Behavioral Responses of Humpback Whales to Approaching Ships in Virginia Beach, Virginia: 2020 Annual Progress Report

Submitted to:

Naval Facilities Engineering Systems Command Atlantic under Contract N62470-15-8006, Task Order 20F4011 and Contract N62470-20-D-0016, Task Order 21F4005 issued to HDR, Inc.

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Submitted by:

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Virginia Beach, VA

April 2021

Suggested Citation:

Shearer, J.M., Z.T. Swaim, H.J. Foley, and A.J. Read. 2021. *Behavioral Responses of Humpback Whales to Approaching Ships in Virginia Beach, Virginia: 2020 Annual Progress Report.* Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Systems Command Atlantic, Norfolk, Virginia, under Contract N62470-15-8006, Task Order 20F4011, and Contract N62470-20-D-0016, Task Order 21F4005 issued to HDR Inc., Virginia Beach, Virginia. April 2021.

Cover Photo Credit:

Humpback whale (*Megaptera novaeangliae*) with DTAG near the shipping lanes. Photographed by Zach Swaim, Duke University, taken under General Authorization 16185 held by Andrew Read, Duke University.

This project is funded by U.S. Fleet Forces Command and managed by Naval Facilities Engineering Systems Command Atlantic as part of the U.S. Navy's marine species monitoring program.

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Acronyms and Abbreviations

AIS	Automatic Identification System
CBBT	Chesapeake Bay Bridge-Tunnel
DTAG	digital acoustic tag
GPS	Global Positioning System
R/V	research vessel
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 and 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 state-space model-indicated Area Restricted Search behavior (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 8 January 2021), 145 humpback whales have stranded on the U.S. East Coast, causing the National Marine Fisheries Service to declare an Unusual Mortality Event (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. 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, 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 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 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 is anticipated to run from January through march 2021.

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.

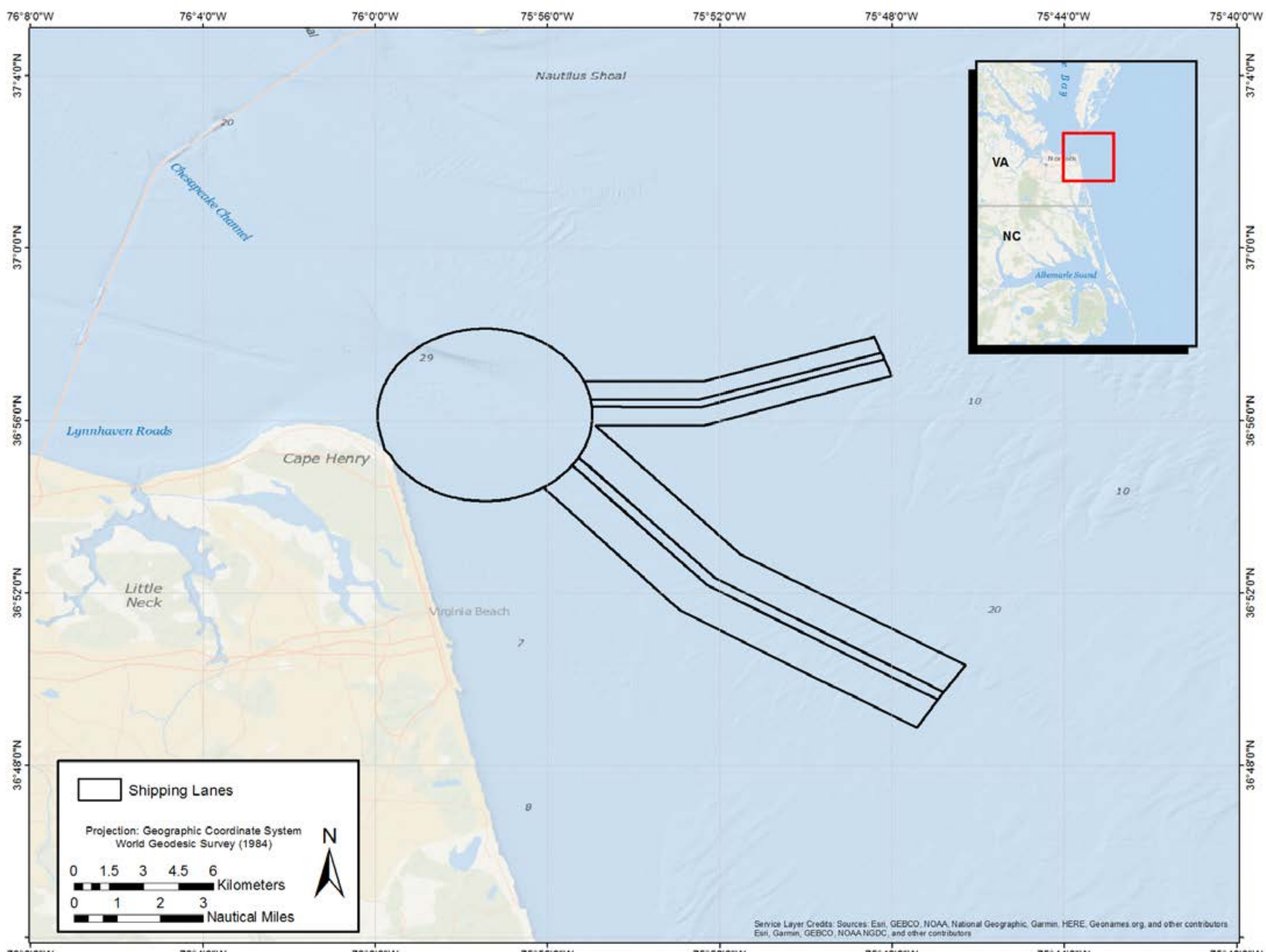

Figure 1. Map of the Virginia Beach study area, including the shipping lanes into the area.

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-create the animal's track. The other two team members 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 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 (**Figure 3**). 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 (**Figure 3**). Because the jerk varies depending on tag placement and tag slides, 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 (**Figure 4)**. These rolling lunges were detected if the animal exhibited a greater than 50 degree roll 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). We also identified a number of potential lunges in the tag records in which animals exhibited some, but not all, of our criteria (**Figure 5)**. We marked these as 'potential lunge events' and plan to solicit expert opinion from other humpback whale researchers to determine if these are also foraging events. In some cases, these potential lunges failed our criteria because they did not exhibit an increase and drop in flow noise due to high levels of ship noise masking.

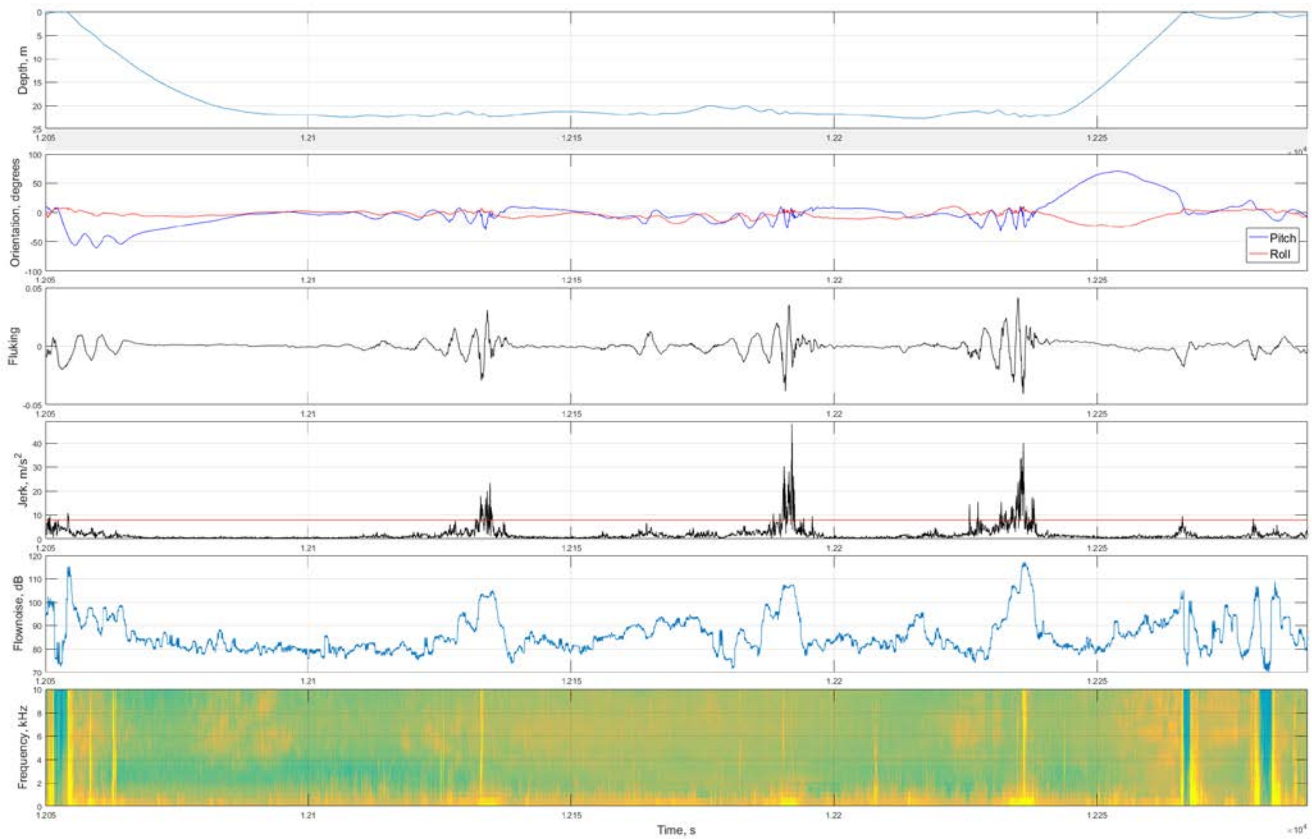

Figure 3. Example of three clear lunges from tag mn20_040a. The red horizontal line in the 4th panel indicates the jerk threshold for this section. This figure covers 240 seconds to show the entire dive.

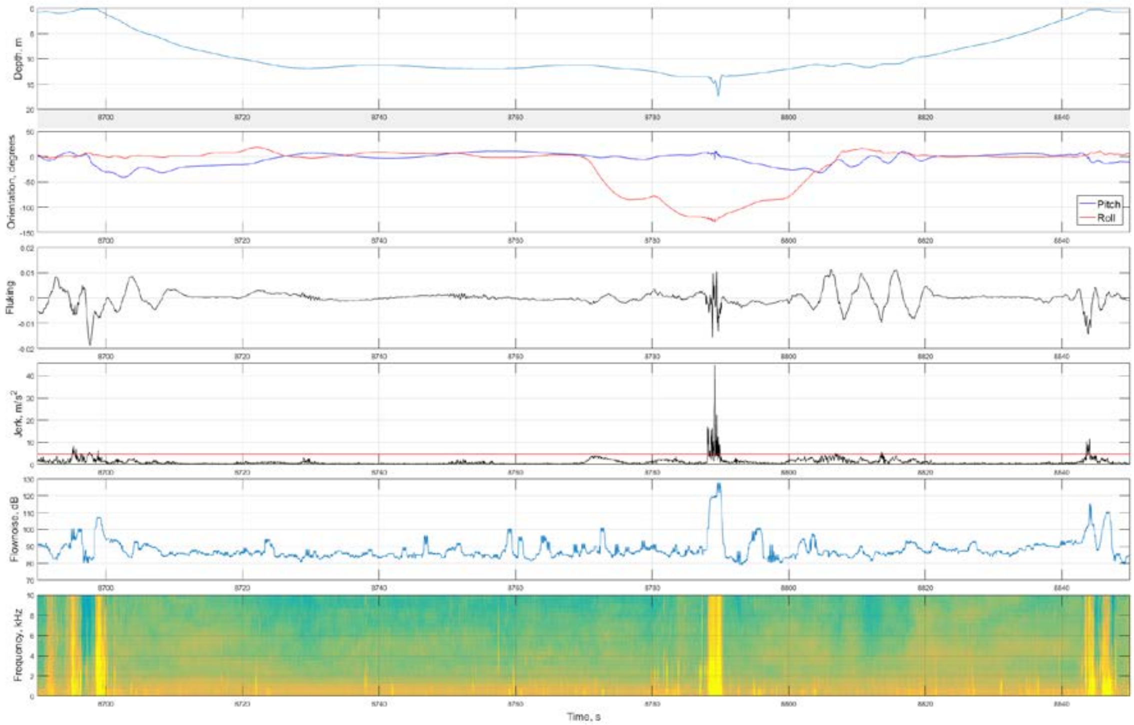

Figure 4. Example of a rolling lunge from tag mn20_040a. The red horizontal line in the 4th panel indicates the jerk threshold for this section. The broadband sound at 8790s appears to be the impact of the tag hitting the seafloor. This figure covers 160 seconds to show the entire dive.

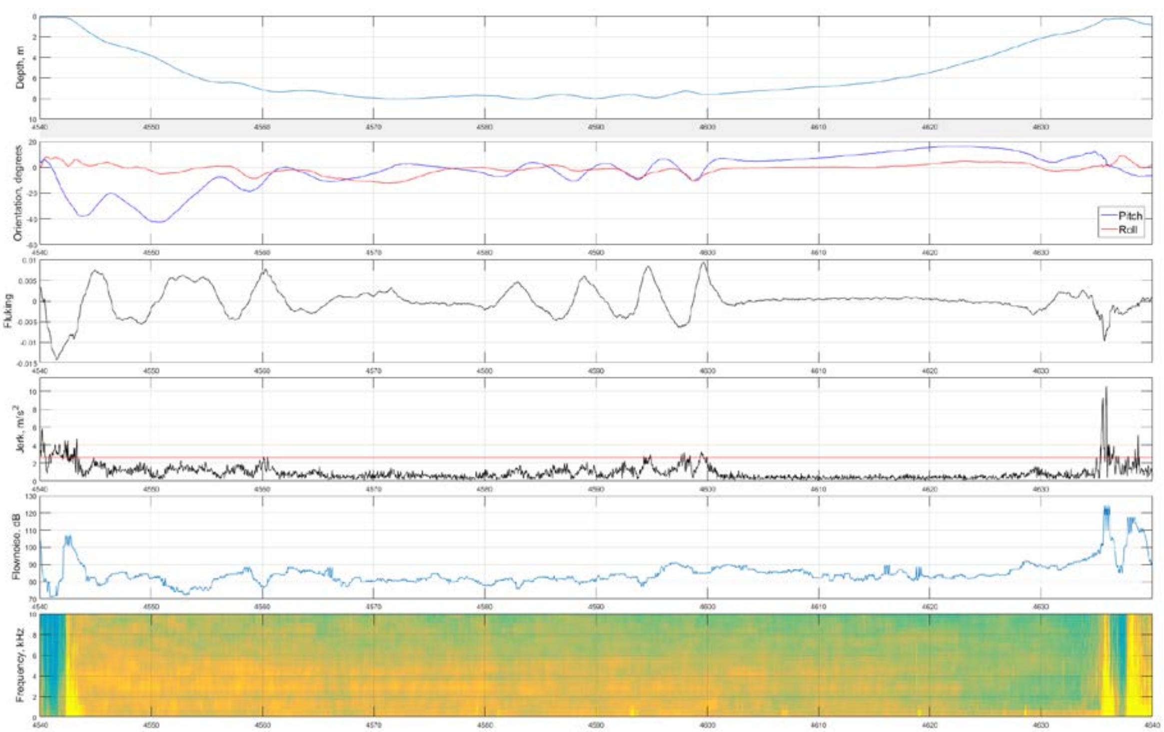

Figure 5. A potential lunge from tag mn20_040a. The red horizontal line in the 4th panel indicates the jerk threshold for this section. Flow noise is masked by ship noise and the jerk signal is just over the threshold. This figure covers 100 seconds to show the entire dive.

3. Results

3.1.1 Vessel Survey Effort

Ten days of suction-cup tagging effort were conducted in the Virginia Beach shipping lanes in the 2019-2020 season, totaling 640 kilometers during 60 hours of survey effort (**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 2019-2020.

Date	Sea State	Km surveyed	Survey Time (hrs:min)	At Sea Time (hrs:min)	Platform
15-Jan-20	1-2	67.3	8:54	9:17	R/V *R.T. Barber*
3-Feb-20	1-2	74.8	8:29	9:11	R/V *R.T. Barber*
4-Feb-20	2	68.9	6:07	6:57	R/V *R.T. Barber*
8-Feb-20	2-3	44.2	4:18	5:07	R/V *R.T. Barber*
9-Feb-20	2	103.7	8:39	9:16	R/V *R.T. Barber*
10-Feb-20	2-4	35.1	3:10	4:16	R/V *R.T. Barber*
22-Feb-20	2	40.8	3:56	4:21	R/V *R.T. Barber*
23-Feb-20	2	109.8	7:51	9:16	R/V *R.T. Barber*
24-Feb-20	1-3	72.3	6:49	7:30	R/V *R.T. Barber*
25-Feb-20	3-4	22.0	1:31	2:06	R/V *R.T. Barber*

3.1.2 Humpback Whale Sightings

Humpback whales were sighted on 19 occasions totaling 25 whales (**Table 2, Figure 6**). Single animals were the most common (14 of 19 sightings), followed by groups of two. No whales were observed in groups larger than three animals.

Table 2. Humpback whale sightings observed during suction-cup tagging in the Virginia Beach shipping lanes study area in 2019–2020.

Date	Time (UTC)	Latitude	Longitude	Species	Common Name	Group Size	Tags Deployed	Photo-ID Images
15-Jan-20	14:40	36.86417	-75.87783	*M. novaeangliae*	Humpback whale	2	mn20_015a	730
3-Feb-20	14:55	36.90942	-75.88525	*M. novaeangliae*	Humpback whale	1	mn20_034a	313
3-Feb-20	21:18	36.96595	-75.96486	*M. novaeangliae*	Humpback whale	1	0	43
4-Feb-20	14:49	36.95708	-76.01071	*M. novaeangliae*	Humpback whale	1	0	107
4-Feb-20	17:39	36.95614	-76.01187	*M. novaeangliae*	Humpback whale	2	0	160
4-Feb-20	19:09	36.96656	-76.02108	*M. novaeangliae*	Humpback whale	1	0	5
8-Feb-20	18:40	36.93834	-75.93129	*M. novaeangliae*	Humpback whale	1	0	23
8-Feb-20	19:42	36.93120	-75.91381	*M. novaeangliae*	Humpback whale	1	0	78
8-Feb-20	20:20	36.92272	-75.89685	*M. novaeangliae*	Humpback whale	1	0	160
9-Feb-20	14:16	36.96866	-76.04811	*M. novaeangliae*	Humpback whale	1	mn20_040a	127
9-Feb-20	18:29	36.91082	-75.92914	*M. novaeangliae*	Humpback whale	1	mn20_040b	381
10-Feb-20	14:07	36.95796	-76.08530	*M. novaeangliae*	Humpback whale	1	mn20_040a (retrieved)	159
22-Feb-20	15:28	36.86006	-75.85291	*M. novaeangliae*	Humpback whale	1	mn20_053a	230
23-Feb-20	15:45	37.04255	-75.75531	*M. novaeangliae*	Humpback whale	2	0	345
23-Feb-20	17:09	37.01633	-75.72632	*M. novaeangliae*	Humpback whale	1	mn20_054a	355
24-Feb-20	14:46	36.93432	-75.9342	*M. novaeangliae*	Humpback whale	1	0	32
24-Feb-20	15:24	36.95182	-75.96119	*M. novaeangliae*	Humpback whale	1	0	285
25-Feb-20	17:22	36.91949	-75.96233	*M. novaeangliae*	Humpback whale	3	0	27
25-Feb-20	17:58	36.90738	-75.92103	*M. novaeangliae*	Humpback whale	2	0	46

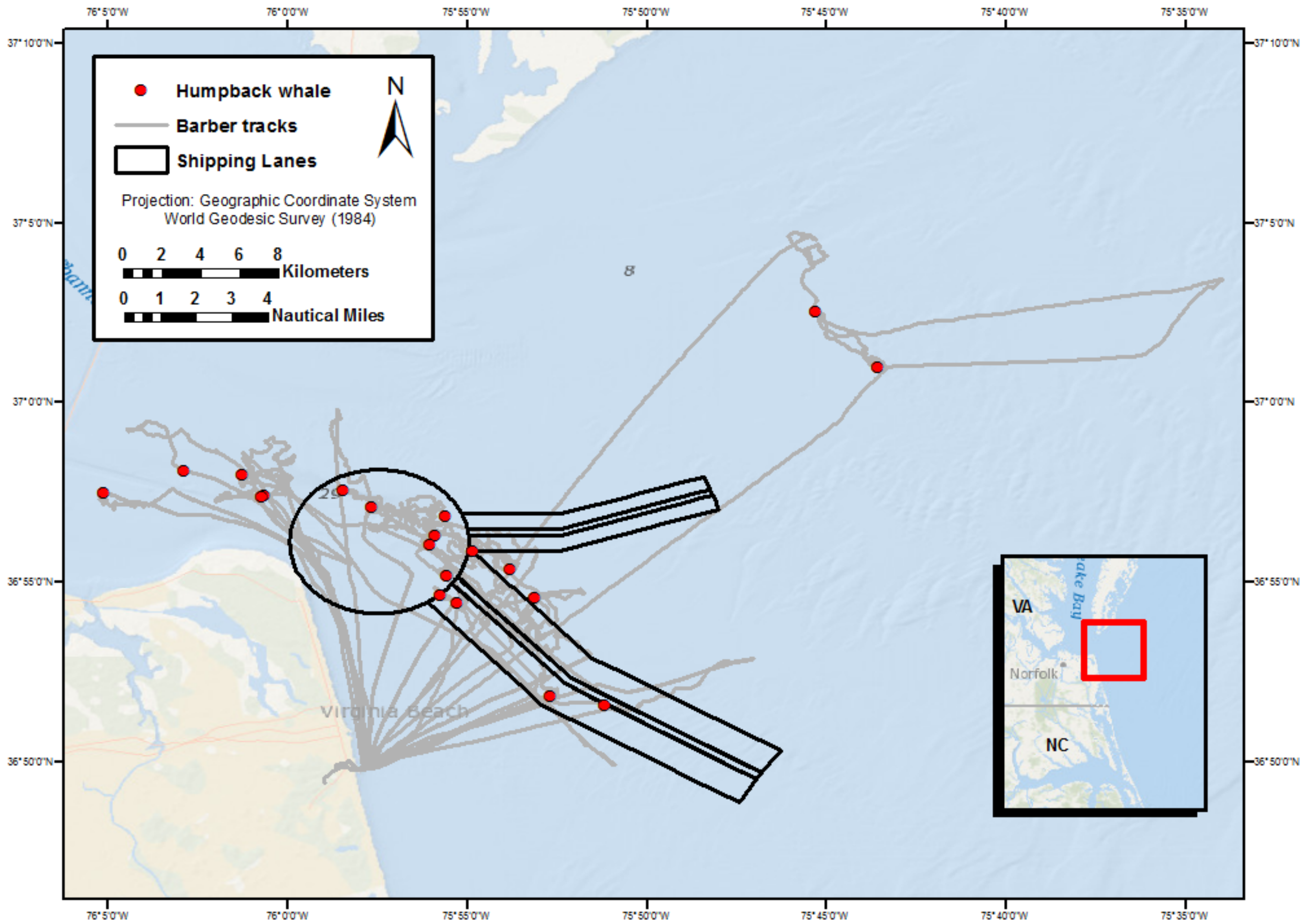

Figure 6. Survey tracks and locations of all sightings during humpback whale suction-cup tagging effort in the Virginia Beach shipping lanes study area in 2019/20.

3.1.3 DTAGs Deployed

Six DTAGs were deployed on humpback whales during the 2019–2020 season (**Table 3, Figure 7)**. Two tags were deployed on humpbacks already tagged with a satellite tag by HDR, Inc. (mn20_040a and mn20_053a). Five tags were deployed in or near the shipping lanes; 1 tag was deployed offshore (mn20_054a). Mn20_015a remained in the shipping lanes for the entirety of the deployment and spent most of its time foraging (**Figure 8)**. Mn20_034a covered nearly the same track as mn20_015a but showed little foraging behavior (**Figure 9)**. Instead, this animal vocalized for 3.2 hours of the deployment (See Section 3.1.6). A biopsy was not successfully obtained from this animal, so its sex is not known. Deployment mn20_040a lasted 25.5 hours, marking the first successful overnight DTAG in this area (**Figure 10)**. It showed clear lunges throughout the daytime hours, with reduced foraging effort at night (see Section 3.1.5 for detailed foraging description). This animal was satellite tagged by HDR (PTT 180779). Mn20_040b was exhibiting unusual logging behavior at the time of tagging. The tag was only attached by two of the four suction cups on the tag, complicating analysis of the accelerometry. The animal's dives were very shallow, with unusually slow ascents and no clear evidence of foraging (**Figure 11**). There were several recreational and commercial whale-watching boats in the area during the deployment. Given its unusual behavior, the field team watched closely for evidence of entanglement, but no gear was apparent. Deployment mn20_053a was also satellite tagged by HDR and was programmed as an overnight tag. This animal was tagged in the shipping lanes, but soon after tagging, travelled east offshore (**Figure 12)**. The focal follow was discontinued due to worsening offshore conditions and the tag was recovered the following morning approximately 20 nautical miles offshore after having released from the animal 7 hours into the deployment. After 3 hours of deployment, the animal breached several times on the tag and the acceleration data become unstable after this point, likely caused by one or more suction cups becoming dislodged. Mn20_054a was tagged offshore and showed several foraging attempts (**Figure 13**).

Table 3. Suction-cup tag information from deployments on humpback whales in the Virginia Beach shipping lanes study area in 2019–2020. Deployments mn20_040a and mn20_053a were on animals also tagged with satellite tags by HDR, Inc (PTT 180779 and 180778, respectively.

Date	Time (UTC)	Latitude	Longitude	Species	Tag Type	Tag ID	Duration (hrs:min)
15-Jan-20	15:52	36.8853	-75.8848	*M. novaeangliae*	DTAG	mn20_015a	7:39
3-Feb-20	16:00	36.8915	-75.8759	*M. novaeangliae*	DTAG	mn20_034a	4:37
9-Feb-20	14:26	36.9754	-76.0521	*M. novaeangliae*	DTAG	mn20_040a	25:33
9-Feb-20	18:55	36.8989	-75.9161	*M. novaeangliae*	DTAG	mn20_040b	2:05
22-Feb-20	16:03	36.8616	-75.8336	*M. novaeangliae*	DTAG	mn20_053a	6:58
23-Feb-20	18:09	37.0242	-75.7320	*M. novaeangliae*	DTAG	mn20_054a	3:05

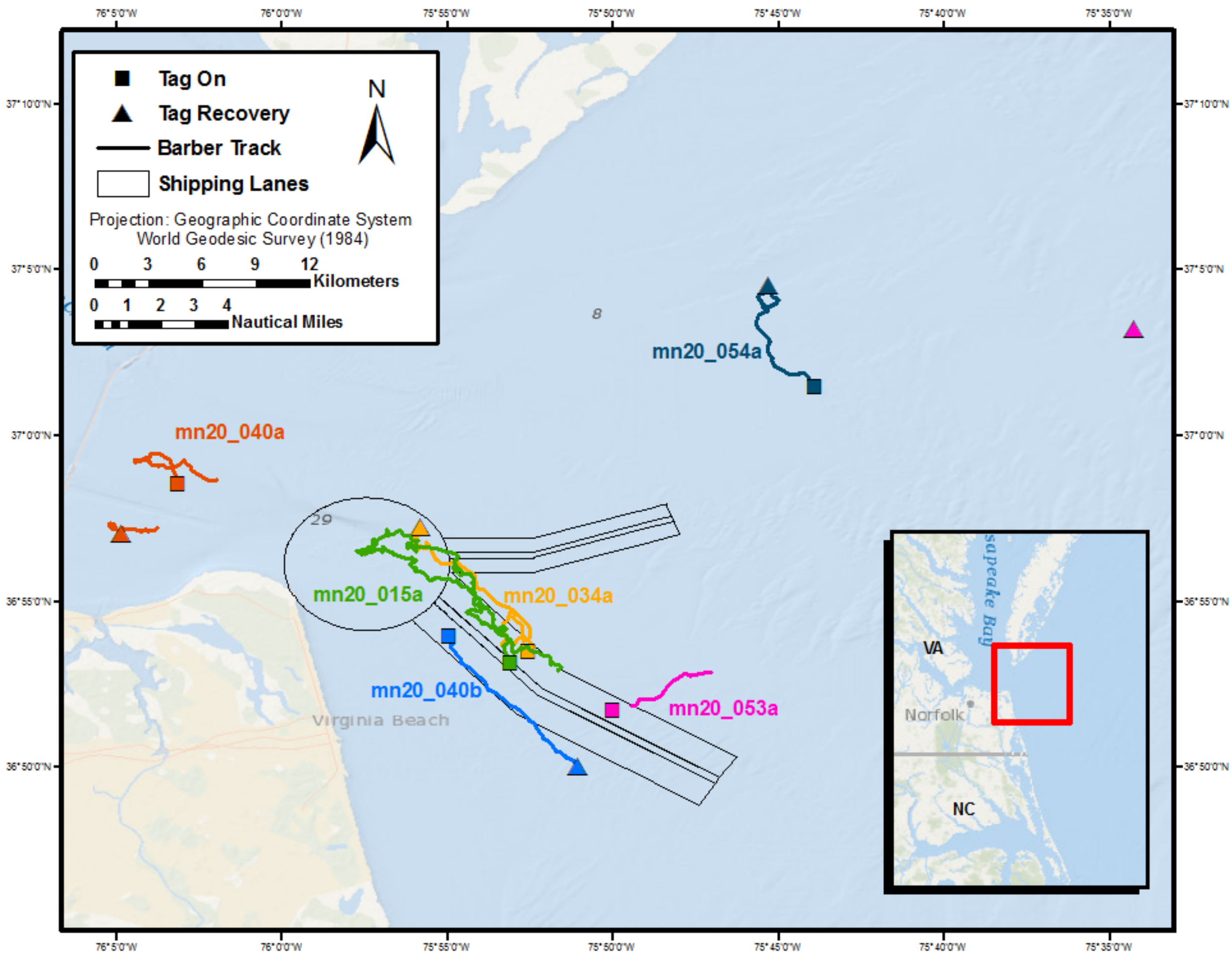

Figure 7. Tagging location and tag recovery location for all suction-cup deployments in the Virginia Beach shipping lanes study area in 2019/20. Each colored line represents the R/V Barber's track during the focal follow of the animal. Squares indicate locations of tagging and triangles indicate tag recovery locations.

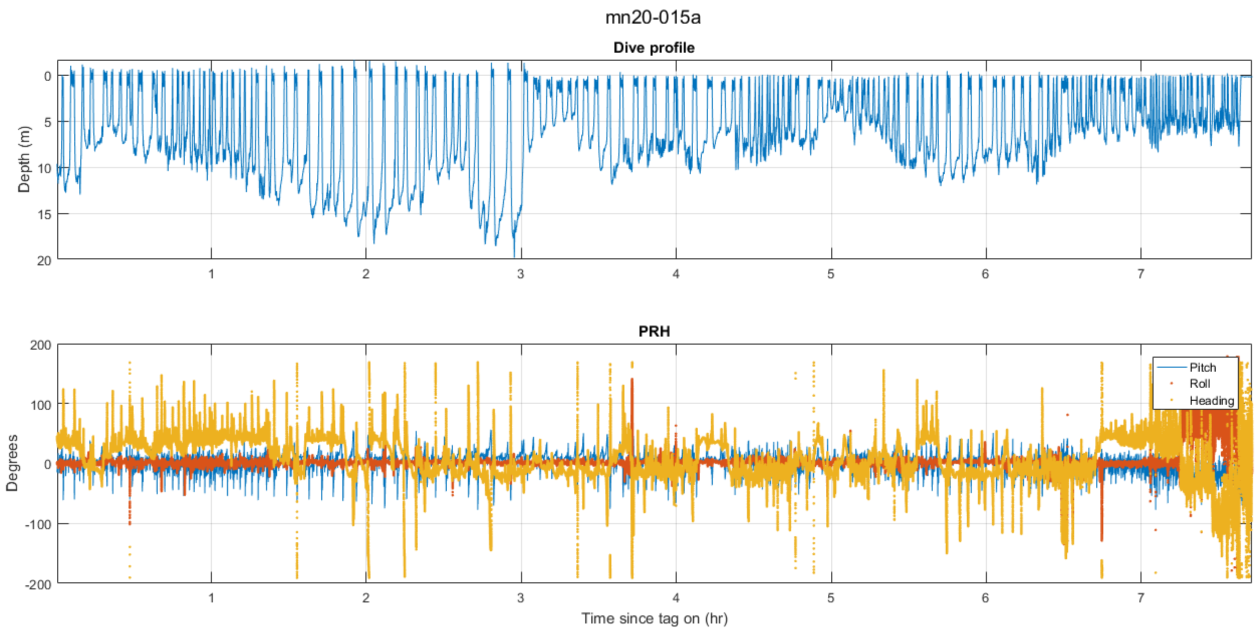

Figure 8. Dive-depth profile and accelerometry metrics (pitch, roll, and heading) for tagged animal mn20_015a.

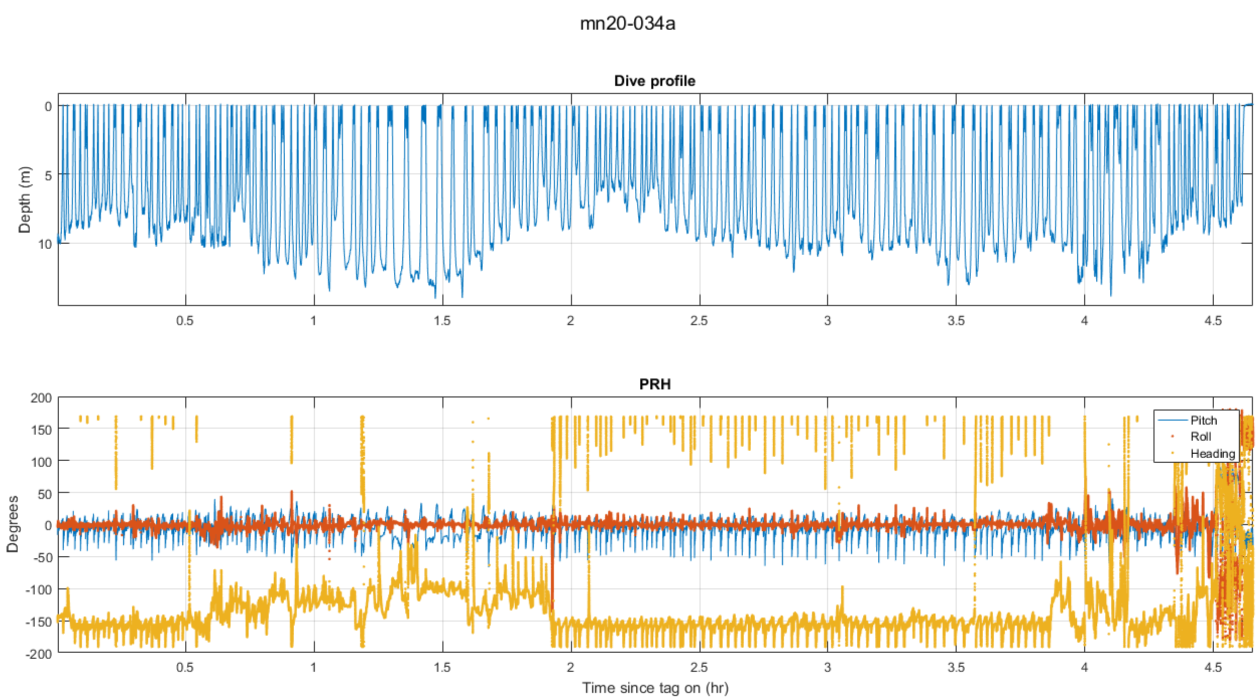

Figure 9. Dive-depth profile and accelerometry metrics (pitch, roll, and heading) for tagged animal mn20_034a.

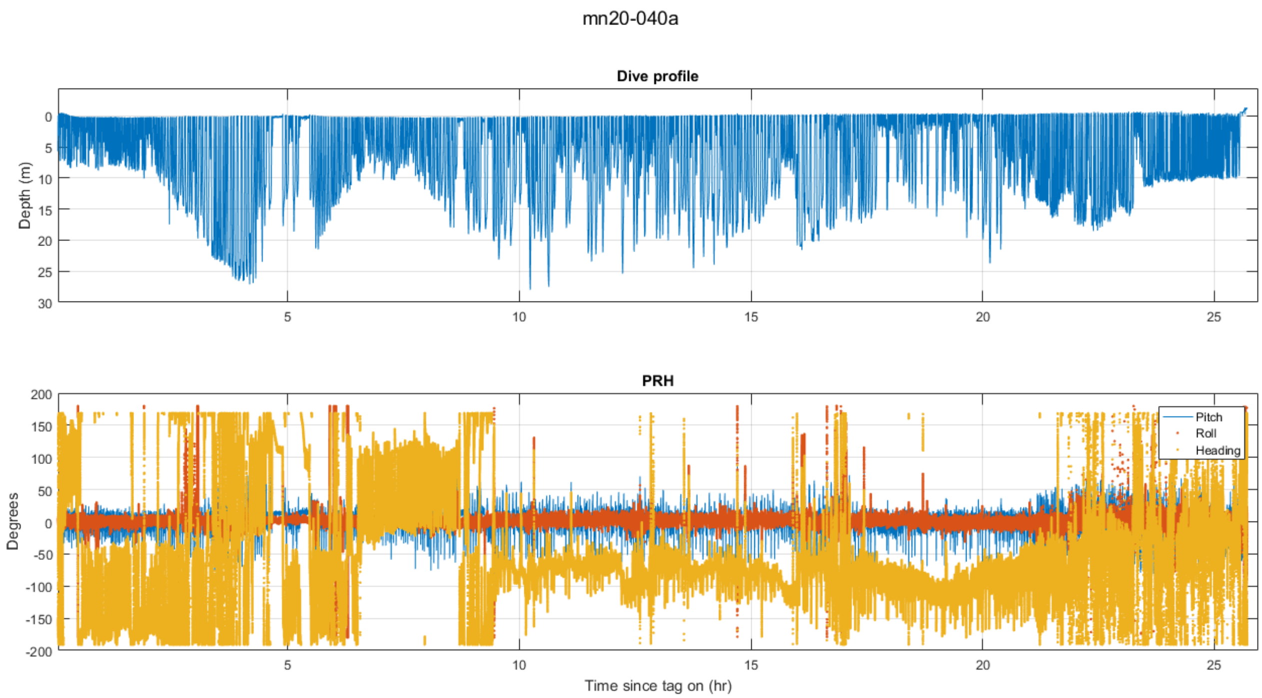

Figure 10. Dive-depth profile and accelerometry metrics (pitch, roll, and heading) for tagged animal mn20_040a.

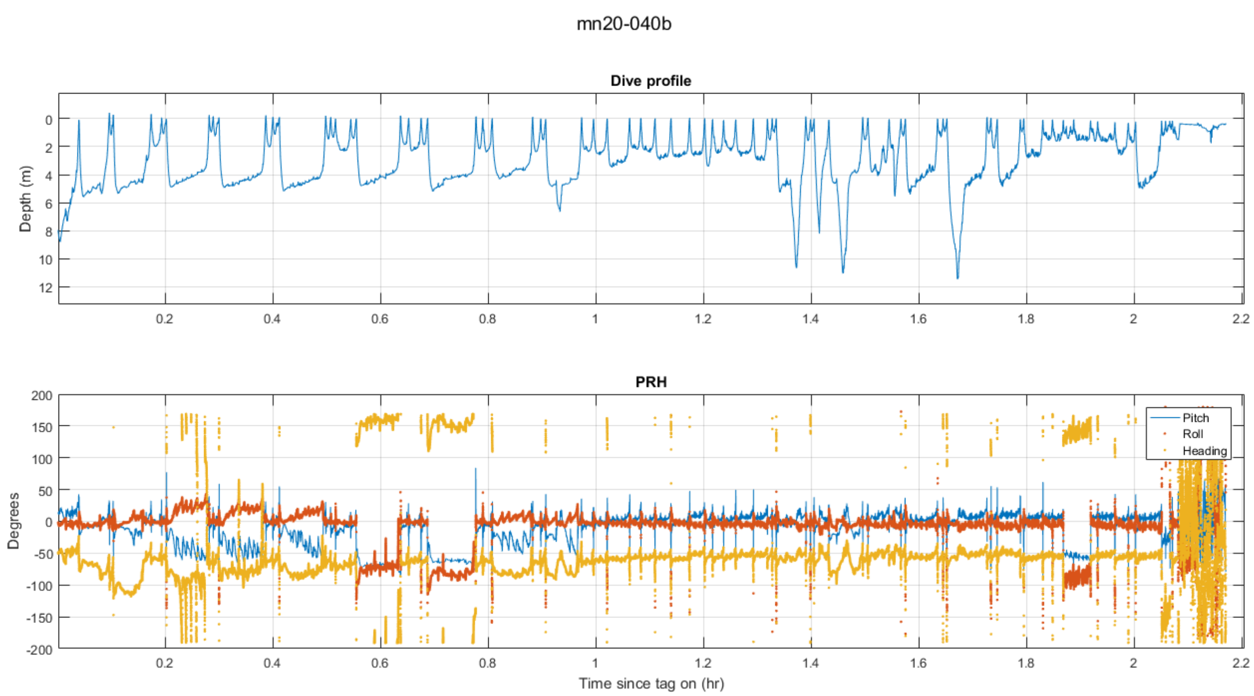

Figure 11. Dive-depth profile and accelerometry metrics (pitch, roll, and heading) for tagged animal mn20_040b.

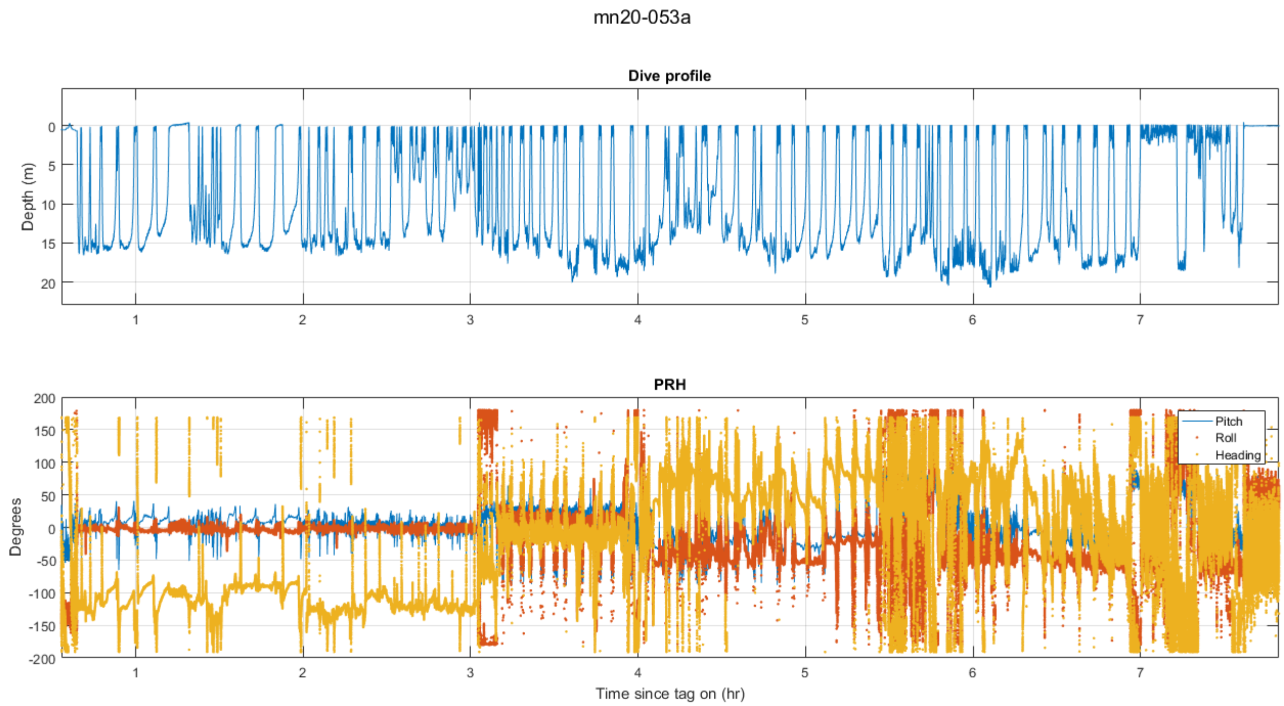

Figure 12. Dive-depth profile and accelerometry metrics (pitch, roll, and heading) for tagged animal mn20_053a. The whale appears to breach on the tag just after 3 hours into the deployment. The acceleration data after this point are highly unstable, indicating that the tag is being held by only 1 or 2 suction cups.

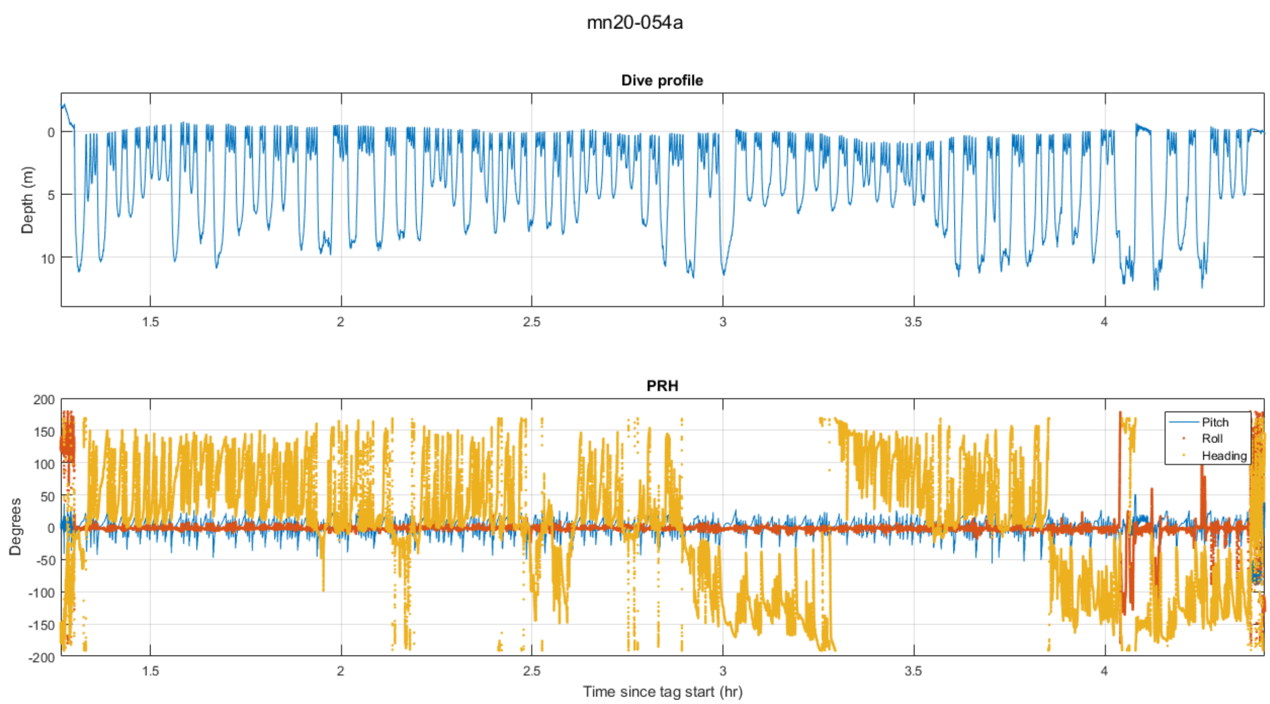

Figure 13. Dive-depth profile and accelerometry metrics (pitch, roll, and heading) for tagged animal mn20_054a.

3.1.4 Animal and ship positions

Focal-follow data were collected throughout most of the tag deployments except times when the team attempted to tag additional animals, during overnight hours, or in poor weather conditions. Each animal's distance and bearing from the known position of the research vessel were used to recreate the animal's position during the follows. Because of issues in decoding, AIS data were purchased from the VesselFinder database and used to determine the locations of all large ships during the focal follow. Figures 14 through 19 show animal positions from each focal follow along with ship tracks that occurred over the same time window. Because of the long deployment durations, ship tracks that cross or come near an animal position do not mean that the animal and ship were in the same location at the same time.

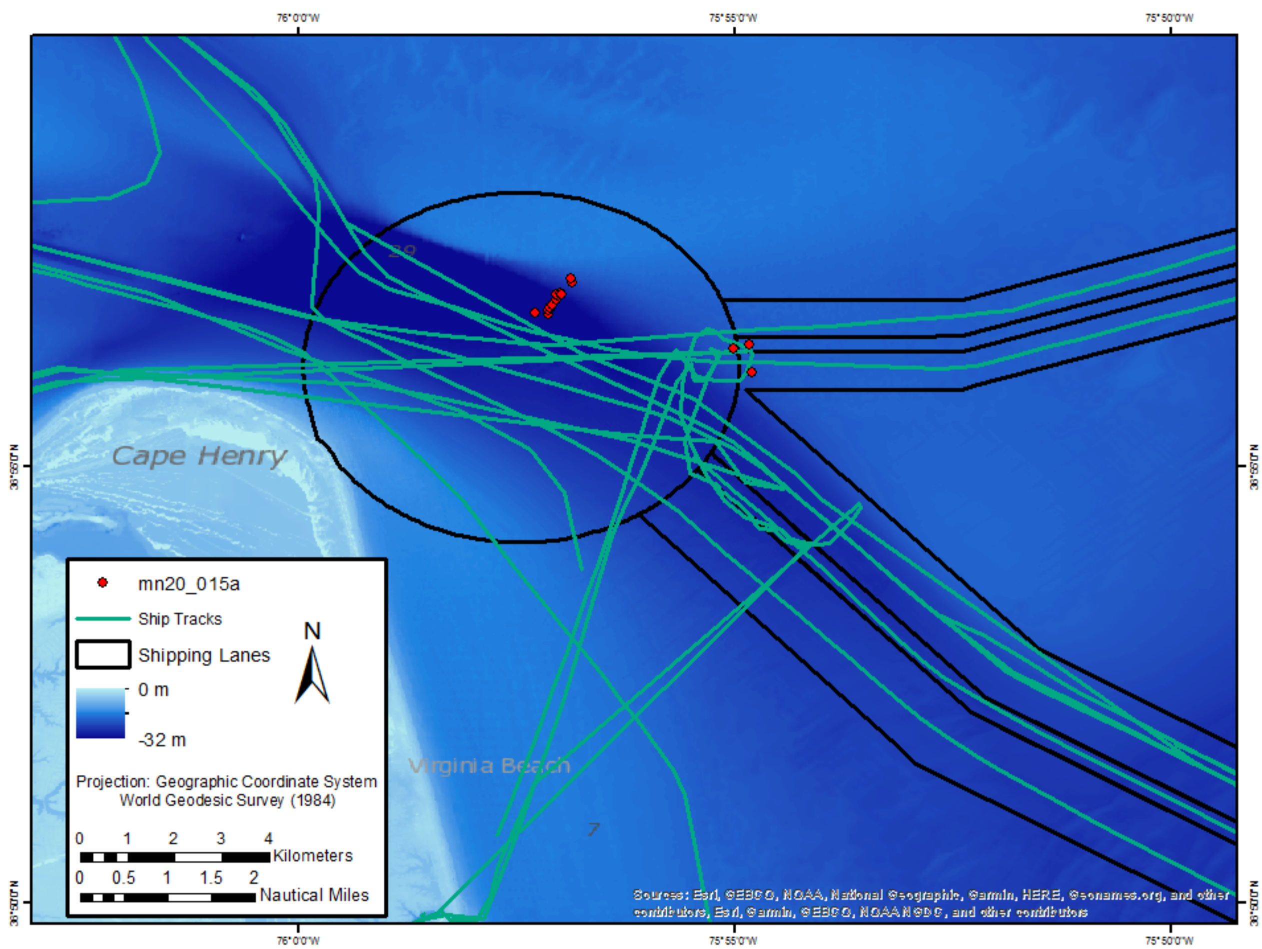

Figure 14. Whale positions (red circles) and ship tracks (green lines) for deployment mn20_015a. Whale positions are derived from the focal-follow distance and bearing and the Barber's GPS track. Ship positions were obtained from the VesselFinder AIS service. Ship locations included are those that overlap 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.

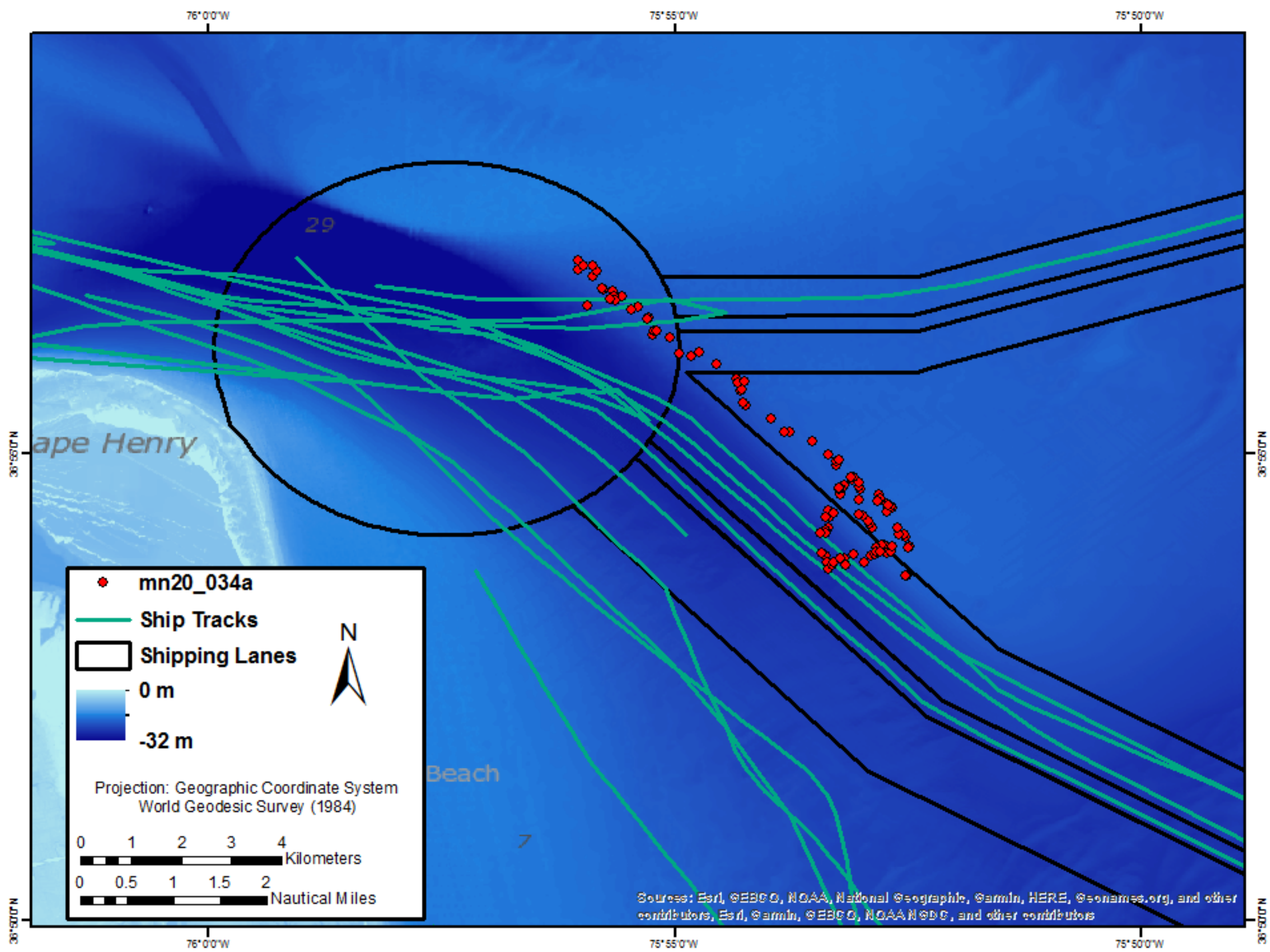

Figure 15. Whale positions (red circles) and ship tracks (green lines) for deployment mn20_034a. Whale positions are derived from the focal follow distance and bearing and the Barber's GPS track. Ship positions were obtained from the VesselFinder AIS service. Ship locations included are those that overlap 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.

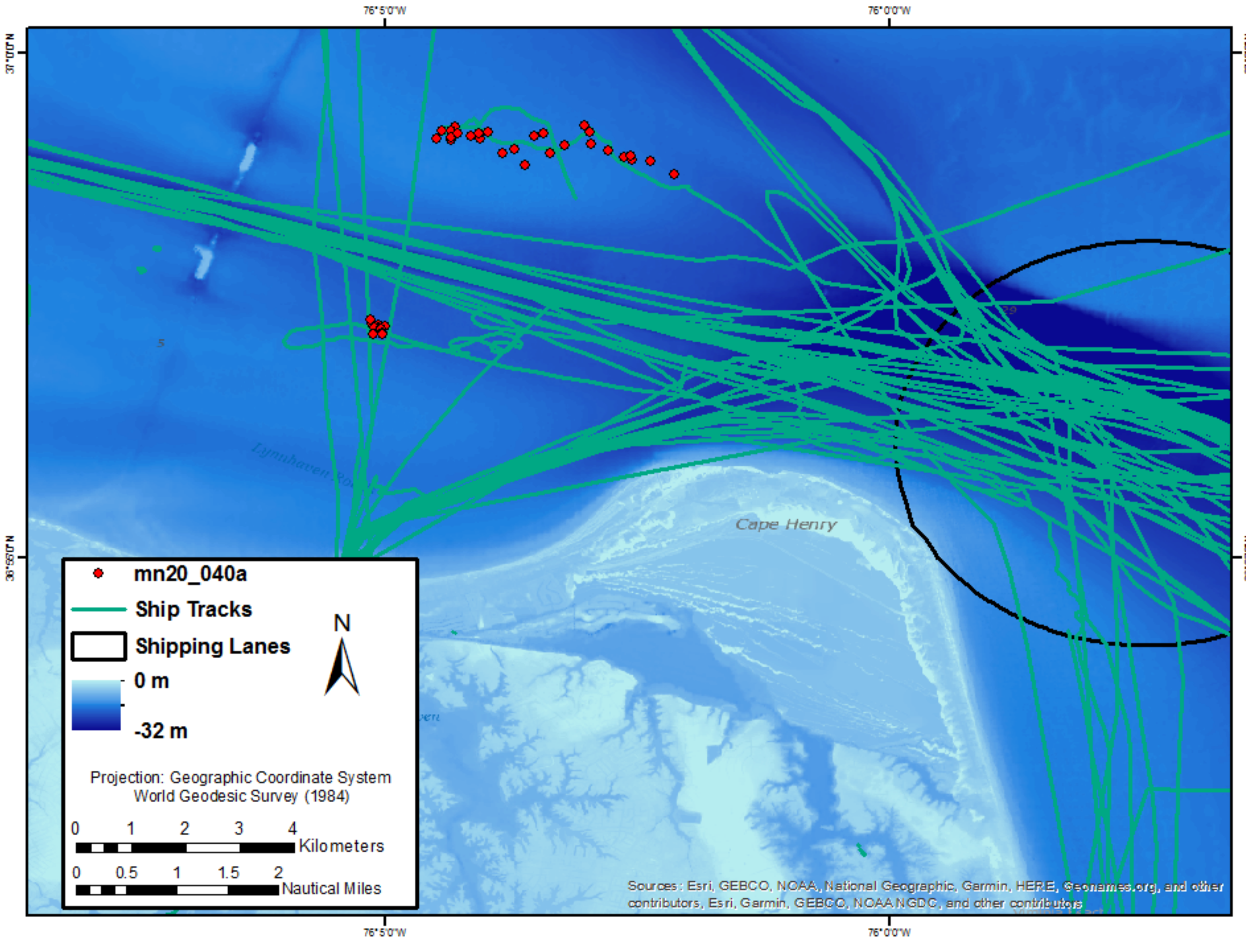

Figure 16. Whale positions (red circles) and ship tracks (green lines) for deployment mn20_040a. Whale positions are derived from the focal follow distance and bearing and the Barber's GPS track. Ship positions were obtained from the VesselFinder AIS service. Ship locations included are those that overlap in time with any point on the tag record. Proximity or crossing tracks does not indicate that the ship and the animal were in the same location at the same time.

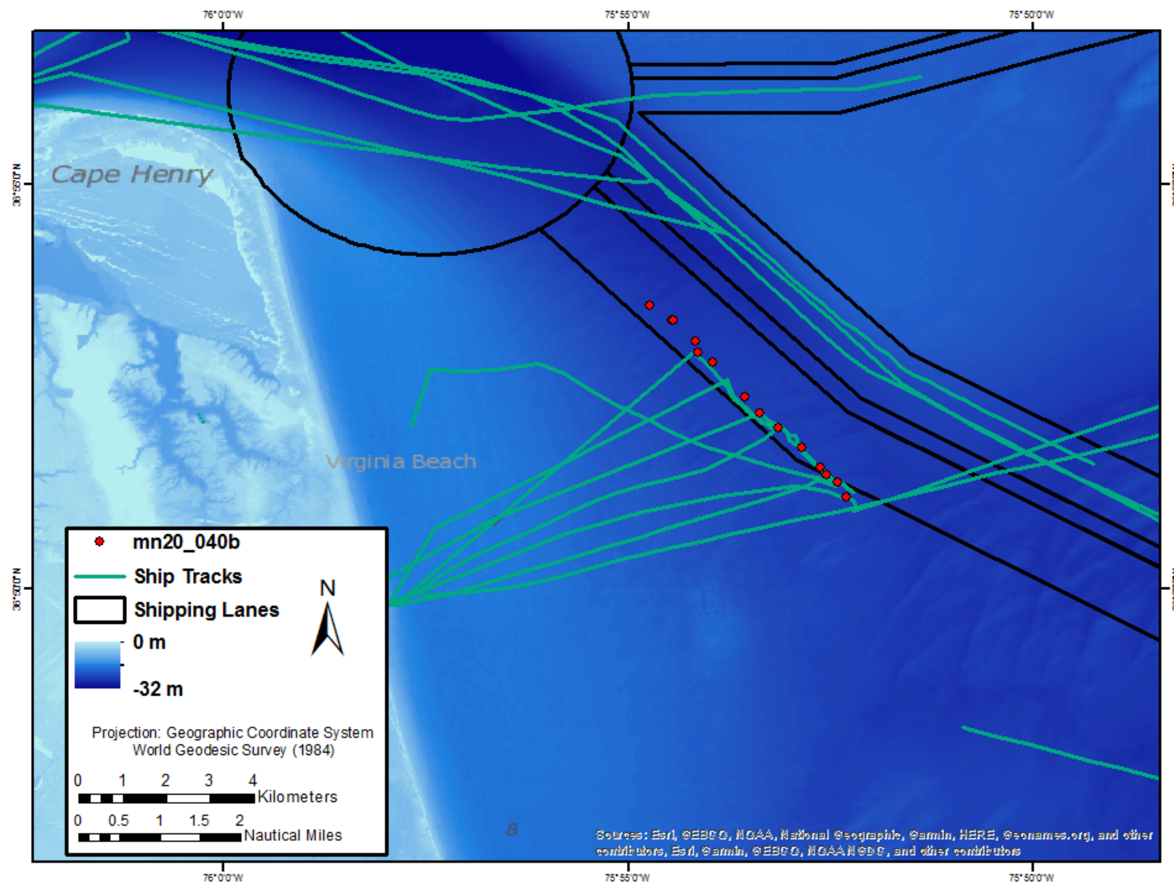

Figure 17. Whale positions (red circles) and ship tracks (green lines) for deployment mn20_040b. Whale positions are derived from the focal follow distance and bearing and the Barber's GPS track. Ship positions were obtained from the VesselFinder AIS service. Ship locations included are those that overlap in time with any time 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.

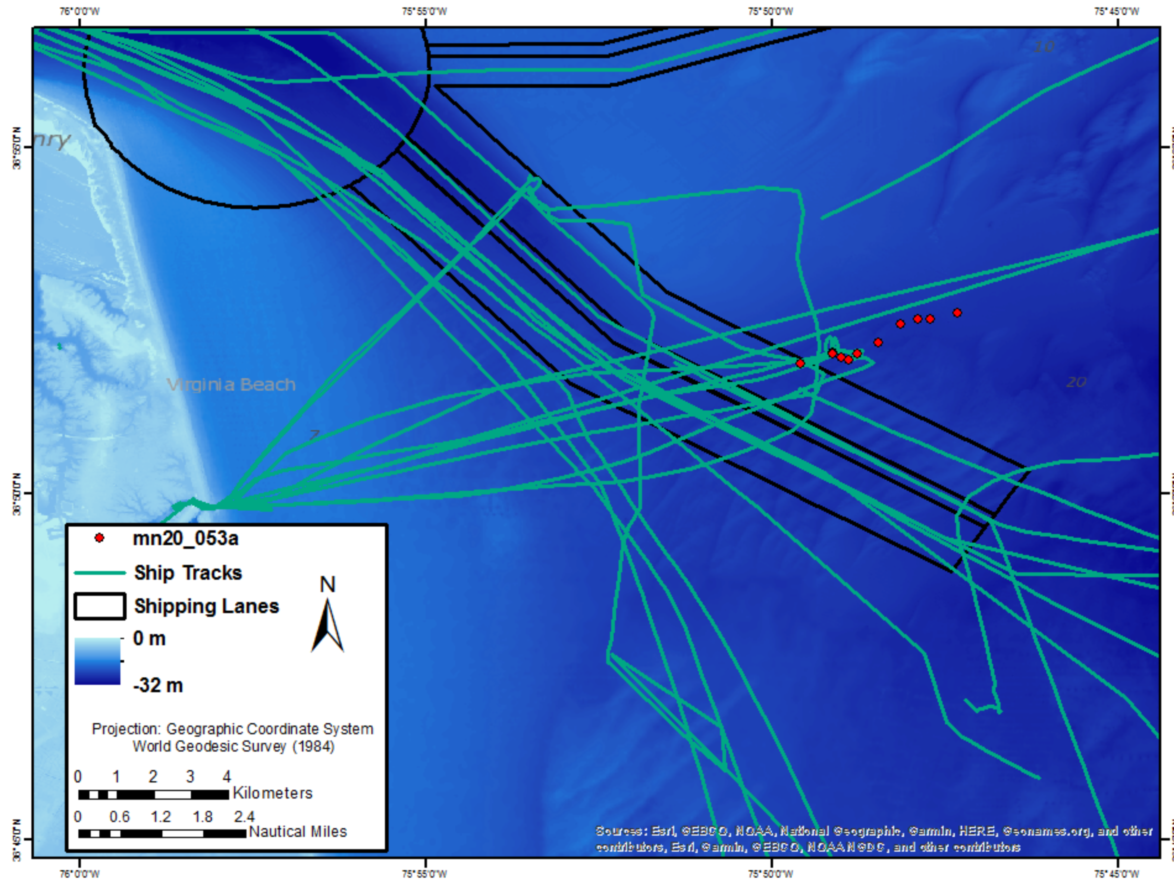

Figure 18. Whale positions (red circles) and ship tracks (green lines) for deployment mn20_053a. Whale positions are derived from the focal follow distance and bearing and the Barber's GPS track. Ship positions were obtained from the VesselFinder AIS service. Ship locations included are those that overlap in time with any time 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.

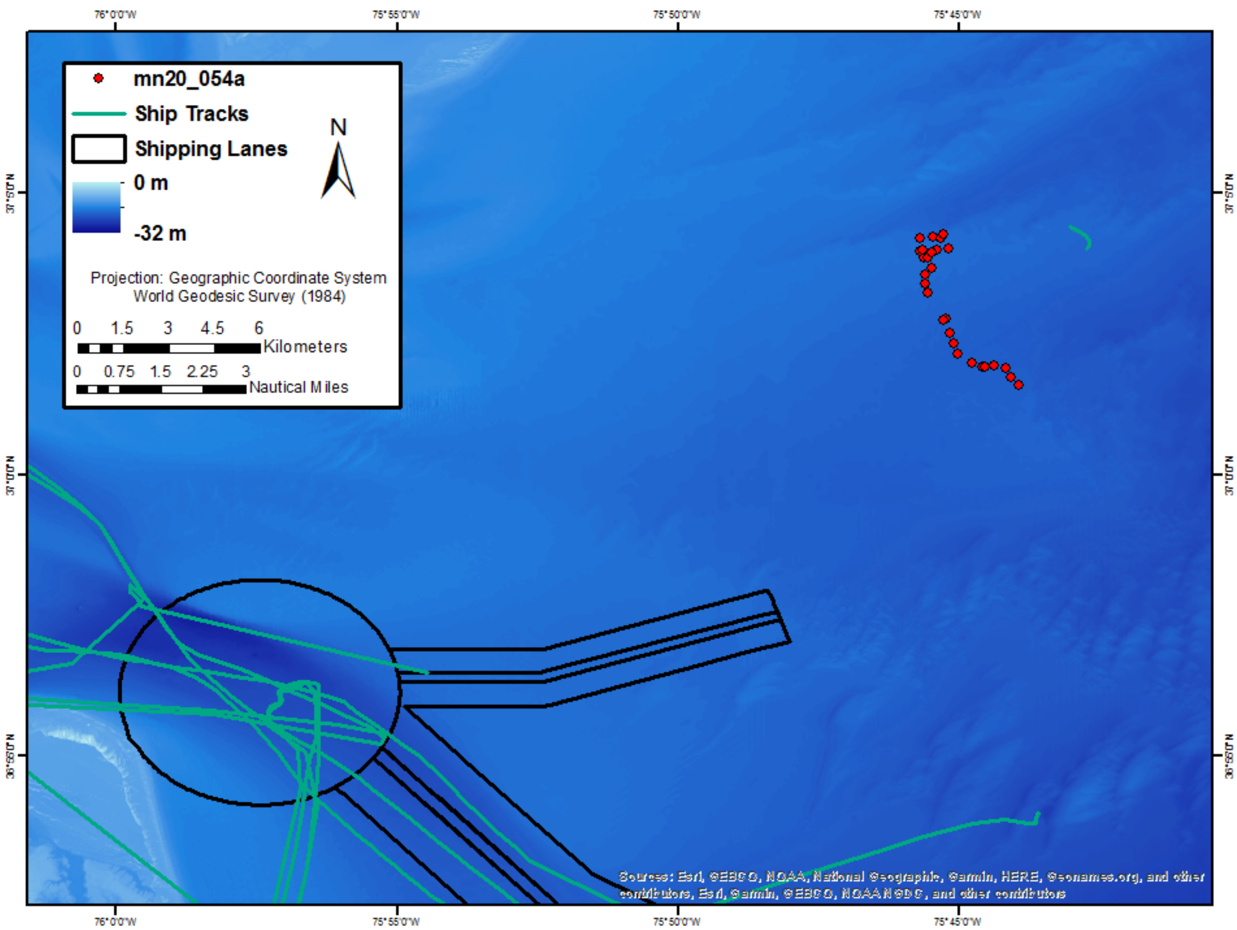

Figure 19. Whale positions (red circles) and ship tracks (green lines) for deployment mn20_054a. Whale positions are derived from the focal follow distance and bearing and the Barber's GPS track. Ship positions were obtained from the VesselFinder AIS service. Ship locations included are those that overlap in time with any time 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.

3.1.5 Foraging behavior

Four of the six animals tagged in 2020 exhibited clear lunges and rolling lunges, as well as numerous potential lunges. For the lunge analysis, we also included the two animals tagged in 2019 (mn19_008a and mn19_066a). Of the 2019 animals, both exhibited rolling lunges and one exhibited clear regular lunges. We recorded 323 clear lunges from these five animals, ranging from 3 to 193 lunges per animal (**Table 4)**. For dives containing a lunge, there was a median of one lunge per dive, ranging from one to seven lunges per dive. Lunges occurred on average at a rate of 6.9 per hour (ranging from 0.7 to 13.1 per hour). The deepest lunge occurred at 25.7 meters depth, near the maximum possible depth in this area. On average, lunges occurred at approximately 10 meters depth. Animals were oriented nearly horizontally during lunges, with average pitches around -3.6 degrees and roll around -0.4 degrees. Pitch and roll were calculated as the median of the pitch or roll over the duration of the lunge. These median pitch angles ranged from -28 to +16 degrees during lunges, while roll ranged from -18 to +14 degrees.

Table 4. Lunge characteristics from clear lunges recorded from humpbacks tagged off the coast of Virginia Beach, Virginia, in 2019 and 2020.

Tag ID	**Total number of lunges**	**Lunges per dive** median (range)	**Lunges per hour**	**Depth (meters)** median (max)	**Median pitch during lunge (degrees)** median (range)	**Median roll during lunge (degrees)** median (range)
mn19_066a	21	1 (1:2)	3.3	12.9 (17.1)	-5.3 (-28:+6)	-0.5 (-10:+14)
mn20_015a	95	1 (1:7)	13.1	8.7 (18.2)	-2.8 (-23:+14)	0.1 (-18:+ 9)
mn20_034a	3	1 (1)	0.7	11.3 (12.1)	-2.0 (-11:0)	-8.7 (-17:-3)
mn20_040a	193	1 (1:5)	7.6	12.9 (25.7)	-4.3 (-22:+16)	-0.7 (-17:+10)
mn20_054a	11	1 (1:2)	3.6	8.5 (10.1)	-1.4 (-10:+2)	-1.9 (-4:+1)
Total	323	1 (1:7)	6.9	10.4 (25.7)	-3.6 (-28:+16)	-0.4 (-18:+14)

Two animals had dive profiles that extended into the night (mn20_015a and mn20_040a). For these two deployments, we compared lunge characteristics between daytime and nighttime lunges, but there were too few lunges to support a statistical analysis (**Table 5**). Tag mn20_015a had 6.5 hours of daytime and 0.86 hours of nighttime data. Mn20_040a had 12.2 hours of daytime and 13.4 hours of nighttime data. Overall, there were considerably fewer nighttime lunges (53 in 14.3 hours) than daytime lunges (235 in 19.8 hours). Lunges occurred 3 times more frequently during the day, with 11.9 lunges per hour during the day compared to 3.7 lunges per hour at night. Lunge depth differed between individuals but showed little diel difference. Likewise, animal orientation was relatively horizontal and showed little difference between daytime and nighttime lunges.

Table 5. Daytime and nighttime characteristics of lunges recorded from humpbacks tagged off the coast of Virginia Beach, Virginia, in 2020.

Tag ID		**Total lunges**	**Lunges per dive** median (range)	**Lunges per hour**	**Depth (meters)** median (max)	**Median pitch during lunge (degrees)** median (range)	**Median roll during lunge (degrees)** median (range)
mn20_015a	day (6.4 hrs)	87	1 (1:7)	13.6	8.75 (18.2)	-2.7 (-23:+14)	0.2 (-18:+9)
	night (0.86 hrs)	8	1 (1:2)	9.3	6.6 (7.7)	-6.2 (-10:+2)	-0.4 (-1:+2)
mn20_040a	day (12.2 hrs)	148	1 (1:5)	12.1	12.3 (25.7)	-5.1 (-21:+9)	-0.2 (-17:+10)
	night (13.4 hrs)	45	1 (1-3)	3.4	13.4 (24.5)	-1.3 (-18:+16)	-3.4 (-9:+4)

Six animals (2 in 2019 and 4 in 2020) showed rolling behaviors associated with jerk that we describe as 'rolling lunges.' 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 6**).

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 lunges than regular lunges (n = 57 rolling lunges *vs* n = 323 regular lunges). Dives with rolling lunges had a median of 1 rolling lunge and no more than 3 rolling lunges per dive. Rolling lunges ranged from 0.1 to 3.6 lunges per hour and occurred at a median depth of 10 meters. There was a much larger range in pitch during rolling lunges than regular lunges. Overall, the median pitch during all rolls was close to horizontal, but individual rolls ranged from -60° to +73° pitch. This indicates that animals were sometimes oriented toward the surface and sometimes oriented toward the seafloor during rolling lunges, resulting in the median pitch being averaged to zero. Similarly, the overall median roll was 20.9°, but the range of median rolls during individual lunges was from -139 to +149°. Therefore, animals are rolling in different directions, averaging out the median roll.

Table 6. Characteristics of rolling lunges recorded from humpbacks tagged off the coast of Virginia Beach, Virginia, in 2019 and 2020.

Tag ID	**Total number of rolling lunges**	**Lunges per dive** median (range)	**Lunges per hour**	**Depth (meters)** median (max)	**Median pitch during lunge (degrees)** median (range)	**Median roll during lunge (degrees)** median (range)	**Absolute roll** (min:max)
mn19_008a	8	1 (1:2)	3.6	6.9 (8.4)	-12.3 (-43:+44)	-10.8 (-99:+110)	-180:+180
mn19_066a	7	1 (1:2)	1.1	14.6 (16.5)	25.5 (-39:+73)	7.9 (-112:+149)	-180:+180
mn20_015a	1	1 (1)	0.1	9.9 (9.9)	-0.4	101.4 (+101:+101)	-12:+141
mn20_034a	6	1 (1:2)	1.3	8.3 (9.3)	-11.7 (-14:+ 3)	29.5 (-64:+44)	-83:+60
mn20_040a	30	1 (1:3)	1.2	12.0 (20.7)	-3.5 (-60:+63)	25.9 (-139:+107)	-180:+180
mn20_054a	5	2 (1:2)	1.62	11.5 (11.7)	-6.3 (-18:+11)	-80.5 (-106:+46)	-180:+179
Total	57	1 (1:3)	1.2	10.3 (20.7)	-3.9 (-60:+73)	20.9 (-139:+149)	-180:+180

One animal (mn20_040a) had rolling lunges during both daytime and nighttime hours (**Table 7**). There were twice as many rolling lunges per hour during the day than at night. Rolling lunges during the day were on average to deeper depths (median 12.3 m) than at night (median 5.6 m), but maxima were similar (18.2 daytime to 20.7 nighttime). This animal appeared to be pitched toward the seafloor more often during daytime lunges and toward the surface more often during nighttime rolling lunges. Individual roll median values were similar between the day and night.

Table 7. Daytime and nighttime characteristics of lunges recorded from humpback mn20_040a tagged off the coast of Virginia Beach, Virginia, in 2020.

Tag ID		**Total number of rolling lunges**	**Lunges per dive** median (range)	**Lunges per hour**	**Depth (meters)** median (max)	**Median pitch during lunge (degrees)** median (range)	**Median roll during lunge (degrees)** median (range)	**Absolute roll** (min:max)
mn20_040a	day (12.2 hrs)	19	1 (1:2)	1.6	12.3 (18.2)	-7.3 (-58:+6)	-15.3 (-139:+97)	-180:180
	night (13.4 hrs)	11	1 (1:3)	0.8	5.6 (20.7)	22.2 (-60:+63)	36.6 (-94:+107)	-180:180

Figures 20 through 27 show dive profiles for all animals with lunges (green stars), potential lunges (red stars), and rolling lunges (blue stars) marked. Gray shaded areas indicate nighttime hours.

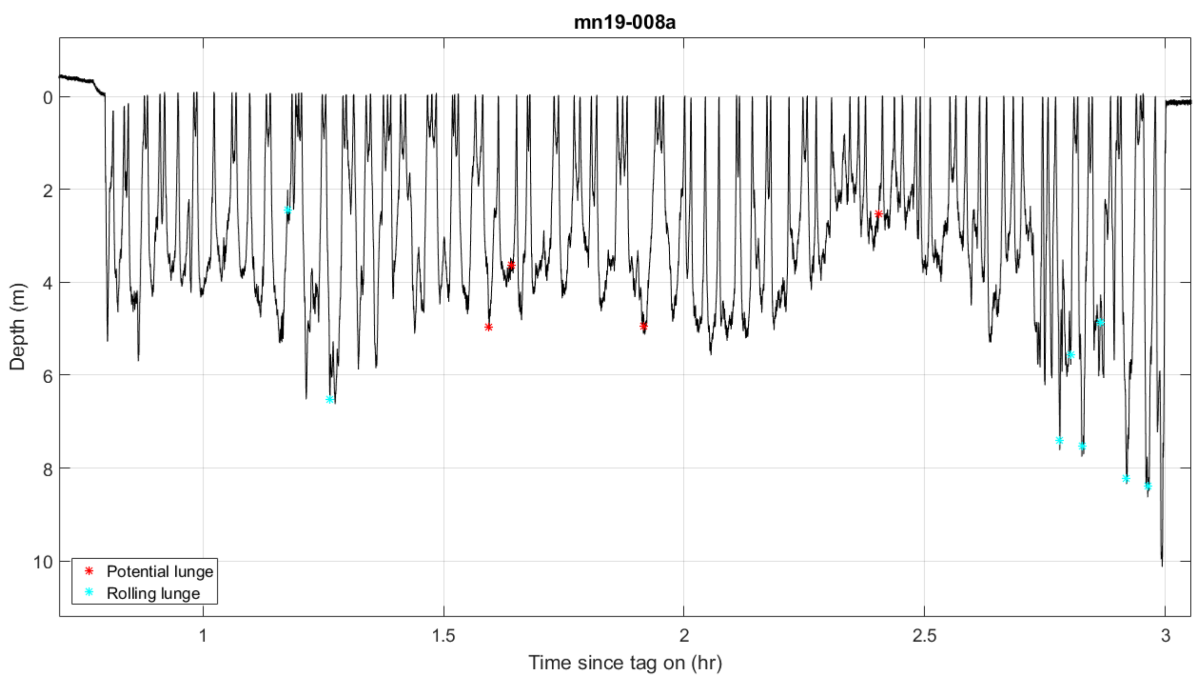

Figure 20. Dive profile for mn19_008a with lunges overlaid.

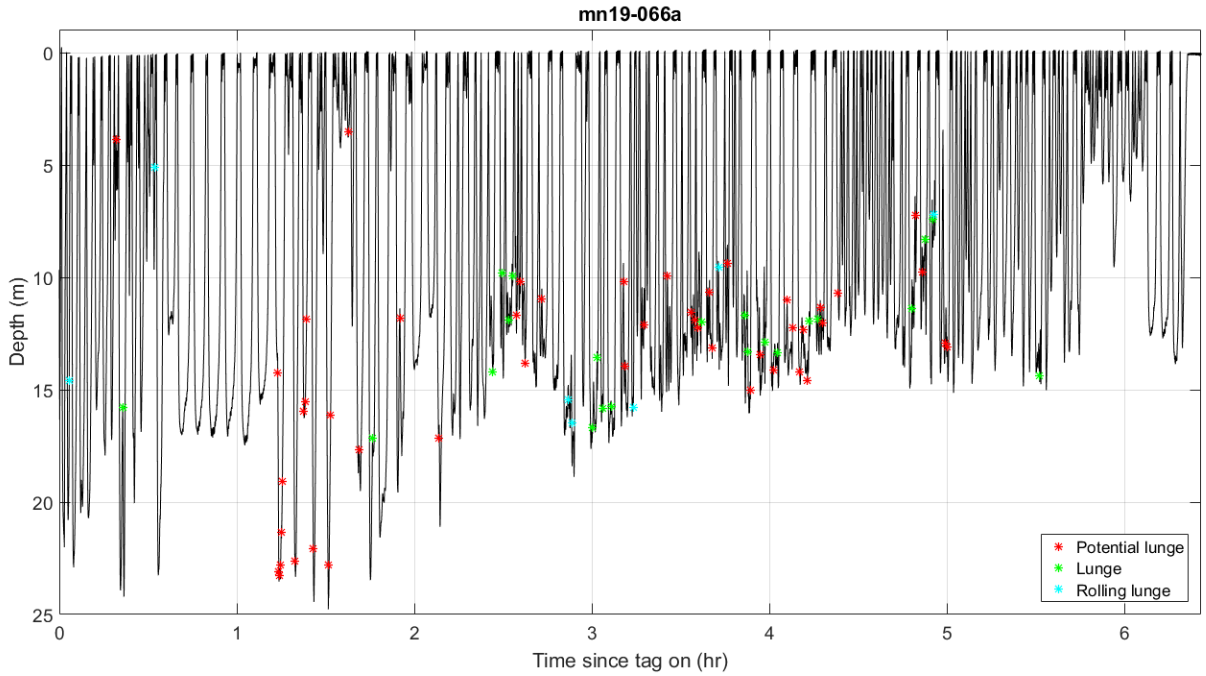

Figure 21. Dive profile for mn19_066a with lunges overlaid.

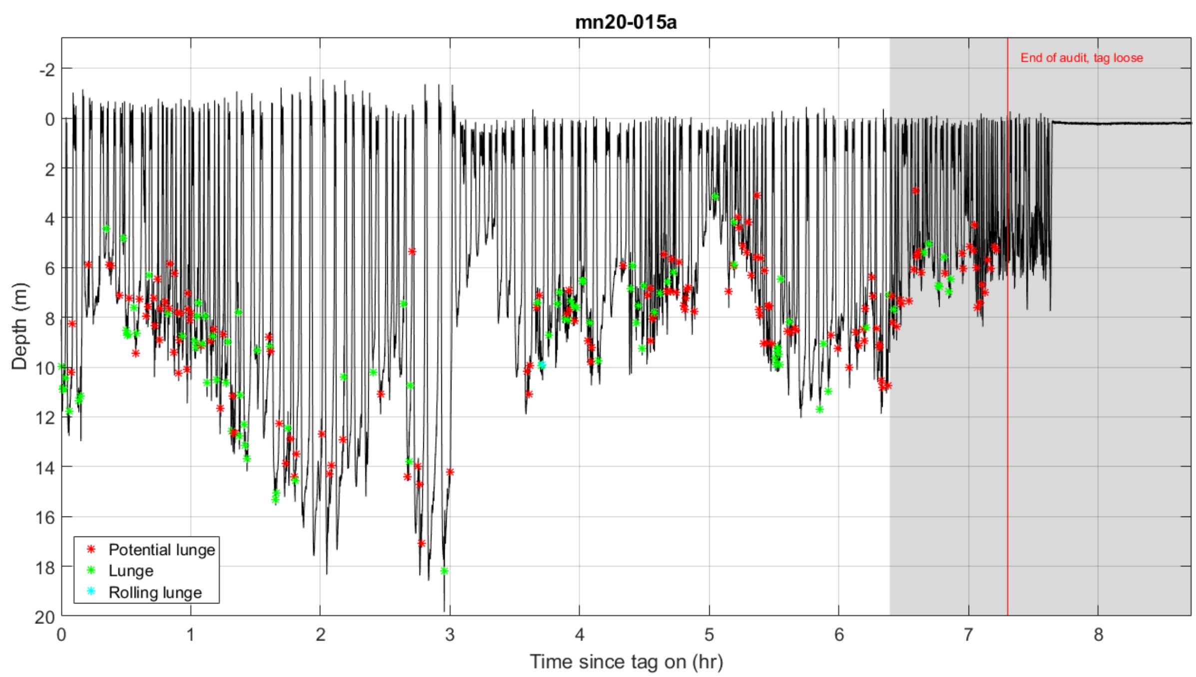

Figure 22. Dive profile for mn20_015a with lunges overlaid. Shaded area indicates nighttime hours.

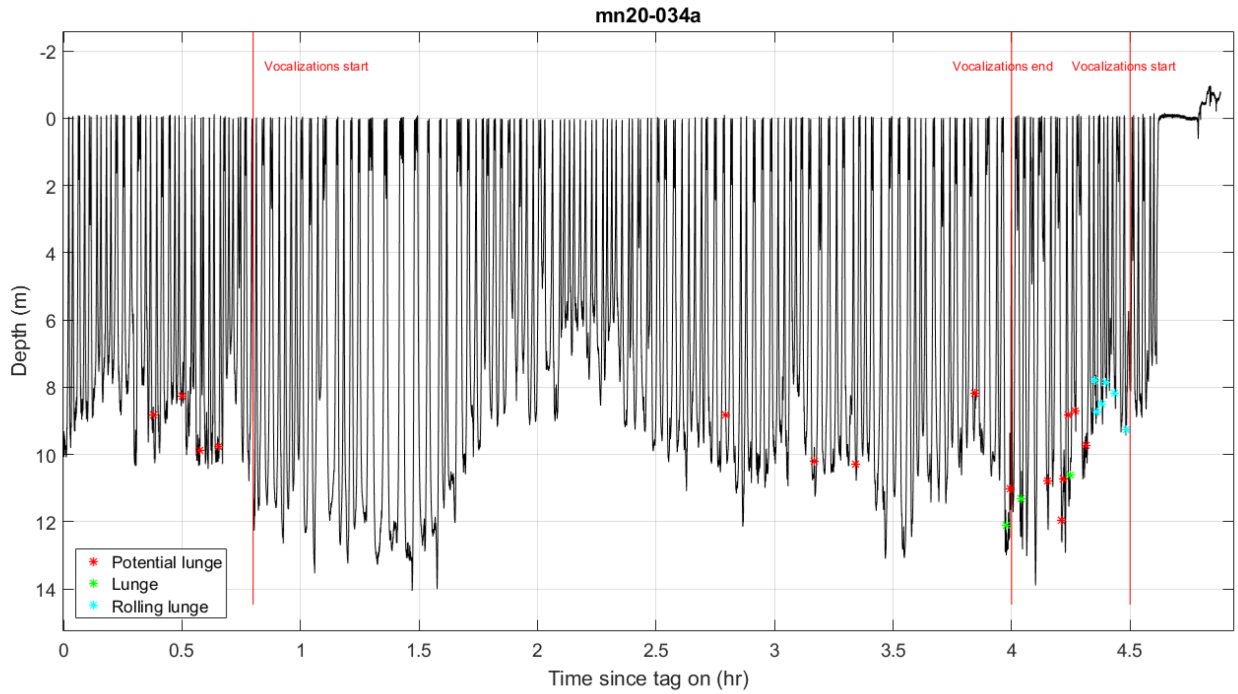

Figure 23. Dive profile for mn20_034a with lunges overlaid. Vocalization start and stop times are also marked.

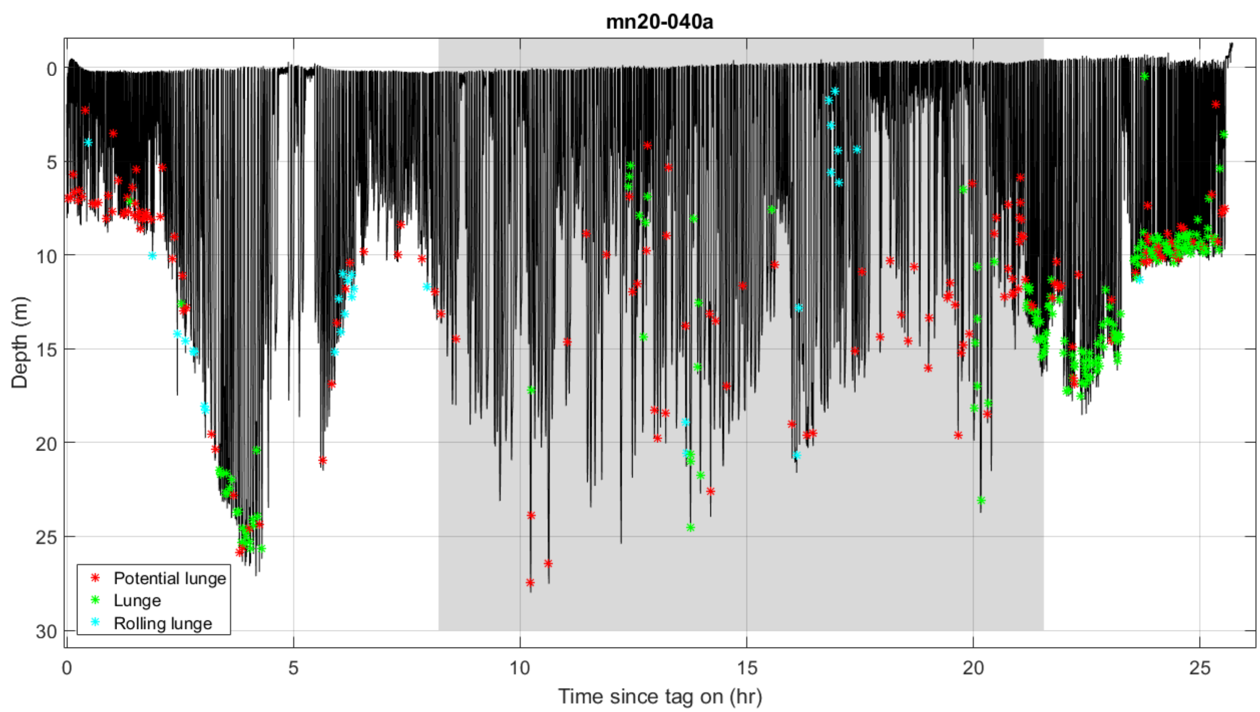

Figure 24. Dive profile for mn20_040a with lunges overlaid. Shaded area indicates nighttime hours.

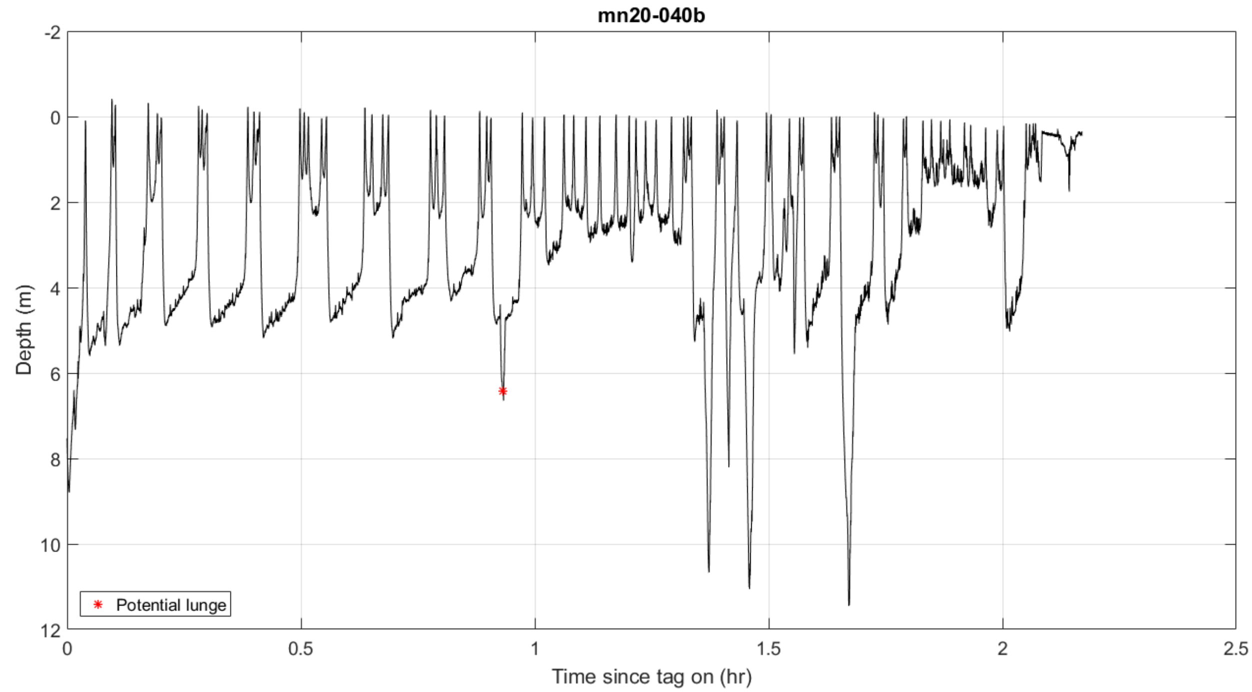

Figure 25. Dive profile for mn20_040b with lunges overlaid.

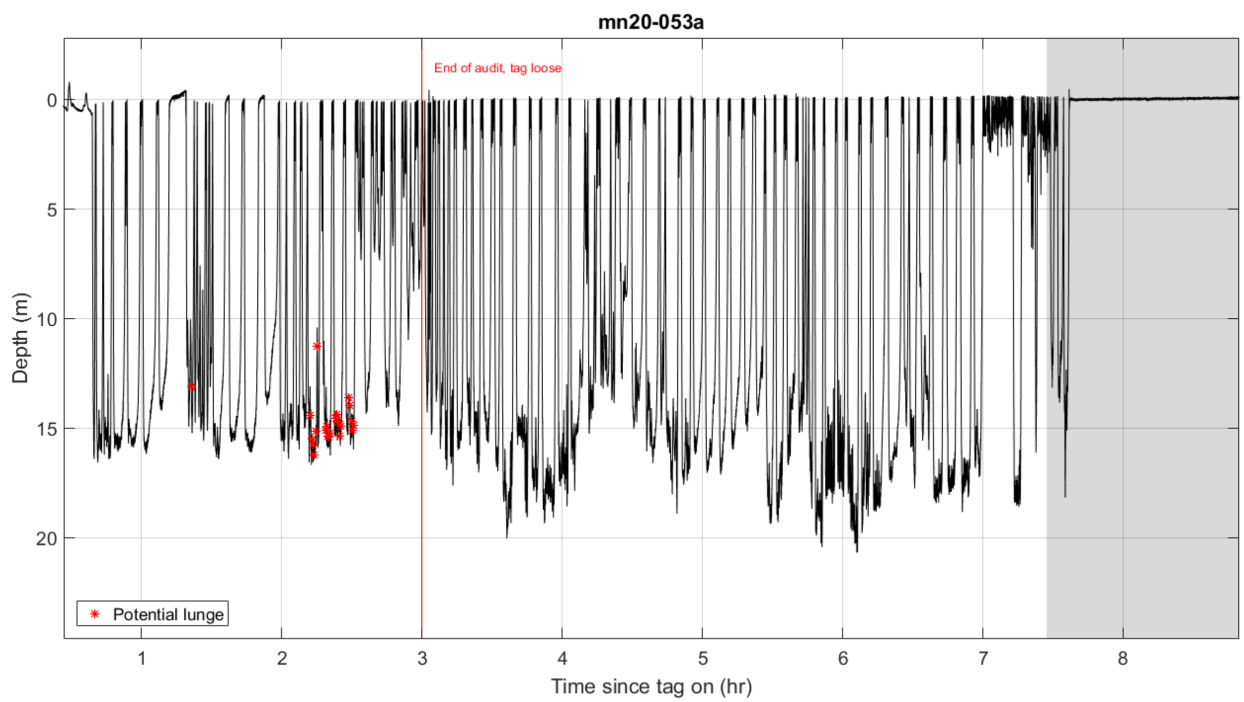

Figure 26. Dive profile for mn20_053a with lunges overlaid. Shaded area indicates nighttime hours.

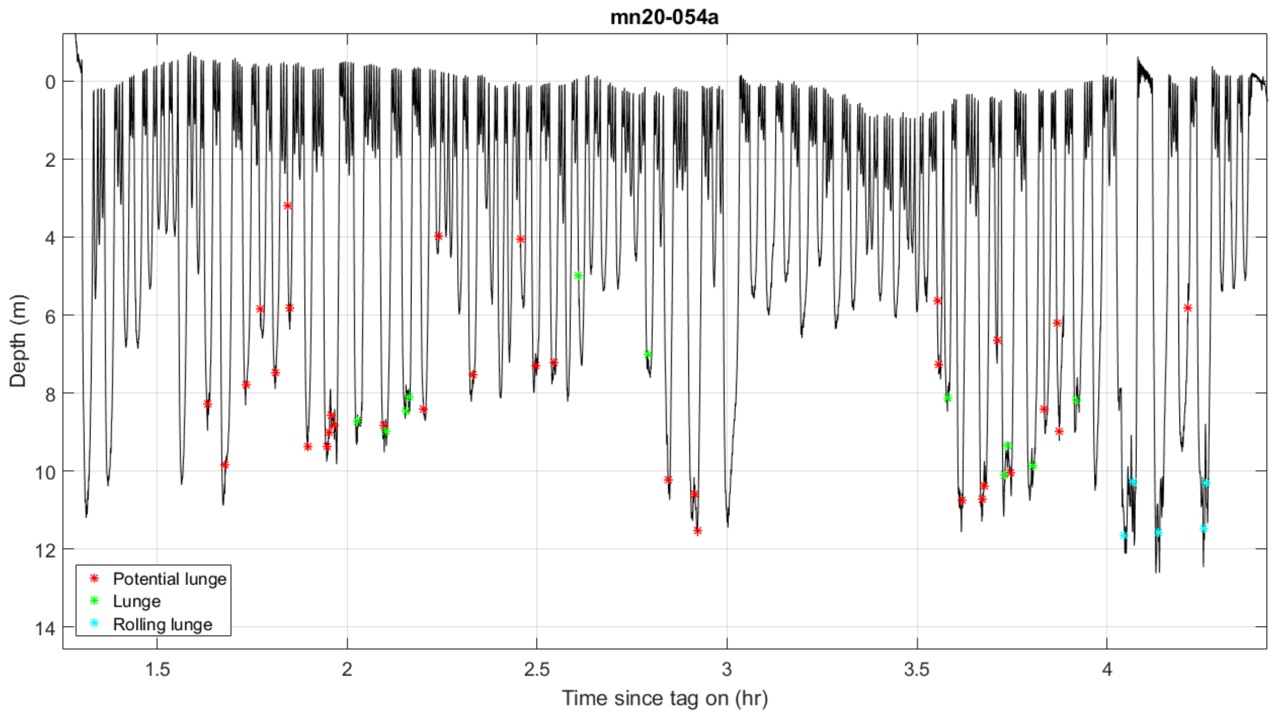

Figure 27. Dive profile for mn20_054a with lunges overlaid.

3.1.6 Vocal behavior

During audits, we heard vocalizations on one tag deployment (mn20_034a). These tonal sounds appear to contain elements of song and ranged from low-pitched ‘woop’ calls to high-pitched sounds akin to whistles (**Figure 28**). The sex of the tagged animal is unknown. Vocalizations occurred at a high rate for 3.2 hours, followed by a 30-minute break before resuming again at a lower rate for 9 minutes until the tag came off. Vocalizing dives ranged from 3 to 14 meters with a median of 10 meters. Little acceleration occurred during vocalizing, with evidence of few fluke strokes and little jerk signal. Distinct foraging lunges did not appear until after the first vocalization period. During approximately 33 minutes of 10- to 14-meter dives early in the vocalization period, the animal remained pitched downward between -20 and -40 degrees for the entirety of the bottom portion of the dive, a posture similar to that adopted by singers (Au et al. 2006) (**Figure 29**). Vocalizations were not detected on any other tag.

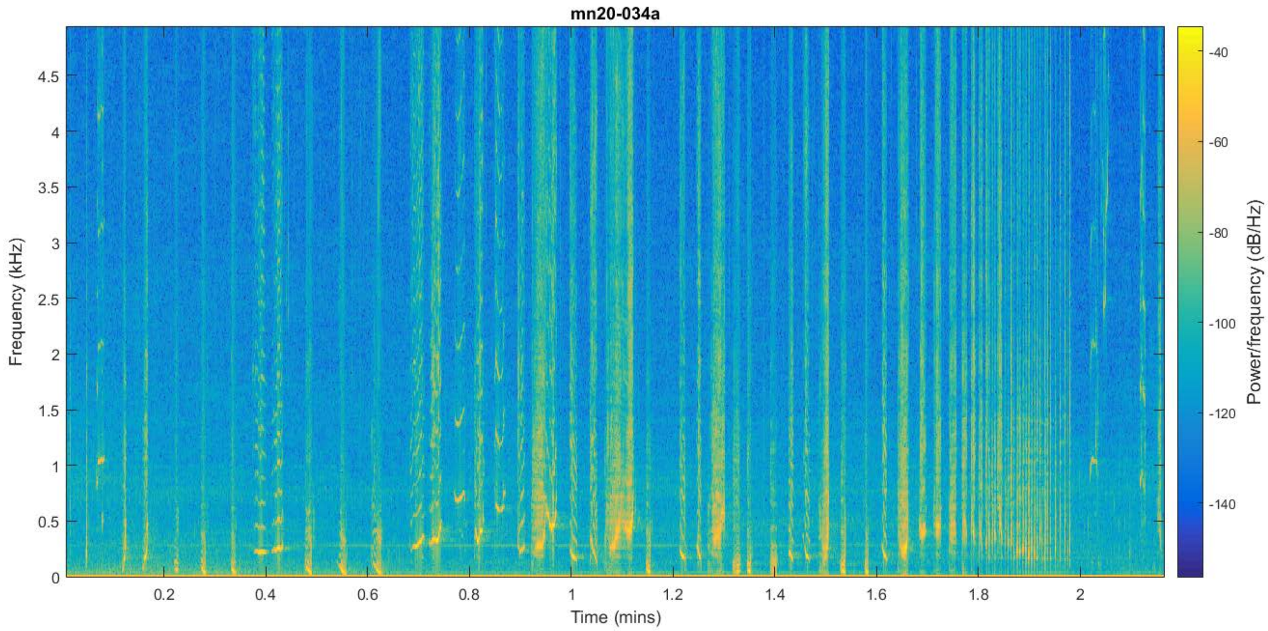

Figure 28. Spectrogram showing range of vocalizations by mn20_034a.

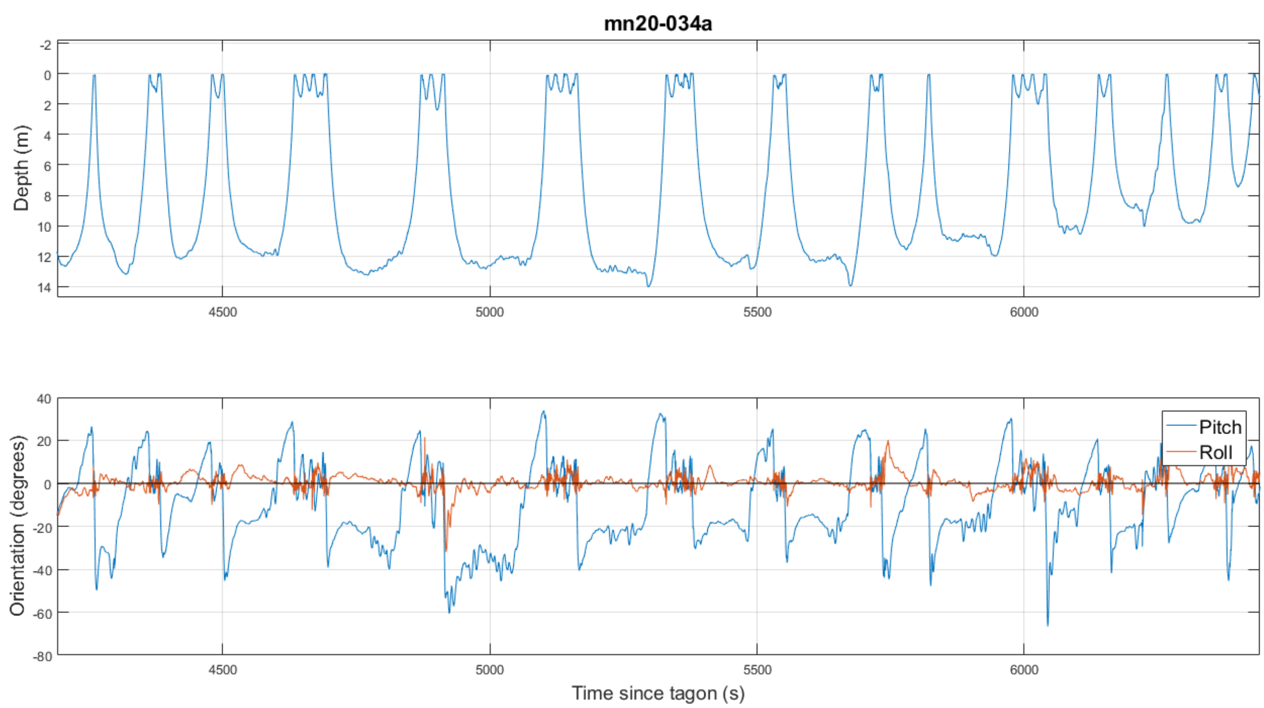

Figure 29. Thirty minutes of dive profile and acceleration data for mn20_034a during its vocalizing period, in which the animal is pitched downward between -20 and -40 degrees during the bottom portion of dives.

4. Discussion and Future Analysis

This year we built on the first year's pilot study by deploying six DTAGs. Of these deployments, only three had encounters with ships, precluding extensive analysis of the response to ship approaches. However, many of the animals displayed evidence of foraging, and our analysis this year focused on identifying and describing those foraging events. As cessation of foraging is often considered a response to disturbance, identifying the presence and frequency of foraging events will add another variable to our analysis of ship responses. We assume that foraging opportunities explain why animals are spending time in this area; hence understanding these foraging events is critical to determining the impacts of ship disturbance. We can use deployments without ship approaches as a control to determine how foraging behavior may be affected by ship disturbance.

The mouth of the Chesapeake Bay is shallower than most other places in which humpback foraging behavior has been documented; as a result, the acceleration signals we see here are somewhat different from those described elsewhere. As expected, animals in this area appear to lunge in a more horizontal orientation, rather than exhibiting the steep pitch angles seen elsewhere (Goldbogen et al. 2008; Simon et al. 2012). In many cases, they are foraging in water that is barely deeper than the length of their body, making steeply pitched lunges difficult or impossible. Humpbacks in this area also executed fewer lunges per dive than in other areas (Friedlaender et al. 2013; Goldbogen et al. 2008; Simon et al. 2012; Ware et al. 2011). This is likely due to the proximity of the surface and, thus, the low cost of returning to the surface after a few lunges. Foraging behavior occurred less frequently at night than during daytime, and rolling lunges were, on average, shallower at night, although nighttime data are limited. This is in contrast to some other locations where animals forage throughout the day and night (Friedlaender et al. 2009) or primarily at night (Friedlaender et al. 2013; Nowacek et al. 2011). 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.

We also recorded the first evidence of vocalizing humpback whales on this feeding ground, and further analysis of this behavior is warranted. This animal produced a considerable range of vocalization types. No other animals were present while it was vocalizing, and none were heard responding on the tag record, but the calls would have been audible at some range. The vocalizing animal did not appear to forage during the vocalization period and showed little acceleration. It is unclear whether it was swimming slowly or drifting with the current, as it did move some distance during this time.

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

- *conversion of animal distance and bearing from the research vessel into lat/long positions*
- *detecting foraging lunges and other foraging events from accelerometry data streams and flow noise on tag records*

Analytical tools currently being developed include the following:

- *acoustically detecting ship approaches on tag records, which will also allow for analysis of 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.*

Fieldwork is currently being conducted during the 2021 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

This project is funded by the U.S. Fleet Forces Command and we thank Joel Bell (Naval Facilities Engineering Systems Command Atlantic) for his continued support and guidance of this work. We also thank the numerous graduate students who volunteered to help in the field. We express our gratitude to Jessica Aschettino and Dan Engelhaupt with HDR, Inc. for coordinating with us to facilitate double-tagging already satellite-tagged animals. Additionally, we thank Jessica Aschettino and Dan Engelhaupt from HDR, Inc. and Erin Delionbach from Duke University for their work in administering this contract. Finally, we thank Sue Barco and Sarah Mallette from the Virginia Aquarium and Marine Science Center for providing additional volunteers to fill out our crew.

Research activities were conducted under National Oceanic and Atmospheric Administration Scientific Research Permit 14809 issued to Doug Nowacek, Duke University and General Authorization 16185 issued to Andrew Read, Duke University.

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