# Passive Acoustic Monitoring for Marine Mammals offshore of Norfolk Canyon
# June 2017–June 2018

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Risso's Dolphin (*Grampus griseus*)
*Photo Credit: Katherine Whitaker*

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Additional information on previous HARP deployments and availability of all associated reports is available on the project profile page of the U.S. Navy's Marine Species Monitoring Program web portal.

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# Executive Summary

A High-Frequency Acoustic Recording Package (HARP) was deployed from June 2017 to June 2018 to detect marine mammal and anthropogenic sounds in the Navy's Virginia Capes Range Complex offshore from Norfolk Canyon (NFC). The HARP was located 75 nm offshore in approximately 950 m of water. The HARP recorded sound in the frequency band 10 Hz – 100 kHz. Data analysis consisted of analyst scans of long-term spectral averages (LTSAs) and spectrograms, and automated computer algorithm detection when possible. Three frequency bands were analyzed for marine mammal vocalizations and anthropogenic sounds: (1) Low-frequency, between 10-500 Hz, (2) Mid-frequency, between 10-5,000 Hz, and (3) High-frequency, between 5-100 kHz.

Ambient sound levels of 80-85 dB re: $\mu\text{Pa}^2/\text{Hz}^2$ were observed at 45 kHz, and were predominantly due to basin-wide commercial shipping. From August 2017 – March 2018, a peak in ambient noise at 15-25 Hz is related to the seasonal presence of fin whales. Sound levels at 200-1,000 Hz are higher January through March, and are related to wind and wave noise associated with higher sea states.

Four baleen whale species were recorded: fin, minke, sei, and humpback whales. No Bryde's whale, blue whale, or right whale calls were found. Fin whales were detected throughout the monitoring period with higher activity from November to December 2017 and in March 2018. Sei whales were detected primarily from January to May 2018, while minke whales were detected only in September 2017 and April 2018. Humpback whale call types were detected from March to May 2018.

Several known odontocete signals were detected, along with odontocete signals that cannot yet be distinguished to species. Cuvier's, Gervais', and Sowerby's beaked whales, as well as sperm whales, were regularly detected throughout the monitoring period. Blainville's beaked whales were detected once in July 2017. *Kogia* spp. echolocation clicks were also found in low numbers throughout the recording period, with the majority of detections occurring from September 2017 to February 2018. One acoustically identifiable delphinid species was Risso's dolphins, whose echolocation clicks were identified regularly from March to June 2018. Odontocete signals that could not be distinguished to species were common throughout the recordings. However, three distinct click types (CT) of unknown species origin were identified and designated as CT 1, CT 4, and CT 6. Unidentified odontocete whistles were detected and categorized as either above or below 5 kHz.

Seven types of anthropogenic sounds were identified. Explosions were detected intermittently throughout the recording period and airguns were detected primarily between October 2017 and February 2018. LFA sonar was detected infrequently between July and October 2017 and MFA sonar was detected intermittently throughout the recording period. Underwater communications were detected twice in July and August 2017. Echosounders were detected in low numbers but were highest in December 2017. Ships were detected throughout the deployment.

## Project Background

The US Navy's Virginia Capes Range Complex is located in the coastal and offshore waters of the western North Atlantic Ocean adjacent to Delaware, Maryland, Virginia, and North Carolina. The seafloor features a broad continental shelf, with an inner zone of less than 200 m water depth, and an outer zone extending to water depths of 2000 m. A diverse array of marine mammals is found in this region, including baleen and toothed whales.

In March 2012, an acoustic monitoring effort was initiated within the boundaries of the Virginia Capes Range Complex with support from U.S. Fleet Forces under contract to HDR and Duke University. The goal of this effort was to characterize the vocalizations of marine mammal species present in the area, to determine their seasonal presence patterns, and to evaluate the potential for impact from naval operations. This report documents the analysis of data recorded by a High-Frequency Acoustic Recording Package (HARP) that was deployed within the Virginia Capes Range Complex offshore from Norfolk Canyon and collected data from June 2017 to 2018 (Figure 1).

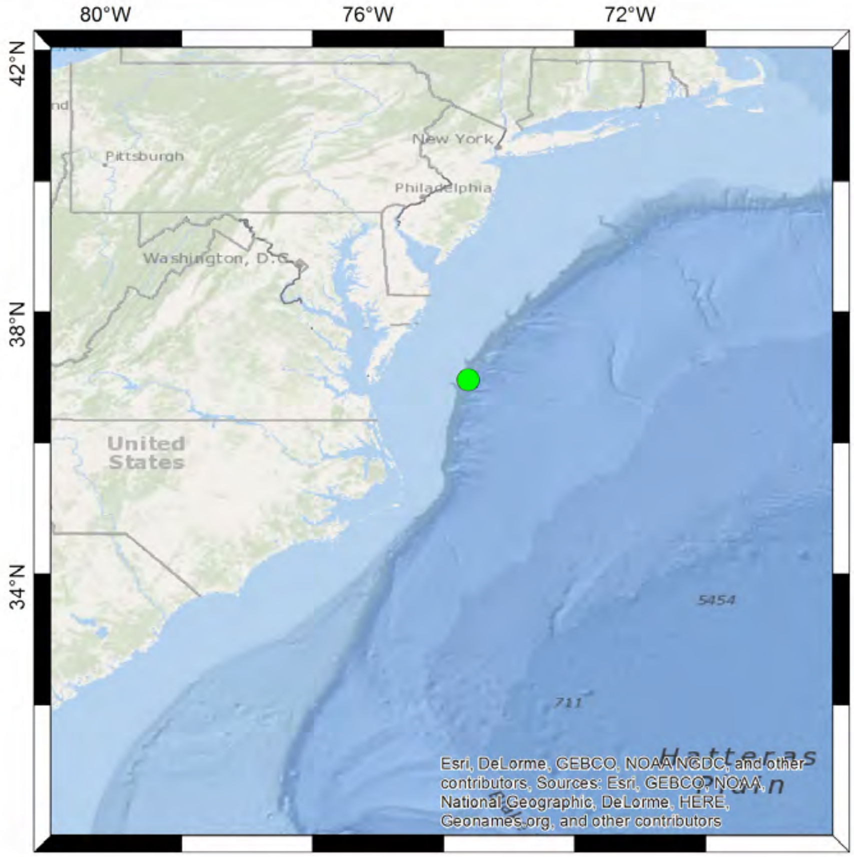

**Figure 1: Location of High-Frequency Acoustic Recording Package (HARP) at NFC Site A (37° 10.04 N, 74° 27.98 W, depth 950 m) deployed offshore from Norfolk Canyon study area from June 2017 to 2018.**

# Methods

### High-Frequency Acoustic Recording Package (HARP)

HARPs are autonomous underwater acoustic recording packages that can record sounds over a bandwidth from 10 Hz up to 160 kHz and that are capable of approximately 300 days of continuous data storage. The HARP was deployed in a small mooring configuration with the hydrophone suspended approximately 22 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

One HARP recorded from June 2017 to 2018 at NFC Site A (37° 10.044 N, 74° 27.980 W, depth 950 m) and sampled continuously at 200 kHz to provide 100 kHz of effective bandwidth. The instrument recorded 337.25 days from June 30, 2017 to June 3, 2018, for a total of 8,094 hours of data analyzed. Earlier data collection at the NFC site is documented in previous detailed reports (Rafter *et al.* 2018; Debich *et al.*, 2016). Intermittent data gaps appeared toward the beginning half of the deployment due to a data logger malfunction. Recording coverage began at 100% and was 84% at the end of the recording period.

# Data Analysis

To visualize the acoustic data, frequency spectra were calculated for all data using a time average of 5 seconds. These data, called Long-Term Spectral Averages (LTSAs), were then examined 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 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 this band in the NFC region, and the procedures used to detect them. For effective analysis, the data were divided into three frequency bands: (1) Low-frequency, 10–500 Hz, (2) Mid-frequency, 500–5,000 Hz, and (3) High-frequency, 5–100 kHz.

Each band was analyzed for the sounds of an appropriate subset of species or sources. Blue, Bryde's, fin, minke sei, and North Atlantic right whale sounds, as well as low frequency active sonar less than 500 Hz, were classified as low-frequency. Humpback whales, nearby shipping, explosions, airguns, underwater anthropogenic communications, low frequency active sonar greater than 500 Hz, and mid-frequency active sonar sounds were classified as mid-frequency. The remaining odontocete and sonar sounds were considered high-frequency. Analysis of low-frequency recordings required decimation by a factor of 100. For the analysis of the mid-frequency recordings, the data were decimated by a factor of 20.

We summarize acoustic data collected at NFC Site A between June 2017 and June 2018. 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 Ambient Soundscape

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

## Low-Frequency Marine Mammals

The Virginia Capes Range Complex is inhabited, at least for a portion of the year, by blue whales *(Balaenoptera musculus),* Bryde's whales *(B. edeni)*, fin whales *(B. physalus),* minke whales *(B. acutorostrata),* sei whales *(B. borealis),* and North Atlantic right whales *(Eubalaena glacialis)*. 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 s 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 1,500 and 2,000 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 North Atlantic blue whale A calls and arch calls, fin whale 40 Hz calls, Bryde's whale Be7 and Be9 calls, sei whale downsweeps, minke whale pulse trains, and North Atlantic right whale up-calls was determined by manual scrutiny of low-frequency LTSAs and spectrograms. Detections were logged in hourly bins. Fin whale 20 Hz calls were detected automatically using an energy detection method and are reported as a daily average termed the 'fin whale acoustic index'.

## Blue Whales

Blue whales produce a variety of calls worldwide (McDonald *et al.*, 2006). Blue whale calls recorded in the western North Atlantic include the North Atlantic A call and the arch call (Mellinger and Clark, 2003).

### *North Atlantic Blue Whale A Calls*

The North Atlantic blue whale A call is an 18-19 Hz tone lasting approximately 8 s, often followed by an 18-15 Hz downsweep lasting approximately 11 seconds (Figure 2). There were no detections for blue whale North Atlantic A calls during the recording period.

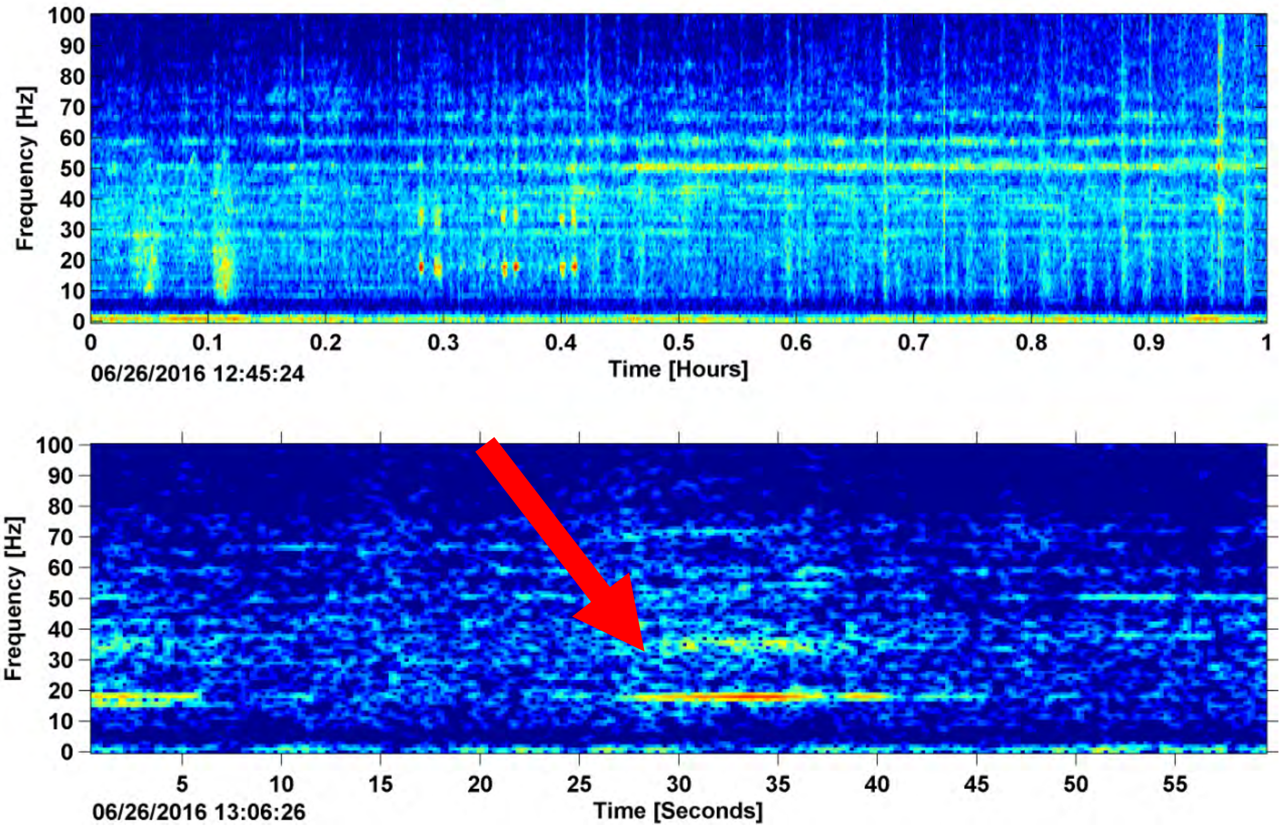

**Figure 2. North Atlantic blue whale A calls in the LTSA (top) and spectrogram (bottom) recorded in the Jacksonville Range Complex, June 2016.**

## Bryde's Whales

Bryde's whales inhabit tropical and subtropical waters worldwide (Omura, 1959; Wade and Gerrodette, 1993).

### *Be7 Calls*

The Be7 call is one of several call types in the Bryde's whale repertoire, first described in the Southern Caribbean (Oleson *et al.*, 2003). The average Be7 call has a fundamental frequency of 44 Hz and ranges in duration from 0.8 to 2.5 s with an average intercall interval of 2.8 minutes (Figure 3). There were no detections for Bryde's whale Be7 calls during this recording period.

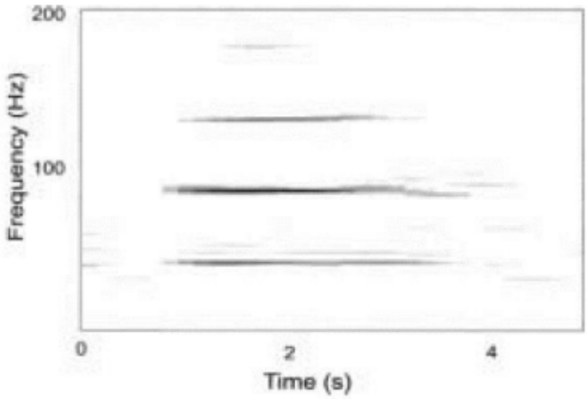

**Figure 3. Spectrogram of Bryde's whale Be7 call from Oleson *et al.*, 2003.**

### *Be9 Calls*

The Be9 call type, described for Bryde's whales in the Gulf of Mexico (Širović *et al.*, 2014), is a downswept pulse ranging from 143 to 85 Hz, with each pulse approximately 0.7 s long (Figure 4). There were no detections of Bryde's whale Be9 calls during the recording period.

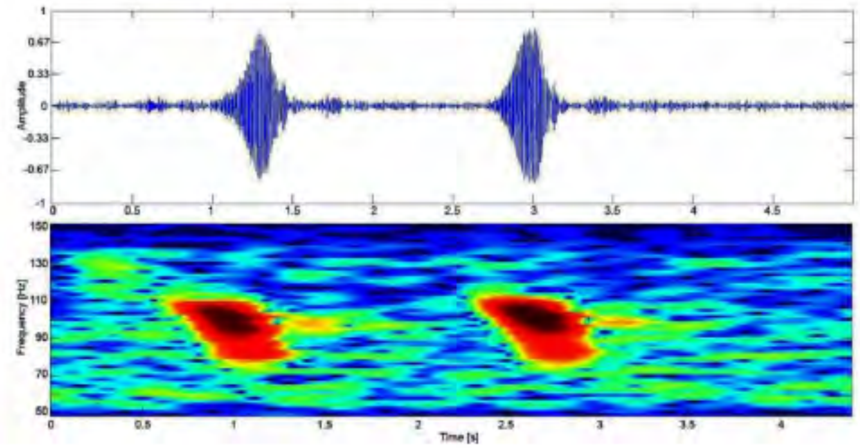

**Figure 4. Waveform (top) and spectrogram (bottom) of Bryde's whale Be9 call from the Gulf of Mexico (Širović *et al.*, 2014).**

## 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 (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.

### *Fin Whale 20 Hz Calls*

Fin whale 20 Hz calls (Figure 5) were detected automatically using an energy detection method (Širović *et al.*, 2014). The method uses a difference in acoustic energy between signal and noise, calculated from a 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. The resulting ratio is termed fin whale acoustic index and is reported as a daily average. All calculations were performed on a dB scale.

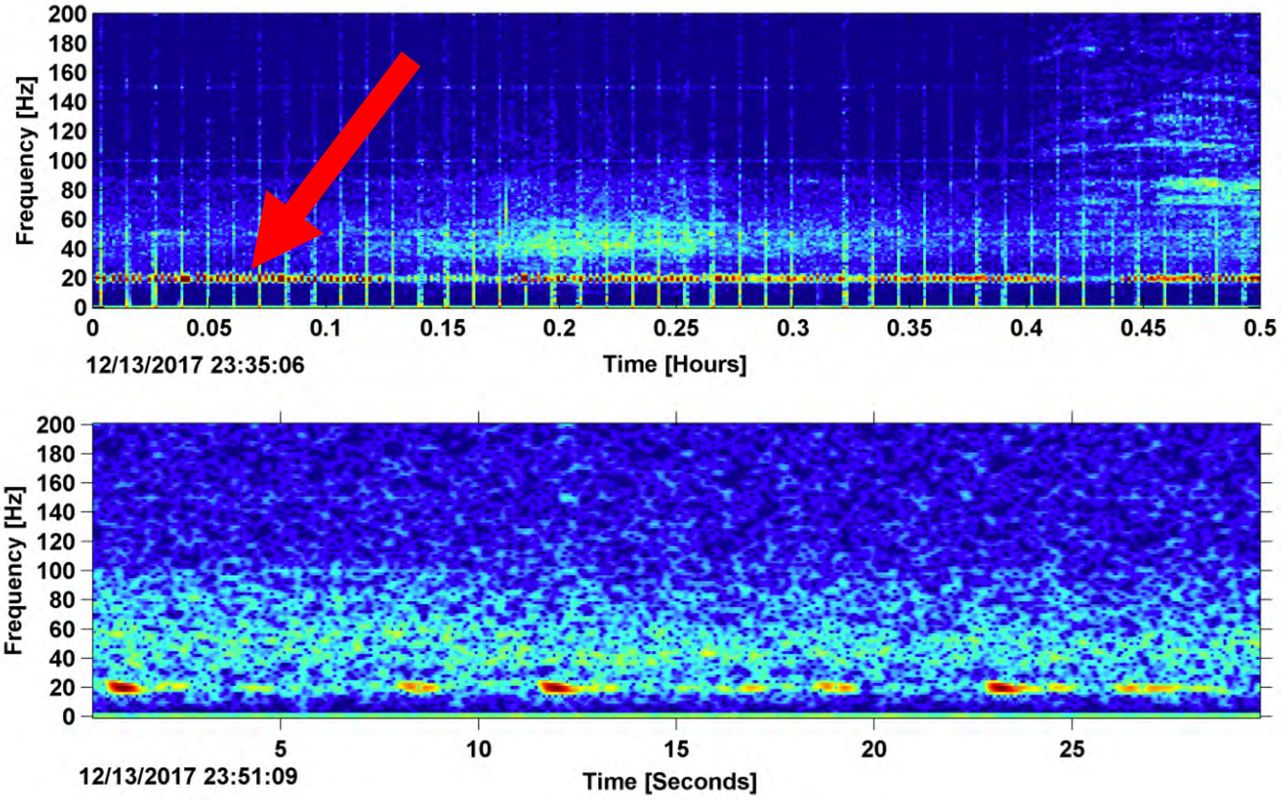

**Figure 5. Fin whale 20 Hz call in LTSA (top) and spectrogram (bottom) at NFC Site A, December 2017.**

### *Fin Whale 40 Hz Calls*

The presence of fin whale 40 Hz calls (Figure 6) was examined via manual scanning of the LTSA and subsequent verification from a spectrogram of the frequency and temporal characteristics of the calls.

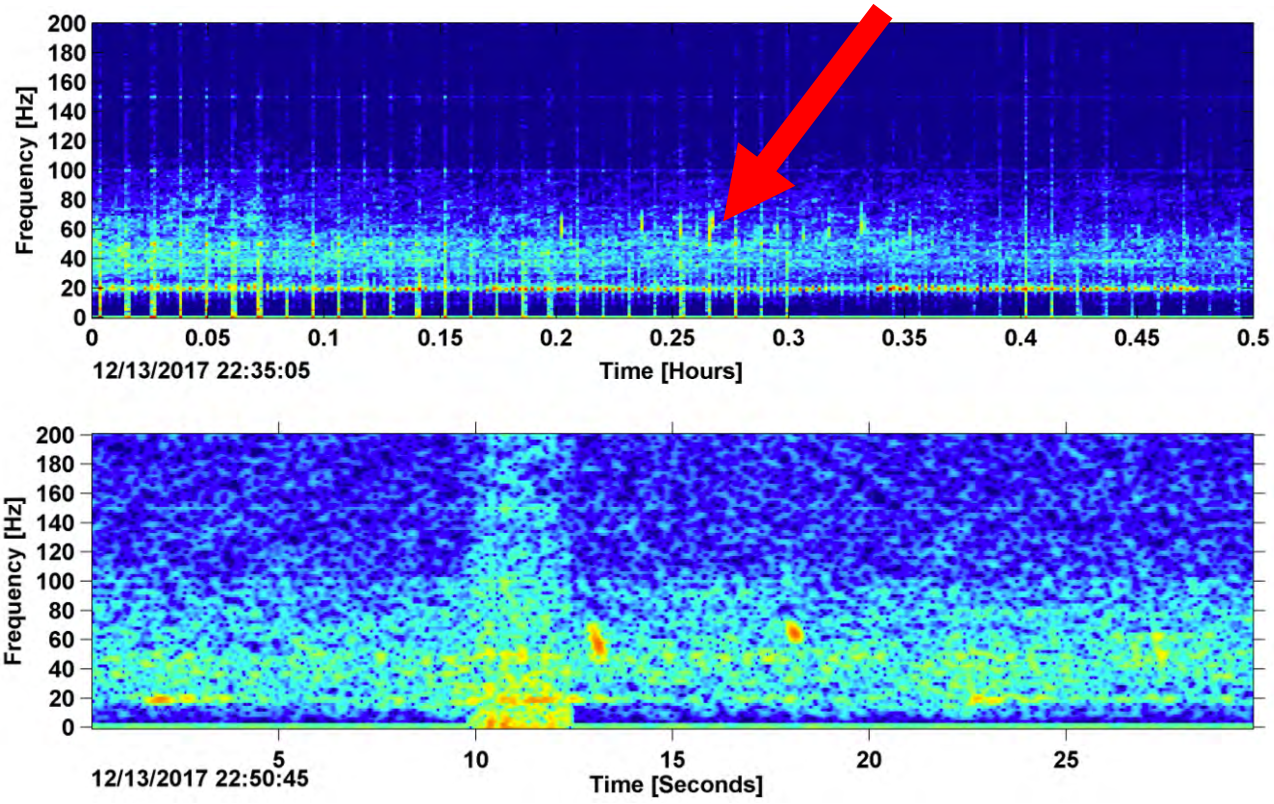

**Figure 6. Fin whale 40 Hz call in LTSA (top) and spectrogram (bottom) at NFC Site A, December 2017.**

## Minke Whales

Minke whales in the North Atlantic produce long pulse trains. Mellinger *et al.* (2000) described minke whale pulse sequences near Puerto Rico as speed-up and slow-down pulse trains, with increasing and decreasing pulse rates respectively. Recently, these call types were detected in the North Atlantic and they were expanded to also include pulse trains with non-varying pulse rates (Risch *et al.*, 2013) (Figure 7). The presence of pulse trains was marked but effort was not expended to denote whether they were slow-down, speed-up, or constant types.

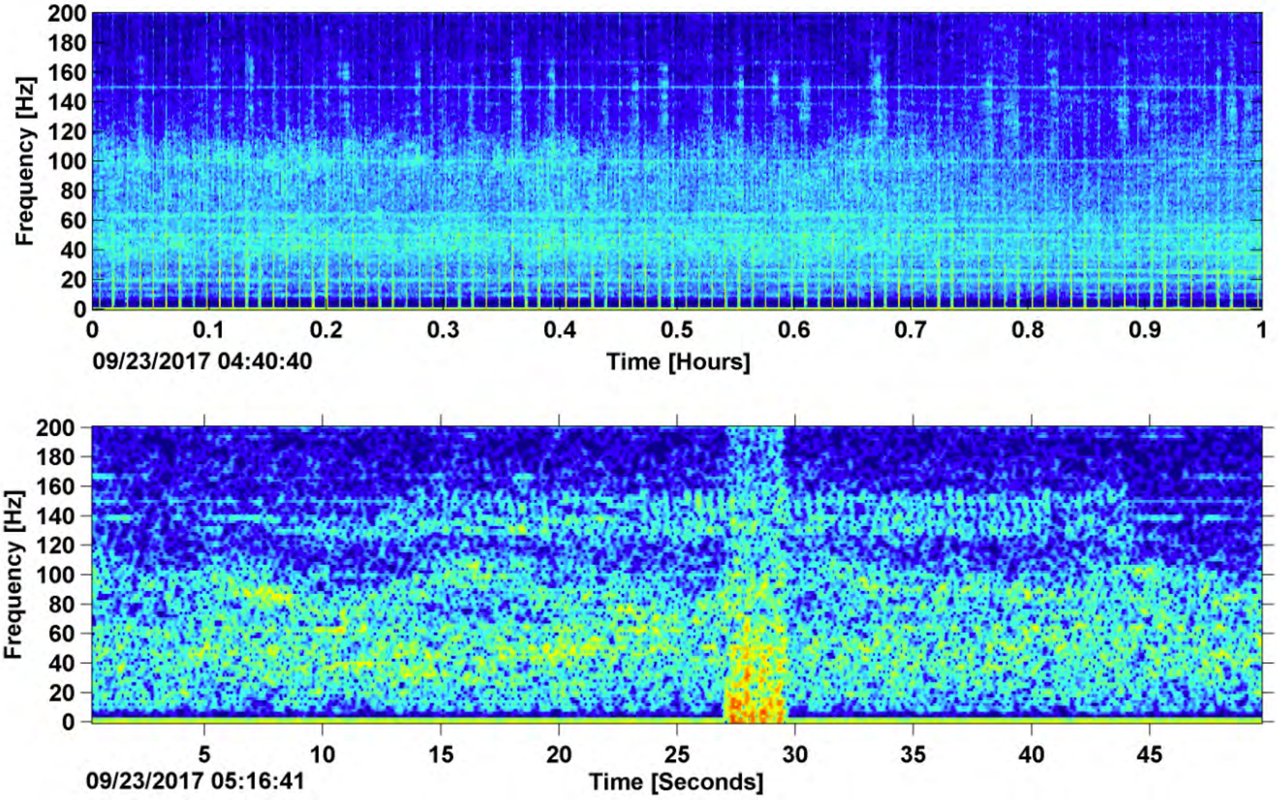

**Figure 7. Minke whale pulse train in the LTSA (top) and spectrogram (bottom) recorded at NFC Site A, September 2017.**

## Sei Whales

Sei whales are found primarily in temperate waters and undergo annual migrations between lower latitude winter breeding grounds and higher latitude summer feeding grounds (Mizroch *et al.*, 1984; Perry *et al.*, 1999). Multiple sounds have been attributed to sei whales, including a low-frequency downsweep (Baumgartner and Fratantoni, 2008; Baumgartner *et al.*, 2008). These calls typically sweep from a starting frequency around 100 Hz to an ending frequency around 40 Hz (Figure 8).

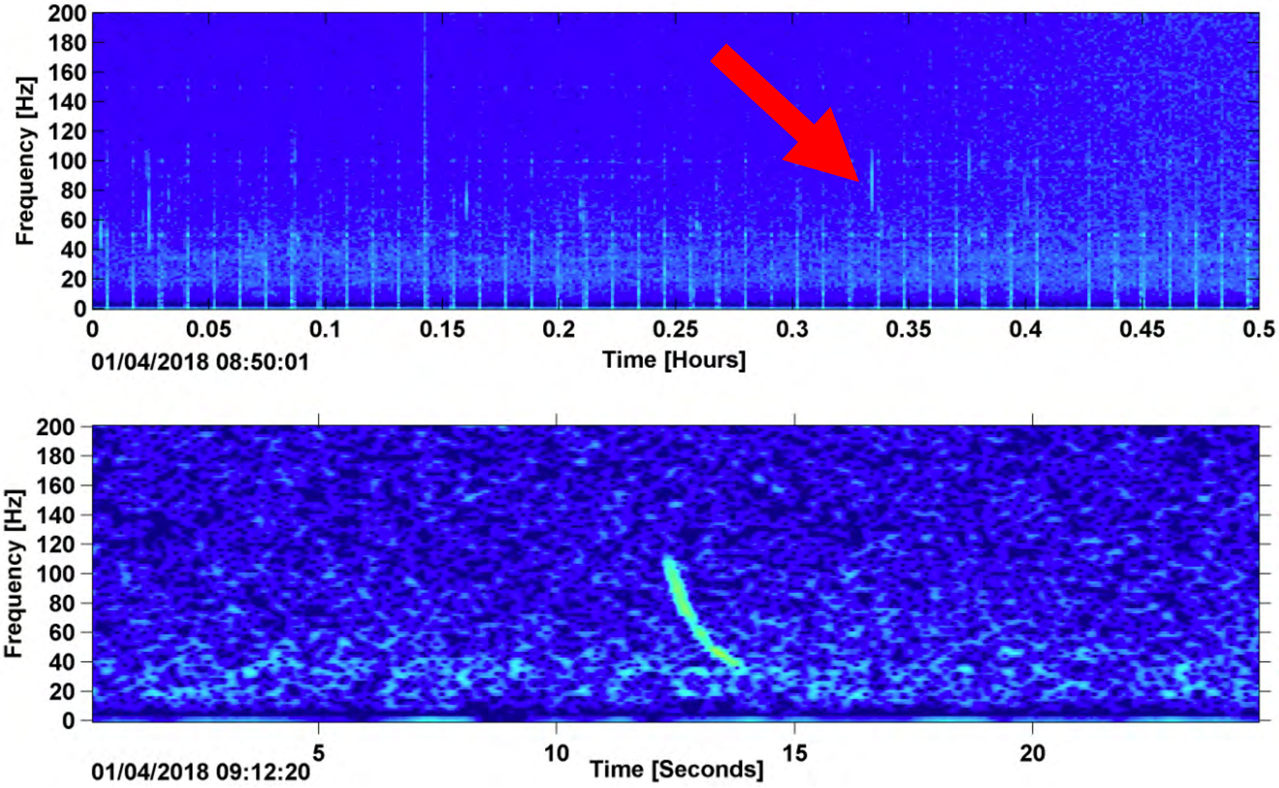

**Figure 8. Downsweep calls from sei whales in the LTSA (top) and spectrogram (bottom) from NFC Site A, January 2018.**

### Northern Atlantic Right Whales

The critically endangered North Atlantic right whale is found in the Western North Atlantic. Several call types have been described for the North Atlantic right whale, including the scream, gunshot, blow, upcall, warble, and downcall (Parks and Tyack, 2005). For low-frequency analysis, we examined the data for upcalls, which are approximately 1 s in duration and range between 80 Hz and 200 Hz, sometimes with harmonics (Figure 9). There were no detections for North Atlantic right whale up-calls during the recording period.

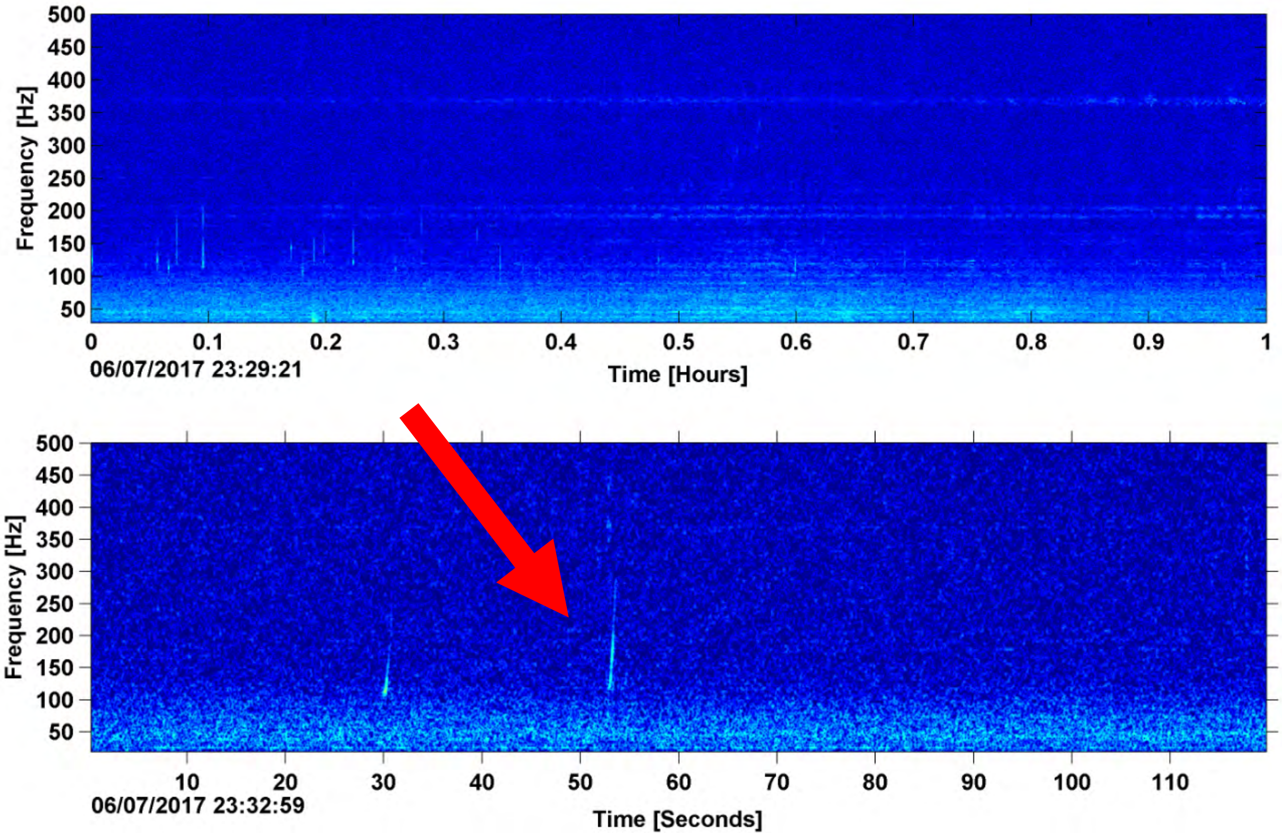

**Figure 9. Right whale up-calls in the LTSA (top) and spectrogram (bottom) recorded at NFC Site A, June 2017.**

## Mid-Frequency Marine Mammals

Humpback whales (Megaptera novaeangliae) were the only marine mammal species in the Virginia Capes Range Complex with calls in the mid-frequency range monitored for this report. We detected humpback whale calls using an automatic detection algorithm based on the generalized power law (Helble *et al.*, 2012). The detections were subsequently verified for accuracy by a trained analyst. When humpback calls were identified in the LTSA or spectrogram, they were logged according to the start time and end time of the encounter. An encounter was consider to end when there were no calls for 30 min. The encounter durations were added to estimate cumulative hourly presence.

### Humpback Whales

Humpback whales produce both song and non-song calls (Payne and McVay 1971, Dunlop *et al.* 2007, Stimpert *et al.*, 2011). The song is categorized by the repetition of units, phrases, and themes of a variety of calls as defined by Payne and McVay (1971). Most humpback whale vocalizations are produced between 100 - 3,000 Hz (Figure 10).

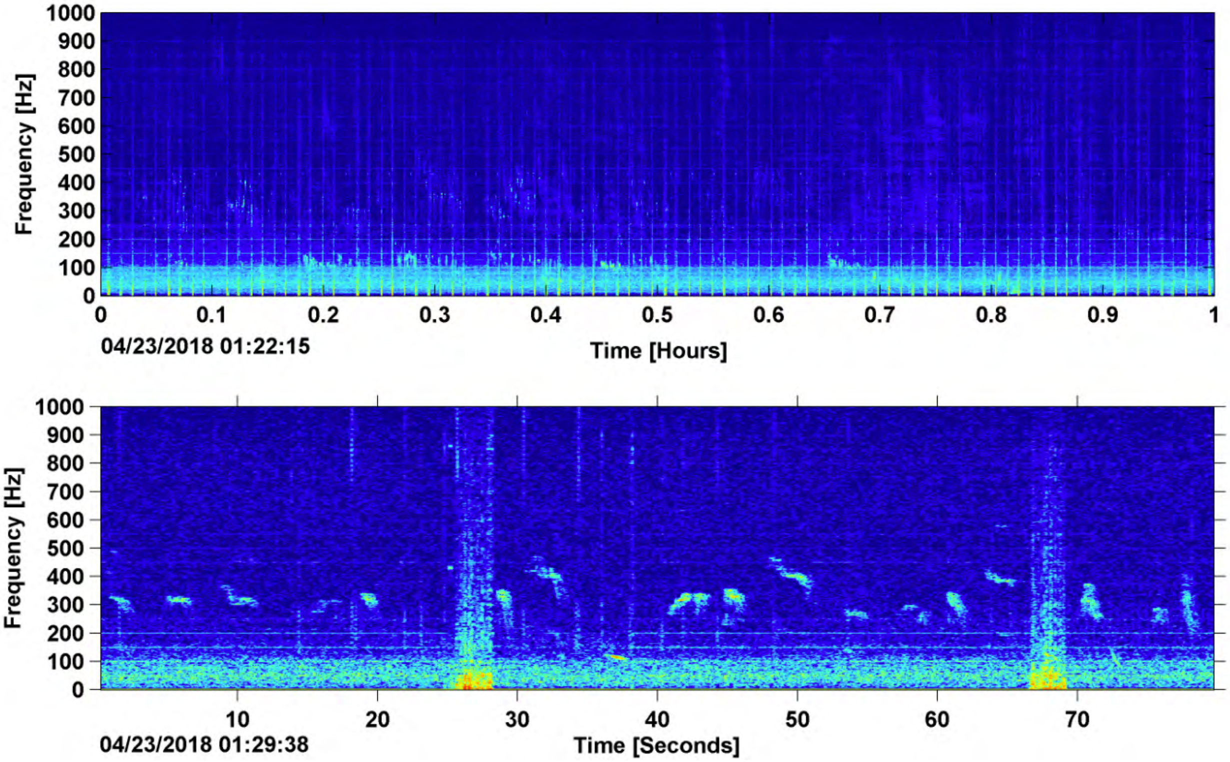

**Figure 10. Humpback whale calls in the LTSA (top) and spectrogram (bottom) recorded at NFC Site A, April 2018.**

## High-Frequency Marine Mammals

Marine mammal species with sounds in the high-frequency range and possibly found in the Virgnia Capes Range Complex include bottlenose dolphins (*Tursiops truncatus*), short-finned pilot whales (*Globicephala macrorhynchus*), long-finned pilot whales (*G. melas*), short-beaked common dolphins (*Delphinus delphis*), Atlantic spotted dolphins (*Stenella frontalis*), pantropical spotted dolphins (*Stenella frontalis*), spinner dolphins (*Stenella longirostris*), striped dolphins (*Stenella coeruleoalba*), Clymene dolphins (*Stenella clymene*), rough-toothed dolphins (*Steno bredanensis*), Risso's dolphins (*Grampus griseus*), Fraser's dolphins (*Lagenodelphis hosei*), killer whales (*Orcinus orca*), pygmy killer whales (*Feresa attenuata*), melon-headed whales (*Peponocephala electra*), sperm whales (*Physeter macrocephalus*), dwarf sperm whales (*Kogia sima*), pygmy sperm whales (*Kogia breviceps*), Cuvier's beaked whales (*Ziphius cavirostris*), Gervais' beaked whales (*Mesoplodon europaeus*), Blainville's beaked whales (*Mesoplodon densirostris*), True's beaked whales (*Mesoplodon mirus*) and Sowerby's beaked whales (*Mesoplodon bidens*).

### High-Frequency Call Types

Odontocete sounds can be categorized as echolocation clicks, burst pulses, or whistles. Echolocation clicks are broadband impulses with peak energy between 5 and 150 kHz, dependent upon the species. Buzz or burst pulses are rapidly repeated clicks that have a creak or buzz-like sound quality; they are generally lower in frequency than echolocation clicks. Dolphin whistles are tonal calls predominantly between 1 and 20 kHz that vary in frequency content, their degree of frequency modulation, as well as duration. These signals are easily detectable in an LTSA as well as the spectrogram (Figure 11).

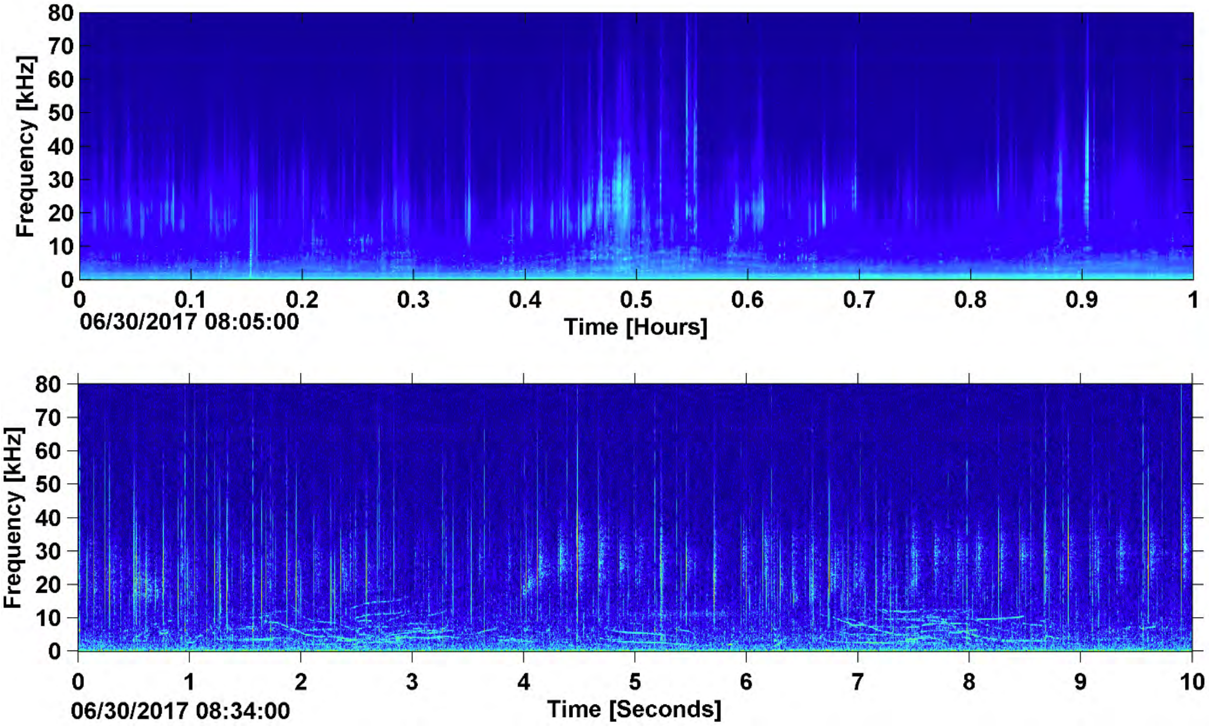

**Figure 11. LTSA (top) and spectrogram (bottom) demonstrating odontocete signal types at NFC Site A, June 2017.**

## Beaked Whales

Beaked whales can be identified acoustically by their echolocation signals (Baumann-Pickering *et al.*, 2014). These signals are frequency-modulated (FM) upsweep pulses, which appear to be species specific and distinguishable by their spectral and temporal features. Identifiable signals are known for Gervais', Blainville's, Cuvier's, and Sowerby's beaked whales. An acoustic description based on towed array recordings also now exists for True's beaked whales, and suggests that they produce FM pulses remarkably similar to the echolocation signal of Gervais' beaked whale (DeAngelis *et al.*, 2018).

Beaked whale FM pulses were detected with an automated method. This automated effort was applied for all identifiable beaked whale signals found in Norfolk Canyon. 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, was used to label the automatically detected segments to pulse type level and reject false detections (Baumann-Pickering *et al.*, 2013). The rate of missed segments is approximately 5%, varying slightly across deployments.

## Blainville's Beaked Whale

Blainville's beaked whale echolocation signals are, like most beaked whales' signals, polycyclic, with a characteristic frequency-modulated upsweep, peak frequency around 34 kHz and uniform inter-pulse interval (IPI) of about 280 ms (Johnson *et al.*, 2004; Baumann-Pickering *et al.*, 2013). Blainville's FM pulses are also distinguishable in the spectral domain by their sharp energy onset around 25 kHz with only a small energy peak at around 22 kHz (Figure 12).

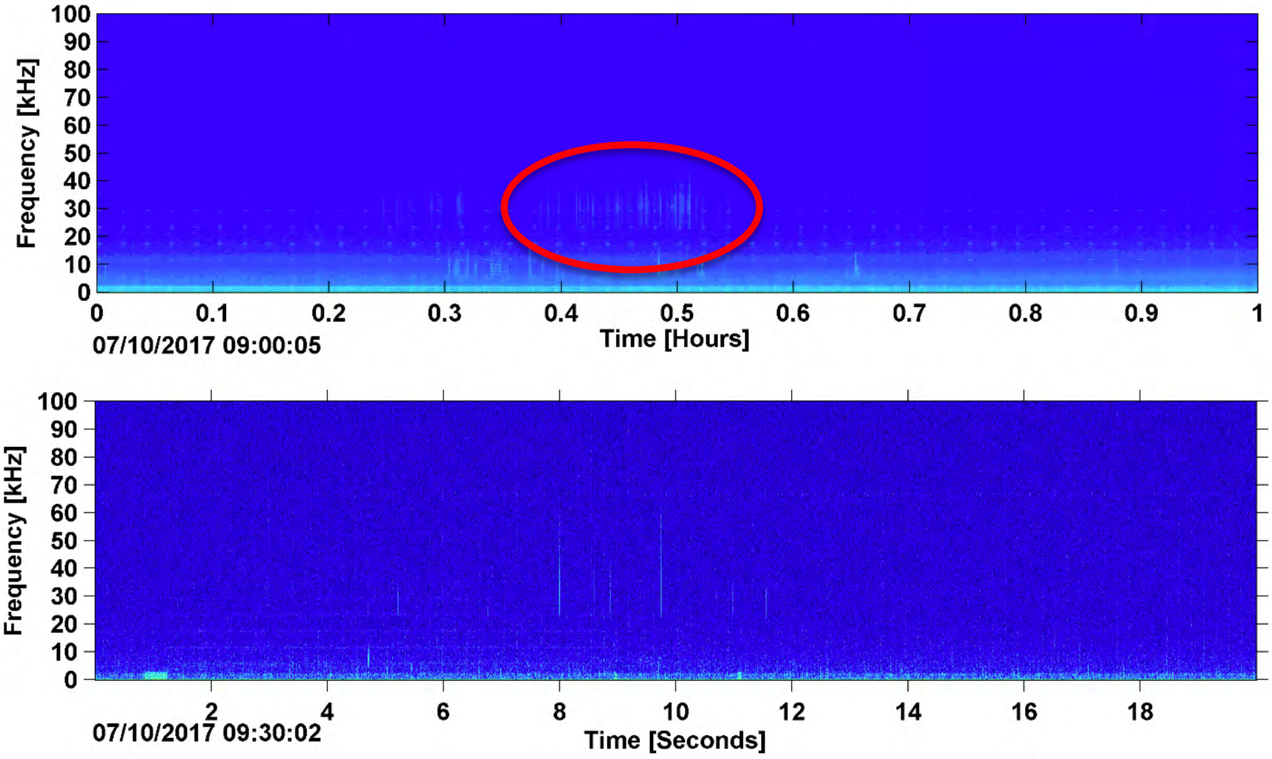

**Figure 12. Blainville's beaked whale echolocation clicks in the LTSA (top) and spectrogram (bottom) from HARP recording at NFC Site A, July 2017.**

## Cuvier’s Beaked Whales

Cuvier’s echolocation signals are polycyclic, with a characteristic FM pulse upsweep, peak frequency around 40 kHz (Figure 13), and uniform inter-pulse interval of about 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 two characteristic spectral peaks around 17 and 23 kHz.

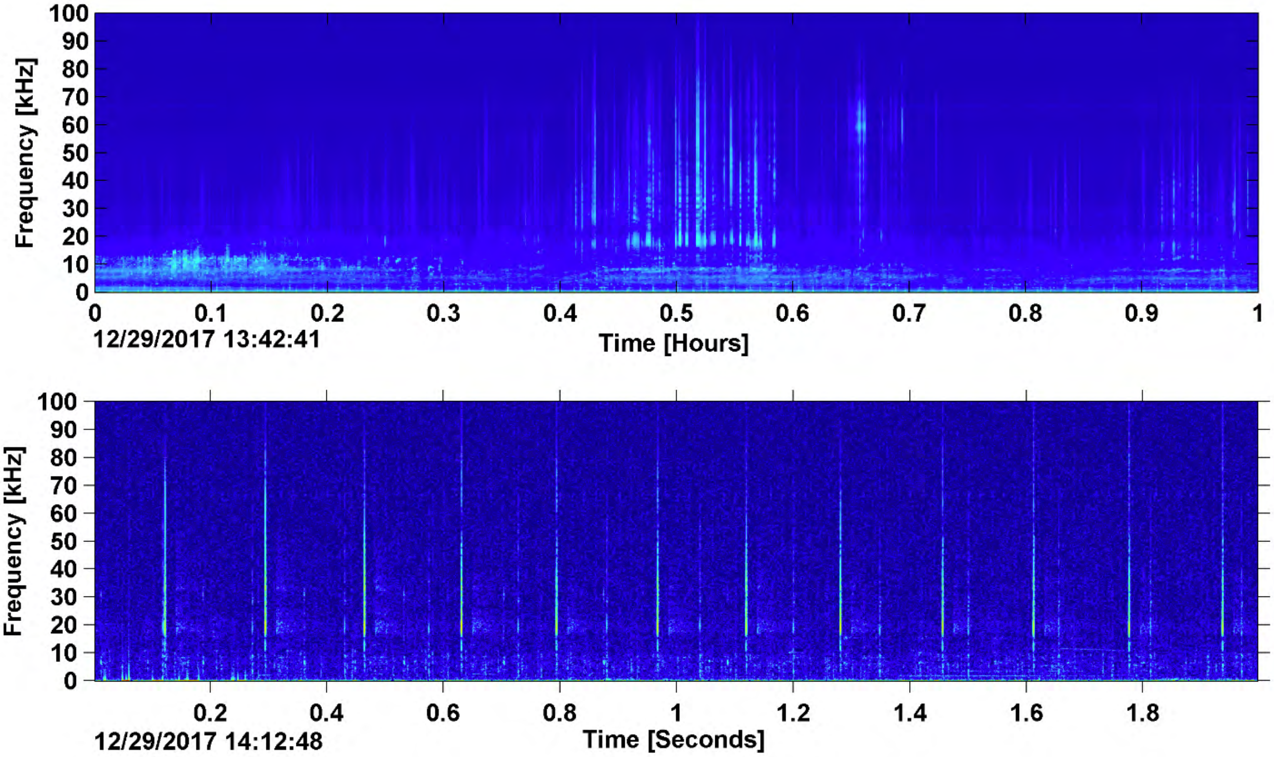

**Figure 13. Cuvier’s beaked whale signals in LTSA (top) and spectrogram (bottom) from HARP recording at NFC Site A, December 2017.**

## Gervais' Beaked Whales

Gervais' beaked whale signals have energy concentrated in the 30 – 50 kHz band (Gillespie *et al.*, 2009), with a peak at 44 kHz (Baumann-Pickering *et al.*, 2013). While Gervais' beaked whale signals are similar to those of Cuvier's and Blainville's beaked whales, the Gervais' beaked whale FM pulses are at a slightly higher frequency than those of the other two species. Similarly, Gervais' beaked whale FM pulses sweep up in frequency (Figure 14). The IPI for Gervais' beaked whale signals is typically around 275 ms (Baumann-Pickering *et al.*, 2013). At this time, Gervais' and True's beaked whale signals are difficult to distinguish, thus encounters classified as Gervais' beaked whale may include True's beaked whale.

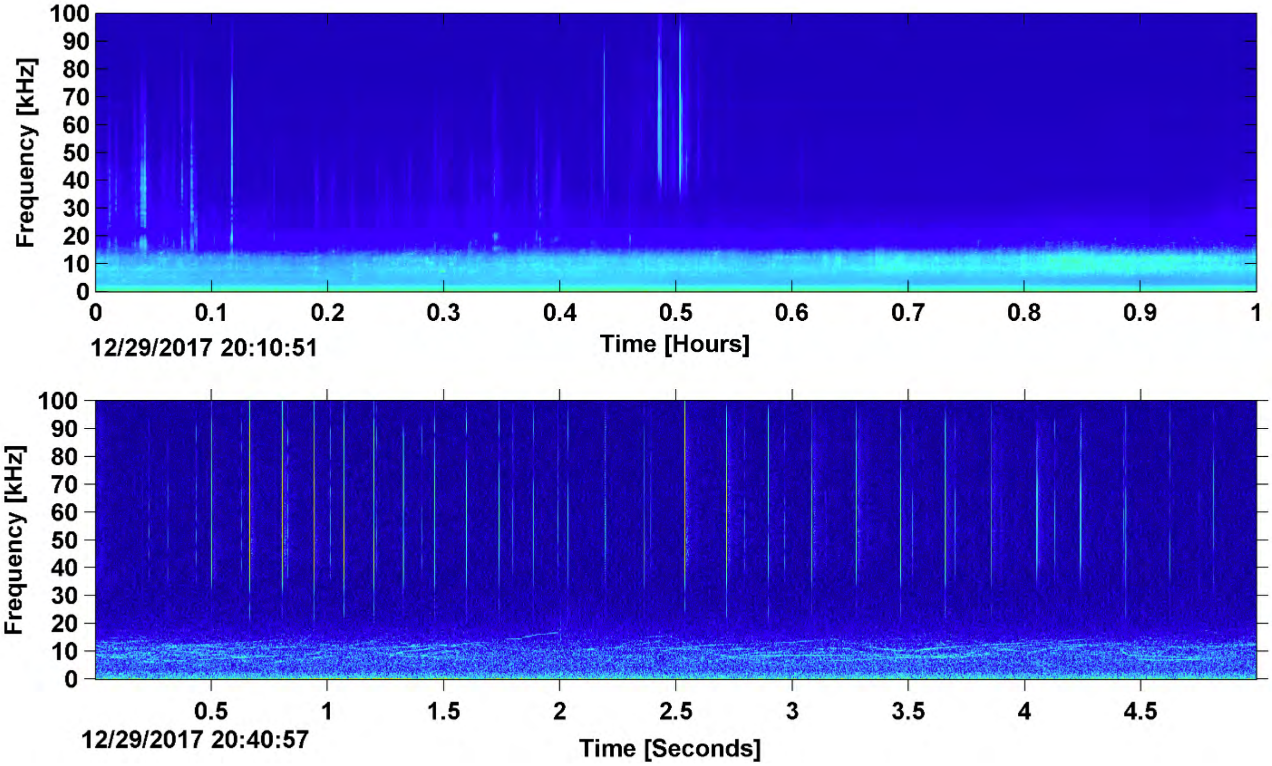

**Figure 14. Gervais' beaked whale signals in LTSA (top) and spectrogram (bottom) from HARP recording at NFC Site A, December 2017.**

## Sowerby’s Beaked Whales

Sowerby’s beaked whale echolocation signals have energy concentrated in the 50 – 95 kHz band, with a peak at 67 kHz (Figure 15). Sowerby’s beaked whale signals have a characteristic FM upsweep, and are distinguishable from other co-occurring beaked whale signal types by their higher frequency content and a relatively short inter-pulse interval of around 150 ms (Cholewiak *et al.*, 2013).

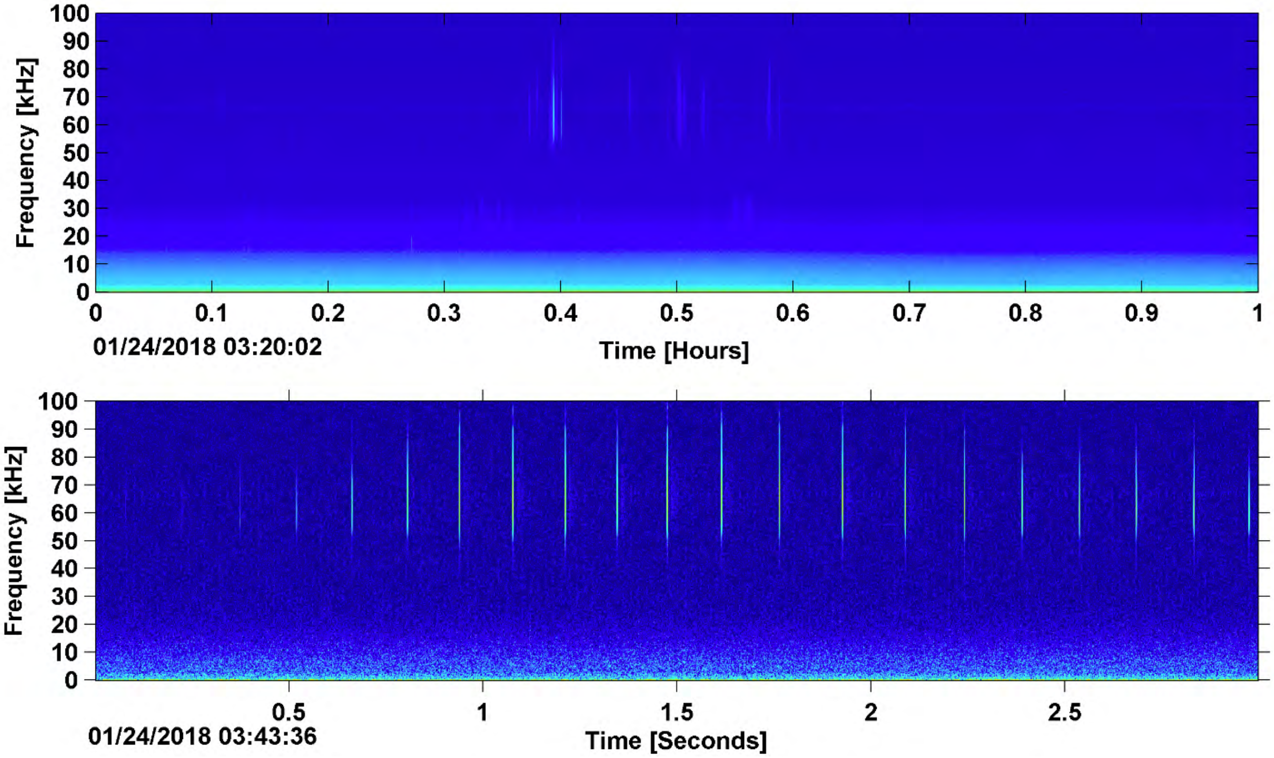

**Figure 15. Sowerby’s beaked whale echolocation clicks in LTSA (top) and spectrogram (bottom) from HARP recording at NFC Site A, January 2018.**

## Dolphins

### *Echolocation Clicks*

Delphinid echolocation clicks were detected automatically using an energy detector with a minimum peak-to-peak received level threshold of 120 dB re: 1 μPa (Frasier *et al.*, 2015). Dominant click types at this site were identified automatically by dividing detections into successive five-minute windows and determining the dominant click type(s) in each window. An automated clustering algorithm was then used to identify recurrent click types as well as false positives across all windows (Frasier *et al.*, 2017). Detections were automatically labeled by a classifier based on the automatically identified categories. All classifications were then verified by an analyst who reviewed LTSAs and mean spectra for each detected bout. A bout was defined as a period of clicking separated before and after by at least 15 minutes without clicking.

### *Whistles*

Many species of delphinids produce tonal calls known as whistles. These frequency-modulated signals are predominantly found between 1 and 20 kHz. Whistles were detected manually in LTSAs and spectrograms, and characterized based on their frequency content as unidentified odontocete whistles either above or below 5 kHz.

## Unidentified Odontocetes

Many Atlantic delphinid sounds are not yet distinguishable to species based on the character of their clicks, buzz or burst pulses, or whistles (Roch *et al.*, 2011; Gillespie *et al.*, 2013). For instance, common dolphin species (short-beaked and long-beaked) and bottlenose dolphins make clicks that are thus far indistinguishable from each other (Soldevilla *et al.*, 2008). Risso’s dolphin clicks are distinguishable, and were identified based on known characteristics (Soldevilla *et al.*, 2008). Since delphinid signals are detectable in an LTSA as well as the spectrogram, they were monitored during this analysis effort, but were characterized as unidentified odontocete signals.

### Risso's Dolphins

Risso's dolphin echolocation clicks can be identified to species by their distinctive banding patterns observable in the LTSA (Figure 17). Studies show that spectral properties of Risso's dolphin echolocation clicks vary based on geographic region (Soldevilla *et al.*, 2017), although the multiple sharp frequency peaks and average inter-click interval (ICI) found at these North-Western Atlantic sites are similar to what has been found elsewhere. Risso's dolphin clicks detected in this recording period had peaks at 23, 26, and 33 kHz (Figure 17). Modal inter-click interval (ICI) was 165 ms.

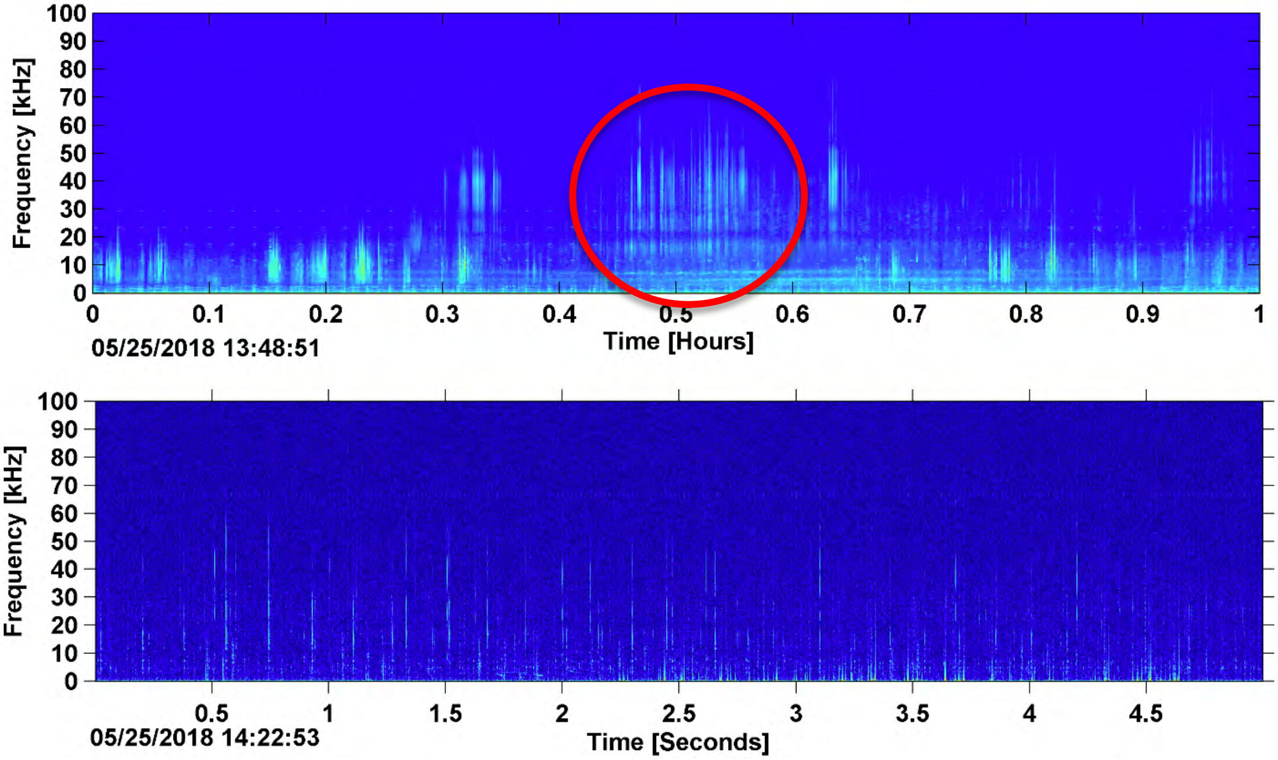

**Figure 16. Risso's dolphin acoustic encounter in LTSA (top) and spectrogram (bottom) from HARP recording at NFC Site A, May 2018.**

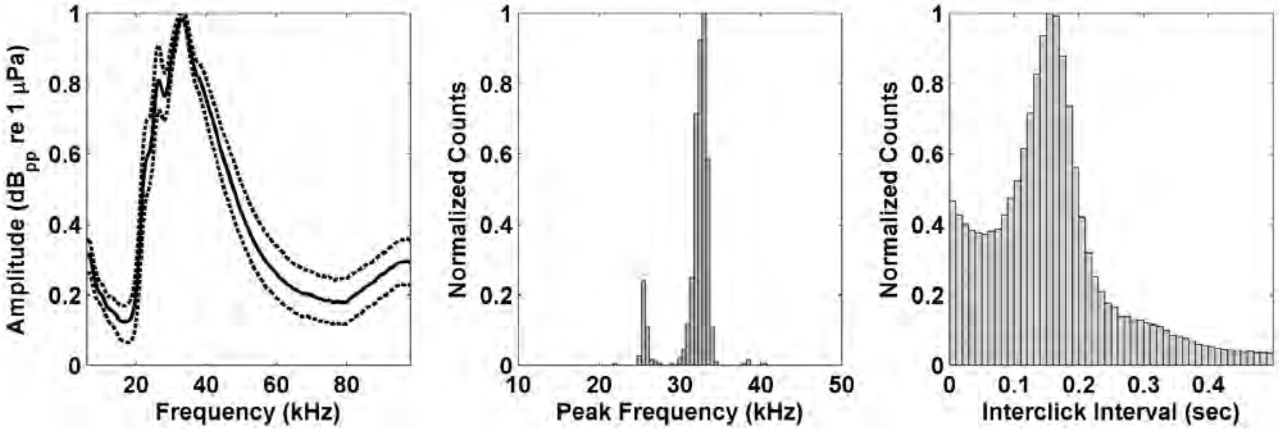

**Figure 17. Risso's dolphin click type detected at NFC Site A from June 2017-2018. *Left:* Mean frequency spectrum of click cluster (solid line) and 25th and 75th percentiles (dashed lines); *Center:* Distribution of click cluster peak frequencies; *Right:* Distribution of inter-click intervals (ICI) within cluster.**

## Other Echolocation Click Types

An automated clustering procedure was used to identify recurrent delphinid click types (CT) in the dataset. Three click types were identified (Figures 19-24). These click types are not currently identified to species, but have consistent spectral shapes and ICI distributions, making them candidates for future identification. CT 1 has a simple spectral shape with peak frequency at approximately 32 kHz, and a modal ICI of 75 ms (Figure 18). An example encounter is shown in Figure 19.

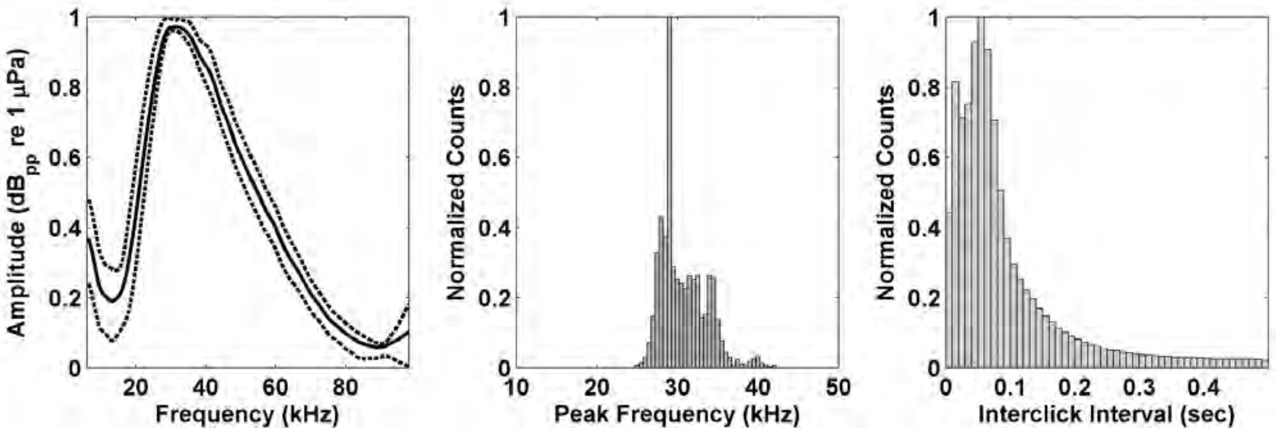

**Figure 18. Click type CT 1 detected at NFC Site A from June 2017-2018.** ***Left:*** **Mean frequency spectrum of click cluster (solid line) and 25th and 75th percentiles (dashed lines);** ***Center:*** **Distribution of click cluster peak frequencies;** ***Right:*** **Distribution of inter-click intervals (ICI) within cluster.**

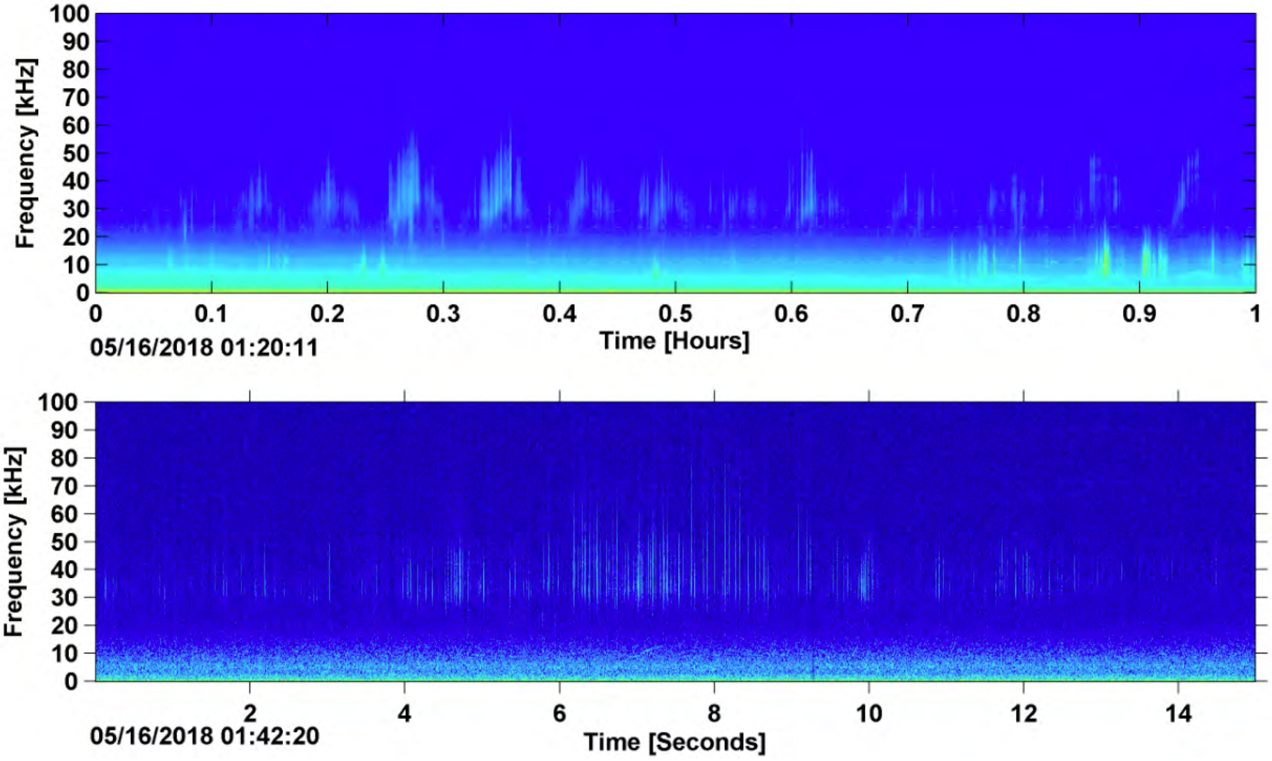

**Figure 19. Click type CT 1 acoustic encounter in LTSA (top) and spectrogram (bottom) recorded at NFC Site A, May 2018.**

CT 4 spectra has a complex banding pattern with peaks at 8, 21 and 28 kHz and a main peak frequency at 45 kHz (Figure 21). The modal ICI was 65 ms. An example encounter is shown in Figure 21.

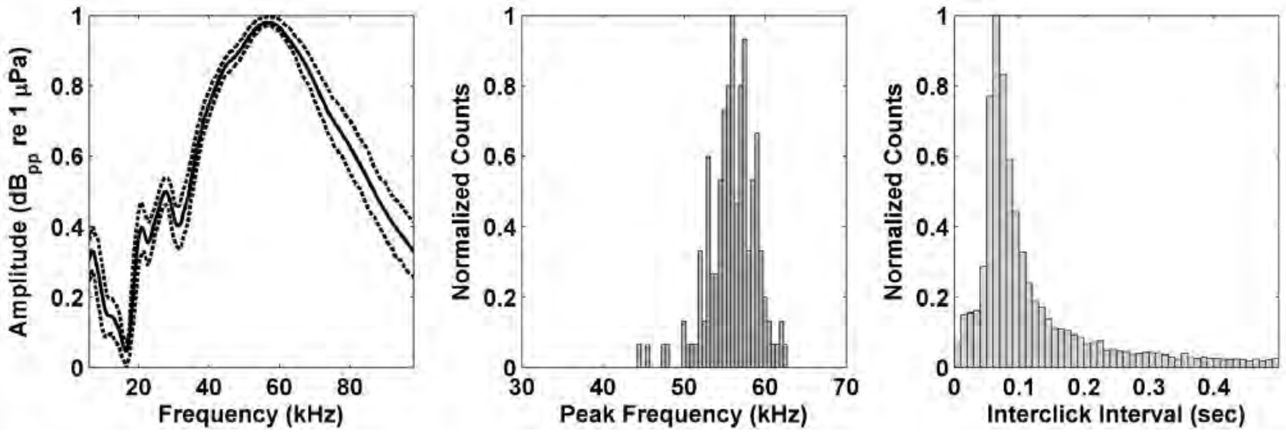

**Figure 20. Click type CT 4 detected at NFC Site A from June 2017-2018.** ***Left:*** **Mean frequency spectrum of click cluster (solid line) and 25th and 75th percentiles (dashed lines);** ***Center:*** **Distribution of click cluster peak frequencies;** ***Right:*** **Distribution of inter-click intervals (ICI) within cluster**.

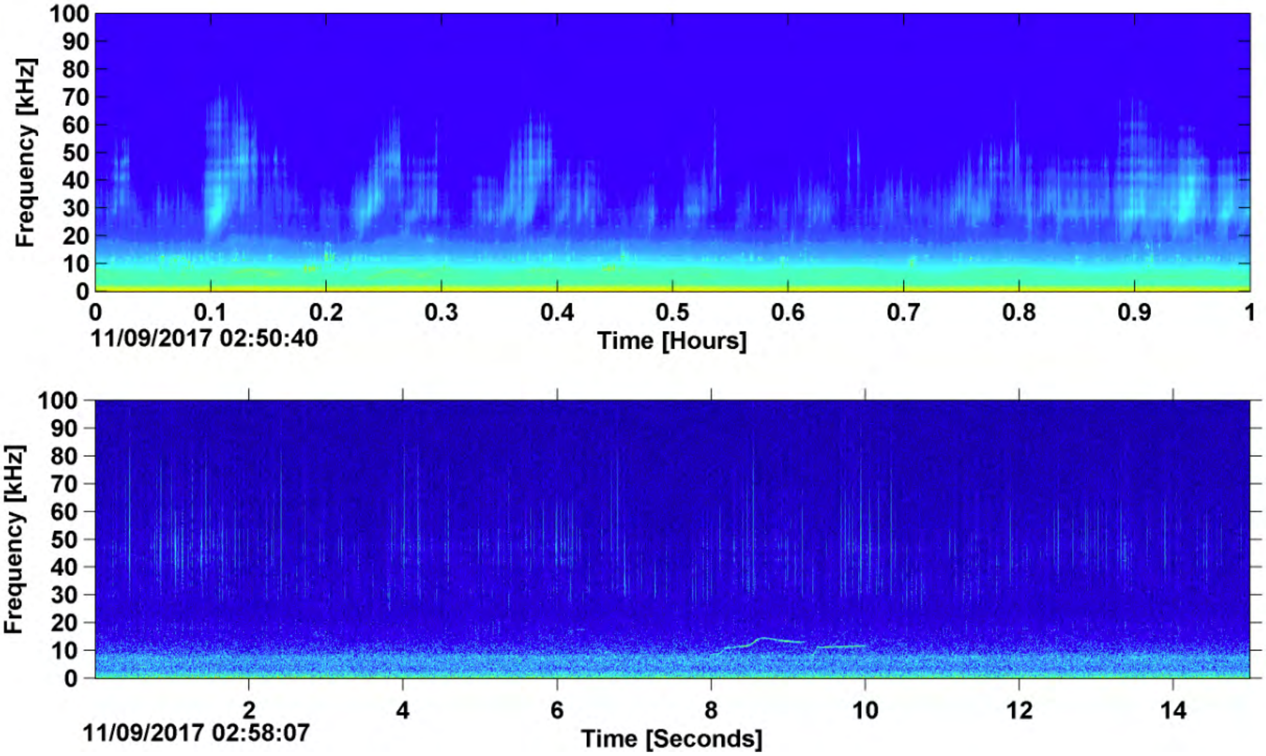

**Figure 21. Click type CT 4 acoustic encounter in LTSA (top) and spectrogram (bottom) recorded at NFC Site A, November 2017.**

CT 6 has a frequency distribution with a peak near 24 kHz, and a modal ICI of 165 ms (Figure 23). An example encounter is shown in Figure 23.

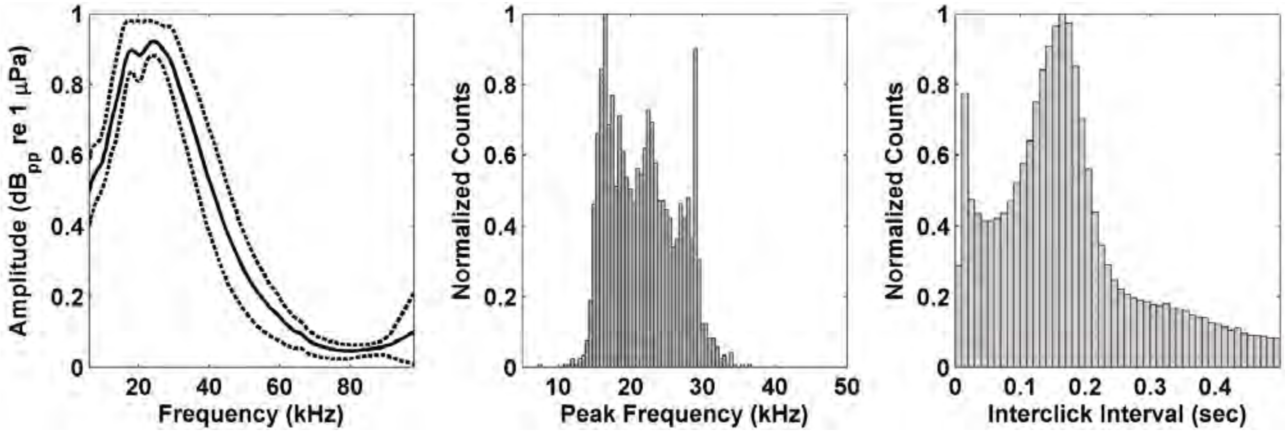

**Figure 22. Click type CT 6 detected at NFC Site A from June 2017-2018.** ***Left:*** **Mean frequency spectrum of click cluster (solid line) and 25th and 75th percentiles (dashed lines);** ***Center:*** **Distribution of click cluster peak frequencies;** ***Right:*** **Distribution of inter-click intervals (ICI) within cluster.**

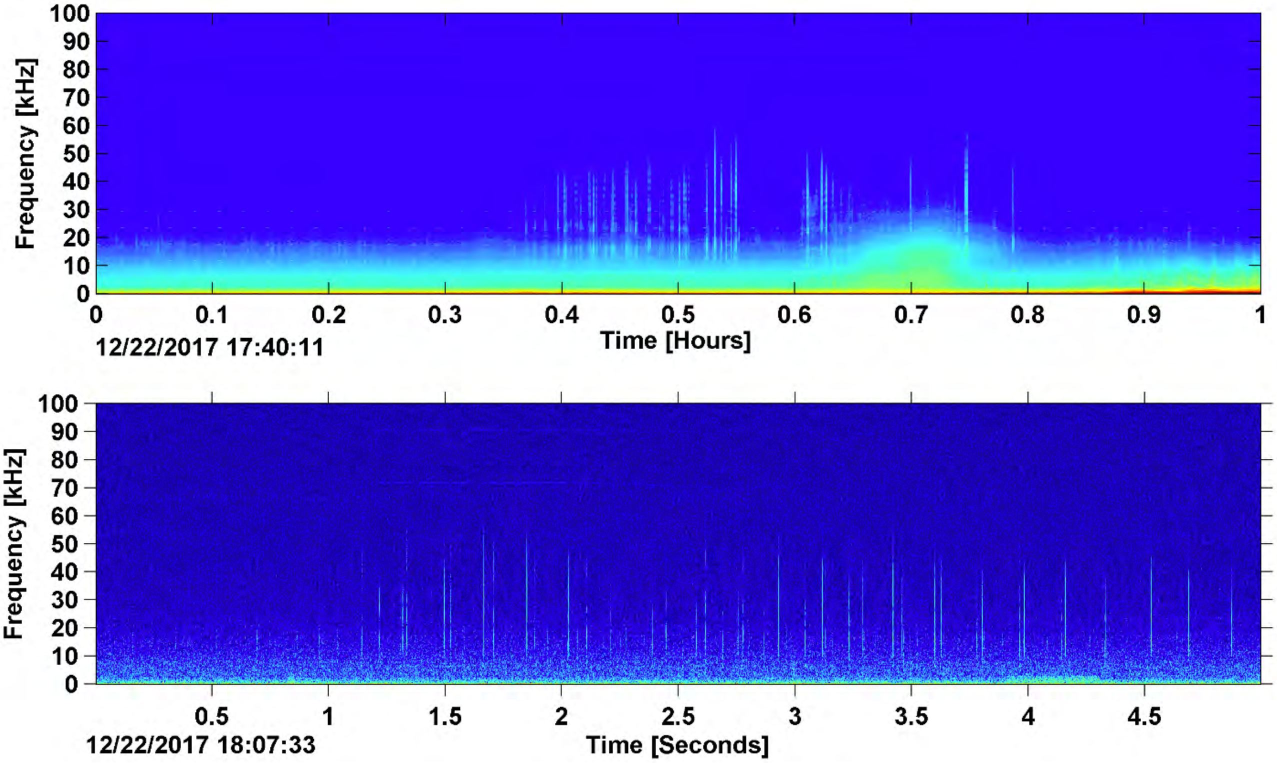

**Figure 23. Click type CT 6 acoustic encounter in LTSA (top) and spectrogram (bottom) recorded at NFC Site A, December 2017.**

## Sperm Whales

Sperm whale clicks contain energy from 2-20 kHz, with most energy between 10-15 kHz (Møhl *et al.*, 2003) (Figure 24). Regular clicks, observed during foraging dives, demonstrate an ICI from 0.25-1 s (Goold and Jones, 1995; Madsen *et al.*, 2002a). Short bursts of closely-spaced clicks called creaks are observed during foraging dives and are believed to indicate a predation attempt (Wysocki *et al.*, 2006). Slow clicks (> 1 s ICI) are used only by males and are more intense than regular clicks with long inter-click intervals (Madsen *et al.*, 2002b). Codas are stereotyped sequences of clicks which are less intense and contain lower peak frequencies than regular clicks (Watkins and Schevill, 1977). Effort was not expended to denote whether sperm whale detections were codas or regular or slow clicks.

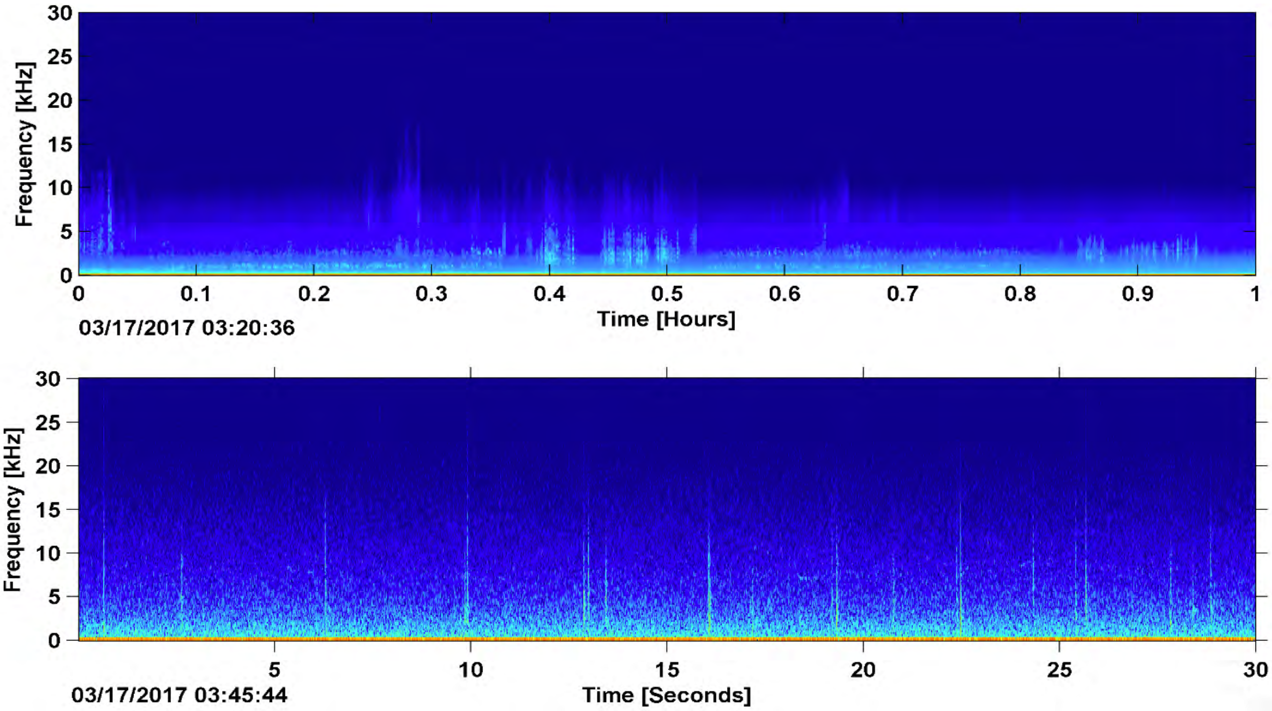

**Figure 24. Sperm whale echolocation clicks in LTSA (top) and spectrogram (bottom) recorded at NFC Site A, March 2017.**

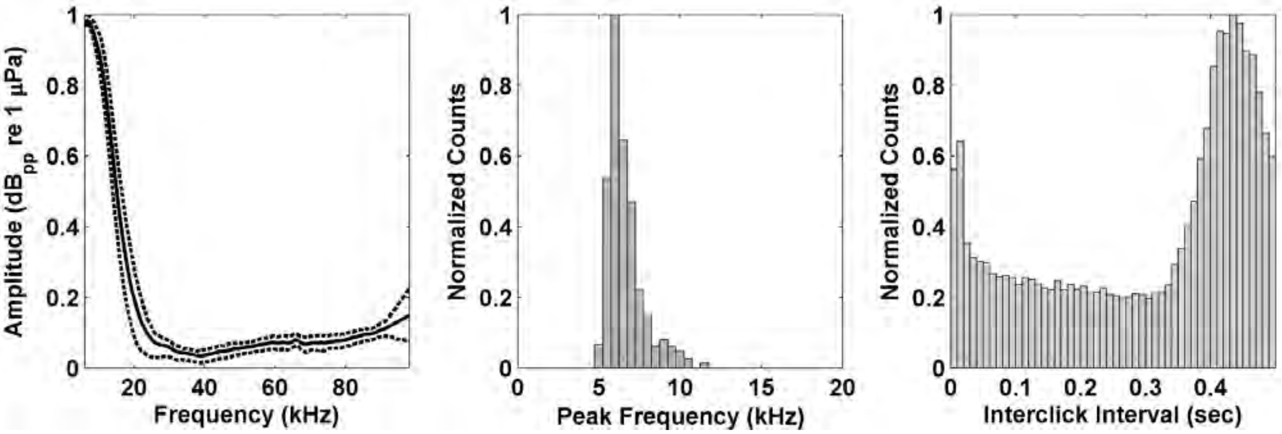

**Figure 25. Sperm whale echolocation clicks detected at NFC Site A from June 2017-2018. *Left:* Mean frequency spectrum of click cluster (solid line) and 25th and 75th percentiles (dashed lines); *Center:* Distribution of click cluster peak frequencies; *Right:* Distribution of inter-click intervals (ICI).**

### *Kogia* spp.

Dwarf and pygmy sperm whales emit echolocation signals that have peak energy at frequencies near 130 kHz (Au, 1993). While this is above the frequency band recorded by the HARP, the lower portion of the Kogia energy spectrum is within the 100 kHz HARP bandwidth (Figure 26). The observed signal may result both from the low-frequency tail of the Kogia echolocation click spectra, and from aliasing of energy from above the Nyquist frequency of 100 kHz (Figure 27). Kogia echolocation clicks were analyzed using a multi-step detector. The first step was to identify clicks with energy in the 70-100 kHz band that simultaneously lacked energy in lower frequency bands. An expert system then classified these clicks based on spectral characteristics, and finally an analyst verified all echolocation click bouts manually.

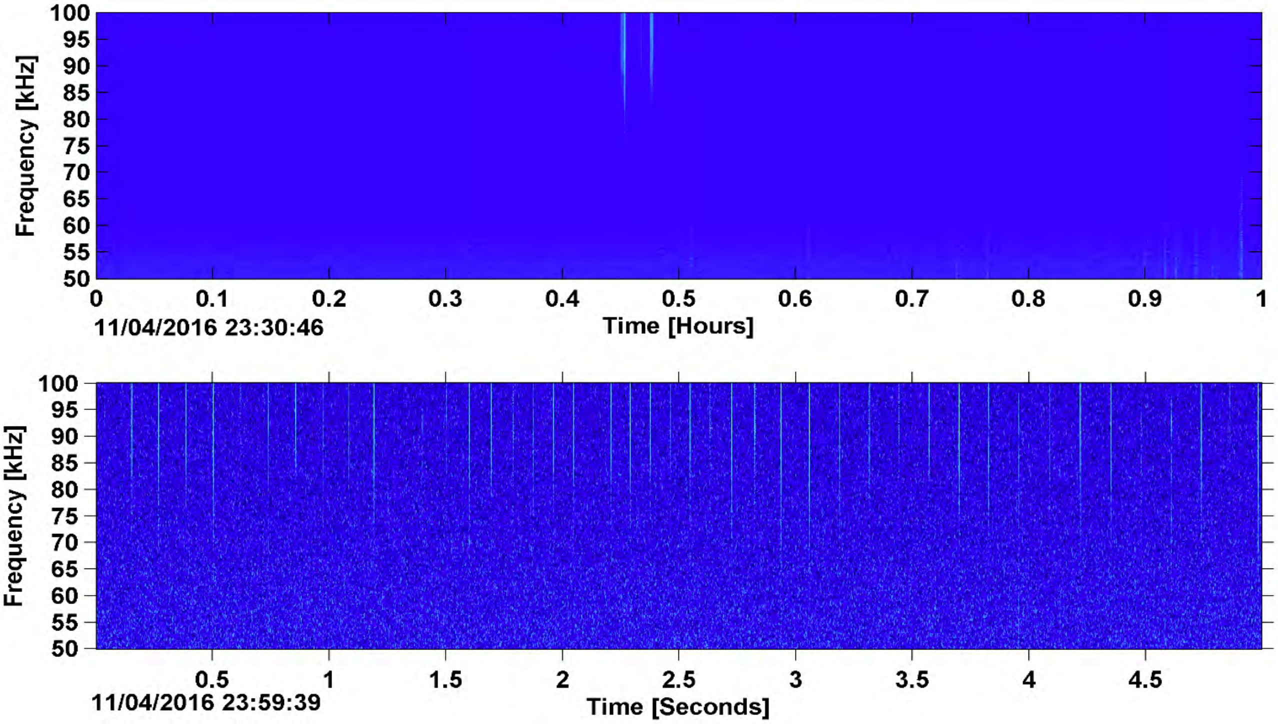

**Figure 26. *Kogia* spp. echolocation clicks in LTSA (top) and spectrogram (bottom) recorded at NFC Site A, November 2016.**

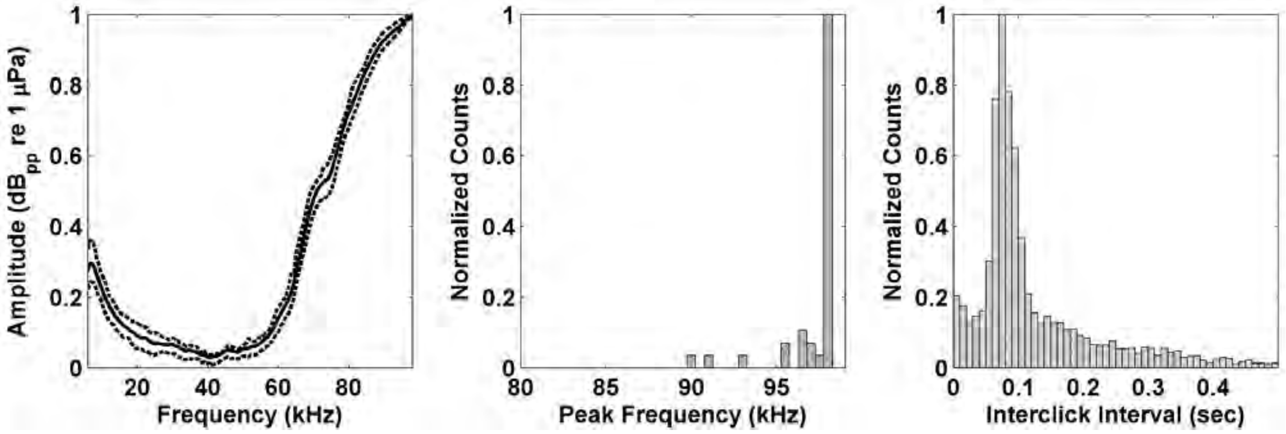

**Figure 27. *Kogia* spp. detected at NFC Site A from June 2017-2018. Left: Mean frequency spectrum of click cluster (solid line) and 25th and 75th percentiles (dashed lines); Center: Distribution of click cluster peak frequencies; Right: Distribution of inter-click intervals (ICI) within cluster.**

## Anthropogenic Sounds

Several anthropogenic sounds including broadband ship noise, Low-Frequency Active (LFA) Sonar, Mid-Frequency Active (MFA) sonar, High Frequency Active (HFA) sonar, echosounders, underwater communications, explosions, and airguns were monitored for this report. The LTSA manual search parameters used to detect these sounds are given in Table 1. The start and end of each sound or session was logged and their durations were added to estimate cumulative hourly presence. Airguns and explosions were analyzed by using a detector, described below.

**Table 1. Anthropogenic sound data manual effort analysis parameters.**

| Sound Type | LTSA Search Parameters | |
|---|---|---|
| | Plot Length (Hour) | Display Frequency Range (Hz) |
| Broadband Ship Noise | 3 | 10 – 5,000 |
| LFA Sonar | 1 | 10 – 1,000 |
| HFA Sonar | 1 | 10,000 – 100,000 |
| MFA Sonar | 1 | 1,000 – 5,000 |
| Echosounder | 1 | 5,000 – 100,000 |
| Underwater Communications | 1 | 5,000 – 100,000 |

## Broadband Ships

Broadband ship noise occurs when a ship passes within a few kilometers of a hydrophone. Ship noise can occur for many hours at a time, but broadband ship noise typically lasts from 10 minutes up to 3 hours at a time. 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 broadband ship and the receiver (Figure 28). Ship noise can extend above 10 kHz, although typically falls off above a few kHz. Broadband ship analysis effort consisted of manual scans of the LTSA set at 1 hour with a frequency range of 10-5,000 Hz.

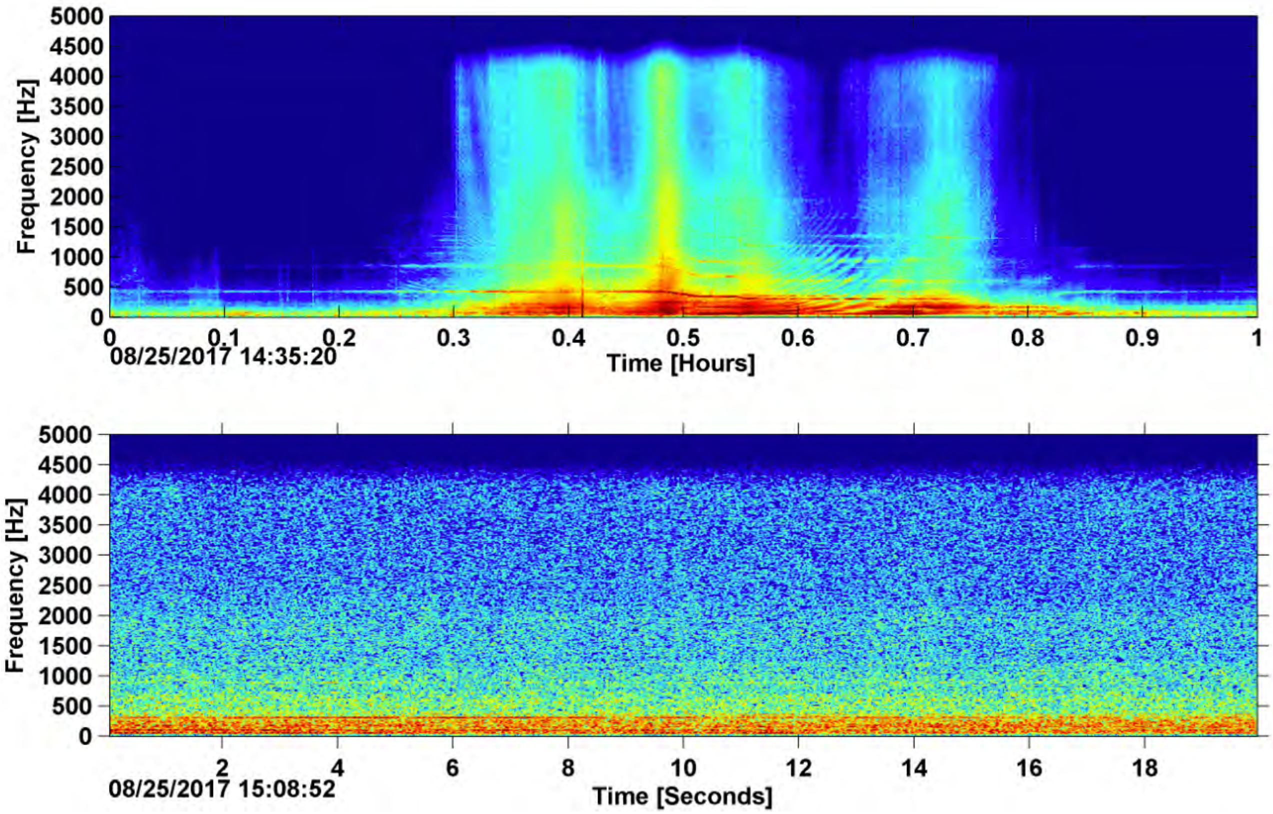

**Figure 28. Broadband ships in LTSA (top) and spectrogram (bottom) recorded at NFC Site A, August 2017.**

## Low-Frequency Active Sonar

Low-frequency active sonar includes military sonar between 100 and 500 Hz and other sonar systems up to 1 kHz. There was effort for LFA sonar both greater than 500 Hz and less than 500 Hz but there were no detections of LFA sonar greater than 500 Hz (Figure 29).

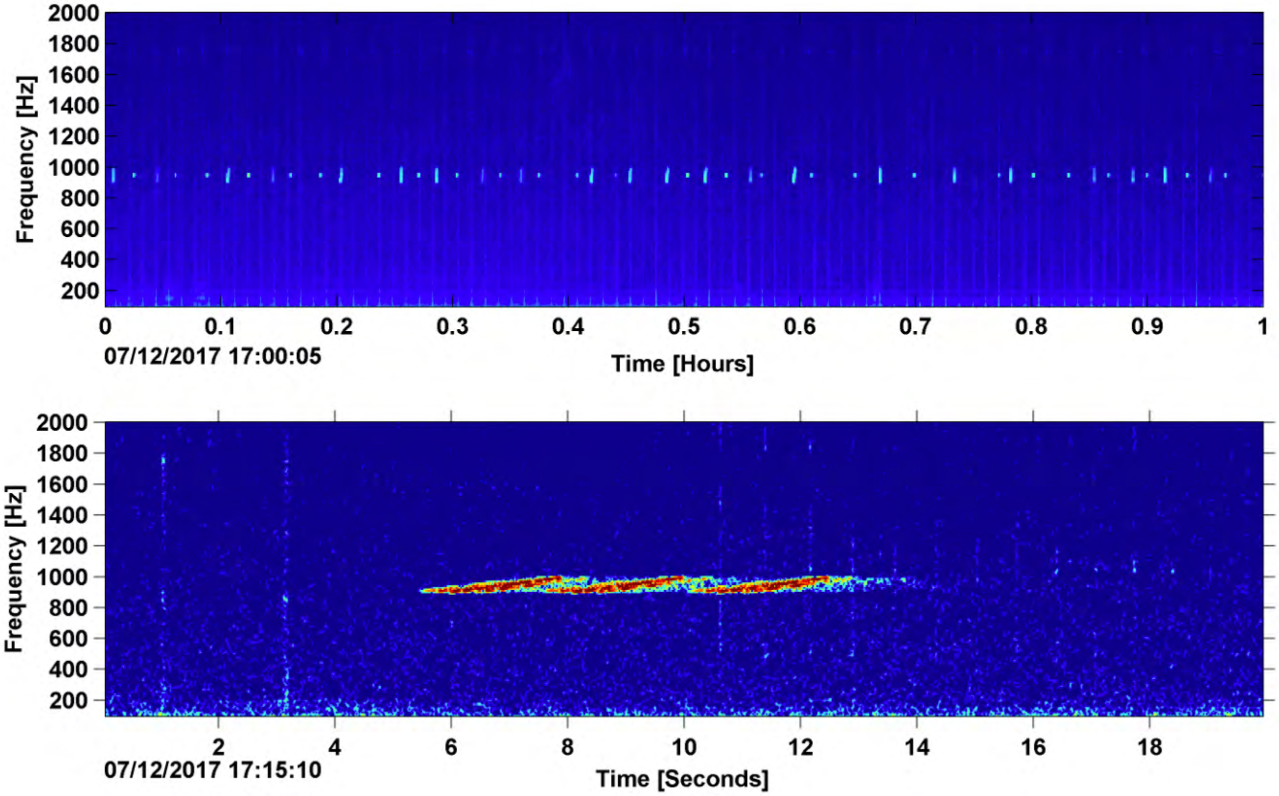

**Figure 29. Low-frequency active sonar in Hz in the LTSA (top) and spectrogram (bottom) recorded at NFC Site A, July 2017.**

### Mid-Frequency Active Sonar

Sounds from MFA sonar vary in frequency (1–10 kHz) and are composed of pulses of both frequency modulated (FM) sweeps and continuous wave (CW) tones grouped in packets with durations ranging from less than 1 s to greater than 5 s. Packets can be composed of single or multiple pulses and are transmitted repetitively as wave trains with inter-packet-intervals typically greater than 20 s (Figure 31). In the Virginia Capes Range Complex, the most common MFA sonar packet signals are between 2 and 5 kHz and are known more generally as '3.5 kHz' sonar.

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

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

These start and end times were used to read segments of waveforms upon which a 2.4 to 4.5 kHz bandpass filter and a simple time series energy detector was applied to detect and measure various packet parameters after correcting for the instrument calibrated transfer function (Wiggins, 2015). For each packet, maximum peak-to-peak (pp) received level (RL), sound exposure level (SEL), root-mean-square (RMS) RL, date/time of packet occurrence, and packet RMS duration (for RLpp 10dB) were measured and saved.

Various filters were applied to the detections to limit the MFA sonar detection range to ~20 km for off-axis signals from an AN/SQS 53C source, which resulted in a received level detection threshold of 130 dB pp re 1 μPa (Wiggins, 2015). Instrument maximum received level was ~162 dB pp re 1 μPa, above which waveform clipping occurred. Packets were grouped into wave trains separated by more than 1 hour. Packet received levels were plotted along with the number of packets and cumulative SEL (CSEL) in each wave train over the study period. Wave train duration and total packet duration were also calculated. Wave train duration is the difference between the first and last packet detections in an event. The total packet duration of for a wave train is the sum of the individual packet (i.e., group of pings) durations, which is measured as the period of the waveform that is 0 to 10 dB less than the maximum peak-to-peak received level of the ping group.

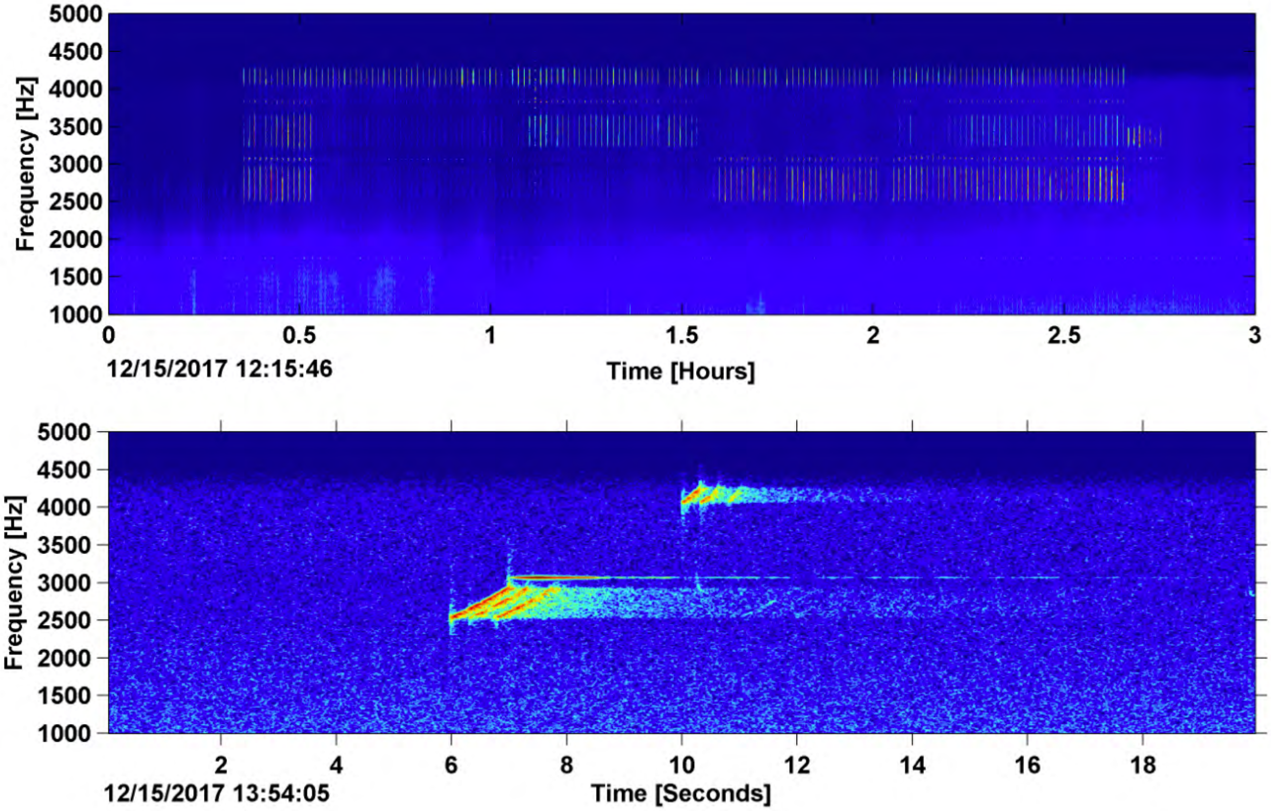

**Figure 30. Mid-frequency active sonar in LTSA (top) and spectrogram (bottom) at NFC Site A, December 2017.**

## High-Frequency Active Sonar

HFA sonar is used for specialty military and commercial applications including high-resolution seafloor mapping, short-range communications, such as with Autonomous Underwater Vehicles (AUVs), multi-beam fathometers, and submarine navigation (Cox, 2004). HFA sonar upsweeps between 10 and 100 kHz were manually detected by analysts in LTSA plots (Figure 31) for this deployment. There were no detections for high-frequency active sonar in the recording period.

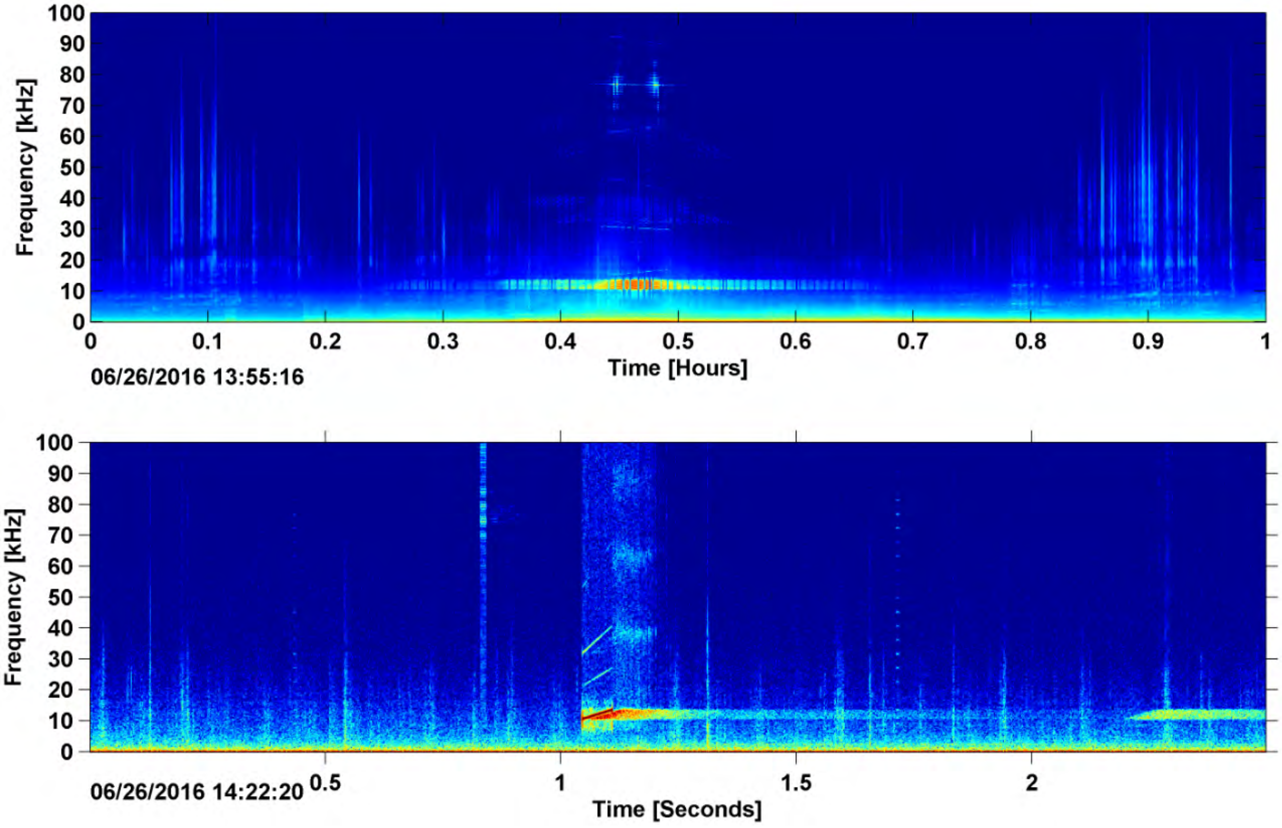

**Figure 31. High-frequency active sonar in LTSA (top) and spectrogram (bottom) in NFC Site A, April 2015.**

## Echosounders

Echosounding sonars transmit short pulses or frequency sweeps, typically in the high-frequency (above 5 kHz) band (Figure 32), 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. High-frequency echosounders were manually detected by analysts reviewing LTSA plots.

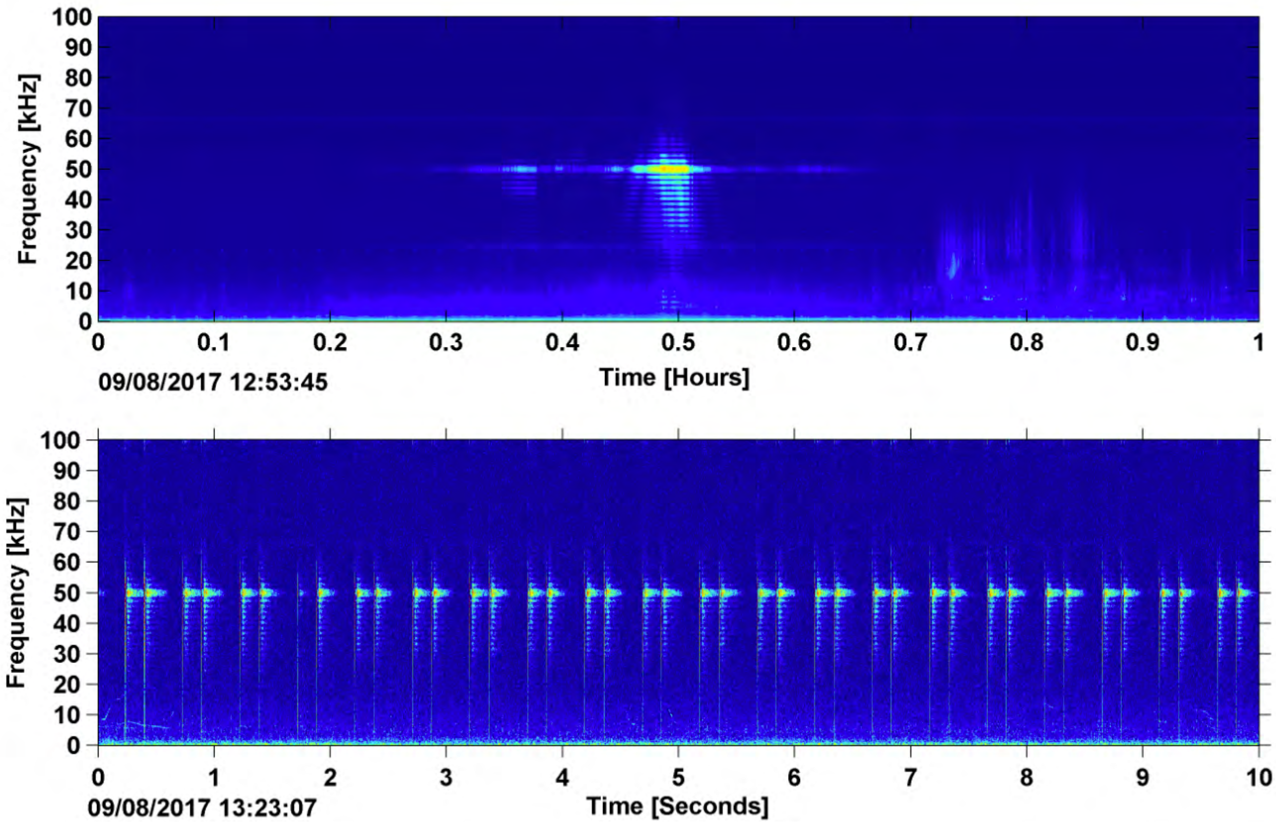

**Figure 32. Echosounders in LTSA (top) and spectrogram (bottom) recorded at NFC Site A, September 2017.**

### Explosions

Effort was directed toward finding explosive sounds in the data including military explosions, subseafloor 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 and has sharp onset reverberant decay (**Figure 33**). Explosions were detected automatically using a matched filter detector on data decimated to a 5 kHz bandwidth. The time series was filtered with a 10th order Butterworth bandpass filter between 200 and 2,000 Hz. Cross correlation was computed between 75 s of the envelope of the filtered time series and the envelope of a filtered example explosion (0.7 s, Hann windowed) as the matched filter signal. The cross correlation was squared to 'sharpen' peaks of explosion detections. A floating threshold was calculated by taking the median cross correlation value over the current 75 s of data to account for detecting explosions within noise, such as shipping. A cross correlation threshold 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 separation of 2 s to be detected. A 300-point (0.03 s) floating average energy across the detection was computed. The start and end above threshold was determined when the energy rose by more than 2 dB above the median energy across the detection. PP and root-mean-squared (RMS) received levels (RL) were computed over the potential explosion period and a time series of the length of the explosion template before and after the explosion. The potential explosion 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 shorter than 0.03 and longer than 0.55 s of duration. These thresholds were evaluated based on the distribution of histograms of manually verified true and false detections. A trained analyst subsequently verified the remaining potential explosions for accuracy. Explosions have energy as low as 10 Hz and may extend up to 2,000 Hz or higher, lasting for a few seconds including the reverberation. Explosions were automatically detected and then manually verified to remove false positives associated with airgun activity and fish sounds.

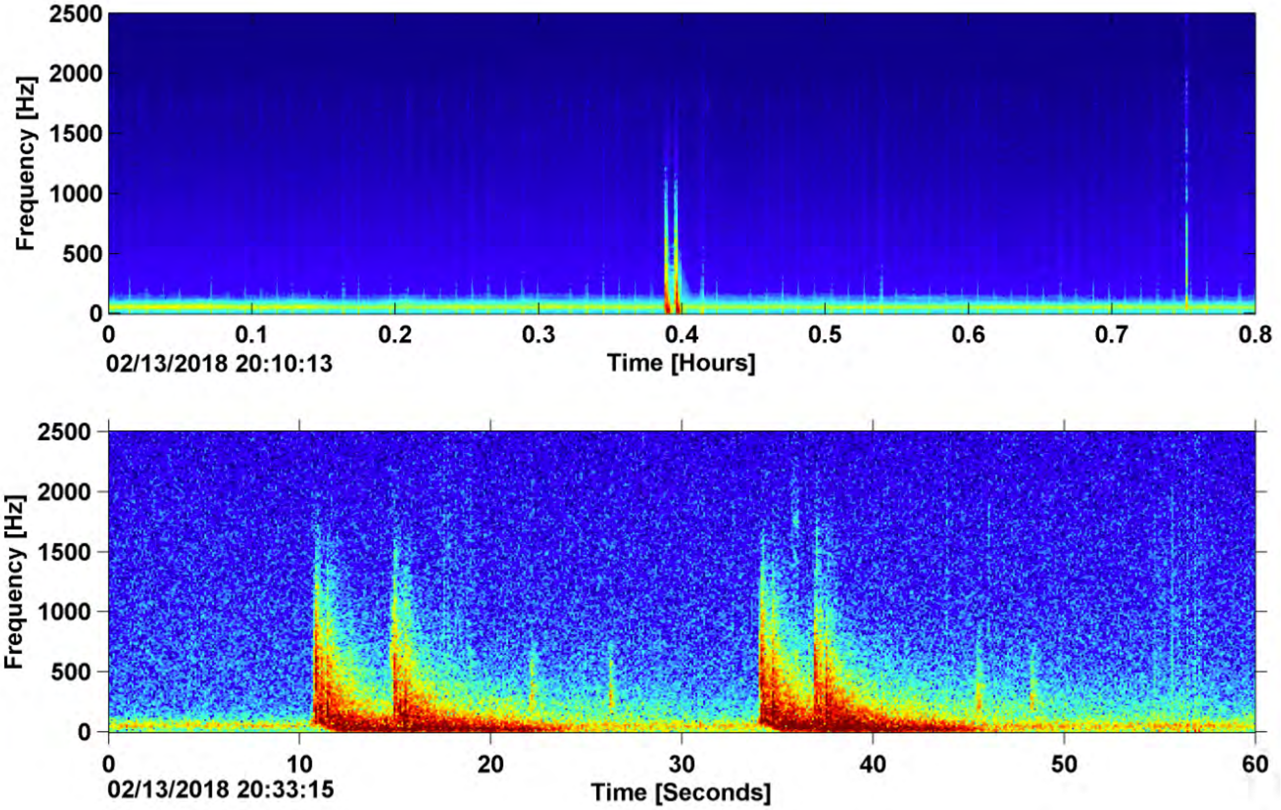

**Figure 33. Explosions recorded in LTSA (top) and spectrogram (bottom) in NFC Site A, February 2018.**

## Underwater Communications

Underwater communications are used to transmit information. They can sound like distorted voices underwater or electronic transmissions (Figure 34).

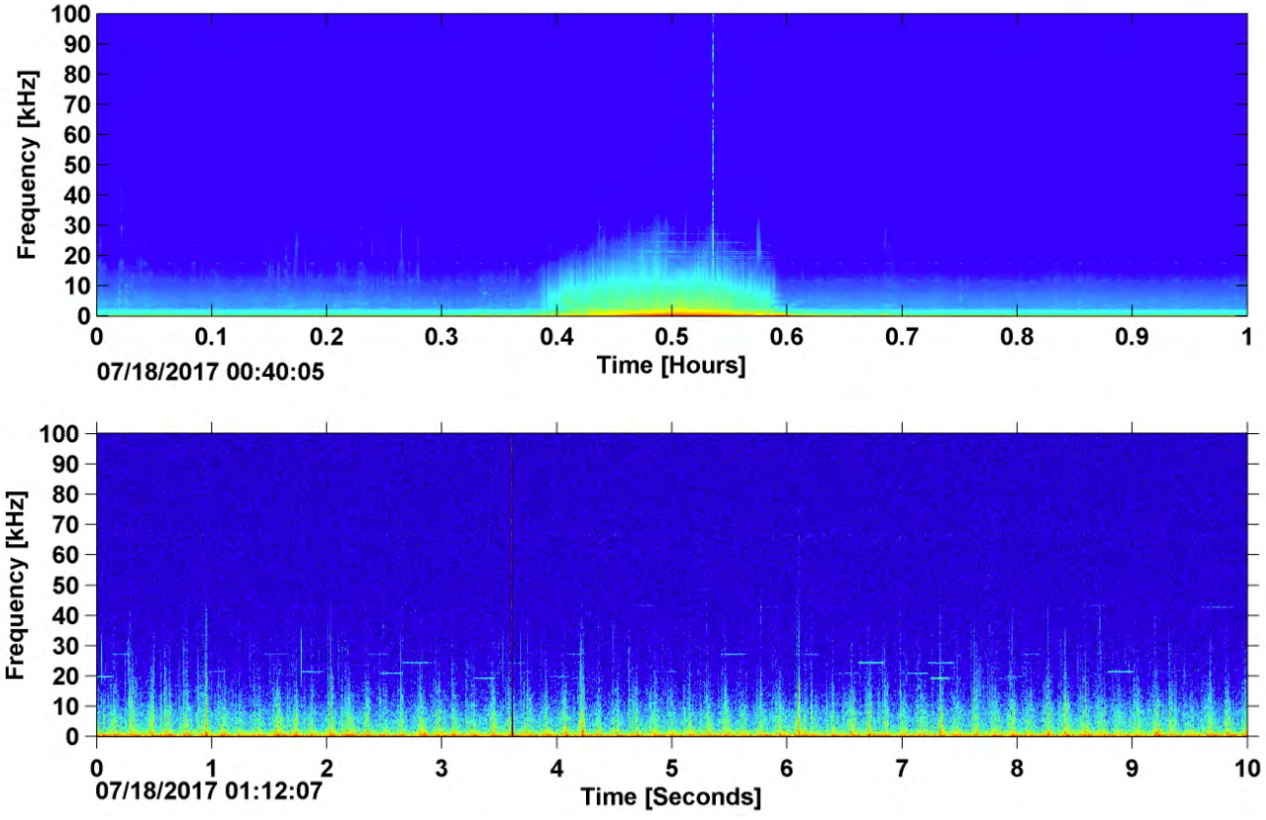

**Figure 34. Underwater communications recorded in LTSA (top) and spectrogram (bottom) in NFC Site A, July 2017.**

## Airguns

Airguns are regularly used in seismic exploration to investigate the ocean floor and what lies beneath it. A container of high-pressure air is momentarily vented to the surrounding water, producing an air-filled cavity which expands and contracts violently several times (Barger and Hamblen, 1980). While most of the energy produced by an airgun array falls below 250 Hz, airguns can produce significant energy at frequencies up to at least 1 kHz (Blackman, *et al.*, 2004). Source levels tend to be 200 dBpp re 1 µPa-m (Blackman *et al.*, 2004; Amundsen and Landro, 2010). These shots typically have an inter-pulse-interval of approximately 10 s and can last from several hours to days (Figure 35). Airguns were detected automatically using a matched filter detector on data decimated to 1 kHz sampling rate. The time series was filtered with a 10th order Butterworth bandpass filter between 25 and 200 Hz. Cross correlation was computed between 75 s of the envelope of the filtered time series and the envelope of a filtered example explosion (0.7 s, Hann windowed) as the matched filter signal. The cross correlation was squared to 'sharpen' peaks of airgun blast detections. A floating threshold was calculated by taking the median cross correlation value over the current 75 s of data to account for detecting airguns within noise, such as shipping. A cross correlation threshold of $3x10^{-3}$ above the median was set. When the correlation coefficient reached above this threshold, the time series was inspected more closely. Consecutive airgun shots were required to have a minimum time distance of 2 s to be detected. A 300- point (0.03 s) floating average energy across the detection was computed. The start and end times above the threshold were marked when the energy rose by more than 2 dB above the median energy across the detection. PP and RMS received sound pressure levels (RL) were computed over the potential signal period as well as a timeseries of the length of the airgun shot template before and after the explosion. The potential airgun shot was classified as a false detection and deleted if 1) the dB difference of PP and RMS between signal and time AFTER the detection was less than 0.5 dB; 2) the dB difference of PP and RMS between signal and time BEFORE the signal was less than 0.5 dB; and 3) the detection was shorter than 0.5 or longer than 10 s. The thresholds were evaluated based on the distribution of histograms of manually verified true and false detections. A regular airgun shot interpulse interval was used to discard potential airgun detections that were not part of a sequence. A trained analyst subsequently verified the remaining potential airgun detections for accuracy. Airgun shots have energy as low as 10 Hz and can extend up to 250 Hz or higher, lasting for a few seconds including the reverberation.

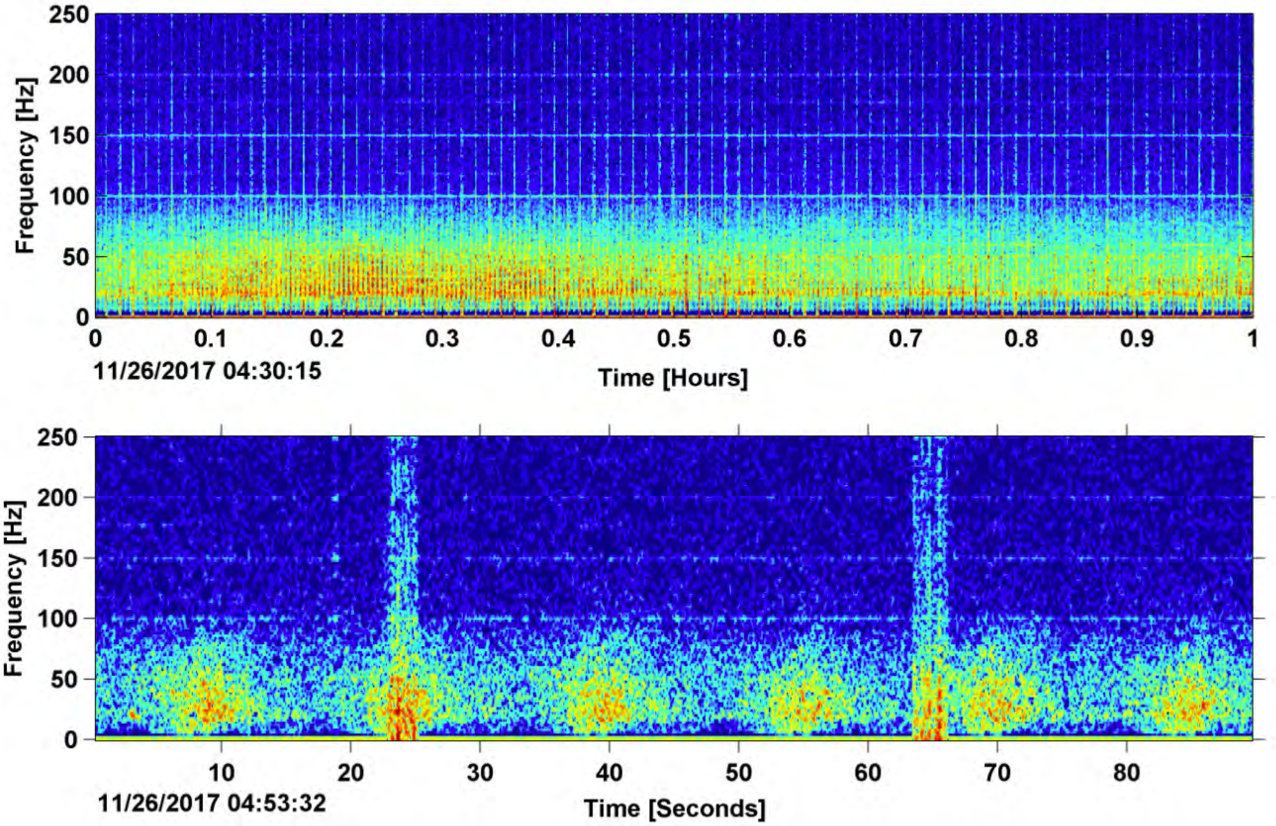

**Figure 35. Airguns in LTSA (top) and spectrogram (bottom) recorded at NFC Site A, November 2017.**

## Results

The results of acoustic data analysis at NFC Site A from June 2017-2018 are summarized, and the seasonal occurrence and relative abundance of marine mammal acoustic signals and anthropogenic sounds are documented.

### Low-Frequency Ambient Soundscape

To provide a means for evaluating seasonal sound spectral variability, daily-averaged spectra were processed into monthly averages (Figure 36) and plotted so that months could be compared. Incomplete days were removed from the analysis, but incomplete months were not. Incomplete months are designated by an asterisk (*) in the color legend of Figure 36 and are detailed in Table 2. Long-term spectrograms were generated using daily-averaged spectra (Figure 37).

- The broad peak at 45 kHz is a result of commercial shipping activity (Figure 36).
- From August 2017-March 2018, a peak in spectrum levels from 15-25 Hz is related to the seasonal increase in fin whale 20 Hz calls (Figure 36).
- Sound levels at 200-1000 Hz are higher during January and March, related to wind and wave noise associated with higher sea states (Figure 37).

**Table 2. Incomplete months included in the ambient soundscape analysis during this recording period.**

| Deployment | Month / Year | Days of Data / Days In Month |
|---|---|---|
| NFC_A_03 | June 2017 | 4 / 30 |
|  | June 2018 | 3 / 30 |

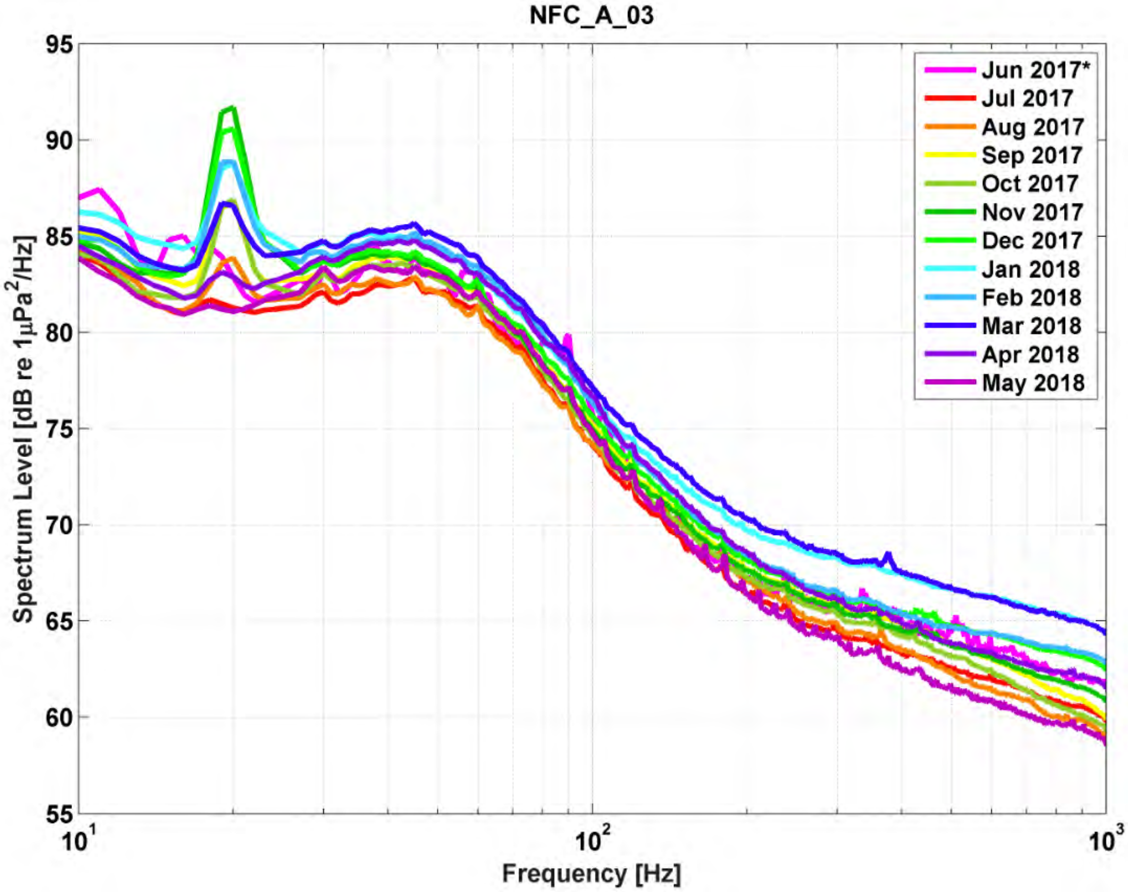

**Figure 36. Monthly averages of ambient soundscape at NFC Site A for each month from June 2017-2018. Legend gives color coding by month. Months with an asterisk are partial recording periods.**

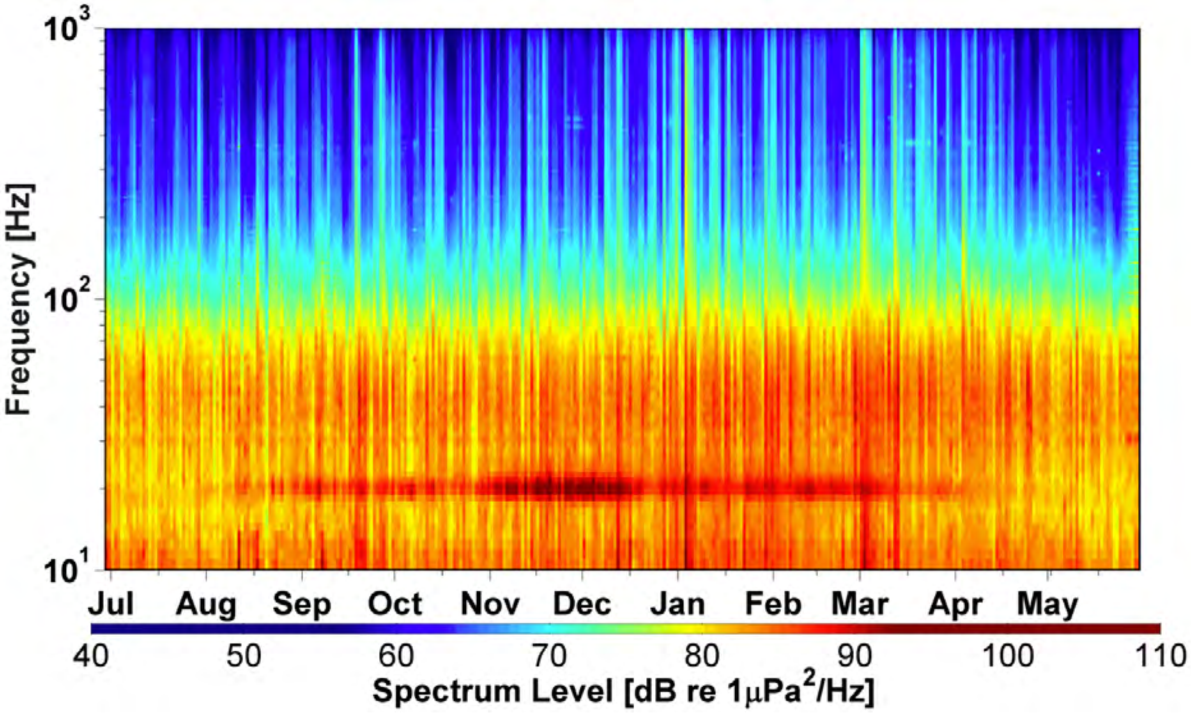

**Figure 37. Long-term spectrograms using daily-averaged spectra for NFC Site A from June 2017-2018.**

## Mysticetes

Four known baleen whale species were recorded from June 2017 to 2018: fin whales, minke whales, sei whales, and humpback whales. More details of each species' presence are given below.

### Fin Whales

- The Fin whale acoustic index, a proxy for 20 Hz calls, was highest between November 2017 and January 2018 (Figure 38).
- Fin whale 40 Hz calls were detected in low numbers from June 2017 to 2018 (Figure 39).
- There was no discernible diel pattern for fin whale 40 Hz calls (Figure 40).

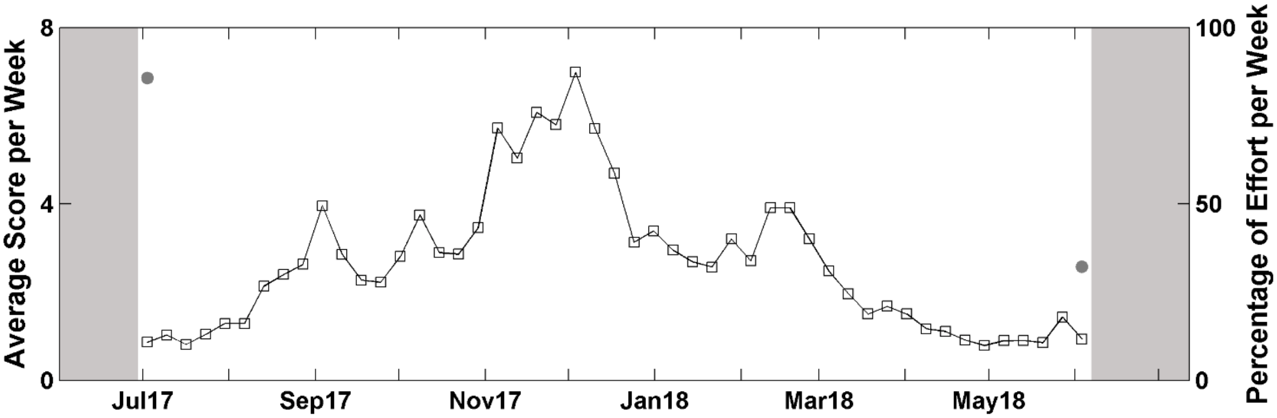

**Figure 38. Weekly value of fin whale acoustic index (proxy for 20 Hz calls) detected from June 2017 to June 2018 at NFC Site A. Gray dots represent percent of effort per week in weeks with less than 100% recording effort. Where gray dots are absent, full recording effort occurred for the entire week. X-axis labels refer to month and year of recording.**

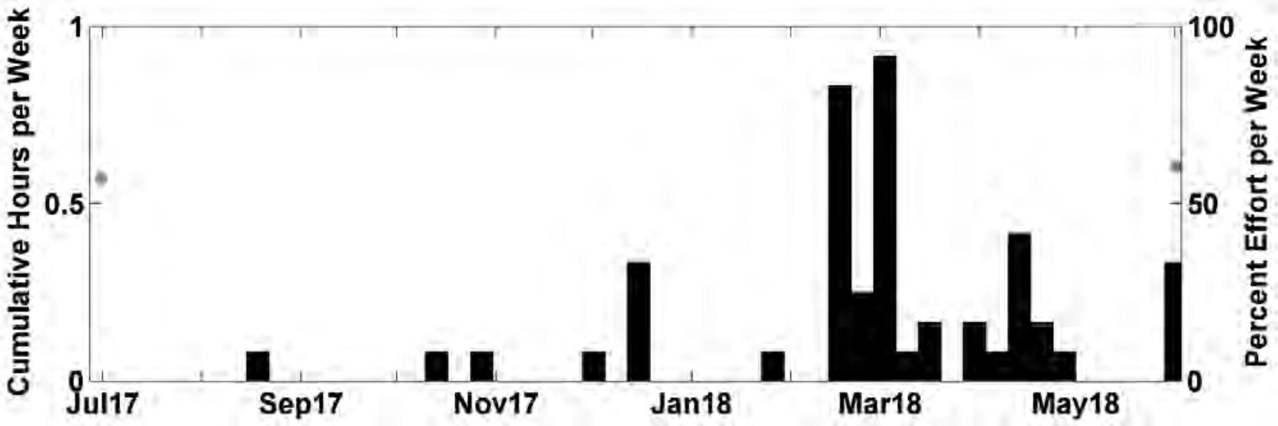

**Figure 39. Fin whale 40 Hz calls detected from June 2017 to June 2018 at NFC Site A. Effort markings are described in Figure 39.**

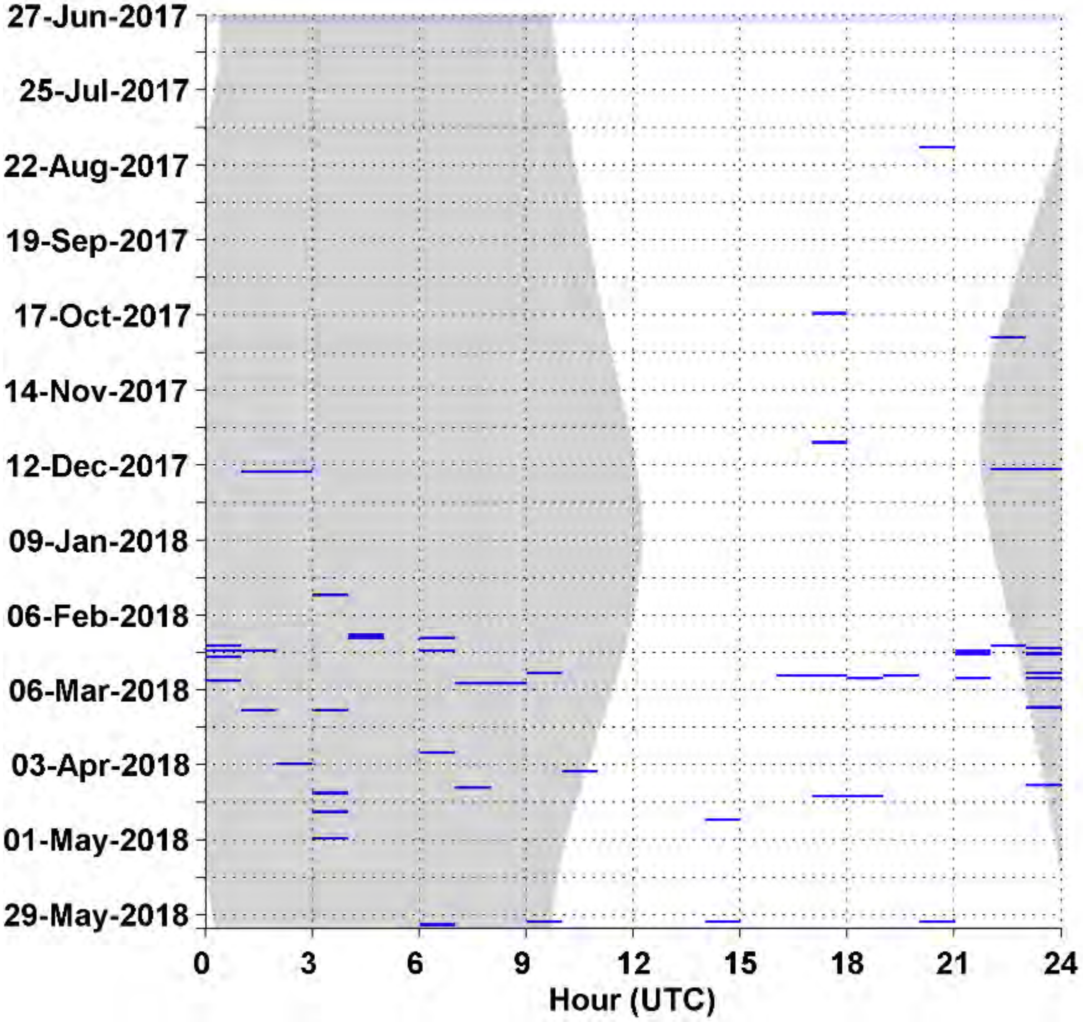

**Figure 40. Fin whale 40 Hz calls in hourly bins at NFC Site A from June 2017 to 2018. Gray vertical shading denotes nighttime.**

**Minke Whales**

- Minke pulse trains were detected in low numbers throughout the recording period. Detections occurred in September 2017 and April 2018 (Figure 41).
- There was no discernible diel pattern for minke pulse trains (Figure 42).

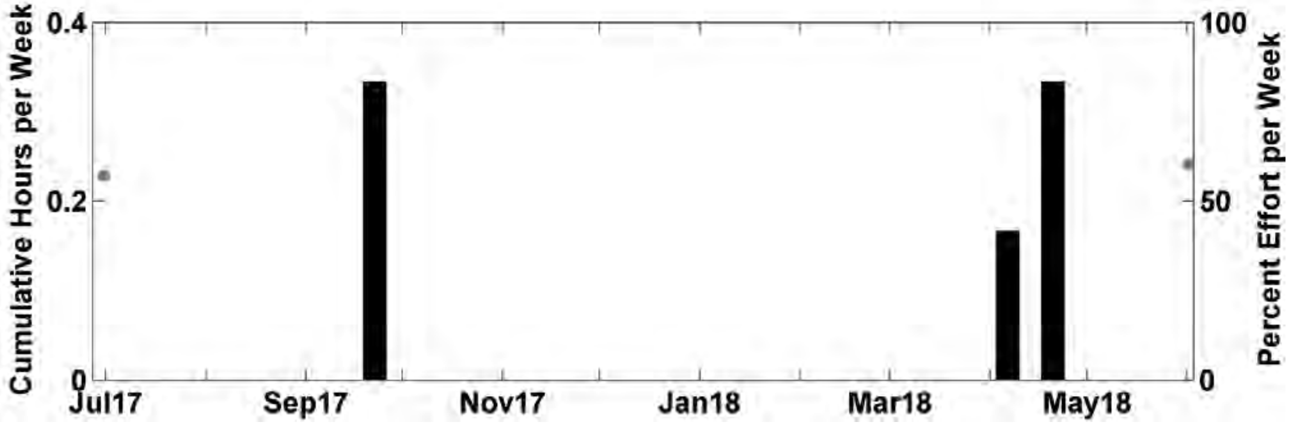

Figure 41. Weekly presence of minke whale pulse trains from June 2017 to June 2018 at NFC Site A. Effort markings are described in Figure 39.

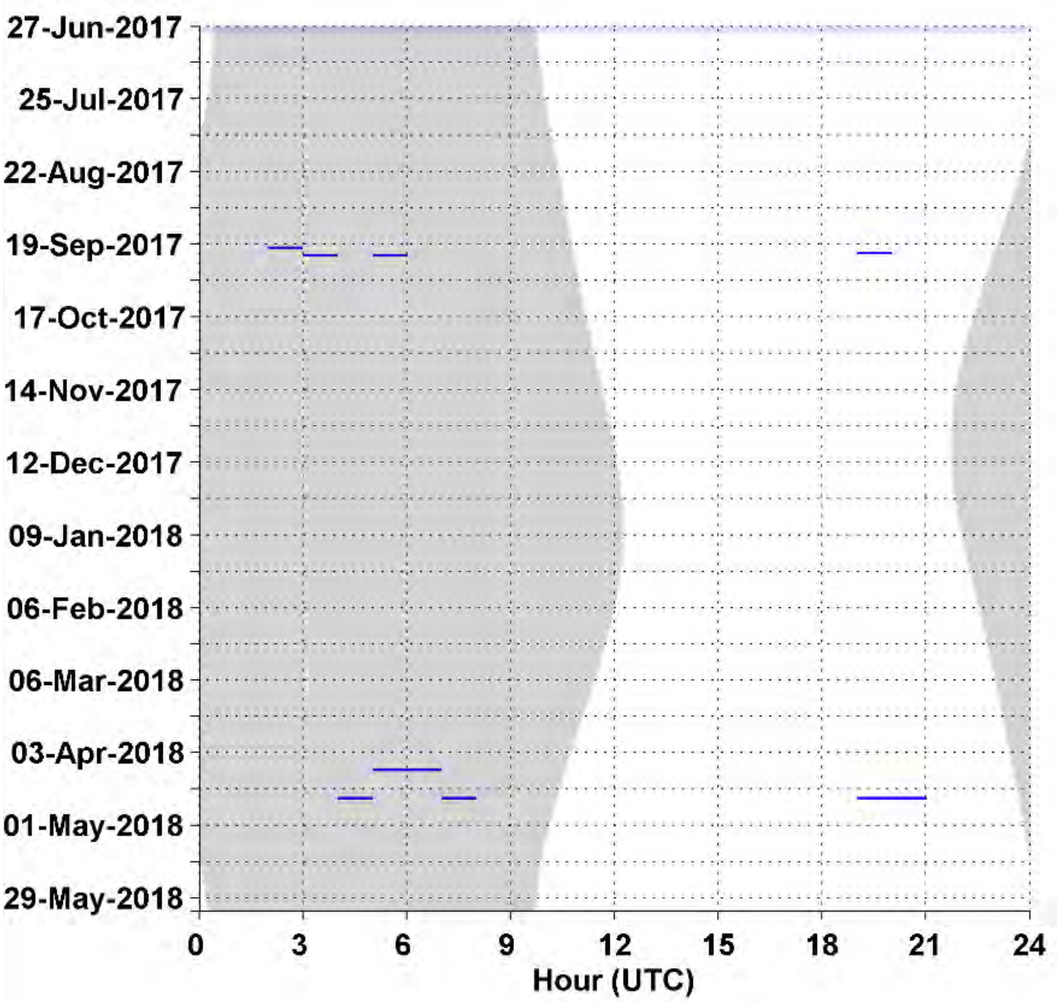

Figure 42. Minke whale pulse trains in hourly bins at NFC Site A from June 2017 to 2018. Gray vertical shading denotes nighttime.

**Sei Whales**

- Sei whale downsweeps were observed primarily between December 2017 and May 2018 (Figure 43).
- There was no discernible diel pattern for sei whale downsweeps (Figure 44).

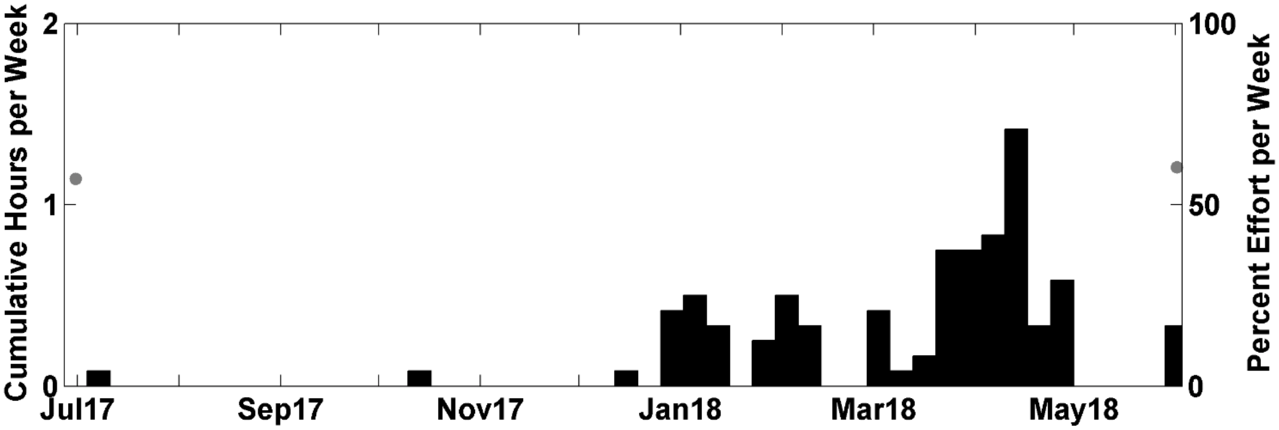

**Figure 43. Weekly presence of Sei whale downsweep calls from June 2017 to June 2018 at NFC Site A. Effort markings described in Figure 39.**

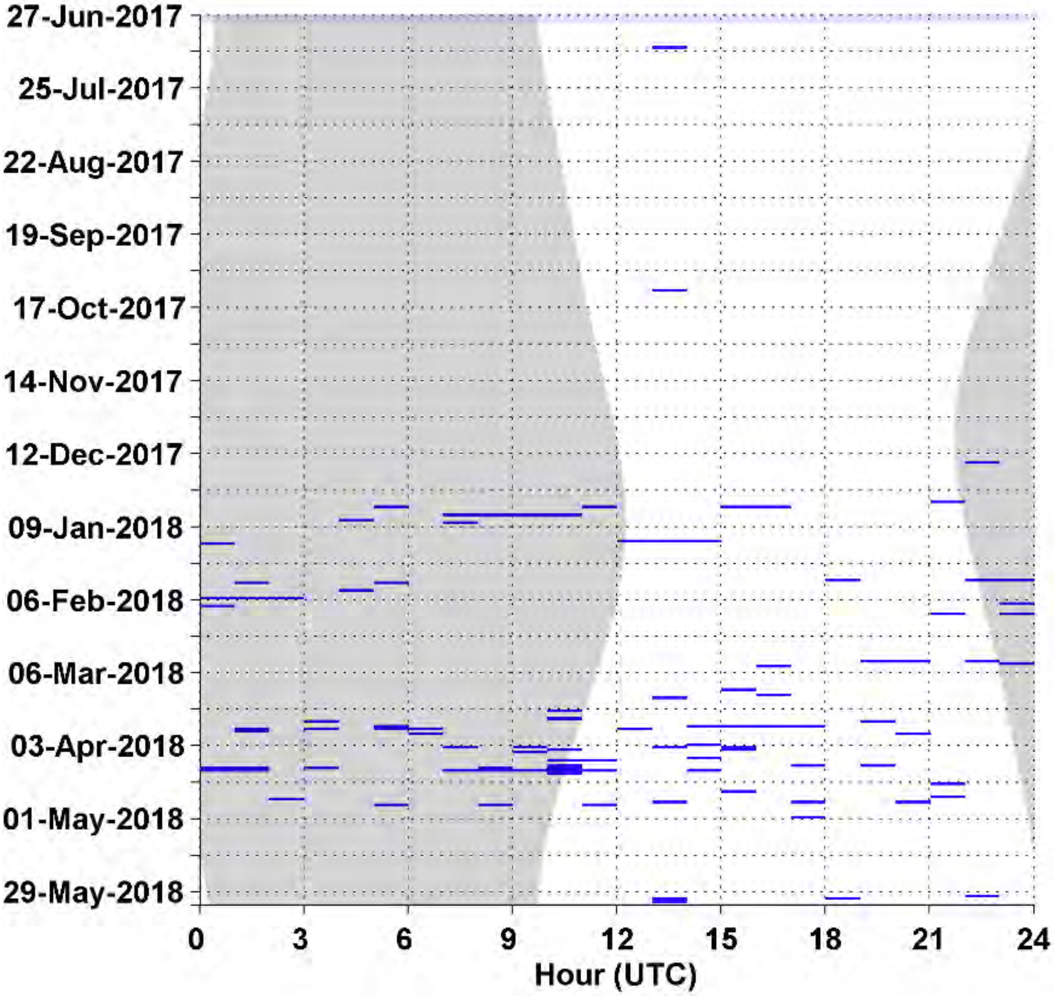

**Figure 44. Sei whale downsweep calls in hourly bins at NFC Site A from June 2017 to 2018. Gray vertical shading denotes nighttime.**

**Humpback Whales**

- Humpback whale call types were observed from March to May 2018 during the recording period (Figure 45).
- There was no discernible diel pattern for humpback whale calls during the recording period (Figure 46**Error! Reference source not found.**).

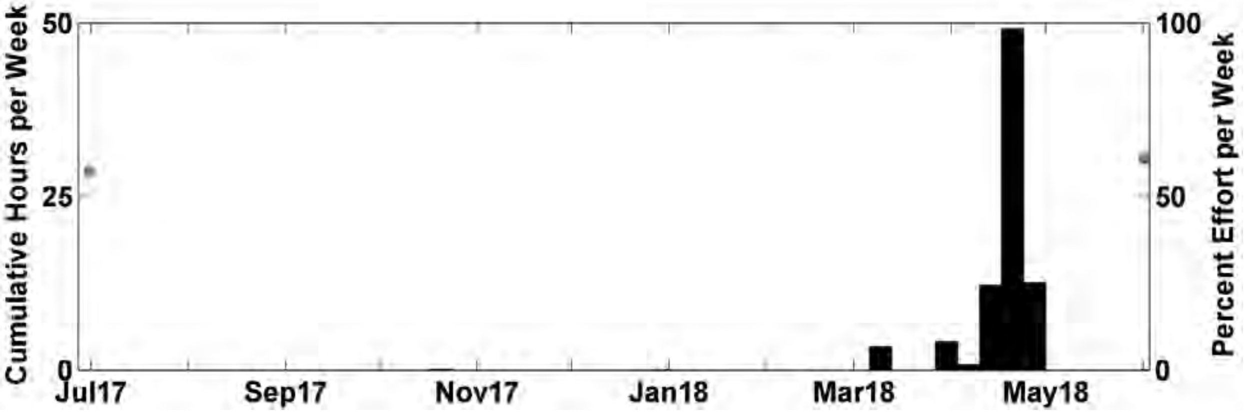

**Figure 45. Weekly presence of humpback whale calls from June 2017 to June 2018 at NFC Site A. Effort markings described in Figure 39.**

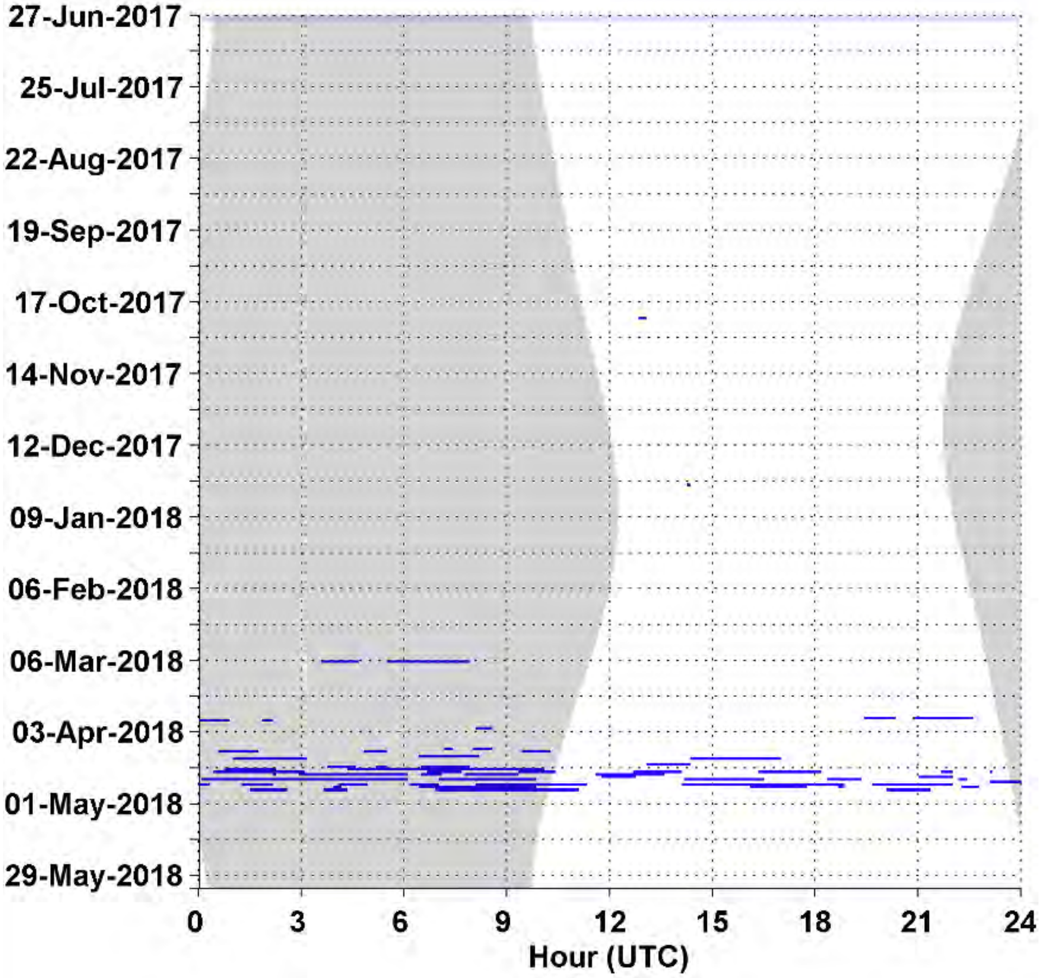

**Figure 46. Humpback whale calls in hourly bins at NFC Site A from June 2017 to 2018. Gray vertical shading denotes nighttime.**

## Odontocetes

Clicks from Blainville's beaked whale, Cuvier’s beaked whale, Gervais’ beaked whale, Sowerby’s beaked whale, Risso’s dolphins, clicks of three types that are not yet assigned to a species, clicks of unidentified odontocetes, sperm whales, and *Kogia* spp. were discriminated. Whistles from unidentified odontocete species were detected both above and below 5 kHz. Details of each species’ presence at these sites are given below.

**Blainville's Beaked Whale**

- Blainville's beaked whale echolocation clicks were detected once on July 10, 2017 (Figure 47).
- The single encounter occurred during daytime. There were too few detections to determine a diel pattern for Blainville's beaked whale (Figure 48).

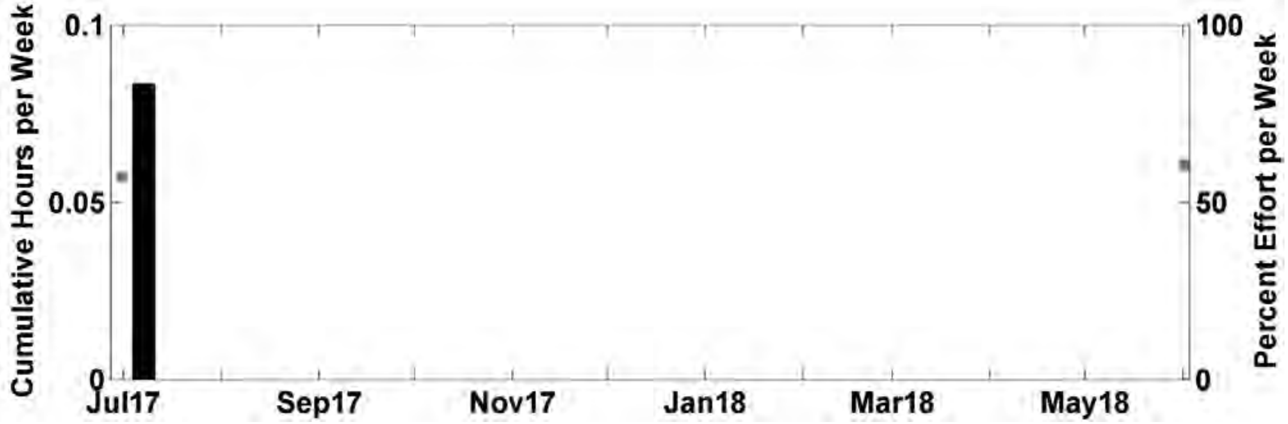

**Figure 47. Weekly presence of Blainville's beaked whale echolocation clicks from June 2017 to 2018 at NFC Site A. Effort markings are described in Figure 39.**

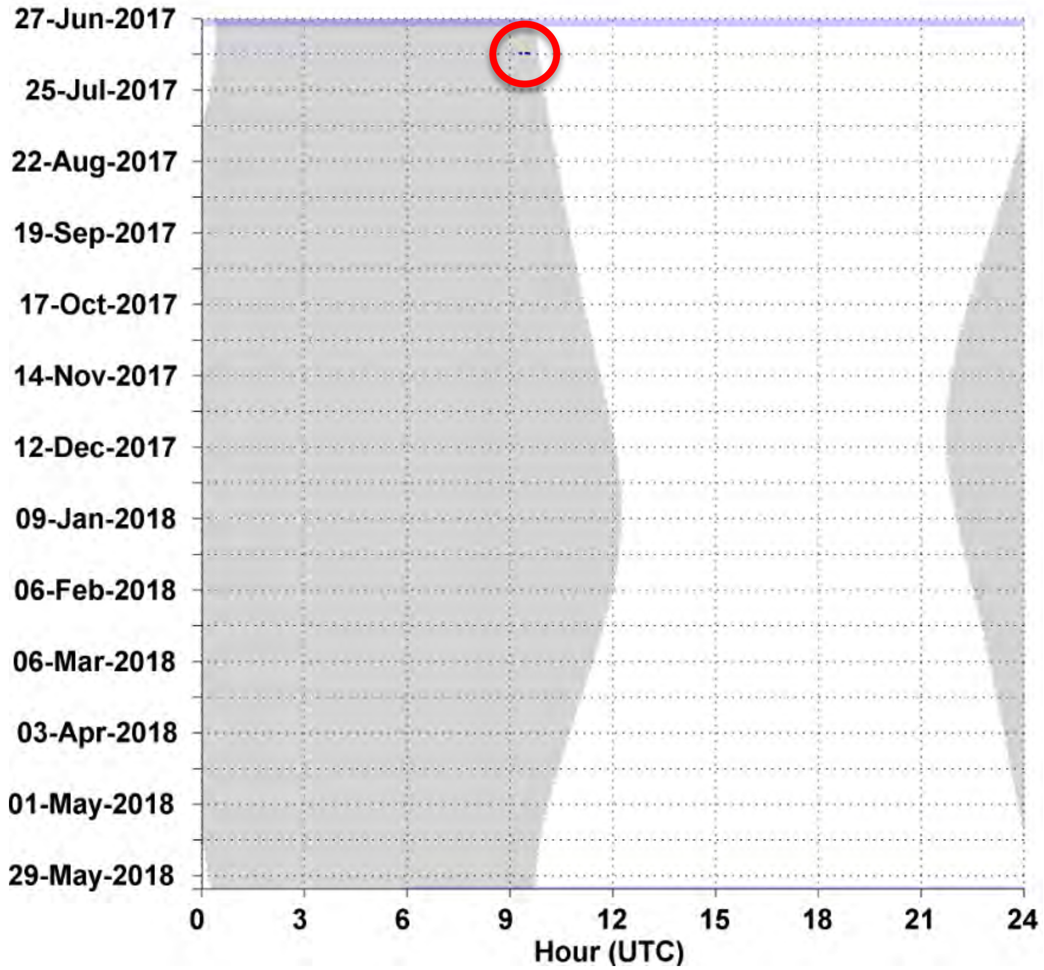

**Figure 48. Blainville's beaked whale echolocation clicks in one-minute bins at NFC Site A from June 2017 to 2018. Gray vertical shading denotes nighttime.**

**Cuvier's Beaked Whale**

- Cuvier's beaked whale echolocation clicks were detected intermittently throughout the recording period but detections were highest in January 2018 (Figure 49).
- There was no discernible diel pattern for Cuvier's beaked whale echolocation clicks (Figure 50).

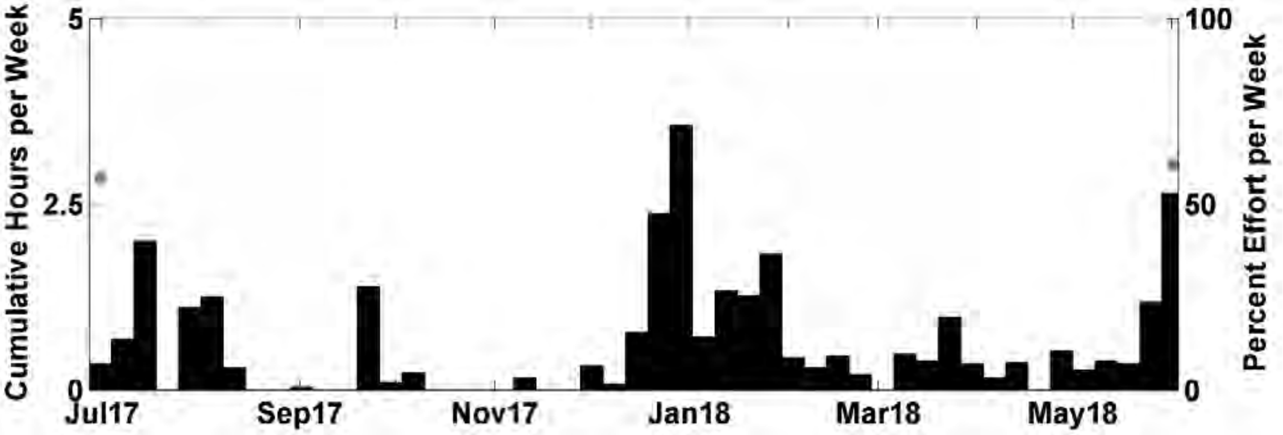

**Figure 49. Weekly presence of Cuvier's beaked whale echolocation clicks from June 2017 to 2018 at NFC Site A. Effort markings are described in Figure 39.**

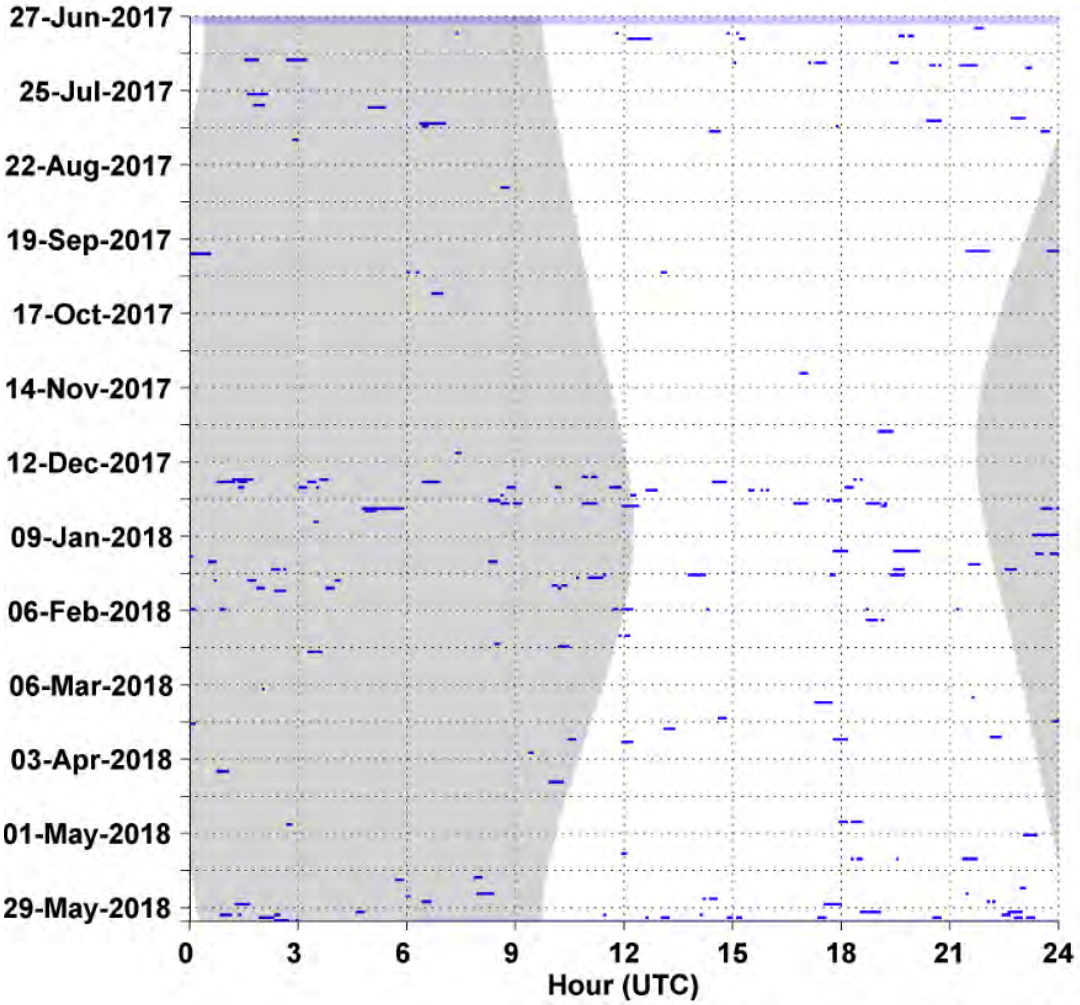

**Figure 50. Cuvier's beaked whale echolocation clicks in one-minute bins at NFC Site A from June 2017 to 2018. Gray vertical shading denotes nighttime.**

**Gervais' Beaked Whale**

- Gervais' beaked whale echolocation clicks were detected intermittently throughout the recording period but were highest in February 2018 (Figure 51).
- There was no discernible diel pattern for Gervais' beaked whale echolocation clicks (Figure 52).

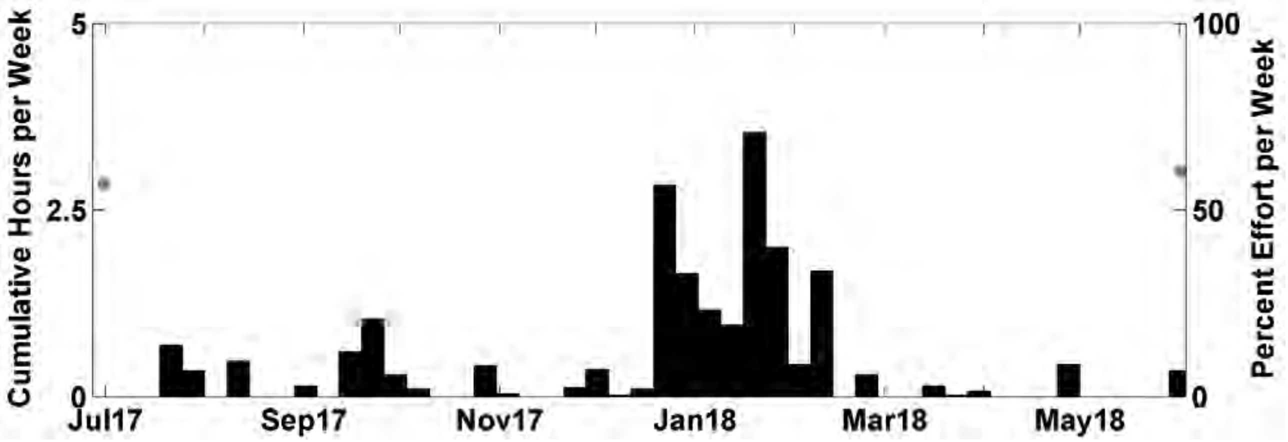

**Figure 51. Weekly presence of Gervais' beaked whale echolocation clicks from June 2017 to 2018 at NFC Site A. Effort markings are described in Figure 39.**

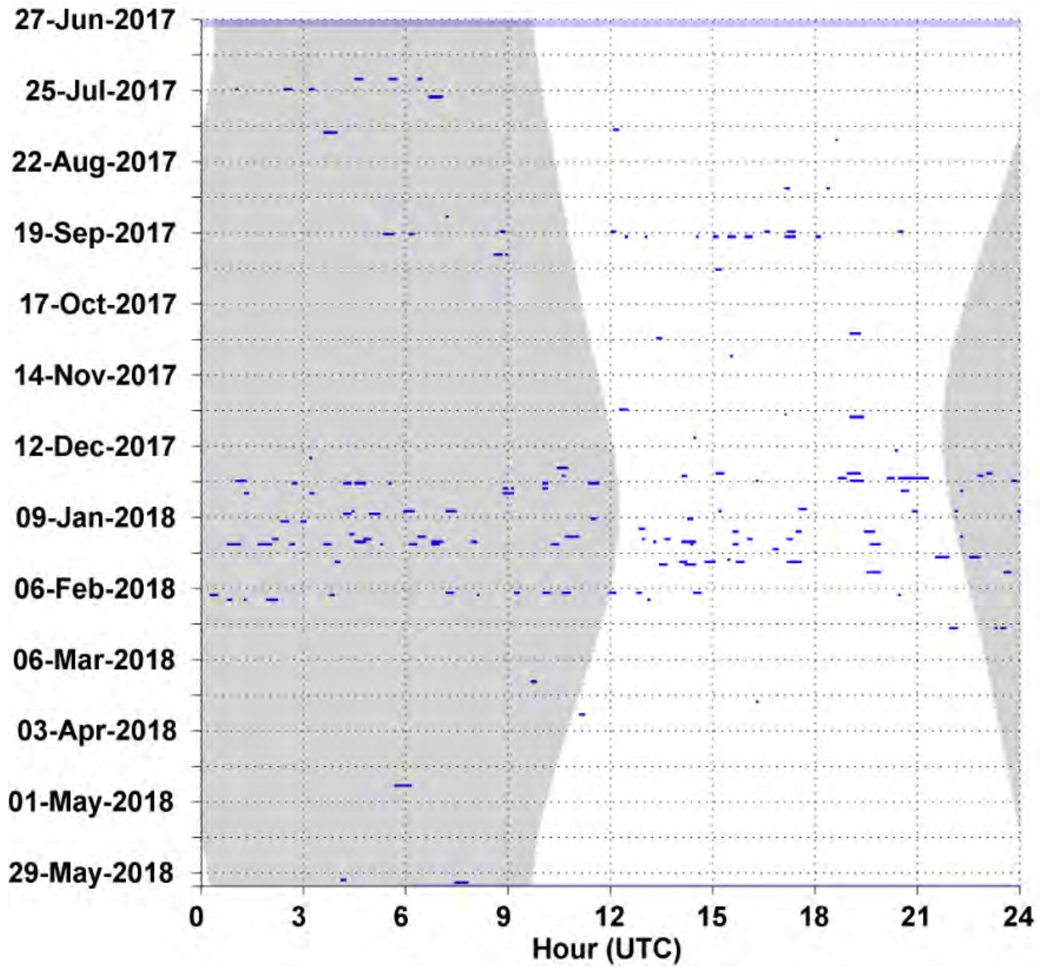

**Figure 52. Gervais' beaked whale echolocation clicks in one-minute bins at NFC Site A from June 2017 to 2018. Gray vertical shading denotes nighttime.**

**Sowerby's Beaked Whale**

- Sowerby's beaked whale echolocation clicks were regularly detected in low numbers throughout the recording period but were highest in May 2018 (Figure 53).
- There was no discernible diel pattern for Sowerby's beaked whale echolocation clicks (Figure 54).

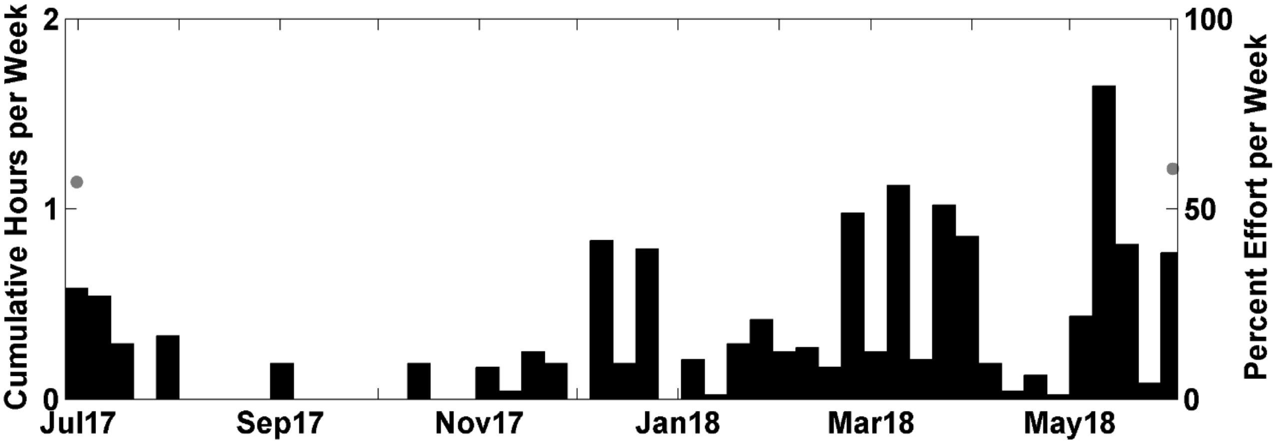

Figure 53. Weekly presence of Sowerby's beaked whale echolocation clicks from June 2017 to 2018 at NFC Site A. Effort markings are described in Figure 39.

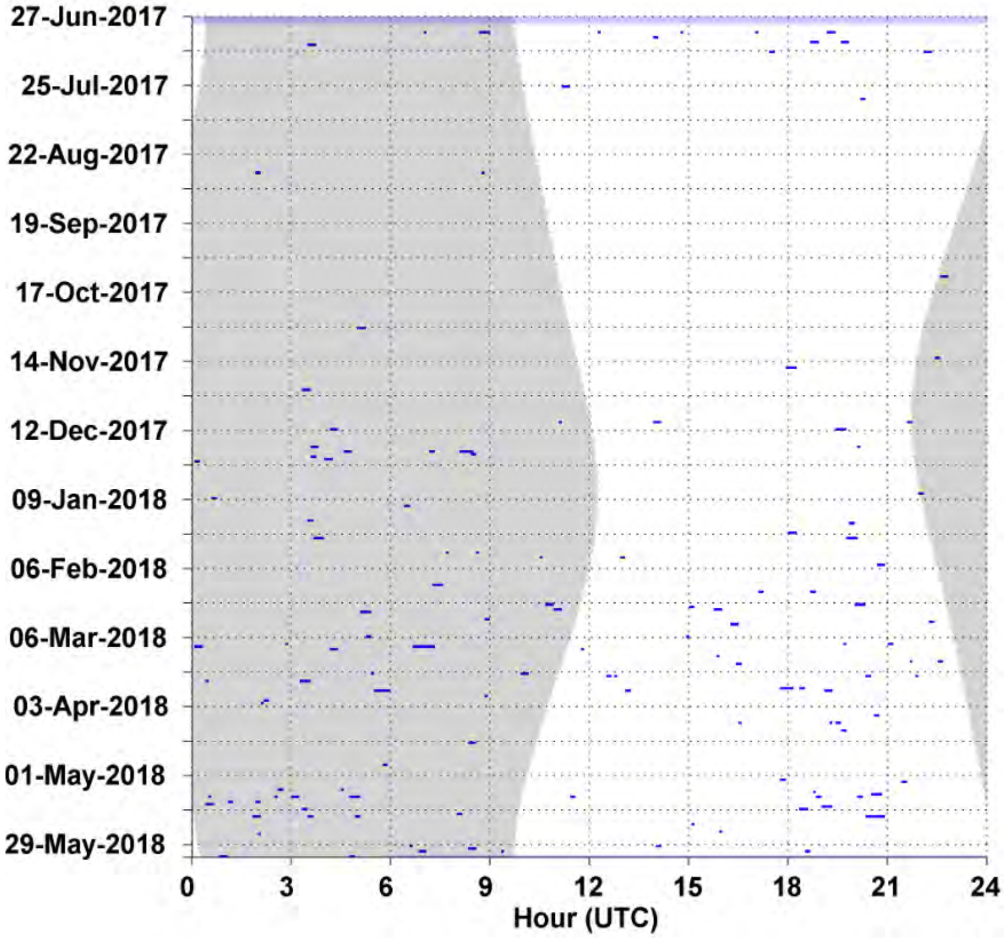

Figure 54. Sowerby's beaked whale echolocation clicks in one-minute bins at NFC Site A from June 2017 to 2018. Gray vertical shading denotes nighttime.

**Risso's Dolphins**

- Risso's dolphin echolocation clicks peaked in September 2017 and May 2018 (Figure 55).
- There was no discernible diel pattern for Risso's dolphin echolocation clicks (Figure 56).

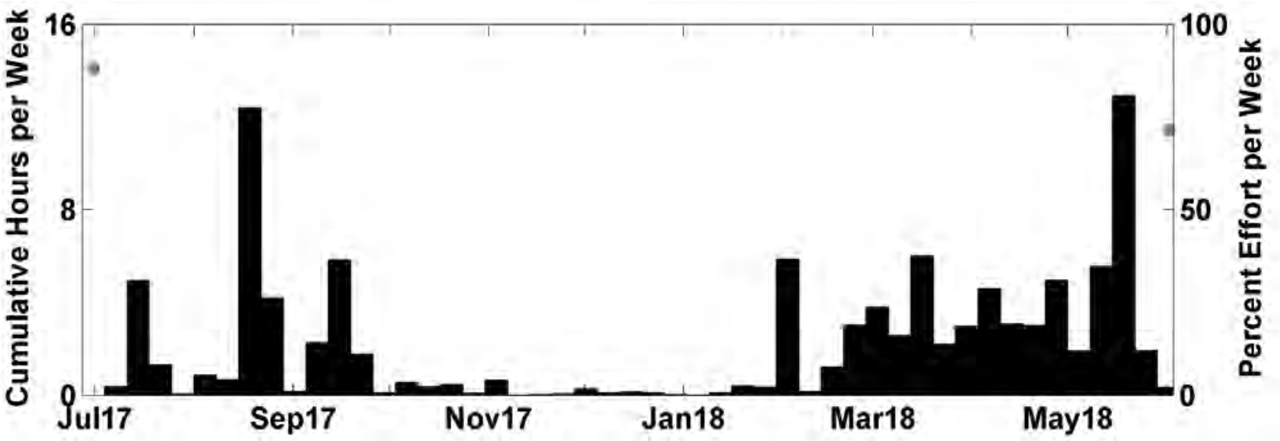

**Figure 55. Weekly presence of Risso's dolphin echolocation clicks from June 2017 to 2018 at NFC Site A. Effort markings are described in Figure 39.**

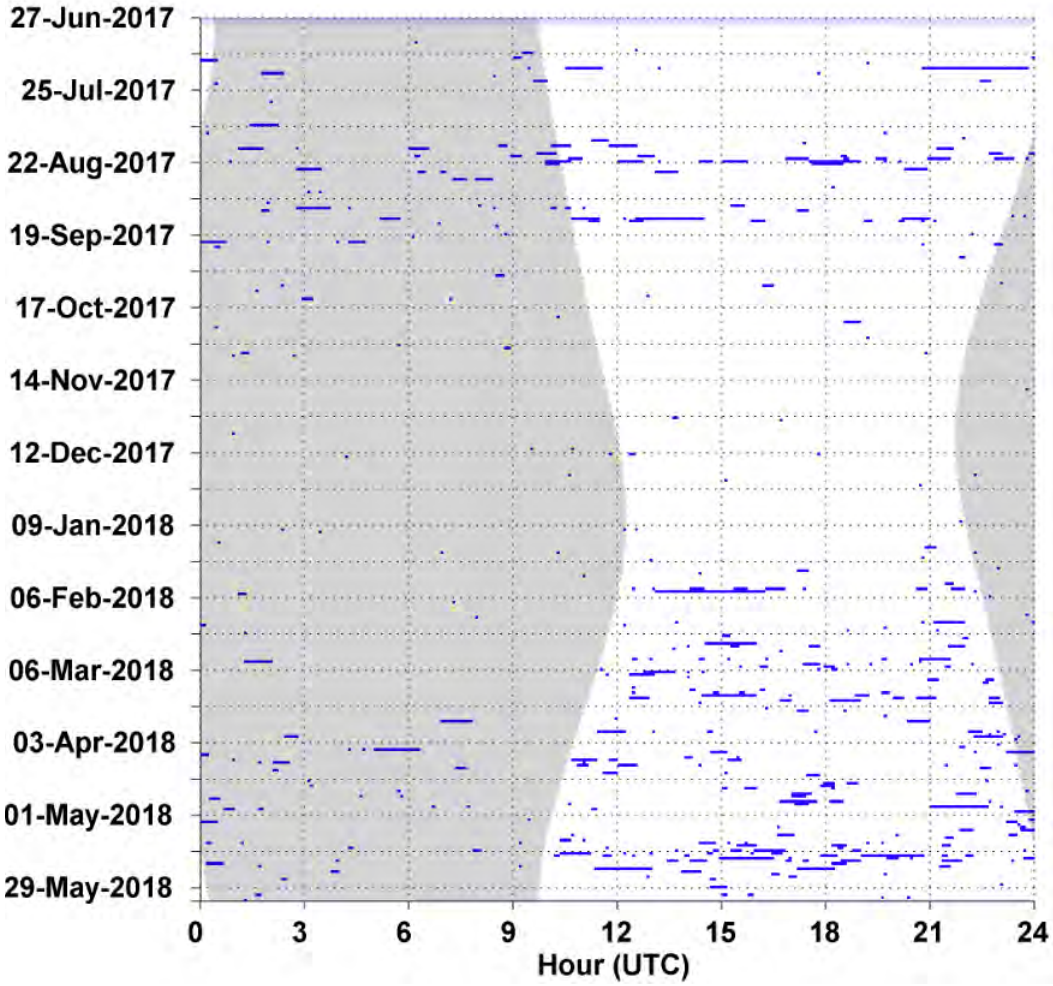

**Figure 56. Risso's dolphin echolocation clicks in five-minute bins at NFC Site A from June 2017 to 2018. Gray vertical shading denotes nighttime.**

### Unidentified Odontocete Clicks

Signals that had characteristics of odontocete sounds (both whistles and clicks), but could not be classified to species were labeled as unidentified odontocetes. Clicks were left unidentified if too few clicks were detected in a time bin, or if detected clicks were of poor quality (e.g. low amplitude or masked).

- Unidentified odontocete clicks were detected throughout the recording period (Figure 57).
- There was no discernible diel pattern for unidentified dolphin clicks (Figure 58).

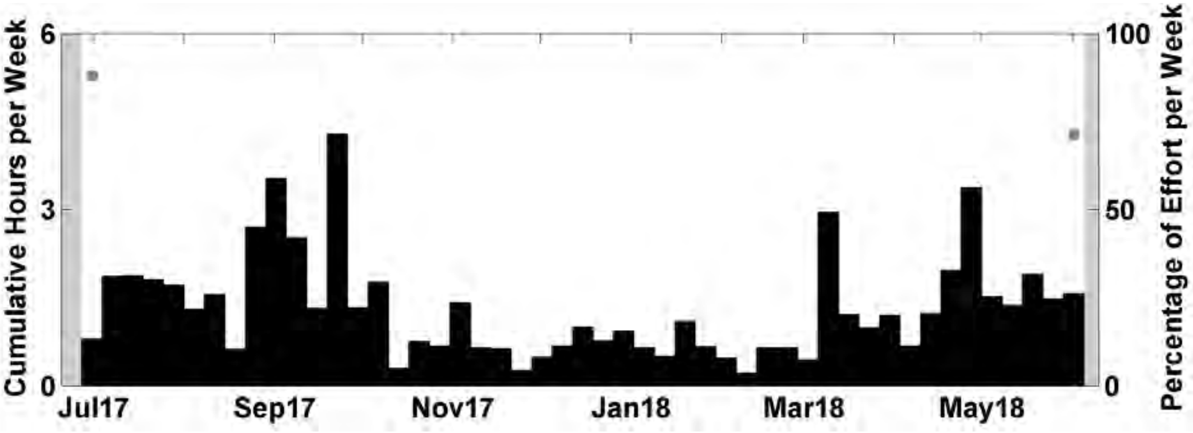

**Figure 57. Weekly presence of unidentified odontocete clicks from June 2017 to 2018 at NFC Site A. Effort markings are described in Figure 39.**

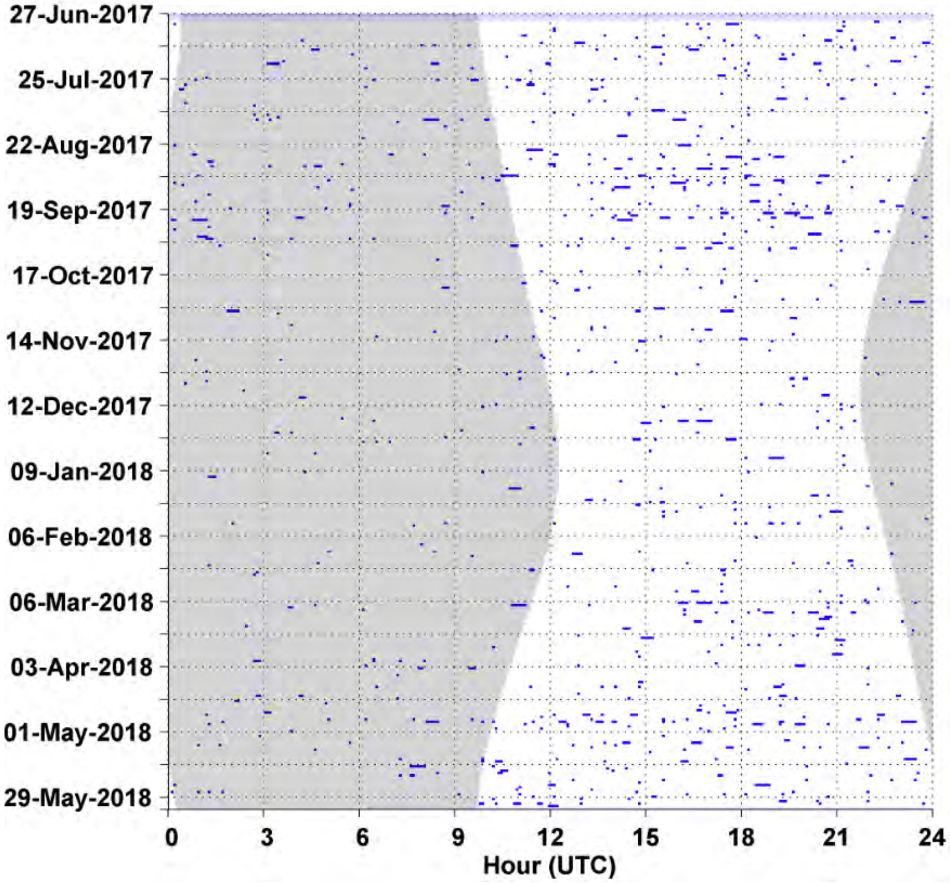

**Figure 58. Unidentified odontocete clicks in five-minute bins at NFC Site A from June 2017 to 2018. Gray vertical shading denotes nighttime.**

**Click Type 1**

- CT 1 was detected consistently throughout the deployment but began to increase starting in November 2017 (Figure 59).
- CT 1 was more often detected during nighttime (Figure 60).

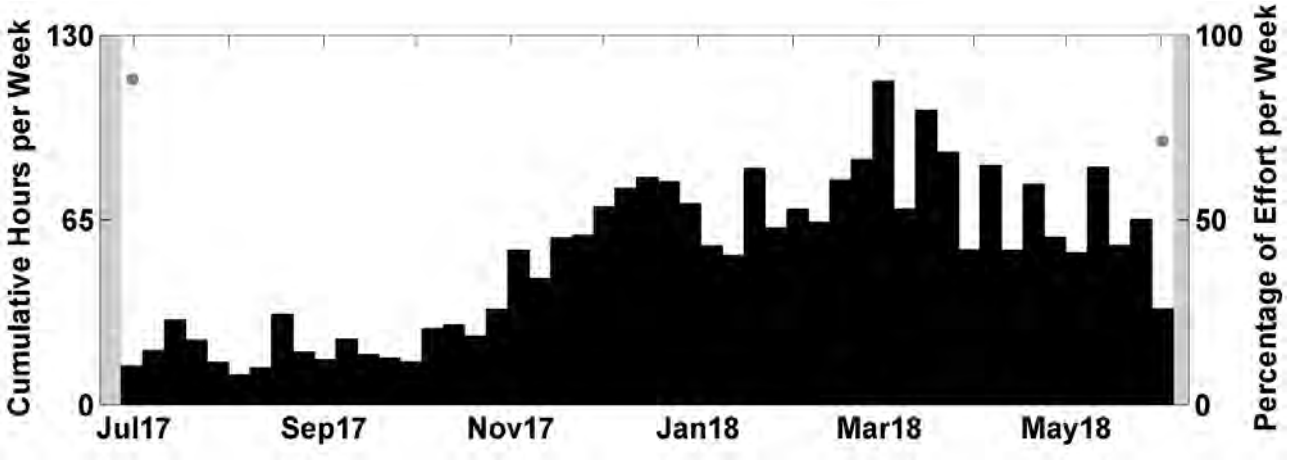

**Figure 59. Weekly presence of CT 1 from June 2017 to 2018 at NFC Site A. Effort markings are described in Figure 39.**

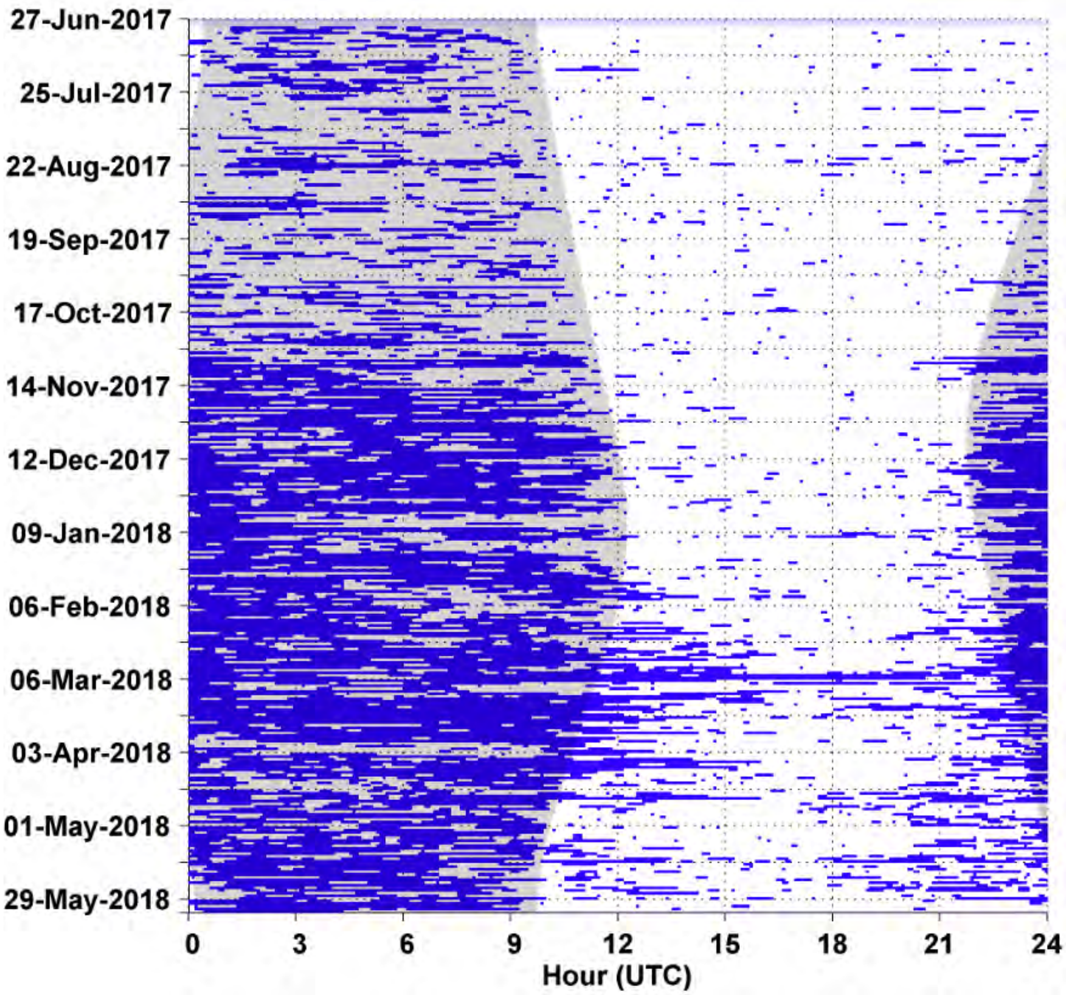

**Figure 60. CT 1 in five-minute bins at NFC Site A from June 2017 to 2018. Gray vertical shading denotes nighttime.**

**Click Type 4**

- CT 4 was detected consistently throughout the deployment with peaks November 2017 and April 2018 (Figure 61).
- CT 4 was detected predominantly during nighttime (Figure 62).

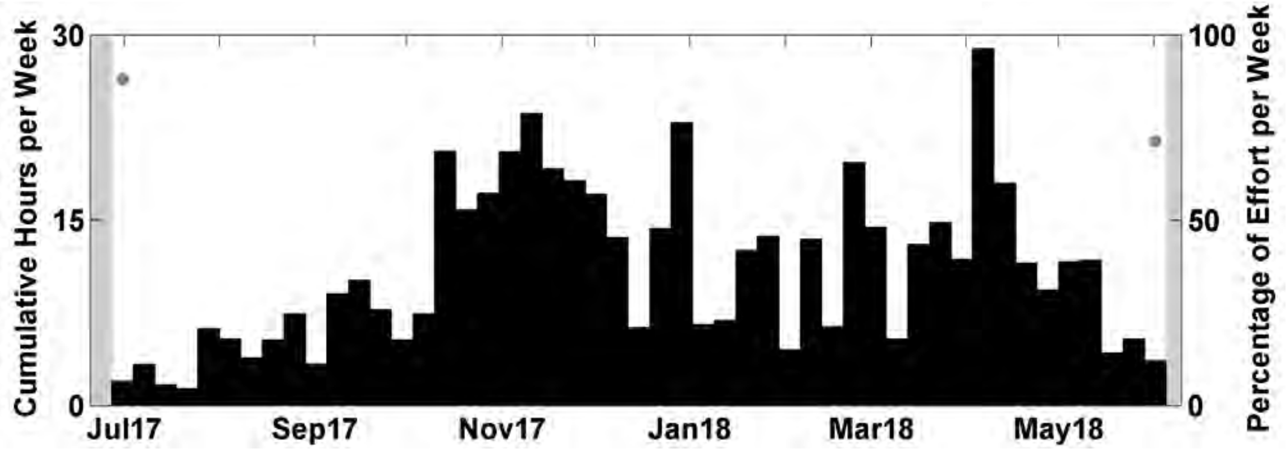

**Figure 61. Weekly presence of CT 4 from June 2017 to 2018 at NFC Site A. Effort markings are described in Figure 39.**

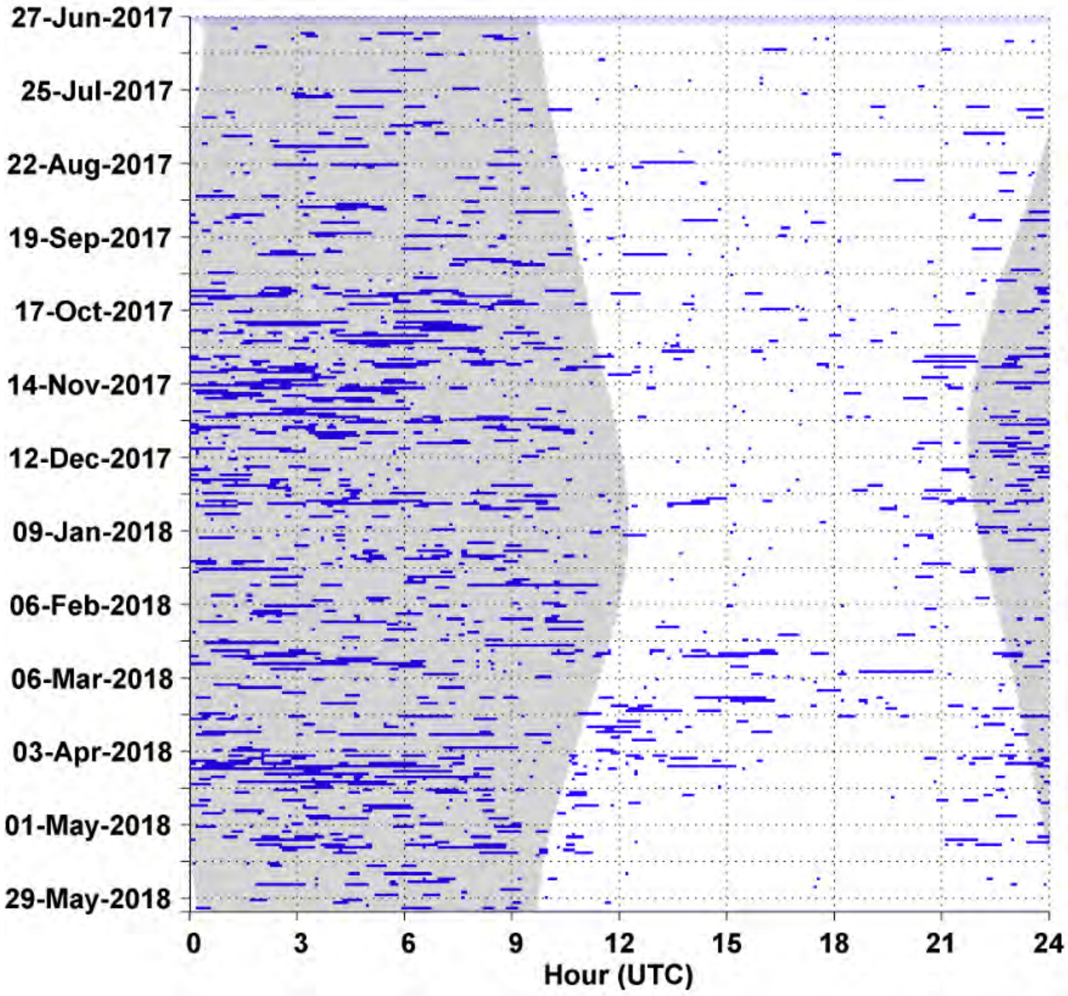

**Figure 62. CT 4 in five-minute bins at NFC Site A from June 2017 to 2018. Gray vertical shading denotes nighttime.**

**Click Type 6**

- CT 6 was detected consistently throughout the deployment with fewer detections starting in March 2018 (Figure 63).
- There was no discernible diel pattern for CT 6 detections (Figure 64).

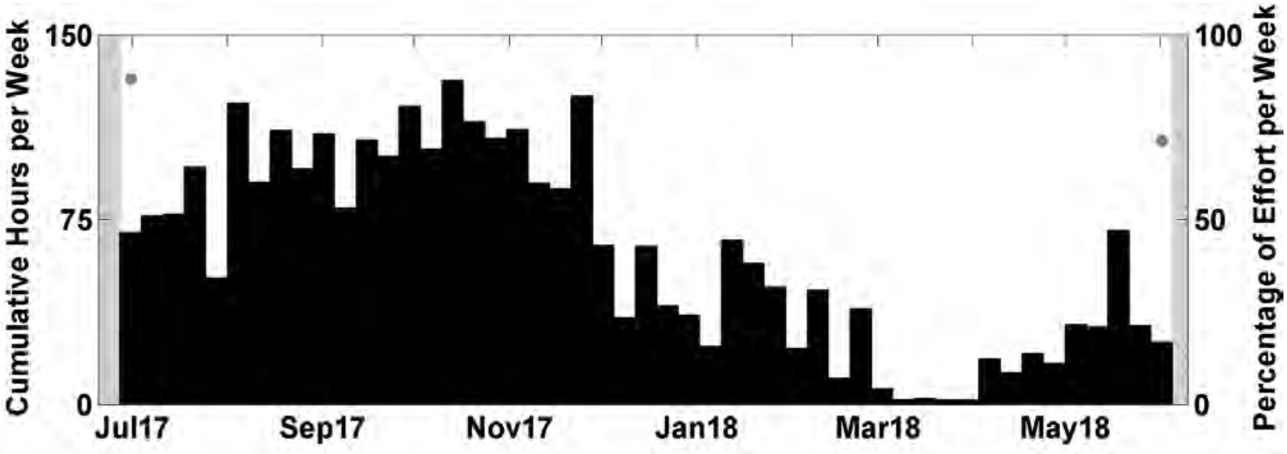

**Figure 63. Weekly presence of CT 6 from June 2017 to 2018 at NFC Site A. Effort markings are described in Figure 39.**

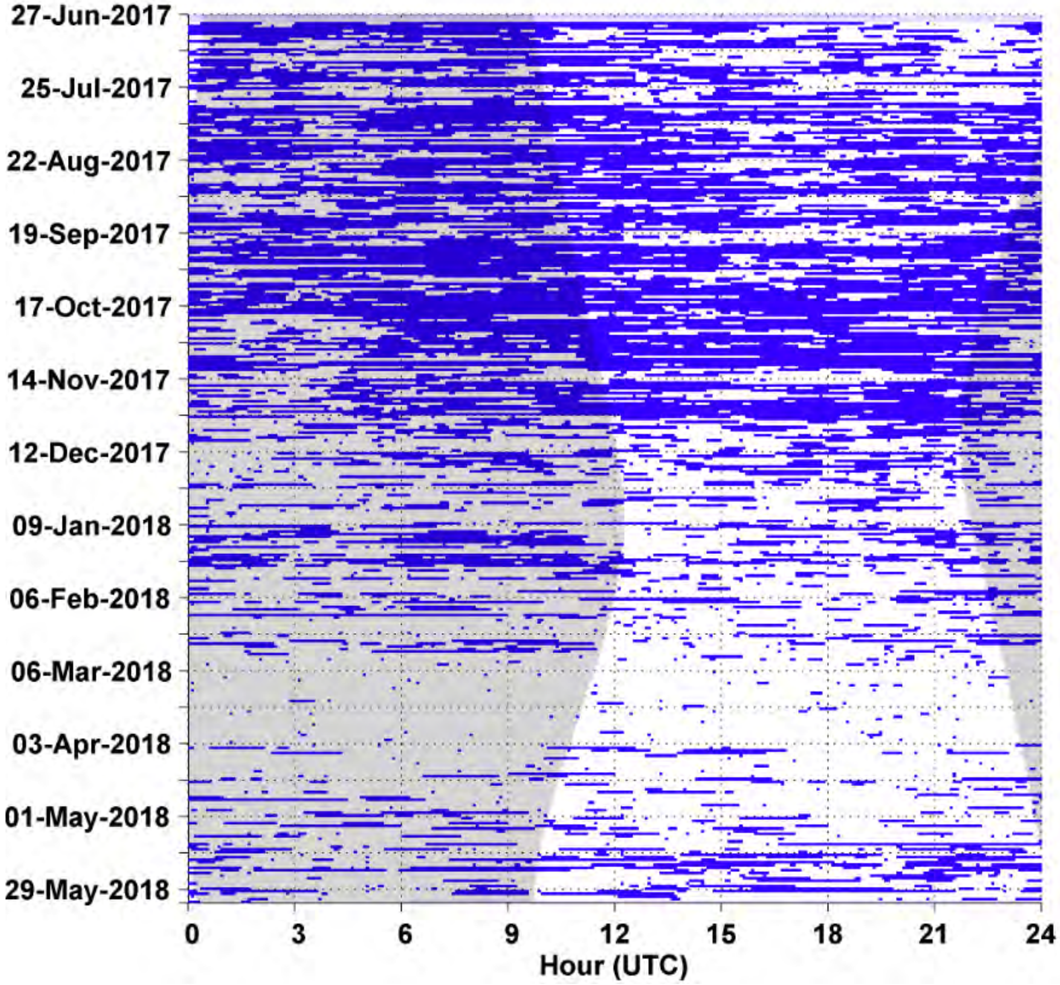

**Figure 64. CT 6 in five-minute bins at NFC Site A from June 2017 to 2018. Gray vertical shading denotes nighttime.**

### Unidentified Odontocete Whistles Less Than 5 kHz

- Unidentified odontocete whistles less than 5 kHz were detected in high numbers throughout the recording period with the highest detections occurring from June to December 2017 (Figure 65).
- There was no apparent diel pattern for unidentified whistles less than 5 kHz (Figure 66).
- Pilot whales most likely produced these whistles, though it is possible they are from other blackfish species that have overlapping distributions.

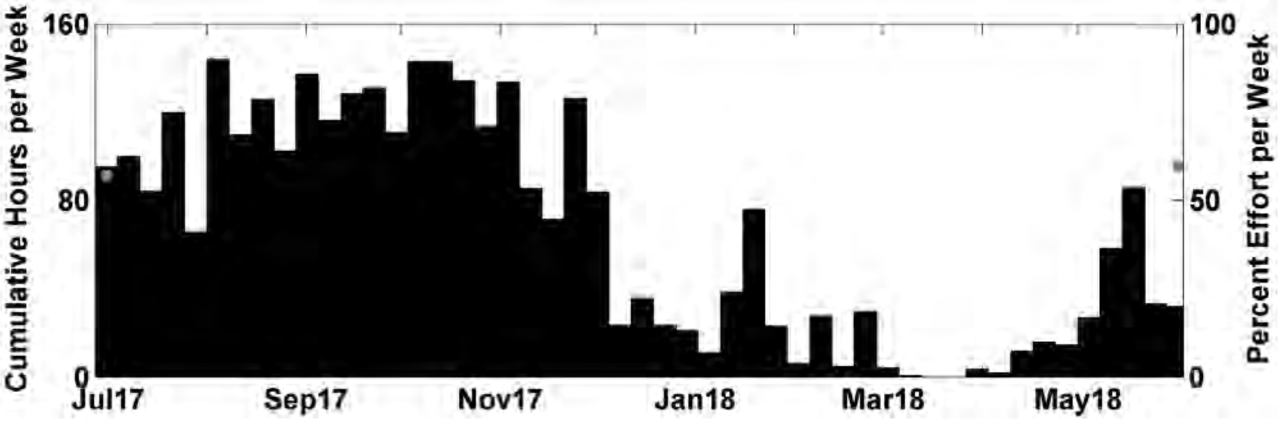

**Figure 65. Weekly presence of unidentified odontocete whistles less than 5 kHz from June 2017 to 2018 at NFC Site A. Effort markings are described in Figure 39.**

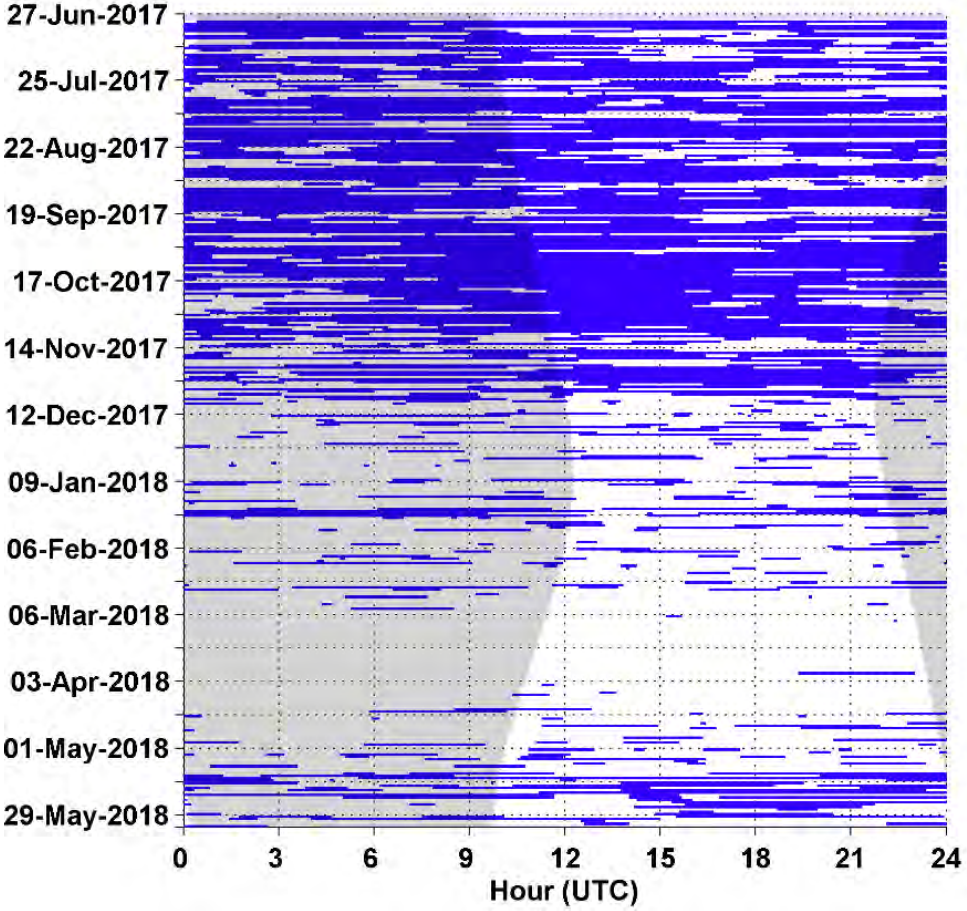

**Figure 66. Unidentified odontocete whistles less than 5 kHz in five-minute bins at NFC Site A from June 2017 to 2018. Gray vertical shading denotes nighttime.**

### Unidentified Odontocete Whistles Greater Than 10 kHz

- Unidentified odontocete whistles greater than 10 kHz were detected in high numbers between November 2017 and January 2018 and from May to June 2018 (Figure 67).
- There was no diel pattern for whistles greater than 10 kHz (Figure 68).

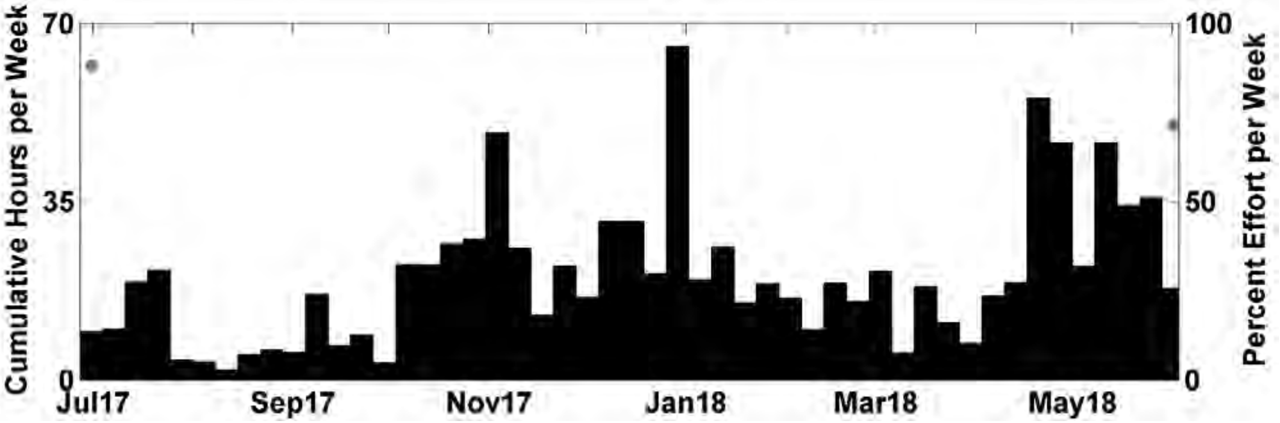

**Figure 67. Weekly presence of unidentified odontocete whistles greater than 10 kHz from June 2017 to 2018 at NFC Site A. Effort markings are described in Figure 39.**

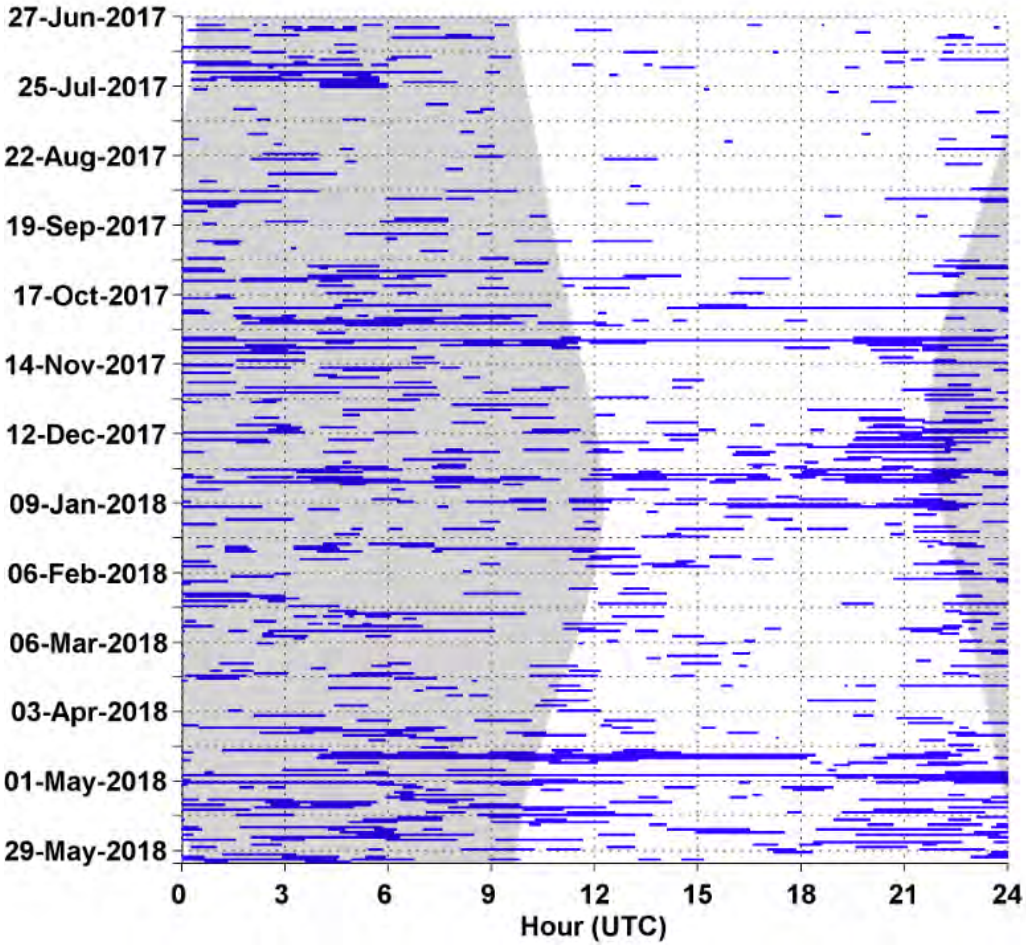

**Figure 68. Unidentified odontocete whistles greater than 10 kHz in five-minute bins at NFC Site A from June 2017 to 2018. Gray vertical shading denotes nighttime.**

**Sperm Whales**

- Sperm whale clicks were detected intermittently throughout the monitoring period but were highest in October 2017 and from March to June 2018 (Figure 69).
- There was no discernible diel pattern for sperm whale clicks (Figure 70).

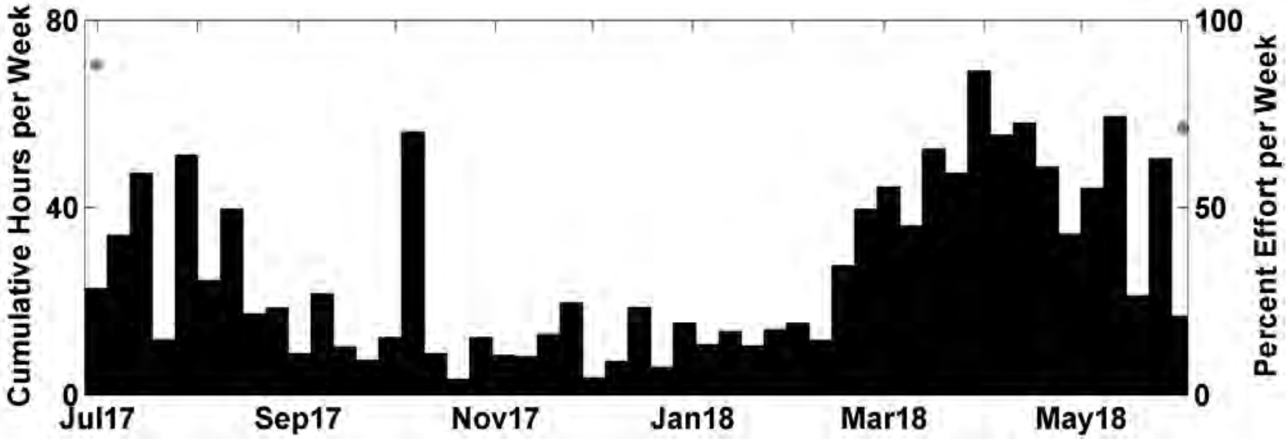

**Figure 69. Weekly presence of sperm whale clicks from June 2017 to 2018 at NFC Site A. Effort markings are described in Figure 39.**

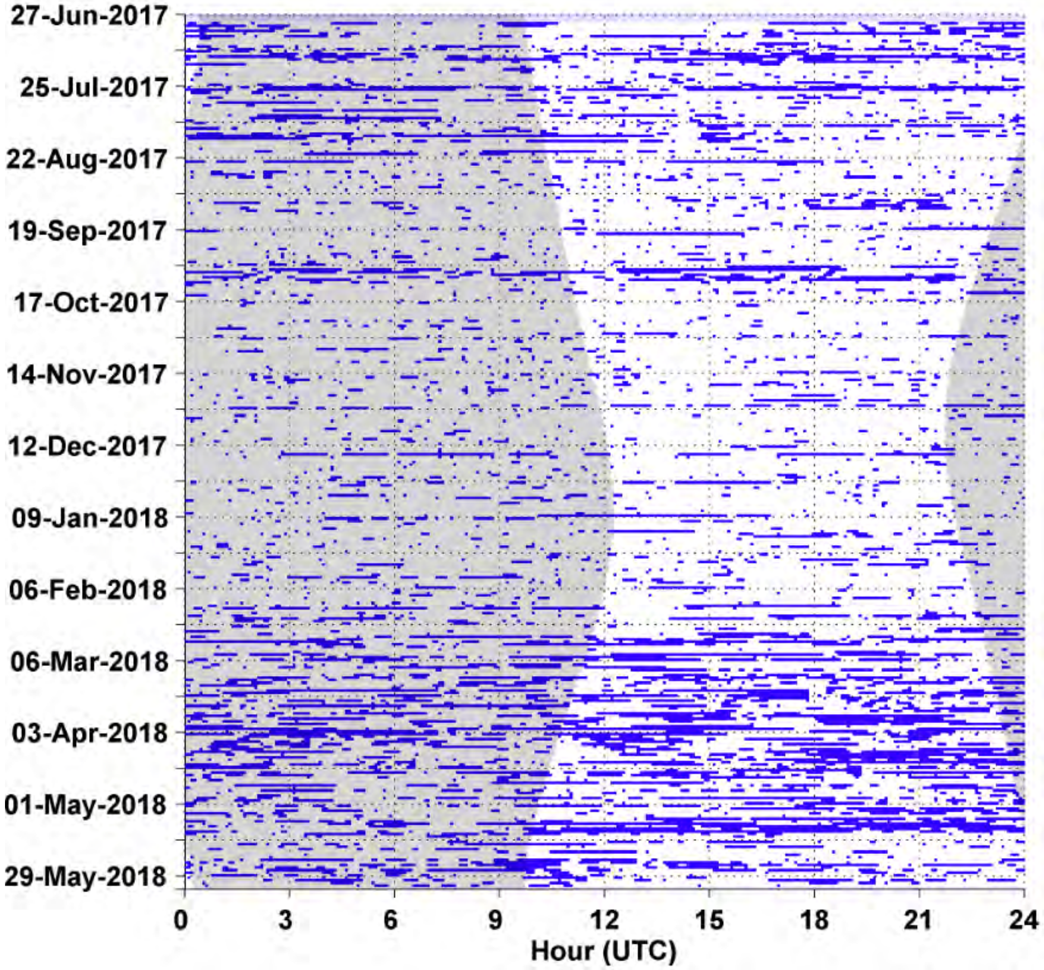

**Figure 70. Sperm whale clicks in one-minute bins at NFC Site A from June 2017 to 2018. Gray vertical shading denotes nighttime.**

***Kogia* spp.**

- *Kogia* spp. echolocation clicks were detected in low numbers throughout the recording period, with most of the detections in October 2017 (Figure 71).
- There was no discernible diel pattern for *Kogia* spp. echolocation clicks (Figure 72).

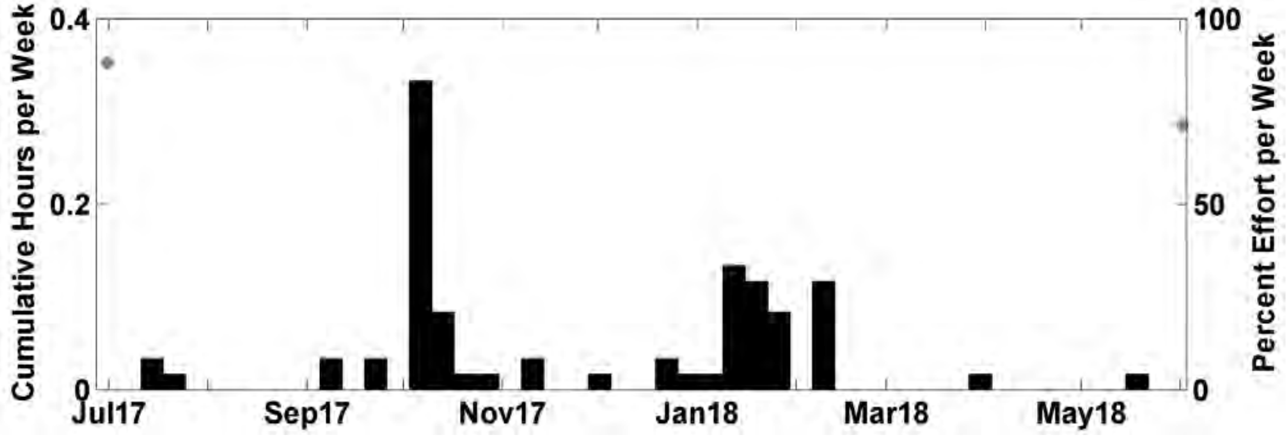

**Figure 71. Weekly presence of *Kogia* spp. clicks from June 2017 to 2018 at NFC Site A. Effort markings are described in Figure 39.**

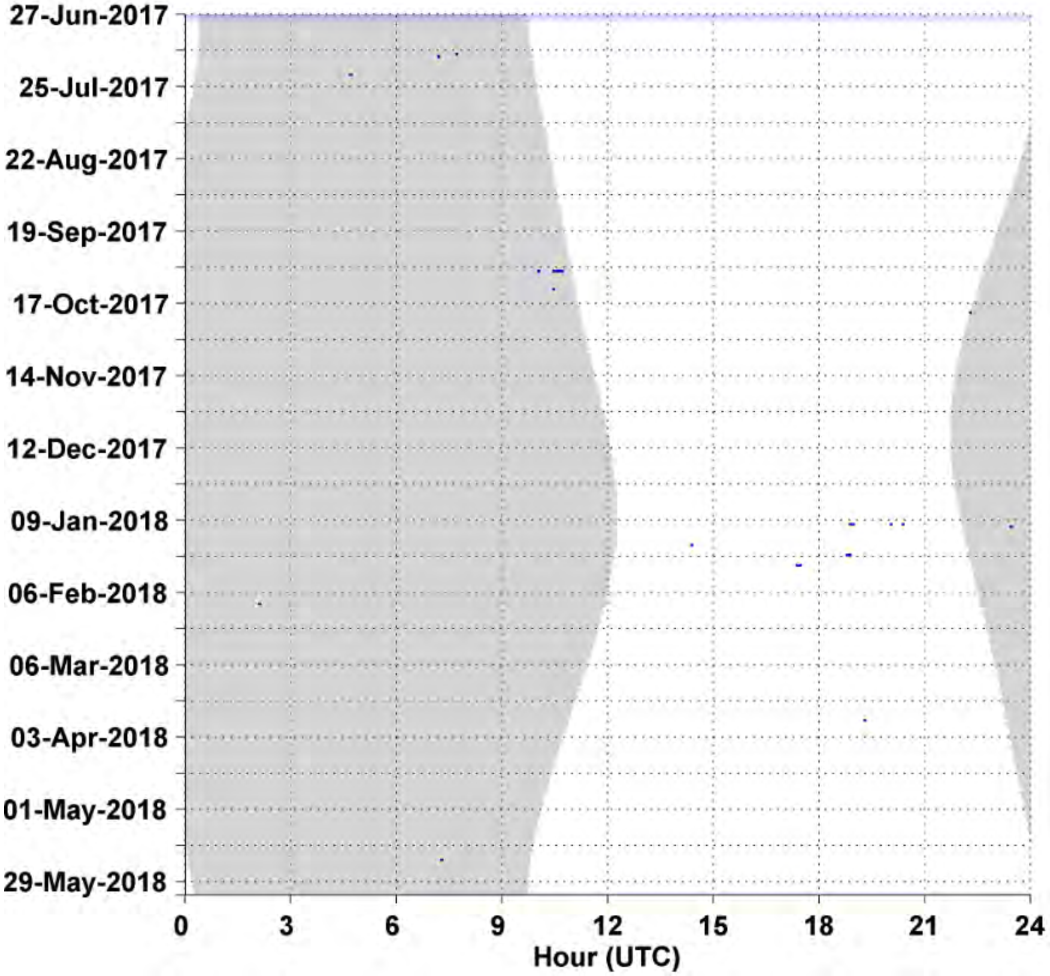

**Figure 72. *Kogia* spp. clicks in one-minute bins at NFC Site A from June 2017 to 2018. Gray vertical shading denotes nighttime.**

## Anthropogenic Sounds

Seven types of anthropogenic sounds were detected: broadband ships, LFA sonar, MFA sonar, echosounders, underwater communications, explosions, and airguns.

### Broadband Ships

- Broadband ship noise was detected regularly throughout the recording period. Detections were highest in August and September 2017 (Figure 73).
- There was no discernible diel pattern for broadband ships during the recording period (Figure 74).

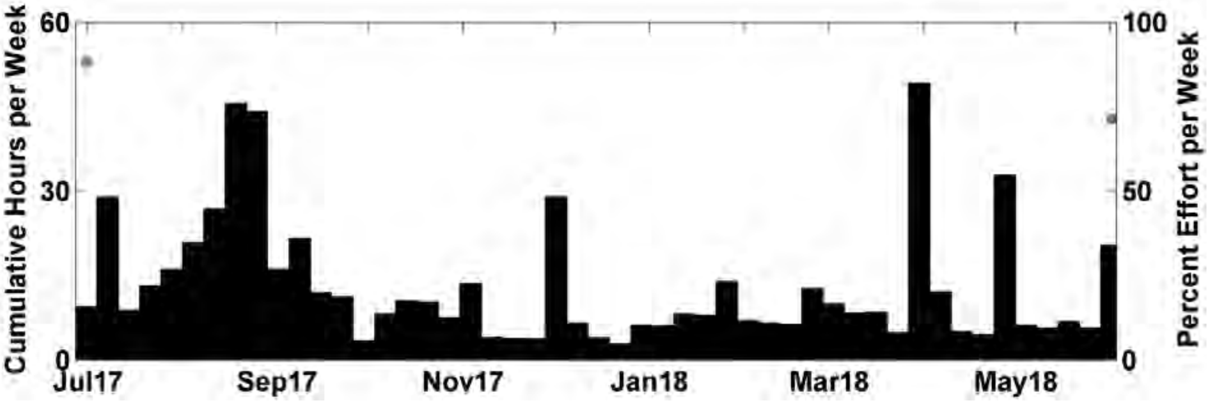

**Figure 73. Weekly presence of broadband ships from June 2017 to 2018 at NFC Site A. Effort markings are described in Figure 39.**

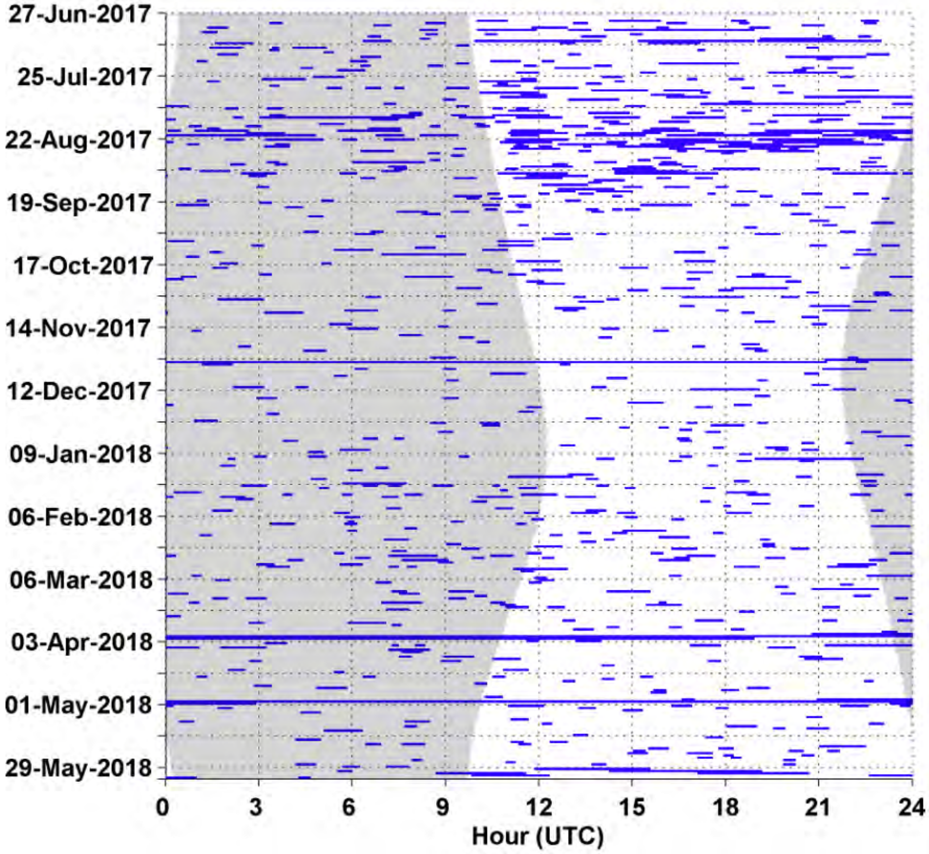

**Figure 74. Broadband ship noise in one-minute bins at NFC Site A from June 2017 to 2018. Gray vertical shading denotes nighttime.**

**LFA Sonar**

- LFA sonar greater than 500 Hz was detected in low numbers during the recording period. Detections occurred between July and October 2017 (Figure 75).
- LFA sonar occurred primarily during the daytime (Figure 76).

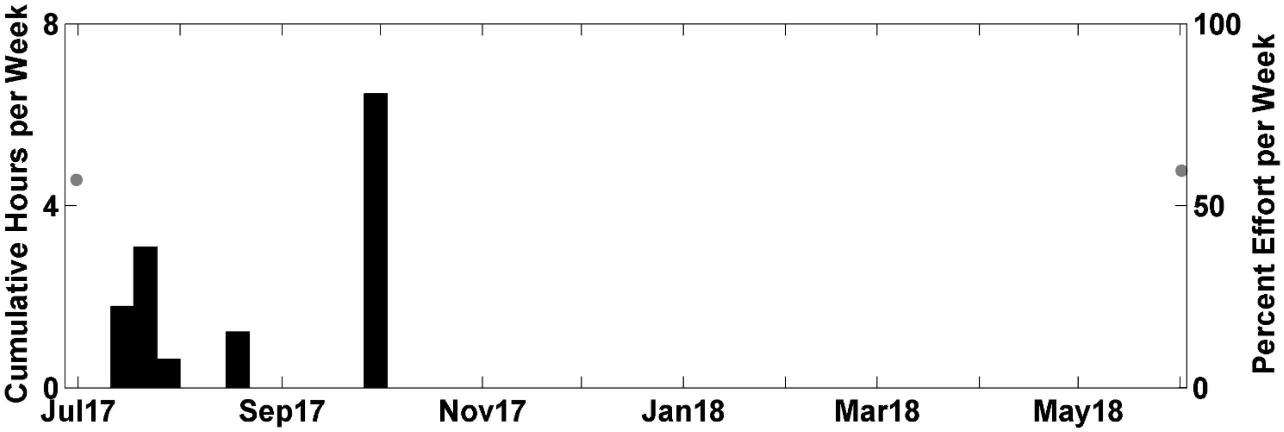

Figure 75. Weekly presence of LFA sonar from June 2017 to 2018 at NFC Site A. Effort markings are described in Figure 39.

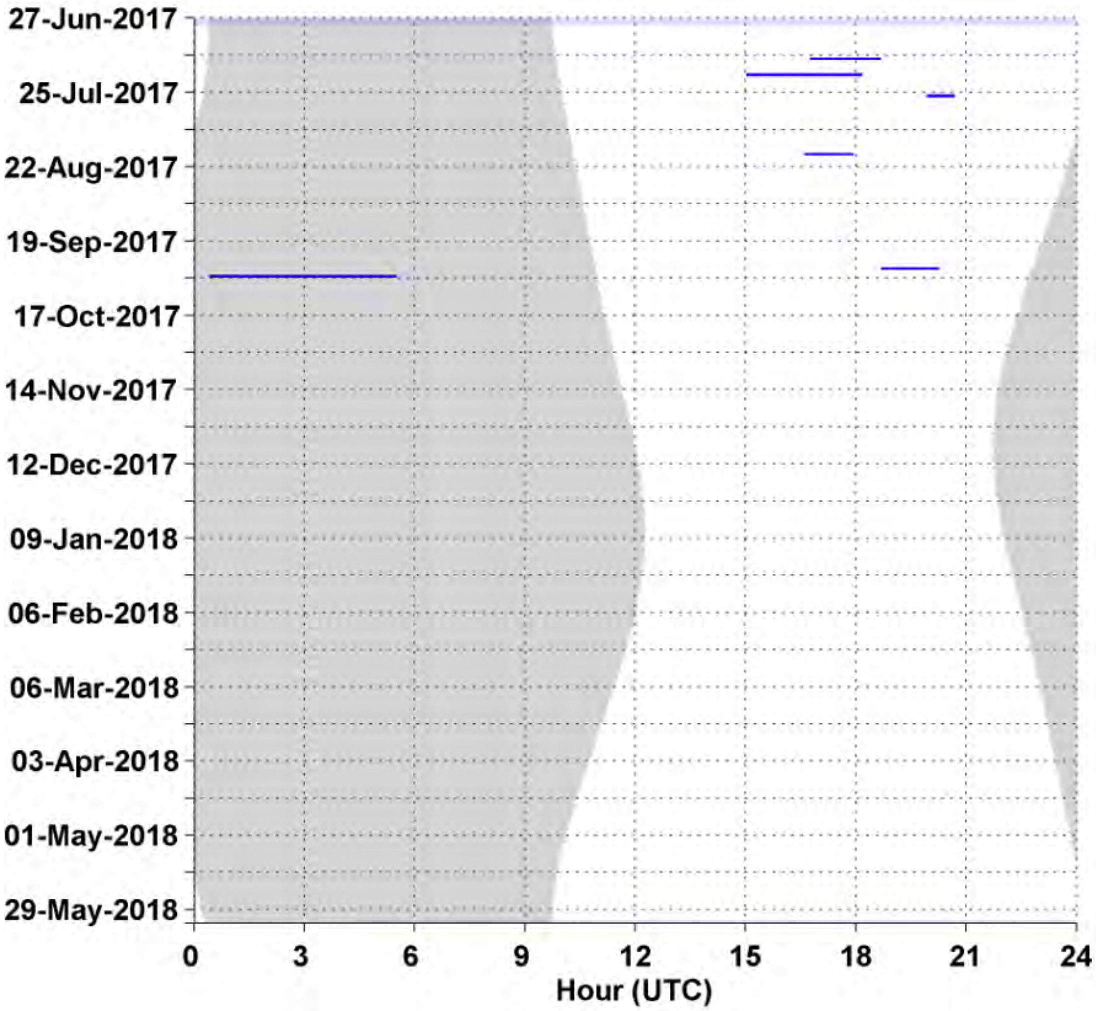

Figure 76. LFA sonar in one-minute bins at NFC Site A from June 2017 to 2018. Gray vertical shading denotes nighttime

## MFA Sonar

- MFA sonar less than 5 kHz was detected intermittently throughout the recording period but was highest in April 2018 (Figure 77).
- There was no discernible diel pattern for MFA sonar less than 5 kHz during the recording period (Figure 78).
- About 5% of analyst-defined MFA events contained packets which exceeded the minimum thresholds required for further analysis (Table 3).
- Highest number of packets (>600) and Cumulative Sound Exposure Levels (CSEL) (> 160 dB re 1 µPa s) MFA events were detected in December 2017. The maximum peak-to-peak RL was 131 dB (Figure 79).

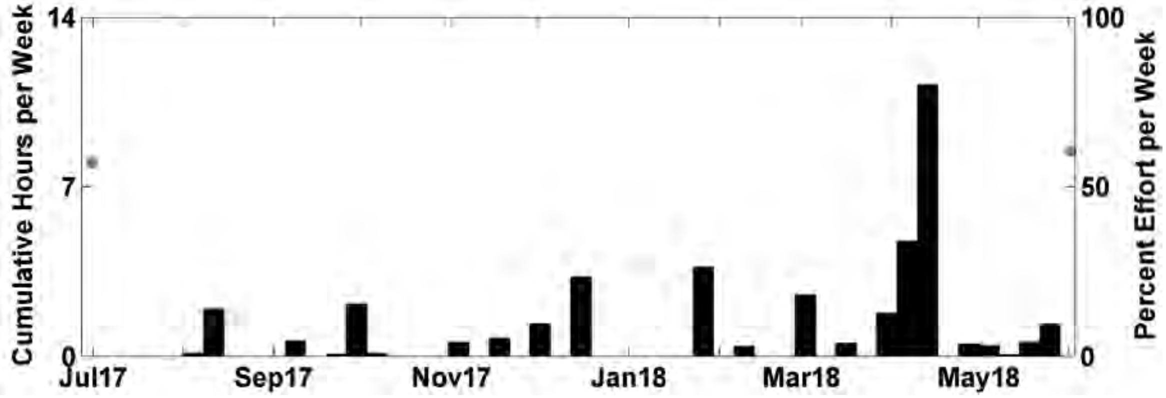

**Figure 77. Weekly presence of MFA sonar less than 5 kHz from June 2017 to 2018 at NFC Site A. Effort markings are described in Figure 39.**

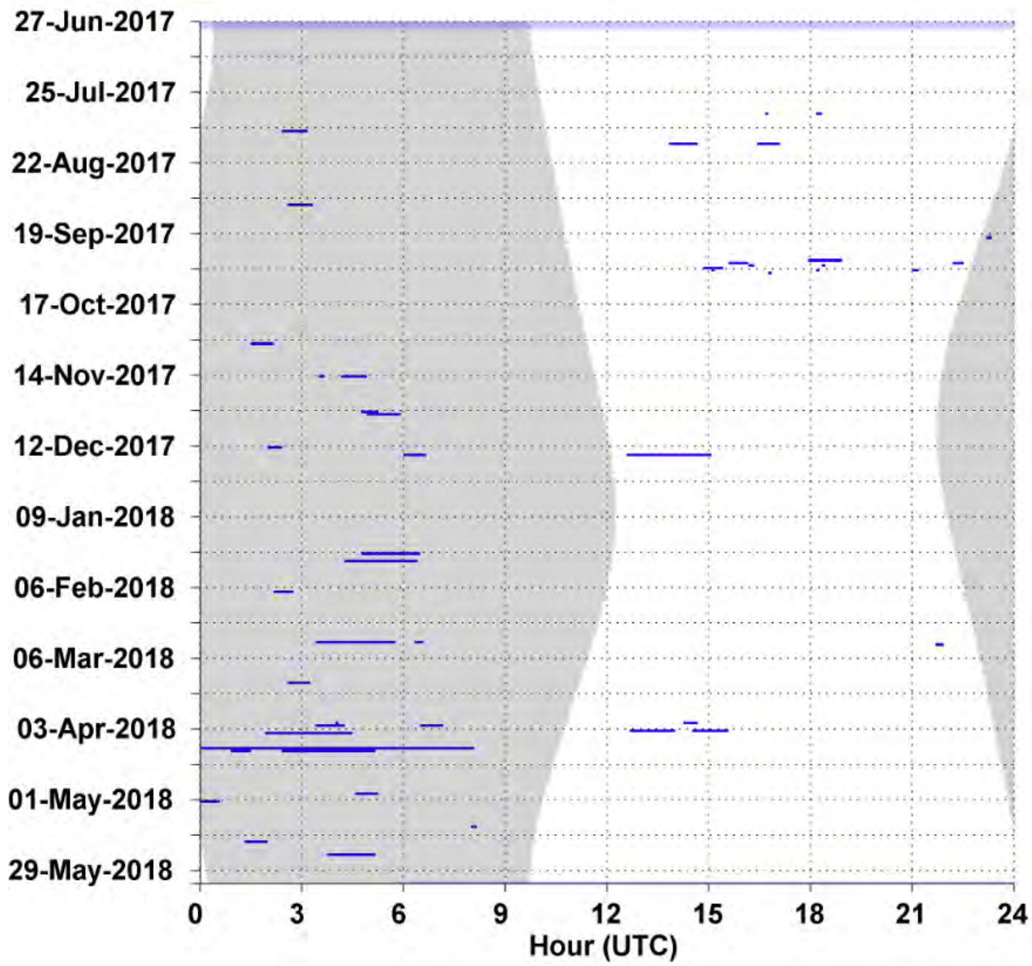

**Figure 78. MFA sonar less than 5 kHz in one-minute bins at NFC Site A from June 2017 to 2018. Gray vertical shading denotes nighttime.**

**Table 3. Number of analyst-defined MFA events, with wave trains and packets detected by energy detector for this recording period.**

| Deployment | Period Analyzed Days (Years) | Number of Wave Trains | Wave Trains per Year | Number of Packets | Packets per Year |
|---|---|---|---|---|---|
| NFC_A_03 | 337 (0.92) | 6 | 6.5 | 274 | 298 |

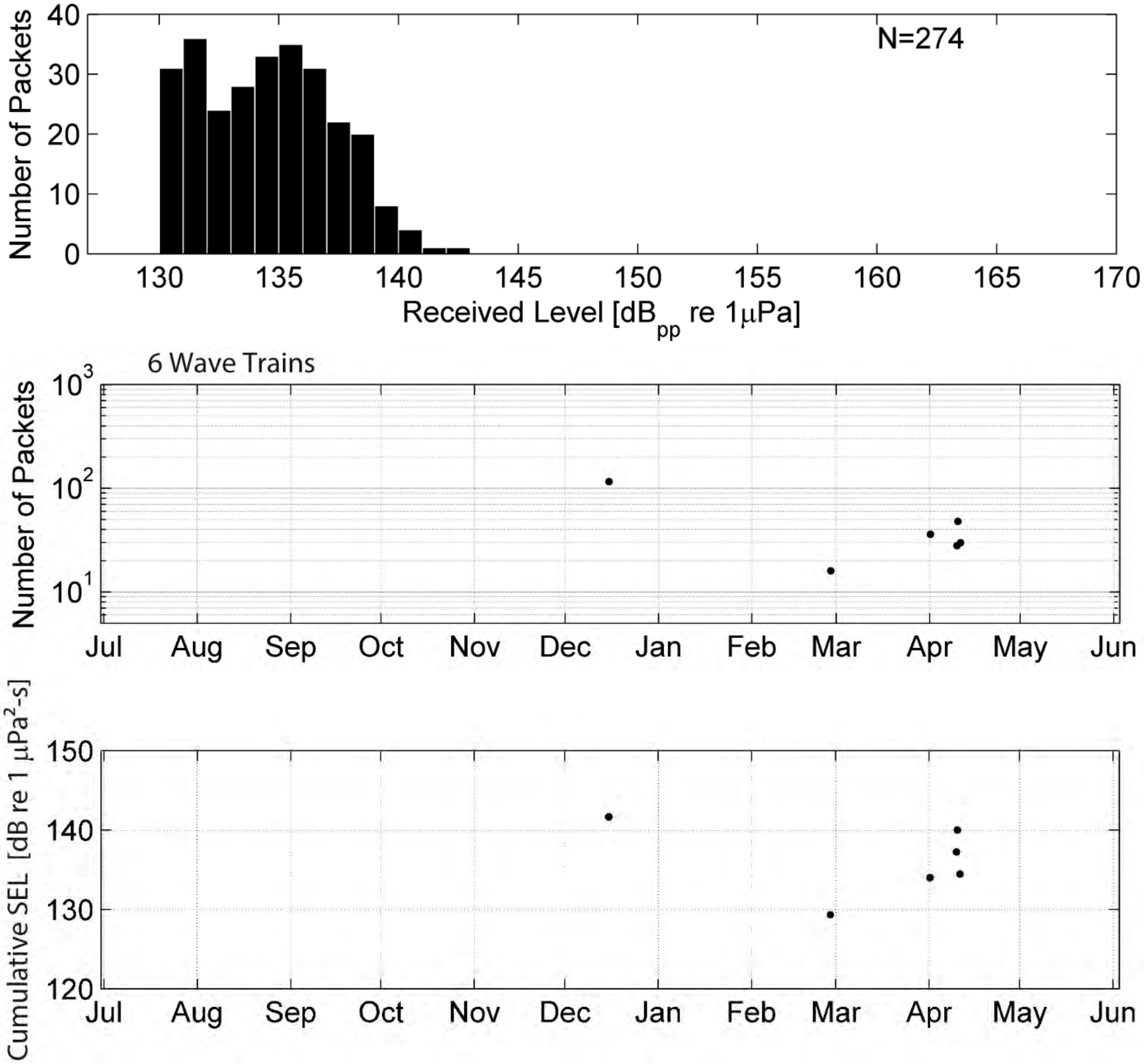

**Figure 79.** ***Top:*** **Distribution of received levels (RL) of detected MFA packets.** ***Center:*** **Number of MFA packets detected in each wave train exceeding the minimum RL threshold (130 dBpp re 1μ Pa).** ***Bottom:*** **Cumulative Sound Exposure Levels (CSEL) associated with each wave train.**

**Echosounders**

- Echosounders greater than 5 kHz were detected highest in December 2017 (Figure 80).
- There was no apparent diel pattern for echosounder detections (Figure 81).

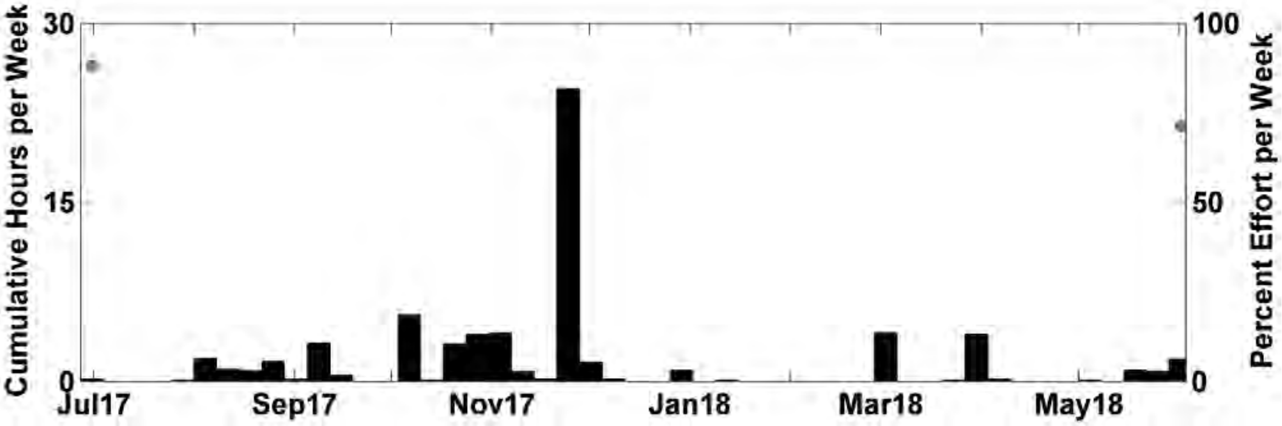

**Figure 80. Weekly presence of echosounders greater than 5 kHz from June 2017 to 2018 at NFC Site A. Effort markings are described in Figure 39.**

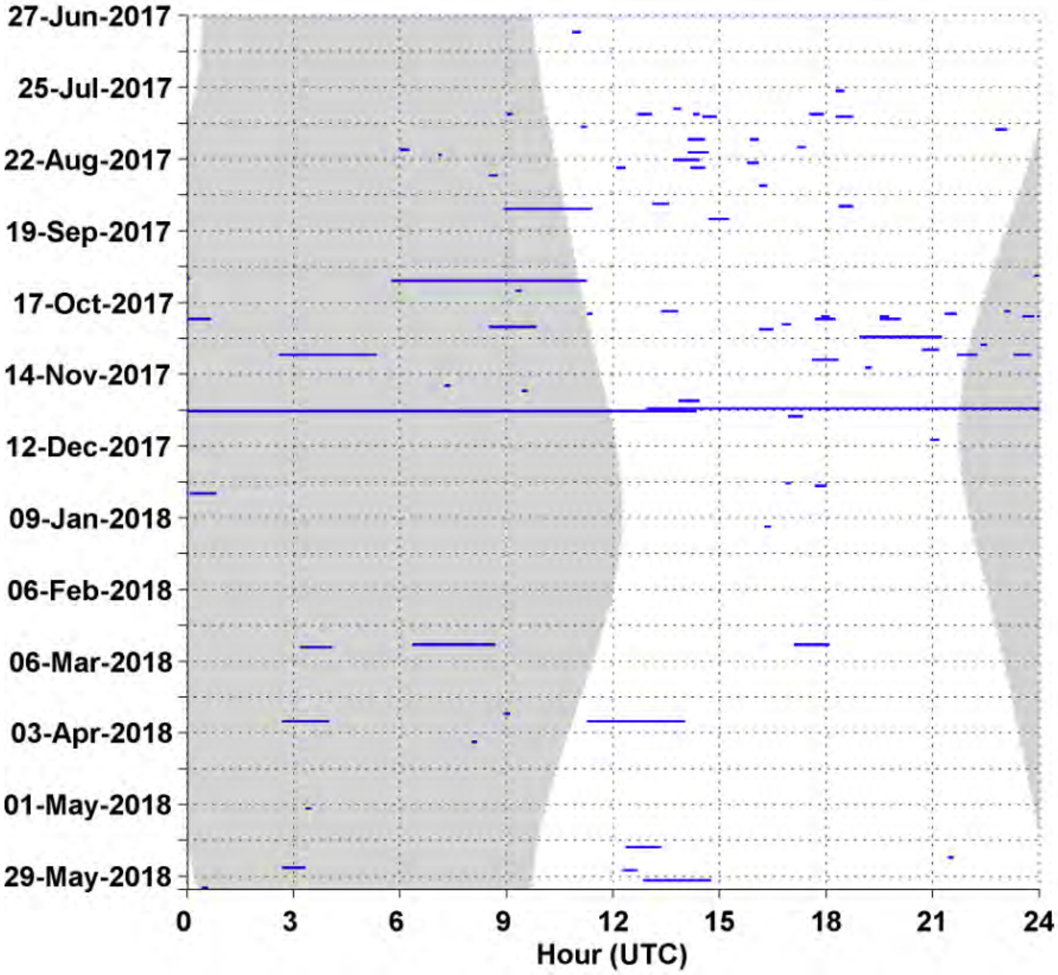

**Figure 81. Echosounders greater than 5 kHz in one-minute bins at NFC Site A from June 2017 to 2018. Gray vertical shading denotes nighttime.**

**Underwater Communications**

- Underwater communications occurred twice during the recording period on July 18, 2017 and August 8, 2018 (Figure 82).
- The only detection of underwater communications occurred during the night, but there were not enough detections to establish a diel pattern (Figure 83).

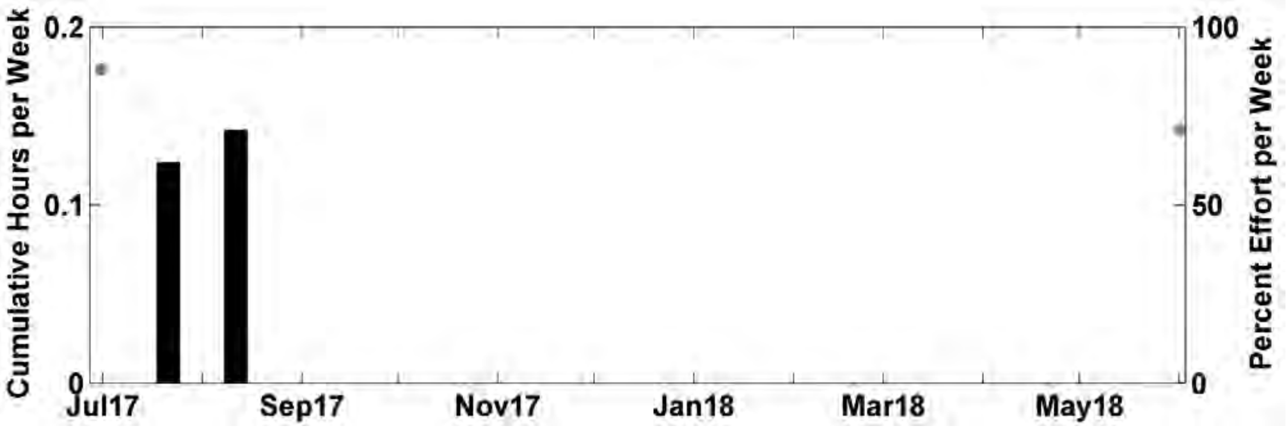

**Figure 82. Weekly presence of underwater communications from June 2017 to 2018 at NFC Site A. Effort markings described in Figure 39.**

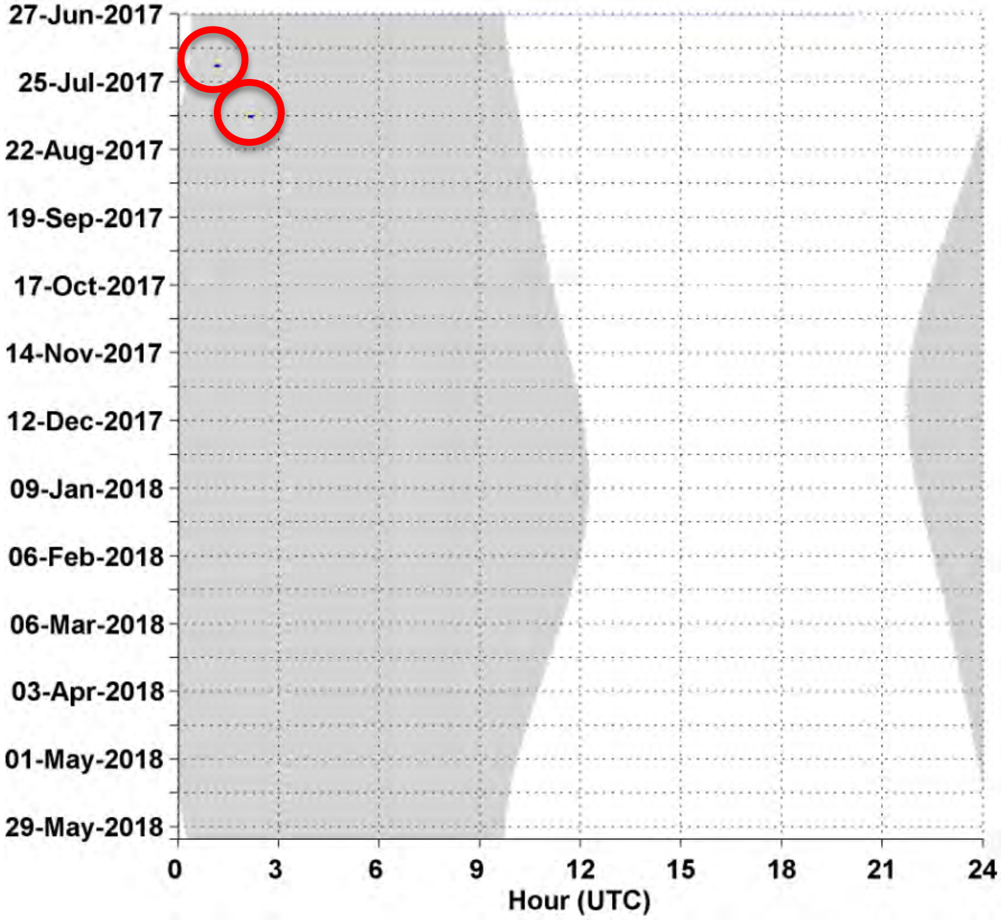

**Figure 83. Underwater communications in one-minute bins from June 2017 to 2018 at NFC Site A. Gray vertical shading denotes nighttime.**

**Explosions**

- 17 explosions were detected throughout the recording period between August and September 2017 and between January and April 2018 (Figure 84).
- Explosions were detected only during the daytime ().

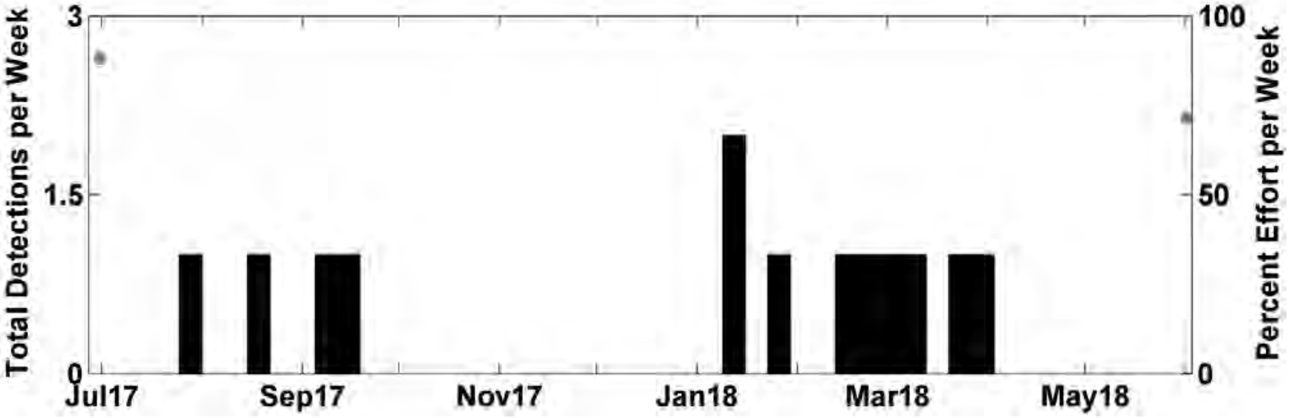

**Figure 84. Weekly presence of explosions detected from June 2017 to 2018 at NFC Site A. Effort markings are described in Figure 39.**

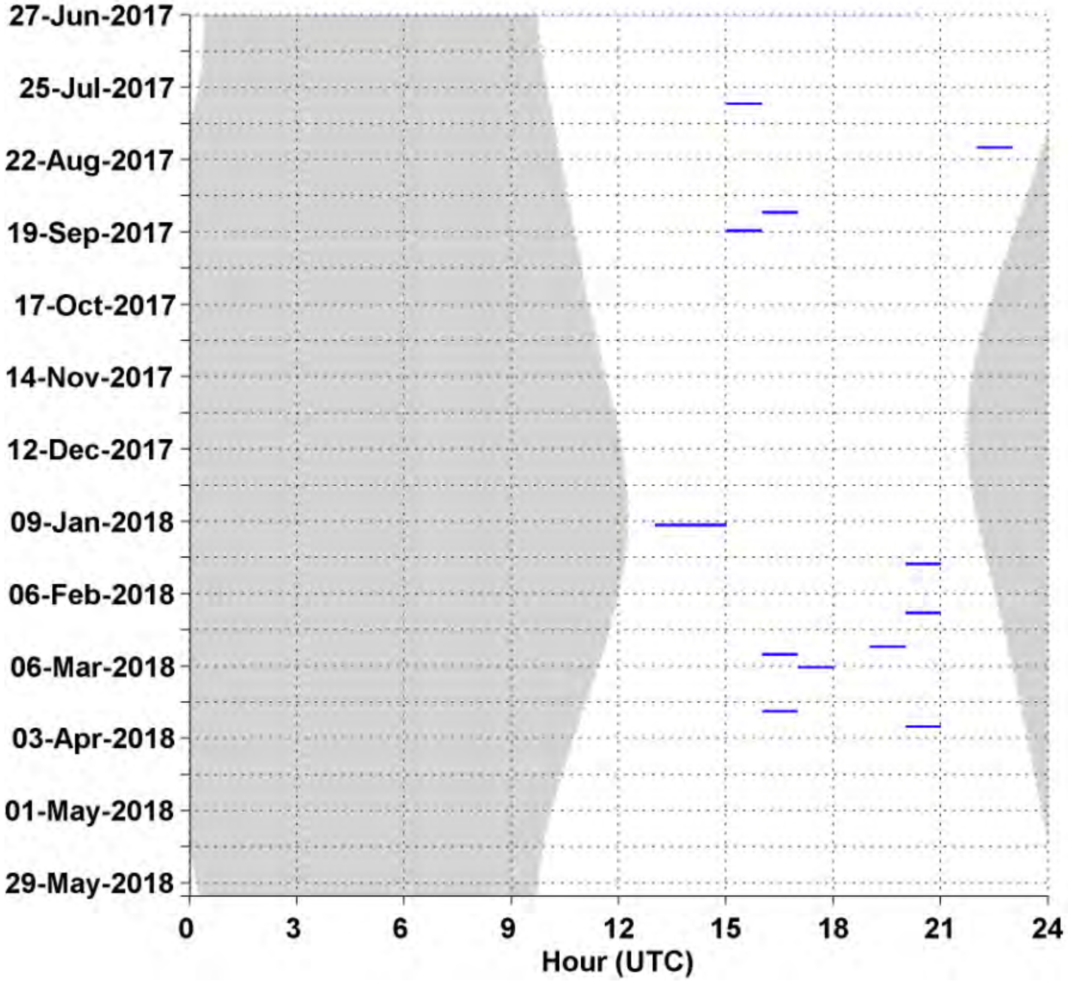

**Figure 85. Explosions in one-minute bins at NFC Site A from June 2017 to 2018. Gray vertical shading denotes nighttime.**

### Airguns

- Airguns were detected in August 2017 and between October 2017 and March 2018 (Figure 86).
- There was no apparent diel pattern for airgun detections (Figure 87).

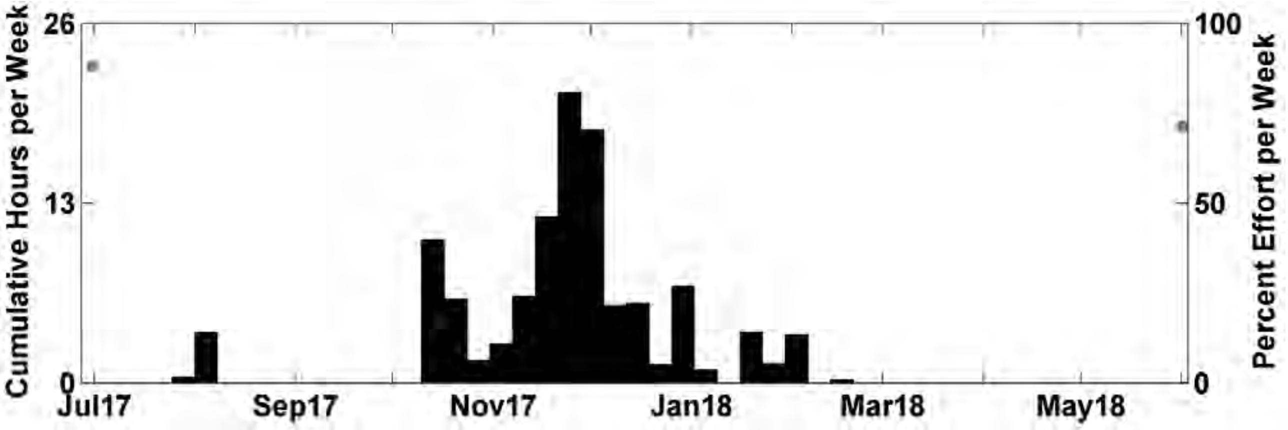

**Figure 86. Weekly presence of airguns detected from June 2017 to 2018 at NFC Site A. Effort markings are described in Figure 39.**

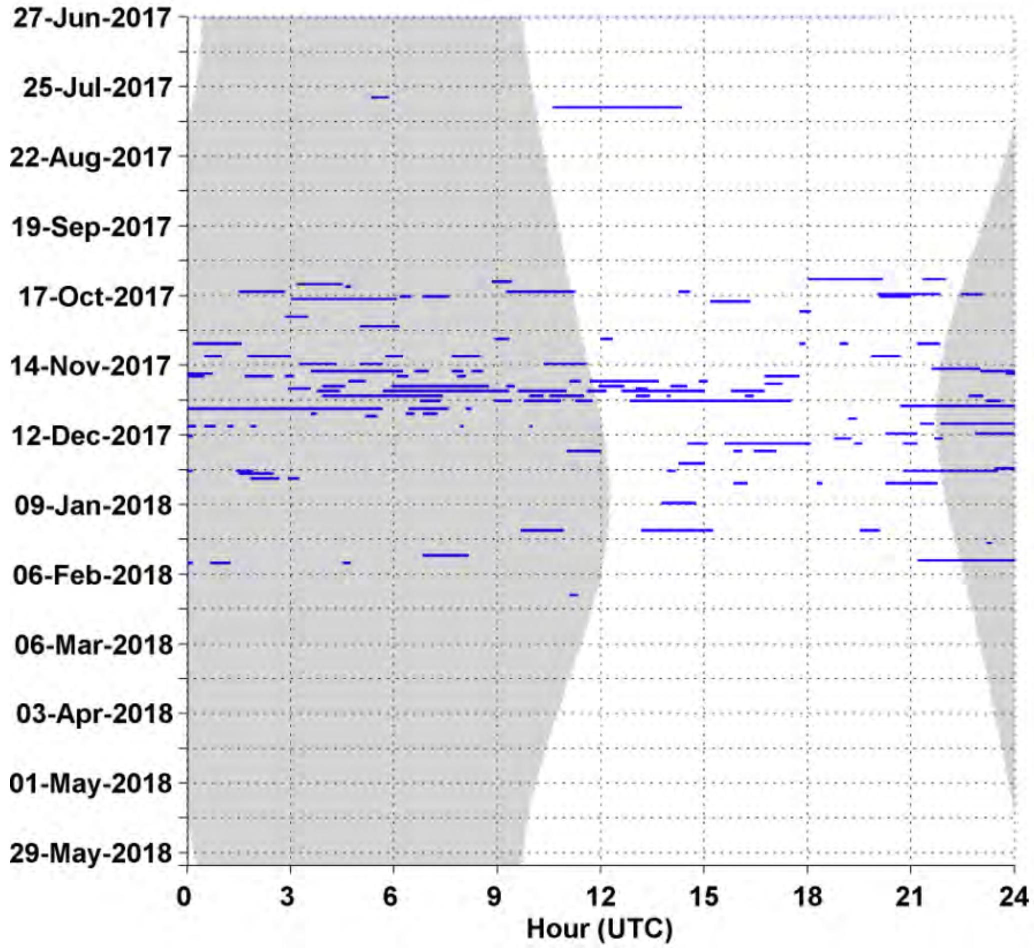

**Figure 87. Airguns in one-minute bins at NFC Site A from June 2017 to 2018. Gray vertical shading denotes nighttime.**

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