Submitted in support of the U.S. Navy's 2019 Annual Marine Species Monitoring Report for the Pacific

Passive Acoustic Monitoring for Marine Mammals in the Gulf of Alaska Temporary Maritime Activities Area September 2017 to September 2019

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

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

Humpback whale, Photo by Katherine Whitaker

MPL TECHNICAL MEMORANDUM #646
February 2020

Suggested Citation:

Rice, A.C., Posdaljian, N., Rafter, M., Trickey, J.S., and Wiggins, S.M., Baumann-Pickering, S., Hildebrand, J.A. (2020) “Passive Acoustic Monitoring for Marine Mammals in the Gulf of Alaska Temporary Maritime Activities Area September 2017 to September 2019” Marine Physical Laboratory, Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, MPL Technical Memorandum #646 under Cooperative Ecosystems Study Unit Cooperative Agreement N62473-18-2-0016 for U.S. Navy, U.S. Pacific Fleet, Pearl Harbor, HI.

Author contributions:

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

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
02-2020

2. REPORT TYPE
Monitoring report

3. DATES COVERED *(From - To)*
September 2017 - September 2019

4. TITLE AND SUBTITLE
PASSIVE ACOUSTIC MONITORING FOR MARINE MAMMALS IN THE GULF OF ALASKA TEMPORARY MARITIME ACTIVITIES AREA SEPTEMBER 2017 TO SEPTEMBER 2019

5a. CONTRACT NUMBER
N62470-15-D-8006

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Ally C. Rice
Natalie Posdaljian
Macey Rafter
Jennifer S. Trickey
Sean M. Wiggins
Simone Baumann-Pickering
John A. Hildebrand

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Marine Physical Laboratory
Scripps Institution of Oceanography
University of California San Diego
La Jolla, CA 92037

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Commander, U.S.Pacific Fleet, 250 Makalapa Dr. Pearl Harbor, HI

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Passive acoustic monitoring was conducted in the Gulf of Alaska Temporary Maritime Activities Area (GATMAA) from September 2017 to June 2018 and from April to September 2019 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 two locations: a continental slope site in deep water (~900–1,000 m depth, site CB) and a deep-water site off Kodiak Island (~1,000 m depth, site KOA).
The low-frequency ambient soundscape showed spectrum level peaks at both sites during winter and fall, related to the seasonally increased presence of blue and fin whales.

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 (low, mid, and high frequency) and each band was analyzed for marine mammal and anthropogenic sounds.

Three baleen whale species were recorded: blue, fin, and humpback whales. No gray whale M3 calls or 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 during the fall at both sites. Blue whale D calls were highest during the spring and summer. Central Pacific tonal calls were the least common blue whale call type but were detected at both 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 at site CB. Humpback whales were detected only at site CB during the winter and early spring.

Signals from four known odontocete species are reported: killer whales, sperm whales, Cuvier's beaked whales, and presumable Stejneger's beaked whales. Killer whale pulsed calls occurred throughout the recordings at both sites but were highest at site CB during the summer. Sperm whale clicks occurred throughout the recordings at both sites but were highest at site CB during summer and fall. Cuvier's beaked whales were detected only at site CB in the winter. Stejneger's beaked whales were detected at both sites but were more common at site CB.

Three anthropogenic signals were detected: mid-frequency active (MFA) sonar, low-frequency active (LFA) sonar, and explosions. MFA sonar was detected only in May 2019 at both sites, which overlapped with a known naval training exercise (13¬–24 May 2019). Site CB had the most MFA sonar packet detections normalized per year in 2019 and had the highest cumulative sound exposure levels. A tonal LFA sonar was detected only at site CB in April and May 2019. The Navy confirmed that no LF sources from the Navy were used during this time. Explosions were detected in high numbers at site KOA and peaked in August. The Navy confirmed that no at-sea explosives were used by the Navy during the 13–24 May 2019 training exercise.

15. SUBJECT TERMS

Monitoring, passive acoustic monitoring, High-frequency Acoustic Recording Packages, marine mammals, baleen whales, Gulf of Alaska, Gulf of Alaska Temporary Maritime Activities Area

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT** UU	**18. NUMBER OF PAGES** 58	**19a. NAME OF RESPONSIBLE PERSON** Department of the Navy
a. REPORT Unclassified	**b. ABSTRACT** Unclassified	**c. THIS PAGE** Unclassified			**19b. TELEPONE NUMBER (*Include area code)*** 808-471-6391

Table of Contents

List of Tables

List of Figures

Executive Summary

Passive acoustic monitoring was conducted in the Gulf of Alaska Temporary Maritime Activities Area (GATMAA) from September 2017 to June 2018 and from April to September 2019 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 two locations: a continental slope site in deep water (~900–1,000 m depth, site CB) and a deep-water site off Kodiak Island (~1,000 m depth, site KOA).

The low-frequency ambient soundscape showed spectrum level peaks at both sites during winter and fall, related to the seasonally increased presence of blue and fin whales.

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 (low, mid, and high frequency) and each band was analyzed for marine mammal and anthropogenic sounds.

Three baleen whale species were recorded: blue, fin, and humpback whales. No gray whale M3 calls or 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 during the fall at both sites. Blue whale D calls were highest during the spring and summer. Central Pacific tonal calls were the least common blue whale call type but were detected at both 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 at site CB. Humpback whales were detected only at site CB during the winter and early spring.

Signals from four known odontocete species are reported: killer whales, sperm whales, Cuvier's beaked whales, and presumable Stejneger's beaked whales. Killer whale pulsed calls occurred throughout the recordings at both sites but were highest at site CB during the summer. Sperm whale clicks occurred throughout the recordings at both sites but were highest at site CB during summer and fall. Cuvier's beaked whales were detected only at site CB in the winter. Stejneger's beaked whales were detected at both sites but were more common at site CB.

Three anthropogenic signals were detected: mid-frequency active (MFA) sonar, low-frequency active (LFA) sonar, and explosions. MFA sonar was detected only in May 2019 at both sites, which overlapped with a known naval training exercise (13–24 May 2019). Site CB had the most MFA sonar packet detections normalized per year in 2019 and had the highest cumulative sound exposure levels. A tonal LFA sonar was detected only at site CB in April and May 2019. The Navy confirmed that no LF sources from the Navy were used during this time. Explosions were detected in high numbers at site KOA and peaked in August. The Navy confirmed that no at-sea explosives were used by the Navy during the 13–24 May 2019 training exercise.

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 whales, 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 (*Physeter macrocephalus*) whales. 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.

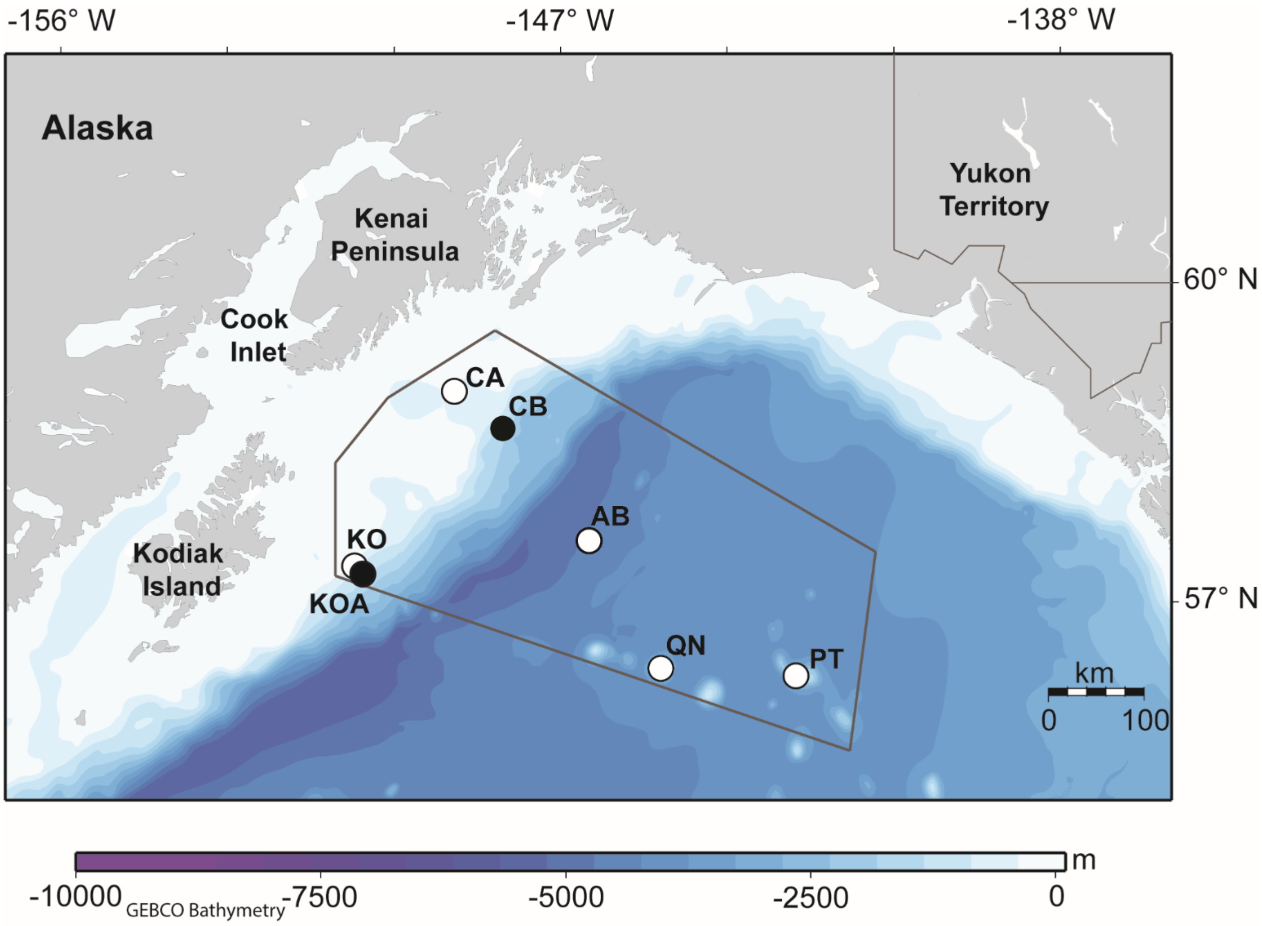


**Figure 1. Locations of current (black circles) and previous (white circles) High-frequency Acoustic Recording Package (HARP) deployment sites in the GATMAA (gray line).
Color indicates bathymetric depth with darker colors being deeper.**

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 and KO and QN in 2013 (Table 1). In 2017, site AB was added to examine a deep-water site that is not located at a seamount, and in 2019, site KOA was added to monitor an area near the North Pacific right whale critical habitat (Table 1). This report will cover only sites CB and KOA, as monitoring effort was suspended for sites CA, KO, and PT in 2014, QN in 2017, and AB in 2017.

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	2011–2019
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
KOA	57° 13.44 N	150° 31.70 W	1000	2019

This report documents the analysis of data recorded by two High-frequency Acoustic Recording Packages (HARPs) that were deployed within the GATMAA from September 2017 to June 2018 and April to September 2019 (Figure 1). The two sites include a continental slope site in deep water (site CB) and a deep-water site off Kodiak Island (site KOA) (Table 1). Data from site CB was analyzed for September 2017 to June 2018 and April to September 2019 (Table 2). Data from site KOA was analyzed from April to September 2019 (Table 2).

Table 2. GATMAA acoustic monitoring since July 2011. Deployment periods analyzed in this report are shown in bold.
Results from previous reporting periods are described in Baumann-Pickering et al. (2012), Debich et al. (2013), Debich et al. (2014), and Rice et al. (2015) and Rice et al. (2018).

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
CB09	**9/14/2017 – 6/16/2018**	**275.13**	**6603**	**200**
KOA1	**4/24/2019 – 9/27/2019**	**155.95**	**3742**	**200**
CB10	**4/25/2019 – 9/27/2019**	**154.79**	**3715**	**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 up to approximately one year of continuous data storage. The HARPs were deployed in a seafloor mooring configuration with the hydrophones suspended at least 10 m above the seafloor. Each HARP hydrophone is calibrated in the laboratory to provide a quantitative analysis of the received sound field. Representative data loggers and hydrophones were also calibrated at the Navy's Transducer Evaluation Center facility to verify the laboratory calibrations (Wiggins and Hildebrand, 2007).

Data Collected

Acoustic 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 sites CB and KOA (Table 1). A total of 14,060 hours, covering 585 days, of acoustic data were recorded in the deployments analyzed in this report. Data from site CB was analyzed for September 14, 2017 to June 16, 2018 and from April 25 to September 27, 2019 (Table 2). Data from site KOA were analyzed from April 24 to September 27, 2019 (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 and 1,000 Hz
(2) Mid-frequency, between 10 and 5,000 Hz
(3) High-frequency, between 1 and 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, killer whale pulsed calls, explosions, and mid-frequency active sonar sounds were classified as mid-frequency. Beaked whale and sperm whales were classified as high-frequency. Analysis of low-frequency recordings required decimation by a factor of 100. For the analysis of mid-frequency recordings, data were decimated by a factor of 20. The LTSAs were created using a 5 s time average with 1 Hz frequency resolution for high-frequency analysis, 10 Hz resolution for mid-frequency analysis, and 100 Hz resolution for low-frequency analysis.

We summarize results of the acoustic analysis and 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, 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 call types. The LTSA frequency was set to display between 1 and 300 Hz with a 1-h 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, its presence during that hour was logged. Blue whale D calls were detected automatically using the automatic detection method described below and are reported as the total number of detections per week. Fin whale 20 Hz pulses were also detected automatically using the energy detection method described below 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 a 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.

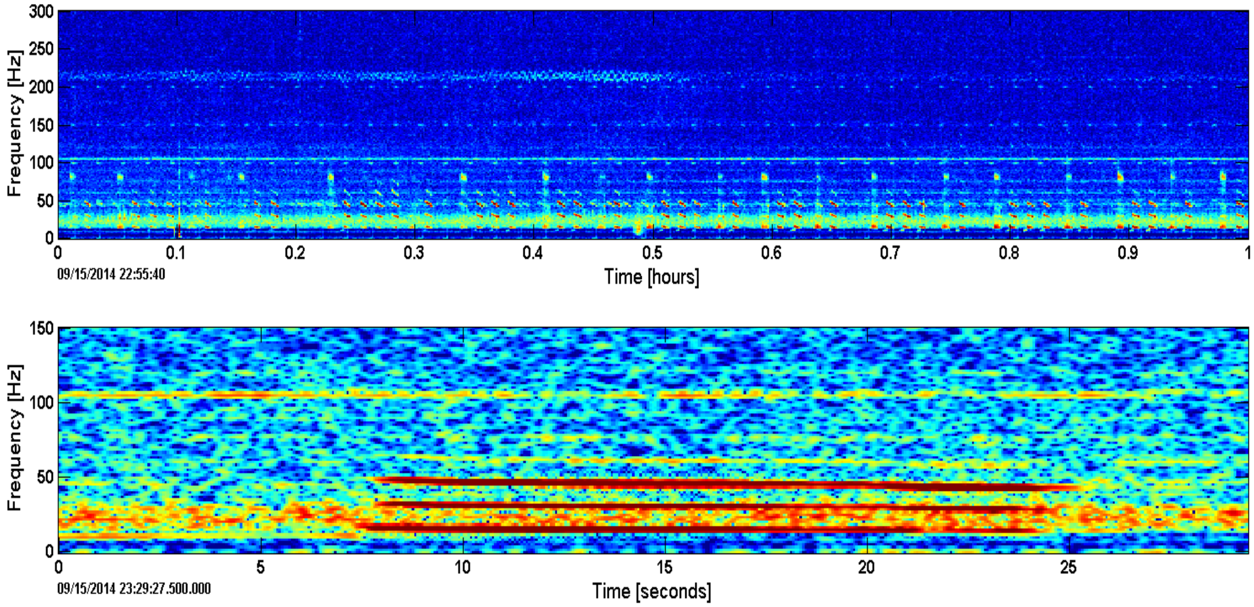


Figure 2. Northeast Pacific blue whale B calls (just below 50 Hz) in Long-term Spectral Average (LTSA; top) and an individual call shown in a spectrogram (bottom) previously recorded at site CB.

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.

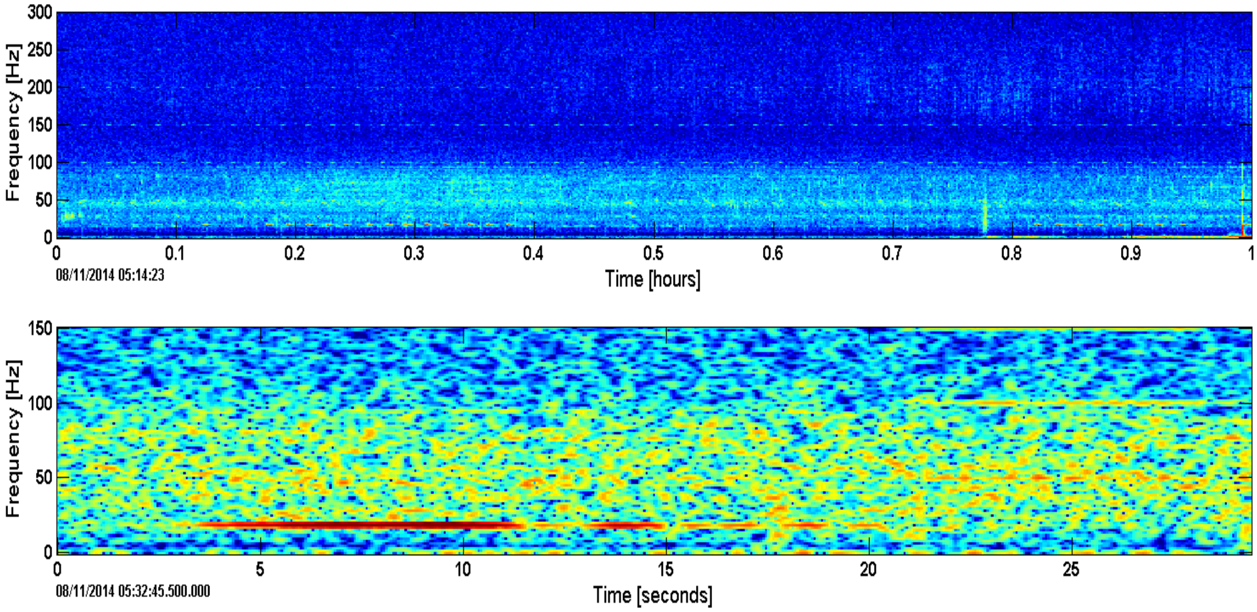


Figure 3. Central Pacific tonal calls (just below 20 Hz) in an LTSA (top) and an individual call shown in a spectrogram (bottom) previously recorded at site CB.

Blue whale D calls

Blue whale D calls (Figure 4) were detected using an automatic algorithm based on a generalized power law (Helble *et al.*, 2012). This algorithm was adapted for the detection of D calls by modifying detection parameters that included the frequency space over which the detector operates. A trained analyst subsequently verified the detections (Figure 4).

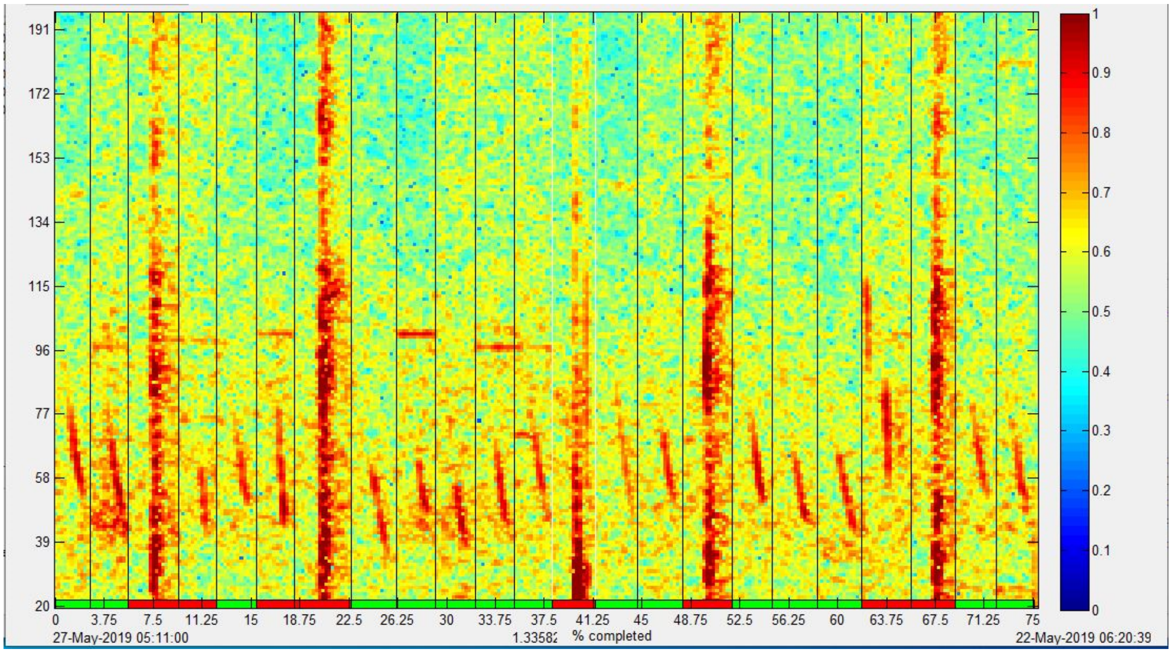


Figure 4. Blue whale D calls from site CB in the analyst verification stage of the detector. Green along the bottom evaluation line indicates true detections and red indicates false detections.

Fin Whales

Fin whales produce two types of short (approximately 1 s duration), low-frequency calls: downsweeps in frequency from 30 to 15 Hz, called 20 Hz calls (Watkins, 1981), and downsweeps from 75 to 40 Hz, called 40 Hz calls (Širović *et al.*, 2013). 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.

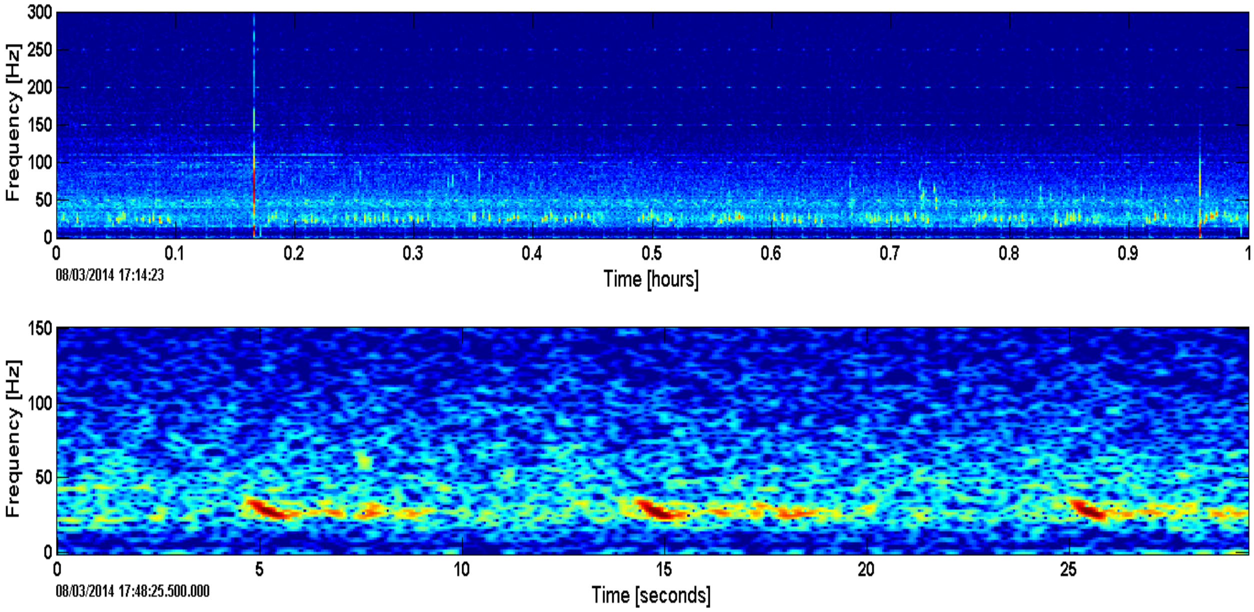


Figure 5. Fin whale 20 Hz calls in an LTSA (top) and three individual calls shown in a spectrogram (bottom) previously recorded at site CB.

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.

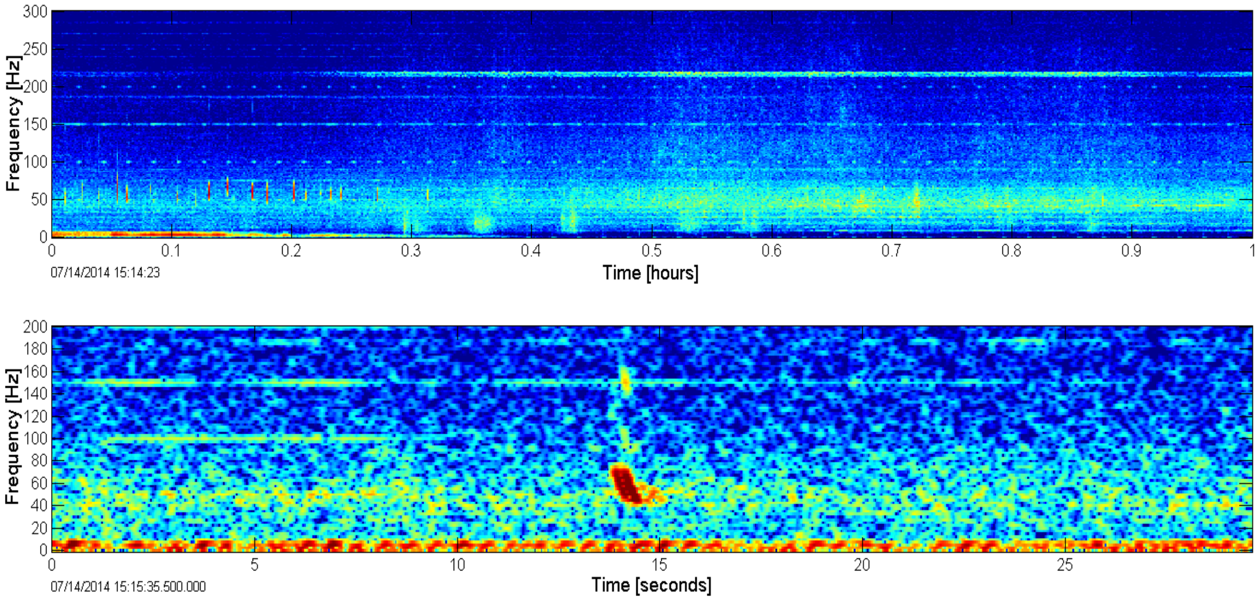


Figure 6. Fin whale 40 Hz calls in an LTSA (top) and an individual call shown in a spectrogram (bottom) previously recorded at site CB.

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). There were no gray whale M3 calls detected during the reporting period.

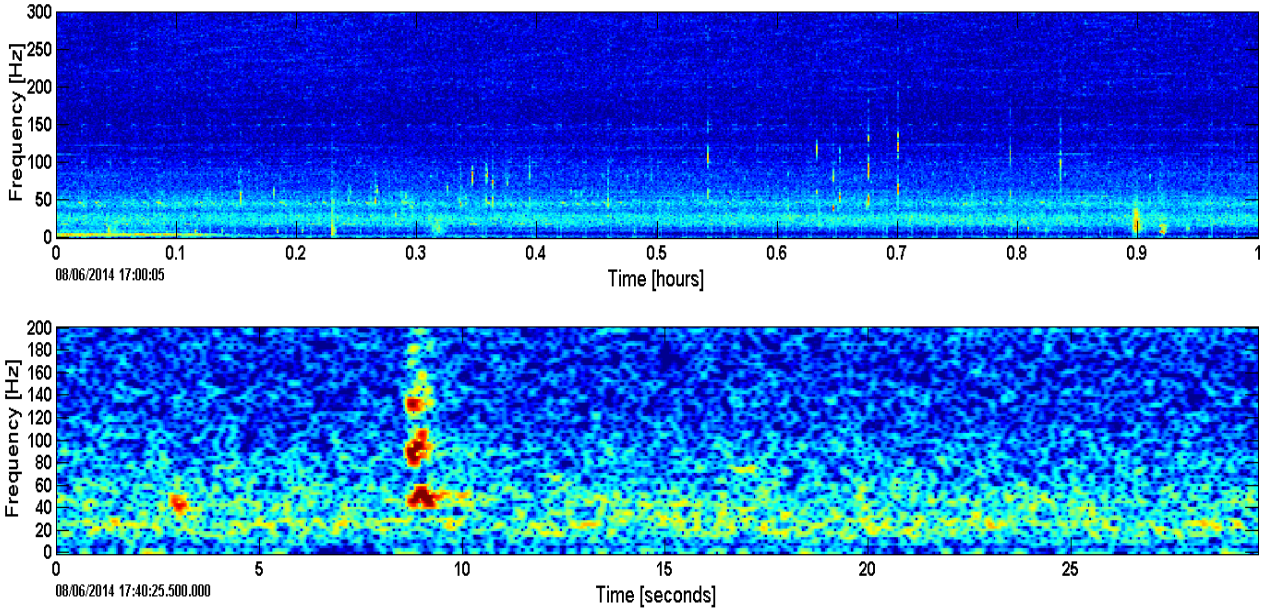


Figure 7. Gray Whale M3 calls in an LTSA (top) and an individual call shown in a spectrogram (bottom) previously recorded at site KO.

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.

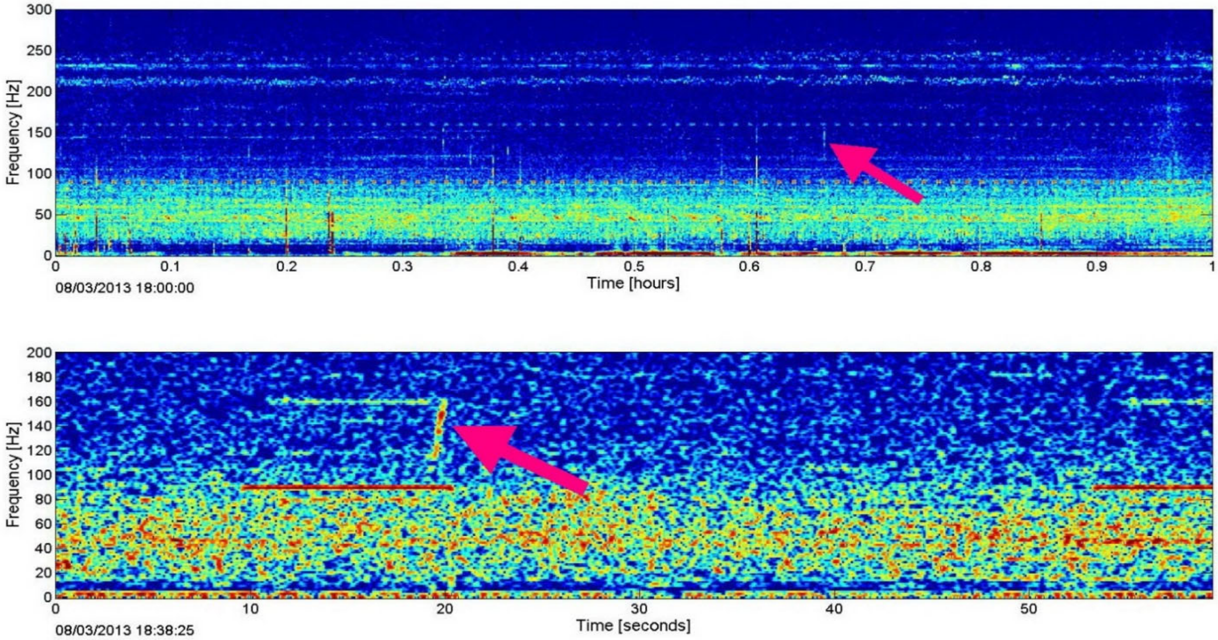


Figure 8. North Pacific right whale up call in an LTSA (top) and an individual call shown in a spectrogram (bottom) previously recorded at site QN.

Mid-Frequency Marine Mammals

Humpback whales and killer whales (*Orcinus orca*) 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 a generalized power law (Helble *et al.*, 2012). The detections were subsequently verified for accuracy by a trained analyst (Figure 9). Killer whale pulsed calls (Figure 10) were detected by manual scrutiny of LTSAs and spectrograms in the custom software program *Triton*. The LTSAs were created using a time average of 5 s and a frequency bin size of 10 Hz. The LTSA frequency was set to display between 1 and 5,000 Hz with a 1-h plot length. To observe individual signals, the spectrogram window was typically set to display 1–5,000 Hz with a 30 s plot length. The FFT was generally set at 1000 data points with a 90% overlap. When humpback and killer whale calls were identified, they were logged according to the start time and end time of the encounter. An encounter was considered 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 and 3,000 Hz. There was no effort to separate song and non-song calls.

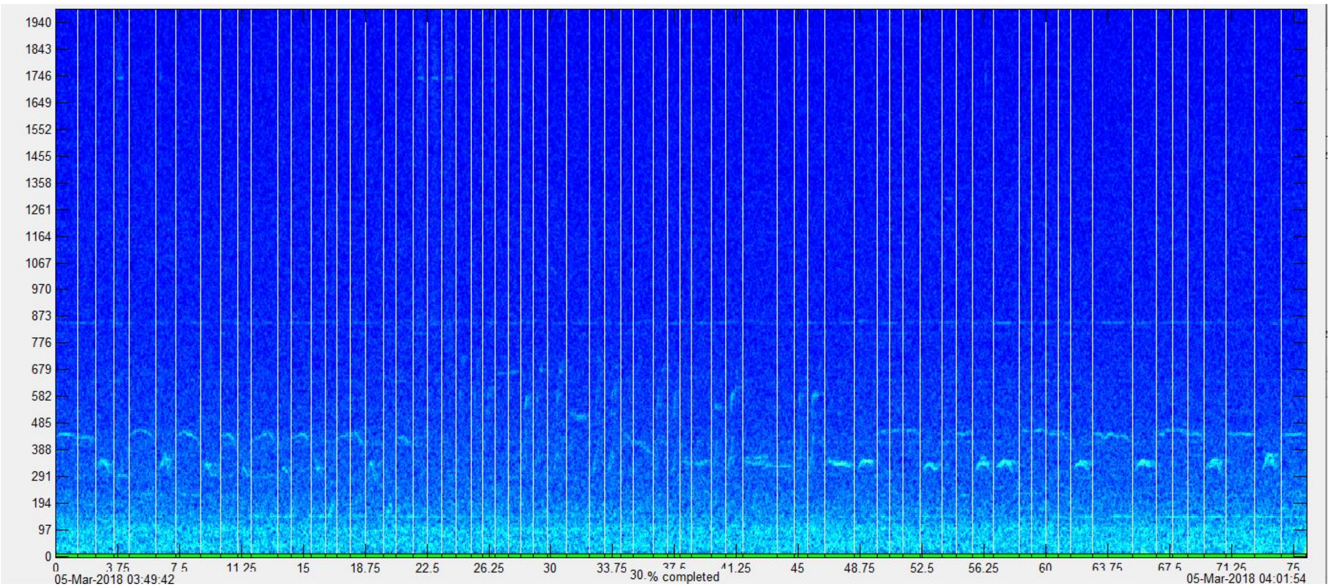


Figure 9. Humpback whale song shown in the analyst verification stage of the detector recorded at site CB.

Killer Whales

Killer whales are known to produce four call types: pulsed calls, high-frequency modulated (HFM) signals, echolocation clicks, and low frequency whistles (Ford, 1989; Samarra *et al.*, 2010). Killer whale pulsed calls are well documented and are the best described of all killer whale call types (Ford and Fisher, 1983). The primary energy of pulsed calls is between 1 and 6 kHz, with high frequency components occasionally >30 kHz and duration primarily between 0.5 and 1.5 seconds (Ford, 1989). We primarily use pulsed calls (Figure 10) for killer whale species identification. Echolocation clicks and low-frequency whistles are used to a lesser extent for the classification of killer whale signals as these call types are not as easily distinguishable from other odontocete clicks and whistles (e.g. Baird's beaked whales, pilot whales)

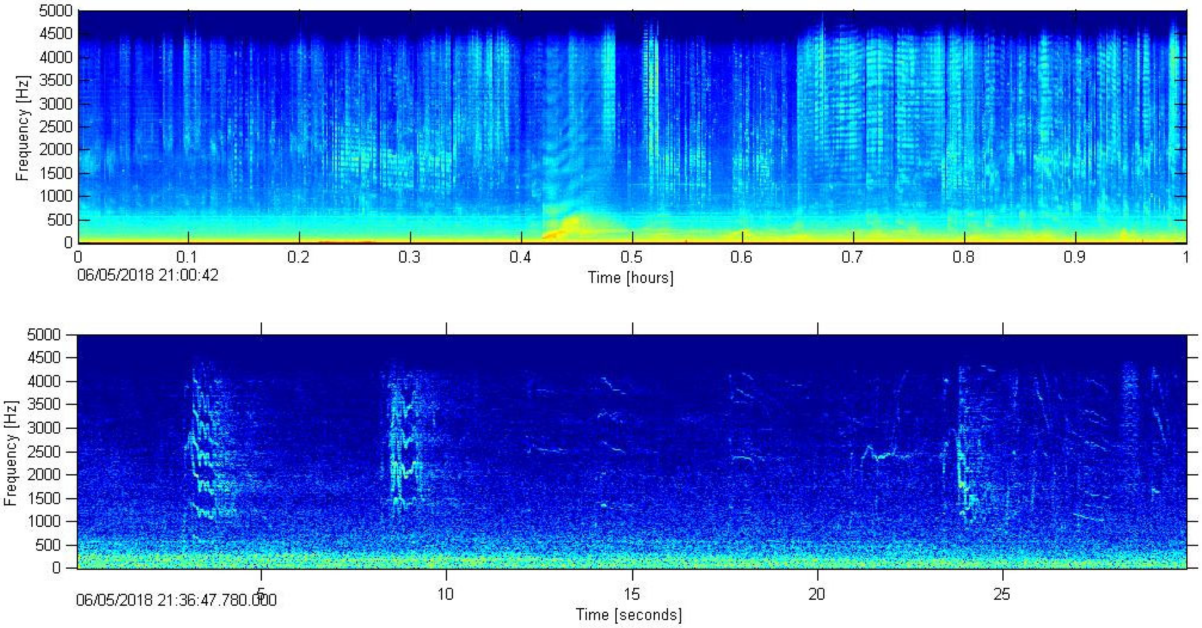


Figure 10. Killer whale pulsed calls shown in an LTSA (top) and spectrogram (bottom) recorded at site CB.

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 and 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 11).

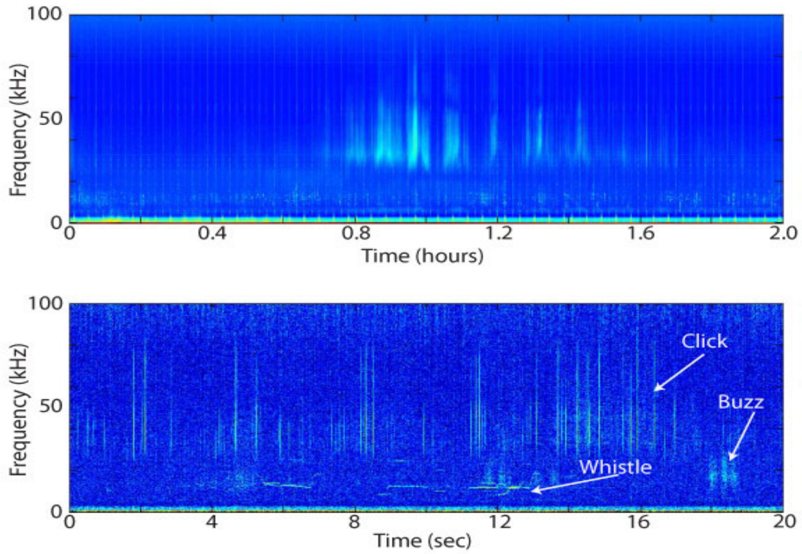


Figure 11. LTSA (top) and spectrogram (bottom) demonstrating odontocete signal types.

Sperm Whales

Sperm whale clicks (Figure 12) generally contain energy from 2 to 20 kHz, with the majority of energy between 10 and 15 kHz (Møhl *et al.*, 2003). Regular clicks, observed during foraging dives, demonstrate a uniform inter-click interval from 0.25 to 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). Sperm whale clicks were detected using the automatic method described below.

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 75 s 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. Although individual sperm whale clicks were detected, they are reported according to the start time and end time of encounters. An encounter was considered to end when there were no clicks for 15 min. The encounter durations were added to estimate cumulative weekly presence.

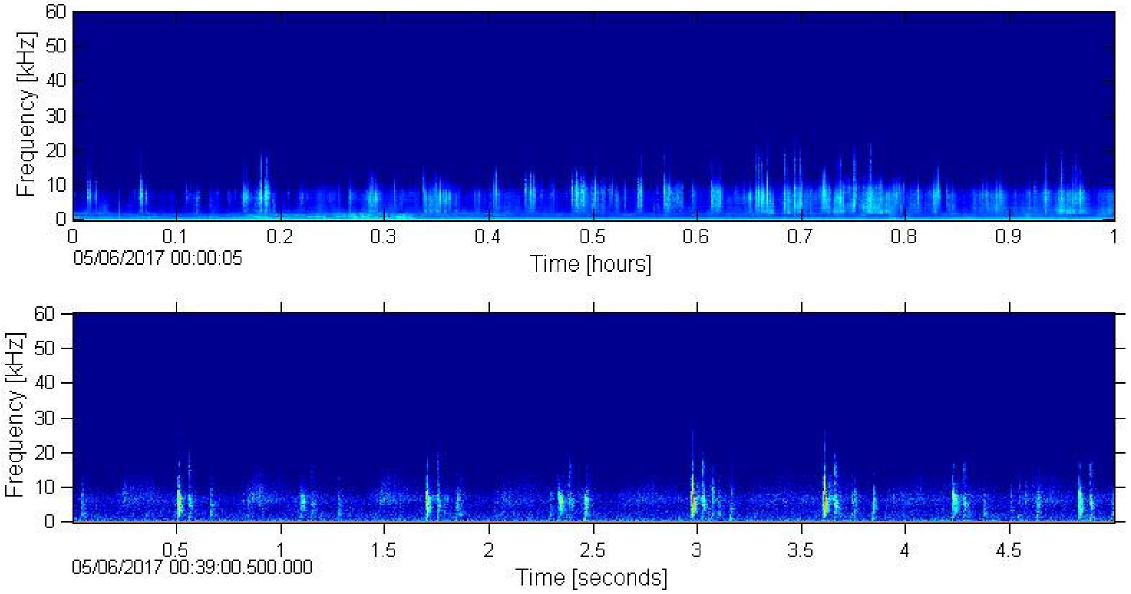


Figure 12. Sperm whale echolocation clicks in an LTSA (top) and spectrogram (bottom) recorded at site CB.

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 possibly occurring in this region are known for Baird's (*Berardius bairddii*), 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 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 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.

Both 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 (Figure 13) 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 FM pulses is that they have characteristic spectral peaks around 17 and 23 kHz.

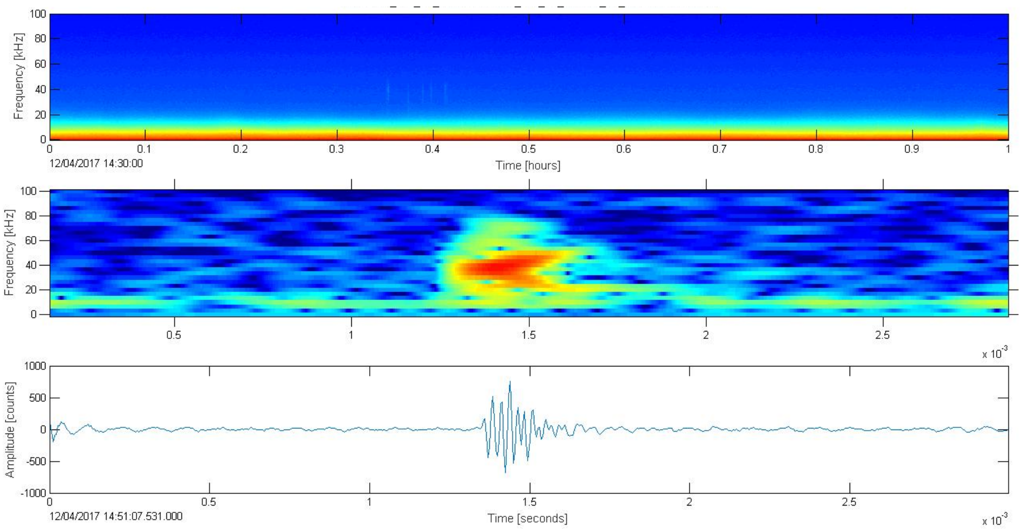


Figure 13. Echolocation sequence of Cuvier's beaked whale in an LTSA (top) and an example FM pulse in a spectrogram (middle) and timeseries (bottom) recorded at site CB.

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 (Figure 14) 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).

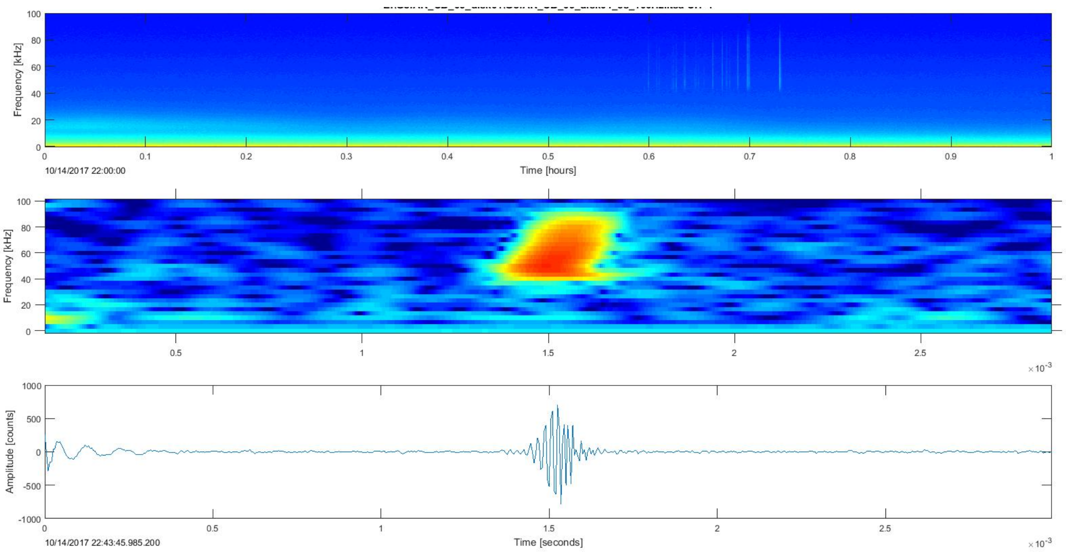


Figure 14. Echolocation sequence of Stejneger’s beaked whale in an LTSA (top) and single FM pulse in a spectrogram (middle) and timeseries (bottom) recorded at site CB.

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 sonar, 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 and 1,000 Hz with a 1-h 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 15). 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.

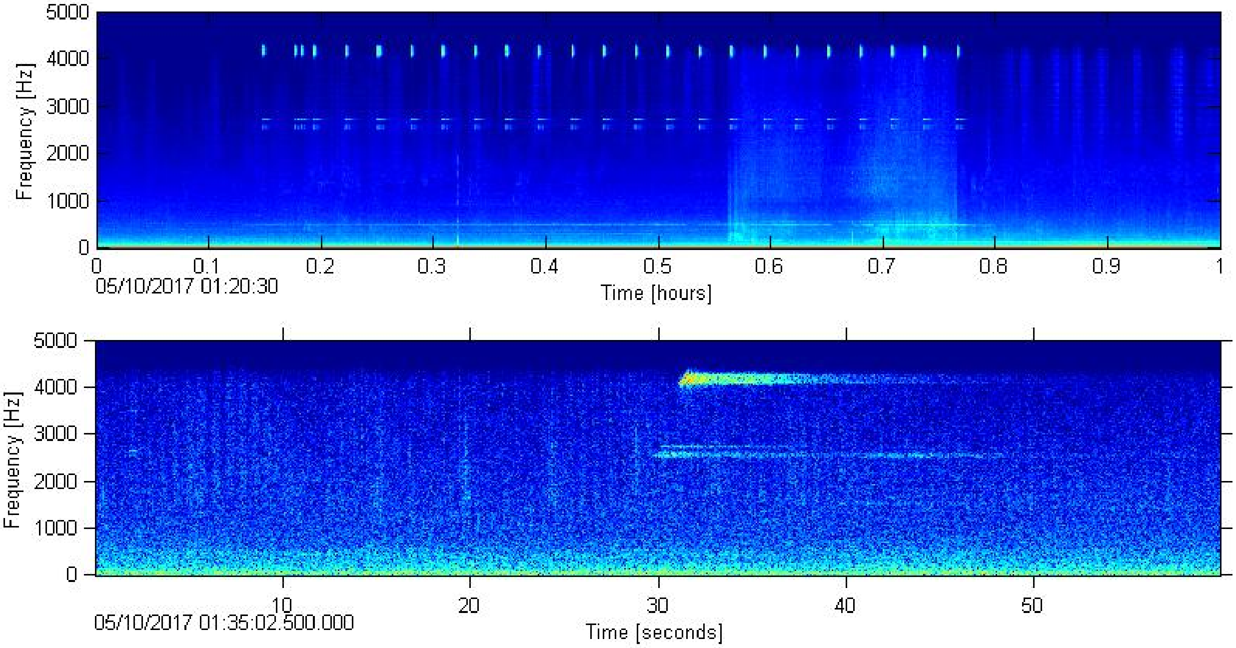


Figure 15. Mid-frequency Active (MFA) sonar wavetrain in an LTSA (top) and an MFA sonar packet in a spectrogram (bottom) recorded at site CB.

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

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

In the second stage of MFA sonar detection, 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 ~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 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 (wave train) 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 (LFA) sonar includes civilian (seismic surveys) and military sonar up to 1 kHz (Figure 16). 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.

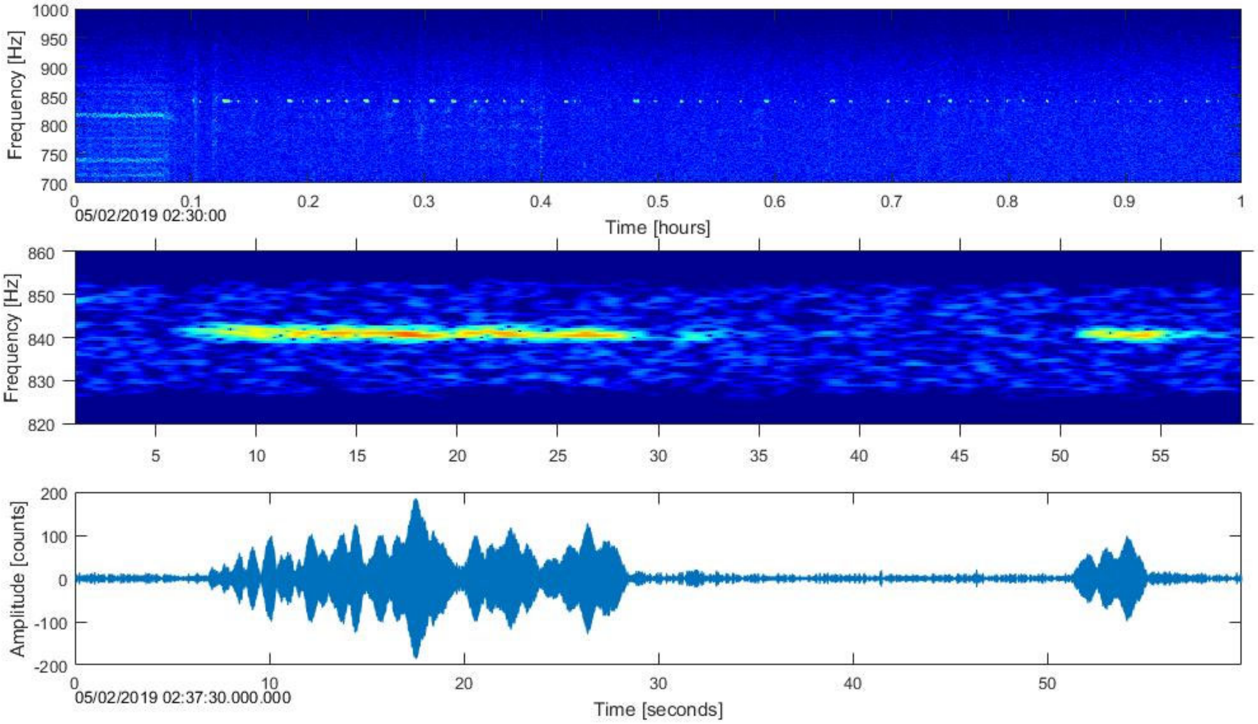


Figure 16. A tonal Low-frequency Active (LFA) sonar in an LTSA (top), spectrogram (middle), and timeseries (bottom) recorded at site CB.

A narrow band pass filter (830–850 Hz) was used for the spectrogram and timeseries to better show the character of the received signal.

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 17). 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 s 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 s of data to account for detecting explosions within noise, such as shipping. A cross correlation threshold of $3x10^{-6}$ 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 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 (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 s. 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.

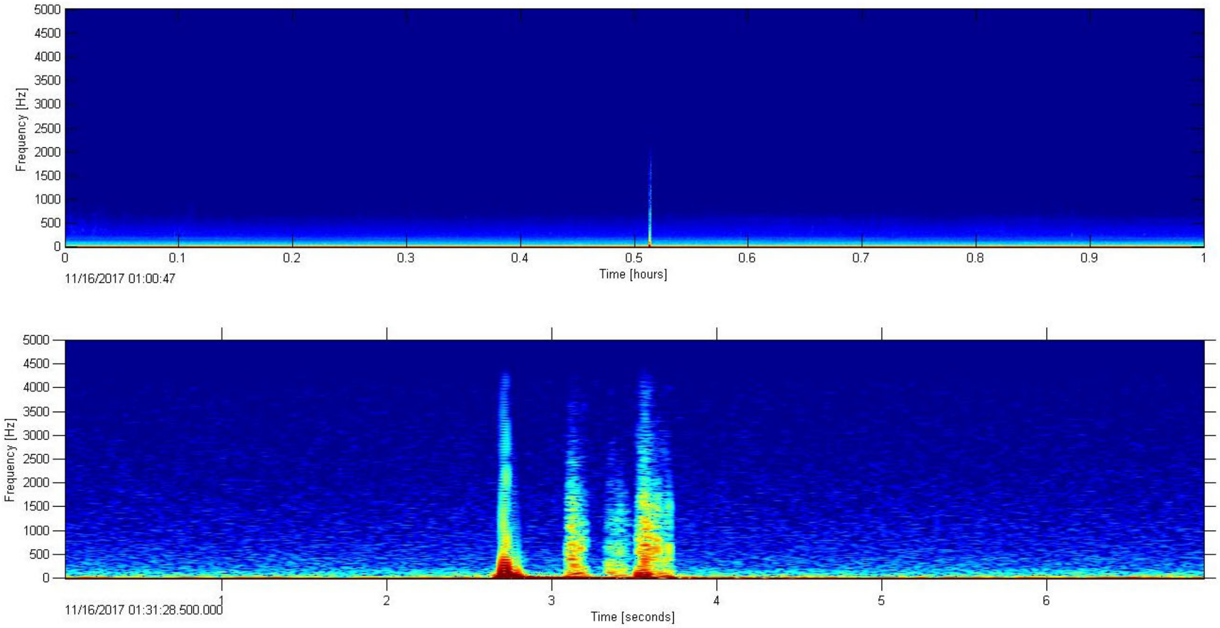


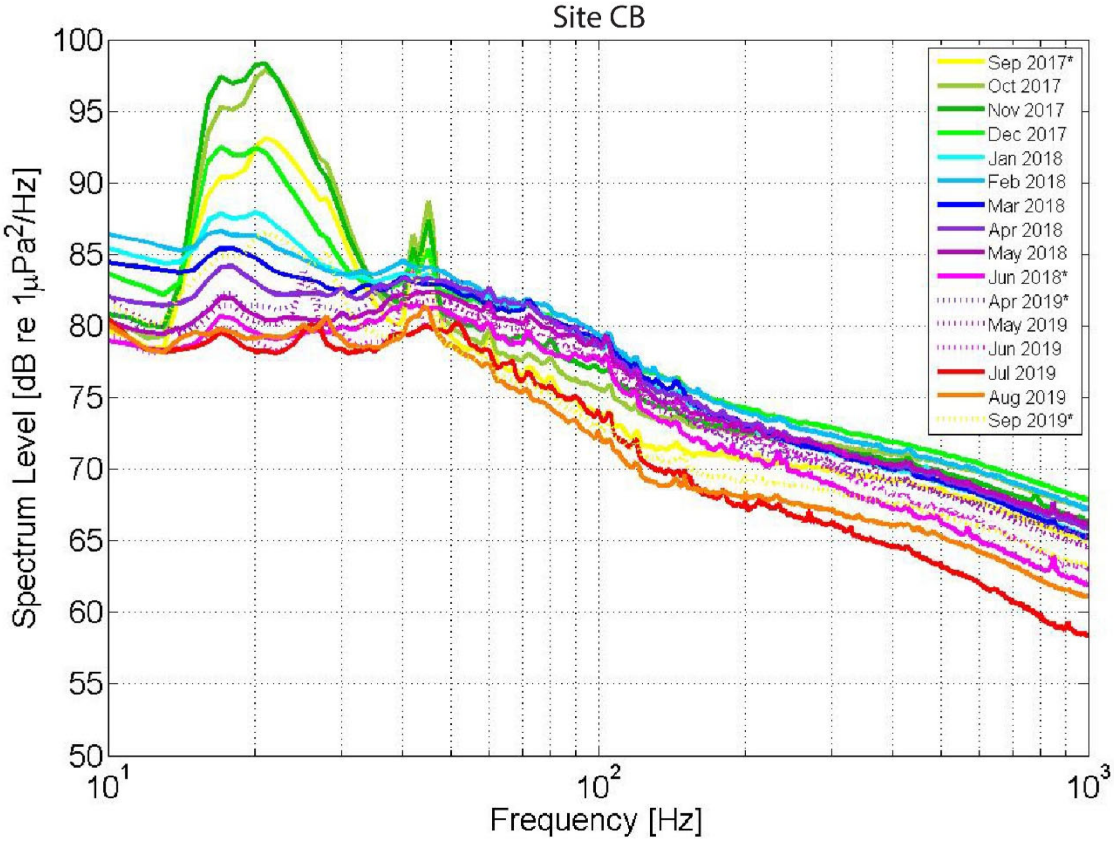
Figure 17. Explosion in an LTSA (top) and a spectrogram (bottom) recorded at site CB.

Results

The results of acoustic data analysis at sites CB and KOA from September 2017 to June 2018 and from April to September 2019 are summarized below. We describe the low-frequency ambient soundscape and the seasonal occurrence and relative abundance of marine mammal acoustic signals and anthropogenic sounds of interest.

Low-Frequency Ambient Soundscape

- Elevated spectrum levels from 15 to 35 Hz during fall and winter at both sites are related to the seasonal increase in fin whale 20 Hz calls (Figure 18).
- The prominent peak from 40 to 50 Hz in fall at both sites is related to the seasonal presence of blue whale B calls (Figure 18).
- Overall, spectrum levels were similar at the two sites for spring and summer 2019 when there was recording effort at both sites.



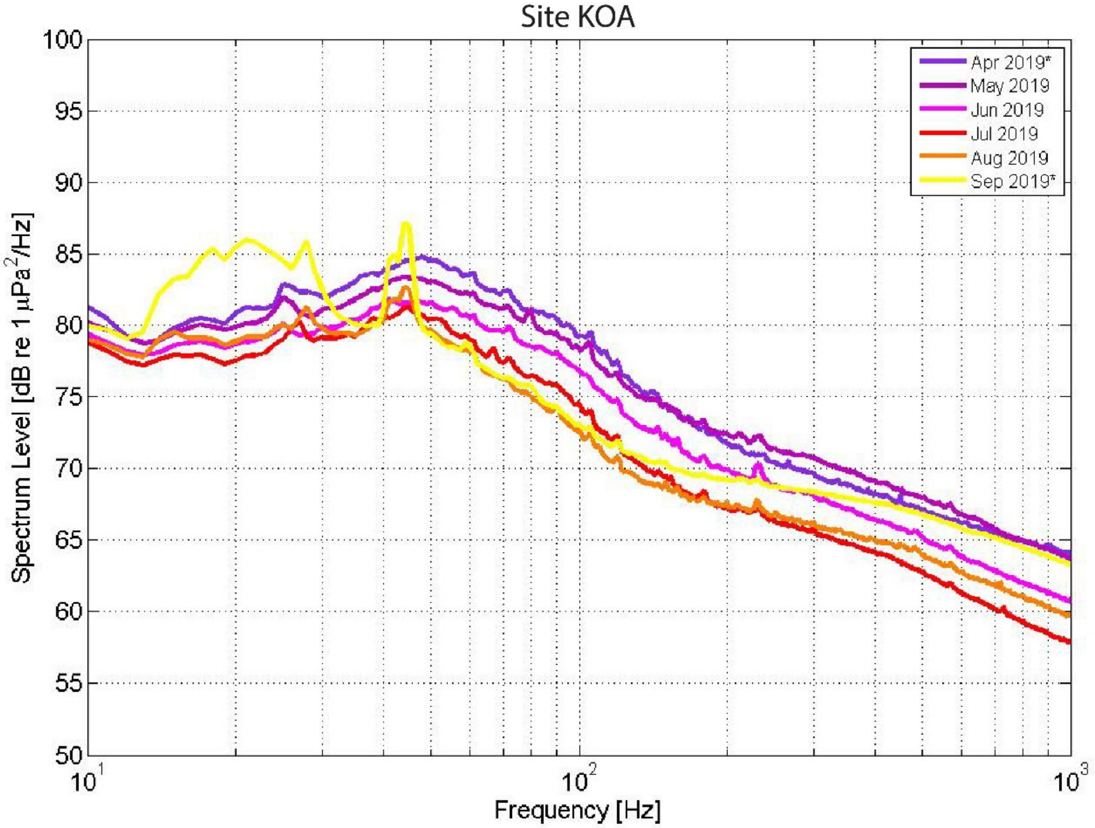


Figure 18. Monthly average sound spectrum levels at sites CB (top) and KOA (bottom). Legend gives color-coding by month. * denotes months with partial effort.

Mysticetes

Three baleen whale species were recorded from September 2017 to June 2018 and from April to September 2019: blue whales, fin whales, and humpback whales. There were no detections of gray whale M3 calls or North Pacific right whale up calls during this monitoring period. More details of each species presence at each site are given below.

Blue whales

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

- Northeast (NE) Pacific blue whale B calls were detected from July to January with a peak during the fall. Detections were high at both site CB and KOA (Figure 19).
- Calling was almost constant throughout the fall at both sites and so there was no clear diel pattern at either site (Figure 20).
- Central Pacific tonal calls occurred mainly in August at site CB and in August and September at site KOA. There were more Central Pacific tonal calls detected at site KOA (Figure 21).
- There was no clear diel pattern for Central Pacific tonal calls (Figure 22).
- Blue whale D calls occurred throughout the spring and summer at both sites. D calls peaked in May and June at site CB and during May and June as well as July and August at site KOA (Figure 23). This bimodality in peak D call occurrence has been observed previously (Debich *et al.*, 2014; Rice *et al.*, 2015; Rice *et al.*, 2018) and may be related to the presence of two different blue whale populations in the Gulf of Alaska.
- There was a diel pattern for blue whale D calls with increased calling around sunset and sunrise, most obvious during the spring (Figure 24).
- Overall, 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; Rice *et al.*, 2018).

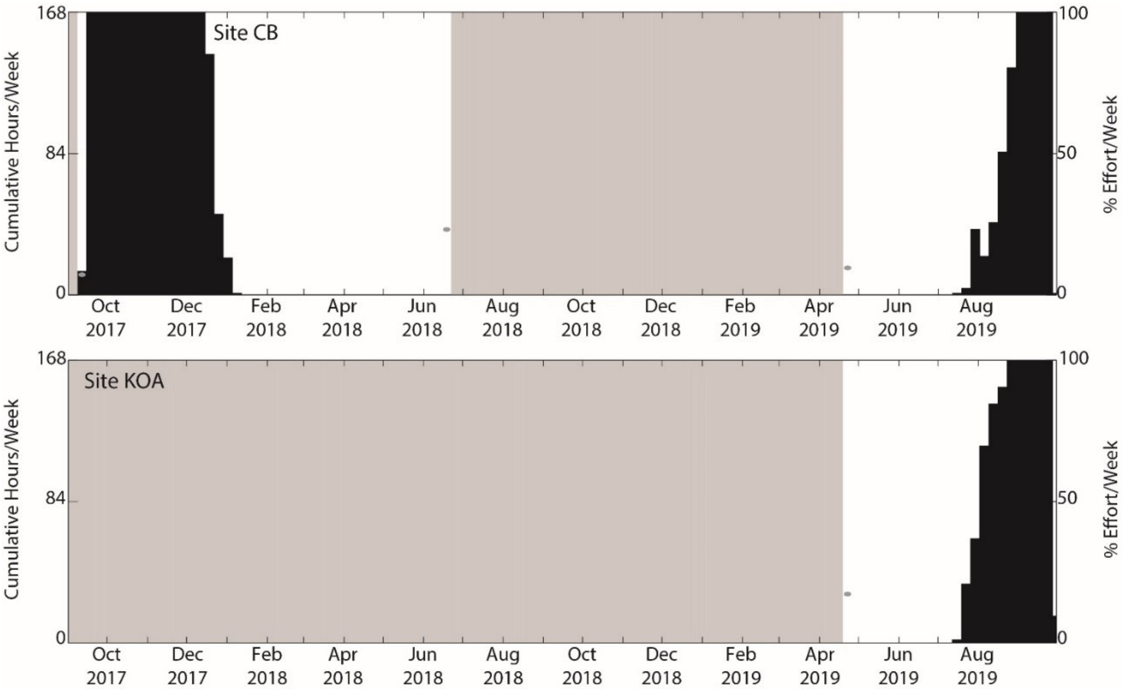


Figure 19. Weekly presence of NE Pacific blue whale B calls from September 2017 to June 2018 and April to September 2019 at sites CB (top) and KOA (bottom).
Gray dots represent the percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

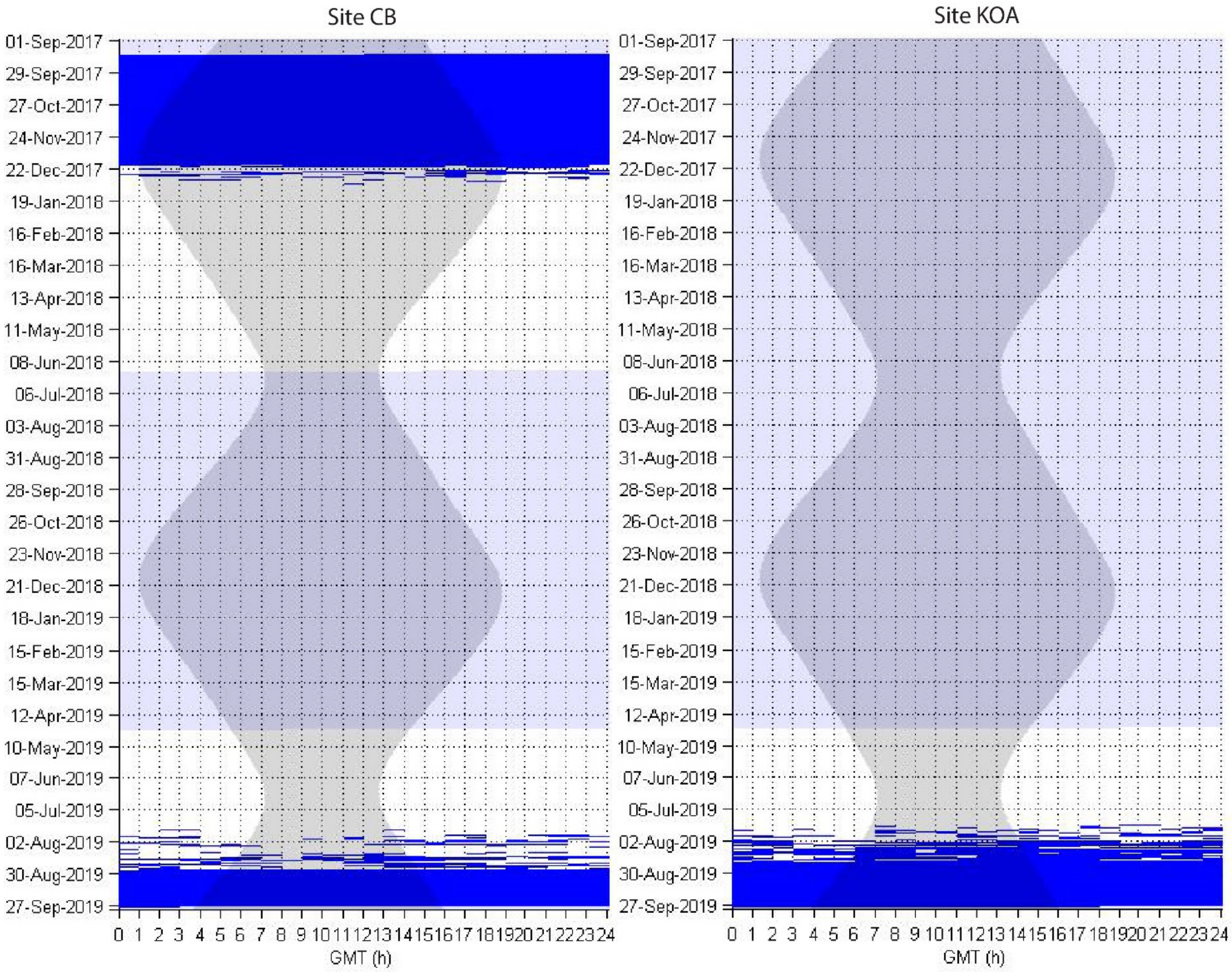


Figure 20. Diel presence of NE Pacific blue whale B calls, indicated by blue dots, in one-hour bins at sites CB (left) and KOA (right).
Gray vertical shading denotes nighttime and transparent blue horizontal shading denotes absence of acoustic data.

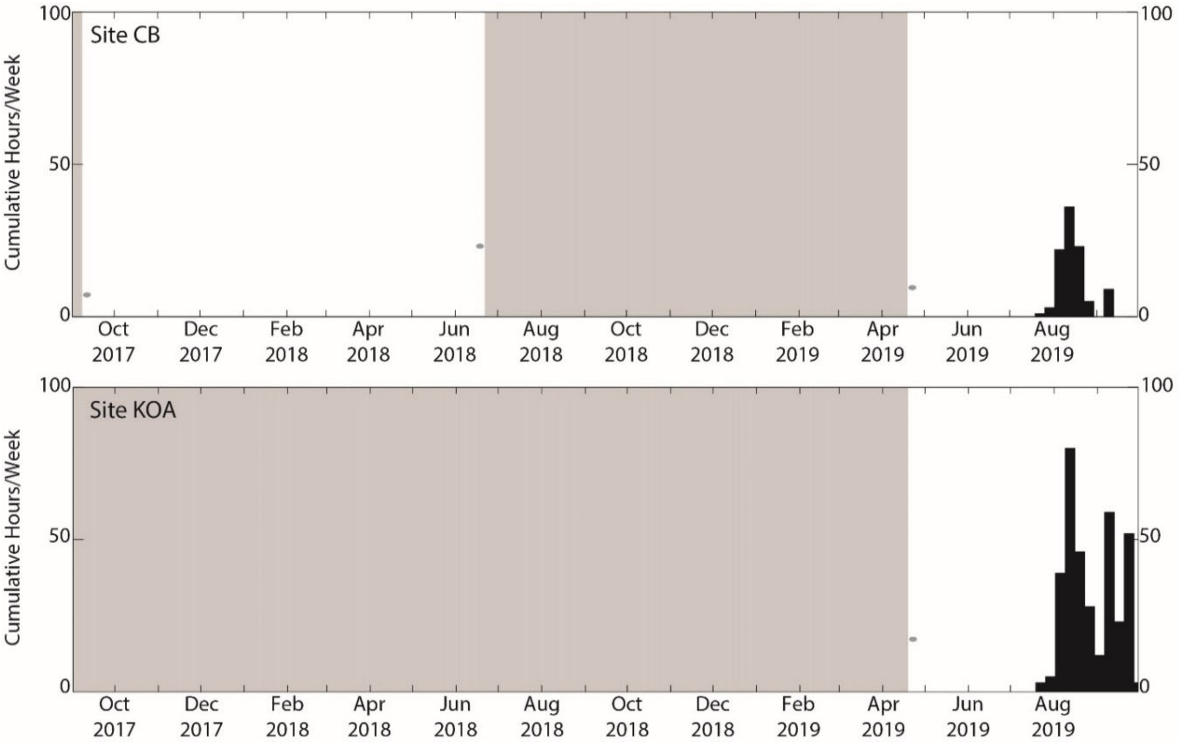


Figure 21. Weekly presence of Central Pacific tonal blue whale calls from September 2017 to June 2018 and April to September 2019 at sites CB (top) and KOA (bottom).

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.

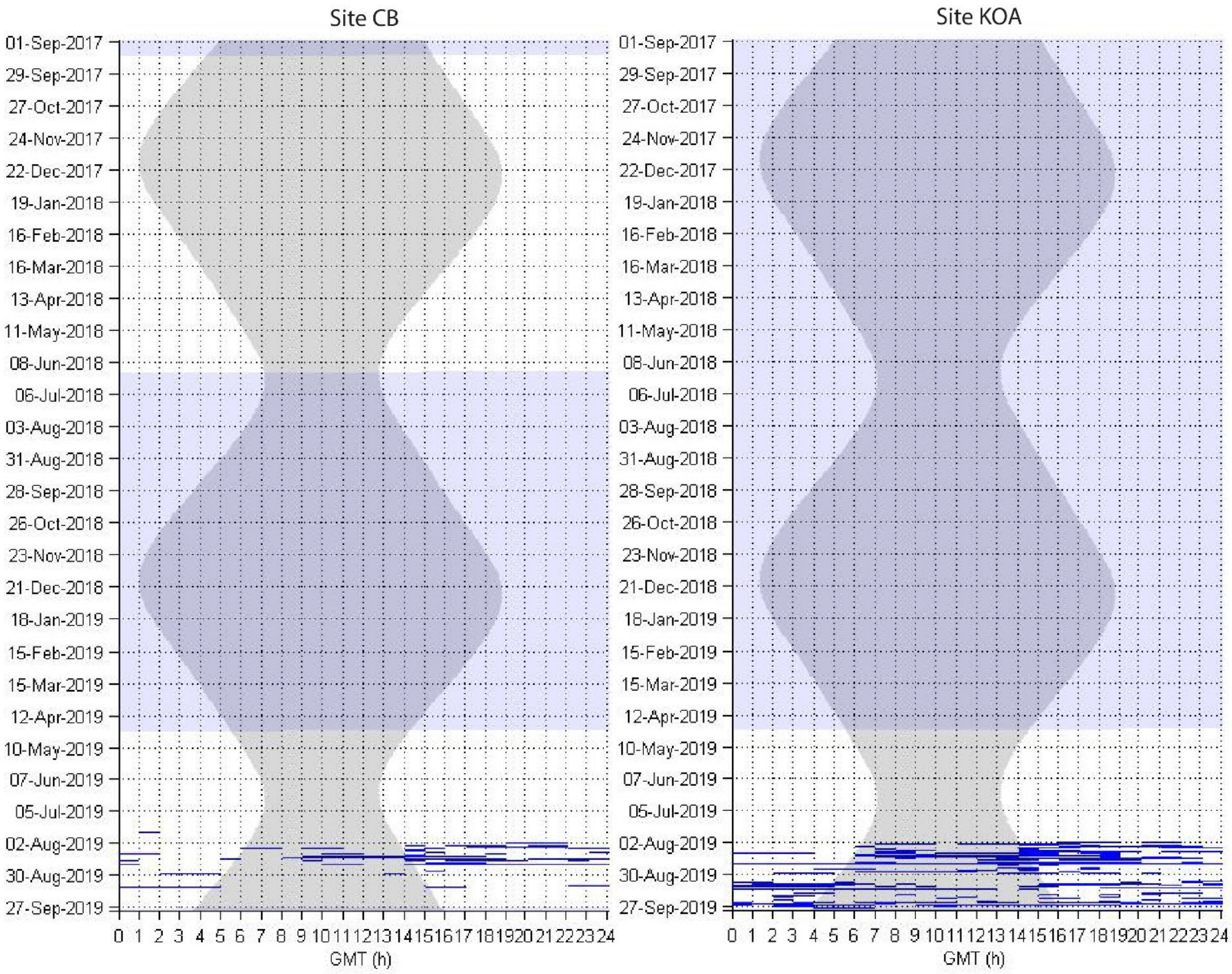


Figure 22. Diel presence of Central Pacific tonal blue whale calls, indicated by blue dots, in one-hour bins at sites CB (left) and KOA (right).
Gray vertical shading denotes nighttime and transparent blue horizontal shading denotes absence of acoustic data.

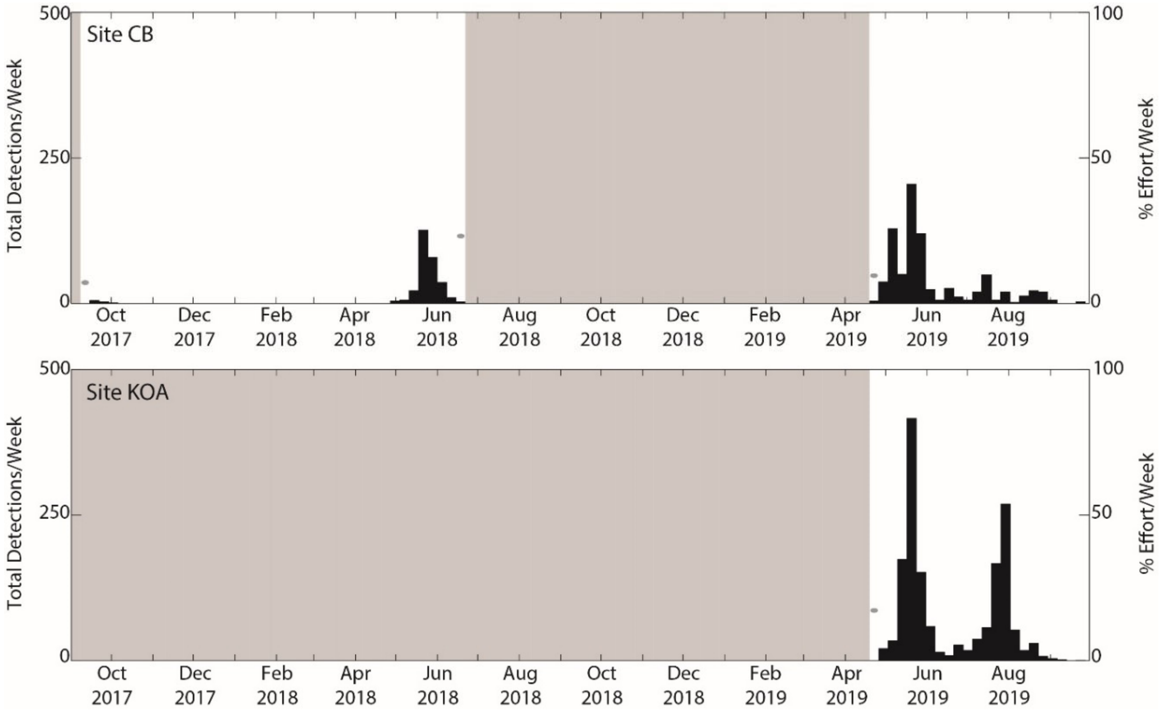


Figure 23. Weekly presence of blue whale D calls from September 2017 to June 2018 and April to September 2019 at sites CB (top) and KOA (bottom).
Gray dots represent the percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

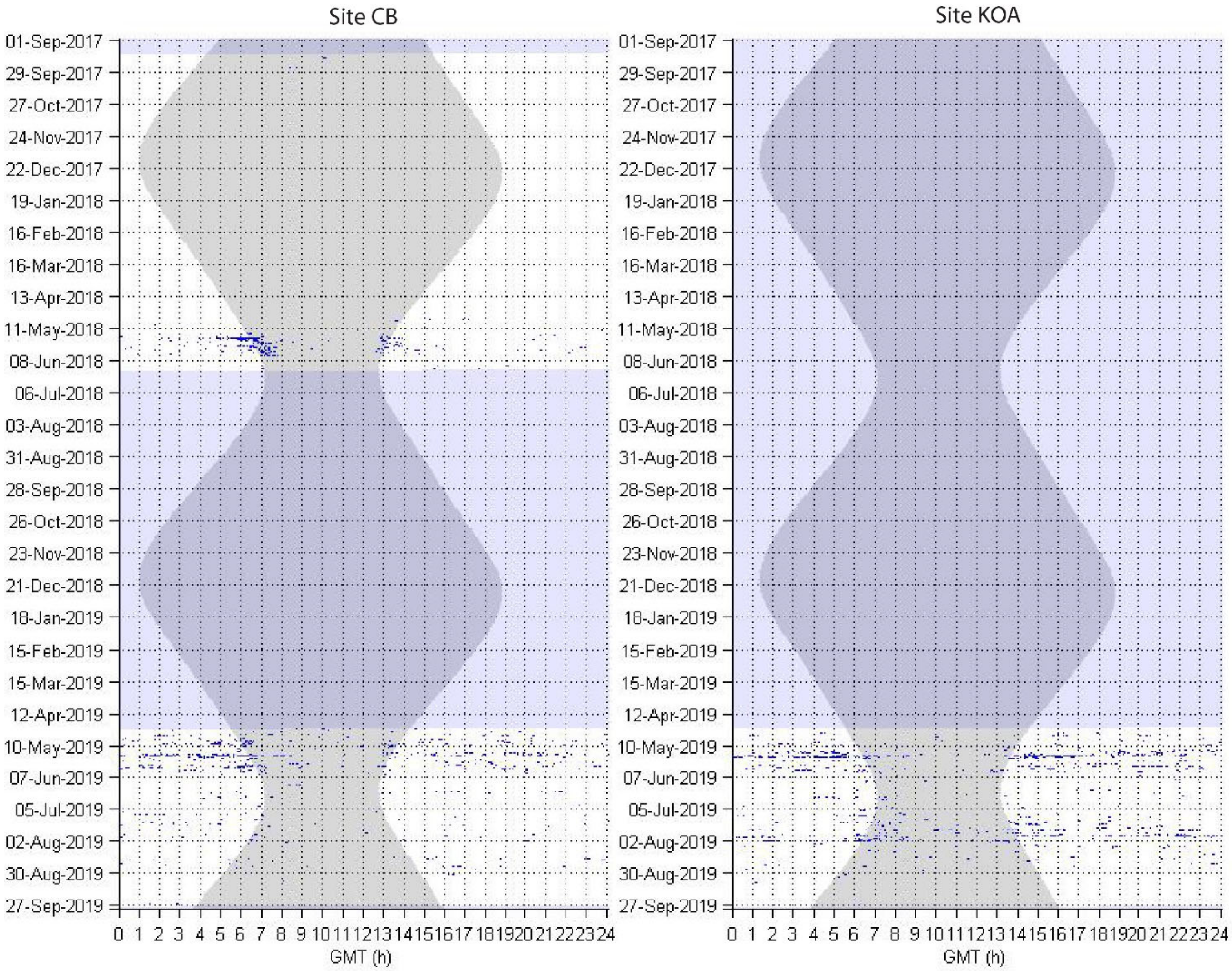


Figure 24. Diel presence of blue whale D calls, indicated by blue dots, in five-minute bins at sites CB (left) and KOA (right).
Gray vertical shading denotes nighttime and transparent blue horizontal shading denotes absence of acoustic data.

Fin whales

Fin whales were detected throughout the recordings at both sites.

- Fin whale 20 Hz calls were detected throughout the recording period at both sites but were highest from September to January. The highest values of the fin whale acoustic index (representative of 20 Hz calls) were measured at site CB, though the index peaked in the fall at both sites (Figure 25).
- Fin whale 40 Hz calls were recorded throughout the recording period at all sites but were higher at site CB. Calling fluctuated throughout the year but fewer calls were recorded during the winter (Figure 26).
- There was no discernable diel pattern for fin whale 40 Hz calls (Figure 27).
- 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; Rice *et al.*, 2018).

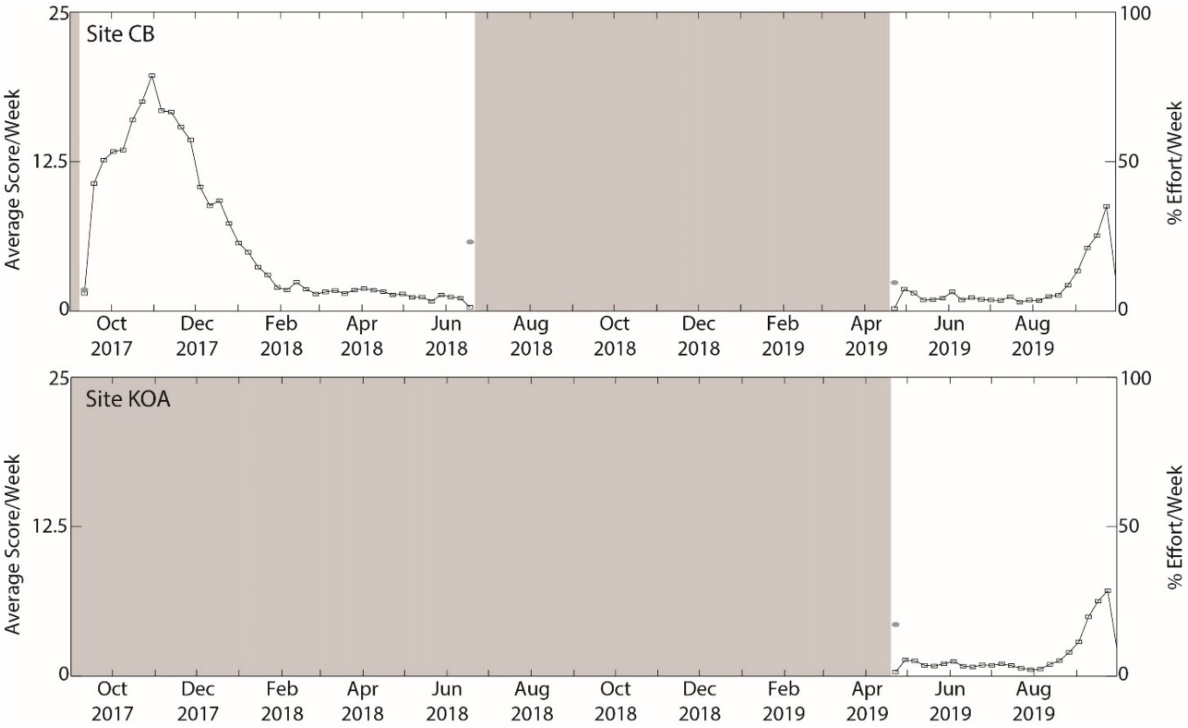


Figure 25. Weekly presence of fin whale acoustic index (proxy for 20 Hz calls) from September 2017 to June 2018 and April to September 2019 at sites CB (top) and KOA (bottom).
Gray dots represent the percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

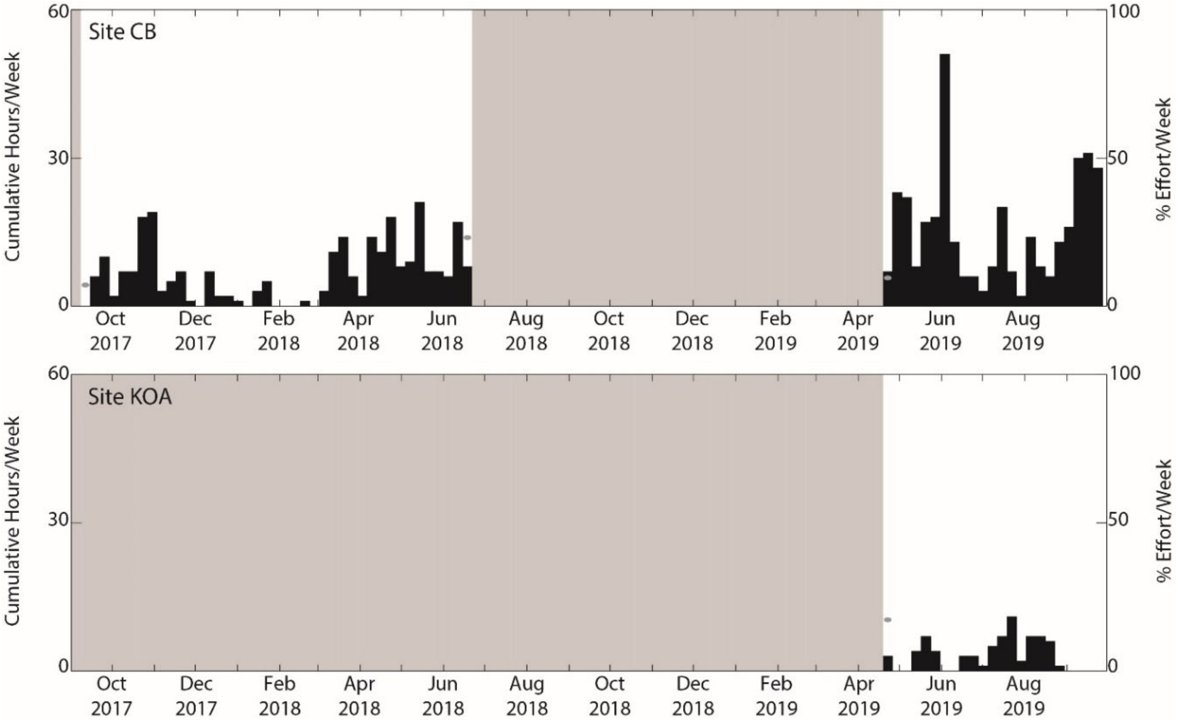


Figure 26. Weekly presence of fin whale 40 Hz calls from September 2017 to June 2018 and April to September 2019 at sites CB (top) and KOA (bottom).

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.

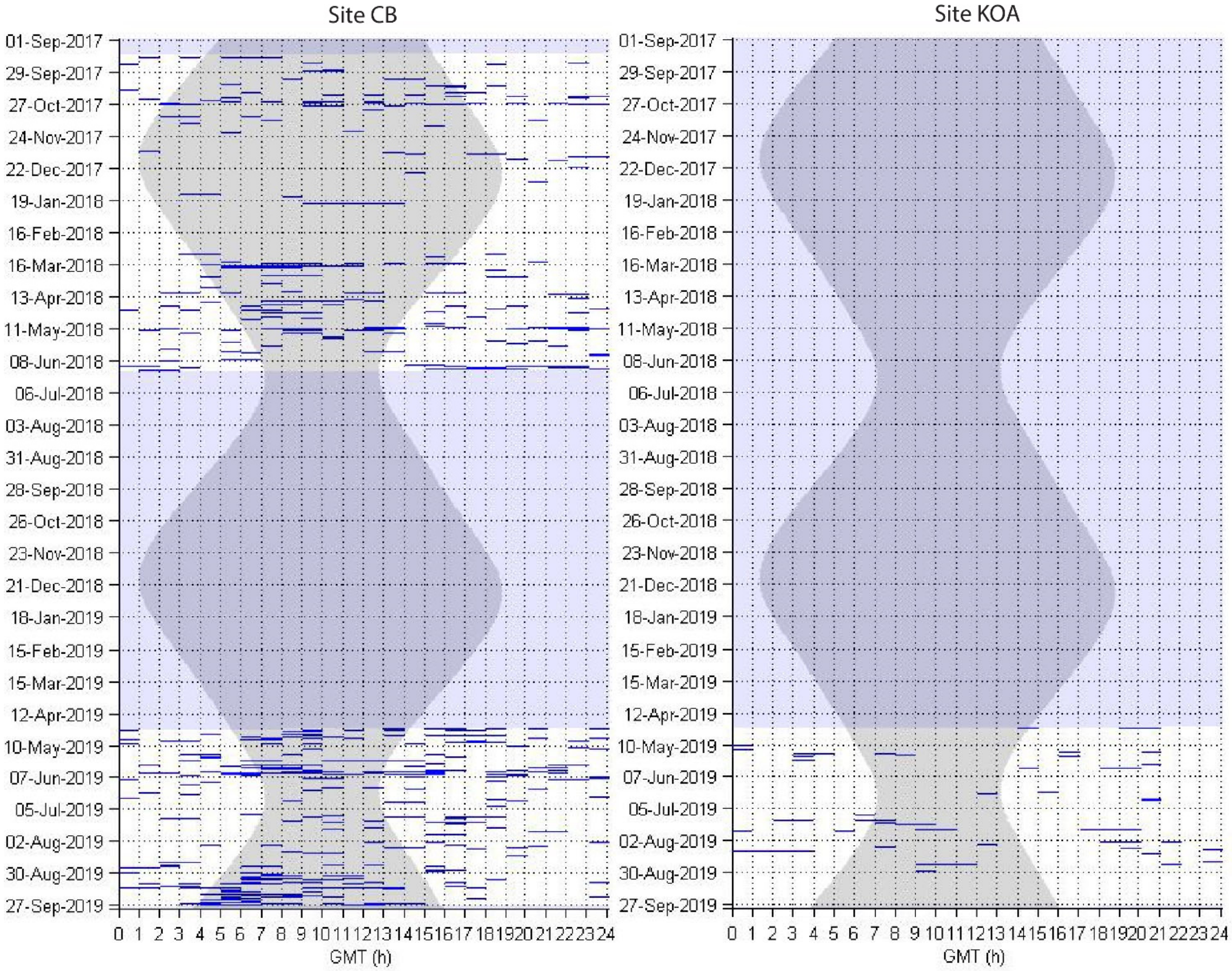


Figure 27. Diel presence of fin whale 40 Hz calls, indicated by blue dots, in one-hour bins at sites CB (left) and KOA (right).
Gray vertical shading denotes nighttime and transparent blue horizontal shading denotes absence of acoustic data.

Humpback Whales

Humpback whale calls were detected only at site CB.

- Humpback whales were detected sporadically only during the winter and early spring at site CB (Figure 28).
- There were not enough humpback whale detections to determine if a diel pattern was present (Figure 29).
- The low number of calls during summer months is consistent with previous monitoring periods at these sites; however, the detections during winter months were the lowest since monitoring

began in 2011 (Baumann-Pickering *et al.*, 2012; Debich *et al.*, 2013; Debich *et al.*, 2014; Rice *et al.*, 2015; Rice *et al.*, 2018)

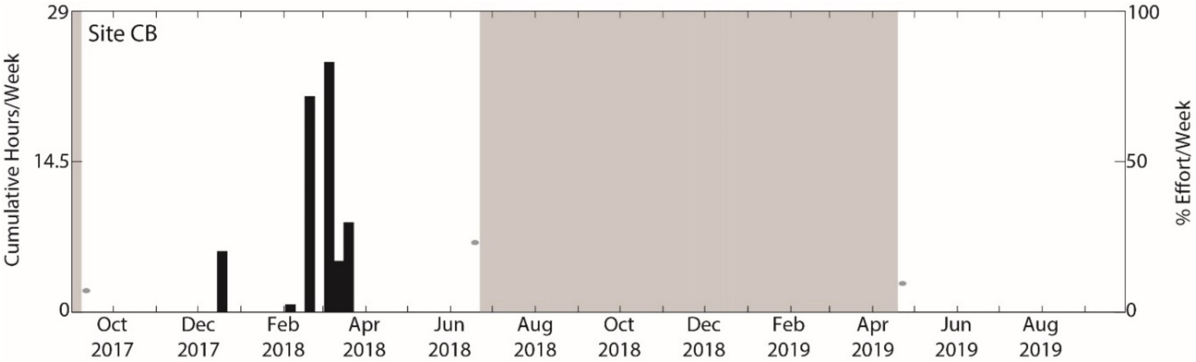


Figure 28. Weekly presence of humpback whale calls from September 2017 to June 2018 and April to September 2019 at sites CB (top) and KOA (bottom).
Gray dots represent the percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

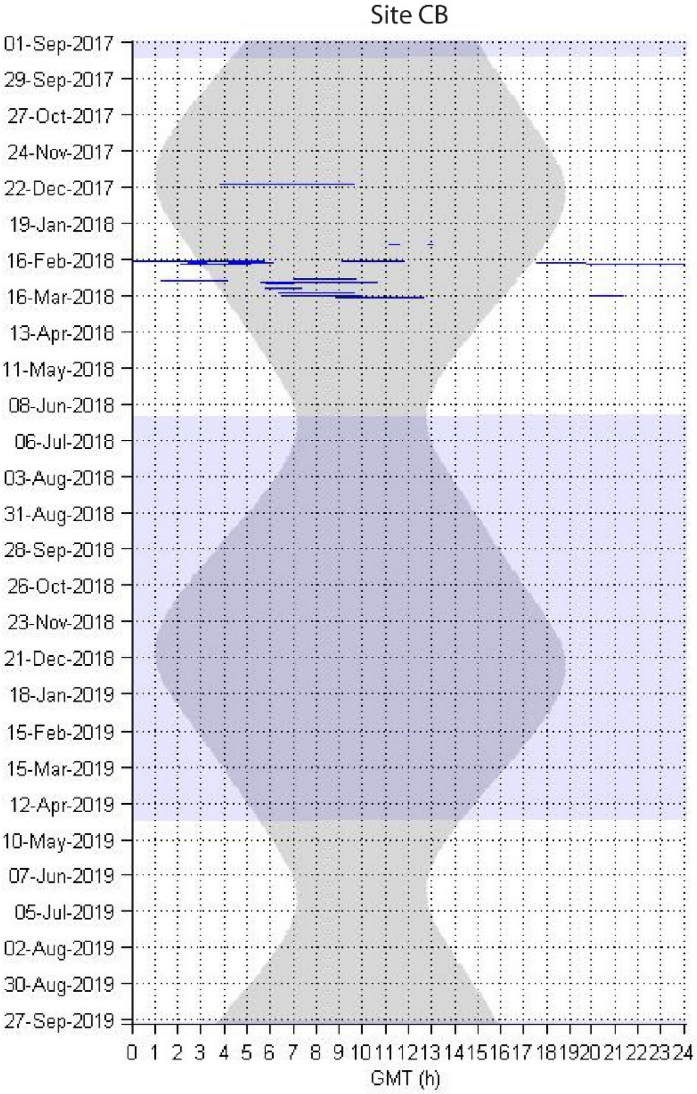


Figure 29. Diel presence of humpback whale calls, indicated by blue dots, in one-minute bins at sites CB (left) and KOA (right).
Gray vertical shading denotes nighttime and transparent blue horizontal shading denotes absence of acoustic data.

Odontocetes

Four odontocete species were acoustically identified to species level from September 2017 to June 2018 and from April to September 2019: killer whales, sperm whales, Cuvier's beaked whales, and Stejneger's beaked whales. More details of each species presence at each site is given below.

Killer Whales

Killer whale pulsed calls were detected at both sites.

- Killer whale pulsed calls occurred throughout the recordings at both sites but were more prevalent at site CB, where calls were highest during the summer (Figure 30).
- There was no discernable diel pattern for killer whale pulsed calls at either site (Figure 31).
- These results are consistent with previous monitoring periods (Baumann-Pickering *et al.*, 2012; Debich *et al.*, 2013; Debich *et al.*, 2014)

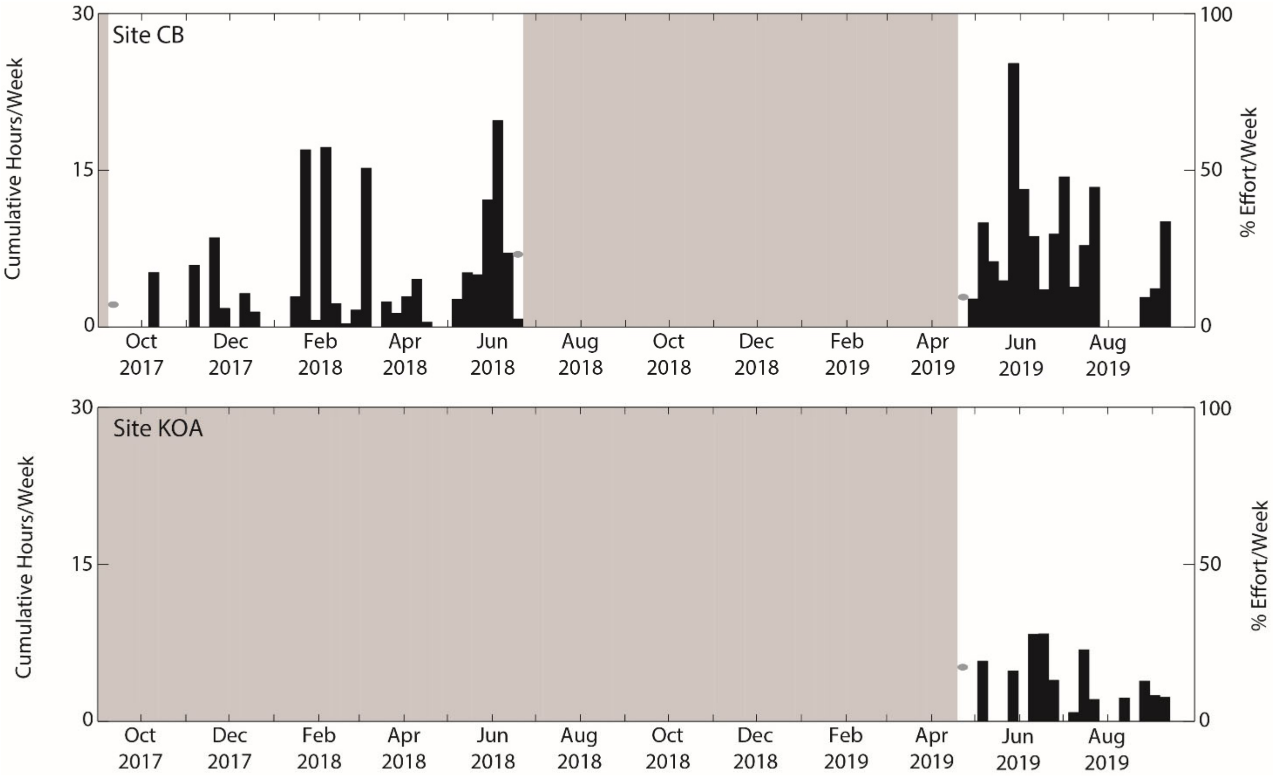


Figure 30. Weekly presence of killer whale pulsed calls from September 2017 to June 2018 and April to September 2019 at sites CB (top) and KOA (bottom).
Gray dots represent the percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

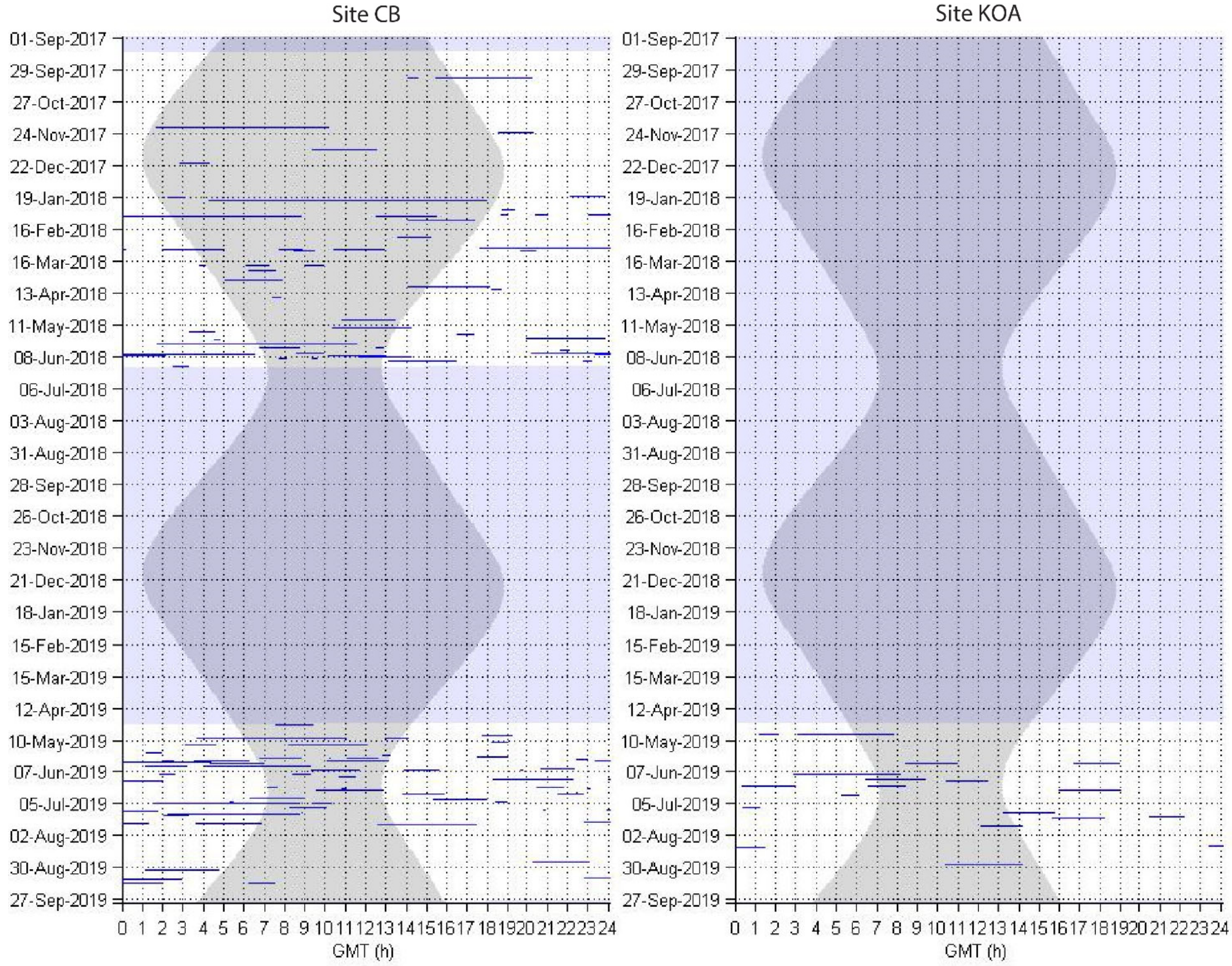


Figure 31. Diel presence of killer whale whistles and pulsed calls, indicated by blue dots, in one-minute bins at site CB (left) and KOA (right).
Gray vertical shading denotes nighttime and transparent blue horizontal shading denotes absence of acoustic data.

Sperm Whales

Sperm whale echolocation clicks were detected at both sites.

- Sperm whale clicks occurred throughout the recordings at both sites but were more prevalent at site CB, where detections were high throughout the summer and fall and decreased only during the winter (Figure 32).
- There were no discernable diel patterns for sperm whale clicks at either 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; Rice *et al.*, 2018).

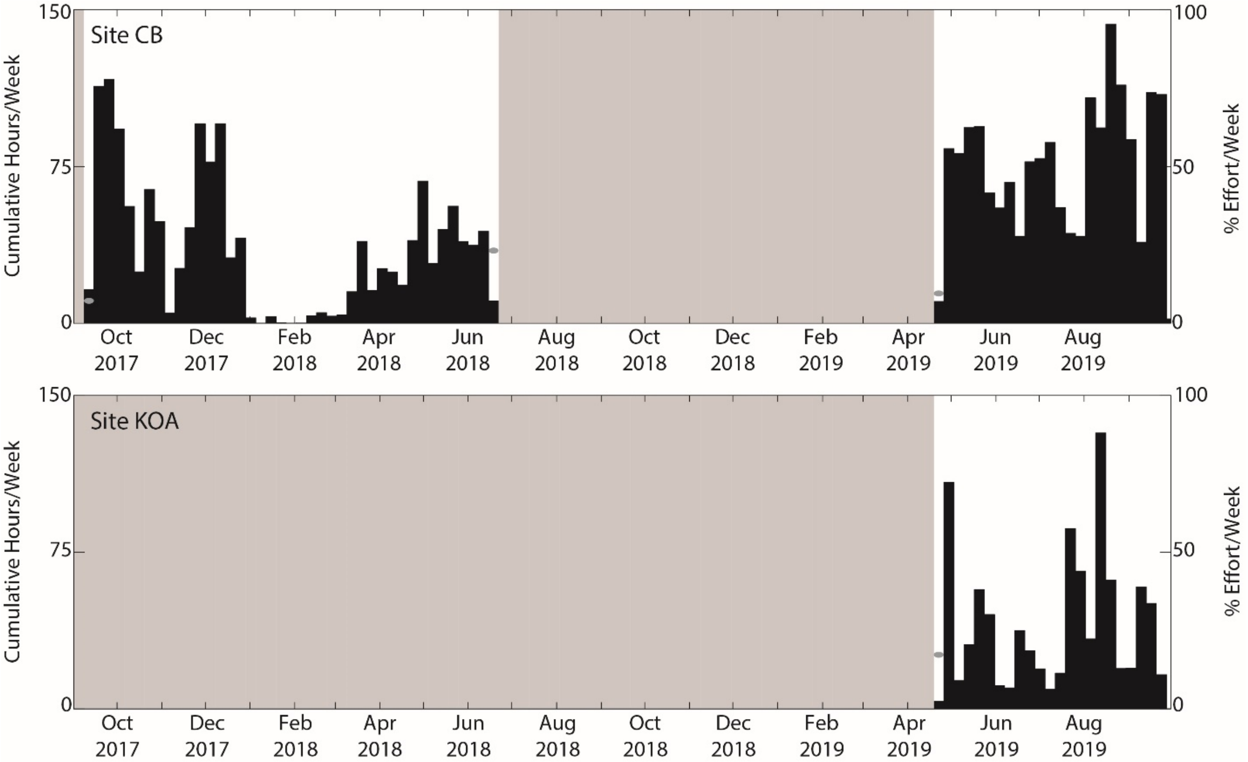


Figure 32. Weekly presence of sperm whale clicks from September 2017 to June 2018 and April to September 2019 at sites CB (top) and KOA (bottom).

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.

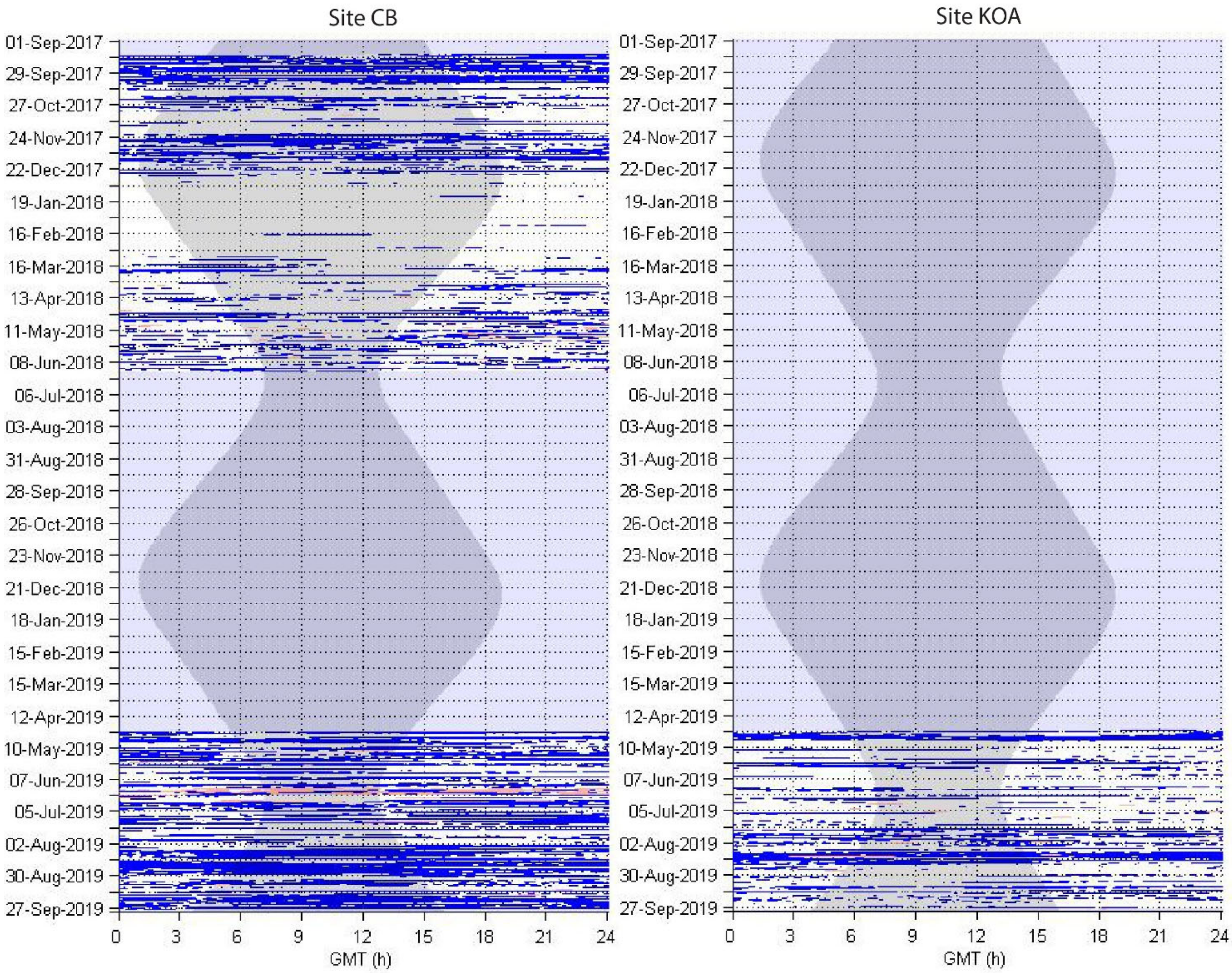


Figure 33. Diel presence of sperm whale clicks, indicated by blue dots, in one-minute bins at site CB (left) and KOA (right).
Light red shading represents times where ships were present and sperm whales could not be detected if they were present. Gray vertical shading denotes nighttime and transparent blue horizontal shading denotes absence of acoustic data.

Cuvier's Beaked Whales

Cuvier's beaked whale FM pulses were detected only at site CB.

- Cuvier's beaked whale FM pulses were only detected on December 4, 2017 at site CB (Figure 34).
- There was no discernable diel pattern for Cuvier's beaked whale detections due to the low number of detections (Figure 35).
- These results are consistent with previous monitoring periods (Baumann-Pickering *et al.*, 2012; Debich *et al.*, 2013; Debich *et al.*, 2014).

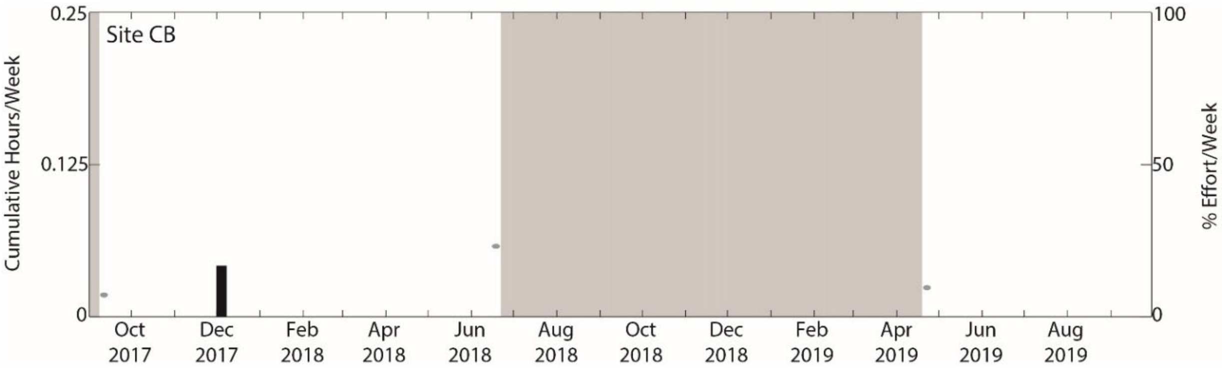


Figure 34. Weekly presence of Cuvier's beaked whale FM pulses from September 2017 to June 2018 and April to September 2019 at site CB. There were no detections of Cuvier's at site KOA.
Gray dots represent the percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

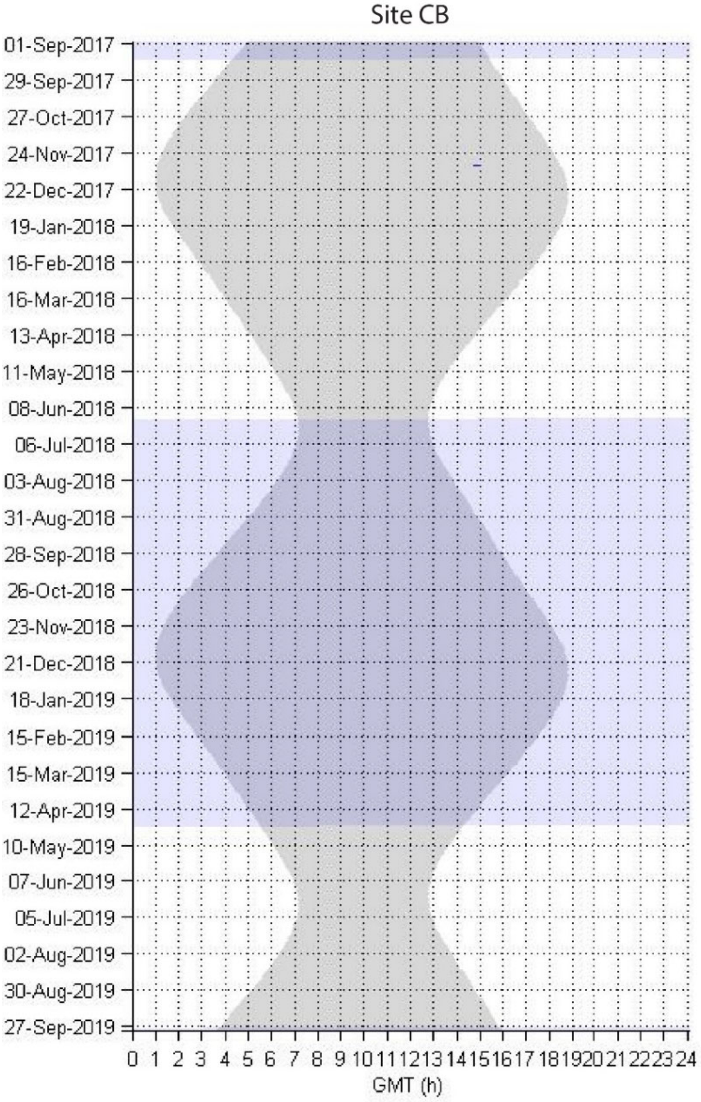


Figure 35. Diel presence of Cuvier's beaked whale FM pulses, indicated by blue dots, in ten-minute bins at site CB. There were no detections of Cuvier's at site KOA.
Gray vertical shading denotes nighttime and transparent blue horizontal shading denotes absence of acoustic data.

Stejneger's Beaked Whales

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

- Stejneger's beaked whale FM pulses were detected throughout the recording period at both sites but were more common at site CB (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; Rice *et al.*, 2018).

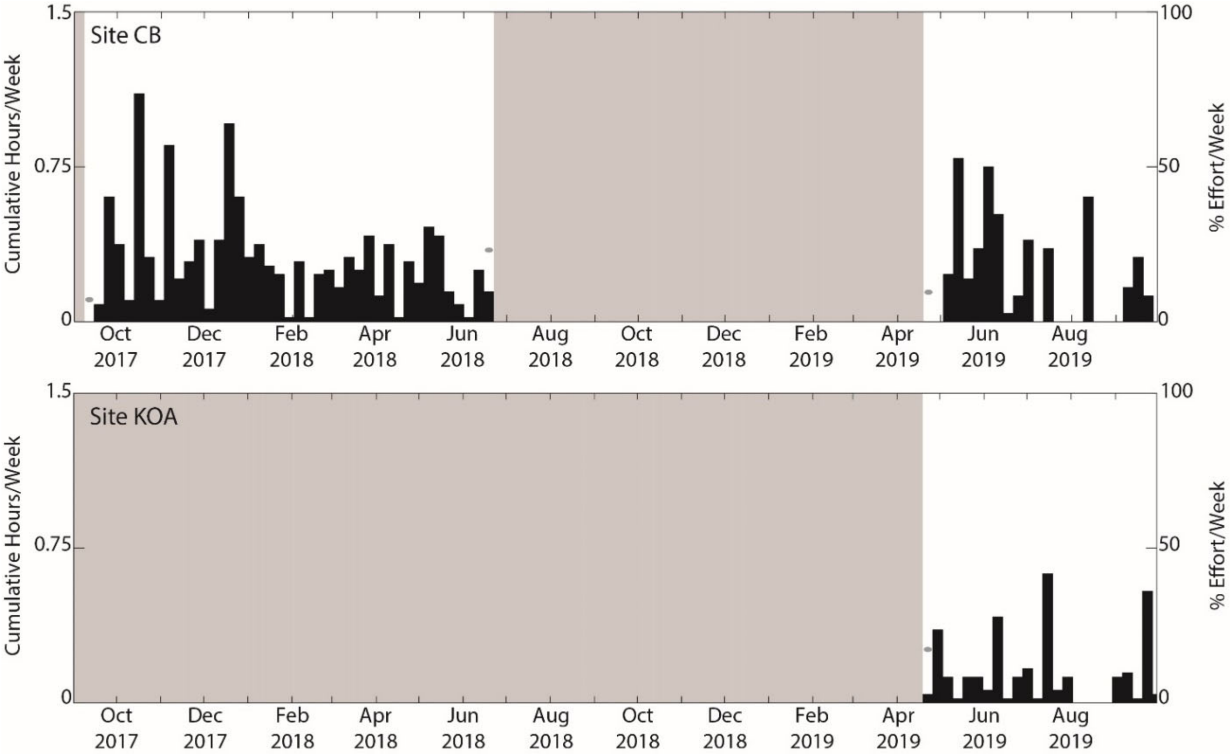


Figure 36. Weekly presence of Stejneger's beaked whale FM pulses from September 2017 to June 2018 and April to September 2019 at sites CB (top) and KOA (bottom).
Gray dots represent the percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

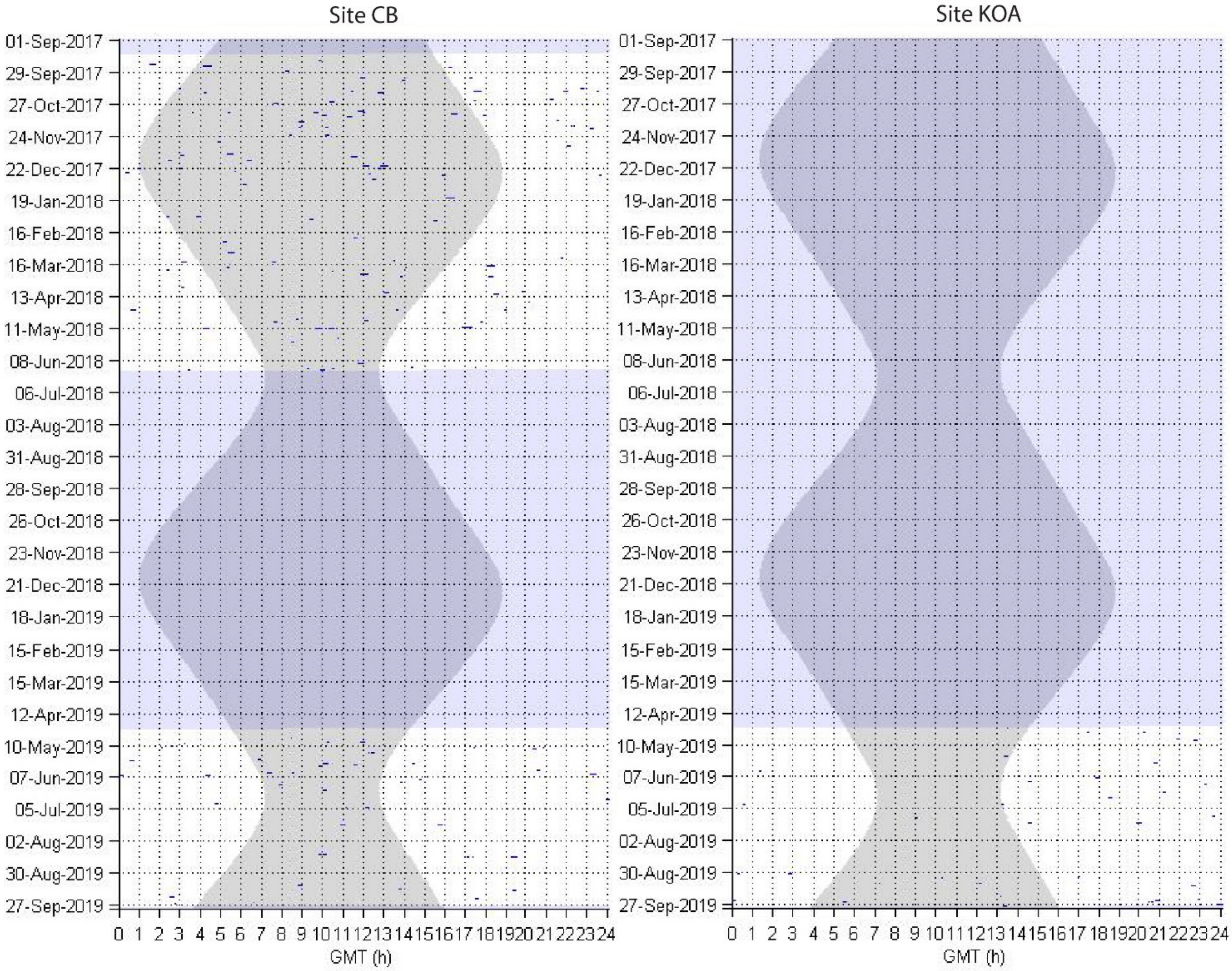


Figure 37. Diel presence of Stejneger’s beaked whale FM pulses, indicated by blue dots, in five-minute bins at sites CB (left) and KOA (right).
Gray vertical shading denotes nighttime and transparent blue horizontal shading denotes absence of acoustic data.

Anthropogenic Sounds

Three types of anthropogenic sounds were acoustically identified in the GATMAA between September 2017 and June 2018 and between April and September 2019: 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 both sites. The Northern Edge Naval exercise occurred in the GATMAA from May 13 to 24, 2019 (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 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 2019 (Table 3).

- MFA sonar was detected at both sites. Detections occurred in May 2019 when a naval training exercise was taking place (Figure 38).
- At site CB, a total of 330 packets were detected in 2019, with a maximum received level of 165 dB_{pp} re 1 μPa (Figure 40). Total event duration was around 7 h (Figure 43) but the total duration of detected pings was only about 0.4 h (1,507.9 s; Figure 44; Table 3; Table 4).
- At site KOA, a total of 201 packets were detected in 2019, with a maximum received level of 138 dB_{pp} re 1 μPa (Figure 40). Total event duration was around 5 h (Figure 43) but the total duration of detected pings was only about 0.2 h (725.8 s; Figure 44; Table 3; Table 4).
- Maximum cumulative sound exposure levels of wave trains occurred during May 2019 at both sites (Figure 41) and were greater than 135 dB re 1 μPa^2 -s. At site CB, maximum levels were around 165 dB re 1 μPa^2 -s and at site KOA, maximum received levels were around 138 dB re 1 μPa^2 -s.
- All MFA sonar wave trains occurred during Navy training exercises (Figure 42).
- All detected MFA sonar occurred during daytime hours (Figure 39).
- The presence of MFA is consistent with the previous monitoring period (Rice *et al.*, 2018) and has not been reported otherwise (Debich *et al.*, 2014; Rice *et al.*, 2015).

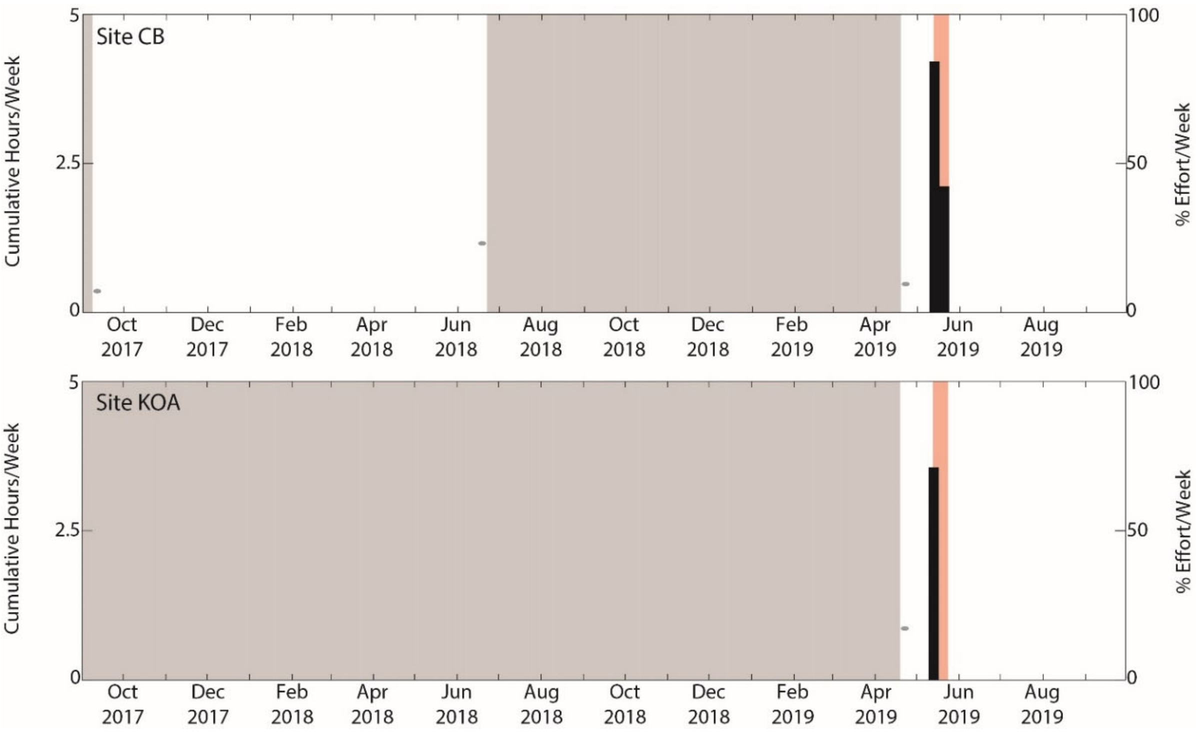


Figure 38. Naval training event (shaded light red) overlaid on weekly presence of MFA sonar < 5 kHz, from the *Silbido* detector, from September 2017 to June 2018 and April to September 2019 at sites CB (top) and KOA (bottom).

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.

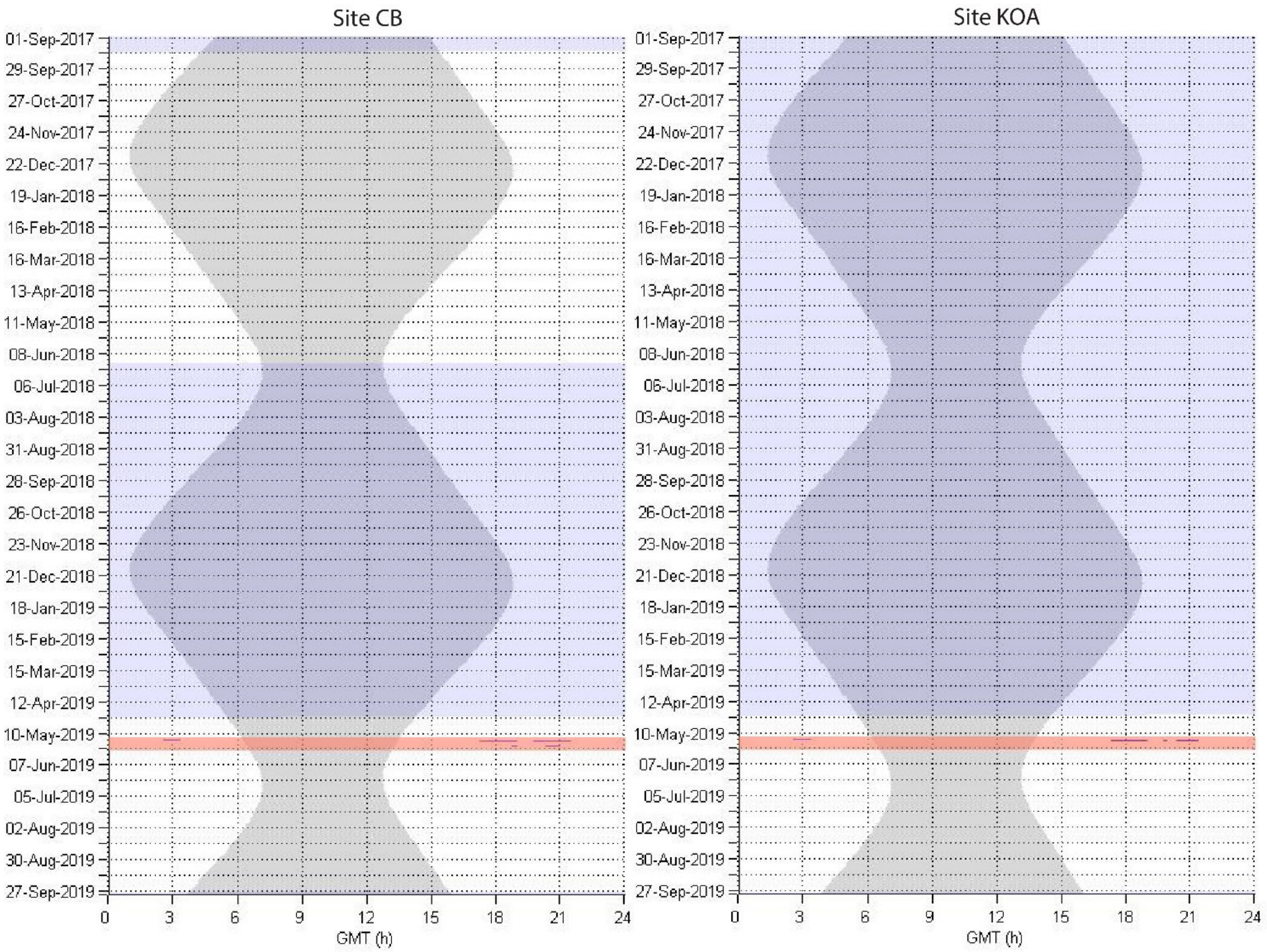


Figure 39. Naval training event (shaded light red) overlaid on diel presence of MFA sonar < 5 kHz signals from the *Silbido* detector, indicated by blue dots, in one-minute bins at sites CB (left) and KOA (right). Gray vertical shading denotes nighttime and transparent blue horizontal shading denotes absence of acoustic data.

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

Site	Days Analyzed (Years)	Number of Wave Trains	Number of Packets	Total Wave Train Duration (h)	Total Packet Duration (s)
CB	155 (0.42)	5	330	6.9	1507.9
KOA	156 (0.43)	2	201	4.9	725.8

Table 4. MFA sonar temporal characteristics for events (wave trains) of detected groups of pings (packets) in the GATMAA at sites CB and KOA from April to September 2019.

Deployment	Event #	First Detection	Last Detection	Event Duration [HH:MM:SS]	Number of Detections	Total Duration of Detected Pings [s]
CB10	1	15-May-2019 02:32:14	15-May-2019 03:20:39	00:48:25	59	249
	2	16-May-2019 17:15:21	16-May-2019 21:28:31	04:13:10	181	695.3
	3	19-May-2019 00:29:47	19-May-2019 01:31:14	01:01:27	53	389.7
	4	19-May-2019 03:45:08	19-May-2019 04:00:56	00:15:48	23	166.8
	5	21-May-2019 20:18:55	21-May-2019 20:55:11	00:36:16	14	7.1
	Total			06:55:06	330	1,507.9
KOA01	1	15-May-2019 02:32:33	15-May-2019 03:22:33	00:50:00	56	186.2
	2	16-May-2019 17:17:33	16-May-2019 21:21:18	04:03:45	145	539.6
	Total			04:53:45	201	725.8

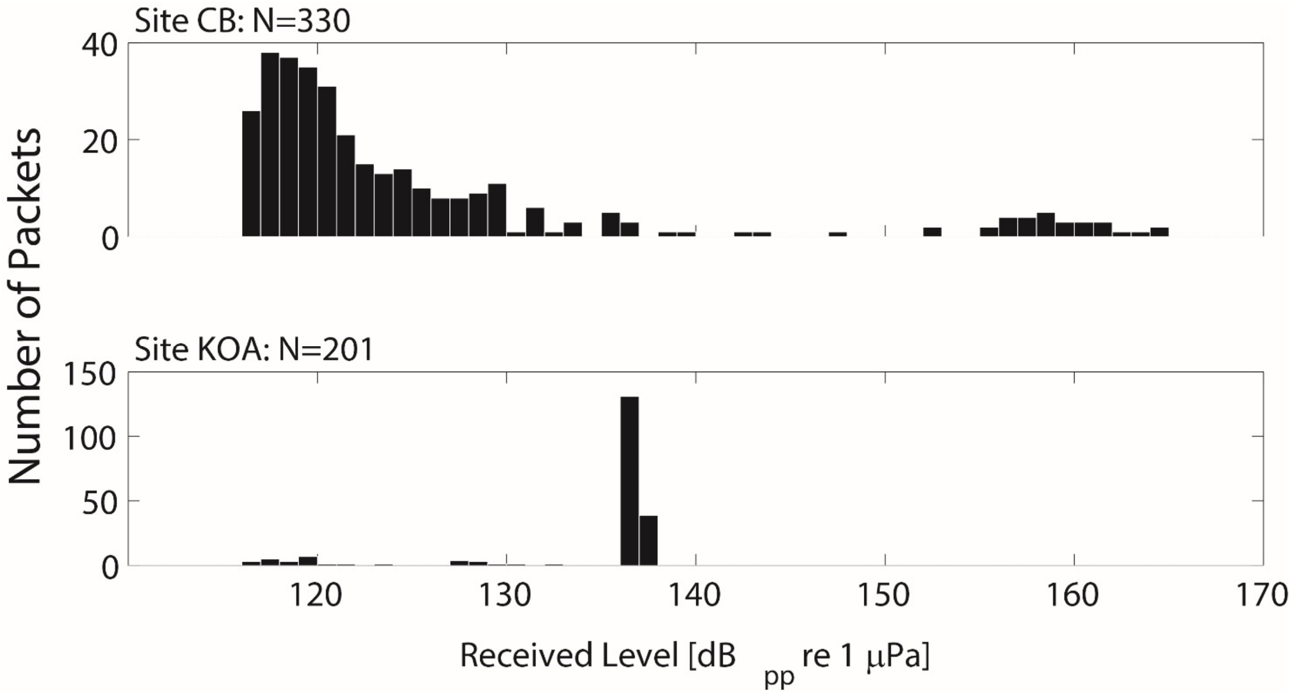


Figure 40. MFA sonar packet peak-to-peak received level distributions for site CB (top) and site KOA (bottom).

The total number of packets detected at each site is given in the upper left corner of each panel. Instrument clipping levels are reached around 161–169 dBpp re 1 µPa, depending on hydrophone configuration. Note the vertical axes are at different scales.

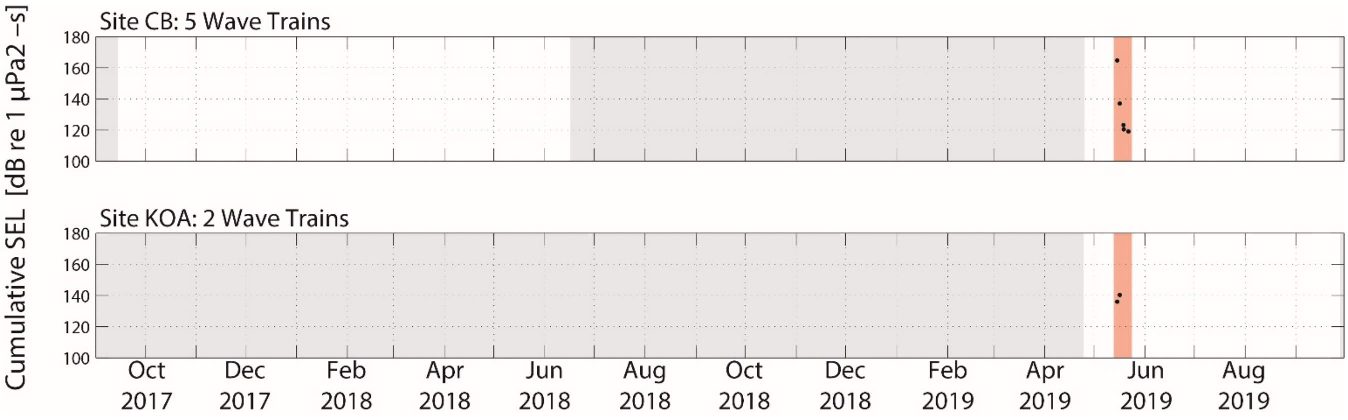


Figure 41. Cumulative sound exposure level for each wave train at site CB (top) and site KOA (bottom).

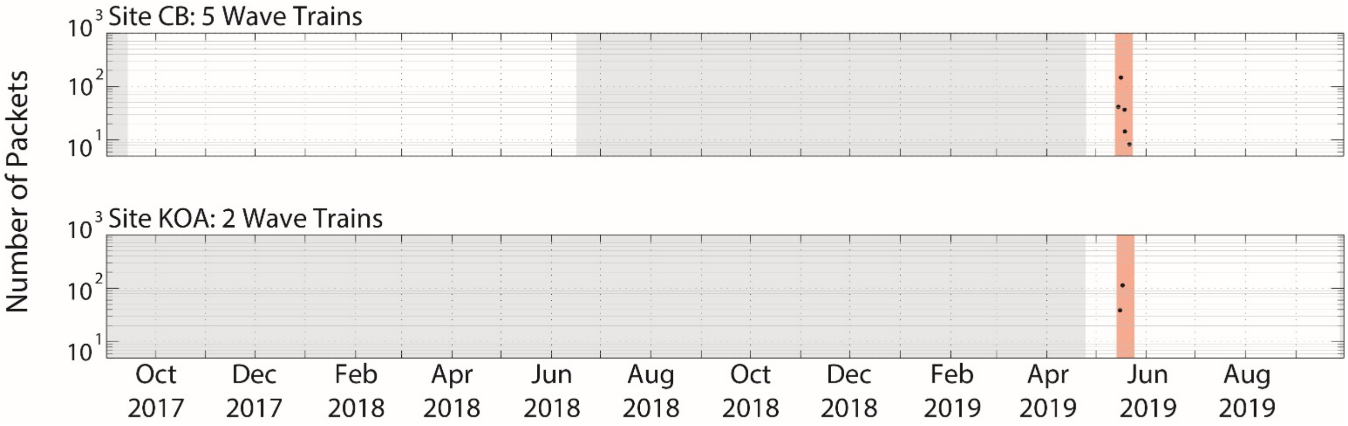


Figure 42. Number of MFA sonar packets for each wave train at site CB (top) and site KOA (bottom). Note the vertical axes are logarithmic base-10.

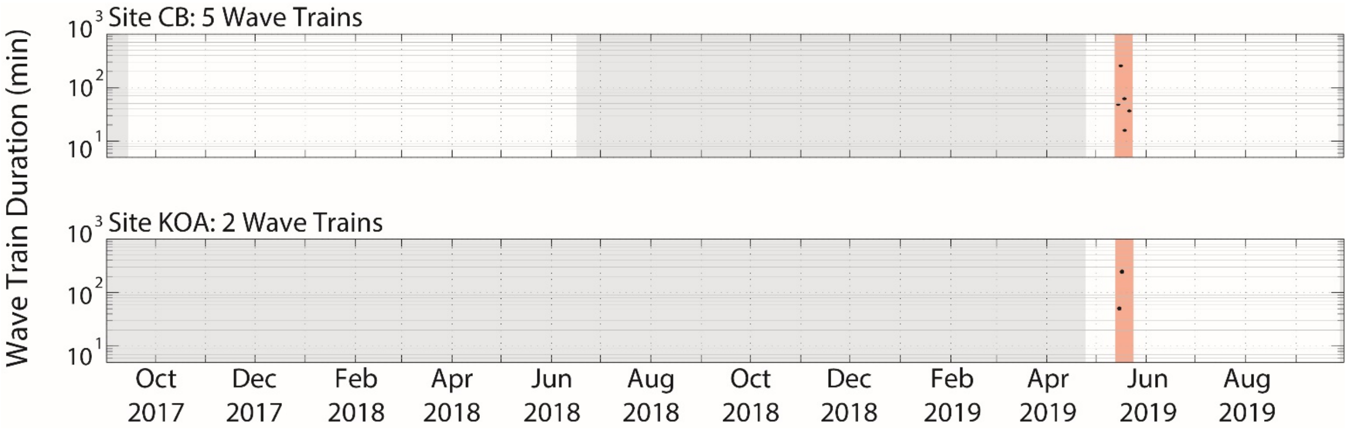


Figure 43. Wave train duration at site CB (top) and site KOA (bottom).
Note the vertical axes are logarithmic base-10.

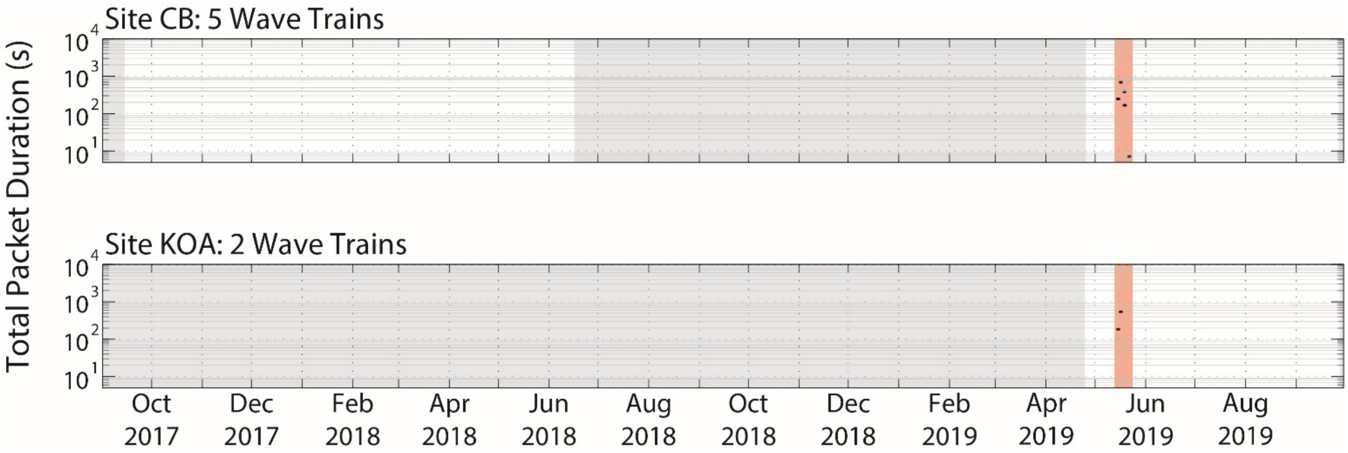


Figure 44. Total packet duration for each wave train at site CB (top) and site KOA (bottom). Note the vertical axes are logarithmic base-10.

Low-Frequency Active Sonar

A tonal LFA sonar was detected in low numbers in the GATMAA at site CB. The US Navy confirmed that this LFA signal was not from a US Navy source.

- LFA sonar > 500 Hz occurred at site CB during April and May 2019, while LFA sonar < 500 Hz occurred only on May 14, 2019 (Figure 45; Figure 47).
- The tonal LFA sonar encountered during this monitoring period had relatively low received levels of ~110 $\mathrm{dB_{pp}}$ re 1 µPa, with a maximum received level of 120 $\mathrm{dB_{pp}}$ re 1 µPa. Signal duration ranged from 5 to 45 s, but was typically 10–20 s. The majority of signals were very narrow band (~842 Hz) and were amplitude modulated, likely due to interference from reflections off of the seafloor and sea surface,
- LFA sonar < 500 Hz, although not generated by the US Navy, overlapped by two days with the Northern Edge exercise that took place from May 13 to 24, 2019 (U.S. Navy Pacific Fleet, personal communication; Figure 47).
- The majority of LFA sonar occurred during daytime hours (Figure 46).
- LFA sonar > 500 Hz has been detected previously at site CB (Rice *et al.*, 2018).

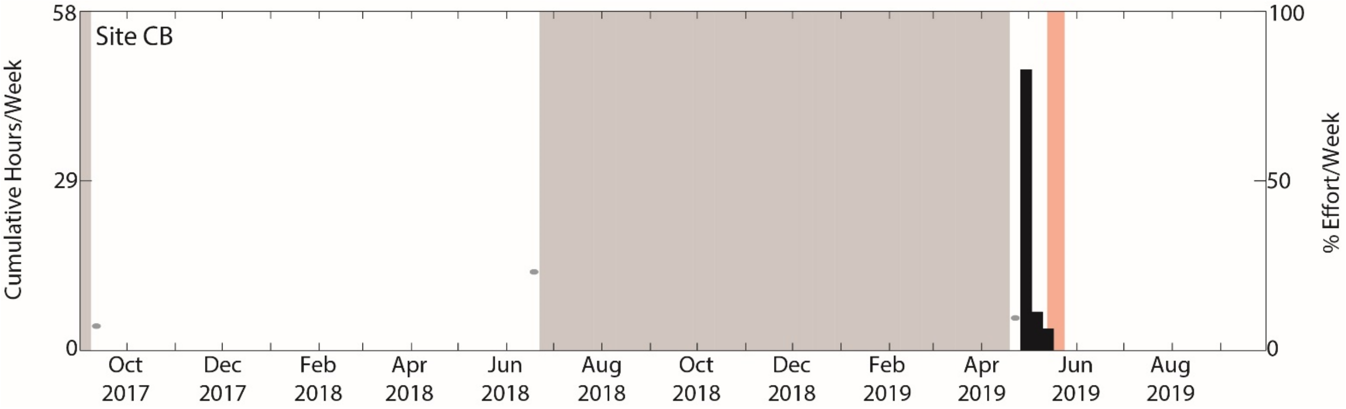


Figure 45. Naval training event (shaded light red) overlaid on weekly presence of LFA sonar > 500 Hz from September 2017 to June 2018 and April to September 2019 at site CB. There was no LFA sonar > 500 Hz detected at site KOA.
Gray dots represent the percent of effort per week in weeks with less than 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.

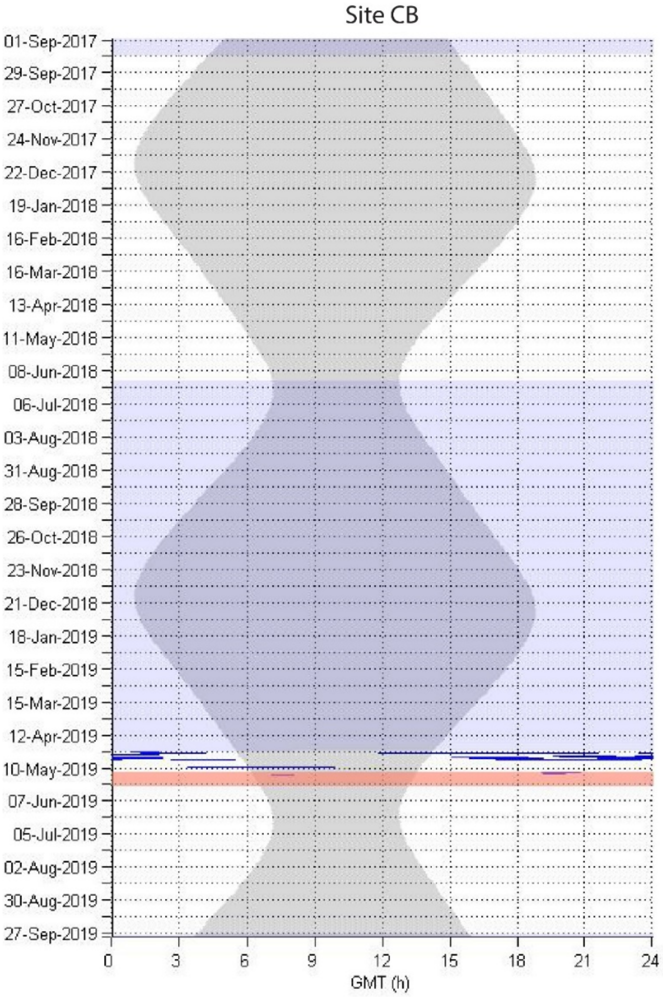


Figure 46. Naval training event (shaded light red) overlaid on diel presence of LFA sonar > 500 Hz signals, indicated by blue dots, in one-minute bins at sites CB. There was no LFA sonar > 500 Hz detected at site KOA.

Gray vertical shading denotes nighttime and transparent blue horizontal shading denotes absence of acoustic data.

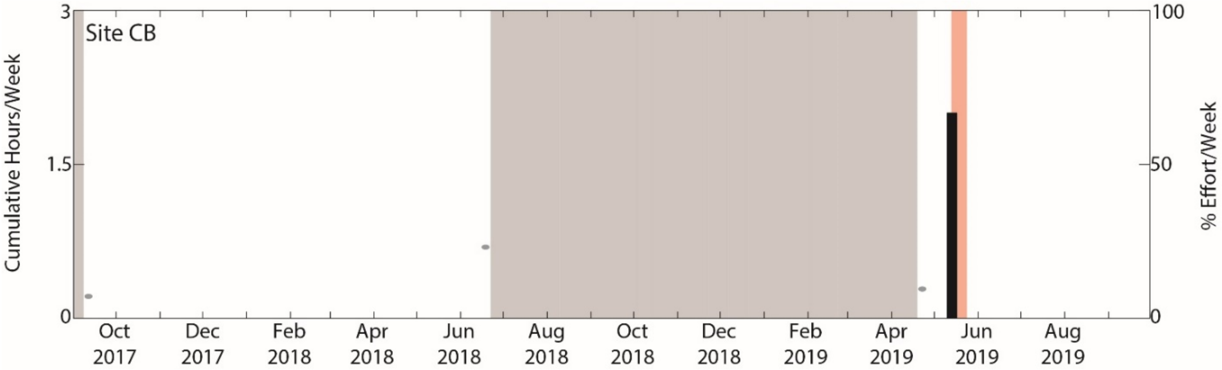


Figure 47. Naval training event (shaded light red) overlaid on weekly presence of LFA sonar < 500 Hz from September 2017 to June 2018 and April to September 2019 at site CB. There was no LFA sonar < 500 Hz detected at site KOA.

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.

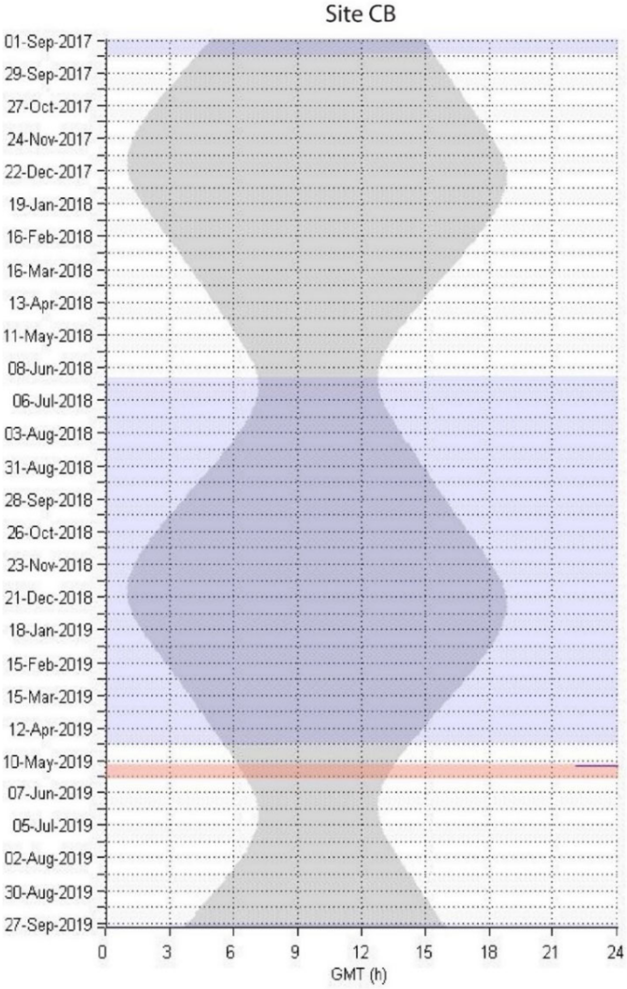


Figure 48. Major naval training events (shaded light red) overlaid on diel presence of LFA sonar < 500 Hz signals, indicated by blue dots, in one-minute bins at sites CB (left). There was no LFA sonar < 500 Hz detected at site KOA.
Gray vertical shading denotes nighttime and transparent blue horizontal shading denotes absence of acoustic data.

Explosions

Explosions were detected at both sites. Peak explosion occurrence did not coincide with the Northern Edge exercise that occurred during this monitoring period. The Navy confirmed no at-sea explosives were used in the GATMAA during the Northern Edge, nor at any time in 2018–2019.

- Explosions occurred sporadically throughout the monitoring period at both sites (Figure 49).
- Explosions were significantly higher at site KOA than at site CB and peaked at KOA at the end of August 2019 (Figure 49).
- Total explosion counts at each site were as follows:
  - 50 at CB (44 in 2017–2018 and 6 in 2019)
  - 1,122 at KOA
- There was no clear diel pattern for explosions at either site (Figure 50).
- There were more explosions during the winter months than have typically occurred during previous monitoring periods at site CB (Debich *et al.*, 2014; Rice *et al.*, 2015).

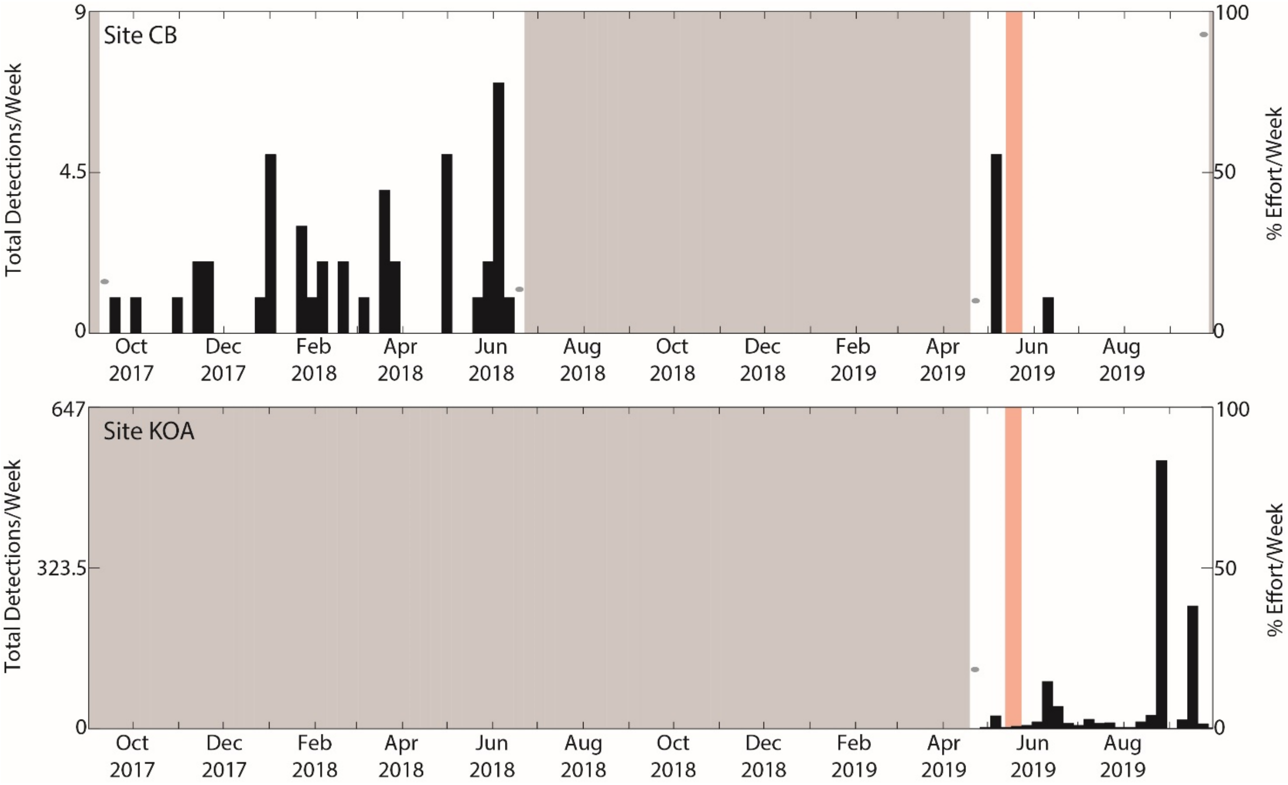


Figure 49. Naval training event (shaded light red) overlaid on weekly presence of explosions from September 2017 to June 2018 and April to September 2019 at sites CB (top) and KOA (bottom). Note the higher y-axis value for site KOA.
Gray dots represent the percent of effort per week in weeks with less 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.

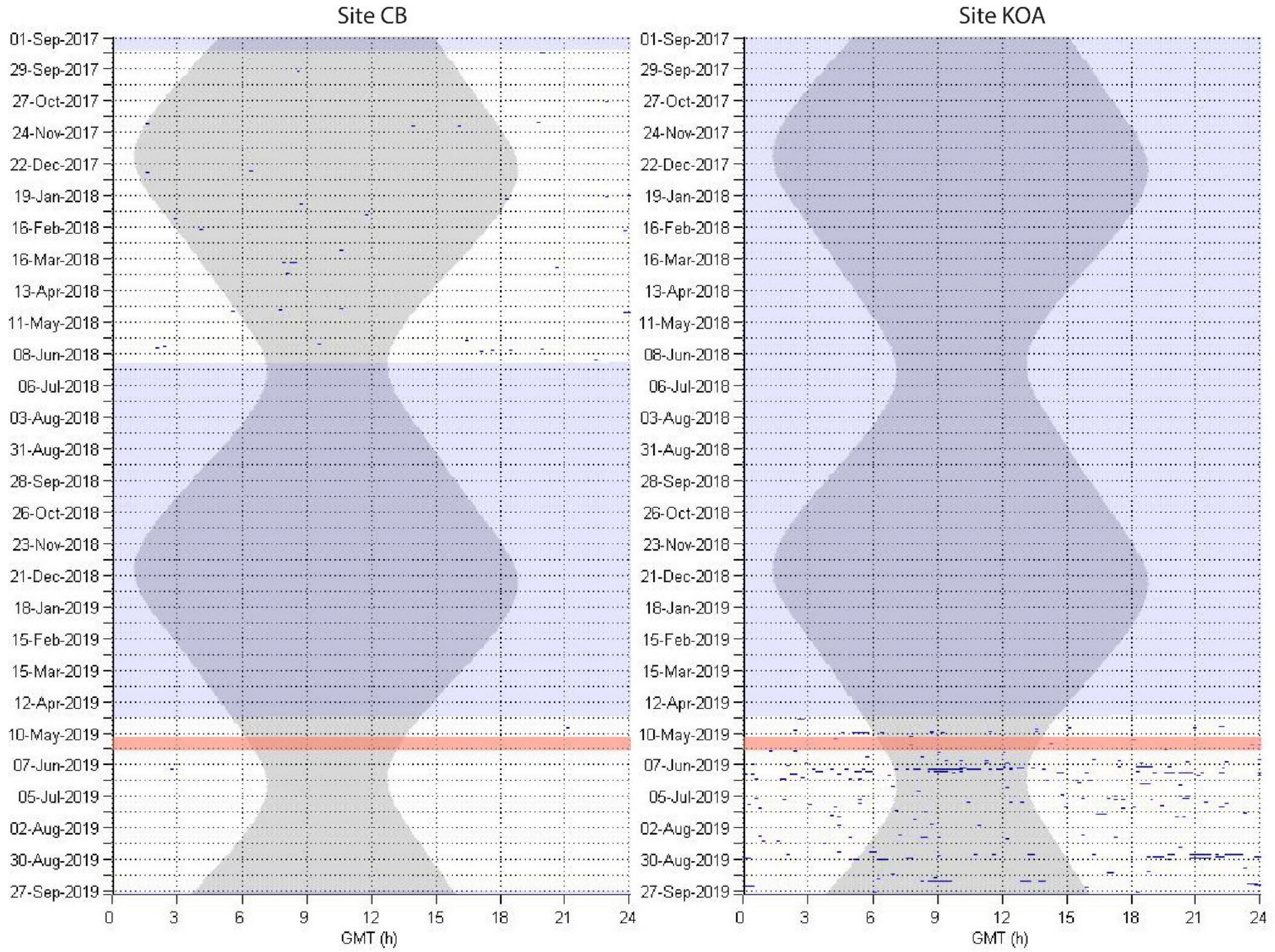


Figure 50. Naval training events (shaded light red) overlaid on diel presence of explosion detections, indicated by blue dots, in ten-minute bins at sites CB (left) and KOA (right).
Gray vertical shading denotes nighttime and transparent blue horizontal shading denotes absence of acoustic data.

Conclusion

Passive acoustic monitoring was conducted at two sites in the GATMAA from September 2017 to June 2018 and from April to September 2019 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. Three baleen whale species were recorded: blue, fin, and humpback whales. Blue whales and fin whales were recorded at all sites while humpbacks were seen in lower numbers overall. Four odontocete species were recorded: killer whales, sperm whales, Cuvier's beaked whales, and presumed Stejneger's beaked whales. Killer whale pulsed calls were present at both sites but were highest at site CB during the summer. Sperm whale clicks occurred throughout the summer at both sites but were most common at site CB. Cuvier's beaked whales were only detected on one occasion at site CB, 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 sonar events detected were concurrent with the

Navy training exercise in the area. Explosions were detected in low numbers at site CB but in very high numbers at site KOA, and were not related to Navy exercises.

Future work in the GATMAA using passive acoustic monitoring with HARPs around times of upcoming 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 on marine mammals.

References

Allen, B. M., and Angliss, R. P. (**2010**). "Alaska marine mammal stock assessments," (NOAA National Marine Fisheries Service, Alaska Fisheries Science Center).

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

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

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

Baumann-Pickering, S., Širović, A., Hildebrand, J. A., Debich, A. J., Gottlieb, R. S., Johnson, S. C., Kerosky, S. M., Roche, L. K., Solsona Berga, A., Wakefield, L., and Wiggins, S. M. (**2012**). "Passive Acoustic Monitoring for Marine Mammals in the Gulf of Alaska Temporary Maritime Activities Area 2011-2012," (Marine Physical Laboratory, Scripps Institution of Oceanography, La Jolla, CA), p. 42.

Brownell, R. L., Clapham, P. J., Miyashita, T., and Kasuya, T. (**2001**). "Conservation status of North Pacific right whales," Journal of Cetacean Research and Management **Special Issue 2**, 269-286.

Crane, N. L., and Lashkari, K. (**1996**). "Sound production of gray whales, *Eschrichtius robustus*, along the migration route: A new approach to signal analysis," Journal of the Acoustical Society of America **100**, 1878-1886.

Debich, A. J., Baumann-Pickering, S., Sirovic, A., Hildebrand, J. A., Alldredge, A. L., Gottlieb, R. S., Herbert, S. T., Johnson, S. C., Rice, A. C., Roche, L. K., Thayre, B. J., Trickey, J. S., Varga, L. M., and Wiggins, S. M. (**2014**). "Passive acoustic monitoring for marine mammals in the Gulf of Alaska temporary maritime activities area 2013-2014," (Marine Physical Laboratory, Scripps Institution of Oceanography, La Jolla, CA), p. 101.

Debich, A. J., Baumann-Pickering, S., Širović, A., Hildebrand, J. A., Buccowich, J. S., Gottlieb, R. S., Jackson, A. N., Johnson, S. C., Roche, L. K., Trickey, J. S., Wakefield, L., and Wiggins, S. M. (**2013**). "Passive Acoustic Monitoring for Marine Mammals in the Gulf of Alaska Temporary Maritime Activities Area 2012-2013," (Marine Physical Laboratory, Scripps Institution of Oceanography, La Jolla, CA), p. 79.

Dunlop, R., Noad, M. J., Cato, D., and Stokes, D. (**2007**). "The social vocalization repertoire of east Australian migrating humpback whales (*Megaptera novaeangliae)*," Journal of the Acoustical Society of America **122**, 2893-2905.

Ford, J. K. B. (**1989**). "Acoustic behavior of resident killer whales (*Orcinus orca*) off Vancouver Island, British Columbia," Can J Zool **67**, 727-745.

Ford, J. K. B., and Fisher, D. (**1983**). *Group-specific dialects of killer whales (Orcinus orca) in British Columbia* (Westview Press, Boulder, CO).

Goold, J. C., and Jones, S. E. (**1995**). "Time and frequency domain characteristics of sperm whale clicks," Journal of the Acoustical Society of America **98**, 1279-1291.

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

Johnson, M., Madsen, P. T., Zimmer, W. M. X., Aguilar de Soto, N., and Tyack, P. L. (**2004**). "Beaked whales echolocate on prey," Proceedings of the Royal Society B: Biological Sciences **271**, S383-S386.

Knudsen, V. O., Alford, R. S., and Emling, J. W. (**1948**). "Underwater ambient nosie," Journal of Marine Research **7**, 410-429.

Loughlin, T. R., Fiscus, C. H., Johnson, A. M., and Rugh, D. J. (**1982**). "Observations of the *Mesoplodon stejnegeri* (Ziphiidae) in the Central Aleutian Islands, Alaska," Journal of Mammalogy **63**, 697-700.

Madsen, P. T., Wahlberg, M., and Møhl, B. (**2002**). "Male sperm whale (*Physete macrocephalus*) acoustics in a high-latitude habitat: implications for echolocation and communication," Behavioral Ecology and Sociobiology **53**.

McDonald, M. A., Hildebrand, J. A., and Webb, S. C. (**1995**). "Blue and fin whales observed on a seafloor array in the Northeast Pacific," Journal of the Acoustical Society of America **98**, 712-721.

McDonald, M. A., Hildebrand, J. A., and Wiggins, S. M. (**2006a**). "Increases in deep ocean ambient noise in the northeast Pacific west of San Nicolas Island, California," Journal of the Acoustical Society of America **120**, 711-718.

McDonald, M. A., Mesnick, S. L., and Hildebrand, J. A. (**2006b**). "Biogeographic characterisation of blue whale song worldwide: using song to identify populations," Journal of Cetacean Research and Management **8**, 55-65.

McDonald, M. A., and Moore, S. E. (**2002**). "Calls recorded from North Pacific right whales (*Eubalaena japonica*) in the eastern Bering Sea," Journal of Cetacean Research and Management **4**, 261-266.

Mead, J. G. (**1989**). "Beaked whales of the genus *Mesoplodon*," in *Handbook of Marine Mammals. Volume 4: River Dolphins and the Larger Toothed Whales* (New York), pp. 349-430.

Møhl, B., Wahlberg, M., and Madsen, P. T. (**2003**). "The monopulsed nature of sperm whale clicks," Journal of the Acoustical Society of America **114**, 1143-1154.

Nieukirk, S. L., Mellinger, D. K., Moore, S. E., Klinck, K., Dzlak, R. P., and Goslin, J. (**2012**). "Sounds from airguns and fin whales recorded in the mid-Atlantic Ocean, 1999-2009," Journal of the Acoustical Society of America **131**, 1102-1112.

Oleson, E. M., Calambokidis, J., Burgess, W. C., McDonald, M. A., LeDuc, C. A., and Hildebrand, J. A. (**2007**). "Behavioral context of call production by eastern North Pacific blue whales," Marine Ecology Progress Series **330**, 269-284.

Payne, R. S., and McVay, S. (**1971**). "songs of humpback whales," (Science), pp. 585-597.

Rice, A. C., Baumann-Pickering, S., Širović, A., Hildebrand, J. A., Brewer, A. M., Debich, A. J., Herbert, S., Thayre, B. J., Trickey, J. S., and Wiggins, S. M. (**2015**). "Passive Acoustic Monitoring for Marine Mammals in the Gulf of Alaska Temporary Maritime Activities Area 2014-2015.," (Marine Physical Laboratory, Scripps Institution of Oceanography, La Jolla, CA), p. 58.

Rice, A. C., Solsona-Berga, A., Posdaljian, N., Rafter, M., Thayre, B. J., Trickey, J. A., Wiggins, S. M., Baumann-Pickering, S., Širović, A., and Hildebrand, J. A. (**2018**). "Passive Acoustic Monitoring for Marine Mammals in the Gulf of Alaska Temporary Maritime Activities Area May to September 2015 and April to September 2017," (Marine Physical Laboratory, Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, MPL Technical Memorandum #627 under Cooperative Ecosystems Study Unit Cooperative Agreement N62473-17-2-0014 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," Journal of the Acoustical Society of America **130**, 2212-2223.

Roch, M. A., Klinch, H., Baumann-Pickering, S., Mellinger, D. K., Qui, S., Soldevilla, M. S., and Hildebrand, J. A. (**2011b**). "Classification of echolocation clicks from odontocetes in the Southern California Bight," Journal of the Acoustical Society of America **129**, 467-475.

Samarra, F. I. P., Deecke, V. B., Vinding, K., Rasmussen, M. H., Swift, R. J., and Miller, P. J. O. (**2010**). "Killer whales (*Orcinus orca*) produce ultrasonic whistles," J Acoust Soc Am **128**, EL205-210.

Scarff, J. E. (**1986**). "Historic and present distribution of the right whale (*Eubalaena glacialis*) in the eastern North Pacific south of 50N and east of 180W," Report of the International Whaling Commission, 43-63.

Širović, A., Hildebrand, J. A., Wiggins, S. M., McDonald, M. A., Moore, S. E., and Thiele, D. (**2004**). "Seasonality of blue and fin whale calls and the influence of sea ice in the Western Antarctic Peninsula," Deep Sea Research Part II - Topical Studies in Oceanography **51**, 2327-2344.

Širović, A., Rice, A., Chou, E., Hildebrand, J. A., Wiggins, S. M., and Roch, M. A. (**2015**). "Seven years of blue and fin whale call abundance in the Southern California Bight," Endangered Species Research **28**, 61-76.

Širović, A., Williams, L., Kerosky, S. M., Wiggins, S. M., and Hildebrand, J. A. (**2013**). "Temporal separation of two fin whale call types across the eastern North Pacific," Marine Biology **160**, 47-57.

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

Stimpert, A. K., Au, W. W. L., Parks, S. E., Hurst, T., and Wiley, D. N. (**2011**). "Common humpback whale (*Megaptera novaeangliae*) sound types for passive acoustic monitoring," Journal of the Acoustical Society of America **129**, 476-482.

Thompson, P. O., Findley, L. T., and Vidal, O. (**1992**). "20-Hz pulses and other vocalizations of fin whales, *Balaenoptera physalus*, in the Gulf of California, Mexico," Journal of the Acoustical Society of America **92**, 3051-3057.

Walker, W. A., and Hanson, M. B. (**1999**). "Biological observations on Stejneger's beaked whale, *Mesoplodon stejnegeri*, from strandings on Adak Island, Alaska," Marine Mammal Science **15**, 1314-1329.

Watkins, W. A. (**1981**). "Activities and underwater sounds of fin whales," Scientific Reports of the Whale Research Institute **33**, 83-117.

Watkins, W. A., and Schevill, W. E. (**1977**). "Sperm whale codas," Journal of the Acoustical Society of America **62**, 1485-1490.

Watwood, S., Miller, P. J. O., Johnson, M., Madsen, P. T., and Tyack, P. L. (**2006**). "Deep-diving behaviour of sperm whales (*Physeter macrocephalus*)," Journal of Animal Ecology **75**, 814-825.

Wenz, G. M. (**1962**). "Acoustic ambient noise in the ocean: Spectra and sources," Journal of the Acoustical Society of America **34**, 1936-1956.

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., Hall, J. M., Thayre, B. J., and Hildebrand, J. A. (**2016**). "Gulf of Mexico low-frequency ocean soundscape impacted by airguns," Journal of the Acoustical Society of America **140**, 176-183.

Wiggins, S. M., and Hildebrand, J. A. (**2007**). "High-frequency acoustic recording package (HARP) for broadband, long-term marine mammal monitoring," in *International Symposium on Underwater Technology 2007 and International Workshop on Scientific Use of Submarine Cables and Related Technologies 2007* (Institute of Electrical and Electronics Engineers, Tokyo, Japan), pp. 551-557.

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