Understanding Impacts of the Sea Scallop Fishery on Loggerhead Sea Turtles through Satellite Tagging

Final Report for 2016 Sea Scallop Research Set-Aside (RSA) Program
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Project Summary:

This research focused on assessing and reducing loggerhead sea turtle (*Caretta caretta*) bycatch in the sea scallop fisheries of the Northwest Atlantic Ocean, specifically in the Mid-Atlantic Bight (MAB), off Southern New England (SNE) and within Georges Bank (GB), by examining loggerhead behavior in areas impacted by scallop fishing. Our primary objectives were to examine sea turtle distributions and behavior in relation to scallop fishing and identify ecological and biological connections between sea turtles and sea scallops. The information collected will aid in evaluating loggerhead abundance estimates, developing scallop-harvesting strategies that minimize harm to sea turtles, and defining critical habitat for loggerheads.

For the 2016 project, CFF purchased fifteen 9000x Satellite Relay Data Loggers (SRDL) with Argos Fastloc GPS tags through the University of St. Andrews's Sea Mammal Research Unit (SMRU). The data from the tags, relayed through the Argos satellite system, provided detailed surfacing locations, temperature through depth, and individual dive (max depth, shape, time at depth, etc.) records which were essential for this project. These data were collected and analyzed to evaluate seasonal distribution, migration patterns, dive profiles, and foraging sites in conjunction with satellite-derived oceanographic data to identify spatiotemporal "hot spots" on the fishing grounds.

We took two trips during the 2016 summer field season. Trip 1 occurred from May 16 – 21 and Trip 2 occurred from Aug 21 – 26. During Trip 1, we used the F/V Kathy Ann and F/V Ms Manya to improve our sightings and capture abilities. This trip was eventually shortened due to the weather, thus allowing us to budget for a second trip in the late summer. We used F/V Kathy Ann only for Trip 2.

During Trip 1, we focused efforts in the southern Mid-Atlantic region, closer to Cape Hatteras. We also went further offshore closer to the Gulf Stream to tag turtles that may be using this prevailing current to travel into Georges Bank. During Trip 2, we scouted in Southern New England and the Mid-Atlantic region from Elephant Trunk to Hudson Canyon and in waters reaching 3000 m. We tagged 15 turtles during the first trip, 14 over the continental shelf and 1 within the Gulf Stream, and 7 during the second trip. During Trip 1, we also tracked 8 turtles with the ROV using higher definition cameras, following 1 as it dove to the sea floor (Figure 1). In addition to the routine biological and morphological sampling, we took cloacal lavage samples to collect fecal matter from the turtles to identify a presence/absence of nematode eggs.

To supplement the lavage samples from turtles caught at-sea, we collaborated with MA Audubon Society to collect fecal samples from turtles that stranded and died along the Cape Cod coastline during the late fall and winter of 2016.

Introduction:

The National Marine Fisheries Service expects scallop gear to catch an estimated average of 140 loggerhead sea turtles each year, with 47% incidental sea turtle mortality (NMFS 2012). Reasonable and Prudent Measures (RPMs) are deemed necessary to minimize estimated incidental turtle mortality in the scallop fishery (NMFS 2012). This research directly addresses RPM's #3, #4, #5 and #6. There is a necessity to continually review available data to determine whether there are areas or conditions within the action area where sea turtle interactions with scallop fishing gear are more likely to occur. For the scallop fishery to maintain an exemption from the prohibitions under Section 9 of the ESA these RPM's, which are non-discretionary, must be implemented for the scallop fishery to continue. While not the highest research priority, this research is required under the law. In the absence of NMFS NEFSC funding, the scallop RSA is the only current source of funding available to allow the scallop fishery to continue meeting ESA requirements.

This research continues over ten years of turtle research and has evolved from a multitude of studies conducted since 2004 under Scallop RSA funding and National Marine Fisheries Service (NMFS) contracts. These projects, besides developing sea turtle excluder gear, have advanced the ability to locate, track, and observe loggerhead sea turtles through innovative use of dredge and ROV mounted video cameras, side-scan sonar, aerial surveys, and satellite tags. Over the duration of these past projects, this CFF/NMFS joint effort has resulted in the tagging of over one hundred loggerheads, and has tracked these turtles for over 50,000 days. We have demonstrated exceptional success in tracking and observing sea turtles throughout the water column with an ROV, from obtaining footage of sea turtles foraging on the sea floor to socializing at the surface. The data from these tags allowed for the first estimate of absolute abundance of loggerheads in the shelf waters of the east coast and has helped to define critical habitat for loggerheads. In addition to morphometric measurements, blood, genetic, and most recently, fecal samples were taken from each turtle tagged.

Methods

At Sea Operations

CFF and NEFSC provided at-sea scientists and crew, while Jim Gutowski at Viking Village Fisheries oversaw vessel coordination and operations of the F/V Kathy Ann and F/V Ms Manya.

Turtle spotting efforts were focused during maximum daylight between 0700 and 1800 hours. Once a turtle was spotted, the vessel maneuvered to within 50 meters of the animal and stopped when in close proximity to the spotted turtle(s). Once the vessel was in the appropriate position, the collection boat, an open 14' Achilles soft bottom zodiac, was launched. Once within six feet of the turtle, a NMFS approved ARC twelve-foot hoop net was used to capture it. The netted turtle was then carefully brought alongside the zodiac and lifted on board with the help of the crewmember. The zodiac was brought alongside the larger vessel, and the handle of the dip net was removed and the net was attached (as a brailer) to a specially rigged winch and boom to transfer the turtle aboard.

Upon the transfer of the turtle to the larger vessel, the turtle was positively photo-identified as a loggerhead sea turtle with the Sea Turtle Species Identification Key (NOAA Technical Memorandum NMFS-SEFSC-579). We then measured the carapace taking the curved and straight carapace lengths and examined it to ensure that it was in suitable condition. Epibionts were removed from the carapace at the intended bonding site of the tag on approved turtles. The transmitters were attached with a two-part cool setting epoxy with the antenna oriented backward, at the point where the first and second vertebral scutes meet. Our NEFSC partners retrieved blood and tissue samples for on-shore analyses. Sea turtles were released over the stern of the boat, with engine gears in a neutral position, in areas where they were unlikely to be recaptured or injured by vessels.

ROV protocols remained the same as previous years, here is an excerpt from Smolowitz et al. 2015 describing those protocols: “ROV operations were conducted with two tether handlers, an ROV assistant, an ROV operator, and a masthead observer. The two tether handlers deployed the ROV off the port rails of the vessel and remained on deck to pay out or retrieve the tether as needed. Commonly, the masthead observer had the best view of the turtle and ROV and coordinated the ROV operations until ROV video contact was made. Communication between the masthead observer and an ROV assistant was via the VHF radio. Once the turtle was spotted with the ROV, the operator was required to monitor the video and sonar feeds continuously. Concurrently, the ROV assistant took notes of the live video events for later review and analysis. To avoid startling the animal, which often caused it to dive, it was determined to have the ROV approach the turtle to within ~3 - 5 m while in their direct line of sight. Occasionally, the turtle would approach the ROV to investigate. When this occurred, the ROV would remain still. Otherwise, the ROV operator worked to his best ability to maintain sight of the sea turtle for the longest duration possible without disturbing its natural actions. When a turtle dove, it was followed to the best of the ROV operator’s abilities, as the turtle was able to dive faster than the ROV. If the turtle was lost on a dive, operator maintained the ROV at the same heading to the sea-floor and used visual observation and the multi-beam sonar to reacquire the subject.”

Fecal Sample Analyses

All fecal samples were analyzed at Roger Williams University in the Roxanne Smolowitz lab. Analyses protocols were developed by Dr. Smolowitz specifically for identifying the presence of nematode eggs. First, each sample was strained through a fine mesh tea strainer to remove large particulate. From each sample, a maximum of 50 ml was used. This 50 ml subsample was centrifuged to remove excess liquid. From the remaining particulate, 15 ml was taken and centrifuged again. Excess liquid was decanted, and then a flotation solution was added. This was then centrifuged again with a cover slip placed as a lid on the sample tube. Due to the density of the flotation solution, the centrifuging pushed the eggs to the surface in contact with the cover slip. This cover slip was placed on a microscope slide and thoroughly analyzed at 10x and 20x magnifications. All noticeable findings from the microscope were photographed (Figure 2).

Data Analysis

We continued to monitor the turtles via satellite telemetry. This included monitoring the dive behavior, along with identifying variations in seasonal home range throughout the year. This year, we put more effort into understanding the relationship of loggerheads and the life cycle of *S. sulcata*. This included unfunded work of collecting and analyzing fecal samples from the necropsied turtles.

Three additional avenues of data analyses have also begun. Two projects are nearing publication submission (Yang et al. *in prep* and Winton et al. *in prep*), while the third is in the exploratory stage. Yang et al. (*in prep*) are conducting blood biochemistry analysis to characterize the range of measured blood variables associated with healthy loggerheads. This is a collaborative project with CFF, NEFSC, DFO Canada and the University of North Carolina Wilmington. Winton et al. (*in prep*) are analyzing the location data to estimate the relative density and distribution of loggerheads in the NW Atlantic. This is a collaborative project combining satellite tag data from CFF, NEFSC, DFO Canada, SEFSC, SC DNR, and VA Aquarium. Leah Crowe at NEFSC is currently analyzing the dive data to understand how loggerheads respond to stochastic events, specifically major storms, including tropical storms through all categorized hurricane. This is a collaboration between CFF and NEFSC.

Blood biochemistry analysis

Below is an excerpt from Yang et al. (in prep) outlining the blood biochemistry analysis:

“In 2012 and 2013, blood gases were analyzed with both CG8+ and CG4+ iStat cartridges, with CG8+ cartridges loaded immediately following blood collection and CG4+ cartridges loaded later via subsampling from GTT vacutainers. An average of seven minutes elapsed between CG8+ and CG4+ loading. Paired T-tests were used to assess differences in blood gas values between the two cartridges to check for discrepancies. Using simple linear regression modeling, the absolute difference in blood gas values measured by different cartridges (|CG8+ - CG4+|) was plotted against the time elapsed (min) between cartridge loading.

In 2012 and 2013, hematocrit (packed cell volume, PCV) was analyzed by iStat Point-of-Care Analyzer (CG8+), IDEXX, and with Hct tubes processed on-board the vessel. Thirty-seven samples were used for an analysis of differences in values obtained from different methodologies. Hematocrit data obtained from all three methods were normally distributed, as indicated by Shapiro-Wilk normality tests, Q-Q normality plots, and frequency/density of distribution histograms. The three methods were compared using one-way analysis of variance (ANOVA) for repeated measures. Tukey’s Honest Significant Difference post-hoc test illustrated that there were significant differences between all three methods.

Correlation analysis through scatterplot distributions and Pearson’s product-moment correlation coefficients were used to assess results obtained for variables measured with both iStat cartridges (CG8+ and CHEM8+) and IDEXX analyzers: Hct, Na+, K+, glucose.”

Distribution and relative density

Below is an excerpt from Winton et al. (*in prep*) outlining the methods for this work:

“To estimate the relative density of the 271 tagged loggerheads over the course of the year, we fitted a space-time geostatistical mixed effects model to counts of daily loggerhead positions on a monthly time step. Under the assumption that tracks of individual turtles represent independent Poisson processes, a model for multiple individuals can be obtained by pooling data; a combination of independent Poisson processes is also a Poisson process (Royle et al. 2014). To account for differences in the length of tag transmission between turtles, individual tracks in each month were weighted inversely according to the number of days reporting. Daily location estimates were binned by month and aggregated over a 20 km resolution spatial grid (areas = 400 km^2) in R using the ‘sp’ (Pebesma et al. 2005; Bivand et al. 2013) and ‘raster’ packages (Hijmans 2015). Though several tagged turtles ventured into the Gulf of Mexico or further north, we only considered locations reported south of Cape Breton Island (< 46.249^{o}N), Canada, and east of Key West, Florida, USA (> -81.780^{o}W).

Given the apparent differences in the distribution of turtles tagged in the mid-Atlantic and south-Atlantic Bights (Figure 3), two separate models were fitted to tags deployed north and south of Cape Hatteras, North Carolina. While six individual tagging programs were involved, there was a broad degree of overlap in the timing and location of tag deployments north and south of Cape Hatteras, North Carolina, due to collaborations between the Northeast Fisheries Science Center, Coonamessett Farm Foundation, the Virginia Aquarium, Fisheries and Oceans Canada, and the Southeast Fisheries Science Center and the South Carolina Department of Natural Resources, respectively. Tags deployed on or near Georges Bank were included with those deployed in the mid-Atlantic due to low sample size (n = 5). Models were fitted in R (R Core Team 2016) and TMB (Kristensen et al. 2016) as described for simulated data sets above. Values for each regional predicted field were scaled from 0 to 1 by conditioning the predicted value in each grid cell on the total. To estimate the combined distribution, scaled predictions for the overall and monthly regional fields were summed and rescaled from 0 to 1; this ensured that tags from each region were equally represented in each month. Scaled values were used to predict the overall and monthly spatial distribution of tagged loggerheads over the 20 km resolution grid."

Results

The 14 turtles tagged on shelf waters, within the MAB, moved north as the summer continued before returning south during the colder months (Figure 4). The turtle tagged offshore, travelled northeast along the edge of the Gulf Stream, until it reached south of Georges Bank. Here the turtle abruptly turned north, and slowed its migration. The turtle then meandered north into Georges Bank during June, July and early August, before eventually migrating out of the region and continuing east (Figure 5). Unfortunately the tag stopped transmitting at the end of August. This is the first loggerhead we have tagged during the spring migration in to travel north into Georges Bank. Even though there has been a history of turtles being spotted in the region, it has not been identified where these turtles come from or how they reach these northeastern waters.

A total of six turtles with nematode eggs were present in the cloacal lavage samples. For one of these turtles, the tag did not function at all, so we do not have telemetry data for this individual. The other five turtles stayed within the MAB and foraged in regions overlapping scallop access areas (Figure 6). From the necropsied turtles, we collected samples from 38 total turtles, 18 loggerheads, 11 Kemp's ridley, and 9 green turtles. From these samples one loggerhead and one Kemp's ridley turtle were positive for *S. sulcata* eggs.

Blood biochemistry analysis

Below is an excerpt from Yang et al. (*in prep*):

"The p-values derived from the paired T-tests indicate statistically significant differences between cartridge values (Table 1). The average value for pCO2 went down with elapsed time between cartridges and average pO2 values went up with elapsed time (Table 1). As venous blood was sampled from the dorsal cervical sinus, these changes could be indicative of blood gases equilibrating with air as a result of sample manipulation. We erred on the side of caution and chose to use values obtained from the first cartridge run (CG8+) to minimize the potential for errors associated with sample manipulation and air exposure."

Distribution and relative density

Below is an excerpt from Winton et al. (*in prep*):

"Based on the fitted space-time geostatistical mixed effects models, the overall predicted density of tagged loggerheads was greatest along the U.S. Atlantic coast from central Florida to New Jersey (Figure 7). Estimated model parameters suggested that variation in the spatial distribution over time was greater than that in space in both regions, which reflects the highly migratory behavior of loggerheads. Estimates of the spatial and spatiotemporal variance were lower for turtles tagged in the southeast, many of which remained in the general vicinity of their tagging location. The predicted monthly random fields indicated that tagged loggerheads were concentrated in continental shelf-waters year-round, but densities shifted seasonally. Monthly variation in the mid-Atlantic was indicative of northward migration to known summer foraging grounds along the shelf in the mid-Atlantic in the spring (April-May), with the reverse southward migration to overwintering areas in the fall (November-December). Predicted densities south of Cape Hatteras were highest in shelf waters from Florida to North Carolina in all months, though a subset of the tagged individuals did migrate to foraging grounds in the mid-Atlantic."

Turtles and storms

For all tracked turtles, 40 were directly impacted by major storms (i.e. tropical storms and hurricanes) while in the MAB. The four storms that impacted the most turtles were Hurricane Irene in August 2011 (Cat. 1 over MAB; n = 18 turtles), Tropical Storm Andrea (n = 8) in June 2013, Hurricane Arthur in July 2014 (Cat. 2 over MAB; n = 4), and Tropical Storm Bonnie in May/June 2016 (n = 3). Currently it is difficult to identify specific trends associated with how turtles reacted to these major disruptions; however this project has provided us with insight into the shift in oceanographic conditions associated with these types of events. Work is still required to quantify the value of these results. Figures 8 and 9 are examples of steps taken for this research.

Discussion

During the 2016 season, we attempted two new techniques with positive results. The first was the successful identification of nematode eggs in loggerhead and a Kemp's ridley turtles through both cloacal lavage on live-caught turtles and examination of fecal samples from stranded turtles. These results provide a very important baseline data for future research. The most important success from this work was that we confirmed our ability to identify the presence of nematode eggs in live caught sea turtles. This opens the door to answering several associated questions that could potentially impact management decisions. For example, continuing this work and increasing our sample size, will allow us to identify potential demographic differences, seasonality, and geographic variation associated with the presence of nematodes in the turtles. By identifying these trends, appropriate mitigations methods can be established.

The second success was the offshore tagging of a loggerhead within the eastern edge of the Gulf Stream. After several attempts of off-shelf tagging during previous seasons, we were able to capture and tag a loggerhead during its northward migration within the Gulf Stream. This is the first data identifying the path that leads some turtles into Georges Bank during the summer months. This turtle migrated along the edge of the Gulf Stream, before abruptly altering its course north into Georges Bank. Although this turtles did not exhibit a similar pattern of localized foraging within Georges Bank, it did take dives to the bottom, although far less than those foraging in MAB. The limited deep dives by this Georges Bank turtle may limit its interactions with bottom fisheries; however it is unclear how this will change in the future. As oceanographic conditions continue to change under a warming climate, changes are expected for the benthic environments of the NW Atlantic region (Kleisner et al. 2017). These changes could lead to shifts in habitat usage of predatory species like sea turtles.

During FY2016, we were able to maintain a consistent dataset of monitoring loggerheads in MAB through telemetry and videography while also expanding our techniques to begin the steps of answering many lingering questions about the ecological relationship between loggerheads and sea scallops that are bound to impact management decisions.

Blood biochemistry analysis

Below is an excerpt from Yang et al. (*in prep*):

"Data obtained through iStat and IDEXX analyses provides a broad range of variables with which to assess the health status of free-ranging loggerhead sea turtles in the Northwest Atlantic. Some variables were measured only by iStat (i.e. blood gases) and some were measured only by IDEXX (i.e. hematology and enzymes). There was a small subset of variables for which both iStat and IDEXX data were available (Table 2). Comparisons of values obtained with both methods illustrated strong and significant correlation for each blood variable. Variability in the results obtained using iStat or IDEXX are likely due to differences in the specific analytical assay or instrumentation used to obtain values. For example, differences in glucose values between methods can be attributed to the differences in how the glucose assay is conducted in the iStat (amperometric measurement via ISE of glucose oxidase-peroxidase reactions) compared to veterinary diagnostic laboratory analyses (colorimetric measurement of hexokinase, glucose-6-phosphate dehydrogenase (G-6-PDH) reactions). Though statistically significant differences are observed between values obtained via iStat and veterinary diagnostic laboratory, these differences may not be biologically or clinically significant. In our study, both iStat and IDEXX provided mean values for blood variables within the range of values published in the peer-reviewed literature."

Distribution and relative density

Below is an excerpt from Winton et al. (*in prep*):

"Our results suggest that tagged loggerheads inhabit the continental shelf along the US Atlantic from Florida to North Carolina year-round but also highlight the importance of summer foraging areas on the mid-Atlantic shelf. Previous satellite tagging studies have documented several different migration and foraging strategies among large juvenile and adult loggerheads in the U.S. Atlantic (Mansfield et al. 2009; Arendt et al. 2012a,b,c; Griffin et al. 2013), which the monthly predicted distributions reflect. Some individuals remain in the south-Atlantic Bight in thermally appropriate habitat year-round, or make smaller-scale migrations from nearshore summer habitat to warmer offshore waters bordering the Gulf Stream during the winter months (Hawkes et al. 2007; Ceriani et al. 2012; Arendt et al. 2012; Griffin et al. 2013). Others travel between summer foraging areas in the mid-Atlantic and overwintering grounds south of Cape Hatteras, North Carolina (Ceriani et al. 2012; Griffin et al. 2013). Areas where the shelf narrows, such as that with the highest overall predicted density of tagged loggerheads off Cape Hatteras, North Carolina, essentially “funnel” loggerheads and other species during migrations between the mid-Atlantic and south-Atlantic Bight (Galuardi and Lutcavage 2011; Griffin et al. 2013; Kneebone et al. 2013).

Seasonal concentrations of the species suggested by the monthly fields are also consistent with trends inferred from other data sources. Loggerhead bycatch rates remain relatively high south of 37^{o}N year-round, but increase in the shelf waters from Virginia to New Jersey in the summer and fall as loggerheads migrate into and out of the mid-Atlantic, with the highest aggregate encounter rates occurring off Cape Hatteras in the fall and winter (Warden 2011; Murray and Orphanides 2013). Distribution estimates based on data collected during shipboard and aerial surveys are similar to those predicted here; survey sightings indicate loggerheads use habitats in the mid-Atlantic from the summer into the fall but occur along the shelf from Florida to North Carolina throughout the year (TEWG 2009). Surveys of inshore waters have also recorded fluctuations in loggerhead sightings north of Cape Hatteras that correspond to seasonal migration patterns (Epperly et al. 1995).”

Future Objectives

Our next steps include continuing to track loggerheads within the MAB and northward, to more thoroughly assess the overlap between this endangered species and scallop fishing. Furthermore, as the concern for parasites in the scallop meats increases, a better understanding of the lifecycle of these nematodes is required before action can be taken for mitigating this issue. As a result, for the 2017 season, we are continuing to collect fecal and urine samples from live-caught and stranded turtles to understand if these animals are carriers for the nematodes and then where they migrate to potentially depositing the eggs. This will improve our understanding of the spatial ecology of these parasites to determine if this is a regional-scale or entire fishery-scale threat. In addition, we plan to take steps to assess the prey species available for loggerheads in the MAB at the known scallop grounds to identify other potential carriers of this nematode. Although previous ROV work did include surveying the benthic environment, limited quantification was accomplished for this footage. We plan to review this footage and use new technologies (CFF Stationary Camera System and HabCam) to study the sympatric species at known scallops grounds. This will inform us on the overall benthic community structure at known scallop grounds to provide insight on the trophic dynamics. We expect 2017 to again provide unique insight into the ecology of this northwest Atlantic loggerhead population, setting up a whole new set of questions requiring investigation in 2018.

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Yang T, Crowe L, Haas H, James M, Patel S, Willard A. *in prep.* Blood biochemistry of healthy loggerhead turtles (*Caretta caretta*) in the Northwest Atlantic Ocean.

Tables and Figures

Table 1: Blood gas parameters taken from two different iStat point-of-care analyzer cartridges, the CG8+ and the CG4+, during the 2012 and 2013 field seasons. The CG8+ cartridges were run first, and CG4+ cartridges were run second, with an average time lapse of 7 min between cartridge loading. These data were analyzed from *n* = 31 loggerhead sea turtles sampled in 2012 and 2013. Paired T-tests were used to assess statistical differences between values obtained from different cartridges. Significant values indicated with *. (Yang et al. *in prep*)

	CG8+ cartridge (*n* = 31)			CG4+ cartridge (*n* = 31)			Results of Paired T-test		
Blood parameter	Range	$\bar{x}$	SD	Range	$\bar{x}$	SD	df	t	p-value
pH	7.208-7.651	7.478	0.115	7.247-7.699	7.508	0.121	30	6.829	1.411e-07*
pCO2 (mmHg)	29.5-59.4	40.3	7.8	21.5-55.9	37.3	7.8	30	-7.2435	4.603e-08*
pO2 (mmHg)	39-101	59	12	45-121	66	17	30	4.546	8.367e-05*
HCO3- (mmol/L)	20.0-48.0	37.9	6.5	19.4-47.5	37.4	6.6	30	-2.3889	0.02339*

Table 2: Correlation analysis for comparable blood variables between iStat analysis (onboard analyzer) and IDEXX analysis (laboratory analyzer) in 2012 and 2013. * indicates significant values (Yang et al. *in prep*)

Blood Variable (units)	Pearson's correlation coefficient	p-value at α = 0.05	n
Na (mmol/L)	0.6558063	*4.36e-06	40
K (mmol/L)	0.7950633	*8.932e-10	40
Glucose (mg/dL)	0.9756197	*< 2.2e-16	40
Hct (%)	0.6045318	*2.84e-05	41

Figure 1: High resolution footage from the ROV of a turtle diving during the May 2016 trip.

Figure 2: Image of *S. sulcata* egg from the lavage sample.

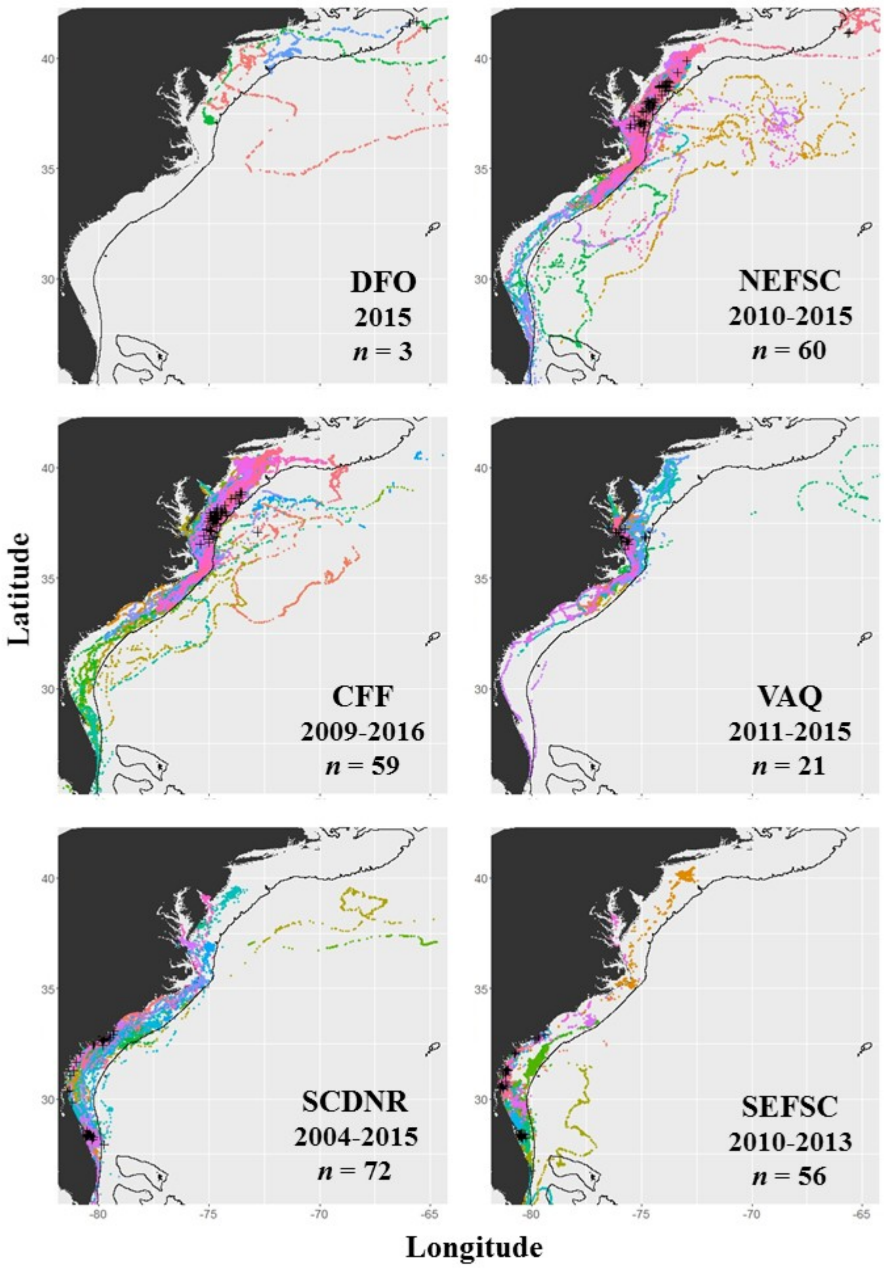

Figure 3. Study area and reconstructed tracks from 271 large juvenile and adult loggerhead turtles tagged by six different tagging programs from 2004-2016. Tracks of individual turtles are indicated by different colors. Tagging locations are indicated by black hatch marks. The black line denotes the 200 m bathymetric contour. DFO = Fisheries and Oceans Canada; NEFSC = NOAA Fisheries Northeast Fisheries Science Center; CFF = Coonamessett Farm Foundation; VAQ = Virginia Aquarium & Marine Science Center; SCDNR = South Carolina Department of Natural Resources; SEFSC = NOAA Fisheries Southeast Fisheries Science Center. (Winton et al. *in prep*)

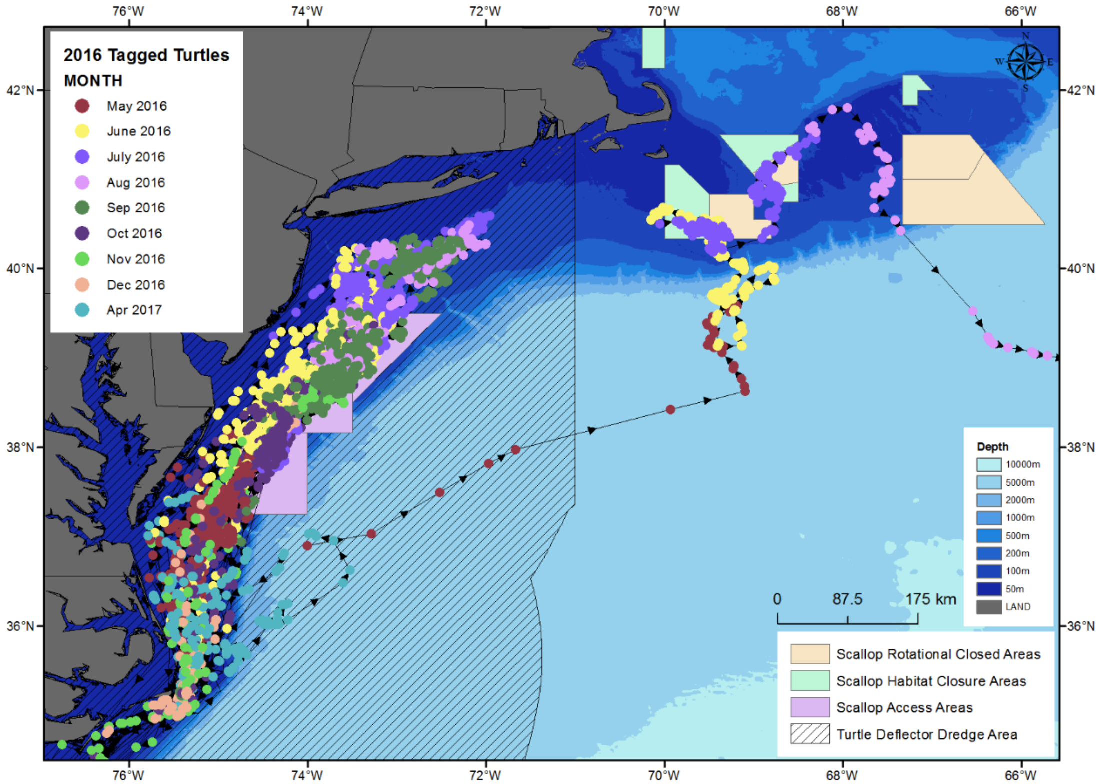

Figure 4: Locations by month for all tracked turtles (n = 21) tagged during the 2016 season.

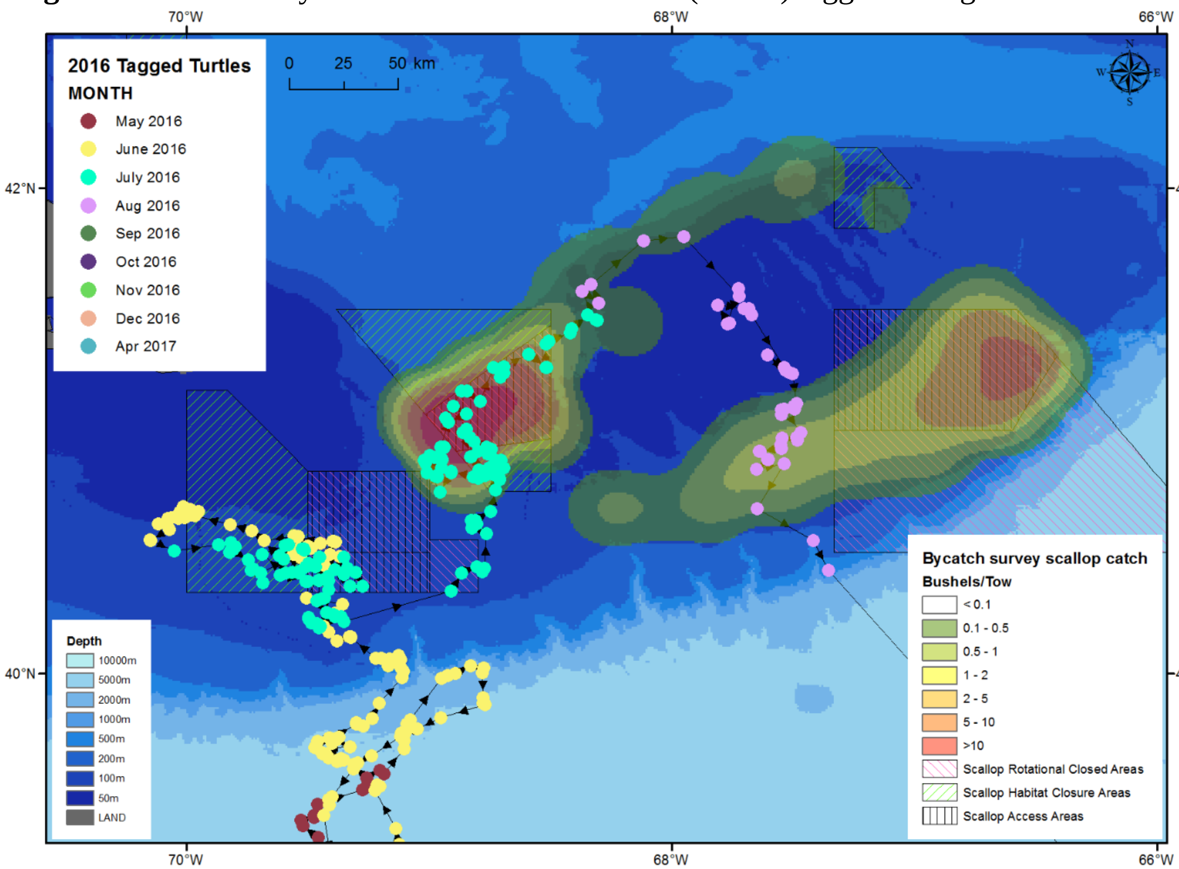

Figure 5: Turtle track while foraging in Georges Bank. This turtle foraged at locations of known

high scallop densities. Scallop data taken from all years, 2011 – 2016, of the CFF Bycatch Survey of Georges Bank, data compiled by Carl Hunstberger, Liese Siemann and Luisa Garcia of CFF.

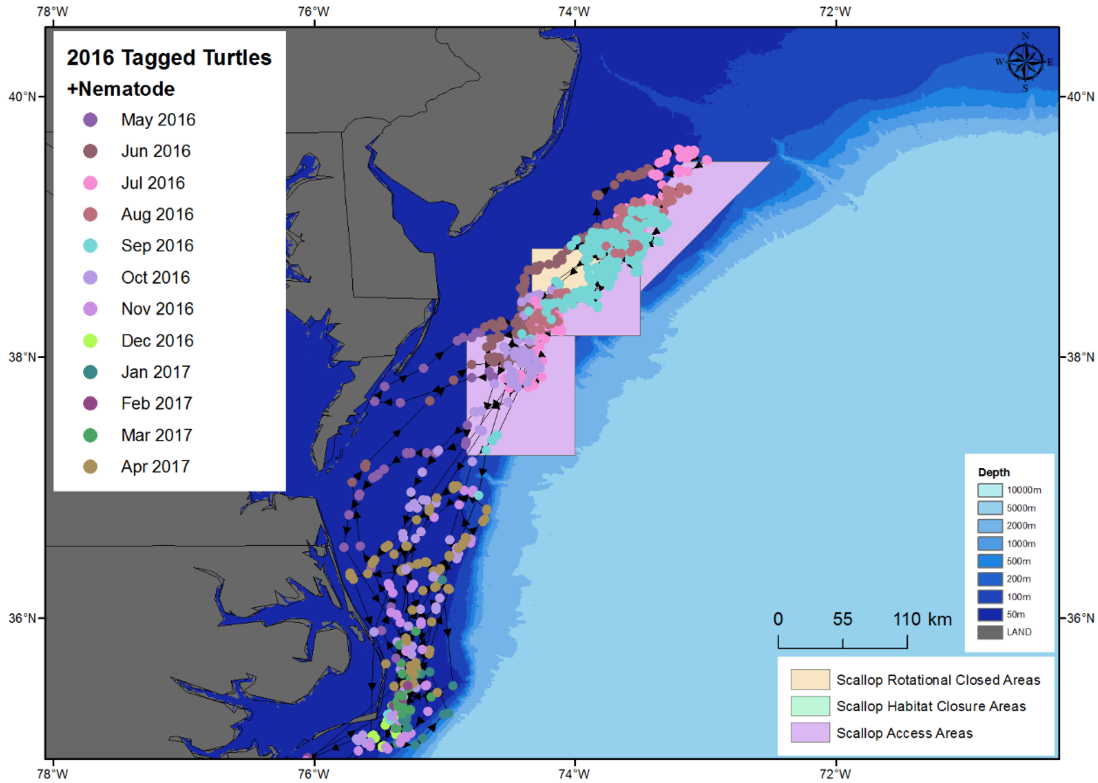

Figure 6: Tracked turtles positive for nematode eggs.

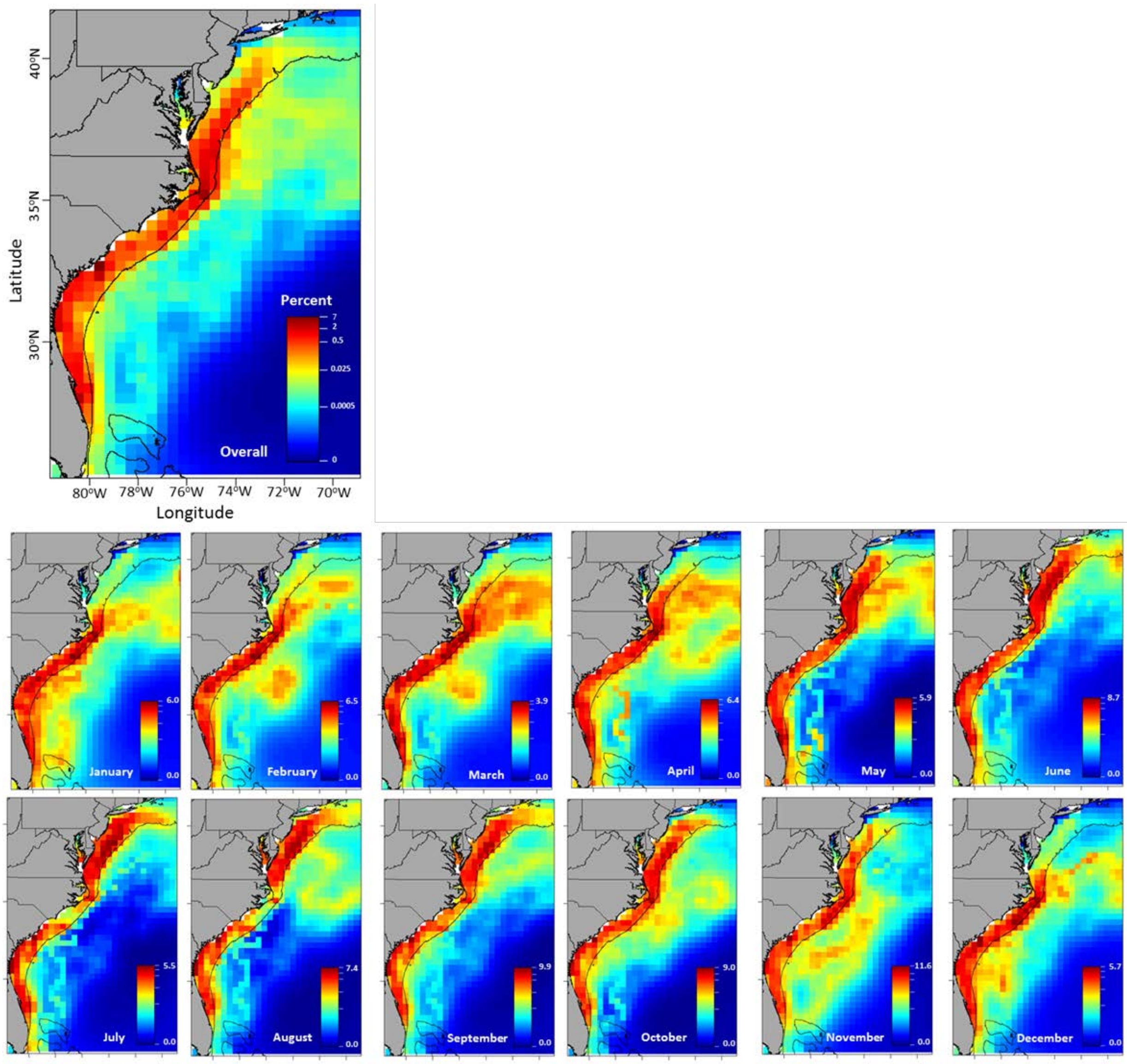

Figure 7: Overall and monthly log density of tagged loggerhead sea turtles per 40 km resolution grid cell as predicted using a space-time geostatistical mixed effects model. Model predictions were based on daily locations reported from 271 large juvenile and adult loggerhead turtles tagged from 2004-2016. Coordinates are expressed in the universal transverse Mercator coordinate system (zone 19). Predicted densities were scaled from 0-1 for comparison purposes. The legend indicates the proportion of the predicted density included in each grid cell. In each month, scale bars are consistent with the overall plot with the exception of the maximum value, which is indicated. The black line denotes the 200 m bathymetric contour. Modified from Winton et al. *in prep*.

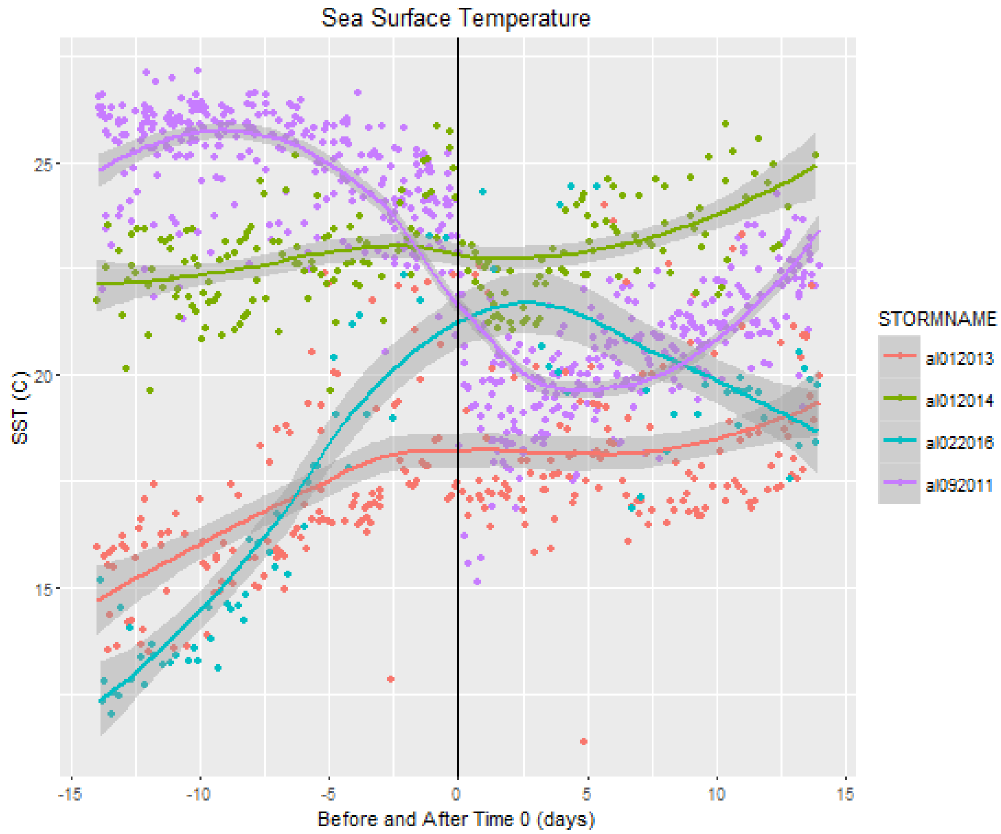

Figure 8: SST data collected from tags on turtles interacting with Irene (al092011; n=18), Andrea (al012013; n=8), Arthur (al012014; n=4), and Bonnie (al022016, n=3). Time 0 is when the storm is within <100 km from turtle. Figure made by Leah Crowe, NEFSC.

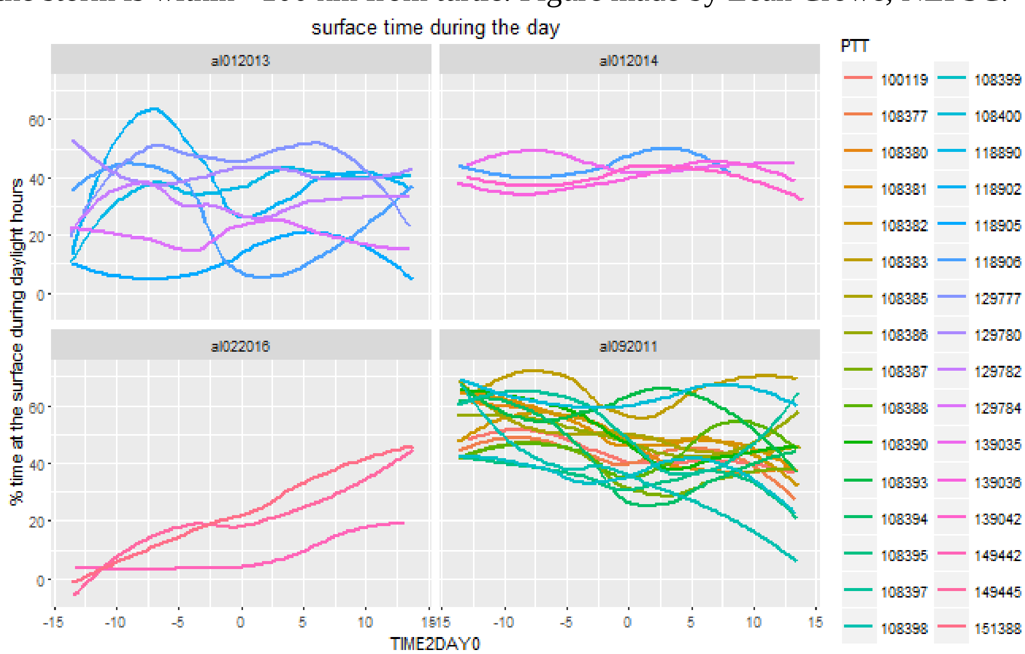

Figure 9: Time spent at surface during daylight hours only (after 0600, before 2200 -- although the latest time in a day was 1900) 15 days prior to storm, at closest interaction (<100km away), and 15 days after storm has passed. Figure made by Leah Crowe, NEFSC.