Behavioral Responses of Humpback Whales to Approaching Ships in Virginia Beach, Virginia: 2018/19 Annual Progress Report

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Cover Photo Credit:

Humpback whale (*Megaptera novaeangliae*). Photographed by Jeanne Shearer, Duke University, taken under General Authorization 16185 held by Andrew Read, Duke University.

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Acronyms and Abbreviations

CBBT	Chesapeake Bay Bridge Tunnel
GPS	Global Positioning System
km	kilometer(s)
m	meter(s)
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
Photo-ID	photo-identification
R/V	research vessel
UME	Unusual Mortality Event
U.S.	United States
VAQS	Virginia Aquarium and Marine Science Center

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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 km (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., 2017, 1993; 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-90s 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 resighted in the mid-Atlantic area in multiple years (Aschettino et al., 2018; Barco et al., 2002) and there are currently over 100 animals in the mid-Atlantic catalog (Aschettino et al., 2018). 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).

Ship strike mortality is an important conservation issue for large whales, particularly in the highly industrialized waters of the 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 July 26, 2019), 100 humpback whales have stranded on the U.S. East Coast, causing the National Marine Fisheries Service (NMFS) to declare an Unusual Mortality Event (UME) (NOAA, 2019). 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. Eight humpback whales have already stranded in 2019 in Virginia and North Carolina alone. In the Virginia Beach area, high rates of ship strikes have been reported, with 8 percent of the catalog showing evidence of ship strike injuries (Aschettino et al., 2018). 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 6th busiest port in the U.S. and Baltimore (Maryland) is the 16th 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 in 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 resighted 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.

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 (~20 meters deep) and areas outside the shipping lanes only 9-12 meters deep. Two shipping lanes allow traffic to pass from the north and south, converging just east of the Chesapeake Bay Bridge Tunnel (CBBT). Container ships pass through the CBBT on their way to the Port of Hampton Roads (VA) and Baltimore, MD, and military ships travel this way in and out of the world's largest naval station at Norfolk, VA.

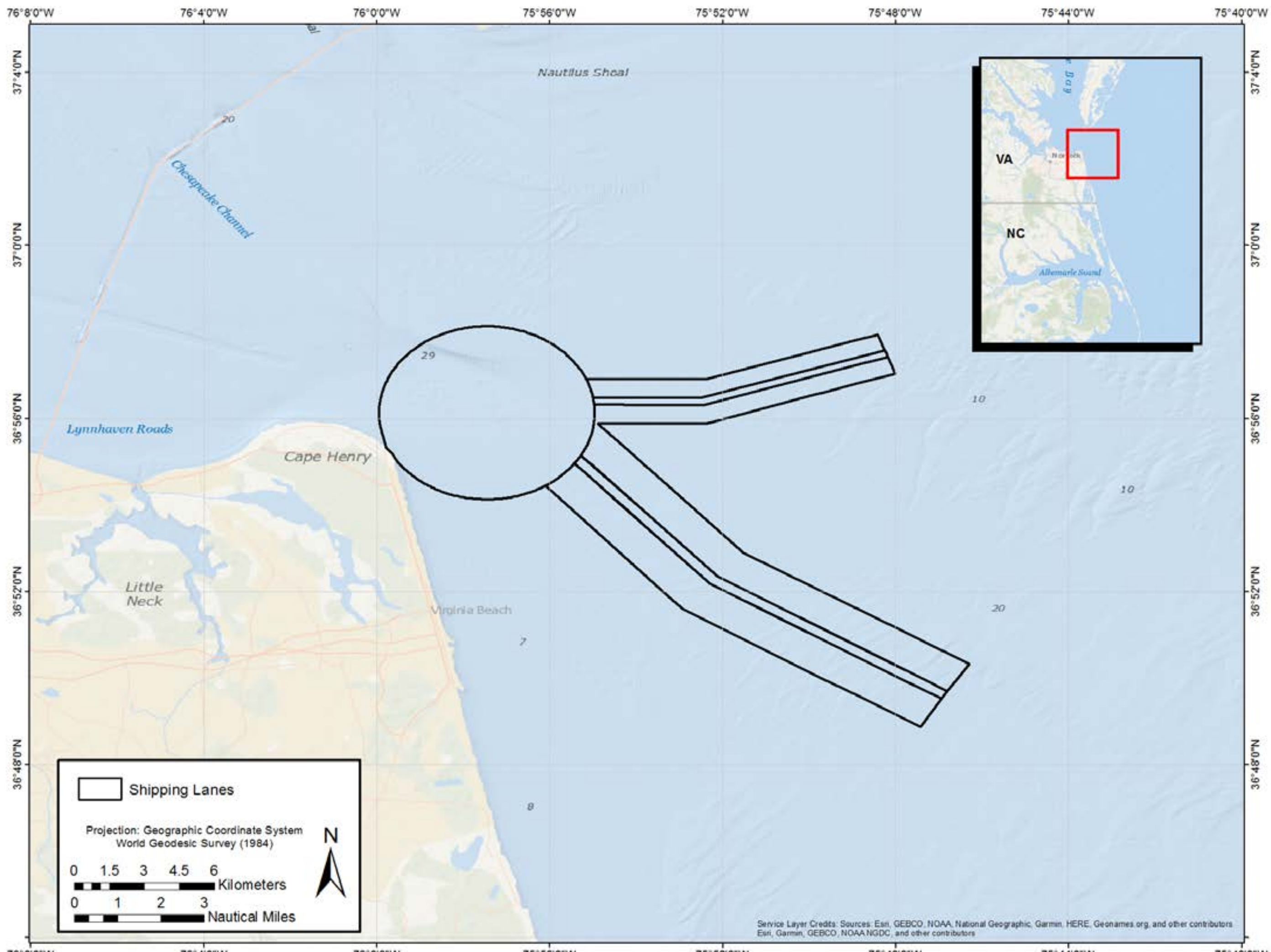

Figure 1. Map of the Virginia Beach study area, including the shipping lanes into the area.

2.2 Data Collection

Fieldwork operations were conducted from the 10 m 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 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 acoustics via two hydrophones sampling at 120 or 240 kHz, and movement with triaxial accelerometers and magnetometers sampling at 250 Hz. 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 DF 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, one team member collected information on the animal's range and bearing in relation to the research vessel, in addition to the animal's heading, to recreate the animal's track. A second team member recorded the animal's behavior using a spoken track recorder. This included the composition and behavior of the group (animals surfacing within 100 m of each other), including group size and surfacing and heading synchrony. This also included information about the animal's behavioral state, any behavioral events or other observations, and the presence of other boats in the area. A third team member collected data on ships within 5 nautical miles, recording distance, bearing, heading, speed, and distance to the focal animal. These were recorded every 5 minutes for distant boats and more often for close boats. Priority was given to small vessels not present on 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 (IMO) 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.

2.2.4 S2A

The Naval Research Laboratory operates a Sealink Advanced Analytics (S2A) system to analyze vessel tracks. This unclassified, proprietary system aggregates multiple data sources, including AIS and RADAR to recreate accurate vessel tracks. Information from this system will be compared with data collected from the research vessel's AIS receiver and the ship focal follow in order to assess field protocols for the next season.

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.

3. Results

3.1.1 Vessel Survey Effort

Seven days of suction-cup tagging effort were conducted in the Virginia Beach shipping lanes in the 2018/19 season, totaling 556 km during 46 hours of survey effort (**Table 1**). Surveys were conducted in Beaufort sea states 2 to 4.

Table 1. Vessel survey effort during suction-cup tagging in the Virginia Beach shipping lanes study area in 2018/19.

Date	Sea State	Km surveyed	Survey Time (hrs:min)	At Sea Time (hrs:min)	Platform
6-Jan-19	2-4	106.8	7:20	7:54	R/V *R.T. Barber*
8-Jan-19	2-4	72.5	5:46	7:30	R/V *R.T. Barber*
12-Jan-19	2-3	75.0	6:03	6:38	R/V *R.T. Barber*
16-Jan-19	2-4	95.4	7:27	7:33	R/V *R.T. Barber*
17-Jan-19	3-4	46.7	2:44	3:18	R/V *R.T. Barber*
18-Jan-19	2-3	118.5	7:18	7:44	R/V *R.T. Barber*
7-Mar-19	2-3	41.2	9:15	10:17	R/V *R.T. Barber*

3.1.2 Humpback Whale Sightings

Humpback whales were sighted on 13 occasions totaling 16 whales (**Table 2, Figure 3**). Single animals were the most common (10 of 13 sightings), followed by groups of 2. No whales were observed in groups larger than 2 animals.

Table 2. Humpback whale sightings observed during suction-cup tagging in the Virginia Beach shipping lanes study area in 2018/19.

Date	Time (UTC)	Latitude	Longitude	Species	Common Name	Group Size	Tags Deployed	Photo-ID Images
6-Jan-19	14:40	36.89553	-75.92856	*M. novaeangliae*	Humpback whale	1	0	148
6-Jan-19	16:21	36.94631	-75.98925	*M. novaeangliae*	Humpback whale	1	0	49
6-Jan-19	19:03	36.93115	-75.96889	*M. novaeangliae*	Humpback whale	1	0	0
6-Jan-19	20:30	36.81419	-75.88515	*M. novaeangliae*	Humpback whale	2	0	0
8-Jan-19	15:50	36.95244	-75.91983	*M. novaeangliae*	Humpback whale	2	mn19_008a	380
12-Jan-19	14:44	36.88609	-75.94475	*M. novaeangliae*	Humpback whale	1	0	179
12-Jan-19	16:08	36.91605	-75.92041	*M. novaeangliae*	Humpback whale	1	0	26
12-Jan-19	16:41	36.93790	-75.93460	*M. novaeangliae*	Humpback whale	1	0	0
12-Jan-19	17:10	36.96799	-75.96995	*M. novaeangliae*	Humpback whale	1	0	72
12-Jan-19	19:13	36.96142	-75.94956	*M. novaeangliae*	Humpback whale	1	mn19_012a	40
16-Jan-19	16:29	36.92026	-75.93711	*M. novaeangliae*	Humpback whale	2	0	737
18-Jan-19	19:42	36.88560	-75.87758	*M. novaeangliae*	Humpback whale	1	0	280
7-Mar-19	13:14	36.93687	-75.98471	*M. novaeangliae*	Humpback whale	1	mn19_066a	383

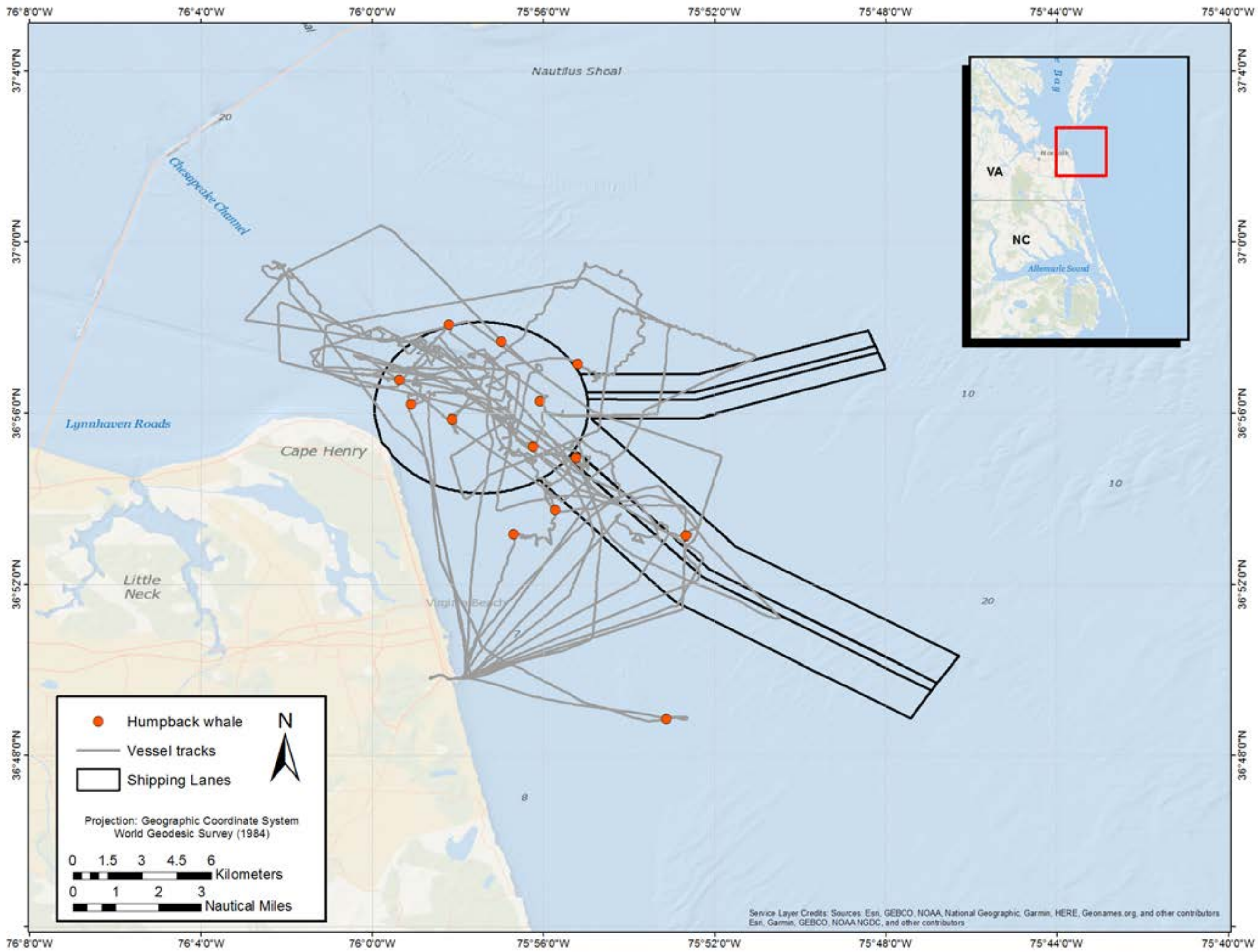

Figure 3. Survey tracks and locations of all sightings during humpback whale suction-cup tagging effort in the Virginia Beach shipping lanes study area in 2018/19.

3.1.3 DTAGs Deployed

Three DTAGs were deployed on humpback whales during the 2018-19 season (**Table 3, Figure 4**). Two tags attached well and remained on the animal for a period of several hours (2.3 and 6.5 hours), while one was removed within 10 minutes by the animal (data from this tag will not be used for analyses). Depth profiles show a maximum of 10 m (mn19_008a) and 25 m (mn19_066a); most dives for animal mn19_008a were to 4-6 m while mn19_066a dove deeper, typically between 10 and 20 m (**Figures 5, 6**). The animal tagged on January 8th (mn19_008a) was in a group of 2; these animals surfaced synchronously or nearly synchronously for the majority of the focal follow. Fine scale analyses of the acceleration data are ongoing. The animal tagged on March 7th (mn19_066a) had been tagged a few days earlier by HDR, Inc., with a FastLoc GPS tag. Positions obtained from the GPS tag facilitated locating the animal for tagging. This animal remained within the shipping lanes for the entire tag deployment. Several large ships passed near the animal during the deployment, including a dredger directly in its path which caused the animal to change course for one surfacing.

Table 3. Suction-cup tag information from deployments on humpback whales in the Virginia Beach shipping lanes study area in 2018/19.

Date	Time (UTC)	Latitude	Longitude	Species	Tag Type	Tag ID	Duration (hrs:min)
8-Jan-19	17:37	36.98544	-75.90125	*M. novaeangliae*	DTAG	mn19_008a	2:17
12-Jan-19	19:18	36.96142	-75.94956	*M. novaeangliae*	DTAG	mn19_012a	0:10
7-Mar-19	15:12	36.96097	75.98061	*M. novaeangliae*	DTAG	mn19_066a	6:29

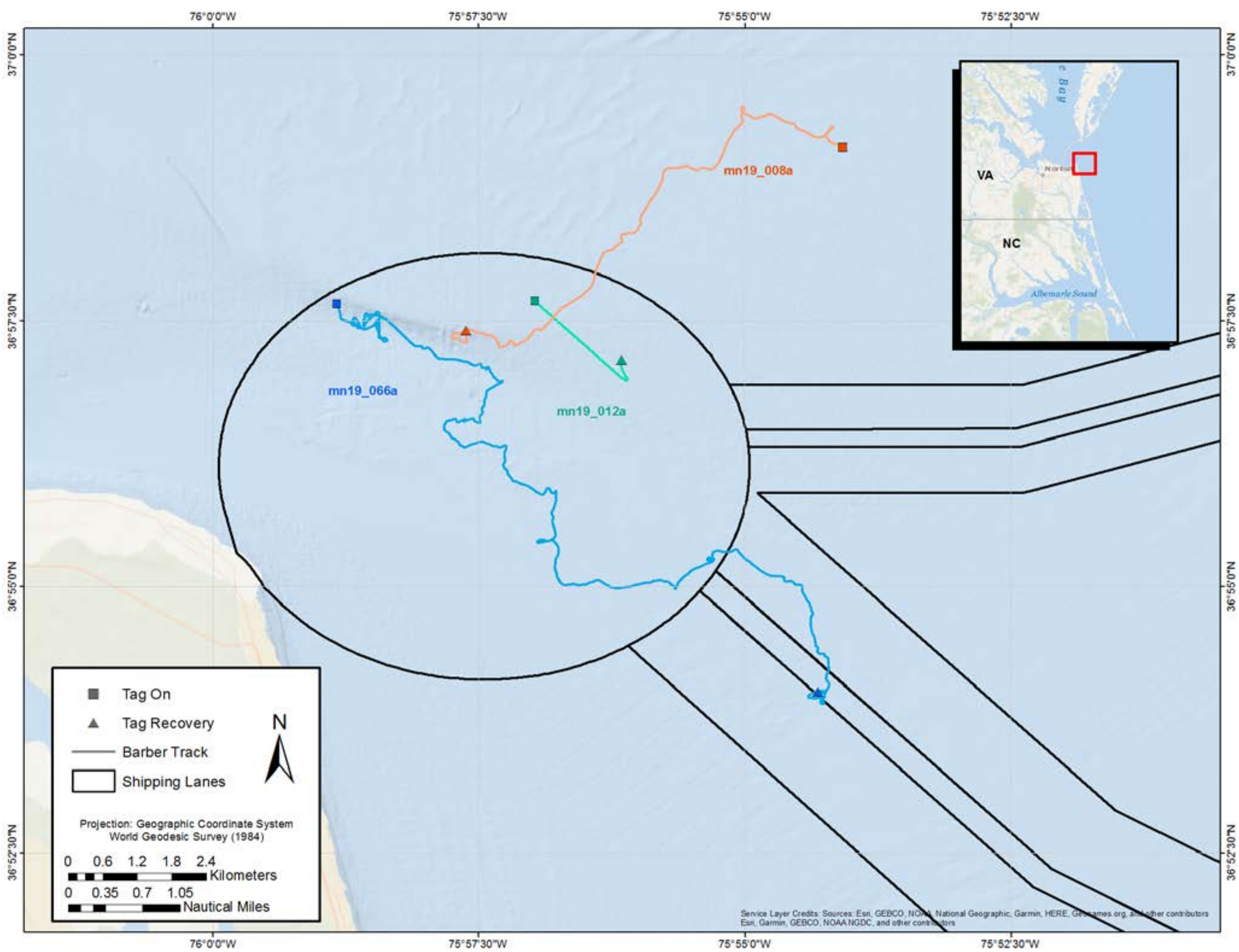

Figure 4. Tagging location and tag recovery location for all suction-cup deployments in the Virginia Beach shipping lanes study area in 2018/19. Each colored line represents the R/V Barber's track during the focal follow of the animal. Squares indicate locations of tagging and triangles indicate tag recovery locations.

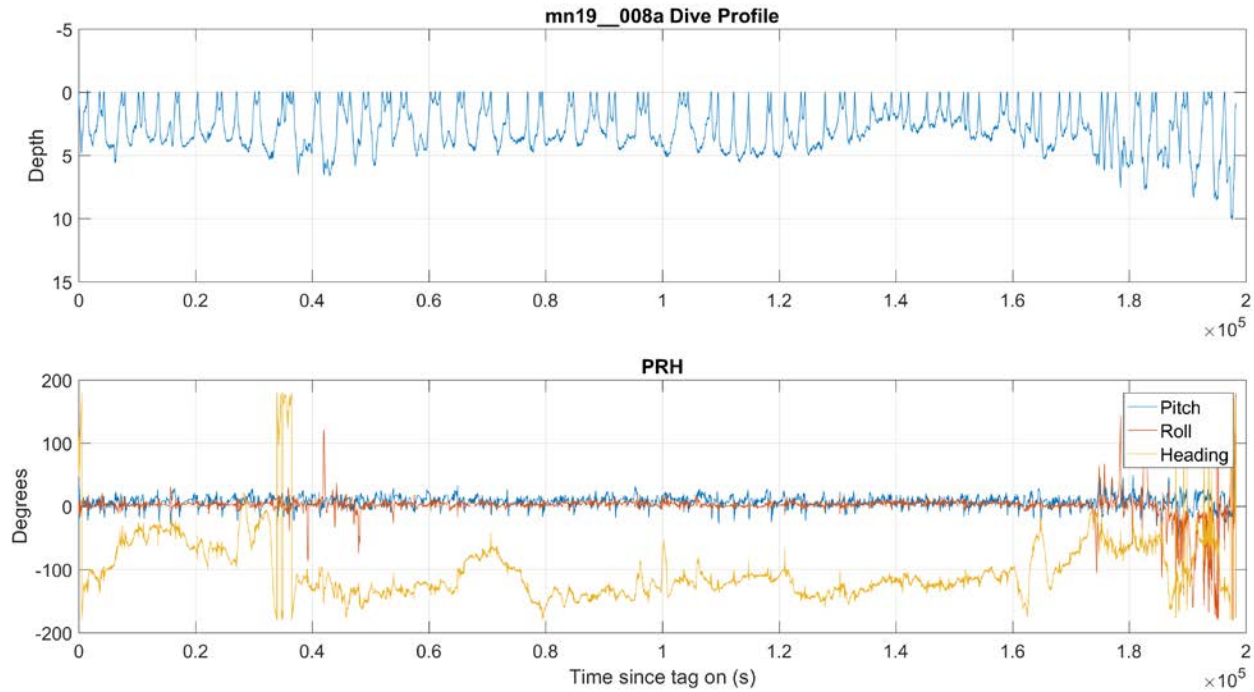

Figure 5. Dive depth profile and accelerometry metrics (pitch, roll, and heading) for tagged animal mn19_008a.

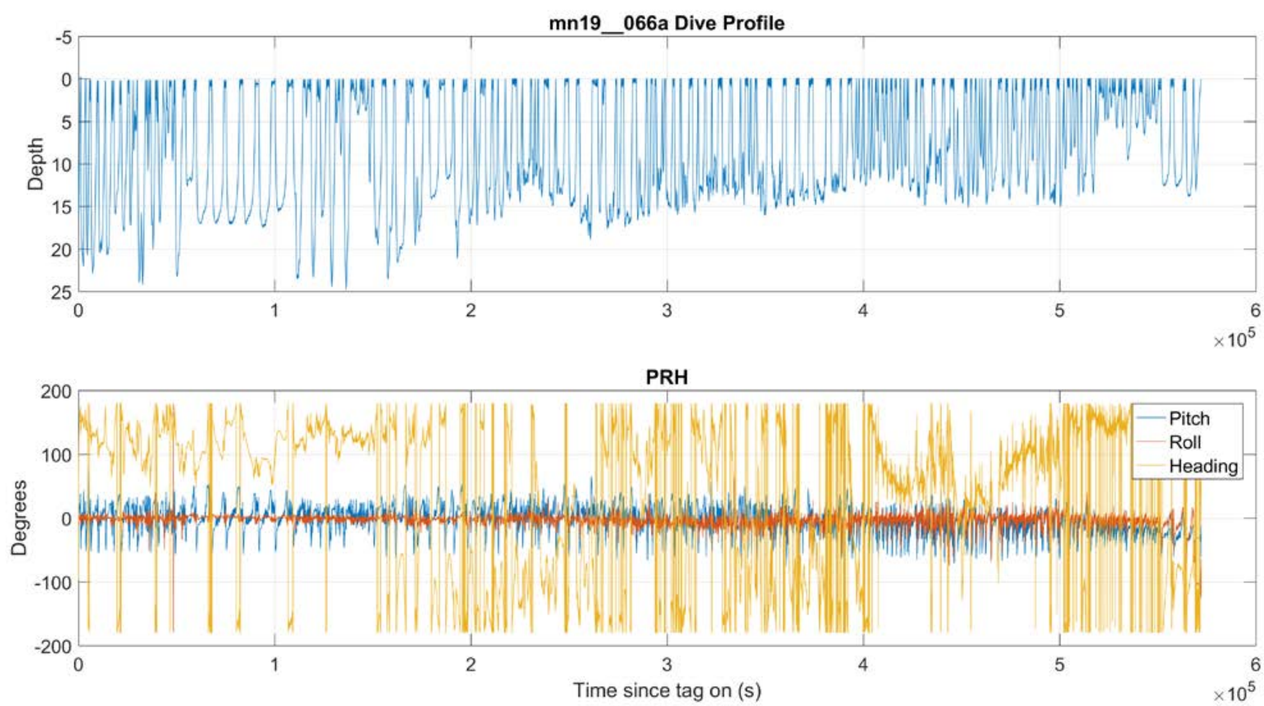

Figure 6. Dive depth profile and accelerometry metrics (pitch, roll, and heading) for tagged animal mn19_066a.

3.1.4 Focal Follows

Focal follow data was collected for the duration of both the January 8th and the March 7th tag deployment. Data are currently being processed, including using the animal's distance and bearing from the research vessel and the research vessel's GPS track to recreate the animal's positions.

3.1.5 Ship positions

AIS data were collected from the R/V Barber during both tag deployments to determine the locations of all large ships during the focal follow. These data are in the process of being decoded. Ship distance and bearing estimates collected by the team are also being processed to obtain positions of small boats that were not transmitting AIS. Finally, the SeaLink Advanced Analytics (S2A) system was used to recreate large ship tracks using AIS and RADAR (**Figure 7, 8**). There were considerably more ships near the animal during the tag deployment on March 7th compared to January 8th. A comparison of these methods will be completed before planning begins for the next field season to determine redundancies and accuracy of the systems.

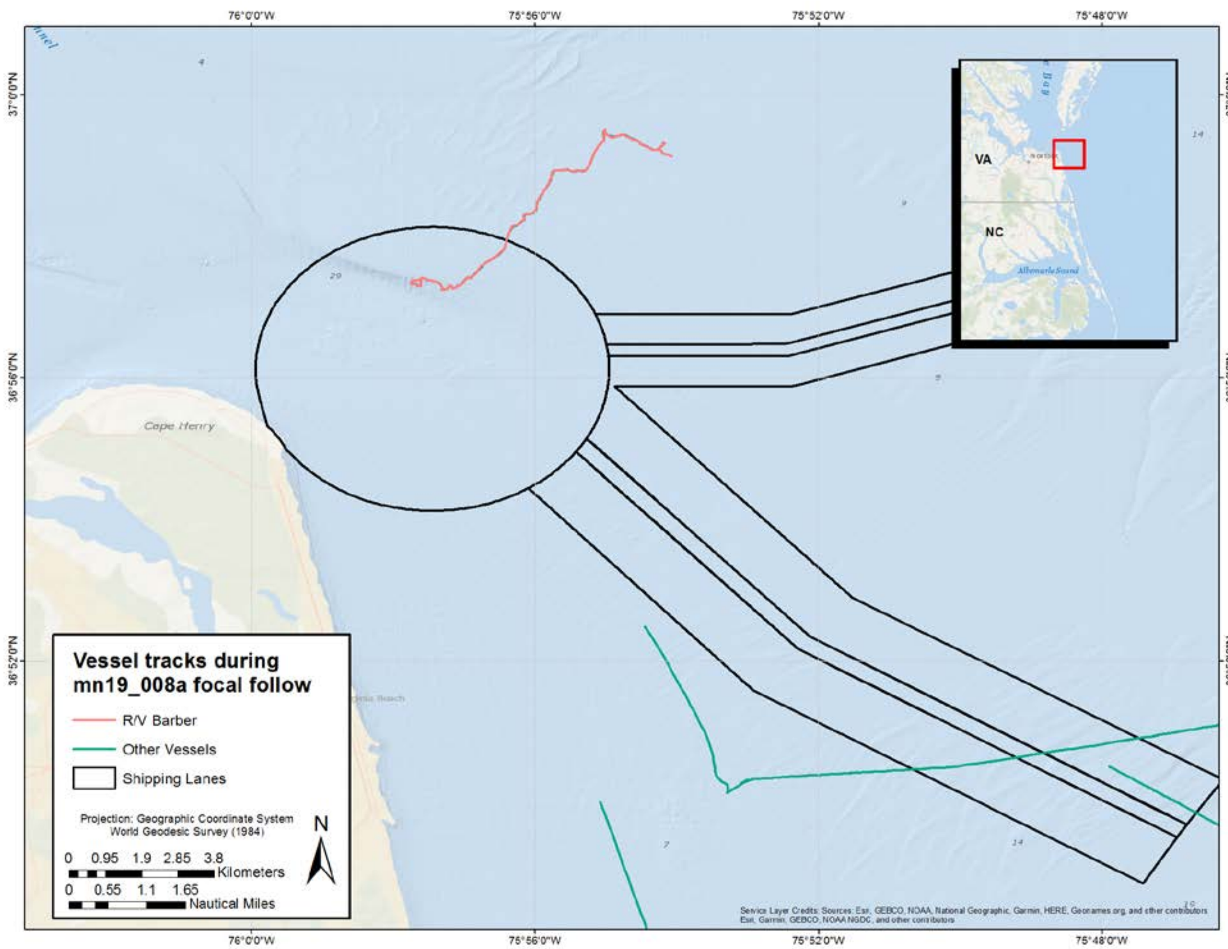

Figure 7. Ship locations taken from the S2A system during the tag deployment of tagged animal mn19_008a. The R/V Barber (travelling near the animal for the duration) is shown in red while the other ships are shown in green. Ship locations included are those that overlap in time with any point on the tag record. Proximity or crossing tracks does not indicate that the ship and animal were in the same location at the same time.

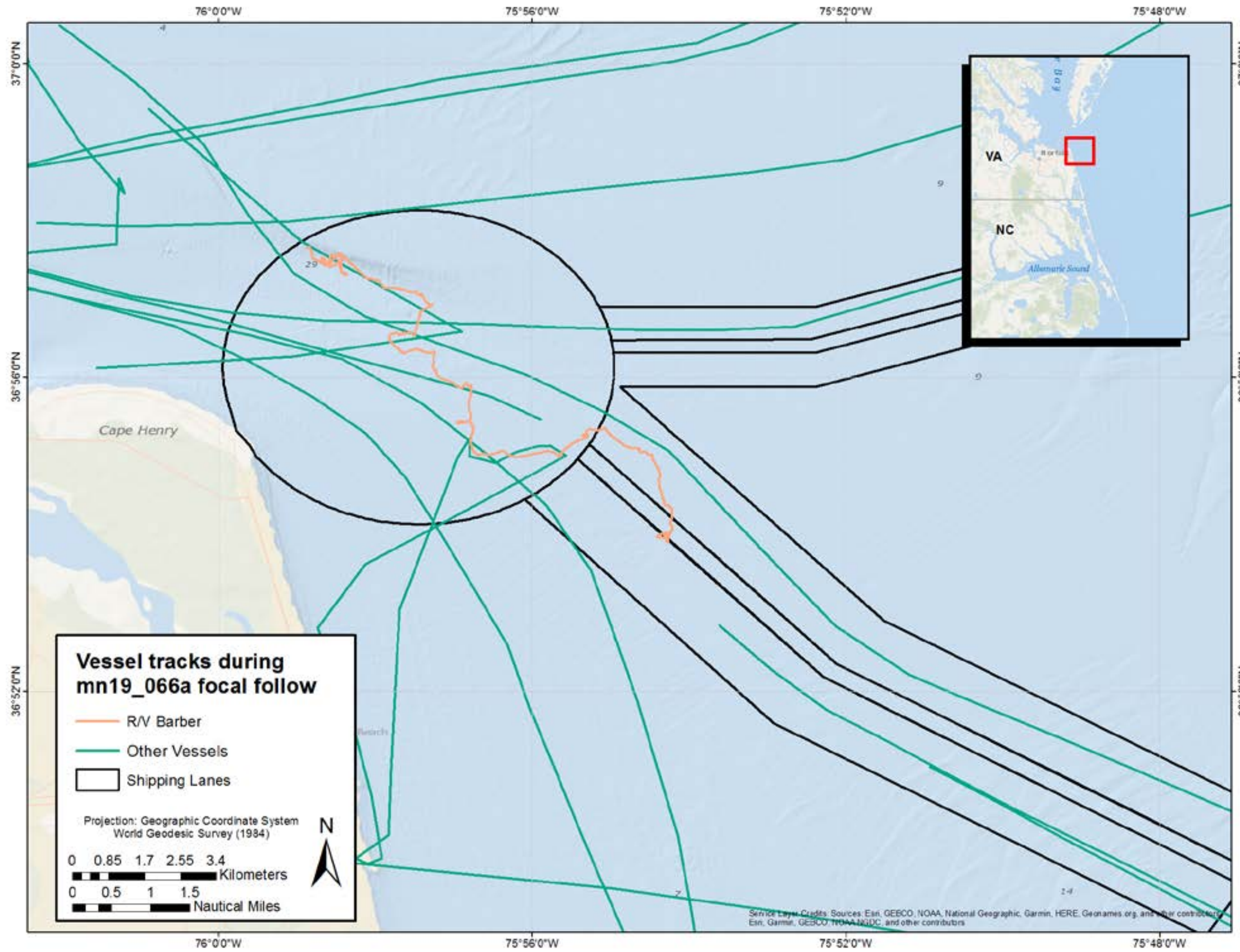

Figure 8. Ship locations taken from the S2A system during the tag deployment of tagged animal mn19_066a. The R/V Barber (travelling near the animal for the duration) is shown in red while the other ships are shown in green. Ship locations included are those that overlap in time with any point on the tag record. Proximity or crossing tracks does not indicate that the ship and animal were in the same location at the same time.

4. Discussion and Future Analysis

The low sample size for this year of the project precludes conclusions being drawn about humpback whale responses to ships in this area. However, this pilot project allows for validation of methods and the development of analytical tools to process and analyze the data. Analytical tools currently being developed and streamlined include:

- *conversion of animal distance and bearing from research vessel into lat/long positions*
- *decoding AIS data into ship positions and time stamps*
- *acoustically detecting ship approaches on tag records (which will also allow for analysis of previous tag records with no focal follows)*
- *tools to deconstruct high-resolution accelerometer and magnetometer data into biologically meaningful movement metrics, such as turning rates and overall body acceleration*

Additional fieldwork is planned for the winter 2019/2010 season, with hopes to improve sample size to offer statistically significant results. Preliminary observations from this field season are promising, with at least one clear avoidance of a ship documented in the field. In addition, next field season we will be exploring options to increase tag durations, potentially increasing the duration of focal follows as well as boat exposures overnight and without the research vessel present. We are also exploring opportunities to work further with HDR, Inc. to DTAG animals they have satellite tagged, in order to both improve location accuracy for the vessel response project and to inform diving behavior for longer duration satellite tags with high resolution DTAGs. These projects will contribute to ongoing efforts to understand the behavior of juvenile humpback whales in the Virginia Beach area and to begin to understand risk factors and potential mitigation measures for ship strikes.

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