Atlantic Behavioral Response Study (Atlantic-BRS): 2021 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. 19903 issued to Andy Read/Duke University.

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This project is funded by U.S. Fleet Forces Command and managed by Naval Facilities Engineering Systems Command Atlantic as part of the U.S. Navy's marine species monitoring program.

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Acronyms and Abbreviations

°N	degrees North
°W	degrees West
BRS	Behavioral Response Study
CAS	continuously active sonar
CEE	controlled exposure experiment
DAF	Douglas ARGOS filtered
dB 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
MFAS	mid-frequency active sonar
nm	nautical mile(s)
NPS	Naval Postgraduate School
ONR	Office of Naval Research
photo-ID	photo-identification
R/V	Research Vessel
RL	received level
RMS	root mean square
SEA	Southall Environmental Associates
SLTRD (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
VHF	very high frequency

Executive Summary

The Atlantic Behavioral Response Study (Atlantic-BRS) was conceived, designed, and initiated through a collaboration building on historical and ongoing United States (U.S.) Navy-funded studies under their Marine Species Monitoring Program. It applies a combination of novel multi-scale tagging approaches to accomplish baseline monitoring and behavioral response studies 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 transitions and 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. 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 collaboratively designed and strategically adapted and improved through increasingly successful and effective field effort. A multi-institutional team applies CEE methods involving mid-frequency active sonar (MFAS)—increasingly 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, and it 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 U.S. Navy, Cuvier's beaked whales.

While the COVID-19 pandemic continued to have some influence on field logistics in 2021, field efforts were successfully conducted at comparable levels as previous field campaigns. Building on the first four field seasons of this project (see Southall et al. 2018, 2019, 2020, 2021), Atlantic-BRS field operations in 2021 substantially expanded measurements of beaked whale responses to MFAS, notably during two CEEs with operational MFAS, one of which included the largest number of beaked whales ever directly monitored in any sonar exposure event. The satellite-transmitting tag programming strategy developed was maintained such that each tag deployment included two weeks of fine-scale time series dive data, in addition to much longer typical periods of positional surface data. The approach was maintained of a single extended field period spanning mid-summer into fall, deploying tags in suitable weather windows ahead of known or possible U.S. Navy vessel availability and fielding teams during CEEs as possible, depending on weather.

Two successful CEEs were conducted with operational U.S. Navy vessels—United States Ship (*USS) Farragut* (DDG 99) and *USS Delbert D. Black* (DDG 119). All CEEs included multiple high-priority beaked whales (n=16 total exposure events) and 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. Analyses of diving behavior, potential horizontal avoidance, and changes in social behavior are yielding increasingly complex, large, and published data using existing and newly developed quantitative metrics. Behavioral changes including strong observed avoidance responses, and changes in diving were again documented during both 2021 operational MFAS source CEEs. More than a dozen peer-reviewed manuscripts regarding

this project are published or well along in the process, and the project will be strongly represented at the upcoming Effects of Sound in the Ocean on Marine Mammals (ESOMM-2022) meeting; abstracts accepted to that meeting are provided in **Section 3 -** Analytical Developments, Results, and Publications and Presentations.

1. Overview

1.1 Overall Project Design and Objectives

The Atlantic Behavioral Response Study (Atlantic-BRS) has been conducted for the past five years (2017 through 2021) through a research collaboration of scientists from Duke University, Southall Environmental Associates (SEA), and the University of St. Andrews. The overall experimental design 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 Cuvier's beaked whales (*Ziphius cavirostris*) and short-finned pilot whales (*Globicephala macrorhynchus*) 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 increasing success and reliable coordination with operational MFAS systems from U.S. Navy surface vessels (e.g., SQS-53C-equipped combat vessels) as well as experimental sound sources simulating these systems.

Given the maturity of the project and the stability in the goals and methods in the past several years, this report briefly summarizes objectives and methods and then focuses primarily on summarizing the field results and ongoing analyses conducted within the 2021 field season. This report also provide a synthesis of the increasingly large number of peer-reviewed papers that have been or are in the process of being published as well as the large number of technical aspects on baseline data, methods development, and behavioral response that were recently presented at the 7th International Conference on the Effects of Sound in the Ocean on Marine Mammals (ESOMM-2022) meeting in Beaufort, North Carolina that was co-chaired by the three lead investigators of the Atlantic-BRS.

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 brings both approaches together and builds on previous experience with both tag types for focal species within the same area. Specifically, the project expands the temporal and spatial scales of previous BRS efforts by combining 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 satellite-linked, time-depth recording tags (SLTRDs 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. As in previous studies, explicit monitoring and mitigation protocols have been established and followed in conducting CEEs 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 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 yielded thus far have already been directly applicable to the U.S. 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 and exposure-response and provide sufficiently large sample sizes to begin addressing questions related to consequences, directly addressing focal areas for the U.S. Navy's Marine Species Monitoring Program.

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 for scientific and general audiences.

1.2 Experimental Design

The overall experimental design has not fundamentally changed in the past year, and readers are referred to earlier reports and published papers from other U.S. Navy-funded work (Southall et al. 2012, 2016, 2019) and Atlantic-BRS publications referenced later for additional details in the design and implementation of these methods. However, the approach involves multiple different kinds of monitoring methodologies and platforms, incorporating lessons learned from a variety of 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 deployed in the general area.

Through close coordination with project collaborators at the U.S. Fleet Forces Command, 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 data periods were much longer (typically 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 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). 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; hereafter dB unless otherwise specified) signals of a constant nominal 53-C waveform type (single ping sequence using three sequential CP/CW 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° 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 the position of a focal animal, 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 were estimated (with error) from positions derived from either sat 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. 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 resolution during a focal period when U.S. Navy ships were expected to be available or simulated MFAS CEEs could otherwise be conducted. The objective was therefore to conduct one CEE within each 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. 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 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, as expected, by the third full field season in 2019 they were sufficiently well developed and efficient that they were largely maintained and applied to the large 2021 data set (see Southall et al. 2020: Section 1.3). All figures included here, as well as those generated for all CEEs and all non-focal individuals, are available here and are 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 2021 mirrored the successful 2020 approach in which field work would occur during a single window beginning in July and extending through October. Based on a combination of anticipated U.S. Navy vessel availability and weather conditions, a boat-based team was deployed for advance deployment of sat tags from a small team (n=4) aboard the Research Vessel (*R/V*) *Barber*, an 8-meter 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 six individuals worked from *R/V Shearwater* (the newly acquired Duke University research fast catamaran) along with, in reasonable conditions, the R/V *Barber* (with an identical crew of four, as above). The *R/V Shearwater* served as an excellent elevated tag tracking and visual observation platform before, during, and after CEEs. These vessels were involved in all tag deployment and CEE efforts, as well as in re-sighting and biopsy sampling of focal individuals thereafter.

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 also 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® Global Positioning Systems were available but not deployed. The highest tagging priority was on Cuvier's beaked whales as this species is of high U.S. Navy interest; pilot whales were identified as a secondary priority but were not tagged in 2021. 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.

Building on successes in 2020 necessitated by the pandemic to remotely coordinate U.S. Navy vessels during field operations, considerable advance planning and coordination occurred within the field team and with the U.S. Navy sponsors and coordination team. The modified and highly successful approach was for extensive and sustained planning discussions between the Atlantic-BRS team and U.S. 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 U.S. Navy personnel coordinated with vessels in the field remotely from onshore sites through secure communications. This approach resulted in two well-coordinated and successful CEEs with operational U.S. 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 U.S. Navy team provided all requested positional and operational data in an unclassified communication related specifically to Atlantic-BRS CEEs.

The pandemic severely limited travel and open meetings, including the U.S. Navy's marine species monitoring program technical review meeting scheduled for spring 2021 that was conducted virtually. However, the Atlantic-BRS team strove to provide information transparently through Duke University Marine Lab (DUML) and SEA blogs and direct coordination with the U.S. Navy on a press release and several associated media stories resulting from the 30 July 2021 CEE with the United States Ship (*USS) Farragut.*[1] Results are increasingly being presented in peer-reviewed papers and scientific meetings (see **Section 3**).

Also of note is that for accomplishments to date in the project, U.S. Fleet Forces Command (USFFC) nominated the Atlantic-BRS team for the 2022 Secretary of Navy Natural Resources Conservation – Team Award. The nomination stated:

> The Atlantic-BRS team consists of U.S. Navy civilians, contractors, and researchers. The objective of this project is to conduct scientific field studies to assess the behavioral responses of marine mammals to mid-frequency active sonar (MFAS) in support of Atlantic Fleet Training and Testing (AFTT) regulatory requirements and Navy environmental stewardship responsibilities. This project is funded by USFFC and managed by Naval Facilities Engineering Systems Command (NAVFAC) Atlantic as part of the U.S. Navy's Marine Species Monitoring Program. Partners on this project include: Southall Environmental Associates, Inc., Duke University Marine Laboratory, Bridger Consulting, University of St. Andrews Sea Mammal Research Unit (SMRU), HDR, Inc., Calvin College, and the Naval Postgraduate School.

[1] See links provided at:
https://sites.nicholas.duke.edu/read/2021/08/06/first-cee-of-2021/
https://www.usff.navy.mil/Press-Room/News-Stories/Article/2722664/navy-conducts-marine-mammal-study-off-cape-hatteras/
https://l.facebook.com/l.php?u=https%3A%2F%2Fwww.usff.navy.mil%2Fenvironmental%2F%3Ffbclid%3DIwAR1cxJhFPsE0x5JE5wJh9E-xPGG4VJL_7wUF0e5ycz6GmPfXvo-vjC503bY&h=AT36SJJiYAgX7l_JqQWw-WxcXCiT6OML2tptLgWCABN-t3D8qFxomxPepIYwJFgHG6ZK7I7g3_2BYRAphZ8xcxatToHbVebh_ww2cbbkER-lOnhS5_B6r46qGIypy-eX_8H0IA

2. Field Effort

2.1 Summary of 2021 Field Effort: Accomplishments and Assessment

Field dates:

- **15 June**: First possible field effort following all requisite development and implementation of testing, quarantine, and travel protocols for the advance tag deployment team. The field team began mobilizing, but mechanical issues with the *R/V Barber* and supply chain issues getting replacement parts provided some delays and challenges.
- **29 June – 6 July**: Field effort on weather permitting days from the *R/V Barber* resulted in **10 beaked whale sat tag deployments** ahead of U.S. Navy ship availability slated for 15 July.
- **13 July**: The *R/V Shearwater* deployed from DUML to Hatteras field area to support tagging and tracking ahead of CEE operations.
- **15 July**: The *R/V Barber* and *R/V Shearwater* conducted on water tracking of tagged whales and successfully deployed a DTAG on another Cuvier's beaked whale in the area around already sat tagged whales (n=10). The ship planned for coordination suffered an engineering casualty and was not available for the CEE. The team continued to track the whales, including the DTAG whale. This tag malfunctioned and did not release as anticipated. It was ultimately recovered 2 days later after an extensive search and only because of the external very high frequency (VHF) antenna. Several hours of data were ultimately recovered but this did not include any exposure periods or the targeted overnight period.
- **26–28 July:** Second wave of satellite-tagging field effort on weather permitting days from *R/V Barber* resulting in **three additional beaked whale tag deployments** ahead of U.S. Navy ship availability.
- **30 July**: **CEE #2021_01 successfully coordinated in the field with *USS FARRAGUT*** with 12 of 13 focal whales tagged previously (one tag failed shortly before the CEE). Weather conditions precluded direct involvement of the *R/V Barber* but the *R/V Shearwater* was in good focal follow with three focal Cuvier's beaked whales using goniometer detections and some focal follow observations of focal whales.
- **16–17 August**: Following several potential U.S. Navy ships that were unavailable, the *R/V Barber* team conducted a field effort to relocate tagged whales and collect 13 Cuvier's beaked whale biopsy samples and many photo-IDs, including from focal whales involved in CEE #2021_01.
- **11–15 September**: Third wave of satellite-tagging field effort on weather permitting days from the *R/V Barber*, resulting in **three additional beaked whale tag deployments** ahead of U.S. Navy ship availability.

- **23 September:** The *R/V Shearwater* deployed from DUML to Hatteras field area to support tagging and tracking efforts ahead of CEE operations. Two potential vessels had been slated for coordination just before and after this period but were unavailable; however, another vessel was identified for several days out from this.
- **25 September: CEE #2021_02 successfully coordinated in the field with the *USS Delbert D. Black*** with four focal whales tagged previously (one recently deployed tag failed shortly before the CEE). Both the *R/V Barber* and *R/V Shearwater* were in the field and in good focal follow with two focal Cuvier's beaked whales using goniometer detections and some visual observations of focal whales.
- **26–29 September:** Completed follow-up re-sightings, photo-ID, in situ data acquisition, and biopsy effort from focal whales.
- **19 November**: Last data message from 2021 Cuvier's beaked whale sat tags.

Accomplishments:

- Fielding an effective team and successfully completing a comparable level of tag deployments and CEEs as in previous years despite continuing travel, workplace restrictions, and supply chain issues due to the ongoing pandemic.
- Successful deployment of 16 sat tags (all Cuvier's beaked whales).
- Two successful CEEs with operational U.S. Navy vessel, full-scale 53C MFAS CEEs. Both were conducted at or near Cuvier's beaked whale target RLs (140 dB RMS).
- Continued success with 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 and an extensive and remarkable DTAG recovery despite tag release failure.
- Successful deployment, tracking, and recovery of a long-duration (20-plus hour) DTAG on priority Cuvier's beaked whale, which includes long-sought-after overnight baseline deployment. Unfortunately, it did not release when planned due to tag malfunction and while 4.8h of data were ultimately extracted, none of the sought baseline overnight data were obtained from this tag.
- 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 collect a large number of biopsy samples, including of focal whales.
- Sustained high-quality satellite-transmitting tag dive data thanks to earlier progress in tag deployment strategies to reduce/eliminate gaps in sat tag data and to improve temporal resolution on diving and behavioral data. Successfully collected continuous dive data for 2-week periods, strategically covering CEE periods, as designed. Long duration (up to 79 days) function of tags in reporting ARGOS positions was again experienced, potentially due to improved batteries in SPLASH tags.

Assessment of field approach:

- Fielding a team safely given all the persistent challenges with the pandemic was again remarkable and a testament to the adaptability and determination of the field team.
- Sustained success using advance planning and support and close coordination among members of the research team and the USFFC team. Land-land and at-sea coordination between research and operational vessels was also successfully coordinated.
- Very good conditions occurred during several windows, with workable weather at least in July and September when tags were deployed and CEEs were conducted. Overall, weather conditions were not optimal for most days, including both CEE days.
- Continued to have success in locating and tagging Cuvier's beaked whales, to the point where no second priority pilot whales were tagged in 2021.
- DTAG deployments were limited by tag failures, including a number that were sent back for repairs and/or replacement and a long-duration (20-plus hour) baseline tag that failed ~ 5h into the deployment. While this tag was very likely on the focal whale for the duration or longer and would have been useful to assess diurnal behavior previously unavailable for this location, it did not successfully release as planned and was barely recovered. Modifications to overcome previous VHF limitations were the only reason the tag was recovered at all. Unfortunately, no overnight baseline data were collected but several hours of data prior to failure were extracted.

2.2 Tag Deployments

Sat tag deployments were conducted by researchers from Bridger Consulting in coordination with the Atlantic-BRS team aboard Duke University vessels. A summary of sat tag deployments for 2021 is provided in **Table 1**. Overall, 16 sat tags were deployed—all on Cuvier's beaked whales. Maps showing Douglas-filtered ARGOS positions for all Cuvier's beaked whales tagged in 2021 are shown in **Figure 1**. Individual (by-animal) plots of Douglas-filtered ARGOS positions are also given for the entire sat tag deployment periods (for tags that successfully transmitted data) for Cuvier's beaked whales (**Figures 2** through **16**). For whales that were tagged during CEEs, the start and end location of the respective CEEs are indicated on the individual plots.

One DTAG was deployed on a Cuvier's beaked whale during the 2021 field effort (**Table 2**), but as noted above, only limited baseline data were collected from this tag due to battery failure.

Table 1. Satellite tag deployments for Cuvier's beaked whales during Atlantic-BRS field efforts in 2021

Species[a]/ Tag ID	Deployment date	Deployment latitude (°N)	Deployment longitude (°W)	Dive data streams	Tag duration (days)
ZcTag112	06/29/21	35.5471	-74.7080	5-min time series	31
ZcTag113	06/29/21	35.5470	-74.7038	5-min time series	67
ZcTag114	06/29/21	35.5318	-74.7181	5-min time series	76
ZcTag115	07/05/21	35.4441	-74.7325	5-min time series	26
ZcTag116	07/05/21	35.4416	-74.7438	5-min time series	57
ZcTag117	07/05/21	35.4373	-74.7327	5-min time series	58
ZcTag118	07/06/21	35.4262	-74.6778	5-min time series	66
ZcTag119	07/06/21	35.4264	-74.6656	5-min time series	72
ZcTag120	07/06/21	35.4190	-74.5990	5-min time series	70
ZcTag121	07/06/21	35.4206	-74.6145	5-min time series	60
ZcTag122	07/27/21	35.6263	-74.7552	5-min time series	79
ZcTag123	07/27/21	35.6101	-74.7645	5-min time series	71
ZcTag124	07/27/21	35.5580	-74.7641	5-min time series	42
ZcTag125	09/12/21	35.5870	-74.6807	5-min time series	68
ZcTag126	09/14/21	35.4883	-74.7432	5-min time series	62
ZcTag127	09/14/21	35.4842	-74.7461	5-min time series	5

Key: °N=degrees North; °W=degrees West; min=minute

[a] Zc = *Ziphius cavirostris*

Table 2. DTAG deployments for Cuvier's beaked whales during Atlantic-BRS field efforts in 2021

Tag ID[a]	Deployment date	Deployment latitude (°N)	Deployment longitude (°W)	Baseline or CEE number	Tag duration	Recovered?
Zc21_196a	7/15/21	35.6140	-74.5850	Baseline	20+ hours	Yes, but battery malfunction; 4.8h data obtained without CEE exposure or baseline diurnal data

[a] Zc = *Ziphius cavirostris*

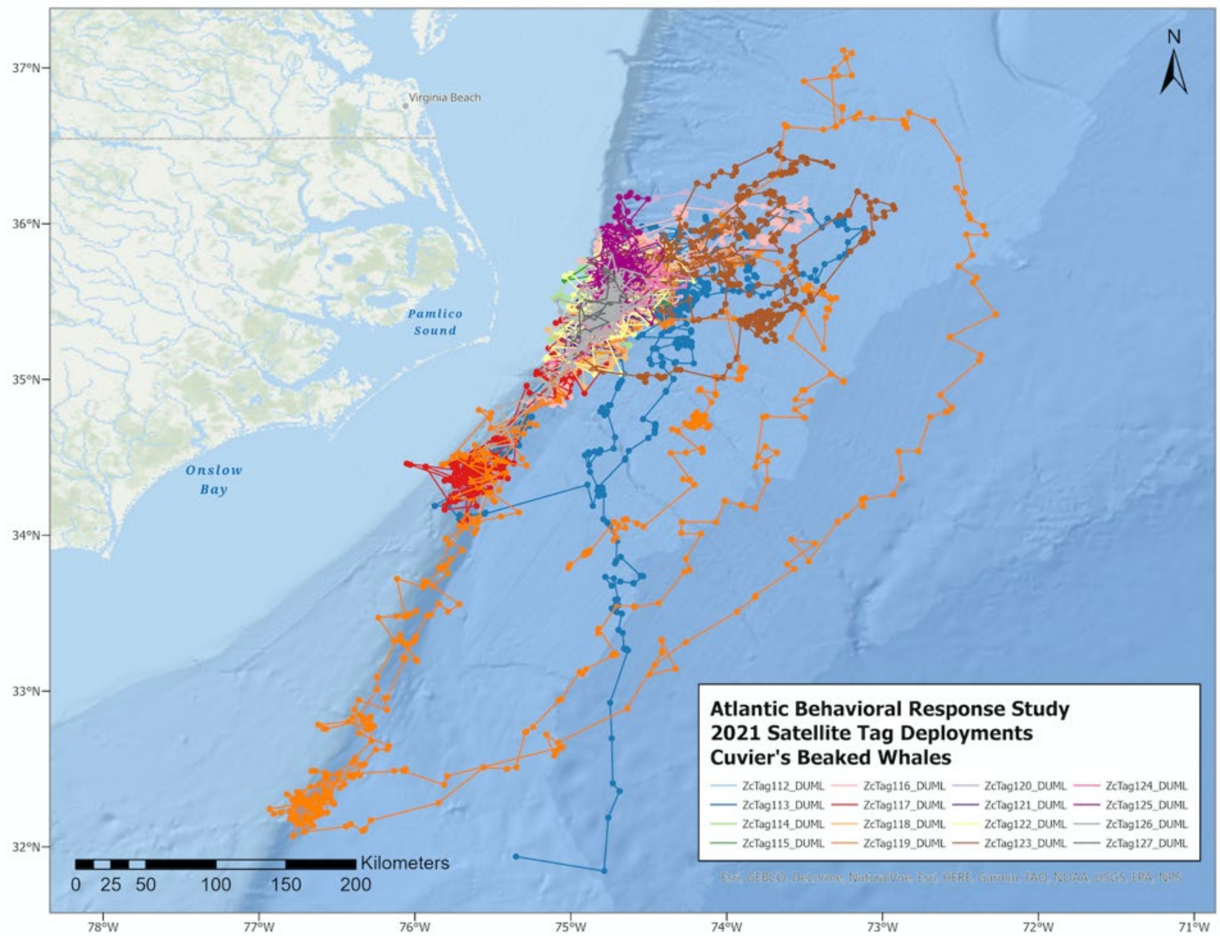

Figure 1. Douglas-filtered ARGOS positions for all Cuvier's beaked whales (n=16) tagged during Atlantic-BRS field efforts in 2021

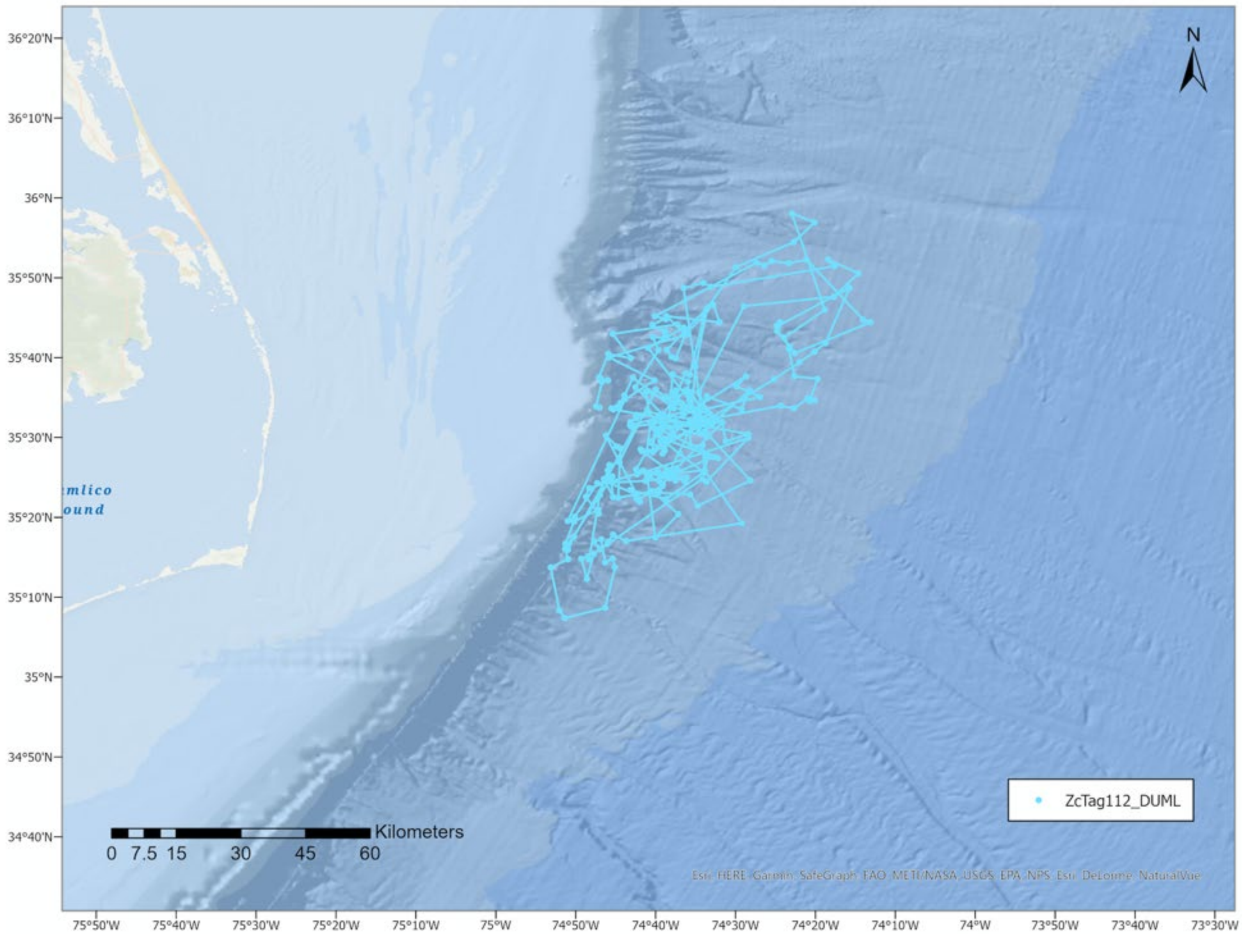

Figure 2. Douglas-filtered ARGOS positions for entire track of ZcTag112 (tag duration 31 days); no CEE locations are shown as this tag ceased functioning prior to either 2021 CEE

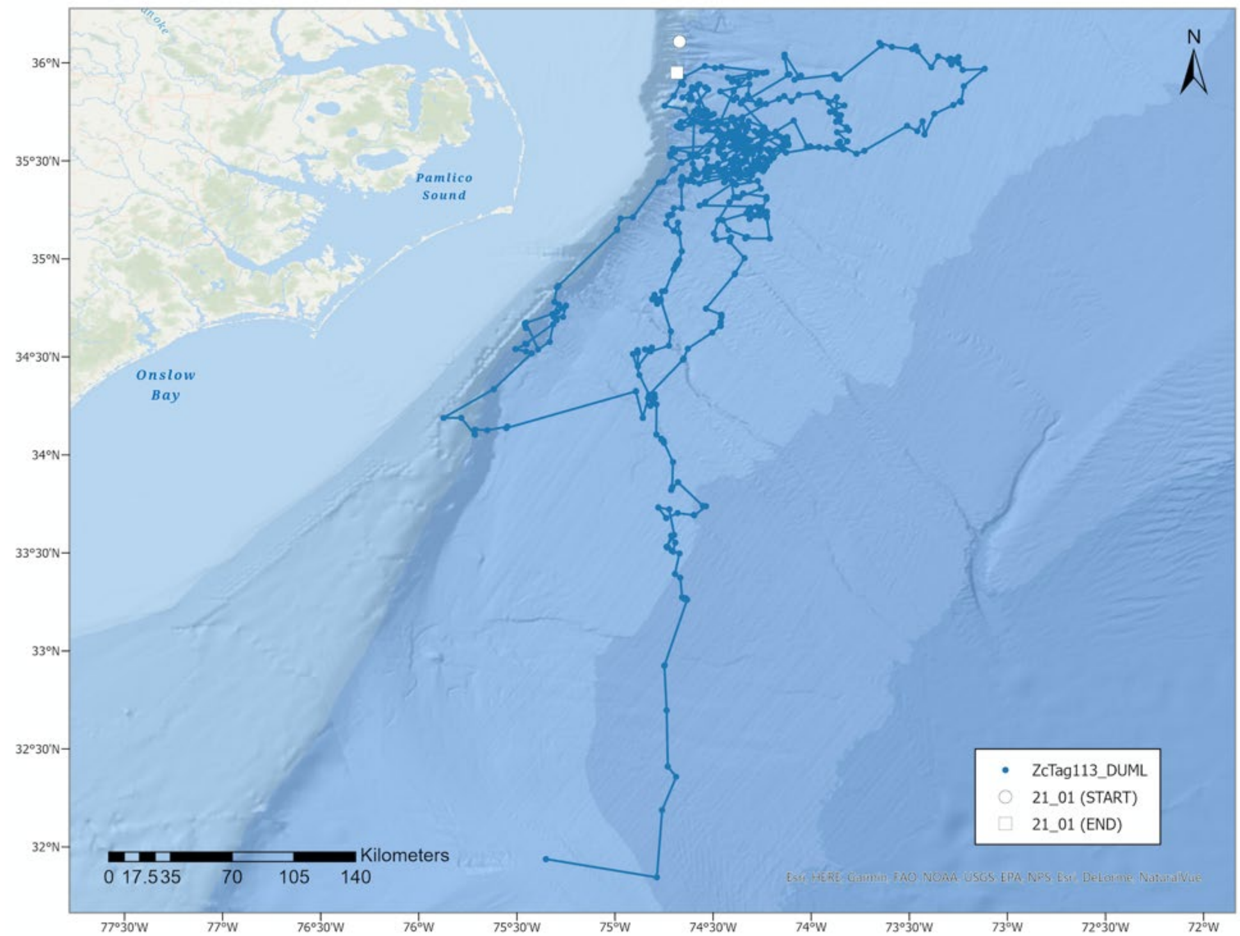

Figure 3. Douglas-filtered ARGOS positions for entire track of ZcTag113 showing positions of CEEs conducted while tag was deployed (tag duration 67 days)

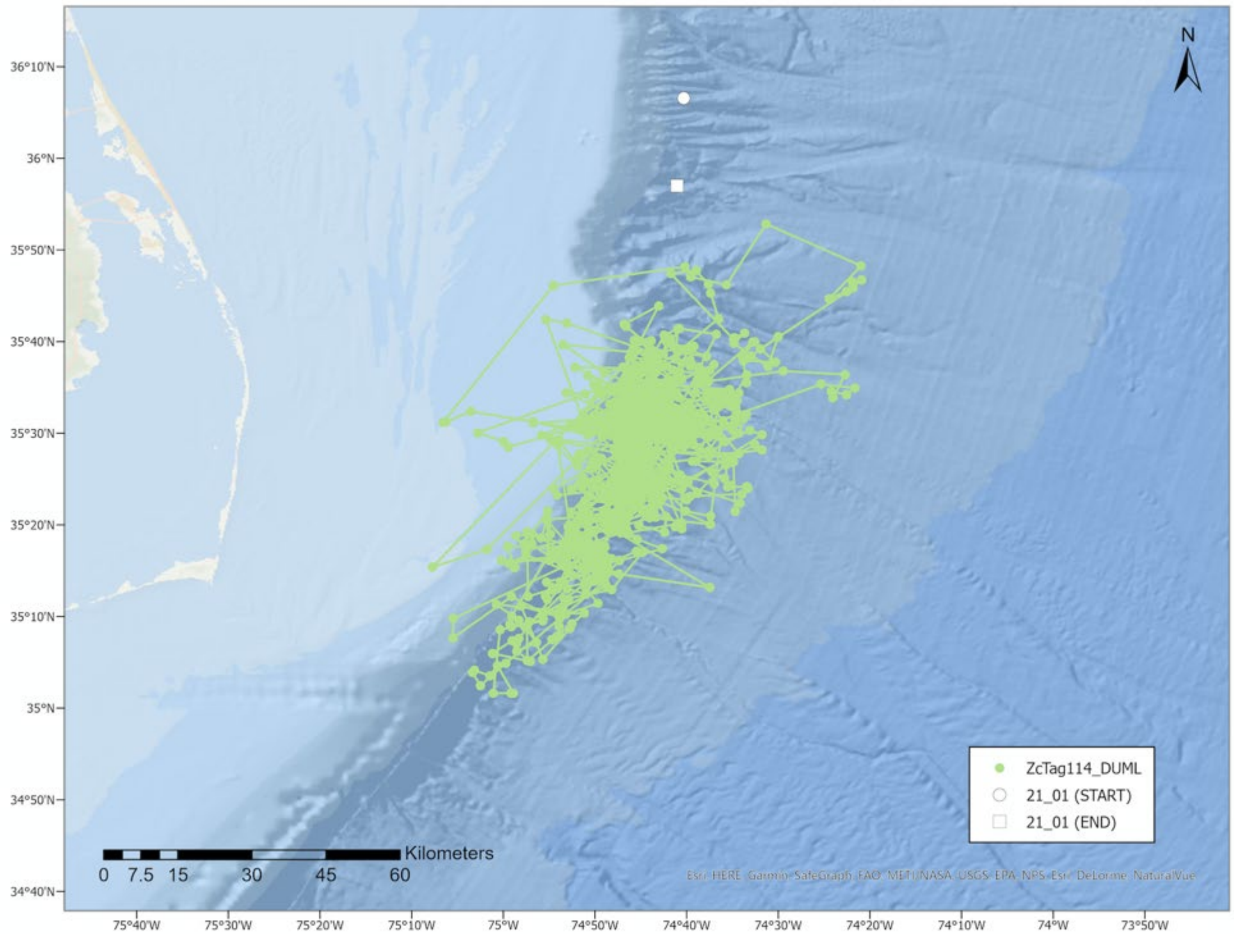

Figure 4. Douglas-filtered ARGOS positions for entire track of ZcTag114 showing positions of CEEs conducted while tag was deployed (tag duration 76 days)

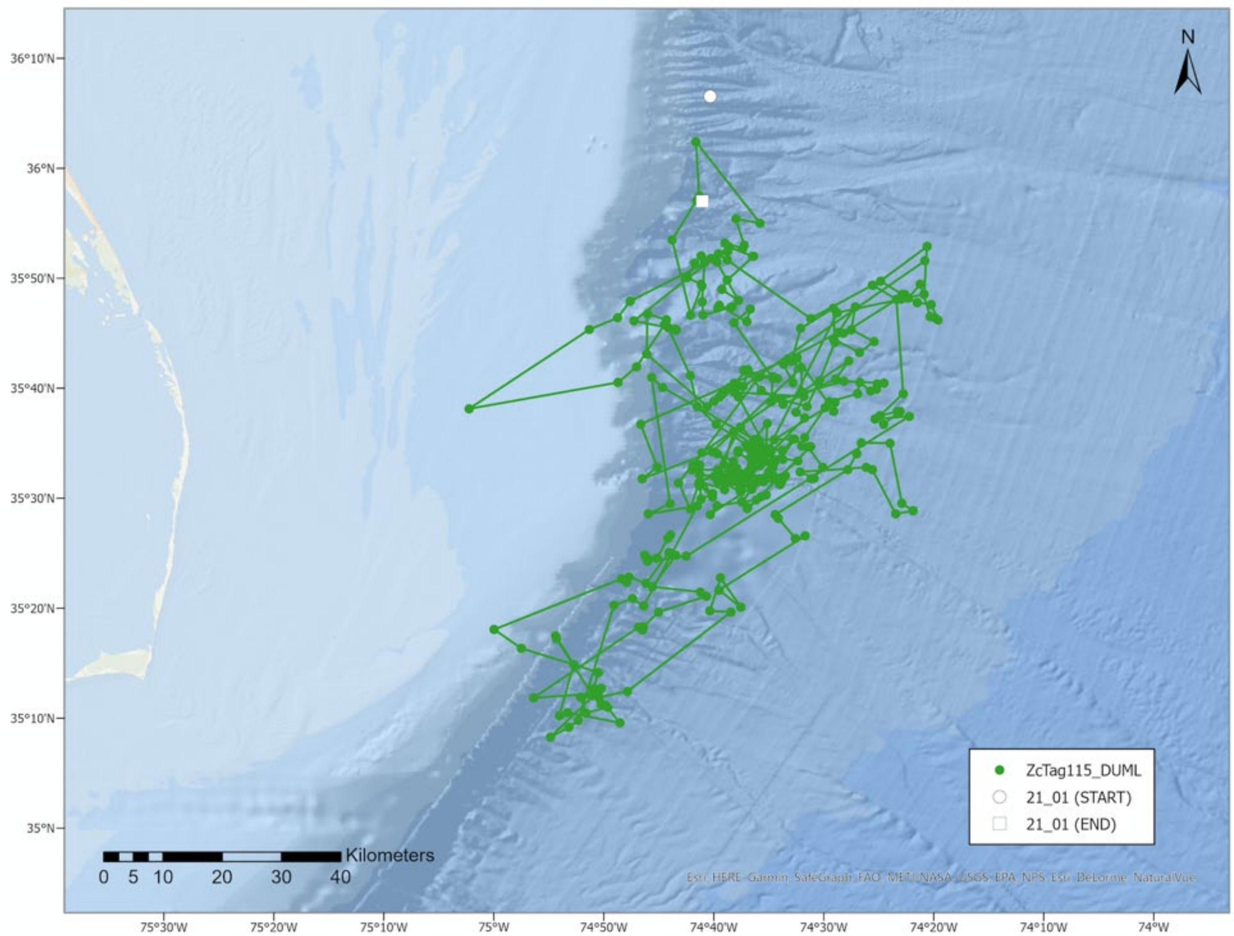

Figure 5. Douglas-filtered ARGOS positions for entire track of ZcTag115 showing positions of CEEs conducted while tag was deployed (tag duration 26 days)

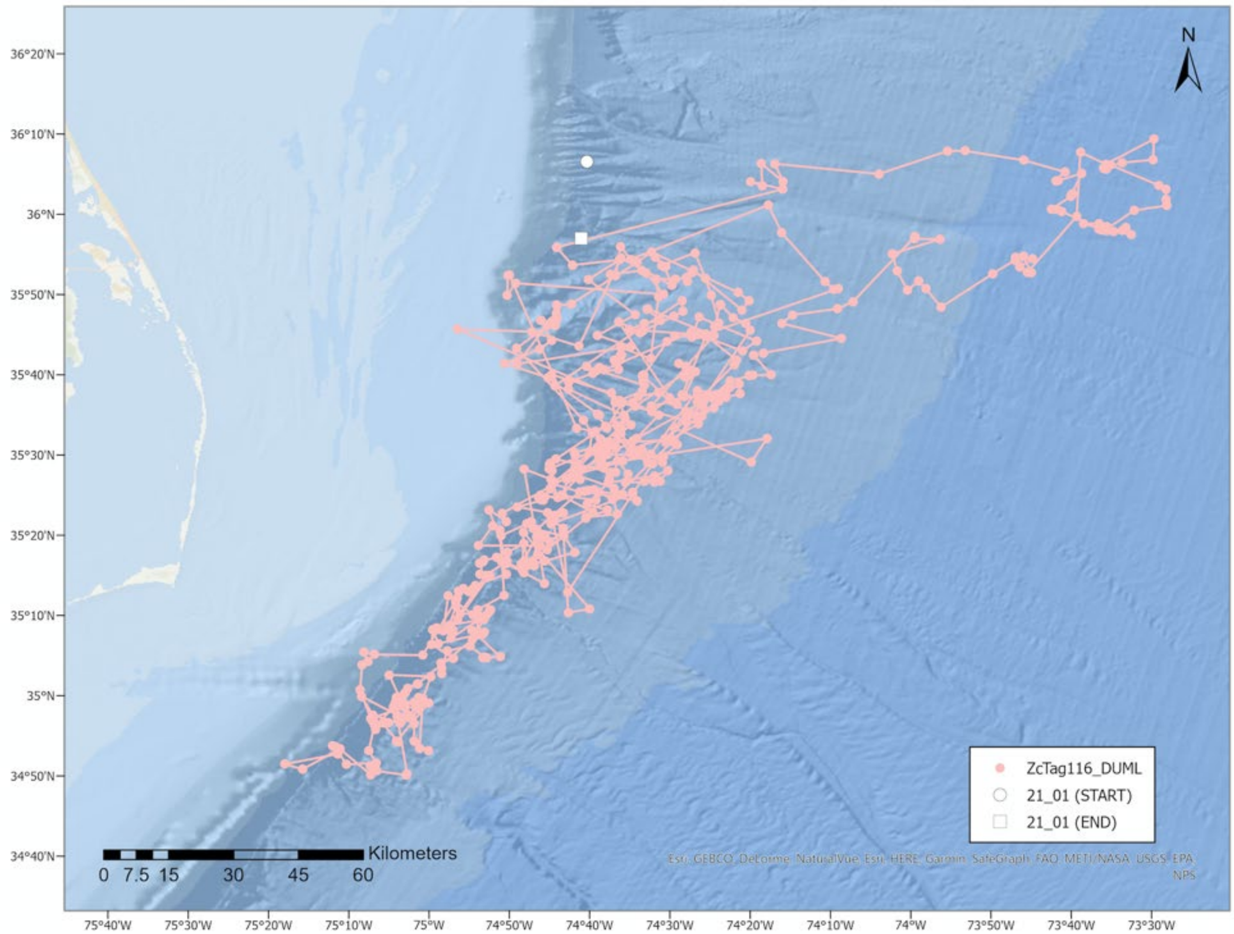

Figure 6. Douglas-filtered ARGOS positions for entire track of ZcTag116 showing positions of CEEs conducted while tag was deployed (tag duration 57 days)

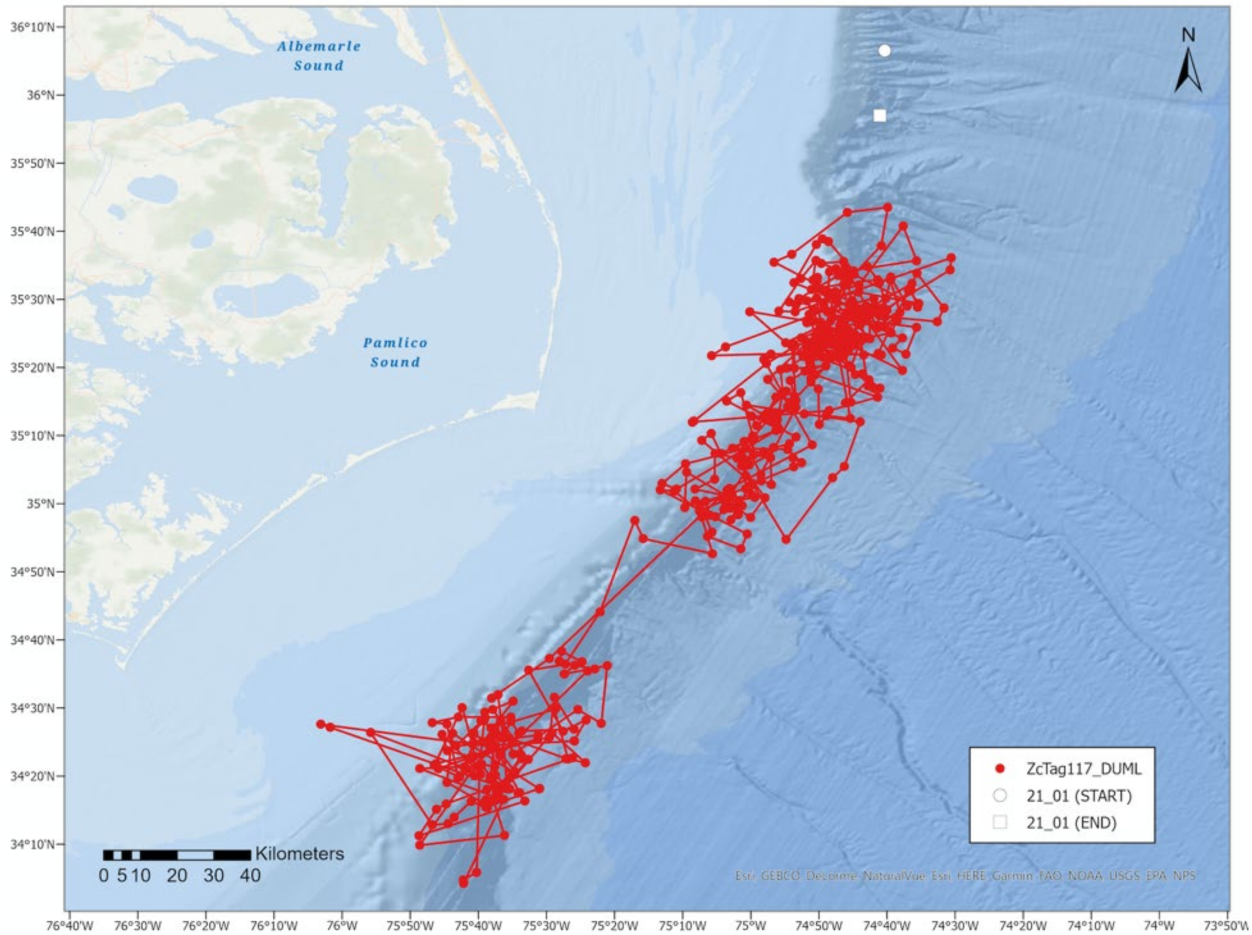

Figure 7. Douglas-filtered ARGOS positions for entire track of ZcTag117 showing positions of CEEs conducted while tag was deployed (tag duration 58 days)

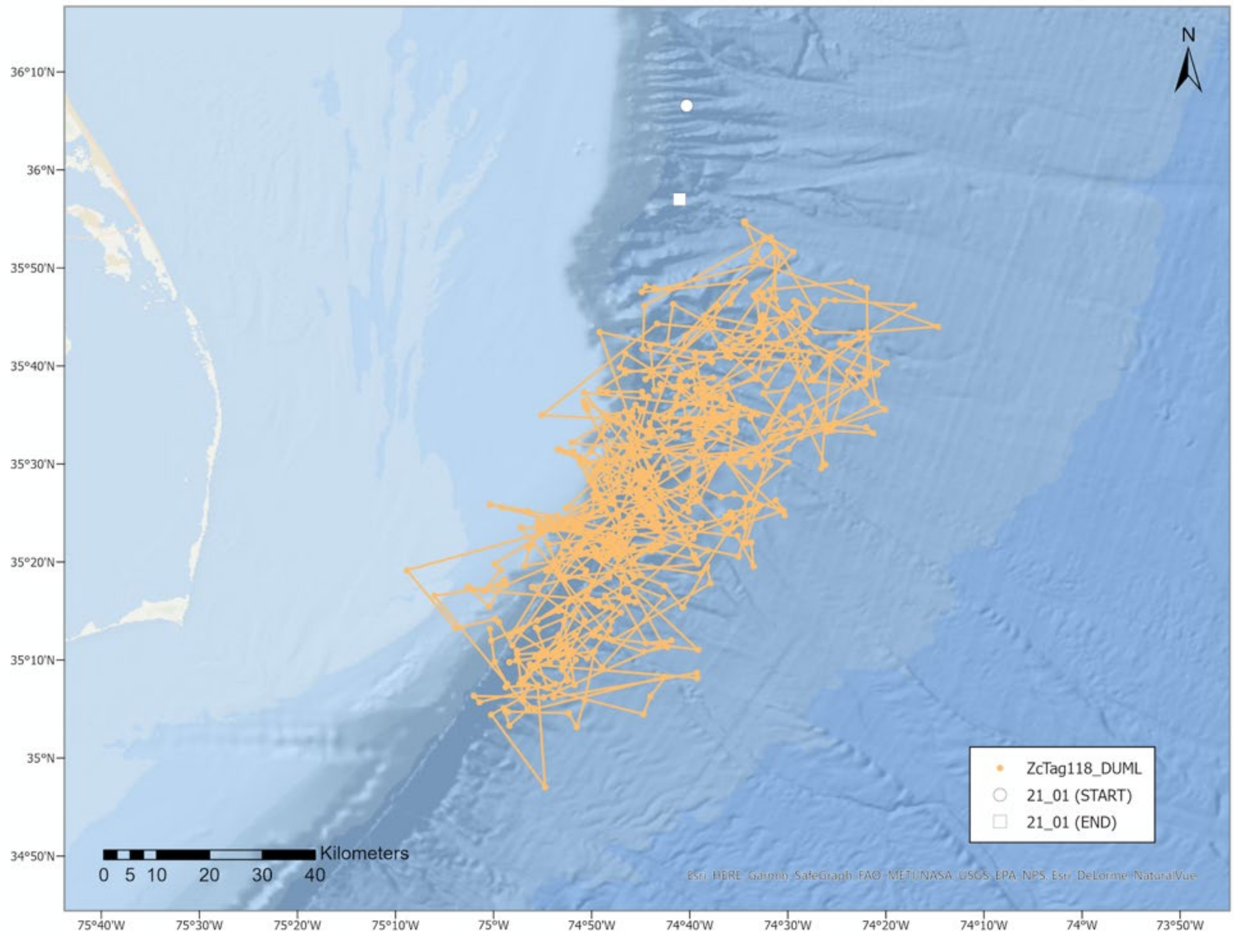

Figure 8. Douglas-filtered ARGOS positions for entire track of ZcTag118 showing positions of CEEs conducted while tag was deployed (tag duration 66 days)

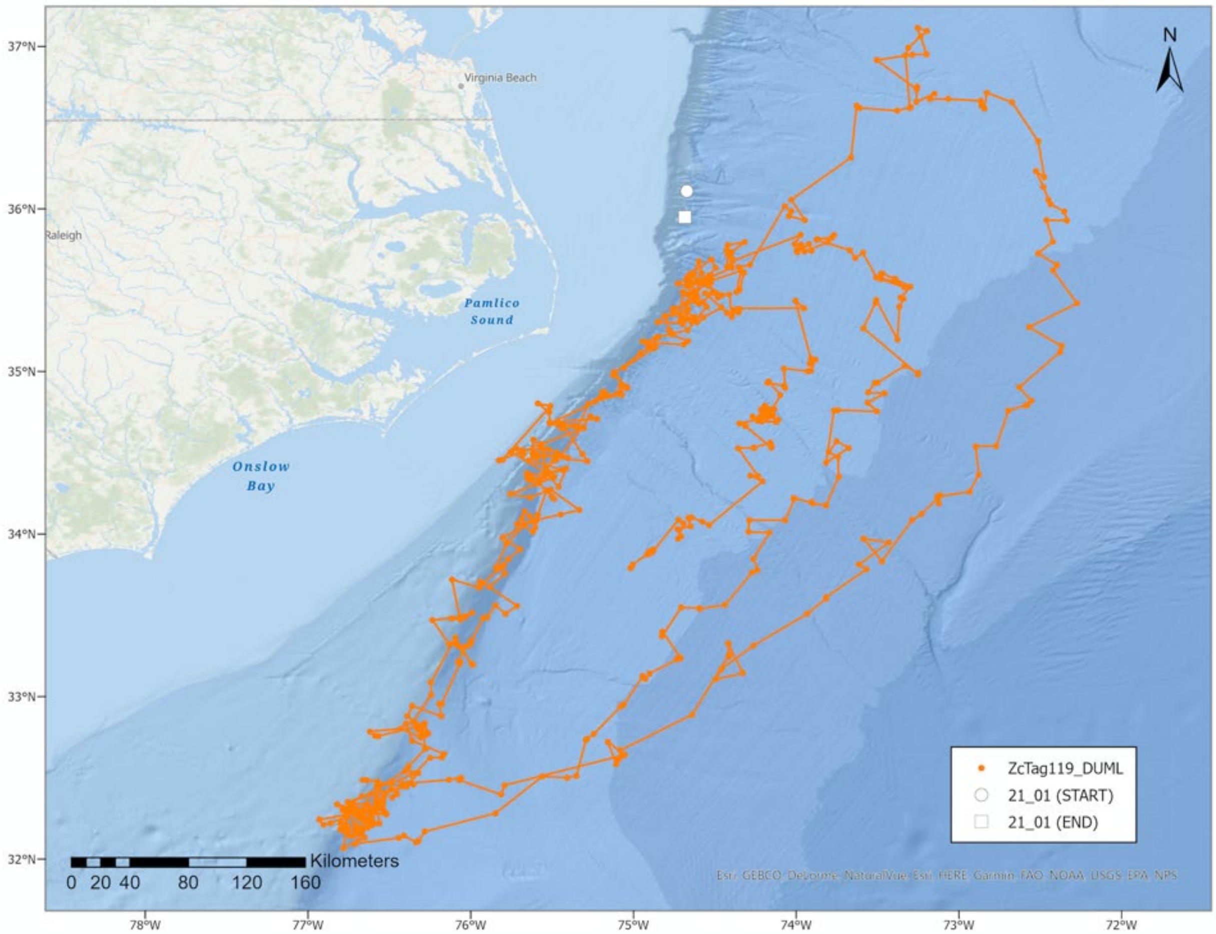

Figure 9. Douglas-filtered ARGOS positions for entire track of ZcTag119 showing positions of CEEs conducted while tag was deployed (tag duration 72 days)

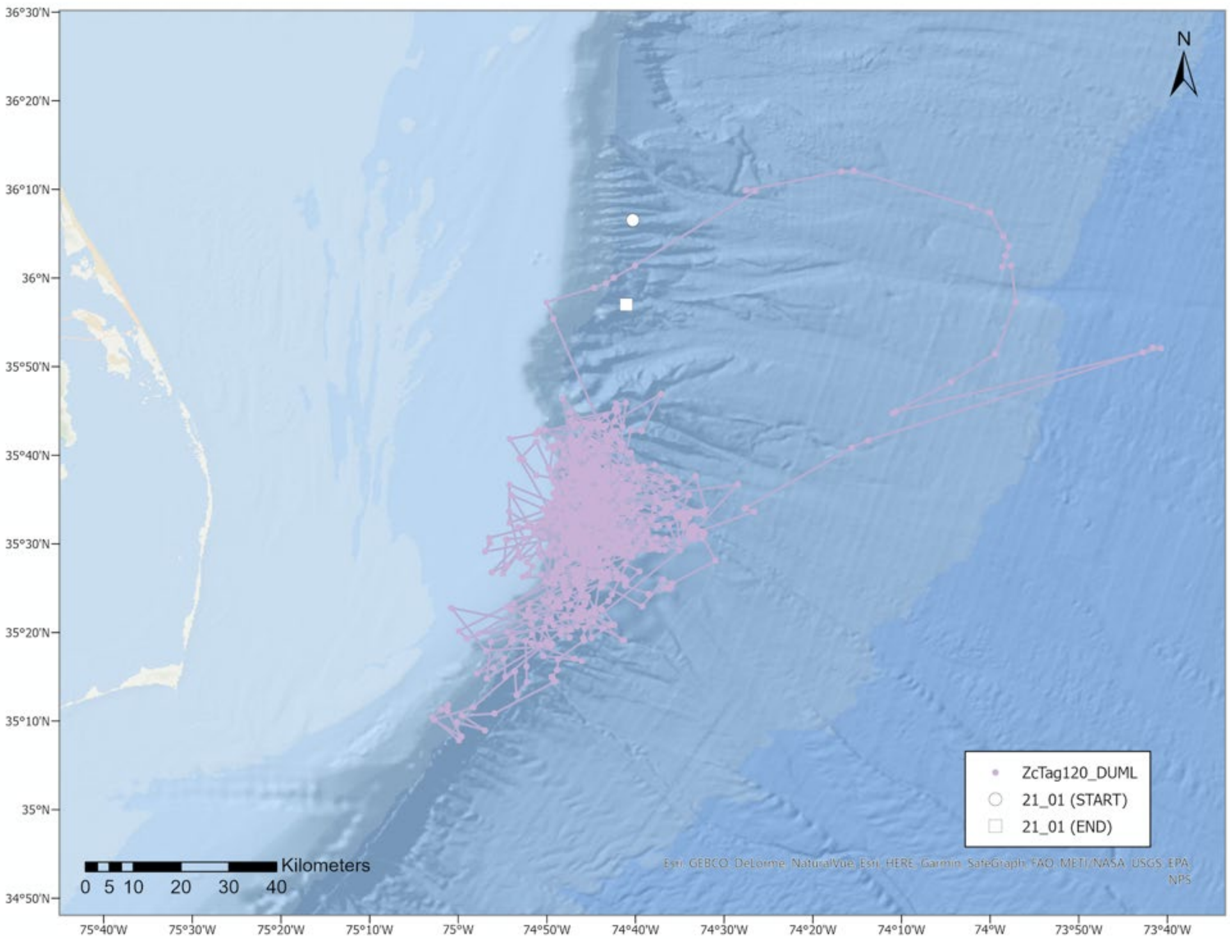

Figure 10. Douglas-filtered ARGOS positions for entire track of ZcTag120 showing positions of CEEs conducted while tag was deployed (tag duration 70 days)

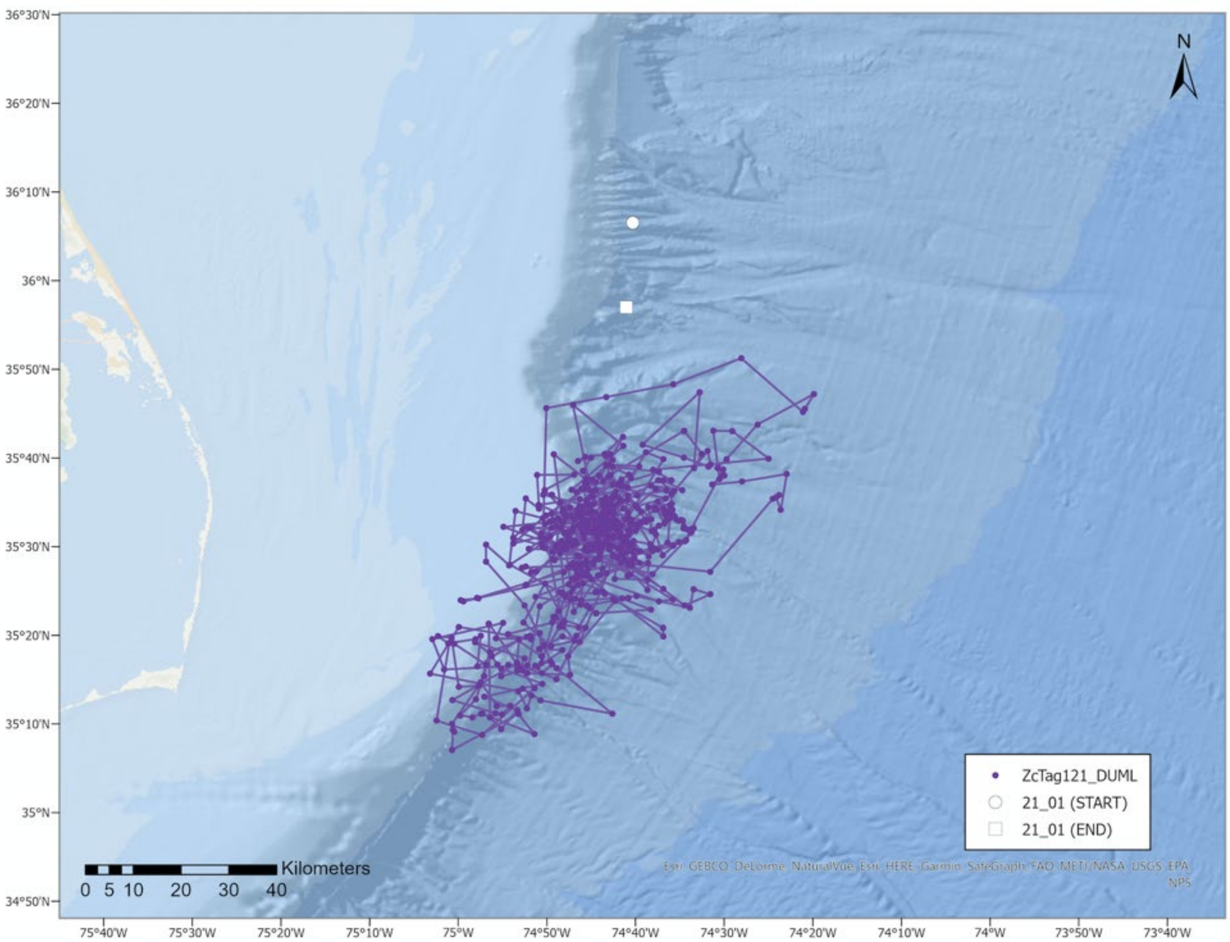

Figure 11. Douglas-filtered ARGOS positions for entire track of ZcTag121 showing positions of CEEs conducted while tag was deployed (tag duration 60 days)

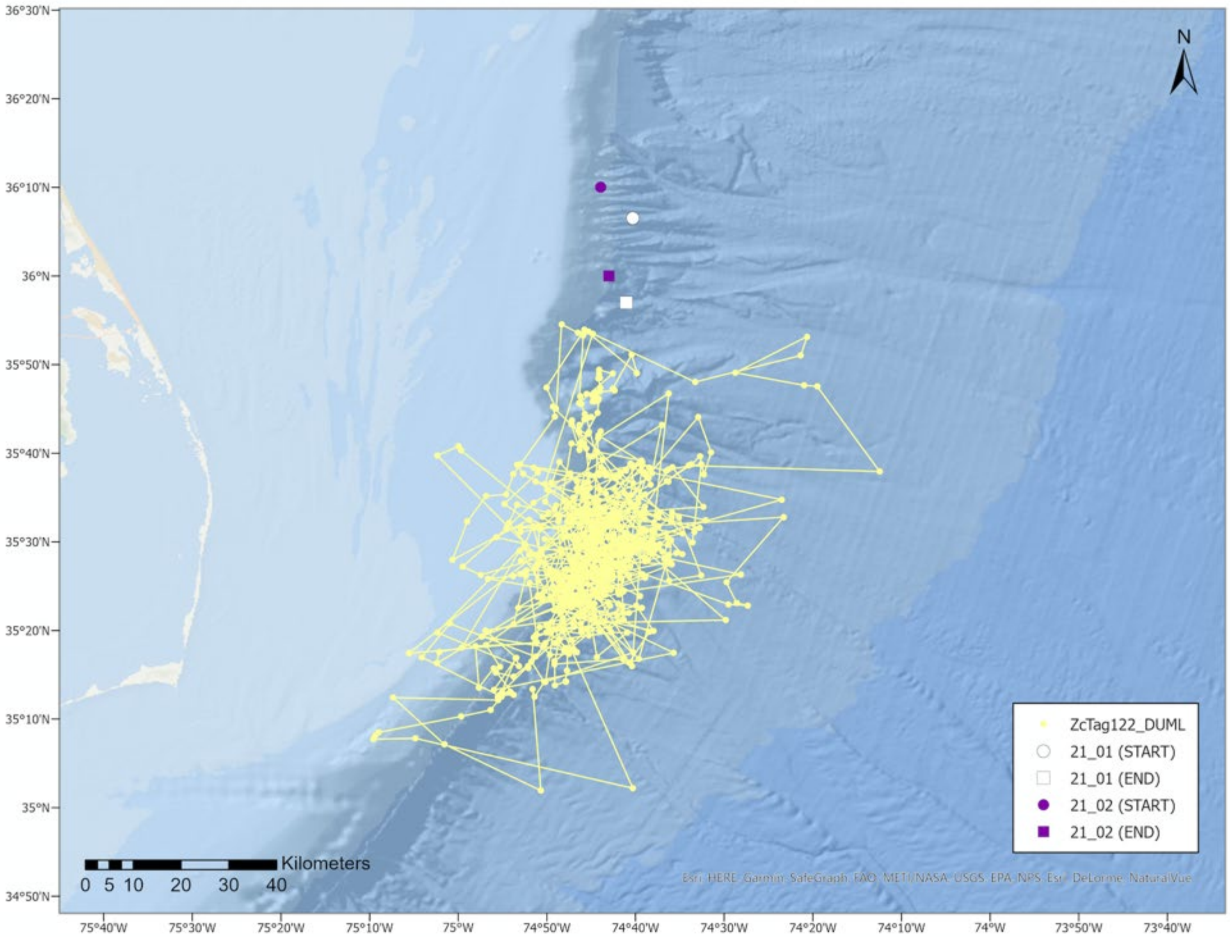

Figure 12. Douglas-filtered ARGOS positions for entire track of ZcTag122 showing positions of CEEs conducted while tag was deployed (tag duration 79 days)

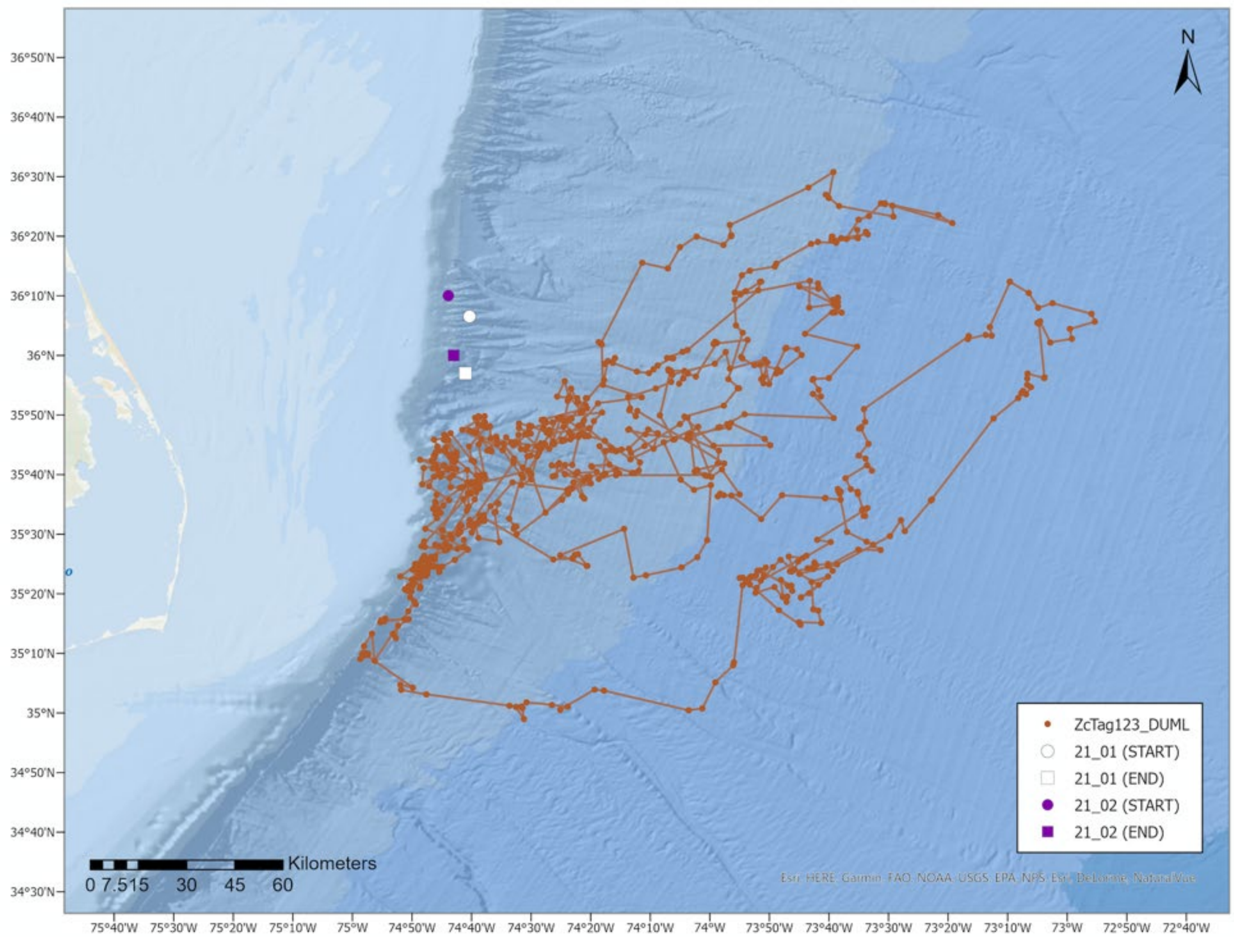

Figure 13. Douglas-filtered ARGOS positions for entire track of ZcTag123 showing positions of CEEs conducted while tag was deployed (tag duration 71 days)

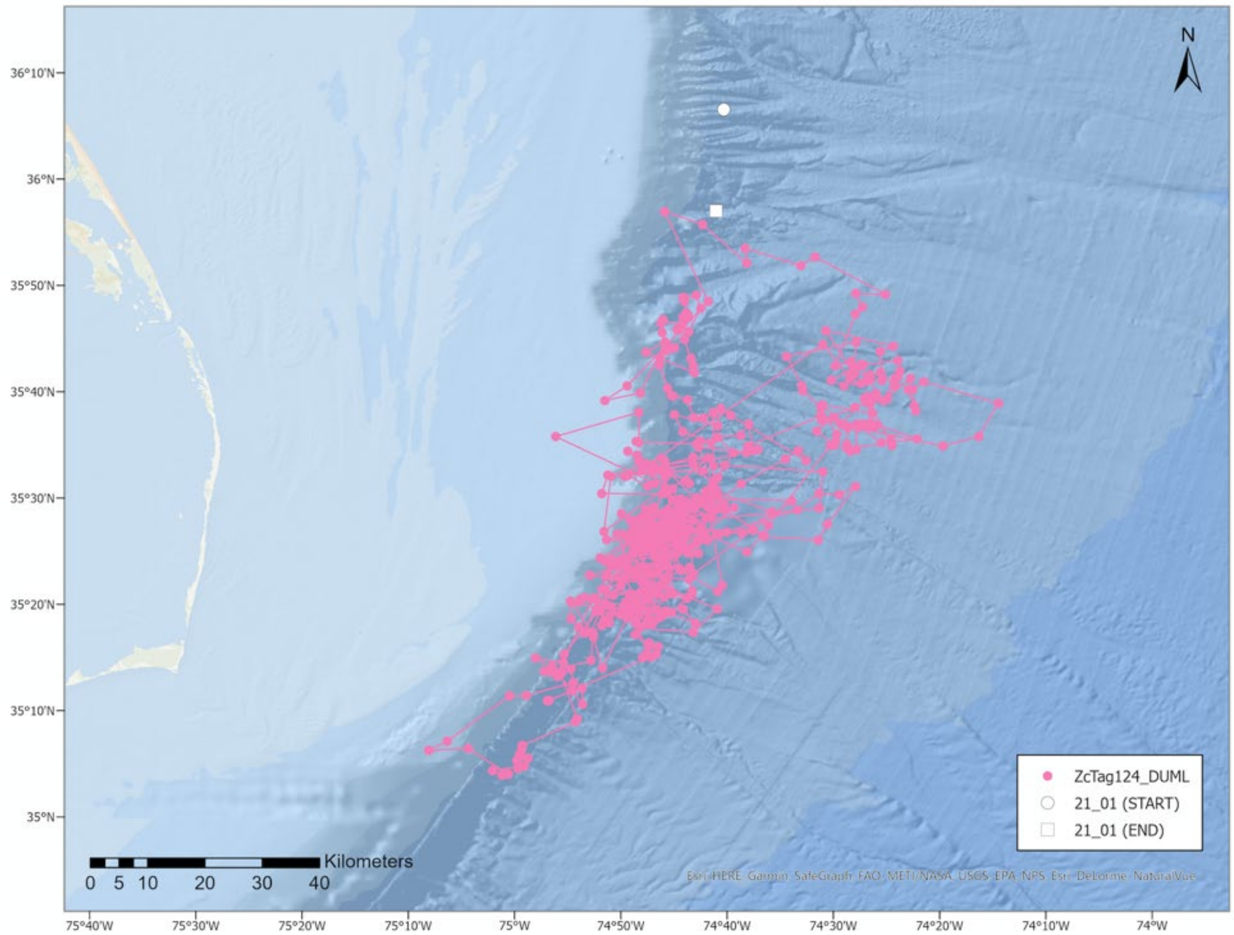

Figure 14. Douglas-filtered ARGOS positions for entire track of ZcTag124 showing positions of CEEs conducted while tag was deployed (tag duration 42 days)

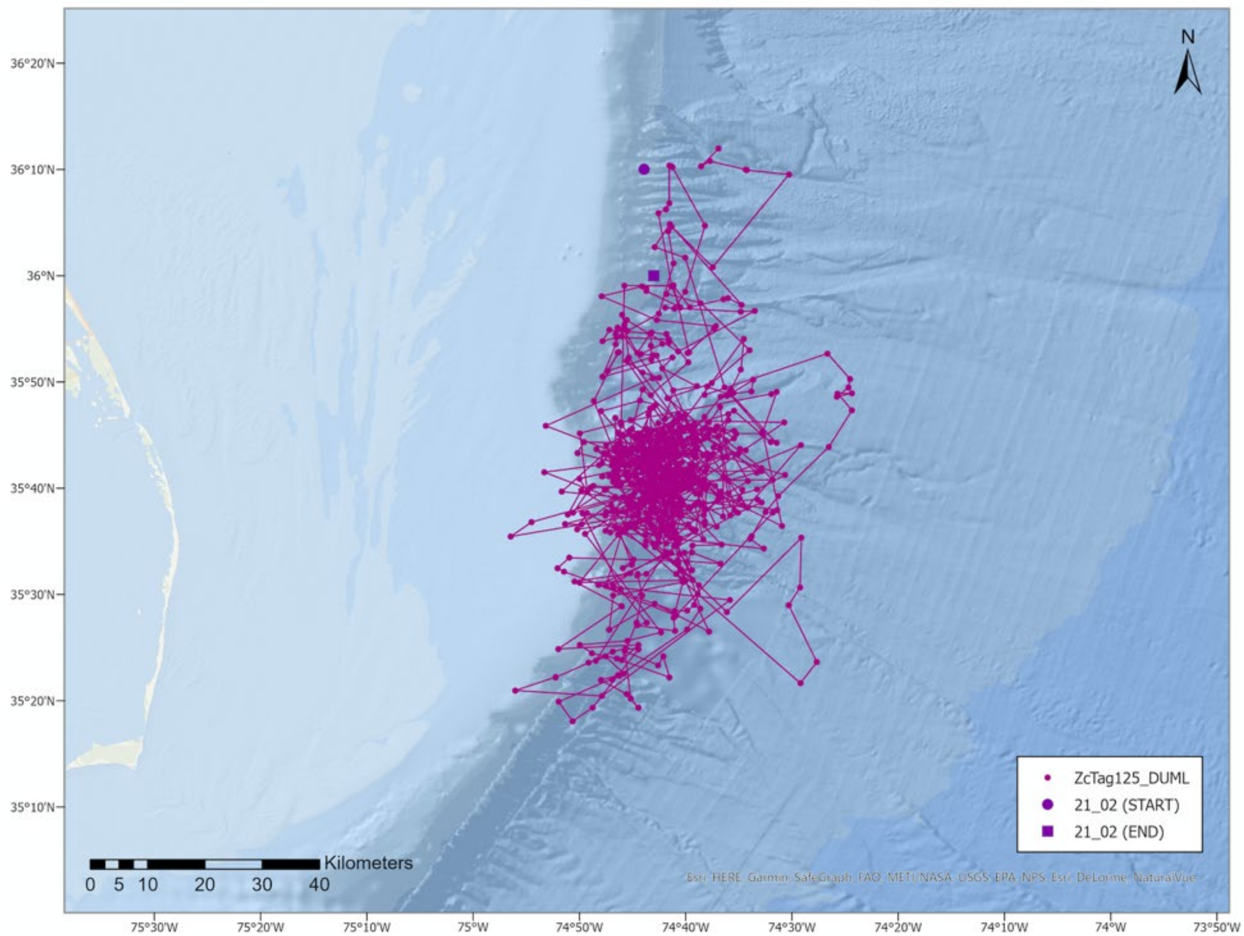

Figure 15. Douglas-filtered ARGOS positions for entire track of ZcTag125 showing positions of CEEs conducted while tag was deployed (tag duration 68 days)

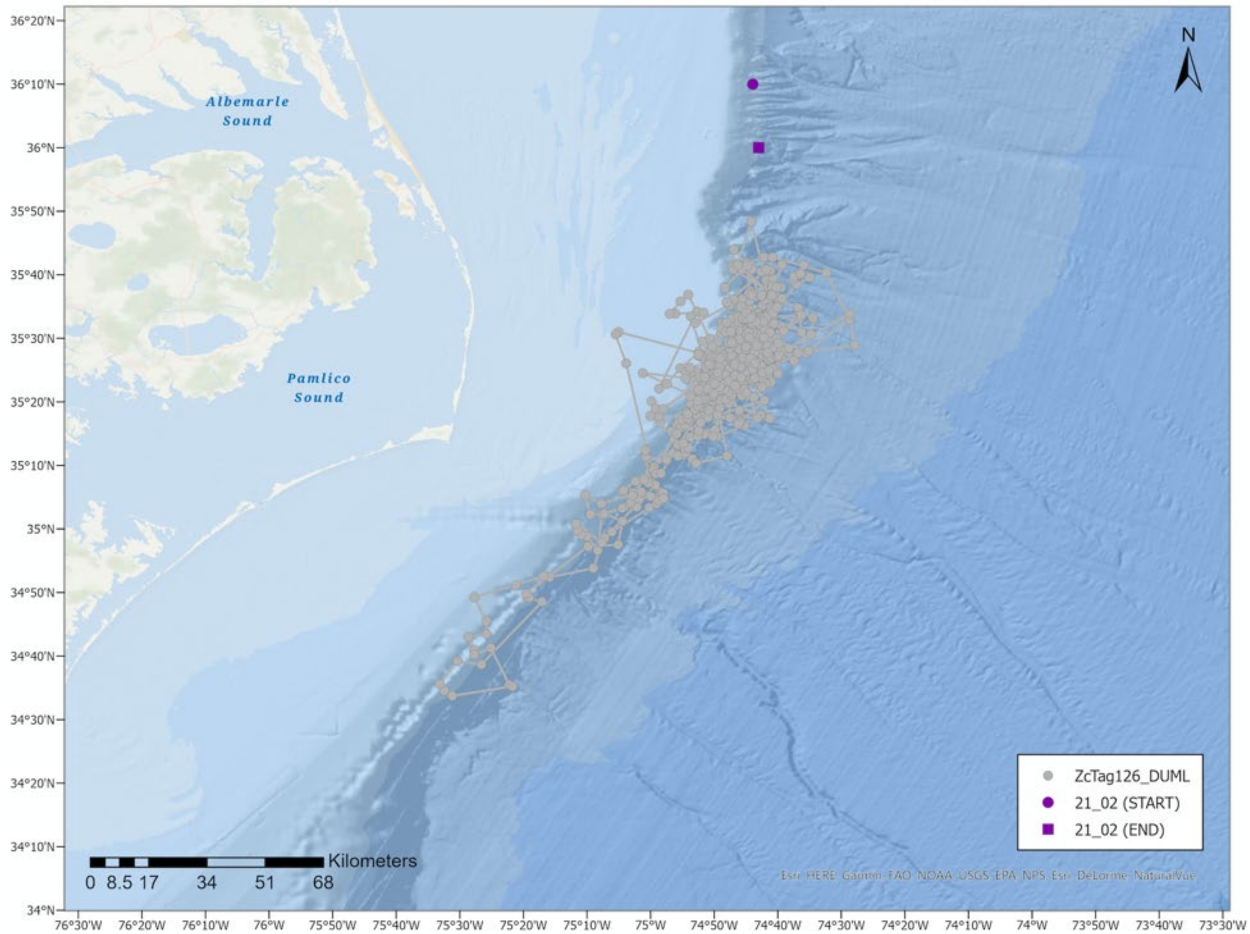

Figure 16. Douglas-filtered ARGOS positions for entire track of ZcTag126 showing positions of CEEs conducted while tag was deployed (tag duration 62 days)

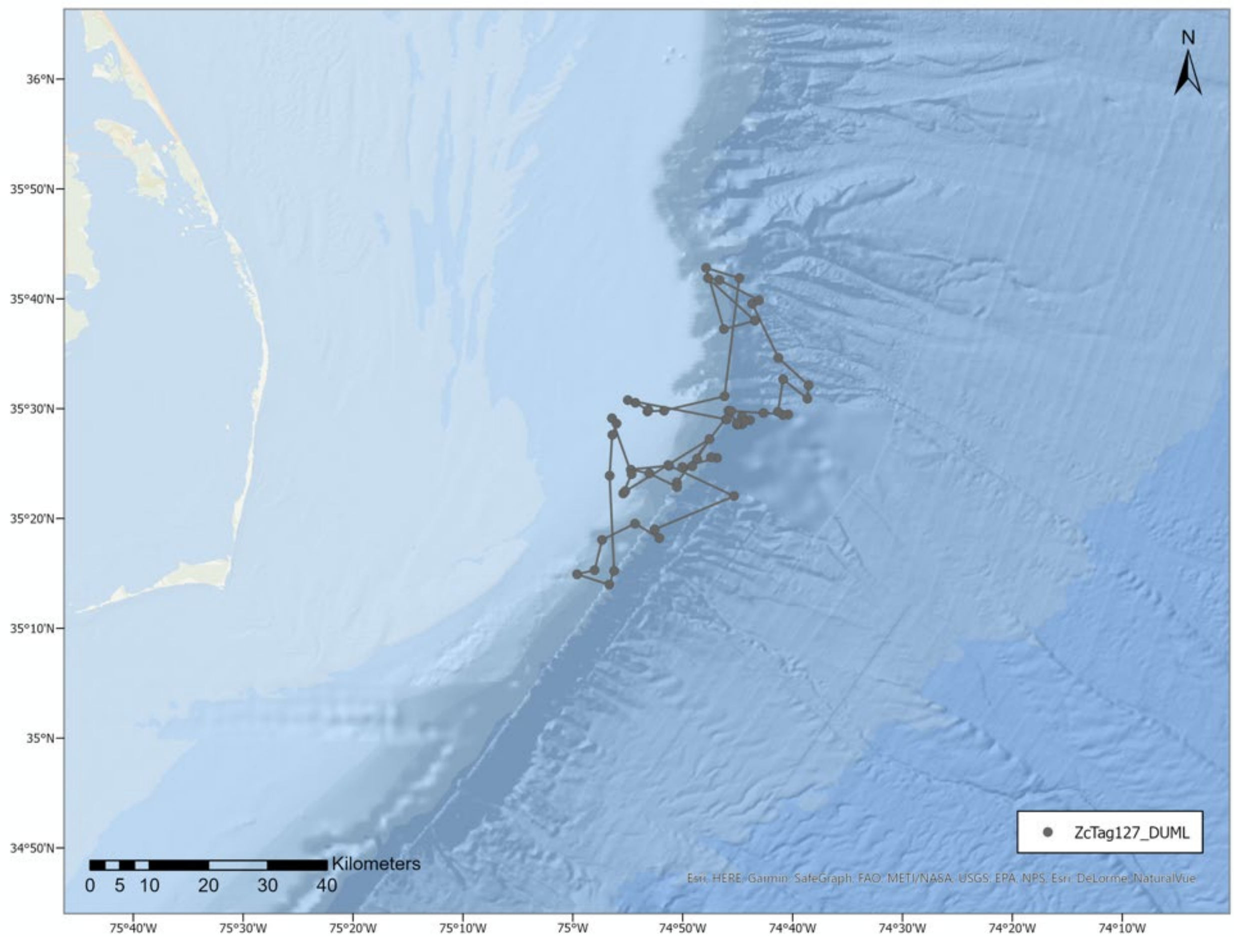

Figure 17. Douglas-filtered ARGOS positions for entire track of ZcTag127 showing positions of CEEs conducted while tag was deployed (tag duration 5 days); no CEE locations are shown as this tag ceased functioning prior to CEE #2021_02

2.3 CEEs Conducted

Two CEE sequences were conducted during the Atlantic-BRS 2021 field effort. This included two successful, complete, operational Navy SQS/53C MFAS CEEs coordinated with separate vessels (**Table 3**).

Table 3. CEEs conducted during 2021 Atlantic-BRS field efforts

CEE ID	Date	CEE Type	Focal whales	CEE duration (min)	Start CEE source latitude (°N)	Start CEE source longitude (°W)
#2021_01	7/30/21	Operational MFAS (*USS Farragut)*	ZcTag122; ZcTag123; ZcTag124	60	36.109	-74.672
#2021_02	9/25/21	Operational MFAS (*USS Delbert D. Black*)	ZcTag125; ZcTag126	60	35.950	-74.449

Subsequently, a summary synthesis of each CEE conducted with standardized tables and figures is provided, including (1) metadata summaries; (2) planning and post-hoc RL modeling results; (3) modeled positions from sat tag locations for individuals before, during, and after each CEE; and (4) dive records for sat-tagged whales before, during, and after CEEs (**Sections 2.3.1** and **2.3.2**). 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 #2021_01: Operational Navy Vessel MFAS[2]

Table 4. Metadata summary for Atlantic-BRS CEE #2021_01

CEE # 2021_01	
Date:	30 July 2021
Type:	MFAS Source: USS FARRAGUT (DDG 99)
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):	17:05
Start lat/lon (source):	36.109; -74.672
End time (UTC):	18:05
End lat/lon (source):	35.95; -74.684
Beaked whales tagged during CEE:	(n=12) – ZcTag122, ZcTag123, ZcTag124(focal sat tag animals); ZcTag113, ZcTag114, ZcTag115, ZcTag116, ZcTag117, ZcTag118, ZcTag119, ZcTag120, ZcTag121 (incidental whales)
Pilot whales tagged:	none
Estimated Range (start CEE):	37 km (20 nm) @ start for ZcTag122 and ZcTag124 (est. interpolated)
Modeled Max RL:	141 dB RMS @ 10m and 500m for ZcTag122 and ZcTag124 (est. interpolated); 140 dB RMS @ 1000m for focal whales

CEE #2021_01 - Narrative Summary

This was the most successful CEE conducted to date in the Atlantic-BRS effort given the large number of whales tagged during an event with an operational sonar (more than triple any previous such event anywhere in the world), the precise and complete requested support of the FARRAGUT, and the spatial configuration of focal and incidental whales. Three focal whales (beaked whales Zc122, Zc123, and Zc124) had been tagged several weeks prior to the CEE and were being tracked using satellite-transmitting tags and on-water visual observations for days prior to and at the time of the CEE. These positions were used in effectively adapting the CEE location of the Farragut to meet experimental objectives. Each of these tags were transmitting position and continuous time series dive data. Ten other tagged whales (Zcs 112-121) had been tagged approximately a month prior to the CEE and had been the anticipated focal cohort for a previous CEE for which the Navy ship was unavailable due to mechanical issues. These tags went through their scheduled period of successfully delivering continuous dive data during that planned window and were transmitting just positional data during the FARRAGUT CEE and were thus selected as incidental animals. However, these tags collected a large quantity of continuous baseline dive data and had among the longest pre-exposure baseline positional data for any CEEs conducted in the Atlantic-BRS study to date. Focal whales were predicted to have been exposed in the experimental target range of 110-140 dB RMS at ranges of about 12-30 nm with incidental whales occurring out to ~80 nm and variable ranges.

[2] All figures provided below as well as additional supplementary figures not highlighted here are available at: https://app.box.com/folder/155557961673?v=atlanticbrs-2021-sup-figs as well as in the Atlantic-BRS GitHub at: https://atlanticbrs.github.io/report_2021_supplementary_figures/

Table 5. Sequential positioning and actual start/end positions for *USS Farragut* for Atlantic-BRS CEE #2021_01

Position Request for *USS Farragut*	Description	Latitude (°N)	Longitude (°W)	Heading
1	Nominal Navy Ship Start	35.867	-74.35	Not specified
2	48hrs pre (28 July 0900 EDT): Anticipated start position based on interpreted ARGOS posit centroid for three focal whales over previous day	35.932	-74.702	171
3	24hrs pre (29 July 1200 EDT): Anticipated start position based on interpreted ARGOS posit centroid for three focal whales over previous day	36.100	-74.700	178
4	Actual start position (30 July 1100 EDT)	36.101	-74.685	179
5	Actual end position and course from *USS Farragut* navigation (INS 01)	36.109	-74.672	180 (maintained)

Key: EDT=Eastern Daylight Time

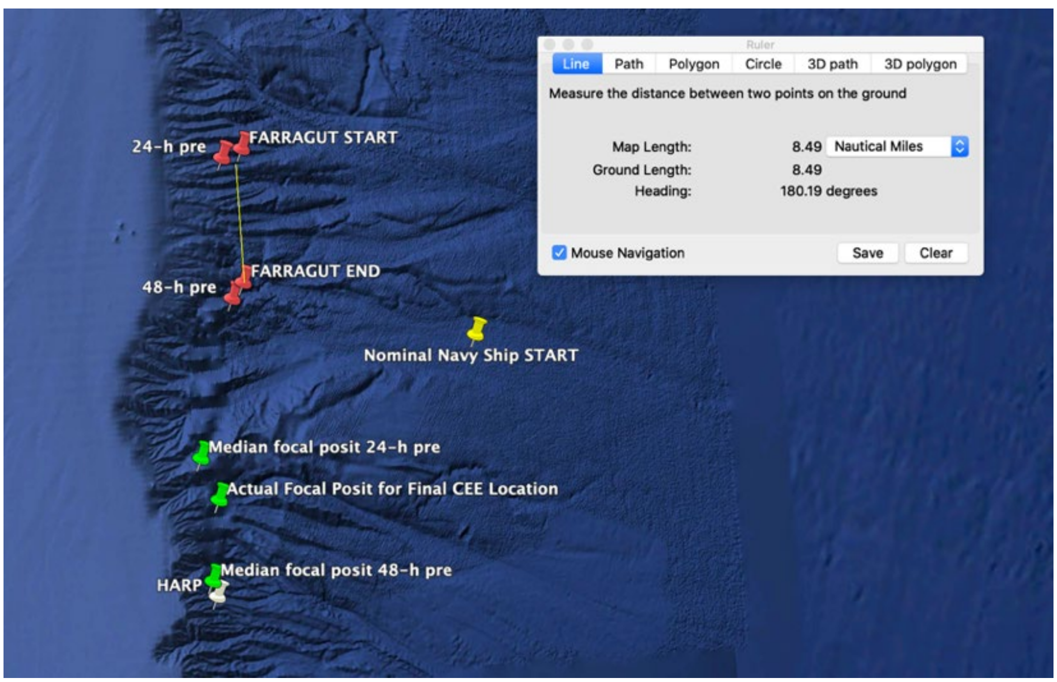

Figure 18. Sequential requested USS Farragut positions shown relative to focal animal centroid position estimates used in RL model estimates based on interpretations of ARGOS positions. See Table 5 above for descriptions.

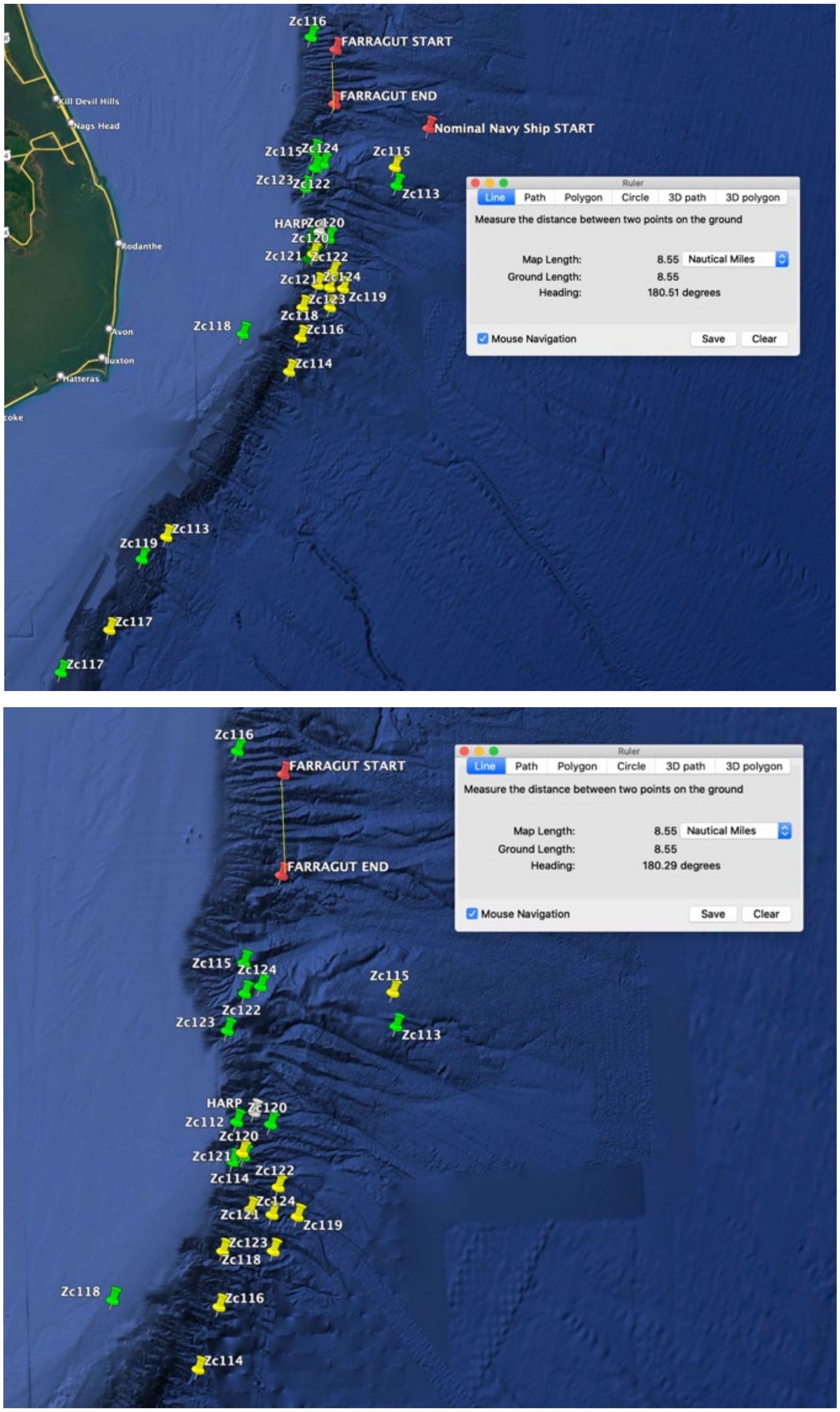

Figure 19. Broad view maps of all focal (Zcs 122, 123, 124) and incidentally exposed beaked whales with requested ship track showing best estimate positions immediately before (green) and 12–24 hours (yellow) after *USS Farragut* CEE (note: bottom image slightly zoomed to show greater resolution)

Table 6. Summary of RL model predictions before and during CEE #2020_01[3]

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
10	28 July 0900 EDT	Focal centroid (10)	35.5981	-74.7612	20–13	110	140	140
11	28 July 0900 EDT	Focal centroid (900)	35.5981	-74.7612	20–13	115	131	137
12	29 July 1200 EDT	Focal centroid (10)	35.745	-74.765	21–13	114	140	140
13	29 July 1200 EDT	Focal centroid (1000)	35.745	-74.765	21–13	123	135	135
14	30 July 0800 EDT	Zc122 & 124 (10)	35.8158	-74.7084	22–14	109	143	143
15	30 July 0800 EDT	Zc122 & 124 (500)	35.609	-74.717	22–14	114	140	140
16	30 July 0800 EDT	Zc122 & 124 (1200)	35.609	-74.717	22–14	118	124	136
17	30 July 0930 EDT	Zc122 & 124 (10)	35.764	-74.7431	20–13	109	141	141
18	30 July 0930 EDT	Zc122 & 124 (1000)	35.764	-74.7431	20–13	120	140	140
19	30 July 0930 EDT	Zc122 & 124 (500)	35.764	-74.7431	20–13	119	137	141
20	Post-hoc for known CEE location with best field posit estimate during	Zc122 & 124 (10)	35.735	-74.763	19	**141**	**141**	**141**
21	Post-hoc for known CEE location with best field posit estimate during	Zc122 & 124 (350)	35.735	-74.763	19	**142**	**142**	**142**

Key: Lat=Latitude; Lon=Longitude; m=meter(s); nm=nautical mile(s)

[3] Note: all corresponding RL model runs are available at: https://app.box.com/folder/155557967416

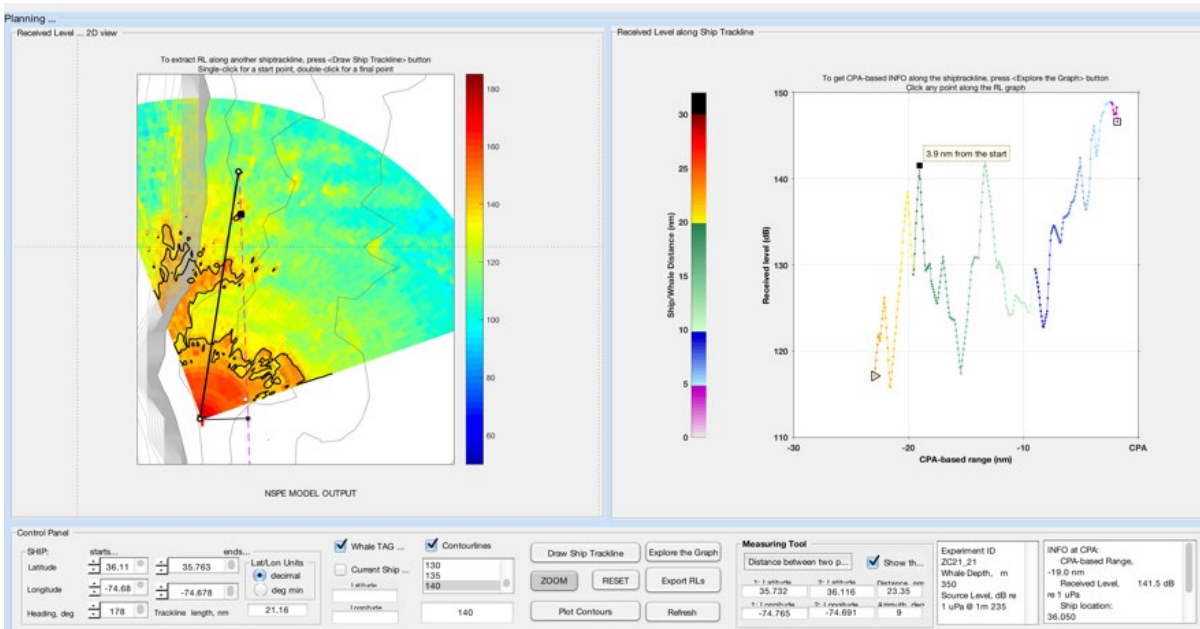

Figure 20. Post hoc RL model prediction at a 10-meter depth (model run #20 from Table 6) for focal whales ZcTag122 and ZcTag124 based on interpolated position and *USS Farragut* positions during Atlantic-BRS CEE #2020_01; modeled RL at this depth and estimated position was 141.5 dB RMS

NOTE: All RL model prediction plots (as shown in **Figures 20** and **21**) were generated using the NPS sound propagation tool used in the field to estimate RLs 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.

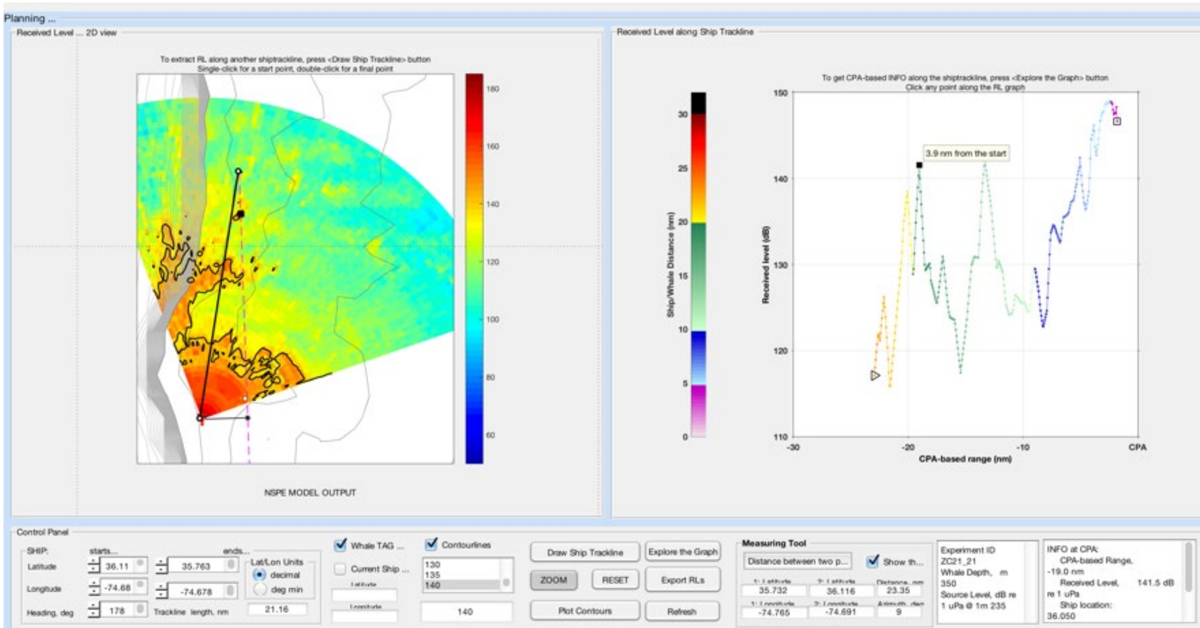

Figure 21. Post hoc RL model prediction at a 350-meter depth (model run #21 from Table 6) for focal whales ZcTag122 and ZcTag124 based on interpolated position and *USS Farragut* position during Atlantic-BRS CEE #2021_01; modeled RL at this depth and estimated position was 142.3 dB RMS

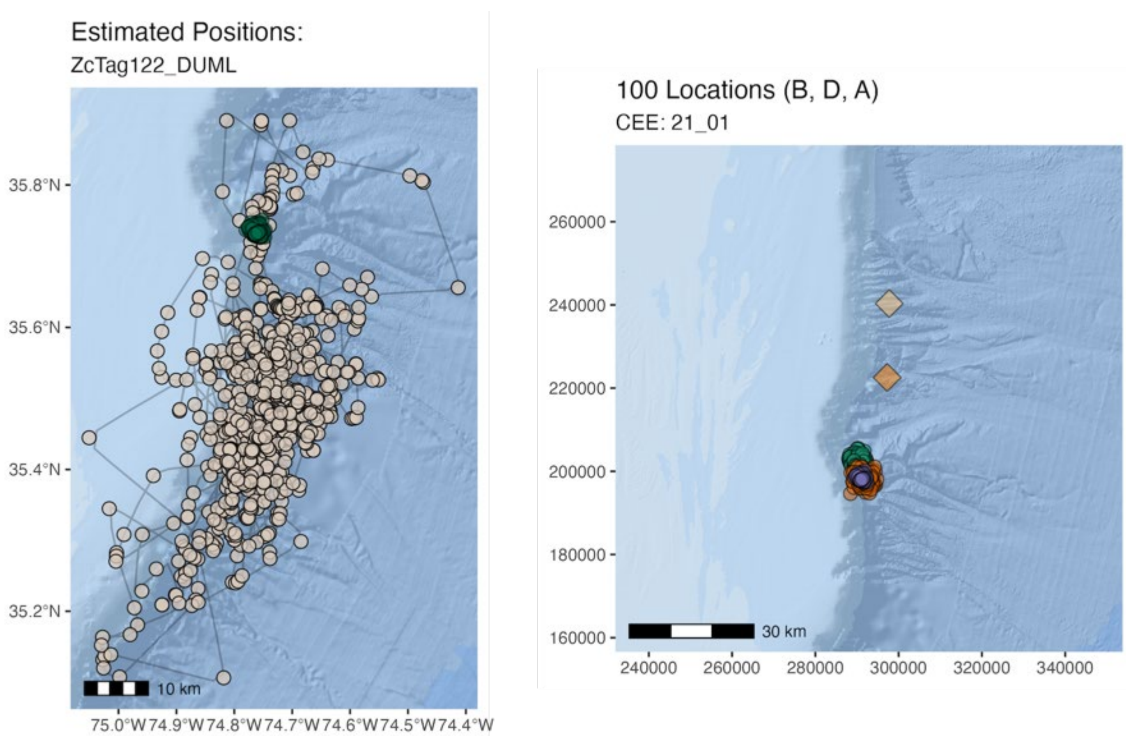

Figure 22. Estimated surface positions for focal whale ZcTag122 before, during, and after Atlantic-BRS CEE #2021_01

NOTE: All estimated surface position plots (as shown in **Figures 22** through **24**) 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 (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 1-hour before CEEs (green dots), at the start of CEEs (red dots), and 1-hour after CEEs (purple dots). Note: all surface positions for focal whales are given here and all non-focal whales are available at: https://app.box.com/folder/155558649083

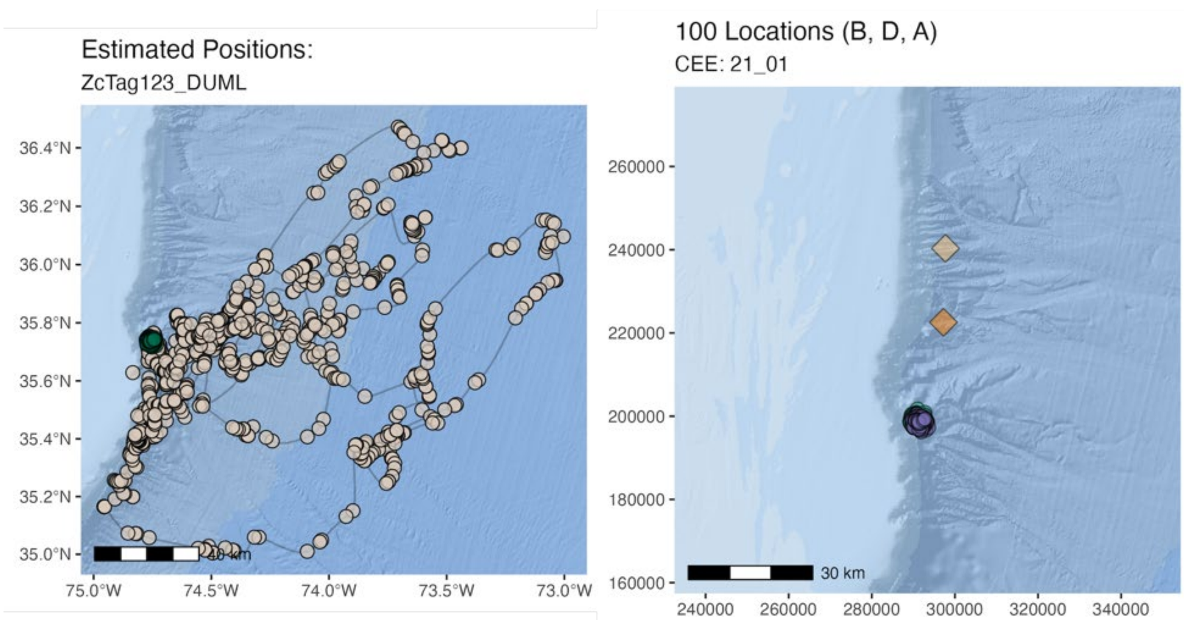

Figure 23. Estimated surface positions for focal whale ZcTag123 before, during, and after Atlantic-BRS CEE #2021_01

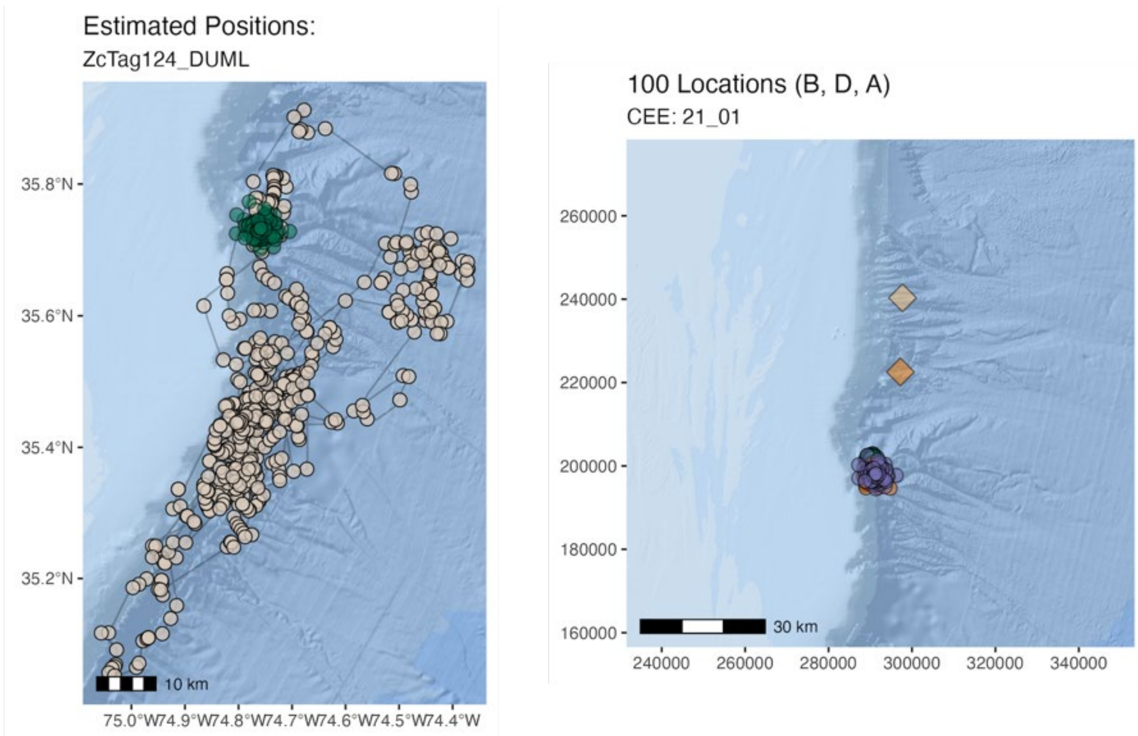

Figure 24. Estimated surface positions for focal whale ZcTag124 before, during, and after Atlantic-BRS CEE #2021_01

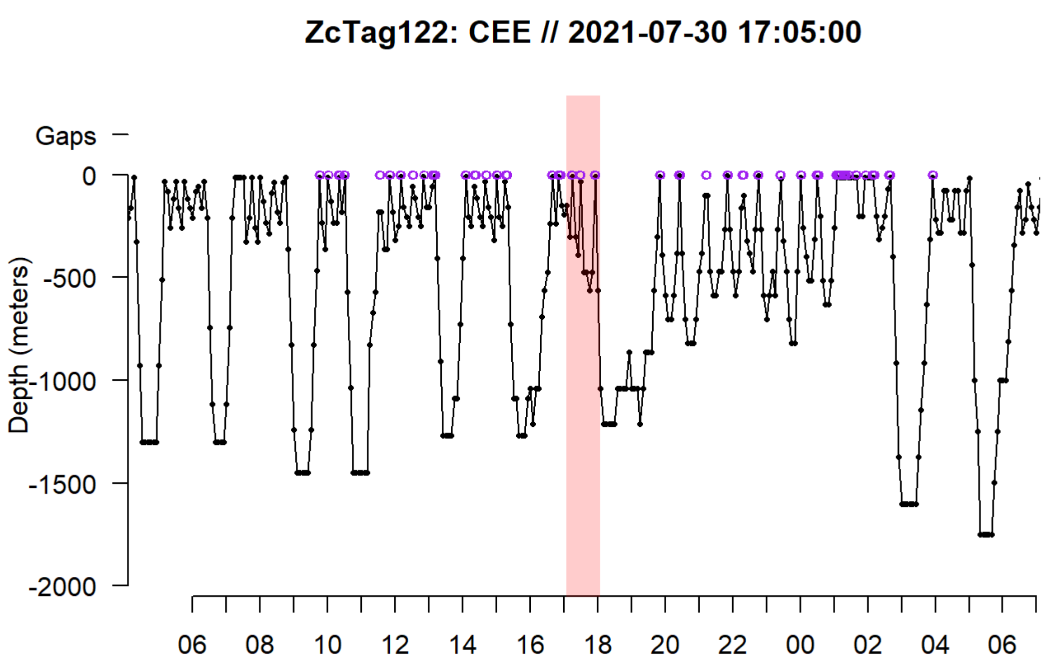

Figure 25. Available dive data for focal whale ZcTag122 before, during, and after Atlantic-BRS CEE #2021_01. Pink shading denotes duration of CEE transmissions.

NOTE: All dive plots (as shown in **Figures 25** through **27**) illustrate dive data for days during which CEEs occurred. Time (in Greenwich Mean Time [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. Note: all dive plots for focal whales are given here and all non-focal whales are available at: https://app.box.com/folder/155558715080

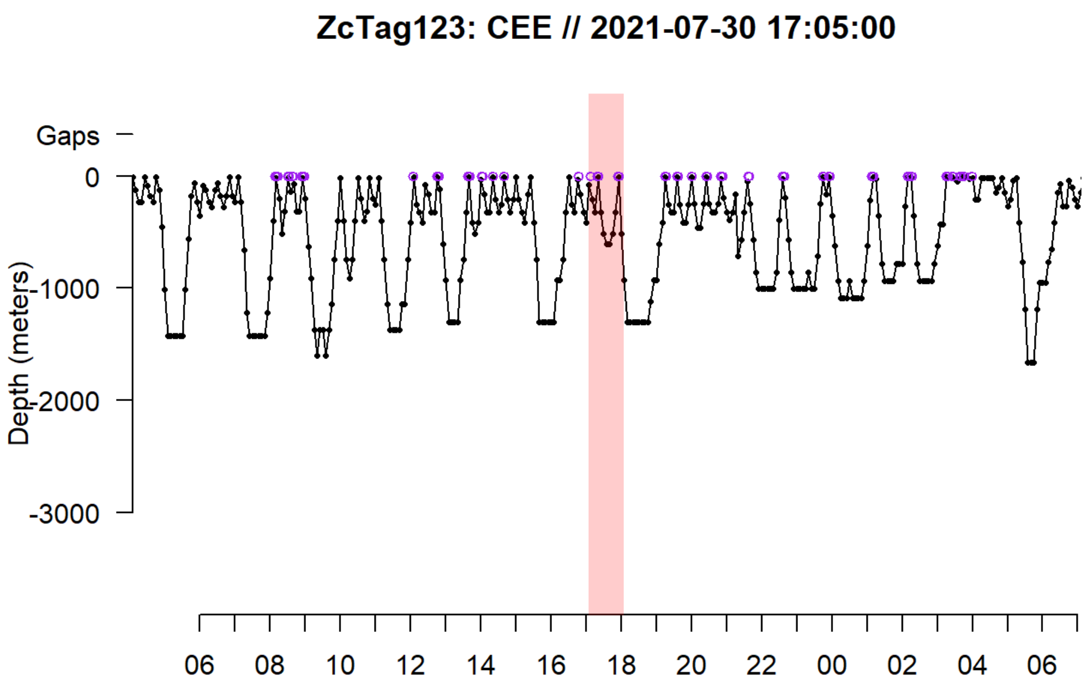

Figure 26. Available dive data for focal whale ZcTag123 before, during, and after Atlantic-BRS CEE #2021_01. Pink shading denotes duration of CEE transmissions.

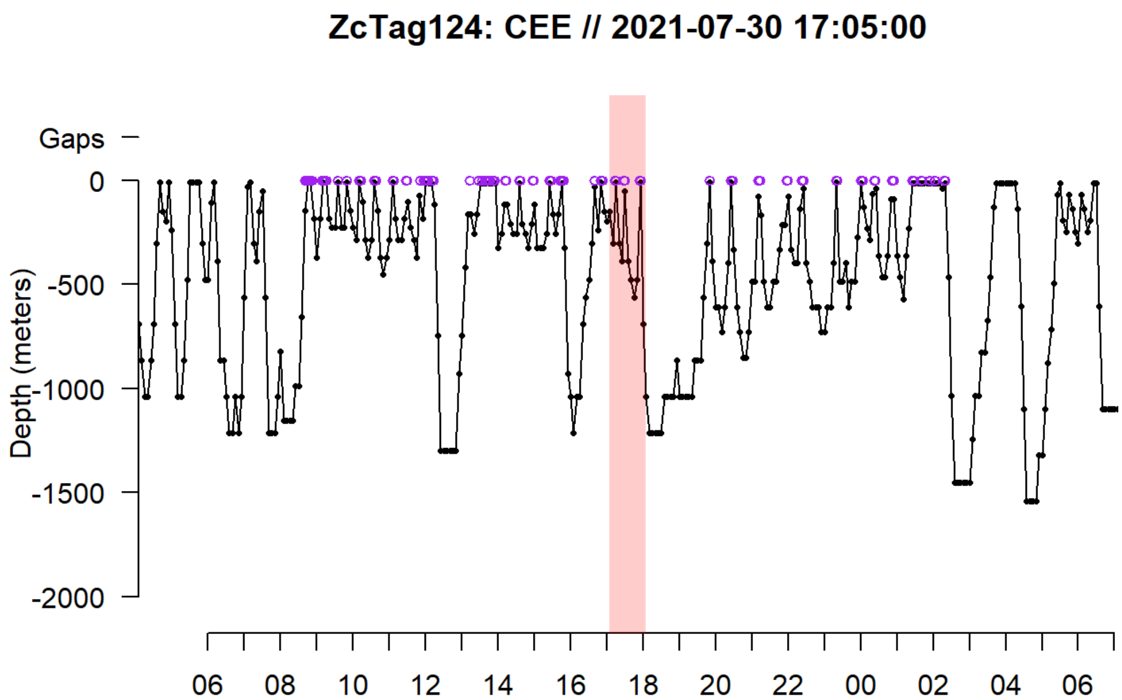

Figure 27. Available dive data for focal whale ZcTag124 before, during, and after Atlantic-BRS CEE #2021_01. Pink shading denotes duration of CEE transmissions.

2.3.2 CEE #2021_02: Operational Navy Vessel MFAS[4]

Table 7. Metadata summary for Atlantic-BRS CEE #2021_02

CEE # 2021_02	
Date:	25 September 2021
Type:	MFAS Source: USS DELBERT D. BLACK (DDG 119)
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):	16:29
Start lat/lon (source):	36.167; -74.732
End time (UTC):	17:41 (note slightly longer than requested 60 min)
End lat/lon (source):	36.0; -74.7167
Beaked whales tagged during CEE:	(n=4) – ZcTag125, ZcTag126 (focal sat tag animals); ZcTag122, ZcTag123 (incidental whales)
Pilot whales tagged:	none
Estimated Range (start CEE):	46 km (25 nm) @ start for ZcTag125 and similar for ZcTag126 (est. interpolated)
Modeled Max RL:	146 dB RMS @ 10m; 141 dB RMS @ 500m; 142 dB RMS @900m for focal whale ZcTag125

CEE #2021_02 - Narrative Summary
Two focal whales (beaked whales Zc125 and Zc126) had been tagged over a week prior to the CEE and were transmitting position and dive data and were being tracked using satellite-transmitting tags and on-water visual observations. Two other tagged whales (Zcs 122 and Zc123) had been tagged nearly two months prior to the CEE and were incidentally exposed transmitting just positional data. These animals were involved in the 30 July USS FARRAGUT CEE but their tags collected a large quantity of continuous baseline dive data for six weeks prior to this event. Weather conditions precluded deployment of additional tags, but calibrated acoustic recordings were obtained in close proximity to focal animals during the CEE. Communications and coordination with the DELBERT BLACK were clear and successful through established shore-side means. Focal whales were predicted to have been exposed at the lower half of the experimental target range at depth (110-125 dB RMS) and across the full target range (110-140 dB RMS) at the surface at ranges of ~22-30 nm with incidental whales occurring out to ~50 nm. Observers in the field reported a lack of clear behavioral avoidance in focal whales during and following the CEE as has been observed in previous experiments.

[4] All figures provided below as well as additional figures not highlighted here are available at: https://app.box.com/folder/155558752353

Table 8. Sequential positioning and actual start/end positions for *USS Dilbert D. Black* for Atlantic-BRS CEE #2020_02.

Position Request for *USS Laboon*	Description	Latitude (°N)	Longitude (°W)	Heading
1	Nominal Navy Ship Start	35.867	-74.350	Not specified
2	48hrs pre (23 Sept 1100 EDT): Anticipated start position based on interpreted ARGOS posit centroid for Zc125 over previous day	36.060	-74.630	184
3	24hrs pre (24 Sept 1100 EDT): Anticipated start position based on interpreted ARGOS posit centroid for Zc125 over previous day	36.090	-74.600	178
4	Updated pre (25 Sept 0900 EDT): Start position based on overnight and morning actual positions in situ for Zc125 and 126	36.150	-74.680	176
5	Actual start position (25 Sept 1400 EDT)	36.180	-74.720	179
6	Actual end position and course from *USS Laboon* navigation (INS 01)	36.167	-74.732	179 (maintained)

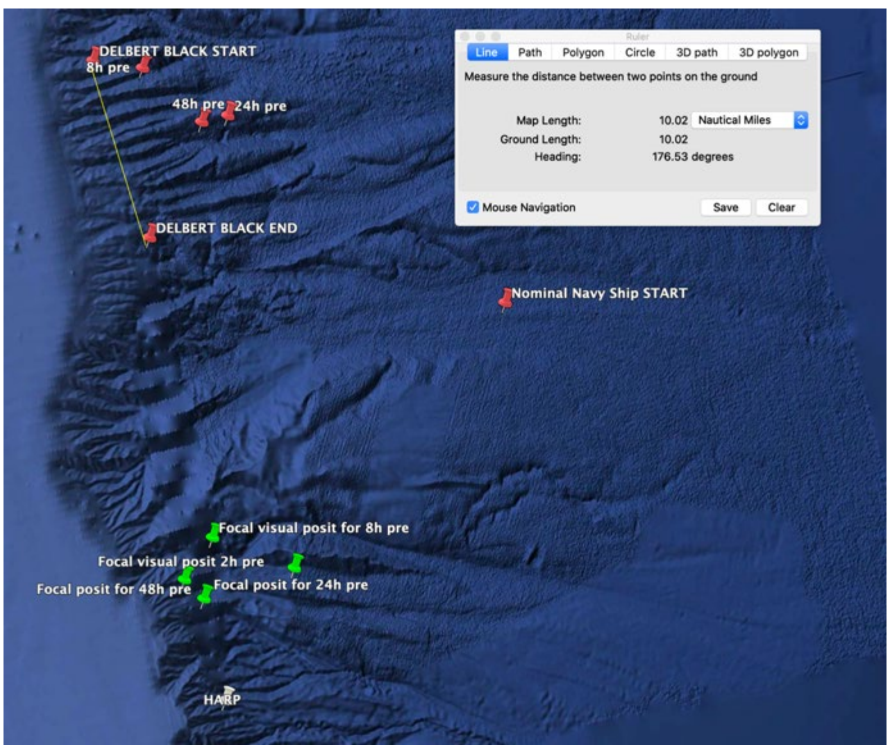

Figure 28. Sequential requested *USS Delbert D. Black* positions shown relative to focal animal centroid or actual position estimates used in RL model estimates. See Table 8 above for descriptions.

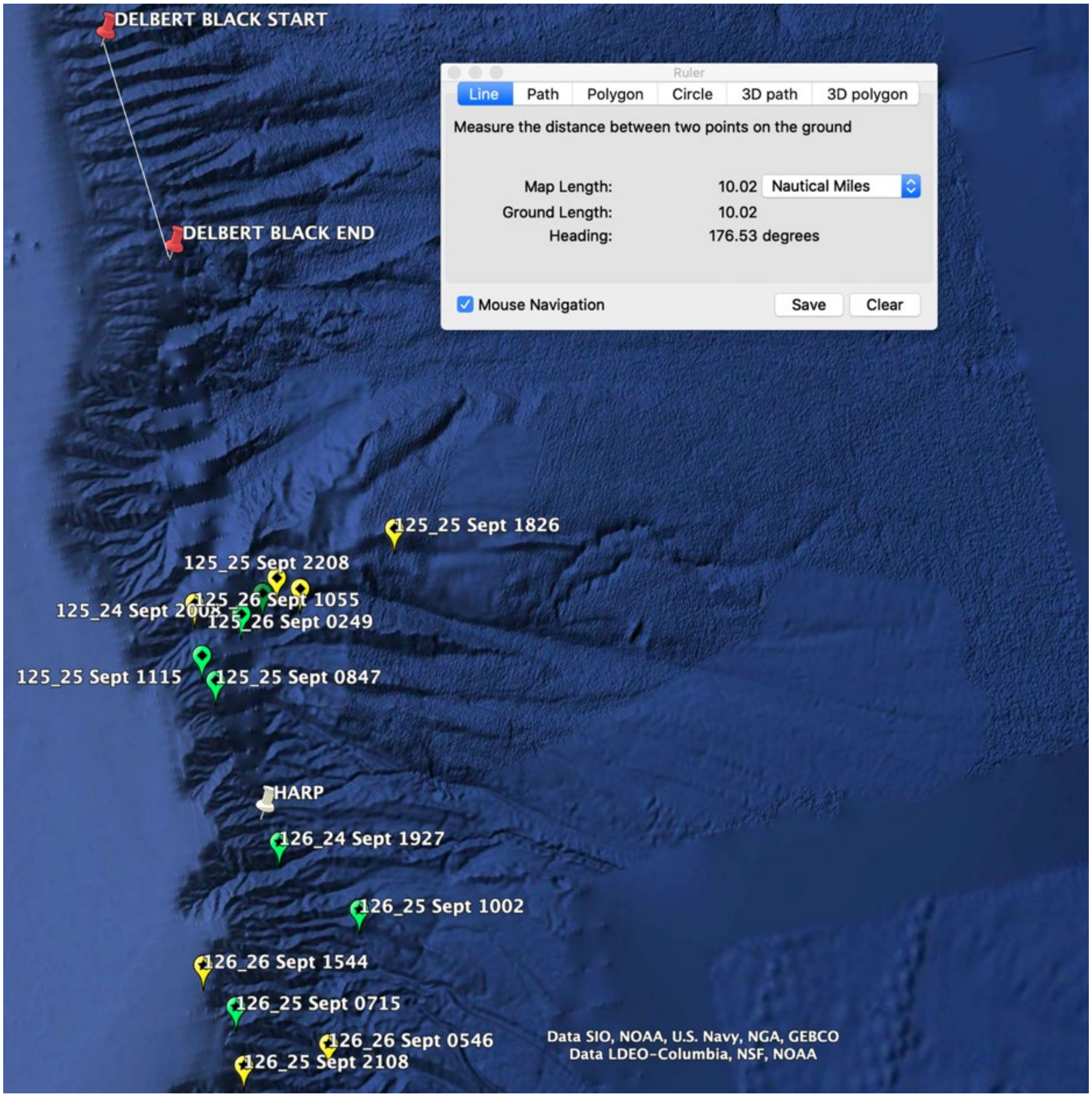

Figure 29. Composite map of *USS Delbert D. Black* track during 25 Sept CEE (1629–1741 EDT) with Zc125 (diamonds) and Zc126 (stars) known (visual) or high confidence (field goniometer detected or ARGOS LC2) positions at selected times before (green) and after (yellow) on day of and after CEE

Table 9. Summary of RL model predictions before and during CEE #2021_02.[5]

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
23	23 Sept 1100 EDT	Zc125 (10)	35.6729	-74.7525	28–20	116	144	144
24	23 Sept 1100 EDT	Zc125 (1000)	35.6729	-74.7525	18–12	116	144	144
25	24 Sept 1100 EDT	Zc125 (10)	35.6808	-74.6471	27–19	134	140	142
26	24 Sept 1100 EDT	Zc125 (1600)	35.6808	-74.6471	19–11	118	140	140
27	25 Sept 0900 EDT	Zc125 (10)	35.7248	-74.7272	30–22	108	146	146
28	25 Sept 0900 EDT	Zc125 (500)	35.7248	-74.7272	22–14	116	140	140
29	25 Sept 0900 EDT	Zc125 (1200)	35.7248	-74.7272	27–19	116	140	140
30	25 Sept 1100 EDT	Zc125 (10)	35.6905	-74.7776	36–27	116	143	143
31	25 Sept 1100 EDT	Zc125 (700)	35.6905	-74.7776	25–17	127	140	140
32	25 Sept 1200 EDT	Zc125 (10)	35.7187	-74.7686	25–17	127	141	146
33	25 Sept 1200 EDT	Zc125 (500)	35.7187	-74.7686	25–17	123	140	141
34	25 Sept 1200 EDT	Zc125 (900)	35.7187	-74.7686	25–17	123	140	142

[5] Post-hoc estimates are highlighted as estimated RL for the closer focal whale (ZcTag100) at different depths for model runs 32–34 (**Figures 30** to **32**). Note: all corresponding RL model runs are available at: https://app.box.com/folder/155558628000

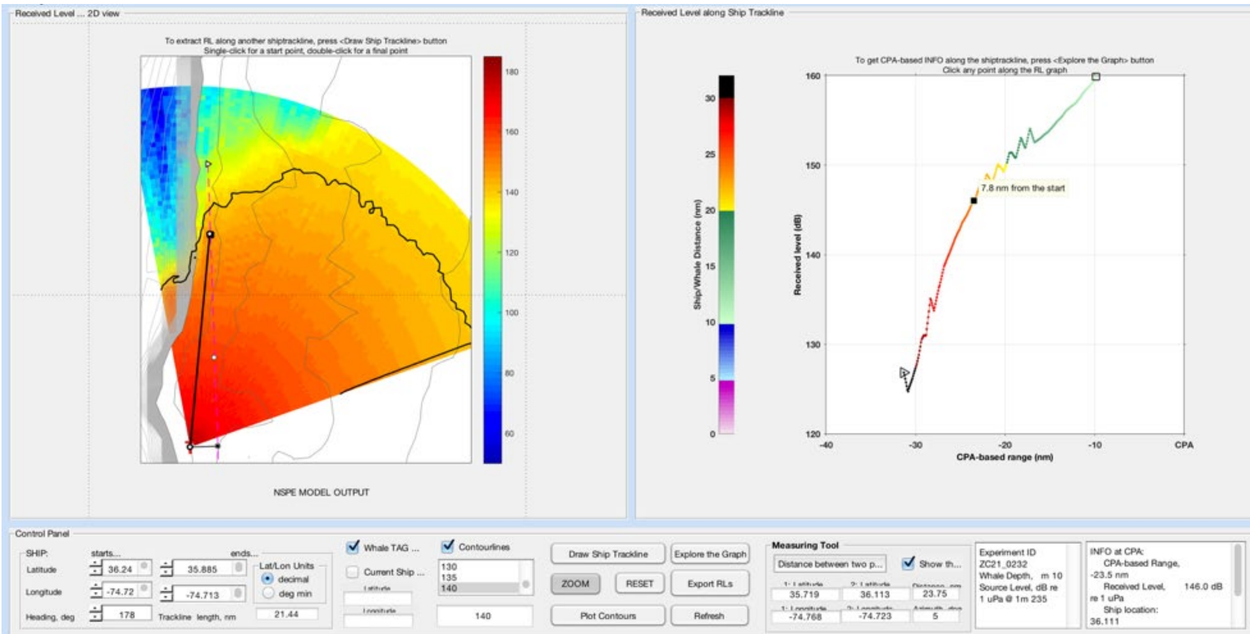

Figure 30. Post hoc RL model prediction at a 10-meter depth (model run #32 from Table 9) for focal whale ZcTag125 based on interpolated position and *USS Delbert D. Black* end position during Atlantic-BRS CEE #2021_02; modeled RL at this depth and estimated position was 146 dB RMS

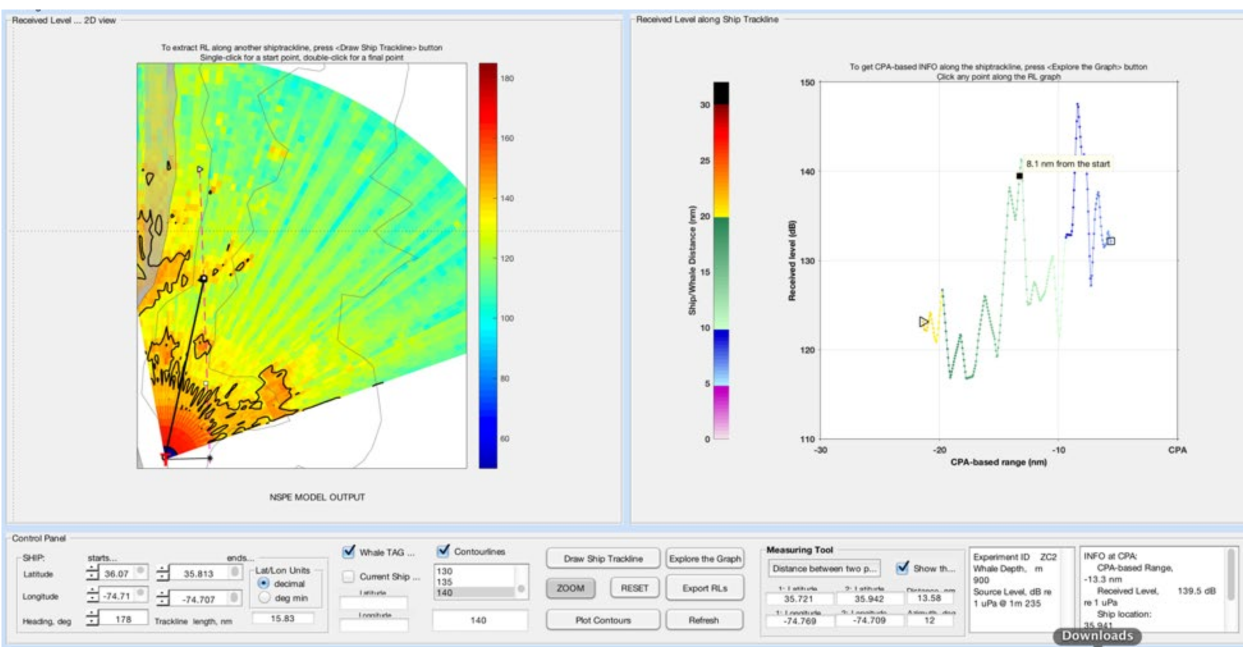

Figure 31. Post hoc RL model prediction at a 500-meter depth (model run #33 from Table 9) for focal whale ZcTag125 based on interpolated position and *USS Delbert D. Black* end position during Atlantic-BRS CEE #2021_02; modeled RL at this depth and estimated position was 139.5 dB RMS

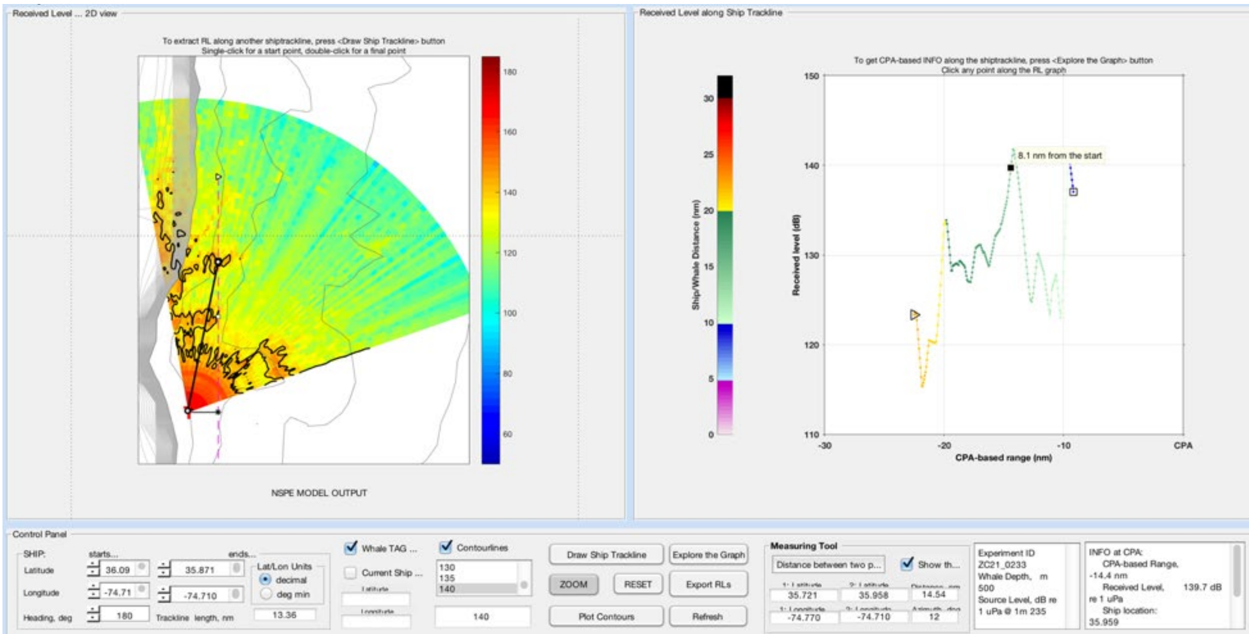

Figure 32. Post hoc RL model prediction at a 900-meter depth (model run #34 from Table 9) for focal whale ZcTag125 based on interpolated position and *USS Delbert D. Black* end position during Atlantic-BRS CEE #2021_02; modeled RL at this depth and estimated position was 139.7 dB RMS

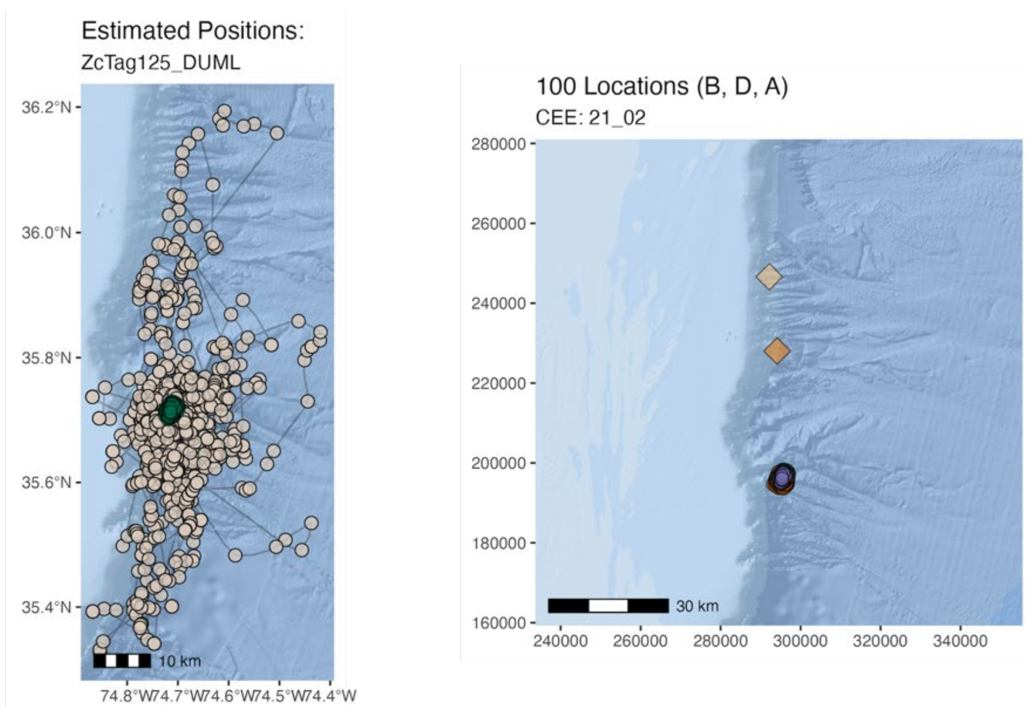

Figure 33. Estimated surface positions for focal whale ZcTag125 before, during, and after Atlantic-BRS CEE#2021_02[6]

[6] Also see: https://app.box.com/folder/155559615525

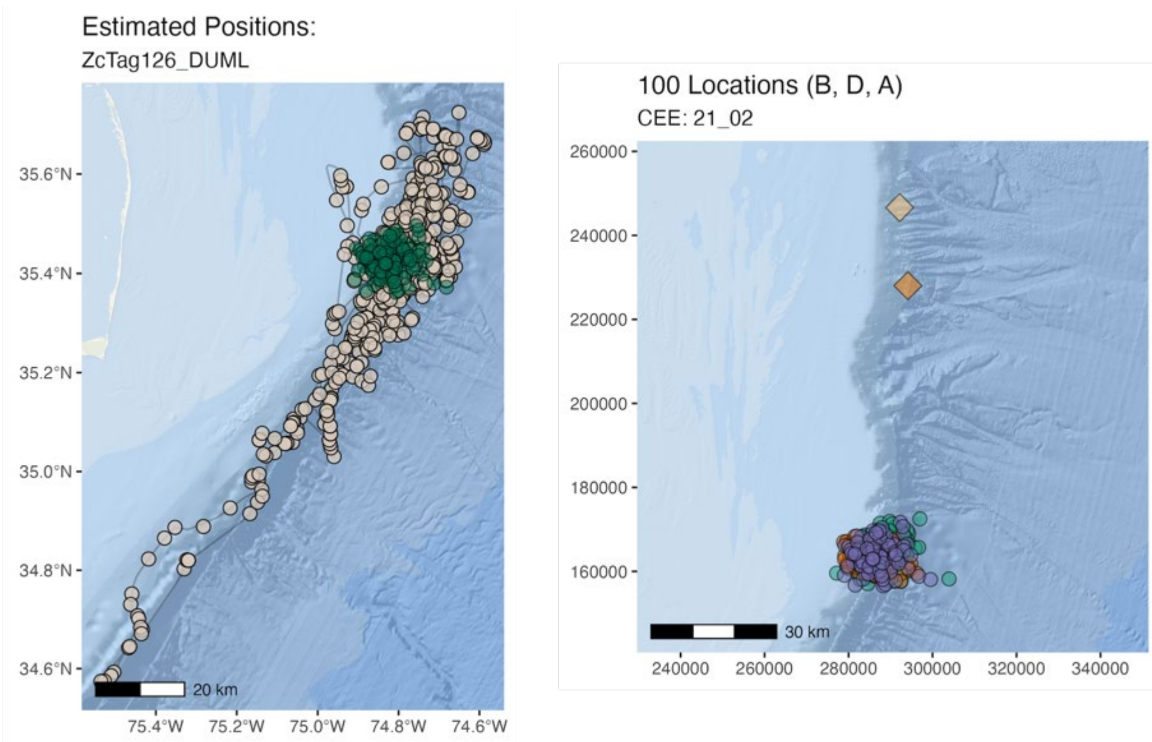

Figure 34. Estimated surface positions for focal whale ZcTag126 before, during, and after Atlantic-BRS CEE#2021_02

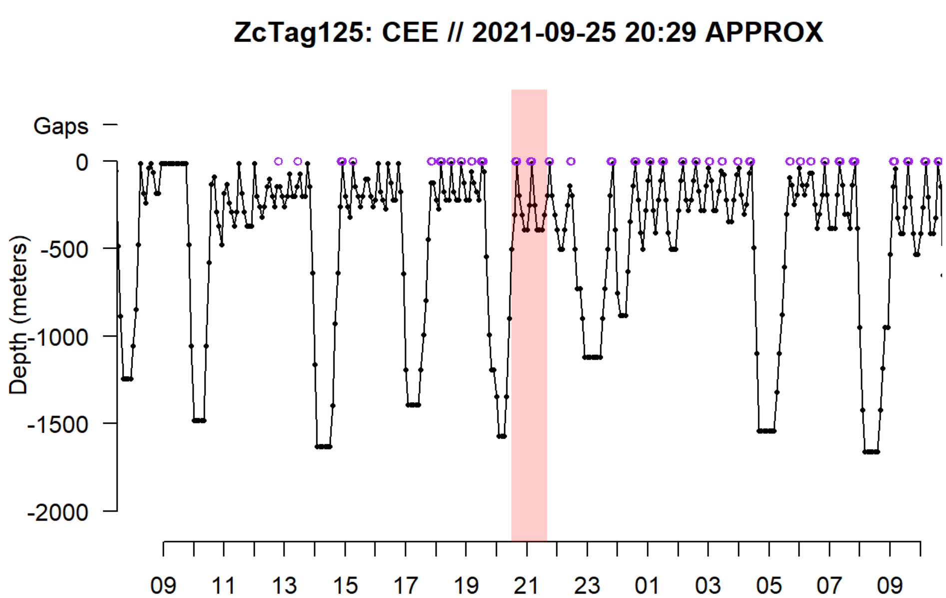

Figure 35. Available dive data for focal whale ZcTag125before, during, and after Atlantic-BRS CEE #2021_02[7]. Pink shading denotes duration of CEE transmissions.

[7] Also see: https://app.box.com/folder/155558168893

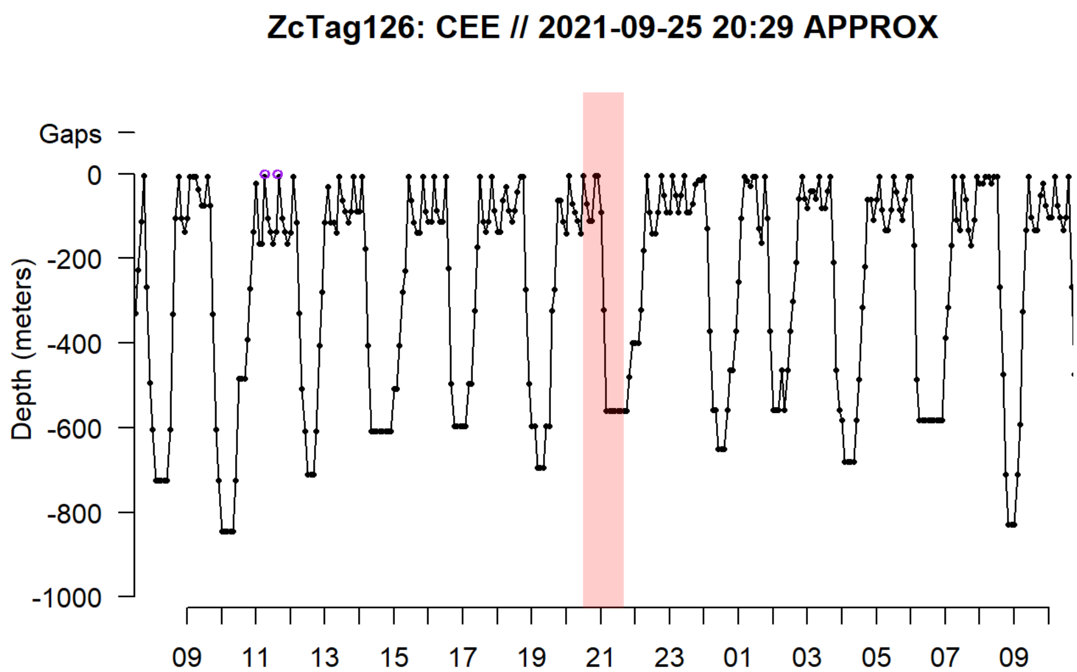

Figure 36. Available dive data for focal whale ZcTag126 before, during, and after Atlantic-BRS CEE #2021_02. Pink shading denotes duration of CEE transmissions.

3. Analytical Developments, Results, and Publications and 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 visualization that continue to be applied in the presentation and publication of results.

As the Atlantic-BRS project has progressed, it is consistently and increasingly producing peer-reviewed publications both directly through the project and in collaboration with the ONR-funded Double Mocha effort, which is developing analytical methods and testing and applying them to Atlantic-BRS data. A summary of papers that are published, in review, or in advanced stages of development is included in **Table 10**; direct links to publications are provided where available.

Table 10. 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 behavior of Cuvier's beaked whales (*Ziphius cavirostris*)	Quick (Duke)	Final preparation
Baseline behavior	Shallow night intervals in *Ziphius cavirostris*	Cioffi (Duke)	In review
Baseline physiology	Baseline variation of steroid hormones in short-finned pilot whales (*Globicephala macrorhynchus*)	Wisse (Duke)	In preparation
Baseline behavior	Possible orientation behavior in Ziphius	Quick (Duke)	In preparation
Methodology – technology	Continuous time series data programming regime	Cioffi (Duke)	In preparation

Category	Nominal Title/Subject	Lead Author (Institution)	Status
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

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. The following includes updates on developments and progress in baseline data collection, methodological development, and behavioral response analyses. The abstracts of all (n=12 successfully accepted abstracts as they appear in the ESOMM-2022 program) are given alphabetically by co-author last name.

Catriona M. Harris[1], Phil Bouchet[1], Len Thomas[1]

Affiliations

[1] Centre for Research into Ecological and Environmental Modelling, University of St Andrews, St Andrews, UK; catriona.harris@st-andrews.ac.uk, pb282@st-andrews.ac.uk, len.thomas@st-andrews.ac.uk

Title: **Estimating dose-response functions for cetaceans exposed to naval sonar.**

Abstract

Bayesian hierarchical dose-response models have been used to fit dose-response functions to data from controlled exposure experiments (CEEs) conducted on free-ranging cetaceans. These models have the flexibility to accommodate data from multiple species and include explanatory covariates and different functional forms (monophasic and biphasic). However, computationally efficient model selection methods are required to assess empirical support for shared patterns in species responsiveness and to select between functional forms and covariates. A reversible jump Markov chain Monte Carlo (RJMCMC) approach for model selection that aligns with the Bayesian dose-response framework has been developed and compiled into an R package (espresso: **ES**timating **P**atterns of **RES**ponsiveness to Navy **So**nar) to facilitate use by the US Navy Environmental Compliance team and others. A complete dataset of expert-scored and severity-scored exposures to CEEs has been compiled and comprises data on 12 species along with associated contextual variables for each exposure event. The Bayesian dose-response model, the RJMCMC algorithm, and the CEE dataset are being used together to better understand the support for different species groupings, covariate effects (particularly whale-source range) and functional forms. In addition, this framework has been used to assess the effect of uncertainty in the dose metric (e.g., whether the dose is measured on the tag or modelled) on the resulting dose-response function through simulation. We show that sample size is the more dominant driver of uncertainty in dose-response functions and that behavioral responses detected on satellite tags, where dose has to be inferred, can be a valuable addition to existing datasets.

Authors: Joshua Hewitt[1], Alan E. Gelfand[1], Nicola J. Quick[2], William R. Cioffi[2], Brandon L. Southall[2,3], Stacy L. DeRuiter[4*], and Robert S. Schick[2].

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[1]Department of Statistical Science, Duke University, Durham, NC, USA 27708
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Title: Monte Carlo testing for exposure response detection to mid-frequency active SONAR in Cuvier's beaked whales (*Ziphius cavirostris*) using satellite-linked telemetry tags.

Abstract:

Given the prevalence of anthropogenic noise in marine environments, it is crucial to quantify potential associated effects on marine mammals. Measuring responses is challenging because most species spend most of their time submerged making behavior difficult or impossible to observe from the surface. It can thus be difficult to determine if, following an exposure to sound, an observed dive differs from previously recorded dives.

Direct, fine-scale measurement of such behavior often employs on-animal tags to record movement. We focus on analyzing data collected via satellite-linked tags, which have the advantage of collecting data for weeks to months, but with a tradeoff in data resolution. The tag data we examine samples diving behavior at five-minute intervals, and dive depths are recorded as centers of an arbitrarily created set of depth bins.

To identify possible behavioral responses in diving, and to inform the design of subsequent individual and population-level response analyses, we propose a battery of Monte Carlo tests employing summary statistics that compare pre-exposure and post-exposure observation windows. The summary statistics, with regard to the windows, are sensitive to both local and global features of dive data. The statistics are tested against a null distribution arising from analogous windows without exposure. These test statistics enable explicit interpretation of different types of diving responses. We illustrate this methodology with data from two animals. When we identify possible behavioral responses, they are individual-specific and depend on the context and type of exposure, but help characterize responses to facilitate later population level inference.

*Presenting Author. Lead author is unable to attend

Authors: Joshua Hewitt[1], Alan E. Gelfand[1], Nicola J. Quick[2], and Robert S. Schick[2,*].

Affiliations:
[1]Department of Statistical Science, Duke University, Durham, NC, USA 27708
[2]Nicholas School of the Environment, Duke University, Durham, NC, USA 27708

Title: Identifying vertical avoidance diving behavior in Cuvier's beaked whales using long-duration, low-resolution satellite telemetry devices

Abstract:

Mid-frequency active sonar (MFAS) has been linked to behavioral impacts and mass strandings in beaked whales. To quantify responses, controlled exposure experiments (CEEs) have been conducted, in which tagged whales are exposed to MFAS at various source levels. We use data from Cuvier's beaked whales collected during the Atlantic Behavioral Response study to identify vertical responses, defined as the onset of deep dives to avoid MFAS exposure. Vertical responses may increase a whale's risk of physiological complications associated with extended deep diving. Diving responses have been observed in previous CEEs, but we address two challenges in using statistical models to identify vertical responses from satellite tag data. First, routine, deep foraging dives must be separated from deep response dives. We separate dives by modeling the vertical diving speed and the relative timing of routine, foraging dives. Second, satellite tags record depth data in low-resolution. A depth range (i.e., 0-20m) is recorded once every 5 minutes, meaning dives are only represented via a handful of coarse depth observations. We define a multi-state continuous-time model for animal movement between discrete depth bins. Out-of-sample validation demonstrates our model can predict if a deep dive following MFAS exposure would likely have been non-deep in the absence of MFAS exposure, providing evidence for vertical responses. More broadly, our process-driven model can be adapted to different species, providing a basis for identifying a wide range of disturbances at multiple time scales from relatively low-resolution satellite tag data.

*Presenting Author. Lead author is unable to attend

Andrew Read[1], Robin Baird[2], Joel Bell[3], Will Cioffi[1,4], Stacy DeRuiter[5], Ron Filipowicz[3], Heather Foley[1], Catriona Harris[6], Josh Hewitt[1], Megan McKenna[4,7], Doug Nowacek[1], Nicola Quick[1], Rob Schick[1], Jeanne Shearer[1], Kristin Southall[4], Zachary Swaim[1], Len Thomas[6], Danielle Waples[1], Daniel Webster[8], Jillian Wisse[1], and Brandon Southall[1,4]

[1] Duke University
[2] Cascadia Research Collective
[3] U.S. Navy
[4] Southall Environmental Associates
[5] Calvin College
[6] University of St. Andrews
[7] Stanford University
[8] Bridger Consulting

Title: A Multi-Scale Controlled Exposure Experiment to Assess the Response of Cuvier's Beaked Whales to MFAS Signals off Cape Hatteras, NC, USA

Requested ESOMM Session: Behavioral effects of noise, Controlled Exposure Experiments (CEEs); Field studies

Requested format: Oral Presentation (Lead author intends to attend in person)

Abstract: Since 2017, we have conducted controlled exposure experiments (CEEs) in productive shelf-break habitats to assess responses of Cuvier's beaked whales to military mid-frequency (3-5 kHz) active sonar (MFAS). Unlike most previous studies conducted on instrumented military training ranges, tactical military sonars occur but are infrequent at our study site. Our CEEs build on a very large baseline dataset for this species in this habitat. We deployed 88 satellite-linked tags and six digital acoustic tags since 2014, a subset of which were involved in CEEs. We measured responses of 30 tagged beaked whales during seven CEEs using operational MFAS produced by Navy vessels. We also conducted nine CEEs with experimentally-simulated MFAS signals, yielding a total of 50 exposure events for tagged beaked whales. Several factors have been central to the success of these experiments, including the high density of beaked whales in our study area and our ability to relocate tagged whales using an Argos Goniometer. We have benefited from the application of advanced field methods, including real-time acoustic propagation modeling to predict received levels and associated error, validated by empirical measurements, and a variety of new analytical approaches, developed by colleagues in the Double MOCHA project. Vital to our success has been the development of effective coordination with operational Navy vessels, including formal scheduling, regular open communication, and real-time coordination in the field. Baseline behavior, methodological advances, and behavioral response of Cuvier's beaked whales to simulated MFAS signals from this research program will also be presented elsewhere at this meeting.

Authors: Robert S. Schick[1,*], Amy Bu[2], Larry Chen[2], William R. Cioffi[1,4], Camaren Dayton[2], Heather J. Foley[1], John E. Joseph[3], Nick Kaney[2], Tetyana Margolina[3], Jennifer Schultz[2], Zachary T. Swaim[1], Nathan Yu[2], Larry Zheng[2], Brandon Southall[1,4]

Affiliations:
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[2]Trinity College, Duke University, Durham, NC USA 27708
[3]Oceanography Department, Naval Postgraduate School, Monterey, CA USA 93943
[4]Southall Environmental Associates, Aptos, CA USA 95003

Title: Reducing uncertainty in position and received levels of simulated sonar to improve understanding of response by Cuvier's beaked whales (*Ziphius cavirostris*) off Cape Hatteras, North Carolina

Abstract:
Reliable measures of noise received levels (RLs) in controlled exposure experiments (CEEs) are needed to determine exposure for application in exposure-response probability assessments. Here we document a process to better estimate RLs when animal-borne hydrophones are absent, for instance in the use of relatively long duration satellite-transmitting tags. We use a dataset of 16 satellite-transmitting tags that provide position and relatively frequent depth (but not acoustic) data. These tags were deployed on Cuvier's beaked whales in the spring and summer of 2019 during the Atlantic Behavioral Response Study. The duration of all but one tag overlapped with at least one of four CEEs, where target RLs were up to 140 dB re 1µPa. We augmented the positional data returned from the ARGOS system with information on individual tags from focal follow vessels equipped with Argos Goniometers. This positional data was included as input to an Ornstein-Uhlenbeck movement model to generate 100 estimates of position at each 5-minute interval during a CEE. These estimates, along with the depth data, were co-registered with output from a sound propagation model to estimate RL in the water column. For instance, during a 30-minute CEE in August, 2019, the focal animal received an estimated RL of 133 dB re 1µPa (121 - 144 dB re 1µPa, 95% CI). We found that including ancillary information substantially reduced uncertainty in positional estimates and RL estimates. Narrowing uncertainty, both in terms of distance and RL, is critical to better understanding and developing predictive functions of different responses.

*Presenting Author.

Title: Deciphering how stress impacts the hypoxia response in cetaceans using novel cetacean cell culture models

Lead: Jason Somarelli (will attend in person)

Authors: Jillian Wisse[1], Larry Zheng[2], Emma Schmaltz[2], Sarah Plumlee[3], Kathryn E. Ware[2,4], Thomas F. Schultz[1], Nicola Quick[1], Jason A. Somarelli[2,4]
[1]Nicholas School of the Environment, Duke University Marine Laboratory
[2]Department of Medicine, Duke University Medical Center
[3]Department of Orthopaedics, Duke University Medical Center
[4]Department of Orthopaedic Surgery, Duke University Medical Center

Theme: 'New technologies for monitoring and research' or 'Physiological effects of noise exposure: stress response to sonar exposure'

Preferred Presentation Format: Oral

Abstract:

Deep-diving cetaceans, such as beaked whales, are especially susceptible to disturbance from anthropogenic noise. Noise induces stress in these animals and leads to increased glucocorticoid signaling, and there remains an urgent need to understand how these stress pathways may impact animal dive capacity.

Studies of the interconnections between stress and dive capacity have been hampered by difficulties in obtaining samples from these species. However, new developments in lab-based cell culture systems have enabled us to study the interplay between stress (glucocorticoid) signaling and low oxygen (hypoxia) tolerance at the cellular level . Using RNA-Seq data from cultured cells, we analyzed gene networks across six cetacean species, identifying a core network of genes connecting hypoxia tolerance with the glucocorticoid-induced stress response. Using an qRT-PCR assay of hypoxia-inducible genes, we observed that treatment of Curvier's beaked whale (*Ziphius cavirostris*) cells with varying doses of hydrocortisone (0nM, 1nM, 100nM, 1uM) suppressed the hypoxia-mediated increase in these genes, suggesting that the addition of hydrocortisone dampens the ability of Cuvier's beaked whale cells to properly respond to hypoxia. These results directly link stress and diving capacity through hypoxia suppression in beaked whale cell cultures. These studies underscore the power of combining genomics and cell-based studies to reveal critical insights with implications for the design and interpretation of observed behavioral responses during studies on the effects of anthropogenic noise on beaked whales.

Brandon Southall[1,2], Robin Baird[3], Will Cioffi[1,2], Stacy DeRuiter[4], Heather Foley[2], Catriona Harris[5], Josh Hewitt[2], Megan McKenna[1,6], Doug Nowacek[1], Nicola Quick[1], Rob Schick[2], Jeanne Shearer[2], Zach Swaim[2], Len Thomas[5], Danielle Waples[2], Daniel Webster[7], Jillian Wisse[2], and Andrew Read[2]

[1] Southall Environmental Associates Duke University
[2] Duke University
[3] Cascadia Research Collective
[4] Calvin College
[5] University of St. Andrews
[6] Stanford University
[7] Bridger Consulting

Title: "Behavioral responses of Cuvier's beaked whales to simulated military sonar"

Requested format: Oral Presentation (Lead author will attend in person)

Requested ESOMM Session: 6. Behavioral effects of noise: CEEs (Field)

Abstract: We conducted nine controlled exposure experiments (CEEs) using simulated navy mid-frequency (3-5 kHz) active sonar (MFAS) and two control (known MFAS absence) with tagged Cuvier's beaked whales (*Ziphius cavirostris*) off Cape Hatteras, NC, USA. During CEEs, three individuals were tagged with high-resolution, short-term movement and acoustic tags (DTAGs) and 43 individuals were tagged with lower-resolution, longer-term movement and dive satellite-transmitting tags. A total of 50 unique exposure-response events occurred during CEEs; 43 were initial exposures within individuals and seven were known repeat exposures days or weeks following initial exposures. For focal individuals, MFAS received levels (RLs) were experimentally controlled between 110-140 dB (RMS) re: 1µPa at ranges of between 1-10 nm from an experimental vertical line array source transmitted at 212 dB. Incidentally exposed (non-focal tagged) whales were tracked over comparable to much greater ranges (up to > 100 nm). Response analyses using existing and novel time-series statistical methods were applied to quantify individual behavioral changes during MFAS relative to baseline conditions. Responses during and following CEEs included horizontal avoidance of the CEE area, changes in diving behavior, and initial observations of changes in beaked whale social interactions following sonar exposure. As the largest such dataset with known and controlled MFAS exposure obtained to date for beaked whales, results will contribute substantially to probabilistic exposure risk functions for these sensitive species and provide important contrasts for analysis of a similarly large sample of tagged beaked whales exposed to operational Navy sonar in an ongoing study in the same region.

Swaim, Zachary T[1]., Cioffi, William[1,2], Waples, Danielle W. [1], Foley, Heather J. [1], Webster, Daniel L. [3,4] and Andrew J. Read[1]

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When seconds count: Active platform tracking and animal monitoring at sea using an Argos Goniometer

Effective at-sea tracking of focal animals is a critical component of behavioral response studies. Offshore Cape Hatteras, North Carolina, Cuvier's beaked whales (*Ziphius cavirostris*) regularly perform hour-long foraging dives interspersed with a series of shorter dives. Their surface intervals average a little over two minutes, so early detection of each surfacing bout is critical to successfully approaching a focal tagged animal. Here we describe the benefits of using an Argos Goniometer to locate, track and tag one of the world's most elusive marine mammals. We deployed 58 satellite-linked tags on Cuvier's beaked whales between 2014 and 2019 off Cape Hatteras as part of a behavioral response study for the U.S. Navy. Beginning in 2017, we used an Argos Goniometer to re-locate tagged individuals. The Goniometer intercepts the tag's signal when the whale surfaces, and we developed a custom software program to display bearing and signal strength of the tag relative to the vessel, allowing us to relocate tagged animals quickly, tag other animals in the group, and obtain additional photo-identification data. As a result, since 2017 we have averaged 2.2 tag deployments/day, compared to 1.5 deployments/day between 2014 and 2016. The number of re-sightings of individuals increased from 12% in 2016 to 32% by 2019 and the within season re-sight rate of tagged individuals has increased by 23% since 2017. We conclude that use of the Argos Goniometer has significantly increased our encounter rates with tagged whales, allowing us to more effectively conduct behavioral responses studies.

Len Thomas[1], Richard Glennie[1], Rob Schick[2], Alan Gelfand[3], Theo Michelot[1], Joshua Hewitt[3], Nicola Quick[4], Catriona Harris[1]

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Title Estimating behavioral response to Navy sonar using continuous-time models of horizontal and vertical movement

Abstract

We describe the Double MOCHA project, which aims to develop new quantitative methods for inferring behavioral response of marine mammal species to Navy sonar. The outputs of the first MOCHA project substantially enhanced our ability to quantify marine mammal responses to various acoustic stimuli. However, as BRS studies have continued to evolve so have the analytical requirements. Specifically, the collection of data across multiple spatial and temporal scales from a variety of different platforms presents new analytical challenges. Methods development has focused on DTAG and satellite tag data from beaked whales exposed to scaled and real-ship Navy sonar, to characterize baseline behavior and detect responses in dive behavior and horizontal movement. For example, continuous-time movement models have been fitted to DTAG data within a stochastic differential equation (SDE) framework, to capture time-varying behaviors within each dive, and the deviation from baseline during exposure events. Continuous-time discrete space (CTDS) models have been developed to characterize baseline dives from satellite tag data and then detect unusual dive patterns given the sequence of dives prior to exposure. Extensions of these models are also under consideration for horizontal movement. The development of continuous-time models marks substantial progress for the analysis of data collected across multiple scales. The analytical tools developed within Double MOCHA are integrated into the suite of methods utilized by the Atlantic BRS project and include publications and R packages, to facilitate further uptake.

Authors: [1]Waples, Danielle M., [1,2]Cioffi, William R., [1]Swaim, Zachary T. [1]Foley, Heather J., [3,4]Webster, D.L., [4]Baird, R.W., [1]Nowacek, D.P., [2]Southall, B.L. and [1]Read, Andrew J.

[1]Duke University Marine Laboratory, Beaufort, NC, USA
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[3]Bridger Consulting Group, Bozeman, MT, USA
[4]Cascadia Research Collective, Olympia, WA, USA

Title: Cuvier's beaked whale group dynamics investigated through tag telemetry and photo-identification.

Theme: Future Directions- Horizon Scan

Preferred presentation: Poster

Lead author participation: In-person

Social behavior changes in response to disturbance can have serious consequences for fitness. Additionally, behavioral context has the potential to mediate the type, magnitude, and severity of response to disturbance. Indeed, fission events have been observed following sound exposures at our study site. Here we examine group dynamics in Cuvier's beaked whales (*Ziphius cavirostris*) using satellite-linked depth-recording telemetry tags and photo-identification. Our objective is to establish a baseline from which future perturbations, associated with disturbance, can be detected. Our photo-identification catalog of Cuvier's beaked whales encountered off Cape Hatteras contains 234 unique individuals from 189 sightings (since 2011). Group size ranged from one to eight whales (median 3). In a high proportion of sightings all animals in the group were photographed and identifiable. Seventy-four (32%) individuals have been resighted at least once and 39 (17%) over multiple years (maximum 7 years). Pairs of individuals in the same group were tagged on 10 occasions and trios were tagged in the same group three times, allowing investigations of short-term group dynamics. Our results show little evidence of long-term social associations (2 multiyear resights: male pair, mixed sex pair), but whales are often associated in the same group for days to weeks, with some fission and fusion. On average, group membership changed at 0.5 events per day. Telemetry data from concurrently instrumented individuals can be used to identify when in a dive cycle fission or fusion events occur and be used with photo-identification to produce social metrics of disturbance during controlled exposure experiments.

Title: Hormone Responses of Short-Finned Pilot Whales (Globicephala macrorhynchus) to Mid-Frequency Active Sonar (MFAS)

Lead: Jillian Wisse (will attend in person)

Authors: Jillian Wisse[1], Nick Kellar[2], Brandon Southall[3], Andy Read[1], Doug Nowacek[1]
[1]Nicholas School of the Environment, Duke University Marine Laboratory
[2]Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration
[3]Southall Environmental Associates, Inc.

Theme: Physiological effects of noise exposure: stress response to sonar exposure

Preferred Presentation Format: Oral

Abstract:

Physiological response studies are critical for fully understanding the impacts of human disturbance. Some deep-diving odontocetes are particularly susceptible to disturbance caused by mid-frequency active sonar (MFAS), but we have yet to establish a direct link between acoustic stressors and hormone responses.

To determine whether MFAS elicits physiological stress responses in short-finned pilot whales (Globicephala macrorhynchus) we conducted three controlled exposures with simulated MFAS signals off Cape Hatteras, NC, US. For each 30-minute exposure, the source level was 200 dB RMS. Received levels, estimated by a transmission loss model and source-to-animal distances, were between 115 and 160 dB RMS. Following exposure, we collected remote blubber biopsies from 18 unique individuals. To assess the temporal response of hormones in blubber, we collected biopsies over a two-hour period post-exposure. We used liquid chromatography tandem mass spectrometry to analyze biopsies for 11 stress and reproductive hormones, then assessed responses to MFAS and interactions between hormones.

Increased cortisol concentrations indicated an acute physiological response to MFAS. Using AIC, we compared several statistical models fitting these data. The best fit described a quadradic relationship between blubber cortisol and time after initial exposure, with cortisol concentrations increasing and peaking 50 mins after sonar exposure ended, and then gradually declining. Additional hormone analyses of non-exposed animals are ongoing and may provide insight to these results. This is one of the first experimental demonstrations of an adrenal response to noise in free swimming cetaceans. The results can inform the temporal frame and magnitude of endocrine responses in odontocetes.

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Title: Reproducible research and visualization techniques in support of the Atlantic BRS on Cuvier's beaked whales (*Ziphius cavirostris*) off Cape Hatteras, North Carolina

Abstract:
Conducting a Behavioral Response Study (BRS) with free-ranging marine mammals is difficult and multi-faceted. To parameterize the relationship between exposure and response, 3D positions of exposed animals in relation to a sound source are needed in order to appropriately apply modeled sound fields to estimate exposure. Variable spatial and temporal resolution positional and acoustic data are collected using satellite-transmitting and archival animal-borne tags, and on vessels with GPS units, Argos Goniometers and acoustic devices. Sound propagation fields are modeled separately and integrated with the observed positional data to estimate received levels (RLs). Here we describe a reproducible research workflow we developed as part of an undergraduate research program at Duke University (MUSER) to help visualize and analyze the data collected during the 2019 Atlantic BRS season. We developed four components: 1) an R data package containing all of the observed and ancillary data on animal movements and diving patterns, as well as the timing and location of each of 4 controlled exposure experiments; 2) a dashboard that summarizes the data at a high-level, 3) an R Shiny app that provides detailed information on the location, movements, and diving patterns of beaked whales; and 4) an R Shiny app that allows the user to visualize the 3D position of the animals in relation to the modeled sound propagation. We demonstrate each of these 4 components during an interactive presentation and document how reproducible research approaches are critical in complex and multivariate projects typical of marine mammal research.

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4. Overall Assessment and Recommendations for 2022 Effort

4.1 General Assessment of Atlantic-BRS 2021 Accomplishments

- Sustained effort, patience, and adaptability was required to conduct field operations successfully again during a pandemic.
- Successful deployment of a large number (n=16) of tags on high-priority Cuvier's beaked whales and collection of tens of thousands of hours of movement and diving behavior and movement. No secondary priority pilot whales were tagged given the success with beaked whales.
- Very successful coordination and adaptive planning with USFFC colleagues to accomplish two complete and as-designed CEEs with U.S. Navy vessels. These events evolved flawlessly thanks to extensive, sustained coordination and effort with U.S. 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 and U.S. Navy teams. There were multiple focal whales during both CEEs, with RLs spanning the entirely of the target range, including a CEE with the *USS Farragut* that represents, by far, the largest number (n=12) of Cuvier's beaked whales ever tagged during a known U.S. Navy sonar exposure event. Data requested from U.S. Navy vessels was provided in a complete, timely, and unclassified manner.
- DTAG reliability continues to be a concern. The single successful DTAG deployment that would have included overnight baseline data unfortunately failed due to battery malfunction, and only limited baseline daytime data were obtained.
- Target RLs for Cuvier's beaked whales were maintained at 110 to 140 dB RMS based on an assessment of results and indications of quite strong responses to simulated MFAS from previous years at the upper end of these levels. These target levels were achieved again with real vessels at realistic operational ranges (10 to 40 nautical miles [nm]), as intended, 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 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 in 2019 and 2020, with very positive results. Many of the 2021 tags again achieved greater duration deployments for returning ARGOS position data in addition to 2 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 relocating tagged individuals many times to obtain photographs and 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.

- Continued contribution to long-term photo ID records for Cuvier's beaked whales in this priority Navy operating area (see: Waples et al., 2021).
- Extensive progress in publications and upcoming presentations have been made in terms of baseline behavior and methodological advances, including tag settings, RL modeling, and new behavioral response methods, which have major implications and improvements in the underlying data and analyses and are also directly contributing to other U.S. Navy-funded efforts.

4.2 Recommendations

- With five 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, it is recommended to wrap up field operations for the current phase of the Atlantic-BRS experiment during the 2022 campaign. No changes in methodological or field approaches are suggested within CEE protocols. However, based on target sample sizes for operational vessel CEEs and accomplishments to date, we suggest focusing the effort to ensure a single, high sample size, closely coordinated with U.S. Navy vessel CEE in sufficiently acceptable weather conditions to allow tracking at attempts to deploy high-resolution tags. As discussed with USFFC colleagues, this will require advance coordination and planning for multiple ship opportunities to select a single event. A slight reduction in the total field time is envisaged though retaining enough effort for multiple tag deployment windows to enable this adaptive, selective approach.
- 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 advance testing of DTAGs for all sensors should be conducted ahead of deployments given battery and multiple sensor failures in 2020 and 2021 deployments.
- Field efforts to locate tagged animals with validated locations using goniometer detections, visual observations, and photo-ID should be maintained before and after CEEs, as successfully done with increased effort in 2021.
- It is also recommended that 2022 serve as the analysis and publication wrap up period for the current effort. Some of the reduced field cost inherent in the above recommendation could be applied to expand analytical and writing time.
- Given the interest and intent to test continuously active sonar (CAS) signals in CEEs using the Atlantic-BRS field and methodological teams and approaches, it is recommended that some initial planning and coordination occur in 2022 with an eye to field operations pivoting to CAS signals in 2023 and beyond.

5. References

Hewitt, J., R.S. Schick, and A.E. Gelfand (2021). Continuous-time Discrete-state Modeling for Deep Whale Dives. *JABES* . https://doi.org/10.1007/s13253-020-00422-2

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. http://dx.doi.org/10.1098/rsos.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.

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., 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.

Waples, D.M. and A.J. Read. 2021. *Photo-Identification Analyses in the Cape Hatteras Study Area: 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 19F4026 issued to HDR, Inc., Virginia Beach, Virginia. February 2021.