Atlantic Behavioral Response Study (Atlantic-BRS): 2022 Annual Progress Report

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Cuvier's beaked whale (*Ziphius cavirostris*) with the Duke University Marine Laboratory *R/V Shearwater* off Cape Hatteras. Photographed by Will Cioffi, taken under National Marine Fisheries Service Scientific Research Permit No. 22156 issued to Andy Read/Duke University.

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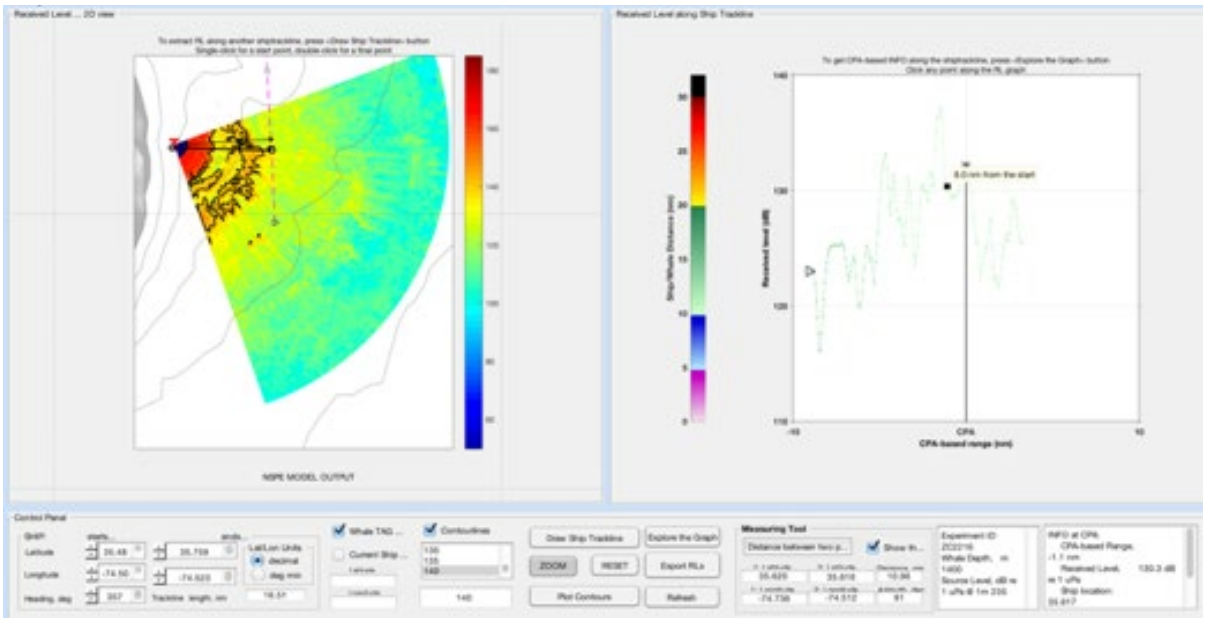

Tables

Acronyms and Abbreviations

°N	degrees North
°W	degrees West
BRS	Behavioral Response Study
CEE	controlled exposure experiment
dB (RMS) re 1 µPa	decibel(s) referenced to 1 micro Pascal
DTAG	digital acoustic recording tag
DUML	Duke University Marine Lab
EDT	Eastern Daylight Time
ESOMM	Effects of Sound in the Ocean on Marine Mammals
h	hour
ID	Identification Number
km	kilometer(s)
LIMPET	Low-impact Minimally Percutaneous Electronic Transmitter
m	meter(s)
Max.	Maximum
MFAS	mid-frequency active sonar
min	minute
n/a	not applicable
nm	nautical mile(s)
NPS	Naval Postgraduate School
ONR	Office of Naval Research
photo-ID	photo-identification
R/V	Research Vessel
RHIB	rigid-hulled inflatable boat
RL	received level
RMS	root mean square

SEA	Southall Environmental Associates
SLTDR (or sat tag)	satellite-linked, time-depth recording tag
SOCAL	Southern California
U.S.	United States
USFFC	U.S. Fleet Forces Command
USS	United States Ship
UTC	Coordinated Universal Time
VHF	very high frequency
Zc	*Ziphius cavirostris*

Executive Summary

The Atlantic Behavioral Response Study (BRS) was conceived, designed, adapted, and applied through a collaboration building on historical and ongoing United States (U.S.) Navy-funded studies under their Marine Species Monitoring Program. It uses a combination of novel, multi-scale tagging approaches for baseline monitoring and BRSs at multiple temporal and spatial scales for key marine mammal species: primarily, Cuvier's beaked whales (*Ziphius cavirostris*) and, secondarily, short-finned pilot whales (*Globicephala macrorhynchus*) off the coast of Cape Hatteras, North Carolina. The project advances approaches developed from previous BRS field and analytical work supported by the U.S. Navy's Living Marine Resources program and Office of Naval Research (ONR). 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.

An experienced, multi-institutional team collaboratively designed and strategically adapted the Atlantic-BRS. CEE methods involve mid-frequency active sonar (MFAS)—successfully coordinated with operational SQS-53C from U.S. Navy vessels—using strategically deployed, complementary tag sensors on many individuals simultaneously. The project is ongoing but nearing completion of the current approach and methodology focused on mid-frequency active sonar (MFAS). It continues to add to the largest and most comprehensive data set available for sonar exposure and response for Cuvier's beaked whales - one of the highest-priority marine mammal species for the U.S. Navy.

By design, the 2022 field season included both strategically focused field effort as well as intensive analysis. A single, extended, field period spanned mid-summer into fall, deploying tags during suitable weather windows ahead of anticipated U.S. Navy vessel availability. Building on earlier field seasons of this project (see Southall et al. 2018, 2019, 2020, 2021, 2022), Atlantic-BRS field operations included two control CEEs focused on single tagged individuals and achieved the primary objective of conducting one CEE with operational MFAS in coordination with the United States Ship (*USS) Farragut* (DDG 99) and a large number of tagged beaked whales (n=8). This CEE strategically included the multi-scale, experimental design with: (1) a focal individual tagged with a satellite-transmitting tag; (2) a focal individual with a short-term, high-resolution archival tag; and (3) multiple non-focal individuals at variable ranges from an operational MFAS source with long-term, pre-exposure data.

Extensive analytical effort, coordinated with other U.S. Navy-funded analysis development, substantially advanced the existing large data sets for both simulated and operational MFAS CEEs, each of which will be the subject of separate papers. Behavioral changes, including apparent observed avoidance responses, and changes in diving behavior were again documented during the 2022 operational MFAS source CEEs. Many peer-reviewed manuscripts regarding this project are published or well along in the process, and the project was heavily represented at the Effects of Sound in the Ocean on Marine Mammals (ESOMM) 2022 meeting that was chaired and hosted by the Atlantic-BRS team during the current reporting period.

1. Overview

1.1 Overall Project Design and Objectives

The Atlantic-BRS has been conducted over sequential successful field efforts off the coast of Cape Hatteras, North Carolina through a research collaboration of scientists from Duke University, Southall Environmental Associates (SEA), Bridger Consulting, Calvin University, and the University of St. Andrews. The overall experimental design was adapted from methods previously developed in the Southern California Behavioral Response Study (SOCAL-BRS), funded primarily by the U.S. Navy's Living Marine Resources program and Office of Naval Research. Novel integrations and strategic deployments of different tag sensors and CEEs on variable time and space scales have been applied to the primary focal species, Cuvier's beaked whales (*Ziphius cavirostris*), and secondary focal species, short-finned pilot whales (*Globicephala macrorhynchus*). This collaboration has substantial success in tagging beaked whales and conducting CEEs due to reliable coordination with operational MFAS systems from U.S. Navy surface vessels (e.g., SQS-53C-equipped surface vessels).

The overall objective of the study is to directly measure exposure and behavioral responses to U.S. Navy MFAS and quantify behavioral response probability in relation to key exposure variables (e.g., received sound level, proximity, and animal behavioral state). These measurements have and will directly contribute to more informed assessments of the probability and magnitude of potential behavioral responses of these species. These data support the U.S. Navy in meeting their mandated requirements to assess the impacts of training and testing activities on protected species, specifically regarding baseline behavior and exposure-response, and by providing sufficiently large sample sizes to begin addressing exposure consequences, thus directly addressing focal areas for the U.S. Navy's Marine Species Monitoring Program.

Previous studies have used short-term, high-resolution acoustic tag sensors to measure fine-scale behavior in response to experimentally controlled noise exposure. Other studies have used coarser-scale, longer-term measurements of movement and diving behavior associated with incidental exposures during sonar training operations. This study brings both approaches together, applying experience with different tag types and experimental approaches. Notably, this study expanded the temporal and spatial scales of previous BRSs by combining (1) short-term, high-resolution acoustic archival tags (or digital acoustic recording tags [DTAGs]) providing short-term (hours) but very high-resolution movement and calibrated acoustic data, with (2) satellite-linked, time-depth recording tags (SLTDRs or "sat tags"]) providing much longer-term (weeks to months) data on movement and increasingly higher resolution dive data, which are simultaneously deployed on multiple individuals of focal species in the same CEEs. Strategically specified categories of potential behavioral responses are evaluated using a variety of adaptive and innovative methods, namely (1) potential avoidance of sound sources that influence habitat usage, (2) changes in foraging behavior, and (3) changes in social behavior.

The 2022 field season represented an important milestone in the overall research program. It was determined prior to this season that a sufficient sample size for simulated MFAS CEEs had been obtained, and one additional CEE with operational vessel MFAS, provided it was conducted with multiple individuals, would adequately round out the data set desired for a

comparison of results. Therefore, the field objective for the 2022 field season was to conduct a single, high sample size CEE with an operational vessel, allowing as many additional control sequences as possible. A relatively intensive analytical emphasis was also planned, given the progression of parallel U.S. Navy-funded analytical development and implementation. In fall 2022, the lead principal investigator of the Atlantic-BRS project also visited USFFC and Naval Facilities Engineering Systems Command staff in Norfolk, Virginia, and provided a synthesis update briefing regarding the project's status and progress. The U.S. Navy team provided requested positional and operational data in unclassified communications. All teams provided updates and information through various public channels as appropriate[1], and results are increasingly being presented in peer-reviewed papers and scientific meetings (see **Section 3**).

This progress report provides a relatively brief synthesis of experimental methods, then summarizes the results of the operational vessel MFAS CEE conducted within the 2022 field season. It also provides a synthesis of the peer-reviewed papers that have been or are in the process of being published.

1.2 Experimental Design

The overall experimental design did not fundamentally change in the 2022 field season; readers are referred to earlier project reports and published papers from other U.S. Navy-funded work (Southall et al. 2012, 2016, 2019; Schick et al. 2019). Atlantic-BRS publications referenced later provide additional details regarding the design and implementation of these methods. Broadly speaking, the approach involves multiple tracking and monitoring methodologies and platforms, incorporating lessons learned from many research and monitoring programs funded by the U.S. 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.

Through close coordination with project collaborators at the U.S. Fleet Forces Command (USFFC), the methods had been successfully applied during Atlantic-BRS and by seven 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 60-minute minimum for animals with DTAGs and a 24-hour minimum for animals with sat tags. Most baseline SLTDR data periods were much longer (often weeks) in practice for sat tags. Pre-exposure baseline behavioral data collection primarily involved data from tag sensors, supplemented by focal follows of tagged animals when possible.

Sonar transmissions during CEEs occurred in the same manner as in SOCAL-BRS (see Southall et al. 2012) and earlier efforts for this project (see Schick et al. 2019). Vessels were positioned at ranges from subjects that met experimental objectives for received levels (RLs). Full-scale sources included transmission of full power (235 decibels [root mean square] referenced to 1 micro Pascal [dB [RMS] re 1 µPa]; hereafter dB unless otherwise specified) signals of a constant nominal 53-C waveform type (single ping sequence using three sequential

[1] See links provided at: https://sites.nicholas.duke.edu/read/2022/08/25/atlantic-brs-2022-cee-with-the-uss-farragut/; https://www.dvidshub.net/news/427538/us-navy-destroyer-farragut-assists-marine-mammal-behavior-study

continuous phase/continuous waveforms of 0.5-second duration each, with 0.1-second separation for total ping series 1.6-second duration). Signals were transmitted with a 25-second repetition rate, using surface duct sector search mode, and 3 degrees downward vertical steering. Transmissions occurred for a total duration of 60 minutes, with the transmitting ship transiting in a direct course at a net (over-ground) speed of 8 knots.

Based on focal animal locations, the starting position and course for the transmitting vessel was determined using custom in situ propagation modeling tools developed and supported by the Naval Postgraduate School (NPS). The experimental design allows for positioning of MFAS sources, resulting in target RLs 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 RLs that were not explicitly controlled but estimated (with error) from positions derived from either sat tags or field observations.

The course of the vessel was designed to result in an escalation in RL at the presumed location of focal individuals based on their movement. 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 RL. Target RLs for focal animals ranged from 120 to 160 dB, depending upon species and the aggregate location of focal individuals (120 to 140 dB for beaked whales, 135 to 160 dB for pilot whales).

Satellite-transmitting tag setting approaches successfully developed in earlier efforts were maintained to provide approximately 2 weeks of continuous, relatively high-duration (5-minute time series) dive data, with ARGOS positional data being collected for several weeks longer. This was done to increase the data resolution during a focal period when U.S. Navy ships were expected to be available. The objective was, therefore, to conduct one CEE within a 2-week window following sat tag deployment windows, with a priority on conducting CEEs with operational MFAS systems.

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. Analyses of potential response type, probability, and severity apply methods developed in other BRSs and Atlantic-BRS efforts to date, including close coordination with other U.S. Navy-funded analytical development teams (e.g., the recently completed ONR-supported “Double Mocha” project). Specific questions and methods are derived for differences in available data (tag type) and species in question, specifically considering 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 many tag deployments made 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 the previous reports, several tables and figures describing detailed aspects of data processing and analyses were provided to demonstrate these approaches. These evolved and became more

complex within the first several years; however, by 2019, they were sufficiently mature that they were maintained and applied to subsequent data sets (see: Southall et al., 2020, Section 1.3).

1.4 Field Logistics and Configuration

Atlantic-BRS field efforts for 2022 mirrored successful earlier approaches, with fieldwork occurring during a single window spanning summer through early autumn. Based on a combination of weather conditions and U.S. Navy vessel availability, a small boat-based team (n=4) aboard the Research Vessel (*R/V*) *Barber*, an 8-meter, aluminum-hulled vessel, conducted advanced deployment of satellite-transmitting tags. 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 six individuals worked from the fast catamaran *R/V Shearwater* along with, in reasonable conditions, the R/V *Barber* (with crew of four, as noted above). The *R/V Shearwater* served as an excellent, elevated, tag tracking and visual observation platform before, during, and after CEEs. These vessels were generally involved in tag deployment and CEE efforts, as well as in re-sighting and biopsy sampling of focal individuals thereafter, augmented by contracted private fishing vessels as needed.

Multiple version 3 DTAGs from the University of Michigan were leased for available field periods and deployed in strategic windows. Up to 30 Low-impact Minimally Percutaneous Electronic Transmitter (LIMPET) satellite-linked tags were also available. Priority was placed on the use of SPLASH10-A satellite-transmitting tags that provide position and depth data, given the interest in feeding and diving behavior. Almost all tags available were of this type. A small number of SPLASH-10F tags that incorporate Fastloc® Global Positioning Systems were also available, and one was deployed in 2022. Exclusive tagging priority was placed on Cuvier's beaked whales during the 2022 field season. Efforts were again made to deploy multiple tags in social groups of either species to evaluate potential changes in social associations as a response metric during CEEs.

Previous successful approaches were again applied in planning and coordination between Atlantic-BRS team and U.S. Navy representatives facilitating Navy vessel participation in CEEs. This began months in advance of field operations and included advance briefing of potential participant vessels. During CEE periods, dedicated U.S. Navy personnel coordinated with vessels in the field remotely from onshore sites through secure communications. During the 2022 field season, given the objective of conducting a single, high sample size CEE with an operational U.S. Navy vessel, the team deliberately worked to schedule multiple potential vessels during different periods throughout the field season in order to maximize the probability of a successful CEE based on tags deployed, weather, and realized vessel availability. The research team coordinated before, during, and after the field effort through designated representatives, including regular updates and quick-look summaries following field operations.

2. Field Effort

2.1 Summary of 2022 Field Effort: Accomplishments and Assessment

Field Dates:

- **1 June**: First possible field effort for advance tag deployment team (*R/V Barber*); some field personnel deployed and ready to go at Manteo field site.
- **21–30 June**: Field effort on selected weather-permitting days from the *R/V Barber* resulted in **three beaked whale sat tag deployments** ahead of U.S. Navy ship availability, slated for early July.
- **11–15 July**: Scheduled trip for *R/V Shearwater*, deployed from the Duke University Marine Lab (DUML) to Cape Hatteras field area to support tagging and tracking ahead of CEE operations, was pushed back due to the relatively small number of tags in the primary operational area (one tag was not working; one animal had moved very far north) and poor weather conditions. The study team belayed its request for the U.S. Navy vessel slated for this period.
- **15–25 July**: *R/V Barber* team mobilized and ready, but marginal conditions resulted in few full on-water days and no successful tag deployments ahead of scheduled U.S. Navy vessel availability.
- **25–29 July:** Second possible *R/V Shearwater* window for U.S. Navy vessel CEE operations was pushed back again due to the small number of tags in the primary operational area and poor weather conditions. The study team again belayed its request for the U.S. Navy vessel slated for this period.
- **2–5 August**: *R/V Shearwater* deployed from the DUML to Cape Hatteras field area to support tagging and tracking ahead of CEE operations. **Two successful control CEEs (CEE #2022_01, 2022_02) were conducted** with previously sat tagged animals, which were re-located and successfully followed. Concurrently, several outstanding weather days allowed a satellite-tagging field effort from the *R/V Barber*, resulting in **five additional beaked whale tag deployments.**.
- **7 August: CEE #2022_03 successfully coordinated in the field with the *USS Farragut*,** with seven beaked whales sat tagged previously as well as an overnight DTAG deployed earlier this day. The *R/V Barber* was in the field tracking and following one focal whale. A charter fishing vessel with Atlantic-BRS researchers was also fielded and conducted focal animal tracking and goniometer collection of tag data.
- **8–10 August:** Conducted follow-up re-sightings, photo-ID, in situ data acquisition, and biopsy effort from focal whales from multiple platforms.
- **19 October**: Last data message received from 2022 Cuvier's beaked whale sat tags.

Accomplishments:

- Successful deployment of eight sat tags on Cuvier's beaked whales.
- Successful deployment, data collection, and recovery of a long-sought overnight DTAG on a Cuvier's beaked whale within a social group including another sat tagged beaked whale.
- Two successful control CEEs using simulated MFAS CEE design for avoidance analysis integration.
- Successful CEE with an operational U.S. Navy vessel, using full-scale SQS-53C MFAS CEEs, conducted with eight Cuvier's beaked whales (seven satellite-transmitting tags [all with ARGOS positions, one with time series dive data, one in focal follow] and one with DTAG in focal follow). All eight whales were within target RL range for this species (120 to 140 dB).
- Continued success with research platform *R/V Shearwater* augmented by chartered fishing vessels. Highly successful in locating and tracking animals, including successful overnight tracking.
- 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, social interactions, and biopsy samples.

Assessment of Field Approach:

- Field teams were adaptive, resilient, and dedicated in working through some of the worst conditions experienced in a decade of field effort during June and July. Outstanding conditions during a very small window in early August enabled most of the success in tagging and completing CEEs.
- Continued success in locating and tagging Cuvier's beaked whales, such that no second-priority pilot whales were tagged in 2022.
- Sustained success using advance planning and support as well as close coordination among members of the research team and the USFFC team. This included substantial challenges for the U.S. Navy team given the different approach in 2022 of scheduling multiple vessels with the intention of conducting only one CEE, based on a combination of available tagged animals and workable weather. While expected, the Atlantic-BRS team belaying requests for coordination with scheduled U.S. Navy ships was a new development for study team coordination. This was extremely well managed and communicated by the USFFC team to U.S. Navy fleet operators, as was the CEE that was ultimately coordinated in an adaptive manner. When this CEE was conducted, land-land and at-sea coordination between research and operational vessels was very successful, including specific fine-tuning on timing requested by the BRS field team and accomplished by the *USS Farragut*.
- Following a series of challenges and failures in VHF radio transmissions and sensor systems with prior DTAGs, the strategically targeted deployment ahead of the MFAS CEE (#2022_03) was successful in all aspects. Data were collected for the entire 24-hour period,

including acoustic and overnight dive data. Detachment and transmissions occurred as programmed allowing relatively easy recovery.

- Sustained high-quality satellite-transmitting tag dive data due to earlier progress in tag programming strategies to reduce/eliminate gaps in sat tag data and to improve temporal resolution on diving and behavioral data. The team successfully collected continuous dive data for 2-week periods, strategically covering CEE periods, as designed. Long-duration (up to 76 days) functioning of tags in reporting ARGOS positions was again experienced, potentially due to improved batteries in SPLASH tags.
- Due to challenging sighting and tagging conditions, only a single Fastloc sat tag (SPLASH-10F) was deployed in a test configuration, which was designed to assess the feasibility of collecting simultaneous FastGPS and time-series depth messages. This tag performed well below expectation, probably due to a low (non-optimal) deployment location on the animal. This instrument only uplinked five unique FastGPS messages before ceasing all uplinks after 17 days. For these reasons, future deployments are recommended (see **Section 4.2**) to increase the sample size of Fastloc tags and develop a better understanding of their average performance and limitations.

2.2 Tag Deployments

A researcher from Bridger Consulting, in coordination with the Atlantic-BRS team aboard Duke University vessels, conducted satellite-transmitting tag deployments. **Table 1** provides a summary of sat tag deployments for 2022. Overall, eight satellite-transmitting tags were deployed—all on Cuvier's beaked whales. **Figure 1** shows Douglas-filtered ARGOS positions for all Cuvier's beaked whales tagged in 2022. A simple plot showing all Douglas-filtered beaked whale locations in 5 km^2 hexagonal grids across the entire study areas for all whales is also provided (**Figure 2**). Individual (by-animal) plots of Douglas-filtered ARGOS positions are shown for the entire satellite-transmitting tag deployment periods for each tagged beaked whale (**Figures 3** through **10**). For whales that were tagged during CEEs, the start and end location of the respective CEEs that occurred are indicated on the individual plots.

One DTAG was successfully deployed on a Cuvier's beaked whale during the 2022 field effort (**Table 2**). It collected data before, during, and after the successful single MFAS CEE conducted with an operational U.S. Navy SQS-53C sonar on the ***USS Farragut*** (see **Section 2.3**).

Table 1. Satellite tag deployments for Cuvier's beaked whales during Atlantic-BRS field efforts in 2022.

Species[a]/ Tag ID	Deployment Date	Deployment Latitude (°N)	Deployment Longitude (°W)	Dive Data Streams	Tag Duration (days)
ZcTag128_DUML	06/21/22	35.6560	-74.7486	5-min time series	8
ZcTag129_DUML	06/21/22	35.6462	-74.7548	5-min time series	76
ZcTag130_DUML	06/30/22	35.6461	-74.7237	5-min time series	76
ZcTag131_DUML	08/03/22	35.7150	-74.6052	5-min time series	11
ZcTag132_DUML	08/03/22	35.6946	-74.5853	5-min time series	74
ZcTag133_DUML	08/05/22	35.6300	-74.7061	5-min time series	68
ZcTag134_DUML	08/05/22	35.6282	-74.7024	5-min time series	41
ZcTag135_DUML	08/05/22	35.6197	-74.6305	5-min time series	27

Key: ID = Identification Number; °N=degrees North; °W=degrees West; min=minute(s)
[a] Zc = *Ziphius cavirostris*

Table 2. DTAG deployments for Cuvier's beaked whales during Atlantic-BRS field efforts in 2022.

Tag ID[a]	Deployment Date	Deployment Latitude (°N)	Deployment Longitude (°W)	Baseline or CEE Number	Tag Duration	Recovered?
Zc22_219a	8/7/22	35.6178	-74.7244	CEE #2022_03	23.7 h	Yes – Released on time, as scheduled; all data successfully recorded and obtained

Key: h = hour(s); ID = Identification Number; °N=degrees North; °W=degrees West
[a] Zc = *Ziphius cavirostris*

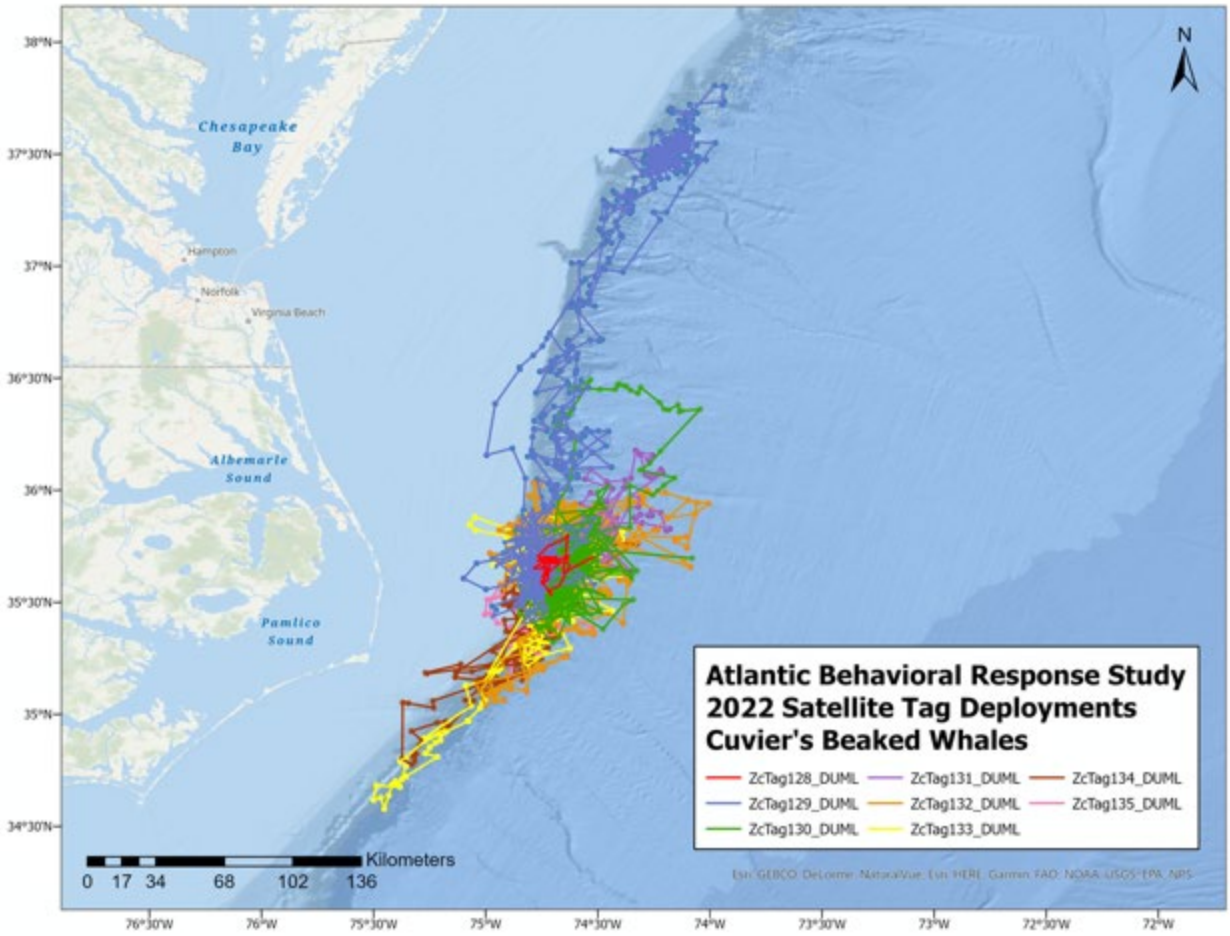

Figure 1. Douglas-filtered ARGOS position tracks for all Cuvier's beaked whales (n=8) tagged during Atlantic-BRS field efforts in 2022.

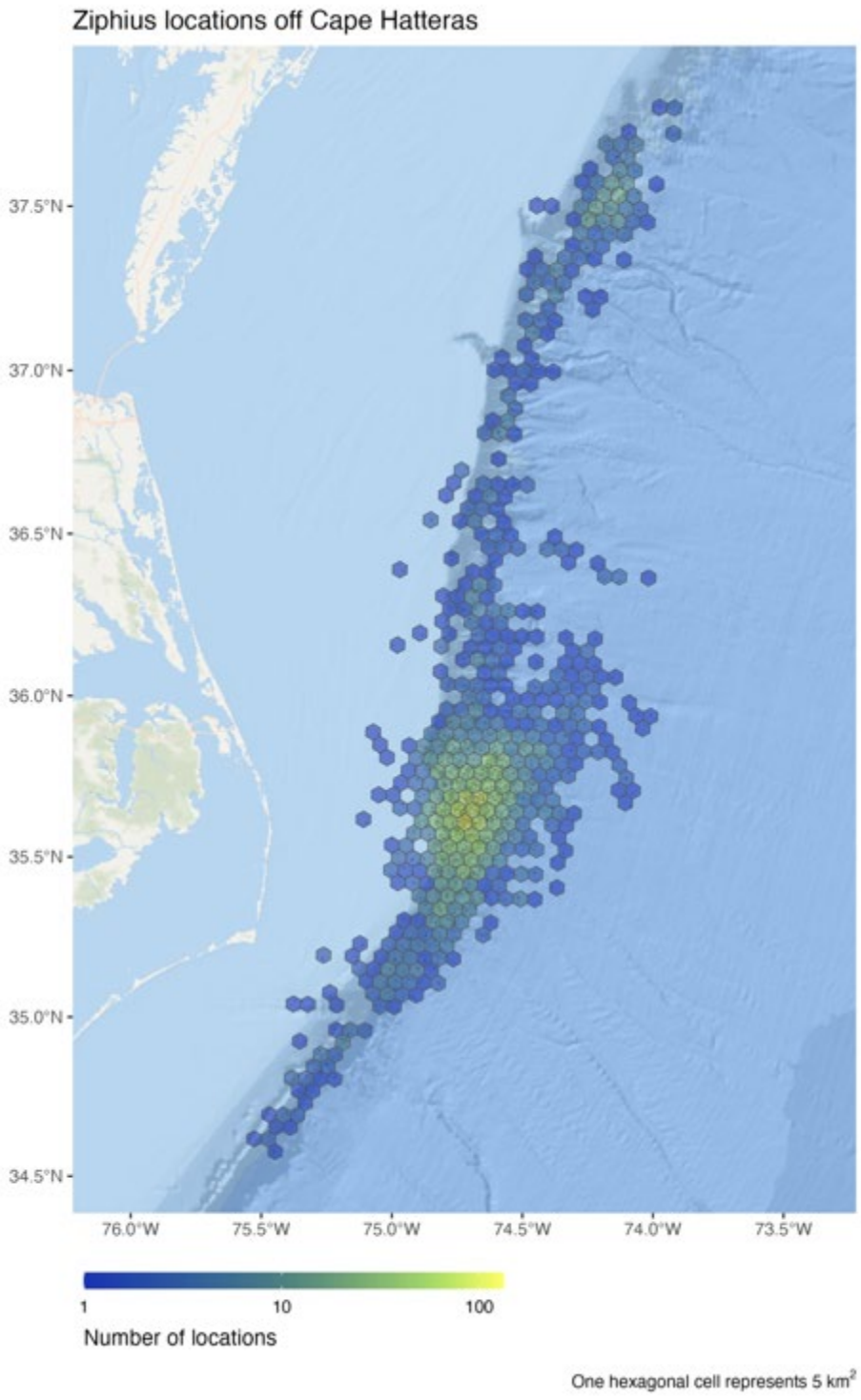

Figure 2. Douglas-filtered ARGOS locations for all 2022 tagged Cuvier's beaked whales aggregated in 5-square-kilometer km² hexagonal grid cells.

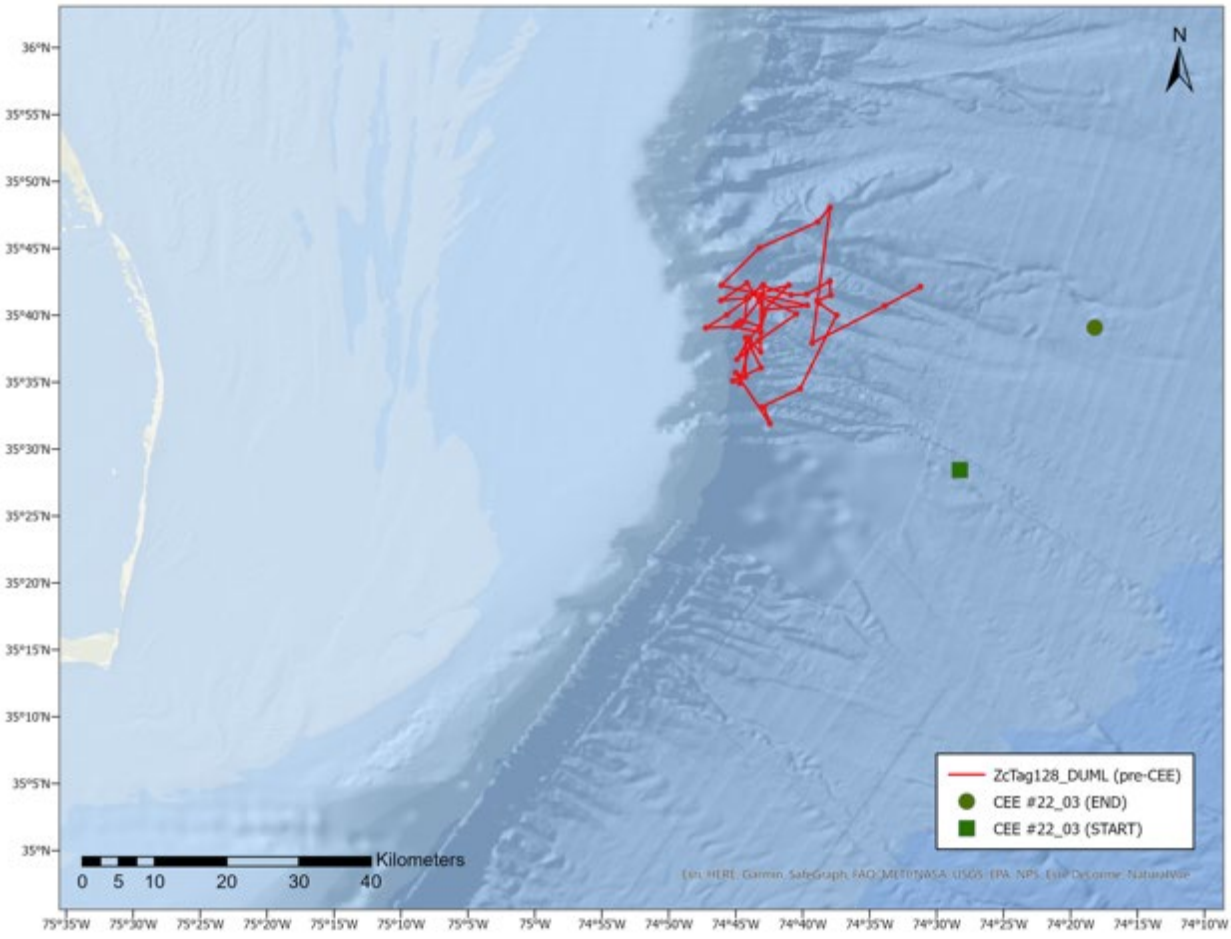

Figure 3. Douglas-filtered ARGOS positions for entire track of ZcTag128_DUML. This was a relatively short tag deployment (8 days) which ended prior to the active sonar CEE #22_03; start and end positions of the *USS Farragut* during that CEE are shown for reference.

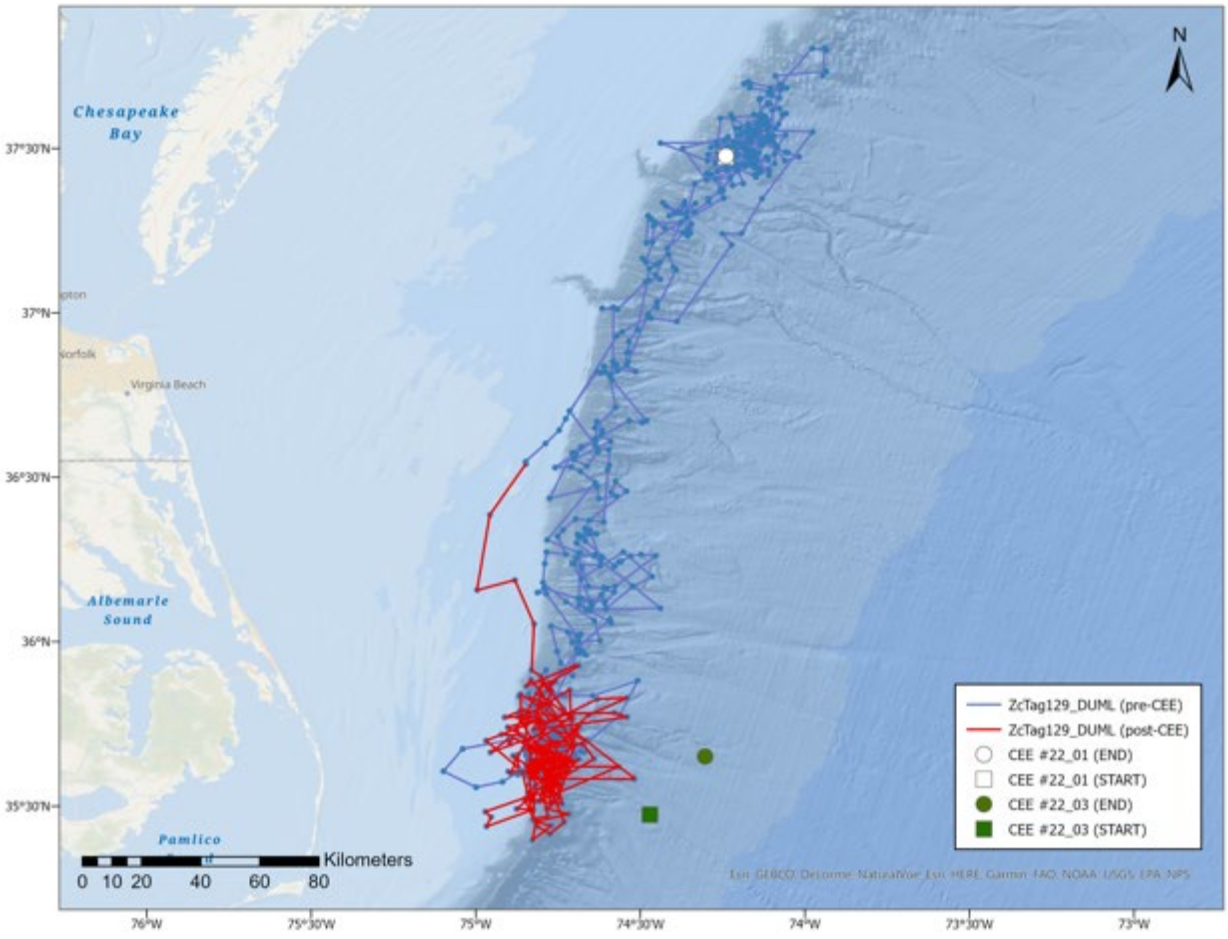

Figure 4. Douglas-filtered ARGOS positions for entire track of ZcTag129_DUML. Portions of the track prior to active sonar CEE #22_03 are in blue and portions after are in red. Start and end position of the *USS Farragut* during CEE #22_03 as well as a prior control CEE (#22_01) are shown (tag duration 76 days).

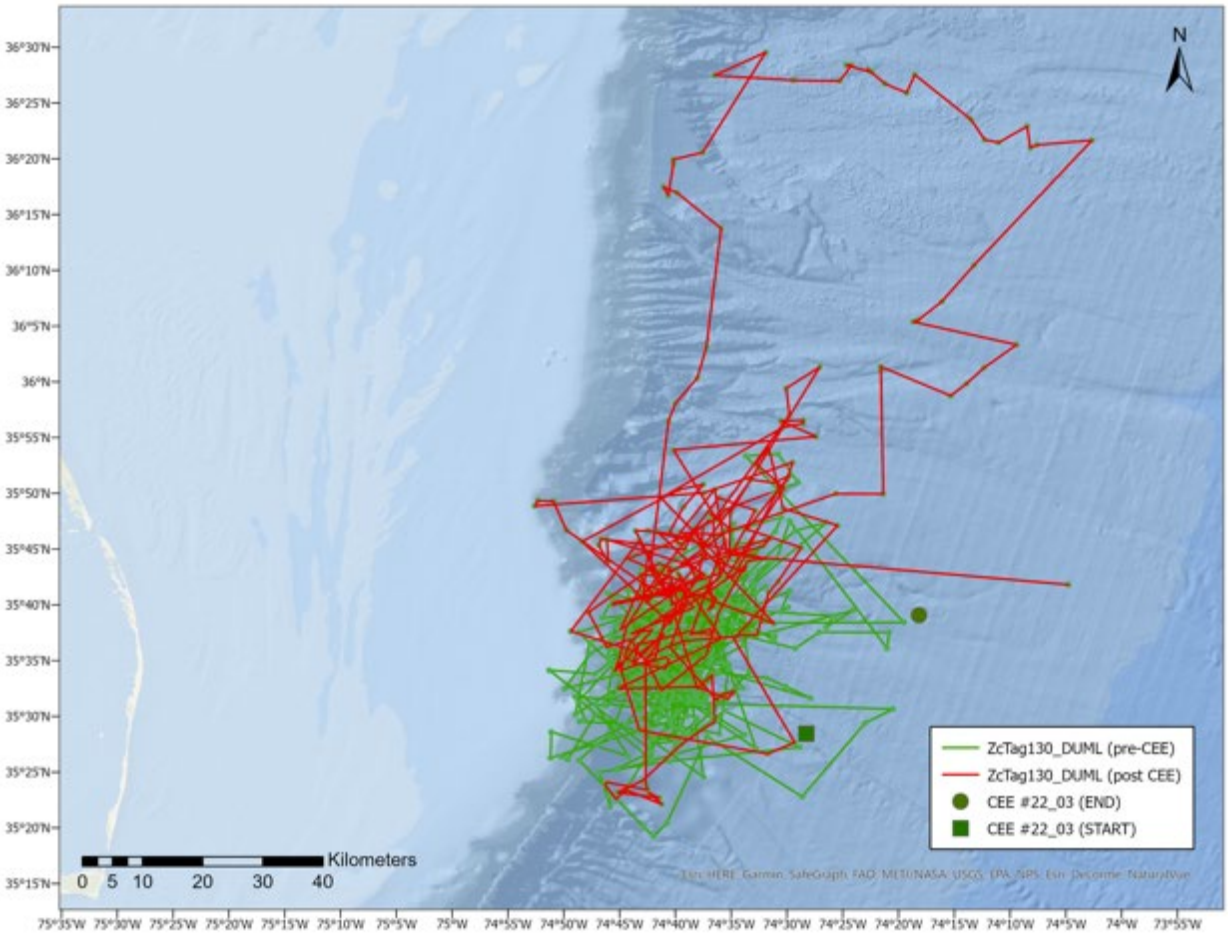

Figure 5. Douglas-filtered ARGOS positions for entire track of ZcTag130_DUML. Portions of the track prior to active sonar CEE #22_03 are in green and portions after are in red. Start and end position of the *USS Farragut* during CEE #22_03 are shown (tag duration 76 days).

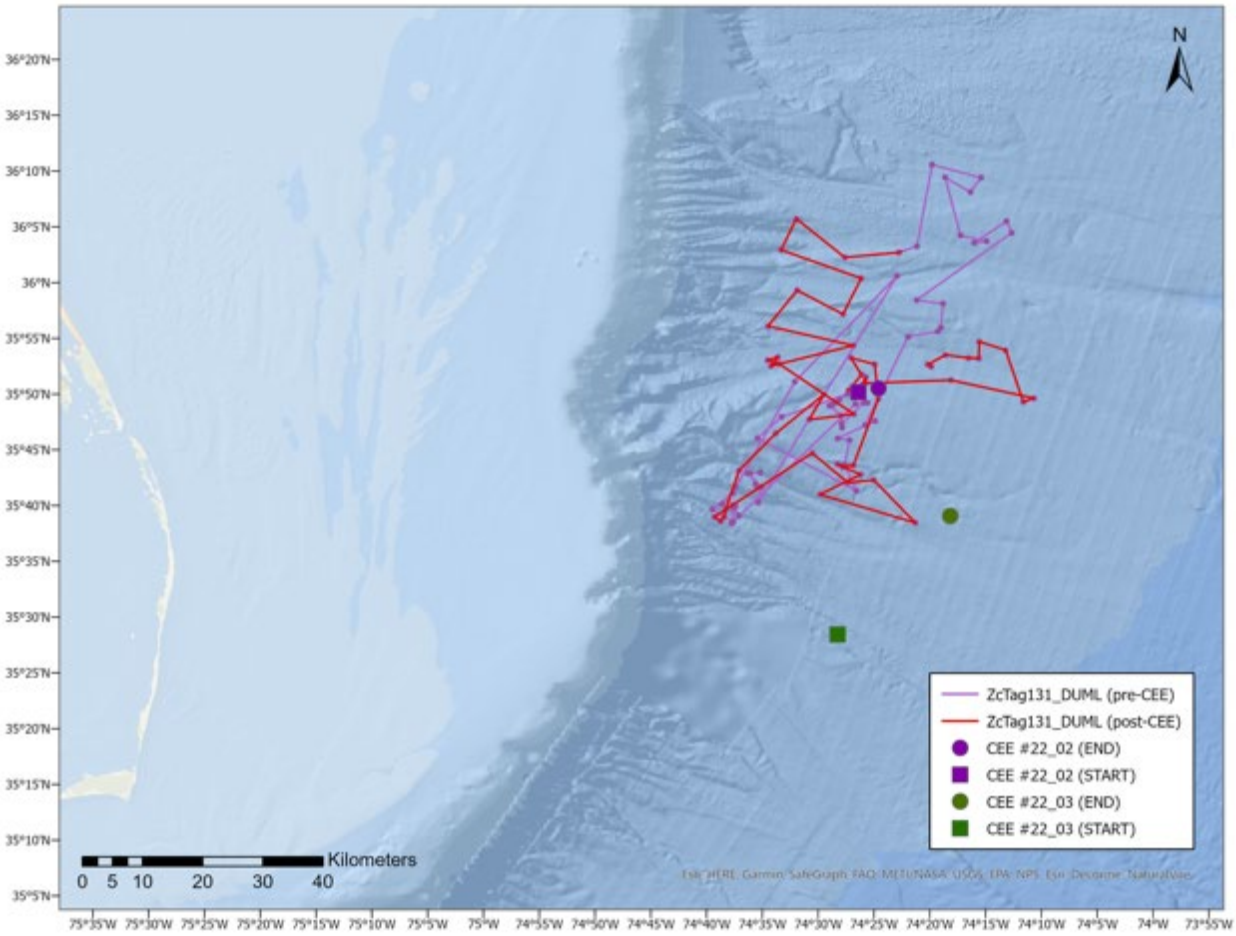

Figure 6. Douglas-filtered ARGOS positions for entire track of ZcTag131_DUML. Portions of the track prior to active sonar CEE #22_03 are in purple and portions after are in red. Start and end position of the *USS Farragut* during CEE #22_03 as well as a prior control CEE (#22_02) are shown (tag duration 11 days).

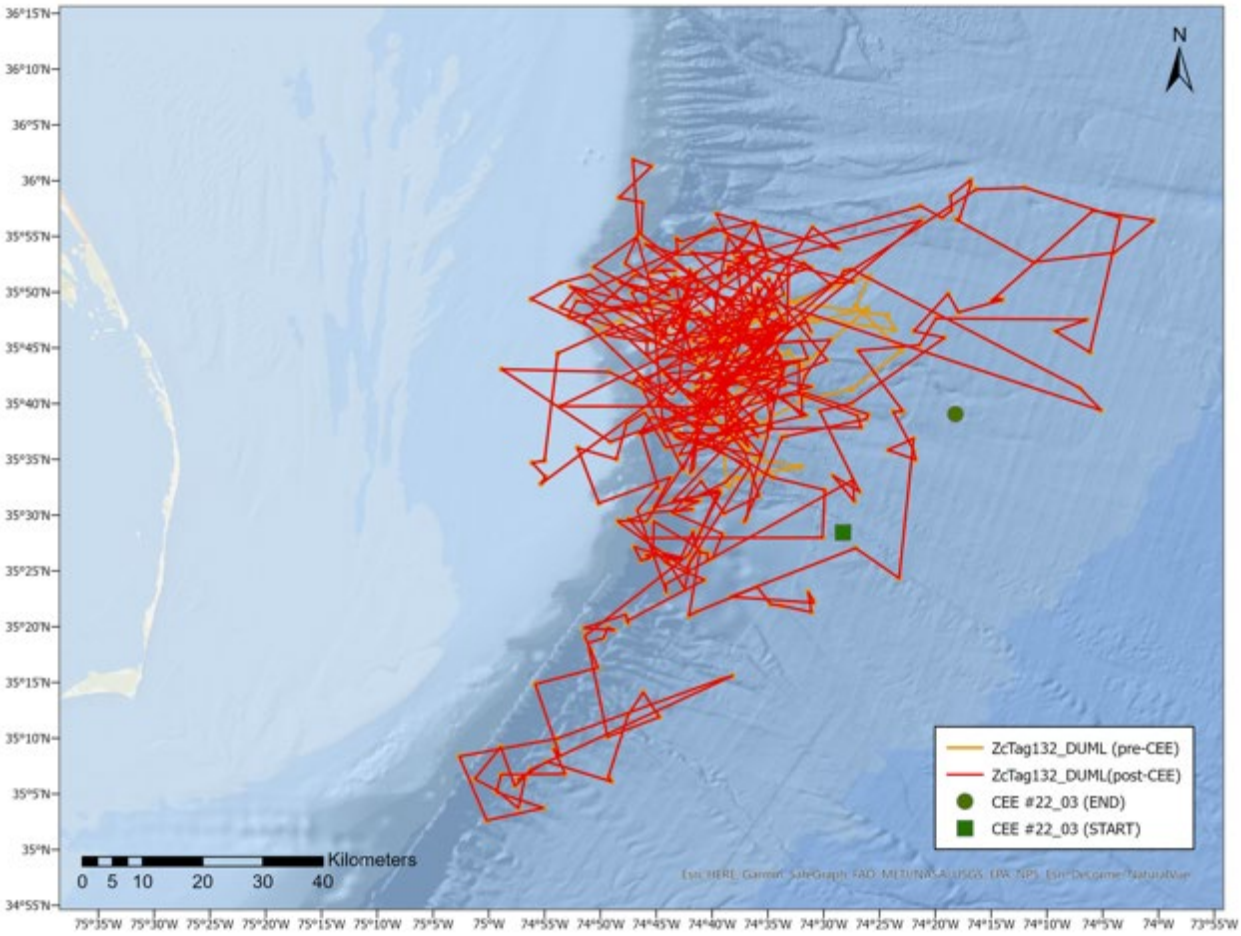

Figure 7. Douglas-filtered ARGOS positions for entire track of ZcTag132_DUML. Portions of the track prior to active sonar CEE #22_03 are in orange and portions after are in red. Start and end position of the *USS Farragut* during CEE #22_03 are shown (tag duration 74 days).

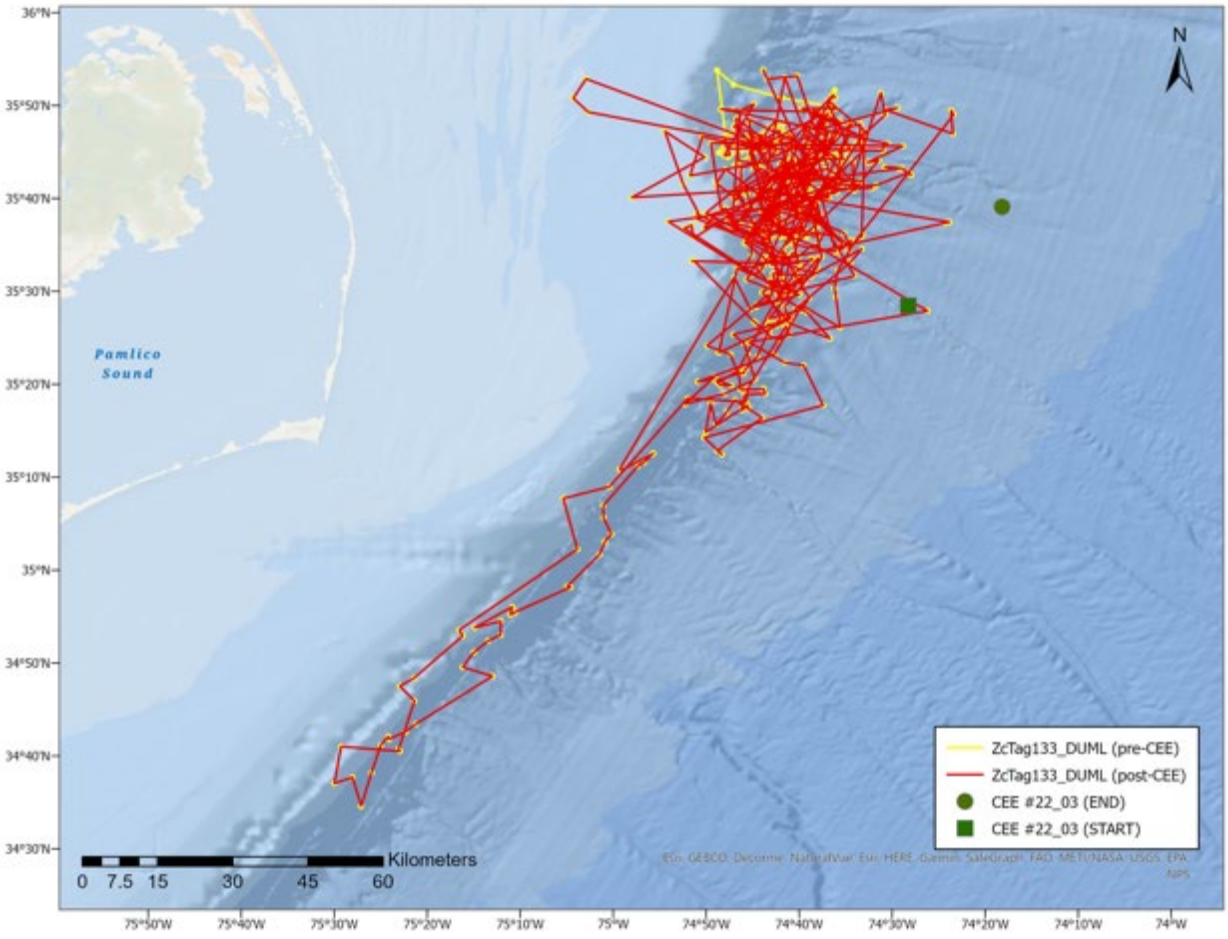

Figure 8. Douglas-filtered ARGOS positions for entire track of ZcTag133_DUML. Portions of the track prior to active sonar CEE #22_03 are in yellow and portions after are in red. Start and end position of the *USS Farragut* during CEE #22_03 shown (tag duration 68 days).

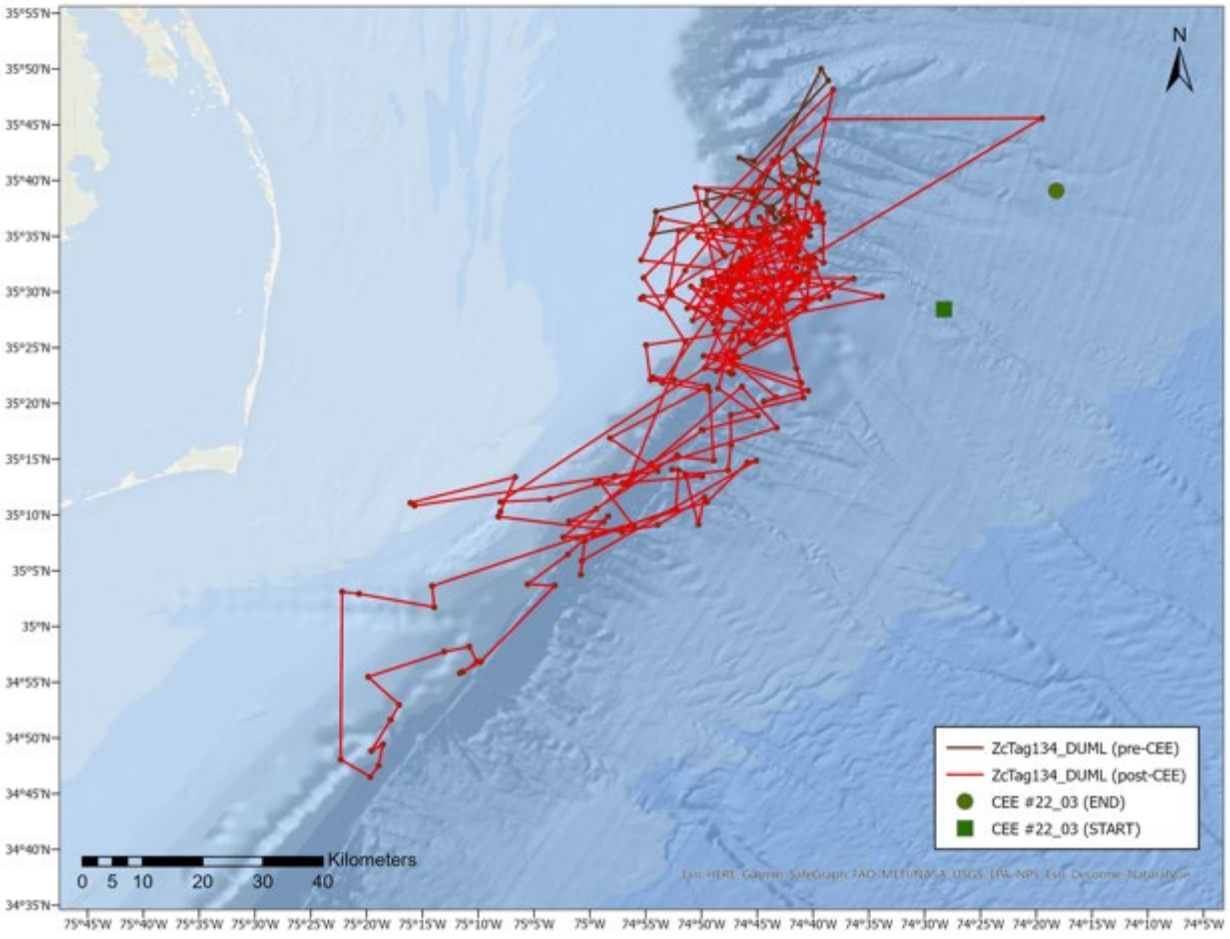

Figure 9. Douglas-filtered ARGOS positions for entire track of ZcTag134_DUML. Portions of the track prior to active sonar CEE #22_03 are in brown and portions after are in red. Start and end position of the *USS Farragut* during CEE #22_03 shown (tag duration 41 days).

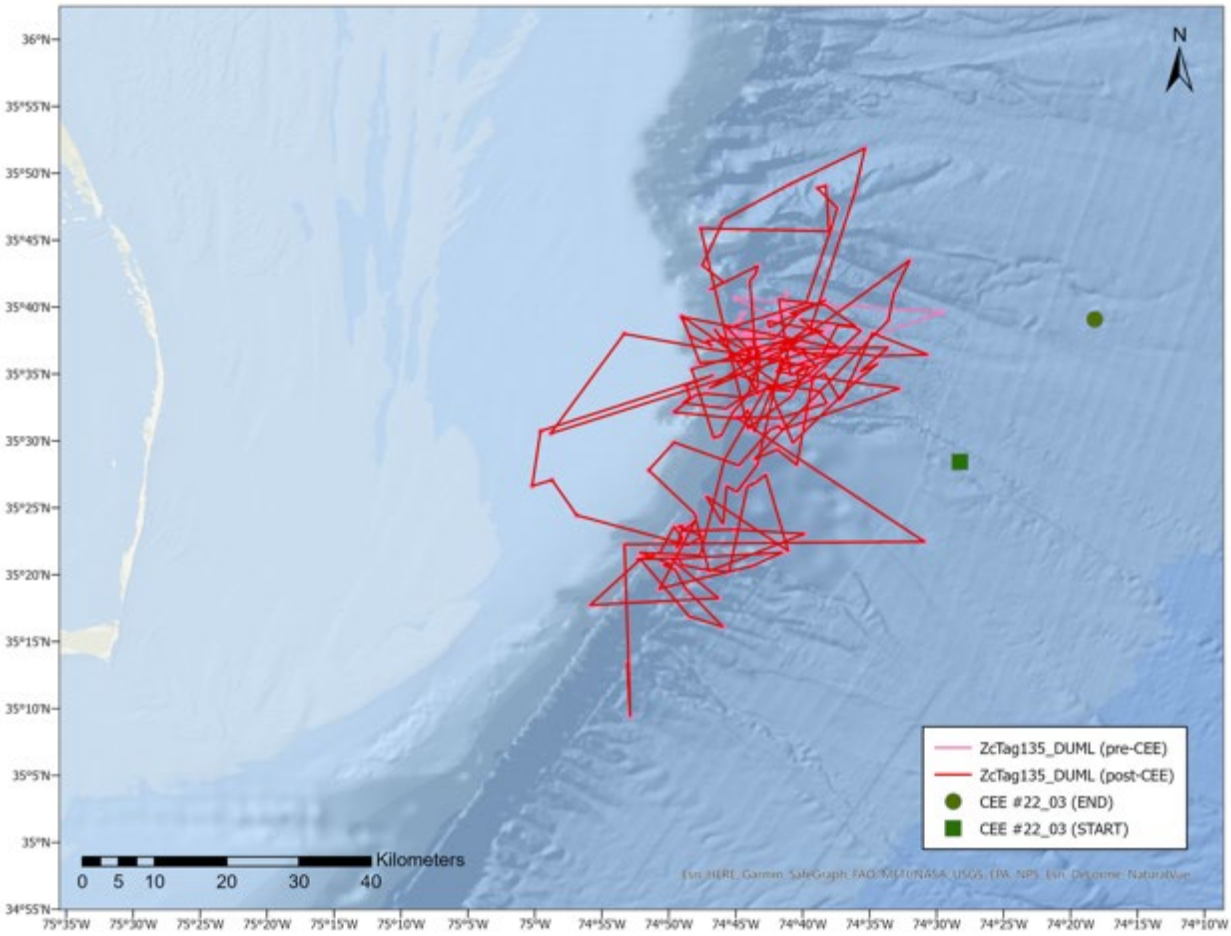

Figure 10. Douglas-filtered ARGOS positions for entire track of ZcTag135_DUML. Portions of the track prior to active sonar CEE #22_03 are in pink and portions after are in red. Start and end position of the *USS Farragut* during CEE #22_03 shown (tag duration 27 days). This individual was the focal whale with a satellite-transmitting tag (along with Zc22_219a tagged with a DTAG) for this CEE.

2.3 CEEs Conducted

Three CEE sequences were conducted during the Atlantic-BRS 2022 field effort. This included two control (no sonar) CEEs focused on single tagged individuals and one successful, complete, operational SQS-53C MFAS CEE (primary 2022 objective) with two focal whales (one with a satellite-transmitting tag and one with a DTAG) and six non-focal whales (**Table 3**).

Table 3. CEEs conducted during Atlantic-BRS 2022 field efforts.

CEE ID	Date	CEE Type	Focal Whales	Non-focal Whales	CEE Duration (min)	Start CEE Source Latitude (°N)	Start CEE Source Longitude (°W)
#2022_01	8/4/22	CONTROL	**ZcTag129**	ZcTag130 ZcTag131 ZcTag132	30	37.4736	-74.2399
#2022_02	8/5/22	CONTROL	**ZcTag131**	ZcTag129 ZcTag131 ZcTag132	30	35.8362	-74.4400
#2022_03	8/7/22	Operational MFAS	**ZcTag135; Zc22_219a**	ZcTag129 ZcTag130 ZcTag131 ZcTag132 ZcTag133 ZcTag134	60	35.4740	-74.4710

Key: ID = Identification Number; °N=degrees North; °W=degrees West; min=minute(s)

Short, narrative summaries for each of the two control sequences are provided in **Section 2.3.1**. The primary focus in this report is a comprehensive synthesis of the operational MFAS CEE (#2022_03), including a metadata summary; planning and post-hoc RL modeling results; and modeled spatial positions and dive records from sat tag locations for all focal (shown first) and non-focal individuals before, during, and after MFAS exposure for this CEE (**Section 2.3.2**).

2.3.1 2022 Atlantic-BRS Control CEEs (#2022_01 and 2022_02)

Table 4 and **Table 5** provide the metadata summaries for the Atlantic-BRS CEE #2022_01 and 2022_02, respectively.

Table 4. Metadata summary for Atlantic-BRS (CONTROL) CEE #2022_01.

CEE # 2022_01	
Date:	**04 August 2022**
Type:	**CONTROL** (no MFAS)
Signal parameters:	*n/a* Positioned *R/V Shearwater* as done during simulated source CEEs for pre, exposure, and post-exposure phase.
Start time (UTC):	12:30
Start lat/lon (source):	37.4736; -74.2399
End time (UTC):	13:00 (30 min exposure duration matched to simulated MFAS)
End lat/lon (source):	37.4763; -74.2429
Beaked whales tagged during CEE:	(n=1) – **ZcTag129** (focal sat tag animal); Note: ZcTag130, ZcTag131, ZcTag132 had active tags during this CEE but were > 100 km away
Pilot whales tagged:	none
Estimated Range (start CEE):	1.8 km (1 nm) @ start
Modeled Max RL:	*n/a* since no MFAS transmission, but model runs at surface and depth with post hoc positions from 131.2-141.5 dB RMS if transmissions had occurred

CEE #2022_01 - Narrative Summary
At the point in the 2022 field season when this CEE occurred, two whales had been tagged and tracked for nearly two months, while several additional tags had been deployed the previous day. Given the location of these tags and poor weather forecast in the primary research area, the research team in the field on the *R/V Shearwater* focused on ZcTag129 who was far to the north (near Washington Canyon) both to resight it and obtain recent positional data and to conduct a focused control CEE. Given the timing in the tag sequence, data were limited to XY positional data (and thus analyses of potential avoidance behavior) without diving data. There were three other tagged whales (ZcTag130, ZcTag131, and ZcTag132) during this period but they were over 100 km from the CEE location and not deemed effectively part of this CEE. Note: no RHIBs were tracking during this control sequence given conditions and locations. *R/V Shearwater* located and tracked the focal tagged whale, which alone as seen and photographed before and after the CEE in normal tracking and positioning approaches. *R/V Shearwater* was positioned ~1nm from last surface series prior to the control 'exposure' sequence. The focal whale (ZcTag129) was located easily following the CEE in the general area and with no obvious change in behavioral state.

Key: km = kilometer(s); n/a = not applicable; nm = nautical mile(s); RHIB = rigid-hulled inflatable boat; UTC = Coordinated Universal Time; Zc = *Ziphius cavirostris*

Table 5. Metadata summary for Atlantic-BRS (CONTROL) CEE #2022_02

CEE # 2022_02	
Date:	**05 August 2022**
Type:	**CONTROL** (no MFAS)
Signal parameters:	*n/a* Positioned *R/V Shearwater* as done during simulated source CEEs for pre, exposure, and post-exposure phase.
Start time (UTC):	16:55
Start lat/lon (source):	35.8362; -74.4400
End time (UTC):	17:25 (30 min exposure duration matched to simulated MFAS)
End lat/lon (source):	35.8420; -74.410
Beaked whales tagged during CEE:	(n=3) – **ZcTag131** (focal sat tag animal); ZcTag130, ZcTag132 (non-focal sat tags). Note: ZcTag129 was active during this CEE but >100 km away
Pilot whales tagged:	none
Estimated Range (start CEE):	1.8 km (1 nm) @ start
Modeled Max RL:	*n/a* since no MFAS transmission, but model runs at surface and depth with post hoc positions from 126.5-140.7 dB RMS if transmissions had occurred
CEE #2022_02 - Narrative Summary	
Given the location of tagged whales in the main study area and excellent weather forecast the *R/V Shearwater* had returned from the location of control CEE #22_01 quite far to the north. The team was supporting the *R/V Barber* in locating and identifying candidate groups for tagging; three additional tags were deployed later this day. A control CEE focused on ZcTag131 which was in a group of four whales resighted with high confidence over four surface series to obtain recent positional data and conduct a focused control CEE. XY positional and dive data were obtained. Two other (non-focal) tagged whales (ZcTag130 and ZcTag132) were in the general area during this period; ZcTag 129 was over 100 km from the CEE location and not deemed effectively part of this CEE. Note: no RHIBs were tracking during this control sequence as they were engaged in additional tagging effort in advance of CEE#22_03. *R/V Shearwater* located and tracked the focal tagged whale group, which was photographed before and after the CEE in normal tracking and positioning approaches. *R/V Shearwater* was positioned ~1nm from the focal group at the last surface series prior to the control 'exposure' sequence. The group and focal whale ZcTag131 were located easily following the CEE in the general area and with no obvious change in behavioral state	

Key: km = kilometer(s); n/a = not applicable; nm = nautical mile(s); RHIB = rigid-hulled inflatable boat; UTC = Coordinated Universal Time; Zc = *Ziphius cavirostris*

2.3.2 CEE #2022_03: Operational Navy SQS-53C MFAS

Table 6 provides the metadata summary for the Atlantic-BRS CEE #2022_03. **Table 7** provides sequential positioning and start/end positions for the *USS Farragut* for Atlantic-BRS CEE #2022_03.

Table 6. Metadata summary for Atlantic-BRS CEE #2022_03.

CEE # 2022_03	
Date:	**07 August 2022**
Type:	**Operational MFAS Source: *USS FARRAGUT*** (DDG99)
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):	17:10
Start lat/lon (source):	35.483; -74.500
End time (UTC):	18:11 (61 min exposure duration matched to other operational MFAS)
End lat/lon (source):	35.605; -74.7317
Beaked whales tagged during CEE:	(n=8) – **ZcTag135** (focal sat tag animal); Zc22_219a (focal DTAG animal); ZcTag129, ZcTag130, ZcTag131, ZcTag132, ZcTag133, ZcTag134 (non-focal sat tags).
Pilot whales tagged:	none
Estimated Range (start CEE):	13.4 nm @ start for focal whale ZcTag135 13.0 nm @ start for focal whale Zc22_219a (was with ZcTag135 before CEE but not @ start)
Modeled Max RL:	Focal whale ZcTag135: 140.9 dB RMS @ 10m; 140.4 dB RMS @900m Focal whale Zc22_219a: 139 dB RMS @ 10m; 137.3 dB RMS @1400m (note: measured max RL on DTAG for Zc22_219a = 139.3 dB RMS)
CEE #2022_03 - Narrative Summary	
For the current CEE, there were a total of eight beaked whales tagged, including two focal whales. This included Zc22_219a, tagged with a DTAG ~3.5h before the CEE, and ZcTag135 tagged with a satellite-transmitting position and depth sensor tag deployed two days earlier. Both focal animals were tracked with on-water visual observations at the time of the CEE from separate vessels. Six other tagged whales (Zcs 129-134) had been tagged from as long as six weeks to as few as two days prior to the CEE. Zcs129 and 130 were transmitting just positions at the time of the CEE (but had some of the longest pre-CEE baseline data of any Atlantic-BRS CEEs) while Zcs131-134 were transmitting both positions and dive data. Offshore conditions on the day of the CEE were suitable for small boat operations and the RHIB *R/V Barber* deployed the DTAG and tracked Zc22_219a before, during, and after the CEE and collected passive acoustic data from a calibrated hydrophone at known locations. A separate charter vessel was used to track Zc135 and collect additional data from other incidentally exposed whales. The Atlantic-BRS chief scientist coordinated through shore-based Fleet Forces Command colleagues, facilitating coordination with the USS FARRAGUT that was ultimately communicated to verify start and end of operations in the field via VHF radio. As designed for the 2022 field season for the Atlantic-BRS effort, this included a large number of whales tagged during an event with an operational sonar with precise and complete requested ship support, tags of both types deployed and successfully recovered, and an optimal spatial configuration of focal and incidental whales. Focal whales were predicted to have been exposed in the experimental target range of 110-140 dB RMS at ranges of ~10-15 nm with incidental whales occurring at variable ranges out to ~60 nm with RLs of ~90-130 dB RMS.	

Key: h = hour(s); m = meter(s); min = minute(s); n/a = not applicable; nm = nautical mile(s); RHIB = rigid-hulled inflatable boat; UTC = Coordinated Universal Time; VHF = very high frequency; Zc = *Ziphius cavirostris*

Table 7. Sequential positioning and actual start/end positions for *USS Farragut* for Atlantic-BRS CEE #2022_03.

Position Request for *USS Farragut*	Description	Latitude (°N)	Longitude (°W)	Heading
1	Nominal initial posit	36.033	-74.583	Not specified
2	5 August 1300 EDT (~48-hour pre) based on centroid from multiple prop model runs for in situ sightings and known locations for five tagged whales	36.000	-74.500	185
3	6 August 1300 EDT (~24-hour pre) based on centroid from multiple higher quality ARGOS posits for three tagged whales [note: The team provided both a possible northern starting location and a contingency southern track based on projected vessel location on 7 August]	Northern: 36.000 Southern: 35.483	Northern: -74.500 Southern: -74.500	Northern: 185 Southern: 351
4	7 August 1100 EDT: Final requested start position – settled on southern start with northerly track based on *USS Farragut* location and timing; retained 24-hour pre location but modified requested course	35.483	-74.500	357
5	Actual start position and course from *USS Farragut* navigation	35.474	-74.471	358

Key: EDT = Eastern Daylight Time; °N=degrees North; °W=degrees West

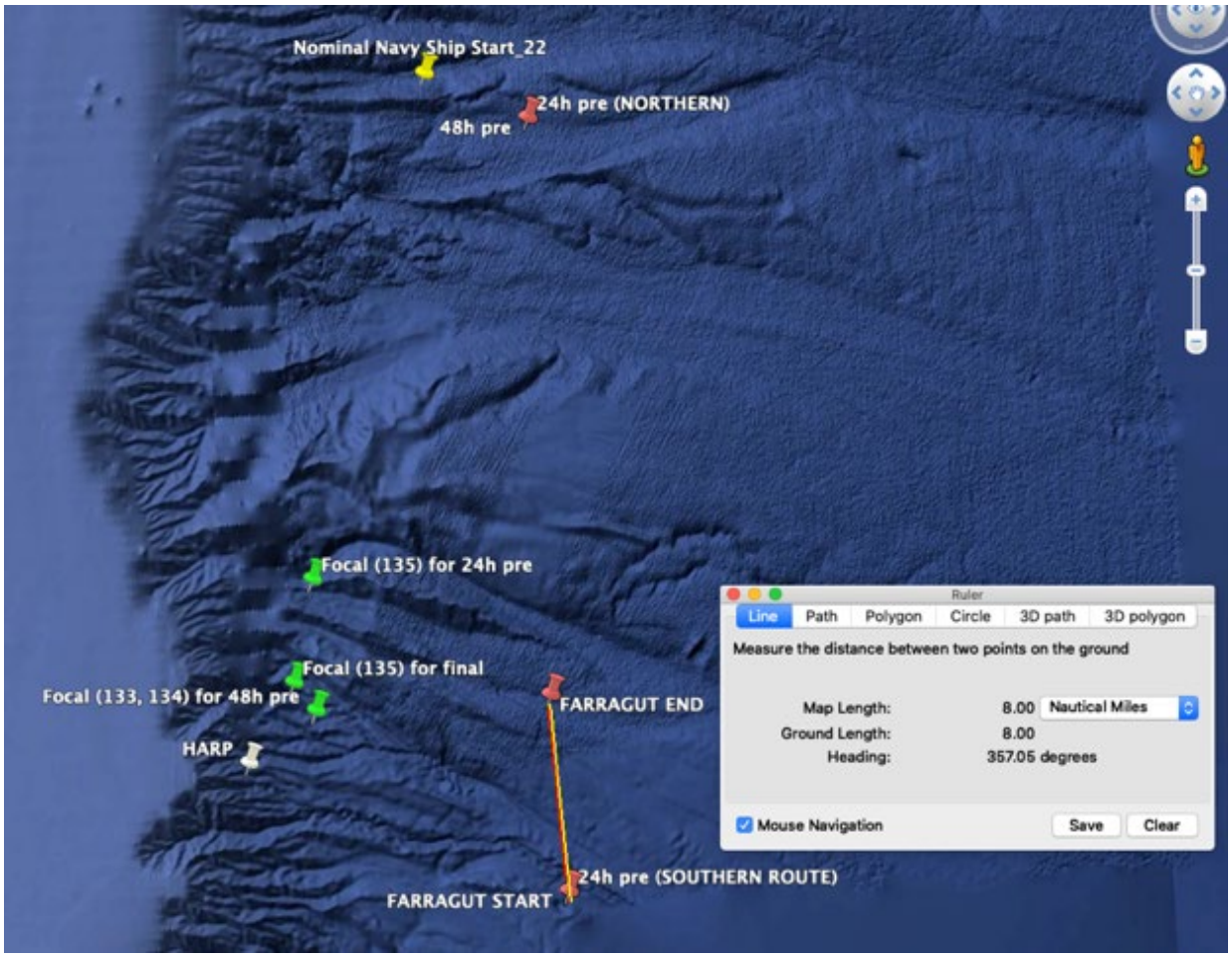

Figure 11. Sequential requested *USS Farragut* start positions shown relative to focal animal centroid or actual position estimates used in RL model estimates; see Table 7 for descriptions.

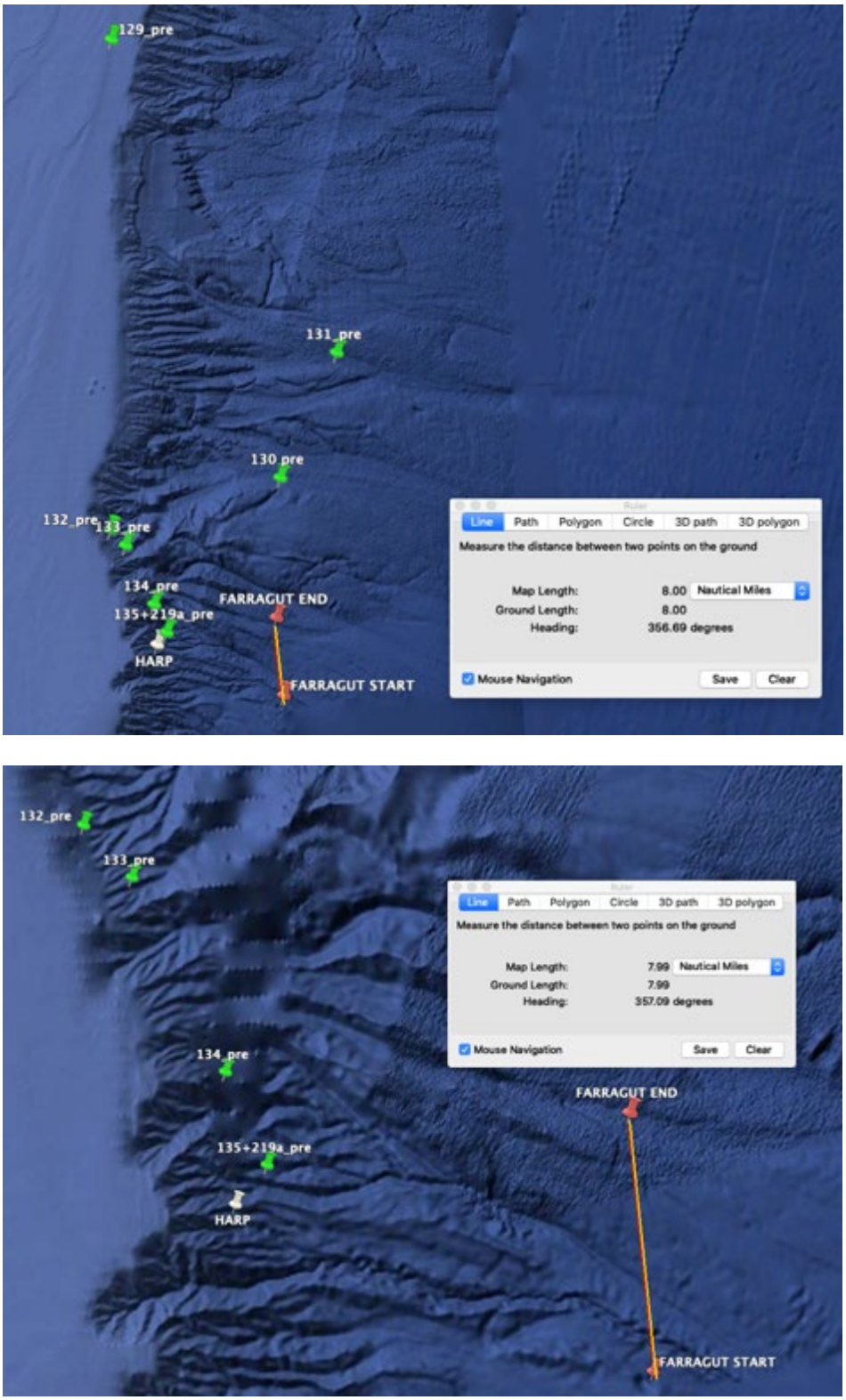

Figure 12. Broad view (top) of focal (Zc22_219a; Zc135) and incidentally exposed beaked whales (Zcs129–134) with actual *USS Farragut* track showing best whale estimated positions (green) at CEE start (Note: bottom image zoomed in to show more resolution for focal whales).

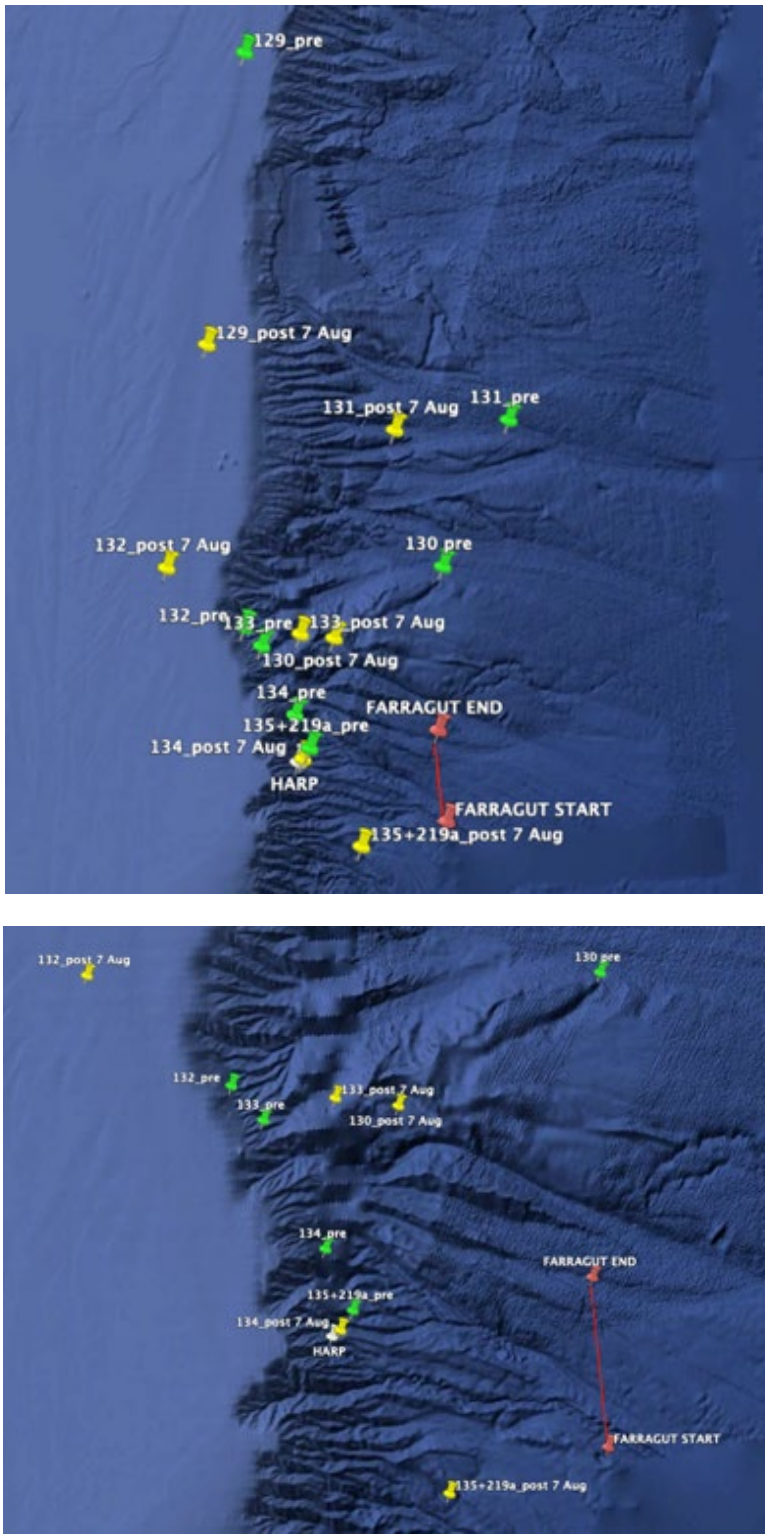

Figure 13. Broad view (top) of focal (Zc22_219a; Zc135) and incidentally exposed beaked whales (Zcs129–134) with actual *USS Farragut* track showing best estimate positions (green) at CEE start and ~6 hours post CEE on 7 August (yellow) (Note: bottom image zoomed in to show more resolution for focal whales).

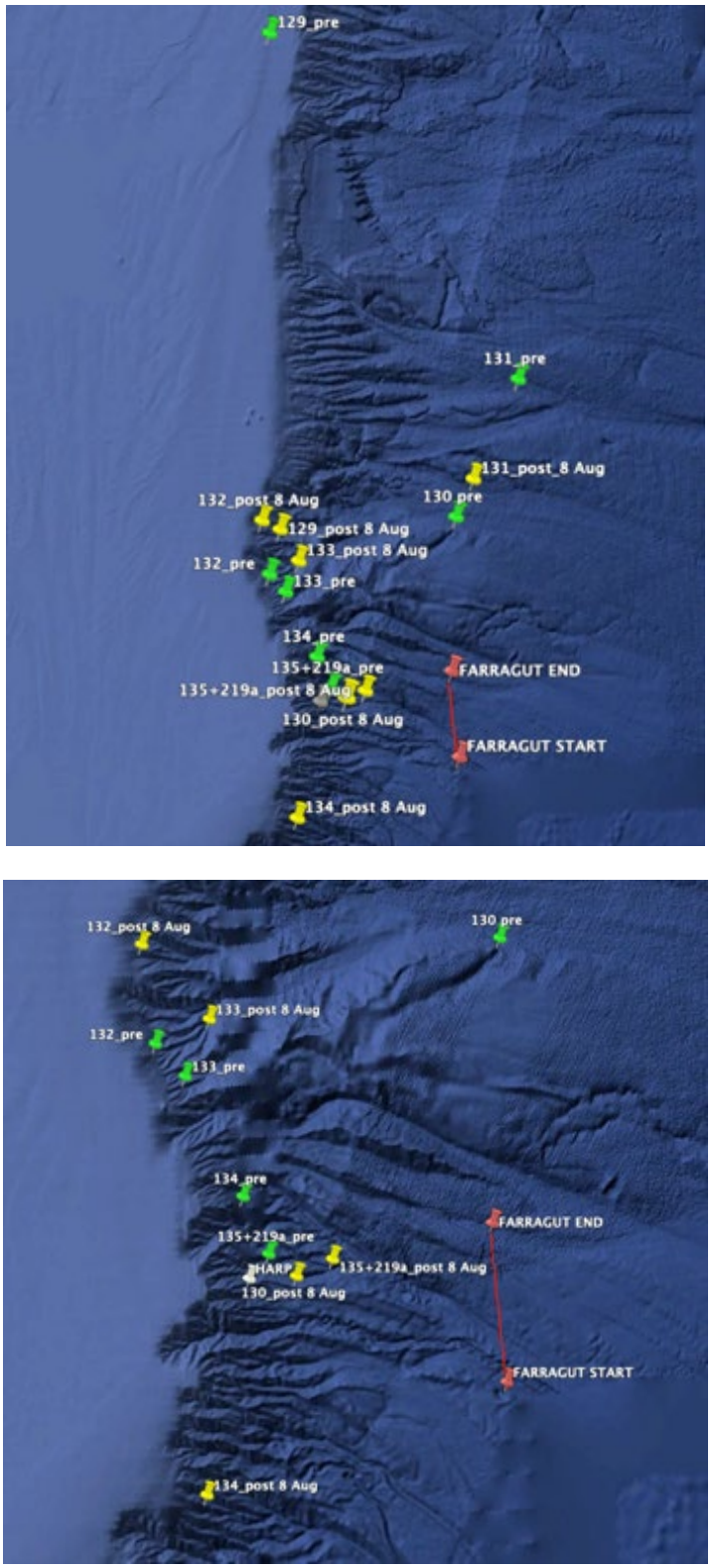

Figure 14. Broad view (top) of focal (Zc22_219a; Zc135) and incidentally exposed beaked whales (Zcs129–134) with actual *USS Farragut* track showing best estimate positions (green) at CEE start and ~24 hours post CEE on 8 August (yellow) (Note: bottom image zoomed in to show more resolution for focal whale.

Received level (RL) model predictions were generated *in situ* for different focal animal's known or estimated locations at multiple depths using the custom NPS sound propagation planning tool. Model runs are shown for different focal animals and different depths in the water column. This was done sequentially in the days and hours leading up to the CEE to inform strategic positioning of the source vessel (see **Table 8**).

Table 8. RL model runs for CEE #2022_03 with *USS Farragut*.

Model Run	Description	Animal (Depth – m)	Animal Latitude	Animal Longitude	Estimated Range (nm) Start – End	Model RL Start	Model RL End	Model RL Max.
05	05 August 0700 EDT	Zc130 (131, 132 nearby) (1500)	35.6485	-74.6934	19 – 12	126	140	140
06	05 August 0700 EDT	Zc130 (131, 132 nearby) (10)	35.6485	-74.6934	17 – 9	96	141	141
07	05 August 1000 EDT	Zc133; 134 (10)	35.6122	-74.6992	17 – 10	97	142	142
08	05 August 1000 EDT	Zc133; 134 (10)	35.6122	-74.6992	19 – 11	116	140	140
09	06 August 0700 EDT	Zc135 (130, 134 nearby) (1500)	35.700	-74.6966	17 – 11	119	141	141
10	06 August 0700 EDT	Zc135 (130, 134 nearby) (10)	35.700	-74.6966	15 – 8	127	141	141
11	06 August 1100 EDT	Zc135 centroid (10)	35.6109	-74.7210	19 – 11	123	141	141
12	06 August 1100 EDT	Zc135 centroid (1500)	35.6109	-74.7210	16 – 10	127	140	140
13	07 August 0850 EDT	Zc135 (Zc22_219a soon after) (10)	35.6117	-74.7161	17 – 10	126	141	141
14	07 August 0850 EDT	Zc135 (Zc22_219a soon after) (1500)	35.6117	-74.7161	13 – 8	124	140	140
15	Post-hoc for known CEE location with best field posit estimate	Zc22_219a (500)	35.6259	-74.7317	13 – 10	134	134	143
16	Post-hoc for known CEE location with best field posit estimate	Zc22_219a (10)	35.6259	-74.7317	13 – 10	138	134	139
17	Post-hoc for known CEE location with best field posit estimate	Zc22_219a (1400)	35.6259	-74.7317	13 – 10	123	130	137

Key: EDT = Eastern Daylight Time; m = meter(s); Max. = Maximum; nm = nautical mile(s)

This report provides multiple depth predictions based on post-hoc known locations and depths for model runs 15 through 17 for focal whale Zc22_219a (**Figures 15** through **17**). These figures show estimated RLs for animals at known/estimated tag locations (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 correspond to the estimated position based on an interpolation of surface locations from focal follow observations. **Figure 18** provides measured RLs for DTAG focal whale Zc22_219a for all received MFAS signals during CEE #2022_03. All model runs in **Table 8** were included in an after-action report provided to the U.S. Navy, which is available upon request.

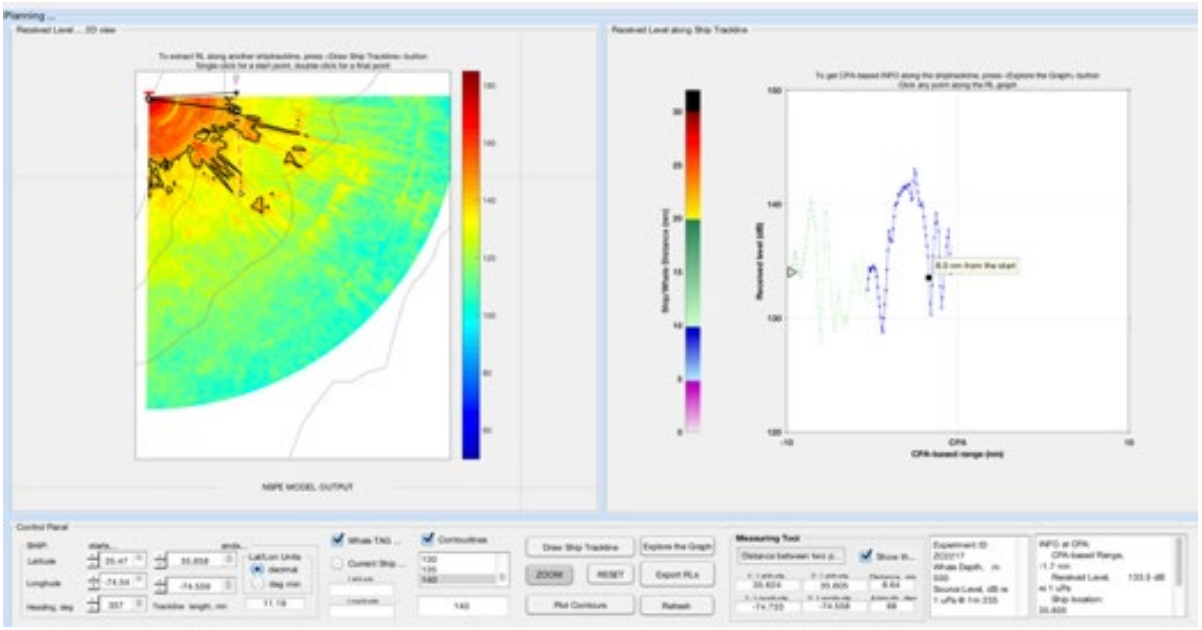

Figure 15. Post hoc RL model prediction at 500-meter depth (model run #15 from Table 8) for focal whale Zc22_219a based on interpolated position and *USS Farragut* position during Atlantic-BRS CEE #2022_03; modeled maximum RL at this depth was 143.0 dB RMS.

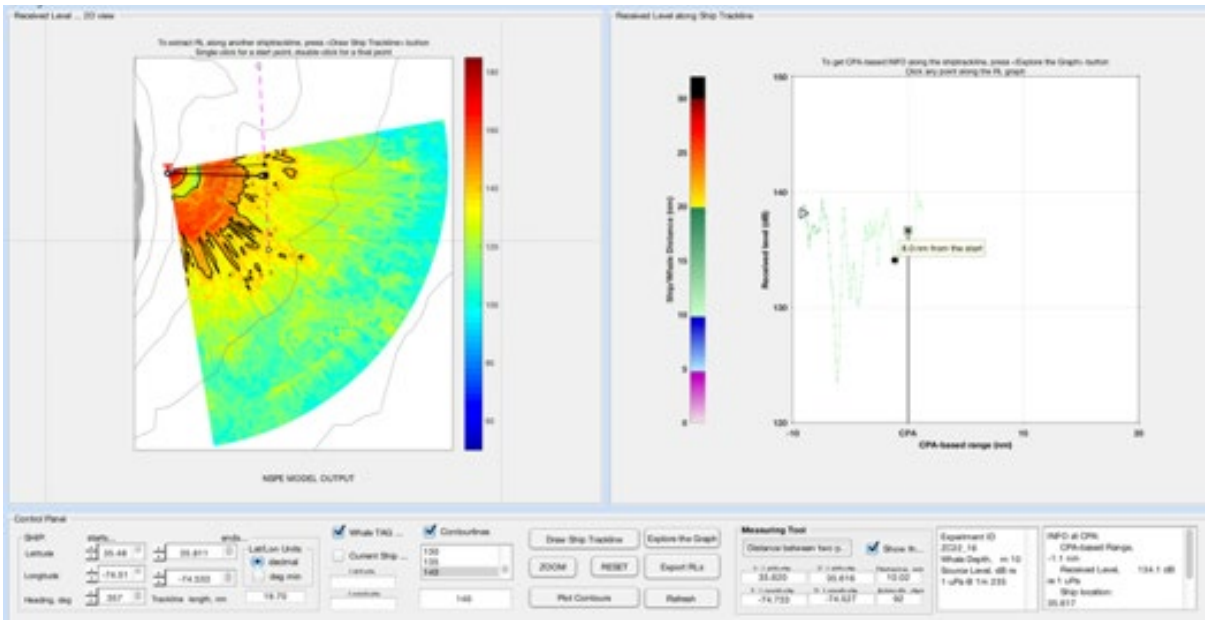

Figure 16. Post hoc RL model prediction at 10-meter depth (model run #16 from Table 8) for focal whale Zc22_219a based on interpolated position and *USS Farragut* position during Atlantic-BRS CEE #2022_03; modeled maximum RL at this depth was 139.0 dB RMS.

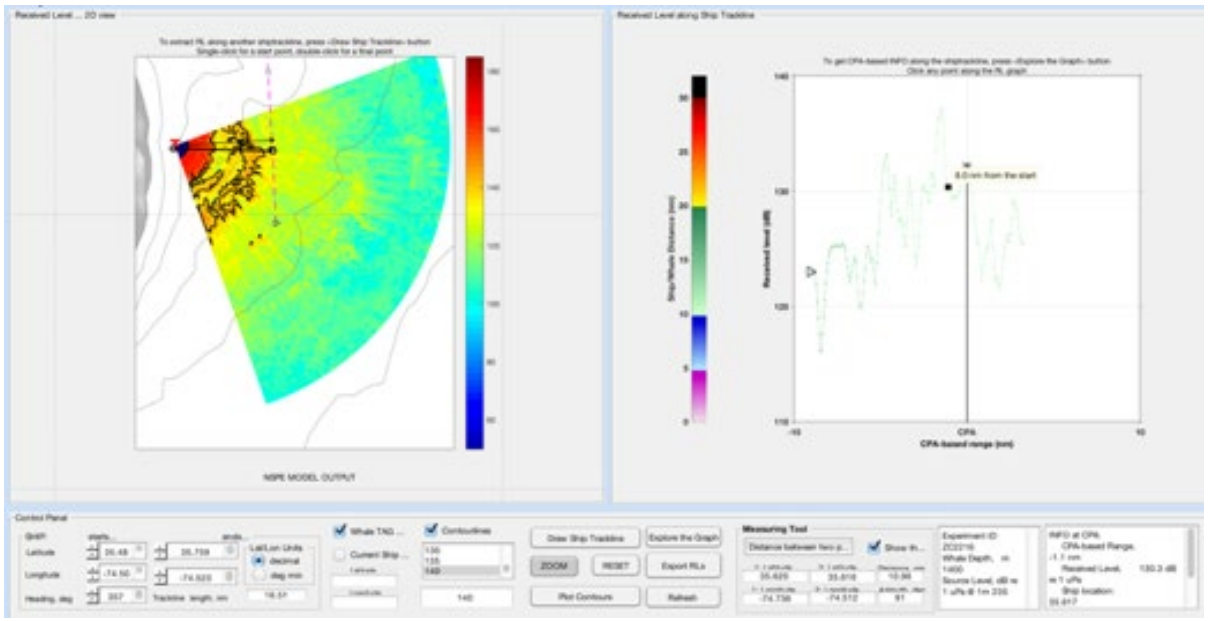

Figure 17. Post hoc RL model prediction at 1,400-meter depth (model run #17 from Table 8) for focal whale Zc22_219a based on interpolated position and *USS Farragut* position during Atlantic-BRS CEE #2022_03; modeled maximum RL at this depth and estimated position was 137.0 dB RMS.

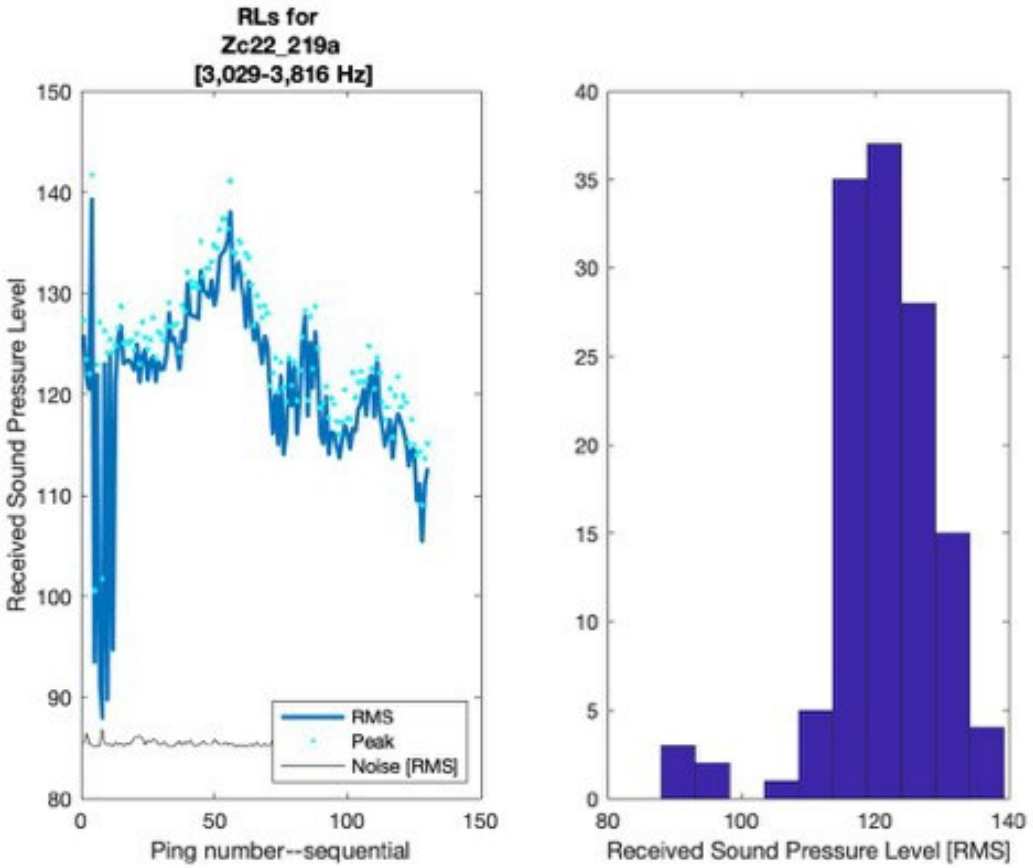

Figure 18. Measured RLs for DTAG focal whale Zc22_219a for all (n=130) received MFAS signals during CEE #2022_03. The panel on the left gives RLs in dB RMS and dB peak as well as RMS noise levels prior to each ping.

Estimated surface position plots are given for satellite-transmitting focal (**Figure 19**) and non-focal animals (**Figures 20** through **25**). These two-panel maps indicate the entire track of the animal (left panel) and estimated locations around the CEE (right panel). The left panel is a predicted track from a continuous time correlated random walk model with predictions made every 3 hours. The cluster of orange points along the track denote 100 estimated locations of the animal at the start of CEE 22_03. The right panel shows 100 points for each of four time periods: (1) 1 hour **before** the start of the CEE; (2) the **start** of the CEE; (3) the **end** of the CEE; and (4) 1 hour **after** the CEE ends. These four periods are shown with increasingly saturated orange colors. The position of the *USS Farragut* at the start and end of the CEE are shown in the light and dark green diamonds. Mean distance to the *USS Farragut* is shown below the right map panel.

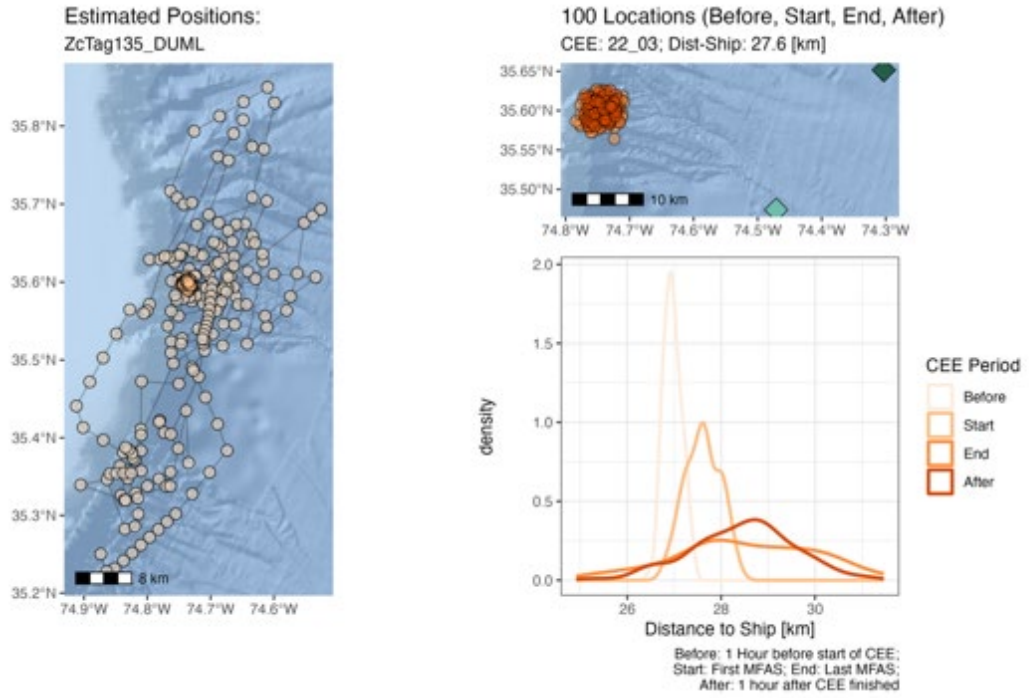

Figure 19. Estimated surface positions for focal whale ZcTag135_DUML before, during, and after Atlantic-BRS CEE#2022_03.

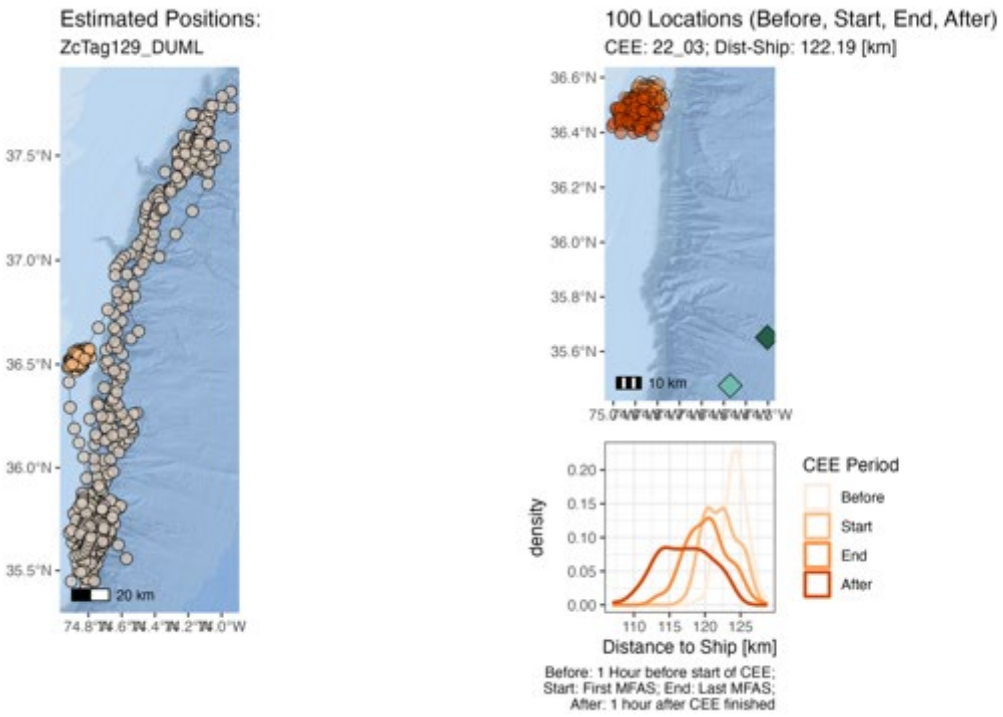

Figure 20. Estimated surface positions for non-focal whale ZcTag129_DUML before, during, and after Atlantic-BRS CEE#2022_03.

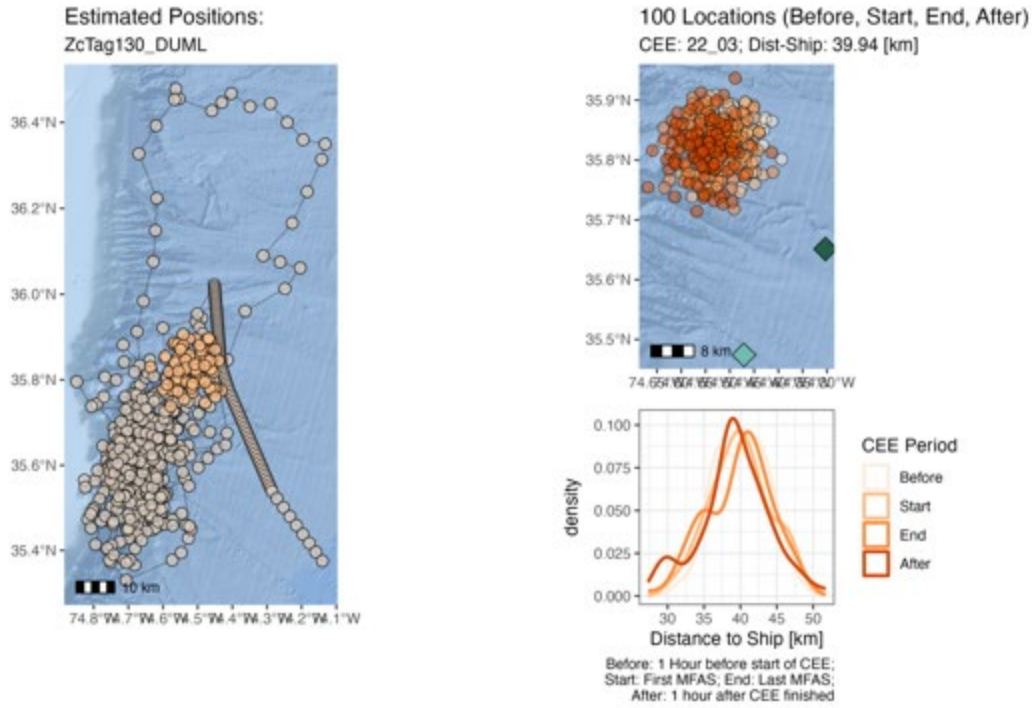

Figure 21. Estimated surface positions for non-focal whale ZcTag130_DUML before, during, and after Atlantic-BRS CEE#2022_03.

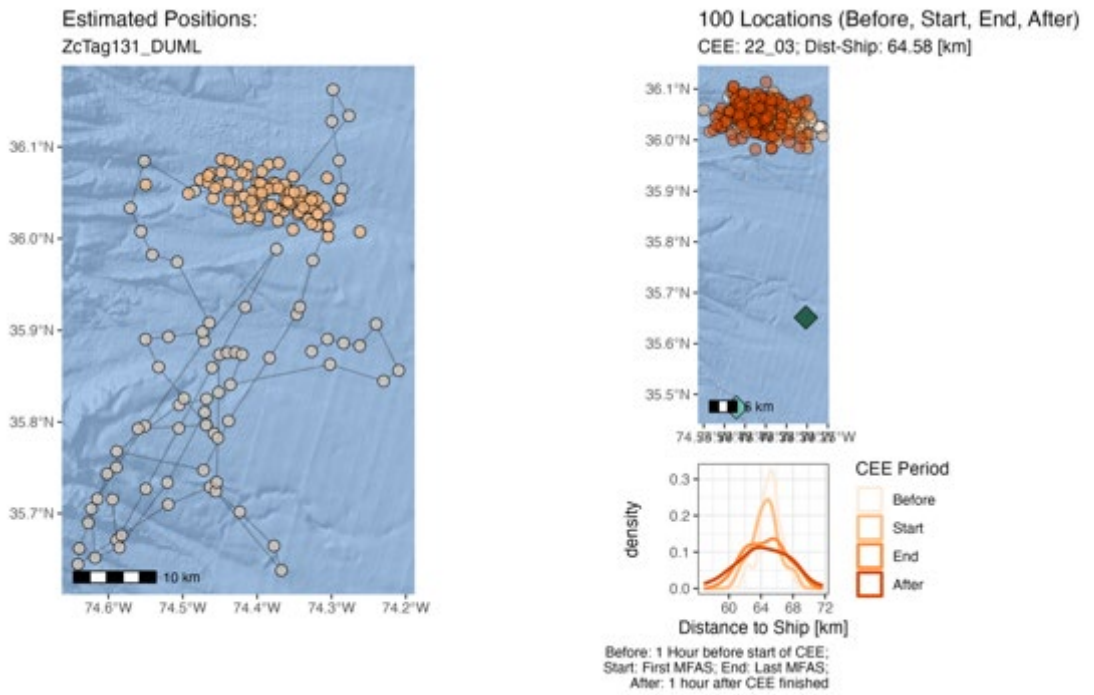

Figure 22. Estimated surface positions for non-focal whale ZcTag131_DUML before, during, and after Atlantic-BRS CEE#2022_03.

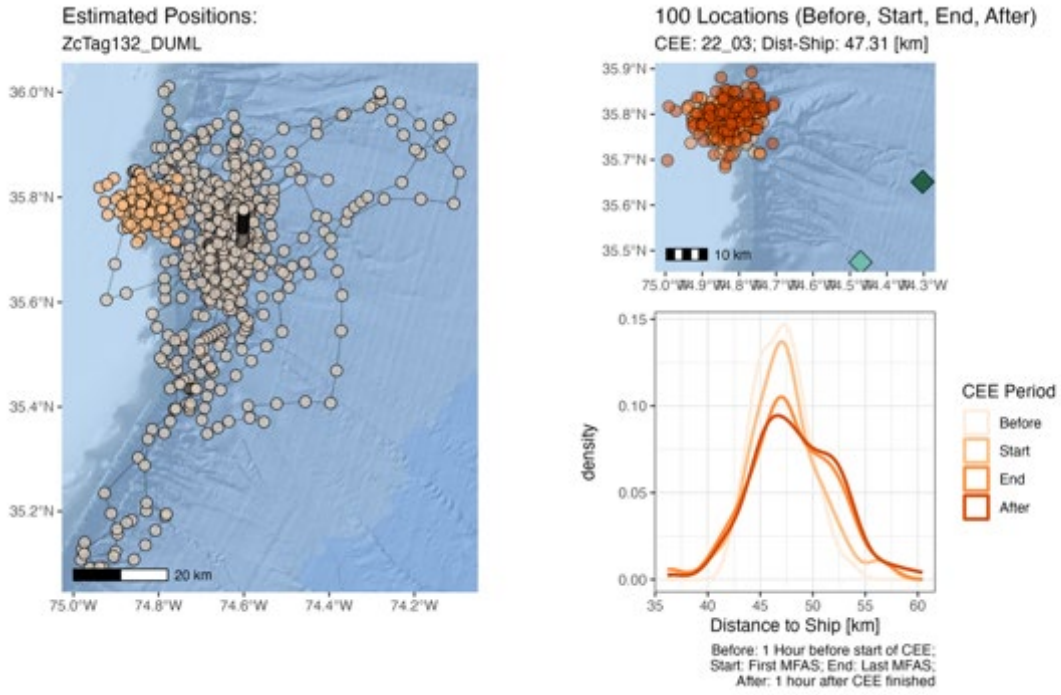

Figure 23. Estimated surface positions for non-focal whale ZcTag132_DUML before, during, and after Atlantic-BRS CEE#2022_03.

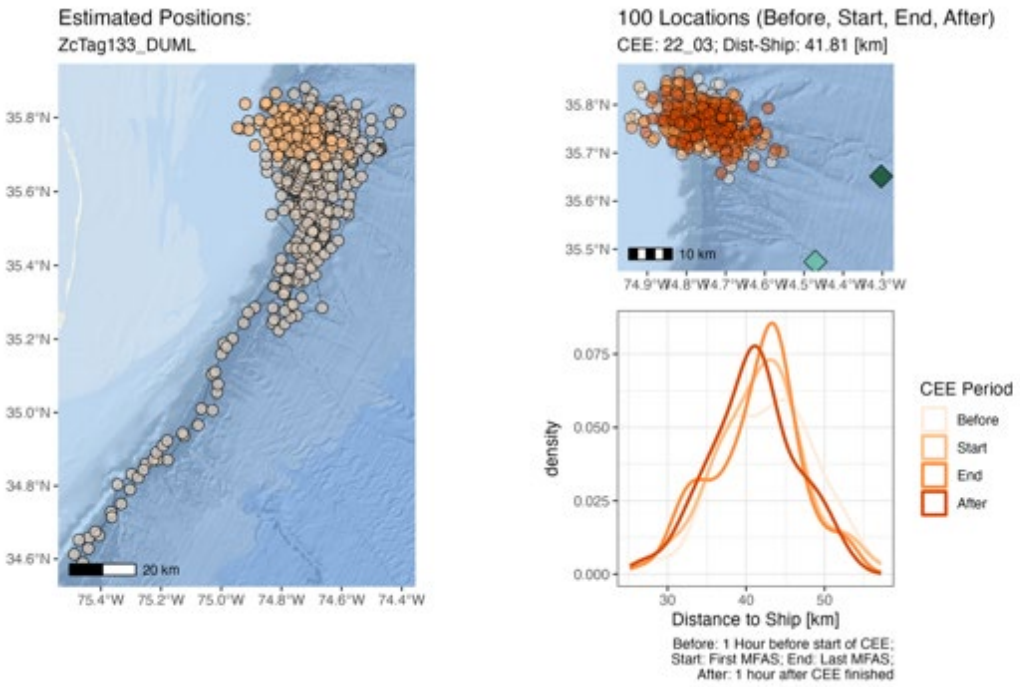

Figure 24. Estimated surface positions for non-focal whale ZcTag133_DUML before, during, and after Atlantic-BRS CEE#2022_03.

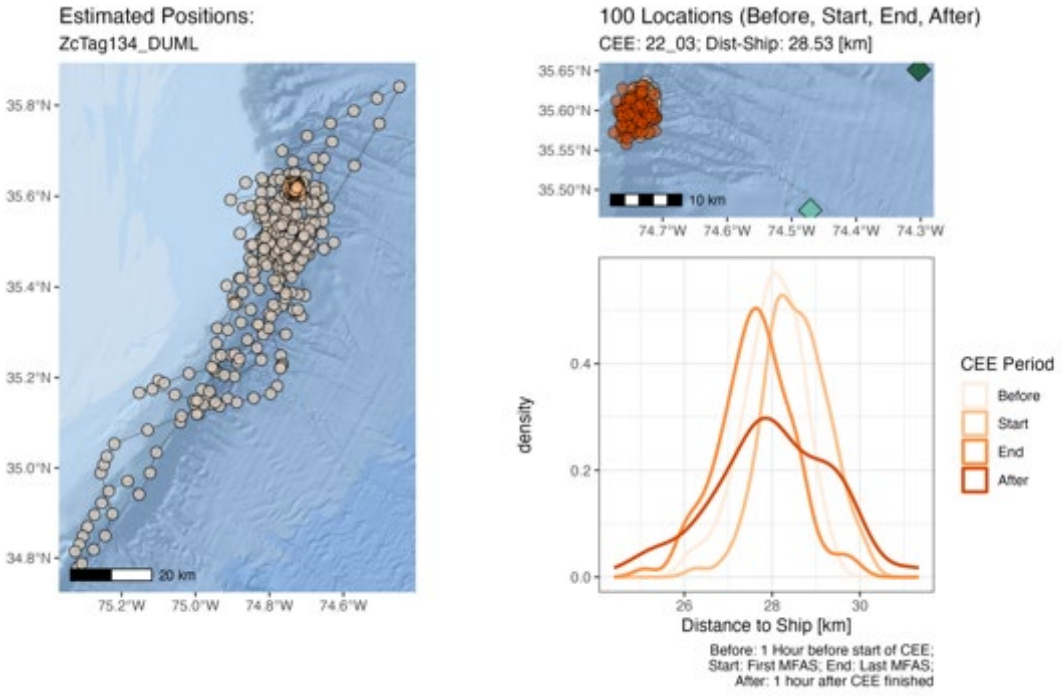

Figure 25. Estimated surface positions for non-focal whale ZcTag134_DUML before, during, and after Atlantic-BRS CEE#2022_03.

Dive plots for focal (**Figure 26**) and non-focal (**Figures 27** through **30**) whales for which satellite-transmitting tags were reporting dive data during the CEE are given in a standard format. Time (in Greenwich Mean Time, which is +4 hours from Eastern Daylight Time 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 when field teams detected the tagged individual using goniometers. These figures show 24-hour periods occurring before and after CEE #2022_03, which was 1 hour in duration. Dive profiles for focal DTAG whale Zc22_219a are shown without and with calibrated RLs in **Figures 31** and **32**, respectively.

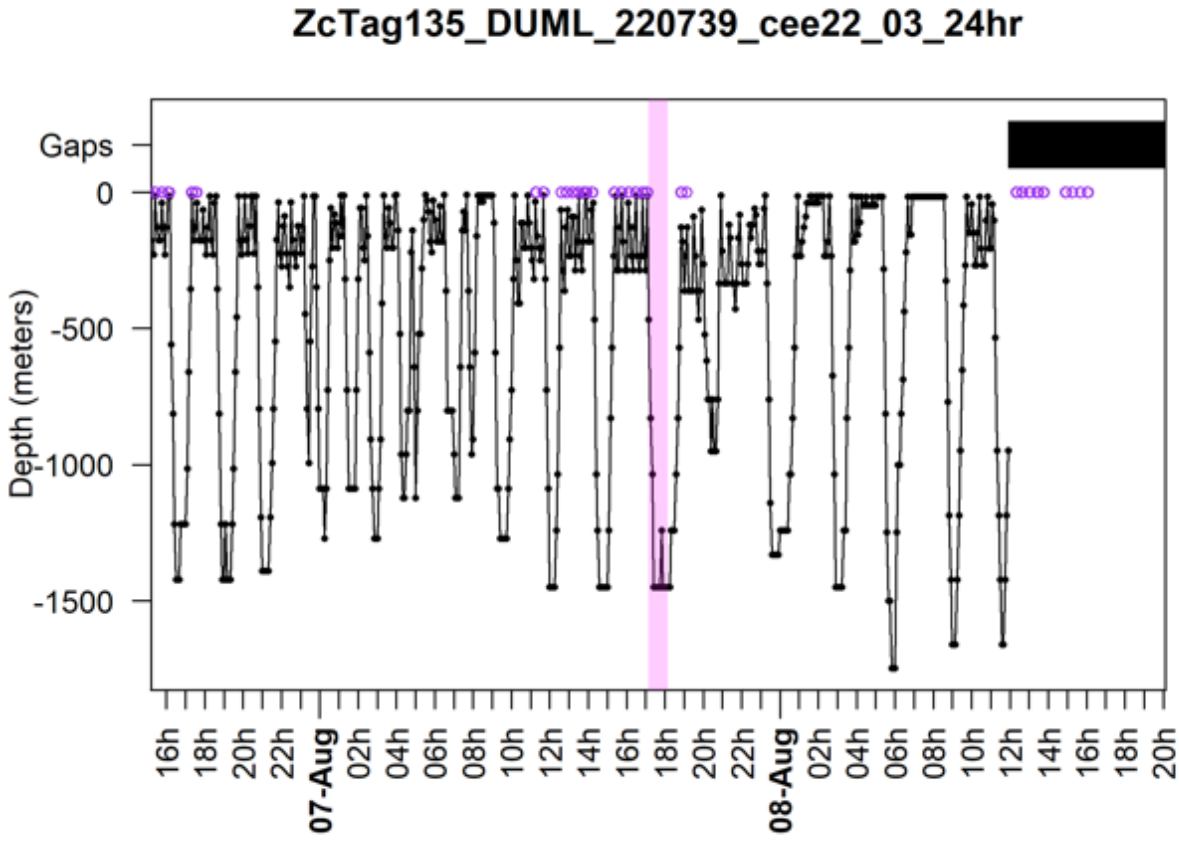

Figure 26. Available dive data for focal whale ZcTag135_DUML before, during, and after Atlantic-BRS CEE #2022_03. Pink shading denotes duration of CEE transmissions, purple circles denote in-situ goniometer detections of surface series.

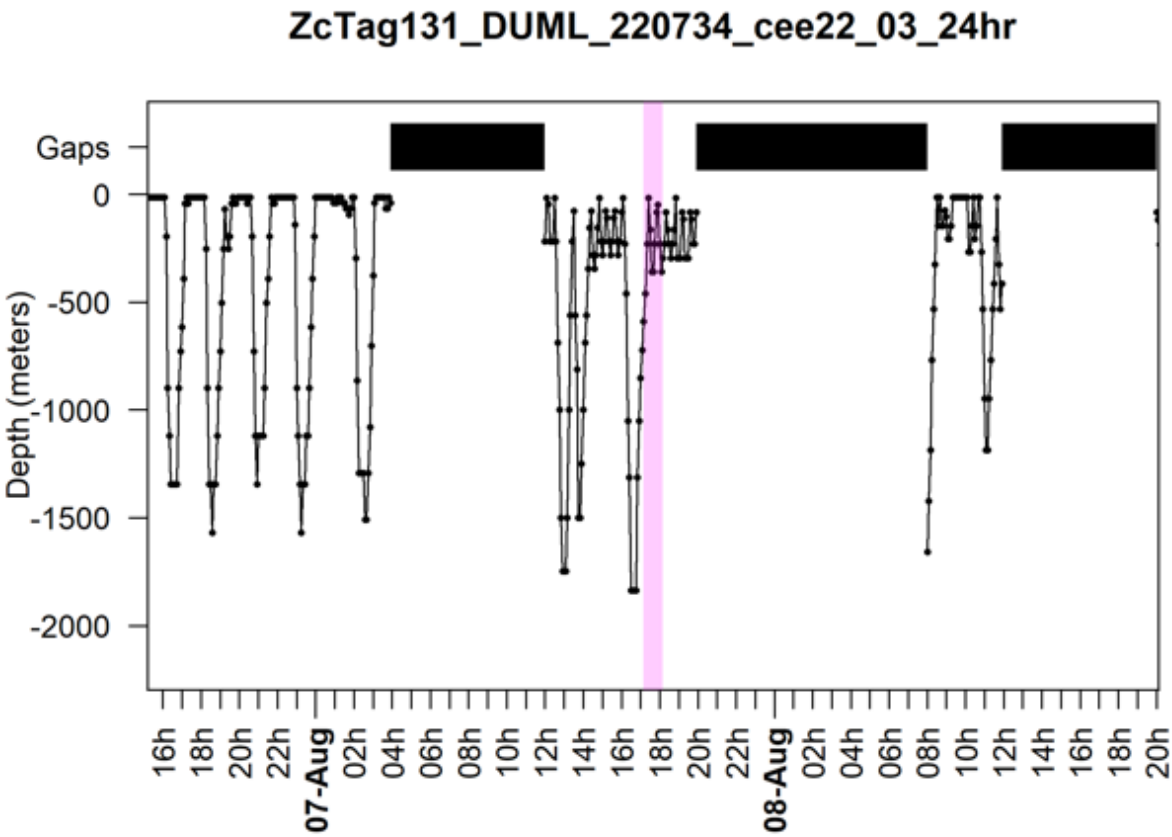

Figure 27. Available dive data for non-focal whale ZcTag131_DUML before, during, and after Atlantic-BRS CEE #2022_03. Pink shading denotes duration of CEE transmissions.

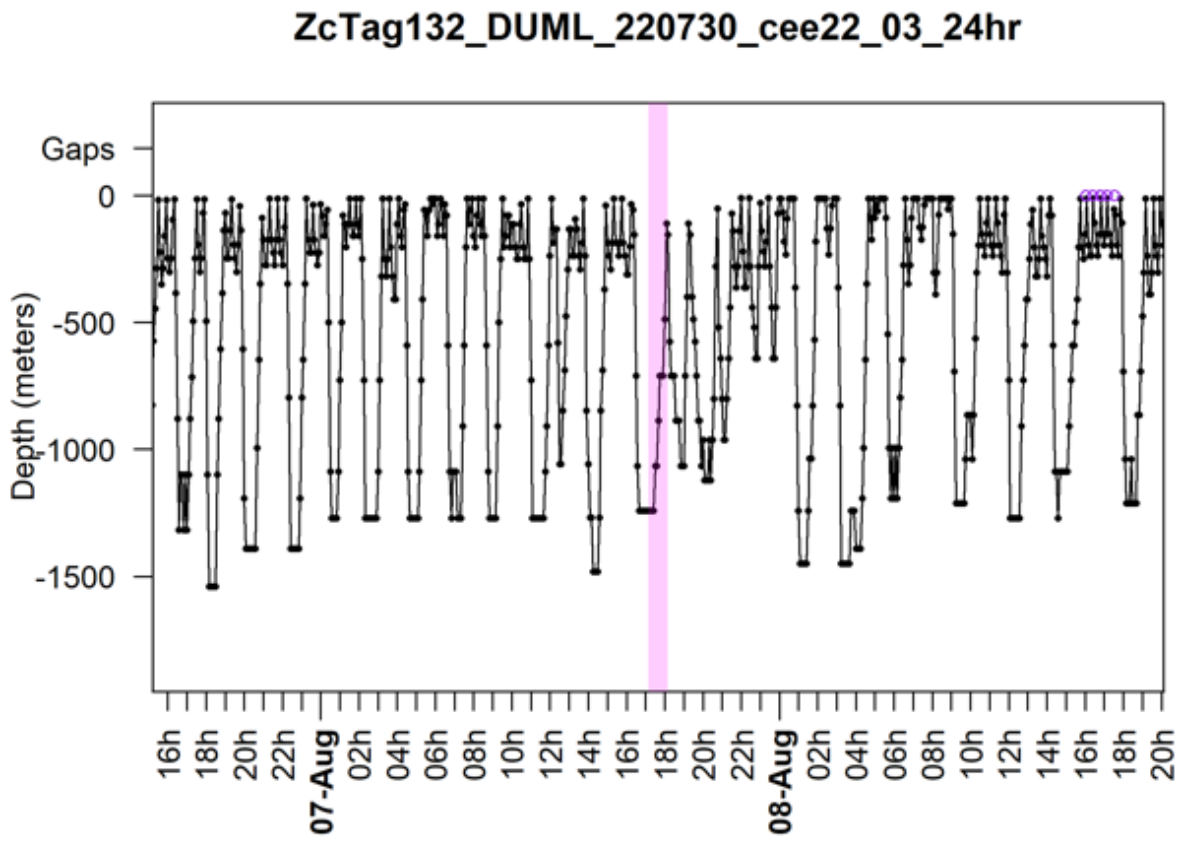

Figure 28. Available dive data for non-focal whale ZcTag132_DUML before, during, and after Atlantic-BRS CEE #2022_03. Pink shading denotes duration of CEE transmissions, purple circles denote in-situ goniometer detections of surface series.

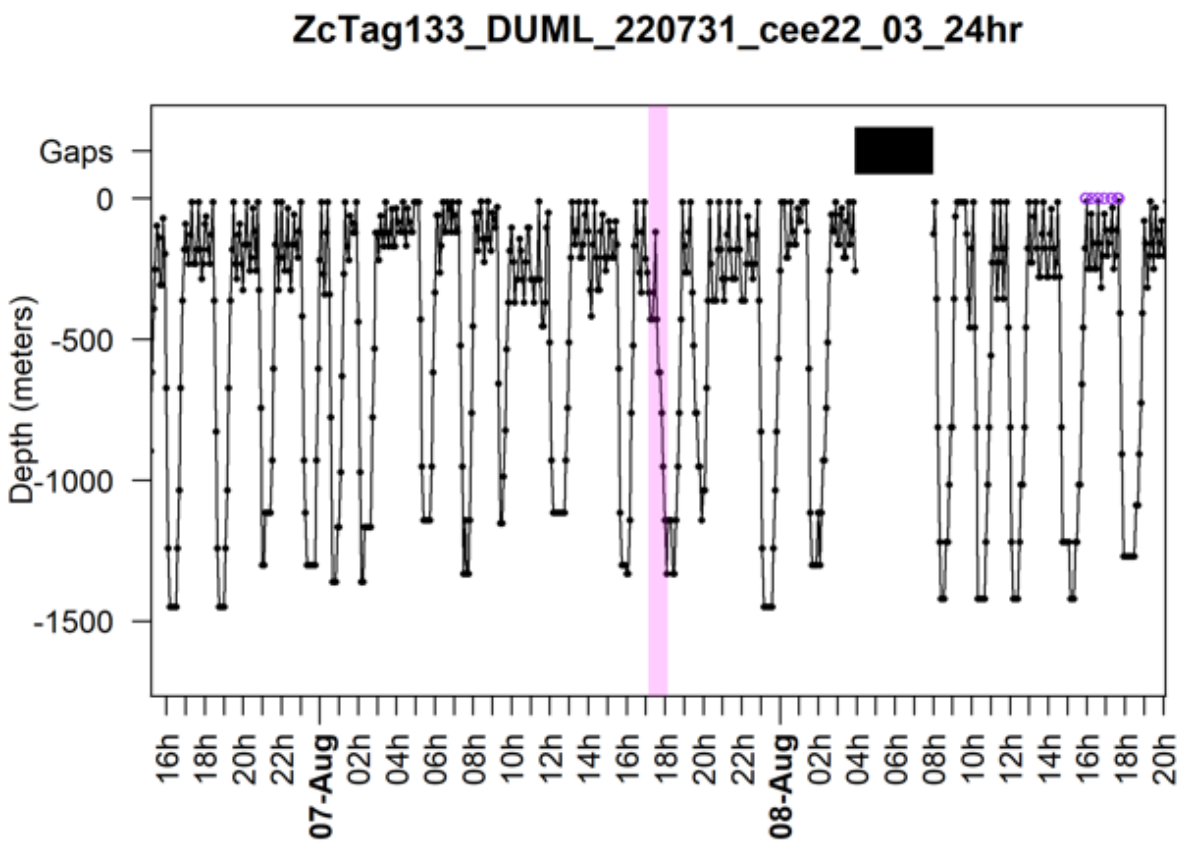

Figure 29. Available dive data for non-focal whale ZcTag133 before, during, and after Atlantic-BRS CEE #2022_03. Pink shading denotes duration of CEE transmissions, purple circles denote in-situ goniometer detections of surface series.

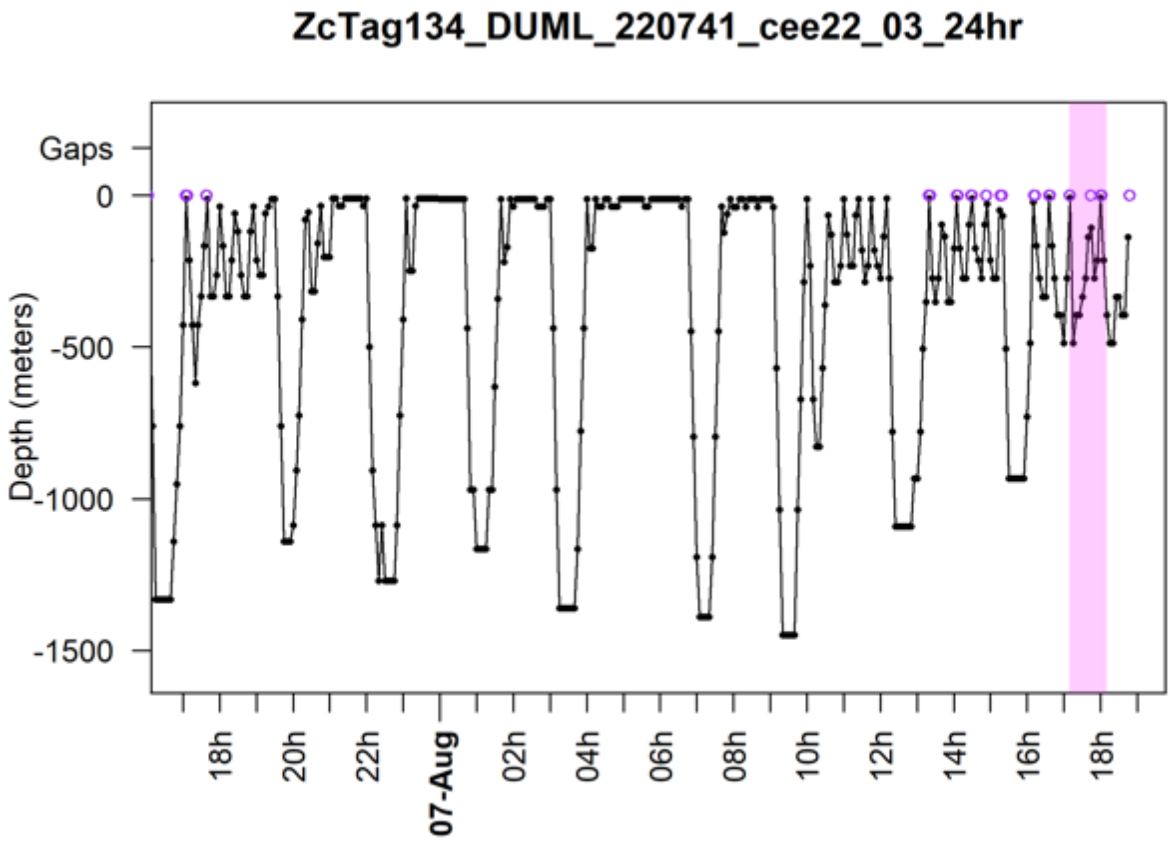

Figure 30. Available dive data for non-focal whale ZcTag134 before, during, and after Atlantic-BRS CEE #2022_03. Pink shading denotes duration of CEE transmissions, purple circles denote in-situ goniometer detections of surface series.

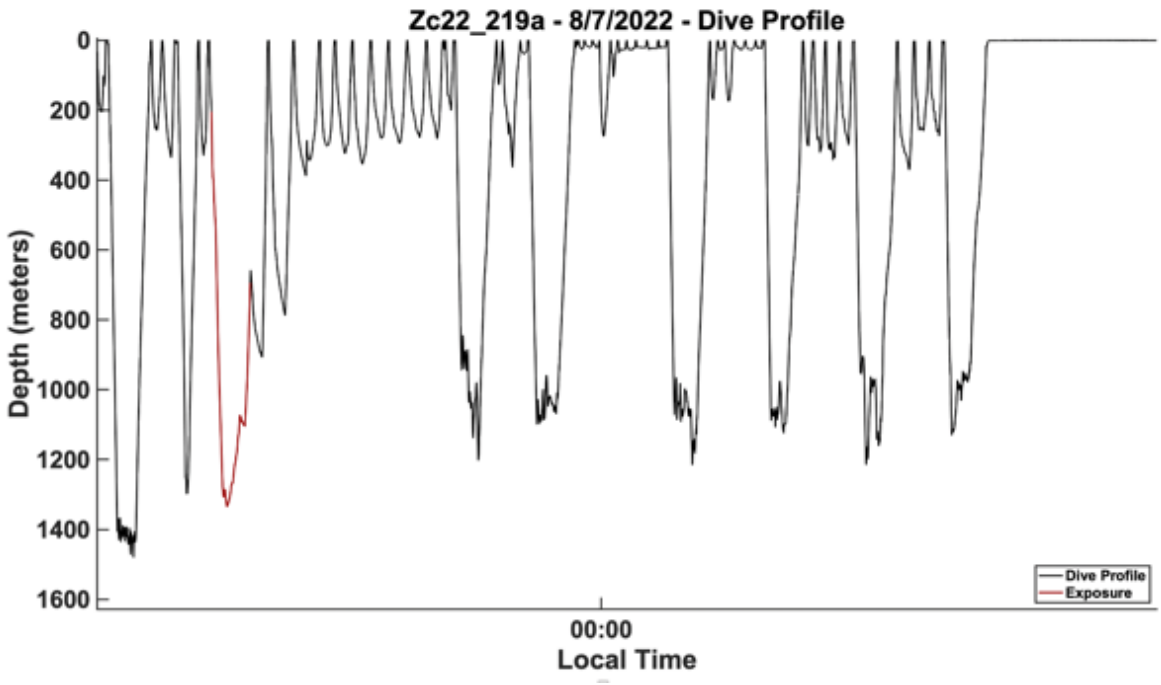

Figure 31. Dive profile for focal whale Zc22_219a before, during, and after Atlantic-BRS CEE #2022_03 (CEE exposure phase is highlighted in red).

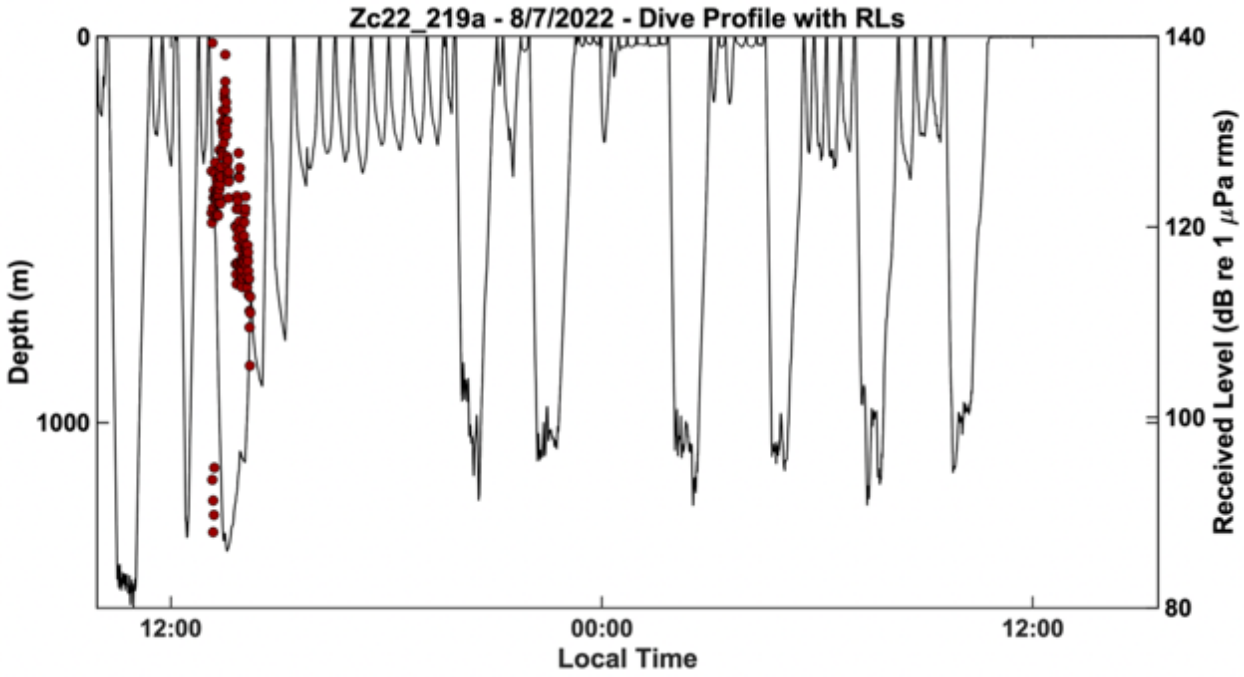

Figure 32. Dive profile for focal whale Zc22_219a before, during, and after Atlantic-BRS CEE #2022_03 (Red dots during the CEE exposure phase show calibrated RLs of individual pings).

3. Analytical Developments, Results, and Publications & Presentations

Readers are referred to Section 3.1 of the 2020 Atlantic-BRS annual report (Southall et al. 2021) for extensive details on data analyses and visualizations that continue to be applied in the presentation and publication of results.

As the Atlantic-BRS project has progressed, it is consistently producing peer-reviewed publications both directly through the project and in collaboration with the ONR-funded Double Mocha effort, which developed analytical tools and methods that are now being applied for Atlantic-BRS response analyses. **Table 9** provides a summary of papers that are published, in review, or in advanced stages of development; direct links to publications are provided when available.

Table 9. 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
Methodology – technology	Monte Carlo testing to identify behavioral responses to exposure using satellite tag data	Hewitt (Duke) [Double Mocha]	Published
Methodology – technology	Time-discretization approximation enriches continuous-time discrete-space models for animal movement	Hewitt (Duke) [Double Mocha]	Published
Methodology – technology	Varying-Coefficient Stochastic Differential Equations with Applications in Ecology	Michelot (St. Andrews) [Double Mocha]	Published

Category	Nominal Title/Subject	Lead Author (Institution)	Status
Methodology – technology	Kernel density estimation of conditional distributions to detect responses in satellite tag data	Hewitt (Duke) [Double Mocha]	Published
Methodology – technology	Continuous-time modelling of behavioural responses in animal movement	Michelot (St. Andrews) [Double Mocha]	In review; uploaded online
Methodology – technology	Trade-offs in telemetry tag programming for deep-diving cetaceans: data longevity, resolution, and continuity	Cioffi (SEA)	Published
Methodology – technology	Detecting changes in foraging behavior in Cuvier's beaked whales exposed to sonar using coarse resolution data	Glennie (St. Andrews) [Double Mocha]	Final preparation
Baseline behavior	More than metronomes: variation in diving behavior of Cuvier's beaked whales (*Ziphius cavirostris*)	Quick (Duke)	Final preparation
Baseline behavior	Shallow night intervals in *Ziphius cavirostris*	Cioffi (Duke)	Final preparation
CEE exposure-response	Behavioral responses of Cuvier's beaked whales to simulated mid-frequency active military sonar off Cape Hatteras, NC	Southall (SEA)	In preparation
Methodology – technology	Estimating RLs and horizontal avoidance with dynamic covariates in exposed animals	Schick (Duke)	In preparation
Baseline behavior	Possible orientation behavior in Ziphius	Quick (Duke)	In preparation
CEE exposure-response	Behavioral responses of Cuvier's beaked whales operational mid-frequency active military sonar off Cape Hatteras, NC	Southall (SEA)	In preparation
Baseline physiology	Baseline variation of steroid hormones in short-finned pilot whales (*Globicephala macrorhynchus*)	Wisse (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

4.1 General Assessment of Atlantic-BRS 2022 Accomplishments

- Overall, the 2022 field season was the most challenging field conditions in over a decade of tagging effort in the Cape Hatteras location. Success relied on the field team's great deal of patience, persistence, and dedication.
- Despite challenges, the study experienced eventual successful deployment of a large number (n=8) of tags on high-priority Cuvier's beaked whales and the collection of tens of thousands of hours of movement and diving behavior. No secondary-priority pilot whales were tagged due to the tagging success with beaked whales.
- Strategic objectives focused parallel efforts on an intense analytical push to complete analyses for simulated MFAS CEE results and successful completion of a single CEE coordinated with operational U.S. Navy vessel MFAS.
- Successful coordination and adaptive planning with USFFC colleagues to accomplish a complete and as-designed CEE with the *USS Farragut*. Given strategic objectives and a selective approach, conducting one successful CEE with many whales this season also required patience, communication, and adaptability on the U.S. Navy's part. This was achieved with sustained coordination and effort with U.S. Navy personnel, working with vessels ahead of their deployment and maintaining close, real-time communication of time and locations of possible coordination using shore-based personnel from both the Atlantic-BRS and U.S. Navy teams. Data requested from U.S. Navy vessels was provided in a complete, timely, and unclassified manner. A coordinating and planning briefing between the Atlantic-BRS and US Navy teams in Norfolk, Virginia, was a useful and positive interaction in terms of situational awareness and planning.
- Target RLs for Cuvier's beaked whales were achieved at approximately 110 to 140 dB for focal whales in the operational vessel MFAS CEE. Model estimates based on post hoc location and diving behavior for focal whales were very similar to measured, calibrated RLs from DTAG deployments. These target levels were achieved at realistic operational ranges (10 to 50 nautical miles [nm]) with focal and non-focal Cuvier's beaked whales. Some, but not all, exposed whales showed clear changes in movement and diving patterns, similar to those observed previously with simulated MFAS sources at closer range (2 to 3 nm), based on field observations and initial analysis of data collected.
- Sat tag deployment settings were maintained as developed in earlier years with very positive results. Many of the 2022 tags again achieved greater duration deployments for returning ARGOS position data in addition to up to 3 weeks of focused, high-resolution, continuous time series dive data.
- Continued efforts to apply and improve methods of receiving and signals from sat tags using an ARGOS goniometer remained essential in tracking and re-locating tagged individuals many times to obtain photographs and biopsy samples, and locate other individuals for tagging attempts.

- Extensive progress in publications and many presentations at ESOMM and other recent conferences have been made in terms of baseline behavior and methodological advances, including tag settings, RL modeling, and new behavioral response methods.

4.2 Future Effort and Recommendations

- The Atlantic-BRS project is at a pivotal point going into 2023, in terms of both analysis and subsequent field effort.
- Analytical tools have been developed and applied to the simulated MFAS CEE data set, and the associated publication is well along. This paper will be submitted by summer 2023, and will be followed with common analytical methods in a subsequent paper focusing on operational U.S. Navy vessel CEEs. With the strategically focused single CEE in 2022, the data set for operational MFAS sources is of comparable magnitude. Data have been processed, but effort remains to replicate all analyses and complete the second paper. This will occur in parallel with additional field effort.
- Field efforts in 2023 will pivot to the use of continuously active sonar (CAS) signals. While it is important that experimental methodologies remain as similar as possible in terms of contextual and logistical aspects of field operations, tag settings/types, and others, some modifications will be required. Planning discussions have occurred and are ongoing. An experimental plan summarizing the approach will be provided at or following the April 2023 program review meeting and discussed with the U.S. Navy. Coordination with U.S. Navy vessels should be maintained using identical approaches as previous seasons.
- The combination of sat tags (with series settings for Cuvier's beaked whales) and DTAG deployments should be maintained, with additional effort to simultaneously deploy DTAGs within groups with sat-tagged individuals.
- Further deployments of the study's remaining Fastloc sat tags are recommended for the next season in order to assess their feasibility as well as optimize configurations and settings. The study team will assess the performance of these tags to increase movement model precision around exposures while retaining an ability to uplink simultaneous dive data. Additionally, the study team will attempt to use these Fastloc tags to calibrate a functional relationship between distance and signal strength of boat-based ARGOS goniometer receptions, which could be used to increase the precision of movement modeling across all tags with these receptions.
- Field efforts to locate tagged animals with validated locations using goniometer detections, visual observations, and photo-ID should be maintained before and after CEEs.

5. References

Hewitt, J., R.S. Schick, and A.E. Gelfand. 2021. Continuous-time Discrete-state Modeling for Deep Whale Dives. *JABES* .

Hewitt, J., A.E. Gelfand, N.J. Quick, W.R. Cioffi, B.L. Southall, S.L. DeRuiter, and R.S. Schick. 2022. Kernel density estimation of conditional distributions to detect responses in satellite tag data. *Animal Biotelemetry* 10(1):28.

Quick, N.J., W.R. Cioffi, D.L. Webster, Z.T. Swaim, H.J. Foley, and A.J. Read. 2019. Mind the gap: Optimising satellite tag settings for time series analysis of foraging dives in Cuvier's beaked whales. *Animal Biotelemetry – Short Communication* 7:5. https://doi.org/10.1186/s40317-019-0167-5

Schick, R.S., M. Bowers, S. DeRuiter, A. Friedlaender, J. Joseph, T. Margolina, D.P. Nowacek, and B.L. Southall. 2019. Accounting for Positional Uncertainty When Modeling Received Levels for Tagged Cetaceans Exposed to Sonar. *Aquatic Mammals,* 45(6):675–690. DOI: 10.1578/AM.45.6.2019.675.

Shearer J.M., N.J. Quick, W.R. Cioffi, R.W. Baird, D.L. Webster, H.J. Foley, Z.T. Swaim, D.M. Waples, J.T. Bell, and A.J. Read. 2019. Diving behaviour of Cuvier's beaked whales (*Ziphius cavirostris*) off Cape Hatteras, North Carolina. *Royal Society Open Science* 6:181728.

Southall, B.L, R.W. Baird, M. Bowers, W. Cioffi, C. Harris, J. Joseph, N. Quick, T. Margolina, D. Nowacek, A. Read, R. Schick, and D.L. Webster. 2018. *Atlantic Behavioral Response Study (BRS): 2017 Annual Progress Report*. Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command Atlantic, Norfolk, Virginia, under Contract No. N62470-15-D-8006, Task Order 18F4036, issued to HDR Inc., Virginia Beach, Virginia. July 2018. https://www.navymarinespeciesmonitoring.us/index.php/download_file/view/1792/

Southall, B.L, R.W. Baird, M. Bowers, W. Cioffi, H. Foley, C. Harris, J. Joseph, N. Quick, T. Margolina, D. Nowacek, A. Read, R. Schick, and D.L. Webster. 2019. *Atlantic Behavioral Response Study (BRS): 2018 Annual Progress Report*. Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command Atlantic, Norfolk, Virginia, under Contract No. N62470-15-D-8006, Task Order 18F4036, issued to HDR Inc., Virginia Beach, Virginia. July 2019.

Southall, B.L, M. Bowers, W. Cioffi, H. Foley, C. Harris, J. Joseph, N. Quick, T. Margolina, D. Nowacek, A. Read, R. Schick, and D.L. Webster. 2020. *Atlantic Behavioral Response Study (BRS): 2019 Annual Progress Report*. Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command Atlantic, Norfolk, Virginia, under Contract No. N62470-15-D-8006, Task Order 18F4036, issued to HDR Inc., Virginia Beach, Virginia. July 2020.

Southall, B.L, W. Cioffi, H. Foley, C. Harris, N. Quick, D. Nowacek, A.J. Read, R. Schick, Z.T. Swaim, D.M. Waples, D.L. Webster, and J. Wisse. 2021. *Atlantic Behavioral Response Study (BRS): 2020 Annual Progress Report*. Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Systems Command Atlantic, Norfolk, Virginia, under Contract No. N62470-15-D-8006, Task Order 20F4029, issued to HDR Inc., Virginia Beach, Virginia. March 2021.

Southall, B.L, W. Cioffi, R. Schick, D. Alvarez, H. Foley, C. Harris, N. Quick, D. Nowacek, A.J. Read, Z.T. Swaim, D.M. Waples, D.L. Webster, and J. Wisse. 2022. *Atlantic Behavioral Response Study (BRS): 2021 Annual Progress Report*. Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Systems Command Atlantic, Norfolk, Virginia, under Contract No. N62470-15-D-8006, Task Order 20F4029, issued to HDR Inc., Virginia Beach, Virginia. June 2022.

Southall, B.L., D.P. Nowacek, P.J.O. Miller, and P.L.T. Tyack. 2016. Synthesis of Experimental Behavioral Response Studies Using Human Sonar and Marine Mammals. *Endangered Species Research* 31:291–313. doi:10.3354/esr00764

Southall, B.L., D. Moretti, B. Abraham, J. Calambokidis, and P.L. Tyack. 2012. Marine Mammal Behavioral Response Studies in Southern California: Advances in Technology and Experimental Methods. *Marine Technology Society Journal* 46:46–59.