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

FY 2020 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 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, in coordination with 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 2020 have been to refine species occurrence analyses, including completing analyses of baleen whale occurrence and working to improve the classification algorithms for odontocetes; exploring new acoustic metrics to describe species diversity; and developing frameworks to assess impacts of anthropogenic noise on the acoustic ecology and acoustic behavior of protected species. The first manuscript for the project was submitted in June 2020.

Objectives

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

I. Assessing the seasonal and spatial occurrence of baleen whales
II. Improving automated classification for beaked whales
III. Assessing effects of anthropogenic noise on beaked whale vocal activity
IV. Assessing the prevalence of seismic survey noise along the eastern seaboard
V. Novel broad-scale approach to assessing acoustic niche and anthropogenic contributors, and assessing the utility of new acoustic metrics

Acoustic Data Collection

Continuous passive acoustic recordings were collected along the Atlantic continental shelf break of the United States at eleven sites beginning as early as 2015 by both NEFSC and the U.S. Navy. The sites deployed starting in 2015 include Heezen Canyon, Oceanographer Canyon, 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 deployed at depths of 800-1100 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 and Hildebrand, 2007.

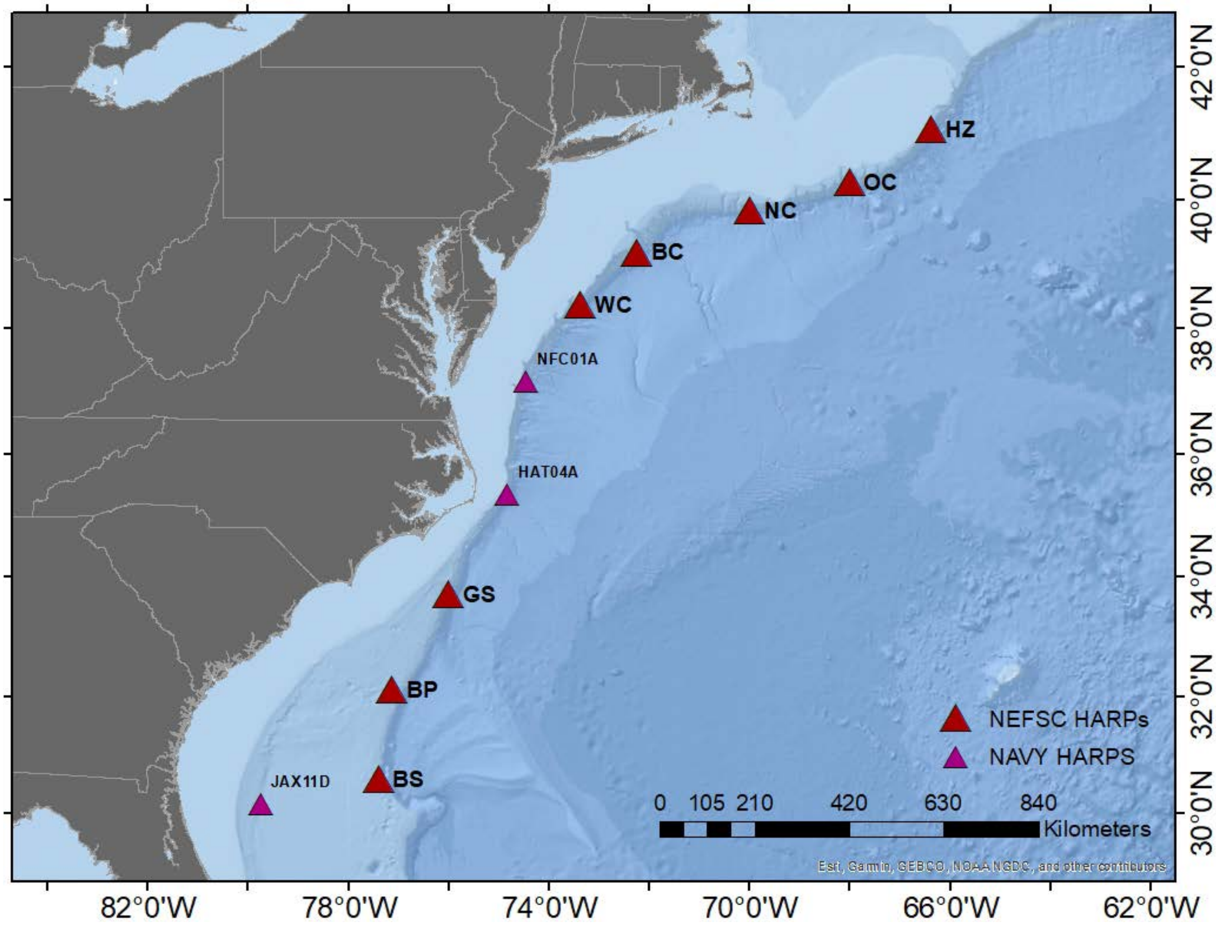

Figure 1. *HARP deployment sites for data collected from 2015 through 2019.*

Table 1. *HARP deployment sites, recording dates and recording durations for 2015-2019. All HARPs recorded continuously at a sampling rate of 200 kHz. The first and last day of each deployment represent partial recording days.*

Site Name, Location	Recording Date Range	Latitude	Longitude	Recorder Depth (m)
WAT_HZ; Heezen Canyon	Jun 2015 - Mar 2016 Apr 2016 - Jun 2017 Jul 2017 - Jan 2018 Jun 2018 - May 2019	41.0619	-66.3515	845
WAT_OC; Oceanographer Canyon	Apr 2015 - Feb 2016 Apr 2016 - May 2017 Jul 2017 - May 2019	40.2633	-67.9862	1000
WAT_NC; Nantucket Canyon	Apr 2015 - Sep 2015 Apr 2016 - May 2017 Jul 2017 - Apr 2018 Jun 2018 - Jun 2019	39.8325	-69.9821	977
WAT_BC; Babylon Canyon	Apr 2016 - May 2019	39.1911	-72.2287	1000
WAT_WC; Wilmington Canyon	Apr 2016 - May 2019	38.3742	-73.3707	1000
NCF; Norfolk Canyon	Apr 2016 – May 2019	37.166	-74.466	1000
HAT; Hatteras	Apr 2016 – May 2019	35.584	-74.749	1100
WAT_GS; Gulf Stream	Apr 2016 - Jun 2019	33.6656	-76.0014	954
WAT_BP; Blake Plateau	Apr 2016 - May 2019	32.1060	-77.0943	945
WAT_BS; Blake Spur	Apr 2016 - Jun 2019	30.5838	-77.3907	1005
JAX; Jacksonville	Apr 2016 – Jun 2019	30.152	-79.771	750

Methods

I. Assessing the seasonal and spatial occurrence of baleen whales

The low-frequency acoustic data sets for all sites were used to extract the presence of five mysticete species: blue (*Balaenoptera musculus*), fin (*Balaenoptera physalus*), humpback (*Megaptera novaeangliae*), North Atlantic right (NARW) (*Eubalaena glacialis*), and sei whales (*Balaenoptera borealis*). An automated detector, the Low-Frequency Detection and Classification System (LFDCS), was used to identify and distinguish species-specific vocalizations. Our call library included the following species-specific vocalizations obtained from acoustic data collected in our region: blue, fin, North Atlantic right and humpback whales. Further details on the LFDCS are described in Davis et al., 2017.

The LFDCS outputs were manually reviewed by a trained analyst. Species presence was determined on a daily scale, in which a species was considered "present" on a given day if the number of verified true pitch-tracked detections met or exceeded minimum criteria established for each species. Progress made during 2020 included analyses of the 2017-2018 WAT dataset.

II. Improving automated classification for beaked whales &
III. Assessing effects of anthropogenic noise on beaked whale vocal activity

The purpose of this effort is to expand the analysis of automatic identification of beaked whales to click-level and subsequently develop a statistical approach to investigate the potential impacts of mid-frequency active (MFA) sonar in the Western North Atlantic. The goal is to refine existing data of several species of beaked whales for acoustic behavioral response 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 have focused largely on the Navy HARP sites, as presence of MFA sonar is higher there than on the WAT sites. Here we document the progress made on data preparation, defining methods for automated identification of beaked whales to click-level and parameters to be used in upcoming statistical analysis.

1. Beaked whale detections

Beaked whale echolocation click encounters were processed with previous funding for three US Navy sites (NFC, HAT, and JAX) and the year 2015-2016 for three WAT sites (HZ, OC, and NC) (Table 2). Beaked whale encounters were automatically detected and then classified to the species level with analyst-assisted software (Baumann-Pickering et al., 2013), eliminating false encounters. The other sites were evaluated with a clustering method that involves unsupervised learning and neural networks (Frasier et al., 2017). The current clustering method results included a significant amount of false positive detections and overall false labels for beaked whales, which needed to be addressed. 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.

To achieve a click-level resolution, all beaked whale acoustic encounters at the US Navy sites were reviewed to remove false detections of individual clicks and provide a consistent detection threshold (Table 2). Beaked whale clicks were retained when the signal in a 10 – 100 kHz band exceeded a detection threshold of 120 dB pp re: 1µPa. Clicks within acoustic encounters were manually reviewed using the open-software *DetEdit* (Solsona-Berga et al., 2020). *DetEdit* is a highly-configurable interface that provides analysts with signal-level detail and encounter-level context. It allows users to step through acoustic events, displaying a range of signal features, including time series of received levels, long-term spectral averages (LTSA), inter-click intervals, as well as spectral and waveform plots of selected clicks and scatter plots of peak frequency, RMS, and peak-to-peak received levels. Within each encounter, false detections were removed by manually editing, for instance, when spectral amplitude, inter-click interval, or waveform indicated the detections were from delphinids or sources of noise. In addition, this step provided another check on beaked whale species classification, and remaining misidentified or false encounters were corrected or removed.

In addition, we evaluated the performance of an existing network-based classifier intended for delphinids to assess its accuracy. We quantified the discrepancies between the network-based classifier and the manually reviewed detections with *DetEdit* at one of the US Navy sites. We implemented a comparison framework using a modified version of the Triton software (Wiggins et al., 2010) to quantify both outputs' similarities and differences. This assessment provided the insights necessary to improve the network-based classifier on beaked whale species.

Table 2. *Summary of data analysis of all Atlantic sites and description of detection level for the statistical analysis.*

🟦 completed with previous funding 🟧 completed during this funding period 🟪 in progress

	Sonar		Beaked whales	
	Detection	**Params for covariates**	**≥ 5-min level species classification**	**1-min level species classification**
WAT HZ				
2015-2016	🟦	🟧	🟦	
2016-2017			🟦	
2017-2018			🟦	
2018-2019			🟦	
WAT OC				
2015-2016	🟦	🟧	🟦	
2016-2017			🟦	
2017-2018			🟦	
2018-2019			🟦	
WAT NC				
2015-2016	🟦	🟧	🟦	
2016-2017			🟦	
2017-2018			🟦	
2018-2019			🟦	
WAT BC				
2016-2017			🟦	
2017-2018			🟦	
2018-2019			🟦	
WAT WC				
2016-2017			🟦	
2017-2018			🟦	
2018-2019			🟦	
NFC				
2015-2016	🟪	🟪		🟪
2016-2017	🟪	🟪	🟦	🟧
2017-2018	🟦	🟧	🟦	🟧
2018-2019	🟧	🟧		🟧
HAT				
2015-2016	🟦	🟧	🟦	
2016-2017	🟪	🟪	🟦	
2017-2018	🟦	🟧	🟦	🟪
2018-2019	🟧	🟧		
WAT GC				
2016-2017			🟦	
2017-2018			🟦	
2018-2019			🟦	
WAT BP				
2016-2017			🟦	
2017-2018			🟦	
2018-2019			🟦	
WAT BS				
2016-2017			🟦	
2017-2018			🟦	
2018-2019			🟦	
JAX				
2016-2017	🟦	🟧	🟦	🟧
2017-2018	🟪	🟪	🟦	🟧
2018-2019	🟧	🟧	🟦	🟧

2. Mid-frequency active sonar detections

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. The algorithm identifies peaks in time-frequency distributions (e.g., spectrogram) and determines which peaks should be linked into a graph structure based on heuristic rules that include examining the trajectory of existing peaks, tracking intersections between time-frequency trajectories, and allowing for brief signal drop-outs or interfering signals. 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).

Statistical analysis

1. General approach

We selected generalized estimating equations (GEES) as the modeling framework for statistical data analysis. Given that an animal’s echolocation clicks can be detected near the sensor for several minutes, GEEs can accommodate autocorrelation inherent to the data's time series nature. Their strength lies in that they can be used with repeated measurements over space and time, and they provide an estimate of the average response of the population. Here we are presenting preliminary results to train the model. We explore 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.

2. Data formatting

For modeling beaked whale presence in relation to sonar, we formatted the data into 1-min segments as the individual observation units instead of individual detections (Table 2).

Table 3. *Summary of beaked whale echolocation click data and MFA sonar from US Navy sites.*

		Norfolk Canyon (NFC)		**Jacksonville (JAX)**	
	Short name	**1-minute segments**	**Segments with presence**	**1-minute segments**	**Segments with presence**
Cuvier's beaked whale	*Zc*	989,916	87,564	1,120,960	18
Blainville's beaked whale	*Md*	989,916	68	1,120,960	448
Gervais' beaked whale	*Me*	989,916	96,744	1,120,960	18
Sowerby's beaked whale	*Mb*	989,916	21,073	1,120,960	35
MFA sonar	*MFA*	989,916	50,092	1,120,960	66,405
Years		Jul 2017 – May 2019		May 2016 – Jun 2017 Jul 2018 – Jun 2019	

3. Response variables

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 four beaked whale species click types (Table 3).

4. Explanatory covariates

The explanatory covariates (Table 4) 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.

Table 4. *Explanatory covariates for the statistical analyses of beaked whale click data.*

Covariate	Short name	Description	Calculation details
Sonar-related covariates			
Sonar presence	*sPres*	Binary (1/0): presence/absence of sonar pings. Used as a dummy variable in interaction terms.	0 if no sonar in that 1-min segment, 1 if at least 1 sonar ping
Sonar lag	*sLag*	Number of 1-min segments since the last sonar ping.	Each 1-min segment = 0 where *sPres* = 1; otherwise as lag in minutes since last 1-min segment with sonar. Periods after no sonar effort are NA until the first sonar ping.
Proportion of sonar	*sProp*	Proportion of 1-min segment with sonar	Sum of duration of all sonar pings (secs) that fall within 1-min segment / 60 secs.
Sonar received levels	*maxRLpp*	Maximum peak-to-peak received levels per 1-min segment.	0 if no pings, if multiple pings fall in 1-min segment, result is the maximum.
Sound exposure level	*cumSEL*	Cumulative sound exposure level (SEL) in dB for 1-min segment.	Adding up SEL from different pings in the same 1-min segment: bels = SEL/10 intensity = $10^{\wedge bels}$ cumsel = $10*\log_{10}$(sum(intensity))
Non-sonar related covariates			
Time of day	*timeofd*	Time of day in minutes (UTC)	0 if midnight (UTC) in that 1-min segment; otherwise as lag in minutes since last 1-min segment with midnight.
Time since sunrise	*sunriseLag*	Length in minutes since sunrise.	0 for 1-min segment in which sunrise occurred; otherwise as lag in minutes since last 1-min segment with sunrise.
Time since sunset	*sunsetLag*	Length in minutes since sunset.	0 for 1-min segment in which sunset occurred; otherwise as lag in minutes since last 1-min segment with sunset.
Julian date	*jd*	Date in integers	Consecutive day of year: 1-365
Year	*year*	Year of recording	
Day-night	*DN*	Binary (1/0): day/night	

IV. Assessing the prevalence of seismic survey noise along the eastern seaboard

The initial presence of airguns was automatically detected using a matched filter detector, where the time series was filtered with a 10th order Butterworth bandpass filter between 25 and 200 Hz. A cross-correlation was computed on the filtered time series; when a correlation coefficient reached a threshold of $2*10^{-6}$ above the median, a trained analyst manually verified the detections (Rafter et al. 2020). Initial preliminary results suggested a higher level of detected seismic survey activity than anticipated; therefore, subsequent analyses were initiated to more closely review the data with the goal of assessing the approximate region from which these activities are occurring. Upon further review, it was found that there are frequent occasions in which there is a clear and temporary pause in airgun activity, occasionally followed by a sudden start a few minutes later, causing a recognizable gap (**Figure 2**). A detailed review is being undertaking to quantify the occurrence and duration of each gap in survey activity that may be used to align detected pulses across HARP units. The timing of these events is being compared across sites to determine putative time-delay-of-arrivals of seismic signals between pairs of sites. The resultant data are being used to compute bearings to source activity. Progress during 2020 has focused on a thorough evaluation of the 2016-2017 HARP dataset, including both WAT and Navy sites.

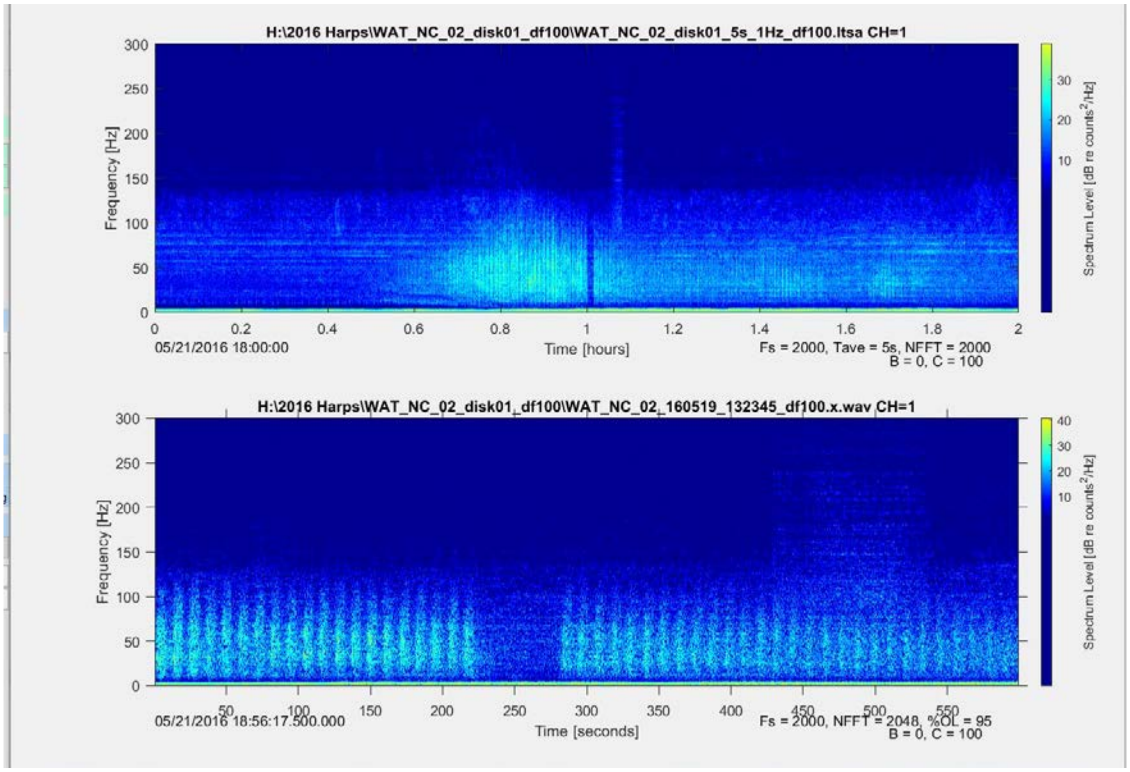

Figure 2. *Airgun analysis example from Triton, from WAT_NC on 05/21/2016 (FFT 2048 pts, 95% overlap). Top panel shows 2 hours of activity; bottom panel shows the sudden stop and start of the airgun pulses at around 19:00:00. The beginning and end times of this gap, as well as an estimation of the length of time, are recorded for comparison across sites.*

V. Novel broad-scale approach to assessing acoustic niche and anthropogenic contributors, and assessing the utility of new acoustic metrics

Building on the acoustic metrics proposed by Roca & Van Opzeeland (2019), we initiated an analysis to determine whether those same metrics could be applied to western North Atlantic acoustic data, with initial focus on WAT HARP data. To do so, the entire dataset from the Heezen Canyon 2017-2018 deployment was broken up into one-minute clips and analyzed to quantify species richness (SR) categories (defined as sample of periods with 0, 1, 2, 3 or more species acoustically present) and species occurrence in those samples for baleen whales in the low-frequency (2kHz) dataset. The goal was to build a ground-truthed dataset of 1-minute files containing a representative sample of periods with 0, 1, 2, 3 or more species acoustically present. Initial analyses included a random selection of 100 samples for months where the highest species diversity was anticipated. After finding that most random samples have SR=0 for those months, the analyst began targeted sampling to try to increase the number of samples at each SR level to at least 100 samples. The targeted sampling was based on analysis done with a Low-Frequency Detection and Classification System (LFDCS; Baumgartner & Mussoline 2011).

Preliminary Results

I. Assessing the seasonal and spatial occurrence of baleen whales

Ongoing analyses have focused so far on four baleen whale species: North Atlantic right whales, as well as blue, fin and sei whales. Analyses of humpback and minke whale acoustic presence are planned in future work. For the 2016-2017 WAT deployments, we detected all four species at the HARP sites. Right whales were rarely detected, but we did detect them on several days at four sites, between March and June in 2016 and 2017 (**Table 4**). However, the more pelagic balaenopterid species had high levels of daily occurrence, with clear seasonal patterns at each site. We frequently detected fin whales between September and March on sites north of Cape Hatteras, with fewer days with detections, primarily concentrated between December and February, on the three southern sites. Sei whale detections were slightly shifted into spring months, with highest levels of daily activity in March through May north of Cape Hatteras. However, they were detected in the winter on all sites in 2016. Interestingly, blue whales were detected from September through March at the northernmost site, but then were detected most consistently from Wilmington Canyon and south, from August through September.

The combined acoustic detections from Marine Autonomous Recording Units deployed along the shelf as part of the AMAPPS project are shown in combination with the the HARP data in Figure 3. We found that blue whales are primarily detected along the shelf break and deepest HARP units on the Blake Plateau, with few detections on the continental shelf. Fin whales and sei whales show a similar pattern, though we detected both species at high levels across the line of Nantucket MARUs, demonstrating the importance of this habitat to both species. Like blue whales, we detected both fin and sei whales on the HARPs extending to the Blake Spur, and on several of the deeper MARUs on the Blake Plateau. Finally, we detected North Atlantic right whales most commonly on the Nantucket MARUs, with few detections at the shelf break, reflecting the coastal distribution of this species. Analyses of the 2018-2019 datasets are ongoing.

Table 4. *Number of days per month with acoustic detections for each of four baleen whale species, from April 2016 through July 2017. Colored shading indicates relative proportion of detection days for each species, to provide a visual cue to interpret the seasonality between sites and species. Blank months represent those with no data*

		2016									**2017**							
	Site	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Total Number of Days**
Blue whales	WAT_HZ	0	0	0	0	1	26	21	9	19	20	16	8	0	0	0	0	120
	WAT_OC	0	0	0	0	0	0	0	0	1	6	9	6	0	0		0	22
	WAT_NC	0	0	0	0	0	0	0	0	2	28	18	0	0	0		0	48
	WAT_BC	0	0	0	0	0	0	0	0	1	18	17	0	0	0	0	0	36
	WAT_WC	0	0	0	0	7	18	23	12	6	4	11	1	0	0	0	0	82
	WAT_GS	0	0	0	0	8	24	27	19	11	2	0	0	0	0	0		91
	WAT_BP	0	0	0	2	23	25	26	26	12	5	0	0	0	0	0	0	119
	WAT_BS	0	0	0	0	11	21	14	9	11	1	1	0	0	0	0		68
Fin whales	WAT_HZ	0	0	0	8	23	30	30	30	31	30	27	20	6	0	0	3	238
	WAT_OC	1	0	0	6	12	25	29	28	29	29	26	29	5	0		6	225
	WAT_NC	3	0	0	1	19	24	29	29	28	31	23	22	4	1		0	214
	WAT_BC	2	0	0	2	11	26	16	27	27	27	24	12	3	0	0	2	179
	WAT_WC	0	0	0	1	10	22	21	21	24	26	12	20	2	1	0	3	163
	WAT_GS	0	0	0	0	1	3	3	6	5	14	12	9	1	0	0		54
	WAT_BP	0	0	0	0	0	1	2	4	7	11	10	5	0	0	0	0	40
	WAT_BS	0	0	0	0	1	0	4	4	3	9	3	4	0	0	0		28
Right whales	WAT_HZ	0	0	**1**	0	0	0	0	0	0	0	0	0	0	**1**	0	0	2
	WAT_OC	0	**1**	0	0	0	0	0	0	0	0	0	0	0	0		0	1
	WAT_NC	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
	WAT_BC	0	0	0	0	0	0	0	0	0	0	0	0	0	**5**	0	0	5
	WAT_WC	0	0	0	0	0	0	0	0	0	0	0	**1**	**1**	0	**1**	0	3
	WAT_GS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
	WAT_BP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	WAT_BS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
Sei whales	WAT_HZ	7	30	4	1	0	1	10	21	19	8	15	18	10	19	6	0	169
	WAT_OC	5	25	1	0	1	0	4	4	19	9	20	19	13	14		0	134
	WAT_NC	8	13	1	1	0	1	6	7	18	8	24	26	13	18		0	144
	WAT_BC	7	7	0	0	0	1	1	17	15	7	12	27	19	15	0	0	128
	WAT_WC	8	2	0	0	0	1	0	6	10	6	6	21	26	3	1	0	90
	WAT_GS	0	0	0	0	0	0	0	3	9	4	2	0	0	0	0		18
	WAT_BP	0	0	0	0	0	0	2	6	10	2	1	1	0	0	0	0	22
	WAT_BS	0	0	0	0	0	0	1	9	9	1	0	0	0	0	0		20
	Sum of blue whale days	0	0	0	2	50	114	111	75	63	84	72	15	0	0	0	0	586
	Sum of fin whale days	6	0	0	18	77	131	134	149	154	177	137	121	21	2	0	14	1141
	Sum of right whale days	0	1	1	0	0	0	0	0	0	0	0	1	1	6	1	0	11
	Sum of sei whale days	35	77	6	2	1	4	24	73	109	45	80	112	81	69	7	0	725

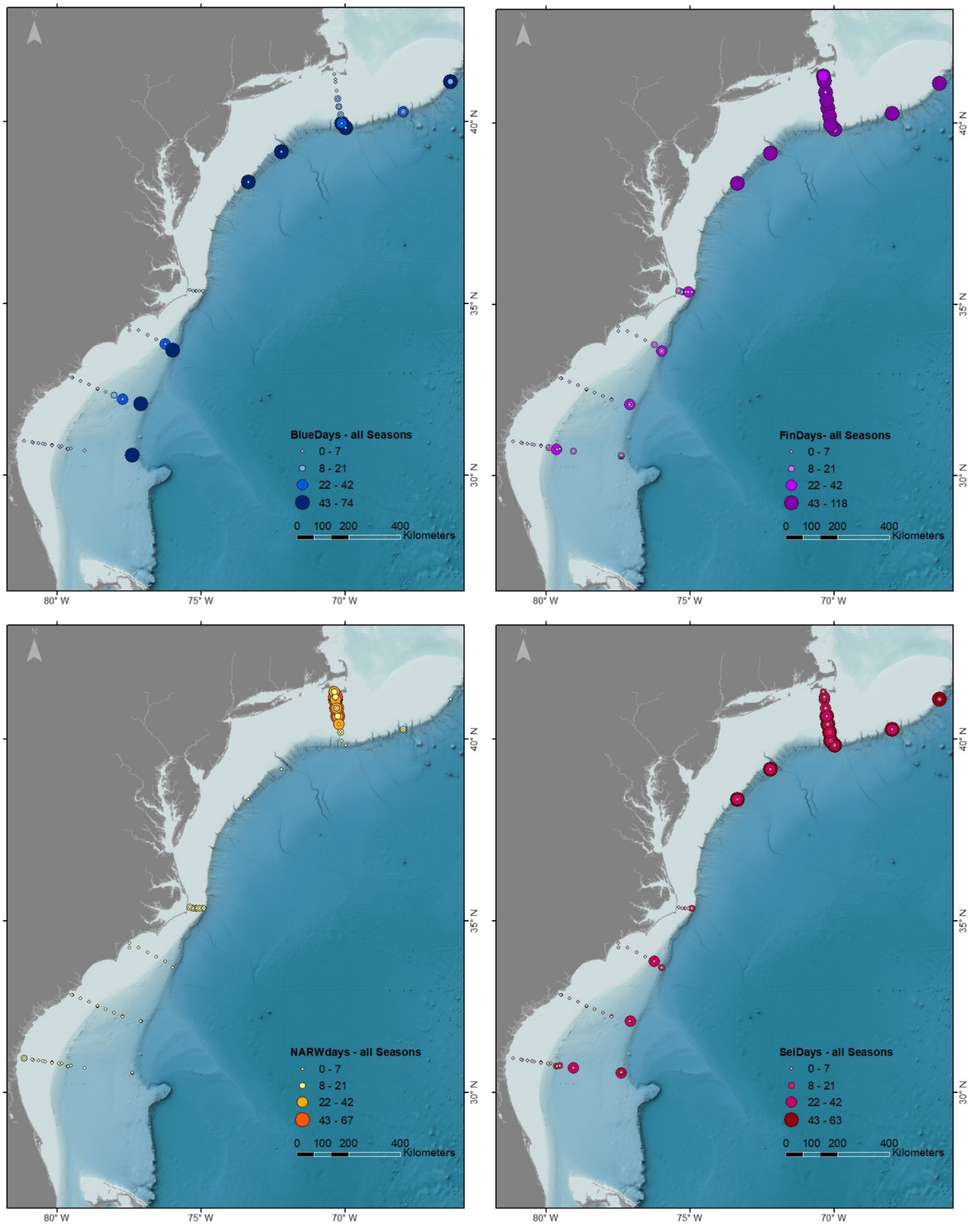

Figure 3. *Spatial distribution of acoustic detections for blue, fin, right and sei whales, for all data analyzed to date (up to 2017 or 2018, depending on site). The size of the circle indicates the number of days with acoustic detections; note that the maximum number of days varies between species.*

II. Improving automated classification for beaked whales &
III. Assessing effects of anthropogenic noise on beaked whale vocal activity

The beaked whale click-level classification for the US Navy site required a total of 3 months of manual editing of 2,089 acoustic encounters and one month for the sonar detections, not including the upkeep of trouble-shooting of computing irregularities. We have partially detected and classified beaked whale echolocation clicks at 1-minute granularity for US Navy sites NFC and JAX (Table 1). We evaluated the network-based classifier's performance at site NFC for two years of data (2016-2018). The results have been presented at a virtual poster symposium (see http://sael.ucsd.edu/posters.html, poster: Evaluation of a Neural Network for Automated Classification of Beaked Whale Echolocation Clicks). We are in the process of refining the network-based classifier to improve the click-level classification for beaked whale species at the remaining Atlantic sites and finalizing the MFA sonar detections and ping measurements (**Table 2**).

Statistical Analysis - Data exploration

We explored the relationship between the presence of beaked whale species and each of the candidate explanatory covariates. To get an idea of the different explanatory covariates' predictive power, we looked at the presence/absence of all species of beaked whales in relation to each explanatory covariate (Figure 1 and 2). Three species of beaked whales (Cuvier's, Sowerby's and Gervais' beaked whale) were detected with high enough acoustic densities at site NFC only (Table 2), which allowed for exploratory analysis and will lead to final statistical models.

The three species showed considerable inter-annual variability, seasonality, and diel patterns (**Figure 4).** However, Sowerby's and Gervais' beaked whale had more similar diel and seasonal patterns to each other compared to Cuvier's beaked whale. The three species had a higher presence with increasing time since cessation of sonar use (sonar lag) and lower presence with increasing peak-to-peak received levels of sonar (max RL_{pp}) and cumulative SEL (cumSEL) **(Figure 5).**

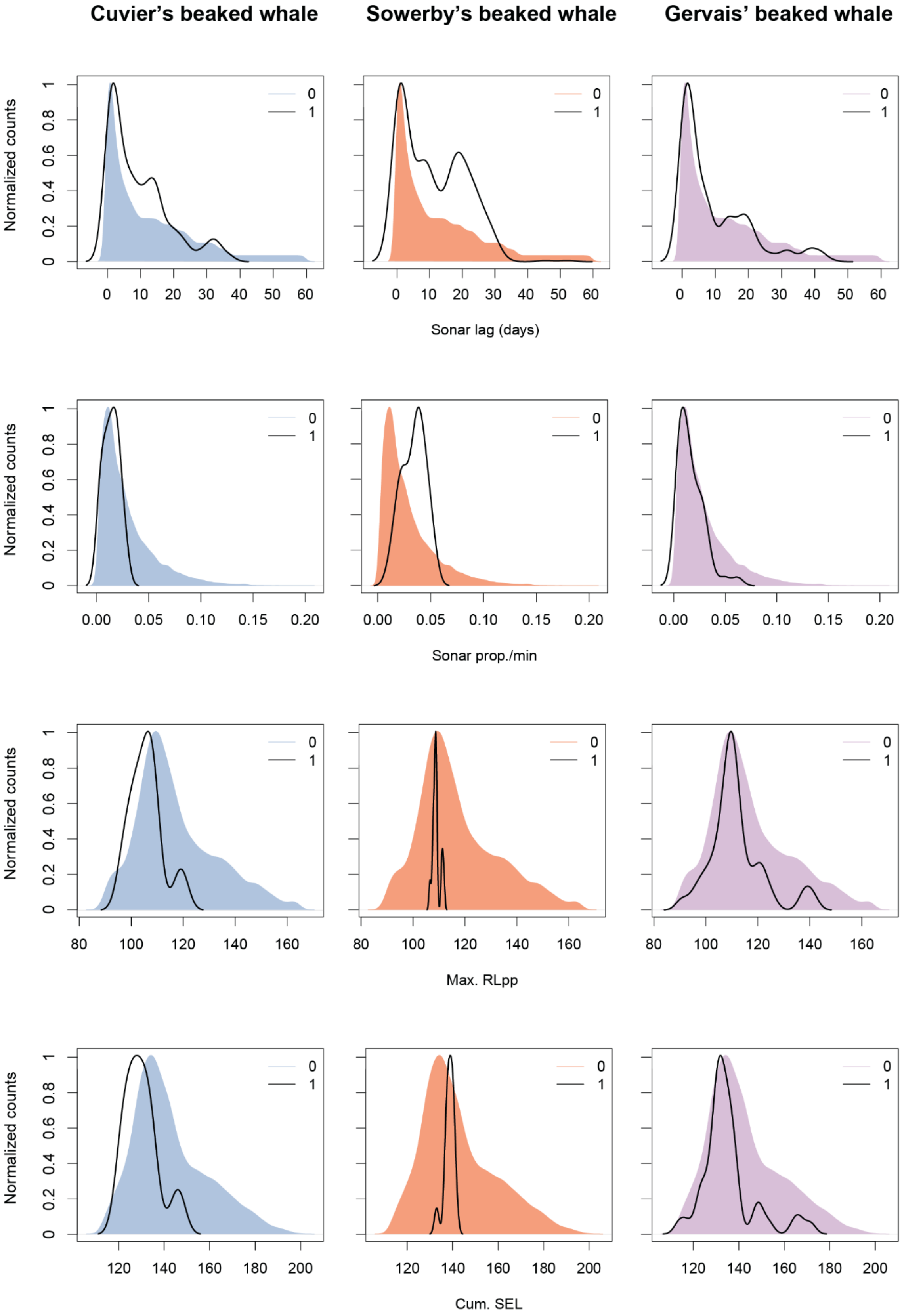

Figure 4. *Acoustic kernel densities of presence/absence (1/0) of beaked whale click types in 1-minute segments to each sonar-related explanatory covariate. Shaded color shows the distribution of each covariate when beaked whales were absent, and solid black line indicate the distribution when beaked whales were present.*

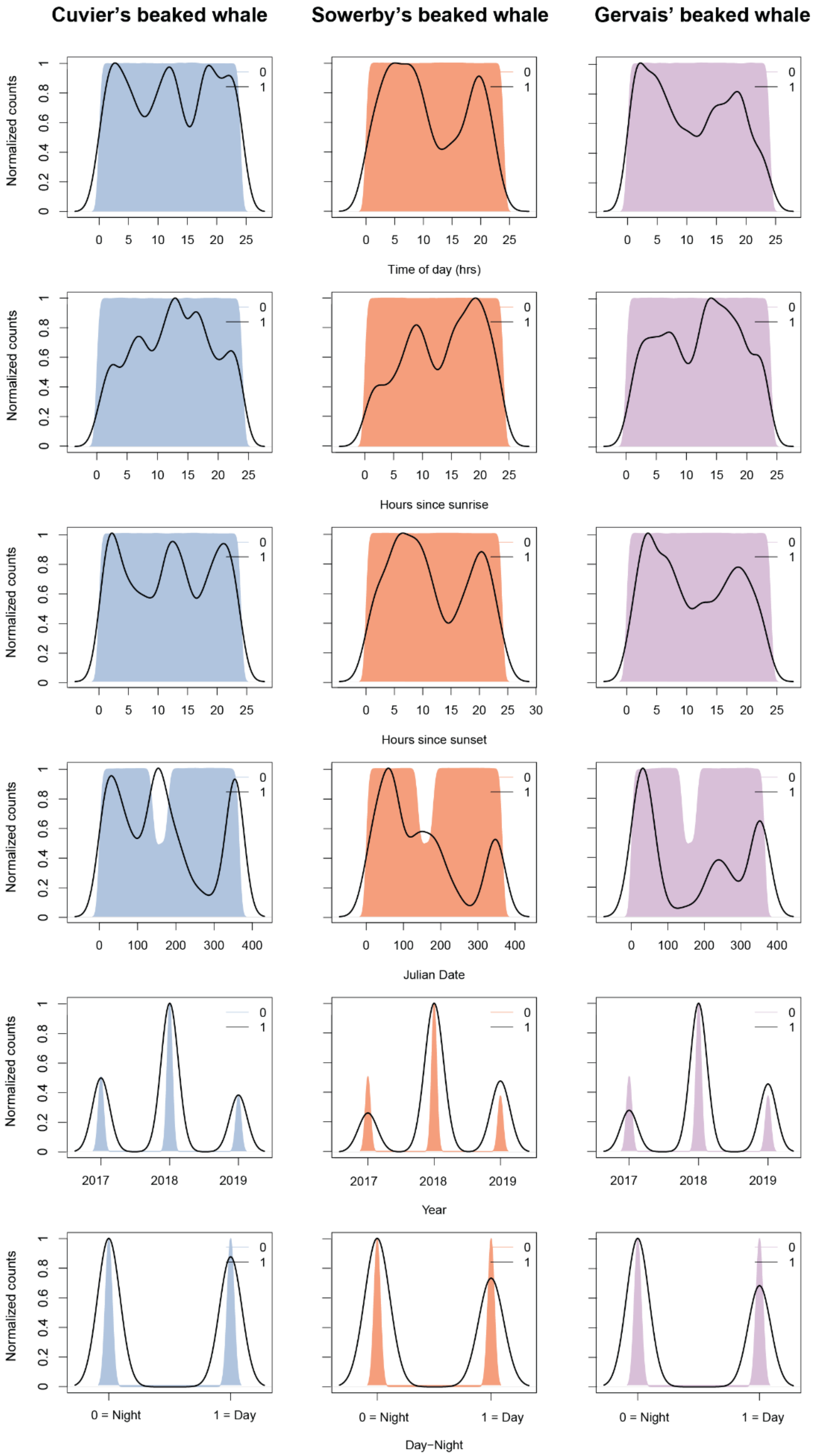

Figure 5. *Acoustic kernel densities of presence/absence (1/0) of beaked whale click types in 1-minutes segments to each non sonar-related explanatory covariate. Shaded color shows the distribution of each covariate when beaked whales were absent, and solid black line indicate the distribution when beaked whales were present.*

VI. Assessing the prevalence of seismic survey noise along the eastern seaboard

Preliminary analyses have revealed detected airgun signals at all 8 HARP sites, from Heezen Canyon to Blake Spur. In the first full month of deployment (May 2016), we detected airguns nearly the entire month (30/31 days) at Heezen, Oceanographer, Babylon and Wilmington Canyon areas**.** Airgun detections were consistently high across all sites north of Cape Hatteras, NC with some similarly high months of activity at the sites south of Cape Hatteras, NC. The daily occurrence of airgun noise for the first 6 months of the 2016 HARP deployment can be seen in Table 5.

Table 5. *Daily presence of airguns from April to September 2016 at HARP sites. For each site and month, we show the number of days with at least one airgun detection per number of analysis days, and the corresponding percentage of days with airguns present.*

Site	HZ	OC	NC	BC	WC	GS	BP	BS
Apr 2016	9/10 (90%)	7/7 (100%)	9/10 (90%)	10/11 (91%)	11/11 (100%)	0/2 (0%)	1/3 (33%)	0/4 (0%)
May 2016	30/31 (97%)	30/31 (97%)	26/31 (84%)	30/31 (97%)	30/31 (97%)	29/31 (94%)	28/31 (90%)	9/31 (29%)
Jun 2016	20/30 (67%)	21/30 (70%)	15/30 (50%)	20/30 (67%)	23/30 (77%)	25/30 (83%)	25/30 (83%)	21/30 (70%)
Jul 2016	22/31 (71%)	23/31 (74%)	25/31 (80%)	22/31 (71%)	22/31 (71%)	20/31 (65%)	14/31 (45%)	21/31 (68%)
Aug 2016	24/31 (77%)	16/31 (52%)	22/31 (71%)	24/31 (77%)	27/31 (87%)	3/31 (10%)	4/31 (13%)	4/31 (13%)
Sep 2016	27/30 (90%)	5/30 (17%)	11/30 (37%)	25/28 (89%)	23/28 (82%)	2/30 (7%)	1/2 (50%)	1/30 (3%)

In addition, analyses of the pauses in airgun activity have revealed that the majority of seismic survey events are detected across more than one HARP site. For the period 2 May to 14 June 2016, a total of 266 acoustic gaps were analyzed across sites. Nearly half (45%) were detected on 5 or more sites. At least 10 events co-occurred across all HARP sites, indicating we could acoustically detect the same seismic surveys across nearly the entire U.S. eastern seaboard (**Table 6**). Full analyses of the 2016-2017 deployment are ongoing.

Table 6. *Results from preliminary analysis of airgun events across HARP sites.The number of distinct acoustic seismic survey events (sudden stops and starts) that could be aligned across HARP sites from May 2nd - June 14th 2016.*

Number of HARPs	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Number of events detected	70	29	27	18	36	30	46	10

V. Novel broad-scale approach to assessing acoustic niche and anthropogenic contributors, and assessing the utility of new acoustic metrics

From the WAT_HZ 2017-2018 dataset, nearly 700 one-minute clips were reviewed for baleen whale presence. A total sample of more than 100 one-minute clips were recorded for Species Richness (SR) levels 0, 1, and 2, but not for 3 (Table 7). A total of 5 unique baleen whale species are represented in the SR 1 clips. While fin whale song comprised the majority of the SR 1 samples, other baleen whale species (blue, sei, humpback, and North Atlantic right whales) were also represented within the SR 1 category (**Figure 5).** Seven unique combinations of baleen whales were found in the clips analyzed for SR 2, with blue and fin whales comprising slightly more than two-thirds of the SR 2 samples (**Figure 6**). 55 one-minute clips were found with SR 3. This was the highest SR level found in the analyzed clips, and was either fin, blue, and sei whales, or fin, blue, and humpback whales (**Figure 6**).

Table 7. *Species Richness Level for Number of one-minute samples analyzed from the Heezen Canyon HARP deployed from June 2018 - May 2019.*

Species Richness Level	Number of one-minute clips analyzed
0	234
1	242
2	164
3	55

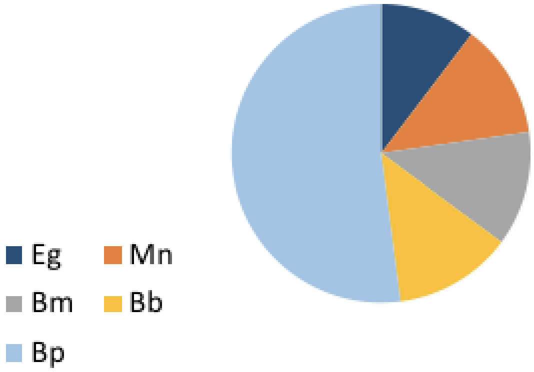

Figure 5. *Number of unique species (Eg=25, Mn=30, Bm=30, Bb=31, Bp=126) comprising species richness level 1 from analyzed one-minute samples (n=695) from a HARP deployed in Heezen Canyon from June 2018 – May 2019.*

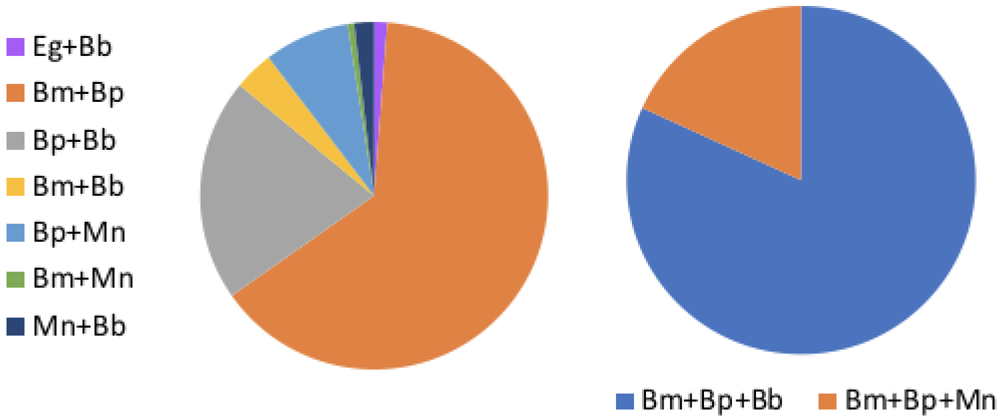

Figure 6. *(left panel) Number of unique species combinations (Eg+Bb=2, Bm+Bp=105, Bp+Bb=34, Bm+Bb=6, Bp+Mn=13, Bm+Mn=1, Mn+Bb=3) comprising species richness level 2. (right panel) Number of unique species combinations (Bm+Bp+Bb=45, Bm+Bp+Mn=10) comprising species richness level 3 from analyzed one-minute samples from the Heezen Canyon HARP.*

All clips were sent to Irene T. Roca to be analyzed and to run the Acoustic Metrics based on a previous study (Roca & Van Opzeeland 2019). A total of 24 different acoustic metrics were computed to characterize the acoustic space from each recording. The accuracy of the classification model to predict SR levels using acoustic metrics is low (58%), and model accuracy for determining species identities varies by species. For blue whale, model accuracy was high to detect blue whale absence (7.8% error rate), but not as accurate detecting presence (43% error rate). Similarly for humpback whales and sei whales, the model accuracy was high for detecting absence (1.9% error rate, 1.6% error rate, respectively) but very low for detecting presence (82% & 83% error rate, respectively). The model performed better for fin and North Atlantic right whales, with higher model accuracy for both absence (12% & 0.1% error rate, respectively) and presence (15% error rate for both). While the Acoustic Metric model accuracy was high for determining species absence, it only performed well to determine North Atlantic right and fin whale presence. Humpback whale song, when present, was soft and the ambient noise levels were high, which may have led to low accuracy; blue whale song may have been difficult to distinguish in the presence of vessel noise. To see if the model performs better in an environment with potentially both louder whale song and higher species richness levels, we are compiling a new groundtruth dataset on one coastal MARU recording dataset for comparison. This work is ongoing.

Finally, in June 2020, we submitted the following manuscript for review at Marine Policy:
Weiss SG, Cholewiak D, Frasier KE, Trickey JS, Baumann-Pickering SM, Hildebrand JA, Van Parijs SM. Monitoring the acoustic ecology of the shelf break of Georges Bank, Northwestern Atlantic Ocean – new approaches to visualizing complex acoustic data.
This manuscript includes the initial results from the deployment of three HARPs in 2015-2016, which were presented in our FY19 annual report. Delays due to COVID-19 have resulted in a lengthy review process.

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Extra Figures in case we need them:

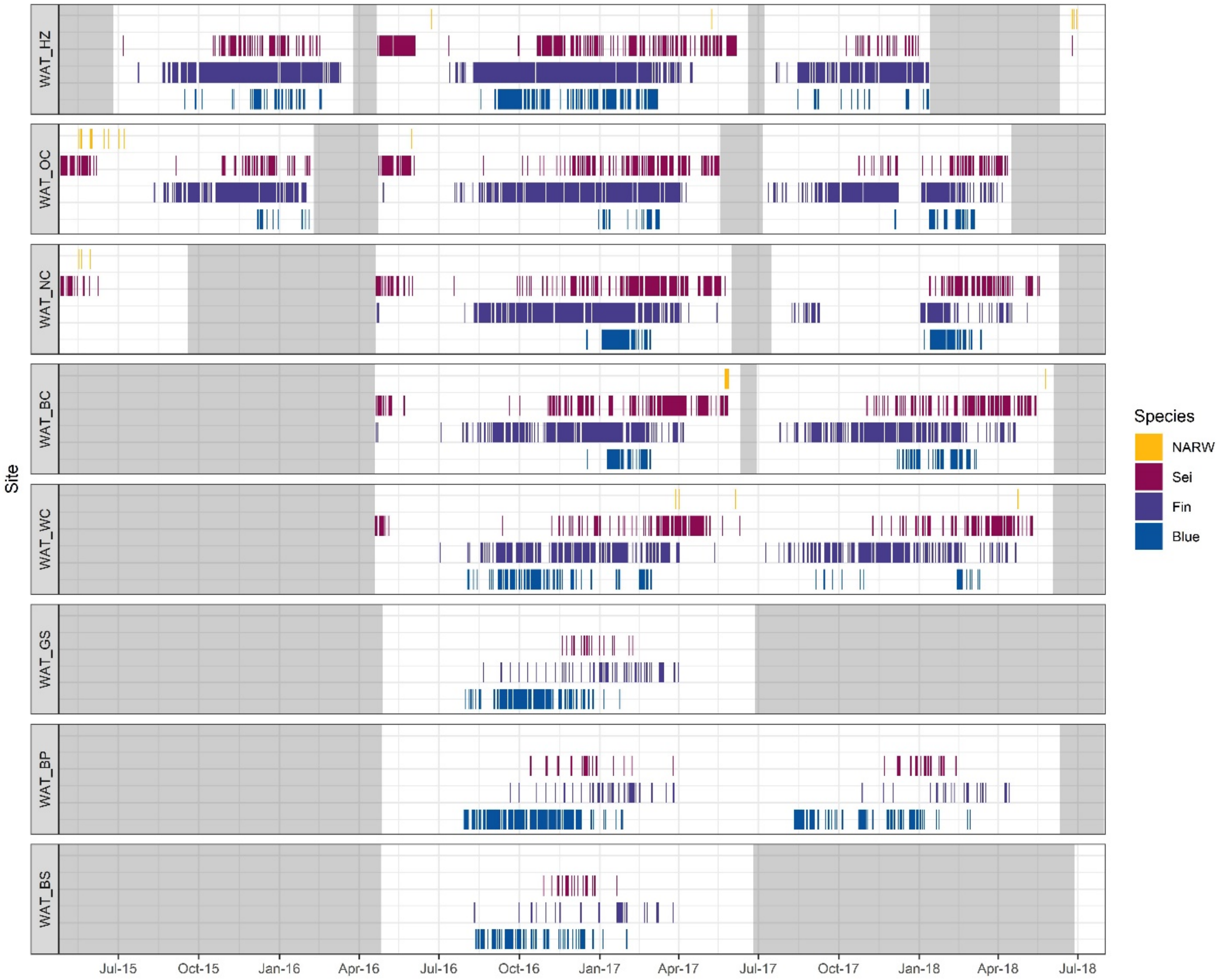

Figure X. Daily presence of four baleen whale species by HARP site from 2015-2018. HARP sites are labelled from north to south, starting with Heezen Canyon and ending with Blake Spur. See Figure 7-10 for more information on location. North Atlantic right whales are shown in gold, sei whales in red, fin whales in purple, and blue whales in blue. Grayed out areas indicate periods where no data were collected or where analyses have not yet been conducted.

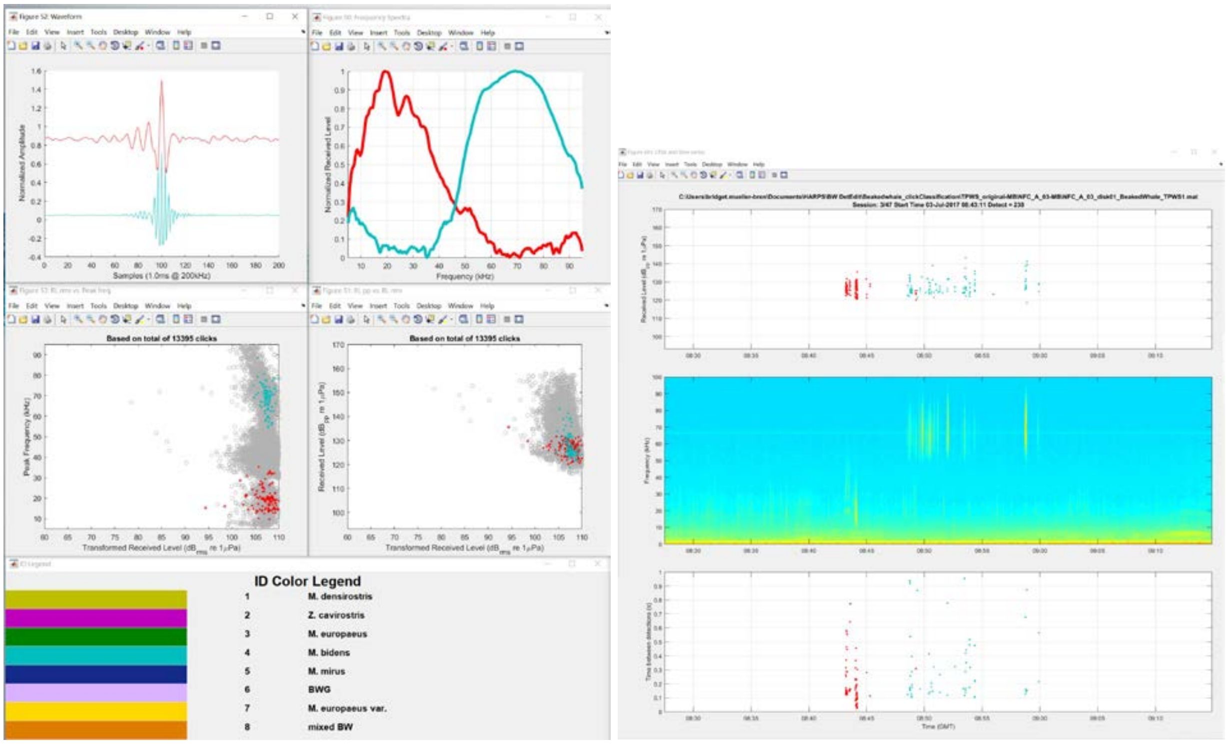

Figure 2a&b. An example of the detEdit screens depicting Sowerby's clicks (cyan) and the removal of dolphin clicks (red). A trained analysis uses information from all of these graphs - a waveform, spectrum, received level over time, and transformed received level vs peak frequency and received level (**a**), and received level, frequency (LTSA) and interclick interval all over time (**b**) - to determine which clicks to keep and which to remove. This example is taken from NFC on 3 Jul 2017.