Final Report

Seal Tagging and Tracking in Virginia: 2019-2020

Submitted to:

Naval Facilities Engineering Command, Atlantic under Contract No. N62470-15-8006, Task Order 19F4147 issued to HDR, Inc.

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Virginia Beach, VA

February 2021

Suggested Citation:

Ampela, K., J. Bort, M. DeAngelis, R. DiGiovanni, Jr., A. DiMatteo, and D. Rees. 2021*. Seal Tagging and Tracking in Virginia: 2019-2020*. Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command Atlantic, Norfolk, Virginia, under Contract No. N62470-15-8006, Task Order 19F4147, issued to HDR, Inc., Virginia Beach, Virginia. February 2021.

Cover Photo Credits:

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 General Authorization #19826-03

Bottom photo: Post-tagging release of a juvenile female harbor seal instrumented with a depth-sensing SPLASH tag at the Eastern Shore of Virginia in in February 2020. Photograph taken by D. Rees, Naval Facilities Engineering Command, Atlantic, under National Marine Fisheries Service Scientific Research Permit #21719.

This project is funded by U.S. Fleet Forces Command and managed by Naval Facilities Engineering Command, Atlantic as part of the U.S. Navy's Marine Species Monitoring Program.

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Acronyms and Abbreviations

a-LoCoH	adaptive local convex hull
ARGOS	Advanced Research and Global Observation Satellite
°C	degrees Celsius
CBBT	Chesapeake Bay Bridge and Tunnel
CBC	Complete Blood Count
cm	centimeter(s)
COLREGS	collision regulation(s)
DMSO	dimethyl sulfoxide
GIS	geographic information system
GPS	Global Positioning System
km	kilometer(s)
km^2	square kilometer(s)
LoCoH	local convex hull
m	meter(s)
NaHep	sodium heparin
Navy	U.S. Navy
NEFSC	Northeast Fisheries Science Center
NOAA	National Oceanic and Atmospheric Administration
Obs	observation(s)
OPAREA	Operating Area
%	percent
PBM	peripheral blood mononuclear cell(s)
PDV	phocine distemper virus
PTT	platform transmitter terminal
SD	standard deviation
SEFSC	Southeast Fisheries Science Center
SPOT	satellite-tracked position-only
TAD	time-at-depth
U.S.	United States
VACAPES	Virginia Capes Range Complex
VTM	viral transport medium
YOY	Young of the year

1. Introduction

Following the enactment of the Marine Mammal Protection Act in the United States (U.S.) in 1972, and as amended (16 United States Code § 1361 14 et seq.), both harbor seal *(Phoca vitulina)* and gray seal *(Halichoerus grypus)* populations rebounded in the northwest Atlantic Ocean (Wood et al. 2011). Both species are year-round coastal inhabitants in eastern Canada and New England, and occur seasonally in the mid-Atlantic U.S. between September and May (Hayes et al. 2020). Individuals of both species move to northern areas for mating and pupping in the spring and summer, and return to 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 are occasionally observed there as well (Ampela et al. 2019; Jones and Rees 2020). Harbor seals' range in the Northwest Atlantic now extends as far south as North Carolina, but this range expansion is not necessarily indicative of an increasing population trend (Hayes et al. 2020).

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 comprise 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. Since 2013, the U.S. Navy has conducted regional harbor seal studies in order to assess the potential impacts on these animals from Navy activities, mitigate potentially harmful interactions, and obtain appropriate authorizations to maintain environmental compliance.

1.1 Project Background

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 (Jones and Rees 2020). Results from these surveys indicate that seals arrive in the area annually each fall and depart in the spring. However, our understanding of seal movements, habitat use, haul-out patterns, and dive behavior, both in Virginia waters and along the Eastern Seaboard, is still very limited. In order to assess potential impacts to seals from Navy activities, mitigate potentially harmful interactions, and obtain appropriate authorizations to maintain environmental compliance, it is important to better understand seal distribution and behavior in these areas.

Since 2017, the Navy has undertaken telemetry (tagging) studies in order to characterize seals' at-sea movements, habitat use, dive behavior, and the environmental variables that may influence their distribution and haul-out patterns. Location-only and depth-sensing tags, which track seals' movements via satellite transmission, were deployed on seven harbor seals in 2018 and two in 2020 (no tags have been deployed to date on gray seals as part of this study). Although tagging was attempted in 2019, no tags were successfully deployed. Detailed results from the 2018 tagging efforts are presented in Ampela et al. (2019). In this report we present key results from the 2018 tagging study, detailed methods and results from the 2020 tagging study, and cumulative analyses of the 2018 and 2020 tag data.

1.2 Key Results from 2018 Tag Deployments

In February 2018, seven harbor seals were captured and instrumented with satellite-tracked tags. Of these, six were satellite-tracked position-only (SPOT) tags and one was a depth-sensing SPLASH tag (Wildlife Computers, Redmond, Washington). SPOT tags recorded information about the animal's horizontal movements, amount of time hauled out, and ambient temperature. SPLASH tags recorded information about dive depth and duration in addition to the data collected by the SPOT tags. Five of the seven seals were also instrumented with VEMCO tags, which signaled the seals' locations via acoustic pings detected on an existing receiver array. Summary information for tagged seals is shown in **Table 1**.

Table 1. Summary of seals tagged in 2018

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‡

*****One depth-sensing SPLASH tag was deployed on seal 1802. All other seals were instrumented with location-only 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 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.

The mean number of tracking days for satellite tags deployed in 2018 was 103 (standard deviation (SD) ± 29.65 days; range 61–143 days). All seals spent at least 60 days in Virginia waters. Seal 1807's platform transmitter terminal (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 coastal Massachusetts (1801 and 1805) before their tags stopped transmitting data.

While tagged seals were in Virginia waters, satellite tag data showed that haul-out sites on the Eastern Shore and Chesapeake Bay Bridge Tunnel (CBBT) Islands most likely functioned as a central resting location between foraging trips, and seals traveled to the Chesapeake Bay or to offshore waters east of the Bay from these sites. There were relatively few VEMCO detections, despite the extensive receiver array in Chesapeake Bay and coastal Virginia, and detections that were recorded occurred close (within ~30 km) to the capture site, mainly around the CBBT islands. An adaptive local convex hull (a-LoCoH) habitat-use analysis using satellite tag data showed that the areas of highest habitat use for tagged seals fell outside of the Navy's VACAPES OPAREA.

1.3 2020 Study Objectives

The 2018 tagging work demonstrated that it is feasible to capture and tag healthy, wild harbor seals on the Eastern Shore of Virginia. All 2018 tags reported animal locations via the Advanced Research and Global Observation Satellite (Argos) satellite network, which has a location accuracy of up to 250 m (ARGOSWEB 2017). In order to allow for more robust conclusions about habitat use in and near Navy training areas, all tags deployed in 2020 were equipped with Fastloc® technology, which provide improved location accuracy of up to 20 m. Data from these tags builds on the data collected in 2018, with the goal of increasing our understanding of harbor seals' residency time in Virginia waters, their local habitat utilization patterns, dive behavior, haul-out behavior, and seasonal movement patterns. The information gathered from this effort will provide valuable baseline data needed to assess potential impacts to seals from Navy activities in Virginia waters and along the Eastern Seaboard.

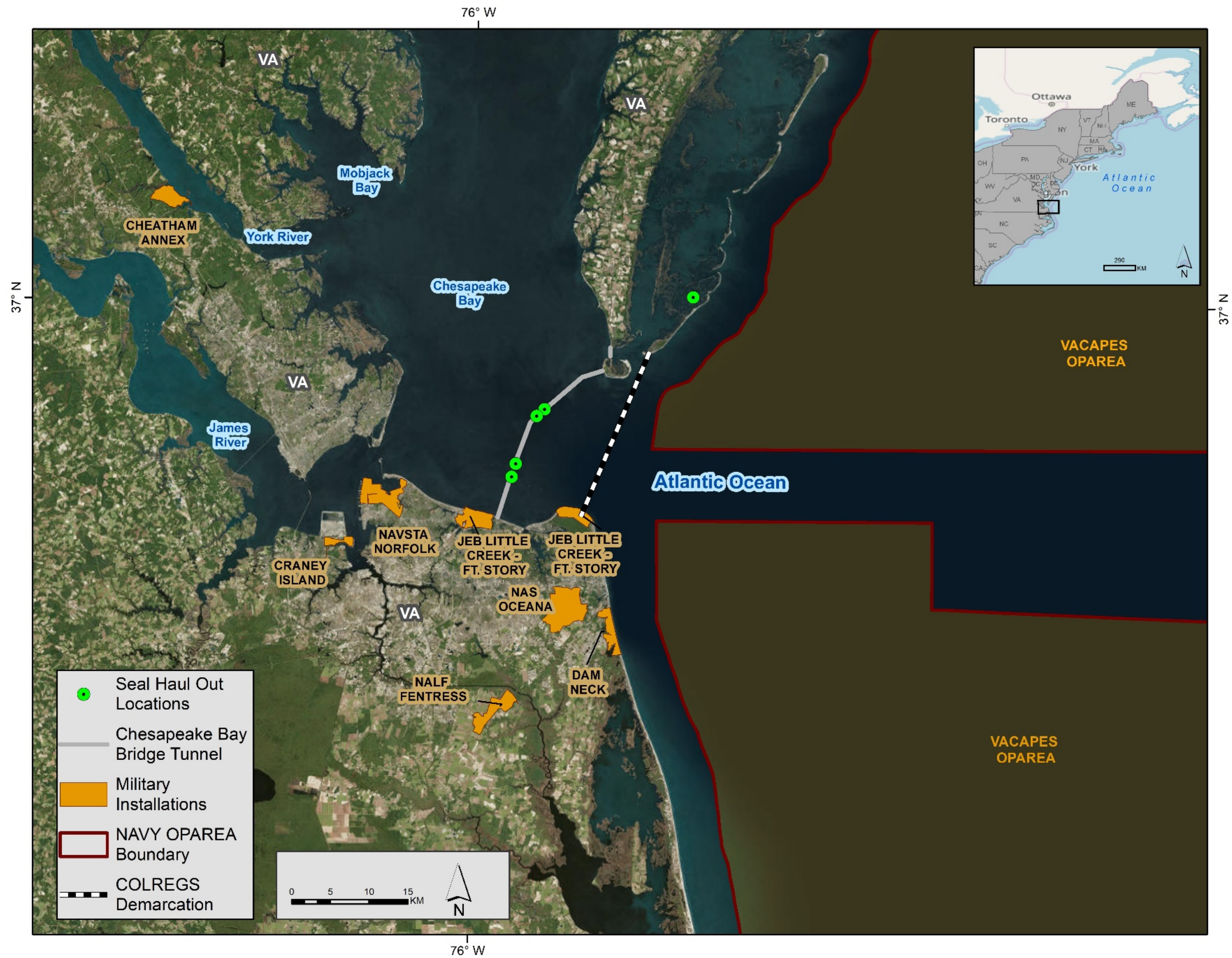

Figure 1. Chesapeake Bay and coastal Virginia waters, including known seal haul-out sites, and the Virginia Capes Range Complex (VACAPES). COLREGS = collision regulations; OPAREA = Operating Area.

2. Methods

2.1 Field Methods

2.1.1 Captures

The capture site was located on the Eastern Shore of Virginia, where harbor seals are regularly observed hauling out between fall and spring. The Eastern Shore haul-out area has several discrete haul-out sites (up to five different locations) clustered within a <1 km^2 area where seals have been observed (Jones and Rees 2020). Seals were captured using a modified seine net deployed in-water adjacent to a haul-out site, following methods outlined in Ampela et al. (2019) (**Figure 2**). The net was promptly brought onto land following deployment, and any seals caught were safely removed from the net. The health assessment team confirmed that a seal was a candidate for tagging[1] before any other actions were taken. Once determined the seal was a candidate, it was then removed from the seine net and placed in a hoop net for holding, prior to its transfer to the restraint board (**Figure 3**) for tagging and biological sampling. A team member was assigned to each seal for monitoring during the holding period.

2.1.2 Tagging

Seals were instrumented with flipper tags and satellite tags. Colored (light blue), flexible, vinyl Allflex™ livestock ear tags were attached to the seal's left hind flipper webbing. These flipper tags feature unique identifiers specific to this study and are used for purposes of individual identification if resighted as they potentially stay attached for multiple years. Each seal was also instrumented with a Global Positioning System (GPS)-enabled depth-sensing satellite tag (SPLASH10-F manufactured by Wildlife Computers, Inc., Redmond, Washington). These tags are data-archiving, satellite-transmitting tags designed for tracking fine-scale horizontal movements as well as vertical (dive) movements. 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 ARGOS network when the tag antenna is above the water surface (**Figure 4**). These tags were designed to fall off during the annual molt in July, following the May-June breeding season.

[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 B**).

Figure 2. Monitoring the deployed net (indicated by red arrows) for seal activity.

Figure 3. Post-tagging release of seal 2001. Photograph by D. Rees, Naval Facilities Engineering Command, Atlantic, taken under National Marine Fisheries Service Permit #21719.

Figure 4. Satellite-tracked depth-sensing (SPLASH) tag (red arrow) and vinyl flipper tag (yellow arrow) affixed to seal 2001. Photograph by D. Rees, Naval Facilities Engineering Command, Atlantic, taken under National Marine Fisheries Service Permit #21719.

2.1.3 Biological Sampling

A series of biological samples was collected from each tagged seal (**Table 2**). Information recorded during the capture and sampling events included 1) time the net was set; 2) time seal was removed from net; 3) time biological sampling began, and 4) time the animal was released. All capture and sampling activities were conducted in accordance with the National Marine Fisheries Service Scientific Research Permit #21719.

Table 2. Biological sample type, purpose, and receiving laboratory.

Sample Type	Sample Purpose	Requesting Researcher	Storage Medium
Swab - Rectal	Virology - PDV	NOAA NMFS	Frozen -80
Serum	Virology - AI	NOAA NMFS	Frozen -80
Whole Blood	Virology - PDV	NOAA NMFS	Frozen -80
Fur	Stable Isotope	Louisiana State University	Room Temp
Whisker	Stable Isotope	Louisiana State University	Room Temp
Whole Blood	Stable Isotope	Louisiana State University	Frozen -80
Blubber	Diet Analysis	NOAA NEFSC	Frozen -20
Skin	Genetics	University of Maine	Room Temp
Swab - Nasal	Virology - AI	Tufts University	VTM, Frozen -80
Swab - Conjunctival	Virology - AI	Tufts University	VTM, Frozen -80
Swab - Rectal	Virology - AI	Tufts University	VTM, Frozen -80
Serum	Virology - AI	Tufts University	Frozen -80

Sample Type	Sample Purpose	Requesting Researcher	Storage Medium
Whole Blood	Contaminants	University of Connecticut	Room Temp
Serum	Cytokine Analysis	University of Connecticut	Frozen -80
Whole Blood	CBC	IDEXX	IDEXX
Serum	Chemistry	IDEXX	IDEXX
Whole Blood	Archive	VAQS	Frozen -80
Serum	Archive	VAQS	Frozen -80
Skin	Genetics	NOAA SEFSC	DMSO

KEY: CBC=Complete Blood Count; DMSO = dimethyl sulfoxide; NEFSC = Northeast Fisheries Science Center; NMFS = National Marine Fisheries Service; NOAA = National Oceanic and Atmospheric Administration; PBM = peripheral blood mononuclear cell; PDV = phocine distemper virus; SEFSC = Southeast Fisheries Science Center; VTM = viral transport medium.

2.2 Data Analysis Methods

2.2.1 Satellite Tag Data Processing

Data returned from the PTTs associated with each satellite (SPLASH) tag included information about the animals' haul-out and dive behavior, short- and long-distance horizontal movements (with location accuracies of up to 20 m), and recorded temperature. SPLASH tags were Fastloc® enabled, meaning that the tags acquired positions every few minutes using GPS. In comparison, Argos-only tags, such as those deployed during the 2018 study, record a maximum of several dozen locations per day. The Fastloc® feature allowed fine-scale movement tracking and more precise identification of haul-out locations. 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 seals' dive behavior, areas of relative habitat use, and to create maps of their transits and haul-out locations. SPLASH tags recorded time in GMT, which was converted to EST/EDT by subtracting 4 or 5 hours, as appropriate.

2.2.2 Dive-depth Data and In-water Temperatures

Depth and temperature thresholds for both SPLASH tags deployed in 2020 were explored using time-series plots and summary statistics of depth and temperature data. Because the relationship between harbor seal in-water behavior and water temperature at depth was of primary interest in this study, temperature data analysis was restricted to in-water values and haul-out (i.e., in-air) temperatures were not included in the analysis. In order to ensure that temperature thresholds were representative of in-water activity only, the percent of time (per hour) a seal spent dry was cross-checked with temperature data recorded by the tags, which was grouped into 4-hour time bins. A given hour was identified as "dry" if the seal was dry more than 50% of that hour. If at least one of the hours within a 4-hour temperature bin was considered "dry", then that observation was removed. The resulting in-water temperature thresholds were ground-truthed via comparison with maximum in-water temperatures recorded by regional National Oceanic and Atmospheric Administration (NOAA) data buoys. Depth and temperature information from the 2020 SPLASH tags was also compared to the single SPLASH tag deployed in 2018.

2.2.3 Haul-out Patterns

TEMPORAL HAUL-OUT PATTERNS (ALL REGIONS)

Probability density plots of time seals spent hauled out (dry) were generated for both SPLASH tags deployed in 2020 using wet/dry sensor data, in order to investigate patterns in haul-out behavior throughout the deployment periods of each tag. Additionally, pooled probability density plots were generated for all 2018 and 2020 tags to investigate haul-out patterns of seals tagged in both years.

HAUL-OUT PATTERNS WITH RESPECT TO ENVIRONMENTAL FACTORS (VIRGINIA WATERS ONLY)

In order to identify ideal environmental conditions for future capture efforts in the region, haul-out patterns of all nine tagged seals from 2018 and 2020 were also investigated (cumulatively) with respect to tidal cycle, time of day, wind speed, water temperature, and air temperature. Environmental data gathered from NOAA data buoy station CHBV2 (37.032 N 76.083 W) approximately 20 kilometers (km) southwest of the Eastern Shore haul-out site, were used in the analysis. This station was chosen because it best represented conditions at the capture site. Because this station does not record air temperature, those data were instead obtained from the NOAA Climatological Data Station WBAN:03739 in Cape Charles, Virginia, located approximately 14 km north of the capture site. Seal locations were plotted in a geographic information system (GIS) for the region of interest (bounded to the south by the mouth of the Chesapeake Bay, and to the north by Delaware Bay [Cape Henlopen]), and this subsample of locations was then used to define the temporal window for the environmental analysis. All tags deployed in 2018 and 2020 were equipped with wet/dry switches, which reported the percentage of time the seal spent dry (i.e., hauled out) per hour. A haul-out event was defined as a one-hour block of time where the seal was dry 100% of that hour. Haul-out behavior was quantified both in terms of the number of haul-out events, and the total amount of time spent hauled out.

COMPARISON OF SATELLITE TAG DATA AND TRAIL CAMERA IMAGERY (VIRGINIA WATERS ONLY)

As part of a separate but related effort, weatherproof trail cameras were installed in November 2019 at multiple haul-out sites at the Little Inlet area of the Eastern Shore (**Figure 5**), with the goal of using imagery to characterize the haul-out patterns of harbor seals in this area. The trail cameras were programmed to record 20-megapixel photos automatically every 15 minutes daily between 06:00 and 18:00, during the seasonal period that seals are present in the area (November through April). All cameras were installed to provide maximum coverage of the known haul-out sites in the Little Inlet area (**Figure 5**). Position and wet/dry (haul-out) data from tagged seals was compared to camera images in order to assess the efficacy of the cameras in terms of temporal and spatial coverage. Time-stamped image files were cross-referenced with known haul-out events for seals 2001 and 2002 at Little Inlet. A haul-out event was defined as a one-hour block of time where the seal was dry 100% of that hour. High-quality locations of tagged seals (GPS and Argos Location Class 3 locations only) were plotted in a GIS to determine which haul-out events occurred at Little Inlet. All images collected by the trail cameras during the time window that tagged seals were known to be in the area (26 February through 31 March 2020) were reviewed for image quality, and the number of seals in the image was recorded for each haul-out site. If a tagged seal was observed in the image, this was noted as well. Only haul-out events that occurred during daylight hours were included in the analysis.

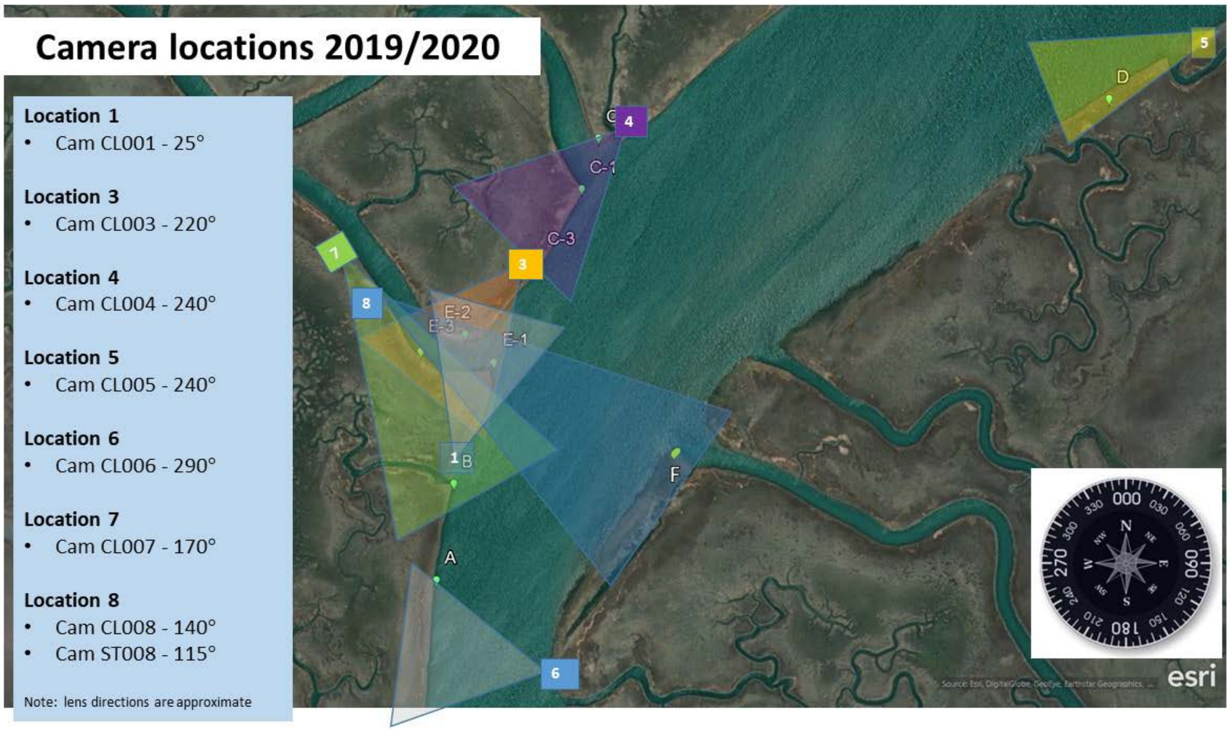

Figure 5. Placement of trail cameras at the Eastern Shore seal haul-out area. Letters A-F indicate specific haul-out sites.

2.2.4 Location Data

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 3**). GPS locations for tags with GPS transmitters (n=2) were retained. All post-filter locations were loaded into an ArcGIS™ Pro 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. In order to limit the analysis to seals' in-water activity, 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 zero meters (i.e., on land) were removed from the data.

Table 3. 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

Parameter	Value
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	0

2.2.5 Habitat-use Analysis

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). Analysis was performed using the R package rhr (R Core Team 2020; Signer and Balkenhol 2015). The 'a' parameter was selected for each deployment as the maximum distance between subsequent relocations.

Limiting locations to a "best-of-day location" was explored, with the goal of creating more parsimonious habitat utilization polygons in ArcGIS. Using best of day locations proved to have too few locations for many tags to produce informative utilization distributions, as some tags transmitted for fewer than three months, resulting in less than 90 locations to derive habitat utilization polygons for half the eastern seaboard of the U.S. Picking locations at twelve- and six-hour intervals was also explored. This resulted in many time spans without locations for most tags and was ultimately not pursued.

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 (defined as the 50% isopleth), and isopleths for each seal were overlaid to create relative habitat use maps that highlight areas utilized by multiple seals.

In Virginia waters, seal "trips" were defined as being *inshore* (within the Chesapeake Bay) if after leaving the haul-out site, the animal crossed the U.S. collision regulation (COLREGS) lines of demarcation and went into the Bay. 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 10 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).

3. Results

3.1 Summary of Tagged Animals

Two harbor seals were captured[3] and instrumented with satellite-tracked tags in late February/early March 2020. Both of these tags were depth-sensing SPLASH tags with Fastloc® capabilities (i.e., GPS-enabled). Vinyl identification (Allflex™) tags were also attached to the hind flipper webbing of each seal. The satellite tag attached to seal 2001, a juvenile female, stayed on for approximately one month longer than the tag attached to the other seal (2002), a juvenile male. **Table 4** summarizes individual seal and deployment information for both of these tags.

Table 4. Individual seals tagged in 2020 and summary of tag deployments.

Animal ID	Sat Tag PTT #	Length (cm)	Girth (cm)	Weight (kg)	Age (est.) and sex	Tag Start Date	Date Left VA	Tag End Date	Tracking Days	Distance Traveled (km)	Distance Traveled in VA Waters
2001	177411	95	80	26.1	Juv. Female	2/26/20	3/31/20	7/12/20	137	7,572	1,897
2002	177410	130	88	47.0	Juv. Male	3/2/20	3/20/20	6/10/20	99	5,743	1,039

PTT = platform transmitter terminal; cm = centimeters; kg = kilogram(s); est. = estimated; VA = Virginia; km = kilometer(s); km2 = square kilometer(s); % = percent; juv. = juvenile.

3.2 Seal Track Maps

3.2.1 2020 Tags

The two PTTs deployed in 2020 recorded 6,032 raw locations. Seal tracks were created using filtered ARGOS locations with the Douglas Filter (**Figures 6** and **7**). These two GPS-enabled tags recorded 281 locations where seals were classified as "hauled-out", 41 (15%) of which were on the Eastern Shore (**Figure 8**). No haul-out locations were identified on the CBBT Islands, although tagged seals moved between the Islands and the Eastern Shore. The remainder of haul-out locations were recorded in coastal areas and islands in Rhode Island or further north, including Cape Cod Bay and coastal Maine.

Both tags pooled together reported a total of 236 tracking days (defined as the number of days from 24 hours post-deployment to last transmission for each tag) from 27 February through 12 July 2020[4]. Data was transmitted on 235 of 236 tracking days (99% of transmission days). For the entire deployment period of both tags, locations were reported every 12 hours on 99% of tracking days, and every 6 hours on 94% of tracking days. Both seals spent at least 22 days in Virginia waters following tag deployments. Both seals returned regularly to the capture site while in the region, but utilized the coastal environment differently. Seal 2002, a juvenile male, used the offshore environment almost exclusively, whereas seal 2001, a juvenile female, spent time both in the Bay and the offshore environment (**Figures 6** and **7**). Seal 2001 departed Virginia on

[3] A total of 15 harbor seals were captured briefly in the net in 2020; however, all but two were able to escape from the net shortly after capture.
[4] Start and end dates of individual tags fell outside of the "pooled" time frame.

20 March 2020 and seal 2002 on 31 March 2020. Both seals tracked northward along the eastern seaboard and traveled as far north as coastal Maine during the tag reporting periods, stopping at haul-out sites in coastal Rhode Island, Massachusetts, and New Hampshire **(Figure 8)**.

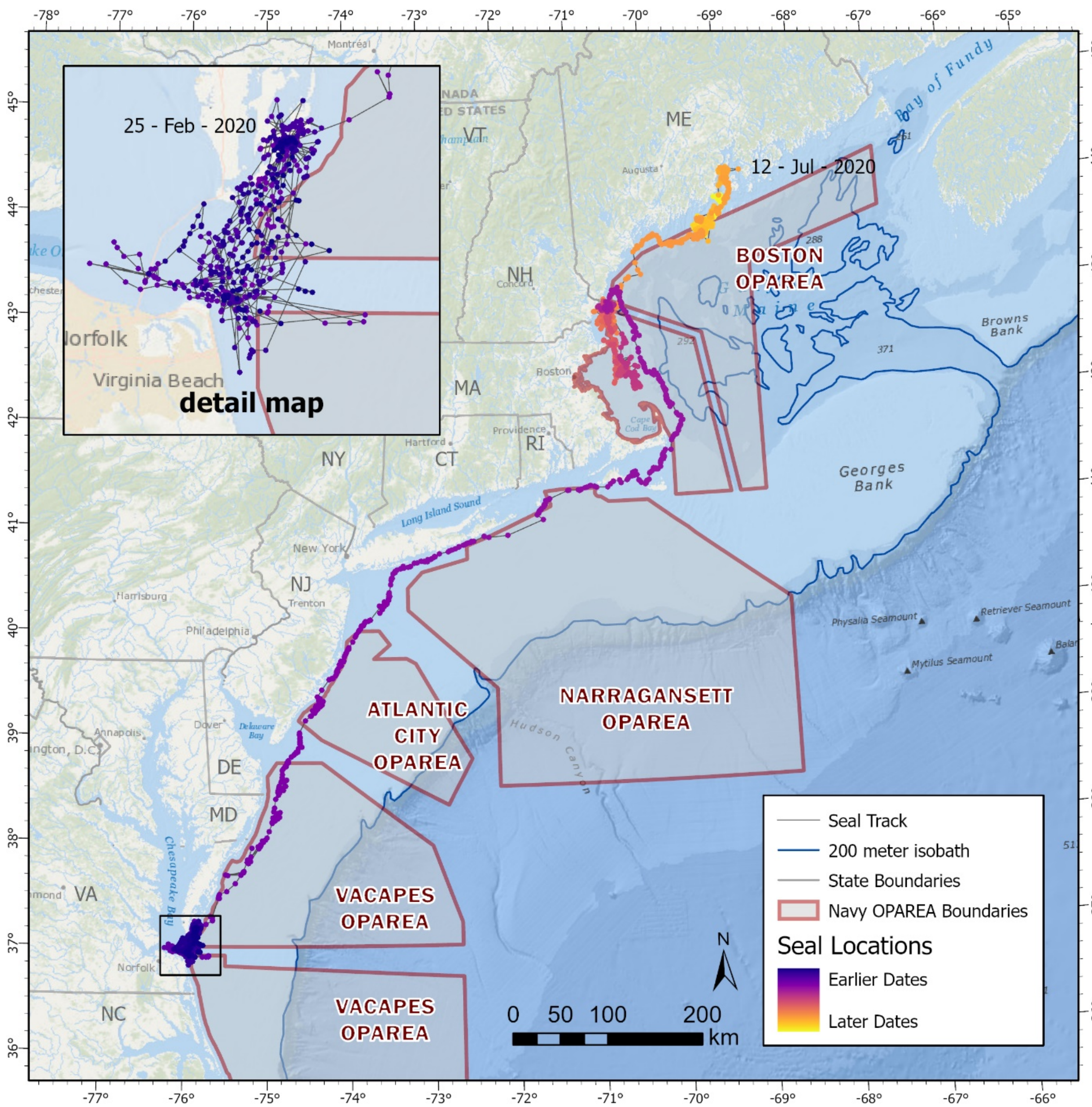

Figure 6. Reconstructed track of seal 2001, a juvenile female harbor seal (tag duration 27 February through 11 July 2020) in relation to Navy operating areas.
OPAREA = Operating Area; VACAPES = Virginia Capes Range Complex.

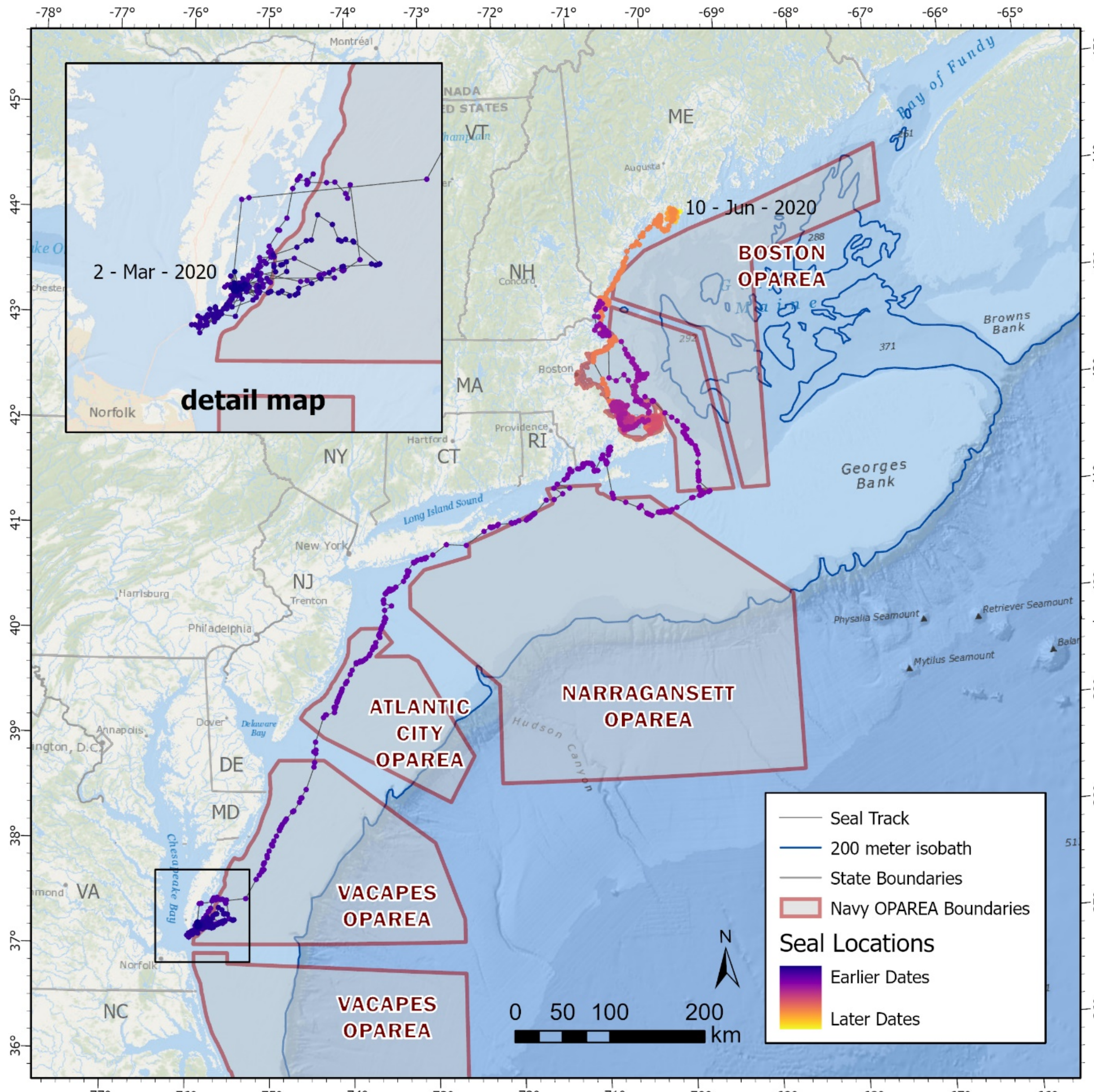

Figure 7. Reconstructed track of seal 2002 (tag duration 3 March through 10 June 2020) in relation to Navy operating areas.
OPAREA = Operating Area; VACAPES = Virginia Capes Range Complex.

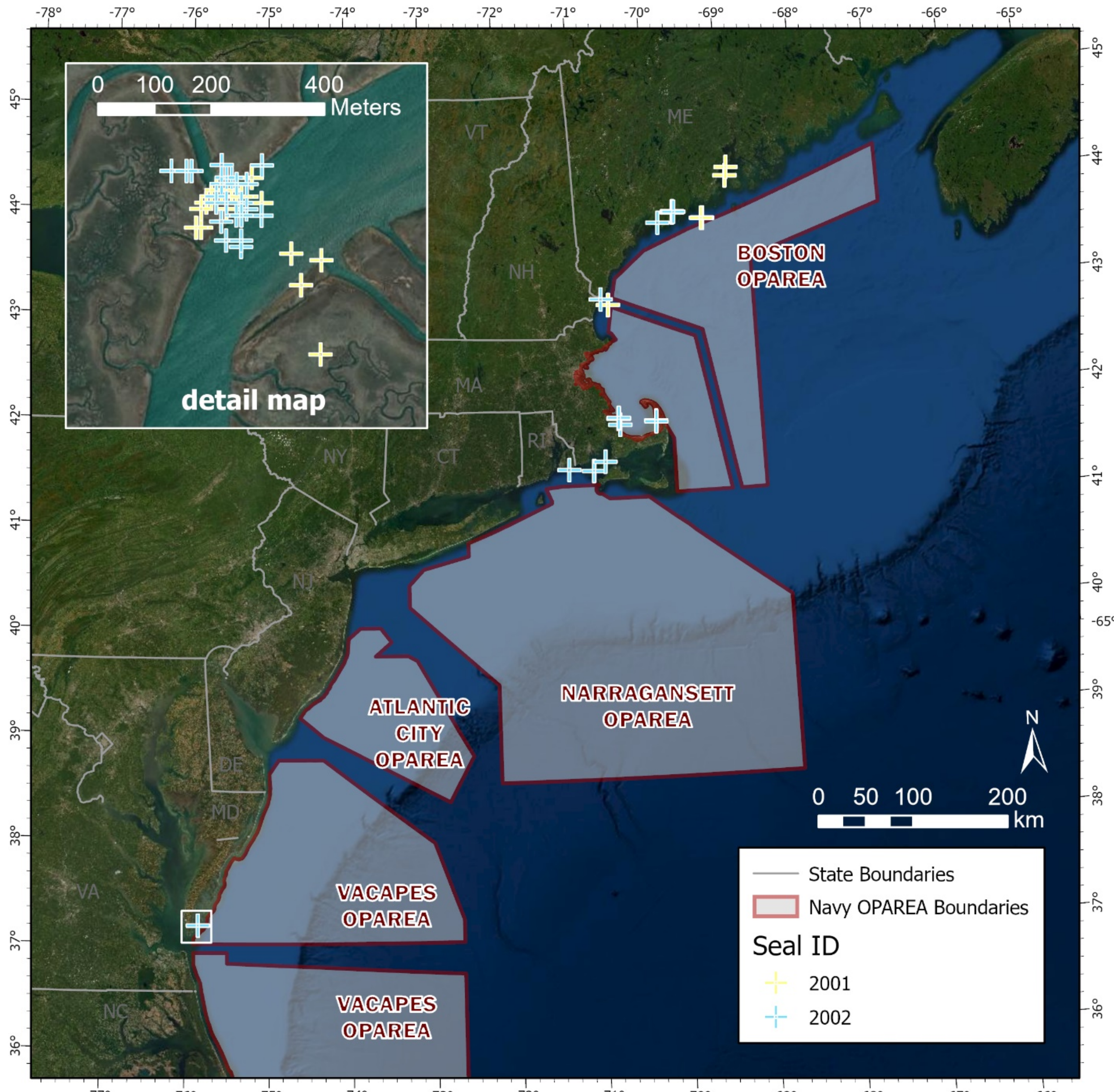

Figure 8. Haul-out locations for the two seals tagged in 2020. Haul-out areas are based on Fastloc® GPS locations classified as "hauled out."
OPAREA = Operating Area; VACAPES = Virginia Capes Range Complex.

3.2.2 2018 and 2020 Tags

All nine PTTs (seven in 2018 and two in 2020) recorded 12,704 Argos/GPS locations. Seal tracks were created using Douglas-filtered Argos locations and, for the two tags deployed in 2020, GPS locations[5] (**Figures 9** and **10**). All nine tags recorded a total of 949 tracking days (defined as the number of days from 24 hours post-deployment to last transmission for each

[5] In 2018, six location-only SPOT tags and one depth-sensing SPLASH tag were deployed; in 2020, two GPS-enabled depth-sensing SPLASH tags were deployed. [6] Tagging efforts originally planned for early 2021 were postponed due to concerns about COVID-19.

tag) between 4 February 2018 and 12 July 2020 (no tags were deployed in 2019). Data was transmitted on 93% of tracking days. The mean number of tracking days was 105 (SD±28.3 days; range 61–204 days). All nine seals were captured at the same Eastern Shore location, and six of these animals traveled as far north as coastal Maine during their respective tag deployment periods. One tag stopped transmitting data while the animal was still in Virginia waters. Two seals only traveled as far north as southern New England before their tags stopped transmitting data.

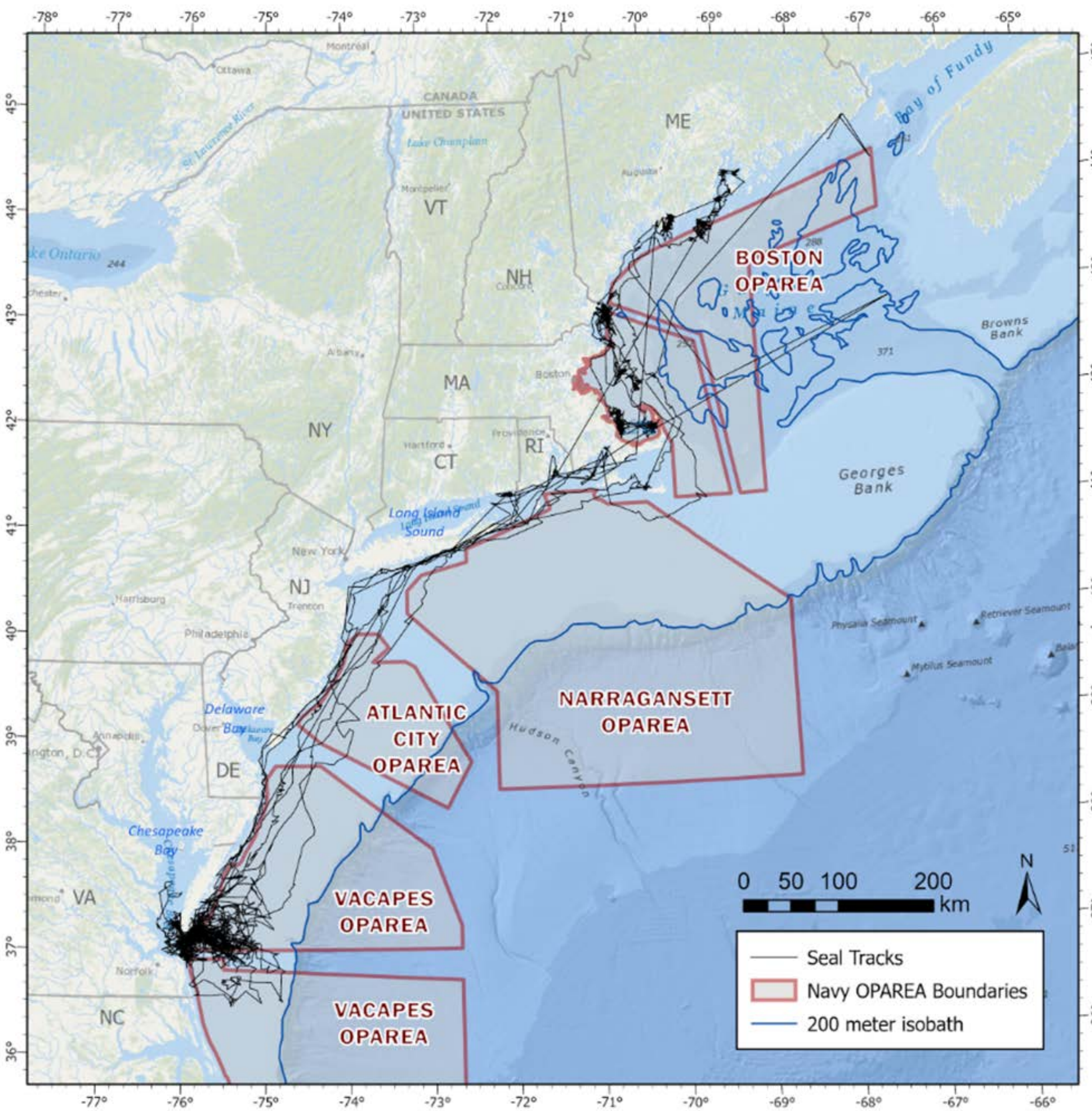

Figure 9. Reconstructed tracks of all nine seals tagged in coastal Virginia (maximum tag duration = 6 months; N = 9) in relation to Navy operating areas.
OPAREA = Operating Area; VACAPES = Virginia Capes Range Complex.

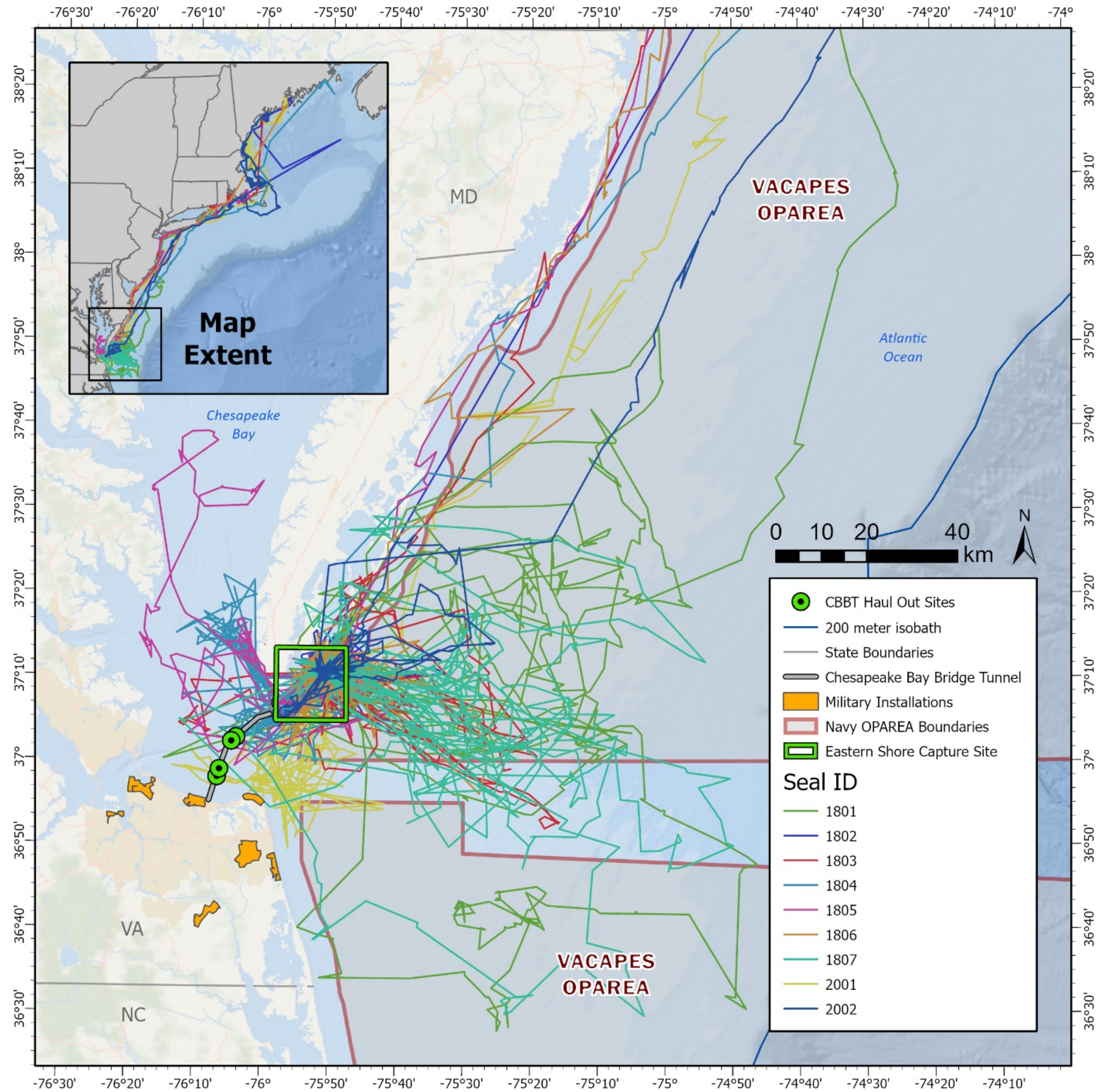

Figure 10. Reconstructed tracks of all nine tagged seals while in Virginia waters, in relation to the Virginia Capes Range Complex (VACAPES) operating area (OPAREA). CBBT = Chesapeake Bay Bridge and Tunnel.

3.3 Habitat Use

3.3.1 2020 Tags

Cumulative habitat use for both seals tagged in 2020 is shown in **Figures 11** and **12** using likelihood predictions generated by the a-LoCoH analysis. Both seals had a 95% habitat-use isopleth and 50% isopleth (core habitat) that extended as far north as coastal Maine. Seal 2001 had a 95% use area of 9,184 km^2 and a 50% use area of 505 km^2, and seal 2002 had a 95% use area of 8,303 km^2 and a 50% use area of 210 km^2.

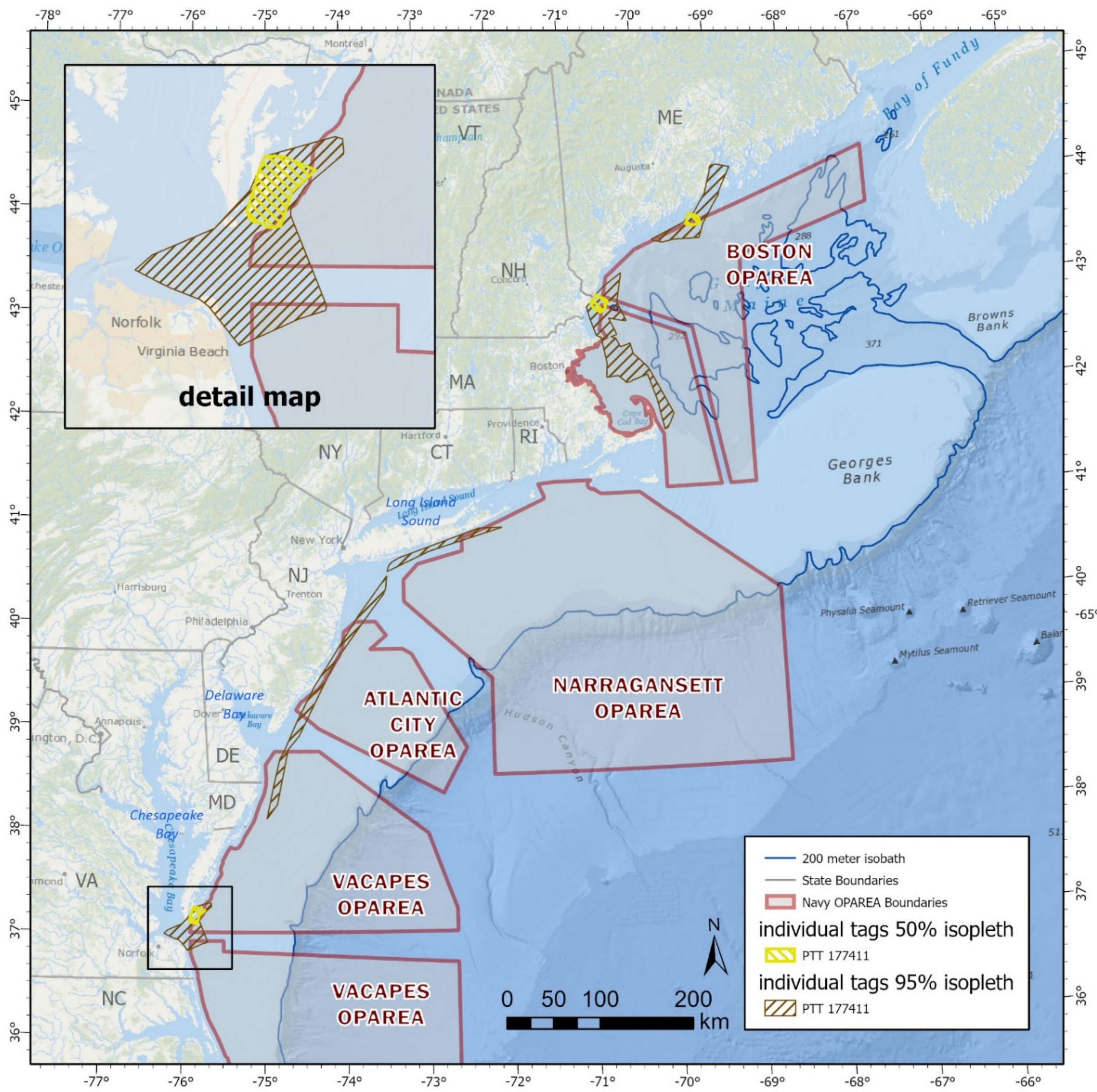

Figure 11. Habitat use map for seal 2001 (tag duration = 28 February through 12 July 2020) in relation to Navy operating areas along the Eastern Seaboard. Brown lined areas represent the 95 percent isopleth. Both the 50% and 95% isopleths overlap with the VACAPES OPAREA.

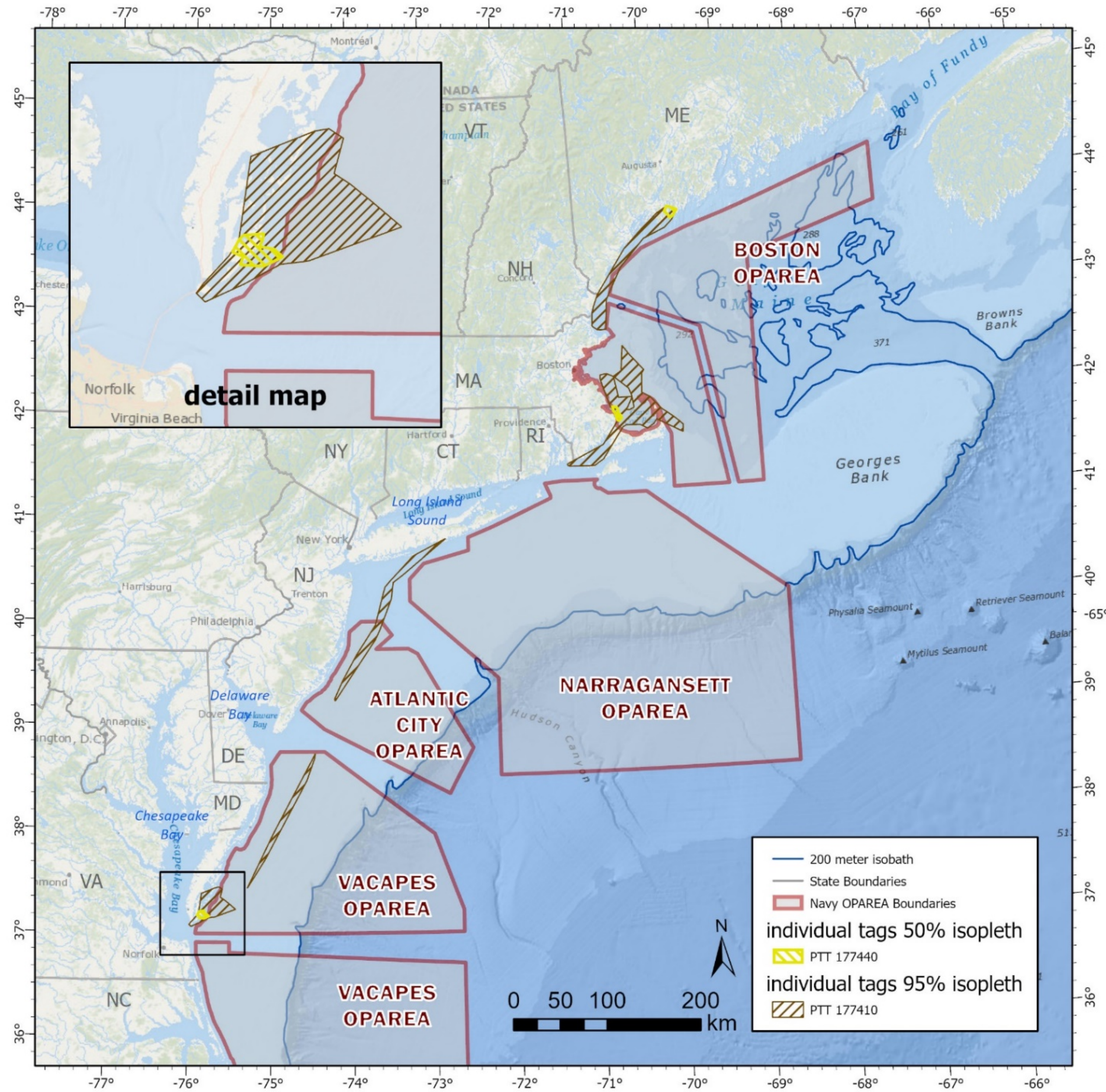

Figure 12. Habitat use map for seal 2002 (tag duration = 2 March through 10 June 2020) in relation to Navy operating areas along the Eastern Seaboard. Brown lined areas represent the 95 percent isopleth.

3.3.2 2018 and 2020 Tags

Cumulative habitat use for all nine seals tagged in 2018 and 2020 is shown in **Figures 13** and **14** using likelihood predictions generated by the a-LoCoH analysis. Based on the 95% isopleth intersection polygon, four seals had a 95% habitat-use isopleth that extended as far north as the coast of Maine, and two additional seals had a 95% likelihood of occurring off the coast of Connecticut, Rhode Island, and Massachusetts (**Figure 13**). 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 two seals 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) during the time they were tracked, while all nine seals had a 50% likelihood of being near the Eastern Shore capture site (**Figure 14**, right panel). The 95% isopleth intersections show that at least one seal had a 95% likelihood of being in the lower Chesapeake Bay. Five 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 14,** left panel). Both the 50% and 95% isopleths intersect overlaps with the VACAPES OPAREA (**Figure 14**). Overall, seals spent a cumulative 450 days in Virginia waters, and on 83 of these days (19%) satellite tags reported locations within the VACAPES OPAREA.

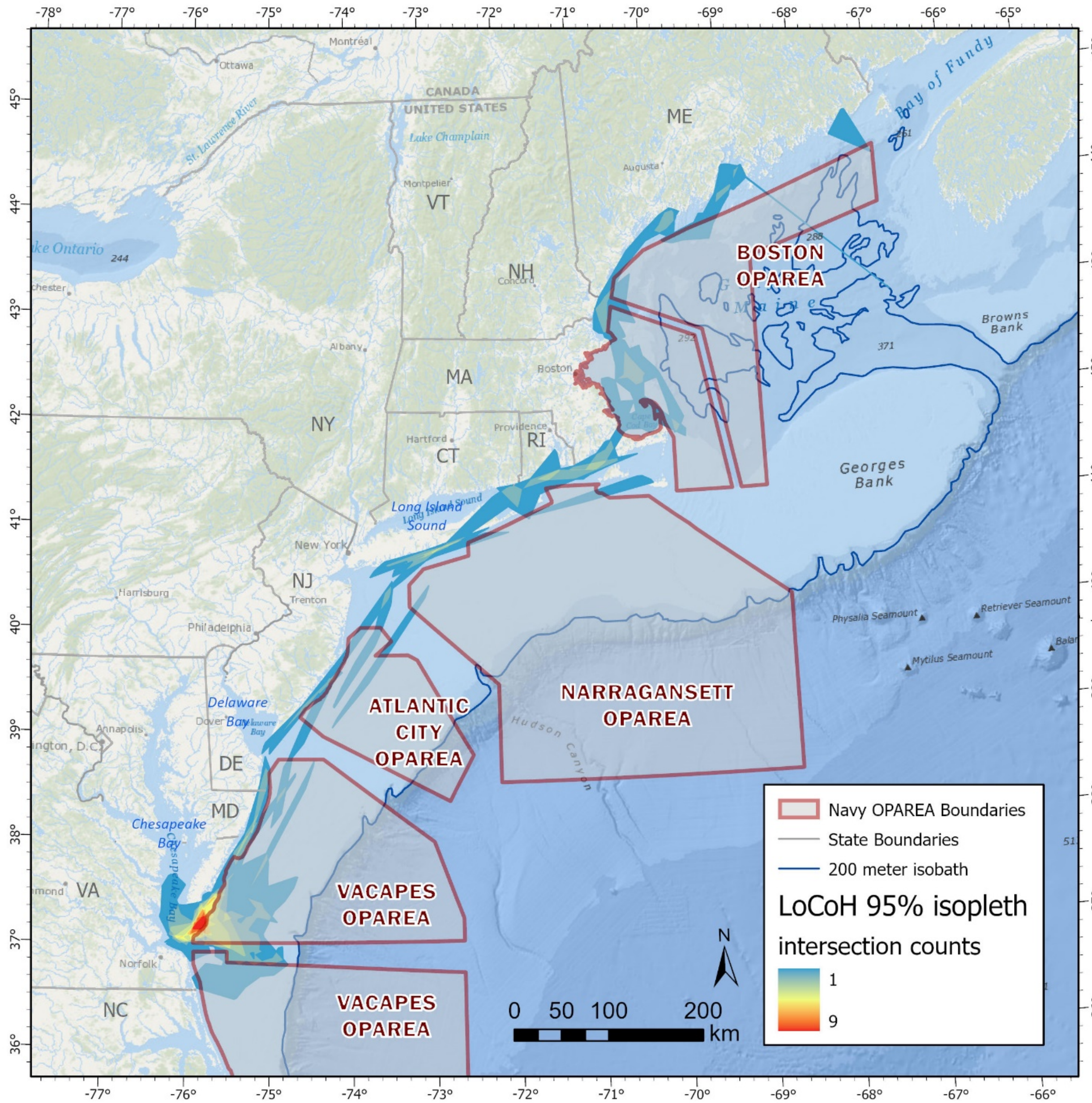

Figure 13. Habitat use map for all nine harbor seals tagged in relation to Navy operating areas (OPAREA) (maximum tag duration = 6 months). Colors represent the number of overlaid individual 95 percent habitat-use isopleths, with cool colors indicating lower counts and warmer colors indicating higher counts. LoCoH = local convex hull; VACAPES = Virginia Capes Range Complex.

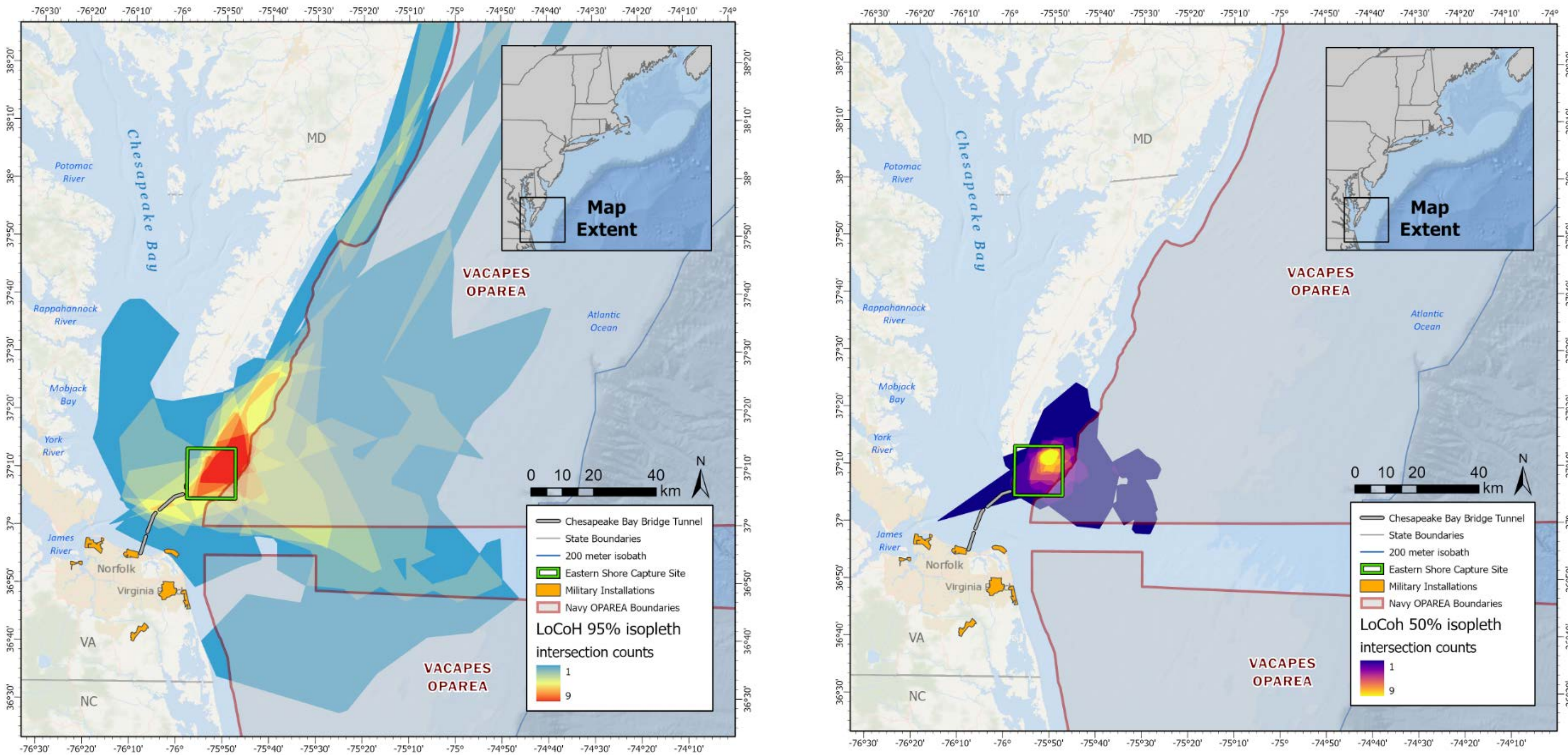

Figure 14. The intersection of all nine harbor seals' 95 percent isopleths (left panel) and 50 percent habitat-use isopleths (right panel) in Virginia waters. Colors represent the number of overlaid individual isopleths, with cool colors indicating lower counts and warmer colors indicating high counts. LoCoH = local convex hull; OPAREA = Operating area; VACAPES = Virginia Capes Range Complex.

All nine seals tagged in 2018-2020 displayed individual differences in their use of the coastal environment while in Virginia waters. Each seal made between 3 and 13 trips to and from the capture site during the time that the satellite tag was transmitting in Virginia waters (**Table 5**). These trips extended from 12 to 139 km away from the capture site, and lasted from one hour to 14 days. Individual seals used offshore vs. estuarine waters differently. Four seals (2002, 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. Seals 1801 and 1803 only visited the Chesapeake Bay once, while seal 1805 only went offshore once.

Table 5. 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
2020							
2001	21	115	12	70	11	5	6
2002	12	139	8	96	6	0	6
2018							
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

3.4 Dive-depth and Temperature

3.4.1 2020 Tags

Dive depth and in-water temperature data for seals 2001 and 2002 are shown in **Figures 15 and 16,** and **Table 6**. The maximum depth recorded throughout the deployment period was 56.33 m (seal 2001 in coastal Maine in June 2020). The mean depth recorded by tags across all months of deployment was 13.50 m (SD ±12.20) (**Table 6**). While in Virginia waters, both seals' mean dive depth was 8.37 m (SD±6.63), and the maximum depth recorded was 12.90 m (seal 2002 in March 2020).

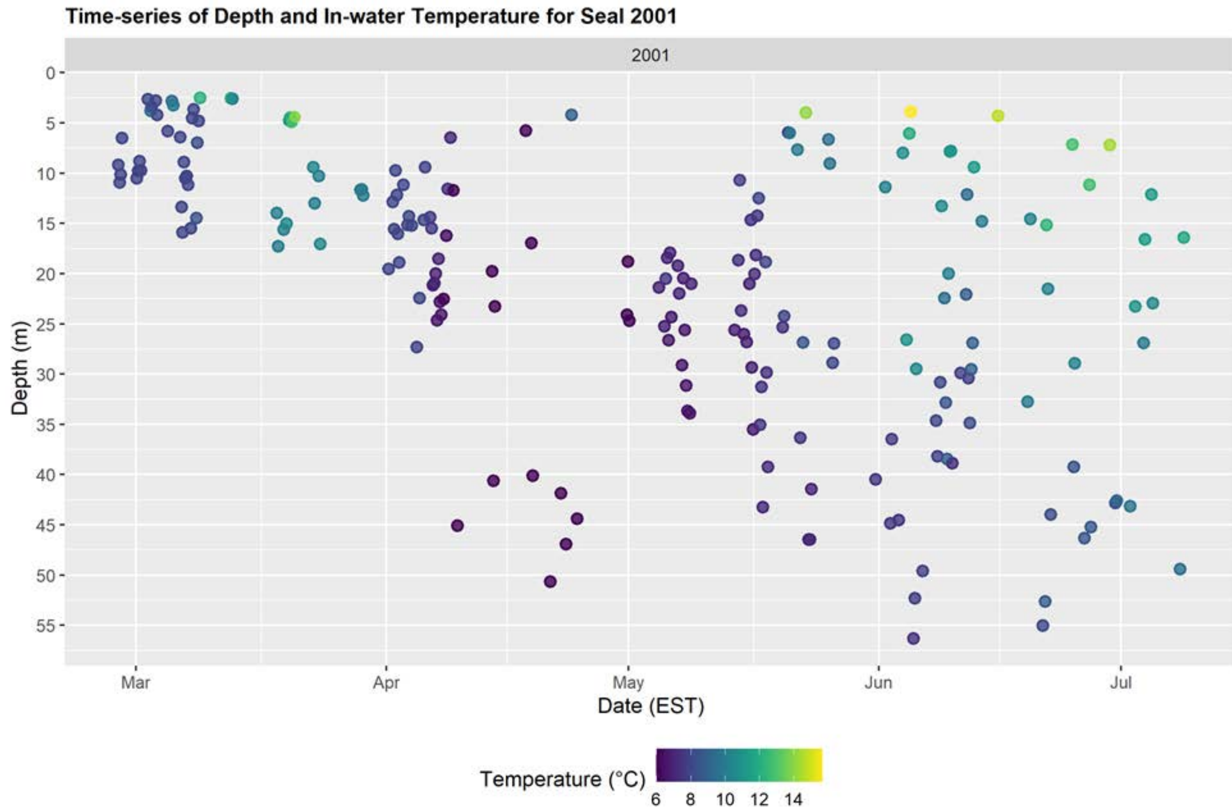

Figure 15. Time-series of depth and in-water temperature for seal 2001 (deployment period = 27 February through 12 July 2020).

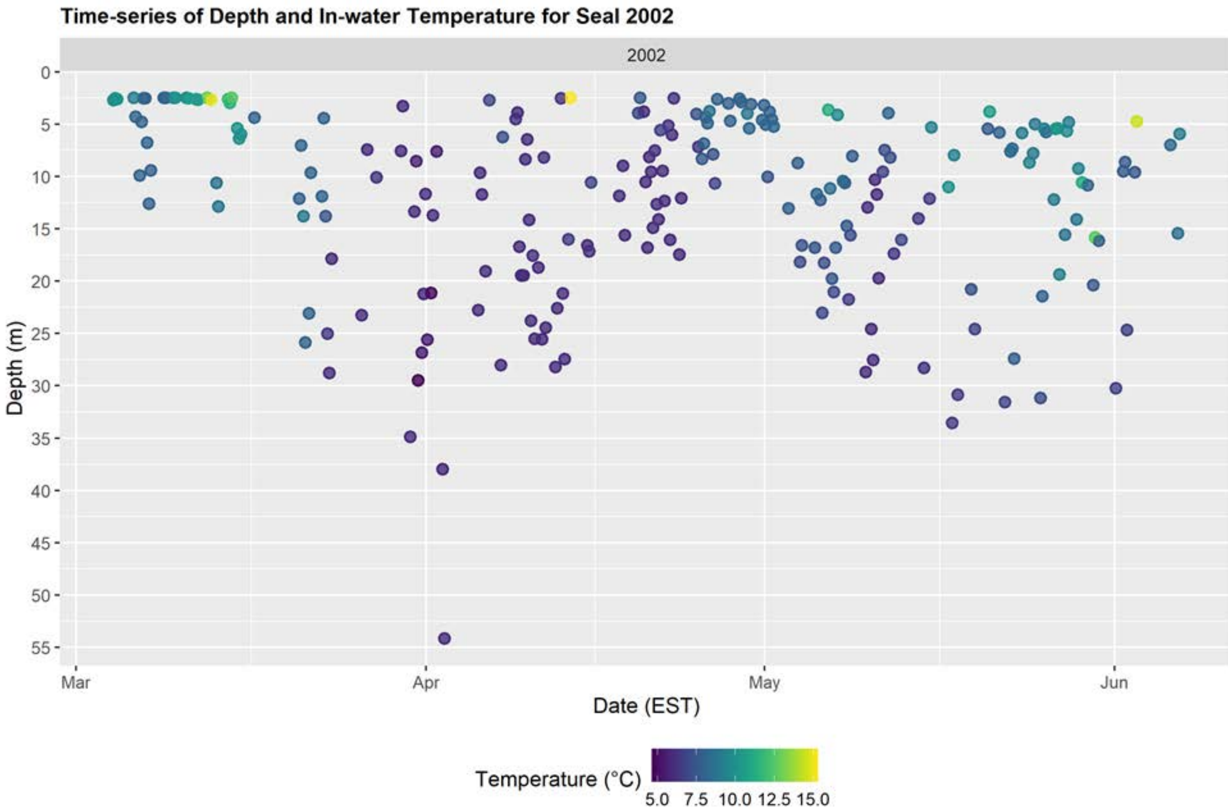

Figure 16. Time-series of depth and in-water temperature for seal 2002 (deployment period = 3 March through 9 June 2020).

Table 6. Monthly depth and in-water temperature statistics for seals 2001 and 2002

Seal ID	Month	Mean	Max	Min	Median	SD	No. of Obs
Depth (m)							
2001	February	9.20	10.95	6.505	9.68	1.94	4
2001	March	8.32	17.28	2.52	8.83	4.76	45
2001	April	21.20	50.67	2.5	18.71	12.39	46
2001	May	24.52	46.49	3.9775	24.43	10.21	57
2001	June	26.55	56.33	3.5175	29.20	16.01	60
2001	July	28.21	49.43	12.125	23.26	13.59	9
2002	March	9.73	34.91	2.5	6.57	8.66	56
2002	April	12.37	54.16	2.5	10.11	9.18	86
2002	May	13.37	33.54	3.21	11.73	7.86	82
2002	June	12.86	30.25	4.7475	9.50	8.92	9
In-water Temperature (°C)							
2001	February	7.99	8.00	7.98	7.99	0.01	5
2001	March	9.42	14.39	7.83	8.55	1.70	47
2001	April	7.03	8.90	6.00	6.91	0.91	44
2001	May	7.49	14.18	6.00	7.20	1.21	60
2001	June	9.76	15.68	7.33	9.14	2.02	57
2001	July	10.53	11.84	9.43	10.59	0.81	11
2002	March	8.51	15.29	4.65	8.01	2.29	56
2002	April	6.61	15.32	4.85	6.01	1.29	82
2002	May	8.05	14.95	6.00	7.92	1.52	87
2002	June	8.70	14.49	6.71	7.90	2.42	12

Obs = Observation(s); SD = Standard deviation

The mean in-water temperature recorded by both tags while seals were in Virginia waters was 8.88^{o}C (SD±2.04). Mean in-water temperatures recorded by the tags increased slightly over the respective deployment periods, with the lowest mean temperatures recorded in April (**Figure 17**). The maximum in-water temperature recorded by either tag was 15.68^{o}C (seal 2001 in June 2020 in Maine) and the minimum temperature was 4.65^{o}C (seal 2002 in March 2020 off Virginia) (**Table 6**).

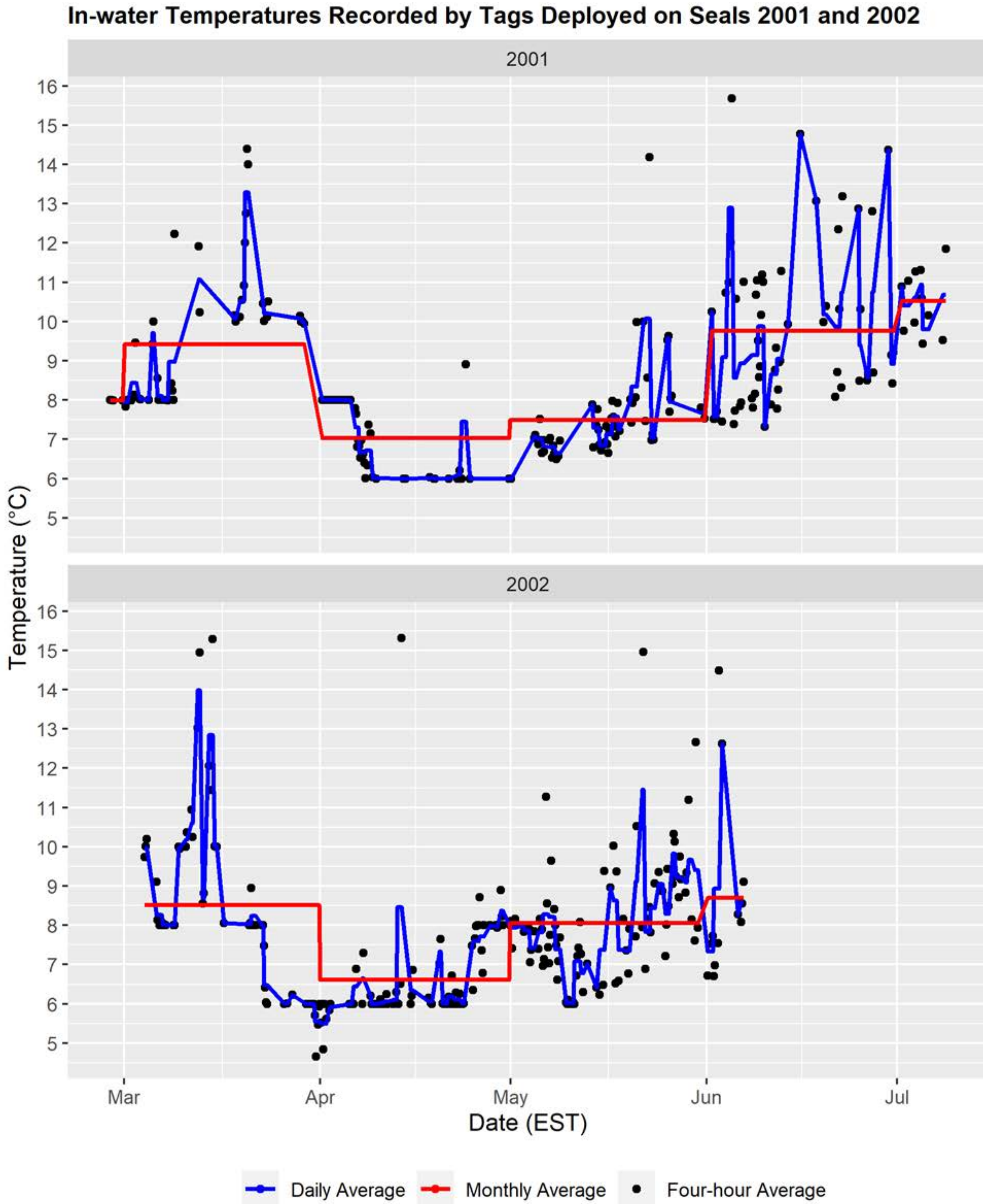

Figure 17. In-water temperature values and averages for each harbor seal tagged in 2020, over the entire duration of the tag reporting periods.

3.4.2 2018 and 2020 Tags

The mean depth recorded for all three seals instrumented with depth-sensing tags (1802, 2001 and 2002) was 13.93 m (SD±11.73) (Ampela et al. 2019). While in Virginia waters, both seals tagged in 2020 had mean dive depths of 8-9 m, relatively close to the capture site. Dive depths increased in April for seal 2001, corresponding to when the seal traveled northward (maximum dive depth was 50.67 m in April 2020). A similar pattern of increased dive depth was also observed for seal 2002, but this individual remained at dive depths <40 m for almost the entire tag deployment period, with the exception of the month of April 2020 (maximum dive depth was 54.16 m). The male seal tagged with a SPLASH tag in 2018 remained in Virginia waters through early April at dive depths of <30 m, and close to the capture site, but deeper dives (104 and 118 m) were recorded off southern Long Island in early April 2018 and Penobscot Bay, Maine, in late May 2018, respectively (Ampela et al. 2019).

The mean in-water temperature recorded for all three seals instrumented with depth-sensing tags (1802, 2001 and 2002) was 8.04°C (SD±2.45) (Ampela et al. 2019). The minimum in-water temperature recorded by these tags was 2.60°C (February 2018 in Virginia for seal 1802) and the maximum was 15.68°C (June 2020 in Maine for seal 2001). This is roughly consistent with maximum water temperatures in the region in June, as recorded by NOAA data buoy 8418150 in Portland, Maine (43.656 N 70.246 W) (approximately 18°C).

3.5 Haul-out Behavior

Haul-out locations for both seals tagged in 2020, as defined by GPS-enabled satellite tags (location accuracy up to 20 m) are shown in **Figure 8**.

TEMPORAL HAUL-OUT PATTERNS

Monthly haul-out probabilities with respect to time of day, for the entire tag deployment periods in 2020, are shown in **Figure 18**. Seal 2001 was more likely to haul out in the evening hours in the month of February, while it was still in Virginia waters, and in the afternoon hours in July, when it had reached Maine (**Figure 18**). Both tagged seals showed roughly similar haul-out probabilities at various times of day in the March –June timeframe. No data was available for seal 2002 in February or July 2020, since the tag deployment period was from 3 March through 9 June. Therefore, haul-out probabilities for February and July 2020 are based on data from a single seal (2001). Reviewing haul-out patterns for all nine tagged seals in 2018 and 2020 (**Figure 19**), a bimodal haul-out pattern was observed in June, which was mainly attributable to two seals (1802 and 1806) tagged in 2018.

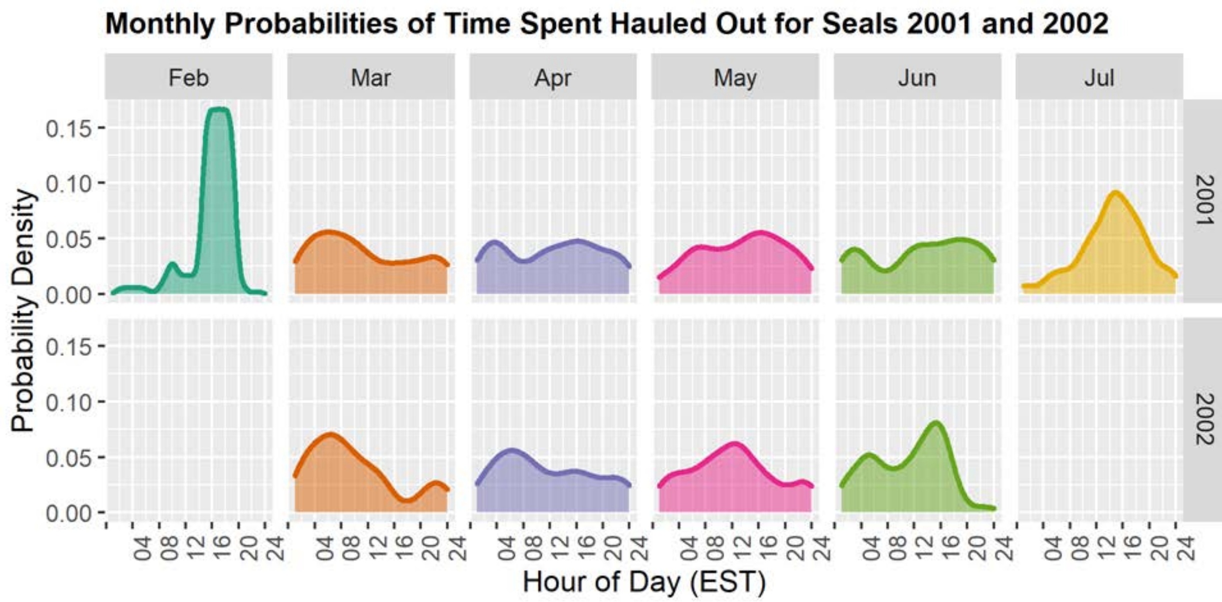

Figure 18. Monthly probability densities of time spent hauled out for seals tagged in 2020 (n=2). Hour-of-day (x-axis) is local 24-hour time.

Pooled monthly haul-out probabilities with respect to time of day for all nine tagged seals, throughout their entire tag deployment periods, are shown in **Figure 19**.

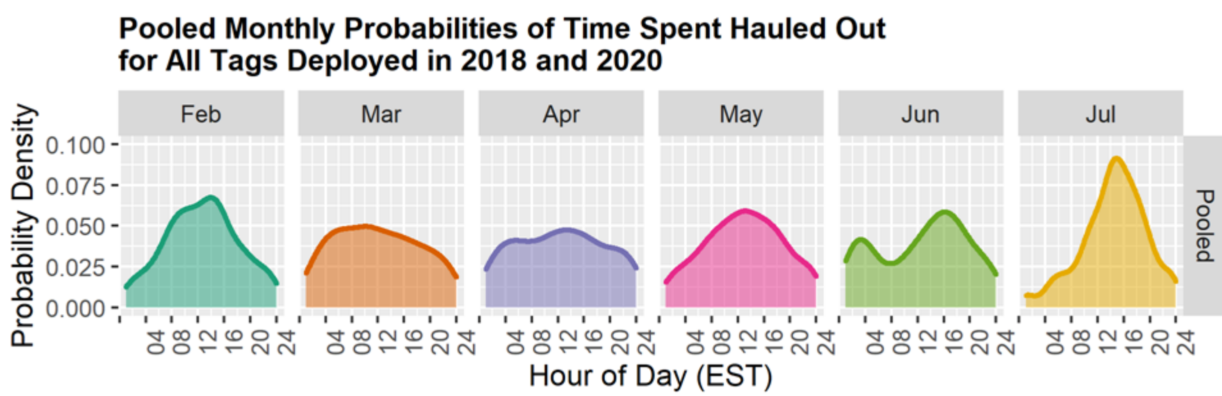

Figure 19. Pooled monthly probability densities of time spent hauled out for all seals tagged in 2018 (n=7) and 2020 (n=2). Hour-of-day (x-axis) is local 24-hour time.

HAUL-OUT PATTERNS WITH RESPECT TO ENVIRONMENTAL FACTORS

Tidal cycle

While in Virginia waters, seals were as likely to haul-out on a high tide as a low tide (**Table 7**). Of the total haul-out events (n=824), 53% of haul-out events occurred during the rising tide through peak high tide, and 47% of haul-out events occurred on the falling tide through dead low tide.

Table 7. Haul-out behavior in relation to tide magnitude for all nine seals tagged in 2018 and 2020.

Tide Level	Rising through High Tide	Falling through Low Tide	Total
Total Haul-out Events	433	391	824
Percentage of Total Events	53%	47%	100%

Time of day

While in Virginia waters, the largest number of haul-out events (all nine tagged seals) occurred at 19:00 (n=53), and the majority of haul-out events occurred between 14:00 and 19:00. In terms of total time spent hauled out, examination of diurnal/nocturnal haul-out patterns revealed that seals tagged in 2018 and 2020 were nearly equally likely to haul out during nighttime hours as daylight hours (**Figure 20**). Overall, tagged seals spent a combined total of 44,571 (46%) minutes hauled-out during daylight hours, and 52,956 (54%) minutes dry during nighttime hours. Only one seal, 2002, spent more time dry during daylight hours (n=12,675 minutes, 59%).

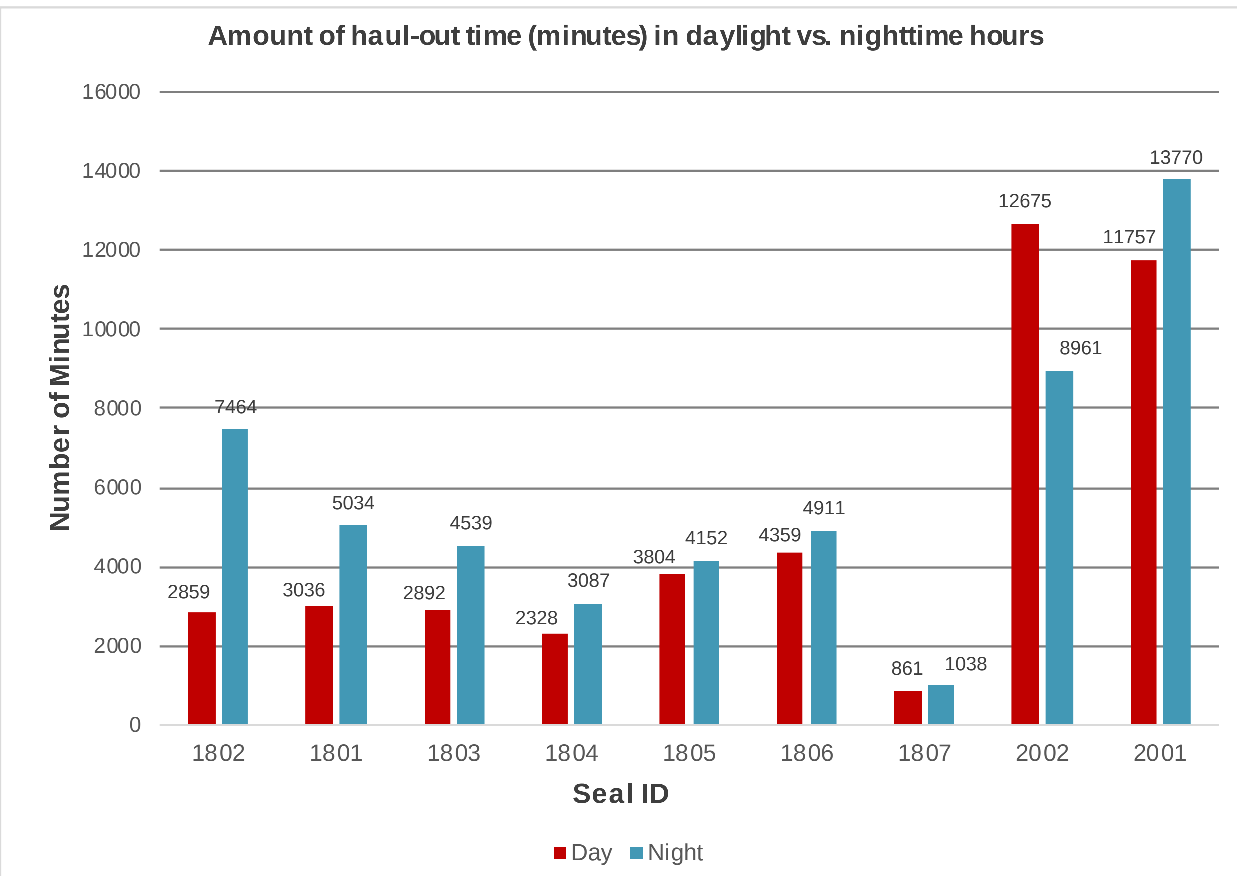

Figure 20. Total number of minutes tagged seals spent hauled out in daylight vs. nighttime hours while in Virginia waters. Data are shown for seals tagged in 2018 and 2020 (n=9).

Wind speed

Of the haul-out events for which animals were dry 100% of the time (i.e., for an entire one-hour block of time), 91.2% (n=746) occurred at wind speeds less than 15 knots, with only 8.8%

(n=79) haul-out events at wind speeds greater than 15 knots. A closer look at the animals, which hauled out at wind speeds less than 15 knots, revealed 29.3% (n=233) hauled out at speeds between 10 and 15 knots and 61.9% (n=513) hauled out at speeds less than 10 knots. Based on these results, tagged seals were more likely to haul out in calmer conditions associated with lower wind speeds.

Water temperature

Water temperatures near the capture area ranged from 2° to 14°C between 4 February 2018 and 15 April 2018 (**Figure 21**), and from 6° to 14°C between 26 February and 31 March 2020 (**Figure 22**) as recorded on NOAA data buoy station CHBV2. During the 2018 season, there were 563 one-hour time blocks when a seal was dry 100% of the hour. One-third of these events (n=186) occurred when the water temperature was 6°C, and over 90% (n=525) occurred at water temperatures between 4° and 9°C (**Figure 23)**. During the 2020 season, there were 99 one-hour time blocks when a seal was dry 100% of the hour. Seals were most likely to haul out when the water temperature was either 8°C (n=35) or 10-11°C (n=42), and 90% of haul-out events occurred at temperatures between 8° and 11°C (**Figure 24**). Overall, while in Virginia waters, tagged seals were most likely to haul out when water temperatures were in the 6°-11°C range.

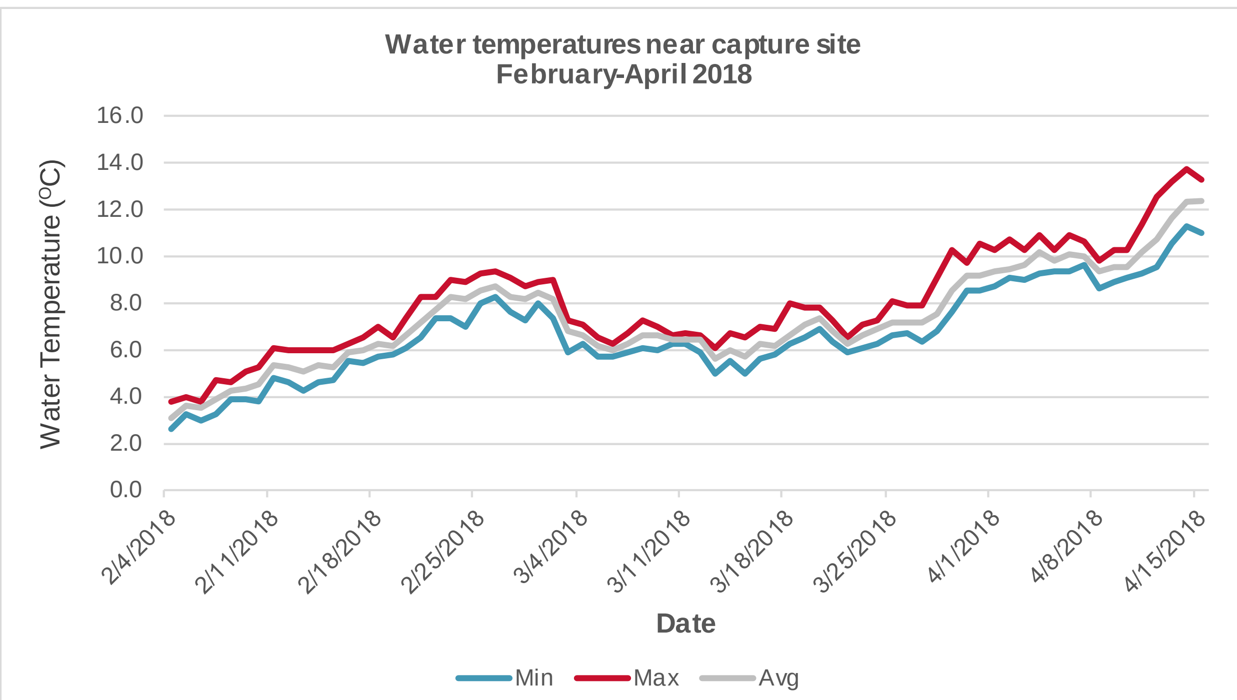

Figure 21. Water temperatures near the capture site, from 4 February through 15 April 2018, as recorded on NOAA data buoy station CHBV2.

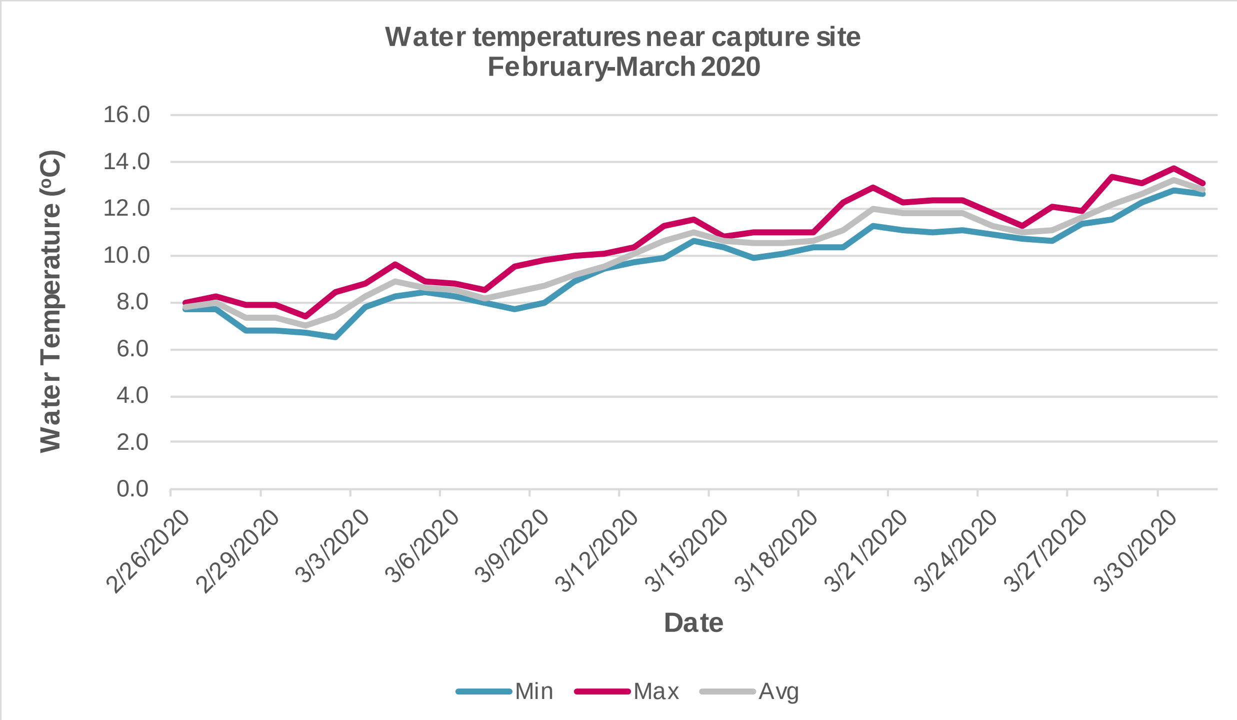

Figure 22. Water temperatures near the capture site, from 26 February and 31 March 2020, as recorded on NOAA data buoy station CHBV2.

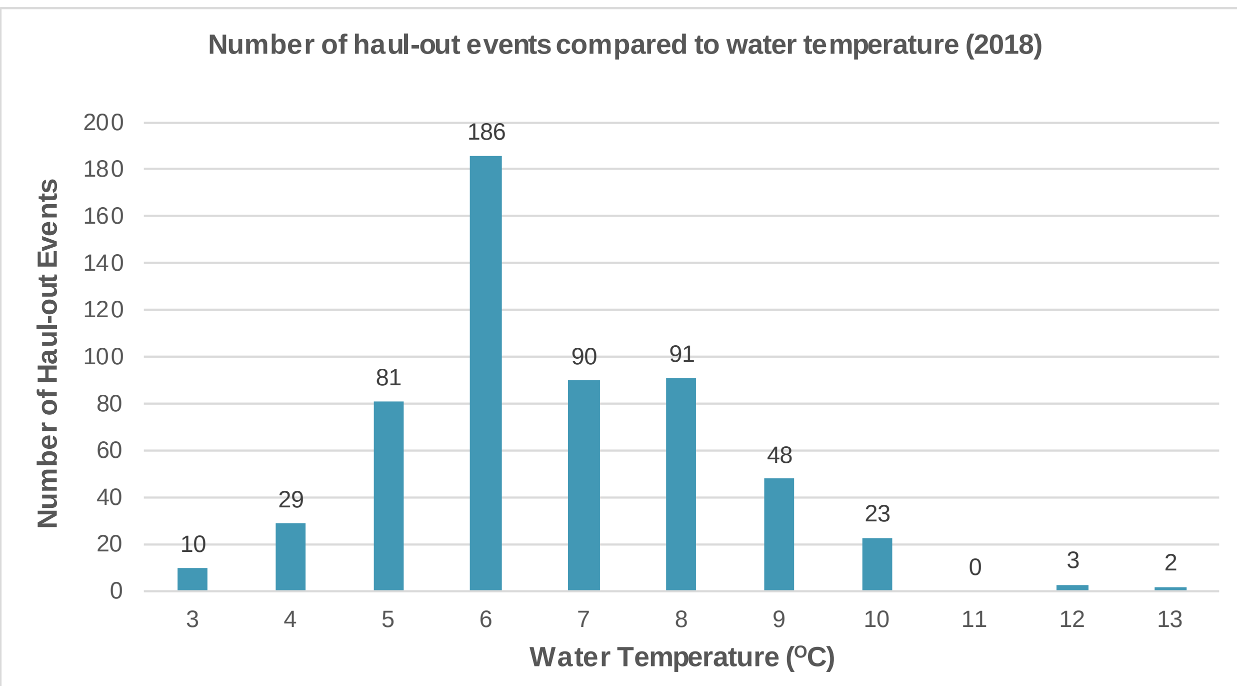

Figure 23. Number of seal haul-out events with respect to water temperature as recorded on NOAA data buoy station CHBV2. Date range = 4 February through 15 April 2018.

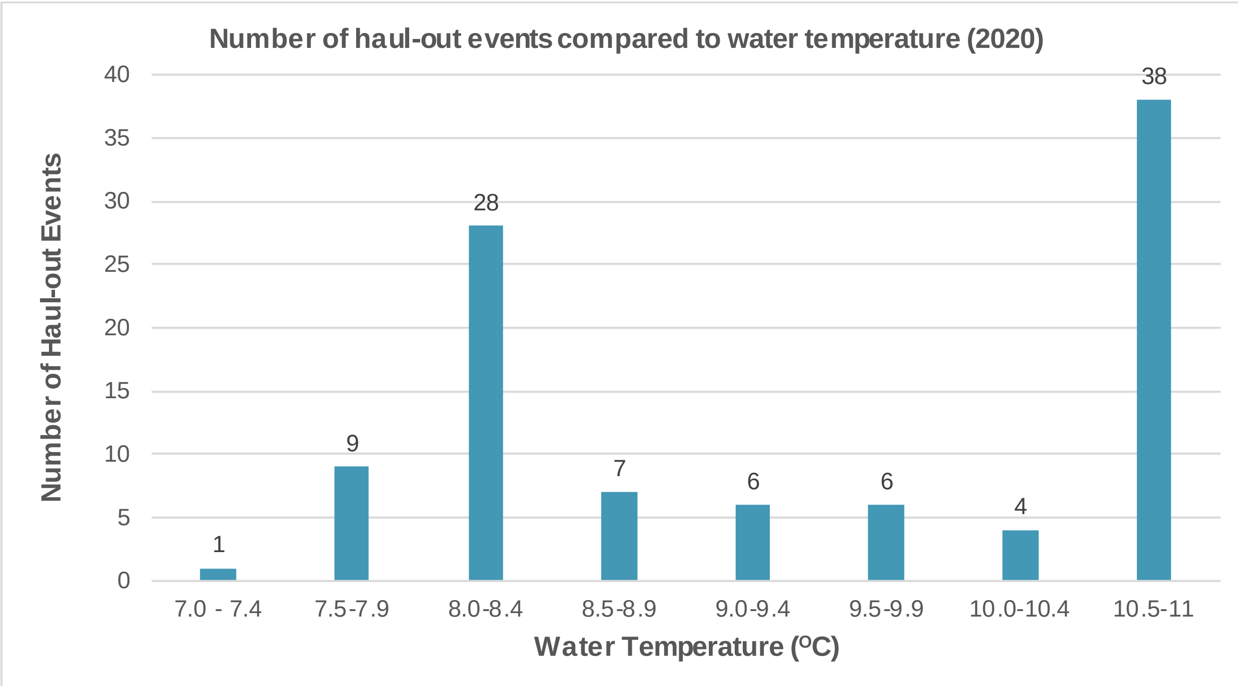

Figure 24. Number of seal haul-out events with respect to water temperature as recorded on NOAA data buoy station CHBV2. Date range = 26 February through 31 March 2020.

Air temperature

Air temperature near the capture site ranged from -5°C to 26°C between 4 February and 15 April 2018 (**Figure 25**), and from -2°C to 28°C between 26 February and 31 March 2020 (**Figure 26**) as recorded at the NOAA Climatological Data Station WBAN:03739 in Cape Charles, Virginia. Air temperature in both field seasons fluctuated widely from one 24-hour period to the next, with respective lows experienced in mid-March 2018 and around 9 March 2020. During the 2018 season, there were 563 one-hour time blocks when a seal was dry 100% of the hour. Twenty-five percent (n=141) of these events occurred when the air temperature was between 4° and 6°C, and 18% (n=103) of events occurred between 7° and 9°C (**Figure 27**). During the 2020 season, there were 99 one-hour time blocks when a seal was dry 100% of the hour. Thirty-eight percent (n=38) of these events occurred when the air temperature was between 11° and 13°C, and 96% (n=95) of events occurred between 5° and 19°C (**Figure 28**). Overall, while in Virginia waters, tagged seals were most likely to haul out when air temperatures were in the 4°-13°C range.

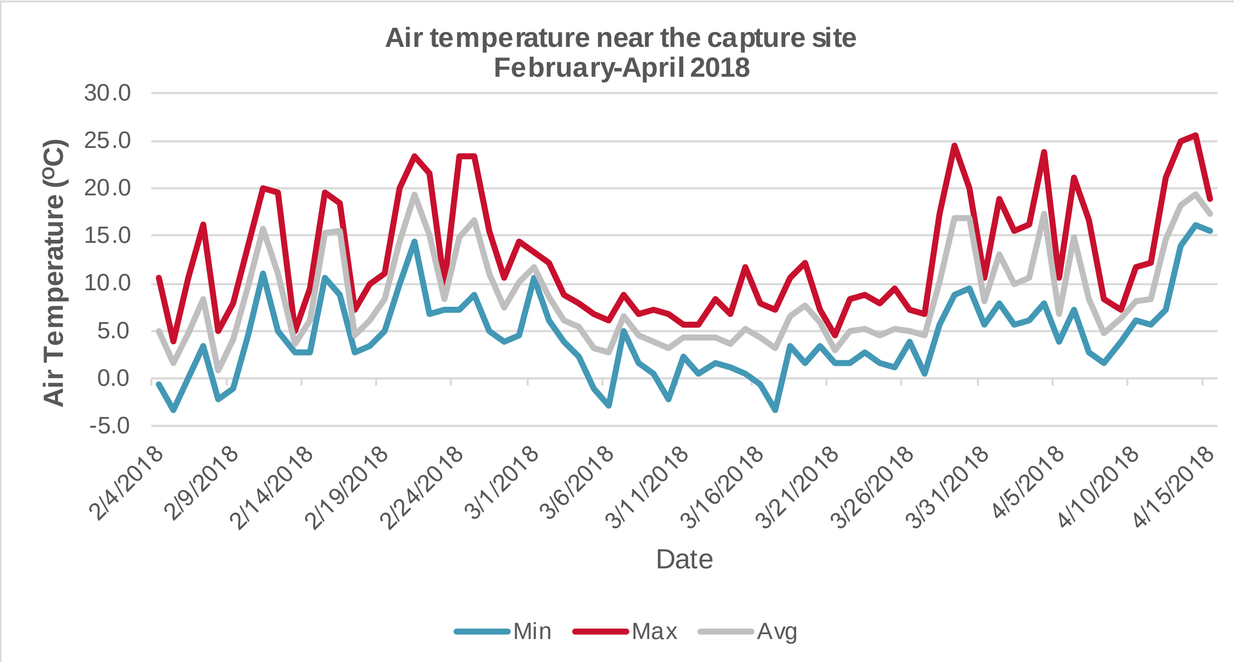

Figure 25. Air temperatures near capture site, from 4 February through 15 April 2018, as recorded at the NOAA Climatological Data Station WBAN:03739 in Cape Charles, Virginia.

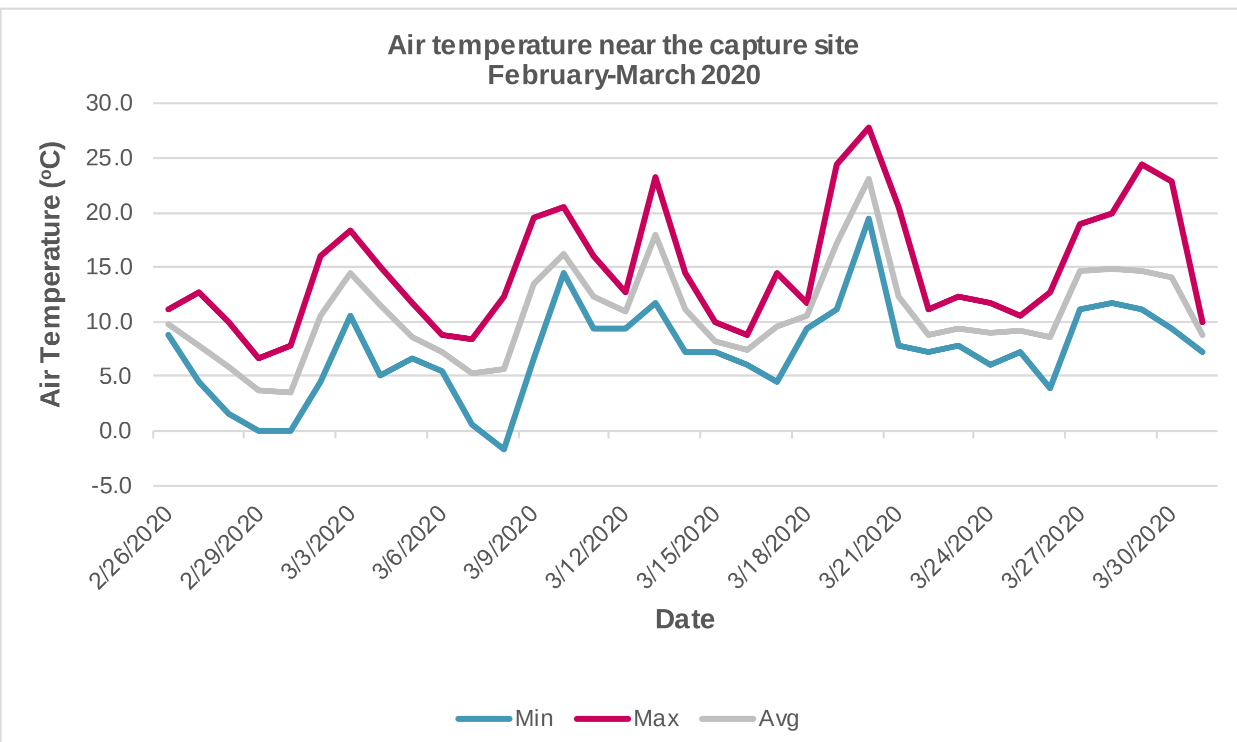

Figure 26. Air temperatures near capture site, from 26 February and 31 March 2020, as recorded at the NOAA Climatological Data Station WBAN:03739 in Cape Charles, Virginia.

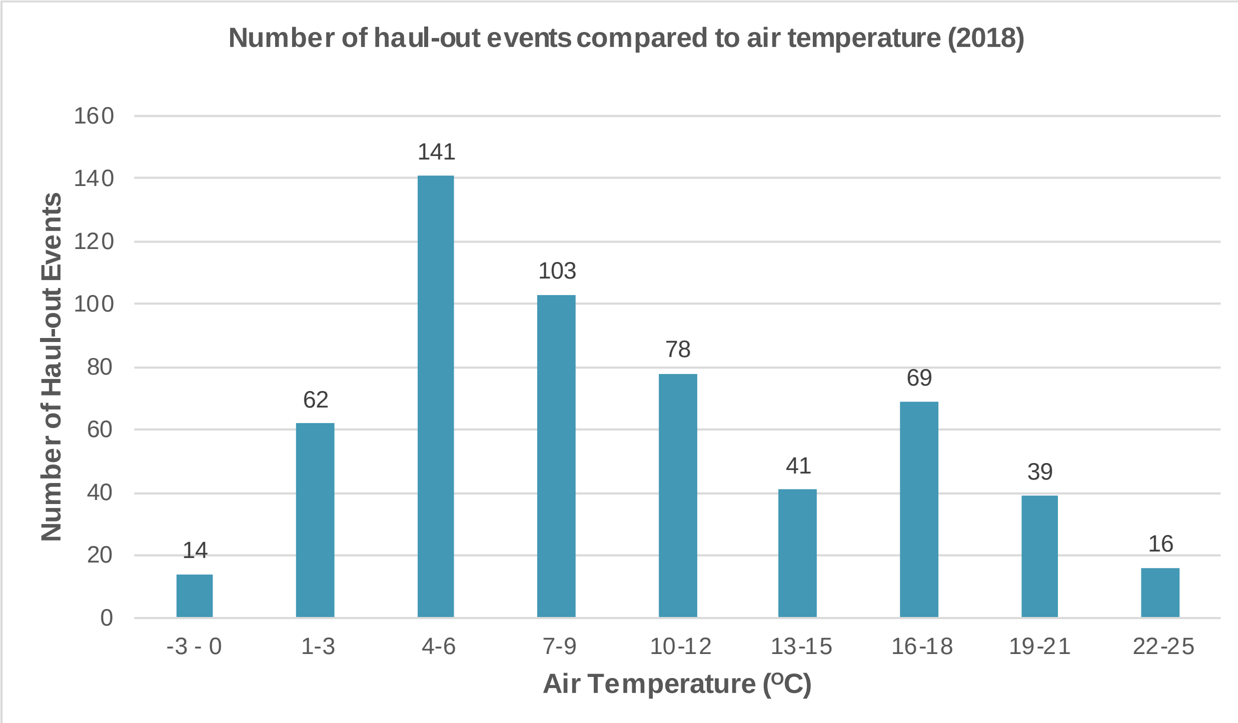

Figure 27. Number of seal haul-out events with respect to air temperature as recorded at the NOAA Climatological Data Station WBAN:03739 in Cape Charles, Virginia. Date range = 4 February through 15 April 2018.

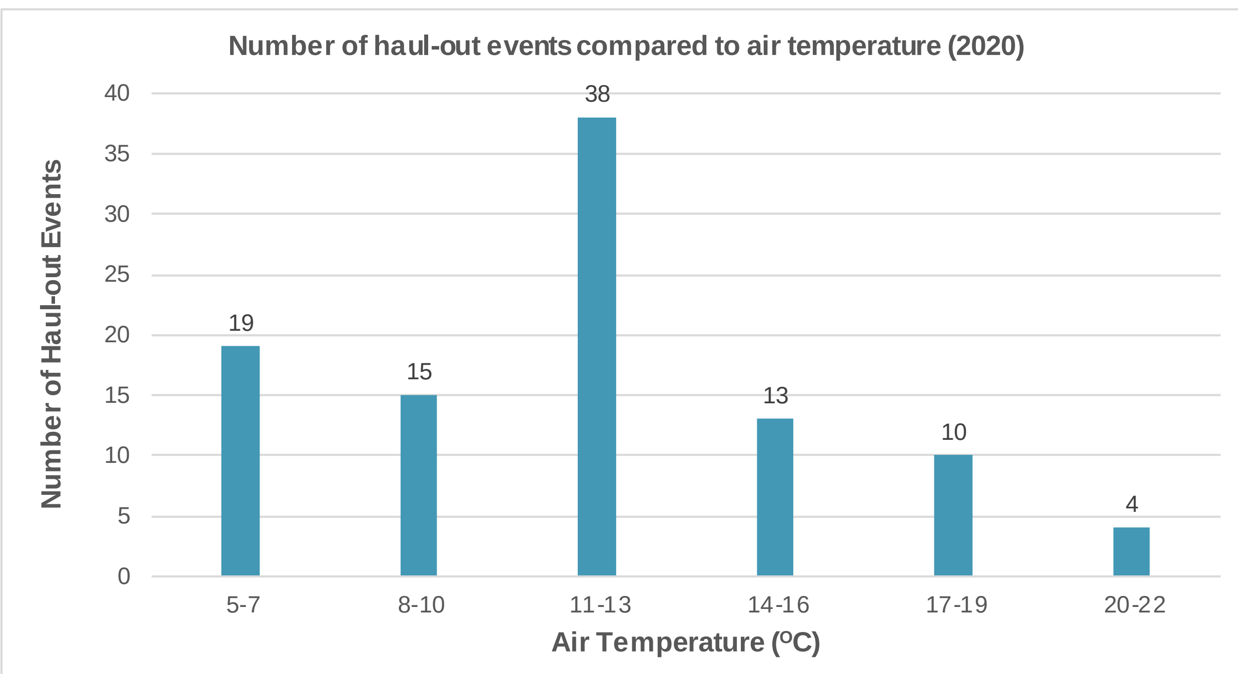

Figure 28. Number of seal haul-out events with respect to air temperature as recorded at the NOAA Climatological Data Station WBAN:03739 in Cape Charles, Virginia. Date range = 26 February through 31 March 2020.

COMPARISON OF SATELLITE TAG DATA AND TRAIL CAMERA IMAGERY

During the 35-day time period when tagged seals were in Virginia waters, over 24,000 photos were collected from the trail cameras installed at the Eastern Shore haul-out area. Images of hauled-out seals were recorded on 26 of these 35 days by one or more of the trail cameras. Satellite tag data from both seals indicated a total of 100 haul-out events between 26 February and 31 March 2020, and 38% of these events occurred during daylight hours (**Tables A-1** and **A-2**), and for each "daylight" haul-out event, hauled-out seals were also recorded on the trail cameras. High-quality locations (GPS and Argos Location Class 3) were available for 63 of the 100 haul-out events, and 28 of these (44%) occurred during daylight hours. An image of a tagged seal was recorded at haul-out site E1 on 12 March 2020 (**Figure 29**). Although the flipper tag number cannot be discerned due to the image quality, this photo was likely of seal 2002 based on data from its satellite tag (**Table A-2**). It should be noted that the quality of the trail camera images may not be sufficient to allow the identification of tagged individuals.

Figure 29. Image taken on 12 March 2020 at haul-out site E1. The red circle indicates a tagged seal, which is likely seal 2002 based on data from its satellite tag.

3.6 Health Assessments

Vital rates and morphometric measurements were recorded for both seals tagged in 2020, and photographs were taken of ventral, lateral, and frontal views (see **Appendix B** for example data sheets). Any wounds or abnormalities were also photographed. During capture and tagging procedures each seal was monitored for respiration and heart rate; quality of breaths (open mouth breathing, wheezing); body condition (emaciated, thin, normal/robust); attitude (alert, lethargic, non-responsive); presence of eye and ear exudate, and whether the animal was shivering. When possible, vital rates were obtained both before and after tagging (pre-release). A full suite of blood and biological samples was collected from each tagged seal (**Table 2**). 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. The complete blood count and chemistry panel results were within normal range for pinnipeds according to values published in Dierauf and Gulland (2001). 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 work is a continuation of seal tagging efforts in coastal Virginia first undertaken in 2017. Although findings are limited to the nine individual seals tagged in this study to date, 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 coastal Virginia, and along the U.S. Eastern Seaboard. All capture and tagging activities were performed under National Marine Fisheries Service (NMFS) Scientific Research Permit #21719.

Both tags deployed in 2020 were GPS (Fastloc®) enabled, which reported locations more frequently, and with better accuracy, than Argos-only tags. Seals tagged in 2020 showed broadly similar spatial extent of seasonal movements as seals tagged in 2018 (Ampela et al. 2019). In both years, seals traveled as far north as coastal Maine, and used similar haul-out areas in southern New England. In Virginia waters, tagged seals utilized both the Chesapeake Bay and offshore waters, and exhibited site fidelity to the haul-out locations on the Eastern Shore and CBBT Islands. Seals are central place foragers (Thompson and Miller 1990; Russell et al. 2015; Huon et al. 2020) and these sites likely function as a central foraging area when seals are in Virginia waters. Habitat use analysis indicated that the most heavily utilized area was near the Eastern Shore capture site, but this may be biased by the fact that this was the tag deployment location, and by the small sample size (n=9). In the future, a state space model that predicts locations at equal time intervals could allow more robust conclusions about habitat use.

The average and maximum dive depths recorded by the SPLASH tags deployed in 2018 and 2020 (n=3) 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). Womble et al. (2014) found that harbor seals dive most frequently (81.6%) to 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 (Jørgensen et al. 2001), and in Prince William sound (Frost et al. 2001). Results from this study suggest that harbor seals may be 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).

Maximum dive depths were substantially different for the 2018 vs. 2020 seal tags. The maximum depth recorded for seal 1802, an adult male tagged in 2018, was 118 m, whereas the maximum depths recorded for the two juvenile seals tagged in 2020 were roughly half this. Age, sex, and body size can influence dive behavior in harbor seals (Coltman et al. 1997; Thompson et al. 1998), as can haul-out location, breeding status, and time of day (Wilson et al. 2014). It is possible that age and body size were influential factors in dive depths observed in this study, although the small sample size prevents a more robust analysis from being conducted.

Previous studies have shown that 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). However, the small number of seals tagged in this study were as likely to haul out on a high tide as on a low tide. Tagged seals spent similar amounts of time hauled out at night and during daylight hours, although they spent slightly more time hauled-out during nighttime hours compared to daylight hours (54% vs. 46% of total minutes dry). This may be due to fewer sources of disturbance present at night, although a detailed analysis of the effects of disturbance on haul-out behavior was beyond the scope of this study. In 2018, seals hauled out most frequently at air temperatures between 4°C and 6°C, and when water temperature was 6°C. In 2020, seals hauled out most frequently when air temperatures were between 11°C and 13°C, and when water temperature was 11°C. A key environmental variable identified with respect to haul-out behavior was wind speed, and tagged seals were more likely to haul out when wind speed was less than 15 knots. These findings suggest that when attempting future captures at the Eastern Shore site, wind speed should be closely monitored when planning capture efforts, and that captures could be attempted throughout daylight hours and at various tidal cycles.

Initial comparison of satellite tag data and trail camera images confirmed that tagged seals are using known haul-out sites at the Eastern Shore capture area, although the spatial and temporal coverage of these areas by the cameras is not complete. For example, seal 2001 was hauled out in the Little Inlet area on 28 February 2020 at 18:00, but there were no seals captured by the cameras outside of daylight hours (**Table A-1**). This highlights the importance of integrating the camera data and satellite tagging data to have a more complete understanding of how seals are using the Eastern Shore haul-out sites at fine spatial scales.

5. Summary and Future Work

Additional tag deployments are planned for early 2022[6] at the same capture location. Future capture efforts will involve use of a modified gill net, in addition to the seine net used in previous years, in order to improve the probability of capture success. Findings from this study will inform methods for future capture efforts at this location, with the goal of increasing the number seal tags deployed. Up to 15 seals will be instrumented with a combination of location-only and depth-sensing tags. Results from this work will further our understanding of harbor seals' movement patterns, dive behavior, habitat use, and haul-out patterns in and near Navy training areas and installations in Virginia, and along the U.S. Eastern Seaboard. Tag data will 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 harbor seal populations. Additional data from depth-sensing tags will help inform Navy analyses of anthropogenic sound on seals at varying depths in the water column. As a next step, the environmental haul-out analysis presented here could be expanded to include a predictive modeling component to better understand seal movements and haul-out behavior in relation to these variables in Virginia waters (e.g. Moll et al. 2017).

This project was a collaborative effort among a variety of organizations, and biological samples taken from captured seals were shared with a number of researchers who are investigating the health, diet, and genetic structure of harbor seals in the Northwest Atlantic. These data can 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. Understanding the distribution and abundance, habitat use, and health status of these seal populations can eventually provide the foundation for a range-wide ecosystem-based analysis. The results from this study contribute new information about the fine-scale movements of harbor seals near 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.

[6] Tagging efforts originally planned for early 2021 were postponed due to concerns about COVID-19.

6. Acknowledgements

We thank Laura Busch at Fleet Forces Command for providing funding for this project. We also thank Danielle Jones at NAVFAC LANT for field support, scientific guidance, and report review, and Mendy Garron (Greater Atlantic Regional Fisheries Office) for field support. Many thanks are due to Sean Hayes and Kimberly Murray (National Oceanic and Atmospheric Administration Fisheries/Northeast Fisheries Science Center [NOAA/NEFSC]) who allowed this work to be performed under NMFS Scientific Research Permit #21719. This project would not have been possible without Gordon Waring and Alli Deperte (Atlantic Marine Conservation Society); Philip Thorson (NAVFAC Northwest); Alex Wilke, Zak Poulton, Marcus Killmon, and Bo Lusk (The Nature Conservancy); Susan Barco, Allyson McNaughton, and Sarah McCormack (The Virginia Aquarium); Ruth Boettcher and Jeremy Tarwater (Virginia Department of Game and Inland Fisheries); Andrea Bogomolni (Northwest Atlantic Seal Research Consortium); Stacey Lowe (U.S. Fish and Wildlife Service, Eastern Shore of Virginia National Wildlife Refuge), and the staff at Kiptopeke State Park. Thanks also to Olga Kosta and Cathy Bacon (HDR, Inc.) for assistance with graphics, statistical analysis, and technical editing.

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A

Appendix A
Comparison of Seal Tag and Trail Camera Data

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Table A-1. The maximum number of seals recorded on the trail cameras during known haul-out events for Animal 2001, as recorded by its satellite tag. Haul-out site designations A-F correspond to those shown in Figure 5.

Seal ID Number	Date	Time (EST)	Code/ Type	HOSiteA	HOSiteB	HOSiteC1	HOSiteC2	HOSiteC3	HOE1cr	HOE1mc	HOSiteE2	HOSiteE3	HOSiteF1	Total Max
2001	2/28/2020	14:00:00	FastLoc	0	0	0	0	0	17	0	0	0	0	17
2001	2/28/2020	15:00:00	FastLoc	0	0	0	0	0	19	0	0	0	0	19
2001	2/28/2020	16:00:00	FastLoc	0	0	0	0	0	19	0	0	1	0	20
2001	2/28/2020	17:00:00	FastLoc	0	0	0	0	0	17	0	3	1	0	17
2001	2/28/2020	18:00:00	FastLoc	0	0	0	0	0	16	0	4	0	0	20
2001	3/2/2020	15:00:00	FastLoc	0	0	0	0	0	0	0	0	0	6	6
2001	3/2/2020	16:00:00	FastLoc	0	0	0	0	0	0	0	0	0	10	10
2001	3/2/2020	17:00:00	FastLoc	0	0	0	0	0	1	0	0	0	7	8
2001	3/9/2020	8:00:00	FastLoc	0	0	0	0	0	32	7	0	0	0	39
2001	3/9/2020	9:00:00	FastLoc	0	0	0	0	0	41	1	0	0	0	42
2001	3/9/2020	10:00:00	Argos 3	0	0	0	0	0	43	3	0	0	0	46
2001	3/13/2020	19:00:00	Argos 3	0	0	0	0	0	23	0	2	8	0	33
2001	3/13/2020	16:00:00	Argos 3	0	0	0	0	0	33	5	0	2	0	40
2001	3/14/2020	8:00:00	Argos 3	0	0	0	0	0	0	0	23	0	0	23
2001	3/17/2020	19:00:00	Argos 3	0	0	0	0	0	2	0	0	0	0	2
2001	3/28/2020	7:00:00	Argos 3	0	0	0	0	0	4	0	0	0	0	4
2001	3/28/2020	8:00:00	Argos 3	0	0	0	0	0	4	0	0	0	0	4
Maximum Number of Seals Recorded per Camera				0	0	0	0	0	43	7	23	2	10	46

HO=haul-out; cr=creek; mc=main channel

Table A-2. The maximum number of seals recorded on the trail cameras during known haul-out events for Animal 2002, as recorded by its satellite tag. Haul-out site designations A-F correspond to those shown in Figure 5.

Seal ID Number	Date	Time (EST)	Code/ Type	HOSiteA	HOSiteB	HOSiteC1	HOSiteC2	HOSiteC3	HOE1cr	HOE1mc	HOSiteE2	HOSiteE3	HOSiteF1	Total Max
2002	3/9/2020	9:00:00	FastLoc	0	0	0	0	0	41	1	0	0	0	42
2002	3/9/2020	10:00:00	Argos 3	0	0	0	0	0	47	4	0	0	0	51
2002	3/11/2020	7:00:00	Argos 3	0	0	0	0	0	0	0	29	0	0	29
2002	3/11/2020	8:00:00	Argos 3	0	0	0	0	10	0	0	30	0	0	40
2002	3/11/2020	9:00:00	Argos 3	0	0	0	0	20	0	0	22	0	0	42
2002	3/11/2020	10:00:00	Argos 3	0	0	0	0	20	0	0	22	0	0	42
2002	3/12/2020	7:00:00	FastLoc	0	0	0	0	0	0	0	18	0	0	18
2002	3/12/2020	12:00:00	FastLoc	0	0	0	0	0	0	16	0	0	0	16
2002	3/14/2020	7:00:00	FastLoc	0	0	0	0	0	0	0	14	0	0	14
2002	3/14/2020	8:00:00	FastLoc	0	0	0	0	0	0	0	23	0	0	23
Maximum Number of Seals Recorded per Camera				0	0	0	0	20	47	16	30	0	0	51

HO=haul-out; cr=creek; mc=main channel

B

Appendix B
Sample Data Sheets

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NAVFAC ATLANTIC PINNIPED TAGGING 2020: Animal Information Datasheet

ANIMAL INFORMATION

Field #: NAVFAC2020___ ___ Date: __________ Species: □ Harbor □ Grey Seal

Animal Sex: _________ Animal Sentinel:__________ GPS WP:_____________

GPS Coordinates (where tagged): ______________ °N, _______________ °W

Team Lead:_______ Data Recorder:_________ Restrainers: (H)_____(R)_____

MORPHOMETRICS

Weight with Net (Kg):_______ Weight of Net:______ Animal Weight:______

Straight Length (cm):________ Axillary Girth (cm):_________

TAGGING & SAMPLING

Initial Heart Rate: _____________

PRIORITY 1A: Sat Tag

Tagger:___________

PTT:

____

Time start mixing:_____

Time warm:_________

Time Hard:__________

☐ Tape removed

PRIORITY 1B: Flipper Tag

Tagger:____________

Flipper Tag ID:

____

Flipper Tag Color:_____

☐ Left biopsy collected

PRIORITY 2: Bloods

Sampler:____________

Bleed Site:

☐ Ex. intravertabral

☐ Hind flipper

Time: _________

#Sticks: (1-3):_______

☐ Lg Lavender

☐ Red/Yellow

☐ Red/Black

☐ Green

☐ White

☐ Sm Lavender

☐ Other:__________

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:_______________

Monitoring Time:_______________

Time Sampling Start:_____________

Time Epoxy Start: 1:_______ 2: ______

Time Lidocaine admin :___________

Target Release Time (45min):_______

Actual Release Time:_____________

Total Time Sampled: ____________

PHOTOS

☐ Left Head- ☐ Right Head

☐ Sat Tag Num ☐ Sat Tag on Seal

☐ Flipper Tags ☐ Full body

Photo #:

NOTES:______________________

____

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Date Data Entered:________________ **Entered By:**____________________ **Updated: 2/21/2020**

Net Deployments

Date	Set Time	Location	Latitude	Longitude	Set #	Seals 0= no 1=yes	Species	# Pv taken	# caught	# escaped	# sampled	SI/Mort 0=no 1=yes	Notes	Photo Numbers

Environmental																	
Date	Data Recorder	Start Time	End Time	Set Number	Cloud Cover (%)	Visibility	BSS	Tidal Height (ft) (~)	Offset	Tidal State	Wind Speed (mph)	Wind Gusts (mph)	Wind Dir.	Wind Direction Degrees	Air Temp (F)	Water Temp (F)	Notes