Behavioral Responses of Humpback Whales to Approaching Ships in Virginia Beach, Virginia: 2022 Annual Progress Report

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Cover Photo Credit:

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

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Acronyms and Abbreviations

AIS	Automatic Identification System
CBBT	Chesapeake Bay Bridge-Tunnel
DTAG	digital acoustic tag
Feb	February
GPS	Global Positioning System
ID	identification
Jan	January
max	maximum
min	minimum
R/V	research vessel
U.S.	United States
UTC	Universal Time
VHF	very high frequency

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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), with little feeding on the breeding grounds or during migration. They travel up to 7,000 kilometers (Stevick et al. 1999) from breeding grounds to summer feeding areas ranging from the Gulf of Maine to Norway. Individual whales return to discrete feeding grounds each summer within 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 feeding grounds have been observed on the Caribbean breeding grounds (Stevick et al. 2003a).

These migratory patterns are the norm for most adults, but some younger humpback whales remain on feeding grounds or making only partial migrations during winter (Christensen et al. 1992; Whitehead 1987). Since the early 1990s, juvenile humpback whales have been documented feeding along the mid-Atlantic coast during winter, and the number of animals using this area during the colder months is growing (Swingle et al. 1993, 2017; Wiley et al. 1995). Many of these humpbacks appeared to be 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, with a few matches to other summer feeding aggregations (Barco et al. 2002). There are currently 245 unique individuals in the local humpback catalog maintained by HDR from field work conducted since 2015, with many being re-sighted in the mid-Atlantic area over multiple years. Results from satellite-tagging studies and photo-identification efforts near Virginia Beach, Virginia, show that animals remain in this area for weeks to months, often feeding in shipping lanes (Aschettino et al. 2023, 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 along 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 (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 17 January 2023), 176 humpback whales have stranded on the U.S. East Coast, and the National Marine Fisheries Service has declared an Unusual Mortality Event in April 2017 (NOAA 2023). One-third of these strandings occurred in the mid-Atlantic, and half of the animals examined post-mortem showed evidence of ship strike or entanglement. In the Virginia Beach area, high rates of ship strikes have been reported, with 10 percent of cataloged whales showing evidence of ship-strike injuries (Aschettino et al. 2023).

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

Humpback whales in Virginia Beach are exposed constantly to vessel traffic. Hampton Roads (Virginia) is the sixth busiest port in the U.S. and Baltimore (Maryland) is the sixteenth busiest. Vessel access to both ports is through shipping lanes that pass through the mouth of the Chesapeake Bay at Virginia Beach, making these shipping lanes extraordinarily busy. This continuous 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). Humpback whales remain in the Virginia Beach area for days to months, and have been re-sighted over multiple years (Aschettino et al. 2023). 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. Whales 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 to oncoming vessels in this area 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 three field seasons of this project conducted during the winters of 2019, 2020, and 2021 resulted in 11 DTAG deployments, several of those with accompanying satellite telemetry tags deployed by HDR (see Shearer et al. 2020, 2021, 2022 for details). The fourth field season for this project began on 13 January 2022 and ended on 11 February 2022 and is covered in this report. Four DTAGs were deployed.

Future work will consist of mapping potential prey using an EK80 high-precision scientific echo sounder in the shipping lanes of the study area. Of particular interest is determining whether prey density is higher within the shipping channels than in adjacent waters.

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); areas outside the shipping lanes are 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 use these channels to access the world's largest naval station in Norfolk, Virginia.

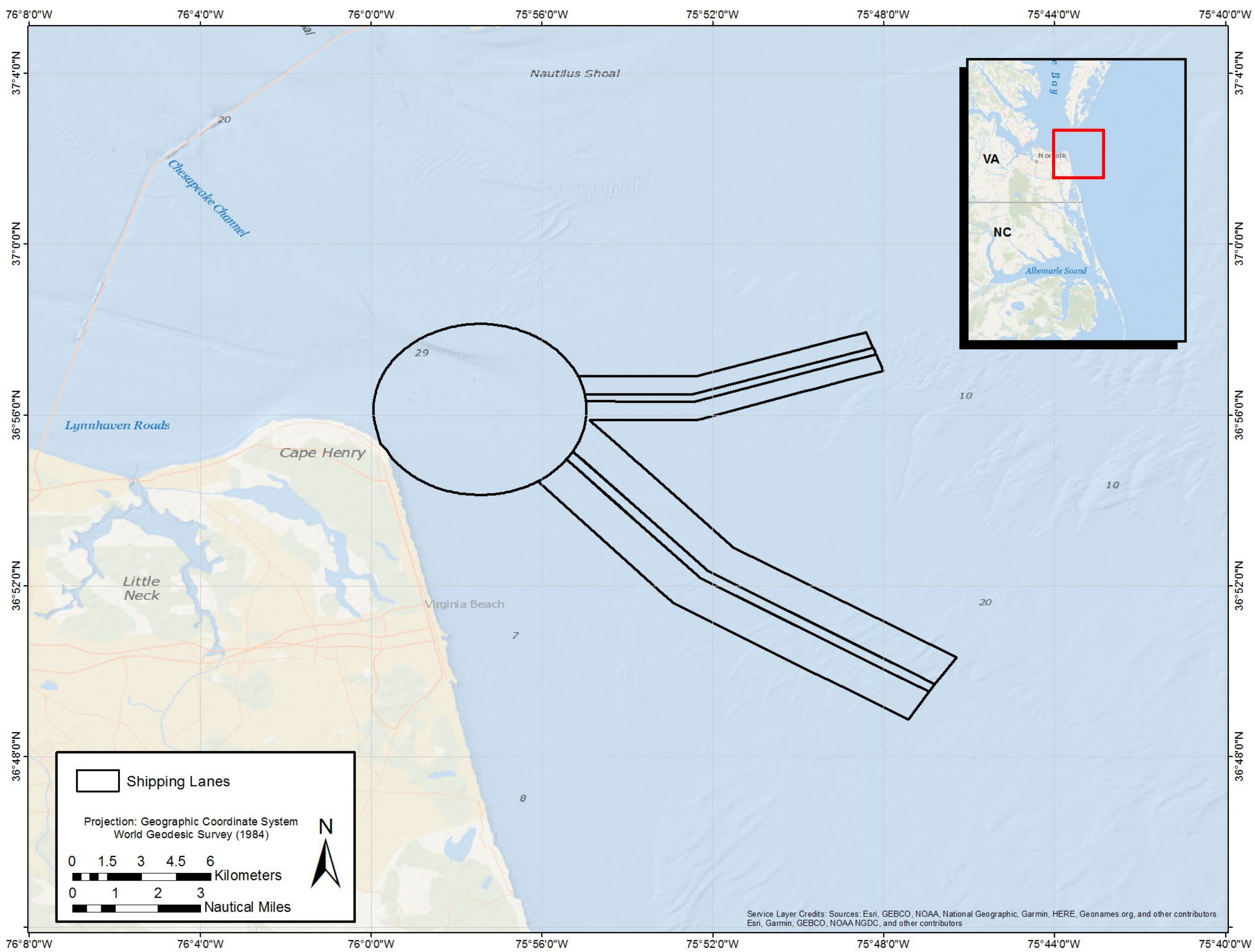

Figure 1. Map of the Virginia Beach study area, including the shipping lanes entering the Chesapeake Bay.

2.2 Data Collection

Fieldwork operations were conducted from the 10-meter research vessel (R/V), the *R/V Richard T. Barber* (**Figure 2**). During field operations, the team continually scanned for whales and communicated with the local whale-watch fleet, and scientists from HDR Inc. who were conducting satellite-tagging operations in the area. 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 single-lens reflex (SLR) cameras (equipped with 100- to 400-millimeter zoom lenses) in 24-bit color at a resolution of 6016 × 4016 pixels and saved in .jpg format. These images were provided to colleagues 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, the team 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. The tags 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 very high frequency (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 that displays the bearing of the received signal.

2.2.2 Focal Follow

During tag deployments, the field team conducted focal follows on both whale behavior and ship movements. The tagged whales were tracked using a VHF signal from the DTAG, allowing the research team to remain in close proximity to the animal(s). During the focal follow, two team members collected information on the animals' range and bearing in relation to the research vessel, in addition to the animals' heading to reconstruct the animal movement tracks. 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 Automatic Identification System

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, 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, the team 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 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 or three fluke strokes, a flow noise peak and drop, and a jerk peak. The jerk depends on tag placement and tags may slide during an attachment, so we considered a jerk peak to be above 2 standard deviations of the average jerk, updated for each tag slide. 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 marked 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. This extremely shallow environment is very different from other areas in which humpback lunge feeding has been described, so we could not use all of the criteria often used to classify lunges (e.g., changes in depth and vertical speed).

3. Results

3.1 Vessel Survey Effort

The team conducted 9 days of tagging effort in Virginia Beach in the 2022 season, with a total of 538 kilometers during 60.3 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 2022.

Date	Sea State	Kilometers Surveyed	Survey Time (hr:min)	At Sea Time (hr:min)
13-Jan-22	1–2	30.6	6:35	6:47
18-Jan-22	1–4	45.4	7:11	7:48
24-Jan-22	2	55.6	6:43	7:08
25-Jan-22	1–2	31	8:26	8:51
2-Feb-22	3	23.6	2:49	3:12
8-Feb-22	1–2	57.4	5:07	5:39
9-Feb-22	1–2	135.2	7:57	8:40
10-Feb-22	2–4	92.6	10:08	10:41
11-Feb-22	2–4	66.7	5:23	5:39

Note: Feb = February; hr = hour; Jan = January; min = minute

3.2 Humpback Whale Sightings

The team sighted humpback whales on 19 occasions totaling 22 individuals, with 2 re-sights of previously tagged whales (**Table 2, Figure 3**). Single animals were most common (16 of 19 sightings), with three pairs of animals.

Table 2. Humpback whale sightings and DTAG deployments within the Virginia Beach shipping lanes study area in 2022.

Date	Time (UTC)	Latitude	Longitude	Species	Group Size	Tags Deployed
13-Jan-22	16:28	36.85584	-75.89747	*M. novaeangliae*	1	0
13-Jan-22	17:54	36.87573	-75.92175	*M. novaeangliae*	1	0
13-Jan-22	19:40	36.87701	-75.8876	*M. novaeangliae*	1	0
18-Jan-22	21:04	36.87379	-75.88122	*M. novaeangliae*	1	0
25-Jan-22	14:45	36.90749	-75.91213	*M. novaeangliae*	1	mn22_025a

Date	Time (UTC)	Latitude	Longitude	Species	Group Size	Tags Deployed
25-Jan-22	15:18	36.91229	-75.92542	*M. novaeangliae*	1	0
2-Feb-22	15:23	36.88419	-75.97200	*M. novaeangliae*	1	0
8-Feb-22	17:52	36.78156	-75.95267	*M. novaeangliae*	1	0
8-Feb-22	21:14	36.89000	-75.90167	*M. novaeangliae*	1	0
8-Feb-22	21:24	36.88127	-75.90909	*M. novaeangliae*	1	0
9-Feb-22	14:07	36.75273	-75.904089	*M. novaeangliae*	1	mn22_040a
9-Feb-22	19:02	36.94295	-75.95523	*M. novaeangliae*	1	0
9-Feb-22	19:16	36.95257	-75.96744	*M. novaeangliae*	2	0
9-Feb-22	19:22	36.95041	-75.97831	*M. novaeangliae*	1	0
9-Feb-22	21:23	36.73230	-75.93204	*M. novaeangliae*	1	mn20_040a *resight
10-Feb-22	14:27	36.88033	-75.87837	*M. novaeangliae*	2	mn22_041a
10-Feb-22	18:42	36.90026	-75.90922	*M. novaeangliae*	1	mn22_041b
11-Feb-22	12:52	36.86856	-75.89703	*M. novaeangliae*	1	mn21_041b *resight
11-Feb-22	16:41	36.90289	-75.91410	*M. novaeangliae*	2	0

Note: Feb = February; Jan = January; UTC = Universal Time

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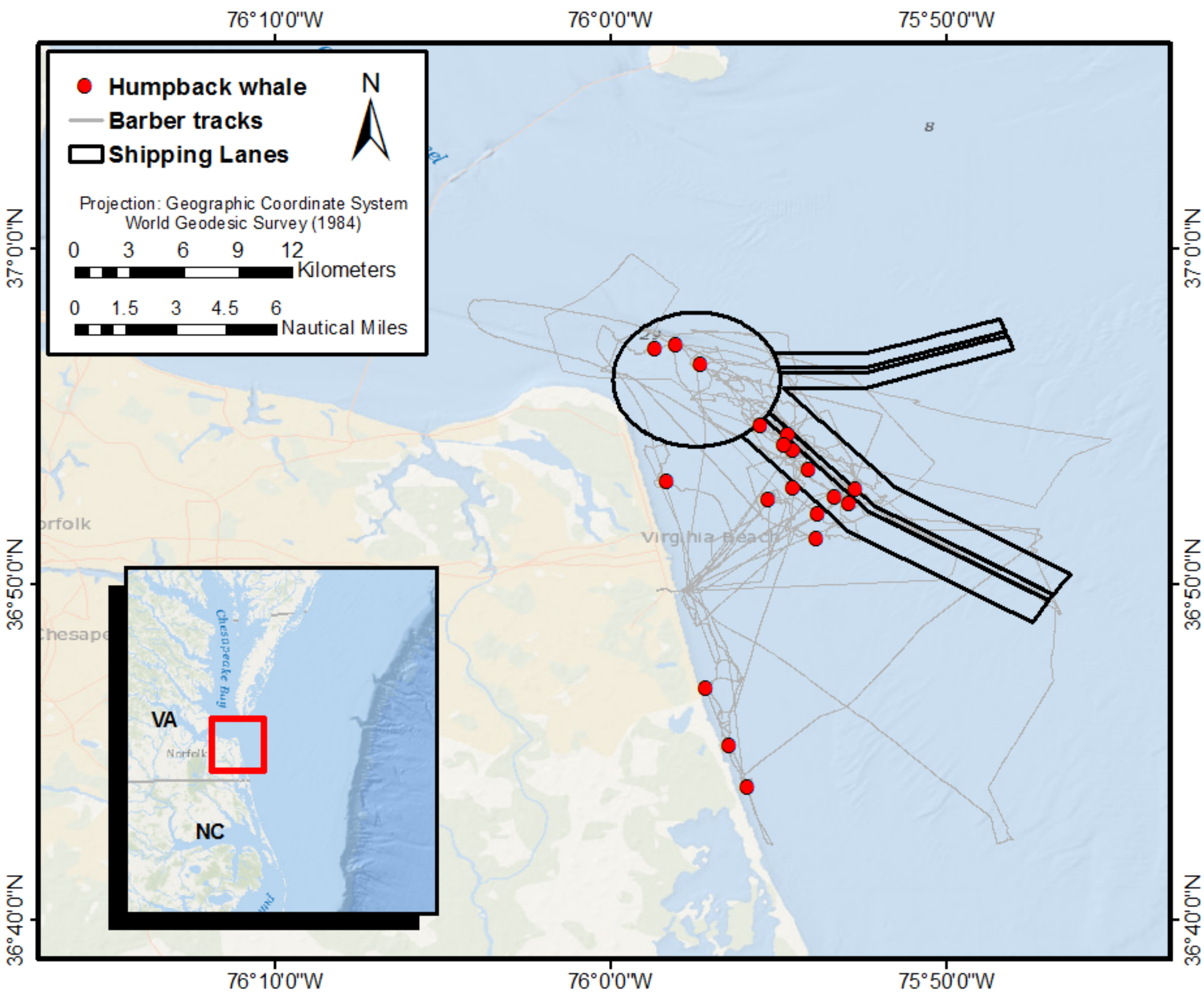

Figure 3. Survey tracks and locations of all humpback whale sightings during suction-cup tagging effort within the Virginia Beach shipping lanes study area in 2022.

3.3 DTAG Deployments

The team deployed four DTAGs on humpback whales during the 2022 season (**Table 3, Figures 4** through **7**); two of those deployments were on animals also equipped with satellite telemetry tags deployed by HDR. One DTAG was not recovered. Two deployments were made with DTAGs that also contained a Fastloc® GPS receiver. Foraging lunges were present on two of the three records from recovered tags (**Figures 8** and **9** in **Section 3.4**). One animal, deployment mn22_040a, was tagged very near shore in shallow water; this animal had no dives deeper than 4 meters for the first 9 hours of deployment and did not appear forage.

Table 3. Suction-cup tag information from deployments on humpback whales within the Virginia Beach shipping lanes study area in 2022.

Date	Time (UTC)	Latitude	Longitude	Species	Tag Type	Tag ID	Duration (hr:min)
25-Jan-22	18:04	36.94586	-75.95108	*M. novaeangliae*	DTAG/ Fastloc	Mn22_025a	3:39
9-Feb-22	14:28	36.76070	-75.94497	*M. novaeangliae*	DTAG/ Fastloc	Mn22_040a	11:40
10-Feb-22	15:41	36.89021	-75.88011	*M. novaeangliae*	DTAG	Mn22_041a	0:57
10-Feb-22	19:10	36.89986	-75.90898	*M. novaeangliae*	DTAG	Mn22_041b	Not recovered

Note: Feb = February; hr = hour; Jan = January; min = minute; UTC = Universal Time

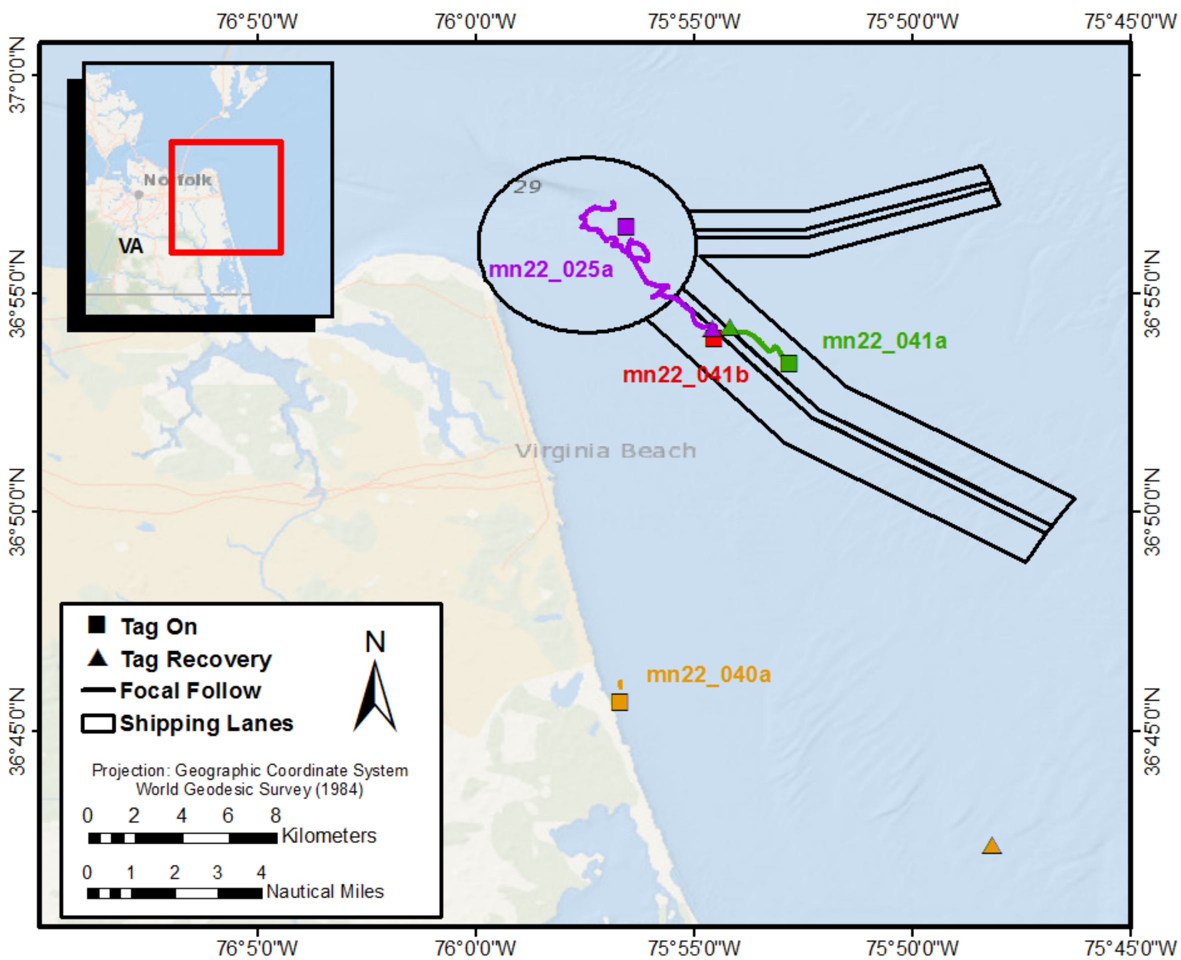

Figure 4. Tagging location (squares) and tag recovery location (triangles) for all suction-cup deployments within the Virginia Beach shipping lanes study area in 2022. Each colored line represents the *R/V Richard T. Barber*'s track during the focal follow of the animal.

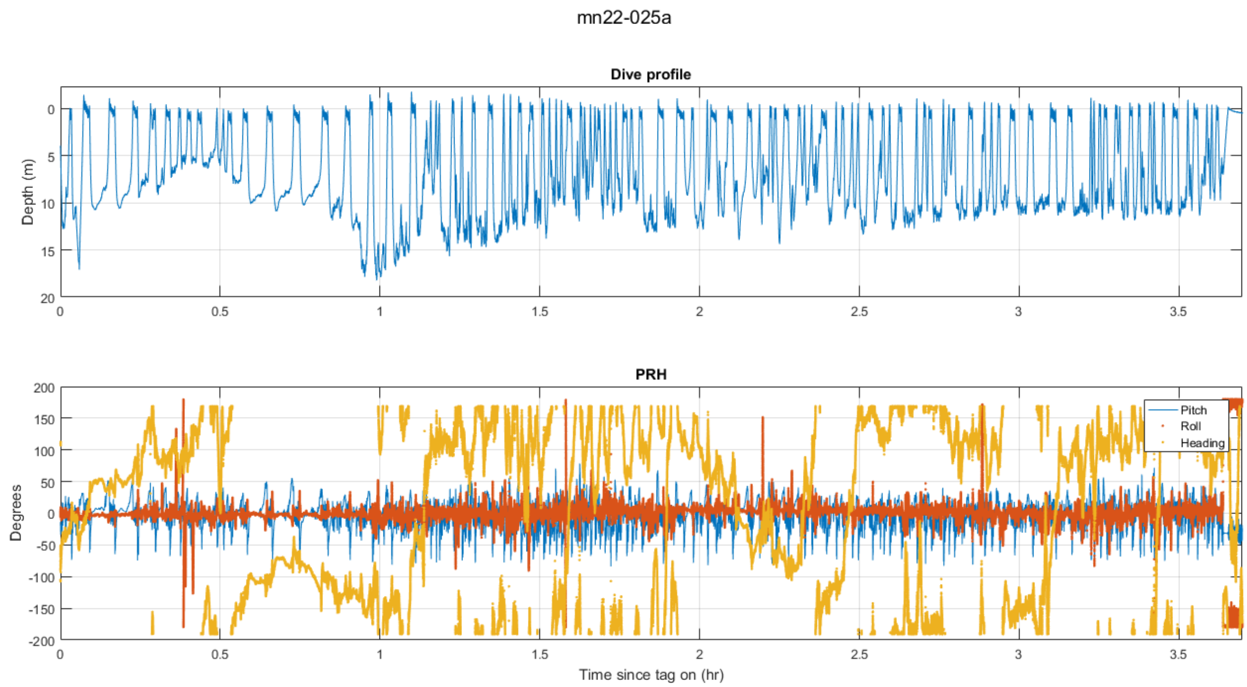

Figure 5. Dive-depth profile (top) and accelerometry metrics (bottom; pitch [blue], roll [red], and heading [yellow]) for tagged animal mn22_025a.

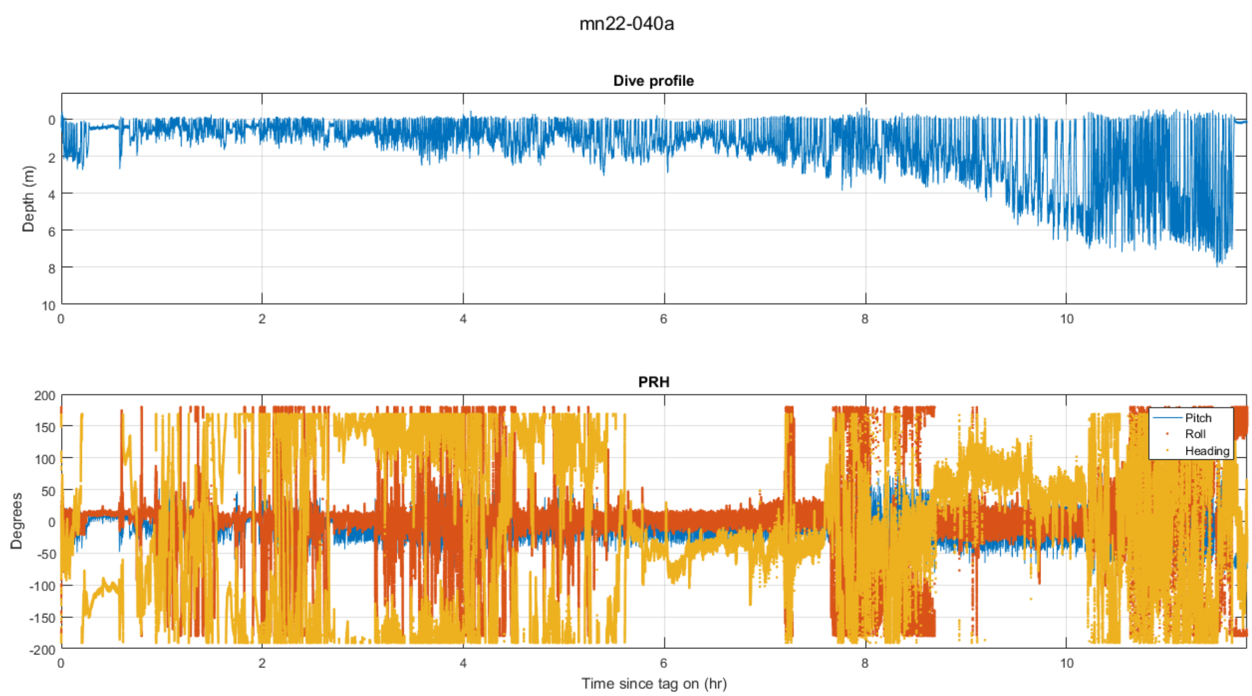

Figure 6. Dive-depth profile (top) and accelerometry metrics (bottom; pitch [blue], roll [red], and heading [yellow]) for tagged animal mn22_040a.

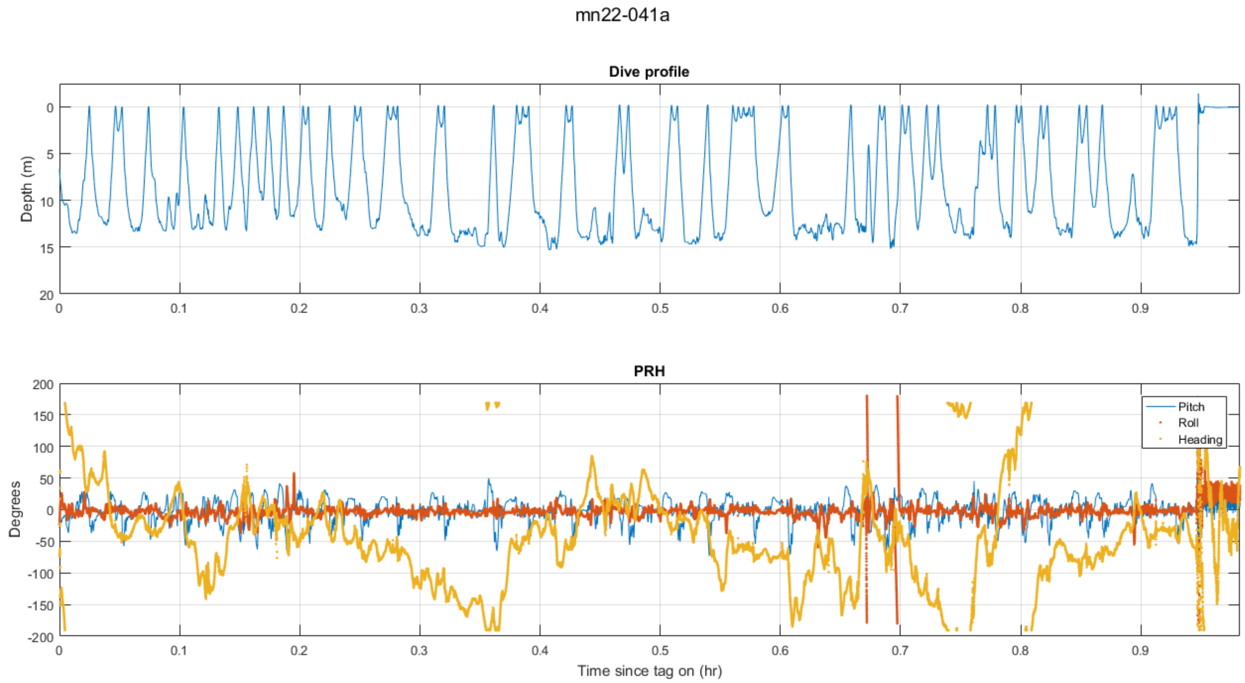

Figure 7. Dive-depth profile (top) and accelerometry metrics (bottom; pitch [pitch], roll [red], and heading [yellow]) for tagged animal mn22_041a.

3.4 Foraging behavior

Two of the three animals with recovered tags in 2022 exhibited clear foraging lunges, although at lower rates than animals tagged in previous years (**Table 4, Figures 8 *and* 9**). The only animal with data that extended into nighttime hours did not appear to forage. Lunges averaged 10.9 meters deep, with the deepest at 14.7 meters deep (**Table 4**). Lunges were relatively horizontal, with median pitch during the lunge ranging from -21 (head down) to +29 (head up) degrees and roll ranging from -39 (right) to +28 (left) degrees (**Table 4**).

Table 4. Lunge characteristics from lunges recorded from humpbacks tagged off the coast of Virginia Beach, Virginia, in 2022.

Tag ID	Total Number of Lunges	Median Depth (max)	Median Pitch during Lunge (range)	Median Roll during Lunge (range)
mn22_025a	21	10.1m (13.8m)	-3.9 degrees (-21.0 to 29.2)	-1.2 degrees (-38.6 to 27.5)
mn22_040a	0	—	—	—
mn22_041a	9	13.2m (14.7m)	-2.4 degrees (-9.2 to 17.7)	2.2 degrees (-11.0 to 7.9)

Notes: ID = identification; m = meters; max = maximum

All three tagged animals showed rolling behavior that might 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**). Rolls can be performed in either direction, so these summary statistics do not necessarily capture the full picture of the animal's motion.

There were fewer rolling events than regular lunges (n = 10 rolling lunges versus n = 30 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 +179 degrees. Therefore, the animals were 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 2022.

Tag ID	Total Number of Rolling Lunges	Median Depth (max)	Median Pitch during Lunge (range)	Median Roll during Lunge (range)	Absolute Roll (min:max)
mn22_025a	7	7.3m (12.4m)	6.2 degrees (-7.5 to 23.2)	20.0 degrees (-70.9 to 106.9)	-180:172
mn22_040a	1	1.5m	-13.0 degrees	92.8 degrees	174
mn22_041a	2	14.1m (14.9m)	15.9 degrees (11.2 to 20.6)	-12.1 degrees (-9.5 to -14.6)	-180:178.5

Notes: ID = identification; m = meters; max = maximum; min = minimum

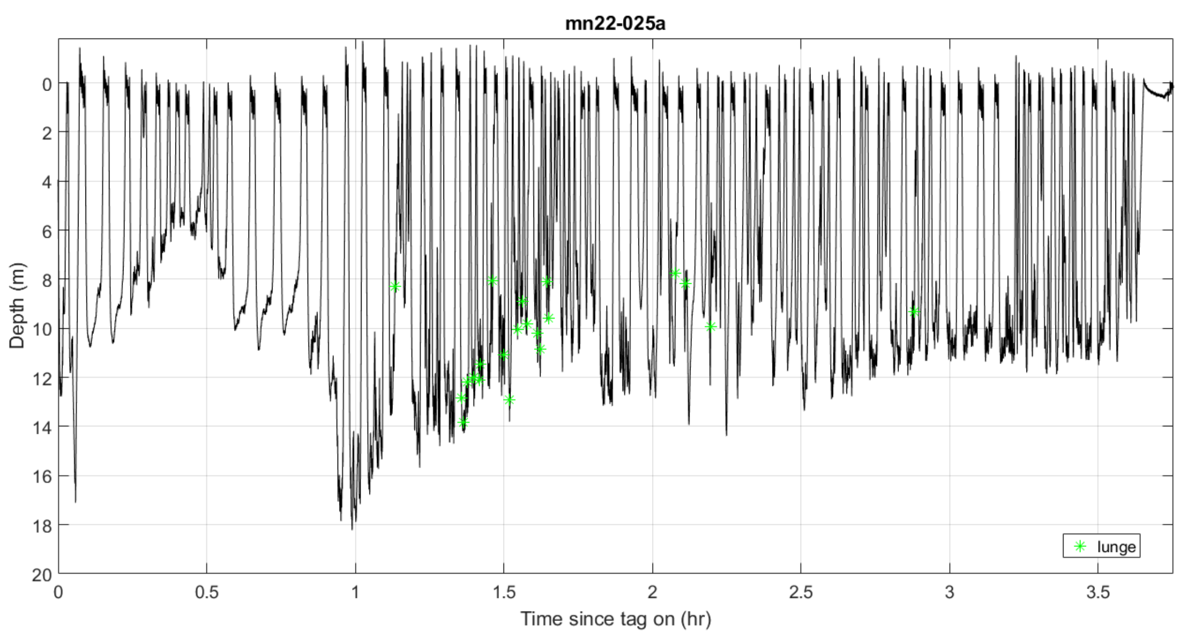

Figure 8. Dive profile for mn22_025a with detected lunges overlaid as green stars.

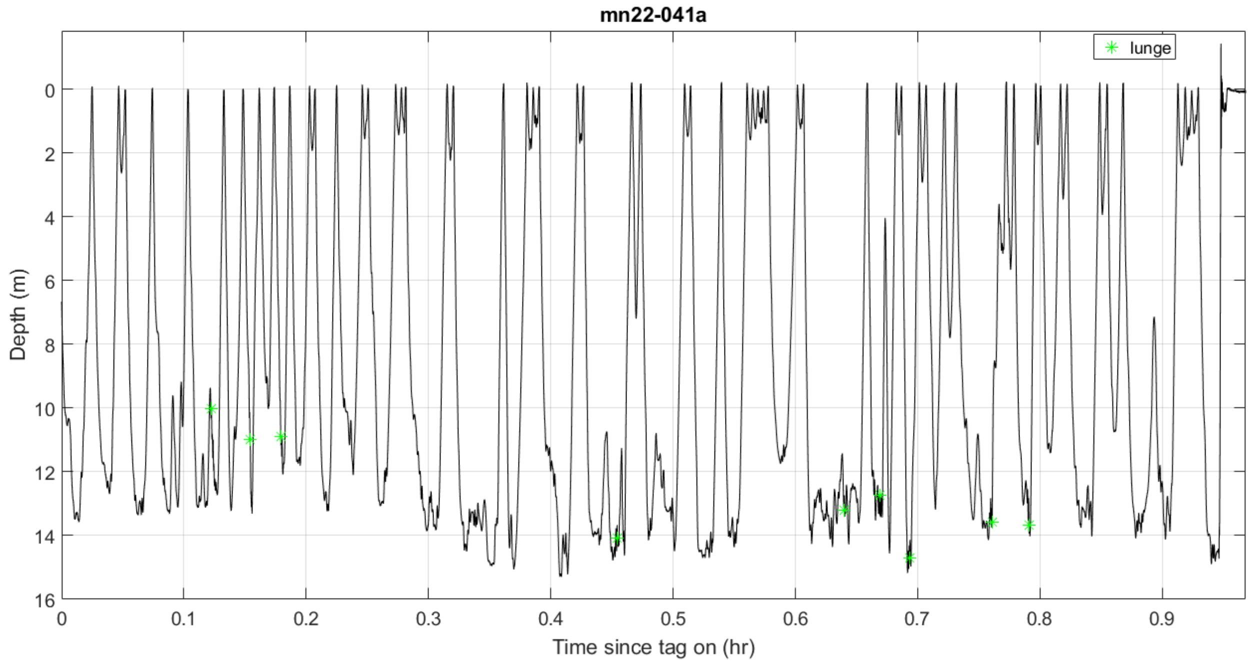

Figure 9. Dive profile for mn22_041a with detected lunges overlaid as green stars.

4. Discussion and Future Analysis

The project team's work in 2022 built on previous years of research in this area and deployed four additional DTAGs on humpback whales near the Virginia Beach shipping lanes. Two of the three tagged whales showed foraging behavior, with similar depths and orientations to those from tags previously deployed within this area. As cessation of foraging is often considered a response to disturbance, identifying the presence and frequency of foraging events contributes to the understanding of humpbacks' responses to ships, and highlights the importance of this area as a winter feeding ground for these animals. 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 near the seafloor or within the water column, as well as their precise foraging locations relative to the shipping lanes.

This year, the team focused the analysis of foraging behavior from all tags deployed to date in this project by quantifying foraging rates and kinematic behaviors for regular lunges and rolling events, and identifying potential diel patterns in foraging lunges. We will include this analysis in a manuscript currently in preparation for submission to a journal this year. In the coming year, we will also continue to refine the correlation between distance to the nearest vessel from focal follows and received noise level on the tags. If we can predict the ship's distance from the received level with accuracy, we can estimate ship distances from portions of the tag record without focal follows. Finally, we will use concurrent satellite tag and DTAG records from double-tagged animals to predict foraging behavior on longer-duration satellite tags using information from the high-resolution DTAGs.

The team also refined foraging lunge detection from accelerometry data streams and flow noise and worked on development of several analytical tools this year, including:

- *Tools to deconstruct high-resolution accelerometer and magnetometer data into biologically meaningful movement metrics, such as turning rates and overall body acceleration.*
- *Refinement of the ship distance/received level regression to increase predictive power*
- *A combination of DTAG records with concurrent satellite records to make predictions about foraging behavior in lower-resolution, longer-duration satellite tag records*

In the 2023 season, project fieldwork will consist of acoustic prey mapping using the EK80 active acoustic system on the R/V *Shearwater*. The team will map prey density in and outside of the shipping lanes at multiple times of day to assess spatial and diurnal variation in prey density. This work will inform our analysis of humpback foraging behavior and help us to predict their vulnerability to ship encounters. We will not conduct tagging during the 2023 season but will conduct prey mapping around animals tagged by HDR, if those tag deployments occur while the R/V *Shearwater* is within the area. Project fieldwork and analyses will focus on contributing to ongoing efforts to understand the behavior of juvenile humpback whales within the Virginia Beach area and to better understand risk factors and develop potential mitigation measures for ship strikes.

5. Acknowledgements

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6. Literature Cited

Allen, A. N., Goldbogen, J. A., Friedlaender, A. S., and Calambokidis, J. (2016). Development of an automated method of detecting stereotyped feeding events in multisensor data from tagged rorqual whales. *Ecology and Evolution 6*(20): 7522–7535. https://doi.org/10.1002/ece3.2386

Aschettino, J. M., Engelhaupt, D., Engelhaupt, A., Richlen, M., and DiMatteo, A. (2023). *Mid-Atlantic Humpback Whale Monitoring, Virginia Beach, Virginia: 2021/22 Annual Progress Report*. *Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command Atlantic, Norfolk, Virginia, under Contract N62470-15-8006, Task Order 21F4005, Issued to HDR, Inc., Virginia Beach, Virginia*

Aschettino, J. M., Engelhaupt, D., Engelhaupt, A., Richlen, M., and DiMatteo, A. (2018). *Mid-Atlantic Humpback Whale Monitoring, Virginia Beach, Virginia: 2017/18 Annual Progress Report*. *Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command Atlantic, Norfolk, Virginia, under Contract N62470-15-8006, Task Order 17F4013, Issued to HDR, Inc., Virginia Beach, Virginia.*

Aschettino, J. M., Engelhaupt, D. T., Engelhaupt, A. G., DiMatteo, A., Pusser, T., Richlen, M. F., and Bell, J. T. (2020). Satellite telemetry reveals spatial overlap between vessel high-traffic areas and humpback whales (*Megaptera novaeangliae*) near the mouth of the Chesapeake Bay. *Frontiers in Marine Science 7*(March),:1–16. https://doi.org/10.3389/fmars.2020.00121

Barco, S. G., Mclellan, W. A., Allen, J. M., Asmutis-Silvia, R. A., Meagher, E. M., Pabst, D. A., Robbins, J., Seton, R. E., and Swingle, W. M. (2002). Population identity of humpback whales (*Megaptera novaeangliae*) in the waters of the US mid-Atlantic states. *Journal of Cetacean Research Management 4*(2):135–141.

Christensen, I., Haug, T., and Oien, N. (1992). Seasonal distribution, exploitation and present abundance of stocks of large baleen whales (Mysticeti) and sperm whales (*Physeter macrocephalus*) in Norwegian and adjacent waters. *ICES Journal of Marine Science 49*:341–355.

Christiansen, F., and Lusseau, D. (2014). Understanding the ecological effects of whale-watching on cetaceans. In J. Higham, L. Bejder, & R. Williams (Eds.), *Whale-watching: Sustainable Tourism and Ecological Management*. Cambridge University Press.

Clapham, P. J., Baraff, L. S., Carlson, C. A., Christian, M. A., Mattila, D. K., Mayo, C. A., Murphy, M. A., and Pittman, S. (1993). Seasonal occurrence and annual return of humpback whales, *Megaptera novaeangliae*, in the southern Gulf of Maine. *Canadian Journal of Zoology 71*(2):440–443. https://doi.org/10.1139/z93-063

Friedlaender, A. S., Tyson, R. B., Stimpert, A. K., Read, A. J., and Nowacek, D. P. (2013). Extreme diel variation in the feeding behavior of humpback whales along the western Antarctic Peninsula during autumn. *Marine Ecology Progress Series 494*:281–289. https://doi.org/10.3354/meps10541

Goldbogen, J. A., Calambokidis, J., Croll, D. A., Harvey, J. T., Newton, K. M., Oleson, E. M., Schorr, G., amd Shadwick, R. E. (2008). Foraging behavior of humpback whales: kinematic and respiratory patterns suggest a high cost for a lunge. *Journal of Experimental Biology 211*(23):3712–3719. https://doi.org/10.1242/jeb.023366

Jensen, A. S., and Silber, G. K. (2004). Large whale ship strike database. In *NOAA Technical Memorandum NMFS-OPR-25*. https://doi.org/10.1093/nar/gki014

Johnson, M. P., and Tyack, P. L. (2003). A digital acoustic recording tag for measuring the response of wild marine mammals to sound. *IEEE Journal of Oceanic Engineering 28*(1):3–12. https://doi.org/10.1109/JOE.2002.808212

Katona, S., Baxter, B., Brazier, O., Kraus, S., Perkins, J., and Whitehead, H. (1979). Identification of humpback whales by fluke photographs. In H. E. Winn & B. L. Olla (Eds.), *Behavior of Marine Animals. Volume 3: Cetaceans* (pp. 33–44). Springer.

Katona, S. K., and Beard, J. A. (1990). Population size, migrations and feeding aggregations of the humpback whale (*Megaptera novaeangliae*) in the western North Atlantic ocean. *Report of the International Whaling Commission*, *Special Issue 12*:295–305.

Mallette, S. D., and Barco, S. G. (2019). Mid-Atlantic and Southeast Humpback Whale Photo-ID Catalog : 2018 Annual Progress Report. *Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command Atlantic, Norfolk, Virginia, under Contract No. N62470-15-8006, Task Order 18F4032, Issued to HDR, Inc., Virginia Beach, Virginia*, *June*.

NOAA (National Oceanic and Atmostpheric Administration). (2023). *2016-2023 Humpback Whale Unusual Mortality Event along the Atlantic Coast*. https://www.fisheries.noaa.gov/national/marine-life-distress/2016-2023-humpback-whale-unusual-mortality-event-along-atlantic-coast

Ruegg, K., Rosenbaum, H. C., Anderson, E. C., Engel, M., Rothschild, A., Baker, C. S., and Palumbi, S. R. (2013). Long-term population size of the North Atlantic humpback whale within the context of worldwide population structure. *Conservation Genetics 14*(1):103–114. https://doi.org/10.1007/s10592-012-0432-0

Simon, M., Johnson, M., and Madsen, P. T. (2012). Keeping momentum with a mouthful of water: behavior and kinematics of humpback whale lunge feeding. *Journal of Experimental Biology 215*(21):3786–3798. https://doi.org/10.1242/jeb.071092

Smith, T. D., Allen, J., Clapham, P. J., Hammond, P. S., Katona, S., Larsen, F., Lien, J., Mattila, D., Palsbøll, P. J., Sigurjónsson, J., Stevick, P. T., and Oien, N. (1999). An ocean-basin-wide mark-recapture study of the North Atlantic humpback whale (*Megaptera novaeangliae*). *Marine Mammal Science 15*(1):1–32. https://doi.org/10.1111/j.1748-7692.1999.tb00779.x

Stevick, P. T., Allen, J., Bérubé, M., Clapham, P. J., Katona, S. K., Larsen, F., Lien, J., Mattila, D. K., Palsbøll, P. J., Robbins, J., Sigurjónsson, J., Smith, T. D., Øien, N., and Hammond, P. S. (2003a). Segregation of migration by feeding ground origin in North Atlantic humpback whales (*Megaptera novaeangliae*). *Journal of Zoology 259*(3):231–237. https://doi.org/10.1017/S0952836902003151

Stevick, P. T., Allen, J., Clapham, P. J., Friday, N., Katona, S. K., Larsen, F., Lien, J., Mattila, D. K., Palsbøll, P. J., Sigurjónsson, J., Smith, T. D., Øien, N., and Hammond, P. S. (2003b). North Atlantic humpback whale abundance and rate of increase four decades after protection from whaling. *Marine Ecology Progress Series 258*:263–273.

Stevick, P. T., Allen, J., Clapham, P. J., Katona, S. K., Larsen, F., Lien, J., Mattila, D. K., Palsbøll, P. J., Sears, R., Sigurjónsson, J., Smith, T. D., Vikingsson, G., Øien, N., and Hammond, P. S. (2006). Population spatial structuring on the feeding grounds in North Atlantic humpback whales (*Megaptera novaeangliae*). *Journal of Zoology 270*(2):244–255. https://doi.org/10.1111/j.1469-7998.2006.00128.x

Stevick, P. T., Oien, N., and Mattila, D. K. (1999). Migratory destinations of humpback whales from Norwegian and adjacent waters: evidence for stock identity. *Journal of Cetacean Research and Management 1*(2):147–152.

Swingle, W. M., Barco, S. G., Costidis, A. M., Bates, E. B., Mallette, S. D., Phillips, K. M., Rose, S. A., and Williams, K. M. (2017). Virginia Sea Turtle and Marine Mammal Stranding Network 2016 Grant Report. *A Final Report to the Virginia Coastal Zone Management Program Department of Environmental Quality, Commonwealth of Virginia*, *NOAA Grant #NA15NOS4190164*, *Task #49*. http://www.seaturtle.org/PDF/SwingleWM_2014_VAQFTechReport.pdf

Swingle, W. M., Barco, S. G., Pitchford, T. D., McLellan, W. A., & Pabst, A. (1993). Appearance of juvenile humpback whales feeding in the nearshore waters of Virginia. *Marine Mammal Science 9*(3):309–315.

Ware, C., Wiley, D. N., Friedlaender, A. S., Weinrich, M., Hazen, E. L., Bocconcelli, A., Parks, S. E., Stimpert, A. K., Thompson, M. A., and Abernathy, K. (2014). Bottom side-roll feeding by humpback whales (*Megaptera novaeangliae*) in the southern Gulf of Maine, U.S.A. *Marine Mammal Science 30*(2):494–511. https://doi.org/10.1111/mms.12053

Watkins, W. A. (1986). Whale reactions to human activities in Cape Cod waters. *Marine Mammal Science 2*(4):251–262. https://doi.org/10.1111/j.1748-7692.1986.tb00134.x

Whitehead, H. (1987). Updated status of the humpback whale, *Megaptera novaeangliae*, in Canada. *Canadian Field-Naturalist 101*(2):284–294.

Whitehead, H., and Moore, M. J. (1982). Distribution and movements of West Indian humpback whales in winter. *Canadian Journal of Zoology 60*(9):2203–2211. https://doi.org/10.1139/z82-282

Wiley, D. N., Asmutis, R. A., Pitchford, T. D., and Gannon, D. P. (1995). Stranding and mortality of humpback whales, *Megaptera novaeangliae*, in the mid-Atlantic and southeast United States, 1985-1992. *Fishery Bulletin 93*(1):196–205.