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

SCRIPPS Whale Acoustics

Passive Acoustic Monitoring for Marine Mammals in the Virginia Capes Range Complex October 2012 – April 2015

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Short-finned pilot whales, photo by Amanda J. Debich

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Additional technical reports for HARP deployments in the Atlantic under the Navy's Marine Species Monitoring Program are available at:
http://www.navymarinespeciesmonitoring.us/reading-room/

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Contents

Executive Summary

To monitor for the presence of marine mammals, High-frequency Acoustic Recording Packages (HARPs) were deployed at two sites within the Navy's Virginia Capes Range Complex. There were three deployments at one site, located offshore from Cape Hatteras (HAT), between October 2012 and December 2014. There was one deployment at the other site, located offshore from Norfolk Canyon (NFC), between June 2014 and April 2015. Both sites were located approximately 75 nmi offshore in about 1000 m of water.

The HARPs recorded underwater acoustic data between 10 Hz and 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 10-300 Hz, (2) Mid-frequency, between 10-5,000 Hz, and (3) High-frequency, between 1-100 kHz.

Six baleen whale species were detected: blue whales, fin whales, sei whales, minke whales, North Atlantic right whales, and humpback whales. Blue whale calls were more common at the HAT site and peaked October – November 2012. Fin whale calls were present throughout the monitoring period at both sites with peaks in detections during winter months. Sei whale calls peaked January – February at the HAT site while detections at the NFC site peaked in December 2014 and again in April 2015. Humpback whale calls were detected in low numbers sporadically at both sites with a peak in detections at the HAT site in March 2013. Minke pulse trains were common December through March at the HAT site and were detected in low numbers at the NFC site. North Atlantic right whale up-calls were detected in low numbers at the HAT site. There were no North Atlantic right whale up-calls detected at the NFC site.

Echolocation clicks from three known odontocete species were detected: Risso's dolphins, sperm whales, and *Kogia spp*. Six different click types that are not yet assigned to a species were also detected. Risso's dolphins were detected sporadically and in low numbers at both sites. Sperm whale detections peaked in February 2013 and 2014 with smaller peaks in detections during summer months. *Kogia spp*. echolocation clicks were detected throughout both deployments. Beaked whale detection effort is described in a separate report.

Airguns and broadband ships were the most commonly detected anthropogenic sounds. Other anthropogenic sounds detected include Mid-Frequency Active (MFA) sonar, Low-Frequency Active (LFA) sonar greater than 500 Hz, and explosions. Broadband ship noise peaked in summer months at both sites. Airguns were detected throughout the recording period at HAT with peaks in detections in June 2013 and June – October 2014. Airgun detections at NFC peaked in October 2014. MFA sonar was more common at the NFC site, with a peak in detections in March 2015. LFA sonar greater than 500 Hz was detected in low numbers at the NFC site. There were no LFA detections at the HAT site.

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 US 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 High-frequency Acoustic Recording Packages (HARPs) that were deployed at two sites (designated site HAT and site NFC), within the Virginia Capes Range Complex and that collected data from October 2012 - December 2014 at site HAT, and June 2014 - April 2015 at site NFC (Figure 1).

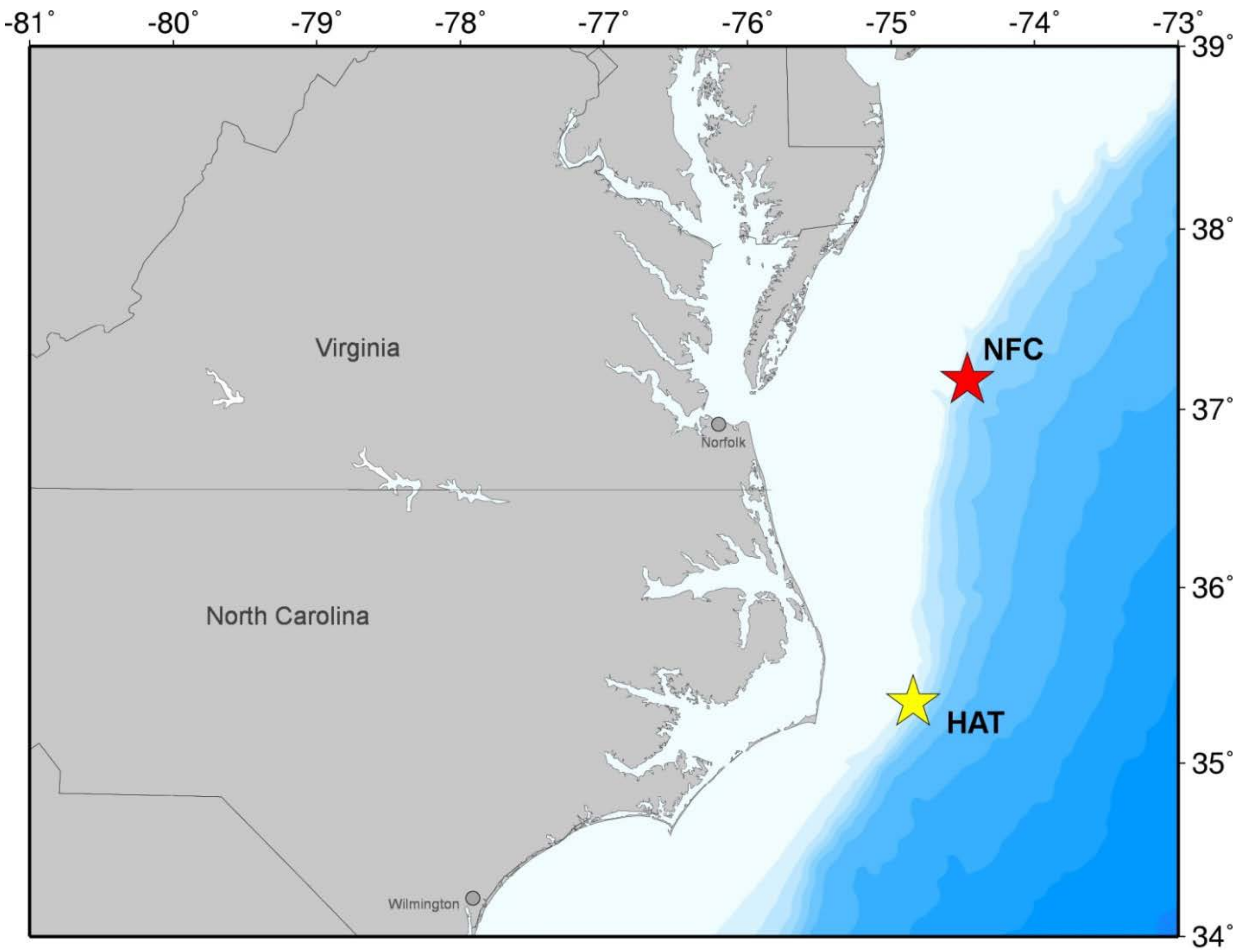

Figure 1. Location of High-frequency Acoustic Recording Packages (HARPs) at site HAT (35° 20.81 N, 74° 50.88 W, depth 840 m) deployed October 2012 - December 2014, and site NFC (37° 09.97 N, 74° 28.02 W, depth 980 m) deployed June 2014 - April 2015.

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 HARPs at HAT were in a large mooring configuration with the hydrophones suspended approximately 10 m above the seafloor. The HARP at NFC was a compact small mooring with the hydrophone suspended approximately 20 m above the seafloor. Each HARP was 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

During this study period, three HARP deployments occurred at the HAT site, while one HARP deployment occurred at the NFC site (Table 1). A total of 1,009 days of recordings were analyzed. All HARPs analyzed in this report sampled continuously at 200 kHz.

Table 1. Acoustic monitoring in the Virginia Capes Range Complex since 2012. Periods of instrument deployment analyzed in this report are shown in bold.

Deployment Name	Start Date	End Date	Recording Duration (days)	Recording Duration (hours)
HAT01A	3/15/2012	4/11/2012	26	636
HAT02A	**10/9/2012**	**5/9/2013**	**212**	**5093**
HAT03A	**5/29/2013**	**3/15/2014**	**290**	**6965**
HAT04A	**5/9/2014**	**12/11/2014**	**217**	**5207**
NFC01A	**6/19/2014**	**4/5/2015**	**290**	**6951**

Data Quality

The vast majority of the data collected were found to be error free. Highly stereotyped broadband digital errors (glitches) were found in three of the deployments included in this reporting period: HAT02A, HAT03A, and NFC01A. These glitches are very short in duration (between 100 microseconds and 10 milliseconds) and in all instances, they appear gradually around 2/3rd of the way into the data set and increase in occurrence throughout the end of the data set. These digital glitches are present in less than one percent of the impacted xwav format data. To repair these glitches, the data were overwritten using a detector that is calibrated to the observed amplitude and duration of the glitches. This procedure was tested so that it does not overwrite any real broadband signals in the data. Data repair was done on HAT02A and HAT03A, but has not yet been applied to the NFC01A data. We do not believe either the glitches or their repair have a significant impact on the resulting data analysis.

The end of the HAT04A recording was cut short, likely because of disk error issues.

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 HAT and NFC regions, and the procedures used to detect them. For effective analysis, the data were divided into three frequency bands: (1) Low-frequency, 10-300 Hz, (2) Mid-frequency, 300-5,000 Hz, and (3) High-frequency, 5,000-100 kHz.

Each band was analyzed for the sounds of an appropriate subset of species or sources. Blue, fin, Bryde's, sei, minke, and North Atlantic right whale sounds were classified as low-frequency. Humpback, 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 between October 2012 – December 2014 at the HAT site and June 2014 – April 2015 at the NFC site. 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 Virginia Capes Range Complex is inhabited, at least for a portion of the year, by blue whales (*Balaenoptera musculus*), fin whales (*B. physalus)*, Bryde's whales (*B. edeni*), sei whales (*B. borealis*), minke whales (*B. acutorostrata*), 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. LTSAs were created using a time average of 5 seconds and frequency bins of 1 Hz. The same LTSA and spectrogram parameters were used for manual detection of all call types using the custom software program *Triton*. During manual scrutiny of the data, the LTSA frequency was set to display between 1-300 Hz with a 1-hour plot length. To observe individual calls, the spectrogram window was typically set to display 1-250 Hz with a 60 second plot length. The FFT was generally set between 1500 and 2000 data points, yielding about 1 Hz frequency resolution, with an 85-95% overlap. When a call of interest was identified in the LTSA or spectrogram, its presence during that hour was logged.

The hourly presence of North Atlantic blue whale calls, blue whale arch sounds, 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 fin whale acoustic index. This is the first time the fin whale acoustic index has been used for east coast HARP analysis.

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 tonal call and the arch call (Mellinger and Clark, 2003).

Blue Whale North Atlantic Calls

The blue whale tonal call is an 18-19 Hz tone lasting approximately 8 s, often followed by an 18-15 Hz downsweep lasting approximately 11 s (Figure 2).

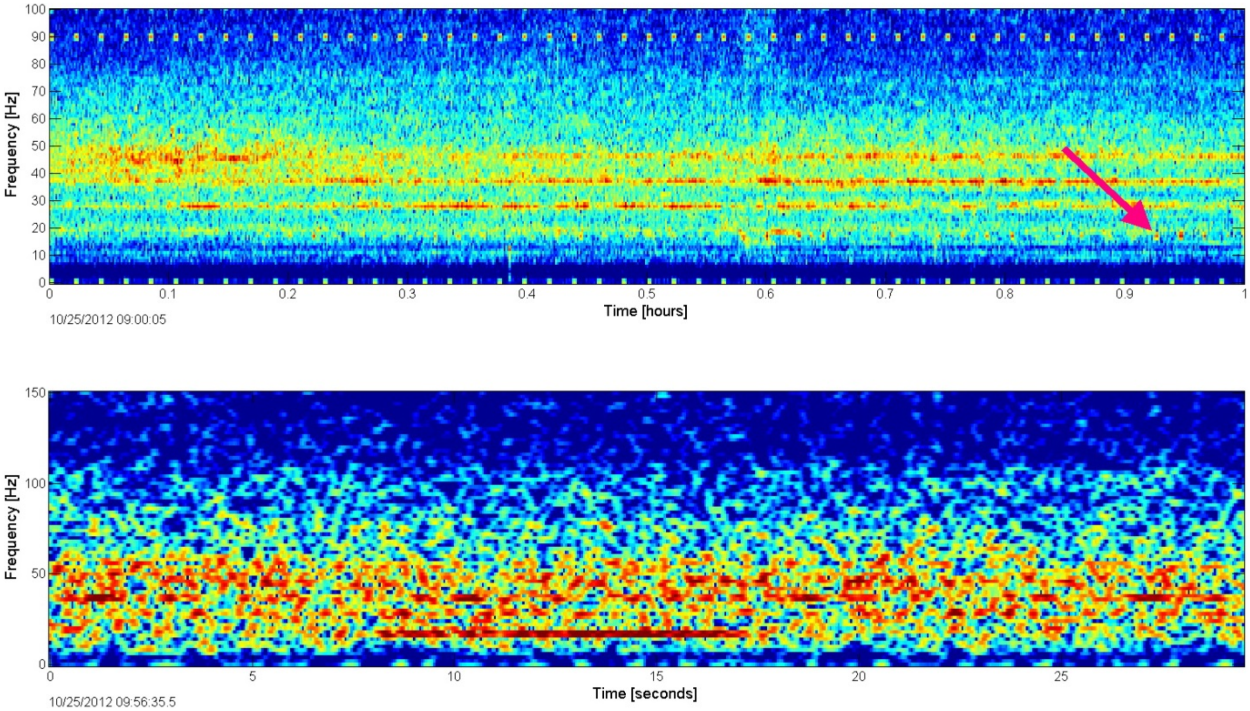

Figure 2. North Atlantic blue whale calls in the LTSA (top) and spectrogram (bottom) at HAT.

Blue Whale Arch Calls

The blue whale arch calls are variable frequency modulated calls, usually covering frequencies between approximately 70 and 35 Hz over a period of about 6 s (Figure 2).

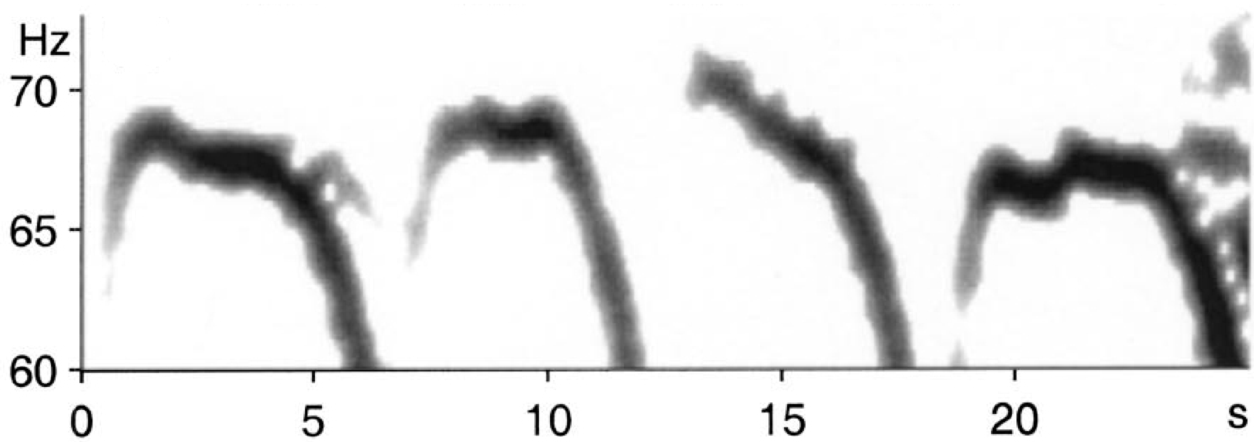

Figure 3. Blue whale arch calls from Mellinger and Clark (2003).

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 4) and downsweeps from 75-40 Hz, called 40 Hz calls (Figure 5). 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 4) were detected automatically using an energy detection method (Širovic *et al.*, 2015). The method used 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.

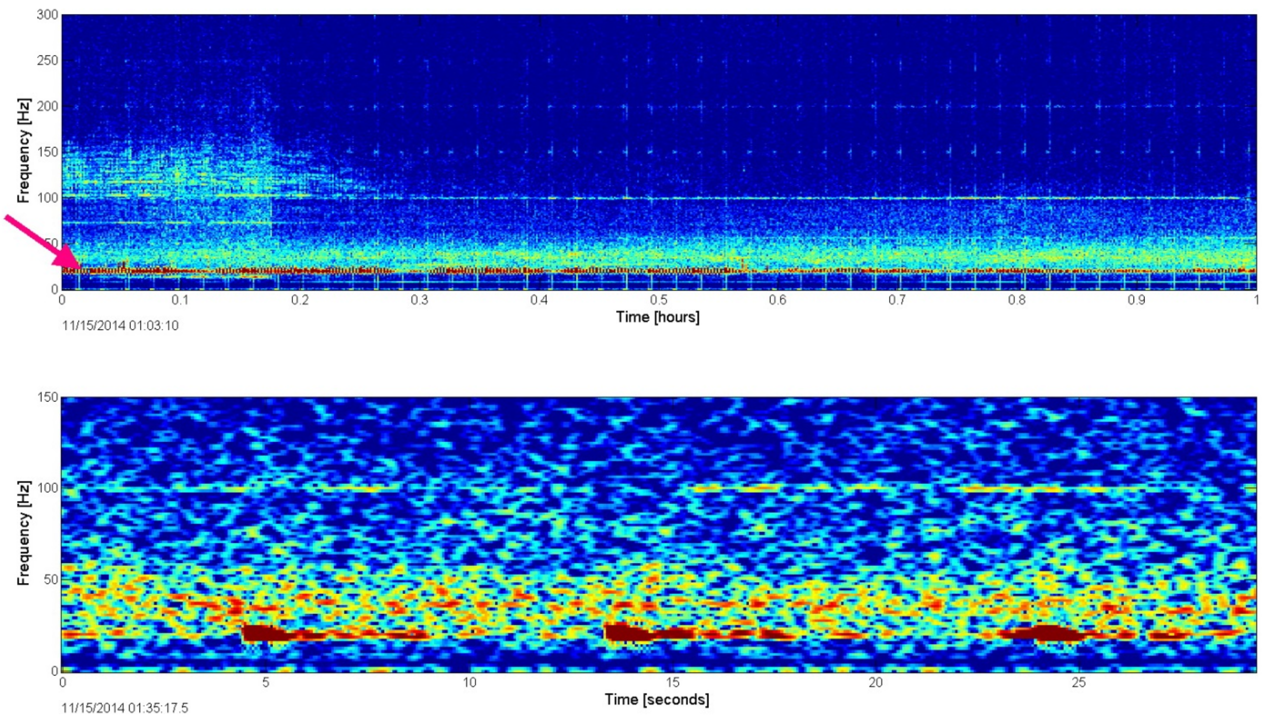

Figure 4. Fin whale 20 Hz calls in the LTSA (top) and spectrogram (bottom) at NFC.

Fin Whale 40 Hz Calls

The presence of fin whale 40 Hz calls (Figure 5) was examined via manual scanning of the LTSA and subsequent verification from a spectrogram of the frequency and temporal characteristics of the calls.

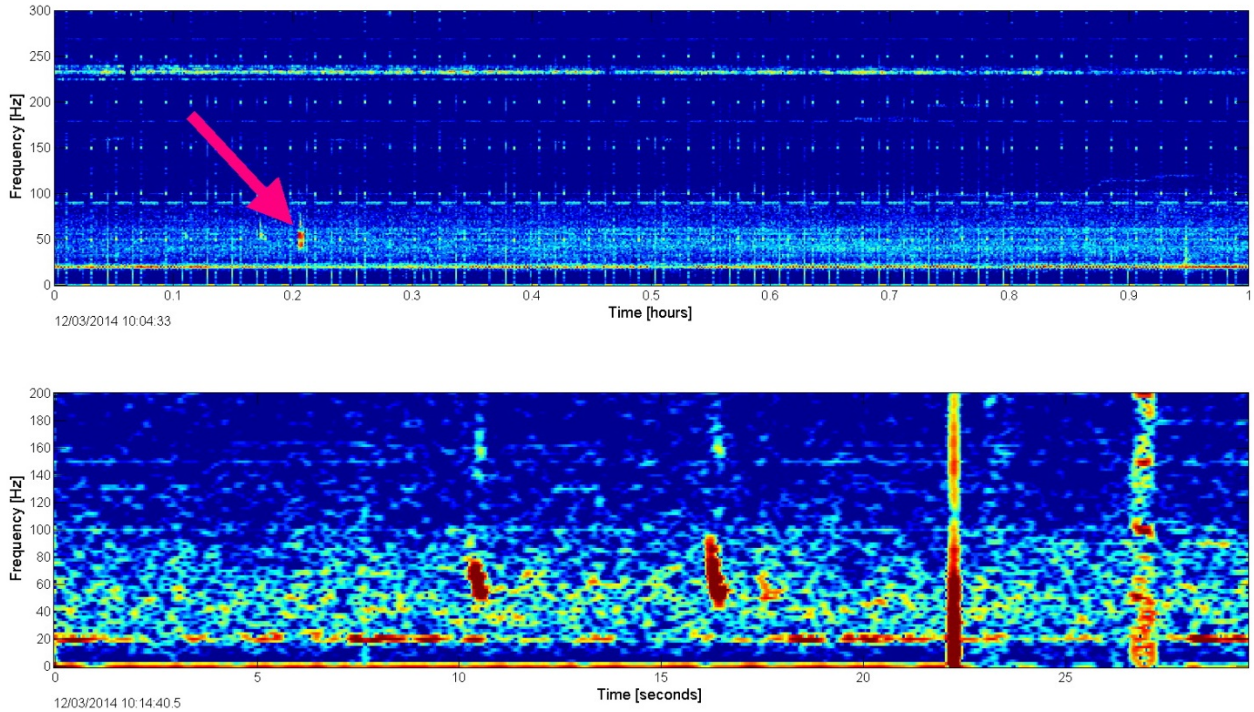

Figure 5. Fin whale 40 Hz calls in the LTSA (top) and spectrogram (bottom) at HAT.

Bryde's Whales

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

Be 7 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 between 0.8 and 2.5 s with an average intercall interval of 2.8 minutes (Figure 6). There were no detections for Bryde's whale Be7 calls in these recordings.

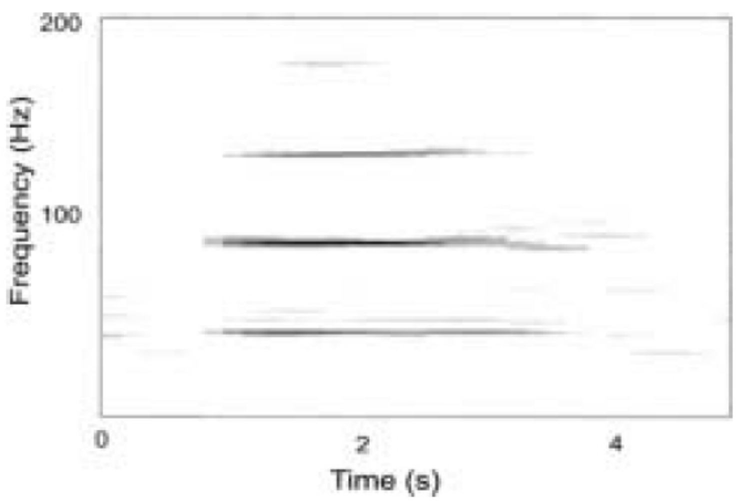

Figure 6. Bryde's whale Be7 call from Oleson *et al*. (2003).

Be 9 Calls

The Be9 call type, described for 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 7). There were no detections for Bryde's whale Be7 calls in these recordings.

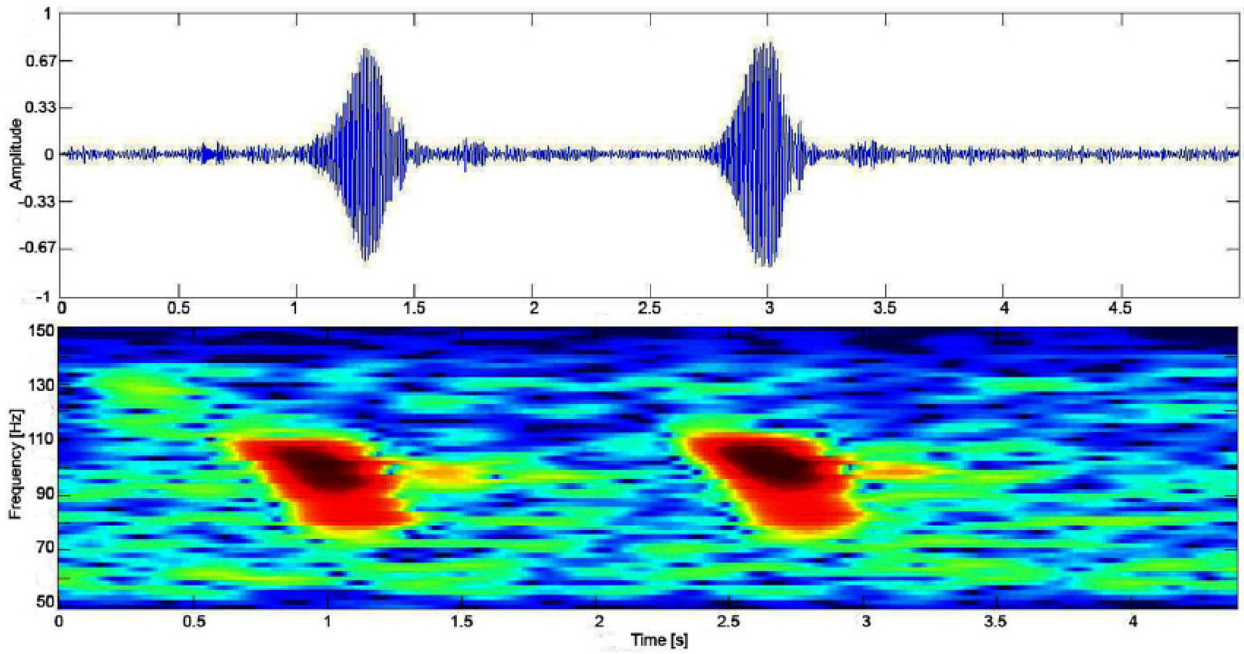

Figure 7. Bryde's whale Be9 calls from the Gulf of Mexico (Širović et al., 2014).

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). These downswept calls can occur as single calls, doublets, and triplets, but no effort was expended to differentiate how they occurred as they were logged on an hourly basis.

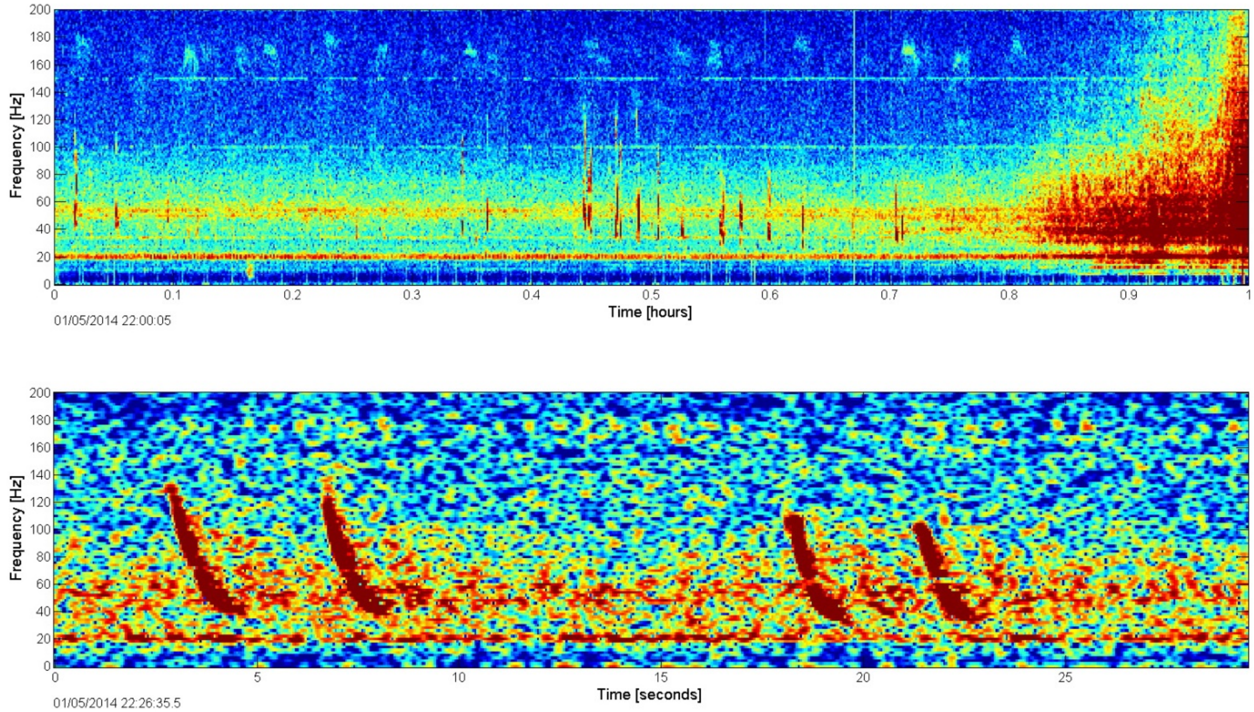

Figure 8. Sei whale downsweep calls in the LTSA (top) and spectrogram (bottom) at HAT.

Minke Whales

Minke whales in the North Atlantic produce long pulse trains. Mellinger *et al.* (2000) describe 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 9). Effort was not expended to denote whether the pulse trains were slow-down, speed-up, or constant types.

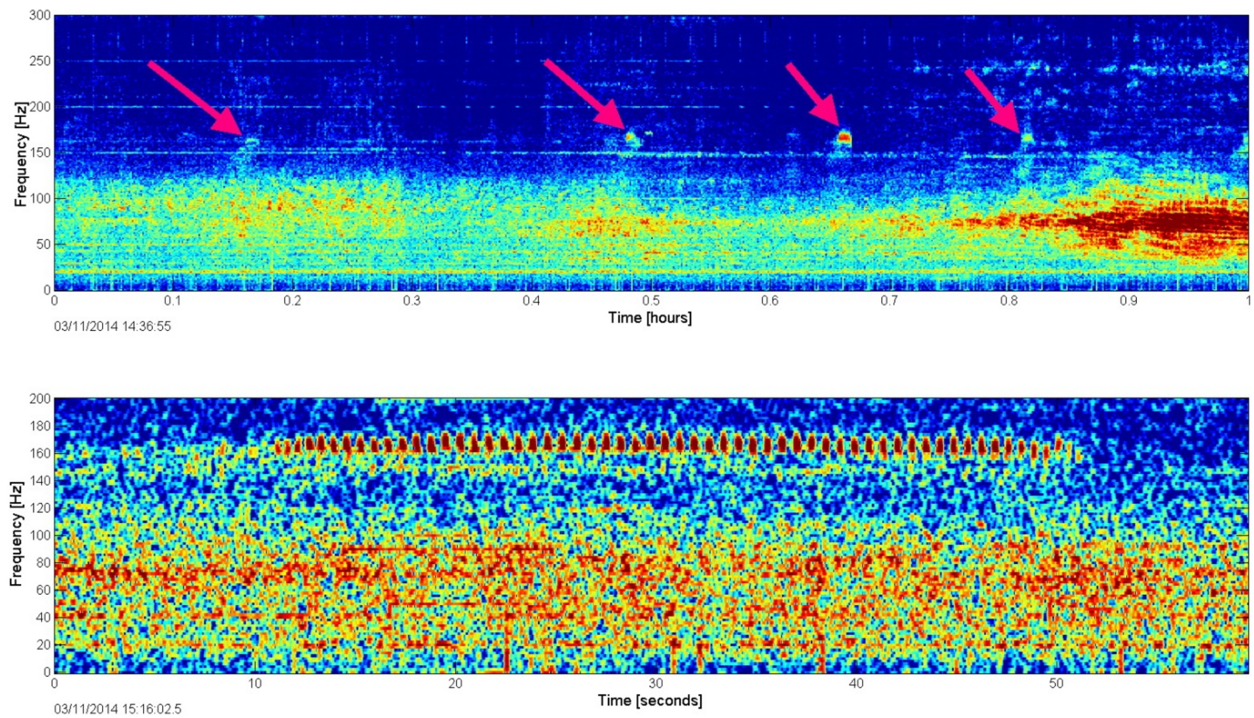

Figure 9. Minke whale pulse train in the LTSA (top) and spectrogram (bottom) at HAT.

North Atlantic Right Whales

The critically endangered North Atlantic right whale is found in the Western North Atlantic. Several call types that have been described for the North Atlantic right whale include the scream, gunshot, blow, up-call, warble, and down-call (Parks and Tyack, 2005). For low-frequency analysis, we examined the data manually for up-calls, which are approximately 1 second in duration and range between 80 Hz and 200 Hz, sometimes with harmonics (Figure 10). Up-calls were logged as detections only when humpback song was not present in the same frequency band.

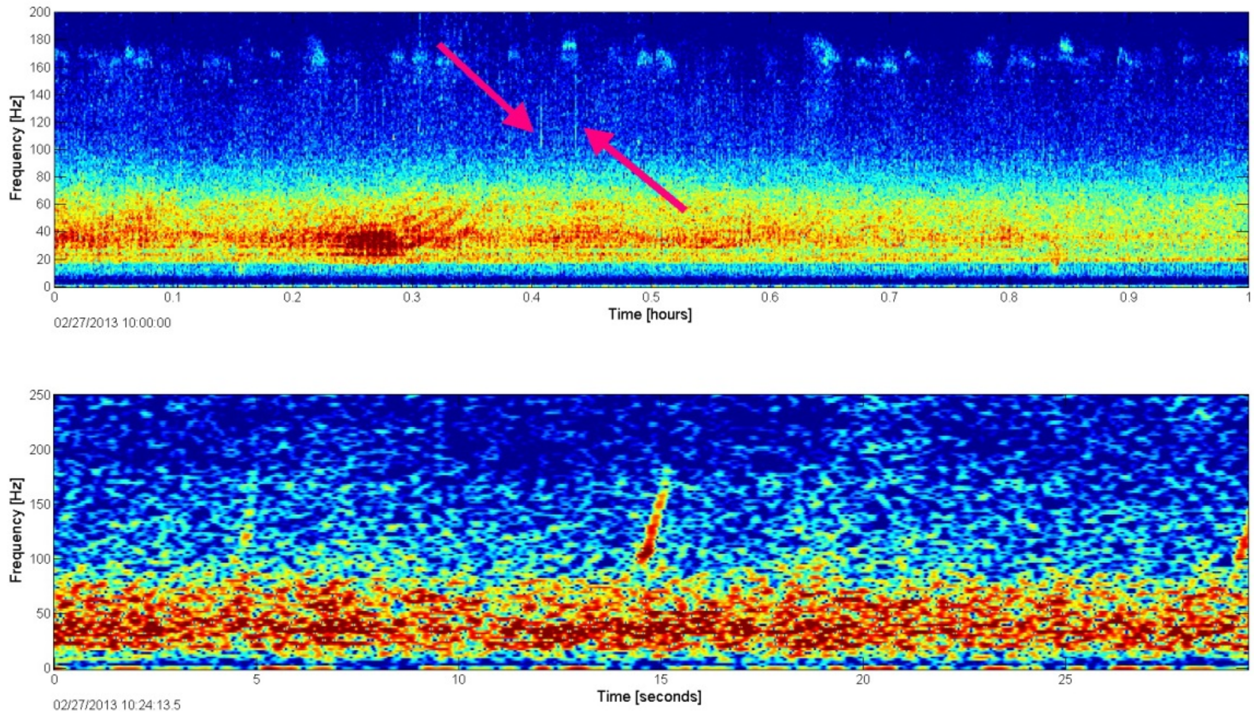

Figure 10. North Atlantic right whale up-calls in the LTSA (top) and spectrogram (bottom) at HAT.

Mid-Frequency Marine Mammals

Marine mammal species with sounds in the mid-frequency range expected in the Virginia Capes Range Complex include humpback whales (*Megaptera novaeangliae*). For mid-frequency data analysis, the 100 kHz data were decimated by a factor of 20 for an effective bandwidth of 5 kHz. The LTSAs for mid-frequency analysis were created using a time average of 5 seconds, and a frequency bin size of 10 Hz. The presence of each call type was determined using an encounter-granularity, to one-minute precision, for each mid-frequency dataset. Humpback whales were detected automatically as described below.

Humpback Whales

Humpback whales produce both song and non-song calls (Payne and McVay, 1971; 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 11). There was no effort to separate song and non-song calls.

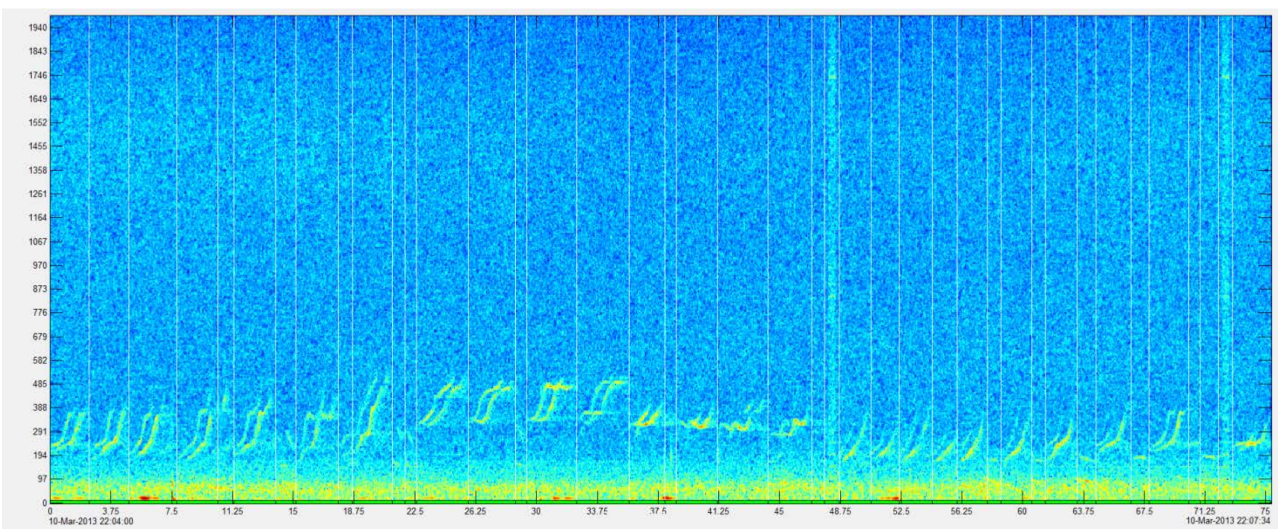

Figure 11. Humpback whale song from the HAT site in the analyst verification stage of the detector. Green in the bottom evaluation line indicates true detections.

High-Frequency Marine Mammals

Marine mammal species with sounds in the high-frequency range and possibly found in the Virginia 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*), killer whales (*Orcinus orca*), pygmy killer whales (*Feresa attenuata*), melon-headed whales (*Peponocephala electra*), sperm whales (*Physeter macrocephalus*), dwarf sperm whales (*Kogia sima*), and pygmy sperm whales (*Kogia breviceps*). Several beaked whales are also found in the Virginia Capes Range Complex; beaked whale detection effort is described in a separate report.

High-Frequency Call Types

Odontocete sounds can be categorized as echolocation clicks, burst pulses, or whistles. Echolocation clicks are broadband impulses with peak energy between 5 and 150 kHz, dependent upon the species. Buzz or burst pulses are rapidly repeated clicks that have a creak or buzz-like sound quality; they are generally lower in frequency than echolocation clicks. Dolphin whistles are tonal calls predominantly between 1 and 20 kHz that vary in frequency content, their degree of frequency modulation, as well as duration. These signals are easily detectable in an LTSA as well as the spectrogram (Figure 12).

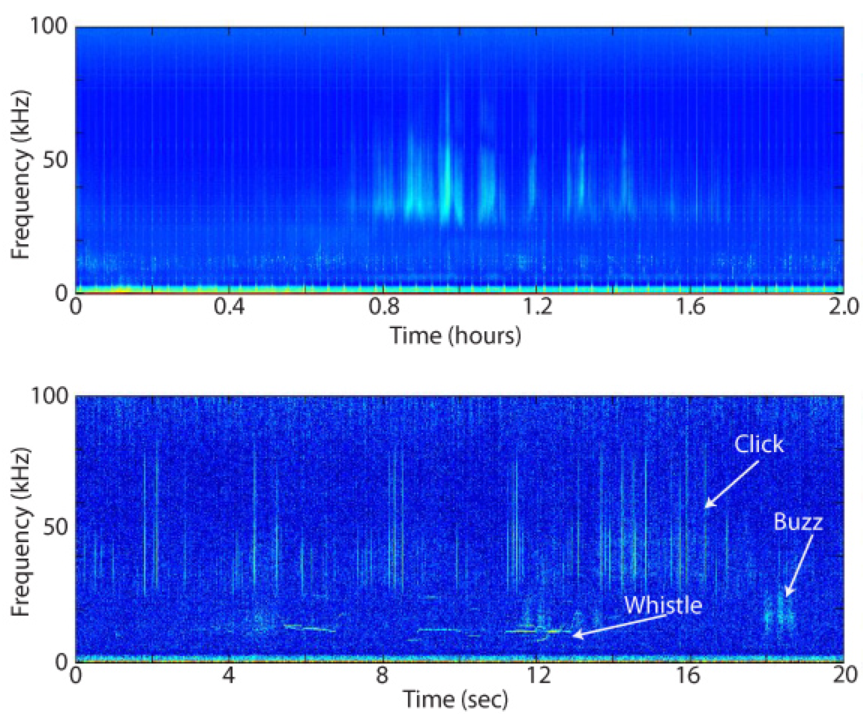

Figure 12. LTSA (top) and spectrogram (bottom) demonstrating odontocete signal types.

Risso's Dolphins

Risso's dolphin clicks (Figure 13 and Figure 14) have frequency peaks at 20, 26 and 32 kHz. These clicks have a modal inter-click interval of 0.16 seconds (Figure 14). Past studies have shown that spectral properties of Risso's dolphin clicks have slight variations with geographic region (Soldevilla *et al.*, In prep), 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.

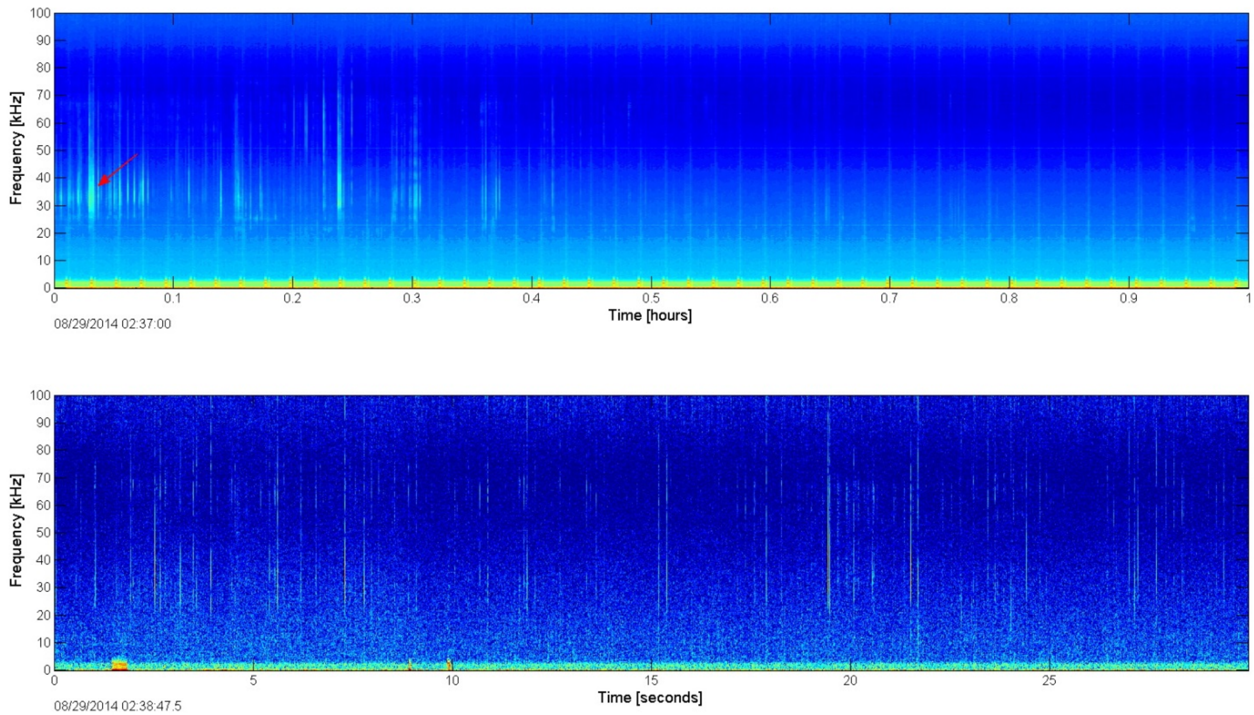

Figure 13. Risso's dolphin clicks in the LTSA (top) and spectrogram (bottom) at NFC.

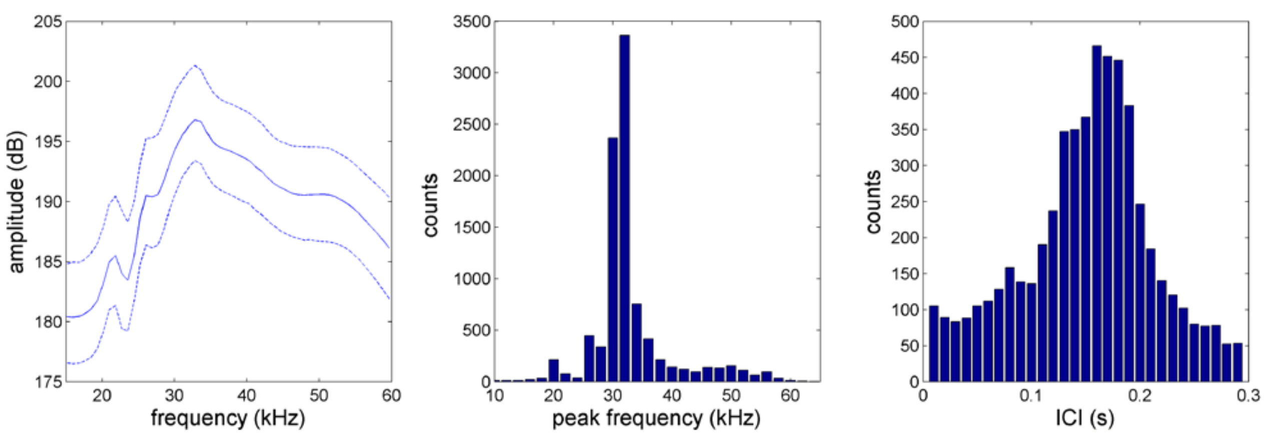

Figure 14. Left: Mean spectra of Risso's dolphin clicks (solid line) and 25th and 75th percentiles (dashed lines); Center: Distribution of click peak frequencies with primary peak at 32 kHz and secondary peaks at 20 and 26 kHz; Right: Distribution of inter-click-intervals with modal peak at 0.16 seconds .

Sperm Whales

Sperm whale clicks contain energy from 2-20 kHz, with the majority of energy between 10-15 kHz (Møhl *et al.*, 2003) (Figure 15). Regular clicks, observed during foraging dives, demonstrate an ICI from 0.25-2 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 (Watwood *et al.*, 2006). Slow clicks are used only by males and are more intense than regular clicks with long inter-click intervals (Madsen *et al.*, 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.

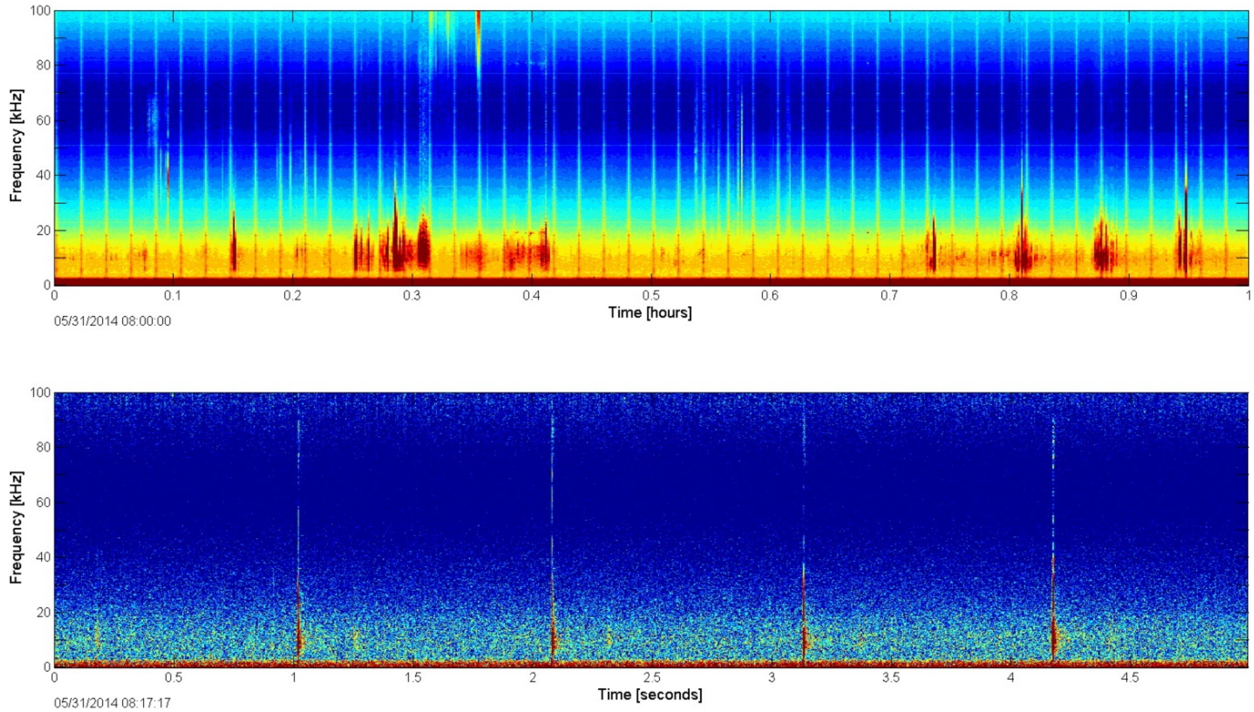

Figure 15. Sperm whale echolocation clicks in LTSA (top) and spectrogram (bottom) at HAT.

Kogia *Spp.*

Dwarf and pygmy sperm whales emit echolocation signals which have peak energy at frequencies near 130 kHz (Au, 1993). While this is above the upper frequency band recorded by the HARP during these deployments, the lower portion of the *Kogia* energy spectrum is within the 100 kHz HARP bandwidth (Figure 16). 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 18). *Kogia* echolocation clicks were analyzed using a new 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.

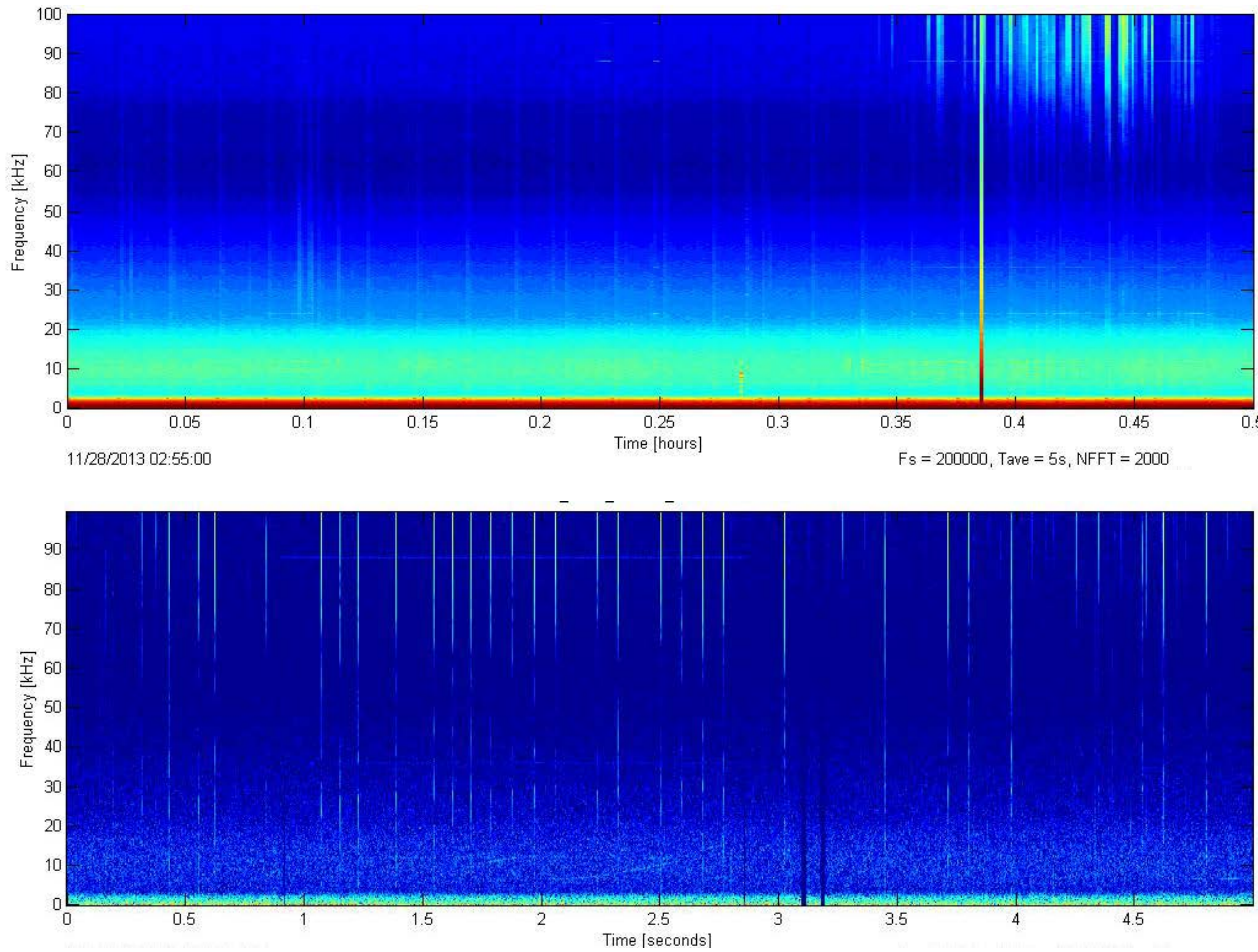

Figure 16. Kogia *spp.* echolocation clicks in the LTSA (top) and spectrogram (bottom) from site HAT.

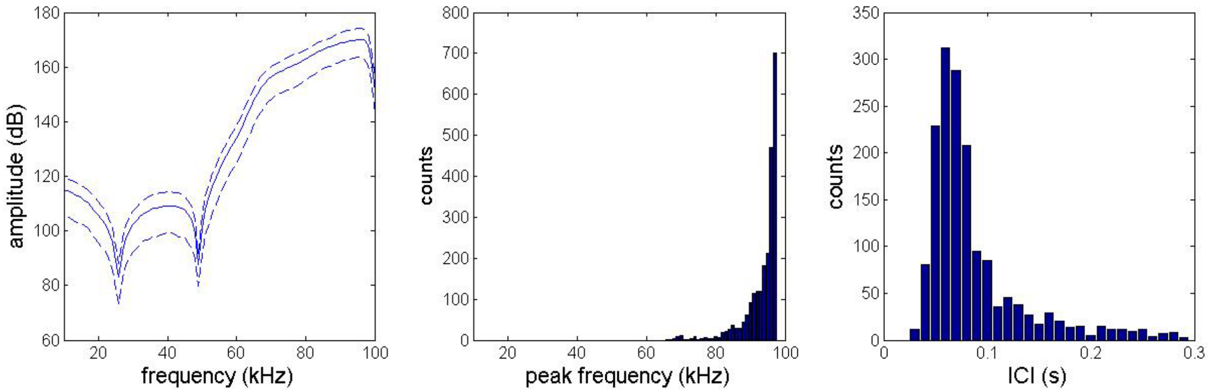

Figure 17. Left: Kogia mean spectra computed from deployment HAT03 (solid line) with 25th and 75th percentiles (dashed lines); Center: Distribution of click peak frequencies with peak near the Nyquist frequency (100 kHz); Right: Distribution of inter-click-intervals with modal peak at 0.07 seconds.

Echolocation Click Types

An analysis was conducted to describe echolocation clicks from the family Delphinidae and classify acoustic encounters to a certain click type (CT). Echolocation clicks were detected using a modified version of a Teager energy detector (Soldevilla et al. 2008, Roch et al. 2011). This uses an energy threshold to identify clicks, reducing the impact of changing noise conditions on detectability. The automatic click detector identified clicks with received levels greater than or equal to $120dB_{pp}$. Click events were reviewed manually to remove instances where a false positive source had triggered the detector and LTSAs were then manually examined to identify reoccurring echolocation click types. When a click of interest was found in the LTSA, the spectra were examined to further classify the sound. Click signals were band pass filtered from 10 to 90 kHz for further analysis. Clicks were manually classified into separate types based on characteristics such as inter-click-interval, spectral peaks/troughs and peak frequency. Classification was carried out by comparison to species-specific spectral characteristics from HARP recordings in the Gulf of Mexico (Frasier, 2015). Based on a complete analysis of all deployments reported here, 6 distinct click types were identified. All click types had dominant energy above 15 kHz. They differed in the prominence of spectral peaks between 10-68 kHz, and inter-click interval peaks between 0.05-0.16 seconds. Descriptions of the different click types are described below.

Click Type 1

Click type 1 (Figure 18 and Figure 19, left) has two small frequency peaks at 13 and18 kHz and then reaches maximum amplitude at 40 kHz with a final peak at 58 kHz. It has a modal ICI at 0.07 seconds (Figure 19, right). The modal ICI of this echolocation click is similar to what is found in species belonging to the *Stenella* genus (Figure 19).

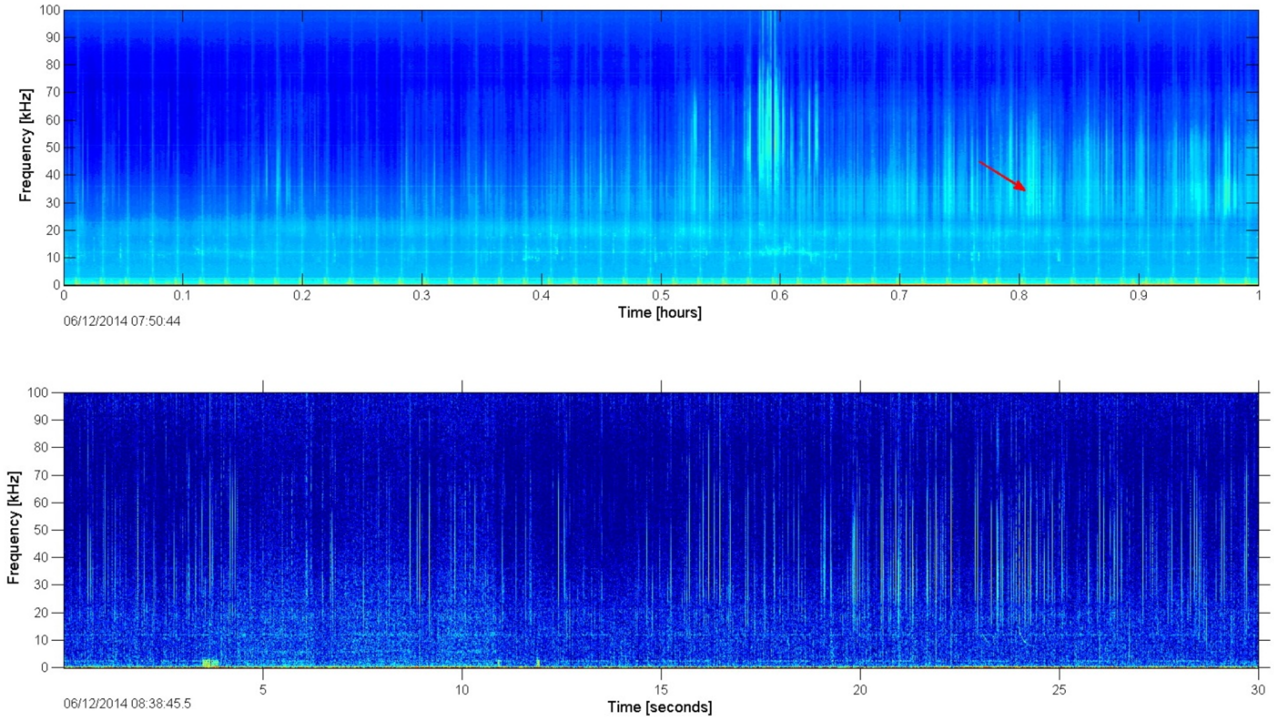

Figure 18. CT 1 in the LTSA (top) and spectrogram (bottom) at HAT. Pink arrow points to area where LTSA was expanded to spectrogram.

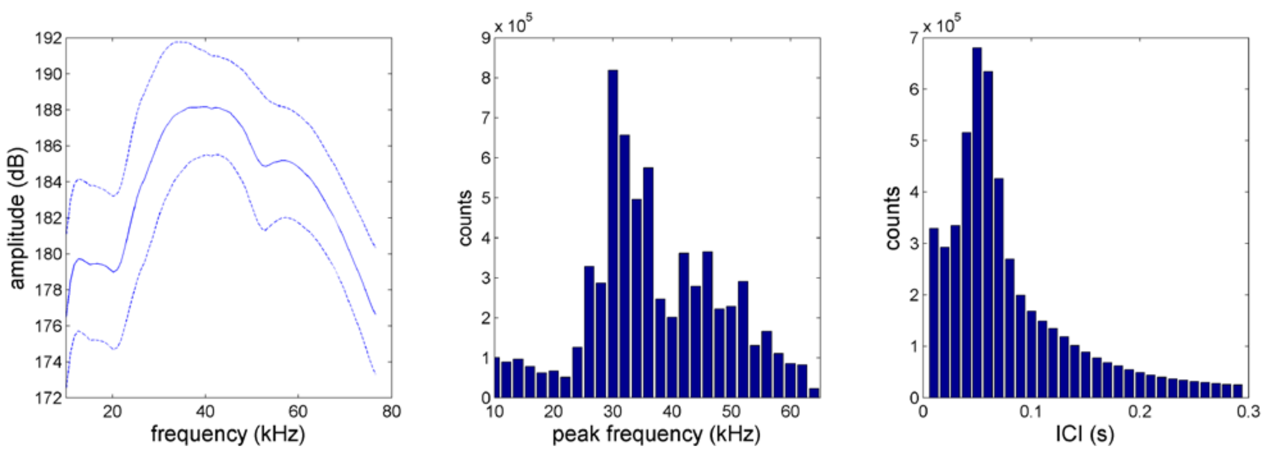

Figure 19. Left: Click type 1 mean spectra computed from a random sub-sample of 10^5 clicks (solid line) with 25th and 75th percentiles (dashed lines); Center: Distribution of click peak frequencies; Right: Distribution of inter-click-intervals with modal peak at 0.07 seconds.

Click Type 2

Click type 2 (Figure 20) was only recorded at the end of the Norfolk Canyon deployment. It has a variable peak frequency distribution (Figure 21, center) with an average peak frequency of 46 kHz (Figure 21, left) and a modal inter-click interval at 0.15 seconds (Figure 21, right).

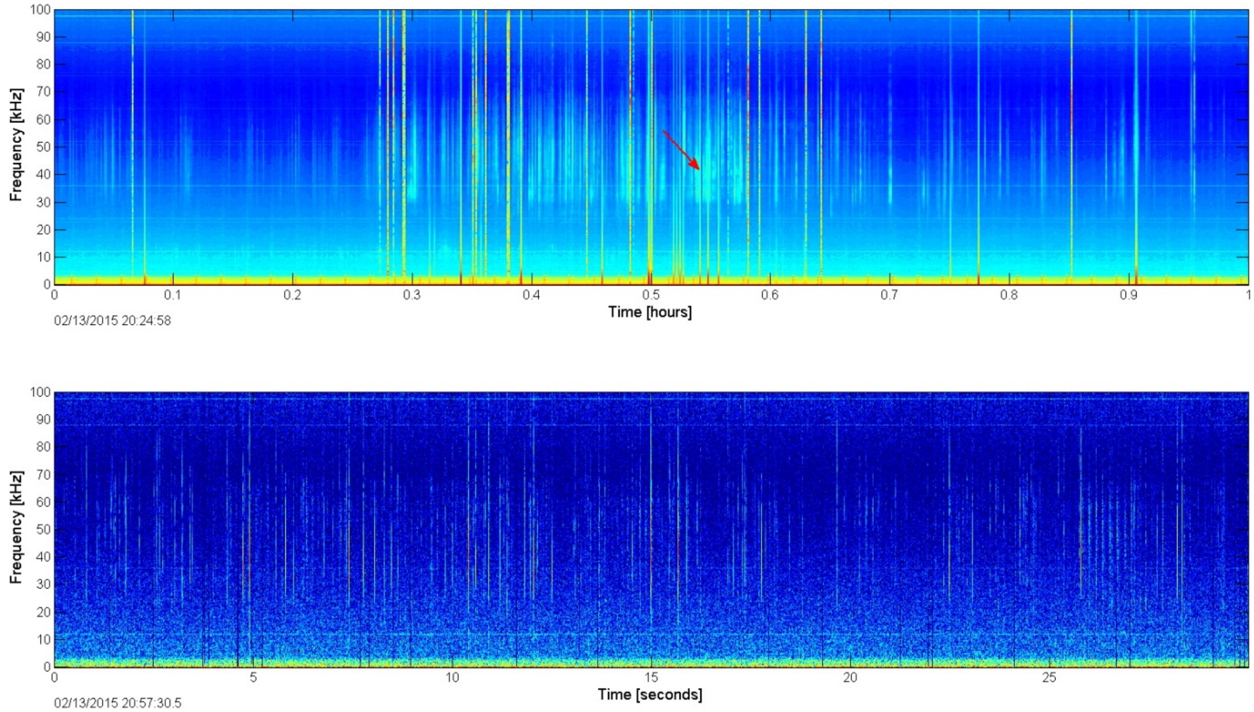

Figure 20. CT 2 in the LTSA (top) and spectrogram (bottom) at NFC. Pink arrow points to area where LTSA was expanded to spectrogram.

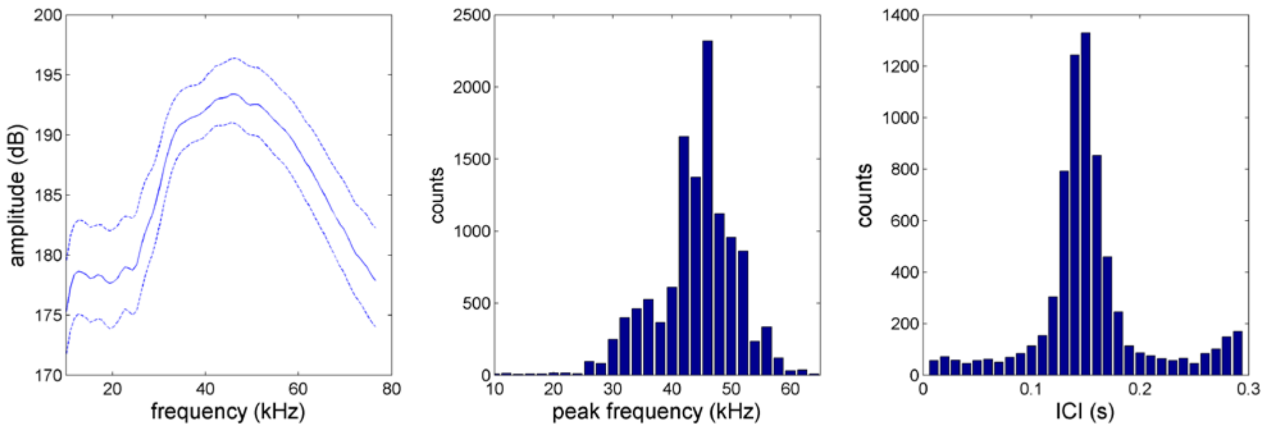

Figure 21. Left: Click type 2 mean spectra (solid line) with 25th and 75th percentiles (dashed lines); Center: Distribution of click peak frequencies; Right: Distribution of inter-click-intervals with modal peak at 0.15 seconds.

Click Type 3

Click type 3 (Figure 22 and Figure 23, left) has spectral peaks at 18 and 46 kHz. A trough occurs in the mean spectrum at 22 kHz. The modal ICI is 0.16 seconds (Figure 23 right). Clicks similar to this type have been seen in the Gulf of Mexico (Frasier 2015), where this type was associated with short-finned pilot whale based on geographical location and rates of occurrence.

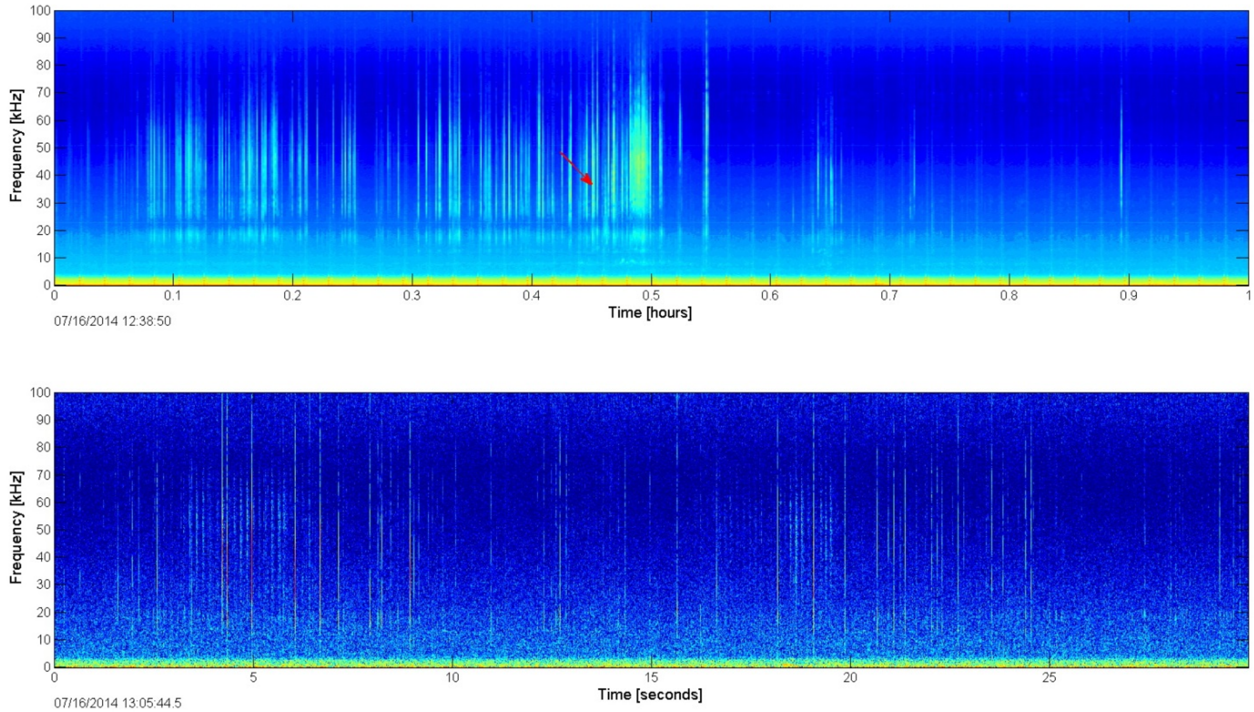

Figure 22. CT 3 in the LTSA (top) and spectrogram (bottom) at NFC. Pink arrow points to area where LTSA was expanded to spectrogram.

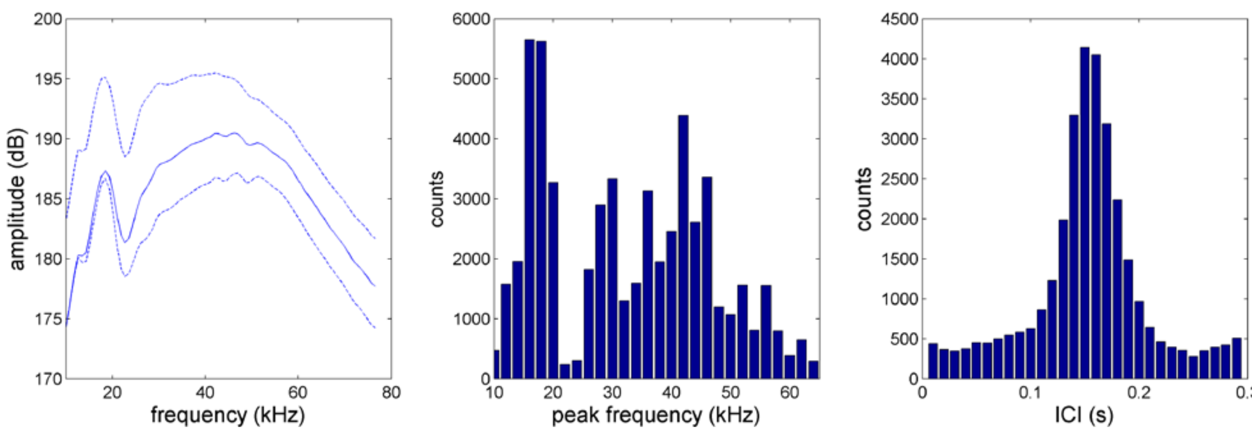

Figure 23. Left: Click type 3 mean spectra (solid line) with 25th and 75th percentiles (dashed lines); Center: Distribution of click peak frequencies; Right: Distribution of inter-click-intervals with modal peak at 0.16 seconds .

Click Type 4

Click type 4 (Figure 24 and Figure 25, left) has characteristic spectral peaks at 21 and 27 kHz and has a mean peak frequency at 57 kHz. The ICI is very short with a modal value of 0.06 seconds (Figure 25, right). Clicks similar to this type have been seen in the Gulf of Mexico (Frasier 2015), where they were associated with pelagic dolphins of the genus *Stenella* based on geographic location and rates of occurrence.

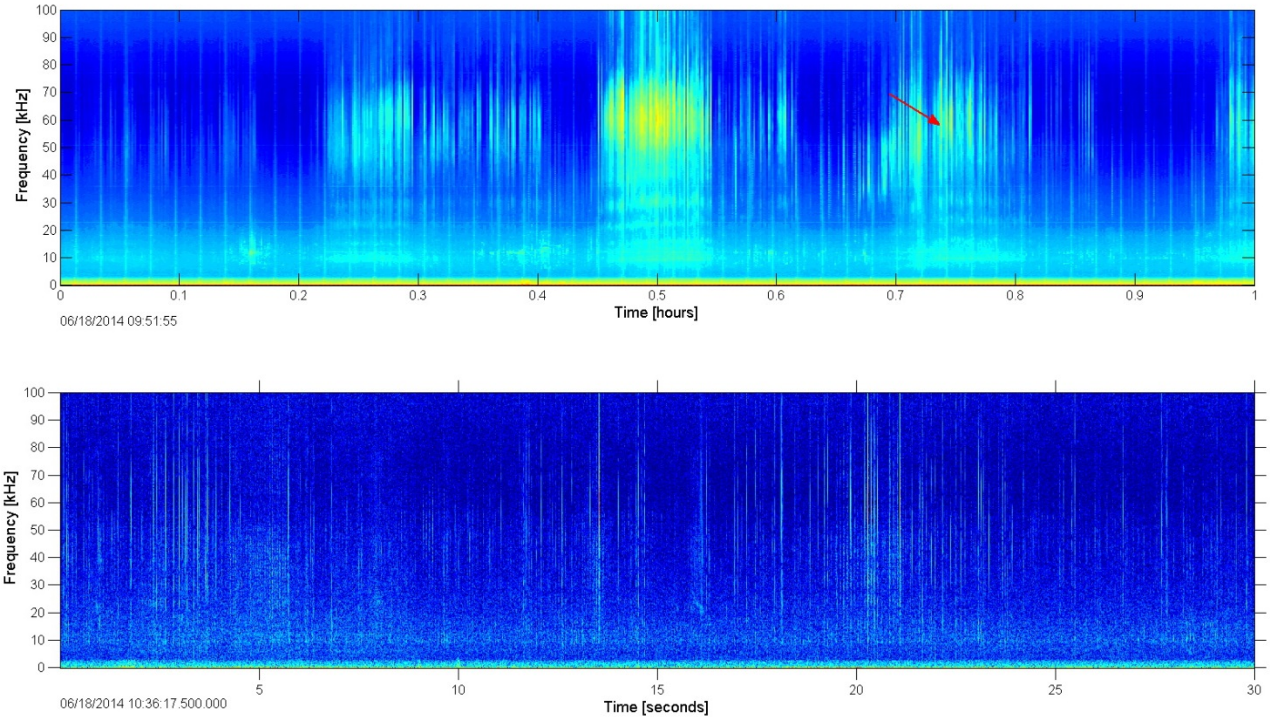

Figure 24. CT 4 in the LTSA (top) and spectrogram (bottom) at HAT. Pink arrow points to area where LTSA was expanded to spectrogram.

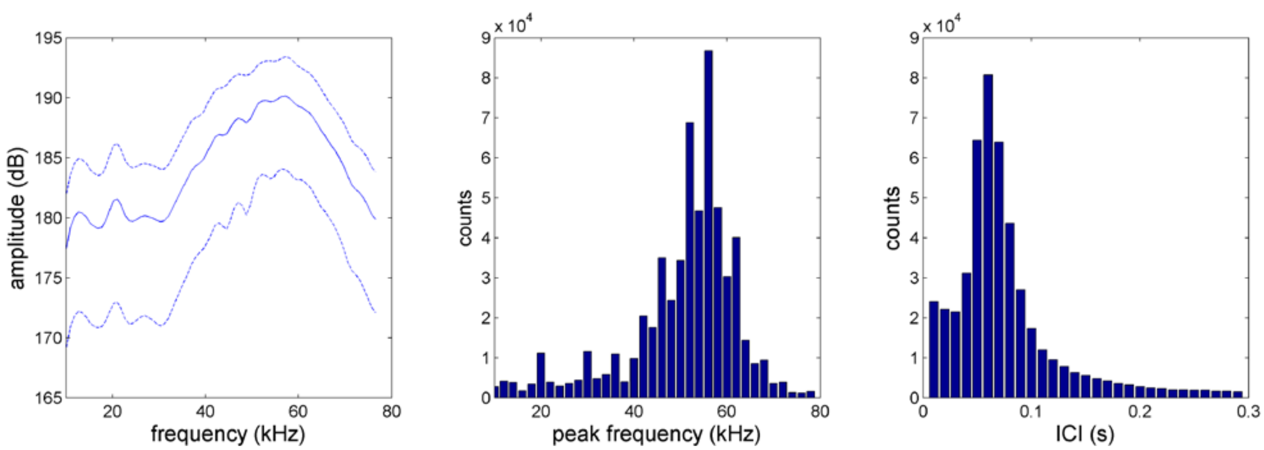

Figure 25. Left: Click type 4 mean spectra (solid line) with 25th and 75th percentiles (dashed lines); Center: Distribution of click peak frequencies; Right: Distribution of inter-click-intervals with modal peak at 0.06 seconds.

Click Type 5

Click type 5 (Figure 26 and Figure 27, left) has spectral peaks at 12, 17, 46 and 57 kHz. This click type has a very low ICI with most clicks occurring between 0.01 and 0.05 seconds from each other (Figure 27, right). This click type was only encountered in the spring of 2013 at site HAT. The clicks were recorded in high numbers and right on top of each other suggesting these animals were in a large group. It is known that short-beaked common dolphins venture south in the spring towards Cape Hatteras and travel in large group sizes. This makes them the prime candidate species for this click type.

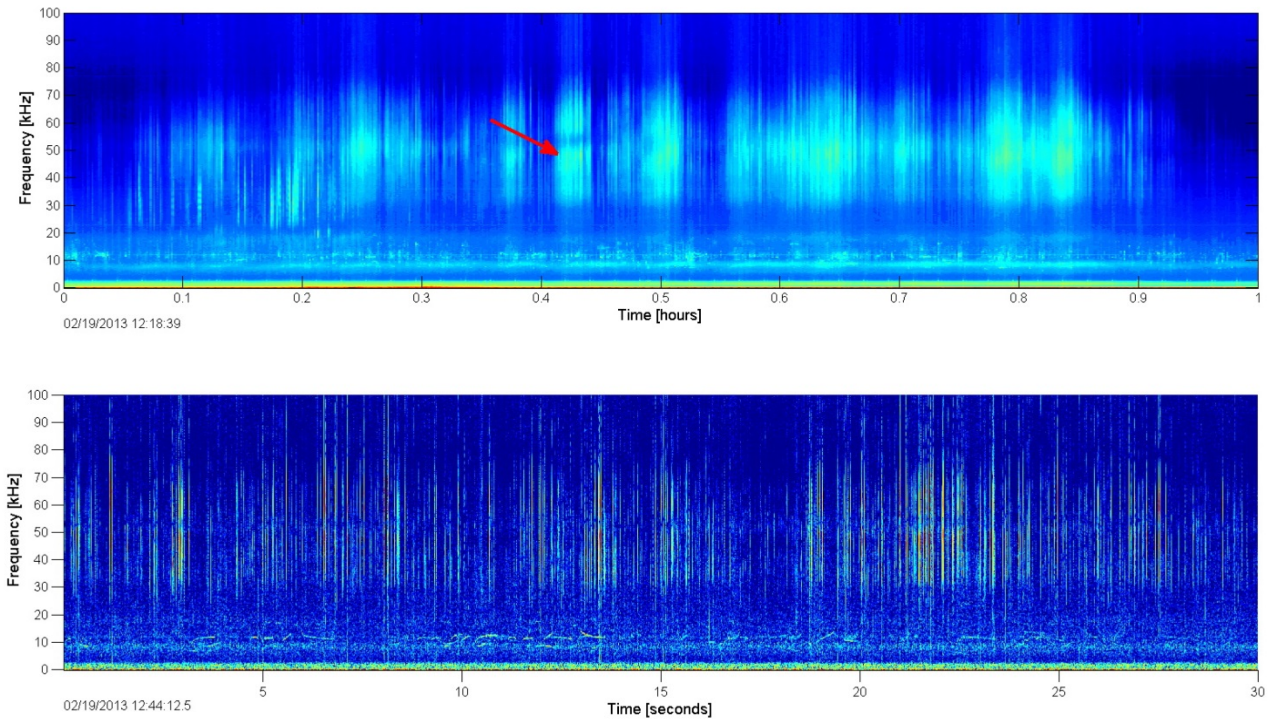

Figure 26. CT 5 in the LTSA (top) and spectrogram (bottom) at HAT. Pink arrow points to area where LTSA was expanded to spectrogram.

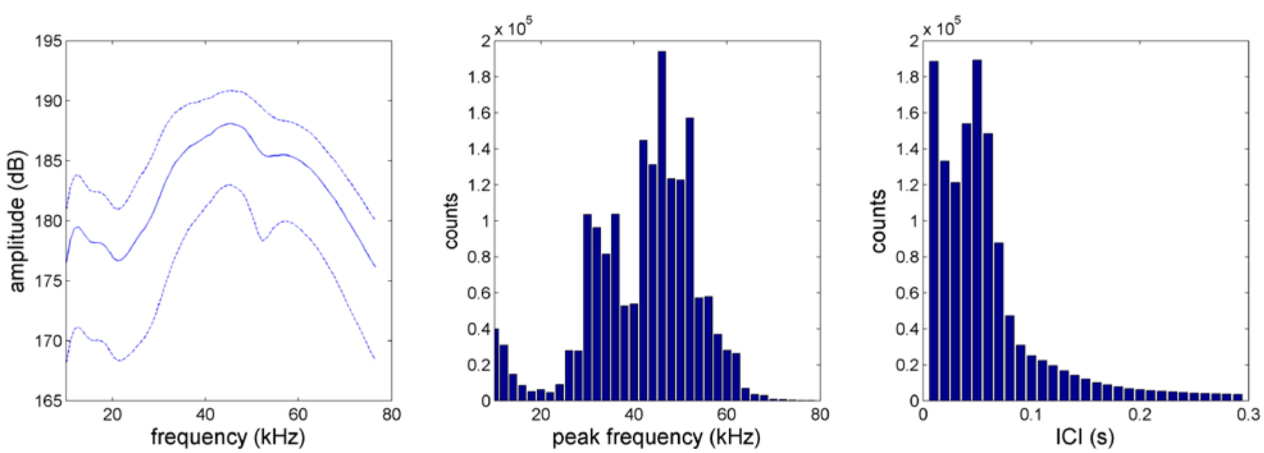

Figure 27. Left: Click type 5 mean spectra (solid line) with 25th and 75th percentiles (dashed lines); Center: Distribution of click peak frequencies; Right: Distribution of inter-click-intervals.

Click Type 6

Click type 6 (Figure 28 and Figure 29, left) has spectral peaks at 19 and 32 kHz. It has modal inter-click interval peaks at 0.07 and 0.13 seconds (Figure 29, right). The average ICI of this click type is longer than what is commonly found in echolocation clicks of smaller dolphins, suggesting that this click might belong to one of the blackfish species (Baumann-Pickering *et al*., 2015).

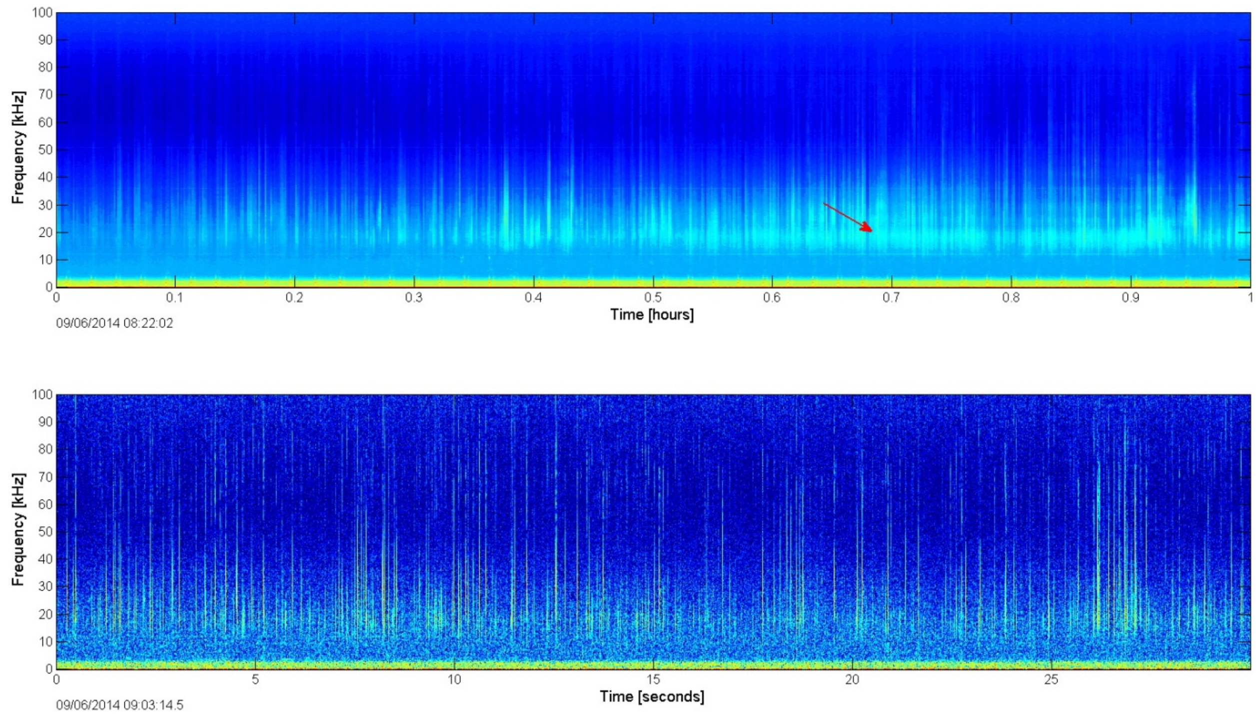

Figure 28. CT 12 in the LTSA (top) and spectrogram (bottom) at NFC. Pink arrow points to area where LTSA was expanded to spectrogram.

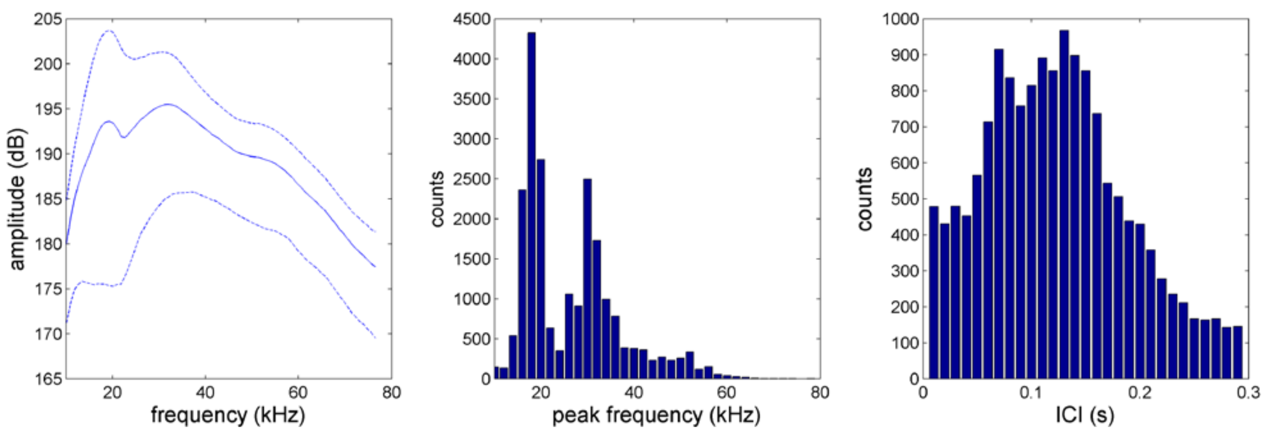

Figure 29. Left: Click type 6 mean spectra (solid line) with 25th and 75th percentiles (dashed lines); Center: Distribution of click peak frequencies; Right: Distribution of inter-click-intervals with modal peaks at 0.07 and 0.13 seconds.

Anthropogenic Sounds

Several anthropogenic sounds were monitored for this report: broadband ship noise, airguns, MFA sonar, LFA sonar greater than 500 Hz, and explosions. The start and end of each sound or session was logged and their durations were added to estimate cumulative hourly presence. Manual effort was expended for broadband ship noise, airguns, MFA, and LFA greater than 500 Hz (Table 2). The start and end of each session was logged and their durations were added to estimate cumulative hourly presence. A detector was used for explosion analysis, described below.

Table 2. Anthropogenic sound data analysis parameters.

Sound Type	LTSA Search Parameters	
	Plot Length (hr)	Frequency Range (Hz)
HFA Sonar	1	5,000 – 100,000
Echosounders	1	1,000 – 100,000
Broadband Ship Noise	3	10 – 5,000
Airguns	0.75	10 – 2,000
MFA Sonar	0.75	1,000 – 5,000
LFA Sonar >500 Hz	0.75	10 – 1,000

Broadband Ship Noise

Broadband ship noise occurs when a ship passes within a few km of 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 30). Noise can extend above 10 kHz, though it typically falls off above a few kHz. Broadband ship analysis effort consisted of manual scans of the LTSA set at 3 hours with a frequency range of 10 – 5,000 Hz.

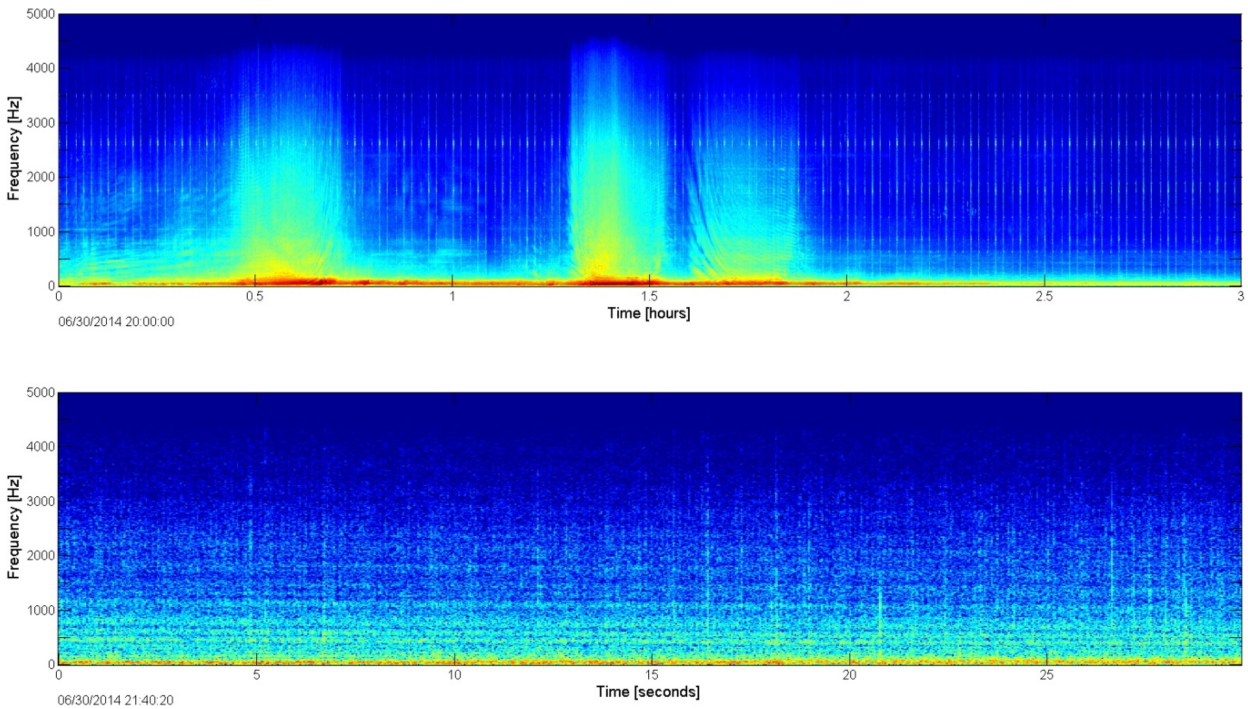

Figure 30. Broadband ship noise in the LTSA (top) and spectrogram (bottom) at NFC.

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 31). Explosions were detected automatically using a matched filter detector on data decimated to 10 kHz sampling rate. The timeseries was filtered with a 10^{th} order Butterworth bandpass filter between 200 and 2,000 Hz. Cross correlation was computed between 75 seconds of the envelope of the filtered timeseries and the envelope of a filtered example explosion (0.7 s, Hann windowed) as the matched filter signal. The cross correlation was squared to 'sharpen' peaks of explosion detections. A floating threshold was calculated by taking the median cross correlation value over the current 75 seconds of data to account for detecting explosions within noise, such as shipping. A cross correlation threshold of $3*10^{-6}$ above the median was set. When the correlation coefficient reached above threshold, the timeseries was inspected more closely. Consecutive explosions were required to have a minimum time distance of 0.5 seconds to be detected. A 300-point (0.03 s) floating average energy across the detection was computed. The start and end times above the threshold were 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 explosion period as well as a timeseries of the length of the explosion template before and after the explosion. The potential explosion was classified as a 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 the signal was less than 3 dB or 1 dB, respectively; and 3) the detection was shorter than 0.03 or longer than 0.55 seconds 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 potential explosions 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.

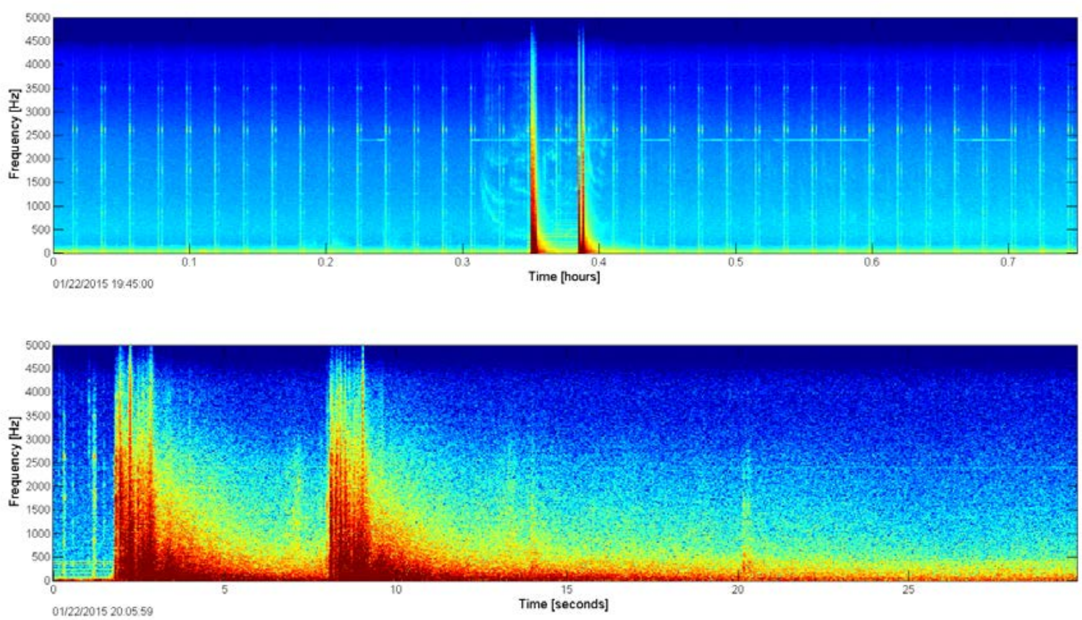

Figure 31. Explosions in the LTSA (top) and spectrogram (bottom) at NFC.

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 air gun 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 over 200 dB re 1 µPa-m (Amundsen and Landro, 2010). These blasts typically have an inter-pulse-interval of approximately 10 seconds and can last from several hours to days (Figure 32).

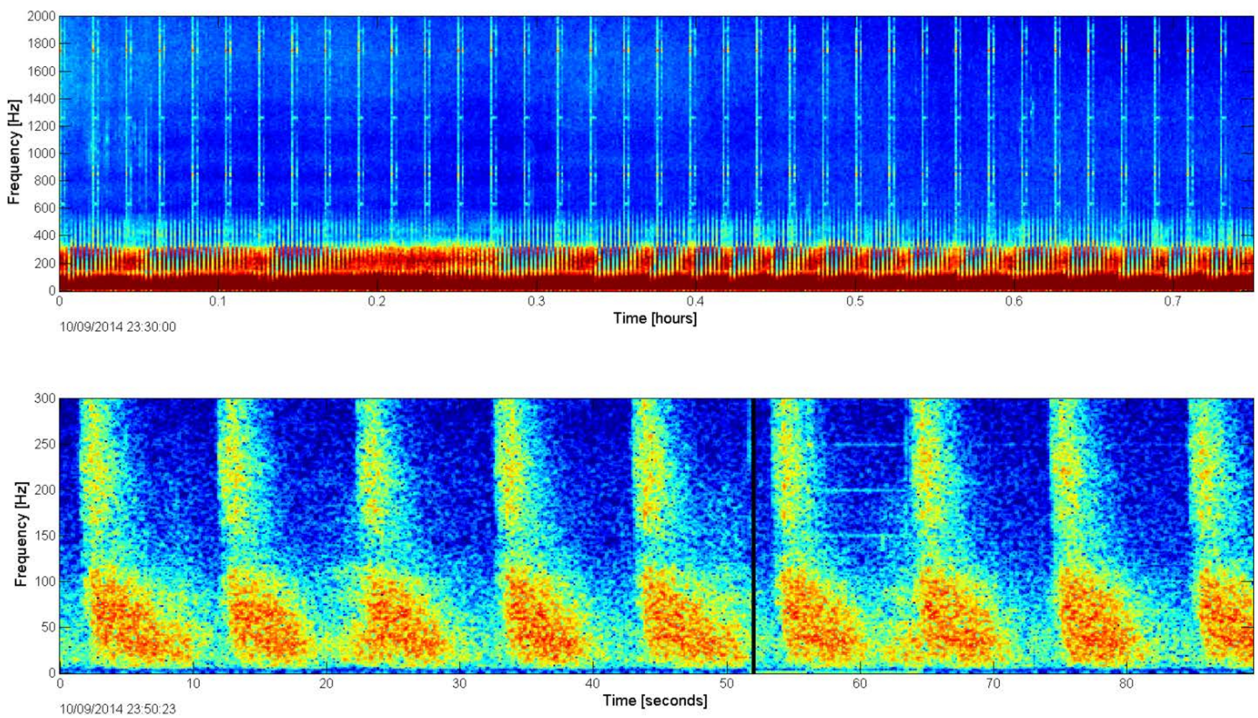

Figure 32. Airgun pulses in the LTSA (top) and spectrogram (bottom) at NFC.

High-Frequency Active Sonar

Sonar sounds above 10 kHz that were not classified as echosounders were classified as high-frequency active sonars (Figure 33). Analysts manually scanned LTSAs for sonar bout start and end times.

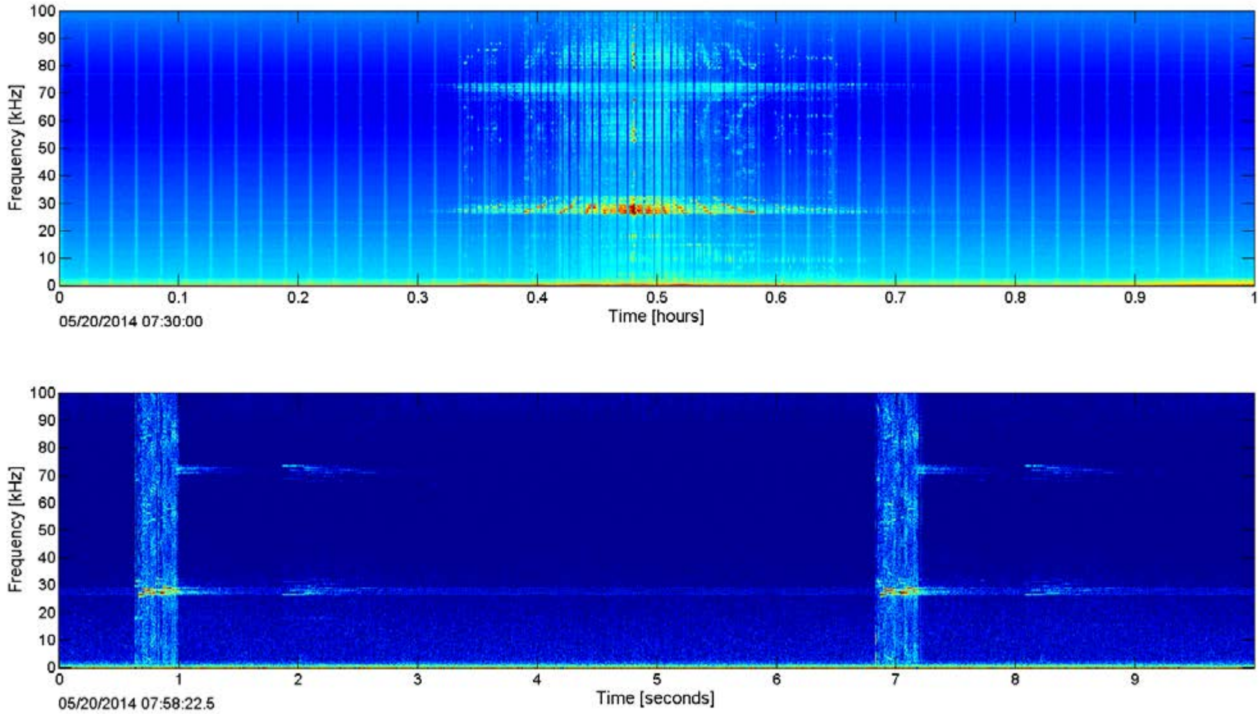

Figure 33. High-frequency Active sonar pings in the LTSA (top) and spectrogram (bottom) at HAT.

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 sonars can span frequencies from about 1 kHz to over 50 kHz, most mid-frequency sonars are between 2.0 and 5.0 kHz and are sometimes generically known as '3.5 kHz' sonar (Figure 34). Analysts manually scanned LTSAs for sonar bout start and end times.

A custom software routine was used to detect sonar pings within the analyst-defined bouts and to calculate peak-to-peak (PP) received sound pressure levels (Wiggins, 2015). For this detector, a sonar ping is defined as the presence of sonar within a 5 s window and may contain multiple individual pings. The detector calculates the average spectrum level across the frequency band from 2.4 to 4.5 kHz for each 5 s time bin. This provides a time series of the average received levels in that frequency band. Minimum values were noted for each 5 s time bin, and used as a measure of background noise level over the sonar event period. Spectral bins that contained system noise (disk writing) were eliminated to prevent contaminating the results. Each of the remaining average spectral bins was compared to the background minimum levels. If levels were more than 3 dB above the background, then a detection time was noted. These detection times were then used to index to the original time series to calculate PP levels. Received PP levels were calculated by differencing the maximum and minimum amplitude of the time series in the 5 s window. The raw time series amplitudes are in units of analog-to-digital converter (ADC) counts. These units were corrected to µPa by using the calibrated transfer function for this frequency band. Since the instrument response is not flat over the 2.4 – 4.5 kHz band, a middle value at 3.3 kHz was used. For sonar pings less than this middle frequency, their levels are overestimated by up to about 5 dB and for those at higher frequency their levels are underestimated by up to about 4 dB. While all sonar was manually detected, only the sonars between 2.4 and 4.5 kHz were further analyzed in the received levels analysis.

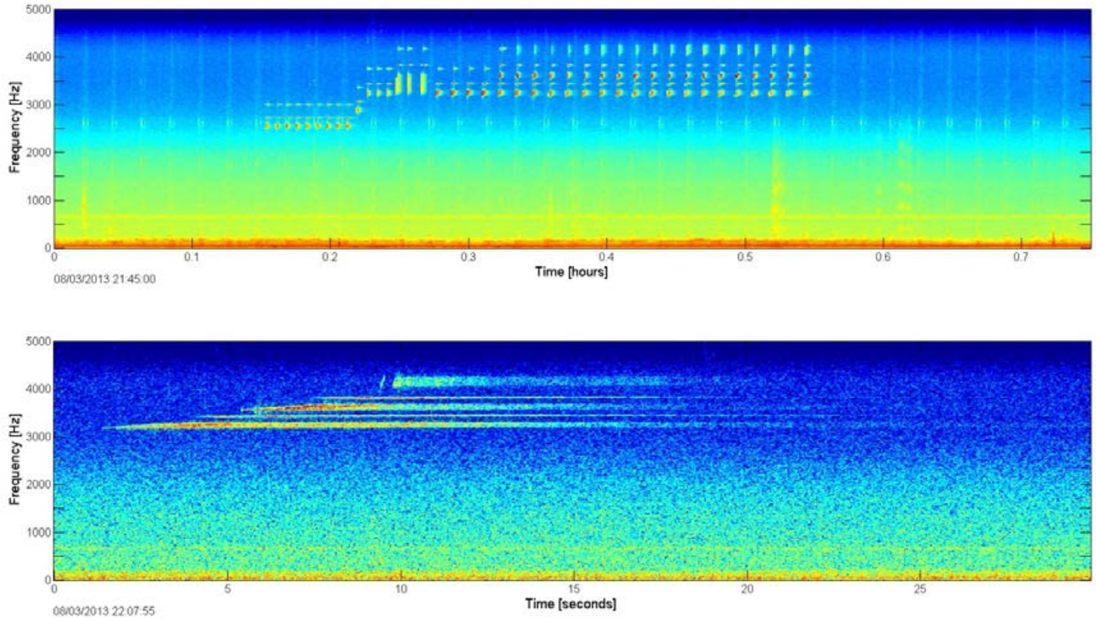

Figure 34. MFA sonar in the LTSA (top) and spectrogram (bottom) at HAT.

Active Sonar Between 500 Hz and 1 kHz.
Effort was expended for LFA sonar between 500 Hz and 1 kHz (Figure 35).

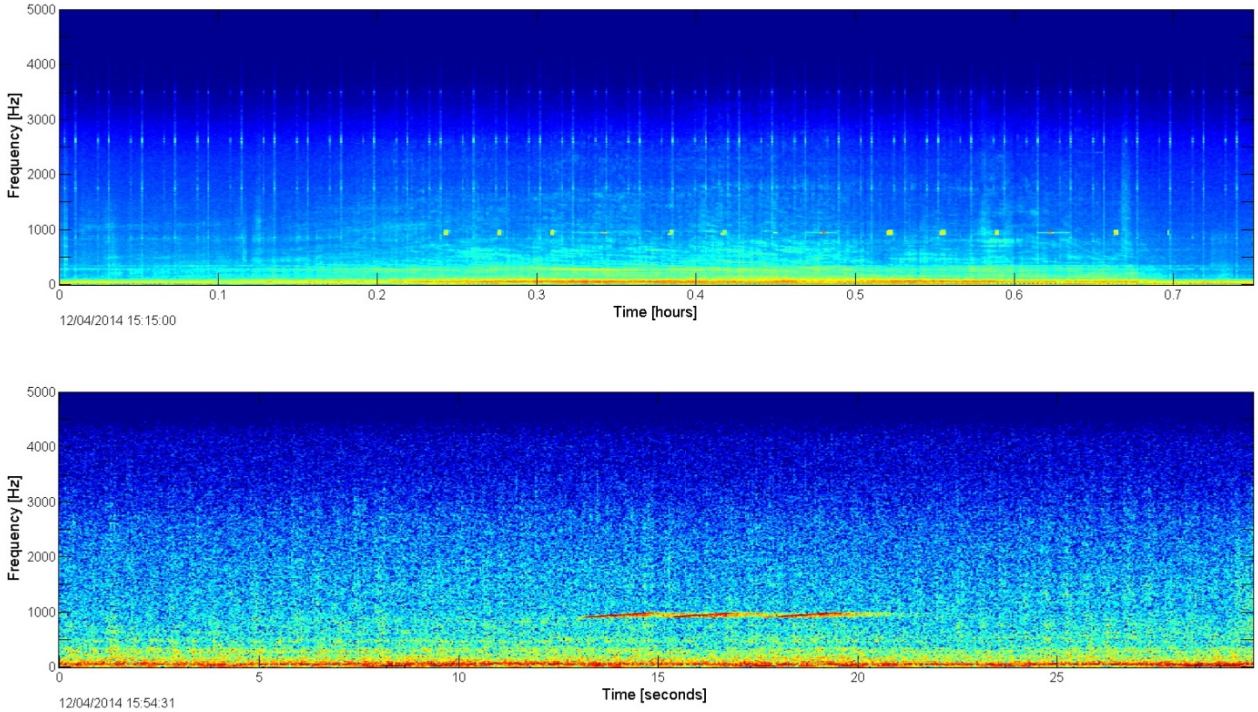

Figure 35. LFA at 950 Hz in the LTSA (top) and spectrogram (bottom) at NFC.

Results

The results of acoustic data analysis at HAT (October 2012 – December 2014) and NFC (June 2014 – April 2015) are summarized. We describe ambient noise and the seasonal occurrence and relative abundance of several marine mammal acoustic signals and anthropogenic sounds of interest.

Ambient Noise

To provide a means of evaluating seasonal spectral variability, daily-averaged spectra were processed into monthly-averages and plotted using the same monthly color scheme for each of the deployments so that months from different years and sites could be compared. It is important to note that while incomplete days have been removed from analysis, incomplete months were not. Partial months include an asterisk (*) in the color legend and are detailed in Table 3.

Table 3. Incomplete months included in ambient noise analysis during this recording period.

Deployment	Month/Year	Days of Data / Days in Month
HAT02A	10/2012	22/31
HAT03A	05/2013	2/31
HAT03A	3/2014	14/31
HAT04A	5/2014	23/31
HAT04A	12/2014	11/31
NFC01A	06/2014	11/30
NFC01A	04/2015	4/30

- Underwater ambient noise at HAT and NFC had spectral shapes with higher levels at low frequencies, owing to the dominance of ship noise at frequencies below 100 Hz (Figure 36, Figure 37, Figure 38, and Figure 39).
- Overall ambient noise levels were similar at both sites, likely owing to similar depths and proximity to the shoreline.
- Prominent peaks in noise were observed around 20 Hz and are related to the seasonally increased presence of fin whale calls, with highest levels during winter months.
- Peaks observed around 120 and 170 Hz at HAT are related to the seasonally increased presence of minke whale pulse trains, with highest levels during winter months.
- Peaks around 600-700 Hz at HAT are related to instrument noise.

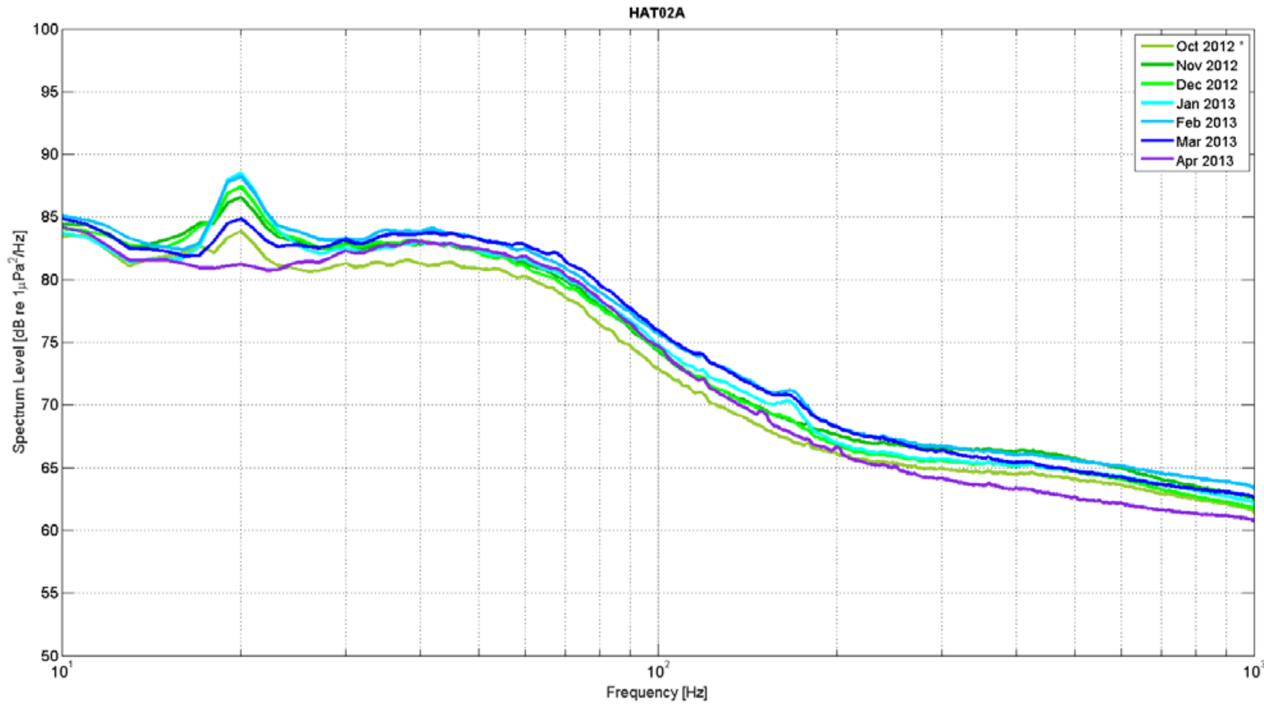

Figure 36. Monthly averages of ambient noise at HAT October 9, 2012 – April 30, 2013. Legend gives color-coding by month. Months with an asterisk (*) are partial recording periods.

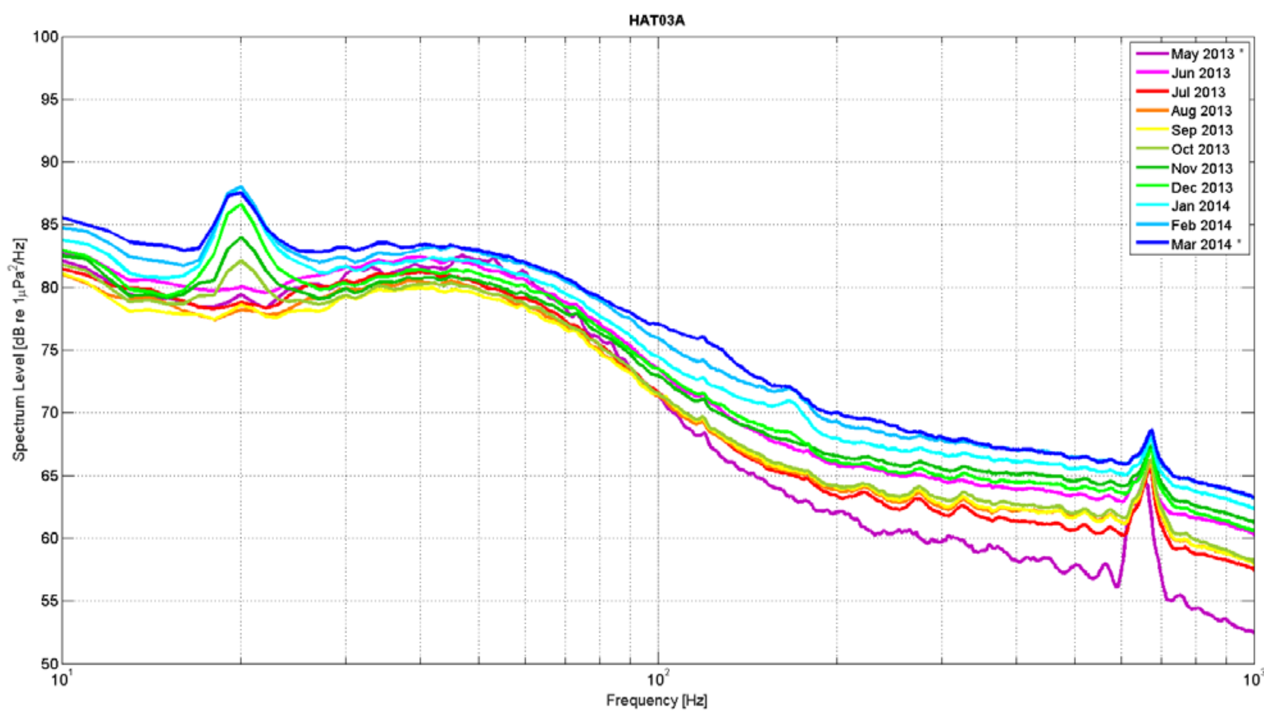

Figure 37. Monthly averages of ambient noise at HAT May 29, 2013 – March 15, 2014. Legend gives color-coding by month. Months with an asterisk (*) are partial recording periods.

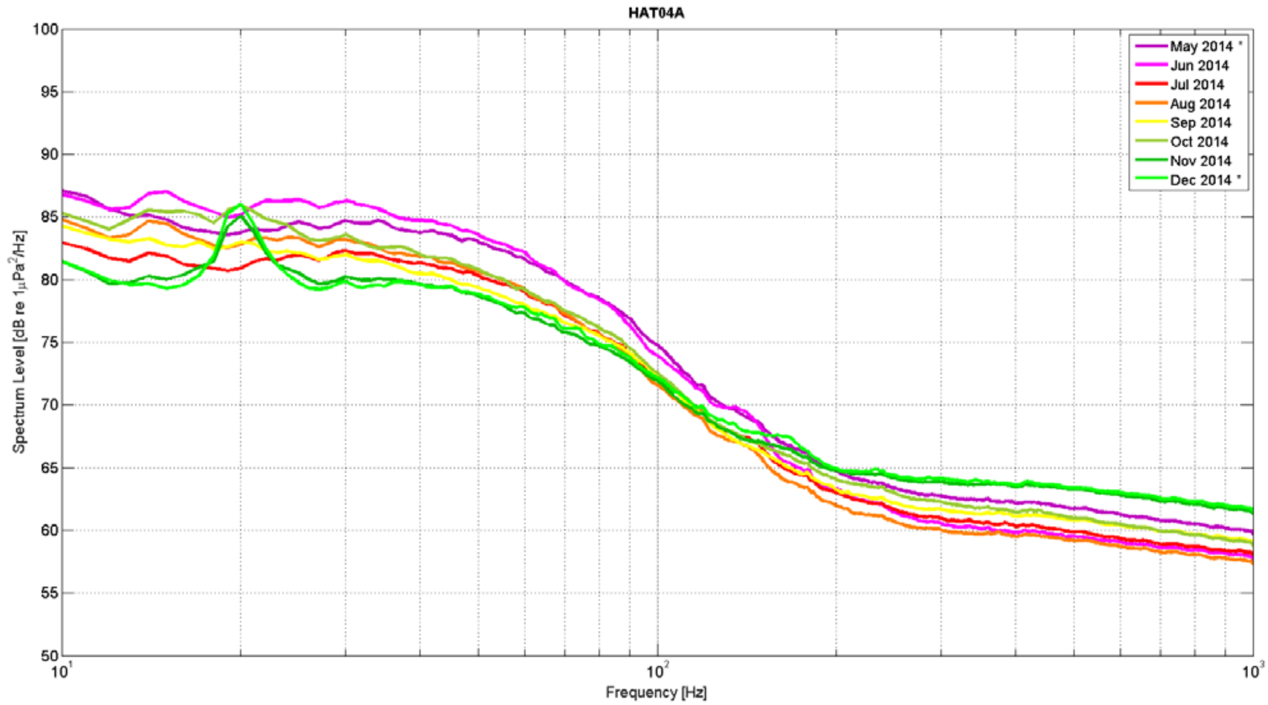

Figure 38. Monthly averages of ambient noise at HAT May 9, 2014 – December 11, 2014. Legend gives color-coding by month. Months with an asterisk (*) are partial recording periods.

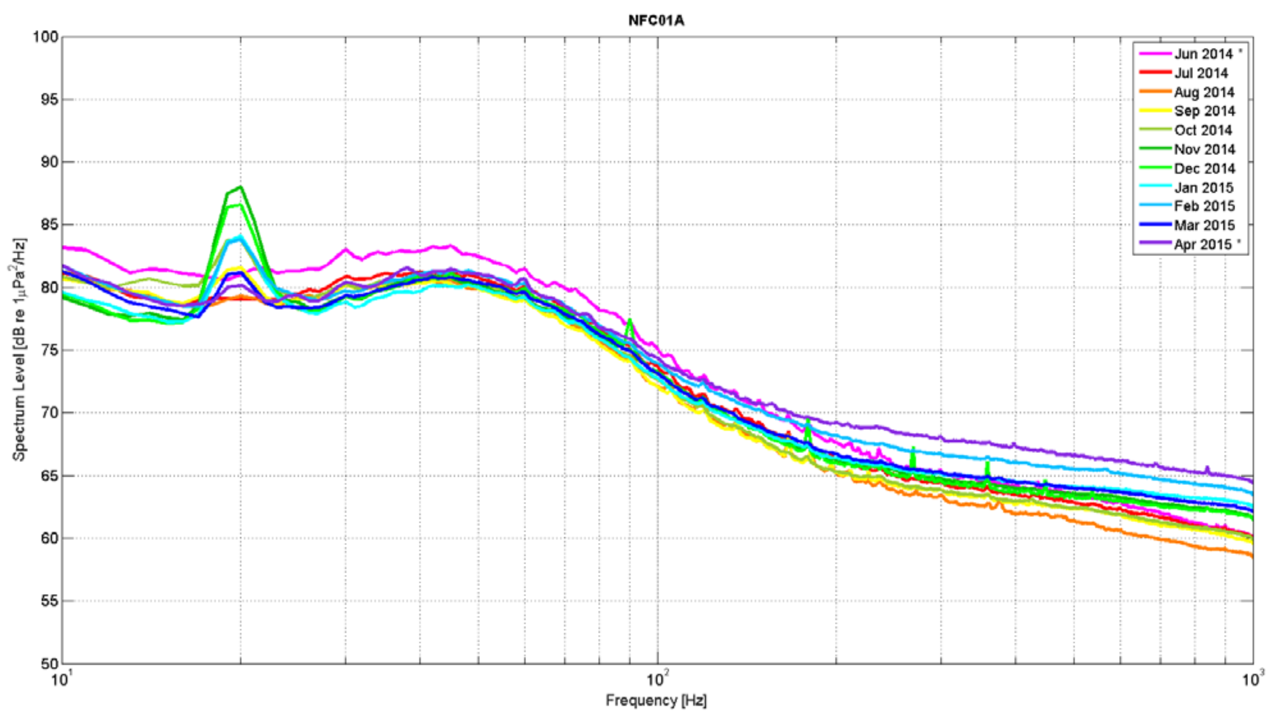

Figure 39. Monthly averages of ambient noise at NFC June 19, 2014 – April 5, 2015. Legend gives color-coding by month. Months with an asterisk (*) are partial recording periods.

Mysticetes

Six known baleen whale species were recorded between October 2012 and April 2015: blue whales, fin whales, sei whales, humpback whales, minke whales, and North Atlantic right whales. More details of each species' presence at these two sites are given below.

Blue Whales

- N Atlantic blue whale calls peaked in October and November each year at the HAT site. The highest numbers of blue whale calls occurred in 2012 (Figure 40).
- N Atlantic blue whale calls were detected in small numbers at the NFC site (Figure 40).
- There was no clear diel pattern for the N Atlantic blue whale calls (Figure 41).
- There were no arch calls detected in these deployments.

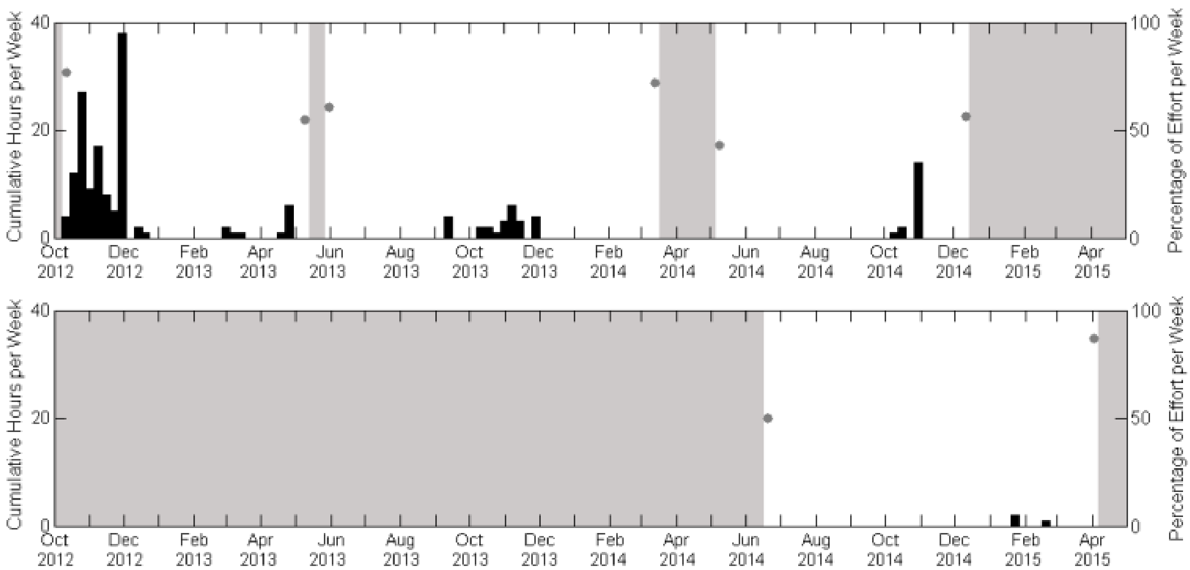

Figure 40. Weekly presence (black bars) of N Atlantic blue whale calls October 2012 – April 2015 at HAT (top) and NFC (bottom). Gray dots represent percent of effort per week in weeks with less than 100% recording effort, and gray shading represents periods with no data recorded. Where gray dots or shading are absent, full recording effort occurred for the entire week.

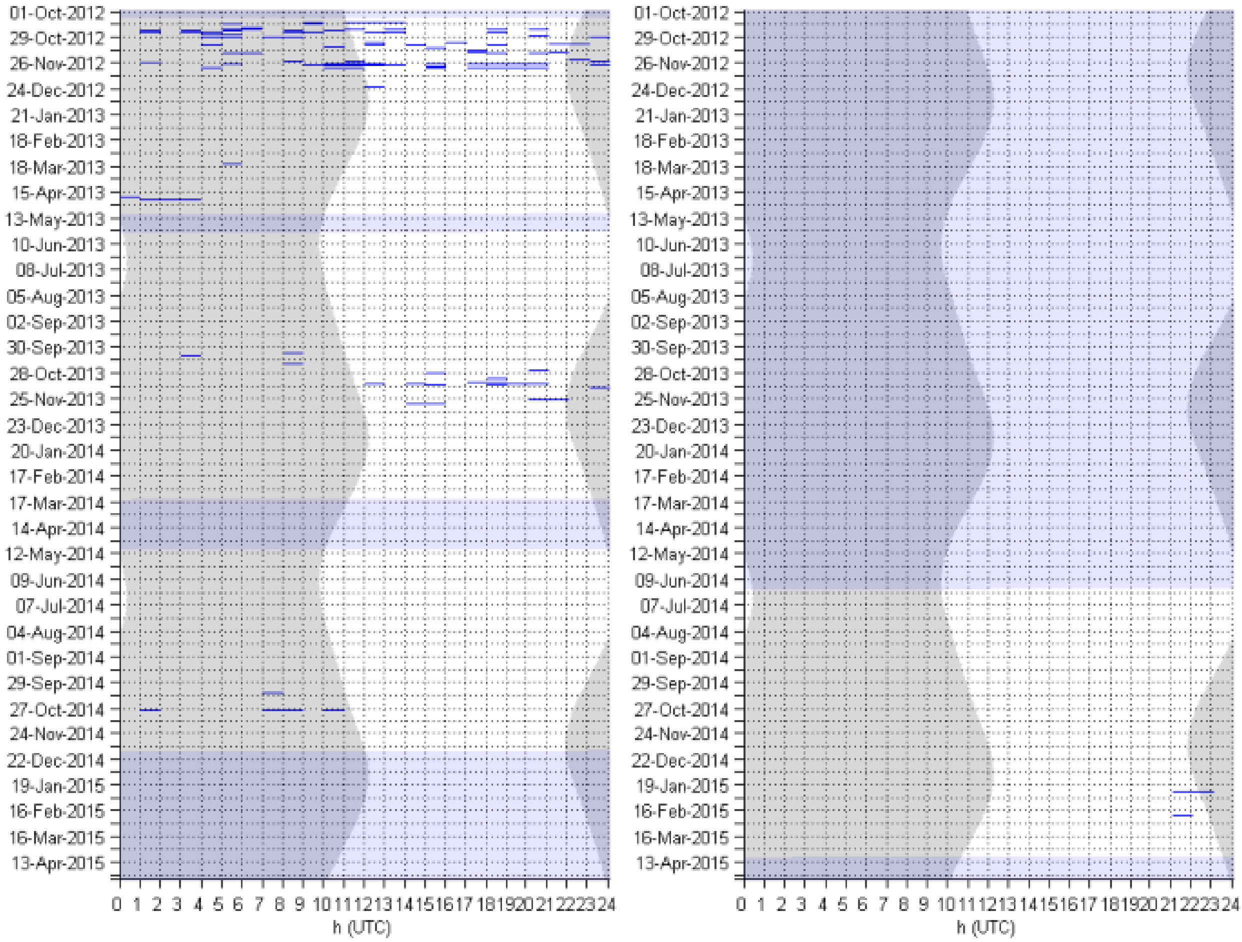

Figure 41. Blue whale N Atlantic calls in hourly bins (blue bars) at HAT (left) and NFC (right). Gray vertical shading denotes nighttime. Light purple horizontal shading denotes absence of acoustic data.

Fin Whales

- Fin whale 20 Hz calls (as measured by the acoustic index, (Širovic *et al.*, 2015)) were detected throughout the recordings at both sites with peaks in calling December – January (Figure 42).
- Fin whale 40 Hz calls were detected in low numbers at the HAT site, with peaks in hourly call detections in March. Fin whale 40 Hz calls were detected at the NFC site also in low numbers, with a peak occurring November – December 2014 (Figure 43).
- There was no discernable diel pattern for fin whale 40 Hz calls (Figure 44).

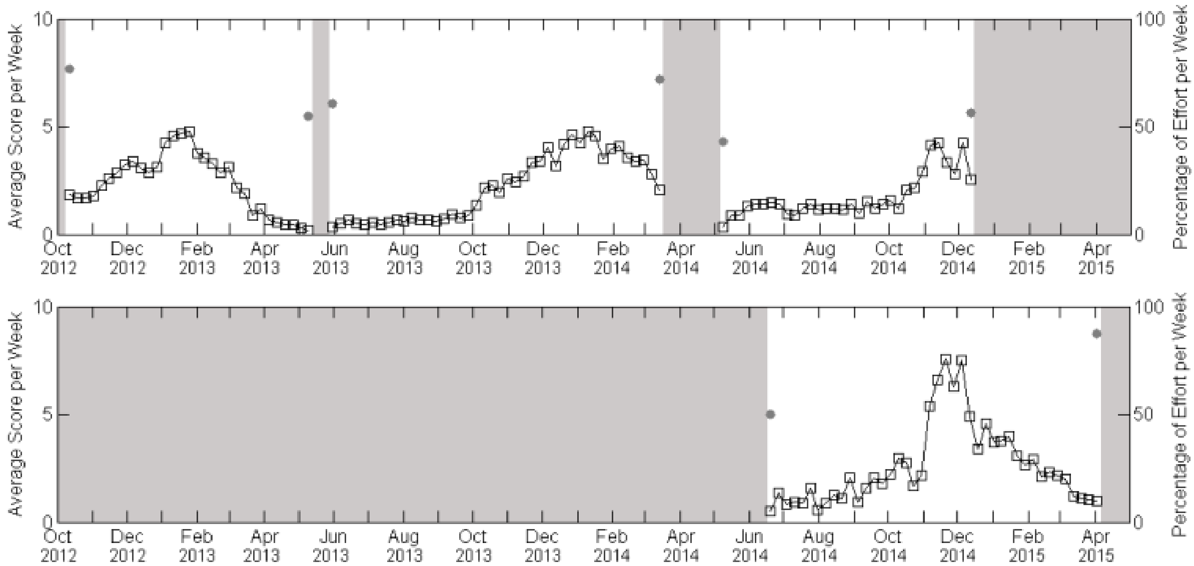

Figure 42. Weekly value of fin whale acoustic index (proxy for 20 Hz calls) October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described in Figure 40.

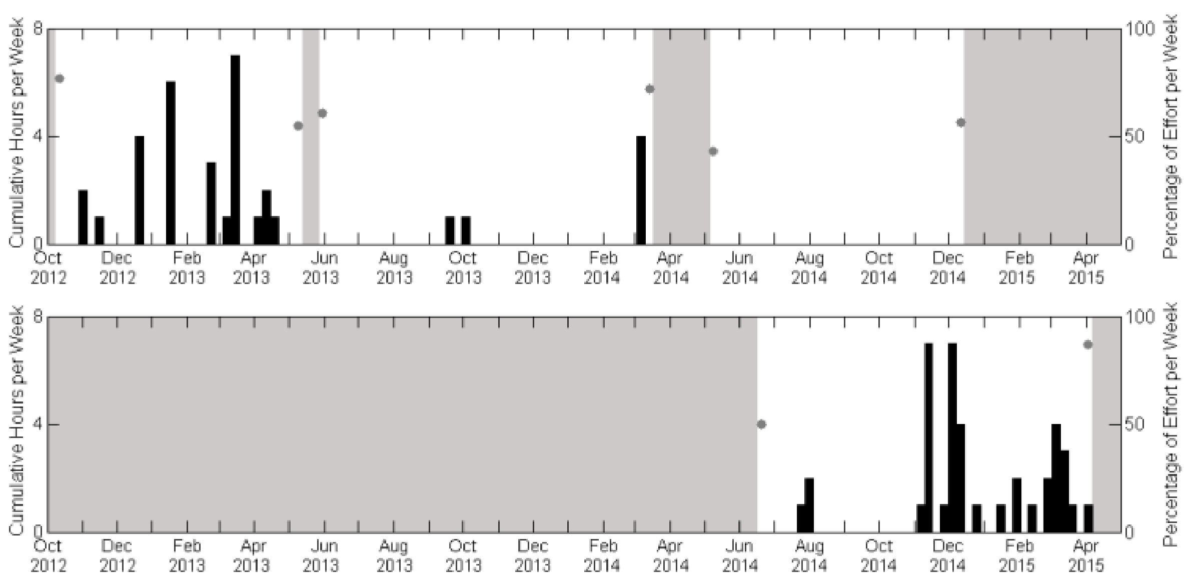

Figure 43. Weekly presence (black bars) of fin whale 40Hz calls October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described in Figure 40.

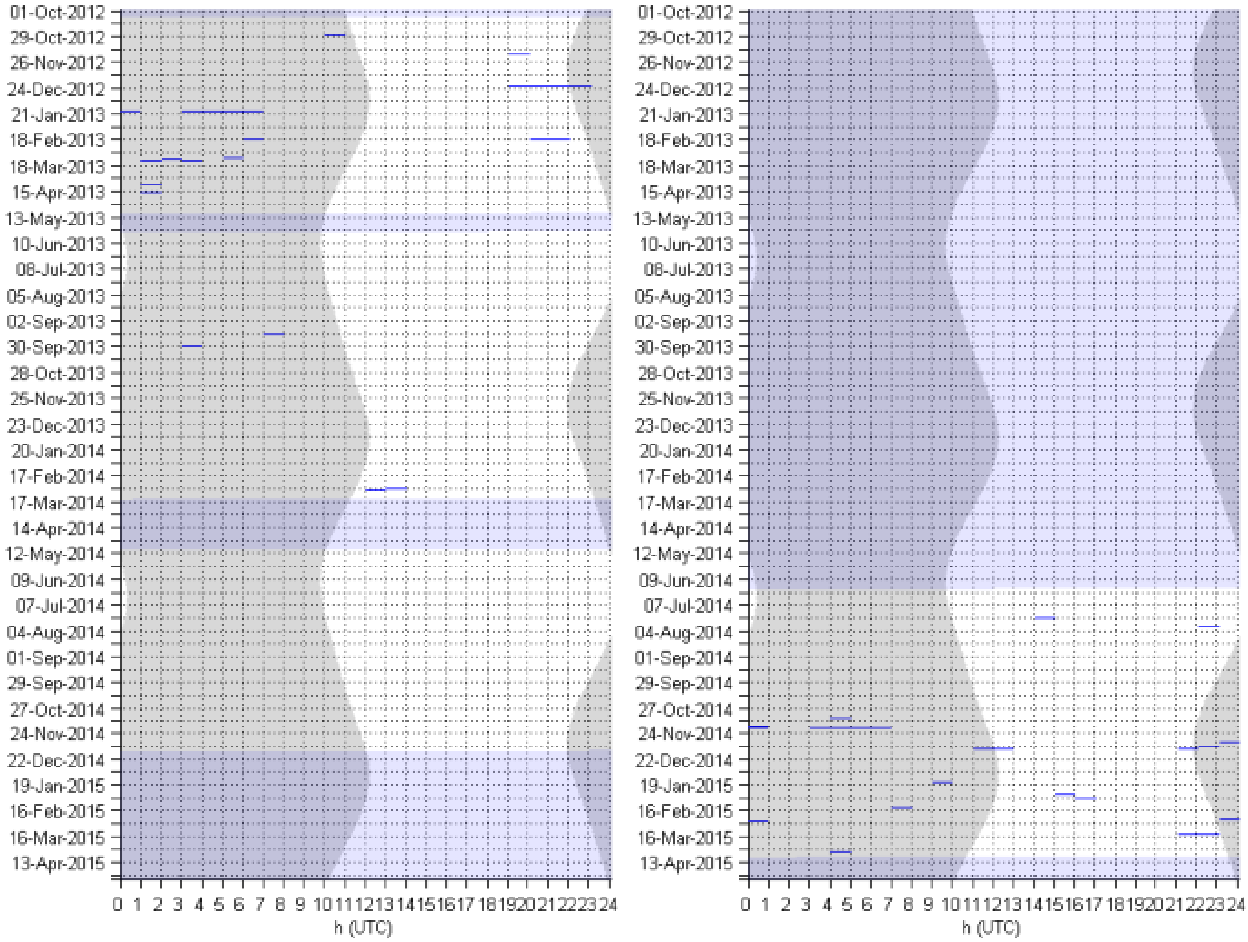

Figure 44. Fin whale 40Hz calls in hourly bins (blue bars) at HAT (left) and NFC (right). Effort markings are described in Figure 41.

Sei Whales

- Sei whale downsweep call detections peaked December – March in 2013 and 2014 at the HAT site (Figure 45).
- Detections at the NFC site peaked in December 2014 and again in April 2015 at the NFC site (Figure 45).
- There was no clear diel pattern for sei whale downsweep calls at either site (Figure 46).

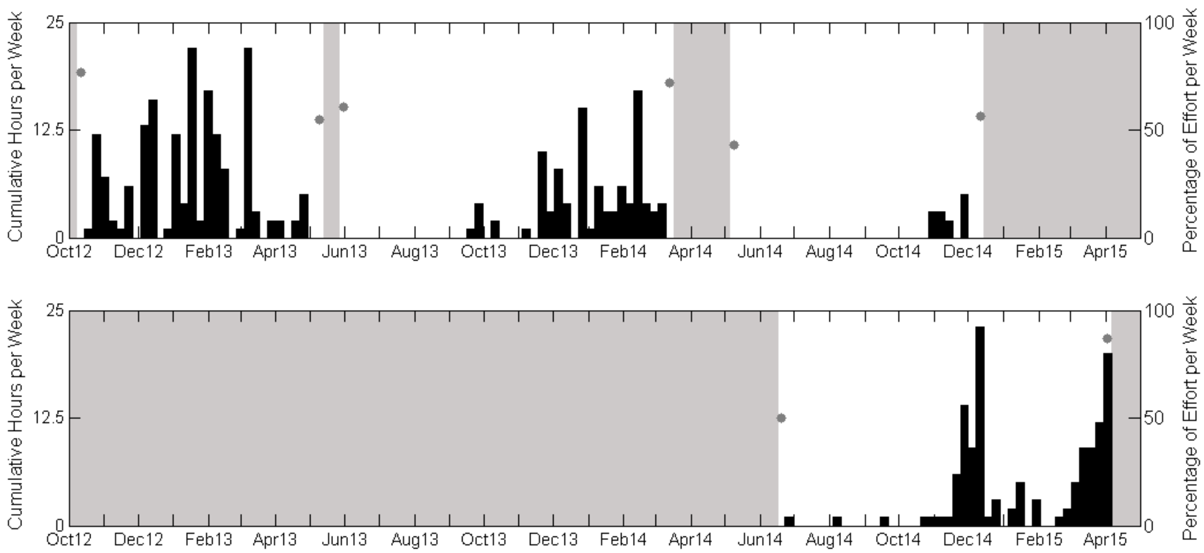

Figure 45. Weekly presence (black bars) of sei whale downsweep calls October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described in Figure 40.

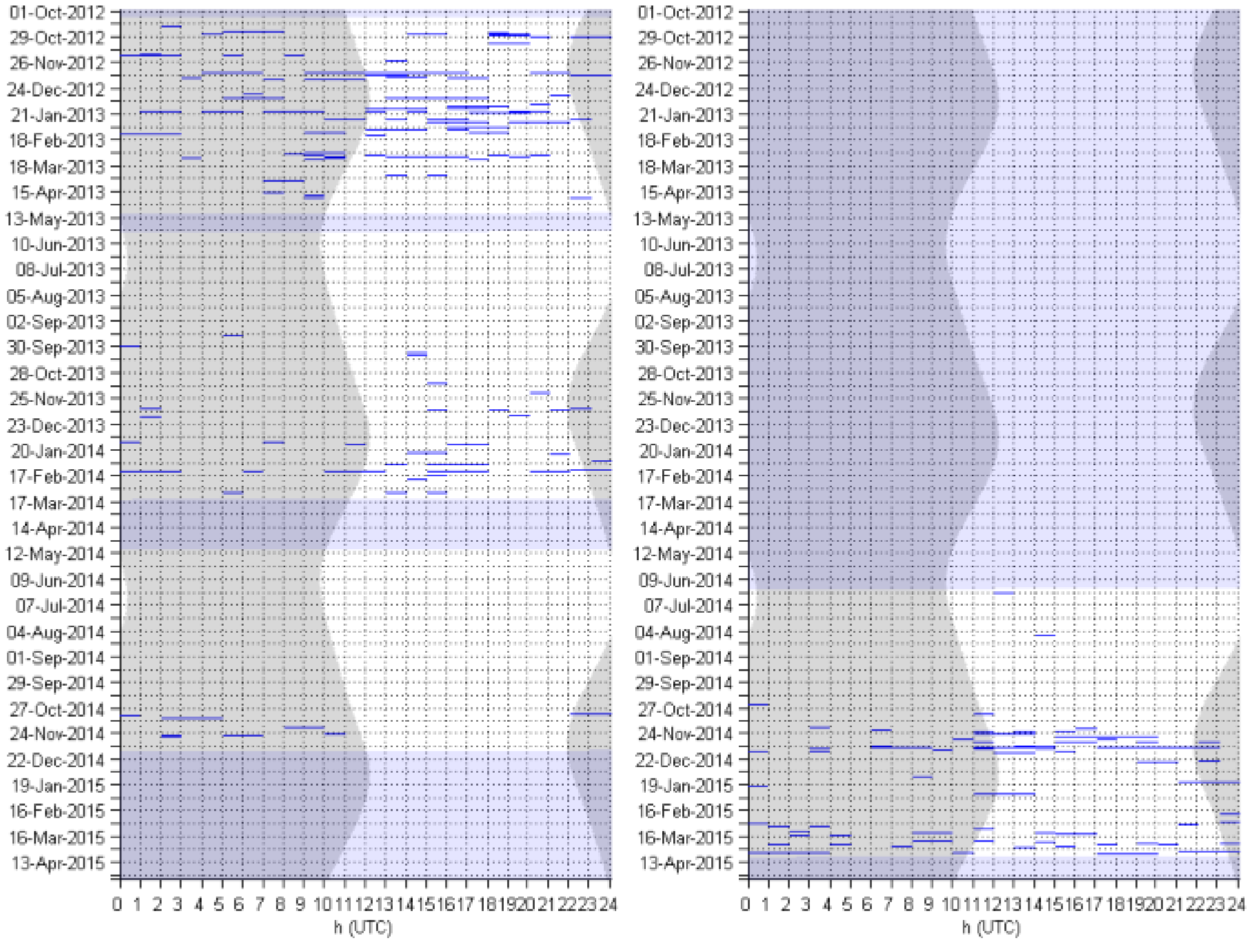

Figure 46. Sei whale downsweep calls in hourly bins (blue bars) at HAT (left) and NFC (right). Effort markings are described in Figure 41.

Minke Whales

- There was a strong seasonal pattern in minke whale pulse trains, with a peak from December – February at the HAT site (Figure 47).
- There were very few minke pulse trains detected at the NFC site (Figure 47).
- There was no discernable diel pattern for minke whale pulse trains (Figure 48).

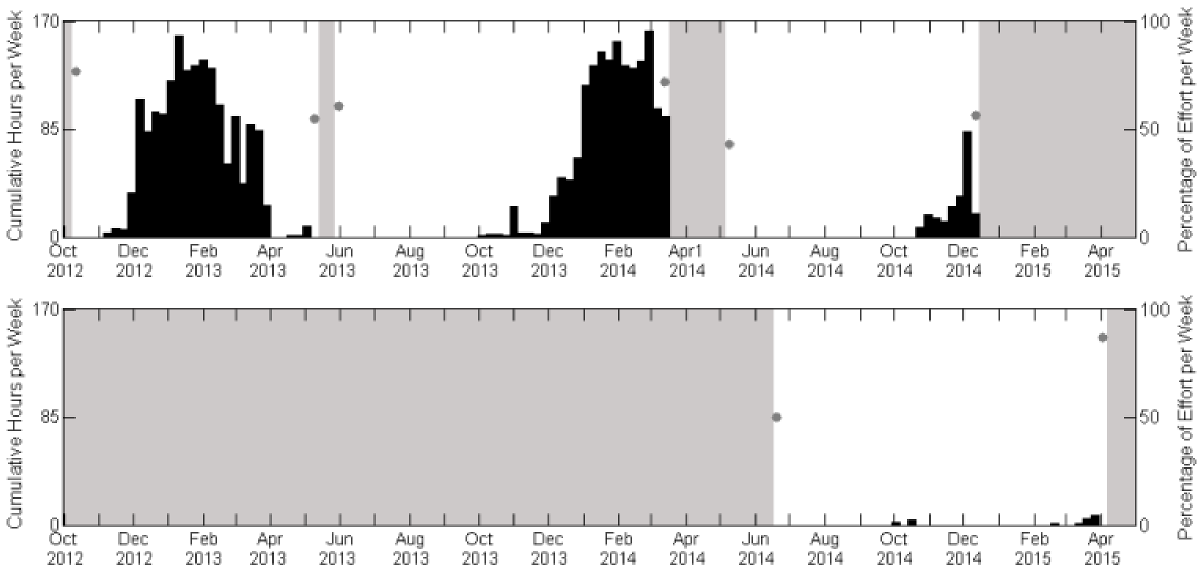

Figure 47. Weekly presence (black bars) of minke whale pulse trains October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described Figure 40.

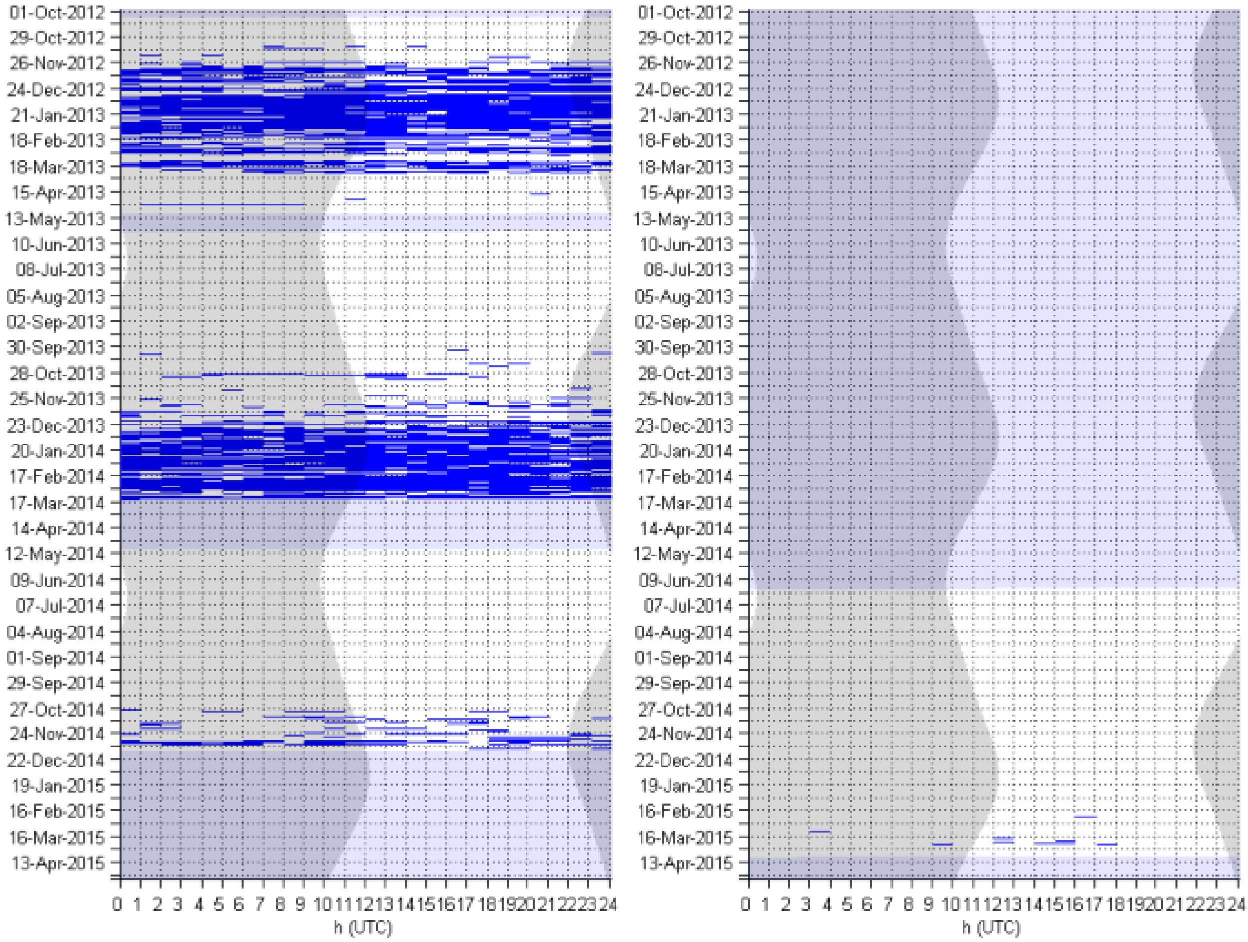

Figure 48. Minke whale pulse trains in hourly bins (blue bars) at HAT (left) and NFC (right). Effort markings are described in Figure 41.

North Atlantic Right Whales

- North Atlantic right whale up-calls were detected in low numbers at the HAT site, and their timing is consistent with passing of migratory animals in the spring and fall (Figure 49).
- There were no detections at the NFC site (Figure 49).
- There were too few detections to determine a diel pattern (Figure 50).

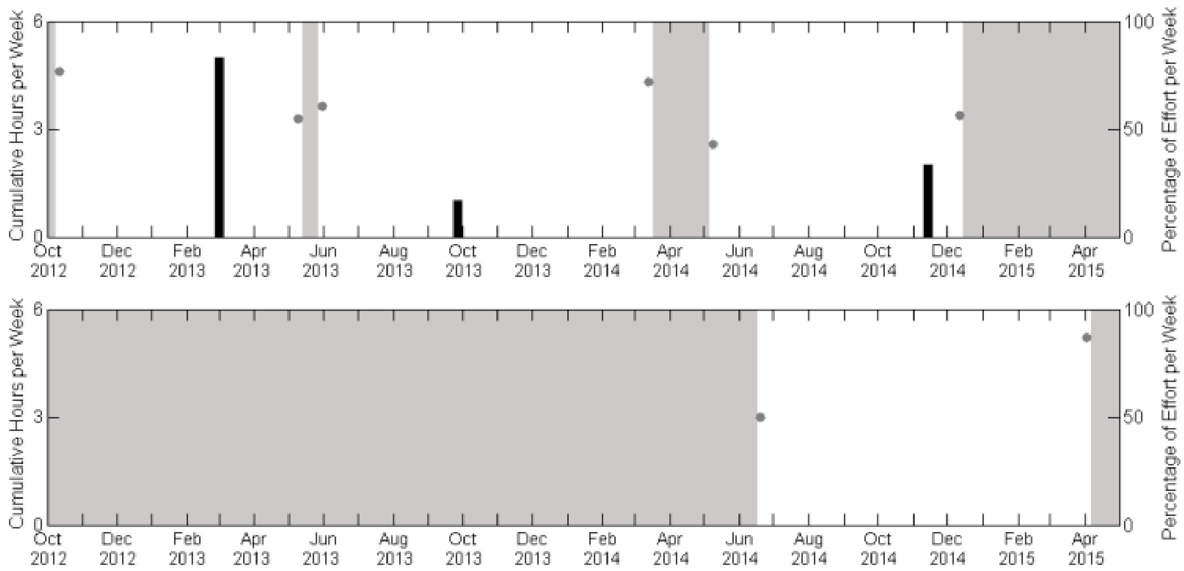

Figure 49. Weekly presence (black bars) of right whale up-calls October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described in Figure 40.

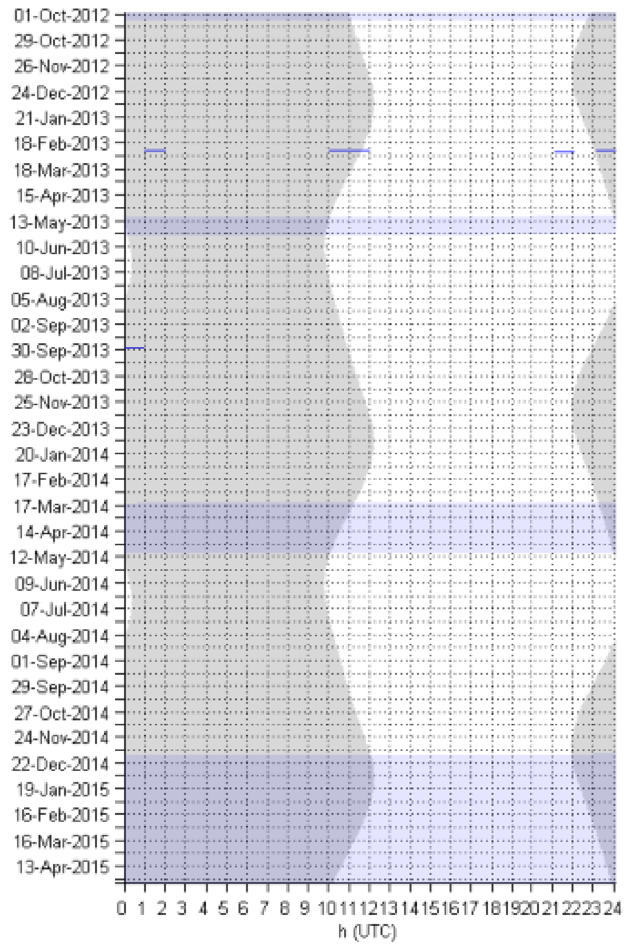

Figure 50. Right whale up-calls in hourly bins (blue bars) at HAT. Effort markings are described in Figure 41.

Humpback Whales

- Humpback whale calls were detected in very low numbers at both sites. A peak in detections at the HAT site occurred in March 2013 (Figure 51).
- There were too few detections to determine a diel pattern for humpback whale calls (Figure 52).

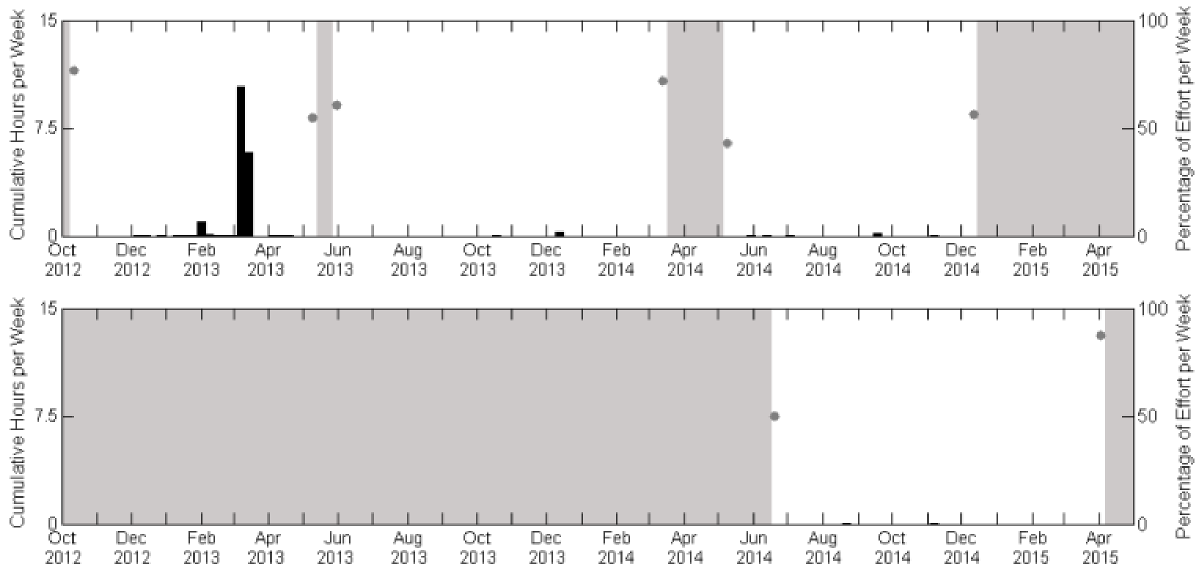

Figure 51. Weekly presence (black bars) of humpback whale calls October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described in Figure 40.

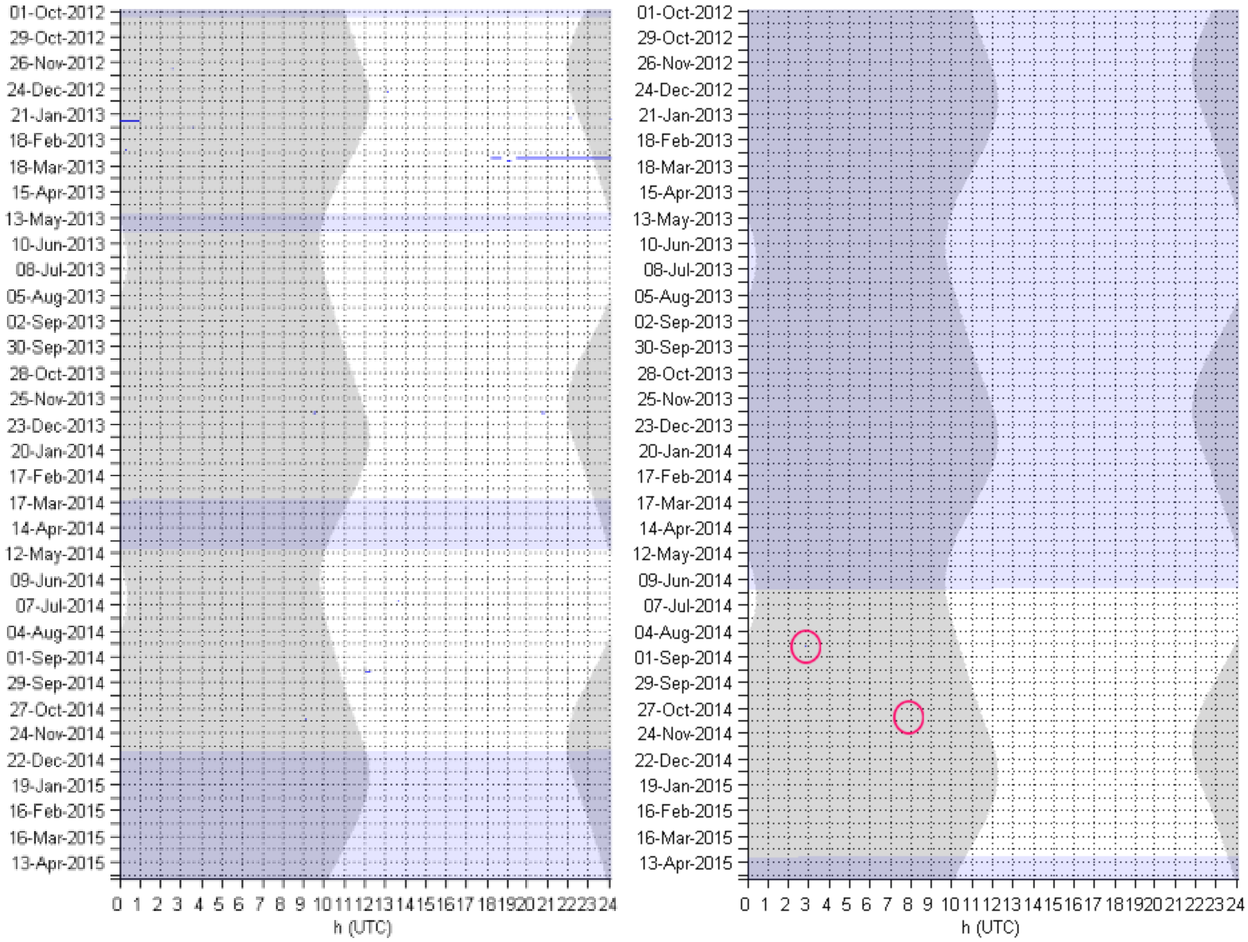

Figure 52. Humpback whale calls in one-minute bins (blue bars) at HAT (left) and NFC (right). Effort markings are described in Figure 41.

Odontocetes

Unidentified odontocete whistles were detected throughout the recordings at each site. Echolocation clicks from three known odontocete species were detected: Risso's dolphins, sperm whales, and *Kogia spp*. Six different click types that are not yet assigned to a species were also detected. More details of each species' presence at these sites are given below.

Unidentified Odontocete Whistles

Unidentified odontocete whistles were detected throughout the recordings at each site.

- Detections of whistles less than 5 kHz peaked in October-December 2013 at HAT and in October 2014 at NFC (Figure 53).
- Detections of whistles >5 kHz peaked in October-December 2012 and in October – November 2013 and November – December 2014 at NFC (Figure 54).
- There was no diel pattern detected for whistles less than 5 kHz (Figure 55).
- While whistles greater than 5 kHz occurred throughout all hours of the day, these whistles were detected slightly more often during nighttime hours (Figure 56).

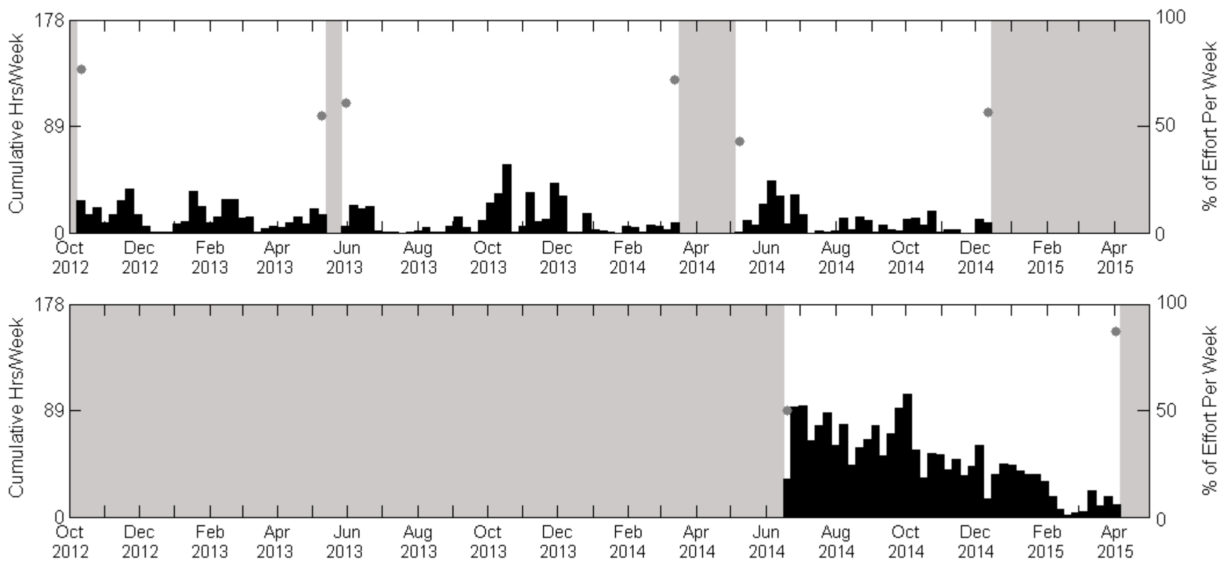

Figure 53. Weekly presence (black bars) of unidentified odontocete whistles less than 5 kHz October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described in Figure 40.

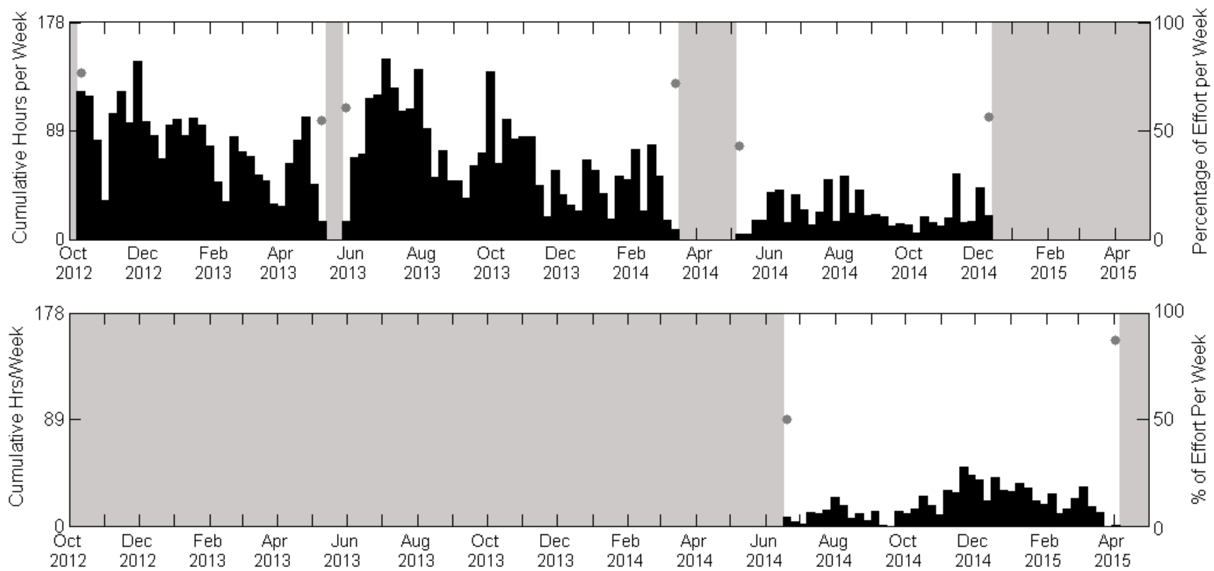

Figure 54. Weekly presence (black bars) of unidentified odontocete whistles greater than 5 kHz October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described in Figure 40.

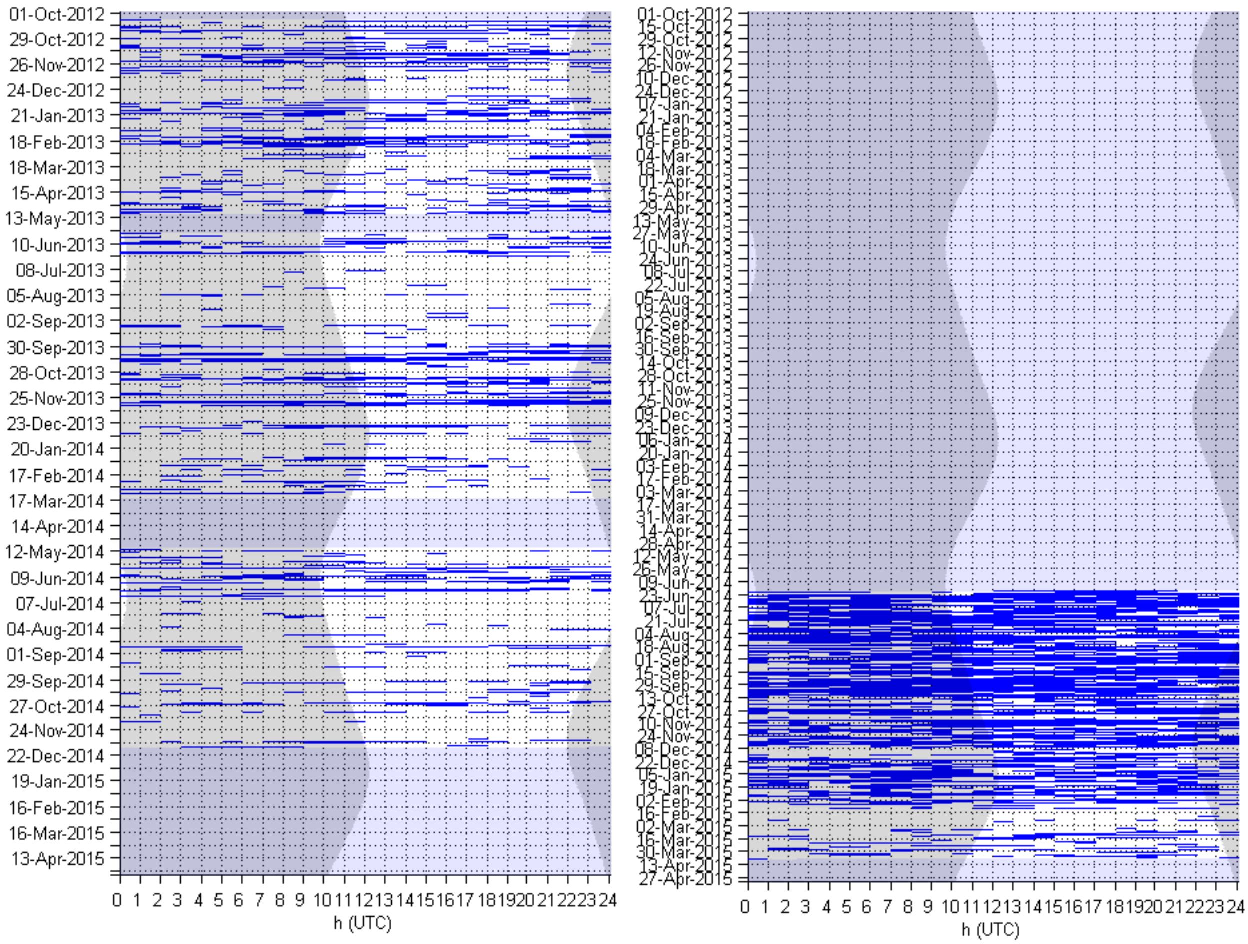

Figure 55. Unidentified odontocete whistles less than 5 kHz in one-minute bins (blue bars) at HAT (left) and NFC (right). Effort markings are described in Figure 41.

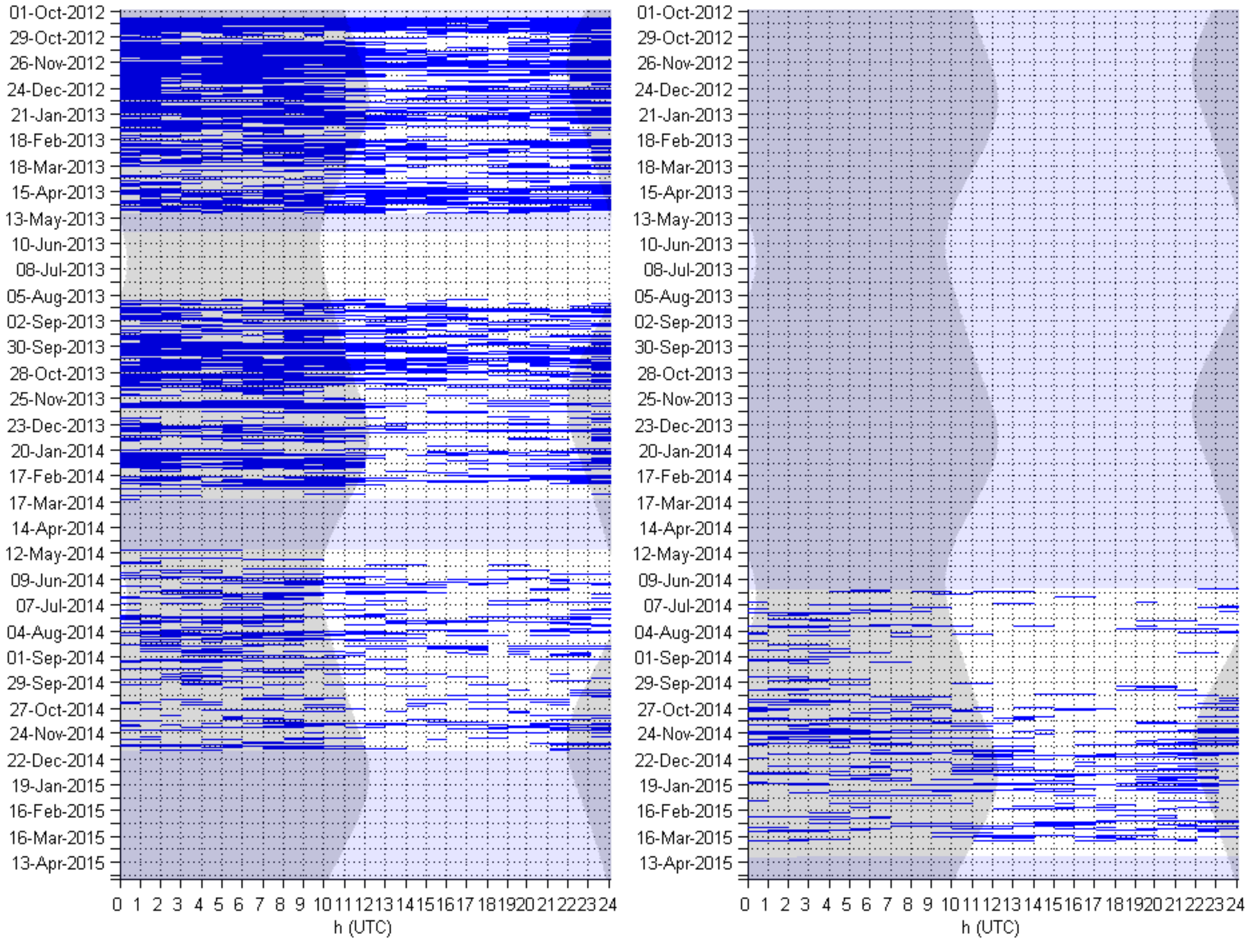

Figure 56. Unidentified odontocete whistles greater than 5 kHz in one-minute bins (blue bars) at HAT (left) and NFC (right). Effort markings are described in Figure 41.

Risso's Dolphins

- Risso's dolphin click detections were sporadic throughout HAT. Detections at NFC peaked in September 2014 (Figure 57).
- More clicks were detected during nighttime hours at HAT, suggesting nighttime foraging. There was no discernable diel pattern at NFC (Figure 58).

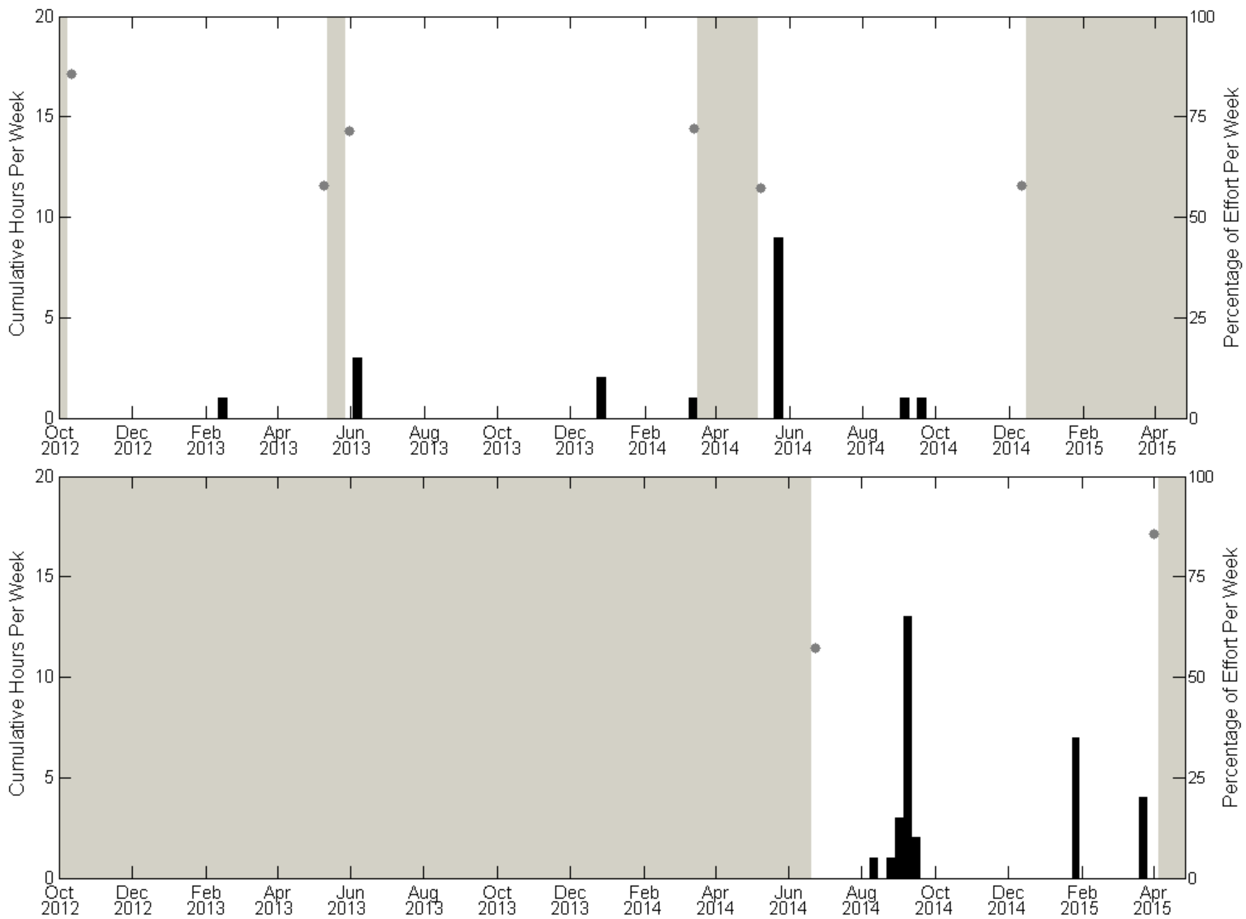

Figure 57. Weekly presence (black bars) of Risso's dolphin clicks October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described in Figure 40.

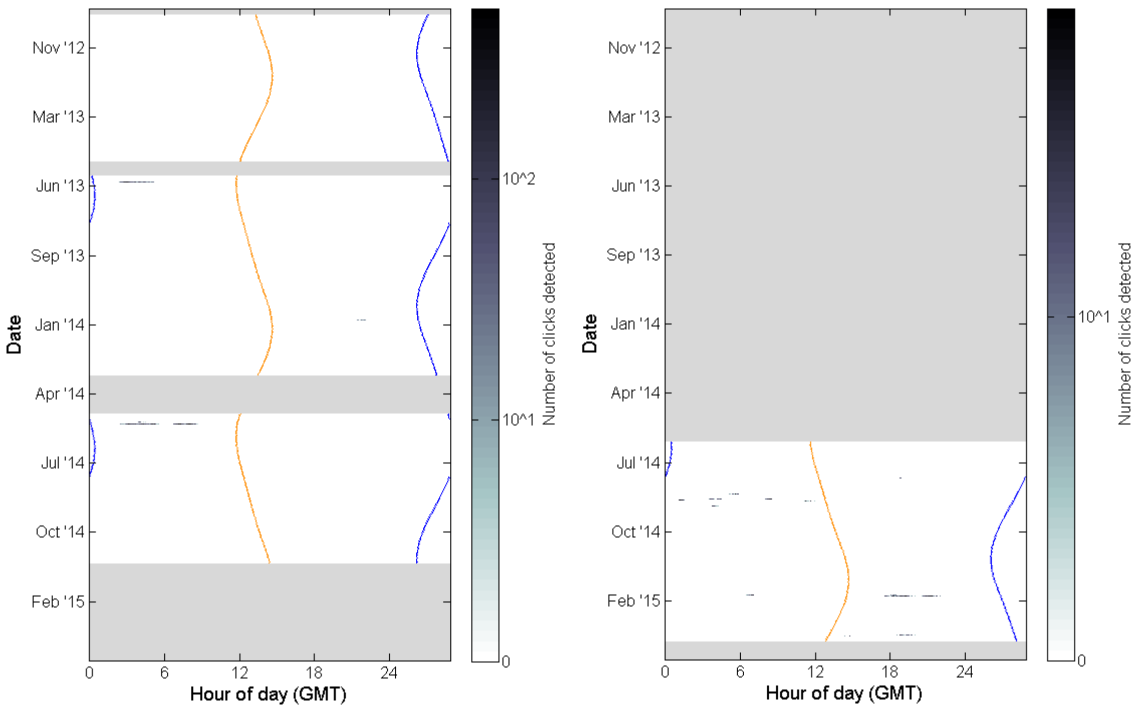

Figure 58. Risso's dolphin clicks in one-minute bins at HAT (left) and NFC (right). The wavy orange line represents sunrise while the wavy violet line represents sunset. The color bar on the right represents number of clicks detected. Gray shading denotes absence of acoustic data.

Sperm Whales

- Sperm whale clicks were detected throughout the deployments at each site. Peaks in detections at the HAT site occurred January through February 2013 and 2014 and again in summer months (Figure 59). Sperm whale detections peaked at the NFC site in August 2014 and April 2015 (Figure 59), indicating a possible seasonal migration past both sites towards more southern areas over winter.
- There were no diel patterns for sperm whale clicks at either site (Figure 60).

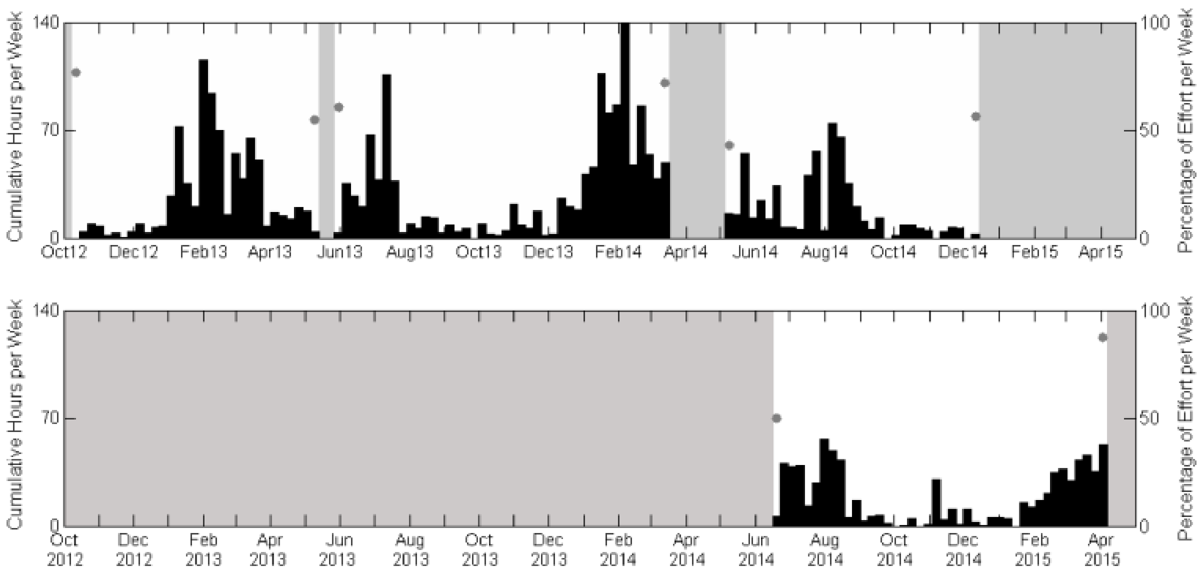

Figure 59. Weekly presence (black bars) of sperm whale clicks October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described in Figure 40.

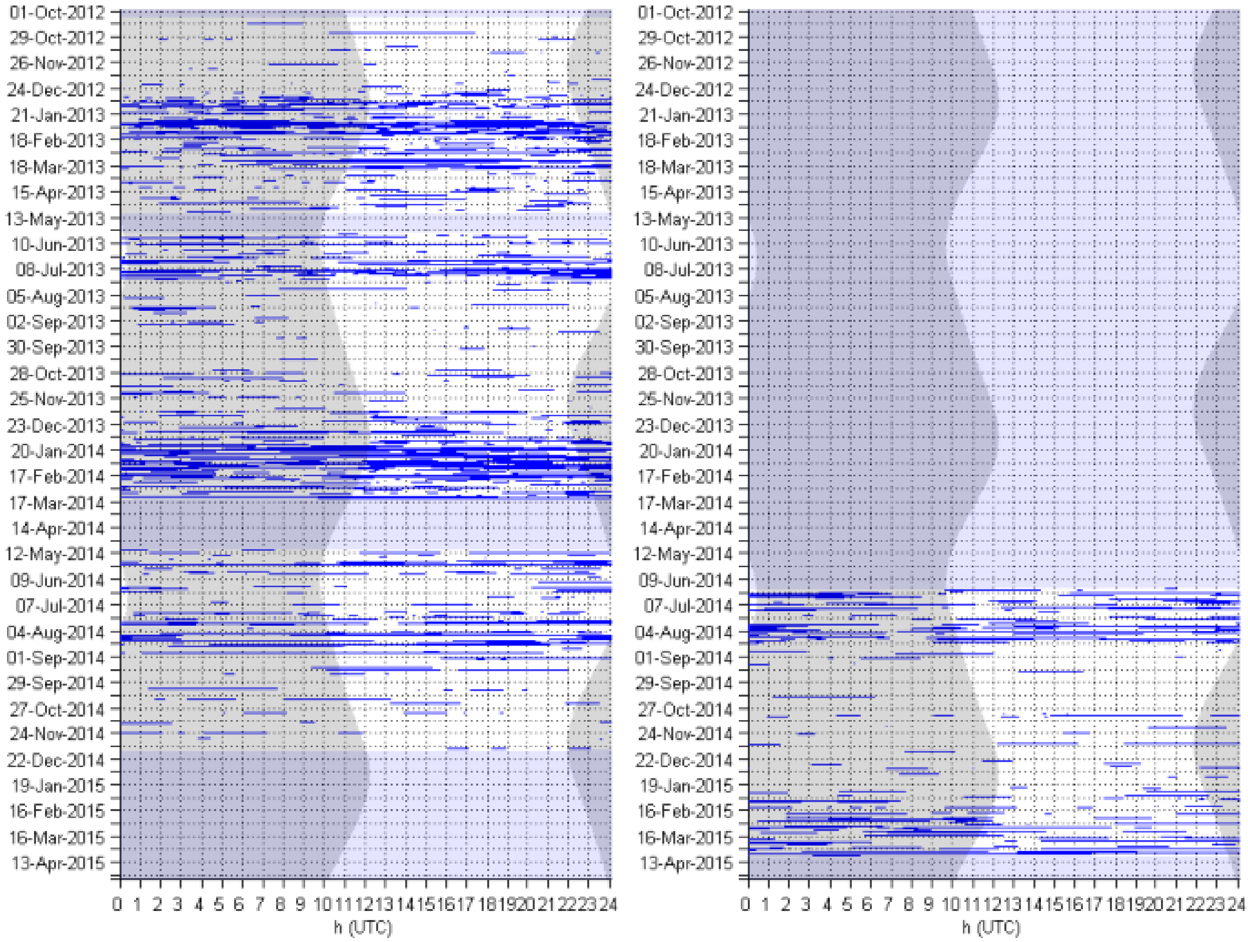

Figure 60. Sperm whale echolocation clicks in one-minute bins (blue bars) at HAT (left) and NFC (right). Effort markings are described in Figure 41.

Kogia *Spp*.

- *Kogia spp*. echolocation clicks were detected throughout the recording period at both sites; however there were more detections at HAT than NFC (Figure 61). Peaks in detections at HAT occurred during winter months (Figure 61).
- There were no diel patterns for *Kogia spp*. clicks (Figure 62).

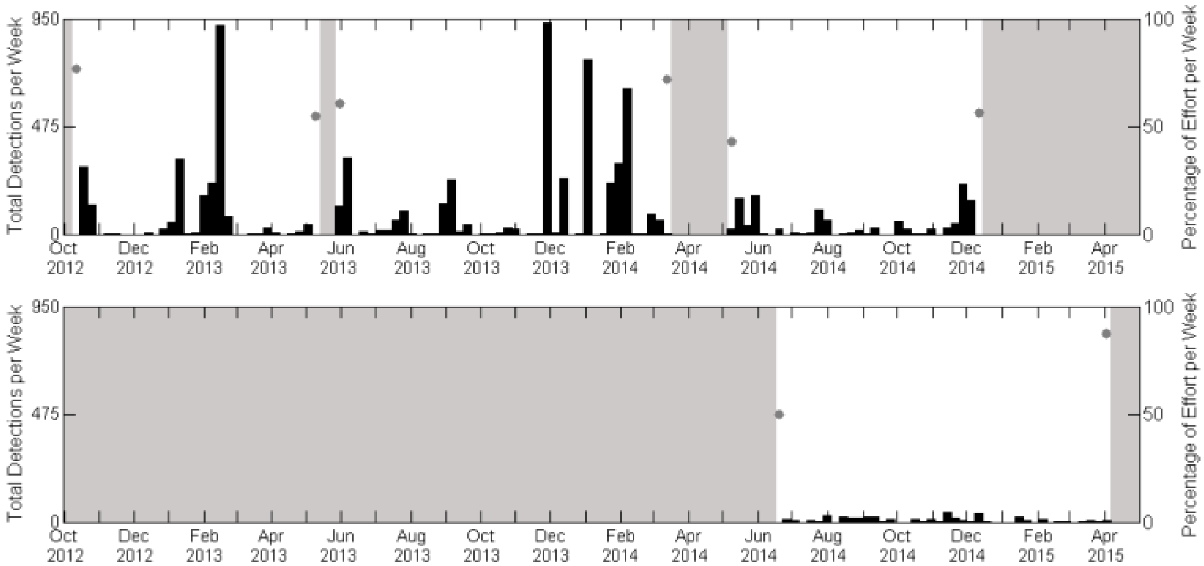

Figure 61. Weekly presence (black bars) of *Kogia spp*. clicks October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described in Figure 40.

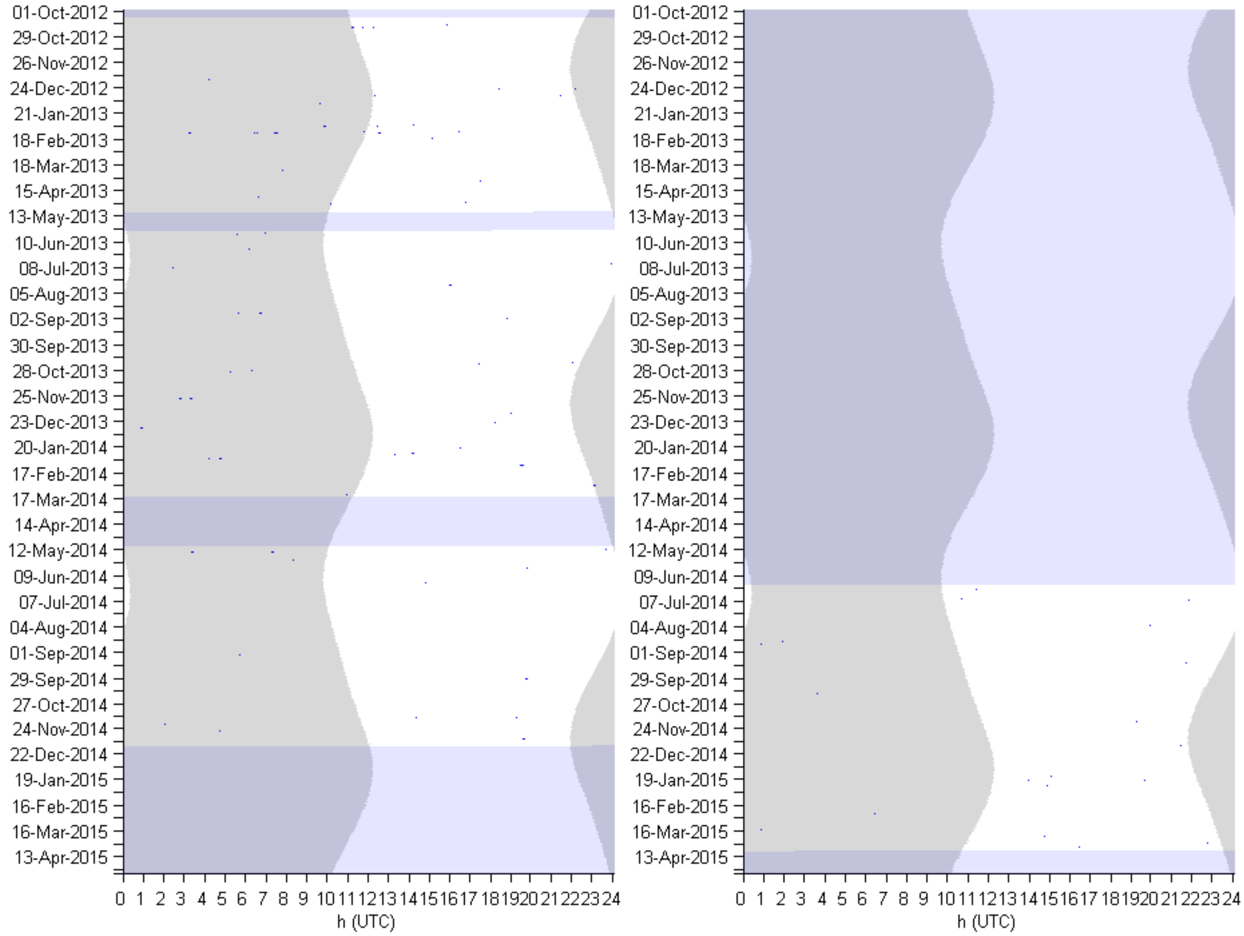

Figure 62. ***Kogia spp*. clicks in one-minute bins (blue bars) at HAT (left) and NFC (right). Effort markings are described in Figure 41.**

Echolocation Click Types

Click Type 1

- Click type 1 was detected throughout the recording period at both sites. A peak in detections occurred in April 2013 at the HAT site, while a peak in detections occurred in January 2015 at the NFC site (Figure 63).
- The majority of click type 1 detections occurred during nighttime hours, indicating foraging at night (Figure 64).
- The average ICI of this echolocation click is similar to what is found in species belonging to the *Stenella* genus.

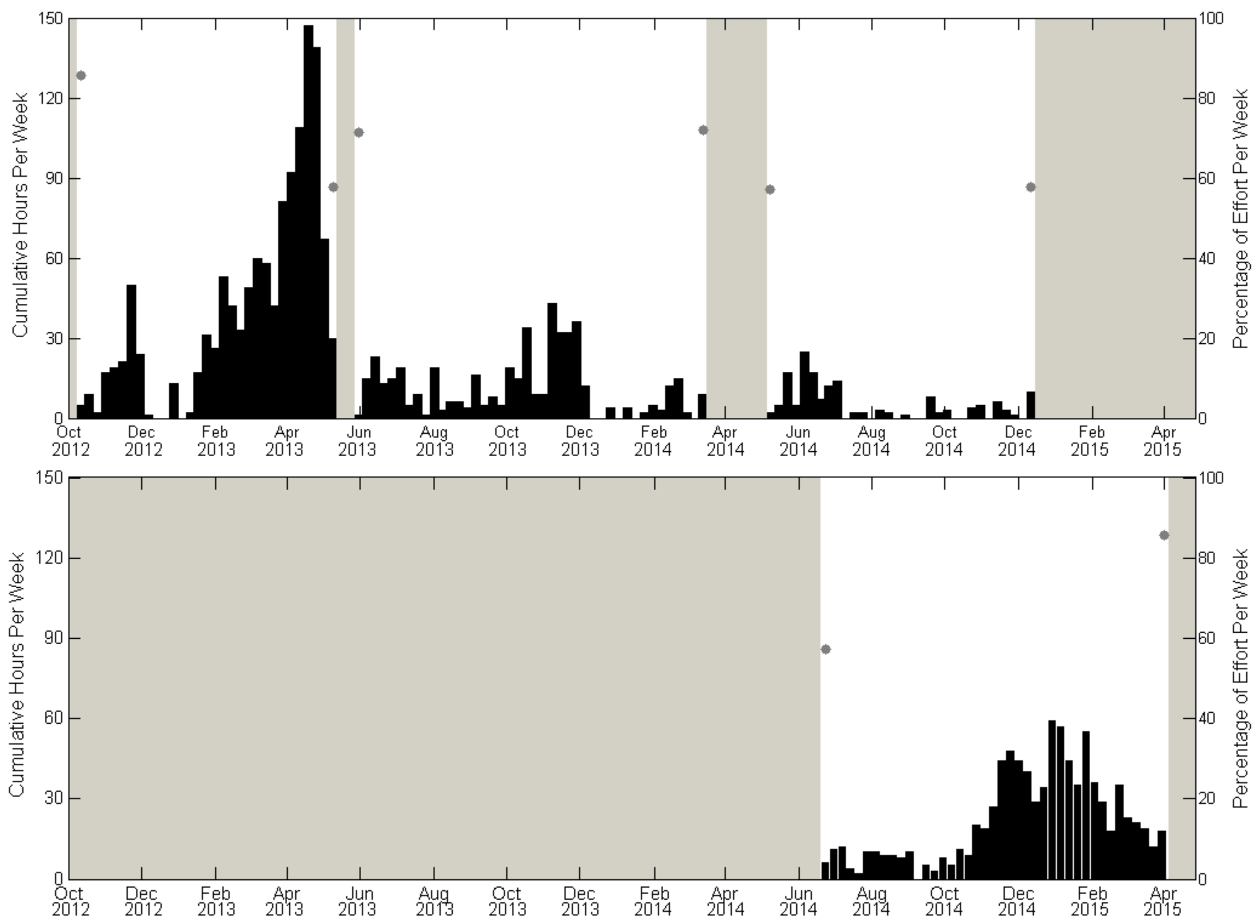

Figure 63. Weekly presence (black bars) of Click Type 1 detections October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described in Figure 40.

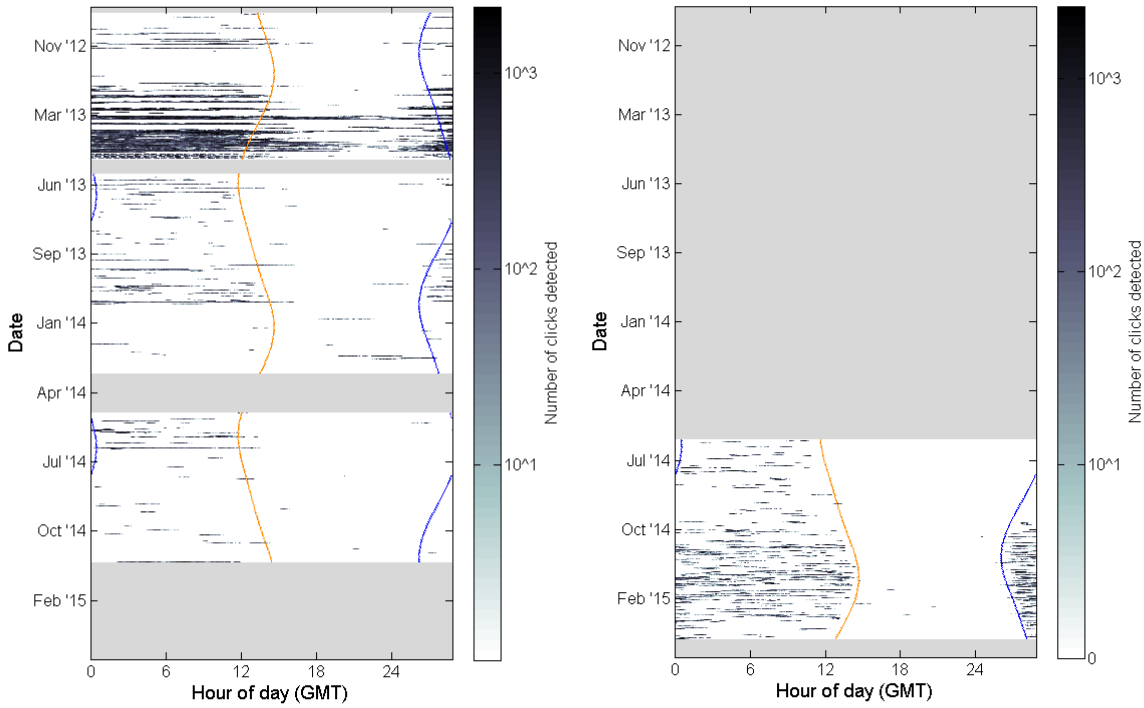

Figure 64. Click Type 1 detections in one-minute bins at HAT (left) and NFC (right). Effort markings are described in Figure 58.

Click Type 2

- Click type 2 was detected only a few hours per week at NFC in March 2015. There were no click type 2 detections at HAT (Figure 65).
- All detections of click type 2 occurred during daytime hours at NFC (Figure 66).

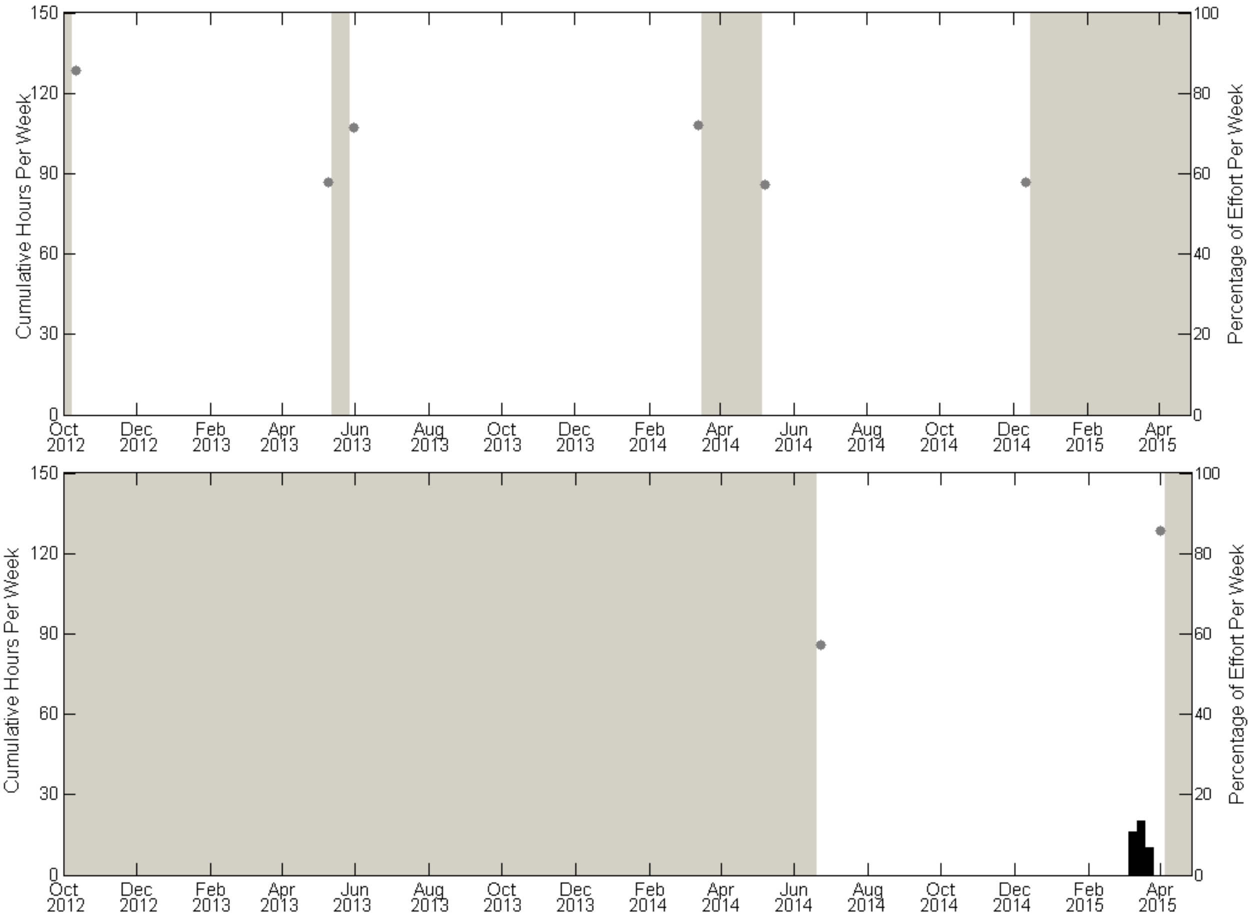

Figure 65. Weekly presence (black bars) of Click Type 2 detections October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described in Figure 40.

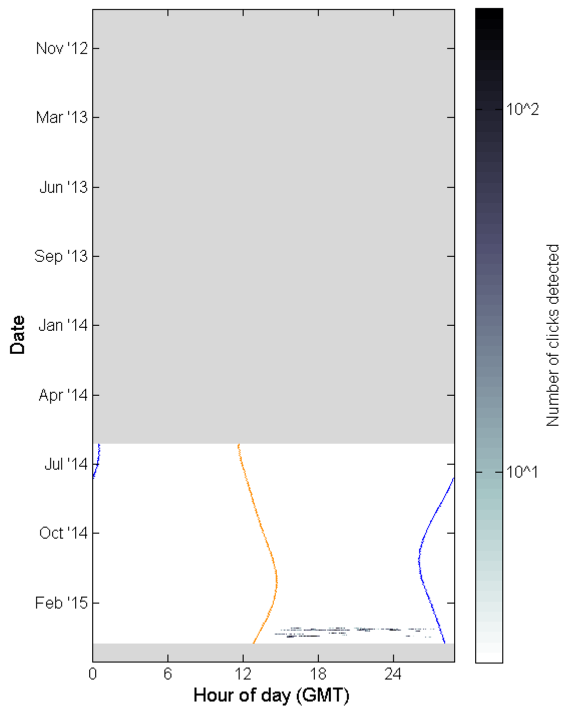

Figure 66. Click Type 2 detections in one-minute bins (blue bars) at NFC. Effort markings are described in Figure 58.

Click Type 3

- Click type 3 was detected throughout the recording period at both sites (Figure 67).
- Most clicks occurred during daytime hours at NFC. The diel pattern was not as clear at HAT, since numerous detections happened during nighttime hours at HAT, but most click detections still occurred during the day at this site (Figure 68).

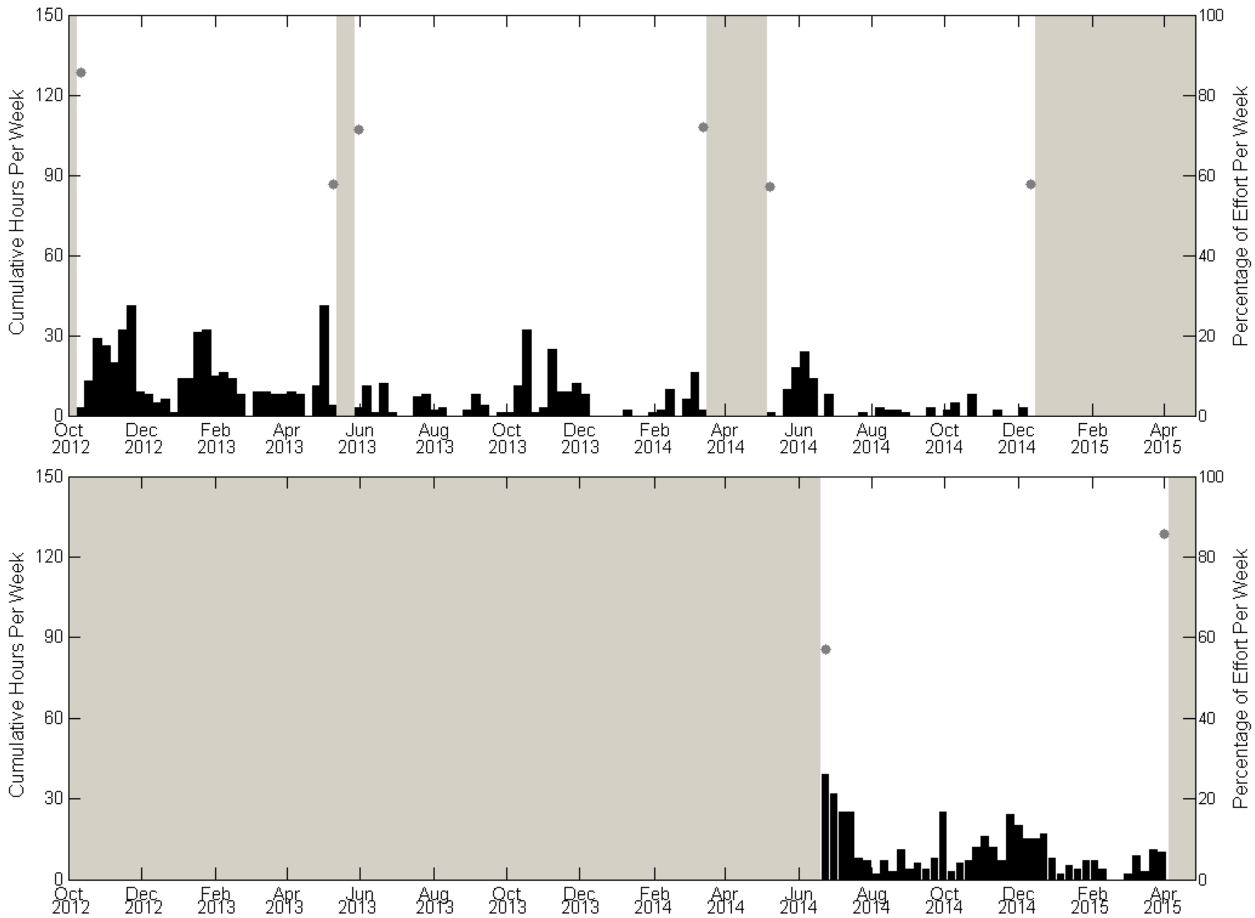

Figure 67. Weekly presence (black bars) of Click Type 3 detections October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described in Figure 40.

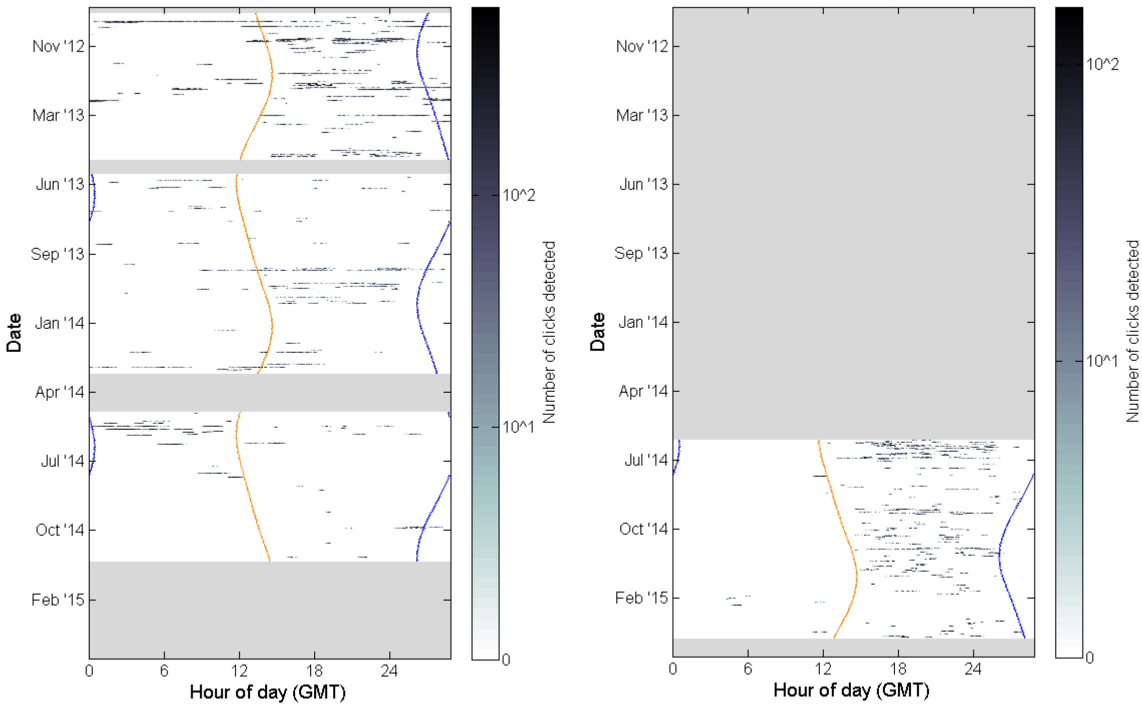

Figure 68. Click Type 3 detections in one-minute bins at HAT (left) and NFC (right). Effort markings are described in Figure 58.

Click Type 4

- Click type 4 had a strong presence throughout the recording period at both sites; however, more hours per week were detected at HAT than NFC (Figure 69).
- Detections at HAT peaked in December 2012 and showed an overall decrease from year to year (Figure 69).
- Click type 4 was detected predominantly at night, suggesting nighttime foraging (Figure 70).

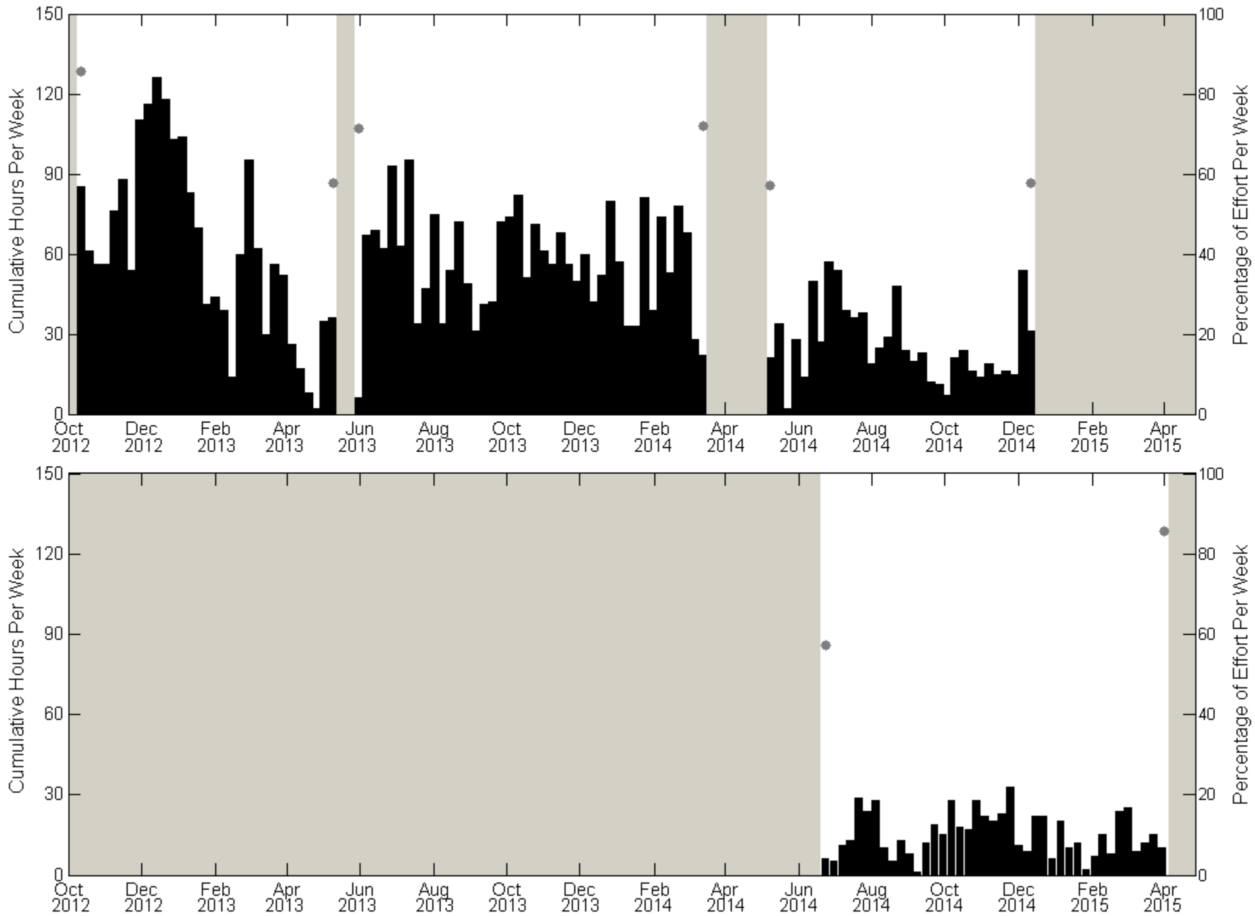

Figure 69. Weekly presence (black bars) of Click Type 4 detections October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described in Figure 40.

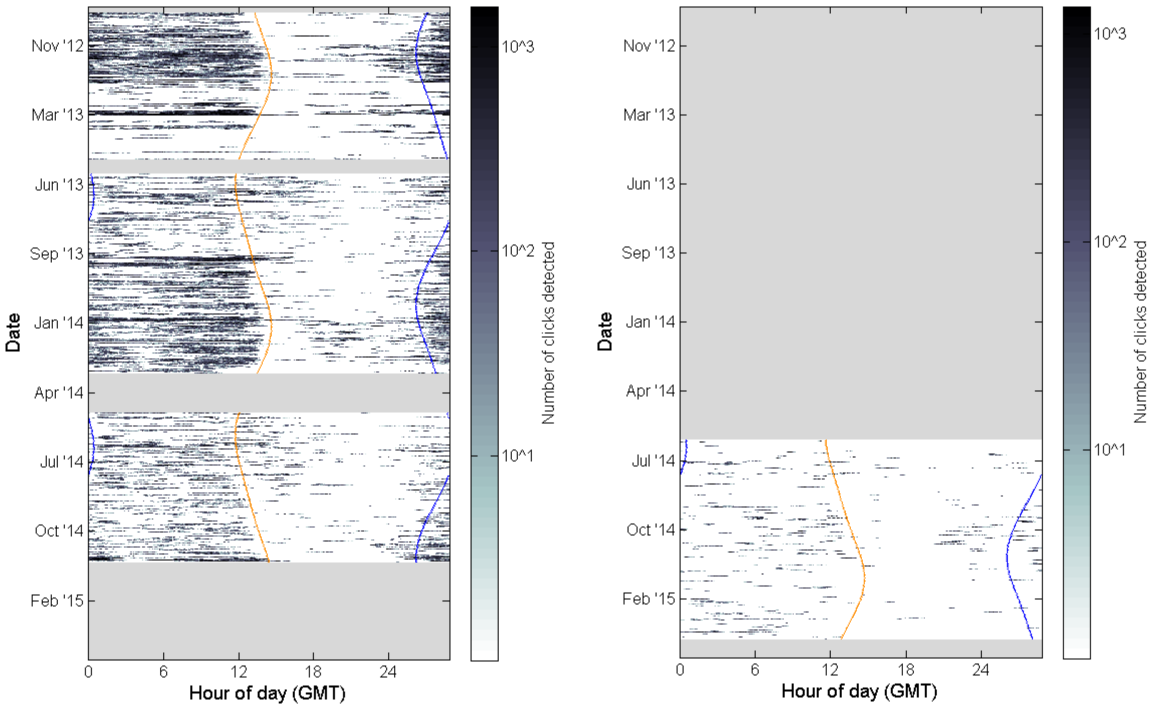

Figure 70. Click Type 4 detections in one-minute bins at HAT (left) and NFC (right). Effort markings are described in Figure 58.

Click Type 5

- Click type 5 was detected October 2012 – December 2013 at HAT, with a peak in detections from February to April 2013. There were no click type 5 detections at NFC (Figure 71).
- There was no discernable diel pattern for click type 5 (Figure 72).

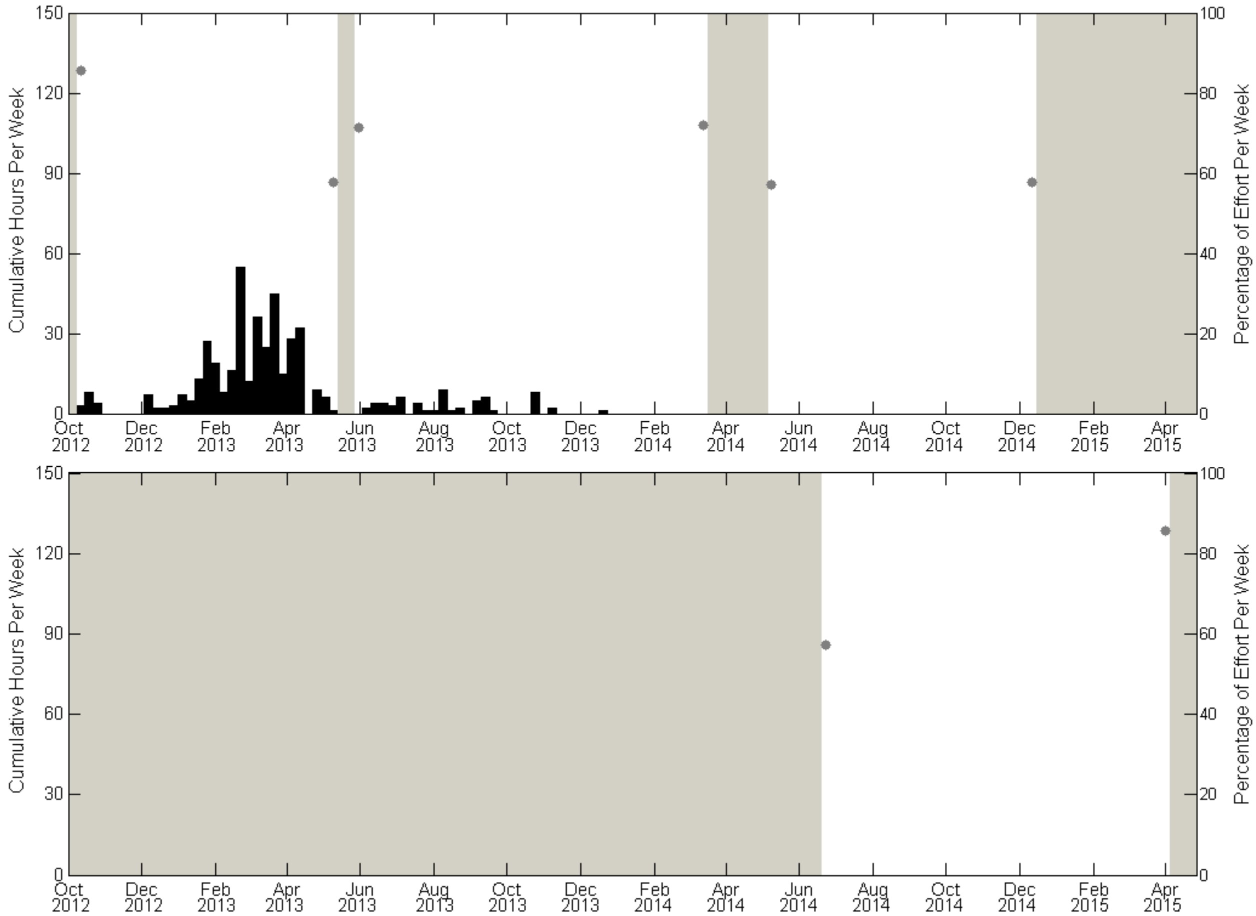

Figure 71. Weekly presence (black bars) of Click Type 5 detections October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described in Figure 40.

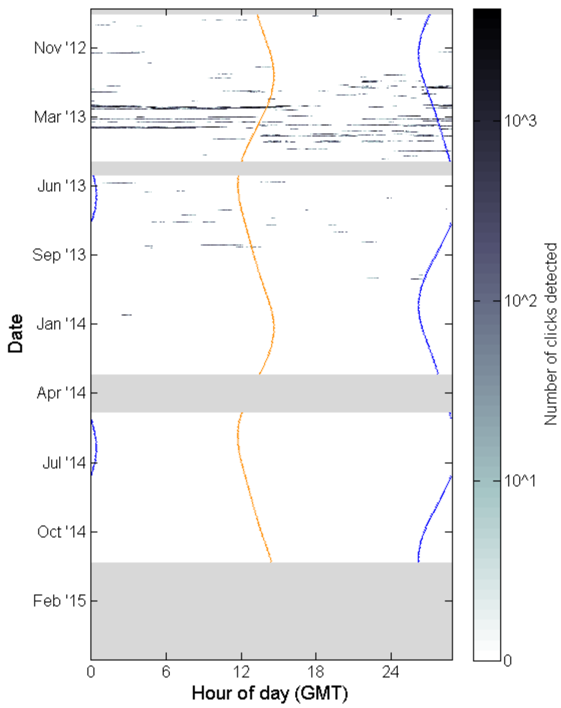

Figure 72. Click Type 5 detections in one-minute bins at HAT. Effort markings are described in Figure 58.

Click Type 6

- Click type 6 was detected with very few hours per week at both sites (Figure 73).
- Most click type 6 detections occurred during nighttime hours, suggesting foraging at night (Figure 74).

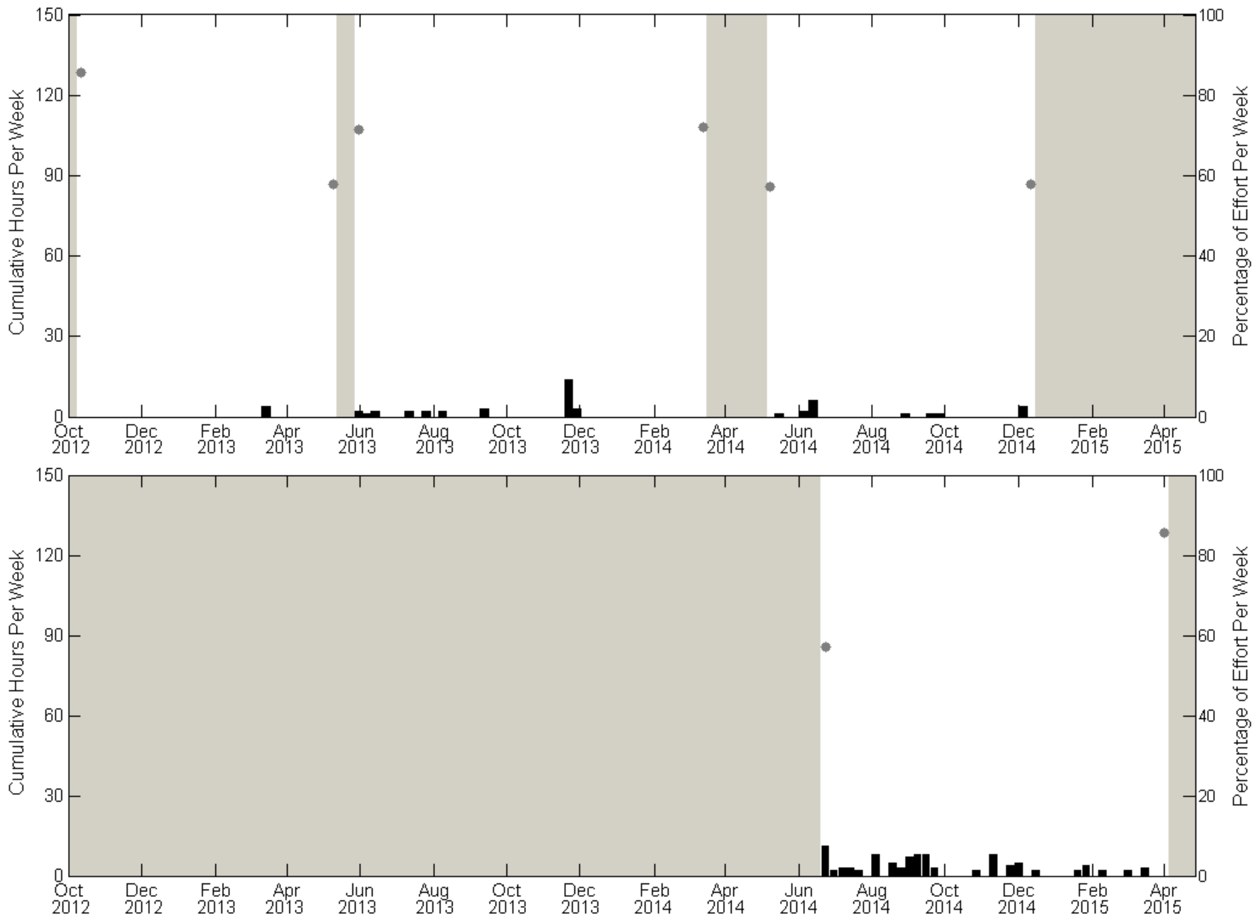

Figure 73. Weekly presence (black bars) of Click Type 6 detections October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described in Figure 40.

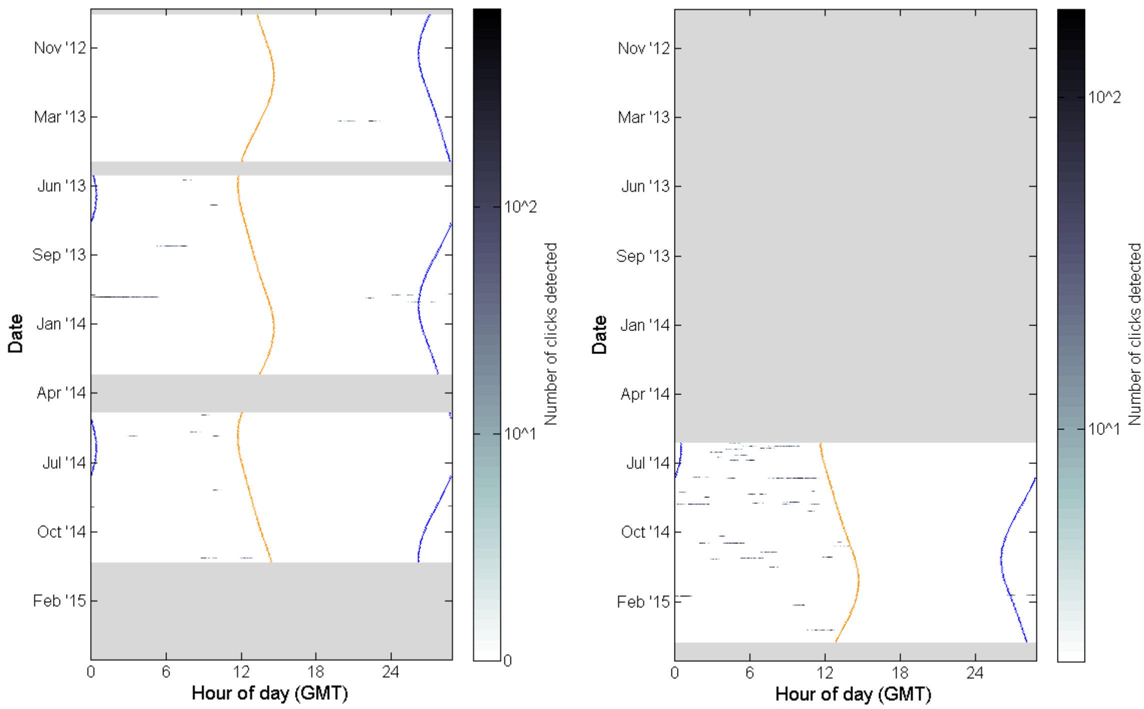

Figure 74. Click Type 6 detections in one-minute bins at HAT (left) and NFC (right). Effort markings are described in Figure 58.

Anthropogenic Sounds

Seven types of anthropogenic sounds were detected: broadband ship noise, echosounders, explosions, airguns, HFA sonar, MFA sonar, and LFA sonar (500-1000 Hz).

Broadband Ship Noise

- Broadband ship noise was detected throughout the deployments at both sites. Detections at the HAT site peaked in August 2013 while detections at the NFC site peaked in July 2014 (Figure 74).
- There was no discernable diel pattern for broadband ship noise at either site (Figure 75).

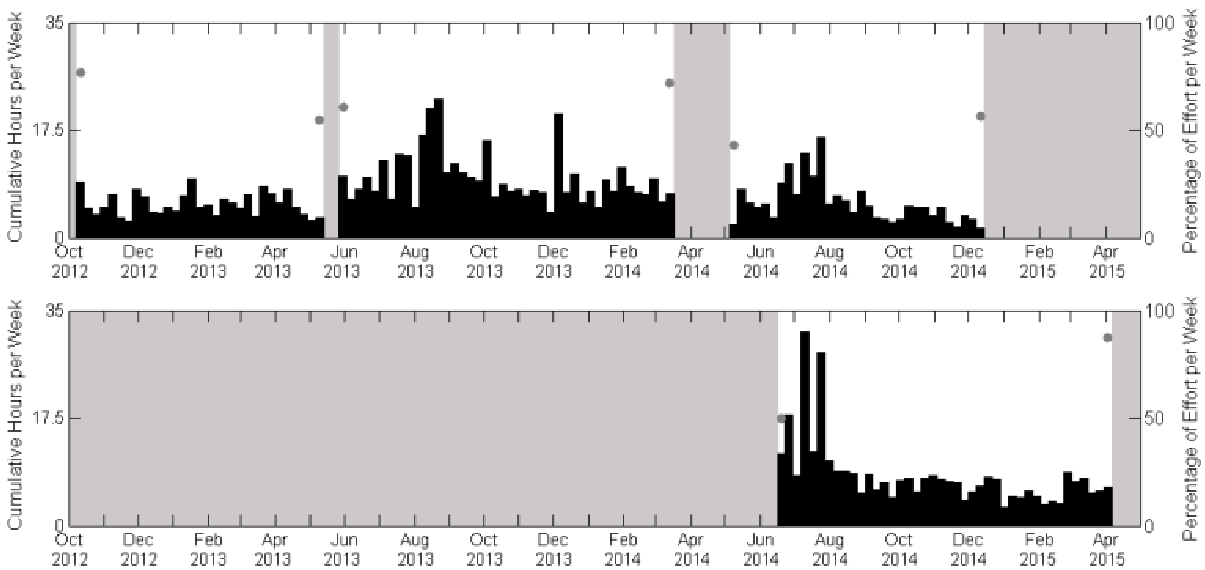

Figure 75. Weekly presence (black bars) of broadband ship noise October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described in Figure 40.

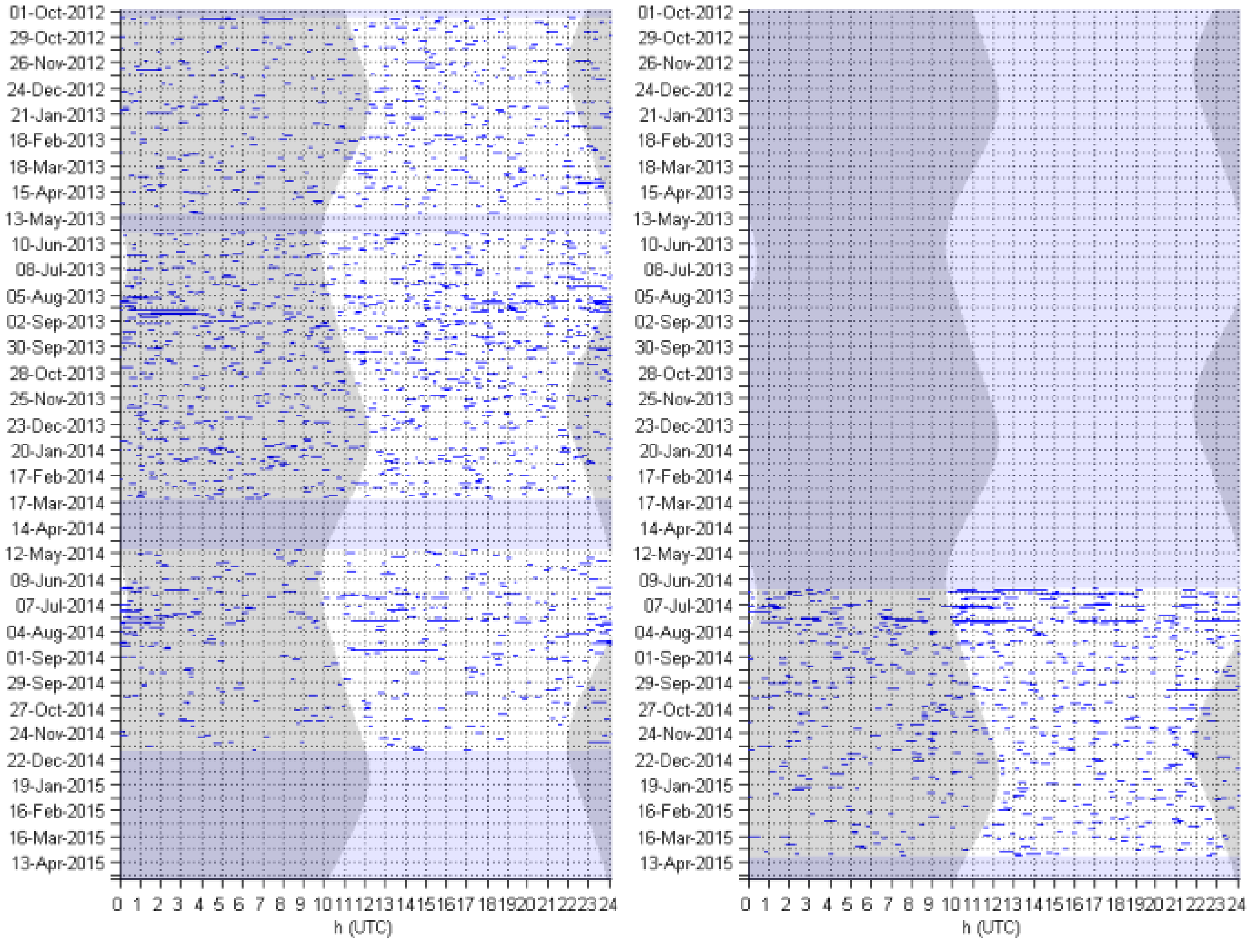

Figure 76. Broadband ship noise in one-minute bins (blue bars) at HAT (left) and NFC (right). Effort markings are described in Figure 41.

Explosions

- Explosions were detected in low numbers in November 2013 at the HAT site. There were no explosions detected at the NFC site (Figure 77).
- There were too few detections to determine a diel pattern (Figure 78).
- Most of these explosions were strong signals that were broadband with a duration of several seconds, suggesting naval activity.

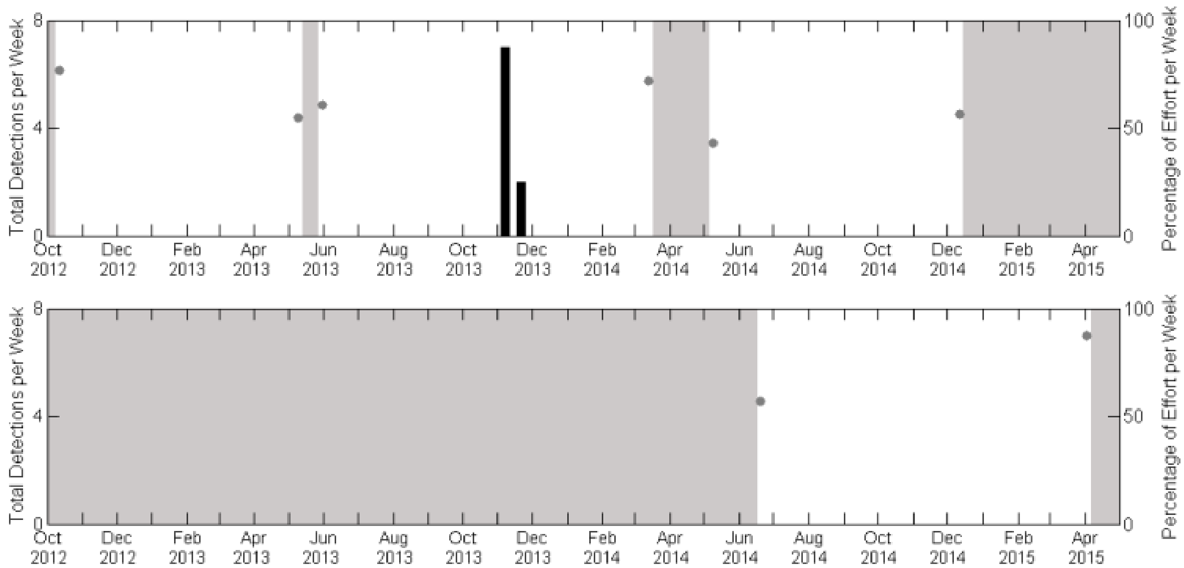

Figure 77. Weekly presence (black bars) of explosions October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described in Figure 40.

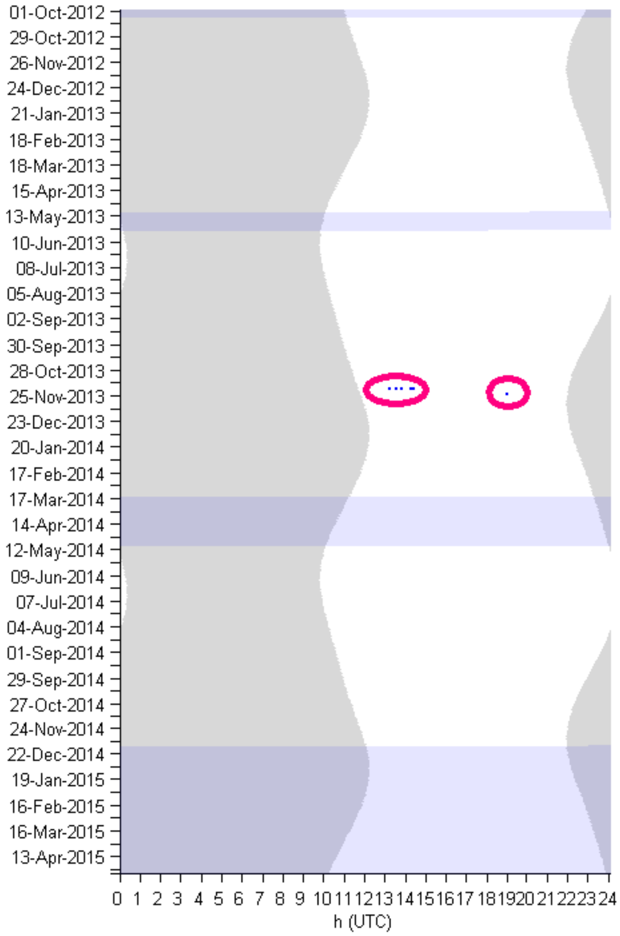

Figure 78. Explosion detections in one-minute bins (blue bars circled in pink) at HAT. Effort markings are described in Figure 41.

Airguns

- Airguns were detected throughout the entire recording at HAT. Peaks in airgun detections occurred June 2013 and again June – October 2014 (Figure 79).
- Peaks in airgun detections at NFC occurred October 2014 (Figure 79).
- The majority of airgun detections were of low received level indicating distant surveys.
- There was no discernable diel pattern for airguns at either site (Figure 80).

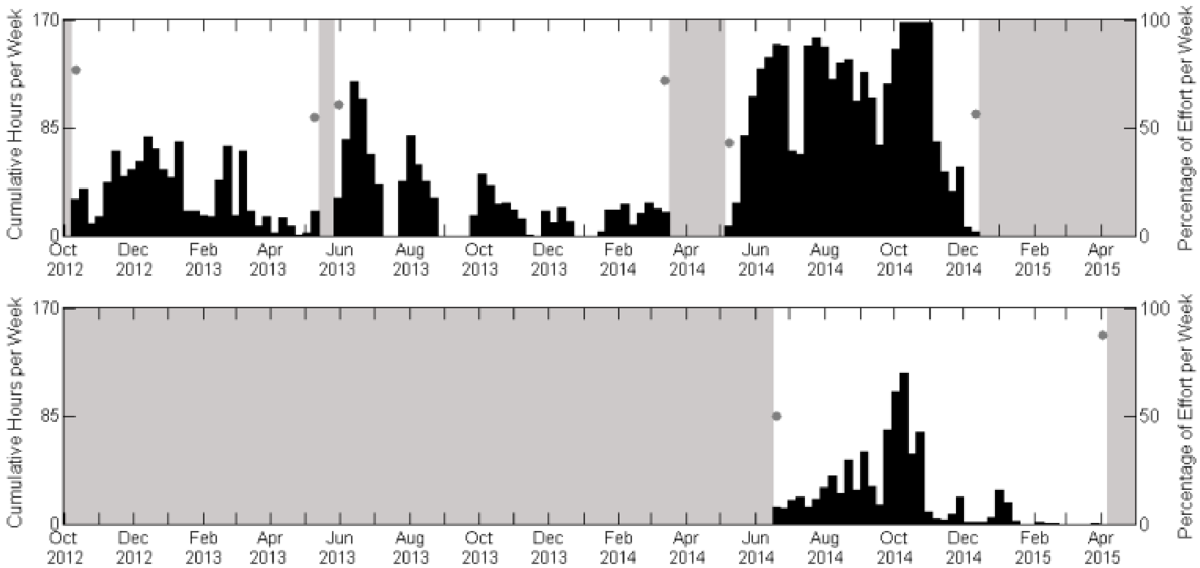

Figure 79. Weekly presence (black bars) of airguns October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described in Figure 40.

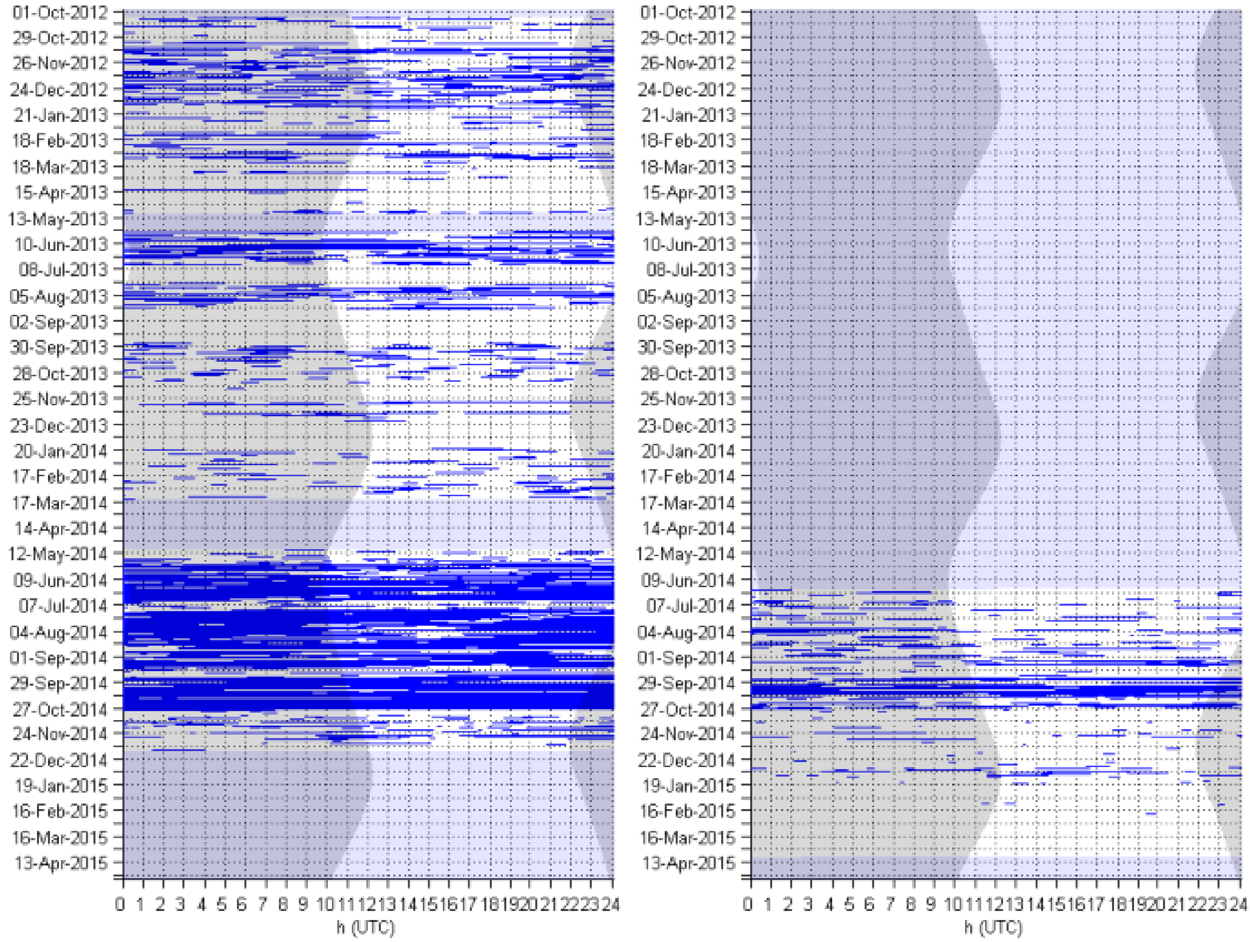

Figure 80. Airgun detections in one-minute bins (blue bars) at HAT (left) and NFC (right). Effort markings are described in Figure 41.

High-Frequency Active Sonar

- High-frequency active sonar greater than 5 kHz was detected in May 2014 at HAT (Figure 81). There were no detections at NFC.
- There were too few detections to determine a diel pattern (Figure 82).

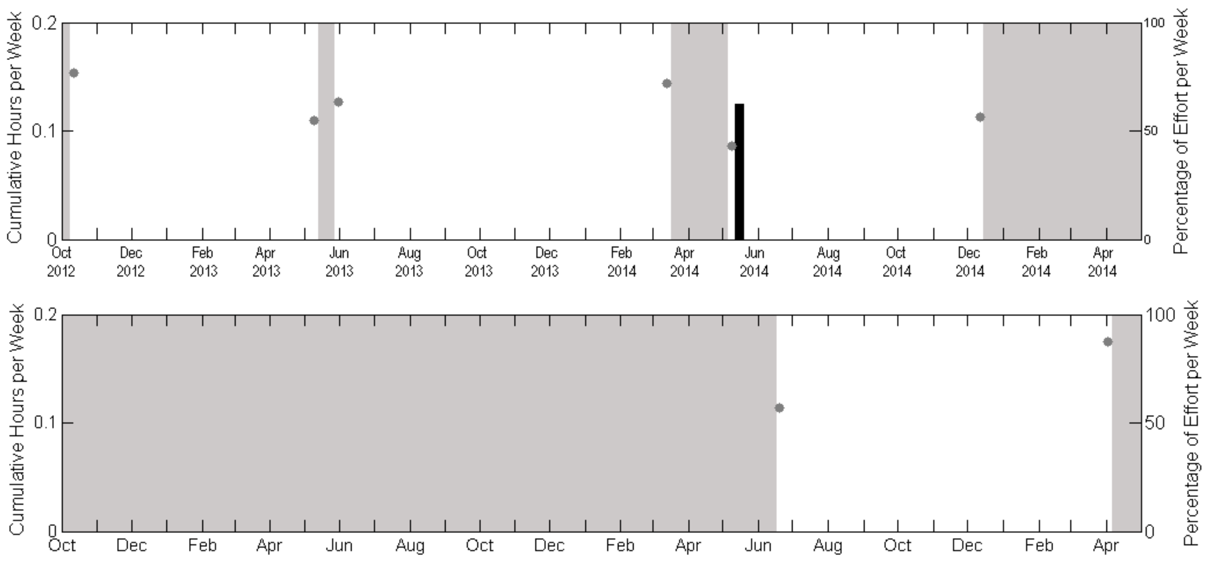

Figure 81. Weekly presence (black bars) of high-frequency active sonar October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described in Figure 40.

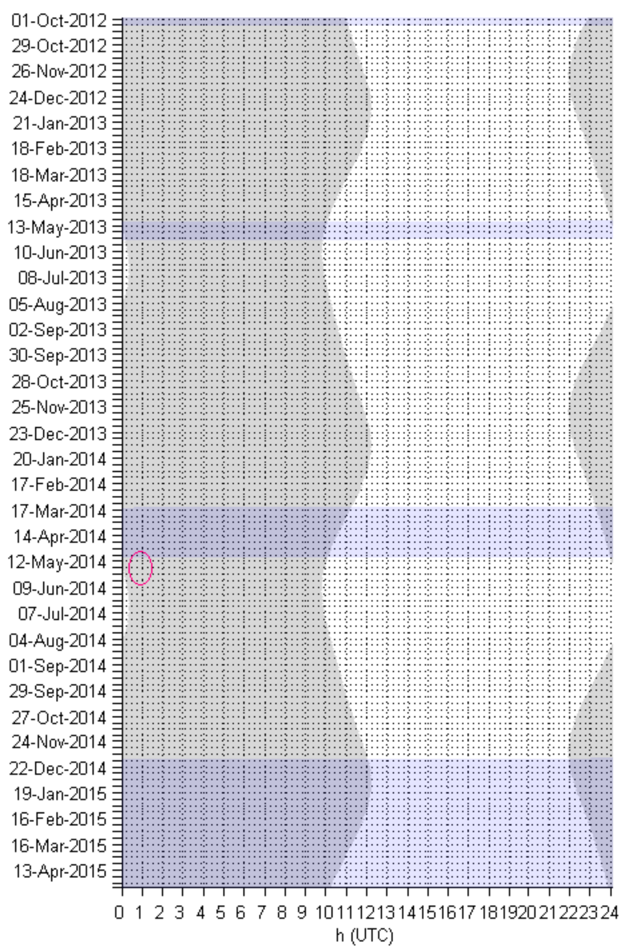

Figure 82. High-frequency active sonar detections in one-minute bins (blue bar circled in pink) at HAT. Effort markings are described in Figure 41.

Echosounders

- Echosounders were detected throughout the recordings at both sites (Figure 83).
- There was no discernable diel pattern for echosounders at either site (Figure 84).

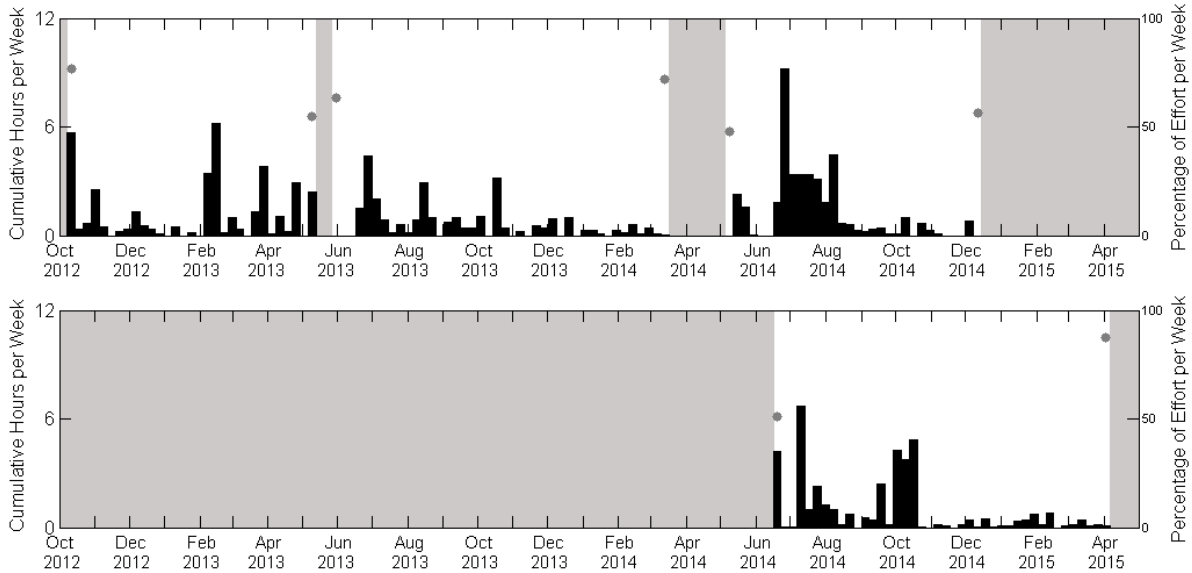

Figure 83. Weekly presence (black bars) of echosounders October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described in Figure 40.

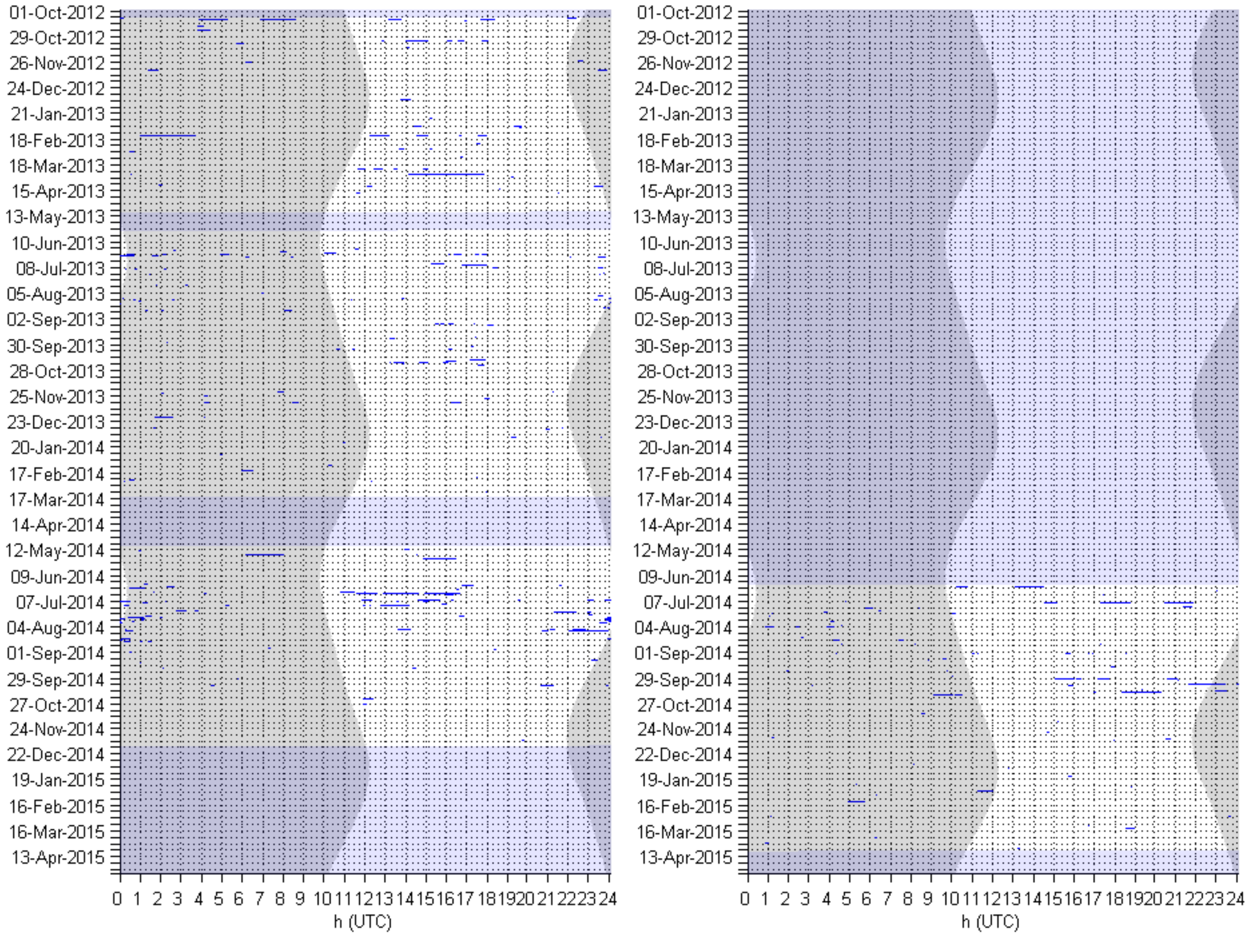

Figure 84. Echosounder detections in one-minute bins (blue bars) at HAT (left) and NFC (right). Effort markings are described in Figure 41.

Mid-Frequency Active Sonar

- MFA sonar was detected intermittently with a peak in detections occurring in late-October 2012 at the HAT site. At the NFC site, MFA sonar was detected throughout the deployment, with peaks in detections occurring late-September and late-November 2014, and late-February 2015 (Figure 84).
- There was no discernable diel pattern for MFA at the HAT site. At the NFC site, most MFA sonar detections occurred during nighttime (Figure 85).
- The vast majority of the MFA packets were filtered out by the energy detector at both sites because of low peak-to-peak received levels (Table 4).
- The majority of packets that met the minimum detector thresholds at HAT were 2-3 seconds in duration. Most of these packets had peak-to-peak received levels of 130-133 dB re 1 µPa and RMS received levels of 114 dB re 1 µPa (Figure 87, Figure 88, and Figure 89).
- The majority of packets that met the minimum detector thresholds at NFC were 2 seconds in duration. Most of these packets had peak-to-peak received levels of 132 dB re 1 µPa and RMS received levels of 114 dB re 1 µPa (Figure 90, Figure 91, and Figure 92).

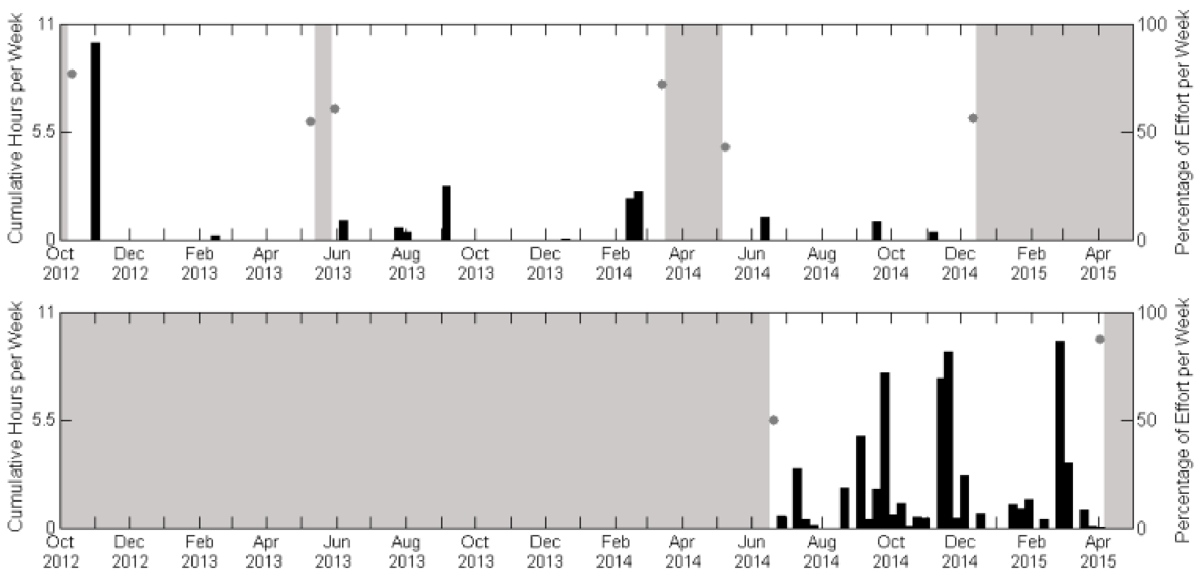

Figure 85. Weekly presence (black bars) of MFA sonar October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described in Figure 40.

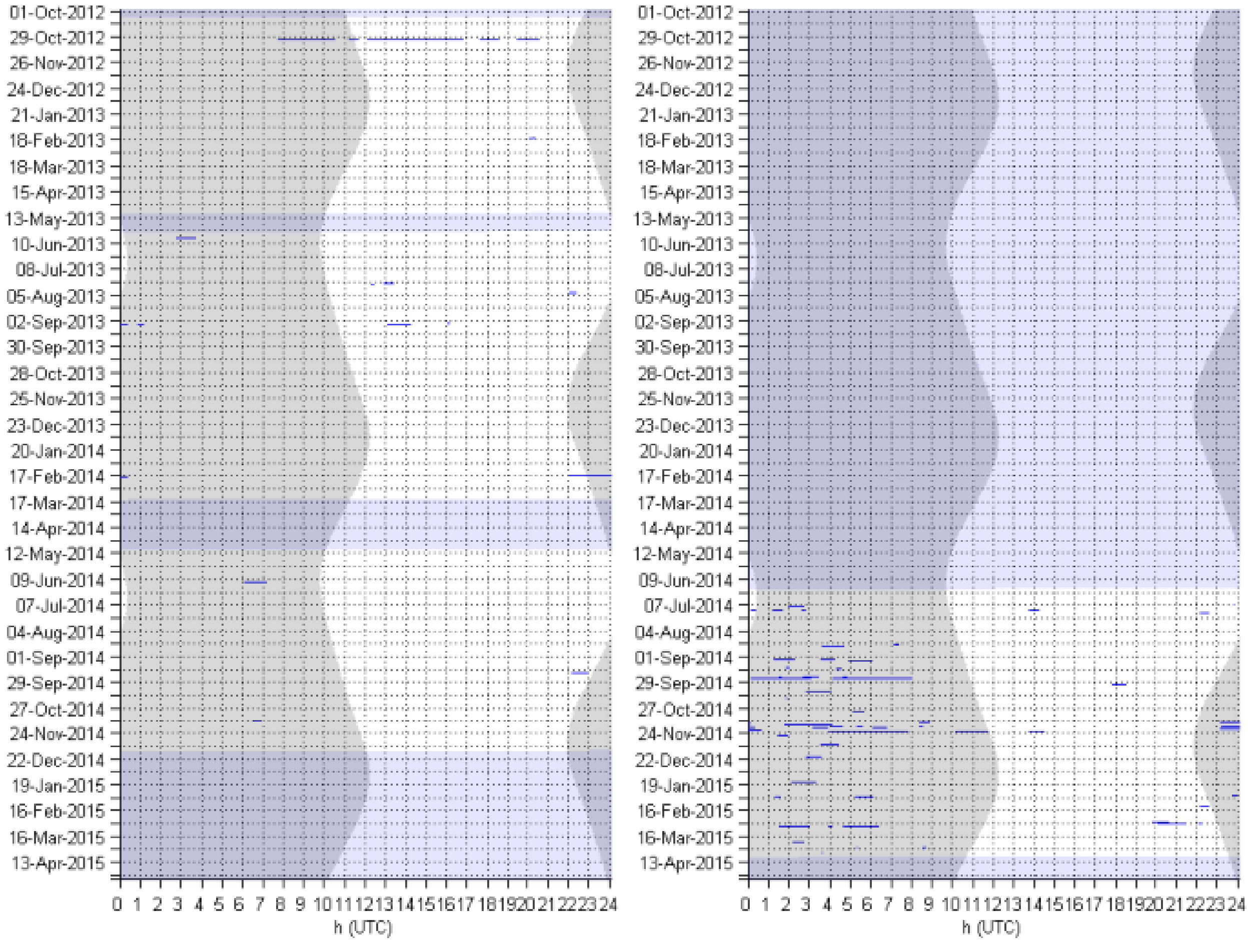

Figure 86. MFA sonar in one-minute bins (blue bars) at HAT (left) and NFC (right). Effort markings are described in Figure 41.

Table 4. Number of analyst defined events, with wave trains and packets detected by energy detector for this recording period.

Deployment	Analyst Defined Events	Wave Trains (filtered)	Detected Packets (filtered)
HAT02A	7	2	25
HAT03A	11	0	0
HAT04A	3	0	0
NFC01A	81	5	67

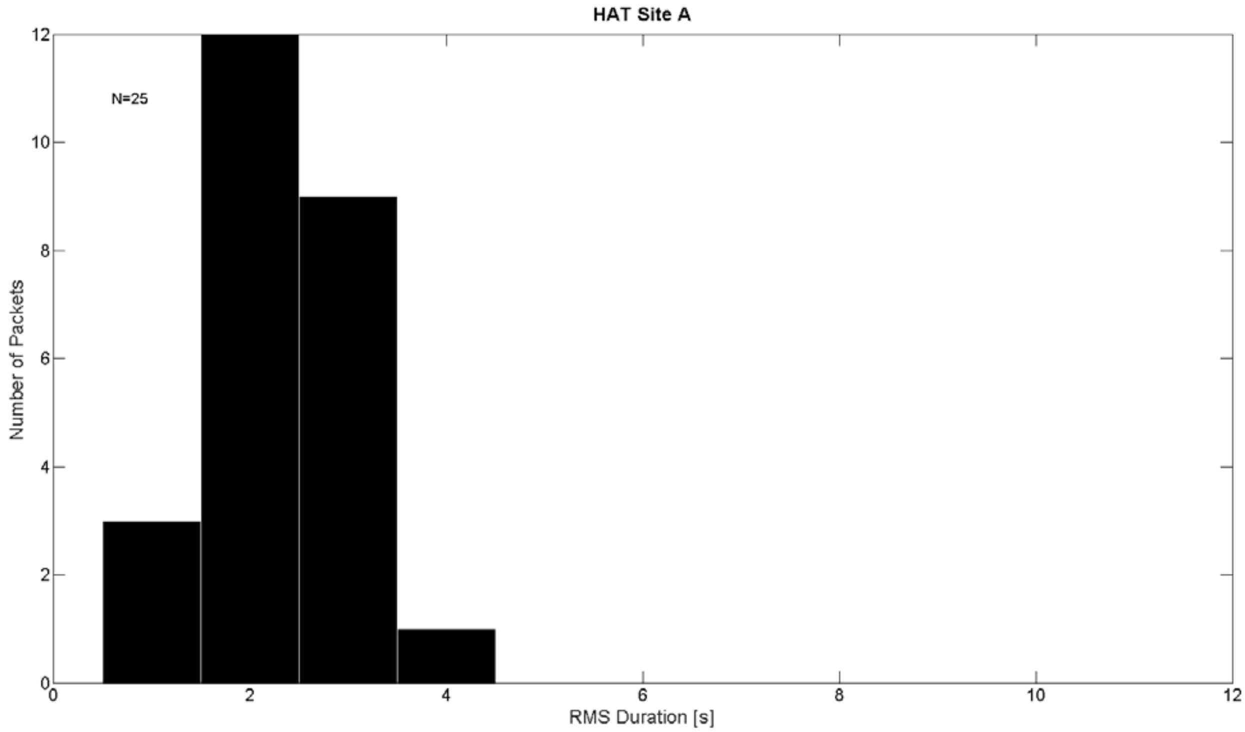

Figure 87. Packet RMS duration distribution at HAT. The total number of packets detected (after filtering) is given in the upper left corner of each panel.

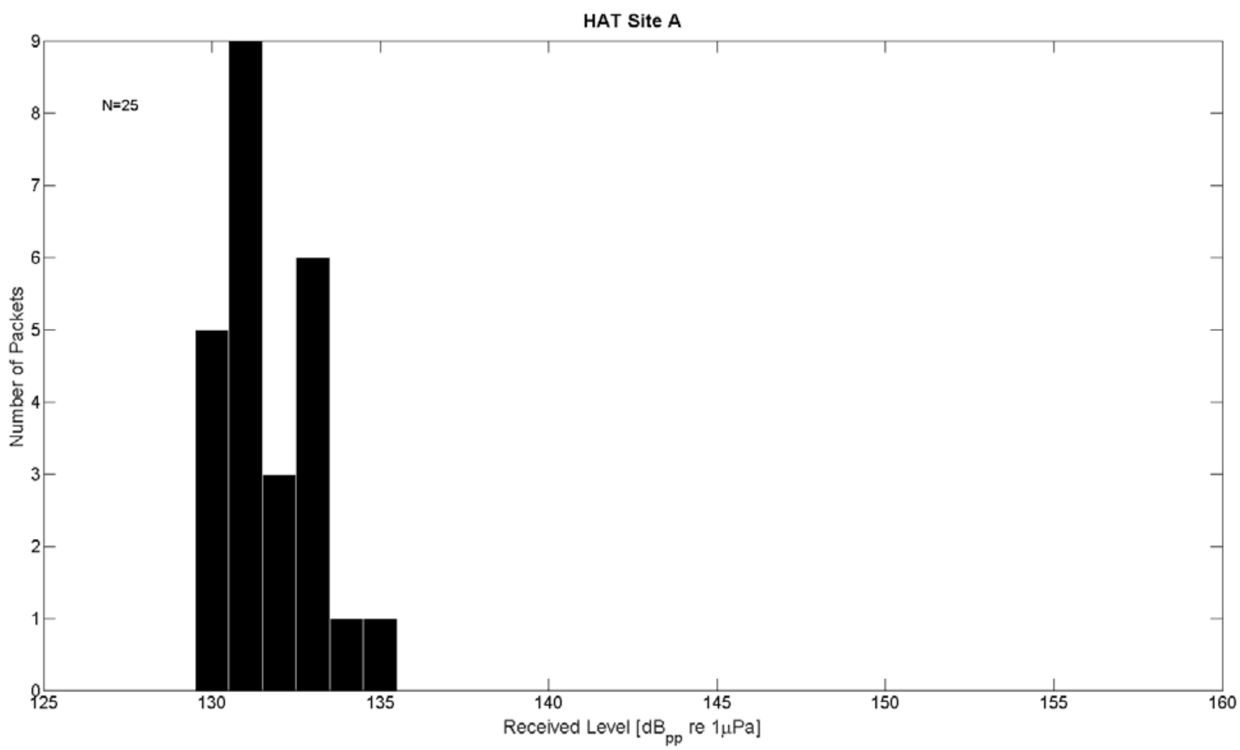

Figure 88. MFA sonar packet maximum peak-to-peak received level distribution at HAT. The total number of packets detected (after data filtering) at each site is given in the upper left corner of each panel.

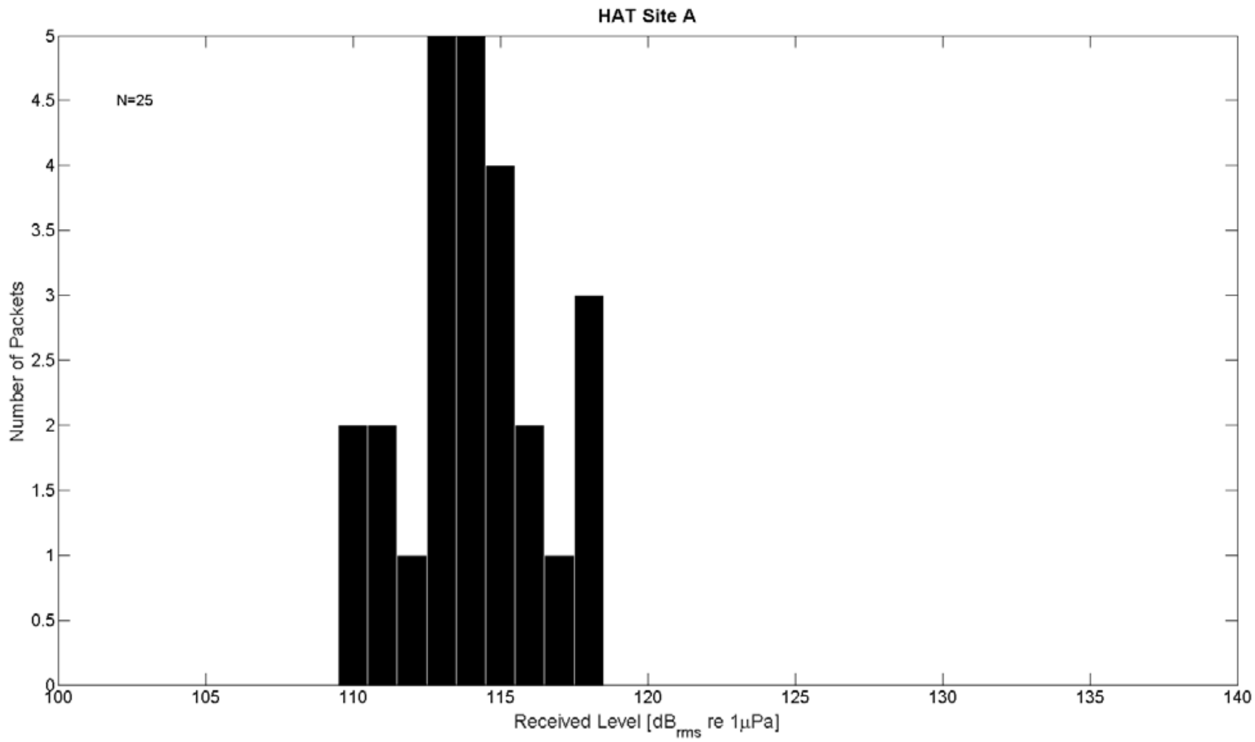

Figure 89. MFA sonar packet maximum RMS received level distribution at HAT. The total number of packets detected (after data filtering) at each site is given in the upper left corner of each panel.

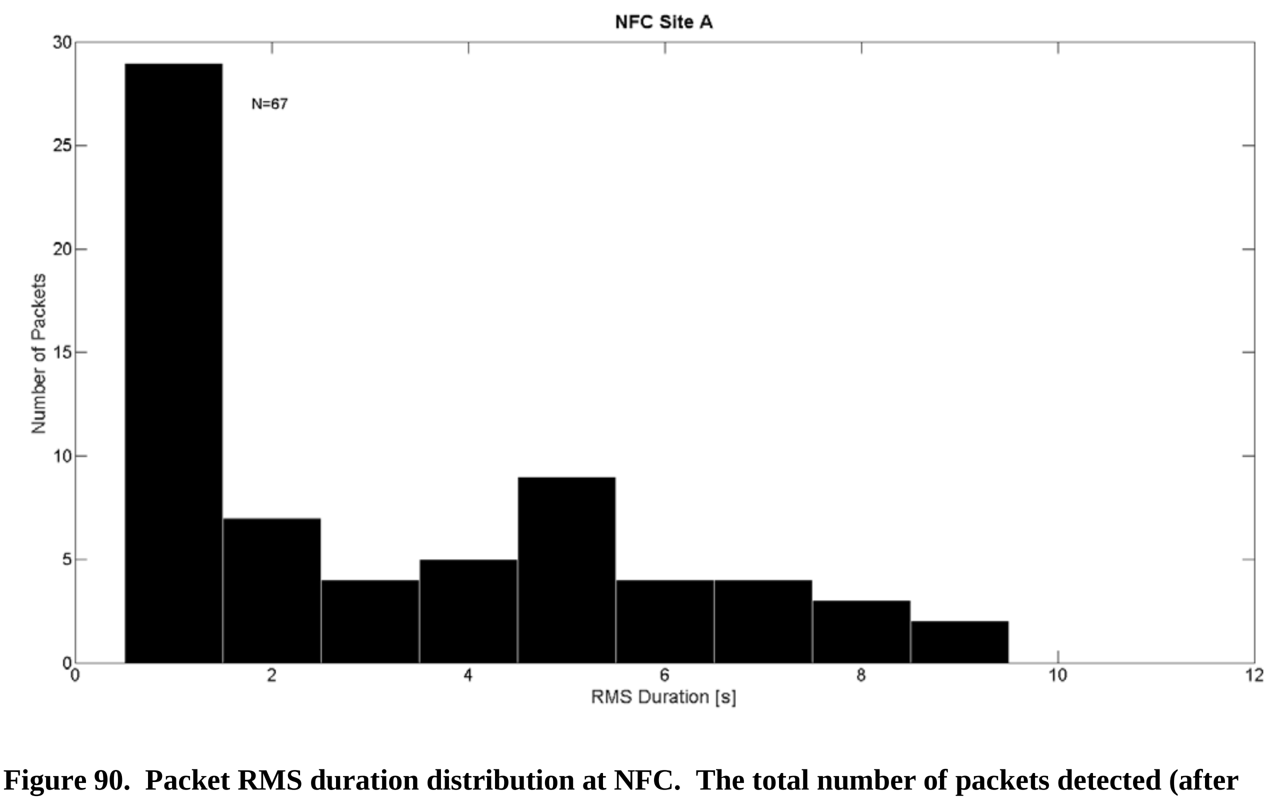

Figure 90. Packet RMS duration distribution at NFC. The total number of packets detected (after filtering) is given in the upper left corner of each panel.

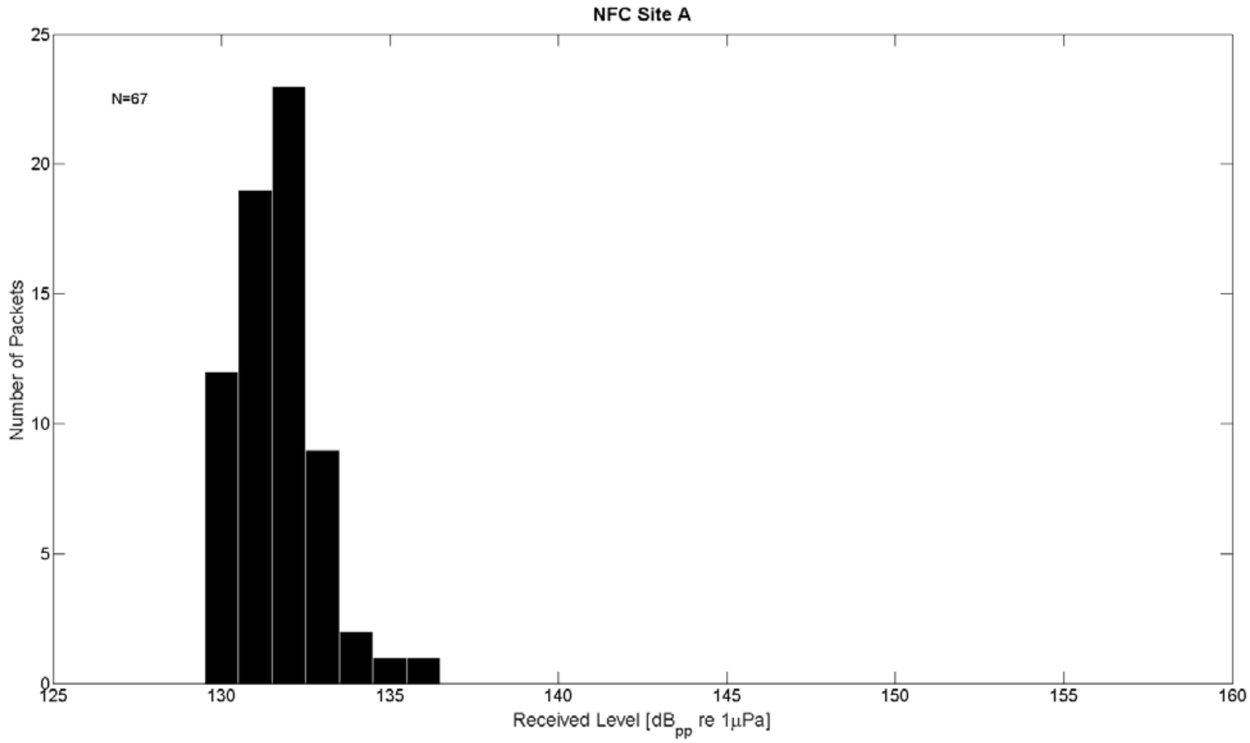

Figure 91. MFA sonar packet maximum peak-to-peak received level distribution at NFC. The total number of packets detected (after data filtering) at each site is given in the upper left corner of each panel.

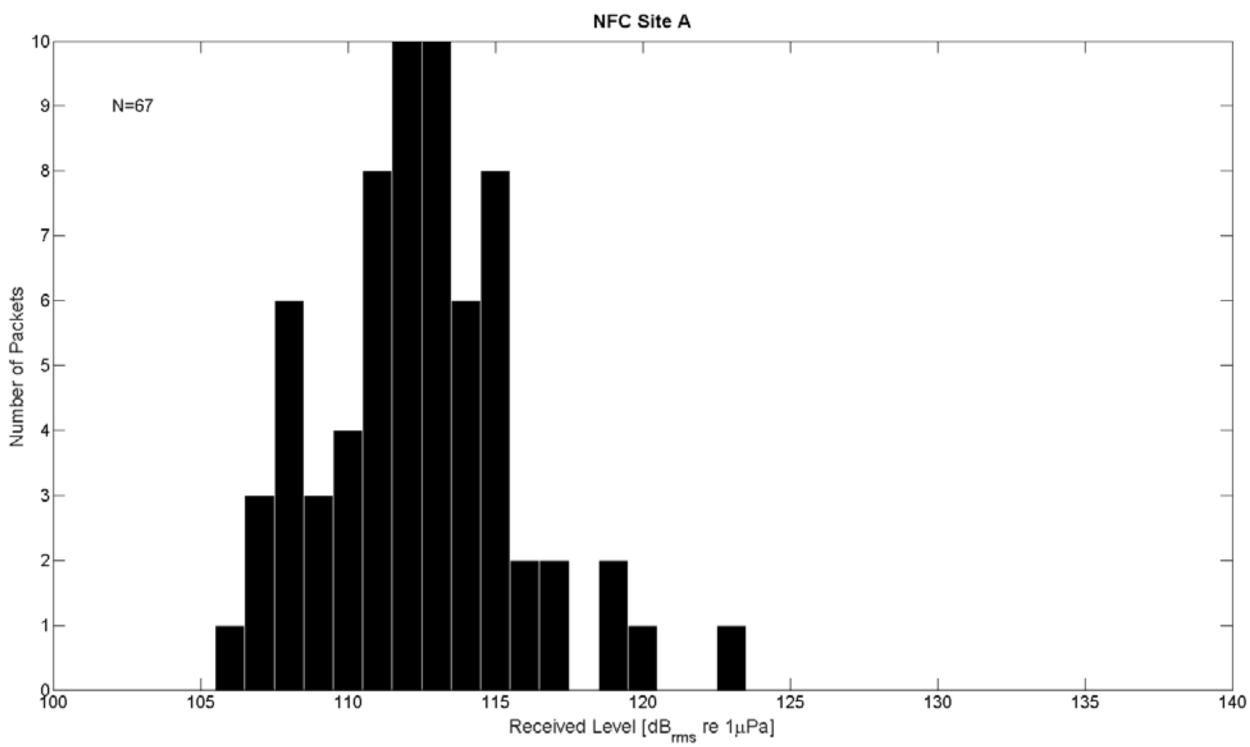

Figure 92. MFA sonar packet maximum RMS received level distribution at NFC. The total number of packets detected (after data filtering) at each site is given in the upper left corner of each panel.

Low-Frequency Active Sonar

- LFA sonar greater than 500 Hz was detected sporadically at NFC. There were no detections at HAT (Figure 93).
- Most LFA sonar detections occurred during daytime hours (Figure 94).

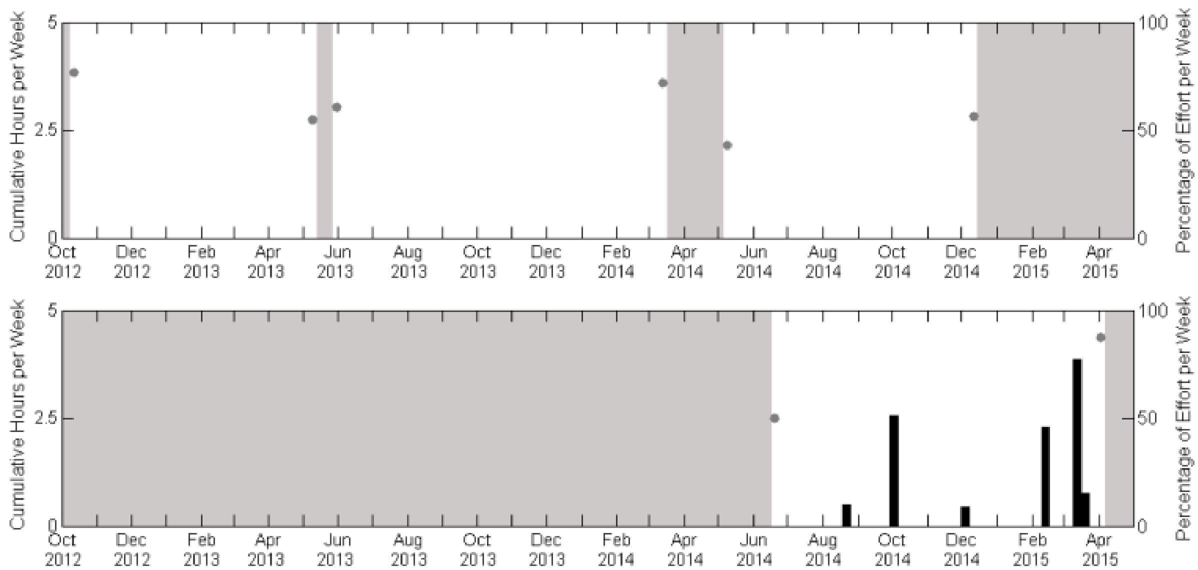

Figure 93. Weekly presence (black bars) of LFA sonar greater than 500 Hz October 2012 – April 2015 at HAT (top) and NFC (bottom). Effort markings are described in Figure 40.

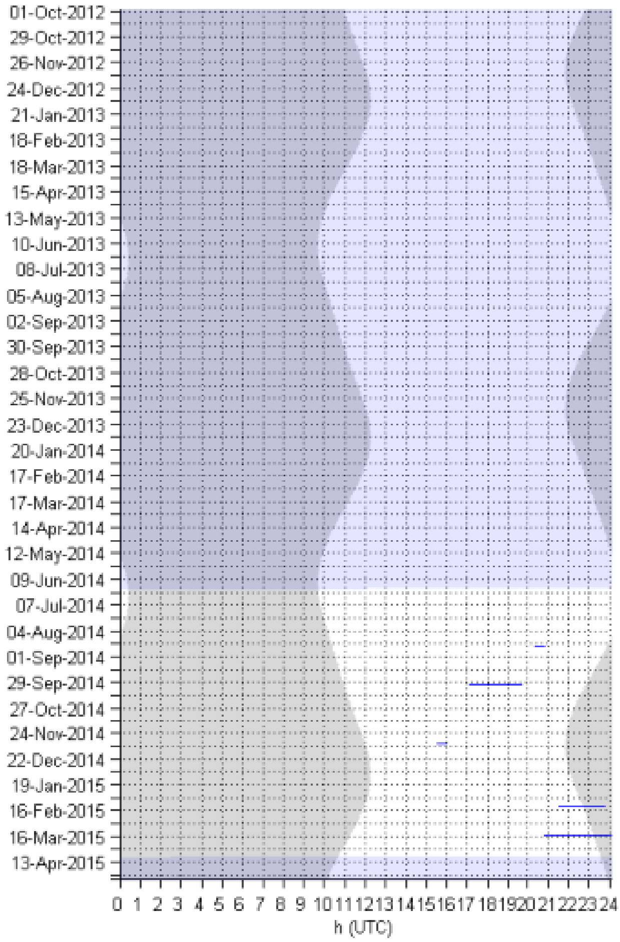

Figure 94. LFA sonar greater than 500 Hz in one-minute bins (blue bars) at NFC. Effort markings are described in Figure 41.

References

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