



NOAA Technical Memorandum NMFS-SEFSC- 605

SURFACING BEHAVIOR OF LOGGERHEAD (*CARETTA CARETTA*) SEA TURTLES IN
ESTUARINE AND COASTAL WATERS OF NORTH CAROLINA

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Cover Photo: Releasing a satellite tagged loggerhead (M. April Goodman photo).



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Surfacing Behavior of Loggerhead (*Caretta caretta*) Sea Turtles in Estuarine and Coastal Waters of North Carolina

Executive Summary

To be in compliance with the Endangered Species Act, the United States Department of the Navy is required to assess the potential environmental impacts of conducting at-sea training operations on sea turtles. As a result, the National Marine Fisheries Service (NMFS) was contracted to examine the seasonal distribution and density of sea turtles within North Carolina's Core and Pamlico Sounds where the U.S. Navy Marine Corps Air Station (MCAS) Cherry Point performs at-sea bombing operations. The NMFS's current assessment of sea turtle populations likely underestimated sea turtle density because they did not account for surfacing behavior when calculating density (Goodman et al. 2007). To improve the assessment, we satellite tagged sea turtles to estimate the amount of time they spent at the surface of the water, and then applied a correction factor to previous density estimates.

We deployed 8 Wildlife Computer SPOT5 satellite tags from July to October 2007 and 13 Wildlife Computer SPLASH satellite tags from May to June 2008 on 20 loggerhead (*Caretta caretta*) sea turtles (one turtle was tagged with both a SPOT5 and SPLASH satellite tag) incidentally captured in pound nets set in Core and Pamlico Sounds. Transmitters measured the amount of time per 24-hour period that a tag's salt water switch was dry; thus, providing us with a minimum estimate of percent time the turtle spent at the surface per any given 24-hour period. The tags also calculated the percent time spent at temperature bins of <8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 30 and >30° C. In addition, SPLASH tags were equipped with a pressure sensor to calculate the percentage of time spent at different depths. We reasoned that turtles swimming within 1 meter of the surface would most likely be visible to observers during an aerial survey. We archived and filtered the data from satellite tags using the Satellite Tracking and Analysis Tool (STAT) (Coyne and Godley 2005) and tested surface interval data for differences among habitats (coastal versus estuarine) and seasons.

Length of transmission ranged 0 to 276 days for SPOT5 tags and 26 to 224 days for SPLASH tags. Loggerhead sea turtles spent 0.1 to 12.5% of their time on the surface of the water, with a minimum of 23% of their time spent within 1 m of the surface of the water. They spent a significantly greater average amount of time on the surface of the water in coastal (2.4%, t-test, $P < 0.01$) than estuarine waters (0.7%). Applying the average percentage of time spent on the surface of estuarine and coastal waters along with the percentage of time spent within 1 m of the surface of the water to population estimates reported by Goodman et al. (2007), we recalculated density and abundance estimates. Corrected density estimates ranged from 0.01 to 2.2 turtles/km² in the sounds and from 0.2 to 25.6 turtles/km² in the coastal region. Abundance estimates ranged from 16 to 4497 turtles in the sounds and from 44 to 3552 in the coastal region. Although we found no significant difference among seasons in the amount of time turtles spent on the surface of the estuary, they spent significantly more time on the surface along the coast of North Carolina during autumn (2.7%, Kruskal-Wallis, $p < 0.01$) than in the summer (2.4%)

Introduction

To comply with the Endangered Species Act, the United States Department of the Navy is required to assess the potential environmental impacts of conducting at-sea training operations to sea turtles. The Navy's Marine Corps Air Station (MCAS) Cherry Point operations areas (OPAREAs) (Fig. 1), located within Core and southern Pamlico Sounds, North Carolina, lie within the developmental habitat and foraging areas for sea turtles (Epperly et al. 1995a,b). Because training exercises at two bombing ranges (BT-9 and BT-11) occur on a regular basis (Fig 1), the National Marine Fisheries Service (NMFS) was contracted to survey the waters of Core and Pamlico Sounds within restricted area R-5306A and the coastal region within one mi of the coastline to document the seasonal distribution and abundance of sea turtles (Goodman et al. 2007). Aerial surveys allowed NMFS to assess the seasonal occurrence and relative abundance of sea turtles from July 2004 to April 2006. Their data suggest that sea turtles were most likely to be encountered within OPAREAs when sea surface temperatures (SSTs) were $\geq 11^{\circ}\text{C}$, and that mean seasonal density estimates were higher in the coastal than estuarine waters among all seasons except winter when no turtle were sighted in either region.

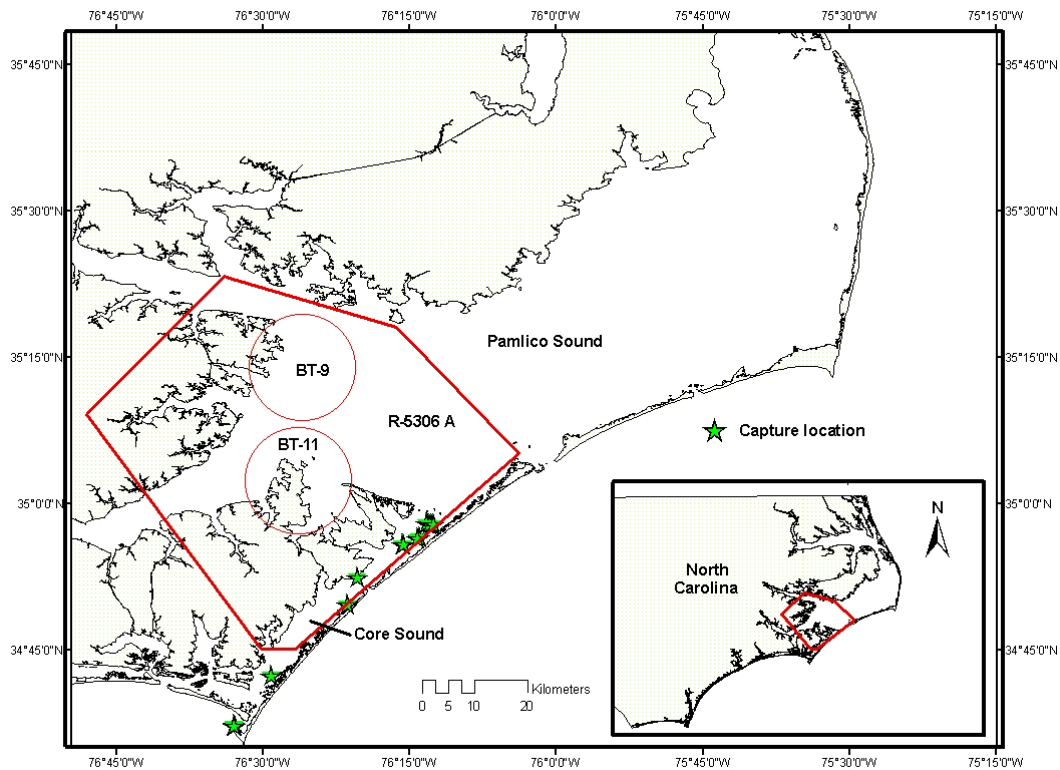


Fig. 1 Map of Core and Pamlico Sounds, N.C., USA. Restricted airspace R5306A depicted by red, hexagonal box; bombing targets BT-9 and BT-11 shown as red circles. Loggerheads were captured in pound nets denoted by green stars on map.

However, because little is known about the surfacing behavior of sea turtles within North Carolina's estuarine and coastal waters, researchers were not able to account for the proportion of animals that were below the surface at a given time and thereby undetectable during aerial surveys. In the Chesapeake Bay, loggerhead (*Caretta caretta*) sea turtles spent 5.3% of their time on the surface during summer and autumn (Byles 1988). In contrast, Mansfield (2006) found that surfacing behavior of loggerheads varied seasonally and could be as high as 9.9% - 30.0% in the spring. Likewise, Nelson (1996) observed juvenile loggerhead sea turtles spending a greater percentage of their time (19.0%) on the surface in the spring compared to other times of the year. Although surfacing intervals of loggerheads inhabiting Virginia's estuarine and coastal waters have been determined, Goodman et al. (2007) did not incorporate a correction factor into their density calculations, as the proportion of time turtles spend at the surface can vary geographically, as was found for loggerheads in the Chesapeake Bay when compared to those in the ocean (Mansfield 2006). Therefore, Goodman et al. (2007) were able only to provide relative numbers of turtles sighted as an index of abundance that can be compared among seasons. However, surfacing interval information can easily be acquired through satellite telemetry.

Since the 1950's, radio telemetry has been used to determine spatial, physiological, and behavioral data of free ranging animals (Tomkiewicz Jr. 1999). In the early 1970's, the advent of satellite telemetry and use of the ARGOS system to track wide ranging species, resulted in improvements in the longevity of battery time, reduction in the size of transmitters, and new sensor technologies that have provided researchers with the ability to gather additional information, such as the timing, routes and stopovers of migratory bird species, as well as the surfacing times and dive depths and dive profiles of marine animals. In addition, the memory function of satellite transmitters allows for data to be obtained without the researcher being in the field, as data is linked through a satellite system from remote locations.

By attaching satellite transmitters to the carapaces of loggerhead sea turtles, we were able to achieve the following objectives:

1. Determine surfacing intervals of loggerhead sea turtles in relation to habitat (estuarine versus coastal) and season in North Carolina;
2. Improve density estimates provided by Goodman et al. (2007) by incorporating a surfacing interval correction factor into the equation.

Methods

We attached satellite transmitters (Wildlife Computer SPOT5 and SPLASH, Redmond, Washington, USA) to loggerhead sea turtles, ranging in size from 54.2cm to 95.8cm SCL (mean=70.1cm \pm 10.9 SD). These loggerheads, the most common sea turtle species in North Carolina, were incidentally captured in pound nets set in Core and Pamlico Sounds (Fig. 1) during an ongoing in-water sampling effort by the NMFS, NOAA Beaufort Lab in the summers of 2007 and 2008. Pound nets are a stationary fishing gear into which turtles enter but are able to surface to breathe; thus, mortality is rare (*see* Epperly et al. 2007 for a detailed description of this gear). We measured, weighed, and flipper tagged turtles using Inconel Style 681 tags (National

Band and Tag Company, Newport, Kentucky, USA) applied to the trailing edge of each rear flipper and injecting 125 kHz unencrypted Passive Integrated Transponder (PIT) tags (Destron-Fearing Corp., South St. Paul, Minnesota, USA) subcutaneously in the left front flipper in the triceps superficialis muscle.

Both transmitter types measured the amount of time per 24-hour period that a tag's salt water switch was dry, providing a minimum estimate of percent time the turtle spent at the surface in a 24-hour period. The transmitters also calculated percent time spent at temperature bins of <8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 30 and >30° C. In addition, SPLASH tags were equipped with a pressure sensor to calculate the percentage of time spent at different depths. Because objects below the surface of clear water usually are visible during aerial surveys (Epperly et al. 1995b), we reasoned that turtles swimming within 1 meter of the surface should be visible to observers as well. All transmitters weighed less than 1% of the turtles' body weight. We programmed transmitters to transmit daily over a 10 h period beginning from just after dawn to near dusk.

After removing all epibiota from the first and second vertebral and costal scutes, we lightly scrubbed the area with sandpaper, rinsed with fresh water, and dried with acetone. To obtain the optimum transmission when the turtle surfaced to breathe, we positioned the transmitters between the second and third vertebral scutes of the carapace.



Fig. 2a We attached the base of the transmitters to the carapace using a high-strength, low-temperature epoxy adhesive (Power Fast™, Powers Fasteners, Brewster, New York, USA; Mitchell 1998) (Lisa R. Goshe photo).



Fig. 2b We further secured the SPOT5 transmitters using fiberglass cloth and resin, following the procedure of Balazs et al. 1996 (Lisa R. Goshe photo).



Fig. 3 We released turtles as close to the site of capture as possible. (M. April Goodman photo)

Whenever the turtle surfaced to breathe, position and sensor data were transmitted to NOAA’s Polar Orbiting Environmental Satellites (POES) on which ARGOS has instruments that can receive ultra-high frequency (UHF) messages sent from the transmitters (ARGOS User’s Manual 2008). All data were transferred from the NOAA satellites to the ARGOS processing centers which calculated a transmitter’s location using the Doppler Effect on transmission frequency and processed the sensor data collected by the transmitter. We received the data from the ARGOS processing center via email.

We archived and filtered the data from satellite tags using the Satellite Tracking and Analysis Tool (STAT) (Coyne and Godley 2005). We filtered the position data based on the accuracy of transmissions, (LC of 0,1,2,3,A, and B; Table 1), likely swimming speed between locations (<6 km hr), likely distance between locations for relatively stationary (<75 km) and migrating (<100 km) turtles, locations received in time intervals greater than or equal to one hour, and locations over water (topography <0.5 m). From sea surface temperature (SST) data provided by STAT (Coyne and Godley 2005), we calculated the range of SST in which each turtle traveled. We also report percentage of time turtles spent in different water temperatures based on each tag’s programmed temperature bins. Surface interval data were tested for differences among habitats (estuarine versus coastal) and seasons (winter—Dec. to Feb., spring—Mar. to May, summer—June to Aug., autumn—Sept. to Nov.). Surface interval data are expressed as the percent of time that a turtle spent on the surface of the water each day; data are binned into one hour periods. Prior to analysis we arcsine transformed the data (Zar, 1999). Differences between surfacing intervals of turtles in estuarine waters and in coastal waters were determined using a t-test. The surfacing intervals of turtles among seasons within each habitat (i.e., coastal and estuarine) were compared using a Kruskal-Wallis with subsequent multiple comparison tests (Siegel and Castellan 1988) using the pgirmess package in R statistical software. In cases where the Kruskal-Wallis found differences but the multiple comparison tests using the method of Siegel and Castellan (1988) found no difference, a Bonferroni pairwise t-test was also performed, using R.

Table 1. ARGOS location accuracy codes (LC) and estimated accuracy (ARGOS User’s Manual 2008)

Class Code	Number of messages received per satellite pass	Accuracy
3	4 messages or more	<250m
2	4 messages or more	250m – 500m
1	4 messages or more	500m – 1500m
0	4 messages or more	>1500m
A	3 messages	No accuracy estimation
B	2 messages	No accuracy estimation

Results

We deployed 8 Wildlife Computer SPOT5 satellite tags from July through October 2007 and 13 Wildlife Computer SPLASH satellite tags (one turtle was tagged with both a SPOT5 and SPLASH satellite tag) from May through June 2008 on 20 loggerheads ranging in size 54.2 cm to 95.8 cm SCL (mean = 70.1 cm \pm 10.9 SD). Length of transmission ranged from 0 to 276 days for SPOT5 tags and from 26 to 224 days for SPLASH tags (Tables 2 and 3). The majority (54.5%) of ARGOS location classes received from deployed tags were classes A (18.4%) or B (36.1%) (Tables 2 and 3).

Table 2. Deployment date, length of transmission, and filtered ARGOS location code distribution for SPOT5 satellite track data, 2007-2008

Tag ID	Deployment Date	Length of Transmission (Days)	Filtered ARGOS Location Code					
			3	2	1	0	A	B
75425	7/24/2007	276	4	20	23	14	22	54
75426	7/31/2007	31	0	0	0	0	0	16
75427	8/7/2007	208	5	14	10	18	19	41
76454	8/24/2007	245	8	23	31	46	52	86
76455	10/9/2007	185	7	22	17	34	8	26
76456	10/11/2007	192	0	11	30	55	22	33
76457	10/11/2007	187	10	24	32	24	25	36
76458	11/1/2007	0	0	0	0	0	0	0

Table 3. Deployment date, length of transmission, and filtered ARGOS location code distribution for SPLASH satellite track data, 2008-2009

Tag ID	Deployment Date	Length of Transmission (Days)	Filtered ARGOS Location Code					
			3	2	1	0	A	B
42600	5/5/2008	57	1	2	2	4	13	28
43699	5/5/2008	216	0	1	3	1	10	29
42599	5/7/2008	98	1	0	0	2	8	9
42605	5/14/2008	169	3	2	2	1	13	17
43697	5/14/2008	69	1	1	1	1	14	40
42601	5/19/2008	45	0	1	1	0	4	13
42604	5/19/2008	164	9	8	14	7	31	68
42602	5/28/2008	40	1	8	2	0	5	10
42603	5/28/2008	26	3	4	2	1	7	11
43638	6/2/2008	224	4	6	11	4	16	32
43639	6/2/2008	64	0	1	2	3	8	13
42664	6/4/2008	47	1	0	0	2	7	8
43635	6/13/2008	133	31	68	73	56	29	46

Table 4. Summary statistics derived in STAT (Coyne and Godley 2005) or SATPAK (Wildlife Computers) from satellite telemetry data, 2007 to 2008.

Tag ID	GOES SST Range (° C)	AVHRR SST Range (° C)	Mean percentage time on surface	Mean percentage time in water \leq 1 m
SPOT5				
Tags				
75425	15 - 29	13 - 28	3.9	N/A
75426	25 - 30	27 - 28	0.1	N/A
75427	9 - 30	12 - 28	2.1	N/A
76454	8 - 28	16 - 29	2.9	N/A
76455	8 - 25	13 - 27	3	N/A
76456	8 - 26	13 - 26	2.5	N/A
76457	10 - 26	13 - 26	7.7	N/A
76458	N/A	N/A	N/A	N/A
SPLASH				
Tags				
42600	17 - 22	17 - 26	3	32
43699	19 - 22	26 - 28	0.1	51
42599	N/A	21 - 28	0.1	25
42605	N/A	20 - 29	0.1	25
43697	N/A	21 - 28	6	29
42601	N/A	21 - 28	0.2	53
42604	N/A	21 - 28	5.5	25
42602	N/A	22 - 27	0.9	33
42603	N/A	24 - 27	0.5	50
43638	N/A	19 - 29	0.8	23
43639	N/A	23 - 27	0.6	40
42664	N/A	23 - 27	0.1	23
43635	N/A	19 - 27	12.5	56

Details of each individual's satellite track are provided below.

SPOT5 Satellite tags

Tag ID# 75425; Master Tag TTS236

Turtle TTS236 was captured on July 24, 2007 in a pound net set in Core Sound (34.876N; -76.340W) and released the same day off Harkers Island, NC (34.685W; -76.526N). Transmissions from the tag lasted 276 days. The turtle remained within the vicinity of its release location through the end of September (Appendix, Fig. 4a). We received only one transmission in October, but transmissions resumed on November 24 when the turtle began a southerly migration. It remained within the nearshore waters of South Carolina and appeared to be making a northerly migration when transmissions ended on April 25, 2008. SST (obtained from STAT) in which this turtle traveled ranged between 15 and 29°C (Table 4) while water temperatures recorded by the PTT where it spent > 96% of its time ranged from 14 to 30°C (Fig. 4b). It spent an average of 3.9% of its time on the surface of the water (Fig. 4c).

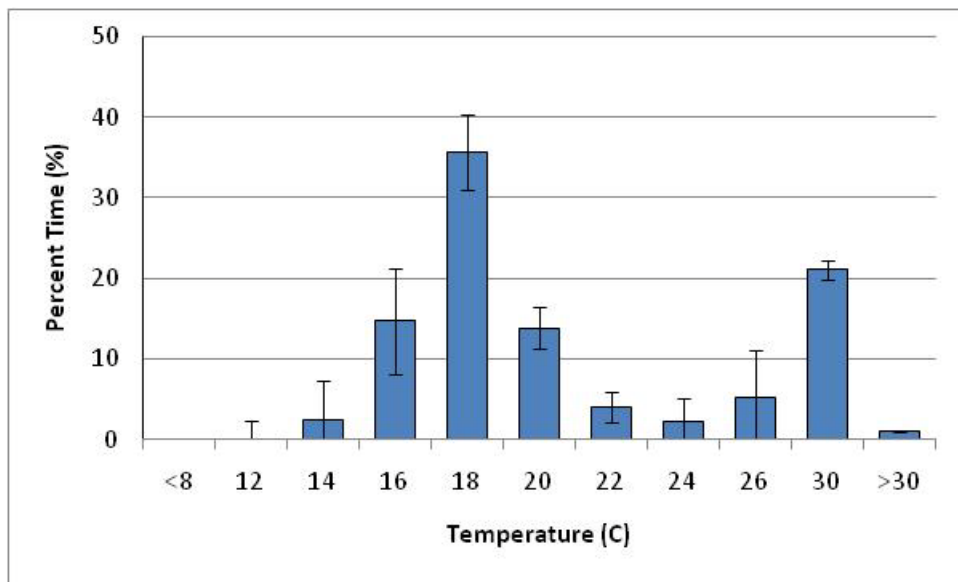


Fig. 4b Percentage of time spent within binned temperatures for Turtle TTS236.

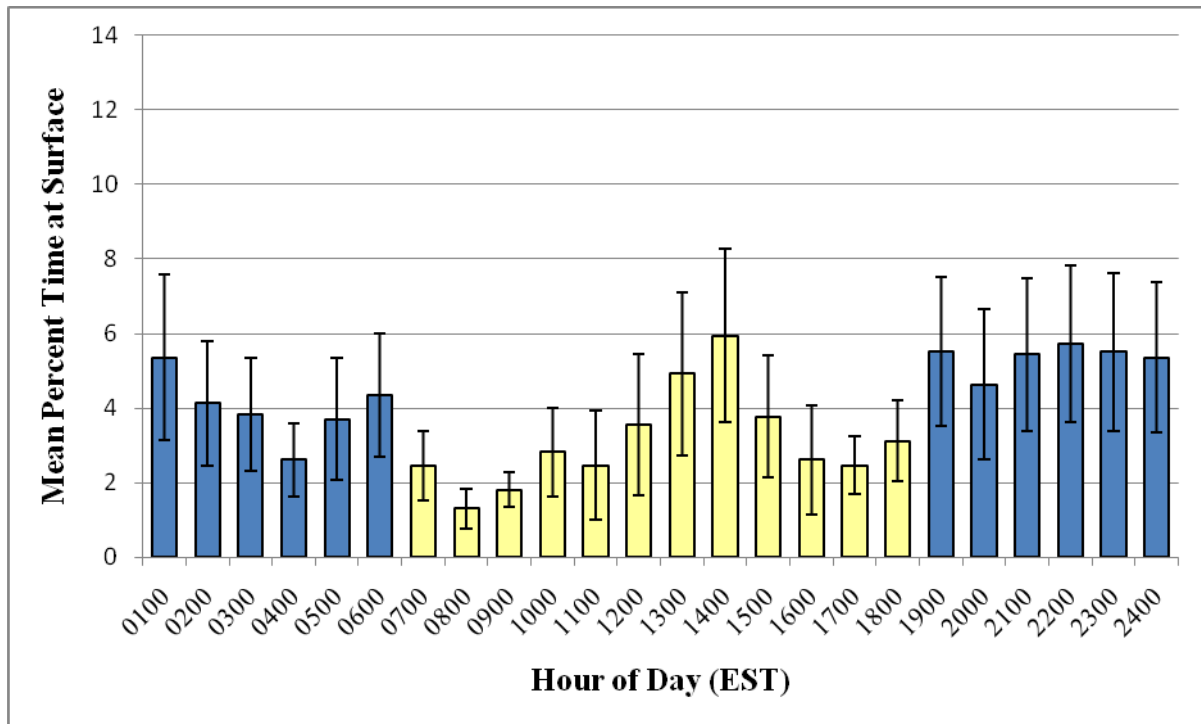


Fig. 4c Percentage of time spent on surface of water for Turtle TTS236.

Tag ID# 75426; Master Tag TTS233

Turtle TTS233 was captured on July 31, 2007 in a pound net set in Core Sound (34.876N; -76.340W) and released the same day off Harkers Island, NC (34.685W; -76.526N). Transmissions from the tag lasted only 31 days, and the turtle remained within the vicinity of its release location the entire time (Appendix, Fig. 5a). We received its last transmission on August 31, 2007. SST (obtained from STAT) in which this turtle traveled ranged between 25 and 27° C (Table 4) while water temperatures recorded by the PTT where it spent > 96% of its time ranged from 26 to 30° C (Fig. 5b). It spent < 1% of its time on the surface of the water (Fig. 5c).

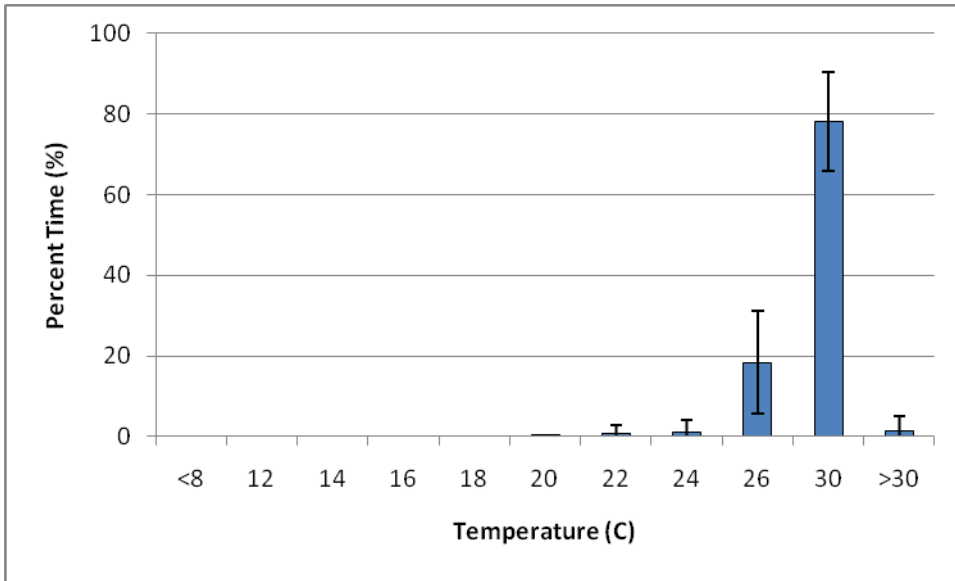


Fig. 5b Percentage of time spent within binned temperatures for Turtle TTS233.

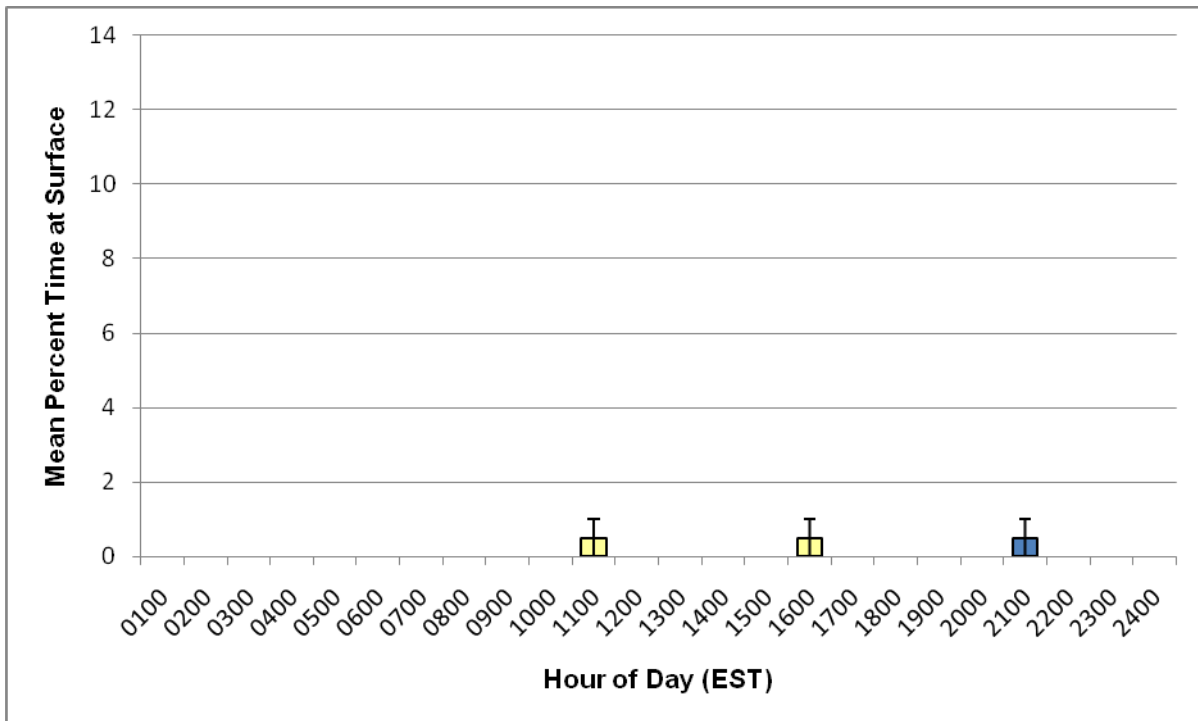


Fig. 5c Percentage of time spent on surface of water for Turtle TTS233.

Tag ID# 75427; Master Tag RRS949

Turtle RRS949 was captured on August 7, 2007 in a pound net set in Core Sound (34.830N; -76.357W) and released the same day off Harkers Island, NC (34.685W; -76.526N). Transmissions from the tag lasted 208 days. The turtle remained within the vicinity of its capture location until early December, 2007 when it traveled to the nearshore waters of Cape Lookout (Appendix, Fig. 6a). It remained there until the end of its transmission history on March 2, 2008. SST (obtained from STAT) in which this turtle traveled ranged between 9 and 30° C (Table 4) while water temperatures recorded by the PTT where it spent > 98% of its time ranged from 14 to 30° C (Fig. 6b). It spent an average of 2.1% of its time on the surface of the water (Fig. 6c).

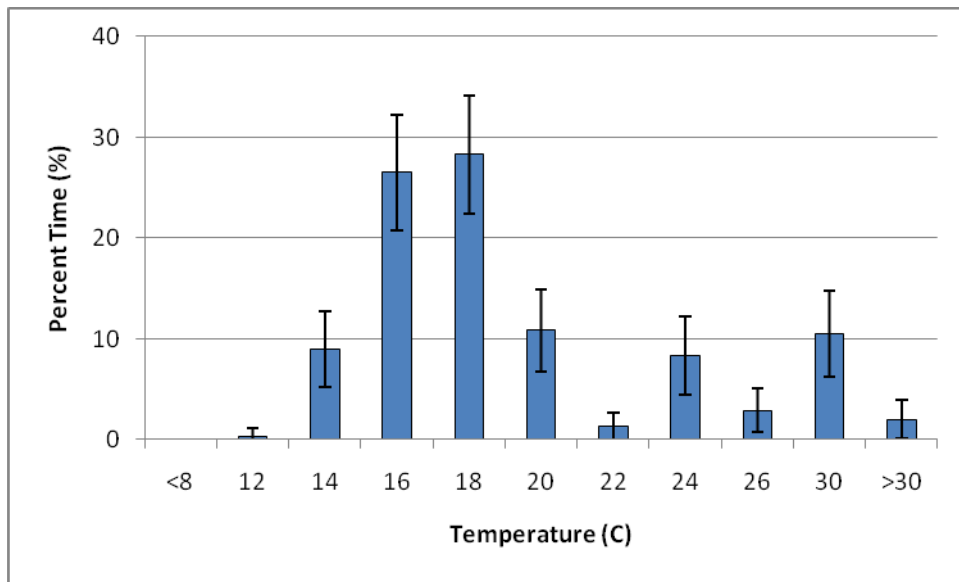


Fig. 6b Percentage of time spent within binned temperatures for Turtle RRS949.

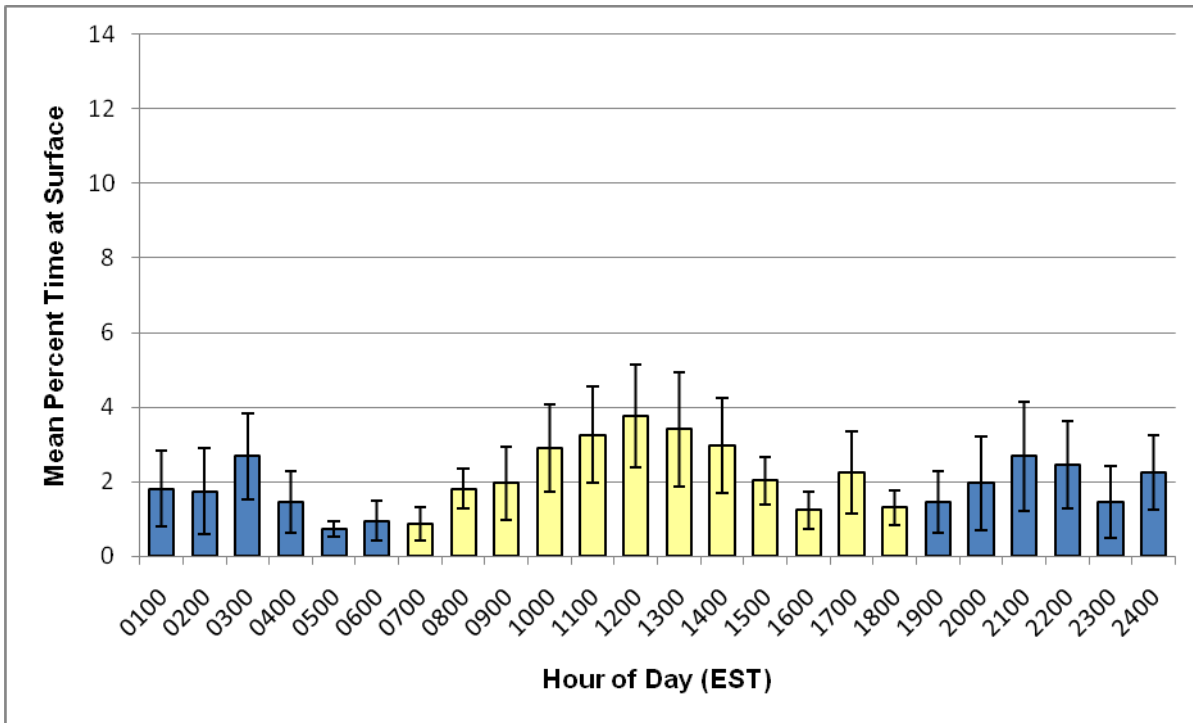


Fig. 6c Percentage of time spent on surface of water for Turtle RRS949.

Tag ID# 76454; Master Tag SSR505

Turtle SSR505 was captured on August 24, 2007 in a pound net set in Core Sound (34.876N; -76.340W) and released the same day off Harkers Island, NC (34.685N; -76.526W). Transmissions from the tag lasted 245 days. The turtle traveled offshore of its release location and headed north to Ocracoke Inlet before beginning a southerly migration in early September. It continued traveling south until it reached the South Carolina/Georgia border by early October and remained there until the end of its transmission history on April 25, 2008 (Appendix, Fig. 7a). SST (obtained from STAT) in which this turtle traveled ranged between 8 and 28° C (Table 4) while water temperatures recorded by the PTT where it spent > 99% of its time ranged from 18 to 30° C (Fig. 7b). It spent an average of 2.9% of its time on the surface of the water (Fig. 7c).

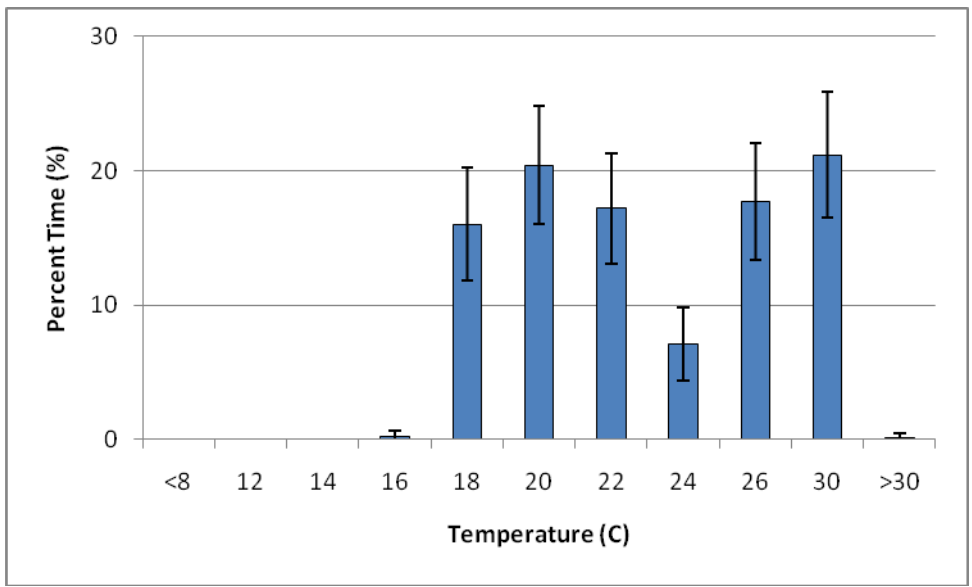


Fig. 7b Percentage of time spent within binned temperatures for Turtle SSR505.

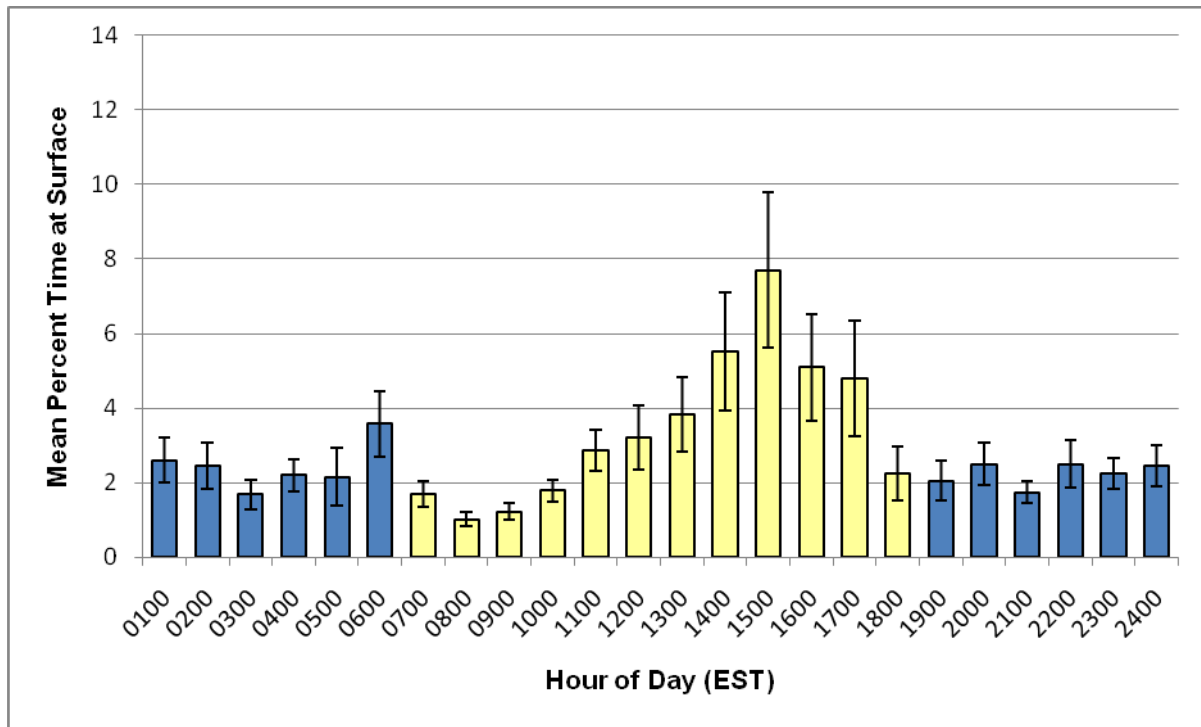


Fig. 7c Percentage of time spent on surface of water for Turtle SSR505.

Tag ID# 76455; Master Tag RRS098

Turtle RRS098 was captured on October 9, 2007 in a pound net set in Core Sound (34.830N; -76.357W) and released the same day off Harkers Island, NC (34.685W; -76.526N). Transmissions from the tag lasted 185 days. The turtle remained in the vicinity of its capture location before heading offshore in early November. After remaining offshore of its capture location for a few weeks, it moved southward and remained offshore of Bogue Banks until the end of its transmission history on April 11, 2008 (Appendix, Fig. 8a). SST (obtained from STAT) in which this turtle traveled ranged between 8 and 25°C (Table 4) while water temperatures recorded by the PTT where it spent > 99% of its time ranged from 14 to 30°C (Fig. 8b). It spent an average of 3.0% of its time on the surface of the water (Fig. 8c).

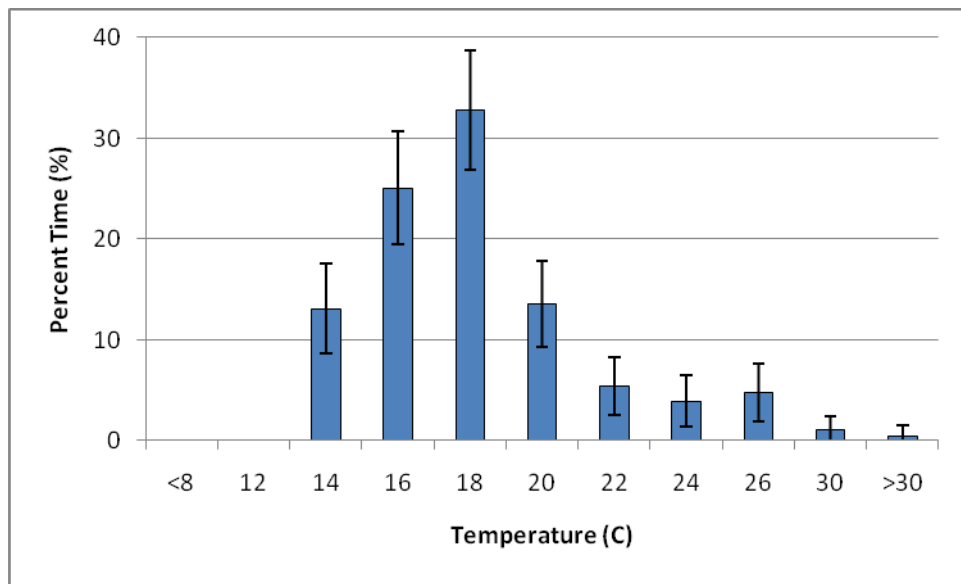


Fig. 8b Percentage of time spent within binned temperatures for Turtle RRS098.

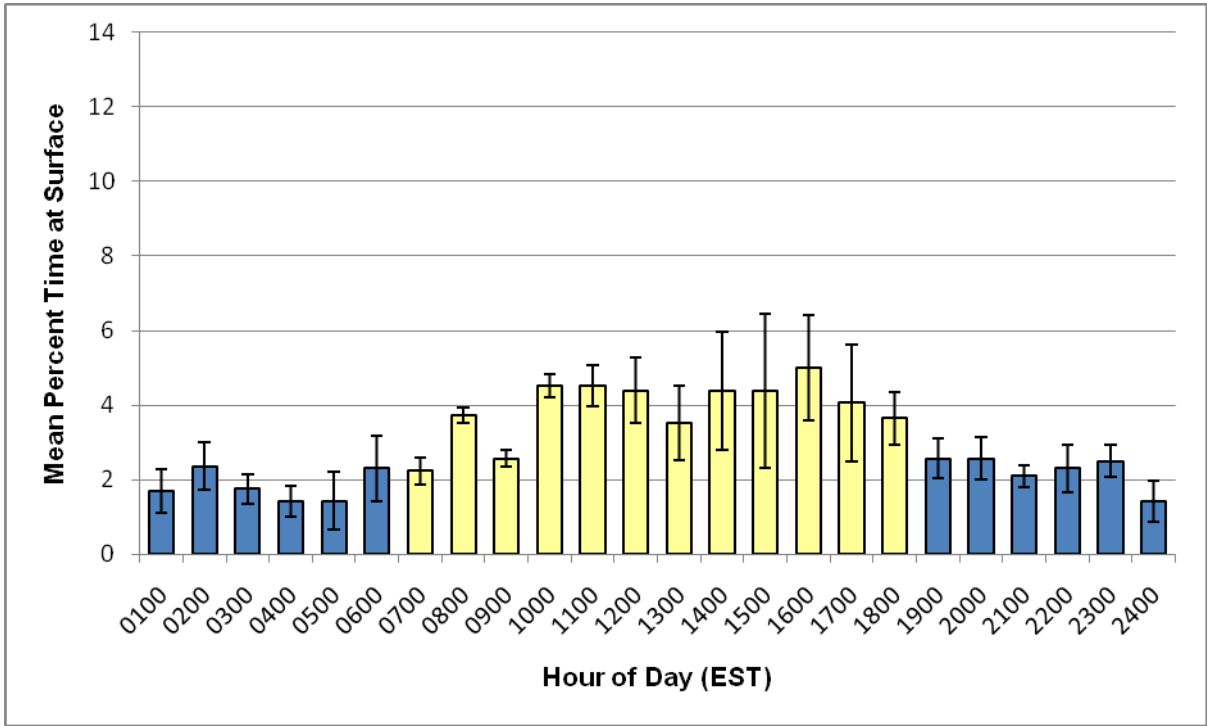


Fig. 8c Percentage of time spent on surface of water for Turtle RRS098.

Tag ID# 76456; Master Tag RRS412

Turtle RRS412 was captured on October 11, 2007 in a pound net set in Core Sound (34.932N; -76.261W) and released the same day off Atlantic, NC (34.873W; -76.343N). Transmissions from the tag lasted 192 days. The turtle traveled south of its release location through Core Sound and went offshore of Cape Lookout in early November. It remained in this area until the end of its transmission history on April 20, 2008 (Appendix, Fig. 9a). SST (obtained from STAT) in which this turtle traveled ranged between 8 and 26° C (Table 4) while water temperatures recorded by the PTT where it spent > 99% of its time ranged from 16 to 26° C (Fig. 9b). It spent an average of 2.5% of its time on the surface of the water (Fig. 9c).

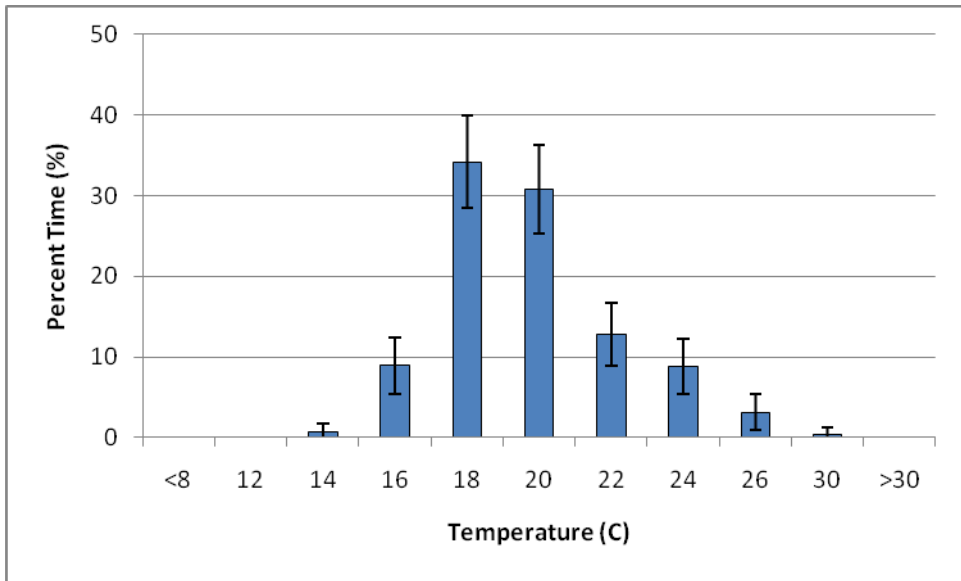


Fig. 9b Percentage of time spent within binned temperatures for Turtle RRS412.

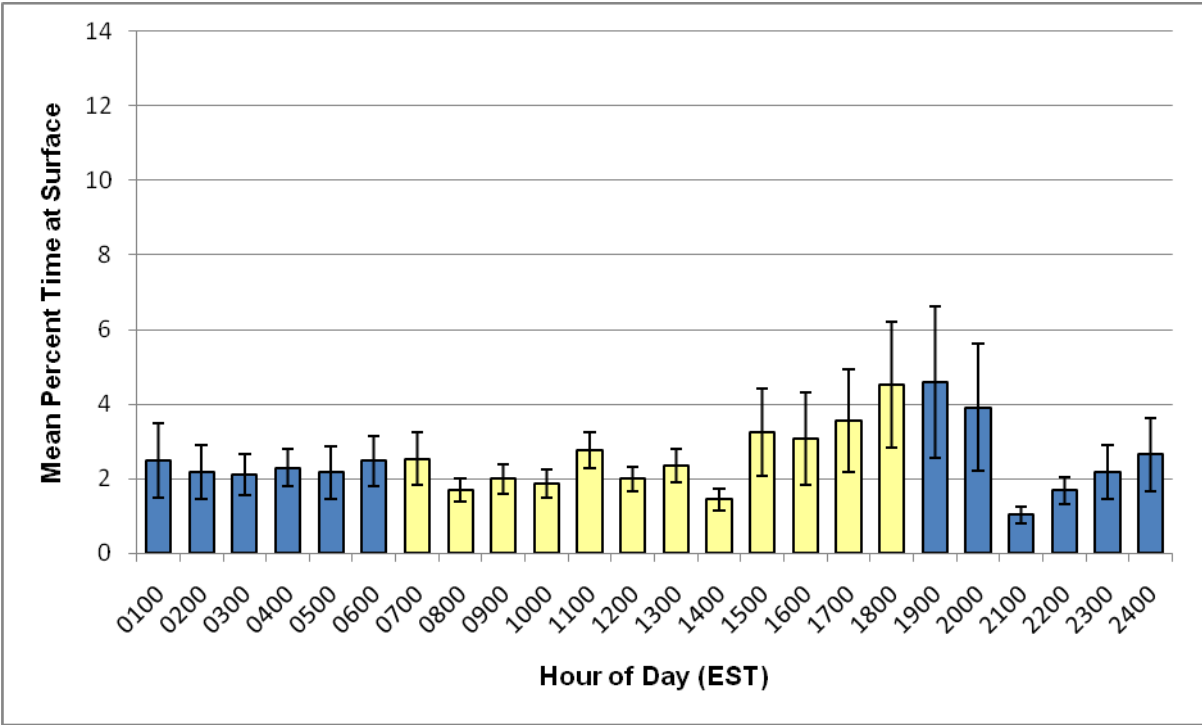


Fig. 9c Percentage of time spent on surface of water for Turtle RRS412.

SPOT5 Tag ID# 76457 and SPLASH Tag ID#42664; Master Tag XXN027

Turtle XXN027 was captured on October 11, 2007 in a pound net set in Core Sound (34.942N; -76.236W) and released the same day off Atlantic, NC (34.873W; -76.343N). Transmissions from the SPOT5 tag lasted 187 days. The turtle remained in the vicinity of its release location until late October when it traveled south through Core Sound. In early November it exited the sound and remained offshore of southern Core Banks until the end of its transmission history on April 15, 2008 (Appendix, Fig. 10a – red squares). We recaptured the turtle on June 2, 2008 in a pound net set in Core Sound, NC (34.931N; -76.263W). After removing the SPOT5 and replacing it with SPLASH tag 42664, we released the turtle on June 3 off Cedar Island, NC (34.951N; -76.281W). Transmissions from the SPLASH tag lasted 47 days. The turtle remained in the vicinity of its release location until its transmissions ended July 21, 2008 (Appendix, Fig. 10b – black squares).

While wearing SPOT5 tag #76457 (October 11, 2007 to April 15, 2008), SST (obtained from STAT) in which this turtle traveled ranged between 10 and 26° C (Table 4) while water temperatures recorded by the PTT where it spent > 96% of its time ranged from 14 to 26° C (Fig. 10c). It spent an average of 7.7% of its time on the surface of the water (Fig. 10d).

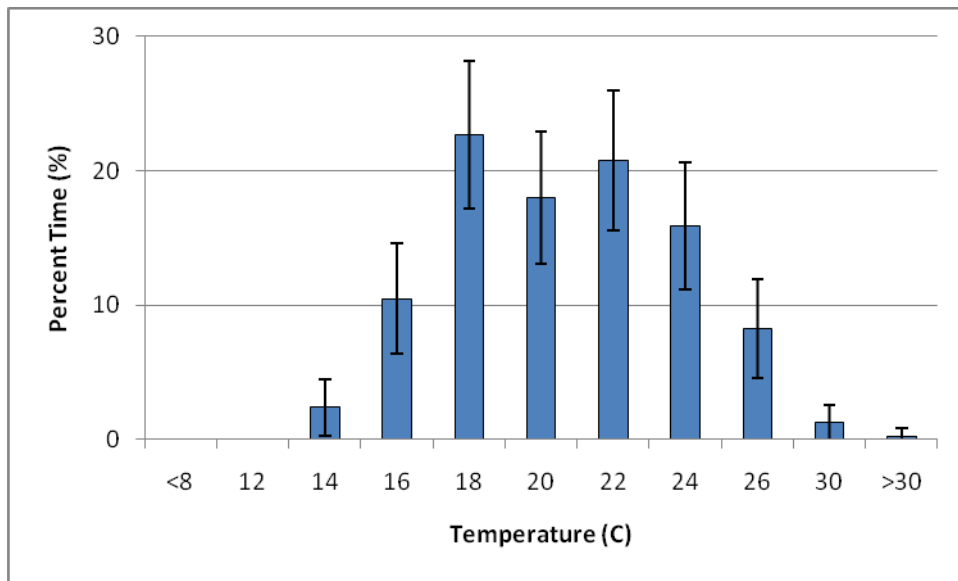


Fig. 10c Percentage of time spent within binned temperatures for Turtle XXN027 while wearing SPOT5 tag #76457.

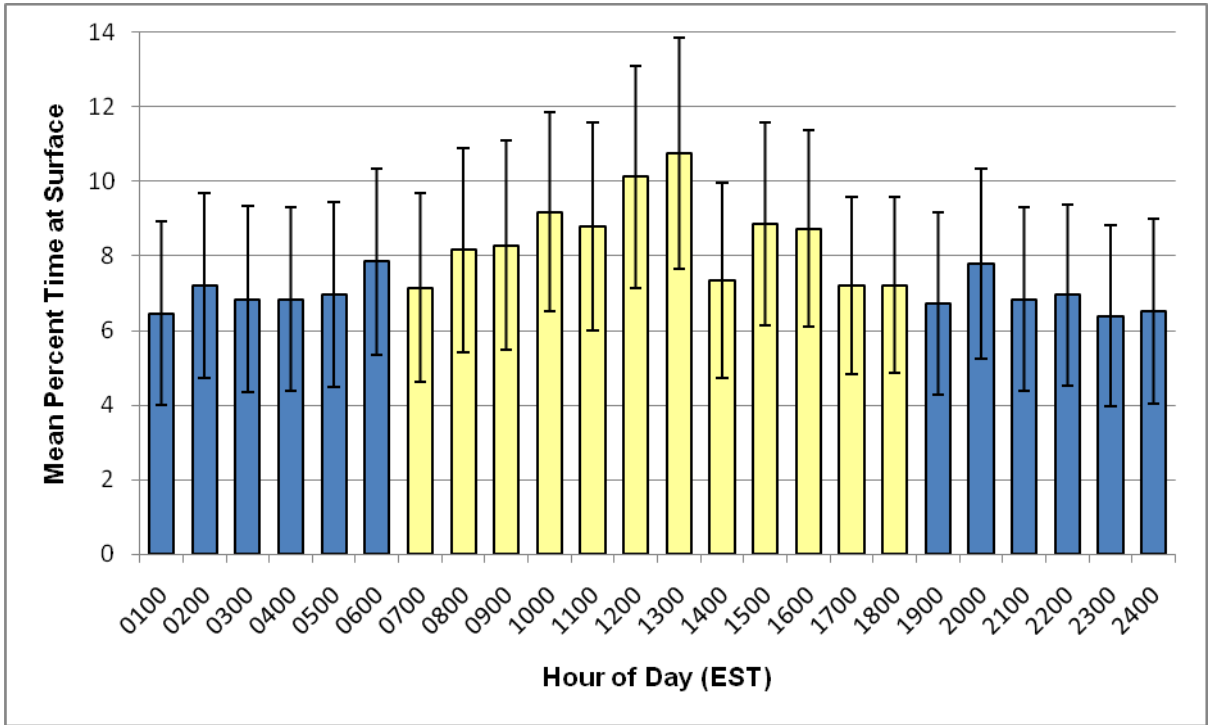


Fig. 10d Percentage of time spent on surface of water for Turtle XXN027 while wearing SPOT5 tag #76457.

However, while wearing SPLASH tag #42664 (June 3 to July 21, 2008), SST (obtained from STAT) in which this turtle traveled ranged between 23 and 27° C (Table 4) while water temperatures recorded by the PTT where it spent 98% of its time ranged from 22 to 30° C (Fig. 10e). It spent < 1.0% of its time on the surface of the water (Fig. 10f).

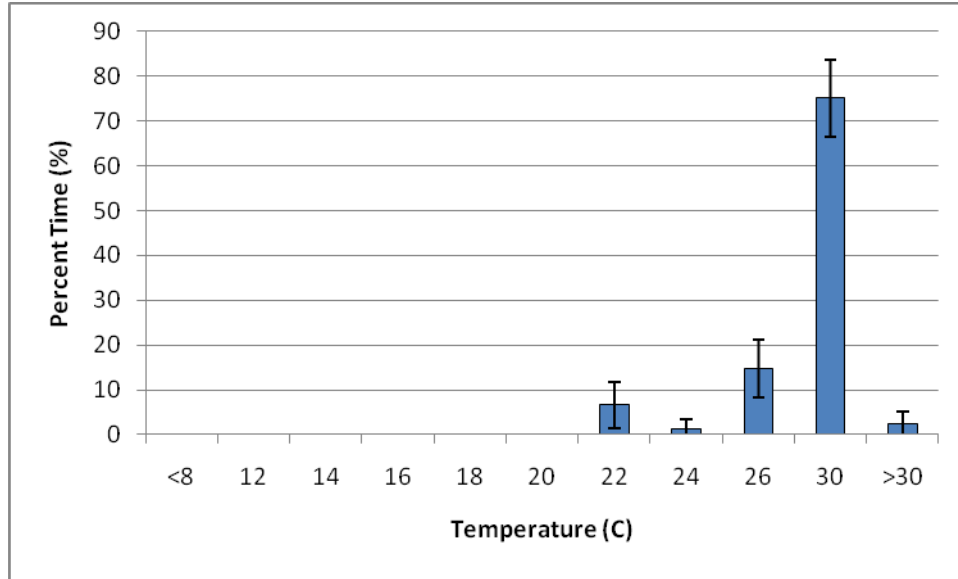


Fig. 10e Percentage of time spent within binned temperatures for Turtle XXN027 while wearing SPLASH tag #42664.

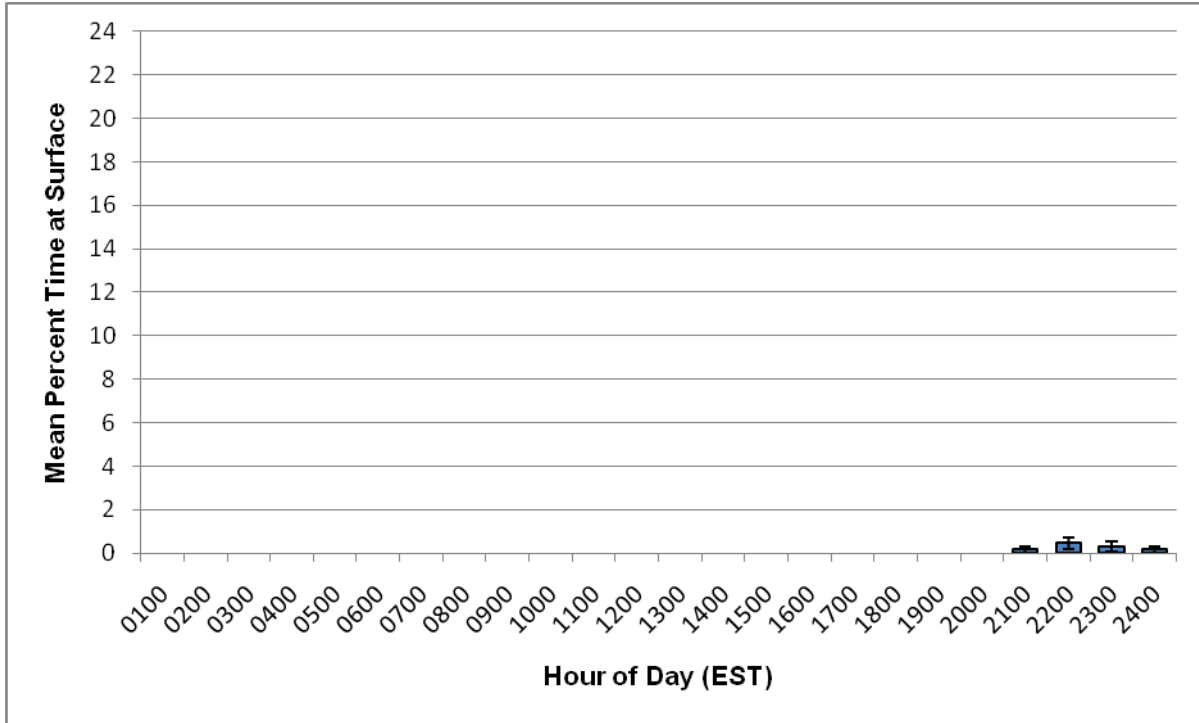


Fig. 10f Percentage of time spent on surface of water for Turtle XXN027 while wearing SPLASH tag #42664.

Tag ID# 76458; Master Tag TTS618

Turtle TTS618 was captured on November 1, 2007 in a pound net set in Core Sound (34.943N; -76.233W) and released the same day off Atlantic, NC (34.971N; -76.270W). We received no transmission from this tag, but did recapture the turtle a few days later in a pound net set in Pamlico Sound (35.028N; -76.146W).

SPLASH Satellite tags

Tag ID# 42600; Master Tag TTS450

Turtle TTS450 was captured on May 5, 2008 in a pound net set in Core Sound (34.966N; -76.210W) and released the same day off Cedar Island, NC (34.951W; -76.281N). Transmissions from the tag lasted 57 days. The turtle left Core Sound within days of its release and traveled the coastal waters north toward Virginia where it entered the Chesapeake Bay and James River late May/early June (Appendix, Fig. 11a). It went up the James River as far as Williamsburg, VA then remained in the James River until we lost transmissions on July 1, 2008.

SST (obtained from STAT) in which this turtle traveled ranged between 17 and 26° C (Table 4) while water temperatures recorded by the PTT where it spent > 97% of its time ranged from 16 to 30° C (Fig. 11b). According to its PTT, it spent an average of 3.0% of its time on the surface of the water (Fig. 11c).

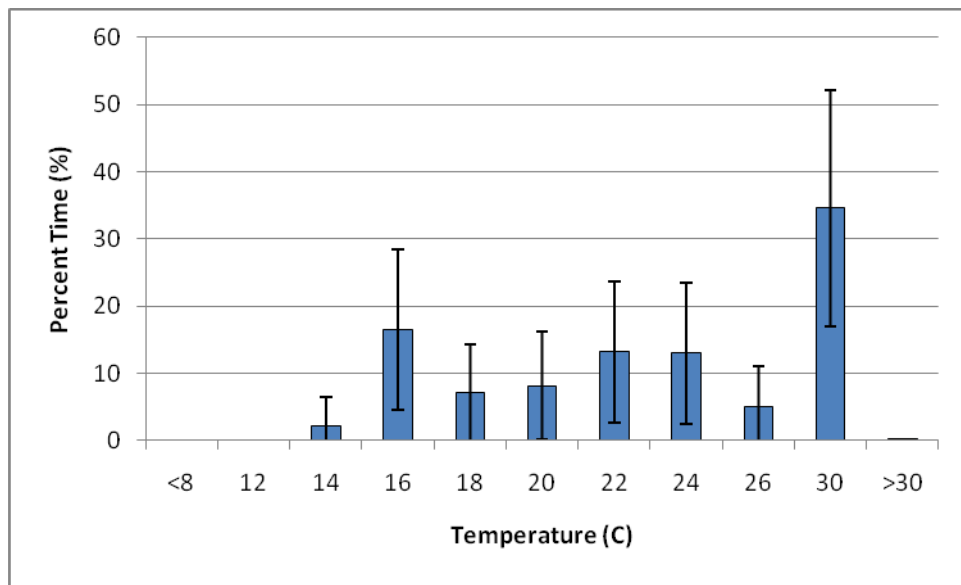


Fig. 11b Percentage of time spent within binned temperatures for Turtle TTS450.

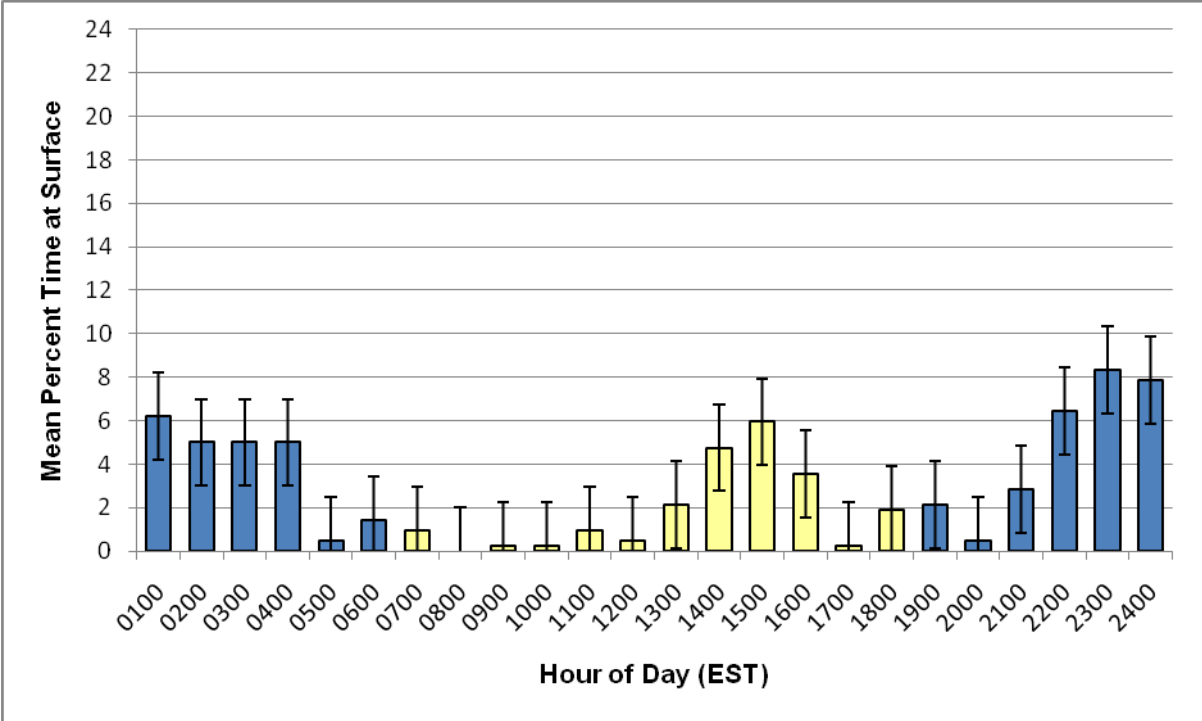


Fig. 11c Percentage of time spent on surface of water for Turtle TTS450.

Tag ID# 43699; Master Tag TTS448

Turtle TTS448 also was captured on May 5, 2008 in a pound net set in Core Sound (34.968N; -76.220W) and released the same day off Cedar Island, NC (34.951N; -76.281W). Transmissions from the tag lasted 122 days. The turtle remained in Core Sound during its entire track history when the tag ceased transmitting on September 4, 2008 (Appendix, Fig. 12a). The turtle was recaptured in a pound net set in Pamlico Sound (35.295N; -75.688W) on October 27, 2008. The tag was not removed; however, it was later retrieved from another pound net and returned to our lab. We sent this tag along with the SPOT5 (Tag ID#76457) to Wildlife Computers for refurbishment and plan on re-deploying them in the future. SST (obtained from STAT) in which this turtle traveled ranged between 19 and 28° C (Table 4) while water temperatures recorded by the PTT where it spent > 93% of its time ranged from 16 to 30° C (Fig. 12b). It spent < 1.0% of its time on the surface of the water (Fig. 12c).

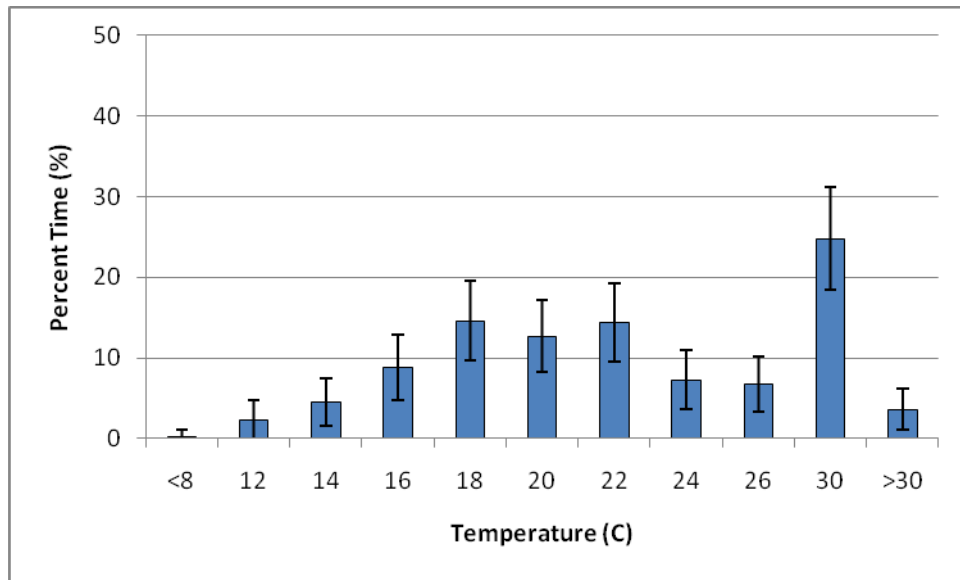


Fig. 12b Percentage of time spent within binned temperatures for Turtle TTS448.

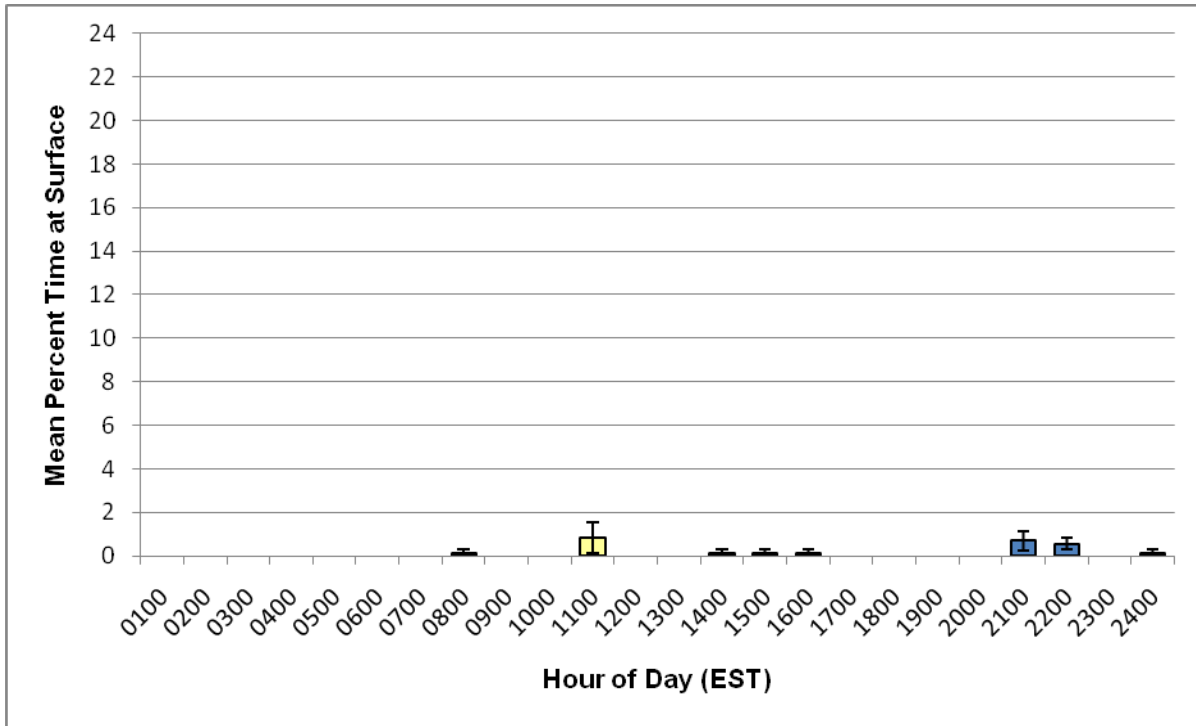


Fig. 12c Percentage of time spent on surface of water for Turtle TTS448.

Tag ID# 42599; Master Tag TTS514

Turtle TTS514 was captured on May 7, 2008 in a pound net set in Core Sound (34.968N; -76.220W) and released the same day off Cedar Island, NC (34.951N; -76.281W). Transmissions from the tag lasted 98 days. The turtle left Core Sound within a few days of its release and traveled south, staying within the nearshore waters of Bogue Banks until the tag stopped transmitting on August 13, 2008 (Appendix, Fig. 13a). SST (obtained from STAT) in which this turtle traveled ranged between 21 and 28° C (Table 4) while water temperatures recorded by the PTT where it spent > 99% of its time ranged from 20 to 30° C (Fig. 13b). It spent < 1.0% of its time on the surface of the water (Fig. 13c).

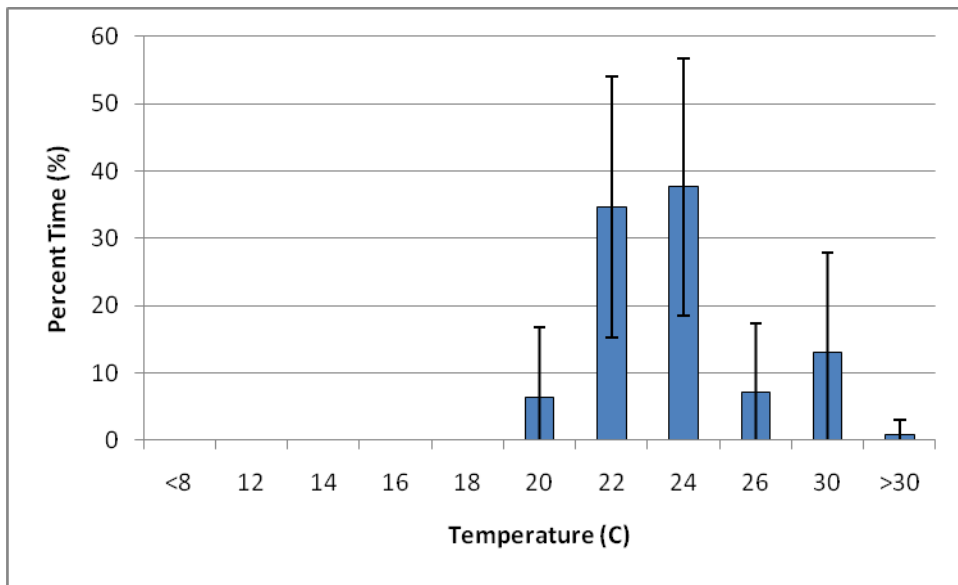


Fig. 13b Percentage of time spent within binned temperatures for Turtle TTS514.

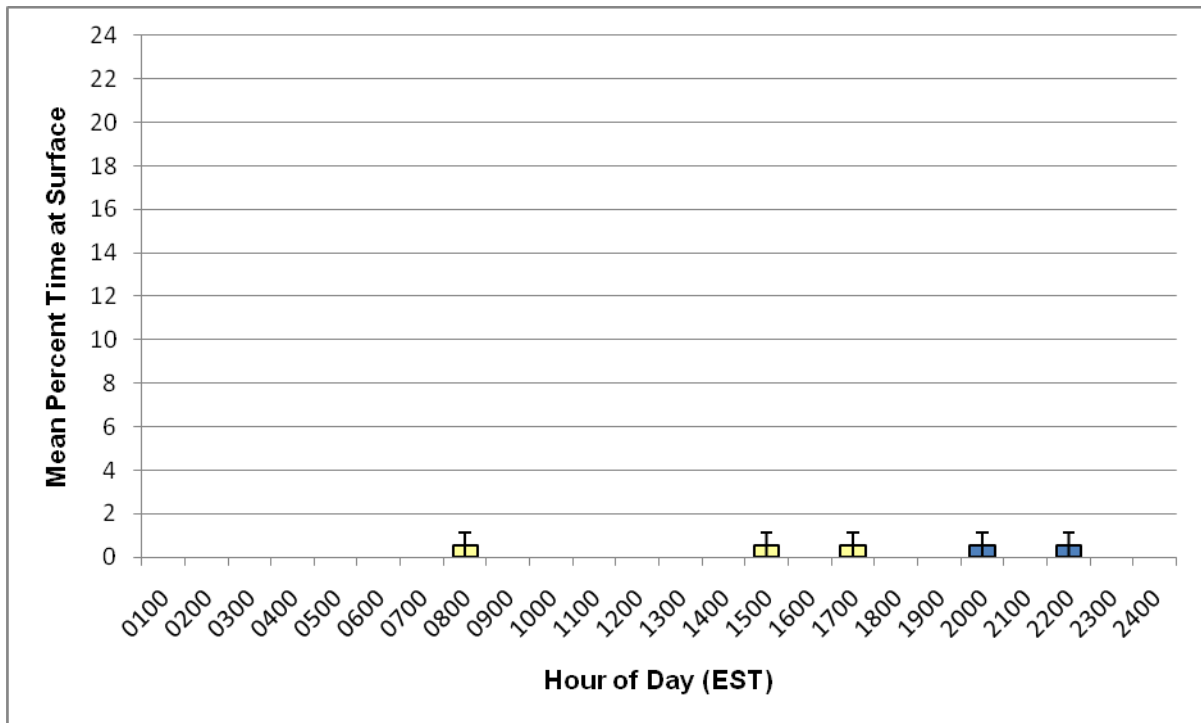


Fig. 13c Percentage of time spent on surface of water for Turtle TTS514.

Tag ID# 42605; Master Tag TTS599

Turtle TTS599 was captured on May 14, 2008 in a pound net set in Core Sound (34.966N; -76.213W) and released the same day off Atlantic, NC (34.876N; -76.340W). Transmissions from the tag lasted 169 days. The turtle traveled in a southerly direction through Core Sound within a few days of its release and entered the coastal waters off Cape Lookout (Fig. 14a). In early June, it entered Bogue Sound and remained there until late October when it returned to the vicinity of Cape Lookout. The tag stopped transmitting on October 30, 2008. SST (obtained from STAT) in which this turtle traveled ranged between 20 and 29° C (Table 4) while water temperatures recorded by the PTT where it spent > 99% of its time ranged from 20 to > 30° C (Fig. 14b). It spent < 1.0% of its time on the surface of the water (Fig. 14c).

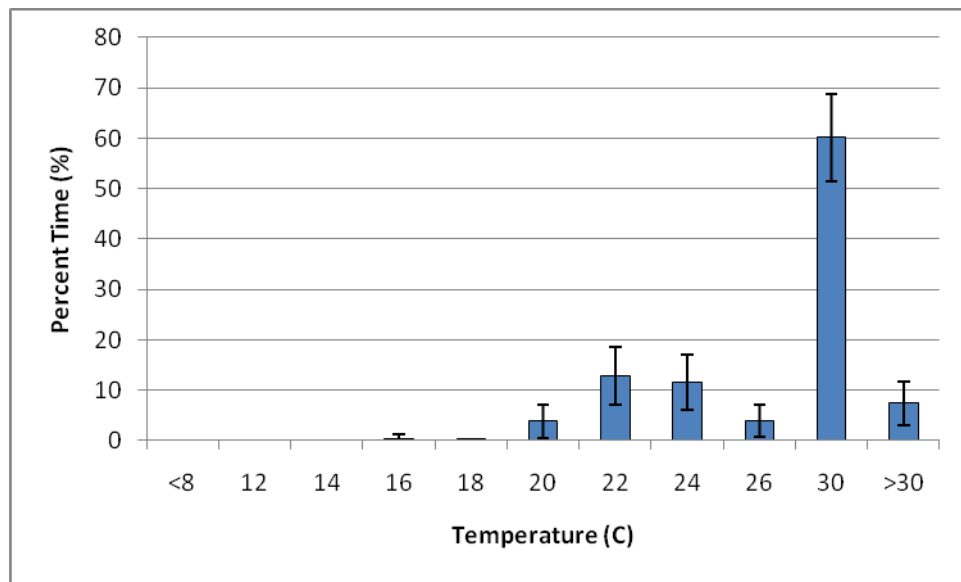


Fig. 14b Percentage of time spent within binned temperatures for Turtle TTS599.

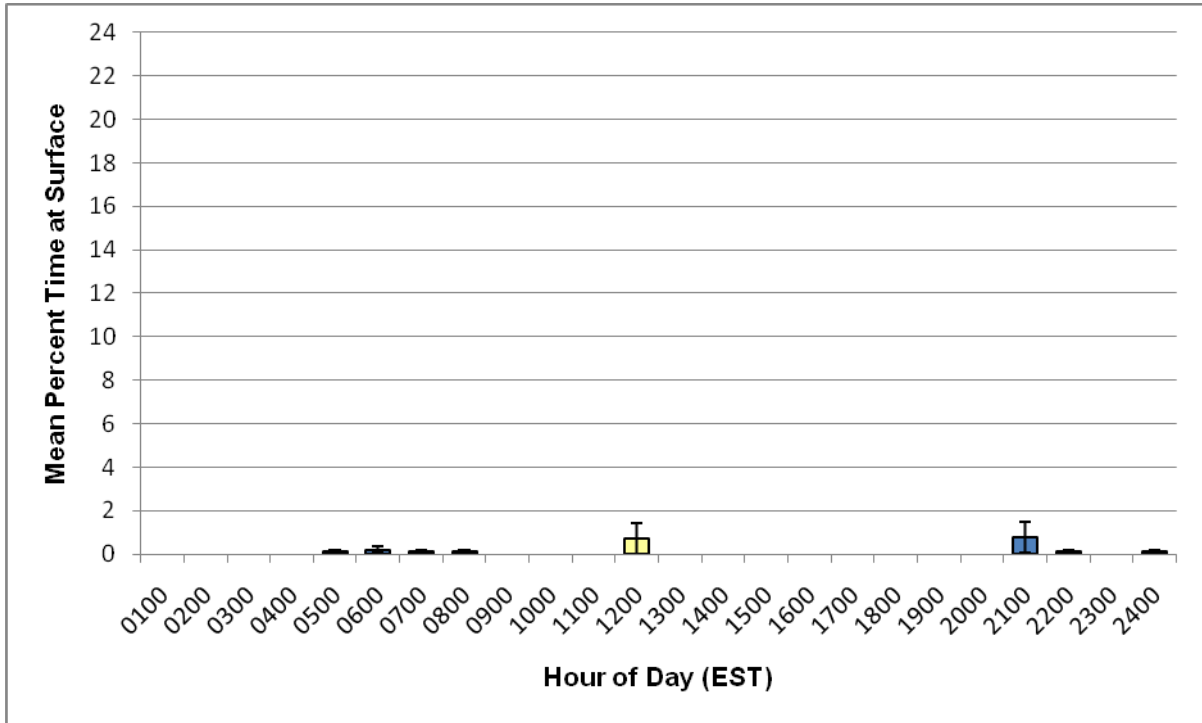


Fig. 14c Percentage of time spent on surface of water for Turtle TTS599.

Tag ID# 43697; Master Tag TTS612

Turtle TTS612 also was captured on May 14, 2008 in a pound net set in Core Sound (34.966N; -76.210W) and released the same day off Cedar Island, NC (34.951N; -76.281W). Transmissions from the tag lasted 69 days. The turtle remained within the vicinity of its release location until the tag stopped transmitting on August 22, 2008 (Appendix, Fig. 15a). SST (obtained from STAT) in which this turtle traveled ranged between 21 and 28° C (Table 4) while water temperatures recorded by the PTT where it spent > 95% of its time ranged from 22 to > 30° C (Fig. 15b). It spent < 1% of its time on the surface of the water (Fig. 15c).

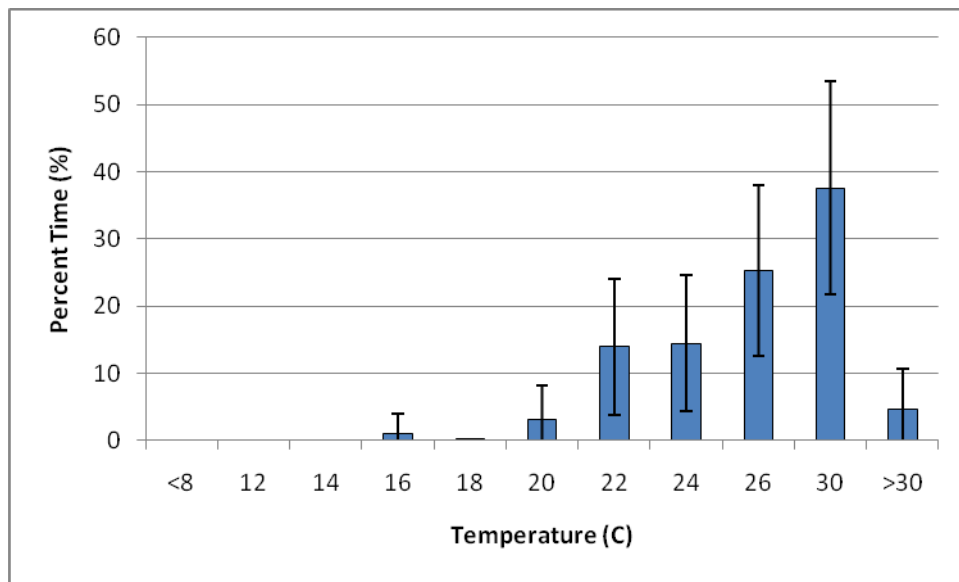


Fig. 15b Percentage of time spent within binned temperatures for Turtle TTS612.

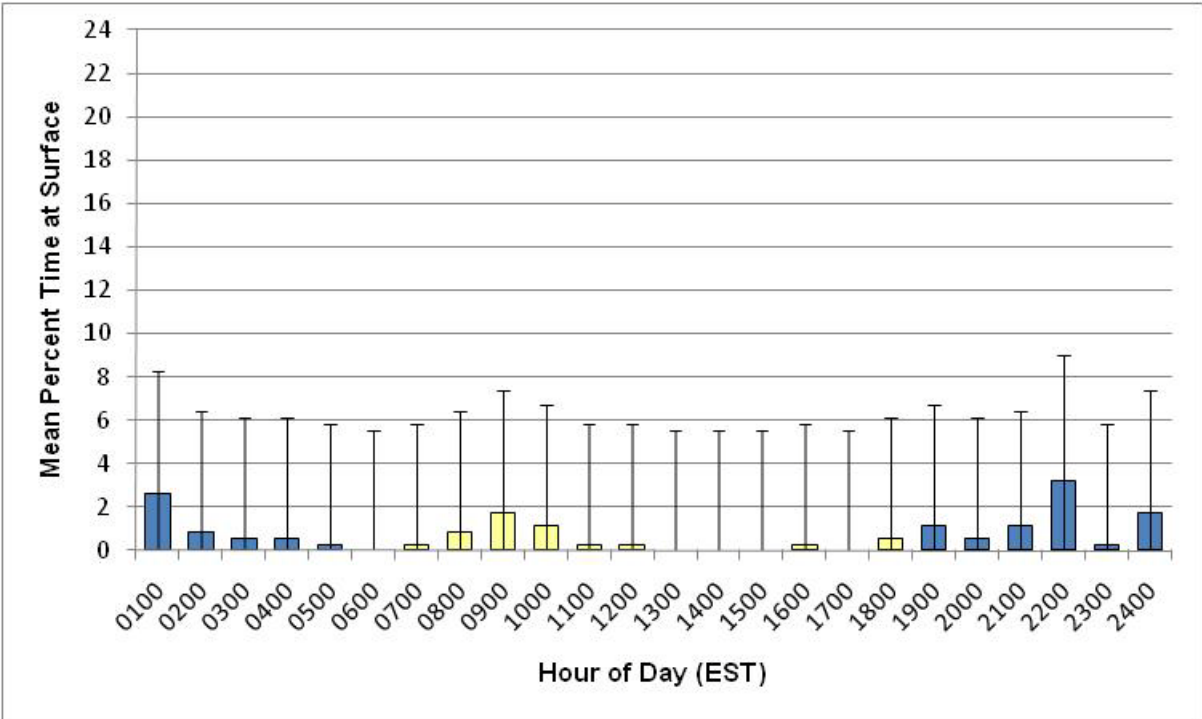


Fig. 15c Percentage of time spent on surface of water for Turtle TTS612.

Tag ID# 42601; Master Tag PPX316

Turtle PPX316 was captured on May 19, 2008 in a pound net set in Core Sound (34.967N; -76.217W) and released the same day off Atlantic, NC (34.876N; -76.340W). Transmissions from the tag lasted 45 days. The turtle remained within the vicinity of its release location until the tag stopped transmitting on July 3, 2008 (Appendix, Fig. 16a). SST (obtained from STAT) in which this turtle traveled ranged between 21 and 28° C (Table 4) while water temperatures recorded by the PTT where it spent > 99% of its time ranged from 22 to 30° C (Fig. 16b). It spent < 1.0% of its time on the surface of the water (Fig. 16c).

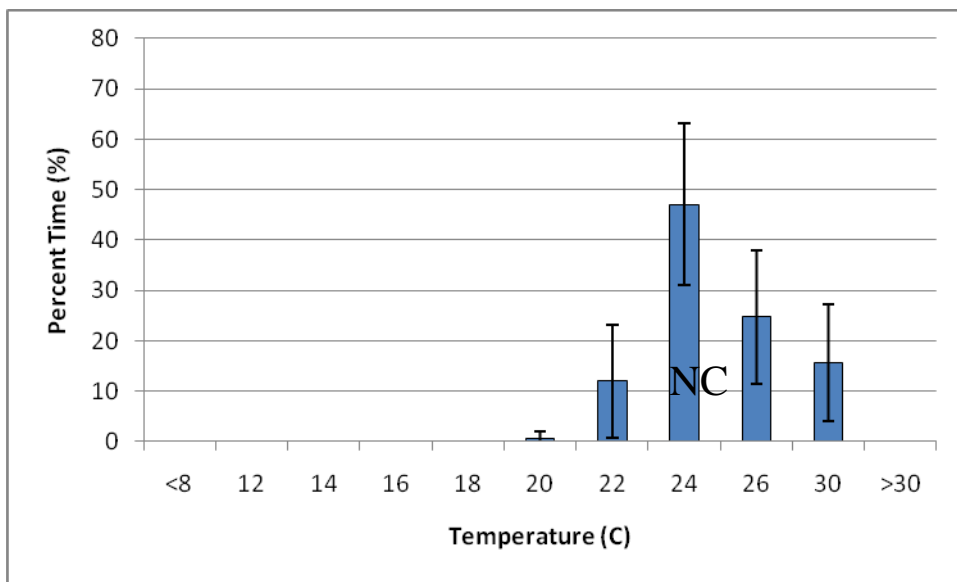


Fig. 16b Percentage of time spent within binned temperatures for Turtle PPX316.

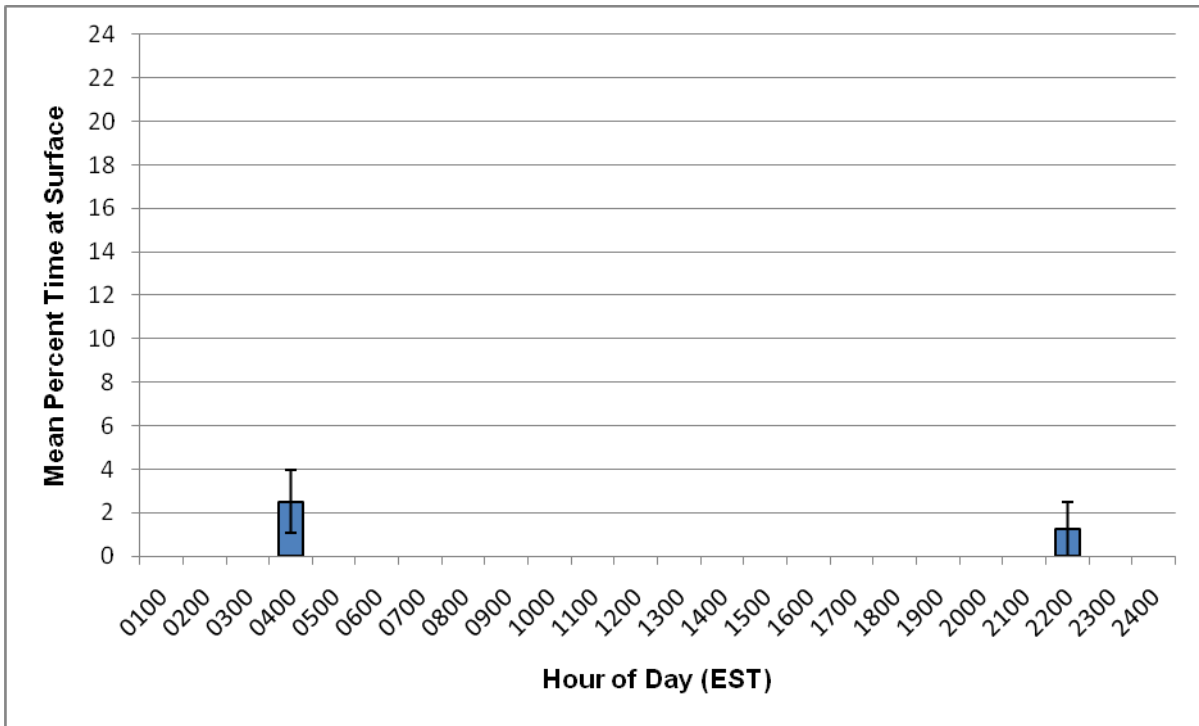


Fig. 16c Percentage of time spent on surface of water for Turtle PPX316.

Tag ID# 42604; Master Tag TTS633

Turtle TTS633 also was captured on May 19, 2008 in a pound net set in Core Sound (34.966N; -76.210W) and released the same day off Atlantic, NC (34.876N; -76.340W). Transmissions from the tag lasted 164 days. The turtle moved south of its release location, entering the coastal waters off of Cape Lookout by the end of May (Appendix, Fig. 17a). It continued traveling south, reaching South Carolina by mid-June, Georgia by early July, and Florida by mid-July. It remained off the coast of Florida during the rest of July then appeared to enter the Gulf Stream and quickly traveled north (nearly 170 km in 8 days) to off the coast of Georgia. It again traveled south, reaching the coastal waters of Florida by mid-September and remained off of Florida until the tag stopped transmitting on October 30, 2008. SST (obtained from STAT) in which this turtle traveled ranged between 21 and 28° C (Table 4) while water temperatures recorded by the PTT where it spent > 96% of its time ranged from 22 to 30° C (Fig. 17b). It spent an average of 5.5% of its time on the surface of the water (Fig. 17c).

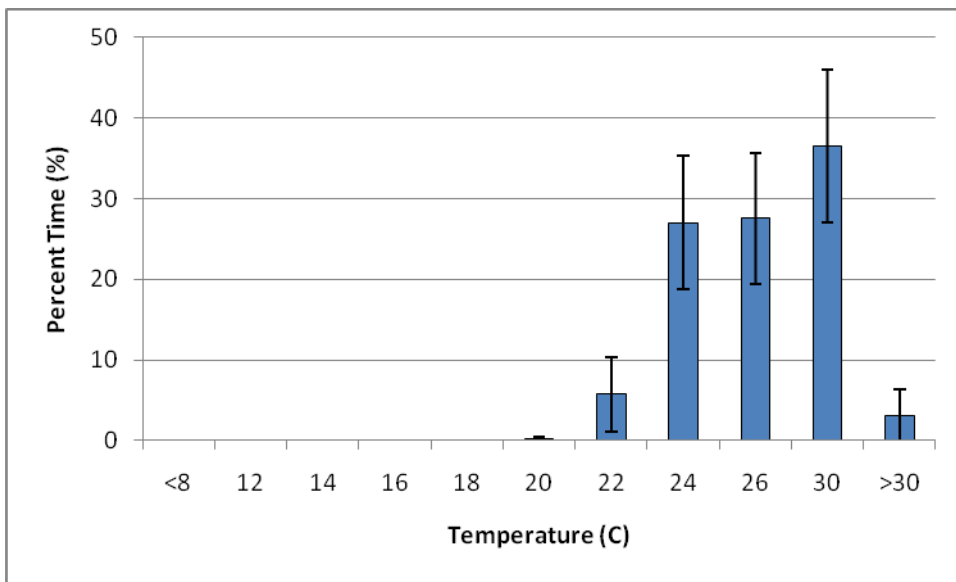


Fig. 17b Percentage of time spent within binned temperatures for Turtle TTS633.

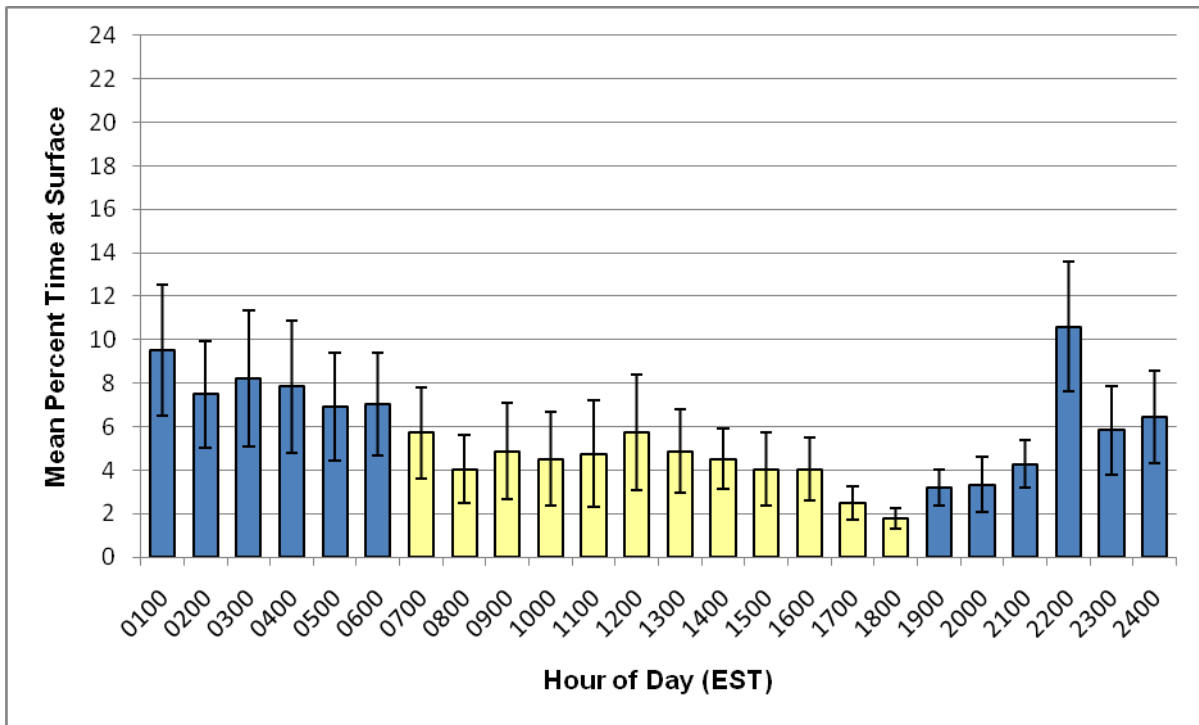


Fig. 17c Percentage of time spent on surface of water for Turtle TTS633.

Tag ID# 42602; Master Tag RRS255

Turtles RRS255 was captured on May 28, 2008 in a pound net set in Core Sound (34.968N; -76.220W) and released the same day off Cedar Island, NC, NC (34.951N; -76.281W). Transmissions from the tag lasted 40 days. The turtle remained in the vicinity of its release location until the tag stopped transmitting on July 7, 2008 (Appendix, Fig. 18a). SST (obtained from STAT) in which this turtle traveled ranged between 22 and 27° C (Table 4) while water temperatures recorded by the PTT where it spent > 96% of its time ranged from 22 to 30° C (Fig. 18b). It spent < 1.0% of its time on the surface of the water (Fig. 18c).

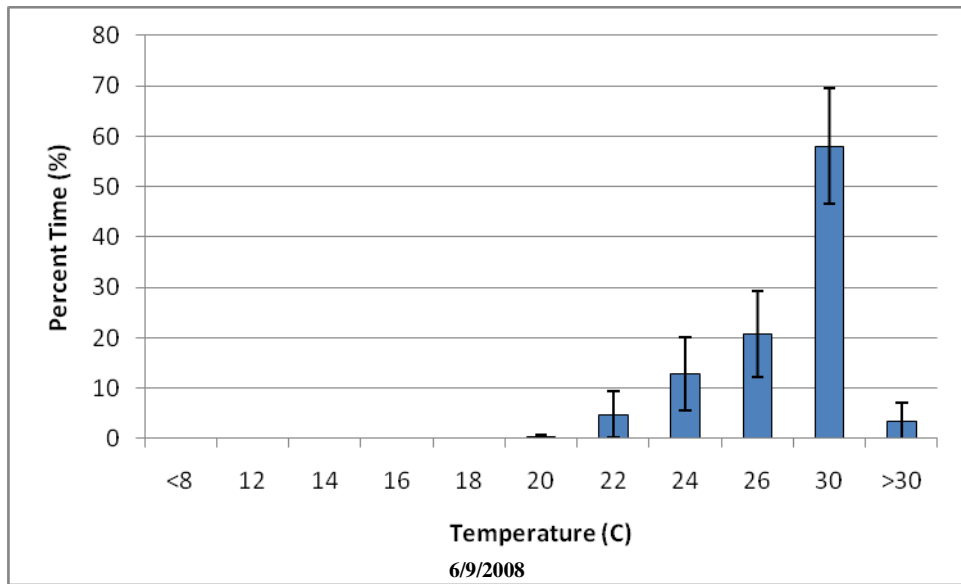


Fig. 18b Percentage of time spent within binned temperatures for Turtle RRS255.

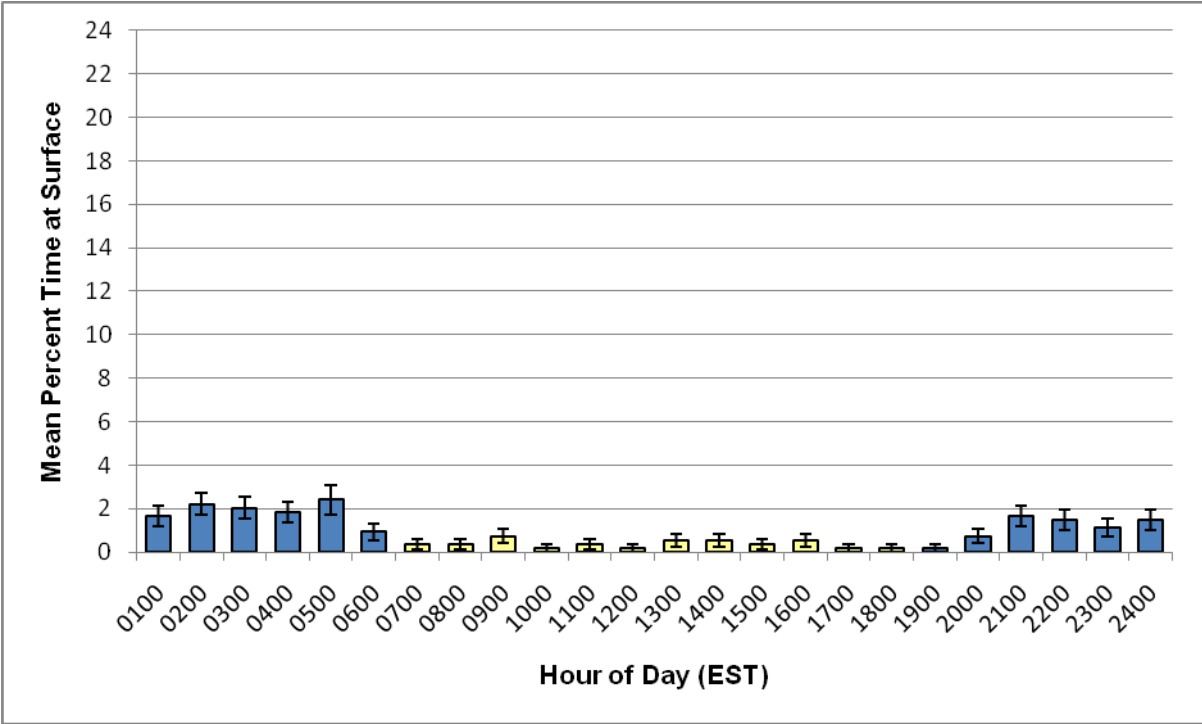


Fig. 18c Percentage of time spent on surface of water for Turtle RRS255.

Tag ID# 42603; Master Tag XXE502

Turtle XXE502 also was captured on May 28, 2008 in a pound net set in Core Sound (34.968N; -76.220W) and released the same day off Cedar Island, NC (34.951N; -76.281W). Transmissions from the tag lasted 26 days. Similar to turtle #42602, this turtle remained in the vicinity of its release locations until the tag stopped transmitting on June 23, 2008 (Appendix, Fig. 19a). SST (obtained from STAT) in which this turtle traveled ranged between 24 and 27° C (Table 4) while water temperatures recorded by the PTT where it spent 100% of its time ranged from 22 to > 30°C (Fig. 19b). It spent < 1.0% of its time on the surface of the water (Fig. 19c).

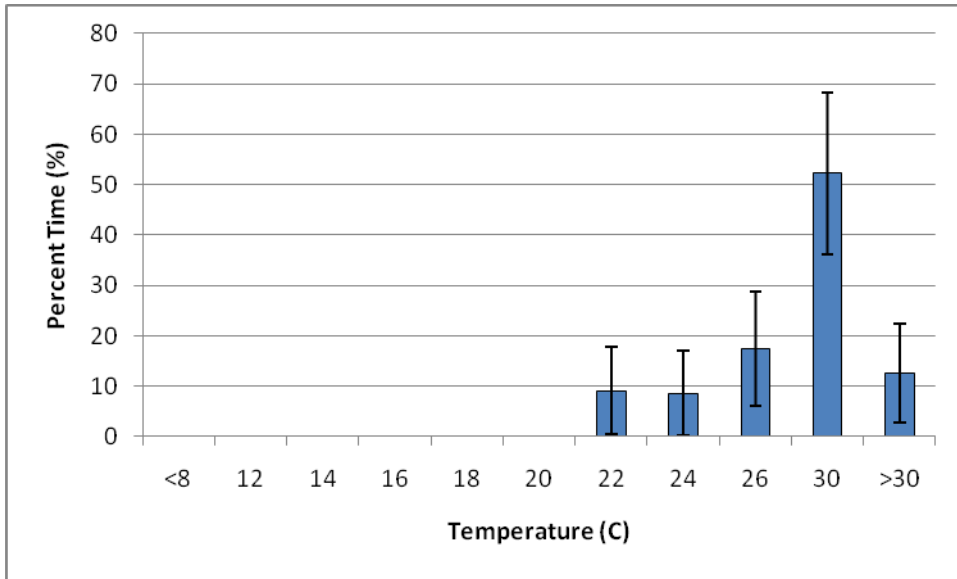


Fig. 19b Percentage of time spent within binned temperatures for Turtle XXE502.

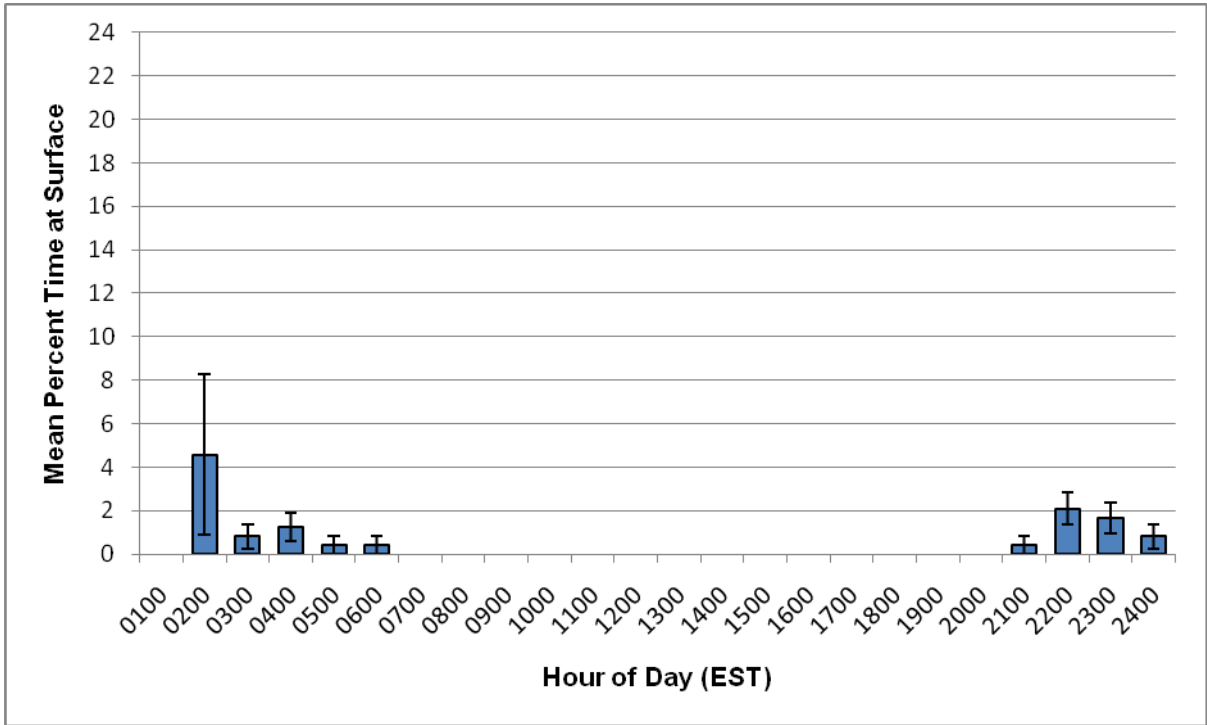


Fig. 19c Percentage of time spent on surface of water for Turtle XXE502.

Tag ID# 43638; Master Tag TTS643

Turtle TTS643 was captured on June 2, 2008 in a pound net set in Core Sound (34.968N; -76.222W) and released the same day off Cedar Island, NC (34.951N; -76.281W). Transmissions from the tag lasted 224 days. The turtle remained in the vicinity of its release location until late October when it moved offshore of Core Banks (Appendix, Fig. 20a). We continued receiving transmissions from this tag until January 1, 2009. SST (obtained from STAT) in which this turtle traveled ranged between 19 and 29° C (Table 4) while water temperatures recorded by the PTT where it spent 98% of its time ranged from 18 to 30° C (Fig. 20b). It spent < 1.0% of its time on the surface of the water (Fig. 20c).

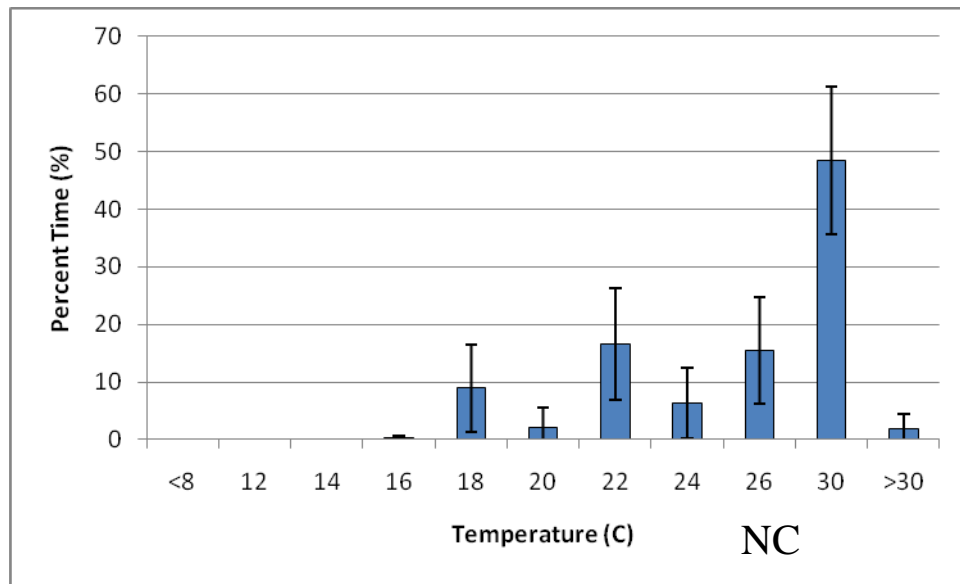


Fig. 20b Percentage of time spent within binned temperatures for Turtle TTS643.

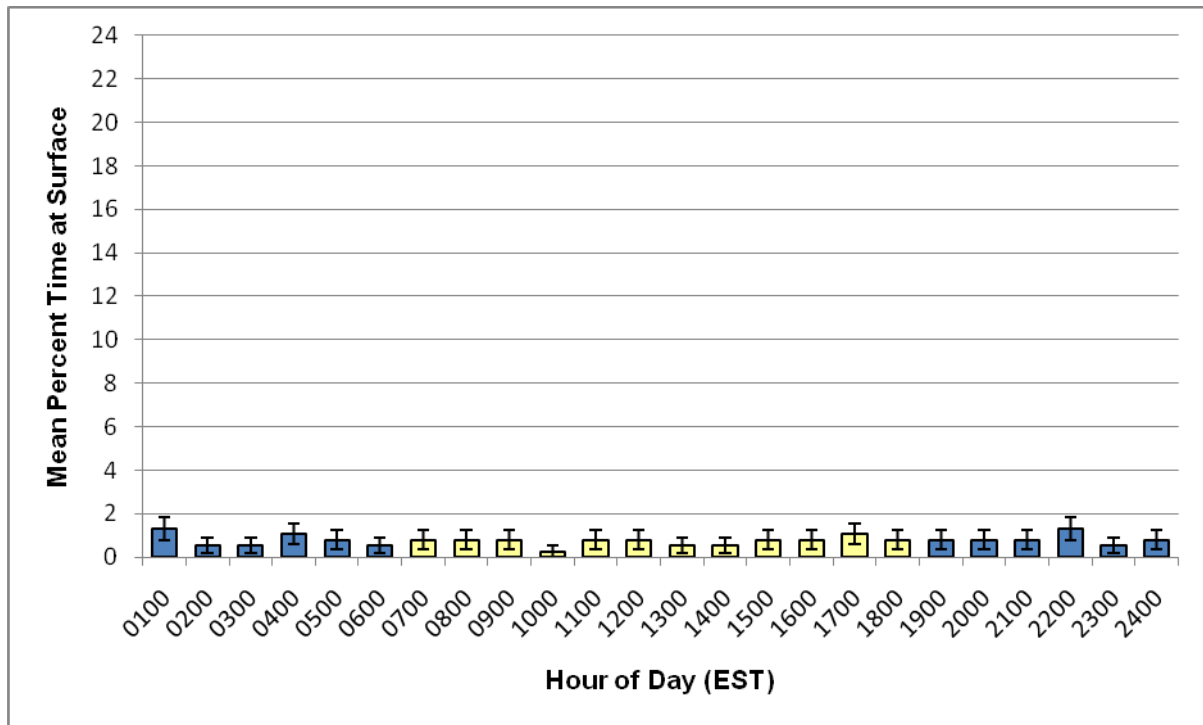


Fig. 20c Percentage of time spent on surface of water for Turtle TTS643.

Tag ID# 43639; Master Tag TTS651

Turtle TTS651 also was captured on June 2, 2008 in a pound net set in Core Sound (34.966N; -76.210W) and released the same day off Cedar Island, NC (34.951N; -76.281W). Transmissions from the tag lasted 64 days. The turtle remained in the vicinity of its release location until its transmissions ended August 5, 2008 (Appendix, Fig. 21a). SST (obtained from STAT) in which this turtle traveled ranged between 23 and 27° C (Table 4) while water temperatures recorded by the PTT where it spent 97% of its time ranged from 22 to >30° C (Fig. 21b). It spent < 1.0% of its time on the surface of the water (Fig. 21c).

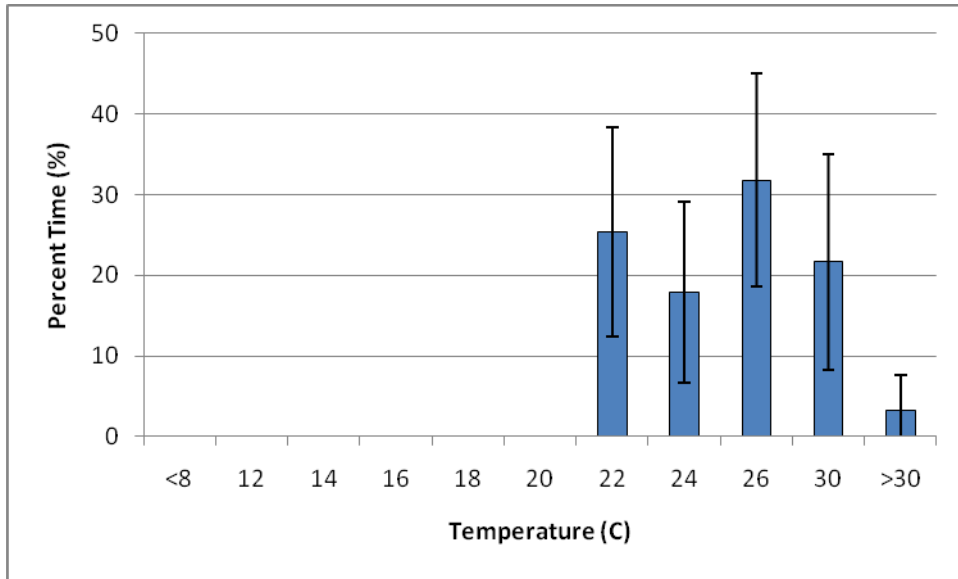


Fig. 21b Percentage of time spent within binned temperatures for Turtle TTS651.

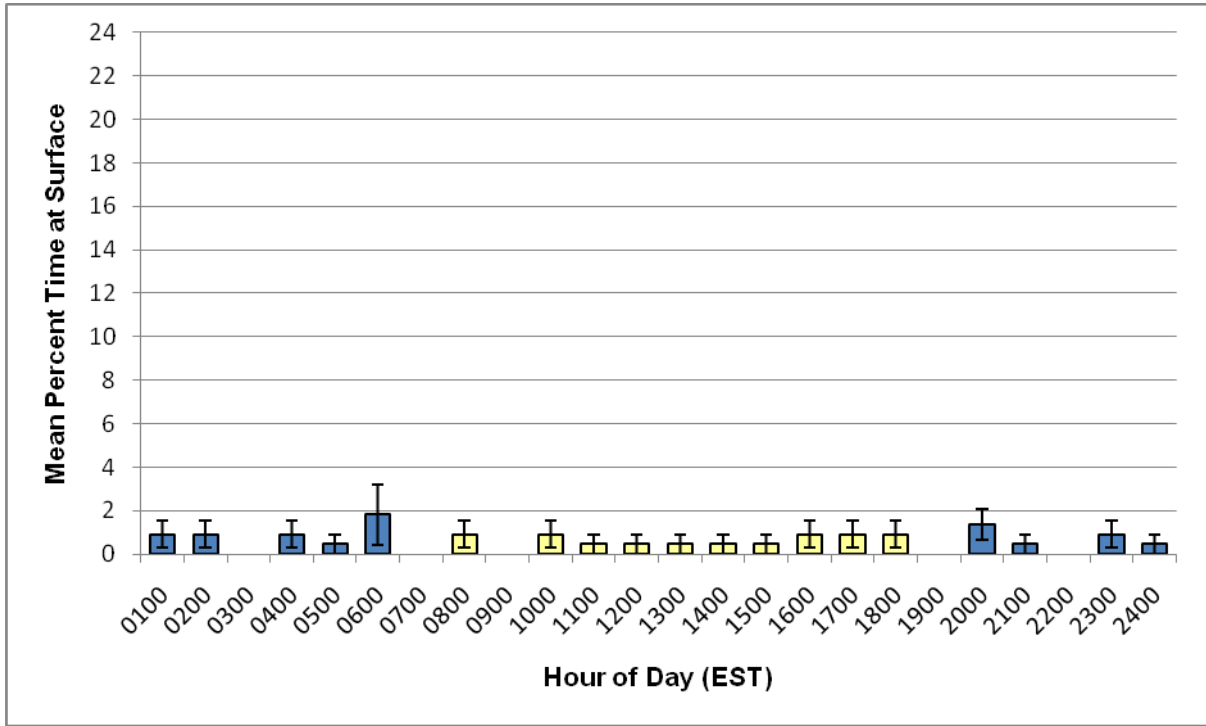


Fig. 21c Percentage of time spent on surface of water for Turtle TTS651.

Tag ID# 43635; Master Tag TTS551

Turtle TTS551 was captured on June 13, 2008 in a pound net set in Core Sound (34.966N; -76.210W) and released the same day off Cedar Island, NC (34.966N; -76.220W). Transmissions from the tag lasted 133 days. The turtle left Core Sound within days of its release and migrated north, reaching the coastal waters of New Jersey by mid-July (Appendix, Fig. 22a). It continued north and spent the rest of the summer off New York, beginning a southern migration in mid-September. By the end of October it had returned to offshore of its release location and transmissions ended October 24, 2008 (Appendix, Fig. 22a). SST (obtained from STAT) in which this turtle traveled ranged between 19 and 27° C (Table 4) while water temperatures recorded by the PTT where it spent 98% of its time ranged from 12 to 30° C (Fig. 22b). It spent an average of 12.5% of its time on the surface of the water (Fig. 22c).

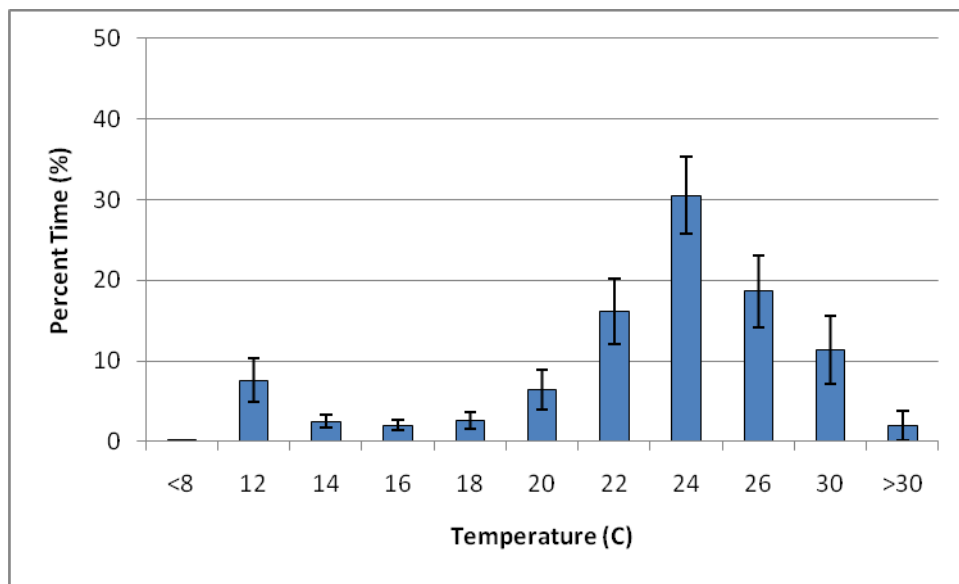


Fig. 22b Percentage of time spent within binned temperatures for Turtle TTS551.

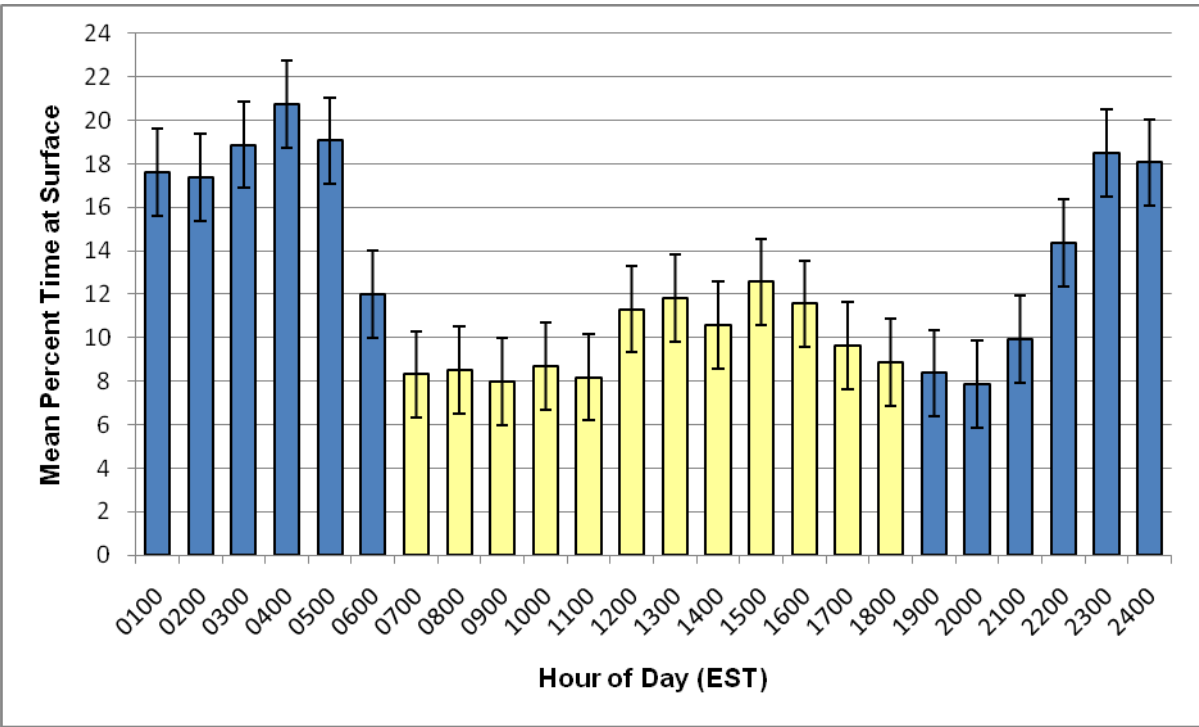


Fig. 22c Percentage of time spent on surface of water for Turtle TTS551.

Surfacing Behavior

Both the SPOT5 and SPLASH satellite tags were equipped with a salt water switch, so were able to provide us with a minimum estimate of percent time the turtle spent at the surface per any given 24-hour period. From these surfacing interval data, we determined that individual loggerheads spent from 0.1 to 12.5 % of their time on the surface of the water (Table 4). Because the SPLASH tags had the additional capability of determining depth, we also could derive the percentage of time each turtle spent in water ≤ 1 m, using this datum as a means of establishing when the turtles were close to the surface of the water and therefore likely to be visible during an aerial survey. All turtles equipped with a SPLASH satellite tag spent a minimum of 23 % of their time within 1 m of the surface of the water (Table 4).

Estuarine versus Coastal Surfacing Behavior

Because we did not have geo-locations for all of the surfacing interval data points (acquired via the salt water switch), we were not able to assign all surfacing intervals to an estuarine or coastal area. Regardless, we detected a total of 3816 surfacing intervals in estuarine waters and 6840 in coastal waters. Loggerhead turtles spent a significantly greater amount of time on the surface in coastal waters (2.4%, paired t-test, $p < 0.01$) than they did in estuarine waters (0.7%) (Fig. 23).

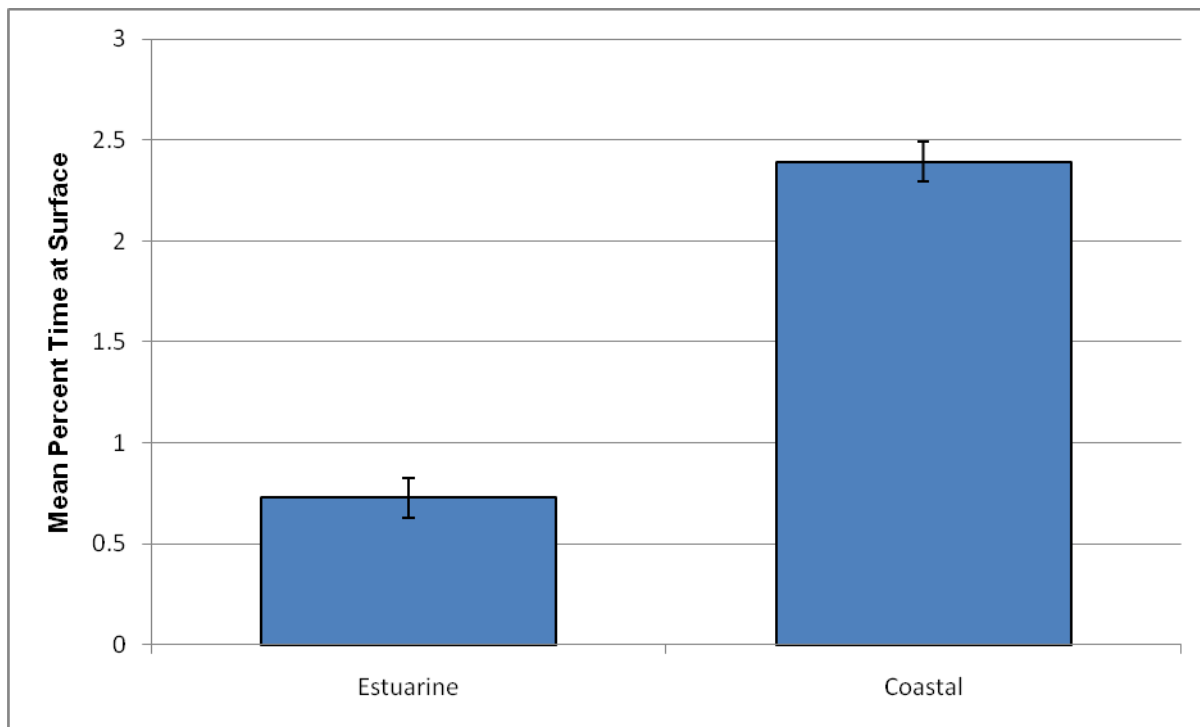


Fig. 23 Percentage of time spent at surface in estuarine versus coastal waters.

Corrected density and abundance estimates for Core and Pamlico Sounds and coastal areas

Applying the average percentage of time spent on the surface of estuarine and coastal waters along with the percentage of time spent within 1 m of the surface of the water to population estimates reported by Goodman et al. (2007), we recalculated density and abundance estimates (Table 5). Corrected density estimates ranged from 0.01 to 2.2 turtles/km² in the sounds and from 0.3 to 25.6 turtles/km² in the coastal region. Corrected abundance estimates ranged from 16 to 4997 turtles in the sounds and from 44 to 3552 turtles in the coastal region.

Table 5. 2004-2006 mean seasonal estimates of density (turtles/km²) and abundance for turtles on the surface of the Core and Pamlico Sounds and the coastal region of North Carolina, corrected for different surfacing behavior or sightability. SE is standard error.

Year	Season	Sounds (2,221.38 km ²)						Coastal Region (138.5 km ²)					
		Mean Seasonal Density Estimate (SE)			Mean Seasonal Abundance Estimate (SE)			Mean Seasonal Density Estimate (SE)			Mean Seasonal Abundance Estimate (SE)		
		Uncorrected ^a	Corrected ^b	Corrected ^c	Uncorrected ^a	Corrected ^b	Corrected ^c	Uncorrected ^a	Corrected ^b	Corrected ^d	Uncorrected ^a	Corrected ^b	Corrected ^d
2004													
	Summer	0.0103	0.0410	1.0261	23	99	3256	0.0726	0.3157	3.0250	10	44	419
		0.0048	0.0191	0.4786	10.6	46.2	1518.8	0.0445	0.1936	1.8554	6.2	26.8	257.0
	Autumn	0.0033	0.0146	0.4782	7	32	1062	0.0947	0.4117	3.9457	13	57	546
		0.0025	0.0110	0.3598	5.6	24.3	799.3	0.0716	0.3112	2.9827	9.9	43.1	413.1
2005													
	Winter	0.0000	0.0000	0.0000	0	0	0	0.0000	0.0000	0.0000	0	0	0
	Spring	0.0033	0.0143	0.4691	7	32	1042	0.3788	1.6469	15.7828	52	228	2186
		0.0033	0.0143	0.4691	7.3	31.7	1042.0	0.2678	1.1645	11.1601	37.1	161.3	1545.7
	Summer	0.0115	0.0499	1.6393	25	111	3641	0.6155	2.6762	25.6471	85	371	3552
		0.0032	0.0139	0.4572	7.1	30.9	1015.6	0.2199	0.9561	9.1629	30.5	132.4	1269.1
	Autumn	0.0157	0.0685	2.2495	35	152	4997	0.1894	0.8235	7.8914	26	114	1093
		0.0087	0.0378	1.2405	19.3	83.9	2755.7	0.0489	0.2126	2.0376	6.8	29.4	282.2
2006													
	Winter	0.0000	0.0000	0.0000	0	0	0	0.0000	0.0000	0.0000	0	0	0
	Spring	0.0017	0.0074	0.2425	4	16	539	0.0947	0.4117	3.9457	13	57	546
		0.0017	0.0074	0.2425	3.8	16.4	538.6	0.0947	0.4117	3.9457	13.1	57.0	546.5

^aGoodman et al. (2007)

^b23% sightability

^c0.7% sightability

^d2.4% sightability

Seasonal Surfacing Behavior

Due to the significant difference in surfacing behavior between estuarine and coastal locations, we separated the locations by region (estuarine or coastal) before examining seasonal differences in surfacing behavior. Although we found no significant difference in the amount of time turtles spent on the surface of estuarine waters at different times of the year, they did spend a significantly greater amount of time on the surface of coastal waters in the autumn than in the summer (Kruskall-Wallis, $p < 0.01$, Table 6).

Table 6. Percentage of time spent seasonally at surface in coastal and estuarine waters

	Spring	Summer	Autumn	Winter
Coastal	1.9	2.4	2.7*	2.5
Estuarine	<1	<1	<1	---

Discussion

The estimates of sea turtle populations in Core and Pamlico Sounds provided by Goodman et al. (2007) underestimated turtle density and abundance, as they did not incorporate a correction factor accounting for the time the turtles spent underwater. Our estimates showed a 4 to 100-fold increase over theirs, depending on which correction factor we used in the calculation. As an example, Goodman et al. (2007) estimated 23-25 turtles in the sounds during the summer while we estimated 99 to over 3600 turtles. In addition, we found that loggerheads were spending a significantly greater percentage of their time on the surface of coastal than estuarine waters which may partially explain why Goodman et al. (2007) estimated turtles densities higher in coastal than estuarine waters.

However, we acknowledge that both methodologies used in assessing surfacing behavior of turtles had limitations. For instance, McClellan and Read (2007) observed turtles they satellite tagged raise their heads out of the water to breathe but not surface high enough to expose the salt water switch of the tags attached to their carapaces. Thus, turtles may have been spending more time on the surface of the water where they would be visible to observers during aerial surveys than would be indicated by the activation of the salt water switch on their satellite tags. Likewise, we were reasoning that turtles spending time within 1 meter of the water's surface would be visible during an aerial survey, when in fact turbidity may interfere with sightability. Thus, the percentage of time spent in 1 m of water could be an overestimate of the amount of time the turtles were spending on the surface. Because of the limitations of the

technology we were using, we applied not one, but two correction factors to Goodman et al.'s (2007) population estimates – 0.7% or 2.4% for the time the salt water switch was activated in estuarine or coastal waters, respectively, and 23% for the time turtles spent within 1 meter of the water's surface. Consequently, we are confident that the actual density and abundance of sea turtles in Core and Pamlico Sounds falls within the ranges we have provided (Table 5).

Although we have provided an accurate range of sea turtle density and abundance estimates, further refinement of these estimates and additional information on the use of restricted area R-5306A by all protected species can be collected utilizing other techniques. Because of their easier accessibility and abundance, we exclusively satellite tagged loggerhead sea turtles. However, both green and Kemp's ridley sea turtles have been documented utilizing R-5306A (North Carolina Division of Marine Fisheries unpublished data, North Carolina Wildlife Resources unpublished data), and detailed information on their movements within the restricted area also could be obtained via satellite telemetry. Likewise, acoustic arrays can be used to record the movements of several different tagged species simultaneously within a particular habitat (Grothues et al. 2005). Finally, hydroacoustic surveys can be used to detect and count individuals underwater along transects (<http://www.soundmetrics.com/>). All these techniques can further define the abundance and use of protected species within restricted area R-5306A.

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Fig. 4a Satellite movements of Loggerhead TTS236 July 24, 2007 to April 25, 2008

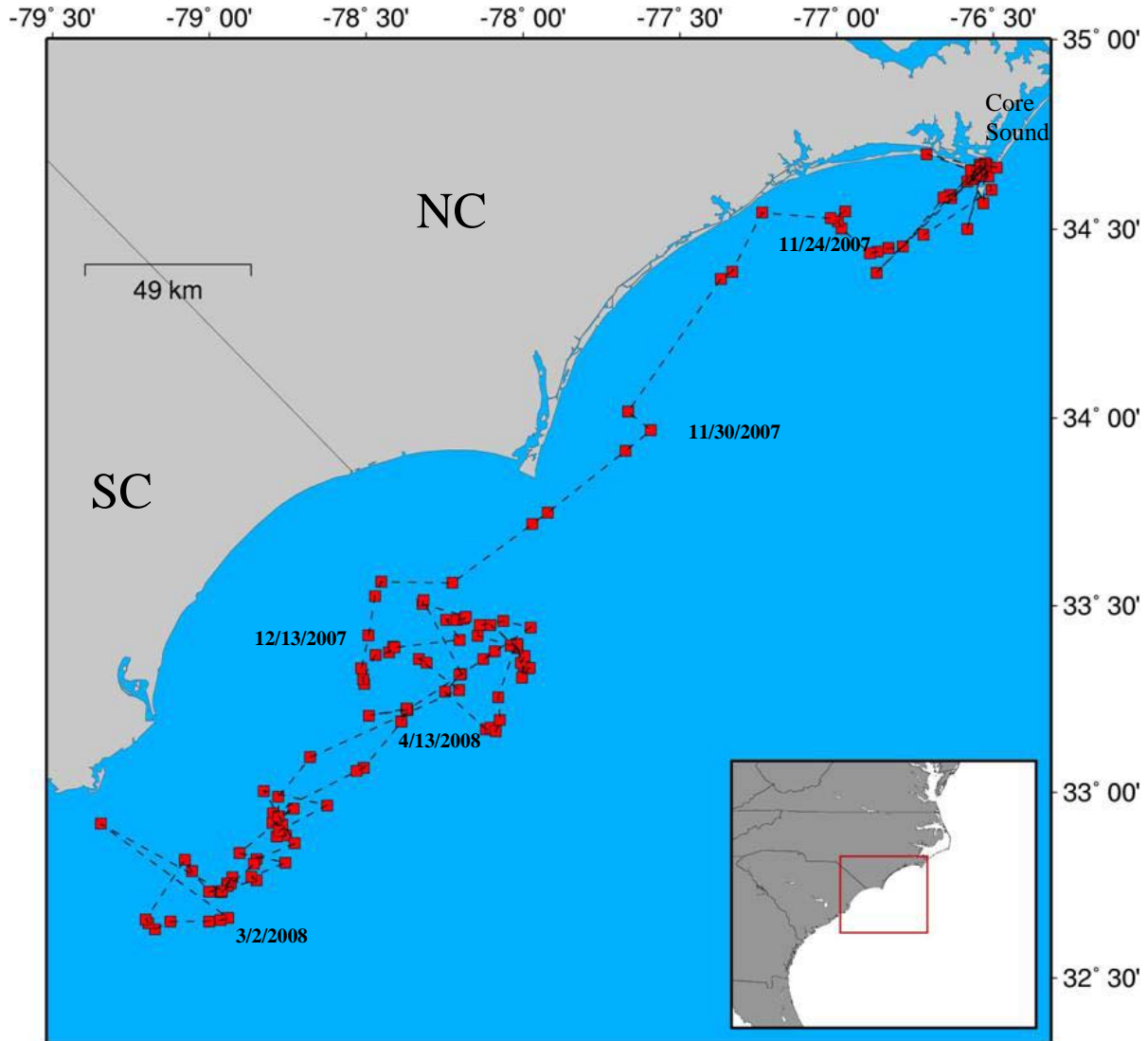


Fig. 5a Satellite movements of Loggerhead TTS233 July 31 to August 31, 2007.

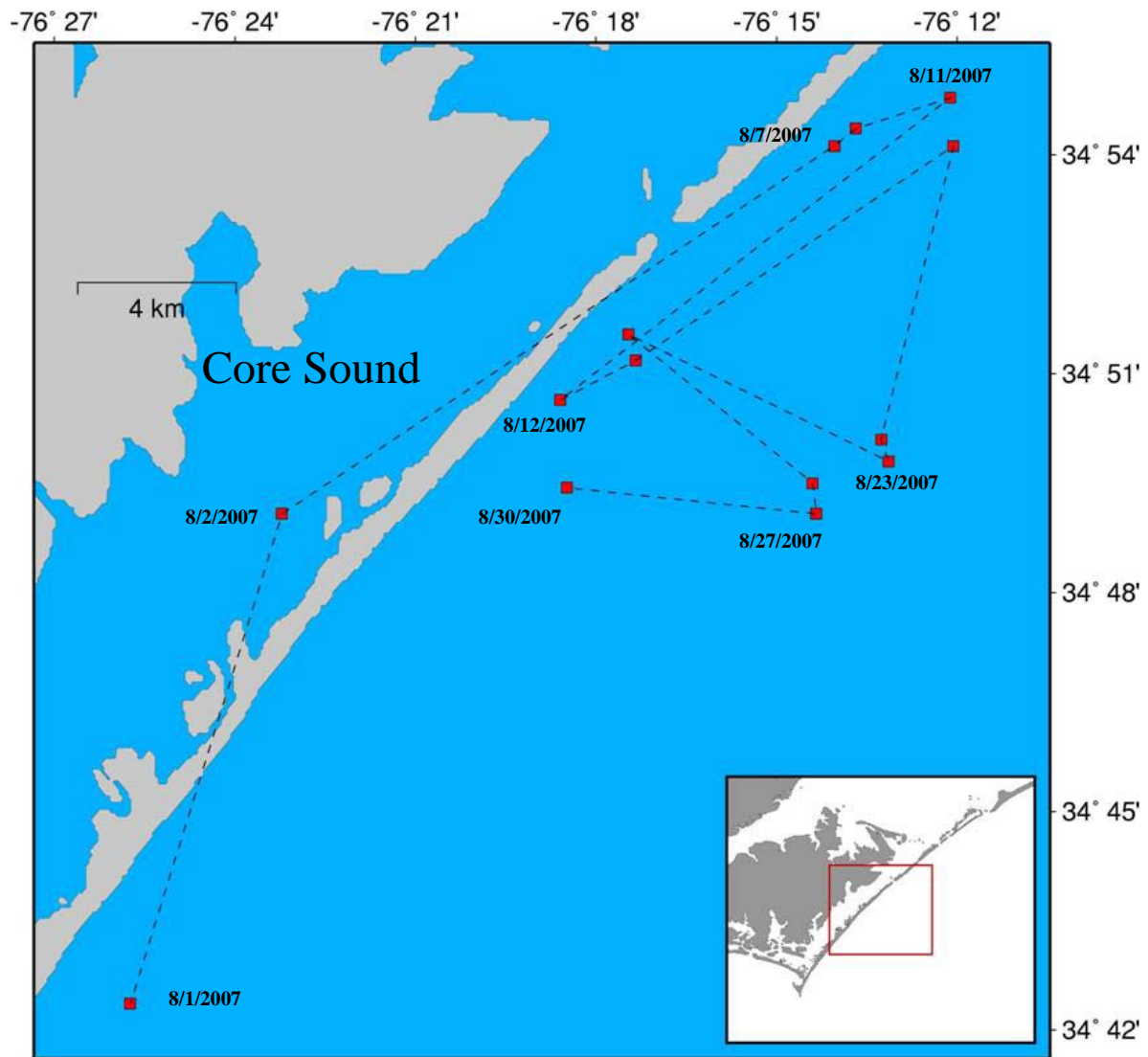


Fig. 6a Satellite movements of Loggerhead RRS949 August 7, 2007 to March 2, 2008

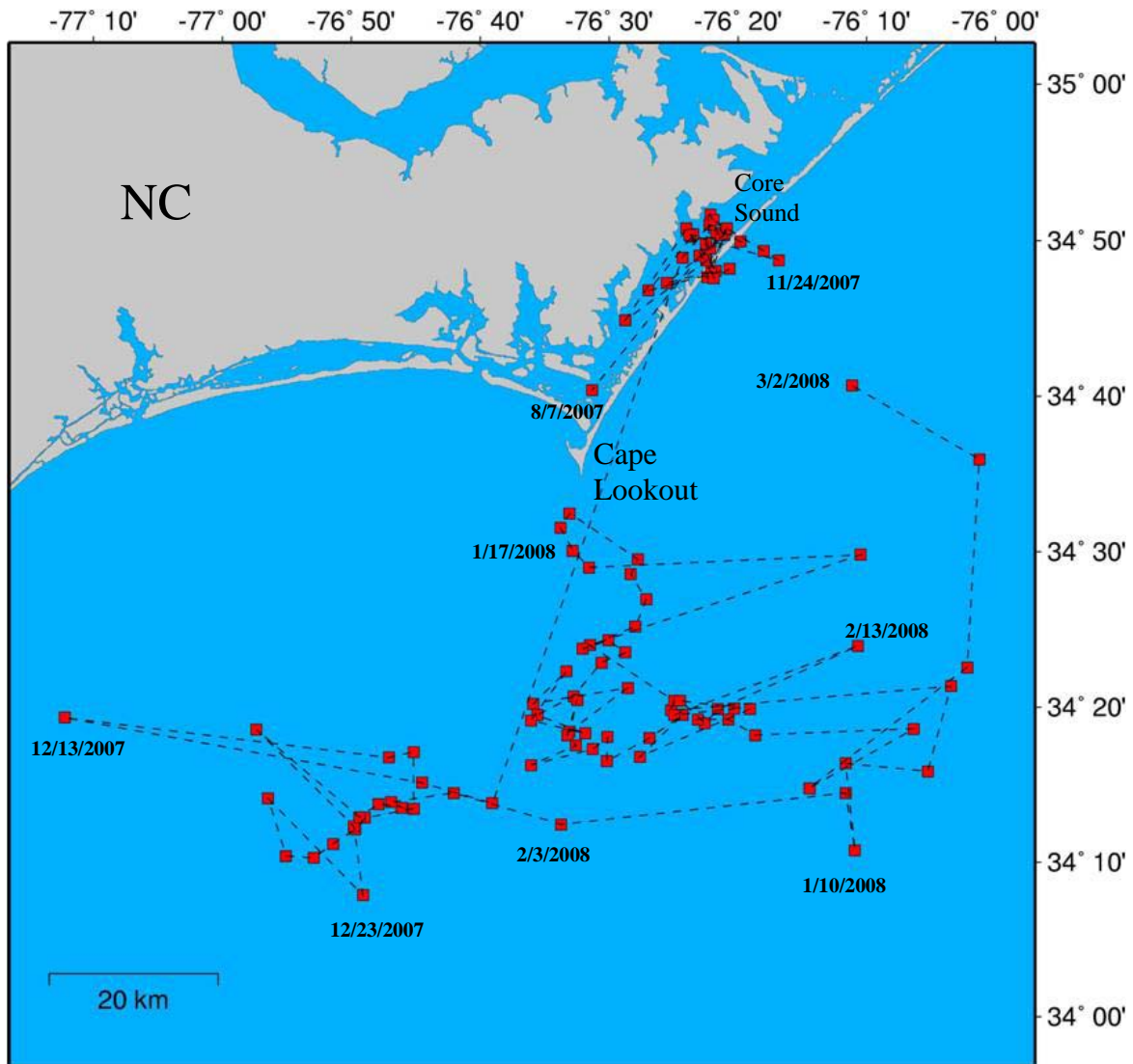


Fig. 7a Satellite movements of Loggerhead SSR505 August 24, 2007 to April 25, 2008

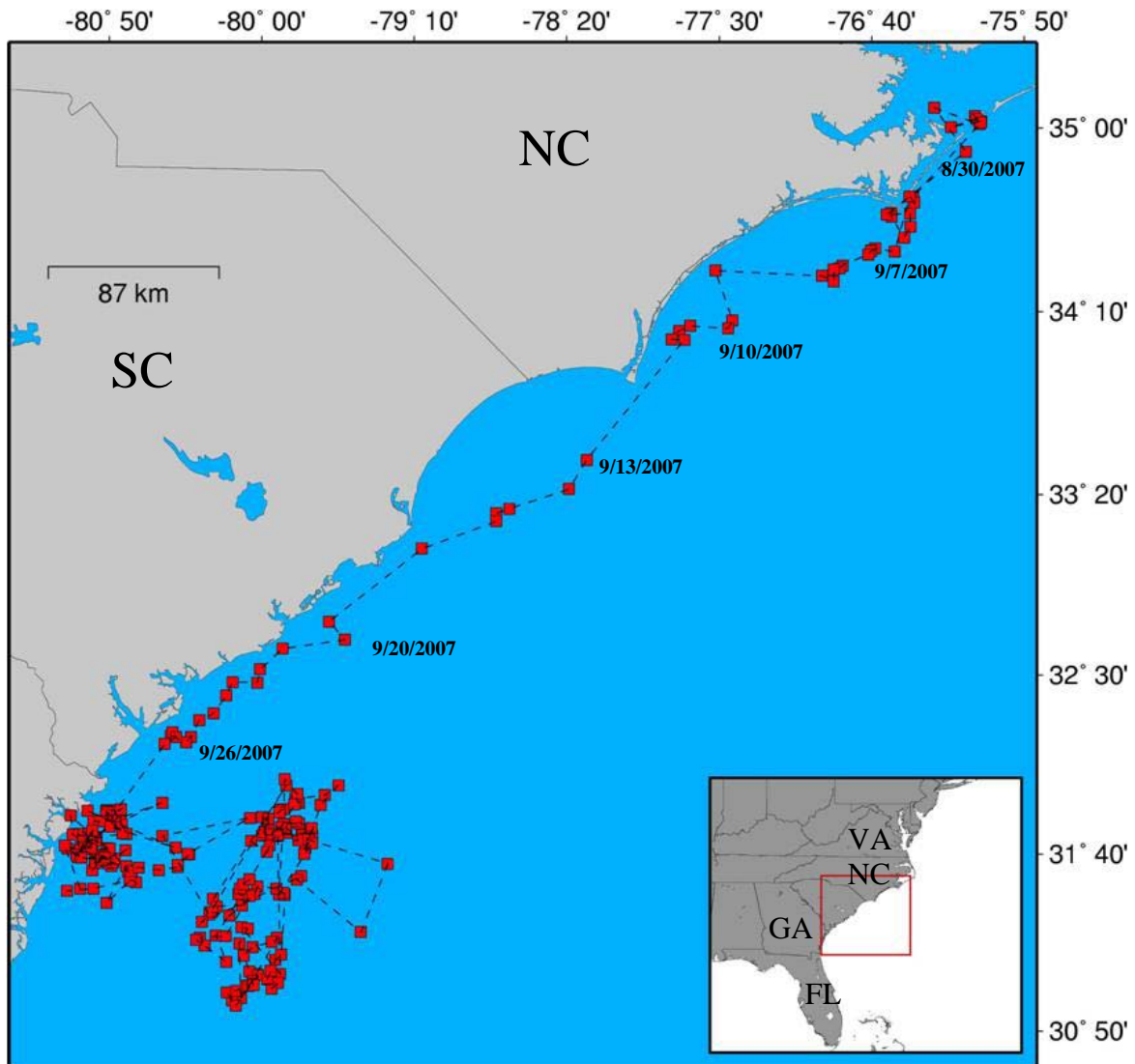


Fig. 8a Satellite movements of Loggerhead RRS098 October 9, 2007 to April 11, 2008

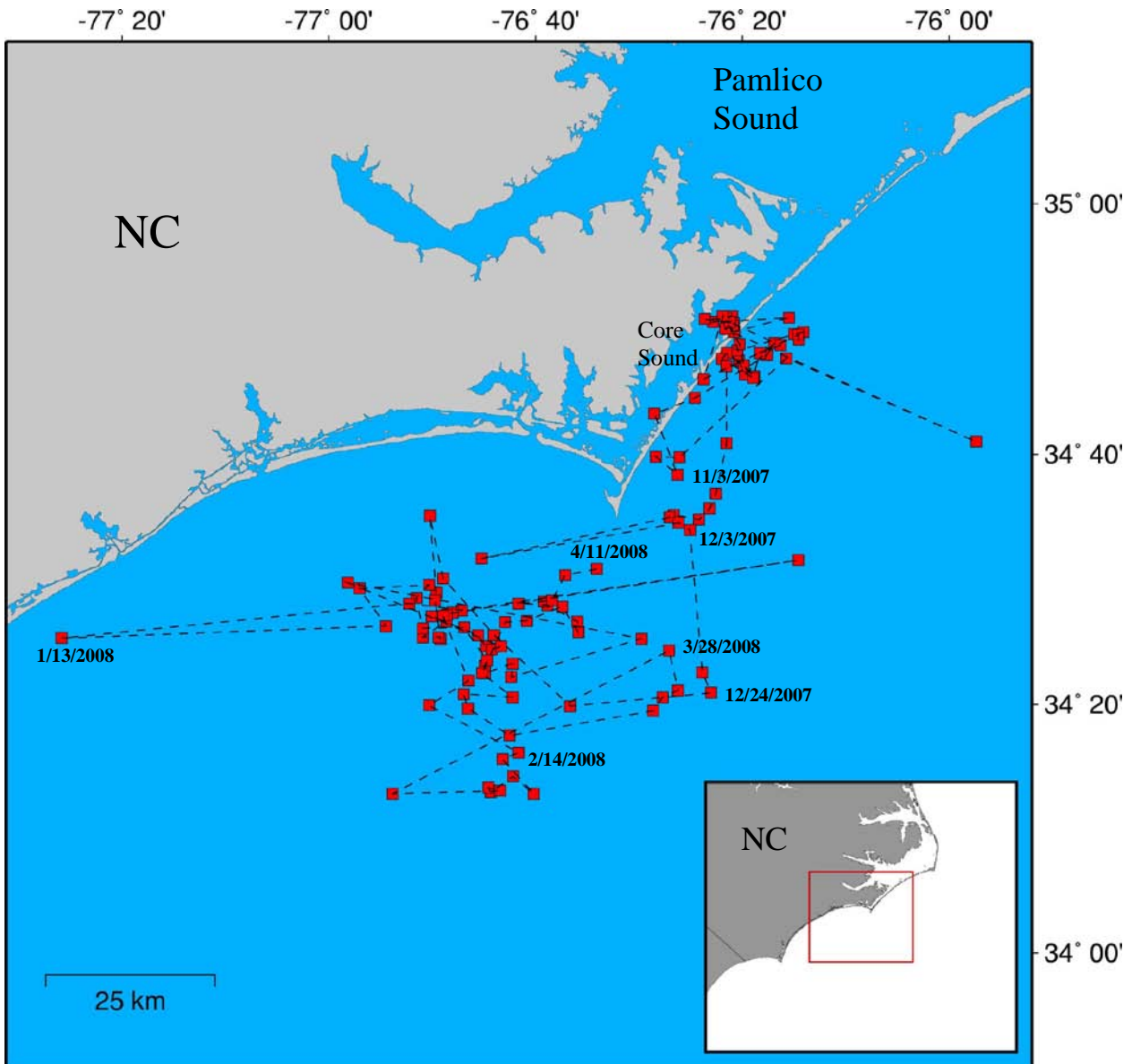


Fig. 9a Satellite movements of Loggerhead RRS412 October 11, 2007 to April 20, 2008

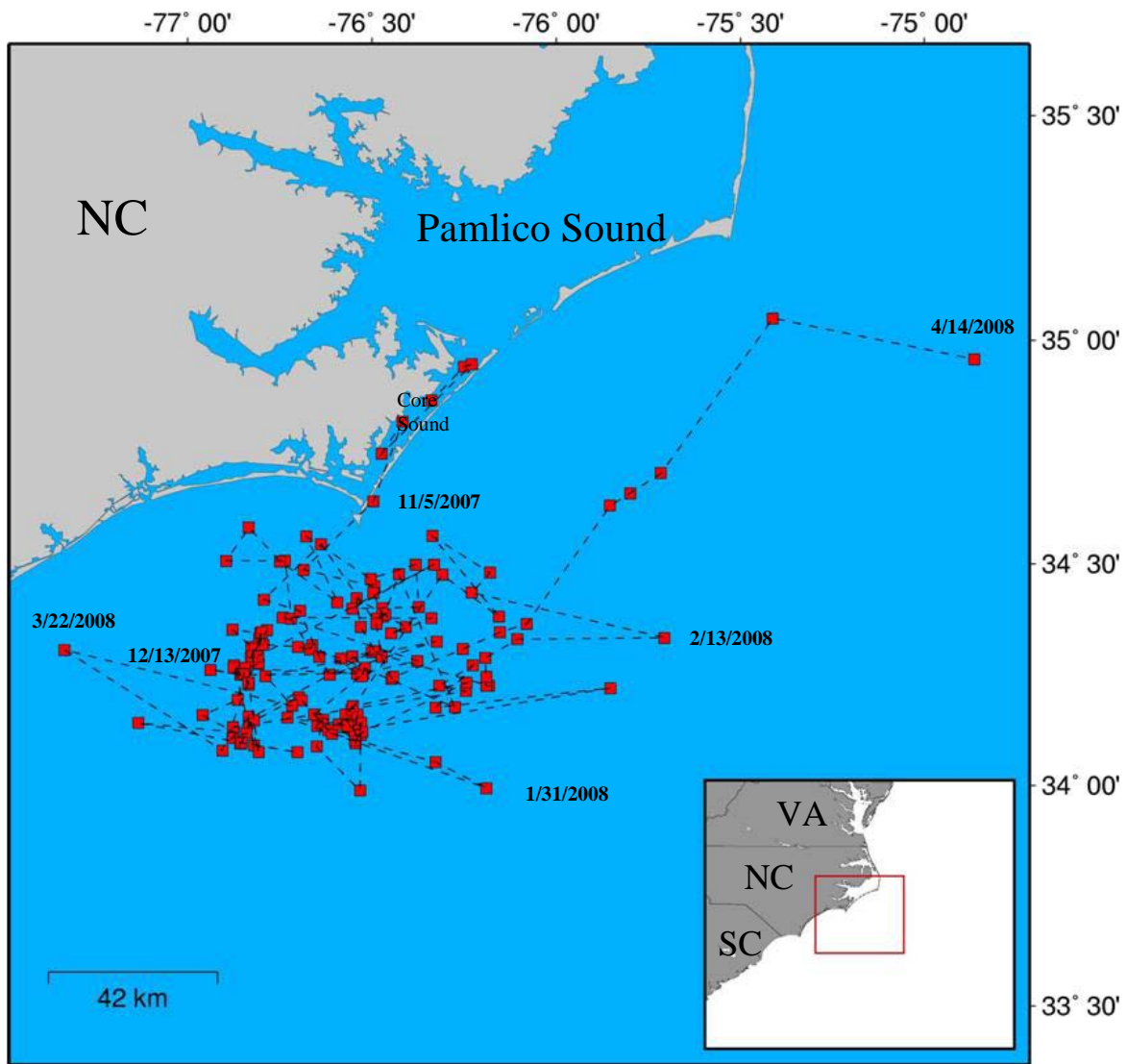


Fig. 10a Satellite movements of Loggerhead XXN027 tagged with SPOT5 #76457 October 11, 2007 to April 15, 2008 (red squares) and SPLASH #42664 June 3 to July 21, 2008 (black squares).

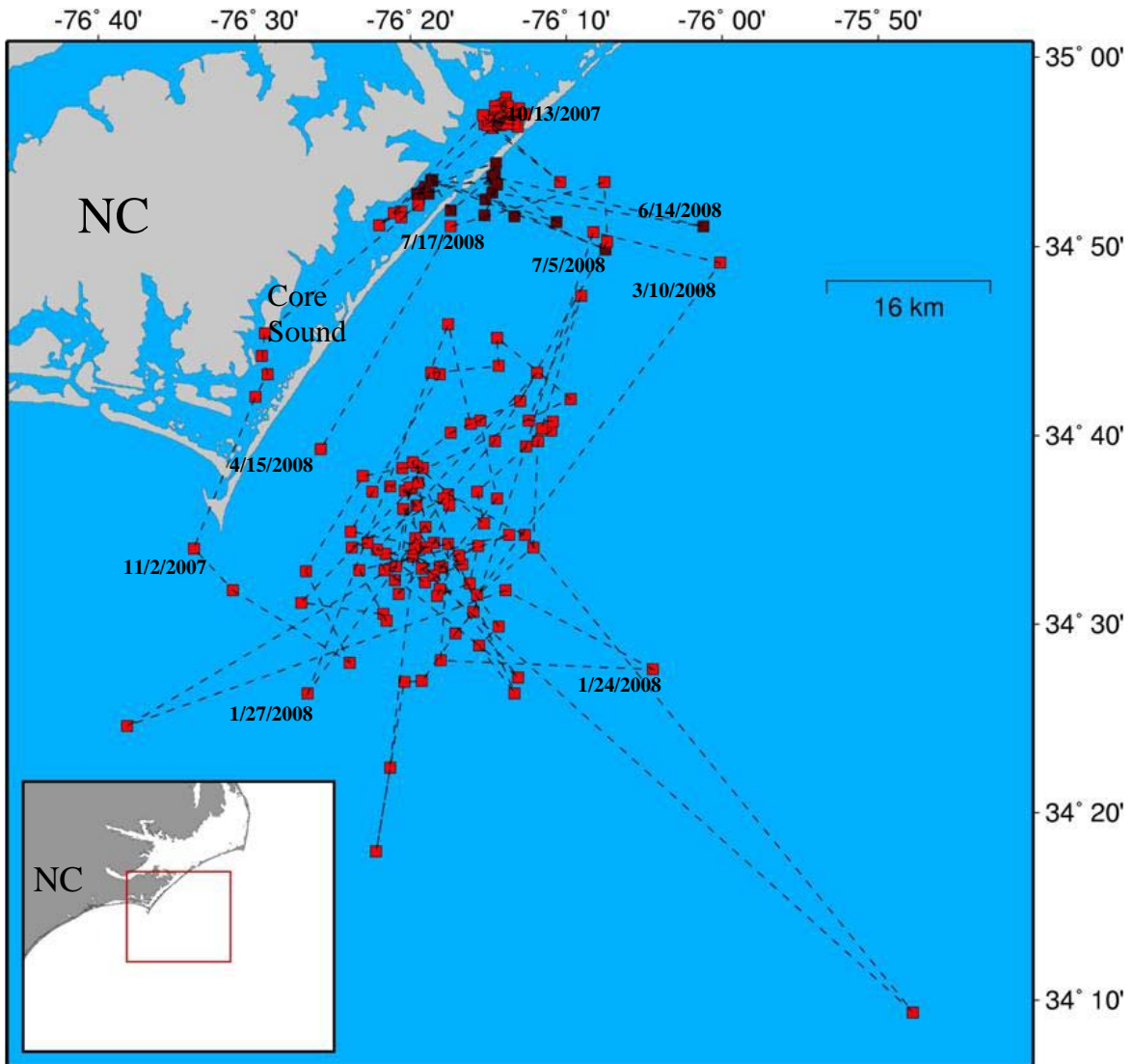


Fig. 11a Satellite movements of Loggerhead TTS450 May 5 to July 1, 2008

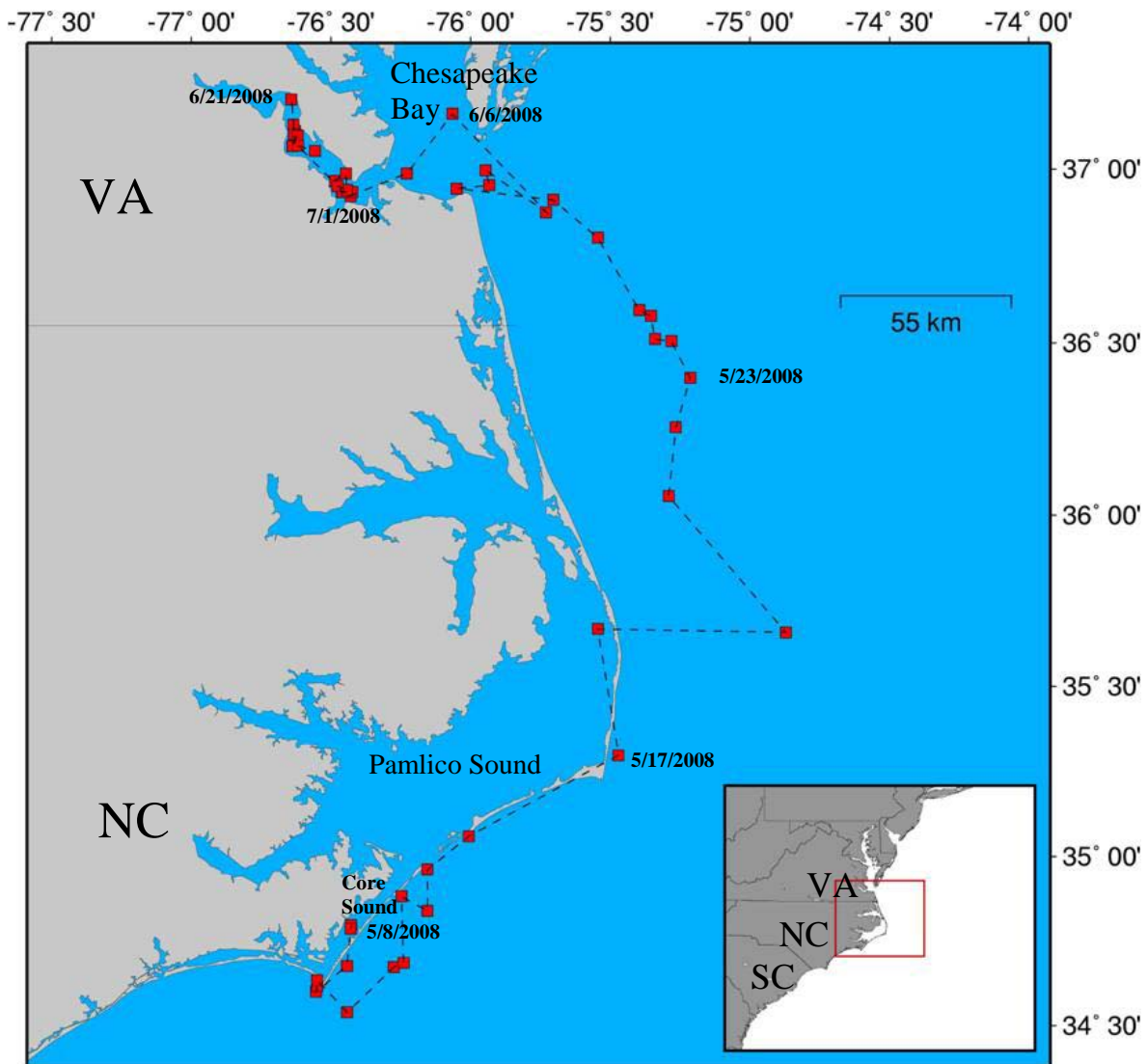


Fig. 12a Satellite movements of Loggerhead TTS448 May 5 to September 4, 2008

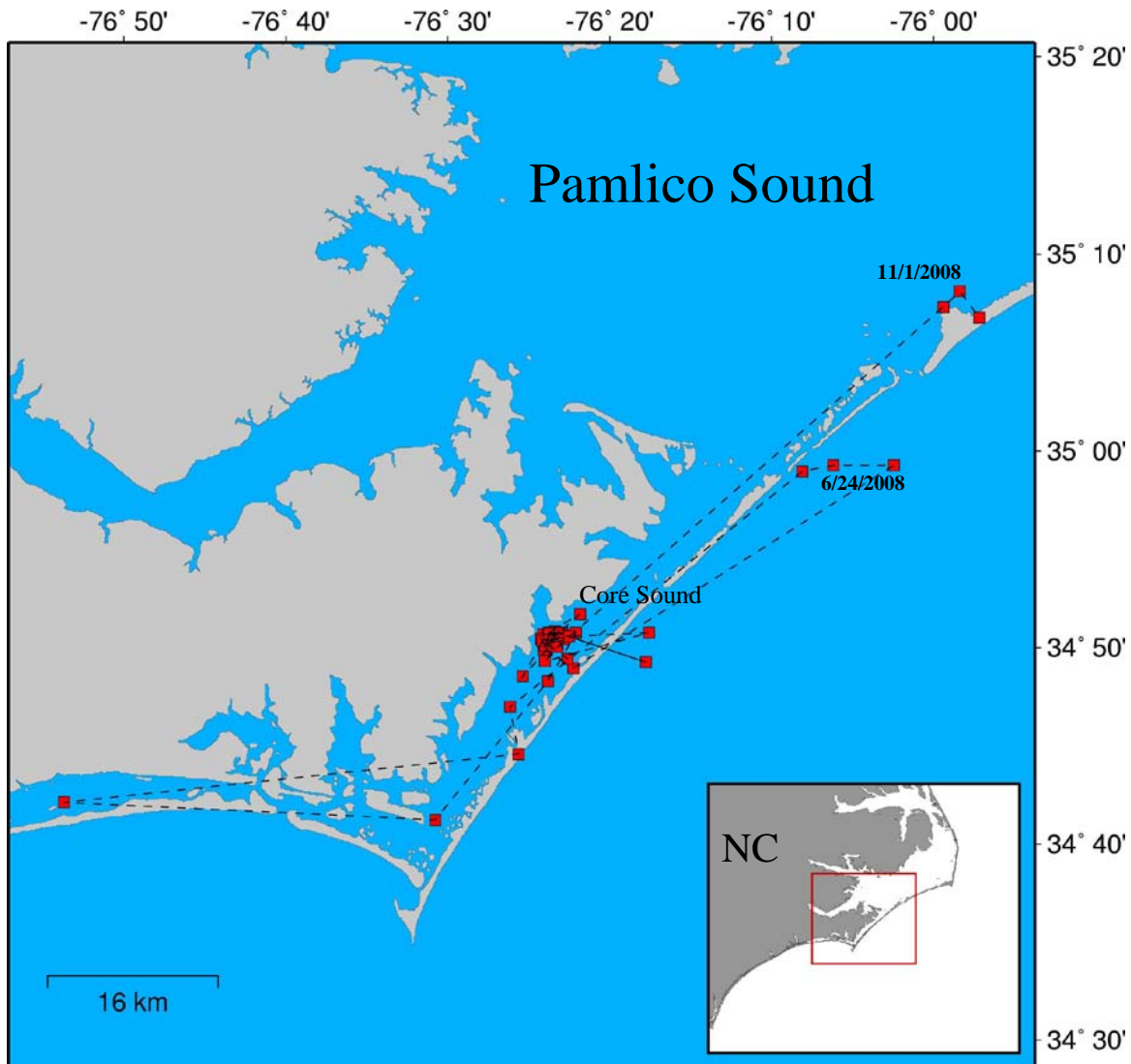


Fig. 13a Satellite movements of Loggerhead TTS514 May 7 to August 13, 2008

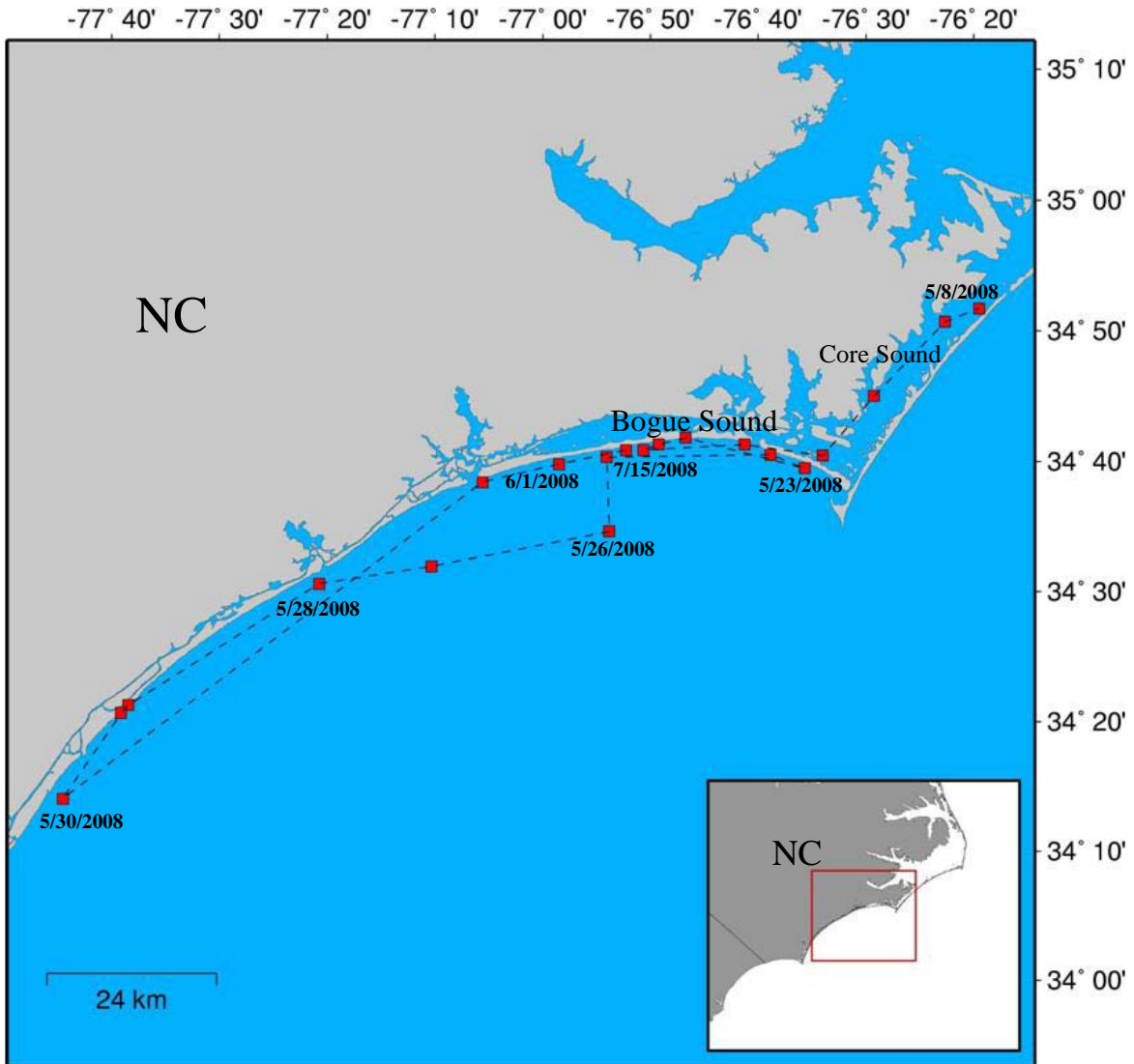


Fig. 14a Satellite movements of Loggerhead TTS599 May 14 to October 30, 2008

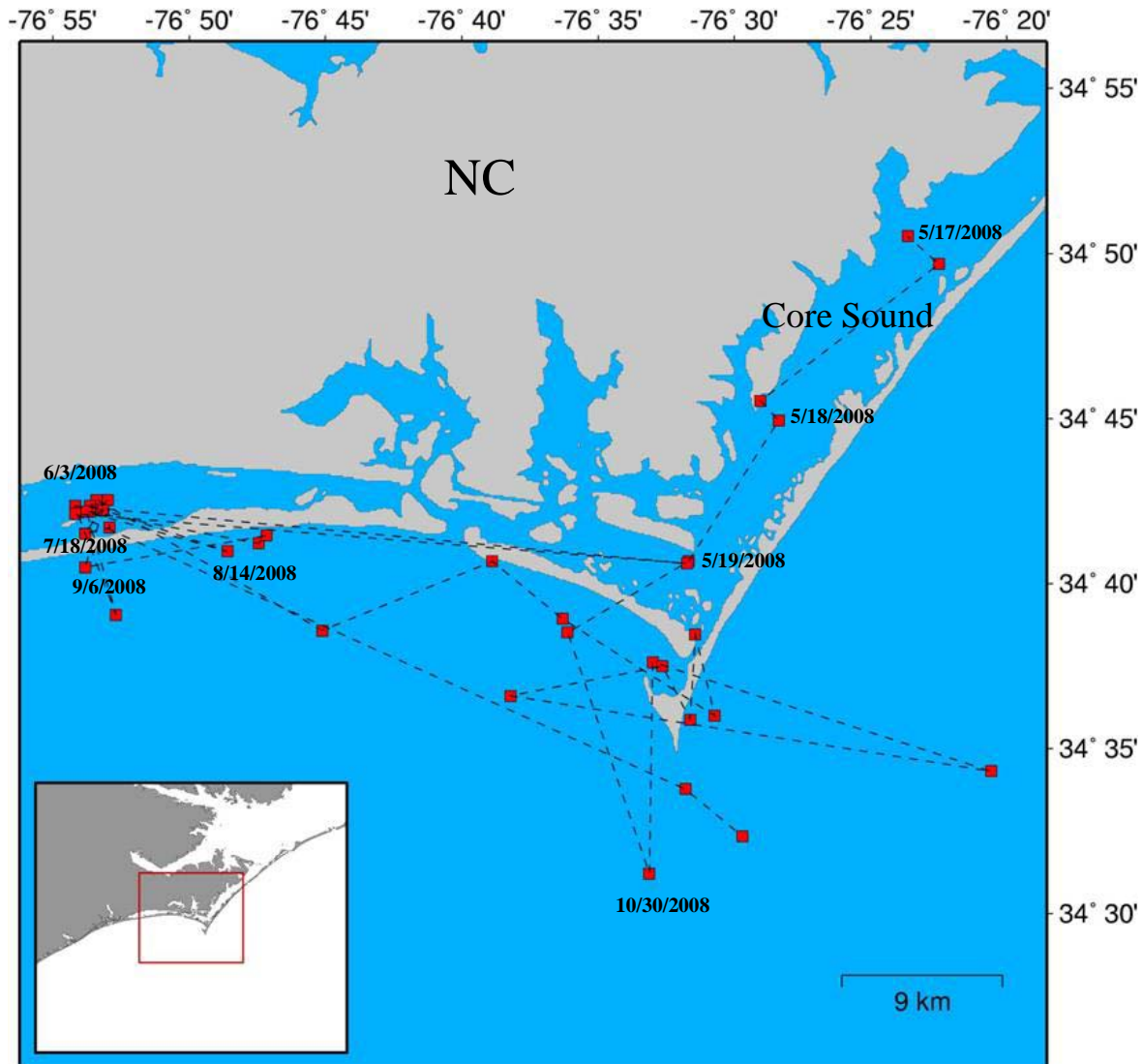


Fig. 15a Satellite movements of Loggerhead TTS612 May 14 to August 22, 2008

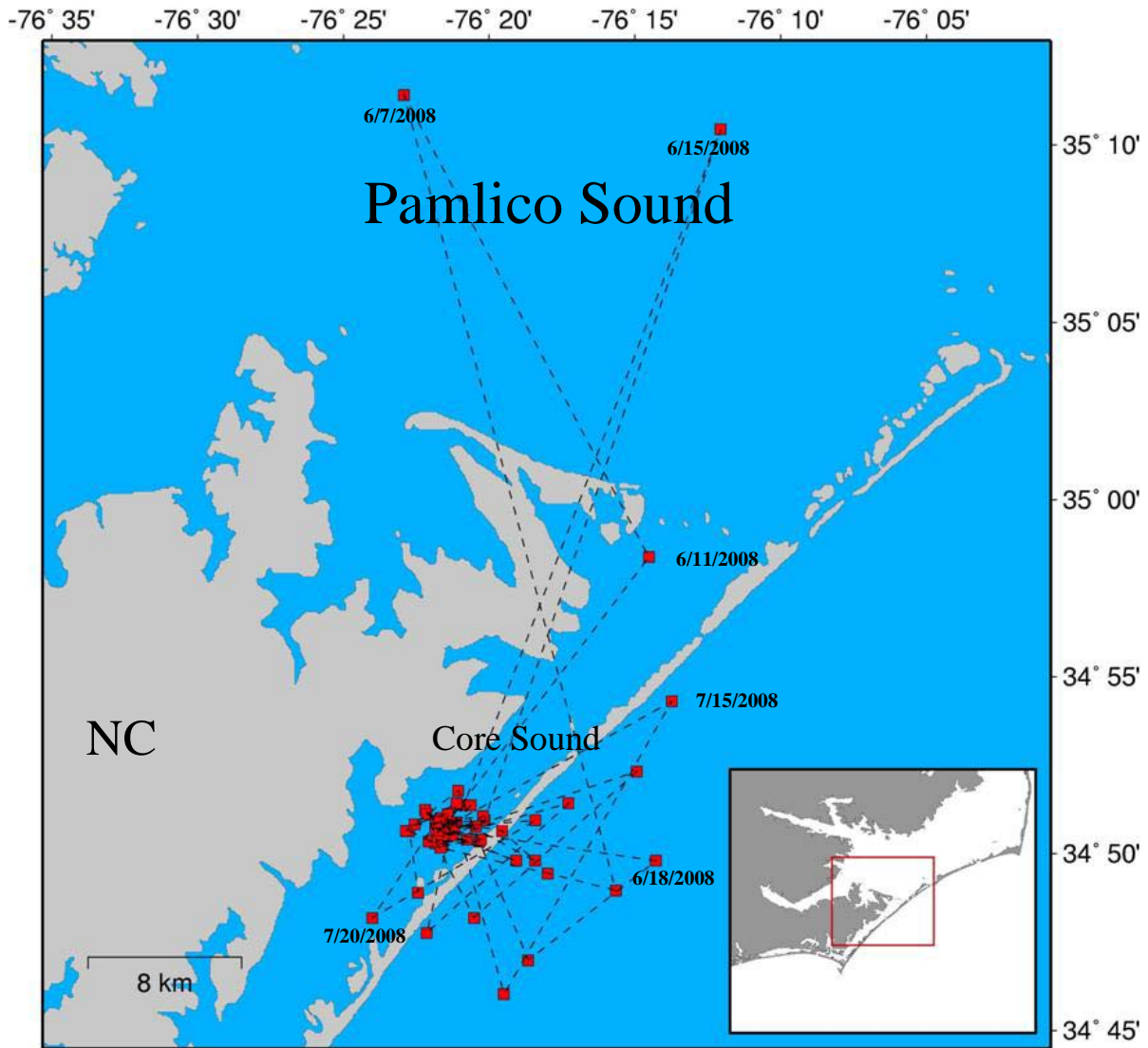


Fig. 16a Satellite movements of Loggerhead PPX316 May 19 to July 3, 2008

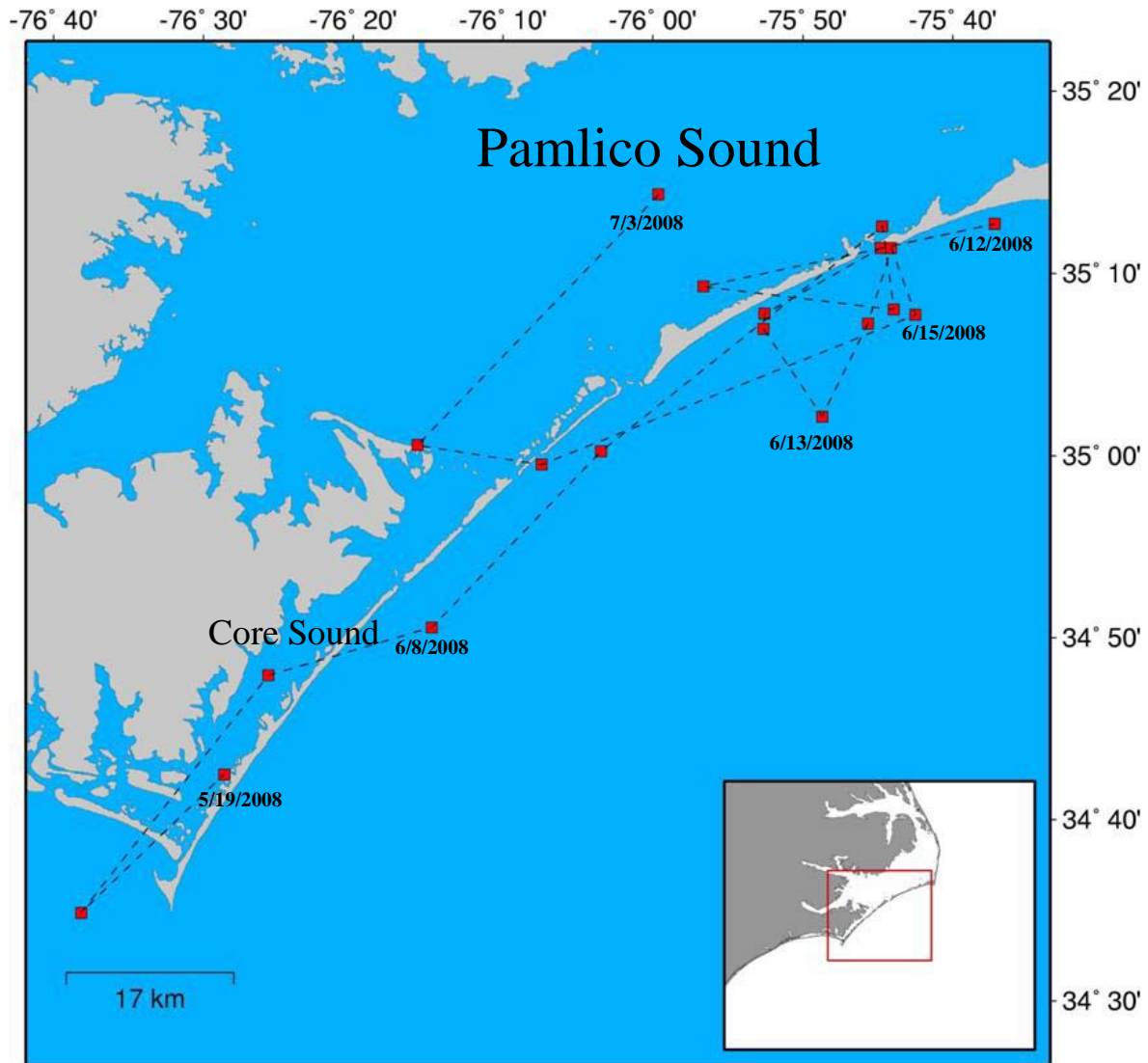


Fig. 17a Satellite movements of Loggerhead TTS633 May 19 to October 30, 2008.

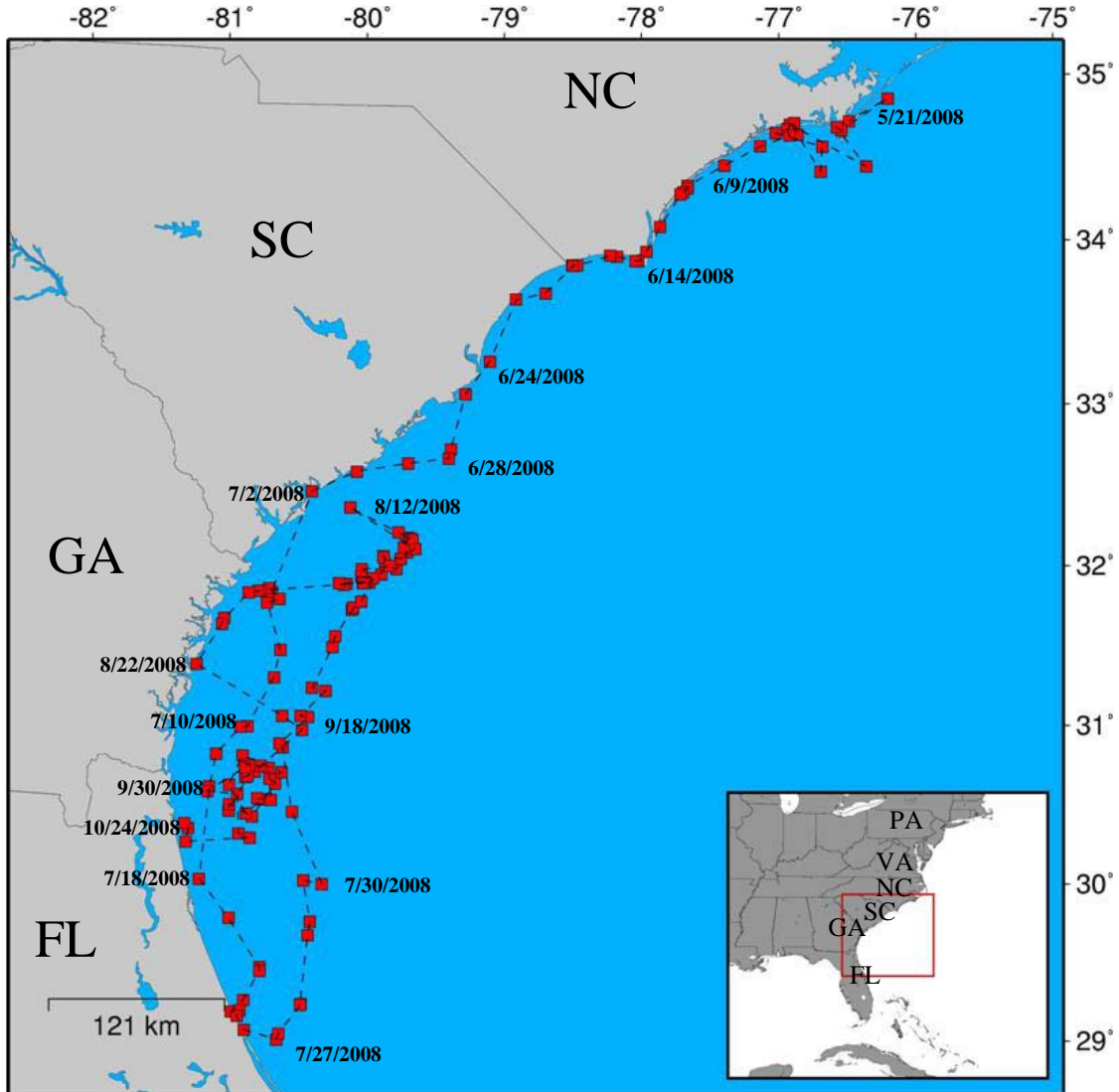


Fig. 18a Satellite movements of Loggerhead RRS255 May 28 to July 7, 2008.

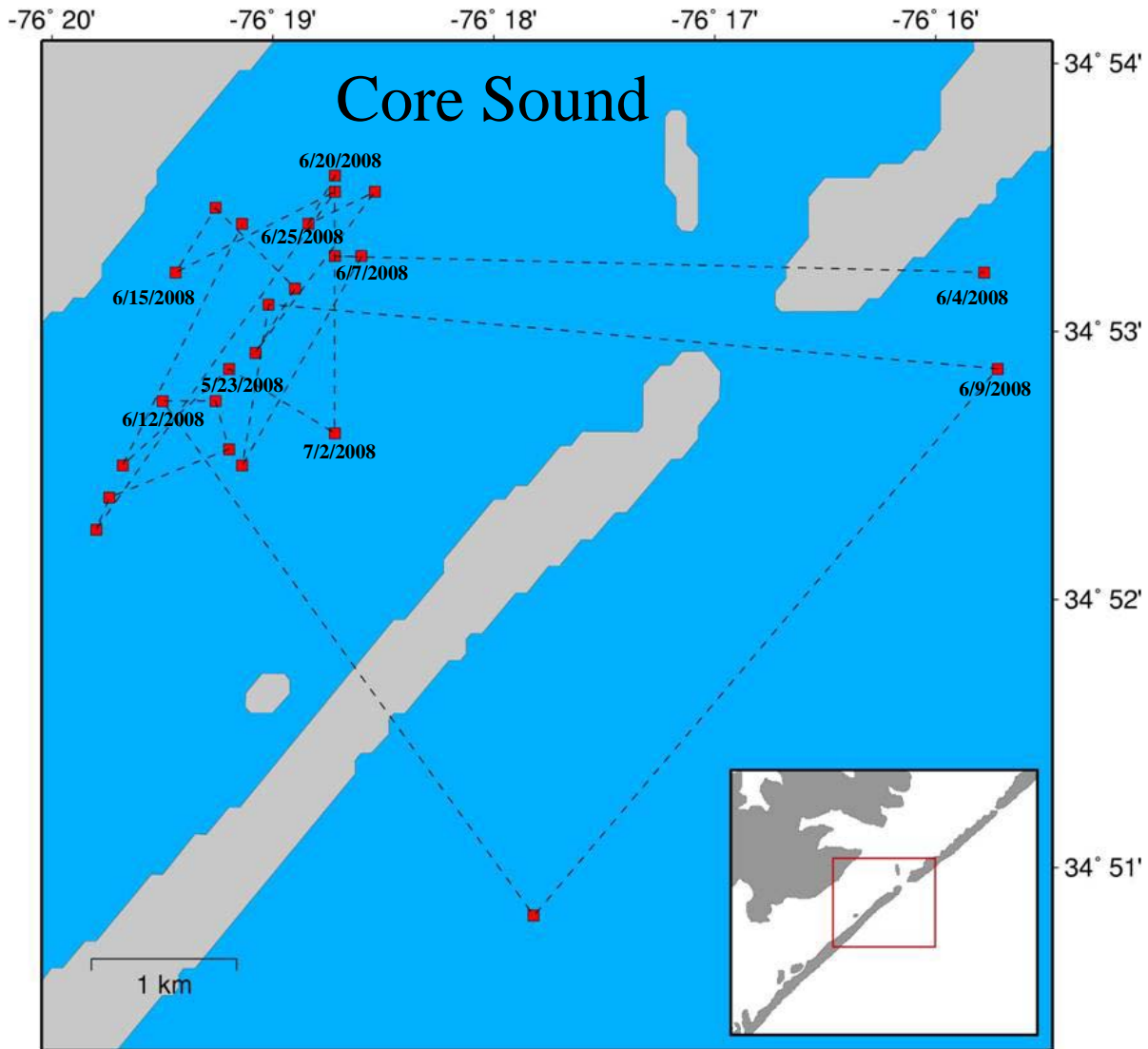


Fig. 19a Satellite movements of Loggerhead XXE502 May 28 to June 23, 2008.

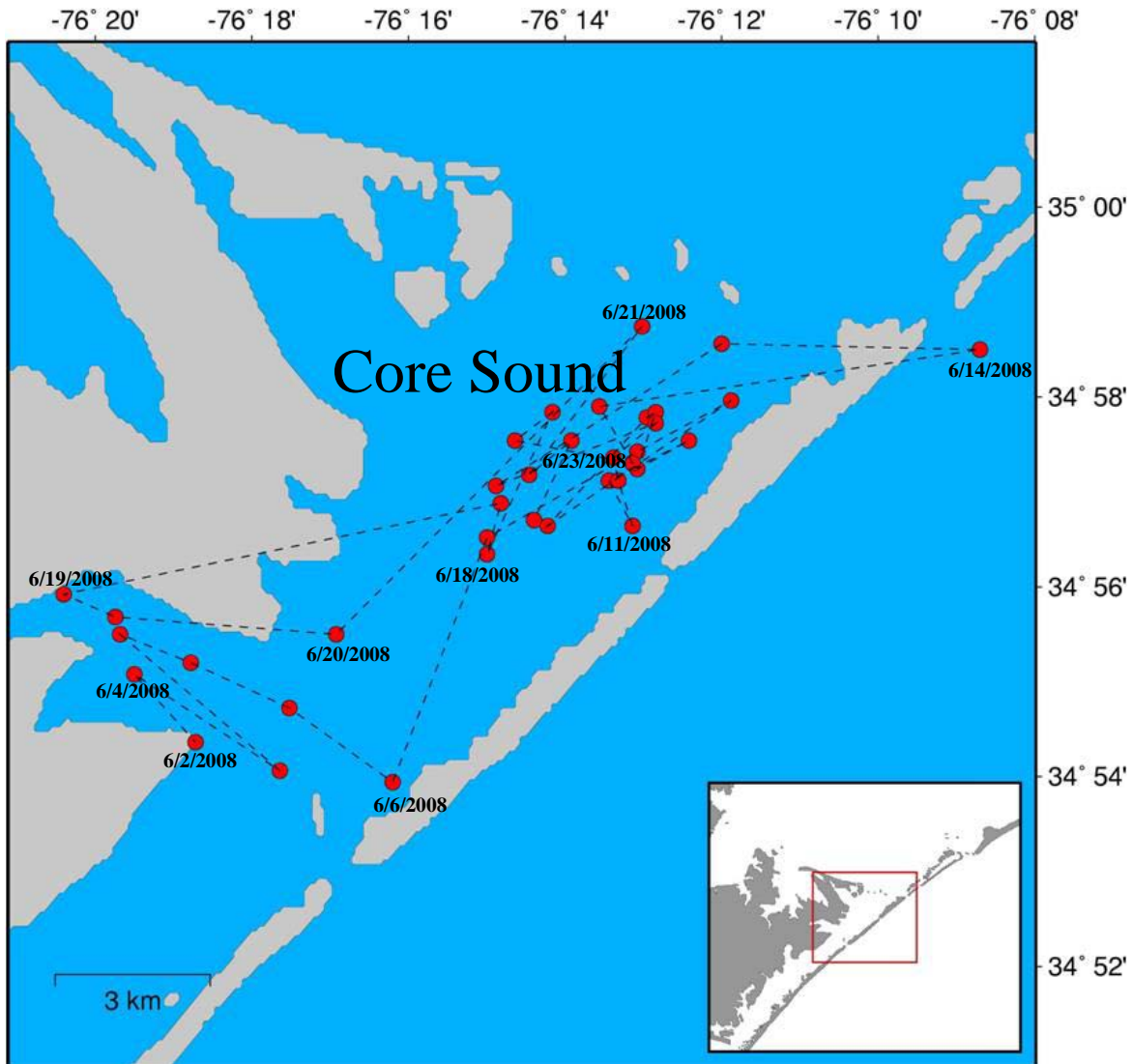


Fig. 20a Satellite movements of Loggerhead TTS643 June 2, 2008 to January 1, 2009.

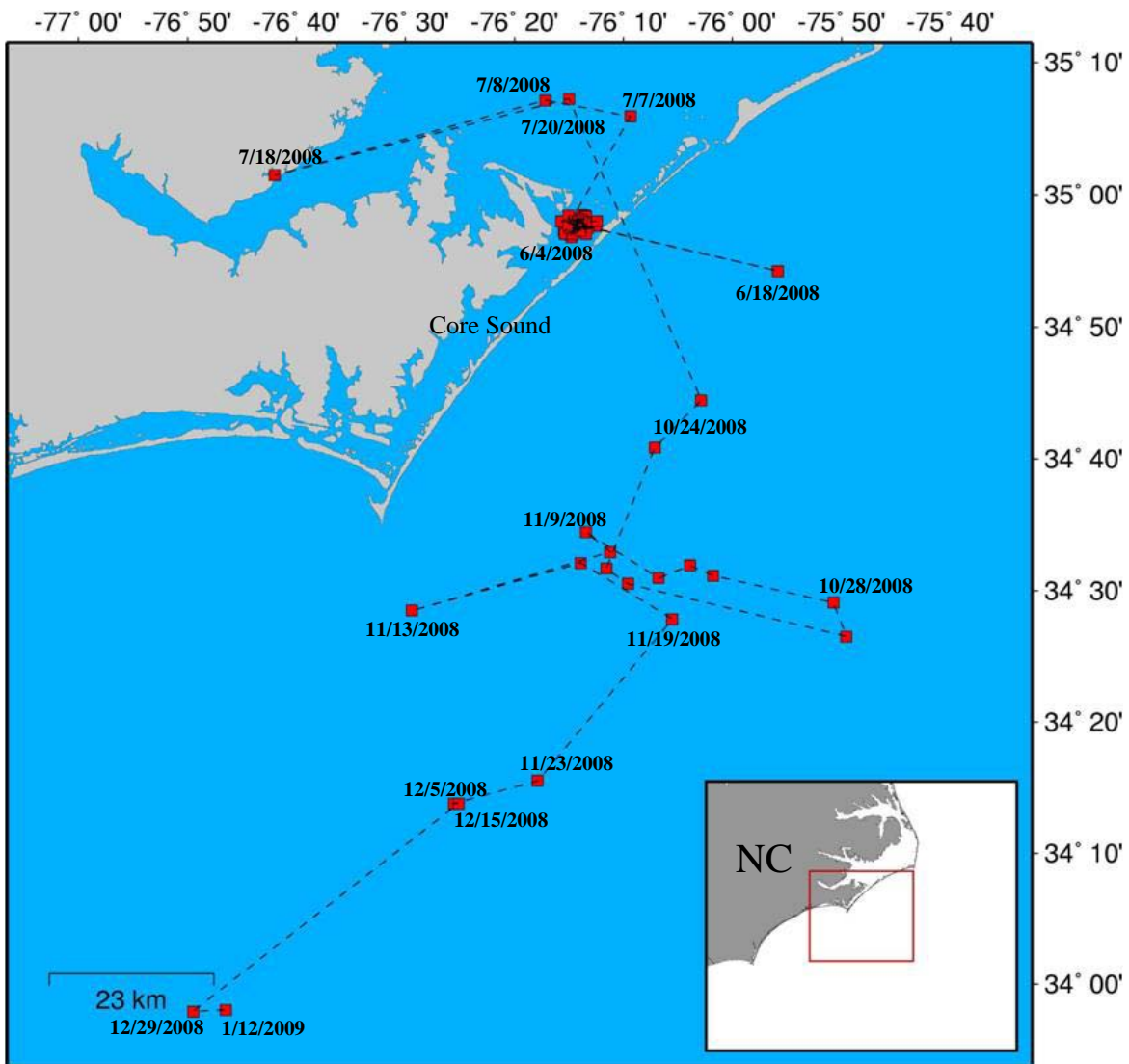


Fig. 21a Satellite movements of Loggerhead TTS651 June 2 to August 5, 2008.

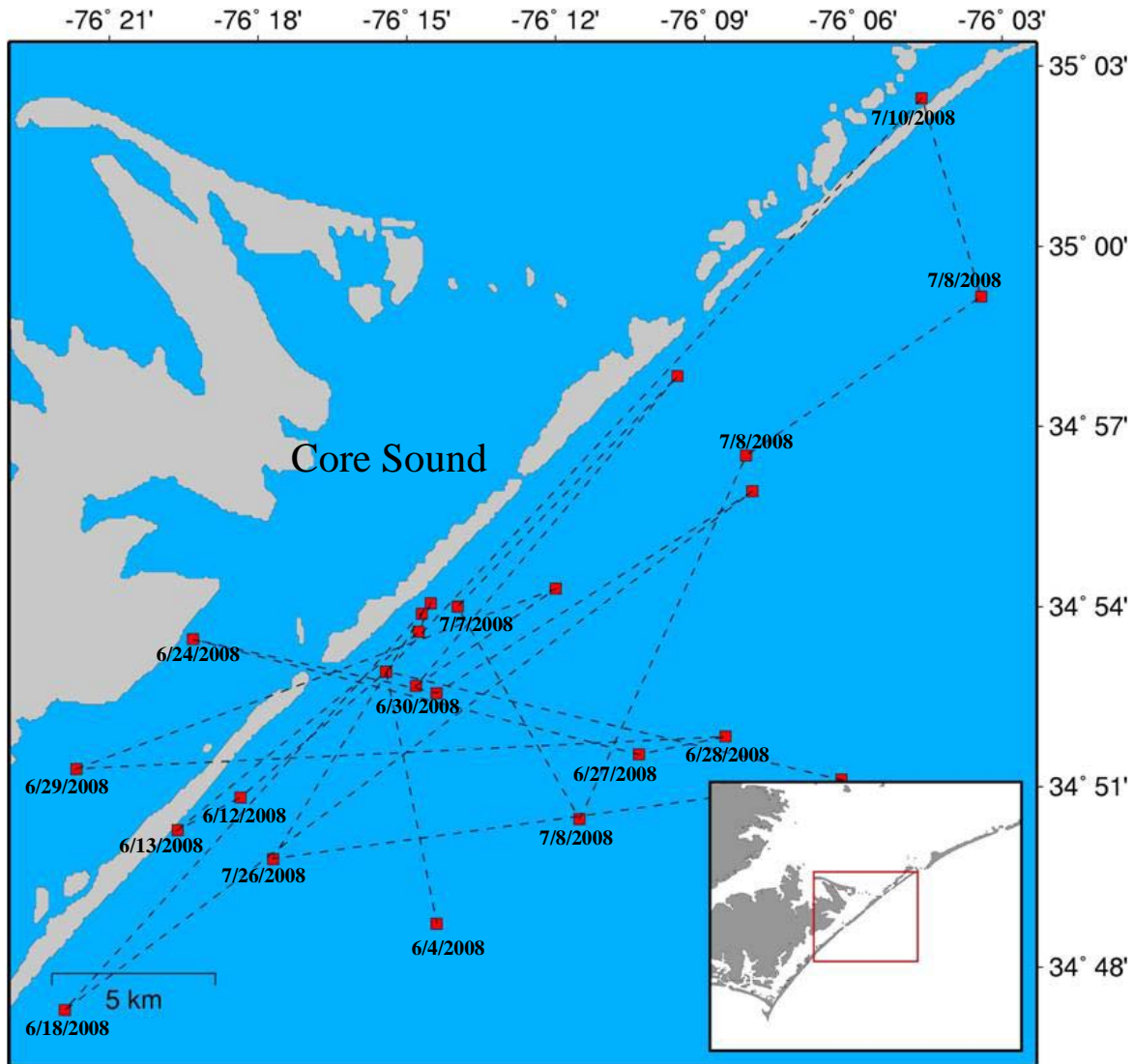


Fig. 22a Satellite movements of Loggerhead TTS551 June 13 to October 24, 2008.

