Behavioral Responses of Humpback Whales to Approaching Ships in Virginia Beach, Virginia: 2021 Annual Progress Report

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Cover Photo Credit:

Humpback whale (*Megaptera novaeangliae*) near the coast of Virginia Beach, VA. Photographed by Andrew Read, Duke University, taken under General Authorization 16185 held by Andrew Read, Duke University.

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Acronyms and Abbreviations

AIS	Automatic Identification System
dB	decibel
CBBT	Chesapeake Bay Bridge-Tunnel
DTAG	digital acoustic tag
GPS	Global Positioning System
hr	hour
kHz	kilohertz
km	kilometer
min	minute
R/V	research vessel
SLR	single-lens reflex
U.S.	United States

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1. Introduction

The western North Atlantic population of humpback whales is one of the most well-studied populations of baleen whales, with long-term photo-identification studies dating back to the early 1970s (Katona et al. 1979). These whales breed and give birth in the Caribbean in winter (Whitehead & Moore 1982) and little feeding occurs on the breeding grounds or on migration routes. They travel thousands of kilometers (up to 7,000 kilometers; Stevick et al. 1999) from breeding grounds to summer feeding areas that range from the Gulf of Maine to Norway. Individual whales return to distinct feeding grounds each summer in the Gulf of Maine, Gulf of St. Lawrence, Newfoundland, Greenland, Iceland, and Norway (Katona & Beard 1990; Stevick et al. 2003a, 2006). There is little exchange between feeding grounds and individuals show high site fidelity both within and between years (Clapham et al. 1993; Katona & Beard 1990; Stevick et al. 2006). However, individuals from all of the feeding grounds have been seen in the Caribbean breeding grounds (Stevick et al. 2003a).

These migratory patterns are the norm for most adults, but some humpback whales remain on feeding grounds during winter (Christensen et al. 1992; Whitehead 1987). Since the early 1990s, juvenile humpback whales have been documented feeding along the coasts of the mid-Atlantic states in winter and increasing numbers of animals are using this area during the colder months (Swingle et al. 1993, 2017; Wiley et al. 1995). Many of these humpbacks appeared to be young, sexually immature animals based on estimates of body length (Barco et al. 2002; Swingle et al. 1993; Wiley et al. 1995). Photo-identification efforts have been ongoing since the mid-1990s and a number of live and stranded animals in the mid-Atlantic have been matched to the Gulf of Maine feeding aggregation, along with a few matches to other summer feeding aggregations (Barco et al. 2002). Animals have been re-sighted in the mid-Atlantic area in multiple years (Aschettino et al. 2018; Barco et al. 2002), and there are currently over 332 animals in the mid-Atlantic catalog (Mallette & Barco 2019). Results from satellite-tagging studies and photo-identification efforts near Virginia Beach, Virginia, show that animals remain in this area for weeks to months, and their distribution overlaps significantly with shipping lanes in the area (Aschettino et al. 2018, 2020). Foraging behavior is evident from focal-follow observations of lunge feeding and defecation, and Area Restricted Search behavior shown by state-space modeling (Aschettino et al. 2020).

Ship-strike mortality is an important conservation issue for large whales, particularly in the highly industrialized waters of the United States (U.S.) Atlantic Coast, which has the highest occurrence of ship strikes in North America (Jensen & Silber 2004). The North Atlantic humpback whale population is recovering from the effects of past commercial whaling, with population estimates increasing since the 1980s (Katona & Beard 1990; Ruegg et al. 2013; Smith et al. 1999; Stevick et al. 2003b). However, the pace of this recovery has been slowed by mortality caused by entanglement in fishing gear and collisions with large vessels (Barco et al. 2002). Since January 2016 (through 2 February 2022), 155 humpback whales have stranded on the U.S. East Coast, causing the National Marine Fisheries Service to declare an Unusual Mortality Event (NOAA 2022). One-third of these strandings occurred in the mid-Atlantic and half of the animals that were examined post-mortem showed evidence of ship strike or entanglement. In the Virginia Beach area, high rates of ship strikes have been reported, with 8 percent of the cataloged whales showing evidence of ship-strike injuries

(Aschettino et al. 2018, 2020). In addition, three animals added to the mid-Atlantic catalog in the winter of 2016/17 were later killed by collisions with ships (Aschettino et al. 2018).

Humpback whales in Virginia Beach are exposed constantly to ships. Hampton Roads (Virginia) is the sixth busiest port in the U.S. and Baltimore (Maryland) is the sixteenth busiest. Both ports are reached via the shipping lanes that pass through the mouth of the Chesapeake Bay at Virginia Beach, making these shipping lanes extraordinarily busy. This consistent exposure to ships could cause animals to become habituated to ship approaches and, therefore, perhaps less responsive. Habituation to vessel traffic has been documented by baleen whales near Cape Cod (Watkins 1986). However, some types of abrupt, startling sounds may lead to sensitization, or an increased sensitivity to the noise (Götz & Janik 2011). Humpback whales remain in the Virginia Beach area for days to months, and have been re-sighted over multiple years (Aschettino et al. 2018). This suggests that the disturbance from repeated ship exposures is not causing long-term displacement but may put the whales at heightened risk of being struck, given multiple encounters. Theoretically, animals are more likely to remain in good foraging areas even if they are risky, because the potential to be gained from productive foraging outweighs the heightened risk (Christiansen & Lusseau 2014). Therefore, responses may be short-lived and subtle, and require fine-scale sampling to detect. Understanding the behavior of these animals around ships is critical to developing measures to reduce the risk of ship strike mortality and promote the recovery of this population.

The objective of this work is to build upon the ongoing Mid-Atlantic Humpback Whale project conducted under the U.S. Navy's Marine Species Monitoring Program by deploying high-resolution digital acoustic tags (DTAGs) to measure humpback whale responses to close ship approaches. The following questions will be addressed:

1. *Do humpback whales respond to ship approaches, and if so, which behavioral or movement parameters change?*
2. *Which aspects of a ship approach (including the ship's acoustic and behavioral characteristics) elicit which types of responses?*
3. *Does the behavioral context of the animal (foraging/nonforaging) affect the probability of responding to a ship approach?*

The first field season for this project began on 6 January 2019 and ended on 7 March 2019. Three DTAGs were deployed during this pilot season and methodology was established.

The second field season for this project began on 2 January 2020 and ended on 25 February 2020. Six DTAGs were deployed, including two on animals that were carrying satellite tags deployed by HDR, Inc. One of these deployments was 25.5 hours long, marking the first overnight DTAG deployment on a humpback whale in this area.

The third field season for this project began on 11 January 2021 and ended on 26 January 2021. Two DTAGs were deployed, both on satellite-tagged animals; one remained on the animal for 26 hours.

The final field season for this project is anticipated to run from January through March 2022.

2. Methods

2.1 Study Area

Fieldwork was conducted in the coastal waters off Virginia Beach, Virginia, less than 20 kilometers from shore (**Figure 1**). The area is very shallow, with shipping lanes dredged to 50 feet (approximately 20 meters deep) and areas outside the shipping lanes only 9 to 12 meters deep. Two shipping lanes allow traffic to pass from the north and south, converging just east of the Chesapeake Bay Bridge-Tunnel (CBBT). Large commercial ships follow designated channels through the CBBT on their way to and from the ports of Hampton Roads (Virginia) and Baltimore, Maryland, and military ships travel this way in and out of the world's largest naval station at Norfolk, Virginia.

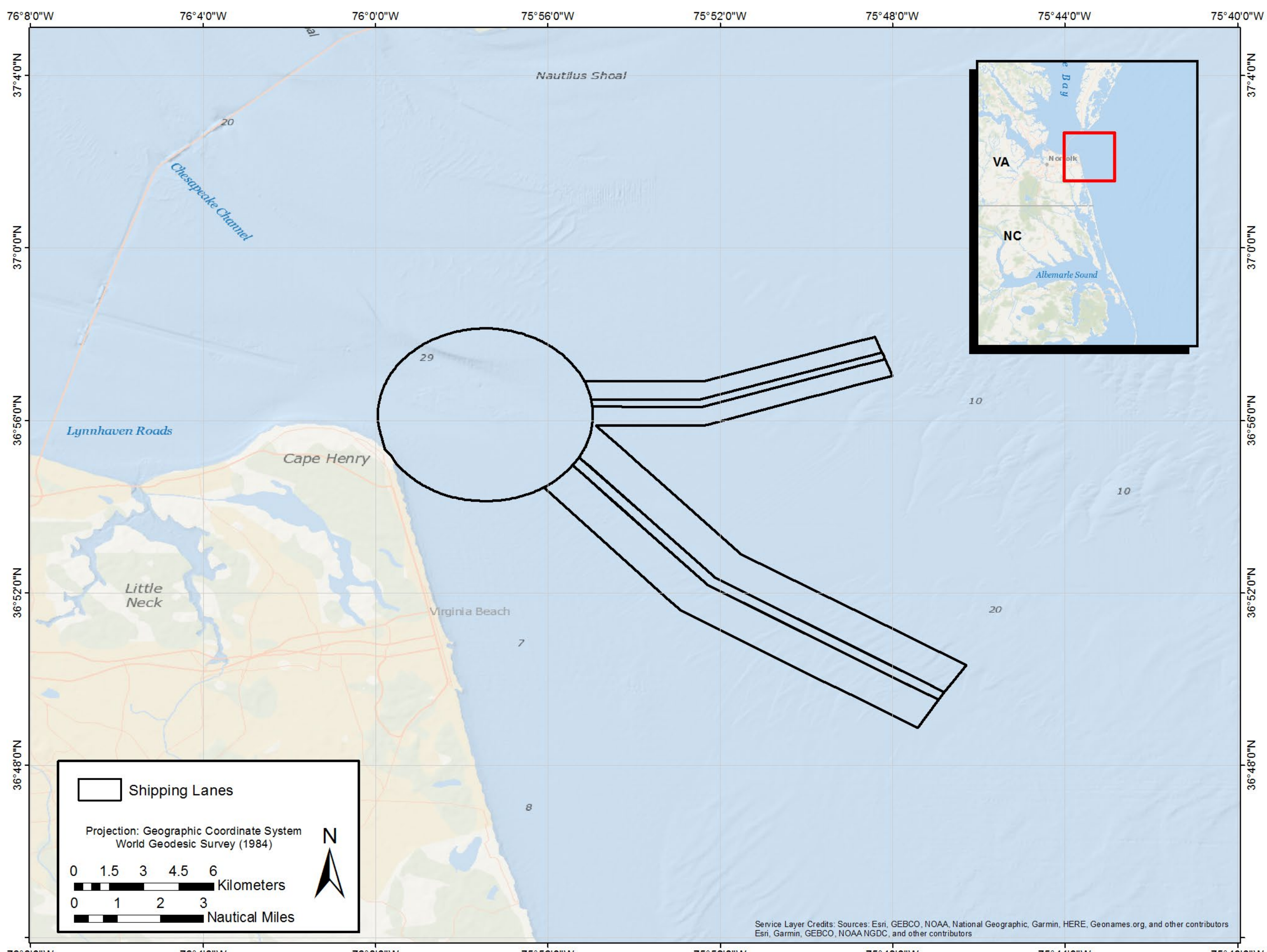

Figure 1. Map of the Virginia Beach study area, including the shipping lanes into the area.

2.2 Data Collection

Fieldwork operations were conducted from the 10-meter research vessel, the R/V *Richard T. Barber* (**Figure 2**). During field operations, the team continually scanned for whales. We also employed communications with the local whale-watch fleet and scientists from HDR Inc., who were conducting satellite-tagging operations in the area, to locate whales. Environmental conditions were collected at each sighting and both environmental conditions and sighting information were recorded on an iPad® tablet linked to a Global Positioning System (GPS) unit. During each sighting and tagging attempt, photographs were taken for individual identification. Photographs of dorsal fins and flukes (when possible) were taken with Canon or Nikon digital SLR cameras (equipped with 100- to 400-millimeter zoom lenses) in 24-bit color at a resolution of 6,016 × 4,016 pixels and saved in .jpg format. These images were provided to colleagues at the Virginia Aquarium and Marine Science Center who curate the mid-Atlantic humpback whale catalog.

Figure 2. The R/V *Richard T. Barber*.

2.2.1 DTAG

After suitable animals were located, we deployed digital sound and movement tags (DTAGs version 3) (Johnson & Tyack 2003). These tags record sounds via two hydrophones sampling at 120 or 240 kilohertz, and movement with triaxial accelerometers and magnetometers sampling at 250 Hertz. They are attached via suction cup and deployed with a 5-meter carbon-fiber pole. Tags were programmed to remain on the animal for a period of several hours. To facilitate retrieval of the tag (and data), the tags broadcasted a VHF signal when at the surface. Tags were tracked via handheld Yagi antennas attached to R1000 radios as well as an array of antennas connected to a direction-finding Horton device which displays the bearing of the received signal.

2.2.2 Focal Follow

During tag deployments, the field team conducted focal follows on both whale and ship behavior. The whale was tracked using the VHF signal, allowing the research team to remain close to the animal. During the focal follow, two team members collected information on the animal's range and bearing in relation to the research vessel, in addition to the animal's heading, to re-construct the animal's track. The other two team members collected data on ships within 5 nautical miles, recording distance, bearing, heading, speed, and distance from the focal animal. These were recorded every 5 minutes for distant vessels and more often for nearby vessels. Priority was given to small vessels not tracked by the Automatic Identification System (AIS).

2.2.3 AIS

AIS is a maritime safety system that requires ships over a certain tonnage to transmit information about their location, speed, and course to prevent collisions at sea as a supplement to traditional radar. AIS messages are received over VHF channels by base stations along the coast and by receivers on other vessels, as well as via satellite. Messages include information about the ship's identity, GPS location, course, speed, size, and cargo, among others. All international travelling ships above 300 gross tonnage and all passenger ships are required by the International Maritime Organization to transmit AIS. During tag deployments we used the research vessel's AIS receiver to record positional information from all transmitting ships within range. Positions updated every few seconds and were logged to a text file, providing information from large ships but not including recreational boats that are not required to transmit AIS.

2.3 Data Analysis

2.3.1 DTAG Processing

Raw DTAG files were converted into depth (pressure), acceleration, and magnetometer readings using custom-written tools in MATLAB (MathWorks, Inc.). Trigonometric functions were used to calculate the animal's pitch, roll, and heading from the accelerometer and magnetometer data.

2.3.2 Lunge detection

We detected foraging events by auditing tags in 2-minute blocks using an adaptation of the DTAG audit tool (soundtags.org). The audit plot shows the animal's dive profile, pitch and roll, fluking, jerk (differential of triaxial acceleration), flow noise (calculated in the 1/3 octave band centered at 100 Hertz), and spectrogram. Two types of foraging events were detected. Lunge feeding, as has been described in many studies of humpback foraging (e.g., Allen et al. 2016; Friedlaender et al. 2013; Goldbogen et al. 2008; Simon et al. 2012), was marked if the animal exhibited two to three fluke strokes, a flow noise peak and drop, and a jerk peak. Because the jerk varies depending on tag placement and tags may slide during an attachment, we considered a jerk peak to be above 2 standard deviations of the average jerk in each 2-minute audit window. Jerk peaks associated with clear lunges easily exceeded this threshold. We also identified rolling foraging events, which we called 'rolling lunges,' although they do not exhibit the clear lunge pattern of fluke strokes and increased flow noise. These rolling lunges were detected if the animal exhibited a roll of 50 degrees or more associated with a jerk peak. This behavior appears to be similar to the 'bottom side roll' described by Ware et al. 2014. In some cases, impact with the seafloor during the roll was audible on the tag, indicating that at least some of these rolling events occur at the bottom. Because this extremely shallow environment is very different from other areas in which humpback lunge feeding has been described, we could not use all of the criteria often used to classify lunges (e.g., changes in depth and vertical speed).

2.3.3 Ship acoustic audits and distance estimation

To determine the relationship between ship distance and the received level of sound on the tag, a preliminary analysis was conducted using four tags from previous years (mn19_066a, mn20_015a, mn20_034a, and mn20_040a). Acoustic records were audited for ship noise using tools adapted from the DTAG toolbox. The start and end of discernable vessel noise was marked, as well as any other biological or anthropogenic sounds. Ship positions were obtained from the VesselFinder database for all ships in the area during the time of deployment. The animal's positions were re-constructed using the distance and bearing from the known position of the research vessel, collected during the focal follows. We interpolated the whale and ship tracks to obtain points every second and then estimated the distance between the whale and ship at each time point. We made a linear regression using the closest distance between the whale and ship and the received level of the ship noise (low-pass filtered at 10 kHz) on the tag at that time point to determine the relationship between ship distance and received sound level.

3. Results

3.1.1 Vessel Survey Effort

Nine days of suction-cup tagging effort were conducted in the Virginia Beach shipping lanes in the 2021 season, totaling 583 kilometers during 51.5 hours of survey effort on the R/V Richard T. Barber (**Table 1**). Surveys were conducted in Beaufort Sea States 1 to 4.

Table 1. Vessel survey effort during suction-cup tagging in the Virginia Beach shipping lanes study area in 2021.

Date	Sea State	Km surveyed	Survey Time (hr:min)	At Sea Time (hr:min)
11-Jan-21	1-2	63.6	6:49	7:24
12-Jan-21	2-3	44.8	6:29	7:19
13-Jan-21	1-4	110.6	7:37	9:07
14-Jan-21	2-4	116.7	6:10	6:35
19-Jan-21	2-4	38.5	3:25	4:03
21-Jan-21	2	42	2:07	2:54
22-Jan-21	2-4	40.7	3:15	3:42
25-Jan-21	1-3	72.4	7:21	8:02
26-Jan-21	3	53.5	2:01	2:21

3.1.2 Humpback Whale Sightings

Humpback whales were sighted on 15 occasions totaling 16 whales (**Table 2, Figure 3**). Single animals were the most commonly sighted (14 of 15 sightings), along with one pair of animals.

Table 2. Humpback whale sightings during suction-cup tagging in the Virginia Beach shipping lanes study area in 2021.

Date	Time (UTC)	Latitude	Longitude	Species	Common Name	Group Size	Tags Deployed
11-Jan-21	14:32	36.96193	-76.01974	*M. novaeangliae*	Humpback whale	1	0
12-Jan-21	14:07	36.96041	-76.02705	*M. novaeangliae*	Humpback whale	1	mn20_012a
13-Jan-21	13:57	36.96516	-76.03264	*M. novaeangliae*	Humpback whale	1	0
13-Jan-21	18:31	36.83131	-75.54154	*M. novaeangliae*	Humpback whale	2	0
13-Jan-21	20:35	36.78299	-75.49813	*M. novaeangliae*	Humpback whale	1	0
13-Jan-21	21:04	36.79779	-75.67529	*M. novaeangliae*	Humpback whale	1	0
14-Jan-21	15:27	36.98089	-75.99284	*M. novaeangliae*	Humpback whale	1	0
19-Jan-21	14:31	36.90304	-75.92043	*M. novaeangliae*	Humpback whale	1	0
19-Jan-21	14:56	36.92875	-75.94492	*M. novaeangliae*	Humpback whale	1	0
21-Jan-21	21:19	36.96653	-76.03470	*M. novaeangliae*	Humpback whale	1	0
22-Jan-21	15:43	36.96817	-75.94204	*M. novaeangliae*	Humpback whale	1	0
25-Jan-21	14:17	36.97789	-76.05561	*M. novaeangliae*	Humpback whale	1	0
25-Jan-21	18:50	36.95107	-75.94229	*M. novaeangliae*	Humpback whale	1	0
25-Jan-21	18:56	36.94985	-75.94652	*M. novaeangliae*	Humpback whale	1	mn20_025a
26-Jan-21	15:57	36.941	-76.027	*M. novaeangliae*	Humpback whale	1	0

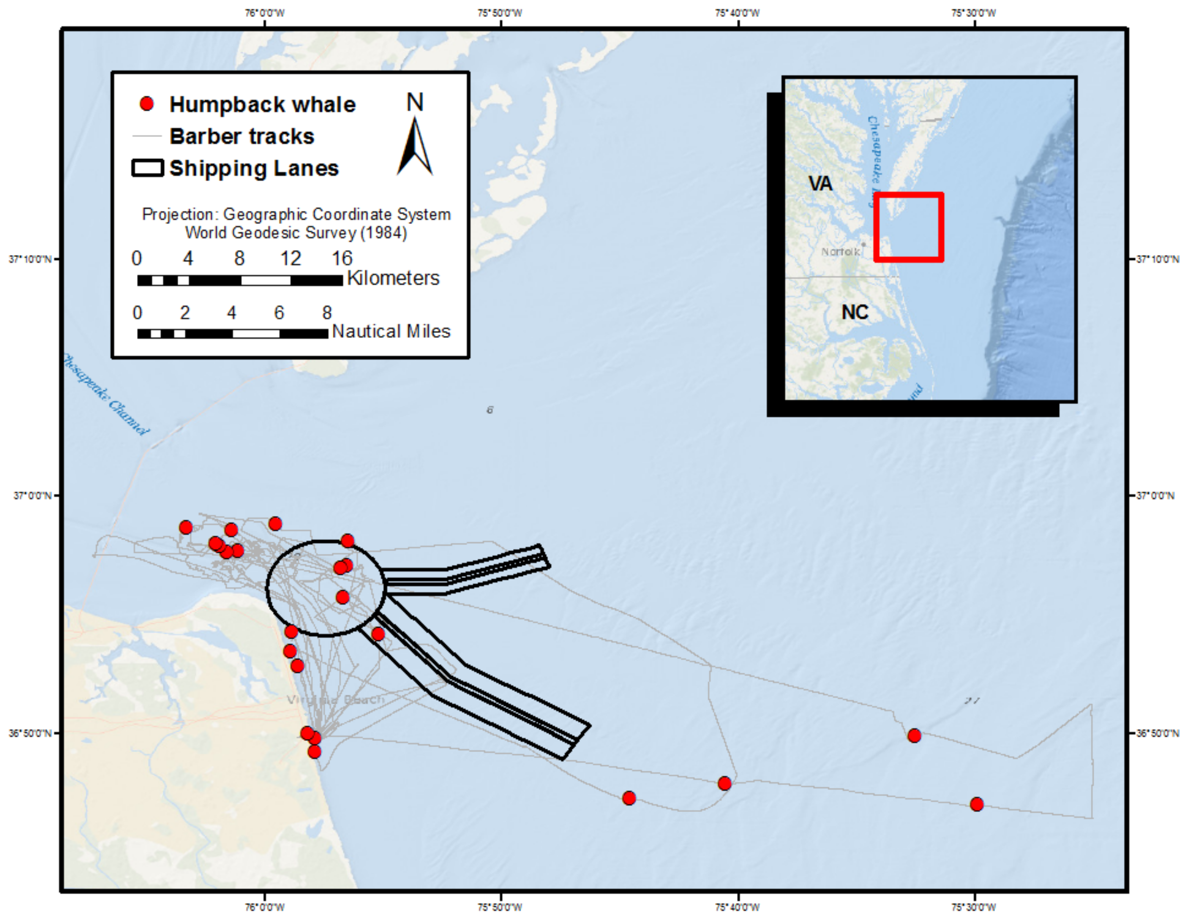

Figure 3. Survey tracks and locations of all humpback whale sightings during suction-cup tagging effort in the Virginia Beach shipping lanes study area in 2021.

3.1.3 DTAGs Deployed

Two DTAGs were deployed on humpback whales during the 2021 season (**Table 3, Figure 4**), both on animals already tagged with satellite tags by HDR, Inc. Deployment mn21_012a lasted for nearly 26 hours, making it the longest DTAG deployment to date in this area (**Figure 5**). The tagged whale foraged nearly continuously, with the exception of a short period in the middle of the night. Deployment mn21_025a lasted for 6 hours and showed some foraging behavior (**Figure 6**). The tag was recovered west of the CBBT. This animal foraged only at night.

Table 3. Suction-cup tag information from deployments on humpback whales in the Virginia Beach shipping lanes study area in 2021.

Date	Time (UTC)	Latitude	Longitude	Species	Tag Type	Tag ID	Duration (hr:min)
12-Jan-21	15:05	36.98523	-76.04039	*M. novaeangliae*	DTAG	mn21_012a	25:56
25-Jan-21	20:02	36.95159	-75.93289	*M. novaeangliae*	DTAG	mn21_025a	6:11

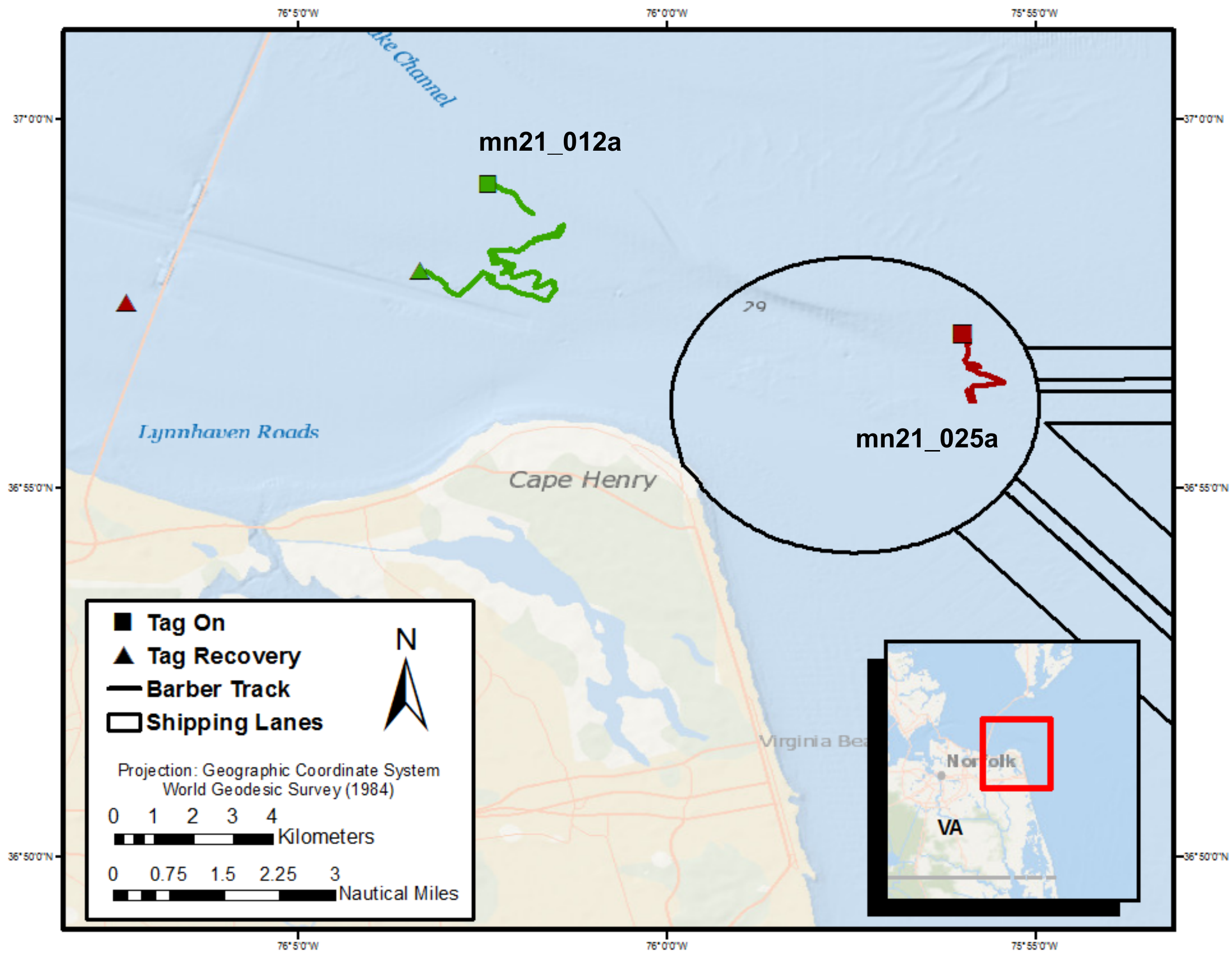

Figure 4. Tagging location and tag recovery location for all suction-cup deployments in the Virginia Beach shipping lanes study area in 2021. Each colored line represents the R/V Barber's track during the focal follow of the animal. Squares indicate locations of tagging and triangles indicate tag recovery locations.

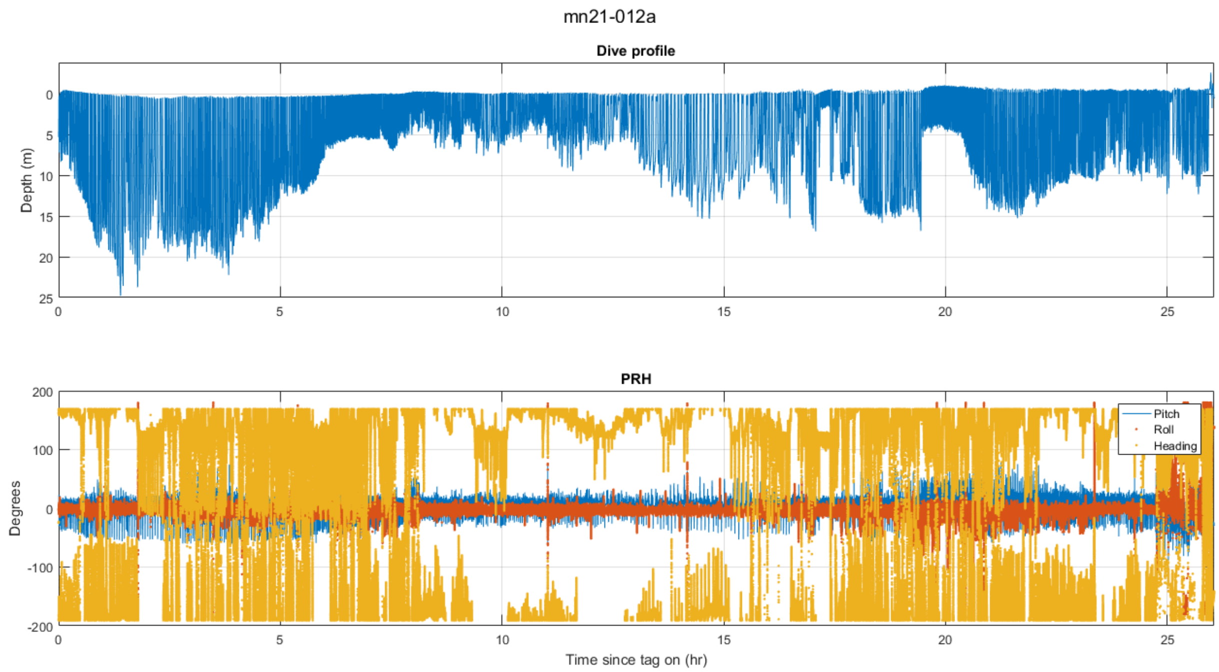

Figure 5. Dive-depth profile (top) and accelerometry metrics (bottom; pitch, roll, and heading) for tagged animal mn21_012a.

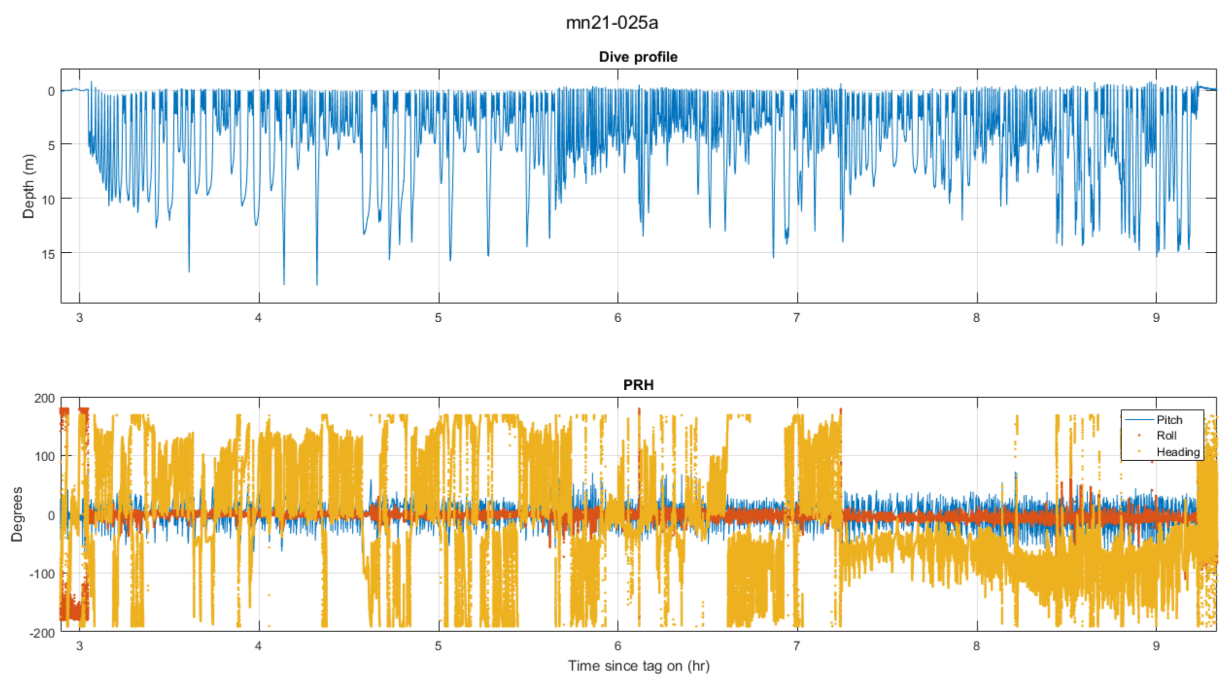

Figure 6. Dive-depth profile (top) and accelerometry metrics (bottom; pitch, roll, and heading) for tagged animal mn21_025a.

3.1.4 Foraging behavior

Both animals tagged in 2021 exhibited clear lunges. Mn21_012a, the 26-hour duration tag, had the most foraging lunges (370) of any animal tagged to date in this area (**Table 4**). These were recorded during most hours of the day and night (**Figure 7**), with 202 of the lunges occurring at night (55%). The deepest lunge was at 24.3 meters for this animal, with an average of 10.2 meters. Lunges were relatively horizontal, with pitches ranging from -30 (head down) to +18 (head up) degrees and roll ranging from -35 (right) to +24 (left) degrees. Mn21_025a had 44 total lunges. These lunges were shallower with an average of 5.7 meters and a maximum of 12.9 meters. They also had more variation in pitch, with a range of -55 to +58 degrees, but roll was similar at -32 to +4 degrees. All lunges from mn21_025a occurred at night (**Figure 8**).

Table 4. Lunge characteristics from lunges recorded from humpbacks tagged off the coast of Virginia Beach, Virginia, in 2021.

Tag ID	Total number of lunges	Depth (meters) median (max)	Median pitch during lunge (degrees) median (range)	Median roll during lunge (degrees) median (range)
mn21_012a	370	10.2 (24.3)	-1.5 (-30.7 to 18.3)	-7.4 (-34.8 to 24.0)
mn21_025a	44	5.7 (12.9)	-2.6 (-54.4 to 58.2)	-9.5 (-31.8 to 3.8)

Both animals also showed rolling behaviors associated with jerk that may also indicate foraging events. We measured the same parameters for these events as regular lunges, as well as the absolute maximum and minimum roll performed during a lunge by the animal (**Table 5**). Because rolls can be performed in either direction, summary statistics do not necessarily capture the full picture of the animal's motion.

There were fewer rolling events than regular lunges (n = 9 rolling lunges *vs* n = 414 regular lunges). Rolling events occurred at shallower depths than regular lunges. Pitches were still relatively horizontal. Median rolls were also low, but the range of absolute rolls during individual lunges was from -180 to +180°. Therefore, animals are rolling in different directions, averaging out the median roll.

Table 5. Characteristics of rolling lunges recorded from humpbacks tagged off the coast of Virginia Beach, Virginia in 2021.

Tag ID	Total number of rolling lunges	Depth (meters) median (max)	Median pitch during lunge (degrees) median (range)	Median roll during lunge (degrees) median (range)	Absolute roll (min:max)
mn21_012a	7	4.8 (17.4)	7.4 (-4.0:32.4)	-12.9 (-27.8:-9.5)	-180:180
mn21_025a	2	2.8 (3.5)	-11.3 (-27.5:4.8)	-1.2 (-1.6:-0.8)	-149:106

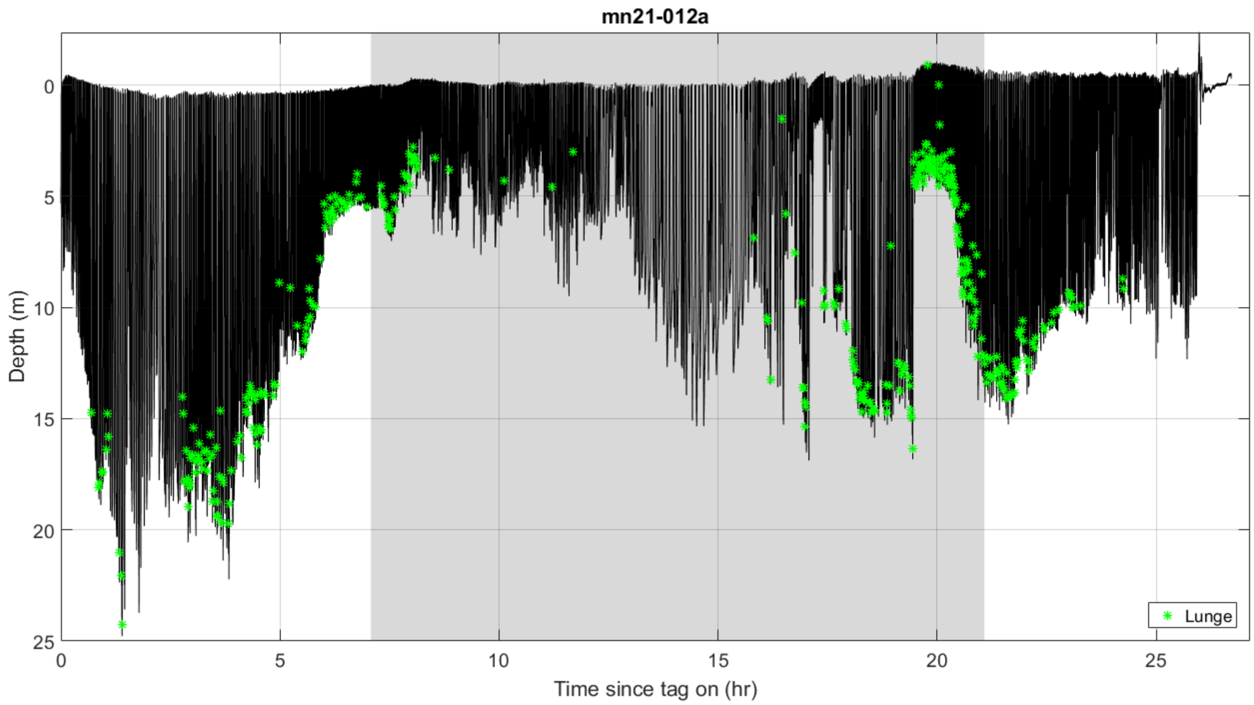

Figure 7. Dive profile for mn21_012a with lunges overlaid as green stars. Gray shaded areas indicate nighttime hours.

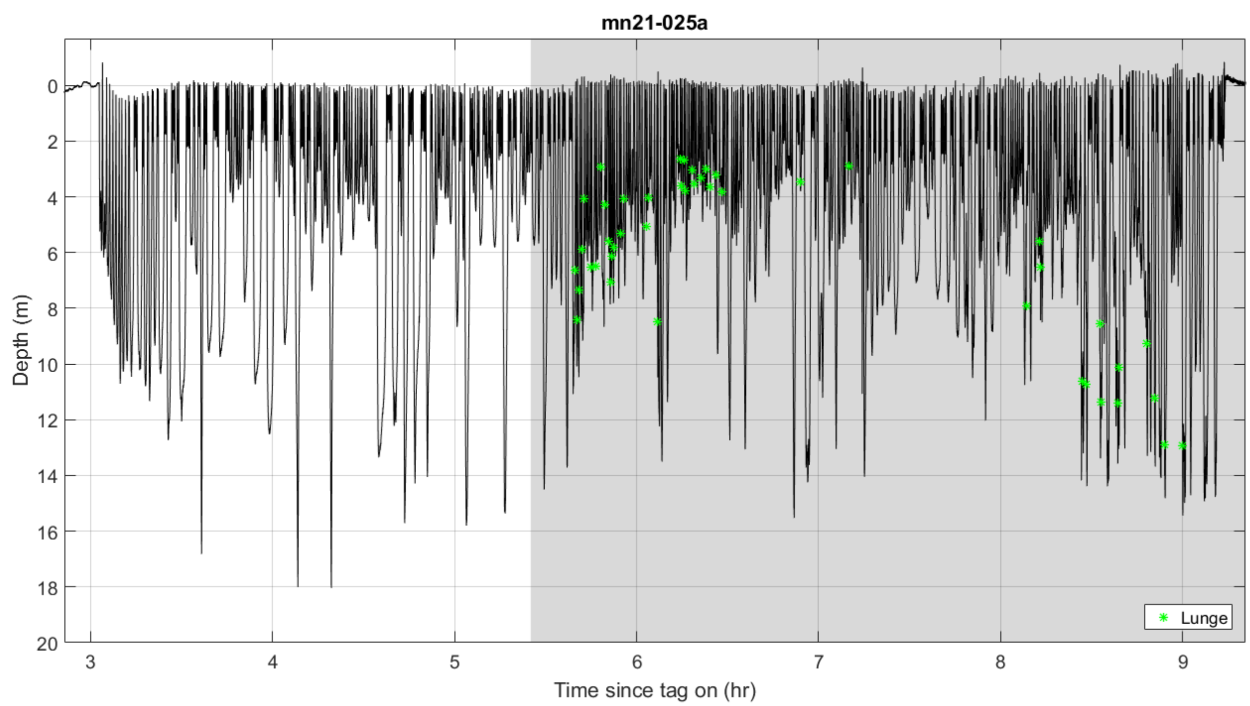

Figure 8. Dive profile for mn21_025a with lunges overlaid as green stars. Gray shaded areas indicate nighttime hours.

3.1.5 Ship distance and received level

Received noise level at the tag and distance to the ship showed a weak negative relationship (lower sound levels at longer distances, **Figure 9**). The p-value of the linear regression was <0.005 (i.e., the slope of the regression line was significantly different from 0), but the R-squared value was 0.145, indicating poor predictive power.

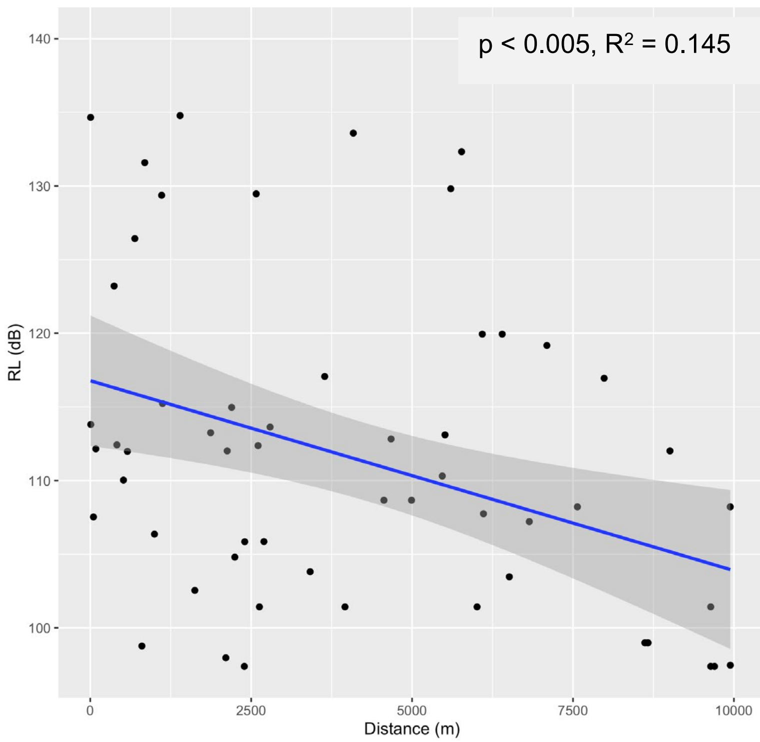

Figure 9. Received level (dB) vs distance (m) for 4 animals for which acoustic audits were completed.

4. Discussion and Future Analysis

We continued to build upon previous years of tagging effort by deploying 2 additional tags on satellite-tagged animals. Both tags recorded nighttime data, which will allow us to determine diel patterns in foraging as well as ship-approach risk. Both animals foraged extensively, highlighting the importance of this area as a winter feeding ground. As cessation of foraging is often considered a response to disturbance, identifying the presence and frequency of foraging events contributes to our understanding of humpbacks' responses to ships. Future work will combine the lunge data from these DTAGs with the synoptic satellite tag locations collected by HDR and available high-resolution bathymetry data to determine whether animals are foraging at the seafloor or in the water column, as well as their exact foraging locations relative to the shipping lanes.

This year, we focused our analysis on acoustic audits of ship records and comparing the received level of sound on the tags with the ship's known distance to the animal. This preliminary analysis showed a weak linear relationship. We plan to continue to refine this regression, adding data from more animals and changing variables such as the frequency band in which the ship noise was calculated, to attempt to increase predictive power. We also intend to add other variables, such as the ship's speed and type, to the model. If we can predict the ship's distance from the received level with accuracy, we can estimate ship distances from parts of the tag record without focal follows.

We developed several analytical tools this year, including the following:

- *continued refinement of foraging lunge detection from accelerometry data streams and flow noise*
- *acoustically detecting ship approaches on tag records*

Analytical tools currently being developed include the following:

- *tools to deconstruct high-resolution accelerometer and magnetometer data into biologically meaningful movement metrics, such as turning rates and overall body acceleration.*
- *refining the ship distance/received level regression to increase predictive power*

Fieldwork is currently being conducted during the 2022 season (January–March) to increase the number of tagged whales with ship approaches for analysis. We will continue to prioritize coordination with HDR, Inc., to deploy DTAGs on whales equipped with satellite tags. This allows us to extend tag deployment durations and deploy overnight DTAGs. In addition, double-tagging animals improves the accuracy of location estimates for whales in the vessel response project (particularly when tags have been deployed overnight and focal follows are not possible), and provides fine-scale information on the diving behavior of satellite-tagged whales. Both projects will contribute to ongoing efforts to understand the behavior of juvenile humpback whales in the Virginia Beach area and to better understand risk factors and develop potential mitigation measures for ship strikes.

5. Acknowledgements

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