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BOEM 2023-071

Spatial and Acoustic Ecology of Marine Megafauna (SPAM): Marine Mammal Passive Acoustics and Spatial Ecology (MAPS)

Marine Mammal
Passive Acoustics
& Spatial Ecology

U.S. Department of the Interior
Bureau of Ocean Energy Management
Sterling, VA

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DISCLAIMER

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ABOUT THE COVER

Cover photos were taken aboard the research vessel (RV) *Song of the Whale* during 2019 MAPS research cruises. On the left are two breaching Gervais' beaked whales (*Mesoplodon europaeus*). On the right are three sperm whales (*Physeter macrocephalus*), one of which had been tagged with a DTAG. The survey efforts were carried out under NOAA permits 14809-03 (Duke University) and 16473 (University of North Carolina Wilmington [UNCW]).

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List of Abbreviations and Acronyms

AIC	Akaike's Information Criterion
AMAPPS	Atlantic Marine Assessment Program for Protected Species
BOEM	Bureau of Ocean Energy Management
CABLE	Cachalot Automatic Body Length Estimator
CATS	Customized Animal Tracking Solution
CDVS	Center for Data Visualization Sciences
CI	confidence interval
CINMS	Channel Islands National Marine Sanctuary
CV	coefficient of variation
DSM	density surface modeling
DTAG	digital acoustic recording tag
eDNA	environmental DNA
EShW	effective strip half width
HARP	High-frequency Acoustic Recording Package
GAM	generalized additive model
GE	growth equation
GMM	gaussian mixture model
HARPS	High-frequency Acoustic Recording Packages
ICI	inter-click interval
IPI	inter-pulse interval
IR	infrared
MAPS	Marine Mammal Passive Acoustics and Spatial Ecology
MCDS	multiple covariates distance sampling
MCR	Marine Conservation Research
MGEL	Marine Geospatial Ecology Lab (Duke University)
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
OBIS-SEAMAP	Ocean Biodiversity Information System-Spatial Ecological Analysis of Megavertebrate Populations
OCS	Outer Continental Shelf
PAM	passive acoustic monitoring
PCR	polymerase chain reaction
RV	research vessel
SD	standard deviation
SST	sea surface temperature
TMA	target motion analysis
UNCW	University of North Carolina Wilmington
USECGOM	Unites States Atlantic and Northern Gulf of Mexico
VHF	very high frequency
WAV	Waveform audio file format

Preface: A Note on "Citizen Science"

A major component of this project pertains to citizen science. We recognize that in recent years this term has come into question as potentially exclusionary, by implying that a person's legal status regarding citizenship is a prerequisite for participating in voluntary scientific projects.

When the term was first coined in the 1990s to describe public involvement and contributions to scientific research, "citizen" was a collective term for volunteer participants who gave their time and talents, in the context of "a good citizen" and referring to the quality of an individual's actions for the support and betterment of their community, not their legal standing.

We understand that times change, and with it the meanings of certain terms. We also recognize the abundance of literature, theory, and policy upon which our present work is founded that identifies this concept as "citizen science," and feel that it would be a disservice to the readers of this report to abruptly change terminology, particularly since with *what* to replace "citizen science" is still very much a topic of debate.

We are keenly aware of the tremendous value that all people can bring to the pursuits of science that benefit all of us and our planet. As a result, we are eager for ongoing engagement with this issue, to arrive at inclusive ways of naming that which we as scientists highly value.

1 Introduction

The Marine Mammal Passive Acoustics and Spatial Ecology (MAPS) project was initiated to gather cetacean data and to establish a framework for providing critical marine species data that will enable BOEM to make more informed decisions relevant to its mission. The study primarily focused on pelagic deep-diving cetaceans in the Atlantic but was envisioned more broadly as a project to understand marine species in a way that informs all BOEM programs and regions. As such, the ultimate goal was to develop methods and technologies to gather information on species distribution, movement, and ecology—information critical to meeting requirements under numerous Federal statutes (e.g., the Marine Mammal Protection Act, Endangered Species Act, and National Environmental Policy Act).

The MAPS project comprised four components: visual and passive acoustic monitoring (PAM) of cetaceans across a section of the Mid-Atlantic Outer Continental Shelf (OCS), improvements to open-source tag visualization software, streamlining of citizen science data-gathering technologies, and communication and outreach efforts.

Recognizing that we cannot fully understand the impacts of offshore wind energy development and other OCS activities under BOEM's purview on marine species unless we first understand the species themselves, PAM is used regularly in BOEM-regulated activities as a monitoring and mitigation tool, and BOEM has already invested significant resources in a number of baseline surveys and PAM studies. The MAPS project components collectively aimed to allow BOEM to better leverage data we already have, as well as the data we are currently collecting and anticipate collecting in the future.

We anticipated that this project would strengthen BOEM decision-making through environmental reviews that are based on the best available scientific information and would yield innovative and meaningful approaches to assess risk and comply with environmental laws and regulations. It would also allow BOEM to describe environmental risks transparently to all audiences (e.g., decision-makers, stakeholders, and the general public) through purposeful stakeholder engagement. The MAPS project provides an opportunity to develop national-level guidance and best practices for rigorous environmental analyses. We viewed the MAPS project as "Science for Informed Decisions."

1.1 Research Component: Visual and Passive Acoustic Monitoring Vessel Surveys Across the OCS from South Carolina to Virginia

Marine mammals occur throughout the Mid- and South-Atlantic regions of the US East Coast, and they are of particular concern because of their protected status (through the Marine Mammal Protection and Endangered Species Acts) and potential sensitivities to human activities such as geophysical and geotechnical surveys, marine construction, commercial shipping, naval activity, research, and fishing. Significant data gaps exist for acoustic cue (calling) rates of OCS cryptic species, such as deep divers, and/or understudied species of concern.

In this study, we used vessel based and animal-borne technology to sample these species of concern along the shelf-break area off the coast of Virginia, North Carolina, and South Carolina. Our study area off the coast of North Carolina contains the highest diversity of cetaceans of any other location within the US Exclusive Economic Zone (Roberts et al. 2016 and see maps at http://seamap.env.duke.edu/models/Duke-EC-GOM-2015/), making it both a region of scientific interest and special management concern.

With our partners, existing visual survey and PAM data were examined to identify the specific spatial and temporal gaps in our knowledge of the OCS species that would be targeted for the MAPS project. The

MAPS cruises were thus planned to occur in winter and spring, and to include areas beyond the continental shelf break. This work focused on, and successfully measured, the occurrence and other parameters of two deep diving groups that are of concern for anthropogenic disturbance: sperm whales (*Physeter macrocephalus*) and beaked whales (*Mesoplodon* spp. and *Ziphius cavirostris*). This study focused on marine mammal behavioral and acoustic ecology using PAM techniques and tagging of individual animals. PAM was conducted primarily using a towed hydrophone array from the RV *Song of the Whale* during the MAPS cruises, and supplementary stationary PAM data was incorporated to provide maximal temporal and spatial coverage to address the study's objectives. Several manuscripts describing these results have been produced, and this work has contributed data to ongoing occurrence and density modeling efforts with co-principal investigator Halpin and MGEL at Duke University.

The primary goals were to use both traditional and state-of-the-art methods to describe the acoustic, behavioral, and foraging ecologies of pelagic deep diving cetaceans; update uncertainty analyses; and verify or establish acoustic cue rates. Sea time was leveraged to explore the potential of collecting environmental DNA (eDNA) samples and thermal images of deep diving cetaceans. The specific objectives of this study included the following:

1. To utilize visual and PAM line transect surveys to collect high-quality data on cetaceans in the study area in winter and spring. These seasons were chosen after a research planning meeting and rigorous review of all existing survey data to fill temporal data gaps (for full details, see the research report at https://espis.boem.gov/Final%20Reports/BOEM_2019-058.pdf).
2. To deploy, when possible, DTAGs to directly measure the diving and acoustic behavior of the deep-diving sperm whale.
3. To utilize acoustic data to address availability bias (cue rates) to generate meaningful g(0) for acoustic line transect surveys for sperm whales.
4. To utilize acoustic detections to estimate density and abundance of cryptic cetacean species (beaked and sperm) in the survey area using both design-based estimates and Density Surface Modeling techniques.
5. To integrate PAM data into the OBIS-SEAMAP (Ocean Biodiversity Information System-Spatial Ecological Analysis of Megavertebrate Populations) information system for integration with other relevant data, archival, and dissemination.
6. To compare photogrammetry and acoustic methods to estimate the size of sperm whales encountered during 2019 surveys.
7. To explore the potential of refining acoustic localization techniques during surveys by deploying 3-D acoustic array in addition to linear array (carried out during spring 2019 surveys and dedicated July 2022 survey).
8. To collect samples that could be used to characterize cetacean presence in OCS waters using eDNA—a proof-of-concept project.
9. To collect infrared thermal images of deep divers over time to investigate changes in surface temperature with time at the surface.
10. To assist with broader research community's understanding of the behavior of deep-diving cetaceans by building upon existing development of open-source tag visualization software.

1.2 Build on Existing Development of Open-Source Tag Visualization Software

Software for the visualization of multi-sensor marine mammal dive tag data currently exists, but existing packages suffer from various weaknesses: (1) tag visualization packages are not well documented; (2) available software does not readily accept commonly used tag data formats; (3) packages are no longer under active development; and/or (4) software is no longer compatible with modern operating systems. The goal of the work proposed in this component of the MAPS program was to explore methods to enhance the tools for multi-sensor tag data visualization and analysis. This goal would be accomplished by building on best practices in cognitive science and, where possible, in collaboration with existing visualization software authors. A specific goal of this component of the program was to involve students directly in the process, by creating focused courses on tag visualization in the electrical and computer engineering department at Duke University.

1.3 Citizen Science Component

Citizen science leverages the involvement of volunteers in data gathering initiatives. Citizen scientists help to solve research challenges that are based in unmet, labor-intensive data collection needs. The principle enabling technologies that can allow for scaling of efforts across the US OCS for citizen science are smartphone apps and the internet, through which a distributed network of participants can record and share data and observations.

The citizen science component of the MAPS project was aimed at enabling cost-effective monitoring of marine species distribution and movement across vast areas of ocean. Dozens of apps for tracking and reporting ocean species are currently available, yet the existence of so many apps, usually family specific (e.g., birds, sharks, whales) and with divergent data repositories and data quality standards, hinders effective distribution and use of the data. Data and methodologies are often inconsistent and siloed, agencies and wildlife organizations reinvent the wheel with each new app, and the overabundance of apps leads to user burnout. The goal of this component was to develop a streamlined system that would connect multiple stakeholder groups and effectively disseminate authoritative data for use by scientists and resource managers across BOEM offices and between Federal agencies.

The overall strategy of the citizen science component was to

- Connect existing networks into a single “one-stop shop” for ocean species sightings
- Lay the foundation for a national observation network of partner Federal agencies and stakeholders
- Operationalize the resulting data and network for dynamic ocean management

The central technology was envisioned as Ocean Alert, a reconfiguration and expansion of the existing Whale Alert platform. Ocean Alert was planned to connect citizen scientists, agency scientists, and resource managers with streamlined sightings information and a platform for image management and distribution. Such a system would manifest through partnerships with government, non-governmental organizations, and industry partnerships; could accept incoming data (sighting reports and photos) across regions; could disseminate real-time, spatially appropriate situational awareness data,;and could serve as a tool for researchers and provide a robust experience for citizen scientist participants.

1.4 Communications and Outreach Component

A critical feature of the MAPS project was to ensure that its goals, accomplishments, and products were shared broadly across multiple communities, from local to global, including technical and nontechnical audiences, industry and scientific groups, and students and the general public. To this end, Ms. Imogen Scott, of Wilderness Communications, joined the team and developed a communications plan that was integrated into the research and citizen science components of the project. The specific communications products are described in the methods section and broadly included program fact sheets, infographics, videos, blogs, and a website. Results of this work have also been presented at scientific meetings, and work continues toward publishing in the scientific literature. We specifically targeted outreach and education opportunities to local organizations, with the goal of stimulating student interest and conversations about ocean science and motivating the next generation of marine scientists and engineers. Therefore, the communications plan was a vital component to our study and hopefully will serve as a foundation for future BOEM outreach efforts under the Environmental Studies Program and other programs and projects.

2 Methods

2.1 Research Component: Visual and Passive Acoustic Monitoring Vessel Surveys Across the OCS from South Carolina to Virginia

We conducted three research cruises to investigate the acoustic, behavioral, and foraging ecologies of deep diving cetaceans. The first two cruises were visual and PAM line transect surveys conducted aboard the RV *Song of the Whale* during the winter and spring of 2019. The survey efforts were carried out under NOAA permits 14809-03 (Duke University) and 16473 (UNCW). The third cruise was focused on deployment of the 3D passive acoustic array conducted aboard the RV *Shearwater* in July 2022. This survey was carried out under NOAA permit 14809-03 (Duke University). These research efforts are described in more detail below and as an infographic in Appendix A.

2.1.1 Visual and PAM Line Transect Vessel Surveys Across the OCS from South Carolina to Virginia—Winter and Spring 2019

The study area included the OCS and deep offshore waters off South Carolina, North Carolina, and southern Virginia (see Figure 2.1). This area included 220,605 km^2 of complex hydrography distinguished by heterogeneous habitats, including continental shelf, steep slopes, canyon systems, ridges, and gullies (Rhoads and Hecker 1994). Oceanographic conditions in the study area are driven by interactions between local topography, the Gulf Stream, and the Labrador Current (Csanady and Hamilton 1988). In 2019, this area was surveyed from 17 January through 24 February (winter) and from 6 April through 19 May (spring). These surveys were undertaken at this time to fill spatial and temporal gaps in our knowledge of deep divers across the OCS.

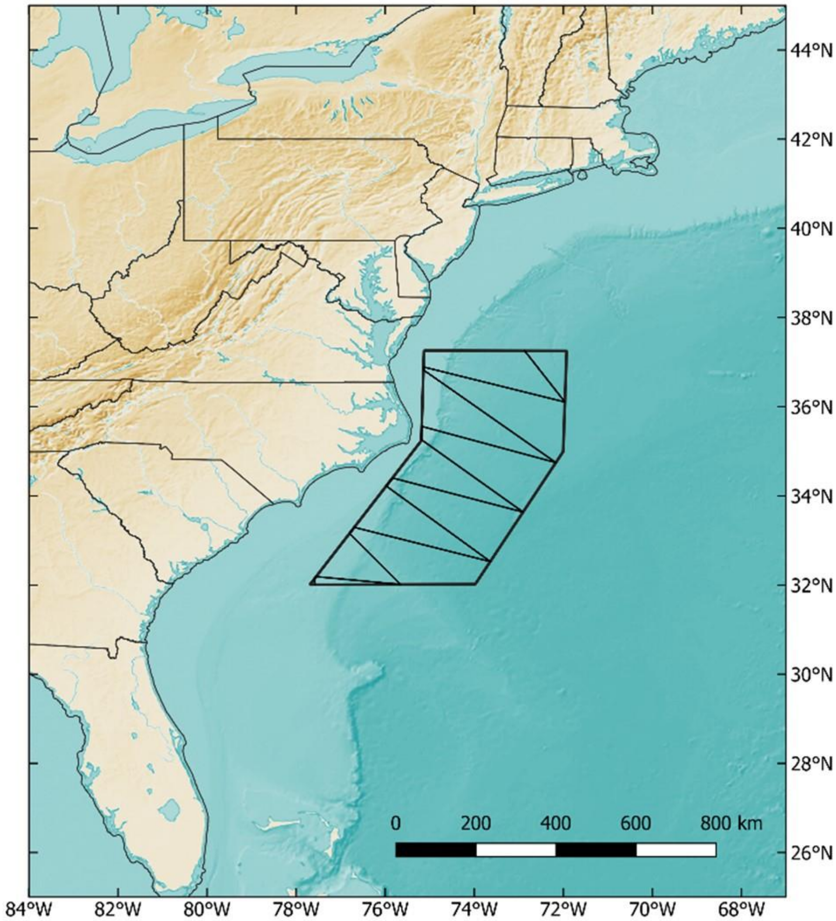


Figure 2.1. The 2019 winter and spring MAPS study area, showing transect lines that covered the OCS and deep offshore waters of South Carolina, North Carolina, and southern Virginia.
Topography and bathymetry from naturalearthdata.com.

2.1.1.1 RV *Song of the Whale* Visual and PAM Survey Design

The RV *Song of the Whale*—a purpose-built 21-meter auxiliary powered, cutter-rigged, sailing research vessel—was used to carry out the 2019 surveys. The RV *Song of the Whale* was designed and built specifically as a platform for cetacean visual and passive acoustic surveys. The vessel has a 5-m, elevated A-frame that provides a platform for visual surveying, specially designed outriggers for towing acoustic hydrophone arrays, and a dedicated computer and communications room for acoustic detection and data logging. The engine room and propulsion systems were specified and designed to minimize both airborne and structure borne noise and include innovative soundproofing materials. Equipped with a 370-hp Yanmar engine, the RV *Song of the Whale* can use sail power when appropriate and in combination with other features, including marine wind turbines, a high efficiency Stirling engine combined heat and power generator, and a five-bladed propeller designed to be very efficient while minimizing cavitation and therefore noise. The full vessel specifications and capabilities can be accessed at https://www.marineconservationresearch.co.uk/rv-song-of-the-whale/.

Detailed descriptions of the methods for the MAPS winter and spring surveys can be found in Boisseau et al. (accepted) and Boisseau et al. (in progress) and are excerpted here. The survey transects were designed as equal-spaced zigzags using the software package Distance 7.3 (Thomas et al. 2010) to provide almost uniform coverage probability. The transects were designed to provide an acoustic coverage of at least 10% based on a likely maximum half strip width of 4 km for beaked whale and 10 km for sperm whale (*Physeter macrocephalus)* clicks (Zimmer et al. 2008, Lewis et al. 2018). We designed a total of 3,005 km of survey effort. The intention was to survey all 10 transects in both surveys to derive separate winter and spring density estimates; however, the winter transects could not be completely surveyed due to bad weather, and seasonal comparisons were made only for those areas covered in both surveys.

Two dedicated observers conducted visual surveys from the A-frame elevated platform during daylight hours when weather and sea state conditions permitted. One observer scanned the sector from 0–90 degrees and the other from 270–360 degrees; the observers used 7x50 binoculars with internal compass and reticles to confirm details of sightings. When cetaceans were seen, the observer reported the details to a third team member, who acted as the data recorder. The sighting time, species, distance (estimated by eye), relative bearing (from angle boards), relative heading, number of animals, cue, and behavior for all animals observed were recorded to a survey database using Logger software (marineconservationresearch.org). Observers were able to practice range estimation using an Automatic Identification System and radar targets at the start of each research leg.

Acoustic surveys were conducted 24 hours a day to maximize survey effort in appropriate water depths (more than 50 m deep without submerged obstacles). The towed array used consisted of a 400-m tow cable attached to multiple hydrophone elements in an oil-filled tube; a deck cable ensured the full tow cable was deployed to position the array 400 m behind the vessel. The array incorporated three pairs of broadband elements (Magrec HP03) with a flat frequency response (±3 dB) from 1 to 100 kHz and receiving sensitivity of -204 dB re 1V/µPa; these elements could detect most vocalizations produced by odontocetes including beaked and sperm whales. Each hydrophone pair was separated by 0.25 m, with each of the three pairs spaced unevenly in the linear array to provide separations of 1, 3, and 4 m respectively. Array outputs were digitized at 500 kHz by two four-channel SAIL DAQ cards (SA Instrumentation). The six elements were monitored in real-time using a click detector module in PAMGuard (Gillespie et al. 2008) configured to detect potential beaked and sperm whale clicks. Continuous recordings of raw audio were also written to disk as 16-bit Waveform audio file format (WAV) files.

The vessel's track was logged to a database every second from the vessel's GPS along with the heading from a GPS gyro sensor, the wind speed and direction from masthead instruments and various other parameters. The RV *Song of the Whale* maintained survey speeds of 5 to 8 knots; a minimum speed of 5 knots to stream the array and a maximum of 8 knots to reduce cable strum. Research platforms should travel at least two to three times faster than the average speed of focal animals during distance-sampling surveys to avoid biases related to animal movement (Buckland et al. 2015). The average at-depth horizontal travel speeds for Cuvier's (*Ziphius cavirostris*). beaked whales are 2 knots (Johnson et al. 2004), and the mean speed of travel for sperm whales is approximately 2.1 knots (Whitehead 2018).

2.1.1.2 PAM Density and Abundance Estimate Methods—Beaked and Sperm Whales

Acoustic data analysis for both beaked and sperm whales began by examining recordings made in the field in PAMGuard to identify clade-specific click trains (Gillespie et al. 2008). Analyses of depth of vocalizing animal, slant angle, and subsequent estimates of density varied across beaked and sperm whales and are described in detail in Boisseau et al. (accepted) and Boisseau et al. (in progress), respectively, and are excerpted here.

2.1.1.2.1 Beaked Whales

Typical beaked whale clicks have the distinctive form of a relatively long duration (~200 µs) FM upsweep with dominant energy between 25 and 80 kHz (Johnson et al. 2004, Gillespie et al. 2009, Clarke et al. 2019). Thus, candidate beaked whale clicks were identified if they had significant energy in the 25 to 80 kHz energy band, a waveform resembling that of published data for other beaked whale species, an upswept narrowband structure revealed in a Wigner plot and formed part of a click train, i.e., with similar bearings and regular inter-click intervals. We used differences in bearing information to identify individual click trains and estimate cluster size (minimum, maximum, and 'best' estimate). The cluster size of acoustic detections was evaluated subjectively using the bearing information derived for each click train in PAMGuard, with click trains separated by at least 5° being considered separate animals. The 'best' estimate of cluster size was used in subsequent assessments of density (see below).

Estimates of the slant range were made in PAMGuard using the Target Motion Analysis (TMA) module's 2D simplex optimization algorithm; we estimated of depth of vocalizing beaked whales following the methodology of DeAngelis et al. (2017).

Acoustic species identification was investigated using hierarchical cluster analysis (Ward's minimum variance method) to ascertain if there were meaningful differences between the click trains based on their peak frequency, 3 dB bandwidth, 10 dB bandwidth, and inter-click interval (ICI). These parameters were all estimated using Raven Pro 1.4 (Bioacoustics Research Program, Ithaca, NY). Ward's method minimizes total within-cluster variance, and, at each step of the analytical process, we merged the pair of clusters with the lowest between-cluster distance. Ward's method usually creates compact, even-sized clusters and can outperform other hierarchical methods in deriving homogeneous and interpretable clusters (Punj and Stewart 1983). Clusters in the dataset were subsequently defined by the largest change in the distance coefficient. The characteristics of resulting clusters were compared to published descriptions of species-specific vocalizations.

To estimate beaked whale acoustic detection functions and densities using multiple covariates distance sampling (MCDS), corrected perpendicular distances to beaked whale clicks were imported into the program Distance 7.3 (see Boisseau et al. [accepted] for methods used to maximize sample size). In addition to cruise identity (winter vs. spring), candidate species (Cuvier's vs. Gervais' beaked whale, *Mesoplodon europaeus*), and cluster size (based on subjective 'best' estimates), several 'effort covariates' that could modify the noise field around the hydrophone array, and thus affect the likelihood of detecting beaked whale clicks, were included in the MCDS approach. Sea surface temperature (SST), for example, has the potential to influence acoustic pathways for a near-surface sensor as soundwaves refract towards slower (cooler) waters (Kinsler et al. 1982). Covariates were thus able to modify the scale of the detection function without affecting its shape. These effort covariates were estimated in the field at least every hour and included sea state (Beaufort scale), wave height (m), and swell height (m); in addition, instruments on the research vessel logged SST (°C), wind speed (knots), engine speed (rpm), vessel heading (° true), and vessel speed (knots) every 10 seconds. Covariates were first investigated for correlation using Spearman's correlation coefficient to remove any potential redundancy; all remaining covariates and their combinations were incorporated into model generation. Models were initially produced with single covariates; models combining two, three, and four covariates were subsequently produced. The selection of the best detection function was made using Akaike's Information Criterion (AIC). Densities for both cruises could then be estimated using traditional designed-based approaches (Marques et al. 2013).

Beaked whale densities were estimated with a correction for availability. Availability for detection is influenced by both whale behavior (specifically the proportion of time beaked whales spend clicking) and by survey protocol (as survey speed affects the length of the finite time window during which beaked whales can be detected). Following Barlow et al. (2013), g(0) for Cuvier's beaked whales was estimated as:

$$g(0) = \frac{E(a) + t}{E(a) + E(u)},$$

where $E(a)$ is the expected time for which a whale is available for detection (i.e., foraging time), $E(u)$ is the expected time for which a whale is unavailable for detection (i.e., time between foraging events), and t is the time window during which an animal could feasibly be detected.

As whales can theoretically be detected both ahead of and behind the array up to a distance equal to EShW (the effective strip half width estimated when modeling the detection function), the time window can be defined as twice the EShW divided by average survey speed. The variance for $g(0)$ over a finite time window was estimated using the delta method (Seber 2002). As the estimates made by Barlow et al. (2013) for Cuvier's beaked whales used data from a variety of non-Atlantic locations (Ligurian Sea, Hawaii, and Southern California), supplementary dive data for Cuvier's beaked whale were incorporated from satellite tags deployed off North Carolina between 2014 and 2016, including minutes in foraging dives, minutes between foraging dives and minutes in dives not clicking (Shearer et al. 2019).

A second analytical stage assumed local density varied in space and in response to specific environmental covariates. The survey transects were divided into short segments of homogeneous effort type and density surface modeling (DSM) was subsequently used to obtain detection probabilities for clusters of beaked whales. Counts were summarized per segment and a generalized additive model (GAM; Wood 2006) was then constructed with the per-segment counts as the response corrected for detectability using the detection function selected above. Survey effort was divided into segments approximately twice the truncation distance of the dataset (i.e., 8 km), making the two-dimensional shape of a segment approximately square. Several bathymetric and oceanographic parameters were used to produce the DSM, including SST, chlorophyll, water velocity, multiple slopes, and distances to oceanographic features (see Boisseau et al., accepted, for 23 variables tested) and were selected on the basis of their potential to influence beaked whale distribution and their availability for the whole survey area. Smooth functions of the environmental covariates were constructed using thin plate regression splines with shrinkage. The Tweedie distribution with logarithmic link function was assumed for the response variable, as this approach adequately handles zero-inflated spatial models (Miller et al. 2013). GAMs were fitted using the "dsm" R package (Miller et al. 2013), implemented within Distance 7.3. Model selection was conducted by adding one candidate explanatory variable at a time in a forward approach. The model selected at each step was chosen by looking for an improvement in the Restricted Maximum Likelihood score and percentage of variation explained; QQ and residual plots were also examined for normality, auto-correlation, and homoscedasticity.

A prediction grid was generated by dividing the study area into 2,980 cells, with each cell having a resolution of 8-km latitude by 8-km longitude (Albers equal conic area projection); grid resolution was selected to correspond with the length of segments and (approximately) with the lowest resolution of the available data. All 23 covariates investigated were averaged over each grid cell. Maps showing distribution patterns were created in Quantum GIS 3.18.2 (https://qgis.org/en/site/) using the outputs from the DSM procedure.

Please see Boisseau et al. (accepted) for a more detailed description of, and methods for determining confidence in, each these analytic steps.

2.1.1.2.2 Sperm Whales

Regular sperm whale clicks have distinctive waveforms (rapid onset/offset and evidence of multiple pulses within each click), spectral properties (most energy at or below 12 kHz), and inter-click intervals (a regular click being produced every 1-2 seconds) (Leaper et al. 1992, Møhl et al. 2003). Candidate clicks were further identified as being part of a click train if they displayed at similar bearings with regular inter-click intervals. Differences in bearing were used to identify unique click trains, therefore allowing detections to be made at the individual rather than the group level (Lewis et al. 2018). Estimates of slant range to individual whales were made in PAMGuard using the TMA module's 2D simplex optimization algorithm.

For those whales detected on a transect when the research vessel was following the survey protocol (i.e., traveling at 5–8 knots), slant ranges were imported into Distance 7.3 to generate acoustic detection functions, and subsequent density estimates using MCDS. Effort covariates that could modify the noise field around the hydrophone elements, and thus impact the likelihood of detecting clicks, were included in the analysis to modify the scale of the detection function without affecting its shape. These effort covariates were logged at least every hour in the field and included sea state (Beaufort scale), wave height (m), swell height (m), and rain condition (heavy, light, or none); in addition, instruments on the research vessel logged wind speed (knots), SST (°C), engine speed (rpm), vessel heading (° true), and vessel speed (knots) every second. These covariates were investigated for collinearity using Pearson's correlation coefficient to remove any redundancy; all remaining covariates were subsequently incorporated into model generation. Initial exploration considered cruise identity (winter vs. spring) to ascertain whether the same detection function could be used for both cruises. Subsequent models were initially generated with single effort covariates; following this, models combining up to three effort covariates were generated. The best-fitting detection function was selected using AIC. Densities could then be estimated using traditional design-based approaches (Marques et al. 2013) with a correction for availability; see information on digital acoustic recording tags (DTAG) study below.

As for beaked whales, DSM was used to investigate how sperm whale density varied across the survey block in response to specific environmental covariates by dividing survey transects into short segments of homogeneous effort type. Counts were summarized per segment, and a GAM was then constructed with the per-segment counts as the response corrected for detectability using the detection function selected in the MCDS procedure. This calculation was achieved by first dividing the vessel's track in to segments whose lengths were approximately equal to the lowest resolution of the environmental covariates. Several bathymetric and oceanographic parameters were used to produce the DSM—including position, SST, multiple slopes, and distances to oceanographic features (see Boisseau et al. [in progress] for 22 variables tested)—and were selected based on their potential to influence sperm whale distribution. Smooth functions of the environmental covariates were constructed using thin plate regression splines with shrinkage, except for the circular variables aspect and water direction, which used cyclic cubic regression splines. The Tweedie distribution with logarithmic link function was assumed for the response variable, and GAMs were fitted using the "dsm" R package (Miller et al. 2013). Model selection was conducted by adding one candidate explanatory variable at a time in a forward approach. The model selected at each step was chosen based on AIC score and percentage of variation explained; QQ and residual plots were also examined for normality, auto-correlation, and homoscedasticity.

As for beaked whales, a prediction grid was generated by dividing the study area into 2,980 cells, with each cell having a resolution of 8-km latitude by 8-km longitude (Albers equal conic area projection). Latitude and longitude were used in the model both separately (i.e., x and y) and together (as a bivariate smooth); the remaining covariates were averaged over each grid cell. Maps showing abundance patterns were created in Quantum GIS 3.18.2 (https://qgis.org/en/site/) using the DSM outputs.

Availability for acoustic detection is influenced in part by the proportion of time sperm whales spend clicking when submerged. To quantify the vocal output of local sperm whales, we attempted to attach DTAGS (version 3; Johnson and Tyack 2003) to adult whales during the vessel surveys; we were successful in one such effort during the spring survey. The DTAG was attached with suction-cups to the back of the focal animal using a 10-m carbon-fiber pole from a 4.2-m Grand Raid Mk2 Zodiac. The DTAG provided 16-bit acoustic recordings (sampling rate 500 kHz) with a flat frequency response (62 dB) from 0.5–50 kHz. Additionally, the DTAG collected data on tag depth and orientation throughout its deployment (via a pressure sensor, tri-axial accelerometer, and magnetometer sampled at 50 Hz). The tag remained on the subject whale for 6.5 hours and was retrieved using a VHF radio signal. Clicks recorded on the DTAG were used to estimate the acoustic *g*(0), the probability of detecting sperm whales at zero meters from the trackline. Although acoustic *g*(0) for sperm whales is often assumed to be unity, individuals are known to spend prolonged periods silent, for example during short reoxygenation dives at the surface. We therefore estimated the acoustic availability of sperm whales using a Monte Carlo simulation (following Fais et al. 2016). This approach assumes the survey vessel is moving along a transect of length *l* km (*l* being randomly set between 100 and 1,000 km) at the average on-track survey speed (5.6 knots). A number of stationary whales (N = 1–300) were randomly distributed along the trackline, each undertaking virtual dives. A virtual dive incorporated a period spent echolocating (t_e, defined as the interval between the start and end of clicking within a dive), followed by a period not echolocating at the surface (t_{ne}, the interval between the end of clicking and the subsequent resumption on the following dive). After each virtual dive, new values of t_e and t_{ne} were selected randomly from a distribution of t_e and t_{ne} values derived from the DTAG dataset. Virtual whales on the trackline were considered detected if they were vocalizing at any point within EShW (estimated during the MCDS procedure) as it traveled at the average survey speed. Acoustic *g*(0) was estimated by dividing the number of detected whales n by the total number of whales present in the simulation. The simulation was performed 2,000 times to estimate mean availability and its standard deviation.

2.1.1.3 Photogrammetry and Cachalot Automatic Body Length Estimator (CABLE) Methods to Estimate Sperm Whale Sizes

Demographic data provide key insights to understanding a population’s behavior and ecology and to creating effective management strategies (Koons et al. 2006; Schaub and Abadi 2011; Chiquet et al. 2013). Body size, in particular, can highlight regional variation in globally distributed species and the life stage structure and/or depletion of a population (Koons et al. 2006; Lindenfors et al. 2007; Wearmouth and Sims 2008). This portion of the study aimed to estimate the size of sperm whales encountered during the 2019 winter and spring research cruises. We estimated body lengths using both acoustic data and visual, vessel-based photogrammetric analyses. General visual and PAM survey methods that support this study are described in Section 2.1.1.1. In addition, to improve estimates of body length for both methods, morphometric data from local sperm whale strandings were used to create a regionally specific, allometric growth equation (GE).

Detailed descriptions of the methods for this portion of the study can be found in Clabaugh et al. (in progress) and are excerpted here.

2.1.1.3.1 Passive Acoustic and CABLE Analyses

While diving, sperm whales produce loud, regularly spaced clicks. The unique architecture of the sperm whale nasal complex results in each click being composed of distinct, regularly spaced pulses, and the spacing of these pulses (the inter-pulse interval, IPI) is fairly constant (Norris and Harvey 1972). These pulses are caused by reflection of sound by the distal and frontal air sacs surrounding the spermaceti organ and partial interception of the forward-propagating pulse by the distal air sac (Madsen et al. 2002; Møhl et al. 2003). The IPI is, therefore, directly related to the length of the spermaceti organ, and because there is an allometric relationship between the length of the spermaceti and body length, IPIs can be used to estimate an individual whale’s body length (Norris and Harvey 1972; Gordon 1991; Growcott et al. 2011). This method allows researchers to collect data that can identify body size in any weather condition, during any time of day, and while whales are diving or otherwise visually inaccessible.

Passive acoustic recordings of sperm whale clicks were recorded as described in Section 2.1.1.2.2. The recordings were then run through the CABLE software program, a publicly available software program used to automatically estimate sperm whale body lengths, using methods outlined in Beslin et al. (2018). CABLE automatically isolates on-axis echolocation clicks and looks for neighboring clicks that are structurally similar with the same IPI, filtering out any IPIs that do not meet the program’s criteria. Once the IPIs have been filtered, CABLE clusters them using Gaussian mixture models (GMMs), with each cluster representing an individual whale and its corresponding IPI (se examples in Figure 2.2). From that IPI, the program calculates two body length estimates using equations from Gordon (1991) and Growcott et al. (2011). Audio files from focal follows of individual or groups of sperm whales (or encounters where recordings were split into multiple files) were manually stitched together using the software Audacity to make a single WAV file. Longer audio files provide CABLE with a larger acoustic sample for each whale and allow more accurate size estimation.

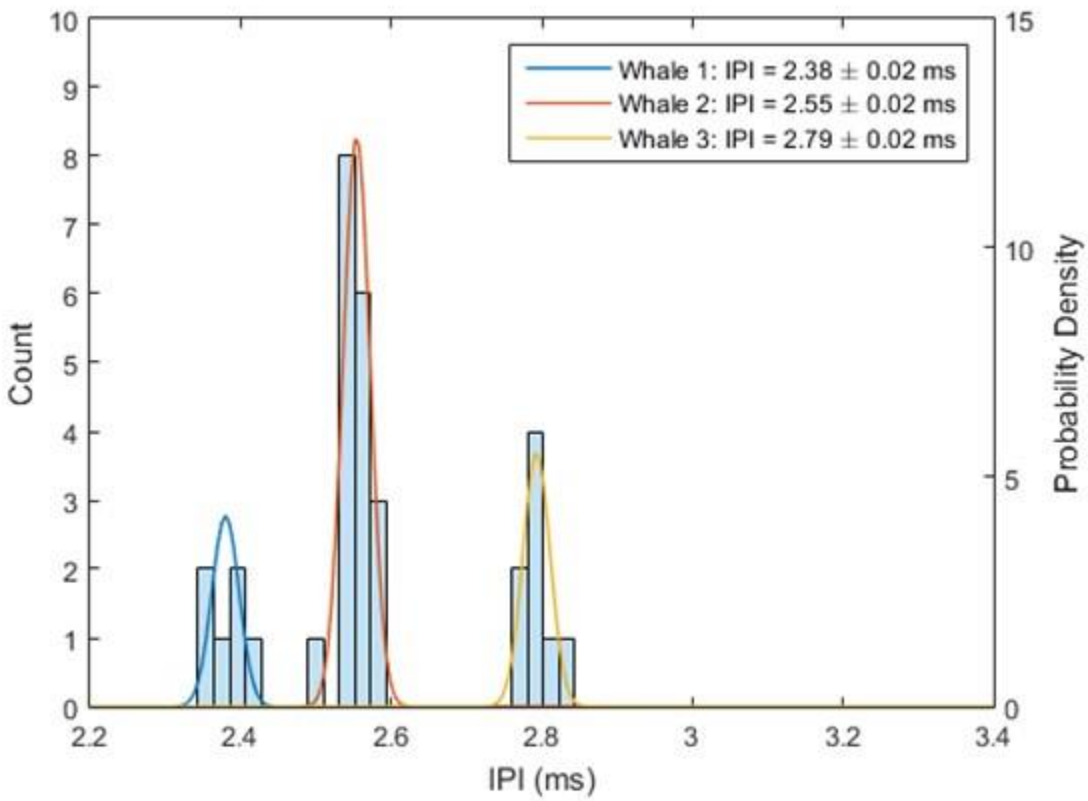


Figure 2.2. Example GMM plot produced by CABLE from acoustic recordings of at least three sperm whales collected during winter Cruise 1 on 27 January 2019.

The CABLE algorithm automatically constrains the IPI range to 2–9 ms to avoid false positives, but these IPI limits omit individuals smaller than 7.7 m and larger than approximately 17 m (Marcoux et al. 2006, Growcott et al. 2011, Beslin et al. 2018). However, calves less than 1 year old have been recorded vocalizing with IPIs less than 2 ms (Tønnesen et al. 2018). To try to capture these individuals using CABLE, recordings from days where smaller and larger whales were visually observed were rerun through CABLE with the lower bound IPI set to 1ms and the upper bound IPI set to 10 ms. For all other recordings, click detection parameters were set to default (nIPIreps = 2). Resulting GMM clusters that contained fewer than five IPI detections for the same individual were rejected (Beslin et al. 2018). In addition, when comparing individuals from one recording, those with IPIs within 0.2 ms of each other were evaluated manually. For GMM clusters containing fewer than five IPI detections or IPI clusters within 0.2 ms of each other, a manual evaluation could find an alternative solution more appropriate than the one selected automatically (Bottcher et al. 2018).

All recordings that resulted in an output from CABLE were subsequently reviewed by one of our team to confirm that the software had not given a positive result for sounds similar to sperm whale clicks. False positives can result from biological and non-biological sounds, such as dolphin vocalizations, snapping shrimp, or propeller noise. False positives were removed from further analyses.

2.1.1.3.2 Photogrammetric Analysis

When sighting conditions permitted, photographs of the dorso-lateral aspect of sperm whales were taken in the field from the deck (eye height of 3.2 m) or the elevated A-frame (5.2 m) using a Canon 7D with either a 70–200 mm or a 100–400 mm lens. Measurements of the distance, in pixels, between the blowhole and the posterior emargination of the dorsal fin were converted to meters using the height of the camera above the water, the focal length of the lens, a count of the pixels between the horizon and the waterline of the animal, the known radius of the earth and the known geometry of the camera sensor as follows (see Figure 1, Gordon 2001):

$$Blowhole\ to\ dorsal\ (m) = \left(\frac{Camera\ to\ whale\ (m)}{Focal\ length\ (mm)}\right) \times \left(\frac{Sensor\ width\ (mm) \times Blowhole\ to\ dorsal\ (px)}{Sensor\ width\ (px)}\right)$$

where:

$$Camera\ to\ whale\ (m) = (R + h) \times \cos\beta - \sqrt{((R + h)^2 \times (\cos\beta)^2) - ((R + h)^2 + R^2)}$$

and the angle between the camera and the waterline of the whale (β) was estimated by:

$$\beta = 90 - \sqrt{\frac{(2Rh + h^2)}{R}} - \tan^{-1}\left(\frac{Horizon\ to\ whale\ (px) \times \frac{Sensor\ height\ (mm)}{Sensor\ height\ (px)}}{Focal\ length\ (mm)}\right)$$

where R is the radius of the earth (considered as 6,356,766 m), and h is the height of the camera above the water (Gordon 2001, Fearnbach et al. 2011).

2.1.1.3.3 Regional Sperm Whale Morphometrics from Strandings

The morphometry recorded from locally stranded animals were collected from animals stranded in North Carolina from neonates, sub-adults, and adults of both sexes (n = 7). These data were used to develop a linear relationship (R^2 = 0.97) between measurements, which could be used to estimate body length from whales encountered in the field

$$Body\ Length\ (m) = 0.6447(Blowhole\ to\ dorsal\ fin(m)) - 0.7891$$

This regional GE was in broad agreement with those generated elsewhere, such as for sperm whales measured during whaling operations in the South Pacific and South Atlantic (Matthews 1938; Fujino 1956; Clarke 1978). This regression equation was subsequently used to scale up the estimates of the distance between the blowhole and the dorsal fin to total body length for the photogrammetry analysis, as well as estimate body length from IPI from the CABLE analysis:

$$Body\ Length\ (m) = -0.5573(0.5 \times IPI(ms) \times 1430)^2 + 5.6365(0.5 \times IPI(ms) \times 1430) - 0.0597$$

The regional body length estimates from the CABLE analysis were also compared to estimates from the Gordon (1991) and Growcott et al. (2011) equations.

2.1.1.4 eDNA Collection and Analysis Methods

Although eDNA analyses were not part of the scope of the original cooperative agreement, we wished to leverage our unique at sea opportunity to investigate whether we could collect and isolate eDNA samples from cetaceans, including deep divers, during our winter and spring research cruises. Water samples were collected at every sighting, at the ends of each trackline, and at intermediate points along the lines. eDNA sampling in general is early in its development, with important questions remaining about efficacy and applicability, e.g., at what ranges can animals be detected. To attempt to address some of these questions, as part of the eDNA collection, we included some 'test' samples, in which we collected a sample at the fluke print of a sighting (e.g., sperm whale) and then we moved 500 m away from that point and took another sample. In doing so, we hoped to add, at least incrementally, to the broader use of this technique to detect species from systematically collected samples during surveys.

At Duke, eDNA samples were extracted from the frozen filters collected while at sea. Low priority samples then were used to test the cetacean specific primers developed by faculty and students at Duke. Barcoded polymerase chain reaction (PCR) products were created for subsets of the eDNA samples and sequenced using Nanopore technologies.

2.1.1.5 Thermal Imaging of Sperm Whales

Deep diving cetaceans must maintain a high, relatively constant body temperature as they thermally "migrate" between warm surface and cold deep waters multiple times per day. Although they possess anatomical and physiological adaptations to conserve heat, there exist few direct measures of the thermal biology of these mammals. We used infrared (IR) thermography to investigate the thermal biology of sperm whales (*Physeter macrocephalus*) encountered during the 2019 research cruises. We also attempted to collect a time series of IR photographs of DTAG-ed individuals to correlate body surface temperatures with independently measured dive behavior, including time at depth, acoustic, and movement data.

Digital IR images of sperm whales were captured using a FLIR P60 (FLIR Systems, Inc., Wilsonville, OR, USA) infrared thermal camera from the RV *Song of the Whale* or and/or a small rigid-hulled inflatable boat. Whales were imaged opportunistically when encountered (typically during surface intervals associated with respiration or logging) and when weather and sea state permitted (Figure 3.16). For each image, we recorded the IR photo #, date, time, and description of sighting. Images were imported into ThermaCam Researcher Pro software (FLIR Systems, Inc.) on a laptop and analyzed following methods similar to Barbieri et al. (2010) to determine body surface temperatures. Only images of good quality (i.e., in sharp focus and angle of the body surface being photographed estimated to be less than 30º to the plane of the camera) were included in analyses. Surface temperature measurements were taken of the head, dorsolateral body, dorsal fin, and flukes of sperm whales. Body and fin margins were avoided. The number of sites analyzed varied between images and locations on the body. For example, more area could be sampled along the exposed dorsolateral body than at the relatively smaller dorsal fin. Mean surface temperature per body site was calculated for each image. The difference between mean body surface temperature and independently measured mean water temperature (collected on keel mounted thermometer at approximately 1-m depth) (T_{body} - T_{water}) was calculated for each photo.

2.1.2 Deployment of the 3D Passive Acoustic Array Along North Carolina Shelf and OCS Waters in 2022

The 2019 MAPS research cruises utilized 2D passive acoustic arrays to detect and record vocalizing deep divers. As described in Section 2.1.1.2, these recordings were used to estimate the density and abundance of beaked and sperm whales. In July 2022, the research team deployed a 3D acoustic array, designed and built by Marine Conservation Research (MCR), which could gather more in-depth behavioral data on deep divers. Thus, the goal of this research cruise was to deploy the 3D array, which was successfully field-trialed in March 2022, to acoustically monitor deep diving beaked and sperm whales.

The 3D array could also address a technical difficulty in 2D acoustic density estimates. It can be difficult to estimate accurately the depth of beaked whales (required for estimates of perpendicular distance from the trackline in acoustic distance sampling density estimation methods) detected by 2D arrays if there are indistinct surface echoes in a click train and/or complicated flow regimes in the survey area. This cruise therefore was planned to take place during, and in coordination with, on-going studies by Duke University colleagues focused on satellite tagging multiple Cuvier's beaked whales. Targeting the 3D acoustic tracking on tagged beaked whales, for which depth could be independently determined via tagging, would provide data to address this critical measurement. We planned to target our acoustic tracking on these tagged beaked whales and to track sperm whales if encountered outside of dedicated beaked whale tagging events. The area of interest was the OCS and shelf-break near Cape Hatteras, North Carolina, an area of high beaked whale density (McLellan et al. 2018) and one regularly visited by sperm whales (Stanistreet et al. 2017).

The final MAPS research cruise took place aboard Duke University's RV *Shearwater* from 5–9 July 2022. Although weather conditions kept our Duke colleagues onshore during our cruise, we did receive daily updates on the location of previously satellite-tagged *Z. cavirostris*, which permitted us to target areas of known beaked whale distribution. The goniometer aboard the RV *Shearwater* was used to attempt to locate beaked whales based upon their last known location.

Each day, we used both visual and acoustic methods to detect cetaceans. A team of four rotating observers, positioned on the vessel's upper deck, carried out visual observations for cetaceans throughout daylight hours unless sea state precluded such efforts. In addition, we towed a traditional linear array 300 m behind RV *Shearwater*. This array incorporated three pairs of HP03 elements, plus a pair of low-frequency AQ-4 elements (Teledyne Benthos) with a flat frequency response (±1.5 dB) from 1 Hz to 30 kHz and receiving sensitivity of -201 dB re 1V/μPa. Pre-amplifiers with 39 dB gain mitigated voltage drops. The spacing between each broadband hydrophone pair was optimized for deriving bearing information for ultrasonic clicks (0.25 m); the low-frequency pair was spaced 3 m apart to provide optimal spacing for sperm whales.

We conducted acoustic surveys 24 hours a day using the linear array to maximize survey effort in appropriate water depths (more than 50 m deep without submerged obstacles). The linear array identified acoustic events of interest, including the click trains of sperm whales and ziphiids. As the 3D array required some adjusting in the field, it was mostly deployed following promising detections on the linear array and/or in the vicinity of sighted odontocetes.

The 3D hydrophone array (Figure 2.3) was towed behind RV *Shearwater* from a 400-m tow cable. This experimental array consisted of a tow body housing four separate broadband elements (Magrec HP03) with a flat frequency response (±3 dB) from 1 to 100 kHz and receiving sensitivity of -204 dB re 1V/μPa; these elements could detect most vocalizations produced by odontocetes, including ziphiids. Pre-amplifiers with 39 dB gain prevented voltage drops. Each hydrophone element was separated from all others by at least 0.25 m, with the maximum separation between two elements at 1.03 m (Figure 2.3). In addition to these hydrophone elements, a pair of HP03 elements in an oil-filled tube were towed 3 m behind the tow body. Array outputs were digitized at 100 kHz by two four-channel SAIL DAQ cards (SA Instrumentation). In the bandwidth of interest for beaked whale clicks (25 to 80 kHz), the response of the system is approximately flat (± 1.5 dB). The six elements were monitored in real-time using a click detector module in PAMGuard (Gillespie et al. 2008) configured to detect potential odontocete clicks. Recordings were also written to disk as 16-bit WAV files. The track was logged to a database every second from a GPS unit.

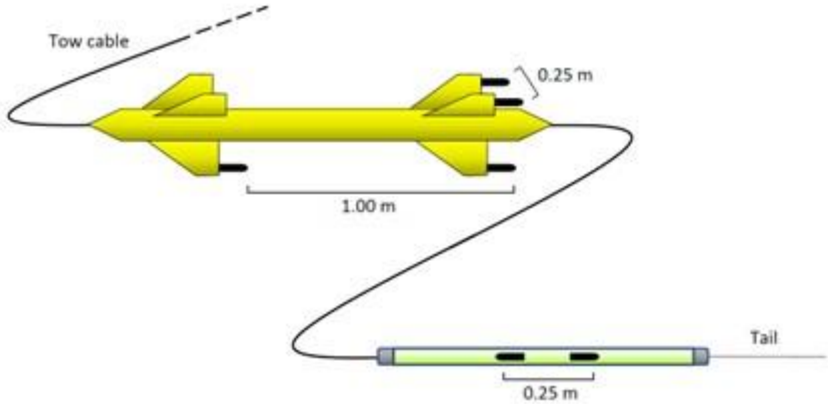


Figure 2.3. Geometrical arrangement of four elements in the 3D array's tow body plus two elements in the oil-filled tail.

The tow body incorporated a 40-bar depth sensor (Keller PA-20Y), an analogue dual-axis ±90° inclinometer (Rion SCA128T), and an analogue compass (Rion HCM508B) in order to characterize the towing characteristics of the array. Unlike equivalent digital sensors, analogue devices do not to introduce electrical noise into the analogue hydrophone channels and thus into the recording system. The separate voltage outputs representing depth, pitch, roll, and heading were sampled every second by a Measurement Computing USB-1208FS acquisition card on board RV *Shearwater*. This information was then passed to a hydrophone array manager in PAMGuard, which in turn made it available to other modules, including a click detector configured to identify odontocete clicks. True bearings and slant angles could therefore be derived for candidate clicks in real-time. RV *Shearwater* maintained a variety of survey speeds (0 to 9 knots over ground) as the towing characteristics of the 3D array in the Gulf Stream were being assessed; the mean speed when surveying with the 3D array was 4.0 knots.

2.2 Build Upon Existing Development of Open-Source Tag Visualization Software

The goal of the work proposed in this component of the MAPS program was to explore methods to enhance the tools for multi-sensor tag data visualization and analysis. During the Research Meeting in May 2018, Dave Haas (Duke University) reviewed the strengths and weaknesses of existing tag visualization software and presented an initial plan for the Duke University engineering student project to create a more user-friendly, adaptable software. Two possible courses in the electrical and computer engineering department at Duke were identified as possible crucibles for developing visualization software. Additionally, we identified resources in the Duke Library's Data and Visualization Services department (https://library.duke.edu/data/data-visualization and https://guides.library.duke.edu/datavis) as valuable resources for this pursuit.

In 2019–2020, the Duke University team reviewed the existing tag visualization methods and attempted to collaborate with colleagues who wrote existing software. They also collaborated with Dr. Eric Monson from the Duke Center for Data Visualization Sciences (CDVS), focusing on the potential use of ParaView for tag data visualization. ParaView, which is open-source, allows users to build visualizations to analyze data using qualitative and quantitative techniques. ParaView was developed to analyze extremely large datasets using distributed memory computing resources. It can be run on supercomputers to analyze datasets of petascale size, as well as on laptops for smaller data, and has become an integral tool in many national laboratories, universities, and industry.

In fall 2020, Nowacek engaged five Duke University undergraduate electrical and mechanical engineering students to program tag data visualization tools. The goal was to develop code capable of running kinematic analysis and creating interactive visualization playbacks on commonly used tag data formats (e.g., DTAG; Johnson and Tyack 2003), OpenTag (Loggerhead Instruments), and CATS tags.

2.3 Citizen Science Component

The citizen science component of the MAPS project was to identify how best to leverage citizen science data for protected species monitoring. To that end, the Office of Environmental Programs held a workshop on 20–21 June 2018, called "Streamlining Citizen Science in Support of Efficient Environmental Assessment on the U.S. Outer Continental Shelf." The workshop was hosted by the US Department of the Interior at its headquarters in Washington DC and was facilitated by the consulting firm 10X Collective. Workshop attendees included BOEM staff from all regions, our NOAA counterparts, energy industry representatives, species distribution specialists, and citizen scientist specialists. Workshop presenters included representatives from the Federal government, conservation agencies, consultants, academics, and non-profit organizations. Discussions and breakout groups focused on the needs and challenges faced by BOEM in integrating citizen science data in their environmental assessments, following presentations on the current state of the science, tools used to manage large datasets, and lessons learned on how to best manage large-scale citizen science data.

Specifically, the workshop objectives were to (1) articulate a united vision across BOEM regions for the inclusion of citizen science data on protected species, (2) understand available technologies for ensuring data quality and integrating mariner outreach through existing mobile platforms, and (3) identify and discuss the best methods to take a step toward that larger vision within the scope of the MAPS study.

Presentations on the first day of the workshop were given by experts in citizen science project coordination and software development on the challenges and benefits of collecting citizen science data and the current and future availability of relevant software. These discussions included the development of software used by the Channel Islands National Marine Sanctuary for their marine mammal monitoring program, the Sharktivity app used by the Atlantic White Shark Conservancy, and the use of artificial intelligence for animal image identification by WildMe, including the Flukebook app, which enables identification of individual whales by fluke and dorsal fin patterns. The second day of the workshop focused on establishing requirements for a comprehensive citizen science platform that would effectively integrate functionalities of multiple ocean animal sighting applications in current use.

This workshop, and subsequent post-workshop meetings held on the 22 and 26 June 2018, set the groundwork for the MAPS citizen science team. In addition, in an effort to establish the photo-identification workflow, a meeting was held on 23 October 2018 with members of the two development teams, MAPS project leaders, Channel Island Marine National Sanctuary staff piloting the platform, and BOEM staff. During this meeting, participants discussed in detail the specifics of the pilot workflow of data collection in the field and photo-identification to isolate and identify the particulars of the process and ensure that changes to development were such that needs were met.

2.4 Communications and Outreach Component

The development of the MAPS Communication Plan (Appendix B) was a collaborative effort between Ms. Imogen Scott, BOEM, and the members of the research and citizen science teams. Overall, the communications plan set out a framework for achieving the following objectives:

- Highlight why the study objectives are important to BOEM's mission
- Raise awareness among target audiences of the objectives of MAPS and why they were important

- Enable key target audiences to collaboratively contribute data to a streamlined workflow for the understanding of the spatial ecology of cetaceans
- Engage target audiences in BOEM science and marine mammal research through citizen science initiatives, NOAA Ocean Today Kiosk networks, etc.
- Engage new citizen science users through multiple citizen science initiatives

The specific products of the Communication Plan included those that described all aspects of the MAPS project, and others specific to either the research or citizen science component of the project. For example, the MAPS website (https://sites.duke.edu/oceansmart/) and Program Fact Sheet (Appendix C) characterized the entire project. Component-specific infographics visually depicted the overall goals and methods of the research and citizen science projects (Appendices B and E, respectively). Below, we describe in more detail the communication, outreach, and education methods employed for each of these project components.

2.4.1 Research Component: Education and Outreach Projects

The winter and spring 2019 research cruises aboard the RV *Song of the Whale* were the foundation for multiple educational and outreach products. We developed an explanatory video (Studying Sperm Whales and Beaked Whales in the Atlantic: The MAPS Project – YouTube), and, during the research cruises, Scott maintained an active social media presence and updated the National Geographic Open Explorer site. Unfortunately, the National Geographic Open Explorer site was discontinued later in 2019. MCR International, Duke Marine Lab and UNCW SPARC Twitter accounts were also active during both research cruises, and the MAPS website was updated with photos from the cruises. Steve De Neef was contracted to video-document the research efforts during the spring 2019 cruise for use in the NOAA Ocean Today Kiosk program.

In addition to these products, which had global reach, three efforts were aimed at educating local students about the MAPS research project. These efforts included an on-board visit by the Boys and Girls Club of Morehead City; the development of educational camp programs for Marine Quest, the official marine science outreach program for the UNCW and its Watson School of Education, and the Center for Marine Science; and the development of the first virtual marine camp for the North Carolina Aquarium at Ft. Fisher, Kure Beach, North Carolina.

3 Results

3.1 Research Component: Visual and Passive Acoustic Monitoring Vessel Surveys Across the OCS from South Carolina to Virginia

3.1.1 Visual and PAM Line Transect Vessel Surveys Across the OCS from South Carolina to Virginia—Winter and Spring 2019

Cruise 1 (Winter 2019): The RV *Song of the Whale* departed for Beaufort, North Carolina, on 8 November and arrived 11 December 2018. Cruise 1 (winter) began on 17 January 2019 and was completed on 24 February 2019. Due to bad weather, only 58% of the designed tracklines could be surveyed (see Figure 3.1.A and Table 3.1 for effort completed).

The survey acoustically detected large numbers of sperm whales, with several accompanying visual sightings (including young calves). Many of the acoustic detections occurred well offshore of the deep shelf break region and out into very deep water (~4,000 m). These sightings and detections are within a broad geographic area that early whalers called the “Charleston Ground,” suggesting this region has been historically important to sperm whales, although few, if any, modern data existed here before Cruise 1. The large numbers of detections of echolocating sperm whales suggests the importance of this geographic region as a foraging area in the winter. The sightings of social groups with very young calves suggest that it may also be of reproductive importance to this cryptic species. We had both visual and acoustic detections of beaked whales (*Ziphius cavirostris* and mesoplodonts) in the deep waters explored by the RV *Song of the Whale* as well. These data add importantly to our understanding of these acoustically sensitive species in our region.

A single sighting of a highly endangered North Atlantic right whale approximately 40 nm off the Cape Hatteras region of North Carolina was a critical result. Although there have been right whale acoustic detections off the mid-Atlantic year-round, this sighting demonstrates that this species can be found further offshore than has been previously demonstrated in this region in the winter. We successfully deployed a DTAG on a single 10–11 m sperm whale, and gathered important observational data on its diving behavior, thermal images of skin surface temperatures after dives, and a skin biopsy sample. We unfortunately did not, however, retrieve the tag. We also gathered the first (of which we are aware) thermal images for sperm whales under various behavioral conditions. We collected eDNA samples at every cetacean sighting and at the ends of each trackline.

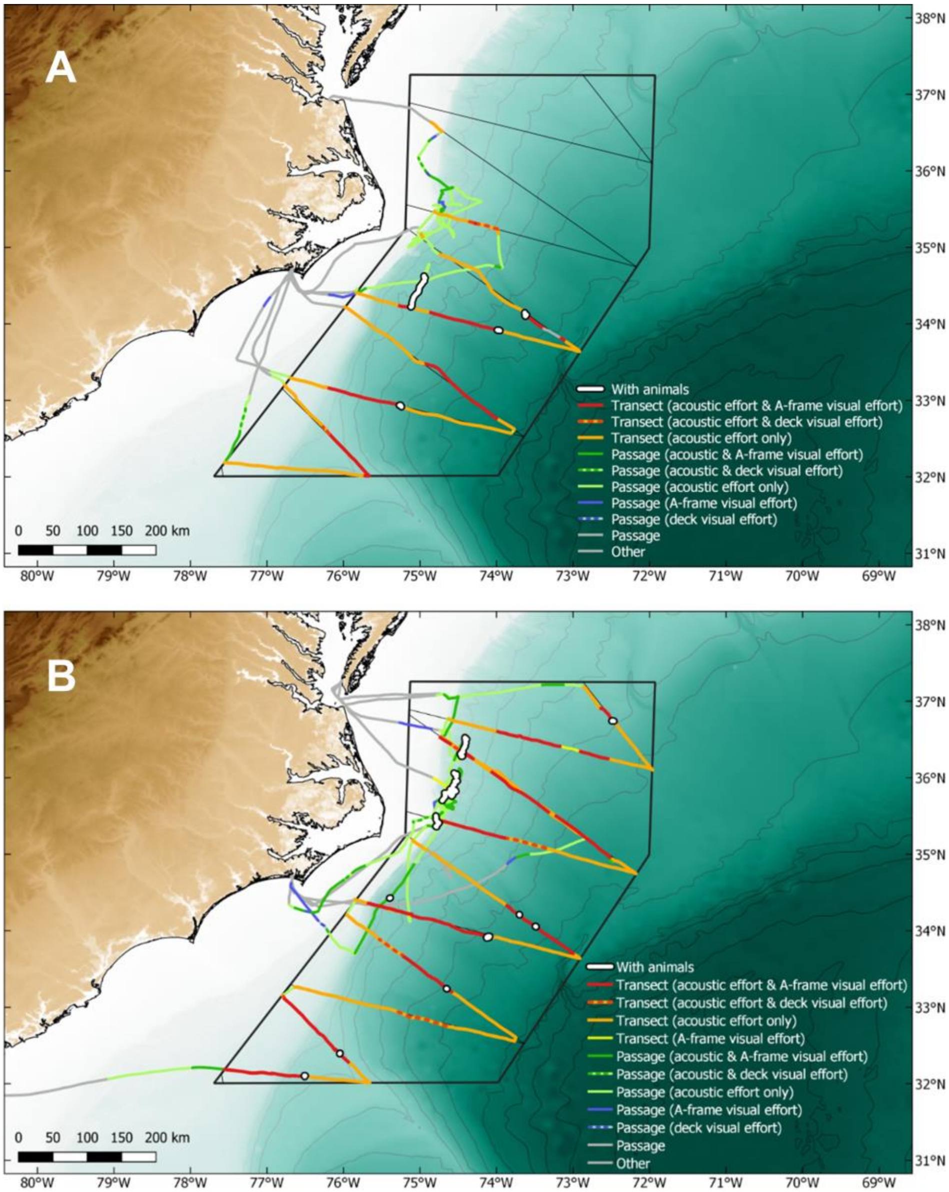


Figure 3.1. Realized survey effort aboard RV *Song of the Whale* for (A) Cruise 1 (winter), from 17 January through 24 February 2019 and (B) Cruise 2 (spring), from 6 April through 19 May 2019. Type of effort and visual sightings identified.

Table 3.1. Tabulated effort for Cruise 1 (winter) from 17 January through 24 February 2019.

TOTAL EFFORT	Miles	Kilometers	Time
Passage+acoustic+ aframe	152	281	32:50:15
Passage+acoustic+ deck	56	104	11:43:23
Passage+aframe	35	64	05:37:17
Passage+deck	34	64	05:21:17
Passage+acoustic	704	1,303	166:45:36
Passage	898	1,663	164:36:57
Trans+acoustic+ aframe	251	465	40:59:01
Trans+acoustic+deck	34	63	06:39:30
Transect+acoustic	634	1,175	113:21:06
With animals	43	80	13:37:40
Anchored/moored	4	8	02:53:06
Other	13	24	03:49:11
Unknown	2	4	01:02:22
Track total	2,861	5,298	569:16:47

Cruise 2 (Spring 2019): The RV *Song of the Whale* embarked from Beaufort, North Carolina, on Cruise 2 on 5 April 2019 and completed the cruise on 19 May 2019. During Cruise 2, all tracklines were completed (see Figure 3.1.B and Table 3.2 for effort completed).

The survey both acoustically and visually detected sperm whales, though the animals generally were farther north than during Cruise 1. We also had both visual and acoustic detections of beaked whales, including an unusual sighting of multiple male Gervais' whales (*Mesoplodon europaeus*) synchronously breaching multiple times (see image on cover). In the Norfolk Canyon area, there was a rich, multi-species acoustic record—including multiple small delphinids, pilot whales, and beaked whales—which highlights the importance of this geographic region to cetaceans. In addition, we acoustically and visually detected endangered fin whale. We also gathered thermal images of more sperm whales. On 16 May, we successfully deployed a DTAG on a sperm whale that could easily be identified as it was missing a portion of its left fluke blade. The DTAG was retrieved after approximately 7 hours of recording on the whale, demonstrating that this research method could be used in the far offshore waters. Detailed analysis of the tag data was critical for consideration of acoustic g(0) for sperm whales in this geographic region (Section 3.1.2.2).

Professional photographer Steve De Neef participated on leg 3 of Cruise 2 and gathered video, stills, and preliminary interview data with the team, which were incorporated into the second series of videos for the MAPS project (Section 3.4.1). We also collected eDNA samples at every sighting, at the ends of each trackline, and at intermediate points along the lines (Section 3.1.4).

Although beaked (i.e., *Ziphius cavirostris* and mesoplodonts) and sperm whales were visually detected during the 2019 surveys, sightings were insufficient for density estimation due to their low sample size. There were two sightings of beaked whale groups (one *Z. cavirostris* and one unidentified) in the winter Cruise 1 (761 km of on-track effort) and five (two *Z. cavirostris*, two *Mesoplodon europaeus*, and one unidentified) in the spring Cruise 2 (1,246 km of on-track effort). There were only four visual sightings of sperm whale groups (from 1–20 individuals) in the winter Cruise 1 (761 km of on-track visual effort) and eight (1–16 individuals) in the spring Cruise 2 (1,246 km of on-track visual effort). Thus, we estimated densities and abundances for these deep divers, as described below.

Table 3.2. Tabulated effort for Cruise 2 (spring) from 6 April through 19 May 2019.

TOTAL EFFORT	Miles	Kilometers	Time
Passage + acoustic + aframe	347	642	60:49:56
Passage + acoustic + deck	38	71	09:37:49
Passage + aframe	80	148	11:29:03
Passage + deck	12	23	02:52:28
Passage + acoustic	767	1,421	158:22:13
Passage	997	1,847	179:51:25
Trans + acoustic + aframe	586	1,086	107:29:55
Trans + acoustic + deck	101	187	15:37:18
Transect + acoustic	853	1,580	152:46:22
With animals	109	201	03:30:17
Anchored/moored	0	0	00:17:51
Other	63	117	20:01:31
Unknown	43	80	08:38:28
Track total	3,997	7,402	755:24:42

All visual sightings, cetacean acoustic detections, and effort data from the 2019 MAPS surveys were uploaded to OBIS-SEAMAP. The links are here:

- Sightings from RV Song of the Whale during the spring 2019 MAPS survey (NMFS permit 14809)
- Sightings from RV Song of the Whale during the winter 2019 MAPS survey (NMFS permit 14809)
- Acoustic detections from RV Song of the Whale during the winter 2019 MAPS survey (NMFS permit 14809)
- Acoustic detections from RV Song of the Whale during the spring 2019 MAPS survey (NMFS permit 14809)

3.1.2 PAM Density and Abundance Estimates for Deep Divers

3.1.2.1 Beaked Whales

Out of a total of 181 beaked whale acoustic events, we detected 105 high confidence beaked whale acoustic events during the two surveys: 45 during the winter Cruise 1 (of which 12 were on-track) and 60 during the spring Cruise 2 (39 on-track; Boisseau et al., accepted). As stated above, there were very few visual sightings, and, as might be expected, these sightings were not associated with any of the acoustic detections, since beaked whales are typically silent at the surface and vocalize on their deep, foraging dives (Johnson et al. 2004, Tyack et al. 2006).

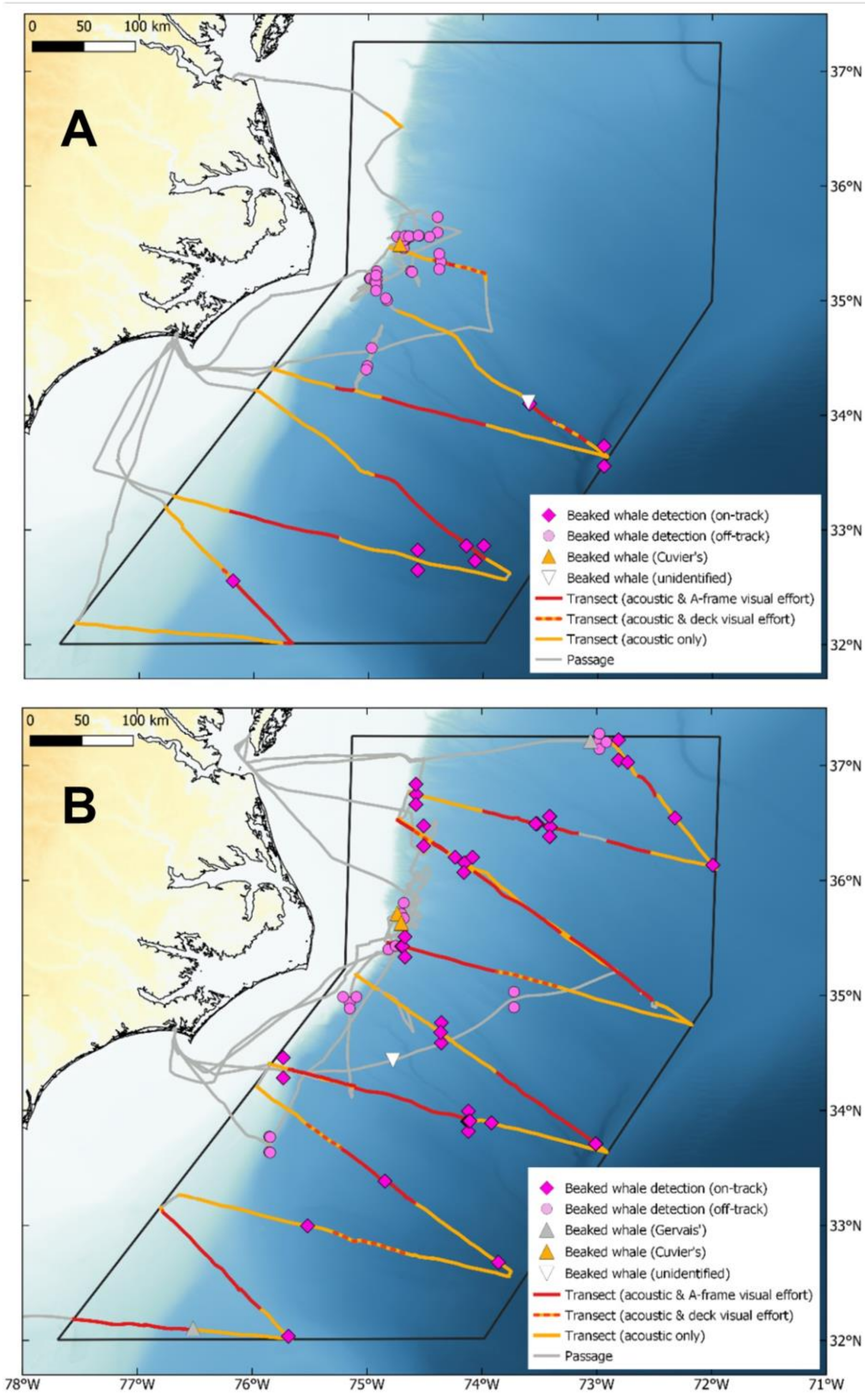


Figure 3.2. Acoustic detections of high confidence beaked whale events (on-track = pink diamonds; off-track = pink circles) during (A) winter Cruise 1 and (B) spring Cruise 2.
Sightings of beaked whales (which were not used for density estimates) shown as colored triangles; survey effort is categorized as either acoustic-only or joint acoustic-visual.

Within the 105 acoustic events identified with high confidence as beaked whale click trains, there was measurable variation in peak frequency and bandwidth. Hierarchical cluster analysis, using Ward's minimum variance method, identified two clusters characterized by peak frequencies centered on 40 and 47 kHz, with average 3 dB bandwidths estimated as 7.4 and 10.8 kHz and 10 dB bandwidths as 15.9 and 22.0, and ICIs of 0.27 and 0.16 s, respectively. There was no evidence of the 66 kHz clicks characteristic of Sowerby's beaked whale (Cholewiak et al. 2013, Clarke et al. 2019). Click trains in the first cluster had lower peak frequencies (centered at 40 kHz) with relatively narrow 3 dB and 10 dB bandwidths, and longer inter-click intervals, whereas those in the second cluster had higher peak frequencies (centered at 47 kHz) with broader 3 dB and 10 dB bandwidths, and shorter inter-click intervals (Figure 3.3). The two clusters may represent Cuvier's and Gervais' beaked whales respectively, two species known to inhabit the study area (Stanistreet et al. 2017, McLellan et al. 2018). Cuvier's beaked whale clicks have been described as having lower peak frequencies, narrower bandwidths and longer inter-click intervals than Gervais' beaked whales (Baumann-Pickering et al. 2013, Hildebrand et al. 2015, DeAngelis et al. 2018, Li et al. 2020), suggesting cluster 1 (n = 51) in this study may represent clicks produced by Cuvier's beaked whale, and cluster 2 (n = 54) may represent Gervais' beaked whale (Figure 3.4). Both types of click trains were detected during both the winter and spring cruises.

Our understanding of the vocal repertoires for most beaked whale species is still largely under development, but these acoustic characteristics align well with those known for Cuvier's and Gervais, and these species are known to inhabit the study area. Both clusters showed slight latitudinal gradients, with a higher likelihood of cluster 1 detections (candidate Cuvier's) in the south of the study area, and cluster 2 detections (candidate Gervais') in the north (Figure 3.5).

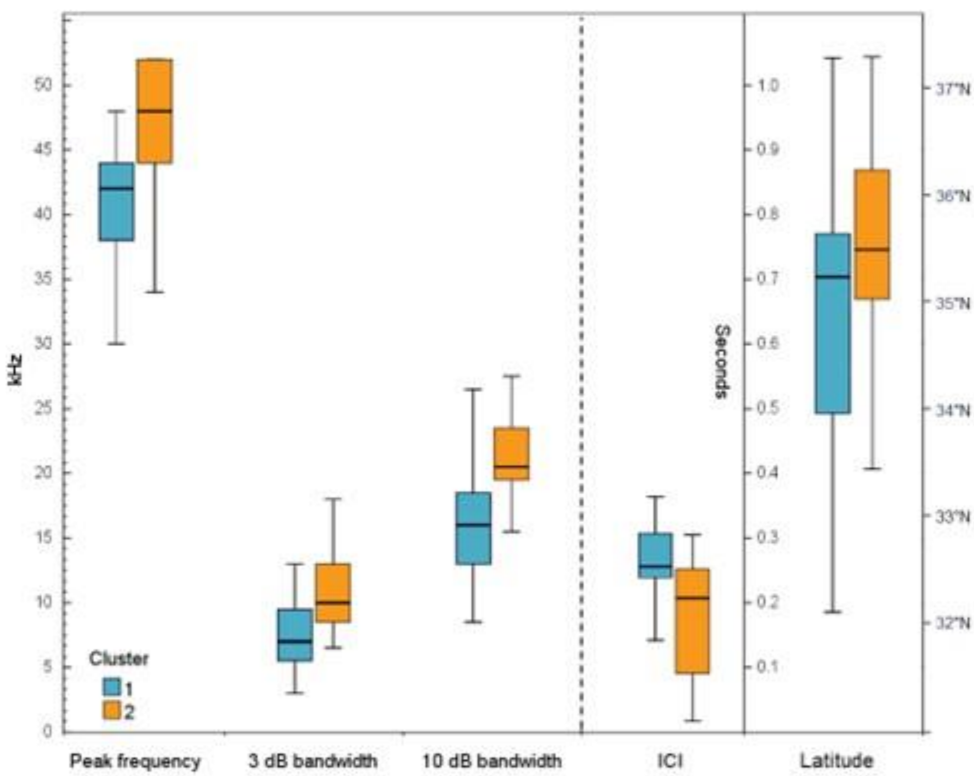


Figure 3.3. Boxplots of the four parameters used in hierarchical cluster analysis to identify the number of clusters in the beaked whale acoustic dataset.

Note inter-click interval is plotted on the secondary y-axis. Cluster 1 (blue) parameters match those published for Cuvier's beaked whale and cluster 2 (orange) parameters match those for Gervais' beaked whale. Although not used in cluster analysis, boxplots of latitude are also shown on the right of the figure.

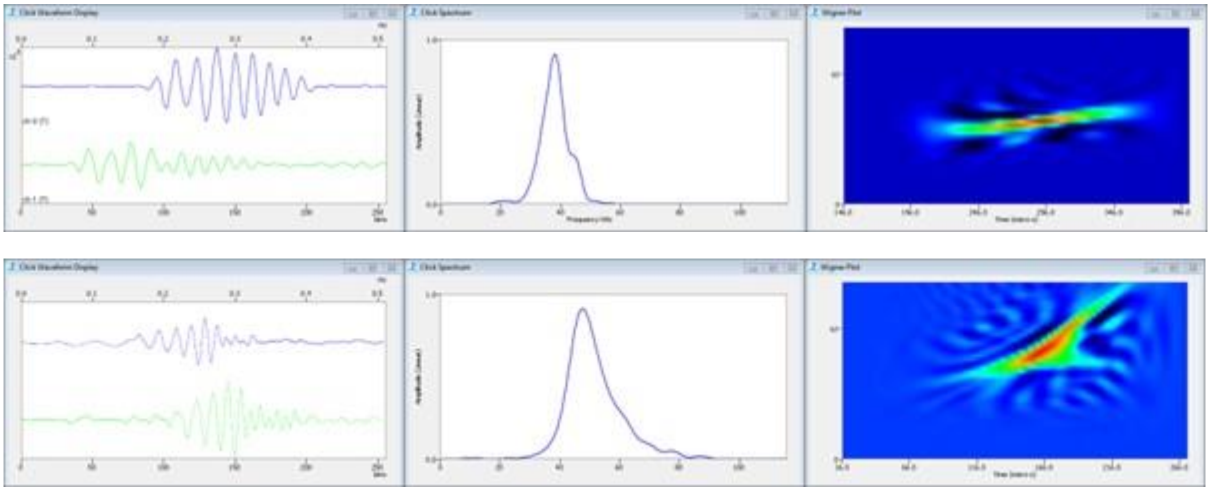


Figure 3.4. Examples from PAMGuard of detections of cluster 1 (candidate Cuvier's beaked whale) and cluster 2 (candidate Gervais' beaked whale) click trains.
Cluster 1 clicks had lower peak frequencies and narrower 3 and 10 dB bandwidths than cluster 2.

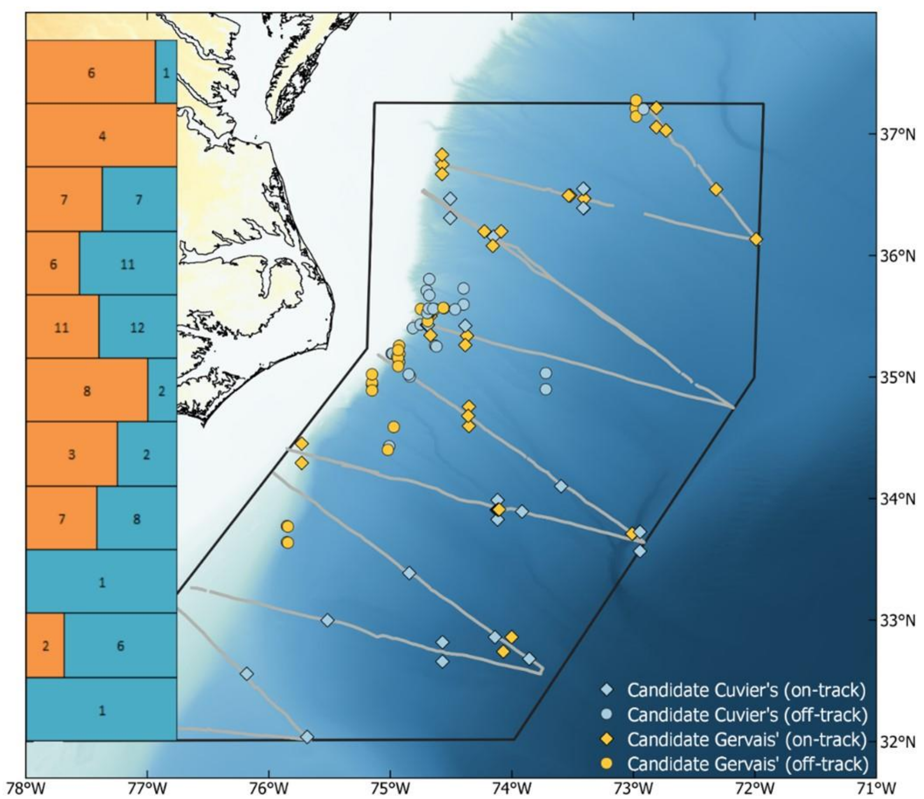


Figure 3.5. Distribution of all beaked whale click trains allocated to cluster 1 (candidate Cuvier's) and cluster 2 (candidate Gervais').
On-track effort for both winter and spring cruises shown as gray line. At each latitude, the proportion of both on- and off-track clusters are shown on the left of the figure (numbers represent counts).

Reliable depth estimated could be made for 67 of the 105 high confidence beaked whale detections. When considering candidate species identity, the mean depth for Cuvier's beaked whale clicks was 783 m (299–

1,588 m; standard deviation [SD] = 399 m) and for Gervais' was 661 m (252–1,384 m; SD = 309 m). Where available, depth estimates were used to correct the slant range estimates made in PAMGuard to derive perpendicular distances to the trackline. There was broad agreement between the estimates of slant range and the corrected perpendicular distances (linear regression $R^2 > 0.99$).

A subset of 51 on-track acoustic detections were included in subsequent estimation of encounter rate, 12 from the winter cruise and 39 from the spring cruise. Preliminary investigation comparing a model without any covariates to a model containing candidate species identity suggested species identity did not improve the fit of the model, based on AIC score, in either the winter or spring cruise. There were too few detections to fit detection function models to each cruise and/or candidate species independently, so the data were pooled across surveys and species to derive a global detection function. An additional 44 off-track detections were incorporated to estimate detection functions and increase the sample size ($n = 95$). The corrected perpendicular distance data were right truncated at 4,000 m prior to the analysis, excluding 4 % of the largest distance estimates.

Of the eight 'effort covariates' initially considered for improving the detection function, four were excluded for being significantly correlated ($p < 0.05$) with at least one other, leaving swell height, engine revs, vessel heading, and SST for inclusion in modeling of the detection function. A hazard rate key function with a cosine adjustment term produced a detection function with the closest fit to the distance estimates based on AIC scores. The covariate 'cruise ID' did not improve the model fit, suggesting the detection probability of beaked whales did not vary between winter and spring. Regression analysis suggested there was little distance-dependent variation in the cluster sizes estimated subjectively; cluster size did not subsequently improve model fit. Inclusion of swell height and SST had the most pronounced effect on the detection function and were subsequently included in the final model, as they derived the lowest AIC score. An increase in swell height tended to be associated with an increased likelihood of acoustically detecting beaked whales (i.e., a broadening of the detection function). Lower SST was also linked to broader detection functions. The EShW was 1,906 m with a coefficient of variation (CV) of 8.1% (confidence interval [CI] 1,623–2,240).

We estimate densities both with and without a correction for availability. Following the approach of Barlow et al. 2013, g(0) for Cuvier's beaked whale was estimated as 0.43 (CV 0.03). This estimate was used as a multiplier in the MCDS analysis to correct for availability in density estimation (Table 3.3). As only 6 of the 10 survey transects were fully surveyed in the winter cruise, abundance was only estimated for the smaller study block that received survey effort. During the spring survey, all 10 transects were fully surveyed, and thus abundance could be estimated for the entire study area. However, to provide a seasonal comparison, abundance was also estimated for the smaller block containing only the six southernmost transects ("reduced" in Table 3.3).

Table 3.3. Density and abundance estimates for both winter and spring cruises.

Cruise	Area (km²)	CV %	Density (per/km²)	Abundance (N)
1: Winter	99,300	57.1	0.0075 (0.0022–0.0252)	743 (221–2,497)
2: Spring (reduced)	99,300	51.2	0.0063 (0.0022–0.0183)	623 (213–1,821)
2. Spring (all transects)	181,190	28.9	0.0164 (0.0088–0.0303)	2,963 (1,597–5,497)
TOTAL (reduced)	198,600	39.3	0.0069 (0.0031–0.0153)	1,366 (615–3,036)
TOTAL (all transects)	280,474	25.5	0.0137 (0.0081–0.0231)	3,831 (2,262–6,489)

Notes: The detection function was modeled using a hazard rate key function with a cosine adjustment term. Estimates are corrected for acoustic availability, with g(0) = 0.43. Values in parentheses for density and abundance represent 95% confidence limits. For comparative purposes, a reduced analysis is presented for the spring survey using the same six transects surveyed in winter.

Because beaked whale detections were only evident on 26 segments across both surveys, the DSM procedure in the second analytical stage pooled the 503 segments from both surveys and considered the dataset to represent a single survey period (i.e., January to June). This analysis used the global detection function estimated in the MCDS analytical stage (i.e., a hazard rate key function incorporating swell and SST as covariates). The final DSM model selected included the variables mean slope and mean SST (averaged from January to June), the former having the most pronounced effect on the model. Both covariates were considered significant ($p < 0.01$) and explained 21.5% of the deviance in the model. Densities were highest in regions of steepest slope (> 4°) and in those areas with coolest SST (< 22°C; Figure 3.6). The DSM derived an abundance estimate of 1,821 beaked whales (CV 0.32) over the course of the two surveys when corrected with a g(0) of 0.43 (Barlow et al. 2013) (Figure 3.7).

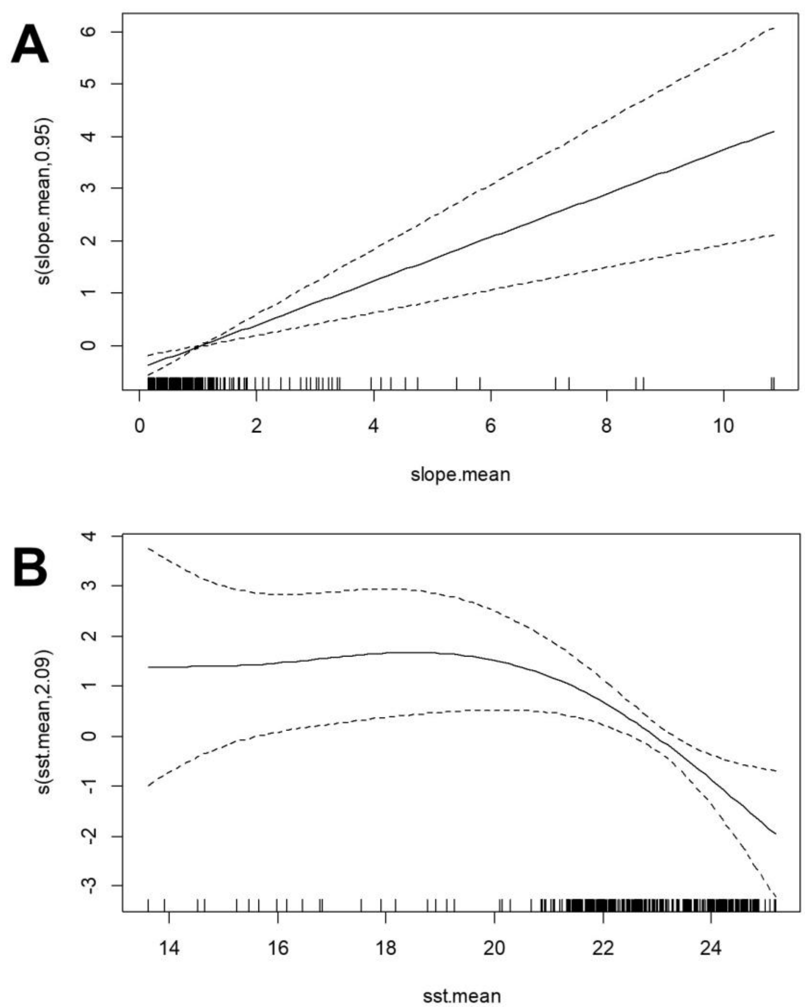


Figure 3.6. Plot of the GAM smooth fit of density across (A) slope and (B) mean SST (°C) averaged from January to June for both cruises (winter and spring) pooled.
The solid line represents the best fit; the dashed lines representing 95% CIs. Vertical lines on the x-axis are observed data values.

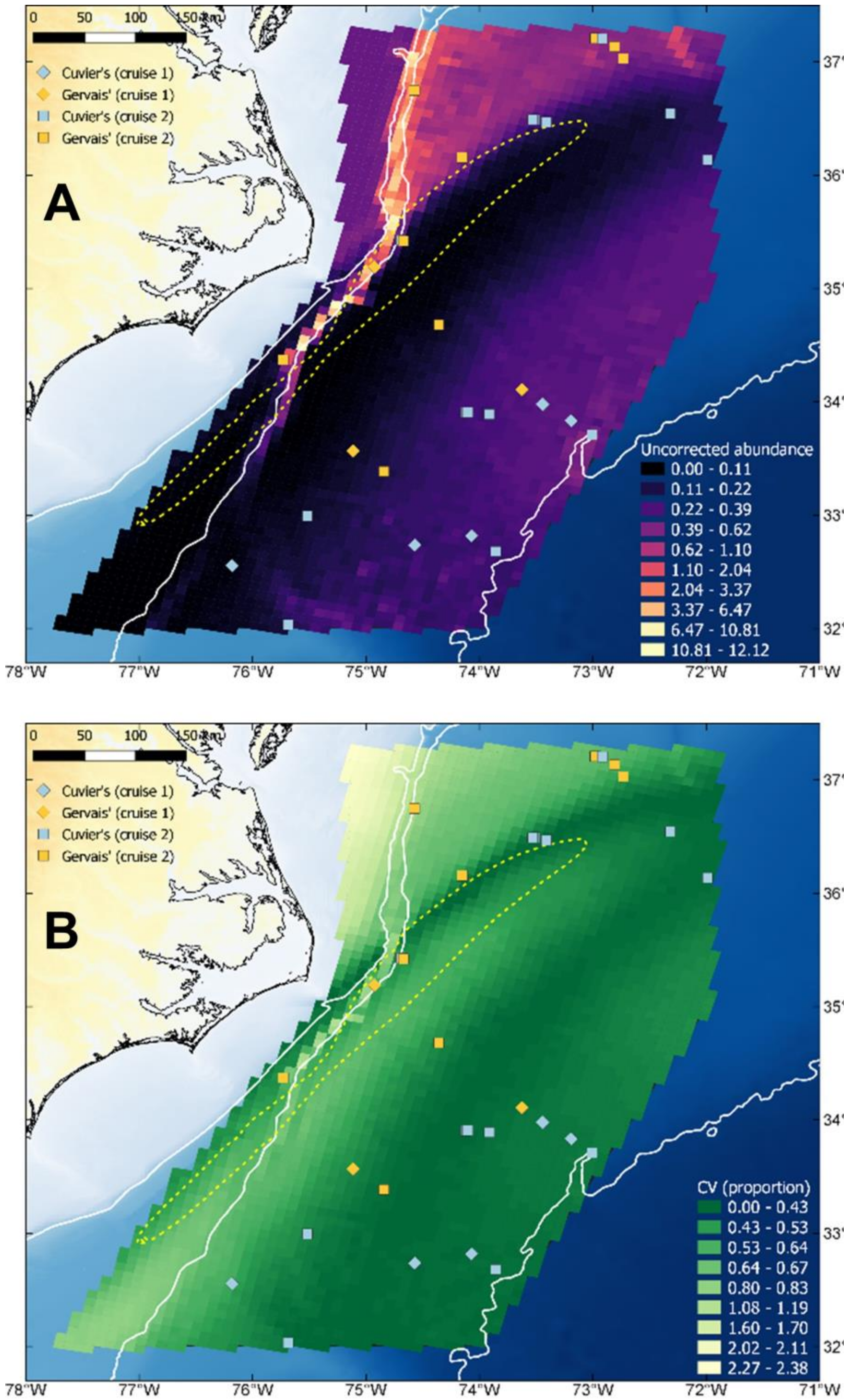


Figure 3.7. Density surface map showing (A) corrected abundance and (B) corresponding coefficients of variation for the study area.

On-track candidate Cuvier's beaked whale events are blue (*n* = 29), candidate Gervais' beaked whales are orange (*n* = 22). The 125 m, 1,000 m and 5,000 m isobaths are shown. Water velocities greater than 1 ms^{-1} (averaged from January to June) are represented by a yellow dashed contour.

3.1.2.2 Sperm Whales

We acoustically detected a total of 238 individual sperm whales on the transects during the two surveys (Figure 3.8): 115 during the winter Cruise 1 (with a further 65 off-track detections) and 123 during the spring Cruise 2 (with a further 99 off-track detections). As stated above, visual sightings were not used for density estimation due to the low sample size.

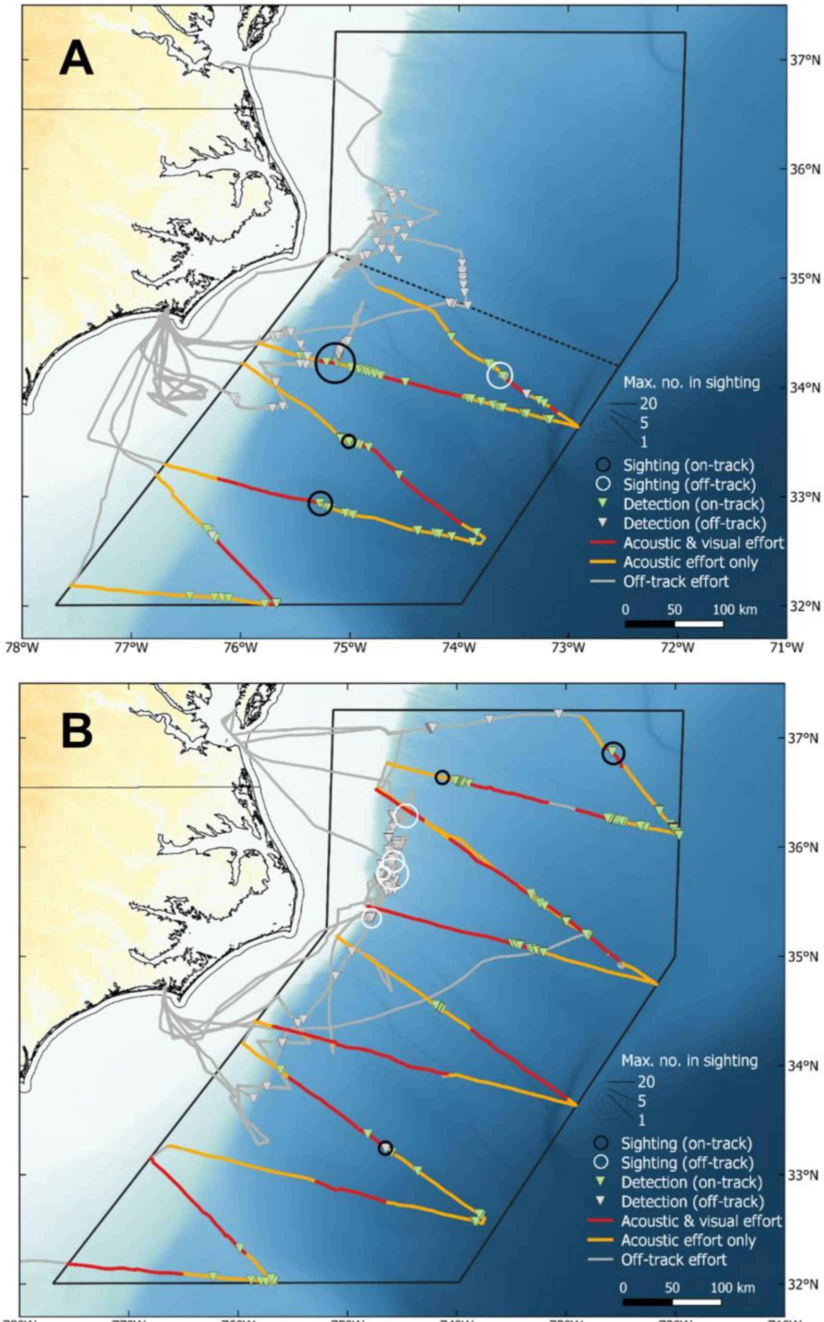


Figure 3.8. Acoustic detections of individual sperm whales (on-track = green triangles; off-track = gray triangles) during (A) the winter Cruise 1 and (B) spring Cruise 2.
Sightings of sperm whale groups are shown as black (on-track) or white (off-track) circles (areas proportional to the maximum estimates of group size). Survey effort on tracklines is categorized as either joint acoustic-visual or acoustic-only. The dotted line in (A) marks the truncated area used for the estimate of winter abundance.

Acoustically modeling sperm whale density requires an understanding of their acoustic availability. We utilized data from the single successful DTAG of a sperm whale from the spring Cruise 2 to gain insights into this critical metric. The DTAG was successfully deployed and recovered after approximately 7 hours, on 16 March 2019. The tagged individual was believed to be male based upon estimated total body length, which was 10.5 m (via photogrammetry) and 11.2 m (via acoustic length estimation) (Section 3.1.3). The tagged sperm whale undertook four deep foraging dives, with three corresponding silent inter-dive periods spent at the surface. This individual then stayed at or near the surface for approximately 3 h 13 min without vocalizing before the tag detached (Figure 9). This latter behavior is analogous to the ‘head-down’ drift-dives reported from various parts of the world (Miller et al. 2008), whereby a whale will dive head-down to a position one to two body lengths below the surface before passively turning head-up and remaining in that position for some time. Although drift-dives were identified in 53% of the tags investigated by Miller et al. (2008), they typically only accounted for 7.1% of recording time. In contrast, the drift-dive shown in Figure 9 accounted for 50.7% of the total tag deployment. Because it is not known if this short tag deployment provides a representative characterization of sperm whale diving behavior in this region, acoustic availability was estimated both without the drift dive (termed here the “typical” estimate, using only the first 3 h 18 min of the deployment), and with the drift dive (termed here the “atypical” estimate using the full 6 h 31 min dataset).

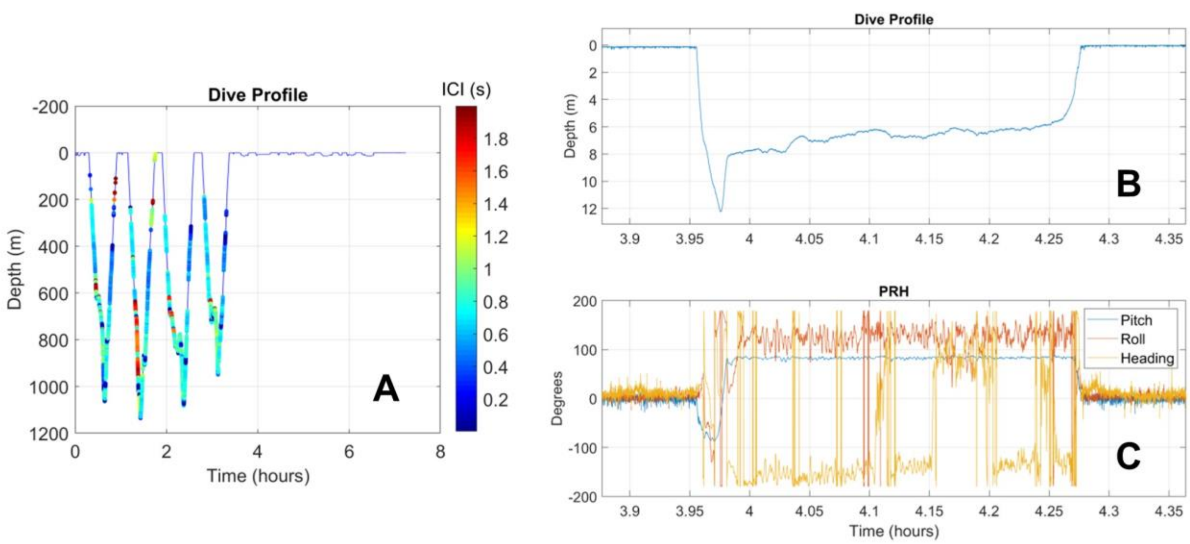


Figure 3.9. Summary of the single DTAG deployed and recovered from a sperm whale on 16 May 2019 during the spring Cruise 2.

Notes: (A) Full time-depth record of the tagged whale. Vocalizations are represented by thicker traces with colors relating to ICI; feeding buzzes appear as dark blue regions. (B) A representative section of the time-depth record displaying the whale’s acoustically silent “drift-dive”. In total, the whale stayed within 15 m of the surface for ~3 h 13 min without vocalizing. (C) A record of the individual’s attitude in the water—including pitch, roll, and heading—during the same period shown in (B).

Estimates of acoustic g(0) were calculated for an EShW of 3.5 km and the average on-track survey speed of 5.6 knots for both the winter and spring cruises. The Monte Carlo simulation exercise estimated the typical g(0) as 0.872 (SD = 0.069) and the atypical g(0) as 0.600 (SD = 0.099). Both estimates were used to scale subsequent density and abundance estimates.

All on-track detections of sperm whales (n = 238) were included in subsequent estimation of encounter rate. Initial investigation comparing an MCDS model without covariates to a model containing cruise identity improved the fit of the model, suggesting the detection probability of sperm whales varied between winter and spring. Detections functions therefore were fitted to each cruise independently. The slant range data were right truncated at 8,000 m prior to the analysis, which excluded 3% of the largest distance estimates.

Of the eight 'effort covariates' initially considered for improving of the detection function, four were excluded for being significantly correlated ($p < 0.05$) with at least one other, leaving swell height, engine revs, vessel heading, and SST for inclusion in the detection function. For the winter cruise, a half-normal key function without adjustment provided the closest fit to slant range estimates based on AIC scores; for the spring cruise, a hazard rate key function without adjustment was selected. Inclusion of SST had the most pronounced effect on the detection function for the winter cruise, with lower sea surface temperatures associated with an increased likelihood of acoustically detecting sperm whales (i.e., a broadening of the detection function). Swell height was included in the spring detection function, as a decrease in swell height tended to be linked to a broadening of the detection function. The estimated EShW for the winter cruise was 4,258 m with a CV of 7.0 % (CI 3,710–4,888); for the spring cruise it was 3,190 m with a CV of 7.5 % (CI 2,750–3,670).

Densities were estimated with a correction for availability. The estimates of both typical and atypical g(0) described above (0.87 and 0.60, respectively) were used as multipliers in the MCDS analysis to correct for availability in density estimation (Table 3.4). As only the 6 southernmost of the 10 tracklines were fully surveyed during the winter Cruise 1, abundance was only estimated for this smaller study block. During the spring survey, all 10 transects were fully surveyed, and thus abundance could be estimated for the entire study area. However, to provide a seasonal comparison, abundance was also estimated for the smaller block containing only the six southernmost transects ("reduced" in Table 3.4).

Table 3.4. Density and abundance estimates derived using MCDS for both winter and spring cruises.

Cruise	Area (km^2)	CV %	Density (per/1,000 km^2) (Typical)	Abundance (N) (Typical)	Density (per/1,000 km^2) (Atypical)	Abundance (N) (Atypical)
1: Winter	99,300	28.9	10.46 (5.17–21.14)	1,038 (514–2,099)	15.2 (7.52–30.73)	1,509 (747–3,051)
2: Spring (reduced)	99,300	38.9	3.70 (1.52–8.99)	367 (151–893)	5.38 (2.21–13.07)	524 (220–1,297)
2: Spring (all transects)	181,190	30.7	8.89 (4.35–17.31)	1,610 (827–3,137)	12.92 (6.63–25.17)	2,341 (1,202–4,560)

Notes: Estimates are corrected for both typical acoustic availability (with a g(0) = 0.872) and atypical availability (with a g(0) = 0.60). Values in parentheses for density and abundance represent 95% confidence limits. For comparative purposes, a reduced analysis is presented for the spring survey using the same six transects surveyed in winter.

Sperm whale detections were evident on 44 of 183 segments during winter Cruise 1 and 37 of 320 segments during spring Cruise 2. As the MCDS analysis suggested different detection functions should be used for each cruise, the DSM procedure was also conducted separately for the winter and spring cruises and used the same relevant detection functions estimated in the MCDS analytical stage for each cruise. The final DSM model selected for winter Cruise 1 included a bivariate of position and mean slope (° horizontal), as these were deemed to have the most pronounced effect on the model; both covariates were considered significant ($p < 0.05$) and explained 32% of the deviance in the model (Figure 3.10). Densities were highest towards the center of the study block in regions of low slope (< 2°; Figure 3.11). The DSM derived a corrected winter abundance estimate of 1,055 sperm whales with a CV of 28.6% (CI 609–1,828) when corrected with the typical g(0) of 0.872; this estimate rose to 1,534 (CI 914–2,573) when corrected with the atypical g(0) of 0.600. The final DSM model selected for spring Cruise 2 included a bivariate of position and mean SST; both covariates were considered significant ($p < 0.001$) and explained 54 % of the deviance in the model (Figure 3.12). Densities were highest towards the northeast of the study block and in regions of low SST (< 23°; Figure 3.13). The DSM derived a corrected spring abundance estimate of 1,587 sperm whales with a CV of 26.9 % (CI 946–2,663) when corrected with the typical g(0), which rose to 2,307 (CI 1,375–3,871) when corrected with the atypical g(0).

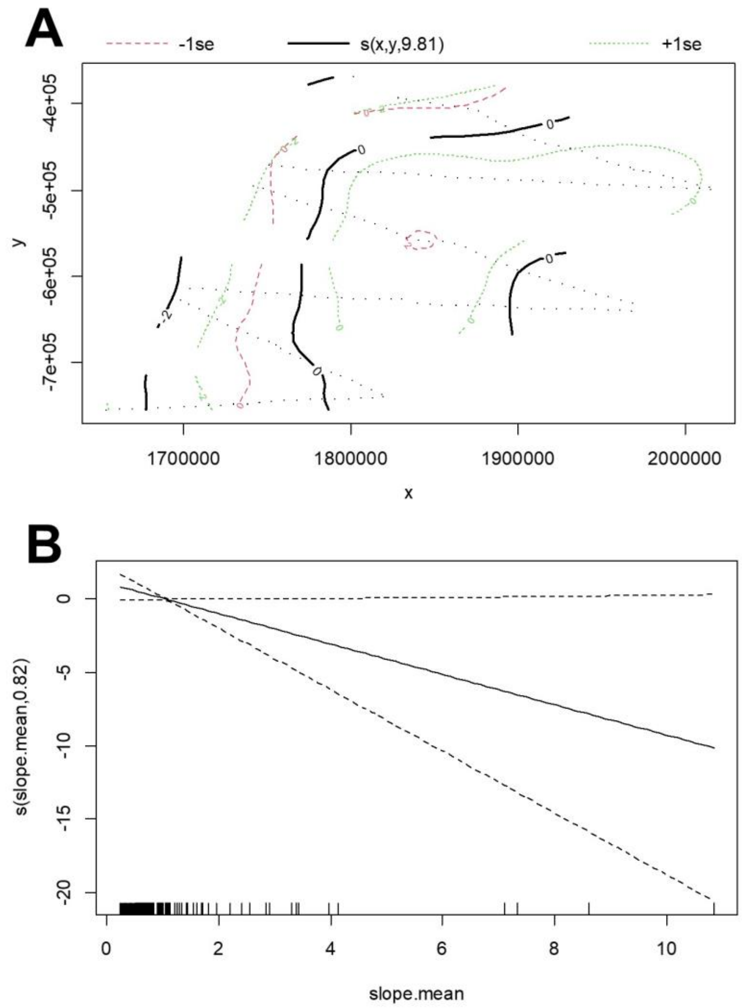


Figure 3.10. Plot of the GAM smooth fit of density across (A) position and (B) mean slope (°) during winter Cruise 1.
The solid line represents the best fit; the dashed lines represent 95% CIs. Vertical lines on the x-axis of (B) are observed data values.

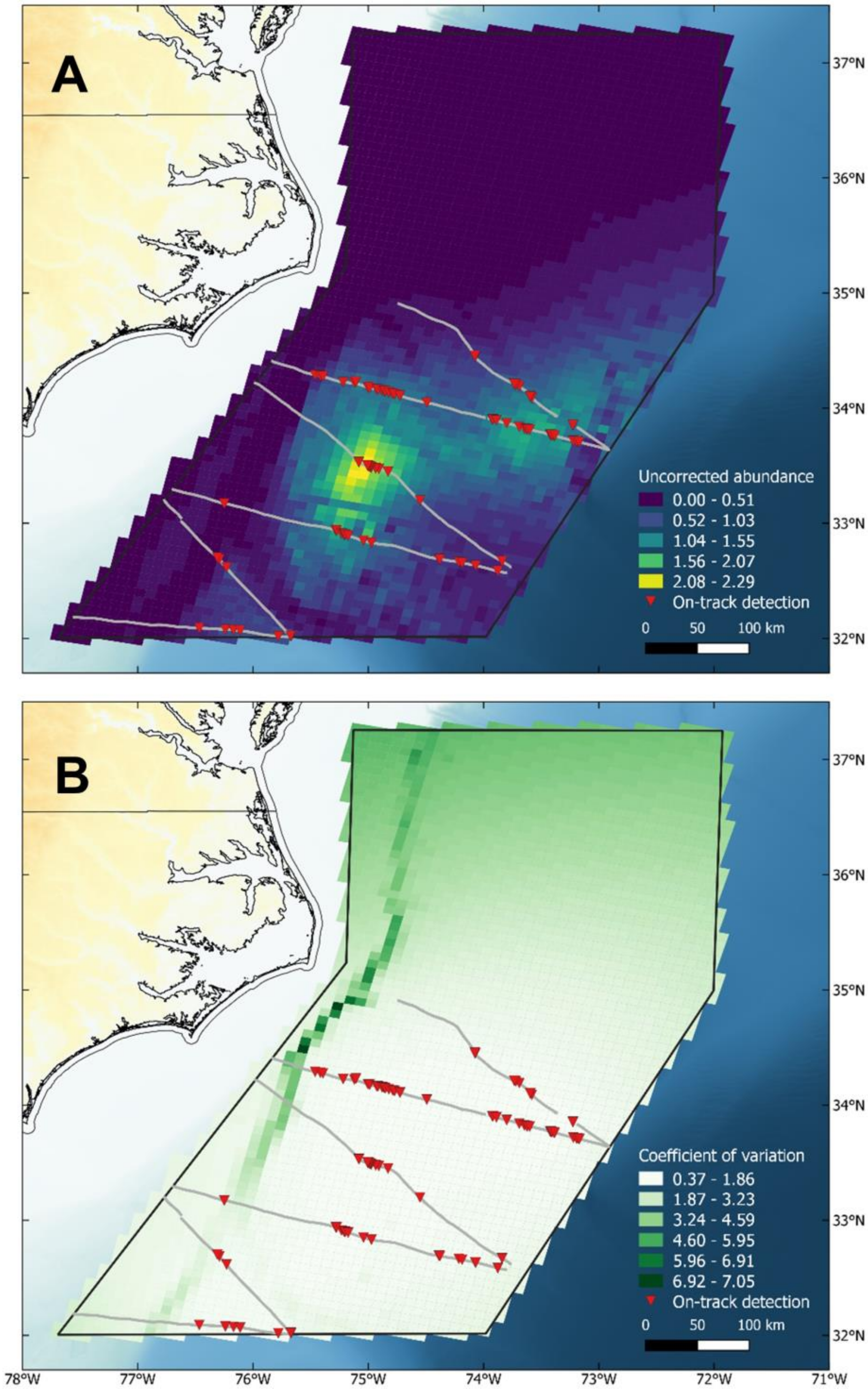


Figure 3.11. Density surface map showing (A) uncorrected abundance and (B) corresponding coefficients of variation for winter Cruise 1.

Red triangles = on-track sperm whale individuals (n = 115); gray lines = segments with on-track acoustic effort.

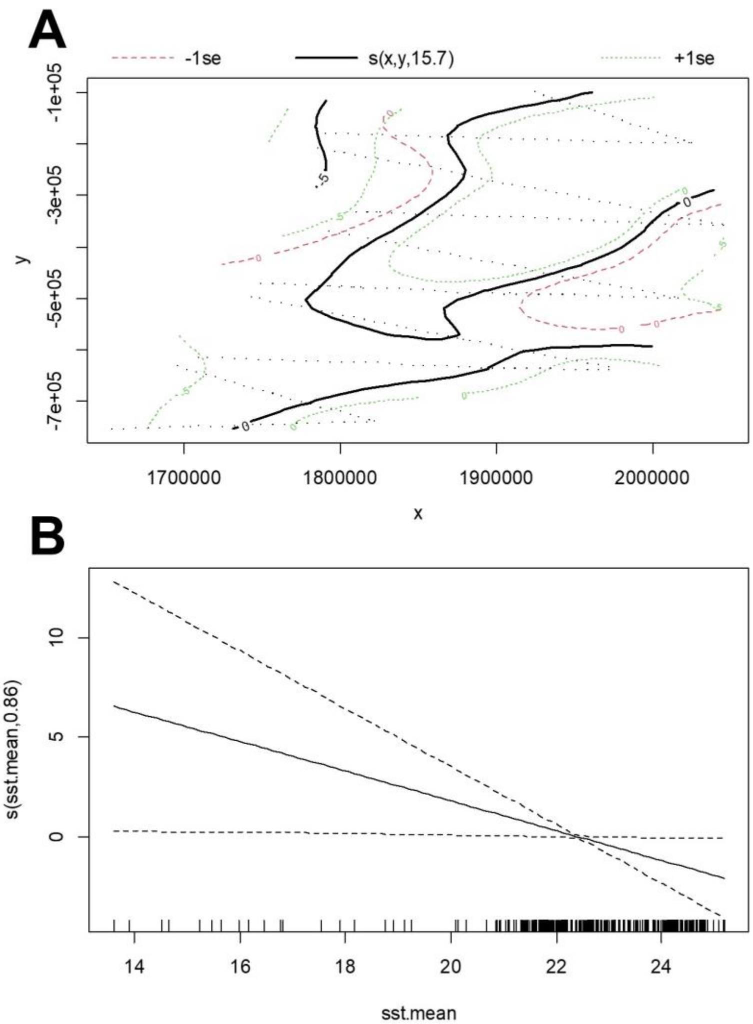


Figure 3.12. Plot of the GAM smooth fit of density across (A) position and (B) mean SST (°C) during spring Cruise 2.
The solid line represents the best fit; the dashed lines represent 95% CIs. Vertical lines on the x-axis of (B) are observed data values.

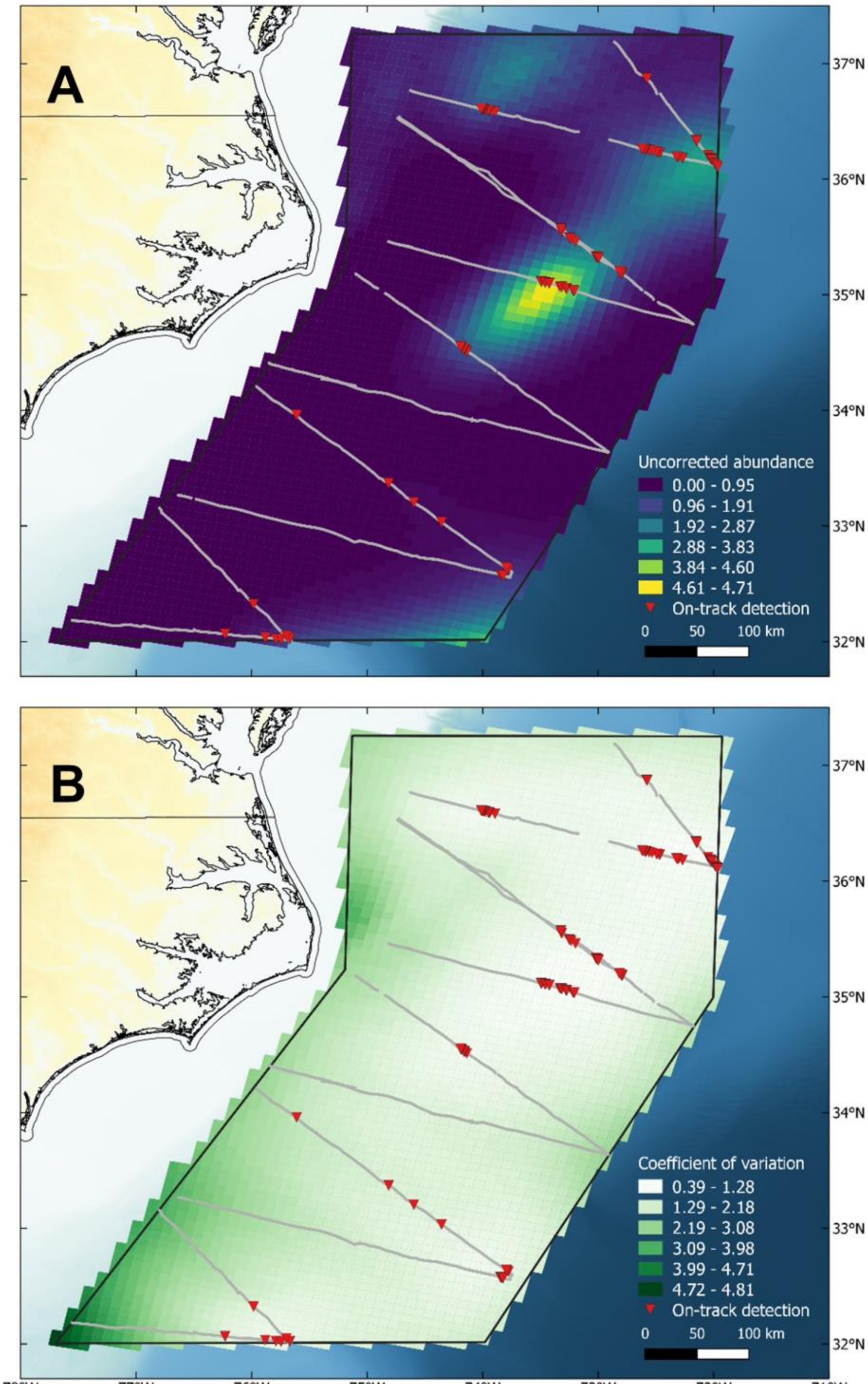


Figure 3.13. Density surface map showing (A) uncorrected abundance and (B) corresponding coefficients of variation (below) for spring Cruise 2.
Red triangles = on-track sperm whale individuals (n = 123); gray lines = segments with on-track acoustic effort.

3.1.3 Photogrammetry and CABLE Estimates of Sperm Whale Size

The acoustic and visual sightings of sperm whales during both winter and spring surveys described above in Section 3.1.2 provided the data used to estimate total body lengths of whales encountered. The specific locations of encounters utilized for the photogrammetry and CABLE analytic methods are shown in Figure 3.14.

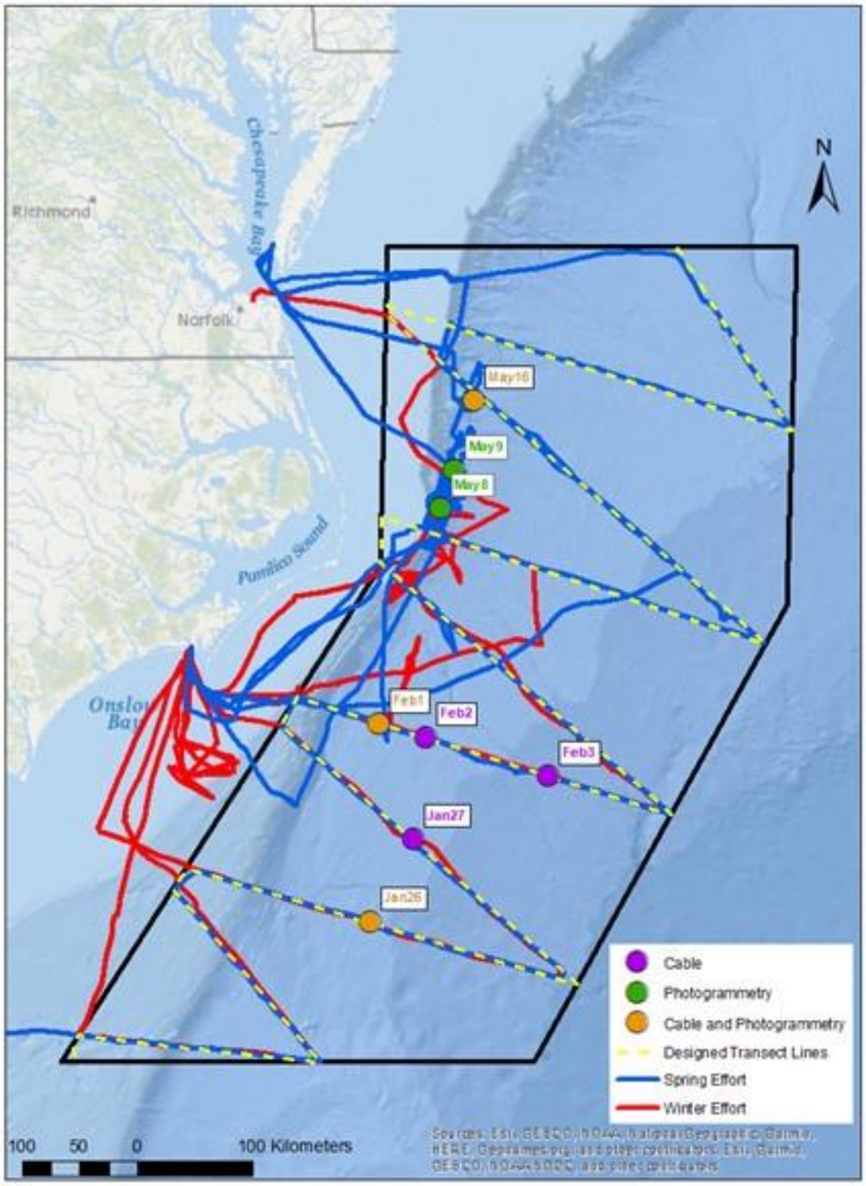


Figure 3.14. Tracklines designed for both winter and spring surveys (dashed yellow line). Map shows the realized transects surveyed by, and transit paths of, RV *Song of the Whale* during winter (red line) and spring (blue line) surveys. Locations of sperm whales with length estimations from CABLE, photogrammetry, or both, are marked by points and labelled with date of recordings.

On three separate survey days, sperm whale individuals or groups were identified using the CABLE software program and were simultaneously available for photogrammetric analysis (Figure 3.14). On 26 January, a small group of sperm whales was encountered late in the day. There were at least two adult females observed with calves, and a notably larger individual, present. On 1 February, a group of at least

16 individuals was encountered. Based on visual observations, there were several adult females and/or immature males; at least one large, scarred adult; and a few small calves present. During this encounter, one adult individual was tagged with a DTAG (although this tag was not recovered), and the group was subsequently followed for several hours. Numerous photographs were taken of this group, including a breaching calf. On 16 May, a large sperm whale, which was easily identified by its missing half fluke, was tagged with a DTAG. This tag was deployed for approximately 7 h and recovered (Section 3.1.2). This distinct individual provided a rare opportunity to directly compare individual acoustic vocalizations with photographic measurement.

3.1.3.1 PAM and CABLE Estimates of Sperm Whale Size

The acoustic recordings made during both the winter and spring cruises (906 and 850 hours, respectively) were run through the software program CABLE, using methods outlined in Beslin et al. (2018). The CABLE software identified 25 individual sperm whales ranging in size from 3.8 m to 12.1 m over six different survey days (Table 3.5).

CABLE provided six separate size estimates for the DTAG-ed individual encountered on 16 May, ranging from 12.0 m to 12.3 m. Because this was the only extended encounter during which it was known that the acoustic recordings analyzed by CABLE were of the same individual, all six estimations were combined to create an average for each of the growth models (Table 3.5).

Table 3.5. Length estimates for sperm whales based upon CABLE software analyses.

Date	# Individuals	Gordon 1991 (m)	Growcott 2011 (m)	Regional GE (m)	Mean IPI (and SD) (ms)
26 January	3	8.1 8.3 9.1	8.5 8.7 9.4	7.5 7.9 9.3	2.2 (±0.03) 2.4 (±0.03) 2.9 (±0.03)
27 January	3	8.3 8.5 8.9	8.7 9.0 9.2	7.9 8.4 9.0	2.4 (±0.02) 2.6 (±0.02) 2.8 (±0.02)
1 February	12	6.3 6.7 7.3 7.6 7.9 8.2 8.5 8.8 9.0 9.4 9.6 9.9	7.0 7.3 7.9 8.2 8.4 8.6 8.9 9.2 9.3 9.7 9.9 10	*3.8 *4.6 *6.0 *6.6 7.3 7.7 8.3 8.8 9.1 9.8 10.2 10.5	(±0.04) (±0.04) 1.7 (±0.04) 1.9 (±0.04) 2.1 (±0.04) 2.3 (±0.04) 2.5 (±0.04) 2.7 (±0.04) 2.9 (±0.04) 3.1 (±0.04) 3.3 (±0.04) 3.5 (±0.04)
2 February	1	9.3	9.6	9.6	3.1 (±0.02)
3 February	4	7.8 8.8 9.2 9.4	8.3 9.1 9.5 9.7	7.0 8.7 9.5 9.8	2.0 (±0.05) 2.7 (±0.05) 3.0 (±0.05) 3.2 (±0.05)
16 May	1	11.2	11.2	12.1	4.4 (±0.05)

Notes: Length estimates (m) and corresponding IPI (ms), for sperm whales encountered during both winter and spring surveys. Length estimates calculated from Gordon (1991), Growcott et al. (2011), and the regional GE developed for this study. *Individuals identified using custom lower bound IPI parameter of 1 ms.

3.1.3.2 Photogrammetry Estimates of Sperm Whale Size

We conducted photogrammetry as an opportunistic analysis; therefore, few photographs met the required criteria for calculating animal size. From these photographs, length estimates were calculated for 49 individuals from five different days (Table 3.6). These individuals were calculated to range in size from 4 m to 18 m. Each photograph was considered to represent a unique individual or group as we could not be certain of repeat sampling, except in the case of the DTAG-ed whale on 16 May. For the 16 May individual, two photographs that met the photogrammetric analysis parameters were analyzed, with estimates of 10.4 m and 10.5 m, and the mean length estimate from the two photographs is reported in Table 3.6.

Table 3.6. Length estimates for sperm whales based upon photogrammetric analyses for 49 individuals from photographs that met evaluation criteria using the regional GE.

Date	# Photographs	Regional GE (m)
26 January	15	4.2–15.9
1 February	30	4.3–18.0
8 May	2	7.7; 10.2
9 May	4	10.04–1.15
16 May	2	10.5

3.1.4 eDNA Analyses

At the Marine Conservation Molecular Facility at the Duke University Marine Lab, Ms. Anna Clabaugh and several students tested extraction protocols used to remove DNA from the frozen sample filters collected during the MAPS 2019 research cruises. Test extractions, using seawater from the lab's urchin tanks, was deemed successful. Next, Dr. Tom Schultz, Director of the Marine Conservation Molecular Facility at the Duke University Marine Lab, and Ms. Clabaugh used low priority samples taken during the cruises to test the cetacean-specific PCR primers developed by Dr. Schultz and students Ms. Marissa Cartee and Mr. Jack Nowacek. These primers were designed to amplify the DNA from any cetacean species so we could detect as wide a variety of cetaceans as possible. Once the fall 2020 test extractions of eDNA from the cruise samples were successful, more samples were extracted in December 2020. In addition to the 'sighting' samples, 'transect' samples for eDNA were also tested; 'transect' samples were those collected at regular intervals along the sampling transects, which were different from the 'sighting' samples that were collected at or near the location of visual sightings. After confirming that some DNA had been amplified in the PCR with the cetacean-specific primers, we created barcoded PCR products for these eDNA samples and prepared them to be sequenced in house using Nanopore technologies. At the time, the Nanopore system was just coming online, so after about five test runs, the first successful run of sequencing on the Nanopore system on the cetacean samples and subsequent analysis of the sequences revealed the amplification of fin whale DNA from one of the 'sighting' samples and of bottlenose dolphin DNA from one of the 'transect' samples. These results were preliminary, but the Nanopore system successfully read > 200,000 sequences from the control region, CO1, and the 16S amplicons from 12 samples.

3.1.5 Thermal Imaging of Sperm Whales

Ms. Laura Murley opportunistically collected infrared thermal images of short-finned pilot whales, but sperm whales were the most intensely imaged (n = 22 thermal images across a number of individuals).

The results of the sperm whale thermal imaging work were presented as a poster at the World Marine Mammal Conference (Appendix E). In brief, infrared thermography demonstrated that the sperm whale body surface is thermally dynamic and heterogeneous (Figure 3.15). The single analysis of a time series of IR thermal images, collected over a 10-minute period from the first DTAG-ed sperm whale, demonstrated warming of the whale's body surface, as would be predicted, with time spent in the relatively warm surface waters (Figure 3.16). The goal of correlating body surface temperatures with diving behavior was not accomplished because the DTAG was not recovered from the sperm whale for which the time-series was collected. These thermal profiles, though, provide baseline data for future studies to (a) test the efficacy of IR as a detection tool for (e.g., Smith et al. 2020), and (b) directly measure the response of deep divers to anthropogenic stressors such as seismic surveys.

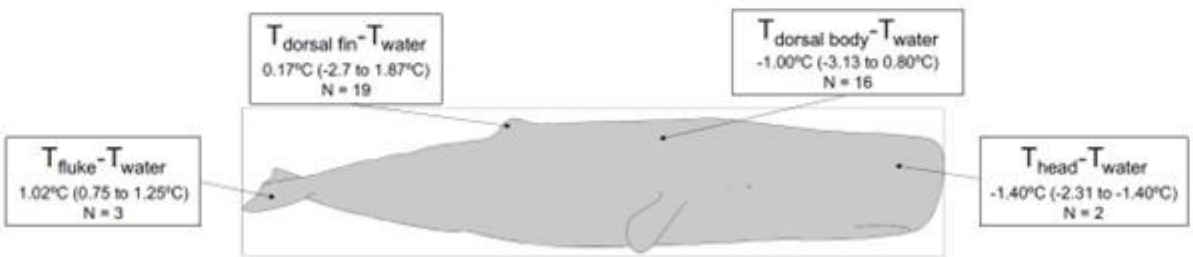


Figure 3.15. Mean (range) of temperature differences between body surfaces and surface waters across all infrared thermal imaged sperm whales.
A total of 22 images were collected for all sperm whales. Body surfaces ranged from -1.40ºC cooler to 1.40ºC warmer than surface waters.

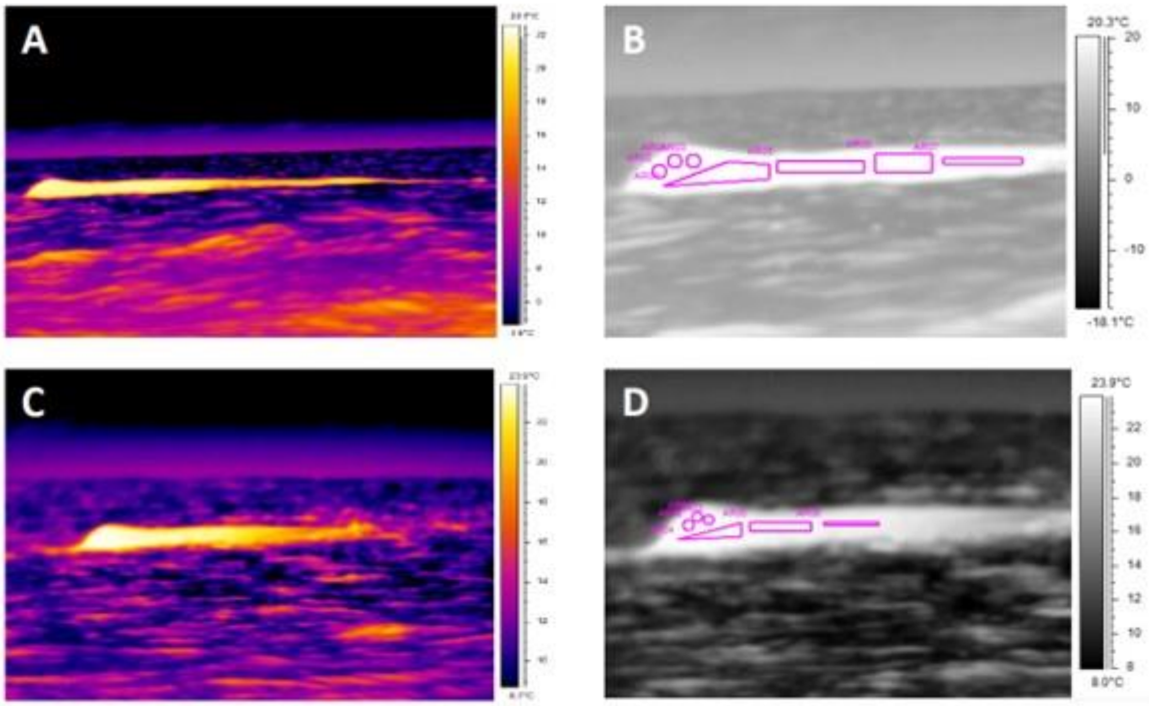


Figure 3.16. A single DTAG-ed sperm whale, tracked over a 10 min period at the surface, displayed warming of the dorsal fin and dorsolateral body.

Images A and C are shown using a pseudo-color “iron” palette to emphasize variation in temperature. All analyses were carried out on gray scale images (B and D), where body margins were more easily determined. (A & B) Images of surfacing whale following a dive. Dorsal fin 1ºC cooler and dorsal body 1.4ºC cooler than water. (C & D) Images of the same whale logging at the surface 10 minutes post-dive. Both dorsal fin and dorsal body had warmed. Dorsal fin now 1ºC warmer and dorsal body 0.6ºC warmer than water. Detailed diving behavior not determined because D-tag was not recovered.

3.1.6 Deployment of the 3D Passive Acoustic Array Along North Carolina Shelf and OCS Waters in 2022

The final MAPS research cruise took place aboard the RV *Shearwater*, captained by Matthew Dawson, from 5–9 July 2022. We departed Beaufort at 14:00 EDT on 5 July and arrived back at the Duke University dock at 11:30 EDT on 9 July. Rather than continue the survey back to Beaufort from offshore throughout our last day, we transited back on the evening of 8 July due to inclement weather and high sea states. The research team included Richard McLanaghan and Olly Boisseau (MCR); Danielle Waples, Danielle Alvarez, Anne Harshbarger, and Allie Lopez (Duke); and Ann Pabst (UNCW). The goal was to deploy the 3-D hydrophone array to acoustically monitor deep diving beaked and sperm whales. The cruise occurred during, and in coordination with, on-going studies by Duke University colleagues focused on satellite tagging multiple Cuvier’s beaked whales (*Ziphius cavirostris*). We received daily updates on the location of previously satellite-tagged *Z. cavirostris*, which permitted us to target areas of known beaked whale distribution. Although the RV *Shearwater* was equipped with a goniometer, we did not receive signals from any of the tagged whales during the cruise. However, we did have multiple beaked and sperm whale encounters, as well as encounters with three species of delphinids (Figure 3.17) and multiple successful deployments of the 3-D array.

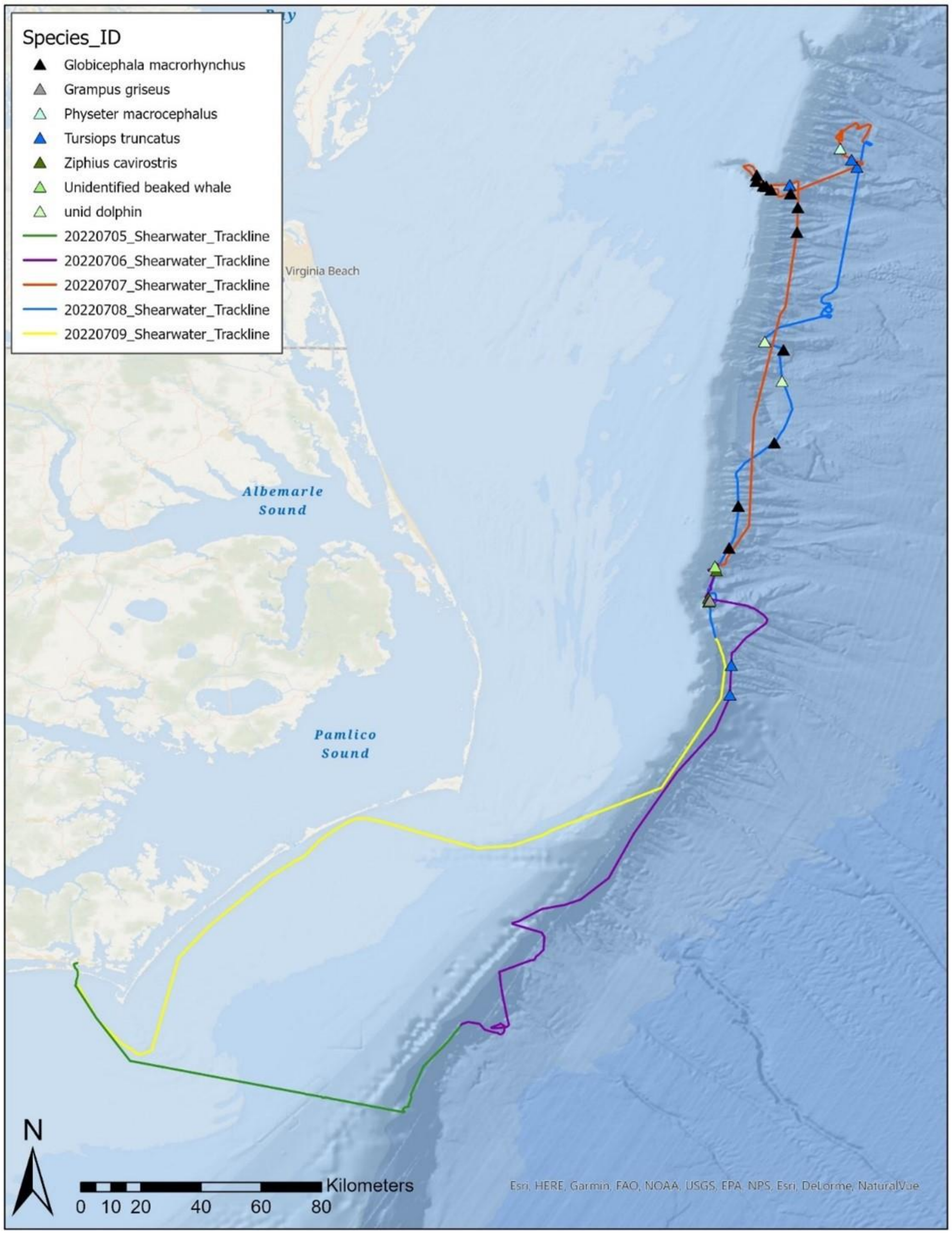


Figure 3.17. Cruise tracks and visual sightings aboard RV *Shearwater* during 5–9 July 2022 cruise.

The research team utilized both visual and passive acoustic monitoring methods to detect cetaceans during the cruise. Visual observers, in rotating teams, were posted throughout the daylight hours (Table 3.7). Acoustic surveys were conducted 24 hours a day for virtually the entire cruise, using the same linear hydrophone array as was used during the 2019 MAPS cruises. When either visual (Table 3.8, Figure 3.17) or acoustic detections were made, we deployed the 3-D acoustic array to gain more detailed spatial and temporal information on the diving odontocetes. The 3-D array was deployed for a total of 35 hours over the course of the cruise.

Table 3.7. Summary of visual observations effort aboard RV *Shearwater* during 5–9 July 2022 cruise.

Date	Sea State	Survey Time	Sightings	Images Taken
5 July	2–3	2:33	0	0
6 July	3–5	13:30	4	29
7 July	2–3	13:15	12	401
8 July	2–3	11:47	9	103

Table 3.8. Summary of cetacean sightings aboard RV *Shearwater* during 5–9 July 2022 cruise.

Date	Time (GMT)	Site #	Sea State	Species	Group Size	Latitude	Longitude	Depth (m)
6 July	15:12:47	1	4	*T. truncatus*	15	35.51861	-74.72133	1,600
6 July	15:46:57	2	4	*T. truncatus*	30	35.60707	-74.71724	-
6 July	20:27:52	3	3	*Z. cavirostris*	5	35.88913	-74.76163	1,250
6 July	22:24:49	4	3	Unidentified beaked whale	2	35.90224	-74.76582	1,215
7 July	10:48:44	1	2	*G. macrorhynchus*	5	36.89898	-74.52088	-
7 July	11:40:47	2	2	*G. macrorhynchus*	7	36.97255	-74.51837	1,150
7 July	12:47:28	3	3	*T. truncatus*	5	37.03992	-74.54266	1,216
7 July	13:21:29	4	3	*G. macrorhynchus*	4	37.03604	-74.61271	-
7 July	13:27:13	5	3	*G. macrorhynchus*	7	37.03761	-74.62150	500
7 July	13:43:58	6	3	*G. macrorhynchus*	50	37.05160	-74.64276	-
7 July	14:47:09	7	3	*G. macrorhynchus*	55	37.06898	-74.64116	450
7 July	15:26:57	8	3	*G. macrorhynchus*	6	37.02580	-74.59866	246
7 July	16:10:46	9	3	*G. macrorhynchus*	6	37.01453	-74.54012	750
7 July	17:40:30	10	3	*T. truncatus*	8	37.09325	-74.34203	1,600
7 July	18:04:22	11	3	*T. truncatus*	4	37.11568	-74.35797	-
7 July	18:29:33	12	3	*P. macrocephalus*	2	37.14866	-74.39193	-
8 July	12:44:29	1	3	Unidentified dolphin	20	36.57278	-74.61716	-
8 July	13:44:10	2	3	*G. macrorhynchus*	6	36.54782	-74.56132	1,500
8 July	14:04:16	3	3	Unidentified dolphin	6	36.45482	-74.56572	1,600
8 July	14:40:46	4	3	*G. macrorhynchus*	3	36.27074	-74.58876	1,500
8 July	16:05:05	5	2	*G. macrorhynchus*	1	36.08207	-74.69639	1,077
8 July	17:24:28	6	2	*G. macrorhynchus*	4	35.95666	-74.72382	888
8 July	18:54:15	7	2	*Z. cavirostris*	4	35.80741	-74.78519	-
8 July	21:02:18	8	2	*Z. cavirostris*	1	35.79561	-74.78460	-
8 July	22:35:06	9	2	*G. griseus*	20	35.80001	-74.78076	1,016

During the cruise, *Z. cavirostris* was visually detected three times, and an unidentified beaked whale species was visually detected once (Table 3.8). The acoustic arrays detected all the visually sighted beaked whales and an additional group of 2–3 unidentified beaked whales that were not visually detected. There was one sighting in which sperm whales were detected both visually and acoustically; sperm whales were also acoustically detected twice with no associated visual detections the cruise (Table 3.9).

The field conditions encountered during the research cruise, including periods of relatively high sea states and the high flow regime of the Gulf Stream, provided a challenging testing environment for the 3-D array. The results demonstrated the efficacy of the 3-D array to detect a broad range of species, including *Z. cavirostris* and sperm whales, and to provide estimates of the 3D position of vocalizing odontocetes in real-time.

Between 5–9 July, the linear array was deployed almost continuously (> 73 hours), with the largest period without effort occurring on 8 July when the array was retrieved to allow RV *Shearwater* to transit around a naval exercise's 10-nm exclusion zone (Figure 3.18). The 3D array was deployed more sparingly (35 hours) due to modifications and adjustments made to the elements between deployments.

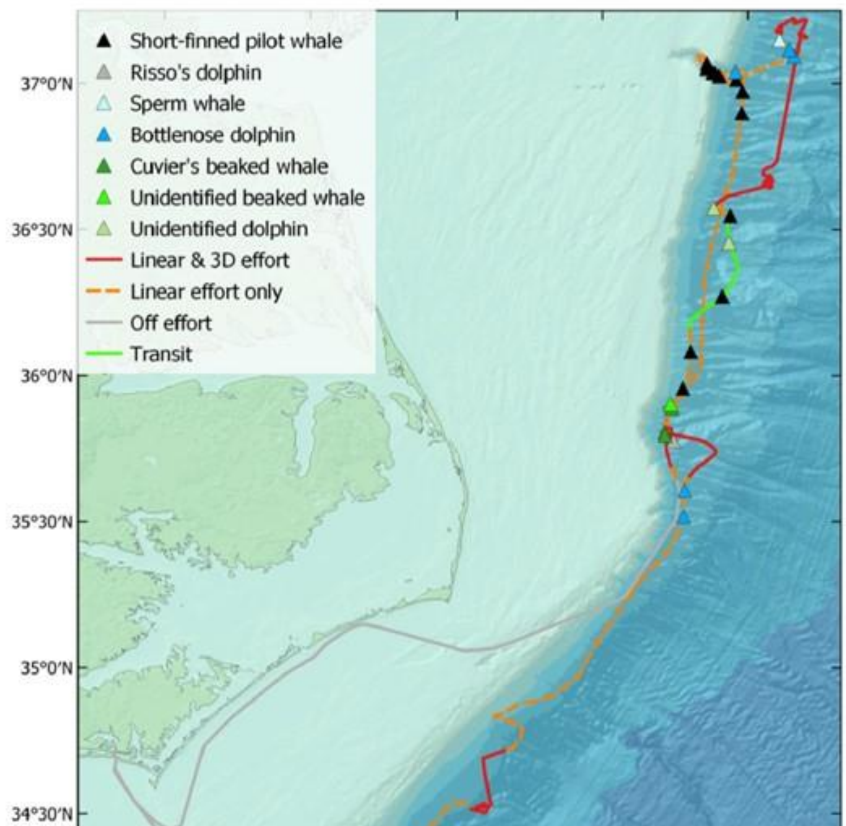


Figure 3.18. Realized acoustic survey effort cetacean sightings made aboard RV *Shearwater* during 5–9 July 2022 cruise.

The 3D array towed well behind RV *Shearwater* at all survey speeds. Mean tow depth of the array was 44 m, with higher speeds causing the array to rise closer to the surface. The mean pitch of the array was 13° (i.e., slightly 'nose-up'), which was typically was most pronounced at lower speeds. Mean roll was 35°, meaning the array typically towed with a starboard roll; this is likely due to the clockwise twisting of the copper cores in the tow cable. Roll did not vary with survey speed, suggesting the fins stabilized the tow body and prevented any excessive rolling beyond the 'structural' roll in the system.

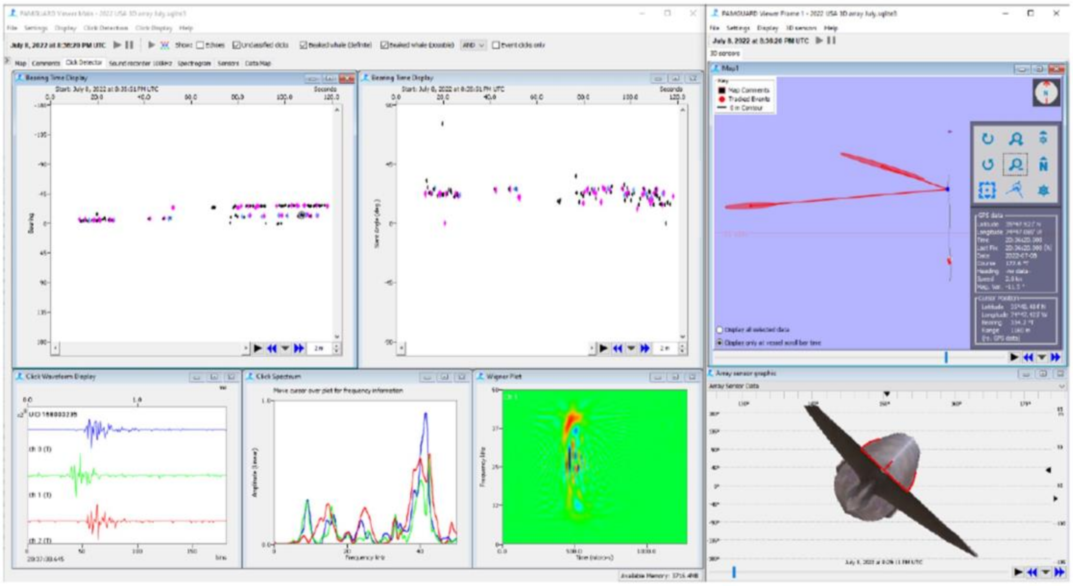
Several of the encounters with sighted cetaceans summarized in Figure 3.18 coincided with acoustic detections on both the linear and 3D arrays (Table 3.9). In addition, several encounters with sperm whales and ziphiids were identified from their characteristic vocalizations alone without any corresponding visual confirmation.

Table 3.9. Summary of key acoustic encounters with cetacean groups during 5–9 July 2022 cruise.

Date	Time (GMT)	Species	Acoustic Array Detection	Visually Observed (and acoustic notes)
6 July	00:07:56	*P. macrocephalus*	3D & Linear	No (at least 5–6 individuals)
6 July	15:12:47	*T. truncatus*	Linear only	Yes
6 July	15:46:57	*T. truncatus*	Linear only	Yes
6 July	20:27:52	*Z. cavirostris*	Linear only	Yes
6 July	22:24:49	Unidentified beaked whale	3D & Linear	Yes
6 July	23:55:42	Unidentified beaked whale	3D & Linear	No (at least 2–3 individuals)
7 July	10:48:44	*G. macrorhynchus*	Linear only	Yes
7 July	11:40:47	*G. macrorhynchus*	Linear only	Yes
7 July	12:47:28	*T. truncatus*	Linear only	Yes
7 July	13:21:29	*G. macrorhynchus*	Linear only	Yes
7 July	13:27:13	*G. macrorhynchus*	Linear only	Yes
7 July	13:43:58	*G. macrorhynchus*	Linear only	Yes
7 July	14:47:09	*G. macrorhynchus*	Linear only	Yes
7 July	15:26:57	*G. macrorhynchus*	Linear only	Yes
7 July	16:10:46	*G. macrorhynchus*	Linear only	Yes
7 July	17:40:30	*T. truncatus*	Linear only	Yes
7 July	18:04:22	*T. truncatus*	Linear only	Yes
7 July	18:29:33	*P. macrocephalus*	Linear only	Yes
8 July	01:39:37	*P. macrocephalus*	3D & Linear	No (at least 3–4 individuals)
8 July	12:44:29	Unidentified dolphin	3D & Linear	Yes
8 July	16:05:05	*G. macrorhynchus*	Linear only	Yes
8 July	17:24:28	*G. macrorhynchus*	Linear only	Yes
8 July	18:54:15	*Z. cavirostris*	3D & Linear	Yes
8 July	21:02:18	*Z. cavirostris*	3D & Linear	Yes
8 July	22:35:06	*G. griseus*	3D & Linear	Yes

We will continue to conduct detailed acoustic analysis to derive 3D positions for the key encounters listed in Table 3.9, although this work is outside the bounds of this report. In the field, though, it was possible to derive real-time 3D information for a number of the acoustic detections (Figure 3.19).

A



B

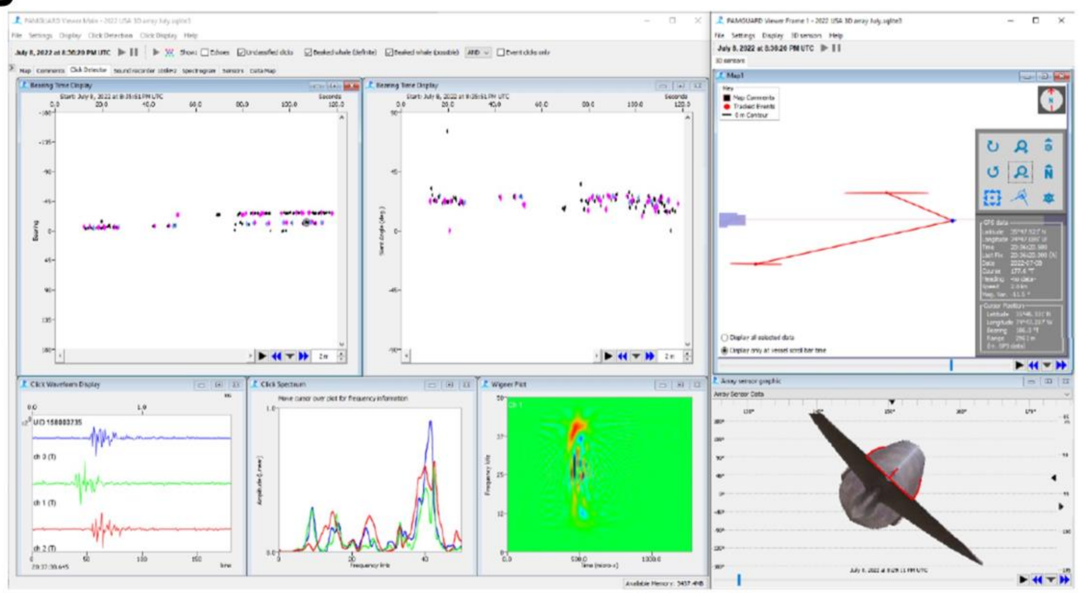


Figure 3.19. Screen grabs taken in the field of the PAMGuard click detector using the 3D array. The two plots displayed in A and B display the same moment in time and are identical, except the top plot A shows a 2D map (top right) presenting the two possible real-time positions for the selected clicks, and the second plot B shows a rotated 3D map that resolves the correct 3D position (i.e., below the sea surface). For both A and B, the top left windows display a PAMGuard click detector module identifying beaked whale clicks (pink diamond = high confidence; blue diamond = medium confidence); several of the unclassified black objects are also likely to be beaked whale clicks. The window on the left provides bearing information and the window on the right provides slant information (i.e., the angle subtended by the water surface and the vocalizing whale). The three windows on the bottom left show waveforms, power spectra and a Wigner plot respectively. In the example shown, the waveforms registered on three of the array's sensors show the characteristic envelope of ziphiid clicks, and the power spectra derived from all three sensors show a distinctive peak centered at approximately 39 kHz. The Wigner plot shows the characteristic upsweep of ziphiid clicks. On the right side of each A and B, the animated sperm whale on the bottom right represents the orientation of the array; the 'structural' starboard roll of the array is evident.

3.2 Build Upon Existing Development of Open-Source Tag Visualization Software

This aspect of the project yielded new, student-driven innovations to visualizing tag data. This task underwent changes in scope, in consultation with BOEM, during the tenure of this project. Here, we articulate the progress made and provide the links to the products of this tag data visualization task.

Throughout 2019 and into early 2020, considerable work was done on this task, focusing on the potential use of ParaView for tag data visualization. ParaView is an open-source, multi-platform data analysis and visualization application. Nowacek and Blawas worked closely with Dr. Eric Monson from the Duke CDVS. Monson and Blawas worked to import into ParaView the data from the sperm whale DTAG attached during the spring Cruise 2. Dr. Monson generated some plots in ParaView and compared them with TrackPlot to identify potential limitations of ParaView for visualizing tag data. Historically, scientific visualization had been developed for activities such as medical imaging or finite-element simulations, where the subject of the visualization takes up most of the space in the region being viewed. However, tag data are very sparse with respect to the total 3D volume in which the whale eventually travels. Also, whether the data are from imaging or simulation, physical constraints and/or computational cost typically limit the time steps over which data are collected. However, we have very spatially sparse data that is temporally sampled very finely and lasts a long time, which something like ParaView has not been optimized to handle. The fine sampling over a long time period even comes into play when considering file formats for loading the data—ParaView has been optimized more for large amounts of data being specified over few times steps, say with one time step per file, not for a very tiny amount of data spread over many time steps.

Thus, the main obstacle by Nowacek and the Duke CDVS identified in using ParaView was a mis-match between the spatial density of data from the tags and the types of data sets for which ParaView has been optimized (e.g., magnetic resonance imaging [MRI] and computed tomography [CT]). There is still merit in focusing additional effort on building on ParaView and/or other open-source available data visualization platforms.

Thus, in fall 2020, Nowacek engaged five Duke University undergraduate electrical and mechanical engineering students to develop tag data visualization tools. The goal was to develop code capable of running kinematic analysis and creating interactive visualization playbacks on commonly used tag data formats (e.g., DTAG [Johnson and Tyack 2003], OpenTag [Loggerhead Instruments], and CATS tags). Plans for the semester included coding a tool that created 2D and 3D plots to display dive data, including pitch, roll, heading, and depth. The group used existing open-source software, such as Paraview and Plotly, to assist in developing these new tools, although much of the development work was done via programming in Python, JavaScript, and HTML.

The effort succeeded in creating a new tag data visualization tool that had the following features:

- Support for known and new tag data formats (DTAG, CATS, etc.)
- Extend kinematic analysis features (e.g., Geographic Information and Decision Analysis) and include support for new data types (e.g., physiological)
- Import 3D bathymetric and oceanographic data (where available) to visualize animal behavior and habitat use
- Acoustic and behavioral auditing and automated search (e.g., attended and unattended classification of behavioral data patterns)
- Integration with extant statistical analysis modules (e.g., DeRuiter et al.'s Tag Tool Kit routines)
- Intuitive user interface with simple playback interactions and easy export of static images and animated movies
- Open-source / open-access licensing scheme

Additional functionality that has been added, e.g., automatic detection of interesting kinematics, will continue to be refined. The group gave a demonstration of the system to a larger group, including BOEM personnel, and the software is in an open-access GitHub repository (https://github.com/NowacekLab/Duke-Whale-TagDataVis); the repository will be maintained and updated with refinements.

Ongoing support for such software platforms remains a challenge as data streams and data formats from tags change periodically, as do the available software packages themselves, especially R as it is developed by users. Our recommendation would be to 'institutionalize' a universal software package so that it has ongoing support.

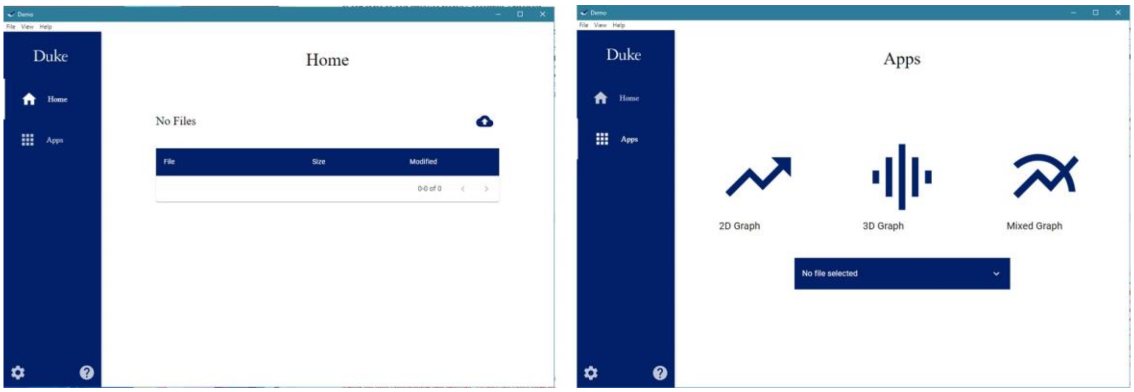


Figure 3.20. Screenshots of the data visualization desktop app as of 15 December 2020.

3.3 Citizen Science Component

3.3.1 Citizen Science Workshop Outcomes

The citizen science workshop gathered experts and stakeholders to identify the scope, utility and quality requirements for data collected by citizen scientists. Following expert presentations on citizen science projects and data collection tools and software, workshop participants discussed the needs of organizations regarding the use of citizen science data. The key outcomes of those discussions were:

- Data utility and useability are critical to adoption of citizen science data, meaning that the format of the data and platforms that hold them must be readily accessible for uploading or downloading, and must avoid any circumstances that would require manual input of the data into the user's platform.
- The type of citizen science data to be collected should consider its utility to multiple user groups. A prime example is the need to collect "non-sightings" as well as sightings, recognizing that citizen science data tends to be biased towards animal presence. Effort data, such as vessel tracks where no sightings are reported, would inform management practices by providing data on how frequently animals are observed versus not observed.
- Best practices and control mechanisms need to be articulated for citizen science data. Controls would provide important validations of data integrity by accounting for the possibility of actors who might be motivated to purposefully bias the data because they favor a particular outcome of the use of that data.

- Citizen science messaging needs to promote the health and welfare of animals, for example by ensuring that animal photography does not inadvertently cause stress because citizen scientist photographers approach too closely or otherwise encroach on animals' routine behavior.
- Data and effort feedback loops, in which data contributors are made aware of how their data is being used and the impact it is having on conservation efforts, are essential to the success of citizen science initiatives by encouraging and maintaining involvement of citizen science data collection.

Workshop participants also assessed user needs and system requirements for citizen science data collection for a range of ocean community groups, including professional mariners, the offshore oil and gas industry, and recreational mariners. The principal identified need is for streamlining disparate datasets and data streams into a common platform.

3.3.2 Citizen Science Tools

The MAPS project deployed several new or modified data collection and reporting apps and platforms, including Flukebook, Whale Alert, and Ocean Alert. Communication initiatives related to these tools included a workshop at the World Marine Mammal Conference in 2019 and a publication in the peer-reviewed journal *Mammalian Biology* in 2022.

Flukebook. Flukebook is a web-based, open-source application within the Wild Me platform for animal image data management and machine-learning powered image matching and animal identification. Like other Wild Me applications, Flukebook enables approved researchers to upload and manage their own cetacean image databases and also to compare their images across other researchers' databases. Citizen scientists are also able to upload images from opportunistic cetacean sightings. Flukebook enables the potential for global reach in individual cetacean identification, according to the number and distribution of contributors using the app. Continuing development and expansion of Flukebook by Wild Me during the course of the MAPS project resulted in the recording of 260,512 cetacean sightings and identification of 49,445 individual animals encompassing 47 species. In addition to supporting the work of 337 researchers from 80 organizations, Flukebook was used by 1,629 citizen scientists during the MAPS project period.

Whale Alert. In another MAPS project component, the Channel Islands National Marine Sanctuary (CINMS) beta-tested the Whale Alert app developed buy a network of non-profit institutions, government agencies and shipping and technology companies. The central objective of the app is to reduce ship strikes on whales. The CINMS effort resulted in the recording of 451 trips covering 32,000 km (17,278 nautical miles). The trips involved 1,689 hours (70 days) of effort, during which 3,396 animals were sighted.

Ocean Alert. The Ocean Alert app (75,655 downloads to date) launched in late 2020 through a partnership with NOAA as an outgrowth of NOAA's Whale Alert app. Ocean Alert is a mobile data collection app (iOS and Android) for researchers and citizen scientists; the app uploads, stores, and manages images, and supports data on species, group size, and behavior, and effort in the form of vessel tracks. Data is fed to appropriate repositories (e.g., Flukebook) for use by resource managers. Geosmart data can be relayed to mariners as real-time alerts to marine megafauna presence and location, providing opportunity for actions to avoid ship strikes. The data also provides an essential database of marine megafauna localization, habitat preference, and movement for BOEM resource managers in planning for offshore wind energy development.

Ocean Alert-Flukebook Workshop at World Marine Mammal Conference, December 2019. The MAPS team participated and played an important leadership role in a workshop on the Ocean Alert-Flukebook system held during the World Marine Mammal Conference in Barcelona Spain. There were 22 attendees from nine countries across the spectrum of users, including academic research biologists (those focused on cetacean or pinnipeds), non-governmental organization researchers and naturalists, marine mammal observers, and government representatives. The goals of the meeting were to introduce the tools, train users, solicit recommendations on app features and future development, encourage adoption and use, and facilitate ongoing and future collaborations on marine megafauna research.

The workshop yielded several key takeaways. Several groups are increasingly interested in joining the platform. Participants praised the flexibility of the app, and the fact that the app linked directly to a photoidentification platform was seen as a critical asset compared to other sightings apps that only store the sightings data. The ability to record effort was also seen as a critical feature that sets Ocean Alert above other applications. Flukebook's flexibility in allowing multiple data sets to be combined from researchers without the need to overwrite one collaborator's annotations or labelling system was identified as a very positive asset for larger, more detailed users. On the citizen science side, the reciprocal open matching allows for the fact that some opportunistic users might submit images but never match them, but more active users would eventually match and include the smaller datasets. It was a key initial goal of the platform to streamline disparate datasets, so it was gratifying to have this recognized as a key feature in Flukebook. There was also support for organization-level security features allowing multiple users to work on the same dataset. One limitation that was outlined was that automated matching was only available for four species at the moment, but productive discussions ensued on existing algorithms that could be incorporated to Flukebook for other species, including gray whales and blue whales.

Peer-reviewed publication on the Ocean Alert-Flukebook app. The MAPS team collaborated with an international group of researchers to publish a peer-reviewed article on the Ocean Alert-Flukebook app. The paper entitled "Flukebook: An Open Source AI Platform for Cetacean Photo Identification" was published online in *Mammalian Biology* on 5 April 2022 (https://doi.org/10.1007/s42991-021-00221-3; https://link.springer.com/content/pdf/10.1007/s42991-021-00221-3.pdf). This article outlines the Flukebook platform as a whole and the Ocean Alert app, and highlights novel techniques in the pipeline that were developed during this project from a methods perspective. This article has generated appreciable impact and continues to be utilized by academicians and the public. As of April 2023, it has been cited 19 times in the scientific literature. Altmetric ranks the article in the 91st percentile (37,474th of 439,071) of tracked articles of a similar age in all journals and the 86th percentile (6th of 36) of tracked articles of a similar age in *Mammalian Biology*. The paper has been accessed 4,083 times, has 36 readers on Mendeley, and has been shared on social media by 32 individuals from more than eight countries as tweets, with 62% of the tweets from the public.

In summary, the citizen science component of the MAPS project resulted in the development and sharing of Ocean Alert, a new mobile data collection app for marine megafauna that provides an essential tool for BOEM resource managers in planning for offshore wind energy development.

3.4 Communications and Outreach Component

The overall design of the Communication Plan and several of the products are described in the Methods section (see also Appendices B–E). Here, we elaborate on a selection of outreach products, which range in the scale in their impact from local to global.

3.4.1 Research Component: Education and Outreach Projects

We used multiple outreach and education products to encourage high public engagement during 2019 MAPS research cruises. Scott maintained an active social media presence and updated the National

Geographic Open Explorer site (which is no longer available). During Cruise 1, the Open Explorer was updated with 13 blog posts, which were promoted via Twitter and resulted in a good click through rate; feedback from National Geographic Open Explorer was excellent (35 subscribers to the expedition, and 2,340 views). Engagement on Twitter was very good, with an average engagement rate of 4.1 and over 9,000 impressions. During Cruise 2, six blogs with images were posted to the Open Explorer page. Accompanying tweets from Scott's account resulted in average engagement rate of 5. Total impressions were 16,606. Unfortunately, the National Geographic Open Explorer site was discontinued later in 2019. MCR International, Duke Marine Lab, and UNCW SPARC Twitter accounts were also active during both research cruises. In addition, Ms. Anna Clabaugh updated the MAPS project website to include information and images for Cruises 1 and 2 (https://sites.duke.edu/oceansmart/).

At the end of the MAPS research cruises, we held an important local outreach event that occurred aboard the RV *Song of the Whale* on 20 May 2019—the Open Boat Event. The Boys and Girls Club of Morehead City, North Carolina, toured the research vessel in two groups. The MCR crew explained the visual and acoustic monitoring methods used during the survey and offered a tour of the vessel, including galley, helm, sleeping rooms, and heads. There was also a final group question and answer session on the deck, and the tour received very positive feedback.

UNCW also worked with colleagues from Marine Quest to develop education and outreach products. Marine Quest colleague, Ms. Laura Sirak-Schaeffer, traveled with Pabst to Beaufort for Open Boat Day on 20 May 2019, spent time with Dr. Olly Boisseau, and learned about PAM methods. This visit, and multiple subsequent meetings with Pabst, led Sirak-Schaeffer to create curricula for a science camps entitled "A Day in the Life of a Scientist Onboard RV *Song of the Whale*" (Appendix F). In the camps, young students would play a variety of roles, from visual observer to deck hand, and collaborate as they work through a survey scenario designed by Marine Quest. Pabst also met with Erin Moran at Marine Quest, who was working on a second "Whale Sounds" camp, to discuss strategies for integrating this camp with their existing "Build a Hydrophone" lesson plan.

Unfortunately, because of the SARS-CoV-2 pandemic, the outreach projects planned for Marine Quest face-to-face summer camps were cancelled. UNCW worked with Marine Quest to develop alternative programming that could be shared remotely. Thus, instead of the in-person camp of "A Day in the Life of a Scientist Onboard RV *Song of the* Whale," Pabst worked with Marine Quest personnel in May 2020 to develop an online camp, entitled "How to Build a Deep Diver," based in part on this BOEM-funded project. In addition, Marine Quest hosted a virtual Sea GEMS program on 12 December 2020, which focused on the "Building a Deep Diver" activity developed during the summer; this event was for female students, ages 12–14, who were doing a multi-series program this academic year with Marine Quest.

Pabst also worked with educational staff at the North Carolina Aquarium at Ft. Fisher, with the initial plan to create science curricular units and teacher kits for 6th, 7th, and 8th grade classes (physics of sound, cetacean biology and diving, and anthropogenic sounds as a type of pollution). Because of the multiple impacts of COVID-19, which caused both the Aquarium and public schools to experience prolonged closures, the Aquarium, led by Mr. Andy Gould, developed their first virtual science camp. This "Oceans Career Camp" shared information about the MAPS project, as well as integrated ways for young campers to think about the ocean and their potential future as marine scientists. This virtual camp also included interviews with graduate student Laura Murley, who participated in the MAPS cruises, and Pabst. The Ocean Careers Camp was offered via Zoom, Monday–Thursday, from 9:00 am-12:00 pm EST on the weeks of 21 June 20 2021, 19 July 19 2021, and 2 August 2 2021. In total, there were 34 participants, 10 from coastal North Carolina, 17 from central North Carolina, and 7 from other states, including New Mexico, New York, Idaho, Alabama, Virginia, and Mississippi. In a novel extension of their educational camps, the Aquarium is maintaining monthly meetings with its ocean career campers, creating a lasting impact of this educational camp experience that will positively benefit the students involved.

Furthermore, Duke University contracted Steve De Neef to produce the final video for both the research and citizen science components. The citizen science video would both be a functional overview of the system and what it does, as well as a broad overview of how to use it. De Neef participated in the last leg of Cruise 2 and traveled to Duke, UNCW, Wild Me, and BOEM to film interviews for the production of educational videos for the MAPS project. The final video on the citizen science portion of the MAPS project, entitled "A.I. and Citizen Science" (https://oceantoday.noaa.gov/whale-tale/welcome.html), premiered on NOAA's Ocean Today site in April 2021 during their "Full Moon Watch Party."

4 Discussion

The MAPS project had two primary and integrated components: (1) the research component, focused on enhancing our understanding of the cryptic and acoustically sensitive, deep-diving cetacean species that inhabit the OCS, and (2) the citizen science component, aimed to create an environment where sightings of these and other OCS species by citizens (e.g., recreational boaters, whale watchers, industry employees) could be recorded and archived. Throughout the project, the team also endeavored to share its work broadly to engage and educate citizens, students, scientists, and managers. Below, we discuss the results of the research and citizen science components and summarize their value to BOEM's mission.

4.1 Research Component

A central pillar of the Research component of the MAPS project was the intensive field effort undertaken across the OCS in 2019 and 2022. The two 2019 visual and passive acoustic monitoring line transect surveys were designed to investigate the acoustic, behavioral, and foraging ecologies of deep diving cetaceans. Because these surveys occurred during winter and spring—seasons that were chosen intentionally to fill critical gaps in survey effort—visual detections were often hampered by high sea states and inclement weather. Thus, our efforts to quantify the presence and describe the behavior of these deep divers relied almost exclusively on PAM data. The methods employed to analyze the PAM data have contributed to advancing the field of acoustically derived density estimates of deep diving cetaceans. The PAM data also provided the opportunity to analyze the body size of sperm whales encountered in 2019 and to compare these sizes to those derived using photogrammetry data.

The 2022 research cruise was aimed once again at advancing PAM methods to investigate deep divers, this time by deployment of an experimental 3D acoustic array. This type of array can gather more detailed, spatially explicit behavioral data on deep divers, as well as provide more accurate estimates of the depth of vocalizing beaked whales. The team also leveraged their rare at-sea time to explore gathering eDNA and infrared thermal images of encountered cetaceans. Together, these results have offered us new insights into beaked and sperm whales that inhabit the OCS off the coasts of South Carolina, North Carolina, and Virginia – areas of importance to BOEM for offshore wind energy development.

In addition to the research cruises, the team also worked towards enhancing the visualization of tag data by a student-led software development project, which is available to the broader community via an open-access GitHub repository.

4.1.1 PAM Density and Abundance Estimates of Beaked Whales

Beaked whales are extremely deep diving, cryptic odontocetes, which can spend almost 90% of their life underwater (Tyack et al. 2006, Shearer et al. 2019). Their long dive times, short surface durations, and inconspicuous surface behavior make them extremely challenging whales to detect visually (reviewed by Barlow 2015, McLellan et al. 2018). PAM surveys have the potential to provide more accurate descriptions of the distribution of individuals, because they vocalize for as much as 35% of their time underwater (Barlow et al. 2013). The results of the MAPS surveys supported this finding, with 51 distinct groups acoustically detected on the survey trackline (plus 54 off-track) but only 2 groups visually observed at the surface (plus 5 off-track).

The 105 high confidence detections fell into two clusters: cluster 1, whose acoustic features matched those of Cuvier's beaked whale (*Ziphius cavirostris*); and cluster 2, whose acoustic features matched those of Gervais' beaked whale (*Mesoplodon europaeus*). Both beaked whale species have been acoustically detected (Stanistreet et al. 2017) and visually detected via aerial line transect surveys (McLellan et al. 2018) in portions of the MAPS survey area. Interestingly, there were some subtle differences in the distribution of acoustic detections between the MAPS study, which utilized towed hydrophone arrays, and that of Stanistreet, which utilized static arrays (High-frequency Acoustic Recording Packages, or HARPs). Using only the on-track detections (n = 51) from the MAPS cruises, some distinctions were observed between the candidate Cuvier's events, which were detected throughout the study area (32.0–37.2 °N), and the candidate Gervais' events, which were more numerous in the north (32.8–37.2 °N; Figure 3.5). This pattern does broadly fit that identified from static recorders stationed off Cape Hatteras (Stanistreet et al. 2017), with candidate Cuvier's beaked whale clicks being much more prevalent at that site (35.3 °N). Stanistreet and colleagues (2017), though, found approximately equal numbers of candidate clicks of both species off the Norfolk Canyon (37.2 °N), while the MAPS study found almost exclusively candidate Gervais' clicks at those latitudes. Approximately equal proportions of both click types were detected a little further south, between 35 and 36.5 °N, suggesting both species likely utilize these waters, at least in winter and spring months of the MAPS cruise. In the MAPS study, candidate Cuvier's clicks were predominant in the south, whereas the static units used by Stanistreet et al. (2017) recorded almost exclusively Gervais' clicks at the Onslow Bay site (33.8 °N). Although care should be taken not to overinterpret these data, since the northern transects were not fully surveyed in winter, these subtle differences in the pattern of acoustic detections suggest the potential for inter-annual and/or inter-seasonal changes in distribution of these two beaked whale species.

Boisseau et al. (accepted) provide in-depth discussions of the effects of beaked whale vocalization behavior and environmental factors on the detection probability, and the uncertainties estimating perpendicular distances required for density estimates. Herein, we describe the overall pattern of estimates of beaked whale density and abundance.

Although only 60% of the transects were surveyed in winter (Figures 3.1 and 3.2), an analysis using the same reduced survey area for the spring survey (Table 3.3) allowed comparative inferences to be made regarding seasonality. The abundance estimate of 743 beaked whales for the winter survey (CI 221–2,467) was similar to that of 623 for the spring survey (CI 213–1,821), suggesting that there was no evident change in local densities between January and May. This lack of seasonality is similar to the findings of Stanistreet et al. (2017) and McLellan et al. (2018). These results are supported by local studies using satellite tags (Foley et al. 2021) and photo-ID (Waples and Read 2020), which suggest high degrees of site-fidelity by individual Cuvier's beaked whales off Cape Hatteras, an area included in our MAPS survey. Thus, it appears the offshore waters of the Mid-Atlantic Coast are able to sustain high numbers of ziphiids throughout the winter months.

If considering the spring survey alone, for which all designed transects were satisfactorily surveyed, beaked whale density in the study area was estimated as 1.64 individuals per 100 km^2 equating to 2,963 whales (CI 1,597–5,497). If the sample of click trains used for species identification is representative of the proportion of ziphiids within the study area in spring, we may expect 1,440 of these individuals to be Cuvier's beaked whales (0.80 per 100 km^2), and the remaining 1,523 to be Gervais' beaked whales (0.84 per 100 km^2). A multi-year modeling exercise investigating cetacean density for the US Atlantic and Northern Gulf of Mexico (USECGOM) estimated 5,215 beaked whales within the MAPS study area (CI 3,069–8,862; Roberts et al. 2016; Roberts et al, 2018). The MAPS density estimate of 1.64 (CI 0.88–3.03) is lower than the USECGOM estimate of 2.87 individuals per 100 km^2 (CI 1.69–4.88), which includes

Cuvier's beaked whale, mesoplodonts, and unidentified ziphiids (Marine Geospatial Ecology Lab 2022). The lower confidence limit of 1.69 for the USECGOM indicates a statistically significant difference with the MAPS point estimate of 1.64; however, as extracting the USECGOM uncertainty did not account for covariance, the total variance is likely to be higher, leading to a wider CI. In this instance, the lower USECGOM limit would likely overlap the MAPS CI.

The USECGOM study derived a mean density of 1.51 Cuvier's beaked whales per 100 km^2 (CI 0.71–3.19) and 1.10 mesoplodonts, including Gervais' beaked whale (CI 0.47–2.59). McLellan et al. (2018) ran monthly aerial surveys between 2011 and 2015 in a smaller survey area off Cape Hatteras (15,765 km^2 vs. 220,605 km^2 in the MAPS surveys). When considering only those parts of the study area with waters deeper than 1,000 m, the density of all beaked whales was estimated as 1.9–4.2 individuals per 100 km^2 (corrected for availability and perception biases and depending on surfacing scenario). The density CI for the scenario in which whales surface individually (1.2–3.0 individuals per 100 km^2) aligned closely with the CI for the MAPS survey (0.9–3.0 individuals per 100 km^2); the alignment was less apparent when considering the scenario in which all group members surfaced synchronously (2.2–5.4 individuals per 100 km^2). McLellan and colleagues (2018) utilized a variety of group surfacing patterns based upon the observations that Cuvier's beaked whales in other regions did display synchronicity. The few sightings (n = 7) of beaked whales made during the MAPS surveys suggest that they may dive with synchronicity because more than one animal was seen in all but one sighting; however, this assertion is anecdotal only due to the fleeting nature of sightings made in challenging visual conditions in winter and spring (69% of the transects were surveyed in sea state 3 or higher). Cioffi and colleagues (2021) have recently demonstrated diving synchronicity in male Cuvier's beaked whales in the study area, which can last for days to weeks. Overall, the results of this survey support those of earlier static acoustic (Stanistreet et al. 2017) and visual (McLellan et al. 2018) surveys and demonstrate that the MAPS survey site hosts high densities of beaked whales in winter and spring.

DSM derived a corrected abundance estimate of 1,821 beaked whales (CI 979–3,386) for the entire study area from January to June, noticeably lower than the corrected design-based estimate of 3,831 (CI 2,262–6,489) representing the same period. Despite the disparity between the model- and design-based estimates, there was overlap in CIs. However, it should be noted that the transects used to derive design-based estimates are generally long, and animal density and environmental covariates may vary markedly along their length. A model-based approach, such as DSM, utilizes short segments rather than whole transects. Due to the variability of biological and physical covariates throughout the MAPS study area, particularly regarding the continental slope and the Gulf Stream, explicit modeling appears to derive lower density estimates in response to the heterogeneity of the environmental space. The DSM provides insights into habitat use in the region. High densities of beaked whales were predicted over slope waters to the west of the study area. Lowest densities were predicted in regions of low slope with high SST, most noticeably the region influenced by the Gulf Stream. To the east of the Gulf Stream, the model suggested densities may increase slightly away from the influence of the faster-moving warm waters.

Many of the acoustic detections were made off Cape Hatteras, where the Gulf Stream deflects eastwards. A complex circulation pattern develops here between the warm, north-east flowing waters of the Gulf Stream and the cooler, south flowing waters of the coastal Labrador Current forming a distinct water mass—the Mid Atlantic Bight—between Cape Hatteras and Nantucket Shoals (Csanady and Hamilton 1988). In addition, a western boundary undercurrent from the north flows under the Gulf Stream near Cape Hatteras and continues southwards into the South Atlantic Bight. The complex hydrographic structure of the waters off Cape Hatteras are thus driven by the complex interaction of the circulation patterns of major currents, ocean fronts, eddies, meanders, water column stratification, and upwelling events (Rhoads and Hecker 1994).

Throughout the Mid Atlantic Bight, the oceanic front formed between shelf waters and oceanic slope waters has been associated with increases in phytoplankton biomass and subsequent high productivity

(Lohrenz et al. 2002). These waters also appear to support extremely high densities of multiple species of cetaceans, with at least 30 species documented in the region (Roberts et al. 2016; McLellan et al. 2018). Although quantifying the exact nature of the interaction between local environmental conditions and beaked whale density is beyond the scope of the MAPS project, beaked whale densities remain high here even in the winter months. Thus, these results support those of Roberts et al. (2016), Stanistreet et al. (2017), and McLellan et al. (2018), which use visual and acoustic detection platforms and multiple modeling methods, and the tagging studies of Cioffi et al. (2021) and Foley et al. (2021), which demonstrate the importance of this habitat to multiple species of beaked whales.

These results represent the first abundance estimates made for beaked whales using a towed hydrophone array across the Atlantic US OCS and fill a critical temporal and spatial gap in data on these cryptic, acoustically sensitive species. Beaked whales have been demonstrated to be vulnerable to anthropogenic acoustic disturbance (Tyack et al. 2011). As discussed by McLellan and colleagues (2018), mass strandings of beaked whales have occurred in association with naval sonar exercises (reviewed in Cox et al. 2006) and possibly seismic survey activities (Taylor et al. 2004). Barlow et al. (2006) noted that better information on abundance and density is required to evaluate the risks to, and mitigate potential impacts of, anthropogenic disturbance on beaked whales. Cox et al. (2006) point out that this information is particularly needed in areas where such anthropogenic impacts are known to occur or are planned.

These results will help inform BOEM about mitigation steps that may be required for beaked whales as offshore energy development moves forward. Indeed, as lease areas are being developed in the deep waters off the US East Coast for floating wind farms, these data for deep diving species should be useful for planning energy development activities.

4.1.2 PAM Density and Abundance Estimates, and Body Sizes of Sperm Whales

The sperm whale (*Physeter macrocephalus*) is currently listed as endangered under the US Endangered Species List and depleted under the Marine Mammal Protection Act (Hayes et al. 2020), in large part due to its whaling history. Whaling efforts targeting sperm whales peaked in the mid-nineteenth century; during this period, the whaling industry accumulated a significant understanding of sperm whale distribution and migratory patterns (Bannister et al. 2008). The American 'Yankee' sperm whale fishery constituted the dominant global hunt (Ellis 2018), and the catches from their logbooks from 1761–1920 were summarized by Townsend in 1935. The "Southern," "Hatteras," and "Charleston" grounds (28˚–41˚N, 60˚–78˚W) were important areas for hunting sperm whales in the western Atlantic from the mid-18th century to the early 20th century (Townsend 1935, Bannister et al. 2008, Smith et al. 2012).

Building on this historical understanding of sperm whale distribution, several recent efforts have attempted to quantify the number of sperm whales utilizing the US OCS. For example, summer abundance estimates have been made for visual and acoustic surveys conducted north of North Carolina (36˚–42˚N) in June–August 2011 (Palka 2012) and August–September 2016 (Palka 2020, Westell et al. 2022), from Florida to Maryland (28˚–38˚N) in June–August 2016 (Garrison 2020), and from Florida to Maine (25˚–45˚N) in March–November 2010–2013 (Chavez-Rosales et al. 2019). However, only one estimate of abundance is available for winter months, which was made using density-habitat models derived from visual line transect data collected by aerial and vessel surveys from 2010 to 2017 along the eastern seaboard of the US (Palka et al. 2021). Even for this survey, though, only aerial survey data could be used for the winter estimates (December to March) because of lack of vessel effort. Despite the paucity of winter density estimates, recordings collected year-round from static acoustic recorders have identified a potential winter peak in occurrence of sperm whales off North Carolina (35°N), with a subsequent peak in detections further north (37˚–40°N) in spring (Stanistreet et al. 2018). In addition, none of the recent surveys conducted in these historical whaling regions have focused on demographics, such as age and sex, of individual sperm whales.

Thus, the 2019 MAPS surveys provided the opportunity to fill critical data gaps in our understanding of sperm whale density and abundance, especially in winter, and of individual body sizes of whales utilizing OCS from South Carolina through Virginia. Our results demonstrated high densities of sperm whales and the presence of calves within groups of larger individuals.

Sperm whale vocalizations were recorded on all but one of the transects surveyed in the winter and spring cruises in 2019, suggesting the study area is used routinely by sperm whales from January to May. Stanistreet et al. (2018), using a static HARP off Cape Hatteras, also documented peak levels of clicking during winter and spring, followed by consistently low levels during the late summer and fall. The same study described a seasonal peak in sperm whale click occurrence being evident later in the year at HARPs North of Cape Hatteras. Cohen et al. (2022) also used HARPs in similar positions but over a different timeframe (2016–2019 cf. 2011–2015 in Stanistreet et al. 2018) and with more units deployed from 30˚–41°N. These authors did not find evidence of a winter peak off North Carolina, and acoustic presence here was noticeably lower than for the recorders positioned further north. Rather, Cohen and colleagues (2022) identified the highest acoustic presence of sperm whales off the eastern seaboard at Hatteras in summer months. This pattern was also evident in another recent study using different recording units (Autonomous Multichannel Acoustic Recorders) in slightly shallower waters (Kowarski et al. 2022). This study documented only an intermittent presence of sperm whales off Hatteras in winter months from 2017–2020. However, the authors note that, overall, Stanistreet et al. (2018) detected whales in more months, a variation attributed to the fact that the recorders in that study were in deeper waters (800–970 m deep) compared to the study by Kowarski et al. (300 m deep off Hatteras). Some of these differences may be due to inter-annual variation; however, the static acoustic recorders in the studies above were typically in waters shallower than those shown to have high sperm whale densities (Roberts et al. 2016) and thus they may not fully capture the local prevalence of sperm whale clicks.

On-track acoustic detections of sperm whales far outnumbered on-track sightings in both cruises, with 115 vs. 3 in the winter cruise and 123 vs. 3 in the spring cruise. This result again highlights the value of using acoustical methods to detect and quantify the presence of deep diving cetaceans, especially under inclement weather conditions. Including cruise identity in MCDS analysis suggested the detection probability of sperm whales varied between winter and spring; therefore, separate estimates were made for each cruise. A robust abundance estimate for the entire study area was only possible for the spring cruise, as not all 10 designed transects were surveyed in winter. The spring abundance was 1,610 whales (CV 0.31; CI 827–3,137), when corrected with the 'typical' scenario for acoustic availability (see Table 3.4 for all results). However, if the density estimated for the winter Cruise 1 was assumed to be representative of the whole study area, the winter abundance would be approximately 18 % higher at 1,895 whales (CV 0.29; CI 915–3,924). The DSM procedure also generated abundance estimates but assumed sperm whale density varied across the survey area in response to specific environmental covariates of bivariate position and mean slope. The corrected winter DSM abundance estimate of 1,055 whales (CI 60–1,828) was similar to that estimated using MCDS (1,038; CI 51–2,099). Likewise, the corrected spring DSM estimate of 1,587 (CI 946–2,663) was similar to the MCDS estimate.

The DSM procedure offered insights into the habitat utilized by sperm whales while they were in the survey area. The results for winter Cruise 1 suggested mean slope had a significant effect ($p < 0.05$) on the model, in addition to a bivariate of position, with detections typically made in regions of low slope (< 2°; Figure 4.1A). Although not included in the spring DSM model, whales detected during Cruise 2 also tended to be detected in regions of low slope; the mean slope for detections made in spring (0.66^{o}) was not significantly different to the mean slope in winter (0.61^{o}) ($t_{236} = 1.43$, $p = 0.16$). Although high slope has been found to be a key driver for sperm whale presence in other regions (Praca et al. 2009, Mannocci et al. 2015, Tepsich et al. 2014), the MAPS surveys support the findings from other studies that have not found such a strong influence (Waring et al. 1993; Pirotta et al. 2011; Breen et al. 2016; Claro et al. 2020; Vachon et al. 2022). It is possible that the presence of warmer Gulf Stream waters over the regions of steepest slope in the study area did not provide ideal habitat for sperm whales. This hypothesis is supported by the spring DSM, where mean SST was found to have a pronounced effect ($p < 0.001$) on sperm whale density, with most detections being made with SSTs lower than 23°C (Figure 4.1B). Although not included in the winter DSM model, whales in the first cruise were also typically encountered in regions of lower SST; the mean SST for detections made in spring (22.2°C) was not significantly different to the mean SST in winter (22.1°C) ($U = 6{,}644$, $p = 0.42$). The sperm whales in the MAPS survey typically avoided regions of warmer water, preferring to forage in cooler waters marginal to the Gulf Stream. Other studies in the west Atlantic have had similar findings. For example, sperm whales from 36°–42°N were typically seen close to the edges of warm core rings (Waring et al. 1993). Sperm whale habitat between 38°–42°N has also been described as being offshore of surface temperature fronts associated with the Gulf Stream (LaBrecque 2016).

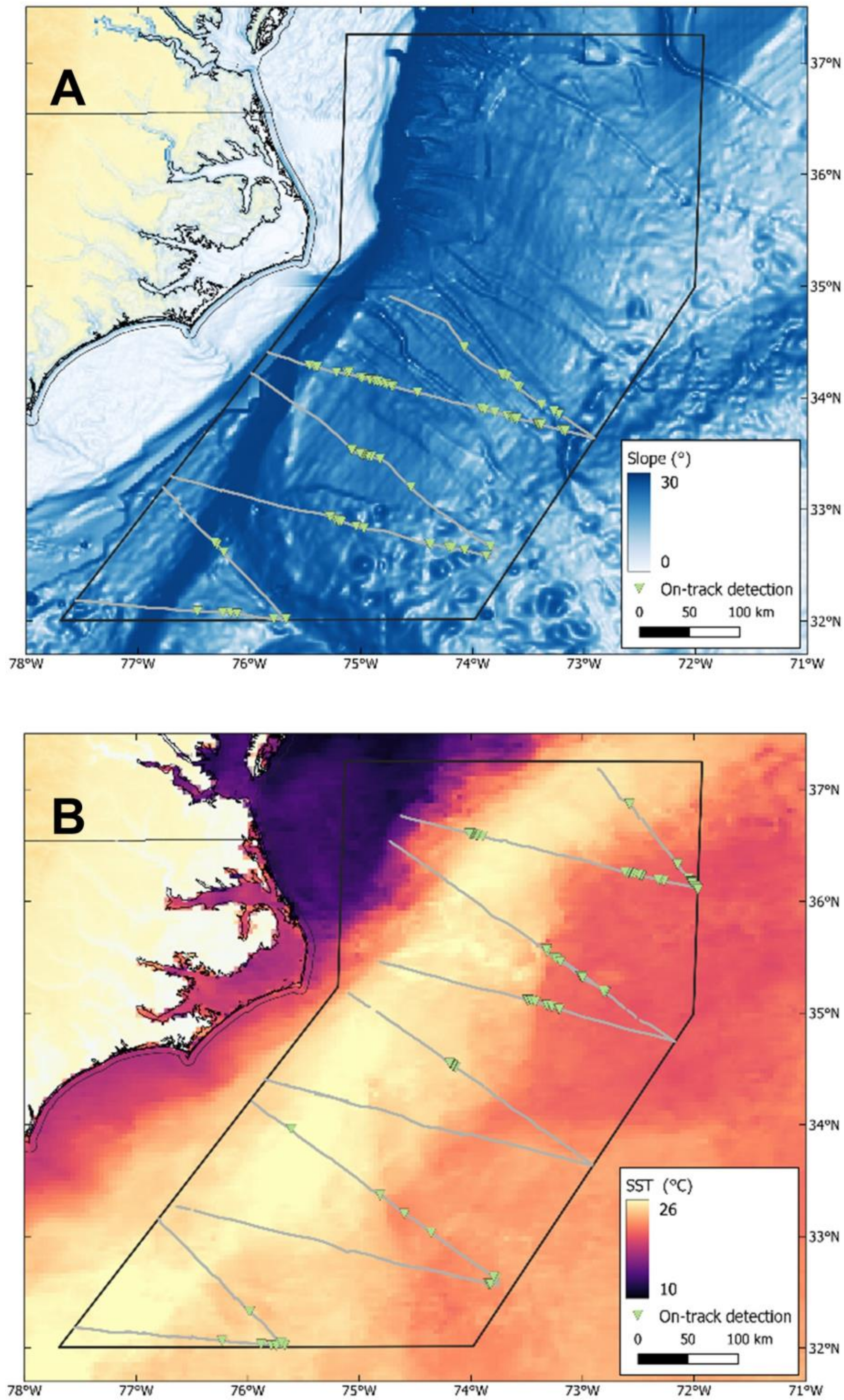


Figure 4.1. Plots representing (A) mean slope (°) throughout the study area and (B) mean SST (°C) in April 2019.

On-track acoustic effort is shown as a gray line for (A) winter and (B) spring; on-track sperm whale detections are shown for each cruise as green triangles. Slope information provided by NOAA ETOPO1 (1.4-km resolution) and SST values provided by NASA MODIS (4-km resolution).

The MAPS density and abundance estimates for winter and spring were typically higher than other estimates made from the eastern seaboard of the US in summer months. An in-depth comparison of the studies mentioned above is provided in Boisseau et al. (in progress). Here we provide a comparison to one of the most intensive surveys of the US Atlantic Coast, NOAA's Atlantic Marine Assessment Program for Protected Species project (AMAPPS). This project covers approximately 36°–42°N, and as described above, includes very little winter survey data. If we compare the MAPS survey results to those of AMAPPS, correcting for the area of each survey, the MAPS densities (measured as whales 1,000 km^{-2}) are 10.46 in winter and 8.89 in spring, compared to AMAPPS global estimate of 3.64. Thus, the MAPS survey, utilizing acoustic detections and data on acoustic availability from a local tagged individual, provides new insights into a geographic area with high sperm whale density.

The acoustic data, as well as visual photogrammetric data, also elucidated the size of individual sperm whales that utilize the OCS in winter and spring off the coasts of South Carolina, North Carolina, and Virginia. The IPIs from sperm whale clicks were analyzed using the CABLE software program (Beslin et al. 2018). The results demonstrate that the OCS supports a range of size and life history classes of sperm whales from the shelf break to the abyssal plain, including very young calves, with length estimates (Tables 3.5 and 3.6) at or near estimated birth length (approximately 4 m, Gosho et al. 1984). On two occasions, young calves were observed in groups: on 26 January, two calves, each with its presumed mother, and one much larger individual; and on 1 February, a few calves, with several adult females and/or immature males, and at least one large, scarred adult. It is interesting to note that, during the winter Cruise 1, there were only three visual sightings of sperm whales, and on two of these occasions, calves were observed. Length estimates for these smaller individuals may be the first for living sperm whale calves in the Mid-Atlantic Bight and suggests this area may provide suitable habitat for calving.

This work aimed to elucidate the population demographics of sperm whales encountered during the MAPS cruises. Although little information exists from the post-whaling era, it is possible to make inferences about the likely population structuring of sperm whales in the region based upon data from other regions of the world. In general terms, female and immature male sperm whales would normally inhabit areas with SSTs above 15°C, which equates approximately to the 40° parallels (Whitehead 2003). Adult males, however, may range to the ice edge at both poles, approximately equivalent to the 70° parallels (Gosho et al. 1984). Adult males typically undertake periodic migration between higher latitude feeding grounds and lower latitude breeding grounds, where they may repeatedly interact with resident female groups (Whitehead 2003). In the survey area of the OCS, one may thus expect to encounter mostly female and immature sperm whale social units; these units may occasionally be visited by bachelor groups or single males over the age of approximately 15 years (Whitehead et al. 1991; Gero et al. 2009). This pattern is observed in other North Atlantic habitats lying at similar latitudes, such as the Azores archipelago 4,000 km to the east (Antunes 2009; van der Linde and Eriksson 2020), and it was the pattern observed in two of the three visual sightings in winter.

In summary, we found high densities of sperm whales, which included life history categories from young calves to large adults, in both winter and spring. Models suggested that high densities were related to interactions between bathymetry and dynamic oceanographic variables, with sperm whales most prevalent in marginal Gulf Stream regions characterized by warm core rings, eddies, and edges. The results demonstrate that the OCS supports a range of size and life history classes of sperm whales from the shelf break to the abyssal plain, including very young calves. As these OCS waters provide important foraging, and potential calving, habitat for sperm whales, appropriate mitigation is required to ensure growing commercial pressures to develop offshore wind energy do not negatively affect this endangered species.

4.1.3 Leveraged Technologies—eDNA, Thermal Imaging, and 3D PAM

In addition to describing the density and acoustic behavior of deep diving beaked and sperm whales, the research cruises provided us the opportunity to explore multiple technologies that could add to our knowledge of these and other cetaceans encountered across the OCS. These technologies included the collection of samples for eDNA analyses, infrared images for thermal analyses, and 3D PAM data for more detailed spatial analyses of diving cetaceans.

Using eDNA for environmental sampling has grown significantly in the past several years. These samples can be used to address questions related to fisheries, coral reefs, harmful algal blooms, invasive and endangered species, and biodiversity monitoring (Thompson and Thielen 2023). By enabling detection of species over space and time, eDNA fulfills a fundamental need of environmental surveys. Oceanographic surveys are expensive, and eDNA offers a sampling method that is relatively cheap, non-invasive, and higher resolution with respect to genetic assessments of environments. However, challenges in quantification, detection limits, reference databases, representativity, and data management and integration remain significant hurdles to efficient eDNA monitoring at global and decadal scale due to the substantial data generated. Our results, while preliminary, indicate that this sampling method could be effective in documenting the presence of cetacean DNA in ocean waters, though significant questions of distribution and thus temporal and spatial resolution remain.

Infrared imaging is a non-invasive tool that has been used to gain insights into the thermal status of small odonotcetes as they experience seasonal changes in environmental temperatures (Barbieri et al. 2010) and as they experience chase and capture events in the eastern tropical Pacific (Pabst et al. 2002). Our specific goal for the MAPS cruise was to measure the surface temperatures of DTAG-ed sperm whales and explore how they correlated with previous diving activity. We were able to gather thermal images from multiple sperm whales, but although we did successfully image one DTAG-ed individual, the tag was not recovered. The results demonstrated that the body surface of sperm whales was thermally heterogeneous, with warmest temperatures generally measured at the thermal windows of the flukes and dorsal fin, and the coolest temperatures at the head. The body surface of the DTAG-ed individual measurably warmed with time spent at the surface, demonstrating the ability to detect thermal changes over time within a single individual. Our ability to use the FLIR infrared thermal camera during the MAPS cruises was affected by the high sea states and inclement weather encountered across the OCS in winter and spring. It would be interesting to utilize this technology in less challenging environments where sperm whales occur and individuals are well-known (for example, in Dominica, Gero et al. 2014). This tool could offer insights into their thermal biology across life history stages and across individuals of different health status. These data could form the foundation for future studies to measure the response of deep divers to anthropogenic stressors such as seismic surveys.

An important outcome of the MAPS project was the deployment of a prototype 3D acoustic array during the visual and acoustic vessel-based survey off Cape Hatteras in July 2022. The primary goal of the research was to refine acoustic localization techniques for deep-diving cetaceans to allow inferences to be made on the sub-surface behavior of animals that have not been tagged. The prototype 3D array was deployed during periods of interest, such as when in the vicinity of sighted odontocetes, and derived a total of 35 hours of effort. A detailed analysis of the recordings made in the field is currently underway. However, the preliminary outcomes of the survey demonstrate the 3D array was towed in a stable fashion, was able to detect the vocalizations of a broad range of species (including sperm whales and Cuvier's beaked whales), and could derive estimates of the 3D position of vocalizing odontocetes in real-time.

This technology is important because, currently, insights into deep-diving cetaceans' sub-surface behavior are only available from tags and/or acoustic sensors; however, deploying either of those techniques typically involves several logistical challenges. Elevated sea states typical of OCS regions can reduce opportunities for tag deployment, very high frequency (VHF) signaling, and/or satellite overpass availability (Tyack et al. 2006; Quick et al. 2019). Indeed, during the MAPS line-transect surveys in 2019, attempts were made to attach suction-cup DTAGs (Nowacek et al. 2001) to deep-diving sperm whales, yet only two tags were successfully deployed, of which one was subsequently lost. The high water velocities associated with the Gulf Stream could potentially prohibit the use of a drifting near-surface hydrophone array (Barlow et al. 2021). Static recorders have been used in the region to characterize sub-surface diving behavior of Cuvier's beaked whale *Ziphius cavirostris* (Wiggins et al. 2018). However, the deployment of deep-sea recording units for prolonged periods may be beyond the scope of many research programs.

The development of a portable 3D volumetric array that can be readily deployed from any appropriate vessel in most environmental conditions would allow insights into sub-surface cetacean behavior that otherwise may not be available.

4.1.4 Enhancements to Open-Source Tag Visualization

The field of high-resolution, multi-sensor tagging of wildlife is very small, and data processing tools have not maintained pace with the available electronics (i.e., sampling rates and thus data quantities). Thus, tools for data processing and analyses are limited and specialized. Our efforts in this area for the MAPS project were revealing, challenging, and successful. We learned that off-the-shelf software packages (e.g., ParaView) may or may not be useful; in this case, ParaView is a powerful analysis package, but it was developed to visualize and analyze data that were sampled at very high resolution on very small temporal and spatial scales. While tag data is sampled at high resolution in time, the geographic scale of those samples made it impossible to use for analysis and visualization of tag data. Our success came in the development of a new software package, developed with students in electrical and computer engineering, computer science, and environmental science. The students assembled a tool effective in automatically importing data, creating a series of initial visualizations (e.g., 2 and 3D graphics), and offering tools to create other visualizations as well as analyses. The package is freely available on GitHub, and we will continue its development.

4.2 Citizen Science Component

The citizen science component of the MAPS project was aimed at enabling cost-effective monitoring of marine species distribution and movement across vast areas of ocean. By partnering with WildMe and Conserve.iO, the MAPS team successfully developed Ocean Alert, the front end mobile app (iOS and Android) for Flukebook (Conserve.IO, https://apps.apple.com/us/app/ocean-alert/id1457113771). The Ocean Alert app allows citizen scientists and research users to submit data through their mobile devices. Supported data includes species, group size, and behavioral data, photos for identification, as well as effort in the form of vessel tracks that are saved on Flukebook. By focusing on an open-source platform, any app that collects this kind of data can connect to Flukebook using an established Application Programming Interface (API), which is a defined standard that allows external programs to communicate with a server. This type of integration is an area of future development, with potential connections with other applications and projects. Of course, such efforts also conform with the privacy and ownership of user-submitted data on Flukebook.

As Blount et al. (2022) state, "Determining which species are at greatest risk, where they are most vulnerable, and what are the trajectories of their communities and populations is critical for conservation and management. Globally distributed, wide-ranging whales and dolphins present a particular challenge in data collection because no single research team can record data over biologically meaningful areas." Ocean Alert, developed by the MAPS team, and Flukebook together provide an easy-to-use mobile app coupled to an open-source web platform, together addressing these data gaps by providing researchers with broad database access and the latest computational tools. These tools provide a step change in our ability to conduct large-scale research on cetaceans across biologically meaningful geographic ranges to rapidly iterate population assessments and abundance trajectories, and engage the public in actions to protect them. The citizen science portion of the MAPS project supports BOEM's goal of leveraging existing data and enhancing the collection of future data from the public and researchers alike.

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Appendix A: Infographic for the Marine Mammal Passive Acoustics and Spatial Ecology (MAPS) Field Research Project

Uncovering secrets of the DEEPEST DIVING WHALES

Marine Mammal Passive Acoustics & Spatial Ecology (MAPS)

Deep diving species, like beaked whales, are difficult to study from the surface, so in winter/spring 2019, MAPS researchers set out to fill critical gaps in our knowledge of them. To study these elusive animals in deep waters off North and South Carolina, we used a combination of highly specialized data collection methods on board *R.V. Song of the Whale*.

R. V. SONG OF THE WHALE

One of the world's quietest research vessels, with specialized passive acoustic monitoring capabilities, and environmentally friendly operations.

AT THE SURFACE

We can identify species, measure length and study behavior using visual surveys, photography and thermal imaging. Skin and fecal samples are collected for information on the sex, possible relatedness, and levels of toxins and hormones.

CAMERAS
to identify individual whale species and record behavior

VISUAL SURVEYS
to monitor sea surface for whales

THERMAL IMAGING
to measure whale surface temperatures and how they may vary with time at depth

BIOPSY SAMPLES
to gain info on sex, relatedness, toxins and hormones

eDNA
water samples collected to test new ecological monitoring tool that gathers genetic particles left by animals in the water, such as skin, feces, saliva

Beaked whales

Kogiids

Pilot

Sperm whales

Beaked whales

500m

1,000m

2,000m

3,000m

BELOW THE SURFACE

Hydrophone arrays stream out behind *R. V. Song of the Whale* to listen to a broad range of frequencies (for different types of whales); whale vocalizations may be used for estimating whale numbers, as well as to give an indication of behavior, such as foraging and communication.

Detailed 3D location data gathered by a specialized acoustic array and multi-sensor tags placed on the whales, can also measure sounds made and heard by whales, and accurately provide location, movement, water temperature and depth.

TOWED ARRAYS
to acoustically detect and record whale vocalizations and other sounds in their environment

TAGS
multi-sensor acoustic recording tags (D-tags) are deployed onto the whales, which record water depth and temperature, and sounds made and heard by the whale

3D LOCALIZATIONS
to record the position of the whale

SURVEY LOCATION

Based from the historic port of Beaufort, NC, the MAPS cruise surveyed a total of 1,958 miles (3,626 km), focusing on the offshore waters, beyond the shelf break and out into waters up to 14,400 feet deep (5,000 m) off North and South Carolina. This was the first time many of these areas have been surveyed in winter.

Combining these data streams gives us exciting new insights into the lives of the deepest diving whales.

BOEM Bureau of Ocean Energy Management

UNCW

Duke Nicholas School of the Environment, Duke University Marine Lab

marine conservation research.org

sites.duke.edu/oceansmart/

Appendix B: BOEM Marine Mammal Passive Acoustics and Spatial Ecology (MAPS) Project Communications Strategy

BOEM Marine Mammal Passive Acoustics and Spatial Ecology Project Communications Strategy

Contents

1. Context

Marine mammals occur throughout the mid and south Atlantic regions of the US east coast. They are of concern to the Bureau of Ocean Energy Management (BOEM) because of their protected species status (through the Marine Mammal Protection and Endangered Species Acts) and their potential sensitivities to human activities, such as oil and gas exploration and production, marine construction, and the cumulative impacts of other Outer Continental Shelf (OCS) uses, such as commercial shipping, naval activity, research and fishing.

The Marine Mammal Passive Acoustics and Spatial Ecology (MAPS) project will explore understudied and cryptic outer continental shelf (OCS) marine megafauna species. The project, known as SPAM internally but renamed for external audiences as MAPS for readability and connections with its intended objectives, is in partnership with BOEM – the Federal government's agency that manages development and activities in the OCS. The concept of the project is to provide data to bolster BOEM's efforts to mitigate impacts from regulated activities on protected and managed species.

The program will include the use of passive acoustic monitoring, biotelemetry, visual surveys, software development, citizen science data collection, and education and outreach. The information collected will further BOEM's mission in its management and potential development of the OCS. It will be undertaken by a team of international research scientists, data analysis specialists/modelers, citizen science experts, communication and education professionals uniquely qualified to explore these species.

Citizen science (citsci) and education are priorities for this project. The development of a mobile app for citsci data contributions is a key feature of the project.

The following communications strategy defines the objectives, the target audiences, stakeholders, the key messages/calls to action we want them to receive and the channels through which they will receive them.

This project spans three years and is divided into four periods, the labelling and definition of which will be refined, but for this initial draft they include the following highlights:

- Period 1 (three months) – data review and gap analysis, communication planning; citsci back-end modifications to link app and web portal, user login, and API
- Period 2 (12 months) – OCS research cruise; acoustic, diving and visual survey data collection and analyses; student training; communications implementation; citsci development includes: UI improvements, server upgrades, expansion of workflow
- Period 3 (12 months) – OCS research cruise; acoustic, diving and visual survey data collection and analyses; student training; communications implementation; citsci development includes additional datafeeds, image analysis; user agreement legal
- Period 4 (12 months) – data analysis, manuscript preparation, citsci software final os update and launch; citsci manuscript preparation.

2. Communications objectives

The plan sets out a framework for achieving the following objectives:

- Highlight why the study objectives are important to BOEM's mission
- Raise awareness among target audiences of the objectives of MAPS and why they are important
- Enable key target audiences to collaboratively contribute data to a streamlined workflow for the understanding of the spatial ecology of cetaceans
- Engage target audiences in BOEM science and marine mammal research through citsci initiative, NOAA Ocean Today Kiosk networks, etc
- Engage new citizen science users through citsci initiatives.

3. Tailored messages for multiple audiences

The following points will be refined into key messages to fit with the objectives. They will communicate what the project is about, why it is necessary, what will change after the project (the results), and they will speak to all audiences but will be tailored in the tactics used to reach the target audiences (communications mix). The messages should be succinct, in plain English, highlight the positives and most interesting points, provide clarity or a clear call to action. A number of our key messages may be refined by our citsci and research workshops planned later this year, so this section is a work in progress. Currently, the standard messages are as follows:

- The BOEM Marine Mammal Passive Acoustics and Spatial Ecology (MAPS) project builds on existing BOEM investments to gather high quality data on OCS marine mammal species to ensure efficient regulatory compliance.

- MAPS will provide high quality scientific data to enable BOEM to comply with NEPA.

- MAPS will provide detailed, high quality information on OCS protected species to enhance predictability of habitat utilization and behavior that will be important to NEPA and more stable industry planning.

- The BOEM Marine Mammal Passive Acoustics and Spatial Ecology (MAPS) project is a national study that aims to fill gaps in the knowledge of select cetaceans, such as acoustically sensitive beaked whales, that are prevalent in the OCS.

- BOEM recognizes that citizen science is a proven and effective way to document rare or cryptic species by enabling many observers to contribute valuable opportunistic data through the streamlining of existing tools to foster greater efficiency of mobile technology.

- Citizen science is a useful way to advance both scientific knowledge of species occurrence and distribution, as well as industry engagement.

- Information provided by MAPS will give a clearer picture of the abundance, distribution and habits of lesser known marine mammals.

- MAPS will provide a better understanding of the behavioral ecology of deep diving whales.

- BOEM will use the information from MAPS to advise resource management in the OCS to ensure minimal disruption to these protected species.

- Citizen science is an important component of this study. In the case of rare species, like the critically endangered right whale, or cryptic ones, such as beaked whales, every sighting matters. This project aims to enhance the efficacy of gathering and sharing such data with all stakeholders, including federal agencies tasked to protect these species.

- The MAPS app will streamline data collection, availability, interoperability; and will lay the groundwork for the efficient and expeditious use of those data in active management plans for OCS protected species (e.g. DAMs).

- The project saves the government significant costs by innovating how ocean research is completed. For example, surveys will be conducted on the R/V *Song of the Whale*, a low emission research vessel. We minimize travel using telepresence, digital data sharing platforms, etc.

4. Target audiences

The following target audiences will be prioritized into primary – those who need to be exposed to the messages, and secondary – those who will influence the primary target audience. **NOTE**: To achieve our objectives, messages will be tailored according to the audience and tactics, taking into consideration current knowledge and perspective.

- Industry and commercial operations who routinely are at sea - can be coastal like whale watchers or more offshore like shipping and service vessels, eg mariners - sailors, whale watchers, shipping and other industry, fishermen
- Government partners
- Scientific peers
- Coastal communities
- Interest groups (Citizen Science association)
- National aquariums on the east coast
- Mainstream media
- Bloggers
- Specialist media
- Naturalists

Stakeholders
Stakeholders are those who need to be involved in planning and delivering aspects of the strategy or key people who need to know about and respond to the project. They will include:

- Bureau of Ocean Energy Management
- Duke University
- University of North Carolina Wilmington
- National Oceanic and Atmospheric Administration/National Marine Sanctuaries/National Marine Fisheries Service

Partners
- Marine Conservation Research - *R/V Song of the Whale*
- Conserve.IO
- Wild Me

- North Carolina Aquarium at Fort Fisher (science outreach at regional scale at aquarium and through public school science program)
- MarineQuest (science outreach program for UNCW)

Further analysis of stakeholders to determine how they may be engaged or involved in the project will be undertaken.

5. Communications tactics

The communications strategy is high profile and proactive with a combination of tactics designed to deliver the key messages/calls to action to the target audiences. The roll-out of these tactics will be staged.

Products
A range of information products may be produced to provide simple, practical information about the project according to the target audience. They will draw out the benefits of the project and provide information on ways in which target audiences can participate. Examples include, but are not limited to:

- Instructional videos (BOEM, UNCW, Duke and potentially developers WildMe and Conserve.iO) on the use of the platform and app and on how BOEM and researchers will use the data to manage cetacean species and use citizen science data in policy development.
- Educational video (BOEM, Duke and UNCW and other organizations as appropriate) on the research conducted on OCS protected species that meets BOEM requirements for posting via websites, the national gallery, YouTube and the NOAA Ocean Today Kiosk Network.

Media
A media strategy will provide a mix of media allowing for tailoring of specific messages according to the audience. Media lists will be required from BOEM/Duke/UNCW. The media strategy will incorporate:

- Identification and negotiation for media/editorial opportunities
- Development of a coordinated plan that incorporates stakeholder communications and issues management
- Media releases (BOEM to be consulted prior to distribution)
- Electronic media kit including background documents, media releases, images, quotes
- Research report launch and highlighting research published in peer reviewed journals
- Interviews with scientists at sea – recorded/live – distributed via social media; live link to *R/V Song of the Whale* to be explored
- Photo/video collateral
- Talking points and Q&As
- Feature staff to profile

Digital

- In coordination with BOEM, social media posts will be made either through existing accounts or through another account of BOEM's choosing. Posts will contain tags for easy reference, eg on Twitter all posts would include references to @BOEM_DOI, @DukeMarineLab and @UNCWilmington, @WildBookORG and @ConserveIO with a project specific hashtag
- A schedule will be developed for social posts, in addition to adhoc timely updates as appropriate
- Identify and reach out to groups on social media (such as Facebook, Twitter) with relevant interests with strong follower numbers
- Identify and reach out to citizen science social media influencers
- Online community development - project updates for public
- Identify and reach out to relevant bloggers.

Events

- Attendance or representation at international and national scientific conferences (Pending BOEM approval)
- *R/V Song of the Whale* visitations with school groups in multiple locations, depending upon cruise planning and dates.

6. Brand guidelines

As noted below, a graphic designer will be commissioned to create a look and feel for project materials, with BOEM approval. The resulting brand guidelines will be distributed to any stakeholders producing materials regarding this project to ensure message and brand consistency and ensure constancy across study.

Stakeholder branding requirements (logo placement etc.) will be accomplished using BOEM guidelines.

7. Issues management

The current administration's announcement of the potential expansion of offshore energy leases, including in this project's research area, has received significant media coverage of the responses of various stakeholders from industry, state government, and the public (see below). These highlight the level of engagement currently surrounding resource development of the OCS, for example:

- https://www.npr.org/sections/thetwo-way/2018/01/04/575441542/trump-administration-opens-door-to-dramatic-expansion-of-offshore-energy-leases
- https://www.seattletimes.com/business/senator-questions-protecting-florida-from-drilling/

- https://www.washingtonpost.com/news/energy-environment/wp/2018/01/04/trump-administration-plans-to-allow-drilling-off-all-u-s-waters/?utm_term=.72c3cf29817d

As such, this project stands a chance to be the focus of significant media attention. To prepare for various perspectives on this work, we will always present the research and citsci MAPS project to support BOEM's mission "to conduct analyses assessing potential impacts to environmental resources as a result of proposed OCS oil and gas activities", always adhering to BOEM's scientific integrity policy.

Once this information is obtained, this will allow us to provide a Q&A and talking points for BOEM partners to address the various facets of this work, and its implications and utility. The key messages in all communications is to highlights BOEM's mandate (as above) and that this project will aid BOEM's efforts to protect marine mammals.

8. Management and reporting

Communications activities will be implemented by the communications contractor, overseen by the project leads. The communications contractor will liaise with BOEM Co-Principal Investigator and COR, Jake Levenson and Co-PI, Jennifer Bosyk, and project team leaders to ensure effective and timely implementation.

A graphic designer will be appointed to develop the overall look and feel of the project and provide creative design services for information materials, and a videographer will be appointed to create the two videos.

9. Evaluation

We will develop performance indicators throughout the project, as we approach our milestones. The research and evaluation tools to be used for this communications plan will comprise a mix of outcome measures, descriptive measures of outputs developed, development and concept testing, and ongoing evaluation of creative development.

Key performance indicators will include:

- Interdisciplinary and diverse user base feedback (e.g. governmental agencies)
- Quality and quantity of earned media
- We will develop measures to evaluate effectiveness of the citsci app
- Quantity of citsci data contributions
- Social media and digital measurement

Further qualitative evaluation of changes in knowledge and awareness would involve benchmark and tracking research which has budget implications.

10. Timeline

Date	Duration	Deliverable	Action
Period 1 15 January 2018	4 weeks	Communications Strategy	Draft communications plan to BOEM
15 February 2018	4 weeks		BOEM signs off final communications plan
Period 2	4 weeks	MAPS look and feel	Graphic designer appointed and briefed Look and feel developed Design guidelines
	2 weeks after submitting		Brand guidelines feedback from BOEM
	2 weeks		Final brand guidelines submitted to BOEM
	2 weeks		BOEM signs off brand guidelines
P2	Ongoing	Social media presence	Social media plan Identify contributors/admins
P2, 3 and 4	Ongoing	Media plan execution	
		Citsci and research educational videos	Footage and data collection
P4	4 weeks	CitSci instructional video storyboard	Draft Storyboard complete and submitted to BOEM
	2 weeks after submitting		Comments on draft storyboard received from BOEM
	2 weeks		Amendments made and submitted
	2 weeks		Final storyboard submitted for BOEM approval
	4 weeks	CitSci instructional video script	Draft Script complete and submitted to BOEM
	2 weeks		Script comments from BOEM received
	2 weeks		Final Script delivered
	6 weeks	Citsci video production	Draft Complete Video

	2 weeks		Feedback and amendments
			Video Dissemination
P4	4 weeks	Research educational video storyboard	Draft Storyboard complete and submitted to BOEM
	2 weeks after submitting		Comments on draft storyboard received from BOEM
	2 weeks		Amendments made and submitted
	2 weeks		Final storyboard submitted for BOEM approval
	4 weeks	Research educational video script	Draft Script complete and submitted to BOEM
	2 weeks		Script comments from BOEM received
	2 weeks		Final Script delivered
	6 weeks	Research educational video production	Draft Complete Video
	2 weeks		Feedback and amendments
			Video Dissemination

11. Glossary and reference

MarineQuest	Marine science outreach program for UNCW
NCAFF	North Carolina Aquarium at Fort Fisher
NOAA	National Ocean and Atmosphere Administration
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NMS	National Marine Sanctuaries
MMPA	Marine Mammal Protection Act
OCS	Outer continental shelf
OBIS-SEAMAP	Ocean Biogeographic Information System - Spatial Ecological Analysis of Megavertebrate Populations
Whale Alert	Data collection application (aka WA2)
Spotter Pro	Data collection application
SOTW	Song of the Whale research vessel
UNCW	University of North Carolina Wilmington

Research techniques:

- The MAPS researchers will use a combination of vessel-based and animal-borne technology to collect information about these understudied species:
    - Passive acoustic monitoring uses technology to record sounds emitted by marine mammals. The data will be collected from a specialized vessel, augmented by data from fixed moorings
    - Biotelemetry involves the application of tags onto individual animals. This technology allows researchers to track the animals’ behavior and physiology in the ocean
    - Visual surveys will detect groups of animals, their composition, age class and behaviors

Appendix C: Marine Mammal Passive Acoustics and Spatial Ecology (MAPS) Research Factsheet for General Public

MAPS - Marine Mammal Passive Acoustics and Spatial Ecology

A research project to improve understanding of marine mammal species

The ocean waters off North and South Carolina are home to one of the richest diversities of marine mammal species in the United States. People also use these waters for recreation, fishing, industry and research. Marine mammals are vulnerable to human-related threats, such as fishery entanglement, ship strike, and noise, including noise created by exploration for resources below the seabed. As protected species, Federal Law requires the public, industry, and government to consider how the actions they take might affect these animals and their marine environment.

To provide the best protection for marine mammals, we need to understand more about them, especially those species that are difficult to study because of their deep-diving habits or unknown movement patterns. The Marine Mammal Passive Acoustics and Spatial Ecology Project (MAPS), the first of its type in the region, draws on the expertise of researchers and citizen scientists to fill the gaps in our knowledge. MAPS will focus on offshore and relatively obscure species, including sperm, beaked and sei whales, and answer questions about their distribution and behavior/habits.

The **research area** is within the US Outer Continental Shelf (OCS) and includes the shelf, shelf-break and deep ocean waters off North and South Carolina. This area hosts some of the highest diversity of marine mammals within US waters. Many of the species found here are also found throughout the US OCS waters, allowing information from this study to be applied to other areas.

A combination of **data collection methods**, including passive acoustic monitoring, animal tagging, visual surveys, software development, and a new citizen science app, will be used to explore these enigmatic marine mammal species.

The data will be used to strengthen marine mammal protection. MAPS will provide detailed, robust information on how OCS marine mammals behave and use their habitats. The data will be used for smart ocean planning and strengthen efforts to avoid or limit the impacts these species might experience from human activities, such as energy resource development.

Who are the researchers?

MAPS brings together a diverse range of people, including:

- Scientists from the University of North Carolina Wilmington, Duke University and Aarhus University
- Marine Conservation Research with their state-of-the-art research vessel - *R/V Song of the Whale*
- YOU! We're working with leading high tech and citizen science experts, Conserve.IO and WildMe, to create an app which you can use to provide vital data to this project. Citizen science is an important component of the MAPS study. In the case of rare species, like the critically endangered right whale, or cryptic ones, such as beaked whales, every sighting matters.

Find out more

www.duke.edu/oceansmart
MAPS@duke.edu

MAPS (Marine Mammal Passive Acoustics and Spatial Ecology Project) is a cooperative agreement between BOEM and the University of North Carolina Wilmington and the Duke University Marine Lab.

Appendix D: Infographic for the Citizen Science and Flukebook Portion of the Marine Mammal Passive Acoustics and Spatial Ecology (MAPS) Research Project

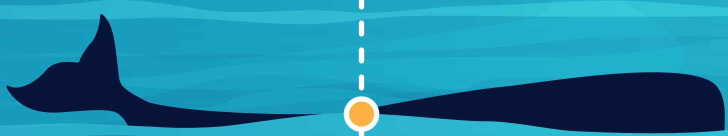
FLUKEBOOK

Marine Mammal Passive Acoustics & Spatial Ecology

MAPS

Strengthening marine mammal population and health studies.

Flukebook helps to protect whales by providing the best available science through collaboration between government, academic, non-government conservation organizations and the maritime industry.



SNAP

Unique markings like scars and fluke shapes identify individual animals of multiple species. Flukebook uses pattern recognition to ID each one.

SUBMIT

Submit photos and other sighting information and Flukebook does the rest. Flukebook helps identify and track individual whales and dolphins across hundreds of thousands of photos. Information is used for monitoring population health.

TRACK

You will be able to follow an individual whale, see who she is friends with, where she goes and who has seen her lately.

ANALYSIS

Sightings, photoID, molecular sampling and a growing number of features help users work with additional software by linking to external programs, including ArcGIS, SOCPROG, Genepop, GenAIEx, WinBugs, and Google Earth.

SECURITY

Flukebook safely backs up your data, you retain full ownership and control who you share it with.

STORAGE

Saving information for future use and multi-institution collaboration, all data is stored safely, and freely in the cloud.

COLLABORATION

Flukebook helps ensure responsible ocean resource management by connecting researchers and ocean users through the collection and analysis of millions of photographs, providing a more detailed picture of marine mammal health.

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UNCW | WILD ME | marine conservation research

Duke Nicholas School of the Environment | Conserve.iO Technology for a Better Planet

BOEM Bureau of Ocean Energy Management | NOAA/NMS (CINMS)

Appendix E: Poster of the Sperm Whale Thermal Imaging Results of the Mammal Passive Acoustics and Spatial Ecology (MAPS) Project Presented at the World Marine Mammal Conference, December 2019

INFRARED THERMAL IMAGING OF SPERM WHALES (*Physeter macrocephalus*) OFF THE WESTERN NORTH ATLANTIC OUTER CONTINENTAL SHELF

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ABSTRACT

Deep diving cetaceans must maintain a high, relatively constant body temperature as they thermally "migrate" between warm surface and cold deep waters multiple times per day. Although they possess anatomical and physiological adaptations to conserve heat, there exist few direct measures of the thermal biology of these mammals. Using infrared (IR) thermography, we investigated the thermal biology of sperm whales (*Physeter macrocephalus*) encountered during research cruises off the western North Atlantic outer continental shelf in winter and spring 2019 (NOAA Permits 14809-03 and 16473). Sperm whales foraging in this region experience a range of ambient temperatures as they travel between warm, Gulf Stream surface waters (mean 22.8 ºC in this study) to cooler, abyssal waters below. IR images (FLIR P60) were collected when weather and sea state permitted and analyzed using FLIR ThermaCam Researcher 2001. Dorsal fin, dorsolateral body, head and fluke surface temperatures were measured and compared to independently collected water temperatures for each sighting. Preliminary analyses of thermal images demonstrate that the dorsal fin and flukes were on average 0.2–1ºC warmer than surface water temperatures, while the head and dorsolateral body surfaces were 1.00–1.5ºC cooler. A single individual, tracked over a 10 min period at the surface, displayed warming of the dorsal fin and dorsolateral body from temperatures 0.5 – 1.0ºC cooler, to temperatures 0.5 – 1.0ºC warmer, than water temperature. These preliminary data demonstrate that the sperm whale body surface is thermally dynamic and heterogeneous. Ultimately, our goal is to collect thermal images of D-tagged individuals to investigate how surface temperatures change with dive behavior. These thermal profiles provide baseline data for future studies that may (a) test the efficacy of IR as a mitigation tool for, and (b) directly measure the response of deep divers to, anthropogenic stressors such as seismic surveys.

GOALS

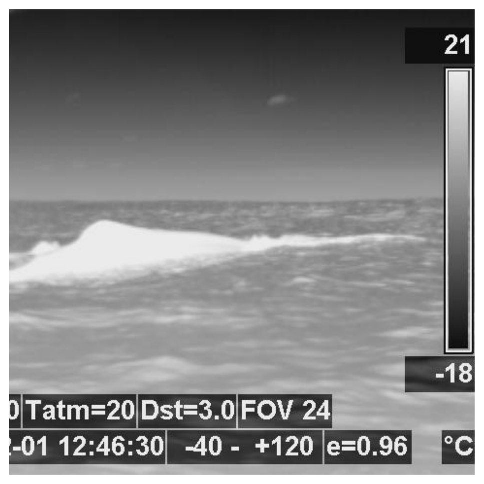
1. To use infrared (IR) thermography to investigate thermal biology of deep diving sperm whales (*Physeter macrocephalus*) encountered during research cruises off the western North Atlantic Continental Shelf in winter and spring 2019.
2. To collect a time series of IR photographs of D-tagged individuals to correlate body surface temperatures with independently-measured dive behavior, including time at depth, acoustic, and movement data.

METHODS

- Digital IR images of sperm whales were captured using a FLIR P60 (FLIR Systems, Inc., Wilsonville, OR, USA) infrared thermal camera from aboard the *R/V Song of the Whale* and/or a small RHIB.
- Whales were imaged opportunistically when encountered (typically during surface intervals associated with respiration or logging) and when weather and sea state permitted. For each image, IR photo #, date, time, and description of sighting were recorded.
- Images were imported into ThermaCam Researcher Pro software (FLIR Systems, Inc.) on a laptop and analyzed following methods similar to Barbieri *et al.* (2010) to determine body surface temperatures.
- Only images of good quality (*i.e.* in sharp focus; angle of the body surface being photographed estimated to be less than 30º to the plane of the camera) were included in analyses.
- Surface temperature measurements were taken of the head, dorsolateral body, dorsal fin and flukes of sperm whales. Body and fin margins were avoided. The number of sites analyzed varied between images and locations on the body. For example, more area could be sampled along the exposed dorsolateral body than at the relatively smaller dorsal fin.
- Mean surface temperature per body site was calculated for each image. The difference between mean body surface temperature and independently measured mean water temperature (collected on keel mounted thermometer at approximately 1m depth) (T_{body} - T_{water}) was calculated for each photo.

REFERENCE

Barbieri, M. M., W. A. McLellan, R. S. Wells, J. E. Blum, S. Hofmann, J. Gannon and D. A. Pabst. 2010. Using infrared thermography to assess seasonal trends in dorsal fin surface temperatures of free-swimming bottlenose dolphins (*Tursiops truncatus*) in Sarasota Bay, Florida. *Marine Mammal Science*. 26:53-66.



RESULTS

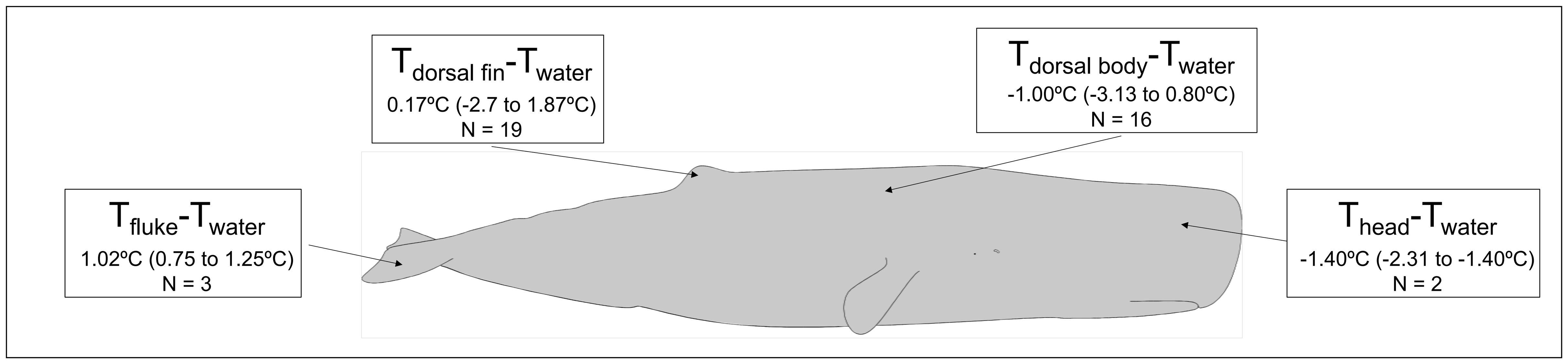


Figure 1. Mean (range) of temperature differences between body surfaces and surface waters across all IR imaged sperm whales. A total of 22 images was collected. Body surfaces ranged from -1.40ºC cooler to 1.40ºC warmer than surface waters.

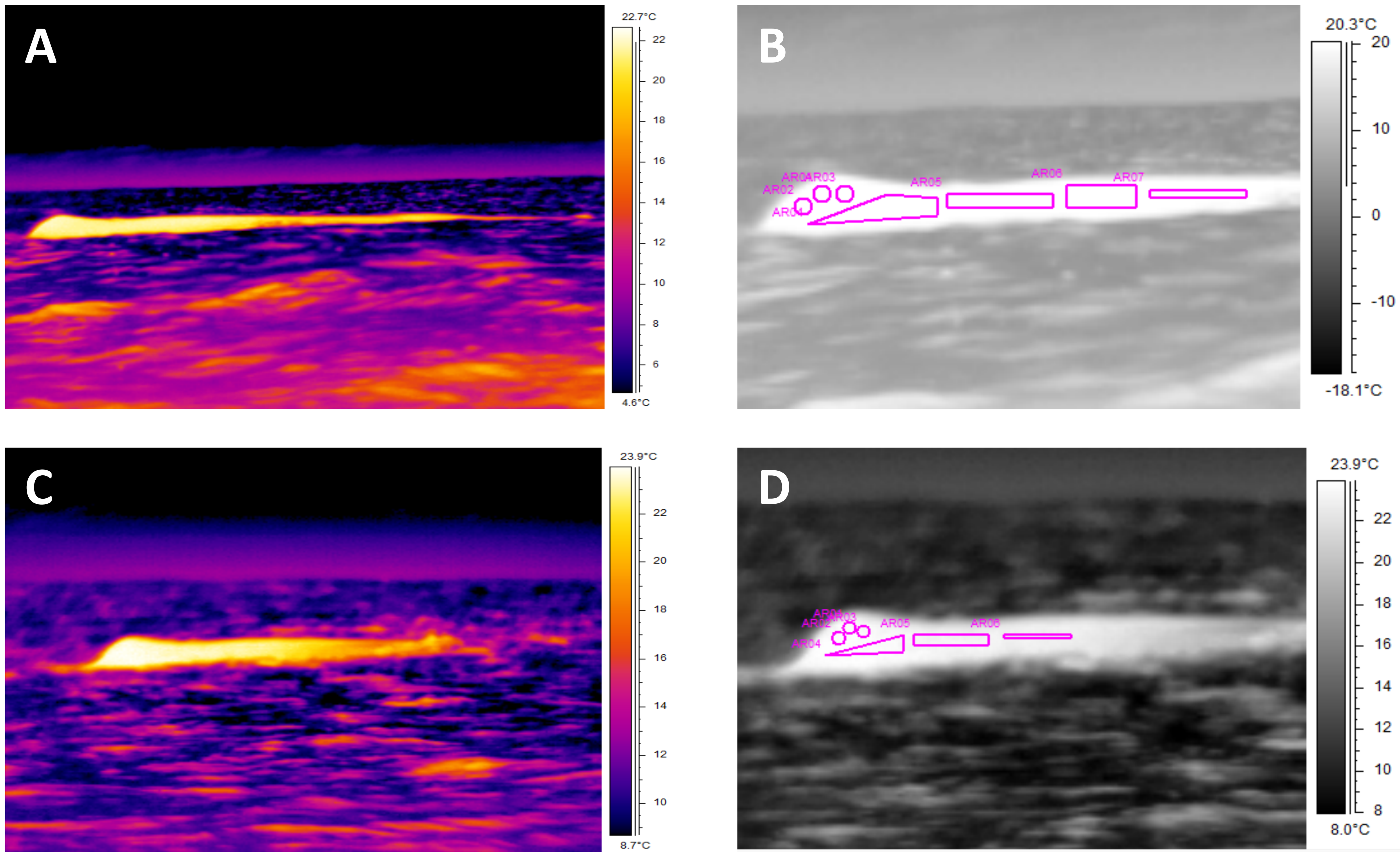


Figure 2. A single D-tagged sperm whale, tracked over a 10 min period at the surface, displayed warming of the dorsal fin and dorsolateral body. Images A and C are shown using a pseudo-color "iron" palette to emphasize variation in temperature. All analyses were carried out on gray scale images (B and D), where body margins were more easily determined. A and B. Images of surfacing whale following a dive. Dorsal fin 1ºC cooler and dorsal body 1.4ºC cooler than water. C and D. Images of the same whale logging at the surface 10 minutes post dive. Dorsal fin 1ºC warmer and dorsal body 0.6ºC warmer than water. Detailed diving behavior not determined because D-tag was not recovered.

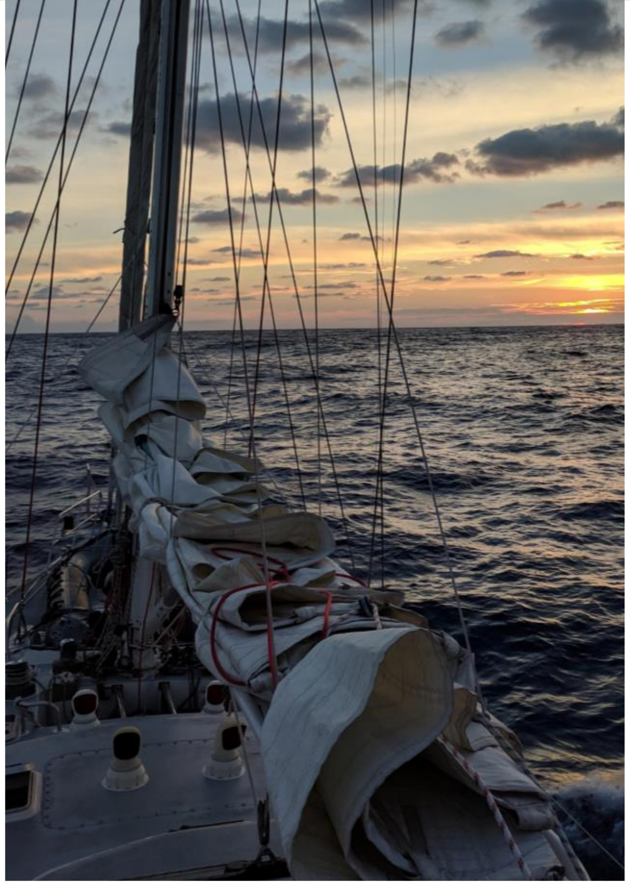
CONCLUSIONS

- Infrared thermography demonstrated that the sperm whale body surface is thermally dynamic and heterogeneous.
- The single analysis of a time series of IR thermal images collected during the cruise demonstrated warming of the whale's body surface, as would be predicted, with time spent in the relatively warm surface waters.
- The goal of correlating body surface temperatures with diving behavior was not accomplished because the D-tag was not recovered. These thermal profiles, though, provide baseline data for future studies to (a) test the efficacy of IR as a mitigation tool for, and (b) directly measure the response of deep divers to, anthropogenic stressors such as seismic surveys.

ACKNOWLEDGEMENTS

This research was supported by BOEM Cooperative Agreement M17AC00013. Work was carried out under NMFS Permit #14809 to Duke University and NMFS Permit #20527 to UNCW. We sincerely thank the crew members of *R/V Song of the Whale,* and Anna Clabaugh, Ellie Heywood, Jillian Wisse, Ashley Blawas, and Amelia Johnson from Duke University, and Tiffany Keenan-Bateman and Carrie Rowlands from UNCW.

Appendix F: An Example of the Outreach Activities of the Marine Mammal Passive Acoustics and Spatial Ecology (MAPS) Research Project: UNCW Marine Quest Camp Entitled “A Day in the Life of a Scientist Aboard the RV Song of the Whale”

A Day in the Life of a Scientist Onboard *RV Song of the Whale*

Insert
MarineQuest
and UNCW logo

MAPS

Marine Mammal Passive Acoustics and Spatial Ecology

A research project to improve our understanding of marine mammals

To provide the best protection for marine mammals we need to understand more about them, especially understudied species.

Understanding the research: https://sites.duke.edu/oceansmart/

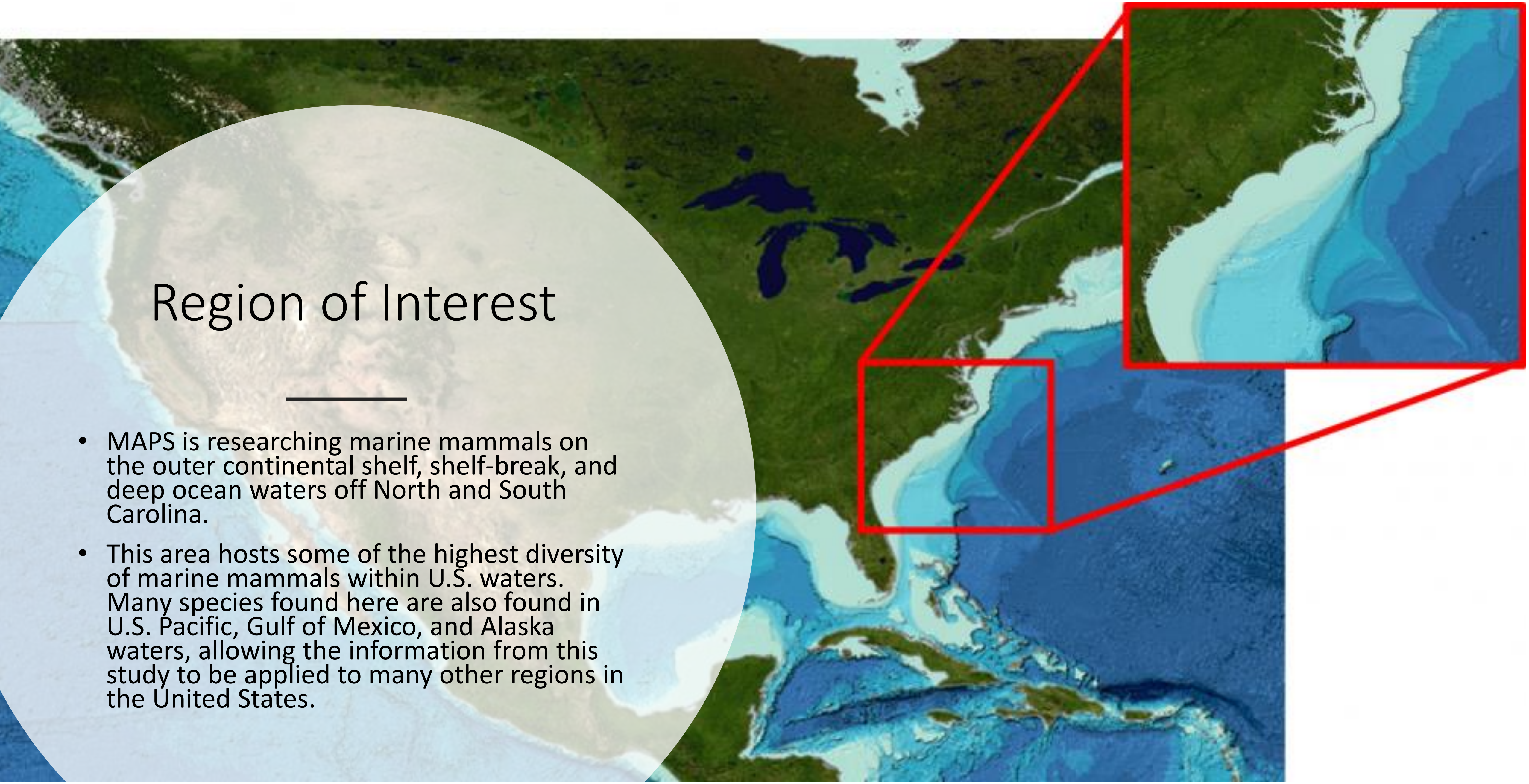
Video Link: https://warpwire.duke.edu/w/EYsCAA/

RV Song of the Whale

- Sailing vessel (21m)
- Built to run very quietly, perfect for acoustic monitoring!
- Observation spots above deck at 5m and 11m
- Linked computer system for easy data collection

Region of Interest

- MAPS is researching marine mammals on the outer continental shelf, shelf-break, and deep ocean waters off North and South Carolina.
- This area hosts some of the highest diversity of marine mammals within U.S. waters. Many species found here are also found in U.S. Pacific, Gulf of Mexico, and Alaska waters, allowing the information from this study to be applied to many other regions in the United States.



Source: https://sites.duke.edu/oceansmart/research/

Daily Research Roles

During our cruise, you will work for 2 hours and then be off for 4 hours

- Visual observer – scans surroundings visually
- Acoustic observer – listens to underwater sounds
- Data recorder – writes down data
- Captain – drives vessel
- Deck hand – helps wherever needed

Visual Observer

- 2 visual observers will work at a time, facing in opposite directions on the raised observation platform of the vessel
- Visual observers will scan surroundings, looking for marine animals or debris
- Visual observers tell the data recorder what they see and include direction

Acoustic Observer

- 2 acoustic observers will work at a time
- They will listen to what the hydrophones are picking up under the water and record any observations


2 data recorders will work at a time, one recording visual observations and the other recording acoustic observations using a data sheet
Data Recorder

Captain

Drives the *RV Song of the Whale* in all weather conditions, following track lines as much as possible

Deck Hand

Help with everything else on board, from fixing the sails, taking thermal images of whales, collecting water samples and marine debris, and cooking/cleaning.

-Coastal, shallow diver (<10m)
-Offshore, mid-water diver (<500m)
-Frequently at the surface breaching and playing

Bottlenose dolphin

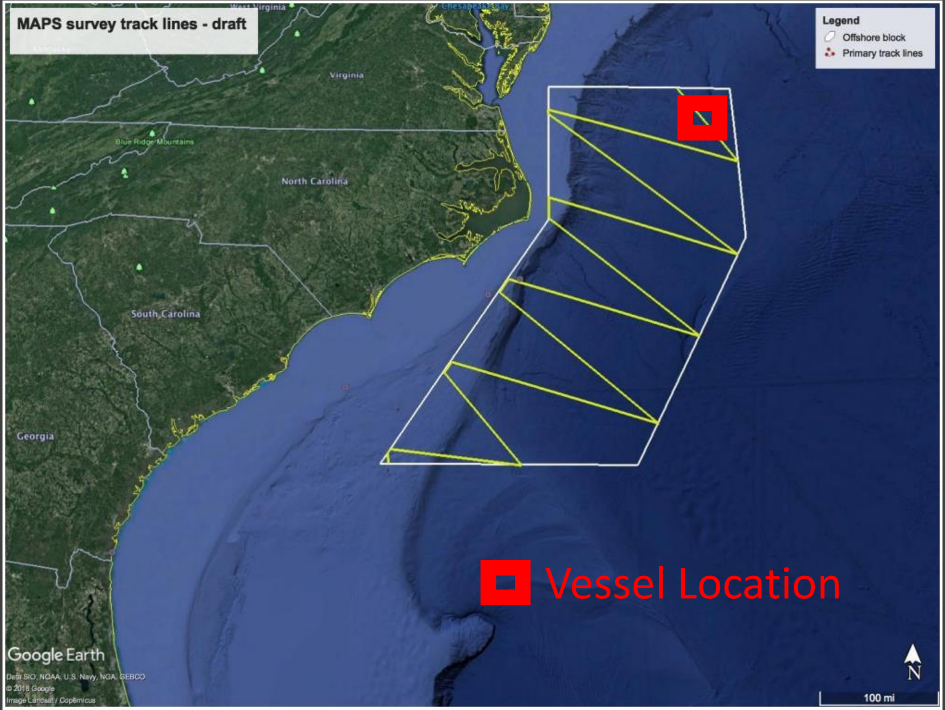
Tursiops truncatus

Bottlenose dolphins at sea

Marine Debris

Research Cruise Time!

Winter Cruise: January 20



Time: 1030

Weather/Sea Condition: Good

Acoustic Observations: Yes, 10

Visual Observations: Yes, 5

Deck hands fish marine debris out of ocean

Discovery: More acoustic detections than visual

Discoveries

- The most common observation was marine debris!
- There were more acoustic detections than visual detections for all species, so it is important to collect data acoustically to really understand what is in the water!
- BUT there are still limitations – this only shows us when animals are present, but does not tell is if they are absent or just silent.

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