Final Report

Seal Tagging and Tracking in Virginia: 2017–2018

Submitted to:

Naval Facilities Engineering Command, Atlantic under Contract No. N62470-15-8006, Task Order 17F4058 issued to HDR, Inc.

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Top photo: Harbor seals resting ("hauled out") on a salt marsh on the Eastern Shore of Virginia in February 2018. Photograph taken by D. Rees, Naval Facilities Engineering Command, Atlantic, under National Marine Fisheries Service research permit #19826-03

Bottom photo: Satellite tag being affixed to the head of a harbor seal. Photograph taken by D. Rees, Naval Facilities Engineering Command, Atlantic, under National Marine Fisheries Service research permit #17670-04

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Acronyms and Abbreviations

a-LoCoH	adaptive local convex hull
ARGOS	Advanced Research and Global Observation Satellite
BOEM	Bureau of Ocean Energy Management
°C	degrees Celsius
CBBT	Chesapeake Bay Bridge and Tunnel
cm	centimeter(s)
COLREGS	collision regulation(s)
DMSO	dimethyl sulfoxide
EDTA	ethylenediaminetetraacetic acid
km	kilometer(s)
km^2	square kilometer(s)
LoCoH	local convex hull
m	meter(s)
NaHep	sodium heparin
Navy	U.S. Navy
NOAA	National Oceanic and Atmospheric Administration
Obs	observation(s)
OPAREA	Operating Area
%	percent
PBM	peripheral blood mononuclear cells
PDV	phocine distemper virus
PTT	platform transmitter terminal
SD	standard deviation
SPOT	satellite-tracked position-only
TAD	time-at-depth
UME	Unusual Mortality Events
VACAPES	Virginia Capes Range Complex
VTM	viral transport medium
YOY	Young of the year

1. Background and Introduction

Since the passage of the Marine Mammal Protection Act in the United States in 1972, and as amended (16 United States Code § 1361 14 et seq.), both harbor seal *(Phoca vitulina)* and gray seal *(Halichoerus grypus)* populations have grown in the Northwest Atlantic Ocean (Wood et al. 2011; Hayes et al. 2017). Both species are year-round coastal inhabitants in eastern Canada and New England, and occur seasonally in the mid-Atlantic United States between September and May (Hayes et al. 2017). Individuals of both species migrate to northern areas for mating and pupping in the spring and summer, and return to more southerly areas in the fall and winter. Within the last decade, harbor seals have been observed returning seasonally to haul-out (resting) locations in coastal Virginia, and gray seals occasionally are observed there as well (Jones et al. 2018).

The U.S. Navy (Navy) regularly engages in training, testing, and in-water construction activities in coastal Virginia and Chesapeake Bay (**Figure 1**) in order to maintain Fleet readiness and structural integrity of military installations. The lower Chesapeake Bay and coastal areas of Virginia represent one of the busiest hubs of naval activity on the east coast and hosts numerous pierside facilities, installations, vessel, shipyards, and in-water training ranges. Seals seasonally inhabiting and transiting through these areas could be impacted by the use of active sonars and explosives, vessel traffic and movement, dredging, pile driving, and other activities.

Navy biologists have been researching seal occurrence in and around the Chesapeake Bay since 2013, and conducting systematic haul-out counts in the region since 2014. Results from these surveys indicate that seals arrive in the area in the fall and depart in the spring (Rees et al. 2016). However, our understanding of seal movements, habitat use, haul-out patterns, and dive behavior in Virginia waters is still extremely limited. In order to assess the potential impacts on seals from Navy activities, mitigate potentially harmful interactions, and obtain appropriate authorizations to maintain environmental compliance, it is important to have a better understanding of seal distribution and behavior in these areas. Although visual haul-out studies are useful for estimating the minimum number of animals present on land at various times of the year, telemetry studies are needed to characterize seals' at-sea movements, habitat use, dive behavior, and the environmental variables that may influence their distribution patterns.

This proof-of-concept study was undertaken to establish whether wild seals could be successfully captured and tagged in coastal Virginia, because this has not been previously attempted in this area. Further, the study sought to establish the feasibility of using satellite tags to better understand seals' residency time in Virginia waters, their local habitat utilization patterns, and where they migrate to in the spring. The information gathered from this effort will provide valuable baseline data needed for the future assessment of harbor seal movements and site fidelity along the U.S. Eastern Seaboard.

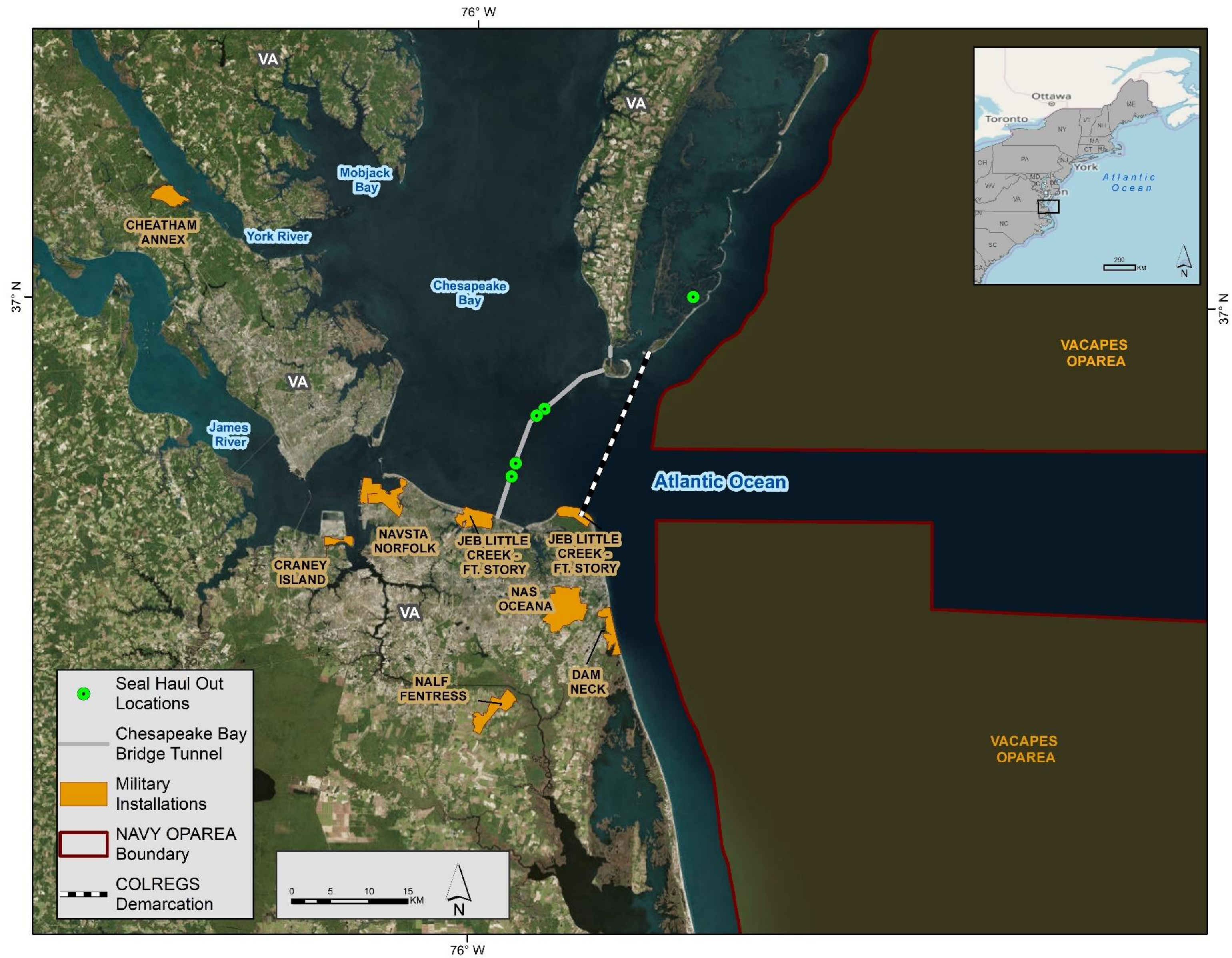


Figure 1. Chesapeake Bay and coastal Virginia waters, including the Virginia Capes Range Complex (VACAPES) and sonar training areas. COLREGS = collision regulations; OPAREA = Operating Area.

2. Methods

2.1 Field Methods

The capture site was located on the Eastern Shore of Virginia, where seals have been observed hauling out between fall and spring (**Figure 2**). The Eastern Shore haul-out area has several discrete haul-out sites (up to five different locations) where seals have been observed (Jones et al. 2018). These haul-outs are in a tidal salt marsh habitat, consisting of muddy banks and vegetation, which is subject to tidal influx. The seals are often seen hauled out in areas with little to no vegetation, or where existing vegetation has been flattened by either the tide or the animals' weight. Seal captures followed a similar protocol as described by Jeffries et al. (1993). Seals were captured using a seine net and three small flat-bottomed vessels with outboard motors. Seals were brought onshore after entering the capture net adjacent to haul-out site(s). This method has been employed successfully in several seal capture projects on the U.S. east and west coasts (Jeffries et al. 1993; Waring et al. 2006; Cronin et al. 2009; Manugian et al. 2016). The seine net was 100 meters (m) long and 7.4 m deep when fully deployed, with mesh size openings between 10 and 15 centimeters (cm). The first vessel had the net onboard, and deployed the trailing end in the water. This vessel cast out the net at high speed as it encircled the haul-out site, eventually bringing the leading end of the net to shore; the second vessel picked up the trailing end of the net and drove it to shore; and the third vessel patrolled the length of the deployed net, monitoring it for any animal activity until it was completely hauled onshore (**Figure 3**). As the net was set, two to three people promptly brought it onto land, and any seals caught were safely removed from the net by the rest of the team. The health assessment team confirmed that a seal was a candidate for tagging[1] before any other actions were taken. While on land, a team member was then assigned to monitor each seal after it was removed from the seine net and placed in a hoop net for holding, prior to its transfer to the restraint board for tagging and biological sampling.

[1] Seals were determined to be candidates for tagging based on health and behavioral criteria, including respiration characteristics, body condition, body posture, and presence/absence of wounds (see **Appendix C**, Health Assessment Datasheet).

Figure 2. Harbor seals (*Phoca vitulina*) resting ("hauled out") on a salt marsh on the Eastern Shore of Virginia in February 2018.

Photograph taken by D. Rees under National Marine Fisheries Service research permit #19826-03.

Figure 3. Monitoring the deployed net (indicated by red arrows) for seal activity.

Seals were outfitted with a combination of flipper tags, satellite tags, and acoustic transmitter tags. Colored (light blue), flexible, vinyl Allflex™ livestock ear tags were attached to each seal's left hind flipper webbing. These flipper tags may stay attached for multiple years, and are used for purposes of individual identification if resighted.) In some cases, seals were also outfitted with acoustic transmitter tags manufactured by VEMCO (Bedford, Nova Scotia, Canada). VEMCO acoustic pinger tags were attached to the vinyl flipper tags using Devcon™ 24-hour Epoxy (**Figure 4a**). Each seal was also instrumented with a satellite tag (either a satellite-tracked position-only [SPOT] tag, or a depth-sensing "SPLASH" tag), manufactured by Wildlife Computers, Inc. (Redmond, Washington). SPOT/SPLASH satellite tags were glued directly to the seals' fur on the head or shoulder area (depending on the size of the animal) using Devcon™ 20845 High Strength 5-Minute Epoxy. Satellite tags were positioned to maximize data transmission, since data are only transmitted to the Advanced Research and Global Observation Satellite (ARGOS) network when the tag antenna is above the surface (**Figure 4b**). These tags were designed to fall off during the annual molt in July, following the May-June breeding season. VEMCO tags had the potential to stay on and collect data past the molting period, since they were attached to flipper tags and not to the animals' fur.

(a)

(b)

Figure 4. (a) Flipper tag with an acoustic transmitter attached to the hind flipper of a harbor seal (*Phoca vitulina*). (b) Satellite-tracked position only (SPOT) tag being affixed to the head of seal 1801 with five-minute epoxy.

Photographs by D. Rees, Naval Facilities Engineering Command, Atlantic, taken under National Marine Fisheries Service research permit #17670-04.

A series of biological samples was collected from each captured seal (**Table 1**). Information recorded during the capture and sampling events included 1) time the net was set; 2) time each animal was disentangled; 3) time biological sampling began; 4) onset of Lidocaine administration for blubber biopsy, and 5) time the animal was released. All capture and sampling activities were conducted in accordance with the National Marine Fisheries Service research permit #17670-04.

Table 1 Biological sample type, purpose, and receiving laboratory.

Sample Type	Sample Purpose	Testing Laboratory	Storage Medium
Fur	Stable isotope analysis	Louisiana State University: Department of Oceanography and Coastal Studies	Frozen -20
Whiskers	Stable isotope analysis	Louisiana State University: Department of Oceanography and Coastal Studies	Frozen -20
Whole blood	Stable isotope analysis	Louisiana State University: Department of Oceanography and Coastal Studies	Frozen -80
Skin	Genetics	University of Maine: School of Marine Science	DMSO
Skin	Genetics	NOAA: National Marine Fisheries	DMSO
Blubber	Fatty acid diet analysis	NOAA: Northeast Fisheries Science Center	Frozen -20
Conjunctiva swab	Influenza A surveillance	Tufts University: Cummings School of Veterinary Medicine	VTM
Nasal swab	Influenza A surveillance	Tufts University: Cummings School of Veterinary Medicine	VTM
Rectal swab	Influenza A surveillance	Tufts University: Cummings School of Veterinary Medicine	VTM
Serum	Influenza A surveillance	Tufts University: Cummings School of Veterinary Medicine	Frozen -80
Serum	Pathology surveillance archive	NOAA: National Marine Fisheries	Frozen -80
Conjunctiva swab	Pathology surveillance archive	NOAA: National Marine Fisheries	Frozen -80
Nasal swab	Pathology surveillance archive	NOAA: National Marine Fisheries	Frozen -80
Rectal swab	Pathology surveillance archive	NOAA: National Marine Fisheries	Frozen -80
Hair	Mercury analysis	Woods Hole Oceanographic Institute	Frozen -20
Skin	Mercury analysis	Woods Hole Oceanographic Institute	Frozen -80
Serum	PDV serology	Woods Hole Oceanographic Institute	Frozen -20
NaHep serum	PBM isolation: immune-assays and in-vitro infection	Woods Hole Oceanographic Institute	Chilled on ice
EDTA whole blood	PBM isolation: immune-assays and in-vitro infection	Woods Hole Oceanographic Institute	Chilled on ice
EDTA whole blood	Health assessment	IDEXX Laboratories Inc.	Chilled on ice
Serum	Health assessment	IDEXX Laboratories Inc.	Chilled on ice
Blood smear	Health assessment	IDEXX Laboratories Inc.	Room temperature

KEY: DMSO = dimethyl sulfoxide; EDTA = ethylenediaminetetraacetic acid; NaHep = sodium heparin; NOAA = National Oceanic and Atmospheric Administration; PBM = peripheral blood mononuclear cell; PDV = phocine distemper virus; VTM = viral transport medium.

2.2 Data Analysis Methods

SPOT tags recorded information about the animals' horizontal movements (i.e., transiting), amount of time spent wet vs. dry (i.e., haul-out behavior), and ambient temperature. Depth-sensing SPLASH tags recorded information about the seals' vertical movements (i.e., dive depth and duration) in addition to location, haul-out, and temperature data. These data were summarized and compressed for transmission to the ARGOS satellite network when the animal surfaced. All satellite transmitters were programmed to collect continuous (i.e. not duty-cycled) location and sensor data. Satellite tag return data were used to investigate areas of relative habitat use throughout the seals' range, and to create maps of their transits and haul-out locations.

Data returned from the platform terminal transmitters (PTTs) associated with each satellite tag included information about the animals' haul-out and in-water behavior, short- and long-distance horizontal movements (with location accuracies of up to 500 m), and recorded temperature. Temperature data analysis was restricted to in-water values; haul-out temperatures were not included in the analysis. . Although the satellite tags recorded water temperature (when the animal was in the water) and air temperature (when the animal was hauled out), the relationship between harbor seal in-water behavior and water temperature at depth was of primary interest in this study. The temperature at the air/water interface reported by telemetry tags was ground-truthed by comparing these values to regional buoys that recorded sea surface temperature, along with other meteorological and oceanographic data. Depth and temperature thresholds for SPLASH tags were investigated using time-series plots, maximum in-water temperatures recorded by the tags, and summary statistics of depth and temperature data. Summary statistics of in-water temperature data were also generated for SPOT tags. Although temperature was recorded by both the SPOT and SPLASH tags, SPOT tags did not report depth information, and therefore it was not possible to delineate a clear in-water temperature threshold for these tags. Instead, in-water temperature thresholds for SPOT tags were estimated using average sea surface temperature reported by the National Oceanic and Atmospheric Administration (NOAA) National Data Buoy Center, specifically for buoys corresponding with tagged seal distribution in space and time. Since seal behavior and times of seasonal arrival and departure in Virginia waters was of primary interest in this study, the in-water temperature analysis for all seals was restricted to coastal Virginia waters. Probability density plots of time seals spent hauled out (dry) were generated for all SPOT and SPLASH tags using wet/dry sensor data, in order to investigate patterns in haul-out behavior throughout the various tag deployment periods.

Location data from PTTs were filtered and managed using www.movebank.org, where a live feed automatically decoded and stored all ARGOS locations. The Douglas ARGOS Filter Algorithm (in Movebank version 8.50) was used to remove implausible locations (Douglas et al. 2012) (**Table 2**). All post-filter locations were loaded into an ArcGIS™ 10.3 workspace. Locations reported during the first 24-hours post-release were removed under the assumption that these data were not representative of the animal's natural behavior. A bathymetry attribute was added to filtered location data by extrapolating the grid values from the ETOPO1 Global Relief Model (Amante and Eakins 2009). All locations that had an elevation greater than 5 m (i.e., on land) were removed from the data.

Table 2. Douglas Advanced Research and Global Observation Satellite (ARGOS) Filter Algorithm parameters used to remove implausible locations. From: Douglas et al. (2012).

Parameter	Value
filter method	best hybrid
keep_lc	3
maxredun	5
offset by one sec.	1
Filter Method	0
keeplast	0
skiploc	0
minrate	5000
r_only	1
ratecoef	25
xmigrate	1
xoverrun	50
xdirect	50
xangle	50
xpercent	50
testp_0a	0
testp_bz	1
best of day filter	1* and 0**

*Best of day filter was used to select the best location point per day that created the utilization distribution in the habitat used analysis.

** Best of day filter was not used for the data that created the track lines.

Resulting location data were used to conduct a habitat-use analysis for all tagged seals. An adaptive local convex hull (a-LoCoH) approach was chosen to determine areas of highest habitat utilization. This method performs well when considering spaces that change abruptly with barriers that can be identified as ecological determinants, such as nearshore estuarine and ocean environments (Getz et al. 2007). Isopleths were calculated from spatial utilization distributions to predict the 50% and 95% likelihood of an animal traversing a given area (Calenge 2006). The resulting isopleths were used to create maps of each animal's home range and core habitat; and isopleths for each seal were overlaid to create relative habitat use maps. In Virginia waters, seal "trips" were defined as being *inshore* (within the Chesapeake Bay) if within the U.S. collision regulation (COLREGS) lines of demarcation. Seal trips were defined as being *offshore* if the track destination (i.e., the point where the animal changed direction and returned to the Eastern Shore capture site) was outside of the COLREGS line, and was greater than or equal to 14 km from the capture site[2] (see **Figure 1**).

[2] This distance threshold was determined post-hoc during data exploration. The ArcGIS Line Statistics tool was used to identify the distance from the capture location in which seal track density was relatively high (>200 km of track line per 5 × 5 km grid).

Data from acoustic VEMCO tags were used to investigate areas of relative habitat use in and around the Chesapeake Bay, as measured by the number of acoustic “pings” or “hits” recorded per animal on each receiver. The VEMCO tags relied on an array of underwater receivers already in place throughout Chesapeake Bay and coastal Virginia waters for detection (**Figure 5**), and acoustic “pings” recorded by the receivers indicated the date and time tagged seals passed nearby. Acoustic hits were recorded and archived on each receiver, and data were then manually downloaded from the array. Data were summarized by number of hits per receiver in each week/month when tagged seals were present in the area, and maps were created showing activity of tagged seals relative to receiver locations. Data were also analyzed in terms of the number of times an individual animal “pinged” a particular receiver. In order to filter the number of detections into discrete times an individual seal was at a receiver, we used 15 minutes as the cutoff in between detections. For example, if a tag was detected at the same receiver on the same day at 7:20 AM and again at 7:25 AM, the number of detections was two, but the number of times the animal “visited” the receiver area was one, because the duration was less than 15 minutes. We chose 15 minutes as the cutoff time because it was assumed that if the animal was not detected at the receiver during that time, it had likely left the immediate area, and if another receiver was close enough, it would have been detected there. In contrast, if the animal was detected multiple times during that 15-minute time interval, we assumed that it could have been exhibiting some type of foraging behavior close enough to the receiver to continue to be detected. Results from satellite and VEMCO tags were compared using a qualitative approach.

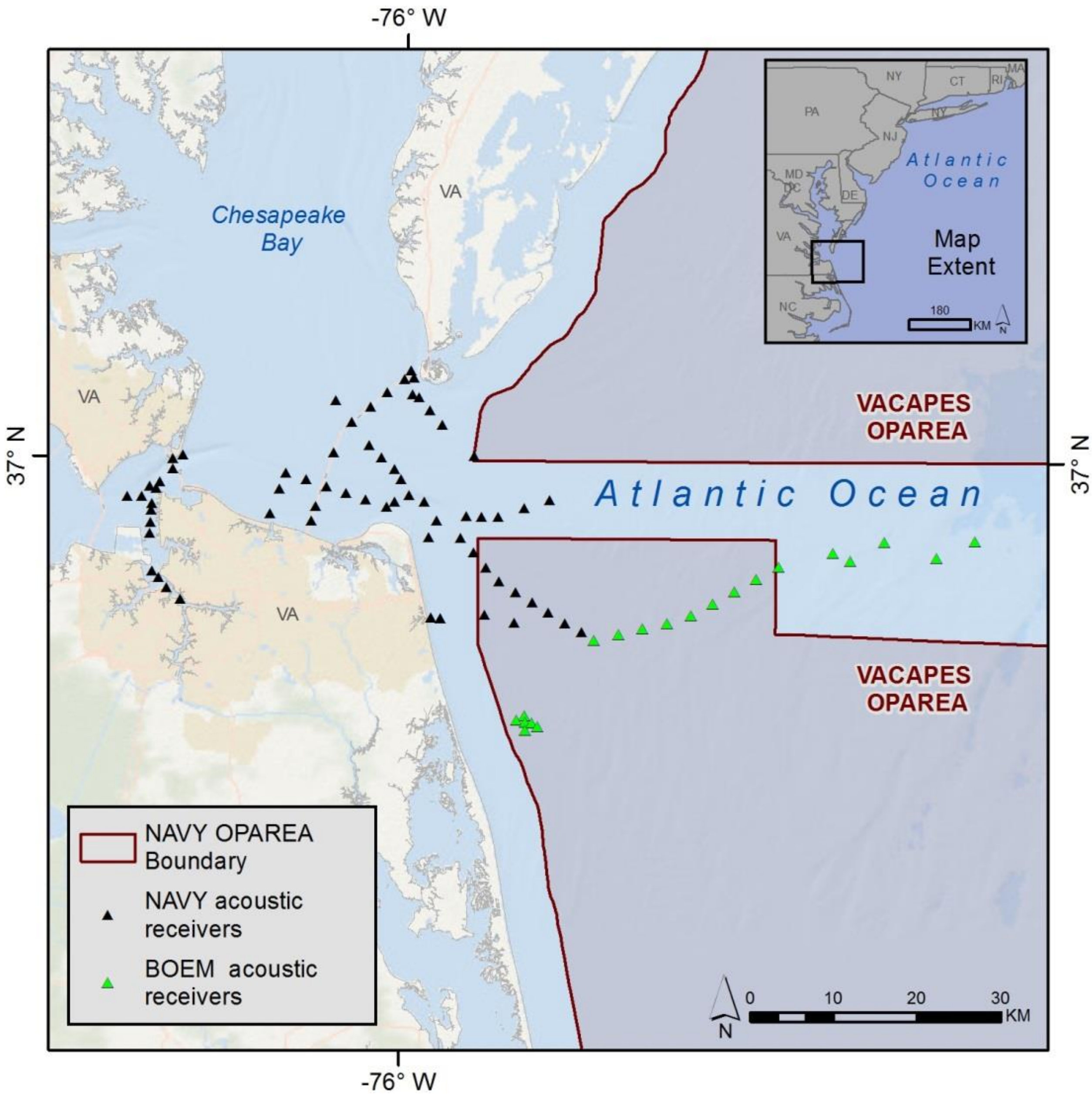


Figure 5. Acoustic receiver array in Chesapeake Bay and coastal Virginia.

BOEM = Bureau of Ocean and Energy Management; OPAREA = Operating Area; VACAPES = Virginia Capes Range Complex.

3. Results

3.1 Summary of Tagged Animals

Over the course of a 10-day field window in February 2018, seven harbor seals[3] were captured and instrumented with satellite-tracked tags. Of these, six were location-only SPOT tags and one was a depth-sensing SPLASH tag. Five of the seven seals were also instrumented with VEMCO tags (**Table 3**). All captured seals were outfitted with vinyl flipper tags. Satellite tags varied in deployment length; the longest tag reporting period was for seal 1802, an adult male, which reported through 29 June (approximately 5 months). The shortest reporting period was for the tag attached to seal 1805, an adult female, which stopped reporting after only two months (the reasons for this are unknown).

Table 3. Summary of tagged seals

Date Tagged	Animal ID	Sat Tag PTT #	Date of Last Transmission	VEMCO Tag #	Length (cm)	Girth (cm)	Weight (kg)	Sex	Estimated Age
2/4/18	1801	166450	5/23/18	15249	102	80	29.0	Male	Juvenile†
2/4/18	1802	166449*	6/29/18	N/A**	153	118	90.4	Male	Adult
2/4/18	1803	166451	5/6/18	15251	129	99	58.8	Female	Juvenile†
2/4/18	1804	166452	5/26/18	15252	143	119	74.8	Female	Juvenile†
2/6/18	1805	166453	4/9/18	15253	121	97	49.8	Female	Adult
2/6/18	1806	173502	6/22/18	N/A	149	116	82.2	Female	Adult
2/8/18	1807	173503	4/26/18	15250***	93	77	24.8	Female	YOY‡

*The depth-sensing SPLASH tag was deployed on seal 1802. All other seals were instrumented with SPOT tags; **Seal 1802 was also initially instrumented with VEMCO Tag #15250 on 04 February, but that tag was later dislodged when he was (unintentionally) recaptured on 06 February; ***VEMCO Tag #15250 was retrieved and deployed on seal 1807 on 08 February. No acoustic "pings" were detected during the time the VEMCO tag was attached to seal 1802; therefore, the data presented here only include results from seal 1807; †Juvenile = 2–4 years old; ‡YOY = Young of the year, up to 1.5 years old. cm = centimeters; kg = kilometer(s); PTT = platform transmitter terminal.

3.2 Satellite Tags

3.2.1 Depth and in-water temperatures

Both temperature and depth data were available for seal 1802, an adult male, which was equipped with a depth-sensing SPLASH tag (**Figure 6**). The maximum depth recorded throughout the deployment period was 118.00 m, with a mean depth across all months of 22.38 m (standard deviation [SD] ±19.53) (**Table 4**). In February and March, while still in Virginia waters, this seal dove to a maximum depth of 24.00 m (mean 6.94 m, SD±4.78) and 31.50 m (mean 6.60, SD±4.53) respectively in each month. Maximum dive depth increased to 104.5 m (mean 25.34, SD±21.34), 118.00 m (24.75, SD±19.26), and 71.00 m (mean 30.54, SD±18.39) in April, May, and June respectively, when the animal moved north to southern New England and then Maine (**Figure B-4**).

[3] One juvenile gray seal was also observed in the water near the capture location and was briefly in the seine net, but escaped before the net was brought to shore.

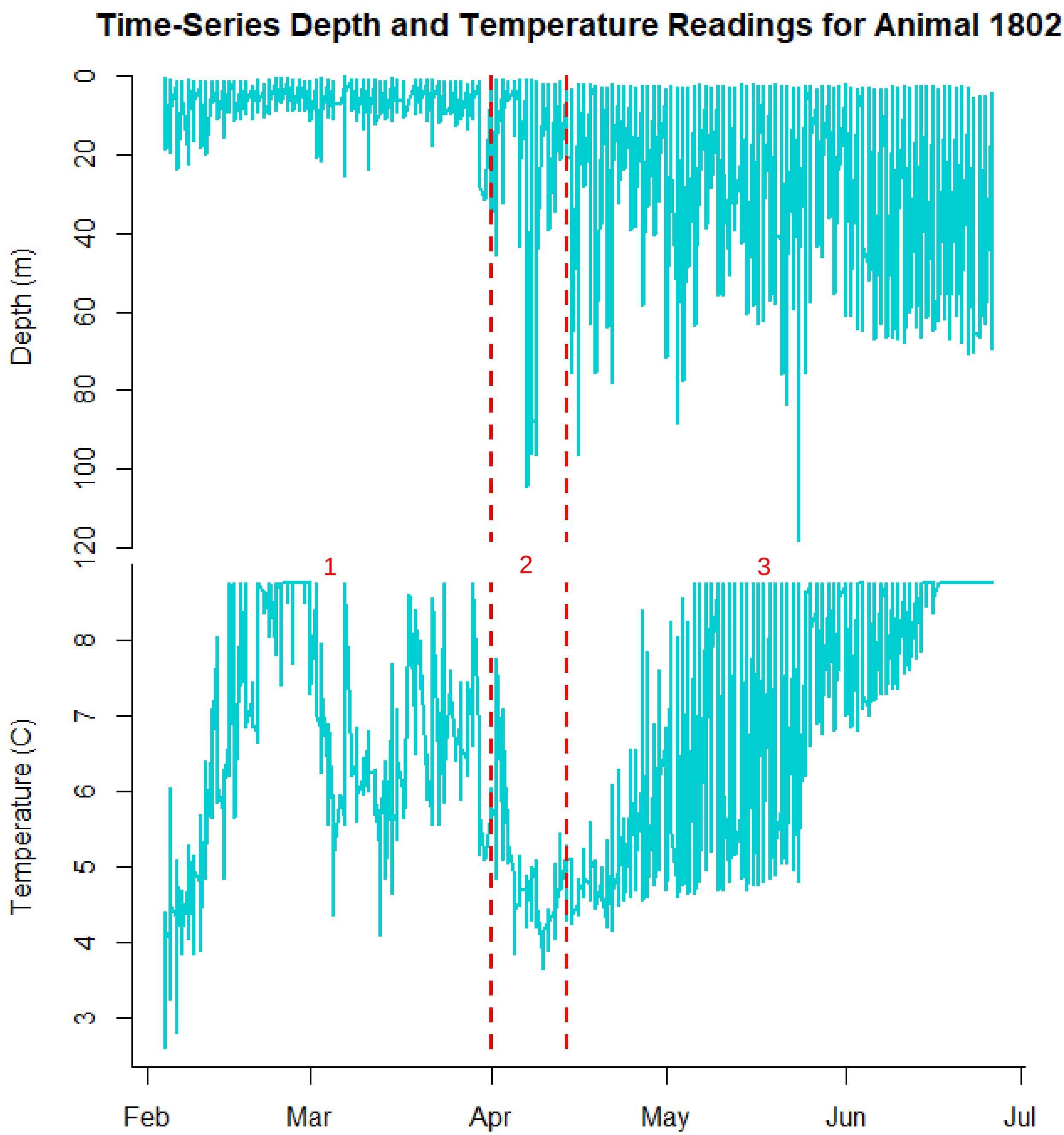


Figure 6. **Time-series of depth and temperature for seal 1802, from 04 February through 29 June 2018.**

Vertical dashed lines demarcate the time periods the animal spent 1) in Virginia (left of the first line), 2) traveling northward (between the two lines), and 3) in Maine (right of the second line).

Table 4. Monthly depth statistics for the SPLASH tag (seal 1802)

Month	Depth (meters)			
	Mean	**Max**	**SD**	**Number Obs.**
February	6.94	24.00	4.78	1,148
March	6.60	31.50	4.53	1,287
April	25.34	104.50	21.34	2,924
May	24.75	118.00	19.26	3,542
June	30.54	71.00	18.39	2,571
Total	**22.38**	**118.00**	**19.53**	**11,472**

Obs = Observation(s); SD = Standard deviation

Seal 1802 remained in coastal Virginal waters until 01 April 2018, and spent most of its time-at-depth (TAD) shallower than 10 m, but executed some dives to approximately 30 m during the tracking period (**Figure 6**). The animal's two deepest dives, 104 and 118 m respectively, coincided with locations off southern Long Island and Penobscot Bay, Maine (**Table 4, Figure B-4**).

Seals were tagged in February 2018 and began leaving Virginia waters in late March. All tagged seals had moved north by mid-April 2018, except for seal 1807, whose tag stopped transmitting data on 26 April while still in Virginia waters. Mean sea surface temperature from February through April 2018, as recorded by the Cape Henry data buoy, approximately 25 km east of the COLREGS line, **Figure 1**), was 7.5 degrees Celsius (°C) (SD±2.2, minimum = 3.3°C, maximum 15.5°C, https://www.ndbc.noaa.gov/station_page.php?station=44099). Based on this information, and the maximum in-water temperature recorded by the SPLASH tag (8.75°C, **Figure 6**), we assumed an in-water maximum temperature of 9°C for the SPOT tags (**Figure 7**). The overall mean temperature recorded by all tags during this period was 6.75°C (SD=1.37). The minimum temperature recorded by any tag while in this area was 2.60°C, recorded in February for seal 1802 (**Table A-1**).

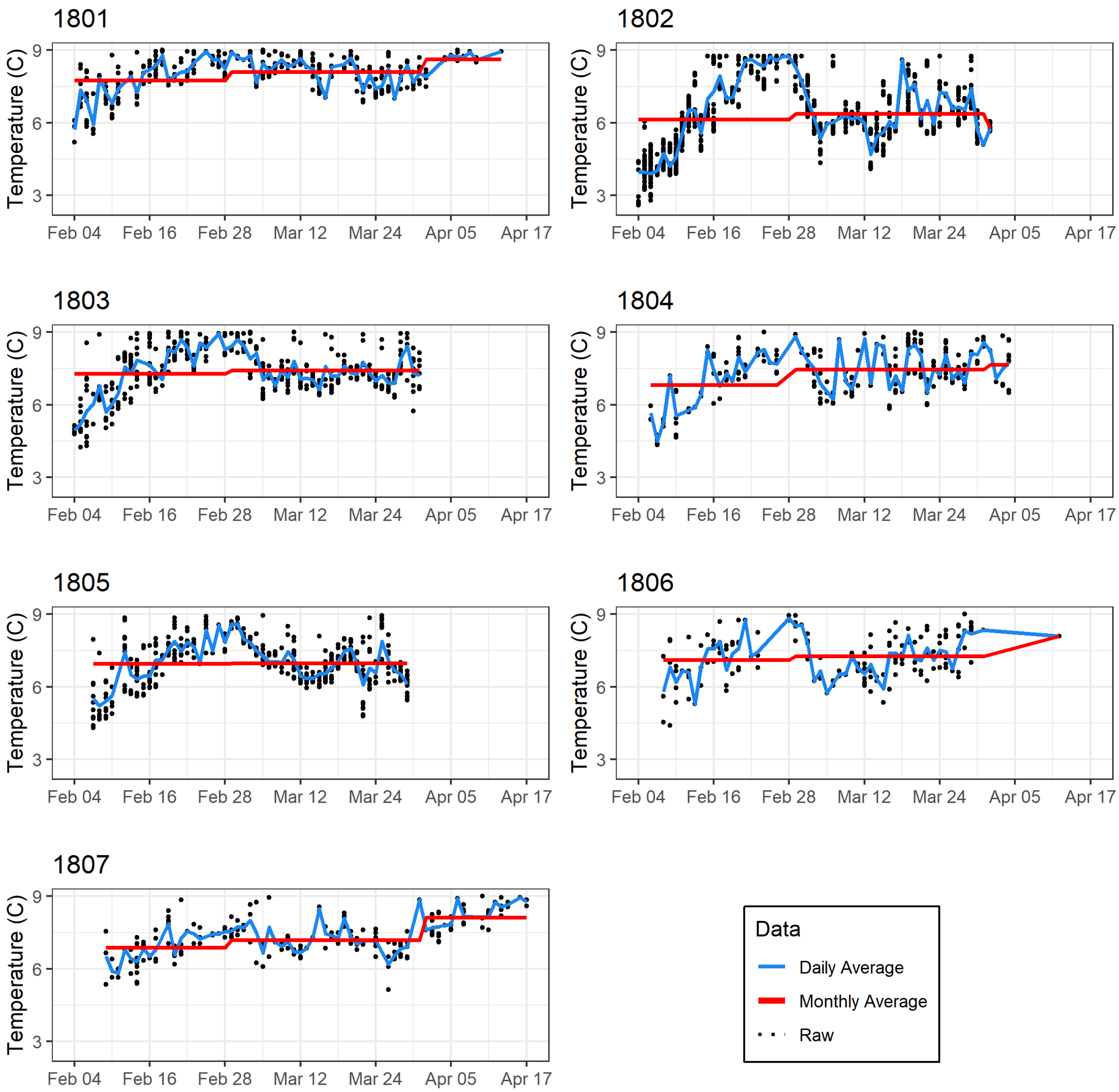


Figure 7. In-water temperature values and averages for seven satellite-tagged seals during the time period that each was in Virginia waters.

3.2.2 Haul-out patterns

Individual seals exhibited varied haul-out behavior patterns throughout the respective satellite tag deployment periods. Seal 1802 exhibited a strong diurnal haul-out pattern from February through May, coming out of the water to rest around 16:00 local time (**Figure 8**). The warmest in-water temperature recorded by this tag was 8.75ºC (**Figure 6**), which indicates that, when compared to the Cape Henry buoy data, the animal was hauled out at temperatures above this value. There was a strong bimodal haul-out pattern for the two tags still reporting in June 2018 (1802 and 1806), indicating that these animals hauled out both in the morning and nighttime hours while in coastal Maine (**Figure 8**). Based on wet/dry data from tagged seals, no clear haul-out pattern emerged with respect to tidal fluctuations at either end of the tagged seals' range.

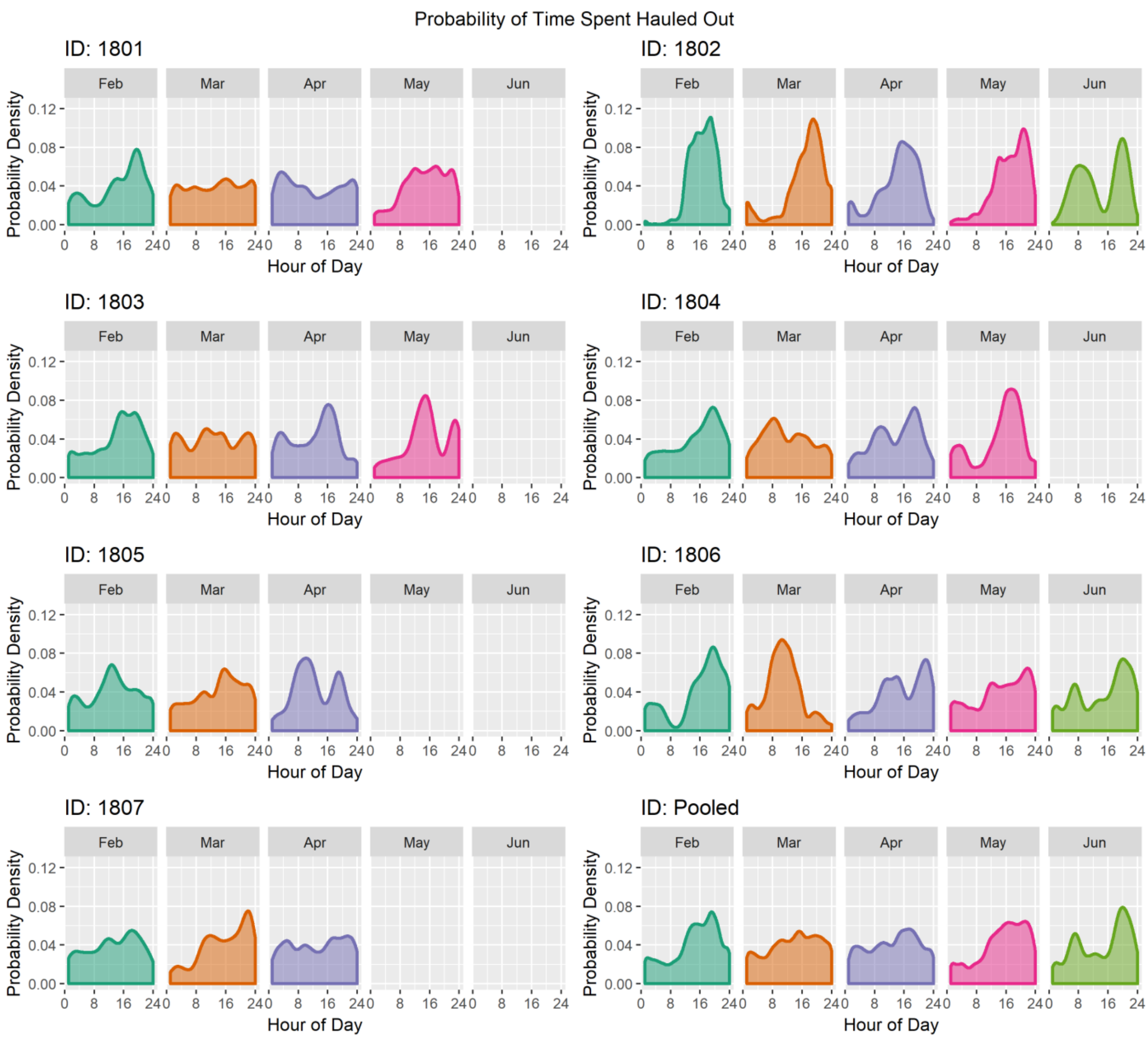


Figure 8. Monthly probability densities of time spent hauled out for all tagged seals. Hour-of-day (x-axis) is local 24-hour time.

3.2.3 Seal tracks and habitat use maps

The seven PTTs recorded 9,055 raw locations. Seal tracks were created using filtered ARGOS locations without the Douglas Filter best point per day selected (**Figures 9** and **10).** From the filtered locations, 699 best point per day selections locations were used for the habitat use analysis (**Figures 11** and **12; Figures B1 through B14**). For all seals pooled together, there was a total of 721 tracking days (defined as the number of days from deployment to last transmission) from 04 February through 29 June 2018. Data was transmitted on 699 of the 721 tracking days (97% of transmission days) (**Table 5**). The mean number of tracking days was 103 (SD ± 29.65 days; range 61–143 days). All seals spent at least 60 days in Virginia waters. Seal 1807's PTT stopped transmitting on 26 April while the animal was in Virginia waters, but the other six PTTs continued transmitting after the animals departed the area. These six seals headed north between 31 March and 15 April 2018. Four seals traveled as far north as coastal Maine during the tag reporting periods (1802, 1803, 1804, and 1806), and two only traveled as far north as southern New England (1801 and 1805) before their tags stopped transmitting data (**Figures B1 through B12**).

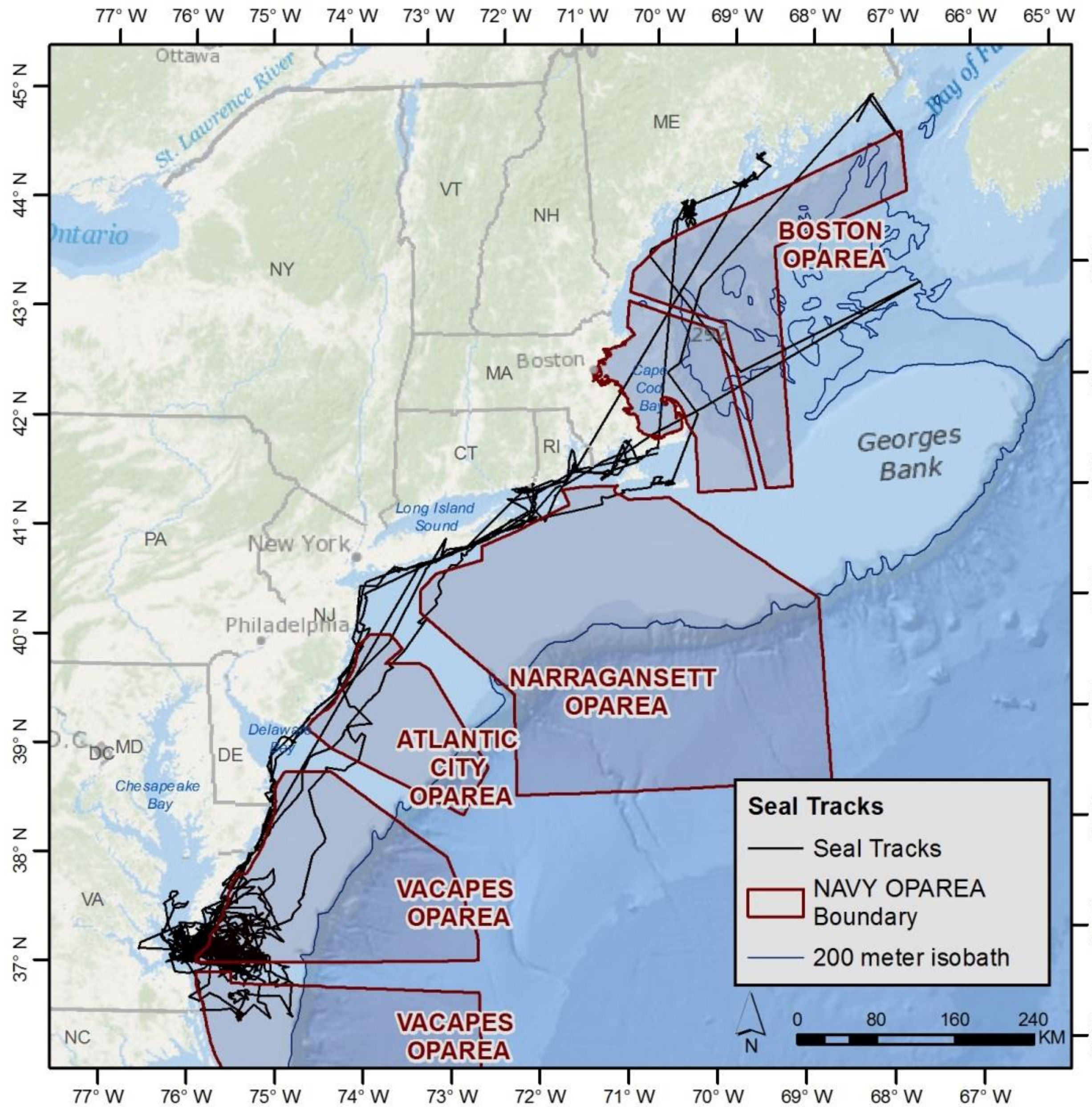


Figure 9. Reconstructed tracks of all seven seals tagged in coastal Virginia in February 2018 (maximum tag duration = 5 months; N = 7) in relation to Navy operating areas.

OPAREA = Operating Area; VACAPES = Virginia Capes Range Complex.

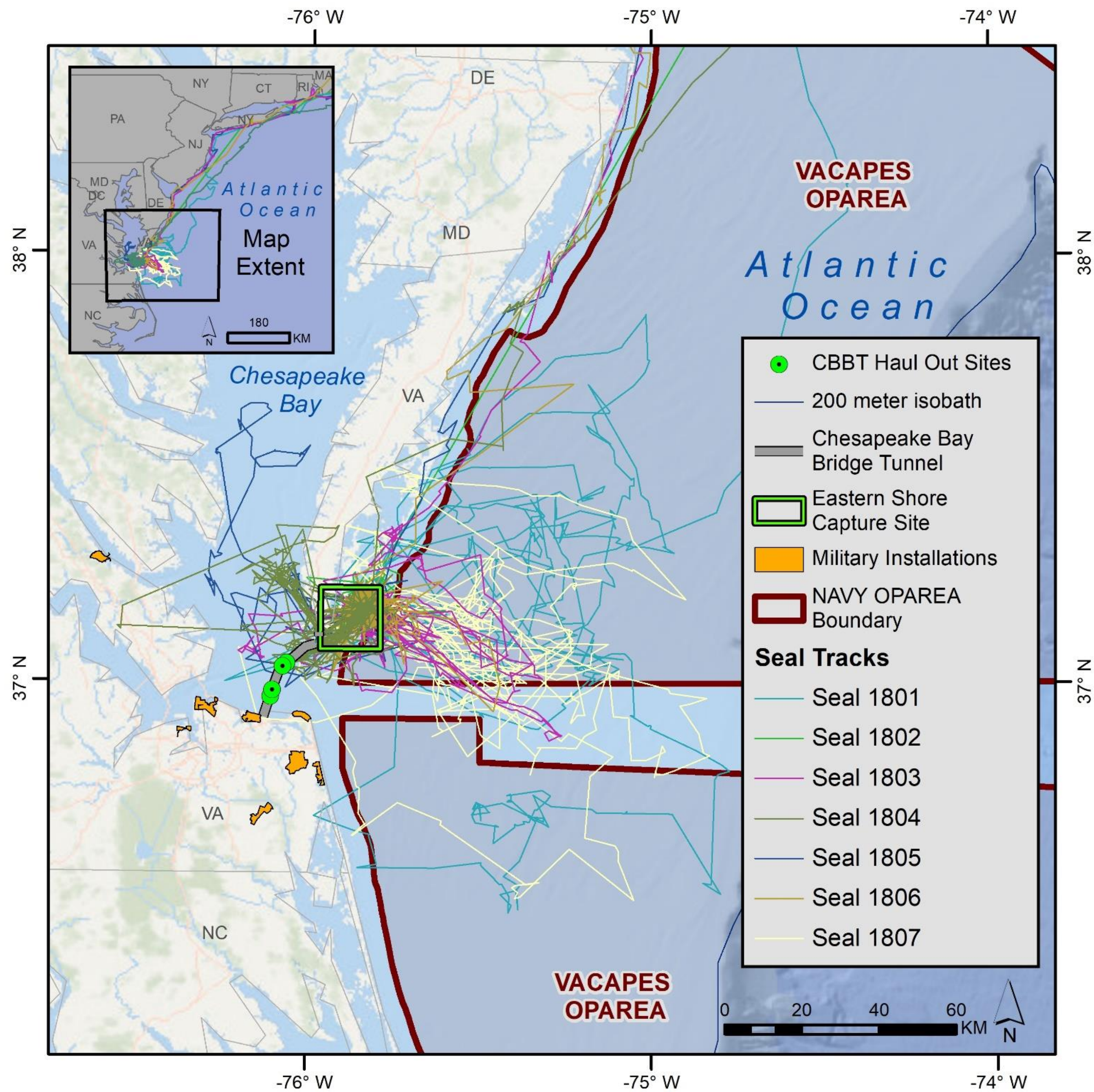


Figure 10. Reconstructed tracks of all seven tagged seals (February through April 2018) in relation to the Virginia Capes Range Complex (VACAPES) operating area (OPAREA).

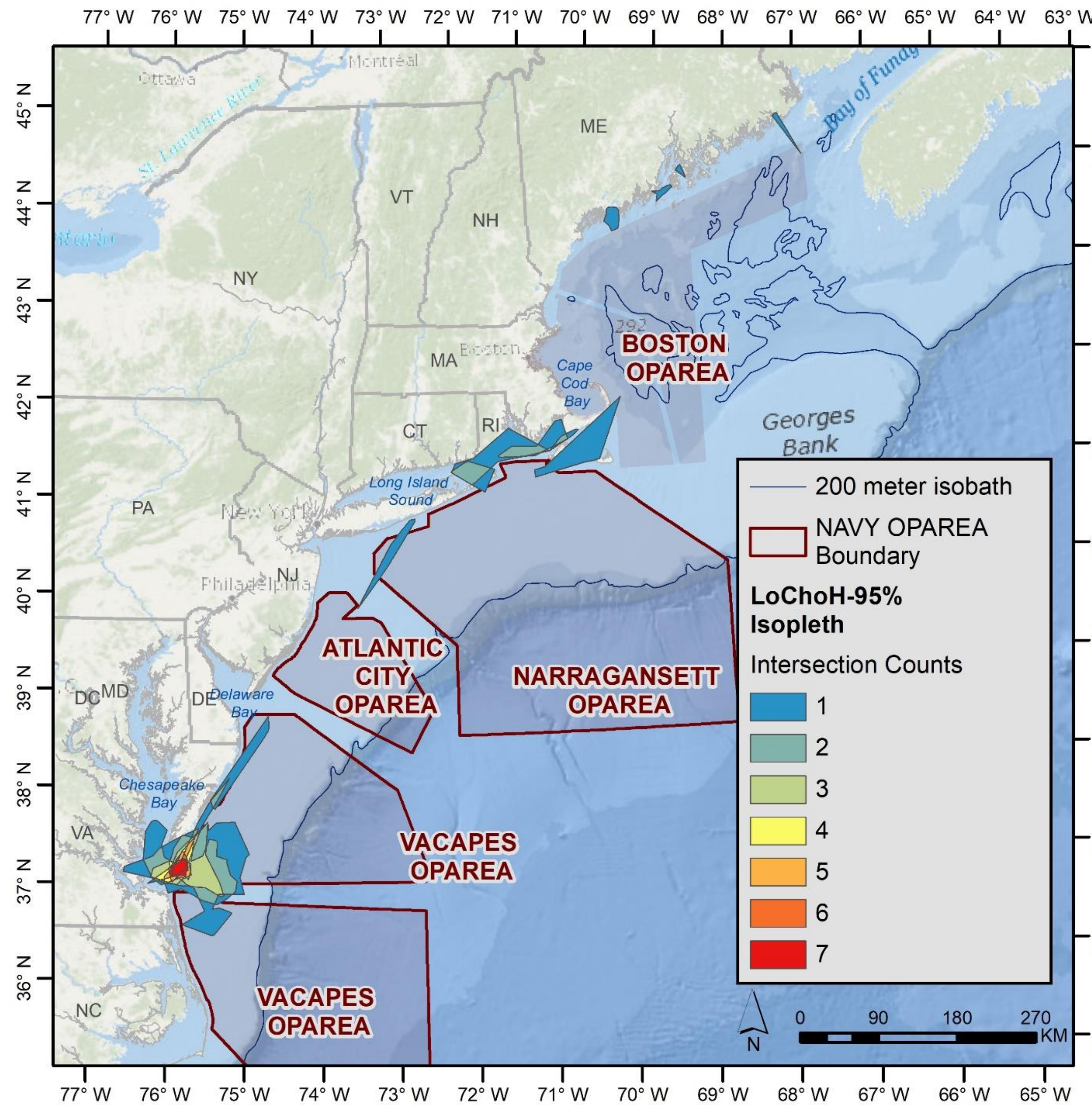
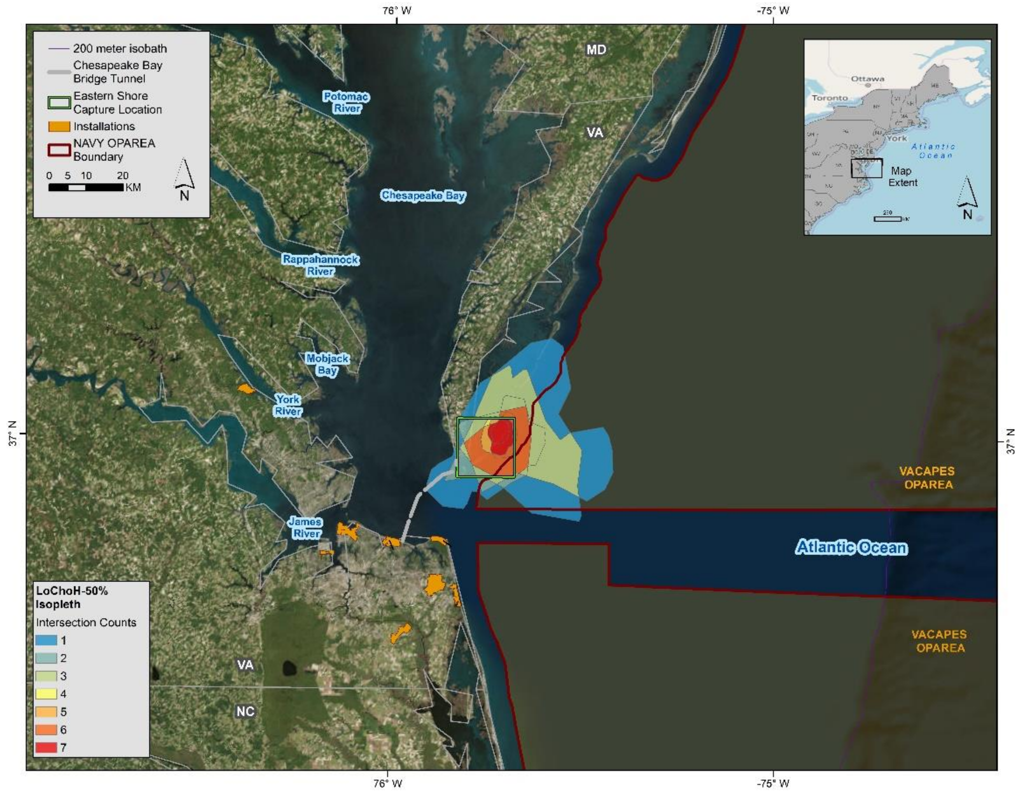


Figure 11. Habitat use map for all seven harbor seals tagged in February 2018, in relation to Navy operating areas (OPAREA) (maximum tag duration = 5 months).

Colors represent the number of overlaid individual 95 percent habitat-use isopleths, with cool colors indicating lower counts and warmer colors indicating higher counts. LoCoH = local convex hull; VACAPES = Virginia Capes Range Complex.



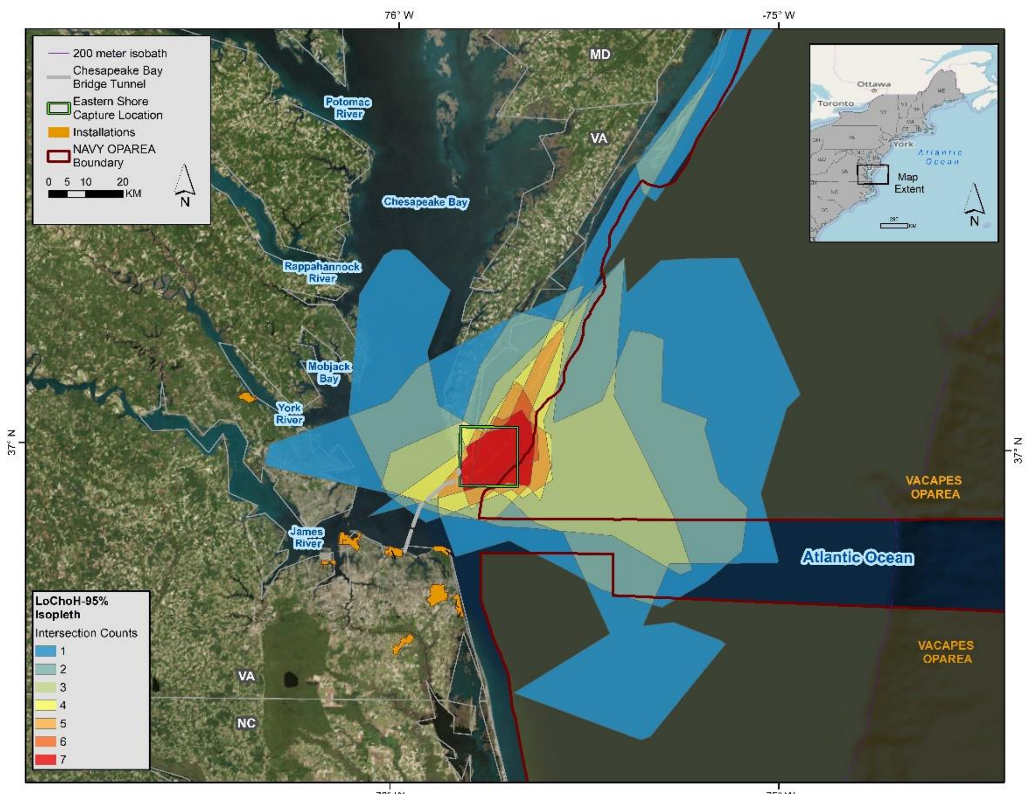


Figure 12. The intersection of all seven harbor seals' 50 percent habitat-use isopleths (upper panel) and 95 percent isopleths (lower panel) located in Virginia waters.

Colors represent the number of overlaid individual isopleths, with cool colors indicating lower counts and warmer colors indicating high counts. LoCoH = local convex hull; OPAREA = Operating area; VACAPES = Virginia Capes Range Complex.

Table 5. Spatial and temporal statistics calculated from Advanced Research and Global Observation Satellite (ARGOS) locations.

Animal ID	Deployment Start Date	Date Left Virginia	Deployment End Date	Tracking Days	Distance Traveled (km)	95% Use Area (km^2)	50% Use Area* (km^2)
1801	2/4/2018	4/15/2018	5/23/2018	107	4,374	7,759	1,101
1802	2/4/2018	4/01/2018	6/29/2018	143	4,002	701	74
1803	2/4/2018	3/31/2018	5/6/2018	90	3,543	6,378	307
1804	2/4/2018	4/4/2018	5/26/2018	108	3,652	6,924	504
1805	2/6/2018	3/29/2018	4/9/2018	61	2,670	3,742	68
1806	2/6/2018	4/14/2018	6/22/2018	135	3,383	556	33
1807	2/8/2018	CBD**	4/26/2018	77	3,438	4,047	872

*Represents core habitat in Virginia waters.

**Cannot be determined, since this seal did not leave Virginia waters during the tracking duration. Km = kilometer(s); km^2 = square kilometer(s); % = percent.

All tagged seals returned regularly to the capture site while in Virginia waters, but utilized the coastal environment differently. Each seal made between 3 and 13 trips to and from the capture site during the time that satellite tag was transmitting in Virginia waters. (**Table 6**). These trips extended from 14 to 104 km away from the capture site, and lasted from one hour to 15 days. Individual seals used offshore vs. estuarine waters differently. Three seals (1802, 1806, and 1807) never made trips into the Chesapeake Bay, while one seal (1804) stayed within the Chesapeake Bay and never visited offshore waters (**Figure 13**). Seals 1801 and 1803 only visited the Chesapeake Bay once, while seal 1805 only went offshore once.

Table 6. Distance, duration, and number of all trips to and from the capture site made by each seal, while in Virginia waters (trips were defined as travel > 10 kilometers (km) away from capture site).

Seal ID	MIN Travel Distance (km)	MAX Travel Distance (km)	MIN Travel Time (hours)	MAX Travel Time (hours)	Total Trips	Trips in Bay	Trips Offshore
1801	27	88	9	340	7	1	6
1802	20	30	12	22	3	0	3
1803	13	61	1	86	8	1	7
1804	20	61	13	136	13	13	0
1805	13	60	13	133	6	5	1
1806	17	43	8	28	6	0	6
1807	34	104	38	166	13	0	13

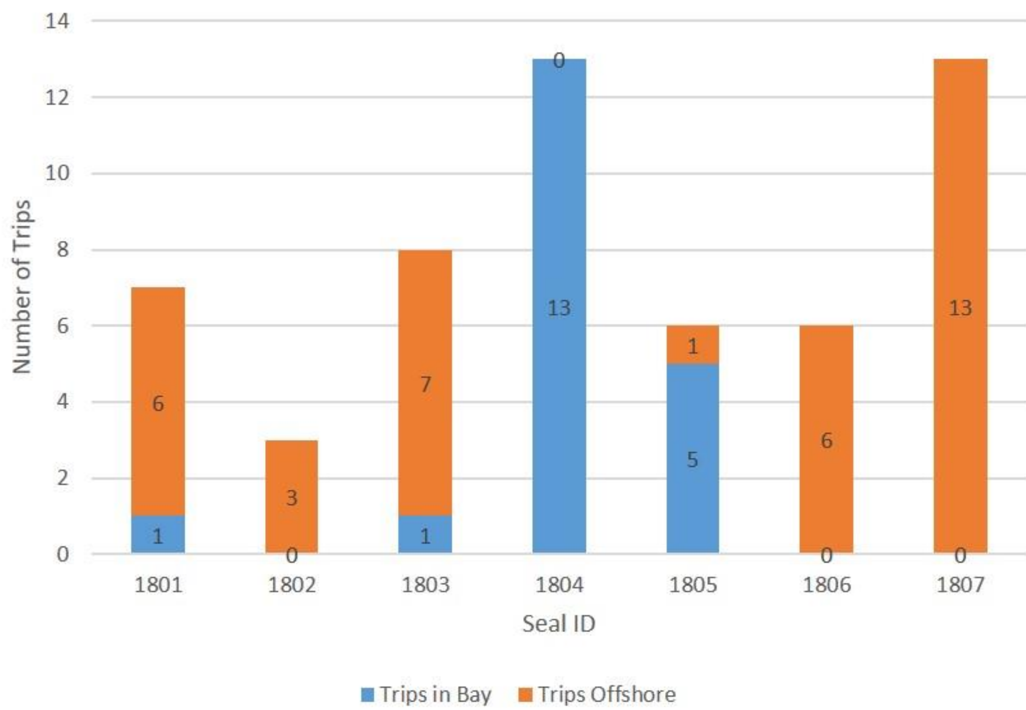


Figure 13. Number of trips made by each seal from the Eastern Shore to the Chesapeake Bay (in blue) and offshore waters (orange).

Each seal is represented by one bar in the histogram.

Habitat use by all tagged seals is shown in **Figures 11** and **12** (and **B1 through B14**), using likelihood predictions generated by the a-LoCoH analysis. Based on the 95% isopleth intersection polygon, we found that at least one seal had a 95% habitat-use isopleth that extended as far north as the coast of Maine, and at least two seals had a 95% likelihood of occurring off the coast of Connecticut, Rhode Island, and Massachusetts (**Figure 11**). In Virginia waters, tagged seals utilized both the Chesapeake Bay and offshore waters, but the area that was utilized most heavily was near the Eastern Shore capture site. The 50% isopleth intersections show that at least one seal had a 50% likelihood of being on the 4th island of the Chesapeake Bay Bridge Tunnel (CBBT) Islands or Fisherman's Island (located at the southern tip of the Eastern Shore), while all seven seals had a 50% likelihood of being near the Eastern Shore capture site (**Figure 12**, upper panel). The 95% isopleth intersections show that at least one seal had a 95% likelihood of being in the upper Chesapeake Bay, as far north as the Rappahannock River mouth. Up to four seals had a 95% likelihood of being around the CBBT Islands, and up to five seals had a 95% likelihood of being near Fisherman's Island (**Figure 12**, lower panel). Both the 50% and 95% isopleths intersect overlaps with the Virginia Capes Range Complex (VACAPES) Operating Area (OPAREA) (**Figure 12**). Overall, seals spent a cumulative 428 days in Virginia waters, and on 83 of these days (19%) satellite tags reported locations within the OPAREA.

3.3 Acoustic Pinger Tags

All five VEMCO tags deployed on harbor seals were detected within the Chesapeake Bay and coastal Virginia receiver array, but the amount of data from each tag varied. **Figure 14** shows the number of detections of VEMCO acoustic pinger tags at certain receivers in the receiver array in the Chesapeake Bay and Virginia coastal waters (see **Figure 5** for a map of the regional array). Two tags were only picked up once, and another tag was only picked up during March. The remaining two animals were detected multiple times at different receivers.

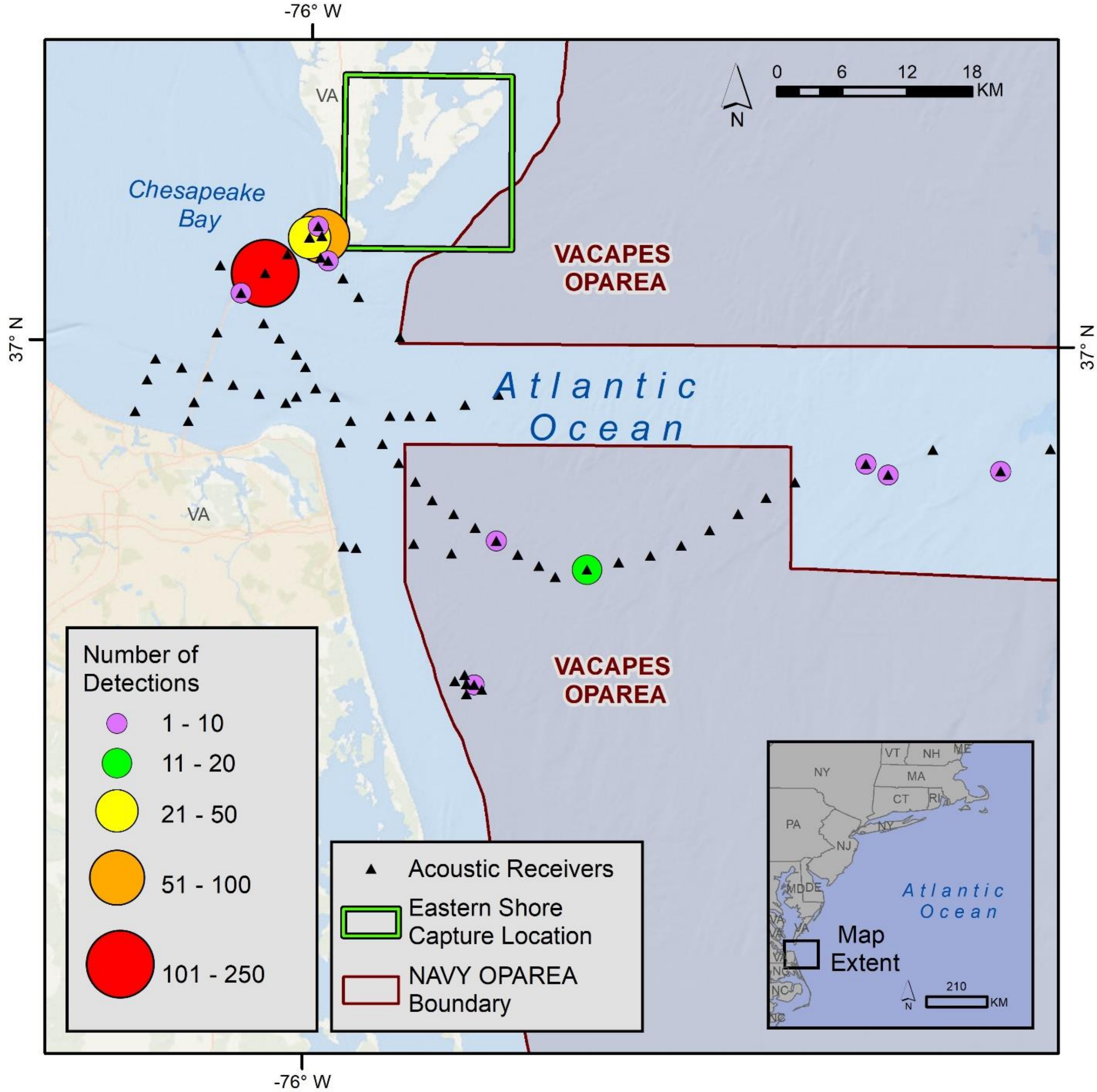


Figure 14. Number of detections of VEMCO acoustic pinger tags (all tagged seals) at selected receivers in the receiver array in Chesapeake Bay and coastal Virginia.

OPAREA = Operating area; VACAPES = Virginia Capes Range Complex.

A total of 591 detections (mean 68.87 detections, SD±22.55) from the five VEMCO-tagged harbor seals were recorded between February and April 2018, and 86% of these detections occurred in February (**Table 7**). Over 75% of detections were at receivers positioned along the CBBT Islands (**Figure 14, Table 7**). One individual, seal 1804, was detected 155 times at a receiver during one day, but using the 15-minute time interval criterion described in **Section 2.2** (Data Analysis Methods), this equated to six "visits" in the vicinity of this receiver on that day (**Figure 15**). This same individual was then detected at a nearby receiver on the same day, but with a 2-hour time gap from the last time it was detected at the first receiver to the first time it was detected at the second. **Figure 6** depicts the time-series and temperature readings for seal 1802 recorded from 04 February through 29 June 2018. Dive depth appeared to change depending on the animal's geographic location, which could be correlated to foraging behavior (e.g., exploiting prey) and/or environment (e.g., depth of the water near haul-out sites). While the animal was present in Virginia waters (**Figure 6**), recorded dive depths were relatively shallow (<40 m). Once the animal left the Virginia area and moved northward (**Figure 6**), a few dives reached as deep as 100 m, but most dives were at or below 50 m. Once the animal reached Maine, where many adult harbor seals typically pup in the spring, dive depths ranged from approximately 20 to 120 m, with the majority of dives shallower than 60 m (**Figure 6**).

Table 7 VEMCO tag receiver detections by week/month.

Receiver/Station	# OF DETECTIONS											TOTAL
	Feb-18				Mar-18					Apr-18		
	Feb 4-10	Feb 11-17	Feb 18-24	Feb 25-28	Mar 1-3	Mar 4-10	Mar 11-17	Mar 18-24	Mar 25-31	Apr 1-21	Apr 22-28	
10 off Cape Charles	5	5	9					1				**20**
B13		2										**2**
CB3											3	**3**
CBBT1	18	66	2					3	6			**95**
CBBT2	171	45	77		10	2		12	13			**330**
CBBT7	39	42	17			1		10				**109**
CC LS	2	6					1					**9**
SBA 4								1				**1**
SCL COMPLEX											14	**14**
WEA 1			3									**3**
WEA 2								2	1			**3**
WEA 4									2			**2**
Total	**235**	**166**	**108**	**0**	**10**	**3**	**1**	**29**	**22**	**0**	**7**	**591**

# of Detections

	1-10
	11-20
	21-50
	51-100
	101-250
	> 250

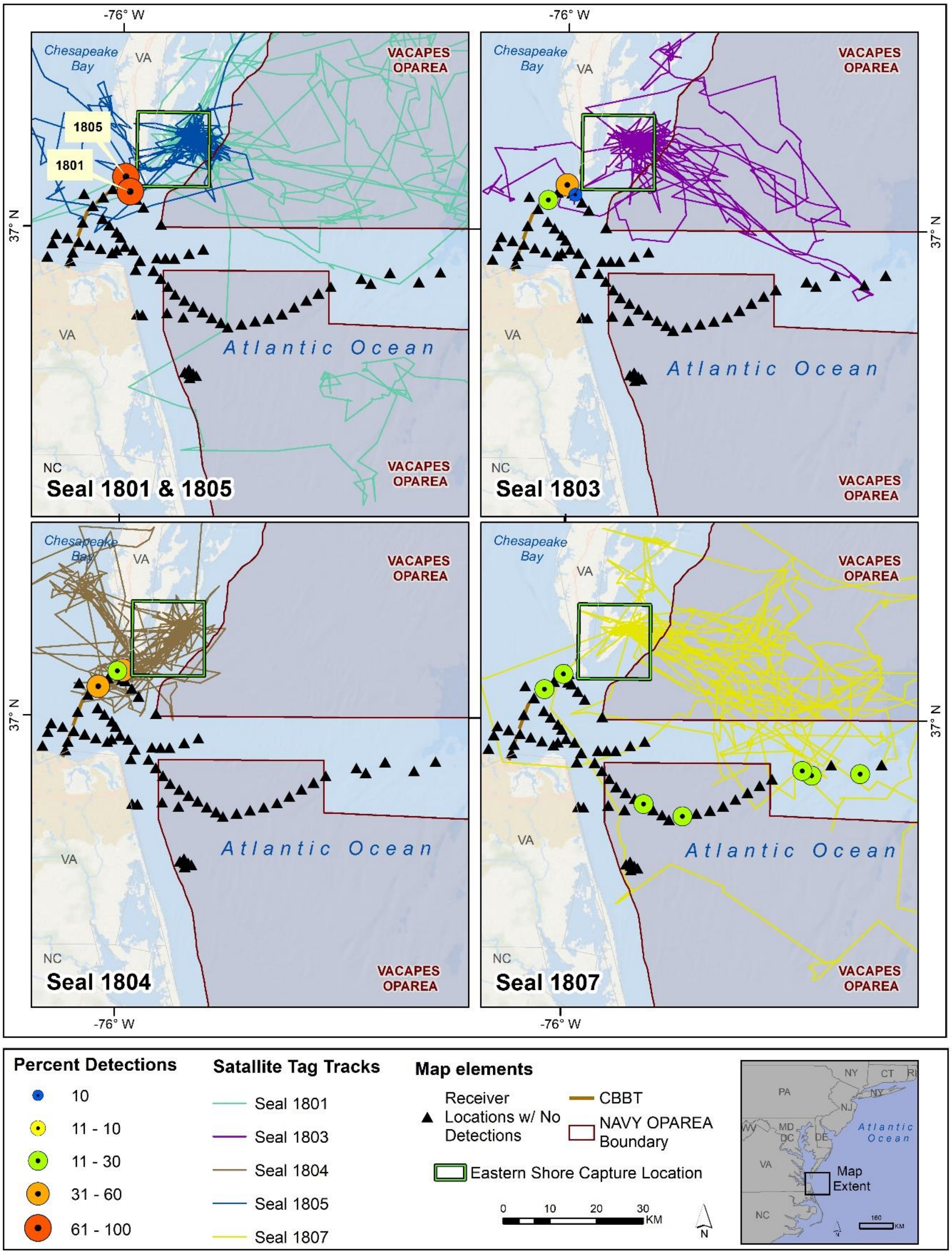


Figure 15. Percentage of time individual VEMCO-tagged seals spent at receivers.

CBBT = Chesapeake Bay Bridge and Tunnel; OPAREA = Operating area; VACAPES = Virginia Capes Range Complex.

3.4 Health Assessments

Vital rates and morphometric measurements were recorded for all seals, and photographs were taken of ventral, lateral, and frontal views. Any wounds or abnormalities were also photographed. See **Appendix C** for complete health assessment criteria. A full suite of blood and biological samples was collected from each captured and tagged seal. Samples were either processed and sent immediately to the requesting lab that same day and upon return from the capture site, or processed and sent to the requesting lab after the field sampling event had concluded for 2018. The complete blood count and chemistry panel results were within normal range for pinnipeds according to values published in Deirauf and Gulland (2001). Several seals presented with lesions that were minor and incidental. Overall the seals were deemed healthy by the consulting veterinarian, based on physical exam findings at the time of handling, and results of routine blood panels[4]. Heart and respiratory rates were obtained and recorded for all seals. When possible, rates were obtained both before and after tagging (pre-release). All seals were observed to have rapid or raspy respirations shortly after they were captured, but respiration rates returned to within normal range during tagging and before release. Heart rates for each seal were monitored throughout the capture period and were within normal range.

4. Discussion

This proof-of-concept study was the first time researchers captured and tagged wild harbor seals in Virginia. Although findings are limited to the seven individual seals tagged in this study under National Marine Fisheries Service research permit #17670-04, these data provide preliminary insight into the habitat use patterns and haul-out behavior of harbor seals in and near Navy training areas and installations in Virginia, and along the U.S. Eastern Seaboard.

4.1 Satellite Tags

4.1.1 Depth and temperature thresholds

The average and maximum dive depths recorded by the single SPLASH tag employed in this study, deployed on an adult male, are consistent with those observed for harbor seals in other regions and ocean basins (Tollit et al. 1998; Frost et al. 2001; Eguchi and Harvey 2005). This animal remained in Virginia waters through early April, spending its TAD < 30 m, and close to the capture site (**Table 4, Figure 6, Figure B-5**). Dive depths increased substantially in April and May, when the seal traveled northward toward coastal New England. The deeper recorded dives during this study (104 and 118 m) occurred off southern Long Island in early April and Penobscot Bay, Maine, in late May, respectively. Other studies have shown that harbor seals feed close to the sea-bed at moderate depths (4-200 m) (Harkonen and Heide-Jorgensen 1991; Bjorge et al. 1995; Tollit et al. 1998; Lesage et al. 1999; Gjertz et al. 2001). In general, the relatively shallow dive depths observed in this study are consistent with other studies of harbor seal dive behavior. Womble et al. (2014) found seals dive most frequently (81.6 percent) to

[4] Two seals (1803 and 1805) later tested positive for avian influenza, and third seal (1806) was seropositive for the virus (i.e., it had antibodies against the avian influenza, but the virus itself was no longer detectable).

depths shallower than 50 m. Gjertz et al. (2001) reported the maximum depth reached by harbor seals to be within the 200–350 m range; however, additional studies have reported shallower maximum dive depths, reaching less than 100 m off of Nova Scotia (Bowen et al. 1999), Svalbard (Jorgensen et al. 2001), and in Prince William sound (Frost et al. 2001). Preliminary results from this study likewise suggest that harbor seals are exploiting food resources at moderate depths and varying distances from shore in different regions throughout their range. Harbor seals in the Northwest Atlantic are known to prey on demersal (bottom-dwelling) fish such as sand lance, gadids, flatfish, and redfish (*Sebastes* spp.), pelagic fish such as clupeids and salmonids, as well as squids (Payne and Selzer 1989; Bowen and Harrison 1996).

All tagged seals left Virginia waters by mid-April 2018, except for one individual that remained in Virginia until its tag stopped transmitting data at the end of April. Maximum in-water temperature for tagged seals in the study was estimated to be about 9^{o}C. In-water temperatures for all tagged seals while in Virginia averaged just below 7^{o}C.

4.1.2 Haul-out patterns

Tidal state is the most consistent factor influencing the daily timing of when seals haul out (Brown and Mate 1983; Schneider and Payne 1983; Stewart and Yochem 1984; Calambokidis et al. 1987; Pauli and Terhune 1987). Lower tides often expose rocky reefs, sandy beaches and mudflats that are favorable haul-out sites for seals because of isolation from land predators and quick access to deep water. Although tides fluctuated considerably near the capture site, it would appear, based on the results of this preliminary study, that it did not affect the availability of haul-out sites. What is not known is whether the seals in this study switched between haul-out sites because of the tides: for example, if their preferred haul-out area was inundated by the tide, but a nearby one was not; or if a haul-out was inaccessible during a low tide due to a steep sloping ledge.

Temporal cycles also play a role in determining the proportion of harbor seals ashore. Peak counts of seals at haul-out sites typically center on low tides that occur during the middle of the day (Yochem et al. 1987; Boveng et al. 2003; Jeffries et al. 2003; Simpkins et al. 2003). When researchers monitored the presence of harbor seals across all hours of the day, most found that more seals were present in daytime vs. nighttime hours (Thompson 1989; Simpkins et al. 2003). The seals in the Chesapeake Bay area also appear to follow this pattern of hauling out in the afternoon and into the evening hours. Although the haul-out area is isolated from human activities, there is some boat traffic that could influence haul-out behavior, particularly as boat traffic would be expected to pass by the haul-out site(s) in the morning and early afternoon and could cause some level of disturbance to hauled-out seals.

Harbor seals are generally considered to be a shallow-water, non-migratory species, and remain within 200 km of their haul-out areas (Bigg 1981, Thompson 1993). However, the seals tagged in this study undertook longer-distance (800-1,000 km) seasonal movements northward to annual breeding grounds in New England. It is beyond the scope of this preliminary study to explain this seasonal shift in distribution, but further study may reveal the causes for this behavior, and place it in the context of the larger Northwest Atlantic harbor seal population.

In general, the annual breeding and molting cycle of seals leads to temporal changes in haul-out behavior. During pupping and weaning, adult females and pups spend more time ashore (Huber et al. 2001), whereas males focus on establishing and defending aquatic territories (Sullivan 1981; Hayes et al. 2004). All age and sex classes, with the exception of pups, go through a complete molt every year. The largest proportion of seals ashore often occurs during the molt period (Everitt and Braham 1980; Stewart and Yochem 1984; Thompson 1989); however, the timing of molt varies with age and sex (Huber et al. 2001; Daniel et al. 2003). Two tags in this study, 1802 and 1806, continued to transmit data around the time when molting was expected. Based on the limited tag data from these two tags, there appeared to be a slight shift in haul-out behavior as these animals approached the molting period (summer) with either more time spent ashore or at different times throughout the day when compared to earlier in the year (winter). This could also be indicative of temporal cycles working in concert with tidal influences in these northern areas to affect the overall pattern of their haul-out behavior, but due to the preliminary results of this study and tag duration limitations, a clear reason cannot be determined.

4.1.3 Habitat use

Harbor seals are central place foragers, and typically return to the same haul-out site(s) between foraging trips (Thompson and Miller 1990; Russell et al. 2015). Results from this study indicate that when in Virginia waters, haul-out sites on the Eastern Shore and CBBT Islands functioned as this central area, while seals traveled west to the Chesapeake Bay or to offshore waters east of the Chesapeake Bay. Individual seals showed strong preference for one area or the other (**Figure 13**). Individual differences in foraging patterns have been documented in other phocid seals, and may be due to differences in age, sex, breeding status, individual buoyancy, or foraging experience (Beck et al. 2000; Breed et al. 2009).

Tagged seals that headed north after leaving Virginia appeared to use known haul-out areas for harbor seals in New England, including Fishers Island in Block Island Sound, Cape Cod and islands in Nantucket Sound, and Penobscot Bay in Maine (Gilbert et al. 2005; Hayes et al. 2017). That said, location data collected north of Virginia waters was patchy and could not be used to consistently characterize habitat use (e.g., spatial and temporal) with the same degree of certainty as that in Virginia waters where at least one high-quality location was collected every day, for each seal. In general, however, the ARGOS location data collected was not fine-scale enough to identify specific haul-out locations. The satellite tags used in this study are only accurate to about 500 m (Costa et al. 2010), and in Virginia seals tend to haul out on marshes close to the waterline, and on small islands, sometimes only within tens of meters of each other. Tags with higher-resolution GPS capabilities would improve the ability to identify specific haul-out sites from location data alone.

Although the regular occurrence of harbor seals in Virginia is a relatively new phenomenon (at least in recorded history) the individuals tagged in this study showed similar habitat use and behavioral patterns as those documented for other harbor seals elsewhere in the Northwest Atlantic. Additionally, the tagged animals appeared to be healthy according to in-situ health assessment observations and IDEXX blood analysis results (McNaughton pers. comm. 2018). Findings from this study, as well as from the Navy’s pinniped photo identification studies (Rees et al. 2016) indicate that the Chesapeake Bay and coastal Virginia is seasonal habitat for healthy juvenile and adult harbor seals. The habitat use analysis in this study indicates that seals seen at the CBBT Islands and Eastern Shore are using areas that overlap with the Navy's VACAPES OPAREA, where Navy training and testing activities (including gunnery exercises, missile exercises, and anti-submarine warfare exercises) are periodically conducted.

4.2 Acoustic Pinger (VEMCO) Tags

Although there was an extensive established receiver array in the Chesapeake Bay and Virginia area most seals were detected primarily at those receivers closest to the capture site. The last animal that was captured and instrumented with a VEMCO tag remained nearby the capture site the longest (nearly three months), but was also detected on receivers farthest away from the capture site. In general, even with the extent of the receiver array, there was a lack of detections from most animals instrumented with VEMCO tags. This is more likely due to the proximity of the animal to the receivers than to tag failure. In addition, there were no receivers directly east of the capture site which, based on the information collected using SPOT tags and the SPLASH tag, would be an area where these individual animals would have been present, but not detected by VEMCO tags (if they passed close enough to a receiver to be detected), because there was an absence of receivers in this area. The VEMCO tag data are supported by the SPOT and SPLASH tag data in the Chesapeake Bay area. There is no indication that any of the acoustic tags failed, so if an individual animal did pass close enough to a receiver, it is assumed that it would have been detected[5]. Studies involving VEMCO tags deployed on gray seals have shown that the detection range for these tags varies, and although detections can occur at up to 1 km from the receiver, in general, observed detections ranged from 50 to 200 m and then dropped off considerably as distance to the receiver increased (Baker et al. 2014). However, based on preliminary analysis of these tags in the Chesapeake Bay/Virginia waters and the location of the existing receiver array, it would appear that the detection range is considerably less than the 200 m described in Baker et al. (2014).

4.3 Comparison of Tagging Approaches

This study combined tagging approaches commonly used in pinniped research, and in other regional seal studies conducted under the same NOAA fisheries research permit (#17670-04). Tagging methods included flipper tags attached to the hind flipper webbing, acoustic tags adhered to the flipper tag, and satellite tags adhered to the animals' fur. Flipper tags, which have identification numbers etched directly on them, are expected to remain on an animal for multiple years. Re-sights can provide information on site fidelity between and over seasons, but would not provide data on the path an animal took, for example, between different haul-out sites. Satellite tags have the ability to archive and transmit several months of data for a single animal, and can therefore provide information about seals' long-distance seasonal movements (including in remote areas), broad-scale habitat use, haul-out behavior, and in the case of the SPLASH tag, dive behavior as well. However, satellite tags are quite costly, particularly those with depth-sensing capabilities. Acoustic tags, such as the VEMCO tags used in this study, are of course contingent on the presence of acoustic receivers to be informative, which satellite tags

[5] Other regional researchers were notified about the VEMCO-tagged seals in this project, but as of this writing no acoustic "hits" have been reported on receivers other than those reported here, in coastal Virginia.

are not. Acoustic tags work well in a variety of environments, and the pings emitted by the tags can travel relatively long distances. Depending on environmental conditions, the detection range can vary and can be degraded by a number of factors including: thermoclines, vegetation, suspended sediment, or noise (e.g., engine noise). Acoustic signals are detected using hydrophones (receivers) and the data are downloaded by the researcher at an interval of their choosing. In this study, the VEMCO tags were attached to the flipper tag, which avoided direct attachment to the animal's fur, therefore increasing the potential duration of attachment. Thus, the acoustic tags used in this project could provide longer term data (when compared to satellite tags that fall off after the molt) on an animal's seasonal movements between years in those areas where acoustic arrays are operational. Another potential limitation of the VEMCO tags is detectability, which is dependent on the seal's location in the water column relative to the receiver, and also on environmental conditions. The preliminary results of this study do demonstrate that there was considerable variability in the quality and quantity of detections for the five VEMCO tagged animals. And while VEMCO tags are less expensive than satellite tags, the receivers required to detect them are costly. (This study took advantage of an established receiver array.) Obtaining data from acoustic tags also requires coordination with researchers and organizations that own and operate the receivers, and is also dependent on whether the array is monitored and active during the time the animals are present.

An in-depth comparison of data products from the SPLASH, SPOT, and VEMCO tags deployed in this study is not possible due to the paucity of data collected by the VEMCO tags, probably caused by variations in the detectability of these tags. However, preliminary results indicate that the satellite tags, although costly, provided more useful information about animal movements (short-and long-term), dive behavior, habitat use, and haul-out patterns, when compared to the VEMCO tags.

4.4 Effects of Capture and Tagging

Of concern in any pinniped tagging study is the potential risk of injury to the tagged animals during capture and tagging procedures, as well as potential impacts to the animal's swimming physiology caused by drag after the tag has been attached. While individual seals captured in this study likely endured some degree of "handling stress," none were injured as a result of capture/tagging activities, and none exhibited a severe stress response that compromised their overall health. For weeks and months post-release, all tagged seals moved to areas where other harbor seals are typically seen, indicating that they resumed normal behavior after the study concluded. There were also several opportunities for direct observation of seals post-tagging. Seal 1802 was observed hauled out at the capture site one day post-tagging, and did not show any signs of injury. It then went into the water adjacent to the haul-out site, and was observed swimming normally. Seal 1803 was observed hauled out near Fisher's Island in New York a little over a month after it had been tagged, with the satellite tag still attached to the head with no sign of injury. This indicates that the seal was able to swim long distances with the tag attached, and access haul-out sites with other non-tagged harbor seals in the area. In addition, none of the seven tagged animals were found injured or stranded between Virginia and Maine in 2018.

It should be noted that tag 1807, attached to a young of the year (YOY) female, stopped transmitting at the end of April while the animal was still in coastal Virginia, and tag 1805, on an adult female, stopped reporting data on 09 April when the animal was in southern New England. Both of these tags stopped reporting well before the molting period, although at this time it cannot be determined whether this was due to tag malfunction, tag loss, natural mortality, or other factors.

We also note that the VEMCO tags used in this study have a source level of 147 dB re 1 μPa, and emit pings every 60-90 seconds at a frequency (69 kHz), which overlaps with the hearing range of harbor seals. Cunningham et al. (2014) reported that harbor seals and California sea lions had detection thresholds of 106 and 112 dB re 1 μPa, respectively, at 69 kHz, and were also able to detect actual VEMCO tags at 113 and 124 dB re 1 μPa, respectively. The impacts of this acoustic overlap have not been quantified and are not well understood, although it is possible that the pinging signals could alter the normal behavior of tagged seals (Cunningham et al. 2014).

5. Summary and Future Work

Data from this project provides preliminary information on movement patterns, habitat use, and haul-out behavior of harbor seals in and near Navy training areas and installations in Virginia, and along the U.S. Eastern Seaboard. Understanding the behavior and changes in local population numbers can help managers make more informed decisions. Tag data can also be used to develop in-water correction factors for use in seal census studies that assess seasonal abundance, density, and distribution of Northwest Atlantic seal populations. Results from this study confirmed that it is feasible to capture and tag healthy, wild seals on the Eastern Shore of Virginia. Additional tag deployments are planned for early 2019 at the same capture location. Up to 15 seals will be instrumented with a combination of location-only and depth-sensing tags, including some equipped with Fastloc® technology, which will provide location accuracy of up to 20 m. Data from these tags will allow for more robust conclusions about habitat use in and near Navy training areas. Additional data from depth-sensing tags will help inform Navy analyses of anthropogenic sound on seals at varying depths in the water column.

The southward trend in harbor and gray seal distribution along the U.S. east coast has been observed in other monitoring projects conducted in and near other naval facilities, such as those conducted in Rhode Island waters (DeAngelis pers comm. 2018). The increase in gray and harbor seals in New York waters has increased from a few groups of animals in the 1990s to hundreds of harbor and gray seals at haul-out sites all around Long Island, New York (DiGiovanni pers comm. 2018). This shift southward has apparently occurred within the last decade (Hayes et al. 2017). Since 2014, Navy researchers have documented an increase in seals at the CBBT Islands, as well as the reoccurrence of animals in successive years (Jones et al. 2018). This pattern of “range expansion” is similar to that observed over the past two decades at other harbor seal haul-out sites near Long Island, New York, and areas along the Pacific Coast.

This work was conducted under the NOAA Northeast Fisheries Science Center’s research permit (#17670-04), which outlines broader ecological questions regarding seals in the

Northwest Atlantic. Data collected as part of these efforts will also contribute to NOAA's objectives for monitoring seal populations along the eastern seaboard. Understanding the distribution and abundance, habitat use, regional prey availability, and health status of these seal populations will eventually provide the foundation for a range-wide ecosystem-based analysis. The results from this study contribute new information about the movements of harbor seals in the southern extent of their current range, and will provide a better understanding of harbor seals' seasonal movements, site fidelity, time spent hauled out vs. at sea, and survivorship of tagged individuals.

In addition to tag data, biological samples were also collected (and will be collected during subsequent tagging efforts) for a general health assessment of individual animals captured in Virginia. This project was a collaborative effort among a variety of organizations, and biological samples were shared with a number of researchers who are investigating the health, diet, and genetic structure of harbor seals in the Northwest Atlantic (**Table 1**). These data could also be used to help monitor population-level health status, particularly in the context of recent Unusual Mortality Events (UME) for the harbor and gray seal North Atlantic stocks, and in support of NOAA's Marine Mammal Health and Stranding Response program. For example, data collected for fatty acid analysis could be compared to data collected by other seal health assessment research and tagging projects conducted in southern New England. Obtaining baseline movement and health data is important because it would enable researchers to assess changes in the status of seal populations throughout their range, and identify potential issues that may be of concern at the local or regional level.

This project presents a unique opportunity to collect baseline information about a newly-established protected species in coastal Virginia. Study protocols and sampling regimes have been designed to be compatible with similar, regional studies, and will contribute to a "big picture" understanding of seal ecology in the Northwest Atlantic. This will better help resource managers to mitigate potentially harmful interactions between humans and marine mammals, and track trends in seal abundance to inform environmental planning documents and maintain regulatory compliance.

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A

In-water Temperature Data Recorded by all Satellite Tags

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Table A-1. Monthly In-Water Temperature Statistics for each SPOT Tag

Animal ID	Month	Temperature (C)				
		Mean	Max	Min	SD	Num Obs.
1801	Feb	7.74	9.00	5.20	0.89	151
1801	Mar	8.10	9.00	6.85	0.56	212
1801	Apr	8.61	9.00	7.50	0.30	34
1802	Feb	6.14	8.75	2.60	1.89	1148
1802	Mar	6.37	8.75	4.10	0.91	1287
1802	Apr	5.78	6.05	5.65	0.09	59
1803	Feb	7.29	9.00	4.25	1.21	221
1803	Mar	7.41	9.00	5.75	0.68	273
1804	Feb	6.80	9.00	4.35	1.32	70
1804	Mar	7.45	9.00	5.85	0.86	180
1804	Apr	7.66	8.85	6.50	0.79	15
1805	Feb	6.94	8.90	4.30	1.14	152
1805	Mar	6.97	8.95	4.80	0.76	318
1806	Feb	7.10	8.95	4.40	1.07	54
1806	Mar	7.26	9.00	5.35	0.84	110
1806	Apr	8.10	8.10	8.10	NA	1
1807	Feb	6.87	8.85	5.35	0.73	74
1807	Mar	7.18	8.95	5.15	0.67	96
1807	Apr	8.11	9.00	7.10	0.52	51

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B

Habitat Use Maps

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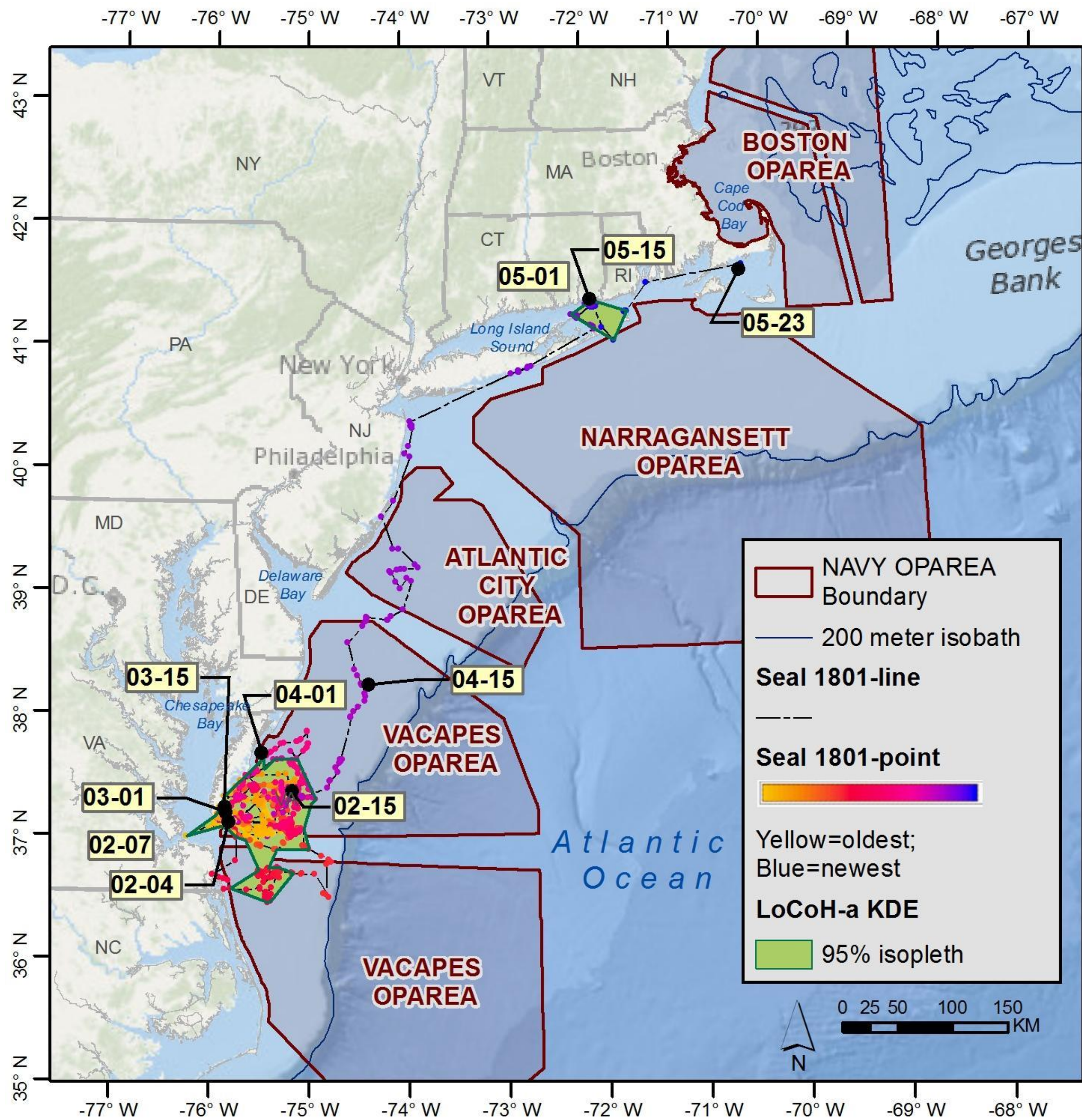

Figure B-1. **Habitat use map for seal 1801 (tag duration = 04 February through 23 May 2018) in relation to Navy operating areas along the Eastern Seaboard. Green areas represent the 95 percent isopleth.**

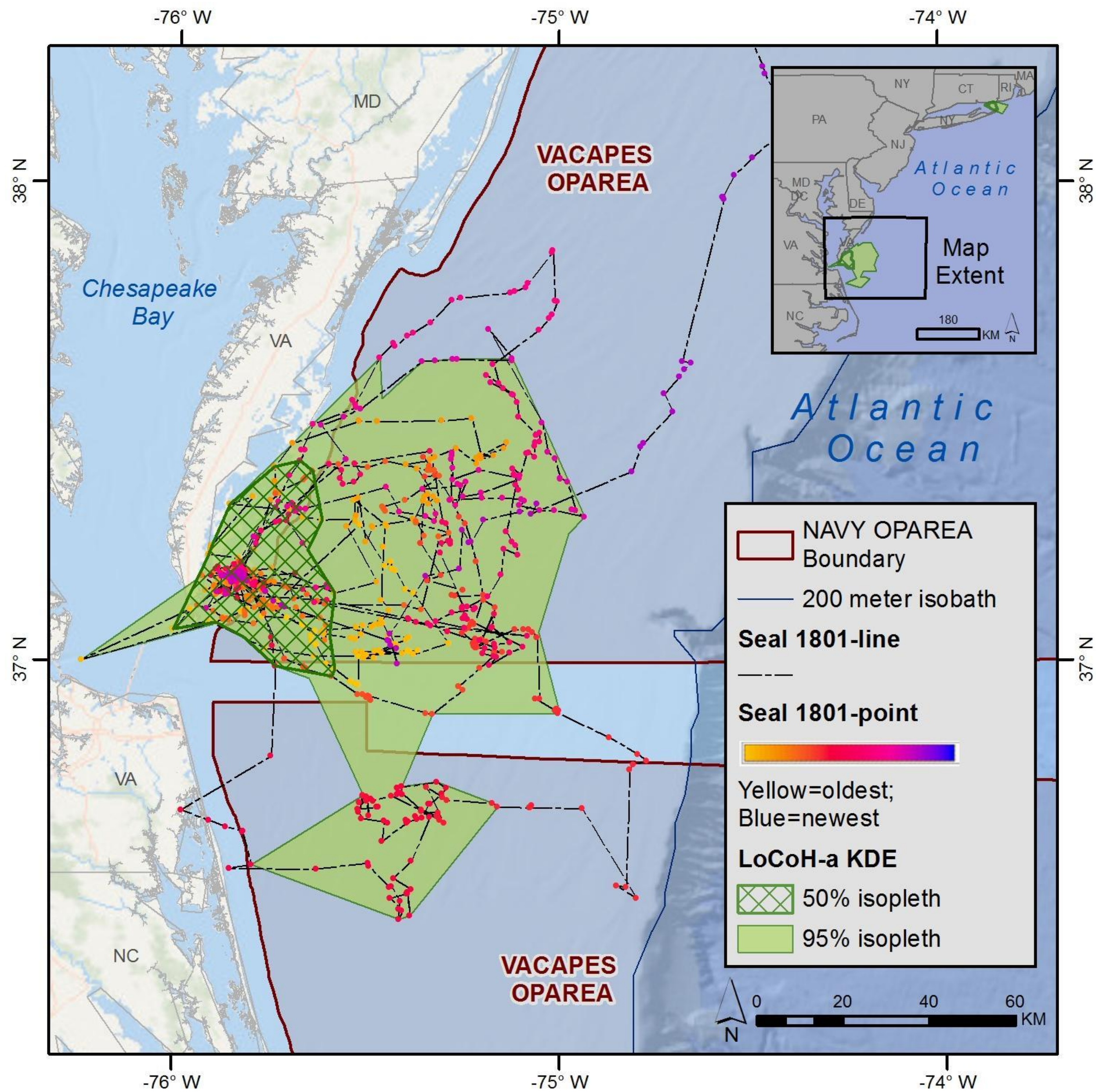

Figure B-2. **Habitat use map for seal 1801 while in Virginia waters (04 February through 15 April 2018) in relation to the VACAPES operating area. Green areas represent the 95 percent isopleth, and crosshatched areas represent the 50% isopleth.**

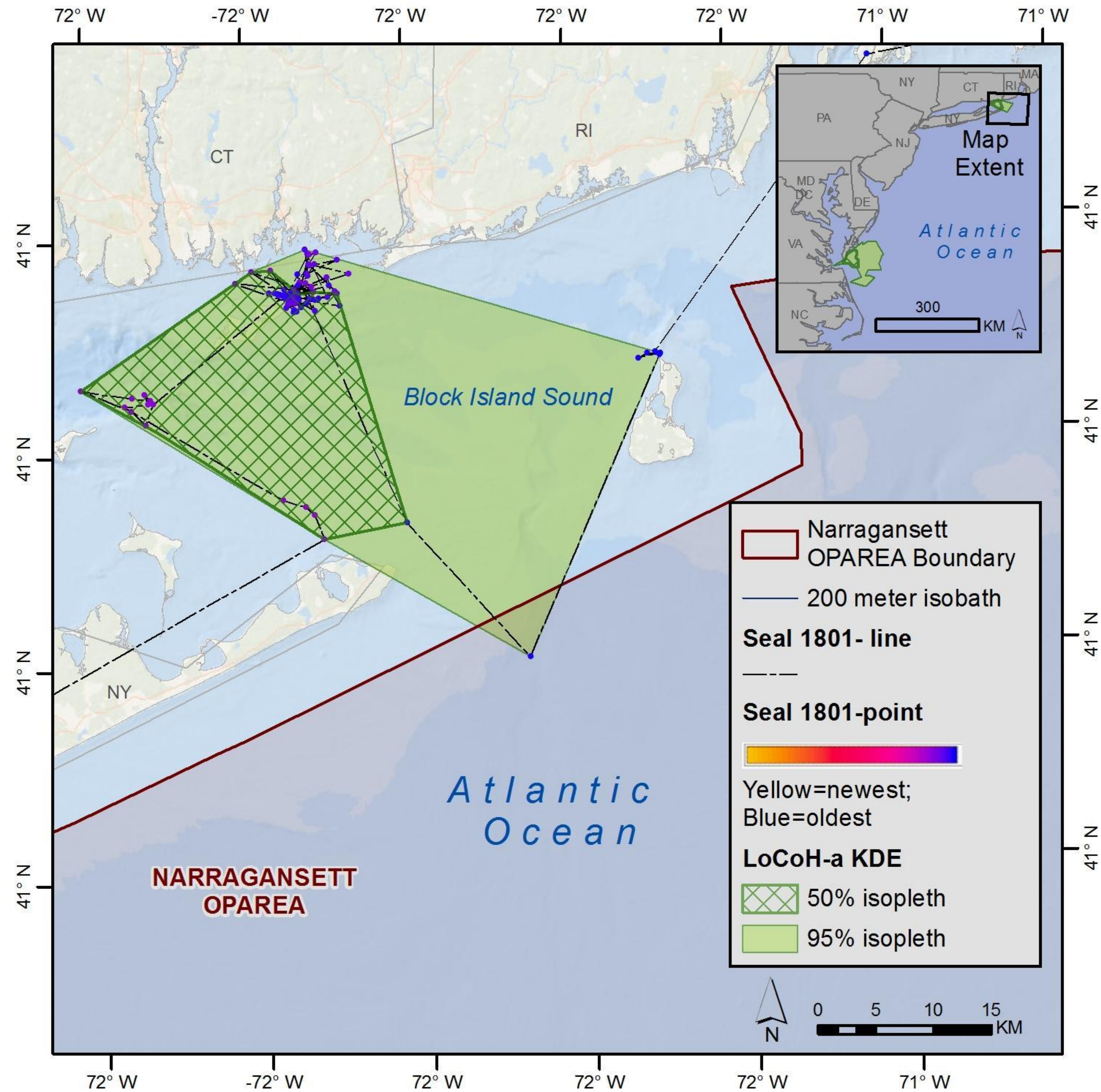

Figure B-3. **Habitat use map for seal 1801 while in Block Island Sound (26 April through 20 May 2018) in relation to the Narragansett operating area. Green areas represent the 95 percent isopleth, and crosshatched areas represent the 50% isopleth.**

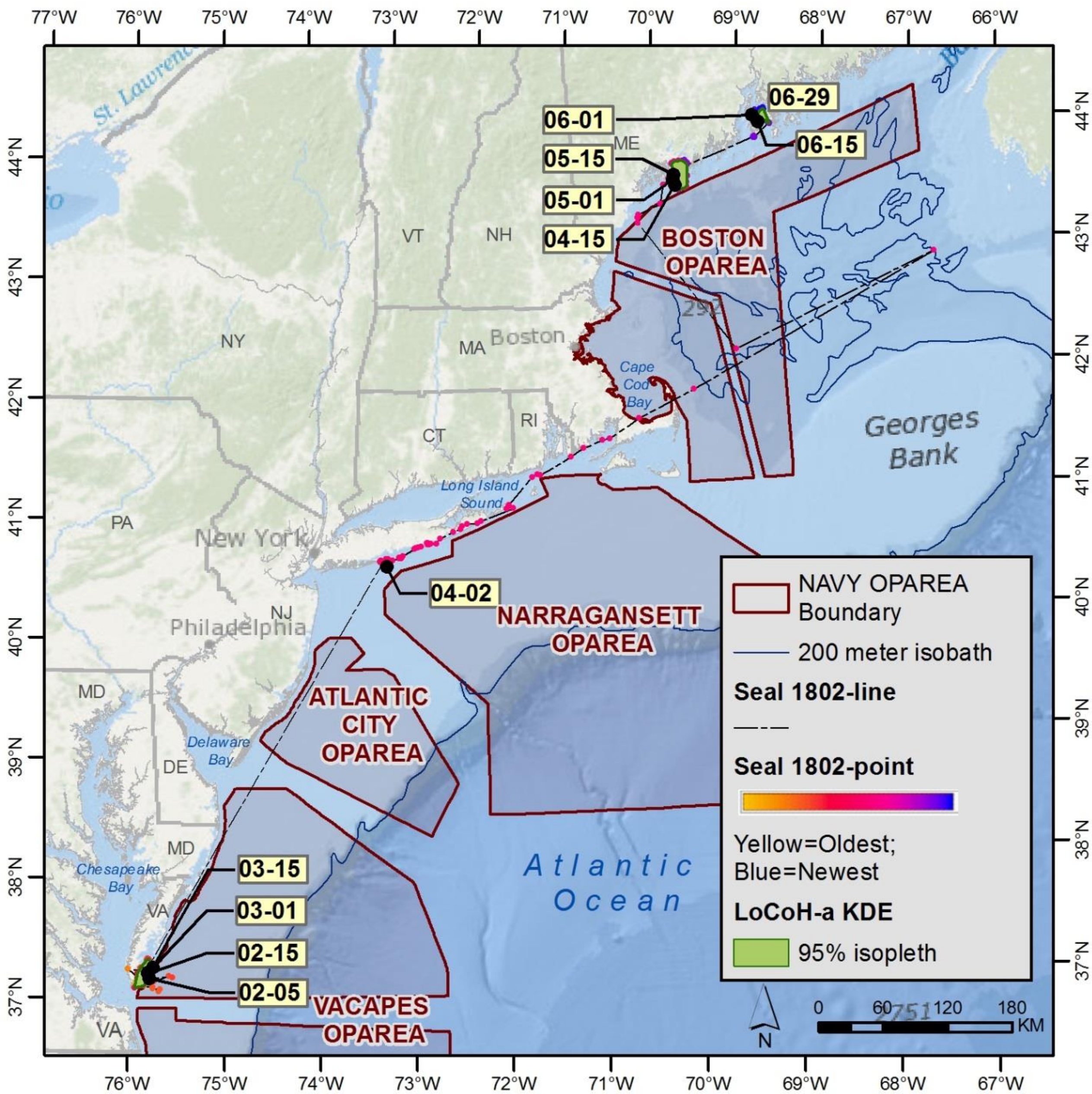

Figure B-4. **Habitat use map for seal 1802 (tag duration = 04 February through 29 June 2018) in relation to Navy operating areas along the Eastern Seaboard. Green areas represent the 95 percent isopleth.**

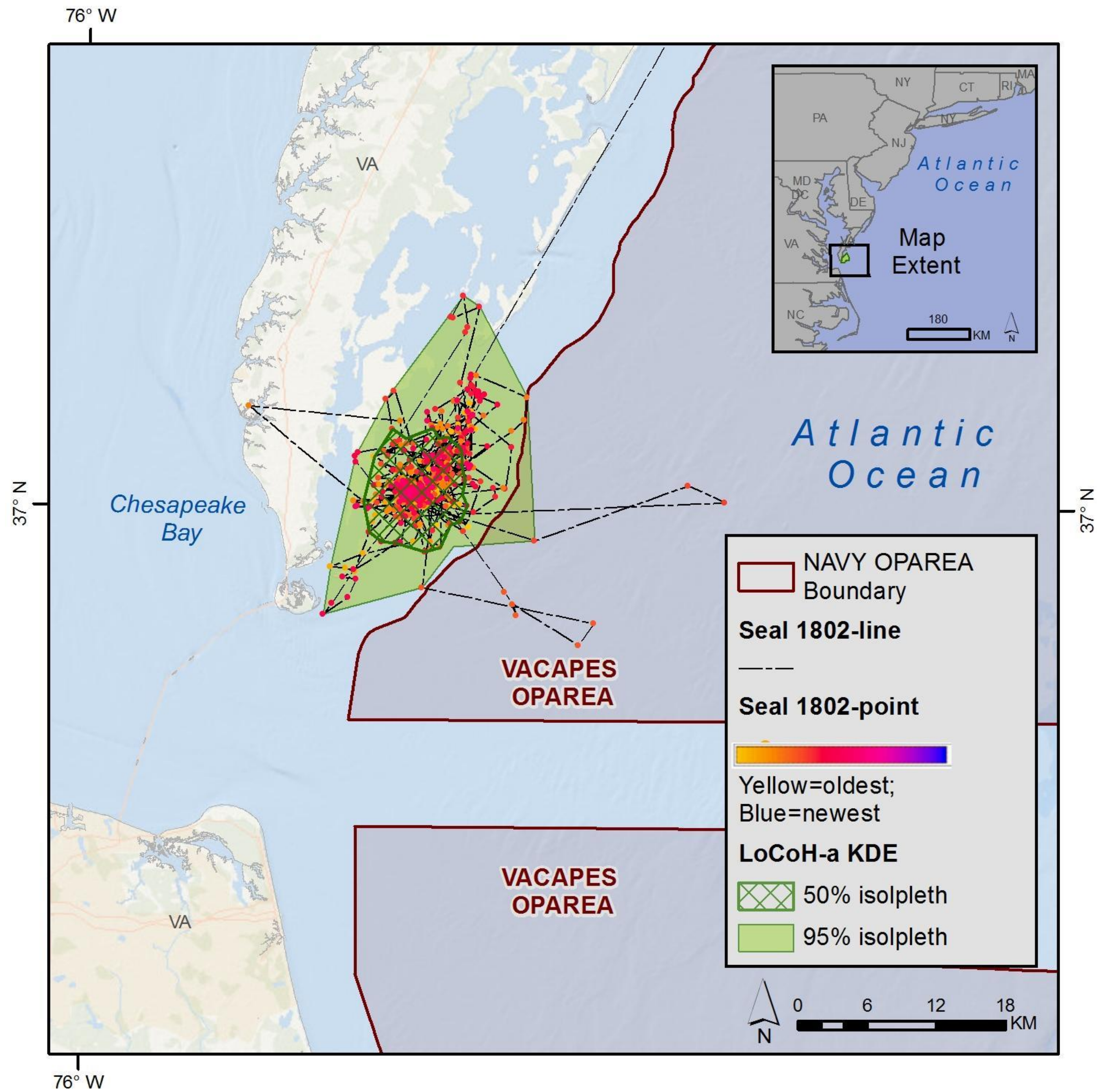

Figure B-5. Habitat use map for seal 1802 while in Virginia waters (04 February through 01 April 2018) in relation to the VACAPES operating area. Green areas represent the 95 percent isopleth, and crosshatched areas represent the 50% isopleth.

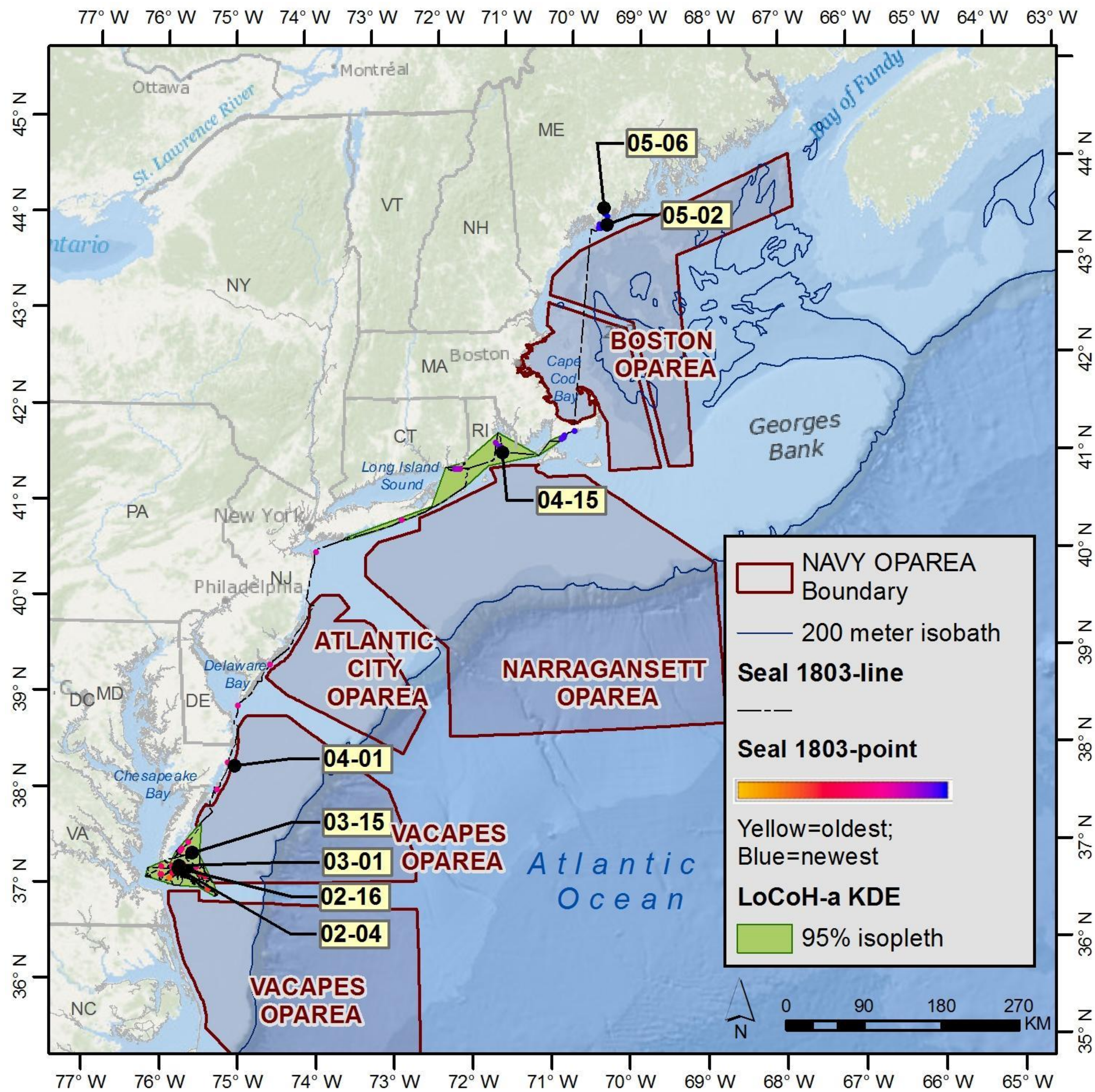

Figure B-6. Habitat use map for seal 1803 (tag duration = 04 February through 06 May 2018) in relation to Navy operating areas along the Eastern Seaboard. Green areas represent the 95 percent isopleth.

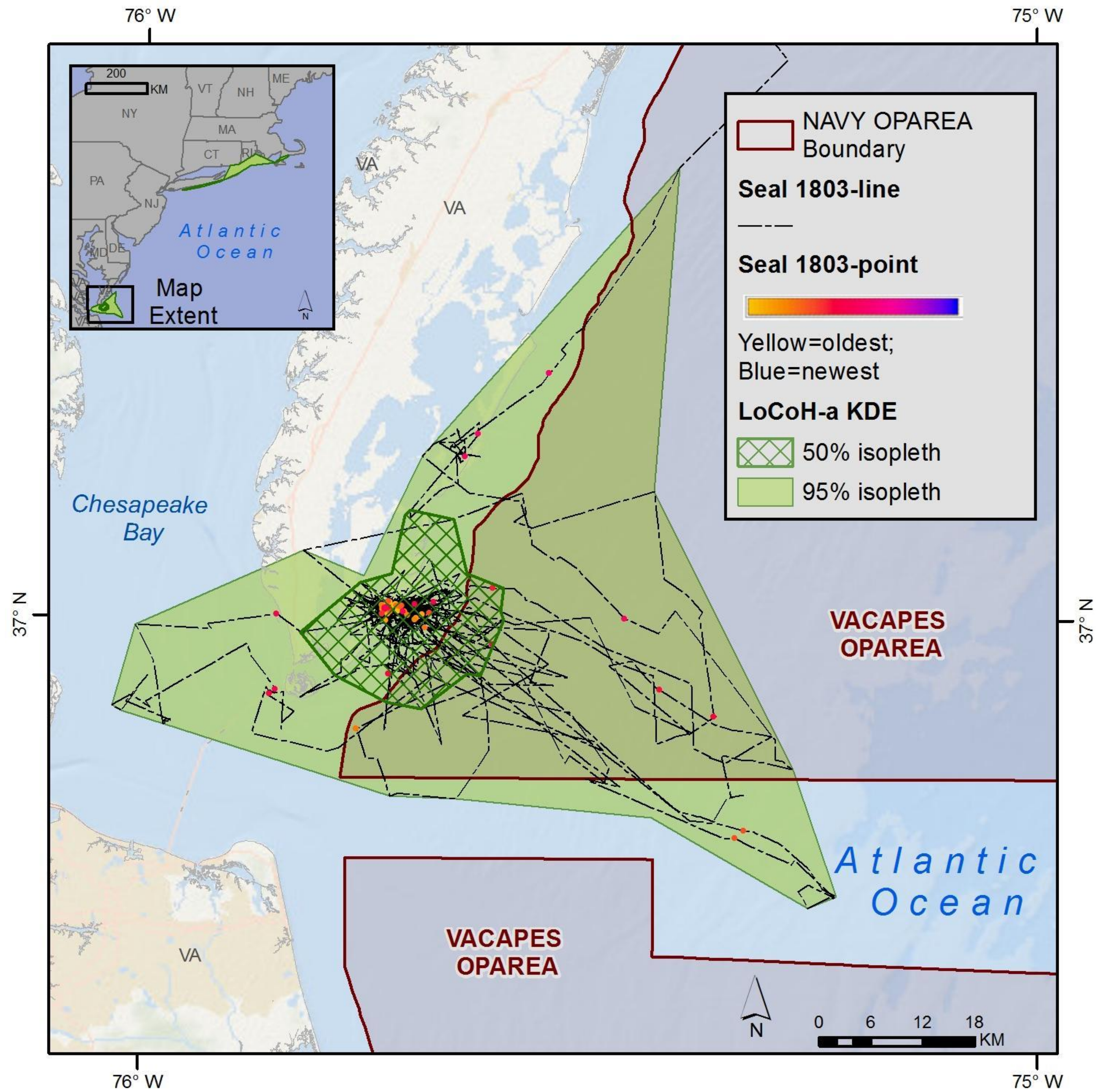

Figure B-7. **Habitat use map for seal 1803 while in Virginia waters (04 February through 31 March 2018) in relation to the VACAPES operating area. Green areas represent the 95 percent isopleth, and crosshatched areas represent the 50% isopleth.**

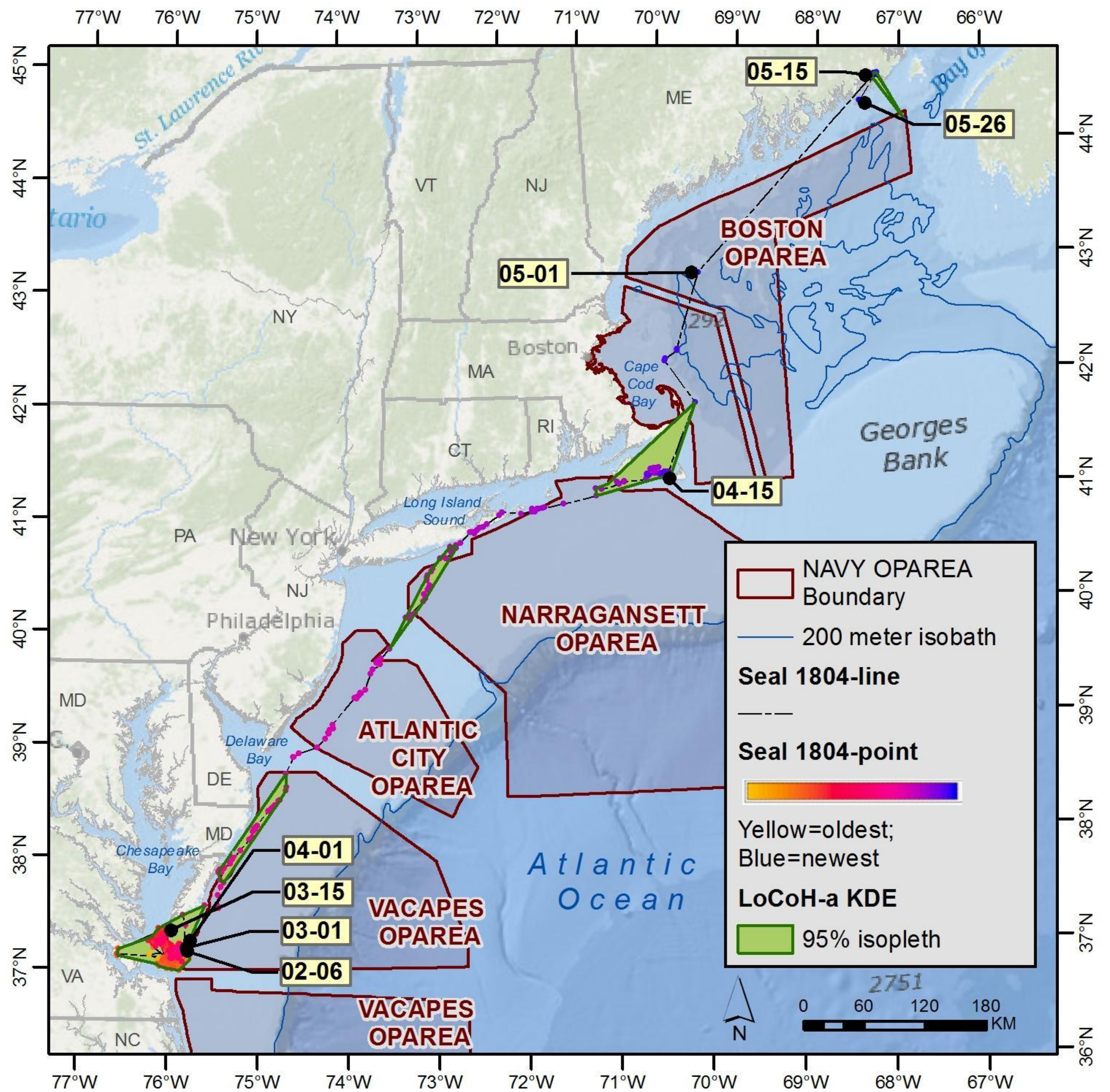

Figure B-8. Habitat use map for seal 1804 (tag duration = 06 February through 26 May 2018) in relation to Navy operating areas along the Eastern Seaboard. Green areas represent the 95 percent isopleth.

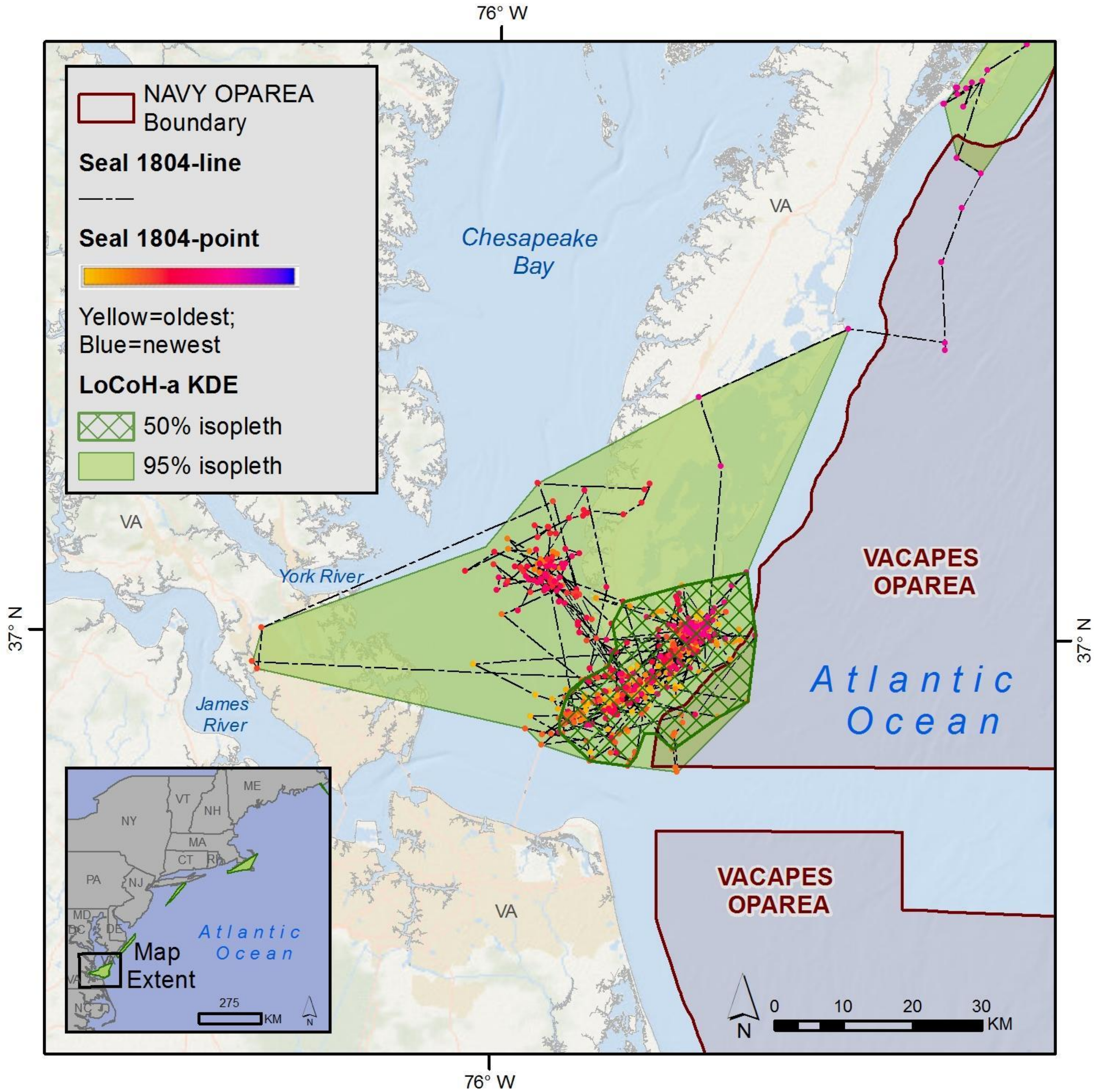

Figure B-9. **Habitat use map for seal 1804 while in Virginia waters (06 February through 04 April 2018) in relation to the VACAPES operating area. Green areas represent the 95 percent isopleth, and crosshatched areas represent the 50% isopleth.**

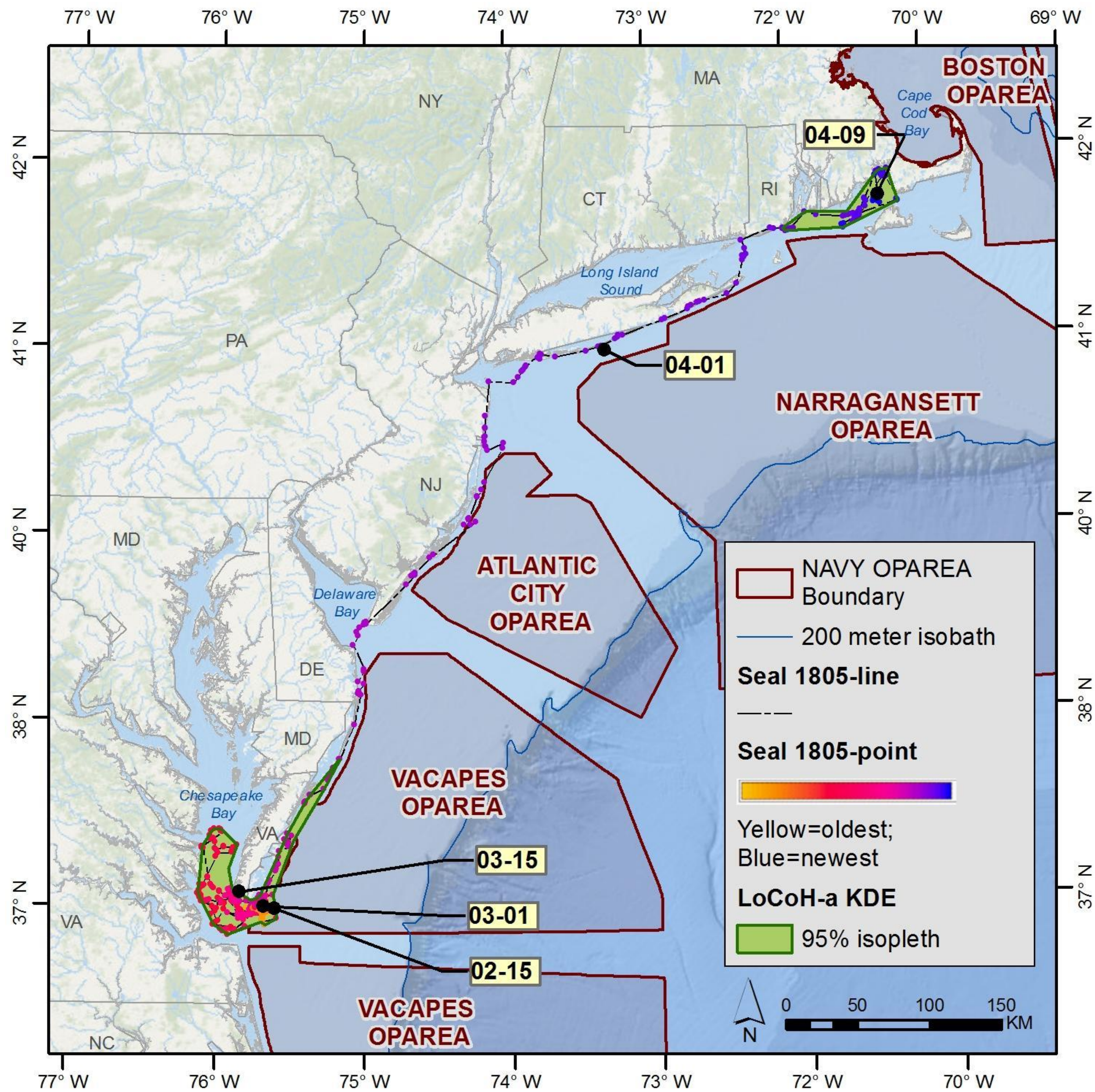

Figure B-10. Habitat use map for seal 1805 (tag duration = 07 February through 09 April 2018) in relation to Navy operating areas along the Eastern Seaboard. Green areas represent the 95 percent isopleth.

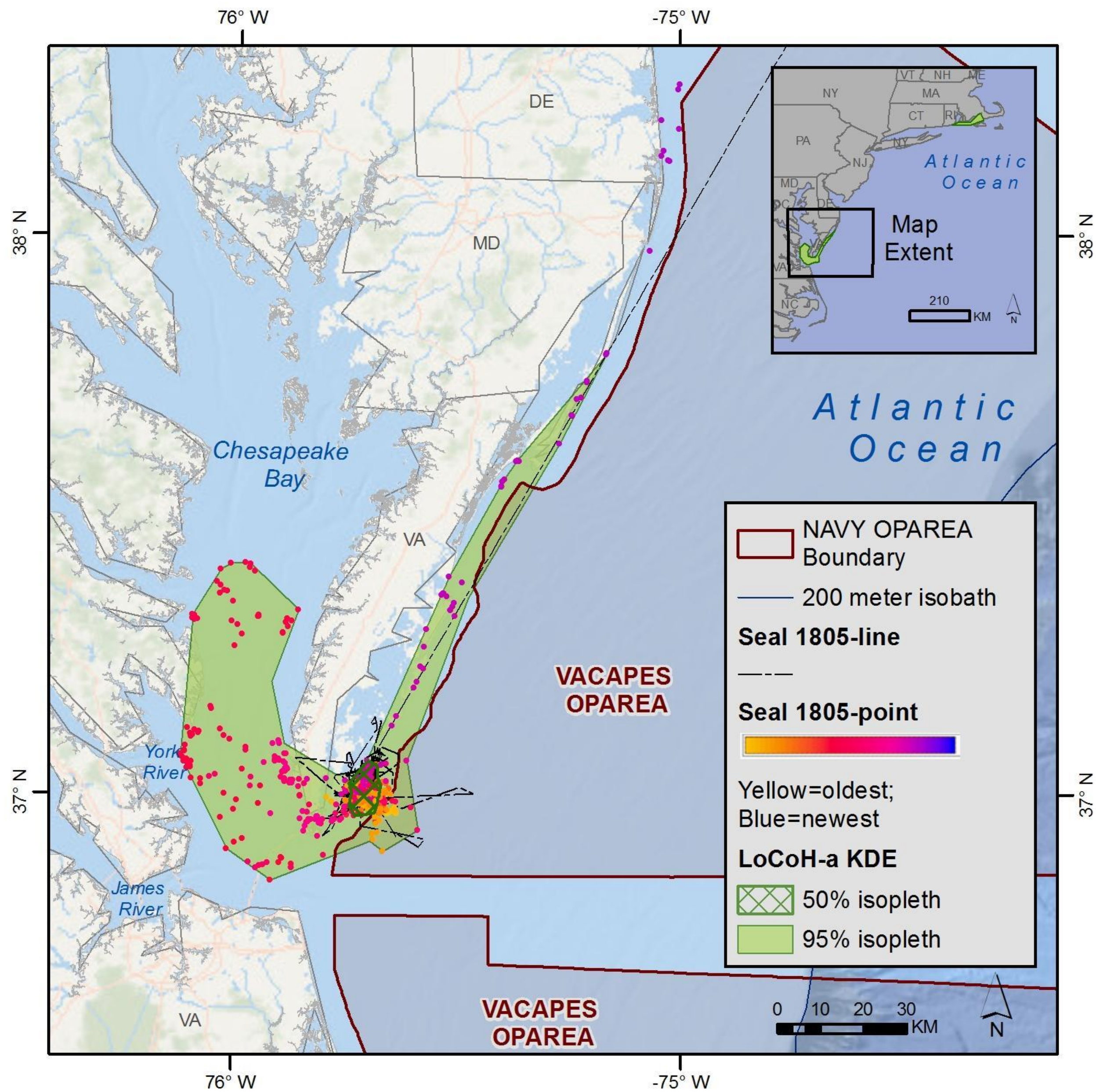

Figure B-11. Habitat use map for seal 1805 while in Virginia waters (07 February through 29 March 2018) in relation to the VACAPES operating area. Green areas represent the 95 percent isopleth, and crosshatched areas represent the 50% isopleth.

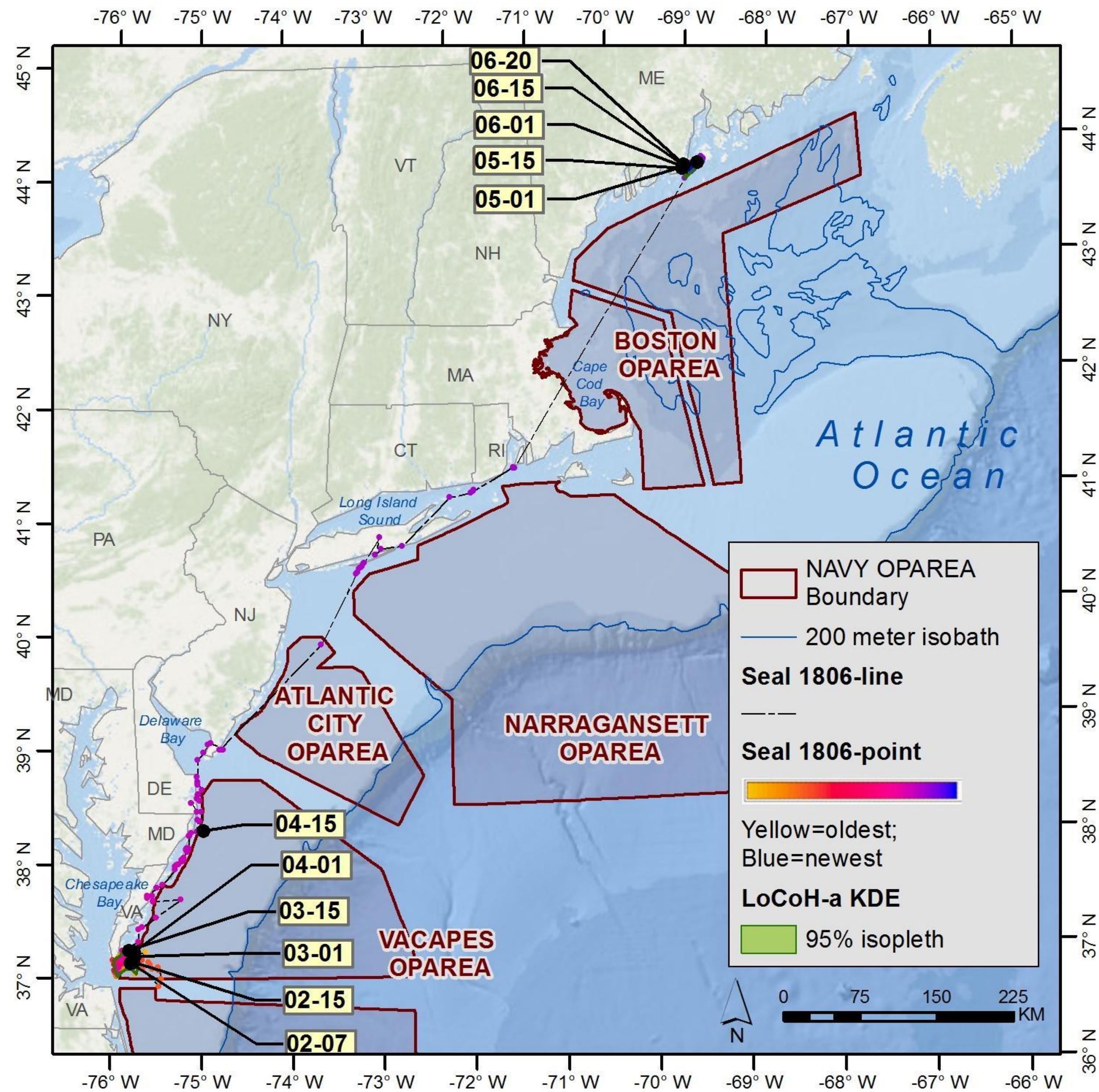

Figure B-12. Habitat use map for seal 1806 (tag duration = 08 February through 22 June 2018) in relation to Navy operating areas along the Eastern Seaboard. Green areas represent the 95 percent isopleth.

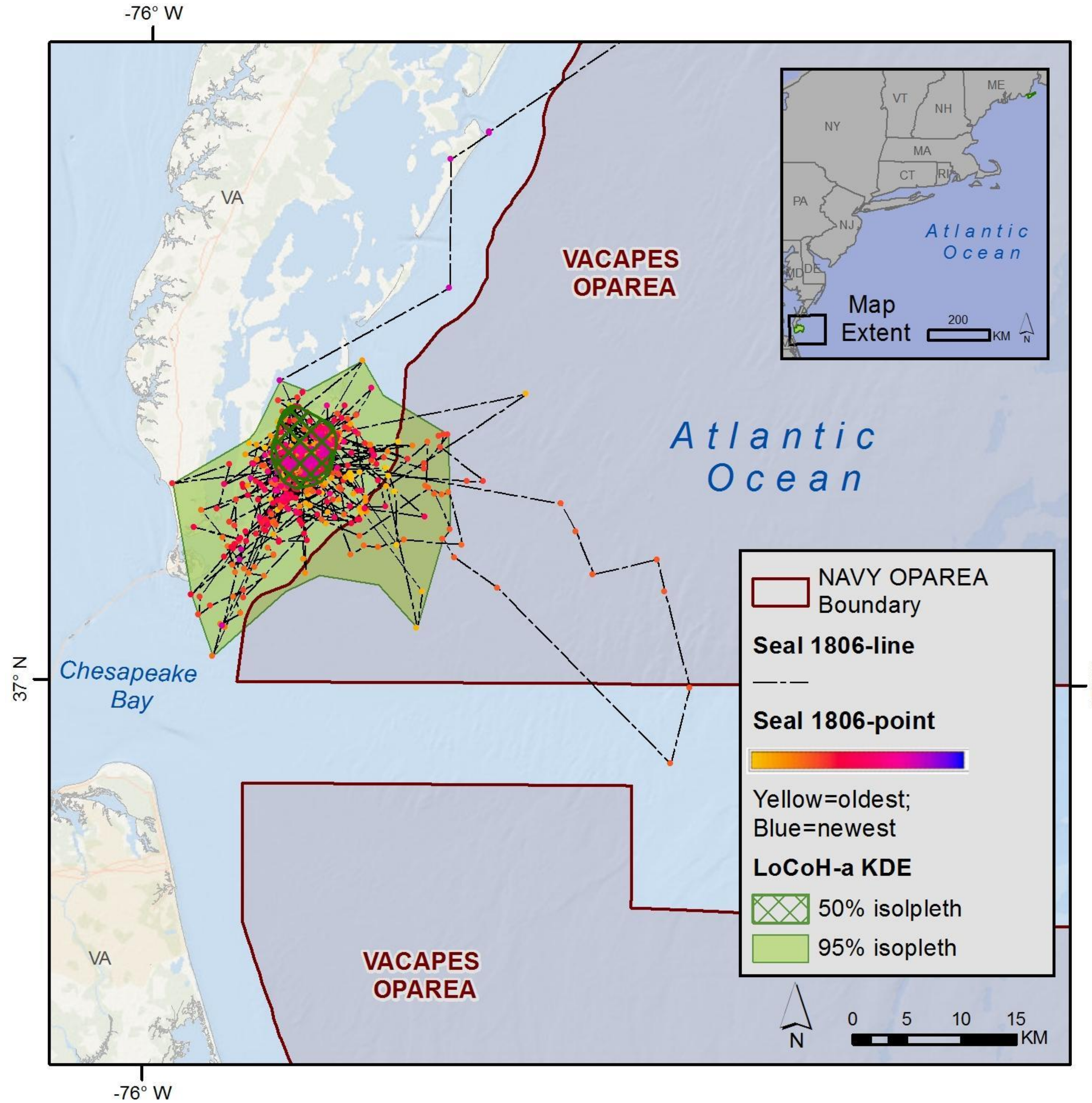

Figure B-13. **Habitat use map for seal 1806 while in Virginia waters (08 February through 14 April 2018) in relation to the VACAPES operating area. Green areas represent the 95 percent isopleth, and crosshatched areas represent the 50% isopleth.**

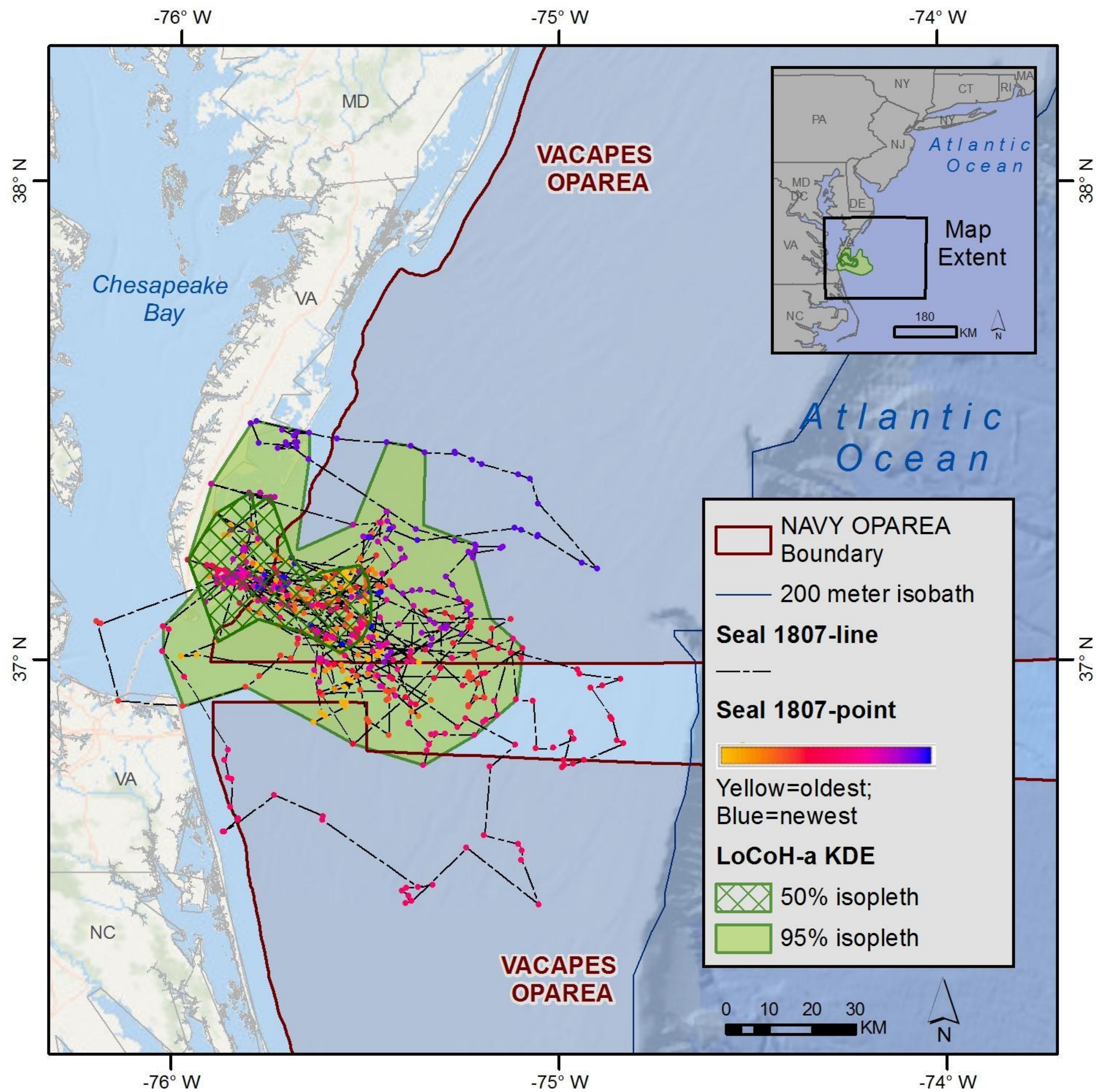

Figure B-14. Habitat use map for seal 1807 (tag duration = 09 February through 26 April 2018) in relation to the VACAPES operating area. Green areas represent the 95 percent isopleth, and crosshatched areas represent the 50% isopleth.

C

Example Data Sheets

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NAVFAC ATLANTIC PINNIPED TAGGING 2018: Animal Information Datasheet

ANIMAL INFORMATION

Field #: NAVFAC2018___ ___ Date: ____________ Species: □ Harbor □ Grey Seal

GPS Coordinates (where tagged): ________________°N, __________________°W

Team Lead:_____________ Data Recorder:__________ Restrainers:____________

MORPHOMETRICS

Weight with Net (Kg):_________ Net Weight:_________ Animal Weight:_________

Straight Length (cm):__________ Axillary Girth (cm):__________

TAGGING & SAMPLING

PRIORITY 1A: Sat Tag

Tagger:_____________

PTT:________________-

Time start mixing:_____

Time warm:__________

Time Hard:___________

☐ Tape removed

PRIORITY 1B: Flipper Tag

Tagger:______________

VEMCO ID:____________-

Flipper Tag ID:_______

Flipper Tag Color:______

☐ Left biopsy collected

☐ Magnet removed

PRIORITY 2: Bloods

Sampler:_____________

Bleed Site:

☐ Ex. intravertabral

☐ Hind flipper

#Sticks: (1-3):_________

☐ Small Red/Black

☐ Purple top

☐ Red top

☐ Large Red/Black top

☐ Large Red/Black top

☐ Large Red/Black top

PRIORITY 3A: Swabs

Sampler:_____________

☐ Nasal L—VTM

☐ Nasal R—DRY

☐ Conjuctiva L-VTM

☐ Conjuctiva R-DRY

☐ Rectal VTM

☐ Rectal Dry

PRIORITY 3B: Other

Sampler:_____________

☐ Blubber sample

☐ Hair

☐ Whisker

HOLDING TIMES

Time Net Set:____________________

Time Out of Net:__________________

Time Sampling Start:______________

Time Lidocaine admin :____________

Target Release Time (45min):________

Release Time (actual):______________

Actual Release Time:______________

PHOTOS

☐ Left Head- ☐ Right Head

☐ Sat Tag Num ☐ Sat Tag on Seal

☐ Flipper Tag ☐ Vemco Tag

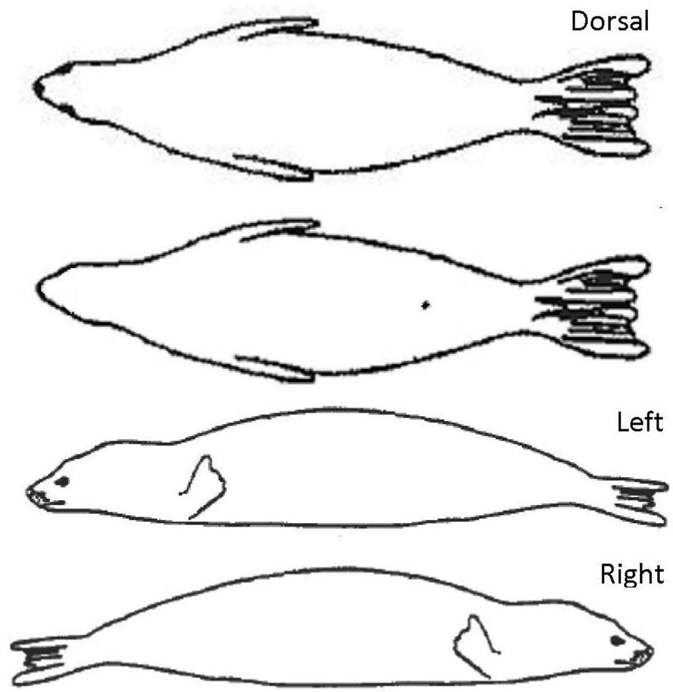
NOTES:______________________________

Date Data Entered:_________________ **Entered By:**_____________________ **Updated: 1/27/2018**

NAVFAC ATLANTIC PINNIPED TAGGING 2018: Health Assessment Datasheet

Field # NAVFAC2018 __ __ Date:________________ Species: □ Harbor □ Grey Seal

Respiratory Rate:	**Heart Rate**:
Initial Time: ____________ RR: ____breaths/min	*Initial* Time: ___________ HR: ________bpm
Pre-Release Time: ____________ RR: ____breaths/min	*Pre-Release* Time: ___________ HR: ________bpm



Respiration:________________________
____
____

Open mouth breathing: ______________
____

Wheezing: __________________________
____

Posture: □Banana Shape □Laying Flat
□Other:______________________________

Attitude:
□Alert □Lethargic □Non-responsive

Body Condition:
□Emaciated □Thin □Normal/Robust

Free of eye/ear exudate: □yes □no **Shivering:** □yes □no **Presence of Wounds:** □yes □no

Notes:

____
____
____
____
____

Date Data Entered:__________ Entered By:______________ Updated: 1/27/2018

Date:______________________________ Page ____ of _____

NAVFAC ATLANTIC PINNIPED TAGGING 2018: Net Set Datasheet

Set #	Set Time	Haul Out Site	WP	Seals 0 =No 1= Yes	# Seals Fushed	# Seals Caught	Time Seals Caught	# Escape/ Released	# Sampled	SI/Mort. 0 = No 1 = Yes	Notes / Photo numbers

COMMENTS:____

Date Data Entered:_________ Entered By:_____________ Updated: 2/2/2018

Date:______________________________ Page ____ of _____

NAVFAC ATLANTIC PINNIPED TAGGING 2018: Net Set Datasheet

Set #	Set Time	Haul Out Sit	WP	Seals 0 =No 1= Yes	# Seals Fushed	# Seals Caught	Time Seals Caught	# Escape/ Released	# Sampled	SI/Mort. 0 = No 1 = Yes	Notes / Photo numbers

COMMENTS:____

Date Data Entered:_________ Entered By:_____________ Updated: 2/2/2018