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

FY 2023 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 2015-2019, 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.

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 datasets collected from 2015-2019. The focus of our efforts in 2023 have been to finalize projects for submission to peer-reviewed journals, and further develop community composition analysis techniques to explore dissimilarity and species co-occurrence across shelf break areas.

Objectives

The work this year was aimed at finalizing components for these key objectives:

I. Submit a manuscript describing the methodology of the beaked whale neural net classifier to be cited in future publications utilizing this approach
II. Submit a manuscript comparing and contrasting two passive acoustic monitoring methodologies - towed array and shelf break HARPs - concerning beaked whale temporal, spatial presence and diving behavior.
III. Utilize passive acoustic data from ten shelf-break environments to evaluate composition and dissimilarity of marine mammal community groups at different latitudes.

Acoustic Data Collection

Both the NEFSC and the U.S. Navy collected continuous passive acoustic recordings along the Atlantic continental shelf break of the United States at eleven sites beginning in 2015. The sites deployed in 2015 include Heezen Canyon, Oceanographer Canyon, and Nantucket Canyon (three 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 band pass filter. Further details of HARP design are described in Wiggins & Hildebrand (2007).

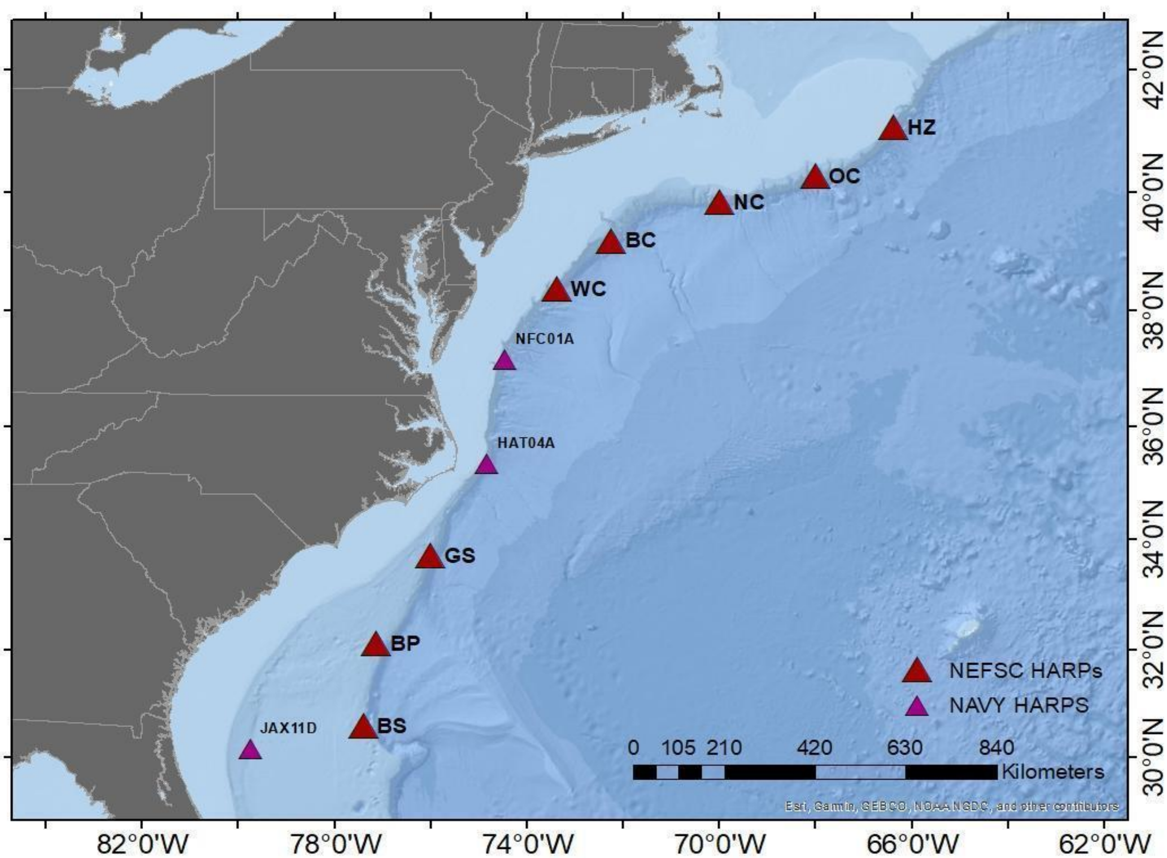

Figure 1. HARP deployment sites for data collected from 2015 through 2019.

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

Analyses

I. Utilize passive acoustic data from ten shelf-break environments to evaluate composition and dissimilarity of marine mammal community groups at different latitudes.

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 multispecies groups throughout the shelf break data.

Code was provided by Professor Hillebrand at the University of Bremen in Grmany, and further developed to explore species richness and community dissimilarity, in addition to conditional inference trees and acoustic niche plots to explore baleen and odontocete species relationships over space (10 HARPs) and time (3 years: 2016 to 2019).

Additionally, multi-year patterns and trends were summarized for each species and site using a modified acoustic niche analysis to visualize when and where specific species are acoustically detected. The "acoustic niche" of each species is also visualized as approximate vocalization range for each species differentiates species that are low-frequency specialists (e.g., blue whales) from species that are high-frequency specialists (e.g. Gervais' beaked whale). In separating the acoustic presence of individual species, the acoustic niche analysis illustrates the species that comprise marine mammal communities at each site.

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 (Solsona Berga et al. *submitted*) to a confidence threshold of 0.99. Below we present new results from data collected at ten HARP sites between 2016 to 2019 as presented by Dr. Samara Haver as an invited speaker at the Ecological Society of America Special Session on Advancing Ecology and Conservation with Bioacoustics in August 2023 and in prep for submission to a peer-reviewed ecology journal (**Figures 2 & 3**).

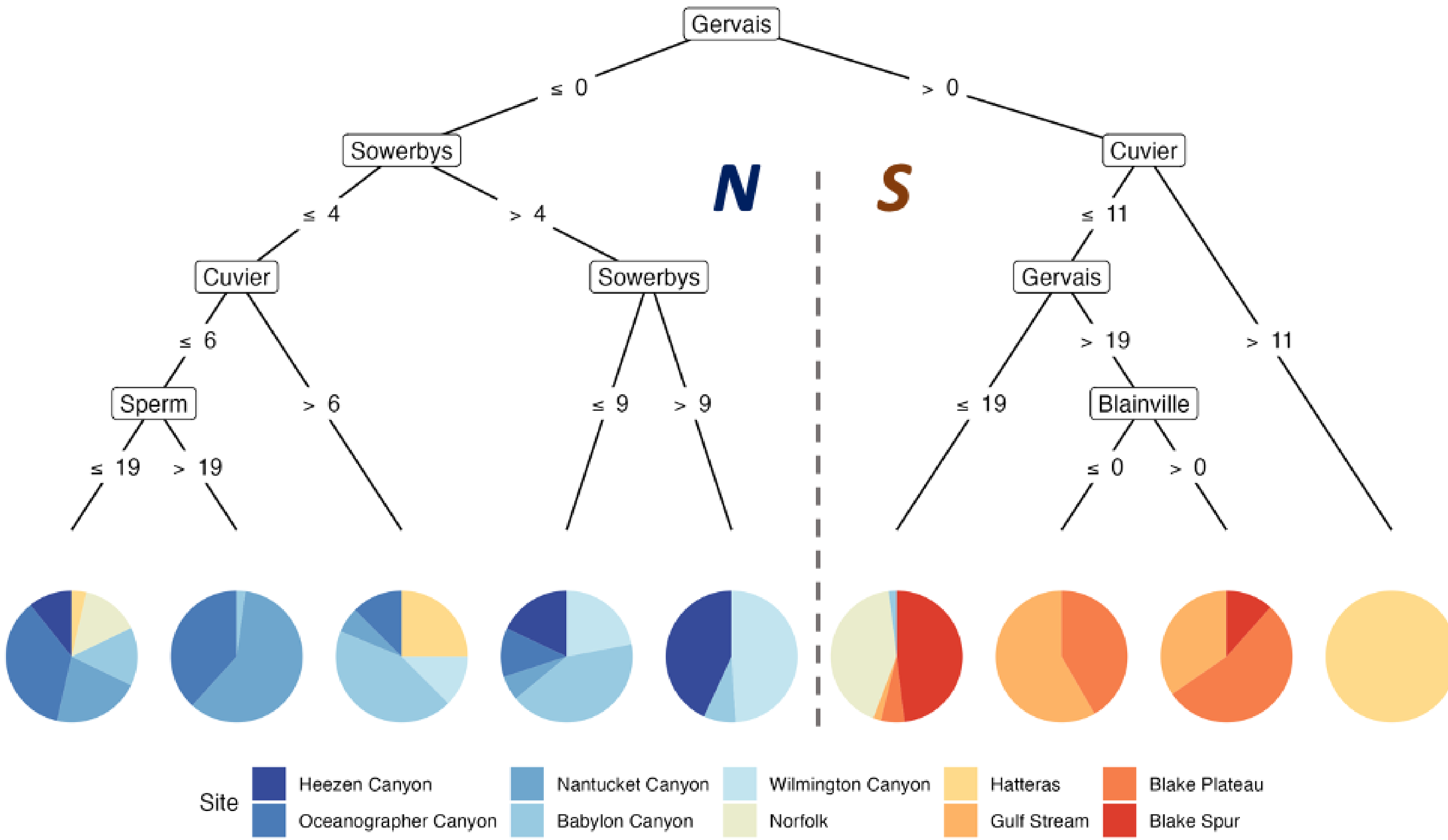

Figure 2 shows the conditional inference tree model results to compare the relative influence of certain species on community groups at different sites. Odontocete species drive the splits between sites indicating that their acoustic presence is a more significant factor in driving dissimilarity across sites compared to the more transitory migrating baleen whale species. In this plot, the presence of Gervais' beaked whale represented the root node and split sites by latitude in the Mid-Atlantic around Maryland and Virginia. Groupings of marine mammals in more northern sites are indicated by shades of blue, while groups at sites to the south are shown in warm/red colors.

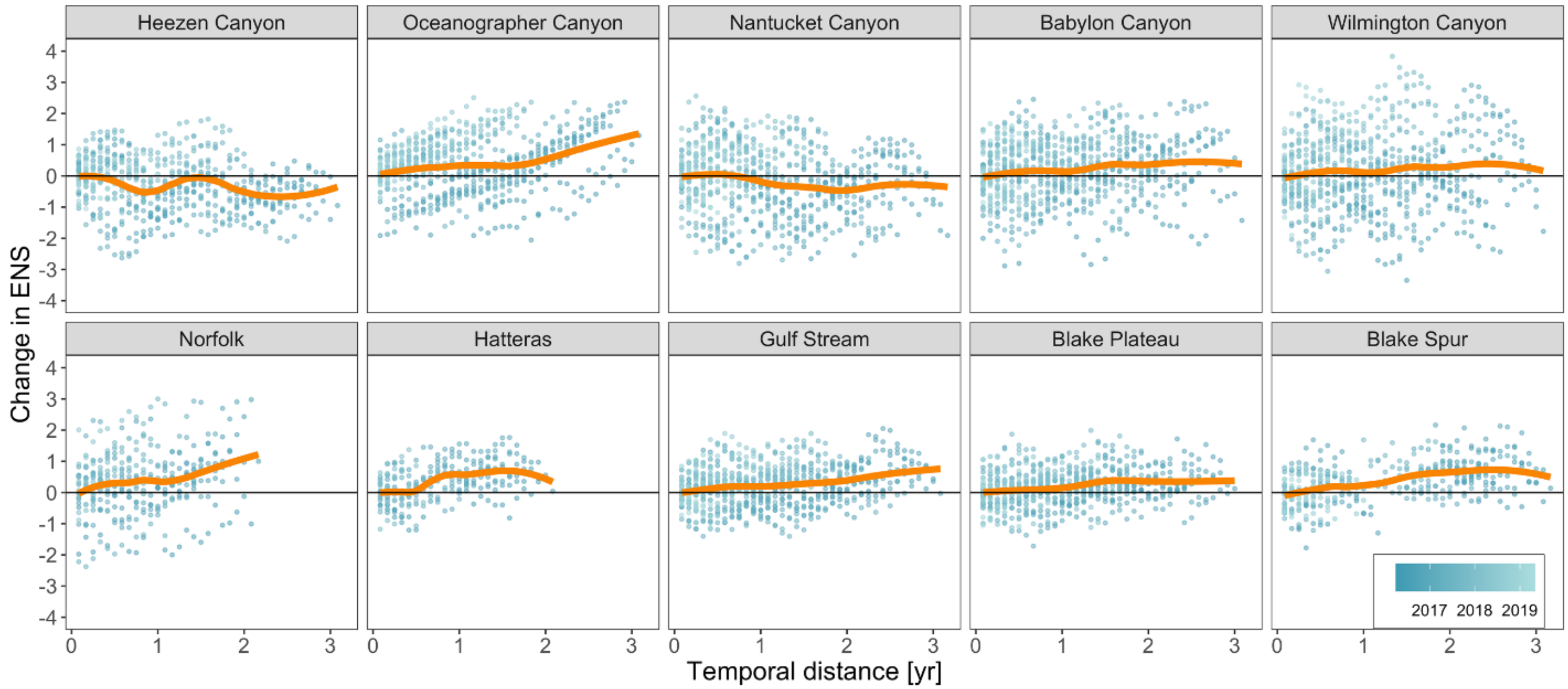

Figure 3 shows the variability in the effective number of species (ENS) detected at each site over time. Specifically, each blue dot represents the change in number of days per month that a single species was detected compared to the previous month. The variability at each site indicates trends of species joining or leaving certain areas; sites with a wider range of ENS change have more turnover and change in community composition throughout the year compared to sites with more consistent community size.

Submitted analyses for publication

I. Machine learning with taxonomic family delimitation aids in the classification of rare and ephemeral beaked whale events in passive acoustic monitoring

A methods paper describing the beaked whale neural net classifier built for North Atlantic HARP data was submitted to Methods in Ecology and Evolution and is currently in review. The abstract from this submission is below.

Passive acoustic monitoring is an essential tool for studying beaked whale populations. This approach can monitor elusive and pelagic species, but the volume of data it generates has overwhelmed researchers' ability to quantify species occurrence for effective conservation and management efforts. Automation of data processing is crucial, and machine learning algorithms can rapidly identify species using their sounds. Beaked whale acoustic events, often infrequent and ephemeral, can be missed when co-occurring with signals of more abundant, and acoustically active species that dominate acoustic recordings. Prior efforts on large-scale classification of beaked whale signals with deep neural networks (DNNs) have approached the class as one of many classes, including other odontocete species and anthropogenic signals. That approach tends to miss ephemeral events in favor of more common and dominant classes. Here, we describe a DNN method for improved classification of beaked whale species using an extensive dataset from the western North Atlantic. We demonstrate that by training a DNN to focus on the taxonomic family of beaked whales, ephemeral events were correctly and efficiently identified to species, even with few echolocation clicks. By retrieving ephemeral events, this method can support improved estimation of beaked whale occurrence in regions of high odontocete acoustic activity.

II. Niche partitioning of beaked whales in the western North Atlantic Ocean using passive acoustics

Acoustic data from the 2016 HARP deployments were combined with passive acoustic data collected from a towed hydrophone array as part of the Atlantic Marine Assessment Program for Protected Species (AMAPPS) to examine niche partitioning of beaked whales in the western North Atlantic. This project was submitted to Marine Ecology Progress Series and is currently undergoing revisions. The abstract for this project is below.

Beaked whales (family Ziphiidae) are cryptic, deep diving cetaceans found offshore. Passive acoustic monitoring of this family allows identification to species and is instrumental in expanding knowledge of their behavior, distribution, and habitat use. From 28 June – 25 August 2016, two broadscale shipboard surveys towed a hydrophone array in the western North Atlantic. Concurrently, 11 bottom-mounted recorders collected continuous passive acoustic data during July and August 2016 along the 1,000 m contour. Five beaked whale species (Cuvier's [Ziphius cavirostris], Gervais' [Mesoplodon europaeus], True's [M. mirus], Sowerby's [M. bidens], and Blainville's [M. densirostris] beaked whales) were present in both datasets. Beaked whales were commonly detected at the bottom-mounted sites (71% total days present), with sites off the United States' Mid-Atlantic Bight containing the greatest species diversity. Using the towed array, Blainville's and Gervais' were found in the Gulf Stream, True's were more commonly found in abyssal waters, and Sowerby's were more common on the continental slope. Cuvier's were present throughout the survey area. Using multipath reflections, click depths were examined for 192 beaked whale events. Among three species tested (Cuvier's, Gervais', and True's), only Cuvier's were found to forage in proximity to the estimated seafloor depth. Combining these datasets expanded our understanding of these species' ranges, identified possible hotspots for True's and Gervais', and demonstrated the importance of placement for bottom-mounted instruments. This is the first study of its kind to provide a comprehensive view of how these whales exhibit niche partitioning over a large area and at depth.

Conference presentations

DeAngelis, A. I., Westell, A., Corkeron, P., Solsona Berga, A., Trickey, J., Rafter, M., Baumann-Pickering, S., Cholewiak, D., Soldevilla, M., Bell, J., Van Parijs, S. "Niche partitioning of beaked whales (family *Ziphiidae*) during the summer in the western North Atlantic." Presented at the Ecological Society of America Conference, Portland, OR. (Also subsequently presented as a guest lecture for BioacousTalks virtual session hosted by Cornell University, and as part of a seminar at UMASS Dartmouth)

Haver, S.M., Corkeron, P., Baumann-Pickering, S., Cholewiak, D., Davis, G., DeAngelis, A., Frasier, K., Posdaljian, N., Rafter, M., Solsona Berga, A., Westell, A., Van Parijs, S.M. (2023, Aug). Eavesdropping on multi-species marine mammal communities along the western North Atlantic Ocean shelf-break. Presented at the Ecological Society of America, Portland, OR.

References

Davis GE, Baumgartner MF, Bonnell JM, Bell J, Berchok C, Bort Thornton J, Brault S et al. 2017. "Long-term passive acoustic recordings track the changing distribution of North Atlantic right whales (*Eubalaena glacialis*) from 2004 to 2014". *Scientific reports* 7, 1: 1-12.

Solsona Berga, A., DeAngelis, A.I., Cholewiak, D.M., Trickey, J.S., Mueller-Brennan, L., Frasier, K.E., Van Parijs, S.M., and Baumann-Pickering, S. *Submitted*. "Machine learning with taxonomic family delimitation aids in the classification of ephemeral beaked whale events in passive acoustic monitoring". PLOS One.

Stanistreet JE, Nowacek DP, Baumann-Pickering S, Bell JT, Cholewiak DM, Hildebrand JA, Hodge L, Moors-Murphy HB, Van Parijs SM, and Read AJ. 2017. "Using passive acoustic monitoring to document the distribution of beaked whale species in the western North Atlantic Ocean". *Canadian Journal of Fisheries and Aquatic Sciences* 74: 2098-2109.

Stanistreet JE, Nowacek DP, Bell JT, Cholewiak DM, Hildebrand JA, Hodge LE, Van Parijs SM and Read AJ. 2018. "Spatial and seasonal patterns in acoustic detections of sperm whales Physeter macrocephalus along the continental slope in the western North Atlantic Ocean". *Endangered Species Research* 35:1-13.

Van Opzeeland, I., and Boebel, O. 2018."Marine soundscape planning: seeking acoustic niches for anthropogenic sound." *Journal of Ecoacoustics* 2.5GSNT.

Van Opzeeland, I. and Hillebrand, H. 2020 "Year-round passive acoustic data reveal spatio-temporal patterns in marine mammal community composition in the Weddell Sea, Antarctica." *Marine Ecology Progress Series* 638 (2020): 191-206.

Weiss SG, Cholewiak D, Frasier KE, Trickey JS, Baumann-Pickering S, Hildebrand JA, Van Parijs SM. 2021. "Monitoring the acoustic ecology of the shelf break of Georges Bank, Northwestern Atlantic Ocean: New approaches to visualizing complex acoustic data". Marine Policy 130:104570.

Wiggins, S. M., & Hildebrand, J. A. 2007. "High-frequency Acoustic Recording Package (HARP) for broad-band, long-term marine mammal monitoring". In *2007 symposium on underwater technology and workshop on scientific use of submarine cables and related technologies* (pp. 551-557). IEEE.