Turtle Tagging and Tracking in Chesapeake Bay and Coastal Waters of Virginia: 2016 Annual Progress Report

Submitted to:

Naval Facilities Engineering Command Atlantic under
Contract No. N62470-15-D-8006, TO 0027
issued to HDR, Inc.

Prepared by:

Susan G. Barco, Sarah A. Rose, and Gwen Lockhart
Virginia Aquarium & Marine Science Center Foundation, Inc.

Submitted by:

HDR
Virginia Beach, VA

June 2017

Suggested Citation:

Barco, S.G., S.A. Rose, and G.G. Lockhart. 2017. *Turtle Tagging and Tracking in Chesapeake Bay and Coastal Waters of Virginia: 2016 Annual Progress Report*. Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command Atlantic, Norfolk, Virginia, under Contract No. N62470-15-D-8006, TO 0027 issued to HDR Inc., Virginia Beach, Virginia. June 2017.

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Preparing the carapace of a stranded juvenile Kemp's ridley turtle for a tag mount that includes a layer of neoprene to allow for shell growth following tag attachment. The blue lines on the carapace are scute margins covered with silicone material to allow for neoprene expansion from growth. Photo courtesy of Virginia Aquarium & Marine Science Center Foundation, Inc.

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.

Table of Contents

Figures

Tables

Acronyms and Abbreviations

°C	degrees Celsius
cm	centimeter(s)
hp	horsepower
hr	hour(s)
kg	kilogram(s)
m	meter(s)
NAVFAC	Naval Facilities Engineering Command
NMFS	National Marine Fisheries Service
OBIS-SEAMAP	Ocean Biogeographic Information System-Spatial Ecological Analysis of Megavertebrate Populations
OE	Ocean Explorer
PCV	Packed cell volume of blood
PIT	passive integrated transponder
PTT	platform terminal transmitter
SCL-NT	straight carapace length notch-to-tip
SD	standard deviation
SPOT	Smart Position and Temperature
U.S.	United States
USFWS	U.S. Fish & Wildlife Service
VAQF	Virginia Aquarium & Marine Science Center Foundation

1. Background & Introduction

Five species of sea turtles occur in the Chesapeake Bay and the coastal waters of Virginia with varying regularity. They include the loggerhead turtle (*Caretta caretta*), Kemp's ridley turtle (*Lepidochelys kempii*), green turtle (*Chelonia mydas*), leatherback turtle (*Dermochelys coriacea*), and hawksbill turtle (*Eretmochelys imbricata*). Loggerhead and Kemp's ridley turtles are the most abundant and regularly occurring species and green turtle numbers have been steadily increasing over the past two decades in Virginia (Barco et al. 2015, Musick and Limpus 1997, Swingle et al. 2014, 2015, 2016).

The goal of this report is to provide the United States (U.S.) Department of the Navy (Navy) with the necessary data to help identify seasonal areas where Kemp's ridley and green turtles are likely to occur in order to inform Navy environmental planning efforts. There are two aspects of this project:

- Characterizing broad-scale movement patterns using satellite telemetry;
- Characterizing turtle presence in areas utilized by the Navy in the lower Chesapeake Bay and nearby Atlantic Ocean using two transmitter types:
    - satellite telemetry
    - acoustic telemetry.

There was no acoustic telemetry effort in 2016, and 2015 acoustic telemetry effort was summarized in the 2016 report. This report is a summary of satellite tag efforts for 2016 and this project to date.

2. Kemp's Ridley and Green Sea Turtle Tagging

2.1 Methods

2.1.1 Access to Turtles

Turtles for this project were acquired in three ways: 1) direct capture by researchers, 2) incidental capture in commercial fisheries or trawl operations associated with dredging, or 3) rehabilitation and release of stranded animals. In addition, the Virginia Aquarium & Marine Science Center Foundation (VAQF) has provided the Navy with data from five historic tags applied to green and Kemp's ridley turtles from 2007 to 2013.

Turtles acquired via direct or incidental capture were taken under the authority of National Marine Fisheries Service (NMFS) Research Permit No. 16134. Dip-netting techniques were used for all direct captures of satellite tagged turtles. The dip net live capture techniques utilized for this study were modeled after the technique developed by the Coonamessett Farm Foundation and Northeast Fisheries Science Center (Smolowitz et al. 2012) to capture sea turtles in the cooler months of May and early June in ocean waters. Two research vessels were utilized for dip netting captures, these included: (1) the Ocean Explorer (OE), a 13.7-meter (m) Doucette boat with a 700-horsepower (hp) Caterpillar diesel inboard motor, flying bridge and observation tower and (2) a 4.9-m soft bottom inflatable vessel equipped with a 20-hp Honda four-stroke outboard motor.

The dip net used in this study had a net hoop of 88 centimeters (cm) inside diameter, an 84.5-cm mesh netting diameter, and a net depth of 101 cm. The mesh measured 5.1 cm × 5.1 cm and was composed of black, knotted polypropylene twine. Dip net capture occurred from the inflatable vessel. The inflatable vessel was either towed behind the OE or lifted with an onboard crane and secured on the deck for transport. When search effort was initiated, the inflatable vessel was towed behind the OE. The OE was used as an observation platform to search for and locate sea turtles basking on the surface. Once a turtle was sighted, the inflatable vessel was deployed to approach and net the turtle using the large dip net, with two to three crew members depending upon how many people would be necessary to lift the turtle into the boat. At least four observers were stationed on or above the flying bridge and driving tower on the OE. Observers were positioned at lookout points stationed at 90 degree angles (i.e., 1200, 0300, 0600, and 0900) and searched in a scanning motion covering at least a 180 degree angle of view at each lookout point. When a turtle was sighted, the observer would maintain visual contact on the turtle and direct the captain in the direction of the turtle. The captain steered the boat from the tuna tower for a higher vantage point to efficiently sight and relocate the turtle after initial observation. A crew member on the OE and the inflatable vessel retained a handheld VHF walkie-talkie to communicate the bearing of the turtle. One person operated the inflatable vessel and maintained contact with the OE while another stood ready on the bow of the vessel with the dip net. When the turtle was in sight, the crew member in charge of the net directed the driver toward the turtle. The turtle was approached so that the bow of the boat was oriented toward the tail end of the turtle. The crew member capturing used an overhand dipping technique placing the furthest point of the hoop in front of the turtle and swiftly scooping the turtle from below. Once the turtle was in the net and the person capturing completed a full downward swoop with the dip net, the operator quickly idled the motor and grabbed the hoop to ensure the turtle did not escape. Each crew member in the boat assisted in lifting the turtle up and over the side of the vessel. The capture vessel immediately returned to the OE for animal processing.

Wild turtles were also removed from the trap area of pound nets, which are a type of fish trap utilized by commercial fisherman to catch a variety of fish species. Researchers worked with two pound net fishermen on the eastern shore of Virginia and one at the southern shore of the Chesapeake Bay mouth in order to gain access to incidentally caught turtles. Turtles occasionally swim into the pound head of these nets where they become trapped, free-swimming, until fisherman fish the nets. The mesh in the pound head is small (approximately 1.5 cm square), and there is little danger of entanglement or drowning. Loggerhead and Kemp's ridley sea turtles are frequently found in the pound nets' heads, unharmed, and consuming fish that are trapped in the head. Some sea turtles have been found to return to pound nets to forage (Mansfield 2006; VAQF unpublished data). Researchers opportunistically collected turtles that were trapped in the nets. A team was organized to respond at the time the fisherman expected to fish the nets. As the net was fished, the fishing crew lifted or bailed the turtle from the net and transferred it to the research vessel. The turtle was transported to a response van where diagnostic and tagging equipment was set up for processing. Once processed, the turtle was released from the shore or a vessel in the vicinity of the capture site.

In addition to wild caught and incidentally caught animals, researchers used data from transmitters that were deployed on rehabilitated and released sea turtles. Since the spring of 2016, all stranded were caught on recreational fishing gear in Virginia and were deemed otherwise healthy.

2.1.2 Tagging and Health Assessment

All turtles utilized in this study were assessed to determine their general state of health and suitability for tagging procedures. Under permit requirements, blood was collected from each wild turtle and a hematocrit or packed cell volume (PCV) reading from centrifuged microhematocrit tubes (e.g., not from a portable blood analyzer made for mammalian blood) was determined. Turtles with obvious wounds or debilitation were taken for rehabilitation, and research samples were not collected. Uninjured turtles with a packed cell volume of blood (PCV) greater than 13 percent with healthy carapace scutes were tagged with satellite transmitters and released.

This project includes Kemp's ridley and green turtles, which are usually smaller than most loggerhead turtles encountered in Virginia. Under our NMFS research permit, weight of telemetry devices (and epoxy) attached to sea turtles must not exceed 3 percent of the animal's body weight, requiring the use of lighter transmitters for these smaller turtles. In 2016, the U.S. Fish and Wildlife Service (USFWS) enacted new rules for rehabilitated turtles that assess drag produced by transmitters instead of weight of transmitters. The new approach required a new process for requesting to tag turtles being released from rehabilitation and for several weeks before the decision was complete, we were unable to tag any turtles released from rehab. Once the process was developed, transmitters that produced less than 5 percent drag were allowed to be attached if the USFWS felt that the reason for attachment was scientifically sound. Since we did not anticipate this new rule, we purchased transmitters for maximum battery life, not reduced drag. There are, in fact, very few battery-operated, transmitters for diving animals on the market that produce less than 5 percent drag on a 6 to 7 kilogram (kg) sea turtle.

Prior to transmitter attachment, the carapace of each turtle was prepared by removing epibiota and dead scute tissue with putty knives and coarse (60 to 100 grit) sandpaper. After sanding, the scutes were wiped clean and washed with acetone. Researchers used Sika Anchorfix-1™ epoxy for transmitter attachments on larger, >40-cm straight carapace length notch-to-tip (SCL-NT), turtles. The epoxy was used to create a teardrop-shaped footprint with the broad, rounded part of the teardrop facing cranially and the narrow, pointed part of the teardrop facing caudally in order to improve hydrodynamics (Jones et al. 2011). In addition to satellite transmitters, all turtles were individually tagged with Inconel flipper tags and a passive integrated transponder (PIT) tag.

Tag retention can be problematic on smaller, hard-shelled turtles compared to larger size classes of the same species (reviewed in Seney et al. 2010). One hypothesis for poor tag performance on smaller turtles is that rapid growth rate combined with rigid epoxy adhesives can be detrimental to tag retention and/or normal turtle growth (Seney 2008). Thus, for turtles less than 40 cm SCL-NT we employed a technique that includes a layer of flexible neoprene between the carapace and rigid epoxy. The neoprene is affixed to the centers of the scutes using rigid epoxy but the seams between the scutes, where growth occurs, is protected by silicone gasket material, allowing for both the silicone and neoprene to stretch as the animal grows. This technique was used on two turtles tagged in 2016 (**Figure 1**).

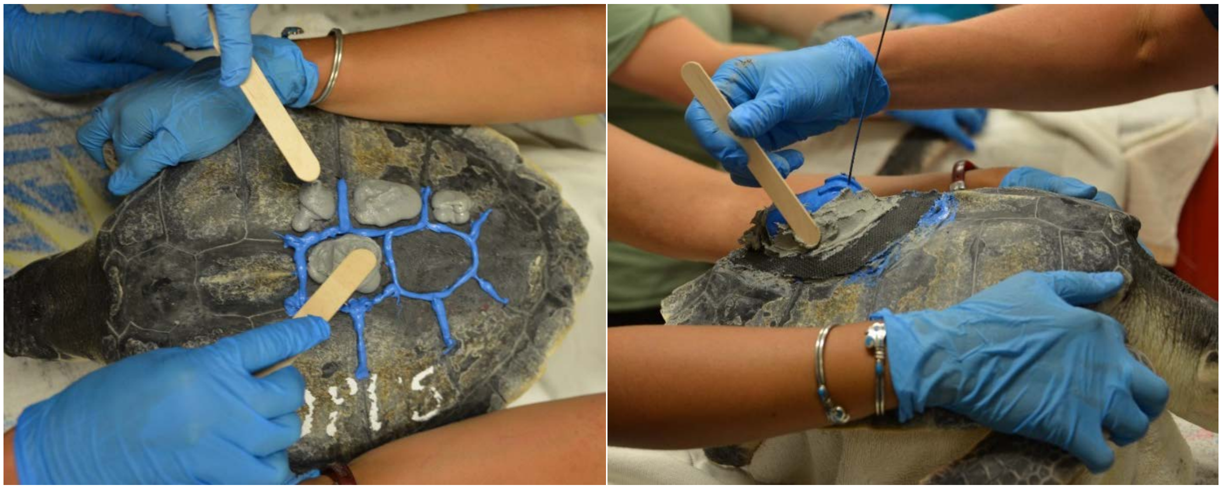

Figure 1: Applying a flexible attachment to a small Kemp's ridley turtle. The blue material applied to the carapace (left image) is silicone gasket material designed to stretch as the turtle grows at the scute margins. A layer of neoprene is affixed to the center of the scutes using rigid epoxy (gray), and then the transmitter is secured to the neoprene (right image).

Tag types deployed in 2016

The researchers used the following three satellite tag models in 2016:

1. Wildlife Computers data-logging SPLASH tags with Argos transmitter, pressure sensor, and ambient temperature sensor.
2. Wildlife Computers Smart Position and Temperature (SPOT) tags with Argos transmitter and ambient temperature sensor.
3. Lotek Sirtrack Kiwisat K2G273 with Argos transmitter

Under NMFS research permit conditions, VAQF could deploy SPLASH tags on turtles that weighed 11 kg or more, and SPOT or Kiwisat K2G273 tags could be deployed on turtles weighing between 8 and 9 kg. Under USFWS' 5 percent drag rule, which was implemented in the spring of 2016 for stranded turtles, none of these tags could be deployed on Kemp's ridley, green, or loggerhead turtles less than 61 cm SCL-NT without a special application and review based on a tag drag tech memo by Jones et al. (2011). In the VAQF stranding data, we have had no live or dead stranded Kemp's ridley turtles over 61 cm SCL-NT in the past 10 years and have recorded one live stranded green over 61 cm SCL-NT in the history of the stranding program (VAQF unpublished data). Since the USFWS implemented the 5 percent drag rule prior to developing a process to apply for an exemption, this rule effectively restricted VAQF from deploying tags on stranded Kemp's ridley and green turtles from May until after mid-July. In practice, limiting tag size based on drag makes sense; however, the drag limit of 5 percent is restrictive since these turtles can acquire natural epibiota that likely produces similar drag. The four stranded Kemp's ridley turtles for which we eventually received permission to tag (49.4, 45.4, 34.0 and 33.7 cm) had estimated increases in drag of 8, 8, 8-9 and 11 percent from two SPLASH, a K2g273 and a SPOT tag respectively.

All satellite tags were programed to collect continuous location and sensor data. SPLASH tags were programed to record the percentages of time over 6-hour (hr) periods that turtles spent within defined ambient water temperature and depth intervals. The temperature intervals were defined by every 2 degrees Celsius (°C) from 8°C to 32°C, and >32°C. The programed depth intervals (in meters [m]) were: <1, 1–2, 2–3, 3–4, 4–5, 5–10, 10–20, 20–30, 30–40, 40–50, 50–100, 100–150, 150–200; and >200. SPOT tags have ambient water temperature sensors and were programed to record the percentages of time over 6-hr periods that turtles spent in 2°C temperature intervals from 12 to 32°C. Sirtrack tags were used as location only tags, and we did not utilize sensors.

There were no acoustic tags deployed in the 2016 field season.

2.2 Results & Discussion

In 2016, the spring weather was unusually windy and overcast, and we were unable to complete any dip net trips to capture wild turtles. The first live, stranded turtle occurred on 30 April 2016, and it was a large Kemp's ridley hooked by a recreational angler at the Virginia Beach fishing pier on the oceanfront. This turtle was followed by 30 additional live Kemp's ridley turtles hooked in May, all but two of which, were recovered for rehabilitation. We released 22 of the Kemp's ridley turtles that stranded in May before we were able to apply to tag stranded turtles. Sixteen of those were large enough to be tagged with either a SPOT or K2G273 transmitter and two could have carried a SPLASH tag. Three additional Kemp's ridley turtles and one green turtle were hooked in June and early July 2016

We did receive permission to tag four hooked and rehabilitated Kemp's ridley turtles in 2016. The first was released on 02 July 2016 after a USFWS permit office decided that the old rules based on tag weight were still in place until a new process was enacted. That decision was reversed shortly afterward when an appeal process was developed. The second turtle was released on 22 July 2016 after the appeal was reviewed, and two more were released on 26 July 2016. No other turtles were eligible for release until after August, and, therefore, were not tagged.

These four Kemp's ridley turtles, in addition to nine previously tagged Kemp's ridleys for this project, make up the 13 Navy tags thus far deployed on juvenile Kemp's ridley turtles (**Table 1**). In addition to the five historic tags, three on green and two on Kemp's ridley turtles, we are beginning to develop a reasonable data set for these two species. Of the eighteen tags deployed thus far, two failed to transmit for more than 48 hr and one transmitted for one day after the 48-hr period (that is usually discarded). The 15 remaining tags transmitted for 11 to 229 days post-release with a mean of 58 days (±56 standard deviation [SD]) and a median of 38 days. The two longest retention times were for Kemp's ridley turtles that were released in October and did not spend much time in Chesapeake Bay, but instead migrated south. The mean and median for turtles released May through September was 34 (±15 SD) and 37 days respectively (**Table 2**). This relatively short tag retention time is consistent with earlier tagging efforts by Jack Musick and colleagues at the Virginia Institute of Marine Science (K. Mansfield pers. comm.).

Table 1: Satellite tagged Kemp's ridley and green turtles.

Field Number	PTT	Species	SCL-NT (cm)	Weight (kg)	Name	Source	Reason/ method	Project
VAQS20132227	138114	Lk	40.2	12.8	Loki	stranded	cold stun	2014 Navy
VAQS20132229	132367	Lk	34.0	7.0	Gaia	stranded	cold stun	2014 Navy
VAQS20142152	138117	Lk	35.1	6.5	Joffrey	stranded	hooked	2014 Navy
VAQR201503	148882	Lk	36.2	ND	Iggy Pop	captured	dip net	2015 Navy
VAQR201504	148880	Lk	34.2	ND	Bob Marley	captured	dip net	2015 Navy
VAQR201505	148886	Lk	51.0	18.0	Jerry Garcia	captured	dip net	2015 Navy
VAQS20142244	148889	Lk	44.0	16.4	Racer 5	stranded	cold stun	2015 Navy
VAQS20152008	148881	Lk	38.1	7.2	Friar Tuck	stranded	hooked	2015 Navy
VAQS20152049	150767	Lk	35.0	6.2	Sven	stranded	hooked	2015 Navy
VAQS20162016	159709	Lk	49.4	16.3	Sage	stranded	hooked	2016 Navy
VAQS20162029	164721	Lk	33.7	5.6	Salt	stranded	hooked	2016 Navy
VAQS20162039	159705	Lk	33.8	5.6	Hops	stranded	hooked	2016 Navy
VAQS20162089	159708	Lk	45.4	11.9	Lemongrass	stranded	hooked	2016 Navy
VAQS20072055	65799	Cm	106.0	150.0	Tiki Jr.	stranded	entangled	historic
VAQS20082129	65800	Cm	34.0	6.0	Kermit	stranded	debris ingestion	historic
VAQS20112010	108054	Lk	36.9	6.5	Argentum	stranded	cold stun	historic
VAQS20122001	117180	Cm	32.5	4.9	Makahiki	stranded	cold stun	historic
VAQS20122175	129021	Lk	44.0	14.0	Caramel	stranded	cold stun	historic

Key:
Cm=*Chelonia mydas* (green turtle); Lk=*Lepidochelys kempii* (Kemp's ridley turtle).
PTT=platform terminal transmitter which is a unique ID associated with each satellite tag

Table 2: Results of satellite telemetry to date.

Field Number	PTT	Species	Release Date	Last transmission	Days	Project	Tag Manufacturer	Tag model
VAQS20132227	138114	Lk	10/20/2014	6/6/2015	229	2014 Navy	Wildlife Computers	SPLASH-10
VAQS20132229	132367	Lk	7/9/2014	8/15/2014	37	2014 Navy	Wildlife Computers	SPOT-5
VAQS20142152	138117	Lk	9/2/2014	10/10/2014	38	2014 Navy	Wildlife Computers	SPOT-5
VAQR201503	148882	Lk	5/18/2015	5/30/2015	11	2015 Navy	Microwave Telemetry	9.5g Solar PTTs
VAQR201504	148880	Lk	5/18/2015	NA	0	2015 Navy	Microwave Telemetry	9.5g Solar PTTs
VAQR201505	148886	Lk	5/29/2015	7/12/2015	44	2015 Navy	Wildlife Computers	SPLASH-10
VAQS20142244	148889	Lk	5/16/2015	7/14/2015	59	2015 Navy	Wildlife Computers	SPLASH-10
VAQS20152008	148881	Lk	5/16/2015	6/23/2015	38	2015 Navy	Microwave Telemetry	9.5g Solar PTTs
VAQS20152049	150767	Lk	6/24/2015	7/5/2015	11	2015 Navy	Wildlife Computers	SPOT-6 278C
VAQS20162016	159709	Lk	7/26/2016	8/27/2016	32	2016 Navy	Wildlife Computers	SPLASH-10
VAQS20162029	164721	Lk	7/26/2016	8/27/2016	40	2016 Navy	Sirtrack	K2G 273
VAQS20162039	159705	Lk	7/22/2016	7/23/2016	1	2016 Navy	Wildlife Computers	SPOT-6 278C
VAQS20162089	159708	Lk	7/2/2016	8/5/2016	34	2016 Navy	Wildlife Computers	SPLASH-10
VAQS20072055	65799	Cm	10/20/2007	2/24/2008	127	historic	Telonics	A-1010
VAQS20082129	65800	Cm	6/22/2009	8/17/2009	56	historic	Telonics	A-1010
VAQS20112010	108054	Lk	6/29/2011	7/15/2011	16	historic	Wildlife Computers	SPLASH-100
VAQS20122001	117180	Cm	6/14/2012	NA	0	historic	Wildlife Computers	SPLASH-100
VAQS20122175	129021	Lk	6/21/2013	7/12/2013	21	historic	Wildlife Computers	SPLASH-284A

The column labeled ‘Days’ is the number of days from release to last transmission.

Researchers believe that short tag transmission times may be related to tag antenna fouling where debris such as dead eelgrass or similar cause the flexible whip-like antenna on Wildlife Computers' tags to lay flat on a turtle's carapace preventing data transmission. For this reason, we have invested in Sirtrack Kiwisat tags, which have stiffer, more upright, antennae compared to Wildlife Computers' SPOT and SPLASH tags. Another possibility for low transmission times in Chesapeake Bay is that the complex environment with multiple structures in the form of bridges, pilings, concrete fish habitat, and stationary vessels provide numerous surfaces upon which turtles can rub, harm, or remove epibiota and attached tags.

Preliminary analysis of satellite telemetry data filtered for location quality suggests that the Poquoson flats area, on the western shore of Chesapeake Bay, north of the Back River and south of the York river, may be a Kemp's ridley foraging area that is not well utilized by loggerheads and that other areas such as seaside eastern shore sounds and river mouths may be more important for Kemp's ridley turtles (**Figure 2**). Because there have been only three satellite tagged green turtles, we have not conducted any analyses on green turtle satellite tracking data.

Seasonally, Kemp's ridley turtles exhibit similar seasonal distribution as loggerhead turtles, but may not spend time foraging in offshore ocean waters as some loggerheads appear to do (**Figure 3**).

2.3 Summary and Future Work

The satellite telemetry data collected from Kemp's ridley turtles for this on-going project are beginning to provide important information on the locations of Kemp's ridley turtles in relation to military facilities and training areas. Continued data collection is needed for Kemp's ridley turtles and we have decided to limit green turtle tagging to acoustic tags because it is unlikely that we will be able to collect a large enough data set using satellite telemetry to conduct a species-specific foraging analysis as we did with loggerhead and plan to conduct with Kemp's ridley turtles. In 2017, we will continue to deploy the three satellite tag types deployed in 2016, as well as a smaller Sirtrack tag that will permit us to more effectively track small juvenile Kemp's ridley turtles. In addition, we will again be using acoustic telemetry to track green and smaller Kemp's ridley turtles.

Our goal is to develop a large enough data set to conduct species-specific foraging analyses similar to what was conducted for loggerhead sea turtles (Lockhart et al. in prep).

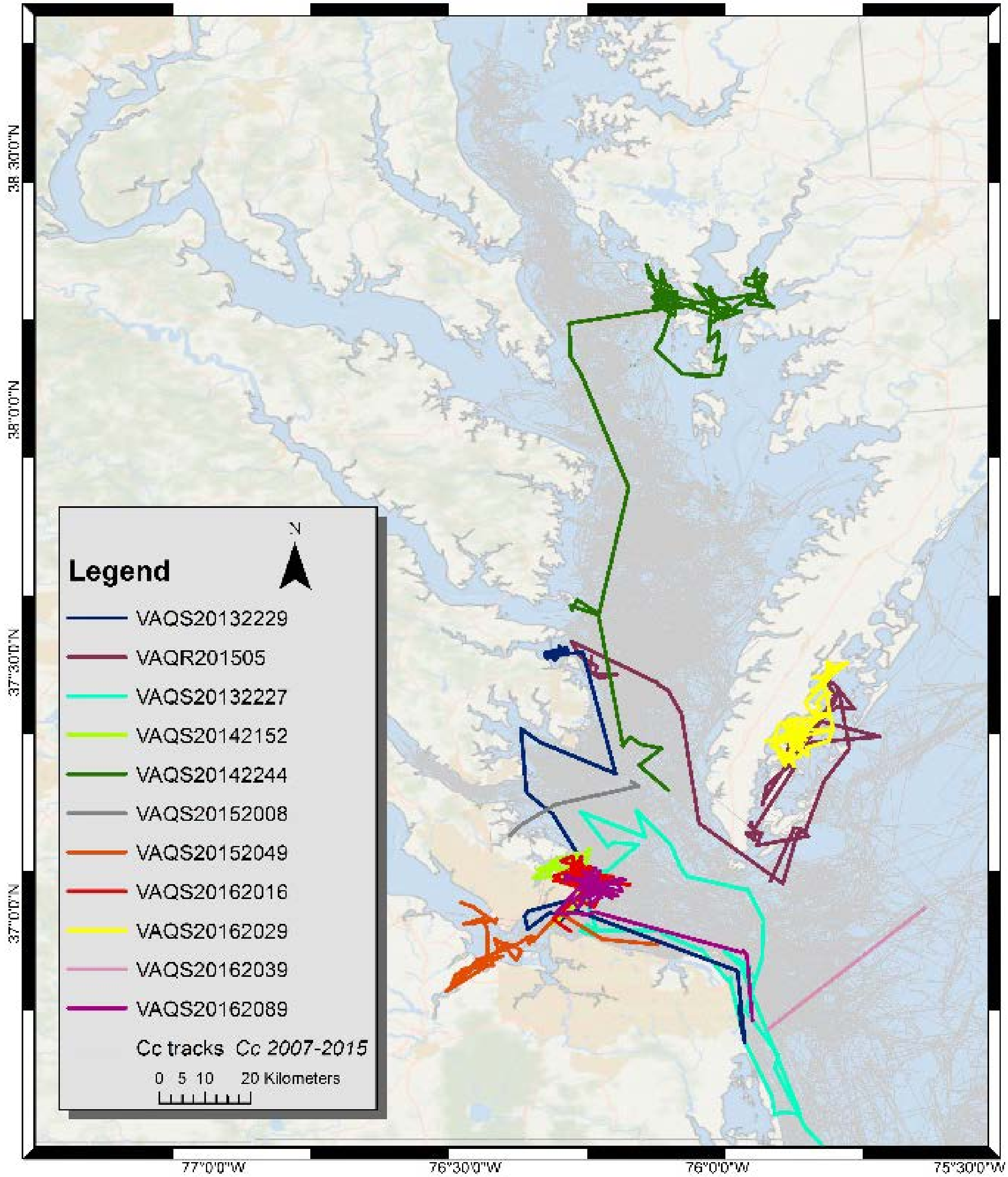

Figure 2: Tracks of 11 Kemp's ridley turtles tagged from 2014 to 2016 as part of this project. The colored Kemp's ridley tracks are overlaid on pale gray loggerhead (Cc) tracks to compare distribution.

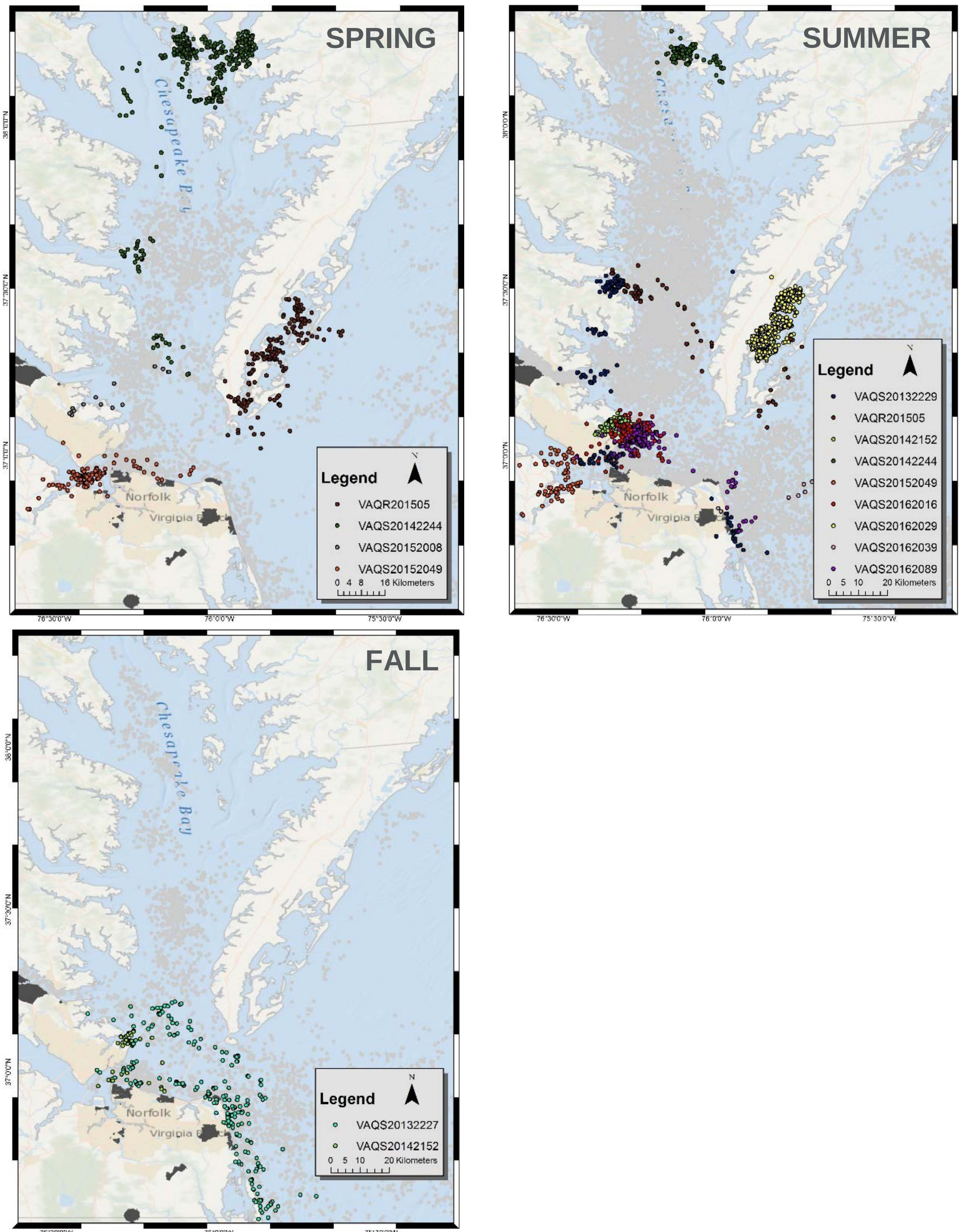

Figure 3: Seasonal distribution of Argos locations (filtered to exclude Class LC, B, and Z) for Kemp's ridley turtles tagged from 2014 through 2016. Spring was defined as April through June, Summer as July through September, and Fall as October through December. There were no locations recorded in the area in Winter (January through March). Background points in gray represent loggerhead locations for the same season.

3. Loggerhead Tagging

3.1 Summary of Tagging Data

The analysis included loggerhead turtles that were released in Virginia or North Carolina, transmitted more than 21 days, and remained between the U.S. shore and the 200-meter western Atlantic bathymetry contour during that time. Nineteen loggerheads were telemetered with tags purchased using funds provided by Fleet Forces Command. Of those, 17 were used in a foraging analysis that combined a switching state-space model SSM) with cumulative home range analysis of foraging points. This project leveraged data from 27 additional loggerhead turtles tagged by VAQF using alternative funding sources. Loggerheads included in this analysis were captured directly (n=5), incidentally captured in a pound net, dredge trawl or swimming enclosure (n=8), or rehabilitated and released (n=32). Thirteen turtles were caught and released onsite. The rehabilitated turtles initially stranded for a number of reasons, including: entanglement in pot gear (n=3), recreational hook and line interaction (n=10), cold stun (n=9), trauma from vessel (n=5), trauma from hopper dredge (n=1), or unknown cause (n=3). Specific details about transmitter types, turtle sources and methodology are included in a manuscript currently being prepared for publication (Lockhart et al. in prep).

3.2 Home Range Analysis and Foraging Behavior

Both GPS and ARGOS locations were used in the analysis to leverage the precision of the GPS data and quantity of the ARGOS data. Data source attributes were preserved in order to enable independent treatment of GPS and ARGOS data in subsequent SSM modeling steps. All locations that passed filtering were loaded into an ArcGIS™ 10.0 workspace where additional filtering was applied. Researchers then added a bathymetry attribute to the filtered location data. For analysis, researchers considered all points separated by 7 or more days to be a separate deployment to avoid over-smoothing of the trackline in the SSM model.

A modified version of the SSM first introduced in Jonsen et al. (2005), and using code from Breed et al. (2009) was applied to all tracks in order to gain inference on animal behavior (foraging versus migration) and secondarily to smooth the track into even time intervals, which helped mitigate spatial autocorrelation within a track. The selected model was originally developed for seals but has been shown to be applicable to marine turtles (Hart et al. 2013). The SSM was run using R (R Core Team 2015) and WinBugs (Thomas 1994). Six hours was used as the time interval to smooth the track and was selected as a compromise between detecting meaningful changes in animal behavior and model processing time. The model attempted to classify smoothed points into two states, nominally foraging and migration. SSM diagnostics were examined to ensure that Monte Carlo Markov Chains (MCMC) were mixing. After assignment, tracks were visually inspected to assess model performance.

In order to understand seasonal changes in foraging behavior, researchers conducted a home-range analysis only using the points identified as “foraging” by the SSM for each turtle and each month. Turtles were included in a monthly analysis if the animal had at least 32 interpolated points over 8 consecutive days in a month. This assured that each animal had at least a week’s worth of consecutive data that visually appeared to represent consecutive foraging activity.

We created convex hull UDs for each turtle in each month and calculated the 10, 25, 50, 75 and 95 percent isopleths (Calenge et al. 2006). We used ArcGIS to convert each isopleth polygon into a raster grid with a cell size of 1,000 × 1,000 meters. The value of each 1,000 × 1,000-m cell was the value of the isopleth under the centroid of each cell. If a cell included in a 75 percent isopleth, it received a value of 75 and if a cell included in a 25 percent isopleth it received a value of 25. All isopleth rasters, for each turtle, in each month, were overlaid and the values were summed. This resulted in monthly raster grids, with each 1,000 ×1,000-m cell indicating a relative level of foraging from all turtles tracked in that month. Cells where foraging behavior was more likely to occur had higher values because isopleths from more turtles were added together. Additionally, all grids from the loggerheads used in the analysis were summed to calculate foraging levels for all months combined. We then grouped the summed grid values for each month's data into five relative foraging area (RFA) levels. This analysis does not make the relative levels of foraging equivalent between months because not all turtles foraged in all months, but it does allow for comparison of foraging distribution among time periods.

The analysis area was divided into the following four geographic zones: 1) upper Chesapeake Bay, 2) lower Chesapeake Bay, 3) waters north of North Carolina/Virginia Border (excluding the Chesapeake Bay), and 4) waters south of the North Carolina/Virginia border (**Figure 4**). The upper Chesapeake Bay was defined of the area north of Mobjack Bay, including the York River and the lower Chesapeake Bay was defined as the areas south of Mobjack Bay and east of the Chesapeake Bay COLREGS line. The waters south of the Virginia/North Carolina border included inland waterways such as Pamlico Sound. The ocean waters north of the Virginia/North Carolina border include the foraging areas on the leeward side of ocean barrier islands and the Delaware Bay. The area, in square kilometers, was calculated for all the RFAs, in each geographic zone, in each season. Minimum, maximum, and mean latitudes for each RFA zone, in each month were tabulated. The areas and coordinates were compared by temporal and spatial difference in foraging levels.

The number of turtles used to create the monthly foraging grids varied from month-to-month and ranged from a low of 13 in March to a high of 27 in July. Foraging maps for the entire data set clearly show that the highest RFA levels were located off the northern coasts of Virginia and Maryland, throughout the Chesapeake Bay, off Cape Hatteras, North Carolina, and in Onslow Bay off the coast of southern North Carolina (**Figure 5**).

Foraging within the Chesapeake Bay was constrained by physical barriers making the spatial patterns less diffuse and denser than patterns in the ocean, with the exception of the area around Cape Hatteras. Higher ocean RFA levels were clearly focused around Cape Hatteras, suggesting that the area offers habitat characteristics favorable for sea turtle foraging which occurs primarily in the winter and early spring. The analysis all foraging activity suggests that similar high levels of relative foraging intensity occur in Chesapeake Bay and off Cape Hatteras and similar medium-high levels occur in ocean waters of Virginia through Delaware and Onslow Bay off southern NC. Many of the loggerhead turtles that were released in Virginia spent cooler months off Cape Hatteras and/or in Onslow Bay suggesting a restricted home range for some of these migratory animals with complimentary levels of foraging in each area at different times of the year.

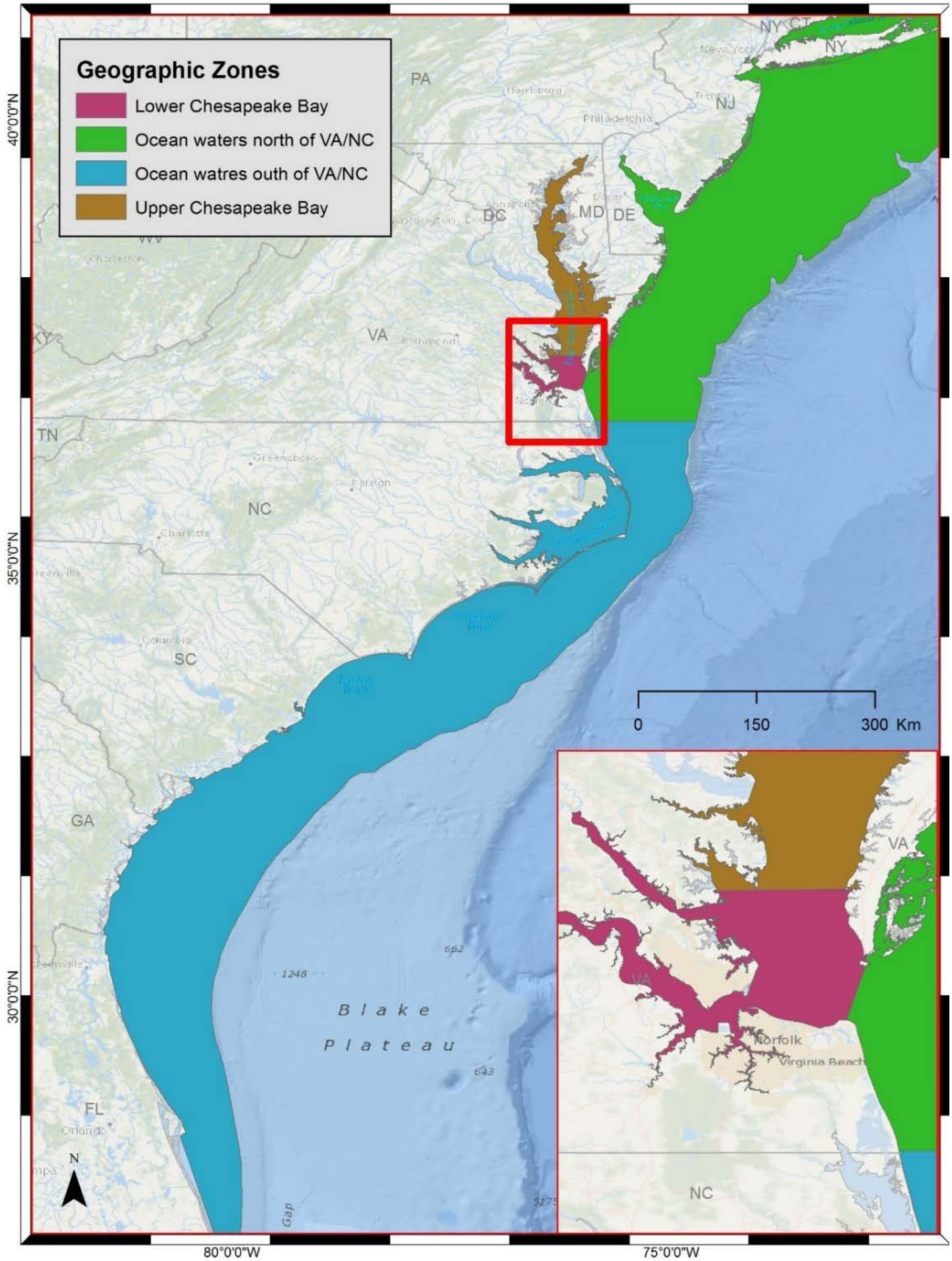

Figure 4: Geographic zones used to create summary statistics.

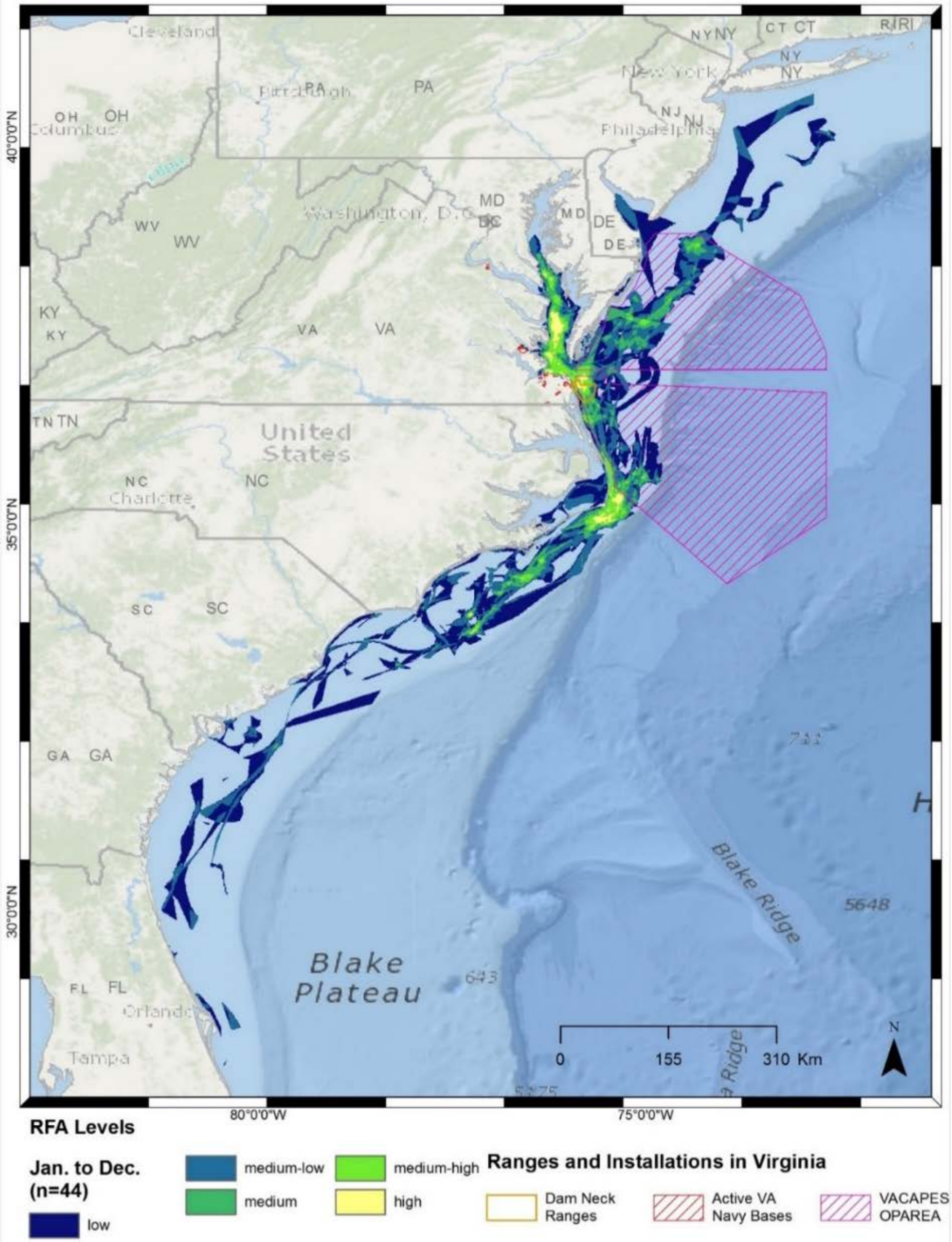

Figure 5: Relative foraging area (RFA) for all loggerheads used in the analyses, with all months combined.

When the RFAs were divided by season, a clear shift in foraging among the geographic zones was seen among seasons. In the winter 100% foraging activity occurred south of 36° N, mostly in NC, with 48%, 19%, and 71% in the spring, summer and fall respectively **(Figure 6)**. In contrast, 52% of the RFA was in the Chesapeake Bay and the northern ocean zone in spring, with 78% and 29% in the summer and fall respectively (**Figure 7**). Although there was likely a bias in the amount of foraging that occurred in Chesapeake Bay since most of the turtles were captured or stranded in or near the bay, these data clearly show the seasonal use of southern mid-Atlantic waters by loggerhead turtles.

Another caveat associated with this analysis is that the RFAs, may be influenced by individual turtle's behavior, especially when fewer turtles are added together in monthly maps. Some of the turtles spent a high proportion of time in very restricted area. For example: VAQR201312 was captured, tagged and released in the York River on July 24, 2013, and spent the next 100 days, through October 31, in a 21-km stretch of the river. When the turtle started moving out of Virginia, it travelled approximately 228 km in 9 days. This is the only turtle that spent any time in the York River, but because of its intensive foraging in that restricted area, this one animal's track suggests that loggerheads forage in the York River but not in other rivers. Alternatively, any areas of Chesapeake Bay and coastal ocean waters without foraging activity may only mean that researchers did not tag a turtle that foraged in that specific area, not that no foraging occurs there. Thus, while the patterns of foraging reflect an interesting distribution of loggerhead turtle foraging activity, the analysis that included all of the turtle data (see **Figure 5**) is probably the best reflection of where and how intensely foraging occurs in any one area as it included all turtle tracks and thus lessens the from individual turtle tracks.

It is interesting to note that only one of the turtles captured in the ocean transmitted from Chesapeake Bay, and that four of the five remaining turtles spent most of their time foraging in the ocean north of Virginia. All of the turtles captured in the ocean were tagged in May or early June, a time when some loggerhead turtles are migrating through Virginia ocean waters to more northern summer foraging areas. Because the turtles in this analysis were captured or primarily stranded in Virginia, these data may not reflect foraging activity in areas outside of Virginia. To accurately reflect, for example, foraging in Delaware Bay, one would need to tag turtles captured or stranded in or near Delaware Bay.

The results presented here and in future analyses will help state and federal protected species managers identify key foraging areas for loggerheads in both state and federal waters. These data can be used to develop critical habitat and to guide permitting for threatening behaviors such as dredging. However, it should be considered that sea turtle behavior is dependent on dynamic oceanographic patterns that are driven by shifts in inter-annual climatic patterns. The analyses presented here report areas where foraging activity is likely to occur on a monthly basis. While useful for risk mitigation, the analysis does not allow managers to predict sea turtle presence based on environmental variables and prey availability data. It is possible to create a predictive resource selection model based on known locations and independent covariates (Manly et al. 2007). Future plans include developing a resource selection model for tagged loggerheads in Virginia and Maryland waters. This would allow managers to predict where and when sea turtles will occur based on multiple predictive variables.

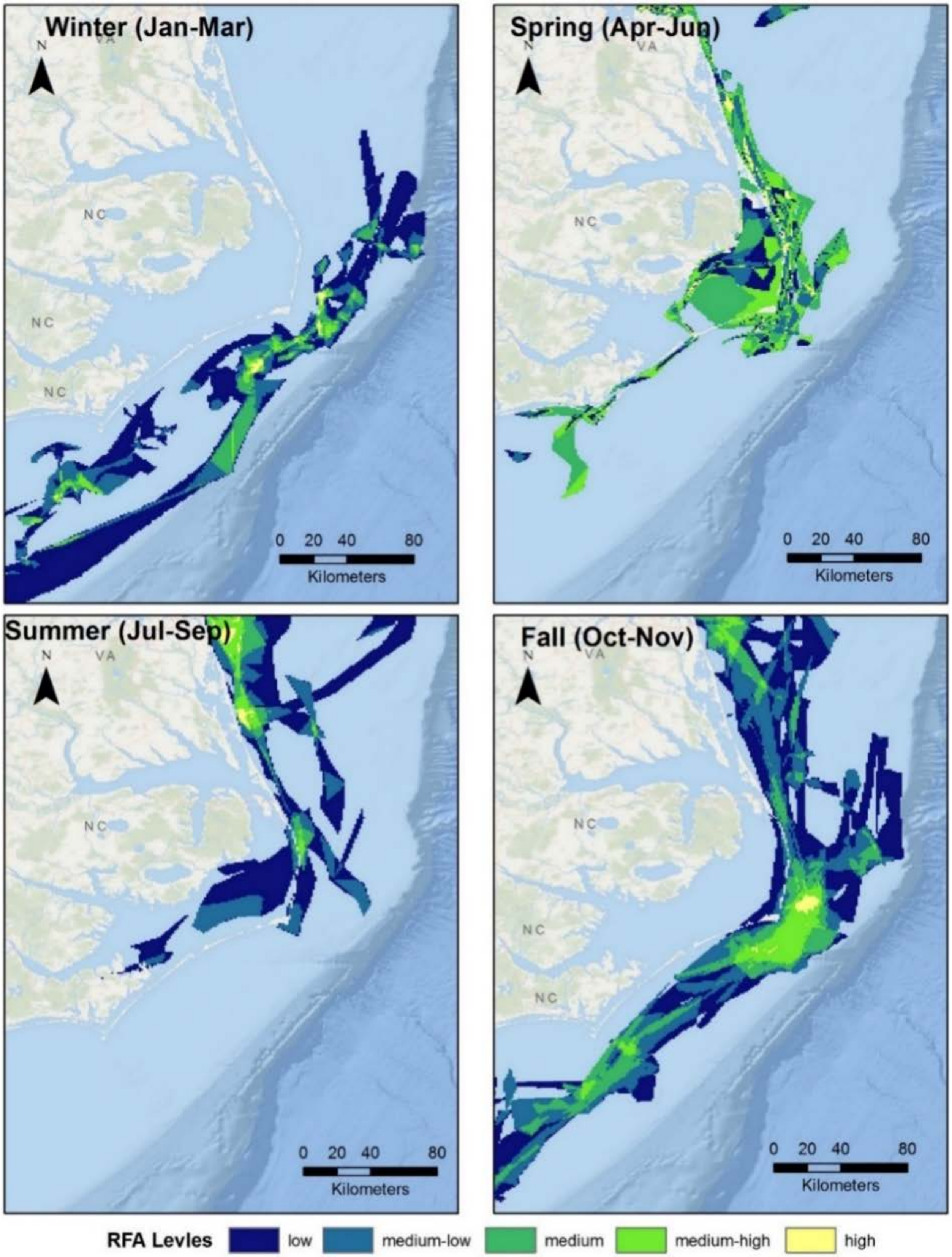

Figure 6: Relative foraging areas (RFAs) by season. The extent in each season shows all RFAs in North Carolina waters.

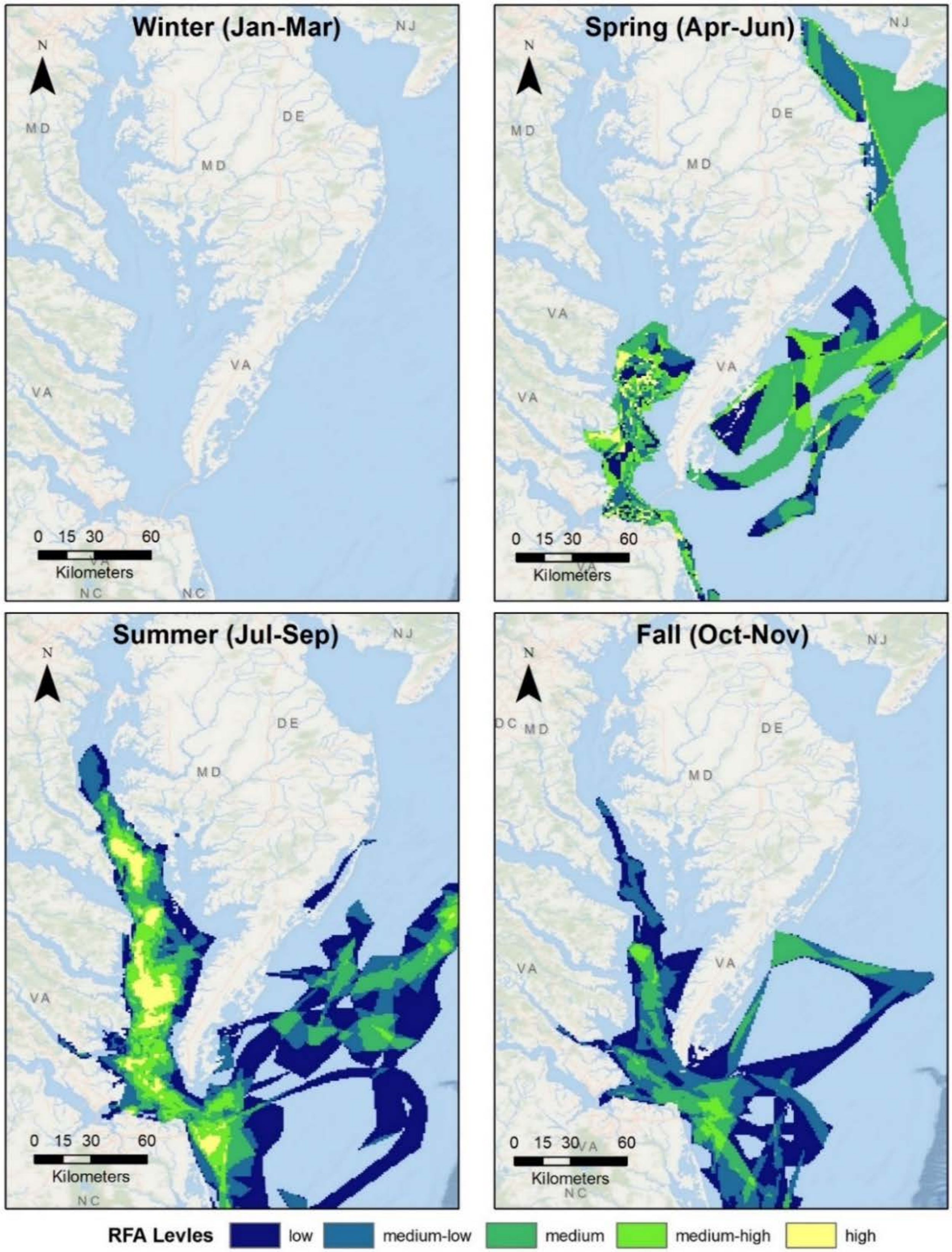

Figure 7: Relative foraging areas (RFAs) by season. The extent, in each season shows all RFAs in Virginia, Maryland, and Delaware waters.

4. Acknowledgements

We would like to thank Andrew DiMatteo and Carter Watterson from Naval Facilities Engineering Command (NAVFAC) Atlantic for their assistance, as well as other NAVFAC personnel who assisted with capture, tagging and release efforts. We would also like to thank the Virginia Aquarium staff, volunteers, interns and apprentices, who assisted with the project and sea turtle recovery/rehabilitation, as well as the recreational fishing piers, anglers, volunteers and Kathy O'Hara who promote and participate in the Virginia Aquarium Pier Partner Program. Sea turtle rehabilitation at the Virginia Aquarium is supported in part by an annual grant from the Virginia Coastal Management Program as well as the Virginia Aquarium Foundation and other donations, grants and contracts to the Virginia Aquarium Foundation.

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