Understanding Impacts of the Sea Scallop Fishery on Loggerhead Sea Turtles

Final Report

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Atlantic Sea Scallop Research Set-Aside Program
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Executive Summary:

Coonamessett Farm Foundation's (CFF) 2021/22 project has continued to add invaluable data to our historical dataset on loggerheads. The focus of this project is to monitor and evaluate changes in the distribution and behavior of loggerhead turtles to better understand their current interactions with the scallop fishery. This improved understanding will determine if ESA requirements for the Atlantic sea scallop fishery are being met and help reduce injury and mortality of turtle takes by scallop dredges.

Two tagging trips occurred in 2021. The first set of tags were deployed opportunistically by the Northeast Fisheries Science Center (NEFSC) gear research team in Cape Hatteras, NC. Their project focused on researching monkfish gillnets that reduce turtle bycatch. As a result, when they encountered a healthy turtle in the gear, they deployed one of nine tags provided by CFF and NEFSC on these individuals. The second tagging trip, which was more consistent with previous tagging work funded by the Sea Scallop Research Set-Aside (RSA) program, occurred in the southern Mid-Atlantic Bight (MAB) from May 24 – 28 on the F/V Kathy Ann (KA). During this trip we deployed 22 satellite tags. We collected lavage samples from 18 turtles, and identified one turtle positive for the nematode.

With the additional nine tags deployed in NC, we identified a movement pattern that is different than the behaviors of turtles previously tagged in offshore MAB waters. The turtles tagged in NC migrated north, similar to the offshore turtles; however, they moved north much earlier than previously documented and generally stayed within shallow inshore waters. Unexpectedly, two of these turtles tagged near NC migrated past Long Island and settled within Buzzard's Bay, MA for the duration of the summer. Both turtles started their return migrations in September, and one turtle reached NC, by early October. This turtle took a very similar route southward as it did northward during its spring migration. This again is earlier than expected for southern migrations, with turtles foraging farther offshore in the MAB typically remaining in their northern foraging territories well into October.

This year we have also taken a closer examination of the transmitted oceanographic data to understand the temperature regime within the MAB. The turtle tags provide the most robust data set of temperature through depth during the summer when compared to traditional oceanographic sampling. This information can help inform management about environmental factors that may have contributed to the decline in scallop biomass in the region.

Since the end of the previously funded loggerhead tagging project (FY19/20), we have contributed data to three publications, all with relevance to fisheries interactions and management of loggerheads in the NW Atlantic. The first, authored by Patel et at. (2021), focused on the shift in available thermal habitat for loggerheads in the NW Atlantic over the next 80 years based on modern climate change models, the second, authored by Robinson et al. (2021), discussed the likelihood of gas embolism in sea turtles during routine dives, and the third, authored by Hatch et al. (2022), calculated the surface time for loggerheads along the US eastern sea board to help improve population estimates made from aerial observations.

1. Purpose

The National Marine Fisheries Service (NMFS) expects scallop dredge and trawl gear to interact with ~1,110 loggerheads every five years with an estimated mortality rate of 35% (NMFS 2021). As a result, nearly 80 loggerheads in the NW Atlantic are expected to perish from scallop gear interactions annually (NMFS 2021). Within the Biological Opinions for each managed fishery, Reasonable and Prudent Measures (RPMs) are established and deemed necessary to minimize estimated incidental mortality of protected species. For the scallop fishery, the RSA-funded sea turtle research directly addresses RPMs #2, #3, #4, #5, and #7 (NMFS 2021; **Table 1**). There is a necessity to continually review available data to determine whether there are areas or conditions 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 Endangered Species Act (ESA), these RPMs, which are non-discretionary, must be implemented for the scallop fishery to continue operation under current conditions, as a result this sea turtle research is required under by law. In the absence of NMFS funding for the NEFSC, the scallop RSA is the only current source of funding available to allow the scallop fishery to continue meeting ESA requirements.

This project continues over 15 years of turtle research and has evolved from a multitude of studies conducted since 2004 under scallop RSA funding and NMFS contracts. These projects have led to the development of sea-turtle excluder gear (turtle chain mats and turtle deflector dredges) and their incorporation into accompanying regulations. Furthermore, they have

Table 1: Samples taken per turtle and the relevant Reasonable and Prudent Measure (RPM) that each sample covers.

Samples Taken Per Turtle	Purpose	Relevance to Scallop Fishery
Morphometric Measurements (shell size and tail length)	To determine size and life stage of each turtle	TDD and turtle chain specifications, correst size for turtles within the region? (RPM#1) Demographic information for population estimates (RPM#7) Calculating Body Condition Index (BCI) (RPM#2)
Blood Sample (12 ml)	Health status, hormone levels (gender), stable istotope values, genetics	Are turtles eating scallops? (RPM#2) Population health and stress levels (RPM#3, 4 and 5)
Skin Sample	Genetics, stable isotope values	Have turtles been eating scallops? (RPM#2) Population health and structure (RPM#4 and 7)
Cloacal Lavage	Identify nematode presence gut microbiome	Nematodes and foraging preferences (RPM#2)
Physical Health Assessment	Check for injuries, both new and healed	Sources of injury, including from fisheries interactions (RPM#4 and 5) Relationship with calculated BCI (RPM#2)
Passive Tagging	For population estimates	Population size and distribution -> likelihood of interactions (RPM#7)
Body Temperature	Health status	Baseline for healthy turtles to improve survival of incidentally taken turtles (RPM#4 and 5)

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. We have demonstrated exceptional success in tracking and observing sea turtles throughout the water column with an ROV and have obtained footage of sea turtles foraging on the sea floor and interacting at the surface. Over the duration of these past projects, this CFF/NMFS joint effort has resulted in the tagging of nearly 250 loggerheads, totaling ~71,000 days of tracking data. The data from these tags were critical for the first ever estimate of absolute abundance of loggerheads in the shelf waters of the east coast and have helped to define critical habitat for loggerheads (NMFS 2011). To maximize the value of the tagging efforts, additional sampling has been done after turtles are captured. In addition to morphometric measurements, blood, genetic, and fecal samples were taken from each tagged turtle to improve our understanding of the overall biology of this species and its interactions with the environment. This has all culminated in a broad range of publications that were used to help determine, in the most recent ESA Biological Opinion, that offshore scalloping was not likley to jeopardize the continued existence of loggerheads in the NW Atlantic (NMFS 2021).

The CFF RSA-funded sea turtle research is a collaborative program, most notably with the NEFSC, to help advance the goals of many entities. This collaborative effort was established due to the complicated nature and high costs of catching and tagging loggerhead turtles in the open ocean. CFF has continued, on a yearly basis, to catalog new data, update distribution maps, and assess new or modified methods while retaining the larger research goal of studying overlap with the sea scallop fishery. As such, the sea turtle research program is like most yearly fisheries surveys, which on an annual basis add important data points to update assessments but require several years of effort before yielding higher level products. Since 2014, this collaborative research program has led to 10 completed peer-reviewed publications, one in the final stages of peer review, and one more manuscript in preparation (**Appendix 1**). Furthermore, the data and field work from this program has been leveraged to obtained additional funding including multiple Saltonstall-Kennedy Grants, internal NOAA funding, and awards from the Massachusetts Environmental Trust.

In general, the annual goals are objectives for the current funding cycle, while programmatic goals are those to be achieved across several years. The programmatic goals were developed to help determine if there are any factors that may be impacting anticipated turtle take rates, a key requirement for initiating an ESA Section 7 Consultation. The 2012 estimated take rates (NMFS 2012) were higher than those calculated in the 2021 Biological Opinion, and this is a direct result of an improved understanding of loggerhead interactions with scallop fishing (NMFS 2021). The 2021 Biological Opinion has now raised the number of exempted takes available to the scallop fishery, including lethal takes available to scallop dredging, in part due to this RSA-funded research verifying that the loggerhead population in the MAB is healthy (NMFS 2021).

Annual goals:

1. *Collect samples from 20 loggerhead turtles caught at-sea.*
2. *Document seasonal distribution of loggerhead turtles within the MAB for transmitters functioning during the funding year.*

3. *Identify presence/absence of nematode parasite and anthropogenic waste in lavage samples.*
4. *Use videography to document potential prey species.*
5. *Expand database of loggerhead turtle biology and ecology to be used by management.*

Programmatic goals:

1. *How do latitudinal distributions change seasonally? Interannually?*
2. *How much time do turtles spend on bottom compared to time spent on the surface?*
3. *Is there a difference in spatiotemporal distributions based on demographics or morphometrics?*
4. *Do turtles display site fidelity to foraging areas?*
5. *How is behavior changed by water temperature?*
6. *What are the primary prey species and does this impact parasite load?*
7. *Do oceanographic features impact migratory patterns?*
8. *How will climate change alter the environmental parameters (temperature, chlorophyll concentration and oceanic currents) impacting loggerheads in this region?*

2. Methods

At-sea Operations

North Carolina Deployments:

During February and March 2022, scientists from the NEFSC spent three weeks conducting a monkfish gillnet study to test the efficacy of a modified net to reduce sea turtle bycatch. During day trips out of Cape Hatteras aboard a commercial gillnet vessel, a control and experimental net was set ~5 – 10 km from shore in areas where turtles were spotted at the surface. Nets, which were soaked for no longer than one hour, were 400 yards in length and comprised of four panels with 12-inch mesh. Like traditional monkfish nets, tie-downs were also incorporated.

Overall, the NEFSC caught over twenty loggerheads in the gillnets, with a reduction in catch in the experimental nets. Of the caught turtles, nine were equipped with satellite tags provided by both CFF and the NEFSC using the sample methodologies as written below for the KA deployments. Turtles were considered healthy and in the same condition as those that would normally be caught using the dipnet during typical loggerhead captures conducted by CFF and the NEFSC. Each satellite tagged turtle was also measured, equipped with passive internal and external flipper tags and skin biopsies were taken. Due to the limited scientific crew and the differing research priorities of the project, the entire suite of loggerhead sampling could not be conducted.

F/V Kathy Ann Deployments:

Similar to previous years, CFF provided at-sea scientists for the research trip, while Jim Gutowski at Viking Village Fisheries oversaw vessel coordination and operations of the KA.

Turtle spotting efforts were restricted to daylight hours, between 0700 and 1800 hours. Once a turtle was spotted, the vessel maneuvered toward it and stopped when within 50 meters of the animal(s). Once the vessel was in the appropriate position, two crew members launched the collection boat, an open 14' Achilles soft bottom zodiac. When the zodiac approached within six feet of the turtle, an NMFS-approved ARC twelve-foot hoop net was used to capture it. The zodiac with the captured turtle was brought alongside the larger vessel, and the turtle was transferred to a large rectangular net that is attached (as a brailer) to a specially rigged winch and boom to safely transfer the turtle aboard the KA.

After transfer, the turtle was positively photo-identified as a loggerhead sea turtle using the Sea Turtle Species Identification Key (NOAA Technical Memorandum NMFS-SEFSC-579). We then measured the carapace, taking the curved (CCL) and straight carapace lengths, and examined the animal to ensure it was in suitable condition for tagging. If the turtle was approved, epibionts were removed from the carapace at the intended bonding site of the tag. The transmitters were attached with a two-part cool setting epoxy at the point where the first and second vertebral scutes meet (**Figure 1**). Biological samples were collected, including blood, tissue and lavage samples for on-shore analyses. Sea turtles were then lowered using the same large rectangular net over the side of the boat, with engine gears in a neutral position, in areas where they were unlikely to be recaptured or injured by vessels.

Figure 1: Turtle safely being returned to the sea after sampling and satellite-tag attachment. The location and orientation of the tag on this turtle is representative of all tag placements.

This year, the deployed tags supplied by the NEFSC included a salinity sensor. As a result, for the first time we were able to monitor salinity through depth in the various regions turtle inhabited. This provides an additional layer of environmental monitoring otherwise difficult to measure using traditional methods.

Fecal Sample Analyses

All fecal samples were analyzed at Roger Williams University in the Roxanna Smolowitz lab. Analysis protocols were developed by Dr. Smolowitz specifically for identifying the presence of eggs from the nematode species *Sulcaris sulcata*. First, each sample was strained through a fine-mesh tea strainer to remove large particulate matter. 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 a flotation solution was added. This mixture was centrifuged a third time with a cover slip placed as a lid on the sample tube. Due to the density of the flotation solution, centrifugation 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, and all noticeable findings were photographed.

This year we also subsampled the feces to determine the gut microbiome for live healthy loggerheads in offshore waters. Gut microbiome compositions can be used to determine health status and foraging preferences (Arizza et al. 2019). We developed protocols for this analysis from samples collected during the 2019 cold stun necropsies managed by MA Audubon Wellfleet Bay Wildlife Sanctuary. An assay was developed to extract genetic material from the samples, amplify the genes using PCR, and then analyze the subsequent reads to determine bacteria types found within each turtle. From the necropsied turtles we collected samples from both directly within the digestive tract and from the cloaca to provide comparison to samples that can be collected from live turtles (Forbes et al. *in review*).

Data Analysis

To complete the annual goals, we summarized telemetry data received from all tags. We then identified the seasonal movement patterns of these tagged turtles to determine the localized hotspots for loggerheads depending on time of year. We compared the 2021 tag data to those from previous seasons. We also updated the full suite of data with the 2021 tags to improve mapping of turtle density during the months the turtle deflector dredge is required in the MAB (May – November).

We investigated diving behavior and transmitted environmental data both throughout the duration of tag deployments and also specifically in the MAB during the TDD-required months. We compared the turtles tagged in NC with those tagged on the KA. We compared distribution, dive behavior, and transmitted temperature and salinity through depth data. We compared the amount of the time at the surface as a proxy for the time spent diving (i.e. more time at the surface indicates less time diving and vice versa). Transmitted data were aggregated into percent of time spent at the surface over six-hour bins. We then compared day of the year with time spent at the surface using a generalized additive model (GAM; family = gaussian; R package = mgcv). We also compared SST with dive behavior using a GAM (gaussian; mgcv) to determine the relationship between these variables. To continue investigation of the Cold Pool, started in Patel et al. (2018), we plotted the temperatures recorded by the tags during surface and deepest dives within the MAB. To help fill the gaps in data, we developed a model to predict temperature based on location, depth, and date. Incorporating all years of data, we first ran a GAM (gaussian; mgcv) to predict temperature as a function of depth, latitude, longitude, and day of the year. This model explained 75% of the deviance in temperature within the region. We then kriged (ordinary kriging, R package = gstat) the residuals from the GAM to generate maps of bottom temperature by month (June – October) within the MAB.

We had one turtle that tested positive for nematodes from the KA loggerheads. We compared this turtle’s distribution with those that tested positive in previous years and mapped the results.

Unfortunately, due to COVID, the scheduled necropsies for the cold-stunned turtles were cancelled for 2021, and as a result we did not have samples to compare from other species of sea turtles that traveled into more northern waters.

3. Results and Discussion

Annual Goal #1: *Collect samples from a minimum of 20 loggerhead turtles caught at-sea.*

During the 2021 season, a total of 31 satellite tags were deployed. Nine were deployed during the NEFSC gillnet research in NC and 22 were deployed during the KA trip (**Figure 2**). Of the 22 tags deployed on KA, two tags were provided by collaborators at University of North Carolina. As a result, these tag data were not included in analyses, however, biological sampling data were.

During the NC trip, SST ranged from 7.9° – 17.6° C. Turtles were tagged between February 28 and March 17, 2021. Turtles caught during this trip were generally smaller than those caught during typical KA trips in the MAB with a mean (± SD) CCL (notch to tip) of 73.7 ± 4.7 cm (**Table 2**). Tags deployed from NC also seemed to function better than those deployed on the KA trip. Tags transmitted for an average (±SD) of 277.3 ± 80.0 days. As a result, we documented the complete spring migration northward, and for two turtles this also included the southward migration in the late-summer/early-fall.

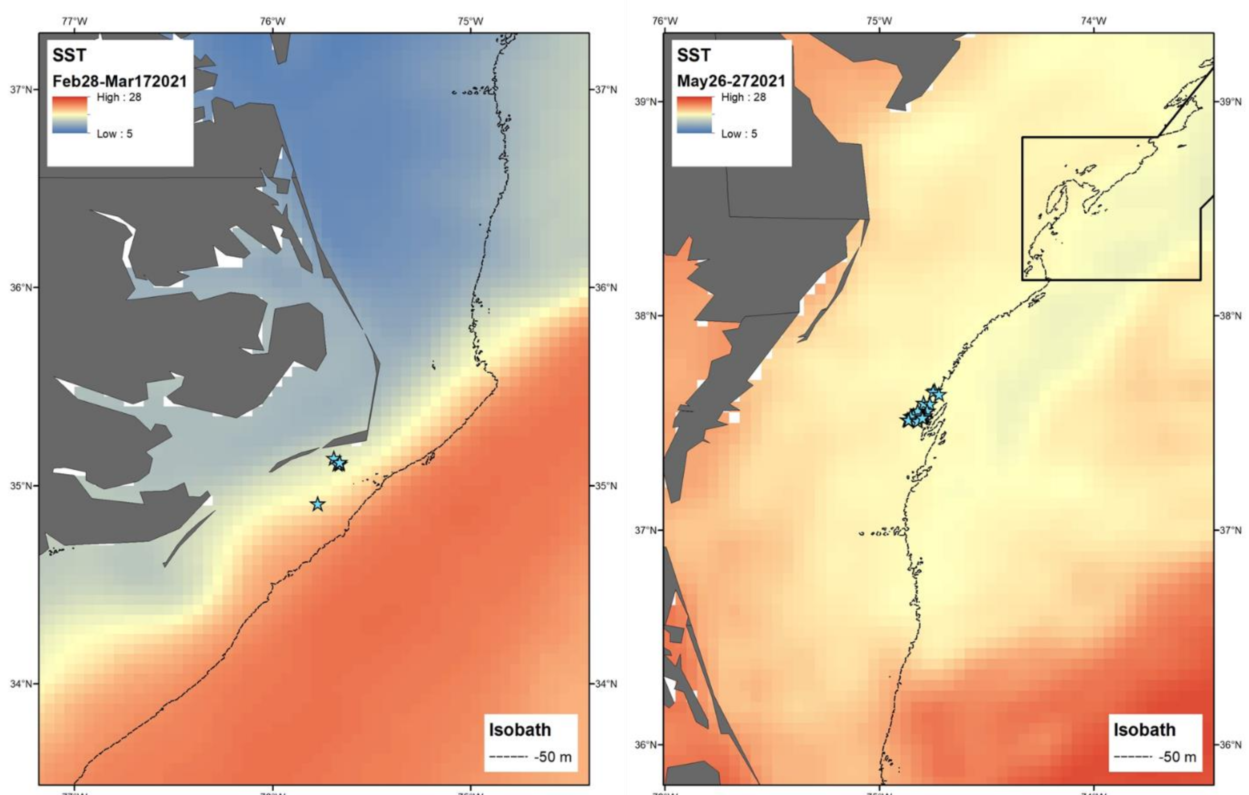

Figure 2: Deployment locations for the NC (right) and KA (left) turtles in 2021, along with SST layer.

In total, during the KA trip, we encountered 30 turtles and captured 22. Unfortunately tag durations from the KA deployments were generally short with an average (± SD) lifespan or 77.1 ± 61.3 days. Based on discussions with the tag manufacturer, it seems the tags have become fouled, thereby blocking the sensors that let the tag know it is above the surface of the water and should transmit. Due to this unexpected reduction in tag durations, we have opted to switch tag manufacturers in future loggerhead research and ensure tags are painted with an anti-fouling coating. However, when combined across all years, we have now accrued ~71,000 transmission days with nearly 250 satellite tag deployments.

Table 2: Summary table for tags deployed in 2021. Green highlighted turtle was positive for nematodes (unpublished CFF and NEFSC data).

Turtle ID	Trip	Deploy LAT	Deploy LON	Date Deployed	Tag Owner	CCL (N-T)	SST
2021.01	NC2021.01	34.91	-75.77	2/28/2021	NEFSC	77.3	7.9
2021.02	NC2021.01	35.11	-75.66	3/4/2021	NEFSC	71	12.8
2021.03	NC2021.01	35.11	-75.67	3/6/2021	NEFSC	73.5	12.8
2021.04	NC2021.01	35.12	-75.66	3/8/2021	NEFSC	66	14.9
2021.05	NC2021.01	35.12	-75.66	3/8/2021	NEFSC	78.2	15
2021.06	NC2021.01	35.12	-75.66	3/10/2021	NEFSC	75	14.4
2021.07	NC2021.01	35.12	-75.66	3/11/2021	CFF	67	13.1
2021.08	NC2021.01	35.14	-75.69	3/12/2021	NEFSC	79	15.6
2021.09	NC2021.01	35.12	-75.66	3/17/2021	NEFSC	76	17.6
2021.10	KA2021.01	37.65	-74.74	5/26/2021	NEFSC	81	15.7
2021.11	KA2021.01	37.65	-74.75	5/26/2021	CFF	76.3	15.8
2021.12	KA2021.01	37.59	-74.79	5/26/2021	NEFSC	90	15.4
2021.13	KA2021.01	37.56	-74.82	5/26/2021	NEFSC	92.6	15.5
2021.14	KA2021.01	37.54	-74.84	5/26/2021	NEFSC	87.9	15.4
2021.15	KA2021.01	37.54	-74.84	5/26/2021	CFF	78.9	15.4
2021.16	KA2021.01	37.54	-74.84	5/26/2021	CFF	71.6	15.4
2021.17	KA2021.01	37.54	-74.84	5/26/2021	CFF	81.6	15.5
2021.18	KA2021.01	37.53	-74.85	5/26/2021	NEFSC	99.4	15.5
2021.19	KA2021.01	37.52	-74.86	5/26/2021	NEFSC	102.4	15.7
2021.20	KA2021.01	37.52	-74.87	5/26/2021	CFF	89.5	15.7
2021.21	KA2021.01	37.52	-74.86	5/26/2021	NEFSC	99	15.6
2021.22	KA2021.01	37.51	-74.82	5/26/2021	UNC	100	15.7
2021.23	KA2021.01	37.56	-74.77	5/26/2021	UNC	102.5	17.8
2021.24	KA2021.01	37.56	-74.77	5/26/2021	CFF	101.2	16.1
2021.25	KA2021.01	37.64	-74.72	5/27/2021	CFF	94.7	15.8
2021.26	KA2021.01	37.59	-74.76	5/27/2021	CFF	89	16
2021.27	KA2021.01	37.56	-74.77	5/27/2021	CFF	88.9	16.2
2021.28	KA2021.01	37.54	-74.78	5/27/2021	CFF	90	16.2
2021.29	KA2021.01	37.53	-74.79	5/27/2021	CFF	99.4	16
2021.30	KA2021.01	37.53	-74.79	5/27/2021	CFF	75.9	16.2
2021.31	KA2021.01	37.53	-74.80	5/27/2021	CFF	84.2	16.2

During the KA trip, SST ranged between 15.4° - 17.8° C. All turtles were caught in shelf waters and mean (±SD) CCL (notch to tip) was 89.9 ± 9.4 cm. Compared to all previous years (2009 – 2019), these turtles were particularly large. CCL mean (±SD) for turtles caught between 2009 and 2019 is 80.4 ± 10.0 cm. Overall, there has been a very slight increase in size of the turtles caught since the RSA funded sea turtle tagging research began. In addition to tag deployments, we accrued a range of biological and morphometric samples to improve understanding of the health and demographics of this population.

Annual Goal #2: *Document seasonal distribution of loggerhead turtles within the MAB for transmitters functioning during the funding year.*

Turtles tagged in 2021 exhibited two distinct movement patterns (**Figure 3**). The subset tagged in NC remained more coastal as they migrated north through the MAB, with two turtles travelling to Buzzard's Bay, MA. This is the first time we have had loggerheads tagged within the US eastern seaboard continental shelf region migrate past Long Island and settle in Southern New England (SNE). In general, the NC turtles started both their northward and southward migrations earlier than we had previously documented. As a result, they were much farther north in May and June than those typically tagged offshore, and they were farther south in the late-summer, having already returned to NC by early October. Although the NC turtles generally stayed in shallower waters, the turtles that migrated the farthest north did move offshore specifically while foraging in Hudson Canyon. It is unclear what prompted the turtles to move offshore while passing through the New York Bight.

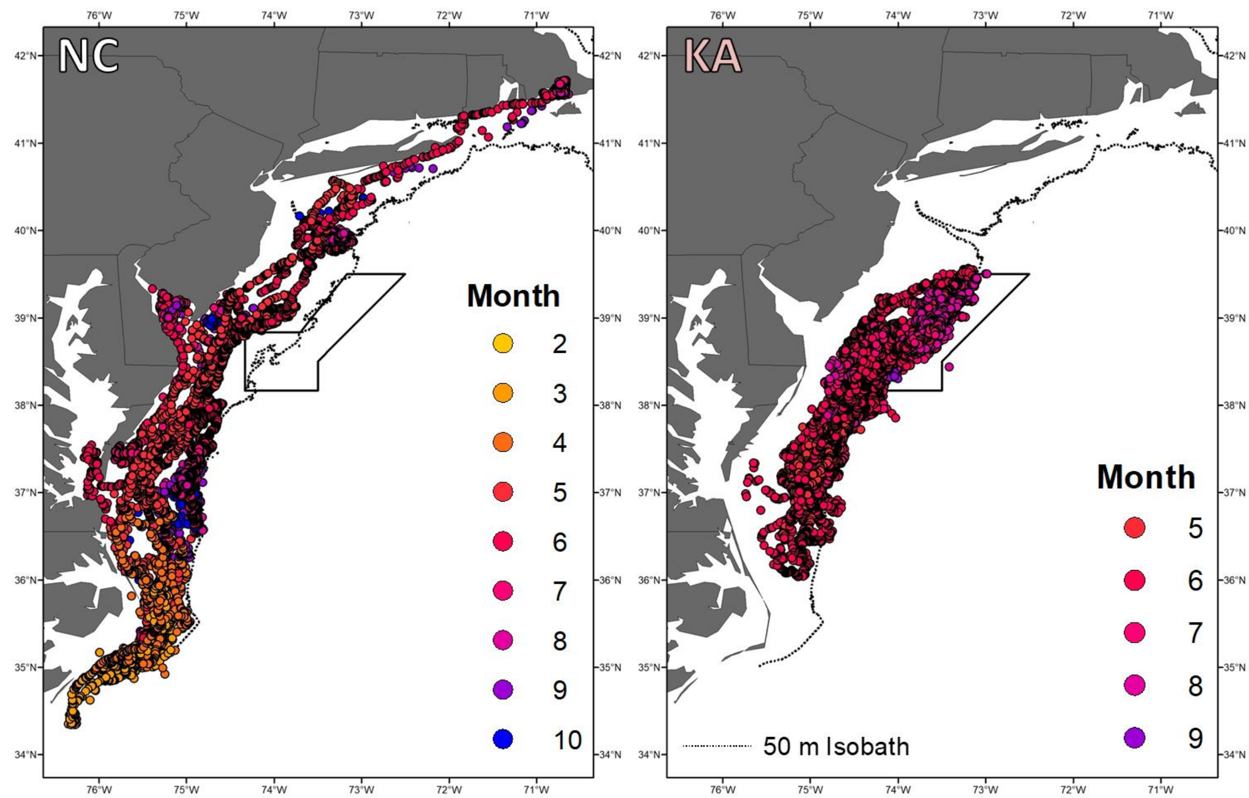

Figure 3: Transmitted locations for turtles tagged in NC (right) and on KA (left; unpublished CFF and NEFSC data).

The KA turtles exhibited a similar movement pattern than what has been previously documented for loggerheads. They remained in waters between 30 – 70 m deep, migrating north through the summer. However, with the short transmission durations, we did not document the southern migrations. Similar to the 2018 and 2019 cohorts of tagged turtles, the 2021 KA turtles remained farther south during their time in the MAB, with no turtle migrating north of latitude 40°N (**Figure 4**). The 2021 turtles had a fairly small distribution range within the MAB, and this was likely due to the shorter transmission durations not capturing the full extent of turtle movements within the region. The 2018 set of tags also had short tag durations; however, by deploying 35 tags this countered the limitations in the data associated with such short deployments.

We compared dive patterns between turtles tagged in NC with those tagged on the KA trip. It's important to understand the drivers of dive behavior to determine what conditions cause loggerheads to be more susceptible to being directly impacted by a dredge (Hawkes et al. 2006). Dive behavior varied based on region and season. In general, day of the year correlated with time spent at the surface for both KA and NC turtles ($p < 0.001$ for both), but only explained 10.5% and 31.4% of the deviances in dive behavior respectively. The NC turtles exhibited a similar pattern to what we have documented in the past regarding seasonality of dive behavior. During the summer months when the NC and KA tags overlapped in time, there was no significant difference (T-test, $p > 0.1$) in the percentage of time spent at the surface, which we used as a proxy for overall dive behavior (**Figure 5**). During the summer, KA turtles averaged (±SD) 31.1% ± 22.2% of dive time at the surface, while NC turtles averaged 30.8% ± 26.2% of dive time at the surface. In the fall and winter months, particularly after the southward or before the northward migrations respectively, NC turtles behaved similarly to what we have documented in previous years and spent much more time submerged and very little time at the surface. NC turtles averaged (±SD) 11.1% ± 20.4% of their time at the surface during the pre/post-summer foraging months. Typically, in the winter, loggerheads exhibit a type of hibernation called brumation, during which they will spend several hours resting at the sea floor.

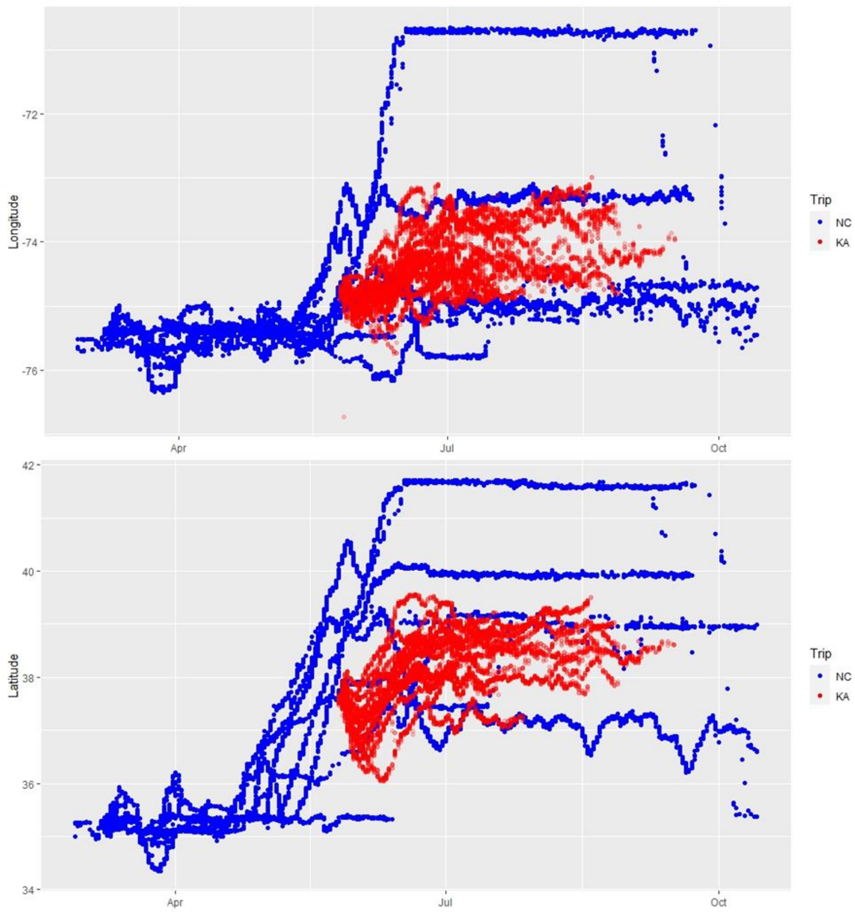

Figure 4: Longitudinal (top) and latitudinal (bottom) range of the NC (blue) vs KA (red) turtles throughout the deployments (unpublished CFF and NEFSC data).

Although diving behavior seemed similar between the two deployment groups, the NC turtles differed in the general habitat usage while migrating through the MAB. The NC turtles inhabited a broader range of both latitudes and longitudes, spending much more time in nearshore waters and foraging in much shallower benthic environments. However, once the NC turtles reached the northern portion of the MAB, they moved offshore, spending considerable amounts of time directly over the Hudson Canyon.

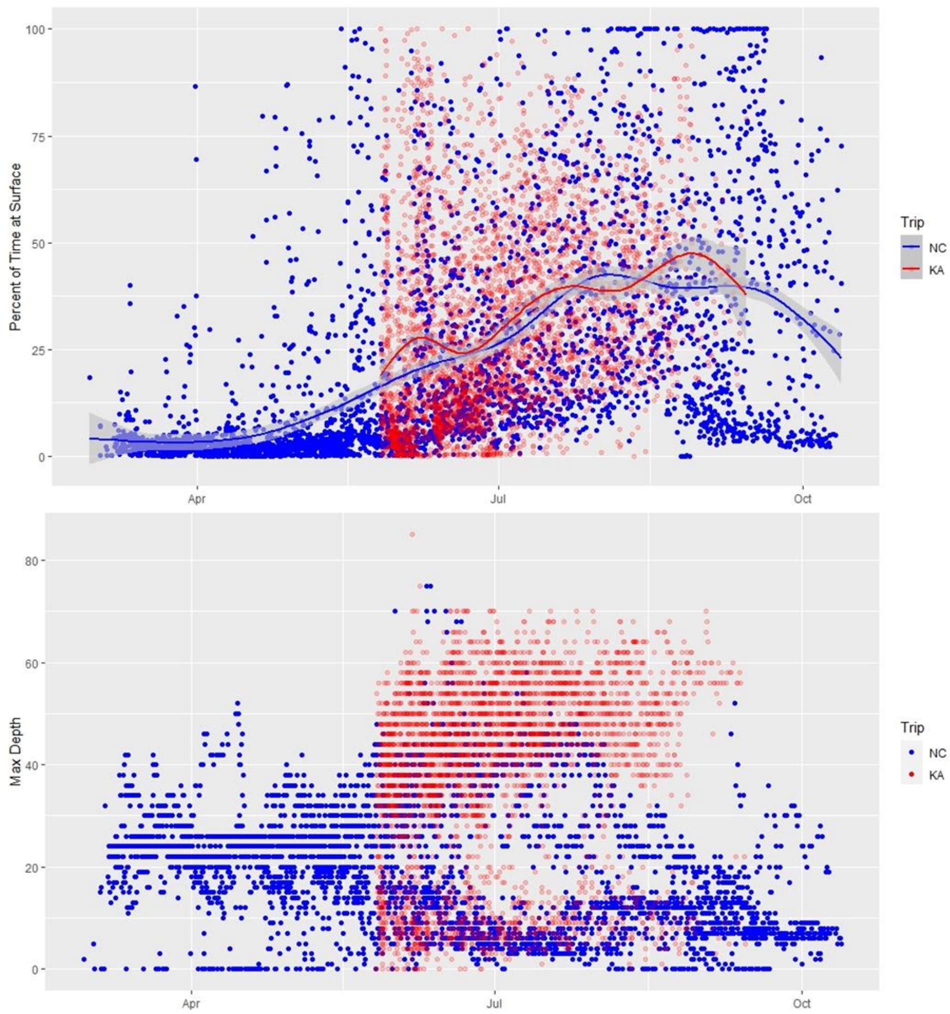

Figure 5: Percent of time at the surface (top) and max dive depth in meters (bottom) for NC (red) and KA (blue) turtles. GAM fit lines applied to top figure, shaded regions represent 95% confidence interval (unpublished CFF and NEFSC data).

As in previous years, SST correlated with diving behavior both for the NC and KA turtles ($p < 0.001$ for both sets of turtles; **Figure 6**). Essentially, as SST warms turtles tend to become more active and spend more time at the surface either migrating or resting between foraging dives. During the colder months, turtles are generally brumating and spending far less time at the surface. For the NC turtles, SST explained 67.2% of the deviance in their percentage of time at the surface, while for the KA turtles, SST explained 46.8% of the deviance. It is likely that SST was a better explanatory variable for the NC turtles due to the larger data set covering a broader portion of the year and the two distinctly different behavioral modes of summer foraging in warm SST vs brumation in much colder SST.

Uniquely, two turtles from NC migrated through the MAB into SNE and settled in Buzzard's Bay, remaining resident for the summer. This is the first time we have tracked loggerheads migrating along the US eastern seaboard and continuing north past Long Island in order to settle in SNE. The waters surrounding Cape Cod are known summer foraging grounds for loggerheads, Kemp's ridleys, green turtles and leatherbacks turtles. The path they take to reach these northern habitats is unknown, particularly for the turtles that end up inhabiting Cape Cod Bay on the northern side of the Cape. Our previous tagging effort has documented two turtles inhabiting Georges Bank (GB) (**Figure 7**). One was tagged in collaboration with the NEFSC on the R/V Bigelow directly in GB, and this turtle meandered through the region, before heading south through SNE and the MAB. The other turtle was tagged in the Gulf Stream east of the Delmarva

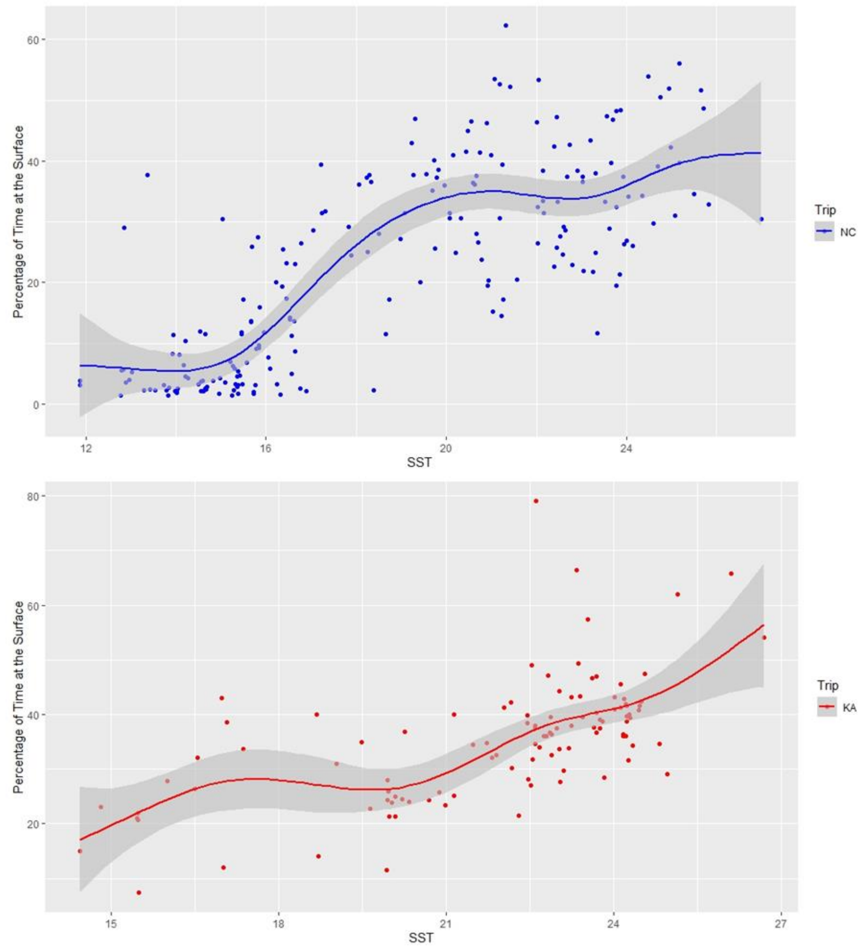

Figure 6: Percent of time at the surface as related to SST for NC (top, blue) vs KA (bottom, red) turtles. GAM fit line applied to both figures, with shaded region representing the 95% confidence interval (unpublished CFF and NEFSC data).

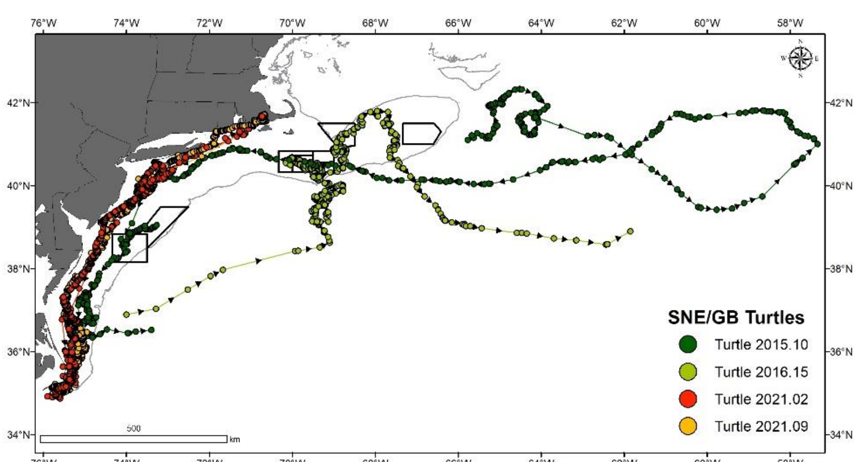

Figure 7: Tagged turtles that have been tracked travelling through shelf waters north of the MAB (unpublished CFF and NEFSC data).

region. This turtle traveled north within the Gulf Stream, before meandering into southern GB. Although, we have not been able to tag turtles that replicate paths leading to GB, documenting two turtles in a single year that both migrated through the MAB to SNE may indicate that this is a more common behavior than we had previously expected. In 2023, we plan to explore these findings by tagging more turtles in the late winter while they are residents of nearshore NC waters.

Annual Goal #3: *Identify presence/absence of nematode parasite and anthropogenic waste in lavage samples.*

Of the 18 turtles that provided a lavage sample during the KA trip, one (Turtle 2021.29) was considered positive for the nematode *S. sulcata.* This positive turtle generally remained farther south than the area where turtles that previously tested positive for nematodes tended to aggregate (2016 – 2018; **Figure 8**). We also assessed the lavage samples for bacterial content as a proxy for the gut microbiome of each turtle.

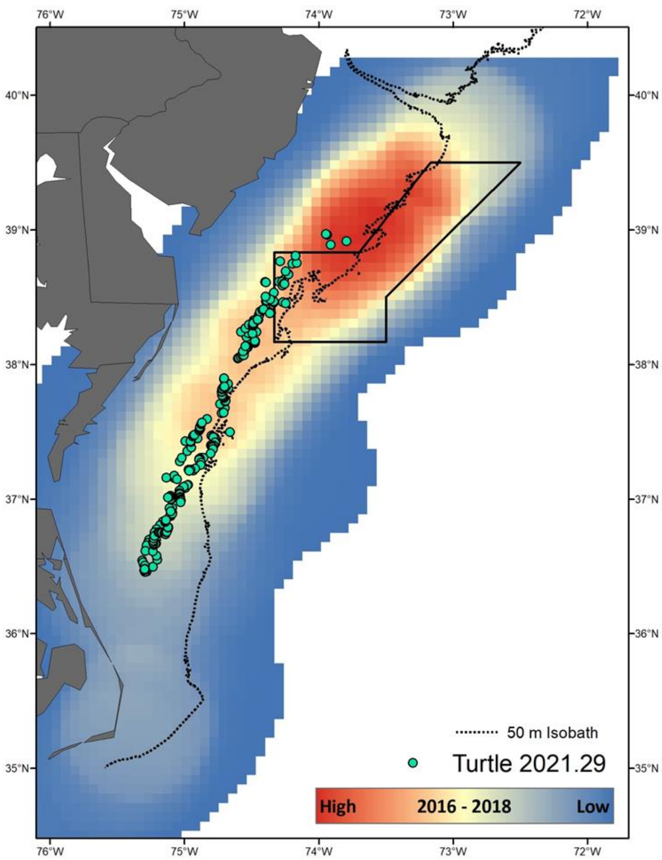

Figure 8: Transmitted locations for Turtle 2021.29 that was positive for nematodes, overlaid on a density map for all positive turtles from 2016 – 2018 (unpublished CFF and NEFSC data).

Without directly identifying foraging preferences, there are a few techniques available to provide a general understanding of prey selection. Stable isotope analysis (SIA) is conducted on the skin samples to help determine trophic level and the marine realm from where loggerheads are foraging (ie. nearshore vs offshore and pelagic vs benthic species). Gut content microbiome research can be used to help supplement the SIA by identifying diversity of prey preferences (ie. herbivory, carnivory, or omnivory), and if turtles have been recently foraging or exhibiting patterns of inappetence likely associated with brumation.

The loggerheads from this study showed a unique fecal microbiome composition (**Figure 9**). At the phyla level, samples were dominated by Proteobacteria (53.7%) and Bacteroidetes (27.9%). Less prevalent were Firmicutes (6.6%), Kiritimatiellaeota (3.1%), Fusobacteria (1.3%), and various unclassified bacteria (5.0%). Proteobacteria abundance was relatively high compared to previous findings, with most studies reporting 11-23% (Abdelrhman et al. 2016, Arizza et al. 2019, Biagi et al. 2019). Bacteroidetes, Firmicutes, and Fusobacteria, which are common gastrointestinal tract inhabitants for sea turtles, were found in amounts comparable to previous reports from loggerheads (Abdelrhman et al. 2016, Arizza et al. 2019, Biagi et al. 2019). Interestingly, Kiritimatiellaeota was found in 10 out of 18 of the sampled loggerheads despite this phylum never being found in the gut microbiome of any sea turtle species. This result, along with high levels of unclassified bacteria found, suggests unique environmental conditions, and dietary or health factors impacting this specific population that have not yet been reported. At the family level, the major taxa were Pseudomonadaceae (17.7%), Flavobacteriaceae (12.4%), Shewanellaceae (8.9%), Marinomonadaceae (4.7%), Pseudoalteromonadaceae (4.41%), and Rikenellaceae (4.2%). Each of these families have previously been reported as prevalent in various sea turtle species.

The loggerheads of this study had an average Proteobacteria prevalence of 53.7%. High levels, 47.2-51.8%, have previously been identified in cold-stunned and nesting loggerheads, both of which were likely undergoing periods of starvation (Abdelrhman et al. 2016, Arizza et al. 2019, Biagi et al. 2019). This association of Proteobacteria with inappetence suggests that the loggerheads of the present study may not have been foraging. Despite a high overall average,

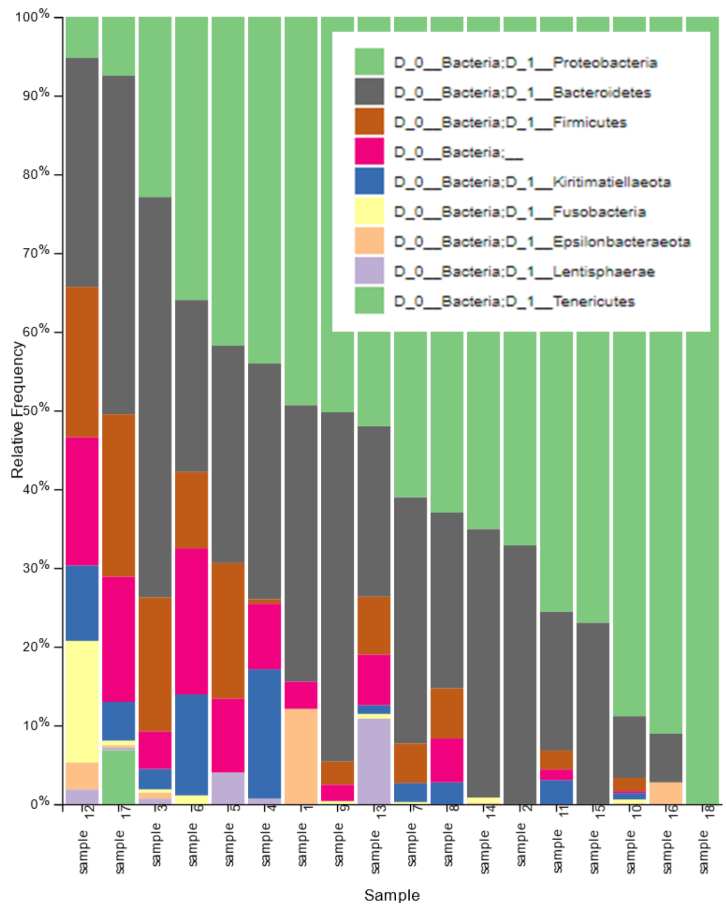

Figure 9: Composition of the gut bacteria from all sampled KA loggerheads (unpublished CFF and NEFSC data). Figure credit: Zachary Forbes.

individual turtles showed a lot of variation, with Proteobacteria levels ranging from 5.2 – 100%. This suggests that some turtles were inappetent while others were actively foraging. These turtles were sampled as they were migrating north after the winter in search of good foraging. Some of them were likely in a brumation state and were not actively feeding during the winter, while others remained active and feeding. The variable levels of Proteobacteria between turtles may be reflective of their winter behavior. Animals with low activity over the winter likely have higher levels of Proteobacteria, while more active animals likely have lower levels. Interestingly, the turtle that was positive for the nematode this year (2021.29) had a gut microbiome composition indicating that it was likely foraging during the winter. This may indicate the nematode is ingested while turtles are farther south, and then brought into the MAB. Since this is only a sample size of one, much more research is required to validate this trend, specifically tagging and sampling turtles in southern waters prior to their northward migrations.

Annual Goal #4: *Use videography to document potential prey species.*

During the KA trip, we also deployed the Deep Trekker ROV and followed two turtles that were swimming nearby the vessel (**Figure 10**). The first turtle was tracked for ~11 minutes. This turtle remained close to the surface and was not bothered by the ROV. At the surface, this turtle seemed to be basking in addition to taking the occasional breath. The second turtle was tracked for ~8 minutes. This turtle was surrounded by barrelfish (*Hyperoglyphe perciformis*). In contrast to the first turtle, this turtle seemed interested in the ROV and swam circles around it, getting caught and freeing itself from the tether twice (**Figure 11**). This is behavior we have documented before while filming turtles with an ROV. This turtle also defecated while encircling the ROV. After following each turtle, we dove the ROV to the bottom to record the presence of any benthic prey items, the temperature, and depth (**Figure 12**). Prey items were scarce, and the temperature at the bottom (35 m deep) was ~15°C, while at the surface it was closer to 20°C. We took some additional bottom dives in adjacent regions in search of other prey items and dove to 48 m,

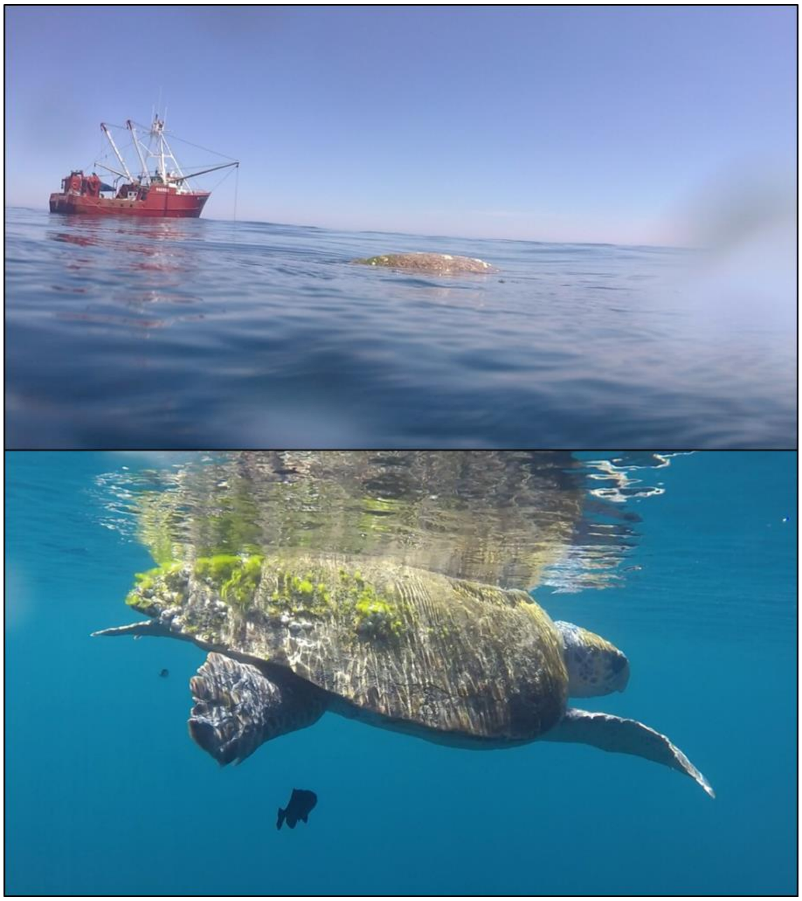

Figure 10: Turtle 1 filmed by the ROV basking near the boat.

where the temperature was ~12°C. Similar to the scallop surveys in the areas, we did not document any scallops but observed sand dollars and shell hash, along with the occasional crab.

Annual Goal #5: *Expand database of loggerhead turtle biology and ecology to be used by management.*

A major component of the transmitted information that can be used by management is the high-resolution temperature data. During this funding year, we took a closer look at the temperature data to assess its breadth and to develop interpolation models to generate more complete representations of bottom temperatures within the

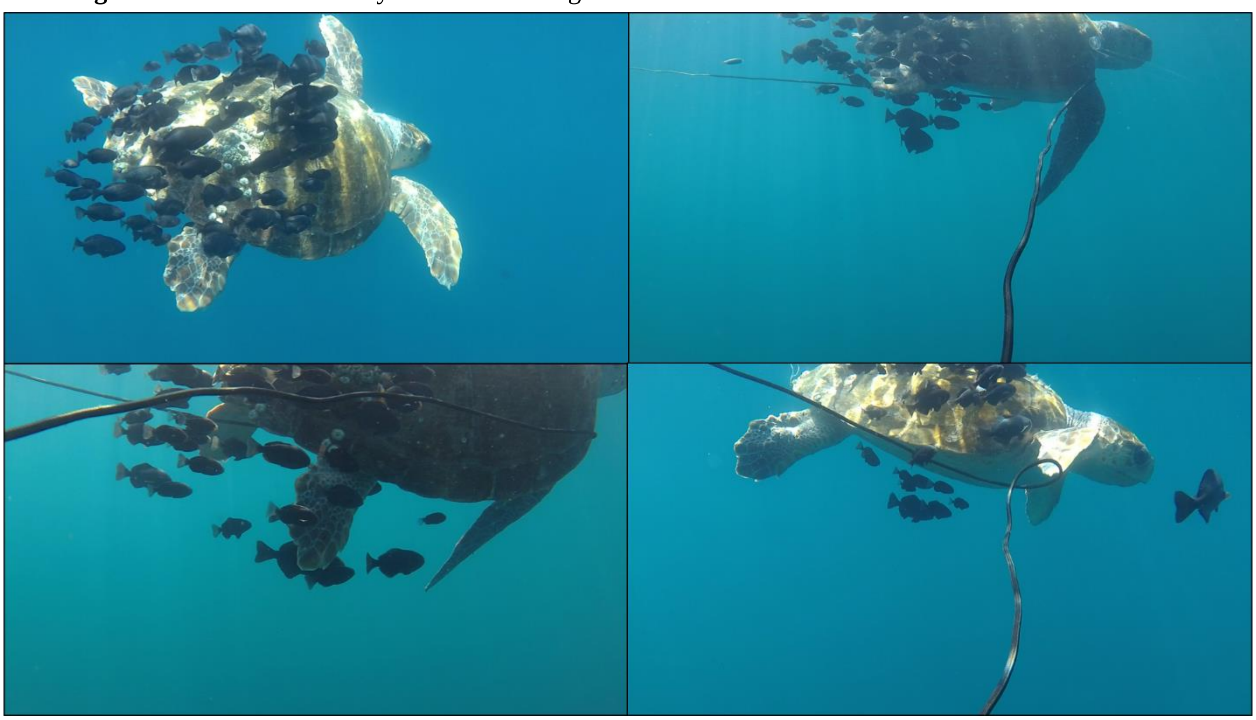

Figure 11: Turtle 2 filmed by the ROV, circled several times and got caught and released itself from the tether, photos are sequential from top-left to bottom-right.

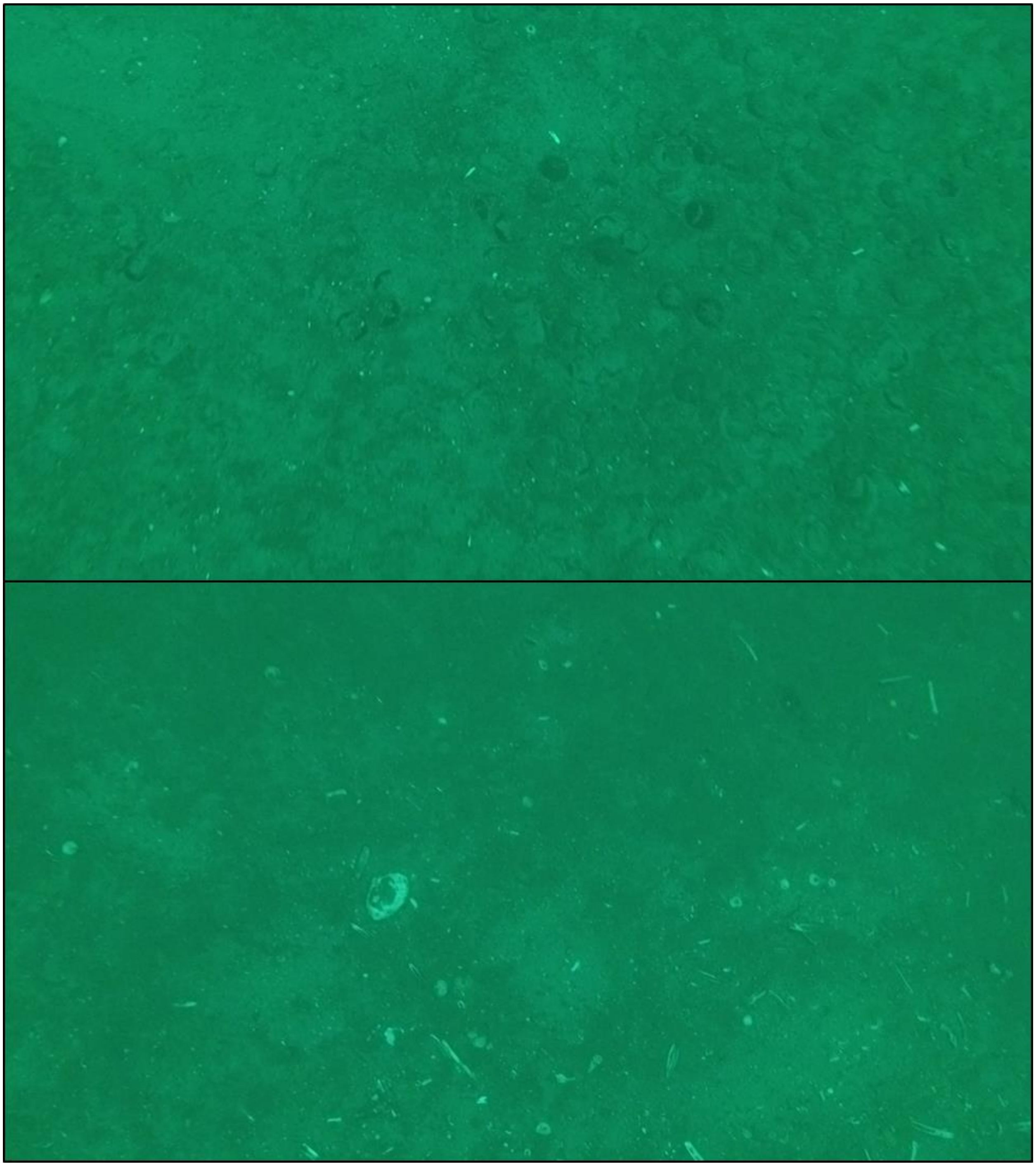

Figure 12: Examples of benthos adjacent to where the two turtles were followed by the ROV and where we captured the loggerheads during the KA trip.

MAB. This work addresses Programmatic Goal #9 “What are the unique oceanographic characteristics of the MAB and how do they impact scallop abundance?” and is a continuation of work conducted by Patel et al. (2018) that identified loggerheads as good ocean observers. During the summer, the MAB experiences a unique phenomenon of the formation of a Cold Pool water mass (CPW). The CPW creates a highly stratified water column, with bottom temperatures nearly 15°C cooler than surface temperatures (**Figure 13**). The CPW intensifies through the summer before rapidly deteriorating in October as storms and hurricanes cause the water column to become mixed. This mixing creates particularly warm bottom temperatures in October (18° - 20° C), which is above lethal temperatures for scallop spat that may be in the region due to the fall spawning event (**Figure 14**).

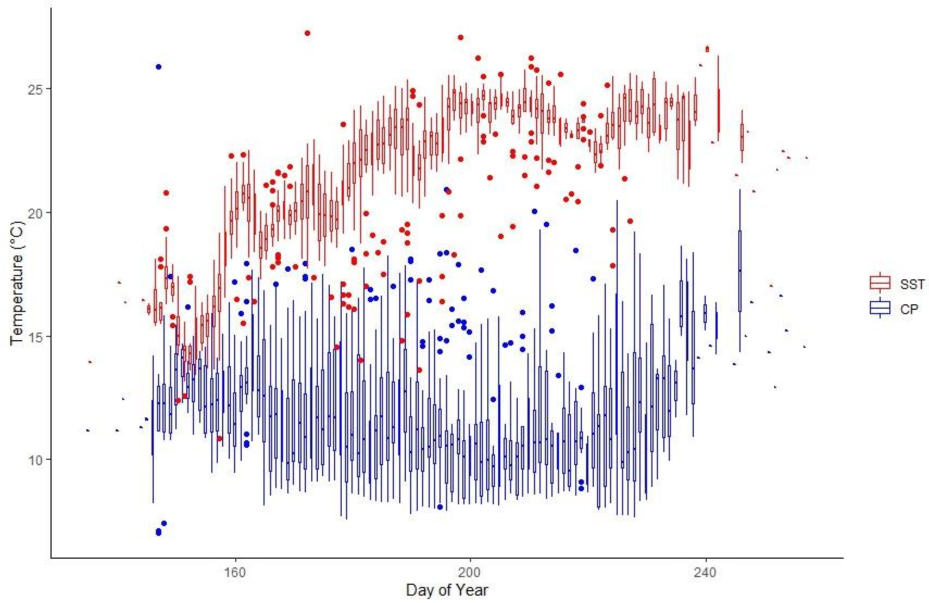

Figure 13: Surface and bottom temperatures recorded by the KA turtles while foraging in the CPW (unpublished CFF and NEFSC data). Figure credit: Nathan Shivers.

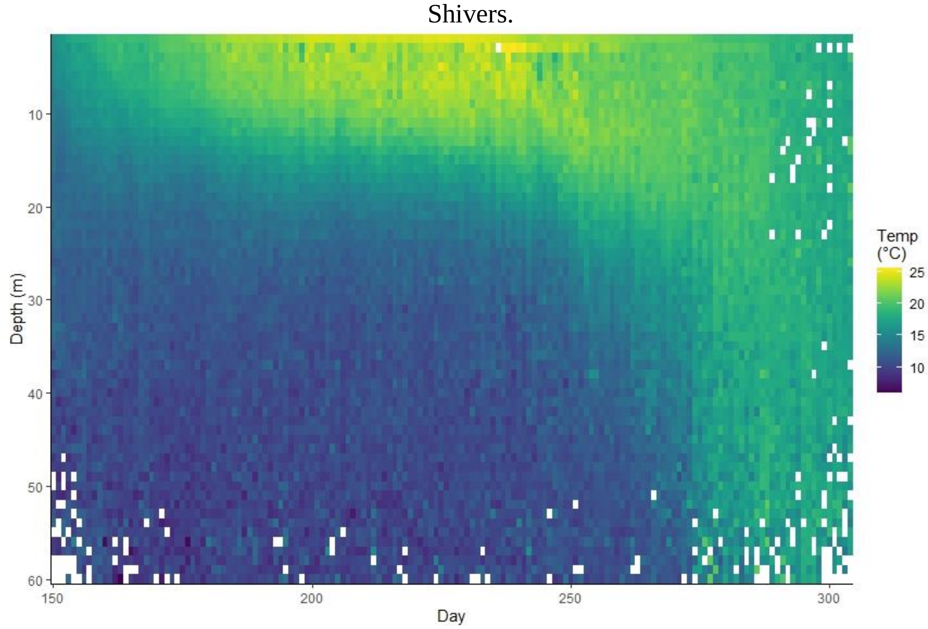

Figure 14: Average water column temperature calculated from all turtles tagged between 2009 – 2021 while in the MAB (unpublished CFF and NEFSC data). Figure credit: Nathan Shivers.

This contrasting trend for water temperature during summer months of cooling proceeded by rapid warming tends to be difficult to model (Chen et al. 2018). Typically, turtles tagged specifically during KA trips forage within the CPW and as a result transmit *in situ* data of the entire water column providing a complete assessment of the depth and temporal range of the CPW. However, due to the variability of annual tag deployments and the migratory behavior of loggerheads, there tends to be gaps in the coverage (**Figure 15**). For example, coverage of the MAB is best in July and August when turtles are the most dispersed in the MAB and the majority of tags are still functioning. In June, September and October we have less coverage in the MAB as turtles are either migrating northward in June or, in the later months, southward plus tags have

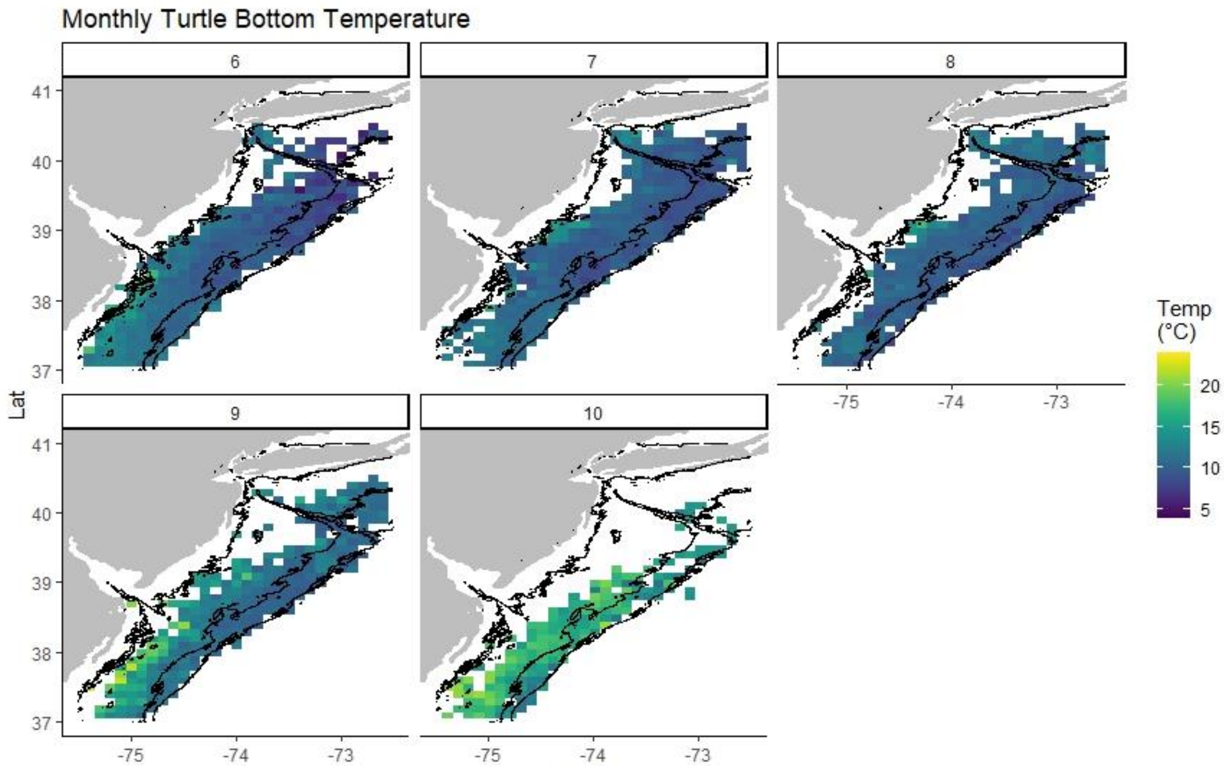

Figure 15: Monthly averaged bottom temperature calculated from all turtles tagged between 2009 – 2021 while in the MAB (unpublished CFF and NEFSC data). Figure credit: Nathan Shivers.

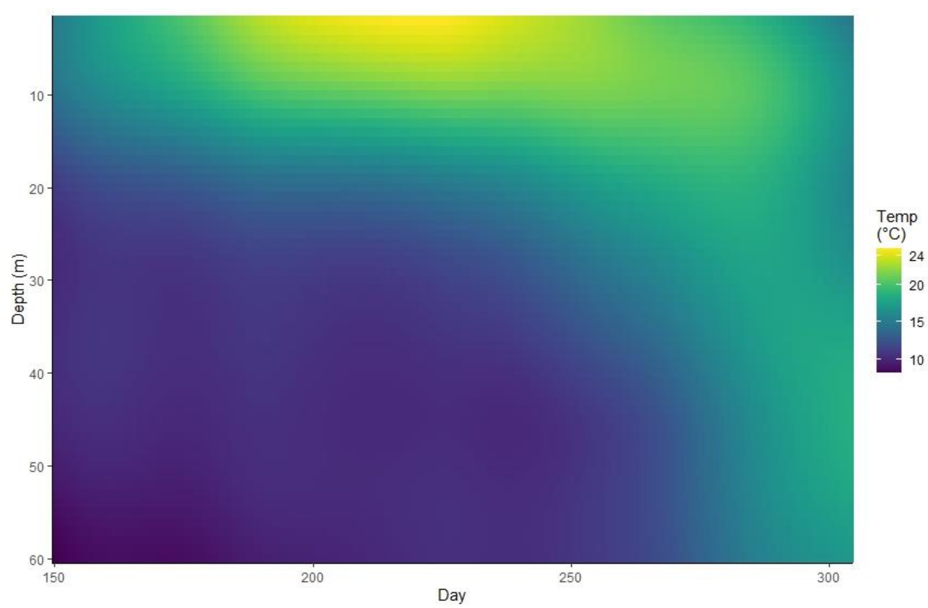

Figure 16: Averaged interpolated water column temperature from all turtles tagged between 2009 – 2021 while in the MAB (unpublished CFF and NEFSC data). Figure credit: Nathan Shivers.

started to fail. To help fill the gaps in coverage we developed a model typically used for interpolating data across a large spatial range (GAM + ordinary kriging) and similar in process to what is used to develop estimates of scallop biomass from the HabCam data (Chang et al. 2017). From this model, we used the GAM to predict temperature across the region (**Figure 16**), and then we kriged the residuals to account for smaller scale variations in the temperature data (**Figure 17**). Although, we are not trying to develop forecast models, we

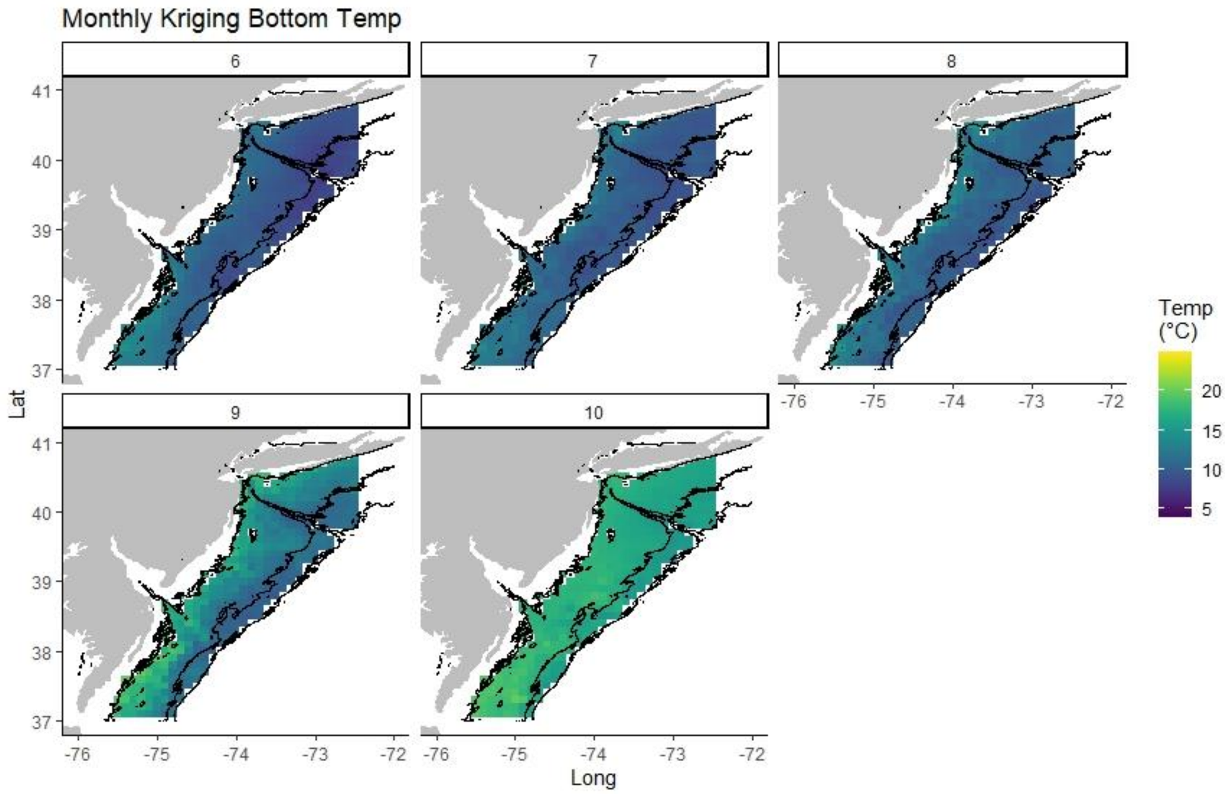

Figure 17: Monthly averaged interpolated bottom temperature calculated from all turtles tagged between 2009 – 2021 while in the MAB (unpublished CFF and NEFSC data). Figure credit: Nathan Shivers.

wanted to understand if our transmitted data provided enough nuance for accurate interpolation of temperatures across the broader range of the MAB, specifically in areas where and when turtle data tends to be less robust due to their seasonal movement patterns. Overall, we found the results of the model to provide realistic estimates of bottom temperature within the MAB especially when compared to existing literature on the seasonal evolution of the CPW (**Table 3**; Chen et al. 2018). We will continue to update our temperature models as more data are collected to help improve understanding of the historical bottom conditions of the MAB.

Table 3: Summary data for the interpolated monthly bottom temperature (°C) within the MAB averaged across years 2009 – 2021 (unpublished CFF and NEFSC data).

Month	Min	1st Qu	Median	Mean	3rd Qu	Max
6	7.298	9.25	10.164	10.416	11.317	17.128
7	8.531	9.774	10.452	10.727	11.421	16.338
8	8.583	10.256	10.79	11.226	11.915	17.676
9	9.639	11.643	13.344	13.787	15.915	20.232
10	14.33	16.15	16.9	16.97	17.69	20.01

In 2021, we had the unique opportunity to collect both temperature and salinity data from the deployments due to the availability of experimental tags contributed by NEFSC. From the KA turtles, we clearly identified their presence within the CPW both from the temperature data, but also from the salinity data (**Figure 18**). Surface salinity was approximately 33 PSU; however, at depth salinity slightly increased to 34 PSU. This matches previous reporting for the conditions of the CPW (Chen et al. 2018). In contrast, the NC turtles tended to remain inshore, including within bays and estuaries, as a result the recorded salinity values were much lower (~22 PSU), including through depth. Salinity tolerances for sea turtles are understudied, however, this large difference in salinity between offshore to inshore environments does change physiological processes within marine reptiles which may lead to differing foraging patterns (Willard et al. 2019). Currently, more research is required to truly understand how loggerhead behavior may differ under varying salinity regimes.

We also analyzed a unique component of loggerhead biology that is used in estimating bycatch mortality in fishing gear (Upite et al. 2019). In Robinson et al. (2022), we examined the likelihood of gas embolisms (GE) in various sea turtle species during routine dives, including loggerheads based on data provided by CFF and NEFSC from three tags that were recovered and thus contained the full time series of dive behavior at four second intervals. A GE is typically considered a consequence of a fisheries interaction and the rapid ascension of the animal from depth to the surface. However, based on model estimates of sea turtle diving physiology, it may be possible that decompression

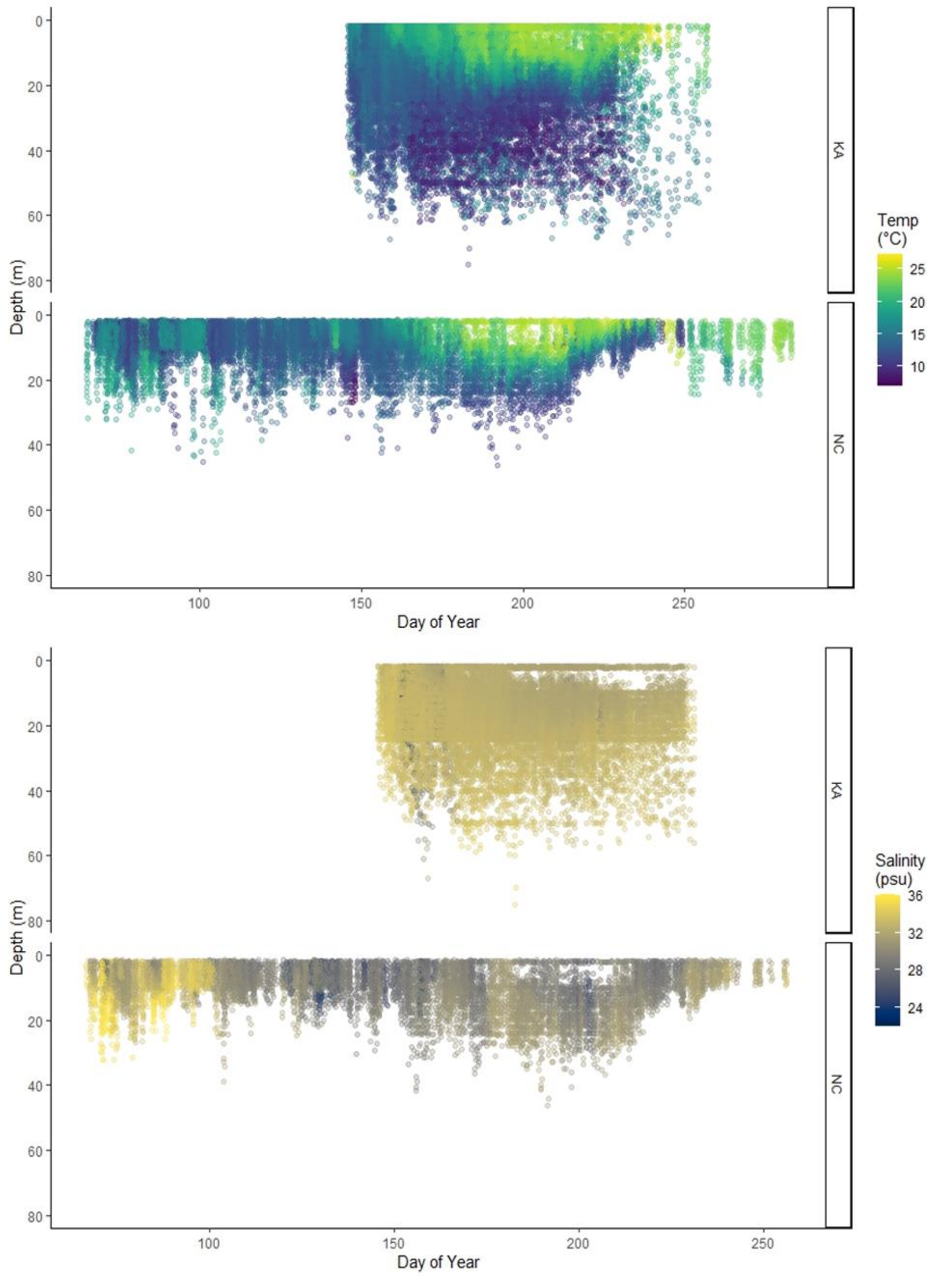

Figure 18: Temperature (green-blue) and salinity (gold-blue) through depth data transmitted from the 2021 tags. In each set of graphs, the KA turtles are on top and the NC turtles are on the bottom (unpublished CFF and NEFSC data). Figure credit: Nathan Shivers.

sickness (DCS) could occur in free swimming sea turtles, including loggerheads. From Robinson et al. (2022): "Our model suggests that during "natural" diving behavior sea turtles experience blood and tissue N2 levels that would cause decompression sickness in land mammals of similar size. Indeed, the maximal end-dive PN2 values between species ranged from 5.03 ATA to 9.40 ATA, which is considerably higher than the level of end-dive PN2 that would result in severe DCS in 50% of similarly sized humans (Fahlman et al., 2020). As it is highly unlikely that sea turtles are perpetually suffering from GE during routine diving behavior, we propose that turtles, much like marine mammals, must have additional behavioral, anatomical, and/or physiological mechanisms to reduce N2 uptake that are not currently considered in this model (García- Párraga et al., 2018; Burggren et al., 2020; Fahlman et al., 2021)." As a result, much more research is required to truly understand how turtles are able to dive to such depths and remain for extended periods without suffering the consequences of DCS. This understanding will help improve the accuracy of bycatch estimates that assume a mortality based on the likelihood of DCS (Upite et al. 2019).

Programmatic Goals

During FY2021/22, we completed each of the annual goals and made progress at completing some of the programmatic goals. Below we have included status reports for each Programmatic Goal. In general, the annual goals are meant to identify specific aspects of the loggerhead ecology project that are achievable with one year's worth of data, funding and time, while the programmatic goals identify topics that need several years of data, funding and time to achieve.

1. *How do latitudinal distributions change seasonally? Interannually?*

Winton et al. (2018) partially addressed this goal when they developed a model, based on tag data from the entire region, to predict the seasonal shift in loggerhead density within the US Atlantic shelf waters. For 2021, we identified a new trend of seasonal movement patterns that have shifted our expectations of when and where loggerheads are likely to be located. The NC cohort migrated north much earlier than expected, reaching northern waters ahead of the KA turtles. The NC turtles also began their southward migration earlier than turtles that forage in deeper MAB waters. As a result, we plan to continue deploying tags in NC on an annual basis to help improve understanding of loggerhead distribution in the MAB through the seasons.

2. *How much time do turtles spend on bottom compared to time spent on the surface?*

Hatch et al. (2022) improved our understanding of when and where loggerheads are exhibiting various dive behaviors, specifically increased time at the surface vs at-depth. From Hatch et al. (2022): "Spatially, the predicted average dive durations were higher inshore, compared to offshore areas defined by bottom depths >200m; although, this pattern was less apparent north of Cape Hatteras, North Carolina. The longest dives appeared to be concentrated along the continental shelf near the coasts of North and South Carolina. Additionally, longer dives were predicted farther south in January, relative to the shorter dives in August along the Mid-Atlantic Bight. We also estimated significantly greater spatiotemporal than spatial variation for the estimated average dive durations, with a relative increase in the marginal standard deviations of roughly 1.5 times. Seasonally, along the continental shelf, the average dive duration was highest during October–May, relative to the warmer summer months of June–September. More variability in average dive duration occurred from October–May, with sharp declines in this pattern during summer. The longest dives occurred farther south in the Carolinas and Chesapeake Bay regions, following a similar seasonal pattern as demonstrated across the entire continental shelf. In the New York Bight area, average dive duration was relatively more stable with consistently shorter dives throughout the year, again with slightly longer dives from October–May."

3. *Is there a difference in spatiotemporal distributions based on demographics or morphometrics?*

This goal has been partially addressed by two collaborators. Ceriani et al. (2014) used stable isotopes from tissue samples to identify foraging preferences of loggerheads based on region and demographic. Yang et al. (2019) have established baseline blood characteristics for these turtles to improve understanding of this cohort. In the FY19/20 final report we reported on the differences in behavior associated with demographic, and in this final report we have identified a very distinct difference in movement patterns based on demographics, as the NC turtles are considerable smaller than the KA turtles. To better understand demographics, we calculated the body condition index (BCI) for all measured turtles since 2009 as a simplified method of determining health status. In general, we found that our turtles did fit within the criteria of healthy based on Barco et al. (2016) that also calculated BCI from turtles captured within the Chesapeake Bay. As we move forward with this research path, we plan to relate BCI with other demographic factors along with spatiotemporal distributions. Overall, this needs more investigation.

4. *Do turtles display site fidelity to foraging areas?*

This goal is being addressed through the use of long-term tags. The first attempt with these types of tags from Wildlife Computers is fully discussed in the FY2018/19 final report. During this funding year we did identify fidelity to the NC region with turtles tagged there returning to the same region at the end of their summer foraging season. From all of the years of tagging, we have over 100 tag deployments that lasted at least one year. We plan to investigate foraging site fidelity using this set of tags in the upcoming years.

5. *How is behavior changed by water temperature?*

Patel et al. (2021) addressed this goal in a larger context by examining how a shift in SST over the next 80 years will impact loggerhead distribution patterns. During their time in the MAB, we found that turtles tend to prefer waters where the SST ranged from 11° - 29.7° C. We combined this with the depth preferences for loggerheads (0 – 105 m) to create a habitat envelope. We then used climate change projections for the NW Atlantic to determine where and when this habitat envelop would occur over the next 80 years. We concluded that the available habitat for loggerheads will increase northward during the spring and fall seasons in particular. With fall showing the largest change in SST. As a result, we expect loggerheads to migrate into the MAB earlier in the year, reach more northern foraging ground, and then return south later into the fall. Meaning sea turtle movement patterns may shift to include regions and months outside of the current spatiotemporal range for the TDD. We plan to continue monitoring these trends and researching how environmental variable will impact turtle behavior in more detail (e.g. dive behavior).

6. *What are the primary prey species and does this impact parasite load?*

Smolowitz et al. (2015) and Patel et al. (2016) have both reported on the results from the extensive ROV research and presented information on prey preferences. Ceriani et al. (2014) also took steps to determine broader foraging preferences of loggerheads in the region through SIA. Since 2016, we have been taking lavage samples to identify the presence of nematodes in the loggerheads and more data are needed before appropriate conclusions can be made. We have also taken steps to analyze foraging preferences base on gut microbiome as presented above.

7. *Do oceanographic features impact migratory patterns?*

As mentioned previously, we have recently published a manuscript describing how a rise in SST will impact the habitat envelop for loggerheads that forage in the MAB (Patel et al. 2021). Regarding other oceanographic features, we have documented turtles inhabiting the Gulf Stream as they move offshore or northward. As we accrue more data we will investigate how ocean current may play a role in migratory patterns.

8. *How will climate change alter the environmental parameters (temperature, chlorophyll concentration and oceanic currents) impacting loggerheads in this region?*

This goal was addressed in Patel et al. (2021), specifically regarding temperature. However, climate models are constantly being updated and so we will continue to monitor the environment based on the data collected from the satellite tags themselves. We also plan to take a close examination of other environmental variables. For example, the Gulf Stream is expected to shift courses and degrade earlier in its path, pushing warm water inshore within the MAB, SNE and GB. This will have a substantial impact on both loggerheads but also their prey species.

9. *What are the unique oceanographic characteristics of the MAB and how do they impact scallop abundance?*

Patel et al. (2018) partially addressed this goal by presenting data on the regionally unique MAB CPW. As written above, we have reexamined the turtle temperature data to help generate updated temperature-depth profiles for the MAB. Although the turtles are not inhabiting this region year-round, they transmit the only high resolution in-situ dataset for the region covering the entire water column from June – October. Currently, it seems as through the water temperature may be too warm for the survival of the scallop spat generated during the fall spawning event as they reach the Delmarva region.

Conclusions

During FY21/22, CFF collected samples from 22 loggerheads, specifically documenting their seasonal locations in the MAB, morphometrics, health statuses, nematode presence, genetics and stable isotope values. Through collaboration with NEFSC, we also tracked an additional nine loggerheads from North Carolina. Since 2009, CFF has contributed to the sampling of nearly 250 loggerheads. Many research goals have been met through this sampling (see list of publications in **Appendix 1**); however, the primary goal of determining the impacts of fisheries on these species requires a particularly large sample size and continued monitoring (Sequeira et al. 2019). For example, observed loggerhead bycatch in the scallop fishery is extremely rare due to the implementation of turtle-specific gear modifications (NMFS 2015). As a result, being able to document these rare interactions between this fishery and loggerheads requires a high level of monitoring both from fisheries observer coverage and direct loggerhead sampling (Murray 2012, Sequeira et al. 2019). This holds true for the other turtle species as well, and in particular for turtle-fisheries interactions with an unknown level of occurrence (Hamelin et al. 2017).

Unfortunately, the scallop industry cannot depend on NMFS to conduct this directed research on loggerheads specifically in regard to interactions with the fishery. Similarly, the industry cannot depend on NMFS to provide a comprehensive survey of the scallop biomass. As a result, just as the industry has designated funding for additional scallop biomass surveys, the scallop industry must take the initiative to ensure their interactions with protected species do not jeopardize their ability to continue fishing. Despite the recent ESA Biological Opinion of the Atlantic sea scallop fishery, the data acquired through RSA-funded research, which demonstrates that the loggerhead population in the MAB is healthy, provided the best defense that the fishery is not causing additional harm to turtles despite having triggered the consultation. The only alternative research path to monitor the loggerhead population is to conduct an aerial survey multiple times a year to ensure that the population is not shrinking or shifting habitats. However, this is far costlier than annual tagging studies and does not provide a direct assessment of the health status of the population. Furthermore, aerial surveys depend on surface availability estimates from satellite telemetry data to calculate the population estimates and cannot be conducted effectively without adequate co-located tagging research to estimate how much time turtles spend near the surface in view of an aerial observer (NMFS 2011). As a result, continued sea turtle research, likely funded by the RSA, is essential to avoid regulatory burdens imposed by the ESA.

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Appendix 1: Publications (**bold**) and select reports and presentations resulting from RSA funding.

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