Atlantic Behavioral Response Study (Atlantic-BRS): 2023 Annual Progress Report

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

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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 micro Pascal
DTAG	digital acoustic recording tag
DUML	Duke University Marine Lab
EDT	Eastern Daylight Time
GPS	Global Positioning System
ID	Identification Number
kHz	kilohertz
km	kilometer(s)
km^2	square kilometer(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
RHIB	rigid-hulled inflatable boat
RL	received level
RMS	root mean square
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 cavirostris*

Executive Summary

The Atlantic Behavioral Response Study (Atlantic-BRS) was conceived, designed, adapted, and conducted by an experienced multi-institutional collaboration of scientists working with the United States (U.S.) Navy. This program has built on historical and ongoing Navy-funded studies under their Marine Species Monitoring Program, as well as the U.S. Navy's Living Marine Resources (LMR) program and Office of Naval Research (ONR). It has evolved through several years and research objectives to evaluate and quantify the behavioral responses of important and protected marine mammals to different kinds of Navy active sonar.

A strategic and adaptive multi-scale tagging approach yielding many simultaneously tagged individuals has been applied for baseline monitoring and conducting BRSs for key species: primarily Goose-beaked whales (*Ziphius cavirostris*), also referred to as *Ziphius* and, secondarily, short-finned pilot whales (*Globicephala macrorhynchus*) off the coast of Cape Hatteras, North Carolina. 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.

The CEE methods have involved several types of mid-frequency active sonar (MFAS) systems, including simulations of pulsed active sonar (PAS); operational PAS from SQS-53C systems on U.S. Navy surface vessels; and recently, continuous active sonar (CAS), also from operational surface vessels. Building on earlier field seasons (see Southall et al. 2018, 2019, 2020, 2021, 2022, 2023), this project has yielded one of the largest and most comprehensive data sets available for baseline behavior and responses to sonar exposure for beaked whales, which is one of the highest-priority marine mammal species for U.S. Navy research and monitoring.

The 2023 field season marked a transition from CEEs using PAS MFAS signals to CAS. A single, extended field period spanned from summer into autumn, with 11 tags deployed on beaked whales during suitable weather windows ahead of anticipated U.S. Navy vessel availability. Through sustained coordination and planning between the field team and U.S. Fleet Forces Command, multiple CAS-capable vessels were identified and scheduled for possible coordination. An ill-timed engineering casualty restricted participation of the primary vessel with which the team had been closely coordinating in final preparation for a CAS CEE. A control (no MFAS) CEE was conducted adaptively given this development, yielding important behavioral data with which to contrast MFAS CEEs.

Extensive analytical effort, coordinated with other U.S. Navy-funded analysis development, continued to substantially advance the existing large data sets for baseline behavior, technological tools, and responses to both simulated and operational PAS. Multiple manuscripts with data and analyses from the Atlantic-BRS project were published in 2023, and papers from two extensive, primary analyses are being submitted in early 2024.

1. Overview

1.1 Overall Project Design and Objectives

The Atlantic Behavioral Response Study (Atlantic-BRS) overall research program has included a series of sequential field efforts to measure 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 initially adapted from methods previously 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 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).

Previous studies have used short-term, high-resolution acoustic tag sensors to measure fine-scale behavior in response to experimentally controlled noise exposure. Other studies have used coarser-scale, longer-term measurements of movement and diving behavior associated with incidental exposures during sonar training operations. The Atlantic-BRS project integrates 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.

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.

The focus of experimental studies using CEEs in previous field seasons has been on pulsed active sonar (PAS) signals from both operational and simulated MFAS sources. These systems typically use 1- to 2-second duration sonar pulses repeated every 20 to 30 seconds. Beginning in 2023, the Atlantic-BRS project is focusing on a different type of MFAS system – continuous active sonar (CAS) in which similar frequency and modulation pattern signals are presented entirely or nearly continuously. While the frequency patterns are similar and the output power of these signals may be similar in terms of total energy, the exposure context is quite different. Consequently, there is interest in directly measuring and contrasting exposure and response from CAS stimuli with the large data set obtained thus far with PAS signals.

The Atlantic-BRS project pivoted to CAS stimuli for the 2023 field campaign to begin to address these potential differences in exposure and response. 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 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 support CEEs, and to coordinate with and plan for CEEs with CAS-capable ships.

This annual progress report provides a synthesis of experimental methods; summarizes field efforts, tagging results, and baseline data; and summarizes the results of the control (no-MFAS) CEE conducted adaptively in 2023. It also provides a detailed summary and analysis of results using FastGPS position sat tag sensors with previous tag approaches and settings. 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 and photo-identification (photo-ID), and remote passive acoustic monitoring from archival recorders.

Despite the pivot of focus from PAS to CAS stimuli, the overall experimental design was deliberately unchanged for the 2023 field season. 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) 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). Atlantic-BRS publications referenced later 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 U.S. Navy surface vessels in earlier field efforts, resulting in eight CEEs with PAS stimuli. This approach includes a period prior to CEEs during which baseline behavioral data are collected prior to the CEE—a 60-minute minimum for animals with DTAGs and a 24-hour minimum for animals with sat tags. Most baseline SLTDR data periods were much longer (often weeks) in practice for sat tags. Pre-exposure baseline behavioral data collection primarily involved data from tag sensors, supplemented by focal follows of tagged animals when possible.

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 Navy vessels were positioned at ranges from subjects that met experimental objectives for RLs based on the publicly available (unclassified) 3 to 4 kHz source level of 235 decibels root mean square referenced to 1 micro Pascal (dB (RMS) re 1 μPa; hereafter dB unless otherwise specified) signals of a constant nominal 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 sound exposure level (SEL; dB re 1μPa^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 root mean square [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 targets 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 CEE within a 2-week window following sat tag deployment windows, with subsequent tagging effort for additional conducting CEEs with operational MFAS systems.

1.3 Overall Analytical Approach

Behavioral response analyses focus on how whales change their behavior from baseline conditions during periods of MFAS exposure in known contexts during CEEs. Analyses of potential response type, probability, and severity apply methods developed 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, they were sufficiently mature that they were maintained and applied to subsequent data sets (see: Southall et al. 2020, Section 1.3).

1.4 Field Logistics and Configuration

Atlantic-BRS field efforts for 2023 were conducted adaptively, based primarily on weather and potential Navy vessel availability, across a single field season spanning summer through early autumn. Field teams included a small boat-based team (4 to 5 members) aboard the Research Vessel (R/V) *Barber*, an 8-meter, 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 and other data from groups. During periods in which DTAG deployments and CEEs were attempted, a research crew of approximately six individuals worked from the fast catamaran *R/V Shearwater*, which remained offshore, 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 all 2023 tag deployment, CEEs, and re-sighting and biopsy sampling of focal individuals thereafter. In previous years, this was augmented by contracted private fishing vessels as needed, but this was not required during 2023.

Multiple version 3 DTAGs from the University of Michigan were leased for available field periods and prepared to be deployed in strategic windows. Up to 30 Low-impact Minimally Percutaneous Electronic Transmitter (LIMPET) satellite-linked tags were also available. Priority was placed on the use of SPLASH10-A satellite-transmitting tags that provide position and depth data, given the interest in feeding and diving behavior. Almost all tags available were of this type. A smaller number of SPLASH10-F-333 FastGPS tags that incorporate Fastloc® Global Positioning Systems (GPS) were also available. Four were strategically deployed during 2023, and a detailed analysis of outcomes and performance for the purposes of the Atlantic-BRS project objectives is given below (see **Section 3**). Exclusive tagging priority was placed on beaked whales during the 2023 field season, which again proved effective given the large number of individuals. Efforts were again made to deploy multiple tags in social groups to evaluate potential changes in social associations as a response metric during CEEs.

Previous Atlantic-BRS efforts with PAS stimuli included both a primary objective of coordination with operational 53C-capable vessels as well as a simulated MFAS source option. With the transition to CAS stimuli, there is intention and ongoing effort to obtain a comparable CAS-capable simulated MFAS source. However, this was not available for 2023 efforts, and the exclusive focus for active MFAS CEEs was operational CAS-capable vessels. Previous successful coordination approaches led by USFF were again applied during planning and coordination between the Atlantic-BRS team and U.S. Navy representatives facilitating Navy vessel participation in CEEs. This began months in advance of field operations and included advance briefing of potential participant vessels. During CEE periods, dedicated U.S. Navy personnel coordinated with vessels in the field remotely from onshore sites through secure communications. The team deliberately worked to schedule 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 multiple capable and willing CAS-capable ships for participation with the Atlantic-BRS project in 2023 and succeeded in deploying many tags on the primary focal species. Unfortunately, the primary candidate vessel suffered an unrelated engineering casualty just prior to supporting the Atlantic-BRS project and was unavailable. Two other possible ships of opportunity were also unable to support the project, and focused on additional tagged whales later in the field year due to conflicting mission requirements.

2. Field Effort

2.1 Summary of 2023 Field Effort: Accomplishments and Assessment

Field Dates:

- 1 June: First possible field effort for advance tag deployment team (*R/V Barber*); some field personnel deployed and ready to go at Manteo field site.
- 9 June – 1 July: *R/V Barber* team staged in Manteo and on water for multiple single-day efforts during this window largely scouting, photo-ID, and biopsy sampling (n=6 obtained) with conditions not suitable for tagging.
- 12–24 July: Several additional *R/V Barber* team days on water but generally marginal conditions or shorter days without successful tagging.
- **25–26 July**: Back-to-back long *R/V Barber* team days in good conditions resulted in **six beaked whale sat tag deployments** ahead of U.S. Navy ship availability, slated for later that week.
- 28–31 July: First scheduled U.S. Navy CAS-capable ship window and planned *R/V Shearwater* trip. Team was informed prior to departure that this ship was unavailable, but a second scheduled ship was shifted earlier to the 3–4 August window. The *R/V Shearwater* schedule was adaptively shifted later by several days to accommodate this change.
- **2–5 August**: *R/V Shearwater* deployed from the Duke University Marine Lab (DUML) to Cape Hatteras field area to support tagging and tracking ahead of CEE operations and to coordinate CEEs. *R/V Barber* was also on water 3–4 August for follow-up re-sightings, photo-ID, in situ data acquisition, additional tag deployments, and to support CEE. U.S. Navy vessel United States Ship (USS) *Winston S. Churchill* was on water en route to support CEE when it experienced a mechanical issue and was unable to provide support. Atlantic-BRS team adjusted plans to run **complete CEE sequence (#2023_01) on 4 August with two focal and two non-focal tagged beaked whales** (two tags had ceased transmissions prior to this CEE).
- **6–7 August**: *R/V Barber* team on water for follow-up re-sightings, photo-ID, in situ data acquisition, and tagging effort achieved **three additional beaked whale sat tag deployments** ahead of possible U.S. Navy ship availability later in August.
- **21 August**: *R/V Barber* team on water for follow-up re-sightings, photo-ID, in situ data acquisition, and tagging effort achieved **three additional beaked whale sat tag deployments** ahead of possible U.S. Navy ship availability later in August.
- **30 August:** Team belayed second possible *R/V Shearwater* window and additional *R/V Barber* team effort for additional sat tags or DTAGs as possible additional U.S. Navy CAS-capable ship support was deemed to have ended for the season.
- **13 October**: Last data message received from 2023 beaked whale sat tags.

Accomplishments:

- Successfully deployed 11 sat tags on beaked whales, including strategic deployment of four FastGPS tags, enabling a more systematic evaluation of these tags in the Atlantic-BRS context (identified as a specific objective in Southall et al., 2023)
- Adaptively conducted successful control CEE using simulated MFAS CEE design from the *R/V Shearwater*.
- Obtained six biopsy samples during the Atlantic-BRS field efforts.
- Continued success with research platform *R/V Shearwater*, which was highly successful in locating and tracking animals, including successful overnight tracking.
- Sustained efforts to relocate sat-tagged animals in the field using goniometer detections, increasing chances of subsequent tag deployments; improving animal pseudotracks by providing high confidence surface locations; and resulting in many photo-ID re-sights to evaluate group composition, social interactions, and biopsy samples.

Assessment of Field Approach:

- The combined team with USFF successfully identified multiple capable and willing CAS-capable ships for participation with the Atlantic-BRS project in 2023 and succeeded in deploying many tags on the primary focal species. Unfortunately, the primary candidate vessel suffered an unrelated engineering casualty just prior to supporting the Atlantic-BRS project and was unavailable. Two other possible ships of opportunity were also unable to support the project, and focused on additional tagged whales later in the field year due to conflicting mission requirements.
- Field teams were adaptive in working through challenging conditions, especially during June again. Very good conditions again occurred during small windows in late July and early August, enabling most of the success in tagging (11 tags in 4 field days). Advance discussions for the 2024 field effort have 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 in 2023.
- Field teams sustained high-quality satellite-transmitting tag dive data due to earlier progress in tag programming strategies to reduce/eliminate gaps in sat tag data and to improve temporal resolution on diving and behavioral data. The team successfully collected continuous dive data for up to 21-day periods, strategically covering CEE periods, as designed. Long-duration (up to 70 days) functioning of tags in reporting ARGOS positions was again experienced, likely due to improved batteries in SPLASH tags.

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 2023. A total of 11 satellite-transmitting tags were deployed, all on beaked whales.

Table 1. Satellite tag deployments for beaked whales (*Ziphius cavirostris*) during Atlantic-BRS field efforts in 2023.

Species[a]/ Tag ID	Deployment Date	Deployment Latitude (°N)	Deployment Longitude (°W)	Dive Data Streams	Tag Duration (days)
ZcTag136_DUML	07/25/23	35.6497	74.7225	5-min time series	68
ZcTag137_DUML	07/25/23	35.5991	74.7219	5-min time series	61
ZcTag138_DUML	07/25/23	35.6089	74.7430	5-min time series	19
ZcTag139_DUML	07/26/23	35.7208	74.6589	5-min time series	29
ZcTag140_DUML	07/26/23	35.7285	74.6515	5-min time series	8
ZcTag141_DUML	07/26/23	35.6300	74.7061	5-min time series	5
ZcTag142_DUML	08/07/23	35.6282	74.7024	5-min time series	67
ZcTag143_DUML[b]	08/07/23	35.6197	74.6305	5-min time series	68
ZcTag144_DUML[b]	08/07/23	35.6282	74.7024	5-min time series	39
ZcTag145_DUML[b]	08/21/23	35.6282	74.7024	5-min time series	7
ZcTag146_DUML[b]	08/21/23	35.6282	74.7024	5-min time series	70

Key: ID = Identification Number; °N = degrees North; °W = degrees West; min = minute(s)
[a] Zc = *Ziphius cavirostris*
[b] Fastloc® GPS 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 of 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, the team ran an additional speed angle distance filter from the R package argosfilter (function sdafilter) with the following parameters: vmax = 10 kph, ang = {15, 25} (degrees), distlim = {2500, 5000} (meters) (Freitas et al. 2008, 2022). **Figure 1** shows filtered ARGOS positions for all beaked whales tagged during 2023.

A simple plot showing all filtered beaked whale locations in 5-square-kilometer (km^2) hexagonal grids across the entire study areas for all whales is provided in **Figure 2**. Individual (by animal) plots of filtered ARGOS positions are shown for the entire satellite-transmitting tag deployment periods for each tagged beaked whale (**Figures 3** through **10**). For whales that were tagged during the simulated source CEE, the location of the CEE vessel is indicated on the individual plots.

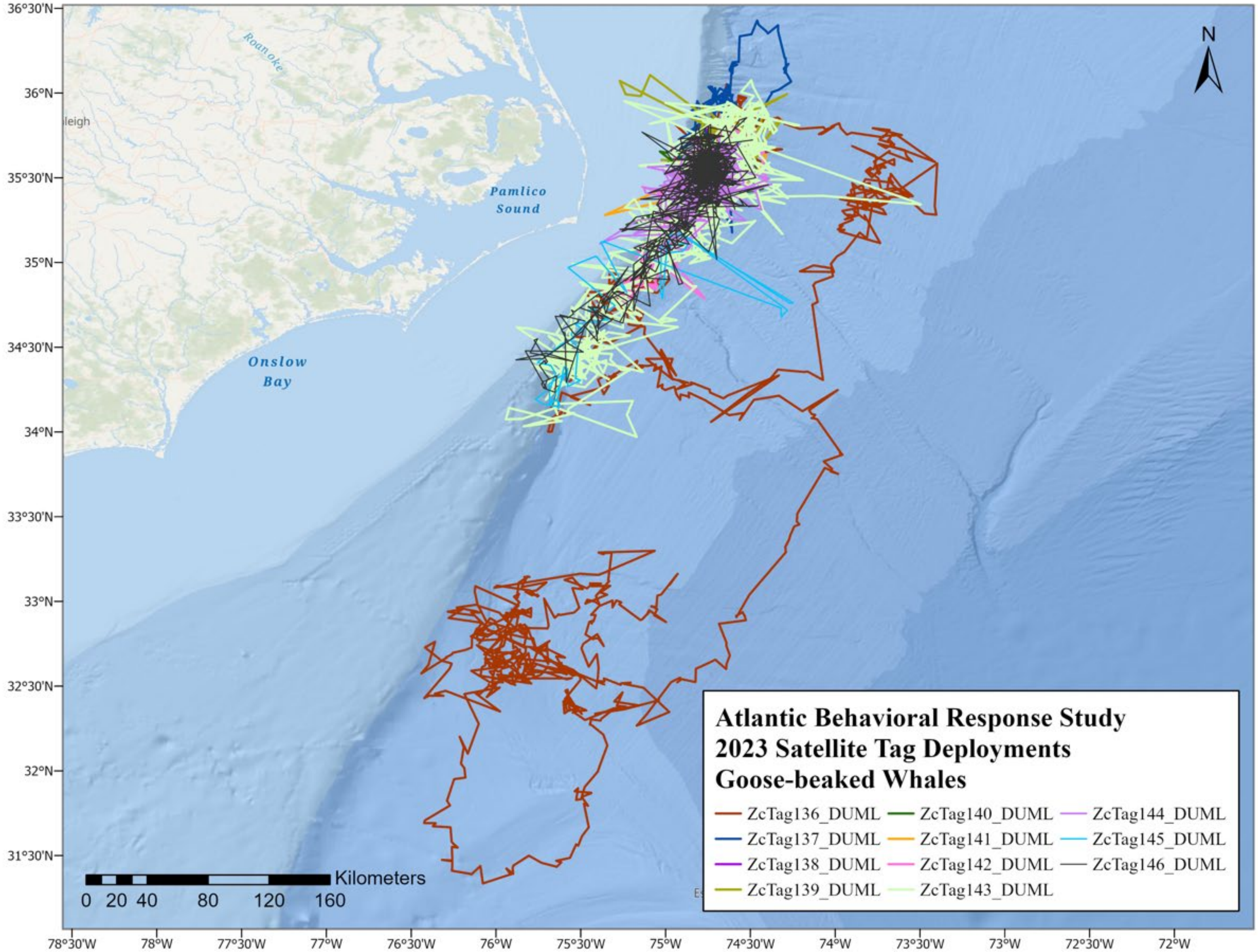

Figure 1. Filtered ARGOS position tracks for all (n=11) beaked whales tagged during Atlantic-BRS field efforts in 2023.

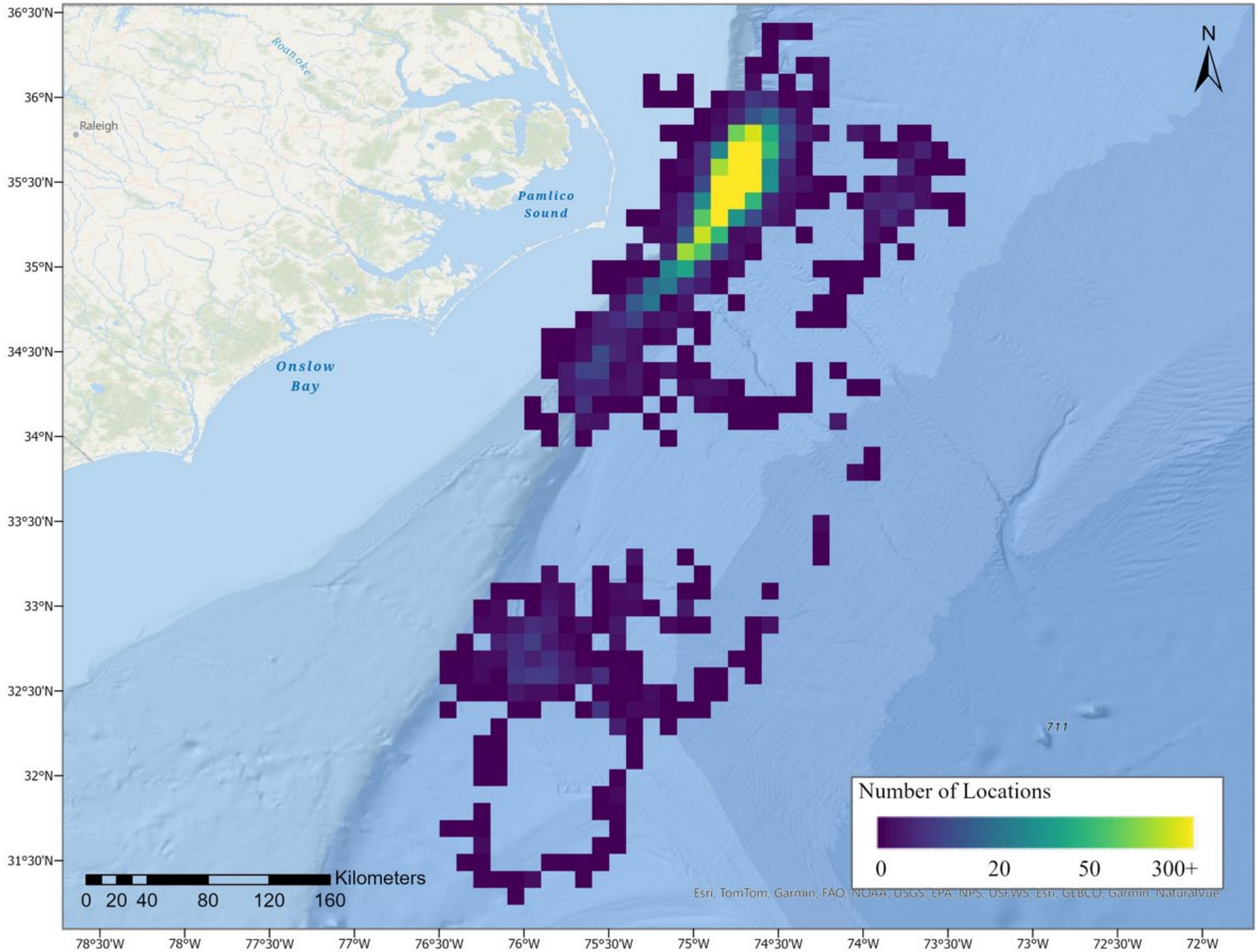

Figure 2. Filtered ARGOS locations for all 2023 tagged beaked whales aggregated in 5-km^2 hexagonal grid cells.

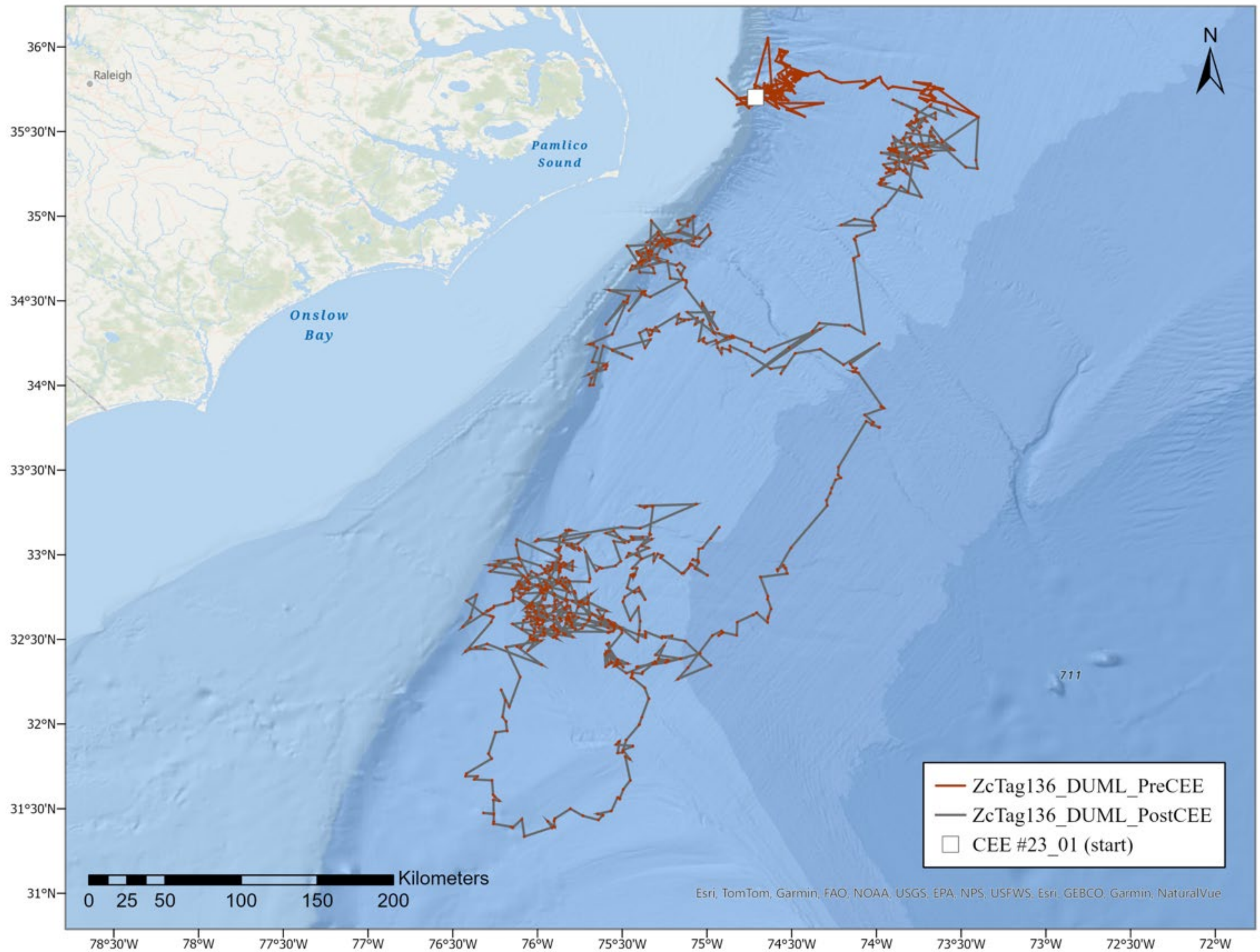

Figure 3. Filtered ARGOS positions for entire track of ZcTag136_DUML (tag duration 68 days). Portions of the track prior to control CEE #23_01 are in red and portions after are in brown. The CEE start location for the (drifting) *R/V Shearwater* (mock sound source platform) is shown.

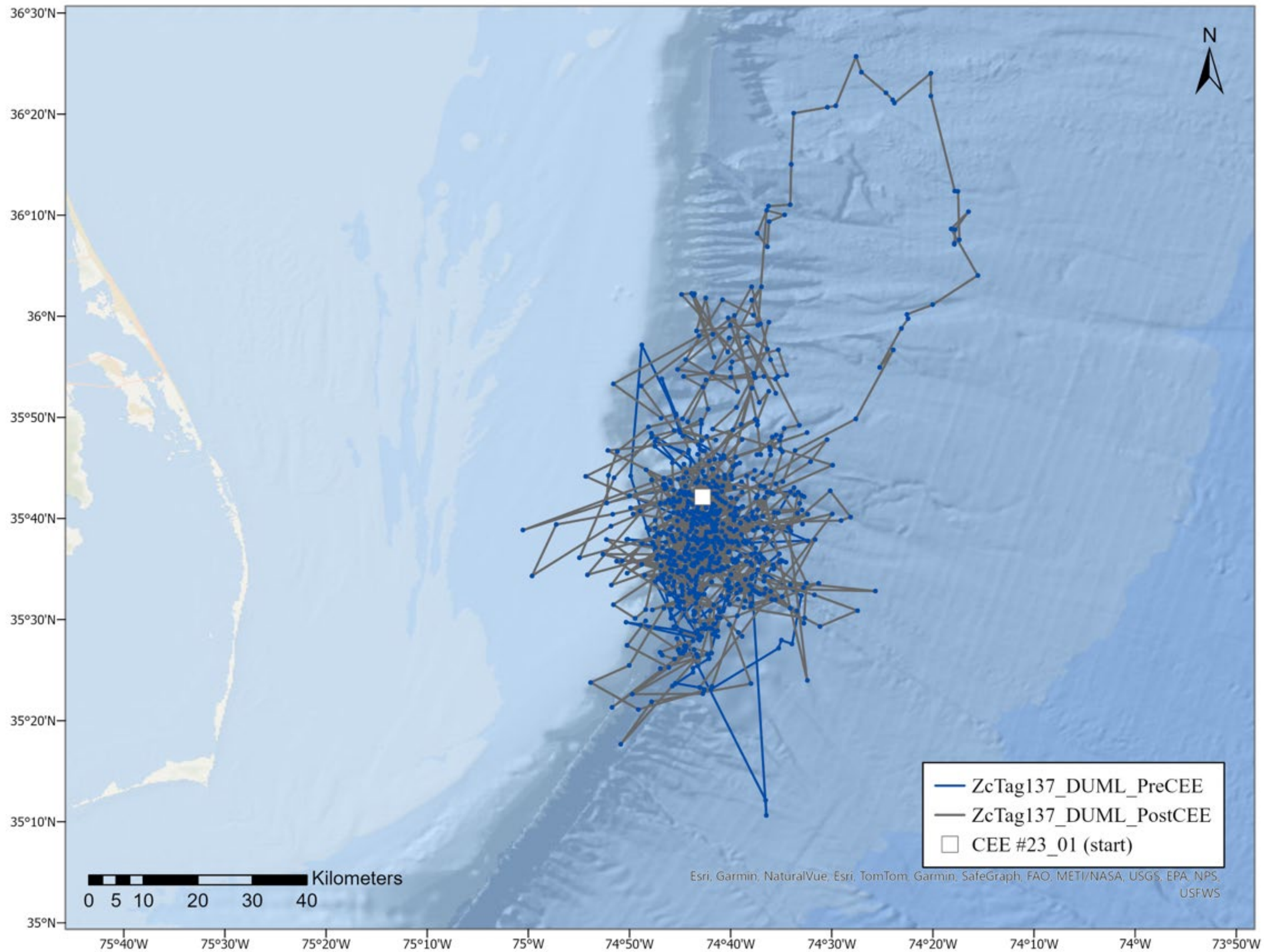

Figure 4. Filtered ARGOS positions for entire track of ZcTag137_DUML (tag duration 61 days). Portions of the track prior to control CEE #23_01 are in blue and portions after are in dark gray. The CEE start location for the (drifting) *R/V Shearwater* (mock sound source platform) is shown.

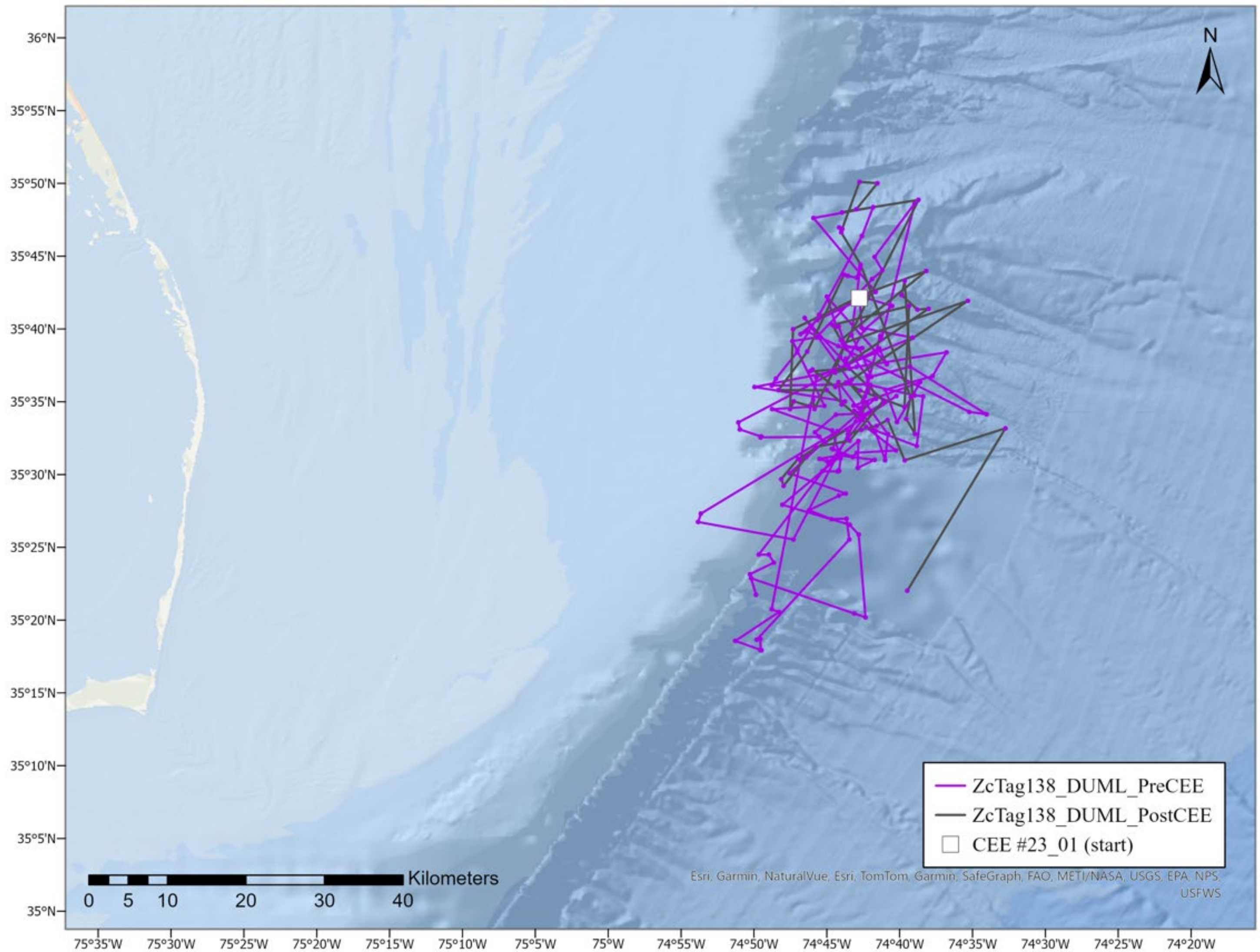

Figure 5. Filtered ARGOS positions for entire track of ZcTag138_DUML (tag duration 19 days). Portions of the track prior to control CEE #23_01 are in purple and portions after are in black. This whale was the focal individual for this control CEE. The CEE start location for the (drifting) *R/V Shearwater* (mock sound source platform) is shown.

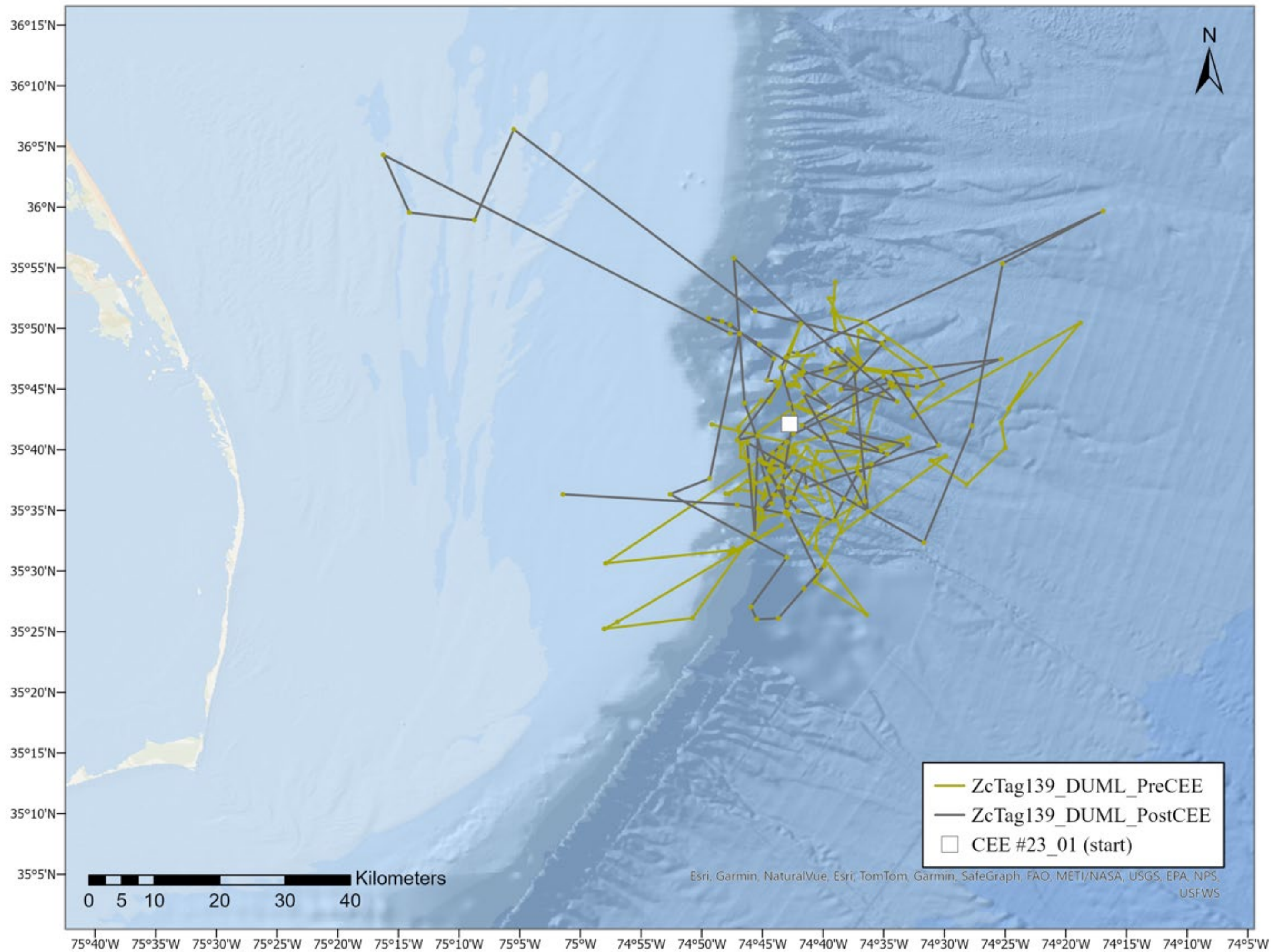

Figure 6. Filtered ARGOS positions for entire track of ZcTag139_DUML (tag duration 29 days). Portions of the track prior to control CEE #23_01 are in yellow-green and portions after are in brown. The CEE start location for the (drifting) *R/V Shearwater* (mock sound source platform) is shown.

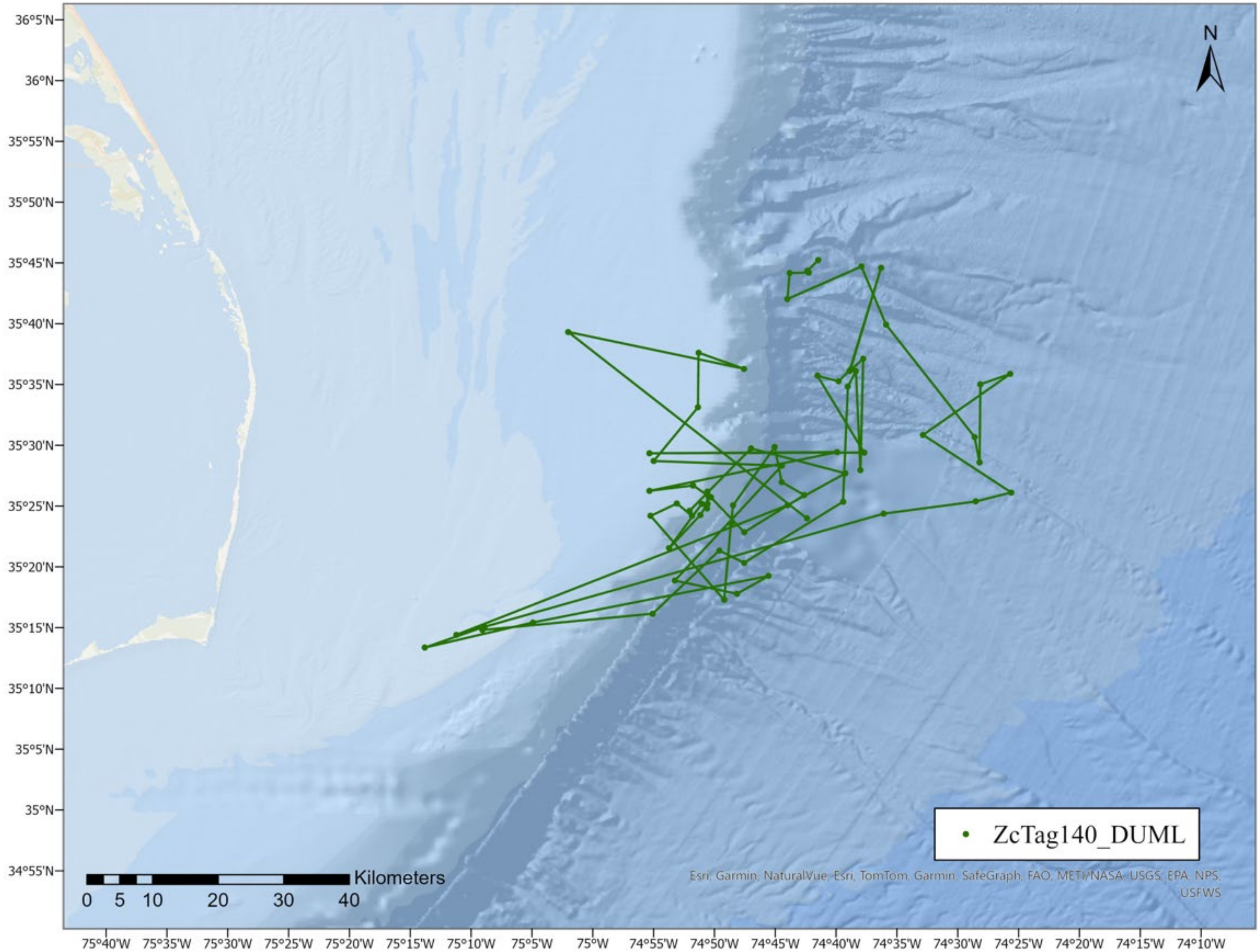

Figure 7. Filtered ARGOS positions for entire track (green) of ZcTag140_DUML (tag duration 8 days). This tag ceased transmitting prior to CEE #23_01, so all data were obtained as baseline behavior.

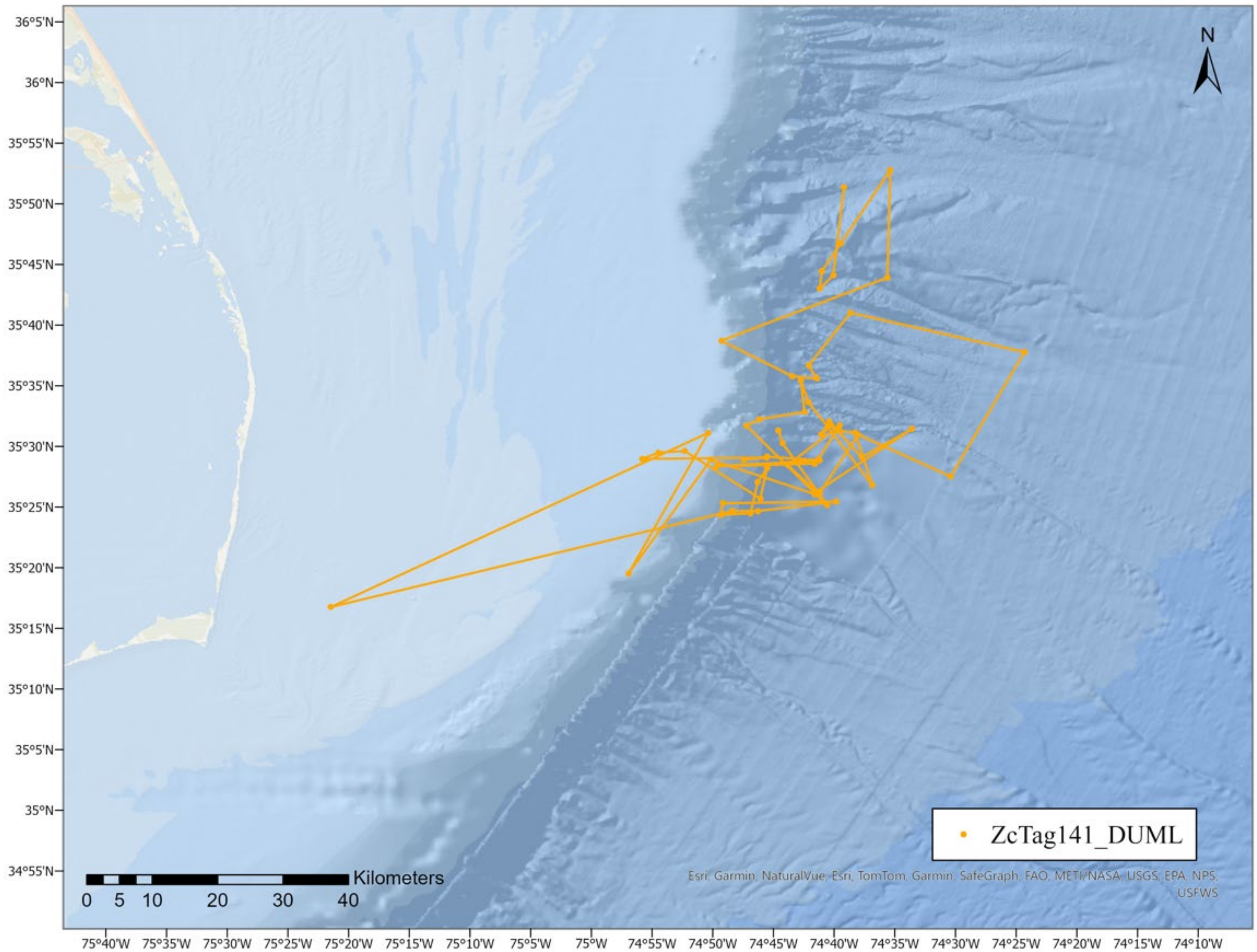

Figure 8. Filtered ARGOS positions for entire track (orange) of ZcTag141_DUML (tag duration 5 days). This tag ceased transmitting prior to CEE #23_01, so all data were obtained as baseline behavior.

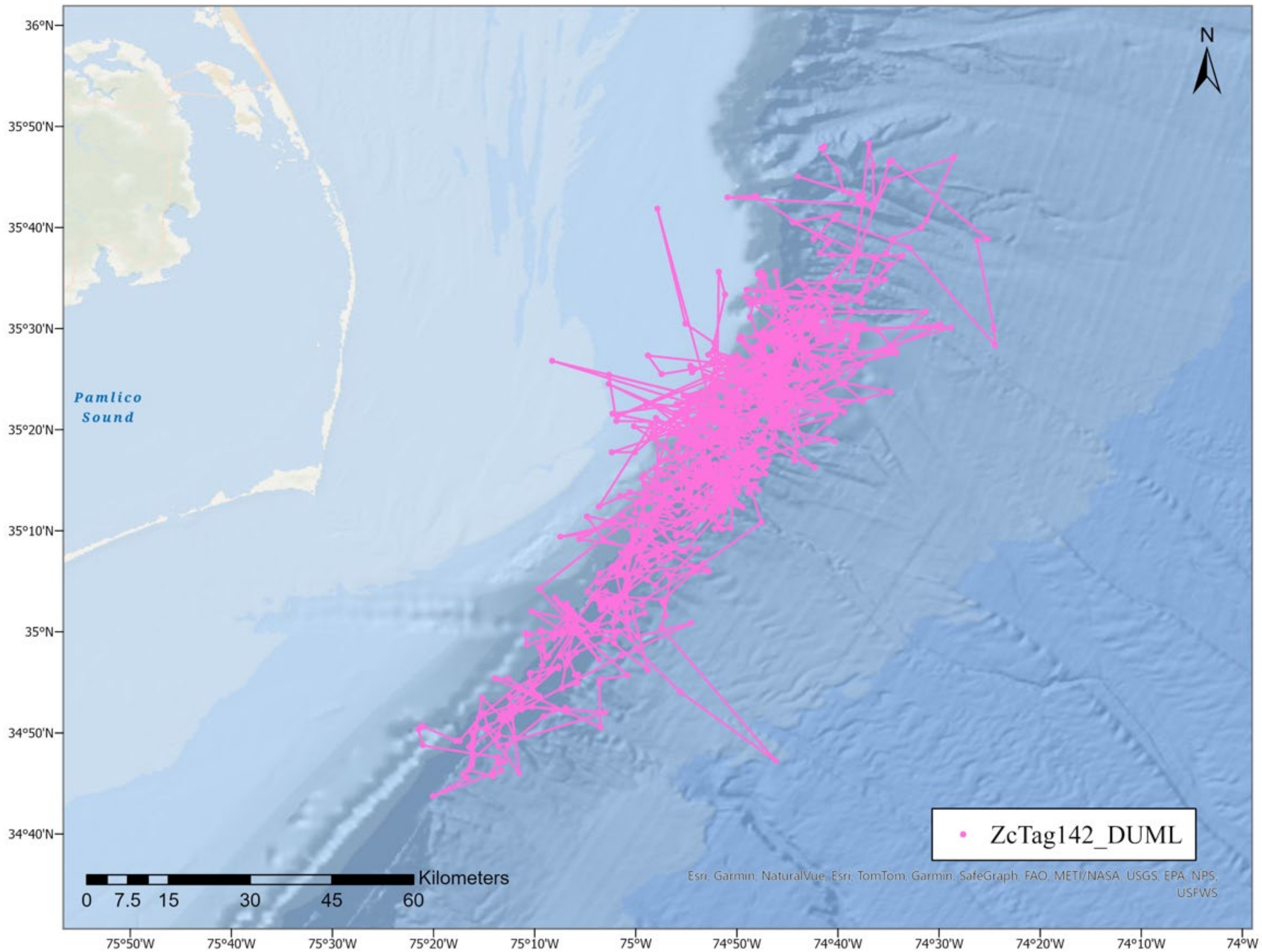

Figure 9. Filtered ARGOS positions for entire track (pink) of ZcTag142_DUML (tag duration 67 days). This tag was deployed after CEE #23_01, and all data were obtained as baseline behavior.

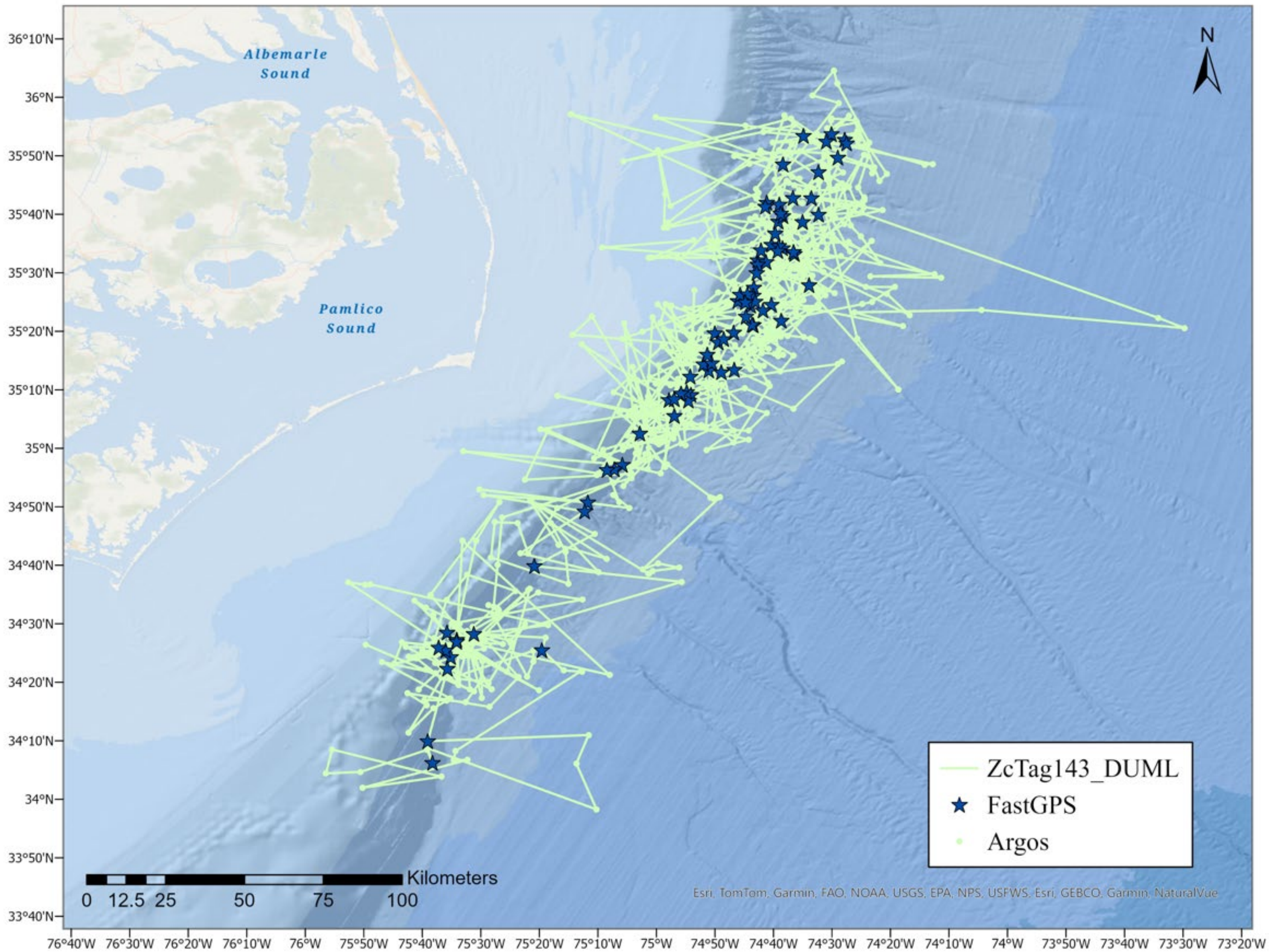

Figure 10. Filtered ARGOS (circles) positions for entire track (light green) and FastGPS locations (blue stars) of ZcTag143_DUML (tag duration 68 days). This tag was deployed after CEE #23_01, and all data were obtained as baseline behavior.

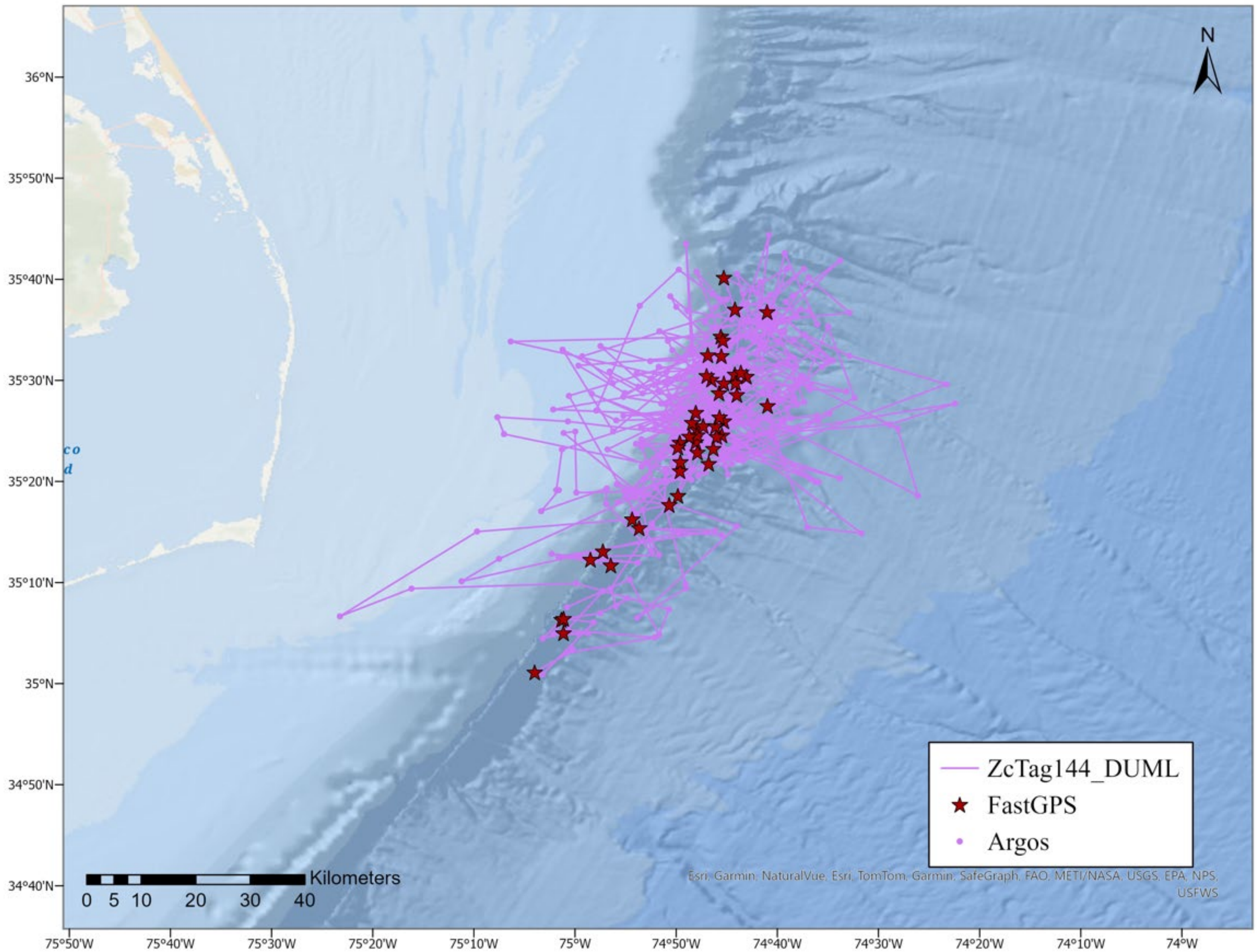

Figure 11. Filtered ARGOS positions (circles) positions for entire track (light purple) and FastGPS locations (red stars) for entire track of ZcTag144_DUML (tag duration 39 days). This tag was deployed after CEE #23_01, and all data were obtained as baseline behavior.

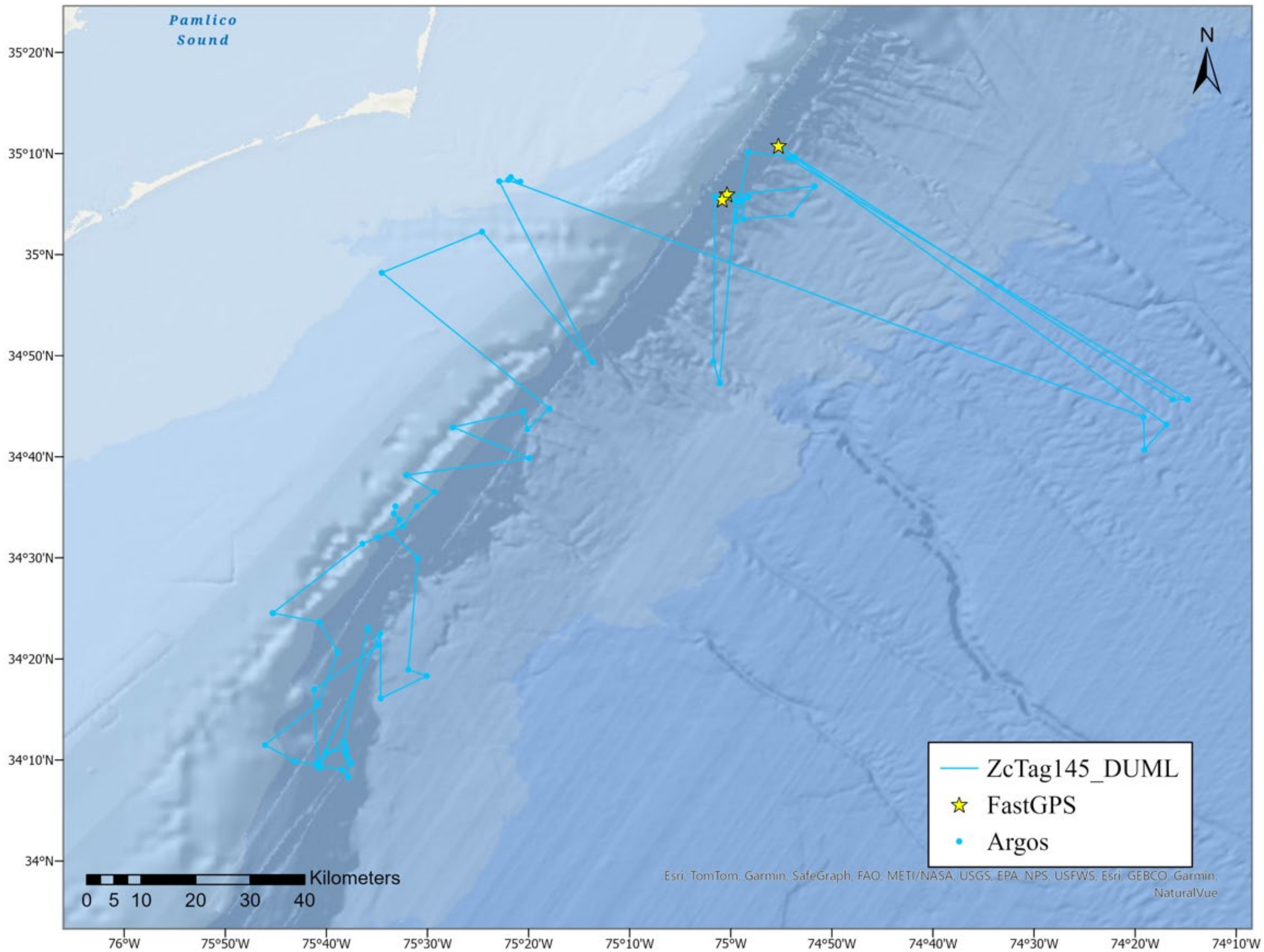

Figure 12. Filtered ARGOS positions (circles) positions for entire track (light blue) and FastGPS locations (yellow stars) for entire track of ZcTag145_DUML (tag duration 7 days). This tag was deployed after CEE #23_01, and all data were obtained as baseline behavior.

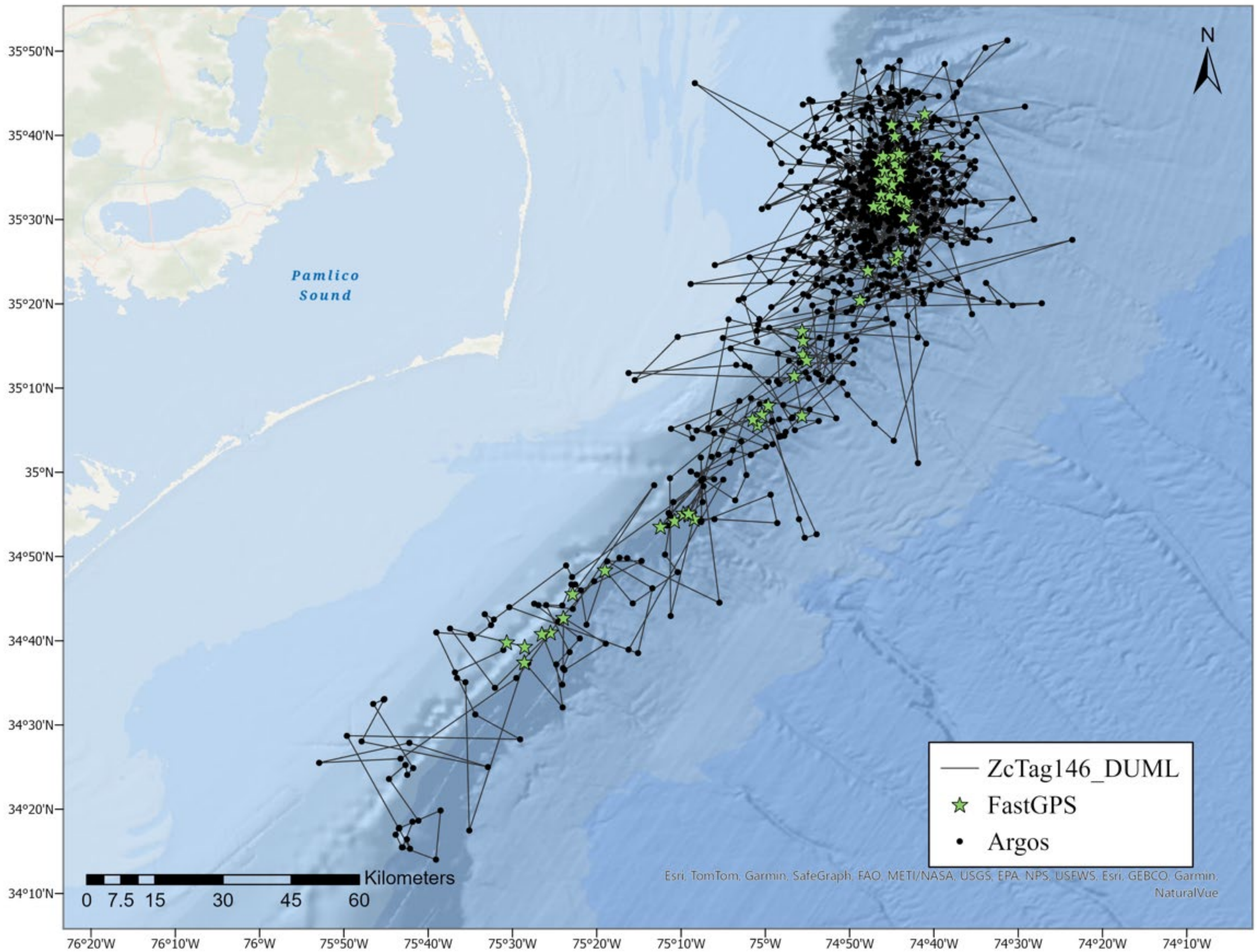

Figure 13. Filtered ARGOS positions (circles) positions for entire track (black) and FastGPS locations (green stars) for entire track of ZcTag146_DUML (tag duration 70 days). This tag was deployed after CEE #23_01, and all data were obtained as baseline behavior.

2.3 CEEs Conducted

One CEE sequence was conducted during the Atlantic-BRS 2023 field effort. As noted above, a dedicated CAS-capable ship (*USS Winston S. Churchill*) was in coordination with the Atlantic-BRS team and was en route to support a MFAS (CAS) CEE when it experienced an engineering casualty. Given that the entire team and vessels were in place with four sat-tagged whales, the decision was made to run a full control sequence. This was successfully conducted with two focal whales and two non-focal whales, all of which were tagged with satellite-transmitting SPLASH-10 tags (CEE #2023_01; see **Table 2**).

Table 2. CEEs conducted during Atlantic-BRS 2023 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)
#2023_01	8/4/23	CONTROL	ZcTag137 ZcTag138	ZcTag136 ZcTag139	30	35.7021	-74.7129

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

A summary of the RL modeling, and associated planning and coordination conducted with the *USS Winston S. Churchill* 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 14**. 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 (07 and 08 in **Table 4**) for the start and end of CAS-vessel transmissions for the focal individuals that informed the final requested vessel tracks are shown for reference (**Figures 15** and **16**); all model runs are available upon request.

A narrative summary and spatial depiction of the control CEE sequence conducted along with dive records from sat tag locations for all focal and non-focal individuals (see **Table 5; Figures 17** through **21**) is provided.

Table 3. Sequential positioning for *USS Winston S. Churchill* ahead of Atlantic-BRS CEE #2023_01.

Position Request for *USS Winston S. Churchill*	Description	Latitude (°N)	Longitude (°W)	Heading
1	Nominal initial posit (provided to ship weeks in advance)	35.9	74.5	Not specified
2	1 August 1200 EDT (~72-hour pre-exposure) based on best estimate of ZcTag136 as nominal focal at that point	36.0	74.25	250
3	2 August 1200 EDT (~48-hour pre-exposure) based on best estimate of ZcTag136 as nominal focal at that point; three other whales farther to west	36.0	74.35	230
4	3 August 1100 EDT: (~24-hour pre-exposure) based on cluster of ZcTags137–139; pivoted to focus on this cluster based on ZcTag136 moving well to the east; track was intended to cut the vessel between 136 to the east and the cluster near the shelf to the west	35.92	74.52	203
5	4 Aug 0630 EDT: Final requested start position for *USS Winston S. Churchill*. Vessel was en route to this location when engineering casualty occurred	35.95	74.36	205

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

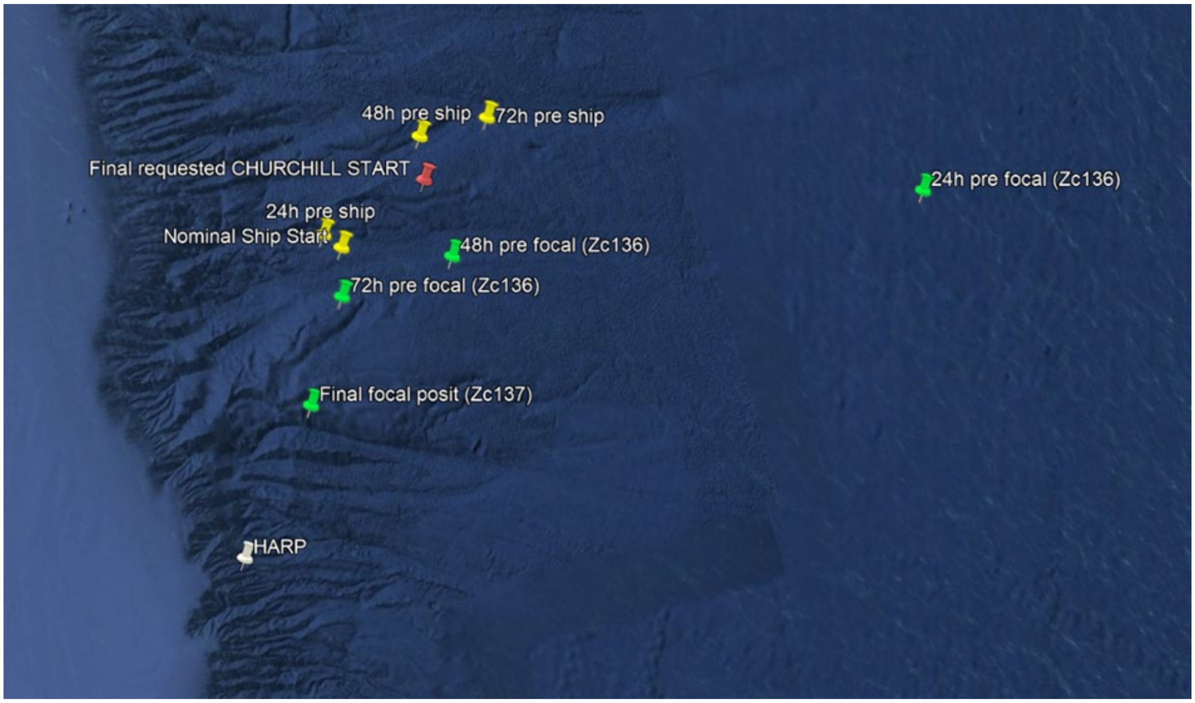

Figure 14. Sequential requested *USS Winston S. Churchill* start positions shown weeks to days in advance (yellow pins) as well as the final position (red pin) requested on the day of the planned CEE. Vessel positions are shown relative to focal animal position estimates (green pins) used in RL modeling and to inform the vessel position requests.

Table 4. RL model runs for CEE #2023_01.

Model Run	Description	Animal (Depth – m)	Animal Latitude	Animal Longitude	Estimated Range (nm) Start – End	Model RL Start	Model RL End	Model RL Max.
01	27 July 1200 EDT	Zc136 (1,500) posit 24-hour post tagging	35.898	74.487	19 – 12	112	131	131
02	01 August 1200 EDT	Zc136 (1,700) Zc137, 138, 139 nearby	35.845	74.518	22 – 16	114	131	134
03	02 August 1200 EDT	Zc136 (1,200) Zc137, 138, 139 nearby	35.856	74.351	21 – 13	109	128	128
04	03 August 0900 EDT	Zc136 (1,700) Zc137, 138, 139 distant	35.789	74.209	20 – 13	109	134	134
05	03 August 1100 EDT	Zc136 (1,700) Zc137, 138, 139 distant	35.782	73.678	23 – 18	110	116	126
06	03 August 1300 EDT	Zc137 (1,100 Zc38, 139 nearby	35.600	74.749	22 – 14	101	119	119
07	03 August 1500 EDT	Zc137 (1,400) Zc138, 139 nearby	35.595	74.724	22 – 15	106	125	125
08	04 August 0500 EDT	Zc137 (1,600) Zc138, 139 nearby	35.733	74.602	17 – 10	104	122	122

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

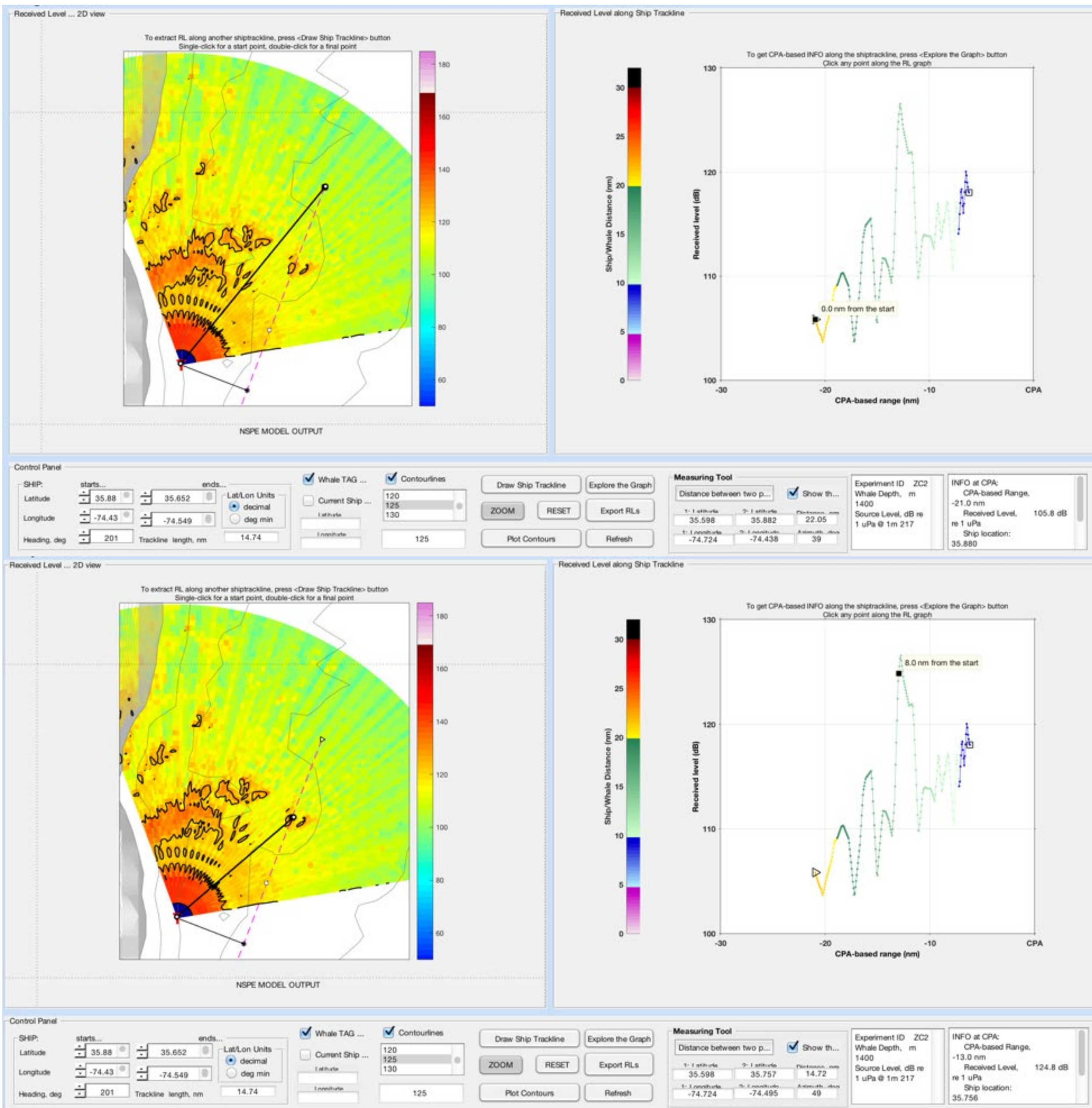

Figure 15. RL model prediction at 1,400-meter depth (model run 07 from Table 4) for focal whale Zc137 ahead of Atlantic-BRS CEE #2023_01 for the start (top; vessel-animal range: 22.1 nm; modeled RL = 105.6 dB) and end (top; vessel-animal range: 14.7 nm; modeled RL = 124.8 dB) of the modeled vessel track.

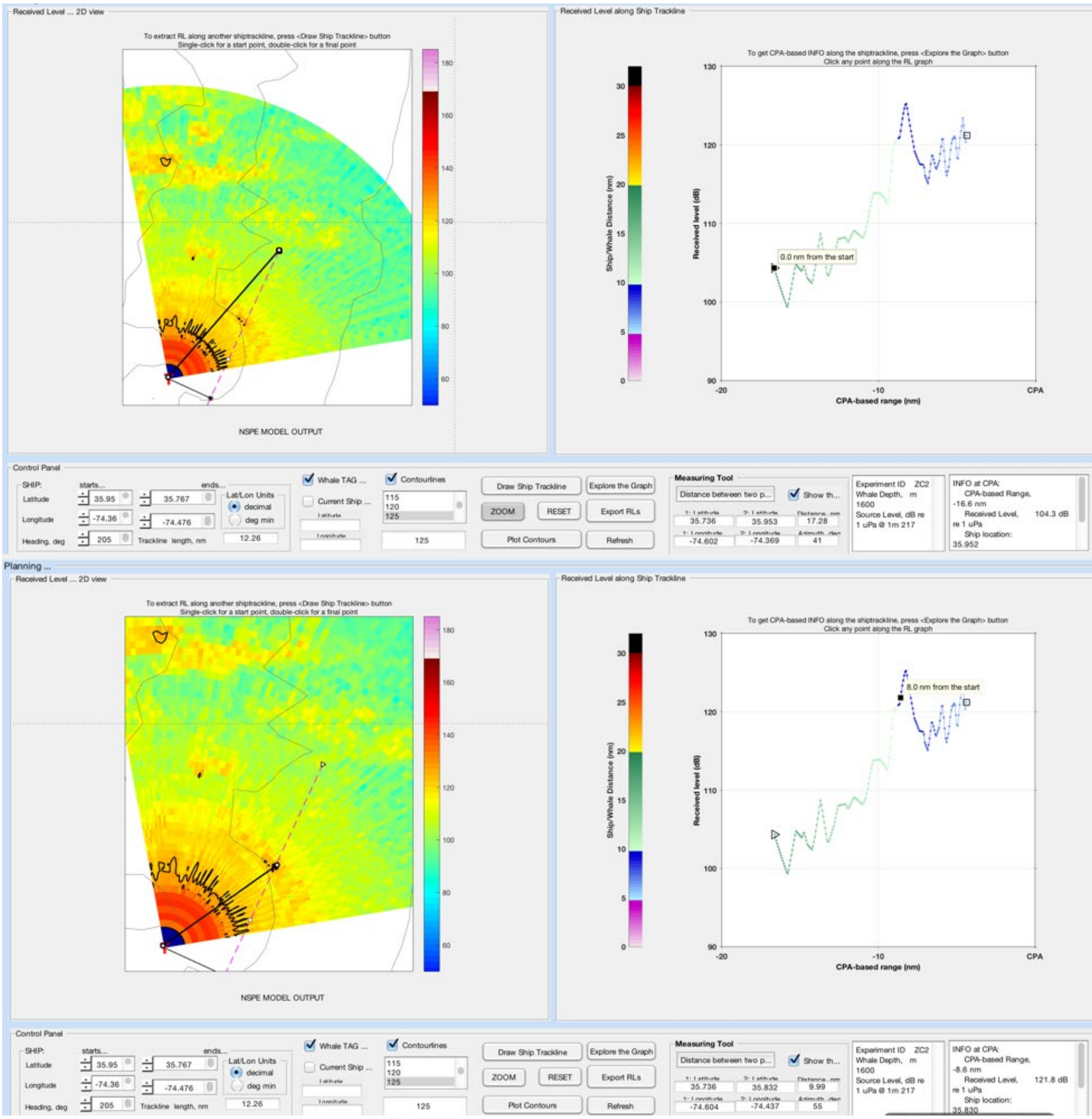

Figure 16. RL model prediction at 1,600-meter depth (model run 08 from Table 4) for focal whale Zc137 ahead of Atlantic-BRS CEE #2023_01 for the start (top; vessel-animal range: 17.3 nm; modeled RL = 104.3 dB) and end (top; vessel-animal range: 10.0 nm; modeled RL = 121.8 dB) of the modeled vessel track.

Table 5. Metadata summary for Atlantic-BRS (CONTROL) CEE #2023_01.

CEE # 2023_01	
Date:	**04 August 2023**
Type:	**CONTROL** (no MFAS)
Signal parameters:	*n/a* Positioned *R/V Shearwater* as done during simulated source CEEs for pre, exposure, and post-exposure phase.
Start time (UTC):	13:37
Start lat/lon (source):	35.7021; -74.7129
End time (UTC):	14:17 (30 min exposure duration matched to simulated PAS MFAS)
End lat/lon (source):	35.7197; -74.7129
Beaked whales tagged during CEE:	(n=4) – **ZcTag137, 138** (focal sat tag animals); Non-focal whales: ZcTag136, 139
Estimated Range (start CEE):	2 km (1.2 nm) @ start
Modeled Max RL:	*n/a* since no MFAS transmission

CEE #2023_01 - Narrative Summary
Following the mechanical issue with the USS CHURCHILL ahead of the planned CAS MFAS CEE, and given that field teams and multiple tagged beaked whales were in place, a control CEE was conducted adaptively. Two tagged focal whales (ZcTag 137 and ZcTag 138) were being tracked from both research vessels in the same area. Two non-focal whales (ZcTag 136 and ZcTag 139) were also reporting tag data but not being tracked in the vicinity of the CEE location. The *R/V Shearwater* served as the mock CEE location and was positioned accordingly using RL modeling estimates used in previous MFAS controls matching PAS CEE parameters and durations. It was positioned approximately 2 km from the final confirmed location of ZcTag 138 accordingly and was floating and stationary with a mock sound source deployed for the 30-min duration of the control CEE. Both focal animals were observed by the *R/V Barber* 1.5-2h following the CEE.

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

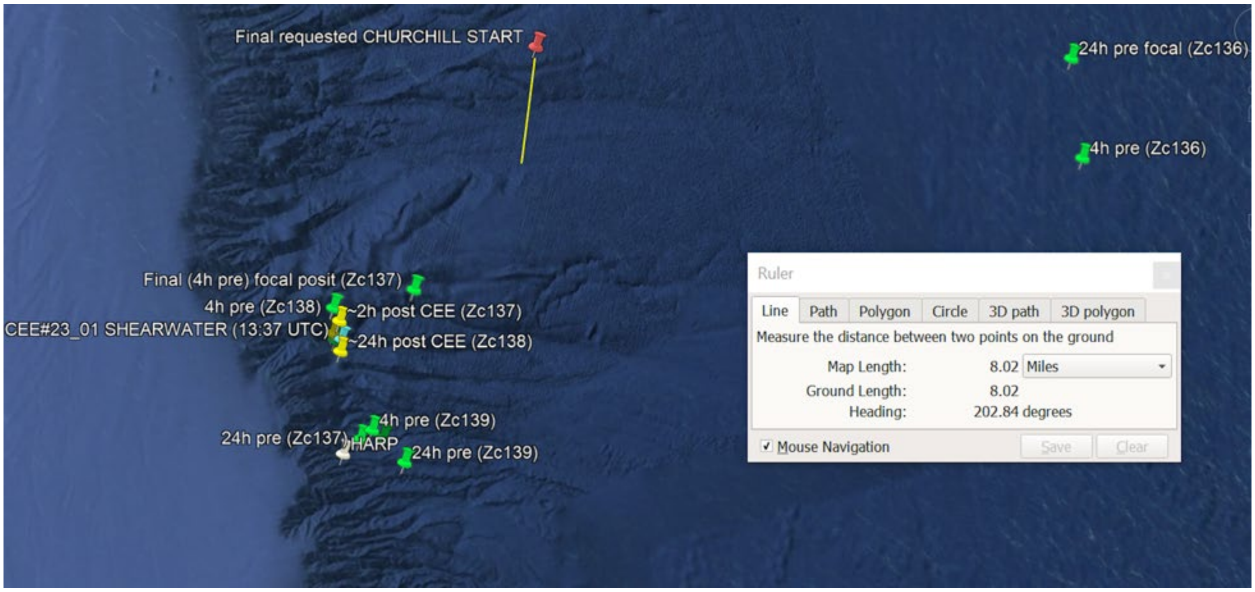

Figure 17. Broad view of focal whales (Zc137, Zc138) and other tagged beaked whales (Zcs136 and 139) before (green pins) and following (yellow pins) control CEE #2023_01. The requested start location (red pin) and track (yellow line) for the *USS Winston S. Churchill* for the planned CAS CEE is shown, as well as the start location of the *R/V Shearwater* (blue pin) from which the control CEE was conducted.

Figure 18. Zoomed view of focal whales (Zc137, Zc138) before (green pins) and following (yellow pins) control CEE #2023_01 relative to the start location of the *R/V Shearwater* (blue pin) from which the control CEE was conducted.

Dive plots for focal (**Figures 19** and **20**) and non-focal (**Figures 21** and **22**) whales for which satellite-transmitting tags were reporting dive data during CEE #2023_01 are given in a standard format. Time (in Greenwich Mean Time, which is +4 hours from Eastern Daylight Time during CEE periods) is indicated on the x-axis, with depth indicated on the y-axis. Simulated CEE periods are indicated as pink bars. These figures show 24-hour periods occurring before and after CEE #2023_01, which was 1 hour in duration.

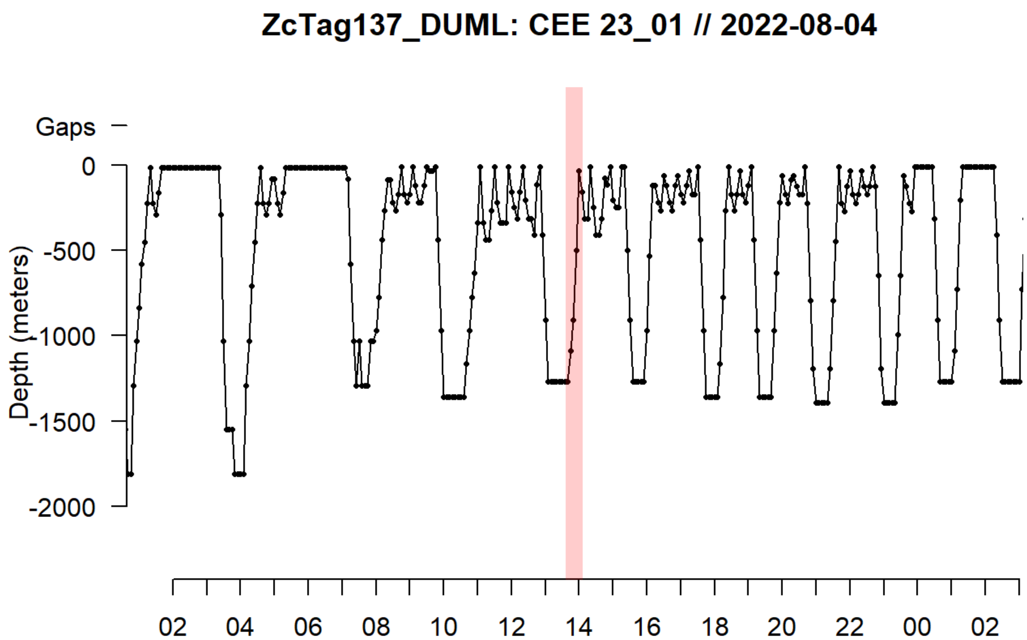

Figure 19. Available dive data for focal whale ZcTag137_DUML before, during, and after Atlantic-BRS CEE #2023_01 (pink shading denotes duration CEE mock exposure period).

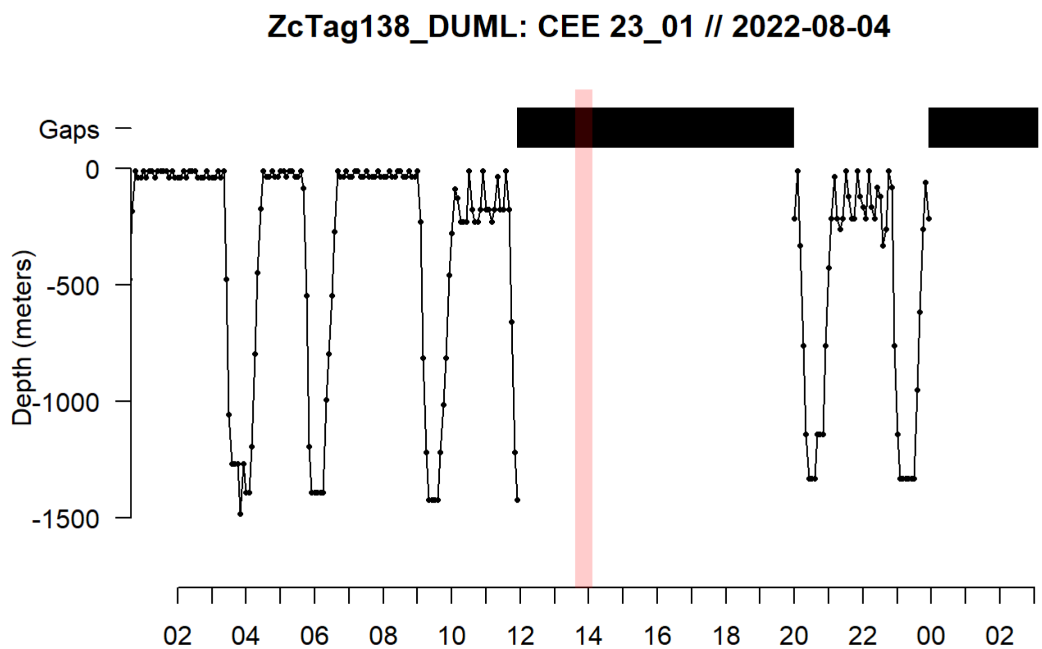

Figure 20. Available dive data for focal whale ZcTag138_DUML before, during, and after Atlantic-BRS CEE #2023_01 (pink shading denotes duration CEE mock exposure period).

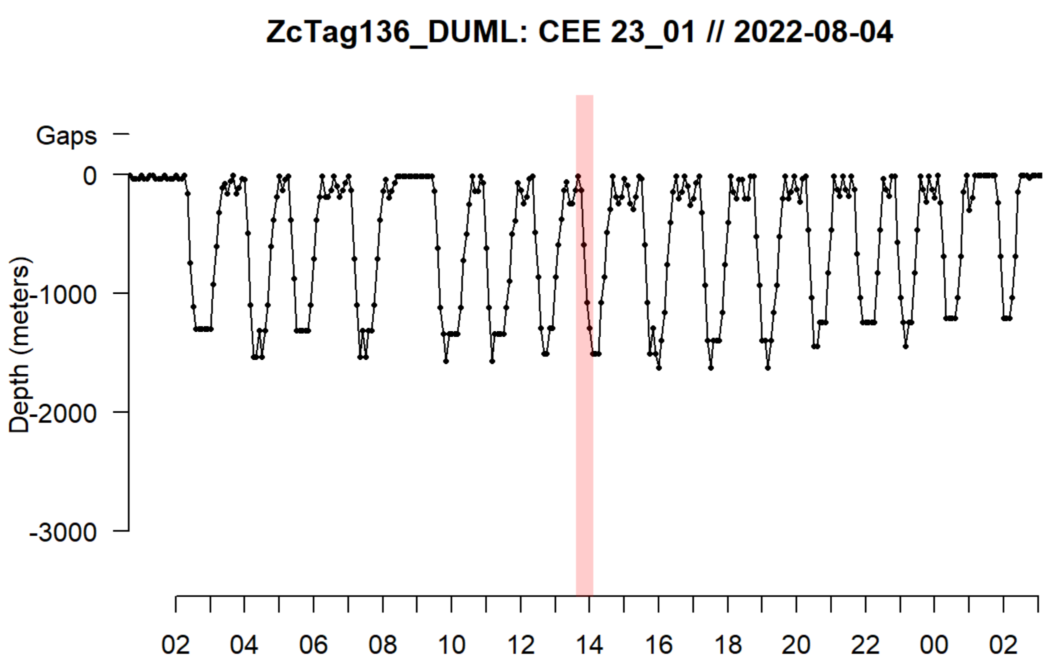

Figure 21. Available dive data for non-focal whale ZcTag136_DUML before, during, and after Atlantic-BRS CEE #2023_01 (pink shading denotes duration CEE mock exposure period).

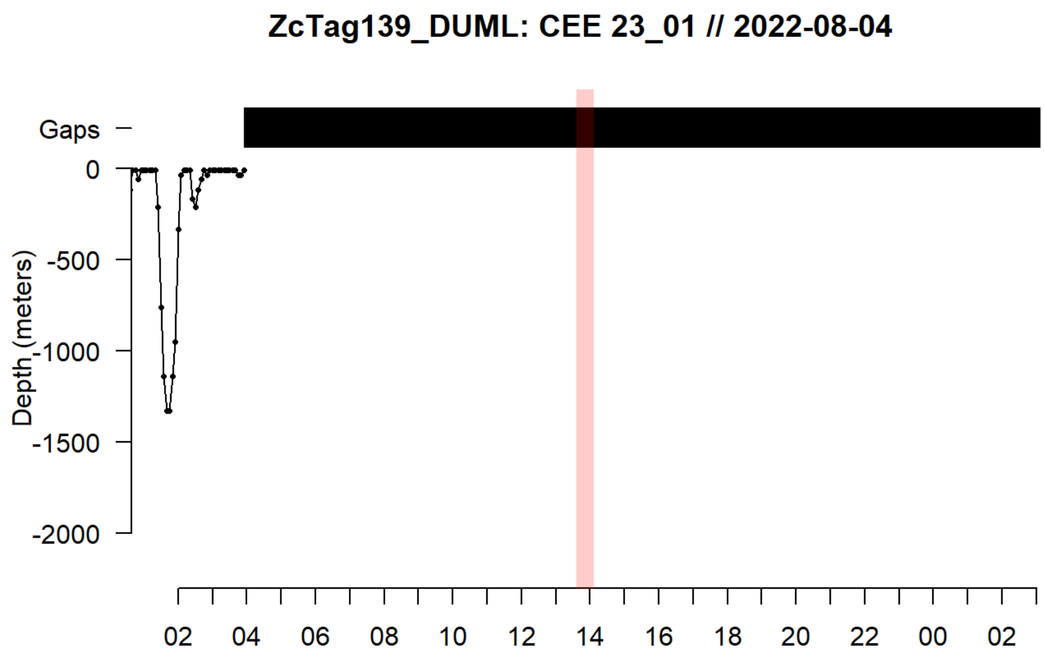

Figure 22. Available dive data for non-focal whale ZcTag139_DUML before, during, and after Atlantic-BRS CEE #2023_01 (pink shading denotes duration CEE mock exposure period).

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 that continue to be applied in the presentation and publication of results.

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

Table 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	Time-discretization approximation enriches continuous-time discrete-space models for animal movement	Hewitt (Duke) [Double Mocha]	Published
Methodology – technology	Varying-Coefficient Stochastic Differential Equations with Applications in Ecology	Michelot (St. Andrews) [Double Mocha]	Published
Methodology – technology	Kernel density estimation of conditional distributions to detect responses in satellite tag data	Hewitt (Duke) [Double Mocha]	Published

Category	Nominal Title/Subject	Lead Author (Institution)	Status
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
Methodology – technology	Estimating RLs and horizontal avoidance with dynamic covariates in exposed animals	Schick (Duke)	Final preparation (submit February 2024)
CEE exposure-response	Behavioral responses of Cuvier's beaked whales to simulated mid-frequency active military sonar off Cape Hatteras, NC	Southall (SEA)	Final preparation (submit March 2024)
Baseline behavior	Shallow night intervals in *Ziphius cavirostris*	Cioffi (Duke)	In preparation
Baseline behavior	Possible orientation behavior in Ziphius	Quick (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

4. Evaluation of FastGPS-enabled satellite-transmitting tag deployments

The following is a systematic evaluation of results, outcomes, and recommendations related to the strategic deployment of additional FastGPS-enabled satellite-transmitting tags during the Atlantic-BRS 2023 field effort. This was identified as a priority objective for the 2023 season by Southall et al. (2023), which was addressed directly with the results and evaluation provided here in detail.

4.1 Background

In 2023, the team deployed four SPLASH10-F-333 FastGPS enabled tags to assess their utility for the Atlantic-BRS in simultaneously collecting high-resolution dive and position data on beaked whales. One tag was also deployed in 2018, which was programmed to only collect and transmit FastGPS positions and no dive data.

Two main aspects of the Atlantic-BRS could be enhanced by the increased accuracy of FastGPS compared to ARGOS alone. The first is in the estimate of RLs on exposed animals when no acoustic recorder is present on or near the animal, since one of the sources of error in this estimation is the positional uncertainty of the animal. Since RL is a key covariate to understanding probability and nature of response to sound sources and can vary substantially in the Atlantic-BRS habitat over a short distance due to the high variance in depths, increased accuracy and precision could be a key benefit of FastGPS. The second area of interest is in the analysis of horizontal displacement and whether the addition of FastGPS positions to track estimation for an animal can aid in the detection of shorter term or finer scale horizontal responses to sound sources.

FastGPS positions may be beneficial on their own if high quality fixes occur during or very close to the time of experimental treatments (sound exposures), but they may also increase the overall accuracy and precision of a modeled animal track when used in concert with the more numerous ARGOS fixes. There are, however, some drawbacks to these tags. The tag is essentially composed of two separate radio components: A GPS radio, which receives information from the satellite that can be later used to estimate FastGPS positions; and an ARGOS radio, which transmits data, including the GPS data to the ARGOS system (or a shipboard receiver) where it can be decoded. Therefore, FastGPS positional data consumes bandwidth out of the project's data transmission budget, which is shared with dive data. A single FastGPS position requires an entire data message, which is equivalent to 48 time-series depth points (4 hours if recording data in a 5-minute sampling period). Therefore, if the team attempts to generate hourly FastGPS positions, the project's data queue for FastGPS quickly surpasses the daily bandwidth requirements for its dive data. Even if the team forgoes all other data streams, including dive data, it is unlikely that the team would be able to densely sample the movement of an instrumented animal during the time scale of a single treatment event that lasts from 30 minutes to 1 hour, plus a post treatment window ranging from 24 to 72 hours past the conclusion of exposure in CEEs. These limitations suggest that the main benefit from FastGPS would be to supplement ARGOS positions in a movement model to produce higher accuracy and precision of tracks.

This report presents a preliminary overview of the FastGPS tag performance on beaked whales, with attention to transmission and reception characteristics to study bandwidth requirements in a real-world scenario, with attention to the accuracy and precision of movement modeled tracks. The main questions for the application of FastGPS data to the Atlantic-BRS for the Atlantic-BRS were:

1. Can SPLASH10-F programming be tuned to produce a satisfactory continuous dive data record along with FastGPS positions?
2. Is the number of FastGPS positions received by this tuning sufficient to increase precision and accuracy in modeled animal positions at a relevant spatial and temporal scale to the team's treatments?

4.2 Programming

As mentioned above, the team used two tag programming configurations for this study: (1) a FastGPS-only (no dive data) configuration deployed in 2018 as an initial test of FastGPS performance on beaked whales, and (2) a FastGPS and depth time-series configuration (see **Table 7** for details). The FastGPS-only configuration attempted a FastGPS position every 0.5 hour, allowing for 96 total attempts per day, including failures, and kept FastGPS data in the ARGOS data transmission buffer for 2 days. The FastGPS and depth time-series configuration attempted FastGPS fixes at a maximum of once per hour, with a 2-hour-on, 2-hour-off duty cycle and maximum total attempts of 40 per day, including failures. All FastGPS and time-series data were kept in a 100-day buffer (longer than our expected deployment life) and tags ceased collecting FastGPS and time-series data after 21 and 14 days respectively in order to transition to transmit-only configuration to catch up on the data backlog (see Cioffi et al. 2023).

Table 7. Salient programming parameters for FastGPS tag configurations.

FastGPS only (n=1)	FastGPS and depth time-series (n=4)
FastGPS: • 2/hour max **successful** FastGPS attempts • 4/hour max **failed** FastGPS attempts • 96/day overall max FastGPS attempts • 0–23 FastGPS attempt hours • Unlimited collection period	**FastGPS:** • 1/hour max **successful** FastGPS attempts • 4/hour max **failed** FastGPS attempts • 40/day overall max FastGPS attempts • 0–23 FastGPS attempt hours • 3–4, 9–10, 15–16, and 21–22 Fastloc® GPS attempt hours
ARGOS transmission: • 470 daily transmissions • 24 hours initial transmission, then 0–3 and 7–23 transmission hours	**ARGOS transmission:** • 470 daily transmissions • 24 hours initial transmission, then 0–3, 8–11, and 12–23 transmission hours
—	**Time-series:** • Depth • 5-minute sampling period • 14-day collection period
Buffer and transmission priority: • 2-day data buffer • High-priority FastGPS	**Buffer and transmission priority:** • 100-day data buffer • High-priority time-series and FastGPS

Key: max = maximum

4.3 Deployments

Five total animals have been instrumented with FastGPS tags during the overall Atlantic-BRS project: ZcTag077_DUML, ZcTag143_DUML, ZcTag144_DUML, ZcTag145_DUML, ZcTag146_DUML, the last four of which were tagged during the 2023 field effort. All but ZcTag145_DUML and ZcTag146_DUML were attached to adult males. ZcTag146_DUML was attached to a male of unknown age, and ZcTag145_DUML was attached to an animal of unknown sex and age but likely not an adult male. Two of the animals had been previously tagged: ZcTag077_DUML was attached to an animal that had also been tagged with ZcTag039; and ZcTag143_DUML was attached to animal that had also been tagged with ZcTag102_DUML, but the previous tags had both fallen off prior to the most recent tagging.

ZcTag077_DUML, ZcTag143_DUML, and ZcTag144_DUML were all attached at or just below the base of the dorsal fin; ZcTag145_DUML was attached below the dorsal fin; and ZcTag146_DUML was attached in the center of the dorsal fin.

4.4 Location Throughput Assessment

The quantity of FastGPS, and the quantity and quality of ARGOS positions received are summarized below (**Table 8)**. The number of satellites tracked per FastGPS position is reported in **Table 9**. Note that while this study reports the number of satellites tracked as a quality proxy for FastGPS, this metric does not predict positional uncertainty directly in all cases. Additionally, note that while this study uses “received” as shorthand, ARGOS positions are calculated from multiple radio transmissions from tag to satellite in a single overhead pass. FastGPS positions are estimated after data reception on the ARGOS network from information collected on GPS satellites overhead by the tag and databases of known satellite movements. ZcTag077_DUML, which was programmed to produce the greatest number of FastGPS positions, successfully transmitted 179 FastGPS positions over 23.7 days (approximately 7.6 positions per day). The four tags transmitting both time-series and FastGPS data did not perform as well, successfully transmitting only an average of 0.6 to 3.9 FastGPS positions per day. The worst performer was ZcTag145_DUML, which also had the lowest deployment, which likely lead to lower average times when the radio could be active in air and higher rates of interrupted radio receptions or transmissions as the animal submerged. This tag also had a short deployment of only approximately 5.2 days. Given the location of the tag, it is possible that the device was shed quickly. This animal will be a high priority for follow up during the next field effort to ascertain the condition of the tag deployment location on the body.

Table 8. ARGOS and FastGPS position counts from FastGPS tags.

ZcTag077_DUML			**ARGOS Days**		**23.7**	**FastGPS Days**		**23.7**
Quality	3	2	1	0	A	B	Z	FastGPS
Count	1	3	9	55	28	92	0	179
Per day	0	0.1	0.4	2.3	1.2	3.9	0	7.6
ZcTag143_DUML			**ARGOS Days**		**67.3**	**FastGPS Days**		**21**
Quality	3	2	1	0	A	B	Z	FastGPS
Count	1	19	68	231	118	328	2	81
Per day	0	0.3	1	3.4	1.8	4.8	0	3.9
ZcTag144_DUML			**ARGOS Days**		**37.9**	**FastGPS Days**		**21**
Quality	3	2	1	0	A	B	Z	FastGPS
Count	1	6	21	83	71	217	0	47
Per day	0	0.2	0.6	2.2	1.9	5.7	0	2.2
ZcTag145_DUML			**ARGOS Days**		**5.2**	**FastGPS Days**		**5.2**
Quality	3	2	1	0	A	B	Z	FastGPS

ZcTag077_DUML			ARGOS Days		23.7	FastGPS Days		23.7
Count	0	2	2	20	8	35	0	3
Per day	0	0.4	0.4	3.8	1.5	6.7	0	0.6
ZcTag146_DUML			**ARGOS Days**		**68.8**	**FastGPS Days**		**21**
Quality	3	2	1	0	A	B	Z	FastGPS
Count	10	33	113	363	117	307	0	65
Per day	0.1	0.5	1.6	5.3	1.7	4.5	0	3.1

Table 9. FastGPS position counts relative to satellites tracked.

Tag ID	Satellites Tracked				
	4	5	6	7	8
ZcTag077_DUML	77	51	36	13	5
ZcTag143_DUML	50	22	8	2	0
ZcTag144_DUML	42	15	0	0	0
ZcTag145_DUML	1	1	1	0	0
ZcTag146_DUML	48	9	9	0	0

Key: ID = Identification Number

4.5 Transmission and Reception Assessment

The study used the “status,” “corrupt,” and “all” data streams to assess the rate of transmission and reception of ARGOS messages. Receptions are straightforward to calculate because they can be counted directly from how many ARGOS transmissions are received on a satellite, but transmissions are more difficult since the current tag count of total transmissions must be uplinked as data itself in the status messages.

The team calculated transmissions per day, as the difference in total reported transmissions between subsequent status messages were at least 12 hours apart. Note that since transmission is duty cycled unevenly throughout the day to align with satellite coverage or boat presence, there may be some variation in these estimates. Only status messages that passed a cyclic redundancy check were included. Therefore, only 3 of the 5 tags transmitted enough data accurately to estimate daily transmit rate, which ranged from 300 to 312 transmissions per day on ARGOS. This is well below the study’s daily cap of 470, suggesting that satellite availability and animal behavior together limit the team’s ability to transmit more data, rather than, for example, battery capacity.

Receptions per day ranged from 22.5 to 57, which represents 8 to 20 percent of transmissions to receptions. In other words, each message must be sent approximately 5 to 10 times to be received on satellite for this cohort of tags. Data received on satellite that is correctly attributed to a specific tag can still be corrupted and therefore unusable (**Figure 23**). These receptions are still helpful in estimating ARGOS position, but do not produce FastGPS or dive information. As expected, the poorest overall performing tag, ZcTag145_DUML, had the highest rate of corrupt message reception accumulation, likely due to the low placement on the ARGOS antenna on the animal's body leading to interrupted transmissions.

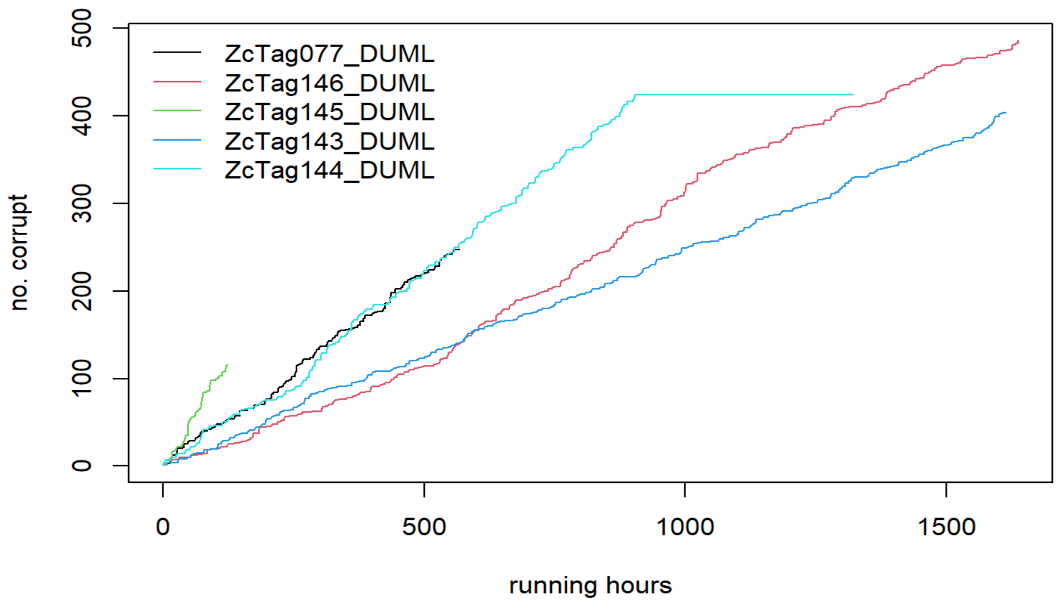

Figure 23. Accumulation of corrupt message receptions on the ARGOS system for FastGPS tags

Figures 24 through **28** show the daily accumulation of successful FastGPS fixes and failures. These can be compared relative to the total numbers of FastGPS fixes successfully transmitted to satellite in **Table 2**. For the most part, the accumulation of FastGPS successes (fixes) and failures is linear, but ZcTag077_DUML shows an increase in failures over the course of deployment for an unknown reason. ZcTag143_DUML also appears to have suffered a bug in which the number of fixes was incorrectly incremented by a very large amount approximately 5 days into deployment, so limited conclusions can be made about the data for this tag. ZcTag077_DUML was set to allow up to 96 total FastGPS fix attempts per day, but only approximately 38.1 fixes per day were attempted on average. This number initially informed the team's choice to limit total FastGPS attempts per day to 40 for the subsequent 4 tags. This also demonstrates that the GPS radio is bandwidth-limited similarly to ARGOS, although it is not clear whether this is due to the animal's behavior only or also satellite availability and/or time it takes to acquire a fix. Of the 4 tags programmed to attempt up to 40 fixes per day, the team could calculate average fixes per day for 2 tags, which were 19.3 and 17.7 for ZcTag144_DUML and ZcTag146_DUML, respectively. ZcTag077_DUML produced on average 1.5 successful fixes for every failed fix; this ratio was similar for ZcTag144_DUML (1.5) and ZcTag146_DUML (1.3) even though the overall number of fixes was fewer for the latter tags. For ZcTag077_DUML, 33.9 percent of (successful) FastGPS fixes uplinked to the satellite, which was also relatively similar for ZcTag144_DUML (21.4 percent) and ZcTag146_DUML (32.2 percent).

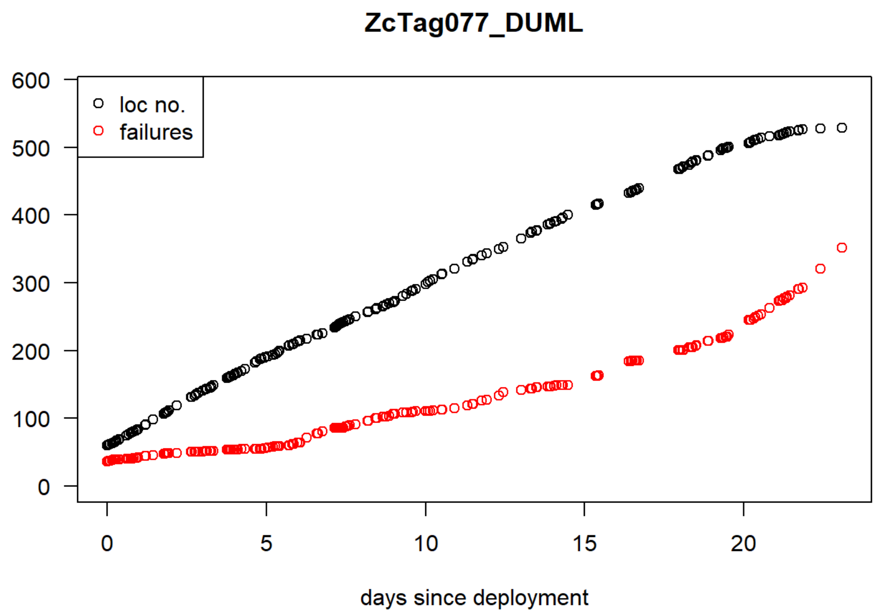

Figure 24. FastGPS successful fixes (black circles) and failures (red circles) over deployment duration in which FastGPS data collection was active for ZcTag077_DUML.

Figure 25. FastGPS successful fixes (black circles) and failures (red circles) over deployment duration in which FastGPS data collection was active for ZcTag143_DUML.

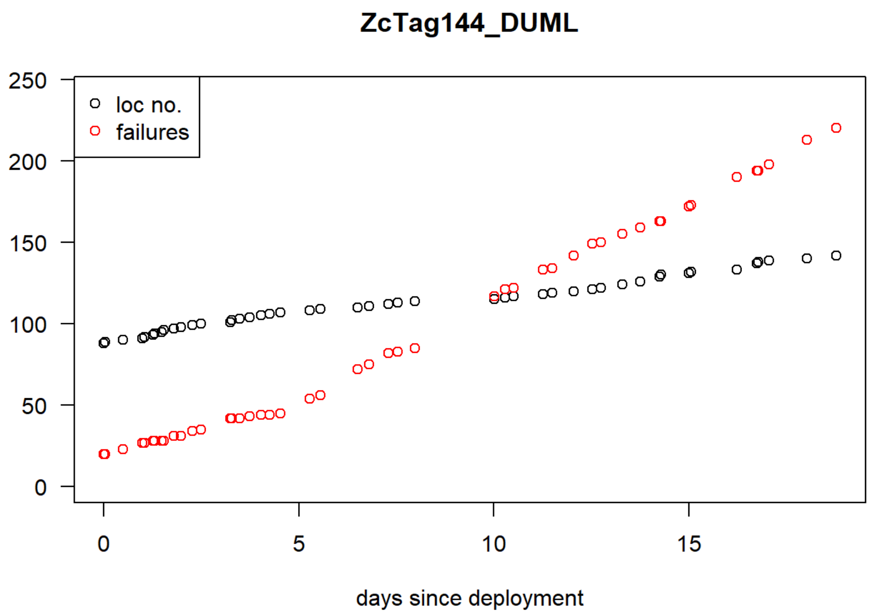

Figure 26. FastGPS successful fixes (black circles) and failures (red circles) over deployment duration in which FastGPS data collection was active for ZcTag144_DUML.

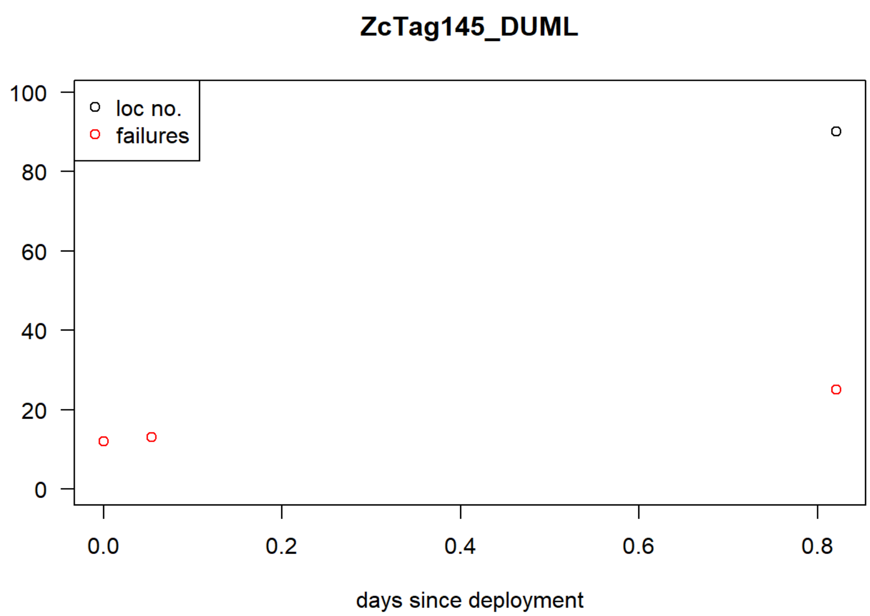

Figure 27. FastGPS successful fixes (black circles) and failures (red circles) over deployment duration in which FastGPS data collection was active for ZcTag145_DUML.

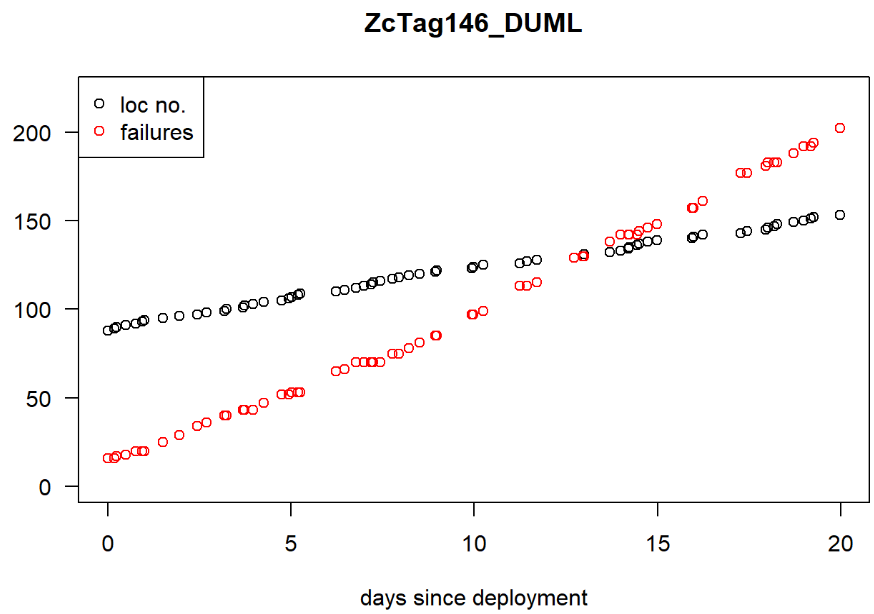

Figure 28. FastGPS successful fixes (black circles) and failures (red circles) over deployment duration in which FastGPS data collection was active for ZcTag146_DUML.

4.6 Time-series Data Quality and Continuity

The team assessed the ability of its programming scheme to produce continuous stretches of time-series depth data that would be suitable for studying dive behavior responses to experimental stimuluses. Two of the four tags programmed to collect time-series data, ZcTag143_DUML (1 data gap) and ZcTag146_DUML (no data gaps), produced suitable data. ZcTag144_DUML produced some data but was plagued with data gaps, and ZcTag145_DUML did not produce a meaningful amount of dive data (**Figures 29** through **33**). These differences were, in part, due to the height of the antenna on the animal. These two best performing tags also produced the fewest corrupt messages (**Figure 34**). Additionally, these were the longest duration tag deployments, giving enough time for data transmission to catch up with the queue of messages.

The team assessed pressure transducer abnormalities if there were two status messages reporting a zero depth greater than +/-10 meters. In this case, the team marked the last good status message as a depth data reliability cut off. Two tags showed pressure transducer abnormalities: ZcTag143_DUML, and ZcTag146_DUML. ZcTag143_DUML shows a pattern that the team interprets as runaway drift; although ZcTag146_DUML showed drift flagged as unacceptably large, it did appear to later recover. The team observed this pattern previously, although the exact cause is unknown. Both of these animals dived past the 2,000-meter rating of the tag on occasion, but not past the 3,000-meter overpressure rating of the transducers, perhaps indicating that repeated dives near or just over the tag rating can lead to casing failure, which could damage the transducer, although the exact failure modes remain unknown.

ZcTag146_DUML, which had a deployment length over 68 days, showed a voltage drop consistent with a drained battery, although a similar voltage drop was not registered on ZcTag143_DUML, which had a very similar deployment duration. Nevertheless, the team can cautiously assess 68 days as a lower bound for maximum battery life for this configuration and programming on beaked whales within the study site.

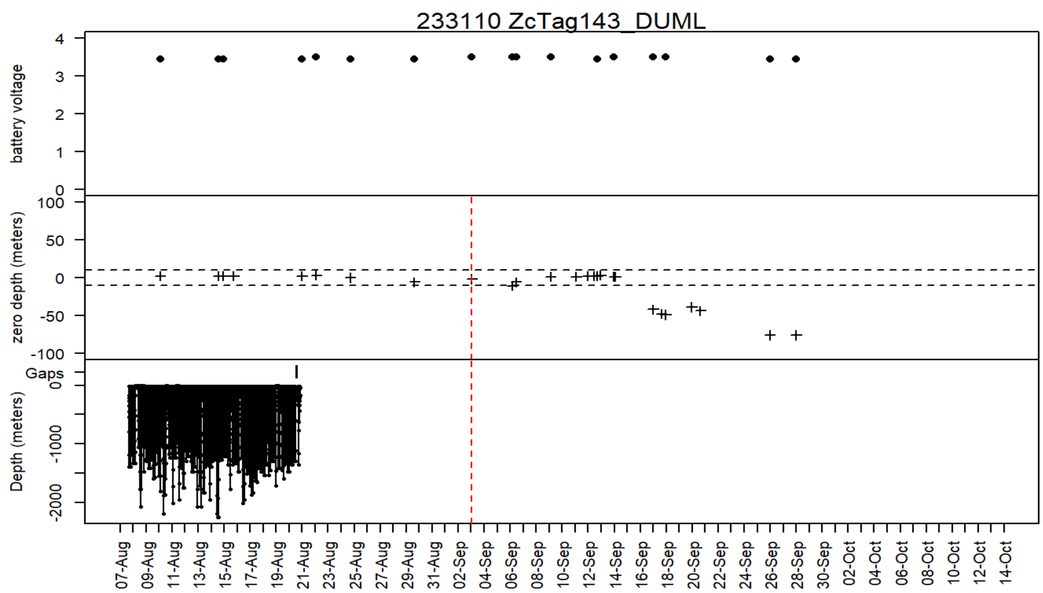

Figure 29. Battery voltage, zero depth measured at the surface by the pressure transducer, and dive data from the time-series data stream (gaps indicated as black bars above plot) for ZcTag143_DUML. Dotted red line indicates a conservative reliable dive data cut off after pressure transducer abnormalities.

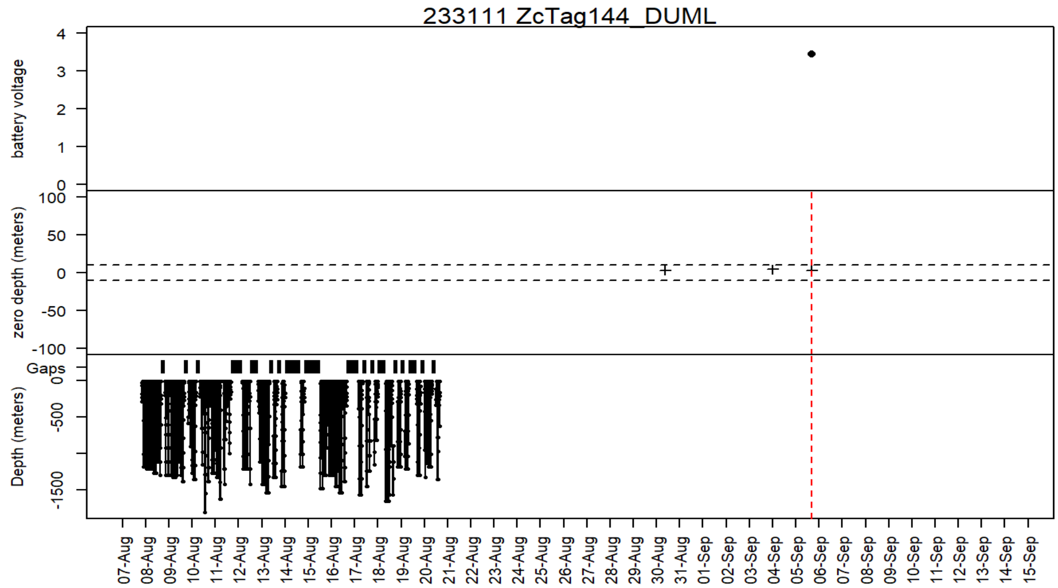

Figure 30. Battery voltage, zero depth measured at the surface by the pressure transducer, and dive data from the time-series data stream (gaps indicated as black bars above plot) for ZcTag144_DUML. Dotted red line indicates a conservative reliable dive data cut off after pressure transducer abnormalities.

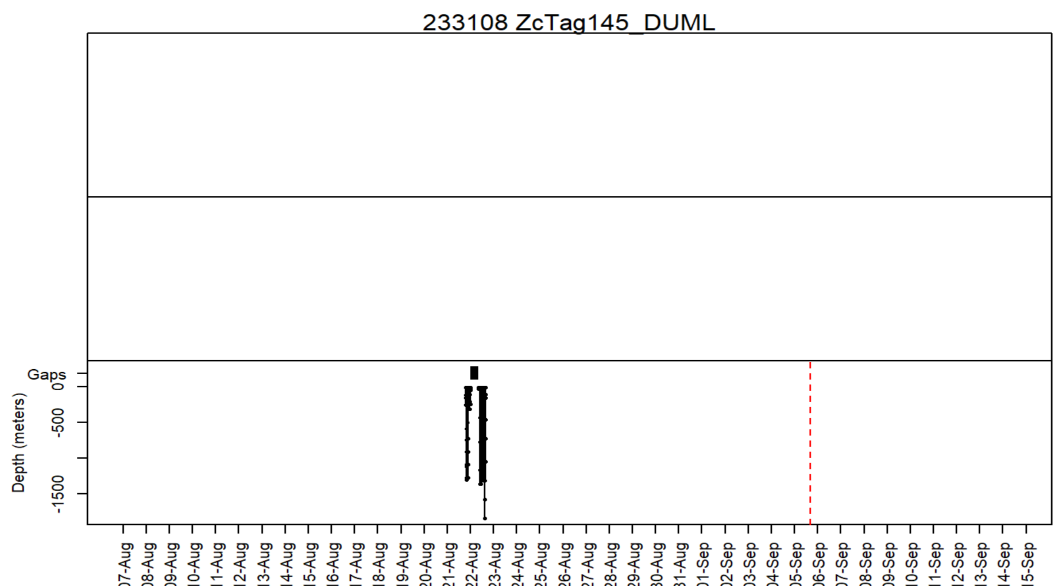

Figure 31. Battery voltage, zero depth measured at the surface by the pressure transducer, and dive data from the time-series data stream (gaps indicated as black bars above plot) for ZcTag145_DUML. Dotted red line indicates a conservative reliable dive data cut off after pressure transducer abnormalities.

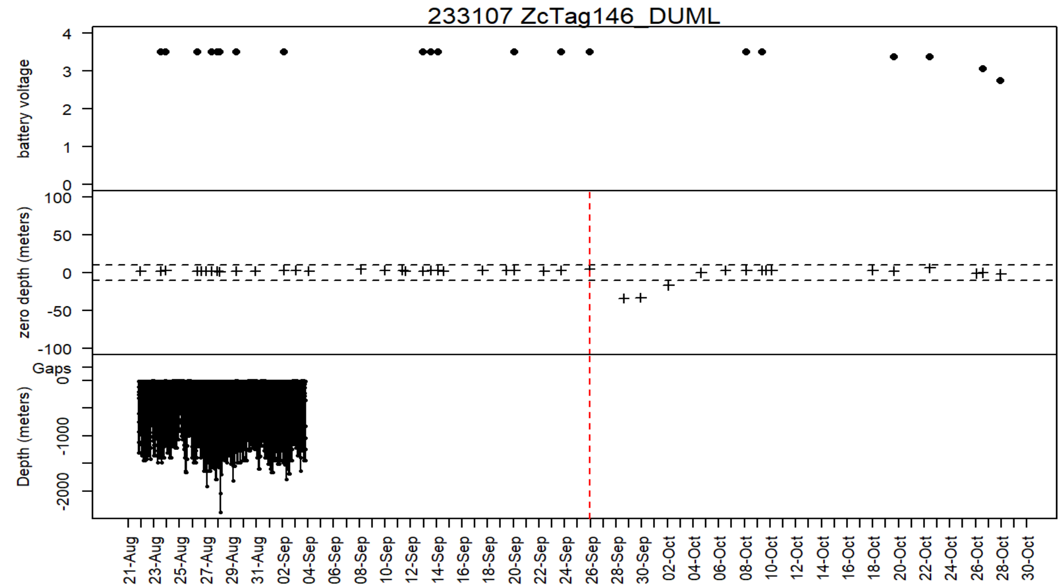

Figure 32. Battery voltage, zero depth measured at the surface by the pressure transducer, and dive data from the time-series data stream (gaps indicated as black bars above plot) for ZcTag146_DUML. Dotted red line indicates a conservative reliable dive data cut off after pressure transducer abnormalities.

4.7 Assessment of Accuracy and Precision in Modeled Tracks

To assess if the number of FastGPS positions improve accuracy and/or precision in movement modeled tracks, the team fit models using aniMotum, a tool for fitting continuous time state-space models specifically tailored to ARGOS and with support for FastGPS data (Jonsen et al. 2020, 2022, 2023). The team used the following filtering steps for all models. Raw positions were filtered with a bounding box around the study area (-80, 30, -70, 40), and any points on land or inside the outer banks of North Carolina were removed. ARGOS location quality Z positions were removed. Positions automatically flagged as suspect in the comments field of the locations data stream for large deviations from mean longitude, latitude, or median speed were also removed. The team used the speed angle distance filter built into aniMotum with the following parameters: *vmax* = 10 KPH, *ang* = {15, 25} (degrees), *distlim* = {2500, 500} (meters). Models were fit using the correlated random walk routine in aniMotum.

The team fit three kinds of models: an ARGOS-only model, an ARGOS and FastGPS model, and a set of models that were ARGOS and FastGPS with a single FastGPS point hold out. To assess precision, the team compared the standard error on the fitted tracks between the ARGOS-only and ARGOS and FastGPS models. It was not possible to run these models on ZcTag145_DUML due to the paucity of positions.

To assess accuracy, the team used the ARGOS-only model and the ARGOS and the set of FastGPS models with 1 point held out. For these models, the team treated the FastGPS as truth data points and predicted back those positions to assess accuracy. While FastGPS can have errors, sometimes substantial, relative to ARGOS, the error is, on average, small enough that the team felt comfortable using these points as its truth data set. The team measured the distribution of distance (calculated with the haversine formula) from the truth FastGPS positions to the predicted position estimated from the model for both the ARGOS-only model and the set of 1 FastGPS position hold out models.

Standard error of the fitted positions decreased in almost all cases between the ARGOS-only and the ARGOS and FastGPS models (**Figures 33** through **36**). Decreases were most noticeable for ZcTag077_DUML. In one case, ZcTag146_DUML, the average standard error in the x direction actually increased with the addition of FastGPS points. The distribution of standard errors was still shifted left in this case, but there was a long right tail that produced the slightly higher average. Decrease in standard error was most dramatic for ZcTag077_DUML, with standard error in both x and y directions more than halved.

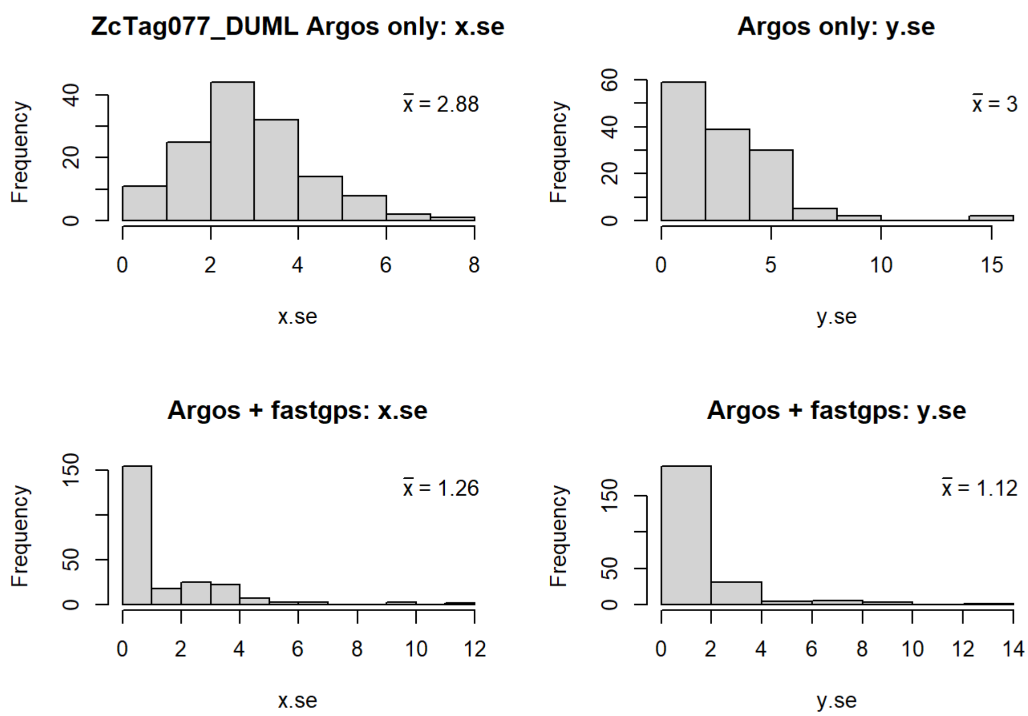

Figure 33. Standard error of the fitted positions (km) for ZcTag077_DUML in the ARGOS-only and ARGOS and FastGPS models.

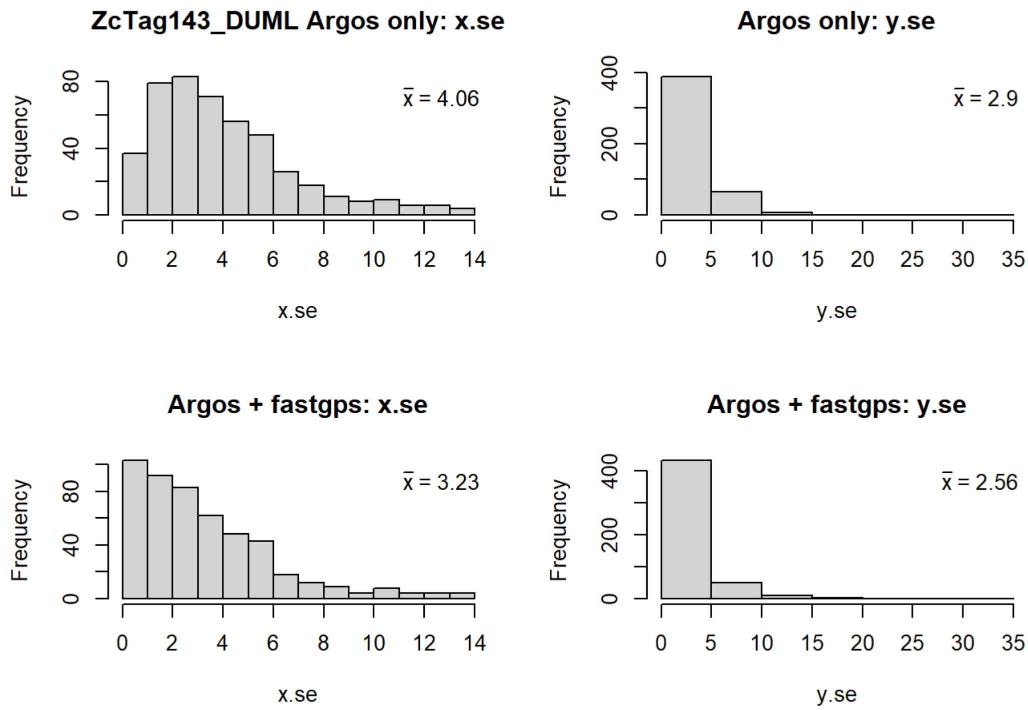

Figure 34. Standard error of the fitted positions (km) for ZcTag143_DUML in the ARGOS-only and ARGOS and FastGPS models.

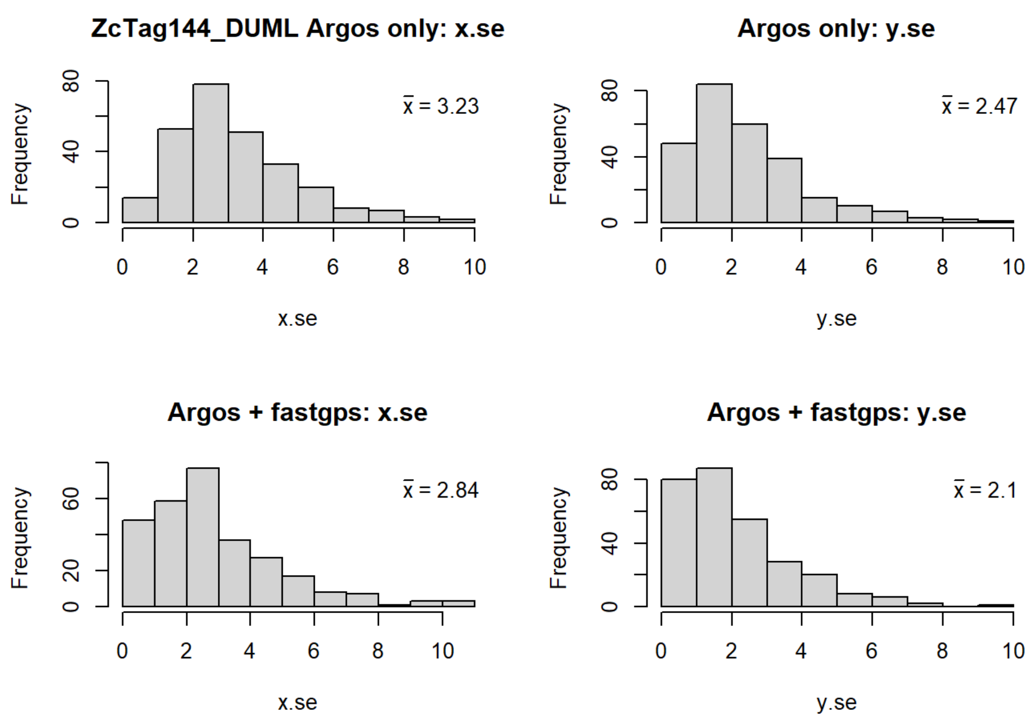

Figure 35. Standard error of the fitted positions (km) for ZcTag144_DUML in the ARGOS-only and ARGOS and FastGPS models.

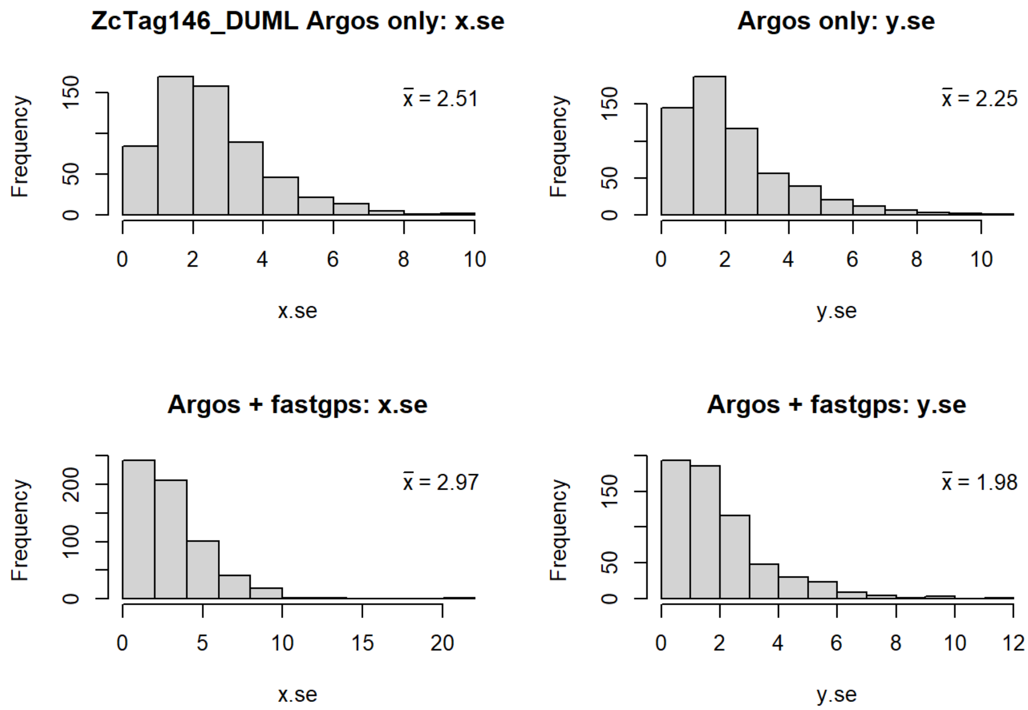

Figure 36. Standard error of the fitted positions (km) for ZcTag146_DUML in the ARGOS-only and ARGOS and FastGPS models.

The accuracy of the predicted points at known FastGPS positions also increased when FastGPS points were added to the movement model as represented by a decrease in mean distance from predicted and truth positions (**Figures 37** through **40**). Standard deviation of these distances also decreased in all but one case, ZcTag146_DUML. Similar to the standard error of the fitted positions, there was a long right tail. As with the standard error of fitted positions measurements above, the most dramatic decrease in distance was for ZcTag077_DUML, which was more than halved from an average of almost 8 to 2.7 kilometers (km). Decreases were more modest for other tags, ranging from 5.4- to 6.4-km average distance, representing decreases of approximately 0.7 to 4.3 km from the ARGOS-only model.

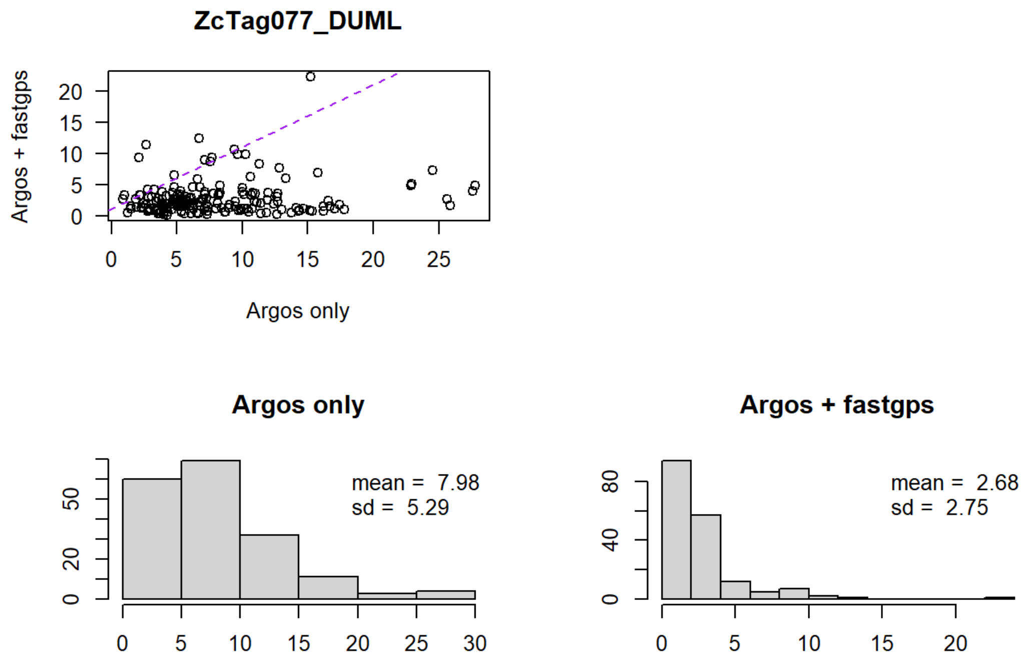

Figure 37. Comparison of predicted positions from the movement model at FastGPS positions for ZcTag077_DUML. Purple dotted line shows the 1:1 line.

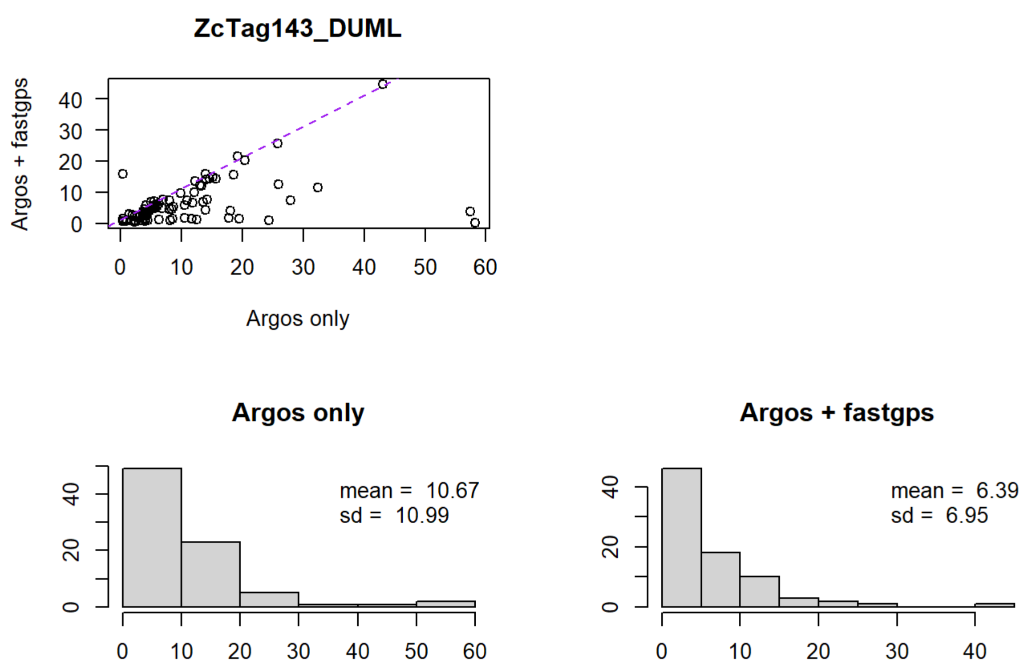

Figure 37. Comparison of predicted positions from the movement model at FastGPS positions for ZcTag143_DUML. Purple dotted line shows the 1:1 line.

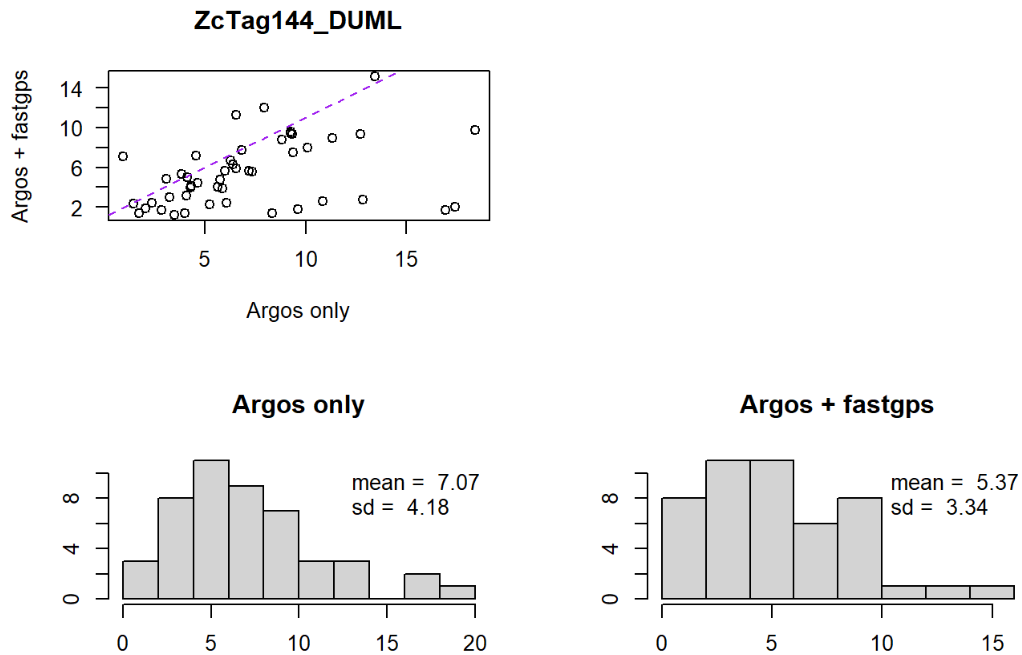

Figure 39. Comparison of predicted positions from the movement model at FastGPS positions for ZcTag144_DUML. Purple dotted line shows the 1:1 line.

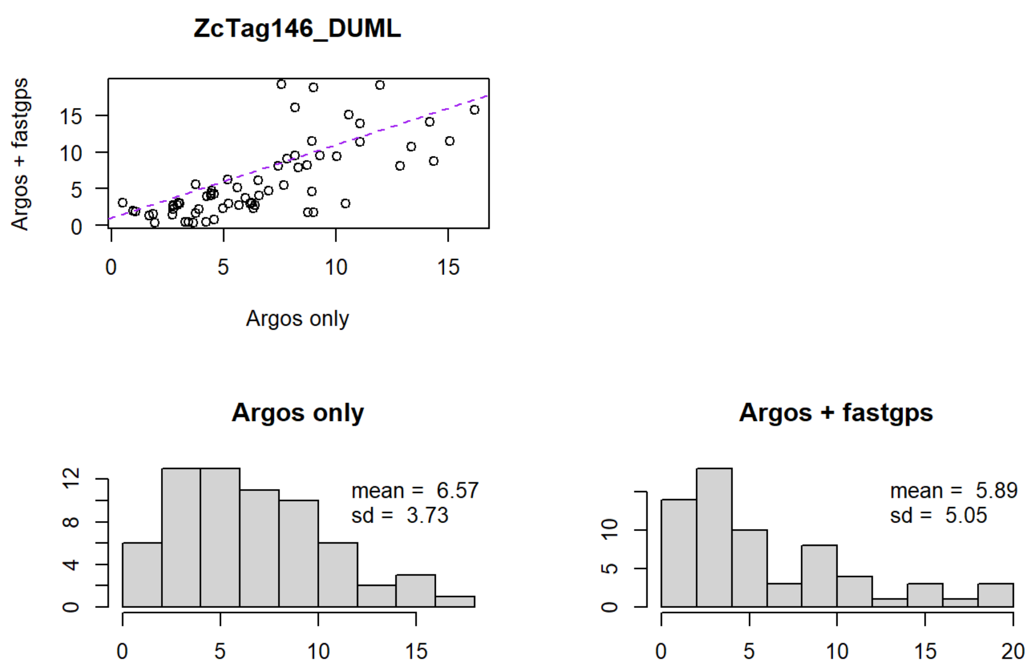

Figure 40. Comparison of predicted positions from the movement model at FastGPS positions for ZcTag145_DUML. Purple dotted line shows the 1:1 line.

4.8 Next Steps and Preliminary Recommendations

This study showed it is possible to collect at least 14 days of near continuous 5-minute time-series depth data simultaneously with several FastGPS positions per day. These FastGPS positions were sufficient to modestly decrease error and increase accuracy in fitted positions from a movement model. While these gains were relatively small (on the order of several kilometers), they may be important in modeling finer scale movement and yielding better RL estimates, which can vary substantially across small distances within the study site. The performance of these tags is sufficient to justify their continued use as a supplement to the study's existing tag configurations, though the team will continue to assess their utility in their impact on downstream analyses for the Atlantic-BRS, including RL estimation and horizontal avoidance detection (Schick et al., in prep.).

Given these pilot data, the programming can continue to be tuned to maximize the number of FastGPS positions received along with the duration and continuity of dive data. Field logistics during 2023 prevented the team from using a shipboard receiver to intercept messages directly from the tag, which has shown to increase message reception rates dramatically (Cioffi et al. 2023), but this can be subsequently implemented to further increase performance. Bandwidth limitation is an important issue for all of the study's tag configurations, especially for tags with FastGPS because of the additional data trying to be transmitted to satellite. An upcoming augmentation to the ARGOS satellite system may increase bandwidth by increasing the number of satellite passes for the study site.

5. Overall Assessment and Recommendations

5.1 General Assessment of Atlantic-BRS 2023 Accomplishments

- Field conditions proved challenging for the 2023 field season, particularly during the first month (June). This extends a longer-term pattern of fewer overall windows of ideal conditions, which require extended periods of adaptive effort to achieve research objectives.
- The 2023 field season had successful deployment of a large number (n=11) of tags on high-priority beaked whales and the collection of tens of thousands of hours of movement and diving behavior. Given this success, no secondary-priority pilot whales were tagged.
- Sat tag deployment settings were maintained as developed during earlier years, with very positive results. Many of the 2023 tags again achieved greater duration deployments for returning ARGOS position data as well as to up to 21 days of focused, high-resolution, continuous time-series dive data.
- The 2023 field season had dedicated and strategic deployment and evaluation of four FastGPS tags with a variety of associated outcomes and recommendations.
- The 2023 field season had successful coordination and adaptive planning with USFF colleagues in scheduling and coordinating with multiple CAS-capable vessels for coordination. Unfortunately, several candidate vessels became unavailable in the days leading up to CEEs, and the primary option, which was en route to the study area with multiple tagged whales in good configurations to meet research objectives, experienced an engineering casualty just hours prior to the scheduled CEE.
- Despite setbacks with Navy ship availability, the team successfully conducted a complete control CEE using the PAS MFAS simulated source criteria.
- The 2023 field season had sustained success and continued enhancement of approaches for receiving data from sat tags using goniometers. These approaches have proven essential in tracking and re-locating tagged individuals many times to obtain photographs and biopsy samples, and locate other individuals for tagging attempts. They have also been proven to increase data magnitude and precision in ways that are demonstrably important in improving animal movement modeling and RL estimation (Schick et al., in prep.).
- 2023 showed extensive progress in several publications in baseline behavior and methodological advances, and extensive effort in two forthcoming paper submissions for RL modeling (Schick et al., in prep.) and new behavioral response methods (Southall et al., in prep.).

5.2 Future Effort and Recommendations

- While efforts to coordinate with a CAS-capable ship in 2023 were regrettably unsuccessful given the poor timing of events described herein, it is important to note the continued success in coordination and planning as well as in terms of deploying many tags on the highest priority species with extensive additional baseline and control data obtained. The team believes all the right plans and preparation for success with CAS CEEs were in place and would recommend maintaining field planning and logistics in a similar manner. An experimental plan summarizing these approaches and status in planning will be provided at the March 2024 program review. Coordination with U.S. Navy vessels should be maintained using identical approaches as previous seasons through sustained and advance planning via USFF.
- The combination of advance deployment of sat tags in weeks to days ahead of CEEs and DTAG deployments and 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.
- Maintaining sat tag time series settings as has been optimized for the Atlantic-BRS field site and objectives is recommended following extensive evaluation and assessment (see: Cioffi et al. 2023). Further deployments of the FastGPS sat tags are also recommended for 2024 as a supplement to existing tag configurations.
- 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.

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