# Passive Acoustic Monitoring for Marine Mammals in the Gulf of Alaska Temporary Maritime Activities Area 2014-2015

*November 2015*

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

SCRIPPS Whale Acoustics

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Fin 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 April 2014 to May 2015 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 (900 m depth, site CB), a slope site offshore Kodiak Island (200 m depth, site KO), a deep offshore site at Pratt Seamount (1000 m depth, site PT), and a deep offshore site at Quinn Seamount (900 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 and anthropogenic sounds.

Four baleen whale species were recorded: blue whales, fin whales, gray whales and humpback whales. No North Pacific right whale calls were noted. Across all sites, blue whales, fin whales and humpback whales were commonly detected throughout the recordings. Blue whale D calls, Central Pacific tonal calls, and fin 40 Hz calls peaked in summer months, while blue whale Northeast Pacific B calls and fin 20 Hz calls peaked later in fall months. Gray whale M3 calls were detected in small numbers throughout the recordings at sites CA and KO. Humpback whale calling peaked from December 2014 to March 2015.

Signals from three known odontocete species were recorded: sperm whales, Cuvier's beaked whales, and Stejneger's beaked whales. Sperm whales were detected at every site. Cuvier's beaked whales were detected at sites PT and QN. Stejneger's beaked whales were detected at sites CB, PT, and QN, with most detections occurring at site CB.

The only anthropogenic sounds detected in the recordings were broadband ships and explosions. Neither mid-frequency active (MFA) nor low frequency active (LFA) sonar events were detected throughout the recordings. Broadband ships were detected regularly throughout the recording periods at all sites. Most explosion detections occurred during summer months with PT having the largest number of detections.

# 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 include blue (*Balaenoptera musculus*), fin (*B. physalus*), humpback (*Megaptera novaeangliae*), North Pacific right (*Eubalaena japonica*), and sperm whale (*Physeter macrocephalus*). North Pacific right whales are of particular interest, as their current abundance estimate is only a few tens of animals, making them the most endangered marine mammal species in U.S. waters. Based on 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.

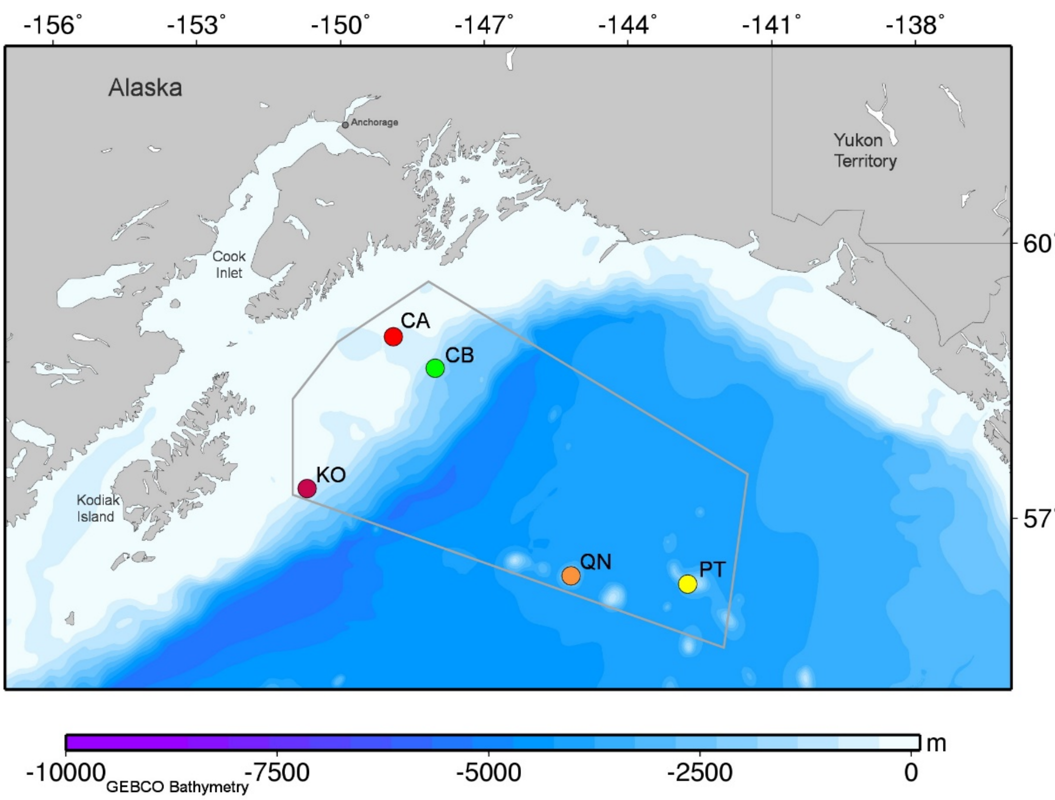


**Figure 1. High-frequency Acoustic Recording Packages sites (CA, CB, KO, PT, and QN) in the GATMAA (gray line) from April 2014 through May 2015. Color bar indicates bathymetric depth.**

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 sounds produced by 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 two more sites were added in 2013. This report documents the analysis of data recorded by five High-frequency Acoustic Recording Packages (HARPs) that were deployed within the GATMAA in April 2014 and collected data through May 2015 (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 GATMAA.**

| Site | Latitude | Longitude | Depth |
|---|---|---|---|
| CA | 59° 0.5 N | 148° 54.1 W | 200 m |
| CB | 58° 40.26 N | 148° 01.45 W | 900 m |
| KO | 57° 20.0 N | 150° 40.1 W | 200 m |
| PT | 56° 14.6 N | 142° 45.46 W | 1000 m |
| QN | 56° 20.48 N | 145° 10.99 W | 900 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 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 sampled at 320 kHz. A total of 23,996 hours, covering 999 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 2014 are described in Baumann-Pickering *et al*. (2012), Debich *et al*. (2013) and Debich *et al.* (2014).**

| 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 |
| 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** |

**Data Quality**

Data acquisition, duration and quality were impacted by two factors: instrument damage and noise related to tidal flow. During the QN03 deployment the power cable between the data logger and battery pressure cases was damaged during the deployment. This resulted in a shorter than typical recording duration and poor data quality caused by increased electronic noise from the shorted power cable. Data quality is also 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 CA and KO (both at 200m depth) that were located on the continental shelf, the location of strong tidal currents.

Ambient noise spectra were calculated on a 1/3 duty cycle, and include only days with more than 90% recording effort. Days with less recording effort and those clearly contaminated (typically at the start and end of a recording when local deployment ship sounds are intense and long lasting) were removed and not used for analysis. Contaminated daily-averaged spectra were easily identified by comparing to overall deployment averaged spectra and then noting and removing extreme outliers. Periods of strumming/tidal flow were detected automatically when the mean spectrum level of the band 1-500Hz in hour bins exceeded a threshold of 80 dB re uPa^2/Hz. Percentages of each month spent strumming are included in Table 3 for sites CA and KO. Strumming at sites CB, PT, and QN 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 (top) and site KO (bottom).**

| **Site CA** | | | |
|---|---|---|---|
| Month/Year | Recording Duration in days | Strumming in days (percent) | Spectra Calculation in days |
| Apr 2014 | 2 | 1.00 ( 50.0% ) | 0.67 |
| May 2014 | 31 | 10.12 (32.7% ) | 10.33 |
| Jun 2014 | 30 | 7.79 ( 26.0% ) | 10 |
| Jul 2014 | 30 | 4.67 ( 15.6% ) | 10 |
| Aug 2014 | 31 | 13.04 ( 42.1% ) | 10.33 |
| Sep 2014 | 8 | 0.87 ( 10.9% ) | 2.67 |
| | | | |
| **Site KO** | | | |
| Month/Year | Recording Duration in days | Strumming in days (percent) | Spectra Calculation in days |
| May 2014 | 30 | 17.45 ( 58.2% ) | 10 |
| Jun 2014 | 30 | 8.71 ( 29.0% ) | 10 |
| Jul 2014 | 31 | 9.83 ( 31.7% ) | 10.33 |
| Aug 2014 | 31 | 6.16 ( 19.9% ) | 10.33 |
| Sep 2014 | 10 | 1.71 ( 17.1% ) | 3.33 |

## 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, North Pacific right whale and low frequency active sonar sounds were classified as low-frequency. Humpbacks, nearby shipping, explosions, and mid-frequency active sonar sounds were classified as mid-frequency. The remaining odontocete 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 April 2014 and May 2015 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 1-200 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 deployments CA05 and KO03, and were detected automatically using computer algorithms described below for deployments CB05, PT04, CB06 and QN04. Fin whale 20 Hz pulses were detected manually for deployments CA05 and KO03 due to instrument noise, and were detected automatically using an energy detection method for all other deployments.

***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 ( <20 Hz), have long duration, and often are regularly repeated. Also detected were blue whale D calls, which are downswept in frequency (approximately 100-40 Hz) with a duration of several seconds (Figure 4). These calls are similar worldwide and are associated with feeding animals; they may be produced as call-counter call between multiple animals (Oleson *et al.*, 2007).

**Northeast Pacific blue whale B calls**

Northeast Pacific blue whale B calls were detected via manual scanning of the LTSA for deployments CA05 and KO03. Blue whale B calls were detected automatically for all other deployments using the spectrogram correlation method (Mellinger and 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 2014 kernel was thus defined as sweeping from 48.2 to 47.3 Hz, 47.3 to 46.6 Hz, 46.6 to 46.4 Hz, and 46.4 to 45.3 Hz during these predefined periods. The fall 2014 kernel was defined as 47.4 to 47 Hz; 47 to 46.4 Hz, 46.4 to 46 Hz, and 46 to 45.7 Hz. The kernel bandwidth was 2 Hz.

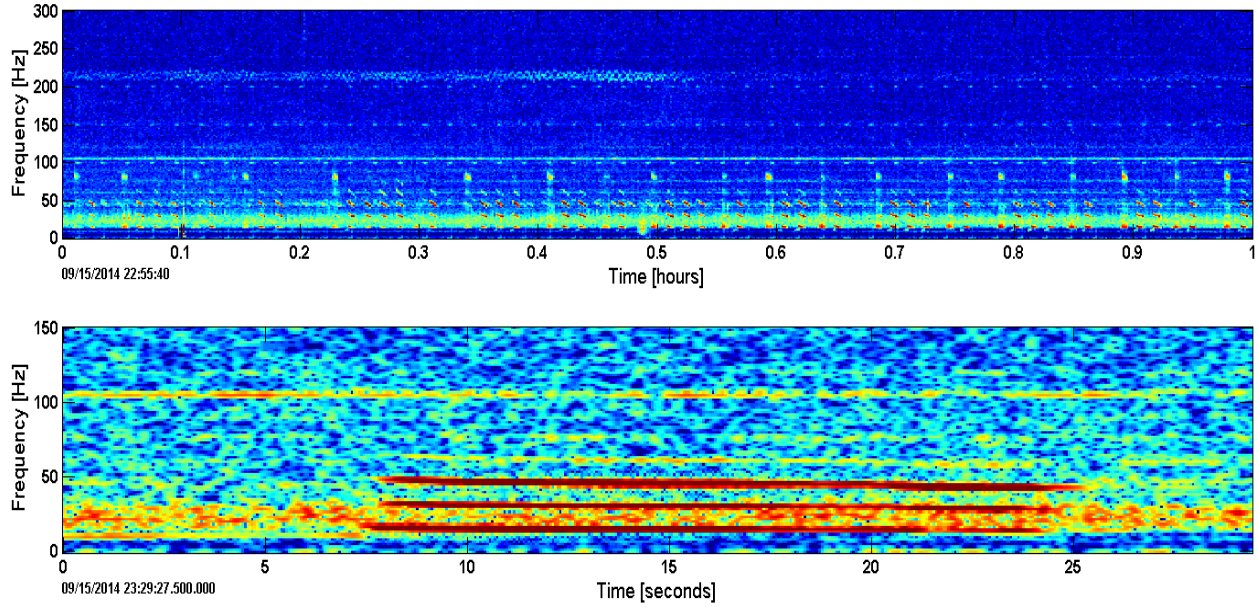


**Figure 2. Northeast Pacific blue whale B call in LTSA (top) and spectrogram (bottom) at site CB.**

## 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.

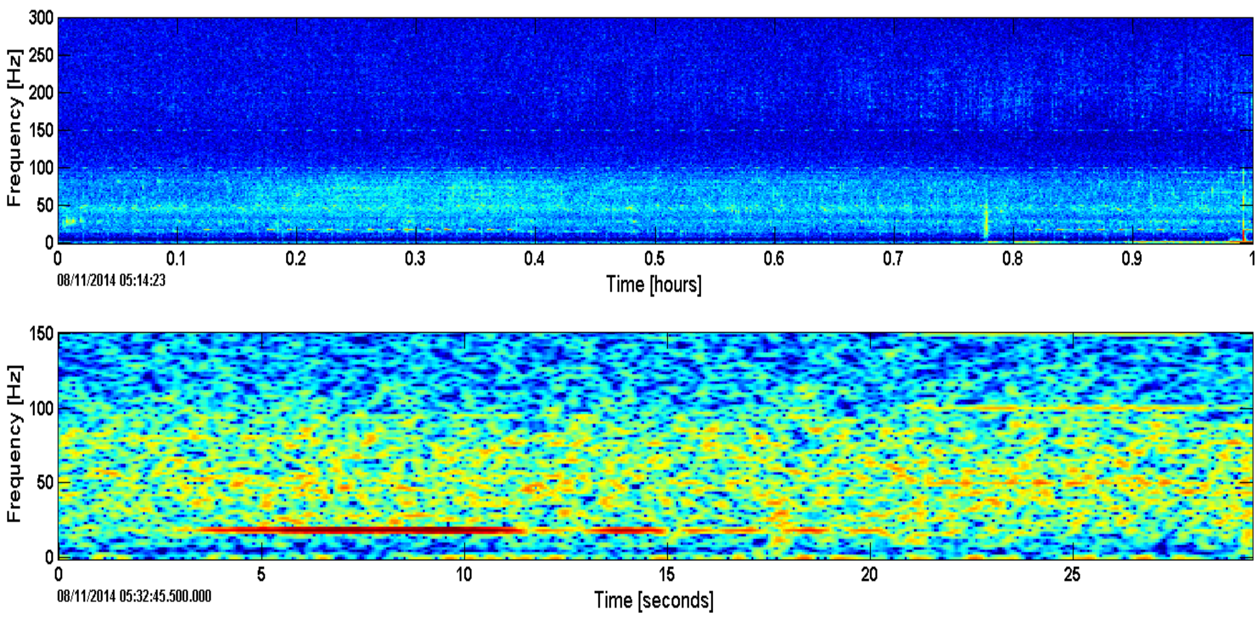


**Figure 3. Central Pacific tonal call in the LTSA (top) and spectrogram (bottom) at site CB.**

### Blue whale D calls

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

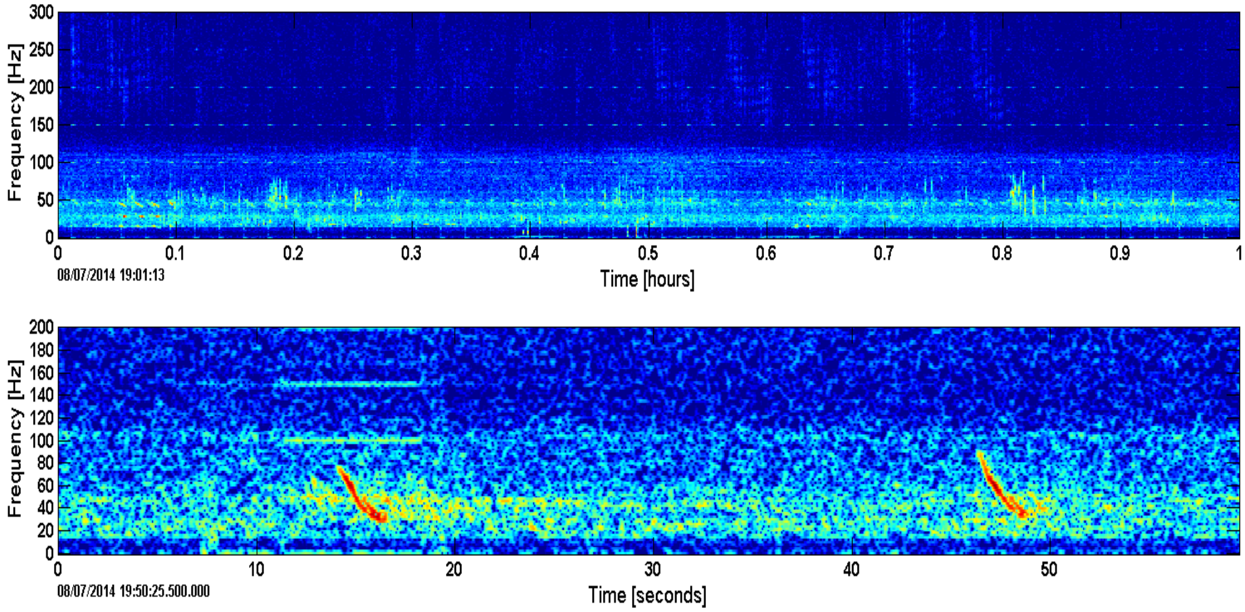


**Figure 4. Blue whale D calls in the LTSA (top) and spectrogram (bottom) at site CB.**

## *Fin Whales*

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

### 20 Hz calls

Fin whale 20Hz calls (Figure 5) were detected via manual scanning of the LTSA for deployments CA05 and KO03. Fin whale 20 Hz calls were detected automatically for all other deployments 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.

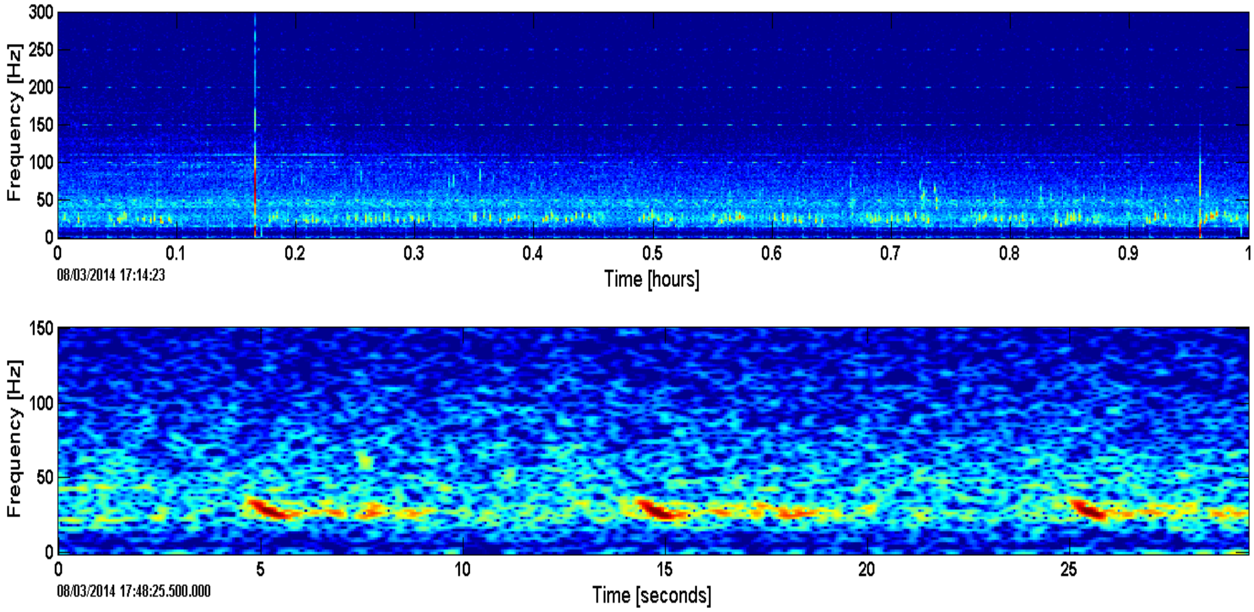


**Figure 5. Fin whale 20 Hz calls in the LTSA (top) and spectrogram (bottom) at site CB.**

## 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.

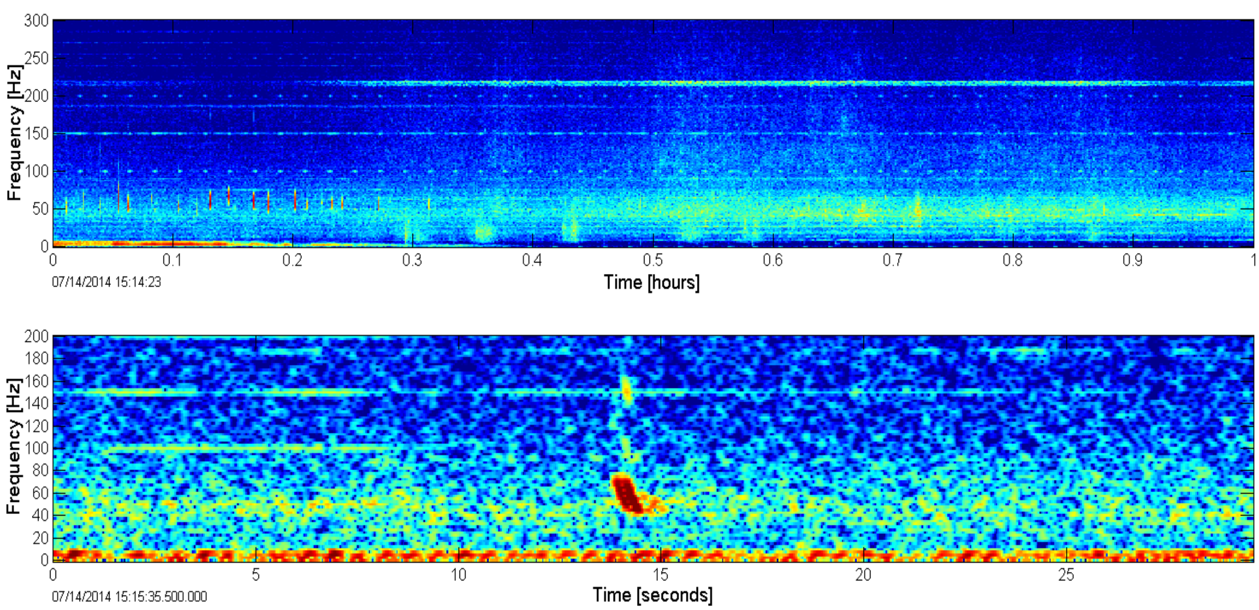


**Figure 6. Fin whale 40 Hz call in the LTSA (top) and spectrogram (bottom) at site CB.**

### *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 and Lashkari, 1996).

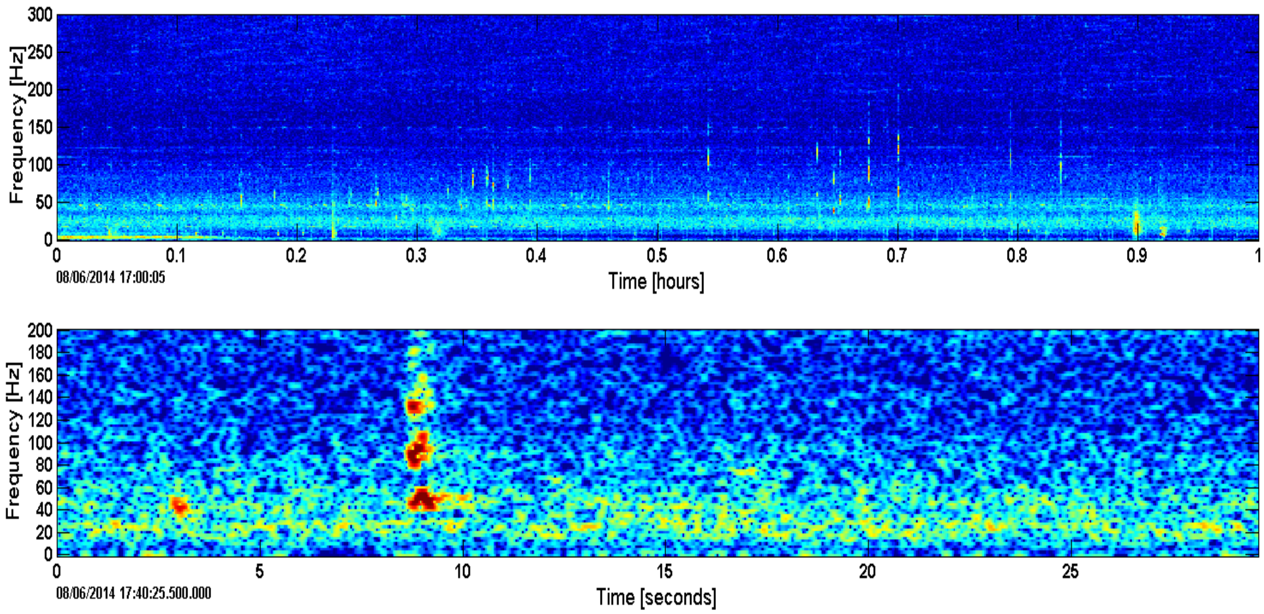


**Figure 7. Gray whale M3 call in the LTSA (top) and spectrogram (bottom) at site KO.**

### *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 whales recorded during this reporting period.

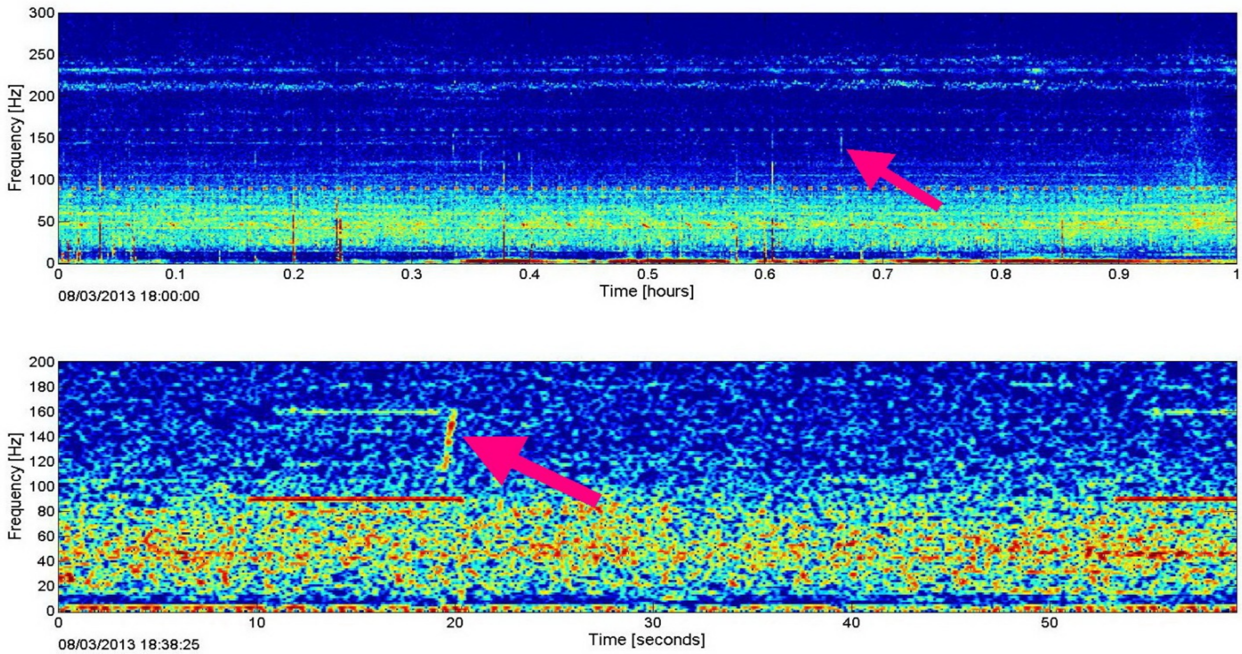


**Figure 8. North Pacific right whale up call in the LTSA (top) and spectrogram (bottom) previously recorded at site QN.**

## Mid-Frequency Marine Mammals

Humpback whales were the only marine mammal species in the Gulf of Alaska with calls in the mid-frequency range monitored for this report. 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. Call presence 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.

### *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.

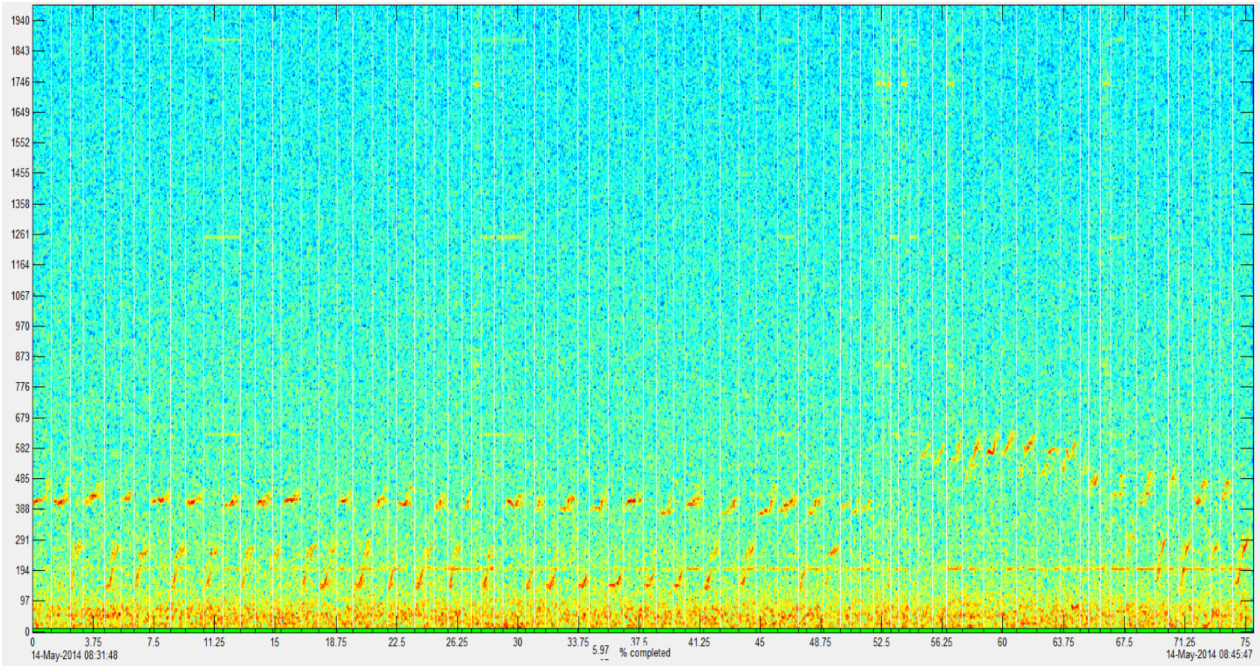


**Figure 9. Humpback whale song from site KO in the analyst verification stage of the detector.**

## 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 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 10).

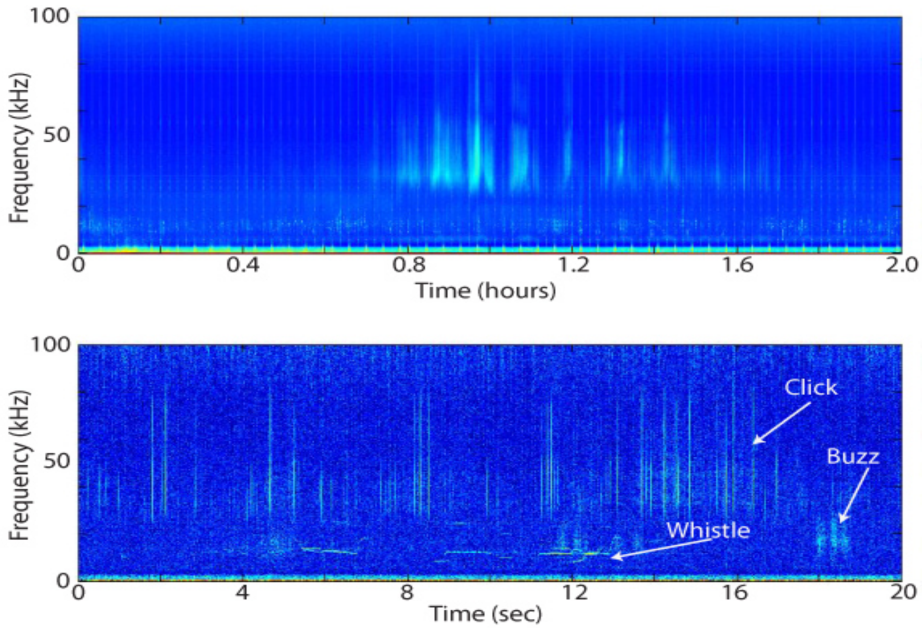


**Figure 10. LTSA (top) and spectrogram (bottom) demonstrating odontocete signal types.**

***Sperm Whales***

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

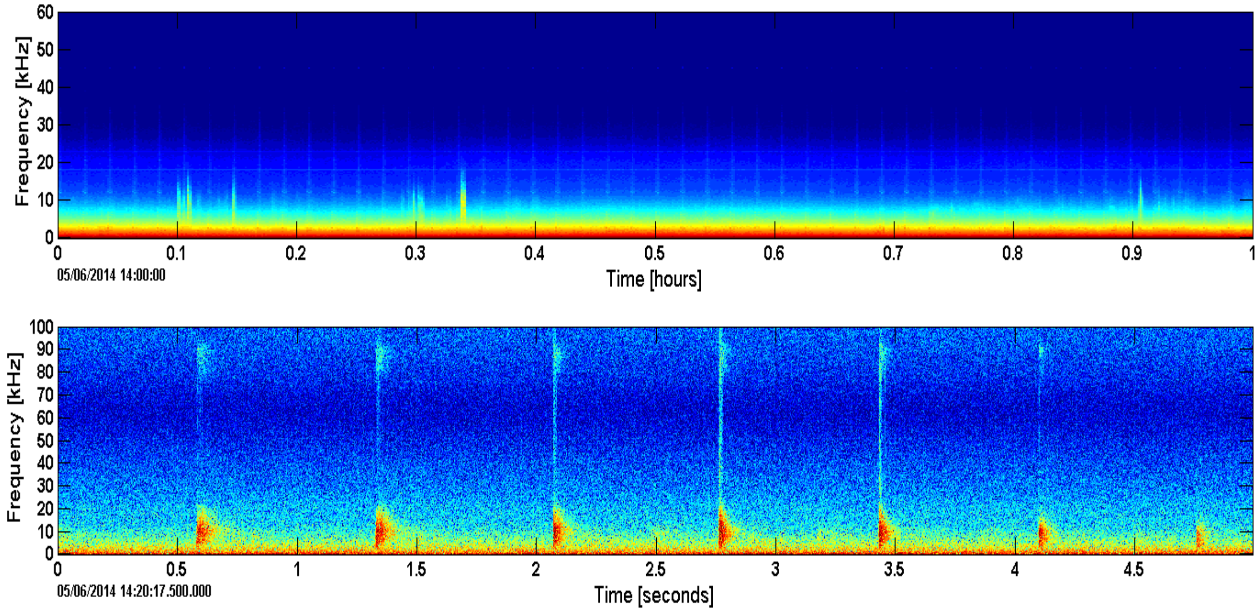


**Figure 11. Sperm whale echolocation clicks in the LTSA (top) and spectrogram (bottom) at site CB.**

### *Beaked Whales*

Beaked whale frequency-modulated (FM) pulses were detected with an automated method. Beaked whale signal types searched for include Cuvier's beaked whales (*Ziphius cavirostris*) and Stejneger's beaked whales (*Mesoplodon stejnegeri* (Baumann-Pickering *et al.*, 2013b). After all echolocation signals were identified with a Teager Kaiser energy detector (Soldevilla *et al.*, 2008; Roch *et al.*, 2011), an expert system discriminated between delphinid clicks and beaked whale FM pulses. A decision about presence or absence of beaked whale signals was based on detections within a 75 second segment. Only segments with more than 7 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. 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.*, 2013). The rate of missed segments was approximately 5%, varying slightly between deployments. Only Cuvier's beaked whales and Stejneger's beaked whales were detected in these deployments.

### Cuvier's Beaked Whales

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

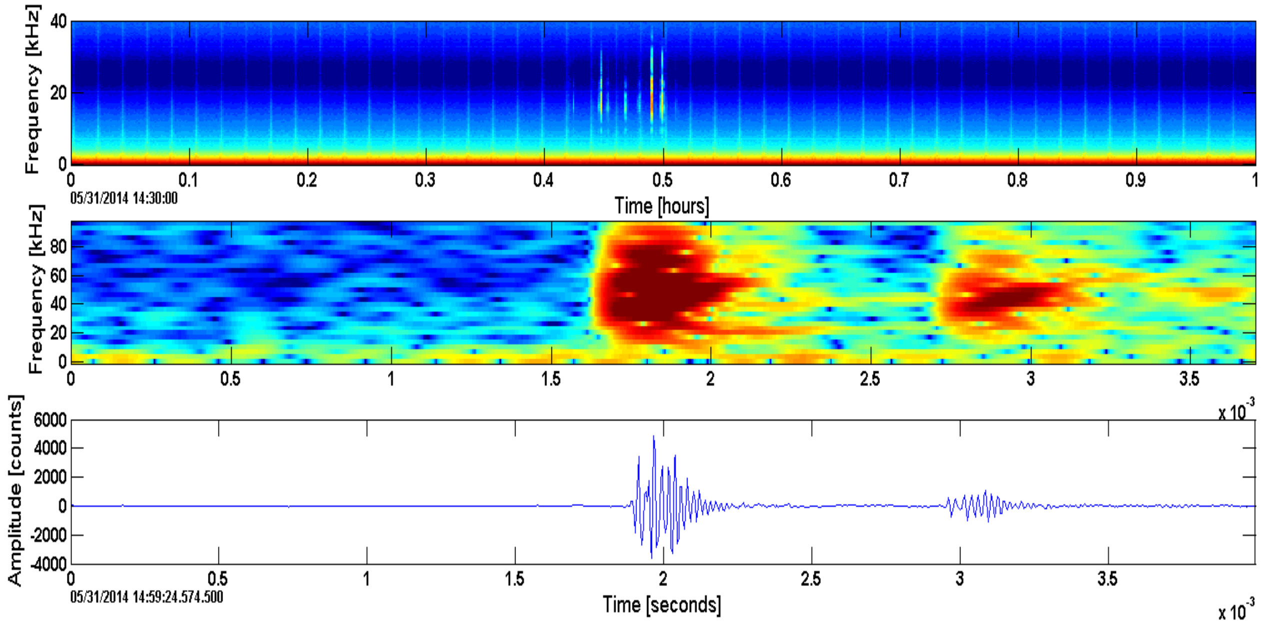


**Figure 12. Echolocation sequence of Cuvier's beaked whale in the LTSA (top) and example FM pulse in the spectrogram (middle) and timeseries (bottom) at site PT.**

### 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 (Loughlin *et al.*, 1982; Mead, 1989; Walker and Hanson, 1999) and their distribution has been inferred from stranded animals (Allen and Angliss, 2010). Their echolocation signals are easily distinguished from other species' acoustic signals; they have the typical beaked whale polycyclic structure and FM pulse upsweep with a peak frequency around 50 kHz and uniform inter-pulse interval around 90 ms (Figure 13) (Baumann-Pickering *et al.*, 2013a; Baumann-Pickering *et al.*, 2013b).

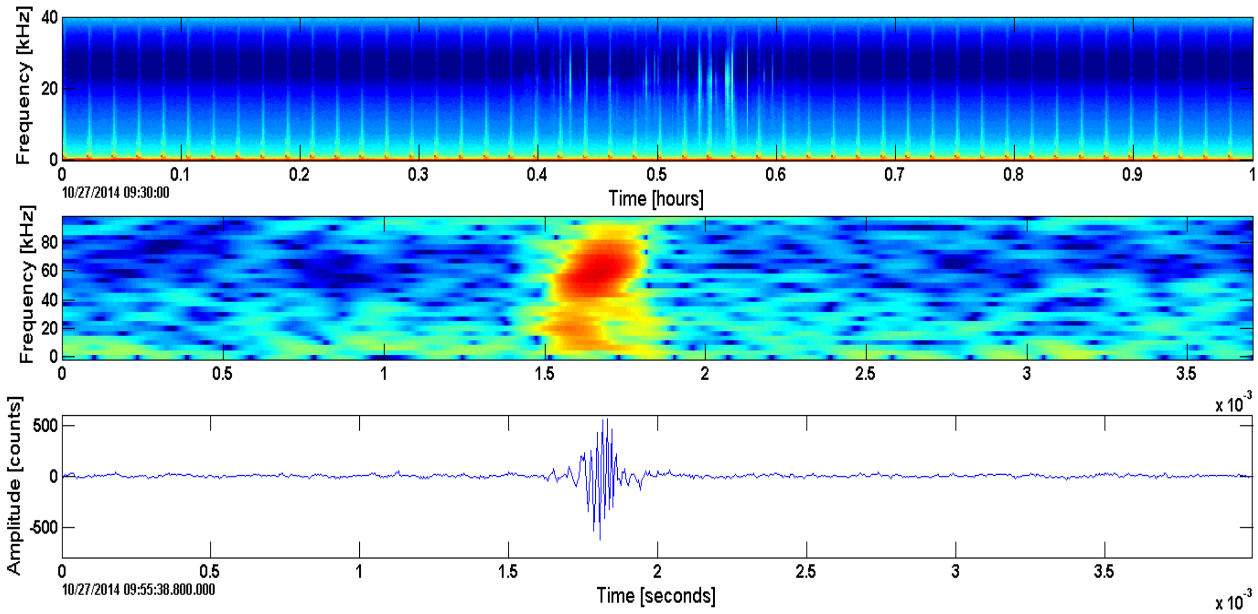


**Figure 13. Echolocation sequence of Stejneger's beaked whale in the LTSA (top) and single FM pulse in the spectrogram (middle) and timeseries (bottom) at site QN.**

## 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, and explosions. The LTSA search parameters used to detect broadband ships and sonar are given in Table 4. Explosions were detected with an automated routine. The start and end of each sound or session was logged and their durations were added to estimate cumulative hourly presence.

**Table 4. 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 | 10 - 1000 |

### *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 14). Noise can extend above 10 kHz, though it typically falls off above a few kHz.

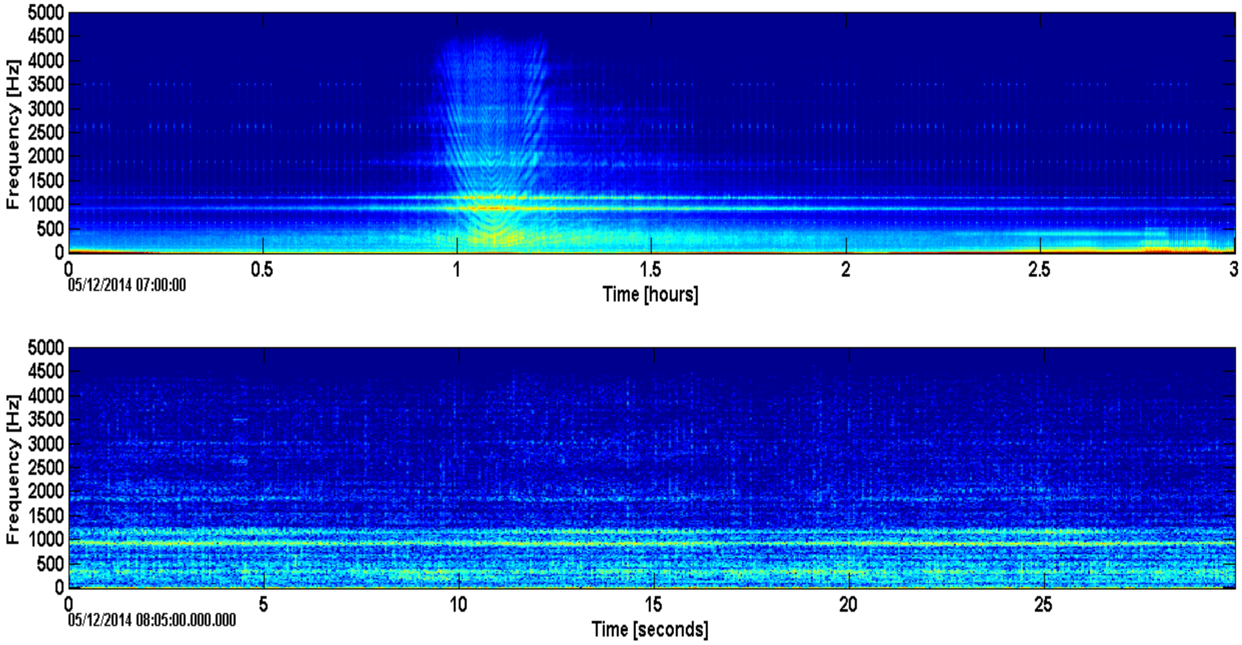


**Figure 14. Broadband ship noise in the LTSA (top) and spectrogram (bottom) at site CB.**

***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 15). There were no MFA detections at any of the sites in this region during this reporting period.

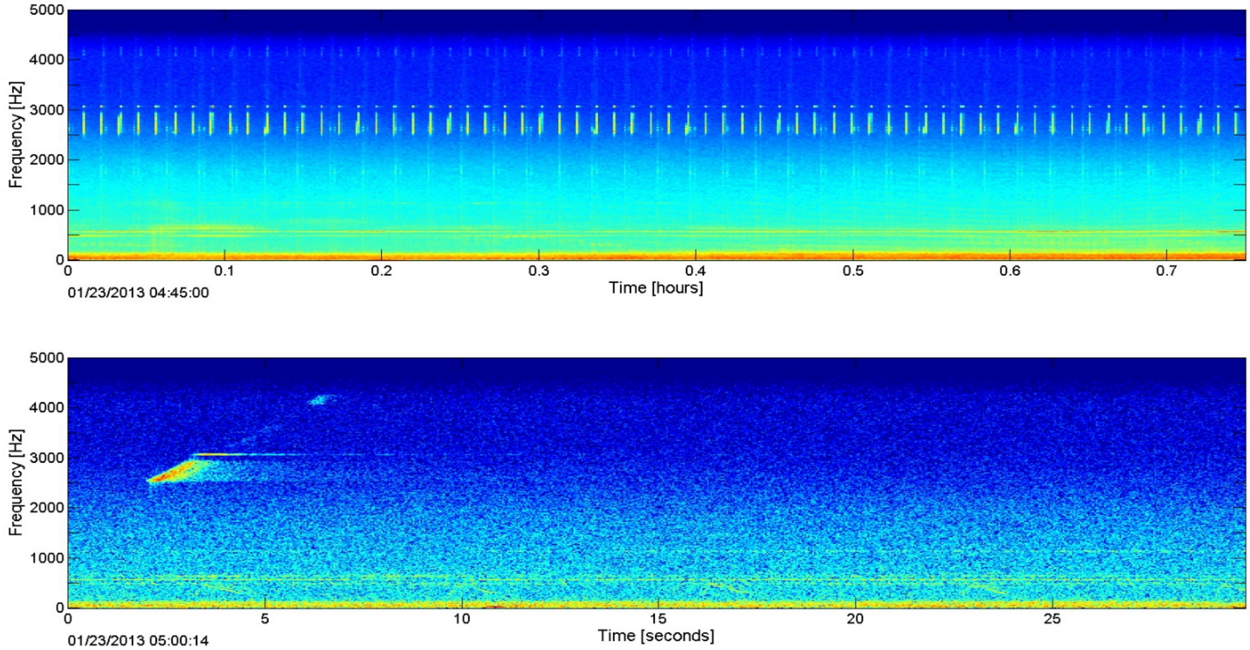


**Figure 15. Example of MFA sonar in the LTSA (top) and spectrogram (bottom) from a recording site off the coast of Washington.**

### *Low-Frequency Active Sonar*

Low-frequency active sonar includes military sonar between 0 and 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 – 1000 Hz. There were no LFA detections at any of the sites in this region during this reporting period.

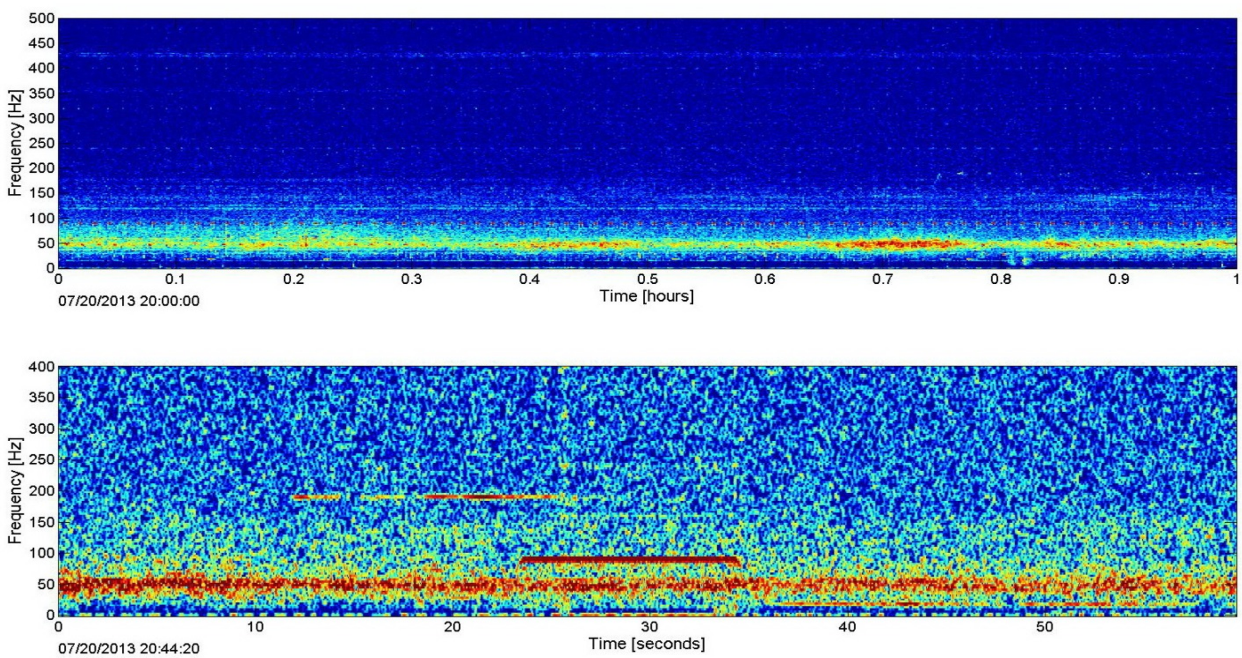


**Figure 16. LFA in the LTSA (top) and spectrogram (bottom) previously recorded at site QN.**

***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 seconds of the envelope of the filtered time series and the envelope of a filtered example explosion (0.7 s, Hann windowed) as the matched filter signal. The cross correlation was squared to 'sharpen' peaks of explosion detections. A floating threshold was calculated by taking the median cross correlation value over the current 75 seconds of data to account for detecting explosions within noise, such as shipping. A cross correlation threshold of $3x10^{-6}$ 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 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 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 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.

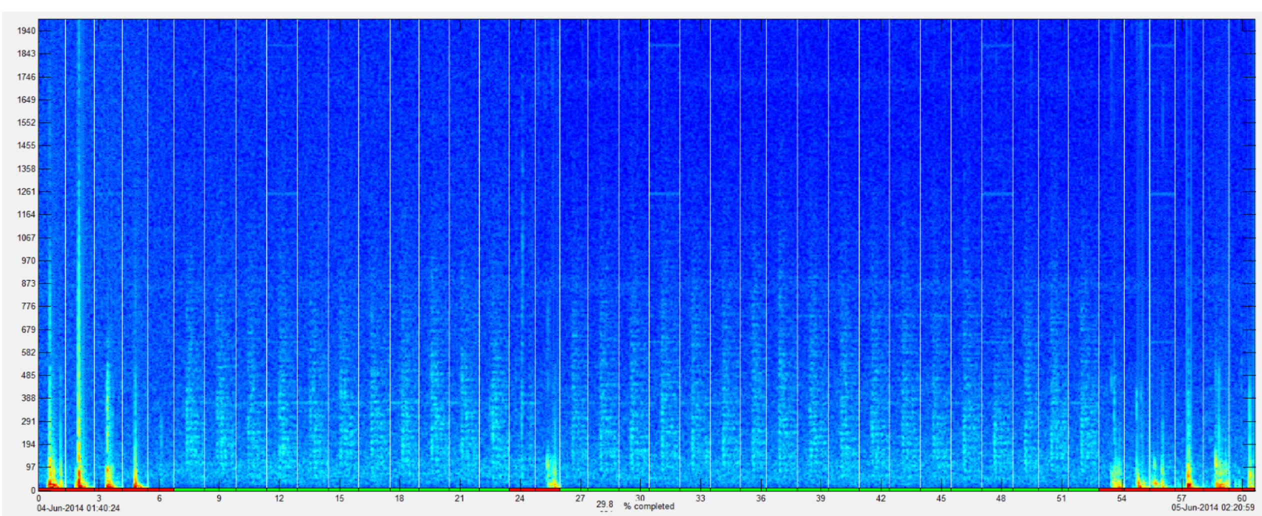


**Figure 17. Example of explosions from site PT in the analyst verification stage of the detector. Green in the bottom evaluation line indicates true and red indicates false detections.**

## Results

The results of acoustic data analysis at sites CA, CB, KO, PT, and QN from April 2014 through May 2015 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 and anthropogenic causes, although some sources were also biotic.

- Prominent seasonal peaks in noise observed at the frequency band 15-30 Hz during the fall and winter across most 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 18, Figure 19, Figure 20, Figure 21, and Figure 22).
- At sites PT and QN, there is some evidence of long-range ship noise at frequencies below 100 Hz (Hildebrand, 2009) (Figure 21 and Figure 22).
- Sites CA and KO show elevated spectrum levels in the 10-100Hz band likely caused by ocean currents and hydrophone support cable strumming from these currents (Figure 18 and Figure 20). Site KO also shows a peak from 200-500Hz due to strumming.
- The peak around 230-240Hz visible at sites CB, PT and QN is likely due to anthropogenic nosie.

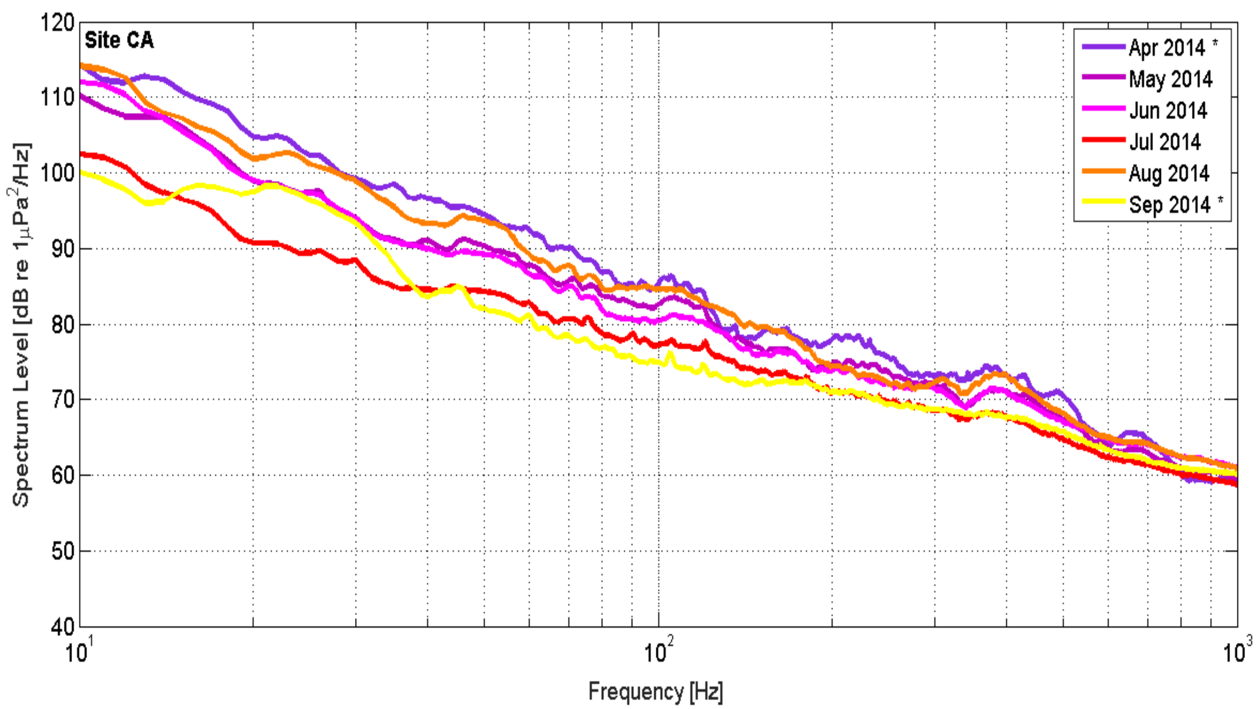


**Figure 18. Monthly averages of ambient noise at site CA. Legend gives color-coding by month. * in the legend denote months where there was partial effort. There was partial effort for April (2 days) and September (8 days).**

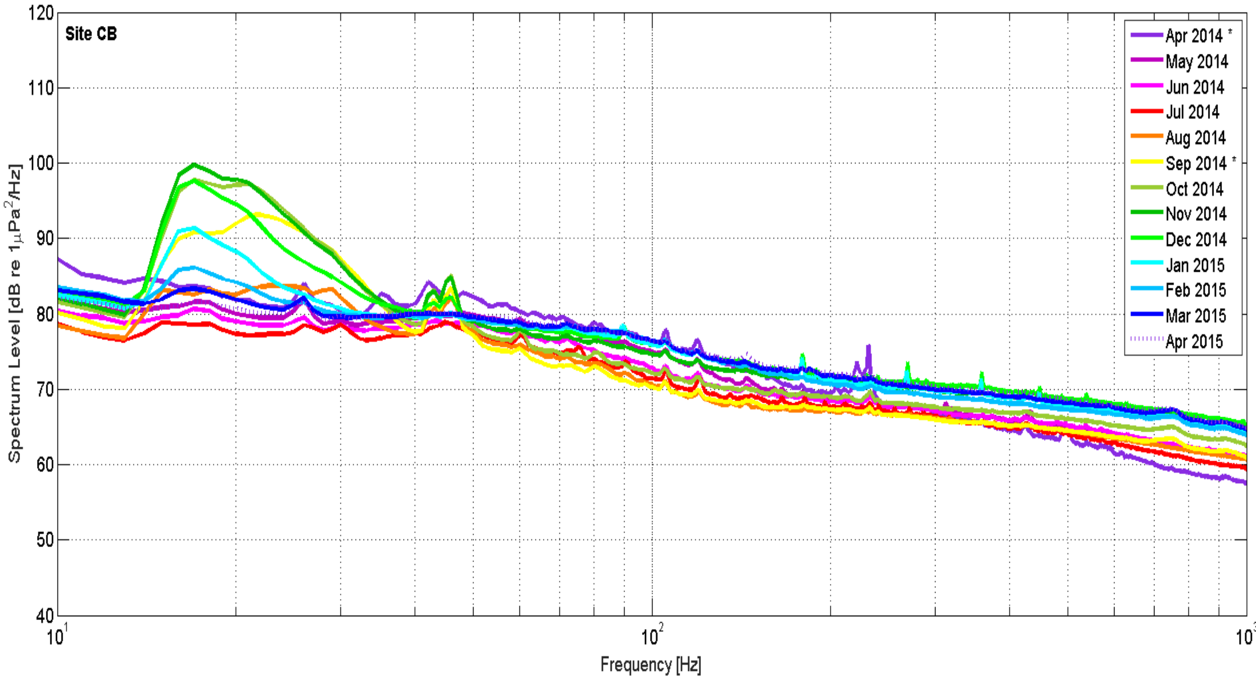


**Figure 19. Monthly averages of ambient noise at site CB. Legend is described in Figure 18. There was partial effort for April 2014 (2 days) and September (29 days).**

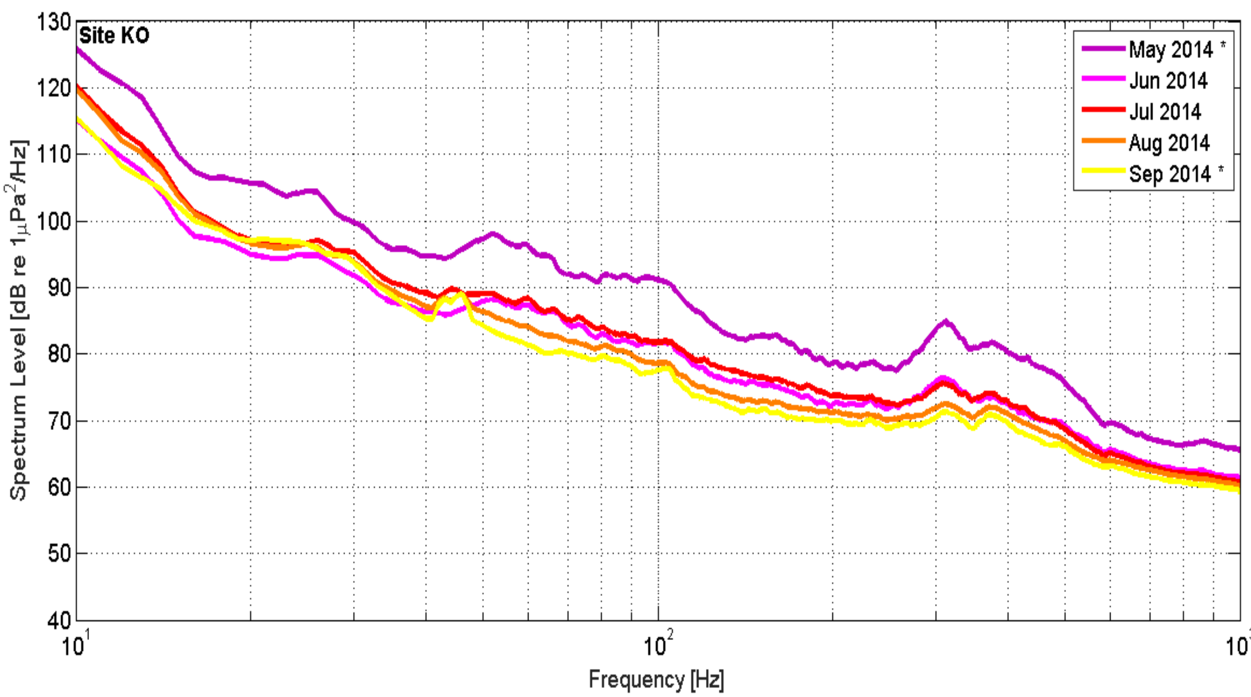


**Figure 20. Monthly averages of ambient noise at site KO. Legend is described in Figure 18. There was partial effort for May (30 days) and September (10 days).**

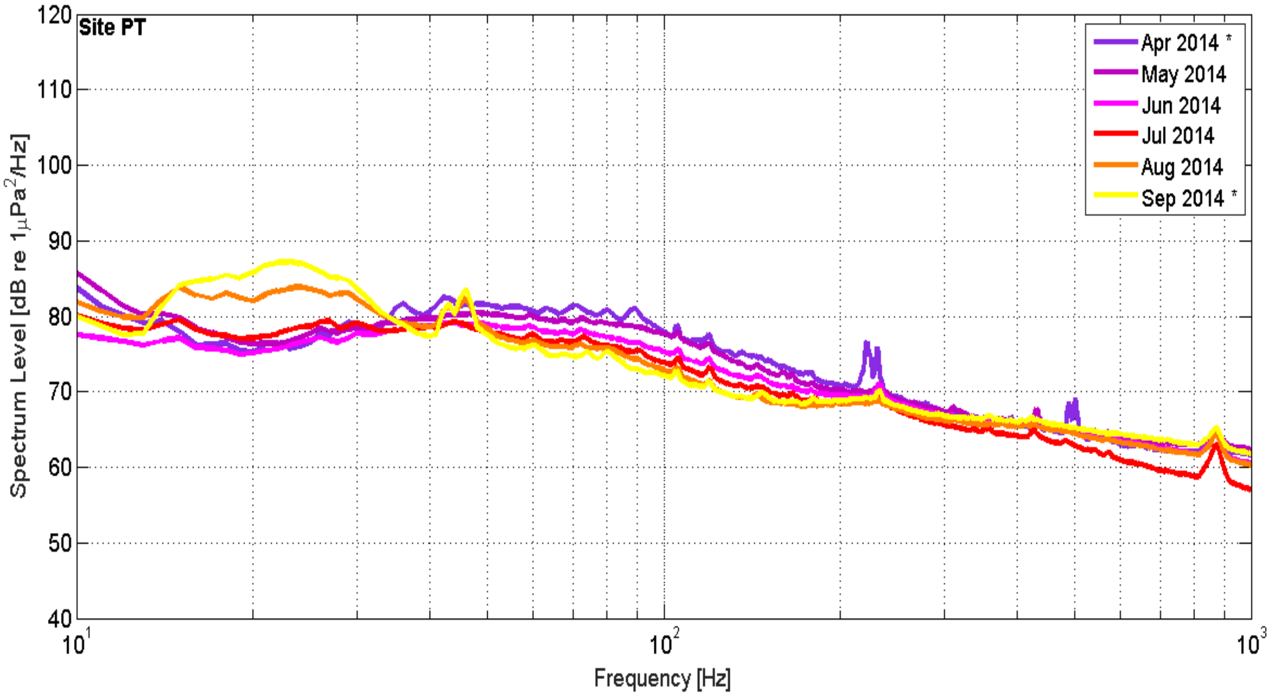


**Figure 21. Monthly averages of ambient noise at site PT. Legend is described in Figure 18. There was partial effort for April (1 day) and September (9 days).**

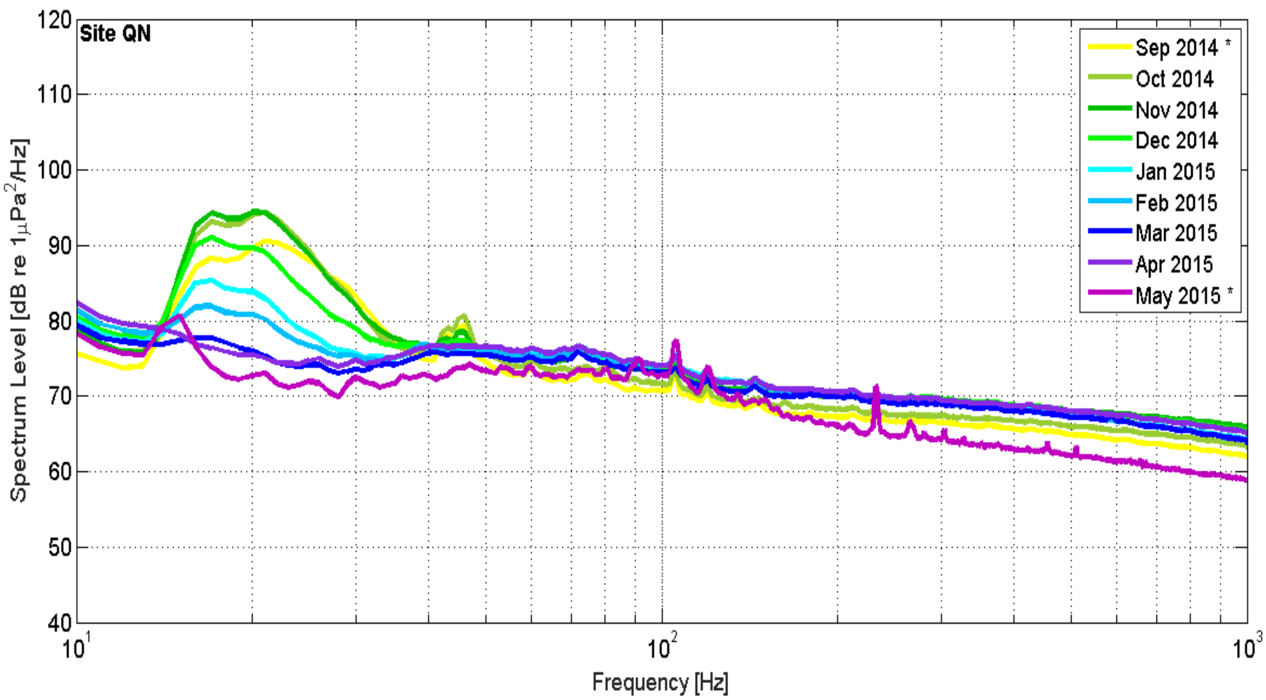


**Figure 22. Monthly averages of ambient noise at site QN. Legend is described in Figure 18. There was partial effort for September (20 days) and May (1 day).**

## Mysticetes

Four baleen whale species were recorded between April 2014 and May 2015: blue whales, fin whales, gray whales, and humpback whales. Relative hourly calling abundance varied among species. More details of each species' presence are given below.

### Blue Whales

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

- Blue whale Northeast (NE) Pacific B calls were detected from May 2014 through January 2015 with a peak in September 2014 and with fewest calls detected at sites CA and QN (Figure 23).
- There was no discernable diel pattern for the NE Pacific B calls (Figure 24).
- Central Pacific tonal calls were detected at sites CA, CB, KO, and PT from July to September 2014 with most detections occurring in August (Figure 25).
- Very few calls were detected at site CA, while most central Pacific tonal call detections occurred at site PT.
- There was no diel pattern for Central Pacific tonal calls (Figure 26).
- Blue whale D call detections were the highest from June to August 2014 (Figure 27). Most D call detections occurred at site PT, while very few D calls were detected at site QN, although the calls occurred through most of the year.
- There was a possible diel pattern for blue whale D calls with more calling around sunset, particularly at sites CB, KO, and PT (Figure 28).
- These results are consistent with earlier recordings at these sites (Baumann-Pickering *et al.*, 2012; Debich *et al.*, 2013; Debich *et al.*, 2014) as well as recordings collected further south in the Gulf of Alaska (Watkins *et al.*, 2000).

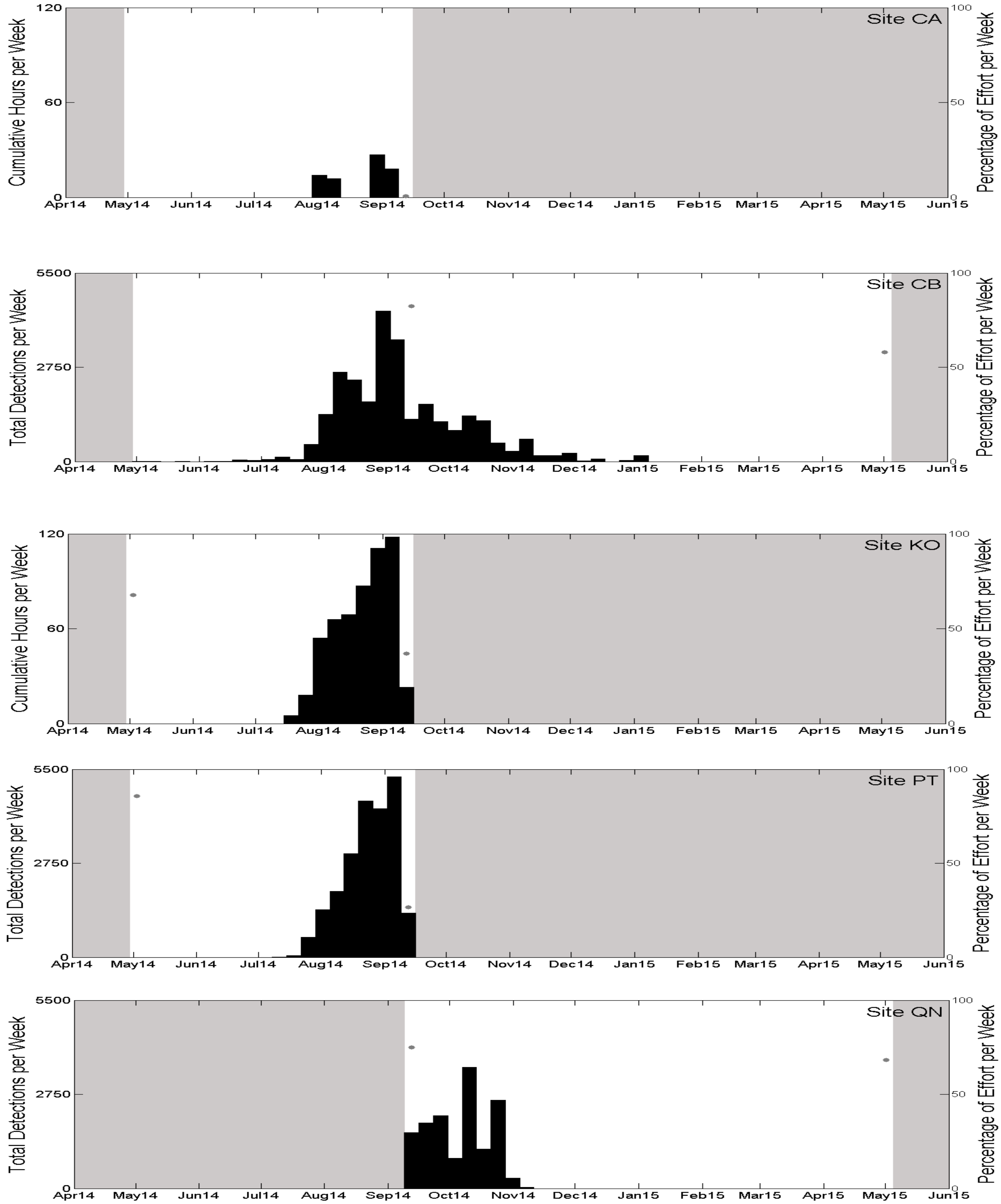


**Figure 23. Weekly presence of NE Pacific blue whale B calls between April 2014 and May 2015 at sites CA (top), CB (second from top), KO (middle), PT (second from bottom), and QN (bottom). Weekly detections shown for sites CA and KO were manually detected in hourly bins. Weekly detections for sites CB, 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.**

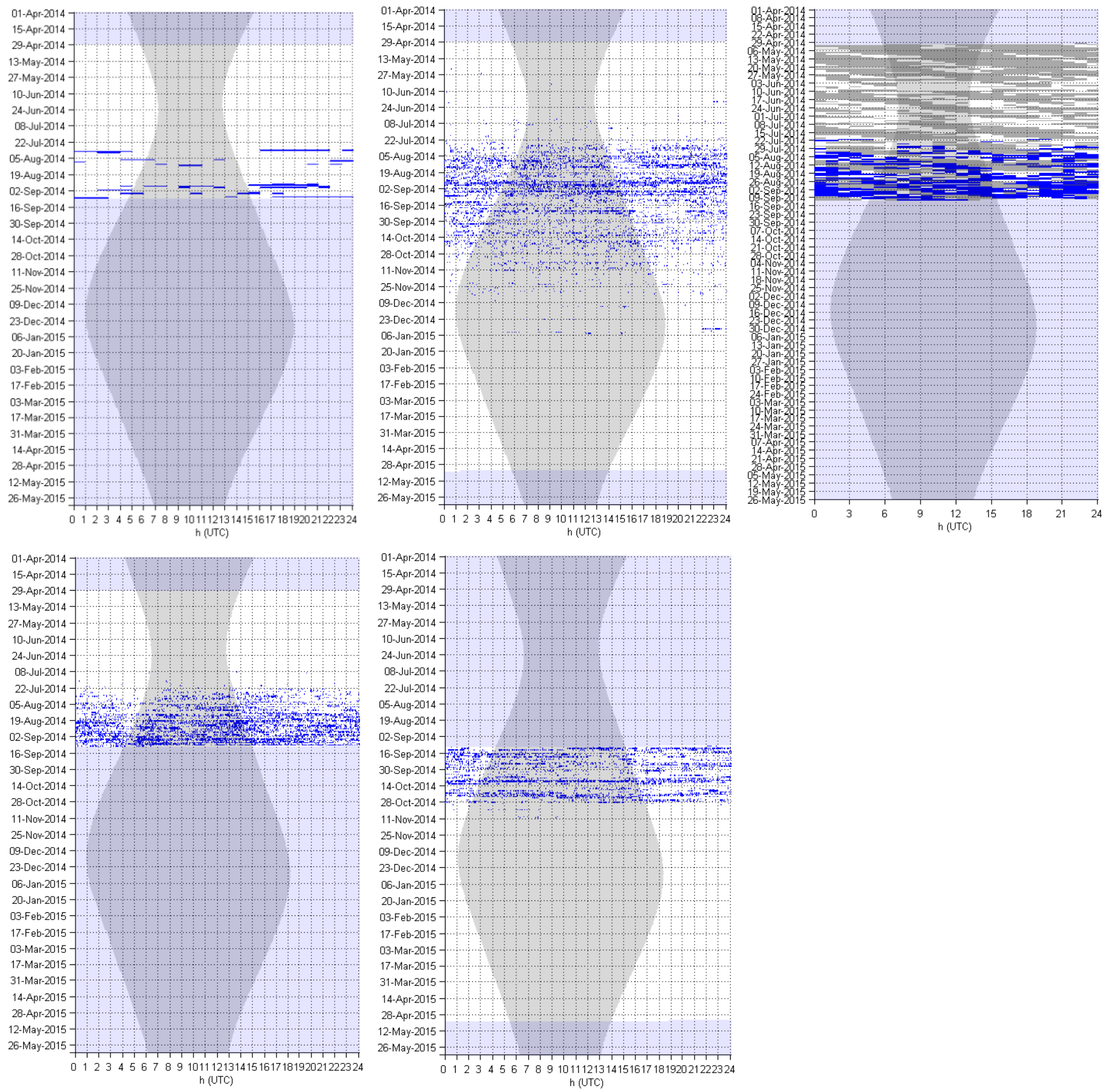


**Figure 24. Diel presence of NE Pacific blue whale B calls between April 2014 and May 2015. Hourly bins are shown for sites CA (top left) and KO (top right). Calls in one-minute bins are shown for sites CB (top middle), PT (bottom left), and QN (bottom right). Dark gray shading denotes instrument strumming. Light gray vertical shading denotes nighttime and light purple horizontal shading denotes absence of acoustic data.**

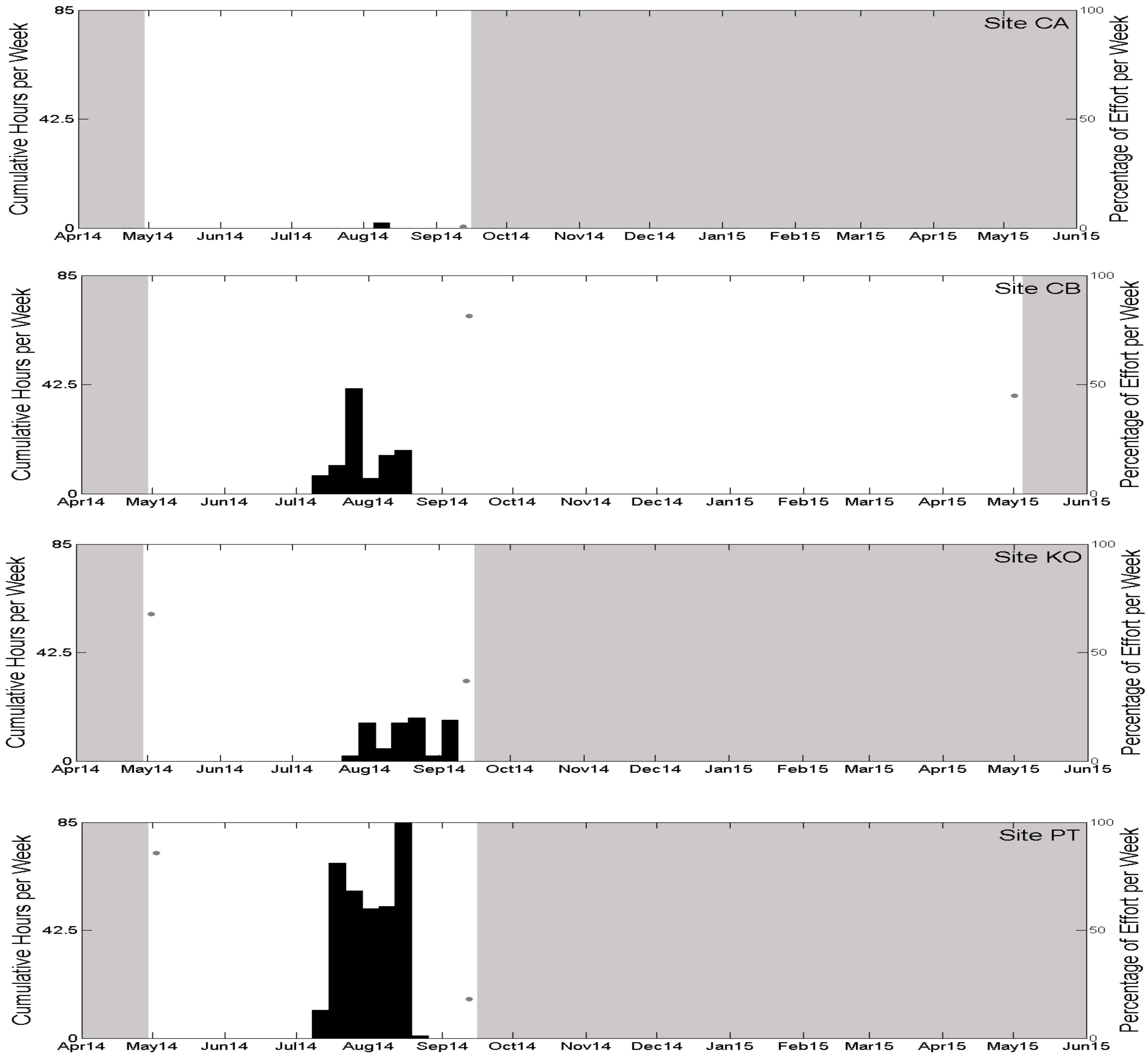


**Figure 25. Weekly presence of Central Pacific tonal blue whale calls between April 2014 and May 2015 at sites CA (top), CB (second from top), KO (second from bottom), and PT (bottom). Effort markings are described in Figure 23.**

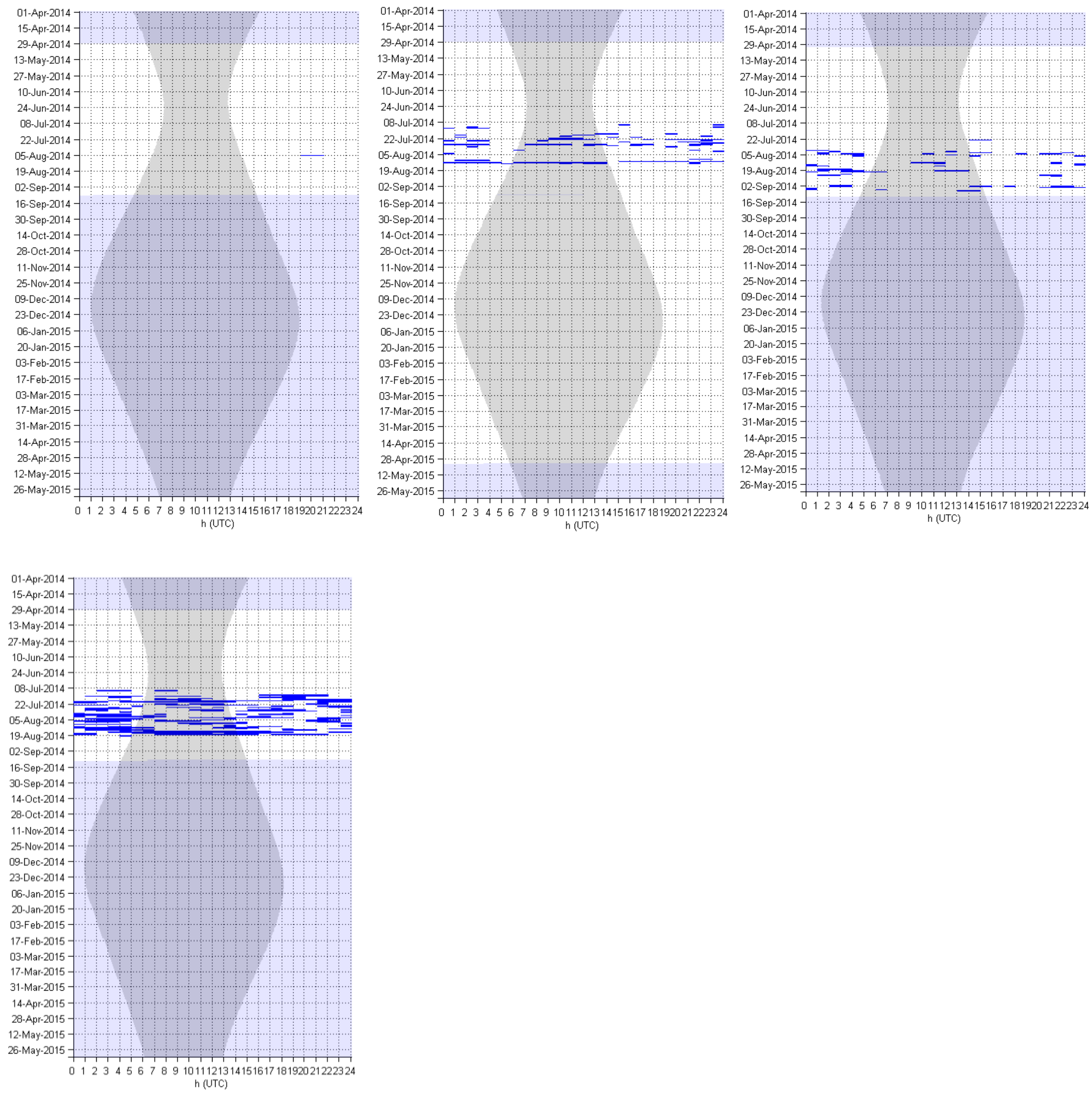


**Figure 26. Central Pacific tonal blue whale calls in hourly bins at sites CA (top left), CB (top middle), KO (top right), and PT (bottom). Effort markings are described in Figure 24.**

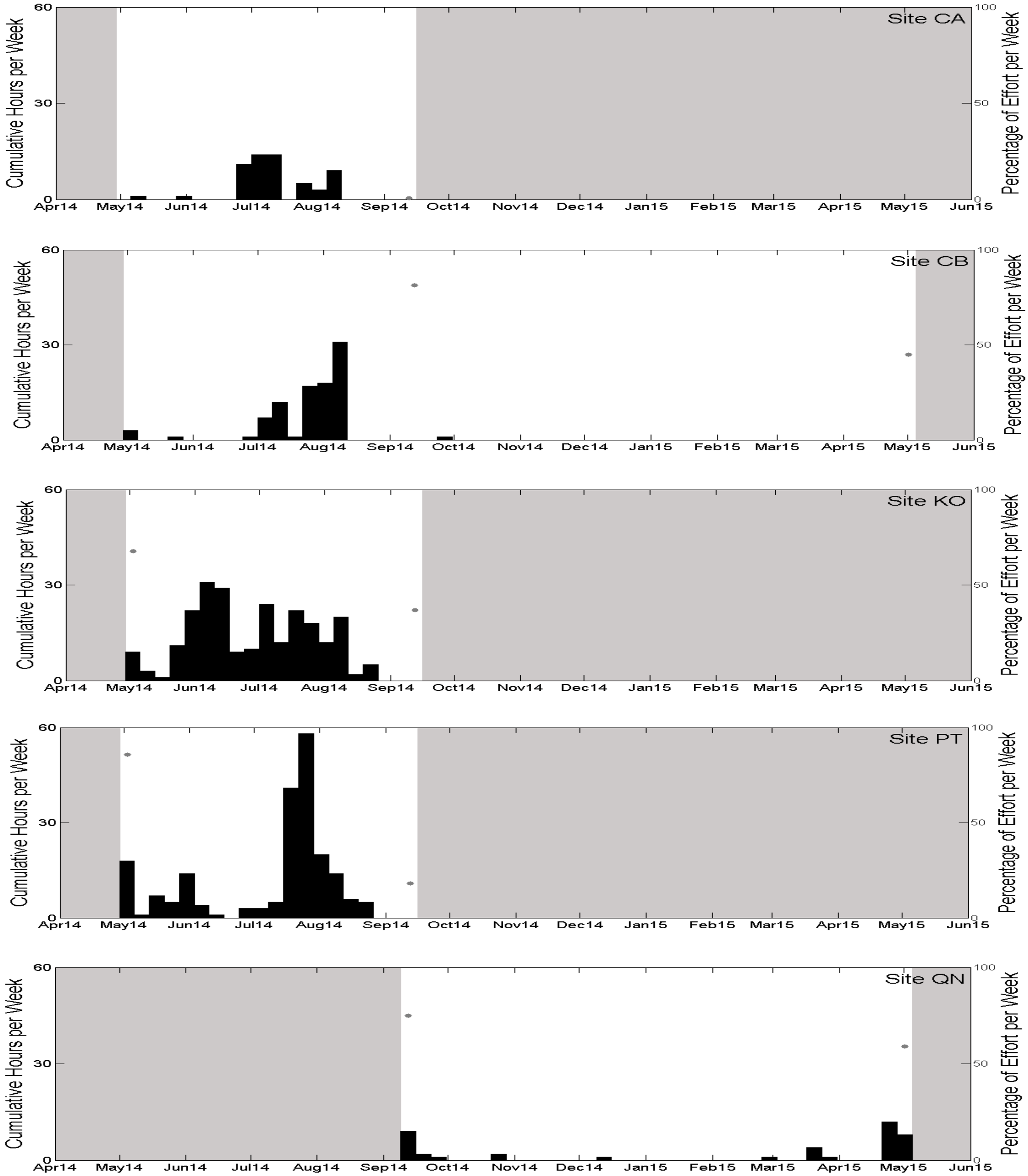


**Figure 27. Weekly presence of blue whale D calls between April 2014 and May 2015 at sites CA (top), CB (second from top), KO (middle), PT (second from bottom), and QN (bottom). Effort markings are described in Figure 23.**

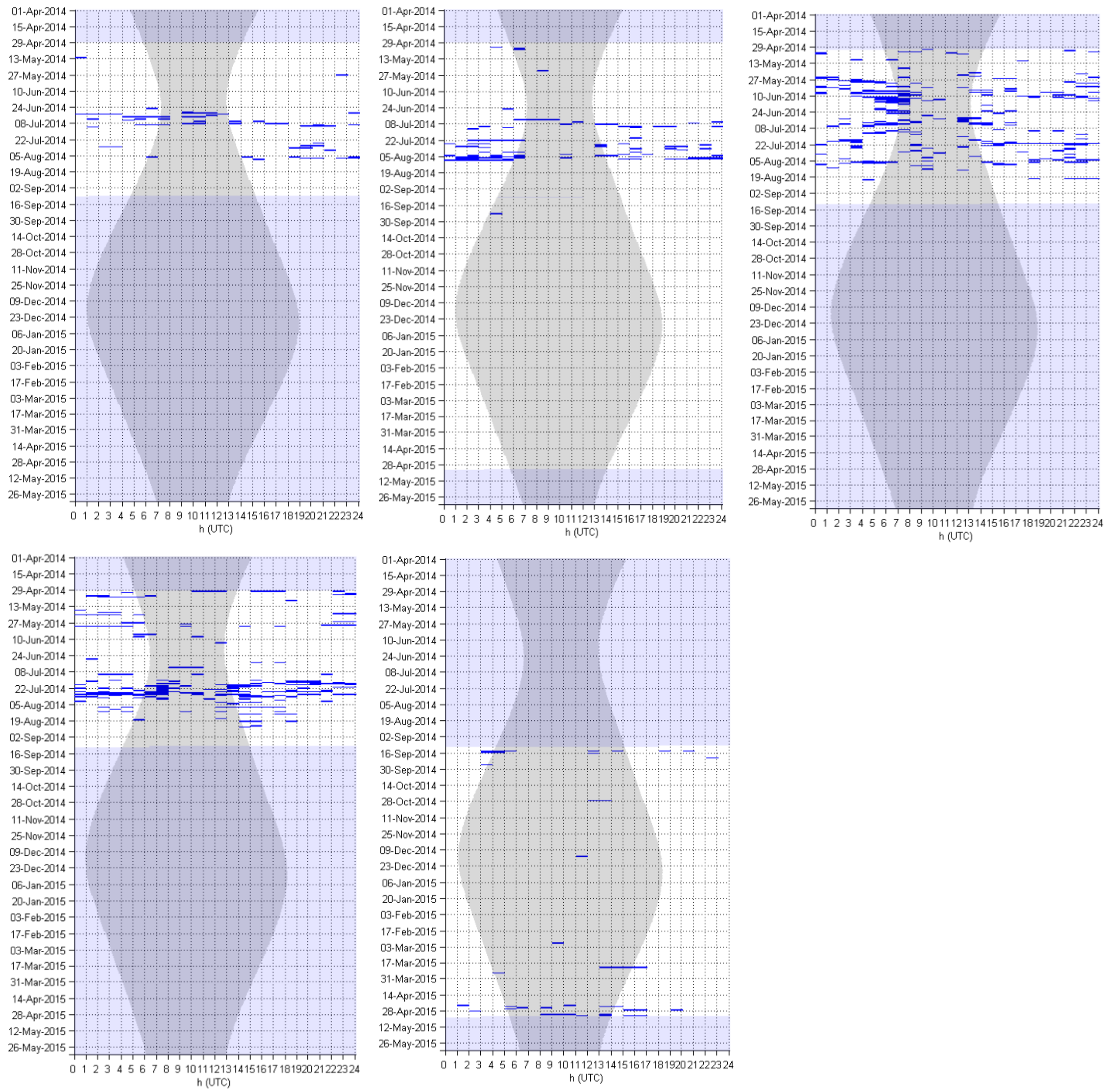


**Figure 28. Blue whale D calls in hourly bins at sites CA (top left), CB (top middle), KO (top right), PT (bottom left), and QN (bottom right). Effort markings are described in Figure 24.**

**Fin Whales**

Fin whales were detected throughout the recordings at all sites.

- Fin whale 20 Hz calls, associated with singing and call-countercall among animals, were the dominant fin whale call type. Peaks in calling occurred September – December 2014 (Figure 29).
- There was no discernable diel pattern for 20Hz calls (Figure 30)
- In the eastern North Pacific, fin whale 20Hz calls are generally detected from October through April (Watkins *et al.*, 2000), corresponding to the pattern we observed at these sites.
- Fin whale 40 Hz calls were recorded throughout the recording period at all sites (Figure 31).
- Peaks in detections occurred in June and August 2014. Site CA had the highest number of detections.
- There was no discernable diel pattern for fin whale 40 Hz calls (Figure 32).
- Differences in the timing of peak calling presence per call type may indicate distinct behavioral functions associated with these call types (Širović *et al.*, 2013)
- These results are consistent with earlier recordings (Baumann-Pickering *et al.*, 2012; Debich *et al.*, 2013; Debich *et al.*, 2014).

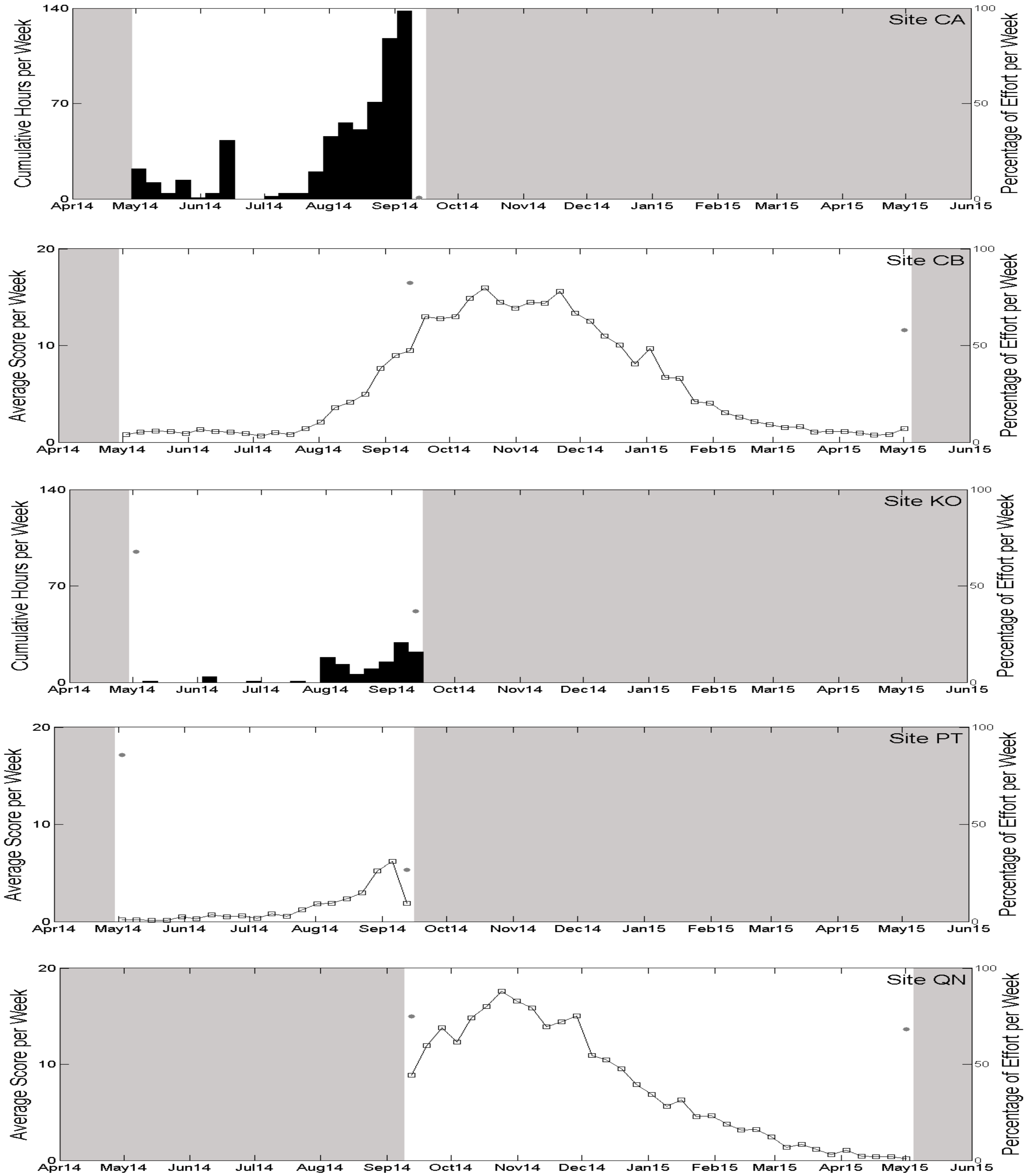


**Figure 29. Weekly presence of fin whale 20 Hz calls between April 2014 and May 2015 at site CA (top) and KO (middle). Weekly value of fin whale call index (proxy for 20 Hz calls) is shown for sites CB (second from top), PT (second from bottom) and QN (bottom). Effort markings are described in Figure 23.**

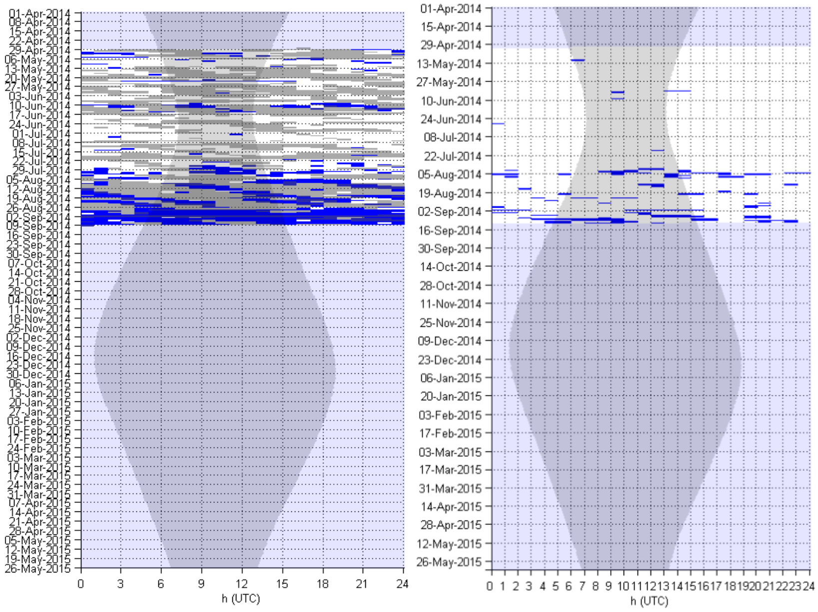


**Figure 30. Fin whale 20Hz calls in hourly bins at sites CA (left) and KO (right). Effort markings are described in Figure 24.**

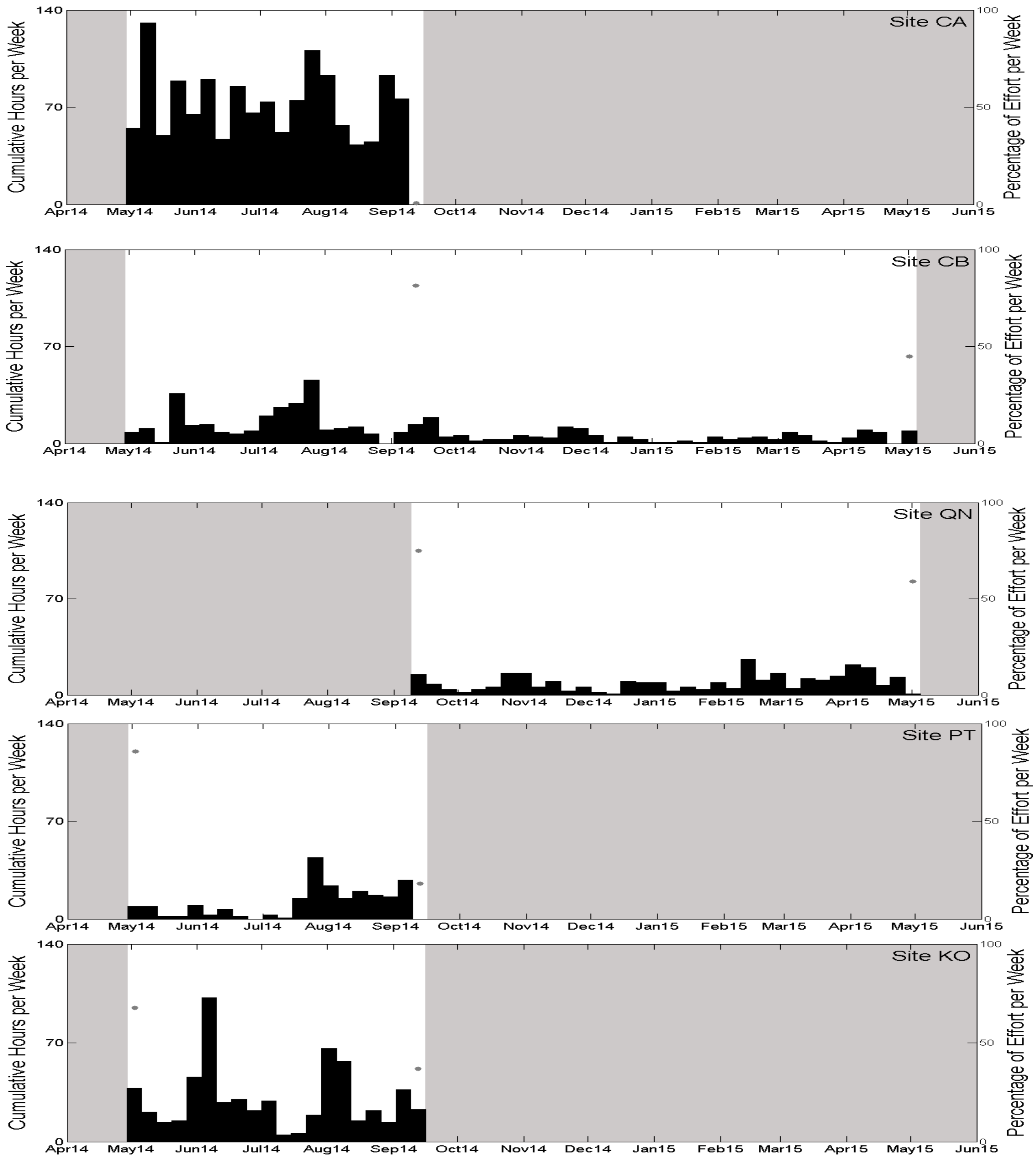


**Figure 31. Weekly presence of fin whale 40 Hz calls between April 2014 and May 2015 at sites CA (top), CB (second from top), KO (middle), PT (second from bottom), and QN (bottom). Effort markings are described in Figure 23.**

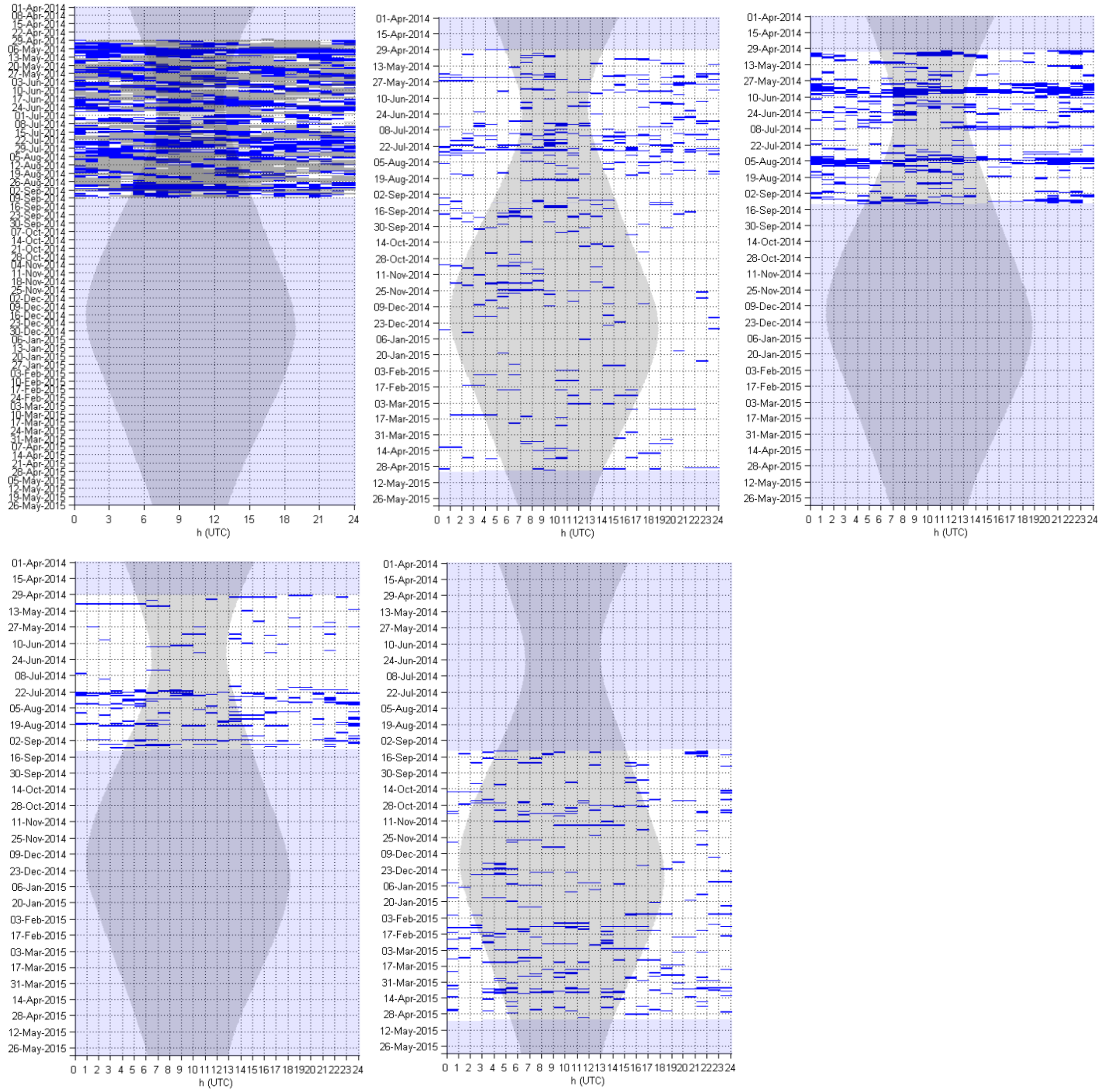


**Figure 32. Fin whale 40 Hz calls in hourly bins at sites CA (top left), CB (top middle), KO (top right), PT (bottom left), and QN (bottom right). Effort markings are described in Figure 24.**

## Gray Whales

Gray whale M3 calls were detected in low numbers.

- Gray whale M3 calls were detected at sites CA and KO (Figure 33).
- Calls occurred throughout the summer and fall period of the recordings at both sites. No grey whale M3 calls were detected at other sites.
- There was no discernable diel pattern for gray whale M3 calls (Figure 34).
- Gray whale M3 calls have been detected in low numbers in previous recordings at sites CA, KO, and at site CB during a single hour on September 29, 2011 (Baumann-Pickering *et al.*, 2012; Debich *et al.*, 2013; Debich *et al.*, 2014).

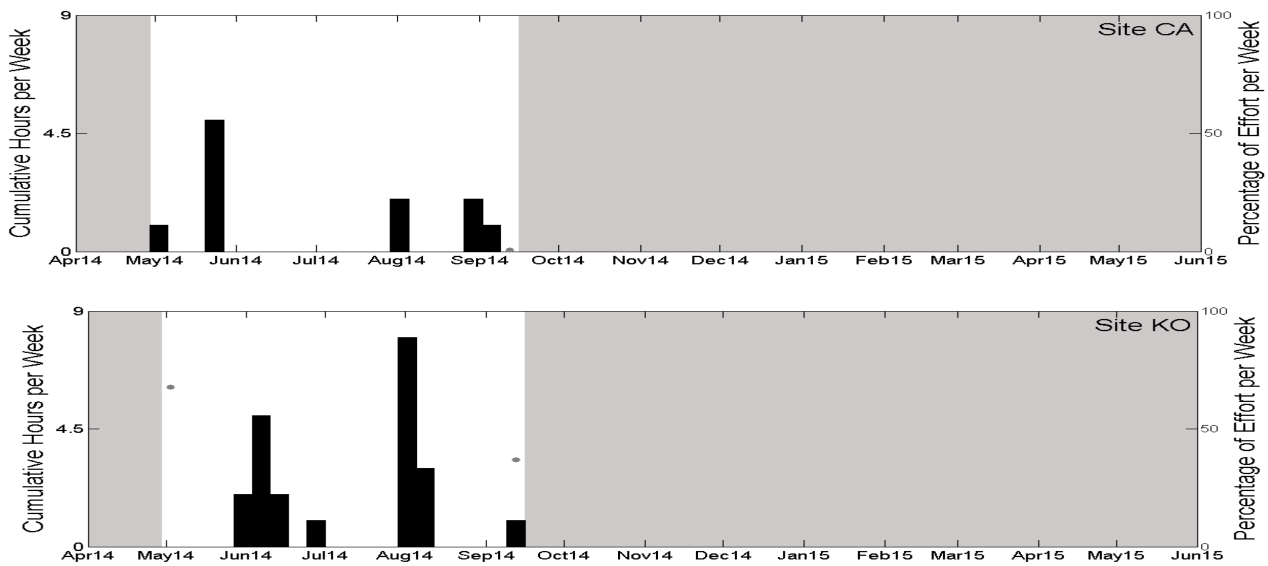


**Figure 33. Weekly presence of gray whale M3 calls between April 2014 and May 2015 at sites CA (top) and KO (bottom). Effort markings are described in Figure 23.**

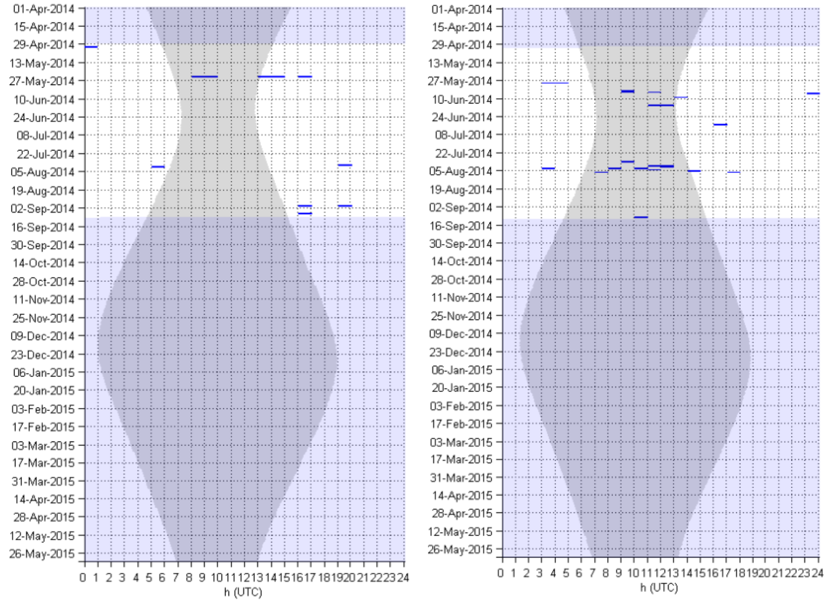


**Figure 34. Gray whale M3 calls in hourly bins at sites CA (left) and KO (right). Effort markings are described in Figure 24.**

**Humpback Whales**

Humpback whales were detected at all sites and were one of the most commonly detected baleen whales in the recordings.

- Humpback whale detections were low from April – November 2014 and high from December 2014 through March 2015 (Figure 35). Site QN had the highest number of detections.
- There was more nighttime calling at site KO, but no discernable diel pattern for the other sites (Figure 36).
- The substantial presence of humpback whales during the 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.
- In general these results are similar to previous recordings (Baumann-Pickering *et al.*, 2012; Debich *et al.*, 2013; Debich *et al.*, 2014). However, it appears that calling continues until later in the year (subsiding around April) than in previous recordings (subsiding around March).

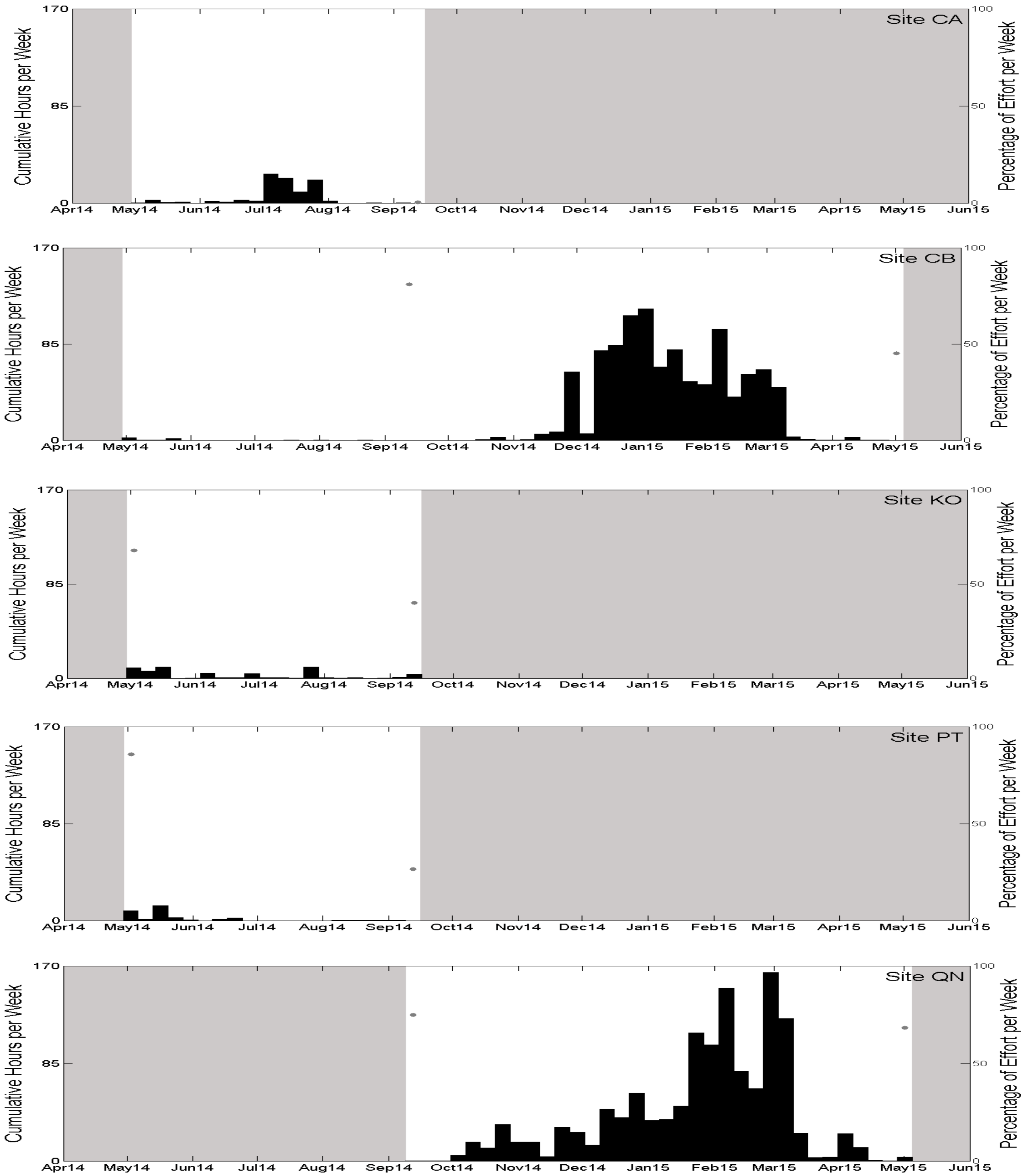


**Figure 35. Weekly presence of humpback whale calls between April 2014 and May 2015 at sites CA (top), CB (second from top), KO (middle), PT (second from bottom), and QN (bottom). Effort markings are described in Figure 23.**

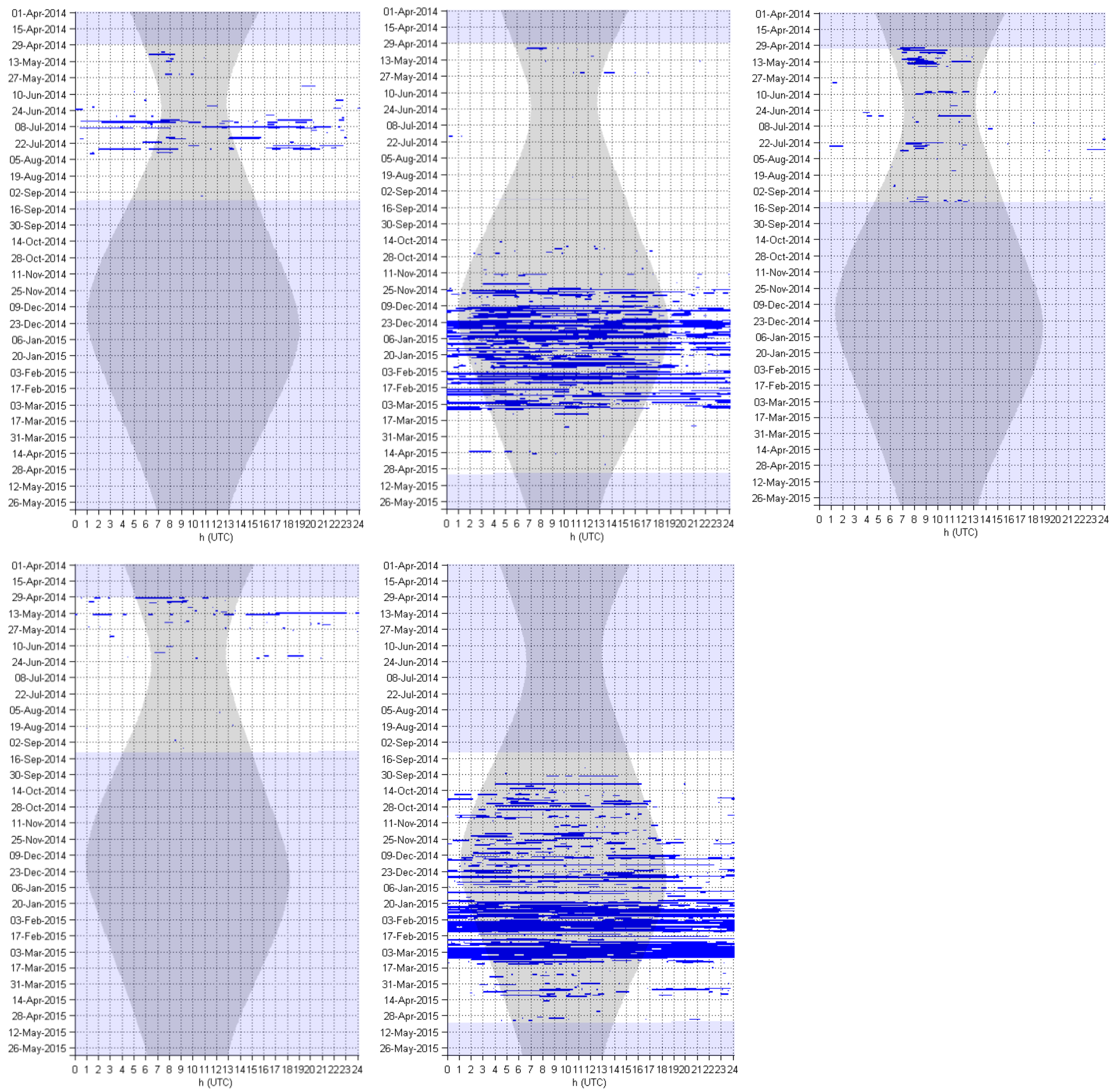


**Figure 36. Humpback whale calls in one-minute bins at sites CA (top), CB (second from top), KO (middle), PT (second from bottom), and QN (bottom). Effort markings described in Figure 24.**

## Odontocetes

Three odontocete species were detected between April 2014 and May 2015: sperm whales, Cuvier's beaked whales, and Stejneger's beaked whales. More details of each species' presence at these sites are given below.

### 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 2014 and again in April – May 2015 (Figure 37). Site CA had the least number of detections.
- There was no discernable diel pattern for sperm whale clicks (Figure 38).
- These results were similar to those in previous monitoring periods for sites CA, CB and KO (Baumann-Pickering *et al.*, 2012; Debich *et al.*, 2013; Debich *et al.*, 2014). Site PT had a peak in detections from August – September and site QN had a peak from March – April, both of which have not been previously reported.

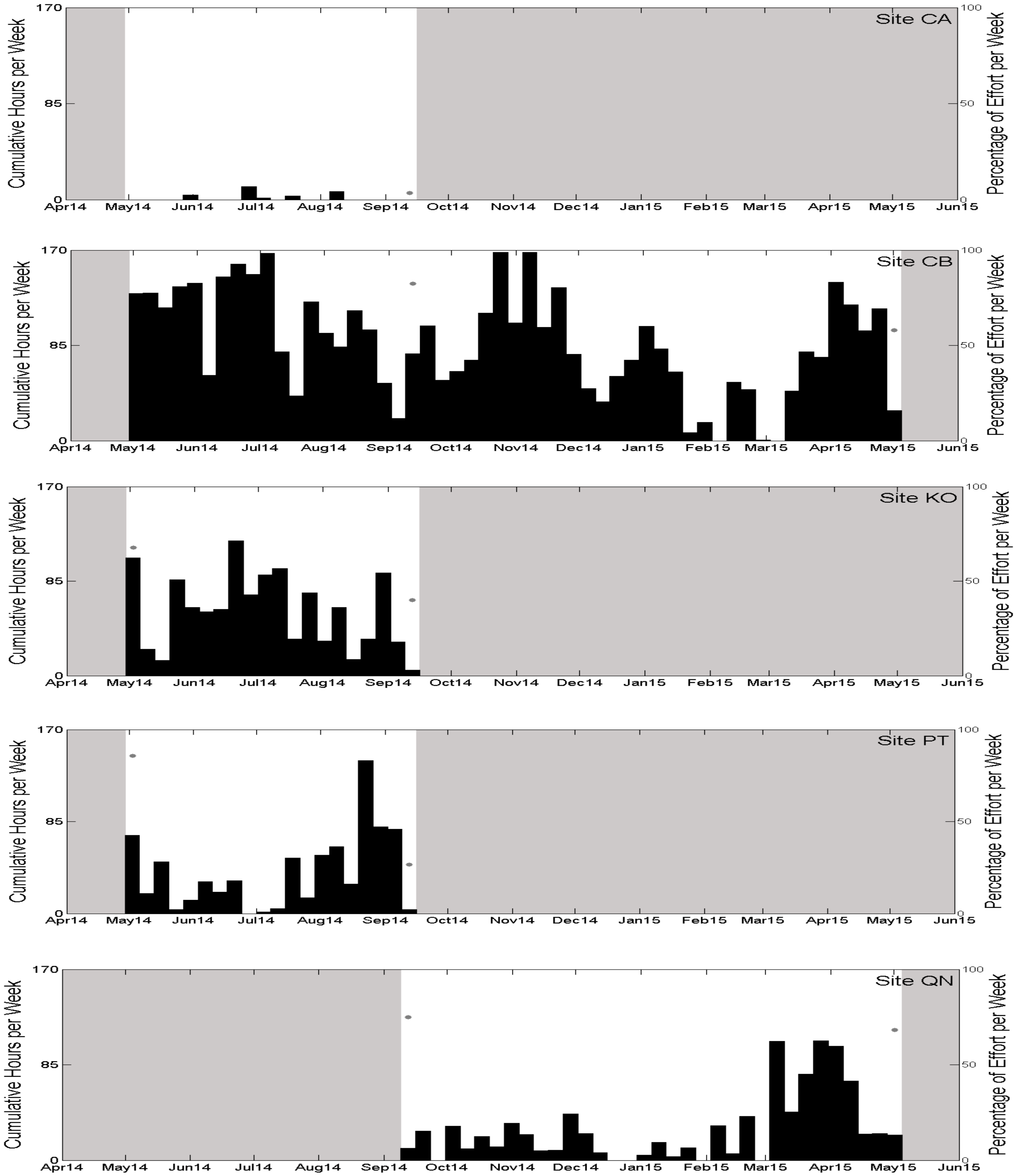


**Figure 37. Weekly presence of sperm whale clicks between April 2014 and May 2015 at sites CA (top), CB (second from top), KO (middle), PT (second from bottom), and QN (bottom). Effort markings are described in Figure 23.**

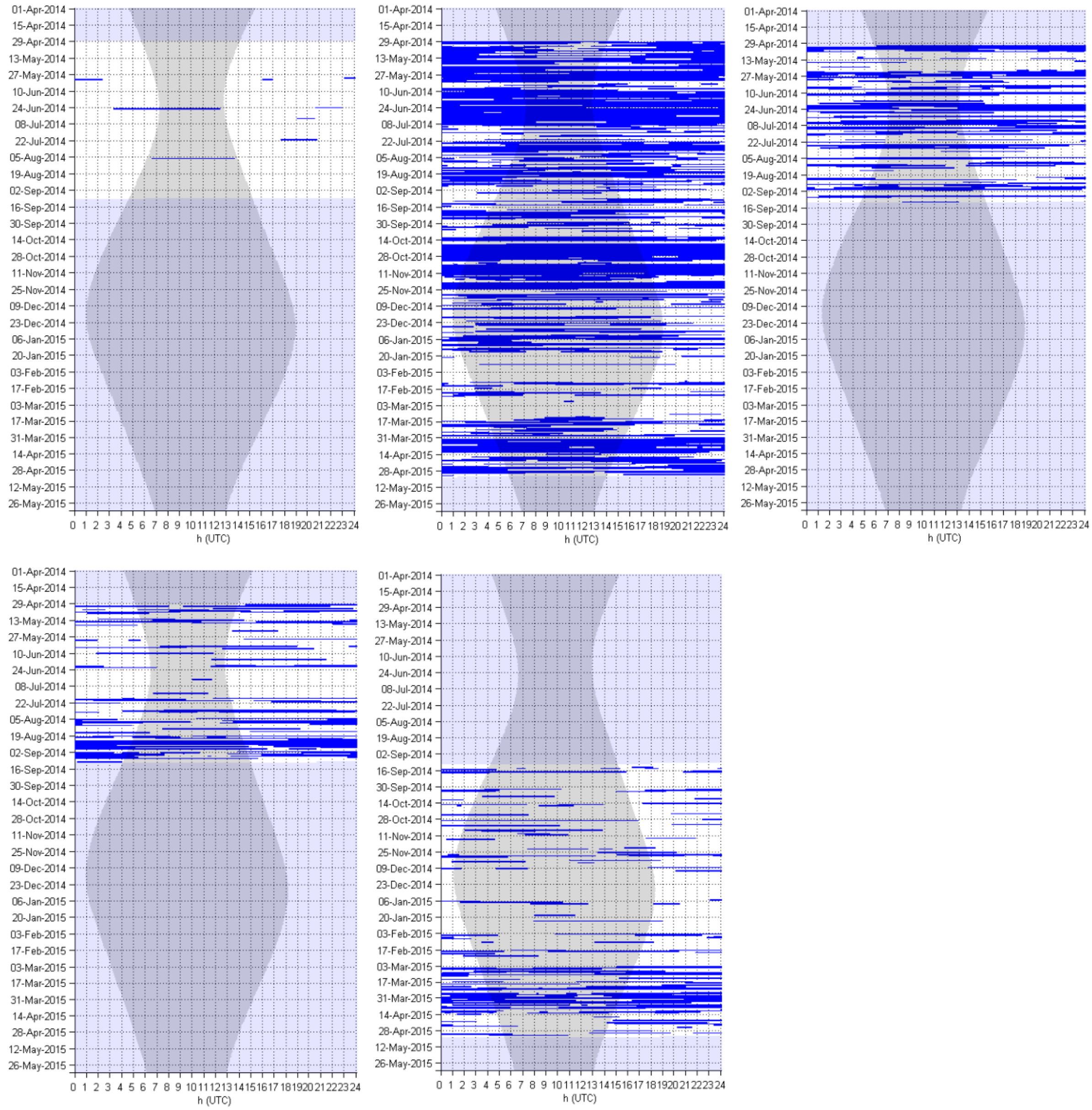


**Figure 38. Sperm whale clicks in one-minute bins at sites CA (top left), CB (top middle), KO (top right), PT (bottom left), and QN (bottom right). Effort markings are described in Figure 24.**

## Cuvier's Beaked Whales

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

- Cuvier's beaked whale FM pulses were detected in low numbers at sites PT and QN (Figure 39). Detections occurred from May – July 2014 at site PT and from October 2014 – March 2015 at site QN.
- There was no discernable diel pattern for Cuvier's beaked whale detections (Figure 40).
- These results were similar to those in previous monitoring periods for sites PT and QN (Baumann-Pickering *et al.*, 2012; Debich *et al.*, 2013; Debich *et al.*, 2014). However, there were detections at site CB during previous monitoring periods which were not seen during this period.

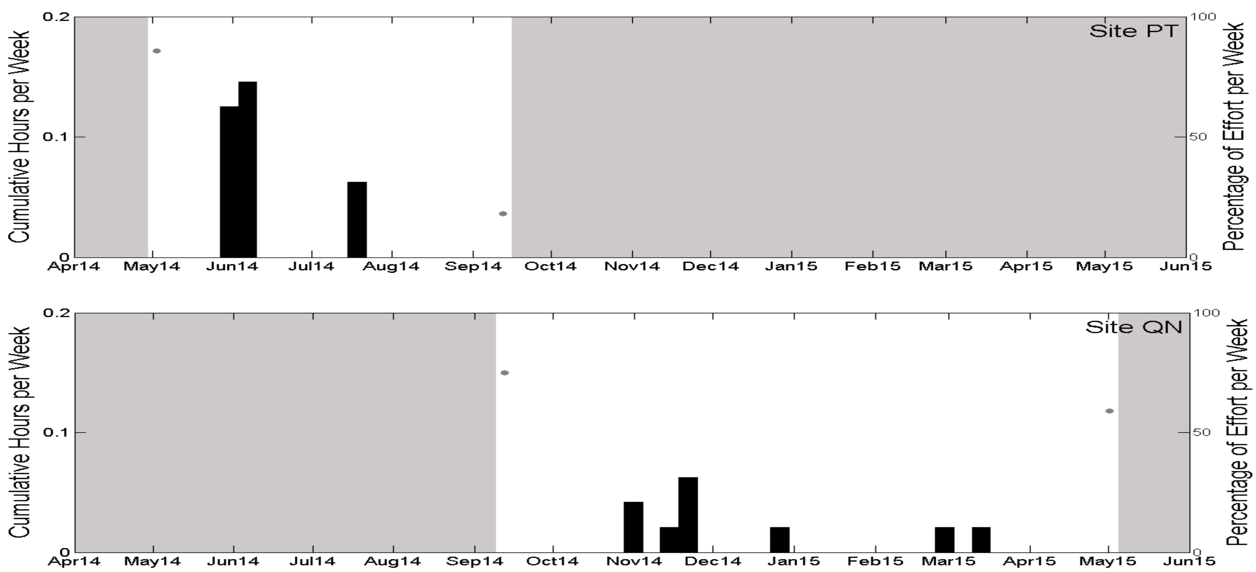


**Figure 39. Weekly presence of Cuvier's beaked whale FM pulses between April 2014 and May 2015 at sites PT (top) and QN (bottom). Effort markings are described in Figure 23.**

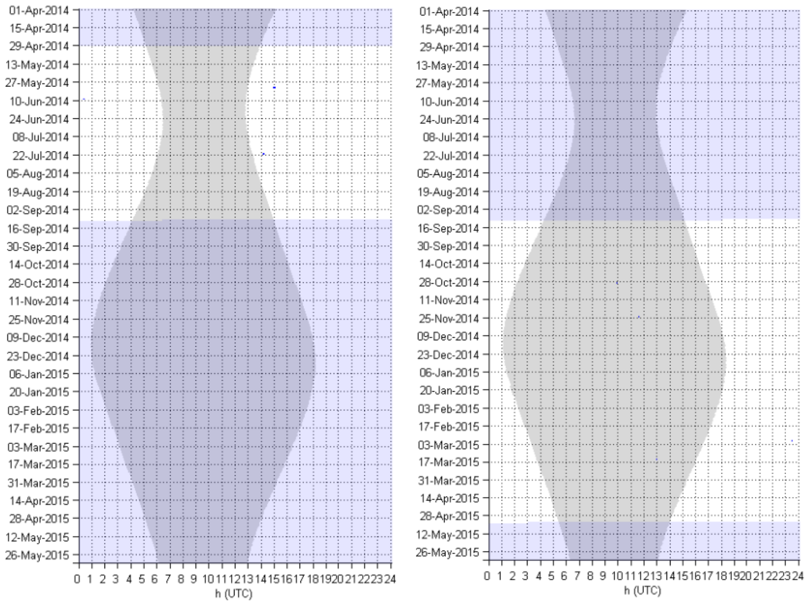


**Figure 40. Cuvier's beaked whale FM pulses in one-minute bins at sites PT (left) and QN (right). Effort markings are described in Figure 24.**

**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 41). Detections were most prevalent at site CB, with a peak in detections in October 2014. Detections occurred in low numbers at sites PT and QN.
- There was no discernable diel pattern for Stejneger's beaked whale detections (Figure 42).
- These results were similar to those from the last monitoring period (Debich *et al.*, 2014) but there were slightly more detections during previous monitoring periods (Baumann-Pickering *et al.*, 2012; Debich *et al.*, 2013).

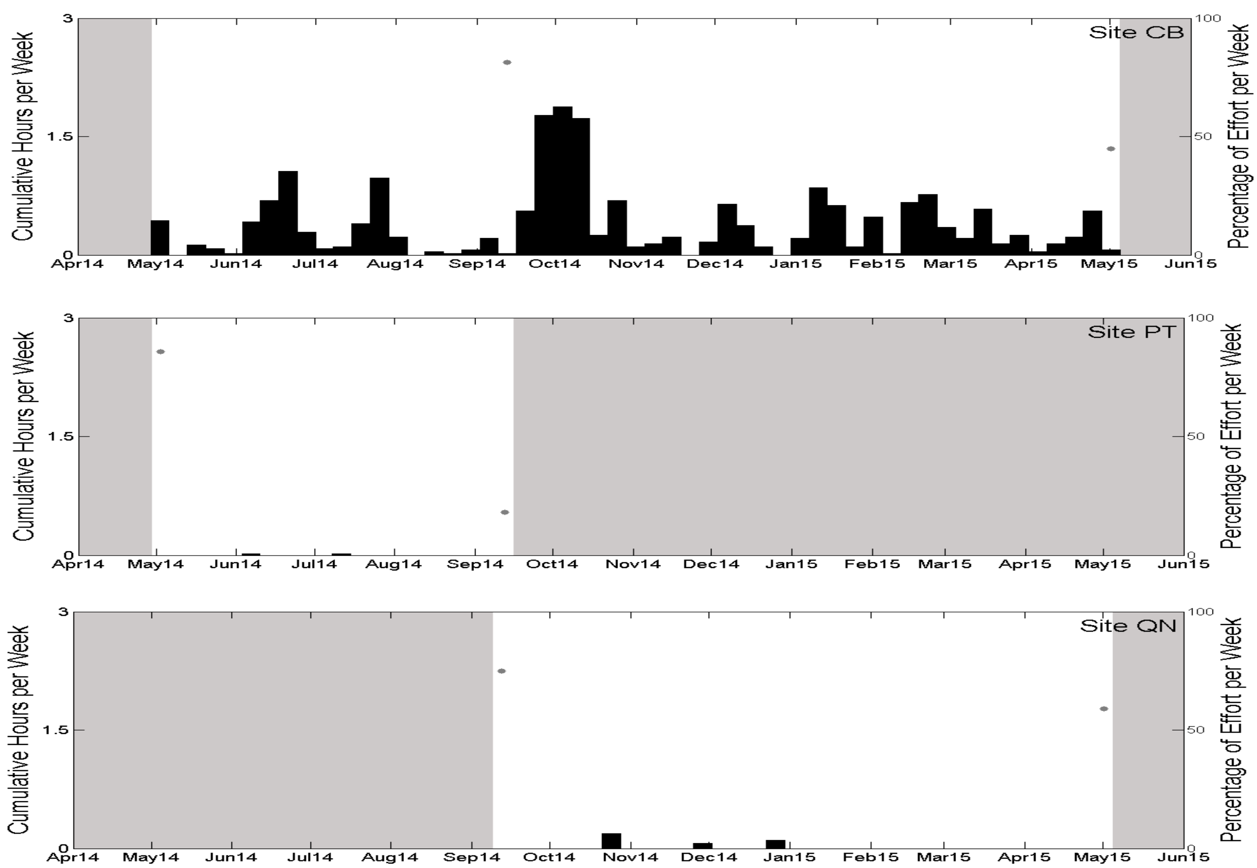


**Figure 41. Weekly presence of Stejneger's beaked whale FM pulses between April 2014 and May 2015 at sites CB (top), PT (middle), and QN (bottom). Effort markings are described in Figure 23.**

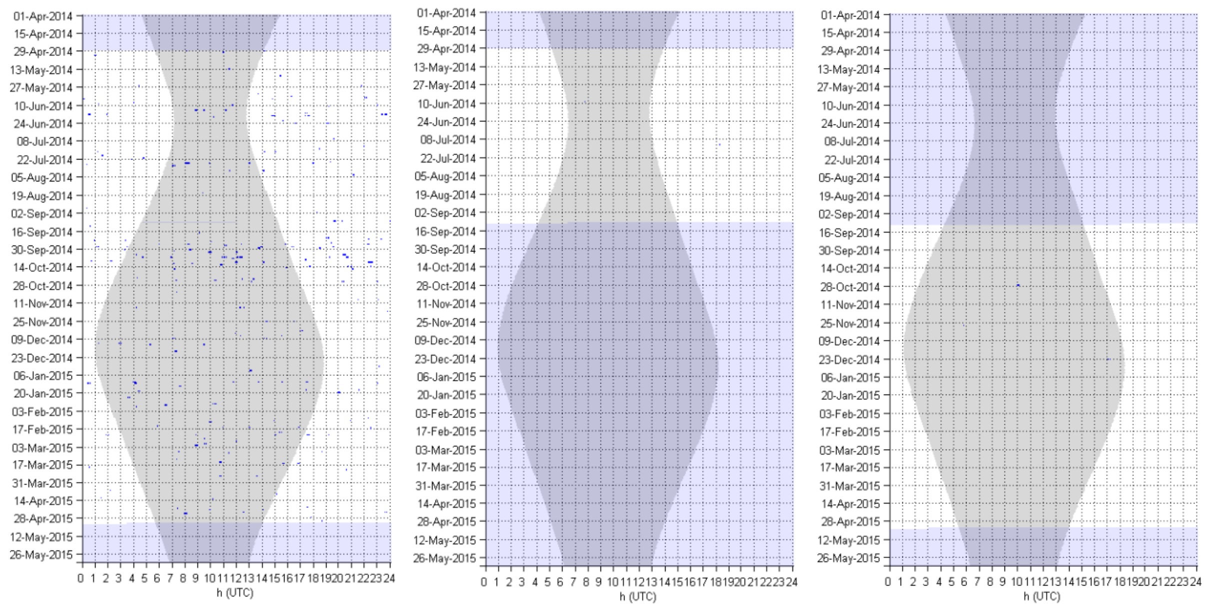

**Figure 42. Stejneger's beaked whale FM pulses in one-minute bins at sites CB (left), PT (middle), and QN (right). Effort markings are described in Figure 24.**

## Anthropogenic Sounds

Broadband ship noise and explosions were detected in the GATMAA between April 2014 and May 2015. There were no MFA or LFA detections.

### Broadband Ship Noise

Broadband ship noise was detected at all sites.

- Broadband ship noise occurred throughout recording periods at all sites, with a peak in May at site CB (Figure 43).
- There was no discernable diel pattern for broadband ship detections (Figure 44).
- In general, there were less broadband ship detections during this monitoring period than in the previous monitoring period (Debich *et al.*, 2014) but a similar number of detections compared to earlier monitoring periods (Baumann-Pickering *et al.*, 2012; Debich *et al.*, 2013).

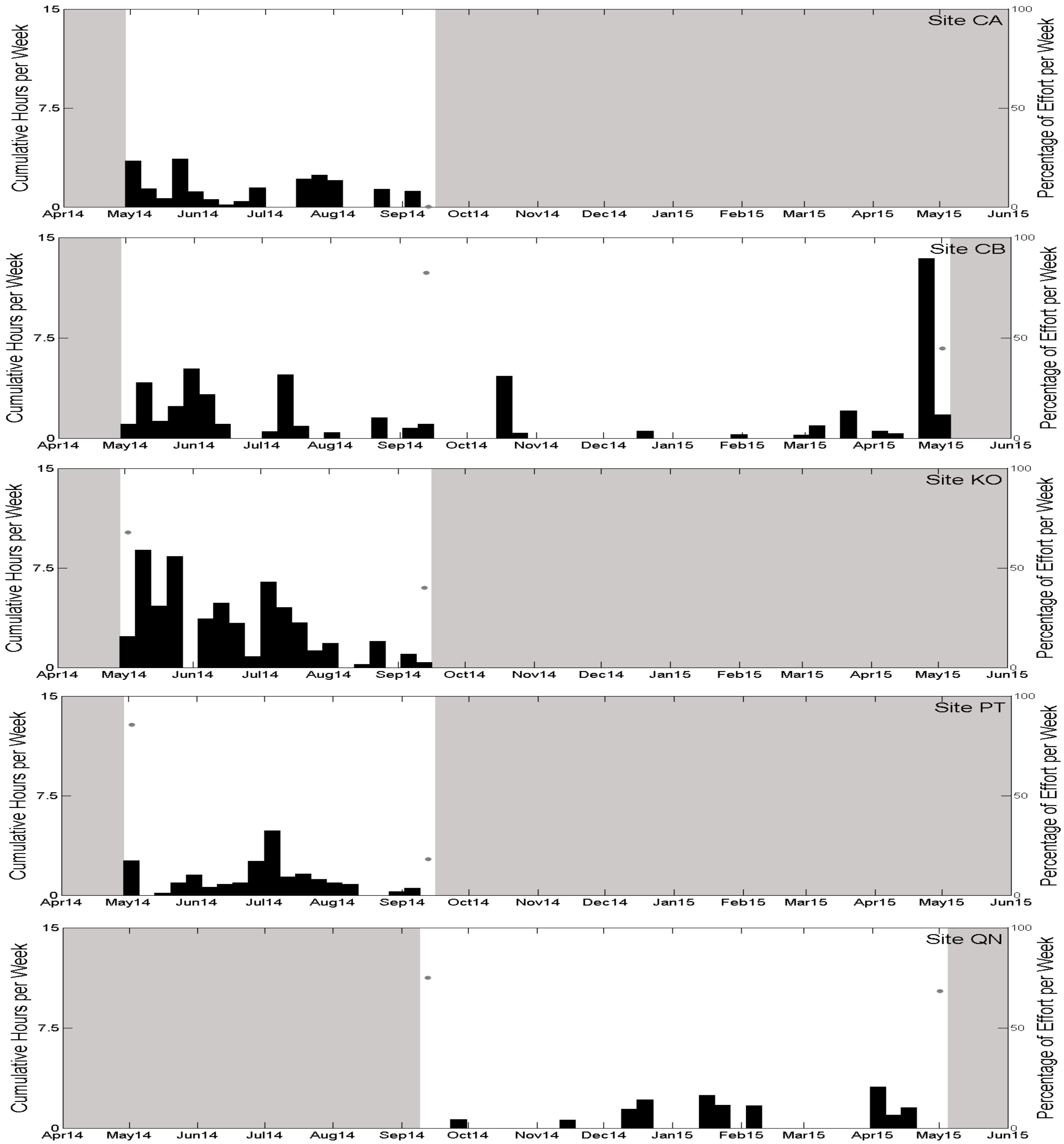


**Figure 43. Weekly presence of broadband ships between April 2014 and May 2015 at sites CA (top), CB (second from top), KO (middle), PT (second from bottom), and QN (bottom). Effort markings are described in Figure 23.**

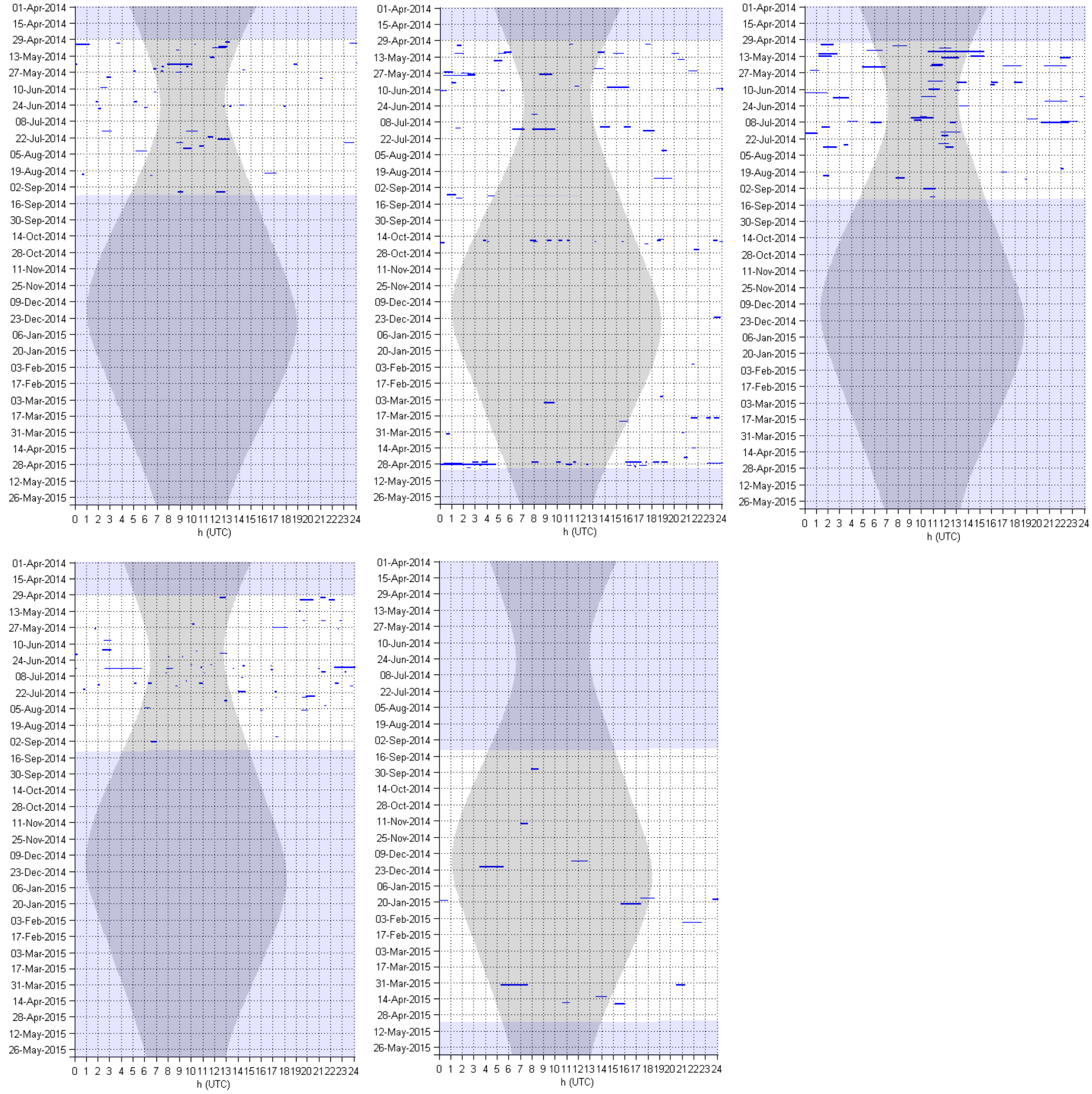


**Figure 44. Broadband ship noise in one-minute bins at sites CA (top left), CB (top middle), KO (top right), PT (bottom left), and QN (bottom right). Effort markings are described in Figure 24.**

**Explosions**

Explosions were detected in low numbers.

- Explosions were detected at sites CA, CB, KO and PT mainly during summer months (Figure 45). The highest number of detections occurred at offshore site PT but there were no detections at the other offshore site QN.
- Explosion counts for each site were as follows: 31 for CA, 7 for CB, 4 for KO, and 125 for PT.
- There were no explosions detected during the winter at site CB and no detections at site QN as were seen during previous monitoring periods (Baumann-Pickering *et al.*, 2012; Debich *et al.*, 2013; Debich *et al.*, 2014).
- Though there were few explosion detections, most occurred during daytime hours (Figure 46).
- The explosions were likely fishery-related seal bombs based on the spectral properties of the signals.

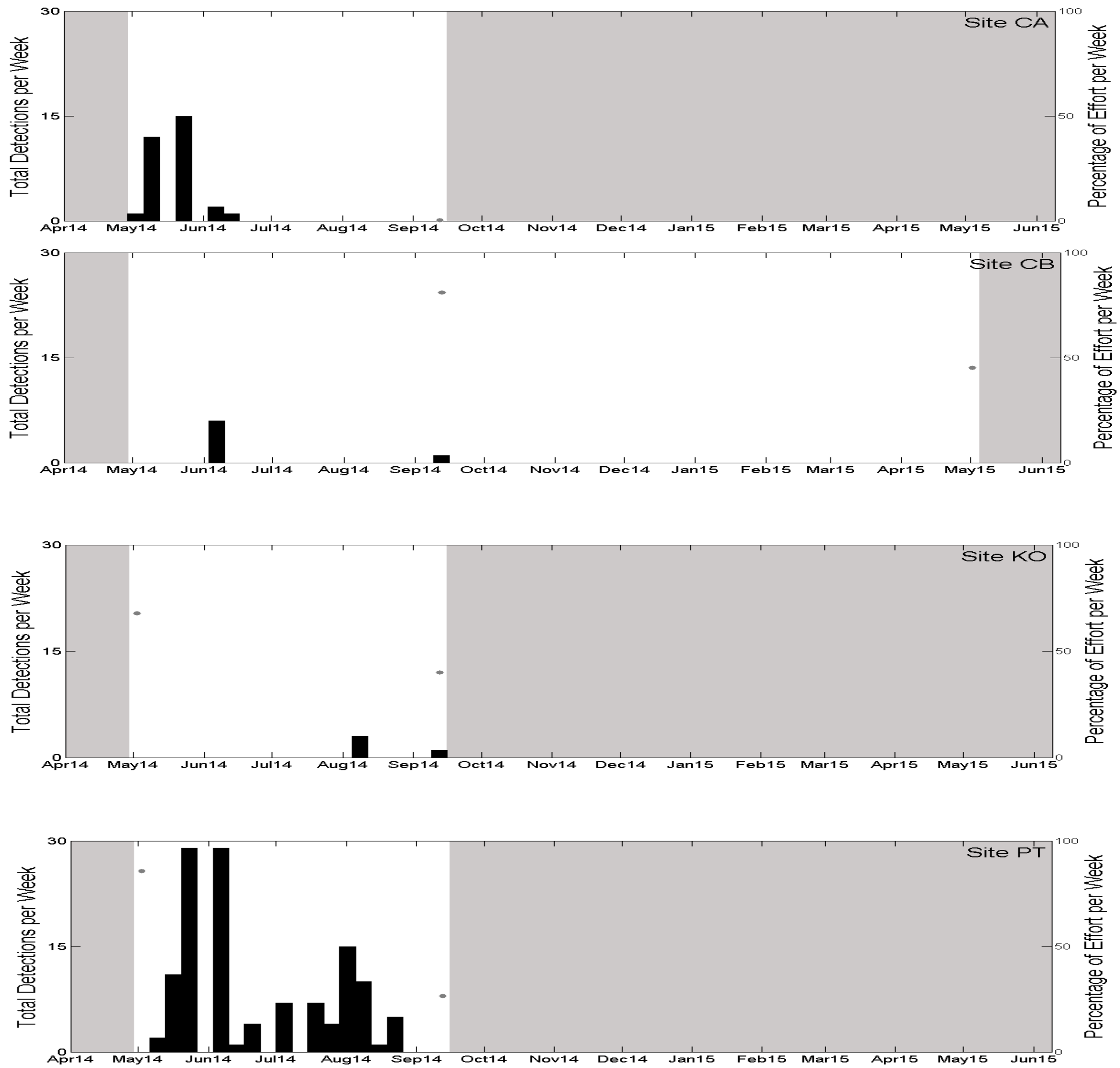


**Figure 45. Weekly detections of explosions between April 2014 and May 2015 at sites CA (top), CB (second from top), KO (second from bottom), and PT (bottom) were detected automatically using a matched filter detector. Effort markings are described in Figure 23.**

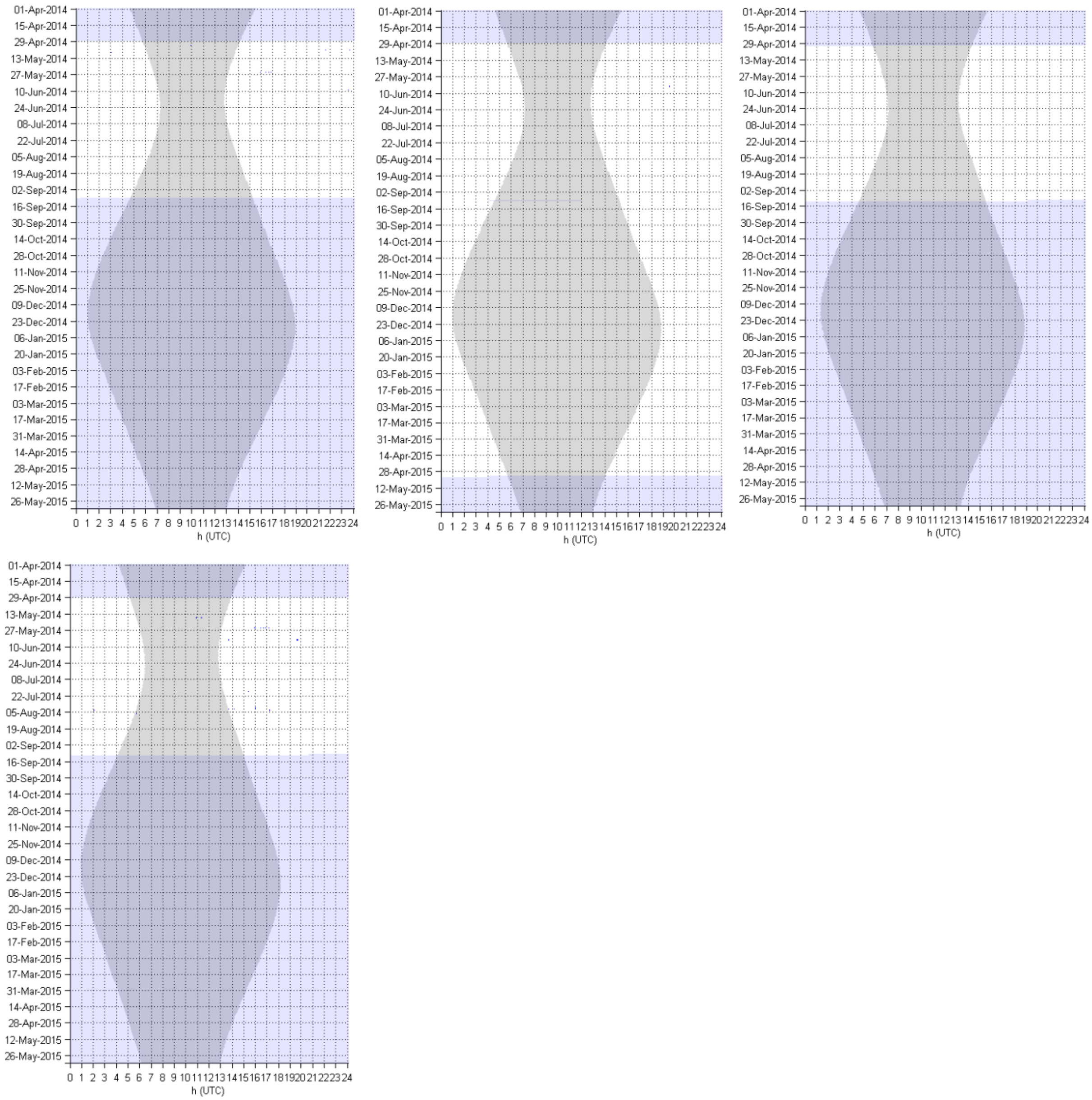


**Figure 46. Explosions in one-minute bins at sites CA (top left), CB (top middle), KO (top right), and PT (bottom). Effort markings are described in Figure 24.**

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