Atlantic Behavioral Response Study (Atlantic-BRS): 2020 Annual Progress Report

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Naval Facilities Engineering Command

Prepared by

Southall Environmental Associates

Duke University

CREEM – University of St. Andrews

Submitted by:

HDR

Virginia Beach, VA

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Cuvier's beaked whale (*Ziphius cavirostris*) with the Duke University Marine Laboratory *R/V Shearwater* off Cape Hatteras. Photographed by Joseph Fader, taken under National Marine Fisheries Service Scientific Research Permit No. 19903 issued to Andy Read/Duke University.

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Acronyms and Abbreviations

BRS	Behavioral Response Study
CEE	controlled exposure experiment
CTMC	Continuous-Time Markov Chain
DAF	Douglas ARGOS filtered
DTAG	digital acoustic recording tag
dB re 1 µPa	decibel(s) referenced to 1 micro Pascal
GEE	generalized estimating equation
m	meter(s)
MFAS	mid-frequency active sonar
min	minute(s)
nm	nautical mile(s)
NPS	Naval Postgraduate School
ONR	Office of Naval Research
photo-ID	photo-identification
RL	received level
RHIB	rigid-hulled inflatable boat
RMS	root mean square
SD	standard deviation
sec	second(s)
SEA	Southall Environmental Associates
SOCAL	Southern California
U.S.	United States

Executive Summary

The Atlantic Behavioral Response Study (Atlantic-BRS) was conceived, designed, and initiated through a collaboration building on historical and ongoing Navy-funded studies under the United States (U.S.) Navy's Marine Species Monitoring Program. It applies a combination of novel tagging approaches to accomplish baseline monitoring of key marine mammal species (Cuvier's beaked whales [*Ziphius cavirostris*] and short-finned pilot whales [*Globicephala macrorhynchus*]) off the coast of Cape Hatteras, North Carolina. The project transitions and advances approaches developed from previous BRS field and analytical work supported by the Navy's Living Marine Resources program and Office of Naval Research. It is the first systematic effort to quantify sonar exposure and behavioral responses of priority marine mammal species to military sonar using controlled exposure experiments (CEEs) off the U.S. Atlantic coast. The Atlantic-BRS was designed through collaborative planning and has been strategically adapted and improved through four years of successful field experience. A specialized, multi-institutional team applies CEE methods involving mid-frequency active sonar (MFAS)—both coordinated with operational SQS-53C from U.S. Navy vessels and an experimental sound source simulating operational signals—using strategically deployed, complementary tag sensors on many individuals simultaneously. The approach employs both short-term, high-resolution acoustic tags and longer-term, coarser resolution satellite-linked location and behavior tags to study responses at multiple temporal and spatial scales. The project is ongoing and continues to add to the largest and most comprehensive data set available for sonar exposure and response for one of the highest-priority marine mammal species for the Navy.

While the ongoing COVID-19 pandemic influenced field operations, personnel, and logistics, given extensive effort, flexibility, and diligence to established associated protocols, field efforts were successfully conducted at comparable levels as in previous field campaigns. Building on the first three field seasons of this project (see Southall et al. 2018, 2019, 2020), Atlantic-BRS field operations in 2020 substantially increased the direct measurements of beaked whale responses to MFAS, notably in the context of operational, full-scale systems. We maintained the satellite-transmitting tag programming strategy developed in 2019 such that each tag deployment included two weeks of fine-scale time series dive data, in addition to (in some cases extensively) longer periods of positional surface data. Given challenges associated with the pandemic, especially in the planned spring field effort, and timing and coordination with Navy vessels, which were also influenced by these challenges, the field team adapted, in coordination with the Navy, to a single extended field period spanning the entire summer and into early fall. Field effort to deploy tags was focused in suitable weather windows ahead of known or possible Navy vessel availability, and then field teams were deployed during CEEs as possible given weather. Notably, this was the first field season that the new research vessel (*R/V Shearwater*), a 65-foot fast catamaran acquired by Duke University Marine Laboratory, was available for use in the Atlantic-BRS. This vessel proved useful as a high-vantage observational platform that covered considerable area in searching and tracking (including overnight) focal animals.

Three successful CEEs were conducted within the single, extended field period, with two successfully coordinated operational U.S. Navy vessels - *USS COLE* (DDG 67) and *USS LABOON* (DDG 58). All CEEs included multiple high-priority beaked whales (n=16 total exposure events) and a smaller number (n=2 exposure events) of secondary-priority pilot

whales. Additionally, we accomplished CEEs with individuals tagged with complementary tag types and with multiple individuals in the same social groups, providing insights into both social structure and behavioral coordination. All CEEs were successfully completed, as designed, with individuals at known ranges of several to many tens of kilometers, spanning the full range of target received levels.

Individual-based analyses of diving behavior, potential horizontal avoidance, and social behavior for data collected across all years are yielding increasingly complex, large, and published data using existing and newly developed quantitative metrics. Clear behavioral changes including strong observed avoidance responses and social responses observed were documented during both 2020 real-ship and simulated MFAS source CEEs. Over a dozen peer-reviewed manuscripts are already published or well along in the process (see section 3.2) using this extensive dataset, and selected data have already been integrated into the Navy-supported Animal Telemetry Network.

1. Overview

1.1 Overall project design and objectives

The Atlantic Behavioral Response Study (Atlantic-BRS) has been conducted for the past four years (2017–2020) through a research collaboration of scientists from Duke University, Southall Environmental Associates (SEA), and the University of St. Andrews. The overall experimental designed was based on methods previously developed under the Southern California Behavioral Response Study (SOCAL-BRS), funded primarily by the United States (U.S.) Navy's Living Marine Resources program, as well as the Office of Naval Research (ONR). Within the Atlantic-BRS, novel integrations and strategic deployments of different tag sensors and controlled exposure experiments (CEEs) are applied to beaked and pilot whales off the coast of Cape Hatteras, North Carolina in order to quantify exposure and potential behavioral responses to U.S. Navy mid-frequency active sonar (MFAS). This collaboration has had unprecedented success in tagging high-priority beaked whales and conducting CEEs with both operational MFAS systems from Navy surface vessels (e.g., SQS-53C-equipped combat vessels) as well as experimental sound sources simulating these systems. This report focuses on objectives, field methods and results, and ongoing analyses conducted within the 2020 field season. We also provide results and syntheses of selected behavioral, exposure, and response analyses from previous seasons, including a synthesis of the increasingly large number of peer-reviewed papers that have been or are in the process of being published.

Most previous studies have either used short-term, high-resolution acoustic tag sensors to measure fine-scale behavior in response to calibrated metrics of experimental noise exposure, or coarser-scale, longer-term measurements of movement and diving behavior associated with incidental exposures during sonar training operations. This study is unique in bringing both approaches together and building on previous experience with both tag types for focal species within the same area. Specifically, the overall design involves expanding the temporal and spatial scales of previous BRS efforts by combining short-term, high-resolution acoustic archival tags (DTAGs) providing short-term (hours) but very high-resolution movement and calibrated acoustic data, and satellite-linked, time-depth recording tags (SLTRDs, i.e., "sat tags") providing much longer-term (weeks-months) data on movement and increasingly higher resolution dive data, simultaneously deployed on multiple individuals of focal species in the same CEEs. As in previous studies, explicit monitoring and mitigation protocols have been established and followed in conducting CEEs in order to meet experimental objectives and ensure compliance with both permit authorizations and ethical standards.

The overall research objective is to provide direct, quantitative measurements of marine mammal behavior before, during, and after known exposures to MFAS signals in order to better describe behavioral response probability in relation to key exposure variables (e.g., received sound level, proximity, animal behavioral state). These measurements have direct implications for and contributions to more informed assessments of the probability and magnitude of potential behavioral responses of these species. Results will be directly applicable to the Navy in meeting their mandated requirements to understand the impacts of training and testing activities on protected species, as well as to regulatory agencies in evaluating potential responses within regulatory contexts. The results here specifically address aspects of baseline behavior, exposure-response, and provide sufficiently large sample sizes to begin addressing questions related to consequences. These collectively represent three of four focal areas for the U.S. Navy's Marine Species Monitoring Program as developed by their scientific advisory group and applied in guiding monitoring objectives.

Strategically specified categories of potential behavioral responses are evaluated using a variety of adaptive and cutting-edge methods, namely (1) potential avoidance of sound sources that influence habitat usage; (2) changes in foraging behavior; and (3) changes in social behavior. Experimental objectives, field work accomplishments, and planned effort are regularly communicated to interested stakeholders through periodic compliance reporting, progress updates, and presentations and discussions in annual meetings of the monitoring program as well as scientific and general audience fora.

1.2 Experimental Design

Considerable value was identified during extensive advanced planning in maintaining consistency with other BRS projects in the initial experimental design of this project. Given this, and the success in deploying many tags and successfully conducting both real ship MFAS and simulated MFAS CEEs in earlier field campaigns, minimal changes were initially made to the field approach prior to 2020 effort. Planned differences were largely in field configurations, timing of effort, tag settings, etc., rather than changes in overall experimental design, although the recent acquisition of the Duke University Marine Lab *R/V Shearwater* and its use within the project was a development in 2020. Such consistency in research methodology is seen as critical to allow comparisons to be drawn among studies and support the meta-analyses needed to derive exposure-response probabilistic functions both within data from this project and, as appropriate, integrated with data from other research and monitoring efforts. The resulting overall design involves multiple different kinds of monitoring methodologies and platforms, incorporating lessons learned from a variety of research and monitoring programs funded by the Navy. These included quantitative measurements of individual behavior using tags of several types, small-vessel-based individual and group focal follow observations, targeted collection of individual tissue biopsy samples and photo-identification (photo-ID), and remote passive acoustic monitoring from archival recorders deployed in the general area.

Given the coordination required with Navy combat vessels equipped with SQS-53C sonar systems for BRS efforts off the coast of Cape Hatteras, the overall experimental design was based on the methods employed in the SOCAL BRS using CEEs with both simulated MFAS and operational vessel-based 53C systems (Southall et al. 2012, 2016, 2019). These methods had been successfully applied in coordination between the Atlantic-BRS and three U.S. Navy surface vessels in earlier field efforts. This approach includes a period during which baseline behavioral data are collected prior to the CEE—a minimum of 60 minutes for animals with DTAGs and a 24-hour minimum for animals equipped with satellite tags. Most baseline data periods were much longer in practice for satellite tags. Pre-exposure baseline behavioral data collection primarily involved data from tag sensors, supplemented by focal follows of tagged animals by observers in small vessels where possible.

Sonar transmissions during CEEs occurred in the same manner as in SOCAL-BRS (see Southall et al. 2012) and earlier efforts in this project (see Schick et al. 2019). Simulated MFAS sources were deployed to a 20-meter (m) depth from a drifting (not under power) vessel and operated for a total of 30 minutes (min) at output source levels from 160 to a maximum of 212 decibels (root mean square) referenced to 1 microPascal (dB [RMS] re 1 µPa). Vessels were positioned at ranges from subjects that met experimental objectives for received levels (RLs). Full scale sources included transmission of full power (235 dB [RMS] re 1 µPa) signals of a constant nominal 53-C waveform type (single ping sequence using three sequential CP/CW waveforms of 0.5-second (sec) duration each, with 0.1 sec separation for total ping series 1.6 sec duration). Signals were transmitted with a 25 sec repetition rate, using surface duct sector search mode, and 3° downward vertical steering. Transmissions occurred for a total duration of 60 min with the transmitting ship transiting in a direct course at a net (over ground) speed of 8 knots. Based on the position of a focal animal, the starting position and course for the transmitting vessel was determined using custom *in situ* propagation modeling tools using the Navy-consistent models and unclassified databases in software developed and supported by the Naval Postgraduate School (NPS). The experimental design allows for positioning of MFAS sources to result in target received levels at focal individuals based on their position and accounting for local bathymetry and dynamic oceanographic conditions. However, other individuals were incidentally exposed at a variety of received levels that were not explicitly controlled but were estimated (with error) from positions derived from either satellite tags or observations in the field. The course of the vessel (or drift of the simulated MFAS sources) was designed to result in an escalation in RL at the presumed location of focal individuals based on their movement, to the extent it is known. Movement of the source was designed to be generally, but not directly, toward individuals. Given the large number of tagged individuals exposed during CEEs, individuals have had (by design) varied MFAS exposure conditions in terms of range and received level. Target received levels for focal animals ranged from 120 to 160 dB RMS (hereafter dB unless otherwise specified), depending upon species and the aggregate location of focal individuals (120 to 140 dB for beaked whales, 135 to 160 dB for pilot whales). Following incremental increases in target levels for the 2018 and 2019 field efforts, these target levels were maintained at 2019 levels for 2020 based on the strong responses observed in multiple CEEs near the top of these target received levels in 2019.

Monitoring of experimental subjects was maintained following exposure sequences, both visually and by the tags. Satellite tags were programmed to continue collecting data consistently for days or weeks following CEEs. Focal animals (particularly for DTAG individuals) were visually monitored for a further 60 min, employing the same focal animal sampling protocol. Attempts to obtain biopsy samples were made for focal individuals as well as other animals in the group following the post-exposure monitoring period. Biopsy samples will be used to determine the sex and reproductive status of the whales and to potentially measure the level stress hormones in exposed individuals.

To maximize the chances of successful coordination with Navy ships engaged in training exercises in areas that are several tens to approximately 100 kilometers from the study site, the experimental design called for a single CEE within each week. This schedule also addressed the potential for habituation or sensitization of animals within the small area and the infrequent sonar use here, compared to other studies which have occurred on training ranges where sonar is used more routinely. For 2020, we maintained satellite-transmitting tag setting approaches successfully developed in 2019 to provide approximately two weeks of continuous, relatively high duration (5 min time series) dive data, with ARGOS positional data being collected for several weeks longer. This was done to increase the resolution during a focal period when Navy ships were expected to be available or simulated MFAS CEEs could otherwise be conducted. The objective was thus to conduct one CEE within each two-week window following satellite tag deployment windows. The clear priority was to conduct CEEs using operational SQS-53C MFAS sonar systems from actual Navy vessels. The simulated MFAS sonar source is more comparable to operational systems such as helicopter dipping sonars (AN/AQS-13) and is thus more appropriate for comparison with those kinds of systems in terms of response. It was thus clearly identified as a secondary priority and reserved for instances where tagged animals are available, weather conditions support CEEs, but Navy ships were unavailable.

It is noted that, like essentially everything else in the world, the Atlantic-BRS project was impacted throughout 2020 on multiple levels by the COVID-19 pandemic. As discussed in Section 1.4, there were a number of logistical and personnel adaptations necessitated by travel and workplace protocols and restrictions, accordingly, to which the project had to adapt. Remarkably, and due to extensive effort and diligence on the part of everyone on the field team, these challenges were overcome, and a full, successful field season was safely and productively achieved despite them. While these adaptations affected timing, logistics, and personnel requirements, no fundamental changes or compromises occurred to experimental design or the quality of data acquired.

1.3 Overall Analytical Approach

Behavioral response analyses focus on how whales change their behavior from baseline conditions during periods of MFAS exposure in known contexts during CEEs. The analytical methods being used directly transition and apply successful methods developed in other BRS studies and Atlantic-BRS efforts to date. Specific questions and methods are derived for differences in the nature of available data (tag type) and species in question. Analyses of behavior and behavioral response are designed to consider questions of (1) potential avoidance behavior, (2) potential changes in behavioral state, and (3) potential changes in social behavior.

In earlier phases of the field effort, extensive progress was made in developing systematic methods to process the tens of thousands of hours of tag, acoustic, and visual data collected during the dozens of tag deployments made within each year. While increasingly efficient, these complex processes require extensive time and effort to process raw data, filter and finalize integrated data streams, and ultimately quantify behavior to address these three questions. In each of our prior reports, several tables and figures describing detailed aspects of data processing and analysis were provided to demonstrate these approaches. These evolved and became more complex within the first several years, but, as expected, by the third full field season in 2019 were sufficiently well-developed and efficient that they were largely maintained and applied to the large 2020 data set, effectively as described for the 2019 field effort (Southall et al. 2020). See Section 1.3 of that report (specifically Tables 1 through 3; Figures 1 through 5) for additional details on these approaches. Further, unlike in previous reports for this project where all propagation modeling, horizontal movement, and dive profile data were provided for every tagged individual and every CEE, herein we provide the most immediately pertinent such results specific to focal individuals. All figures included here as well as all those generated for all CEEs and all individuals are openly available for viewing at the Atlantic BRS Github site, which is internally organized by CEE and figure type. For questions or hard copies of any figures, please contact Brandon.Southall@sea-inc.net.

1.4 Field Logistics and Configuration

Atlantic-BRS field effort for 2020 was initially designed with a comparable field approach as in previous years, including spring (May-June) and summer (August) field campaigns. The initial objective was to conduct two phases of tag deployments within each field campaign, each with a corresponding CEE (i.e., four targeted advance tagging windows and four CEEs) with the goal being each of these to occur with operational U.S. Navy vessels operating SQS/53C MFAS. By March, it was clear that the ongoing pandemic would significantly impact planned field effort, given the challenges associated with travel and working together in confined spaces, as well as institutional and insurance liability requirements and restrictions. A decision was made, in coordination between the field team and the Navy, to belay efforts from the scheduled spring period and focus efforts within a single extended window beginning in July and extended through October, if possible. Extensive and detailed personnel testing, quarantine, and operational protocols were developed for field operations, necessarily resulting in focused effort with smaller, contained teams to ensure compliance and safety. This resulted in a comparable number of tag deployments and CEEs within strategically identified periods during this single extended phase.

Based on a combination of anticipated Navy vessel availability and weather conditions, a small rigid-hulled inflatable boat (RHIB)-based team was deployed for advance deployment of satellite tags followed by a more intensive, larger team effort with a larger vessel during which DTAG deployments were attempted and CEEs were conducted. Satellite tags were deployed by a small team (n=4) aboard the R/V *Barber*, an 8 m aluminum-hulled SAFE vessel capable of handling moderately heavy seas. The field crew transited offshore daily when sea conditions were suitable, located animals, deployed tags, and collected photo-ID and other data from groups.

During periods in which DTAG deployments and CEEs were attempted, a research crew of approximately 10 individuals was involved and worked from the R/V *Barber* (with an identical crew of 4 as above) and the *R/V Shearwater* (the newly acquired Duke University research fast catamaran). The *Shearwater* housed the simulated MFAS sound source and served as an excellent elevated visual and tag tracking and visual observation platform. These vessels were involved in all tag deployment and CEE efforts, as well as re-sighting and biopsy sampling of focal individuals thereafter. The *F/V Kahuna* or other charter vessels based out of Manteo, North Carolina, were used on some days with one researcher or a two-person research team following tag deployments and CEEs to relocate tagged animals at known locations to improve track modeling and acquire photo-IDs, group composition, and social data.

Three version 3 DTAGs from the University of Michigan were leased for most of the available field periods. A total of 30 Low-Impact Minimally Percutaneous Electronic Transmitter (LIMPET) satellite-linked tags were available. Priority was placed (given the interest in feeding and diving behavior) on the use of SPLASH10-A depth transmitting tags; almost all tags available were of this type. A small number of SPLASH-10F tags that incorporate fastloc GPS were available but not deployed. The highest tagging priority was on Cuvier’s beaked whales as this species is of high Navy interest (see Southall et al. 2016); pilot whales were identified as a secondary priority. Efforts were again made to deploy multiple tags in social groups of either species, in order to evaluate potential changes in social associations as a response metric during CEEs. Substantial progress was made in this regard.

Considerable advance planning and coordination occurred within the field team and with the Navy sponsors and coordination team, particularly given challenges associated with the ongoing pandemic. These challenges on the Navy side resulted in the previous approaches of placing a dedicated liaison for the project as a rider on the vessel to aid in coordinating vessel operations ahead of and during MFAS CEEs. The modified approach was for extensive and sustained planning discussions between the Atlantic-BRS team and Navy representatives, beginning months in advance of field operations, and additional advance briefing of potential vessels with which coordination was identified as possible. During potential coordination periods, dedicated Navy personnel coordinated with vessels in the field remotely from onshore sites through secure communications. The Atlantic-BRS chief scientist was also positioned ashore with direct communications to the smaller field team, but also with easier telephone, text, and email real-time connections to the Navy personnel directing ships. This approach resulted in two well-coordinated and successful CEEs with operational Navy vessels. The research team coordinated before, during, and after the field effort through designated representatives, including regular updates and communication, as well as quick-look summaries following field operations. The Navy team provided all requested positional and operational data in an unclassified communication related specifically to Atlantic-BRS CEEs. In addition to the two successful CEEs with operational Navy vessels, on one occasion when multiple animals were tagged it was not possible to coordinate with a Navy vessel, and a simulated MFAS CEE was successfully conducted from the source operated from the *R/V Shearwater*.

While the pandemic severely limited travel and open meetings, including the U.S. Navy's marine species monitoring program technical review meeting scheduled for spring 2020, the Atlantic-BRS team strove to provide information transparently through DUML and SEA blogs on progress to the greatest extent possible. This included close coordination with the Navy on the production of a "Stewards of the Sea" video on the Atlantic-BRS effort released in April 2020 as a public-audience summary of the project.[1] The team also coordinated directly with the Navy on a press-release and several associated media stories resulting from the 15 July 2020 CEE with the *USS COLE.*[2] The Duke team also provided direction regarding research plans and established lines of communication in the unlikely event of any marine mammal stranding during operations with representatives from the Mid-Atlantic Marine Mammal Stranding Network. Finally, results continued to be presented in open (virtual) scientific meetings, including the Acoustical Society of America, as well as four peer-reviewed papers that were either published or accepted for publication in 2020 (see Section 3.2).

[1] See: https://sea-inc.net/2020/04/us-navy-releases-new-atlantic-brs-video/

[2] See links provided at: https://sea-inc.net/2020/07/uss-cole-participates-in-sea-duke-marine-mammal-study/

2. Field Effort

2.1 Summary of 2020 Field Effort: Accomplishments and Assessment

Field dates:

- **5 July 2020**: First possible field effort following all requisite development and implementation of testing, quarantine, and travel protocols for advance tag deployment team. Field team mobilized in Manteo.
- **6-14 July**: Field effort on weather permitting days from *R/V Barber* resulting in one beaked whale and one pilot whale tag deployment ahead of Navy ship availability.
- **13-16 July**: *R/V Shearwater* deployed from DUML to Hatteras field area to support tagging, tracking, and CEE operations.
- **15 July**: *R/V Barber* and *R/V Shearwater* support CEE #2020_01 successfully coordinated with *USS COLE* with tagged focal whales.
- **17-29 July:** Second wave of satellite-tagging field effort on weather permitting days from *R/V Barber* resulting in two additional beaked whale tag deployments ahead of Navy ship availability.
- **30 July**: CEE #2020_012 successfully coordinated remotely with *USS LABOON* with focal whales tagged previously. Weather conditions precluded directly involvement of *R/V Barber* and *R/V Shearwater* but teams all participated in planning and coordination of animal locations used to position the vessel.
- **1-18 August**: Third wave of satellite-tagging field effort on weather permitting days from *R/V Barber* resulting in 11 additional beaked whale tag deployments ahead of Navy ship availability.
- **17-20 August:** *R/V Shearwater* deployed from DUML to Hatteras field area to support tagging, tracking, and CEE operations. CEE #2020_03 successfully conducted on 19 August (with support from *R/V Barber*) using simulated MFAS source with tagged focal whales as well as two DTAGs deployed prior to CEE (one attached during).
- **21 August through end September:** Follow-up re-sightings, photo ID, *in situ* data acquisition, and biopsy sample collection from focal whales.

Accomplishments:

- Fielding an effective team and successfully completing a comparable level of tag deployments and CEEs as in previous years when many other research efforts were terminated due to the ongoing pandemic.
- Successful deployment of 15 satellite tags (14 beaked whales; 1 pilot whale).
- Two successful CEEs with operational Navy vessel, full-scale 53C MFAS CEEs. Both were conducted at or near beaked whale target RLs (140 dB RMS) specified for 2020.

- One successful simulated MFAS conducted at or near target beaked whale levels for focal animals; CEE conducted with large sample size (n=12) beaked whales.
- Successful integration of new research platform *R/V Shearwater* into Atlantic-BRS field effort. Highly successful in locating and tracking animals, including successful tracking over night for both satellite-transmitting and DTAG sensors.
- Successful deployment, tracking, and recovery of both a moderate- (6-hour) and long-duration (23-hour) DTAG on priority beaked whale individuals, both in social groups with other known and satellite-transmitting tagged individuals. Unfortunately, not all data were obtained due to tag failures.
- Sustained efforts to relocate sat-tagged animals in the field using goniometer detections, increasing chances of subsequent tag deployments, improving animal pseudotracks by providing high confidence surface locations, and resulting in many photo-ID resights to evaluate group composition and social interactions. Explicit and novel quantitative metrics for integrating various levels of confidence/quality of detections into modeled track imputations for movement models.
- Additional observations of potential social group responses in beaked whales with individuals with known sighting history in same social group subsequently sighted apart following CEE.
- Sustained high-quality satellite-transmitting tag dive data thanks to earlier progress in tag deployment strategies to reduce/eliminate gaps in satellite tag data and to improve temporal resolution on diving and behavioral data. We successfully collected continuous dive data for two-week periods, strategically covering CEE periods, as designed. We also saw longer than previous overall function of tags in reporting ARGOS positions, potentially due to improved batteries in SPLASH tags.

Assessment of field approach:

- Simply fielding a team safely given all the challenges with the pandemic was fairly remarkable and a testament to the adaptability and determination of the field team.
- Extremely positive developments in planning, coordination, and execution of Navy vessel CEEs. This also required considerable adaptation and effort on the Navy side. Lessons learned are that real vessel CEEs can be successfully accomplished with advance planning and support and close coordination among members of the research team and the Navy team present on land communicating with respective research and Navy vessels at sea in real time. At-sea coordination between research and operational vessels was also successfully coordinated.
- Very good conditions occurred during several windows with workable weather at least for re-sight detections for a number of stretches in July and August. However, major storms were also experienced in the area during this period and into September. Overall, weather conditions were less favorable in 2020 than in any previous field effort.
- We continued to have success in locating and tagging beaked whales. Thanks to a high density of animals and skilled field teams, high rates of tag deployments per field day continue to be achieved. This has resulted in considerably less data for pilot whales than

in earlier years, but this is more than acceptable as beaked whales are the top priority species.

- Both DTAG deployments were limited partially or entirely by tag failures. A long-duration (23-hour) baseline tag that would have been useful to assess diurnal behavior previously unavailable for this location was rendered entirely unusable by pressure sensor and hydrophone failures. A programed shorter (within-day) DTAG yielded useful dive and acoustic data during a CEE, but sensor issues with heading data precluded some analytical assessments. Modifications to overcome previous VHF limitations seemed to be effective in tracking, but these sensor failures unfortunately rendered data recovered being compromised.

2.2 Tag deployments

Satellite tag deployments were conducted by researchers from Bridger Consulting in coordination with the Atlantic-BRS team aboard Duke University vessels. A summary of tag deployments for 2020 is provided below for individuals of both species (**Tables 1** and **2**). Overall, 15 satellite tags were deployed—14 on Cuvier's beaked whales and 1 on short-finned pilot whales. Maps showing Douglas-filtered ARGOS positions for all beaked and pilot whales tagged in 2020 are shown in **Figures 1** and **2**, respectively. Individual (by-animal) plots of Douglas-filtered ARGOS positions are also given for the entire satellite tag deployment periods (for tags that successfully transmitted data) for beaked whales (**Figures 3** through **15**) and one pilot whale (**Figure 16**). For whales that were tagged during CEEs, the start and end location of the respective CEEs are indicated on the individual plots.

Two DTAGs were deployed on beaked whales during the 2020 field effort (**Table 3**). The first (Zc20_231a) was deployed on 18 August on an individual within a group in which another whale was being simultaneously tracked with a satellite-transmitting tag, with the intention of tracking the individual overnight for a long-duration deployment prior to a CEE on the following day. The field team successfully tracked the whale through the night from the *R/V Shearwater* and prepared for a CEE the following day, although it was ultimately conducted after the animal was relocated and the tag detached. This tag offered great promise for insight into baseline (no known exposure), fine-scale, overnight behavioral data, including behavioral synchrony insight with the satellite tagged whale. Unfortunately, multiple failures were experienced with the movement and acoustic sensors and no usable data were recoverable. Another DTAG was deployed (Zc20_232a), and the animal was tracked during a pre-exposure baseline period, following which CEE #2020_03 was conducted with the simulated MFAS source; quick look summaries of DTAG results for this whale are provided in Section 2.3.3.

Table 1. Satellite tag deployments for Cuvier's beaked whales during Atlantic-BRS field efforts in 2020

Species[3]/ Tag ID	Deployment date	Deployment latitude (°N)	Deployment longitude (°W)	Dive data streams	Tag duration (days)
ZcTag098	07/14/20	35.7686	74.7544	5-min time series	41
ZcTag099	07/17/20	35.6848	-74.7443	5-min time series	19
ZcTag100	07/17/20	35.6473	-74.7391	5-min time series	29
ZcTag101	08/07/20	35.5377	-74.7551	5-min time series	66
ZcTag102	08/07/20	35.5230	-74.7632	5-min time series	29
ZcTag103	08/08/20	35.4963	-74.7512	5-min time series	32
ZcTag104[4]	08/08/20	35.4963	-74.7295	5-min time series	0
ZcTag105	08/08/20	35.4937	-74.7226	5-min time series	69
ZcTag106	08/08/20	35.4895	-74.7523	5-min time series	64
ZcTag107	08/09/20	35.6507	-74.7451	5-min time series	68
ZcTag108	08/09/20	35.6558	-74.7350	5-min time series	56
ZcTag109	08/10/20	35.5216	-74.7244	5-min time series	55
ZcTag110	08/10/20	35.5112	-74.7304	5-min time series	85
ZcTag111	08/10/20	35.4990	-74.7544	5-min time series	69

Table 2. Satellite tag deployments for pilot whales during Atlantic-BRS field efforts in 2020

Species[5]/ Tag ID	Deployment date	Deployment latitude (°N)	Deployment longitude (°W)	Dive data streams	Tag duration (days)
GmTag228	7/14/20	35.7703	-74.7084	Behavior categorical	68

Table 3. DTAG deployments for Cuvier's beaked whales during Atlantic-BRS field efforts in 2020

Tag ID	Deployment date	Deployment latitude (°N)	Deployment longitude (°W)	Baseline or CEE number	Tag duration	Recovered?
Zc20_231a	8/18/20	35.5250	-74.6270	Baseline	23 hours	YES
Zc20_232a[6]	8/19/20	35.5450	-74.7047	CEE #2020-03	6 hours	YES

[3] Zc = *Ziphius cavirostris*
[4] Tag failed on deployment
[5] Gm = *Globicephala macrorhynchus*
[6] In group with satellite tagged Zc108 during CEE #2020_03

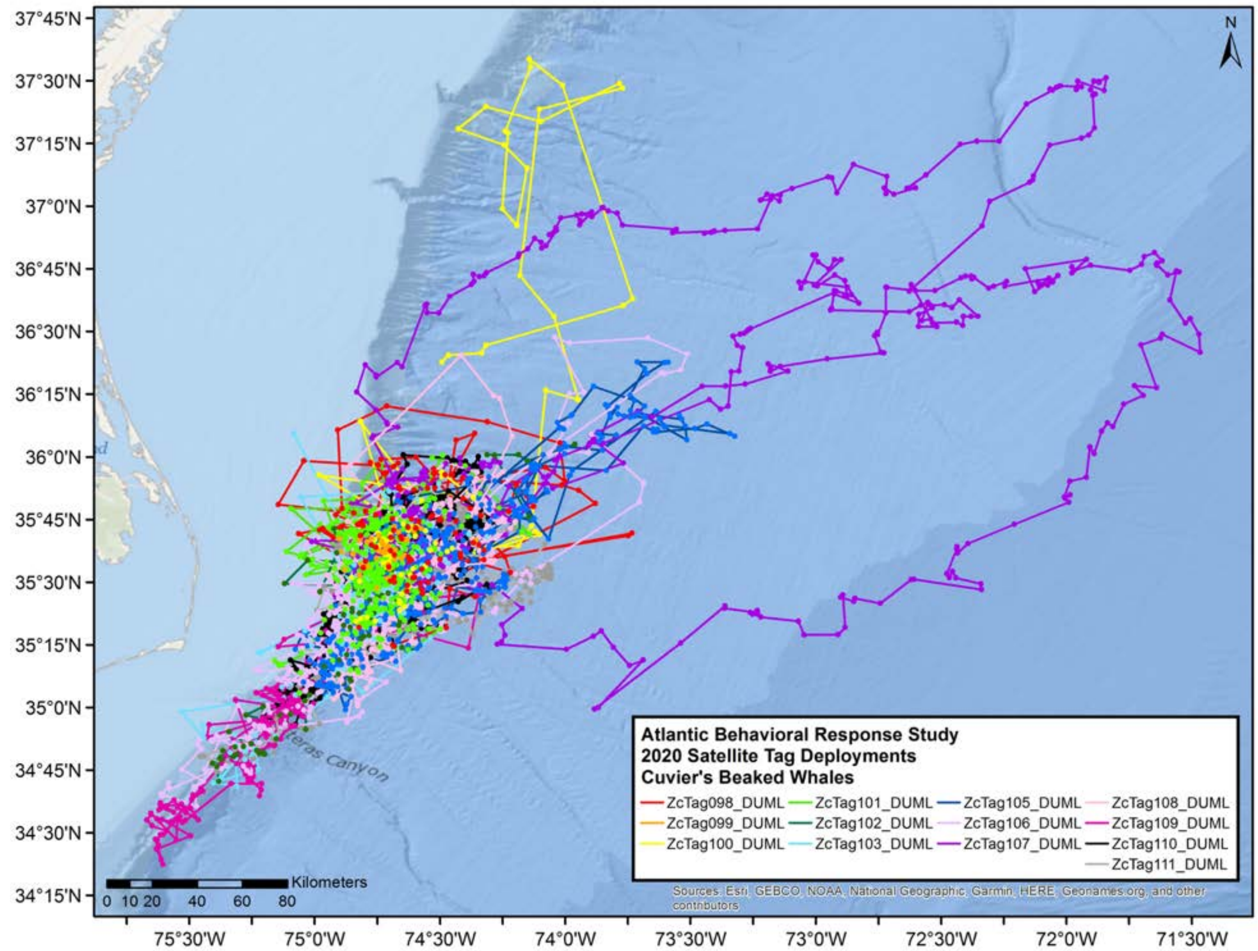

Figure 1. Douglas-filtered ARGOS positions for all Cuvier's beaked whales (n=14) tagged during Atlantic-BRS field efforts in 2020.

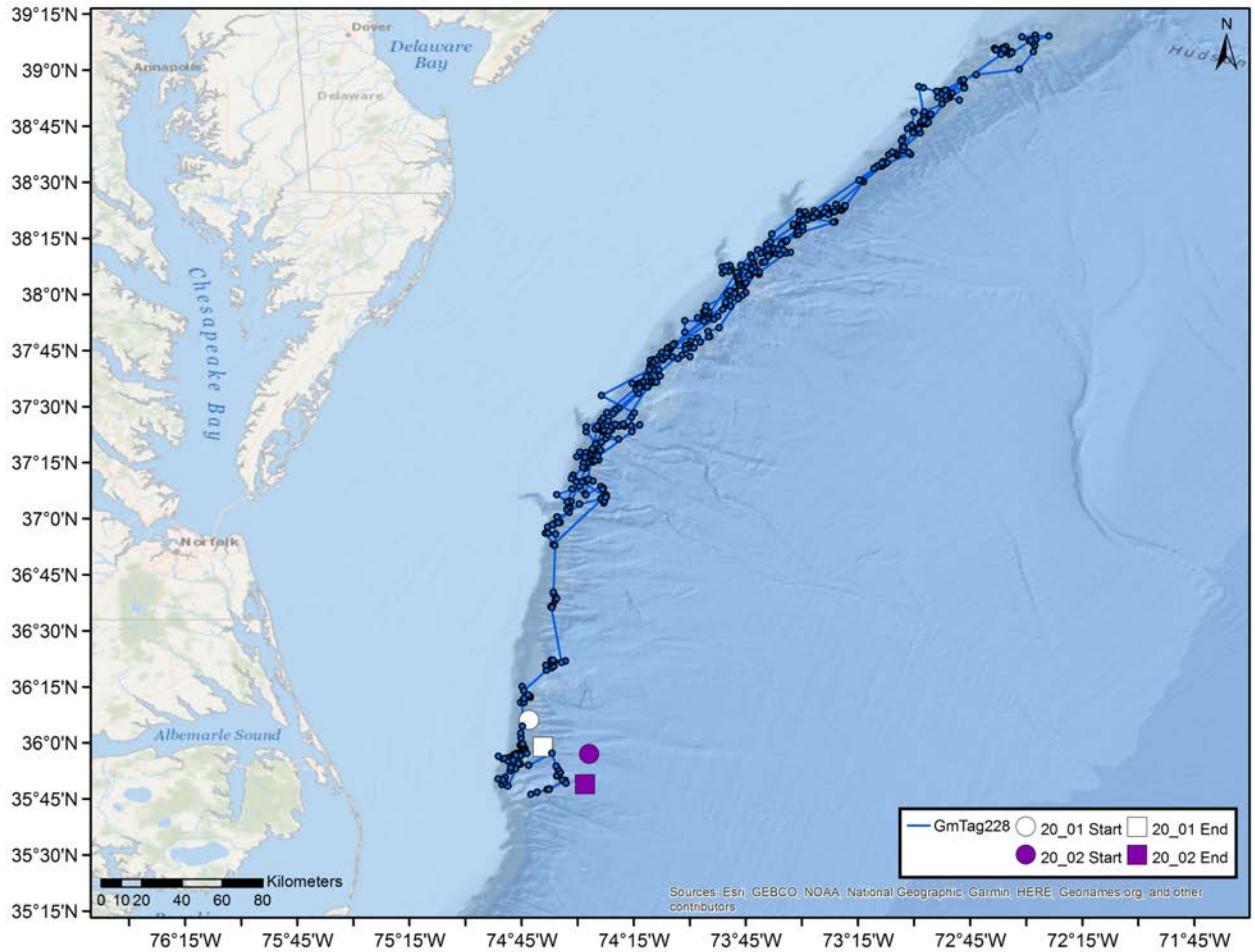

Figure 2. Douglas-filtered ARGOS positions for the single short-finned pilot whale (GmTag228) tagged during Atlantic-BRS field efforts (tag duration 68 days) in 2020.[7]

[7] Note: The location of two CEEs occurring during the tag deployment for this single individual are also noted here.

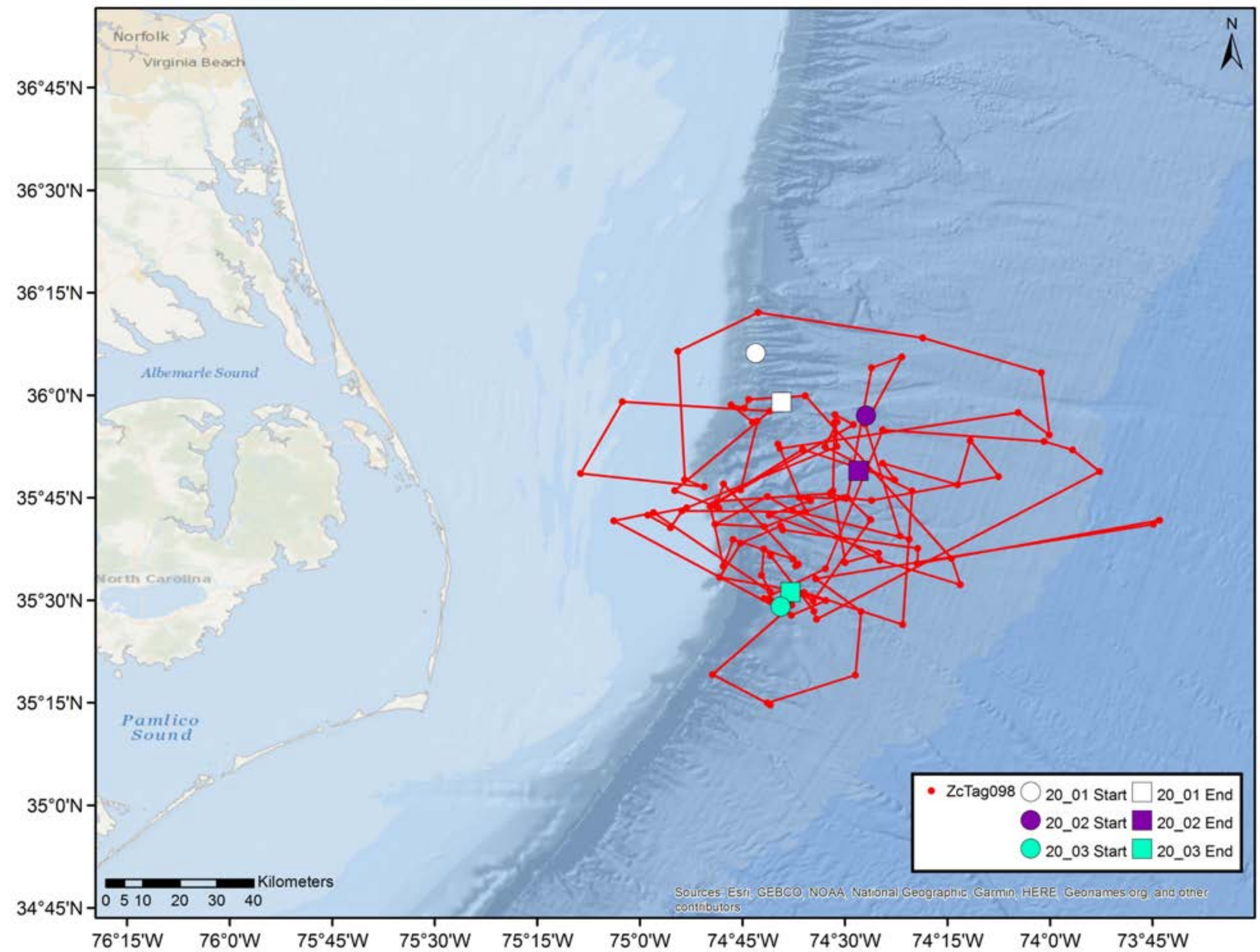

Figure 3. Douglas-filtered ARGOS positions for entire track of ZcTag98 showing positions of CEEs conducted while tag was deployed (tag duration 41 days).

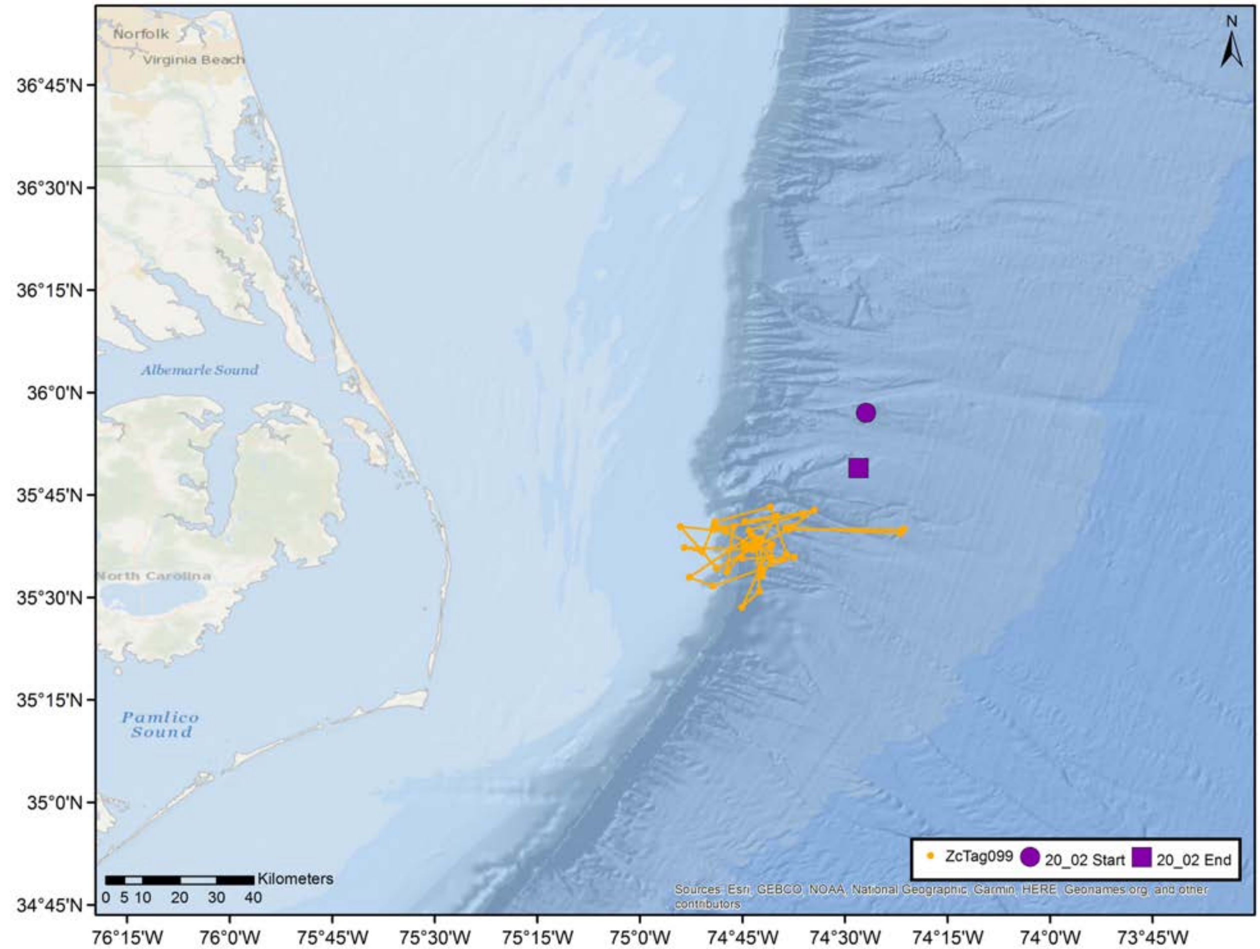

Figure 4. Douglas-filtered ARGOS positions for entire track of ZcTag99 showing positions of CEEs conducted while tag was deployed (tag duration 19 days).

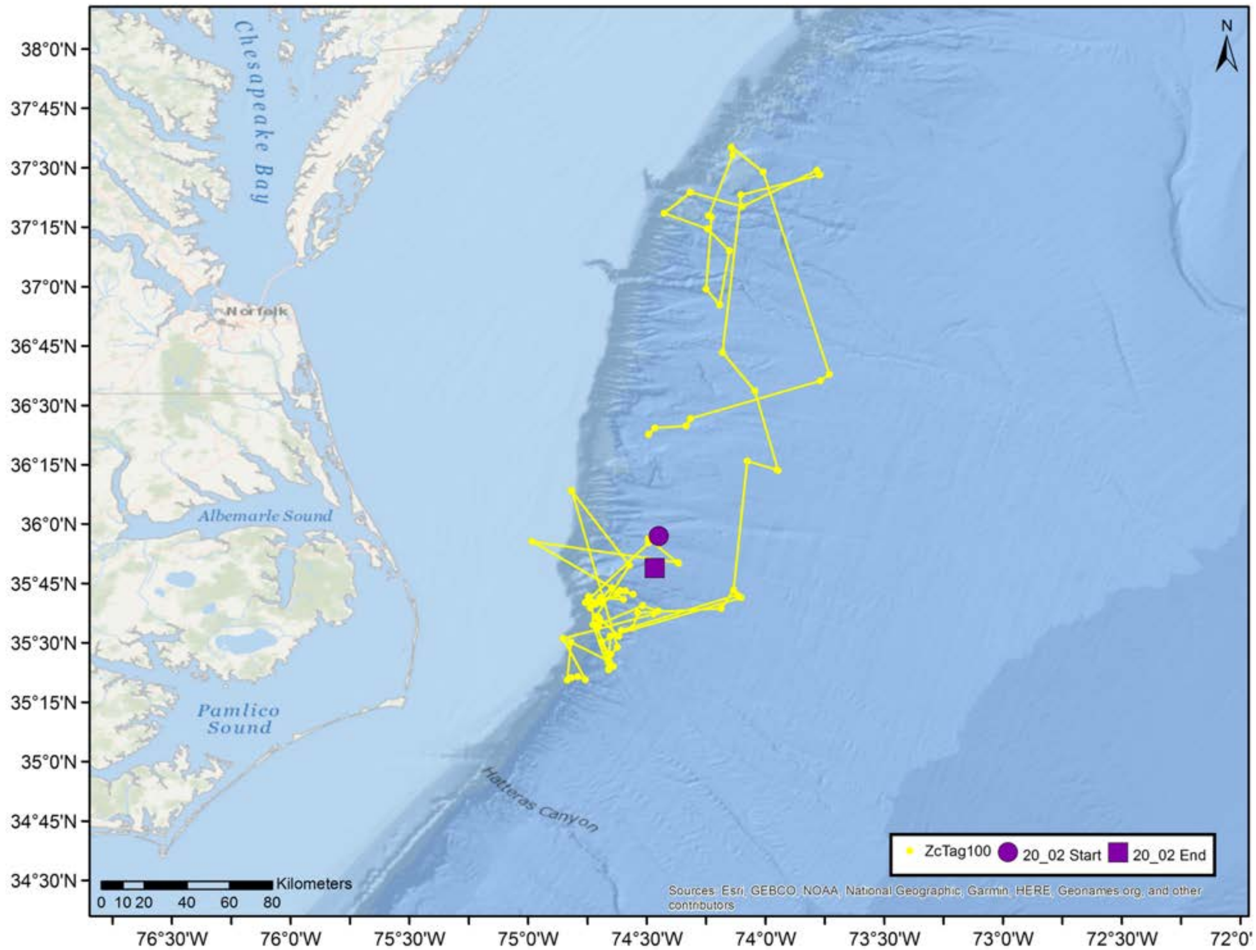

Figure 5. Douglas-filtered ARGOS positions for entire track of ZcTag100 showing positions of CEEs conducted while tag was deployed (tag duration 29 days).

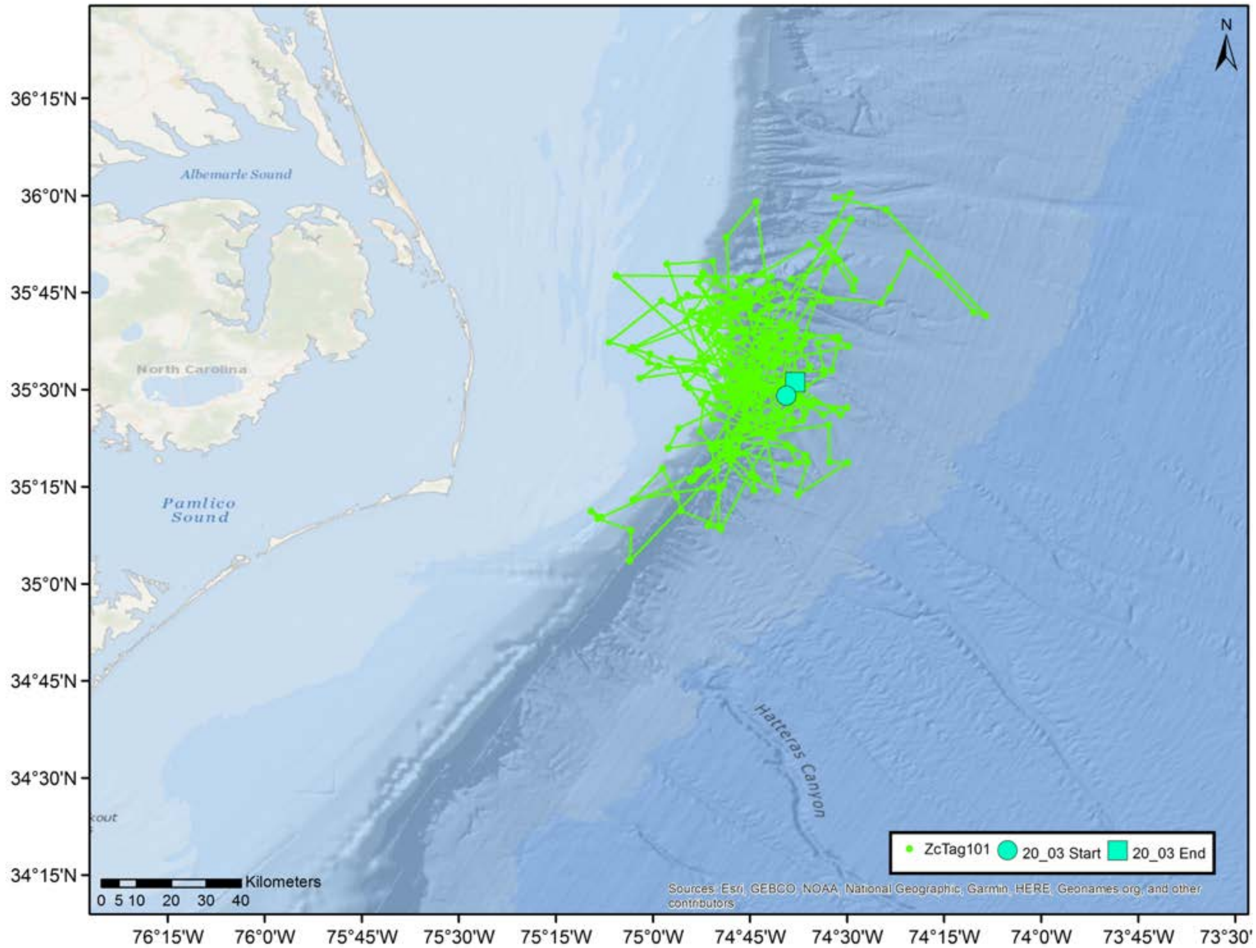

Figure 6. Douglas-filtered ARGOS positions for entire track of ZcTag101 showing positions of CEEs conducted while tag was deployed (tag duration 66 days).

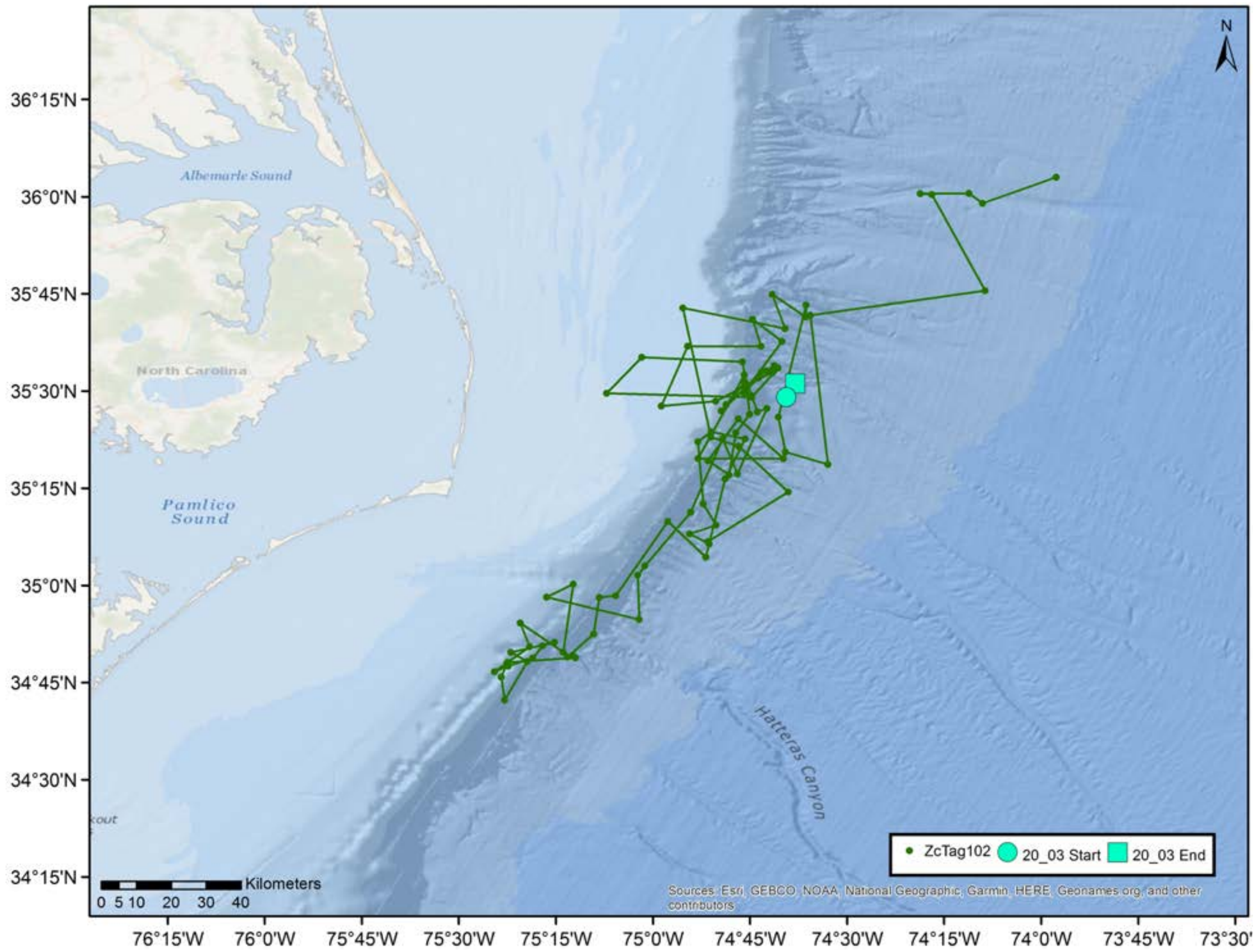

Figure 7. Douglas-filtered ARGOS positions for entire track of ZcTag102 showing positions of CEEs conducted while tag was deployed (tag duration 29 days).

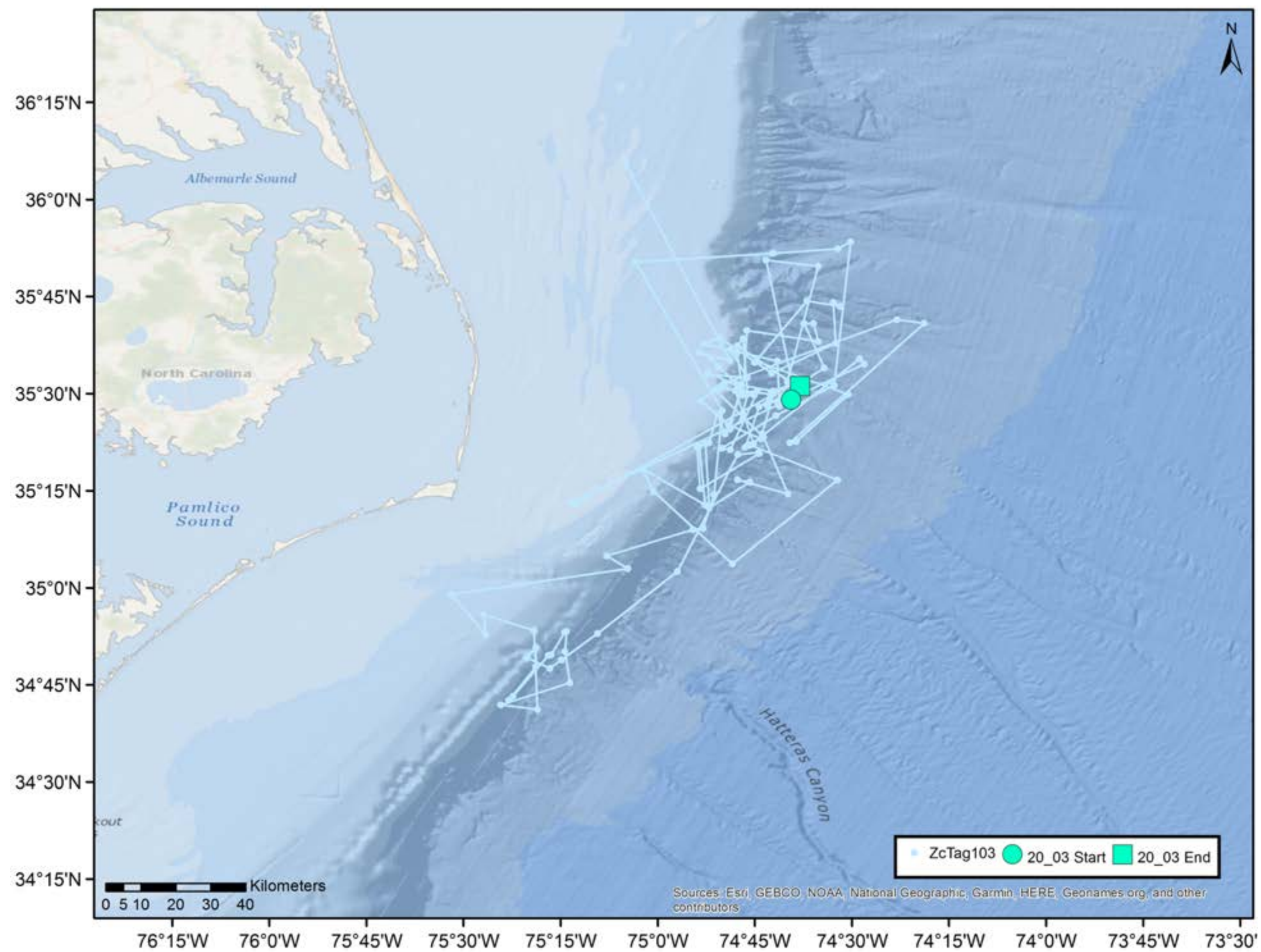

Figure 8. Douglas-filtered ARGOS positions for entire track of ZcTag103 showing positions of CEEs conducted while tag was deployed (tag duration 32 days).

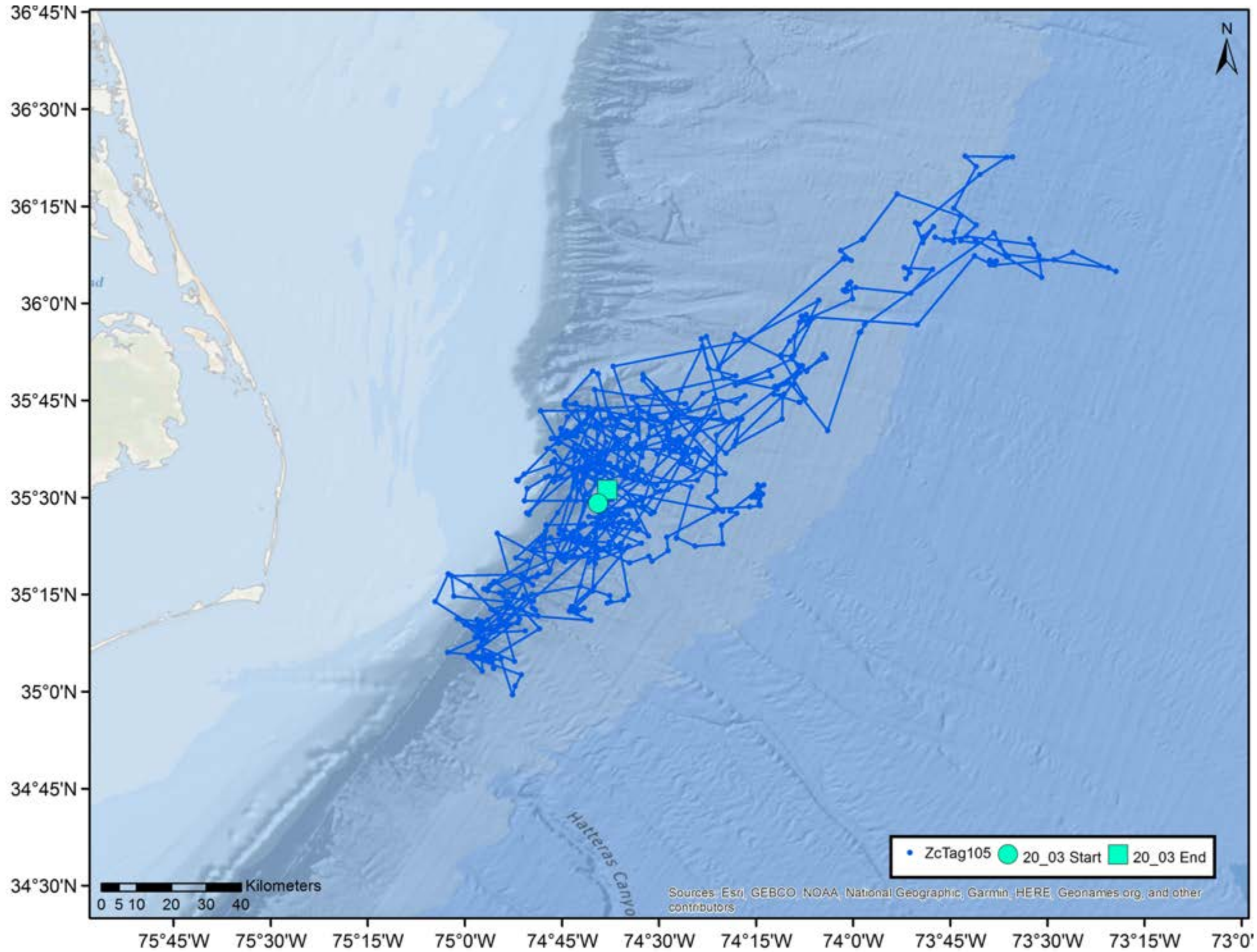

Figure 9. Douglas-filtered ARGOS positions for entire track of ZcTag105 showing positions of CEEs conducted while tag was deployed (tag duration 69 days).

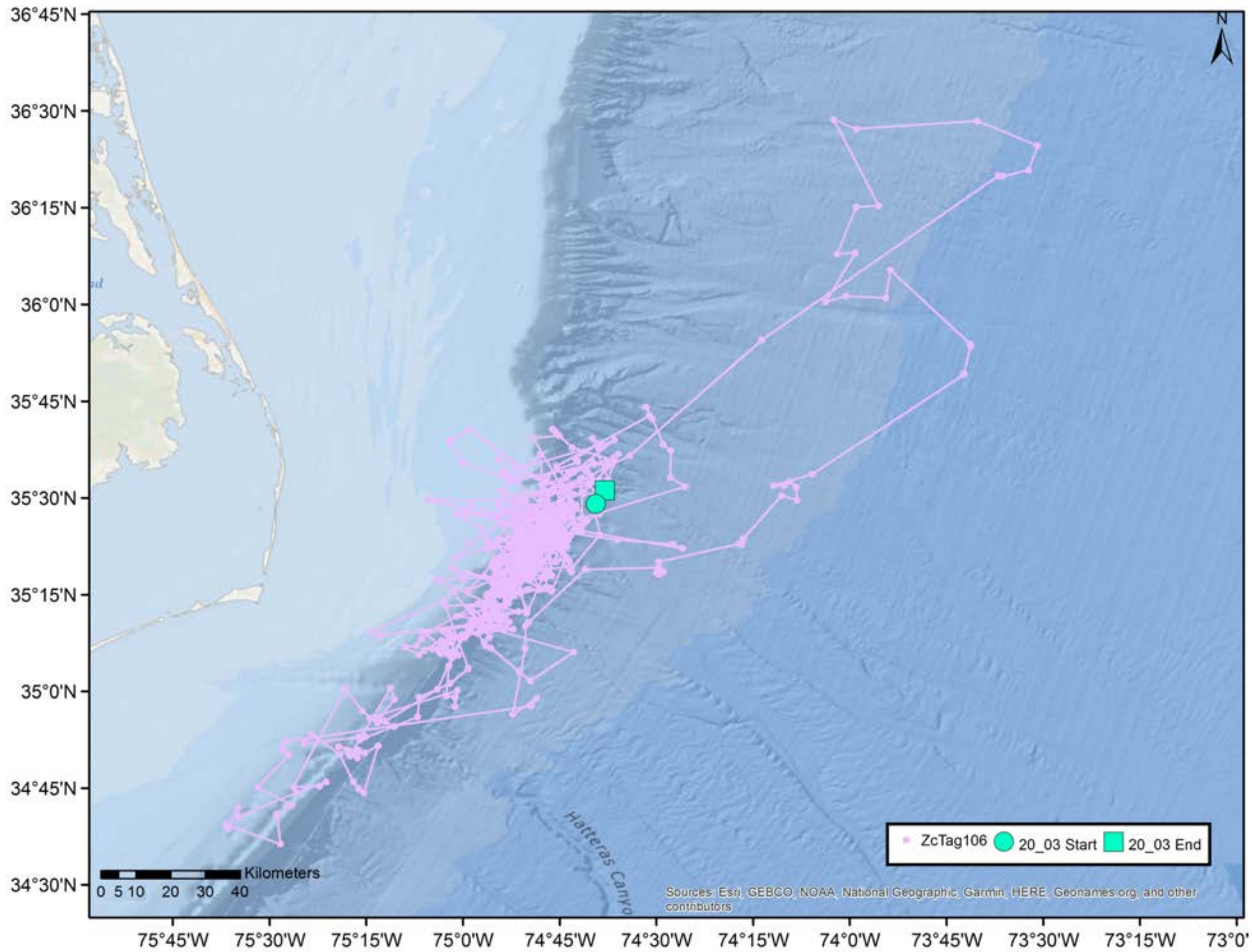

Figure 10. Douglas-filtered ARGOS positions for entire track of ZcTag106 showing positions of CEEs conducted while tag was deployed (tag duration 64 days).

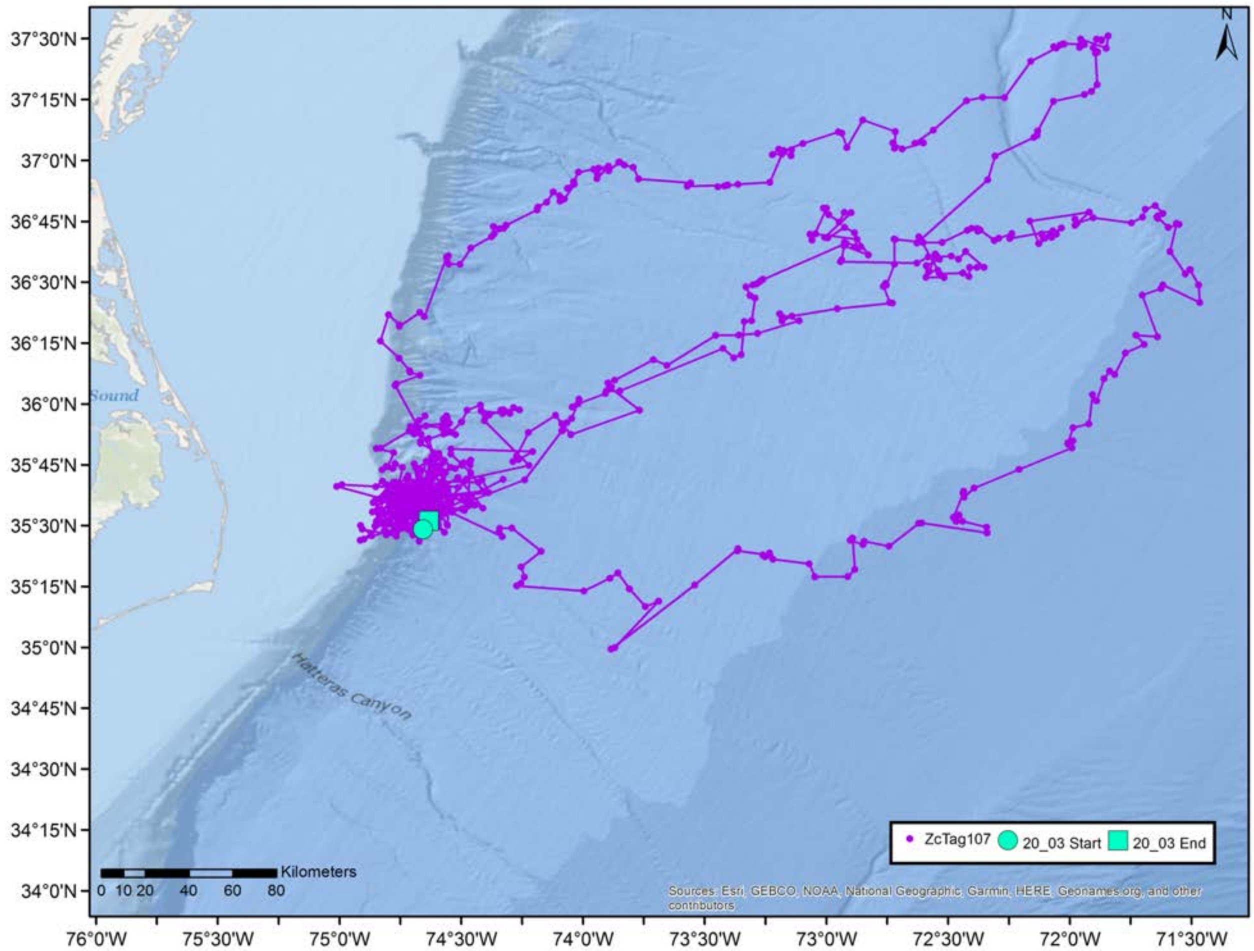

Figure 11. Douglas-filtered ARGOS positions for entire track of ZcTag107 showing positions of CEEs conducted while tag was deployed (tag duration 68 days).

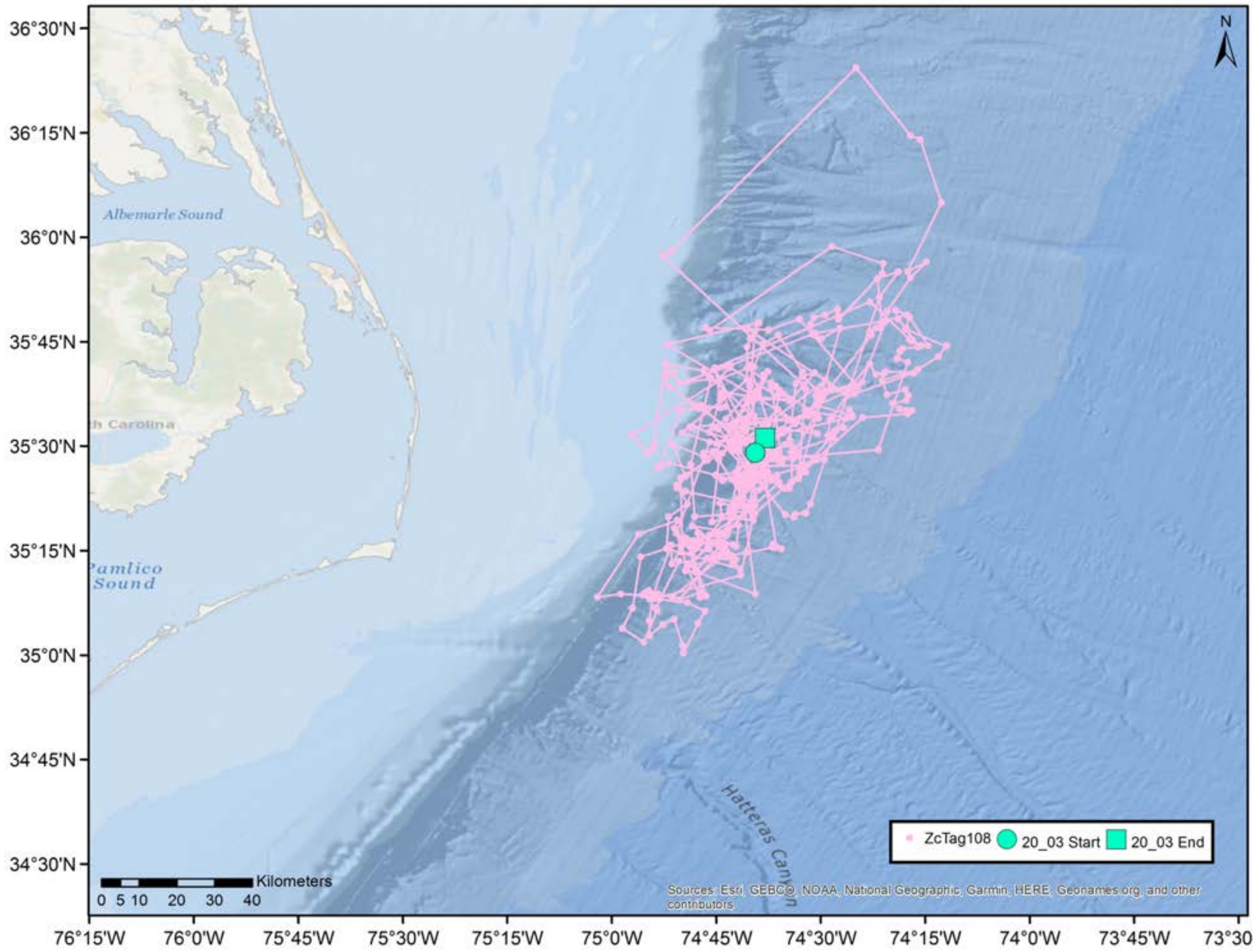

Figure 12. Douglas-filtered ARGOS positions for entire track of ZcTag108 showing positions of CEEs conducted while tag was deployed (tag duration 56 days).

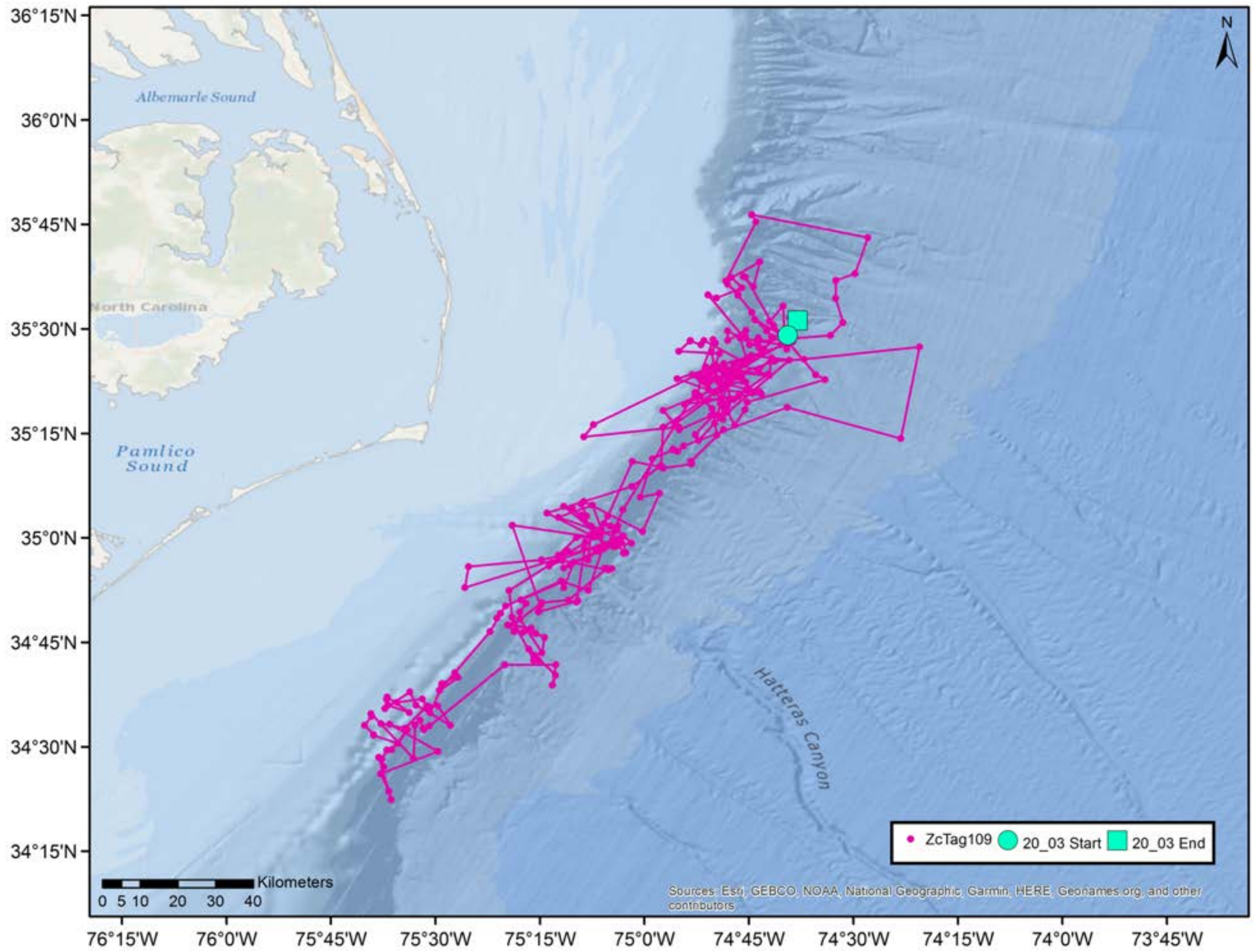

Figure 13. Douglas-filtered ARGOS positions for entire track of ZcTag109 showing positions of CEEs conducted while tag was deployed (tag duration 55 days).

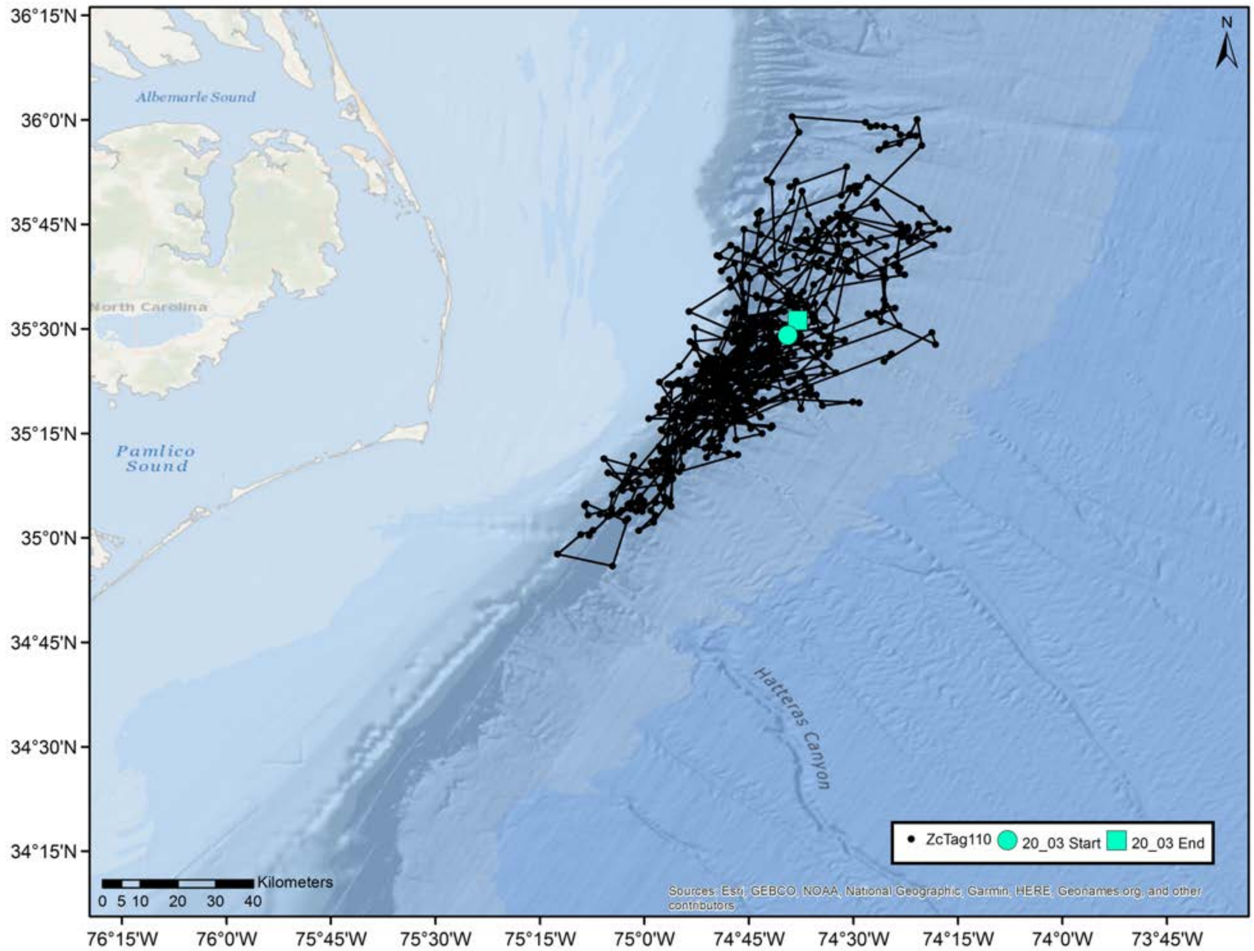

Figure 14. Douglas-filtered ARGOS positions for entire track of ZcTag110 showing positions of CEEs conducted while tag was deployed (tag duration 85 days).

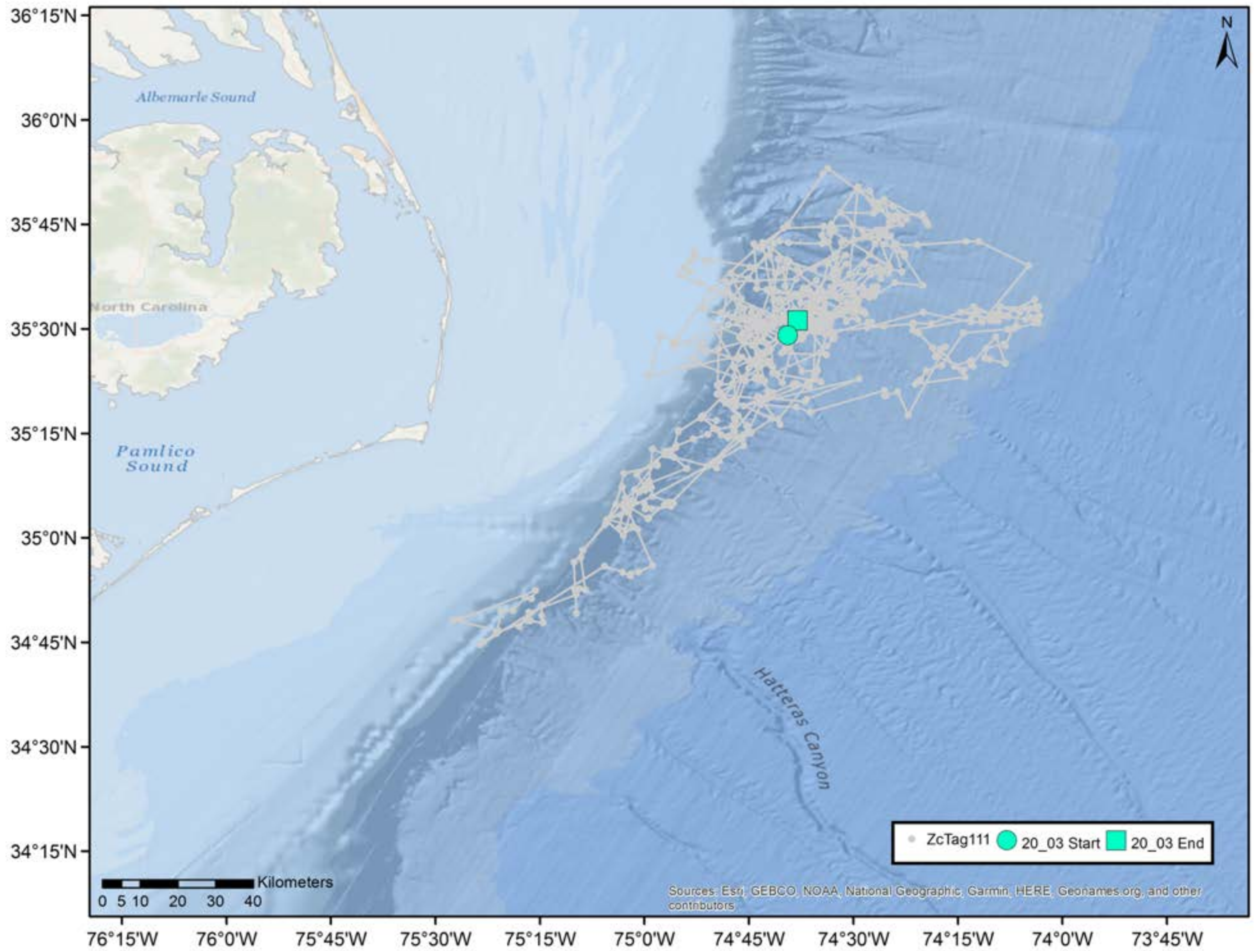

Figure 15. Douglas-filtered ARGOS positions for entire track of ZcTag111 showing positions of CEEs conducted while tag was deployed (tag duration 69 days).

2.3 CEEs Conducted

Three CEE sequences were conducted during the Atlantic-BRS 2020 field effort. This included two successful, complete, operational Navy SQS/53C MFAS CEEs coordinated with separate vessels at requested locations and one successful complete simulated MFAS CEE conducted with the experimental MFAS source (**Table 4**).

Table 4. CEEs conducted during 2020 Atlantic-BRS field efforts.

CEE ID	Date	CEE Type	Focal whales	CEE duration (min)	Start CEE Source latitude (°N)	Start CEE source longitude (°W)
#2020_01	7/15/20	**Operational MFAS (*USS COLE*)**	ZcTag98; GmTag228	60	36.102	74.718
#2020_02	7/30/20	**Operational MFAS (*USS LABOON*)**	ZcTag99; ZcTag100	60	35.950	74.449
#2020_03	8/19/20	**Simulated MFAS**	Zc20_232a & ZcTag108 (same social group) [ZcTag98, ZcTag105, ZcTag110 in vicinity]	30	35.484	74.657

Subsequently, we provide a summary synthesis of each CEE conducted with standardized tables and figures including: (1) metadata summaries; (2) planning and post-hoc RL modeling results; (3) modeled positions from satellite tag locations for individuals before, during, and after each CEE; (4) dive records for satellite tagged whales before, during, and after CEEs; and (5) DTAG quick-look summaries for applicable CEEs (Sections 2.3.1 through 2.3.3). A brief description of each standardized figure type is provided within Section 2.3.1, which is applicable for all subsequent figures of the same type. Figures are provided for focal whales identified in **Table 4** above for each respective CEE period. All RL modeling result figures, modeled positions for tagged whales, and dive records for additional tagged whales exposed during each respective CEE (i.e., non-focal tagged whales) are also available as full resolution figures with links provided in each respective section.

2.3.1 CEE #2020_01: Operational Navy Vessel MFAS[8]

Table 5. Metadata summary for Atlantic-BRS CEE #2020_01.

CEE # 2020_01	
Date:	15 July 2020
Type:	MFAS Source: USS COLE (DDG 67)
Signal parameters:	Two sequential CP/CW waveforms 0.5-second (sec) duration each with 0.1 sec separation for total ping series 1.1 sec duration
Start time (UTC):	15:03
Start lat/lon (source):	36.102; -74.718
End time (UTC):	16:03
End lat/lon (source):	35.983; -74.655
Beaked whales tagged during CEE:	(n=1) – ZcTag98 (focal sat tag animal)
Pilot whales tagged during CEE:	(n=1) – GmTag228 (focal sat tag animal)
Estimated Range (start CEE):	17 km (9.2 nm) @ start (based on interpolated focal follow surface positions)
Modeled Max RL:	152 dB RMS @ 1500m interpolated posit. Max of 146 and 142 dB RMS @ 10 and 350m (interpolated posit).

CEE #2020_01 - Narrative Summary
This was a successful CEE conducted in collaboration between the USS COLE and the Atlantic-BRS field team. It occurred on 15 July 2020 from 1103-1203 EDT (1503-1603Z) near Cape Hatteras, NC. Two focal whales (beaked whale Zc98 and pilot whale GM228) were tagged prior to the CEE and were being tracked using both tag telemetry and visual observations from multiple Atlantic BRS team vessels on the water before, during, and after this CEE. This was a very successful CEE in that complete dive and positional data were obtained from focal whales and the vessel was successfully positioned based on *in situ* propagation model estimates at horizontal ranges that, accounting for bathymetry and real-time oceanography, met target received level experimental objectives. While it should be noted that extensive additional data processing and analyses are ongoing and will be integrated with other CEEs, it appeared from the field and in quick look analysis that the primary focal animal (beaked whale Zc98) responded fairly strongly at median RLs of ~140 dB (max 142-152) by moving rapidly away from the source and changing dive behavior and duration. Pilot whale Gm228 did not exhibit clearly obvious changes, although the horizontal movement of this whale was less precisely tracked.

[8] Note: All figures provided below as well as additional supplementary figures are available at: https://duke.box.com/v/report2020-cee-20-01

Table 6. Sequential positioning for *USS COLE* for Atlantic-BRS CEE #2020_01.

Position Request for *USS COLE*	Description	Lat	Lon	Heading
1	Nominal initial posit	35.867	-74.35	Not specified
2	Late 14 Jul based on 2238 Shearwater posit and accounting for Argos	36.15	-74.65	Not specified
3	Early 15 Jul based on ~0600 EDT Shearwater posit	36.11	-74.67	176
4	Final COLE position requested 0913 EDT 15 Jul	36.115	-74.686	166
5	ACTUAL COLE Start Posit 1103 EDT 15 Jul	36.102	-74.718	166

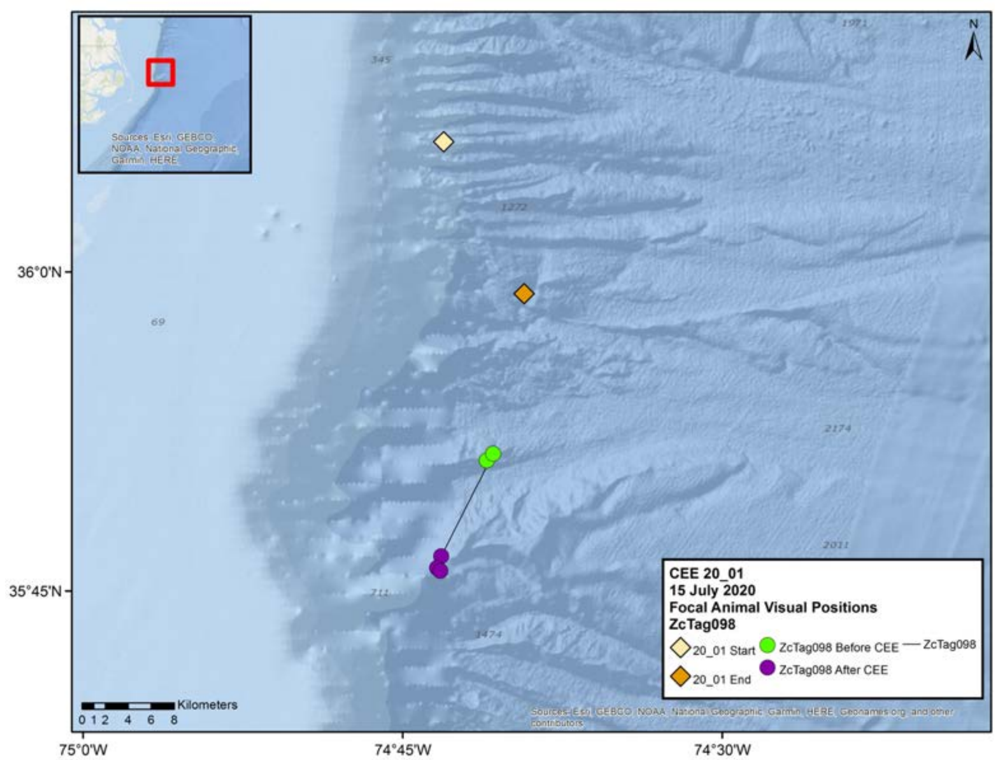

Figure 16. Overview map of source and all focal follow locations for ZcTag098 before and after CEE #2020-01.

Table 7. Summary of RL model predictions before and during CEE #2020_01.[9]

Model Run	Description	Animal (Zc98) Depth (m)	Animal Lat	Animal Lon	Est. Range (nm) Start-End	Modeled RL START	Modeled RL END	Modeled RL MAX
1	Zc98 tag on location	10	35.767	-74.7527	21 – 14	108	129	132
2	Zc98 tag on location	1000	35.767	-74.7527	21 – 14	121	141	141
3	Shearwater posit 2248 EDT 14 July	10	35.803	-74.717	15 – 9	123	141	141
4	Shearwater posit 2248 EDT 14 July	1200	35.803	-74.717	15 – 9	121	152	139
5	Shearwater posit 0600 EDT 15 July	10	35.799	-74.7299	15 – 8	122	140	140
6	Shearwater posit 0600 EDT 15 July	1200	35.799	-74.7299	15 – 8	119	140	140
7	Barber posit 0918 EDT 15 July	10	35.843	-74.723	16 – 9	115	141	152
8	Barber posit 0918 EDT 15 July	1300	35.843	-74.723	16 – 9	124	140	140
9	Barber posit 1058 EDT 15 July	10	35.857	-74.6793	15 – 8	107	136	141
10	Barber posit 1058 EDT 15 July	100	35.857	-74.6793	15 – 8	116	140	148
11	Barber posit 1058 EDT 15 July	300	35.857	-74.6793	15 – 8	128	139	147
12	Barber posit 1058 EDT 15 July	1500	35.857	-74.6793	15 – 8	140	143	150
13	Post-hoc from interpolated focal, known COLE	10	35.833	-74.700	17 – 10	**130**	**134**	**146**
14	Post-hoc from interpolated focal	350 (dive data start)	35.833	-74.700	17 – 10	**141**	**142**	**142**
15	Post-hoc from interpolated focal	1500	35.833	-74.700	17 – 10	**129**	**141**	**152**

[9] Post-hoc estimates are highlighted as estimated RL for ZcTag98 at different depths for model runs 13-15 (**Figures 17** to **19**). Note: all corresponding RL model runs are available at: https://duke.box.com/v/report2020-cee20-01-propmod

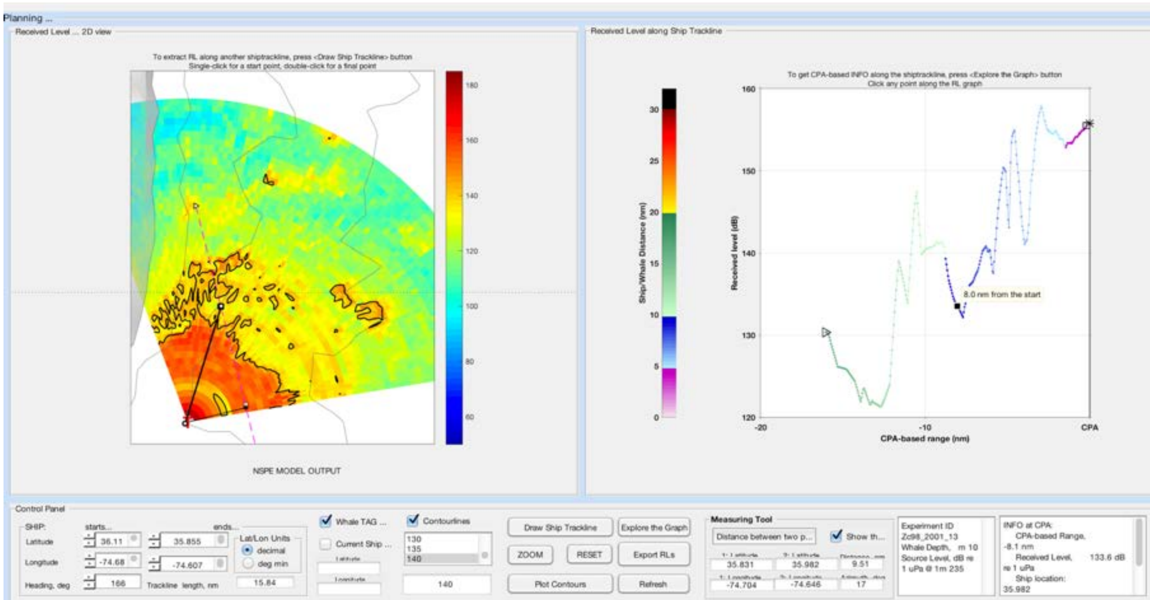

Figure 17. Post hoc RL model prediction at 10 m depth (model run #13 from Table 7) for focal whale ZcTag98 based on interpolated position and *USS COLE* end position during Atlantic-BRS CEE #2020_01. Modeled RL at this depth and estimated position was: 133.6 dB RMS.

NOTE: These RL model prediction plots were generated using the NPS sound propagation tool used in the field to estimate received levels for animals at known/estimated tag location (T) with a MFAS source positioned at a strategic location (small white circle in left plots). Right panels show modeled RLs at different positions along tracks—selected points here correspond to the estimated position based on an interpolation of surface locations from focal follow observations. Model runs are shown for different focal animals (where appropriate) and different animal depths in the water column, based on species and location differences.

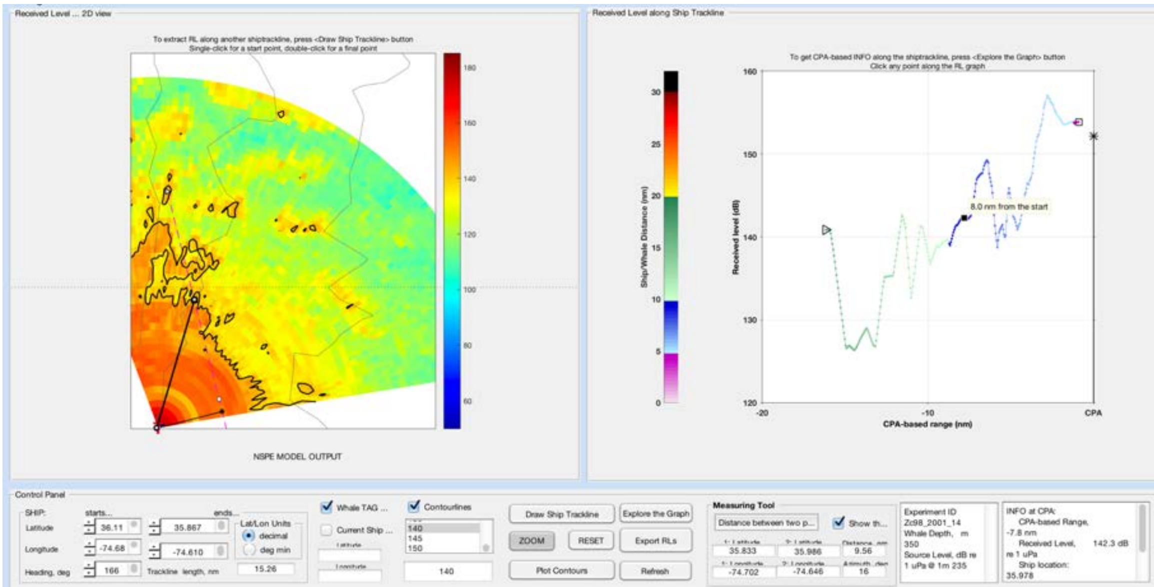

Figure 18. Post hoc RL model prediction at 350 m depth (model run #14 from Table 7) for focal whale ZcTag98 based on interpolated position and *USS COLE* end position during Atlantic-BRS CEE #2020_01. Modeled RL at this depth and estimated position was: 142.3 dB RMS.

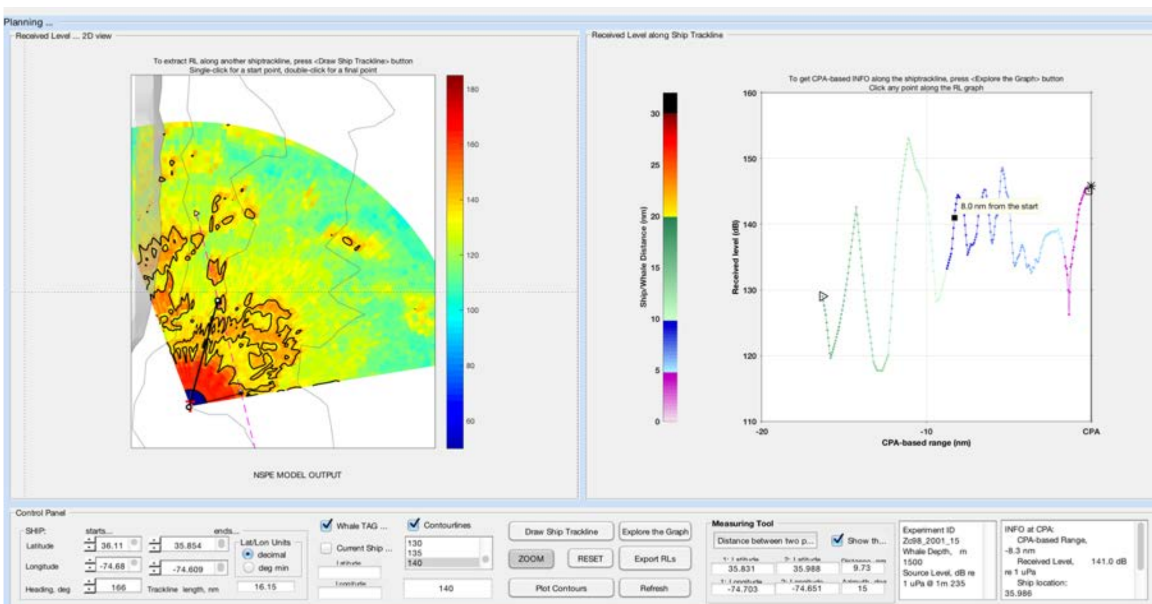

Figure 19. Post hoc RL model prediction at 1,500 m depth (model run #15 from Table 7) for focal whale ZcTag98 based on interpolated position and *USS COLE* end position during Atlantic-BRS CEE #2020_01. Modeled RL at this depth and estimated position was: 141.0 dB RMS.

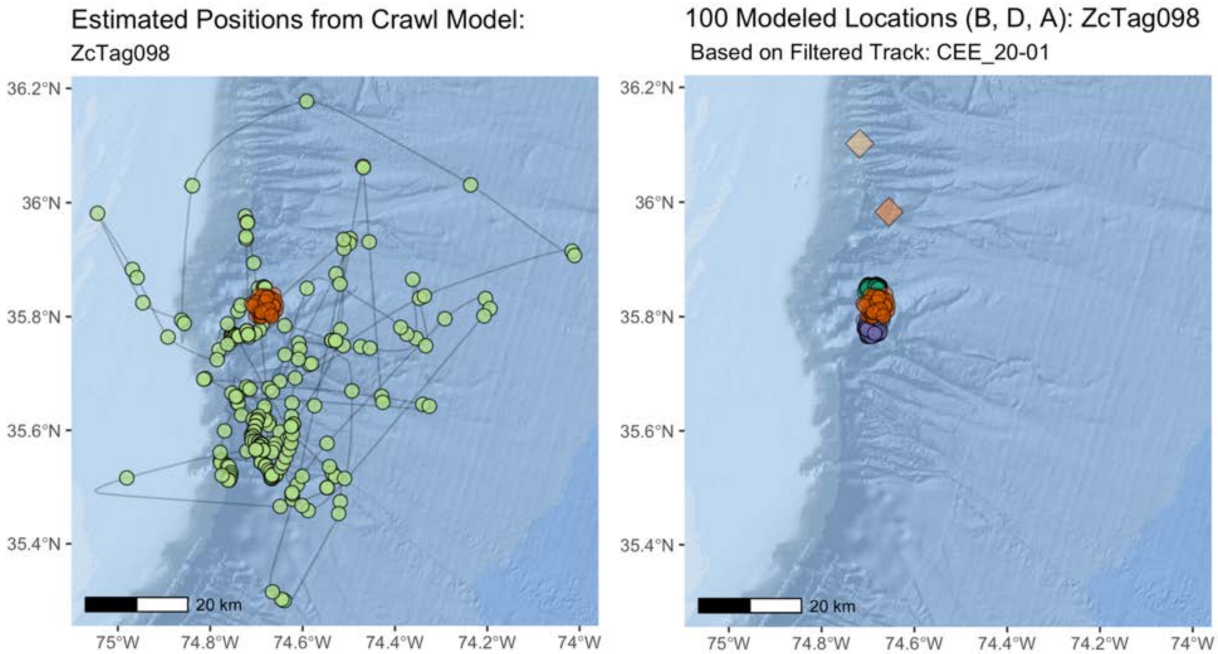

Figure 20. Estimated surface positions for focal whale ZcTag98 before, during, and after Atlantic-BRS CEE #2020_01.

NOTE: These plots have two panels for each individual specific to each CEE. Left panels show modeled animal locations from both Douglas ARGOS filtered (DAF) tracks with the location along the entire track (in green circles) with positions during the respective CEE indicated with track imputations indicated along this track shown as red dots. Right panels show modeled locations from 100 imputed tracks based upon the simple DAF track corrected with surface locations to better account for spatial error in the underlying data. Locations of the MFAS sound source are shown as diamonds, with pale orange representing locations at the start of CEEs and darker orange indicating ending locations. The 100 positions for each imputed track are shown one hour before CEEs (green dots), at the start of CEEs (red dots), and one hour after CEEs (purple dots).

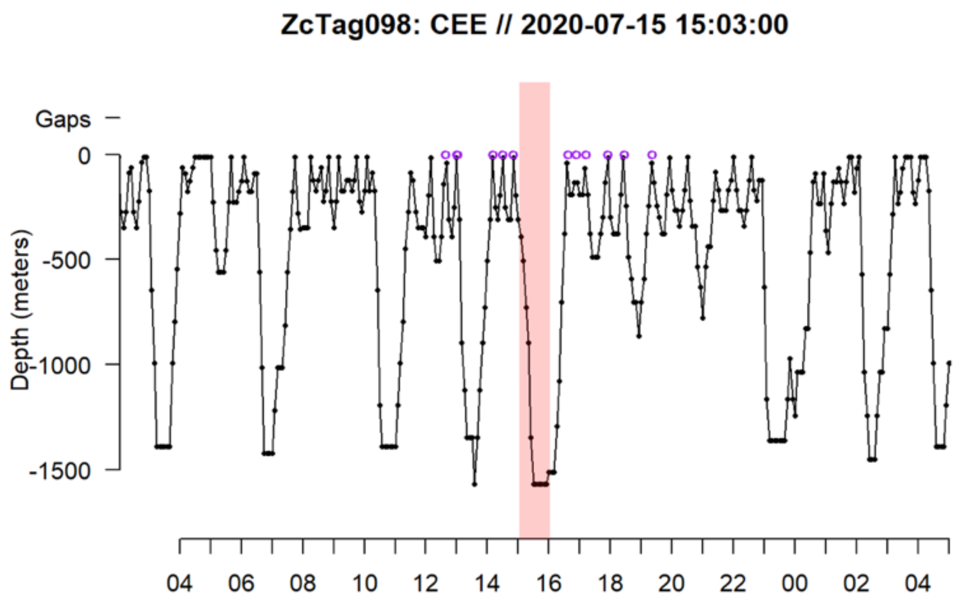

Figure 21. Available dive data for focal whale ZcTag98 before, during, and after Atlantic-BRS CEE #2020_01.

NOTE: These plots illustrate dive data for days during which CEEs occurred. Time (in GMT, which is +4 hours from EDT during CEE periods) is indicated on the x-axis, with depth indicated on the y-axis). CEE periods are indicated as pink bars. Purple circles indicate surface periods where field teams detected the tagged individual using goniometers. Figures are provided for each animal for periods spanning 12-hour periods occurring before and after each CEE (shown here); figures showing 24 hours before and after each CEE (are available at the links provided for each respective CEE). It should be noted that based on satellite-tag (time series) settings, some tags ceased reporting dive data during some CEEs but were still reporting ARGOS position estimates.

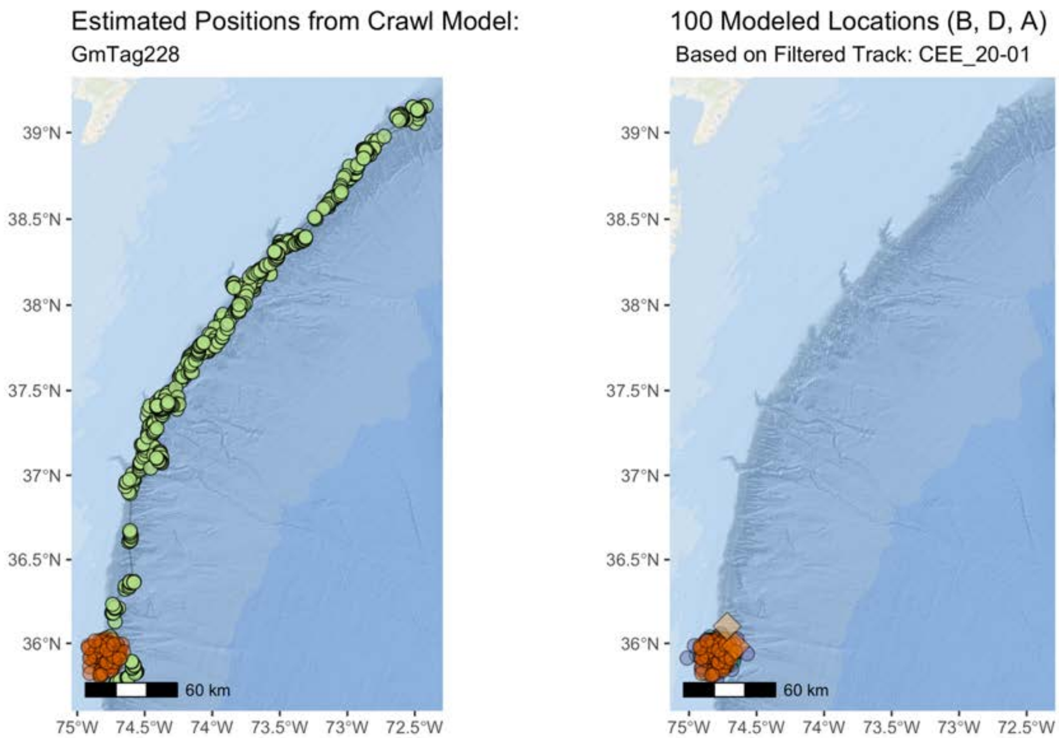

Figure 22. Estimated surface positions for tagged whale GmTag228 before, during, and after Atlantic-BRS CEE #2020_01.

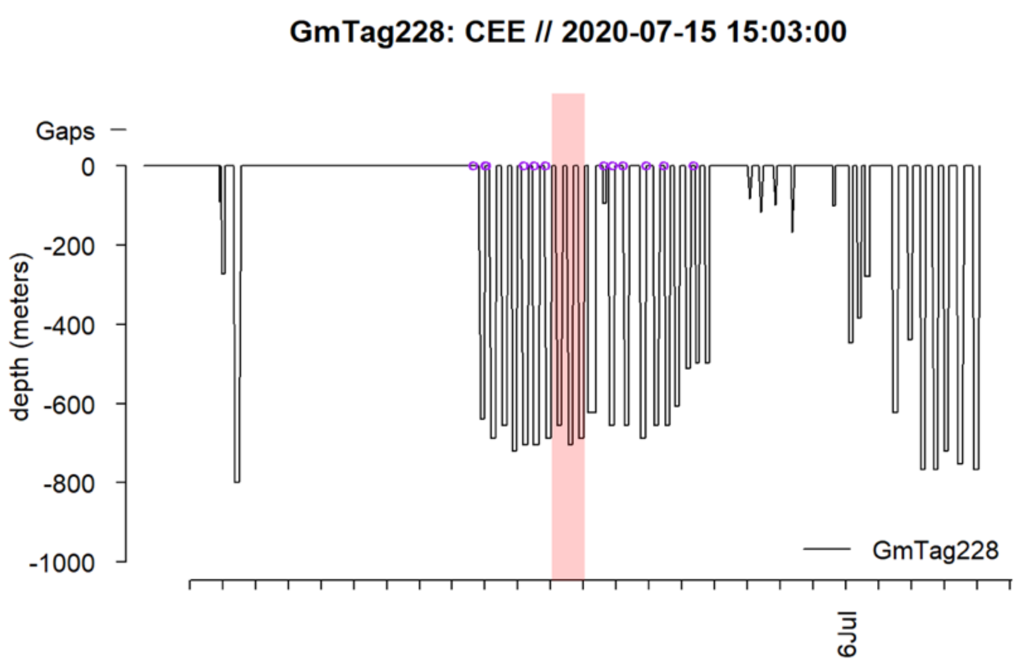

Figure 23. Available dive data for tagged whale Gm228 before, during, and after Atlantic-BRS CEE #2020_01.

2.3.2 CEE #2020_02: Operational Navy Vessel MFAS[10]

Table 8. Metadata summary for Atlantic-BRS CEE #2020_02.

CEE # 2020_02	
Date:	30 July 2020
Type:	MFAS Source: USS LABOON (DDG 58)
Signal parameters:	Two sequential CP/CW waveforms 0.5-second (sec) duration each with 0.1 sec separation for total ping series 1.1 sec duration
Start time (UTC):	10:59
Start lat/lon (source):	35.9499; -74.4492
End time (UTC):	11:59
End lat/lon (source):	35.8158; -74.4668
Beaked whales tagged during CEE:	(n=3) – ZcTag99 & ZcTag100 (focal sat tagged animals) ZcTag98 (incidental sat tag animal)
Pilot whales tagged during CEE:	(n=1) – GmTag228 (incidental sat tag animal; very distant)
Estimated Range (start CEE):	34 km (18.4 nm) @ start for ZcTag99 (est. interpolated) 20 km (10.8 nm) @ start for ZcTag100 (est. interpolated)
Modeled Max RL:	121 dB RMS @ 500m for ZcTag99 (est. interpolated) 136 dB RMS @ 10m for ZcTag100 (est. interpolated)

CEE #2020_02 - Narrative Summary

This CEE was conducted in collaboration between the *USS LABOON* and the Atlantic-BRS field team. It occurred on 30 July 2020 from 0659-0759EDT (1059-1159Z) near Cape Hatteras, NC. Two focal whales (beaked whales Zc99 and Zc100) were tagged prior to the CEE and were being tracked using tag telemetry at the time of the CEE. Several other tagged whales (beaked whale Zc98 and pilot whale Gm228) that had been involved in the COLE CEE several weeks earlier were still tagged and being tracked while incidentally exposed during this CEE at different ranges. Multiple earlier visual sightings of the focal whales were made from BRS team vessels on the water before this CEE, but weather conditions prevented them from tracking whales during it. Complete dive data were obtained from focal whales and the vessel was successfully positioned based on *in situ* propagation model estimates to meet target received level experimental objectives. While additional data processing and analyses are ongoing, from quick look analyses it appears that both focal whales responded at RLs of ~130 dB by moving away from the source potentially in different direction and most notably changed dive behavior and duration during and following the CEE. Both animals were tracked successfully and appeared to return to baseline conditions over subsequent days.

[10] Note: All figures provided below as well as additional supplementary figures are available at: https://duke.box.com/v/report2020-cee-20-02

Table 9. Sequential positioning for *USS LABOON* for Atlantic-BRS CEE #2020_02.

Position Request for *USS LABOON*	Description	Lat	Lon	Heading
1	Nominal initial posit	35.867	-74.35	Not specified
2	28 July 1400 EDT based on interpreted Argos around same time	35.89	-74.73	156
3	29 July 1200 EDT based on interpreted Argos previous 24h	35.95	-74.51	185
4	Final position requested 30 July 0530 EDT based on interpreted Argos and accounting for Zc98	35.95	-74.45	185
5	Actual position and course from LABOON navigation (INS 01)	35.9499	-74.4492	185 (maintained)

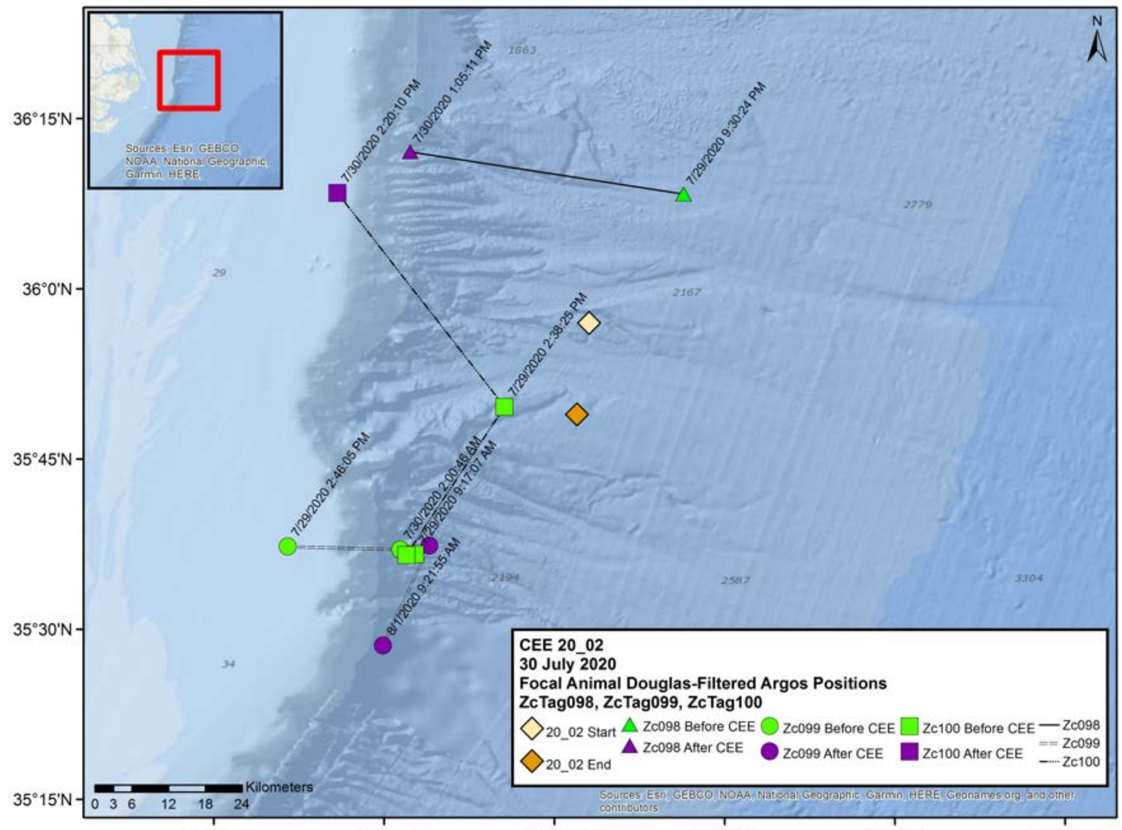

Figure 24. Overview map of source and best estimate locations from quality 0 or higher ARGOS positions for CEE #2020_02.

Table 10. Summary of RL model predictions before and during CEE #2020_02.[11]

Model Run	Description	Animal (Zc98) Depth (m)	Animal Lat	Animal Lon	Est. Range (nm) Start-End	Modeled RL START	Modeled RL END	Modeled RL MAX
1	27 July best	Zc99 (10)	35.6229	-74.7	16 – 9	109	140	140
2	27 July best	Zc99 (1500)	35.6229	-74.7	22 – 14	124	134	134
3	27 July best	Zc100 (10)	35.453	-74.824	30 – 23	94	110	125
4	27 July best	Zc100 (300)	35.453	-74.824	30 – 23	100	109	113
5	28 July 1400 EDT	Zc99 (10)	35.61	-74.64	18 - 10	117	131	145
6	28 July 1400 EDT	Zc99 (1900)	35.61	-74.64	18 – 10	124	149	151
7	28 July 1400 EDT	Zc100 (10)	35.53	-74.65	22 - 14	103	140	151
8	28 July 1400 EDT	Zc100 (1800)	35.53	-74.65	22 - 14	126	123	141
9	29 July 1200 EDT	Zc99 (10)	35.611	-74.758	23 - 16	113	131	131
10	29 July 1200 EDT	Zc99 (1000)	35.611	-74.758	23 - 16	110	131	131
11	29 July 1200 EDT	Zc100 (10)	35.609	-74.717	23 - 15	119	128	131
12	29 July 1200 EDT	Zc100 (1500)	35.609	-74.717	23 – 15	116	131	132
13	30 July 0530 EDT (final; 4)	Zc99 (100)	35.611	-74.758	24 - 17	116	127	127
14	30 July 0530 EDT (final; 4)	Zc99 (500)	35.611	-74.758	24 - 17	116	129	132
15	30 July 0530 EDT (final; 4)	Zc100 (10)	35.609	-74.717	24 - 16	115	120	126
16	30 July 0530 EDT (final; 4)	Zc100 (500)	35.609	-74.717	24 - 16	113	117	123
17	30 July 0530 EDT (final; 4)	Zc98 (10)	35.793	-74.80	19 - 16	112	118	121
18	30 July 0530 EDT (final; 4)	Zc98 (900)	35.793	-74.80	19 - 16	110	114	119
19	Zc99 Argos posit end CEE (5)	Zc99 (10)	35.337	-74.785	41 - 33	87	99	112
20	Post-hoc with best posits (5)	Zc99 (10)	35.45	-74.76	**34 - 26**	**99**	**120**	**120**
21	Post-hoc with best posits (5)	Zc99 (250)	35.45	-74.76	**34 - 26**	**109**	**116**	**117**
22	Post-hoc with best posits (5)	Zc99 (500)	35.45	-74.76	**34 - 26**	**105**	**116**	**121**
23	Post-hoc with best posits (5)	Zc100 (10)	35.797	-74.81	**20 - 16**	**114**	**125**	**136**
24	Post-hoc with best posits (5)	Zc100 (250)	35.797	-74.81	**20 - 16**	**114**	**115**	**119**
25	Post-hoc with best posits (5)	Zc100 (500)	35.797	-74.81	**20 - 16**	**114**	**121**	**122**

[11] Post-hoc estimates are highlighted as estimated RL for the closer focal whale (ZcTag100) at different depths for model runs 23-25 (**Figures 25** to **27**). Note: all corresponding RL model runs are available at: https://duke.box.com/v/report2020-cee20-02-propmod

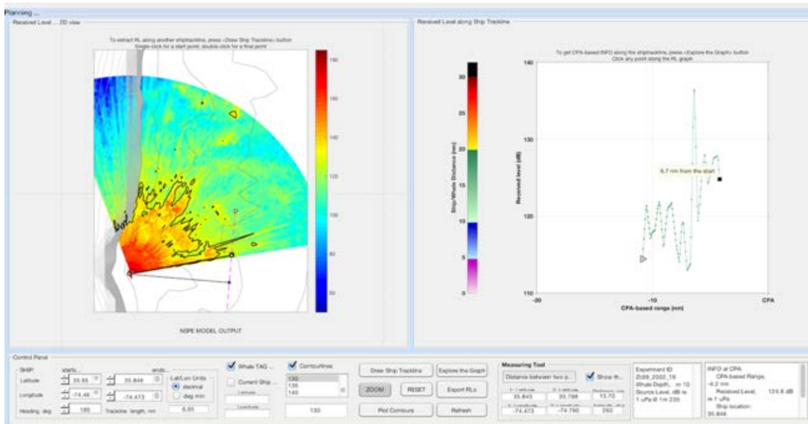

Figure 25. Post hoc RL model prediction at 10 m depth (model run #23 from Table 10) for focal whale ZcTag100 based on interpolated position and *USS LABOON* end position during Atlantic-BRS CEE #2020_02. Modeled RL at this depth and estimated position was: 124.8 dB RMS.

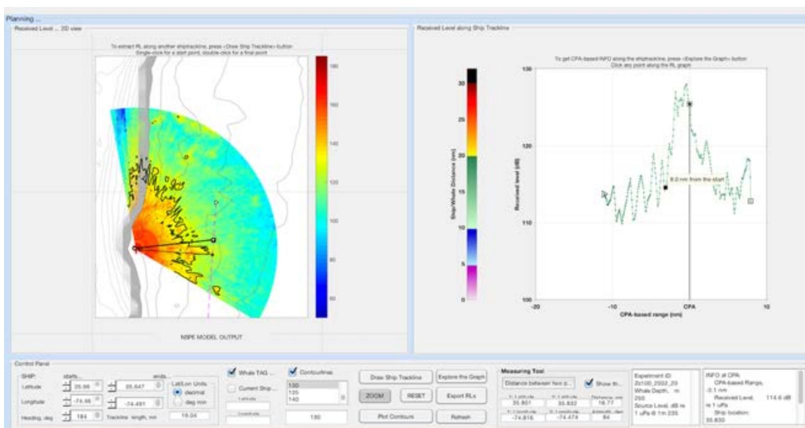

Figure 26. Post hoc RL model prediction at 250 m depth (model run #24 from Table 10) for focal whale ZcTag100 based on interpolated position and *USS LABOON* end position during Atlantic-BRS CEE #2020_02. Modeled RL at this depth and estimated position was: 114.6 dB RMS.

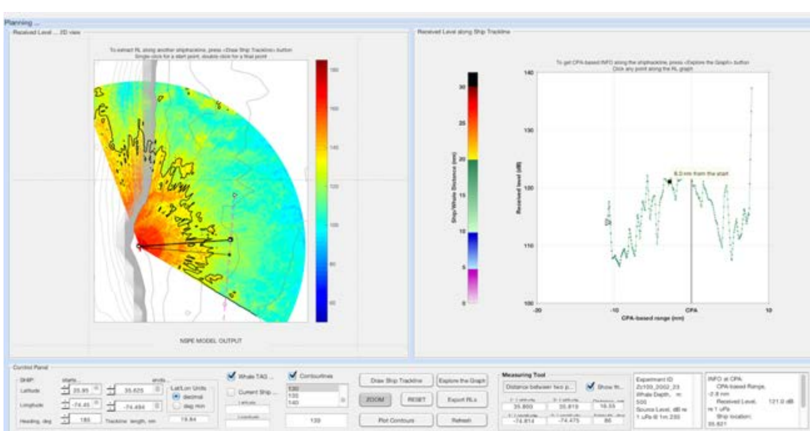

Figure 27. Post hoc RL model prediction at 500 m depth (model run #25 from Table 10) for focal whale ZcTag100 based on interpolated position and *USS LABOON* end position during Atlantic-BRS CEE #2020_02. Modeled RL at this depth and estimated position was: 121.0 dB RMS.

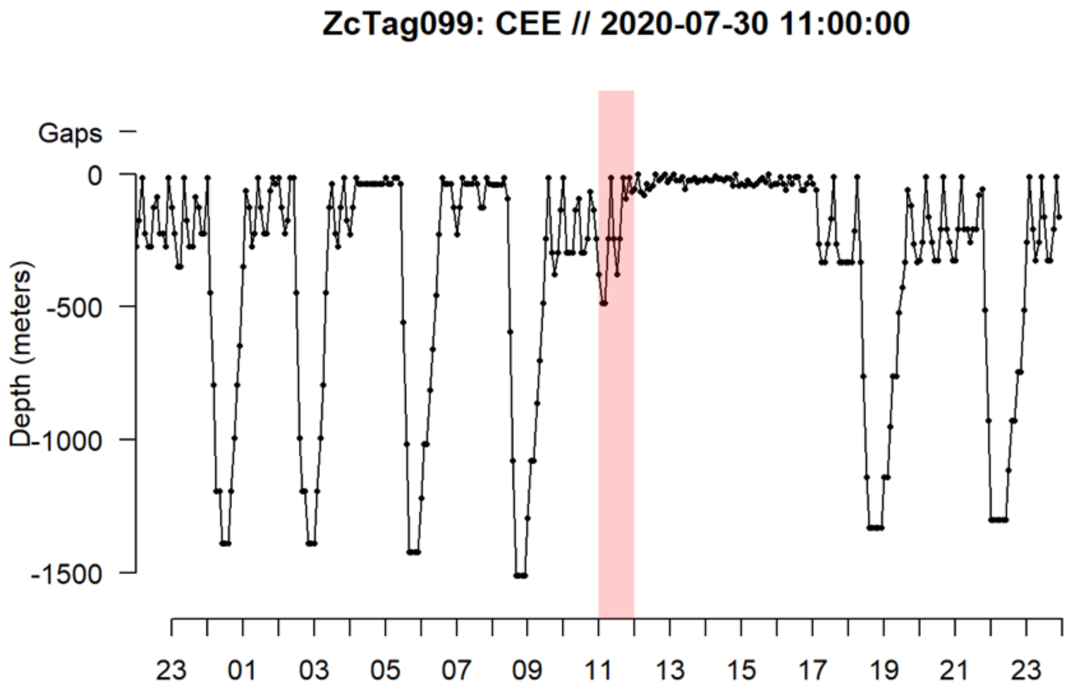

Figure 28. Estimated surface positions for focal whale ZcTag99 before, during, and after Atlantic-BRS CEE#2020_02.

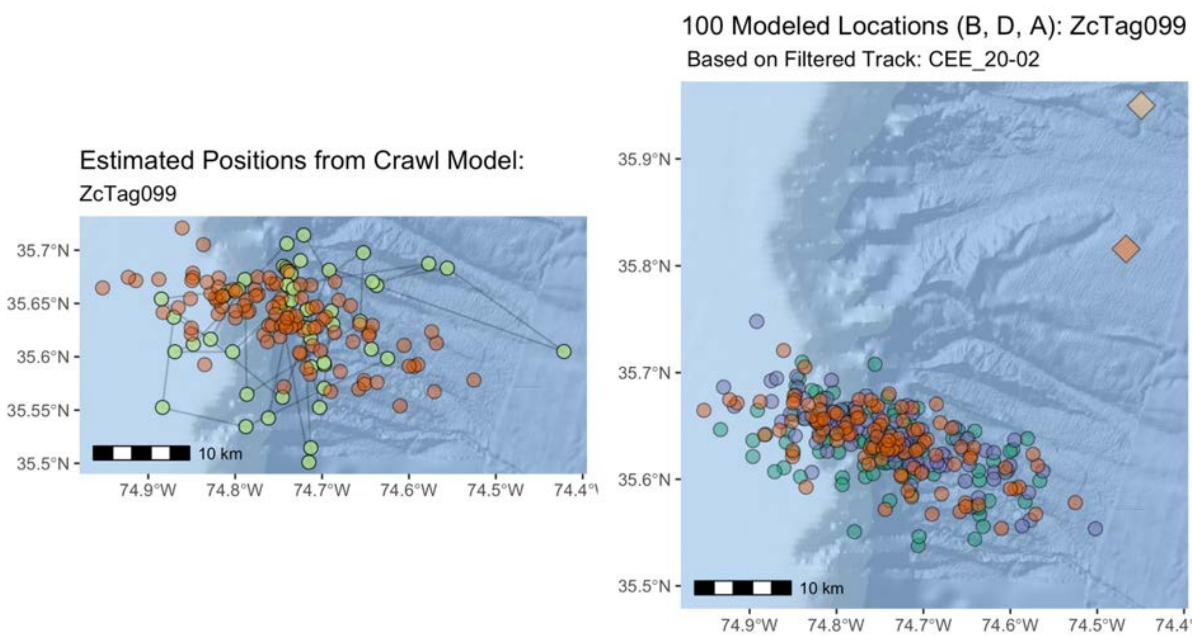

Figure 29. Available dive data for focal whale ZcTag99 before, during, and after Atlantic-BRS CEE #2020_02.

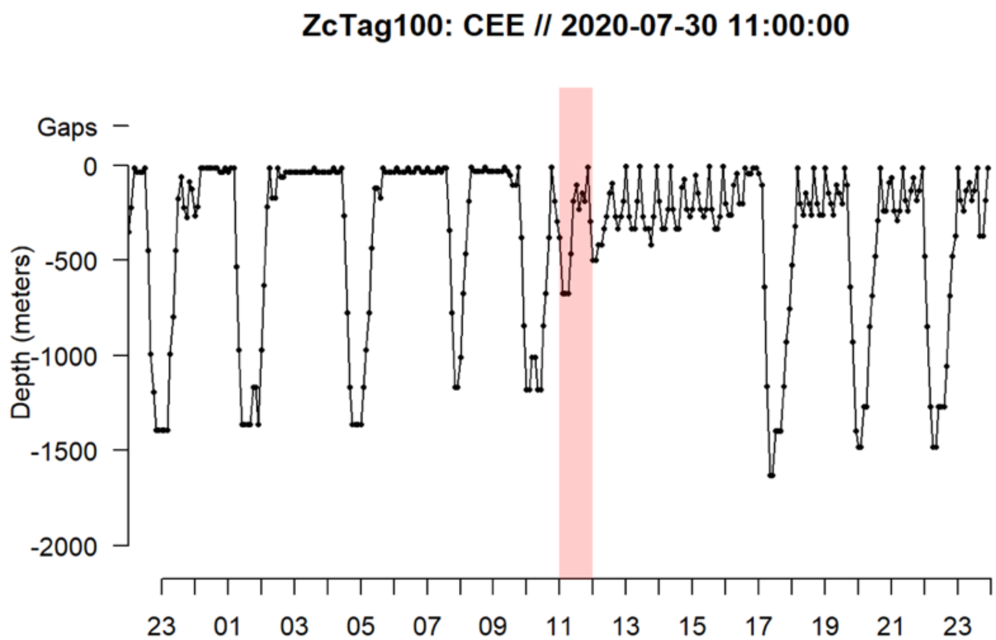

Figure 30. Estimated surface positions for tagged whale ZcTag100 before, during, and after Atlantic-BRS CEE #2020_02.

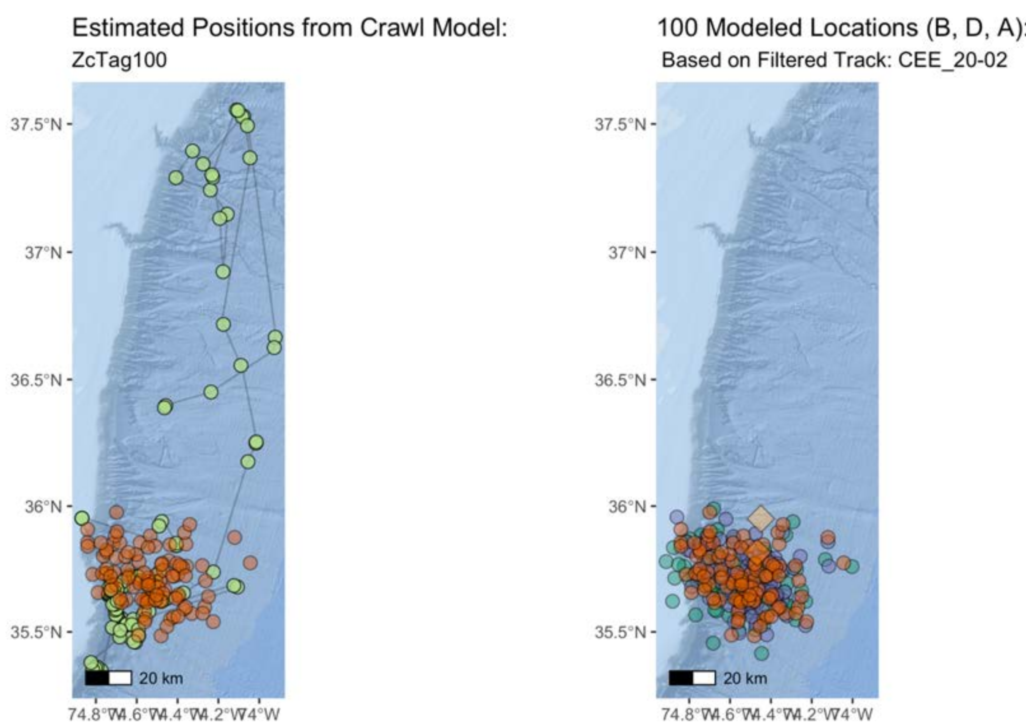

Figure 31. Available dive data for tagged whale ZcTag100 before, during, and after Atlantic-BRS CEE #2020_02.

2.3.3 CEE #2020_03: Simulated MFAS[12]

Table 11. Metadata summary for Atlantic-BRS CEE #2020_03.

CEE # 2020_03	
Date:	19 August 2020
Type:	MFAS Source: Simulated MFAS operated from *R/V Shearwater*
Signal parameters:	Three-segment (1.2 s total duration) pings (3.5–4 kilohertz [kHz]); 212 dB re 1 µPa (RMS) @ source; 25 s rep rate; 72 pings
Start time (UTC):	17:43
Start lat/lon (source):	35.4843; -74.6570
End time (UTC):	18:43
End lat/lon (source):	35.5202; -74.4668
Beaked whales tagged during CEE:	(n=12) – Zc20_232a & ZcTag108 (focal DTAG and sat tagged animals – within same group); ZcTag98, ZcTag105, ZcTag110 (sat tag animals in known vicinity) ZcTag101, ZcTag102, ZcTag103, ZcTag106, ZcTag107, ZcTag109, ZcTag111 (incidental sat tag animals)
Pilot whales tagged:	none
Estimated Range (start CEE):	34 km (18.4 nm) @ start for ZcTag99 (est. interpolated) 20 km (10.8 nm) @ start for ZcTag100 (est. interpolated)
Modeled Max RL:	140 dB RMS @ 10m for Zc20_232a & ZcTag108 (both in focal group; est. interpolated); 141 dB RMS @ 1700m for focal

CEE #2020_03 - Narrative Summary

With a dozen satellite-transmitting tags deployed on beaked whales and a possible candidate Navy vessel for coordination ultimately unavailable, the Atlantic-BRS team proceeded with this CEE using the simulated MFAS source operated from the *R/V Shearwater.* It was conducted from 1343-1413 EDT (1743-1813Z) 19 August 2020 near Cape Hatteras, NC. A DTAG was deployed on the previous day (Zc20_231a) within a group with another whale with a satellite-transmitting tag. The field team successfully tracked the whale through the night from the *R/V Shearwater* and prepared for a CEE the following day, although it was ultimately conducted after the tag detached. Another DTAG was deployed (Zc20_232a) and the animal was tracked during a pre-exposure baseline period, following which CEE #2020_03 was conducted with the simulated MFAS While additional data processing and analyses are ongoing, from quick look analyses it appears that the focal group with both tagged individuals responded during the CEE (with max RLs of ~140 dB) by moving clearly and quickly away from the source (> 11 nm in 5.5h into a 3kt surface current) with clear associated changes in dive behavior and duration during and following the CEE. Using the *R/V Shearwater* as a capable tracking platform, the group was tracked overnight and resighted in apparently more typical baseline conditions over subsequent days, though it remained well to the south of the CEE location.

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[12] Note: All figures provided below as well as additional supplementary figures are available at: https://duke.box.com/v/report2020-cee-20-03

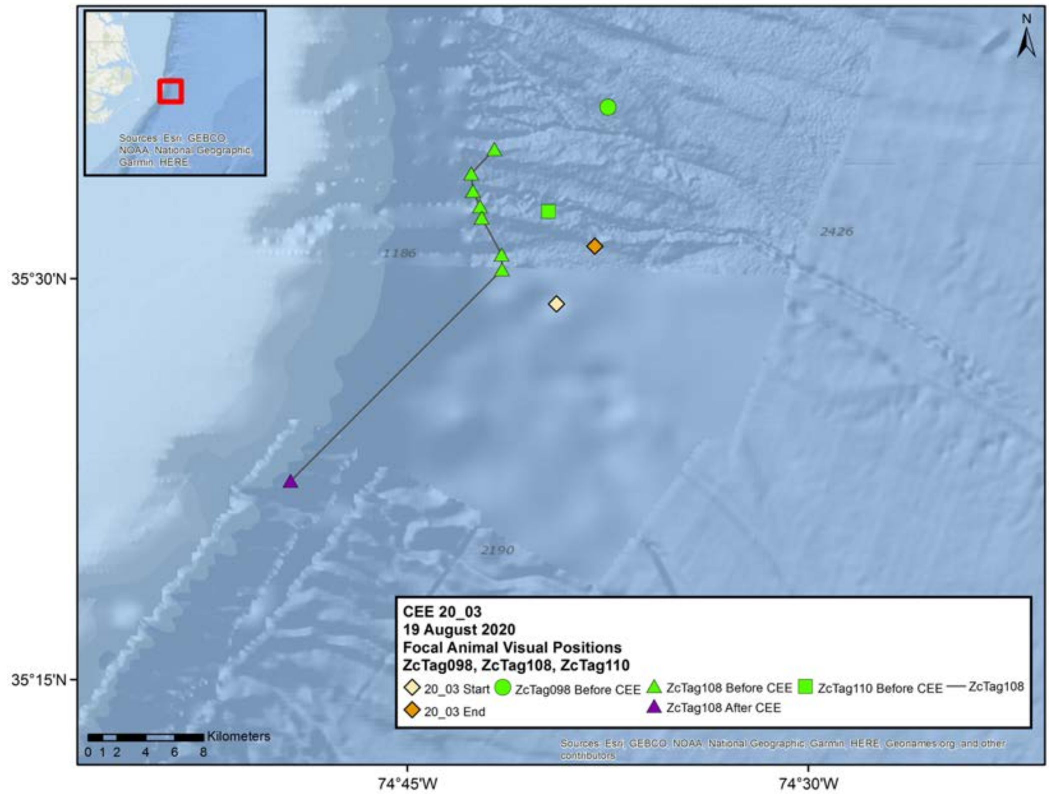

Figure 32. Overview map of source and focal follow locations for CEE #2020_03. Note: Zc20_232a was in the same focal social group as ZcTag108 before and after this CEE.

Table 12. Summary of RL model predictions before and during CEE #2020_03.[13]

Model Run	Description	Animal (Zc98) Depth (m)	Animal Lat	Animal Lon	Est. Range (nm) Start-End	Modeled RL START	Modeled RL END	Modeled RL MAX
1	17 Aug nominal (Argos)	Zc105 (10)	35.585	-74.676	1.7 – 3.1	144	130	144
2	17 Aug nominal (Argos)	Zc105 (1700)	35.585	-74.676	1.7 – 3.1	140	139	144
3	17 Aug nominal (Argos)	Zc110 (10)	35.736	-74.612	1.1 – 2.9	140	132	140
4	17 Aug nominal (Argos)	Zc110 (1700)	35.736	-74.612	1.1 – 2.9	141	134	142
5	18 Aug 1100 EDT Barber	Zc110 (10)	35.623	-74.640	1.1 – 2.8	138	133	138
6	18 Aug 1100 EDT Barber	Zc110 (1800)	35.623	-74.640	1.1 – 2.8	148	135	148
7	18 Aug 1100 EDT Shearwater	Zc105/108 (10)	35.756	-74.620	1.3 – 2.6	141	120	141
8	18 Aug 1100 EDT Shearwater	Zc105/108 (1400)	35.756	-74.620	1.3 – 2.6	142	140	142
9	18 Aug 1325 Barber tag on	Zc20_231a (10)	35.609	-74.699	1.2 – 2.3	139	128	139
10	18 Aug 1325 Barber tag on	Zc20_231a (1700)	35.609	-74.699	2.3 – 3.9	143	132	143
11	18 Aug 2000 Shearwater pos	Zc20_231a (10)	35.547	-74.675	1.5 – 2.6	138	128	140
12	18 Aug 2000 Shearwater pos	Zc20_231a (1700)	35.547	-74.675	3.4 – 4.5	143	122	143
13	19 Aug 0928 Shearwater pos	Zc110 (10)	35.537	-74.656	1.2 - 1.3	138	132	138
14	19 Aug 0928 Shearwater pos	Zc110 (1800)	35.537	-74.656	2.5 – 3.5	133	143	143
15	19 Aug 1043 Barber fluke	Zc20_232a (10)	35.567	-74.710	2.4 – 1.5	137	123	140
16	19 Aug 1043 Barber fluke	Zc20_232a (1700)	35.567	-74.710	2.4 – 1.5	129	135	143
17	19 Aug 1313 Barber pos	Zc20_232a (10)	35.515	-74.690	**2.1 – 1.3**	**133**	**140**	**140**
18	19 Aug 1313 Barber pos	Zc20_232a (1700)	35.515	-74.690	**2.1 – 1.3**	**127**	**140**	**141**

[13] Post-hoc estimates are highlighted as estimated RL for Zc108 and Zc20_232a (in social group together) at different depths for model runs 17–18 (**Figures 33** and **34**). Note: all corresponding RL model runs are available at: https://duke.box.com/v/report2020-cee20-03-propmod

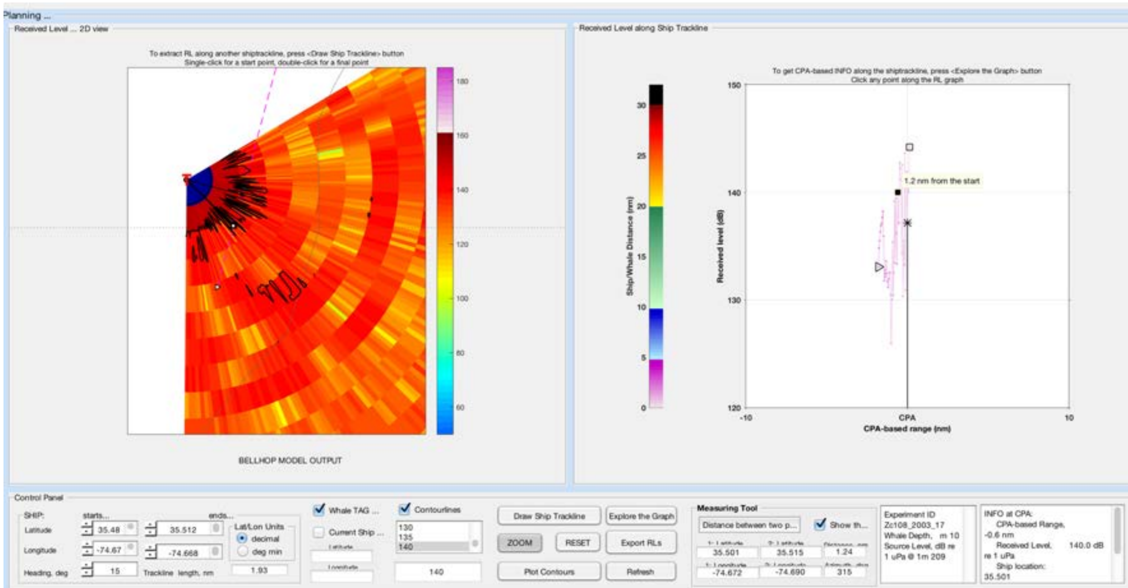

Figure 33. Post hoc RL model prediction at 10 m depth (model run #17 from Table 11) for focal whales ZcTag108 and Zc20_232a based on interpolated position and *R/V Shearwater* end position during Atlantic-BRS CEE #2020_03. Modeled RL at this depth and estimated position was: 140.0 dB RMS.

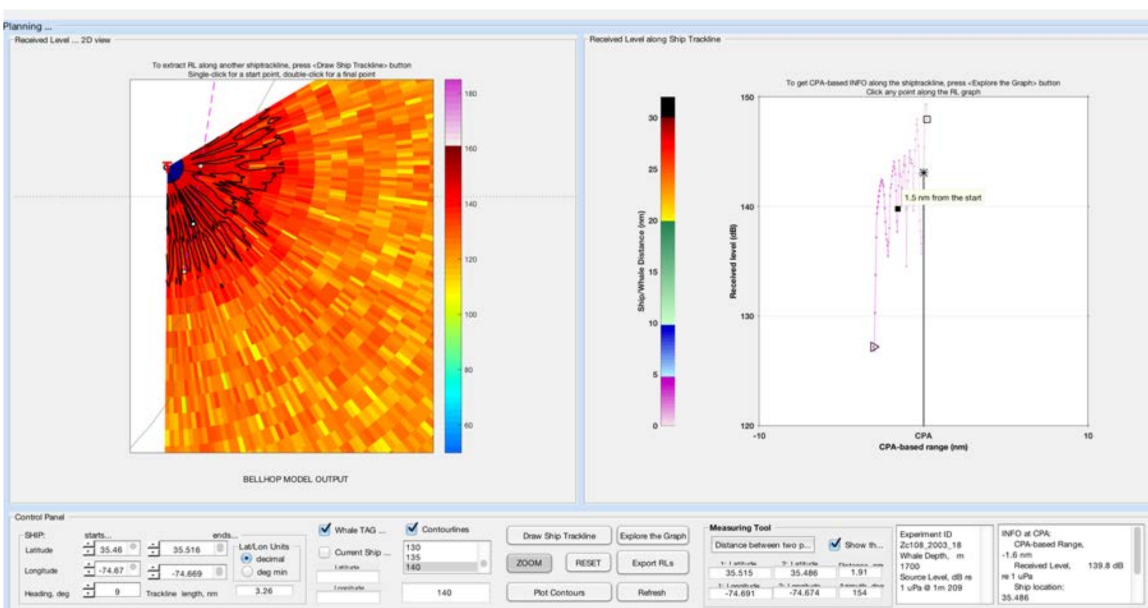

Figure 34. Post hoc RL model prediction at 1,700 m depth (model run #18 from Table 11) for focal whales ZcTag108 and Zc20_232a based on interpolated position and *R/V Shearwater* end position during Atlantic-BRS CEE #2020_03. Modeled RL at this depth and estimated position was: 139.8 dB RMS.

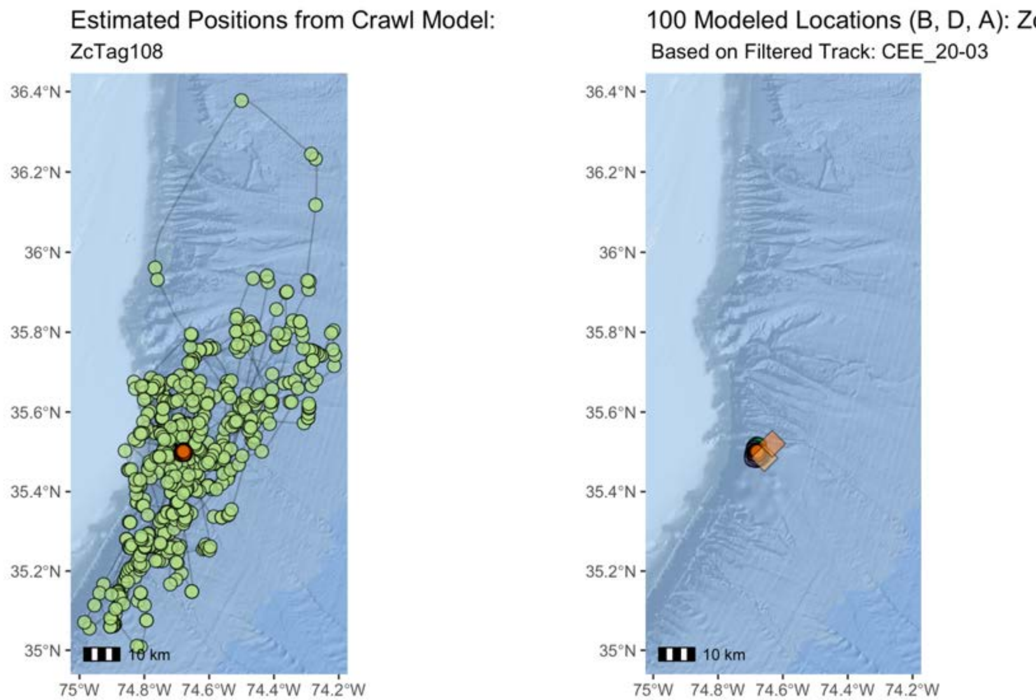

Figure 35. Estimated surface positions for focal whale ZcTag108 before, during, and after Atlantic-BRS CEE#2020_03.

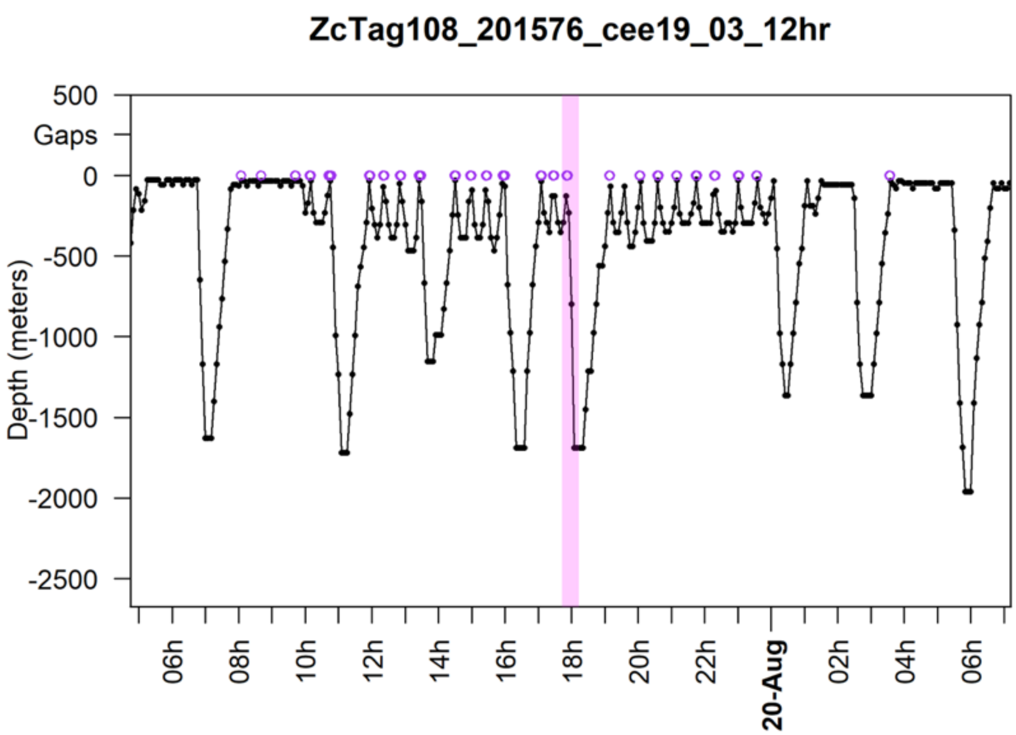

Figure 36. Available dive data for focal whale ZcTag108 before, during, and after Atlantic-BRS CEE #2020_03.

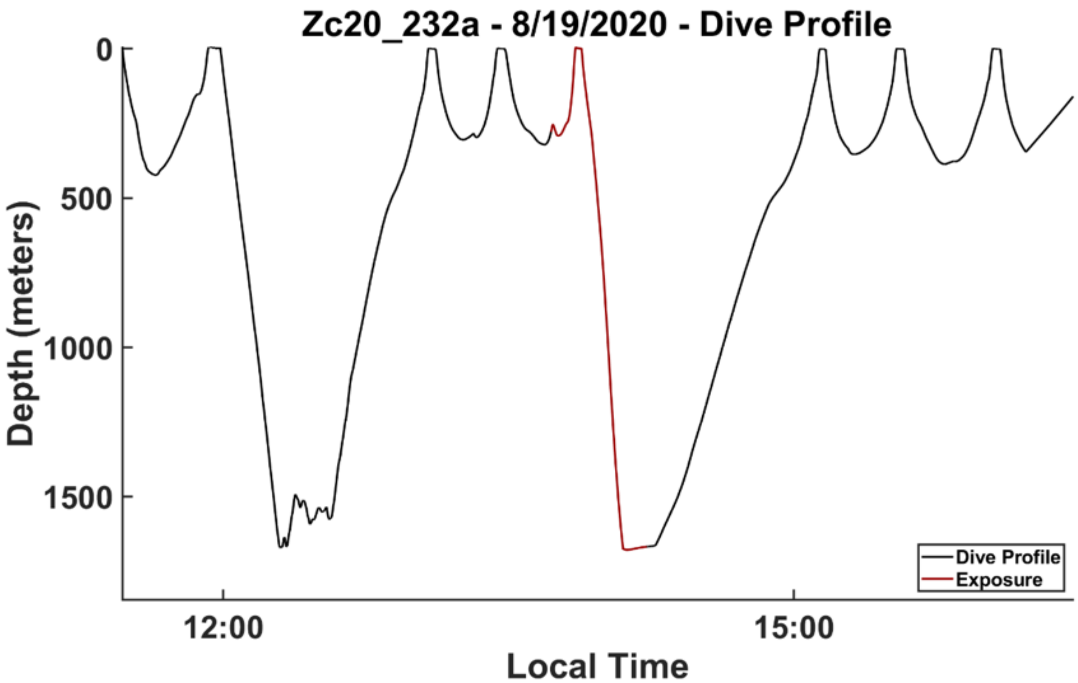

Figure 37. Dive data (from DTAG) for focal whale Zc20_232a before, during, and after Atlantic-BRS CEE #2020_03.

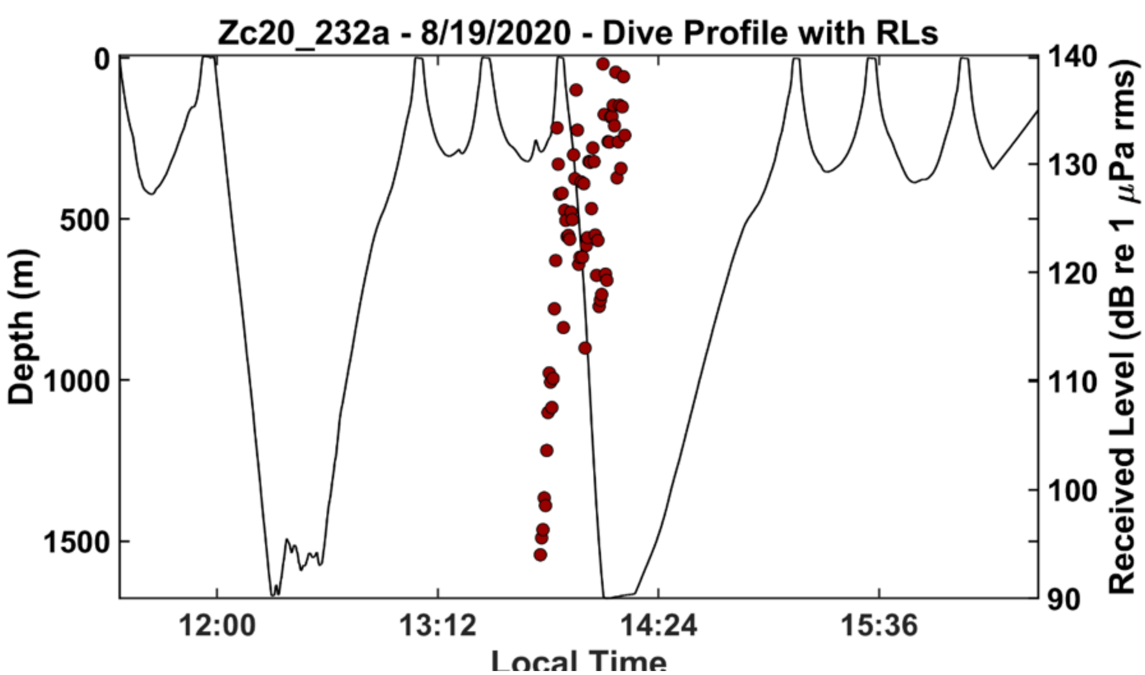

Figure 38. Dive data (from DTAG) with measured RLs for focal whale Zc20_232a before, during, and after Atlantic-BRS CEE #2020_03. NOTE: Max modeled RLs were 140–141 dB RMS for this whale using NPS modeling methods (see Table 11 and Figures 33 and 34).

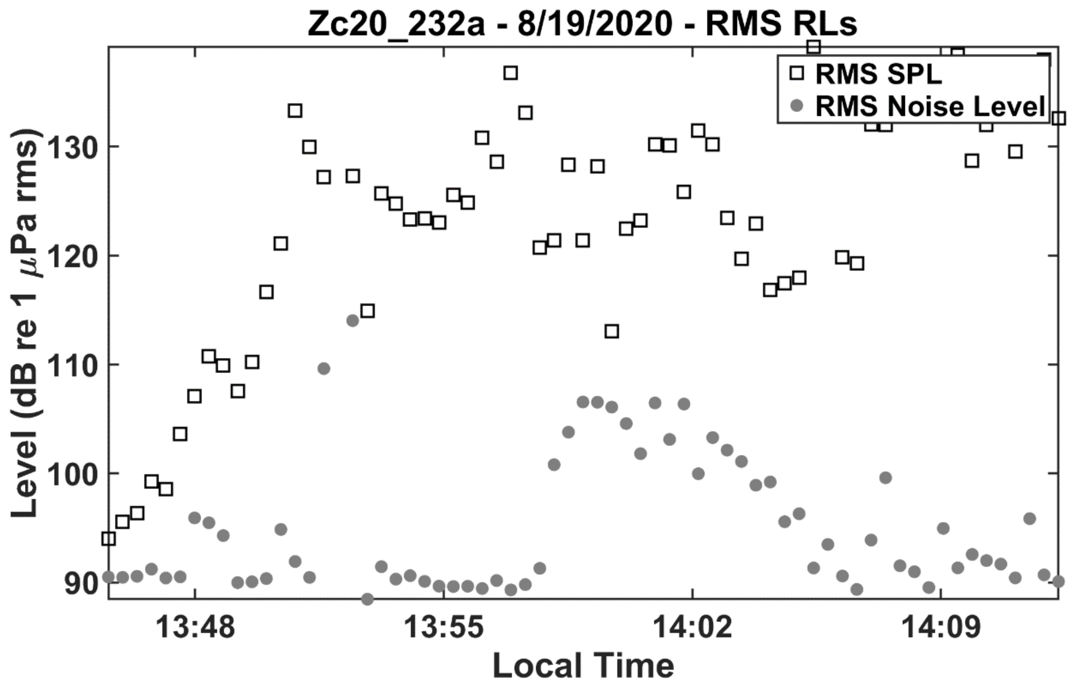

Figure 39. Received MFAS RLs relative to RMS ambient noise levels for focal whale Zc20_232a during Atlantic-BRS CEE #2020_03. NOTE: Increased ambient noise beginning during the CEE ~14:00 is likely an indication of a strong increase in swimming speed.

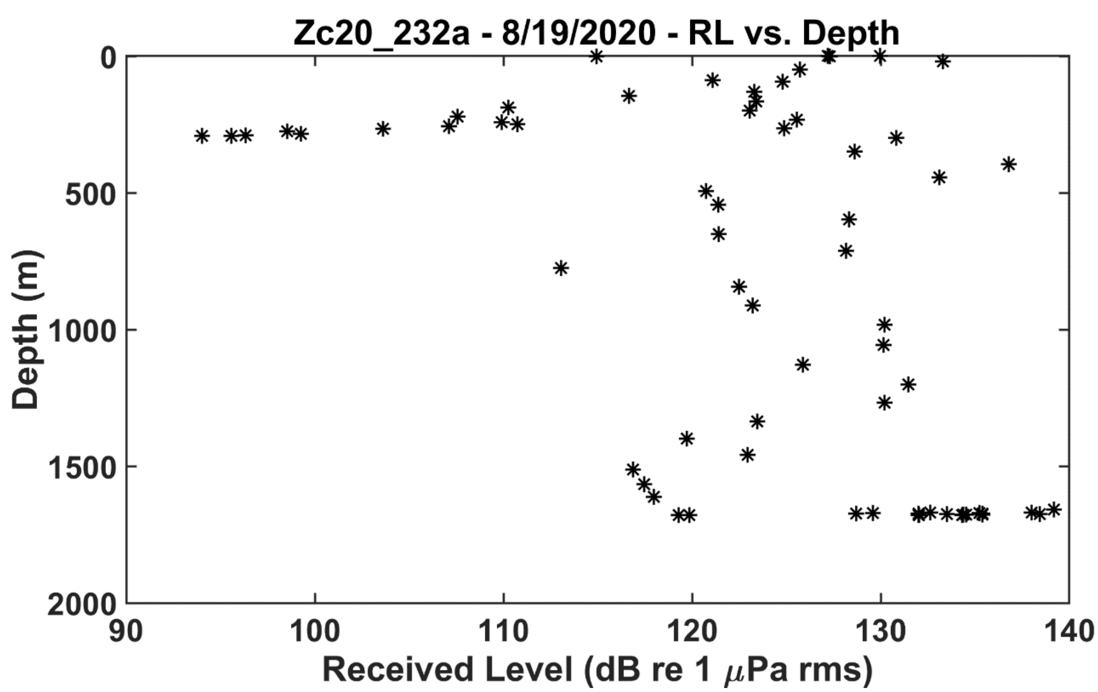

Figure 40. Received MFAS RLs (dB RMS) relative to whale depth for focal whale Zc20_232a during Atlantic-BRS CEE #2020_03.

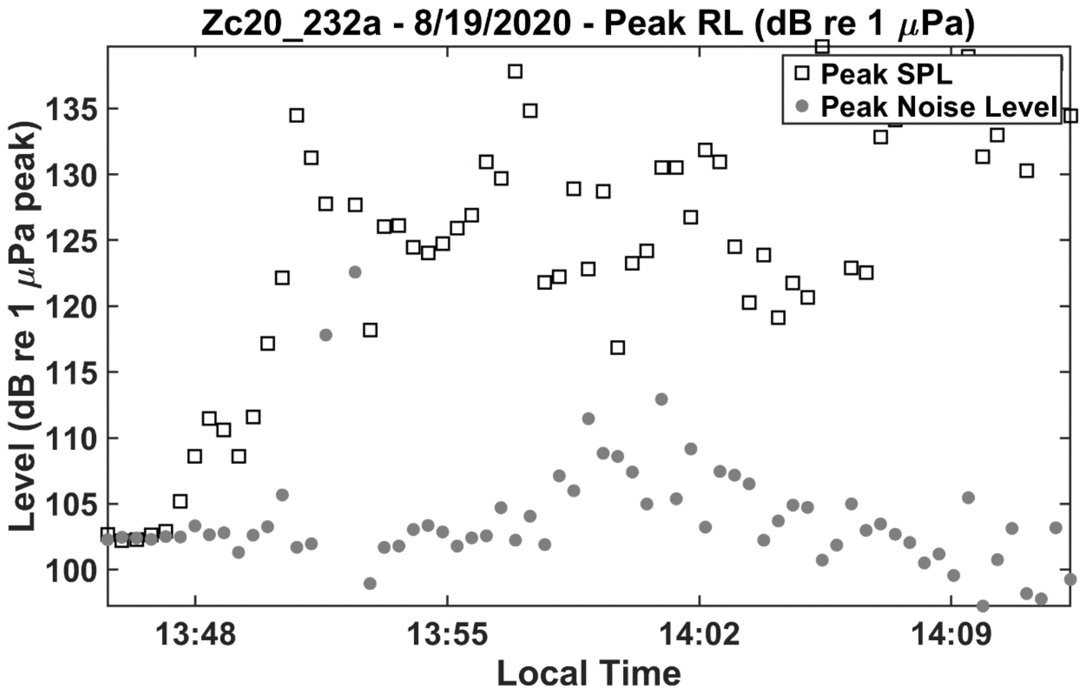

Figure 41. Received MFAS RLs (peak SPL) relative to ambient noise for focal whale Zc20_232a during Atlantic-BRS CEE #2020_03.

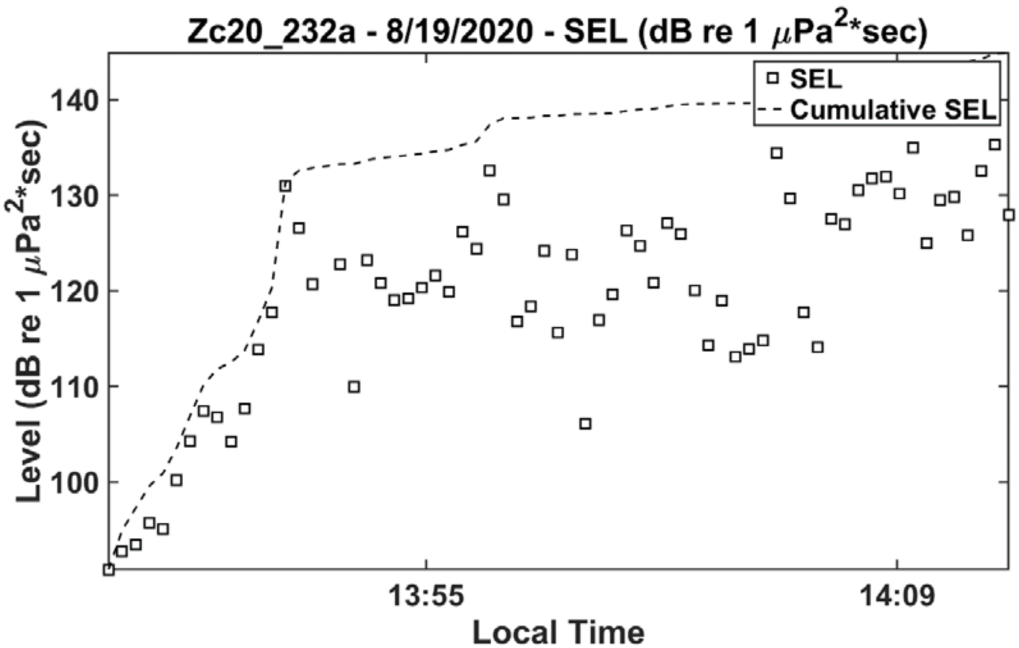

Figure 42. Received MFAS exposure levels (per ping and cumulative sound exposure level) for focal whale Zc20_232a during Atlantic-BRS CEE #2020_03.

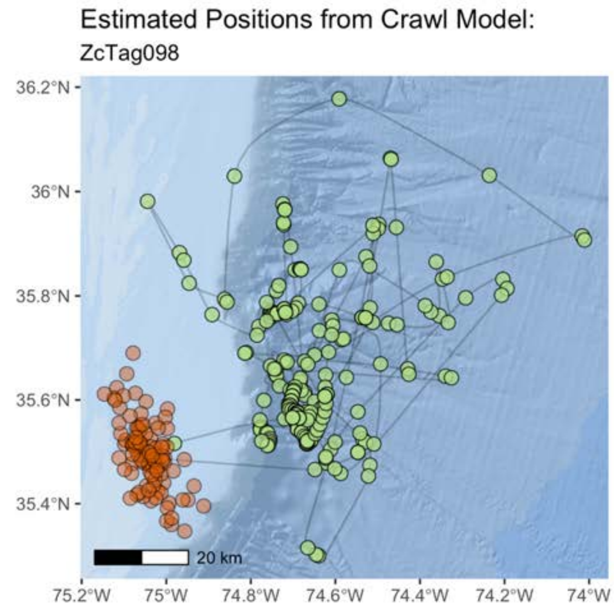

Figure 43. Estimated surface positions for focal whale ZcTag98 before, during, and after Atlantic-BRS CEE #2020_03.

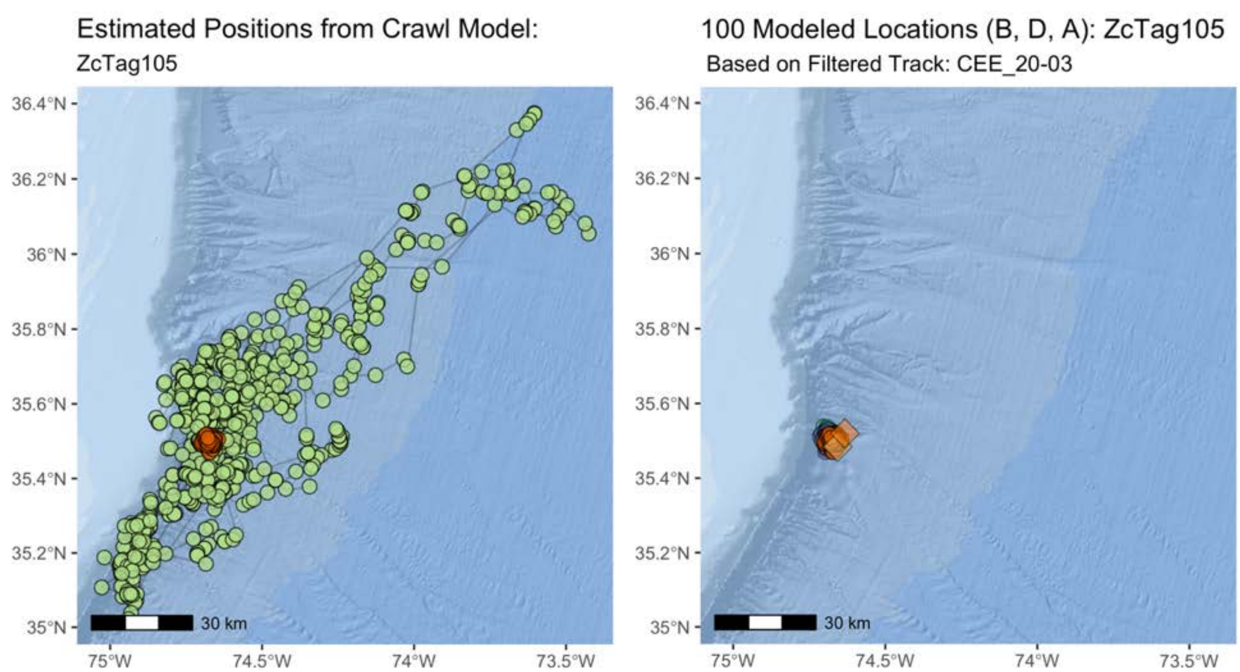

Figure 44. Estimated surface positions for focal whale ZcTag105 before, during, and after Atlantic-BRS CEE #2020_03.

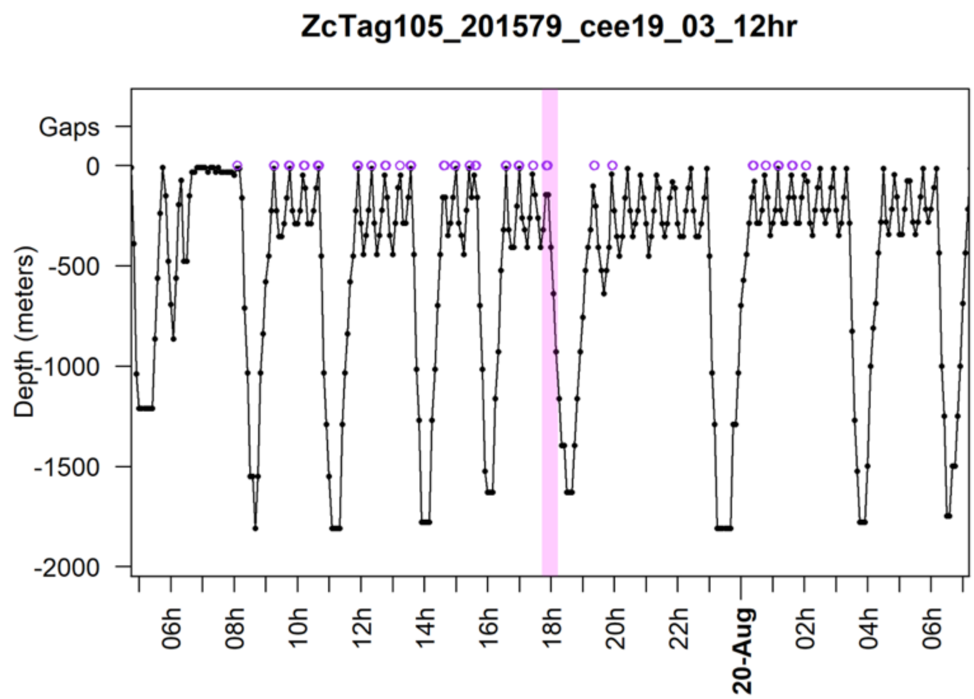

Figure 45. Available dive data for focal whale ZcTag105 before, during, and after Atlantic-BRS CEE #2020_03.

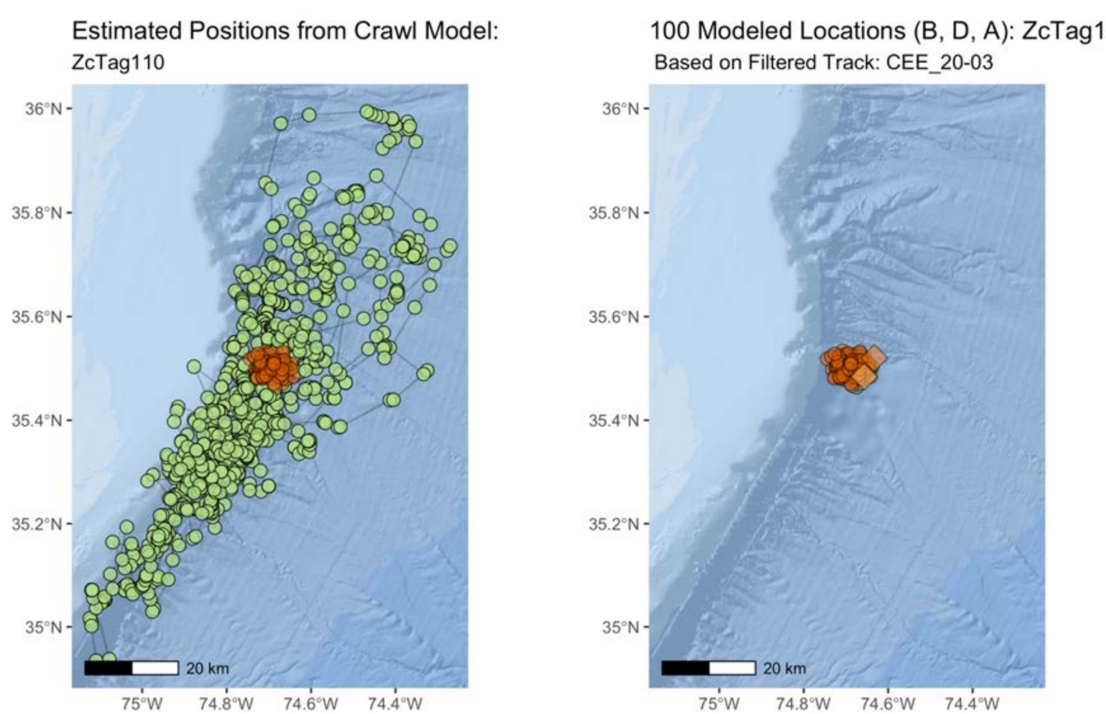

Figure 46. Estimated surface positions for focal whale ZcTag110 before, during, and after Atlantic-BRS CEE #2020_03.

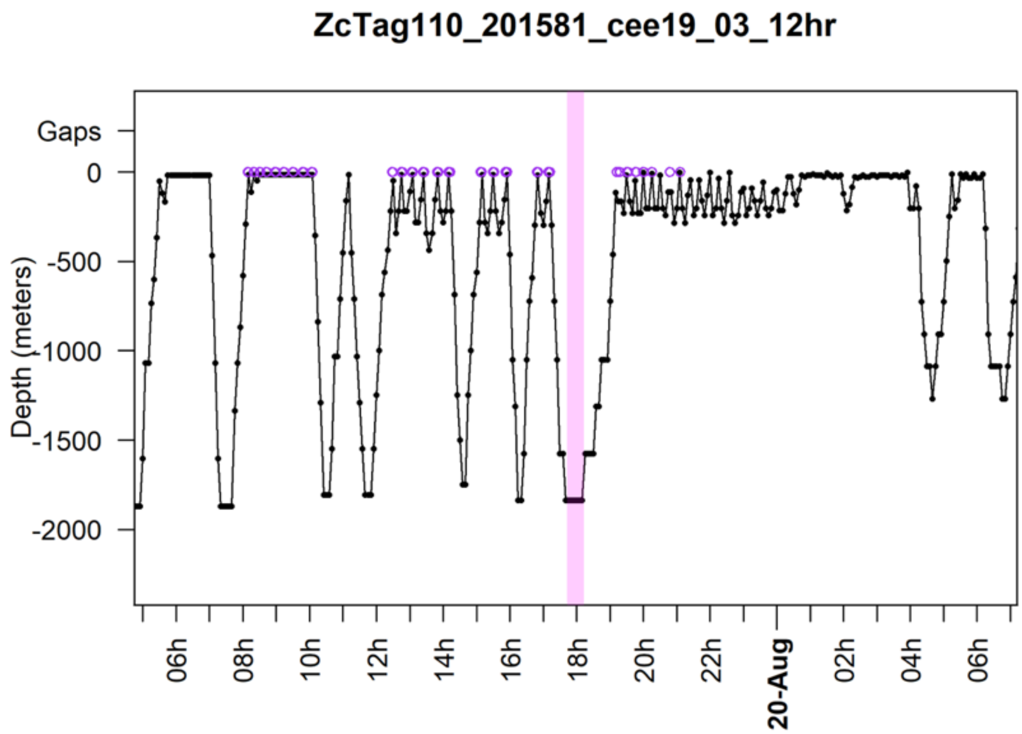

Figure 47. Available dive data for focal whale ZcTag110 before, during, and after Atlantic-BRS CEE #2020_03.

2.3.4 Pilot whale biopsy sampling following known MFAS exposure

An additional field campaign occurred in October 2020 with the objective of collecting remote blubber biopsies from pilot whales after exposure to simulated MFAS. These "tagless" CEEs allowed for more efficient biopsy collection without the risk of compromising behavioral data collected on DTAGs. Through steroid hormone analyses, these biopsies will be used to assess the physiological stress response to simulated MFAS exposure (note: this field effort was partially funded through internal Duke University sources).

Approach: The six-member field team traveled to Manteo, North Carolina, and closely followed requisite COVID-19 protocols. A subset of the field team, including one of our chief scientists, operated the sound source from the *R/V Spray*, while the remainder of the team used the *R/V Barber* for biopsy sampling and photo-ID. The three October CEEs were conducted using the same simulated MFAS source and signal parameters as CEE #2020_03 (**Table 11**) with the exception of using a lower SL (see **Table 13**). Target RLs of focal animals were 140 to 155 dB (RMS) and did not exceed 160 dB.

Table 13. Summary of 2020 "Tagless" MFAS CEEs with Pilot Whales.

Tagless CEE #	Date	Time (UTC)	MFAS Source Level (dB RMS)	Post-CEE Biopsies
1	15-Oct-20	13:44	200 dB	6
2	15-Oct-20	17:13	200 dB	1
3	16-Oct-20	14:38	200 dB	11

Following each 30 min CEE, the *R/V Barber* collected multiple biopsies from the focal group before locating and sampling nearby groups of pilot whales, who were likely exposed at lower RLs. All pilot whales encountered within 2 hours post-CEE were considered 'exposed' and targeted for biopsy sampling. The team aboard the *R/V Spray* also conducted photo-ID and collected post-CEE biopsies when encountering pilot whales within the post-CEE window. Cross-vessel communication was maintained throughout field efforts to ensure groups were not re-sampled.

The team conducted the first CEE around mid-morning on 15 October and collected six biopsies before relocating away from the exposure area. They conducted a second CEE on un-exposed animals that afternoon. The weather created poor sampling conditions soon after the CEE ended, but the team collected one biopsy. On the morning of 16 October, the team conducted a third CEE and collected 11 post-CEE biopsies. Afternoon conditions were not conducive to a fourth CEE.

Next Steps: Biopsies were extracted and processed at the Hollings Marine Lab in Charleston, SC. Through a collaboration with the National Institute of Standards and Technology, our team is using liquid chromatography tandem mass spectrometry to quantify a suite of (stress and reproductive) steroid hormones in each these samples. The analysis of this data is currently underway.

3. Analytical Developments, Results, and Publications & Presentations

3.1 Analytical Developments and Results

3.1.1 Data analysis and visualization

The Atlantic-BRS team has continued to develop analytical and data visualization methods to quantify behavior and behavioral response to MFAS and depict and understand these data. Some analytical progress and next steps are detailed in Section 3.2. Here we describe major progress in data visualization through a concerted effort led by Dr. Rob Schick with the support of seven undergraduate students at Duke University. This effort, focused initially on the processed 2019 satellite-transmitting data and CEE data as a test case, is important in multiple ways. First, it uses cutting-edge data visualization methods to systematically integrate and depict large data sets. This not only provides a common understanding of the existing data and how they relate to one another as a starting foundation for baseline and response analyses, it also provides an easily accessible and visually understandable portal into complex movement and diving data for project managers and others interested in the Atlantic-BRS. Further, by working directly with students, the project is in-kind supported and educates the next generation of researchers in applied research methods that address real-world conservation and management issues.

Dr. Schick led the students through Duke's Matching Undergraduates to Science and Engineering Research (MUSER) program. The students were Amy Bu, Larry Chen, Camaren Dayton, Nick Kaney, Jennifer Schultz, Nathan Yu and Larry Zheng. They comprise a range of undergraduate majors including computer science, statistics, biology and mechanical engineering. The overarching goals of the project were three-fold:

1. Create an R data package to house the 2019 Atlantic BRS data.
2. Create a Shiny app that allows users to interactively view spatial data, CEE summaries, and diving data.
3. Learn about historic and current research in the field of marine mammal acoustics through readings and small group discussion.

Because of the ongoing pandemic, the team met entirely over Zoom almost every week from June through early December. Each week's meetings included three components: 1) ahead of time, one team member would choose a paper for the group to read and during the meeting we would discuss the paper, focusing on what they did, how it related to the team's work on the Atlantic BRS, and what tabular and graphical representation may inspire; 2) the team would review progress on code and visualizations each of three sub-teams made throughout the week; and 3) the team would sketch out plans for the following week's work. During the week, Dr. Schick would often respond to code requests over Microsoft Teams, and/or through one-on-one Zoom meetings. The three sub-teams oriented approximately along a data theme, a code theme, and a visualization theme, although naturally there was considerable overlap between them.

Because the data streams in this project are considerable, the team endeavored to use reproducible research techniques throughout. Thus, coding (mostly in R) was tracked with a version control system (git), and the code base was shared across the team using pull requests on private code repositories on GitHub. Starting with the raw data collected at DUML, a data package was constructed that assimilates four sources of data:

1. The raw satellite data from the Wildlife Computers portal
    a. x,y data
    b. series data on depths
2. Auxiliary data collected in the field concomitant with focal follow and/or deployment data
3. Goniometer locations
4. Metadata about the four CEEs conducted during 2019.

The DataPackageR framework from ROpenSci was used to ingest and process these data and a compiled R package (**Figure 48**) was constructed that can be downloaded and used both in subsequent analyses, e.g., calculating RLs, but also in overview visualizations like the shiny app. The package includes help on installation and use, as well as within R help on individual components (**Figure 48**).

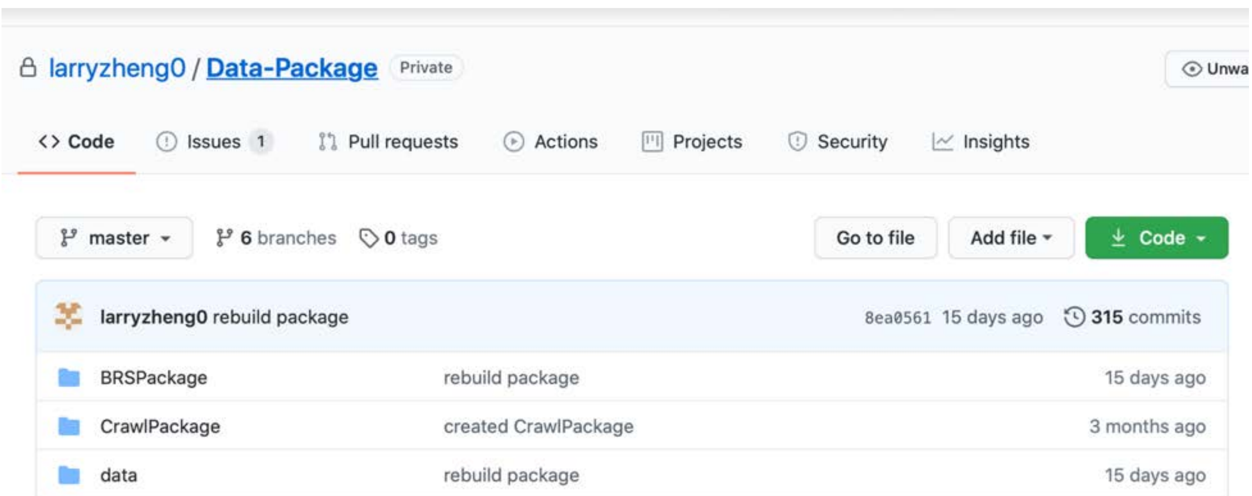

Figure 48. Screen capture of data package repository on GitHub.

README.md

Muser-BRS-Project-Repo

Installation

Type "R CMD INSTALL BRSPackage_1.0.tar.gz" in the terminal.

Overview

This package contains data from controlled exposure events (CEEs) from 2019 on Cuvier's beaked whales (Ziphius cavirostris) and long-finned pilot whales (Globicephala melas). There were 4 CEEs - two in the spring, two in the summer. They were all scaled source exposures, and the summary of the CEE metadata are shown in the cee data frame.

Dataframes

This package provides the following data tables:

- cee
- cee19_01
- cee19_02
- cee19_03
- cee19_04
- locations
- series
- series_xts
- series_range
- processed_locations
- raw_aux
- raw_gonio
- processed_gonio_aux_locs

Figure 49. Screen capture of the README file accompanying the data package.[14]

Data cleaning steps from the National Oceanic and Atmospheric Administration's Marine Mammal Laboratory were applied to prepare the data for mapping and visualization as part of the data package creation. With the data package complete, we then built a Shiny app to showcase different facets of the data. This was also done with version control and reproducible workflows. The goal of this effort was to provide an overview of the data as well as the ability for users to dig into details of individual animals. As the effort progressed, the shiny app was developed into a stand-alone summary dashboard as well as a complete app.

These are deployed and viewable at:

- The dashboard: http://shiny.env.duke.edu/brs/Widgets_Overview.html
- Shiny app: http://shiny.env.duke.edu/brs/BRS-App-master/ShinyApp/

[14] Note: please contact the authors for reach access to the report.

The overview dashboard is intended to show the entirety of the 2019 satellite-transmitting tag data at a glance. As such, the interactivity is not as deep as in the shiny app. Here the temporal extent of the tags (**Figure 50**), the spatial distribution of all of the data (**Figure 51**), as well as tag/CEE specific summaries of the amount of data collected (**Figure 52**).

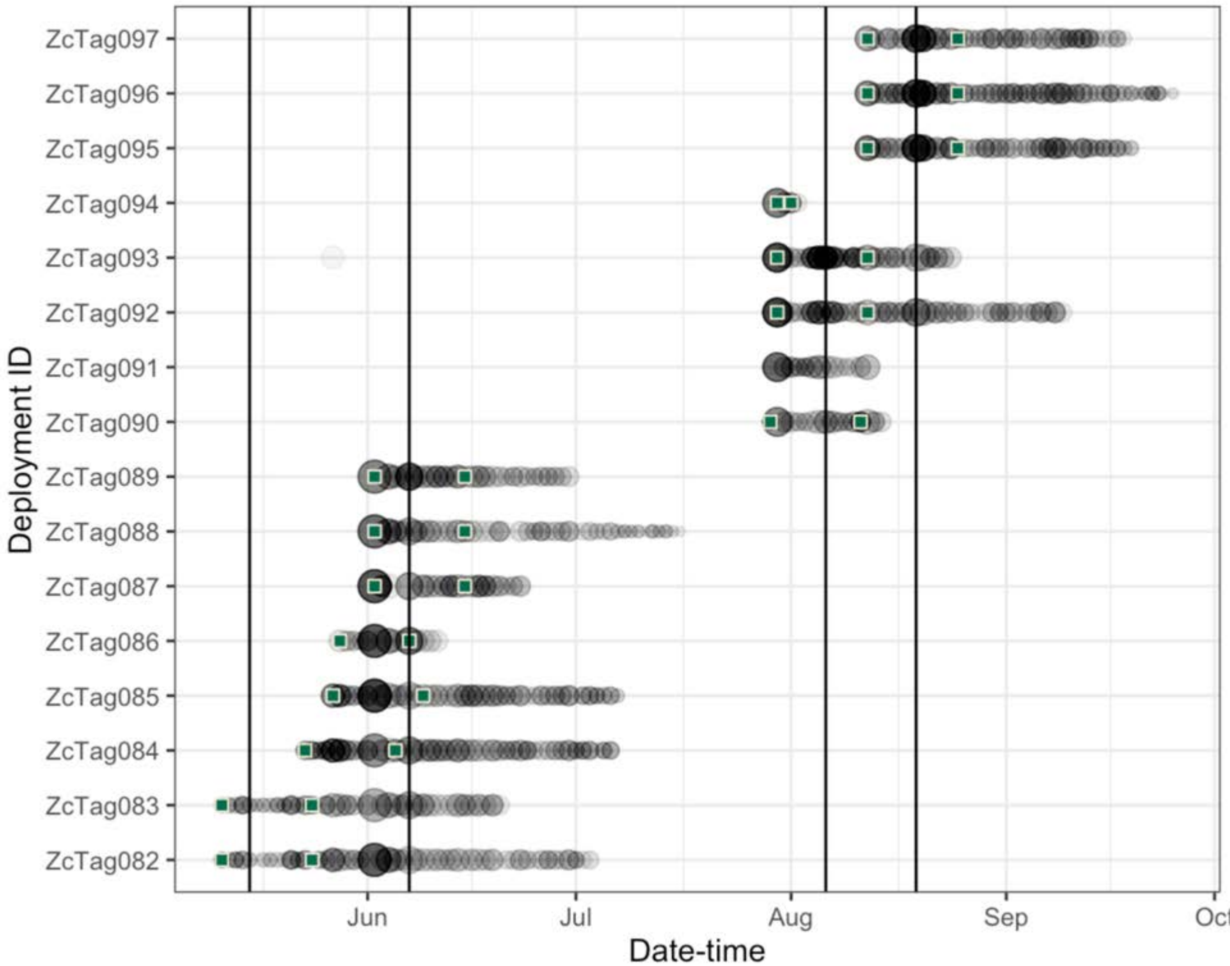

Figure 50. Longevity of individual Cuvier's beaked whale tags. Grey circles denote daily observed x,y locations (from satellite, Goniometer and focal follow data); larger circles correspond to more observations. Green squares correspond to the first and last observation of depth data from the series data stream. Note that both ZcTag091 and ZcTag094 had pressure sensor failures. Dark vertical lines correspond to the four CEE days.

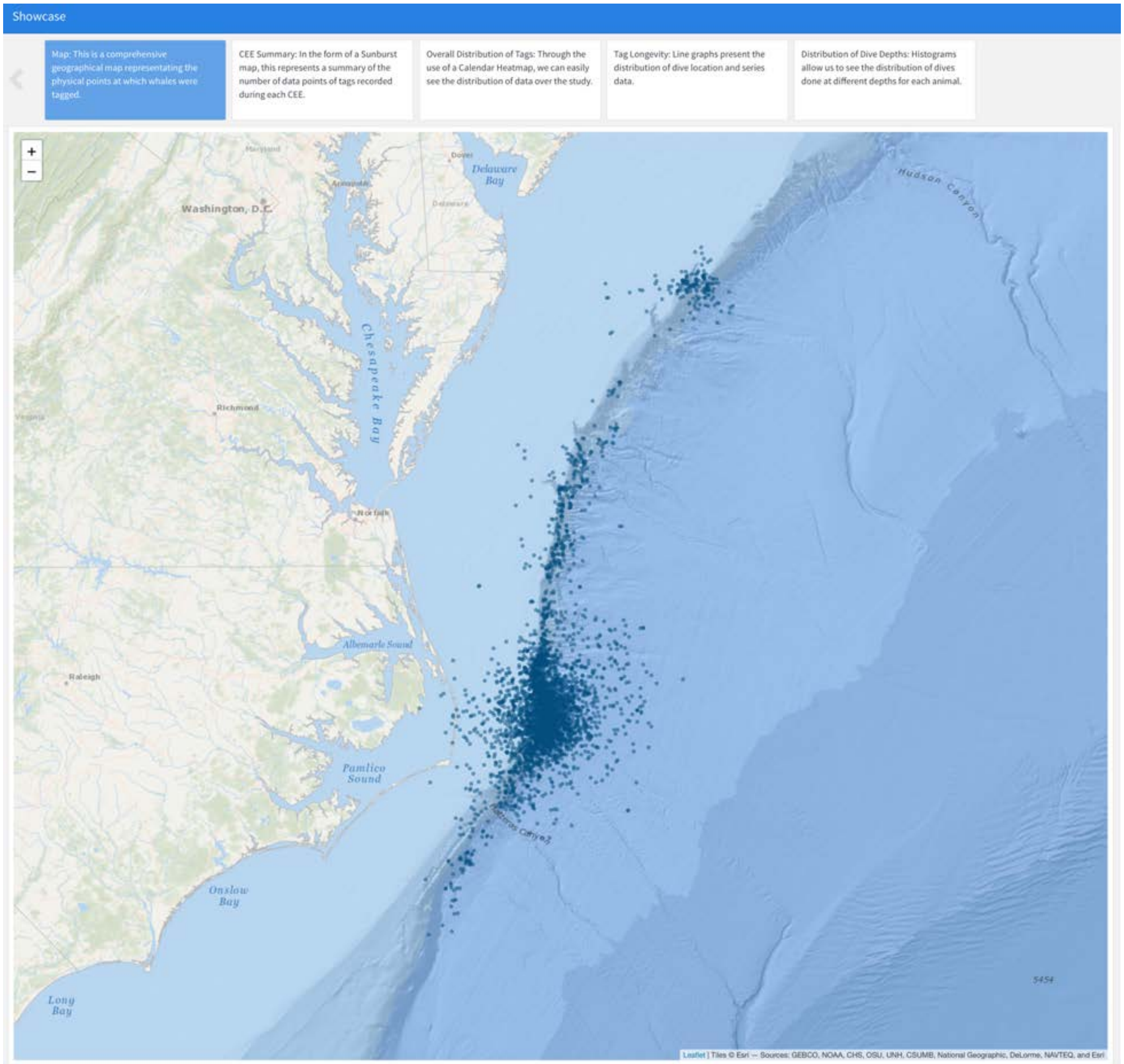

Figure 51. Distribution of all the data collected during the 2019 field effort. Tabs at the top allow the viewer different summary views of the data.

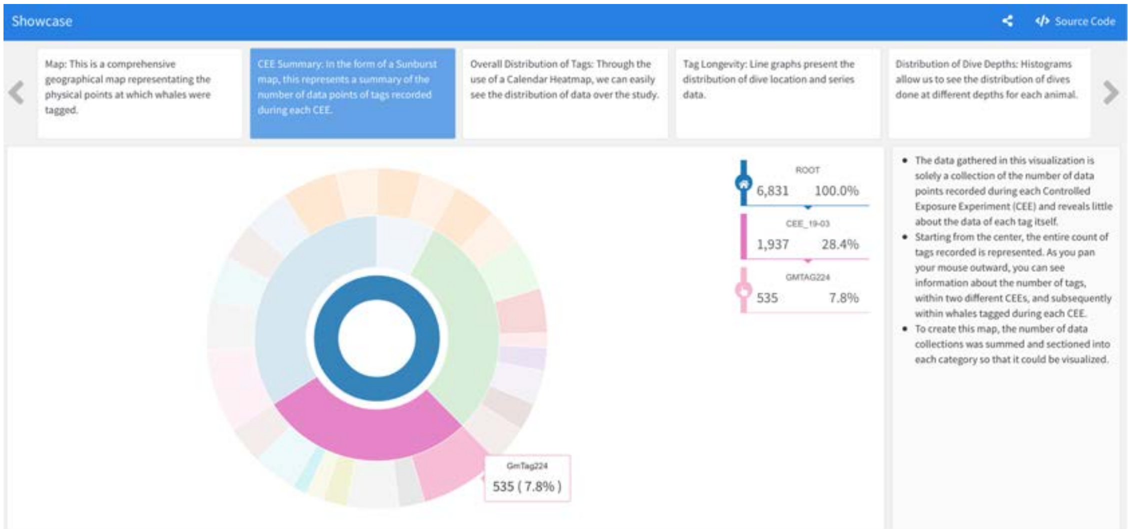

Figure 52. One panel of the summary dashboard for the data collected during the 2019 BRS. This interactive panel shows a hierarchical distribution of points per tag and per CEE, e.g., in 2019 GmTag224 had 535 locations, and was active during CEE_19-03 (1,937 locations across animals. During the entire season in 2019 recorded 6,831 cleaned locations.

In the Shiny app, the user is afforded much greater insight into the data. For example, unlike the overview dashboard, here the user can select individual/cee combinations to view the data (**Figure 53**). The first drop down in the app allows one to select one of four CEEs. The second populates based on which animal's tag was active at the time of the CEE (**Figures 50, 51**). From there, the viewer sees the map, an animation of the track, as well as interactive summaries of the dive data (see links at the top of the map in **Figure 53** – each of these is a panel that displays different views of the data).

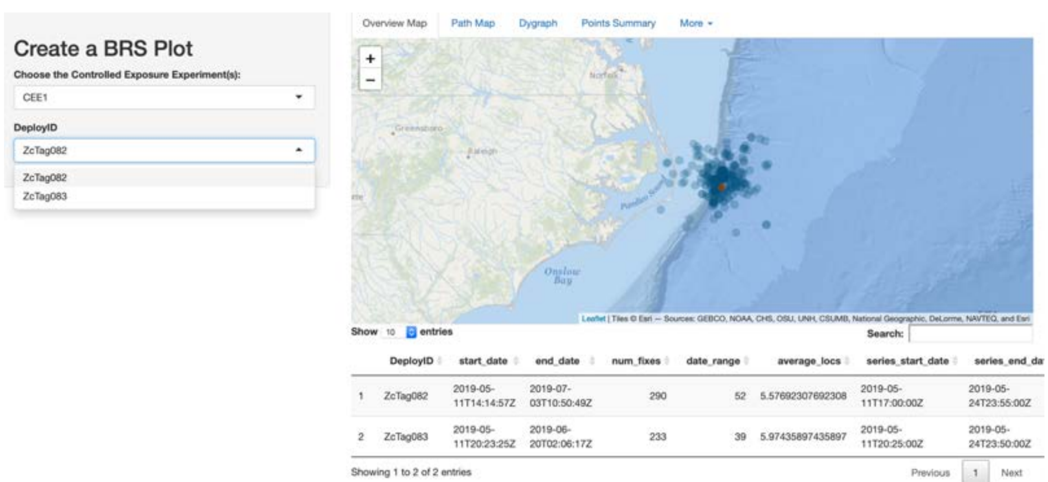

Figure 53. Shiny app that allows for exploration of all 2019 data. The hierarchy of the app includes both the CEE level and the individual level. With drop-down menus on the left, the user can choose a CEE, and then once chosen the available animals populate the second drop-down. Points from this animal are shown on the right, with the location of the CEE ship shown in red. Data table provides a one-line summary of that tag's data stream. Subsequent panels include an animation of the path, an interactive plot of the two weeks' worth of dive data, as well as the raw data in tabular format.

The team is continuing to work together on this effort, with the goals being to submit a manuscript on the 2019 data with respect to the inclusion of the ancillary data to improve positional estimates in the *x,y* domain, as well as including the *z* dimension, when available, to determine where in the water column the whale is. These estimates will also be intersected with the RL output from the NPS sound propagation model to determine what the distribution of RLs is at the time of the CEE. Future efforts will also add visualization of the three-dimensional RL model results as they relate to animal imputed track positions.

3.1.2 Photo ID analysis

Over 17,000 digital images were collected in the Cape Hatteras study area to confirm species, identify individual animals, and conduct follow-up monitoring of satellite-tagged animals during fieldwork supporting the Atlantic BRS in 2020 (please see: Waples and Read (2021) for more details. Digital photographs were taken with Canon or Nikon digital SLR cameras equipped with 100- to 400-millimeter zoom lenses. Photographs were obtained from six species, with most (15,400) taken of Cuvier's beaked whales.

All digital images were individually graded for photographic quality and animal distinctiveness. All images of sufficient quality and distinctiveness were then sorted by individual within a sighting and assigned temporary identifications. The best image for each individual in that sighting was then selected and these images were compiled into a folder for each sighting for later photo-identification (photo-ID) and all images were cropped.

Four of the fourteen Cuvier's beaked whales were satellite-tagged in 2020 were matched to the photo-ID catalog. ZcTag098 was photographed twice in August 2018 and satellite-tagged in July 2020. ZcTag099 was seen in June and August of 2017 and tagged in July 2020. In addition, another two Cuvier's beaked whales that were tagged in 2020 had been previously photographed and satellite-tagged. ZcTag046 was tagged in May of 2016 and was re-sighted in 2017 and in 2020 when it was satellite-tagged again (ZcTag103). ZcTag089 was tagged in June 2019; it was sighted in August 2020 without its original satellite tag and was tagged for a second time (ZcTag109). Interestingly, both Cuvier's beaked whales that were DTAG'd in 2020 and the subject of focal follows and Controlled Exposure Experiments were also whales that had been previously satellite-tagged. Zca_20_231a was satellite-tagged in May 2017 (ZcTag056) and DTAG'd in August 2020 and Zca_20_232a was satellite-tagged in August 2018 (ZcTag071) and also DTAG'd in August 2020. Neither whale had a satellite tag present at the time of the DTAGing.

3.1.3 Analytical developments

The Atlantic-BRS team has continued to expend considerable effort and make progress in processing field data, applying and developing new methods, and integrating data across years in synthesis assessments of baseline behavior and, increasingly, response. A number of recent and ongoing publications listed below demonstrate progress and ongoing new directions. Our collaborators with CREEM at the University of St. Andrews are leading a number of these efforts, both in directly funded aspects of the Atlantic-BRS and through overlapping interest and collaboration with the ONR-funded Double Mocha effort. Both are highlighted briefly here.

The primary focus specific to the Atlantic-BRS funded efforts over the last year has been the development and evaluation of a Continuous-Time Markov Chain (CTMC) method for identifying behavioral change-points and metrics of response intensity for satellite tag data, in particular data collected on tags with the behavior log setting. The CTMC approach allows for joint modelling of dive and surface durations and allows for covariates (such as dive depth, distance to shelf edge, or distance to source vessel) to affect dive and surface durations differently. This approach can capture cyclical/non-linear correlation in the baseline data and look at deviations from any underlying patterns in behavior during exposure. Generalized Linear Models and Generalized Additive Models of dive duration or surface duration alone are similar to the above approach, but they cannot model both processes together.

As part of the initial evaluation of the CTMC method, it was applied to all of the 2017 satellite tags which had exposures. The results were compared with results from previous Mahalanobis Distance analysis of the same tags. The CTMC results aligned well with the Mahalanobis Distance results but captured more of the underlying biological complexity.

Method development has continued and, in particular, we have been working on improved methods for including the exposure term and refining the model selection method. Once method development is complete, we will apply to all available *Ziphius* behavior log satellite tag data. An R package and vignette have been written for the CTMC method, both of which have been kept up to date as the method has evolved. A manuscript describing the method and example application being led by Richard Glennie is currently being drafted.

In addition, we have carried out refinement of an existing algorithm for classifying data collected on tags using the series setting into diving and surfacing periods so that it is in the same format as behavior log data. These tag data can then also be analyzed using the current CTMC method, and responses of *Ziphius* can be compared across all years, regardless of tag setting. The behavior classification algorithm and an example application will be included in the supplementary section of the CTMC manuscript.

The CREEM team has also been considering modifications to the CTMC method to be more directly applicable to data collected using the series setting. The R package has been updated to allow for series tag data to be incorporated, but we anticipate further development of this and are also cognizant of other methods being developed specifically for satellite tags using the series setting that we may want to apply instead of, or in addition to, the CTMC method (e.g., Hewitt et al., 2021 as part of Double MOCHA project).

Double MOCHA progress that is relevant to the Atlantic-BRS and future analysis efforts:
The St Andrews and Duke Double MOCHA teams are pursuing a number of different approaches for analyzing data from both DTAGs and satellite tags, prioritizing baseline data analysis for methodological development with the aim of then incorporating exposure data.

The St. Andrews research team have focused on developing continuous-time movement models that describe animal behavior using a continuous quantity, termed the activity level, rather than by discrete behavioral modes. Movement is modelled using stochastic differential equations whose parameters are smooth functions of covariates such as time (allowing for temporal heterogeneity in behavior) and environmental effects (such as time-of-day or bathymetry). The framework for including covariates has been developed in generality meaning intended inclusion of individual-level effects (e.g., individual heterogeneity, sex, with calf or not) and exposure effects can be included easily. The method has been applied for both DTAGs (analyzing the pitch, roll, and heading data streams together) and for satellite tags (within the continuous correlated random walk approach). A paper describing the method and an application to DTAG data has been submitted to the Journal of Agricultural, Biological and Environmental Statistics.

The Duke research team have focused on creating a simulation framework to learn how well we can detect responses under realistic conditions and with different tools (DTAGS, sat tags, etc.) and investigate the fitting of continuous-time movement models to improve on currently available methods for horizontal movement and vertical dive modelling. Specifically, the team have developed a hierarchical model to better understand and predict features of deep diving behavior. We have built a multi-stage generative model for deep dives of beaked whales using a continuous time Markov chain with depths specified through binning (Hewitt et al. 2021). We are now extending this model in two ways: 1) we are investigating the impact of covariates obtained in the surface or shallow-periods on deep-dives, and 2) we are extending the model to fit to an entire sequence of dive behavior as opposed to the random effects formulation in Hewitt et al. (2021).

In a related Living Marine Resources-funded project developing analytical methods for fitting dose-response functions, a simulation study has been conducted to better understand the balance between high resolution (DTAG) and low resolution (satellite tag) data from CEEs and the effect of the uncertainty in received levels from both data types on the resulting exposure-response functions. The Atlantic-BRS team have been briefed on the results of this study, which are available as a technical report (Bouchet et al. 2020). The team working on this exposure-response project will be involved with the Atlantic-BRS team in fitting exposure-response models and supporting manuscript development.

3.2 Publications and Presentations

As the Atlantic-BRS project has progressed, we are consistently and increasingly producing peer-reviewed publications both directly through the project and also in collaboration with the ONR-funded Double Mocha effort which is developing analytical methods and testing and applying them to Atlantic-BRS data. Below we provide a summary of papers that are either published, in review, or in advanced stages of development (**Table 13**); direct links to publications are provided where available. Given the effective shutdown of most professional scientific and review meetings and public presentations through other venues as a result of the COVID-19 pandemic, few formal presentations outside of virtual meetings occurred in 2020.

Table 14. Atlantic-BRS publications and manuscripts in review and advanced stages of preparation

Category	Nominal Title/Subject	Lead Author (Institution)	Status
Baseline behavior	Diving Behaviour of Cuvier's Beaked Whales (*Ziphius cavirostris*) off Cape Hatteras, North Carolina	Shearer (Duke)	PUBLISHED
Methodology - Technology	Mind the gap - Optimising satellite tag settings for time series analysis of foraging dives in Cuvier's beaked whales	Quick (Duke)	PUBLISHED
Methodology - Technology	Accounting for Positional Uncertainty When Modeling Received Levels for Tagged Cetaceans Exposed to Sonar	Schick (Duke)	PUBLISHED
Baseline behavior	Aerobic dive limits in Cuvier's beaked whales	Quick (Duke)	PUBLISHED
Methodology - Technology	Continuous-time discrete-state modeling for deep whale dives.	Hewitt (Duke) [Double Mocha]	PUBLISHED
Baseline behavior	Residency and movement patterns of Cuvier's beaked whales (*Ziphius cavirostris*) off Cape Hatteras, North Carolina, USA	Foley (Duke) [primarily pre-BRS tags but includes 2017]	PUBLISHED
Baseline behavior	Extreme Synchrony in Diving Behaviour of Cuvier's Beaked Whales (*Ziphius cavirostris*) off Cape Hatteras, North Carolina.	Cioffi (Duke)	PUBLISHED
Baseline behavior	More than metronomes: variation in diving behaviour of Cuvier's Beaked Whales (*Ziphius cavirostris*)	Quick (Duke)	In review
Baseline behavior	Shallow night intervals in *Ziphius cavirostris*	Cioffi (Duke)	In preparation
Baseline physiology	Baseline variation of steroid hormones in short-finned pilot whales (*Globicephala macrorhynchus*)	Wisse (Duke)	In preparation
Baseline behavior	Possible orientation behaviour in Ziphius	Quick (Duke)	In preparation
Methodology - Technology	Continuous time series data programming regime	Cioffi (Duke)	In preparation
Methodology - Technology	Estimating RLs and horizontal avoidance with dynamic covariates in exposed animals	Schick (Duke)	In preparation
Methodology - Technology	Detecting changes in foraging behavior in Cuvier's beaked whales exposed to sonar using coarse resolution data	Glennie (St Andrews) [Double Mocha]	In preparation
Methodology - Technology	Monte Carlo testing to identify behavioral responses to exposure using satellite tag data	Hewitt (Duke) [Double Mocha]	In preparation
CEE Exposure-Response	Meta-analysis of context of beaked whale response to sonar exposure	Quick (Duke)	In preparation
CEE Exposure-Response	Behavioral responses of Cuvier's beaked whales to simulated mid-frequency active military sonar off Cape Hatteras, NC	Southall (SEA; Duke)	In preparation
Disturbance Exposure-Response	Measuring stress responses in short-finned pilot whale biopsies: are field methods confounding our data?	Wisse (Duke)	In preparation

4. Overall Assessment and Recommendations for 2021 Effort

4.1 General Assessment of Atlantic-BRS 2020 Accomplishments

- Developing and successfully implementing adaptive, thorough protocols in order to field research teams and safely achieve comparable field results as in previous years during a pandemic was a major accomplishment.
- Despite the challenges with the pandemic and imperfect weather for effectively the entire period except several workable windows, we again managed to deploy various types of tags on many high-priority beaked whales and collect tens of thousands of hours of movement and diving behavior and movement. Only a single pilot whale was tagged in 2020, though this was largely the result of focus on high priority beaked whales within the optimal conditions that did occur rather than due to an absence of pilot whales.
- We successfully coordinated two complete and as-designed CEEs with Navy vessels, a major accomplishment after none were achieved in 2019. This was especially notable in that due to the pandemic we were unable to place liaison riders aboard vessels to coordinate their operations before and during CEEs. These events evolved flawlessly thanks to extensive, sustained coordination and effort with Navy personnel working with vessels ahead of their deployment and close, real-time communication of time and locations of possible coordination using shore-based personnel from both the Atlantic-BRS team and the Navy team. We had multiple focal whales during both CEEs, with RLs spanning the entirely of the target range, given that vessels went precisely to requested locations and tracks. Data from Navy vessels requested was provided in a complete, timely, and unclassified manner.
- In one instance, where many (12) beaked whales were tagged and a potential Navy vessel for coordination was ultimately unavailable, the simulated MFAS source was used successfully, as planned.
- Field efforts in 2020 were the first to utilize the *R/V Shearwater* as a research platform. It served as an excellent platform for visual observation, tag tracking, MFAS source, and small RHIB base of operations.
- Overall, we two very promising DTAG deployments and both tags were successfully tracked through their full programed deployment and relatively easily recovered. However, various sensor failures limited or rendered the data obtained entirely useless. Thanks to the overnight offshore tracking platform with the *R/V Shearwater*, one of these tags stayed on overnight and had the promise of the first such fine-scale diurnal baseline behavioral data but none were obtained due to sensor and hydrophone failures. The second was notably deployed was on a beaked whale that was in the same social group with a satellite-tagged beaked whale, enabling us to fully achieve the multi-scale design of this experiment within a MFAS CEE for the highest-priority species for the second time. Data from this tag were more complete although aberrant heading data from

sensor issues will preclude analysis of possible orienting responses as observed in other CEEs.

- We maintained target RLs for beaked whales at 140 dB RMS based on assessment of results and indications of quite strong responses to simulated MFAS from previous years at these levels. We achieved these target levels for the first time with real vessels at realistic operational ranges (10 to 15 nautical miles [nm]), as intended, on two occasions in three focal beaked whales. Each whale showed clear changes in movement and diving patterns, similar to those observed with simulated MFAS sources at closer range (2 to 3 nm). While additional samples are needed at these target RLs, these are invaluable data points with important insight in some of the potential range-dependent behavioral responses being evaluated.
- We maintained satellite tag deployment settings as refined in 2019 with very positive results. Notably, some of the more recently obtained tags achieved greater duration deployments for returning ARGOS position data. While the programming regime called for two weeks of focused, high-resolution, continuous time series dive data following which no dive data were reported, and this was highly effective for nearly all whales, the longer-duration deployments with just positions are notable and will be evaluated.
- Continued efforts to apply and improve methods of receiving and signals from satellite tags using ARGOS goniometer remained essential in tracking and relocating tagged individuals many times to obtain photos, biopsy samples, and locate other individuals for tagging attempts. These are essential in evaluating MFAS exposure on social interactions and group composition, as is increasingly possible.
- Many papers were published, submitted for review, or are in progress. These have focused on aspects of baseline behavior and methodological advances, including tag settings, RL modeling, and new behavioral response methods, which have both major implications and improvements in our underlying data and analyses but also are directly contributing to other Navy-funded efforts.

4.2 Recommendations for 2021

- With four successful field seasons of tagging and CEEs in the exceptionally productive study site off Cape Hatteras in which tag types, settings, and experimental approaches have been adapted and improved, we recommend few changes for the 2021 campaign. We have an outstanding, highly experienced, productive team that has proven the ability to adapt according to conditions and deliver results. We suggest few changes in methodological or field approaches. While we hope conditions with the pandemic improve, we are prepared to function under the same requirements and constraints as was done last field season.
- We recommend retaining the approach taken in 2020 with a single, extended possible field effort over the entire summer period, as opposed to a spring and later summer/fall effort, focusing effort before and during available Navy vessel coordination periods, and timed relative to optimal weather windows.
- The highest field priority is to obtain additional operational Navy vessel CEEs for target RLs similar to those evoking strong responses in simulated MFAS CEEs.

- Beaked whales should be maintained as a high priority species for tagging and CEEs, as conditions allow. Where possible, as recommended in 2019, additional deployments of tags of both types on multiple individuals within the same species group should be tagged. Repeat sightings to confirm surface locations, obtain satellite tag data, and obtain photo ID should be sustained. Photos obtained should continue to be coordinated with other Navy-funded monitoring efforts (e.g., Waples and Read 2021).
- Navy ship coordination was extremely well done in 2020, despite the mentioned challenges. We recommend similar close, regular communication and configuration between the field team and Navy personnel communicating with vessels.
- Given the highly productive and efficient experience with the *R/V Shearwater* and unique (to this project) ability to track animals overnight, we will strive to utilize this platform during CEE periods. The vessel is not entirely dedicated to the project and may be unavailable during some periods. During these periods, or for limited efforts in relocating tagged whales where RHIB operations are limited, we recommend retaining the ability to work from day-chartered fishing vessels.
- The combination of satellite tags (with series settings for beaked whales) and DTAG deployments should be maintained, with additional effort to simultaneously deploy DTAGs within groups with satellite tagged individuals. Even further advance testing of DTAGs for all sensors should be conducted ahead of deployments given multiple sensor failures in 2020 deployments.
- Based on the observed responses in some focal beaked whales in 2019 to simulated MFAS and similar measurements in 2020 at comparable RLs from operational MFAS, no further escalation in target RLs is recommended.

5. References

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