Marine Physical Laboratory of the Scripps Institution of Oceanography University of California, San Diego

SCRIPPS Whale Acoustics

Passive Acoustic Monitoring for Marine Mammals in the Gulf of Alaska Temporary Maritime Activities Area 2013-2014

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Gray Whale, photo by Amanda J. Debich

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Executive Summary

Passive acoustic monitoring was conducted in the Gulf of Alaska Temporary Maritime Activities Area (GATMAA) from June 2013 to May 2014 to detect marine mammal and anthropogenic sounds. High-frequency Acoustic Recording Packages (HARPs) recorded sounds between 10 Hz and 100 kHz at five locations: a shelf site offshore Kenai Peninsula (200 m depth, site CA), a continental slope site in deep water (850 m depth, site CB), a slope site offshore Kodiak Island (230 m depth, site KO), a deep offshore site at Pratt Seamount (1000 m depth, site PT), and a deep offshore site at Quinn Seamount (930 m depth, site QN).

Data analysis consisted of detecting sounds by analyst 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 vocalizations and anthropogenic sounds.

Five baleen whale species were recorded: blue whales, fin whales, gray whales, humpback whales, and North Pacific right whales. Across all sites, fin whales and humpback whales were the most commonly detected baleen whales throughout the recordings. Blue whale D calls and Central Pacific tonal calls peaked in summer months, while blue whale Northeast Pacific B calls and fin 20 Hz calls peaked later in fall months. Fin whale 40 Hz calls peaked in summer months at sites CB, PT, and QN whereas these calls peaked in fall months at sites CA and KO. Gray whale M3 calls were detected in small numbers at sites CA and KO, primarily during September 2013. Humpback whale calling peaked in late-November through December 2013, and again in February 2014. North Pacific right whale upcalls were detected at site QN in summer 2013.

Signals from at least 8 known odontocete species were recorded: Risso’s dolphins, Pacific white-sided dolphins, killer whales, sperm whales, Baird’s beaked whales, Cuvier’s beaked whales, Stejneger’s beaked whales, and unidentified porpoise. No signals from dwarf or pygmy sperm whales were detected. Risso’s dolphins were detected in low numbers at sites CA and KO. Site PT was the only site at which Pacific white-sided dolphins were detected. Killer whales and sperm whales were common at every site. Unidentified porpoise echolocation clicks were detected at each site except for QN. Baird’s, Cuvier’s, and Stejneger’s beaked whales were detected at sites CB, PT, and QN, with peaks in detections occurring in winter and early spring months. Baird’s beaked whale was the most commonly detected beaked whale.

Several anthropogenic sounds were detected in the recordings: broadband ship noise, echosounders, low-frequency active (LFA) sonar, and explosions. Broadband ships were detected at all sites, though site CA had the least amount of detections. Echosounders were detected in low numbers at sites CA, CB, KO, and QN. Low Frequency Active (LFA) sonar was detected in June and July 2013 at site QN. No mid-frequency active (MFA) sonar events were detected throughout the recordings. Most explosion detections occurred during summer months at sites CB, KO, PT, and QN and at site CA during late-October 2013.

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 owing to 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 include blue (*Balaenoptera musculus*), fin (*B. physalus*), humpback (*Megaptera novaeangliae*), North Pacific right (*Eubalaena japonica*), and sperm whales (*Physeter macrocephalus*). The 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 a recent visual sighting, a North Pacific Right Whale Critical Habitat was defined on the shelf along the southeastern coast of Kodiak Island, bordering the GATMAA.

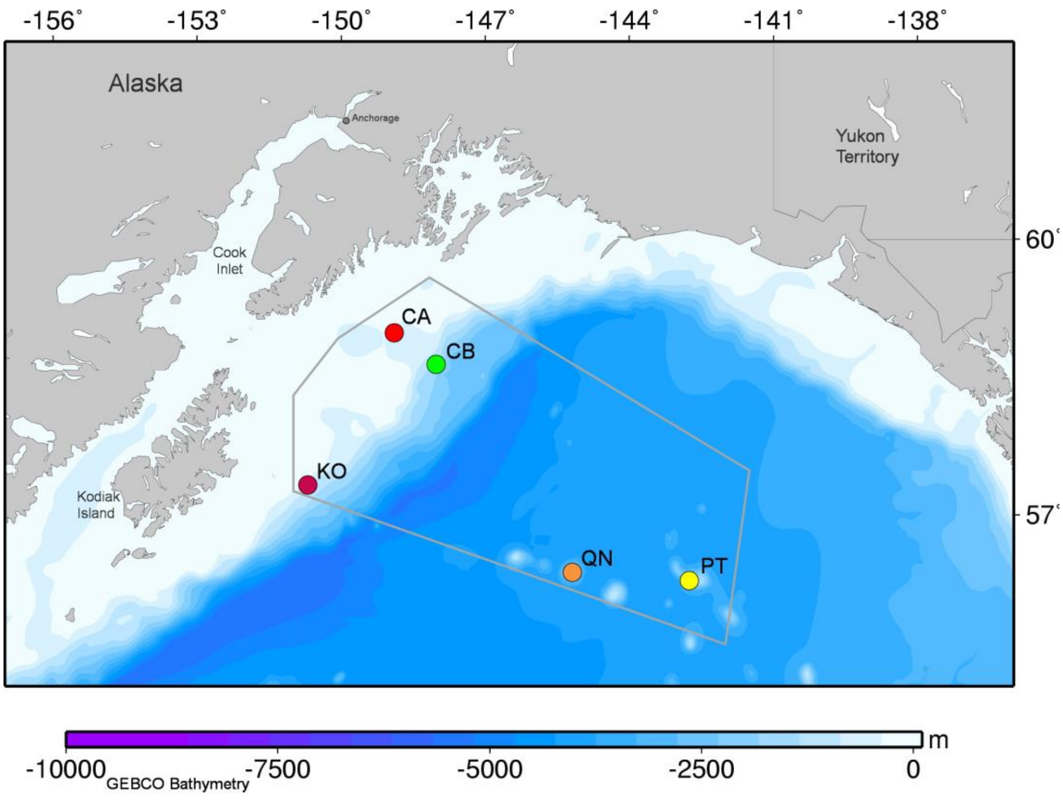

Figure 1. High-frequency Acoustic Recording Packages sites (CA, CB, KO, PT, and QN) in the GATMAA (gray line) from June 2013 through May 2014. Color bar for bathymetric depth.

In July 2011, an acoustic monitoring effort was initiated at two sites 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 vocalizations of marine mammal species present in the area, to determine their seasonal patterns, and to evaluate the potential for impact from naval operations. A new monitoring site was added to this effort in 2012, and in 2013, two more were added. This report documents the analysis of data recorded by five High-frequency Acoustic Recording Packages (HARPs) that were deployed within the GATMAA in June 2013 and collected data through May 2014 (Figure 1). The five sites include a shallow shelf site offshore Kenai Peninsula (site CA), a continental slope site in deep water (site CB), a slope site off Kodiak Island (site KO), a deep offshore site at Pratt Seamount (site PT), and a deep offshore site at Quinn Seamount (site QN) (Table 1).

Table 1. Locations for HARP deployment sites in GAATMA.

Site	Latitude	Longitude	Depth
CA	59° 0.61 N	148° 53.96 W	200 m
CB	58° 40.31 N	148° 01.31 W	850 m
KO	57° 20.14 N	150° 41.99 W	230 m
PT	56° 14.58 N	142° 45.41 W	1000 m
QN	56° 20.36 N	145° 11.24 W	930 m

Methods

High-frequency Acoustic Recording Package (HARP)

HARPs were used to detect marine mammal sounds and characterize anthropogenic sounds and ambient noise in the GATMAA. HARPs can record underwater sounds from 10 Hz up to 160 kHz and are capable of approximately 300 days of continuous data storage. For the GATMAA deployments, the HARPs were in a seafloor mooring configuration with the hydrophones suspended between 10 and 30 m above the seafloor. Each HARP 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 TRANSDEC facility to verify the laboratory calibrations (Wiggins & 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 sampled at 320 kHz. A total of 33,706 hours, covering 1404 days of acoustic data were recorded in the deployments analyzed in this report.

Table 2. GATMAA acoustic monitoring since July 2011. Periods of deployment analyzed in this report are shown in bold. Results through early 2013 are described in Baumann-Pickering *et al*. (2012) and Debich *et al*. (2013).

Designation	Deployment Period	Duration (days)	Duration (hours)	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**

Data Quality

Data acquisition and quality was impacted by two factors: failure of storage media, and noise related to tidal flow. A gap in data acquisition occurred at site CA from 6/17/2013 – 9/5/2013, and at site KO from 6/28/2013 – 9/7/2013. In both cases, the gap was likely caused by failure of storage media within the data logger. Data quality is reduced in the presence of strong tidal currents that can result in low frequency flow noise, as well as high frequency strumming of the hydrophone cable. This was especially prevalent at shallow sites KO (230m depth) and CA (200m depth) that are located on the continental shelf, the location of strong tidal currents.

Ambient noise spectra were calculated on a 1/3 duty cycle. For the purpose of calculating ambient noise levels, periods of strumming/tidal flow were detected automatically. If strumming was detected, those periods were omitted before the 1/3 duty cycle was imposed. The monthly recording durations, presence of strumming, and the number of days used for calculating ambient noise spectra are provided for sites CA, KO, and QN (Table 3, Table 4, and Table 5). Strumming at sites PT, and CB was minimal, and did not mask ambient levels.

Table 3. Monthly recording durations, presence of strumming, and number of days used for calculating ambient noise spectra at site CA.

Month/Year	Recording Duration in days	Strumming in days (percent)	Spectra Calculation in days
June 2013	11.44	6.54 (57.2%)	1.67
September 2013	25.26	16.62 (65.8%)	2.79
October 2013	31	20.31 (65.5%)	3.56
November 2013	30	16.48 (54.9%)	4.51
December 2013	31	16.77 (54.1%)	4.74
January 2013	31	24.64 (79.5%)	2.12
February 2013	28	16.06 (57.4%)	3.98
March 2013	31	18.94 (61.1%)	4.02
April 2013	10.04	6.91 (68.82%)	1.04

Table 4. Monthly recording durations, presence of strumming, and number of days used for calculating ambient noise spectra at site KO.

Month/Year	Recording Duration in days	Strumming in days (percent)	Spectra Calculation in days
June 2013	18.09	9.27 (51.2%)	2.94
September 2013	22.99	14.1 (61.3%)	2.88
October 2013	31	12.24 (39.5%)	6
November 2013	30	11.62 (38.7%)	6.13
December 2013	31	12.59 (40.6%)	6.14
January 2013	31	20.05 (64.7%)	3.65
February 2013	28	15.97 (57.0%)	4.01
March 2013	31	17.63 (56.9%)	4.46
April 2013	12.28	6.74 (54.9%)	1.85

Table 5. Monthly recording durations, presence of strumming, and number of days used for calculating ambient noise spectra at site QN.

Month/Year	Recording Duration in days	Strumming in days (percent)	Spectra Calculation in days
June 2013	20.98	0.3 (1.4%)	6.99
July 2013	31	0.81 (2.6%)	10.36
August 2013	31	3.09 (10.0%)	9.6
September 2013	30	0.09 (0.3%)	9.97
October 2013	31	3 (9.7%)	9.34
November 2013	30	2.52 (8.4%)	9.16
December 2013	31	1.56 (5.0%)	9.81
January 2013	31	4.23 (13.6%)	8.92
February 2013	28	3.6 (12.9%)	8.13
March 2013	31	3.45 (11.1%)	9.18
April 2013	15.99	1.98 (12.4%)	4.67

Data Analysis

To visualize the acoustic data, frequency spectra were calculated for all data using a time average of 5 seconds and variable size frequency bins (1, 10, and 100 Hz). These data, called Long-Term Spectral Averages (LTSAs) were then examined as a means to detect 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 or spectrogram was examined to further classify the sounds to species or source. Signal classification was carried out by comparison to known species-specific spectral and temporal characteristics.

Recording over a broad frequency range of 10 Hz - 100 kHz allows detection of baleen whales (mysticetes), toothed whales (odontocetes), and anthropogenic sounds. The presence of acoustic signals from multiple marine mammal species and anthropogenic noise was evaluated in the data. 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 10-300 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 whale sounds were classified as low-frequency. Humpback, minke, killer whale tonal and pulsed calls, nearby shipping, explosions, underwater communications, and mid-frequency active sonar sounds were classified as mid-frequency. The remaining odontocete and sonar sounds were considered high-frequency. For the analysis of the 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 5s 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 acoustic data collected between June 2013 and May 2014 at sites CA, CB, KO, PT, and QN. We discuss seasonal occurrence and relative abundance of calls for different species and anthropogenic sounds that were consistently identified in the acoustic data.

Low-Frequency Marine Mammals
The Gulf of Alaska is inhabited, at least for a portion of the year, by blue whales, fin whales, gray whales, and North Pacific right whales. For the low-frequency data analysis, the 200 kHz sampled raw data were decimated by a factor of 100 for an effective bandwidth of 1 kHz. Long-term spectral averages (LTSAs) were created using a time average of 5 seconds and frequency bins of 1 Hz. The same LTSA and spectrogram parameters were used for manual detection of all call types using the custom software program *Triton*. During manual scrutiny of the data, 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 1-250 Hz with a 60 second plot length. The FFT was generally set between 1500 and 2000 data points, yielding about 1 Hz frequency resolution, with an 85-95% overlap. When a call of interest was identified in the LTSA or spectrogram, its presence during that hour was logged.

The hourly presence of Northeast Pacific blue whale D and 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. Blue whale B calls were detected manually for both CA deployments, as well as CB03, KO01, and were detected automatically using computer algorithms described below for deployments CB04, KO02, and both PT and QN deployments. Fin whale 20 Hz pulses were detected manually for site CA due to instrument noise. Fin whale 20 Hz calls were detected automatically using an energy detection method for all other sites.

Blue Whales

Blue whales produce a variety of calls worldwide (McDonald *et al*., 2006). 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*., 2006; Oleson *et al*., 2007). They are low-frequency (fundamental 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 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 were detected via manual scanning of the LTSA for both CA deployments, as well as CB03, and KO01. Blue whale B calls were detected automatically for all other deployments using the spectrogram correlation method (Mellinger & Clark, 1997). The kernel was based on frequency and temporal characteristics measured from 30 calls recorded in the data set, each call separated by at least 24 hours. The kernel was comprised of four segments, three 1.5 s and one 5.5 s long, for a total duration of 10 s. Separate kernels were measured for summer and fall periods. The summer 2013 kernel was thus defined as sweeping from 48.4 to 47.7 Hz, 47.7 to 47.1 Hz, 47.1 to 46.8 Hz, and 46.8 to 45.7 Hz during these predefined periods. The fall 2013 kernel was defined as 47.5 to 47.1 Hz; 47.1 to 46.6 Hz, 46.6 to 46.3 Hz, and 46.3 to 45.7 Hz. The kernel bandwidth was 2 Hz.

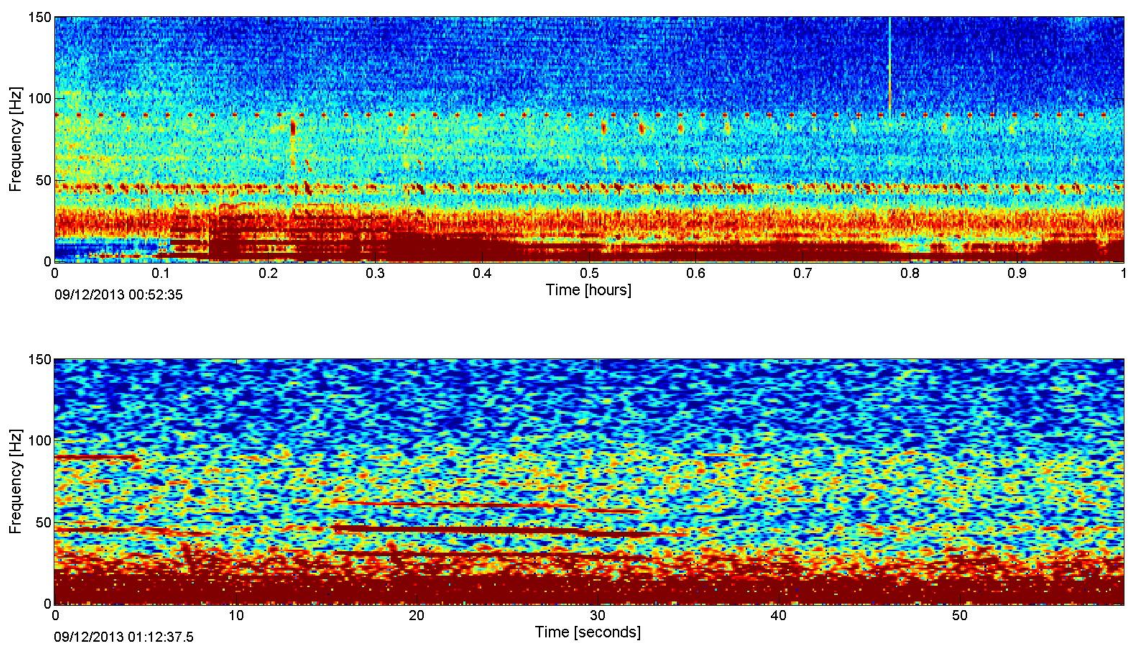

Figure 2. Northeast Pacific blue whale B call in LTSA (top) and spectrogram (bottom) at site QN.

Central Pacific tonal blue whale calls

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

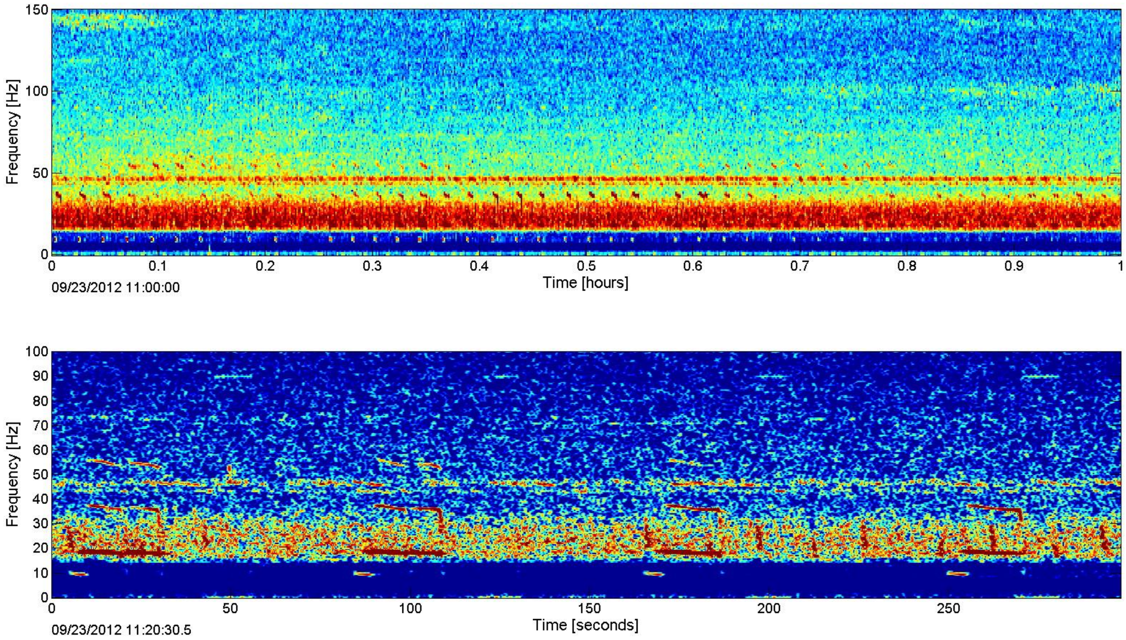

Figure 3. Central Pacific tonal calls with harmonics in the LTSA (top) and spectrogram (bottom) at site PT.

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 at each site.

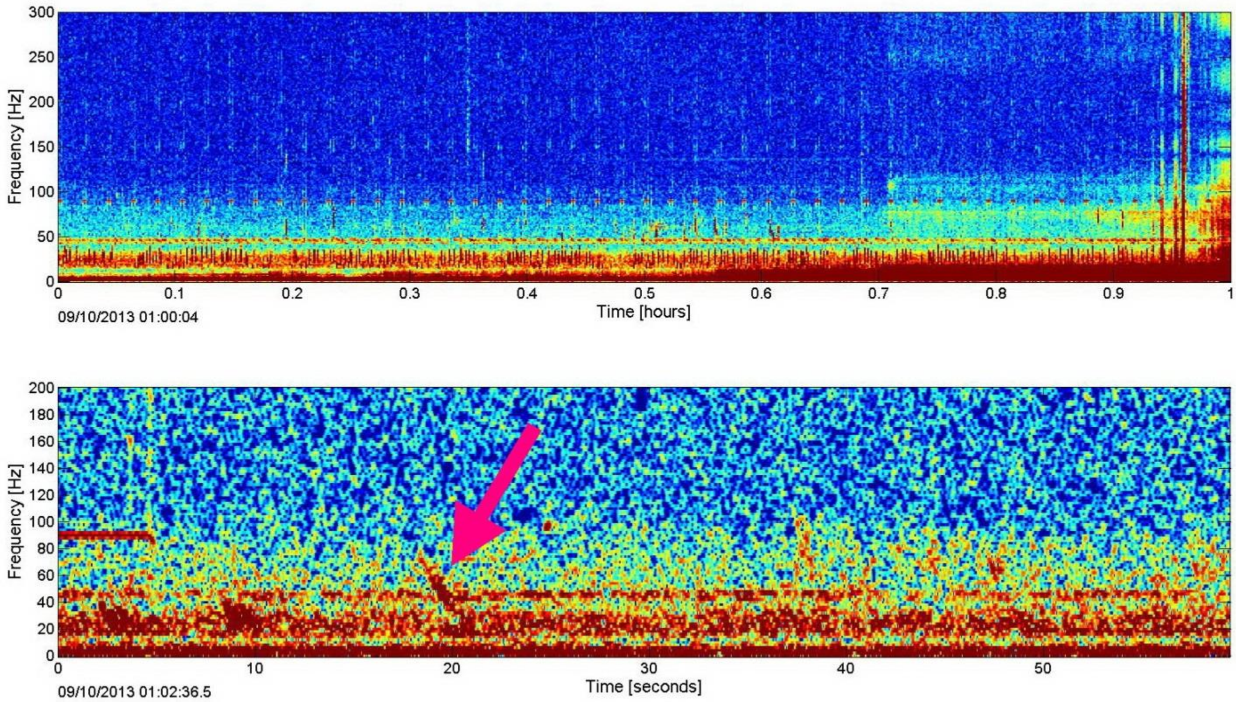

Figure 4. Blue whale D call in the LTSA (top) and spectrogram (bottom) at site KO.

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 were detected automatically using an energy detection method. The method used a difference in acoustic energy between signal and noise, calculated from 5 s LTSA with 1 Hz resolution. The frequency at 22 Hz was used as the signal frequency, while noise was calculated as the average energy between 10 and 34 Hz. All calculations were performed on a logarithmic scale.

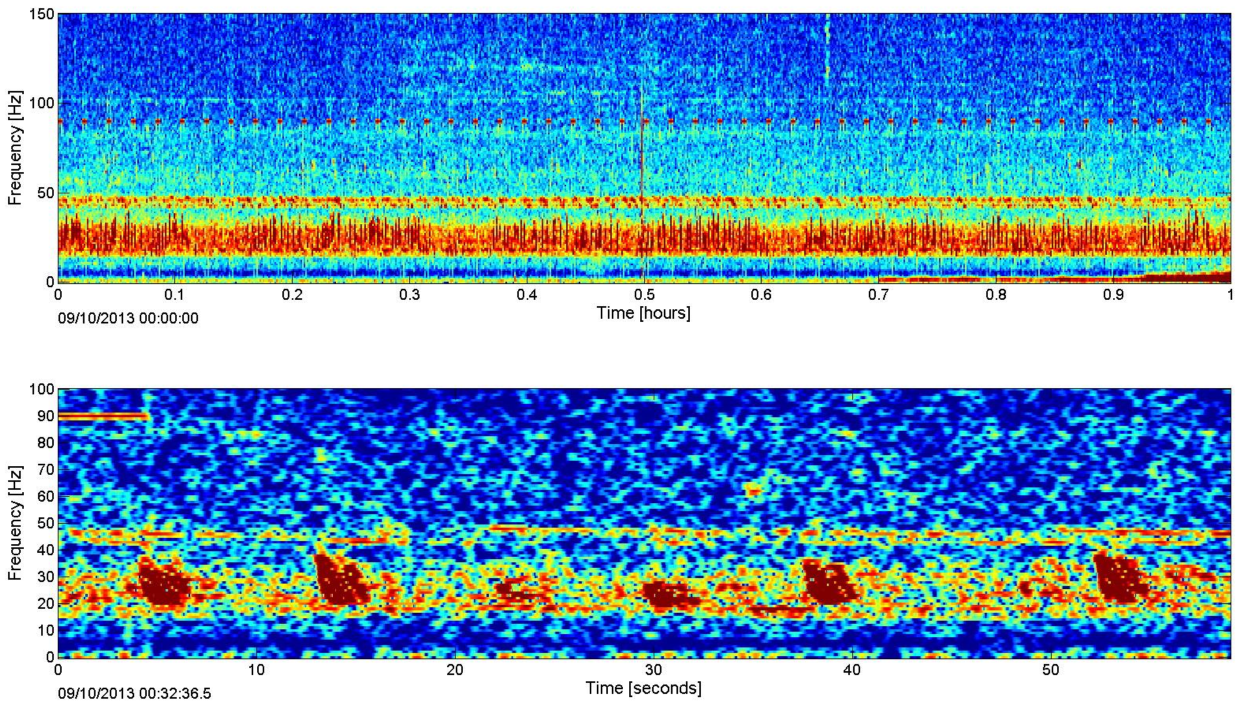

Figure 5. Fin whale 20 Hz calls in the LTSA (top) and spectrogram (bottom) at site KO.

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.

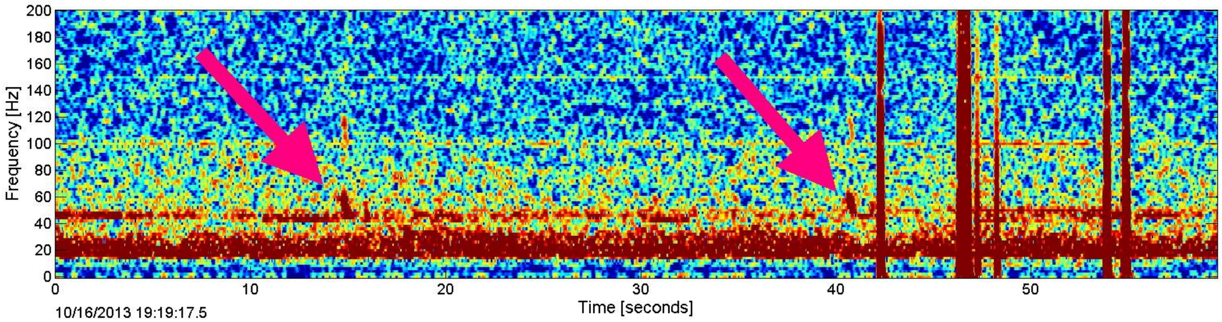

Figure 6. Fin whale 40 Hz calls in the spectrogram at site CB.

Gray Whales

Gray whales produce a variety of calls, which 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 the most common call produced by migrating gray whales (Crane & Lashkari, 1996).

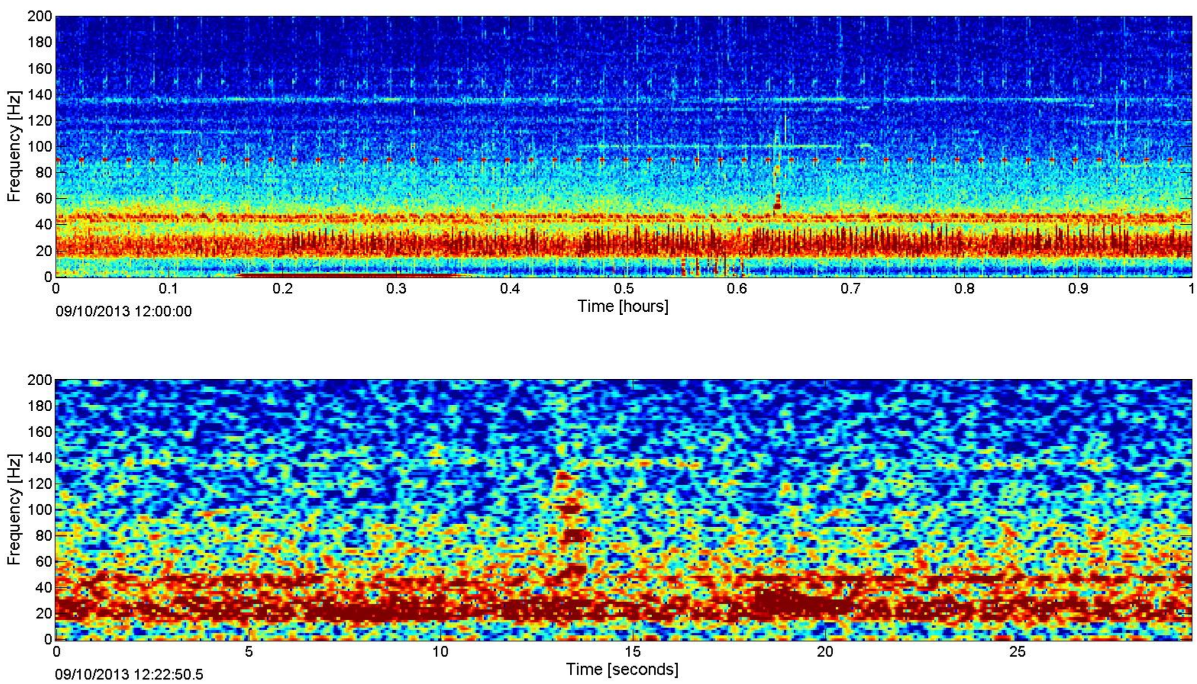

Figure 7. Gray whale M3 call in the LTSA (top) and spectrogram (bottom) at site CA.

North Pacific Right Whales

North Pacific right whales are a highly endangered species that was plentiful in the Gulf of Alaska prior to intense whaling efforts (Brownell *et al*., 2001; Scarff, 1986). 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 & Moore, 2002).

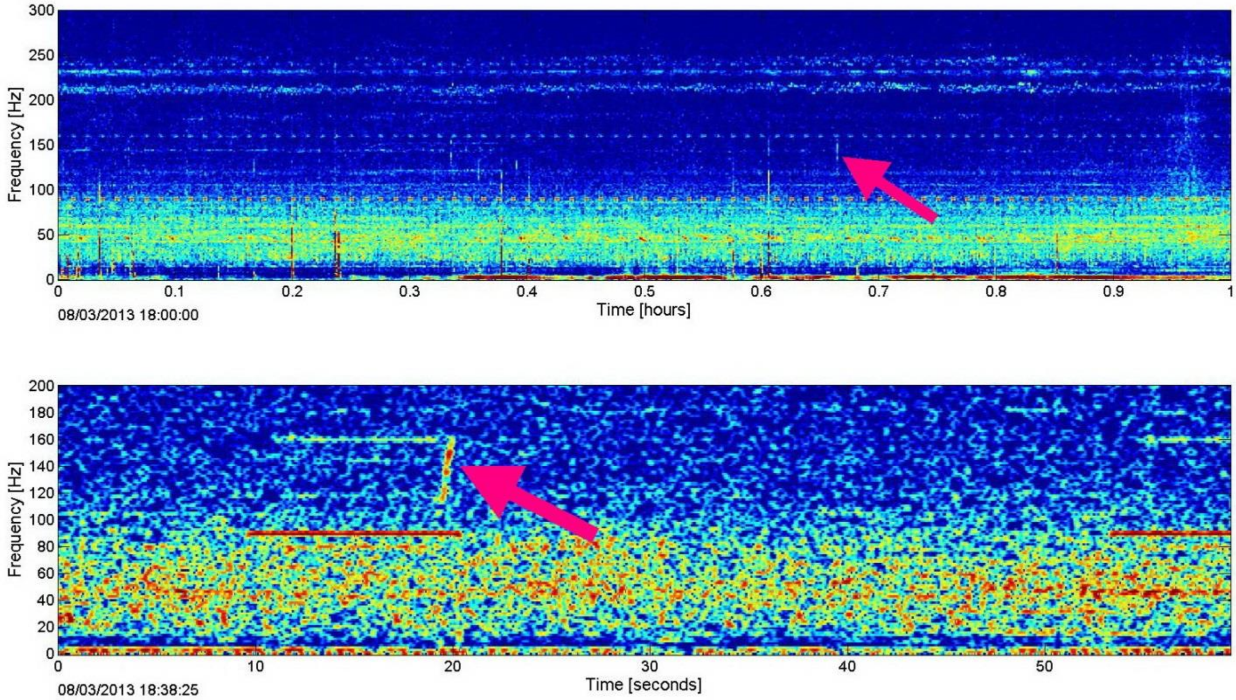

Figure 8. North Pacific right whale up call in the LTSA (top) and spectrogram (bottom) at site QN01.

Mid-Frequency Marine Mammals

Marine mammal species with sounds in the mid-frequency range expected in the Gulf of Alaska include humpback whales, minke whales (*Balaenoptera acutorostrata*), and killer whales (*Orcinus orca*). For mid-frequency data analysis, the 100 kHz data were decimated by a factor of 20 for an effective bandwidth of 5 kHz. The LTSAs for mid-frequency analysis were created using a time average of 5 seconds, and a frequency bin size of 10 Hz. The presence of each call type was determined using an "encounter" granularity, to one-minute precision, for each mid-frequency dataset. Humpback whales were detected automatically as described in the section below. Minke whale boings were logged manually for deployments CA03, CB03, KO01, PT02, and QNO01 and for deployments CA04, CB04, KO02, PT03, and QN02 an automatic detection algorithm based on the generalized power law was used (Helble *et al*., 2012). The detections were subsequently verified for accuracy by a trained analyst. Killer whale whistles were logged manually for all deployments. The LTSA parameters used to manually search for each signal are given in Table 6.

Table 6. Mid-frequency data analysis parameters.

Species / Sound Type	LTSA Search Parameters	
	Plot Length (hr)	Frequency Range (Hz)
minke whale boing	0.5	1,000 – 2,000
killer whale whistles	0.75	10 – 5,000

Humpback Whales

Humpback whales produce both song and non-song calls. 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. We detected humpback calls using an automatic detection algorithm based on the generalized power law (Helble *et al*., 2012). The detections were subsequently verified for accuracy by a trained analyst (Figure 9). There was no effort to separate song and non-song calls.

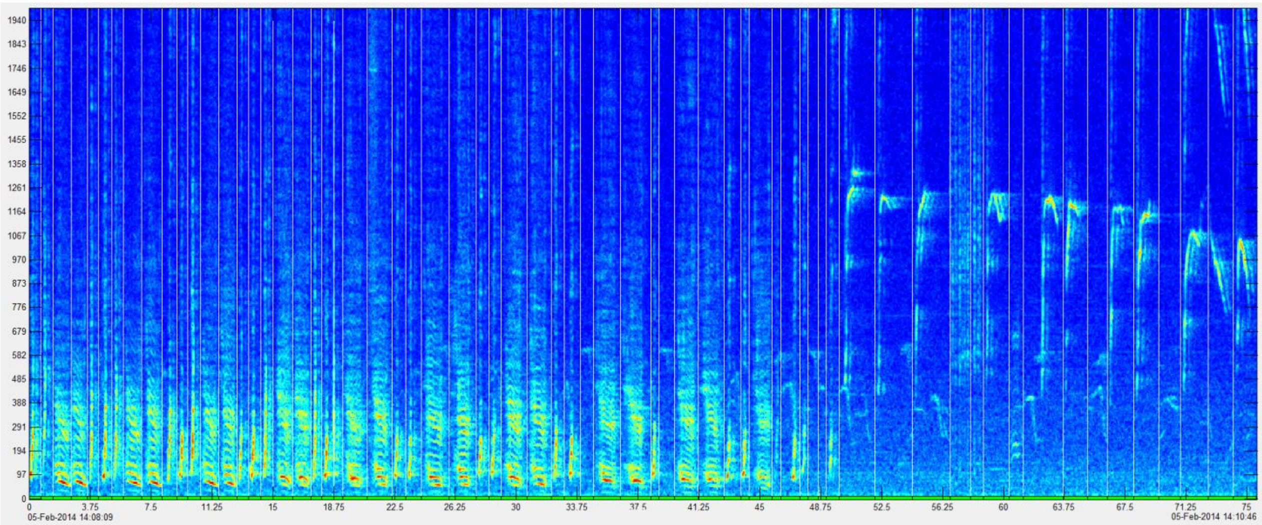

Figure 9. Humpback whale song from site KO in the analyst verification stage of the detector.

Minke Whales

Minke whale "boings" consist of 2 parts, beginning with a burst followed by a long buzz, with the dominant energy band just below 1400 Hz (Figure 10). Boings are divided geographically into an eastern and a central Pacific variant, with a dividing line at about 135°W. Eastern boings have an average duration of 3.6 seconds and a pulse repetition rate of 92 s^{-1} (Rankin & Barlow, 2005). Boing sounds were recently reported from the Chukchi Sea, and seem to match the central Pacific boings (Delarue & Martin, 2013). No minke whale boings were detected at any of the sites analyzed for this report.

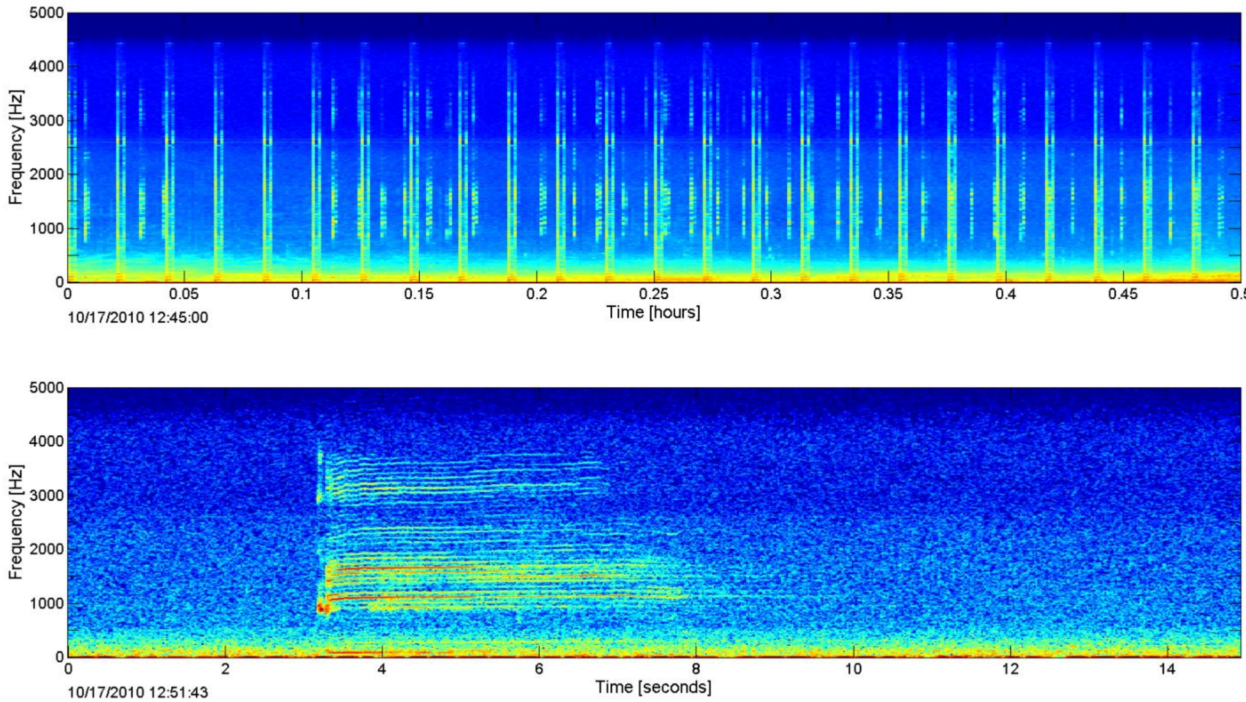

Figure 10. Minke whale boing in the LTSA (top) and spectrogram (bottom) from southern California.

Killer Whale Whistles and Pulsed Calls

Killer whale whistles were detected manually based on their non-pulsed or continuous waveform (Ford & Fisher, 1983). Most whistles contain numerous rapid frequency modulations over their duration and range in length from 50 ms to several seconds (Figure 11). Killer whale pulsed calls were also manually detected based on their abrupt and patterned shifts in repetition rate which are not present in click series (Ford *et al*., 1983). Killer whale pulsed calls are well documented and are the best described of all killer whale call types. Pulsed calls' primary energy 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).

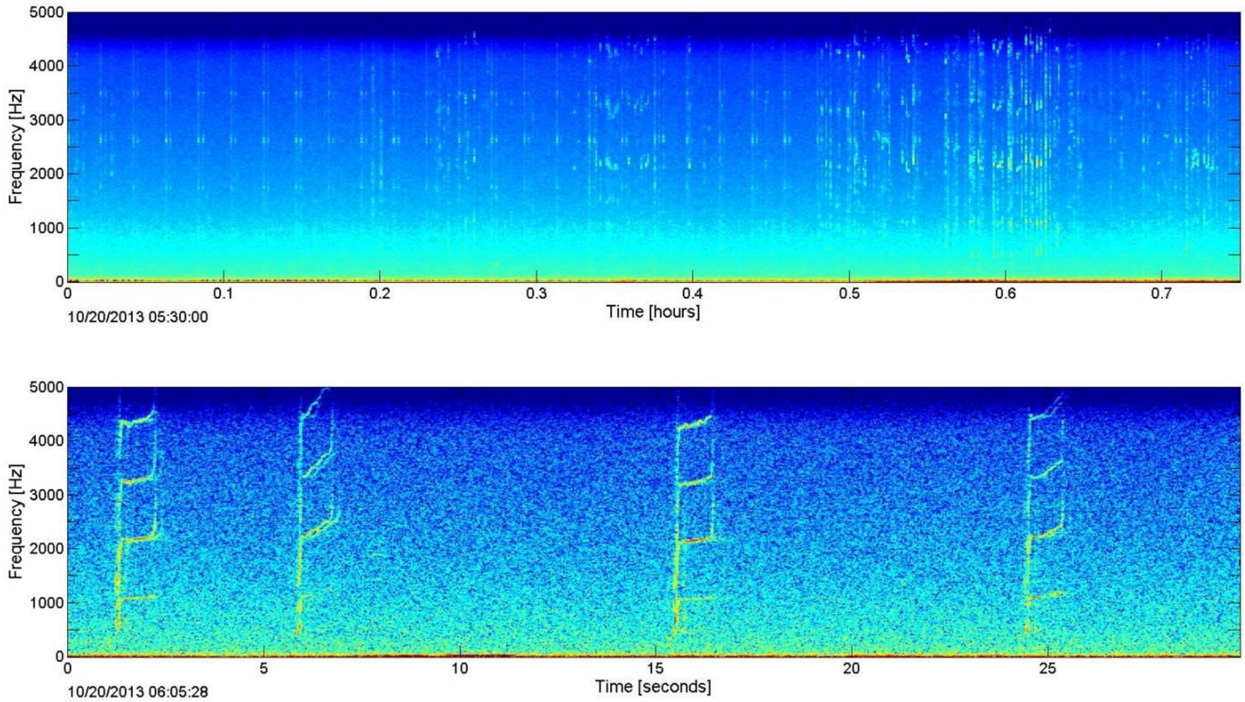

Figure 11. Killer whale whistles in the LTSA (top) and spectrogram (bottom) at site KO.

High-Frequency Marine Mammals

Marine mammal species with sounds in the high-frequency range expected in the Gulf of Alaska include Risso's dolphins (*Grampus griseus*), Pacific white-sided dolphins (*Lagenorhynchus obliquidens*), killer whales (*Orcinus orca*), sperm whales (*Physeter macrocephalus*), Baird's beaked whales (*Berardius bairdii*), Cuvier's beaked whales (*Ziphius cavirostris*), Stejneger's beaked whales (*Mesoplodon stejnegeri*), Dall's porpoise (*Phocoenoides dalli*), and harbor porpoise (*Phocoena phocoena*). For the high-frequency data analysis, spectra were calculated for the full effective bandwidth of 100 kHz. The LTSAs were created using a time average of 5 seconds and a frequency bin size of 100 Hz. The presence of call types was determined in one-minute bins.

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 12).

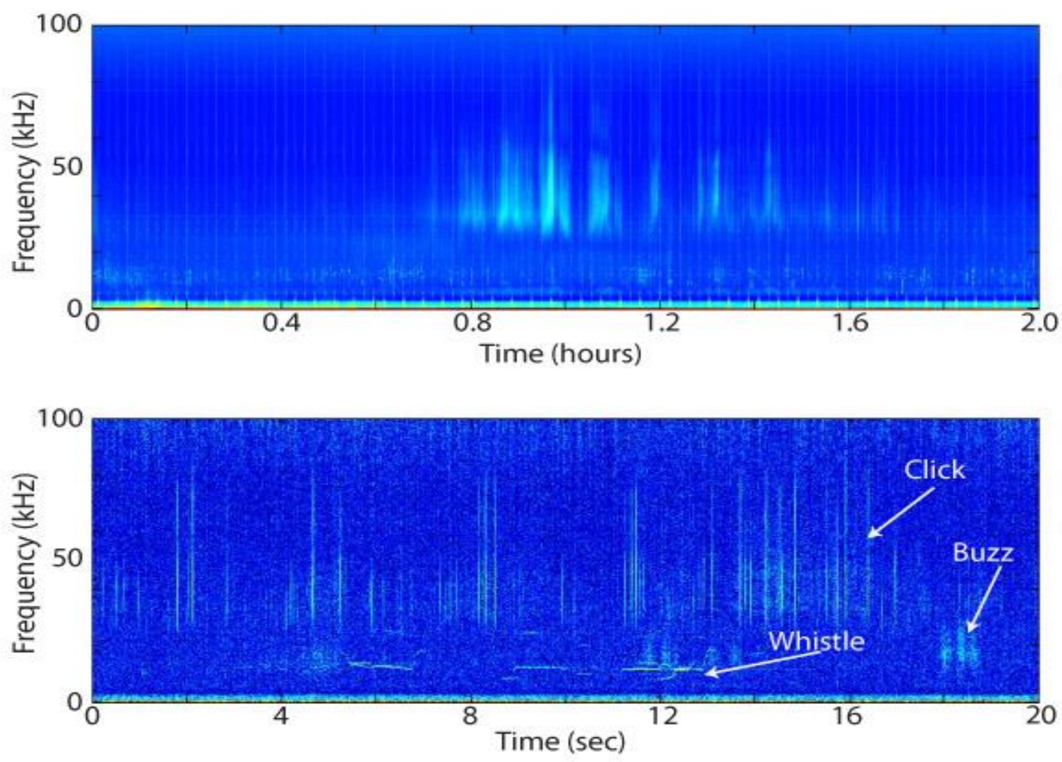

Figure 12. LTSA (top) and spectrogram (bottom) demonstrating odontocete signal types.

Unidentified Odontocetes

Some delphinid sounds are not yet distinguishable to species based on the character of their clicks, buzz or burst pulses, or whistles (Gillespie *et al*., 2013; Roch *et al*., 2011). Since these signals are easily detectable in an LTSA as well as the spectrogram (Figure 13), they were monitored during this analysis effort and are characterized as unidentified odontocete signals.

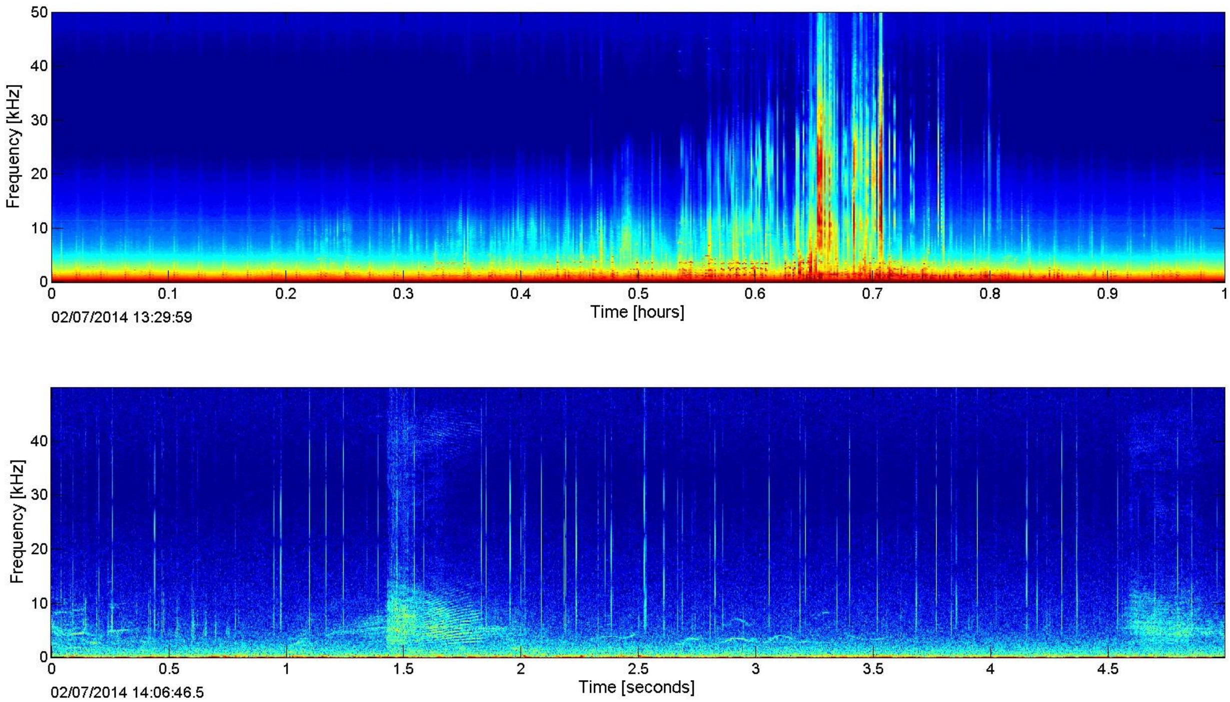

Figure 13. LTSA (top) and spectrogram (bottom) of unidentified odontocete signals at site PT.

Risso's Dolphins

Risso's dolphin echolocation clicks can be identified to species by their distinctive banding patterns observable in the LTSA (Figure 14). Risso's dolphin echolocation clicks have energy peaks at 22, 26, 30, and 39 kHz (Soldevilla *et al.*, 2008).

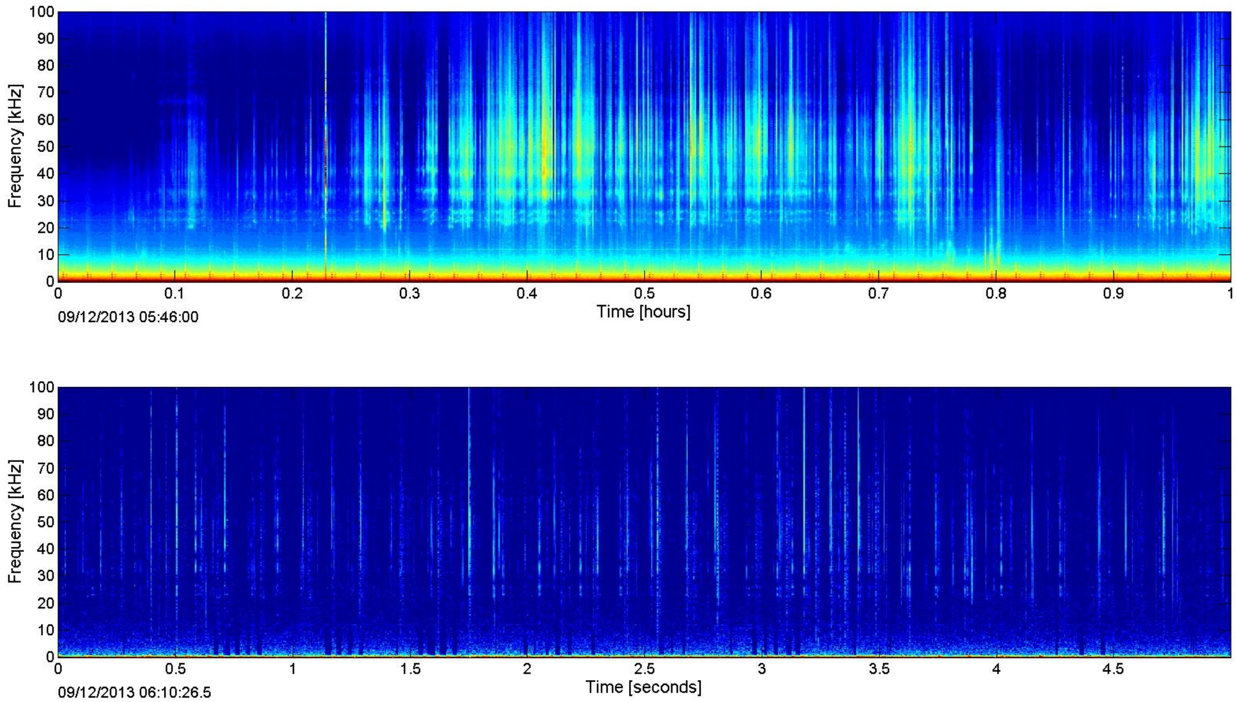

Figure 14. Risso's dolphin acoustic encounter in LTSA (top) and spectrogram (bottom) at site KO.

Pacific White-Sided Dolphins

Pacific white-sided dolphin echolocation clicks also can be identified to species by their distinctive banding patterns (Figure 15). Echolocation clicks recorded from Pacific white-sided dolphins offshore southern California have two distinctive patterns of energy peaks, designated type A and type B (Soldevilla *et al.*, 2010). The type A group occupies the northern portion of the southern California Bight, whereas both groups are known from the southern portion of the Bight. Soldevilla *et al*. (2010) hypothesize that type A signals may be produced by the California/Oregon/ Washington population while type B signals may originate from a southern Baja California population. Since these Pacific white-sided dolphin populations are thought to seasonally migrate, the type A group is more likely to be found within the GATMAA. The type A dolphins' echolocation clicks have energy peaks at 22, 27, 33, and 37 kHz (Soldevilla *et al.*, 2008).

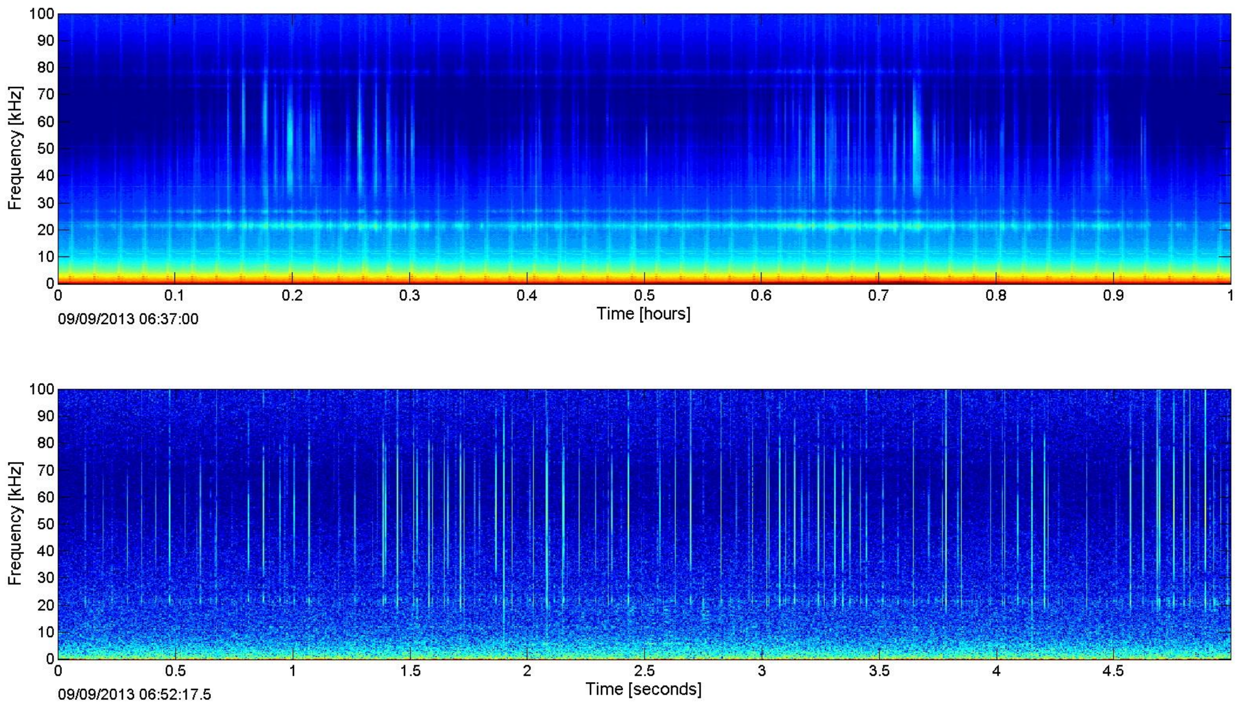

Figure 15. Pacific white-sided dolphin echolocation clicks in LTSA (top) and spectrogram (bottom) at site PT.

Killer Whales

Killer whales are known to produce two high frequency call types: echolocation clicks, and high-frequency modulated signals (HFM) (Ford, 1989; Samarra *et al*., 2010; Simonis *et al*. 2012). These are in addition to the whistles and pulsed calls, described in the mid-frequency data analysis. HFM signals have only recently been attributed to killer whales in both the Northeast Atlantic (Samarra *et al.*, 2010) and the North Pacific (Filatova *et al*., 2012; Simonis *et al*., 2012). These signals have fundamental frequencies between 17 and 75 kHz, the highest of any known delphinid tonal calls. Killer whale clicks, pulsed calls (Figure 16) and HFM signals (Figure 17) were used for killer whale species identification in this analysis.

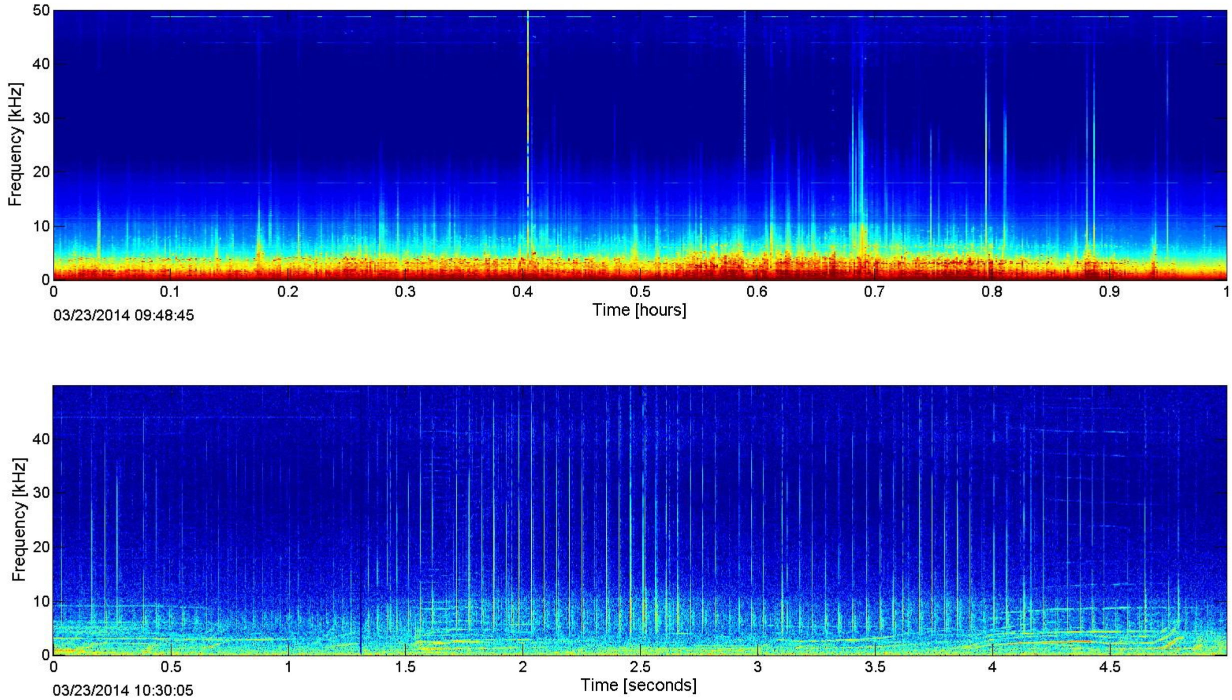

Figure 16. Killer whale pulsed calls in the LTSA (top) and spectrogram (bottom) at site CA.

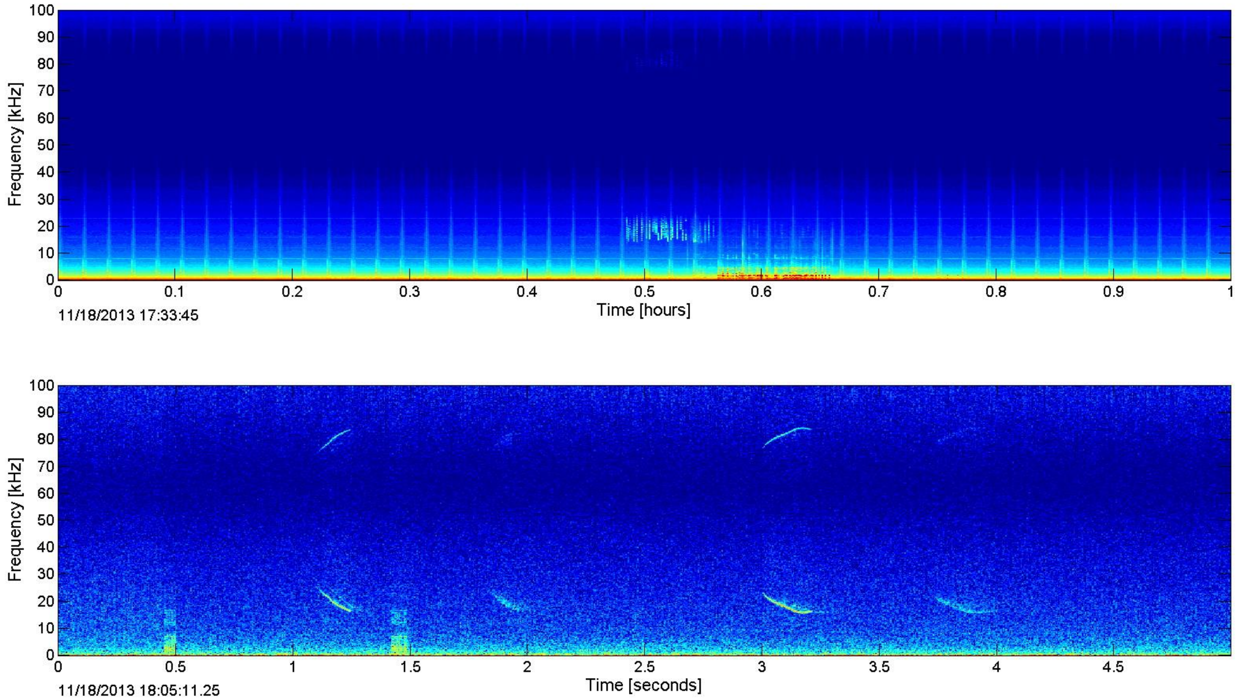

Figure 17. Killer whale HFM signals in the LTSA (top) and spectrogram (bottom) at site PT. Note mirroring of call at 75-85 kHz is an artifact of data collection.

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 18). Regular clicks, observed during foraging dives, demonstrate a uniform inter-click interval from 0.25-2 seconds (Goold & 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 long 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 & Schevill, 1977).

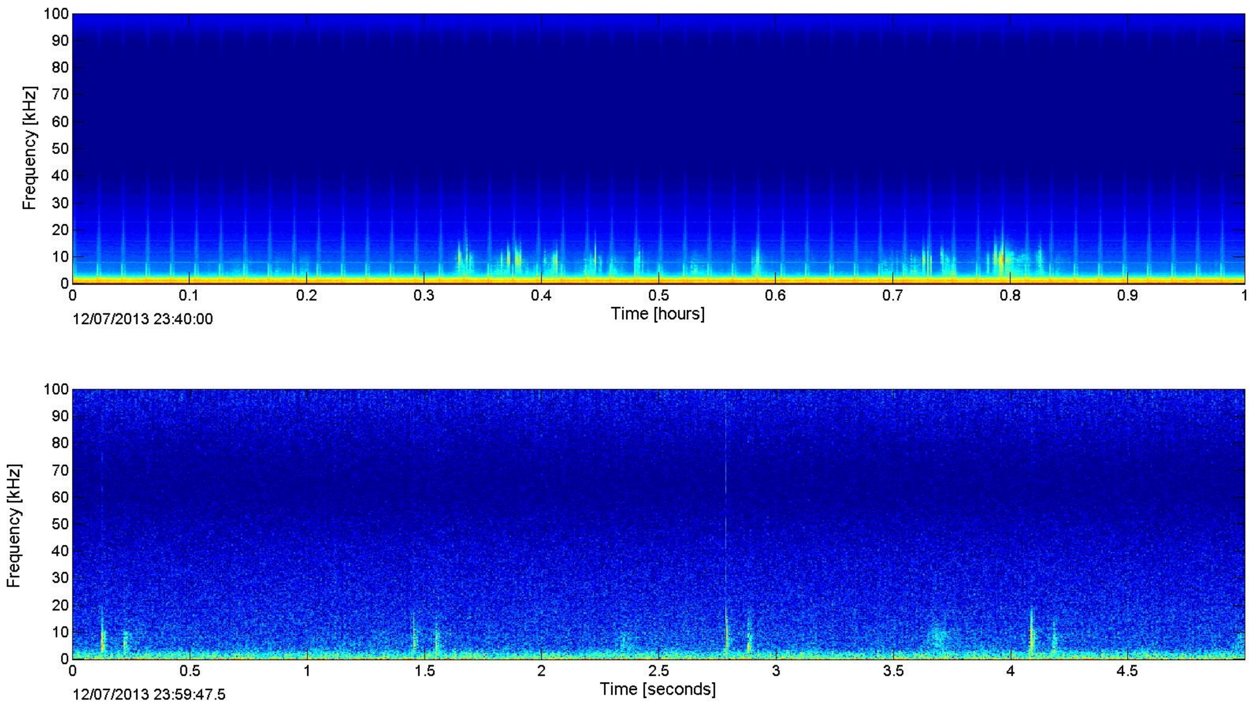

Figure 18. Sperm whale echolocation clicks in the LTSA (top) and spectrogram (bottom) at site PT.

Kogia Species

Dwarf and pygmy sperm whales emit echolocation signals with peak energy at frequencies near 130 kHz (Au, 1993). While this is above the frequency limitation of most of the recordings reported here, the lower portion of the *Kogia* click energy spectrum is within the 100 kHz bandwidth (Figure 19). However, no *Kogia* signals were detected in these recordings.

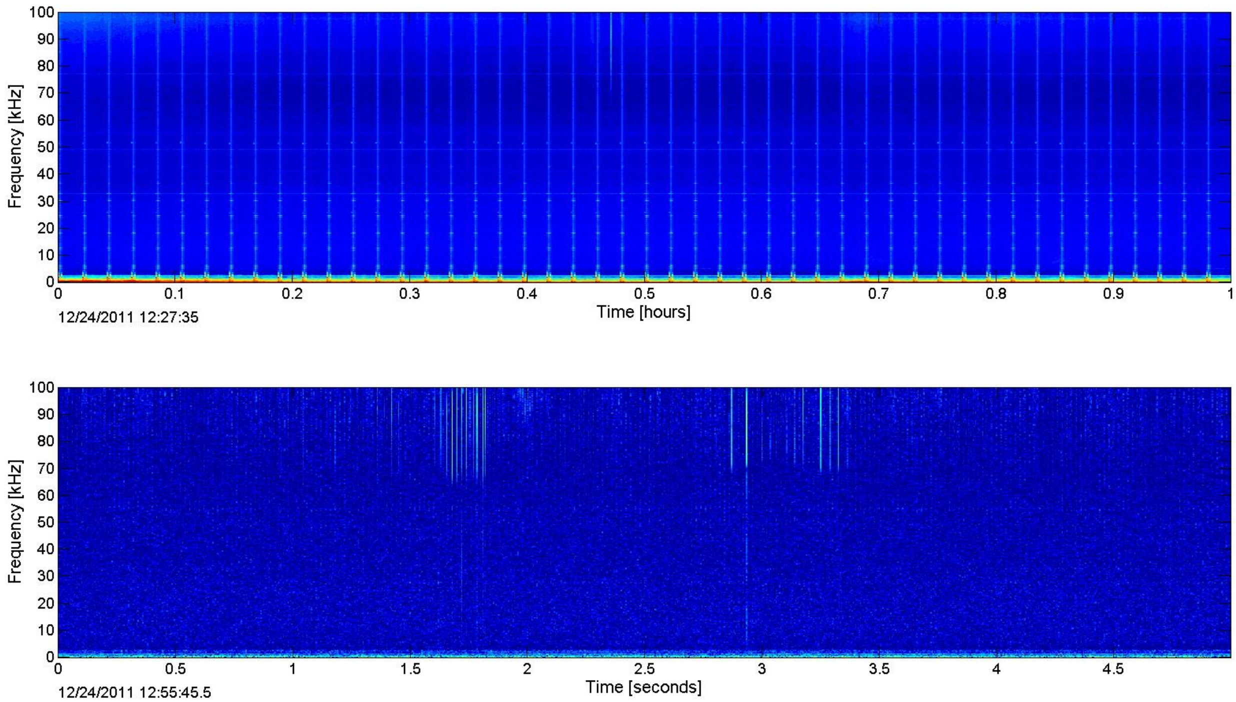

Figure 19. *Kogia spp*. echolocation clicks in the LTSA (top) and spectrogram (bottom) from a HARP recording in Southern California.

Beaked Whales

Beaked whale species expected in the Gulf of Alaska include Baird's beaked whales (*Berardius bairdii*), Cuvier's beaked whales (*Ziphius cavirostris*), and Stejneger's beaked whales (*Mesoplodon stejnegeri*) (Baumann-Pickering *et al*., 2013b). Cuvier's beaked whales and Stejneger's beaked whales were automatically detected while Baird's beaked whales were noted by manually scanning LTSAs and spectrograms. Detector effort also included FM pulses from Blainville's beaked whales (*Mesoplodon densirostris*) and Deraniyagala's beaked whales (*Mesoplodon hotaula*), as well as FM pulses produced by unknown species named BW40, BW43, BW70, and BWC.

Baird's Beaked Whales

Baird's beaked whale is the most commonly visually observed beaked whale species within their range (>30° N, North Pacific Ocean and adjacent seas), probably since they are relatively large and travel in groups of up to several dozen individuals (Allen & Angliss, 2010). Baird's beaked whale echolocation signals are distinguishable from other species' acoustic signals and, aside from dolphin-like clicks, one of their signal types demonstrates the typical beaked whale polycyclic, FM pulse upsweep (Dawson *et al*., 1998). These FM pulses and clicks are identifiable due to their comparably low-frequency content. Spectral peaks are notable around 15, 30, and 50-60 kHz (Baumann-Pickering *et al*., 2013a; Baumann-Pickering *et al*., 2013b). Unlike other beaked whales in the area, Baird's beaked whales incorporate whistles and burst pulses into their acoustic repertoire (Dawson *et al*., 1998).

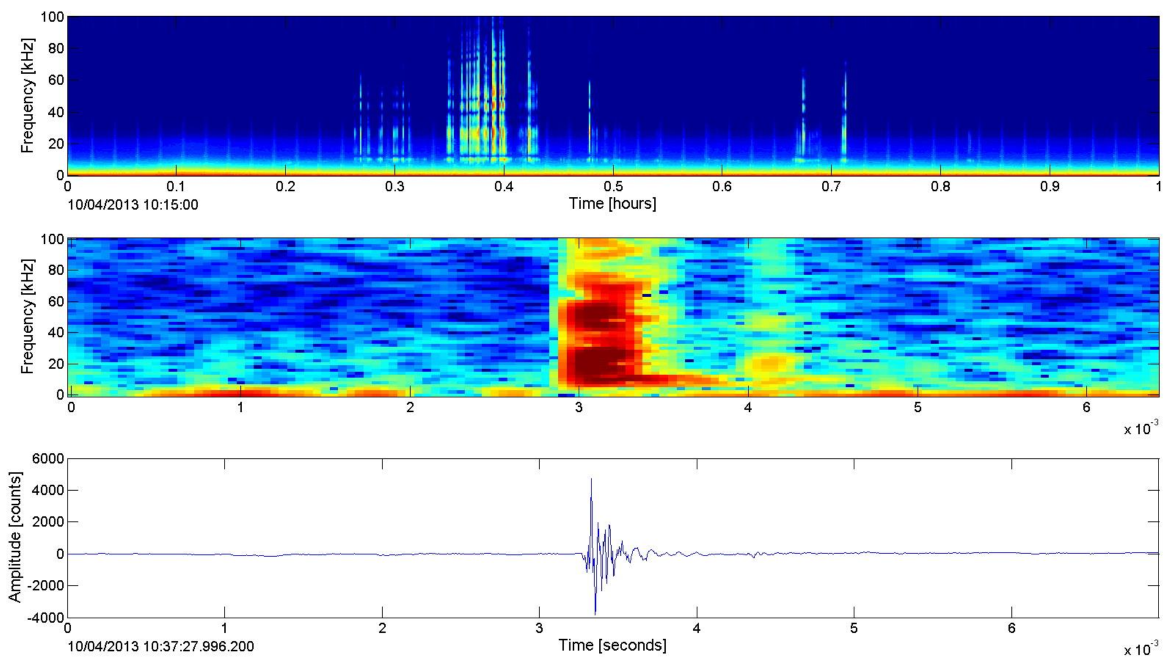

Figure 20. Echolocation sequence of Baird's beaked whale in the LTSA (top) and example FM pulse in the spectrogram (middle) and time series (bottom) at site PT. Note the typical banding pattern of spectral peaks at about 15, 30, and 50-60 kHz.

Cuvier's Beaked Whales

Cuvier's echolocation signals are also 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 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 two characteristic spectral peaks around 17 and 23 kHz (Figure 21).

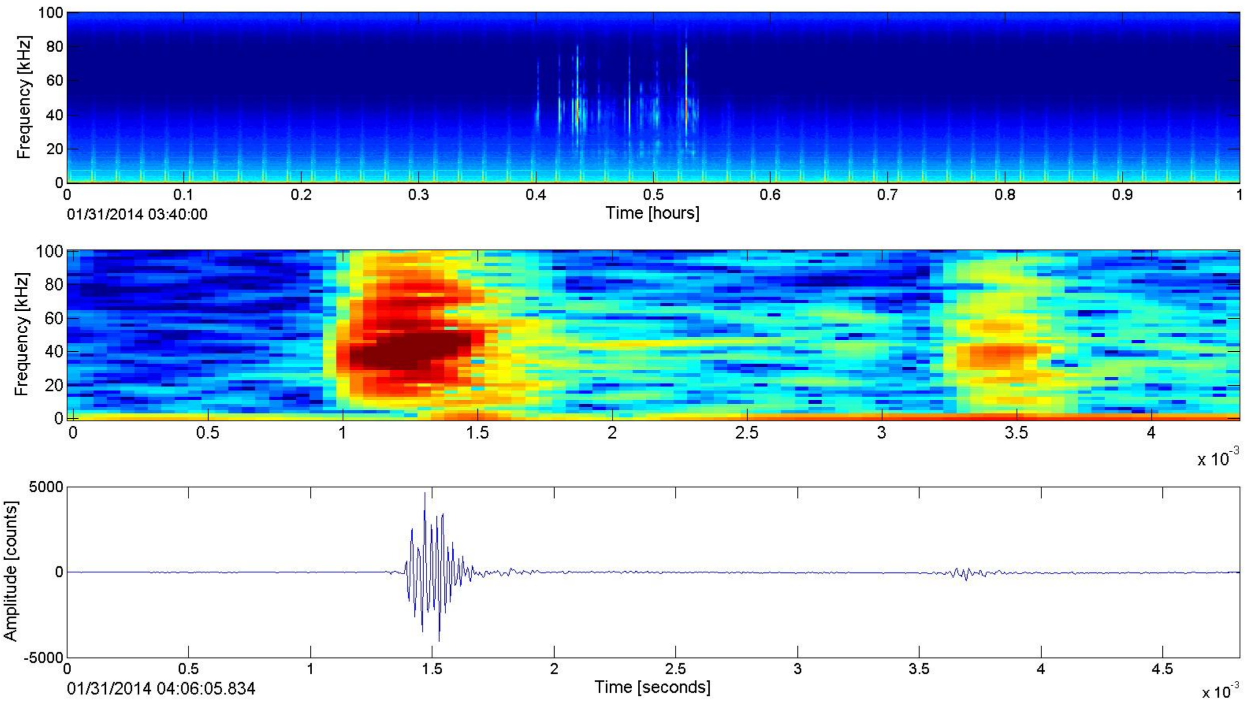

Figure 21. Echolocation sequence of Cuvier's beaked whale in the LTSA (top) and example FM pulse in the spectrogram (middle) and timeseries (bottom) at site PT.

Stejneger's Beaked Whales

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 otherwise (Loughlin *et al*., 1982; Mead, 1989; Walker & Hanson, 1999) and their distribution has been inferred from stranded animals (Allen & 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 (Figure 22) (Baumann-Pickering *et al*., 2013a; Baumann-Pickering *et al*., 2013b).

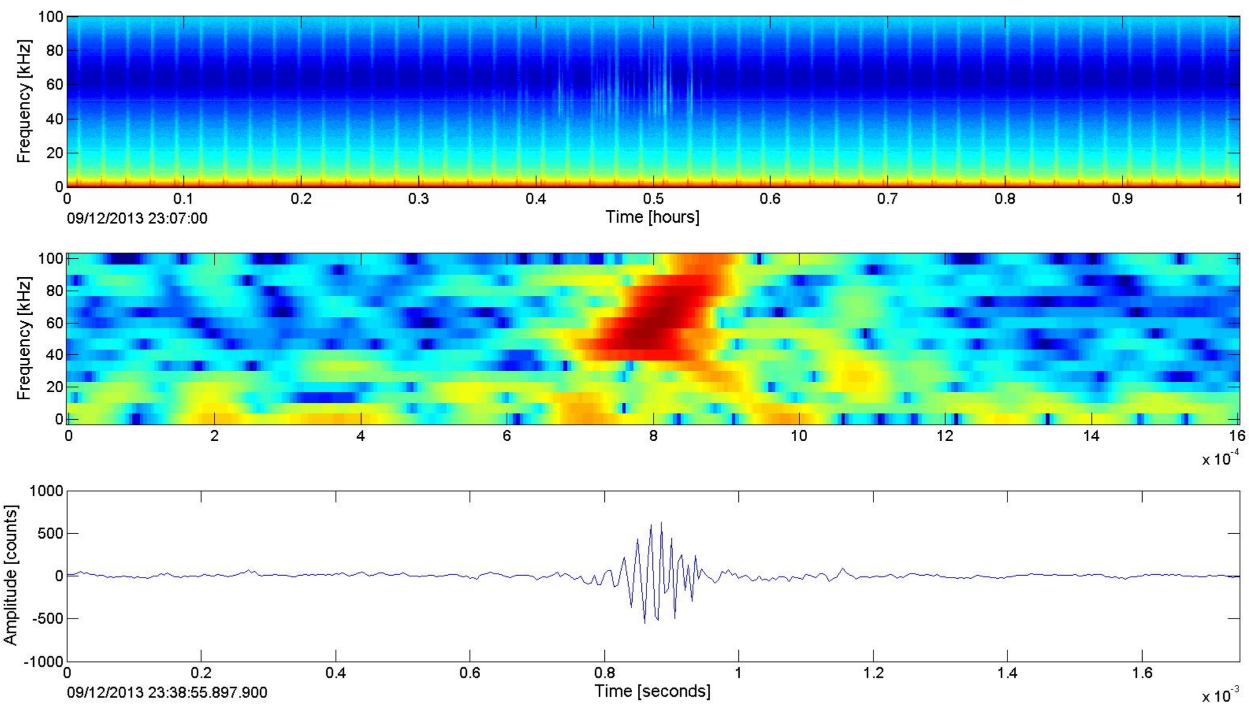

Figure 22. Echolocation sequence of Stejneger's beaked whale in the LTSA (top) and single FM pulse in the spectrogram (middle) and timeseries (bottom) at site PT.

Unidentified Porpoise

Dall's porpoise and harbor porpoise are known to occur in the Gulf of Alaska region. Harbor porpoises tend to inhabit more coastal areas with preferred water depths not exceeding 100 m, while Dall's porpoises are more widely distributed, using shallow as well as deep, oceanic waters (Allen & Angliss, 2010). Both Dall's and harbor porpoises produce clicks that contain energy from 115-150 kHz (Verboom & Kastelein, 1995). Most HARP recordings in this report collected acoustic energy up to 100 kHz, so the peak energy of the porpoise clicks is above the upper frequency limit of the HARPs. However, the HARP anti-alias filter will allow some spectral leakage from energy above 100 kHz, resulting in 120-140 kHz energy appearing at 60-80 kHz (Figure 23). Detection of porpoise clicks is therefore possible when the animals are close to the HARP (< ~1 km) and their received levels are high.

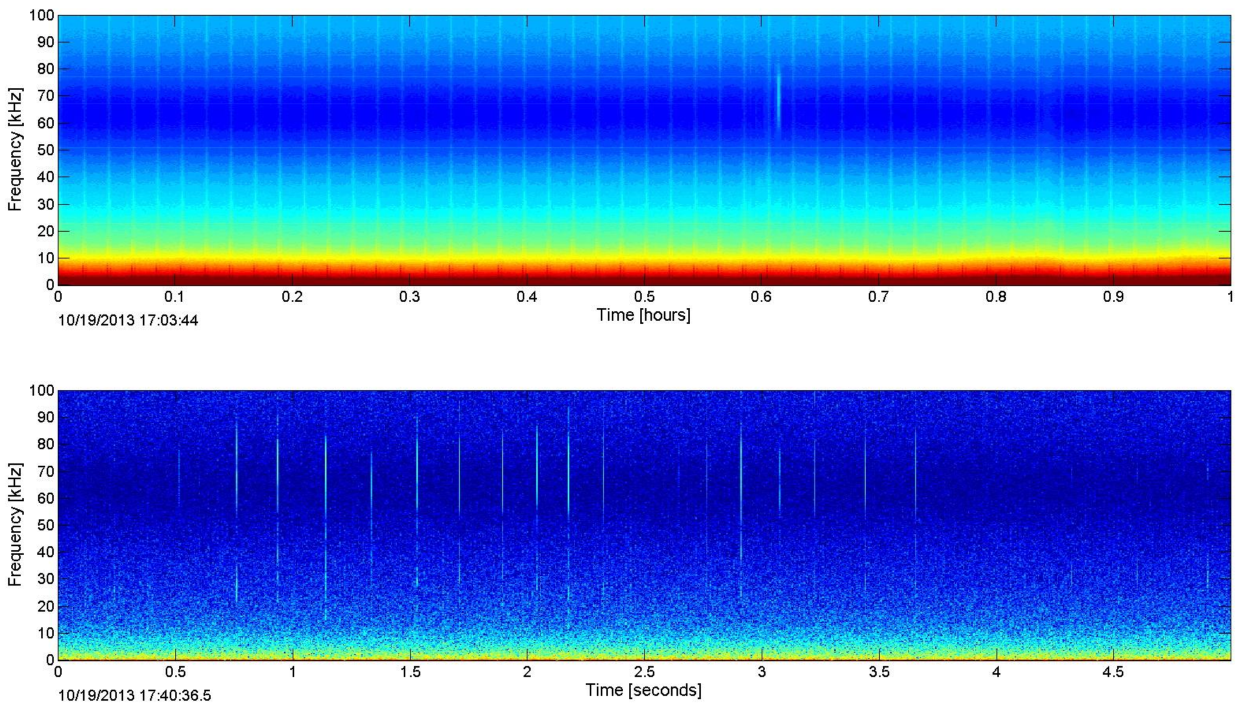

Figure 23. Echolocation sequence of an unidentified porpoise in the LTSA (top) and spectrogram (bottom) at site KO.

Anthropogenic Sounds

Several anthropogenic sounds occurring at low and mid-frequency ranges (<5 kHz) were monitored for this report: broadband ship noise, mid- frequency active (MFA) sonar, low-frequency active (LFA) sonar, echosounders, underwater communications, and explosions. The LTSA search parameters used to detect each sound are given in Table 7. The start and end of each sound or session was logged and their durations were added to estimate cumulative hourly presence.

Table 7. Low and mid-frequency anthropogenic sound data analysis parameters.

Sound Type	LTSA Search Parameters	
	Plot Length (hr)	Frequency Range (Hz)
Broadband Ship Noise	3.0	10 – 5,000
MFA Sonar	0.75	1,000 – 5,000
LFA Sonar	1.0	100 - 500
Echosounders	0.75	10 – 5,000
Underwater Communications	0.75	10 – 5,000
Explosions	0.75	10 – 5,000

Broadband Ship Noise

Broadband ship noise occurs when a ship passes relatively close to the hydrophone. Ship noise can occur for many hours at a time, but broadband ship noise typically lasts from 10 minutes up to 3 hours. Ship noise has a characteristic interference pattern in the LTSA (McKenna *et al*., 2012). Combination of direct paths and surface reflected paths produce constructive and destructive interference (bright and dark bands) in the spectrogram that varies by frequency and distance between the ship and the receiver (Figure 24). Noise can extend above 10 kHz, though it typically falls off above a few kHz.

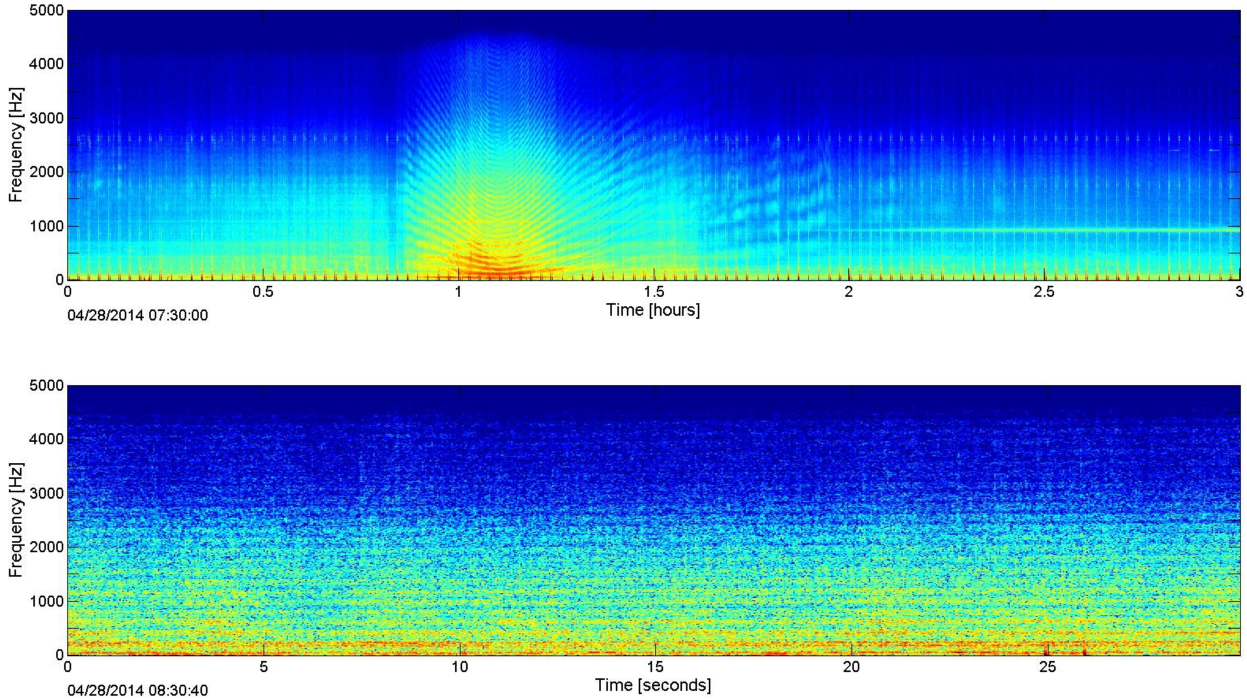

Figure 24. Broadband ship noise in the LTSA (top) and spectrogram (bottom) at site CB.

Mid-Frequency Active Sonar

Sounds from MFA sonar vary in frequency and duration and are a combination of frequency modulated (FM) sweeps and continuous wave (CW) tones. While they can span frequencies from about 1 kHz to over 50 kHz, many are between 2.0 and 5.0 kHz and are more generically known as '3.5 kHz' sonar (Figure 25). There were no MFA detections at any of the sites in this region during this reporting period.

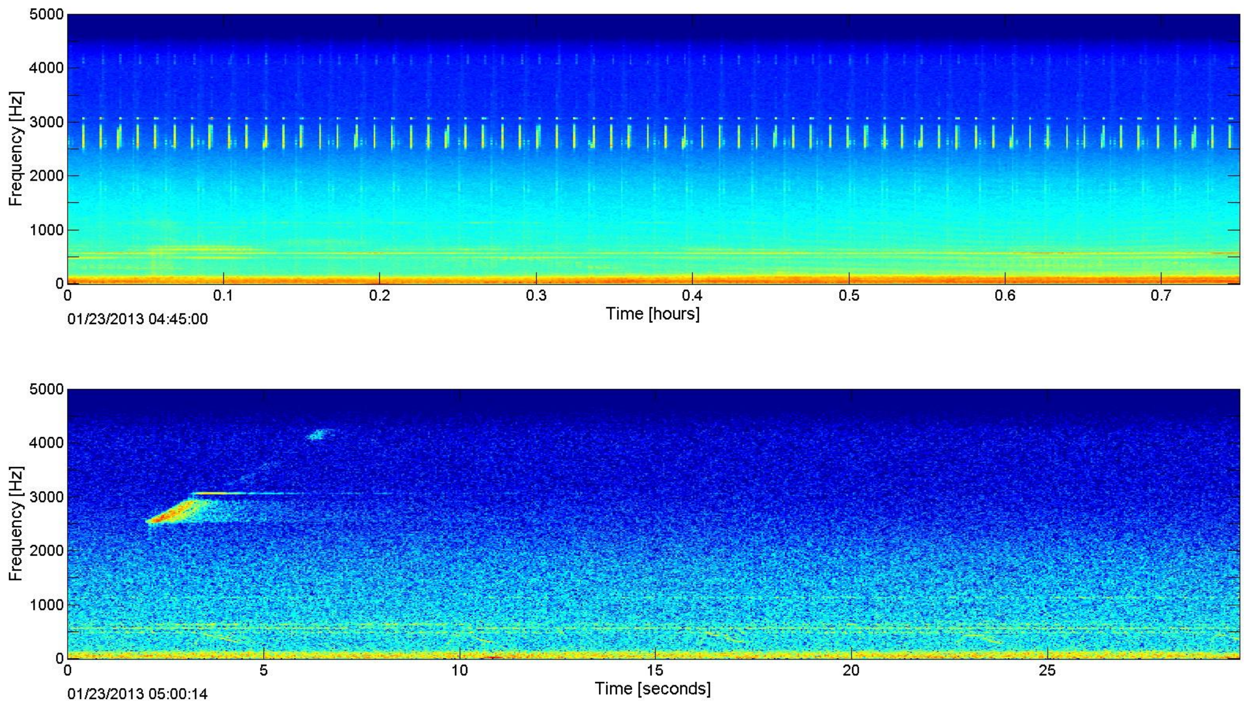

Figure 25. Example of MFA sonar in the LTSA (top) and spectrogram (bottom) from a recording site off the coast of Washington.

Low-Frequency Active Sonar

Low-frequency active sonar includes military sonar between 0 and 500 Hz (Figure 26). This long-range sonar uses low frequencies to minimize absorption effects.

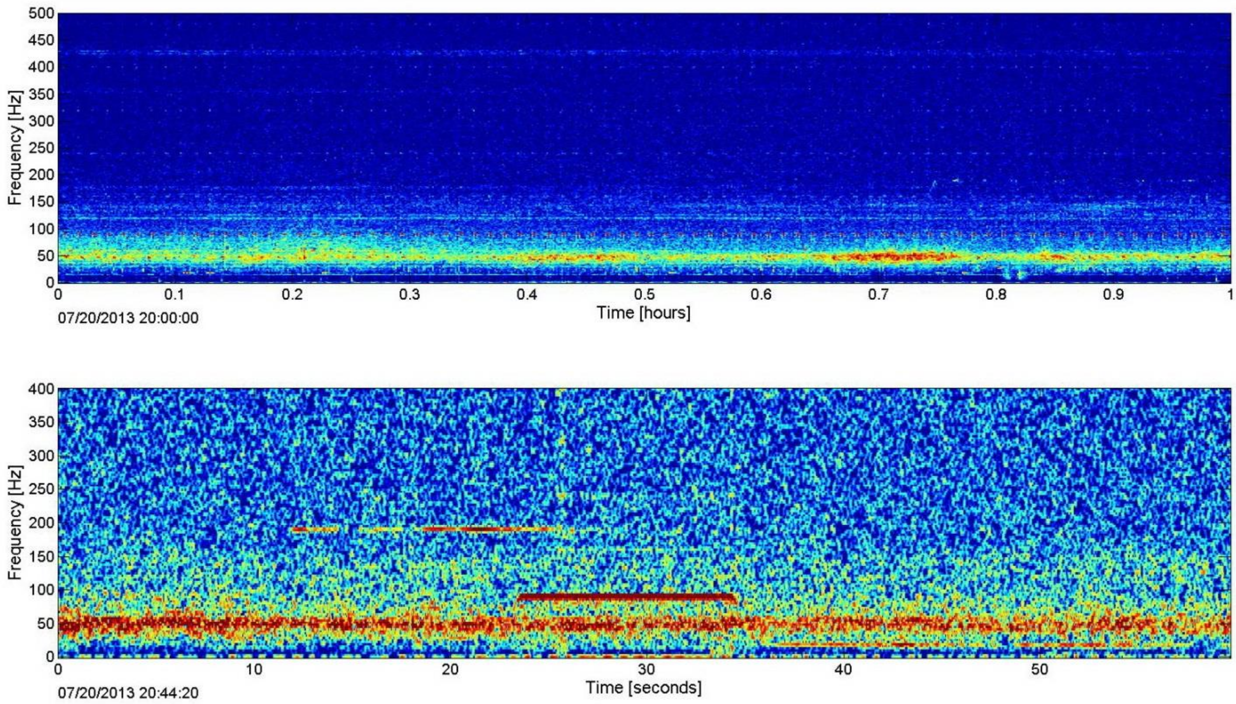

Figure 26. LFA in the LTSA (top) and spectrogram (bottom) at site QN.

Echosounders

Echosounding sonars transmit short pulses or frequency sweeps, typically in the high-frequency (above 5 kHz) band (Figure 27), though echosounders are occasionally found in the mid-frequency range (2-5 kHz). Many large and small vessels are equipped with echosounding sonar for water depth determination; typically these echosounders are operated much of the time a ship is at sea, as an aid for navigation. In addition, sonars may be used for sea bottom mapping, fish detection, or other ocean sensing. Echosounders were detected by analysts using the LTSA plots at both mid- and high-frequency.

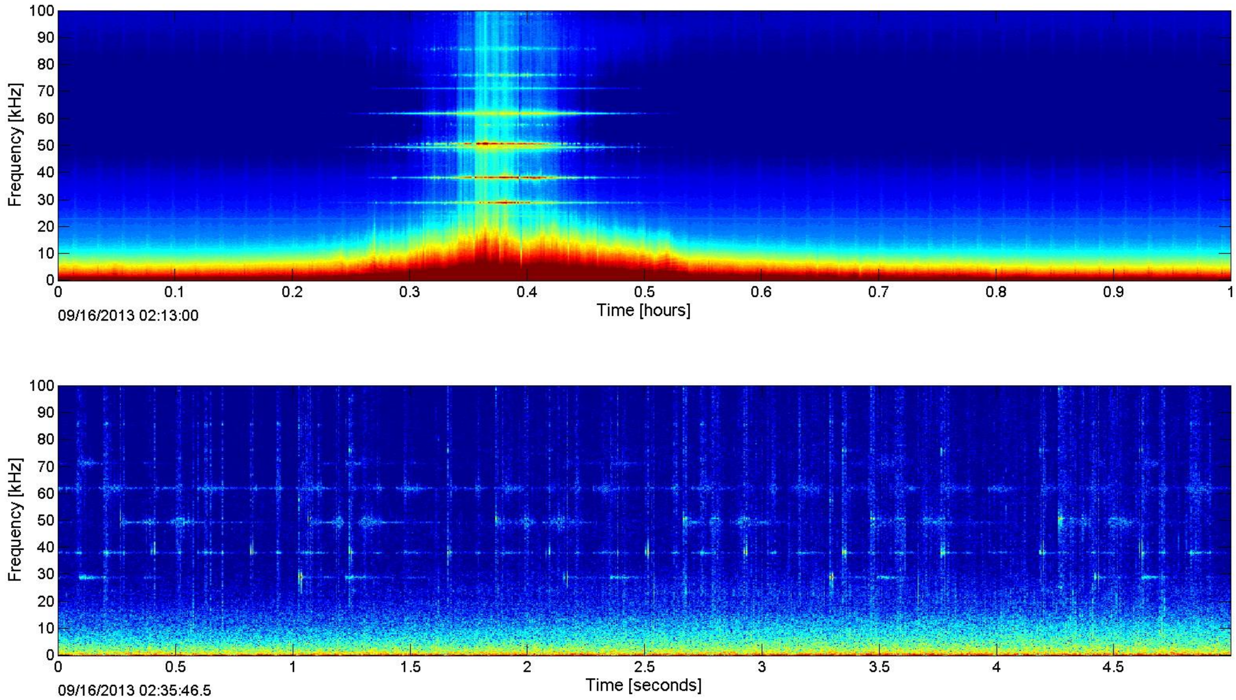

Figure 27. Example of an echosounder in the LTSA (top) and spectrogram (bottom) at site KO.

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 28). Explosions were logged manually for deployments CA03, CB03, KO01, PT02, and QNO01. Explosions were detected automatically for deployments CA04, CB04, KO02, PT03, and QN02 using a matched filter detector on data decimated to 10 kHz sampling rate. The timeseries 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 timeseries 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 0.000003 above the median was set. When the correlation coefficient reached above threshold, the timeseries was inspected more closely.

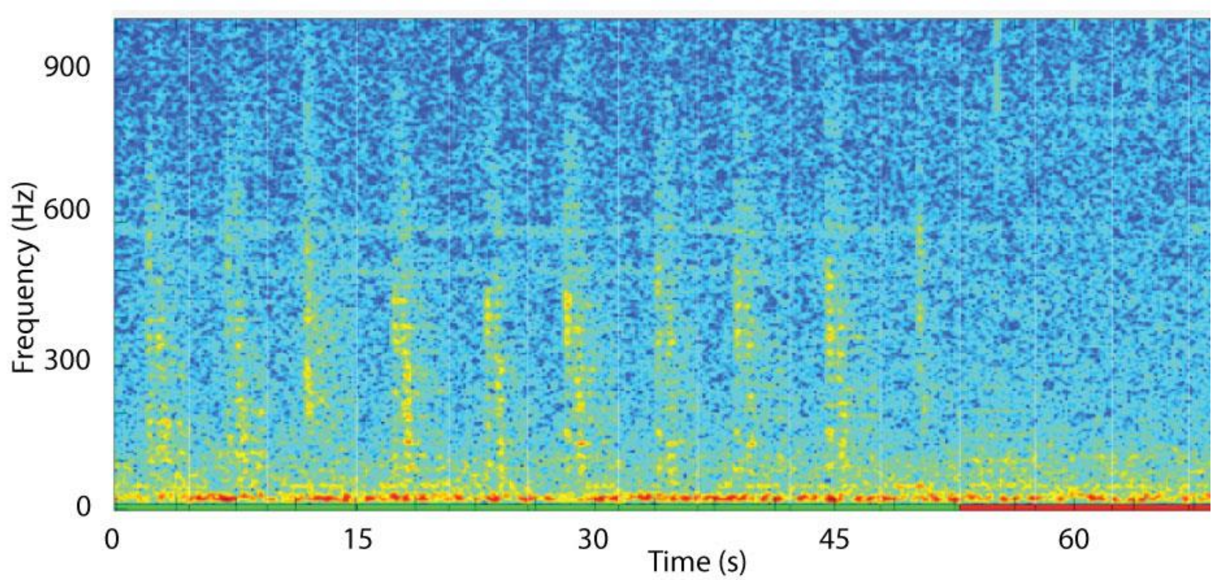

Figure 28. Example of explosions from site PT in the analyst verification stage of the detector. Green in the bottom evaluation line indicates true and red indicates false detections.

Consecutive explosions were required to have a minimum time distance of 0.5 seconds to be detected. A 300-points (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 timeseries of the length of the explosion template before and after the detection. The potential detection was classified as false detection 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 longer than 0.03 and shorter than 0.55 seconds of duration. 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.

Underwater Communications

Underwater communications are used to transmit information. They can sound like distorted voices (Figure 29) or other electronic transmissions. No underwater communications were detected during this reporting period.

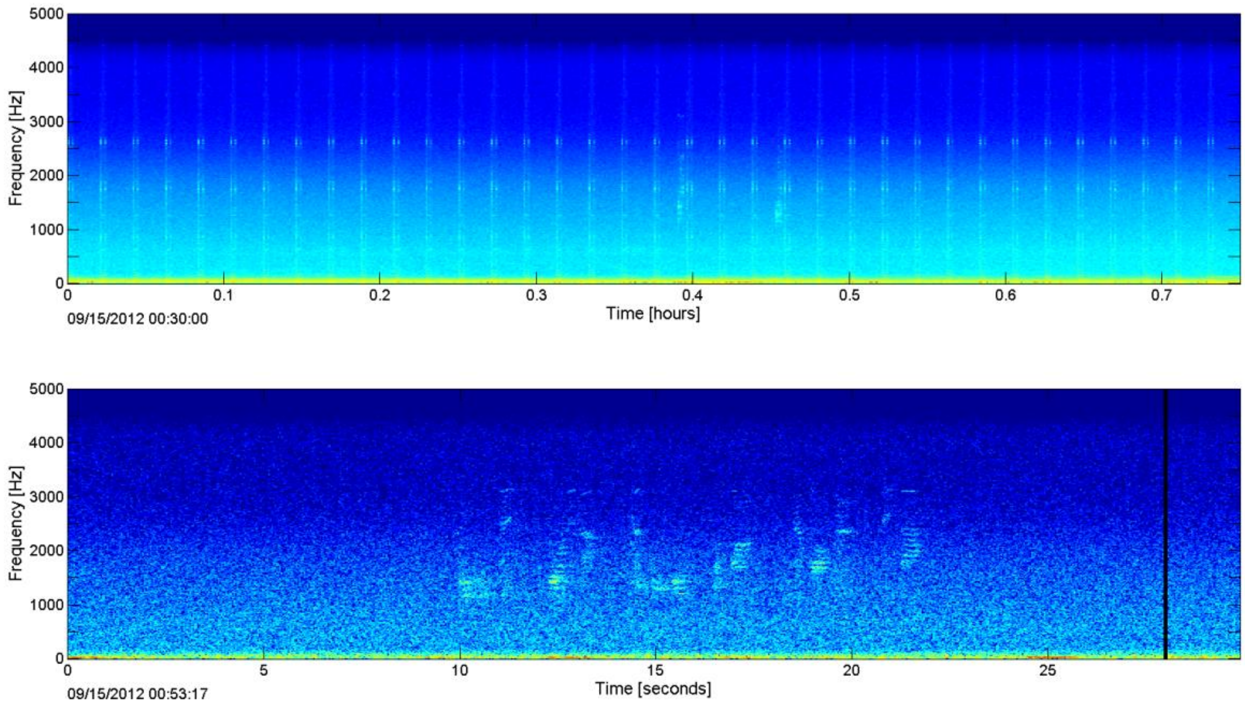

Figure 29. Underwater communications in the LTSA (top) and spectrogram (bottom) from a HARP recording site off the coast of Washington.

Results

The results of acoustic data analysis at sites CA, CB, KO, PT, and QN from June 2013 through May 2014 are summarized. We describe ambient noise, the seasonal occurrence and relative abundance of marine mammal acoustic signals and anthropogenic sounds.

Ambient Noise

High levels of underwater ambient noise were recorded at all sites, mostly from environmental causes, although some sources were also biotic.

- At all five sites, noise levels at frequencies >200 Hz were generally lower in the summer relative to the fall and winter, probably due to decreased noise from wind and waves, particularly at frequencies above 100 Hz (Figure 30, Figure 31, Figure 32, Figure 33, and Figure 34).
- At sites PT and QN, there is evidence of long-range ship noise at frequencies below 100 Hz (Hildebrand, 2009) (Figure 33 and Figure 34).
- Prominent seasonal peaks in noise observed at the frequency band 15-30 Hz during the fall and winter across all sites are related to the presence of fin whale calls, while peaks at 45-47 Hz, relating to blue whale B calls, were present during the late summer and fall at sites CB, KO, PT, and QN (Figure 30, Figure 31, Figure 32, Figure 33, and Figure 34).
- Peaks at approximately 110 Hz, 120 Hz, and 230 Hz are associated with hydrophone strumming.

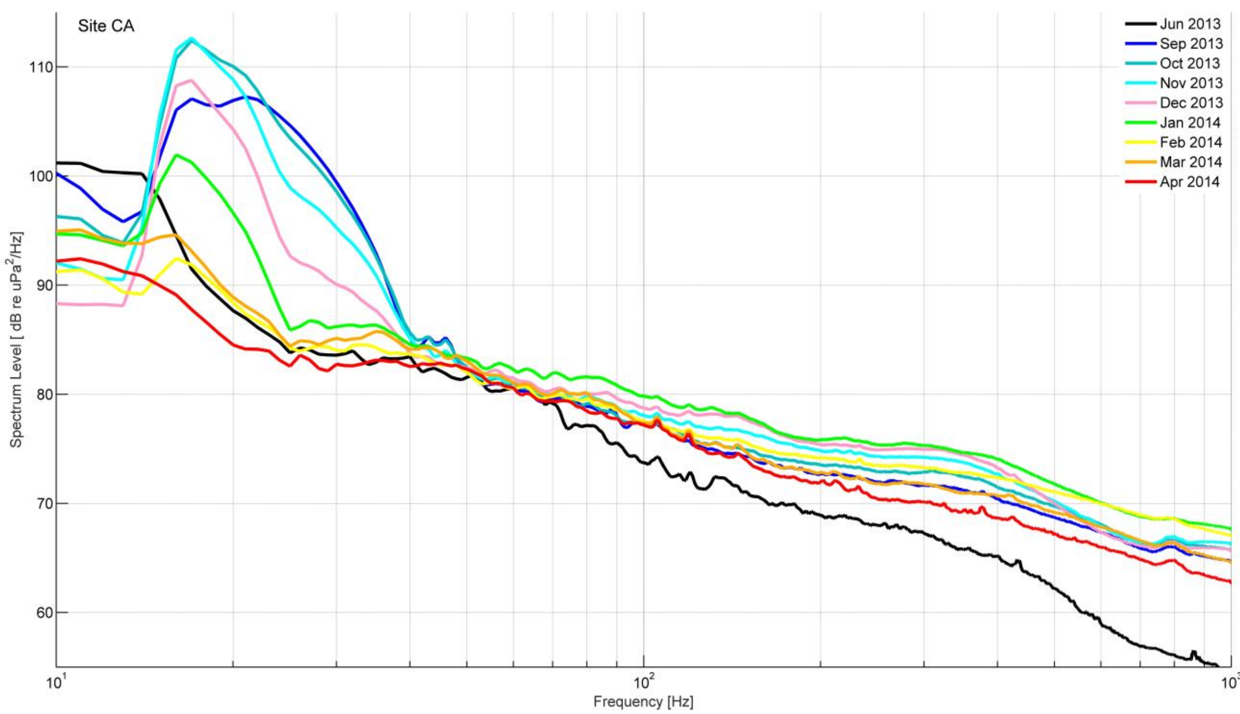

Figure 30. Monthly averages of ambient noise at site CA. Legend gives color-coding by month.

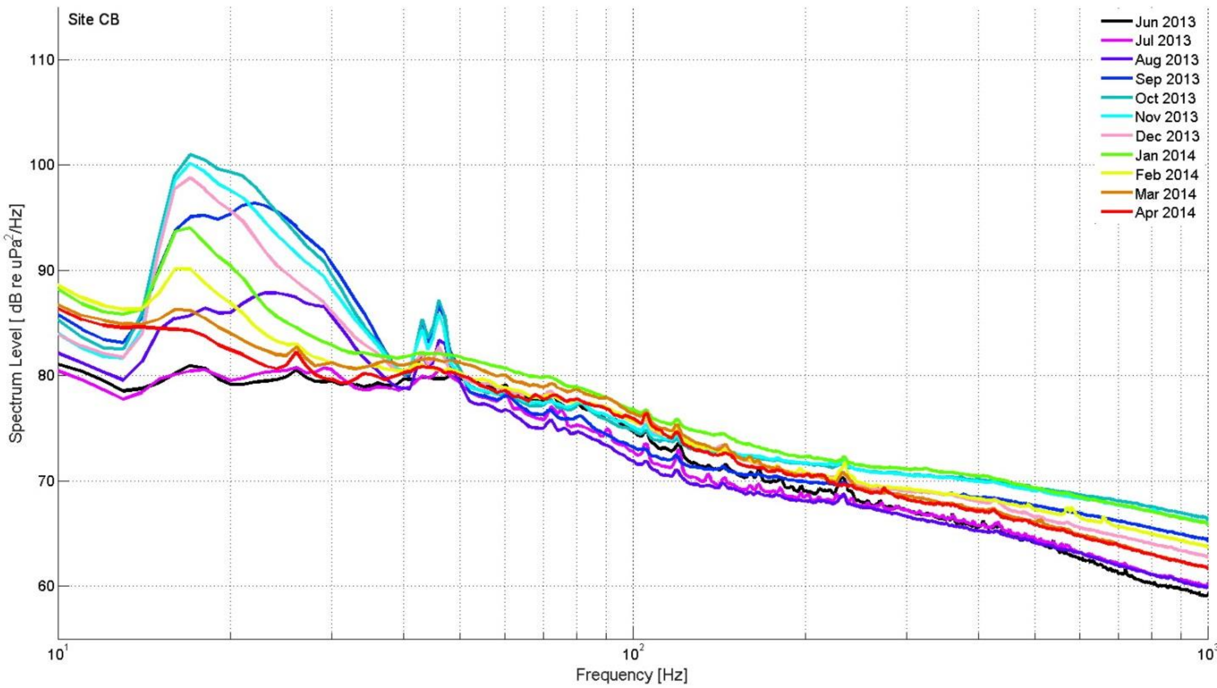

Figure 31. Monthly averages of ambient noise at site CB. Legend gives color-coding by month.

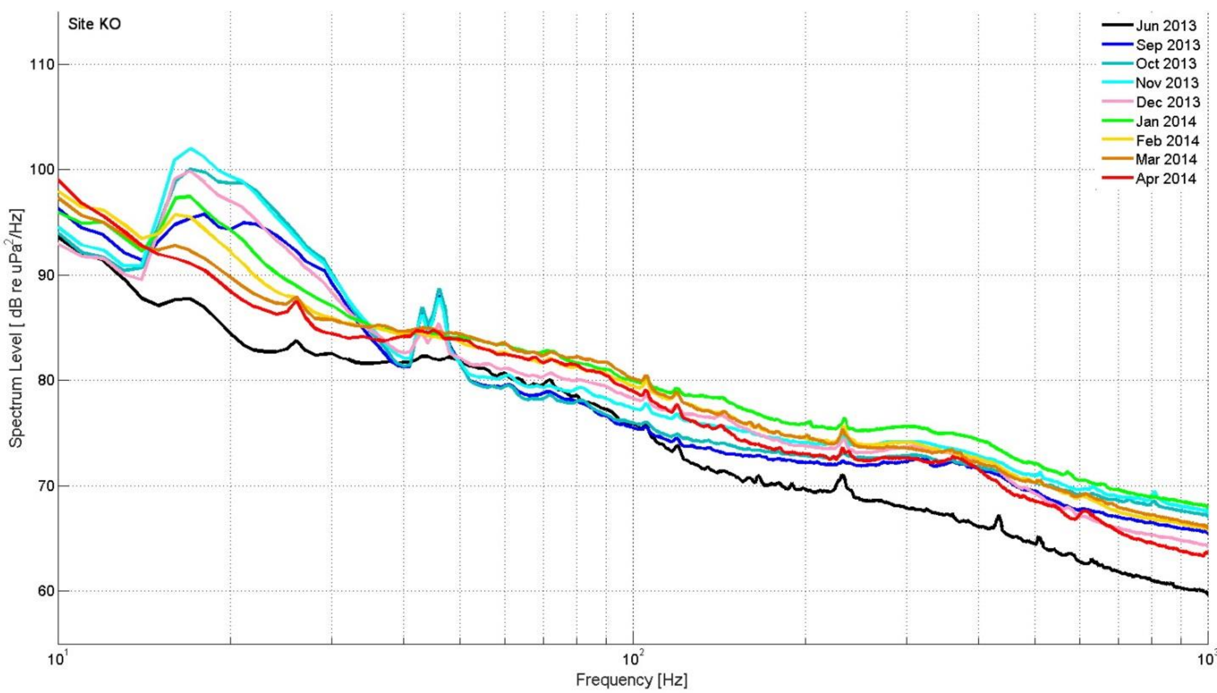

Figure 32. Monthly averages of ambient noise at site KO. Legend gives color-coding by month.

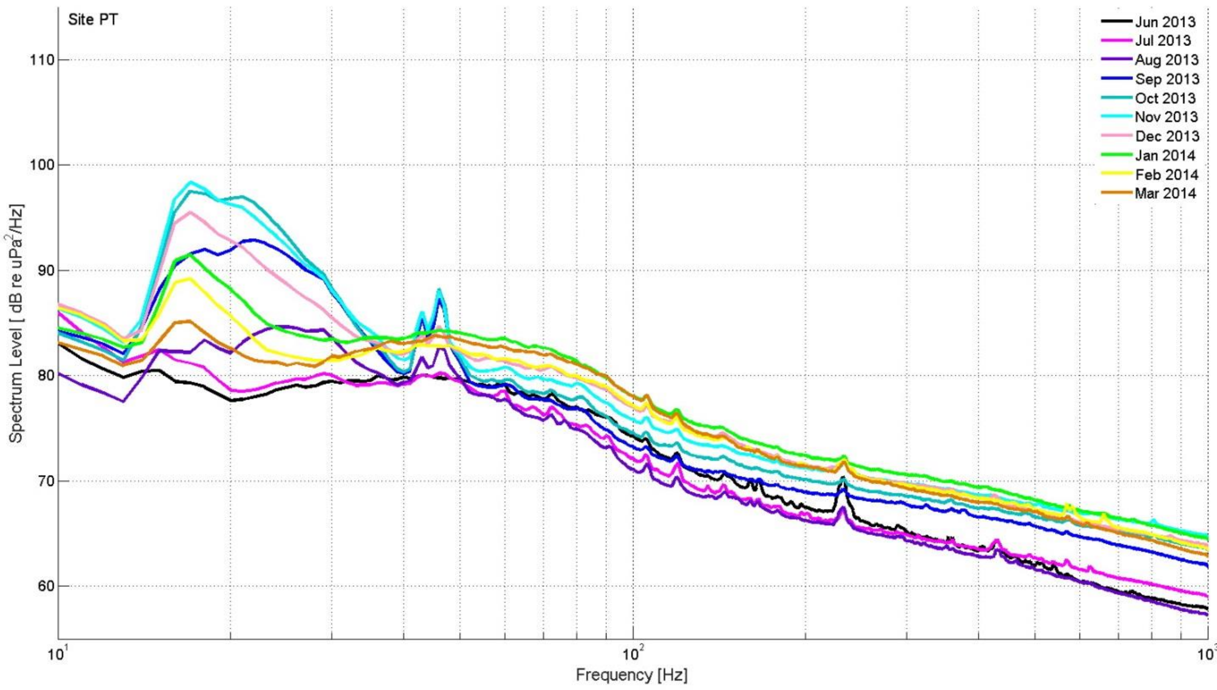

Figure 33. Monthly averages of ambient noise at site PT. Legend gives color-coding by month.

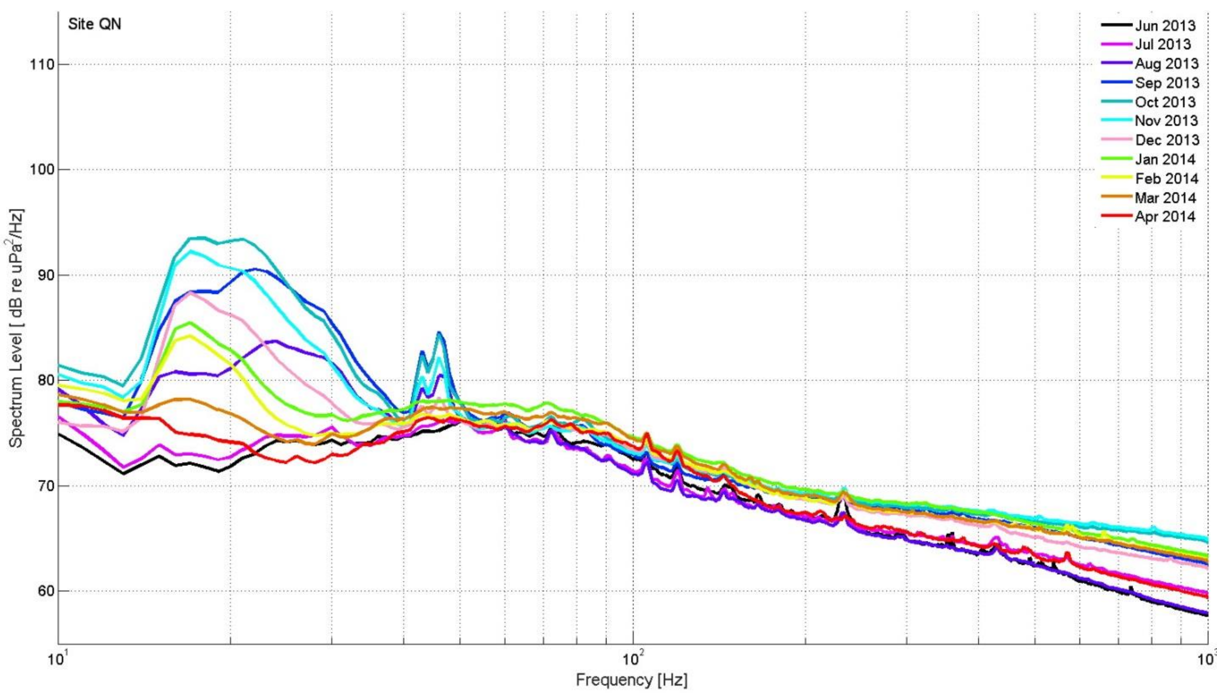

Figure 34. Monthly averages of ambient noise at site QN. Legend gives color-coding by month.

Mysticetes

Five baleen whale species were recorded between 2013 and 2104: blue whales, fin whales, gray whales, humpback whales, and North Pacific right whales. Relative hourly calling abundance varied among species. In general, fewer baleen whale vocalizations were detected at site CA than at any of the other sites, though that site also had lowest quality of recordings. More details of each species' presence are given below.

Blue Whales

Blue whale calls were detected from June 2013 through May 2014, albeit at low numbers after early December 2013.

- Blue whale Northeast (NE) Pacific B calls were detected from June 2013 through March 2014 with a peak in September – October 2013 and with fewest calls detected at sites CA and QN (Figure 35).
- There was no discernable diel pattern for the NE Pacific B calls (Figure 36).
- Central Pacific tonal calls were detected at sites CB, PT, and QN from June to October 2013 with most detections occurring in July and August (Figure 37).
- There was no diel pattern for Central Pacific tonal calls (Figure 38).
- Blue whale D call detections were the highest from June to August 2013 (Figure 39). Very few D calls were detected at site CA, while most D call detections occurred at sites CB and QN.
- There was no discernable diel pattern for blue whale D calls (Figure 40).
- These results are consistent with earlier recordings at these sites (Debich et al., 2013) as well as recordings collected further south in the Gulf of Alaska (Watkins *et al*., 2000).

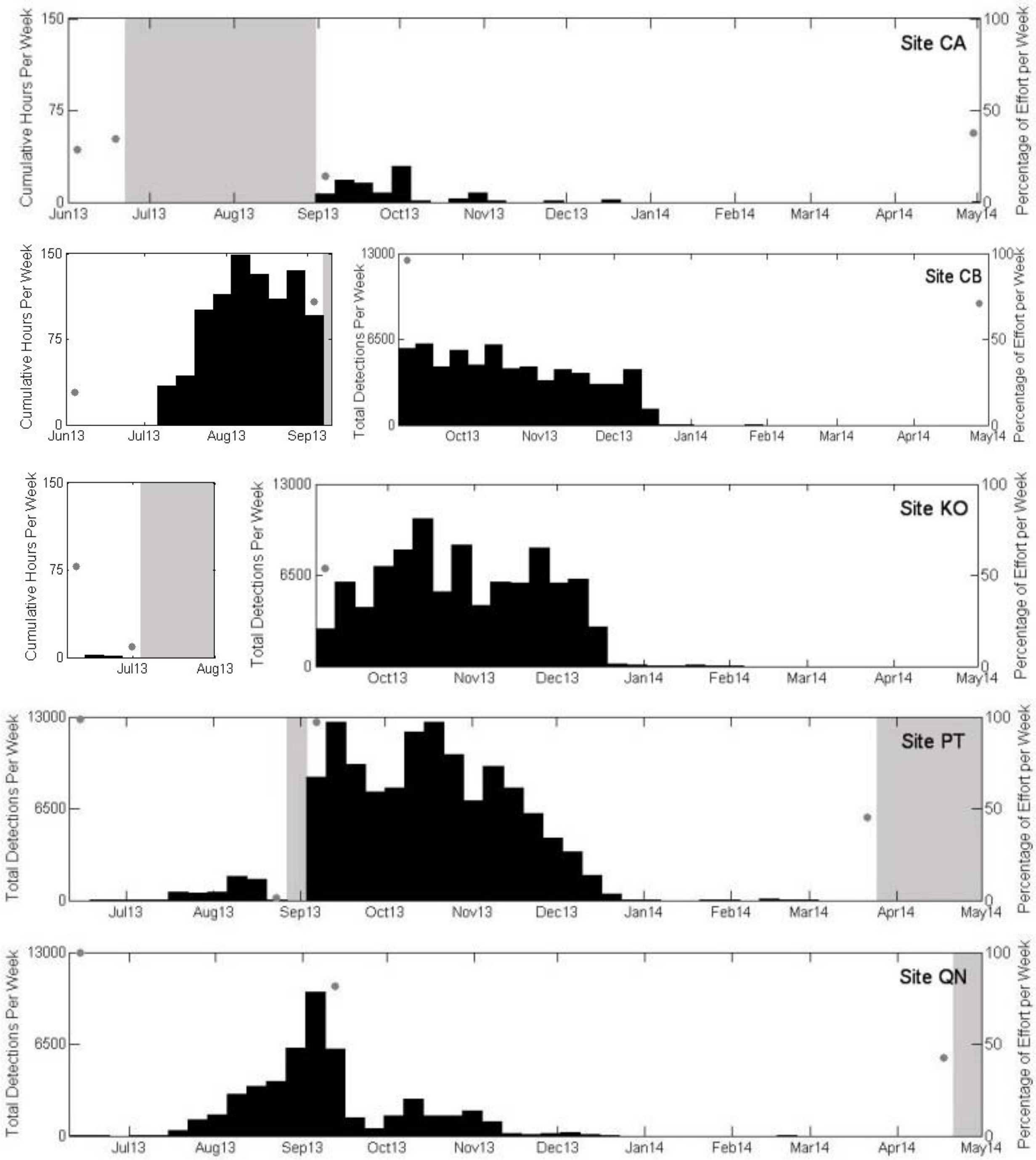

Figure 35. Weekly presence of NE Pacific blue whale B calls between June 2013 and May 2014 at sites CA (top), CB (second from top), KO (middle), PT (second from bottom), and QN (bottom). Weekly detections shown for sites CA, CB (June 6 – September 5, 2013) and KO (June 6 – 27, 2013) were manually detected in hourly bins. Weekly detections for sites CB (September 5, 2013 – May 1, 2014), KO (September 8, 2013 – May 1, 2014), PT, and QN were detected using an automatic spectrogram correlation detector. Gray dots represent percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no recording effort. Where gray dots or shading are absent, full recording effort occurred for the entire week.

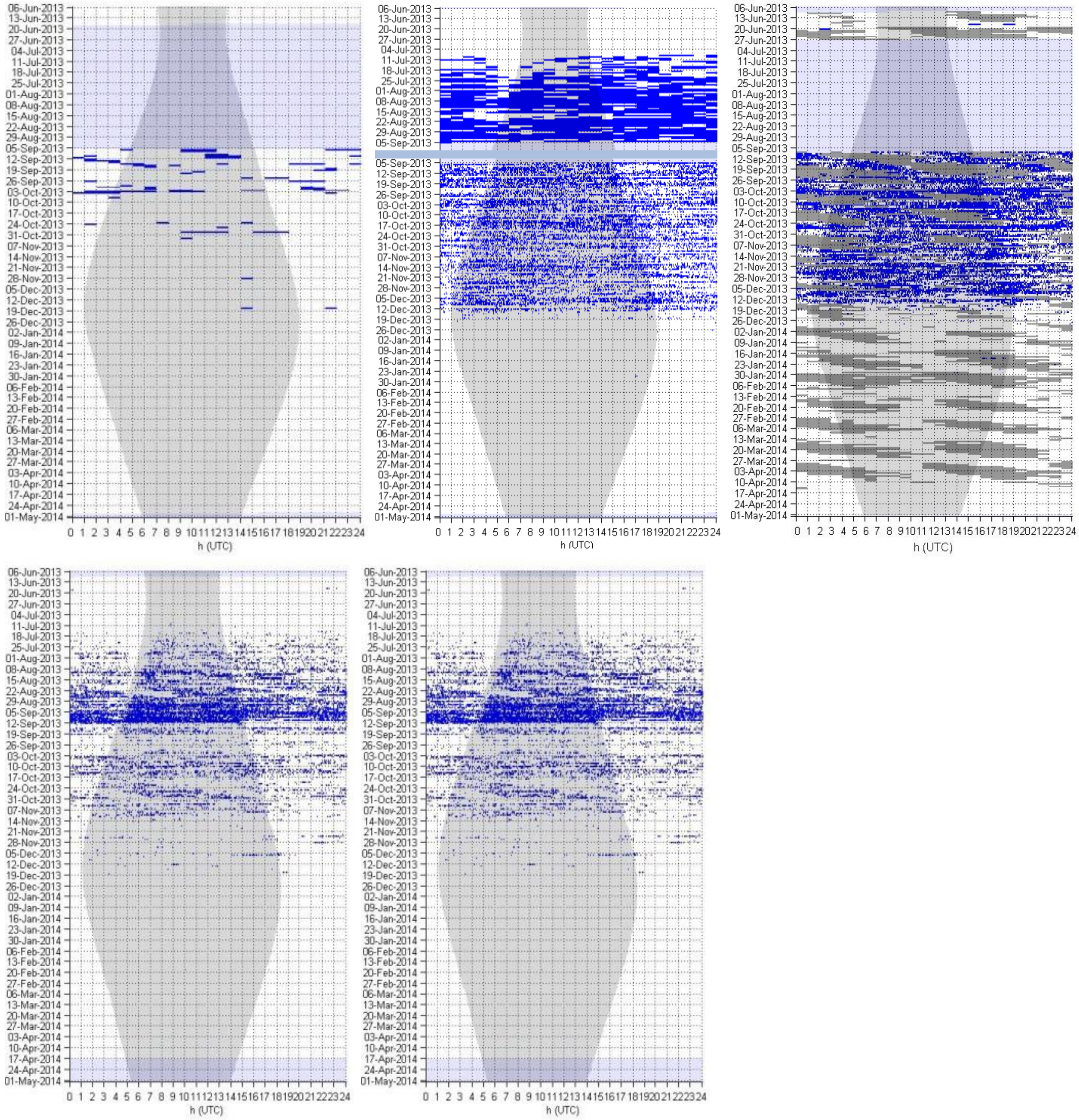

Figure 36. NE Pacific blue whale B calls in hourly bins at site CA (top left). Hourly bins are shown for sites CB (top middle) and KO (top right) for June 6 – September 5, 2013. Calls in one-minute bins are shown for sites CB and KO (September 8, 2013 – May 1, 2014), and PT & QN. Dark gray shading denotes instrument strumming. Light gray vertical shading denotes nighttime and light purple horizontal shading denotes absence of acoustic data.

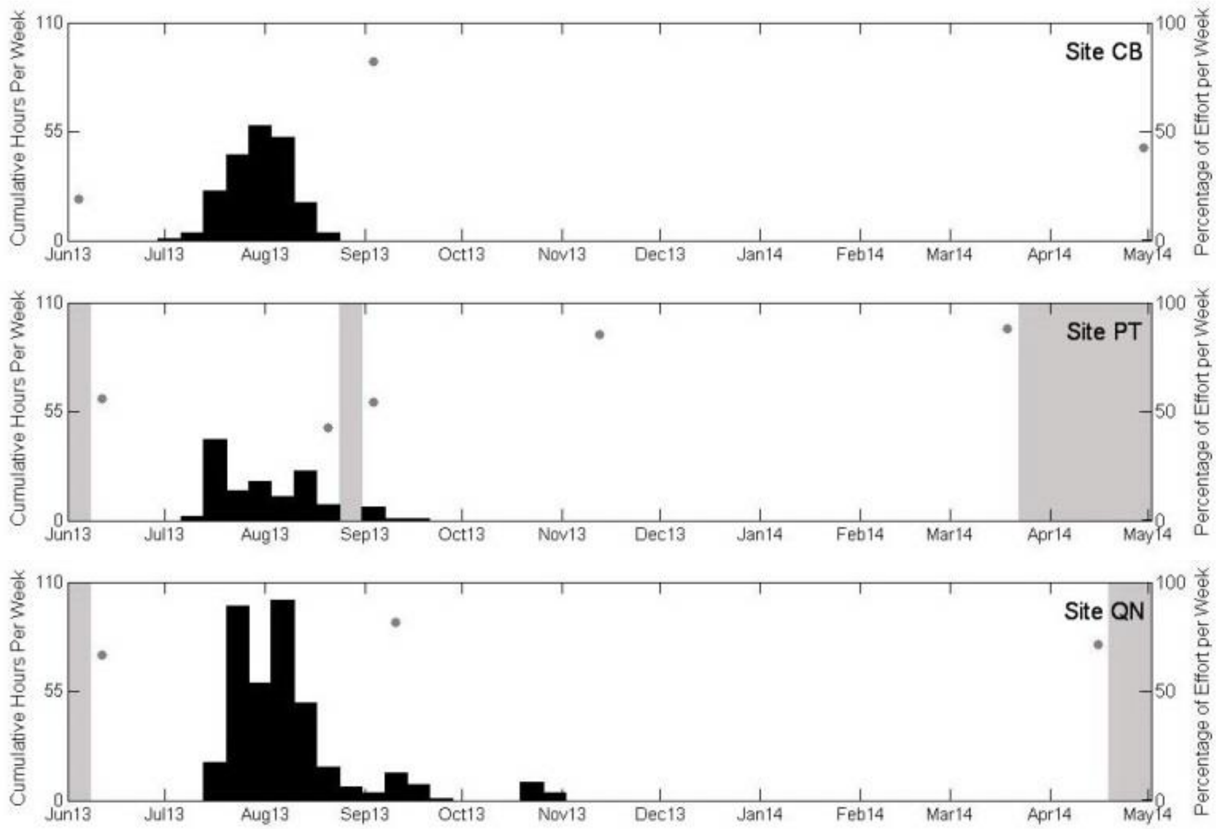

Figure 37. Weekly presence of Central Pacific tonal blue whale calls between June 2013 and May 2014 at sites CB (top), PT (middle), and QN (bottom). Effort markings are described in Figure 35.

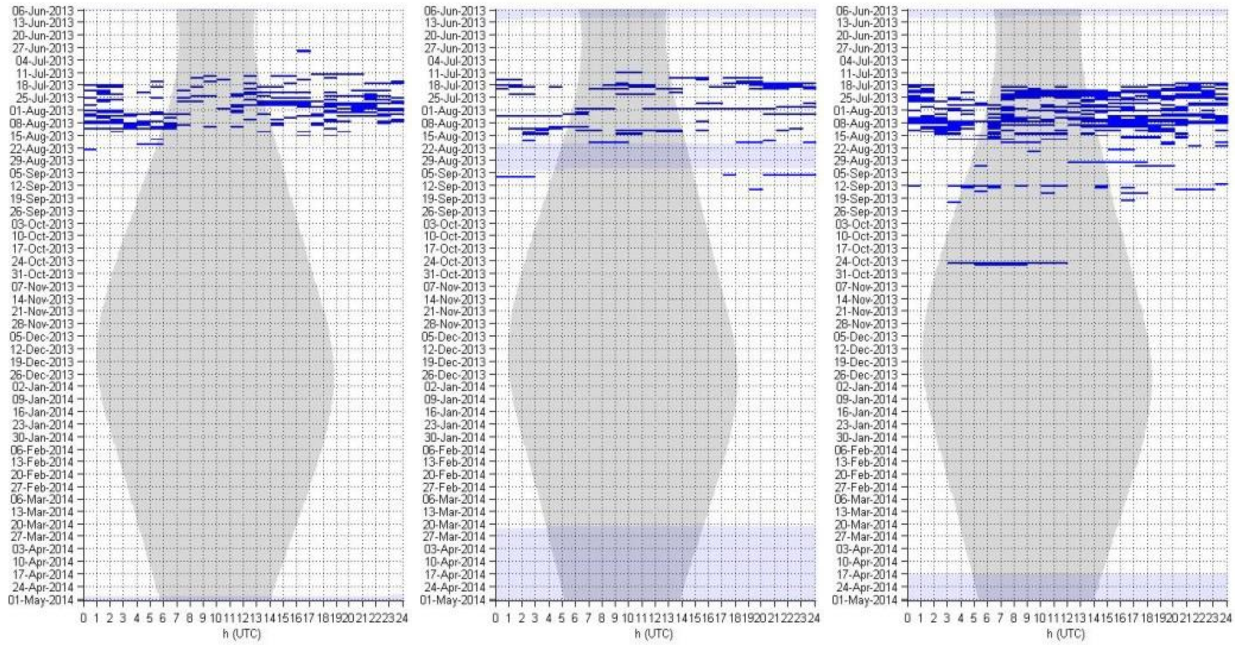

Figure 38. Central Pacific tonal blue whale calls in one-minute bins at sites CB (left), PT (middle), and QN (right). Effort markings are described in Figure 36.

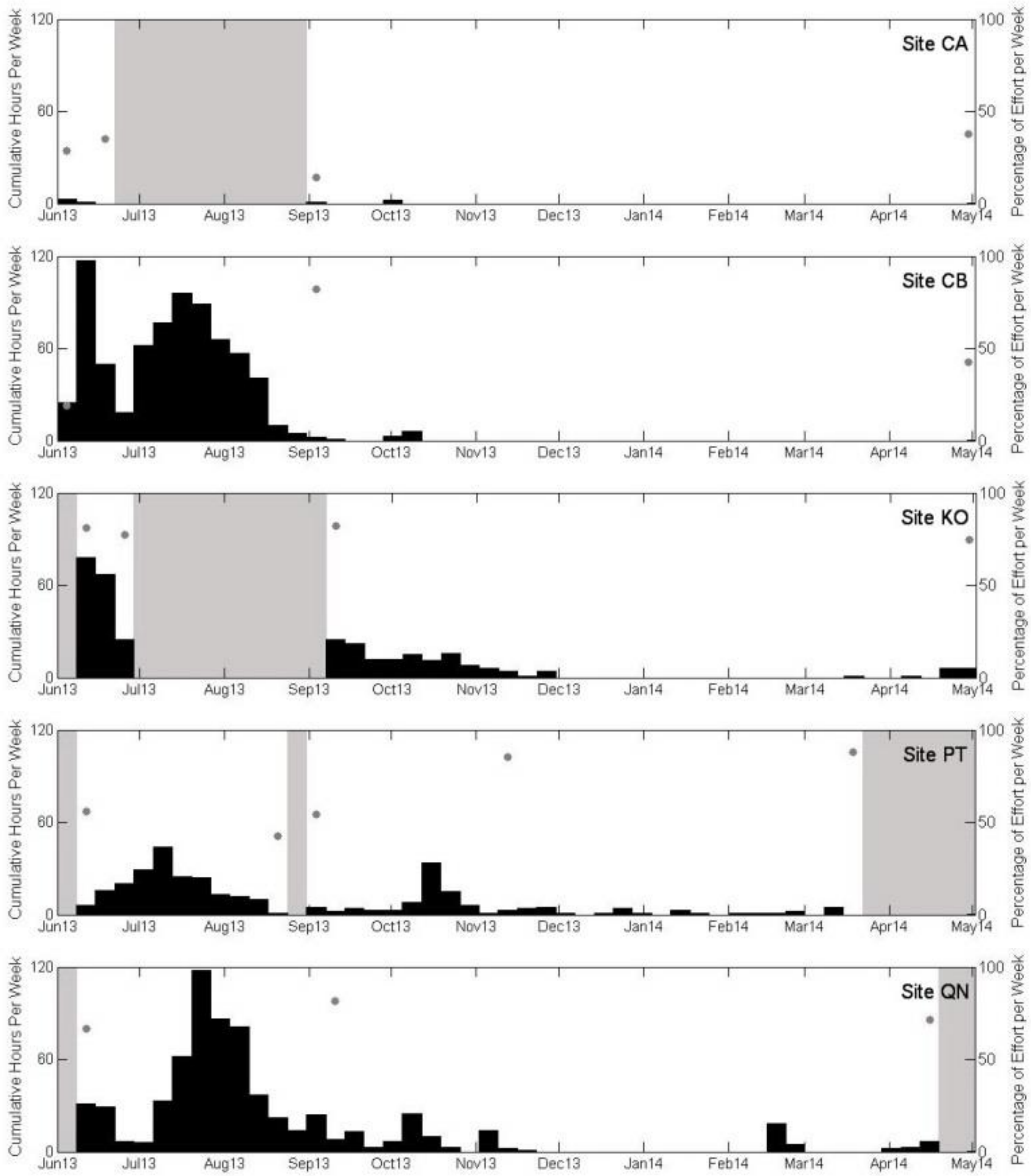

Figure 39. Weekly presence of blue whale D calls between June 2013 and May 2014 at sites CA (top), CB (second from top), KO (middle), PT (second from bottom), QN (bottom). Effort markings are described in Figure 35.

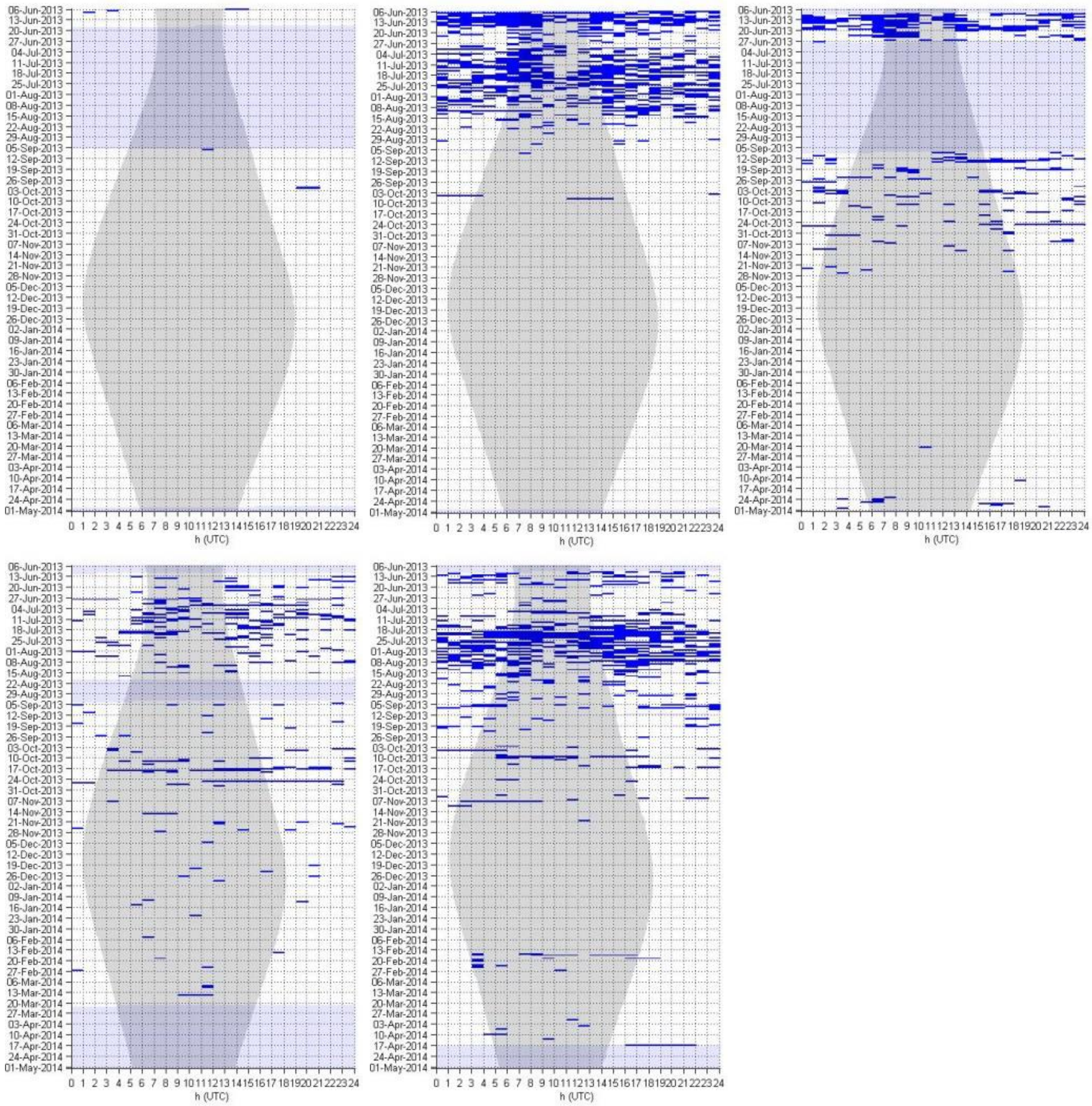

Figure 40. Blue whale D calls in hourly bins at sites CA (top left), CB (top middle), KO(top right), PT (bottom left), and QN (bottom right). Effort markings are described in Figure 36.

Fin Whales

Fin whales were one of the most commonly detected baleen whale throughout the recordings.

- Fin whale 20 Hz calls, associated with singing and call-countercall among animals, were the dominant fin whale call type. Peaks in call index representative of 20 Hz calls occurred September – December 2013 (Figure 41).
- Fin whale 40 Hz calls were frequently recorded from June through December 2013 and again between late February and May 2014(Figure 42). Peaks in detections at sites CA and KO occurred in October 2013 and again in April 2014. Detections at sites CB, PT, and QN peaked June – July 2013 with a secondary peak in the spring months during 2014 at site QN.
- There was no discernable diel pattern for fin whale 40 Hz calls (Figure 43).
- 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).
- In the eastern North Pacific, fin whale calls are generally detected from October through April (Watkins *et al*., 2000), corresponding to the pattern we observed at these sites.
- These results are consistent with earlier recordings (Debich *et al*., 2013).

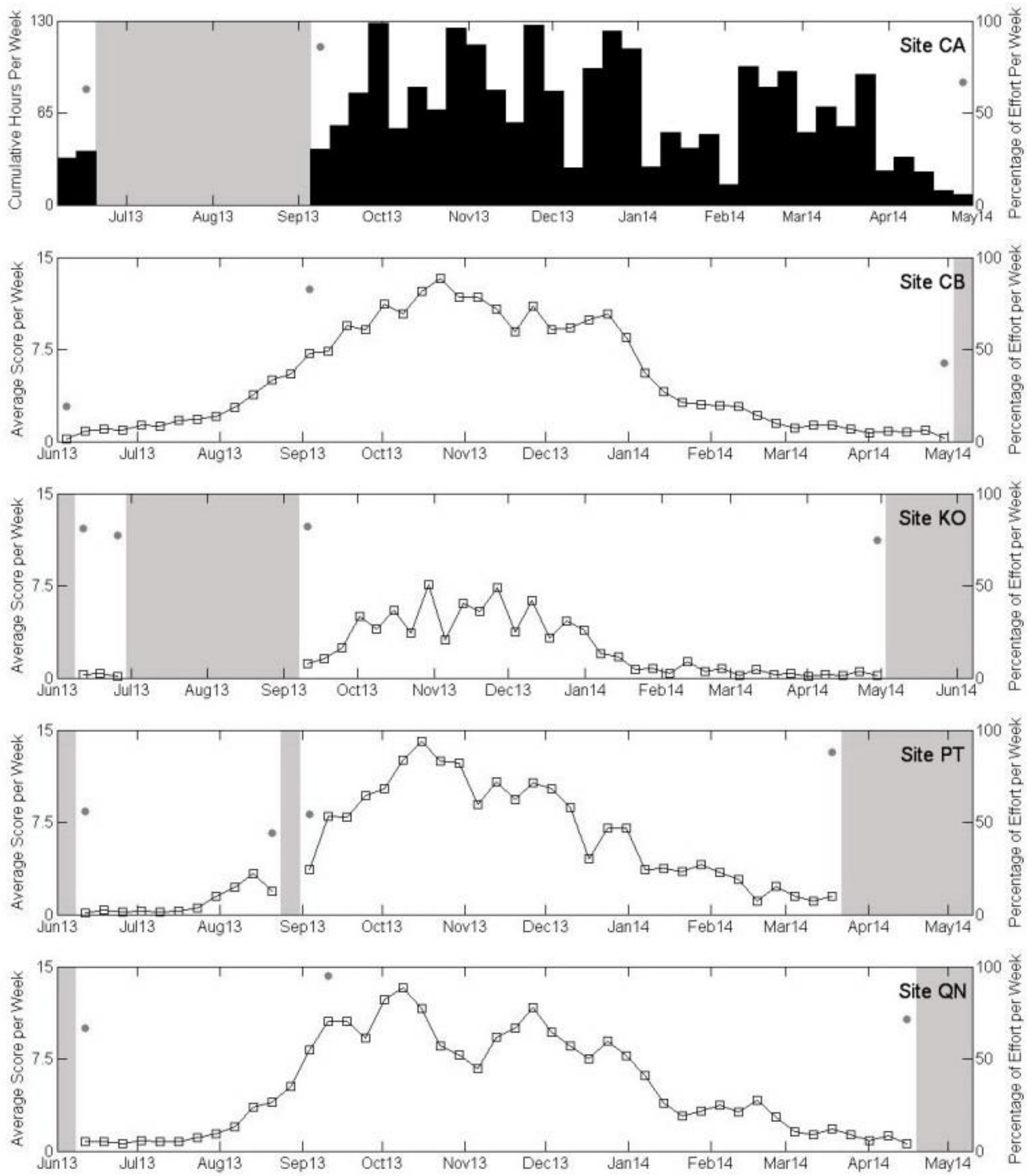

Figure 41. Weekly presence of fin whale 20 Hz calls between June 2013 and May 2014 at site CA (top). Weekly value of fin whale call index (proxy for 20 Hz calls) between June 2013 and May 2014 at sites CB (second from top), KO (middle), PT (second from bottom) and QN (bottom). Effort markings are described in Figure 35.

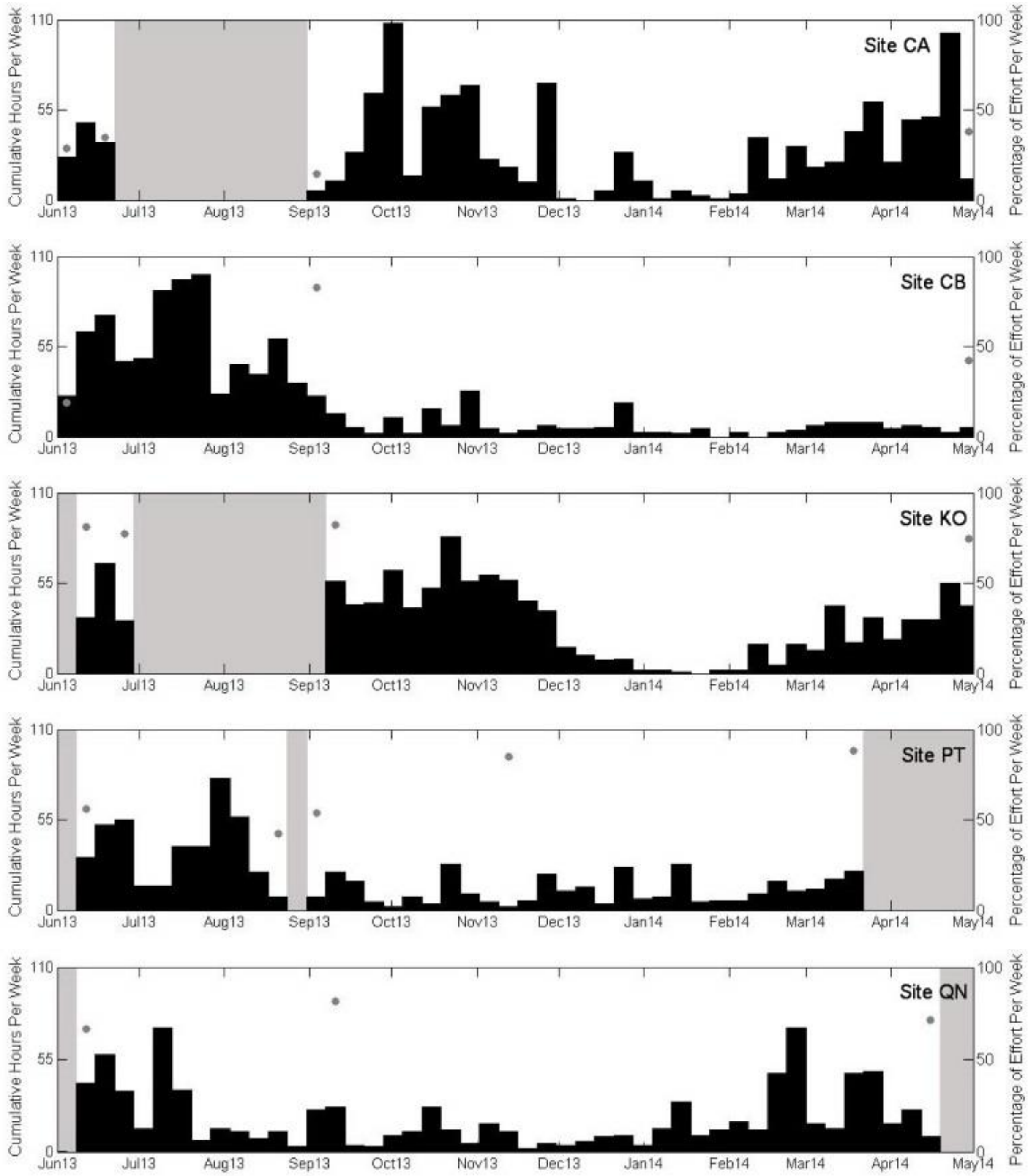

Figure 42. Weekly presence of fin whale 40 Hz calls between June 2013 and May 2014 at sites CA (top), CB (second from top), KO (middle), PT (second from bottom), and QN (bottom). Effort markings are described in Figure 35.

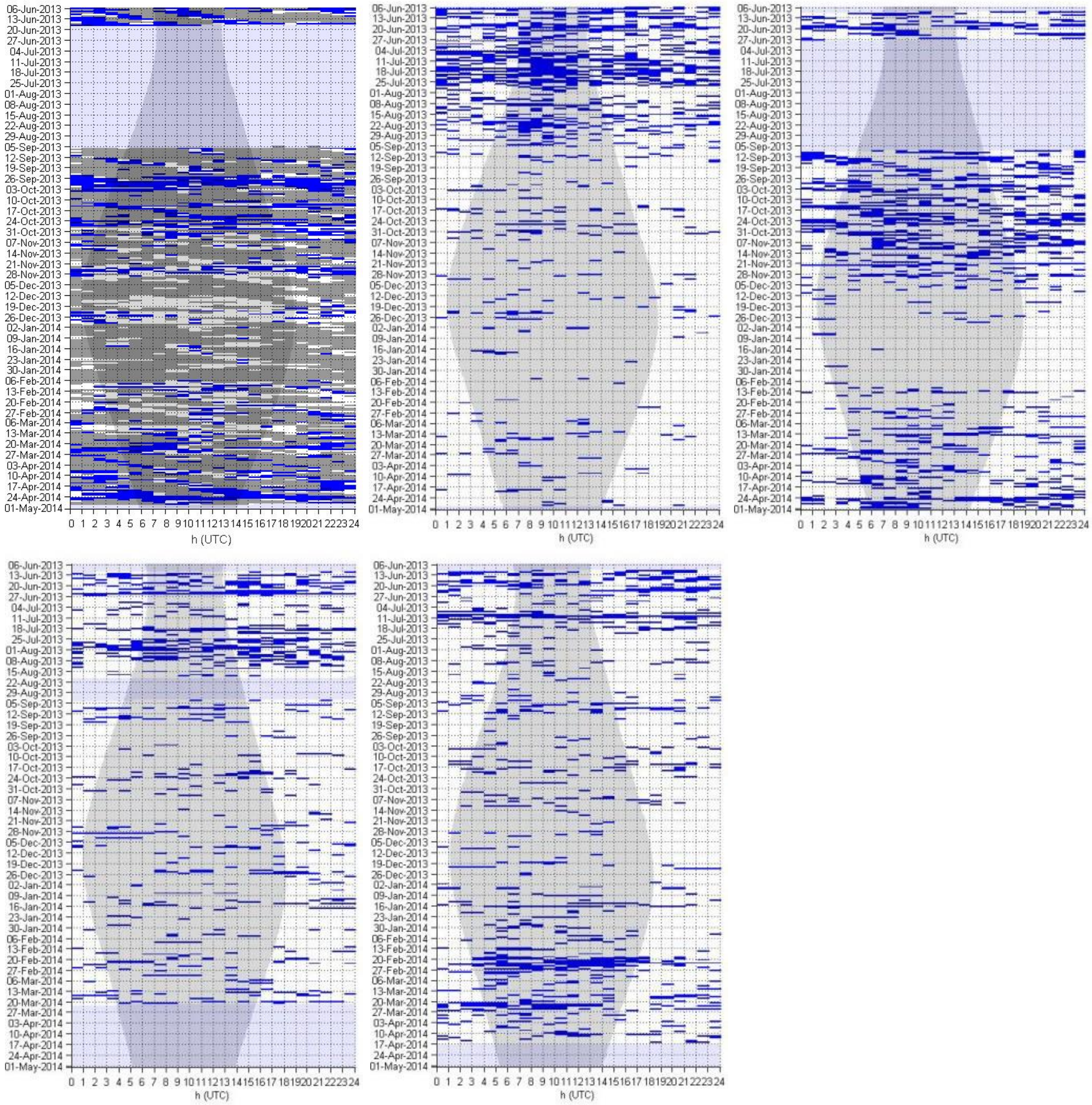

Figure 43. Fin whale 40 Hz calls in hourly bins at sites CA (top left), CB (top middle), KO (top right), PT (bottom left), and QN (bottom right). Effort markings are described in Figure 36.

Gray Whales

Gray whale M3 calls were detected in low numbers.

- Gray whale M3 calls were detected at sites CA and KO (Figure 44). Calls occurred during September until October 1, 2013 at sites CA and KO, and again in December at site CA.
- While there were few detections, almost all detections occurred during daytime hours (Figure 45).
- Gray whale M3 calls have only been detected in previous recordings at site CA during a single hour on September 29, 2011 (Baumann-Pickering *et al*., 2012; Debich *et al*., 2013).

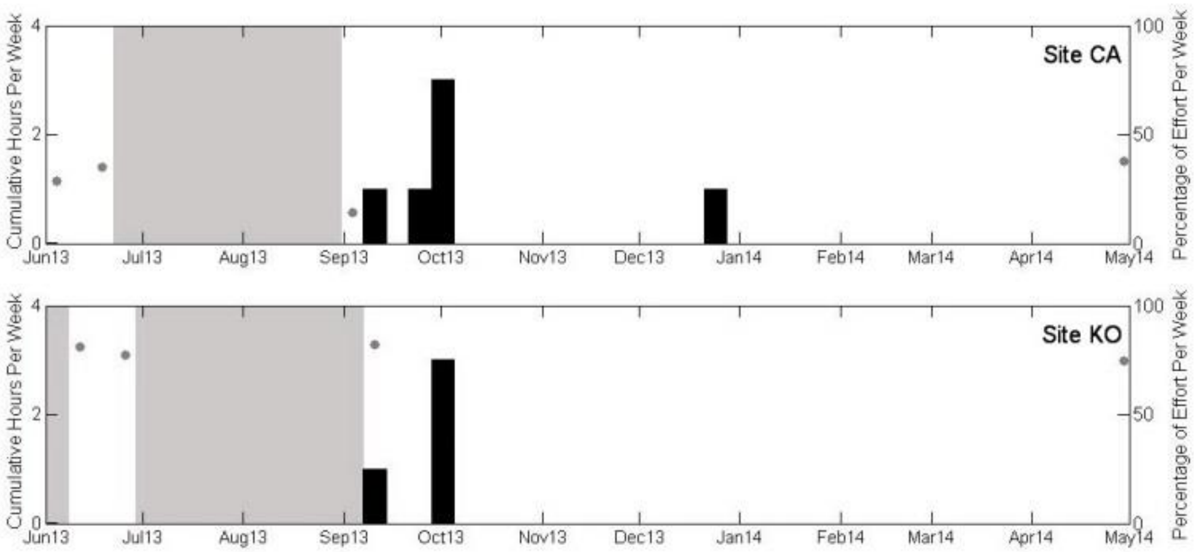

Figure 44. Weekly presence of gray whale M3 calls between June 2013 and May 2014 at sites CA (top), and KO (bottom). Effort markings are described in Figure 35.

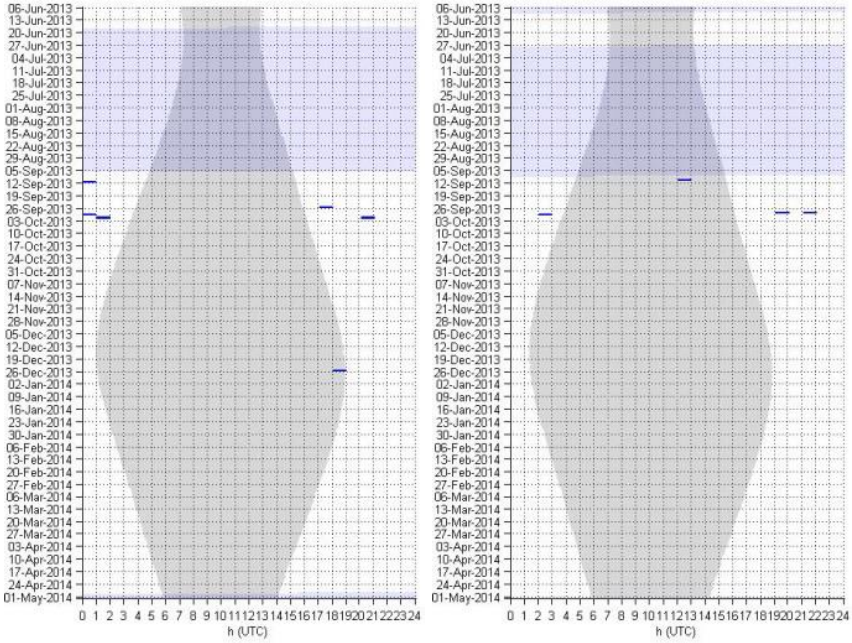

Figure 45. Gray whale M3 calls in hourly bins at sites CA (left) and KO (right). Effort markings are described in Figure 36.

Humpback Whales

Humpback whales were one of the most commonly detected baleen whales throughout the recordings.

- Humpback whale detections were high from late October 2013 through early January 2014 at sites CA and KO while they occurred in December 2013 through February 2014 at sites CB, PT, and QN (Figure 46). Overall, higher detections occurred at sites CA and KO than at other sites.
- The diel pattern suggests a preference for calling during nighttime hours (Figure 47).
- The substantial presence of humpback whales during the late fall at sites CA and KO, and at all sites during winter does not fit models of whale migration to subtropical or tropical waters during the winter breeding season. These data instead suggest that some whales remain in subpolar waters during the winter.
- These results are similar to earlier recordings; however, the brief decrease in detections that occurred in late January 2014 (this report) occurred earlier during the previous winter, in December 2012 (Debich *et al*., 2013).

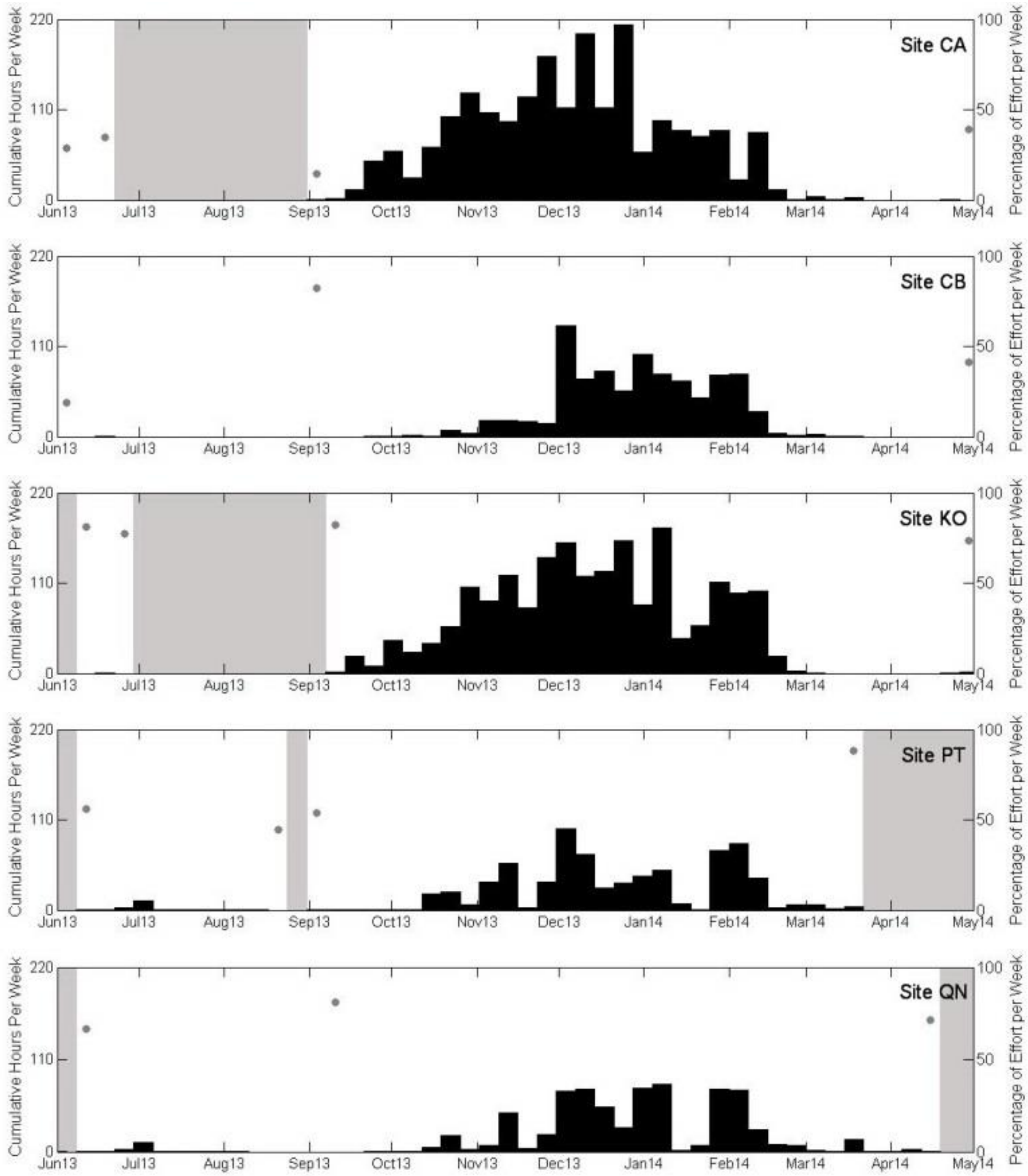

Figure 46. Weekly presence of humpback whale calls between June 2013 and May 2014 at sites CA (top), CB (second from top), KO (middle), PT (second from bottom), and QN (bottom). Effort markings are described in Figure 35.

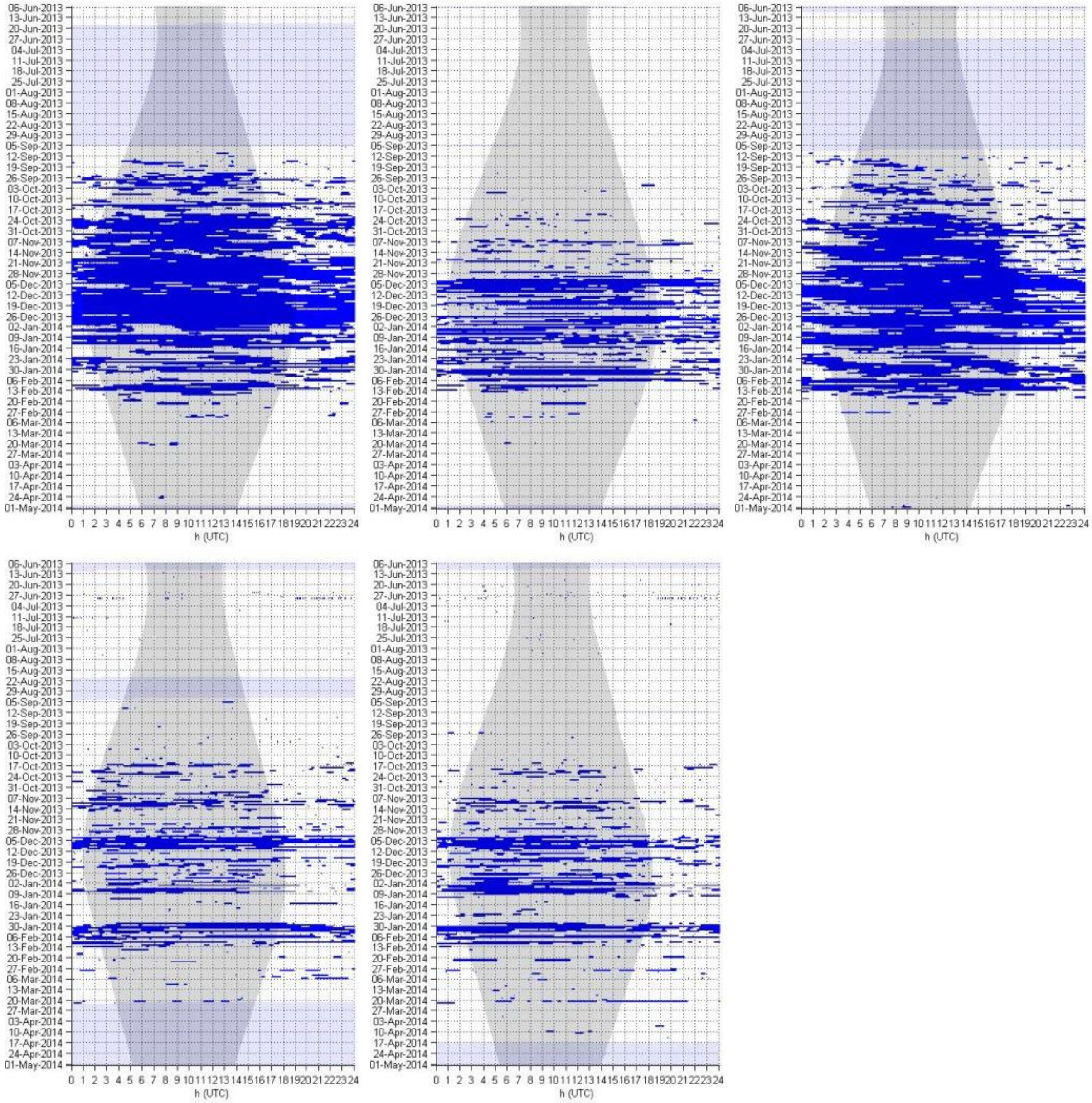

Figure 47. Humpback whale calls in one-minute bins at sites CA (top), CB (second from top), KO (middle), PT (second from bottom), and QN (bottom). Effort markings described in Figure 36.

North Pacific Right Whales

North Pacific right whale up calls were detected in very low numbers.

- North Pacific right whale up calls were detected at site QN in June and August, 2013 (Figure 48).
- Though there were few detections, each call was detected during daytime hours (Figure 49).
- North Pacific right whale upcalls have not been detected in previous recordings at these sites (Baumann-Pickering *et al*., 2012; Debich *et al*., 2013) and these are the first recording of this species in this part of the Gulf of Alaska (Širović *et al.*, in press).

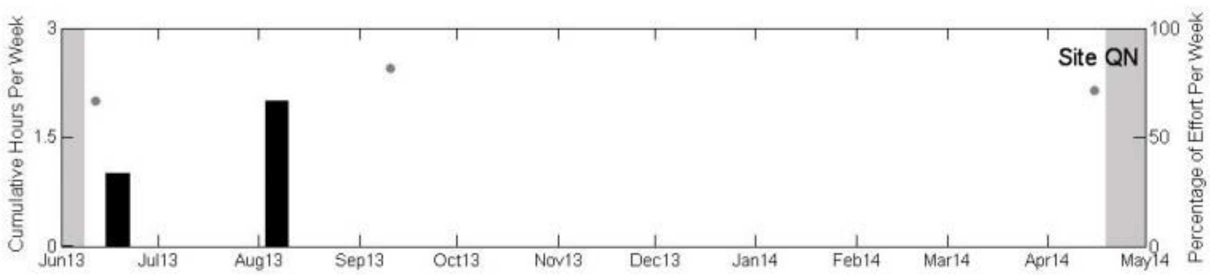

Figure 48. Weekly presence of North Pacific right whale up calls between June 2013 and May 2014 at site QN. Effort markings are described in Figure 35.

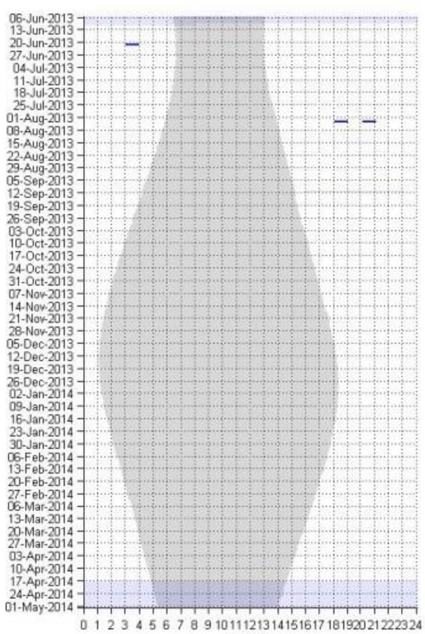

Figure 49. North Pacific right whale up calls in hourly bins at site QN. Effort markings are described in Figure 36.

Odontocetes

At least eight odontocete species were detected between June 2013 and May 2014: Risso's dolphins, Pacific white-sided dolphins, killer whales, sperm whales, Baird's beaked whales, Cuvier's beaked whales, Stejneger's beaked whales, and unidentified porpoise. No calls were detected for dwarf or pygmy sperm whales. More details of each species' presence at these sites are given below.

Unidentified Odontocetes

Signals that had characteristics of odontocete sounds, but could not be classified to species were grouped together as unidentified odontocetes.

- Very few unidentified odontocete signals were detected at site CA (Figure 50). Most of these detections were clicks greater than 20 kHz.
- Sites CB and QN had the most unidentified odontocete detections (Figure 50). Peaks in detections occurred in October 2013 and again in January 2014 at site CB, while peaks in detections occurred at site QN during June and November 2013 and again in late January through late March 2014. Most of these detections were clicks less than 20 kHz.
- Unidentified odontocete signals were detected throughout the recording duration at sites KO and PT (Figure 50). These detections were comprised of clicks less than 20 kHz and greater than 20 kHz.
- There was no discernable diel pattern for unidentified odontocetes (Figure 51).

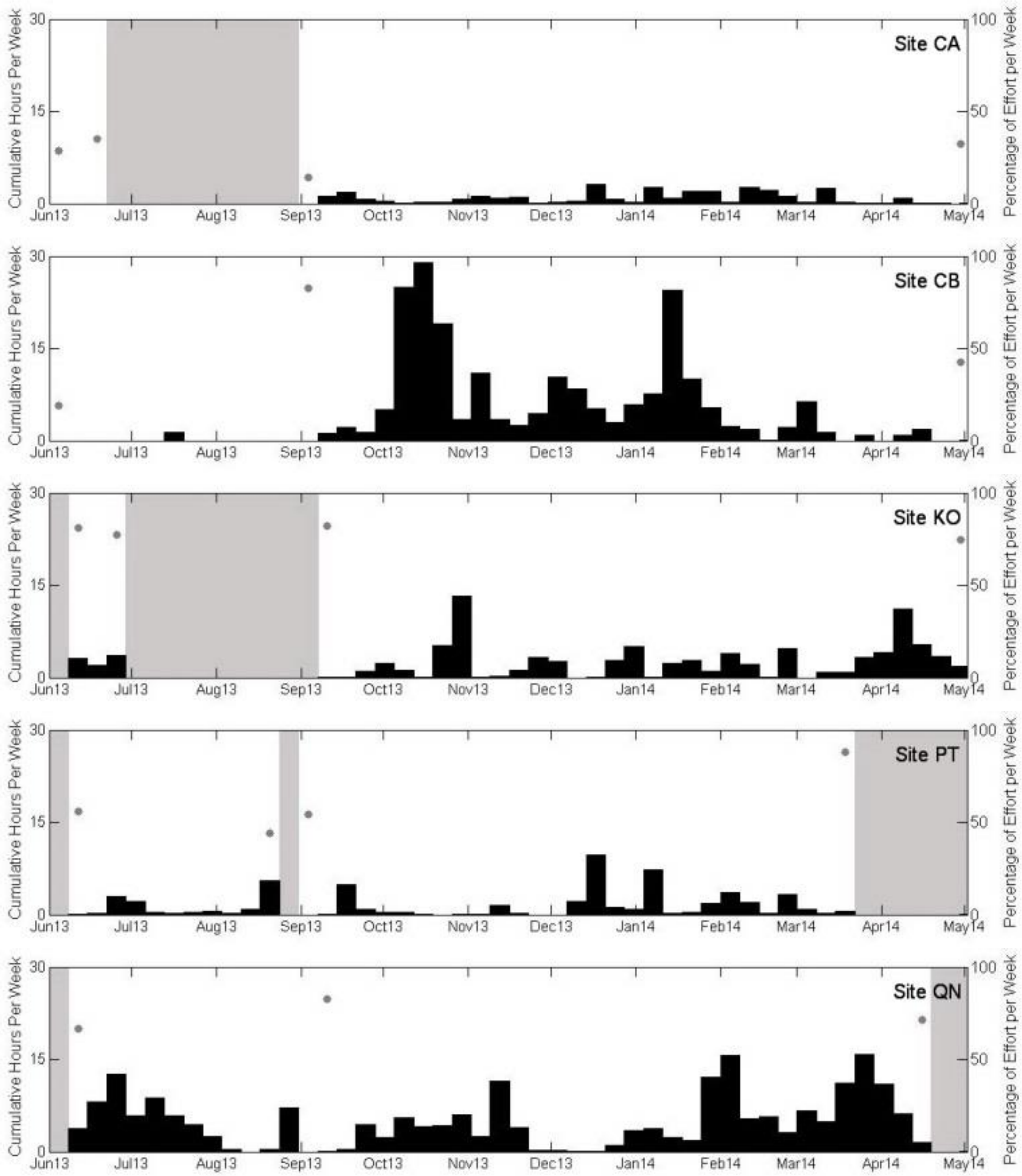

Figure 50. Weekly presence of unidentified odontocete signals between June 2013 and May 2014 at sites CA (top), CB (second from top), KO (middle), PT (second from bottom), and QN (bottom). Effort markings are described in Figure 35.

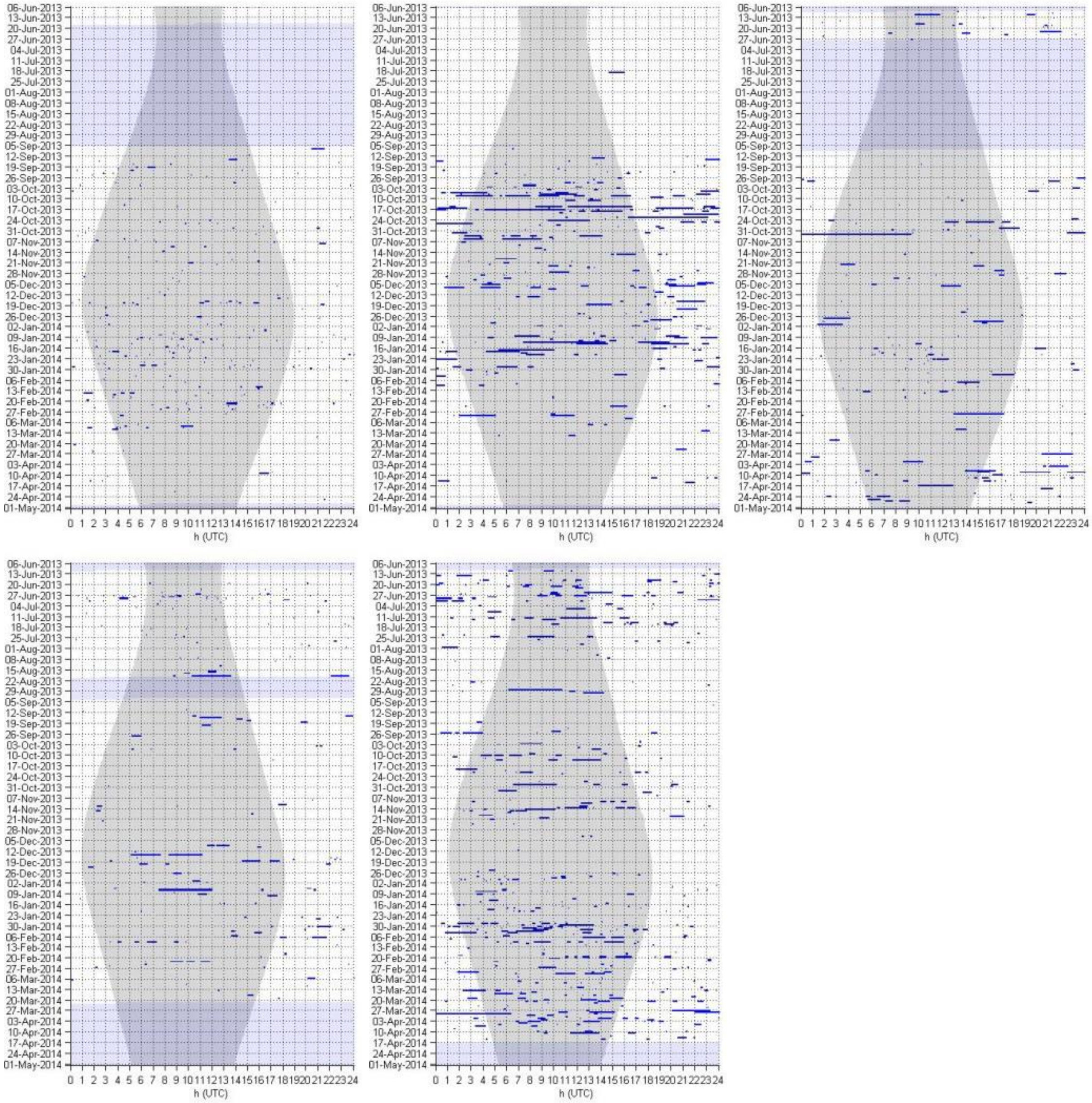

Figure 51. Unidentified odontocete signals in one-minute bins at sites CA (top left), CB (top middle), KO (top right), PT (bottom left), and QN (bottom right). Effort markings are described in Figure 36.

Risso's Dolphins

Risso's dolphin echolocation clicks were detected in low numbers at sites CA and KO.

- Sites CA and KO were the only sites with Risso's dolphin echolocation click detections (Figure 52). September 2013 was the only month in which Risso's dolphin clicks were detected.
- Although few clicks were detected, a possible diel pattern for Risso's echolocation clicks existed, with higher activity at night, indicating nighttime foraging (Figure 53).
- Risso's dolphin detections are uncommon in the GATMAA (Debich *et al*., 2013, Baumann-Pickering *et al*., 2012).

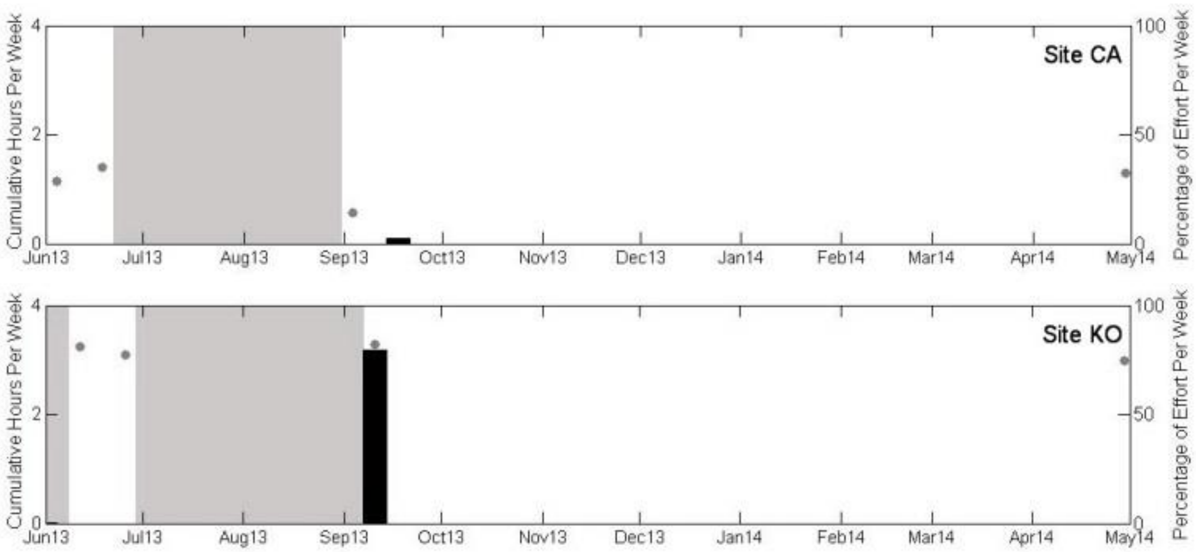

Figure 52. Weekly presence of Risso's dolphin echolocation clicks between June 2013 and May 2014 at sites CA (top) and KO (bottom). Effort markings are described in Figure 35.

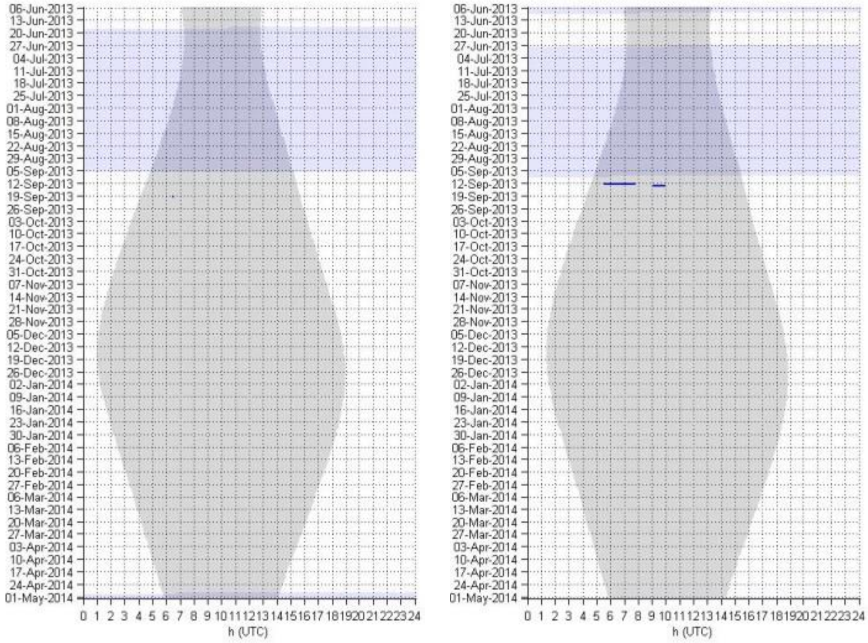

Figure 53. Risso's dolphin echolocation clicks at sites CA (left) and KO (right) in one-minute bins. Effort markings are described in Figure 36.

Pacific White-Sided Dolphins

Pacific white-sided dolphin echolocation clicks were detected at one site.

- Site PT was the only site at which Pacific white-sided dolphins were detected (Figure 54). September 2013 was the only month in which Pacific white-sided dolphins were detected.
- Click type A was the only type of Pacific white-sided dolphin echolocation click detected. Click type B was not detected at any of the sites.
- Almost all of the detections occurred during nighttime hours, indicating nighttime foraging (Figure 55).
- Pacific white-sided dolphin detections are uncommon in the GATMAA. They have not been reported in previous recording periods (Debich *et al*., 2013, Baumann-Pickering *et al*., 2012).

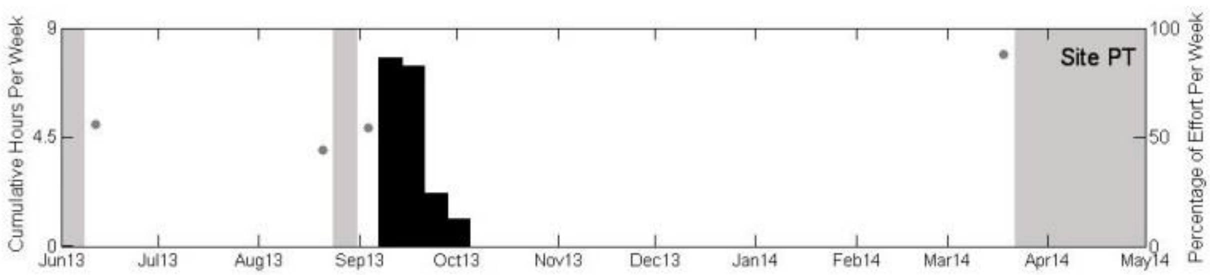

Figure 54. Weekly presence of Pacific white-sided dolphin type B echolocation clicks between June 2013 and May 2014 at site PT. Effort markings are described in Figure 35.

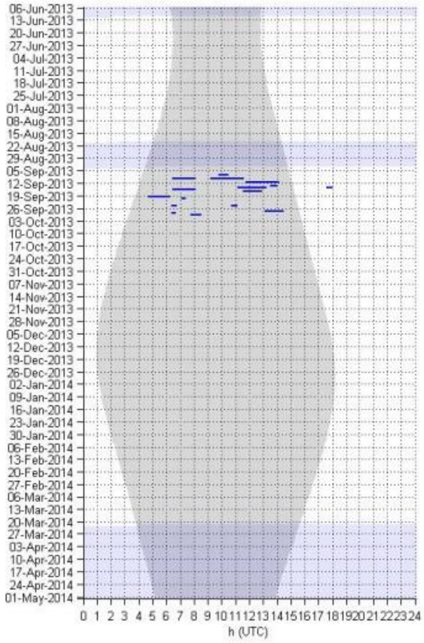

Figure 55. Pacific white-sided dolphin type B echolocation clicks at site PT in one-minute bins. Effort markings are described in Figure 36.

Killer Whales

Killer whales were detected at each site throughout June 2013 and May 2014.

- Killer whale clicks and whistles were more commonly detected than pulsed calls and HFM signals (Figure 56, Figure 58, Figure 60, and Figure 62).
- A potential peak in click detections occurred during winter months at sites CA and KO, while peaks in click detections at sites CB, PT, and QN occurred during the summer and early spring months (Figure 56). These differences could be a result of transient and resident killer whale populations using the shallow sites and deeper sites differently.
- There was no discernable diel pattern for killer whale clicks (Figure 57).
- HFM signals were detected in low numbers at sites KO, PT, and QN. There were no HFM detections at sites CA and CB (Figure 58).
- Though there were few HFM detections, most HFM calls occurred during daytime hours (Figure 59).
- Pulsed calls were detected in low numbers at sites CA, KO, and the least at PT. There were no pulsed call detections at sites CB or QN (Figure 60).
- There was no discernable diel pattern for killer whale pulsed calls (Figure 61).
- Killer whale whistles were most commonly detected at sites CA and KO (Figure 62). A peak in detections at site CA occurred in December 2013, while smaller peaks in whistle detections at site KO occurred in September/October 2013 and January/February and April 2014.
- There was no discernable diel pattern for killer whale whistles (Figure 63).
- These results are similar to those in previous monitoring periods (Debich *et al*., 2013, Baumann-Pickering *et al*., 2012).

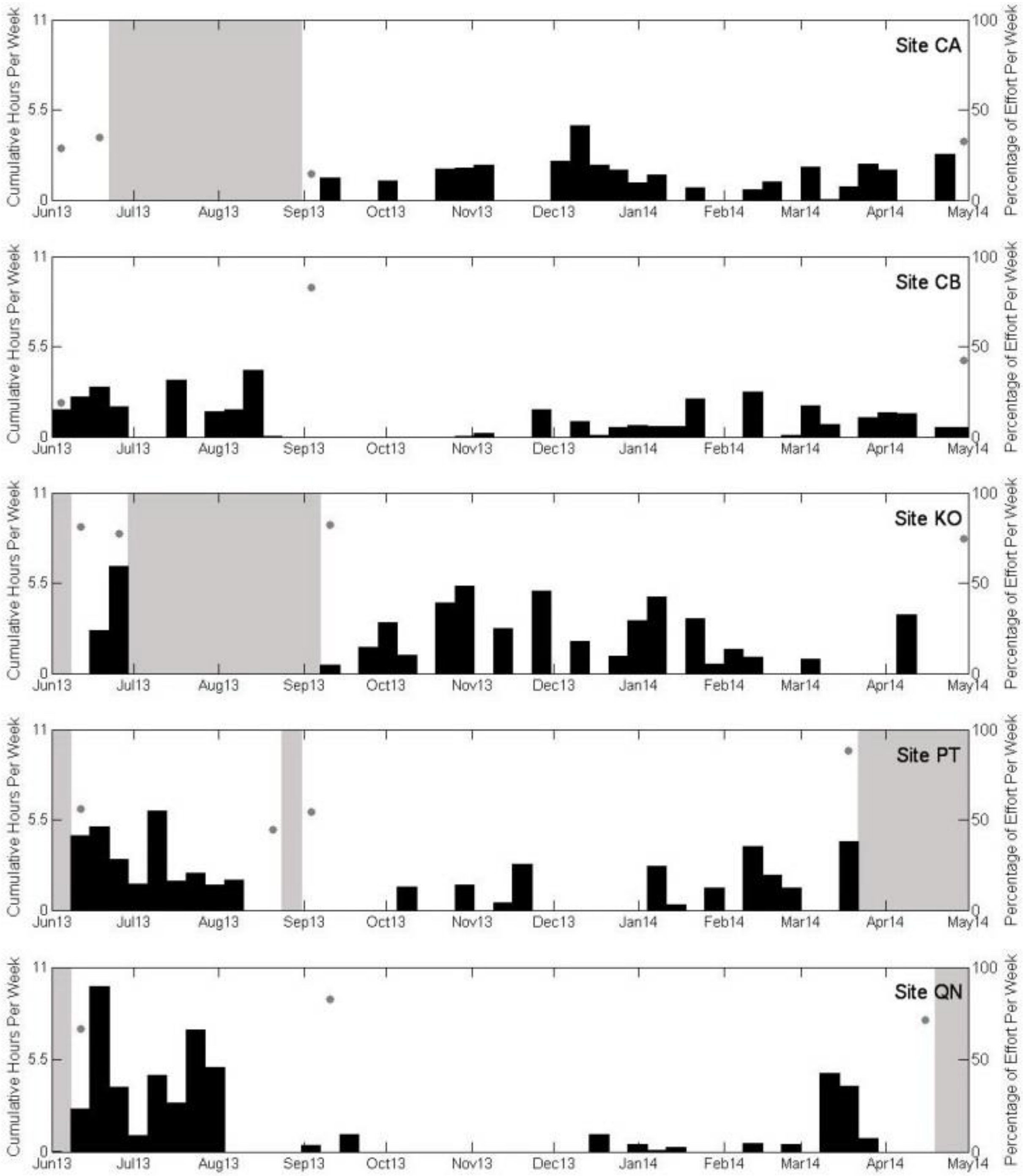

Figure 56. Weekly presence of killer whale echolocation clicks between June 2013 and May 2014 at sites CA (top), CB (second from top), KO (third from top), PT (second from bottom), and QN (bottom). Effort markings are described in Figure 35.

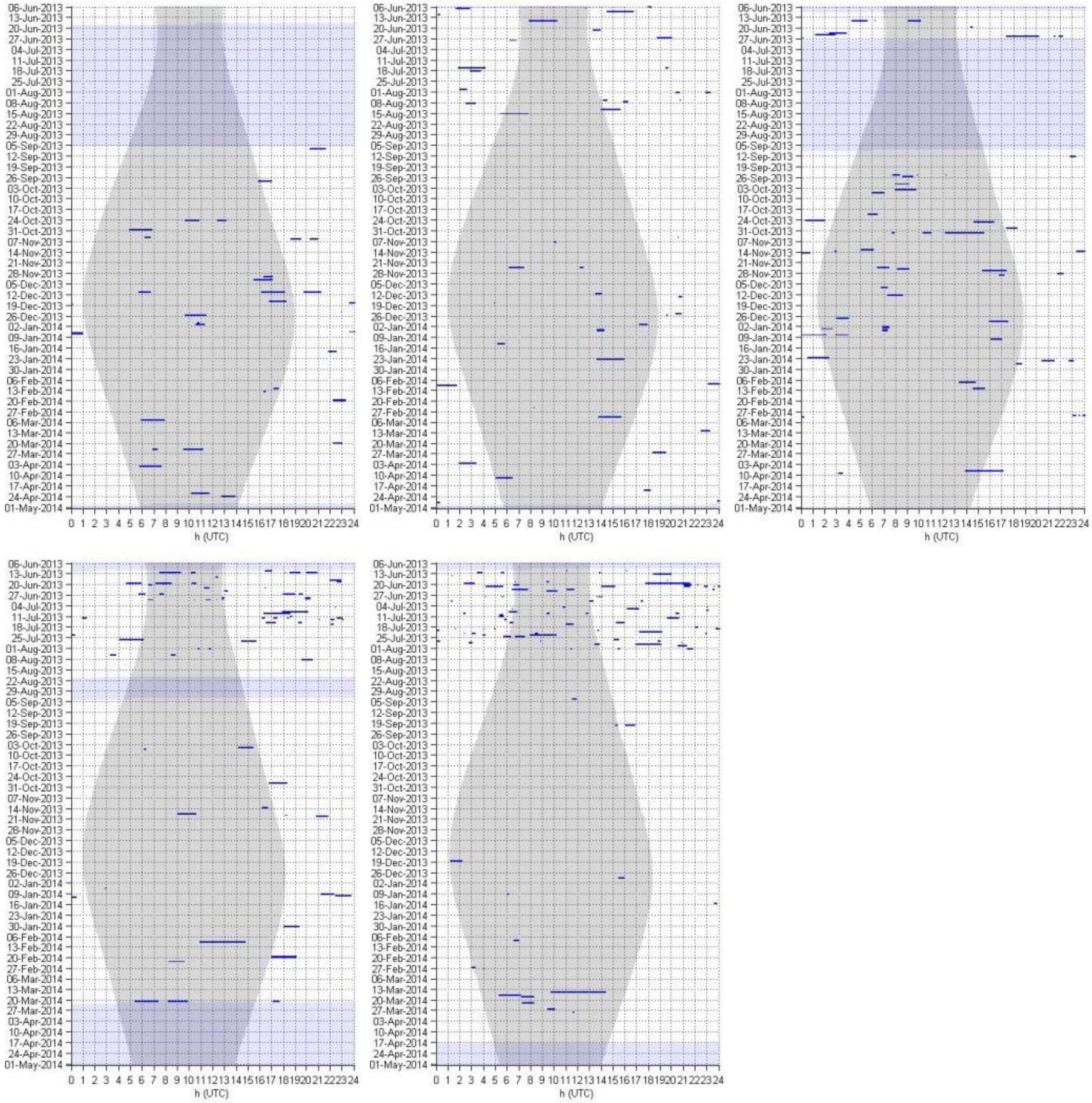

Figure 57. Killer whale echolocation clicks in one-minute bins at sites CA (top left), CB (top middle), KO (top right), PT (bottom left), and QN (bottom right). Effort markings are described in Figure 36.

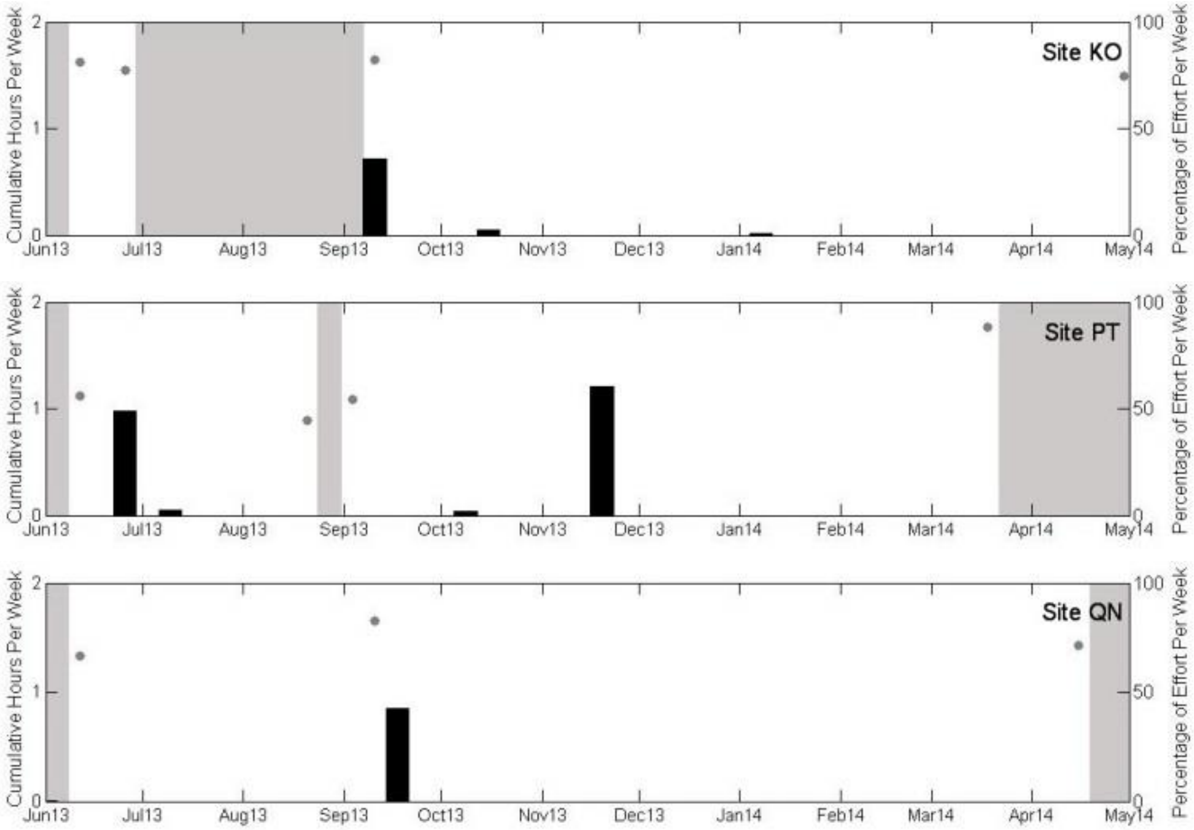

Figure 58. Weekly presence of killer whale HFM signals between June 2013 and May 2014 at sites KO (top), PT (middle), and QN (bottom). Effort markings are described in Figure 35.

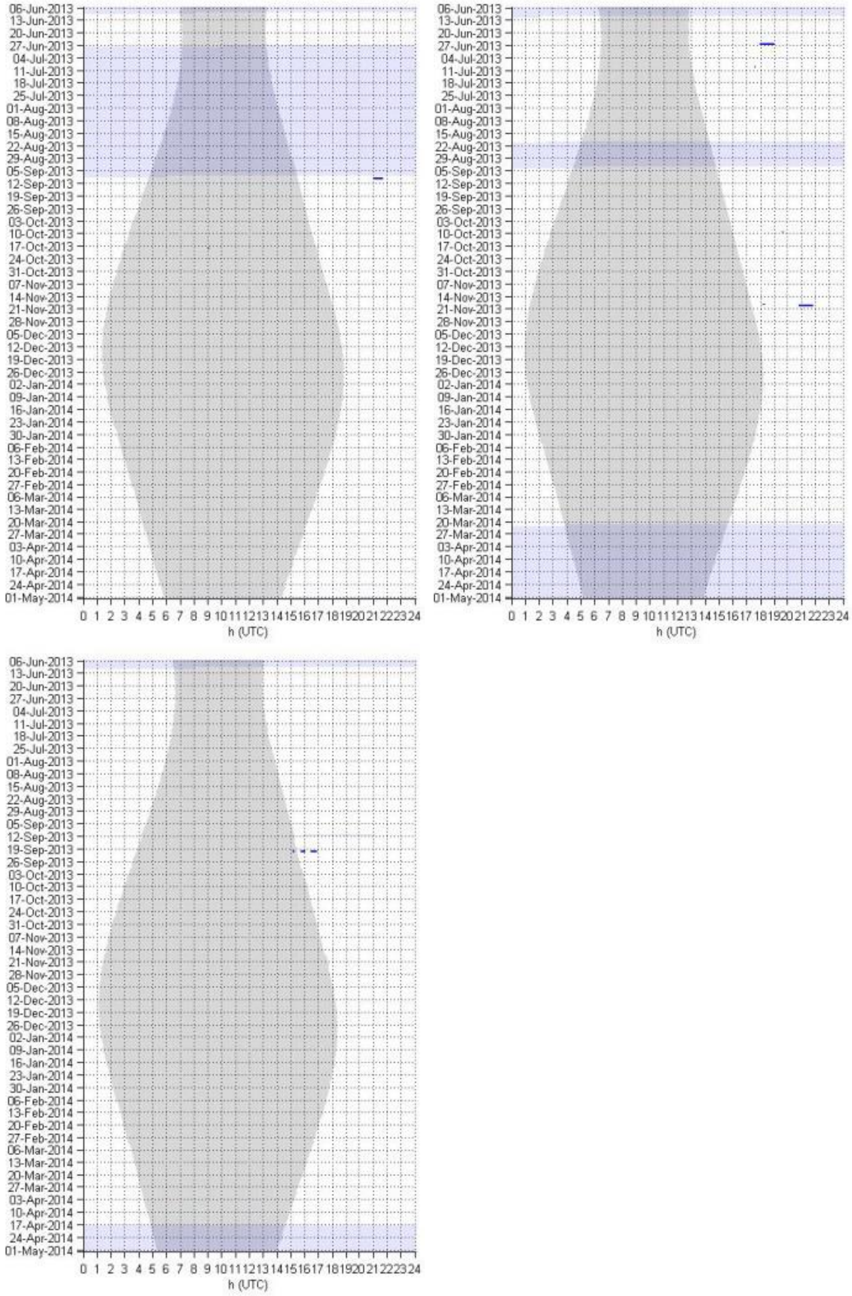

Figure 59. Killer whale HFM signals in one-minute bins at sites KO (left), PT (middle), and QN (right). Effort markings are described in Figure 36.

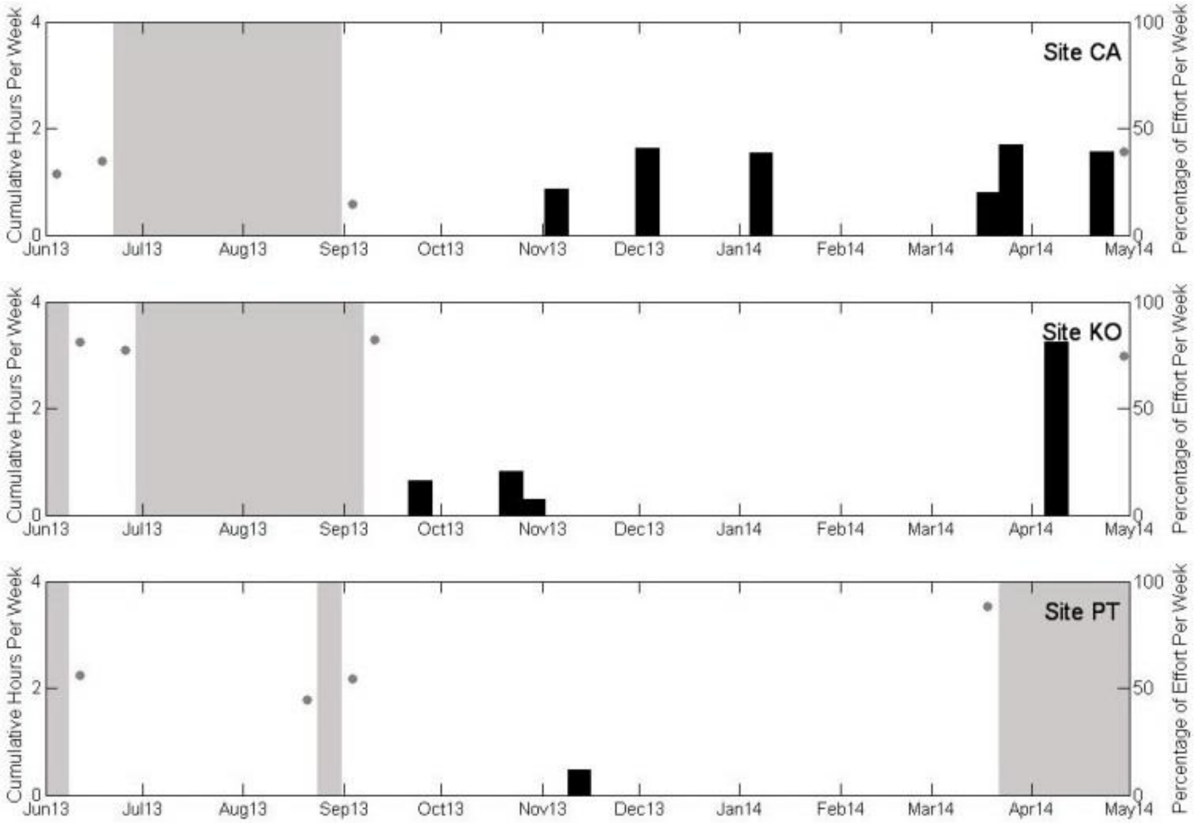

Figure 60. Weekly presence of killer whale pulsed calls between June 2013 and May 2014 at sites CA (top), KO (middle) and PT (bottom). Effort markings are described in Figure 35.

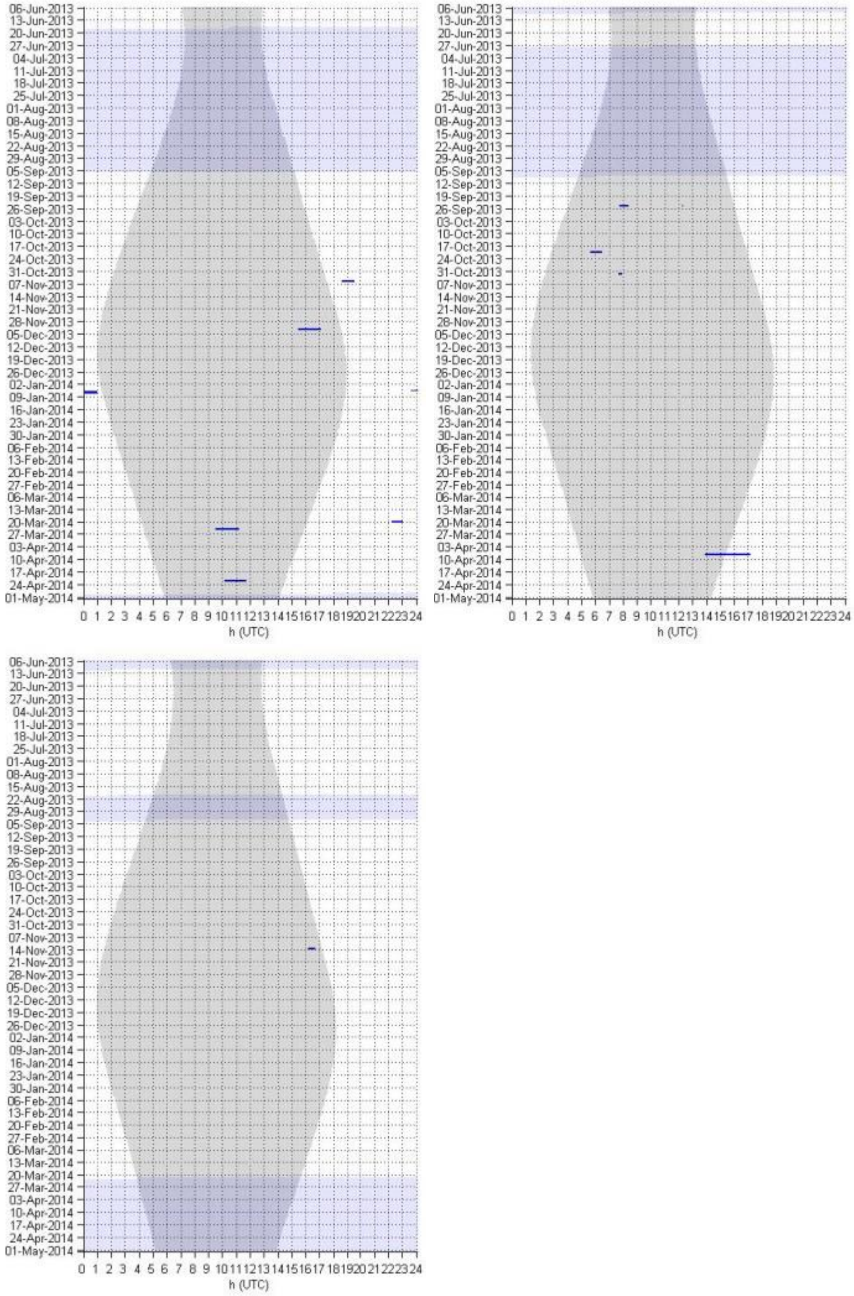

Figure 61. Killer whale pulsed calls in one-minute bins at sites CA (left), KO (middle), and PT (right). Effort markings are described in Figure 36.

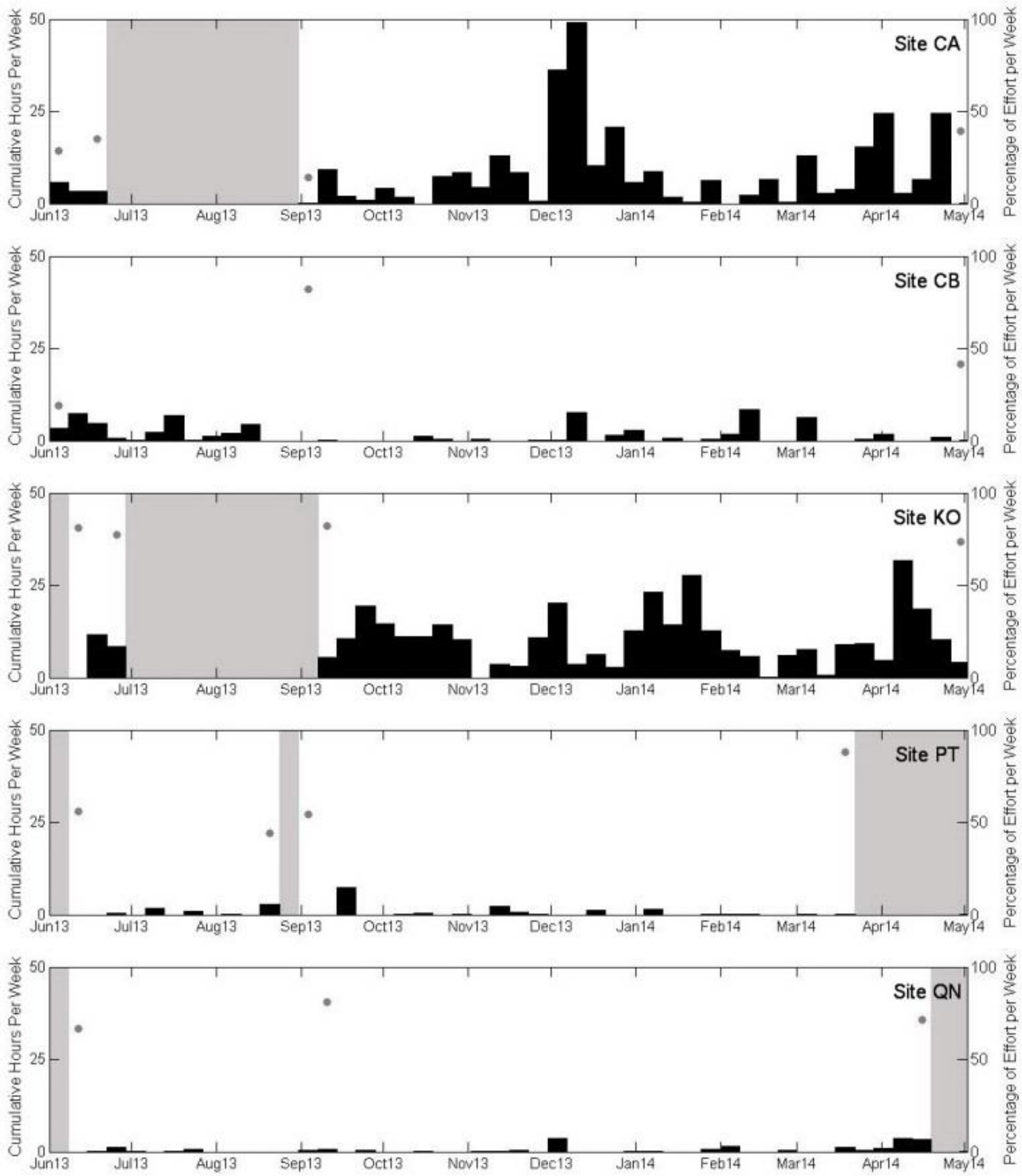

Figure 62. Weekly presence of killer whale whistles between June 2013 and May 2014 at sites CA (top), CB (second from top), KO (middle), PT (second from bottom), and QN (bottom). Effort markings are described in Figure 35.

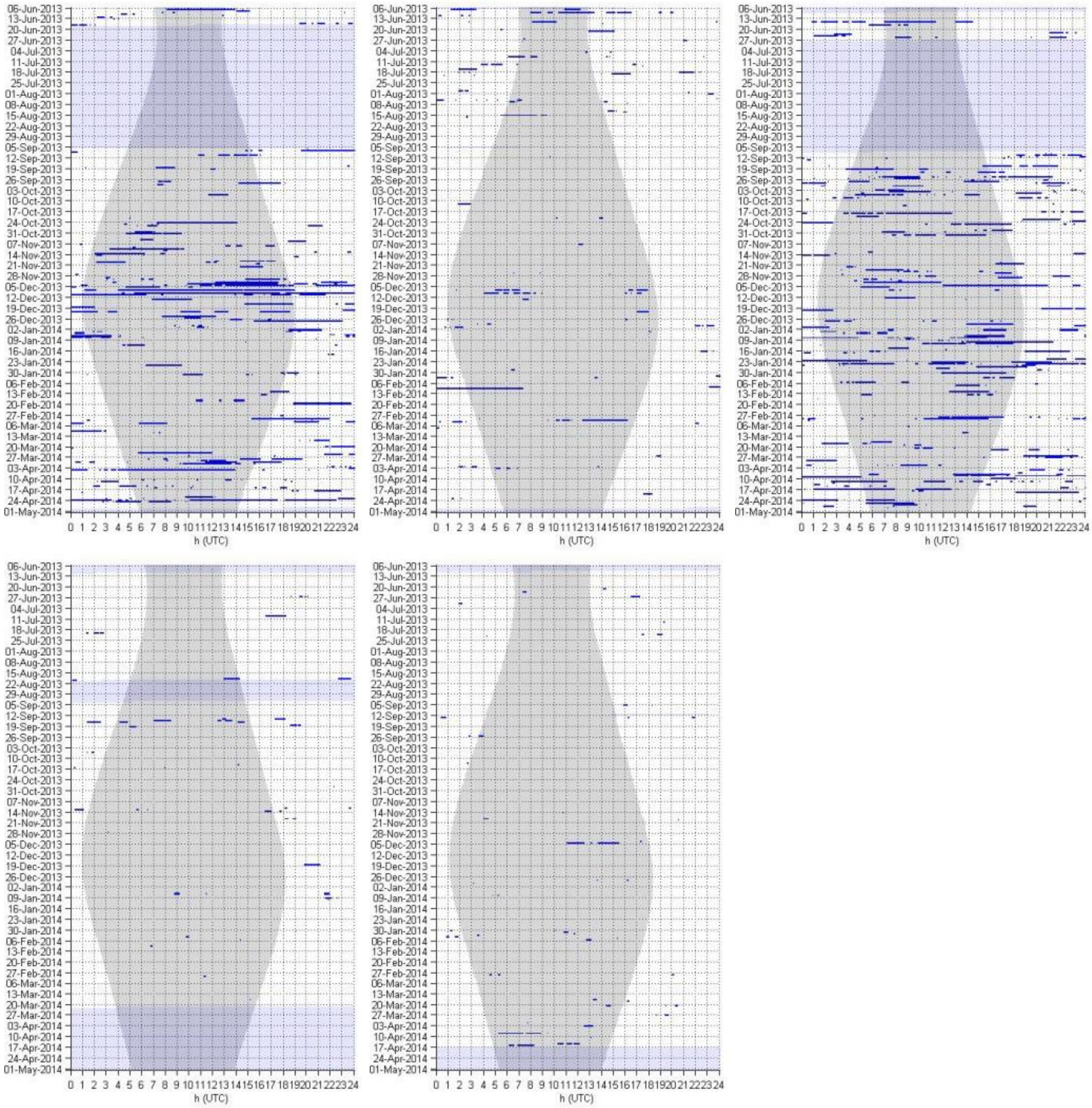

Figure 63. Killer whale whistles in one-minute bins at sites CA (top left), CB (top middle), KO (top right), PT (bottom left), and QN (bottom right). Effort markings are described in Figure 36.

Sperm Whales

Sperm whale echolocation clicks were detected at each site.

- Sperm whale clicks were most prevalent at site CB, with peaks in detections June through late-November 2013 (Figure 64). Site CA had the least number of detections.
- There was no discernable diel pattern for sperm whale clicks (Figure 65).
- Site KO had no sperm whale detections in the months of January through mid April 2014 (Figure 64).
- These results are similar to those in previous monitoring periods (Debich *et al*., 2013, Baumann-Pickering *et al*., 2012).

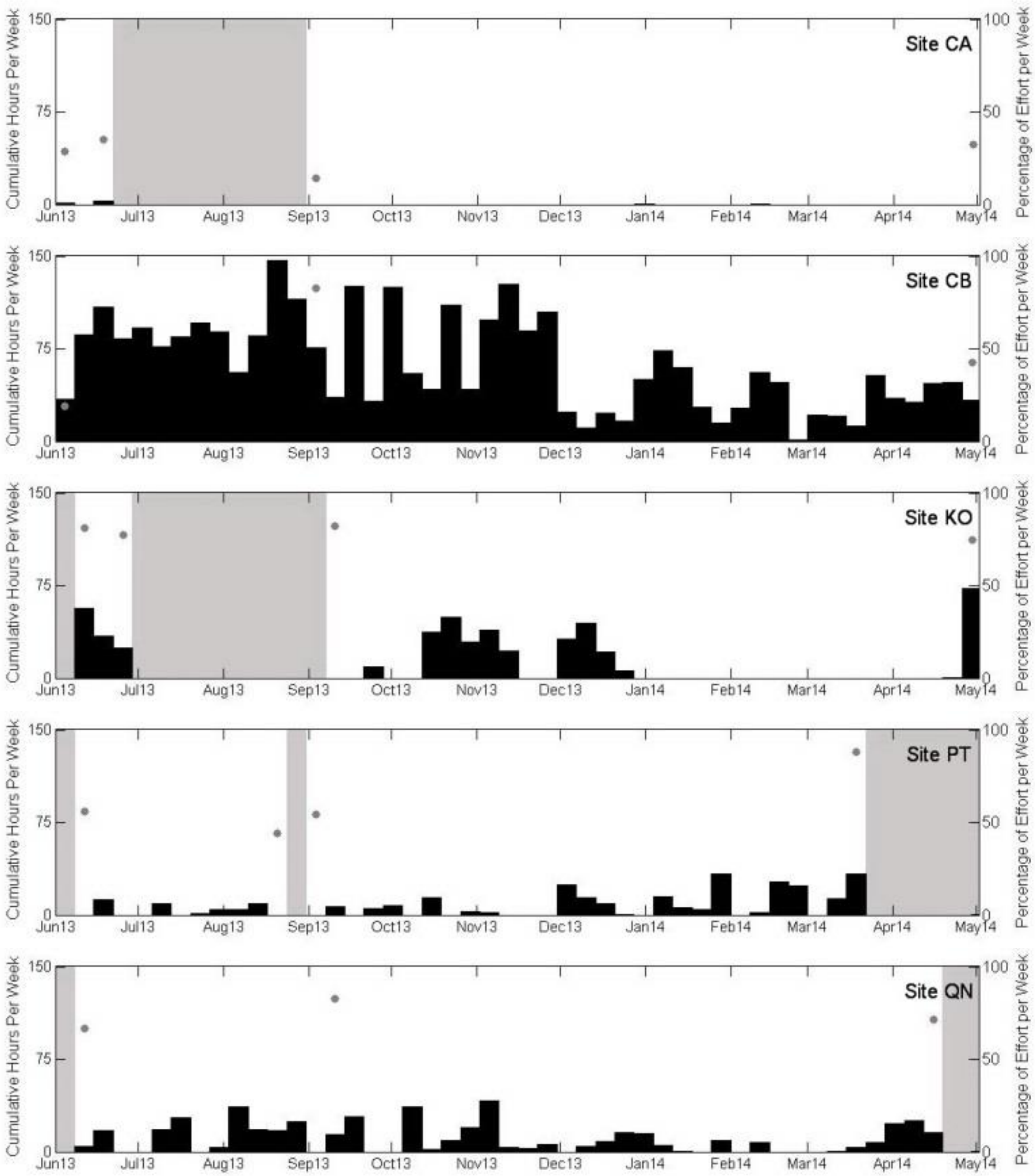

Figure 64. Weekly presence of sperm whale clicks between June 2013 and May 2014 at sites CA (top), CB (second from top), KO (middle), PT (second from bottom), and QN (bottom). Effort markings are described in Figure 35.

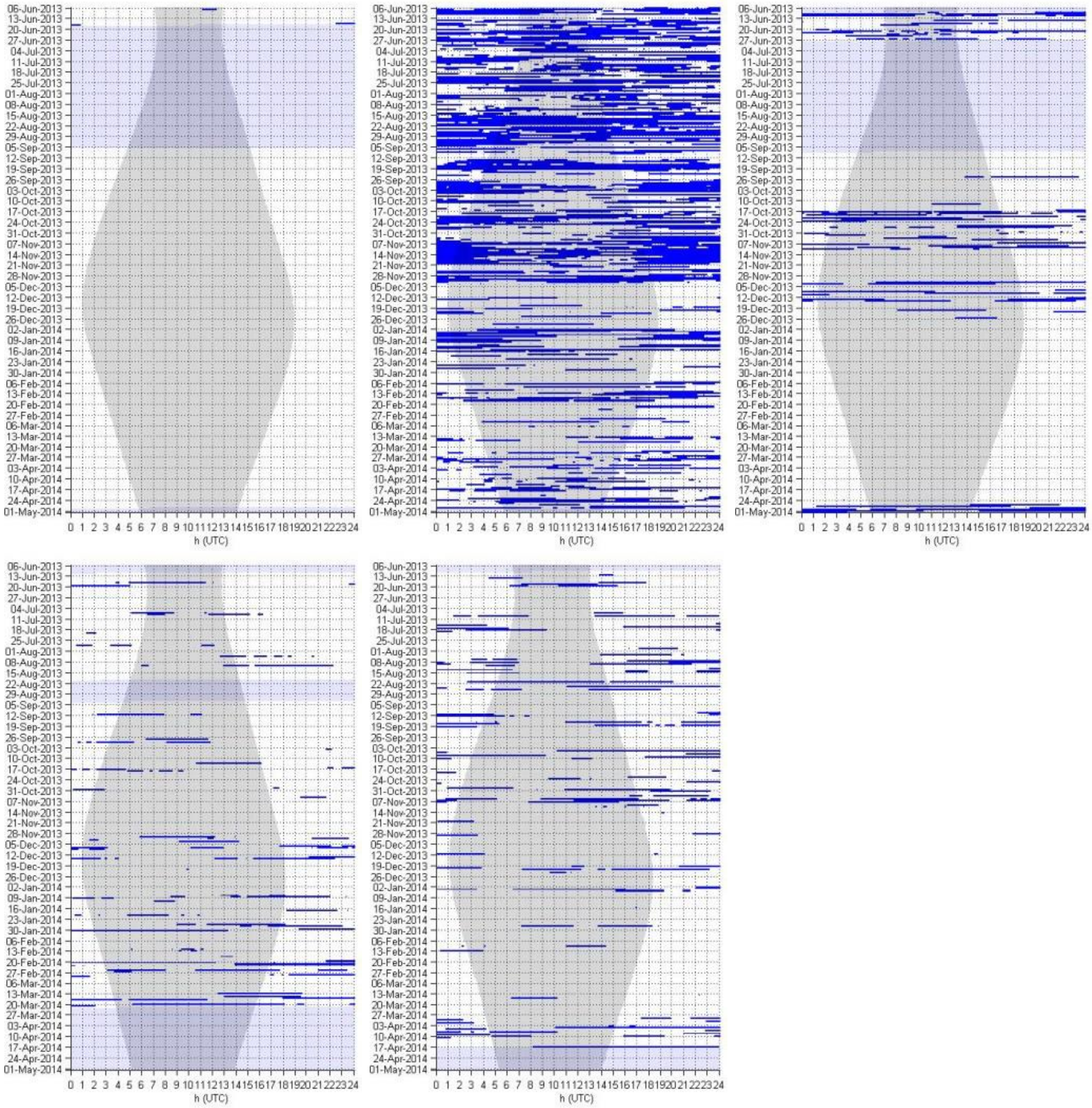

Figure 65. Sperm whale clicks in one-minute bins at sites CA (top left), CB (top middle), KO (top right), PT (bottom left), and QN (bottom right). Effort markings are described in Figure 36.

Baird's Beaked Whales

Baird's beaked whales were the most commonly detected beaked whale in the GATMAA.

- Baird's beaked whale echolocation signals were detected at sites CB, PT, and QN (Figure 66).
- Peaks in detections at site CB occurred during winter months while peaks in detections at site QN occurred during spring months (Figure 66).
- There was no discernable diel pattern for Baird's beaked whale echolocation signals (Figure 67).
- There were slightly more cumulative hours of detections per week of Baird's beaked whales during this monitoring period than previous ones (Debich *et al*., 2013, Baumann-Pickering *et al*., 2012).

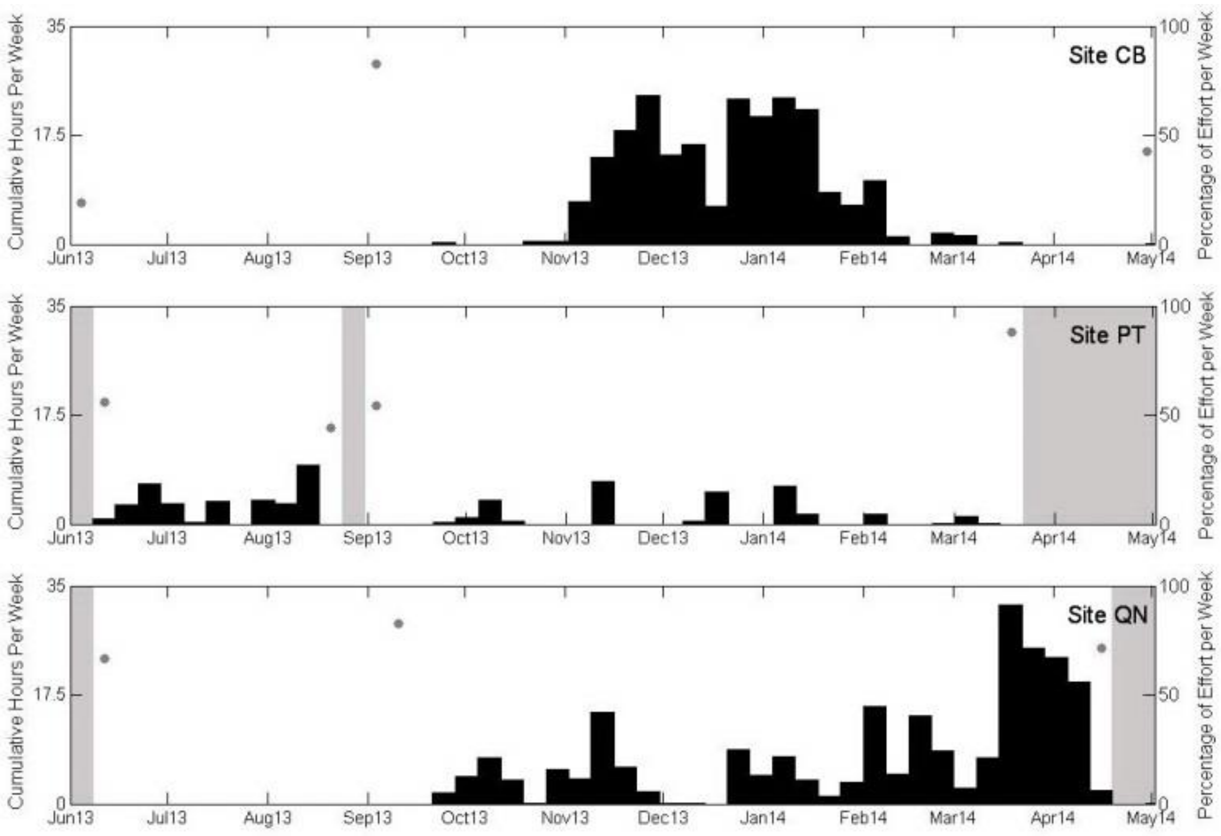

Figure 66. Weekly presence of Baird's beaked whale FM pulses between June 2013 and May 2014 at sites CB (top), PT (middle), and QN (bottom). Effort markings are described in Figure 35.

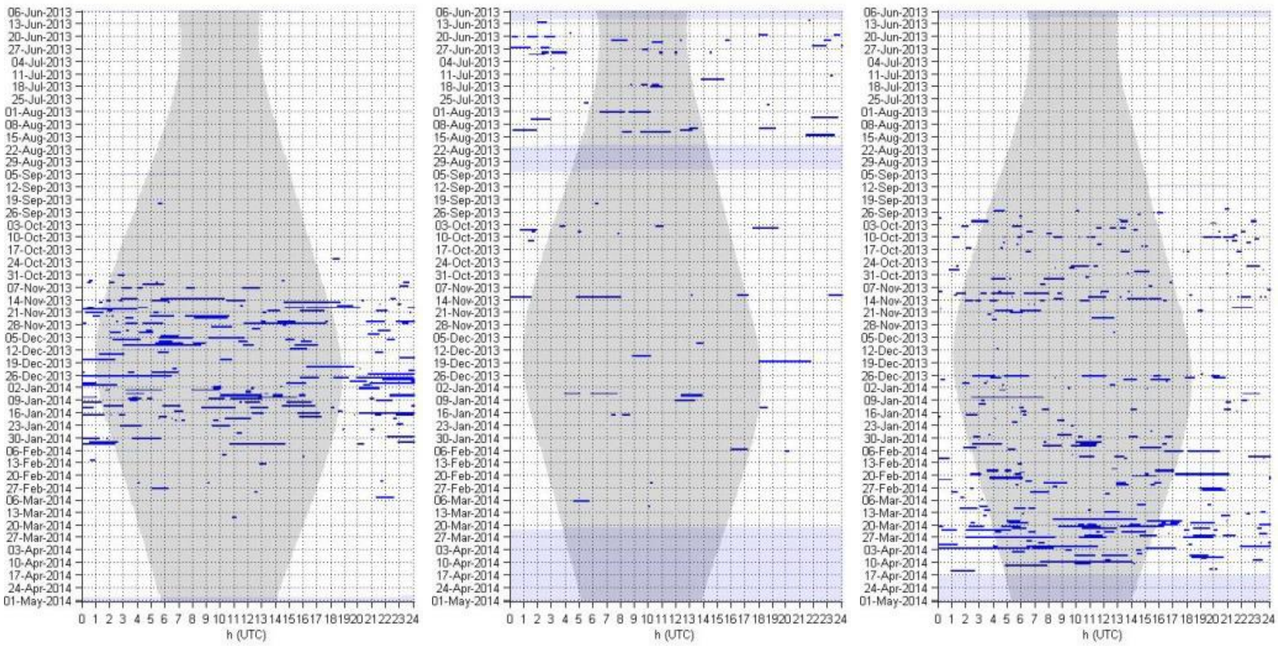

Figure 67. Baird's beaked whale FM pulses in one-minute bins at sites CB (left), PT (middle), and QN (right). Effort markings are described in Figure 36.

Cuvier's Beaked Whales

Cuvier's beaked whale FM pulses were detected at the three sites for which there was effort.

- Cuvier's beaked whale FM pulses were detected at sites CB, PT, and QN (Figure 68).
- Peaks in Cuvier's beaked whale detections occurred in the winter months (Figure 68).
- There was no discernable diel pattern for Cuvier's beaked whale detections (Figure 69).
- These results are similar to those in previous monitoring periods (Debich *et al*., 2013, Baumann-Pickering *et al*., 2012).

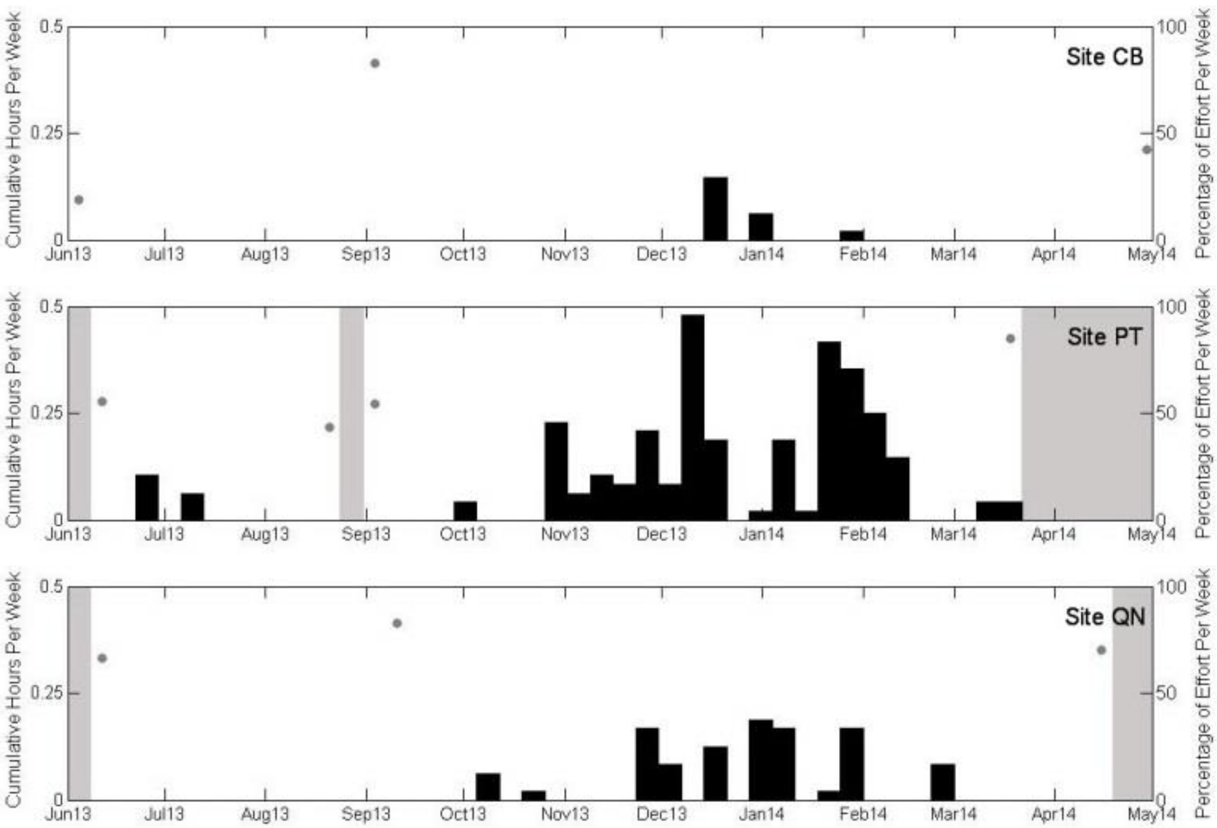

Figure 68. Weekly presence of Cuvier's beaked whale FM pulses between June 2013 and May 2014 at sites CB (top), PT (middle) and QN (bottom). Effort markings are described in Figure 35.

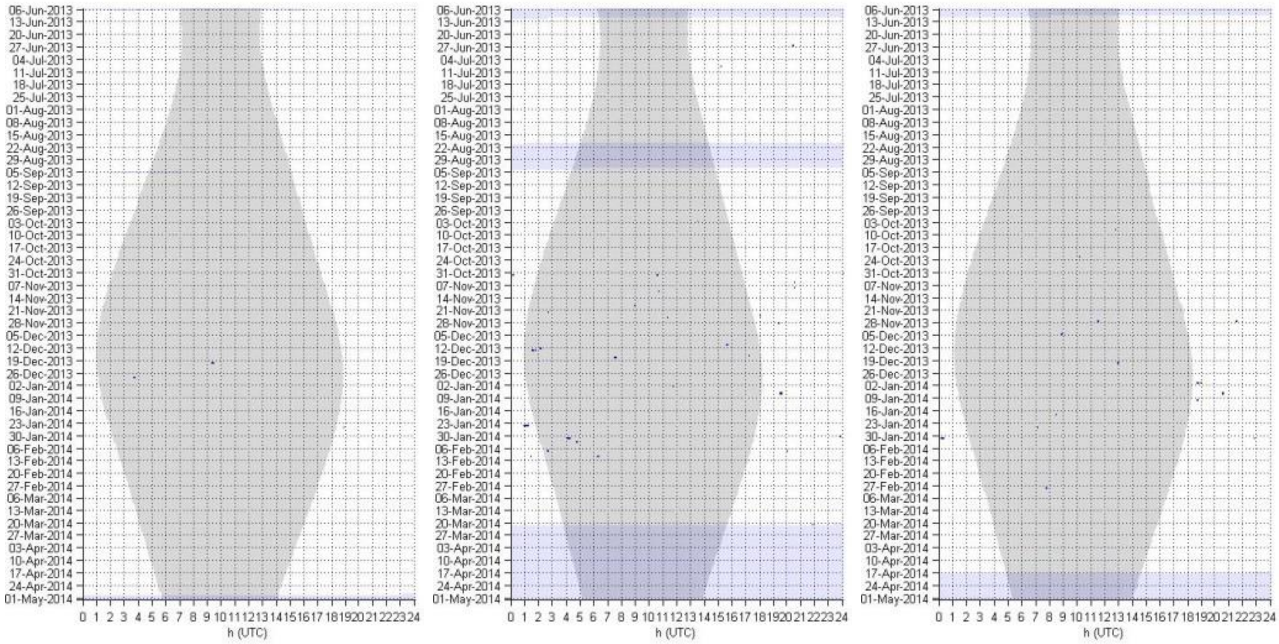

Figure 69. Cuvier's beaked whale FM pulses in one-minute bins at sites CB (left), PT (middle), and QN (right). Effort markings are described in Figure 36.

Stejneger's Beaked Whales

Stejneger's beaked whale FM pulses were detected at the three sites for which there was effort.

- Stejneger's beaked whale FM pulses were detected at sites CB, PT, and QN (Figure 70).
- Stejneger's beaked whale detections were most prevalent at site CB, with a peak in detections in September 2013 and lower detection rates from June through August 2013 (Figure 70).
- There was no discernable diel pattern for Stejneger's beaked whale detections (Figure 71).
- There were slightly fewer detections during this monitoring period compared to previous monitoring periods (Debich *et al.*, 2013, Baumann-Pickering *et al.*, 2012).

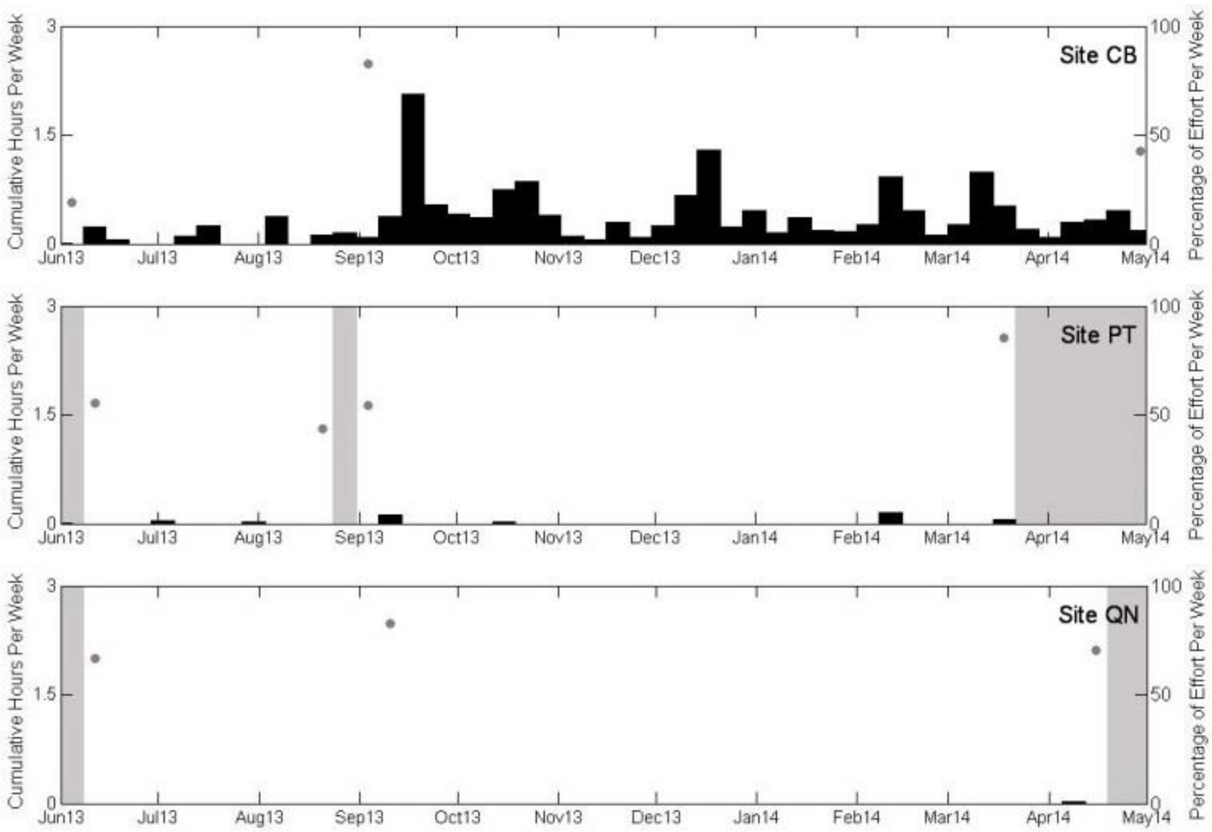

Figure 70. Weekly presence of Stejneger's beaked whale FM pulses between June 2013 and May 2014 at sites CB (top), PT (middle), and QN (bottom). Effort markings are described in Figure 35.

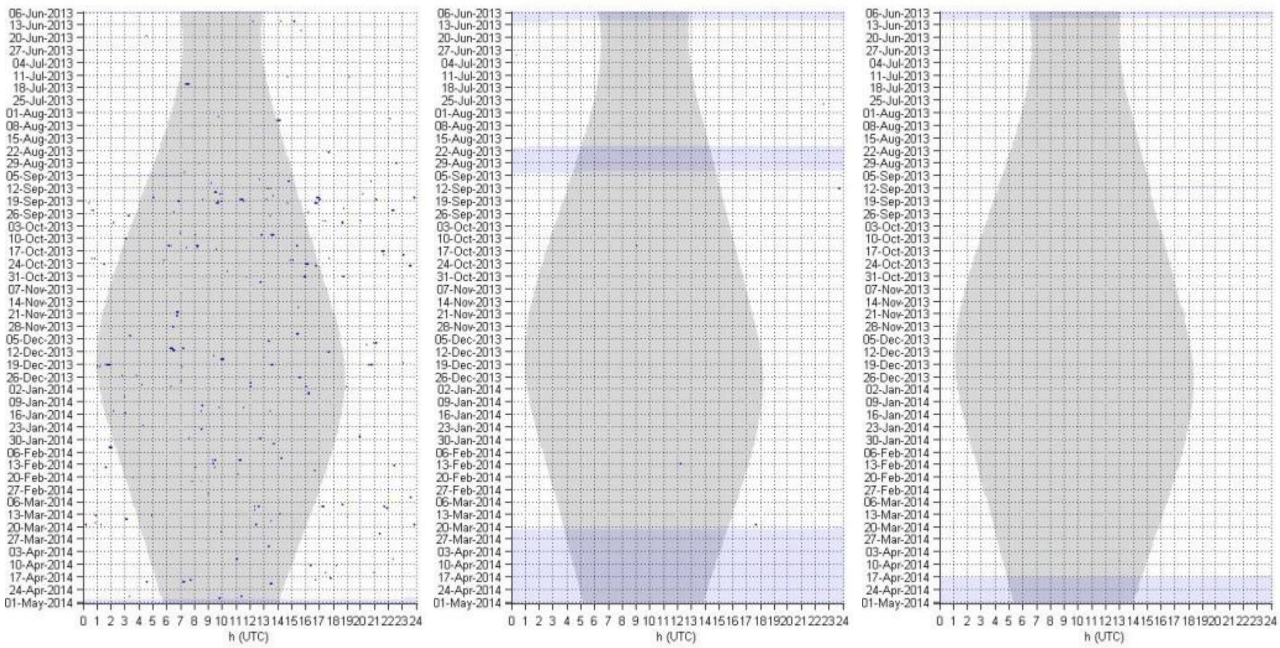

Figure 71. Stejneger's beaked whale FM pulses in one-minute bins at sites CB (left), PT (middle), and QN (right). Effort markings are described in Figure 36.

Unidentified Porpoise

Unidentified porpoise clicks were detected at sites CA, CB, KO, and PT.

- Sites CA and KO had the highest occurrence of unidentified porpoise clicks. Very few porpoise clicks were detected at sites CB and PT (Figure 72).
- Unidentified porpoise click detections peaked between January and March 2014 at site CA (Figure 72).
- There was no discernable diel pattern for unidentified porpoise clicks (Figure 73).
- These results are similar to those in previous monitoring periods (Debich *et al*., 2013, Baumann-Pickering *et al*., 2012).

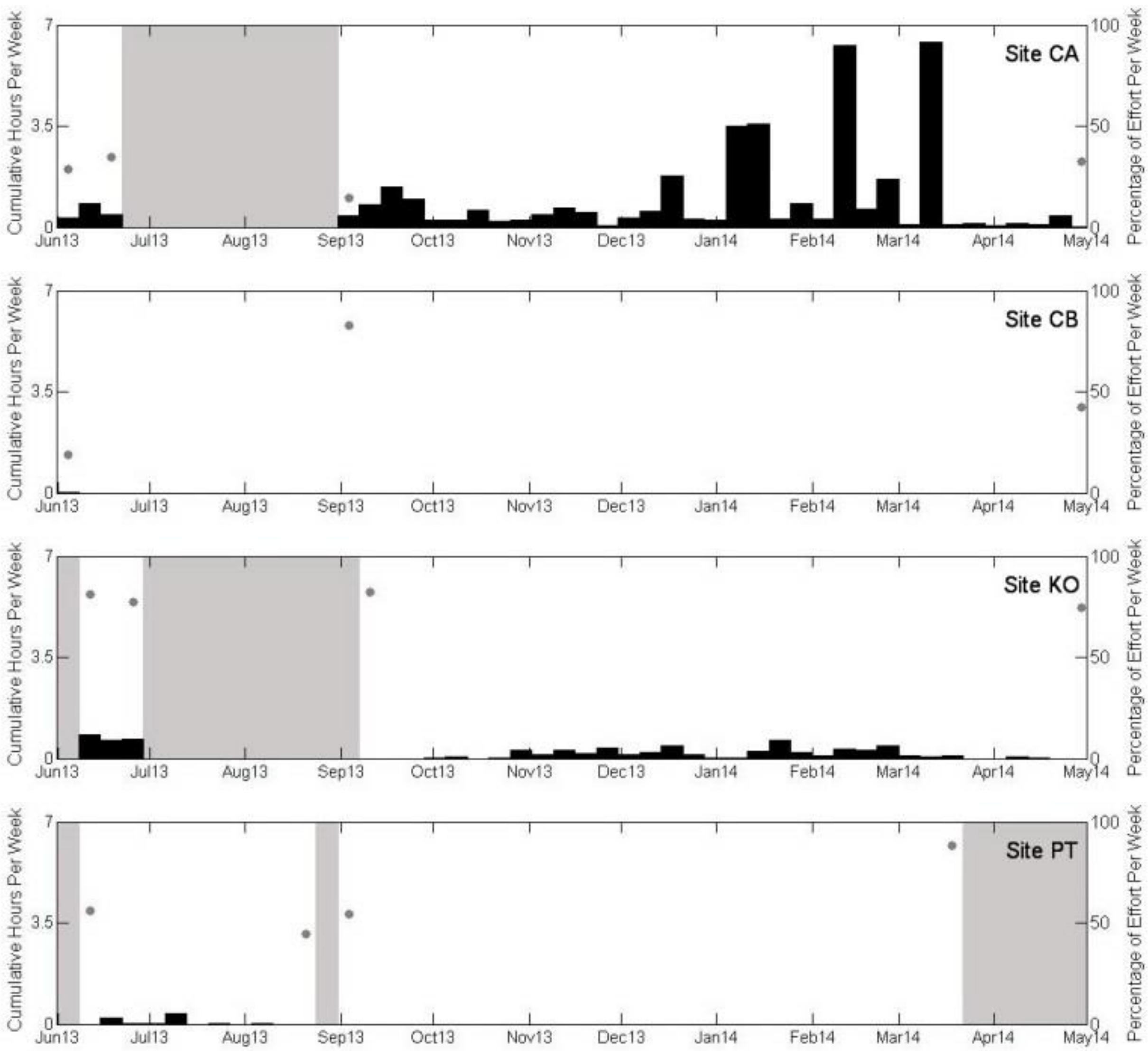

Figure 72. Weekly presence of unidentified porpoise echolocation clicks between June 2013 and May 2014 at sites CA (top), CB (second from top), KO (second from bottom), and PT (bottom). Effort markings are described in Figure 35.

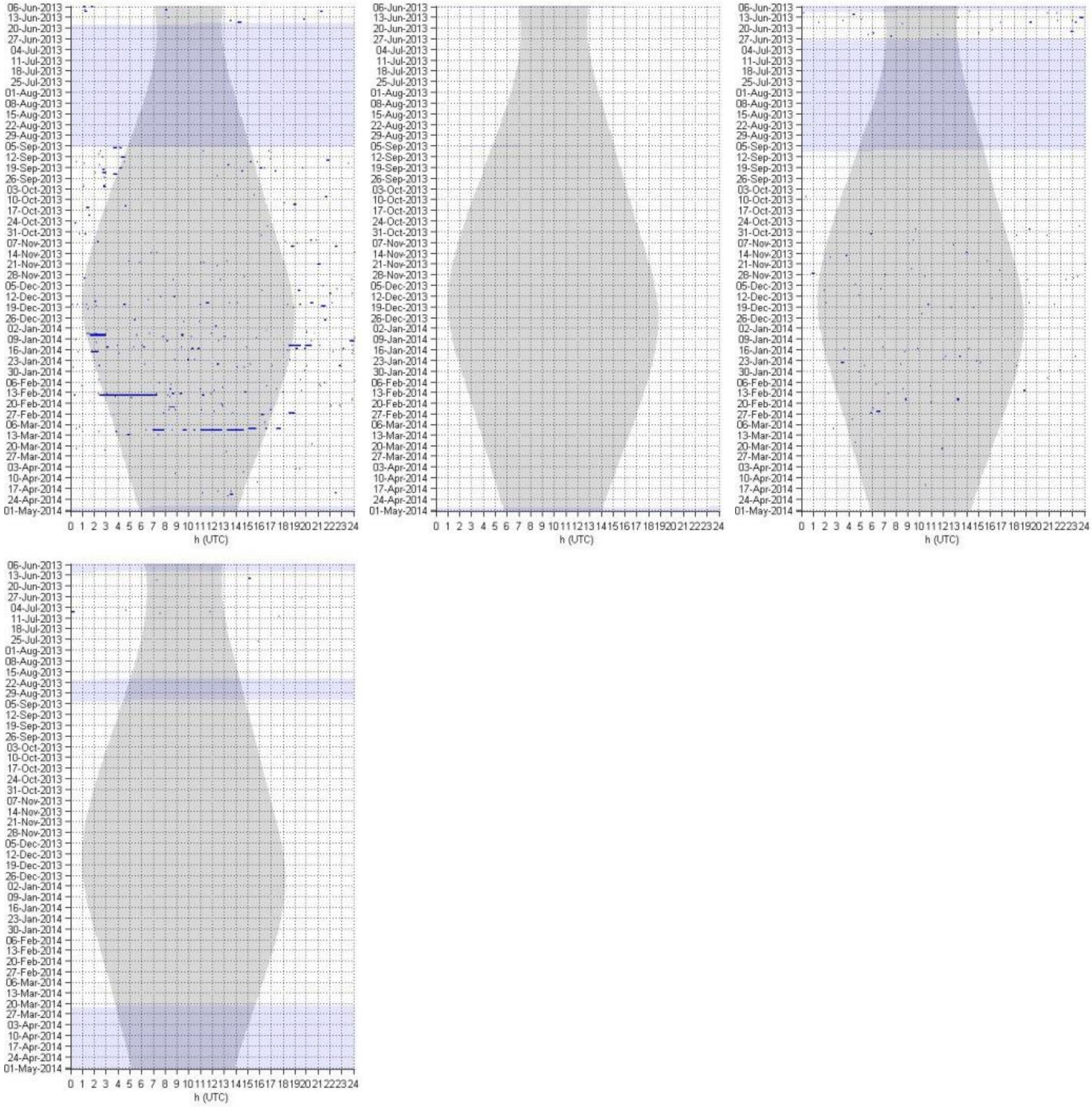

Figure 73. Unidentified porpoise echolocation clicks in one-minute bins at sites CA (top left), CB (top middle), KO (top right), and PT (bottom left). Effort markings are described in Figure 36.

Anthropogenic Sounds

Four types of anthropogenic sounds were detected in the GATMAA between June 2013 and May 2014: broadband ship noise, echosounders, LFA sonar, and explosions. There were no MFA detections.

Broadband Ship Noise

Broadband ship noise was a common anthropogenic sound in the GATMAA.

- Peaks in broadband ship noise occurred in late March and early April 2014 at site CA, late June late fall 2013 at site KO, and in June 2013 and February 2014 at site QN (Figure 74).
- There was a peak in detections beginning at or slightly before sunrise, continuing throughout the daytime hours, at site CB (Figure 75).
- In general, there were more broadband ship detections during this monitoring period than previous monitoring periods (Debich *et al*. 2013, Baumann-Pickering *et al*., 2012).

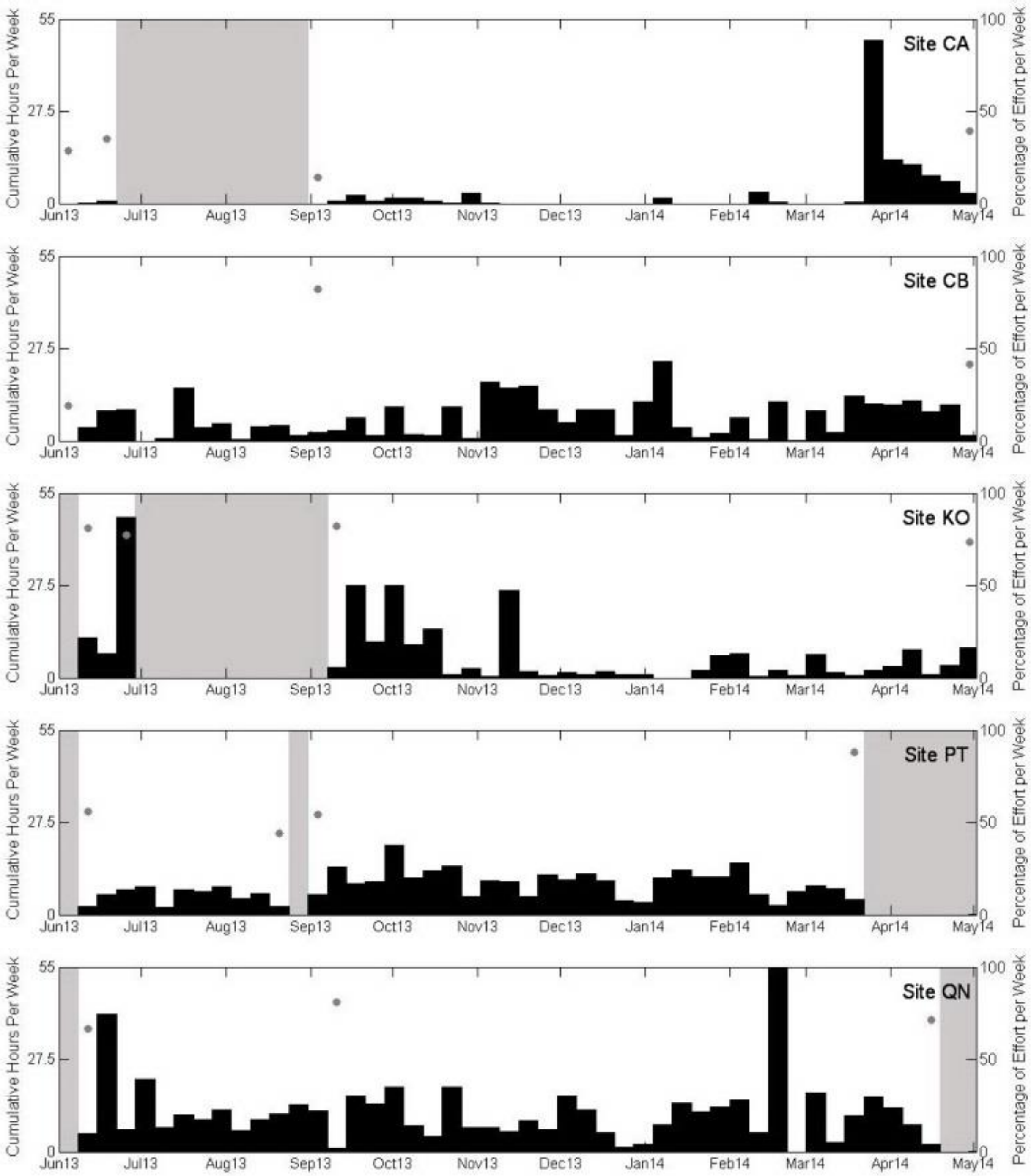

Figure 74. Weekly presence of broadband ships between June 2013 and May 2014 at sites CA (top), CB (second from top), KO (middle), PT (second from bottom), and QN (bottom). Effort markings are described in Figure 35.

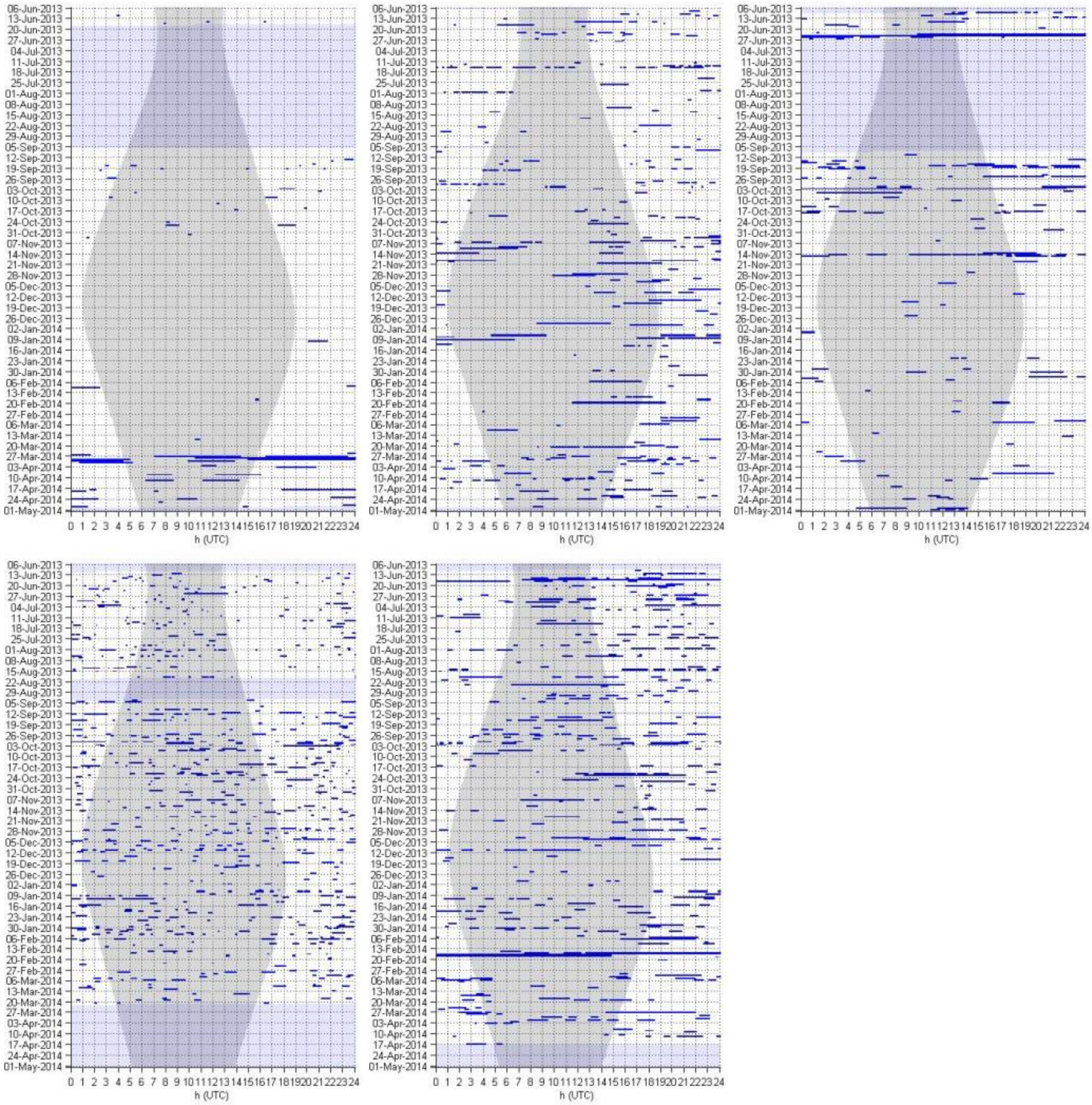

Figure 75. Broadband ship noise in one-minute bins at sites CA (top left), CB (top middle), KO (top right), PT (bottom left), and QN (bottom right). Effort markings are described in Figure 36.

Low-Frequency Active Sonar

LFA was detected in low numbers in the GATMAA.

- Site QN was the only site with LFA detections. Detections peaked in June 2013 (Figure 76).
- There were no detections after July 2013.
- Most detections occurred during daytime hours (Figure 77).

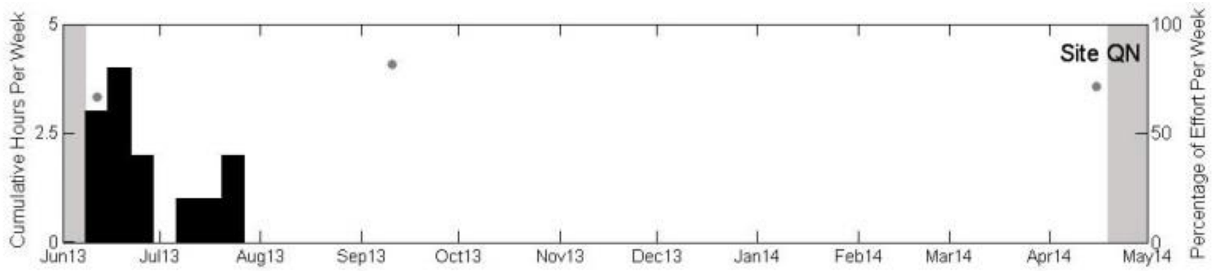

Figure 76. Weekly presence of LFA between June 2013 and May 2014 at site QN. Effort markings are described in Figure 35.

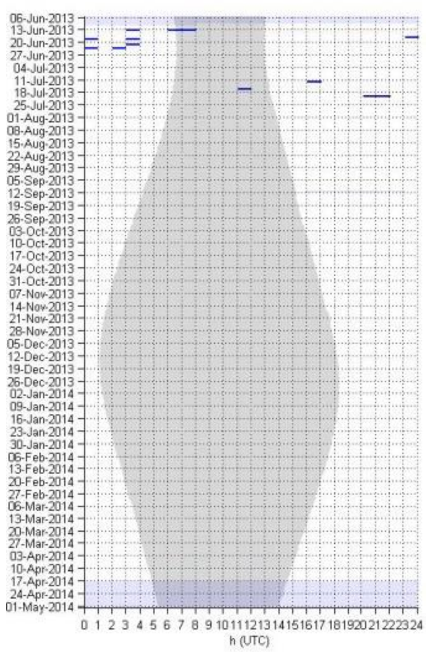

Figure 77. LFA in hourly bins at site QN. Effort markings are described in Figure 36.

Echosounders

Echosounder pings from a variety of frequencies were detected at each site except site PT.

- Echosounder pings were more prevalent at sites CA and CB than other sites (Figure 78). This could indicate closer, local boat sources at sites CA and CB.
- There were no echosounder pings at sites CA, CB, and KO during the late fall and winter months (Figure 78). This corresponds with the lower levels of shipping noise at sites CA and KO.
- Most echosounder pings occurred during daytime hours at site CA (Figure 79). There were too few echosounder ping detections at sites KO and QN to establish a diel pattern.
- These results are similar to previous monitoring periods (Debich *et al*., 2013, Baumann-Pickering *et al*., 2012).

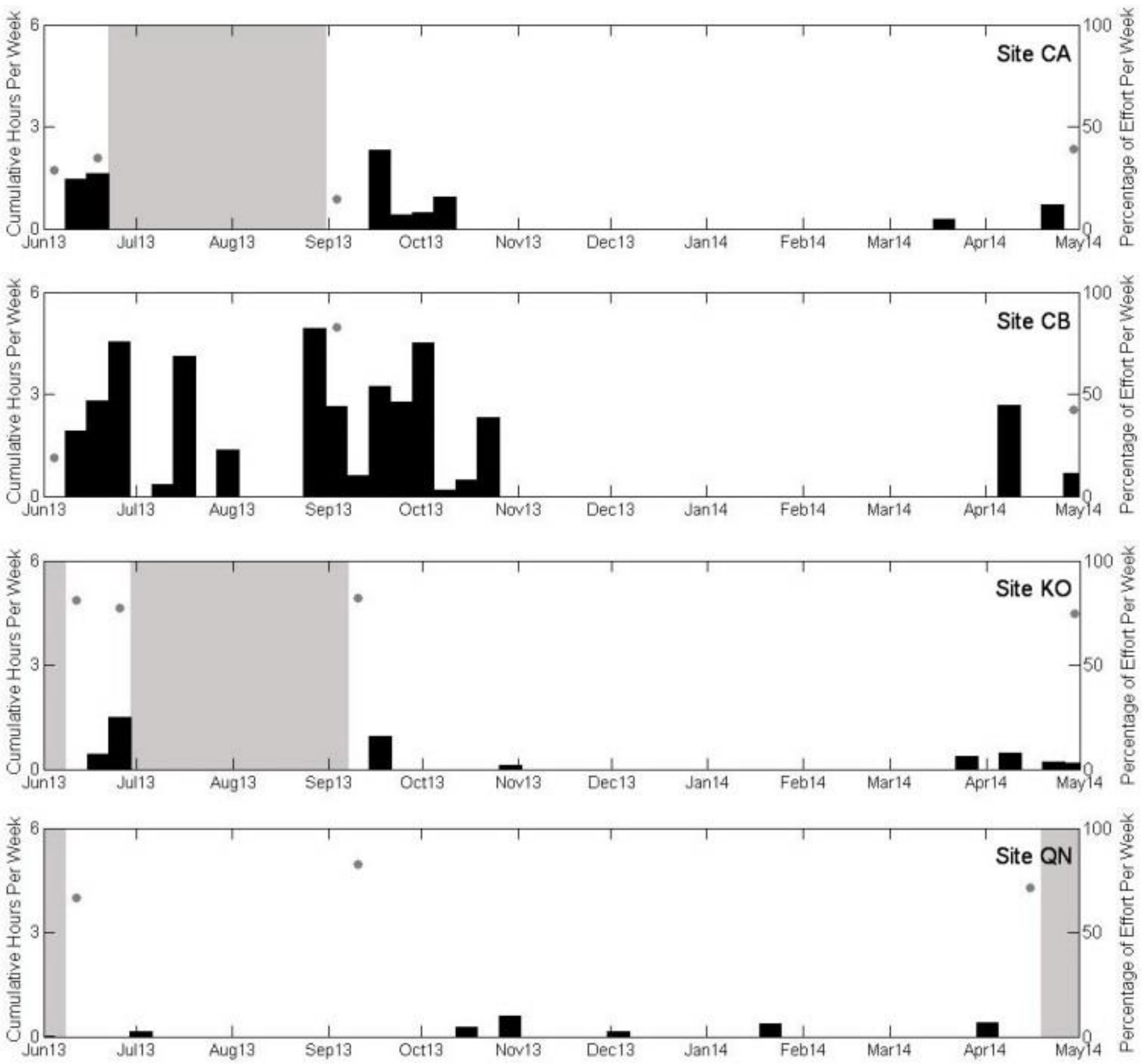

Figure 78. Weekly presence of echosounders between June 2013 and May 2014 at sites CA (top), CB (second from top), KO (second from bottom), and QN (bottom). Effort markings are described in Figure 35.

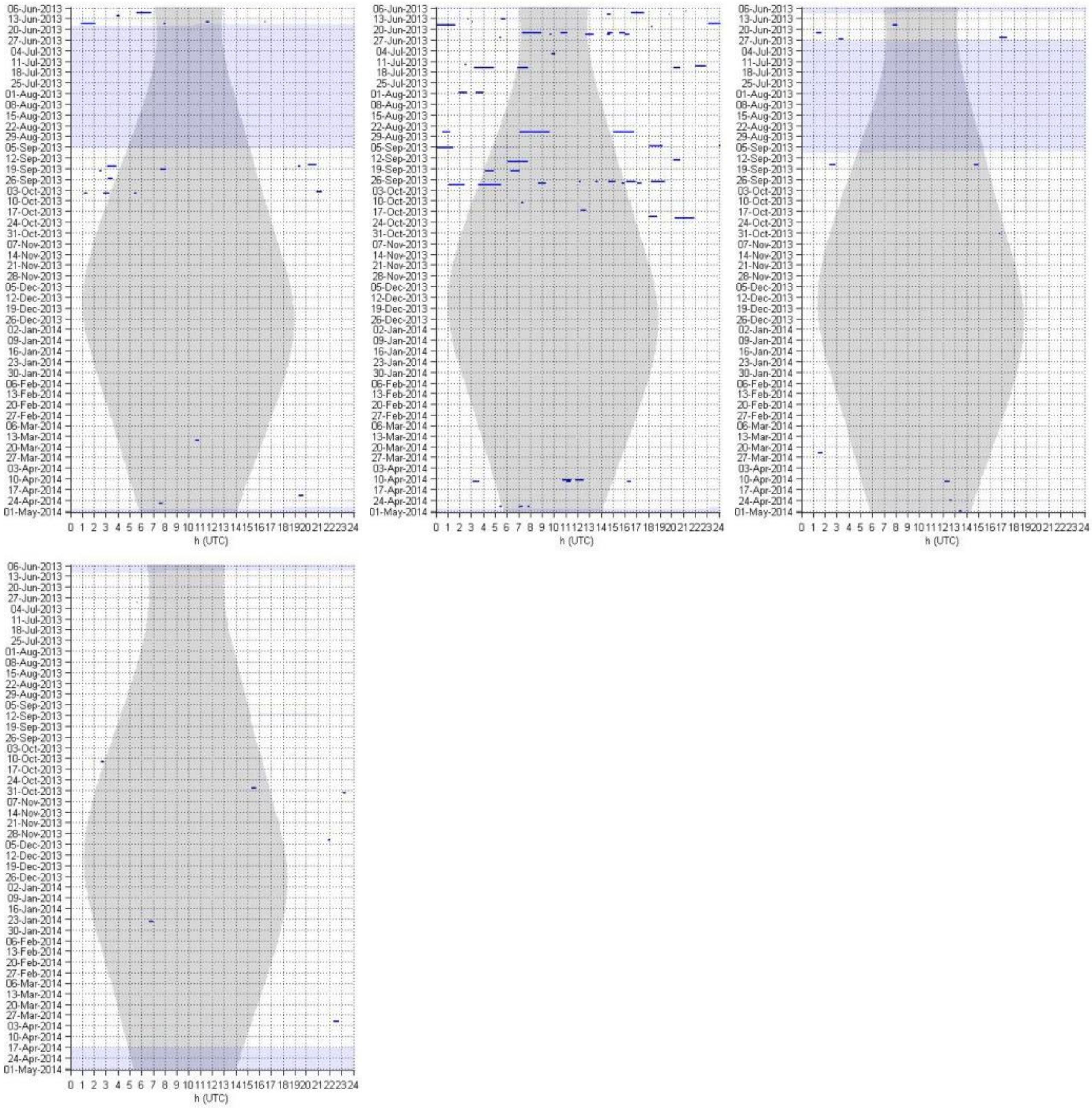

Figure 79. Echosounder detections in one-minute bins at sites CA (top left), CB (top middle), KO (top right), and QN (bottom left). Effort markings are described in Figure 36.

Explosions

Explosions were detected in low numbers at each site.

- Most explosion detections occurred during summer months at sites CB, KO, PT, and QN. A peak in detections at site CA occurred during late-October 2013 (Figure 80).
- During the summer, the explosions were most common at the offshore sites PT and QN, although they were detected at all sites. A peak in detections in fall occurred at site CA during late October 2013, when few detections occurred at sites CB and KO.
- Explosions were low or ceased during winter months at all sites.
- Though there were few explosion detections, most detections occurred during daytime hours (Figure 81).
- The explosions are likely fishery-related seal bombs based on the spectral properties of the signals.
- These results are similar to previous monitoring periods (Debich *et al*., 2013, Baumann-Pickering *et al*., 2012).

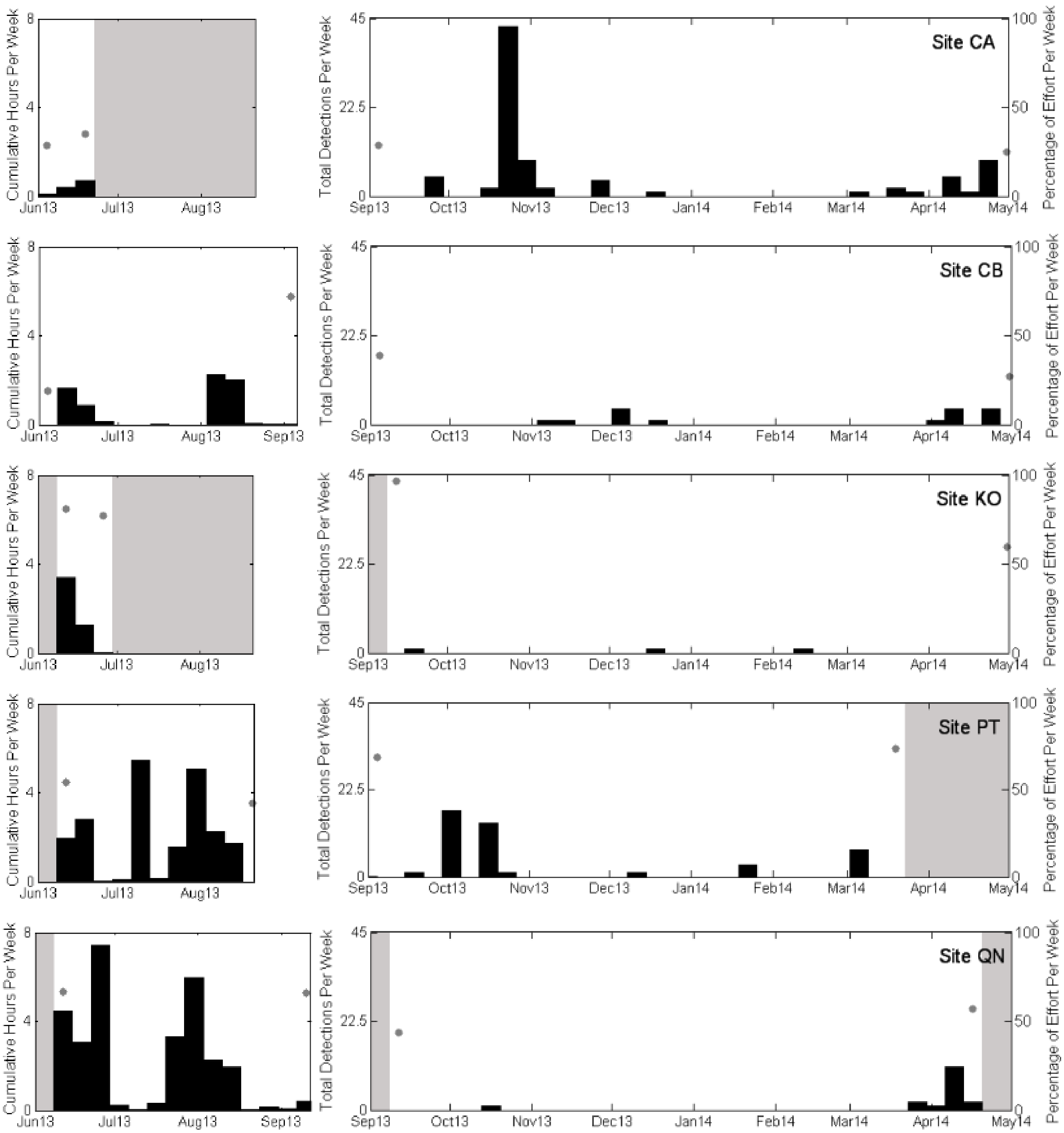

Figure 80. Weekly presence of explosions between June 2013 and May 2014 at sites CA (top), CB (second from top), KO (middle), PT (second from bottom), and QN (bottom); manually detected by a human analyst in one-minute bins. Weekly detections (count) shown for September 11, 2013 – May 1, 2014 were detected automatically using a matched filter detector. Effort markings are described in Figure 35.

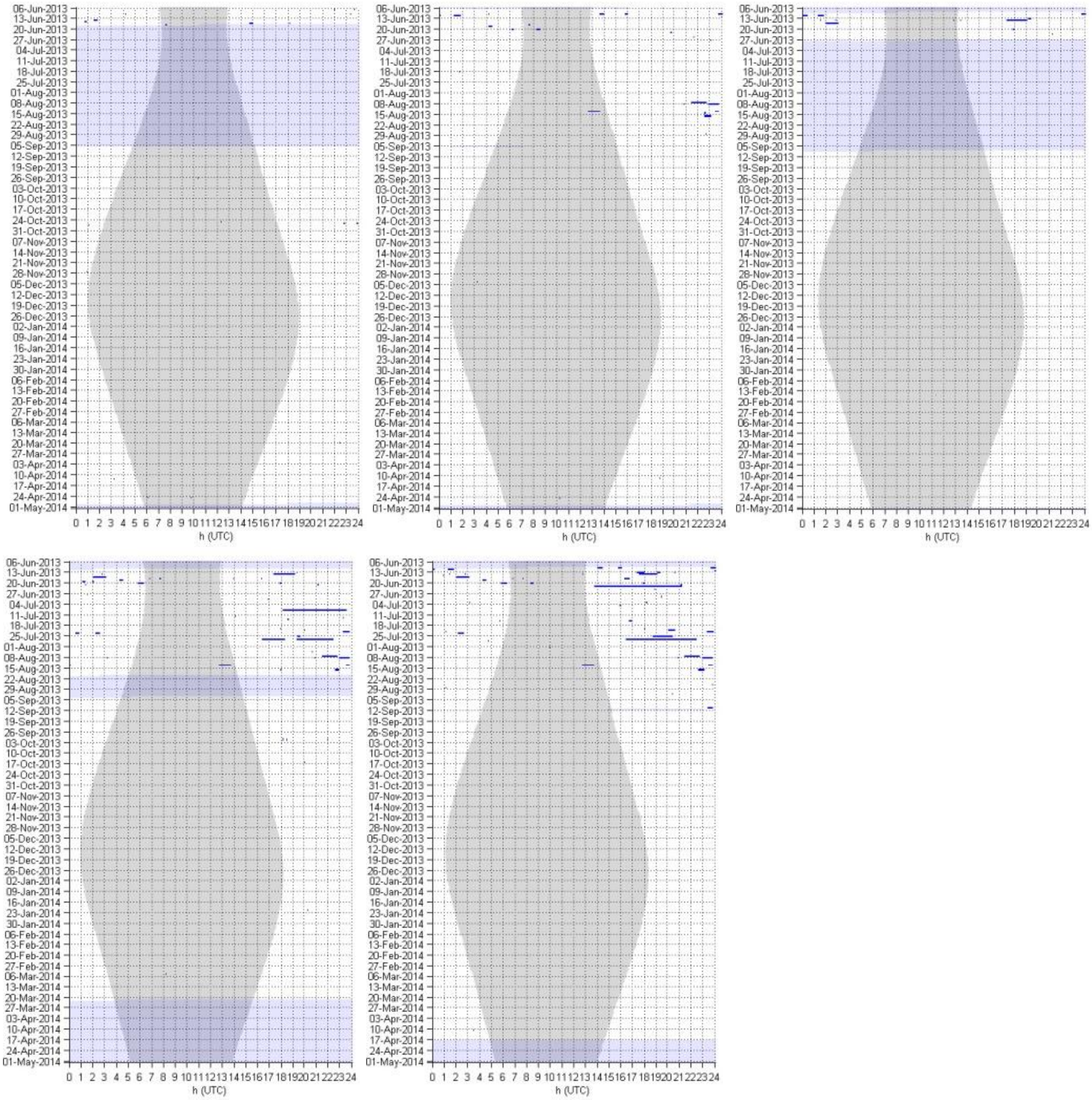

Figure 81. Explosions in one-minute bins at sites CA (top left), CB (top middle), KO (top right), PT (bottom left), and QN (bottom right). Effort markings are described in Figure 36.

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