Mid-Atlantic Humpback Whale Monitoring, Virginia Beach, Virginia: 2017/18 Annual Progress Report

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Cover Photo Credit:

Humpback whales (*Megaptera novaeangliae*) feeding off the coast of Virginia Beach, Virginia. Cover photograph by Jessica Aschettino.

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Acronyms and Abbreviations

ARS	Area Restricted Search
BSS	Beaufort sea state
°C	degrees Celsius
CBBT	Chesapeake Bay Bridge-Tunnel
CTD	Conductivity Temperature Depth
GPS	Global Positioning System
km	kilometer(s)
LIMPET	Low Impact Minimally Percutaneous External-electronics Transmitter
m	meter(s)
MAHWC	Mid-Atlantic Humpback Whale Catalog
MINEX	Mine Neutralization Exercise
NAHWC	North Atlantic Humpback Whale Catalog
NMFS	National Marine Fisheries Service
photo-ID	photo-identification
SPOT	Smart Position and Temperature
UME	Unusual Mortality Event
U.S.	United States
UD	Utilization Distribution
VACAPES	Virginia Capes Operating Area
VAQS	Virginia Aquarium and Marine Science Center

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1. Introduction and Background

Humpback whales (*Megaptera novaeangliae*) of the West Indies distinct population segment (Bettridge et al. 2015) migrate from six northern feeding grounds in the Gulf of Maine, the Gulf of St. Lawrence, Newfoundland/Labrador, western Greenland, Iceland, and Norway to Caribbean Sea waters during the winter months (Katona and Beard 1990, Christensen et al. 1992, Palsbøll et al. 1997). Not all humpback whales, however, end up in the Caribbean waters—some whales use the Mid-Atlantic region to over-winter (Barco et al. 2002). Norfolk, Virginia, is home to the world's largest U.S. Navy installation, and it is also ranked the sixth busiest container port in the United States. These factors, combined with the presence of recreational and fishing vessels, result in a constant and often heavy flow of vessel traffic through the mouth of the Chesapeake Bay and adjacent areas. Understanding the occurrence and behavior of humpback whales in this region is important in mitigating potentially harmful impacts on the species.

In the past, humpback whale sighting information off the Virginia Beach area has been collected via various methods and sporadic field efforts. Shore-based counts in 1991, vessel-based photo-identification (photo-ID) efforts in 1992 (Swingle et al. 1993), and further cataloging efforts using photographs taken on whale-watching excursions and from stranded whales (Wiley et al. 1995, Barco et al. 2002) have been the primary data sources. Such studies have shown that some individuals return in subsequent years, and the area may act as a supplemental winter feeding ground for the returning whales (Barco et al. 2002). Photographs of whales sighted off the coast of Virginia have been matched to cataloged whales from the Gulf of Maine, Newfoundland, and the Gulf of St. Lawrence regions (Barco et al. 2002, Aschettino et al. 2015, 2016, Mallette and Barco 2017). Until recently, information on the movements of individuals within this region has been limited. Such data are important to assess the potential for disturbance to humpback whales found in U.S. Navy training ranges and high-traffic areas in the Chesapeake Bay and mid-Atlantic coastal waters.

The objective of this multi-year project under the U.S. Navy's Marine Species Monitoring Program has been to establish baseline information on occurrence and behavior of humpback whales near Naval Station Norfolk and within the Virginia Capes (VACAPES) Operating Area by addressing the following questions:

- *What age classes (juveniles, sub-adults, adults) are utilizing the waters within and adjacent to the mouth of the Chesapeake Bay?*
- *Do humpback whales exhibit site fidelity over periods of days to years?*
- *Do humpback whales congregate in specific high-traffic and/or high-use U.S. Navy training areas?*
- *Do humpback whales spend significant time within or move through areas of U.S. Navy live-fire and mine neutralization exercise (MINEX) training?*

Primary objectives of this project include the following:

- *Collect baseline occurrence data (location, sex, group size, behavior) of humpback whales (and other species of baleen whales opportunistically).*

- *Obtain identification photographs of humpback whales for inclusion in regional and local catalogs.*
- *Collect biopsy samples of humpback whales for sex determination, mitochondrial control region sequencing and microsatellite genotyping of tissue samples, and stable isotope analysis to assess foraging related to prey consumption.*
- *Conduct satellite tagging to document seasonal humpback whale movement patterns in the nearshore waters off Virginia Beach, specifically whether the whales spend significant time in areas of high shipping traffic and/or areas of U.S. Navy training exercises.*

Since this project's inception, there have been four dedicated field seasons of humpback whale research to address the above objectives. The humpback whale field season off Virginia Beach runs from approximately the end of October through March, typically concentrated between December and February and with a smaller number of sightings occurring outside this timeframe. The first season of dedicated humpback whale surveys began in January 2015 and was completed in May 2015 (see Aschettino et al. 2015). Additional humpback whale sighting information from bottlenose dolphin density surveys running concurrently off Virginia Beach (see Engelhaupt et al. 2016) was also incorporated into these analyses, and the first humpback whale sightings from those density surveys occurred in December 2014. Therefore, the first field season, encompassing sightings from both the dedicated humpback whale surveys and the bottlenose dolphin density surveys, is herein referred to as the 2014/2015 field season. During the 2014/2015 field season, the primary objectives were to collect baseline information from individual humpback whales (or other species of baleen whales) through the use of photo-identification (photo-ID), focal follow, and biopsy sampling methods.

The second season of dedicated humpback whale surveys began in December 2015 (bottlenose dolphin density surveys were no longer being conducted because of the project's completion in August 2015) and surveys were completed in May 2016 (2015/2016 field season – see Aschettino et al. 2016). The objectives for the 2015/2016 also were to collect baseline information using photo-ID and biopsy sampling methods; however, less effort was spent on focal follows due to implementing a satellite-tagging component. Nine satellite tags were deployed and 11 biopsy samples were collected during the 2015/2016 season.

The third season of dedicated humpback whale surveys began in November 2016 and continued through March 2017 (2016/17 field season – see Aschettino et al. 2017). Objectives for the 2016/2017 field season matched those of the 2015/2016 field season—collect baseline information through the use of photo-ID, biopsy sampling, and satellite tagging techniques. Twenty-six satellite tags were deployed and 29 biopsy samples were collected during the 2016/2017 season.

The 2017/2018 field season began on 31 October 2017 and the last dedicated humpback survey was conducted on 10 March 2018. Objectives for the 2017/2018 field season matched those of the previous two field seasons; however, an additional focus was placed on increased survey effort in the W-50 MINEX region and farther offshore.

2. Methods

The study area for this project includes waters in and around the mouth of the Chesapeake Bay as well as the W-50 MINEX region off Virginia Beach (**Figure 1**). Two primary areas of interest in this study are U.S. Navy training areas and commercial shipping lanes. Inbound and outbound shipping lanes are defined by the Traffic Separation Scheme. Initially, the "shipping lane study area" was defined by the Traffic Separation Scheme in the mouth of the Chesapeake Bay (**Figure 1**); however, as tag locations showed movements out of the defined area but within shipping channels, the area was extended using multiple nautical charts and datasets, including the Traffic Separation Scheme, Coastal Maintained Channels in U.S. Waters (U.S. Army Corps of Engineers), and Shipping Fairways, Lanes, and Zones for U.S. Waters (National Oceanic and Atmospheric Administration) as guidelines. The U.S. Navy training areas included portions of the W-50 MINEX range.

Local availability of researchers allowed survey effort to be flexible and take advantage of limited winter weather windows in order to maximize the ability to achieve project objectives. Optimal weather conditions included good visibility and a Beaufort sea state (BSS) of 3 or lower. Once a survey was underway, if BSS reached 4 or 5, or visibility was reduced to less than 1 nautical mile because of rain, fog, or snow, the survey was typically aborted, and the vessel returned to port. Efforts were coordinated with the W-50 MINEX range so that the research vessel had clearance to operate when training was not being conducted. Because of frequent range closures and limited weather windows, it was not always possible to conduct surveys within the W-50 MINEX range.

The survey vessel was an 8.2-meter (m) fiberglass hybrid-foam-collar boat *Whale Research* (**Figure 2**), owned and operated by HDR. Surveys departed from Marina Shores Marina, located in Lynnhaven Inlet, Virginia Beach. The crew typically consisted of four qualified marine mammal scientists with one also serving as the vessel operator. Once departed from the inlet, the vessel would transit to areas where humpback whales were previously seen or reported. If no whales were located in these areas, the vessel would expand the search into waters farther offshore, north, or south of the primary study area (see **Figure 1**). Sightings of non-target species in the survey area (i.e., bottlenose dolphins [*Tursiops truncatus*], harbor seals [*Phoca vitulina*], and harbor porpoise [*Phocoena phocoena*]) were recorded, but not presented in this report.

2.1 Photo-ID

Photographs of humpback, fin (*Balaenoptera physalus*), and minke (*Balaenoptera acutorostrata*) whales were post-processed using ACDSee (Versions 7–9) by cropping the best image of each individual whale's dorsal fin (left and right) and tail flukes (when obtained). Photographs were assembled into a catalog managed by HDR where each new whale was assigned an ID number (e.g., HDRVAMn001 or HDRVABp001) and compared with one another. At the end of the 2014/2015 field season, images of humpback whale flukes were submitted to Allied Whale for comparison to the North Atlantic Humpback Whale Catalog (NAHWC) and images of humpback whale dorsal fins and flukes were submitted to the Virginia Aquarium and

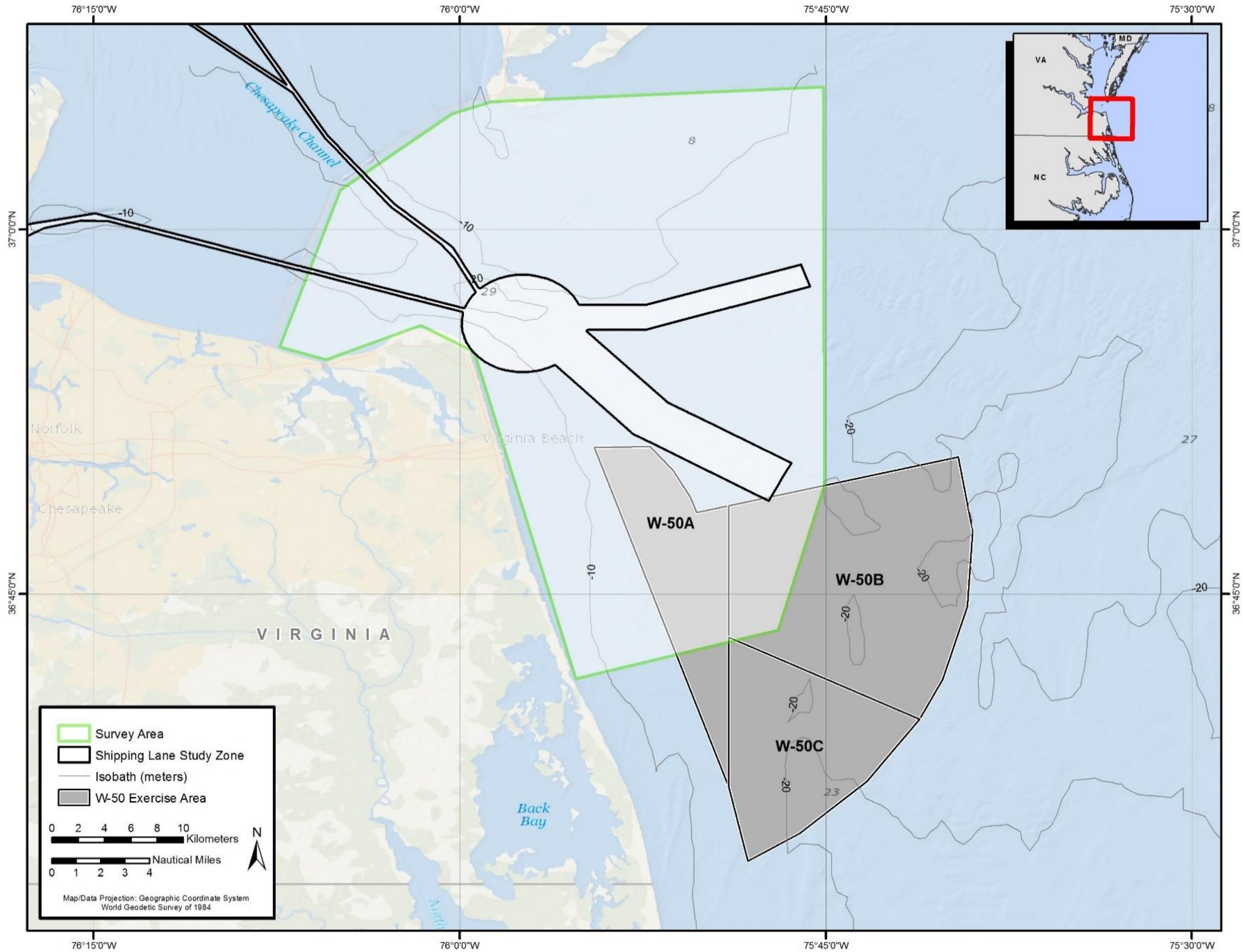

Figure 1. Map of the primary study area, as outlined by the green boundary, which includes waters in and around the mouth of the Chesapeake Bay as well as the W-50 MINEX region off Virginia Beach.

Figure 2. Nearshore survey vessel, *Whale Research.* Photo © Brian Lockwood.

Marine Science Center (VAQS) for comparison and integration with the Mid-Atlantic Humpback Whale Catalog (MAHWC). At the end of the 2015/2016 and 2016/2017 field season, images were submitted to VAQS. Images of fin whales were shared with Duke University as well as researchers from the Center for Coastal Studies in Provincetown, Massachusetts. At the end of the 2017/2018 field season, humpback whale images will once again be shared with VAQS for integration into the MAHWC (see Mallette and Barco 2017, Mallette et al. 2018).

2.2 Biopsy Sampling

Biopsy samples were collected, when possible, from whales of interest. Biopsies were obtained using either a crossbow or biopsy rifle. In the first, Finn Larsen designed crossbow bolts outfitted with 25-millimeter, ethanol sterilized, stainless steel tips were projected by a 68-kilogram pull Barnett crossbow (Barnett Outdoors, LLC, Tarpon Springs, FL). Alternatively, a Paxarms biopsy rifle (Paxarms New Zealand Ltd., Cheviot, New Zealand) fired 6 × 20-millimeter sterilized dart tips propelled by .22 caliber blank cartridges. Samples were post-processed by sectioning the skin into three equal-sized pieces. One third of the skin was placed in a cryovial and frozen (-40 degrees Celsius [°C]) for stable isotope analysis by Duke University, one third was placed in a cryovial with a dimethylsulfate and sodium chloride solution in preparation for analysis by University of Groningen, and one third was frozen (-40°C) for archival storage for Southeast Fisheries Science Center. Blubber was wrapped in foil and frozen for archiving for Southeast Fisheries Science Center. Stable isotope analysis and gender determination was performed on a portion of samples at the end of the 2016/2017 season (see Waples 2017) and will be performed on remaining samples at the end of the 2017/2018 season. Also, at the end of the 2017/2018 field season, all humpback whale samples will be sent to the University of Groningen for processing.

2.3 Satellite Tagging

Beginning in December 2015, a satellite-tagging component was incorporated into the project using location-only Wildlife Computers (Redmond, Washington) Smart Position and Temperature (SPOT6) Argos satellite-linked tags in the Low Impact Minimally Percutaneous External-electronics Transmitter (LIMPET) configuration (Andrews et al. 2008). Fifteen tags were available for the 2017/2018 field season. SPLASH10-F Fastloc® Global Positioning System (GPS) tags with location and dive capabilities were also tested in 2017 on humpback whales and two were available for the 2017/2018 season for deployments on humpback or fin whales. Tags were remotely deployed using a DAN-INJECT JM25 pneumatic projector (www.dan-inject.com). Two 6.8-centimeter surgical-grade titanium darts with six backwards-facing petals were used to attach tags to the dorsal fin or just below the dorsal fin (**Figure 3**). Given existing information on attachment durations of LIMPET tags on humpback whales, maximum tag attachment duration was expected to be on the order of days to weeks. Therefore, tags were programmed to maximize the number of transmissions and locations received during attachment rather than to extend battery life. Based on satellite availability in the area, tags were programmed to transmit for between 20 to 22 hours per day with an unlimited number of transmissions for SPOT6 tags and limited to 350 transmissions per day for SPLASH10-F tags. In order to constitute a “dive” for the Wildlife Computers generated behavior and time-series data outputs of the SPLASH10-F tags, a 10 m and 30 s dive definition was established for fin whales in which a dive needed to be both deeper than 10 m and longer than 30 s in order to be classified as a dive. Locations of tagged individuals were approximated by the Argos system using the Kalman filtering location algorithm (Argos Users Manual © 2007–2015 CLS), and unrealistic locations (i.e., those on land) were manually removed using tools provided within Movebank (www.movebank.og). Biopsy samples were collected from most tagged whales using the same protocol described above.

Figure 3. LIMPET SPOT6 tag being deployed on a humpback whale.

2.4 State-Space Modeling

State-space modeling was performed on all humpback whale satellite tags deployed prior to the 2017/2018 field season (n=35). These analyses were intended to be exploratory in nature and provide initial inference on animal behavior and residency. Follow-on analysis for additional tags and more complex modeling approaches may occur in the future. It was decided that a two-state model, nominally traveling and area restricted search (ARS), would be the best first approach to inferring animal data from Argos data. Though more complex models are available, they often rely on additional data such as dive depth and environmental covariates that were either unavailable or outside the scope of this initial analysis.

The R package 'bsam' (Jonsen et al 2005 and Jonsen 2016) was selected as it allows for hierarchical modeling of tags. This method estimates movement parameters for all animals jointly, as well as an individual effects parameter for each tag. This can be advantageous as it may allow shorter deployments that could not have been modeled individually to give realistic results, as was the case here. The model does assume that animal movements are broadly similar. We suggest that this is reasonable here as all tags were from the same species and region. As with other state space approaches, the track is first smoothed into equal time intervals, with the estimated locations taking Argos location error into account.

2.5 Home Range Analysis

For analysis of behaviors classified as ARS, the priority was to look at home ranges for all animals jointly. Because of the different migration strategies employed by individuals, which would introduce too much variance into parametric approaches, home ranges needed to be calculated individually using non-parametric approaches and combined post hoc. A gridded approach to calculating utilization distributions (UDs) was selected to leverage the ease with which individual home ranges can be combined and interpreted. See Maxwell et al. 2011 for an example of this application. A grid of hexagons with a diameter of five kilometers was used to aggregate locations that were identified as ARS and subsequently were used to generate UDs for each tag. Five kilometers was the average distance between modeled locations (three hour time intervals).

Using the same grid used to generate individual home ranges, several metrics were calculated for all home ranges combined: the number of times each grid cell fell within an individual animal's 50% and 90% utilization distribution, and a weighted sum analysis where the relative contribution of each animal was weighted by the length of the tag deployment. In the weighted sum analysis the longest deployed tag was given a weight of 1 and all other tags were weighted by the proportion of their tag length to the longest tag. Using these weights, the combined 50% and 90% UD results were recalculated to take tag deployment length into account. This assists with, but does not eliminate deployment location bias, as tags that transmitted longer (and consequently animals had an opportunity to travel farther), have a larger influence on the results.

3. Results

3.1 Nearshore Surveys: 2017/18 Field Season

HDR conducted 15 nearshore surveys for humpback whales between 31 October 2017 and 10 March 2018, covering 1,989 kilometers (km) of trackline with over 88 hours of effort (**Table 1**). During these 15 surveys, there were 27 sightings of humpback whales totaling 32 individuals, 7 sightings of fin whales totaling 10 individuals, and 1 sighting of a minke whale totaling 1 individual (**Tables 1 and 2; Figure 4**). Of the 35 total large whale sightings during the 2017/2018 field season, 13 (37.1 percent) occurred in the shipping lanes and 4 (11.4 percent) occurred in the W-50 MINEX zone (all humpback whales).

Table 1. Summary of nearshore survey efforts off Virginia Beach, Virginia: 31 October 2017–10 March 2018.

Date	Survey Time (min)	Distance surveyed (km)	# Sightings Mn	# Individual Mn	# Sightings Bp	# Individual Bp	# Sightings Ba	# Individual Ba
31-Oct-17	300	112.0	2	2	0	0	0	0
02-Nov-17	210	58.2	4	5	0	0	0	0
06-Nov-17	227	89.0	0	0	0	0	0	0
20-Nov-17	228	97.4	0	0	0	0	0	0
27-Nov-17	415	142.6	3	3	0	0	0	0
03-Dec-17	461	157.8	2	2	0	0	0	0
11-Dec-17	393	130.0	2	2	1	1	0	0
22-Dec-17	370	88.8	4	7	0	0	0	0
26-Dec-17	357	123.8	4	4	0	0	0	0
29-Dec-17	271	62.9	5	6	0	0	0	0
10-Jan-18	276	115.7	0	0	0	0	0	0
21-Jan-18	517	201.9	0	0	2	3	1	1
26-Jan-18	557	163.5	1	1	4	6	0	0
28-Feb-18	338	222.7	0	0	0	0	0	0
10-Mar-18	414	223.1	0	0	0	0	0	0
Total	**5,334**	**1,989**	**27**	**32**	**7**	**10**	**1**	**1**

Key: min = minute(s); km = kilometer(s); Mn = *Megaptera novaeangliae*; Bp = *Balaenoptera physalus;* Ba = *Balaenoptera acutorostrata*

3.2 Photo-ID Results

The 27 sightings of 32 total individual humpback whales resulted in 20 unique humpback whales identified during the 2017/2018 field season (**Table 2**). Eighteen (90.0 percent) of those unique whales were categorized as juveniles based on their estimated size and the remaining two (10.0 percent) were categorized as sub-adults. Seven (35.0 percent) of the 20 individuals were re-sights to HDR's catalog; five were first seen during the 2014/2015 field season and two were first seen during the 2015/2016 field season (**Table 2**). The remaining 13 whales were new individuals added to HDRs growing catalog, which, to date, has 119 unique humpback whales

Table 2. Sighting history (by number of days seen per month) and additional information of all photo-identified baleen whales off Virginia Beach, Virginia: December 2014–March 2018.

HDR Catalog ID	2014	2015			2015		2016				2016		2017			2017			2018			Total No. Days Seen	Total No. Seasons Seen	Biopsied? (Y.N)	Satellite Tagged? (Y.N)	Est. Age Class (A/J)	Prop scars or injuries? (Y/N)	Total No. Focal Follows	Total No. Focal Follow Minutes
	Season 1 (2014/15)				Season 2 (2015/16)						Season 3 (2016/17)					Season 4 (2017/18)													
	December	January	February	April	October	December	January	February	March	May	November	December	January	February	March	October	November	December	January	February	March								
Humpback Whales																													
HDRVAMn003	1																					**1**	**1**	**N**	**N**	**A**	**N**	**0**	**-**
HDRVAMn004	1																					**1**	**1**	**N**	**N**	**A**	**N**	**0**	**-**
HDRVAMn005	1	1									2		3									**7**	**2**	**Y**	**Y**	**A**	**N**	**1**	**64**
HDRVAMn006	1	1																				**2**	**1**	**N**	**N**	**J**	**N**	**1**	**69**
HDRVAMn007	1	2	1			1					1		3	3								**12**	**3**	**Y**	**Y**	**J**	**N**	**1**	**60**
HDRVAMn008		5																				**5**	**1**	**N**	**N**	**J**	**N**	**3**	**215**
HDRVAMn009		4																				**4**	**1**	**Y**	**N**	**J**	**N**	**2**	**112**
HDRVAMn010		1				2										1						**4**	**3**	**Y**	**Y(2)**	**J**	**N**	**1**	**76**
HDRVAMn011	1	3									1											**5**	**2**	**Y**	**N**	**J**	**N**	**1**	**60**
HDRVAMn012		2	1				2					2	2	3				2				**14**	**4**	**Y**	**Y(2)**	**J**	**N**	**2**	**25**
HDRVAMn013	1	7	2																			**10**	**1**	**Y**	**N**	**J**	**N**	**4**	**357**
HDRVAMn014		5					1						1				1					**8**	**4**	**Y**	**N**	**J**	**N**	**1**	**60**
HDRVAMn015		2											1									**3**	**2**	**Y**	**N**	**J**	**N**	**1**	**58**
HDRVAMn016		1																				**1**	**1**	**N**	**N**	**U**	**N**	**0**	**-**
HDRVAMn017		1																				**1**	**1**	**N**	**N**	**U**	**N**	**0**	**-**
HDRVAMn018		1																				**1**	**1**	**N**	**N**	**U**	**Y**	**0**	**-**
HDRVAMn019		1																				**1**	**1**	**N**	**N**	**U**	**N**	**0**	**-**
HDRVAMn020		1																				**1**	**1**	**N**	**N**	**U**	**N**	**0**	**-**
HDRVAMn021		2									1	2					1	1				**7**	**3**	**N**	**N**	**SA**	**N**	**1**	**78**
HDRVAMn022		2																				**2**	**1**	**N**	**N**	**J**	**N**	**1**	**85**
HDRVAMn023		1												2	1*	-	-	-	-	-	-	**4**	**2**	**Y**	**Y**	**J**	**N**	**1**	**80**
HDRVAMn024		2																				**2**	**1**	**Y**	**N**	**A**	**P**	**1**	**60**
HDRVAMn025		1																				**1**	**1**	**Y**	**N**	**U**	**N**	**1**	**62**

Key: * = deceased; † = sighting occurred on offshore survey; Y = yes; N = no; P = possible; A = adult; SA = sub-adult; J = juvenile; C = calf; U = unknown

HDR Catalog ID	2014	2015			2015		2016				2016		2017			2017			2018			Total No. Days Seen	Total No. Seasons Seen	Biopsied? (Y,N)	Satellite Tagged? (Y,N)	Est. Age Class (A/J)	Prop scars or injuries? (Y/N)	Total No. Focal Follows	Total No. Focal Follow Minutes
	Season 1 (2014/15)				Season 2 (2015/16)						Season 3 (2016/17)					Season 4 (2017/18)													
	December	January	February	April	October	December	January	February	March	May	November	December	January	February	March	October	November	December	January	February	March								
Humpback Whales (continued)																													
HDRVAMn027		2				2	1						1									**6**	**2**	**Y**	**N**	**J**	**N**	**1**	**61**
HDRVAMn028		1																				**1**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn029			1																			**1**	**1**	**Y**	**N**	**J**	**P**	**1**	**63**
HDRVAMn030				1	1																	**2**	**2**	**N**	**N**	**A**	**N**	**1**	**62**
HDRVAMn031				1							1					1						**3**	**3**	**N**	**Y**	**J**	**N**	**0**	**-**
HDRVAMn032				1																		**1**	**1**	**N**	**N**	**SA**	**N**	**1**	**-**
HDRVAMn033				1																		**1**	**1**	**N**	**N**	**J**	**N**	**0**	**63**
HDRVAMn034				1																		**1**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn035						2																**2**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn036						2																**2**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn037						2	1															**3**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn039						1																**1**	**1**	**Y**	**Y**	**J**	**N**	**0**	**-**
HDRVAMn041						1																**1**	**1**	**N**	**Y**	**J**	**N**	**0**	**-**
HDRVAMn042						4	2															**6**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn043						1																**1**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn044						1																**1**	**1**	**Y**	**Y**	**J**	**Y**	**0**	**-**
HDRVAMn045						2	2	1	1													**6**	**1**	**Y**	**Y**	**J**	**Y**	**0**	**-**
HDRVAMn046						2	2															**4**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn047						1																**1**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn048						2					1											**3**	**2**	**Y**	**Y**	**SA/A**	**N**	**0**	**-**
HDRVAMn049						2					2	2	2			1				1†		**10**	**3**	**Y**	**Y(2)**	**SA/A**	**N**	**0**	**-**
HDRVAMn050						1	3															**4**	**1**	**Y**	**N**	**J**	**N**	**0**	**-**
HDRVAMn051						1	2	5	1													**9**	**1**	**Y**	**N**	**J**	**Y**	**0**	**-**
HDRVAMn052							3															**3**	**1**	**Y**	**N**	**J**	**N**	**0**	**-**
HDRVAMn053							2															**2**	**1**	**N**	**N**	**J**	**Y**	**0**	**-**
HDRVAMn054							3	2	2													**7**	**1**	**Y**	**Y**	**J**	**N**	**0**	**-**

Key: * = deceased; † = sighting occurred on offshore survey; Y = yes; N = no; P = possible; A = adult; SA = sub-adult; J = juvenile; C = calf; U = unknown

HDR Catalog ID	2014	2015			2015		2016				2016		2017			2017			2018			Total No. Days Seen	Total No. Seasons Seen	Biopsied? (Y.N)	Satellite Tagged? (Y.N)	Est. Age Class (A/J)	Prop scars or injuries? (Y/N)	Total No. Focal Follows	Total No. Focal Follow Minutes
	Season 1 (2014/15)				Season 2 (2015/16)						Season 3 (2016/17)					Season 4 (2017/18)													
	December	January	February	April	October	December	January	February	March	May	November	December	January	February	March	October	November	December	January	February	March								
Humpback Whales (continued)																													
HDRVAMn055							2															**2**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn056							2															**2**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn057							1															**1**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn058							1															**1**	**1**	**N**	**N**	**J/SA**	**Y**	**0**	**-**
HDRVAMn059							1				2											**3**	**2**	**Y**	**Y**	**SA**	**N**	**0**	**-**
HDRVAMn060							1															**1**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn061								3														**3**	**1**	**Y**	**Y**	**J**	**N**	**0**	**-**
HDRVAMn062								2	1													**3**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn063								4														**4**	**1**	**Y**	**Y**	**J**	**N**	**1**	**120**
HDRVAMn064								1	1		3	4	1	4			2					**16**	**3**	**Y**	**Y(2)**	**J**	**N**	**0**	**-**
HDRVAMn065									1				1	2								**4**	**2**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn066									2				2									**4**	**2**	**Y**	**Y**	**J**	**N**	**0**	**-**
HDRVAMn068										1												**1**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn069											1											**1**	**1**	**Y**	**Y**	**SA**	**N**	**0**	**-**
HDRVAMn071											2											**2**	**1**	**Y**	**Y**	**SA**	**N**	**0**	**-**
HDRVAMn072											1											**1**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn073											1											**1**	**1**	**N**	**N**	**SA**	**N**	**0**	**-**
HDRVAMn074											1											**1**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn075											1											**1**	**1**	**N**	**N**	**SA**	**N**	**0**	**-**
HDRVAMn076											1											**1**	**1**	**N**	**N**	**SA**	**N**	**0**	**-**
HDRVAMn077											1											**1**	**1**	**N**	**N**	**SA**	**N**	**0**	**-**
HDRVAMn078											1	*	-	-	-	-	-	-	-	-	-	**1**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn079												1		2								**3**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn080												1										**1**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn081												2	4	3								**9**	**1**	**Y**	**Y**	**J**	**N**	**0**	**-**
HDRVAMn082												1		3			*	-	-	-	-	**3**	**1**	**Y**	**Y**	**J**	**N**	**0**	**-**

Key: * = deceased; † = sighting occurred on offshore survey; Y = yes; N = no; P = possible; A = adult; SA = sub-adult; J = juvenile; C = calf; U = unknown

HDR Catalog ID	Season 1 (2014/15)				Season 2 (2015/16)						Season 3 (2016/17)					Season 4 (2017/18)						Total No. Days Seen	Total No. Seasons Seen	Biopsied? (Y.N)	Satellite Tagged? (Y.N)	Est. Age Class (A/J)	Prop scars or injuries? (Y/N)	Total No. Focal Follows	Total No. Focal Follow Minutes
	2014	2015			2015		2016				2016		2017			2017			2018										
	December	January	February	April	October	December	January	February	March	May	November	December	January	February	March	October	November	December	January	February	March								
Humpback Whales (continued)																													
HDRVAMn083												1	1									**2**	**1**	**Y**	**Y**	**J**	**N**	**0**	**-**
HDRVAMn084												1	5	5								**11**	**1**	**Y**	**Y**	**J**	**N**	**0**	**-**
HDRVAMn085												1	4	3								**8**	**1**	**N**	**N**	**J**	**Y**	**0**	**-**
HDRVAMn086												1										**1**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn087													3									**3**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn088													4	2								**6**	**1**	**Y**	**Y**	**J**	**N**	**0**	**-**
HDRVAMn089													1									**1**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn090													4	*	-	-	-	-	-	-	-	**4**	**1**	**Y**	**Y**	**J**	**Y**	**0**	**-**
HDRVAMn091													3	2*	-	-	-	-	-	-	-	**5**	**1**	**N**	**N**	**SA**	**Y**	**0**	**-**
HDRVAMn092													2	4								**6**	**1**	**Y**	**Y**	**J**	**N**	**0**	**-**
HDRVAMn093													2	4								**6**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn094													1									**1**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn095													2									**2**	**1**	**Y**	**Y**	**J**	**N**	**0**	**-**
HDRVAMn096													3	2								**5**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn097													1									**1**	**1**	**N**	**Y**	**J**	**N**	**0**	**-**
HDRVAMn098													3	5								**8**	**1**	**Y**	**N**	**J**	**N**	**0**	**-**
HDRVAMn099													2	4								**6**	**1**	**Y**	**Y**	**J**	**N**	**0**	**-**
HDRVAMn100													1*	-	-	-	-	-	-	-	-	**1**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn101													1									**1**	**1**	**Y**	**Y**	**J**	**N**	**0**	**-**
HDRVAMn102													2	4	1							**7**	**1**	**Y**	**Y**	**J**	**N**	**0**	**-**
HDRVAMn103													1	3								**4**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn104													2	2								**4**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn105													1	2								**3**	**1**	**Y**	**Y**	**J**	**N**	**0**	**-**
HDRVAMn106													1	2								**3**	**1**	**N**	**N**	**J**	**P**	**0**	**-**
HDRVAMn107														2								**2**	**1**	**N**	**N**	**J**	**N**	**0**	**-**
HDRVAMn108														2								**2**	**1**	**N**	**N**	**J**	**N**	**0**	**-**

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HDR Catalog ID	2014	2015			2015		2016				2016		2017			2017			2018			Total No. Days Seen	Total No. Seasons Seen	Biopsied? (Y.N)	Satellite Tagged? (Y.N)	Est. Age Class (A/J)	Prop scars or injuries? (Y/N)	Total No. Focal Follows	Total No. Focal Follow Minutes
	Season 1 (2014/15)				Season 2 (2015/16)						Season 3 (2016/17)					Season 4 (2017/18)													
	December	January	February	April	October	December	January	February	March	May	November	December	January	February	March	October	November	December	January	February	March								
Humpback Whales (continued)																													
HDRVAMn109														2	1							3	1	N	N	J	N	0	-
HDRVAMn110														2								2	1	N	N	J	N	0	-
HDRVAMn111														1								1	1	Y	N	SA/A	N	0	-
HDRVAMn112														1								1	1	Y	N	J	P	0	-
HDRVAMn113																1						1	1	N	N	J	N	0	-
HDRVAMn114																	1		1			2	1	N	N	J	N	0	-
HDRVAMn115																	2					2	1	N	N	J	N	0	-
HDRVAMn116																	1					1	1	N	N	J	N	0	-
HDRVAMn117																	1					1	1	N	N	J	N	0	-
HDRVAMn118																		1				1	1	N	N	J	N	0	-
HDRVAMn119																		2				2	1	N	N	J	N	0	-
HDRVAMn120																		1				1	1	Y	Y	J	N	0	-
HDRVAMn121																		1				1	1	N	N	J	N	0	-
HDRVAMn122																		3				3	1	Y	N	J	N	0	-
HDRVAMn123																		1				1	1	N	N	J	N	0	-
HDRVAMn124																		1				1	1	N	N	J	N	0	-
HDRVAMn125																		2				2	1	N	N	J	Y	0	-
HDRVAMn126																				1†		1	1	Y	Y	SA/A	N	0	
Totals	7	49	5	5	1	30	32	18	9	1	24	19	70	66	2	4	9	12	1	2	0			47	37		10	29	1951
Fin Whales:																													
HDRVABp001		1																				1	1	N	N	A	N	1	61
HDRVABp002		1																				1	1	N	N	C	N	0	-
HDRVABp003		1																				1	1	N	N	A	N	0	-
HDRVABp009								2														2	1	N	N	SA/A	N	0	-
HDRVABp010								2														2	1	N	N	SA/A	N	0	-
HDRVABp011								1														1	1	N	N	A	N	0	-

Key: * = deceased; † = sighting occurred on offshore survey; Y = yes; N = no; P = possible; A = adult; SA = sub-adult; J = juvenile; C = calf; U = unknown

HDR Catalog ID	2014	2015			2015		2016				2016		2017			2017			2018			Total No. Days Seen	Total No. Seasons Seen	Biopsied? (Y.N)	Satellite Tagged? (Y.N)	Est. Age Class (A/J)	Prop scars or injuries? (Y/N)	Total No. Focal Follows	Total No. Focal Follow Minutes
	Season 1 (2014/15)				Season 2 (2015/16)						Season 3 (2016/17)					Season 4 (2017/18)													
	December	January	February	April	October	December	January	February	March	May	November	December	January	February	March	October	November	December	January	February	March								
Fin Whales (continued)																													
HDRVABp035																		1*	-	-	-	**1**	**1**	**N**	**N**	**SA**	**N**	**0**	**-**
HDRVABp020															1†				1			**2**	**2**	**N**	**Y**	**SA**	**N**	**0**	**-**
HDRVABp037																			1			**1**	**1**	**N**	**N**	**SA**	**N**	**0**	**-**
HDRVABp038																			1			**1**	**1**	**N**	**N**	**SA**	**N**	**0**	**-**
HDRVABp016														1†					1			**2**	**2**	**N**	**Y**	**SA**	**N**	**0**	**-**
HDRVABp040																			1			**1**	**1**	**N**	**N**	**SA**	**N**	**0**	**-**
HDRVABp041																			1			**1**	**1**	**N**	**Y**	**SA**	**N**	**0**	**-**
HDRVABp042																			1			**1**	**1**	**N**	**N**	**SA**	**N**	**0**	**-**
Totals	**0**	**3**	**0**	**0**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**0**	**0**	**1†**	**1†**	**0**	**0**	**1**	**7**	**0**	**0**			**0**	**0**		**0**	**1**	**61**
Minke Whales:																													
HDRVABa003														1								**1**	**1**	**N**	**N**	**A**	**N**	**0**	**-**
HDRVABa004														1								**1**	**1**	**N**	**N**	**A**	**N**	**0**	**-**
Totals	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**			**0**	**0**		**0**	**0**	**0**

Key: * = deceased; † = sighting occurred on offshore survey; Y = yes; N = no; P = possible; A = adult; SA = sub-adult; J = juvenile; C = calf; U = unknown

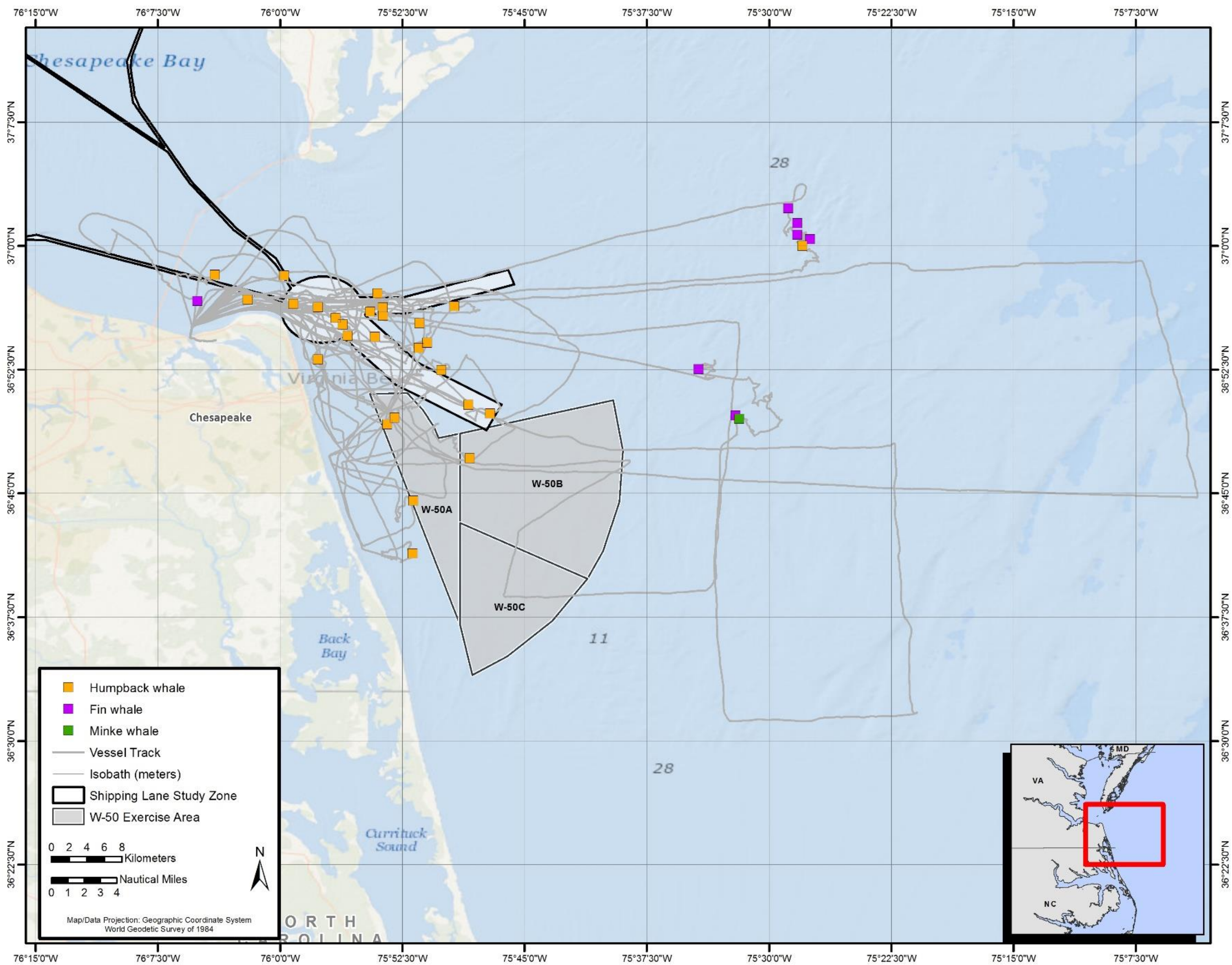

Figure 4. Survey tracks and locations of all humpback (n=27), fin (n=7), and minke (n=1) whale sightings: 31 October 2017–10 March 2018.

(not inclusive of one unique humpback whale identification from the Outer Continental Shelf Break Cetacean Study – see Engelhaupt et al. 2017). Seven of the 32 (21.9 percent) humpback whales were seen on more than one occasion during the 2017/2018 field season, which is considerably fewer than in the previous season (69.5 percent during 2016/2017).

Evidence of vessel interaction is apparent on at least 10 of the 119 (8.4 percent) humpback whales in HDR's catalog. Four of the whales added during the 2016/2017 field season were later found dead. HDRVAMn078 came ashore on Corolla, North Carolina; HDRVAMn090 came ashore on Virginia Beach, Virginia; HDRVAMn091 was towed to Cape Charles, Virginia; and HDRVAMn100 was towed to Norfolk, Virginia. Post-mortem examination revealed three of these were males and one (HDRVAMn078) was a female (pers. comm. Sarah Mallette). Cause of death for three of the four whales (HDRVAMn090, HDRVAMn091, and HDRVAMn100) was likely due to large-vessel interactions (NMFS 2017), with two animals having large propeller wounds (HDRVAMn090 and HDRVAMn100) (**Table 2**). Cause of death for the fourth whale (HDRVAMn078) was linked to human interaction (fisheries) (NMFS 2017), however, when this individual was observed alive by HDR during survey effort, the animal appeared to be severely emaciated to the point where the team opted not to deploy a satellite tag on this whale.

3.3 Satellite Tagging Results

Twenty-three SPOT6 and three SPLASH10-F satellite tags were deployed during the 2016/2017 field season (see Aschettino et al. 2017). Seven SPOT6 and two SPLASH10-F satellite tags were deployed during the 2017/2018 field season (**Figures 5 through 13**). During the 2017/2018 field season, three of the tags (one SPOT6 and two SPLASH10-F) were deployed on fin whales. Tags transmitted between 6.3 and 52.8 days (mean = 13.4 days) during the 2017/2018 field season (**Table 3 and Table 4**) which is consistent with the mean duration of all tags previously deployed during this project (13.6 days, n=35 tags). Two whales (HDRVAMn049 and HDRVAMn126) were tagged during an offshore survey (see Engelhaupt et al. 2018). Four whales (HDRVAMn010, HDRVAMn012, HDRVAMn064, and HDRVAMn049) were also previously tagged, three during the 2016/2017 field season (HDRVAMn012, HDRVAMn064, and HDRVAMn049) and one during the 2015/2016 field season (HDRVAMn010). Based on estimated size in the field, HDRVAMn010 was classified as a sub-adult, HDRVAMn049 was classified as a sub-adult/adult, and HDRVAMn012 and HDRVAMn064 were classified as juveniles (**Table 3**). Comparisons of the tag tracklines between seasons for the same individual show considerable differences in movements (**Figures 14 through 17**). Whales tagged during the 2017/2018 field season spent more time away from the primary study area. All tags from the 2016/2017 field season had Argos locations within shipping channels and 15 of the 26 (57.7 percent) tagged animals had Argos locations west of the Chesapeake Bay Bridge-Tunnel (CBBT). This was a large increase when compared to the 2015/2016 field season where only two of nine (22.2 percent) had locations west of the CBBT (see Aschettino et al. 2016) and there were no movements west of the CBBT during the 2017/2018 field season. Only three out of six humpback whales and one out of three fin whales tagged during the 2017/2018 field season had locations in the shipping channels, whereas five out of six humpbacks and one out of three fin whales had locations in the W-50 MINEX zone. Two humpback whales and all three fin whales also had movements into waters farther offshore.

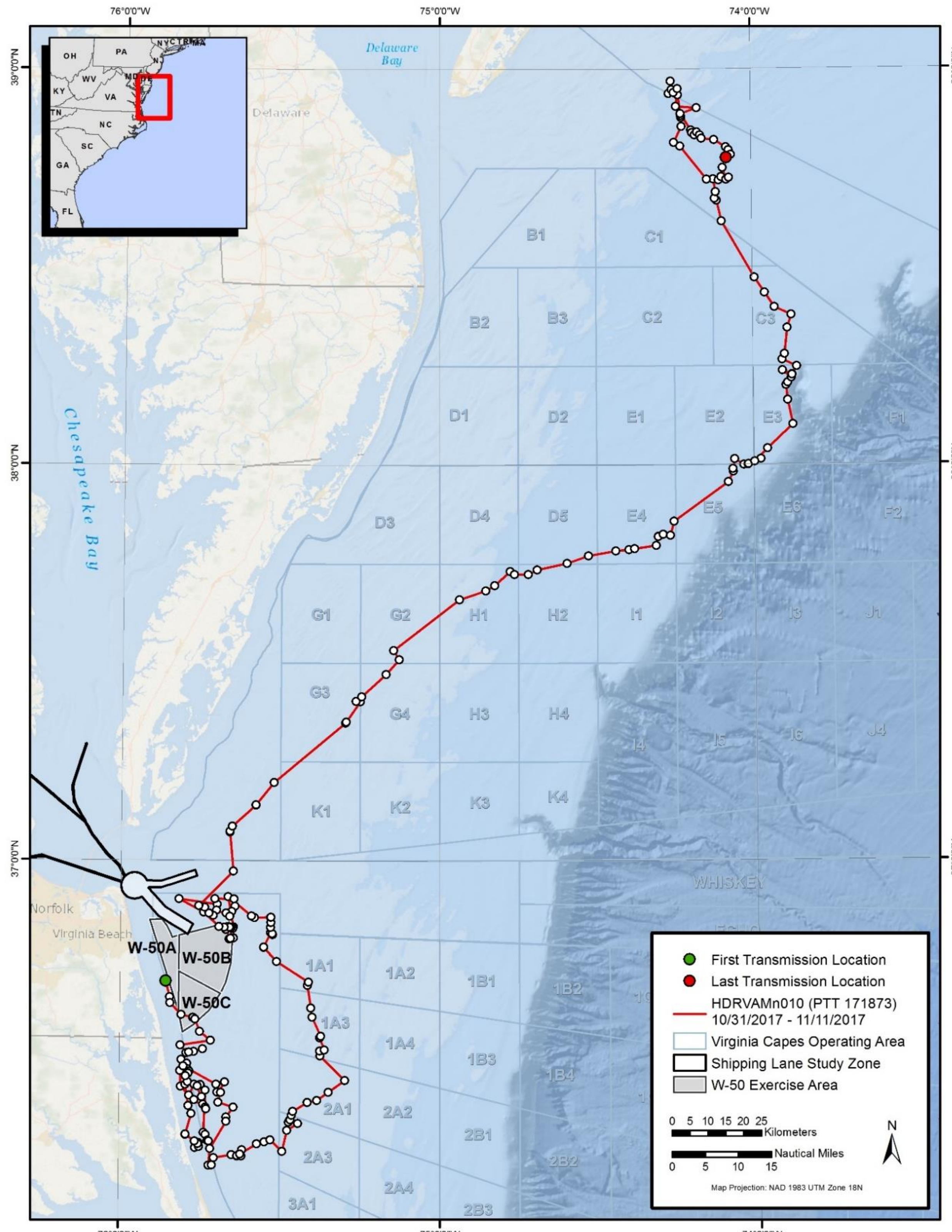

Figure 5. Filtered locations (white dots) and track of humpback whale HDRVAMn010 over 10.3 days of tag-attachment duration.

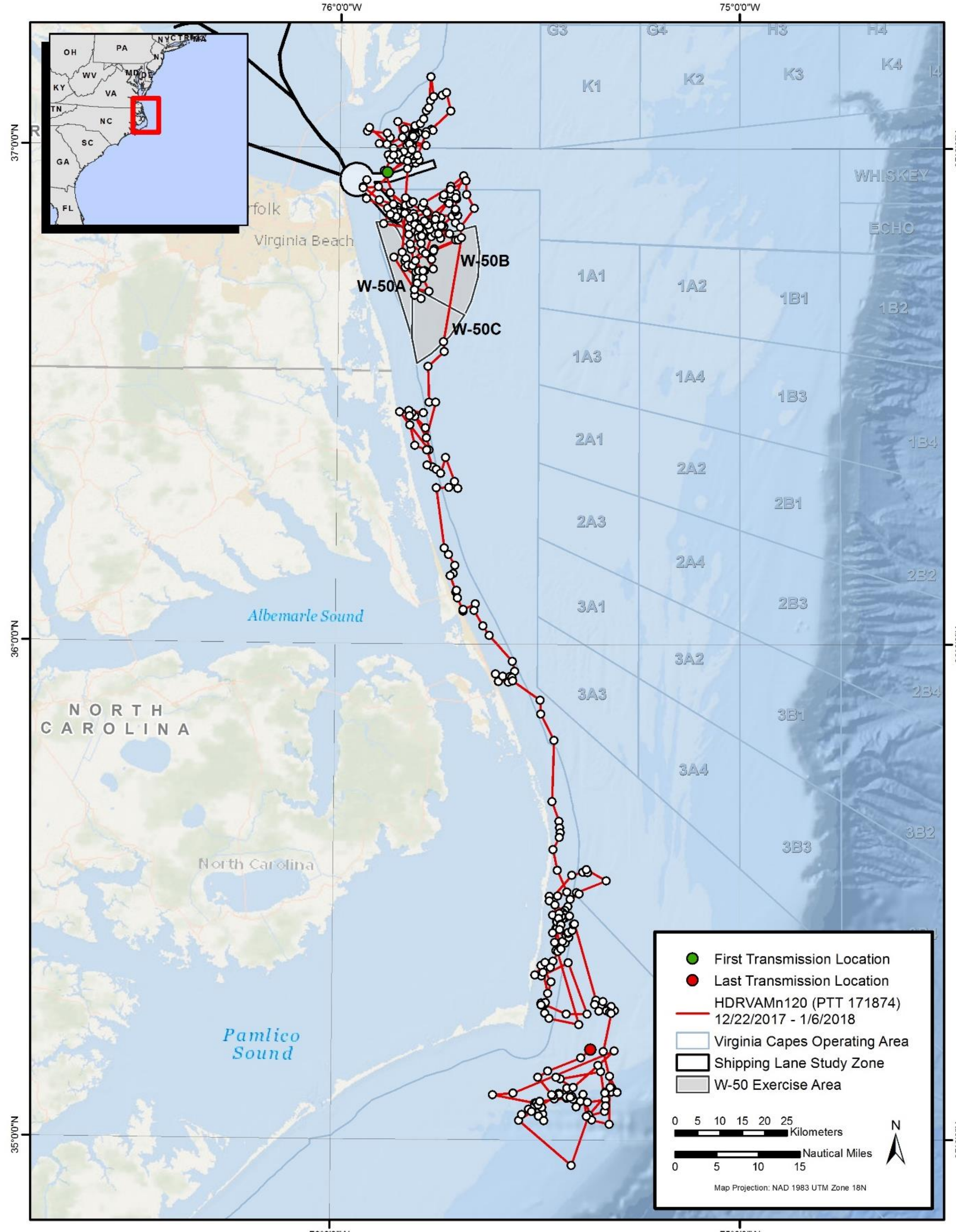

Figure 6. Filtered locations (white dots) and track of humpback whale HDRVAMn120 over 15.1 days of tag-attachment duration.

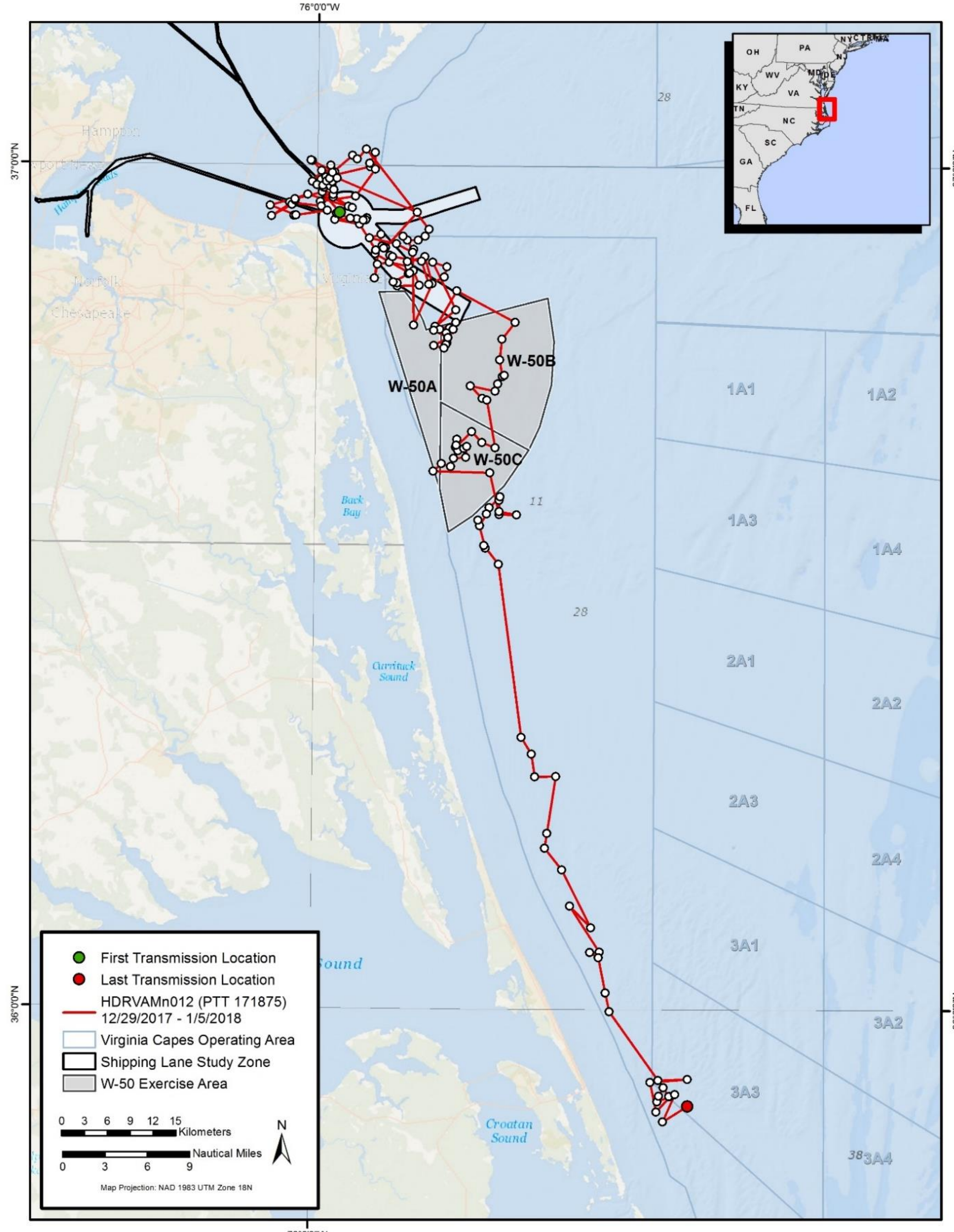

Figure 7. Filtered locations (white dots) and track of humpback whale HDRVAMn059 over 6.0 days of tag-attachment duration.

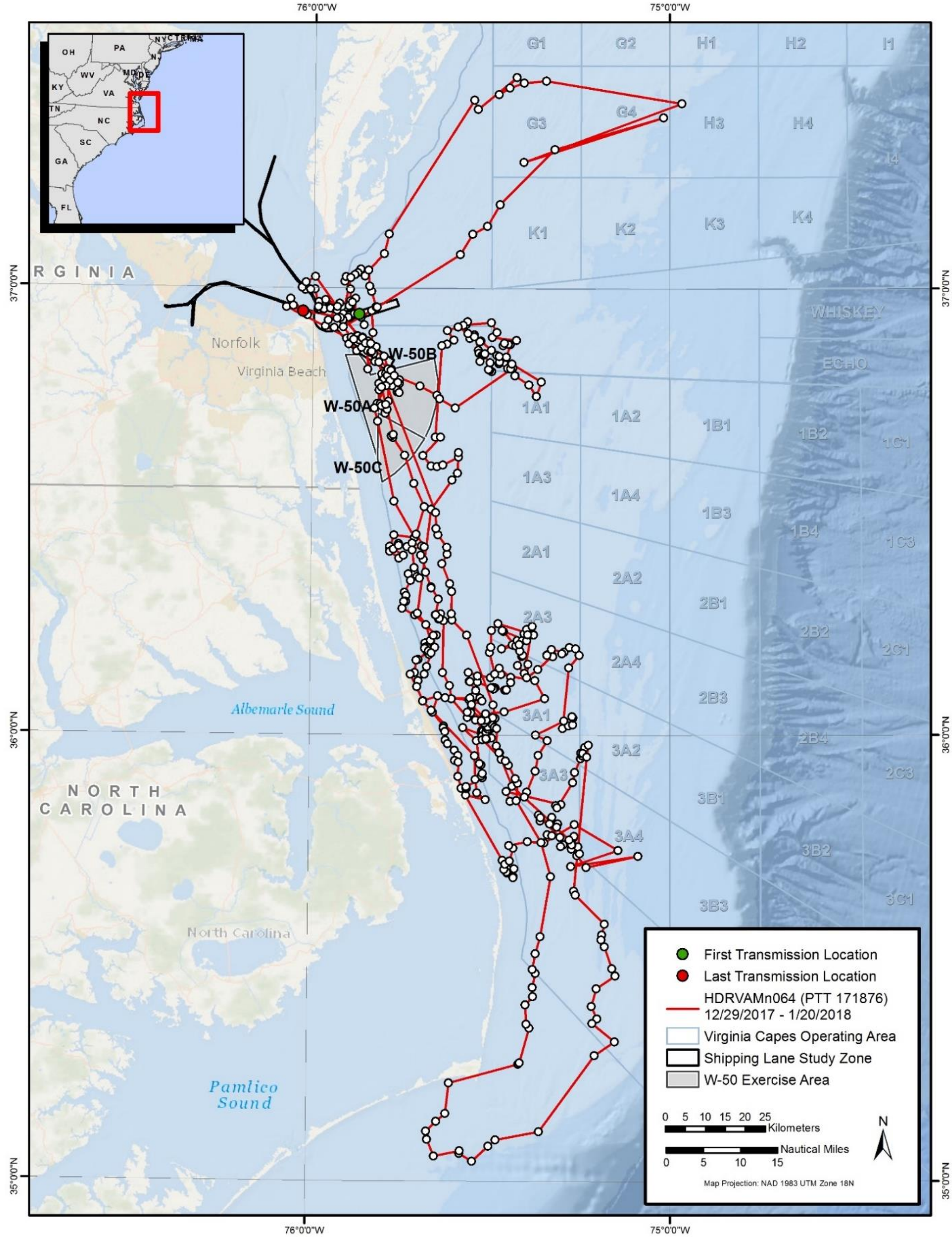

Figure 8. Filtered locations (white dots) and track of humpback whale HDRVAMn064 over 21.8 days of tag-attachment duration.

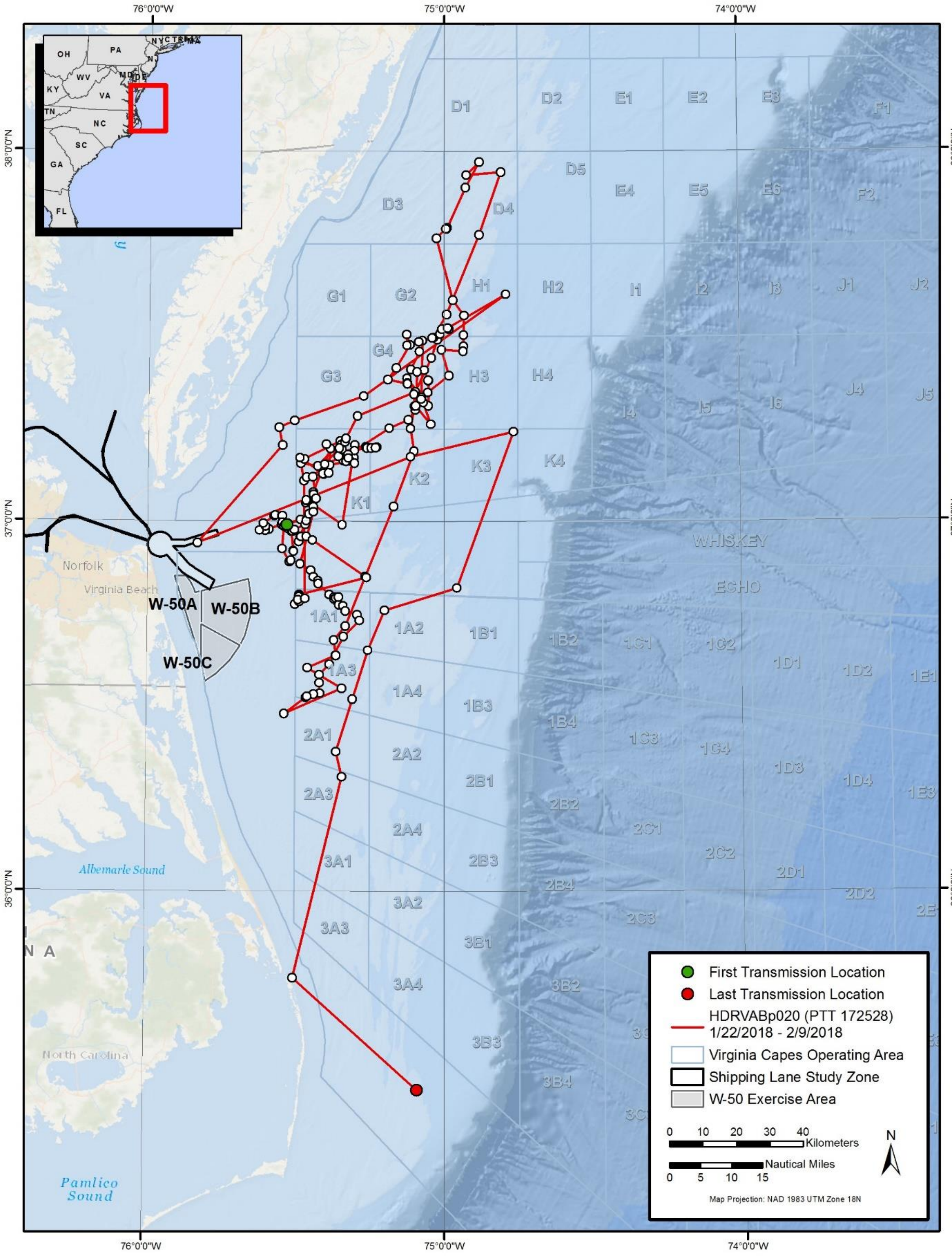

Figure 9. Filtered locations (white dots) and track of fin whale HDRVABp020 over 19.4 days of tag-attachment duration.

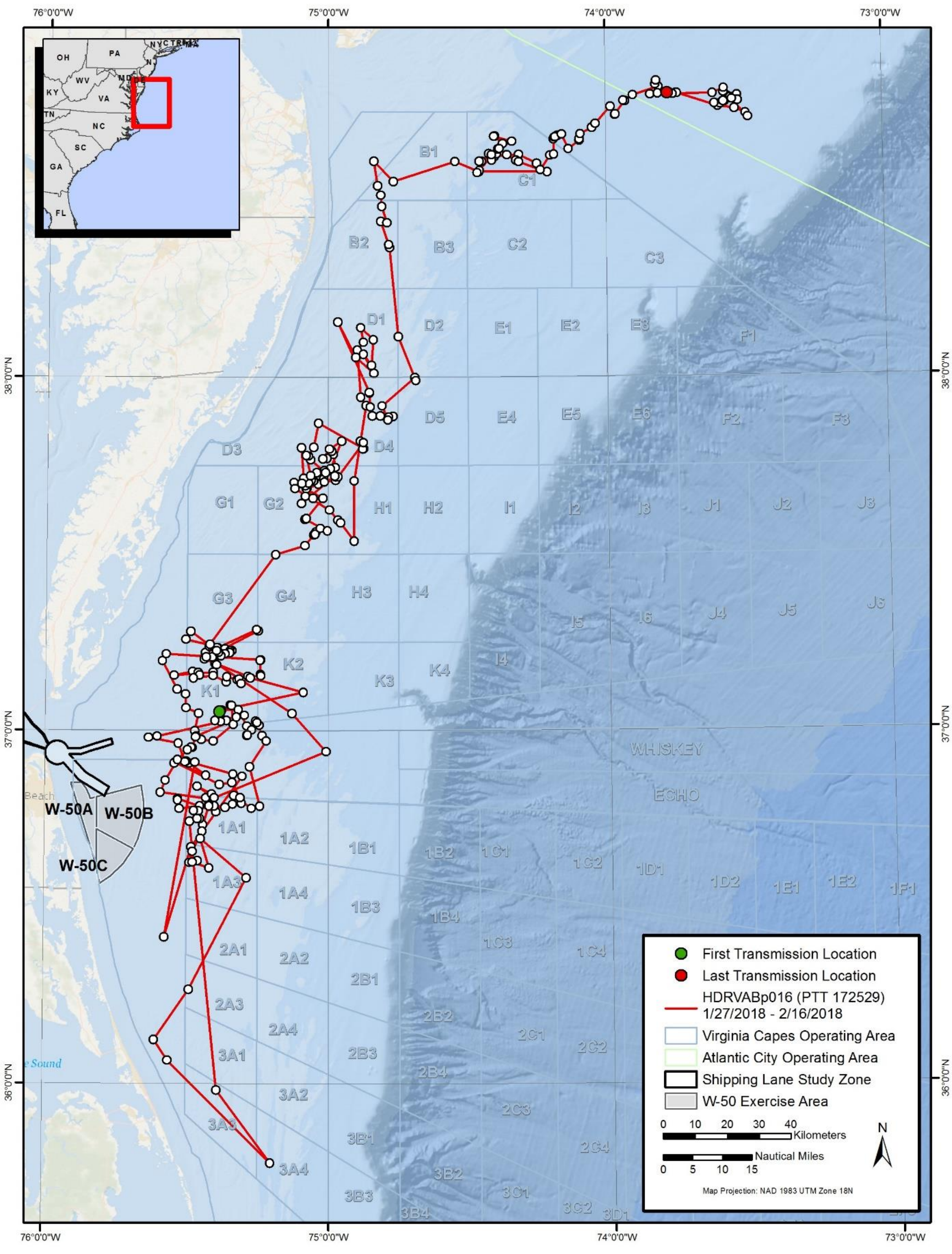

Figure 10. Filtered locations (white dots) and track of fin whale HDRVABp016 over 21.0 days of tag-attachment duration.

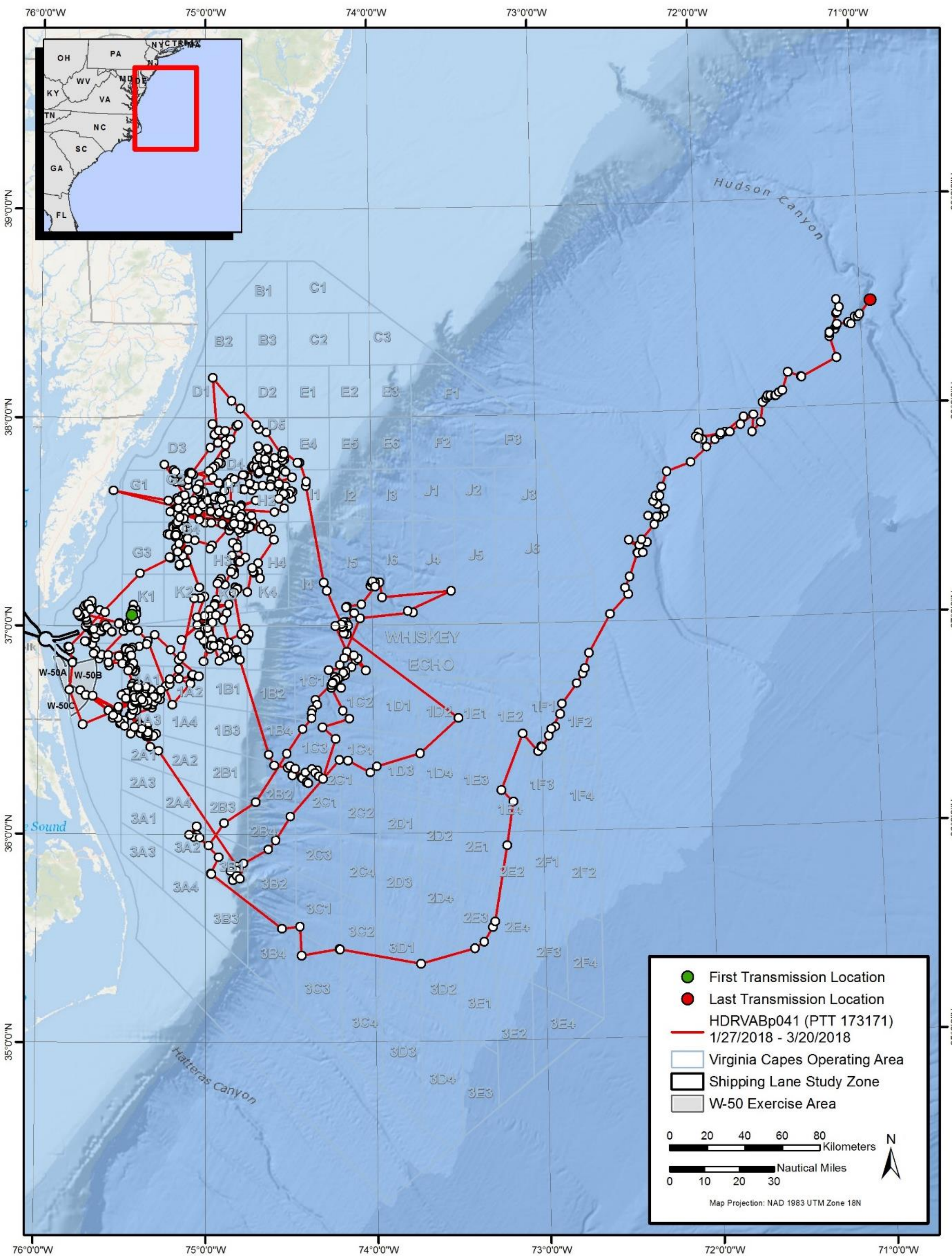

Figure 11. Filtered locations (white dots) and track of fin whale HDRVABp041 over 52.8 days of tag-attachment duration.

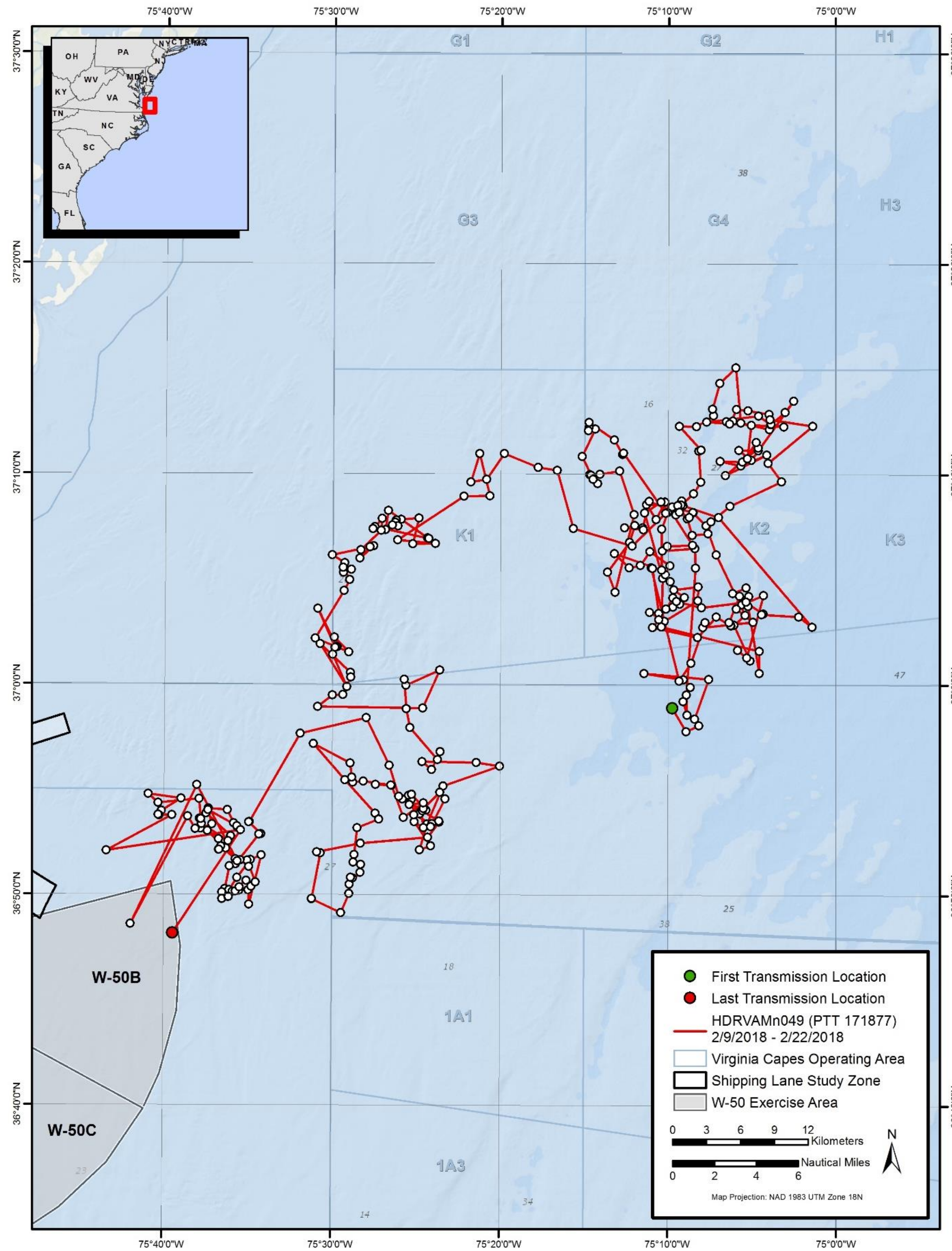

Figure 12. Filtered locations (white dots) and track of humpback whale HDRVAMn049 over 13.3 days of tag-attachment duration.

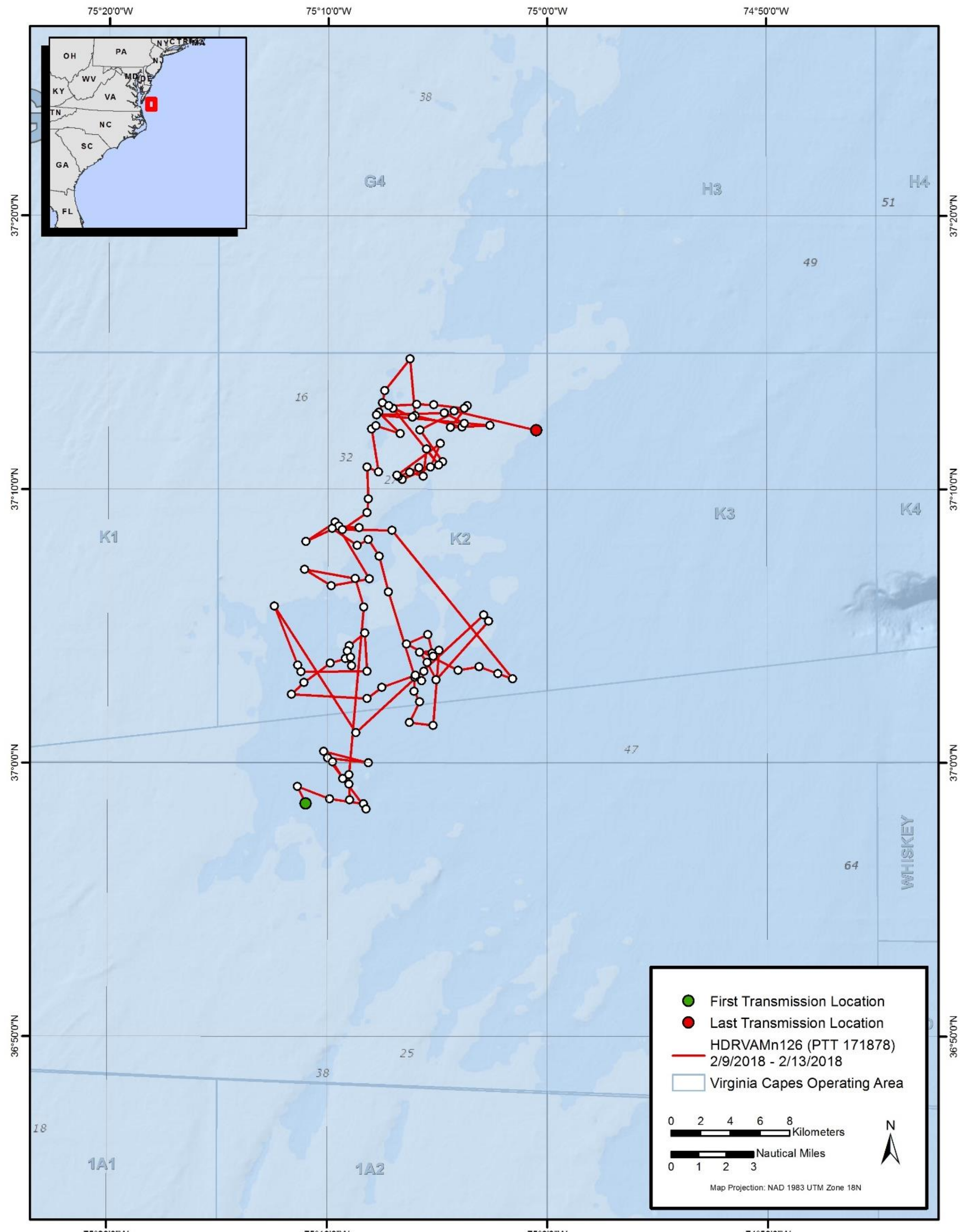

Figure 13. Filtered locations (white dots) and track of humpback whale HDRVAMn126 over 4.1 days of tag-attachment duration.

Table 3. Summary of satellite tag deployment details for all humpback whales tagged during the 2017/18 season.

Animal ID	Estimated Age Class	Tag Type	Argos ID	Deployment (GMT)	Last Transmission (GMT)	Days Trans-mitted
HDRVAMn010	Sub-adult	SPOT6	171873	31-Oct-2017 17:59	11-Nov-2017 02:46	10.3
HDRVAMn120	Juvenile	SPOT6	171874	22-Dec-2017 17:40	06-Jan-2018 21:30	15.1
HDRVAMn012	Juvenile	SPOT6	171875	29-Dec-2017 17:41	05-Jan-2018 03:46	6.3
HDRVAMn064	Juvenile	SPOT6	171876	29-Dec-2017 14:09	20-Jan-2018 15:56	21.8
HDRVAMn049	Sub-adult/ adult	SPOT6	171877	09-Feb-2018 14:12	22-Feb-2018 23:00	13.3
HDRVAMn126	Sub-adult/ adult	SPOT6	171878	09-Feb-2018 15:13	13-Feb-2018 19:11	4.1

Table 4. Summary of satellite tag deployment details for all fin whales tagged during the 2017/18 season.

Animal ID	Estimated Age Class	Tag Type	Argos ID	Deployment (GMT)	Last Transmission (GMT)	Days Trans-mitted
HDRVABp020	Sub-adult	SPLASH10-F	172528	21-Jan-2018 14:46	10-Feb-2018 19:11	19.4
HDRVABp016	Sub-adult	SPLASH10-F	172529	26-Jan-2018 15:42	16-Feb-2018 23:46	21.0
HDRVABp041	Sub-adult	SPOT6	173171	26-Jan-2018 17:39	20-Mar-2018 19:17	52.8

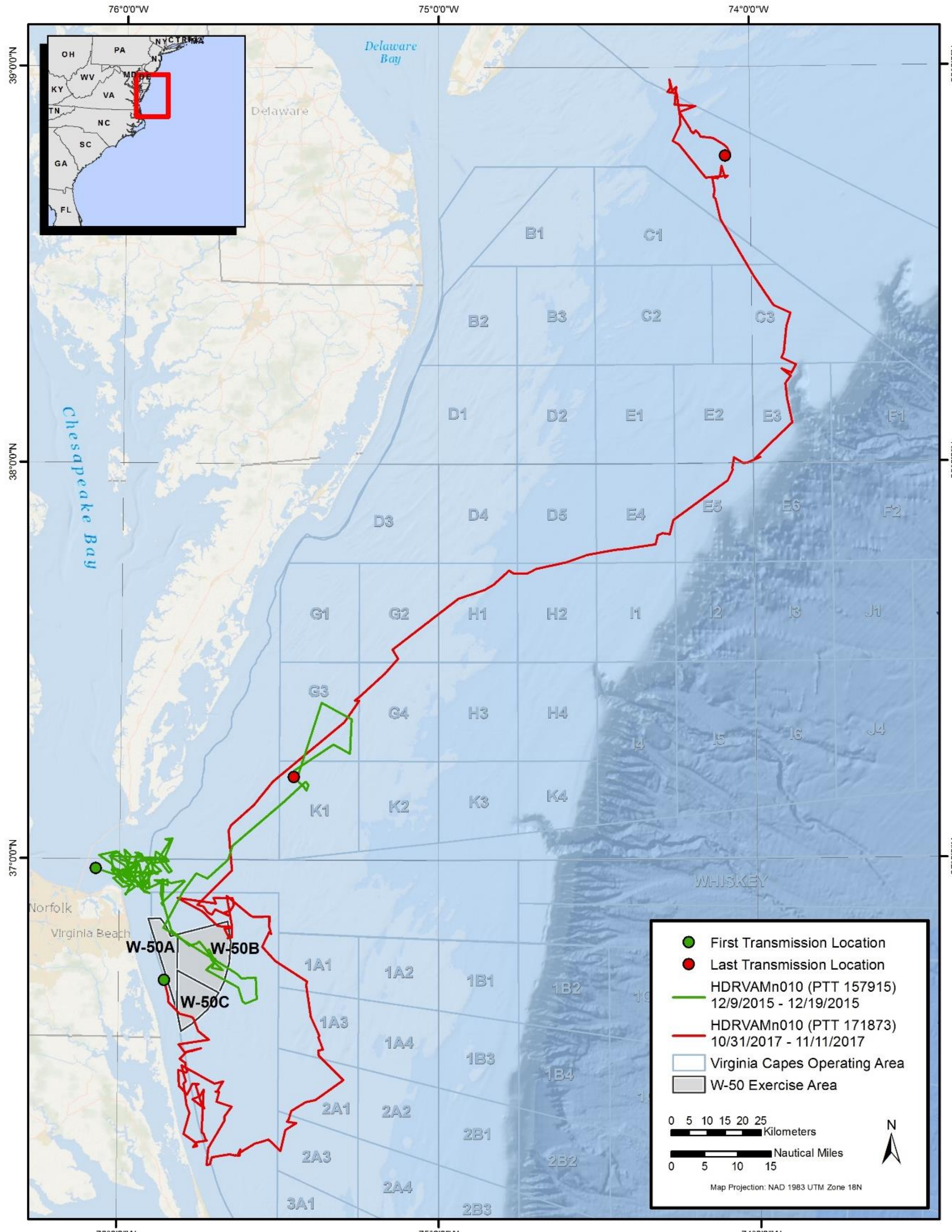

Figure 14. Comparison of tag tracklines for HDRVAMn010 from 2015 (green trackline, 10.5 days) and 2017 (red trackline, 10.3 days).

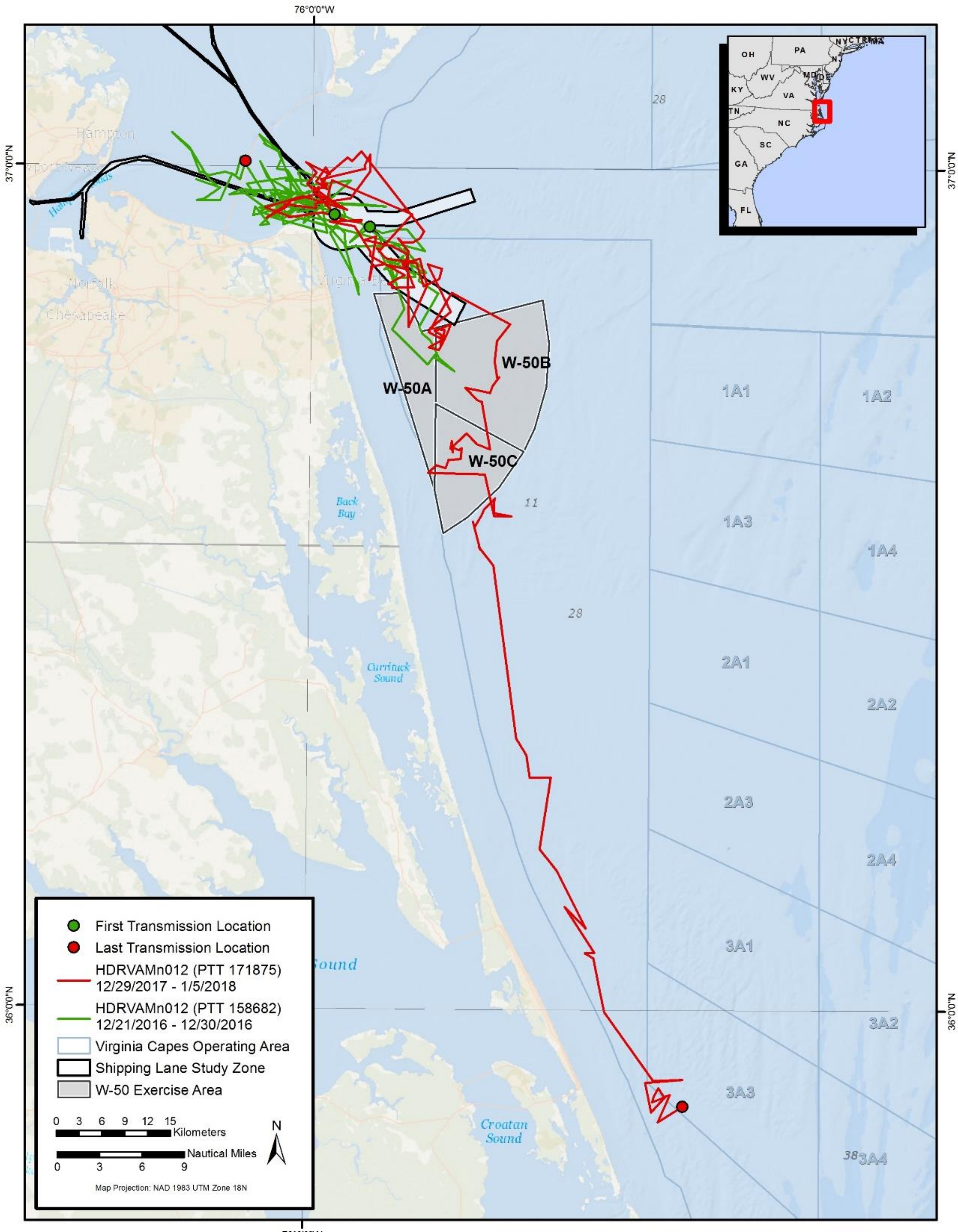

Figure 15. Comparison of tag tracklines for HDRVAMn012 from 2016 (green trackline, 8.4 days) and 2017 (red trackline, 6.3 days).

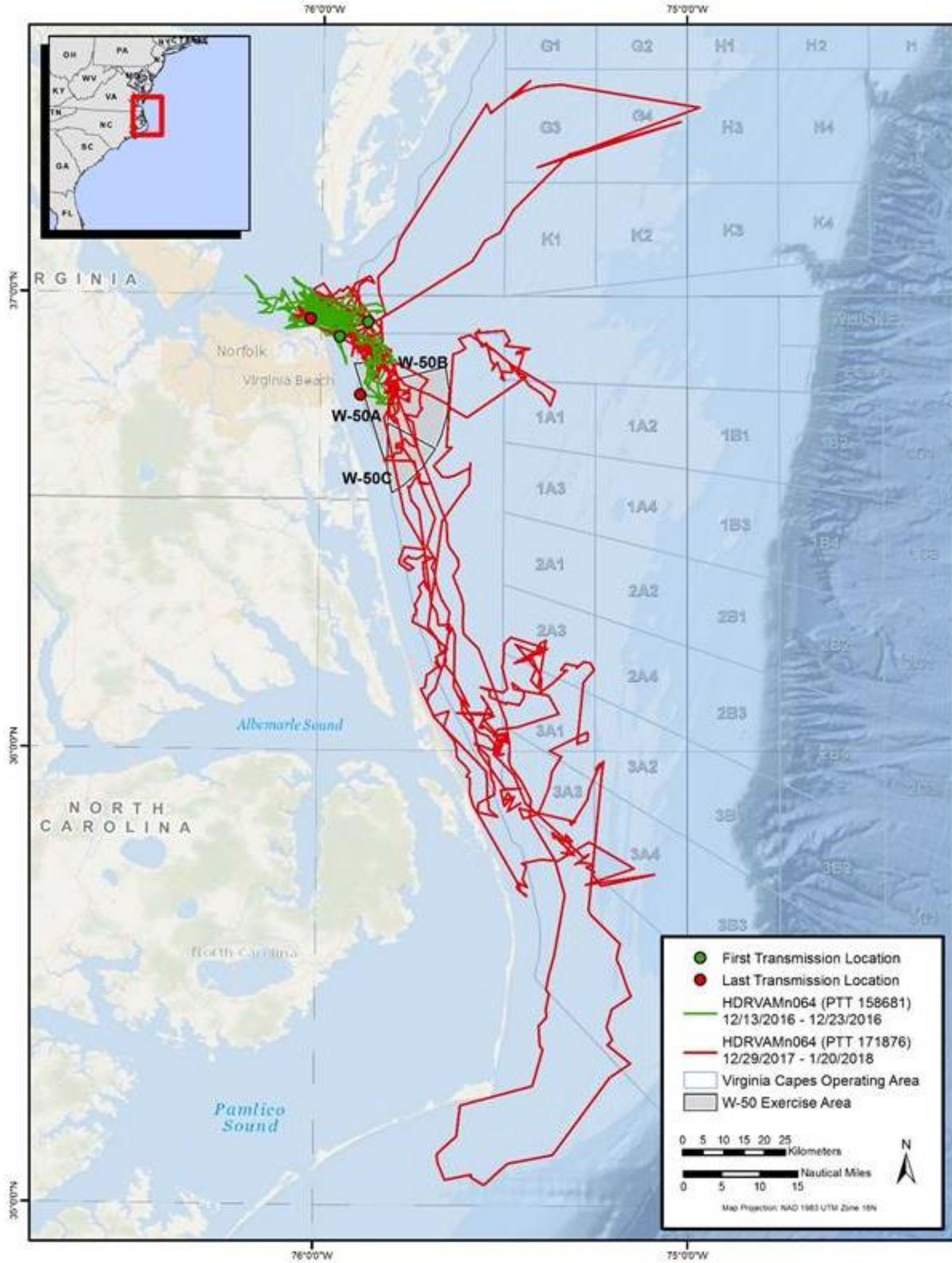

Figure 16. Comparison of tag tracklines for HDRVAMn064 from 2016 (green trackline, 9.3 days) and 2017/2018 (red trackline, 21.8 days).

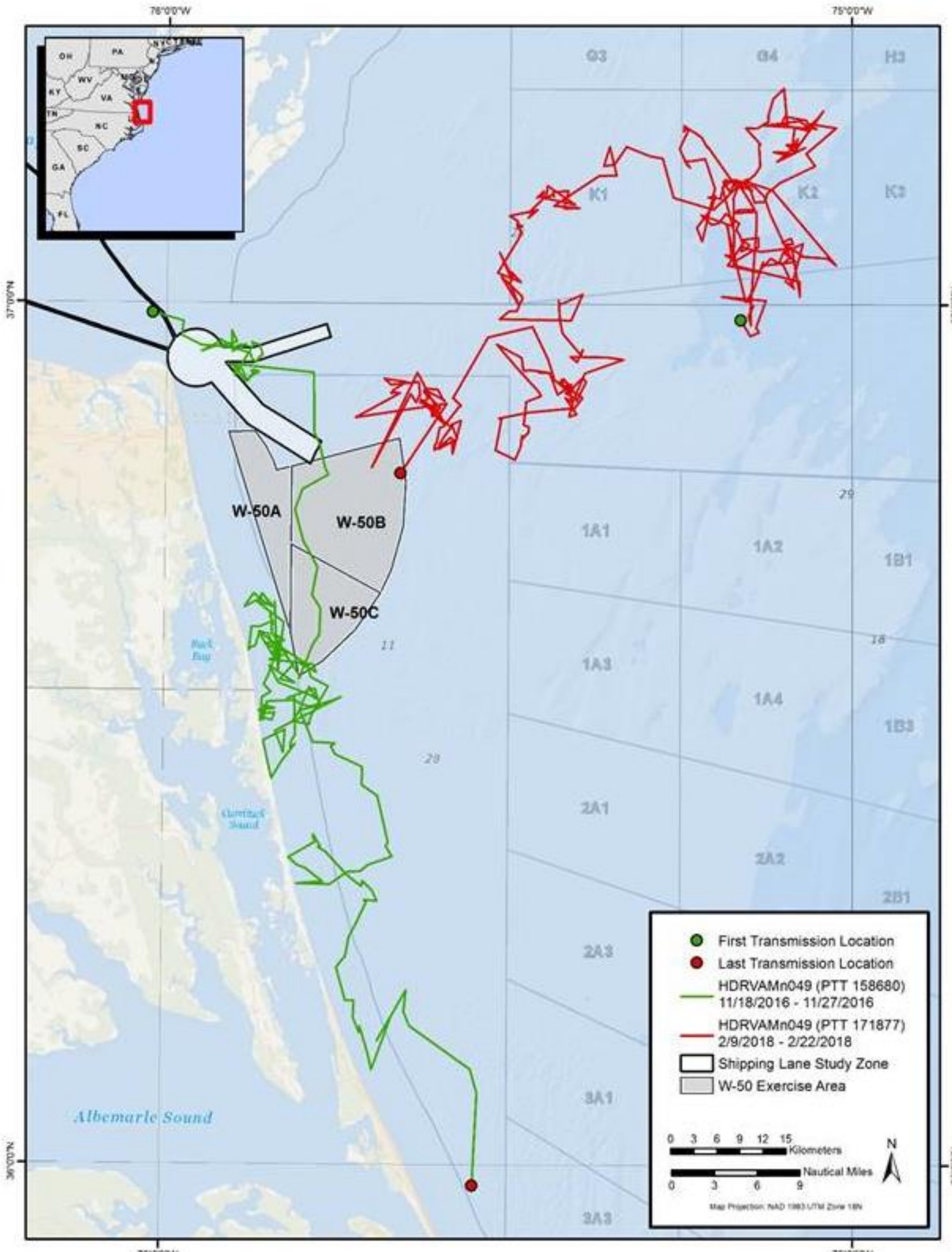

Figure 17. Comparison of tag tracklines for HDRVAMn049 from 2016 (green trackline, 8.4 days) and 2018 (red trackline, 13.3 days).

When zooming in on the primary study area at the mouth of the Chesapeake Bay using tag data collected from all field seasons, the importance of this area to humpbacks whales (and fin whales) is apparent (**Figure 18**). Nearly a quarter (2,570 of 10,517) of all filtered tag locations were inside shipping channels, and approximately 8 percent (808/10,517) of locations were inside the W-50 MINEX zone.

3.4 Biopsy Results

Three humpback whale biopsy samples were collected during the 2017/2018 field season (**Table 2**). Thirty-one samples from the 2014/2015 and 2015/2016 field season, comprised of 29 humpback and two fin (see Engelhaupt et al. 2017) whale samples, were sent to Duke University for stable isotope and gender analysis at the end of the 2016/2017 field season. See Waples 2017 for a report of findings from these analyses. HDR is awaiting their Convention on International Trade in Endangered Species (CITES) export permit and will ship samples to the University of Groningen in the Netherlands for processing and integration into a larger North Atlantic humpback whale population study at the end of the 2017/2018 field season.

3.5 State-Space Model Results

To help determine the appropriate time interval for the state-space model predictions, the average time between received locations amongst all tags was calculated. Two tags were dropped from the analysis completely, PTTs 157922 and 158676 (see Aschettino et al. 2016 and Aschettino et al. 2017) due to extremely short tag durations, low number of reported locations, and no visible discernable behavior. It was determined that even in a hierarchical framework these tags would not produce interpretable results. On average 62 minutes passed between received locations with the maximum gap being almost one day. As such, one hour was the minimum time interval considered for state-space models in bsam. A suite of models was fit in bsam to a representative subset of tags at 1, 3, 6, and 12-hour time intervals. Model diagnostics were examined to ensure models were converging and outputs were examined visually for a qualitative assessment of model performance. Estimated locations were classified into behaviors based on the mean predicted behavioral state from the model runs. Values less than 1.25 were classified as traveling. Values greater than 1.75 were classified as ARS. Values in between were classified as indeterminate behavior. After examining all candidate models, a model with a three-hour time interval and a span parameter of 0.1 was selected as the best model. Parameter convergence was generally good, and the tracks were not overly smoothed between reported locations.

The selected model was applied to all tags included in the modeling analysis and results were reexamined. One tag, PTT 166675 (see Aschettino et al. 2017), was dropped after reviewing the results. This tag had a different duty cycle and few reported locations with long gaps in between which resulted in a modeled track that was clearly over-smoothed. Model diagnostics performed similarly to the model using only a subset of the tags. Overall the selected model performed well. All parameters converged acceptably and autocorrelation between chains was minimal. Markov chain Monte Carlo chains mixed as expected.

Visual inspection of model results was also used to validate model outputs. Generally, the model predicted the behavior that would be expected from reviewing the Argos data qualitatively. Indeterminate locations were most often found as animals were transitioning between traveling and ARS behaviors which is to be expected.

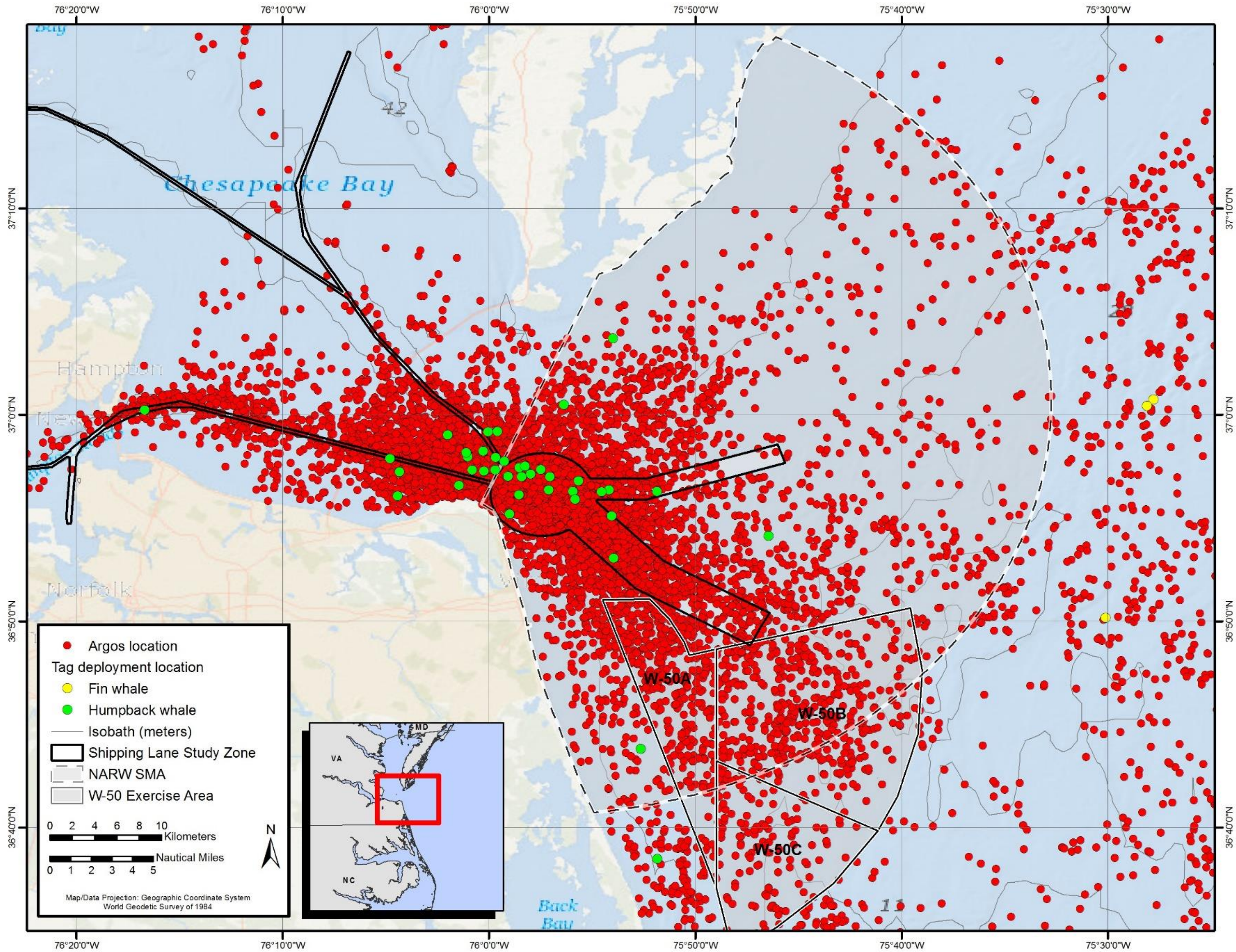

Figure 18. Filtered Argos locations (red dots) of tagged humpbacks in the immediate vicinity of shipping channels at the mouth of the Chesapeake Bay through the 2017/18 field season.

Of 3,714 modeled locations, 458 were identified as traveling, 211 were of indeterminate behavior, and the remaining 3,045 were identified as ARS, which likely represented foraging (**Figure 19**). Location predictions did not cut across land significantly. As such, no locations were dropped from the model output.

3.6 Home Range Analysis Results

Home ranges were calculated only for locations identified as ARS by the state-space model. Because the locations occur in even time intervals, the UD isopleths correspond directly to residency time (in this case, time spent performing ARS). For example, the 50% UD contains 50% of locations identified as ARS and 50% of time spent engaged in ARS behavior. Four tags, PTTs 158675, 158677, 158678, and 158679 (see Aschettino et al. 2017), were excluded from this analysis as the modeled track was too short to produce a meaningful home range. This left 29 tags for the joint home range analysis. **Table 5** contains statistics calculated from all the individual UDs. The 50% and 90% UD isopleths were selected for analysis as cutoffs for core and total home range respectively. Here we report home range metrics in numbers of cells for convenience. Each cell is approximately 16 square kilometers.

Table 5. Utilization distribution area statistics reported as count of grid cells within the 90% and 50% isopleths.

Statistic	90% UD	50% UD
mean	22.88	5.94
standard deviation	17.65	5.55
minimum	3	1
maximum	74	26

From **Table 5** we see substantial variation in the size of home ranges among individuals. This is not surprising given the variation in movement strategies seen in the outputs from the state-space model.

Combining the UDs for all individuals, 317 cells were contained within the 90% UD of at least one animal (**Figure 20**). For the 50% UDs, 100 cells were identified by at least one animal. The majority of cells identified were in the southern extent and mouth of the Chesapeake Bay with secondary concentrations over the shelf parallel with the mouth of Chesapeake Bay, off Cape Hatteras, and along the canyons of the shelf break. The weighted UD analysis somewhat reduced the importance of the deployment locations but results should still be interpreted with caution.

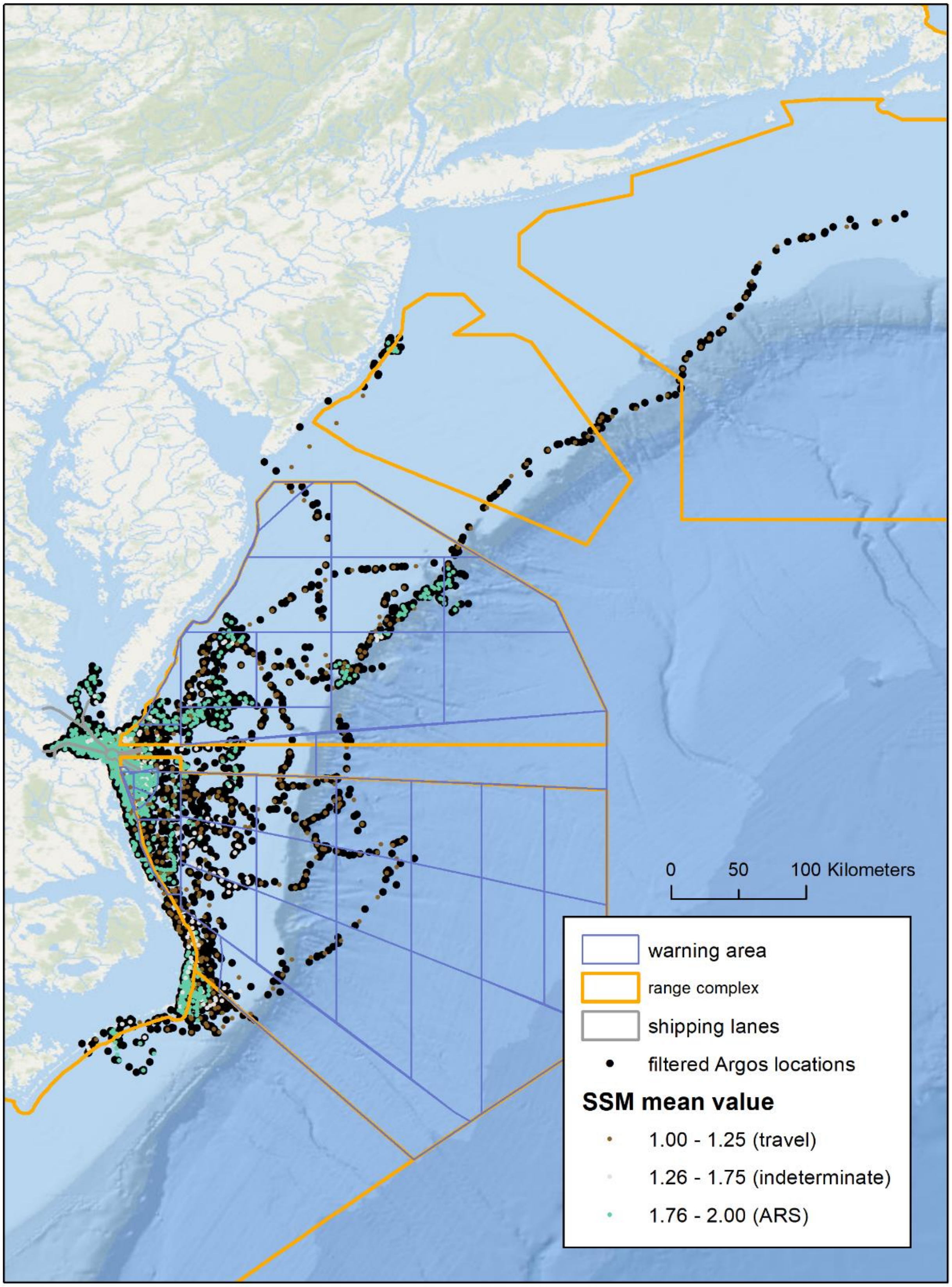

Figure 19. State-Space Modeling for all tagged whales through the end of the 2016/2017 field season showing travel (brown dots), area-restricted search (green dots), and the intermediate state (white dots).

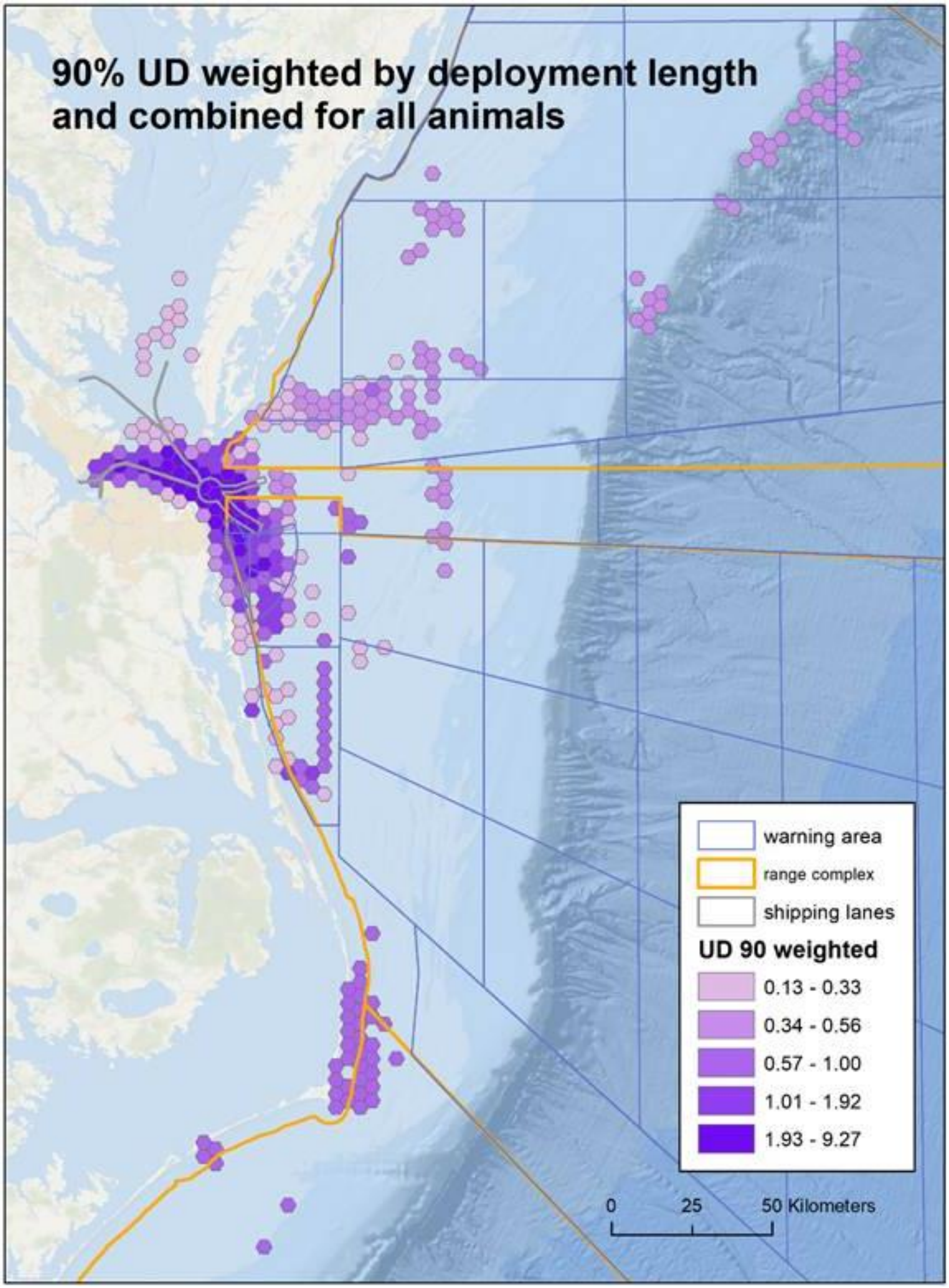

Figure 20. Home Range Analysis using 90% UD weighted by tag deployment duration and combined for all humpback whales tagged through the end of the 2016/2017 field season.

4. Discussion

Analyses of data from this project are on-going; however, results show site fidelity in the study area for many individuals and a high level of occurrence within the shipping channels—an important high-use area by both the U.S. Navy and commercial shipping traffic. These findings are supported by information collected during the first four years of this study, including photo-ID, focal follows, and satellite-tagging results. A smaller number of animals are also spending time close to, or within, the W-50 MINEX box as well as in the offshore VACAPES range complex and are presumably within hearing range of underwater detonation training exercises.

Interactions with vessels, both large and small, are a significant cause for concern for both humpback and endangered fin whales in the study area. During the 2015/16 season, three individual humpback whales were observed with boat injuries (as observed by HDR, Rudee Flippers Tours, and VAQS) ranging from non-life threatening to likely fatal injuries (Mallette et al. 2016, unpublished report). During the 2016/2017 field season, three humpback whales were killed in a 10-day period, all with evidence of vessel interactions that likely led to their deaths (NMFS 2017) (**Figure 21**). A fourth whale was observed with severe injuries from a propeller (**Figure 22**). The 2017/2018 field season also started off with the death of a known humpback whale, HDRVAMn082. In April 2017, NMFS declared an Unusual Mortality Event (UME) for humpback whales in the Atlantic from Maine to North Carolina based on elevated mortalities of this species since January 2016. Given this UME designation, a group of subject matter experts will look further at what is causing or contributing to the increased number of deaths of humpback whales in this area. While the UME team will look at humpback whales of all age classes, more than three-quarters of the humpback whales identified during the four years of effort on this project appear to be juveniles that are spending more time in the study area than larger animals, presumed to be adults, and may be at greater risk for injury. Sightings of sub-adult sized humpback whales are highest early in the field seasons and typically not re-sighted, suggesting that sightings early in the season may be whales that are more likely passing through the area rather than whales that may remain in the primary study area for longer durations. The large percentage of juveniles observed in this study matches both historic stranding data (e.g., Wiley et al. 1995) and observational data (e.g., Swingle et al. 1993) for the area.

The number of humpback whale identifications per season has grown steadily over the course of this project, although plateaued during the 2017/2018 field season. There were 31 unique humpback whales identified during the 2014/2015 season, 37 during the 2015/2016 field season (including 6 individuals seen during the 2014/2015 season) 59 during 2016/2017 field season (including 15 re-sightings from the previous two seasons), and 21 during the 2017/2018 field season (including 7 re-sightings from the previous three seasons). Part of this increase in the first three seasons is likely due to effort—the 2016/2017 and 2017/2018 field seasons began two months earlier than the 2014/2015 season and one month earlier than the 2015/2016 field season. Also, during the 2014/2015 season, effort was focused on collecting focal follows of individual whales, so priority was given with staying with one whale over a longer period of time rather than collecting as many identification photographs of animals in the surrounding areas.

Figure 21. Humpback whale HDRVAMn090 washed ashore on Virginia Beach on 12 February 2017 with fatal propeller slices through its body.

Figure 22. Humpback whale HDRVAMn085 observed by HDR off Virginia Beach on 14 February 2017 with propeller slices through its body. This individual was observed without these injuries on 06 February 2017.

Overall effort on the water, both in terms of days and hours used also increased during the first three field seasons, partially accounting for the increase in sighting information during the 2016/2017 field season. The 2017/2018 field season was somewhat anomalous in terms of temperature. Multiple cold weather systems significantly impacted water temperature in and around the Chesapeake Bay and surrounding waters. The cold-water temperatures likely affected the prey distribution in the area and may have forced animals to look elsewhere for food – either farther south, toward the Outer Banks of North Carolina or farther offshore, as was observed in some of the tag data and evidenced by the need to push effort further offshore. The decrease in the number of overall sightings and overall individuals identified during the 2017/2018 field season may be related to the low water temperatures that began in early January 2018.

State-Space Modeling and home range analysis results provided inference on animal behavior for all but the shortest (or sparsely reporting) tags. This in an important precursor to other analyses that seek to examine drivers of animal behavior or construct more complex models of animal behavior. Animals showed varied movement strategies, the most common of which was ARS centered around the mouth of Chesapeake Bay which is where most tags were deployed. It may be that tags were lost before significant movement was undertaken but it still highlights the lower Chesapeake Bay as an important foraging area for this population. Other strategies included looping down the Outer Banks to feed and then returning north, foraging deeper into the Bay, and long directed movements northwards along the coast and the shelf break before recruiting to additional locations where ARS was performed. Clearly this population engages in diverse feeding movement strategies which need to be taken into account when mitigating impacts and making management decisions. Home range analysis results are still likely biased towards deployment locations given the duration of most deployments. It is likely that the full ARS home range of these animals is not represented here, though it provides a robust first step for the time period and season during which the animals were tracked. Future analysis should focus on teasing out temporal patterns of use, increasing sample size with more tag deployments, simulating longer tracks, and diving deeper into individual space use.

Further analysis of tag data is expected to occur during the summer/fall of 2018, including integrating the remaining tag data into the switching state space model. While only nine satellite tags were deployed during the 2015/2016 field season, satellite tagging efforts during the 2016/2017 field season greatly increased the existing dataset and our overall understanding of where humpback whales are spending their time in and around the Hampton Roads waters. While much of the data have matched sighting locations with ‘hot spots’ in and around the shipping channels, the amount of time some individual tagged whales were spending west of the CBBT during the 2016/2017 field season was somewhat unexpected. Multiple tagged whales had locations near Naval Station Norfolk and Joint Expeditionary Base Little Creek (JEBLC). Although less survey effort focused in waters west of the CBBT, it should be considered a primary area of interest in future years given the high traffic flow, increased vessel speed allowed, and extent of marine-based training occurring at JEBLC. An explanation for increased presence of humpback whales west of the CBBT is likely caused by a combination of factors including but not limited to: 1) a short-term distributional shift related to overall oceanographic conditions causing prey to become more concentrated farther into the bay than in previous years and 2) better documentation of whale presence through an increased number of satellite tags deployed. Tag data from the 2017/2018 field season has shown how much variability can occur inter-annually. Further analysis of water temperature from Conductivity, Temperature, and Depth measurements, buoy data, and tag data may provide a better understanding of thresholds that result in humpback whales (and presumably their prey) remaining in or moving out of the area.

The number of sightings of humpback whales and other species (including endangered fin whales), as well as the level of interaction between whales and vessel traffic to date, support previous recommendations to continue this study using the same techniques described above in order to better understand movement patterns. We remain confident that the inclusion of Wildlife Computer's SPLASH10-F tags with Fastloc® GPS technology (trialed on humpback whales by HDR in February 2017 and on fin whales in February 2018), capable of providing high-resolution data logging, will provide superior quality with respect to accuracy of locations. We also recommend the deployment of D-Tag technology into the current study as a way to examine the three-dimensional movements of humpback whales and fin whales foraging within and around high-traffic shipping channels. Together, all of this information will provide a better understanding of the occurrence and behavior of whales in this area and provide a necessary stepping stone for future mid-Atlantic behavioral response studies.

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