central Pacific tonal call (Figure 3). These geographically distinct calls are possibly associated with mating functions (McDonald *et al.*, 2006b; Oleson *et al.*, 2007). They are low-frequency (<20 Hz), have long duration, and often are regularly repeated. Also detected were blue whale D calls, which are downswept in frequency (approximately 100-40 Hz) with a duration of several seconds (Figure 4). 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__

Northeast Pacific blue whale B calls (Figure 2) were detected via manual scanning of the LTSA and subsequent verification from a spectrogram of the frequency and temporal characteristics of the calls.

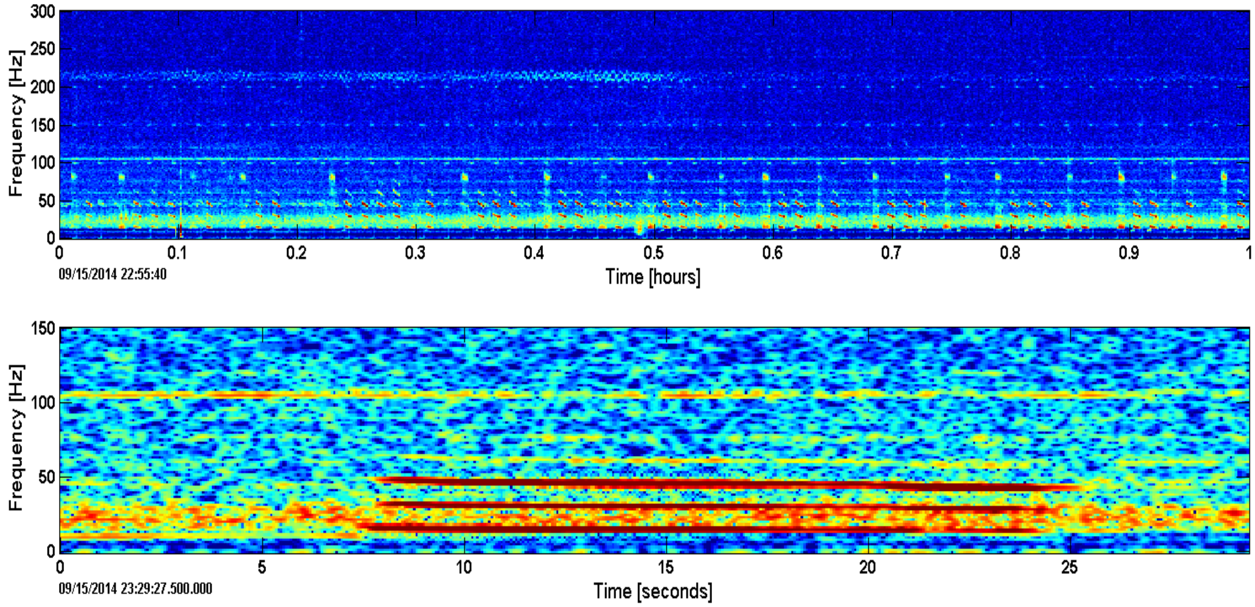

Figure 2. Northeast Pacific blue whale B calls (just below 50 Hz) in Long-term Spectral Average (LTSA; top) and an individual call shown in a spectrogram (bottom) previously recorded at site CB.

__Central Pacific tonal blue whale calls__

Central Pacific tonal blue whale calls (Figure 3) were detected via manual scanning of the LTSA and subsequent verification from a spectrogram of the frequency and temporal characteristics of the calls.

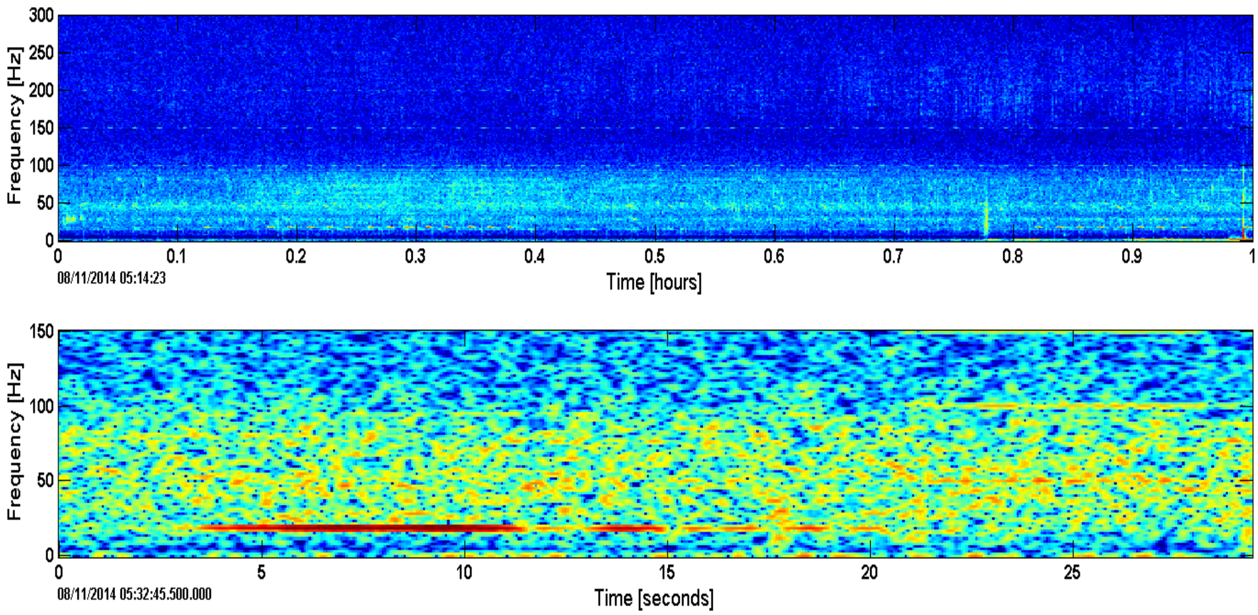

Figure 3. Central Pacific tonal calls (just below 20 Hz) in an LTSA (top) and an individual call shown in a spectrogram (bottom) previously recorded at site CB.

Blue whale D calls

Blue whale D calls (Figure 4) were detected via manual scanning of the LTSA and subsequent verification from a spectrogram of the frequency and temporal characteristics of the calls.

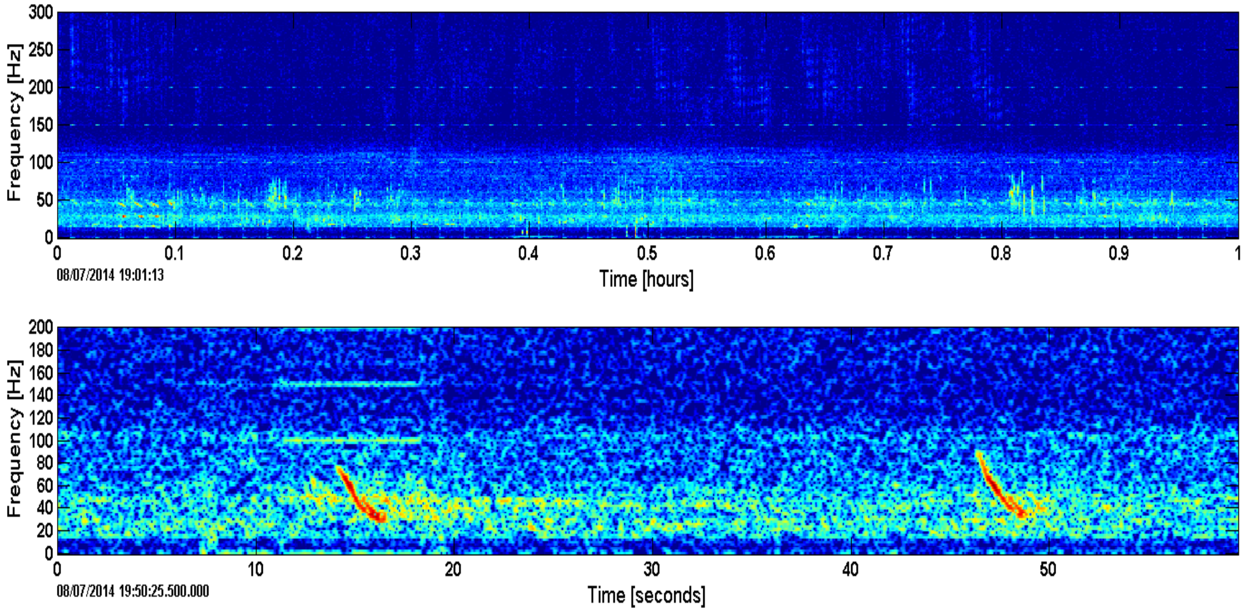

Figure 4. Blue whale D calls (around 50 Hz) in an LTSA (top) and two individual calls shown in a spectrogram (bottom) previously recorded at site CB.

Fin Whales

Fin whales produce two types of short (approximately 1 s duration), low-frequency calls: downsweeps in frequency from 30-15 Hz, called 20 Hz calls (Watkins, 1981; Figure 5), and downsweeps from 75-40 Hz, called 40 Hz calls (Širović *et al.*, 2013: Figure 6). The 20 Hz calls can occur at regular intervals as song (Thompson *et al.*, 1992), or irregularly as call counter-calls among multiple, traveling animals (McDonald *et al.*, 1995). The 40 Hz calls most often occur in irregular patterns.

20 Hz calls

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.

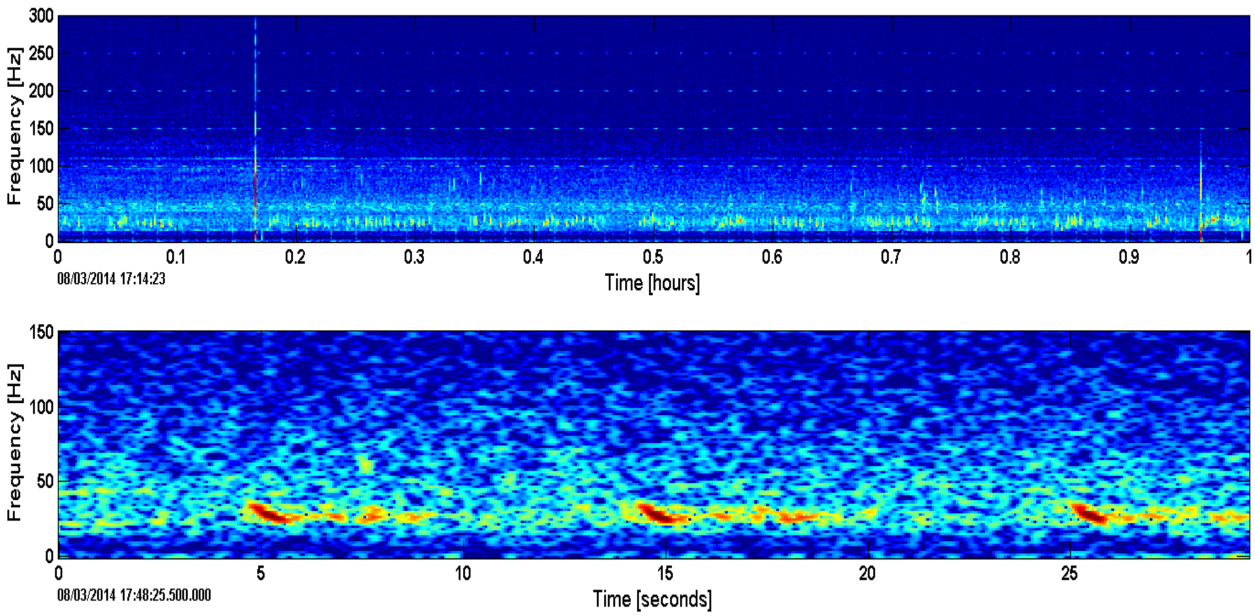

Figure 5. Fin whale 20 Hz calls in an LTSA (top) and three individual calls shown in a spectrogram (bottom) previously recorded at site CB.

40 Hz calls

Fin whale 40 Hz calls (Figure 6) were detected via manual scanning of the LTSA and subsequent verification from a spectrogram of the frequency and temporal characteristics of the calls.

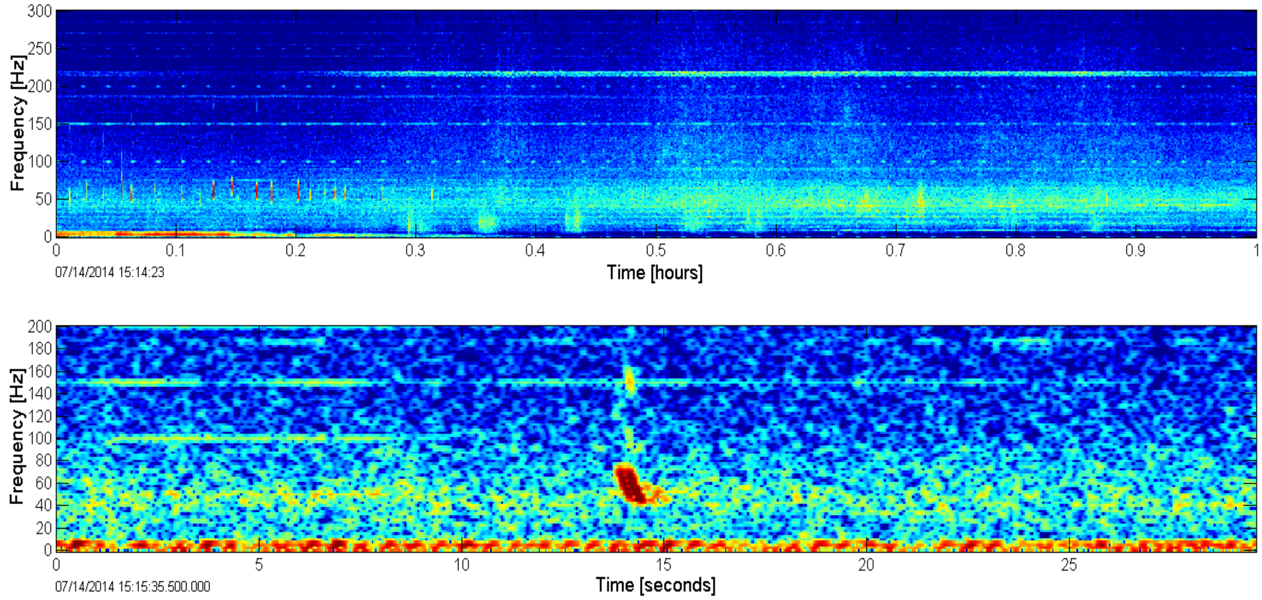

Figure 6. Fin whale 40 Hz calls in an LTSA (top) and an individual call shown in a spectrogram (bottom) previously recorded at site CB.

Gray Whales

Gray whales produce a variety of calls that often have lower source levels than most other baleen whale calls and thus propagate over shorter distances. The only gray whale call type for which there was detection effort during our study was the M3 call, which is a low-frequency, short moan with most energy around 50 Hz (Figure 7), and is the most common call produced by migrating gray whales (Crane and Lashkari, 1996).

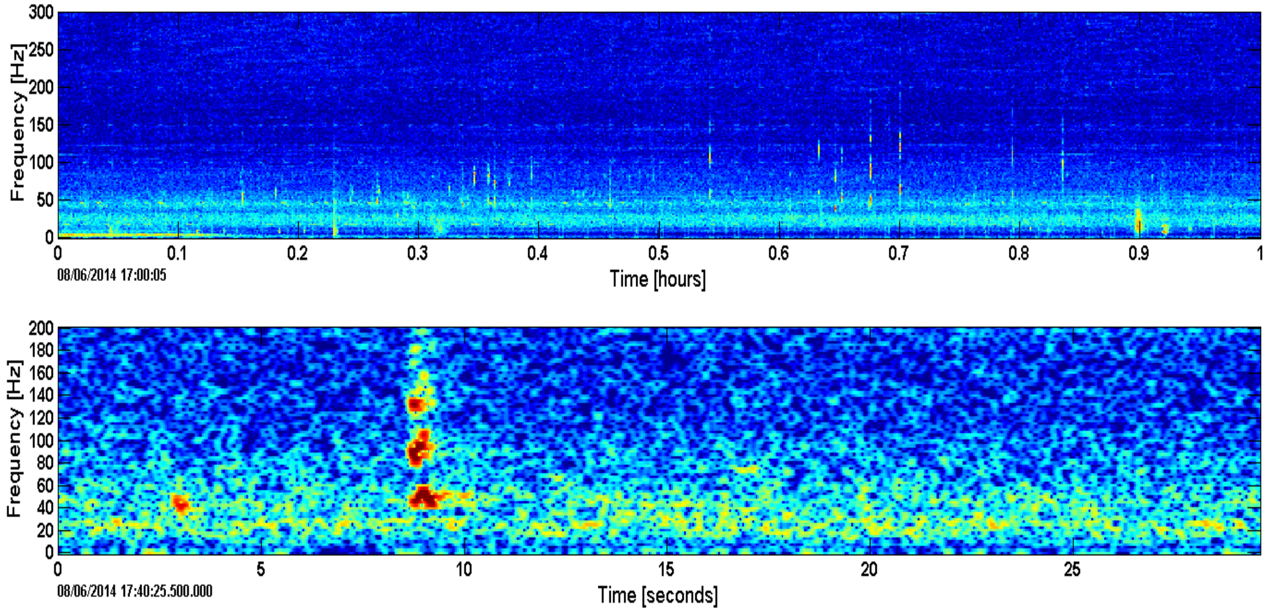

Figure 7. Gray Whale M3 calls in an LTSA (top) and an individual call shown in a spectrogram (bottom) previously recorded at site KO.

North Pacific Right Whales

North Pacific right whales are a highly endangered species that was plentiful in the Gulf of Alaska prior to intense commercial whaling efforts (Scarff, 1986; Brownell *et al.*, 2001). These whales make a variety of sounds, the most common of which is the up call (Figure 8). The up call typically sweeps from about 90 to 150 Hz or as high as 200 Hz, and has a duration of approximately 1 s (McDonald and Moore, 2002). There were no right whale up calls detected during this reporting period.

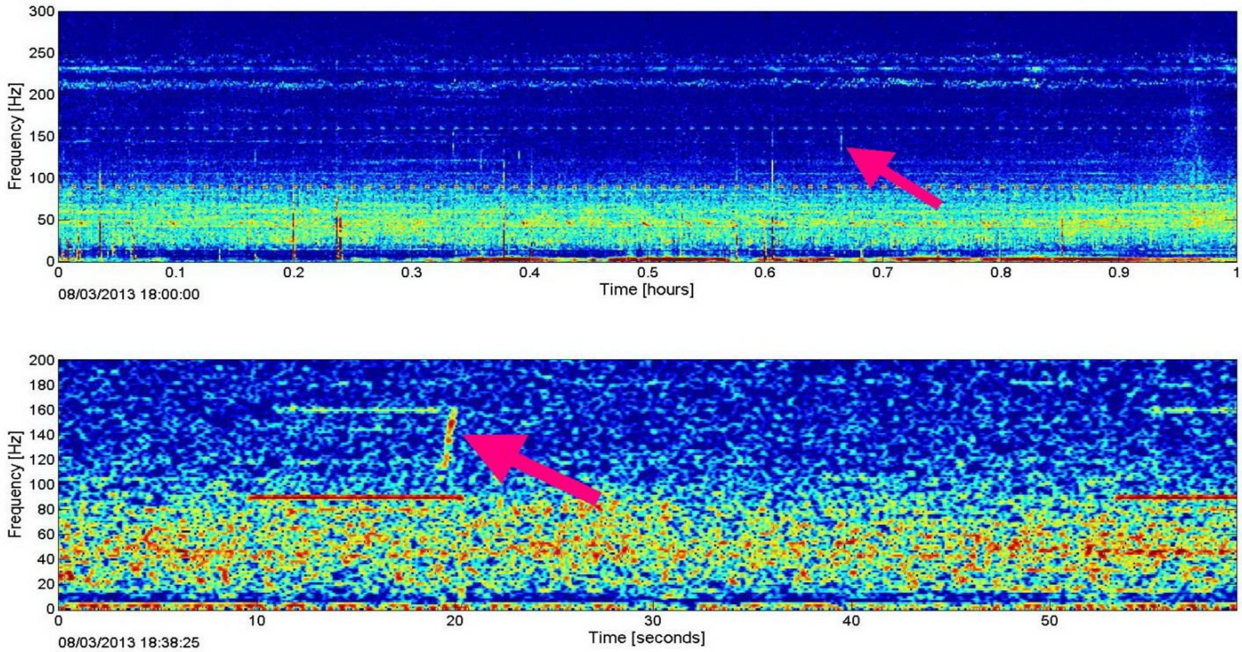

Figure 8. North Pacific right whale up call in an LTSA (top) and an individual call shown in a spectrogram (bottom) previously recorded at site QN.

Mid-Frequency Marine Mammals

Humpback whales were the only marine mammal species in the Gulf of Alaska with calls in the mid-frequency range monitored for this report. We detected humpback whale calls using an automatic detection algorithm based on the generalized power law (Helble *et al.*, 2012) for deployments CB07 and QN05. The detections were subsequently verified for accuracy by a trained analyst (Figure 9). Humpback whale presence was determined by manual scrutiny of mid-frequency LTSAs and spectrograms in the custom software program *Triton* for all other deployments. The LTSA frequency was set to display between 10-5,000 Hz with a 1-hour plot length. To observe individual calls, the spectrogram window was typically set to display 10-3,000 Hz with a 30 s plot length. The FFT was generally set between 1000 and 1500 data points, yielding about a 5 Hz frequency resolution, with a 90% overlap. When humpback calls were identified in the LTSA or spectrogram, they were logged according to the start time and end time of the encounter. An encounter was consider to end when there were no calls for 30 min. The encounter durations were added to estimate cumulative hourly presence.

Humpback Whales

Humpback whales produce both song and non-song calls (song shown in Figure 9). The song is categorized by the repetition of units, phrases, and themes of a variety of calls as defined by Payne & McVay (1971). Non-song vocalizations such as social and feeding sounds consist of individual units that can last from 0.15 to 2.5 seconds (Dunlop *et al.*, 2007; Stimpert *et al.*, 2011). Most humpback whale vocalizations are produced between 100 - 3,000 Hz. There was no effort to separate song and non-song calls.

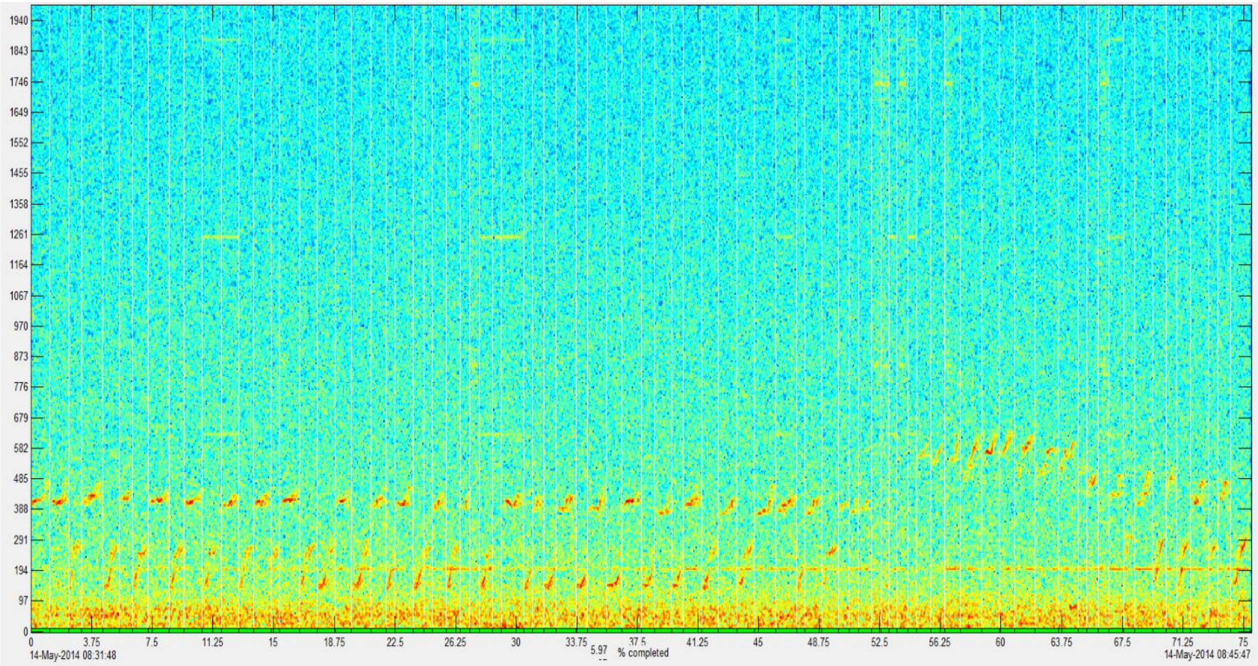

Figure 9. Humpback whale song shown in the analyst verification stage of the detector previously recorded at site KO.

High-Frequency Marine Mammals

Marine mammal species in the Gulf of Alaska with sounds in the high-frequency range monitored for this report include sperm whales (*Physeter macrocephalus*), Cuvier's beaked whales (*Ziphius cavirostris*), and Stejneger's beaked whales (*Mesoplodon stejnegeri*). For sperm whales, individual clicks were detected and their durations summed to determine a weekly average of the number of hours of clicks per day. For beaked whales, the start and end of each call or session was logged and their durations were added to estimate cumulative hourly presence.

High-Frequency Call Types

Odontocete sounds can be categorized as echolocation clicks, burst pulses, or whistles. Echolocation clicks are broadband impulses with peak energy between 5 and 150 kHz, dependent upon the species. Buzz or burst pulses are rapidly repeated clicks that have a creak or buzz-like sound quality; they are generally lower in frequency than echolocation clicks. Dolphin whistles are tonal calls predominantly between 1 and 20 kHz that vary in frequency content, their degree of frequency modulation, as well as duration. These signals are easily detectable in an LTSA as well as the spectrogram (Figure 10).

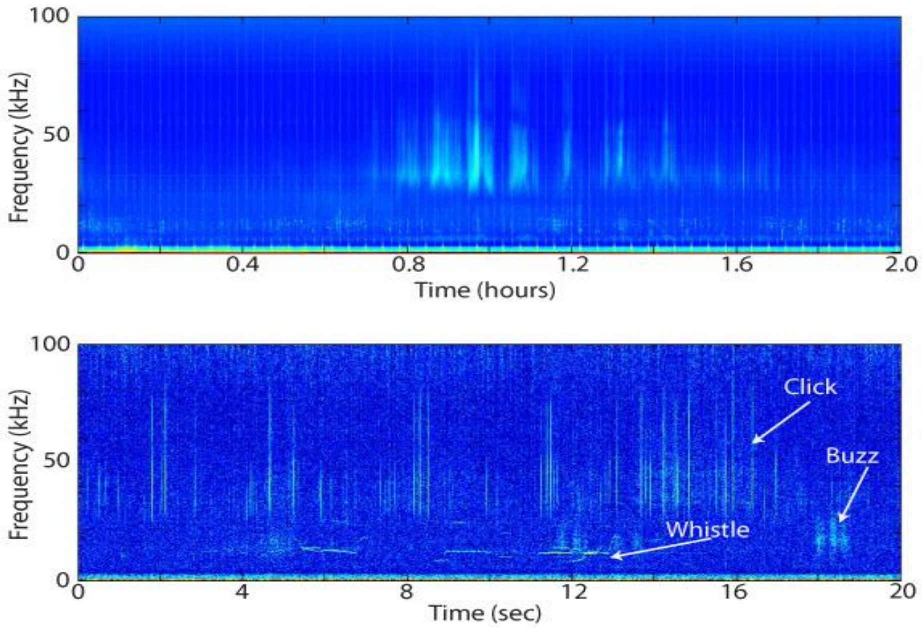

Figure 10. LTSA (top) and spectrogram (bottom) demonstrating odontocete signal types.

Sperm Whales

Sperm whale clicks generally contain energy from 2-20kHz, with the majority of energy between 10-15 kHz (Møhl *et al.*, 2003; Figure 11). Regular clicks, observed during foraging dives, demonstrate a uniform inter-click interval from 0.25-2 seconds (Goold and Jones, 1995; Madsen *et al.*, 2002). Short bursts of closely spaced clicks called creaks are observed during foraging dives and are believed to indicate a predation attempt (Watwood *et al.*, 2006). Slow clicks are used only by males and are more intense than regular clicks with longer inter-click intervals (Madsen *et al.*, 2002). Codas are stereotyped sequences of clicks which are less intense and contain lower peak frequencies than regular clicks (Watkins and Schevill, 1977).

For deployments in 2015 (CB07 and QN05) sperm whale clicks were logged after manual scrutiny of LTSAs and spectrograms in the custom software program *Triton*. For deployments in 2017 (CB08, AB01, and QN06) sperm whale clicks were detected using the automatic method described below. Therefore, plots of sperm whale clicks give cumulative hourly presence per week in 2015 and give a weekly average of the number of hours of individual clicks per day for 2017.

The automatic detection of sperm whale clicks involved two stages of detection. In the first analysis stage, a ship detector based on spectral power and received levels was used to detect time periods that contained shipping noise, as most false detections classified as sperm whales are cavitation pulses of ship motors. It is therefore not feasible to identify sperm whale clicks when ship noise is present. All automatic ship detections were reviewed by a trained analyst. Time periods that contained shipping sounds were removed from further analysis and were considered periods of no effort.

In the second analysis stage, individual sperm whale echolocation clicks were automatically detected with a Teager energy detector (Soldevilla *et al.*, 2008; Roch *et al.*, 2011b). Acoustic encounters were defined as clicks separated by at least 30 mins. All sperm whale acoustic encounters were scrutinized to remove false detections and correct misidentified sperm whale clicks as described below. Since the detector operated on a running average noise floor, a consistent detection threshold based on received levels was applied. Encounters of less than 75s duration were discarded to minimize the number of false detections. The remaining acoustic encounters were manually reviewed using comparative panels showing long-term spectral average, received levels, peak frequency, and inter-pulse interval of individual clicks over time, as well as spectral and waveform plots of selected individual signals.

Within each encounter, periods with false detections were removed by manual editing when the detections were identified as being from vessels, sonar, airguns, delphinids or beaked whales, owing to inappropriate spectral amplitude, ICI, or waveform.

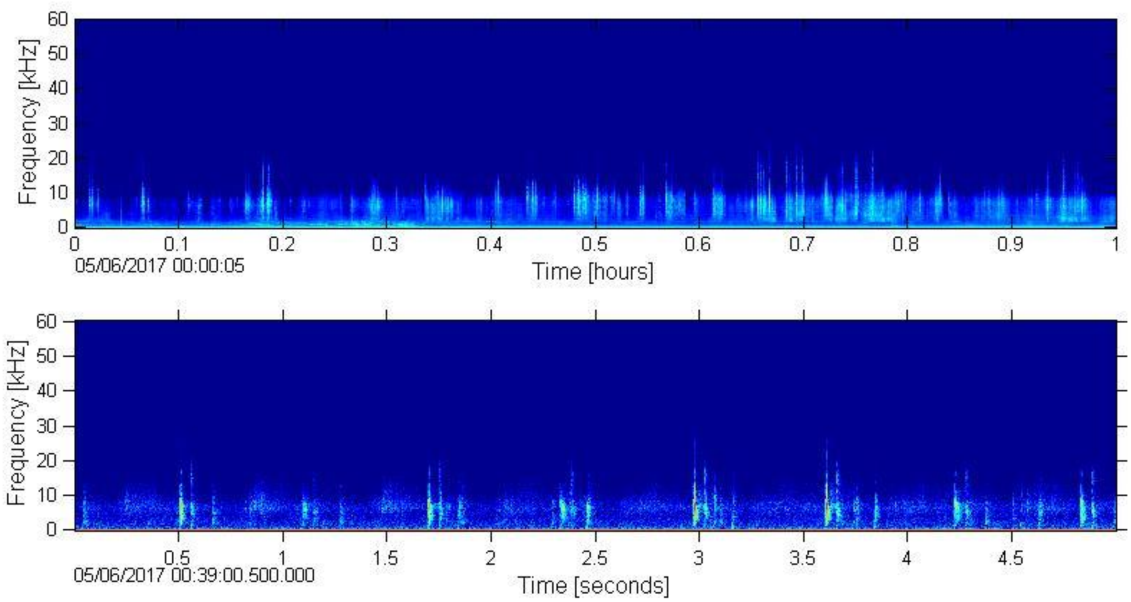

Figure 11. Sperm whale echolocation clicks in an LTSA (top) and spectrogram (bottom) recorded at site CB.

Beaked Whales

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 (*Berardius bairddii*), Blainville's (*Mesoplodon densirostris)*, Cuvier's, and likely Stejneger's beaked whales (Baumann-Pickering *et al.*, 2013b).

Beaked whale FM pulses were detected with an automated method. Beaked whale signal types searched for included Cuvier's and Stejneger's beaked whales (Baumann-Pickering *et al.*, 2013b). After all echolocation signals were identified with a Teager Kaiser energy detector (Soldevilla *et al.*, 2008; Roch *et al.*, 2011b), an expert system discriminated between delphinid clicks and beaked whale FM pulses based on the parameters described below (Roch *et al.*, 2011b).

A decision about presence or absence of beaked whale signals was based on detections within a 75 second segment. Only segments with more than seven detections were used in further analysis. All echolocation signals with a peak and center frequency below 32 and 25 kHz, respectively, a duration less than 355 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 was approximately 5%. The start and end of each segment containing beaked whale signals was logged and their durations were added to estimate cumulative weekly presence.

Only Cuvier's and Stejneger's beaked whale signals were detected during this recording period and their signals are described below in more detail.

Cuvier's Beaked Whales

Cuvier's beaked whale echolocation signals are well differentiated from other species' acoustic signals as polycyclic, with a characteristic FM pulse upsweep, peak frequency around 40 kHz, and uniform inter-pulse interval of about 0.4 – 0.5 s (Johnson *et al.*, 2004; Zimmer *et al.*, 2005: Figure 12). An additional feature that helps with the identification of Cuvier's FM pulses is that they have characteristic spectral peaks around 17 and 23 kHz.

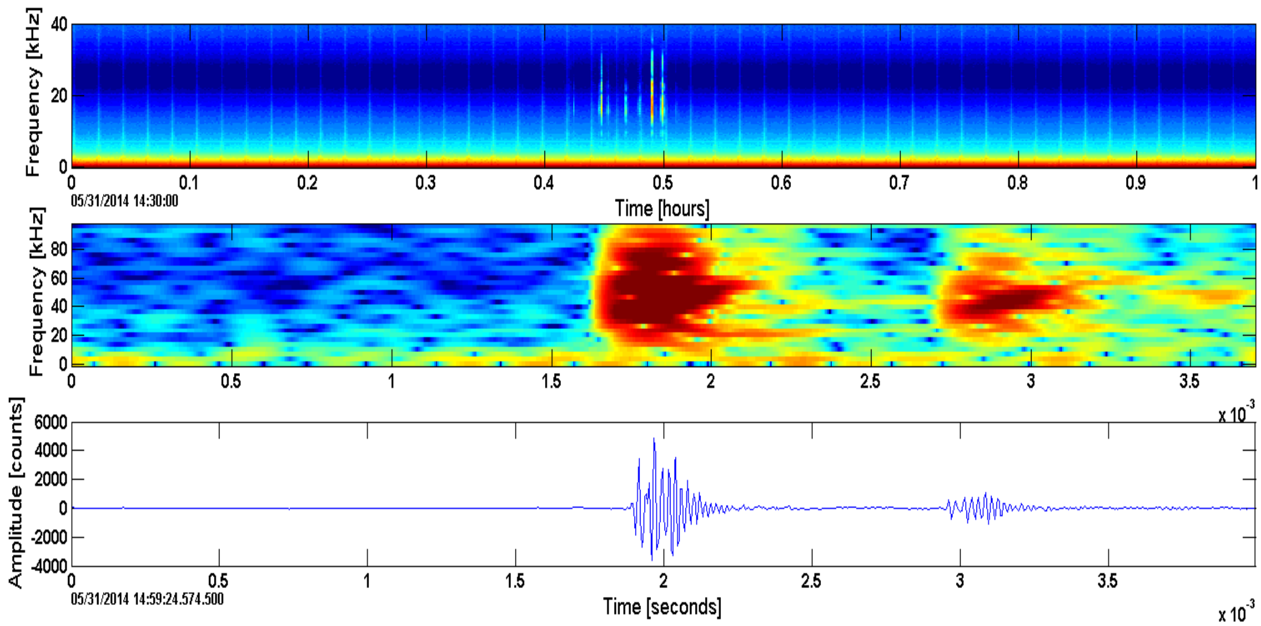

Figure 12. Echolocation sequence of Cuvier's beaked whale in an LTSA (top) and an example FM pulse in a spectrogram (middle) and timeseries (bottom) previously recorded at site PT.

Stejneger's Beaked Whales

Presumed Stejneger's beaked whales are acoustically the most commonly encountered beaked whale in the Aleutian Islands chain (Baumann-Pickering *et al.*, 2013b); however, they have been rarely encountered at sea (Loughlin *et al.*, 1982; Mead, 1989; Walker and Hanson, 1999) and their distribution has been inferred from stranded animals (Allen and Angliss, 2010). Their echolocation signals are easily distinguished from other species' acoustic signals; they have the typical beaked whale polycyclic structure and FM pulse upsweep with a peak frequency around 50 kHz and uniform inter-pulse interval around 90 ms (Baumann-Pickering *et al.*, 2013a; Baumann-Pickering *et al.*, 2013b; Figure 13).

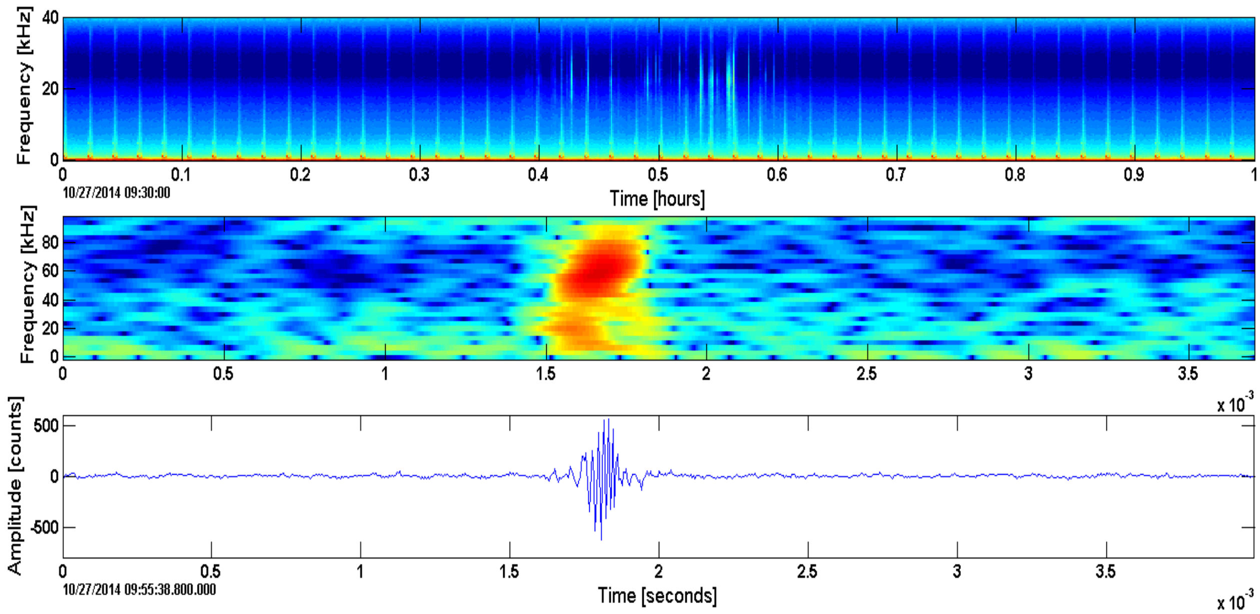

Figure 13. Echolocation sequence of Stejneger's beaked whale in an LTSA (top) and single FM pulse in a spectrogram (middle) and timeseries (bottom) previously recorded at site QN.

Anthropogenic Sounds

Several anthropogenic sounds occurring at low and mid-frequency ranges (<5 kHz) were monitored for this report: mid- frequency active (MFA) sonar, low-frequency active (LFA) sonar, and explosions. MFA sonar, and explosions were detected with automated routines, described separately below. For MFA, the start and end of each sound or session was logged and their durations were added to estimate cumulative hourly presence. For explosions, the total number of detections per week are shown. LFA sonar was detected by manual scrutiny of low-frequency LTSAs and spectrograms in the custom software program *Triton*. The LTSA frequency was set to display between 1-1,000 Hz with a 1-hour plot length. To observe individual signals, the spectrogram window was typically set to display 1-500 Hz, or 500-1,000 Hz, with a 60 s plot length. The FFT was generally set between 1500 and 2000 data points, yielding about a 1 Hz frequency resolution, with a 90% overlap. When a signal of interest was identified in the LTSA or spectrogram, presence during that hour was logged.

Mid-Frequency Active Sonar

Sounds from MFA sonar vary in frequency (1 – 10 kHz) and are composed of pulses of both frequency modulated (FM) sweeps and continuous wave (CW) tones grouped in packets with durations ranging from less than 1 s to greater than 5 s. Packets can be composed of single or multiple pulses and are transmitted repetitively as wave trains with inter-packet-intervals typically greater than 20 s (Figure 14). While they can span frequencies from about 1 kHz to over 50 kHz, the most common MFA sonar signals are between 2 and 5 kHz and are more generically known as '3.5 kHz' sonar.

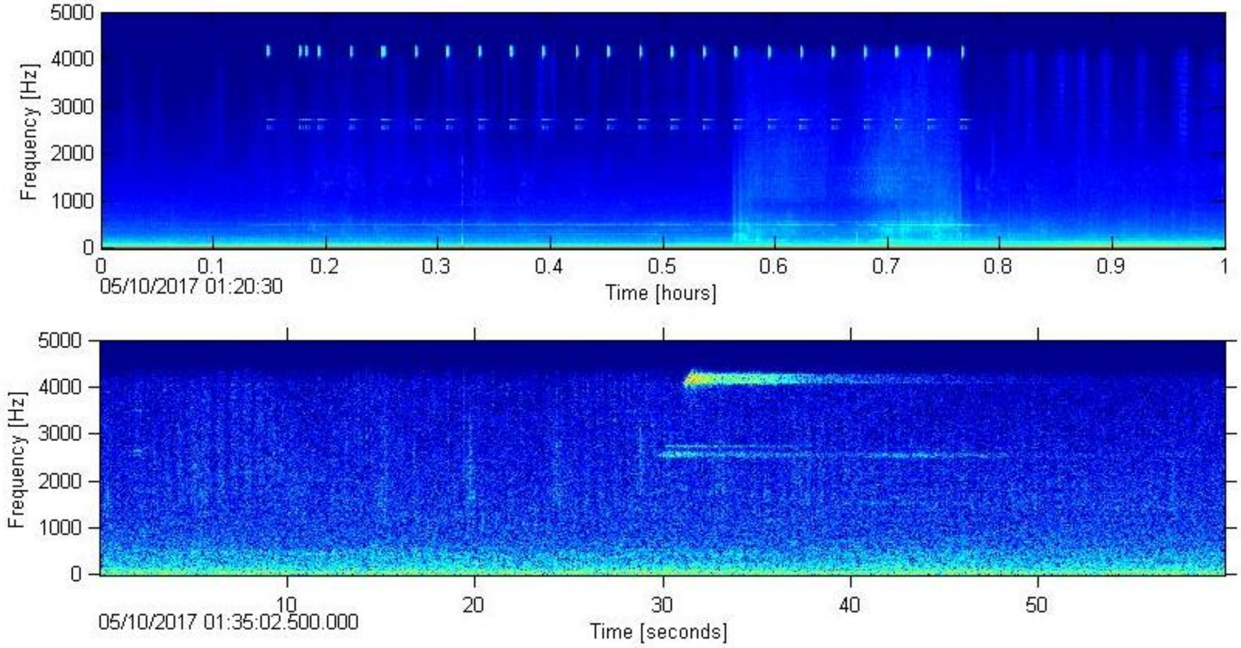

Figure 14. Mid-frequency Active (MFA) sonar in an LTSA (top) and spectrogram (bottom) recorded at site CB.

MFA sonar was detected using a modified version of the *Silbido* detection system (Roch *et al.*, 2011a) originally designed for characterizing toothed whale whistles. The algorithm identifies peaks in time-frequency distributions (e.g. spectrogram) and determines which peaks should be linked into a graph structure based on heuristic rules that include examining the trajectory of existing peaks, tracking intersections between time-frequency trajectories, and allowing for brief signal dropouts or interfering signals. Detection graphs are then examined to identify individual tonal contours looking at trajectories from both sides of time-frequency intersection points. For MFA detection, parameters were adjusted to detect tonal contours at or above 2 kHz in data decimated to a 10 kHz sample rate with time-frequency peaks with signal to noise ratios of 5 dB or above and contour durations of at least 200 ms with a frequency resolution of 100 Hz. The detector frequently triggered on noise produced by instrument disk writes that occurred at 75 s intervals.

Over periods of several months, these disk write detections dominated the number of detections and could be eliminated using an outlier detection test. Histograms of the detection start times modulo the disk write period were constructed and outliers were discarded. This removed some valid detections that occurred during disk writes, but as the disk writes and sonar signals are uncorrelated this is expected to only have a minor impact on analysis. As the detector did not distinguish between sonar and non-anthropogenic tonal signals within the operating band (e.g. humpback whales), human analysts examined detection output and accepted or rejected contiguous sets of detections. Start and end time of these cleaned sonar events were then created to be used in further processing.

These start and end times were used to read segments of waveforms upon which a 2.4 to 4.5 kHz bandpass filter and a simple time series energy detector was applied to detect and measure various packet parameters after correcting for the instrument calibrated transfer function (Wiggins, 2015). For each packet, maximum peak-to-peak (pp) received level (RL), sound exposure level (SEL), root-mean-square (RMS) RL, and date/time of packet occurrence were measured and saved.

Typically (in the Southern California Range Complex), various filters are 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 results in a received level detection threshold of 130 dB pp re 1 µPa. However, in GATMAA a threshold of 116 dB pp re 1 µPa was used, resulting in a detection range greater than 20 km (Wiggins, 2015). Additionally, a shorter pulse lockout period (9 s) was used to account for MFA events with shorter intervals between packets. Instrument maximum received level was ~162 dB pp re 1 µPa, above which waveform clipping occurred. Packets were grouped into wave trains separated by more than 1 hour. Packet received level and duration distributions were plotted along with the number of packets and cumulative SEL (CSEL) in each wave train over the study period. Event duration and the total duration of detected pings were also calculated. Event (wavetrain) duration is the difference between the first and last ping group detection. The total duration of detection pings for an event is the sum of the ping group (packet) 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.

Low-frequency Active Sonar

Low-frequency active sonar includes military sonar up to 1 kHz (Figure 15). This long-range sonar uses low frequencies to minimize absorption effects. Analysts manually scanned LTSAs for LFA sonar bout start and end times between 0 and 500 Hz and 500 to 1000 Hz.

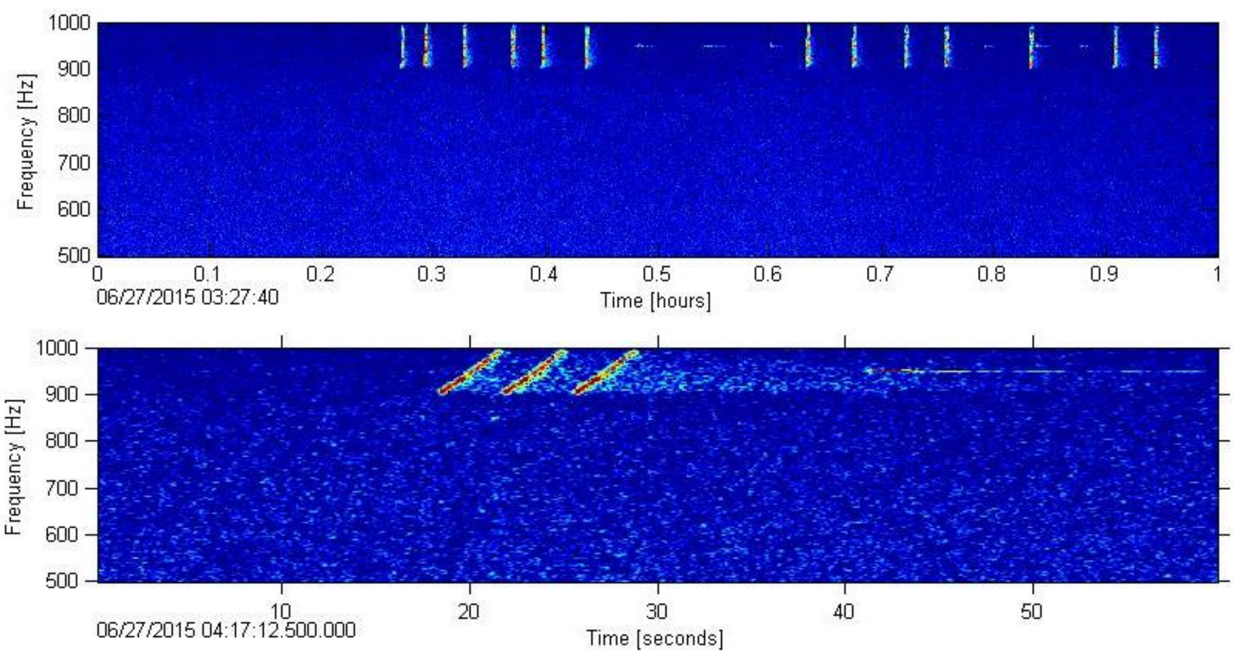

Figure 15. Low-frequency Active (LFA) sonar in an LTSA (top) and a spectrogram (bottom) recorded at site CB.

Explosions

Effort was directed toward finding explosive sounds in the data including military explosions, shots from sub-seafloor exploration, and seal bombs used by the fishing industry. An explosion appears as a vertical spike in the LTSA that, when expanded in the spectrogram, has a sharp onset with a reverberant decay (Figure 16). Explosions were detected automatically for all deployments using a matched filter detector on data decimated to 10 kHz sampling rate. The time series was filtered with a 10^{th} order Butterworth bandpass filter between 200 and 2000 Hz. Cross correlation was computed between 75 seconds of the envelope of the filtered time series and the envelope of a filtered example explosion (0.7 s, Hann windowed) as the matched filter signal. The cross correlation was squared to 'sharpen' peaks of explosion detections. A floating threshold was calculated by taking the median cross correlation value over the current 75 seconds of data to account for detecting explosions within noise, such as shipping. A cross correlation threshold of 3×10^{-6} above the median was set. When the correlation coefficient reached above threshold, the time series was inspected more closely.

Consecutive explosions were required to have a minimum time distance of 0.5 seconds to be detected. A 300-point (0.03 s) floating average energy across the detection was computed. The start and end of the detection above threshold was determined when the energy rose by more than 2 dB above the median energy across the detection. Peak-to-peak (pp) and RMS received levels (RL) were computed over the potential detection period and a time series of the length of the explosion template before and after the detection. The potential detection was classified as false and deleted if: 1) the dB difference pp and RMS between signal and time AFTER the detection was less than 4 dB or 1.5 dB, respectively; 2) the dB difference pp and RMS between signal and time BEFORE signal was less than 3 dB or 1 dB, respectively; and 3) the detection was shorter than 0.03 or longer than 0.55 seconds. The thresholds were evaluated based on the distribution of histograms of manually verified true and false detections. A trained analyst subsequently verified the remaining detections for accuracy. Explosions have energy as low as 10 Hz and often extend up to 2,000 Hz or higher, lasting for a few seconds including the reverberation.

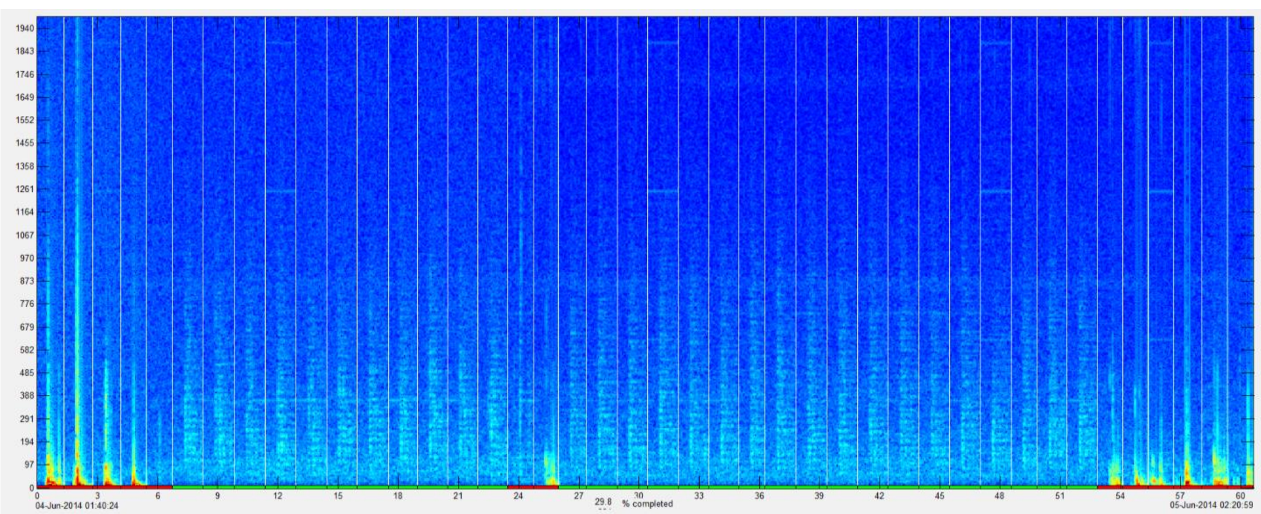

Figure 16. Explosions in the analyst verification stage of the detector previously recorded at site PT. Green in the bottom evaluation line indicates true and red indicates false detections.

Results

The results of acoustic data analysis at sites CB and QN from May to September 2015 and sites CB, AB, and QN from April to September 2017 are summarized below. We describe the low-frequency ambient soundscape, the seasonal occurrence and relative abundance of marine mammal acoustic signals and anthropogenic sounds of interest.

Low-Frequency Ambient Soundscape

- In 2015, site CB had overall elevated sound pressure spectrum levels below 20 Hz, compared to other deployments, likely due to strumming of the hydrophone support line (Figure 17).
- Elevated spectrum levels from 15 - 35 Hz in September 2017 at each site are related to the seasonal increase in fin whale 20 Hz calls (Figure 17).
- The prominent peak from 40 - 50 Hz in September at all sites is related to the seasonal presence of blue whale B calls, though this peak was much greater in 2017 (Figure 17).
- Overall levels from 30-100 Hz at QN were about 2-3 dB higher in 2017 than in 2015 (Figure 17).
- The peak around 150 Hz visible at sites AB and QN in April 2017 is likely due to nearby vessel noise (Figure 17).

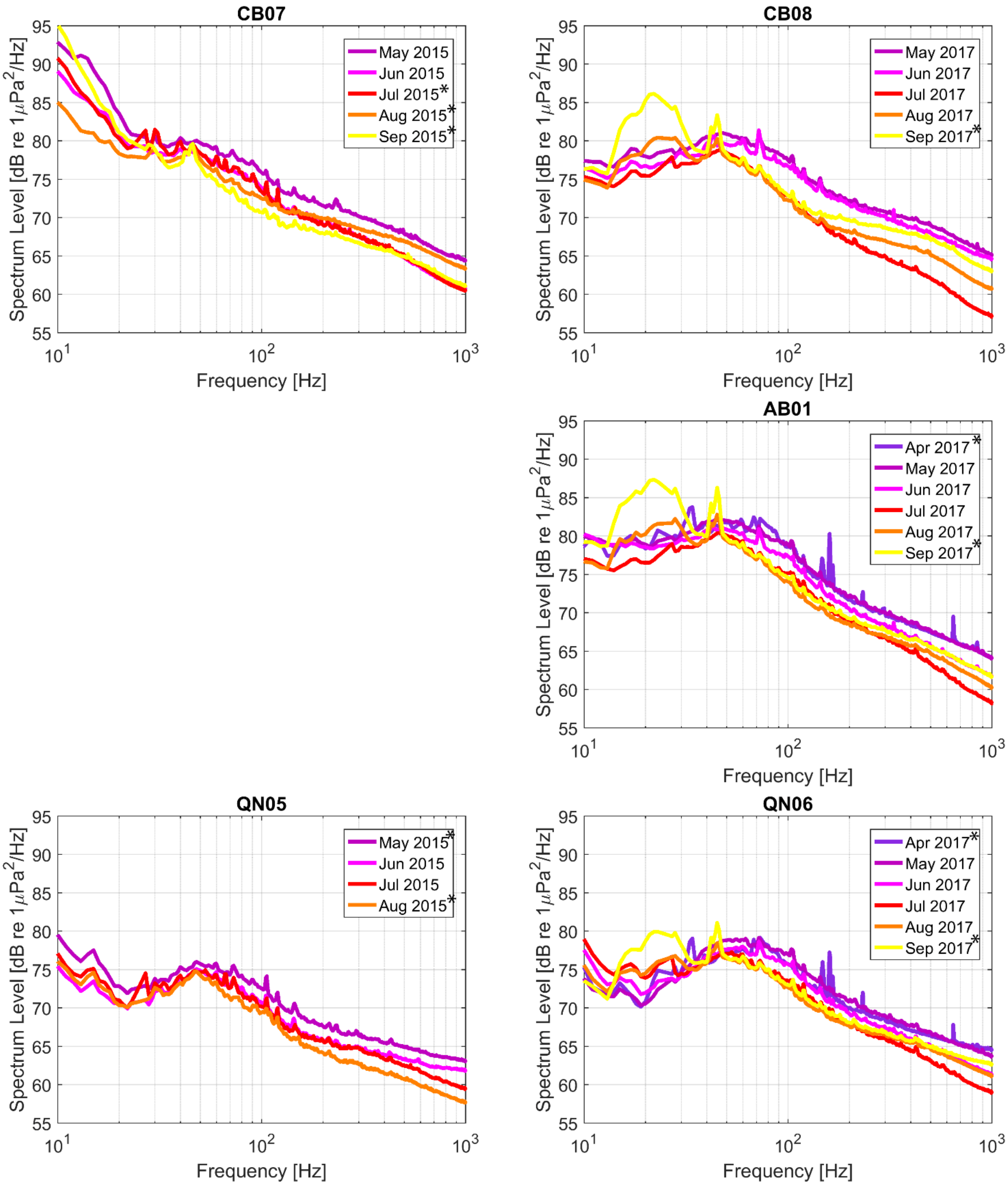

Figure 17. Monthly average sound spectrum levels at sites CB (top), AB (middle), and QN (bottom). Legend gives color-coding by month. * denotes months with partial effort.

Mysticetes

Four baleen whale species were recorded from May to September 2015 and from April to September 2017: blue whales, fin whales, gray whales, and humpback whales. There were no detections of North Pacific right whale up calls during this monitoring period. Relative hourly calling abundance varied among species. More details of each species presence at each site are given below.

Blue whales

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

- Northeast (NE) Pacific blue whale B calls typically started being detected in June and July and peaked in August and September. Detections were highest in 2017 at site AB, although similar numbers of detections occurred at all three sites in 2017 (Figure 18). Detections were overall higher in 2017 than in the same months in 2015, though recordings in 2015 likely did not capture peak calling presence.
- In August 2017 at site AB there were more NE Pacific blue whale B calls detected at night, though overall there was no clear diel pattern at any site (Figure 19).
- Central Pacific tonal calls occurred mainly in August and September at all sites but occurred in relatively low numbers overall, compared to other blue whale call types (Figure 20).
- There was no diel pattern for Central Pacific tonal calls (Figure 21).
- Blue whale D calls occurred throughout the summer at all sites and peaked in July at sites AB and QN (Figure 22). Detections were lowest overall at site CB and highest at QN (Figure 22).
- There was a diel pattern for blue whale D calls with increased calling around sunset and sunrise, most obvious at sites AB and QN (Figure 23).
- These results are consistent with previous monitoring periods at these sites (Baumann-Pickering *et al.*, 2012; Debich *et al.*, 2013; Debich *et al.*, 2014; Rice *et al.*, 2015).

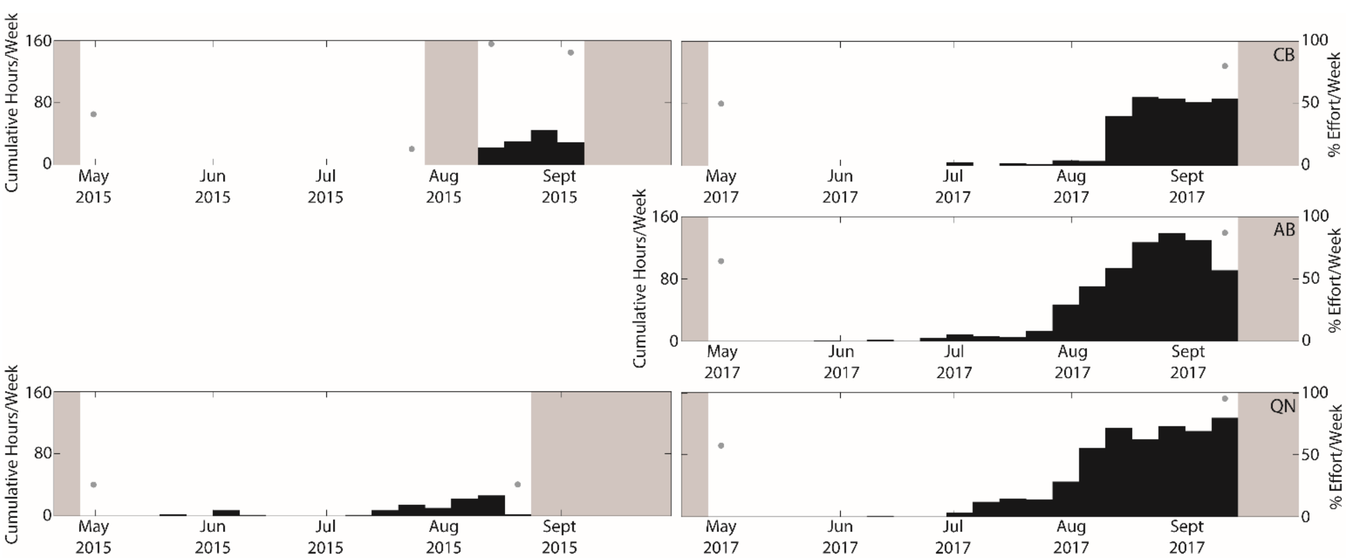

Figure 18. Weekly presence of NE Pacific blue whale B calls from May to September 2015 and April to September 2017 at sites CB (top), AB (middle), and QN (bottom).
Gray dots represent the percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

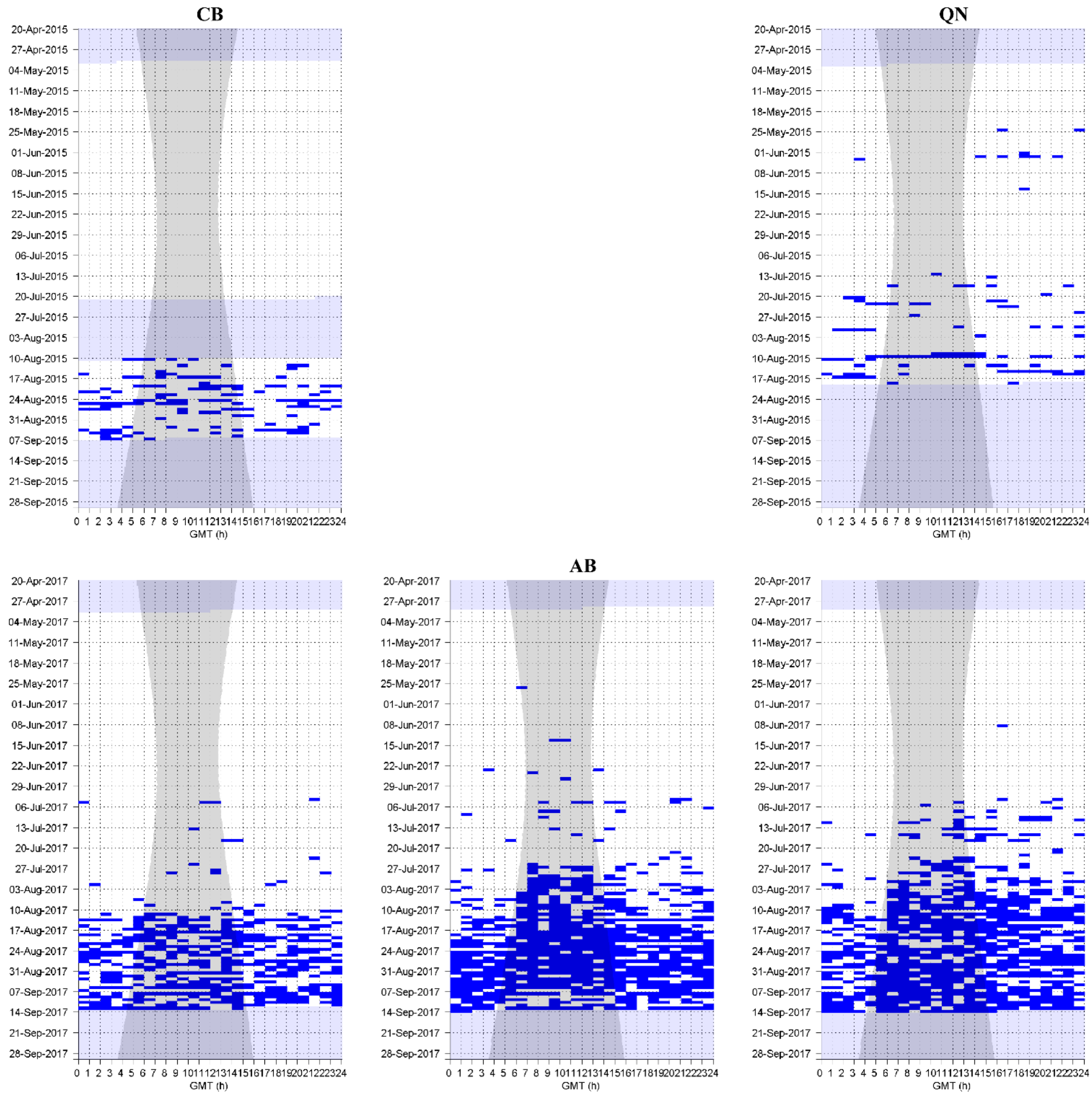

Figure 19. Diel presence of NE Pacific blue whale B calls, indicated by blue dots, in one hour bins at sites CB (left), AB (middle), and QN (right).
Gray vertical shading denotes nighttime and gray horizontal shading denotes absence of acoustic data.

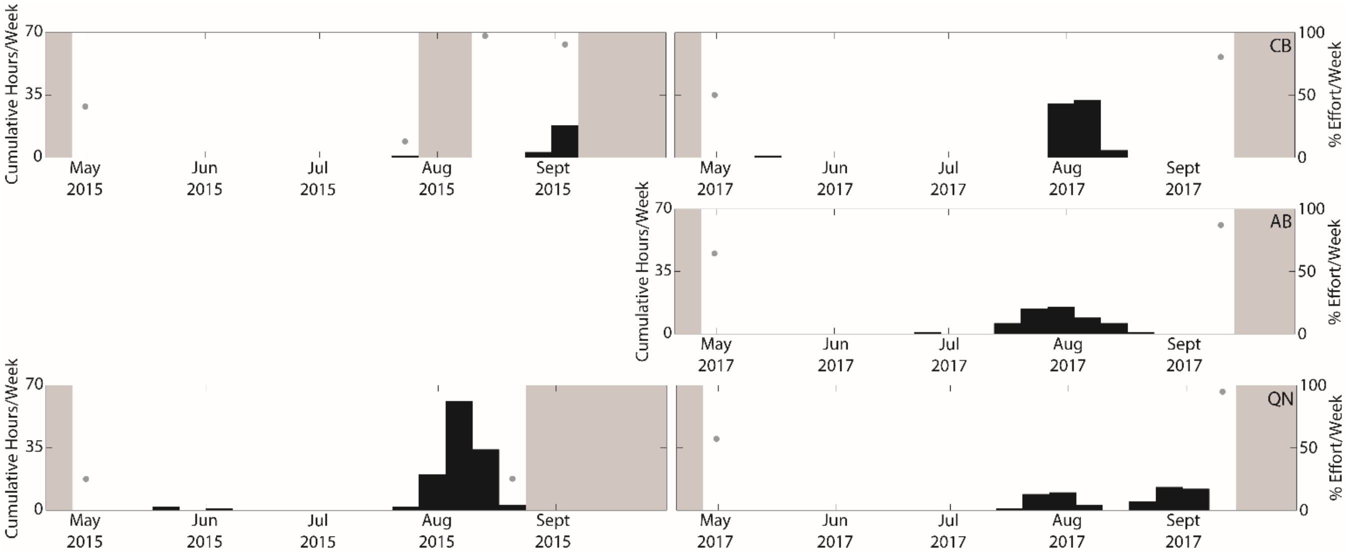

Figure 20. Weekly presence of Central Pacific tonal blue whale calls from May to September 2015 and April to September 2017 at sites CB (top), AB (middle), and QN (bottom).

Gray dots represent the 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.

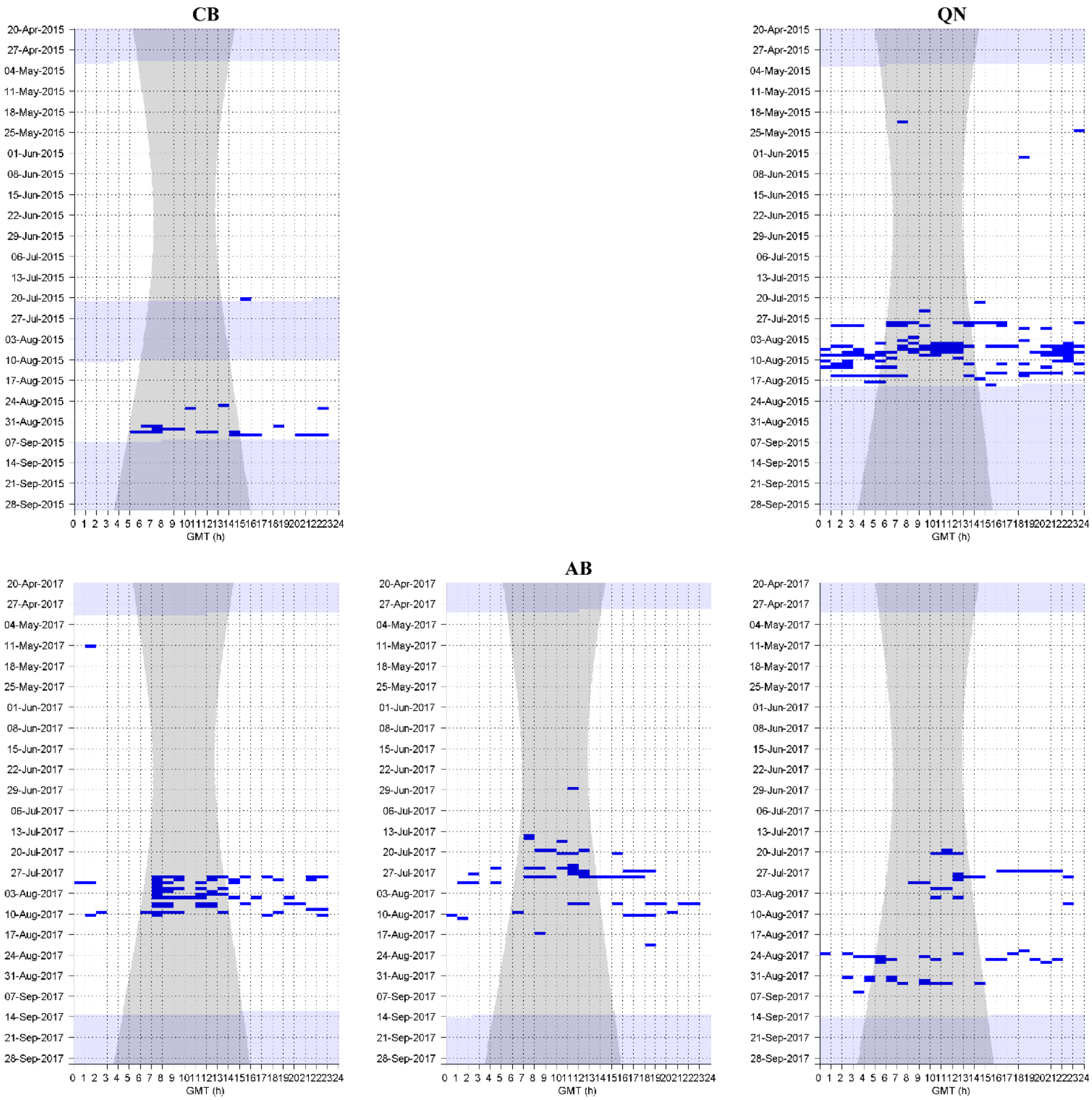

Figure 21. Diel presence of Central Pacific tonal blue whale calls, indicated by blue dots, in one hour bins at sites CB (left), AB (middle), and QN (right).
Gray vertical shading denotes nighttime and gray horizontal shading denotes absence of acoustic data.

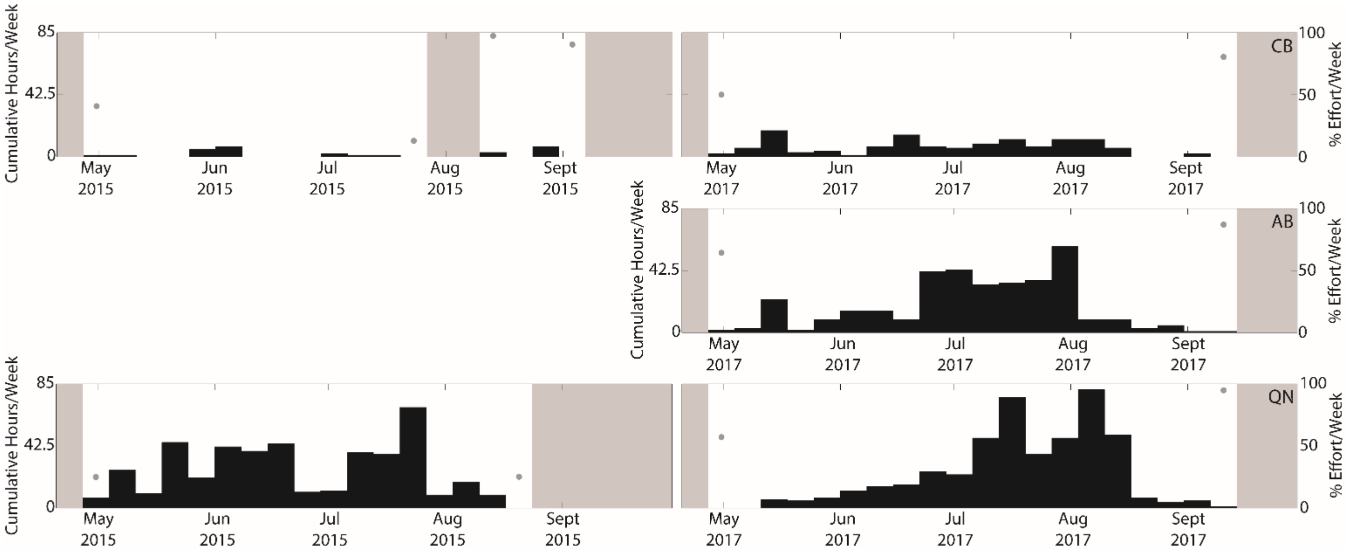

Figure 22. Weekly presence of blue whale D calls from May to September 2015 and April to September 2017 at sites CB (top), AB (middle), and QN (bottom).
Gray dots represent the percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

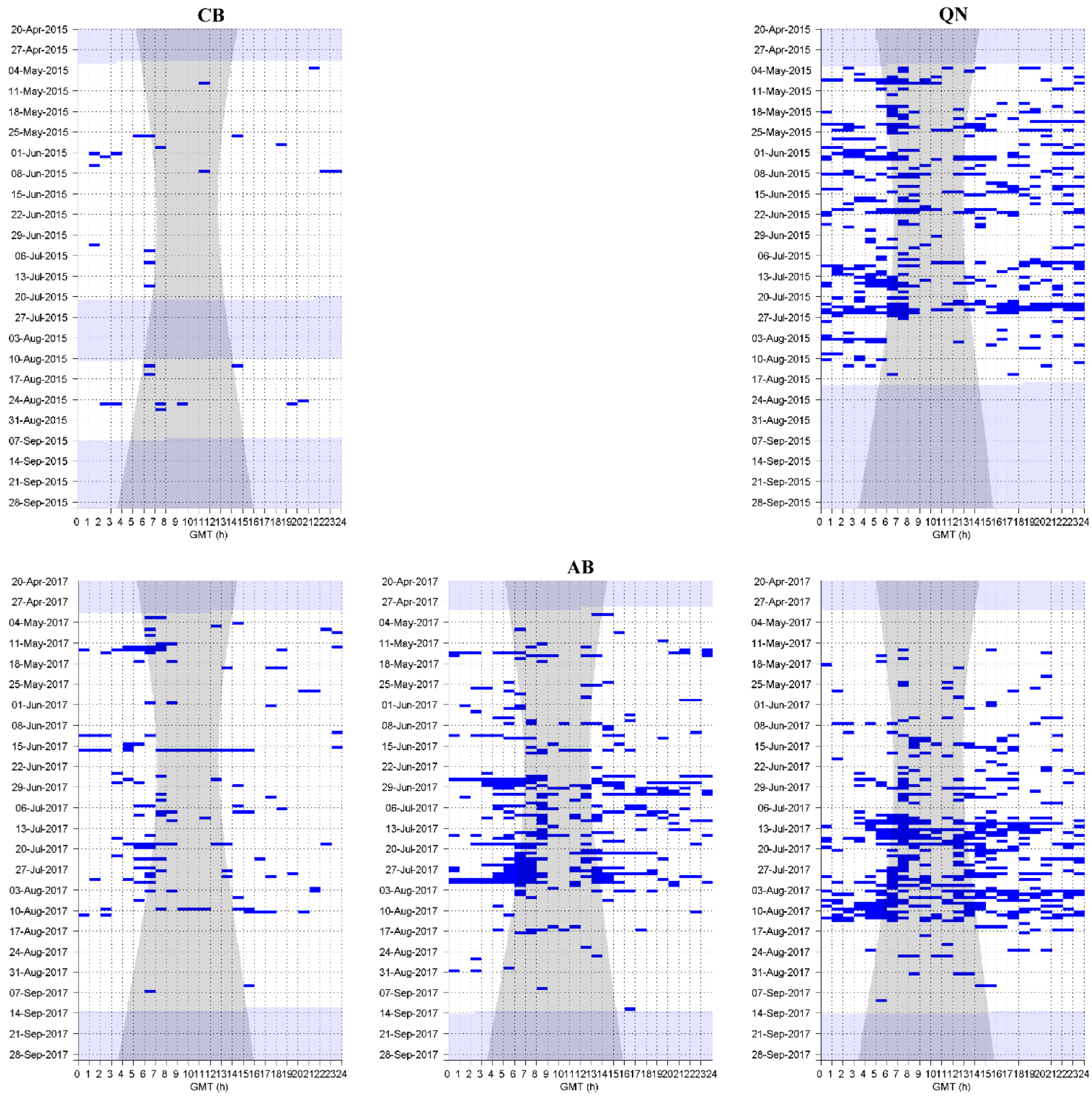

Figure 23. Diel presence of blue whale D calls, indicated by blue dots, in one hour bins at sites CB (left), AB (middle), and QN (right).
Gray vertical shading denotes nighttime and gray horizontal shading denotes absence of acoustic data.

Fin whales

Fin whales were detected throughout the recordings at all sites.

- The highest values of the fin whale acoustic index (representative of 20 Hz calls) were measured at site CB, though the index peaked in August and September 2017 at all sites (Figure 24).
- The fin whale acoustic index was generally low in 2015 (Figure 24).
- In the eastern North Pacific, fin whale 20 Hz calls are generally detected from October through April (Watkins *et al.*, 2000), which explains the very low values of the fin whale acoustic index for most of the recording period (Figure 24).
- Fin whale 40 Hz calls were recorded throughout the recording period at all sites but were lowest at site AB and peaked in spring 2017 at site QN (Figure 25).
- There was no discernable diel pattern for fin whale 40 Hz calls (Figure 26).
- Differences in the timing of peak calling presence per call type may indicate distinct behavioral functions associated with these call types (Širović *et al.*, 2013).
- These results are consistent with previous monitoring periods at these sites (Baumann-Pickering *et al.*, 2012; Debich *et al.*, 2013; Debich *et al.*, 2014; Rice *et al.*, 2015).

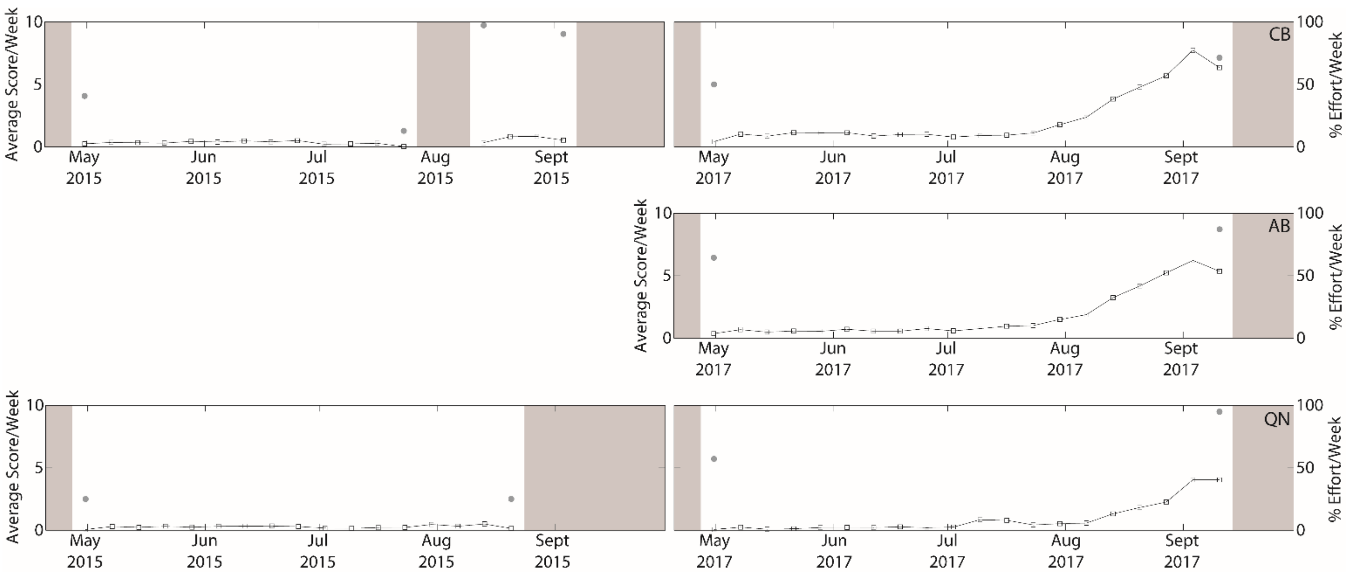

Figure 24. Weekly presence of fin whale acoustic index (proxy for 20 Hz calls) from May to September 2015 and April to September 2017 at sites CB (top), AB (middle), and QN (bottom).
Gray dots represent the percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

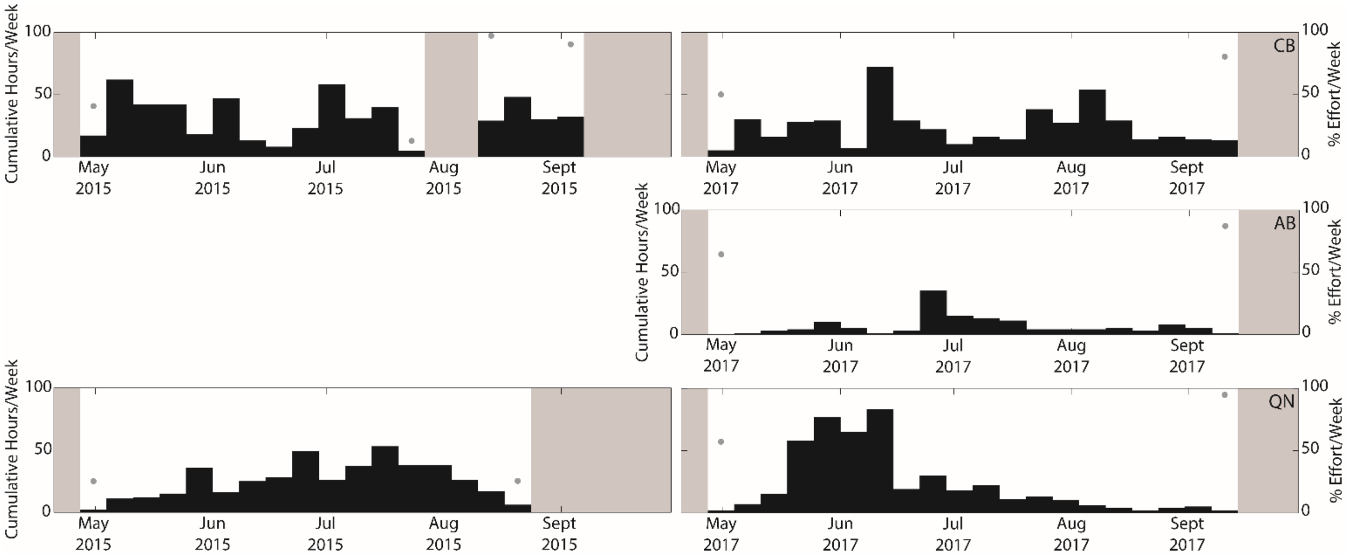

Figure 25. Weekly presence of fin whale 40 Hz calls from May to September 2015 and April to September 2017 at sites CB (top), AB (middle), and QN (bottom).

Gray dots represent the 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.

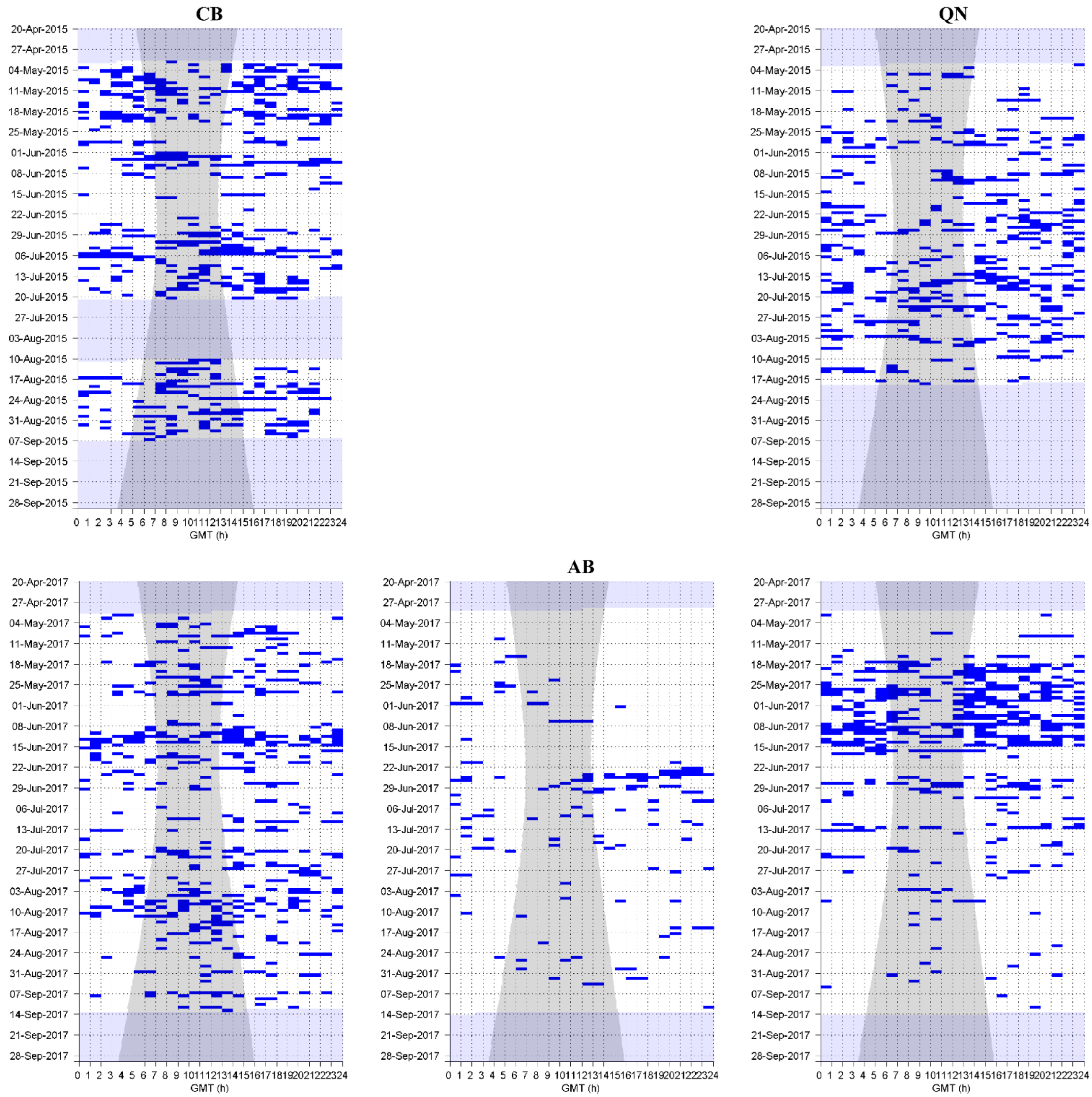

Figure 26. Diel presence of fin whale 40 Hz calls, indicated by blue dots, in one hour bins at sites CB (left), AB (middle), and QN (right).
Gray vertical shading denotes nighttime and gray horizontal shading denotes absence of acoustic data.

Gray Whales

Gray whale M3 calls were detected in low numbers. There were no M3 calls at any site in 2017.

- Gray whale M3 calls were detected at sites CB and QN in 2015 (Figure 27). There were no M3 calls at any site in 2017.
- Calls occurred during July at both sites and during August at site CB (Figure 27).
- There were too few gray whale M3 calls detected to determine a diel pattern, although all detected calls occurred during daytime (Figure 28).
- Gray whale M3 call detections are most common on the continental shelf (Debich *et al.*, 2014; Rice *et al.*, 2015) and have been detected only once previously at site CB (Baumann-Pickering *et al.*, 2012).

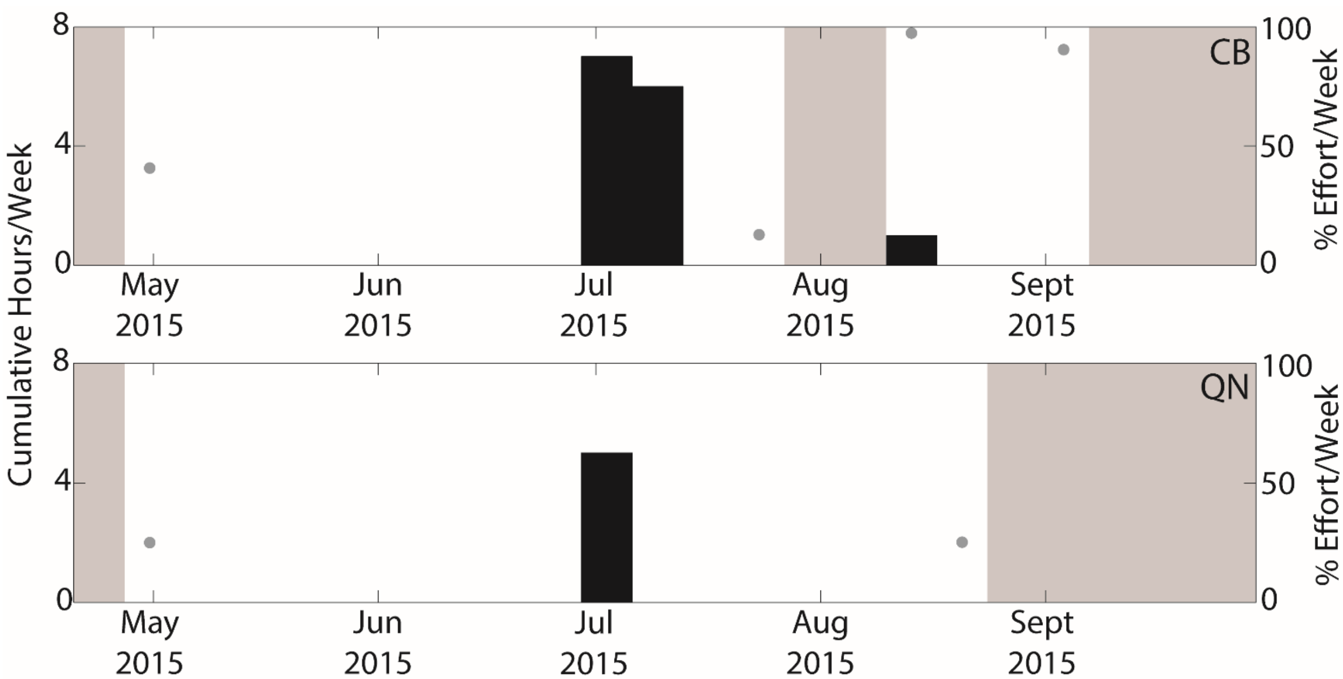

Figure 27. Weekly presence of gray whale M3 calls between May 2015 and September 2017 at sites CB (top) and QN (bottom). There were no M3 calls at any site in 2017.
Gray dots represent the percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

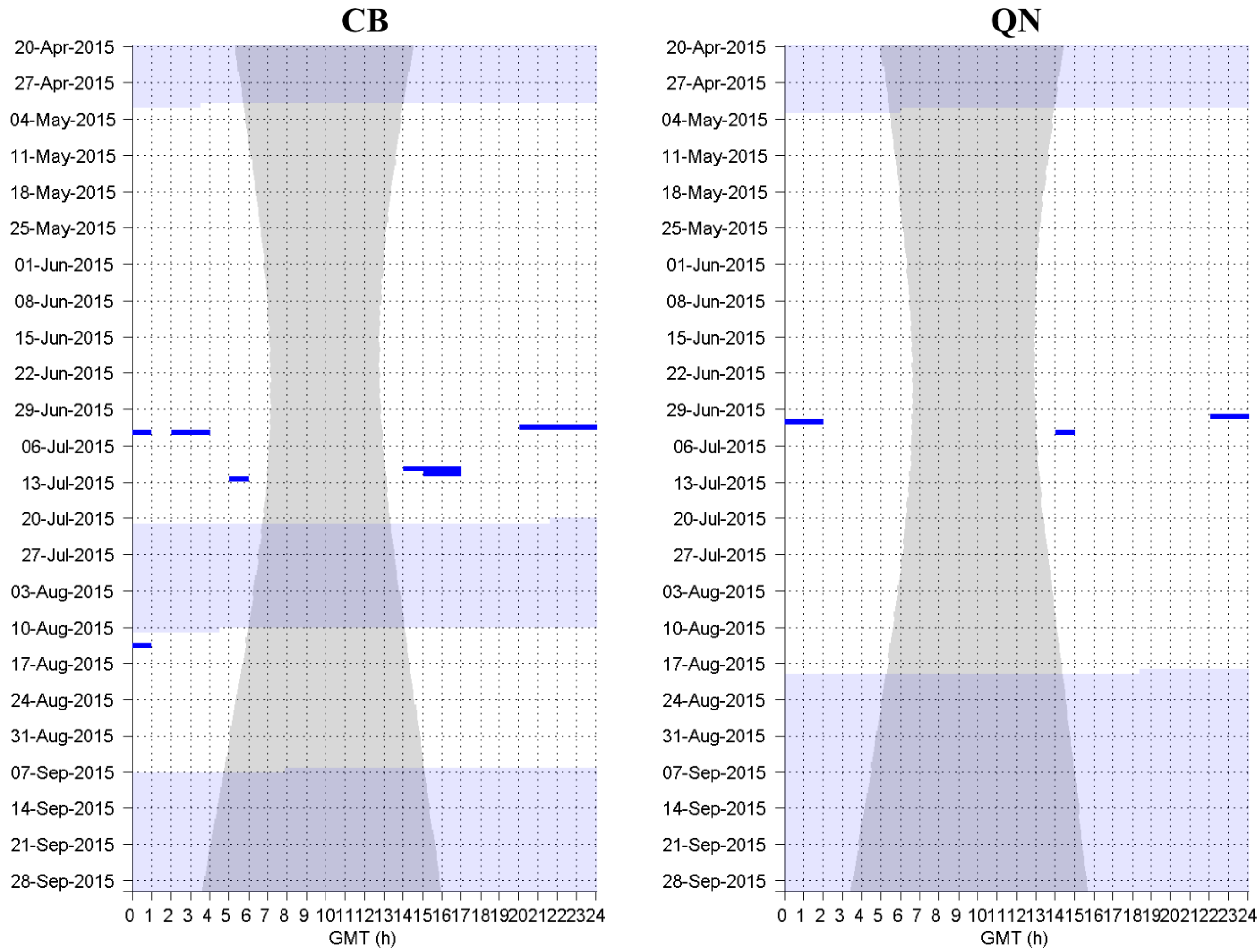

Figure 28. Diel presence of gray whale M3 calls, indicated by blue dots, in one hour bins at sites CB (left) and QN (right) in 2015. There were no M3 detections at any site in 2017.
Gray vertical shading denotes nighttime and gray horizontal shading denotes absence of acoustic data.

Humpback Whales

Humpback whale calls were detected in low numbers at sites CB and QN. They were not detected at site AB in 2017. Calls were detected automatically in 2015 and manually in 2017.

- In 2015, humpback whale detections were highest at site QN but were very low at site CB, occurring on just two days for a very short time period (Figure 29; Figure 30).
- In 2017, humpback whale detections were highest at site CB but were overall very low (Figure 29).
- There was no consistent diel pattern for humpback whale detections but the calls in July and August 2015 at site QN occurred predominantly at night, however in 2017 they occurred only during the day (Figure 30).
- The low number of calls during summer months is consistent with previous monitoring periods at these sites (Baumann-Pickering *et al.*, 2012; Debich *et al.*, 2013; Debich *et al.*, 2014; Rice *et al.*, 2015)

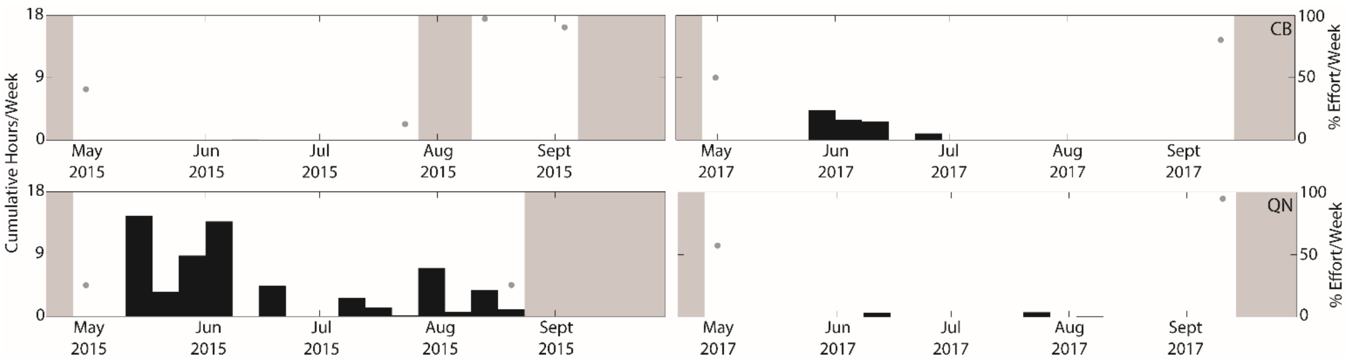

Figure 29. Weekly presence of humpback whale calls from May to September 2015 and April to September 2017at sites CB (top) and QN (bottom). Detections in 2015 at site CB were very short and are difficult to see in the plot. An automatic detector was used for analysis in 2015 while calls were logged manually in 2017. There were no detections of humpback calls at site AB in 2017.
Gray dots represent the 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.

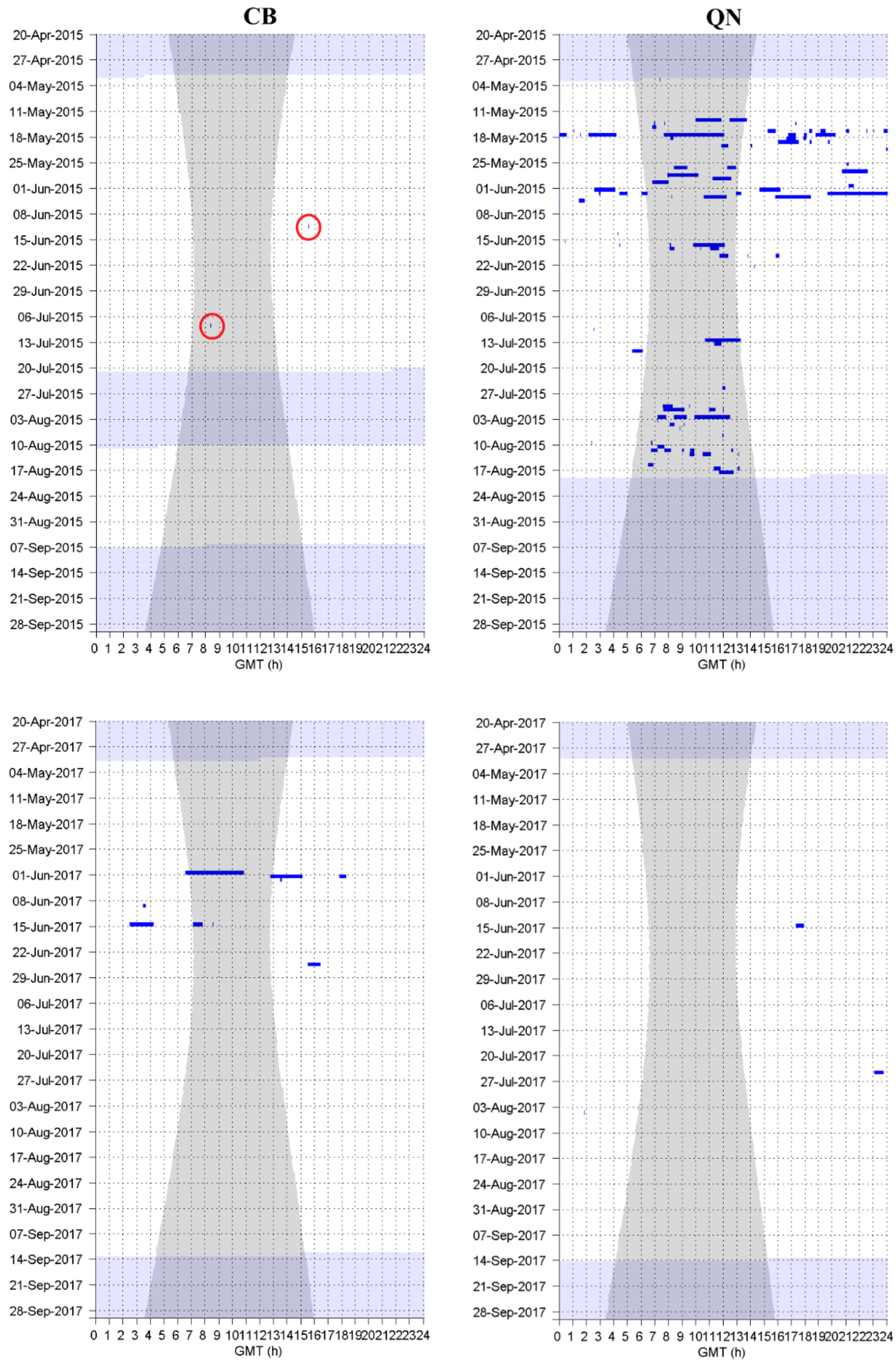

Figure 30. Diel presence of humpback whale calls, indicated by blue dots, in one minute bins at sites CB (left) and QN (right). There were no detections of humpback whale calls at site AB in 2017.
Gray vertical shading denotes nighttime and gray horizontal shading denotes absence of acoustic data.

Odontocetes

Three odontocete species were detected from May to September 2017 and from April to September 2017: Sperm whales, Cuvier's beaked whales, and Stejneger's beaked whales. More details of each species presence at each site is given below.

Sperm Whales

Sperm whale echolocation clicks were detected at each site. In 2015, clicks were logged manually as encounters while in 2017 an automated detector was run on the data to detect individual clicks. Therefore, results are not necessarily comparable across years without further analysis and verification.

- In 2015, sperm whale clicks were most prevalent at site CB, with high numbers of detections occurring throughout the summer (Figure 31).
- In 2017, sperm whale clicks were highest at site CB and QN, though clicks occurred throughout the summer at all sites (Figure 32).
- There were no discernable diel patterns for sperm whale clicks at any site (Figure 33).
- These results are consistent with previous monitoring periods (Baumann-Pickering *et al.*, 2012; Debich *et al.*, 2013; Debich *et al.*, 2014; Rice *et al.*, 2015).

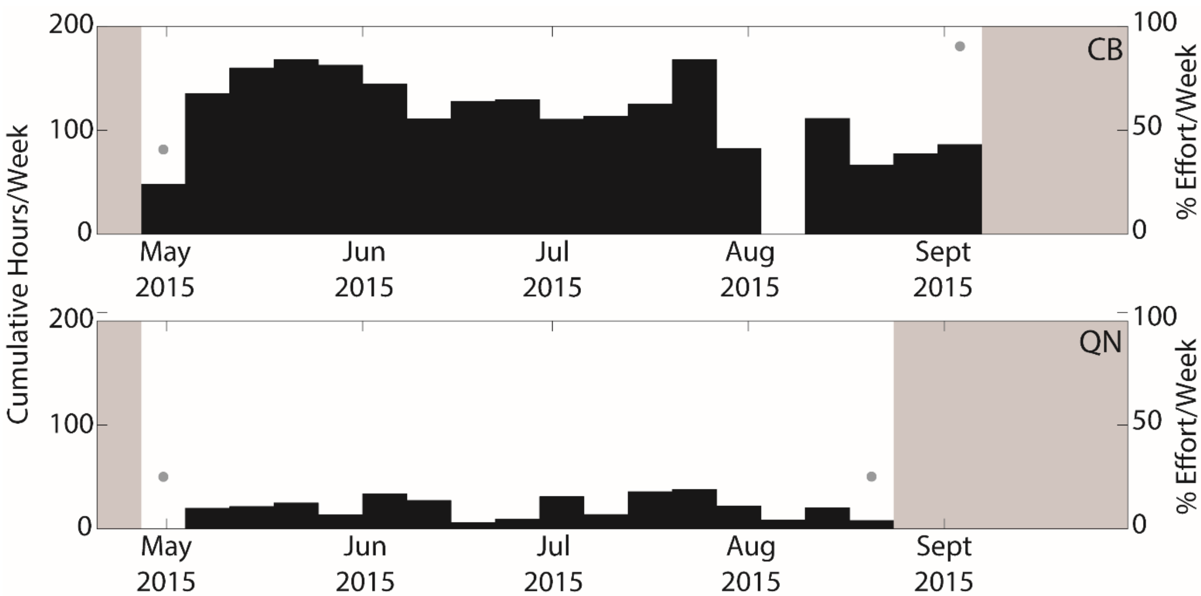

Figure 31. Weekly presence of sperm whale clicks between May and September 2015 at sites CB (top) and QN (bottom).
Gray dots represent the percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

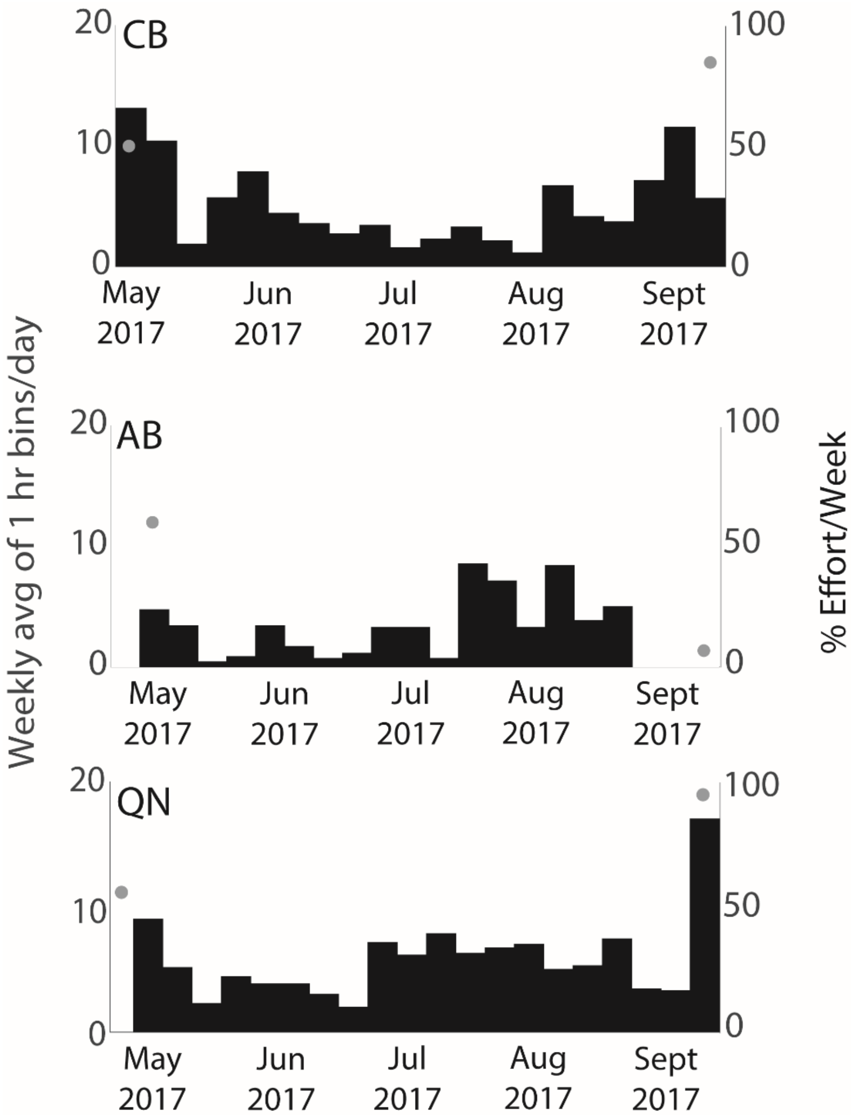

Figure 32. Weekly average of the hours of sperm whale clicks each day between April and September 2017 at sites CB (top), AB (middle), and QN (bottom).
Gray dots represent the percent of effort per week in weeks with less than 100% recording effort. Where gray dots are absent, full recording effort occurred for the entire week.

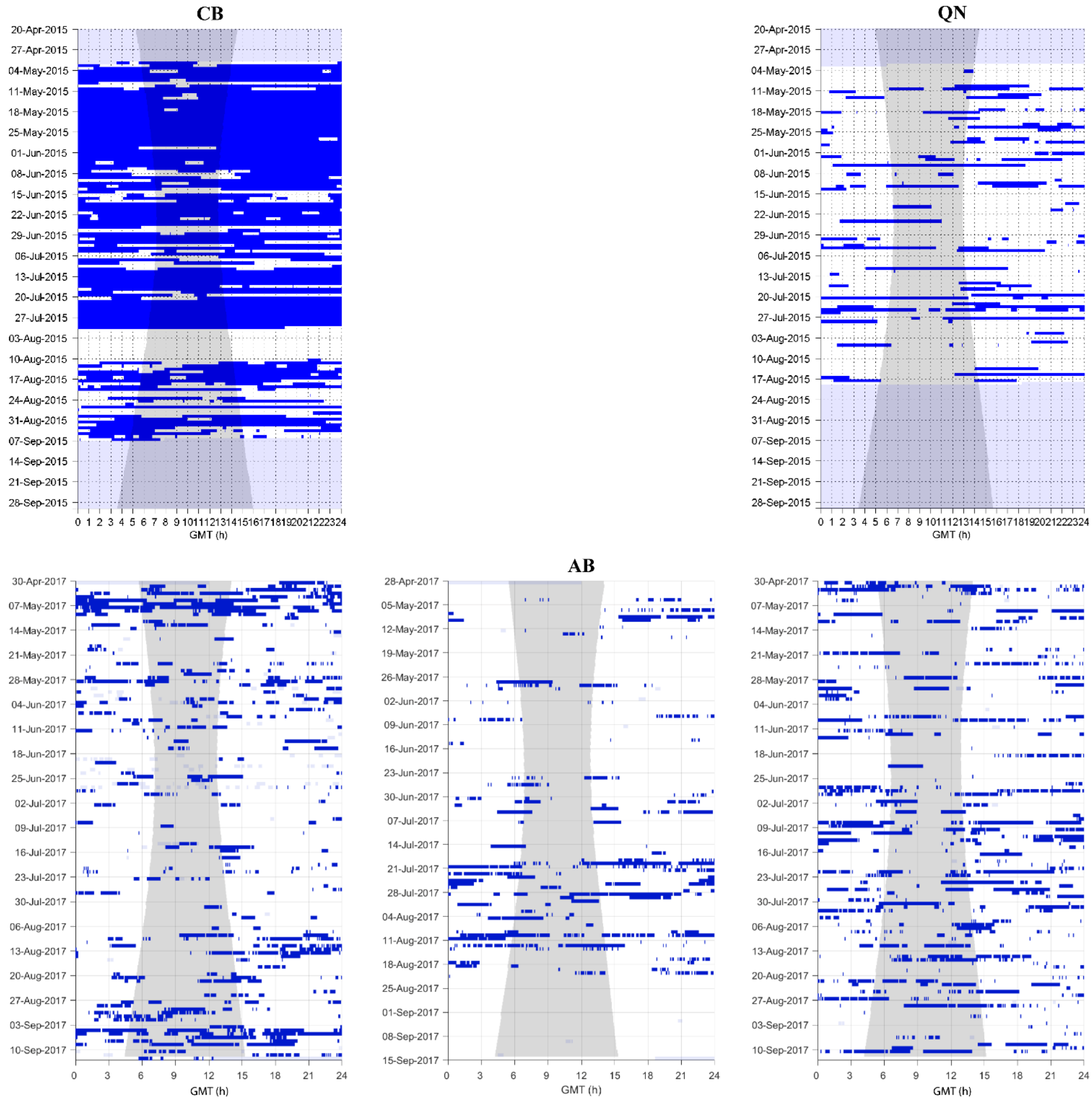

Figure 33. Diel presence of sperm whale clicks, indicated by blue dots, in one minute bins at site CB (left), AB (middle), and QN (right).
Detections in 2015 were logged as encounters in 2015 and individual clicks in 2017. Gray vertical shading denotes nighttime and gray horizontal shading denotes absence of acoustic data.

Cuvier's Beaked Whales

Cuvier's beaked whale FM pulses were detected at sites AB and QN.

- Cuvier's beaked whale FM pulses were most common at site AB during early summer, with no detections occurring July to September (Figure 34).
- There was only one encounter of Cuvier's beaked whale FM pulses at site QN, on August 2, 2015 (Figure 34).
- There were no Cuvier's beaked whale FM pulse detections at site CB or in 2017 at site QN.
- There was no discernable diel pattern for Cuvier's beaked whale detections (Figure 35).
- These results were consistent with previous monitoring periods for site QN (Debich *et al.*, 2014; Rice *et al.*, 2015). This was the first deployment at site AB but detections there were higher than has been seen at other sites during previous summer monitoring periods (Debich *et al.*, 2013; Debich *et al.*, 2014; Rice *et al.*, 2015).

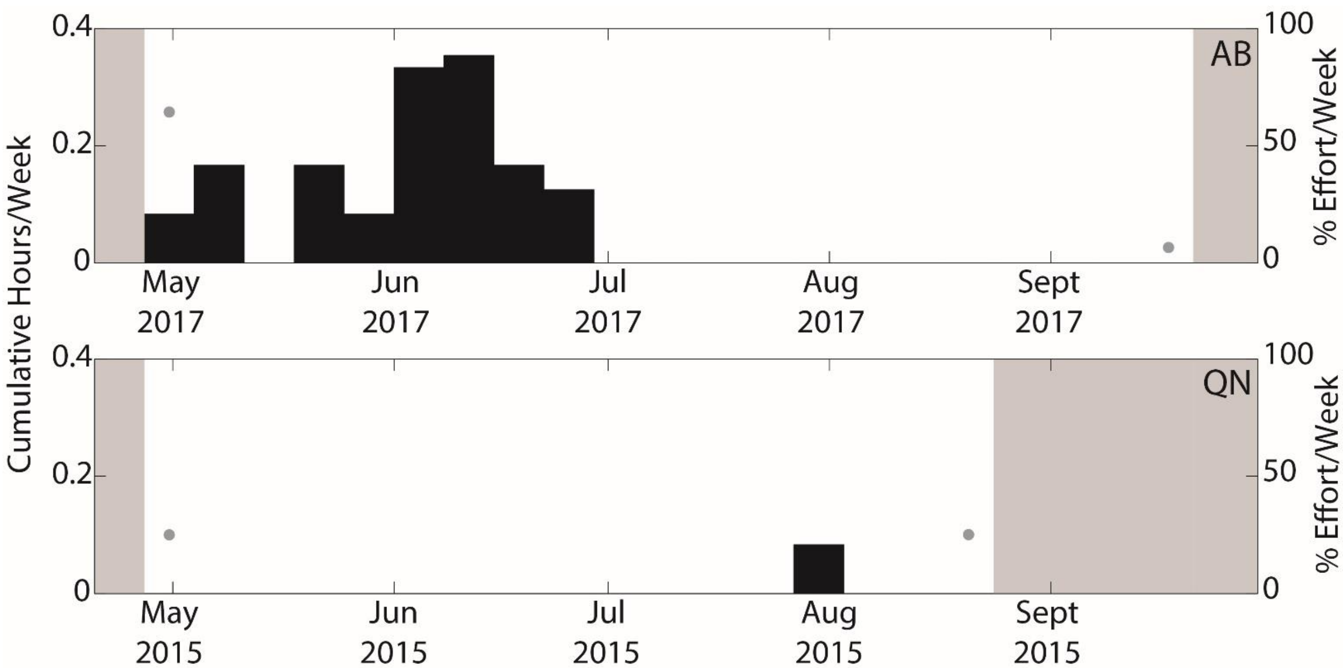

Figure 34. Weekly presence of Cuvier's beaked whale FM pulses from May to September 2015 and April to September 2017 at sites AB (top) and QN (bottom). There were no detections of Cuvier's at site CB or in 2017 at site QN.
Gray dots represent the percent of effort per week in weeks with less than 100% 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.

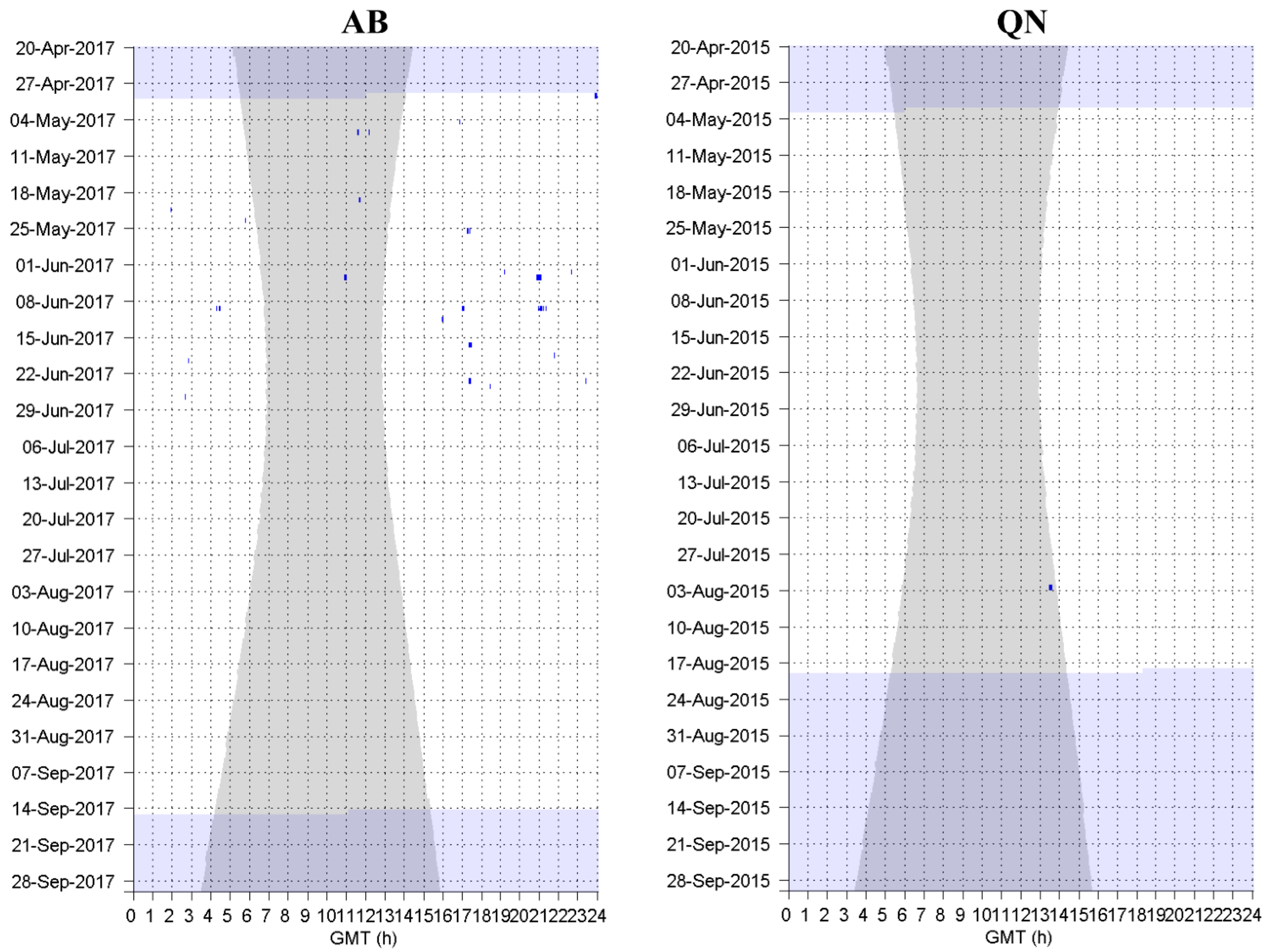

Figure 35. Diel presence of Cuvier's beaked whale FM pulses, indicated by blue dots, in one minute bins at site AB (left) and in five minute bins at site QN (right). There were no detections of Cuvier's at site CB or in 2017 at site QN.
Gray vertical shading denotes nighttime and gray horizontal shading denotes absence of acoustic data.

Stejneger's Beaked Whales

Stejneger's beaked whale FM pulses were detected at all sites.

- Stejneger's beaked whale FM pulses were most common at site CB, with a peak in June 2015, and least common at site QN (Figure 36).
- Detections occurred throughout the summer at sites CB and AB, but only sporadically in early summer at site QN (Figure 36).
- There was no discernable diel pattern for Stejneger's beaked whale FM pulses (Figure 37).
- These results are consistent with previous monitoring periods (Baumann-Pickering *et al.*, 2012; Debich *et al.*, 2013; Debich *et al.*, 2014; Rice *et al.*, 2015).

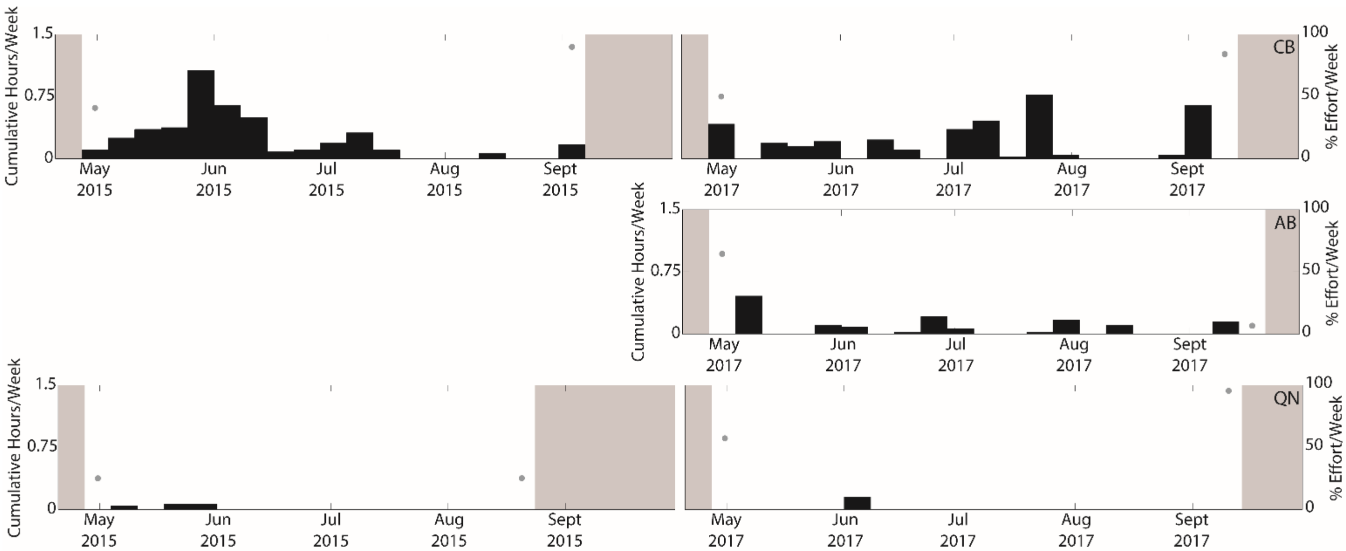

Figure 36. Weekly presence of Stejneger's beaked whale FM pulses between May 2015 and September 2017 at sites CB (top), AB (middle), and QN (bottom).
Gray dots represent the percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

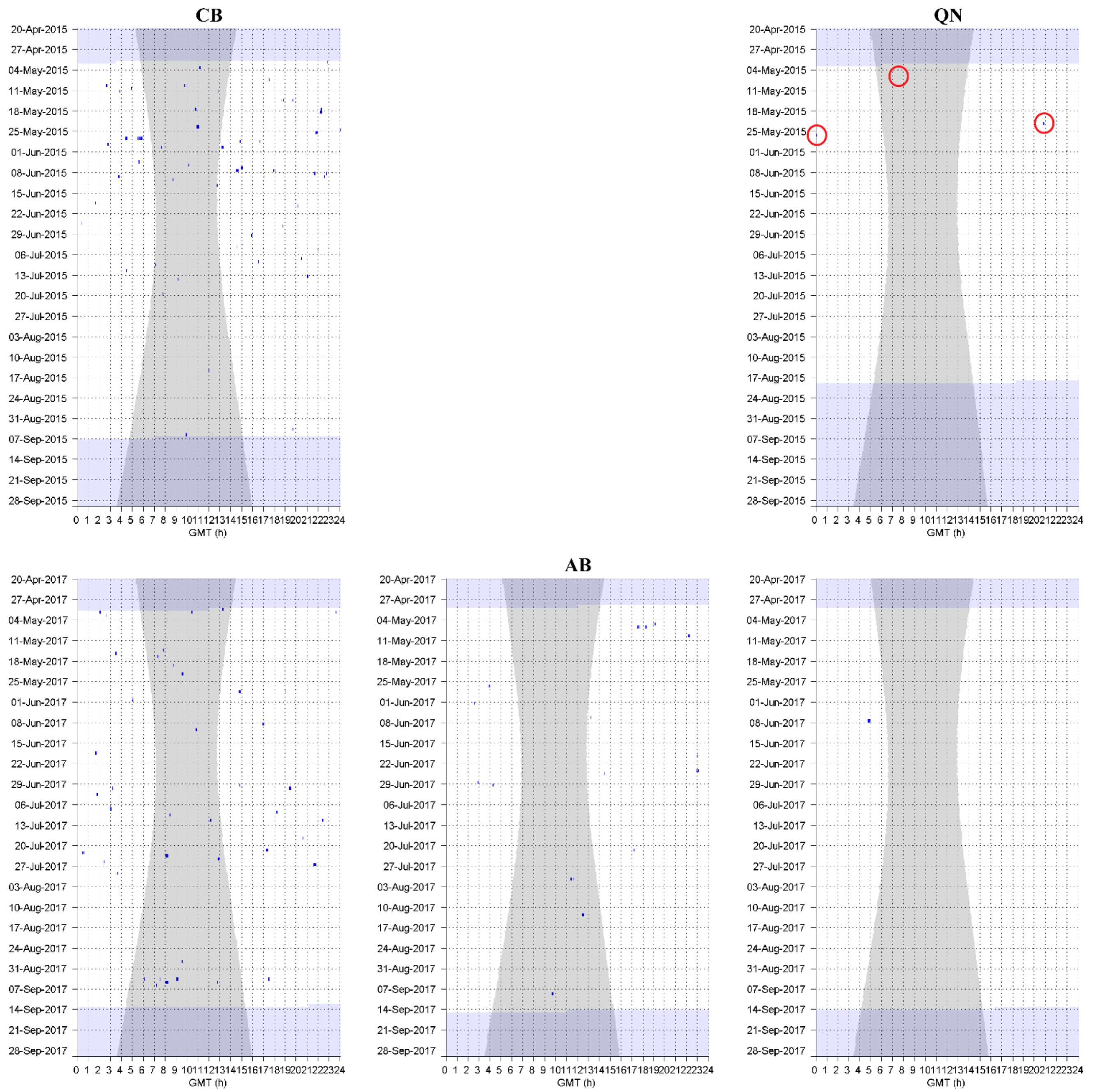

Figure 37. Diel presence of Stejneger's beaked whale FM pulses, indicated by blue dots, in one minute bins at sites CB (left), AB (middle), and QN (right).
Gray vertical shading denotes nighttime and gray horizontal shading denotes absence of acoustic data.

Anthropogenic Sounds

Three types of anthropogenic sounds were detected in the GATMAA between May and September 2015 and between April and September 2017: MFA sonar, LFA sonar, and explosions. More details about the presence of each anthropogenic signal at each site are given below.

Mid-Frequency Active Sonar

MFA sonar was detected in low numbers at all sites. Naval training exercises occurred in the GATMAA from June 15 to 26, 2015 and from May 1 to 12, 2017 (C. Johnson, U.S. Navy Pacific Fleet, personal communication). These dates correspond with the presence of MFA sonar in the recordings from this monitoring period. The two deployments in 2015 were reported on by Wiggins et al. (2017). However, the hydrophone transfer function originally used for site QN was 10 dB too low and so the data were re-analyzed and the corrected results are presented here. The automatically detected packets and wave trains show the highest level of MFA sonar activity (>116 dB_{pp} re 1 µPa) when normalized per year at site CB in 2015 and lowest level at site QN in 2017 (Table 3).

- MFA sonar was detected at all three sites. Detections occurred in June 2015 and May 2017 when naval training exercises were taking place (Figure 38).
- At site CB, a total of 2,054 packets were detected in 2015, with a maximum sound pressure received level of 144 dB_{pp} re 1 µPa and a median received level of 123 dB_{pp} re 1 µPa (Figure 40). Total event duration was around 35 h but the total duration of detected pings was only about 2.1 h (7,598 s; Table 4).
- At site QN, a total of 1,147 packets were detected in 2015, with a maximum received level of 142 dB_{pp} re 1 µPa and a median received level of 119 dB_{pp} re 1 µPa (Figure 41). Total event duration was around 17 h but the total duration of detected pings was only about 1.2 h (4,630 s; Table 6).
- At site CB, a total of 63 packets were detected in 2017, with a maximum received level of 137 dB_{pp} re 1 µPa and a median received level of 129 dB_{pp} re 1 µPa (Figure 42). Total event duration was around 1.5 h but the total duration of detected pings was only about 0.03 h (121 s; Table 4).
- At site AB, a total of 38 packets were detected, with a maximum received level of 149 dB_{pp} re 1 µPa and a median received level of 146 dB_{pp} re 1 µPa (Figure 43). Total event duration was around 1.5 h but the total duration of detected pings was only about 0.01 h (43 s; Table 5).
- At site QN, a total of 24 packets were detected in 2017, with a maximum received level of 124 dB_{pp} re 1 µPa and a median received level of 112 dB_{pp} re 1 µPa (Figure 44). Total event duration was around 0.5 h but the total duration of detected pings was only about 0.008 h (30 s; Table 6).
- Maximum cumulative sound exposure levels of wave trains occurred during June 2015 at site CB (Figure 40) and May 2017 at site AB (Figure 43) and were greater than 140 dB re 1 μPa^2–s. At site CB in May 2017, maximum levels were around 130 dB re 1 μPa^2–s. At site QN in June 2015, maximum received levels were around 140 dB re 1 μPa^2–s, while in May 2017 maximum received levels were around 120 dB re 1 μPa^2–s.
- Most MFA sonar wave trains occurred at site CB in 2015 during navy training exercises (Figure 40). There were fewer wave trains in 2017 than 2015.
- The majority of MFA sonar occurred during daytime hours (Figure 39).
- MFA sonar has not been detected during previous monitoring periods (Baumann-Pickering *et al.*, 2012; Debich *et al.*, 2013; Debich *et al.*, 2014; Rice *et al.*, 2015).

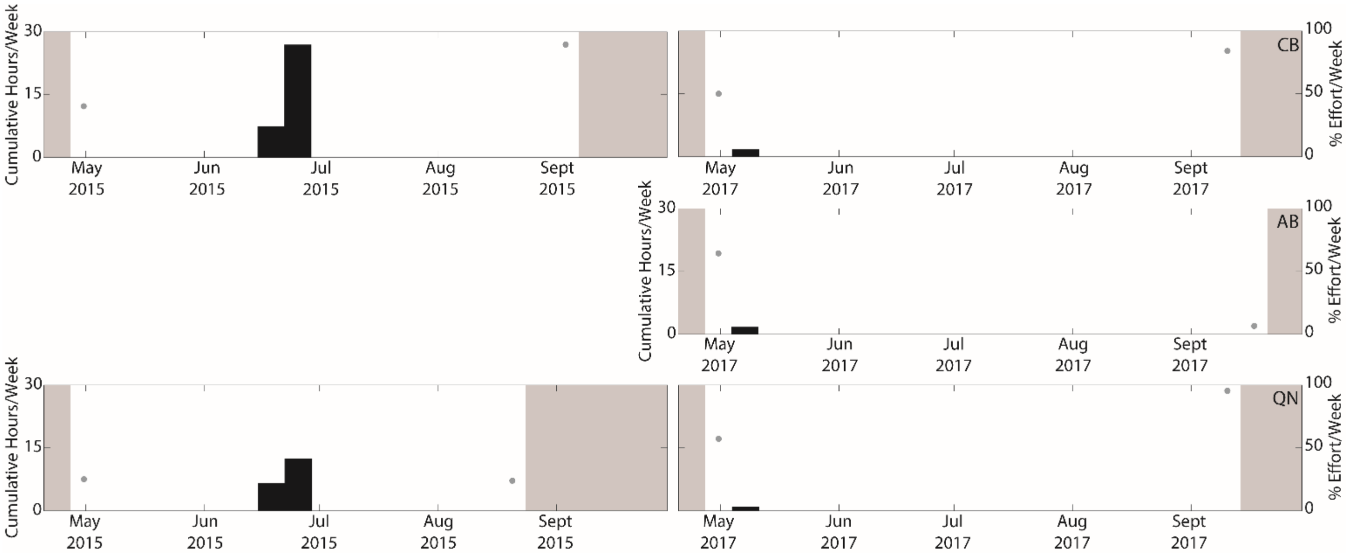

Figure 38. Weekly presence of MFA sonar <5kHz from May to September 2015 and April to September 2017at sites CB (top), AB (middle), and QN (bottom).

Gray dots represent the 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.

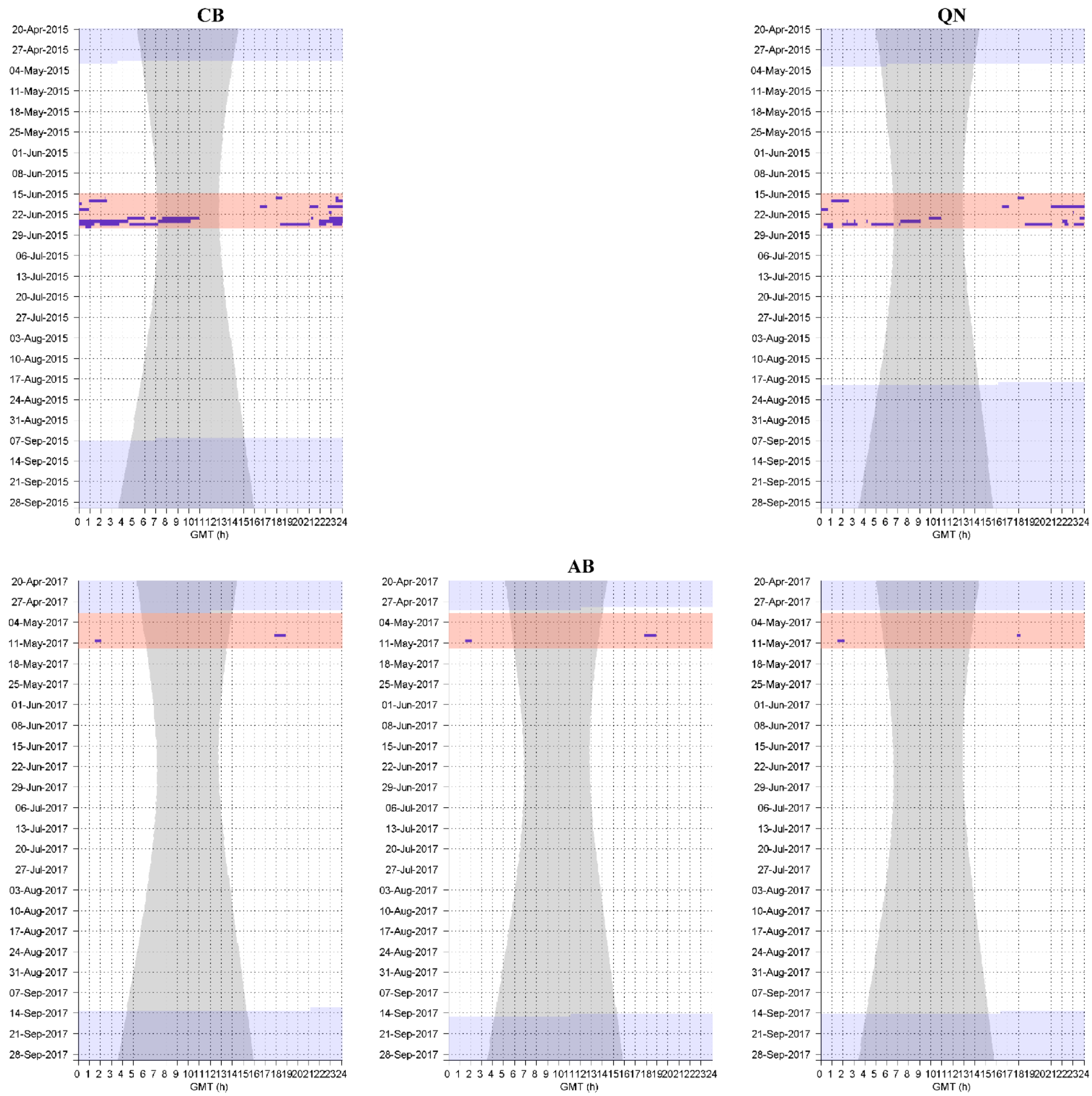

Figure 39. Naval training events (shaded red) overlaid on diel presence of MFA sonar <5kHz signals, indicated by blue dots, in one minute bins at sites CB (left), AB (middle), and QN (right). Gray vertical shading denotes nighttime and gray horizontal shading denotes absence of acoustic data.

Table 3. MFA sonar automated detector results for site CB, AB, and QN.
Total effort at each site in days (years), number of wave trains, and number of packets at each site (> 116 dB_{pp} re 1 μPa).

Site	Year	Days Analyzed (Years)	Number of Wave Trains	Number of Packets
CB	2015	104 (0.28)	13	2,054
	2017	135 (0.37)	2	63
AB	2017	136 (0.37)	2	38
QN	2015	107 (0.29)	11	1,147
	2017	136 (0.37)	1	24

Table 4. MFA sonar temporal characteristics for events (wavetrains) of detected groups of pings (packets) in the GATMAA at site CB during 2015 and 2017.

Deployment	Event #	First Detection	Last Detection	Event Duration [HH:MM:SS]	Number of Detections	Total Duration of Detected Pings [s]
CB07	1	16-Jun-2015 17:52:51	16-Jun-2015 18:28:18	00:35:27	26	85
	2	16-Jun-2015 23:19:18	16-Jun-2015 23:34:57	00:15:38	28	98
	3	17-Jun-2015 00:54:57	17-Jun-2015 01:48:30	00:53:32	66	170
	4	17-Jun-2015 23:20:52	18-Jun-2015 00:14:13	00:53:21	68	68
	5	19-Jun-2015 16:28:56	19-Jun-2015 16:46:28	00:17:32	21	67
	6	19-Jun-2015 23:00:08	20-Jun-2015 00:00:25	01:00:17	12	46
	7	21-Jun-2015 22:44:43	21-Jun-2015 22:57:46	00:13:03	13	41
	8	23-Jun-2015 04:27:00	23-Jun-2015 10:56:08	06:29:08	399	1067
	9	23-Jun-2015 22:45:29	24-Jun-2015 04:28:26	05:42:56	411	1558
	10	24-Jun-2015 07:12:31	24-Jun-2015 10:08:15	02:55:43	250	1358
	11	24-Jun-2015 20:50:51	25-Jun-2015 07:13:41	10:22:50	535	2110
	12	25-Jun-2015 18:18:50	25-Jun-2015 21:00:13	02:41:23	163	658
	13	25-Jun-2015 22:08:22	26-Jun-2015 01:04:53	02:56:31	62	272
	Total			35:17:25	2054	7598
CB08	1	08-May-2017 17:48:38	08-May-2017 18:50:47	01:02:09	35	48
	2	10-May-2017 01:29:24	10-May-2017 02:06:25	00:37:01	28	73
	Total			01:39:10	63	121

Table 5. MFA sonar temporal characteristics for events (wavetrains) of detected groups of pings (packets) in the GATMAA at site AB during 2017.

Deployment	Event #	First Detection	Last Detection	Event Duration [HH:MM:SS]	Number of Detections	Total Duration of Detected Pings [s]
AB01	1	08-May-2017 17:47:41	08-May-2017 18:30:39	00:42:58	15	8
	2	10-May-2017 01:30:00	10-May-2017 02:07:04	00:37:04	23	35
	Total			01:20:02	38	43

Table 6. MFA sonar temporal characteristics for events (wavetrains) of detected groups of pings (packets) in the GATMAA at site QN during 2015 and 2017.

Deployment	Event #	First Detection	Last Detection	Event Duration [HH:MM:SS]	Number of Detections	Total Duration of Detected Pings [s]
QN05	1	16-Jun-2015 17:53:30	16-Jun-2015 18:28:00	00:34:30	26	95
	2	17-Jun-2015 01:03:55	17-Jun-2015 02:32:56	01:29:01	41	60
	3	19-Jun-2015 16:28:18	19-Jun-2015 17:05:17	00:36:59	49	107
	4	19-Jun-2015 20:53:19	20-Jun-2015 00:38:14	03:44:55	309	492
	5	23-Jun-2015 23:31:18	24-Jun-2015 00:28:48	00:57:30	46	220
	6	24-Jun-2015 02:58:48	24-Jun-2015 03:08:35	00:09:47	36	222
	7	24-Jun-2015 07:15:00	24-Jun-2015 09:04:52	01:49:51	39	282
	8	24-Jun-2015 21:55:03	24-Jun-2015 22:25:58	00:30:54	132	941
	9	25-Jun-2015 00:15:03	25-Jun-2015 03:19:41	03:04:37	259	1296
	10	25-Jun-2015 04:35:11	25-Jun-2015 07:14:02	02:38:51	183	828
	11	25-Jun-2015 18:40:49	25-Jun-2015 20:11:18	01:30:29	27	87
	Total			17:07:28	1147	4630
QN06	1	10-May-2017 01:31:41	10-May-2017 02:08:47	00:37:05	24	30
	Total			00:37:05	24	30

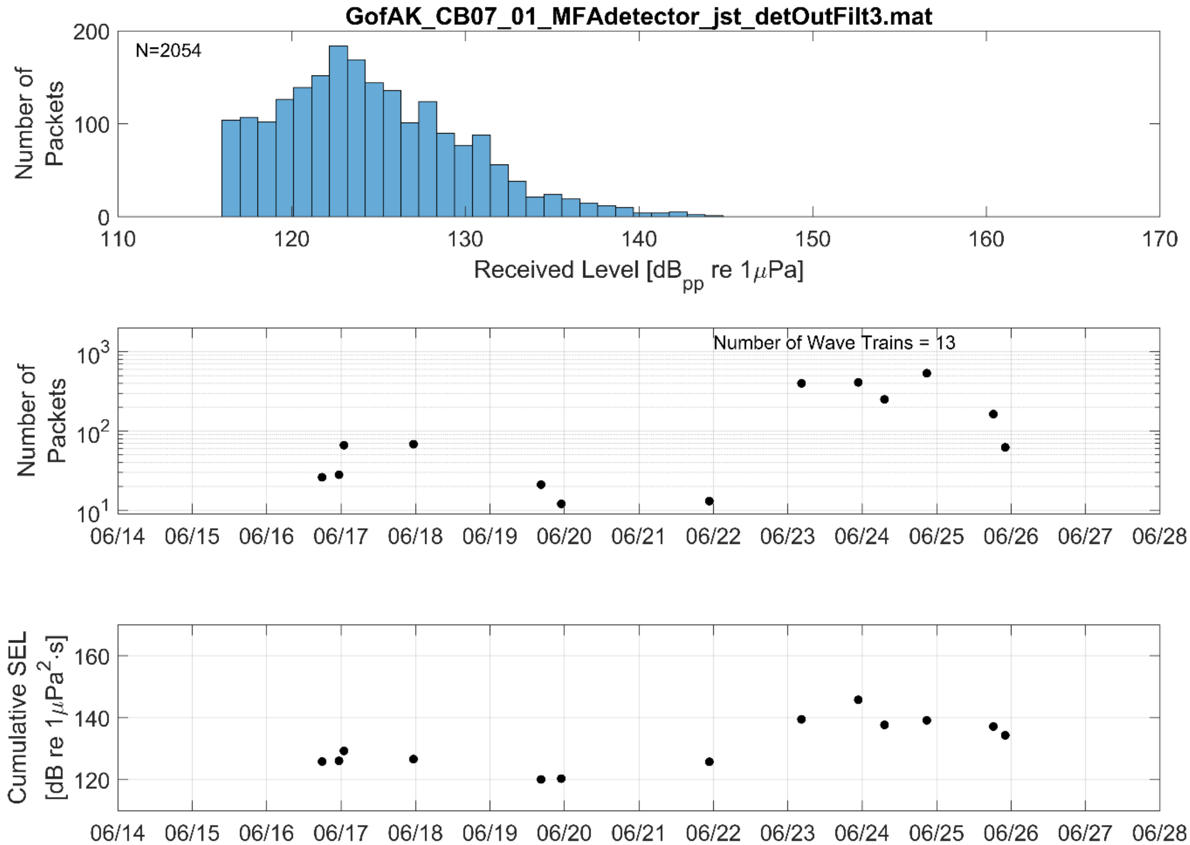

Figure 40. MFA sonar packet peak-to-peak received level distributions (top; N is the total number of packets), number of MFA sonar packets for each wave train (middle; vertical axis is logarithmic base-10), and cumulative sound exposure levels for each wave train (bottom) for site CB in 2015.

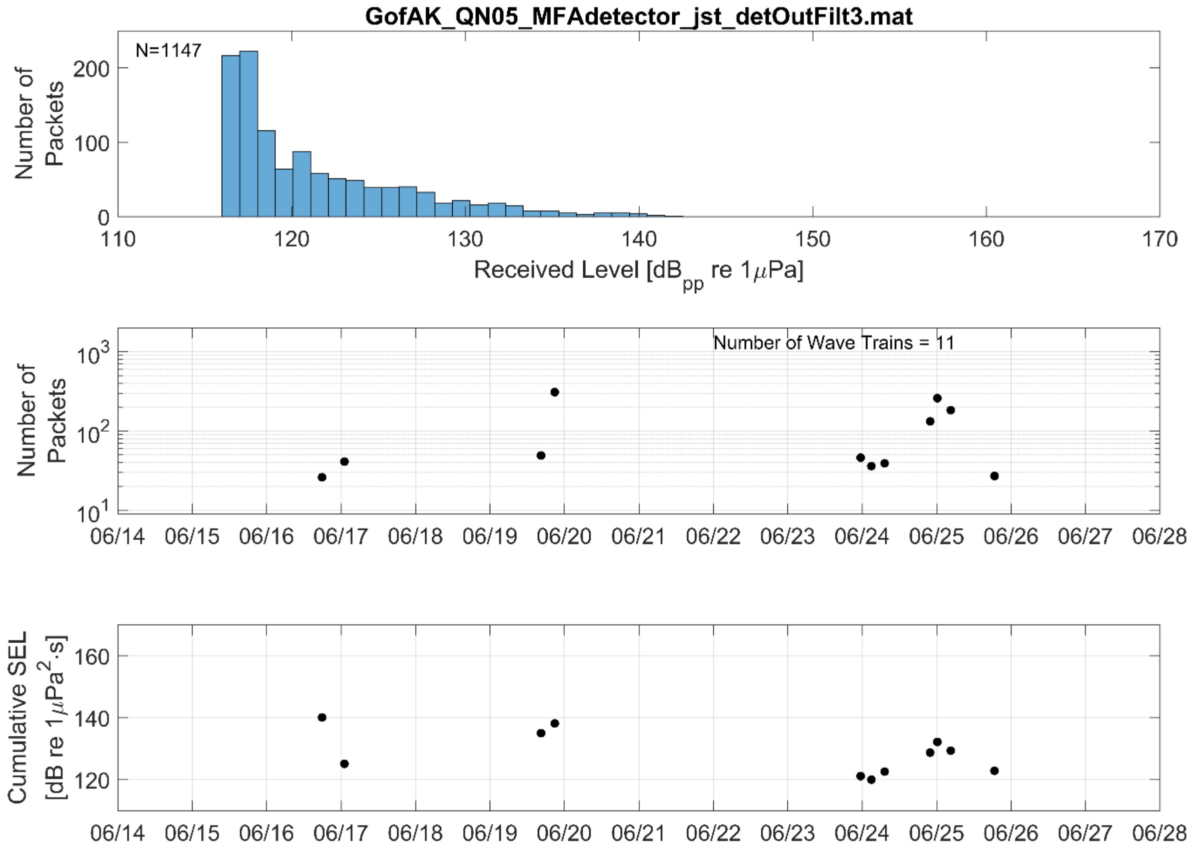

Figure 41. MFA sonar packet peak-to-peak received level distributions (top; N is the total number of packets), number of MFA sonar packets for each wave train (middle; vertical axis is logarithmic base-10), and cumulative sound exposure levels for each wave train (bottom) for site QN in 2015.

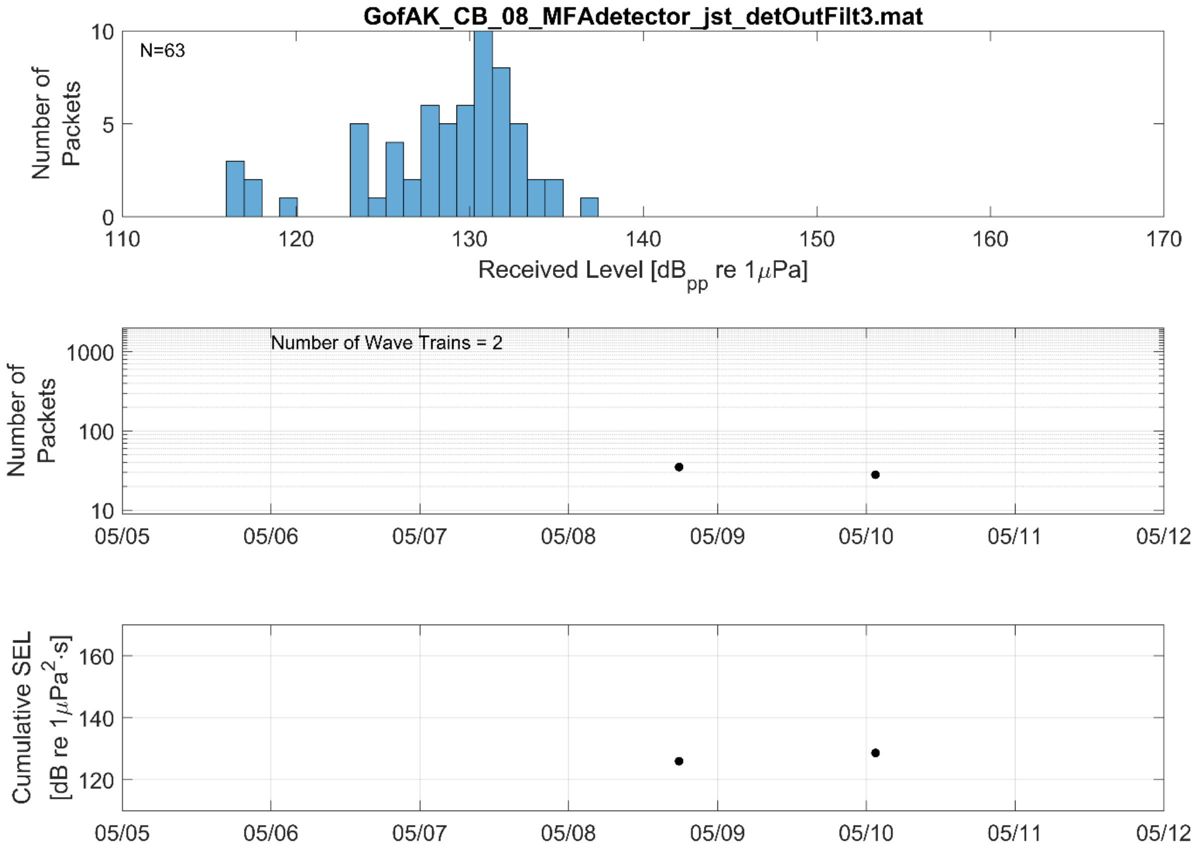

Figure 42. MFA sonar packet peak-to-peak received level distributions (top; N is the total number of packets), number of MFA sonar packets for each wave train (middle; vertical axis is logarithmic base-10), and cumulative sound exposure levels for each wave train (bottom) for site CB in 2017.

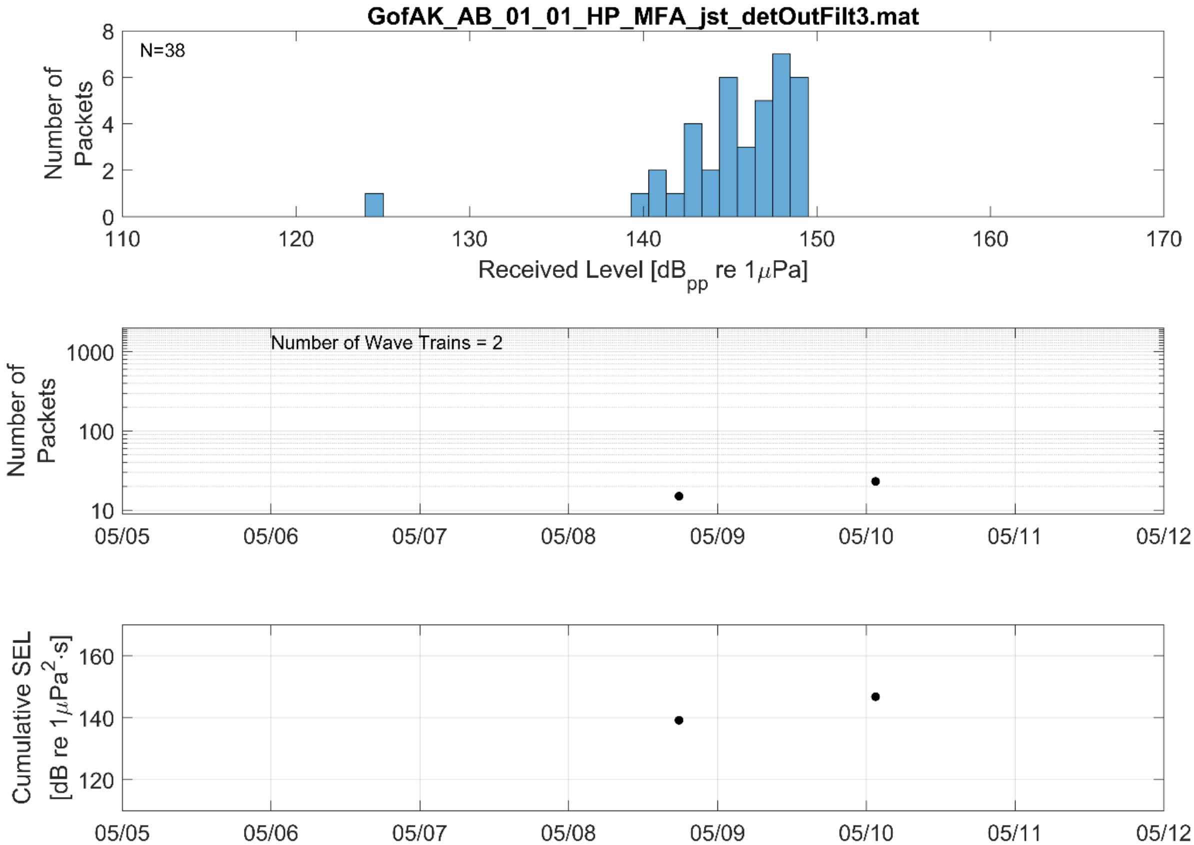

Figure 43. MFA sonar packet peak-to-peak received level distributions (top; N is the total number of packets), number of MFA sonar packets for each wave train (middle; vertical axis is logarithmic base-10), and cumulative sound exposure levels for each wave train (bottom) for site AB in 2017.

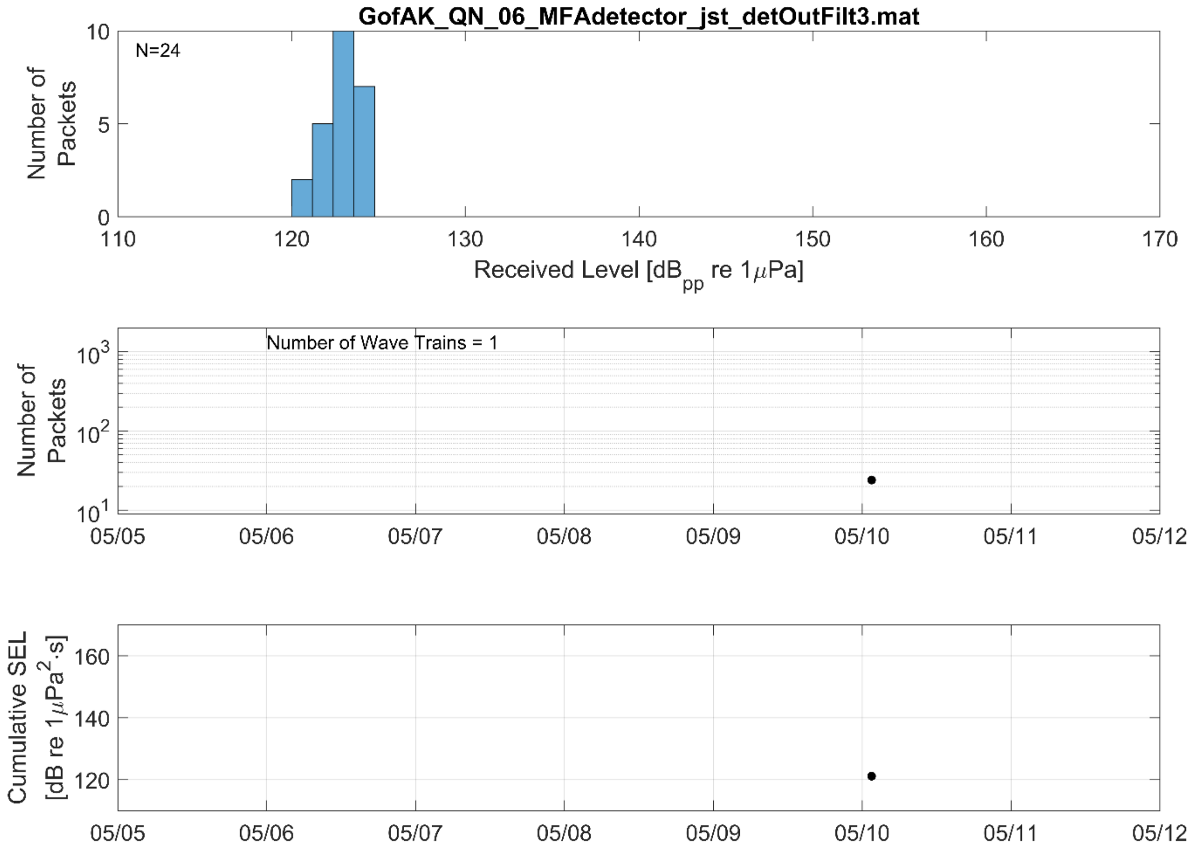

Figure 44. MFA sonar packet peak-to-peak received level distributions (top; N is the total number of packets), number of MFA sonar packets for each wave train (middle; vertical axis is logarithmic base-10), and cumulative sound exposure levels for each wave train (bottom) for site QN in 2017.

Low-Frequency Active Sonar
LFA sonar >500Hz was detected in low numbers in the GATMAA at sites.

- LFA sonar occurred at site QN on June 25, 2015 and at sites CB and QN on June 26 and 27, 2015. This largely overlapped with a navy training event that took place from June 15 to 26, 2015 (C. Johnson, U.S. Navy Pacific Fleet, personal communication; Figure 45).
- There was no LFA sonar detected at any site in 2017. Additionally, there was no LFA sonar <500Hz detected at any site during this monitoring period.
- All LFA sonar occurred during daytime hours (Figure 46).
- LFA sonar has been detected previously at site QN (Debich *et al.*, 2014).

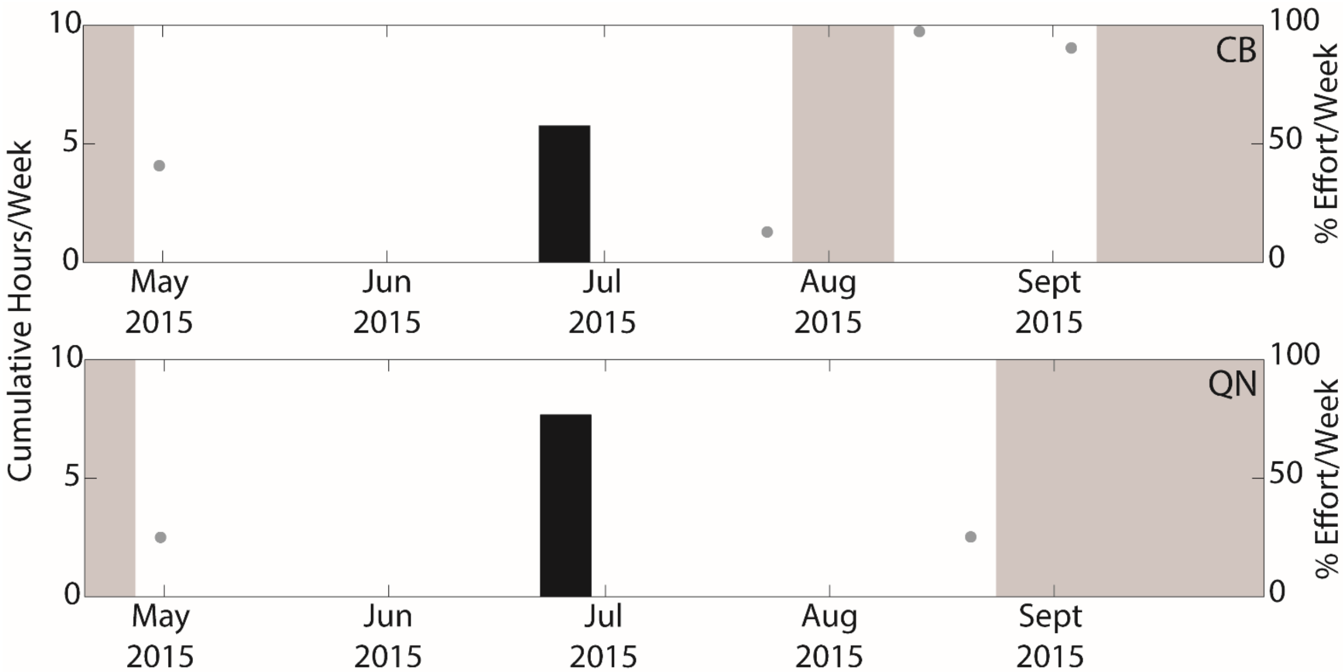

Figure 45. Weekly presence of LFA sonar >500Hz between May and September 2015 at sites CB (top) and QN (bottom). There was no LFA presence at any site in 2017.
Gray dots represent the percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

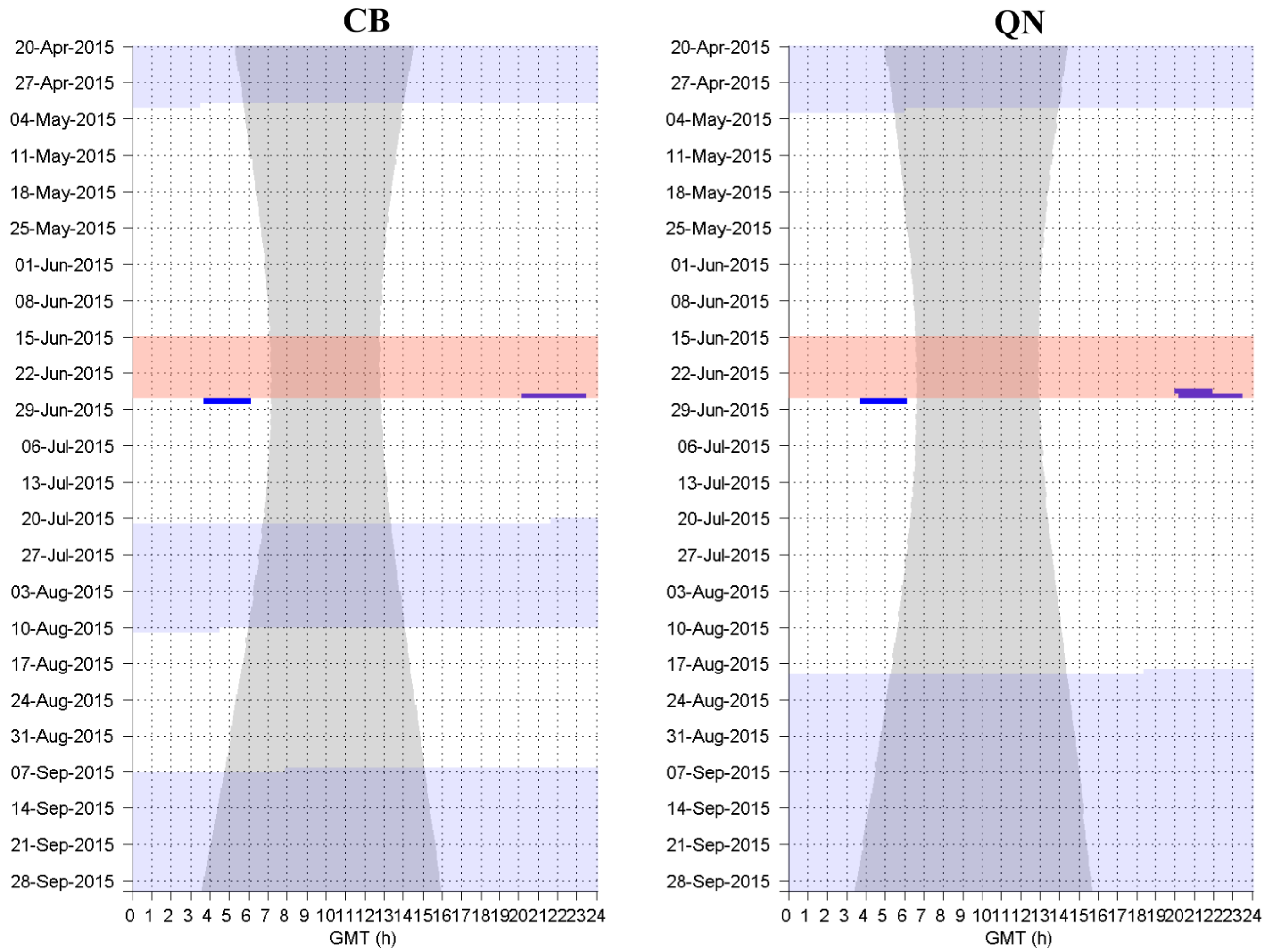

Figure 46. Major naval training events (shaded red) overlaid on diel presence of LFA sonar >500Hz signals, indicated by blue dots, in one minute bins at sites CB (left) and QN (right). There was no LFA presence in 2017.
Gray vertical shading denotes nighttime and gray horizontal shading denotes absence of acoustic data.

Explosions

Explosions were detected in low numbers at all three sites. There was no use of explosives during any navy training events during this monitoring period.

- Explosions occurred sporadically throughout the monitoring period at each site (Figure 47). There were no explosion detections at site CB in 2017.
- Total explosion counts at each site were as follows:
    - 5 at CB
    - 3 at AB
    - 8 at QN (5 in 2015 and 3 in 2017)
- Though the majority of explosions occurred during daytime hours, there were two few explosions detected to determine a diel pattern (Figure 48).
- The number of explosion detections is consistent with previous monitoring periods for site CB (Debich *et al.*, 2014; Rice *et al.*, 2015) but is lower than has been seen previously for site QN (Debich *et al.*, 2014).

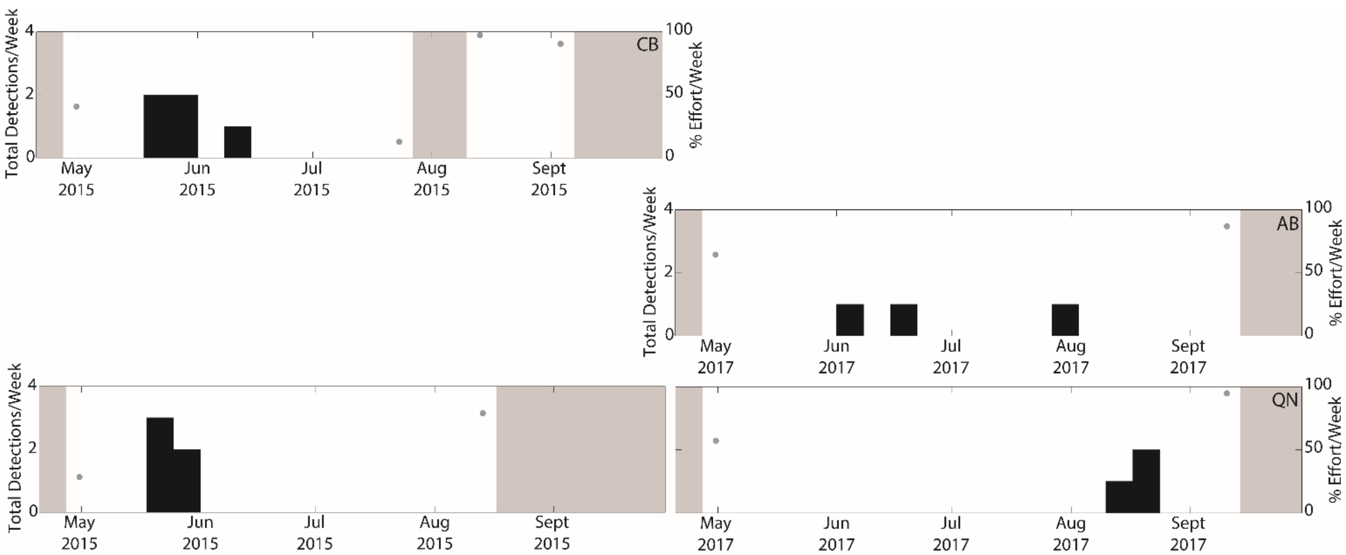

Figure 47. Weekly presence of explosions from May to September 2015 and April to September 2017 at sites CB (top), AB (middle), and QN (bottom). There were no explosion detections in 2017 at site CB. Gray dots represent the percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

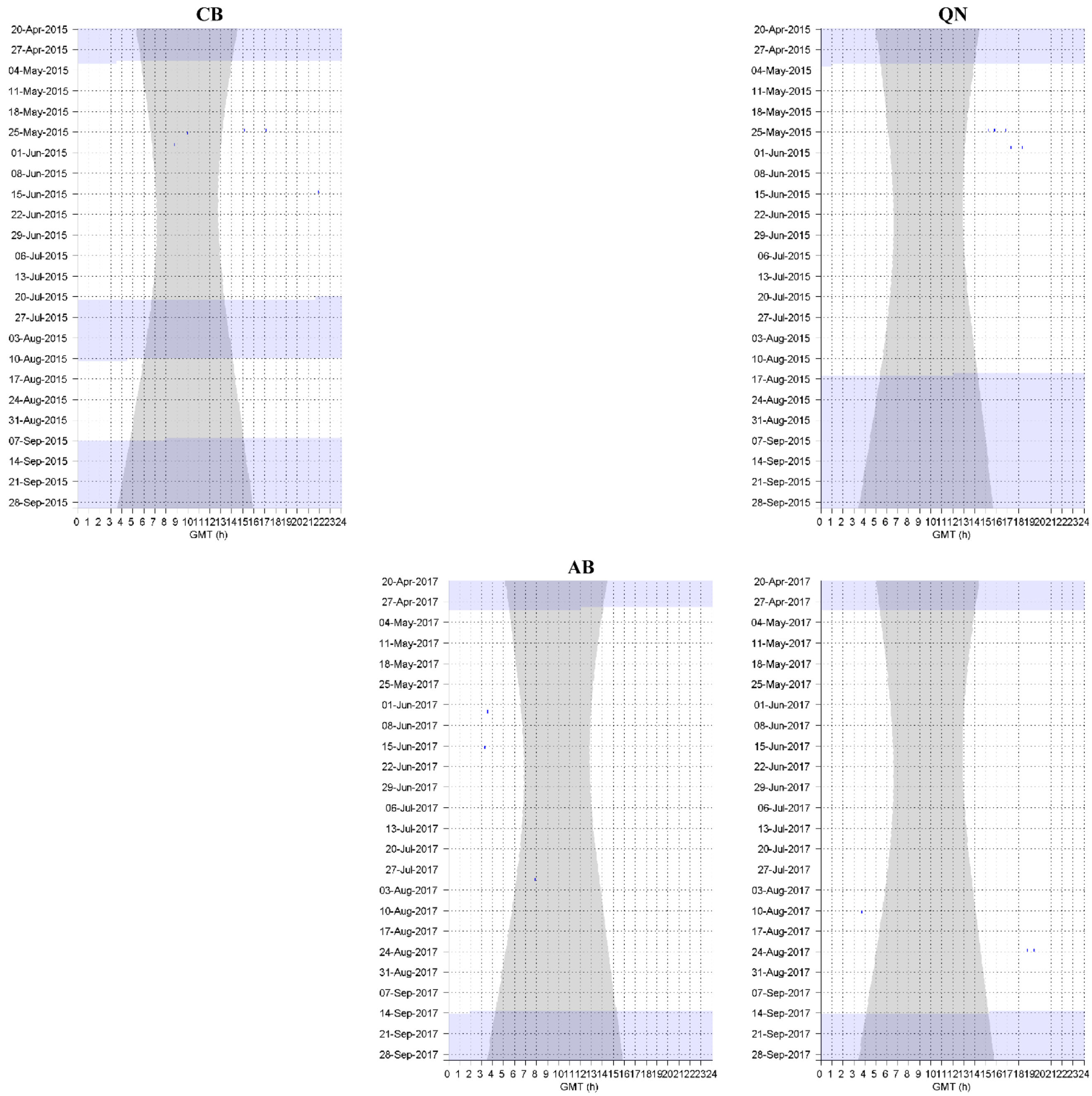

Figure 48. Diel presence of explosion detections, indicated by blue dots, in five-minute bins at sites CB (left), AB (middle), and QN (right). There were no explosion detections in 2017 at site CB.
Gray vertical shading denotes nighttime and gray horizontal shading denotes absence of acoustic data.

Conclusion

Passive acoustic monitoring was conducted at 3 sites in the GATMAA from May to September 2015 and April to September 2017 to record the low-frequency ambient soundscape and marine mammal and anthropogenic signals.

The results from this report are generally consistent with previous reports on the GATMAA. Peaks in ambient sound levels occurred in September at all sites due to the seasonal presence of blue and fin whales. Four baleen whale species were recorded: blue, fin, gray and humpback whales. Blue whales and fin whales were recorded at all sites while gray whales and humpbacks were seen in lower numbers overall. Three odontocete species were recorded: sperm whales, Cuvier’s beaked whales, and presumed Stejneger’s beaked whales. Sperm whale clicks occurred throughout the summer at all sites, but were most common at site CB. Cuvier’s beaked whales were most common at site AB while presumed Stejneger’s beaked whales were most common at site CB. Three anthropogenic signals were detected: MFA sonar, LFA sonar, and explosions. The few MFA and LFA sonar events detected were concurrent with navy training exercises in the area. Explosions were detected in low numbers at all sites, not overlapping with navy training.

Future work in the GATMAA using passive acoustic monitoring with HARPs around times of future navy training exercises will enable documentation of the low-frequency ambient soundscape, the presence of marine mammal species, as well as the presence of anthropogenic signals and possible study of their potential impact marine mammals.

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