# Atlantic Behavioral Response Study (Atlantic-BRS)

# 2024

## *Annual Progress Report*

PREPARED BY

*Southall Environmental Associates*

*Duke University*

*CREEM—University of St Andrews*

March 2025

**Suggested Citation:**

Southall, B.L, W. Cioffi, R. Schick, C. Harris, A. Harshbarger, D. Nowacek, A.J. Read, Z.T. Swaim, D.M. Waples, and D.L. Webster. 2025. *Atlantic Behavioral Response Study (BRS): 2024 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 23F4054, issued to HDR Inc., Virginia Beach, Virginia. March 2025.

**Cover Photo Credits:**

Goose-beaked whale (*Ziphius cavirostris*) being tagged with a satellite telemetry tag off Cape Hatteras. Photographed by Will Cioffi, taken under National Marine Fisheries Service Scientific Research Permit No. 22156, issued to Andy Read/Duke University.

**Acknowledgments:**

The Atlantic-BRS project acknowledges and sincerely appreciates the extensive and tireless efforts of many people in safely and professionally fielding outstanding research teams on the Research Vessel (*R/V*) *Barber* and *R/V Shearwater*.

**This project is funded by United States (U.S.) Fleet Forces Command and managed by Naval Facilities Engineering Systems Command Atlantic and HDR Inc. as part of the U.S. Navy's Marine Species Monitoring Program.**

Science ⚓ Stewardship ⚓ Protection

# Table of Contents

## Figures

## Tables

## Acronyms and Abbreviations

| | |
|---|---|
| °N | degrees North |
| °W | degrees West |
| Atlantic-BRS | Atlantic Behavioral Response Study |
| CAS | continuous active sonar |
| CEE | controlled exposure experiment |
| dB | decibel(s) |
| dB (RMS) re 1 μPa | decibel(s) root mean square referenced to 1 micropascal |
| DTAG | digital acoustic recording tag |
| DUML | Duke University Marine Lab |
| EDT | Eastern Daylight Time |
| ESE | east-southeast |
| GPS | Global Positioning System |
| Hz | hertz |
| ID | Identification Number |
| IDDI | Inter-deep-dive-interval |
| kHz | kilohertz |
| km | kilometer(s) |
| $km^2$ | square kilometer(s) |
| kt | knot(s) |
| LIMPET | Low-impact Minimally Percutaneous Electronic Transmitter |
| LMR | Living Marine Resources |
| m | meter(s) |
| Max. (or max) | Maximum |
| MFAS | mid-frequency active sonar |
| min | minute(s) |
| n/a | not applicable |
| nm | nautical mile(s) |
| NPS | Naval Postgraduate School |
| ONR | Office of Naval Research |
| PAS | pulsed active sonar |
| photo-ID | photo-identification |
| R/V | Research Vessel |
| RL | received level |
| RMS | root mean square |
| s | second(s) |
| SEA | Southall Environmental Associates |
| SEL | sound exposure level |

| | |
|---|---|
| SLTDR (or sat tag) | satellite-linked, time-depth recording tag |
| SOCAL-BRS | Southern California Behavioral Response Study |
| U.S. | United States |
| USFF | U.S. Fleet Forces Command |
| USS | United States Ship |
| UTC | Coordinated Universal Time |
| Zc (Ziphius) | *Ziphius cavirostris* |

# Executive Summary

The Atlantic Behavioral Response Study (Atlantic-BRS) was conceived, designed, adapted, and conducted by a multi-institutional collaboration of experienced scientists working together with the United States (U.S.) Navy. It was built on historical and ongoing U.S. Navy-funded studies under their Marine Species Monitoring Program, and the U.S. Navy's Living Marine Resources program and Office of Naval Research. This project occurs off the coast of Cape Hatteras, North Carolina, and has evolved to evaluate and quantify the behavioral responses of key marine mammal species to different kinds of U.S. Navy mid-frequency active sonar (MFAS) systems. These include simulations of pulsed active sonar (PAS); operational PAS from SQS-53C systems on U.S. Navy surface vessels; and continuous active sonar (CAS), also from operational surface vessels.

An adaptive multi-scale approach prioritizing many simultaneously tagged individuals for baseline monitoring and conducting BRSs is applied for key species: primarily goose-beaked whales (*Ziphius cavirostris*; hereafter *Ziphius*) and, secondarily, short-finned pilot whales (*Globicephala macrorhynchus*). 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, now with multiple sonar systems. Building on earlier field seasons (see Southall et al. 2018, 2019, 2020, 2021, 2022, 2023, 2024), this project has yielded one of the largest and most comprehensive data sets available for baseline behavior and responses to sonar exposure for *Ziphius*, one of the highest-priority marine mammal species for U.S. Navy research and monitoring.

The 2024 field season included the first successful CEE using U.S. Navy CAS MFAS signals for any marine mammal species and the first with any CAS signal to high-priority *Ziphius* individuals. A single, extended field period spanned from summer into autumn. Despite challenging weather conditions and limited focal species availability, four tags were deployed during suitable weather windows ahead of anticipated U.S. Navy vessel availability. Multiple CAS-capable vessels were scheduled for possible coordination, thanks to sustained coordination and planning between the field team and U.S. Fleet Forces Command. A successful CAS CEE was coordinated with the United States Ship *Thomas Hudner* involving three of the tagged *Ziphius*. A second CAS-capable ship was scheduled and available for coordination, but additional tagging efforts in advance of the availability window of the ship were unsuccessful.

Extensive analytical effort continued to substantially advance the existing large data sets for baseline behavior, analytical and technological tools, and responses to both simulated and operational MFAS. Multiple manuscripts with data and analyses from the Atlantic-BRS project were published in 2024, including a very large sample size *Ziphius* MFAS response paper focused on simulated PAS signals.

# 1. Overview

## 1.1 Overall Project Design and Objectives

The Atlantic Behavioral Response Study (Atlantic-BRS) is a research program that has included sequential field efforts to measure baseline behavior and the effects of different kinds of active military sonar systems on marine mammals off the coast of Cape Hatteras, North Carolina. The project has brought together a research collaboration of scientists from Duke University, Southall Environmental Associates (SEA), Bridger Consulting, Calvin University, and the University of St. Andrews. The overall experimental design was adapted from methods initially developed in the Southern California Behavioral Response Study (SOCAL-BRS), funded primarily by the United States (U.S.) Navy's Living Marine Resources (LMR) program and Office of Naval Research (ONR). Novel integrations and strategic deployments of different tag sensors and controlled exposure experiments (CEEs) on variable time and space scales, including different types of active acoustic sources, have been applied to the primary focal species, goose-beaked whales (*Ziphius cavirostris;* referred to hereafter as *Ziphius*), and secondary focal species, short-finned pilot whales (*Globicephala macrorhynchus*). This collaboration has had substantial success in tagging beaked whales and conducting CEEs due to reliable coordination with operational mid-frequency (1 to 10 kilohertz [kHz]) active sonar (MFAS) systems from U.S. Navy surface vessels (e.g., SQS-53C-equipped surface vessels).

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

Many Navy-funded studies of marine mammal responses to MFAS, including the SOCAL-BRS, have focused on the use of short-term, high-resolution acoustic tag sensors to measure fine-scale behavior in response to experimentally controlled noise exposure. Other studies have used coarser-scale, longer-term measurements of movement and diving behavior associated with incidental exposures during sonar training operations. The Atlantic-BRS project applies both approaches, expanding the temporal and spatial scales of previous BRSs by combining (1) short-term, high-resolution acoustic archival tags (or digital acoustic recording tags [DTAGs]) providing short-term (hours) but very high-resolution movement and calibrated acoustic data with (2) satellite-linked, time-depth recording tags (SLTDRs or "sat tags"]) providing much longer-term (weeks to months) data on movement and increasingly higher resolution dive data, which are simultaneously deployed on multiple individuals of focal species in the same CEEs. Strategically specified categories of potential behavioral responses are evaluated using a variety of custom and adapted proven and published statistical methods. These are tuned to address specific, biologically meaningful types of responses, namely (1) potential avoidance of sound sources that influence habitat usage, (2) changes in foraging behavior, and (3) changes in social behavior.

CEEs in earlier field seasons involved pulsed active sonar (PAS) signals from both operational and simulated MFAS sources. These systems typically use approximately 1.5-second sonar pulses repeated approximately every 25 seconds. Beginning in 2023, the Atlantic-BRS project began investigating responses to a different type of MFAS system—continuous active sonar (CAS). While CAS signals are similar in frequency and overall modulation patterns, they are presented entirely or nearly continuously. And while the total output power of these signals may be similar in terms of total energy, the root-mean-square (RMS) sound pressure levels are consequently lower. Thus, the overall exposure context is quite different, and there is interest in directly measuring and contrasting exposure and response from CAS stimuli with the large PAS data set obtained thus far. This shift to focus on CAS was also done to address specified need topics identified by the U.S. Navy's LMR program, which is providing supporting supplemental funding for the program in coordination with the Navy's marine species monitoring program. The team worked directly with the U.S. Fleet Forces Command (USFF) in Norfolk, Virginia, to extend previous successful approaches used in coordinating PAS-capable U.S. Navy surface vessels to conduct CEEs with CAS-capable ships.

This annual progress report provides a synthesis of experimental methods, field efforts, tagging results, and exposure-response results for the first-ever CAS CEE conducted with the United States Ship (*USS*) *Thomas Hudner* in 2024. Finally, it includes a synthesis of peer-reviewed papers that have been or are in the process of being published (see **Section 3**).

## 1.2 Experimental Design

Broadly speaking, the Atlantic-BRS approach involves multiple tracking and monitoring methodologies and platforms, incorporating lessons learned from many research and monitoring programs funded by the U.S. Navy. These included quantitative measurements of individual behavior using tags of several types, small-vessel-based individual and group focal follow observations, targeted collection of individual tissue biopsy samples, photo-identification (photo-ID), and remote passive acoustic monitoring from archival recorders.

The overall CAS CEE experimental design is deliberately held consistent with that used to evaluate PAS MFAS. It was specifically maintained in the structure of identical duration CEE phases (pre-exposure [no MFAS]), exposure (specified MFAS transmissions), post-exposure, tagging approaches, and on-water vessel and observer operations to make the results in terms of animal response be as comparable in terms of methodology and context as possible. Source positions were still determined based on model results using MFAS signal output parameters, with the goal of matching received levels (RLs) at focal receiving individuals; these were normalized in terms of signal energy (sound exposure level [SEL]) given the difference in temporal patterns between repeated signals. Source movement was also designed to be identical for CAS-capable ships as in PAS CEEs. Transmissions were designed to occur 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. For a more detailed discussion of the methodological foundation for the Atlantic-BRS experimental design and how it was developed and evolved, readers are referred to earlier project reports and published papers from other U.S. Navy-funded work

(Southall et al. 2012, 2016, 2019; Schick et al. 2019, 2024). Atlantic-BRS publications referenced in this report (see **Section 3**) provide additional details regarding the design and implementation of these methods.

As noted, through close coordination with collaborators at USFF, the methods had been successfully applied during the Atlantic-BRS and by seven different U.S. Navy surface vessels during earlier field efforts, resulting in eight CEEs with PAS stimuli. This approach includes a period prior to CEEs during which baseline behavioral data were collected—a 60-minute minimum for animals with DTAGs and a 24-hour minimum for animals with sat tags. Most baseline SLTDR data periods were much longer (weeks to months) in practice for sat tags. Pre-exposure baseline behavioral data collection primarily involved data from tag sensors, supplemented by focal follows of tagged animals when possible.

While notable differences exist related to CAS signal parameters that need to be accounted for in designing field configurations to meet experimental objectives, operational approaches to coordinating transmissions for PAS CEEs were deliberately identical in previous Atlantic-BRS efforts as in preceding MFAS CEEs from the SOCAL-BRS project (see Southall et al. 2012; Schick et al. 2019). For PAS CEEs, operational U.S. Navy vessels were positioned at ranges from subjects that met experimental objectives for target RLs based on the publicly available (unclassified) 3- to 4-kHz source level of 235 decibels root mean square referenced to 1 micropascal (dB (RMS) re 1 μPa; hereafter dB unless otherwise specified) signals of a constant nominal 1.6-second duration 53-C waveform type. For planning and coordination of CAS CEEs, a similar approach was used to effectively match RLs for signals of variable duration (using SEL (dB re 1$\mu$Pa$^2$-s). The Atlantic-BRS team used unclassified stimulus parameters provided via USFF for CAS signals, including a slightly lower fundamental frequency range (2.5 to 3.2 kHz [650 hertz bandwidth]) and a 50-second sweep duration that was repeated continuously (100 percent duty cycle). While an unclassified source level was not available, an equal energy assumption (10 log duration) was used as an approximation to relate individual CAS and PAS pings, resulting in an estimated 218 dB source level estimate for the CAS signal band.

Based on focal animal locations, the starting position and course for the transmitting vessel was determined using custom in situ propagation modeling tools developed and supported by the Naval Postgraduate School (NPS). The experimental design allows for positioning of MFAS sources, resulting in target RLs at focal individuals based on their position, and accounting for local bathymetry and dynamic oceanographic conditions. However, other individuals were incidentally exposed at a variety of RLs that were not explicitly controlled but estimated (with error) from positions derived from either sat tags or field observations.

The course of the vessel was designed to result in an escalation in RL at the presumed location of focal individuals based on their movement. Movement of the source was designed to be generally, but not directly, toward individuals. Given the large number of tagged individuals exposed during CEEs, individuals have had (by design) varied MFAS exposure conditions in terms of range and RL. For PAS stimuli, target (and repeatedly achieved) RLs (in terms of per ping RMS values) 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). For CAS stimuli, these target levels were adjusted based on a 10 log (50-second) offset to account for the much longer stimulus duration (i.e., beaked whale target RLs for CAS signals ranged from 103 to 123 dB).

Satellite-transmitting tag setting approaches successfully developed during earlier efforts were maintained to provide up to 20 days of continuous, relatively high-duration (5-minute time series) dive data, with ARGOS positional data being collected for weeks or months longer. This was done to increase the data resolution during a focal period when U.S. Navy ships were expected to be available. The objective was, therefore, to conduct one operational MFAS CEE within a 2-week window following sat tag deployments, with subsequent tagging effort for potentially conducting additional CEEs based on ship availability.

## 1.3 Overall Analytical Approach

Behavioral response analyses focus on how whales change their behavior from baseline conditions during periods of MFAS exposure in known contexts during CEEs. Analyses of potential response type, probability, and severity apply methods developed during other BRSs and Atlantic-BRS efforts to date, including close coordination with other U.S. Navy-funded analytical development teams. Specific questions and methods are derived for differences in available data (tag type) and species in question, specifically considering questions of (1) potential avoidance behavior, (2) potential changes in behavioral state, and (3) potential changes in social behavior.

In earlier phases of the field effort, extensive progress was made in developing systematic methods to process the tens of thousands of hours of tag, acoustic, and visual data collected during many tag deployments made each year. While increasingly efficient, these complex processes require extensive time and effort to process raw data; filter and finalize integrated data streams; and, ultimately, quantify behavior to address these three questions. In each of the previous reports, several tables and figures describing detailed aspects of data processing and analyses were provided to demonstrate these approaches. These evolved and became more complex within the first several years; however, by 2019 (see Southall et al. 2020, Section 1.3), they were sufficiently mature that they were maintained and have continued to be applied in a consistent manner to subsequent data sets.

## 1.4 Field Logistics and Configuration

Atlantic-BRS field efforts for 2024 were conducted adaptively, based primarily on weather and potential U.S. Navy vessel availability, across a single field season from June through early October. Field teams included a small boat-based team (typically four to five members) aboard the Duke University Research Vessel (R/V) *Richard T. Barber* (hereafter R/V *Barber*), an 8-meter (m), aluminum-hulled vessel, conducting advanced deployment of sat tags as well as DTAGs during target windows. The field crew transited offshore daily when sea conditions were suitable; located animals; deployed tags; and collected photo-ID, biopsy, and other data from groups. During periods of good conditions for locating tagging candidates, resighting tagged individuals, collecting photo-ID and additional biopsy samples, and/or attempting DTAG deployments and CEEs, an additional research crew (approximately six science personnel) worked from the Duke University *R/V Shearwater*. a 24-m fast catamaran. This vessel is capable of working offshore for multiple days, along with, in reasonable conditions and daylight hours, the R/V *Barber* (which maintained a shore base of operations). The *R/V Shearwater* provides excellent elevated tag tracking and visual observation platforms before, during, and after CEEs. One or both of these vessels were involved in 2024 tag deployment, CEEs, and re-sighting and biopsy sampling of focal individuals. A privately contracted fishing vessel was also used on one occasion to augment field operations.

Three DTAGs from the University of Michigan were leased for planned field periods and available for deployment during strategic windows. Up to 30 Low-impact Minimally Percutaneous Electronic Transmitter (LIMPET) satellite-linked tags were also available. Priority was placed on the use of SPLASH10-A satellite-transmitting tags that provide position and depth data, given the interest in feeding and diving behavior. Almost all tags available and deployed were of this type. A smaller number of SPLASH10-F-333 FastGPS tags that incorporate Fastloc® Global Positioning Systems (GPS) were also available, and one was deployed. Tagging priority was placed on *Ziphius* during the 2024 field season.

The priority and exclusive focus for active MFAS CEEs during 2024 was operational CAS-capable vessels. Previous successful coordination approaches led by USFF were applied during planning and coordination between the Atlantic-BRS team and U.S. Navy representatives facilitating U.S. Navy vessel participation in CEEs. This began months in advance of field operations and included advance briefing of potential participant vessels. During CEE periods, dedicated U.S. Navy personnel coordinated with vessels in the field, remotely from onshore sites through secure communications. The team scheduled multiple potential vessels during different periods throughout the field season to maximize the probability of a successful CEE based on tags deployed, weather, and realized vessel availability. The combined team successfully identified and scheduled two capable CAS-capable ships for participation with the Atlantic-BRS project during 2024. Importantly, this included some novel scheduling approaches to coordinate with vessels from several home ports, including ships transiting to and from operating areas off the Virginia coast and through the study area.

The field team was successful in deploying four tags on the primary focal species (*Ziphius*) ahead of the first available CAS-capable ship in July. The first-ever CAS CEE was conducted in collaboration with the *USS Thomas Hudner*, involving three of these tagged *Ziphius*. This CEE was coordinated through a different Naval facility and personnel than involved in earlier MFAS PAS CEEs, demonstrating the flexibility of the team and expanding the range of possible options for subsequent field campaigns. A second CAS-capable ship was available during August. Unfortunately, the remaining tagged individual was far from the focal study area, and efforts to deploy additional tags were unsuccessful due to weather as well as lower than expected sightings of focal species within the study area during the few possible offshore working days. Given the slightly atypical sighting conditions and to conduct additional follow-up photo-ID and group composition data collection, several additional field efforts were conducted later in the season.

# 2. Field Effort

## 2.1 Summary of 2024 Field Effort: Accomplishments and Assessment

**Field Dates:**

- **5 June:** First possible field effort for advance tag deployment team (*R/V Barber*); some field personnel deployed and ready to go at Manteo field site.
- **7–20 June:** *R/V Barber* team staged and ready, but limited to several partial day efforts with conditions generally not suitable for tagging.
- **21–22 June**: Back-to-back long *R/V Barber* team days in marginal but workable conditions resulted in **two *Ziphius* sat tag deployments** ahead of U.S. Navy ship availability, slated for early- to mid-July.
- **26 June–8 July:** *R/V Barber* team multiple all-day efforts with workable to some good conditions for tagging; however, very few focal species individuals were sighted, and no tags were deployed.
- **14 July**: Marginal but eventual workable conditions resulted in **two *Ziphius* sat tag deployments** ahead of U.S. Navy ship availability, now slated for mid- to late-July.
- **19–20 July**: *R/V Barber* and *R/V Shearwater* teams on water for resighting, additional tag deployments, and **staging and preparation for CEE**. *Shearwater* **deployed HARP** at Hatteras site en route to field site.
- **21 July**: Atlantic-BRS **completes first CAS CEE sequence (#2024_01) with one focal and two non-focal tagged *Ziphius*** (fourth tag ceased transmissions prior to this CEE).
- **22–23 July**: *R/V Barber* and *R/V Shearwater* teams on water for resighting and follow-up data collection.
- **29 July–17 August:** *R/V Barber* team multiple all-day efforts in marginal to some good conditions for tagging; however, relatively few focal species individuals were sighted, and no additional tags were deployed.
- **18–20 August**: **Second possible CAS-capable ship was scheduled** for this period. Given the large distance between the two remaining *Ziphius* tags (location-only: no dive data) and their distance from the study area, and that no additional tags were deployed, no CEEs were conducted with this vessel.
- **30 August:** Team belayed second possible *R/V Shearwater* window and additional *R/V Barber* team effort for additional sat tags or DTAGs given conditions and possible additional U.S. Navy CAS-capable ship support being deemed to have ended for the season.
- **1–15 September:** Several additional scouting and re-sighting efforts conducted on several days from different platforms to evaluate *Ziphius* distribution.
- **10 September**: **Last data message** received from 2024 *Ziphius* sat tags.

**Accomplishments:**

- Successfully deployed four sat tags on beaked whales, including one FastGPS tag as a specific objective in Southall et al. (2023)
- Conducted first-ever successful CAS CEE with U.S. Navy sources for any species and first-ever for *Ziphius* with any CAS source
- Obtained thousands of photo-ID images
- Continued success with research platform *R/V Shearwater*, which was highly successful in locating and tracking animals, including successful overnight tracking ahead of and following CEE
- Sustained efforts to relocate sat-tagged animals in the field using goniometer detections, increasing chances of subsequent tag deployments. This improved animal pseudotracks by providing high confidence surface locations; and resulting in many photo-ID re-sights to evaluate group composition, social interactions, and biopsy samples
- Determined tagged individuals demonstrated somewhat atypical overall movement patterns, consistent with unusual sighting patterns. We made multiple scouting trips to evaluate and assess this accordingly.

**Assessment of Field Approach:**

- The combined team with USFF successfully identified multiple capable CAS-capable ships and scheduled two for direct participation with the Atlantic-BRS project during 2024. This included several new approaches to consider vessels from multiple bases of operation and coordination. Earlier efforts had focused on vessels based from nearby Norfolk Naval Stations for local training operations, whereas this CEE was with a vessel transiting through the study area from a different geographical location. The resulting success of this slightly different approach opens additional options for scheduling and coordinating vessel participation in subsequent field efforts.
- Field teams were adaptive in working through challenging weather conditions throughout the year, but especially during June. Based on modifications made during 2024 to shift U.S. Navy ship scheduling later, and this observation of poor conditions occurring again earlier in the season, advance discussions for the 2025 field effort have again included plans to shift field effort and requested U.S. Navy ship dates slightly later in the summer.
- Field teams had continued success in locating and tagging beaked whales, such that no second-priority pilot whales were tagged during 2024. However, somewhat atypical sighting frequency and distributions occurred. This limited tag deployment opportunities as well as increased the spread of focal and non-focal animals during potential CEE periods.
- Sat tags collected and transmitted continuous high-quality dive data due to earlier progress in tag programming strategies to minimize gaps in tag data as well as improve temporal resolution on diving and behavioral data. The team successfully collected continuous dive data for up to 24-day periods, strategically covering CEE periods, as designed. Long-duration (up to 71 days) functioning of tags in reporting ARGOS positions was again experienced.

## 2.2 Tag Deployments

A researcher from Bridger Consulting, in coordination with the Atlantic-BRS team aboard Duke University vessels, conducted sat tag deployments. **Table 1** provides a summary of sat tag deployments for 2024. A total of four satellite-transmitting tags were deployed, all on *Ziphius*.

**Table 1. Satellite tag deployments for *Ziphius* during Atlantic-BRS field efforts in 2024.**

| Species[a]/ Tag ID | Deployment Date | Deployment Latitude (°N) | Deployment Longitude (°W) | Dive Data Streams | Tag Duration (days) |
|---|---|---|---|---|---|
| ZcTag147_DUML[b] | 22 June 2024 | 35.5948 | -74.7122 | 5-minute time series | 9 |
| ZcTag148_DUML[c] | 22 June 2024 | 35.5921 | -74.7112 | 5-minute time series | 71 |
| ZcTag149_DUML | 14 July 2024 | 35.5980 | -74.7269 | 5-minute time series | 39 |
| ZcTag150_DUML | 14 July 2024 | 35.6043 | -74.7278 | 5-minute time series | 51 |

Key: ID = Identification Number; °N = degrees North; °W = degrees West

[a] Zc = *Ziphius cavirostris*

[b] note: the "_DUML" portion of full tag IDs removed hereafter for this report

[c] Fastloc® GPS-enabled tags

Transmitted ARGOS positional data were filtered using the following approach and parameters. Location quality Z data were removed. Additionally, a bounding box was used to exclude points far outside the study area, inside the outer banks, or on land. Positions flagged as suspect in the comments field for larger deviations from mean longitude, latitude, or median speed were also removed. Finally, an additional speed angle distance filter from the R package argosfilter (function sdafilter) was run with the following parameters: vmax = 10 kph, ang = {15, 25} (degrees), distlim = {2500, 5000} (meters) (Freitas et al. 2008, 2022). The study team used the R package crawl to fit a continuous-time correlated random walk model to the filtered ARGOS locations. Model fit objects were retained to predict locations, and to draw 100 imputed tracks to highlight predictions and the associated uncertainty in location. **Figure 1** shows the predicted track for the entire deployment for all *Ziphius* tagged during 2024.

Individual (by animal) plots showing all track imputations as well as the best overall track are shown for the entire tag deployment periods for each tagged *Ziphius* (**Figure 2** through **Figure 5**). For tags that were active during the CAS CEE, the location of the source vessel at the start of the experiment is indicated on the individual plots.

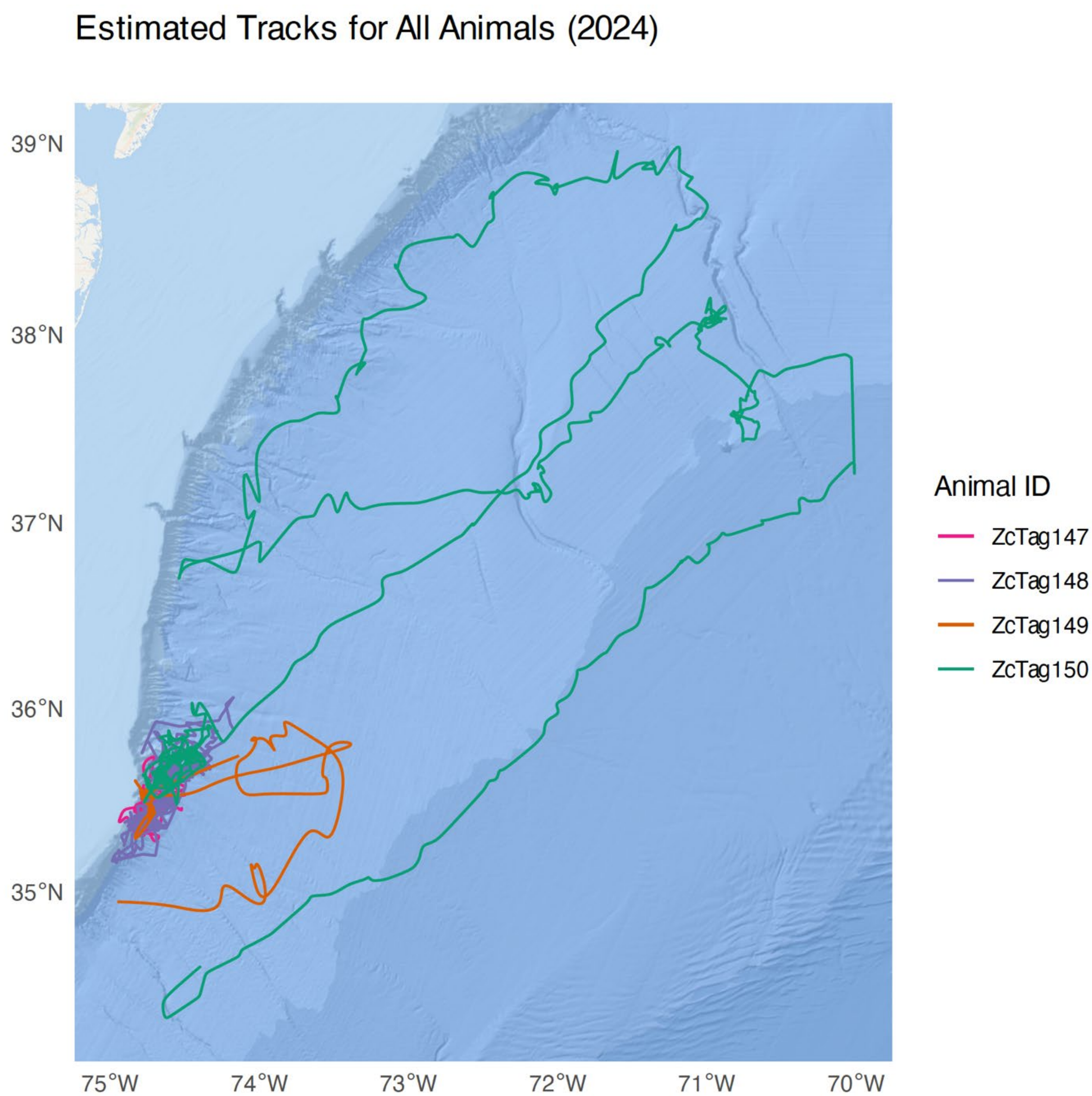


**Figure 1. Predicted tracks from multiple imputations for all (*n*=4) beaked whales tagged during Atlantic-BRS field efforts in 2024.**

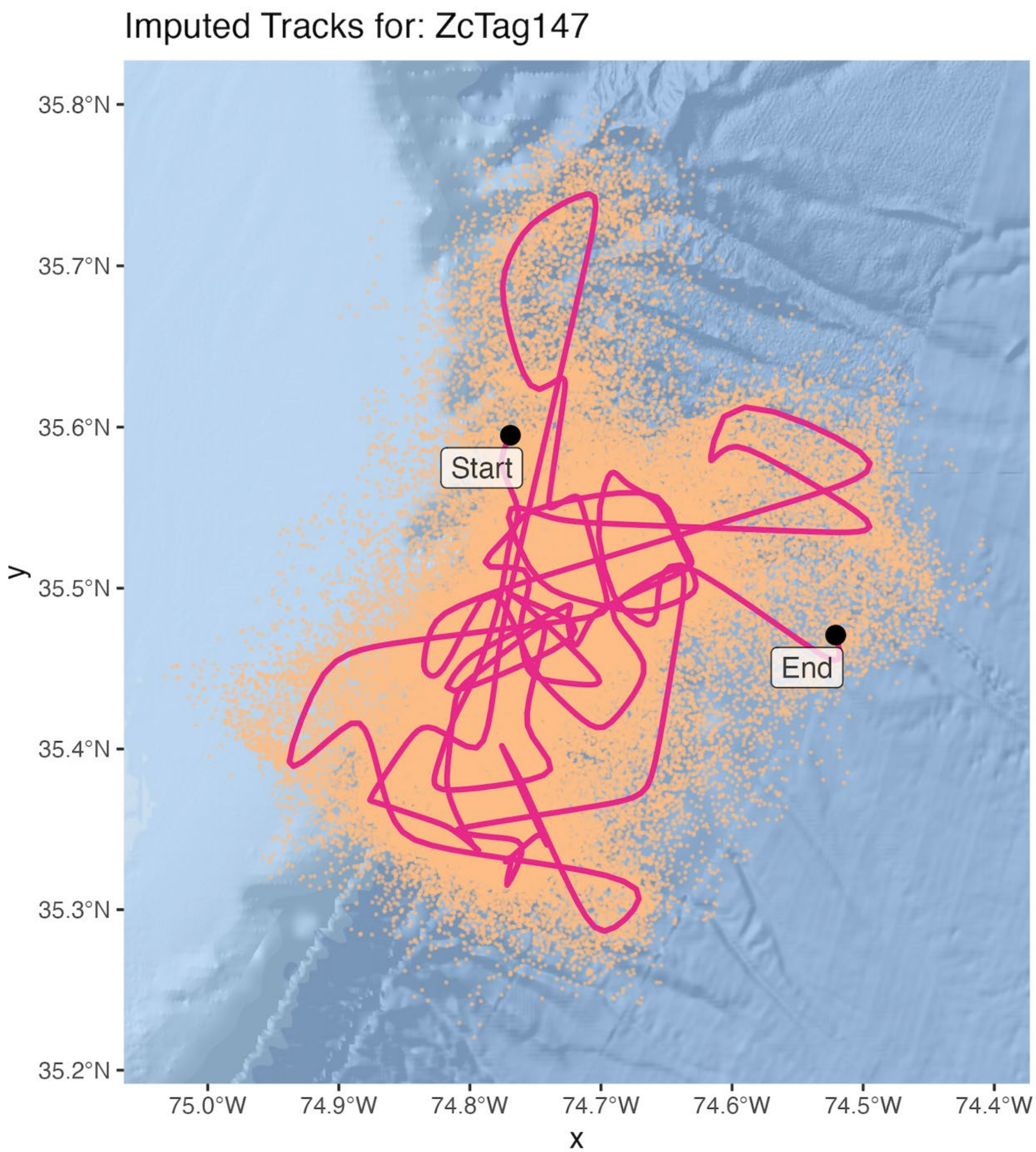


**Figure 2. Predicted track (red) with multiple (*n*=100) track imputations (orange) for ZcTag147 (tag duration 9 days). This tag ceased functioning prior to 2024 CEEs.**

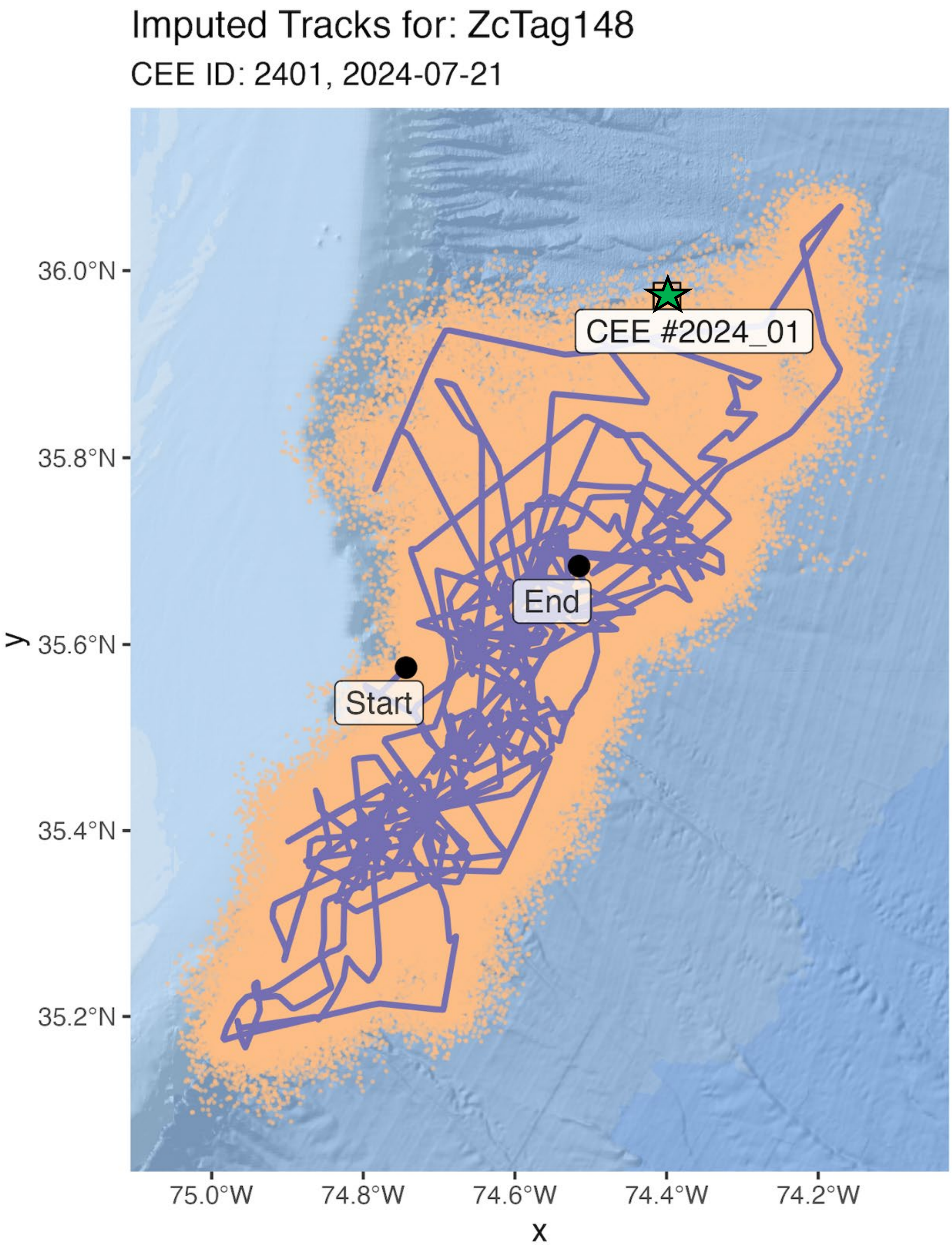


**Figure 3. Predicted track (purple) with multiple (*n*=100) track imputations (orange) for ZcTag148 (tag duration 71 days). This whale was a non-focal individual during CAS CEE #2024_01. The CEE start location for *USS Thomas Hudner* is shown.**

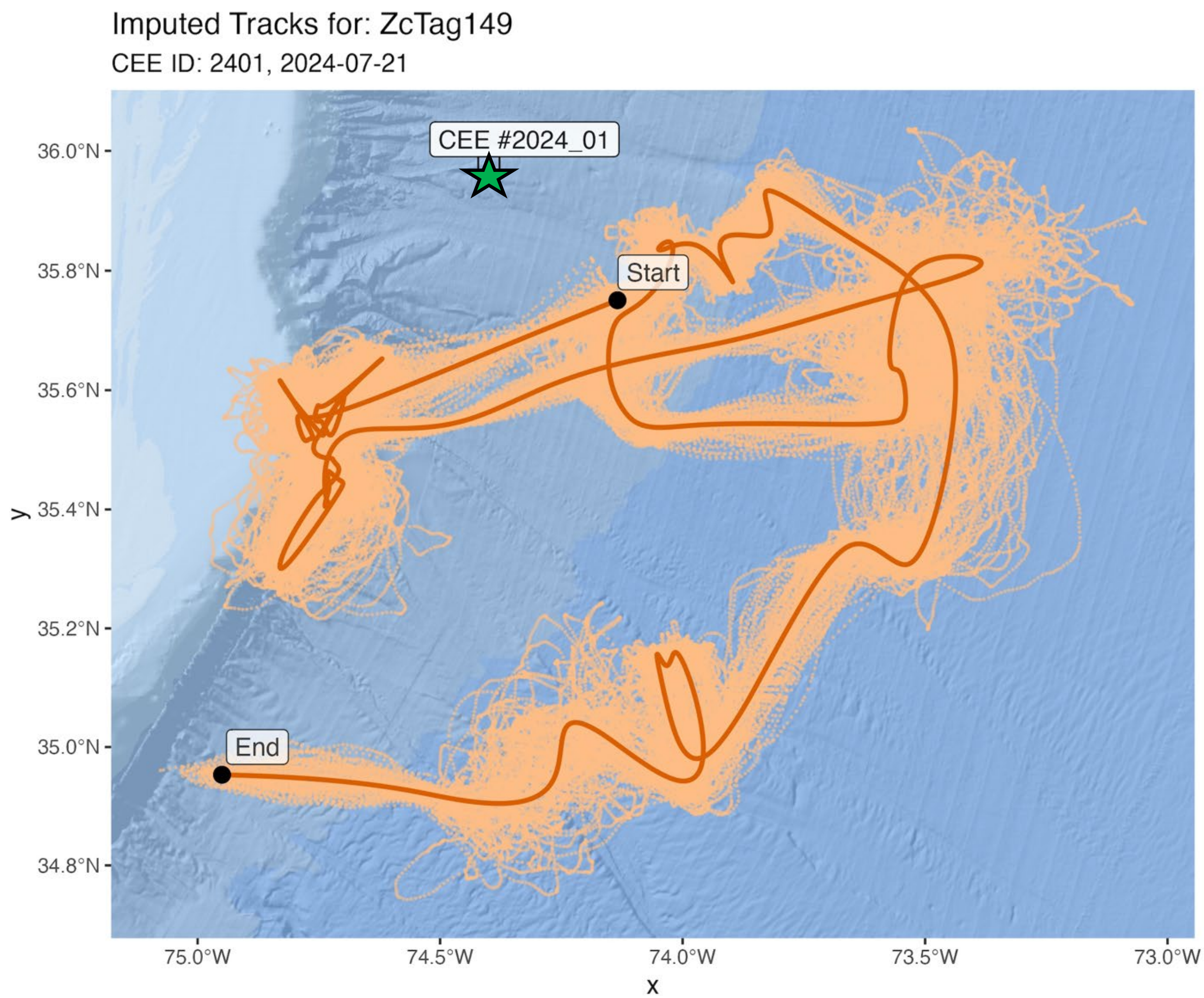


**Figure 4. Predicted track (dark orange) with multiple (*n*=100) track imputations (orange) for ZcTag149 (tag duration 39 days). This whale was a non-focal individual during CAS CEE #2024_01. The CEE start location for *USS Thomas Hudner* is shown.**

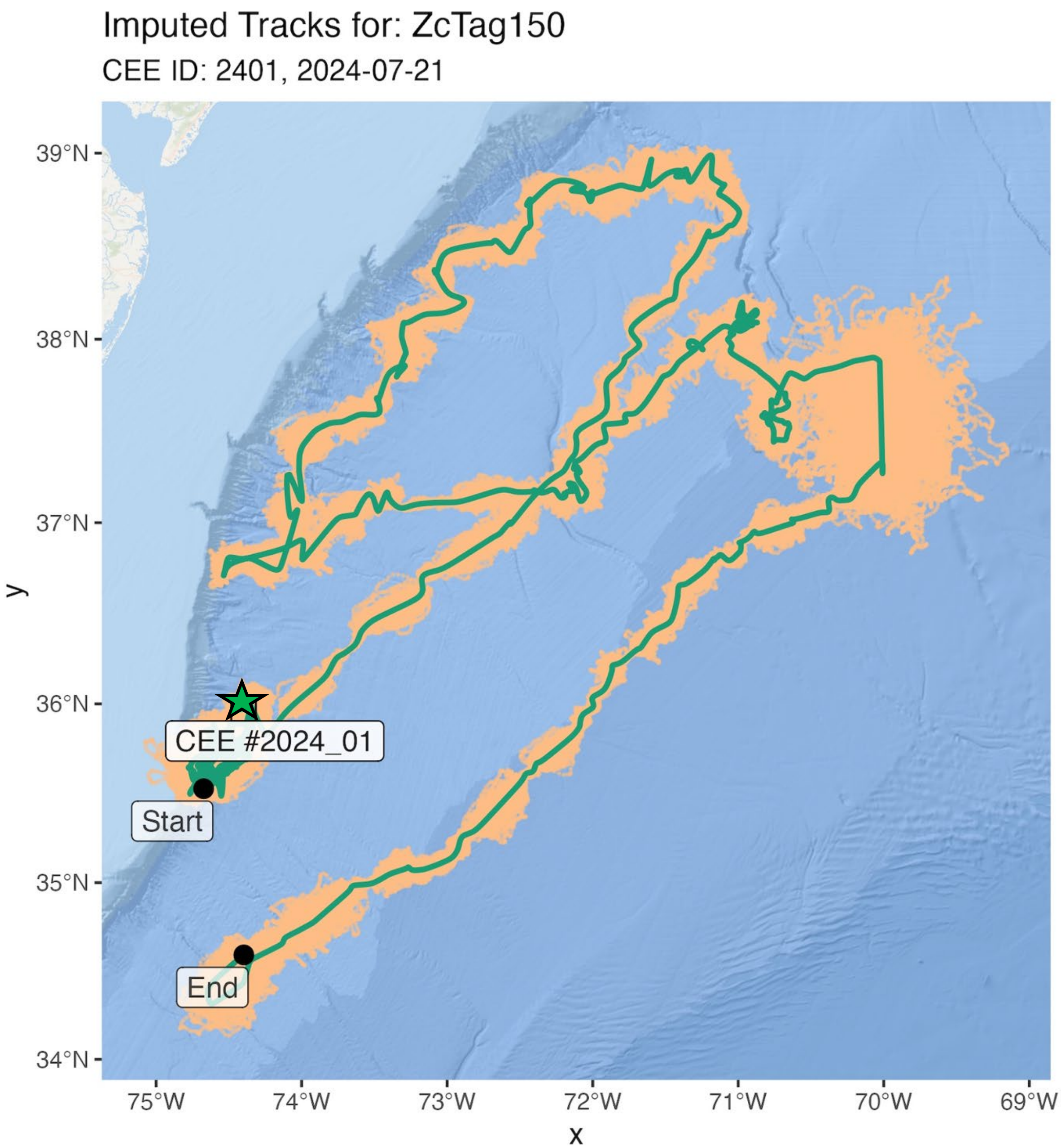


**Figure 5.** **Predicted track (green) with multiple (*n*=100) track imputations (orange) for ZcTag150 (tag duration 51 days). This whale was the focal individual during CAS CEE #2024_01. The CEE start location for *USS Thomas Hudner* is shown.**

## 2.3 CEEs Conducted

One CEE sequence was conducted during the Atlantic-BRS 2024 field effort. As noted above, a dedicated CAS-capable ship (*USS Thomas Hudner*) was scheduled and coordinated with the Atlantic-BRS team to support the first MFAS CAS CEE for this project. Three *Ziphius* with SPLASH-10 tags were monitored visually (focal) and remotely (non-focal) during this experiment (CEE #2024_01; see **Table 2**).

**Table 2. CEEs conducted during Atlantic-BRS 2024 field efforts.**

| CEE ID | Date | CEE Type | Focal Whales[a] | Non-focal Whales[a] | CEE Duration (min) | Start CEE Source Latitude (°N) | Start CEE Source Longitude (°W) |
|---|---|---|---|---|---|---|---|
| #2024_01 | 7/21/24 | MFAS CAS | ZcTag150 | ZcTag148<br>ZcTag149 | 60 | 35.9728 | -74.3994 |

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

A summary of the RL modeling as well as associated planning and coordination conducted with the *USS Thomas Hudner* is provided below for reference in terms of the spatial configuration for the planned CAS CEE. The sequential position requests provided in days and hours leading up to the planned CEE according to the vessel coordination planning approach developed with USFF are provided in **Table 3** and depicted spatially in **Figure 6**. The associated RL model predictions generated in situ for different focal animals' known or estimated locations at multiple depths using the custom NPS sound propagation planning tool and available information regarding CAS stimuli source are provided in **Table 4**. Differences between the PAS and CAS MFAS signals are discussed above; RL estimates here are RMS values per modeled CAS transmission. Model runs (11, 12, 13, and 14 in **Table 4**) for the start and end of CAS-vessel transmissions for the focal individual (ZcTag150) that informed the final requested vessel tracks are shown for reference (**Figure 7** through **Figure 10**); all model runs are available upon request.

A narrative summary and spatial depiction of the CAS CEE sequence (#2024_01) conducted along with dive records from sat tag locations for all focal and non-focal individuals (see **Table 5**; **Figure 11** through **Figure 16**) is provided following the RL model predictions.

**Table 3. Sequential positioning for USS *Thomas Hudner* ahead of Atlantic-BRS CEE #2024_01.**

| Position Request | Description | Latitude (°N) | Longitude (°W) | Heading |
|---|---|---|---|---|
| 1 | Nominal initial position (weeks in advance) | 35.9 | -74.5 | - |
| 2 | 18 July 1200 EDT (~72-hour pre-exposure) based on best estimate of ZcTag150 as nominal focal at that point | 36.0 | -74.35 | 190 |
| 3 | 19 July 1200 EDT (~48-hour pre-exposure) based on best estimate of ZcTag150 as nominal focal at that point; two other whales farther south | 35.88 | -74.4 | 175 |
| 4 | 20 July 1200 EDT (~24-hour pre-exposure) based on best estimate of ZcTag150 as nominal focal at that point; two other whales farther south | 35.9 | -74.45 | 179 |
| 5 | 21 July 0700 EDT: Final requested start position for *USS Thomas Hudner* based on committed focal ZcTag150 with two non-focal whales (ZcTag148 and ZcTag149) farther south; adjusted track to ESE based on overnight movement patterns of focal | 35.98 | -74.35 | 135 |

Key: EDT = Eastern Daylight Time; ESE = east-southeast; °N = degrees North; °W = degrees West; Zc = *Ziphius cavirostris*

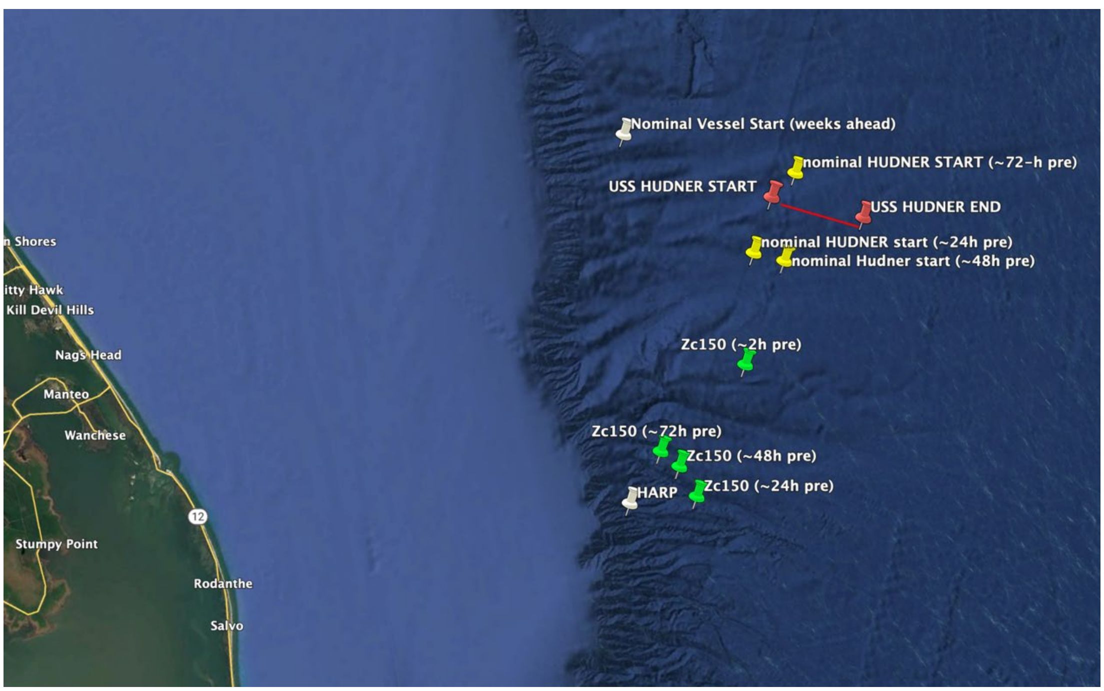


**Figure 6. Sequential requested start positions for the *USS Thomas Hudner* shown weeks (white pin) to specified days in advance (yellow pins) as well as the final start and end positions (red pins; red track ~8 nautical miles) requested on the day of CEE #2024_01. Vessel positions are shown relative to sequential focal animal (ZcTag150) position estimates (green pins) used in RL modeling and to inform the vessel position requests.**

**Table 4. RL model runs for CEE #2024_01.**

| Model Run | Runtime | Focal Animal (Depth – m) | Animal Latitude (°N) | Animal Longitude (°W) | Estimated Range (nm) Start–End | Model RL Start | Model RL End | Model RL Max. |
|---|---|---|---|---|---|---|---|---|
| 01 | 19 July<br>1000 EDT | ZcTag150 (100)<br>best position 48-hours pre | 35.648 | -74.679 | 15–8 | 103 | 120 | 120 |
| 02 | 19 July<br>1100 EDT | ZcTag150 (1,500)<br>best position 48-hours pre | 35.648 | -74.679 | 21–16 | 111 | 124 | 121 |
| 03 | 20 July<br>0600 EDT | ZcTag150 (100)<br>best position 24-hours pre | 35.662 | -74.691 | 16–9 | 104 | 123 | 120 |
| 04 | 20 July<br>0700 EDT | ZcTag150 (1,500)<br>best position 24-hours pre | 35.662 | -74.691 | 20–13 | 106 | 123 | 123 |
| 05 | 20 July<br>0900 EDT | ZcTag150 (100)<br>best position 24-hours pre | 35.601 | -73.567 | 18–11 | 97 | 125 | 125 |
| 06 | 20 July<br>1000 EDT | ZcTag150 (1,800)<br>best position 24-hours pre | 35.601 | -74.567 | 19–14 | 107 | 119 | 119 |
| 07 | 20 July<br>1600 EDT | ZcTag150 (100)<br>actual; for final | 35.575 | -74.623 | 20–13 | 105 | 123 | 121 |
| 08 | 20 July<br>1700 EDT | ZcTag150 (1,800)<br>actual; for final | 35.575 | -74.623 | 20–13 | 106 | 125 | 119 |
| 09 | 20 July<br>2000 EDT | ZcTag150 (100)<br>actual; for final | 35.567 | -74.605 | 19–12 | 114 | 122 | 120 |
| 10 | 20 July<br>2100 EDT | ZcTag150 (1,900)<br>actual; for final | 35.567 | -74.605 | 18–11 | 111 | 124 | 124 |
| 11 | 21 July<br>0500 EDT | ZcTag150 (100)<br>actual; for final | 35.769 | -74.449 | 15–14 | 111 | 123 | 116 |
| 12 | 21 July<br>0600 EDT | ZcTag150 (1,800)<br>actual; for final | 35.769 | -74.449 | 17–15 | 110 | 127 | 119 |
| 13 | 21 July<br>0630 EDT | ZcTag150 (100)<br>actual; for final | 35.758 | -74.461 | 15–13 | 110 | 123 | 121 |
| 14 | 21 July<br>0700 EDT | ZcTag150 (1,800)<br>actual; for final | 35.758 | -74.461 | 14–13 | 123 | 128 | 124 |

Key: EDT = Eastern Daylight Time; m = meter(s); Max. = Maximum; °N = degrees North; nm = nautical mile(s); °W = degrees West; Zc = *Ziphius cavirostris*

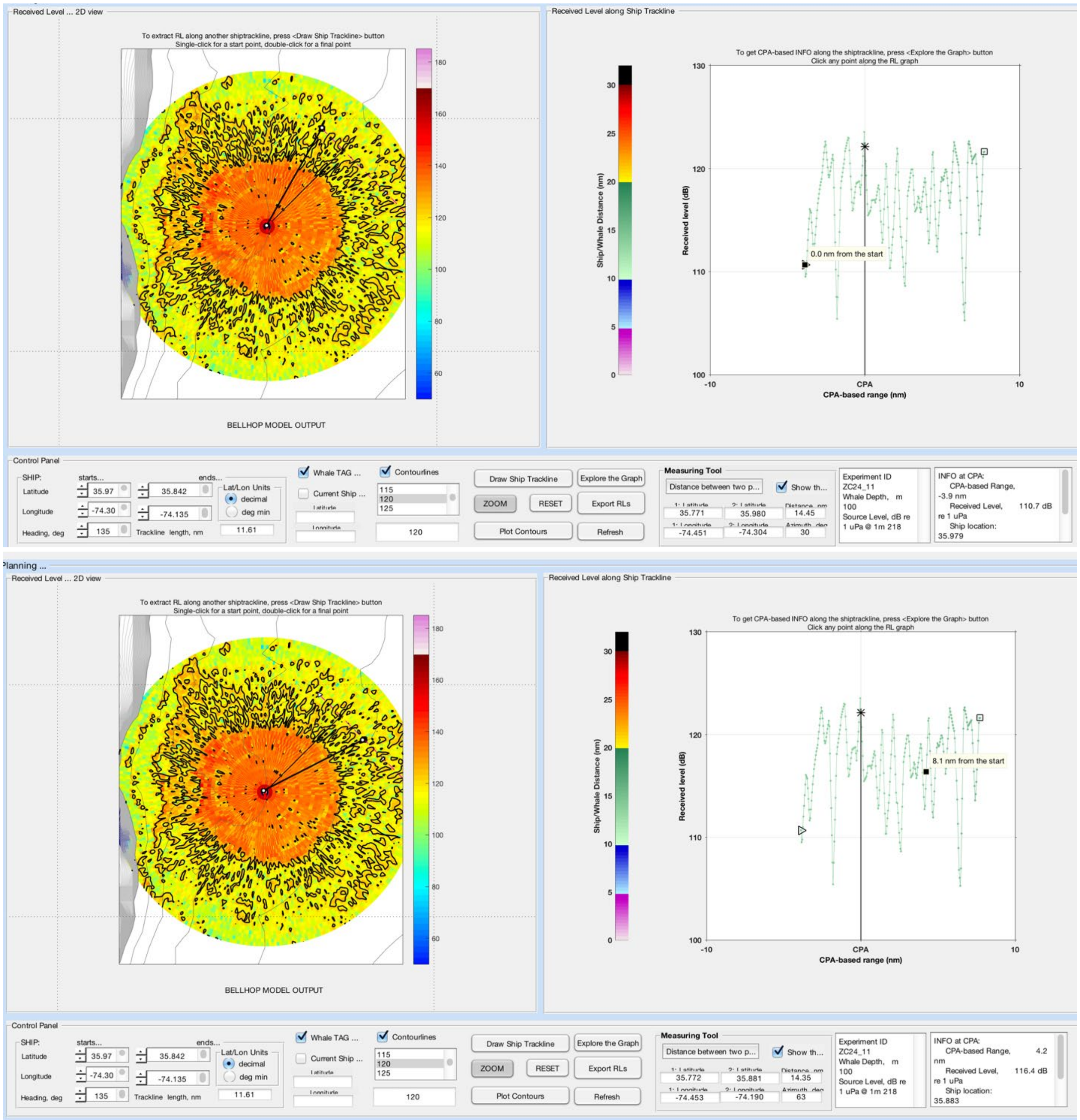

**Figure 7. RL model prediction at 100-m depth (model run 11 from Table 4) for focal whale ZcTag150 ahead of Atlantic-BRS CEE #2024_01 for the start (top; vessel-animal range: 14.5 nm; modeled RL = 110.7 dB) and end (bottom; vessel-animal range: 14.4 nm; modeled RL = 116.4 dB) of the modeled vessel track.**

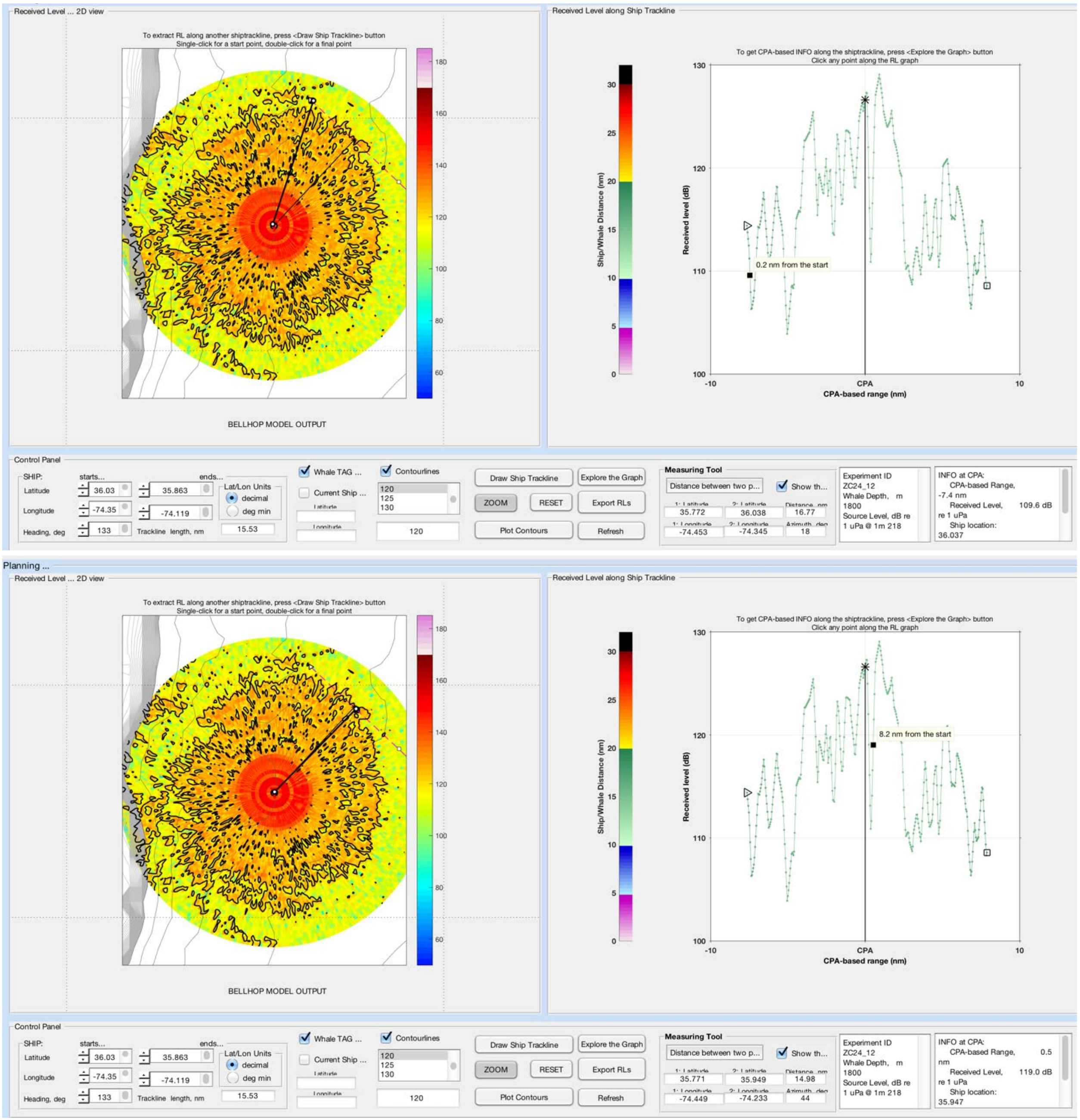

**Figure 8. RL model prediction at 1,800-meter depth (model run 12 from Table 4) for focal whale ZcTag150 ahead of Atlantic-BRS CEE #2024_01 for the start (top; vessel-animal range: 16.8 nautical miles; modeled RL = 109.6 dB) and end (bottom; vessel-animal range: 15.0 nautical miles; modeled RL = 119.0 dB) of the modeled vessel track.**

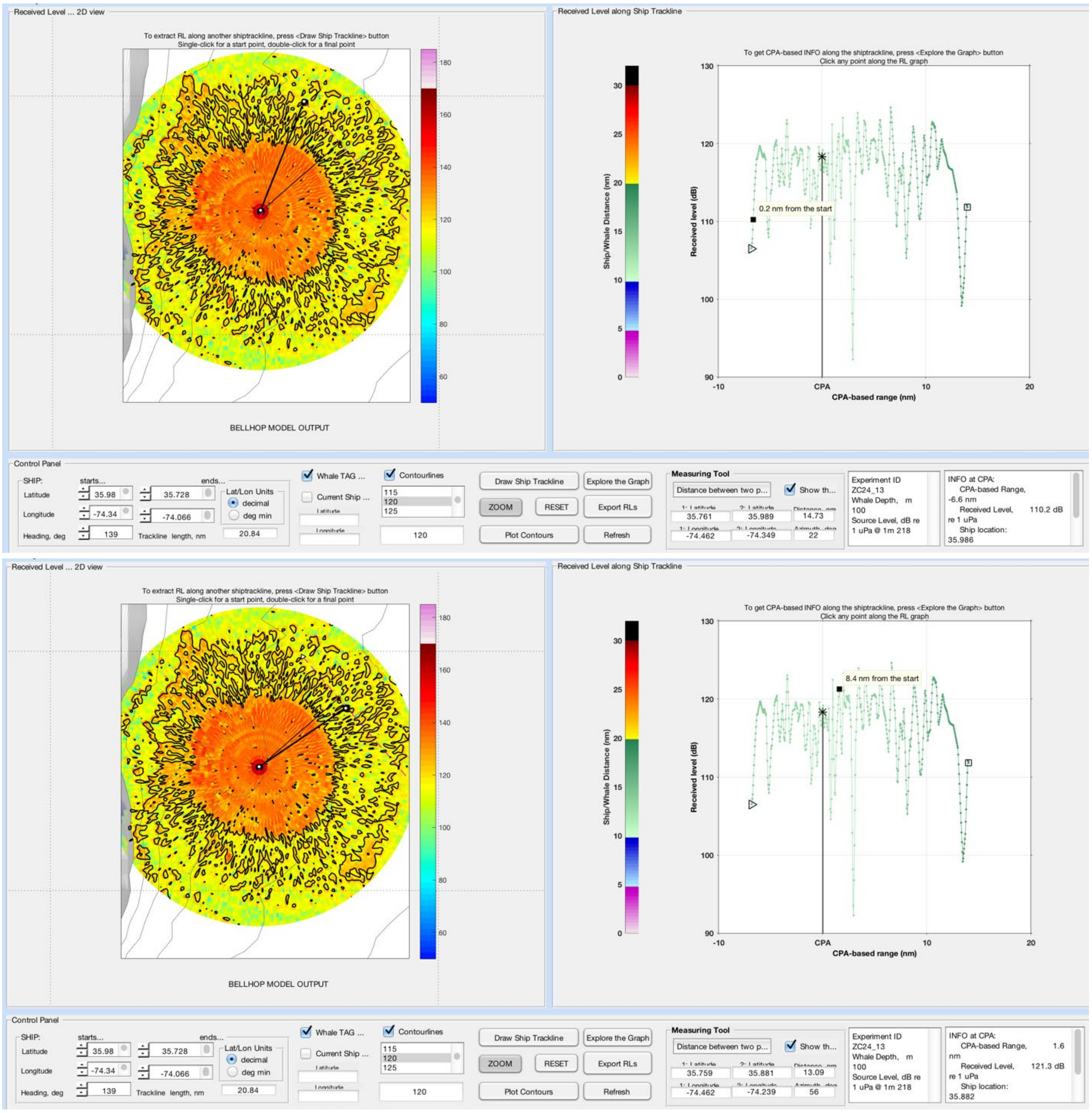


**Figure 9. RL model prediction at 100-m depth (model run 13 from Table 4) for focal whale ZcTag150 ahead of Atlantic-BRS CEE #2024_01 for the start (top; vessel-animal range: 14.7 nautical miles; modeled RL = 110.2 dB) and end (bottom; vessel-animal range: 13.1 nautical miles; modeled RL = 121.3 dB) of the modeled vessel track.**

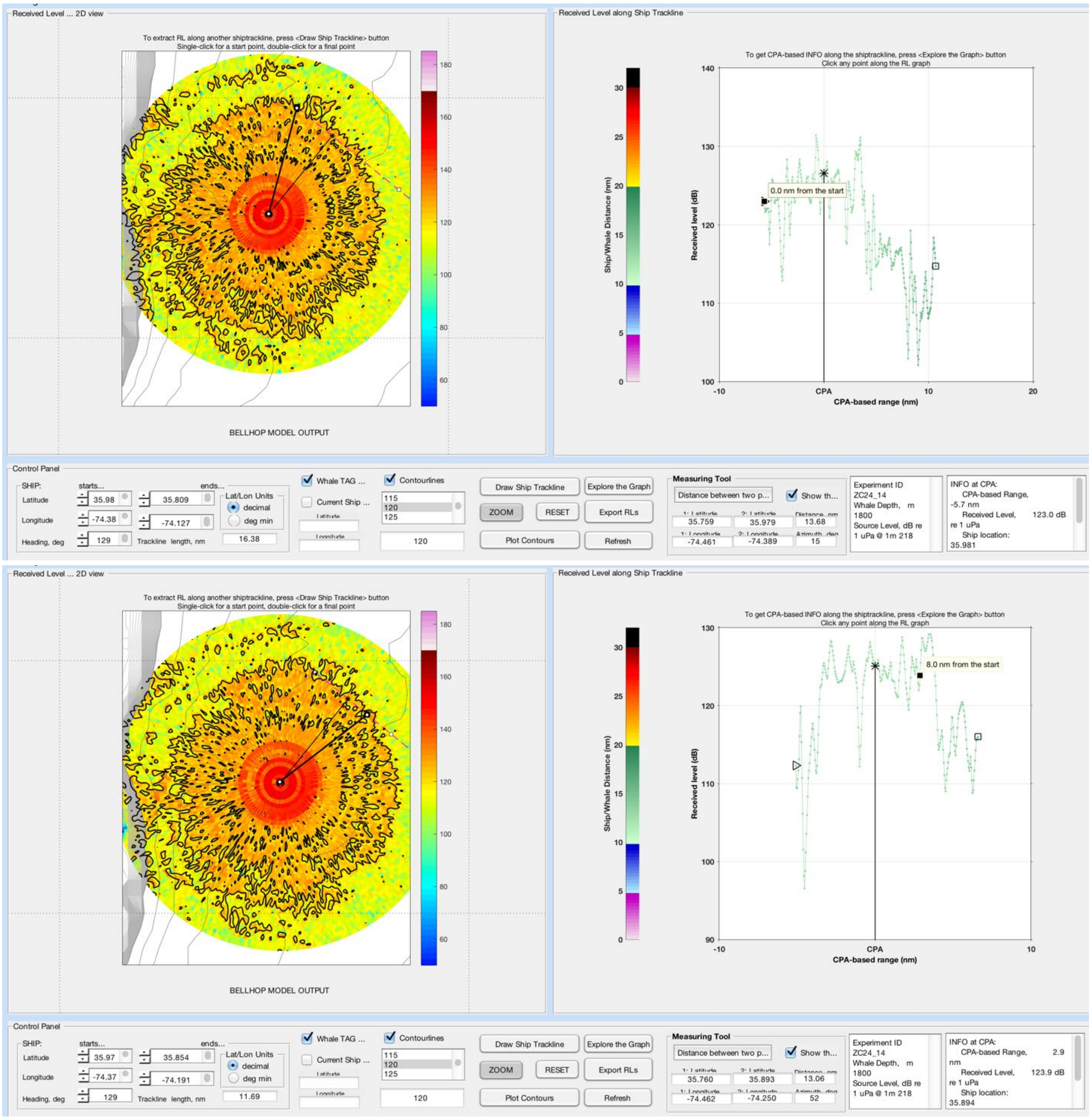


**Figure 10. RL model prediction at 1,800-meter depth (model run 14 from Table 4) for focal whale ZcTag150 ahead of Atlantic-BRS CEE #2024_01 for the start (top; vessel-animal range: 13.7 nautical miles; modeled RL = 123.0 dB) and end (bottom; vessel-animal range: 13.1 nautical miles; modeled RL = 123.9 dB) of the modeled vessel track.**

**Table 5. Metadata summary for Atlantic-BRS CEE #2024_01.**

Key: Hz = hertz; km = kilometer(s); kt = knot(s); min = minute(s); n/a = not applicable; nm = nautical mile(s); s = second(s); UTC = Coordinated Universal Time; Zc = *Ziphius cavirostris*

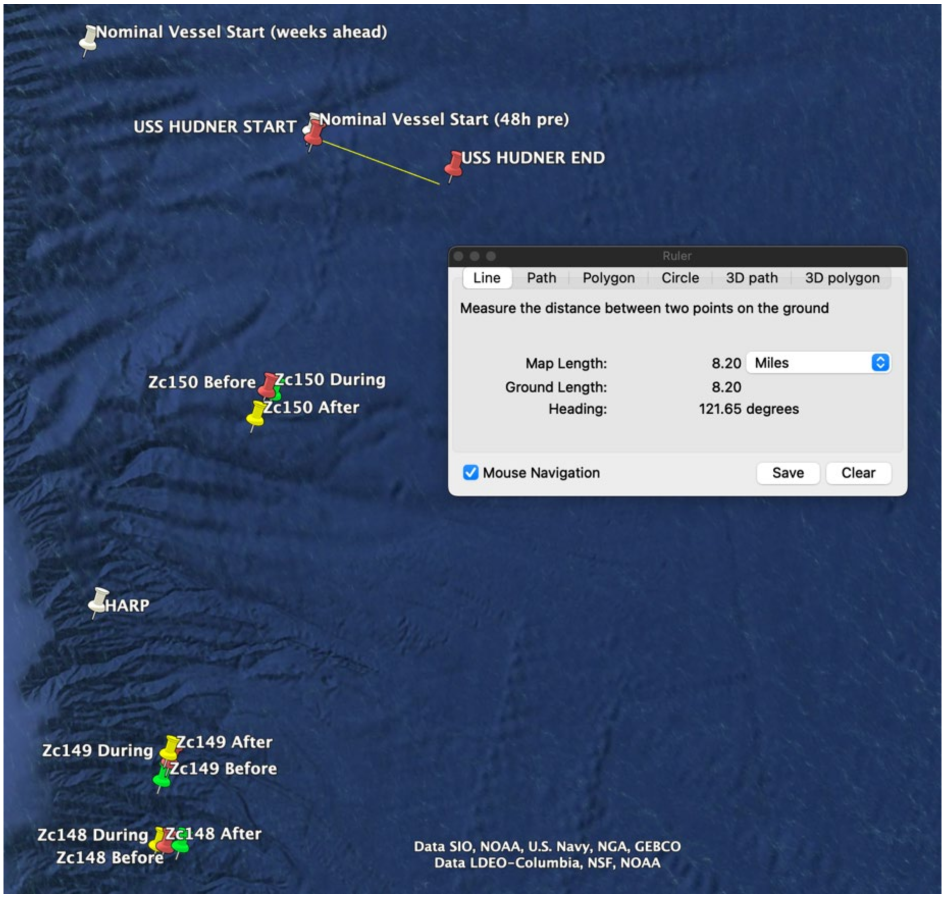


**Figure 11.** **Broad view of focal whale (ZcTag150) and other tagged beaked whales (ZcTag148, ZcTag149) before (green pins), during (red pins), and after (yellow pins) CAS CEE #2024_01. The actual start and end locations (red pins) and track (yellow line) for the *USS Thomas Hudner* is shown.**

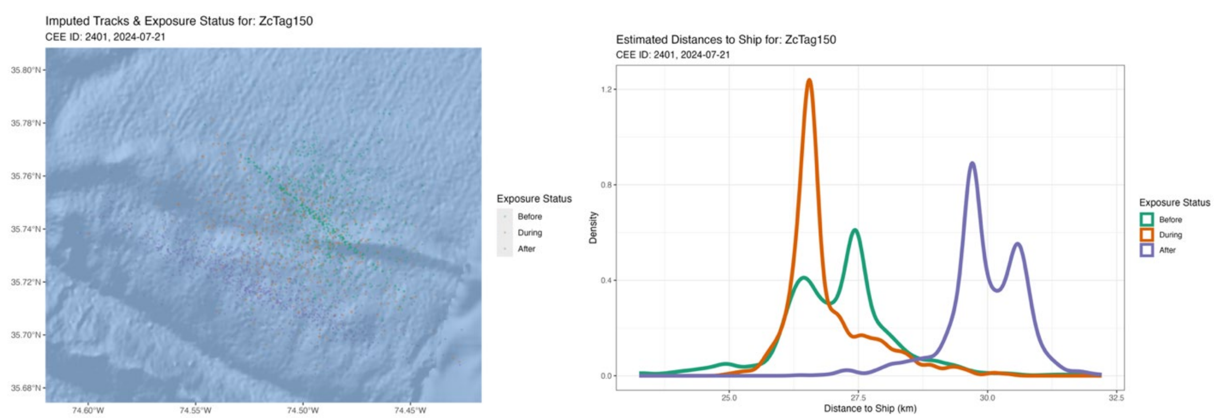


**Figure 12.** **Imputed track locations (left) and corresponding estimated distances to the *USS Thomas Hudner* (right) at the start of CEE #2024_01 for focal whale ZcTag150. Positions and distances are provided for 1-hour windows before (green), during (red), and after (purple) experimental CAS transmissions.**

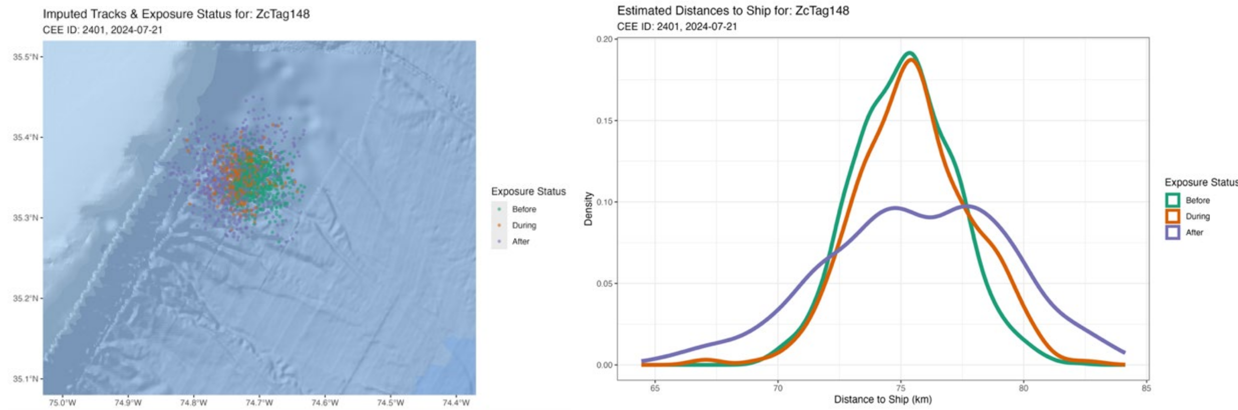


**Figure 13. Imputed track locations (left) and corresponding estimated distances to the *USS Thomas Hudner* (right) at the start of CEE #2024_01 for non-focal whale ZcTag148. Positions and distances are provided for 1-hour windows before (green), during (red), and after (purple) experimental CAS transmissions.**

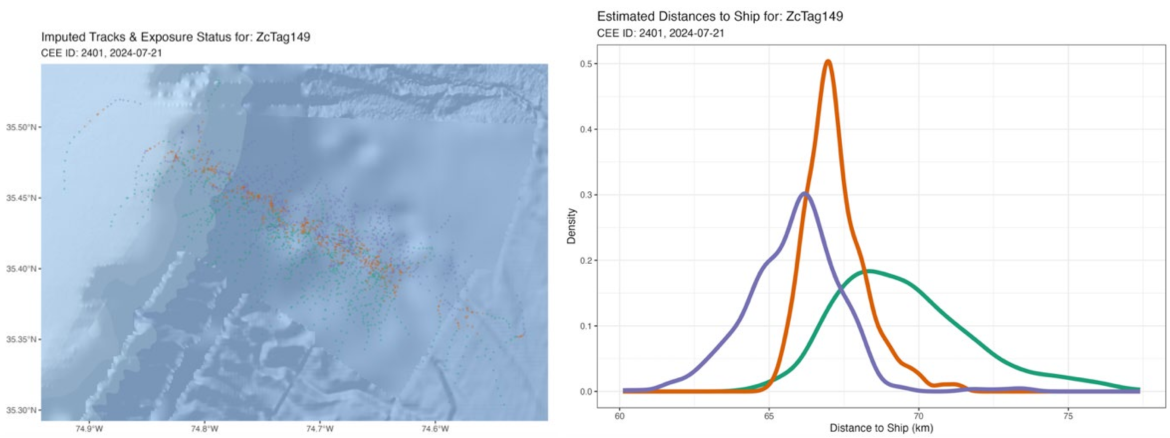


**Figure 14. Imputed track locations (left) and corresponding estimated distances to the *USS Thomas Hudner* (right) at the start of CEE #2024_01 for non-focal whale ZcTag149. Positions and distances are provided for 1-hour windows before (green), during (red), and after (purple) experimental CAS transmissions.**

Dive plots for focal whale ZcTag150, which was the only individual for which satellite-transmitting tags were reporting dive data during CEE #2023_01, are given in a standard format. **Figure 15** shows 24-hour periods occurring before and after CEE #2024_01, which was 1 hour in duration. Time (in Greenwich Mean Time, which is +4 hours from Eastern Daylight Time during CEE periods) is indicated on the x-axis, with depth indicated on the y-axis. Simulated CEE periods are indicated as pink bars. **Figure 16** compares different dive parameters for focal whale ZcTag150 during the CEE exposure period (purple arrows) to the same parameters for all baseline dives for that individual over weeks prior to the CEE. Each panel indicates the percentile for that dive parameter for the exposure dive relative to all baseline dives.

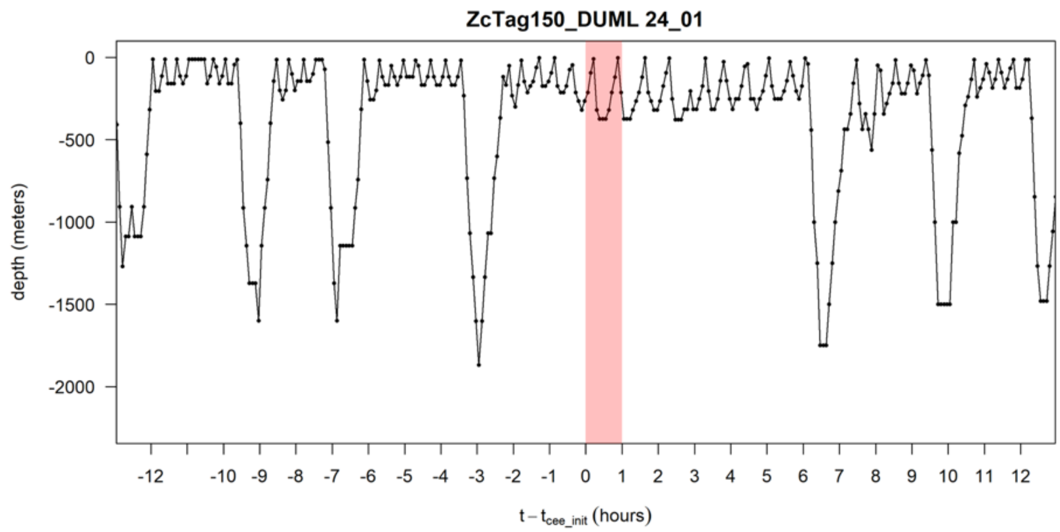


**Figure 15. Available dive data for focal whale ZcTag150 before, during, and after Atlantic-BRS CEE #2024_01 (pink shading denotes the CAS exposure period).**

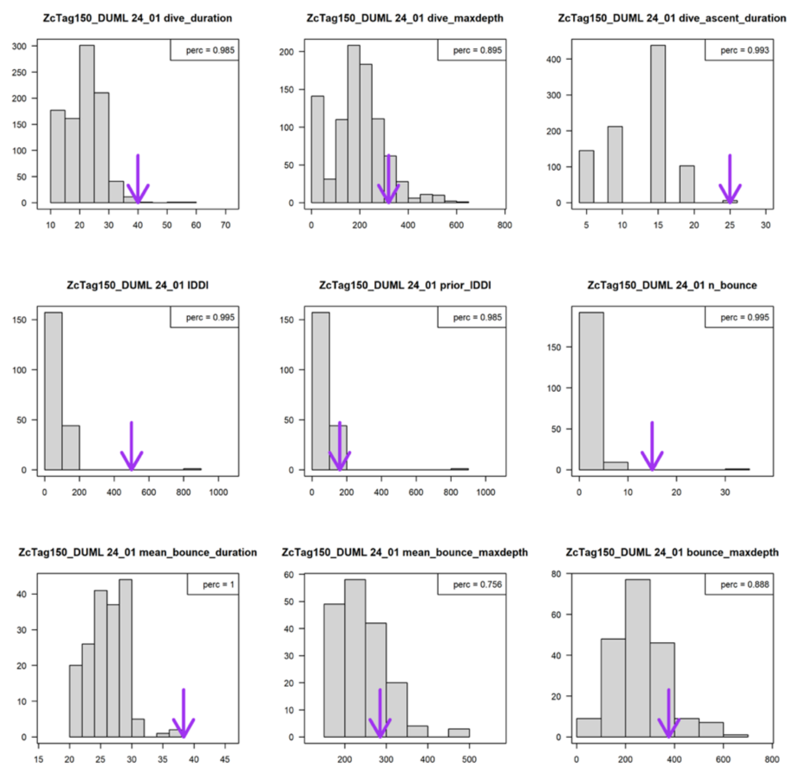


**Figure 16. Dive parameters for focal whale ZcTag150 for dives before (gray bars) and during (purple arrows) Atlantic-BRS CEE #2024_01. Exposure dive percentiles for parameters relative to baseline dives are provided. Dive parameters include (from top left to bottom right): dive duration, maximum dive depth, dive ascent duration, inter-deep-dive-interval (IDDI), IDDI of previous dive, number of 'bounce' (non-foraging) dives, mean duration of bounce dives, mean maximum depth of bounce dives, and absolute maximum depth of bounce dives.**

## 2.4 Preliminary Results

Preliminary results for focal whale ZcTag150 (approximately 25-km range) during and following the CAS CEE (#2024_01) suggest several different types of behavioral responses. As evident in **Figure 12** this animal exhibited a directed horizontal avoidance during and following this CEE, which ultimately persisted for a period of approximately twelve hours as this whale continued to move away from the CAS source location. It should be noted, however, that while this does appear to be a clear movement away from the source timed with its onset, this individual ultimately returned to the area in which the CEE occurred within the subsequent day(s). Over the course of the entire tag deployment for this individual, the broadest wide-scale movements were in fact weeks later when this individual exhibited long-range movements over hundreds of km into more pelagic and northern regions (see **Figure 5**). There is no indication this was the result of the CAS exposure as movement and other behaviors returned to more typical baseline patterns prior to these broader movement patterns.

There are also some evident changes to diving behavior that were relatively uncommon in the baseline behavior of ZcTag150. These included longer than typical inter-deep-dive-intervals as well as more and longer bounce dives than baseline data for this individual. These are similar patterns as other focal *Ziphius* in both simulated and real PAS CEEs at similar RLs (when normalized in terms of dB SEL). Interestingly, however, this whale was on a bounce dive during the exposure; despite these changes, it did not initiate an atypical deep dive as has been observed in many focal Ziphius with PAS sources.

Non-focal whales at greater ranges (approximately 60 to 80 km) did not appear to exhibit avoidance or diving response changes relative to baseline behavior, based assessments

# 3. Atlantic-BRS Publications

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

As the Atlantic-BRS project has progressed, it is consistently producing peer-reviewed publications both directly through the project and in collaboration with the ONR-funded Double Mocha effort, which developed analytical tools and methods that are now being applied for Atlantic-BRS response analyses. **Table 6** provides a comprehensive summary of papers across the entire Atlantic-BRS research program that have been published, are in review, or are in advanced stages of development; direct links to publications are provided when available.

It is also noted that the Atlantic-BRS project was prominently represented with three technical presentations at the 2024 Effects of Sound on Marine Mammals international conference in the Hague, Netherlands. These included invited talks on *Ziphius* behavioral responses to simulated PAS MFAS sonar and the use of ancillary location information in enhancing RL model estimates as well as a contributed paper on benthic foraging tactics in *Ziphius*.

**Table 6. 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 RLs for tagged cetaceans exposed to sonar | Schick (Duke) | Published |
| Baseline behavior | Aerobic dive limits in Cuvier's beaked whales | Quick (Duke) | Published |
| Methodology – technology | Continuous-time discrete-state modeling for deep whale dives | Hewitt (Duke) [Double Mocha] | Published |
| Baseline behavior | Residency and movement patterns of Cuvier's beaked whales (*Ziphius cavirostris*) off Cape Hatteras, North Carolina, USA | Foley (Duke) [primarily pre-BRS tags but includes 2017] | Published |
| Baseline behavior | Extreme synchrony in diving behaviour of Cuvier's beaked whales (*Ziphius cavirostris*) off Cape Hatteras, North Carolina | Cioffi (Duke) | Published |
| Methodology – technology | Kernel density estimation of conditional distributions to detect responses in satellite tag data | Hewitt (Duke) [Double Mocha] | Published |
| Methodology – technology | Continuous-time Discrete-state Modeling for Deep Whale Dives | Hewitt (Duke) [Double Mocha] | Published |
| Methodology – technology | Continuous-time modelling of behavioural responses in animal movement | Michelot (St. Andrews) [Double Mocha] | Published |
| Methodology – technology | Kernel density estimation of conditional distributions to detect responses in satellite tag data | Hewitt (Duke) [Double Mocha] | Published |
| Methodology – technology | Continuous-time modelling of behavioural responses in animal movement | Michelot (St. Andrews) [Double Mocha] | Published |
| Methodology – technology | Trade-offs in telemetry tag programming for deep-diving cetaceans: data longevity, resolution, and continuity | Cioffi (SEA) | Published |

| Category | Nominal Title/Subject | Lead Author (Institution) | Status |
|---|---|---|---|
| Methodology – technology | Estimating RLs and horizontal avoidance with dynamic covariates in exposed animals | Schick (SEA) | Published |
| CEE exposure-response | Behavioral responses of *Ziphius* to simulated mid-frequency active military sonar off Cape Hatteras, NC | Southall (SEA) | In review |
| Baseline behavior | Shallow night intervals in *Ziphius cavirostris* | Cioffi (SEA) | In preparation |
| Baseline behavior | Possible orientation behavior in *Ziphius* | Quick (Duke) | In preparation |
| Baseline behavior | More than metronomes: variation in diving behaviour of goose-beaked whales (*Ziphius cavirostris*) | Quick (Duke) | In preparation |
| Baseline behavior | Wound-healing from satellite tag deployments in *Ziphius* | Read (Duke) | In preparation |
| CEE exposure-response | Behavioral responses of Cuvier's beaked whales to operational mid-frequency active military sonar systems off Cape Hatteras, NC | Southall (SEA) | In preparation |
| Baseline physiology | Baseline variation of steroid hormones in short-finned pilot whales (*Globicephala macrorhynchus*) | Wisse (Duke) | In preparation |
| Disturbance exposure-response | Measuring stress responses in short-finned pilot whale biopsies: are field methods confounding our data? | Wisse (Duke) | In preparation |
| Methodology – technology | Improvements to received level estimates with the use of Fastloc tags in behavioral response studies | Cioffi (SEA) | In preparation |

# 4. Overall Assessment and Recommendations

## 4.1 General Assessment of Atlantic-BRS 2024 Accomplishments

- The Atlantic-BRS team conducted the first-ever CEE with U.S. Navy ship-based, full-scale CAS MFAS projected from the *USS Thomas Hudner*. This CEE was planned and executed as scheduled and planned with regular coordination; adaptive planning using biological data; and close coordination, including final bridge-bridge coordination based on real-time animal behavior.
- Efforts to deploy additional tags following this successful CEE ahead of a second scheduled ship window were not successful, given the challenging environmental and focal species distribution patterns mentioned above. It was notable that a second CAS-capable ship was scheduled and available, but in this instance, the limiting factor precluding another CEE was the lack of additional tagged individuals.
- Operational conditions (wind, sea state) proved challenging for much of the 2024 field season, particularly during the first month (June). This again extends a longer-term pattern of fewer overall windows of ideal conditions, which require extended periods of adaptive effort to achieve research objectives and has influenced the team to focus on windows of potential U.S. Navy ship coordination during July and August, or even into September.
- Somewhat atypical patterns of animal density and distribution were observed during 2024. This included periods with fewer sightings of focal species in workable conditions within the core study area than would be expected. Additionally, several tagged whales moved large distances from the core area of typical distributions. These patterns have been observed previously but were possibly more common than would be expected based on extensive baseline data. Combined, these suggested there may have been some atypical patterns in distribution that made tag deployments more challenging.
- Given the above challenges, the 2024 field season included a relatively low overall number ($n$=4) of tags on high-priority *Ziphius*. However, this is only relative to the very high degree of success for this challenging species repeatedly accomplished within this study area previously. These tags still resulted in the collection of several thousand hours of movement and diving behavior.
- Deployment strategies and sat tag programming settings were maintained as developed during earlier years, again with very positive results. Many of the 2024 tags again achieved relatively long duration deployments for returning ARGOS position data (up to 71 days) as well as to up to 24 days of focused, high-resolution, continuous time-series dive data.

  The 2024 field season had successful coordination and adaptive planning with USFF colleagues in scheduling and coordinating with multiple CAS-capable vessels for coordination. Importantly, this included new adaptive measures of working with transiting vessels, including those from multiple home ports, to increase chances of success with CAS-capable ships.

- The team demonstrated sustained progress in presenting and publishing results in 2024. Multiple invited and submitted technical presentations from the project were given at the international Effects of Sound on Marine Mammals conference. Several publications in baseline behavior and methodological advances occurred, and a large sample size (*n*=72) exposure-response paper for *Ziphius* and simulated PAS that was slated for submission in 2024 also occurred.

## 4.2 Future Effort and Recommendations

- The study team was encouraged and excited about the first CAS CEE, with interesting and important initial findings, and believes the primary need is simply to replicate the overall approach and increase sample size focused on *Ziphius*. While the total numbers of tagged individuals included in this initial CEE (*n*=3) were lower than most of the operational vessel PAS CEEs thus far, this, and the inability to match the availability of a second CAS-capable ship, was a function of somewhat challenging and unusual conditions during 2024. The study team recommends a single, condition-adaptive field effort likely beginning somewhat later in June with an emphasis on U.S. Navy ship coordination during July and August.
- Coordination with U.S. Navy vessels should be maintained using I approaches consistent with previous seasons through advance and sustained planning and coordination via USFF. The study team was encouraged as well by the adaptive approach to engage vessels from multiple home ports and in transit scenarios as well as possible coordination around operational training windows. The study team recommends a similar strategy in scheduling up to four ships across the summer, with a realistic goal of conducting CEEs with two, ideally each with many tagged *Ziphius*.
- Given the repeated and proven record of successful tag deployments of both sat and DTAGs, the study team does not recommend any substantial changes in the overall patterns of field and tagging effort. The study team believes that the combination of advance deployment of sat tags in weeks to days ahead of CEEs and DTAG deployments as well as in the day to hours ahead of CEEs should be maintained in the context of the multi-scale design. Priority should be given to simultaneously deploying DTAGs within groups with sat-tagged individuals. Given the extensive optimization of sat-tag time series settings for the Atlantic-BRS field site (see Cioffi et al. 2023), no substantive changes to sat-tag programming setting are anticipated. Further deployments of the FastGPS sat tags are recommended for 2025 as a supplement to existing tag configurations. The team is considering a possible mix of version-3 and version-4 DTAGs in 2025.
- Field efforts to locate tagged animals with validated locations using goniometer detections, visual observations, and photo-ID should be maintained as much as possible before, and especially after, CEEs given the substantial and demonstrated improvements in spatial movement data, RL model estimates, and other factors.

# 5. References

Cioffi, W.R., N.J. Quick, Z.T. Swaim, H.J. Foley, D.M. Waples, D.L. Webster, R.W. Baird, B.L. Southall, D.P. Nowacek, and A.J. Read. 2023. Trade-offs in telemetry tag programming for deep-diving cetaceans: data longevity, resolution, and continuity. *Animal Biotelemetry* 11(1):23.

Cioffi, W.R., Quick, N.J., Foley, H.J., Waples, D.M., Swaim, Z.T., Shearer, J.M., Webster, D.L., Friedlaender, A.S., Southall, B.L., Baird, R.W. and Nowacek, D.P. (2021). Adult male Cuvier's beaked whales (*Ziphius cavirostris*) engage in prolonged bouts of synchronous diving. Marine Mammal Science, 37(3), 1085-1100.

Foley, H.J., Pacifici, K, Baird, R.W., Webster, D.L., Swaim, Z.T, and Read, A.J. (2021). Residency and movement patterns of Cuvier's beaked whales Ziphius cavirostris off Cape Hatteras, North Carolina, USA. Marine Ecology Progress Series https://doi.org/10.3354/meps13593

Freitas, C., C. Lydersen, R.A. Ims, M.A. Fedak, and K.M. Kovacs. 2008 A simple new algorithm to filter marine mammal Argos locations. *Marine Mammal Science* 24:315–325.

Freitas, C. 2022. argosfilter: Argos Locations Filter. R package version 0.70.

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

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

Michelot, T., R. Glennie, L. Thomas, N. Quick, and C.M. Harris. 2023. Continuous-time modelling of behavioural responses in animal movement. *The Annals of Applied Statistics* 17(4):3570-3588.

Quick, N. J., Cioffi, W. R., Shearer, J. M., Fahlman, A., & Read, A. J. (2020). Extreme diving in mammals: first estimates of behavioural aerobic dive limits in Cuvier's beaked whales. Journal of Experimental Biology, 223(18).

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.

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.

Schick, R.S., W.R. Cioffi, H.J. Foley, J. Joseph, N.A. Kaney, T. Margolina, Z.T. Swaim, L. Zheng, and B.L. Southall. 2024. Estimating received level in behavioral response studies through the use of ancillary data. *The Journal of the Acoustical Society of America*, *156*(6), 4169-4180.

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

Southall, B.L., 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.

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

Southall, B.L, W. Cioffi, R. Schick, D. Alvarez, C. Harris, A. Harshbarger, N. Quick, D. Nowacek, A.J. Read, Z.T. Swaim, D.M. Waples, D.L. Webster, and J. Wisse. 2023. *Atlantic Behavioral Response Study (BRS): 2022 Annual Progress Report*. Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Systems Command Atlantic, Norfolk, Virginia, under Contract No. N62470-15-D-8006, Task Order 20F4029, issued to HDR Inc., Virginia Beach, Virginia. June 2023.

Southall, B.L, W. Cioffi, R. Schick, D. Alvarez, C. Harris, A. Harshbarger, N. Quick, D. Nowacek, A.J. Read, Z.T. Swaim, D.M. Waples, and D.L. Webster. 2024. *Atlantic Behavioral Response Study (BRS): 2023 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. May 2024.