ANALYSIS OF ACOUSTIC ECOLOGY OF NORTH ATLANTIC SHELF BREAK CETACEANS AND EFFECTS OF ANTHROPOGENIC NOISE IMPACTS

FY 2025 PROGRESS REPORT

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Introduction

Over 25 species of cetaceans utilize the shelf break regions of the US eastern seaboard, including several endangered species. Understanding patterns in species distribution, and the anthropogenic and environmental drivers that may impact their distribution, are critical for appropriate management of marine habitats. To better understand patterns in species distribution and vocal activity, NOAA's Northeast Fisheries Science Center (NEFSC) and Scripps Institution of Oceanography (SIO) collaboratively deployed long-term high-frequency acoustic recording packages (HARPs) at eight sites along the western North Atlantic shelf break. This work was conducted from 2015-2021, with financial support from the Bureau of Ocean Energy Management (BOEM). Likewise, the U.S. Navy has been monitoring the shelf break region at 3 to 4 sites since 2007. Together these combined efforts bring the total to 11 recording sites spanning the U.S. eastern seaboard, from New England to Florida.

This project focuses on analyses of the datasets collected from 2015-2021, with the inclusion of older (pre-2015) datasets where relevant. The focus of our efforts in 2025 have been to make substantial progress in the review of various detector classifications (e.g. beaked whale, minke whale, sonar) to support this project's fine scale scientific questions.

Objectives

The work conducted this year focused on these key objectives:

1. Validate neural net classifications of beaked whales across HARP sites, with the goal to use the results for fine scale ecological questions.
2. Assessing effects of anthropogenic noise on beaked whale vocal activity.
3. Analyze minke whale presence on the Navy HARP sites.

Acoustic Data Collection

Starting in 2007, the U.S. Navy collected continuous passive acoustic recordings at the Cherry Point Operating Area (USWTR), and over the course of the next five years, added sites at Jacksonville (JAX), Hatteras (HAT), and Norfolk Canyon (NFC, **Figure 1, Table 1**). In 2015, passive acoustic coverage was expanded by the NEFSC to span the Atlantic continental shelf break of the United States, to complement the existing U.S. Navy monitoring sites. The sites deployed in 2015 include Heezen Canyon, Oceanographer Canyon, and Nantucket Canyon (three northernmost sites). These were expanded in 2016 to include Wilmington Canyon & Babylon Canyon north of Cape Hatteras, and Gulf Stream, Blake Plateau and Blake Spur south of Cape Hatteras (**Figure 1, Table 1**).

HARPs were targeted to be deployed at depths of 700-1100 m, with the hydrophones suspended approximately 20 m above the seafloor. Each HARP was programmed to record continuously at a sampling rate of 200 kHz with 16-bit quantization, providing an effective recording bandwidth from 0.01-100 kHz. HARPs include a hydrophone comprised of two types of transducers: a low-frequency (< 2 kHz) stage utilizing Benthos AQ-1 transducers (frequency response -187 dB re: 1V/µPa, ± 1.5 dB, www.benthos.com), and a high-frequency stage (> 2 kHz) utilizing an ITC-1042 hydrophone (International Transducer Corporation, frequency response -200 dB re: 1V/µPa, ±2dB), connected to a custom built preamplifier board and band pass filter. Further details of HARP design are described in Wiggins & Hildebrand (2007).

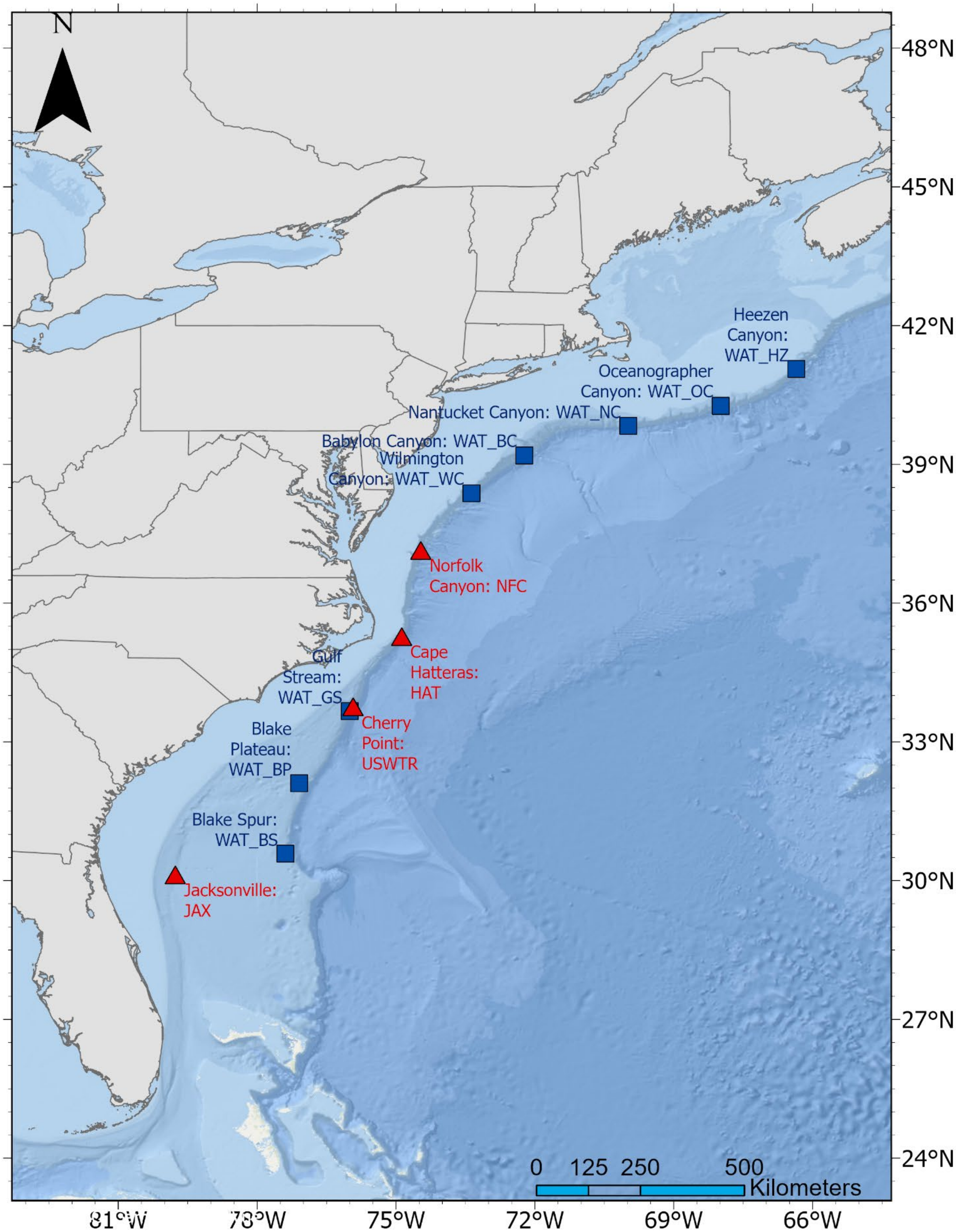

Figure 1. HARP deployment sites for data collected from 2007 through 2021.

Table 1. HARP deployment sites, recording dates for 2007-2021. All HARPs recorded continuously at a sampling rate of 200 kHz. General latitude and longitude values are shown here, as each deployment had slightly different positions. The range of deployment depths are shown, as some deployments had different depths depending on where in the canyon the recorder landed.

Site Name; Location	Recording Date Range	Latitude	Longitude	Recorder Depth Range (m)
WAT_HZ; Heezen Canyon	Jun 2015 - May 2019	41.0619	-66.3515	845-1090
WAT_OC; Oceanographer Canyon	Apr 2015 - May 2019	40.2633	-67.9862	450-1100
WAT_NC; Nantucket Canyon	Apr 2015 - Jun 2019	39.8325	-69.9821	890-977
WAT_BC; Babylon Canyon	Apr 2016 - May 2019	39.1911	-72.2287	997-1000
WAT_WC; Wilmington Canyon	Apr 2016 - May 2019	38.3742	-73.3707	974-1000
NAVY_NFC; Norfolk Canyon	Jun 2014 - Sep 2021	37.1665	-74.4666	950-1050
NAVY_HAT; Cape Hatteras	Mar 2012 - Oct 2020	35.5841	-74.7499	980-1350
NAVY_USWTR; Cherry Point	Oct 2007 - Jun 2013	33.78666	-75.92915	853-952
WAT_GS; Gulf Stream	Apr 2016 - Jun 2019	33.6656	-76.0014	930-953
WAT_BP; Blake Plateau	Apr 2016 - May 2019	32.1060	-77.0943	940-945
WAT_BS; Blake Spur	Apr 2016 - Jun 2019	30.5838	-77.3907	1000-1005
NAVY_JAX; Jacksonville	Apr 2009 - Jun 2020	30.1527	-79.7699	736-750

Analyses

I. Validate neural net classifications of beaked whales across HARP sites

Beaked whale echolocation is considered to be cryptic with respect to other odontocete species. Echolocation periods range from 19 - 35 min (DeAngelis et al. 2025), and due to their high directionality (e.g. Shaffer et al. 2013), small group sizes (Claridge 2006), and synchronized foraging dives (Alcázar-Treviño et al. 2021), a subset of the group's total echolocation is captured on a single sensor (Hildebrand et al. 2015). This is in contrast to less directional echolocating species such as sperm whales, and members of the Delphinidae that occur in relatively larger groups. As such, beaked whales echolocation clicks are considered "ephemeral" and require a tailored click detection process that is able to filter out much of the "noise" caused by the Delphinidae and sperm whales for an analyst to review. Solsona-Berga et al. (2024) designed a two stage machine learning neural network that first removes clicks that match the characteristics of non-beaked whale echolocation clicks (i.e. impulsive clicks) and then bins the remaining data based on classifications learned from a subset of the WAT dataset. These classifications then need to be reviewed by a trained analyst to confirm the species classification.

All of the WAT dataset including the three Navy range HARPs were processed with the neural network. Review of the Navy range HARPs at NFC, HAT, and JAX were previously completed (Van Parijs et al. 2025) progress report and are being used for the sonar impact analysis (section II, this report). Review of three years from the remaining 8 WAT sites is currently in progress (Table 2). Each site is subdivided into hard drive disks, which do not represent a set interval of time.

The neural network output consists of "sessions" containing classifications of clicks. These sessions are reviewed using the Matlab tool detEdit (Solsona-Berga et al. 2020). The clicks can be reassigned a classification by an analyst after reviewing several views including (but not limited to) the power spectral density of the clicks, the inter-click-intervals, and a graph of peak frequency vs received level of the clicks.

As of this report, 39% of the data have been reviewed, with a focus on the 2016 data collection, and of the WAT_BS site (for analysis of BWG-type clicks, Van Parijs et al. 2024). We continue to validate this dataset such that additional fine scale analyses can be performed.

Table 2. Progress of validating the neural network classifications across the WAT HARP sites. Green cells represent disks that have been completely validated, grey cells represent disks with no data collected, and white cells represent those that have yet to be validated.

	2016								2017								2018							
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
HZ								green				green	grey	grey	grey	grey						green	grey	grey
OC	green	green	green	green	green	green	green	grey						green	grey	grey						green		green
NC															grey	grey								
BC	green	green	green	green	green	green	green	green						green	grey	grey								grey
WC	green	green	green	green	green	green	green	green		green					grey	grey								grey
GS								green							green	grey							green	grey
BP	green	green	green	green	green	green										grey							grey	grey
BS	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green	grey	green	green	green	green	green	green	green	grey

II. <u>Assessing effects of anthropogenic noise on beaked whales vocal activity.</u>

The goal for this component of the project is to assess the potential impacts of mid-frequency active (MFA) sonar on beaked whale acoustic activity in the Western North Atlantic. The analyses incorporate data for several beaked whale species to detect acoustic behavioral responses to sonar operations in areas with varying naval activity. Understanding the relationship between MFA sonar and the acoustic behavior of beaked whales is complex and requires the inclusion of natural, temporal, and spatial variability in click densities, e.g., caused by species or population-level seasonality, habitat preference, the behavioral context of echolocating, and individual variability. For this part of the project, analyses focused on the Navy HARP sites where MFA sonar is present.

For this reporting period, we focused on expanding the number of deployments included in this analysis, since previous efforts showed there were not enough data with beaked whale presence and MFA sonar overlap to evaluate potential impacts (Van Parijs et al. 2025). The previous statistical analysis of sonar impact was conducted using beaked whale and MFA sonar acoustic data for Norfolk Canyon (NFC) between 2014-2020, Hatteras (HAT) between 2015-2020, and Jacksonville (JAX) between 2016-2020 (Van Parijs et al. 2025). For each of these three sites, an additional year's worth of data has been added **(Table 3)**. The Cherry Point Operating Area (Onslow) site has also been added **(Table 3)**. Deployments included in this analysis now span across four US Navy sites (NFC, HAT, Onslow, and JAX) between 2011-2021 **(Table 3)**. The current effort processed these additional deployments for detection of MFA sonar and prepared data for modeling **(Table 3)**. Beaked whale signals were detected and classified in 1-min bins using a deep neural network (Solsona-Berga et al. 2024), developed and trained with funding from this project. The resulting labels from the neural network were validated using DetEdit (Solsona-Berga et al. 2020). Automatic detection of MFA sonar was implemented using a modified version of the Silbido detection system (Roch et al., 2011) designed for characterizing toothed whale whistles. Method details for the detection of MFA sonar were reported in Van Parijs et al. (2021).

Table 3. Summary of data analysis of Atlantic Navy HARP sites using automated methods for beaked whale and Navy sonar detections. Newly included deployments are denoted as 'Added'.

Previously completed Completed during current year

			Detection, classification, and validation of beaked whale signals	**Detection of MFA sonar**
Norfolk Canyon (NFC)				
	2014-2015	NFC01A		
Added	2016-2017	NFC_A_02		
	2017-2018	NFC_A_03		
	2018-2019	NFC_A_04		
	2019-2020	NFC_A_05		
	2021-2021	NFC_A_06		
Hatteras (HAT)				
Added	2012-2012	HAT01A		
Added	2012-2013	HAT02A		
Added	2013-2014	HAT03A		
Added	2014-2014	HAT04A		
	2015-2016	HAT_A_05		
	2016-2017	HAT_A_06		
	2017-2017	HAT_B_01_01		
	2017-2018	HAT_B_03_01		
	2018-2018	HAT_B_04_01		
	2018-2019	HAT_B_05		
	2019-2019	HAT_B_06_01		
	2019-2020	HAT_B_07		

Cherry Point Operating Area (Onslow)				
Added	2011-2011	USWTR06E		
Added	2012-2012	USWTR07E		
Added	2012-2013	USWTR08E		
Jacksonville (JAX)				
Added	2014-2015	JAX11D		
	2016-2017	JAX_D_13		
Added	2017-2017	JAX_D_14		
	2018-2019	JAX_D_15		
	2019-2020	JAX_D_16		

Beaked whale detections with a peak-to-peak received sound pressure level (RL) above 118 dB_{pp} re 1μPa and sonar pings with an RL of at least 100 dB_{pp} re 1μPa were retained to maintain a consistent detection range. Acoustic detections were integrated by combining the data into 1-minute segments as detection units instead of individual detections of beaked whales and MFA sonar (**Table 4**). We studied five species of beaked whales—Sowerby's (Mb), Blainville's (Md), Gervais' (Me), True's (Mm), and goose-beaked whales (Zc)—across four Navy sites **(Table 4)**. Overall beaked whale presence was highest at HAT, which also had the lowest MFA sonar activity **(Table 4; Figure 3)**. In contrast, JAX had the highest MFA sonar use and the lowest beaked whale presence **(Table 4; Figure 5)**. The shallower depth of JAX may also influence the reduced occurrence of these deep-diving species. Goose-beaked whales showed particularly high presence at HAT and were the most frequently detected species there, where they also had the greatest overlap with sonar **(Table 4; Figure 3)**. They occurred at low to moderate levels at NFC and at generally low levels with occasional peaks at Onslow **(Table 4; Figures 2 and 4)**. Gervais' beaked whales had especially high presence at Onslow and were the most frequently detected beaked whale species at that site, which was also where their overlap with sonar was greatest **(Table 4; Figure 4)**. The co-occurrence of higher presence and exposure at Onslow allows evaluation of potential sonar impacts on this species. Gervais' beaked whales also occurred at low to moderate levels at HAT **(Table 4; Figure 3)**. Sowerby's and True's beaked whales showed the most consistent and highest presence at the northernmost site, NFC, where they also exhibited the greatest overlap with sonar, enabling assessment of potential impacts **(Table 4; Figure 2)**. These additional data will be incorporated into a comprehensive statistical analysis of MFA sonar effects on beaked whale acoustic behavior in the coming year.

Table 4. Summary of beaked whales and mid-frequency active sonar detections at four US Navy sites (NFC, HAT, Onslow, JAX).

		NFC	**HAT**	**Onslow**	**JAX**
		2014-2021	2012-2020	2011-2013	2014-2020
Beaked whales					
Effort 1-min bins (total in days)		1,831	2,493	217	1,447
Bins with presence	*Zc*	0.38%	12.97%	0.11%	0.03%
	Me	0.02%	0.55%	13.01%	0.02%
	Mb	0.27%	0.006%	0.002%	0.004%
	Md	0.006%	0.006%	0.11%	0.02%
	Mm	0.30%	0.03%	0.01%	0.02%
Mid-frequency active sonar					
Effort 1-min bins (total in days)		1,831	2,493	217	1,447
Bins with presence		0.80%	0.15%	0.45%	1.69%
Beaked whales and mid-frequency active sonar					
Sum 1-min bins with beaked whale clicks that had MFA sonar					
	Zc	34	288	0	0
	Me	2	6	10	2
	Mb	28	0	0	0
	Md	0	0	0	0
	Mm	64	39	0	8
% 1-min bins with beaked whale clicks that had sonar					
	Zc	0.001%	0.008%	—	—
	Me	0.00007%	0.0001%	0.003%	0.00009%
	Mb	0.001%	—	—	—
	Md	—	—	—	—
	Mm	0.002%	0.001%	—	0.0004%

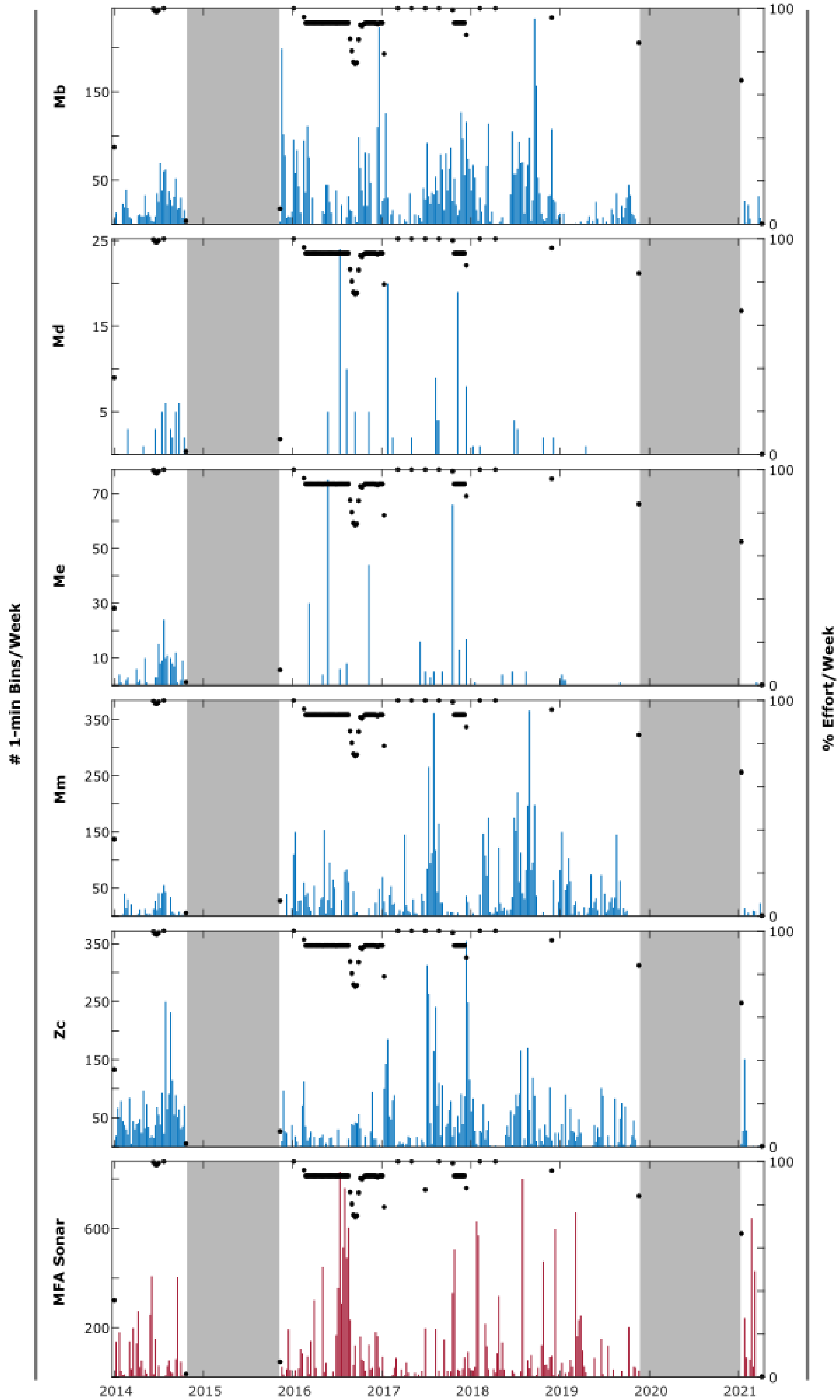

Figure 2. Cumulative weekly presence of beaked whale species and MFA sonar detected at Norfolk Canyon (NFC). Gray bars indicate times of no effort and black dots represent weeks with partial effort.

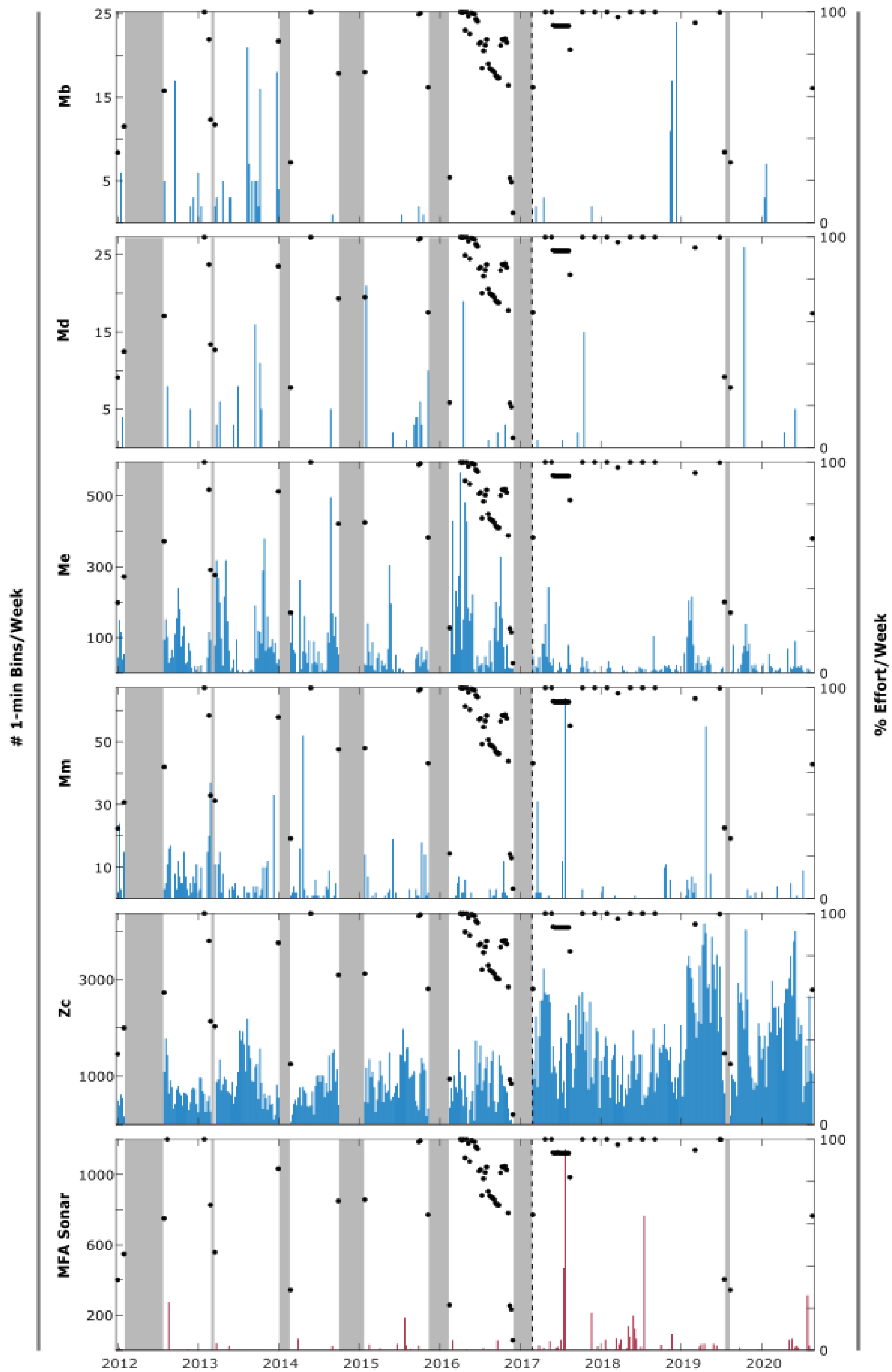

Figure 3. Cumulative weekly presence of beaked whale species and MFA sonar detected at Hatteras (HAT). Gray bars indicate times of no effort and black dots represent weeks with partial effort. The black dashed line delineates the location change from site HAT A to HAT B.

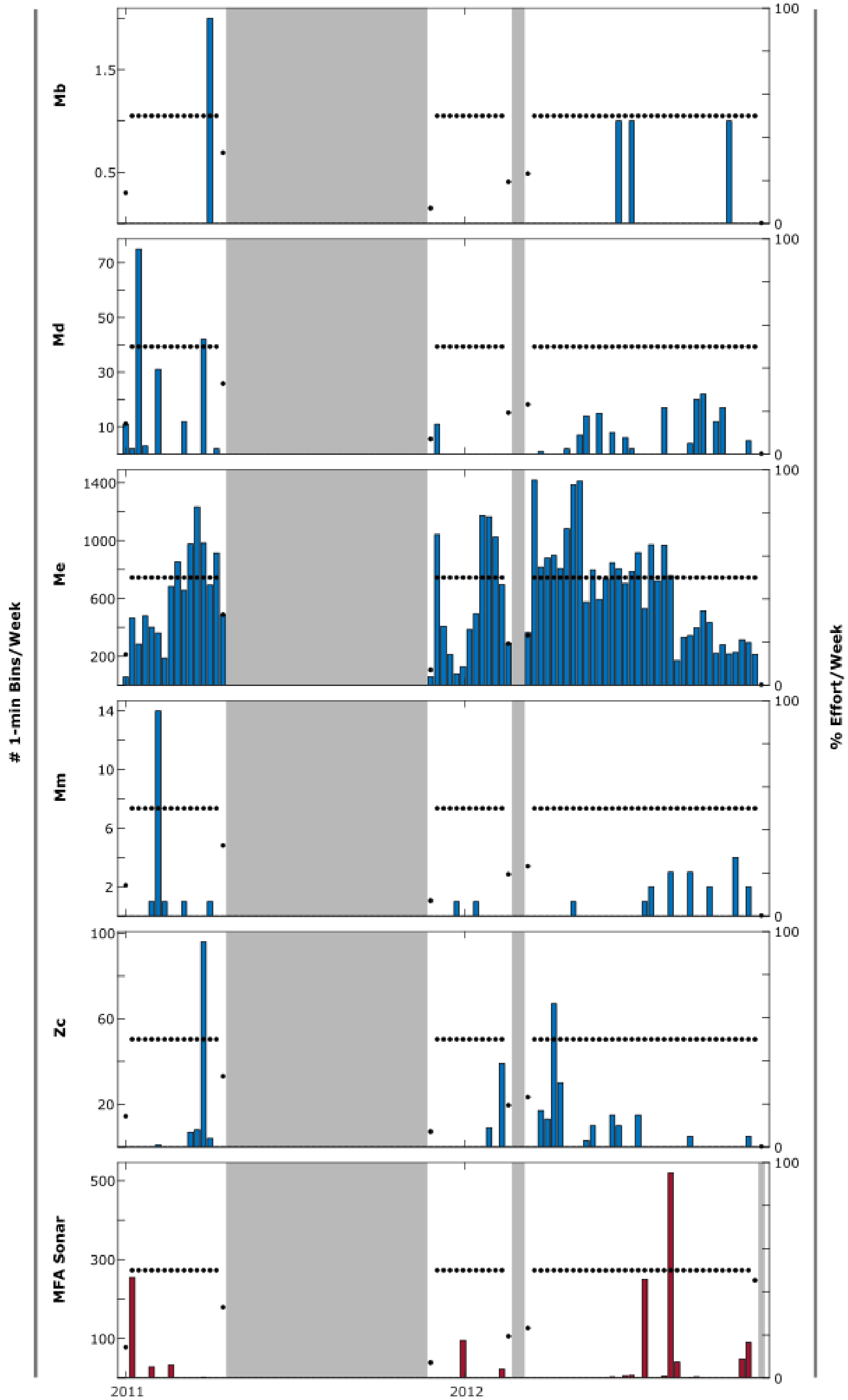

Figure 4. Cumulative weekly presence of beaked whale species and MFA sonar detected at Cherry Point Operating Area (Onslow). Gray bars indicate times of no effort and black dots represent weeks with partial effort.

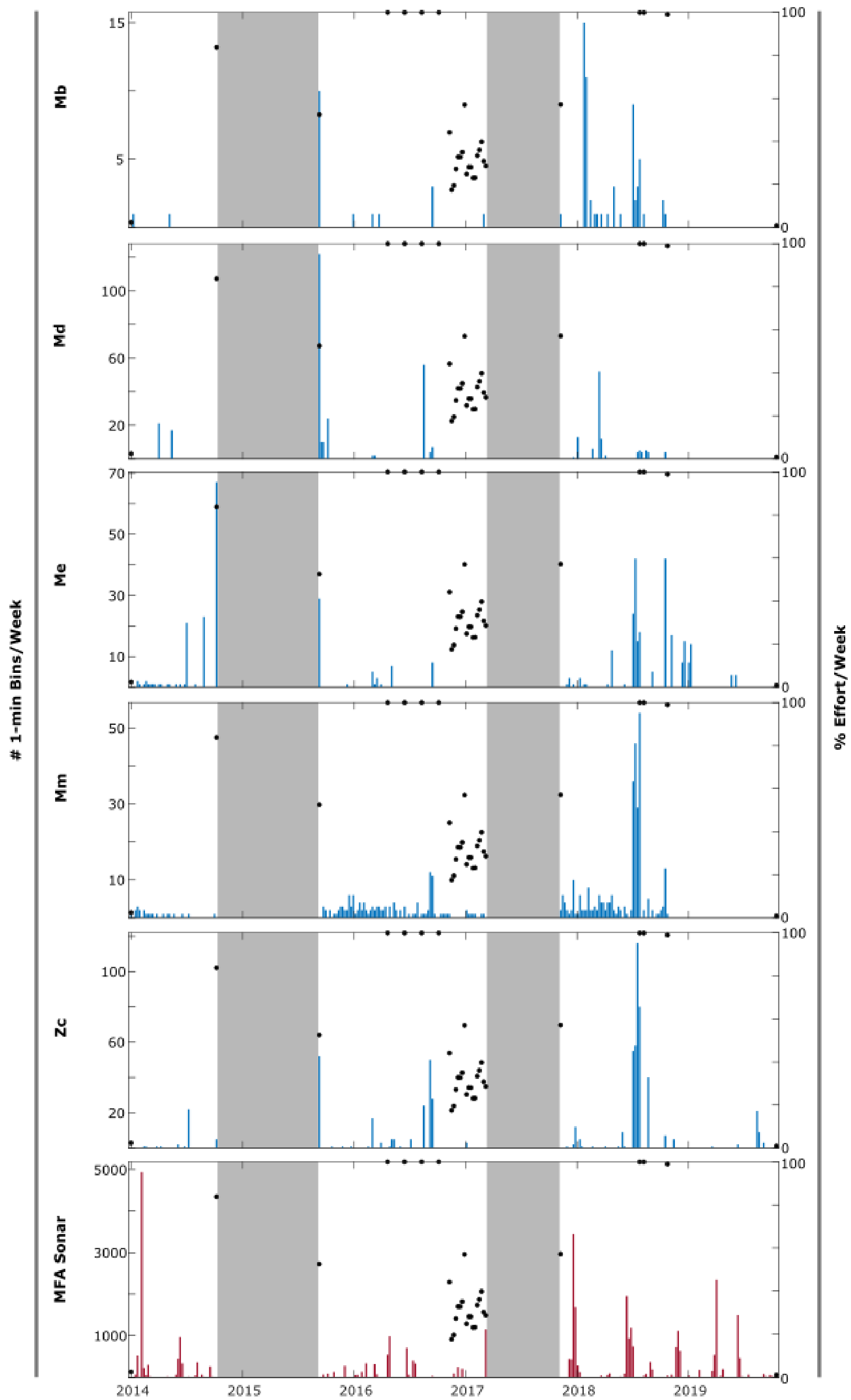

Figure 5. Cumulative weekly presence of beaked whale species and MFA sonar detected at Jacksonville (JAX). Gray bars indicate times of no effort and black dots represent weeks with partial effort.

III. Analyze minke whale presence on the Navy HARP sites.

We completed the daily presence analysis of minke whales at all HARP sites within Navy ranges (NFC, HAT, Onslow, JAX, **Table 5**) using an improved minke whale detection algorithm written in python (https://github.com/xaviermouy/minke-whale-detector). This algorithm uses a binary ResNet18 deep neural network (DNN) to detect and automatically classify minke whale pulse trains based on spectrogram images. An analyst then manually reviewed the detections based on the algorithm's confidence using the spectrograms and audio files written in the detector output. Detections were organized by confidence score per day with the highest confidence detections reviewed first, until a true positive was identified. Detailed results from this analysis can be found in the Navy site comprehensive reports. In general, minke whales were present at all Navy HARP sites during non-summer months (Oct-May).

Table 5. Summary of data analysis of Atlantic Navy HARP sites using automated methods for minke whale detections. Newly included deployments are denoted as 'Added'.

Previously completed Completed during current year

			Detection, classification, and validation of minke pulse trains
Norfolk Canyon (NFC)			
	2014-2015	NFC01A	Previously completed
	2016-2017	NFC_A_02	Previously completed
	2017-2018	NFC_A_03	Previously completed
Added	2018-2019	NFC_A_04	Completed during current year
Added	2019-2020	NFC_A_05	Completed during current year
Added	2021-2021	NFC_A_06	Completed during current year
Hatteras (HAT)			
	2012-2012	HAT01A	Previously completed
	2012-2013	HAT02A	Previously completed
	2013-2014	HAT03A	Previously completed

	2014-2014	HAT04A	
	2015-2016	HAT_A_05	
	2016-2017	HAT_A_06	
	2017-2017	HAT_B_01_01	
	2017-2018	HAT_B_03_01	
Added	2018-2018	HAT_B_04_01	
Added	2018-2019	HAT_B_05	
Added	2019-2019	HAT_B_06_01	
Added	2019-2020	HAT_B_07	
Cherry Point Operating Area (Onslow)			
	2007-2008	USWTR01A	
Added	2008	USWTR02B	
Added	2009	USWTR03A	
	2009-2010	USWTR04A	
Added	2009-2010	USWTR04C	
	2010-2011	USWTR05A	
	2010-2011	USWTR05D	
	2011-2011	USWTR06E	
Added	2012-2012	USWTR07E	
Added	2012-2013	USWTR08E	
Jacksonville (JAX)			
	2009	JAX01B	
	2009	JAX02A	
	2010	JAX04B	
Added	2010-2011	JAX05A	

	2011	JAX06A	
	2011	JAX06B	
	2013	JAX09C	
	2014	JAX10C	
	2014-2015	JAX11D	
	2016-2017	JAX_D_13	
Added	2017-2017	JAX_D_14	
Added	2018-2019	JAX_D_15	
Added	2019-2020	JAX_D_16	

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