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

FY 2022 PROGRESS REPORT

PI's : Sofie Van Parijs, Annamaria DeAngelis & Danielle Cholewiak (Northeast Fisheries Science Center)

Collaborators: Alba Solsona Berga, Kaitlin E. Frasier, Jennifer Trickey, Annabelle C. M. Kok, Taylor Ackerknecht, Chelsea Field, Rebecca Cohen, Clara Schoenbeck, John A. Hildebrand, Simone Baumann-Pickering (Scripps Institution of Oceanography), Samara Haver, Liam Mueller-Brennan (Oregon State University), Annabel Westell (Northeast Fisheries Science Center)

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 2015-2019, with financial support from the Bureau of Ocean Energy Management (BOEM). Likewise, the US 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 Georgia.

Data from earlier HARP recorders have been analyzed in multiple previous studies (e.g. Davis et al. 2017; Stanistreet et al. 2017, 2018). This project focuses on analyses of the new datasets collected from 2015-2019. The focus of our efforts in 2022 have been to finalize species occurrence analyses, including reclassifying beaked whale species using improved classification neural network algorithms; applying frameworks to assess impacts of sonar and seismic noise on the acoustic ecology and acoustic behavior of protected species and developing species ecology approaches for exploring species niche and co-occurrence across shelf break areas.

Objectives

The work this year was aimed at advancing the analytical components for these key objectives:

I. Finalize and reapply the automated neural network classification for beaked whales across the HARP data
II. Continue the analysis on the effects of anthropogenic noise on beaked whale vocal activity
III. Comparing and contrasting two passive acoustic monitoring methodologies - towed array and shelf break HARPs - with regards to beaked whale temporal, spatial presence and diving behavior.
IV. Assessing patterns of richness and composition of marine mammal communities through ecological gradients in our acoustic data across the shelf break.

Acoustic Data Collection

Continuous passive acoustic recordings were collected along the Atlantic continental shelf break of the United States at eleven sites beginning in 2015 by both NEFSC and the U.S. Navy. The sites deployed in 2015 include Heezen Canyon, Oceanographer Canyon, and Nantucket Canyon (3 northernmost sites) and Norfolk Canyon, Hatteras, and JAX (U.S. Navy deployments). 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 bandpass filter. Further details of HARP design are described in Wiggins & Hildebrand (2007).

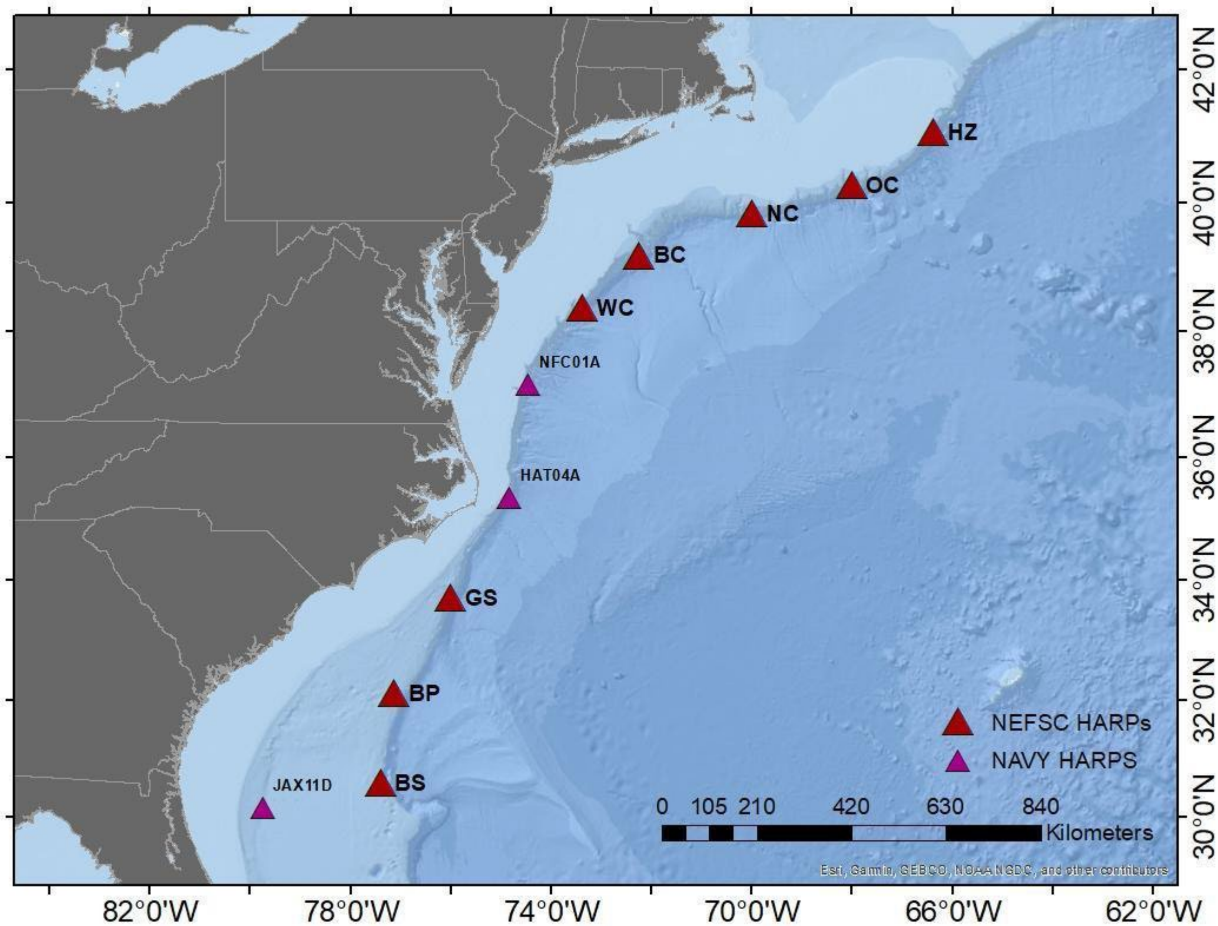

***Figure 1**. HARP deployment sites for data collected from 2015 through 2019.*

***Table 1**. HARP deployment sites, recording dates and recording durations for 2015-2019. 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	Apr 2016 - May 2019	37.1665	-74.4666	950-1050
NAVY_HAT; Cape Hatteras	Apr 2015 - Sept 2019	35.5841	-74.7499	980-1350
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	Jul 2015 - Jun 2019	30.1527	-79.7699	736-750

Methods

I. Applying improved automated classification for beaked whales

The volume of data generated from the 11 recording sites during 2015-2019 presented a challenge for classification of beaked whales to the species level, as it requires expertise and time to manually label echolocation clicks. The purpose of this effort was to design a system to streamline and automate the process of detecting and classifying beaked whale echolocation clicks using deep-learning neural networks. The classification pipeline consisted of multiple steps targeted to efficiently detect beaked whales, often challenging to detect when other species dominate the soundscape. The steps included (1) a generic detector to detect clicks above a received level threshold, (2) a discrimination phase to remove dominant non-beaked whale detections, (3) an unsupervised learning to derive clusters of distinct clicks types based on similarities in the spectral shape, and (4) a trained deep neural network to classify clusters of echolocation clicks based on spectral shape, interclick interval, and click duration.

These steps were finalized and described in detail in Van Parijs et al. 2022. This improved automated classification approach was then re-run through all HARP Atlantic shelf break data. Expert analysts reviewed the clicks classified by the neural network in the program *DetEdit* (Solsona-Berga et al. 2020) to confirm their classification. Additionally, the classification pipeline was tested on a small dataset of two months of data from 2016 to compare classification results where data was previously manually labeled for the effort in section III.

II. Assessing effects of anthropogenic noise on beaked whale vocal activity

The goal for this component of the project is to refine a statistical approach to investigate the potential impacts of mid-frequency active (MFA) sonar on beaked whale acoustic activity in the Western North Atlantic. The analyses include data for several species of beaked whales in order to detect acoustic behavioral responses to sonar operations in areas with varying naval activity. 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, as presence of MFA sonar is higher there than on the WAT sites.

We previously documented the progress made on data preparation, defining methods for automated identification of beaked whales to click-level and parameters to be used in statistical analysis (Van Parijs et al. 2022). The proposed statistical analysis to investigate impact entails presence/absence-level decisions in 1-min segments, which requires beaked whale data to be classified to a finer resolution of at least 1-minute granularity. The previous classification methodology included a clustering method that had a significant proportion of false detections and false classifications, which needed to be addressed. Therefore, for this reporting period, the majority of the effort was focused on the refinement of the species-specific classifier (see above).

A short summary of the progress on this component of the project as reported in Van Parijs et al. 2022 is as follows: 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. Parameters in *silbido* were adjusted to detect tonal contours ≥ 2 kHz (in data decimated to a 10 kHz sample rate) with a signal-to-noise ratio ≥ 5 dB and contour durations > 200 ms with a frequency resolution of 100 Hz. Detections were compiled into MFA sonar events, defined as

MFA sonar detections separated by more than 5 min. For each event, start and stop times were saved, as well as peak-to-peak received level (RL_{pp}, in dB) and sound exposure level (SEL). We selected generalized estimating equations (GEEs) as the modeling framework for statistical data analysis. We explored the power that various explanatory variables have to the response variable, including the time of day and season, sonar presence, and sonar signal characteristics. As a first approach, we focused on two of the Navy sites (NFC, JAX) and limited the response variables to the different beaked whale species' presence in 1-min segments. To investigate the probability of beaked whale signals changing in the presence of sonar, we used a binary response variable which was equal to 1 (presence) for those 1-minute segments during which at least one signal was detected and 0 (absence) for those during which no signal was detected. This was done for the five beaked whale species click types. The explanatory covariates were defined to capture the potential effects of sonar on the response variable in various ways, e.g., the amount of sonar pings, the intensity of sonar received level at the monitoring site, the recovery time since sonar stopped. Non-sonar-related variables such as time of day, date, or year were included to account for natural variability in the response.

While current effort was focused on evaluating classification labels of beaked whale species provided by the neural network using the program *DetEdit*, progress has been made on the statistical analysis of the sonar impact on a preliminary dataset. The dataset only included labels with a high probability score of matching species labels provided by the neural network. Only clicks with a probability score of more than 85% were included for the preliminary analysis of the Navy HARP sites (NFC, JAX, and HAT, **Figure 2**). Additionally, a summary of the data preparation is presented from the validated classification at the click level from these sites, which will be used to continue the modeling effort to examine effects of MFA sonar activities.

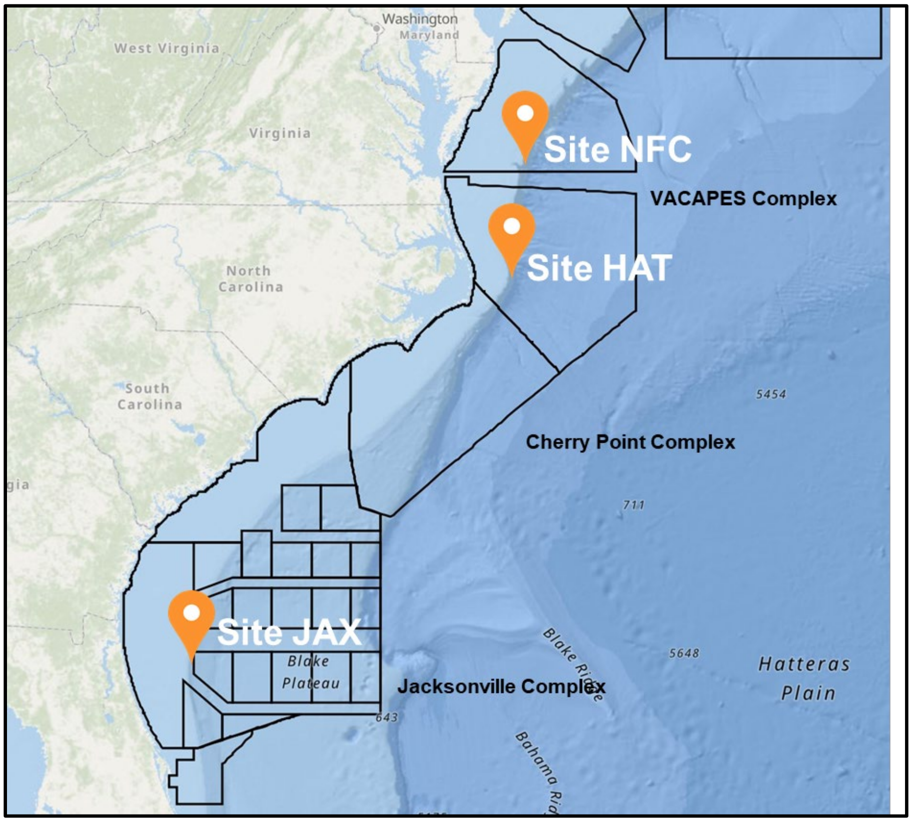

Figure 2*. Navy HARP deployment sites for data collected from 2015 through 2020 and OPAREA complexes with corresponding Navy training and testing ranges.*

III. <u>Comparing and contrasting two methodologies - towed array and shelf break HARP data sets with regards to beaked whale temporal, spatial presence and diving behavior.</u>

A comprehensive east coast [Atlantic Marine Assessment Program for Protected Species]() (AMAPPS) stock assessment survey took place during the summer months of June to August 2016. This survey was concurrent with our shelf break HARP recordings. The towed array survey provides large scale spatial information on beaked whale presence and acoustic behavior, while the shelf break HARP bottom mounted recorders provide detailed temporal coverage (see Figure 3). These two data sets were combined to explore how they can jointly provide data to improve our understanding of species distributions.

11 HARPs and two towed array surveys were analyzed covering July 1 –August 31 2016. Times with active echosounders were excluded from towed array data as Cholewiak et al. (2017) have shown that they negatively affect beaked whale acoustic behavior. All recordings were analyzed at the minute scale. All segment that contained 5+ clicks per species were marked as “present”. Species classification was based on prior literature (e.g. Gillespie et al. 2009, Baumann-Pickering

et al. 2013, DeAngelis et al. 2018, Clarke et al. 2019). Beaked whale species were classified into Sowerby's, *Mesoplodon bidens* (Mb), Blainville's, *Mesoplodon densirostris* (Md), Gervais', *Mesoplodon europaeus* (Me), True's, *Mesoplodon mirus* (Mm), Cuvier's, *Ziphius cavirostris* (Zc). A combined category of "MmMe '' was used for ambiguous True's/Gervais' clicks, and unidentified Mesoplodon (UnidM) (**Figure 2**).

To facilitate the comparison of HARP and towed array datasets, the east coast of the US was subdivided into 11 regions in which each region was approximately the same area from the 200 m to the 4000 m bathy lines (**Figure 3**). Each region contained one HARP recorder and was named based off of that recorder. The HARP data were processed with multi-stage detection algorithms (Baumann-Pickering et al. 2013) and reviewed in DetEdit (Solsona-Berga et al. 2020). The towed array data were processed with PAMGuard (Gillespie et al. 2008) and grouped into acoustic "events" (DeAngelis et al. 2017). The echolocation depth estimation was done using towed array data; each event's clicks were automatically paired with the necessary metadata, and wav clips were created for each click using the R package PAMPal (https://github.com/TaikiSan21/PamBinaries). These were then passed to Matlab, where custom scripts applied an autocorrelation to calculate the time difference of arrival between the direct click and its surface reflected echo (DeAngelis et al. 2017, DeAngelis et al. 2022).

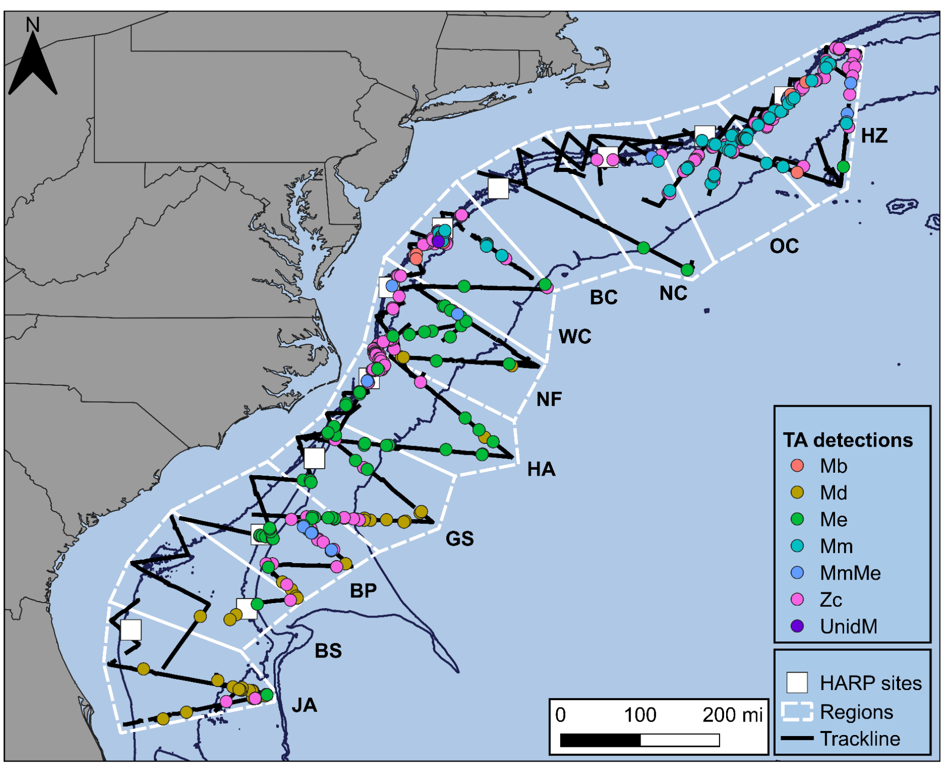

Figure 3. *HARP locations and towed array transect lines (when echosounders are in passive mode) with towed array detections for data collected from July 1st to August 31st 2016.*

IV. Assessing patterns of richness and composition of marine mammal communities through ecological gradients in our acoustic data across the shelf break.

Assessing patterns of richness and composition of marine animal communities through ecological gradients such as latitude and depth and over time are of primary importance in conservation biology as these can provide important warning signs of environmental change, which can aid in designing new management and conservation measures. Fast and reliable methods are required for biodiversity assessments to determine and compare species richness patterns that can be applied in both accessible and remote habitats. The goal for this component of the project is to apply ecological species modeling (as described in Van Opzeeland and Hillebrand 2020) and acoustic niche approaches (Van Opzeeland & Boebel 2018; Weiss et al. 2021) to our large acoustic data set to apply new techniques for understanding species ecology, community structure and acoustic niche interactions between multi species groups throughout the shelf break data.

As a first step, the refined beaked whale species classification data as described in section I, is being integrated with all species detections for baleen whales and other odontocetes. Code was provided by Professor Hillebrand at the University of Bremen in Grmany, developed to explore species richness and co-occurrence, in addition to random forest classification models and acoustic niche plots to explore species relationships over space (11 HARPs) and time (3 years - 2016 to 2019).

Preliminary Results

I. Comparing and contrasting two passive acoustic monitoring technologies for beaked whale monitoring

Temporal summer presence: All five beaked whale species were present across 10 of the 11 HARP shelf break locations, with as many as 3 species present in a single day (**Figure 4**). Beaked whales were present on almost every day in July and August with the exception of OC, NC, and BC where less activity occurred. The Mid-Atlantic sites had the most species diversity (NC, BC, WC and NF). Comparisons between HARP and towed array presence over each HARP site showed consistency between the % minutes present across several regions (**Figure 5).** However, there were several periods when either the towed array only or the HARP recorder only detected a given species (e.g. Zc on the towed array only in BP, BS, and JA regions). This likely is due to the large spatial coverage of the array, traversing both slope and abyssal waters, but also not remaining in a location for a long period of time. However, it does demonstrate that combining these methods are better at providing an accurate representation of species presence, while individually they have the potential to miss the occurrence of certain species.

There were three particular areas with a relatively high proportion of time present in the dataset: Me at BP (HARP), Mm at OC (towed array), and Zc at HAT (HARP and towed array) respectively (**Figure 5**). Given that Zc are known to occur in high densities at HAT (Foley et al. 2021) we argue that these other locations may host resident populations or possibly be 'hotspots' for the other two species as well.

Spatial summer presence: The extended spatial coverage from the towed arrays were able to show that all species occurrence extended into deeper waters beyond the HARP sites. In particular, Blainville's (Md) and Gervais' (Me) extended significantly beyond the shelf break into deeper waters (**Figure 3**). Md and Me were present predominantly from the Mid-Atlantic and to the south. True's (Mm) and Sowerby's (Mb) were mostly present in the Mid-Atlantic and to the north. Cuvier's (Zc) was present throughout the entire study area. These findings support and add detail to the findings of Stanistreet et al. (2017).

Dive depths from the towed array: The average depths at which beaked whales were clicking varied between species and aligned nicely with previous knowledge on dive depths for these species (**Figure 6**, e.g. Tyack et al. 2006, Barlow et al. 2020, Visser et al. 2022, Cholewiak et al. (unpublished data)). Most depths were in the 800- 1200 m range, with Zc showing the most variability between sites.

Figure 4. B*eaked whales species daily presence for July and August 2016 for 10 HARP locations (see Figure 1). There were no beaked whales detected at the JA HARP during the analysis period and are thus not shown here. Species' presence is denoted by color.*

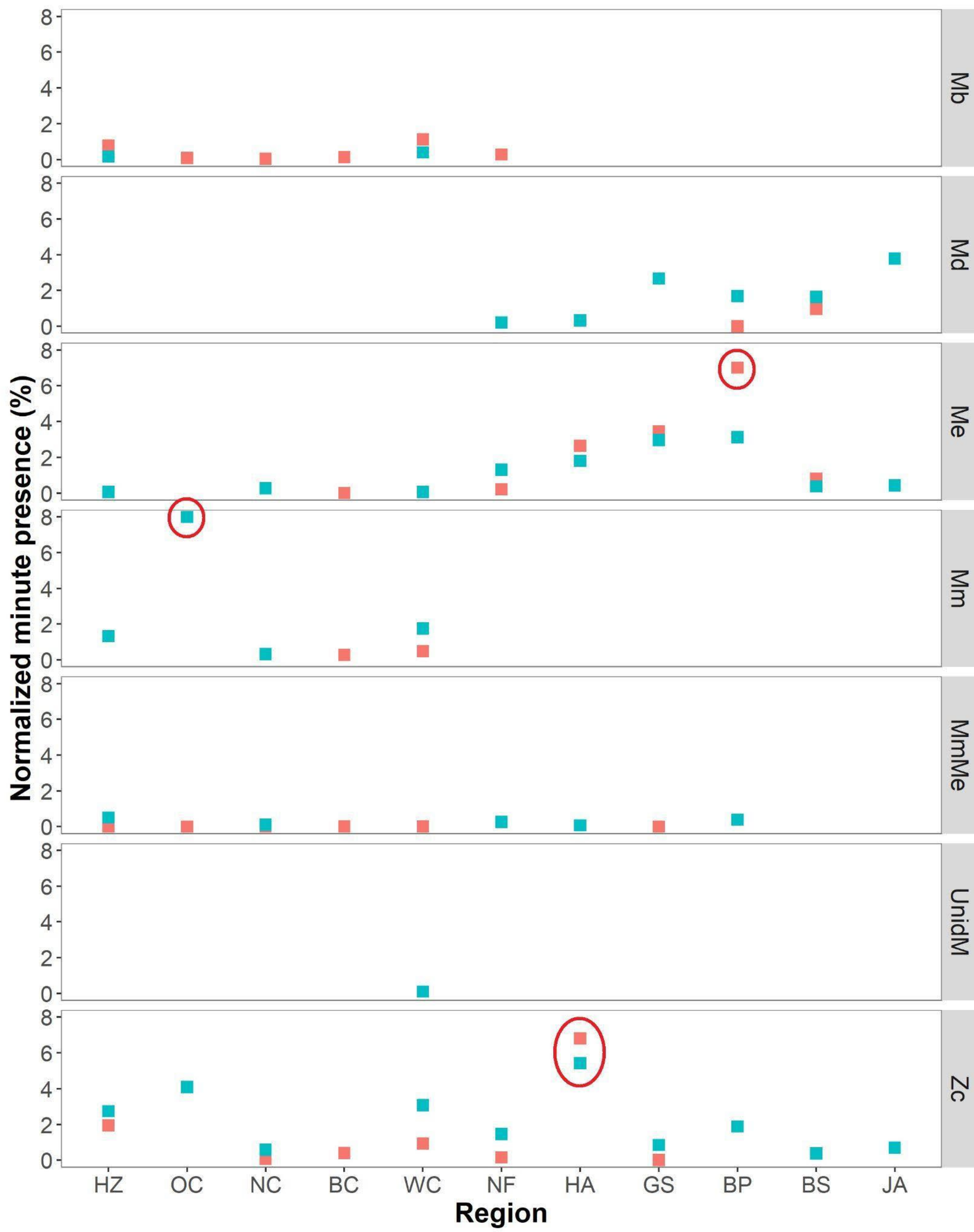

Figure 5. *Percent minute presence of beaked whale species across the 11 regions. Blue squares denote towed array data, red squares HARPs. We saw increased acoustic presence for species in three regions as denoted by the red circles. Based on studies of Cuvier's off Cape Hatteras (Foley et al. 2021) where a resident population or 'hotspot' has been identified, two additional areas of potential resident populations (Gervais' at Blake Plateau [BP], True's at Oceanographer Canyon [OC]) were identified from this analysis.*

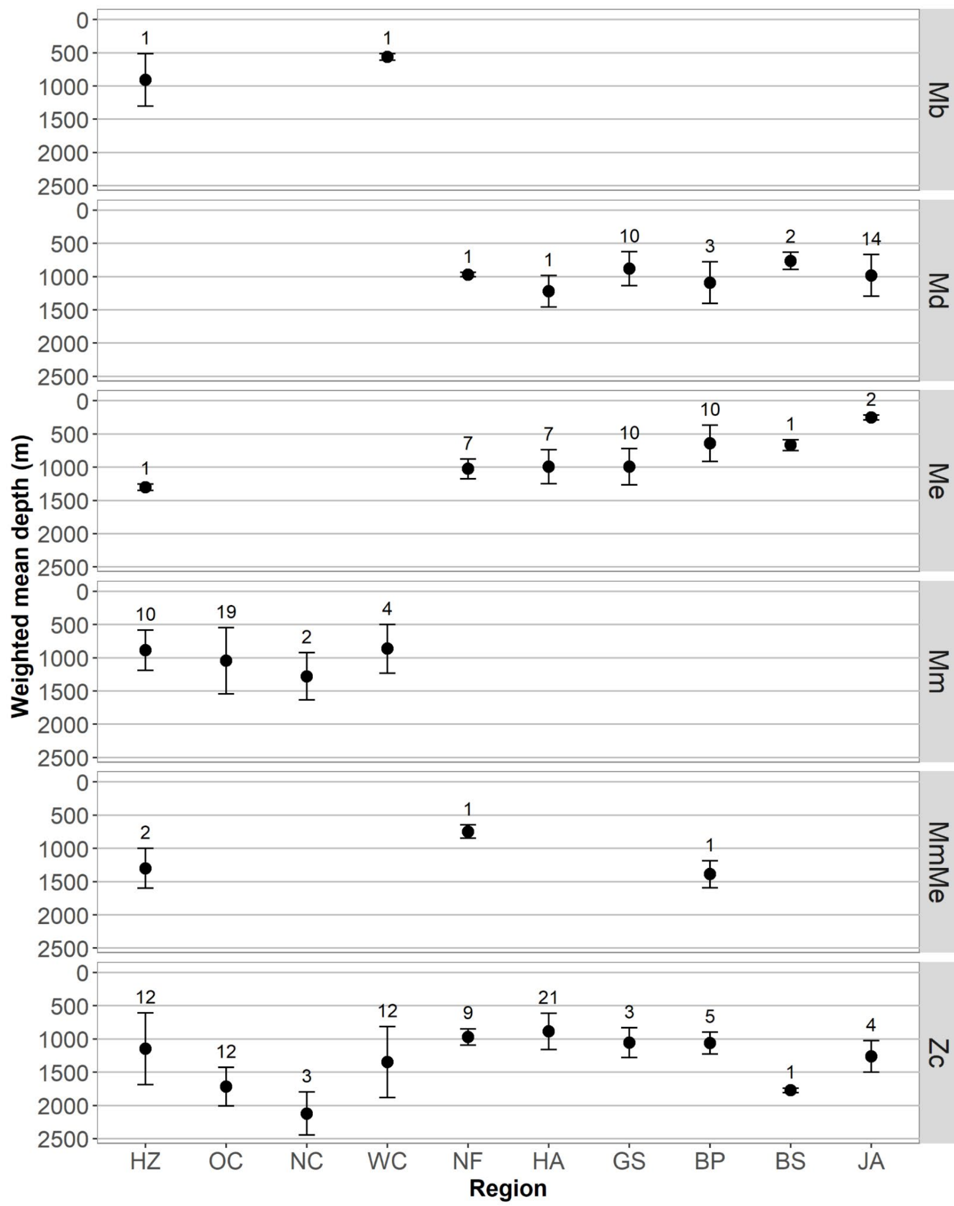

Figure 6. *Weighted mean dive depths (+/- weighted standard deviation) of echolocating beaked whales species across all 11 regions along the east coast of the US. The numbers above each error bar indicate the number of events used to calculate the weighted averages.*

II. Improving automated classification for beaked whales

The classification pipeline performance varied based on species and site (see Van Parijs et al. 2022). During this reporting period, the results were presented at the 24th Biennial Conference on the Biology of Marine Mammals in Palm Beach, Florida, August 2022 ("Automated classification of beaked whale echolocation clicks using machine learning in the western north Atlantic"). The classification pipeline was applied on the summer dataset from 2016, and results were compared with the manual labels (described in section III.). Comparison results are shown for three species (Sowerby's, True's, and Cuvier's beaked whale) detected manually for more than one day at the Babylon Canyon site (**Figures 7-9**). Comparison between the manual and the neural network labels in a 5-min bin resolution showed a consistent accuracy on the species labeling when bins had more than 10 clicks per bin. The neural network also showed promising results in classifying discrete events with less than 10 clicks.

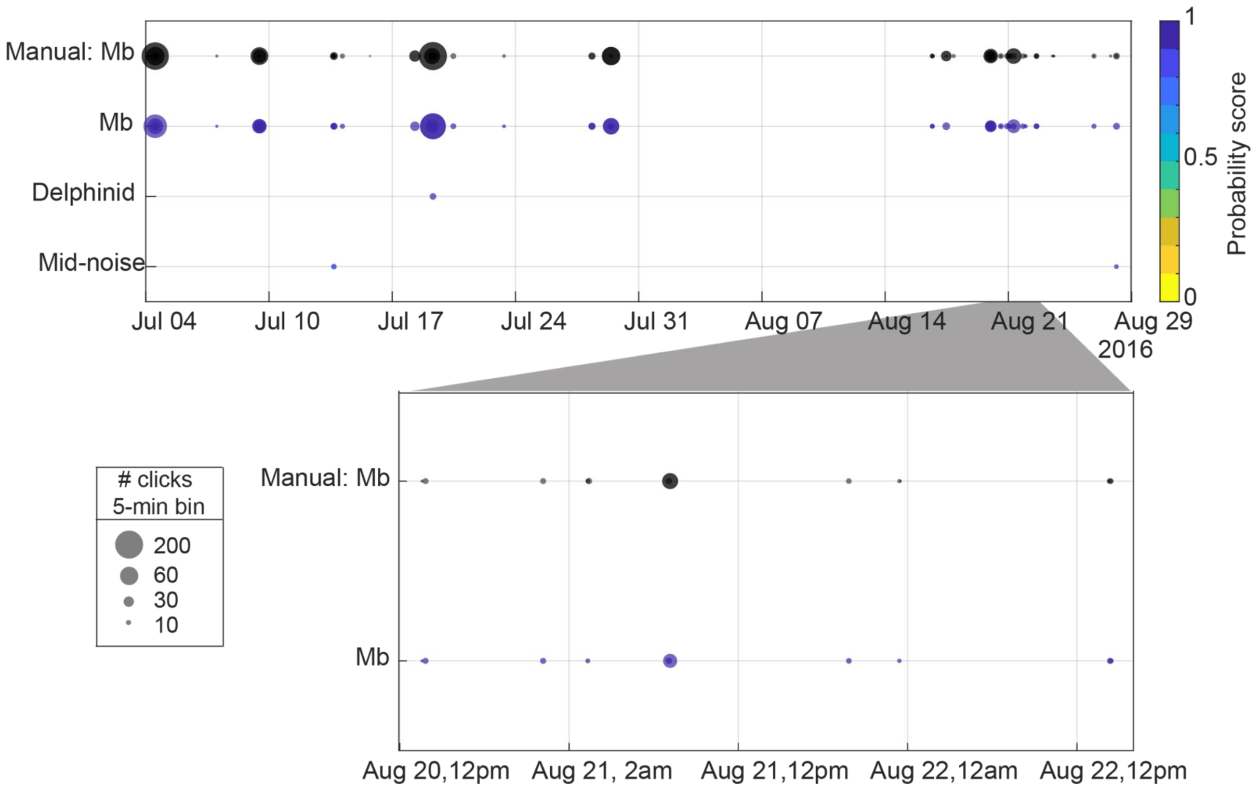

Figure 7. *Comparison of manual labeling and the performance of the deep neural network for Sowerby's beaked whale (Md) detections for data collected from July 1st to August 31st 2016 at the Babylon Canyon site. Circle size indicates the number of clicks per 5-min bins detected manually in black and in color scale the labels given by the neural net with a probability score from yellow to blue [0,1], with dark blue indicating higher confidence. The enlarged section displays a period of time where the number of detections per 5-min bins were very small.*

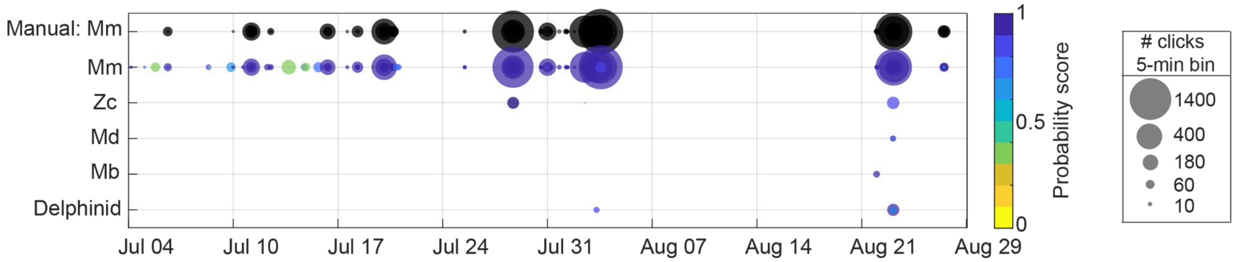

Figure 8. *Comparison of manual labeling and the performance of the deep neural network for True's beaked whale (Mm) detections for data collected from July 1st to August 31st 2016 at the Babylon Canyon site. Circle size indicates the number of clicks per 5-min bins detected manually in black and in color scale the labels given by the neural net with a probability score from yellow to blue [0,1], with dark blue indicating higher confidence.*

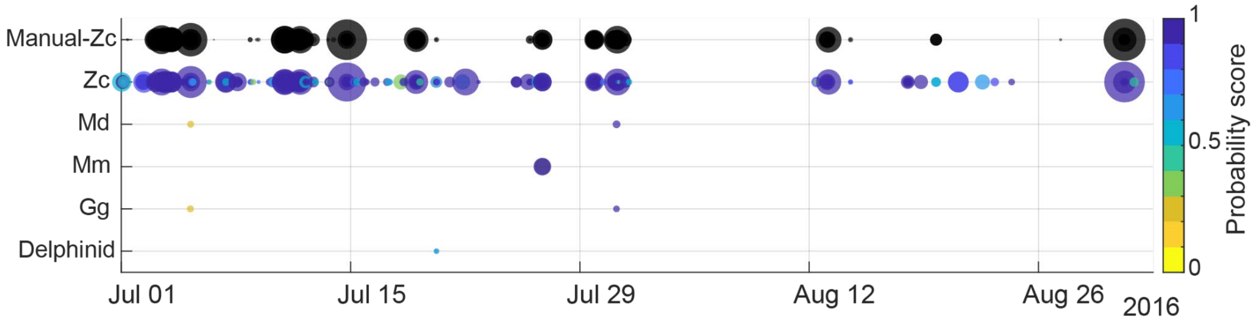

Figure 9. *Comparison of manual labeling and the performance of the deep neural network for Cuvier's beaked whale (Zc) detections for data collected from July 1st to August 31st 2016 at the Babylon Canyon site. Circle size indicates the number of clicks per 5-min bins detected manually in black and in color scale the labels given by the neural net with a probability score from yellow to blue [0,1], with dark blue indicating higher confidence.*

To achieve fine granularity of detections at one-minute level, all beaked whale acoustic encounters were detected at all remaining Atlantic sites from 2015-2019 using the trained deep neural network developed previously under this project. Progress on classification at one-minute level per site and deployment can be found in **Table 2**. To date, all Navy HARP sites and a subset of the WAT dataset (18 out of 35 deployments) have been validated at the click level.

Multiple beaked whale species could be present on the same day, and there were several instances of different species foraging at the same time (**Figures 10-11**). In these cases, the classifier did very well at distinguishing clicks between species.

***Table 2**. Summary of data analysis of all Atlantic sites using automated methods for beaked whale and Navy sonar detection events at one-minute granularity.*

Completed - previous funding | **Completed - during this funding** | **In progress**

			BEAKED WHALES					NAVY SONAR	
			Generic impulse detector	Prune non-beaked whale detections	Unsupervised clustering	Deep network classification	Validate species labels	Detection	Params for covariates
	Heezen								
	2015-2016	WAT_HZ_01	Manual classification						
	2016-2017	WAT_HZ_02							
	2017-2018	WAT_HZ_03							
	2018-2019	WAT_HZ_04							
	Oceanographer's Canyon								
	2015-2016	WAT_OC_01	Manual classification						
	2016-2017	WAT_OC_02							
	2017-2018	WAT_OC_03							
	2018-2019	WAT_OC_04							
	Nantucket Canyon								
	2015-2016	WAT_NC_01	Manual classification						
	2016-2017	WAT_NC_02							
	2017-2018	WAT_NC_03							
	2018-2019	WAT_NC_04							
	Babylon Canyon								
	2016-2017	WAT_BC_01							
	2017-2018	WAT_BC_02							
	2018-2019	WAT_BC_03							
	Wilmington Canyon								
	2016-2017	WAT_WC_01							
	2017-2018	WAT_WC_02							
	2018-2019	WAT_WC_03							
	Norfolk Canyon								
	2015-2016	NFC01A							
IMPACT ANALYSIS	2016-2017	NFC_A_02	Manual classification						
	2017-2018	NFC_A_03	Manual classification						
	2018-2019	NFC_A_04	Manual classification						
	2019-2020	NFC_A_05							
	Hatteras								
	2015-2016	HAT_A_05							
	2016-2017	HAT_A_06							
		HAT_B_01_01							
IMPACT ANALYSIS	2017-2018	HAT_B_03_01							
		HAT_B_04_01							
	2018-2019	HAT_B_05							
	2019	HAT_B_06_01							
	2019-2020	HAT_B_07							
	Gulf Stream								
	2016-2017	WAT_GS_01							
	2017-2018	WAT_GS_02							
	2018-2019	WAT_GS_03							
	Blake Plateau								
	2016-2017	WAT_BP_01							
	2017-2018	WAT_BP_02							
	2018-2019	WAT_BP_03							
	Blake Spur								
	2016-2017	WAT_BS_01							
	2017-2018	WAT_BS_02							
	2018-2019	WAT_BS_03							
	Jacksonville								
IMPACT ANALYSIS	2016-2017	JAX_D_13	Manual classification						
	2018-2019	JAX_D_15	Manual classification						
	2019-2020	JAX_D_16							

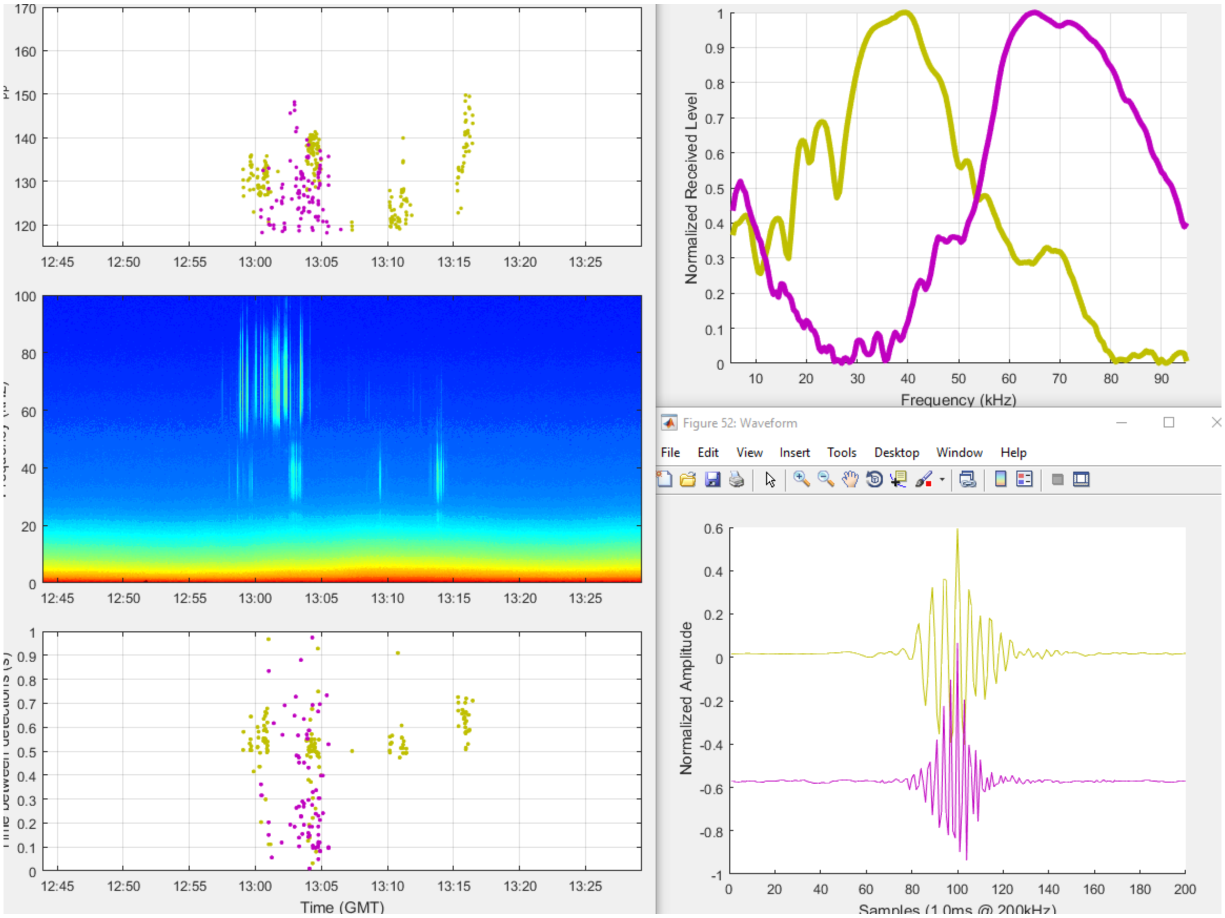

Figure 10. *Example in the detEdit program from Heezen Canyon showing Cuvier's and Sowerby's beaked whales echolocating within the same 5 min period. The clicks shown here were classified using the neural network and have not been edited by an analyst.*

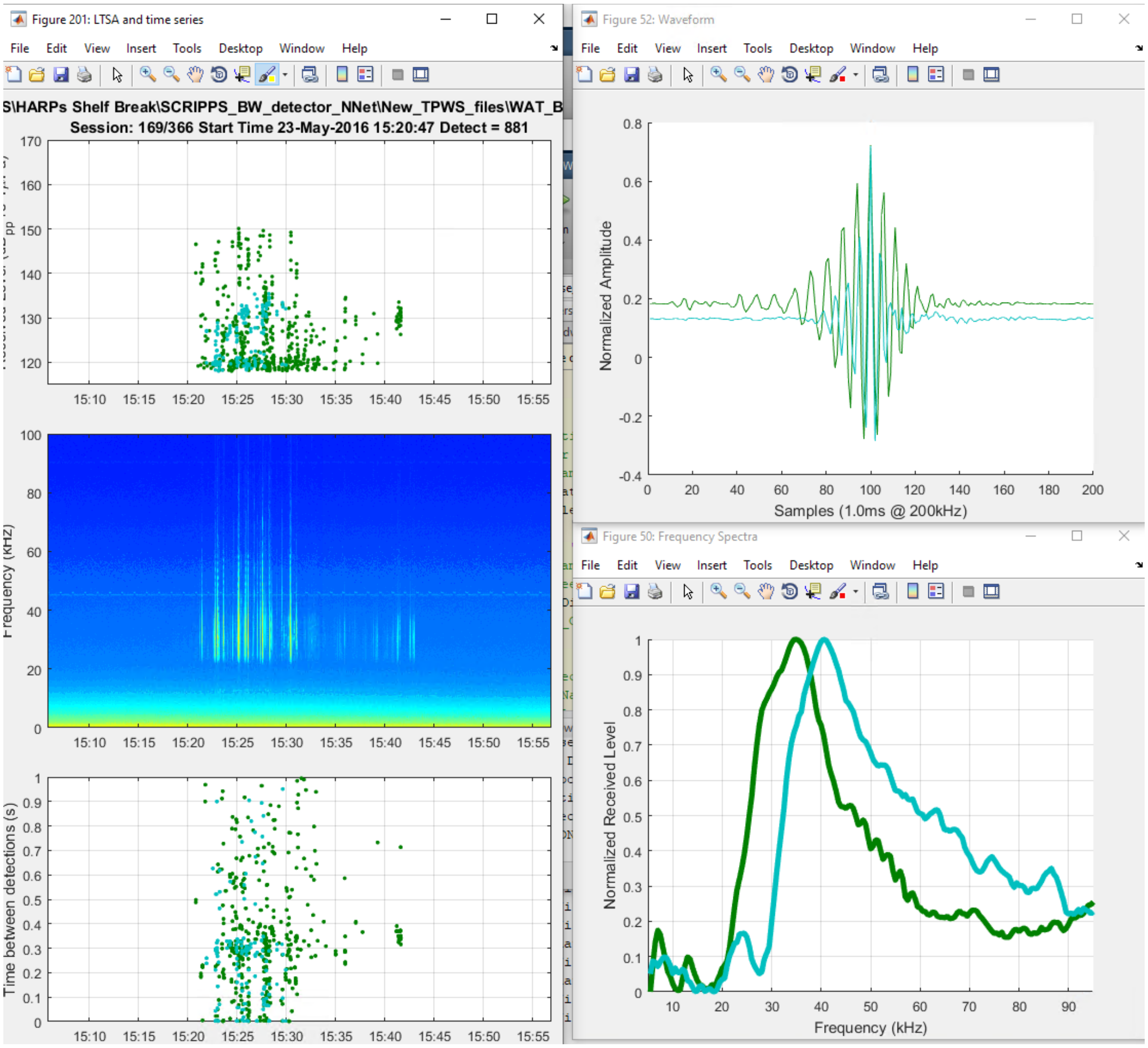

Figure 11. *Example in the detEdit program of Blainville's and Gervais' beaked whales at Blake Spur echolocating within the same 10 min period. The clicks shown here were classified using the neural network and have not been edited by an analyst.*

III. Assessing effects of anthropogenic noise on beaked whale vocal activity

Fine granularity of detections at the one-minute level of beaked whale echolocation clicks and MFA sonar pings have been completed at the US Navy HARP sites between 2015-2020. Beaked whale clicks were previously automatically detected and classified to the species level using an analyst-assisted software (Baumann-Pickering et al., 2013) for three deployments at site NFC and two deployments at site JAX. During the first year of this project false detections for these deployments were eliminated using the DetEdit software. The remaining deployments for these two sites and all data at HAT site were processed using the trained deep neural network.

During this reporting period, all neural network classification labels have been validated using the DetEdit software (**Table 2**). While the automated classification labels were being validated, we explored the statistical analysis on a preliminary dataset which included the neural network results with a probability score higher than 85%. Three species of beaked whales were studied during this preliminary analysis at the three Navy sites, in particular Sowerby's (*Mb*), Gervais' (*Me*) and Cuvier's (*Zc*) beaked whales (**Table 3**). The three species were detected at all sites, although *Mb* was only present for a discrete time of 6 minutes at site JAX. The overall presence of beaked whales was very low at this site, which had the largest presence of MFA sonar, although the HARP in shallower water on the shelf compared to NFC and HAT (**Table 3**). *Zc* was detected in higher numbers at all sites, with the highest presence at HAT, which had the lowest amount of MFA sonar. *Me* were present at all sites, with lower numbers than *Zc* and higher than *Mb*. The highest presence of *Me* was found at HAT.

***Table 3**. Summary statistics of beaked whales and MFA sonar detections of the preliminary dataset with neural network labels with a probability score higher than 85 %.*

		NFC	HAT	JAX
Effort years		2014 – 2020	2015 – 2020	2016 – 2020
Beaked whales				
Effort 1-min segments (total in days)		1,758	1,812	1,130
Segments with presence				
	Mb	0.09 %	0.08 %	* 6-minutes
	Me	0.10 %	0.36 %	0.005 %
	Zc	0.24 %	14.11 %	0.07 %
MFA sonar				
Effort 1-min segments (total in days)		1,333	1,793	1,128
Segments with presence		0.65 %	0.21 %	1.68 %

Generalized estimating equations (GEE) were used to model relationships between the three species of beaked whales' click presence, temporal covariates (e.g. Year, Julian date for seasonality, and time of day for diel patterns) and MFA sonar covariates (e.g. sonar lag, maximum RL pp) in one-minute segments. Presence of *Mb* at all Navy sites was too low for a GEE model to converge and effects of sonar presence were not analyzed for this species. Sites JAX and NFC had less than 1% of one-minute segments with presence of beaked whales and although NFC had the largest percent of segments with MFA sonar, data with beaked whale click presence was scarce for a GEE model to converge at these sites (Table 3). Only site HAT had enough presence of Me and Zc to create a model that could summarize the relationship of the MFA sonar to these two species of beaked whales (**Figure 11**). *Year*, describing inter-annual variability and *Julian day*, describing seasonality were retained by the model as important non-sonar variables for both species. *Zc* shows an increase in presence during the five year period monitored at this site, in contrast *Me* shows a decrease in presence. Seasonality was different between both species, with *Zc* presence higher during the summer-fall months and *Me* higher during spring and lower in the fall. Only *Normalized time of day*, describing a diel pattern was retained by the model for *Zc* with higher presence during the day and lower at night. The probability of detecting both species of beaked whales continued to increase at HAT with increasing time since cessation of sonar use up to about a month. *Maximum peak-to-peak received levels (dB re 1μPa) per minute* were negatively related to the probability of detecting both species of beaked whales at levels above 110 dB re 1μPa. *Proportion of sonar within a minute* was not retained as relevant in the models for either species. In conclusion, both species showed different temporal patterns at HAT (as in Stanistreet et al. 2017) but overall similar response to MFA sonar presence. This analysis was presented at the 7th International Meeting on the Effects of Sound in the Ocean on Marine Mammals in Beaufort, North Carolina, March 2022 ("Impact of Mid-Frequency Active Sonar on Beaked Whales documented by Passive Acoustic Monitoring").

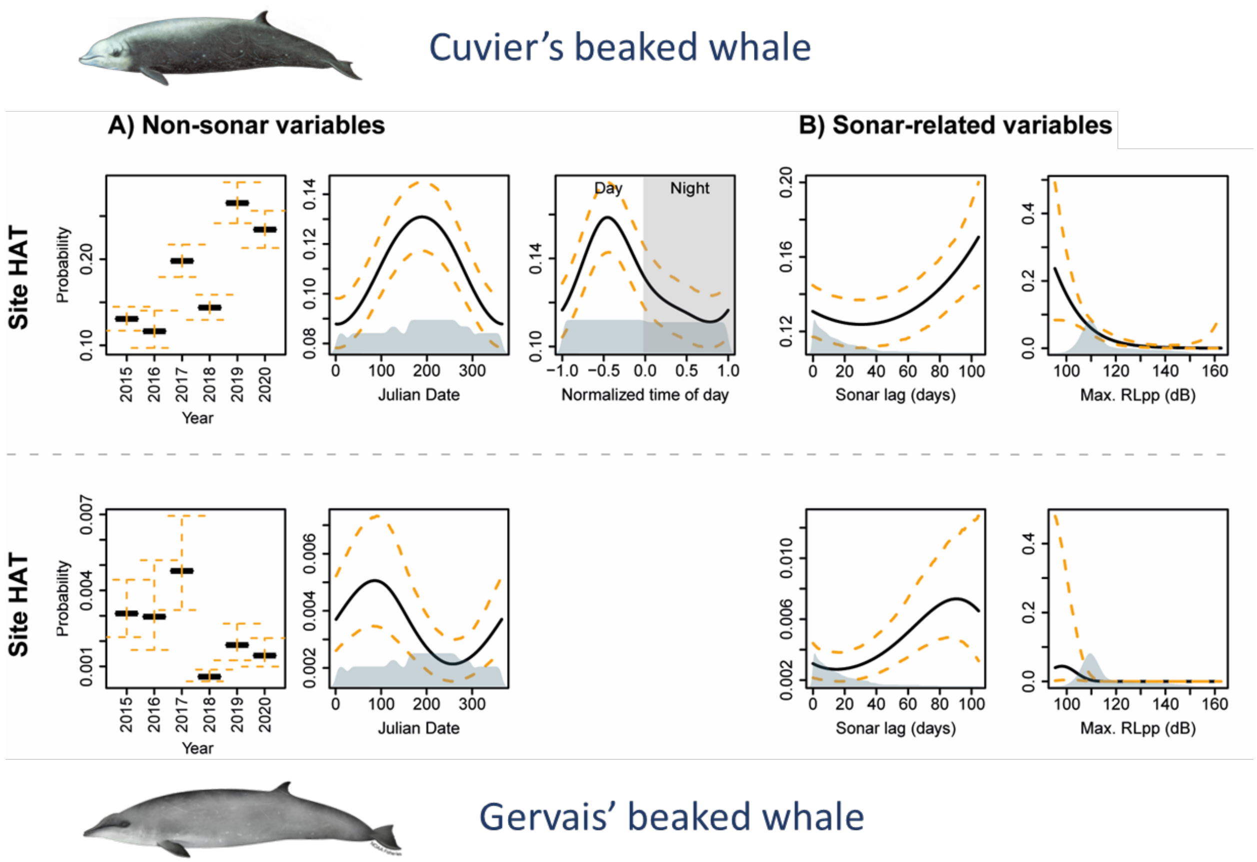

Figure 11. *Generalized Estimating Equation (GEE) model results quantifying acoustical response of Cuvier's (Zc) and Gervais' (Me) beaked whales to MFA sonar for site HAT. Explanatory covariates retained in the final model for both species at site HAT were A) non-sonar variables, documenting inter-annual variability (year as factor), seasonality (Julian date), and only for Zc the diel behavior (normalized time of day); B) sonar-related variables, showing increased site presence after longer time since last use of sonar (sonar lag), and lower sonar peak-to-peak received levels of sonar. Model fit (black line) with confidence intervals (orange dashed line); bottom blue shaded area shows data distribution.*

The next step is to implement the statistical analysis on the entire dataset containing the validated neural network results without constraining the probability score since detections have been validated. Below we present a summary of the data for all the Navy sites. We have begun formatting the data for the statistical analysis and expect to complete the analysis early next year. This data shows that only *Zc* and *Me* were detected at all Navy sites (**Table 4**). Sites NFC and HAT also include the presence of Blainville's (*Md*), and True's (*Mm*) beaked whales. We expect to conduct the same type of statistical analysis for *Zc* and *Me* for NFC since both species are present in sufficient numbers at this site. We will also explore other methods to investigate the relationship between discrete presence and MFA sonar for other species occurring at lower numbers at NFC and HAT.

***Table 4**. Summary statistics of beaked whales and MFA sonar detections of the validated dataset for the HARP Navy sites.*

Site		# Deployments	Start Date	End Date	Effort 1-min seg. (days)	Presence 1-min seg. (%)	Presence min./day mean (SD)	Presence min./day min-max	# Clicks | Pings 1-min seg. mean (SD)
Beaked whales									
NFC		5	06/19/14	05/08/20	2,450,217				
	Mb					42,819	0.88 (3.05)	0 – 45	17.05 (33.44)
	Md					332	0.001 (0.05)	0 – 2	4 (3)
	Me					119,233	1.14 (6.50)	0 – 125	38.69 (57.12)
	Mm					85,395	0.74 (4.49)	0 – 81	51.72 (76.61)
	Zc					143,095	2.09(7.87)	0 – 112	26.90 (32.31)
HAT		8	04/06/15	10/29/20	2,608,789				
	Mb					2,314	0.03 (0.48)	0 – 11	37.72 (57.65)
	Md					1,769	0.03 (0.63)	0 – 25	13.51 (15.49)
	Me					368,404	2.24 (8.67)	0 – 116	36.39 (49.74)
	Mm					19,264	0.13 (1.59)	0 – 51	59.72 (82.23)
	Zc					13,187,291	147.73 (169.93)	0 – 866	36.66 (40.00)
JAX		3	04/26/16	05/31/20	1,627,348				
	Me					1765	0.03 (0.56)	0 – 15	24.17 (25.26)
	Zc					595	0.03 (0.57)	0 – 19	15.26 (17.11)
MFA sonar									
NFC		5	06/19/14	05/08/20	1,919,463	47,508	5.81 (30.95)	0 – 624	3.80 (4.73)
HAT		8	04/07/15	10/29/20	2,608,789	25,011	2.71 (21.92)	0 – 428	4.58 (4.08)
JAX		3	04/26/16	05/31/20	1,624,811	115,794	18.38 (93.50)	0 – 1283	4.25 (3.89)

IV. *Assessing patterns of richness and composition of marine mammal communities through ecological gradients*

The primary aim for this analysis was to apply both our existing approaches to exploring niche level interactions within long term data sets within the shelf break marine mammal communities. We have validated all WAT and Navy sites for beaked whale presence at the daily scale using the output of the neural net dataset to a confidence threshold of 0.99. There are just a few remaining analyses to complete (sperm whales for three Navy deployments, two more disks at one WAT site for beaked whales, one Navy site for baleen whales). Below we present preliminary results using a subset of the data (7 sites from 2016) as presented by Dr. Samara Haver as invited speaker at the Acoustical Society of America Special Session on Acoustic Oceanography, Shelf Break Acoustics December 5-9, 2022 (**Figures 12-15**).

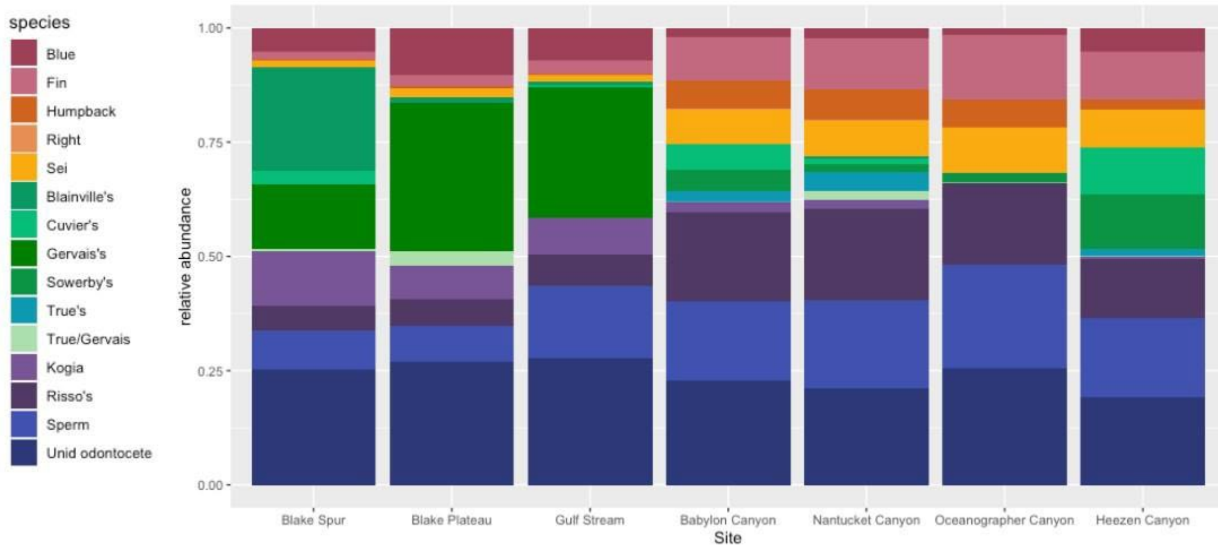

Figure 12 *shows the relationships between sites and relative species abundance. In this figure, it is clear that proportional species acoustic abundance differs between sites. Relationships between latitude, year and site will be explored in detail once the full data set has been processed and is available. Sites are organized left to right from south to north.*

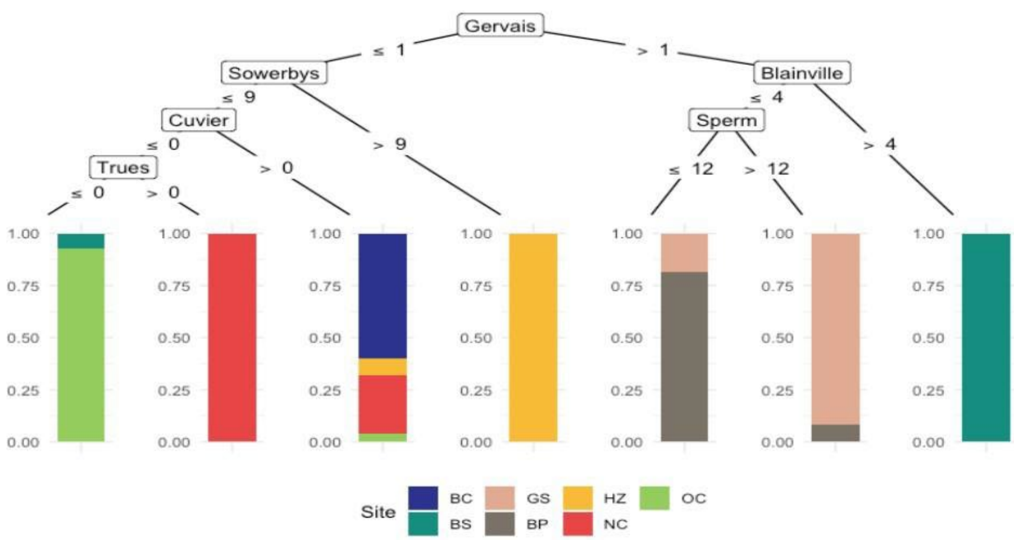

Figure 13 *shows the classification tree relationship splits between sites and species. Odontocete species currently drive the splits between sites indicating that their communities tend to dominate species ecology at sites compared to the more transitory migrating baleen whale species. Furthermore, clear differences are noticeable between the preponderance of given species at certain sites.*

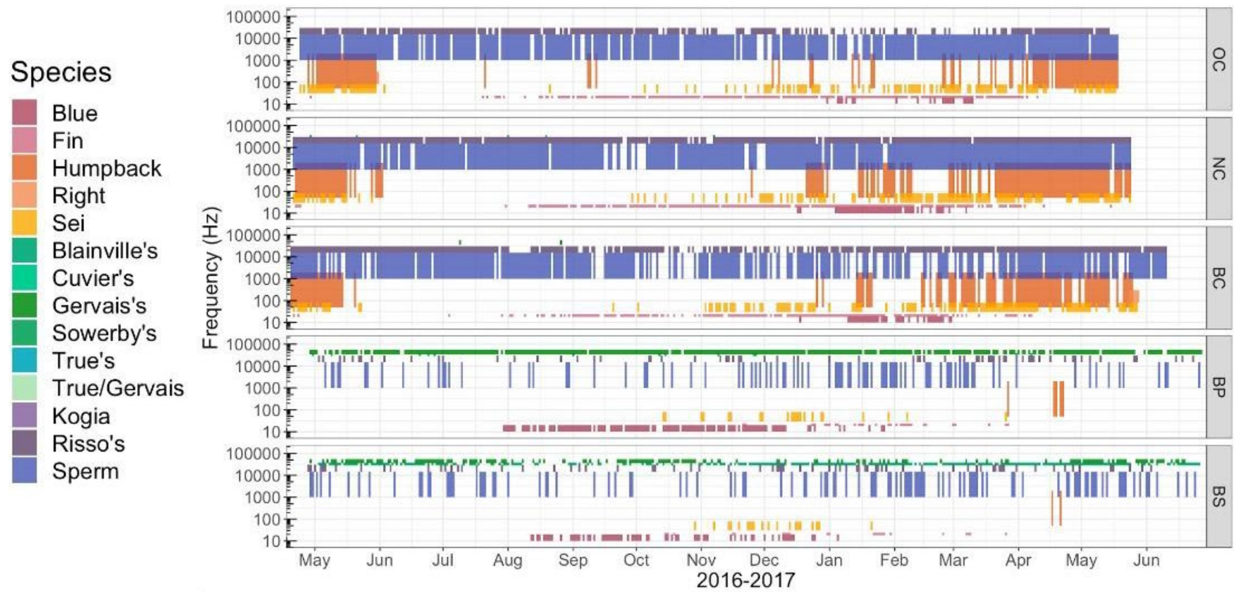

***Figure 14** shows the acoustic niche plots for 5 of the sites across the 2016/2017 year and identified clear seasonal differences in presence with Kogia sp., sperm whales and humpback whales dominating northern sites and beaked whales dominating the southern sites. Again, these are preliminary findings and further years and sites are needed to provide more conclusive results.*

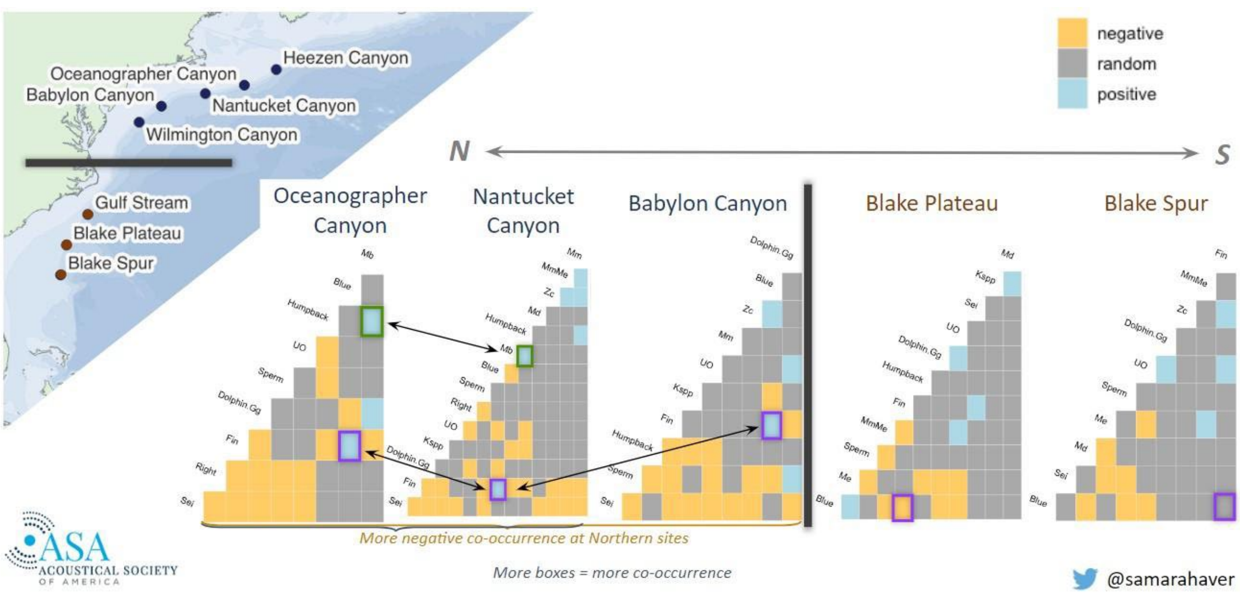

***Figure 15** provides a preliminary look at the co-occurrence models for 5 of the sites over one year. These plots show both negative and positive relationships of co-occurrence. There are positive occurrences between Sowerby's beaked whales, blue whales or humpback whales in the northern sites. However, less co-occurrence of species was noted in the northern versus the southern sites. Clearly, further analysis and exploration of these data is needed to provide more conclusive evidence of co-occurrence relationships between species across space and time. However, as a preliminary pass this provides one of the first approaches to applying community ecology analyses to passive acoustic data.*

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