Passive Acoustic Monitoring for Marine Mammals off Virginia, North Carolina, and Florida Using High-frequency Acoustic Recording Packages: 2016 Annual Report

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Individual technical reports and detailed analyses of HARP deployments are available through the Navy's Marine Species Monitoring Program web portal PAM Deployment Explorer and Reading Room.

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High-frequency Acoustic Recording Package. Photo by Scripps Institution of Oceanography (accessed at http://www.nefsc.noaa.gov/psb/acoustics/psbAcousticsMigration.html)

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Acronyms and Abbreviations

HARP	High-frequency Acoustic Recording Package
HF	high-frequency
HFA	high-frequency active
Hz	Hertz
kHz	kilohertz
LF	low-frequency
LFA	low-frequency active
LTSA	long-term spectral average
MF	mid-frequency
MFA	mid-frequency active
m	meter(s)
ms	millisecond(s)
µs	microsecond(s)
s	second(s)
SIO	Scripps Institution of Oceanography
U.S.	United States
USWTR	Undersea Warfare Training Range

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1. Executive Summary

The U.S. Navy has been using High-frequency Acoustic Recording Packages (HARPs) to conduct passive acoustic monitoring in waters offshore of Virginia, North Carolina, and Florida to determine patterns of occurrence and distribution of cetacean species and anthropogenic sounds since 2007. The datasets discussed in this annual report came from seven HARP deployments made from 2012 through 2016: one near Norfolk Canyon, off the coast of Virginia (982 meter [m] depth) between June 2014 and April 2015; four off Cape Hatteras, North Carolina (850–980 m depths) between October 2012 and April 2016; and two off Jacksonville, Florida (800–806 m depths) between August 2014 and April 2016.

Each HARP dataset was manually scanned for marine mammal vocalizations and anthropogenic sounds using long-term spectral averages (LTSAs) and in some cases, automated detection algorithms. The effective frequency range of the HARP data (10 Hertz [Hz]–100 kilohertz [kHz]) was analyzed by focusing on three frequency bands: 10–1,000 Hz, 10–5,000 Hz, and 1–100 kHz. Only odontocete whistles are discussed in this report for the Norfolk Canyon deployment and three of the four Cape Hatteras deployments, as results from all other marine mammal analyses were previously presented in Hodge et al. 2016.

Three baleen whale species were detected at the Cape Hatteras and Jacksonville sites: fin whale (*Balaenoptera physalus*), minke whale (*Balaenoptera acutorostrata*), and sei whale (*Balaenoptera borealis*). Fin whale calls showed peaks in occurrence during the winter months. Similarly, minke whale pulse trains showed a strong seasonal pattern at both sites. Peaks in detections of sei whale calls occurred between December and January at both sites, although the recordings at the Cape Hatteras site ended in mid-January.

Echolocation clicks from six known odontocete taxa were detected: *Kogia* sp., Risso's dolphin (*Grampus griseus*), sperm whale (*Physeter macrocephalus*), Cuvier's beaked whale (*Ziphius cavirostris*), Gervais' beaked whale (*Mesoplodon europaeus*), and Blainville's beaked whale (*Mesoplodon densirostris*). The only identified delphinid clicks detected at both sites were those of Risso's dolphins; they occurred in low numbers at Cape Hatteras but quite frequently in Jacksonville, with peaks in detections at night and between April and July 2015. *Kogia* sp. clicks were detected throughout all of the recordings from these two locations, with more detections at the Jacksonville site. Sperm whale clicks were detected frequently at Cape Hatteras and more intermittently at Jacksonville. Cuvier's beaked whale clicks were very rarely detected at the Jacksonville site but were the most abundant beaked whale click type found at Cape Hatteras, with increases in detections between September and December and possibly April and May at that site. Gervais' beaked whale clicks were detected a few times at the Jacksonville site and often at the Cape Hatteras site, with fewer detections in September and October at Cape Hatteras. Blainville's beaked whale clicks were detected at both sites but very rarely. Finally, odontocete clicks and whistles that could not be assigned to species were detected throughout all recordings.

Anthropogenic sounds were also detected at both sites. Included in this report are mid-frequency active (MFA) sonar, low-frequency active (LFA) sonar greater than 500 Hz, high-frequency active (HFA) sonar, and airgun detections. MFA sonar was detected throughout the two recordings reported here that had data in that frequency range available. The Jacksonville dataset had peaks in MFA sonar detections in September 2014 and January 2015. LFA sonar greater than 500 Hz was detected on only one day in Cape Hatteras. HFA sonar was detected on only one day in Jacksonville. Airguns were detected throughout the recording made at Cape Hatteras, with peaks in detections in April 2015 and between June and September 2015.

2. Introduction and Background

In October 2005, the United States (U.S.) Department of the Navy proposed the installation of an Undersea Warfare Training Range (USWTR) in one of four sites along the Atlantic coast, for the purpose of anti-submarine warfare training using mid-frequency tactical sonar (1–10 kHz) in outer continental shelf waters. The initial preferred site for the USWTR was Onslow Bay, North Carolina. As part of a multi-institutional monitoring plan for Onslow Bay, an acoustic monitoring effort, funded by the U.S. Atlantic Fleet, was initiated in 2007 by Duke University with assistance from Scripps Institution of Oceanography (SIO). In 2008, the preferred site was changed to Jacksonville, Florida. While acoustic monitoring continued in Onslow Bay, it also began in Jacksonville in 2009, once again led by Duke University with assistance from SIO. In broad support of Atlantic Fleet Training and Testing acoustic monitoring later expanded to an area off Cape Hatteras, North Carolina (2012), and near Norfolk Canyon, off the coast of Virginia (2014). During 2016, passive acoustic data were collected at the Jacksonville, Cape Hatteras, and Norfolk Canyon sites using autonomous bottom-mounted recorders. The primary objectives of the passive acoustic monitoring program are as follows:

1) Determine the patterns of occurrence of marine mammal species at each monitoring site;
2) Compare patterns of occurrence to better understand distributional patterns; and.
3) Document species-specific characteristics of the vocalizations of marine mammal species in each area.

3. General Methods

3.1 Bottom-mounted Recorders

To collect time-series of acoustic data in all three survey areas, autonomous High-frequency Acoustic Recording packages (HARPs; Wiggins and Hildebrand 2007) were utilized. The HARP data-logging system includes a 16-bit analog-to-digital converter; a hydrophone suspended approximately 10–12 m (large mooring, see **Figure 1**), approximately 22 m (small mooring, see **Figure 2**), or approximately 20 m (compact small mooring, see **Figure 3**) above the seafloor; an acoustic release system; ballast weights; and flotation (**Figures 1 through 3**). The data-loggers are capable of sampling up to 200 kHz and can be set to record continuously or on a duty cycle to accommodate variable deployment durations. These instruments combine high- and low-frequency hydrophone elements to detect the vocalizations of both odontocete and mysticete cetaceans. The units sample at rates high enough to capture the clicks of many odontocetes.

3.2 Summary of Deployments

HARPs have been deployed 10 times in Onslow Bay, 16 times in Jacksonville, six times in Cape Hatteras, and twice at the Norfolk Canyon site (**Table 1**). There were two occasions during which two HARPs were recording concurrently at different sites in Onslow Bay, and there were five occasions during which two HARPs were recording concurrently at different sites in Jacksonville (**Table 1**). **Table 1** includes location, depth, deployment and retrieval dates, recording dates, information on duty cycle, mooring type, status of analysis, and reports available. All HARPs sampled at 200 kHz.

Individual technical reports and detailed analyses of all HARP deployments are available through the Navy's Marine Species Monitoring Program web portal PAM Deployment Explorer and Reading Room

Table 1. Details of all HARP deployments in Jacksonville, Onslow Bay, Hatteras, and Norfolk Canyon through 2016. Deployments analyzed in this report are highlighted.

Location	Deployment ID	Latitude (N)	Longitude (W)	Depth (m)	Deployment Date	Retrieval Date	Recording Start Date	Recording End Date	Duty Cycle (min on/off)	Mooring Type	Status of Analysis	Report Available
JACKSONVILLE												
JAX A	JAX01A	30.2771	80.1258	82	30MAR09	16SEP09	02APR09	25MAY09	5/10	large	HF	Yes - T
JAX B	JAX01B	30.2582	80.4282	37	30MAR09	16SEP09	02APR09	05SEP09	5/10	large	HF, M	Yes - T
JAX A	JAX02A	30.2805	80.2160	83	16SEP09	21FEB10	16SEP09	15DEC09	5/10	large	HF, M	Yes - T
JAX B	JAX02B	30.2582	80.4280	39	23SEP09	21FEB10	No data	No data	5/10	large	N/A	No – no data
JAX A	JAX03A	30.2811	80.2153	89	21FEB10	26AUG10	22FEB10	30JUL10	5/10	large	HF, M	Yes - T
JAX B	JAX04B	30.2591	80.4256	38	09MAR10	26AUG10	09MAR10	19AUG10	5/10	large	HF, M	Yes - T, D
JAX A	JAX05A	30.2681	80.2089	91	26AUG10	01FEB11	26AUG10	25JAN11	5/10	large	HF, LF	Yes - T, D
JAX B	JAX05B	30.2570	80.4326	37	26AUG10	01FEB11	27AUG10	01FEB11	5/10	large	HF, LF	Yes - T, D
JAX A	JAX06A	30.2781	80.2208	91	01FEB11	14JUL11	01FEB11	14JUL11	5/10	large	HF, LF	Yes - T, D
JAX B	JAX06B	30.2576	80.4278	37	02FEB11	14JUL11	02FEB11	14JUL11	5/10	large	HF, LF	Yes - T, D
JAX A	JAX08A	30.2850	80.2214	91	24JAN12	abandoned	27JAN12	unknown	continuous	large	abandoned	No – no data
JAX C	JAX09C	30.3328	80.2007	94	12MAY13	17FEB14	13MAY13	20JUN13	continuous	large	HF, LF	Yes - T, D
JAX C	JAX10C	30.3264	80.2049	88	17FEB14	23AUG14	17FEB14	23AUG14	continuous	small	HF, LF	Yes - T, D
JAX D	JAX11D	30.1506	79.7700	806	23AUG14	02JUL15	23AUG14	29MAY15	continuous	small	HF, LF	Yes - T, D
JAX D	JAX12D	30.1489	79.7711	800	02JUL15	26APR16	03JUL15	04NOV15	continuous	small	HF, LF	Yes – T, D
JAX D	JAX13D	30.1518	79.7702	736	26APR16	N/A	26APR16	N/A	continuous	csm	N/A	N/A
ONSLOW												
Onslow Bay A	USWTR01A	33.7913	76.5238	162	09OCT07	27MAY08	10OCT07	16JAN08	5/5*	large	HF, LF	Yes - T
Onslow Bay B	USWTR02B	33.8110	76.4282	232	30MAY08	24NOV08	30MAY08	10SEP08	5/5	large	HF, LF	Yes - T
Onslow Bay A	USWTR03A	33.7895	76.5192	174	24APR09	16SEP09	24APR09	09AUG09	5/5	large	HF, LF	Yes - T
Onslow Bay A	USWTR04A	33.7873	76.5240	171	08NOV09	19JUN10	08NOV09	24FEB10	5/10	large	HF, LF	Yes - T
Onslow Bay C	USWTR04C	33.6778	76.4768	335	08NOV09	19JUN10	08NOV09	20APR10	5/10	large	HF, LF	Yes - T
Onslow Bay A	USWTR05A	33.7931	76.5162	171	29JUL10	10JUN11	30JUL10	03MAR11	5/5	large	HF, LF	Yes - T
Onslow Bay D	USWTR05D	33.5806	76.5501	338	29JUL10	10JUN11	30JUL10	24FEB11	5/5	large	HF, LF	Yes - T
Onslow Bay E	USWTR06E	33.7779	75.9264	952	18AUG11	13JUL12	19AUG11	01DEC11	5/5	large	HF, LF	Yes - T, D
Onslow Bay E	USWTR07E	33.7866	75.9291	914	13JUL12	24OCT12	14JUL12	02OCT12	5/5	large	HF, LF	Yes - T, D
Onslow Bay E	USWTR08E	33.7869	75.9280	853	24OCT12	08AUG13	24OCT12	30JUN13	5/5	large	HF, LF	Yes - T

Location	Deployment ID	Latitude (N)	Longitude (W)	Depth (m)	Deployment Date	Retrieval Date	Recording Start Date	Recording End Date	Duty Cycle (min on/off)	Mooring Type	Status of Analysis	Report Available
CAPE HATTERAS												
Cape Hatteras A	HAT01A	35.3405	74.8576	950	15MAR12	09OCT12	15MAR12	11APR12	continuous	large	HF, LF	Yes - T
Cape Hatteras A	HAT02A	35.3406	74.8559	970	09OCT12	29MAY13	09OCT12	09MAY13	continuous	large	HF, LF	Yes - T, D
Cape Hatteras A	HAT03A	35.3444	74.8521	970	29MAY13	08MAY14	29MAY13	15MAR14	continuous	large	HF, LF	Yes - T, D
Cape Hatteras A	HAT04A	35.3467	74.8480	850	08MAY14	06APR15	9MAY14	11DEC14**	continuous	large	HF, LF	Yes - T, D
Cape Hatteras A	HAT05A	35.3421	74.8572	980	06APR15	29APR16	07APR15	21JAN16	continuous	csm	HF, LF	Yes, T, D
Cape Hatteras A	HAT06A	35.3057	74.8776	~1020	29APR16	N/A	29APR16	N/A	continuous	csm	N/A	N/A
NORFOLK CANYON												
Norfolk Canyon A	NFC01A	37.1662	74.4669	982	19JUN14	07APR15	19JUN14	05APR15	continuous	csm	HF, LF	Yes - T, D
Norfolk Canyon A	NFC02A	37.1652	74.4666	968	30APR16	N/A	30APR16	N/A	continuous	csm	N/A	N/A

Notes: All HARPs sampled at 200 kHz. For Mooring Type: csm = compact small mooring. For Status of Analysis: HF = high-frequency (> 1 kHz) analysis completed; LF = low-frequency (< 1 kHz) analysis completed; M = LF analysis completed only for minke whales; IP = analysis in progress; N/A = not applicable - data are not yet available for analysis. For Report Available: T = technical report; D = detailed report; N/A = not applicable, because HARP is still in the field. Key: JAX = Jacksonville Range Complex; m = meter(s); USWTR = Undersea Warfare Training Range. * = represents the initial duty cycle, but instrument recorded continuously starting 01 January 2008. ** = represents end of normal recording – there were four more files on four different days between 26DEC14 and 15JAN15 (skipping caused by disk error issue).

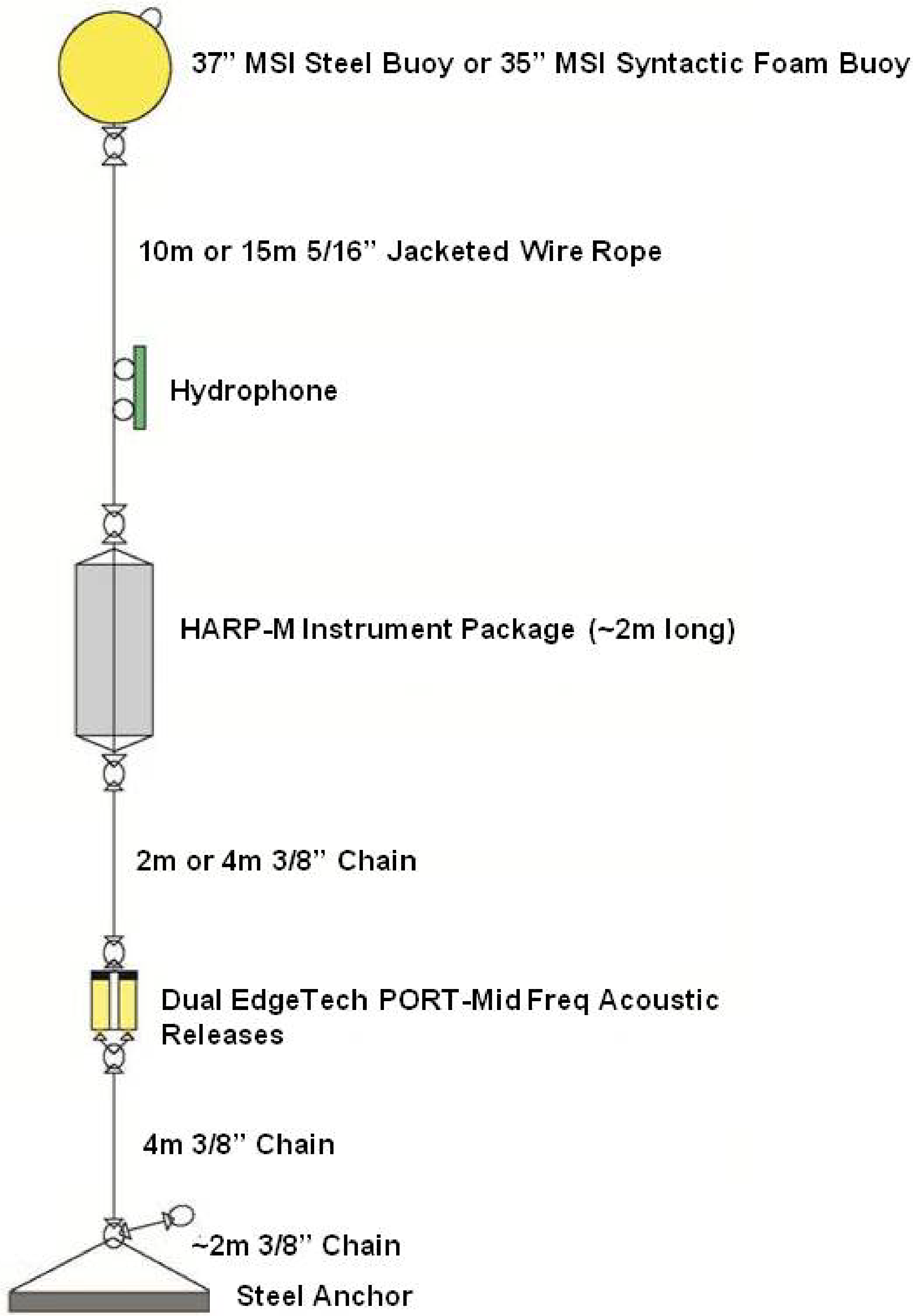


Figure 1. Schematic diagram showing details of a large mooring HARP. Note that diagram is not drawn to scale.

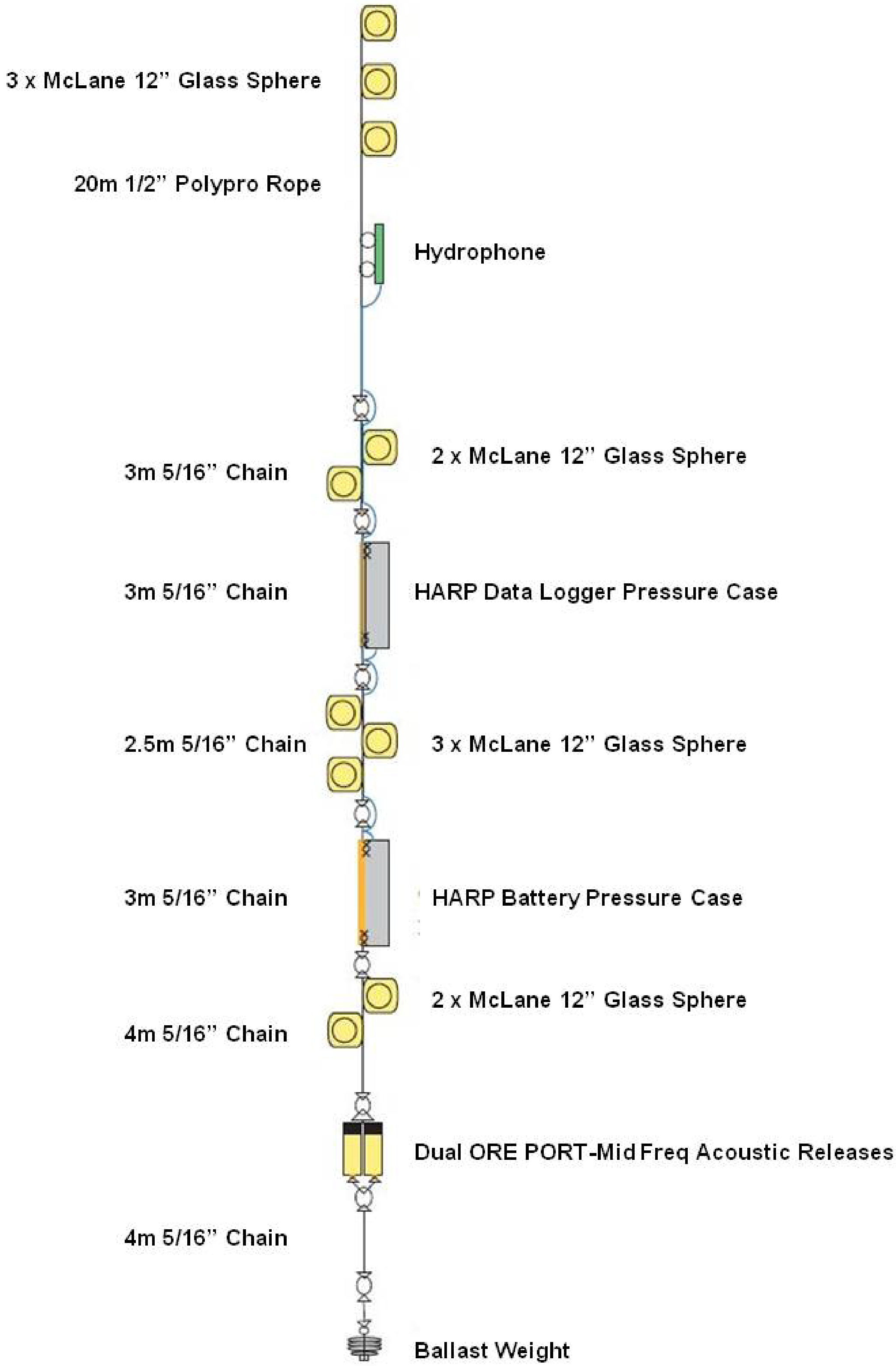


Figure 2. Schematic diagram showing details of a small mooring HARP. Note that diagram is not drawn to scale.

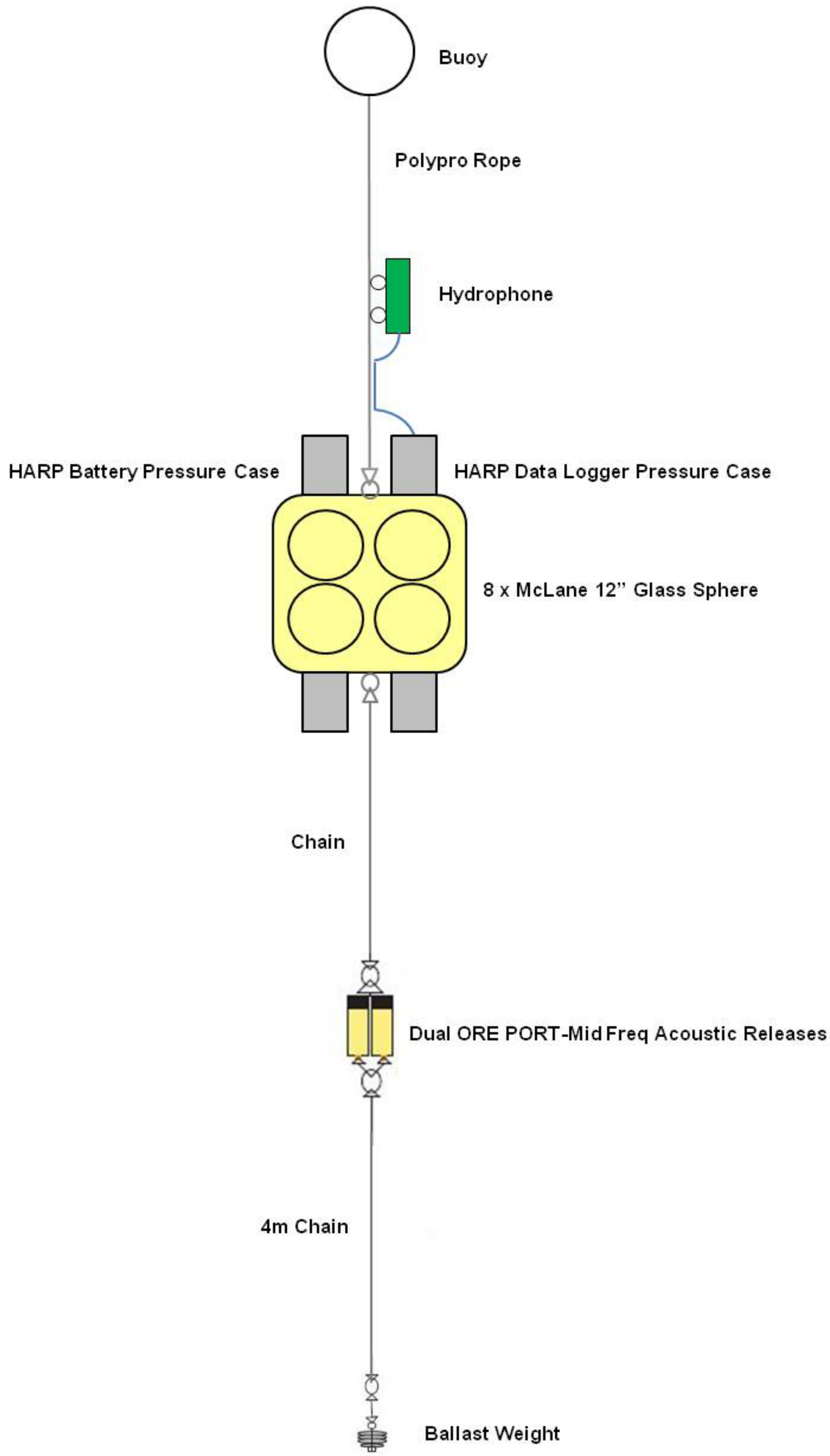


Figure 3. Schematic diagram showing details of a compact small mooring HARP. Note that diagram is not drawn to scale.

3.3 Data Analysis

HARP data require processing prior to analysis, including backing up data in original format, converting data to .wav format, decimating .wav data by a factor of 20 or 100 to aid in detection of baleen whales and anthropogenic sounds, and creating LTSAs. The amount of data collected by HARPs is impractical to analyze manually, so data were compressed for visual overview by using a *MATLAB*-based acoustic analysis program called *Triton* (Hildebrand Lab at SIO, La Jolla, CA) to create LTSAs from the .wav files, which allowed for rapid review of the data. LTSAs are effectively compressed spectrograms created using the Welch algorithm (Welch 1967) by coherently averaging 500 spectra created from 2000-point, 0 percent-overlapped, Hann-windowed data and displaying these averaged spectra sequentially over time.

Each HARP dataset was manually scanned for marine mammal vocalizations and anthropogenic sounds using the “logger” version of *Triton* (Hildebrand Lab at SIO, La Jolla, CA). Automated computer algorithm detectors were also used to analyze the data. The effective frequency range of the HARP data (10 Hz–100 kHz) was analyzed by focusing on three frequency bands: 10–1,000 Hz, 10–5,000 Hz, and 1–100 kHz. The resulting resolutions of the LTSAs were as follows:

- Low-frequency LTSA (LF-LTSA), for the data decimated by a factor of 100: 5 seconds [s] in time and 1 Hz in frequency (10–1,000 Hz band)
- Mid-frequency LTSA (MF-LTSA), for the data decimated by a factor of 20: 5 s in time and 10 Hz in frequency (10–5,000 Hz band)
- High-frequency LTSA (HF-LTSA), for the data not decimated: 5 s in time and 100 Hz in frequency (1-100 kHz band).

The maximum frequency of the LF-LTSAs is 1 kHz, preceded by an energy roll-off associated with the low-pass filter used for decimation. These LF-LTSAs are optimized for detection of very low frequency signals, such as fin whale calls. Mid-frequency signals with energy generally above ~500 Hz (*e.g.*, low-frequency active (LFA) sonar) or signals that are difficult to identify without including the higher frequency information (*e.g.*, ship noise, airguns) were detected in the MF-LTSAs. During manual inspection of LTSAs, the LF-LTSAs were set to display frequencies between 1–300 Hz, while the MF-LTSAs and HF-LTSAs were set to display the entire bandwidth available. Thus, the LF-LTSAs were inspected for sounds produced by blue (*Balaenoptera musculus*), fin (*Balaenoptera physalus*), sei (*Balaenoptera borealis*), Bryde’s (*Balaenoptera edeni*), minke (*Balaenoptera acutorostrata*), and North Atlantic right whales (*Eubalaena glacialis*). Although one of the Jacksonville datasets presented in this report was also inspected for the 5-pulse signal found during previous deployments off of Jacksonville, Florida (Debich et al. 2013), this sound is now thought to come from a fish and therefore is no longer being searched for in any of the datasets. The MF-LTSAs were inspected for humpback whale (*Megaptera novaeangliae*) calls, shipping, explosions, airguns, underwater communications, LFA sonar above 500 Hz, and mid-frequency active (MFA) sonar. Non-decimated LTSAs were inspected for the remaining odontocete sounds. LF sounds were analyzed in hourly bins; MF and HF sounds were analyzed in 1-minute bins (odontocete whistles, sperm whale clicks, *Kogia* clicks, beaked whale clicks) or 5-minute bins (delphinid clicks). Bin sizes (hourly, 1-minute, and 5-minute) represent the metric of animal presence, being an efficient way to estimate presence or absence within a large dataset, and were chosen depending on estimated call detection range and average swim speeds, two parameters that indicate how long an animal is likely in the area. Thus, one hour granularity was used as an approximation for baleen whales, which have larger estimated call detection ranges (> 10 km) and lower average swim speeds than odontocetes, which were analyzed using 1- or 5-minute granularity. Vocalizations were assigned to species when possible. For North Atlantic right whale calls, the data were only examined for up-calls. Information on the detections of shipping, explosions, and underwater communications is not reported here but can be found in Frasier et al. (2016, 2017), and Varga et al. (2017).

Detections of many sounds were made by manually scanning LTSAs. However, automated detectors were used for some calls, including fin whale 20-Hz calls (for the Cape Hatteras dataset only) and humpback whale calls, as well as delphinid, *Kogia* sp., and beaked whale echolocation signals.

For all datasets, humpback whale call detection effort was automated using a power-law detector (Helble et al. 2012). After the generalized power-law algorithm was applied, a trained analyst verified the accuracy of the detected signals. No effort was made to separate song and non-song calls.

Fin whale 20-Hz calls were detected using an energy detection method, which 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 the fin whale acoustic index and is reported as a daily average. All calculations were performed on a decibel scale.

Three steps were involved in the classification of *Kogia* clicks. First, the clicks with energy between 70 and 100 Hz and without energy in lower frequency bands were identified. Then, an expert system classified these clicks based on spectral characteristics, and finally an analyst verified all echolocation click bouts manually as *Kogia* clicks.

Delphinid echolocation clicks were detected using a modified version of a Teager energy detector (Soldevilla et al. 2008, Roch et al. 2011). Events were reviewed manually to remove false detections. LTSAs were then manually examined to identify reoccurring echolocation click types. Clicks were manually classified into separate click 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). See Debich et al. (2016) for a more detailed description of the above analysis methods.

Beaked whale echolocation signals were detected with an automated method for all sites. The detection of these signals began with the same initial automated detection steps described in detail in Debich et al. (2014) to find 75-s recording segments containing potential beaked whale frequency-modulated pulses. A Teager Kaiser energy detector (Roch et al. 2011) was used to find echolocation signals, and criteria based on peak and center frequency, duration, and sweep rate were used to discriminate between delphinid and beaked whale signals (Debich et al. 2014). Then, additional criteria based on the shape and duration of the signal envelope were applied to reduce the high number of false detections of non-beaked whale clicks. All detected signals with a signal envelope increasing after 20 sample points, and remaining above a 50 percent energy threshold for at least 19 sample points but no greater than 70 sample points, were kept; signals not meeting these criteria were removed from analysis. The remaining detections were grouped into detection events, with detections separated by no more than 5 minutes considered to be a single event. A final computer-assisted manual classification step was implemented where each detected event was given a species label by a trained analyst, and any remaining false detections were rejected (as in Baumann-Pickering et al. 2013).

Explosions were also detected automatically, using a matched filter detector described in further detail in Debich et al. (2015).

Airguns were detected automatically and manually verified following the method for explosion detections in Debich et al. (2016). This approach produces more precise airgun counts and imposes a consistent detection threshold.

4. Norfolk Canyon

4.1 Methods

Data Collection

The compact small mooring design HARP that was deployed in Norfolk Canyon at a depth of 968 m at 37.1652° N, 74.4666° W (Norfolk Canyon Site A) on 30 April 2016, is expected to be retrieved in June 2017 (**Table 2**, **Figure 4**). A schematic diagram of the HARP mooring for this deployment is shown in **Figure 5**. The HARP is sampling continuously at 200 kHz.

Table 2. Norfolk Canyon HARP deployments and analyses included in this report.

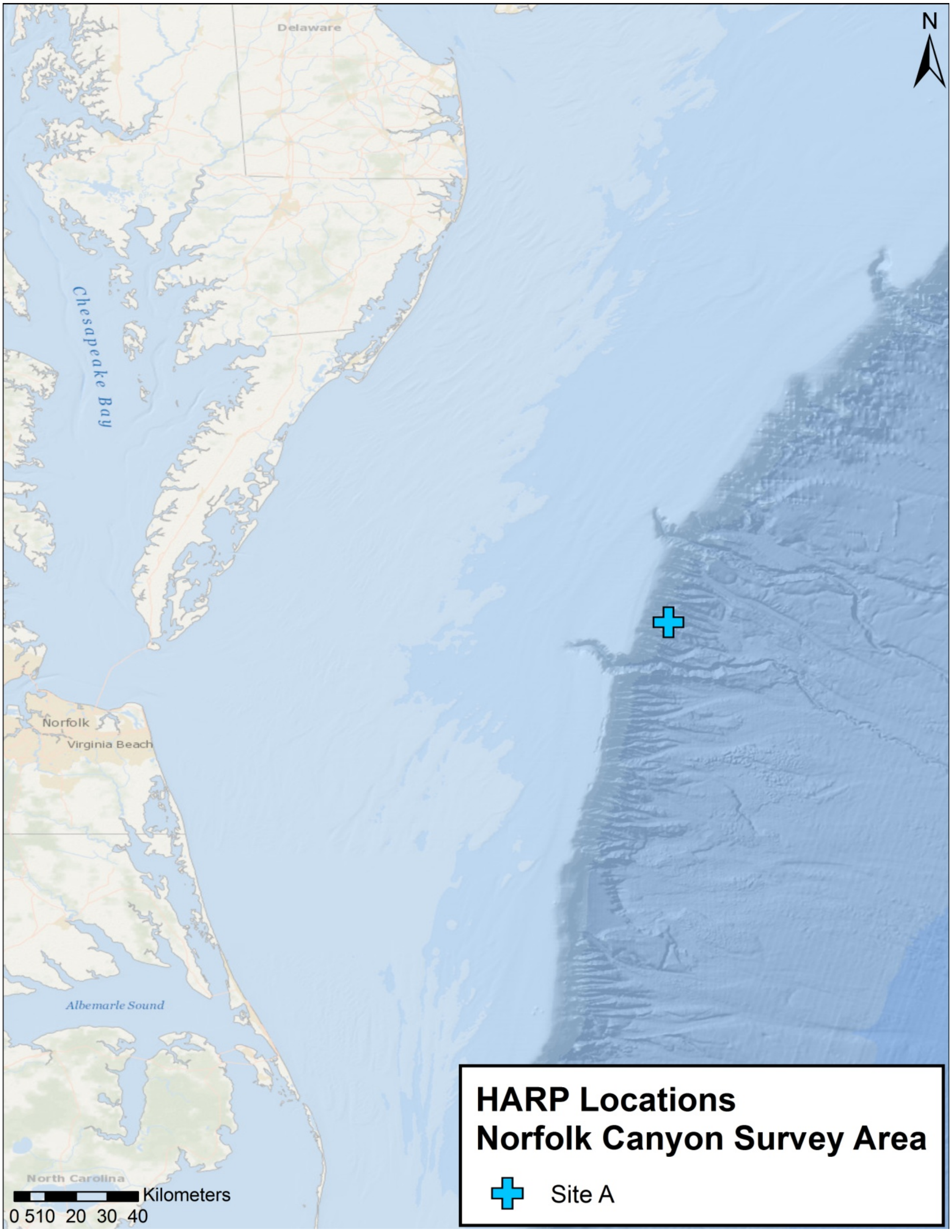
Site	Deployment Date	Retrieval Date	Recording Start Date	Recording End Date	Latitude (N)	Longitude (W)	Depth (m)	Sampling Rate	Duty Cycle
01A	19-Jun-14	7-Apr-15	19-Jun-14	05-Apr-15	37.1662	74.4669	982	200 kHz	continuous
02A	30-Apr-16	N/A	30-Apr-16	N/A	37.1652	74.4666	968	200 kHz	continuous

Data Analysis

The June 2014–April 2015 Norfolk Canyon Site A deployment yielded 6,951 hours of recording time over 290 days of recording (**Table 2**) and analysis of marine mammal and anthropogenic sounds was reported on in Hodge et al. (2016) and Debich et al. (2016), except for odontocete whistles, which will be presented here.

Data Quality

Highly stereotyped broadband digital errors ('glitches') were found in the June 2014–April 2015 Norfolk Canyon dataset. These glitches were short in duration (between 100 microseconds [µs] and 10 milliseconds [ms]) and started in the second half of the dataset, increasing in occurrence once they appeared. It is believed that the glitches do not significantly impact the resulting data analysis.

1 

2 **Figure 4. Location of the HARP deployment site near Norfolk Canyon.**

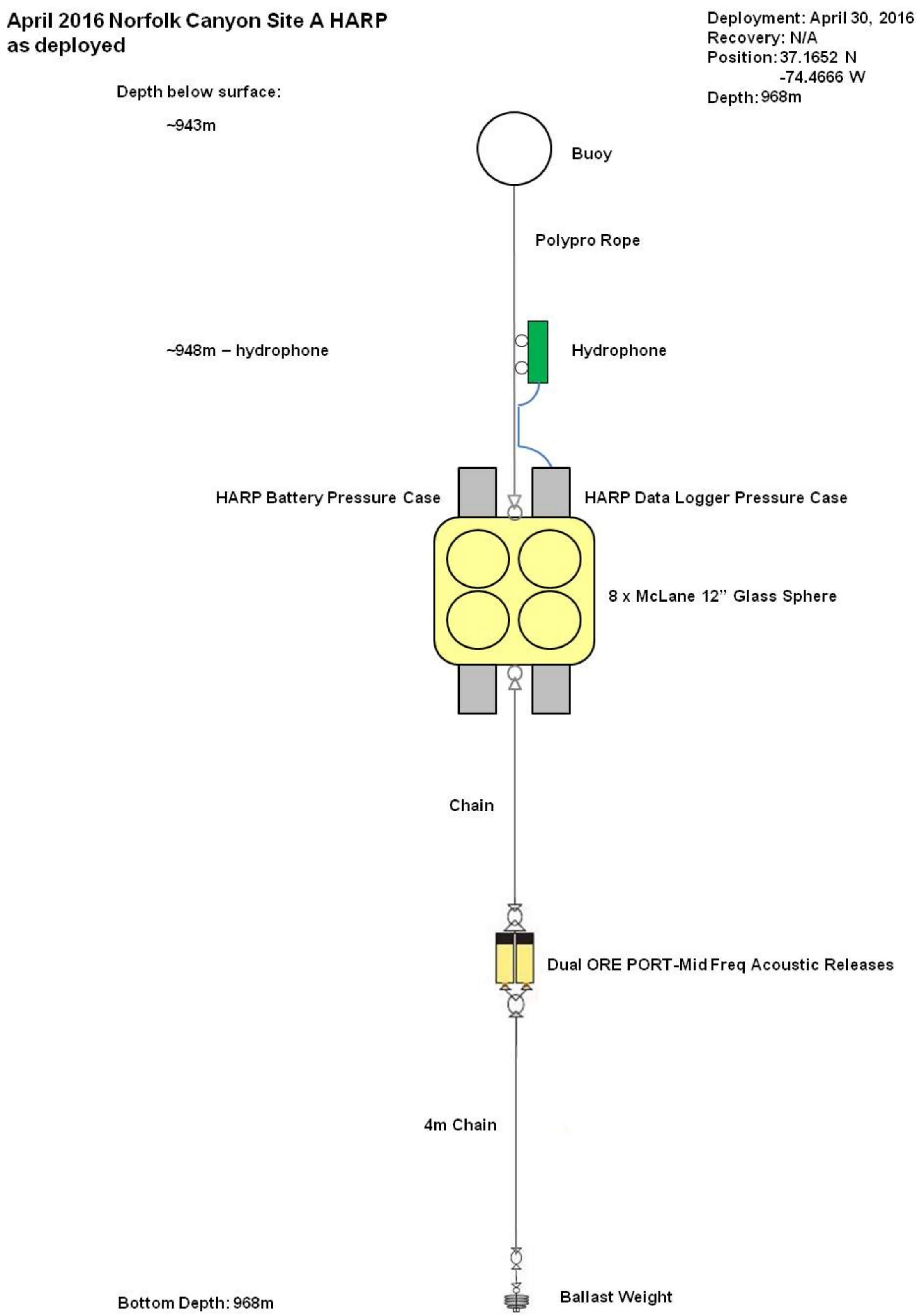


Figure 5. Schematic diagram showing details of the 2016 Norfolk Canyon Site A HARP deployment. Note that diagram is not drawn to scale.

4.2 Results

Table 3 provides information on odontocete whistles detected in the June 2014–April 2015 Norfolk Canyon deployment at site A**. Figures 6 and 7** show the daily occurrence pattern for odontocete whistles, divided into two categories based on frequency, detected in this dataset. The unidentified whistles were present nearly continuously throughout the deployment. Ambient noise results as well as all other marine mammal vocalizations detected in this data set were previously reported in Hodge et al 2016 and Debich et al. 2016..

Table 3. Details for the unidentified odontocete whistles at Norfolk Canyon Site A for June 2014–April 2015. Total duration of vocalizations (hours) and percent of recording duration are based on data analyzed in minute bins.

Species	Call Type	Total Duration of Vocalizations (hours)	Percent of Recording Duration	Days with Vocalizations	Percent of Total Recording Days
Unidentified odontocete	whistles	2541.07	36.57	289	99.31

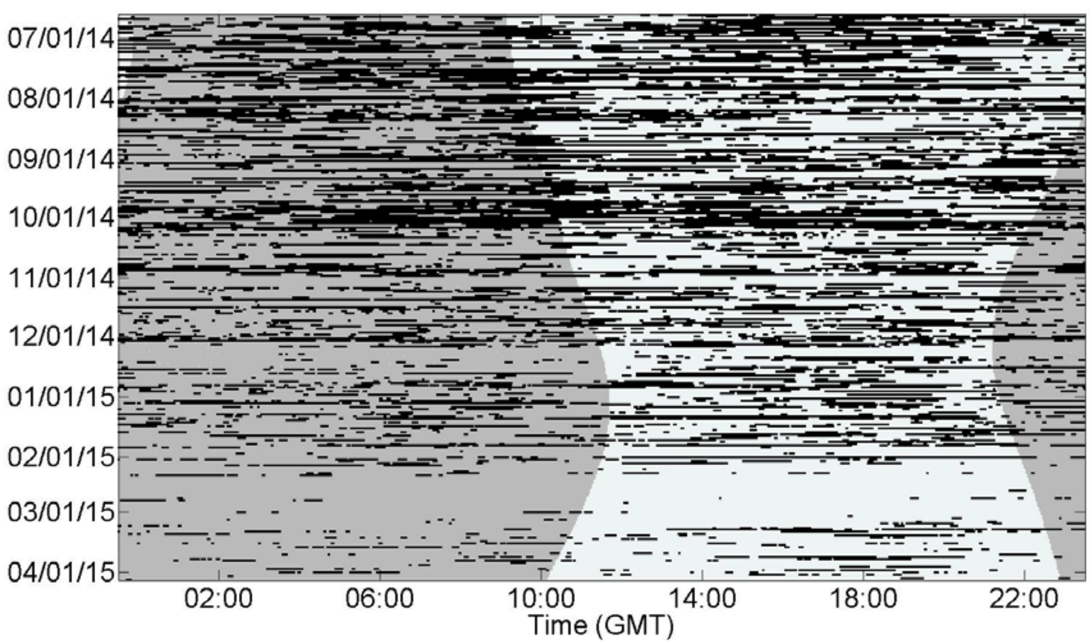


Figure 6. Unidentified odontocete whistles that were lower than 5 kHz (black bars) in 1-minute bins within the June 2014–April 2015 Norfolk Canyon Site A dataset. Gray shading indicates periods of darkness, determined from the U.S. Naval Observatory (http://aa.usno.navy.mil).

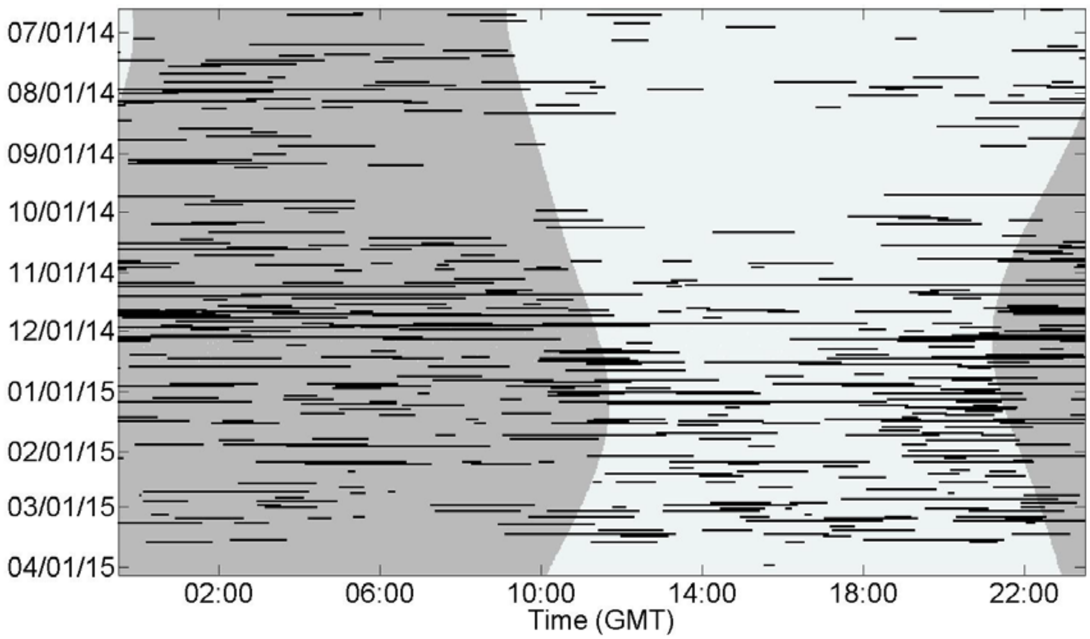


Figure 7. Unidentified odontocete whistles that were higher than 5 kHz (black bars) in 1-minute bins within the June 2014–April 2015 Norfolk Canyon Site A dataset.

5. Cape Hatteras, North Carolina

5.1 Methods

Data Collection

The compact small mooring HARP deployed on 6 April 2015 at 35.34218° N, 74.85726° W (Cape Hatteras Site A) in approximately 980 m was retrieved on 29 April 2016 (**Table 4, Figure 8**). The HARP was redeployed that same day at the same site (35.3057° N, 74.8776° W) in approximately 1,020 m and is still currently in the field, with an expected retrieval date in June 2017 (**Table 4, Figure 8**). The HARP was programmed to sample continuously at 200 kHz for both deployments. A schematic diagram of the HARP mooring for these deployments is shown in **Figure 9**.

Table 4. Cape Hatteras HARP deployments and analyses included in this report.

Site	Deployment Date	Retrieval Date	Recording Start Date	Recording End Date	Latitude (N)	Longitude (W)	Depth (m)	Sampling Rate	Duty Cycle
02A	09-Oct-12	29-May-13	09-Oct-12	9-May-13	35.3406	74.8559	970	200 kHz	continuous
03A	29-May-13	08-May-14	29-May13	15-Mar-14	35.3444	74.8521	970	200 kHz	continuous
04A	08-May-14	06-Apr-15	09-May-14	11-Dec-14	35.3467	74.8480	850	200 kHz	continuous
05A	06-Apr-15	29-Apr-16	07-Apr-15	21-Jan-16	35.3421	74.8572	980	200 kHz	continuous
06A	29-Apr-16	N/A	29-Apr-16	N/A	35.3057	74.8776	~1020	200 kHz	continuous

Data Analysis

Four datasets from deployments at Cape Hatteras Site A have been analyzed for marine mammal and anthropogenic sounds. For three of these datasets (October 2012–May 2013 dataset, May 2013–March 2014 dataset, and the May–December 2014 dataset), all sounds except for odontocete whistles were reported in Hodge et al. (2016) and Debich et al. (2016). The fourth dataset was from the April 2015–April 2016 deployment that yielded 6,948 hours of recording time over 290 days.

Data Quality

Highly stereotyped broadband digital errors ('glitches') were found in the October 2012–May 2013 and the May 2013–March 2014 Cape Hatteras datasets. These glitches were short in duration (between 100 µs and 10 ms) and started in the second half of both datasets, increasing in occurrence once they appeared. To repair the glitches, the data were overwritten using a detector calibrated to the observed amplitude and duration of the glitches. This process does not overwrite any real broadband signals in the data. It is believed that neither the glitches nor the repair process significantly impacted the resulting data analysis.

The May–December 2014 Cape Hatteras deployment experienced disk error issues, causing skipping in the recorded data beginning on December 11. These disk error issues resulted in only four more 75-s files written on four different days between 26 December 2014 and 15 January 2015, which were not included in the analysis.

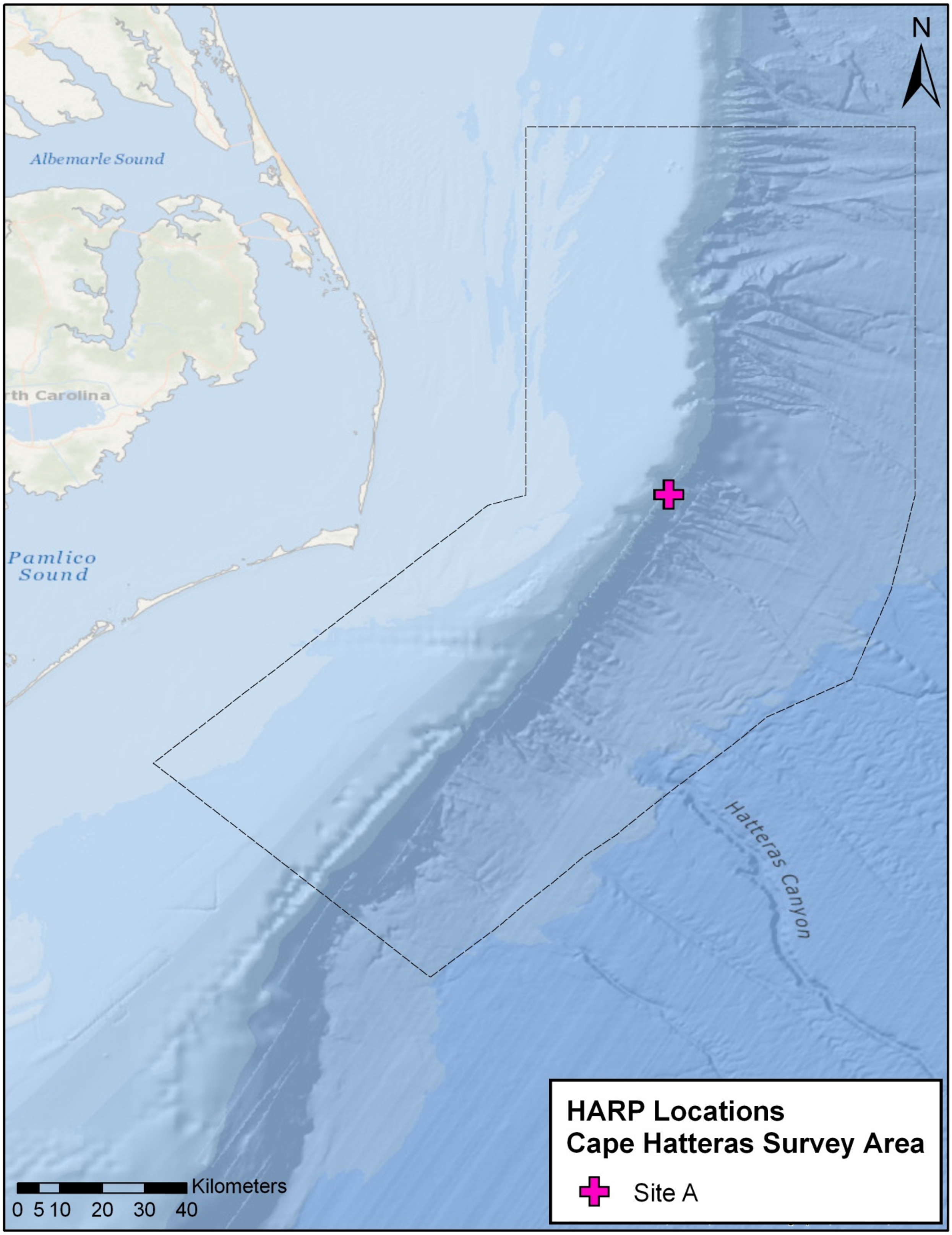


Figure 8. Location of the HARP deployment site in the Cape Hatteras study area.

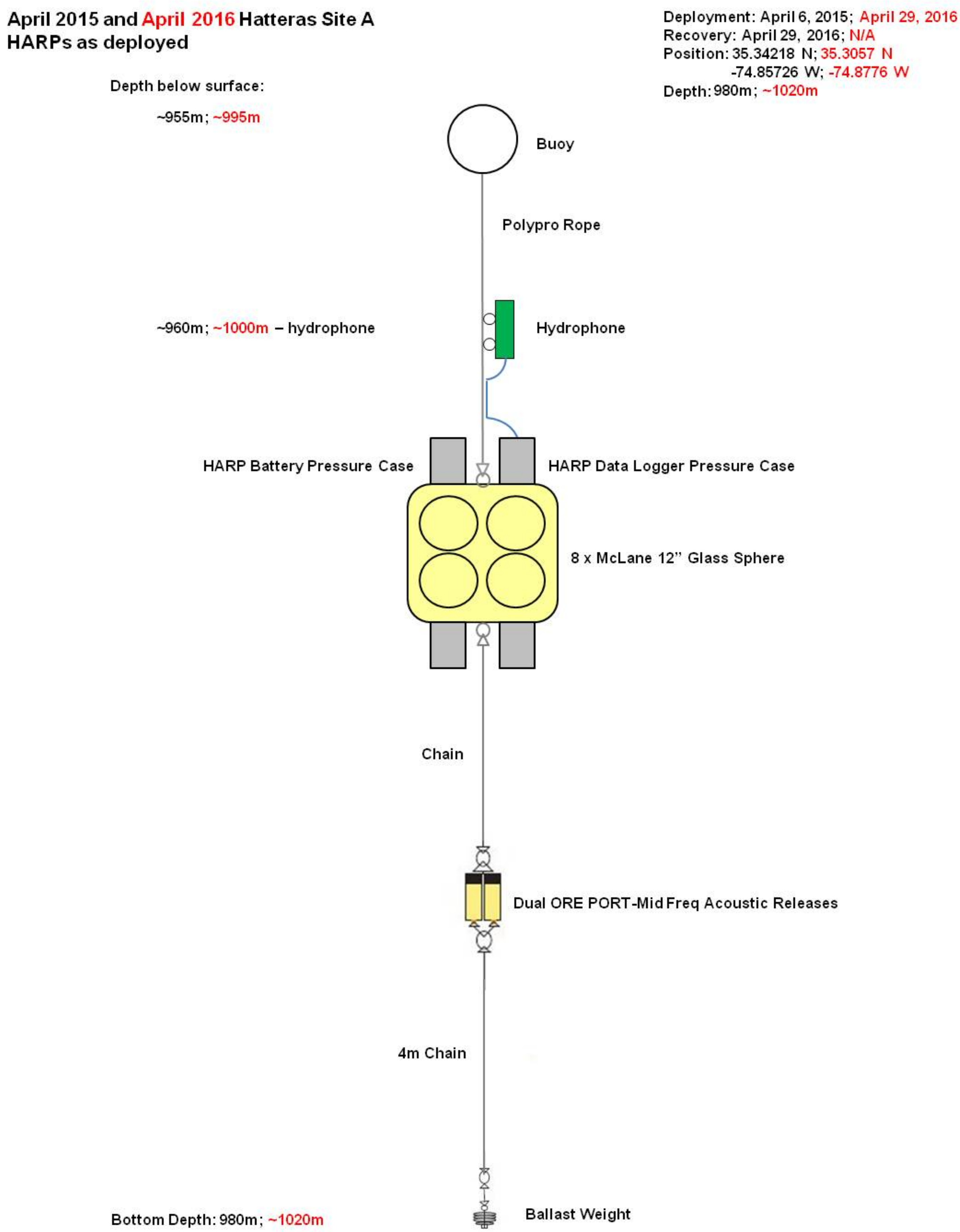


Figure 9. Schematic diagram showing details of the April 2015 and April 2016 Cape Hatteras Site A HARP deployments. Note that diagram is not drawn to scale.

5.2 Results

These results are a summary of Debich et al. (2016) and Frasier et al. (2017). Monthly averages of underwater ambient noise during the April 2015–January 2016 dataset from Cape Hatteras Site A are shown in **Figure 10**. **Table 5** gives details on the detected odontocete whistles during the October 2012–May 2013, May 2013–March 2014, and May–December 2014 datasets, and **Figures 11 through 12** show the daily occurrence patterns of these whistles, separated by frequency. **Table 8** summarizes the detected and identified marine mammal vocalizations during the April 2015–January 2016 dataset**. Figures 13 through 24** show the daily occurrence patterns for the different marine mammal groups (classified to species when possible) and **Figure 25** shows the occurrence of MFA sonar and LFA sonar at Cape Hatteras Site A for the April 2015–January 2016 data set. **Figure 26** shows the occurrence of airguns.

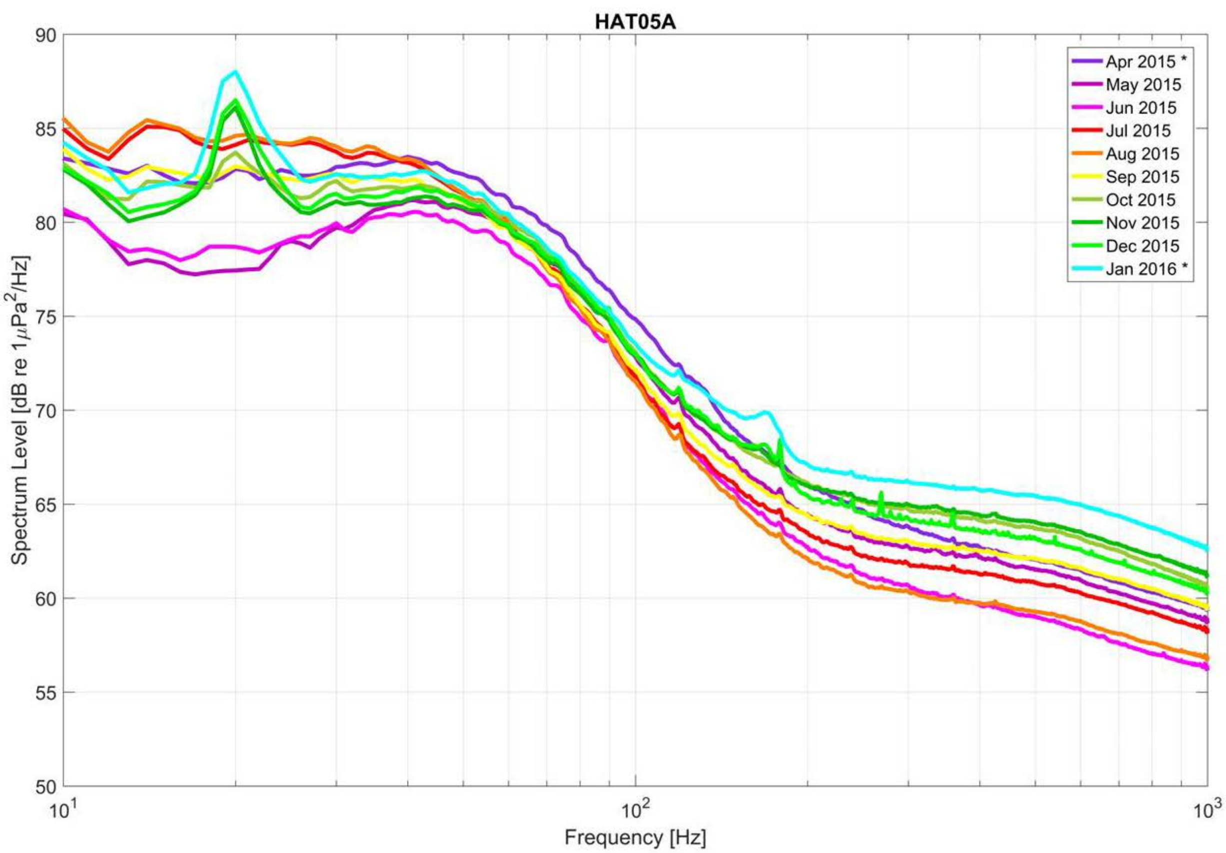


Figure 10. Monthly averages of ambient noise at Cape Hatteras Site A for April 2015–January 2016. Months with an asterisk (*) are partial recording periods. Peaks in noise around 20 Hz during winter months indicate presence of fin whale calls, and peaks around 120 and 170 Hz are related to the presence of minke whale pulse trains. Increased levels between 12-40 Hz during July and August 2015 indicate the presence of seismic airgun surveys. Figure from Frasier et al. (2017).

Table 5. Details for the unidentified odontocete whistles at Cape Hatteras Site A for deployments covering October 2012–December 2014. Total duration of vocalizations (hours) and percent of recording duration are based on data analyzed in minute bins.

Deployment	Call Type	Total Duration of Vocalizations (hours)	Percent of Recording Duration	Days with Vocalizations	Percent of Total Recording Days
Oct 2012 - May 2013	whistles	2567.68	50.42	212	99.53
May 2013 - Mar 2014	whistles	2991.53	43.09	279	95.88
May - Dec 2014	whistles	955.88	18.36	196	90.32

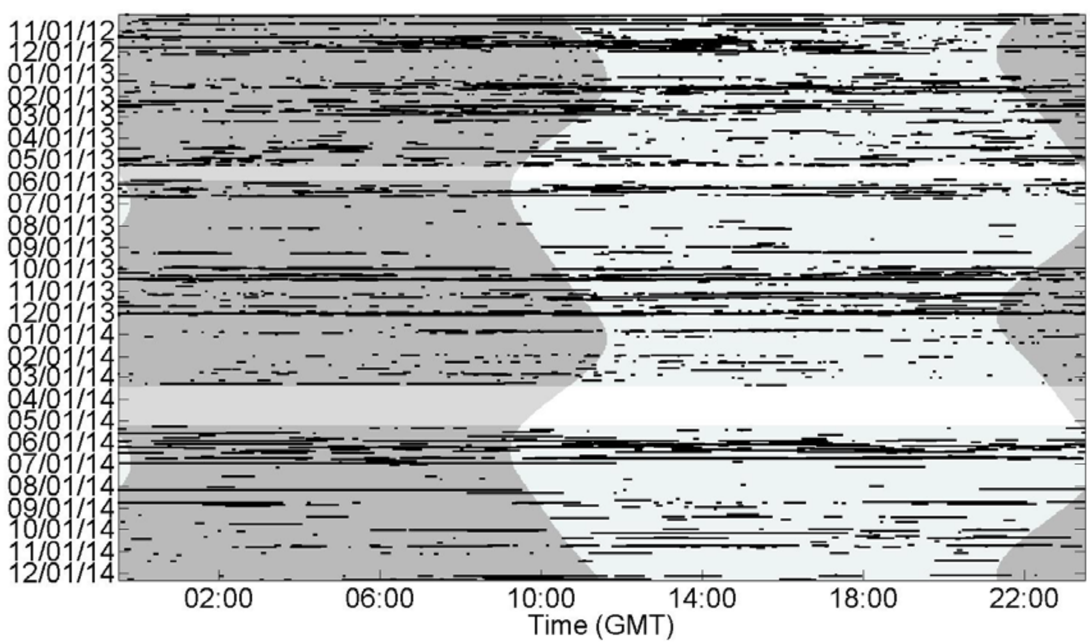


Figure 11. Unidentified odontocete whistle detections that were less than 5 kHz in one-minute bins within the October 2012–May 2013, May 2013–March 2014, and May–December 2014 Cape Hatteras Site A datasets. No data are available for 10–23 May 2013 and 16 March through 8 May 2014.

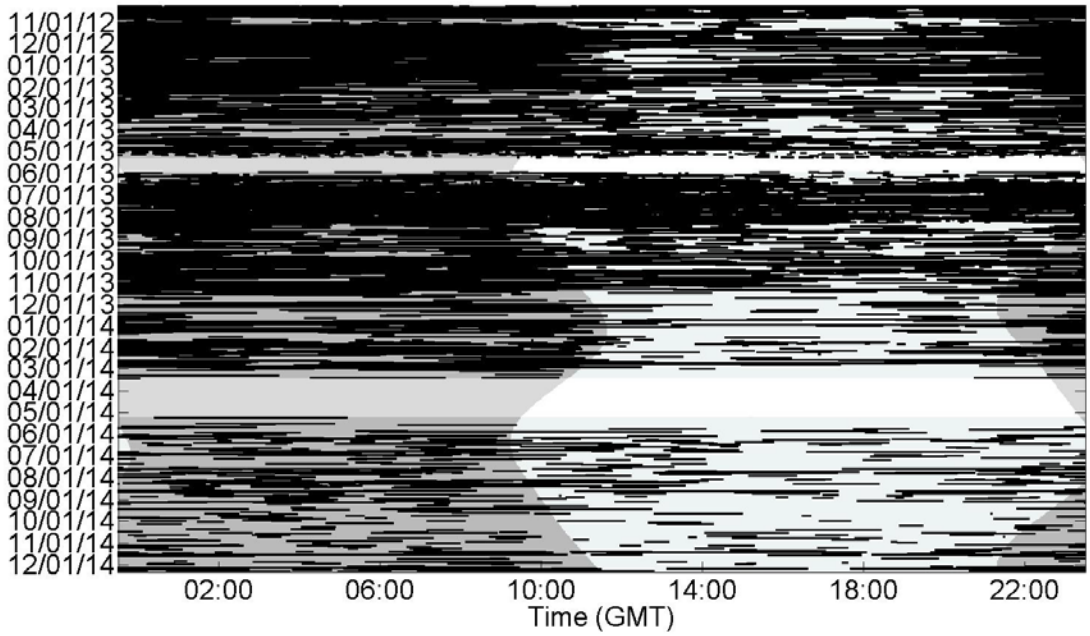


Figure 12. Unidentified odontocete whistle detections that were greater than 5 kHz in one-minute bins within the October 2012–May 2013, May 2013–March 2014, and May–December 2014 Cape Hatteras Site A datasets. No data are available for 10–23 May 2013 and 16 March through 8 May 2014.

Table 8. Summary of detections of marine mammal vocalizations at Cape Hatteras Site A for April 2015–January 2016. Fin whale 20-Hz pulses are not included as they were reported as an acoustic index and not logged with a start and end time to individual detection events.

Species	Call Type	Total Duration of Vocalizations (hours)	Percent of Recording Duration	Days with Vocalizations	Percent of Total Recording Days
Minke whale[a]	pulse train (slow-down, speed-up, regular)	1277	18.38	105	36.21
Sei whale[a]	downsweep	49	0.71	12	4.14
Unidentified odontocete[b]	clicks	1580.02	22.75	281	96.90
Unidentified odontocete[c]	whistles	4804.38	69.17	288	99.31
Kogia sp. [c]	clicks	1.55	0.02	26	8.97
Risso’s dolphin[b]	clicks	16.42	0.24	6	2.07
Sperm whale[c]	clicks	582.93	8.39	162	55.86
Cuvier’s beaked whale[c]	clicks	1375.5	19.80	287	98.97
Gervais’ beaked whale[c]	clicks	108.85	1.57	142	48.97
Blainville’s beaked whale[c]	clicks	0.45	0.006	1	0.34

[a] Analyzed in hourly bins.
[b] Analyzed in five-minute bins.
[c] Analyzed in one-minute bins.

Mysticete detections included fin whales, minke whales, and sei whales. Fin whale 20-Hz pulses (as measured by the acoustic index) were detected throughout the deployment, with detections ramping up in November and peaking in January (**Figure 13**). Minke whale pulse trains showed a strong seasonal pattern, with detections from the beginning of recording (April 2015) through May 2015 and starting again in October 2015 and lasting through the end of recording (January 2016) (**Figure 14**). Sei whale downsweeps were detected starting in December 2015 and lasting through the end of the recording period in January 2016 (**Figure 15**).

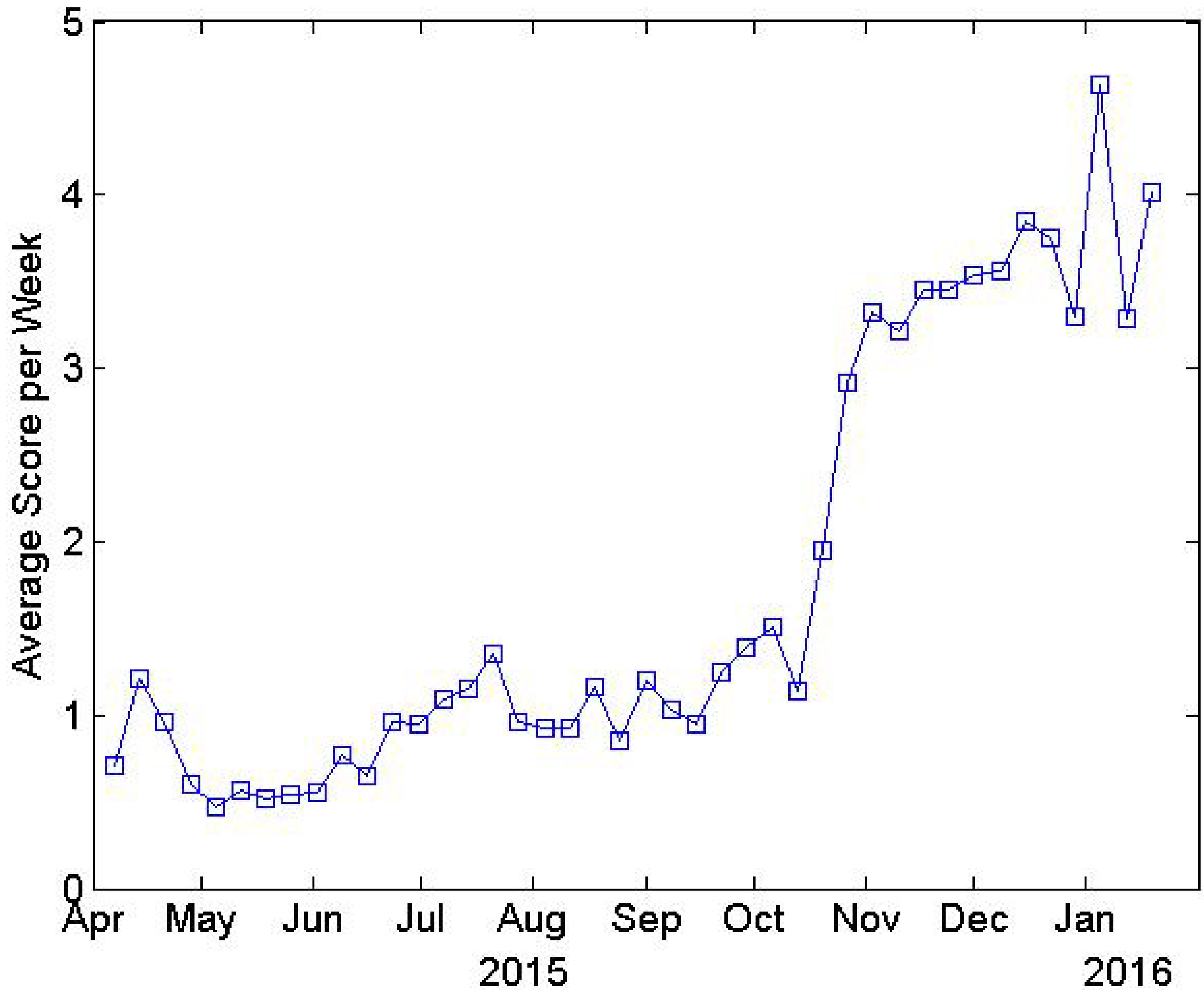


Figure 13. Weekly value of fin whale 20-Hz call acoustic index for the April 2015–January 2016 Cape Hatteras Site A dataset.

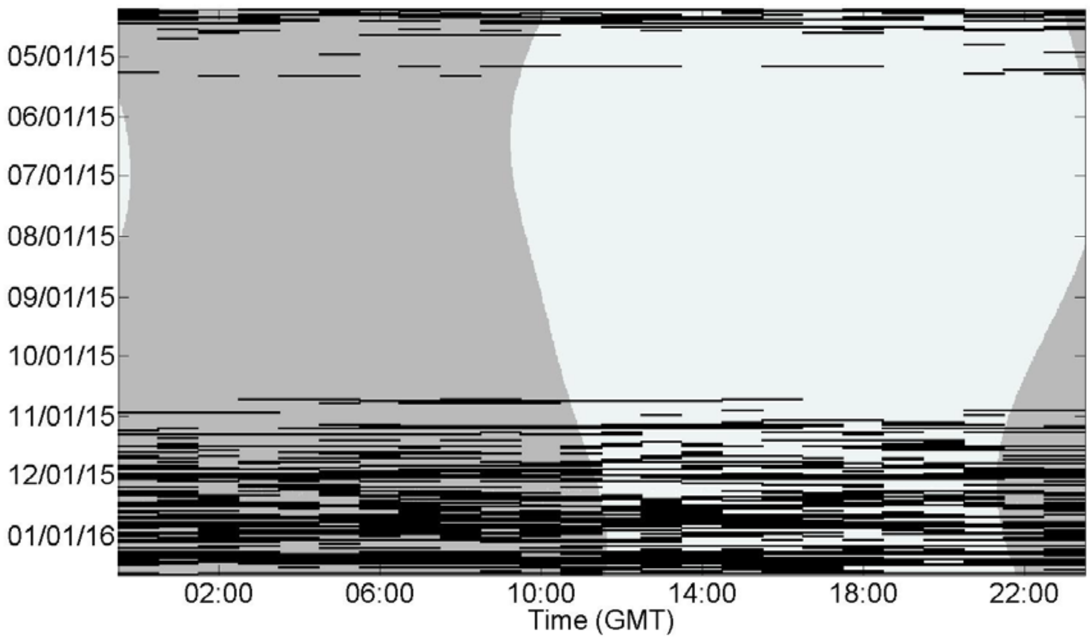


Figure 14. Minke whale pulse train detections (black bars) in hourly bins within the April 2015–January 2016 Cape Hatteras Site A dataset.

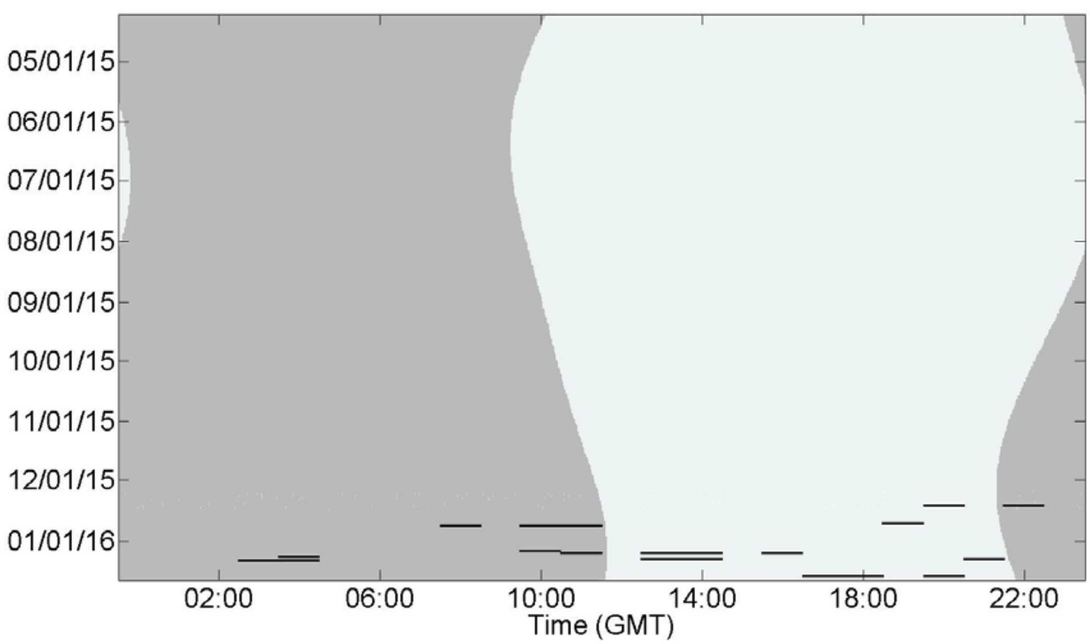


Figure 15. Sei whale downsweeps detections (black bars) in hourly bins within the April 2015–January 2016 Cape Hatteras Site A dataset.

Detected odontocete vocalizations were classified as *Kogia* sp. clicks, Risso's dolphin clicks, sperm whale clicks, Cuvier's beaked whale clicks, Gervais' beaked whale clicks, Blainville's beaked whale (*Mesoplodon densirostris*) clicks, and unidentified odontocete clicks and whistles (with clicks and whistles analyzed for separately, as discussed in Section 3.3). Many of the odontocete click detections could not be classified to species but the unclassified clicks were divided into five main groups based on spectral patterns (**Figure 16**). Altogether, these unclassified clicks were present nearly continuously throughout each recording period. For more details on each of the five groups of clicks and which species may have produced them, see Frasier et al. (2017). Unidentified odontocete whistles both lower and higher than 5 kHz occurred very regularly throughout the April 2015–January 2016 dataset, although there were many more whistles higher than 5 kHz (**Figures 17 and 18**). Clicks produced by *Kogia* sp. were detected sporadically throughout the deployment (**Figure 19**). Risso's dolphin clicks were detected only between May and July (**Figure 20**). Sperm whales were detected throughout the deployment during both day and night, with peaks in click detections between late July and early August as well as from late December to the end of recording in January (**Figure 21**). There were also click detections assigned to three species of beaked whales. Cuvier's beaked whale clicks occurred regularly throughout this deployment, with a slight increase in detections between September and December, as in previous years, as well as between April and May (**Figure 22**). Gervais' beaked whale clicks occurred less frequently than Cuvier's beaked whale clicks at Cape Hatteras Site A. Most Gervais' beaked whale detections occurred between April and July and between November and January (**Figure 23**). Unlike Cuvier's beaked whales, there were very few detections of Gervais' beaked whales between August and October, similar to previous years. Blainville's beaked whale clicks were detected only on one day in January (**Figure 24**).

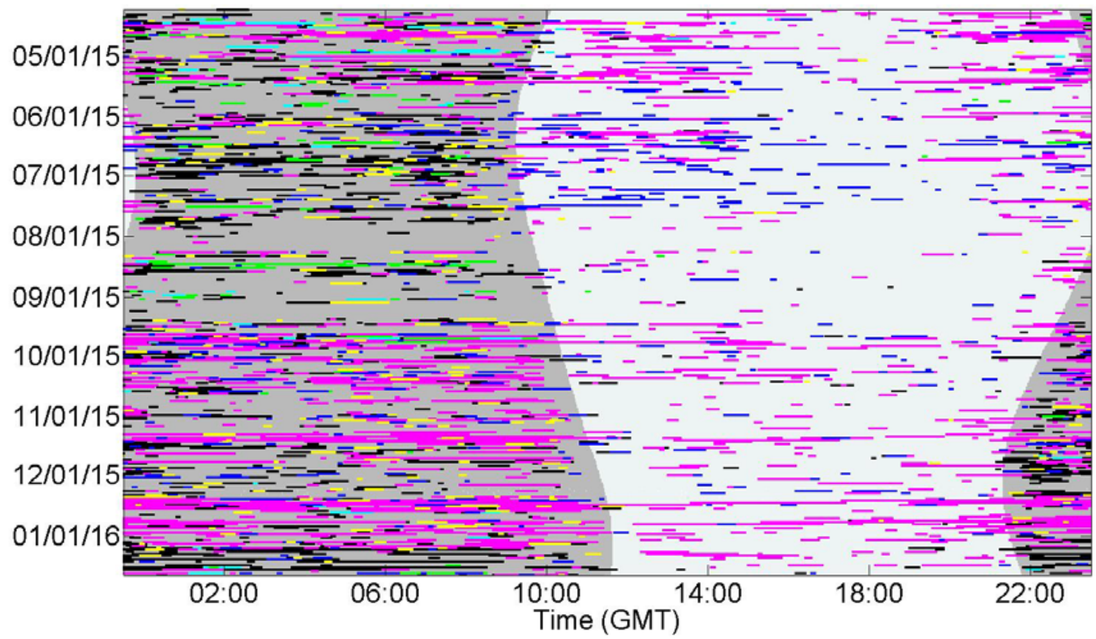


Figure 16. Unidentified odontocete click detections (different colored horizontal bars represent the different groups clicks were divided into, with those in yellow not assigned a category) in 1-minute bins within the April 2015–January 2016 Cape Hatteras Site A dataset.

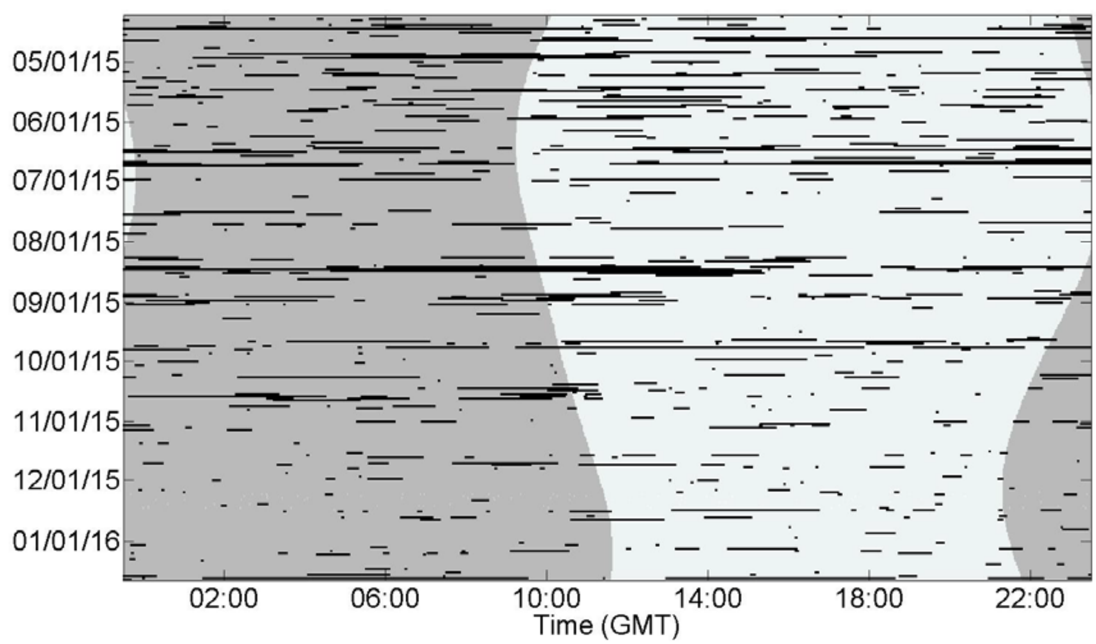


Figure 17. Unidentified odontocete whistle detections lower than 5 kHz in 1-minute bins within the April 2015–January 2016 Cape Hatteras Site A dataset.

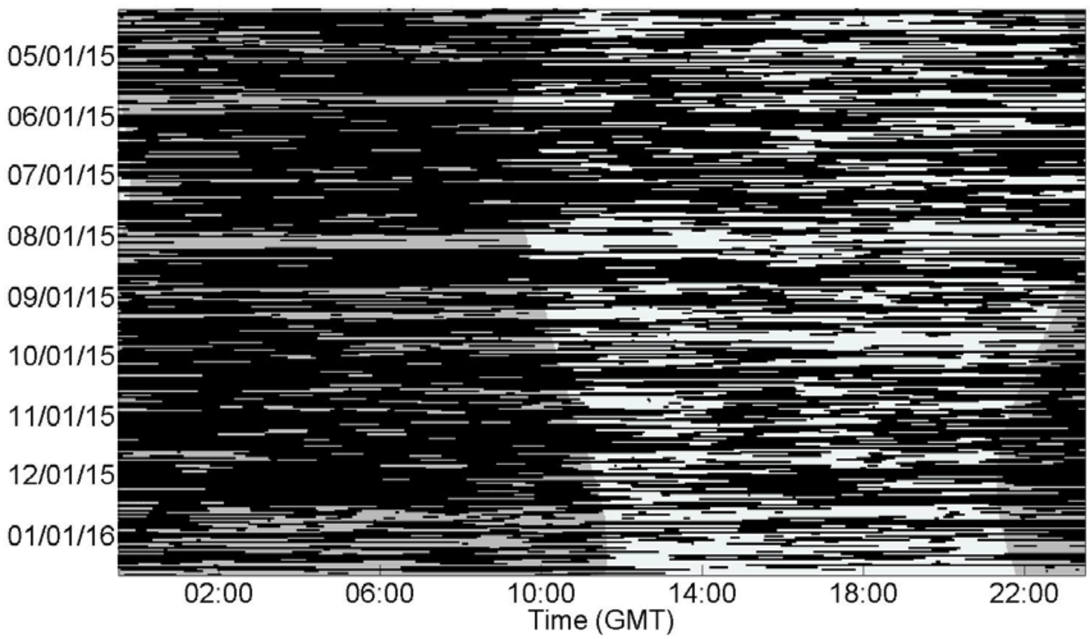


Figure 18. Unidentified odontocete whistle detections higher than 5 kHz in 1-minute bins within the April 2015–January 2016 Cape Hatteras Site A dataset.

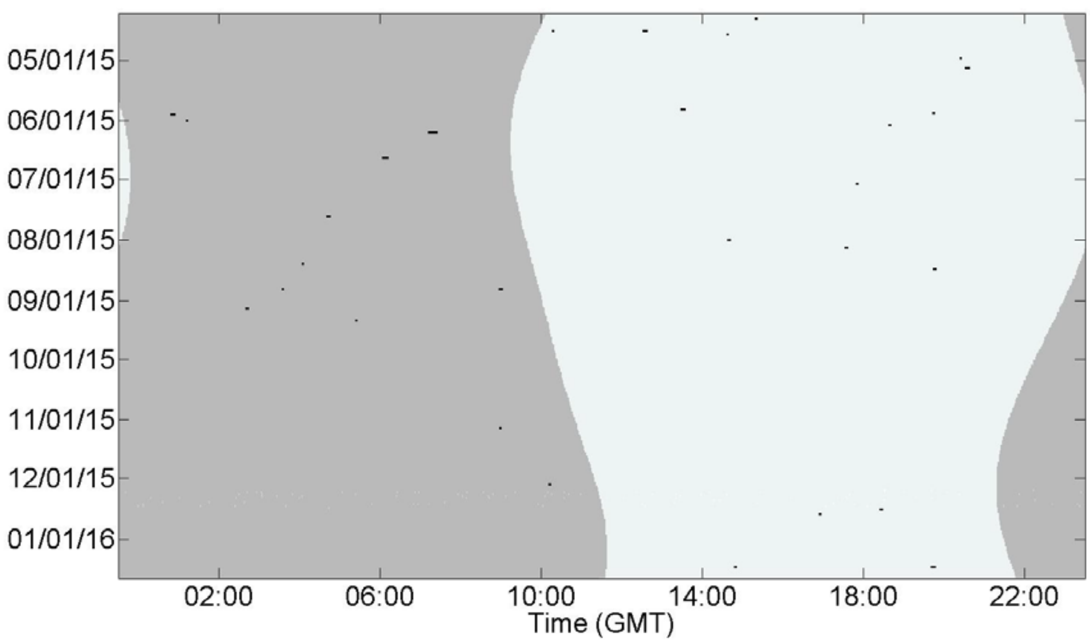


Figure 19. *Kogia* sp. click detections (black bars) in 1-minute bins within the April 2015–January 2016 Cape Hatteras Site A dataset.

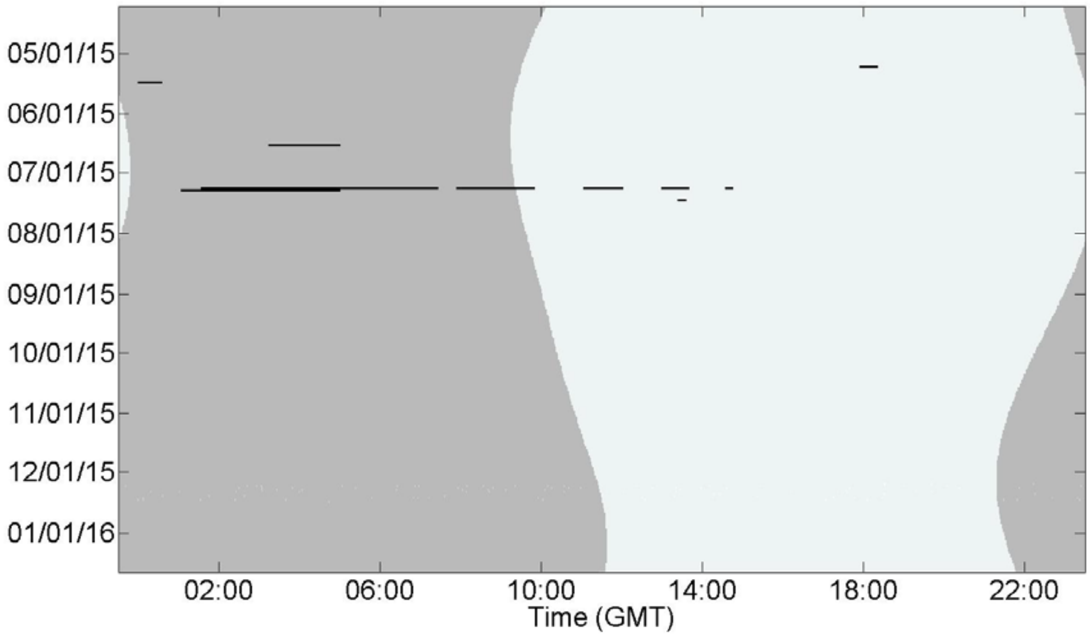


Figure 20. Risso's dolphin click detections (black bars) in 1-minute bins within the April 2015–January 2016 Cape Hatteras Site A dataset.

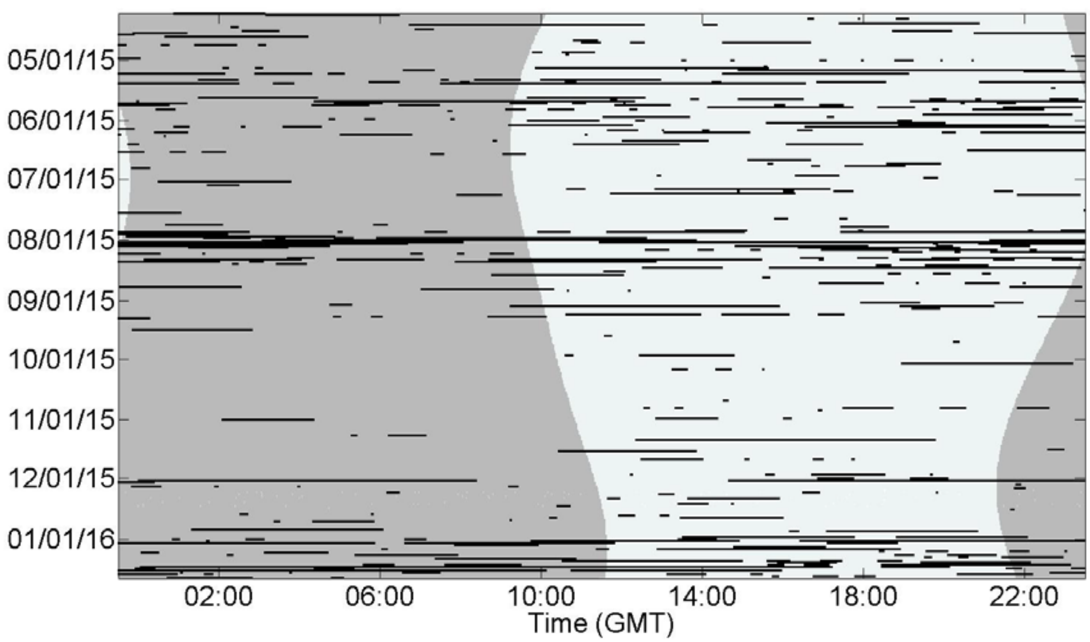


Figure 21. Sperm whale click detections (black bars) in 1-minute bins within the April 2015–January 2016 Cape Hatteras Site A dataset.

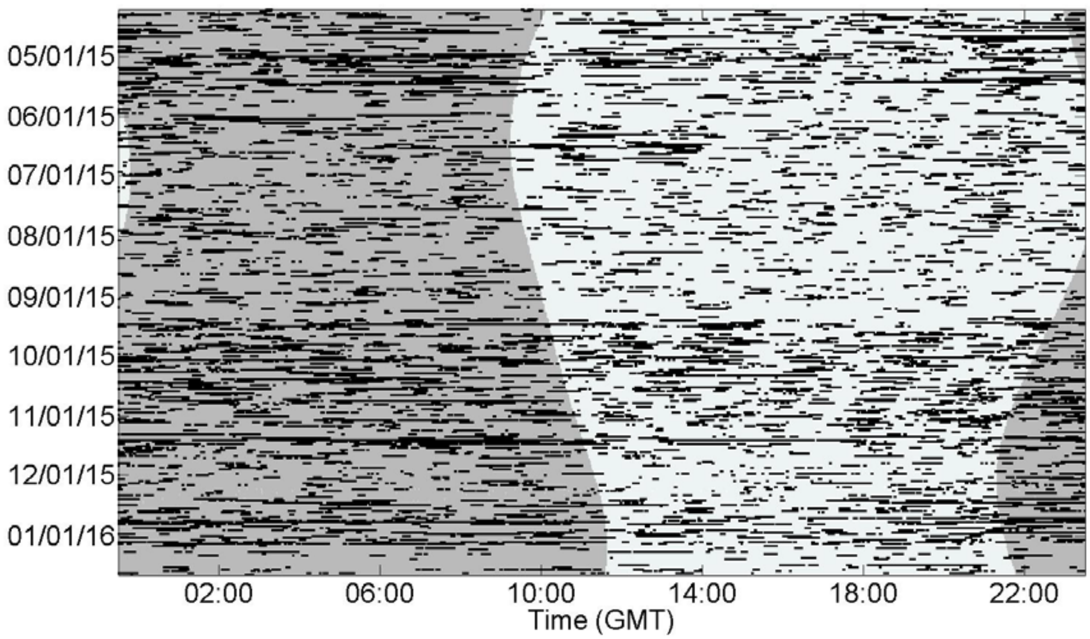


Figure 22. Cuvier's beaked whale click detections (black bars) in 1-minute bins within the April 2015–January 2016 Cape Hatteras Site A dataset.

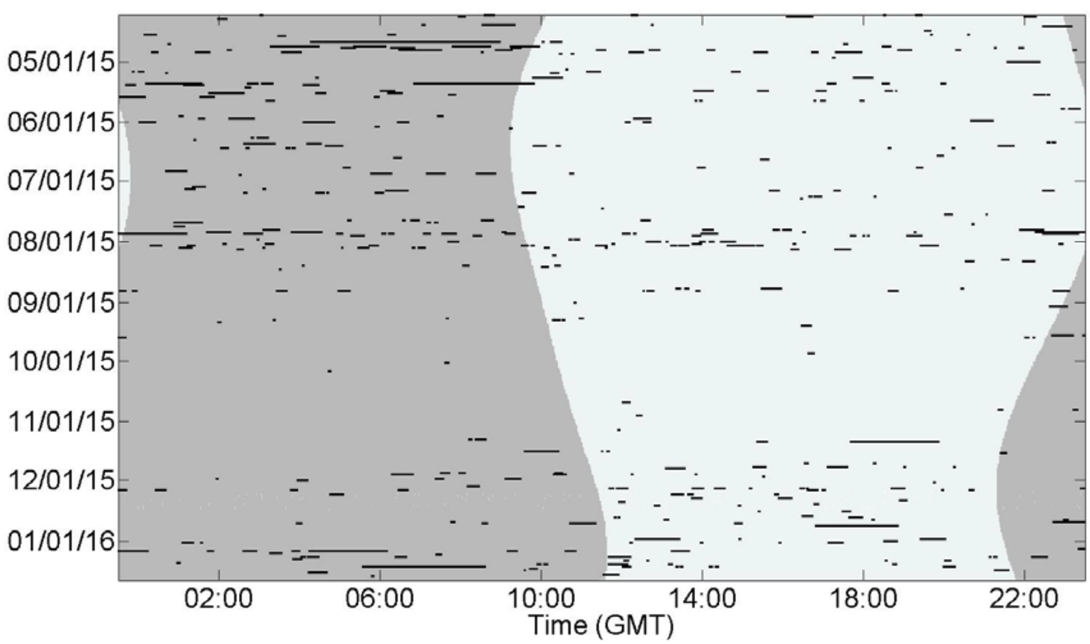


Figure 23. Gervais' beaked whale click detections (black bars) in 1-minute bins within the April 2015–January 2016 Cape Hatteras Site A dataset.

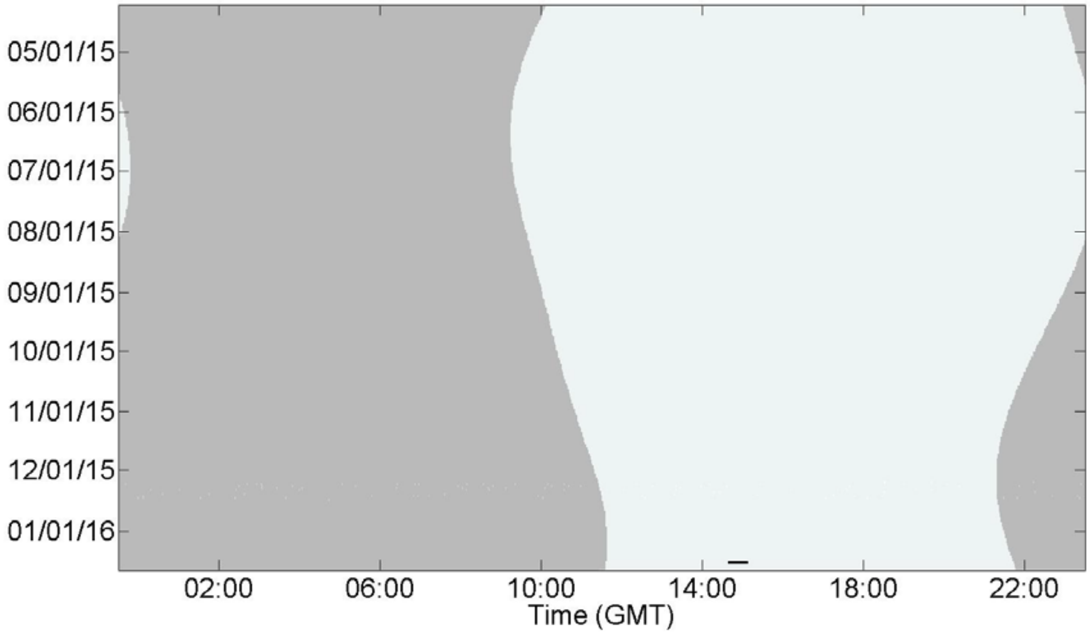


Figure 24. Blainville's beaked whale click detections (black bars) in 1-minute bins within the April 2015–January 2016 Cape Hatteras Site A dataset.

MFA sonar was detected intermittently throughout the April 2015–January 2016 dataset recorded at Cape Hatteras Site A, with a peak in detections occurring in October (**Figure 25**). LFA sonar higher than 500 Hz was detected on one day in September (**Figure 25**). Airguns were detected throughout the deployment during both day and night, with peaks in detections in April 2015 and between June and September 2015 (**Figure 26**).

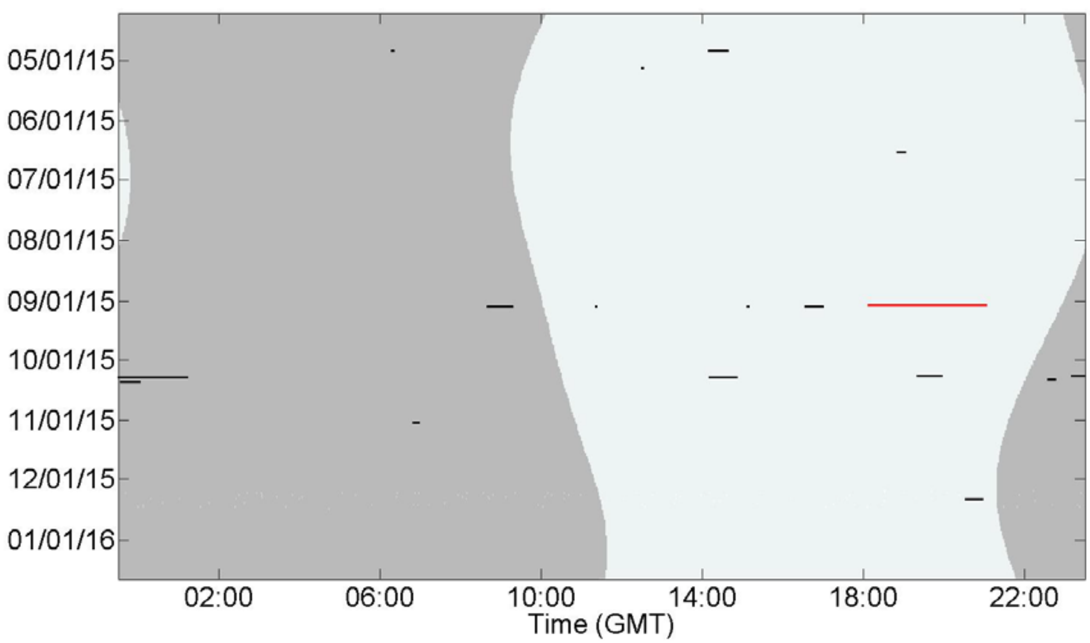


Figure 25. Mid-frequency active sonar (black bars) and low-frequency active sonar higher than 500 Hz (red bars) detected within the April 2015–January 2016 Cape Hatteras Site A dataset.

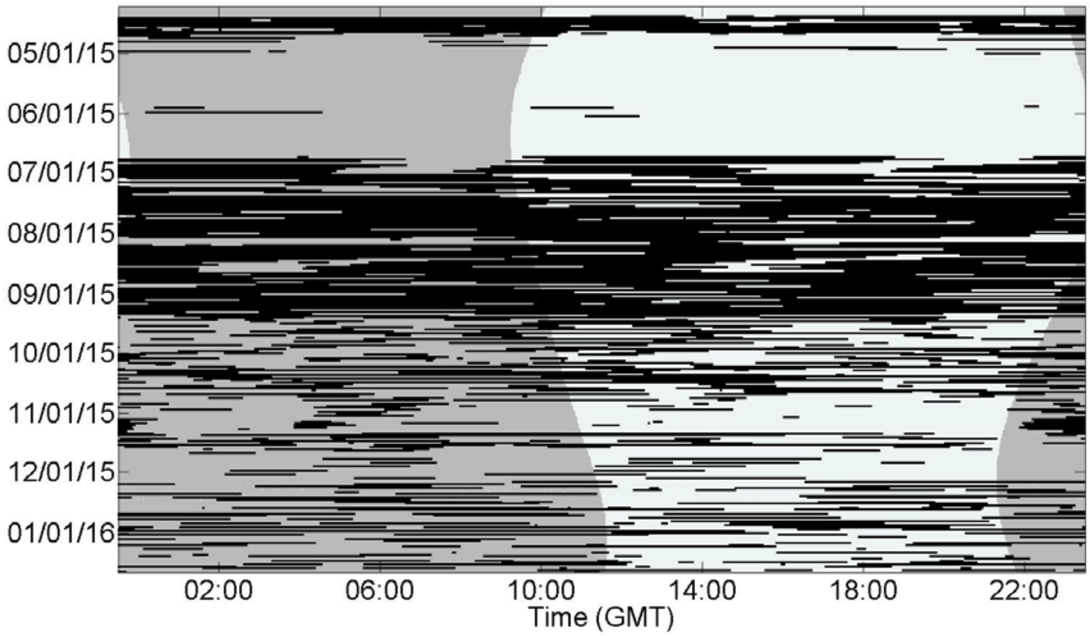


Figure 26. Airgun detections (black bars) within the April 2015–January 2016 Cape Hatteras Site A dataset.

6. Jacksonville

6.1 Methods

Data Collection

The small mooring HARP deployed in 800 m at 30.1489 N, 79.7711 W was recovered on 26 April 2016 (**Table 9**; **Figure 27**) and redeployed that same day at the same site in approximately 736 m at 30.1518 N, 79.7702 W (**Table 9; Figure 27**). This HARP is still out in the field and is scheduled to be recovered in June 2017. Both HARPs were set to sample continuously at 200 kHz. A schematic diagram of the HARP moorings for the July 2015 and April 2016 deployments can be seen in **Figures 28 through 29**.

Table 9. Jacksonville, Florida, HARP data sets analyzed and detailed in this report.

Site	Deployment Date	Retrieval Date	Recording Start Date	Recording End Date	Latitude (N)	Longitude (W)	Depth (m)	Sampling Rate	Duty Cycle
11D	23-Aug-14	2-Jul-15	23-Aug-14	29-May-15	30.1506	79.7701	~806	200 kHz	continuous
12D	2-Jul-15	26-Apr-16	3-Jul-15	4-Nov-15	30.1489	79.7711	800	200 kHz	continuous
13D	26-Apr-16	N/A	26-Apr-16	N/A	30.1518	79.7702	736	200 kHz	continuous

Data Analysis

Data from the August 2014 and July 2015 deployments at JAX Site D have been analyzed for marine mammal and anthropogenic sounds and will be reported here as a summary of Frasier et al. (2016) and Varga et al. (2017). The August 2014–July 2015 deployment yielded 6,697 hours of recording time over 280 days, while the July 2015–April 2016 deployment yielded 2,995 hours of recording time over 125 days.

Data Quality

Approximately three days after the July 2015 deployment, the LF stage of the hydrophone failed. The majority of the remaining data has little to no sensitivity in the lower frequencies (< ~12 kHz), as well as occasional broadband masking from electronic noise. Despite the failure of the LF component of the hydrophone, it remained sensitive to acoustic signals between ~12 and 100 kHz. For these reasons, the July 2015 dataset could not be analyzed for mysticetes, LFA sonar, MFA sonar, or ships.

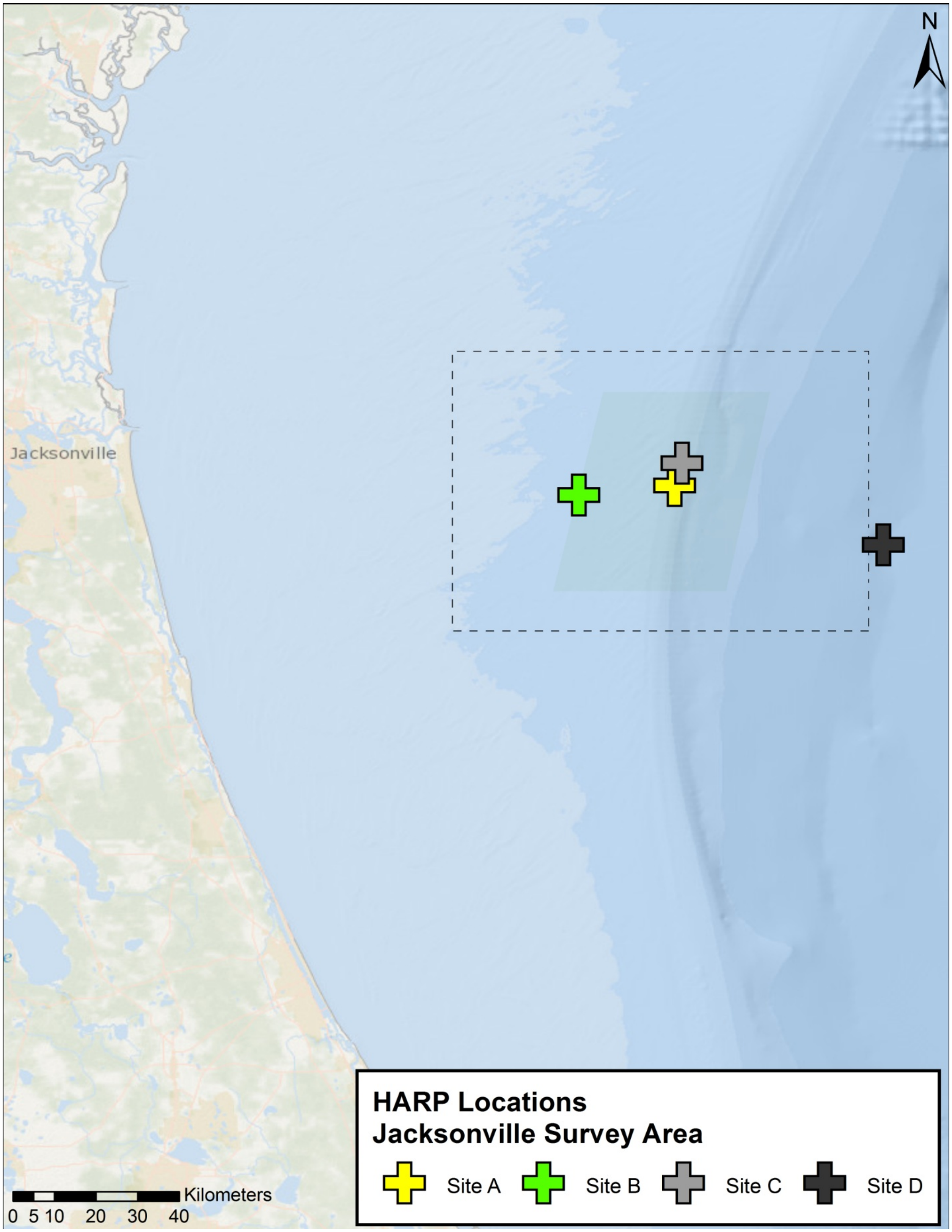


Figure 27. Location of HARP deployment sites in the Jacksonville, Florida, survey area. All data included in this report was collected at Site D.

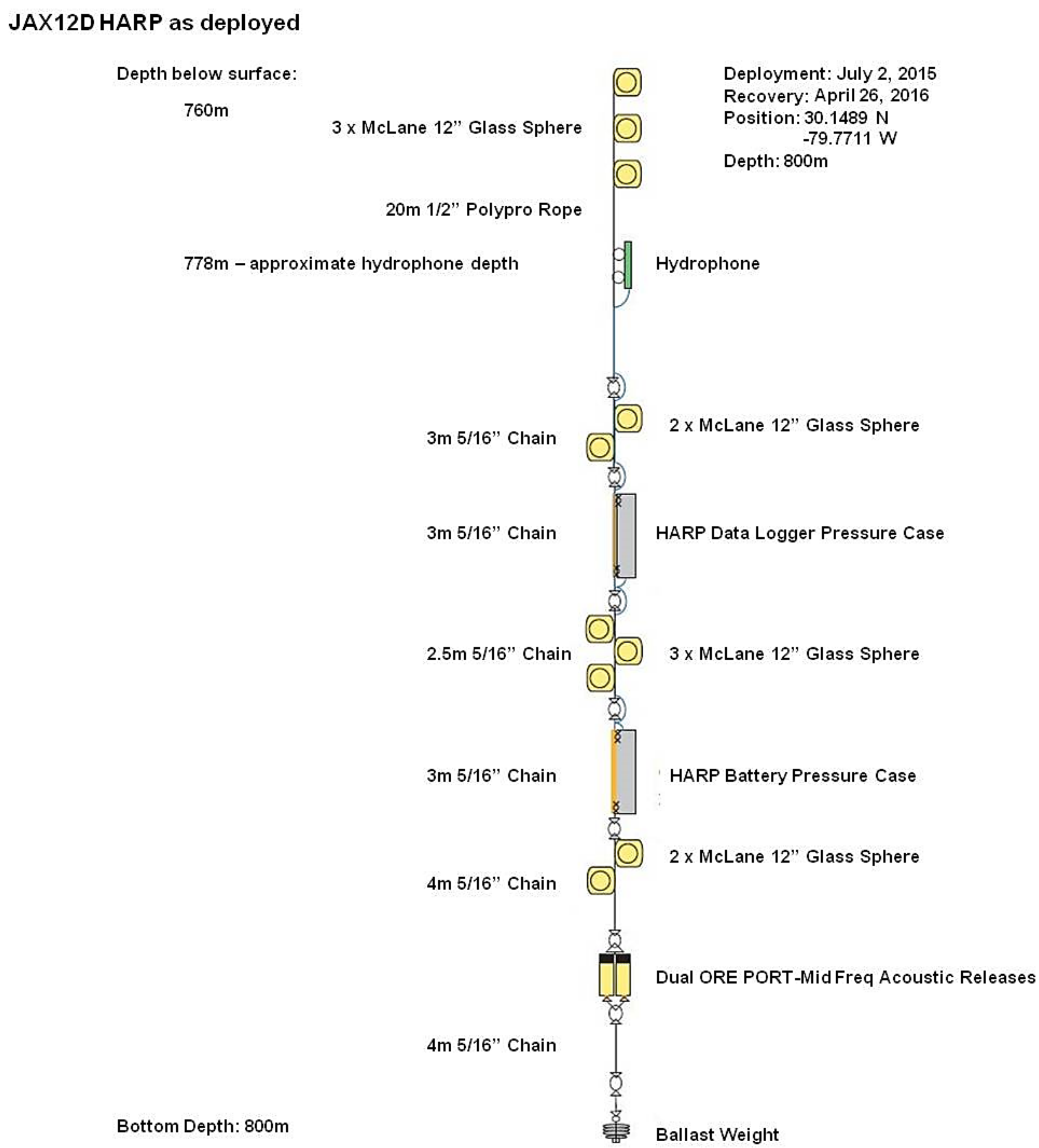


Figure 28. Schematic diagram showing details of the Site D Jacksonville HARP deployment (small mooring) made in July 2015. Note that diagram is not drawn to scale.

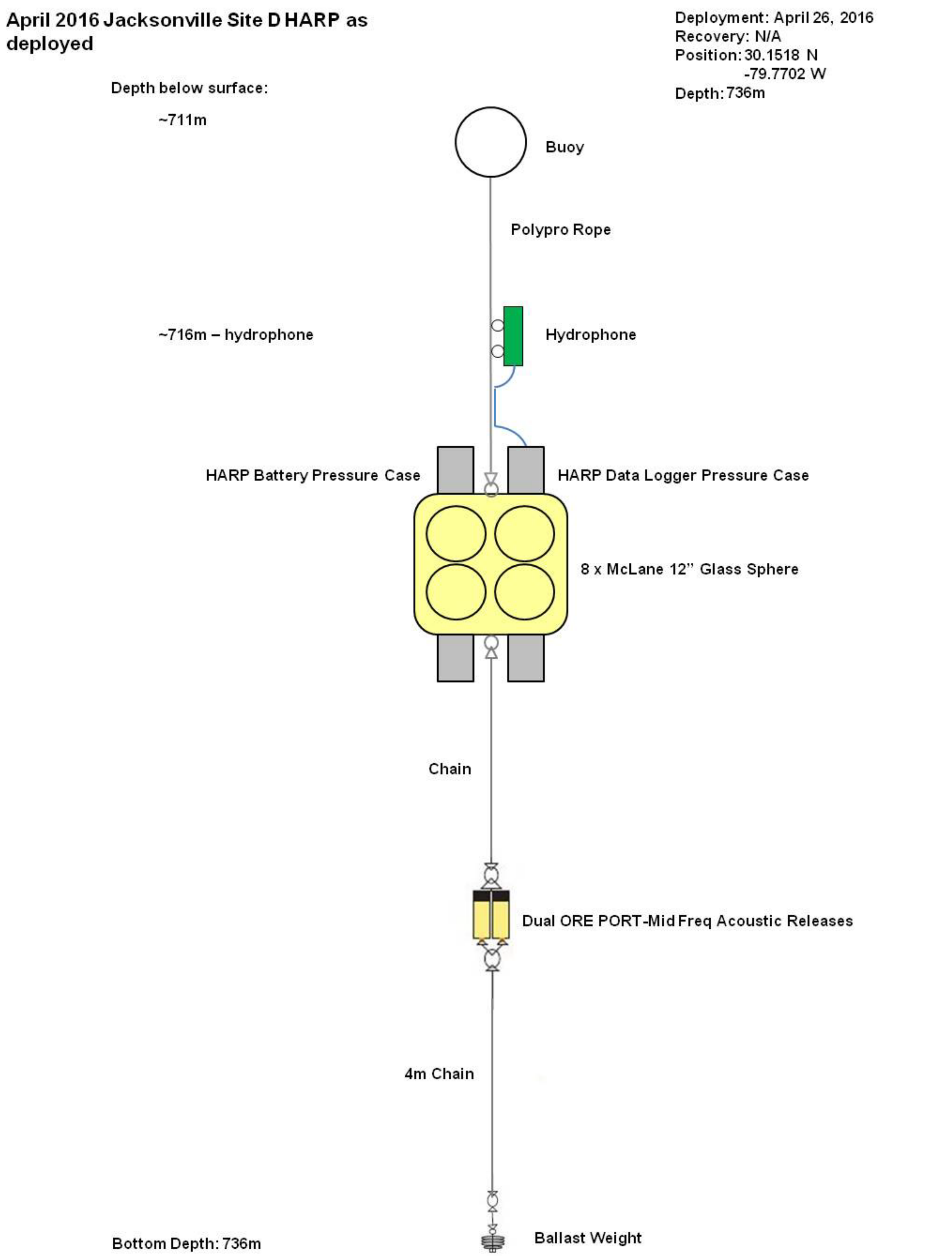


Figure 29. Schematic diagram showing details of the Site D Jacksonville HARP deployment (compact small mooring) made in April 2016. Note that diagram is not drawn to scale.

6.2 Results

These results are a summary of Frasier et al. (2016) and Varga et al. (2017), with beaked whale analysis for the August 2014–May 2015 dataset performed by Joy Stanistreet. Monthly averages of underwater ambient noise during the August 2014–May 2015 JAX Site D dataset described here is shown in **Figure 30**. Underwater ambient noise could not be measured in the July–November 2015 dataset because the low frequency data were not usable for reasons detailed above. **Tables 10 and 11** summarize the detected and identified marine mammal vocalizations during these two datasets, and **Figures 31 through 42** show the daily occurrence patterns for the different marine mammal groups (classified to species when possible). **Figures 43 and 44** show the occurrence of MFA sonar and HFA sonar, respectively.

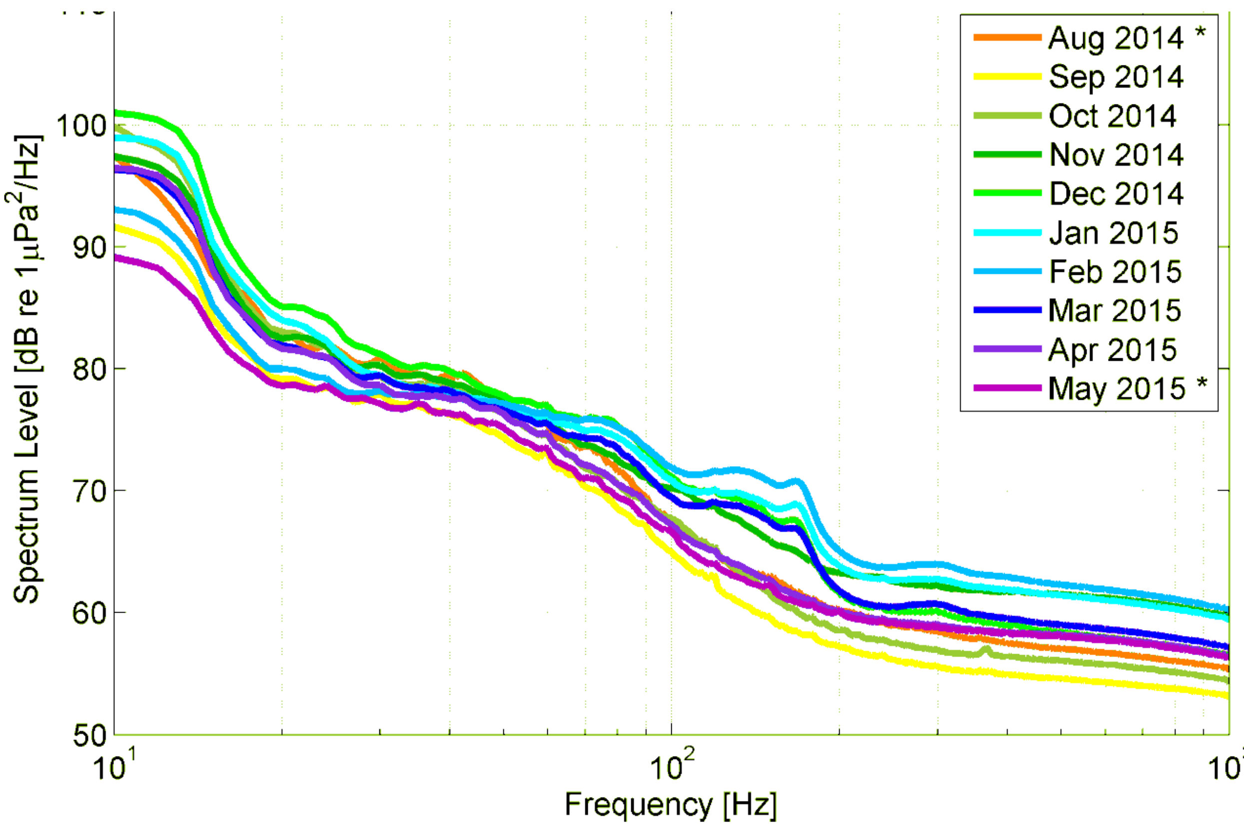


Figure 30. Monthly averages of ambient noise at JAX Site D for August 2014–May 2015. Months with an asterisk (*) are partial recording periods. Increased levels between 100-200 Hz between December and March are from the presence of minke whale pulse trains. Figure from Frasier et al. (2016).

Only the August 2014–May 2015 dataset could be inspected for mysticete calls due to the equipment failure described in Section 4.1. In the August 2014–May 2015 dataset, calls from fin whales, minke whales, and sei whales were detected. Fin whale 20-Hz pulses were detected between January and March 2015 (**Figure 31**). Minke whale pulse trains were detected first in October 2014, with detections ramping up to almost continuous (on an hourly basis) in December and remaining at elevated levels through March 2015 (**Figure 32**). Minke whale pulse trains started decreasing in April and were not detected after early May 2015 (**Figure 32**).

Sei whale downsweeps were detected between November 2014 and January 2015, with a peak in detections in January (**Figure 33**).

Table 10. Summary of detections of marine mammal vocalizations at JAX Site D for August 2014–May 2015.

Species	Call Type	Total Duration of Vocalizations (hours)	Percent of Recording Duration	Days with Vocalizations	Percent of Total Recording Days
Fin whale[a]	20 Hz	76	1.1	13	4.6
Minke whale[a]	pulse train (slow-down, speed-up, regular)	3654	54.6	184	65.7
Sei whale[a]	downsweep	88	1.3	17	6.1
Unidentified odontocete[b]	clicks	382.2	5.7	218	77.9
Unidentified odontocete[c]	whistles	423.3	6.3	181	64.6
Kogia sp. [c]	clicks	10.5	0.2	80	28.6
Risso's dolphin[b]	clicks	93.3	1.4	131	46.8
Sperm whale[c]	clicks	28.6	0.4	11	3.9
Blainville's beaked whale[b]	clicks	0.7	0.01	2	0.7
Gervais' beaked whale[b]	clicks	2.2	0.03	4	1.4

[a] Analyzed in hourly bins.
[b] Analyzed in 5-minute bins.
[c] Analyzed in 1-minute bins.

Table 11. Summary of detections of marine mammal vocalizations at JAX Site D for July–November 2015. Note that detections of unidentified odontocete whistles less than 5 kHz were likely missed due to the hydrophone failure mentioned previously.

Species	Call Type	Total Duration of Vocalizations (hours)	Percent of Recording Duration	Days with Vocalizations	Percent of Total Recording Days
Unidentified odontocete[a]	clicks	73.70	2.46	87	69.6
Unidentified odontocete[b]	whistles	23.92	0.80	33	26.4
Kogia sp. [b]	clicks	14.92	0.15	100	80
Risso's dolphin[a]	clicks	144.75	1.49	180	144
Sperm whale[b]	clicks	79.78	0.82	23	18.4
Blainville's beaked whale[a]	clicks	0.68	0.007	2	1.6
Cuvier's beaked whale[a]	clicks	0.48	0.005	3	2.4
Gervais' beaked whale[a]	clicks	3.58	0.04	8	6.4

[a] Analyzed in 5-minute bins.
[b] Analyzed in 1-minute bins.

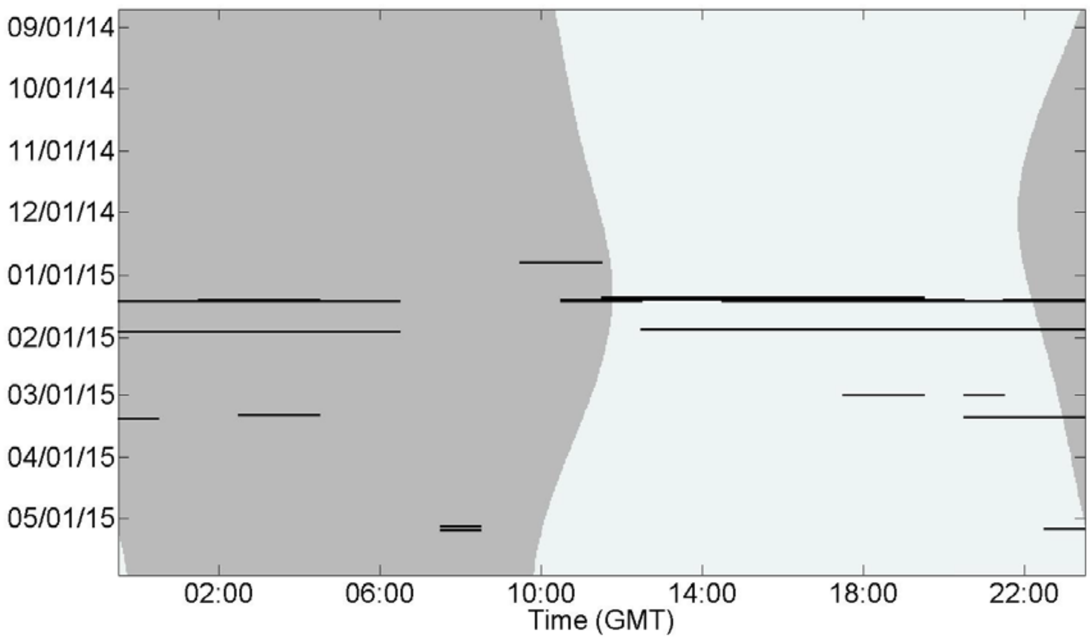


Figure 31. Fin whale 20-Hz pulse detections (black bars) in hourly bins within the August 2014–May 2015 JAX Site D dataset.

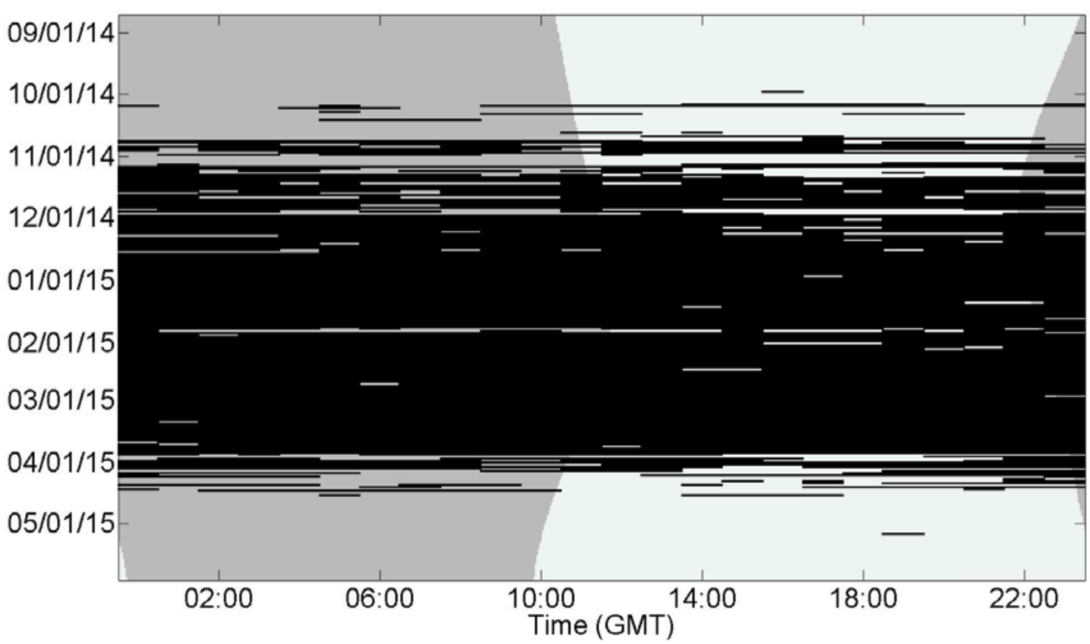


Figure 32. Minke whale pulse train detections (black bars) in hourly bins within the August 2014–May 2015 JAX Site D dataset.

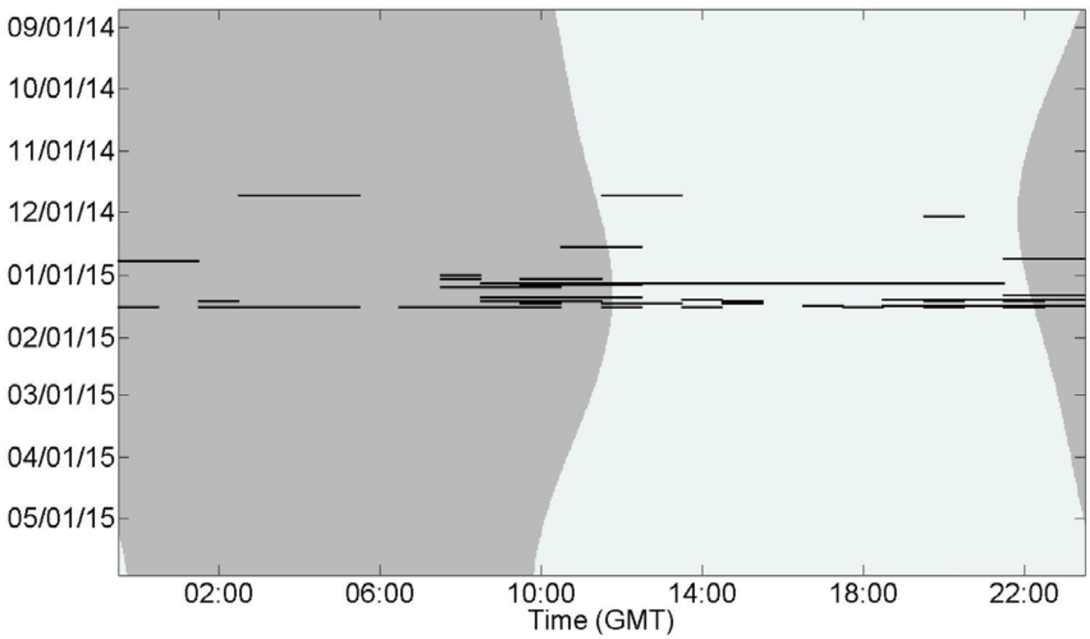


Figure 33. Sei whale downsweep detections (black bars) in hourly bins within the August 2014-May 2015 JAX Site D dataset.

Detected odontocete vocalizations included clicks and whistles (**Figures 34 through 42**). Most of these detections were assigned to the unidentified odontocete category (**Figure 34**), with clicks being divided into three main groups based on spectral patterns in the August 2014–May 2015 dataset and into two main groups based on spectral patterns in the July–November 2015 dataset (see Frasier et al. [2016] and Varga et al. [2017] for more details). Unidentified odontocete whistles lower than 5 kHz were detected mainly between March and May 2015 in the August 2014–May 2015 dataset, mainly during late night and early morning hours (**Figure 35**). There were not many detections of unidentified whistles lower than 5 kHz during the July–November 2015 dataset (**Figure 35**), but that is likely due to the hydrophone failure mentioned previously which undoubtedly resulted in many missed detections. Unidentified odontocete whistles higher than 5 kHz were detected throughout both datasets, with peaks in detections between March and May 2015 (**Figure 36**). Once again, though, there were possibly missed detections in this category during the July–November 2015 dataset if the whistles did not extend above 12 kHz. *Kogia* clicks were detected throughout both datasets examined here, with highest numbers of detections occurring between October 2014 and April 2015 (**Figure 37**). Risso's dolphins were detected in low numbers between August 2014 and April 2015 and in higher numbers in late April through May 2015 and in July 2015, with detections primarily at night (**Figure 38**). Sperm whales were detected intermittently throughout both deployments (**Figure 39**). Blainville's beaked whales were detected on only two days during the August 2014–May 2015 dataset and never during the July–November 2015 dataset (**Figure 40**). Conversely, Cuvier's beaked whale clicks were not detected during the August 2014–May 2015 dataset and detected on only three days during the July–November 2015 dataset (**Figure 41**). Gervais' beaked whales were detected on four days during the August 2014–May 2015 dataset and three days during the July–November 2015 dataset (**Figure 42**). Most beaked whale detections during these deployments occurred at night (**Figures 40 through 42**).

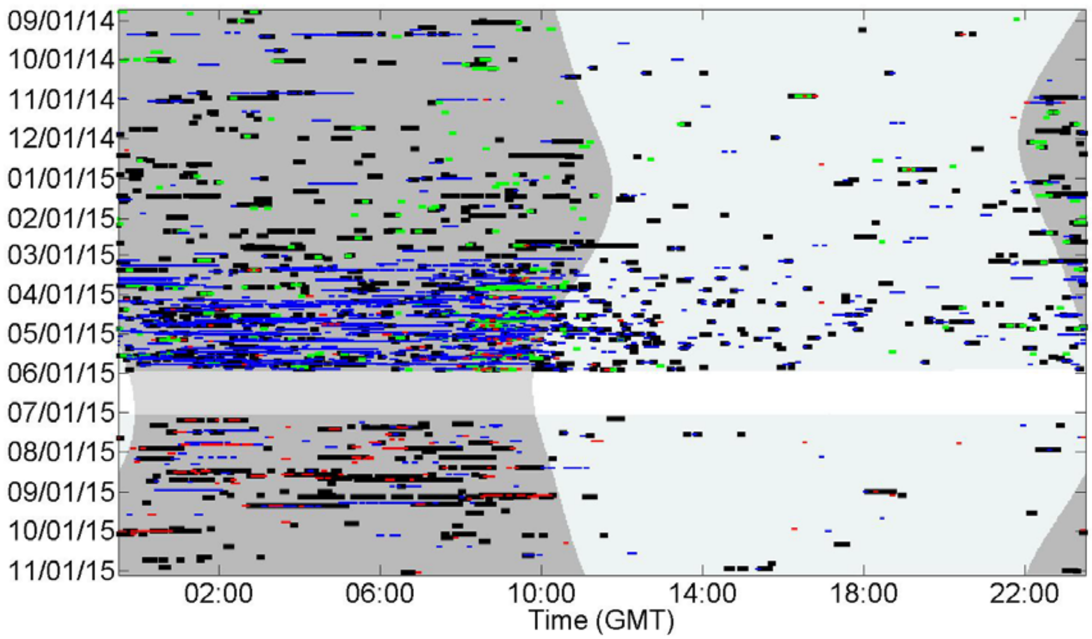


Figure 34. Unidentified odontocete click detections (different colored horizontal bars represent the different groups clicks were divided into, with those in red not assigned a category) in five-minute bins within the August 2014–May 2015 and July–November 2015 JAX Site D datasets.

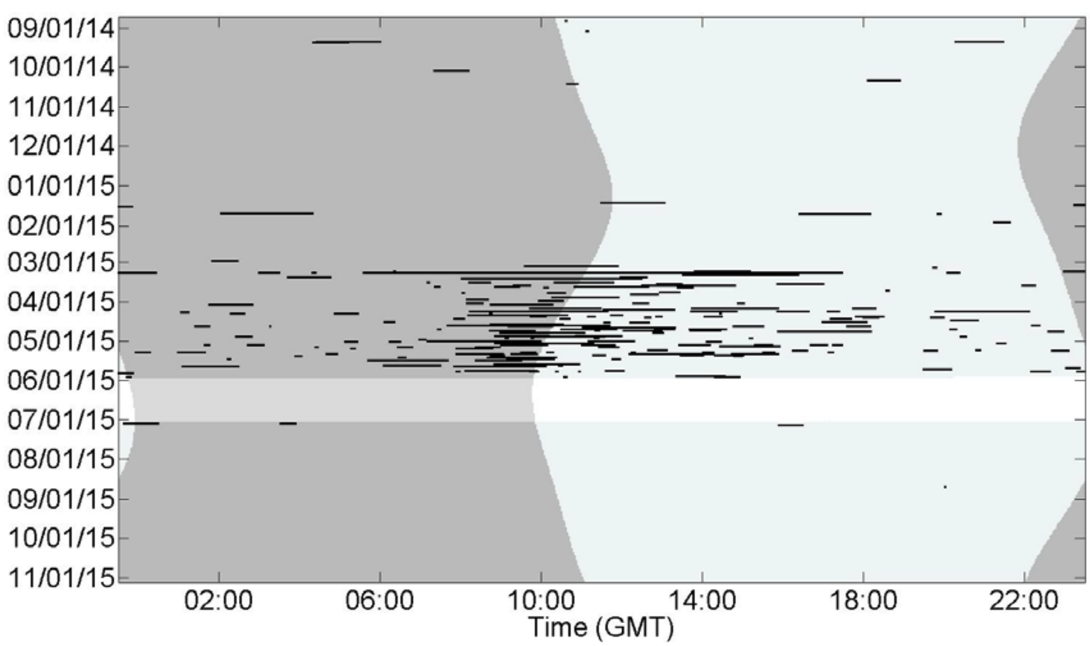


Figure 35. Unidentified odontocete whistle detections lower than 5 kHz (black bars) within the August 2014–May 2015 and July–November 2015 JAX Site D datasets. Note that the many detections of whistles lower than 5 kHz were likely missed in the July–November 2015 dataset due to a hydrophone failure.

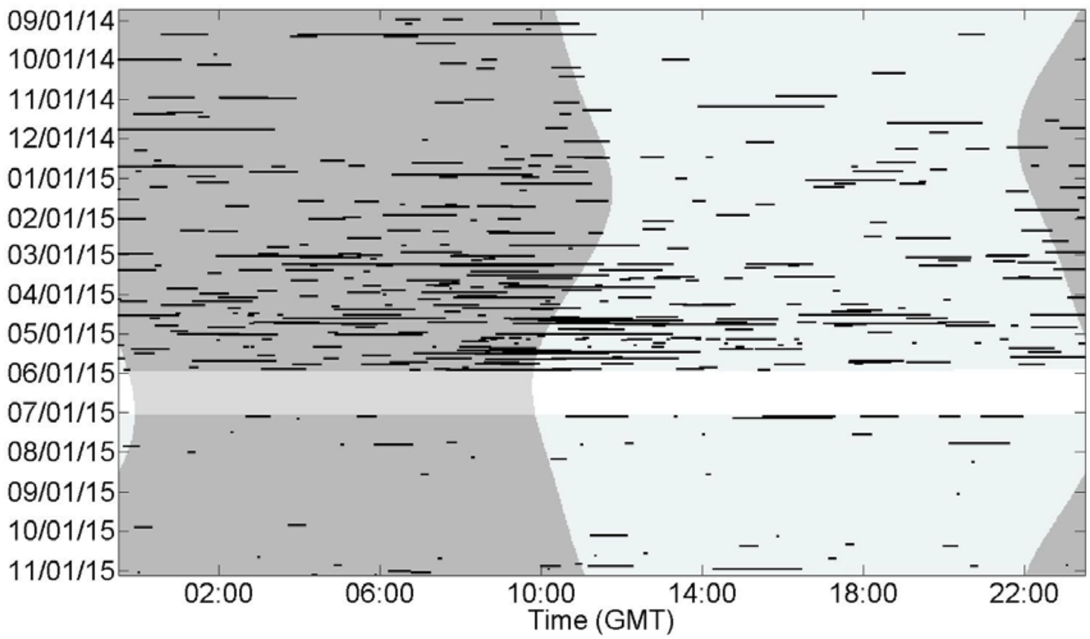


Figure 36. Unidentified odontocete whistle detections higher than 5 kHz (black bars) within the August 2014–May 2015 and July–November 2015 JAX Site D datasets. Note that there may be missed detections of whistles greater than 5 kHz in the July–November 2015 dataset if they did not extend above 12 kHz due to a hydrophone failure.

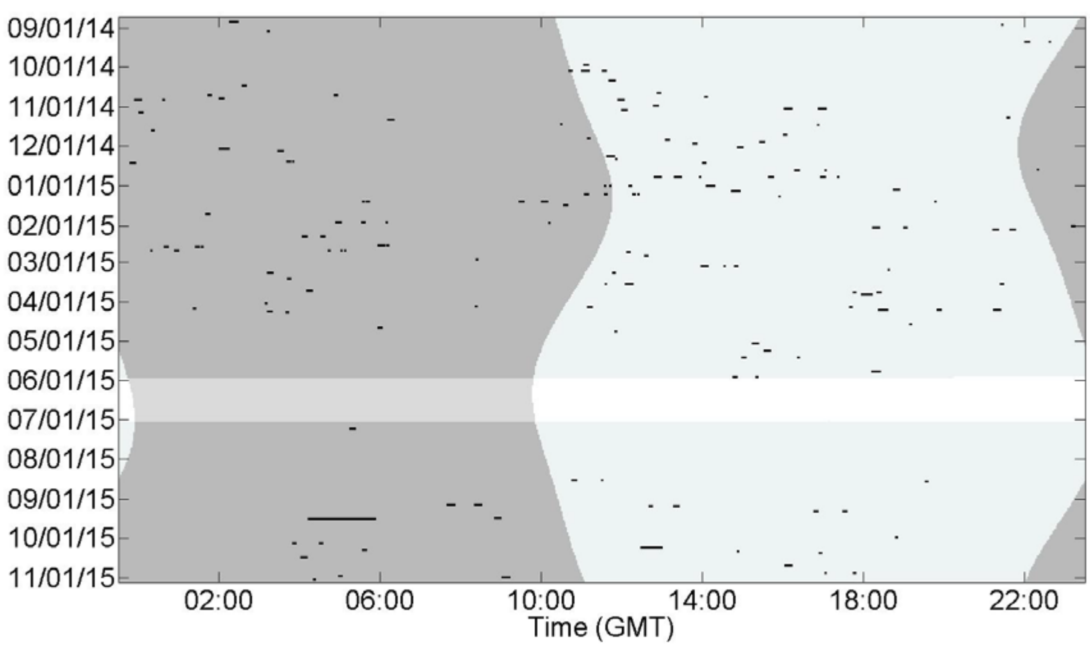


Figure 37. *Kogia* sp. click detections (black bars) in 1-minute bins within the August 2014–May 2015 and July–November 2015 JAX Site D datasets.

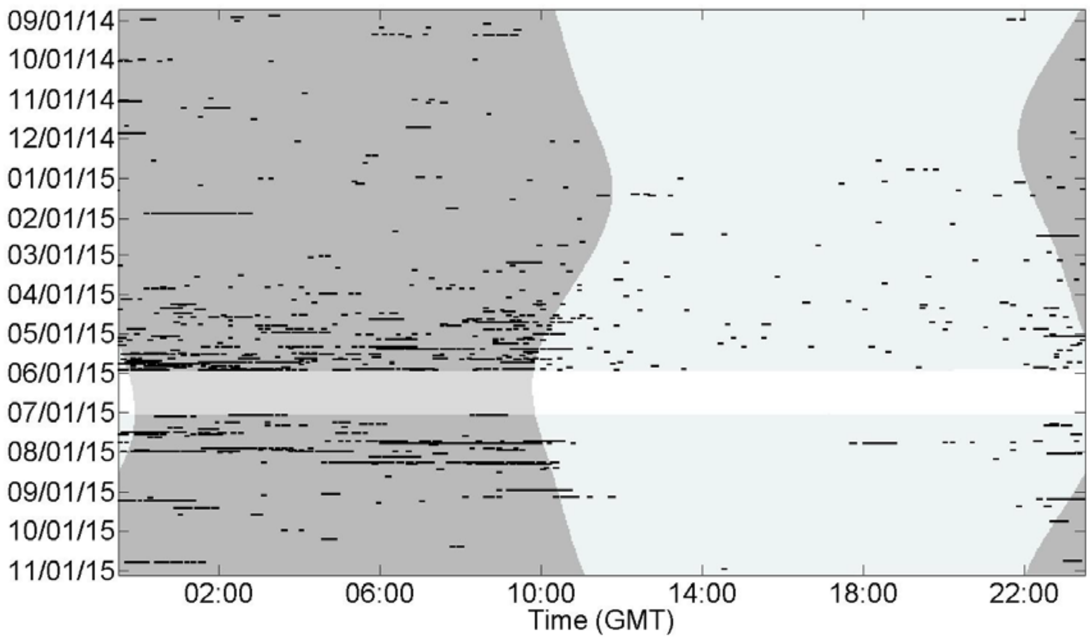


Figure 38. Risso's dolphin click detections (black bars) in 5-minute bins within the August 2014–May 2015 and July–November 2015 JAX Site D datasets.

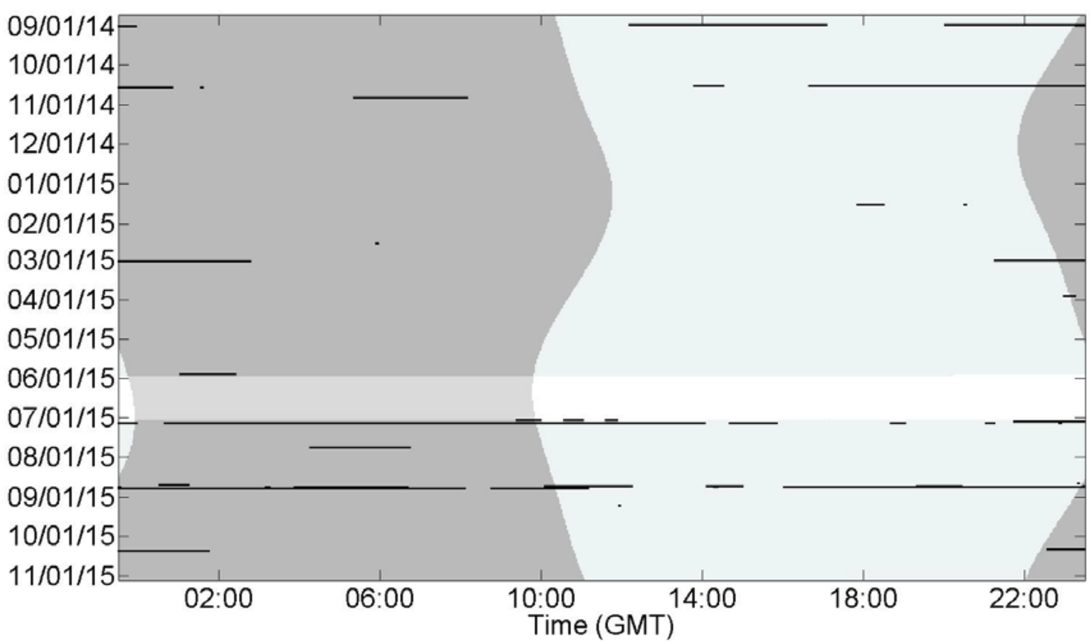


Figure 39. Sperm whale click detections (black bars) in 1-minute bins within the August 2014–May 2015 and July–November 2015 JAX Site D datasets.

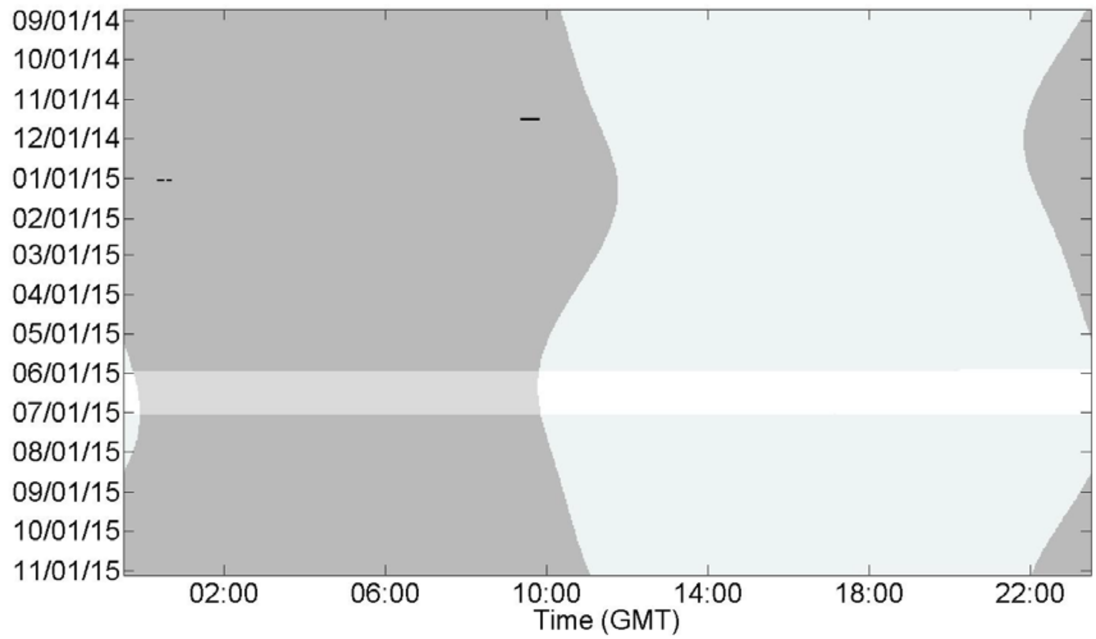


Figure 40. Blainville's beaked whale click detections (black bars) in 1-minute bins within the August 2014–May 2015 and July–November 2015 JAX Site D datasets. Note there were no detections in the July–November 2015 dataset.

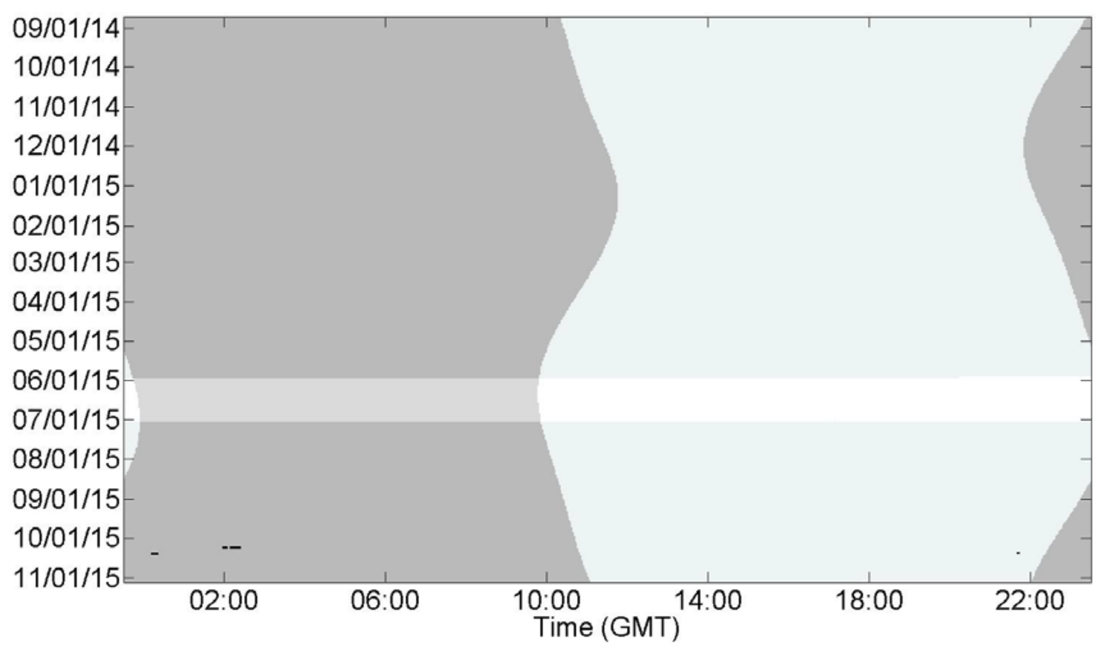


Figure 41. Cuvier's beaked whale click detections (black bars) in one-minute bins within the August 2014–May 2015 and July–November 2015 JAX Site D datasets. Note there were no detections in the August 2014–May 2015 dataset.

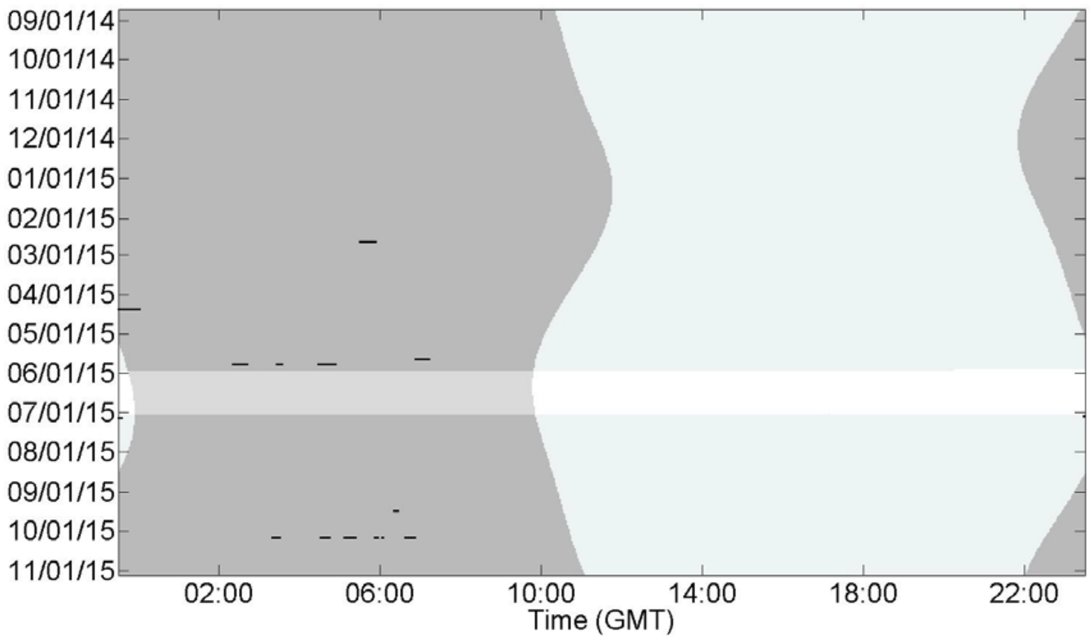


Figure 42. Gervais' beaked whale click detections (black bars) in 1-minute bins within the August 2014–May 2015 and July–November 2015 JAX Site D datasets.

MFA sonar was detected in almost every month during the August 2014–May 2015 dataset, with a peak in detections occurring in September 2014 and January 2015 (**Figure 43**). MFA sonar could not be analyzed in the July–November 2015 JAX Site D dataset due to the hydrophone failure mentioned previously. HFA sonar was detected on one day during the August 2014–May 2015 dataset (**Figure 44**).

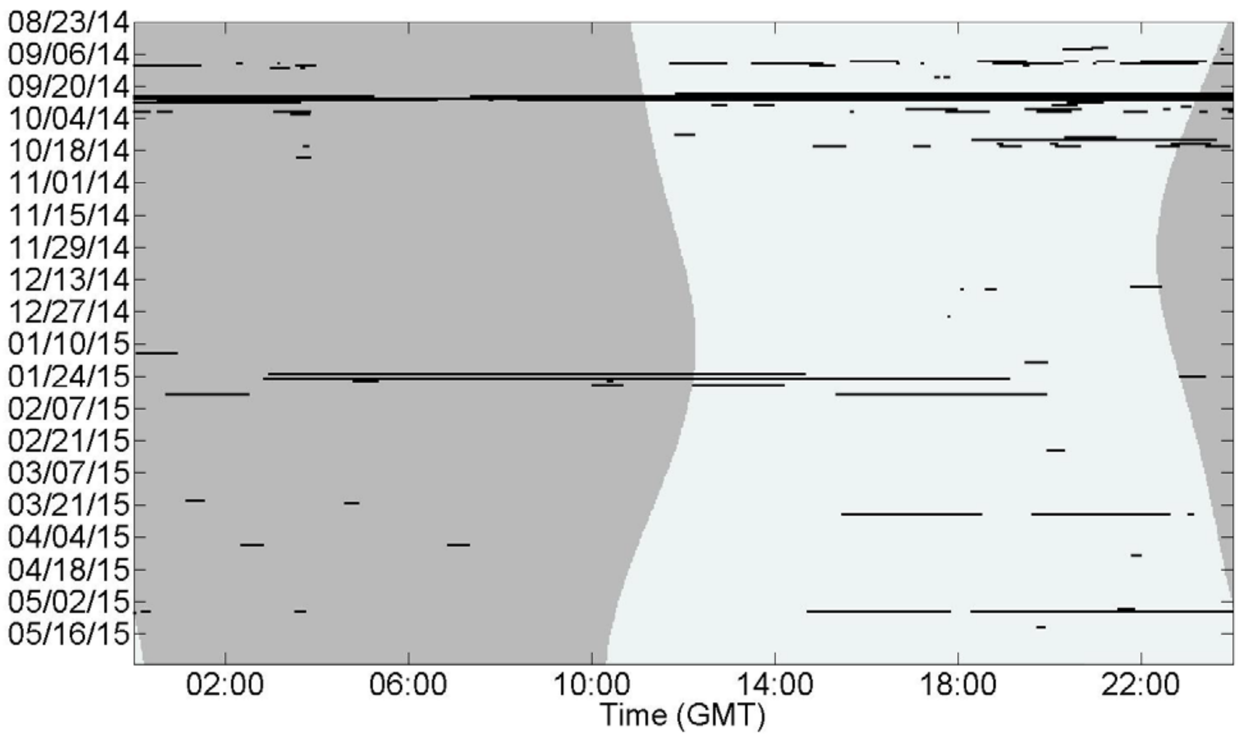


Figure 43. Mid-frequency active sonar (black bars) detected within the August 2014–May 2015 JAX Site D dataset.

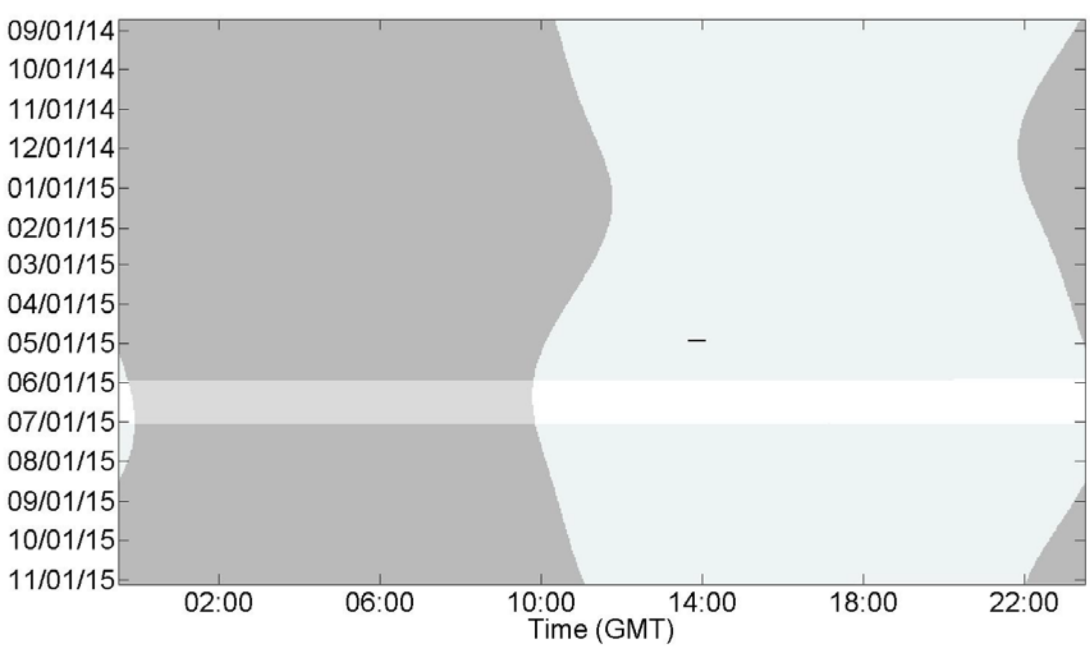


Figure 44. High-frequency active sonar (black bars) detected within the August 2014–May 2015 and July–November 2015 JAX Site D datasets. Note there were no high-frequency active sonar detections in the July–November 2015 dataset.

7. Current and Anticipated Analyses for 2017

Scripps Institution of Oceanography will analyze the April 2016 datasets from Norfolk Canyon Site A, Cape Hatteras Site A, and Jacksonville Site D once they are recovered in June 2017. Detailed and technical reports will be available once the analyses of the datasets are complete.

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