OCS Study
BOEM 2022-088

Discerning Behavioral Patterns of Sea Turtles in the Gulf of Mexico to Inform Management Decisions

U.S. Department of the Interior
Bureau of Ocean Energy Management
New Orleans Office

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Corrected version: rows were added to Table 3

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DISCLAIMER

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ABOUT THE COVER

US Geological Survey Biologist Andrew G. Crowder during release of a satellite tagged loggerhead sea turtle. Photograph by the US Geological Survey.

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List of Abbreviations and Acronyms

Short Form	Long Form
ADL	acceleration data logger
AMAPPS	Atlantic Marine Assessment Program for Protected Species
ARS	area restricted search
BLM	Bureau of Land Management
BOEM	Bureau of Ocean Energy Management
CCL	curved carapace length
CZMA	Coastal Zone Management Act
DOI	Department of the Interior
DPS	distinct population segment
ESA	Endangered Species Act
GAMM	generalized additive mixed modeling
GEODAS	Marine Geophyiscal Data
GIS	geographic information system
GOM	Gulf of Mexico
GOMMAPPS	Gulf of Mexico Marine Assessment Program for Protected Species
GPS	global positioning system
IACUC	Institutional Animal Care and Use Committee
MCMC	Markov Chain Monte Carlo
MCP	minimum convex polygon
MDL	mean daily locations
MMS	Minerals Management Service
MSCIP	Mississippi Coastal Improvements Program
NEPA	National Environmental Policy Act
NGOM	Northern Gulf of Mexico
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
OCS	Outer Continental Shelf
OCSLA	Outer Continental Shelf Lands Act
PIT	passive integrated transponder
PTT	platform terminal transmitter
SCL	straight carapace length
SESC	Southeast Ecological Science Center
SSM	state space model
TAD	time at depth
TAS	time at surface
TSHD	trailing suction hopper dredge
USFWS	United States Fish and Wildlife Service

Short Form	Long Form
USGS	US Geological Survey
WARC	Wetland and Aquatic Research Center

Errata

This is the corrected version of the report. Rows 16–50 have been added to Table 3.

Introduction

The protection of all sea turtles globally has been considered a high priority for decades, with an emphasis on research themes that will result in improvements in monitoring and management for population recovery (Hamann et al. 2010). With declining trends for most sea turtle populations, all sea turtle species are conservation-reliant (Ceriani and Meylan 2015), requiring continued efforts from managers (Scott et al. 2005) to sustain populations. Because all sea turtles within United States (US) waters are currently listed under the US Endangered Species Act (ESA) as endangered or threatened (see below), Section 7 of the ESA requires consultations between federal agencies for all activities where sea turtles may be affected.

The northern Gulf of Mexico (GOM) is home to four species of hard-shelled sea turtles: Northwest Atlantic Ocean distinct population segment (DPS) loggerhead (*Caretta caretta*); Kemp's ridley (*Lepidochelys kempii*); North Atlantic DPS green (*Chelonia mydas*); and hawksbill (*Eretmochelys imbricata*). The loggerhead and green sea turtle DPSs occupying US waters are listed as threatened under the ESA, and the other species are currently listed as endangered.

The GOM includes major nesting beaches for loggerhead turtles including several nesting subpopulations along the Florida coast (Turtle Expert Working Group 2009). The sole nesting habitat for Kemp's ridley turtles is on the western GOM, with nesting areas in Texas and at Rancho Nuevo Mexico (Turtle Expert Working Group 1998; Turtle Expert Working Group 2009; NMFS et al. 2011). Estuarine, continental shelf, and oceanic waters of the GOM are important habitats for sea turtles across their life history stages (Garrison et al. 2019; Lamont et al. 2015a, 2015b; Shaver et al. 2013, 2016; Hart et al. 2013, 2014). Hatchlings emerge from nests laid on sandy beaches and swim offshore, where they will remain in oceanic habitats for several years (Bolten 2003). Many juveniles then recruit to neritic habitats on the continental shelf or in coastal bays until they reach reproductive maturity. Adult turtles in the Western Atlantic and GOM typically establish foraging home ranges in relatively shallow water along the continental shelf and leave those areas only to migrate to nesting beaches (Hart et al. 2014).

There is diversity in habitat use across species (Hart et al. 2018), geographic regions (Hatase et al. 2002, Hart et al. 2014) and among individuals (Vander Zanden et al. 2010). Ensemble niche modeling has highlighted the extent of potential foraging habitat for loggerheads and Kemp's ridleys (Fujisaki et al. 2020), with specific foraging sites spread across the GOM (see Hart et al. 2021), and important migratory corridors (Shaver et al. 2016 Kemp's ridleys; Iverson et al. 2020 loggerheads).Green turtle nearshore habitat use has also been documented in coastal bays and nearshore GOM waters (Lamont et al. 2015b; Lamont and Iverson 2018; Metz et al. 2020; Lamont and Johnson 2021).

Determining distribution, seasonal movements, vital rates and habitat use for all life-stages of marine turtles has been identified by the US Fish and Wildlife Service (USFWS) and US National Marine Fisheries Service (NMFS) as important for achieving recovery for these endangered species (NMFS and USFWS 1991). The green turtle Recovery Plan (NMFS and USFWS 1991) also states that "to adequately protect and enhance survival of sea turtles, we must know where they occur, in what numbers, at what times, and what factors contribute to mortality." Similarly, the Binational Recovery Plan for the Kemp's ridley (NMFS et al. 2011) states, "Identification and protection of essential habitat must be vigorously undertaken".

Sea turtle life history is complex, with only females coming ashore to nest. The eggs incubate in the sandy beach and hatchlings emerge, crawl across the beach and enter the ocean. In the water, hatchlings expend great energy to swim offshore where they will remain, hidden in sargassum and other debris for 1–2 years before moving back into neritic foraging areas. As juveniles they remain at these in-water foraging sites until they reach sexual maturity and move to adult foraging areas. Breeding adults make migratory movements between nesting beaches and adult foraging areas.

Genetic studies have been helpful in defining the boundaries of marine turtle nesting populations in the GOM. Loggerhead turtles nesting along the GOM coast of Florida represent a minimum of four demographically isolated populations (Shamblin et al. 2012). Green turtles nesting in the Dry Tortugas and Marquesas Keys are distinct populations with respect to one another as well as those on the Atlantic coast of Florida (Shamblin et al. 2020). Recent mixed stock analyses using novel genetic markers have demonstrated the distinctiveness of juvenile green turtle foraging aggregations in the northwestern and northeastern GOM (Shamblin et al. 2017; Chabot et al. 2021). However, dispersal and migratory connectivity in juvenile loggerhead turtles has received less attention (Lamont et al. 2015a). Kemp's ridleys are one genetic stock (NMFS et al. 2011).

Only recently has information become available about sea turtle high-use areas along the GOM coast (see Hart et al. 2013; Shaver et al. 2013; Foley et al. 2014; Hart et al. 2014); these data are biased towards nesting females. A recent report (Garrison et al. 2019) presented tracks of turtles in the GOM and focused on general movements and habitat associations of turtles tagged in various locations; this work was also supported by BOEM (BOEM Study 2020-010). However, fine-scale information on dive profiles is still lacking for sea turtles in the GOM. Such information can provide key data on time spent per individual in various portions of the water column, in specific locations. This type of information is important for minimizing risk to turtles interacting with bottom-dredge operations, during which they can be entrained and killed (see Ramirez et al. 2017).

There are very few data on turtle dive-surface behaviors in waters of the GOM. Available dive-surface behavior data from telemetry tags was reviewed by the Loggerhead Turtle Expert Working Group (Turtle Expert Working Group [TEWG] 2009) and found a number of studies for Atlantic waters ranging from Cape Canaveral, Florida to Savannah, Georgia. These studies showed a considerable range in the percentage of time at the surface both spatially and seasonally with values ranging from 3.8% to 48.6% over this spatial range and in multiple seasons (TEWG 2009). More recent data collected along the Atlantic coast was part of the Atlantic Marine Assessment Program for Protected Species (AMAPPS), which also showed a broad range in time at surface for loggerhead turtles and apparent seasonal and spatial variability likely related to migration patterns and/or water temperatures) Similarly, tags deployed on loggerhead turtles in coastal and estuarine waters of North Carolina demonstrated that turtles spent, on average, <1% of their time in the upper one meter of the water column in estuarine waters and 2.4% of their time at the surface in coastal waters with some evidence for seasonal variability (Braun-McNeil et al. 2010). When these estimates of time at surface were applied to previous abundance estimates, it resulted in 4 to 100-fold increases in the estimates of turtle density within their respective habitats (see Warden et al. 2017).

This study provides information on in-water aggregations of sub-adult, juvenile, and adult marine turtles in the northern GOM. Data collected includes individual dive profiles, movements, seasonal site fidelity, genetic population structure, and isotopic signatures. The results can contribute towards a better understanding of sea turtle distribution and abundance in the GOM, which is needed for various agency decisions regarding leasing and management of Outer Continental Shelf (OCS), National Environmental

Policy Act (NEPA) impact analyses, and consultations with private industry. Time at surface information derived from depth-logging tags will be used to improve abundance estimates cacluated from aerial survey data being collected by the National Ocean and Atmospheric Administration (NOAA).

1.1 Background

In 1953, the Outer Continental Shelf Lands Act (OCSLA) [67 Stat. 462], established Federal jurisdiction over the submerged lands of the continental shelf seaward of State boundaries. The Act charged the Secretary of the Interior with the responsibility for administering minerals exploration and development of the OCS. It also empowered the Secretary to formulate regulations so that the provisions of the Act might be met. Subsequent to the passage of the OCSLA of 1953, the Secretary of the Interior designated the Bureau of Land Management (BLM) as the administrative agency responsible for leasing submerged federal lands and the US Geological Survey (USGS) for supervising production. In 1982, the Minerals Management Service (MMS, now BOEM) assumed these responsibilities.

The National Environmental Policy Act (NEPA) of 1969 (42 USC 4321-4347) requires that all federal agencies use a systematic, interdisciplinary approach that will ensure the integrated use of the natural and social sciences in any planning and decision-making that may have an effect on the human environment. BOEM efforts in this direction include environmental impact statements, environmental assessment teams, studies that acquire and analyze marine environmental data, literature reviews, socioeconomic-analysis studies, public conferences, and special studies (toxicity studies, spill-trajectory analyses, etc.).

The Coastal Zone Management Act (CZMA) of 1972 (16 U.S.C. 1451 et seq.) was established to protect the coastal environment from growing demands associated with residential, recreational, commercial, and industrial uses. The CZMA helps states develop coastal management programs to manage and balance competing uses of the coastal zone (i.e., offshore oil and gas activities in same area as marine mineral resources). This includes biological and physical sciences impacts and socioeconomic impacts. BOEM's responsibility for CZMA is to ensure the impacts to states' coastal uses and resources from BOEM activities and federally permited or licensed activities on the OCS are consistent with the enforceable policies of the state's coastal management programs.

1.2 BOEM and USGS Relevance and Benefits

The USGS Wetland and Aquatic Research Center (WARC) provides accurate science on the biology and ecology of aquatic environments throughout the United States and around the world. Founded in 2009, the center was created to bring together scientific experts in biology and ecology throughout the southeastern US and Caribbean. The Center's roots lie in US Fish and Wildlife Service and National Park Service (NPS) research units that were brought into the USGS as the Biological Resources Division in 1994. For almost a decade, research was carried out through the USGS Florida Integrated Science Center, which cultivated an integrated approach to earth and environmental science that focused on problems facing society and answering questions related to management. The WARC continues to support the Department of the Interior's (DOI) commitment to serve communities by providing the most accurate scientific information to the public and resource managers.

WARC scientists apply their expertise to a variety of wetland and aquatic research and monitoring programs that require coordinated, integrated efforts in order to better understand natural environmental processes. By increasing basic understanding of the biology of important species and broader ecological processes, this research provides information to policy-makers and aids resource managers in their stewardship of natural resources.

For this study, USGS and BOEM collaborated to design a study whereby spatial data and dive information would be collected for sea turtles captured in the water. Combining turtle movement and dive data with with genetic stock analyses, population demographics, and diet studies (via stable isotope analysis) begins to address information gaps listed in individual sea turtle species recovery plans. This gathering of missing or incomplete data on species in the GOM in particular improves the ability of BOEM to make informed management decisions regarding projects conducted on the OCS within the GOM, particularly dredge projects. These gaps have been identified through the NEPA process and through ESA Section 7 consultations with USFWS and NMFS. This collaboration between BOEM and USGS fulfilled expertise and permitting needs because USGS possesses the expertise and permits required from NMFS to collect biological samples, tag turtles, and analyze and interpret the resulting spatial and dive data.

The information from this project can be used directly by BOEM. In particular, exploration and development of oil and gas resources in the GOM, renewable energy, and coastal restoration projects using OCS marine minerals will require BOEM to produce information for a variety of NEPA-related decision documents, CZMA state consultations, and maintain compliance with the ESA.

In addition to providing data to support BOEM's management decisions, deploying satellite tags that log dive data on turtles captured in association with hopper dredge relocation trawling activities allows the collection of key data sets on tagged individuals, including depths used, movement patterns, and high-use areas. Tags with dive-logging capabilities transmit location information that provides researchers the ability to test current hypotheses about marine turtle use of preferred zones in the water column. They can also reveal the amount of time spent on the bottom within the vicinity of dredging activities–a factor that influences mortality and entrainment risk. Previously, Eberle (1994) found that the position of turtles in the water column may be related to abiotic factors, including depth, cloud cover, time of day, light intensity, and temperature. Understanding how these and other related environmental factors influence sea turtle dive behaviors are needed to identify optimal dredging times in order to avoid sea turtle interactions when they are on the sea floor.

1.3 Training Suction Hopper Dredges

Hopper dredges are designed to vacuum material (i.e., mud, sand, sediment) from the sea floor through drag arms that load the material into the hold of the vessel. The material is then transported to either an ocean disposal site, where the material is dropped to the sea floor through openings in the bottom of the hull, or at an upland site such as a beach, where the material is pumped ashore by the ship (see Ramirez et al. 2017 for detailed descriptions of training suction hopper dredges [TSHD]). This method is most suited when excavating loose material from open areas for delivery to a distant disposal location.

For example, in the construction phase of the Caminada Headland Beach and Dune Restoration project in coastal Louisiana, hopper dredges were used to excavate and transport sediment from a borrow area on the Ship Shoal submerged sand body on the OCS. Biological opinions issued by NMFS often require a reduction in risk to endangered or threatened species through the use of mitigation tools that would prevent lethal sea turtle takes from hopper dredges. Relocation trawling–rawling in front of the dredge to capture and relocate live sea turtles away from the dredging activity–was selected as the mitigation measure for the project. As a result of the relocation trawling, an exceptionally large number of sea turtles were relocated, exceeding 150 individuals by the end of the first phase of activity and exceeding 500 individuals at the completion of the project.

The use of relocation trawling is a NMFS-mandated activity to move sea turtles away from hopper dredge intake pipes. It can be unsuccessful if sea turtles exhibit high fidelity to the dredging site and/or if there is a short distance between capture and release locations because sea turtles can quickly return to the dredging area (Magnuson et al. 1990). Thus, information on dive profiles and habitat use is important for resident populations of imperiled sea turtles near such in-water operations, particularly for designing methods that will help avoid negative interactions with sea turtles and evaluating efficacy of the mitigation method during dredging activities.

Instigated by the exceptionally high number of turtles relocated during the Caminada project, efforts were undertaken for BOEM and USGS to collaborate on a project to use relocation trawling as a sampling and spatial tagging opportunity for sea turtles. Trawling conducted in association with dredging provided unique access to these difficult-to-sample turtles (i.e., males and immature turtles).

1.4 Goals and Objectives

The goal of this study was to use hopper dredge relocation trawling operations to opportunistically tag sea turtles and collect biological samples to inform OCS management decisions, particularly related to trawling and dredging operations. Tracking turtle movements post-relocation allowed for calculation of distances moved and proximity to capture sites for a subset of turtles in the project. This key information is needed to identify methods to decrease the chances of recapture in relocation trawls and improve the economic feasibility of dredging projects, possibly preventing multiple handlings of the same turtle.

Before this project, few genetic analyses existed for turtles in the northern GOM. What is known comes from nesting beach sampling of adult nesting females (Shamblin 2007, Shamblin et al. 2011, 2012). This study determined genetics origin of turtles captured in the water, and compared mitochondrial haplotype frequencies to known values in the literature.

Finally, the measurement of stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopes in tissues of organisms has formed the foundation of isotopic food web reconstructions, because these values directly reflect assimilated diet. The application of stable isotope measurements of both the organic and inorganic components of food webs has had a long and impressive history. Such measurements are now an indispensable tool for elucidating food web structure, nutrient and contaminant flows, and the foraging ecology of individuals and populations (Peterson and Fry 1987; Rundel et al. 1989; Lajtha and Michener 1994; Fry 2006; Boecklen et al. 2011). Isotopic studies on turtles in the GOM are limited to recent work by VanderZanden et al. (2014, and Pajuelo et al. (2012), both focused on loggerheads), and Reich et al. (2010), focused on Kemp's ridleys). Tracking isotopic values across tissue types (e.g., blood, tissue, carapace) can reveal shifts in resource use over time because both short- and longer-time frame resource use can be inferred (see Vander Zanden et al. 2014). Thus, we determined isotopic signatures of all turtles sampled.

Objectives of this project were to:

- Determine the extent of movements and seasonal site fidelity among sea turtles tagged in the project.
- Collect and characterize dive profiles of sea turtles in sand-dominated areas throughout the year. Identify and assess physical and biological features of specific high-use habitats, especially with respect to BOEM dredging sites.
- Assess the genetic population structure of captured sea turtles by using standard genetic methods.
- Assess the carbon and nitrogen isotopic signatures of sampled sea turtles, across multiple tissue types (blood, tissue, carapace) that represent short-, medium-, and long-time frames of diet and resource use in the marine food web.

Methods

All turtles were captured via trawling for this project. They were either tagged opportunistically, as a part of on-going relocation trawling being performed in conjunction with dredging operations, or by the US Geological Service (USGS) directed trawling on the Outer Continental Shelf (OCS). Relocation trawling involves a contracted trawl vessel capturing and relocating sea turtles in the path of the hopper dredge up to 24 hours a day. In contrast, direct trawling involves a contracted trawler operating 12 hours a day along tracks per-detemined by the USGS research team unrelated to hopper dredge operations. Turtles captured by relocation trawlers were released approximately 8 miles from capture sites; turtles captured by directed trawling were released at their capture sites. Tow times were limited to 30 min and were conducted at between 2 and 4 mph (3 and 6 km/hr.).

1.5 Study Sites

Turtle tagging occurred at four study sites in the northern Gulf of Mexico (GOM) (Figure 1) where relocation trawling was required or direct trawling was permitted. Mean distance to nearest shoreline for capture sites was: 4.1 miles (6.6 km) in Pensacola, Florida; 10.1 miles (16.2 km) in Pascagoula, Mississippi; 10.8 miles (17.4 km) at Ship Shoal, Louisiana; 7.4 miles (12.0 km) in the Chandeleur Islands, Mississippi; depths ranged from 20–50 feet (6–15 meters), on average.

Study site descriptions:

- The Florida site was located offshore of Pensacola and was associated with the Santa Rosa Island Authority relocation trawling. The 137 acre borrow area was located approximately 4 miles offshore, and the goal was to renourish Pensacola Beach. During 2015–2016, 1.75 million cubic yards of sand were moved at a cost of ~$16 million.
- The Mississippi site(s) were clustered at about 10 miles offshore near Cat Island, Ship Island, Petit Bois Island Pass, and Dauphin Island, proximal to Pascagoula. The sites were associated with the Mississippi Coastal Improvements Program (MsCIP) and involved relocation trawling. Numerous borrow areas near these islands were used, as well as several sand resource sites on the OCS. The Comprehensive Plan for MsCIP included restoring the Mississippi barrier islands and over 3,000 acres of wetland and coastal forest habitat. Barrier island restoration occurred through direct sand placement of approximately 22 million cubic yards to restore island structure and enhance sand supply to the littoral transport system over the 2009–2019 time periods at a cost of around $214 million[1].
- The Louisiana relocation trawling site was located at Ship Shoal and was associated with the Caminada Headlands Beach and Dune Restoration project. The borrow areas at Ship Shoal were located 27 miles (43.4 km) from the Caminada site; the goal was to create 303 acres of beach and dune over a six mile (9.7km) stretch. During 2013–2015, approximately 3.3 million yards of sand

[1] A link to the Mississippi Coastal Improvements Program Ship Island barrier island restoration, which used relocation trawling, can be found here: https://www.usgs.gov/special-topic/gom/science/mississippi-coastal-improvements-program-mscip

was dredged and transported from Ship Shoal; this was the first time that sand from this site was being used for a restoration project. The goal was to protect and preserve the structural integrity of the barrier shoreline of the Caminada Headland, which reduces wave energy and salt-water intrusion from the GOM into back-barrier environments. Restoration of these fragile habitats is needed to protect and sustain significant and unique foraging and nesting areas for threatened and endangered species[2].

- The Chandeleur Islands are a chain of low-lying uninhabited barrier isalnds approximately 50 miles (80 km) long, forming the easternmost point of Louisiana. This site was sampled as a part of US Geological Survey (USGS) directed trawling and was not related to a borrow site. The islands have been renourished many times, and they are part of the Breton National Wildlife Refuge, established in 1904. The site is home to many threatened and endangered species[3]. USGS performed directed trawling at this site.

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[2] A link to this approximately $76 million project that used relocation trawling can be found here: https://www.westerndredging.org/phocadownload/2017_Vancouver/Caminada%20Headland%20Beach.pdf

[3] A link to the Breton National Wildlife Refuge is: https://www.fws.gov/refuge/Breton.

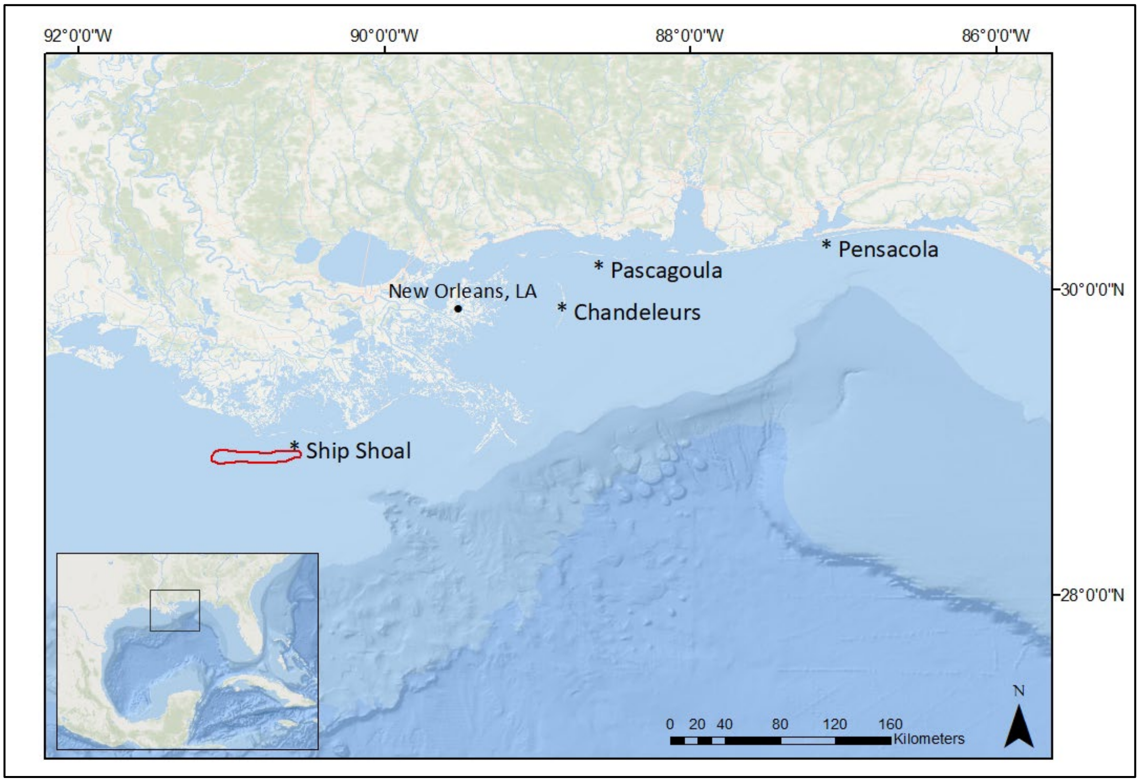


Figure 1. Map of study sites where turtles were sampled as part of ongoing relocation trawling (Pensacola, Ship Shoal and Pascagoula) and USGS directed trawling (Ship Shoal, Chandeleurs), Gulf of Mexico (GOM), 2016–2019

1.6 Training and Permitting

All turtle handling was conducted in accordance with permit requirements identified in NMFS permit 17304 and and Louisiana Department of Wildlife and Fisheries (LNHP-18-006 and WDP-19-006) issued to Kristen M. Hart, Ph.D., Research Ecologist, USGS-WARC, and comply with USGS-WARC Institutional Animal Care and Use Committee standards (IACUC), as well as those approved by the National Marine Fisheries Service (NMFS) (NMFS SEFSC 2008). In 2017, USGS obtained training to get hands-on experience deploying and retrieving nets during 20 minute trawls, ensuring the nets were running properly in the water, safely handling sea turtles captured in nets, safely removing potential hazards from the nets, handling turtles and potential hazards while on board the vessel and while turtles were being processed, sampling and processing samples while on board the vessel, safely returning turtles to the water once sampling was completed, and cleaning and storing the nets and related gear for the night. This training allowed the co-investigators to have trawling added to their list of approved activities on the USGS NMFS permit (#17304) which was then amended, allowing for USGS to contract with a trawling company to perform directed trawling.

1.7 Turtle Sampling

Turtle capture and tagging followed methods identical to those in previous studies (Hart et al., 2013, 2014), and established protocols (NMFS SEFSC 2008) that were approved by the USGS IACUC (USGS/WARC/GNV 2017-04). Each animal was marked with an individual Passive Integrated Transponder (PIT) tag in the right shoulder and uniquely-numbered flipper tags on the trailing-edge of each front flipper. Immediately after marking each animal, standard carapace measurements, including curved (CCL) and straight (SCL) carapace lengths (Hart et al. 2013), were taken. Genetics samples were collected for mitochondrial DNA analyses, and stable isotope samples were collected for examination of diet and resource use. For all turtles, tissue samples were collected from one of the rear flippers, carapace samples were collected from the third lateral scute on the right side using a sterile 6 mm Sklar biopsy punch (Vander Zanden et al. 2010), and 2 ml of whole blood was collected from the dorsal cervical sinus (Owens and Ruiz 1980). Samples were put into individually labeled Corning Cryovials, placed on ice in the field, and then transferred to a -20 °C freezer for storage until later sample processing. A portion of each blood sample was placed onto Flinders Technology Associates (FTA) cards (Whatman, Inc.) and kept dry until processing.

In the lab procedures, tissue and carapace samples were thawed, rinsed with distilled water, and dried at approximately 60 °C for up to 48 hrs. Each sample was then pulverized into a fine powder using a mortar and pestle after first cutting the carapace into smaller pieces with scissors. Whole blood samples were thawed, poured out over glassware, and dried at < 60 °C for at least 24 hrs. They were then scraped off the glassware, and then pulverized with a mortar and pestle to a fine powder. FTA cards were sent directly to the University of Georgia for processing of genetic data.

1.8 Satellite Tracking

Platform transmitter terminals (PTTs) were adhered using slow-curing epoxy (two-part Superbond epoxy) and used several models of Wildlife Computers SPLASH and SPOT tags: SPLASH10-F-296A (15), SPLASH10-F-297A (11), SPLASH10-334E-01 (6), SPLASH10-344D (5), SPLASH10-385C (1), SPOT-293B-00 (6), SPOT-375A-01 (6) (Figure 2). USGS streamlined attachment materials to minimize any buoyancy or drag effects on the turtle's swimming ability and limited the epoxy footprint (see Hart et al. 2021). Tags were set to collect dive data and transmit through the Argos satellite system (Table 1). ln addition to location determination, remote monitoring, and near real time data availability, these tags record dive periods and other sensor data.

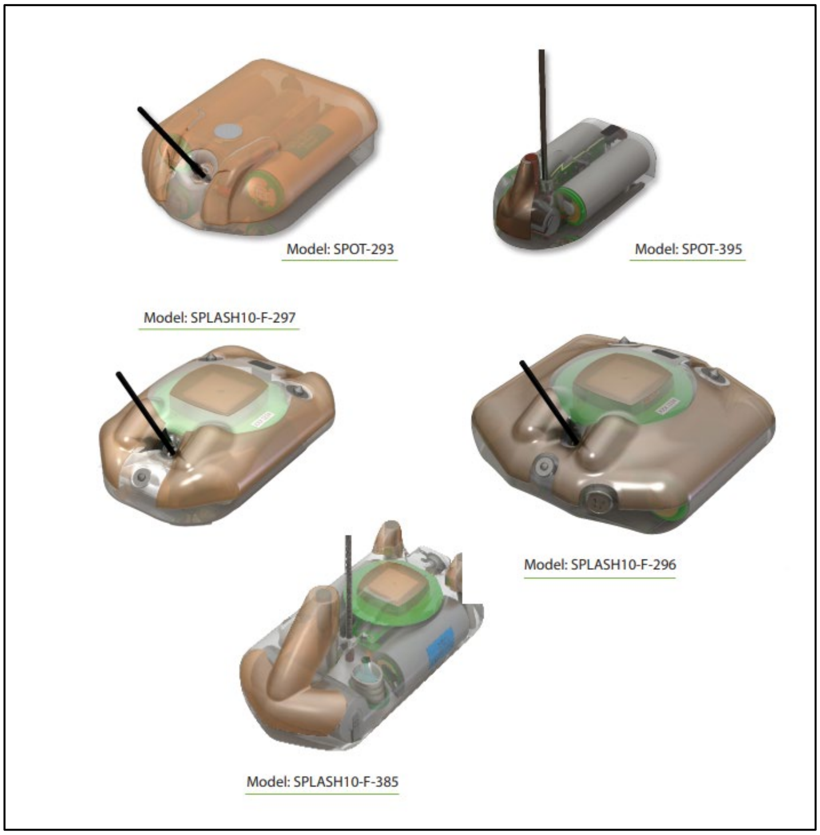


Figure 2. Examples of the Wildlife Computers SPOT and SPLASH tag models used in the study

Table 1. Settings for Wildlife Computer Satellite depth (SPLASH) tags

Data to Archive Settings	
Depth	10 seconds
Internal Temperature	30 seconds
External Temperature	10 seconds
Depth Sensor Temperature	never
Battery Voltage	never
Wet/Dry	never
Wet/Dry Threshold	Dynamic (initial value = 80)
Sampling Mode	Wet or Dry
Automatic Correction of Depth Transducer Drift	disabled
Data to Transmit Settings	
Histogram Selection	
Histogram Data sampling interval	10 seconds
Dive Maximum Depth (m), 12 bins	5; 10; 15; 20; 25; 30; 35; 40; 45; 50; 100; >100
Dive Duration, 14 bins	15 mins ; 30 mins ; 45 mins ; 60 mins ; 90 mins ; 120 mins ; 150 mins ; 180 mins ; 210 mins ; 240 mins ; 270 mins ; 300 mins ; 330 mins ; >330 mins
Time-at-Temperature (C), 14 bins	8; 10; 12; 14; 16; 18; 20; 22; 24; 26; 28; 30; 32; >32
Time-at-Depth (m), 14 bins	0; 1; 2; 3; 4; 5; 10; 20; 30; 40; 50; 100; 150; >150
20-min time-line	disabled
Hourly % time-line (low resolution)	enabled
Hourly % time-line (high resolution)	disabled
Dry/Deep/Neither time-lines	Disabled
PAT-style depth-temperature profiles	enabled with low resolution
Deepest-depth-temperature profiles	disabled
Light-level locations	disabled
Histogram Collection	
Hours of data summarized in each histogram	24
Histograms start at GMT	5:00
Do not create new Histogram-style messages if a tag is continuously dry throughout a Histogram collection period	is disabled
Time-Series Messages	
Generation of time-series messages	is disabled
Dive & Timeline Definition	
Depth reading to determine start & end of dive	1m
Ignore dives shallower than	2m
Ignore dives shorter than	2m
Depth threshold for timelines	Wet/Dry
Behavior Messages	
Generation of behavior messages	is disabled
Stomach Temperature Messages	

Generation of stomach temperature messages	is disabled
Haulout Definition	
A minute is "dry" if Wet/Dry sensor is dry for any ***value*** seconds in a minute	30
Enter haulout state after ***value*** consecutive dry minutes	20
Exit haulout state if wet for any ***value*** seconds in a minute	30
Transmission Control	
Transmit data collected over these last days	7
Pause transmissions if haulout exceeds	never pause
Transmit every eighth day if transmissions are paused	is enabled
Collection days	
January	31-Jan
February	28-Jan
March	31-Jan
April	30-Jan
May	31-Jan
June	30-Jan
July	31-Jan
August	31-Jan
September	30-Jan
October	31-Jan
November	30-Jan
December	31-Jan
Relative transmit priorities	
Histogram, Profiles, Time-lines, Stomach Temperature	med (2 transmission(s))
Fastloc and Light-level Locations	none (0 transmission(s))
Behavior and Time-Series	none (0 transmission(s))
Status	Every 20 transmissions
When to Transmit Settings	
Initially transmit for these hours regardless of settings below	24
Transmit hours	0–2, 10–16, 22, 23
Transmit days	
January	31-Jan
February	28-Jan
March	31-Jan
April	30-Jan
May	31-Jan
June	30-Jan
July	31-Jan
August	31-Jan
September	30-Jan
October	31-Jan

November	30-Jan
December	31-Jan
Daily Transmit Allowance	
January	200 [Accumulate, Optimize for battery life]
February	200 [Accumulate, Optimize for battery life]
March	200 [Accumulate, Optimize for battery life]
April	200 [Accumulate, Optimize for battery life]
May	200 [Accumulate, Optimize for battery life]
June	200 [Accumulate, Optimize for battery life]
July	200 [Accumulate, Optimize for battery life]
August	200 [Accumulate, Optimize for battery life]
September	200 [Accumulate, Optimize for battery life]
October	200 [Accumulate, Optimize for battery life]
November	200 [Accumulate, Optimize for battery life]
December	200 [Accumulate, Optimize for battery life]

2.4.1 GIS Interpretation

Geographic information system (GIS) integration of habitat data and matching location data have proven effective for analyzing marine animal habitat-use patterns (Castelblanco-Martinez et al. 2012). With the addition of onboard readings from time-depth recorders, or salinity and temperature sensors, as well as movement modeling (switching state-space modeling or SSM, see Jonsen et al. 2005), the activity of sea turtles can be categorized into behavior types such as foraging, travelling, resting, or other types (see Hart et al. 2013, 2014). In recent years, habitat modeling has progressed (see Fujisaki et al. 2020) and more sea turtles using the GOM as foraging habitat have been documented (see Hart et al. 2021), along with delineation of migratory corridors (Shaver et al. 2016, Iverson et al. 2020). GIS analysis was used to delineate the areas used by turtles tagged within this study. Depth data was extracted for those turtles equipped with depth-logging tags.

One analysis centered on a subset of 26 turtles captured during relocation trawling at two capture sites in the northern GOM (Ship Shoal and Pensacola). These results are separated specifically to show spatial clustering of home ranges as well as time to return to capture sites that were near or in borrow areas.

For analyses, location data was retrieved using the Wildlife Computers portal and switching state-space modeling was performed in R using the bsam package (see below). For home range analyses, locations requiring swim speeds >5 kph or turning angles < 25º, and those with LC Z (locations failing Argos plausibility tests) were filtered out. Locations were filtered further in ArcGIS 10.4 (ESRI 2016), deleting locations either on land or in water with > 200 m depth, which is the limit of the neritic zone. Hawkes et al. (2011) found that adult female loggerheads did not generally leave the waters of the continental shelf (within -200 m) in the southeast US and previous tracking studies of Kemp's ridleys show they stay primarily within waters with depths up to -100 m (Fritts et al. 1983; Shaver and Rubio 2008; Seney and Landry 2011). To determine bathymetry, we used the National Oceanic and Atmospheric Administration

(NOAA) National Geophysical Data Center (GEODAS) ETOPO1, 1 arc-minute global relief model of Earth's surface[4]. The GIS projection was NAD83.

Site fidelity was calculated using the software program RStudio, version 0.99.893 (R Core Team 2017) and the package adehabitatLT (Calenge 2006). This test compares an animal's movement trajectory to a set of randomly generated tracks. The R-squared and linearity value for the true trajectories were compared to the distribution of R-squared and linearity values of the random replicates. Random walks were constrained to realistic possible movements for turtles; we set the bounds from −200 m to 0 m, but smoothed this with a 5 km inland buffer to account for numerous small bays along the coast, and to allow for the generation of random walks in close proximity to land. Tracks exhibiting site fidelity indicate movements that are not randomly dispersed but are more spatially constrained (Hooge et al. 2001); turtle tracks were defined as non-random and therefore show site fidelity if the probability that the track was more constrained than a random walk was > 0.95.

1.8.2 Bayesian Switching State Space Movement Models (SSMs) for Argos Data

Varying accuracy and precision, and unevenness in space and time of telemetry data can affect the determination of distribution, habitat use and behavioural patterns of animals and therefore bias the calculation of reslting movement metrics (Silva et al. 2014). Advanced statistical methods are necessary to account for spatial error and temporal irregularity in the data and to understand the movement behaviour of the tracked animals. The raw sea turtle tracking data was used to fit a Bayesian hierarchical movement model with behavioral-state switching implemented in the R package 'bsam' (Jonsen et al. 2005, Jonsen 2016). This regularized the data locations in time and accounted for location error. This hierarchical SSM is similar to the model of Jonsen et al. (2005), but jointly estimates the movement parameters that define the behavioral states across all individuals, thus improving the behavioral state estimation. SSMs were fit using Markov chain Monte Carlo (MCMC) parameters that followed our previous studies (Hart et al. 2012), including adaptive sampling (burn-in) for 7,000 samples, then 10,000 samples from the posterior distribution. A time step of one day was used to reduce the autocorrelation. This also allowed USGS to assign a spatial location to the dive data, because not all depth tags record spatial location, by matching the dive data to the SSM output by the animal's unique tag ID. Additionally, as part of the analysis, tag duration was examined for each turtle before any further analysis on movement or dive behavior to ensure that only those tags with sufficient data were used.

1.8.3 Home Ranges

USGS identified one or more areas of disproportionately heavy use within each turtle's home-range boundary using Kernal Density Estimate (KDE) analysis, a non-parametric method with appropriate weighting of outlying observations (Worton 1987, 1989; White and Garrott 1990). The software program R and the package 'adehabitatHR' (Calenge 2006) were used to calculate KDEs. Fixed-kernel least squares cross-validation smoothing factor *(h*cv; Worton 1995; Seaman and Powell 1996) was applied. Before home range calculations, data was re-scaled when the standard deviations of the *x* and *y*

[4] For more information about the model, see http://www.ngdc.noaa.gov/m,gg/geodas/geodas.html; accessed 26 January 2012.

coordinates were unequal (<0.5 or >1.5) by dividing the coordinates by their standard deviation (following Seaman and Powell 1996). The overall home range was represented with 95% KDEs and the core area of activity with 50% KDEs (Hooge et al. 2001).

As input for KDEs, mean daily locations (MDLs) were generated from the filtered satellite locations using the software program RStudio, version 0.99.893 (R Core Team 2017). For tracks with less than 20 MDLs or that did not pass site fidelity tests, 95% minimum convex polygons (MCPs) were created, instead of KDEs. USGS followed Walcott et al. (2012) and chose to use 95% MCPs because it is possible for a proportion of distant filtered locations to represent infrequent movements or explorations external to the home range (sensu Burt 1943; Rodgers and Kie 2011).

ArcGIS™ 10.4 (ESRI 2016) was used to plot the data and to calculate the area (km^2) within each kernel density contour and each MCP. Centroid locations were created from 50% KDE contours and MCPs; if a 50% KDE had multiple activity centers, only the largest activity center was used. Bathymetry values were extracted at all centroids and the distance from each centroid to the nearest land.

To better understand the dynamics of the sea turtle relocations, and whether turtles return to their capture locations or remain near release locations, ArcGIS™ 10.4 (ESRI 2016 was used to calculate the distance 1) between capture and release locations, 2) from each turtle's capture and release locations to the closest edge of their 95% KDE, and 3) from each turtle's capture and release location to their centroid. For turtles that returned and/or remained within 2 km of their capture or release location, the number of days between capture/release was determined and establishing residency in their home range (first date of KDE/MCP). Borrow Areas were also evaluated to see how many home ranges intersected their boundaries.

Hart et al. (2015) suggested that loggerheads foraging in the Bahamas may establish distinct territories as residence areas showed minimal overlap. To investigate that here, the distance from each centroid was calculated to its nearest same-species neighbor for both loggerheads and Kemp's ridleys.

1.8.4 Dives

Dive frequency may indicate behaviors such as resting or foraging, with longer dives at night indicating resting and shorter dives during the day indicating foraging (Godley et at. 2003; Dalleau et al. 2014). Tags that collect dive information have three components: dive duration, maximum depth, and time at depth. For each unique turtle ID, we calculated the proportion of time spent in each pre-defined depth zone. ; histogram zones for time-at-depth were set to 0, 1, 2, 3, 4, 5, 10, 20, 30, 40, 50, 100, and 150 m (Table 1). Tags were programmed to collect data for a full 24-hour period and summarize all data every 12 hours.

Boxplots for dive depth were created using geom_boxplot (R package ggplot2[5]), lower and upper hinges were plotted; these correspond to the first and third quartiles (25th and 75th percentiles). The upper whisker extends from the hinge to the largest value no further than 1.5 * inter-quartile range (IQR) from the hinge. The IQR is the distance between the first and third quartiles. The lower whisker extends from

[5] See package documentation at https://ggplot2.tidyverse.org/reference/geom_boxplot.html

the hinge to the smallest value at most 1.5 * IQR of the hinge. Data beyond the end of the whiskers are called "outlying" points and are plotted individually (black dots).

To examine the proportion of dives across zones (bins), a calculation was performed to divide the number of dives in each bin by the total number of dives across all bins. Before this, dives were characterized by behavioral mode (area restricted search (ARS)/foraging or migration/transiting). For example, if a turtle had 100 dives split across 5 depth bins, the number of dives would be divided by 100 in order to get a proportion; this was done for foraging (ARS) dives and migration (transit) dives separately, reflected in the different colors on the plot. There were 26 proportion values for the 26 turtles with dive data from the depth-logging tags; the boxplots were then created of the 26 values showing the median and IQRs. The dots are outliers and can be interpreted as those turtles with a higher or lower proportion value for that dive bin than what is plotted for the other turtles. In addition to behavioral mode, analyses were performed these operations using species and month.

Time-at- depth (TAD) was calculated as a percent of time a turtle was in each bin over each 24-hour period. First, the percentages were converted into proportions by simply dividing by 100. Then, an overall mean proportion value was calculated for each bin across all the dates the turtle was tracked. For example, if a turtle had a single value per bin across its entire tracking period (but really one for each mode though since also split by modes), this value would be the mean proportion of time that turtle spent in each bin (that is, the average across all tracking days, which each had the percent of time for that day for each bin). Then, boxplots were created that included all turtles' values for each bin.

The proportions of time turtles spent at the surface was also summarized. The surface of the water is defined as the top two meters of the water column. Therefore, the total proportion of time spent in the top three zones or "bins" for each dive observation was calculated. This information was then used to examine patterns across species, sex, behavioral state, season, and spatial location.

1.9 Genetic analysis

Samples were sent to the University of Georgia for mitochondrial DNA analyses. DNA extractions, polymerase chain reaction (PCR) amplifications, and sequencing was conducted as previously described in Section 2.2.1 (Shamblin et al. 2012). In brief, a fragment of the mitochondrial control region approximately 850 base pairs long was amplified using primers LCM16382 and H950. The control region represents the most variable region of the mitochondrial genome in marine turtles, so it is useful for characterizing population boundaries and migratory connectivity. These resulting fragments were sequenced in a single direction using the forward PCR primer and an internal sequencing primer, Cc271. The resulting loggerhead sequences were compared to the Atlantic loggerhead turtle haplotype database maintained by the Archie Carr Center for Sea Turtle Research for haplotype assignment. Resulting Kemp's ridley sequences were compared to NOAA's database maintained by the Southwest Fisheries Science Center's marine turtle genetics group. The resulting haplotype profiles were compared with available data from nesting populations in the region.

1.10 Isotope analysis

Isotope samples were prepared in USGS labs in Davie and Gainesville, Florida. Samples were thawed, rinsed with distilled water, and each flipper tissue sample dried at approximately 60 °C for up to 48 hrs, and then pulverized each one to a fine powder using a mortar and pestle. Carapace samples rinsed with distilled water, dried each one at ~60 °C for up to 48 hrs, cut each one into smaller pieces with scissors, and then ground them to a fine powder. Whole blood samples were thawed, poured out over glassware, and dried at < 60 °C for at least 24 h, scraped off the glassware, and then pulverized with a mortar and pestle to a fine powder. Each sample was weighed into 5x9 mm pressed tin capsules, sealed, and sent to the Bioanalytical Laboratory at University of California, Davis to be analyzed for isotopic values of carbon (referenced to Vienna PeeDee Belemnite) and nitrogen (referenced to atmospheric N_2; Peterson and Fry 1987). Standard analyses were conducted using an elemental analyzer connected to a Finnegan MAT Delta-S stable isotope ratio mass spectrometer via a Finnigan MAT ConFlo II interface. Reproducibility was monitored using organic reference standards and bovine liver (animal tissues). Results were plotted by species, sex, location, and sample type.

Results

1.11 Data Collection and Tag Deployment Schedule

Over the course of the project, the US Geological Survey (USGS) tagged and sampled 50 turtles (26 loggerheads, 24 Kemp's ridleys) with satellite tags funded by the Bureau of Ocean Energy Management (BOEM) (Tables 2 and 3, Figures 1 and 3), and 27 additional turtles that carried tags purchased as part of different projects (Table 4). Mean size of the 50 BOEM turtles captured (Table 3) varied by species and gender. Of the 26 loggerheads, mean size curved carapace length (CCL) of the 22 females was 86.4 cm ± 6.0 Standard Deviation (SD) whereas mean size of males (n = 3) was slightly larger (93.0 cm ± 6.9 SD); these are all adult age class turtles. Also captured was one smaller loggerhead of unknown gender (i.e., immature), which was 68.0 cm SCL. Of the 24 Kemp's ridleys, mean size of the 18 females was 63.6 cm ± 4.6 SD), and the mean size of males (n = 6) was similar (65.2 cm ± 2.8 SD); these again were all adult age class turtles.

Turtles were tagged at both Ship Shoal (n = 2 loggerheads and n = 10 Kemp's ridleys) and the Pensacola site (n = 14 loggerheads; Table 3). Loggerheads in this analysis ranged in size from 78.3 to 101 cm CCL (mean ± SD = 88.3 ± 7.3 cm) and were tracked for 3–192 days (mean ± SD = 100.8 ± 56.1 d) for a total of 1612 tracking days. Kemp's ridleys ranged in size from 59.5 to 70.5 cm CCL (mean ± SD = 65.5 ± 3.6 cm) and were tracked for 76–117 days (mean ± SD = 100.1 ± 15.2 d) for a total of 1001 tracking days.

Table 2. Summary of satellite and depth tags) deployed on turtles captured during ongoing relocation or USGS directed trawling in the northern GOM, May 2016–May 2019

Date	Location	Project	# BOEM Tags Deployed
May-June 2016	Ship Shoal, LA	Caminada Relocation Trawling	12
July 2016	Pensacola, FL	Pensacola Relocation Trawling	14
Jan/Feb 2018	Chandeleur Islands and Ship Shoal, LA	USGS Directed Trawling	1
Aug-Sept-Oct 2018	Pascagoula, MS	MSCIP Relocation Trawling	15
May 2019	Ship Shoal, LA	USGS Directed Trawling	8
TOTAL			50

Table 3. Summary of all turtles captured through relocation or USGS directed trawling in the northern GOM, May 2016–May 2019 that received a BOEM funded satellite (SPOT) or depth-logging (SPLASH) satellite tag

#	Capture Date	Species	RF Flipper Tag	Sex	CCL (cm)	Sat. Tag #	Tag Model	End Tracking Date	Tracking Duration (Days)	Capture Location
1	6/4/2016	CC	UUS161	F	86.3	154834	SPLASH10-F-296A	10/13/2016	131	Ship Shoal, LA
2	6/23/2016	CC	UUS170	F	82.8	154839	SPLASH10-F-296A	1/4/2017	195	Ship Shoal, LA
3	7/21/2016	CC	MMC759	F	88.6	154841	SPLASH10-F-296A	12/11/2016	143	Pensacola, FL
4	7/21/2016	CC	MMC757	F	78.3	161454	SPLASH10-F-297A	7/23/2016	2	Pensacola, FL
5	7/21/2016	CC	MMC761	F	83.0	161464	SPLASH10-F-297A	11/8/2016	110	Pensacola, FL
6	7/22/2016	CC	MMC763	M	89.6	154842	SPLASH10-F-296A	11/20/2016	121	Pensacola, FL
7	7/22/2016	CC	MMC766	F	99.2	154845	SPLASH10-F-296A	10/18/2016	88	Pensacola, FL
8	7/22/2016	CC	LLY494	F	97.6	161456	SPLASH10-F-297A	8/18/2016	27	Pensacola, FL
9	7/24/2016	CC	MMC769	F	100.5	154843	SPLASH10-F-296A	11/28/2016	127	Pensacola, FL
10	7/25/2016	CC	MMC771	M	101.0	154837	SPLASH10-F-296A	12/2/2016	130	Pensacola, FL
11	7/25/2016	CC	MMC774	F	83.6	161457	SPLASH10-F-297A	10/16/2016	83	Pensacola, FL
12	7/25/2016	CC	MMC773	F	80.9	161460	SPLASH10-F-297A	10/8/2016	75	Pensacola, FL
13	7/26/2016	CC	MMC777	F	85.1	161463	SPLASH10-F-297A	9/7/2016	43	Pensacola, FL
14	7/26/2016	CC	MMC781	F	85.7	161465	SPLASH10-F-297A	8/5/2016	10	Pensacola, FL
15	7/26/2016	CC	MMC779	F	82.3	161467	SPLASH10-F-297A	5/3/2017	281	Pensacola, FL
16	7/27/2016	CC	MMC783	M	88.5	154838	SPLASH10-F-296A	2/25/2017	213	Pensacola, FL
17	2/1/2018	CC	BSC2004	F	87.0	171519	SPLASH10-334E-01	10/14/2018	255	Ship Shoal, FL

#	Capture Date	Species	RF Flipper Tag	Sex	CCL (cm)	Sat. Tag #	Tag Model	End Tracking Date	Tracking Duration (Days)	Capture Location
18	8/31/2018	CC	MMX297	F	88.6	171516	SPLASH10-334E-01	2/1/2019	154	Pascagoula, MS
19	9/9/2018	CC	MMX907	F	83.9	171517	SPLASH10-334E-01	5/22/2019	255	Pascagoula, MS
20	10/4/2018	CC	MMW950	F	82.0	171515	SPLASH10-334E-01	5/13/2019	221	Pascagoula, MS
21	10/5/2018	CC	KKH802	F	89.0	171520	SPLASH10-334E-01	1/18/2019	105	Pascagoula, MS
22	5/7/2019	CC	BSC1256	UNK	68.0	176814	SPLASH10-344D	10/25/2019	171	Ship Shoal, LA
23	5/8/2019	CC	BSC1608	F	84.0	176815	SPLASH10-344D	9/23/2019	138	Ship Shoal, LA
24	5/8/2019	CC	BSC1610	F	78.5	181766	SPOT-375A-01	10/24/2019	169	Ship Shoal, LA
25	5/9/2019	CC	BSC1676	F	88.0	176817	SPLASH10-344D	5/9/2019	1	Ship Shoal, LA
26	5/13/2019	CC	BSC1258	F	85.0	181292	SPLASH10-385C	10/25/2019	165	Ship Shoal, LA
27	5/18/2016	LK	UUS146	M	66.5	161461	SPLASH10-F-297A	9/11/2016	116	Ship Shoal, LA
28	5/19/2016	LK	UUS137	F	67.9	154846	SPLASH10-F-296A	9/6/2016	110	Ship Shoal, LA
29	5/19/2016	LK	UUS135	F	59.5	161458	SPLASH10-F-297A	9/3/2016	107	Ship Shoal, LA
30	5/21/2016	LK	UUS142	F	70.5	154835	SPLASH10-F-296A	9/14/2016	116	Ship Shoal, LA
31	5/21/2016	LK	UUS139	M	64.9	154844	SPLASH10-F-296A	8/6/2016	77	Ship Shoal, LA
32	5/22/2016	LK	UUS144	F	64.4	154847	SPLASH10-F-296A	9/9/2016	110	Ship Shoal, LA
33	5/23/2016	LK	UUH366	M	69.5	154840	SPLASH10-F-296A	8/30/2016	99	Ship Shoal, LA
34	6/8/2016	LK	UUS162	M	61.7	154833	SPLASH10-F-296A	9/6/2016	90	Ship Shoal, LA
35	6/9/2016	LK	UUS164	F	62.2	161462	SPLASH10-F-297A	9/9/2016	92	Ship Shoal, LA

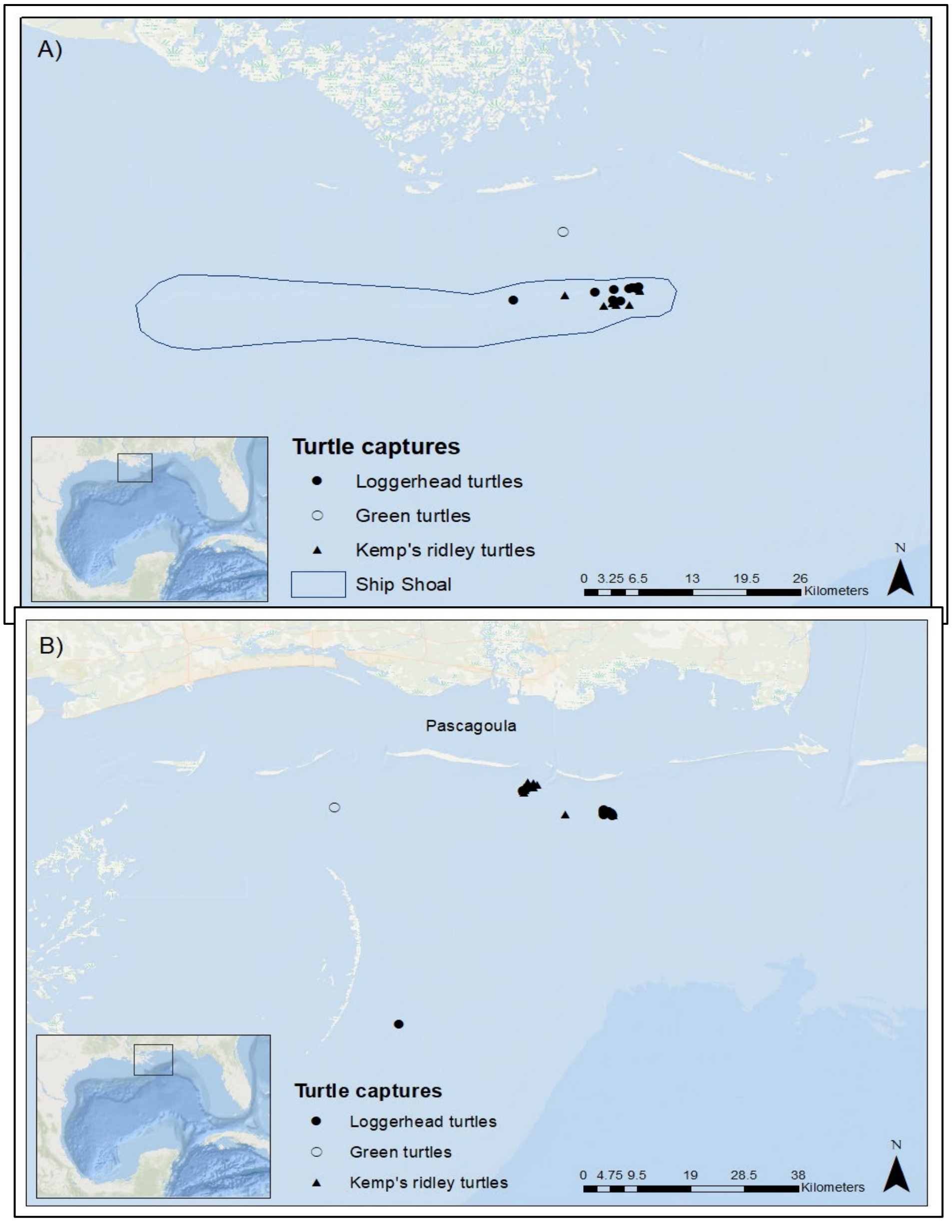
#	Capture Date	Species	RF Flipper Tag	Sex	CCL (cm)	Sat. Tag #	Tag Model	End Tracking Date	Tracking Duration (Days)	Capture Location
36	6/22/2016	LK	UUS168	F	68.0	154836	SPLASH10-F-296A	9/5/2016	75	Ship Shoal, LA
37	9/2/2018	LK	MMX983	F	67.0	176809	SPOT-375A-01	5/5/2019	245	Pascagoula, MS
38	9/7/2018	LK	MMX985	F	62.6	171512	SPOT-293B-00	1/24/2019	139	Pascagoula, MS
39	9/8/2018	LK	MMX905	M	65.8	171518	SPLASH10-334E-01	10/31/2018	53	Pascagoula, MS
40	9/8/2018	LK	MMX991	F	69.1	172260	SPOT-293B-00	11/15/2018	68	Pascagoula, MS
41	10/2/2018	LK	MMW948	F	62.3	171513	SPOT-293B-00	2/25/2019	146	Pascagoula, MS
42	10/4/2018	LK	MMW962	F	56.5	171511	SPOT-293B-00	7/6/2019	275	Pascagoula, MS
43	10/4/2018	LK	MMZ914	F	59.2	171514	SPOT-293B-00	5/26/2019	234	Pascagoula, MS
44	10/5/2018	LK	MMW964	F	64.9	172259	SPOT-293B-00	12/11/2018	67	Pascagoula, MS
45	10/5/2018	LK	MMW916	F	68.5	176810	SPOT-375A-01	2/7/2019	125	Pascagoula, MS
46	10/15/2018	LK	KKH809	F	60.5	176811	SPOT-375A-01	5/20/2019	217	Pascagoula, MS
47	10/15/2018	LK	KKH813	F	53.5	176812	SPOT-375A-01	4/4/2019	171	Pascagoula, MS
48	5/7/2019	LK	BSC1606	F	62.8	181765	SPOT-372A-01	10/25/2019	171	Ship Shoal, LA
49	5/9/2019	LK	BSC1614	F	66.0	176816	SPLASH10-344D	8/1/2019	84	Ship Shoal, LA
50	5/14/2019	LK	BSC1264	M	62.5	176818	SPLASH10-344D	8/22/2019	100	Ship Shoal, LA

Table 4. Summary of sea turtle captures that did not receive a satellite tag or had a non-BOEM funded satellite tag attached

Sources of funding for these tags was GOMMAPPS, Gulf of Mexico Marine Assessment Program for Protected Species, which is funded by BOEM [NSL # GM-16-09d], the US National Park Service [NPS], or other USGS Proirity Ecosystem Science funds. Note turtle in bold previously captured and tagged by USGS at Port Fourchon, Louisiana (first capture 5/6/15, then recaptured 12/8/15, SCL-t 29.3 cm, then 33.4 cm).

#	Capture Date	Species	RF Flipper Tag	Sex	CCL (cm)	Sat. Tag #	Tag Model	Capture Location	Tag Funding
1	1/25/2018	CC	BSC2002	F	81.2	172681	SPOT6	Chandeleurs, LA	GOMMAPPS
2	10/6/2018	CC	KKH803	UNK	62.2	175694	SPLASH10-F-297A	Pascagoula, MS	GOMMAPPS
3	10/16/2018	CC	MMX920	F	84.9	175697	SPLASH10-238Q	Pascagoula, MS	GOMMAPPS
4	10/19/2018	CC	MMW967	F	64.1	172669	SPLASH10	Pascagoula, MS	GOMMAPPS
5	5/9/2019	CC	BSC1678	F	77.3	181768	SPOT-375A-01	Ship Shoal, LA	USGS
6	5/13/2019	CC	BSC1260	UNK	69.9	175691	SPLASH10-F-297A	Ship Shoal, LA	GOMMAPPS
7	5/16/2019	CC	BSC1222	F	88.2	NA	NA	Ship Shoal, LA	NA
8	1/28/2018	CM	KMH974	UNK	33.5	NA	NA	Chandeleurs, LA	NA
9	**2/2/2018**	**CM**	**KMH812**	**UNK**	**45.6**	**NA**	**NA**	**Ship Shoal**, LA	**NA**
10	9/8/2018	LK	MMX987	F	60.2	172673	SPLASH10-238Q	Pascagoula, MS	GOMMAPPS
11	9/8/2018	LK	MMX989	F	67.1	175693	SPLASH10-F-297A	Pascagoula, MS	GOMMAPPS
12	9/9/2018	LK	MMX995	F	68.2	172666	SPLASH10	Pascagoula, MS	GOMMAPPS
13	9/9/2018	LK	MMX993	F	66.8	172675	SPLASH10-238Q	Pascagoula, MS	GOMMAPPS
14	10/6/2018	LK	MMW923	F	58.4	175695	SPLASH10-F-297A	Pascagoula, MS	GOMMAPPS
15	10/15/2018	LK	KKH815	F	66.5	172674	SPLASH10-238Q	Pascagoula, MS	GOMMAPPS
16	10/15/2018	LK	KKH811	F	58.0	175696	SPLASH10-238Q	Pascagoula, MS	GOMMAPPS
17	10/16/2018	LK	KKH817	F	60.9	NA	NA	Pascagoula, MS	NA
18	10/17/2018	LK	KKH821	F	67.3	172041	KiwiSat 202	Pascagoula, MS	NPS

#	Capture Date	Species	RF Flipper Tag	Sex	CCL (cm)	Sat. Tag #	Tag Model	Capture Location	Tag Funding
19	10/17/2018	LK	MMW921	F	63.0	172045	KiwiSat 202	Pascagoula, MS	NPS
20	10/21/2018	LK	KKH829	F	52.2	172040	KiwiSat 202	Pascagoula, MS	NPS
21	10/21/2018	LK	KKH831	F	56.7	172043	KiwiSat 202	Pascagoula, MS	NPS
22	10/21/2018	LK	KKH833	F	65.7	172046	KiwiSat 202	Pascagoula, MS	NPS
23	5/9/2019	LK	BSC1612	UNK	55.5	181767	SPOT-375A-01	Ship Shoal, LA	USGS
24	5/13/2019	LK	BSC1680	F	68.2	172042	KiwiSat 202	Ship Shoal, LA	NPS
25	5/13/2019	LK	BSC1240	F	65.6	172044	KiwiSat 202	Ship Shoal, LA	NPS
26	5/16/2019	LK	BSC1236	F	62.6	NA	NA	Ship Shoal, LA	NA
27	5/16/2019	LK	BSC1238	F	70.0	NA	NA	Ship Shoal, LA	NA



Figures 3A and 3B. Map of where turtles were captured as part of ongoing relocation and USGS directed trawling: A) Ship Shoal, B) Pascagoula and Chandeleurs

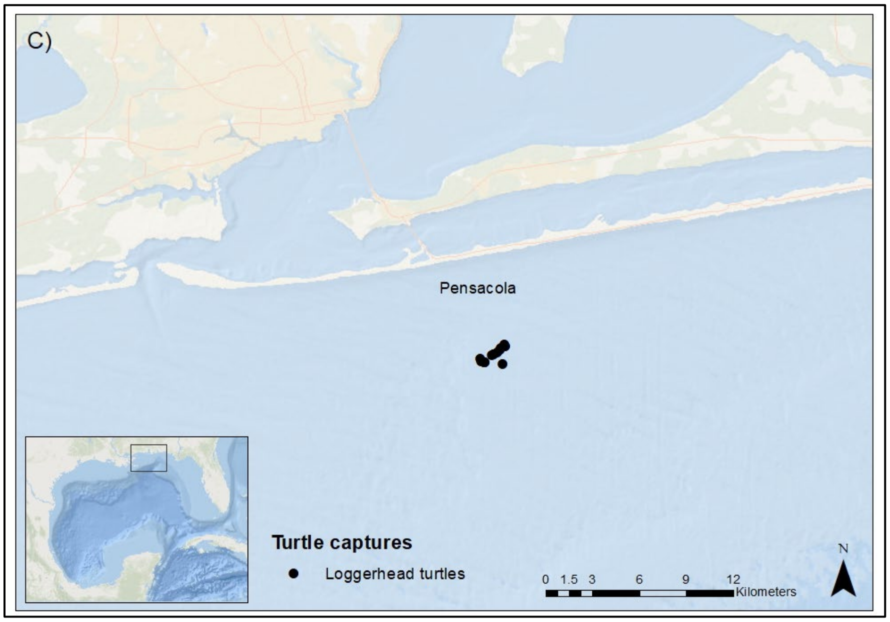
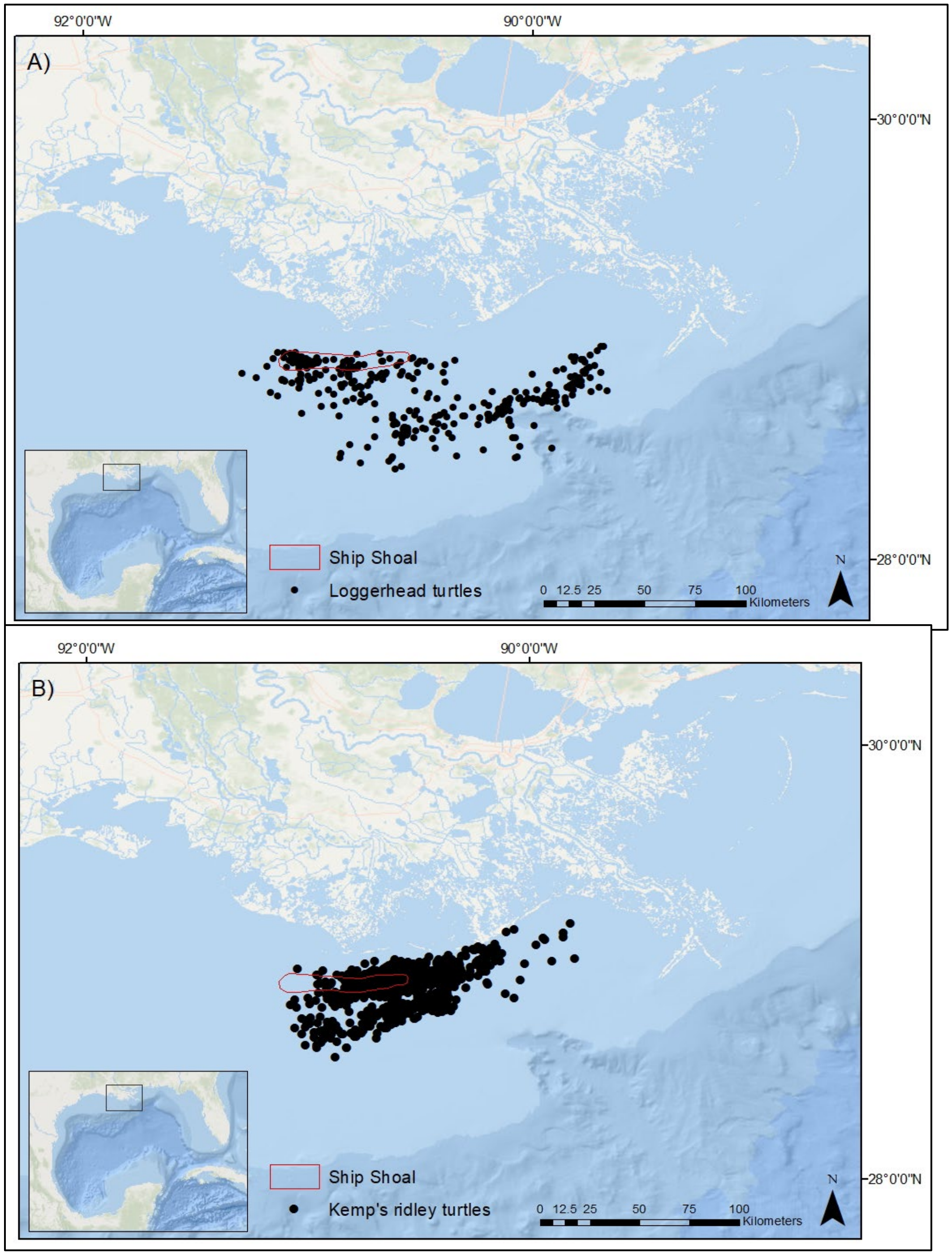


Figure 4C. Map of where turtles were captured as part of ongoing relocation and USGS directed trawling: Pensacola, 2016–2019

1.12 Site-Specific Satellite Tracking

Fieldwork was conducted on multiple research trips. Between 16 May and 24 June 2016, three researchers went on three different trips to join ongoing relocation trawling efforts at the Caminada Headlands Beach and Dune Restoration Project Borrow site off the coast of Louisiana, for a total of 25 field days. During this time, 12 turtles (9 Kemp's ridleys and 3 loggerheads) were outfitted with satellite and depth-logging tags. Standard morphometric measurements and biological samples (blood and tissue) were collected from all turtles (Figure 4; Table 3).



Figures 5A and 4B. Switching State Space Movement Model (SSMs) locations for loggerhead (panel A) and Kemp's ridley (panel B) turtles sampled as a part of relocation trawling within the Caminada Borrow site, May–June 2016

Between 21–28 May 2016, researchers joined ongoing relocation trawling efforts in the Santa Rosa Island Authority project off Pensacola, Florida for a total of 8 field days. During this time, 14 turtles (all loggerheads: 3 males and 11 females) were outfitted with satellite and depth-logging tags. Standard morphometric measurements and biological samples (blood and tissue) were collected from all turtles (Figure 5; Table 3).

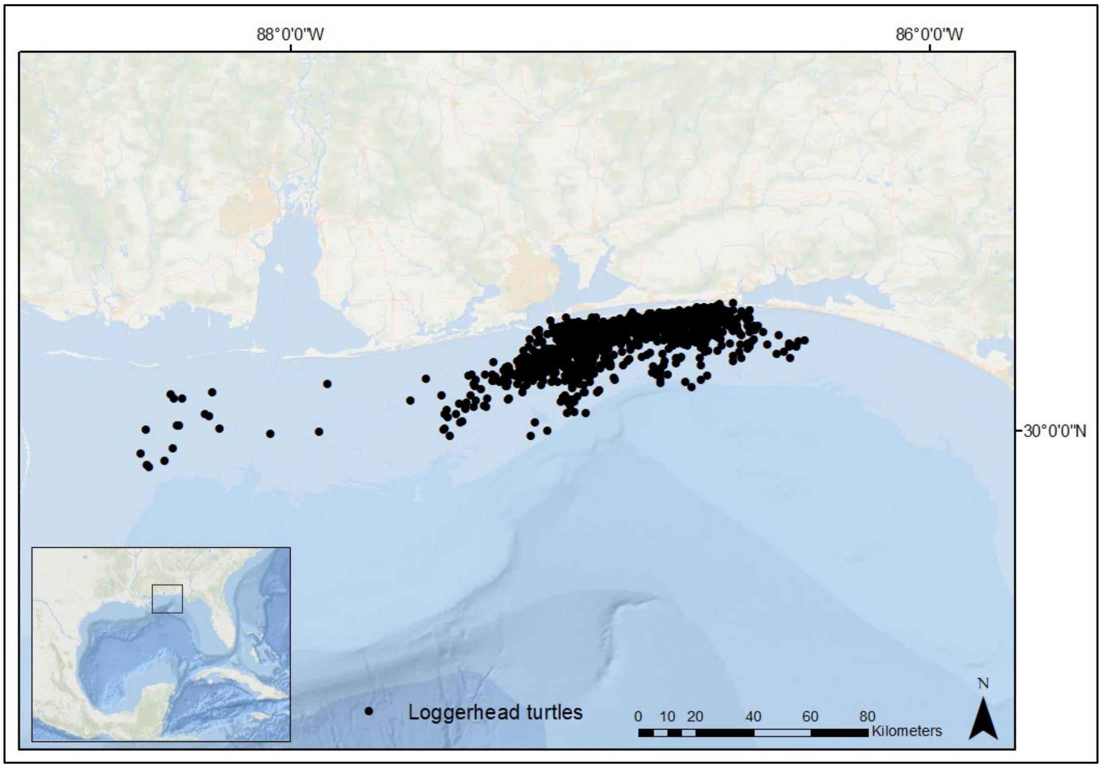
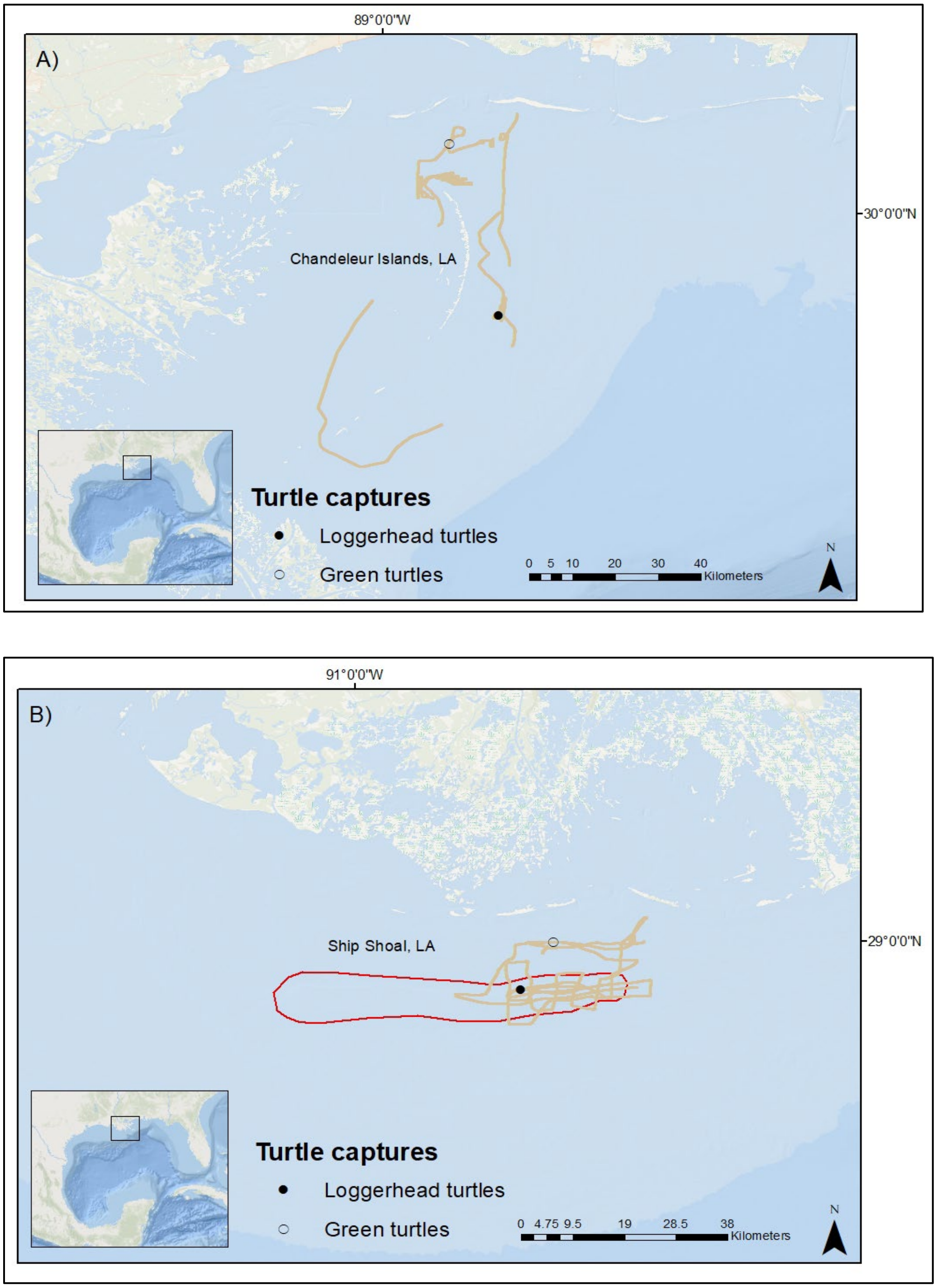


Figure 6. SSMs locations for loggerhead turtles sampled as a part of relocation trawling off the coast of Pensacola, Florida, May 2016

Between 24 January and 5 February 2018, we performed USGS directed trawling in the Chandeleur Islands, Louisiana and Ship Shoal, Louisiana. In the Chandeleur Islands, five full and two half-days of trawling were completed. This included trawling 208.15 km over a 125.41-hour period (Figure 6); two turtles were captured (one loggerhead and one green turtle, Tables 3 and 4). No BOEM tags were deployed off the Chandeluer Islands, because this portion of the trip was funded by a separate grant from the National Fish and Wildife Foundation (NFWF). One tag funded by a separate BOEM-funded project—the Gulf of Mexico Marine Assessment Program for Protected Species (GOMMAPPS) (NSL # GM-16-09d)–was deployed on the loggerhead. In Ship Shoal, we conducted six full days of directed trawling covering over 192.22 km and totaling 120.93 hours (Figure 6). Two turtles (one loggerhead and one juvenile green turtle) were captured and a satellite tag was deployed on the loggerhead (Tables 3 through 4). Note that the juvenile green turtle captured had been previously captured and tagged by USGS on another project at the Belle Pass Jetty in Port Fourchon, Louisiana in May 2015. Standard morphometric measurements and biological samples (blood and tissue) were collected from all turtles (Tables 3 and 4).



Figures 7A and 6B. Maps showing trawling tracks and capture locations

(A) trawling tracks and capture locations of loggerhead and green turtles captured during USGS directed (NFWF funded) trawling in the Chandeleur Islands, Louisiana, January 2018, (B) trawling tracks and capture locations during USGS directed trawling at Ship Shoal, Louisiana, January–February 2018

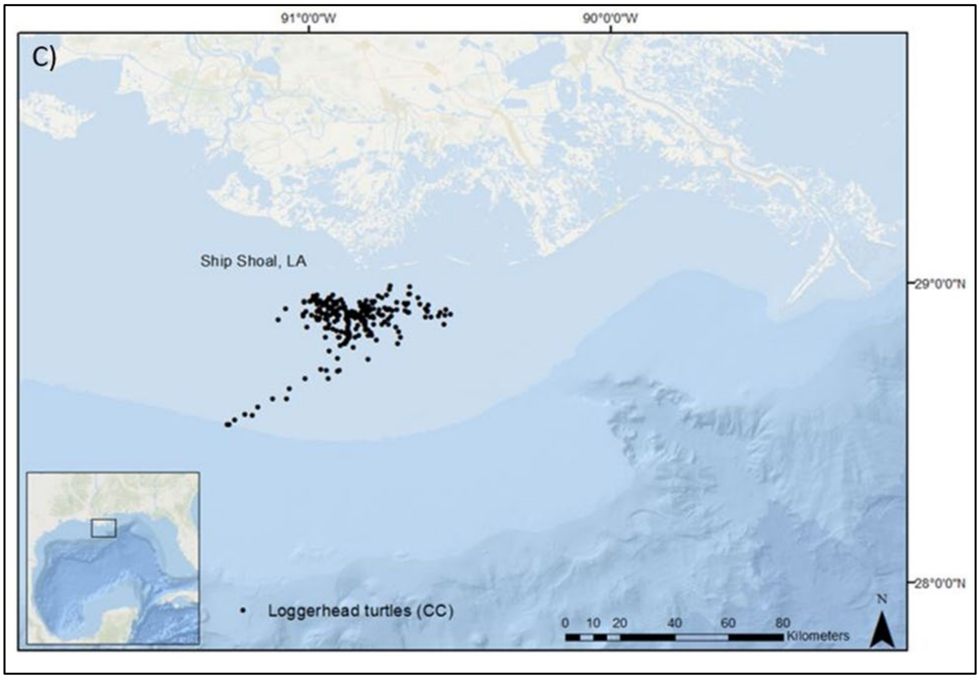
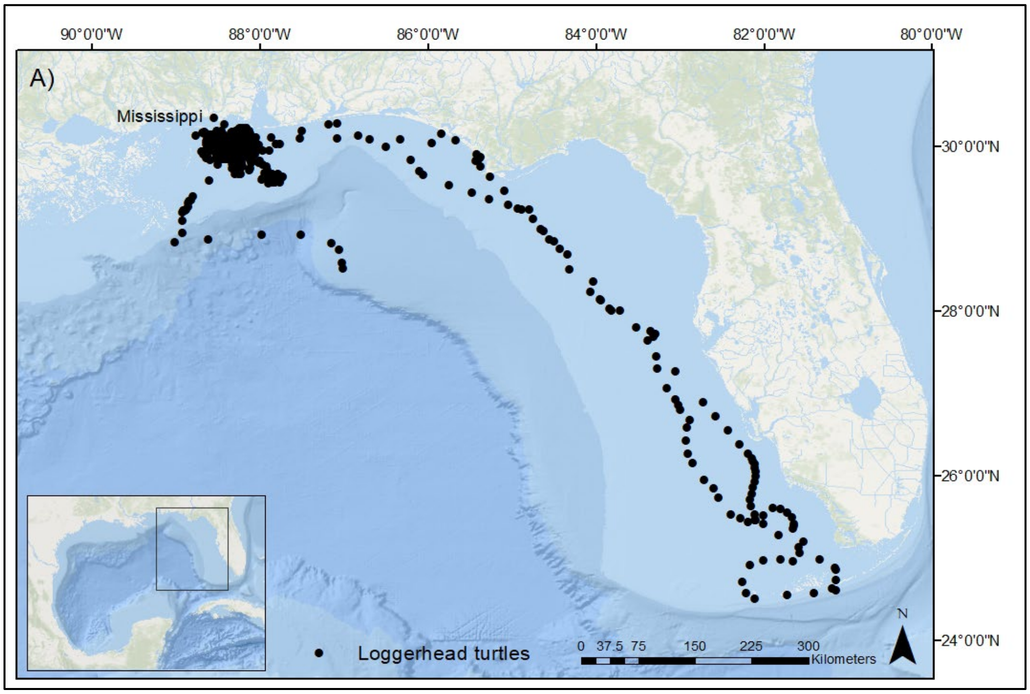
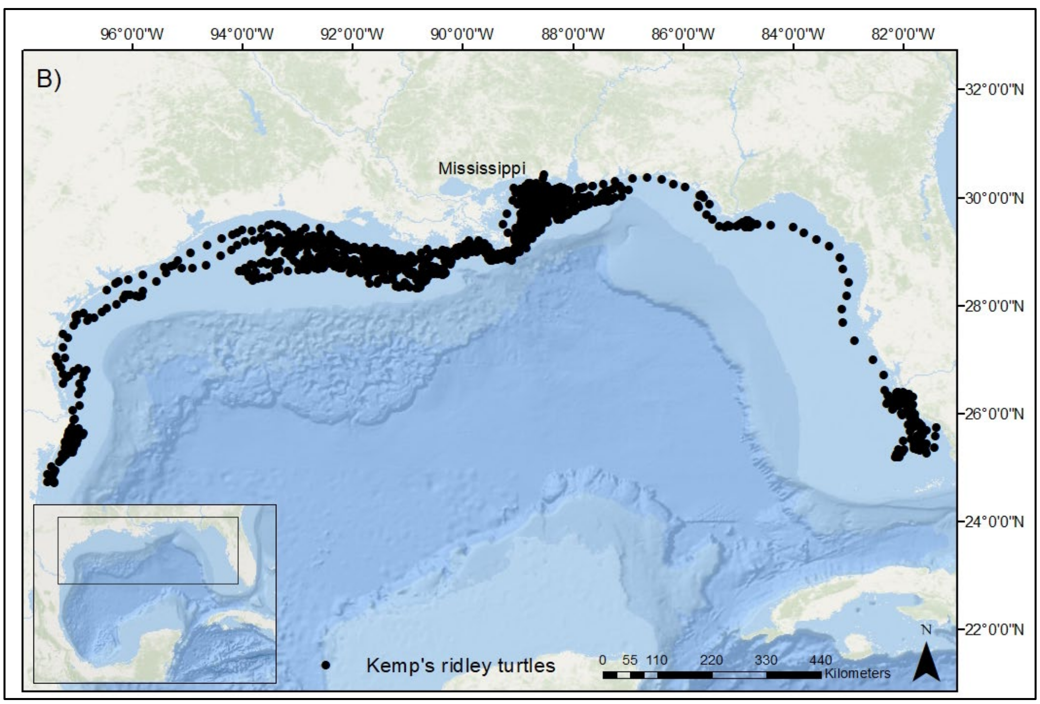


Figure 6C. Map showing SSMs locations for loggerhead turtles captured during USGS directed trawling at Ship Shoal, Louisiana, January–February 2018

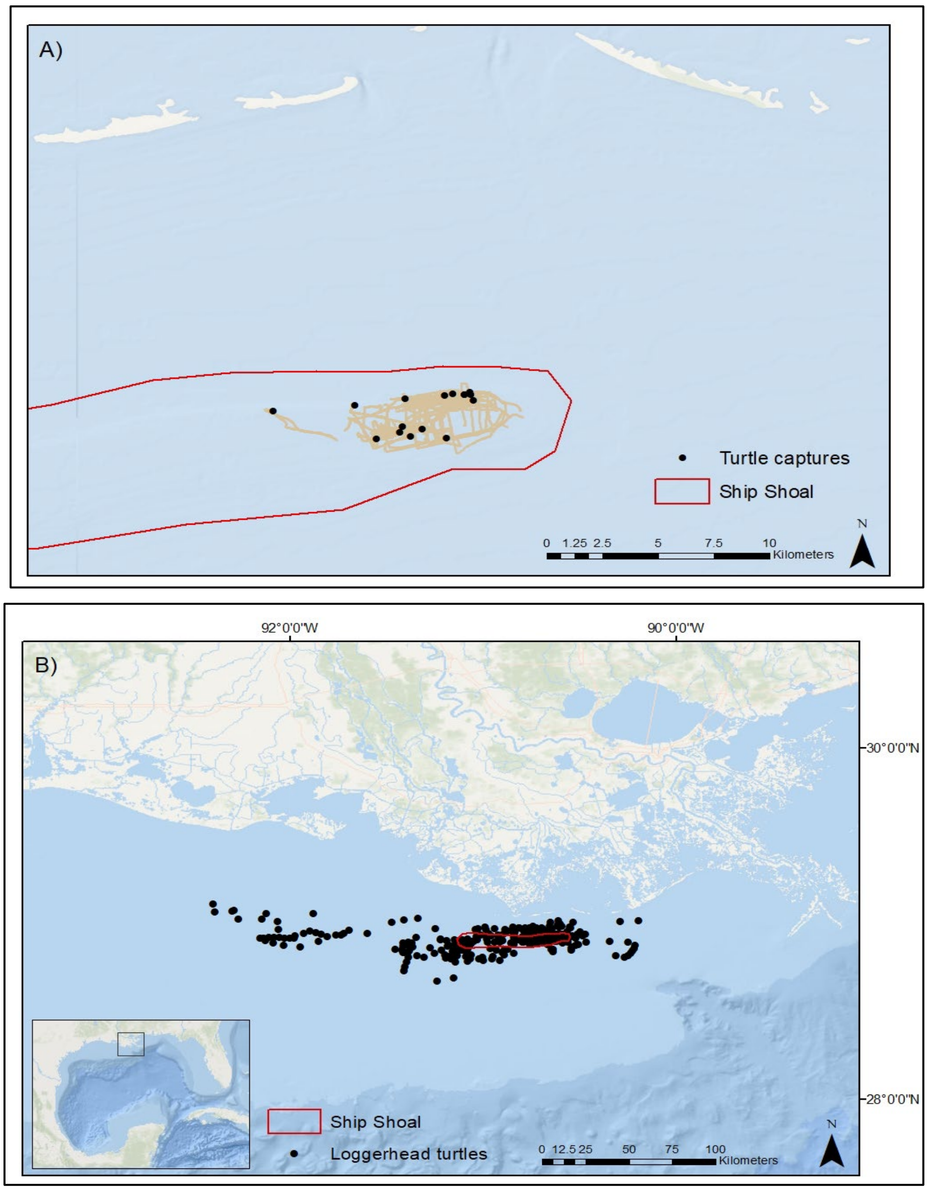
Between 27 August and 21 October 2018, four researchers were ferried out to a relocation trawler on days when trawlers captured at least one turtle offshore of Pascagoula, Mississippi. Over the 14 days total on the water, researchers deployed tags on 15 turtles (11 on Kemp's ridleys and 4 on loggerheads), as well as 15 additional turtles, with tags supported by different funding sources; 10 funded by GOMMAPPS [7 Kemp's ridleys, 3 loggerheads], 5 funded by NPS; all Kemp's ridleys], for a total of 30 satellite tags (see Tables 3 and 4). One additional Kemp's ridley was captured that was not satellite tagged. Standard morphometric measurements and biological (blood and tissue) samples were collected from all turtles (Figure 7; Tables 3 and 4).





Figures 8A and 7B. Maps showing SSMs locations for loggerhead (panel A) and Kemp's ridley (panel B) turtles sampled as a part of relocation trawling off the coast of Mississippi, August–October 2018

Between 6 and 17 of May 2019, USGS conducted directed trawling at Ship Shoal, Louisiana, where six full and three half days of trawling were completed. During this trip, USGS trawled 285.35 km over a 71.41-hour period, where 16 turtles (8 Kemp's and 8 loggerhead) were captured. They deployed a total of 13 tags (8 funded by this project, 1 funded by GOMMAPPS, 2 funded by USGS Priority Ecosystem Studies (PES) funds, and 2 funded by NPS; tags were deployed on 6 Kemp's ridleys and 7 loggerhead turtles. Three turtles were captured but did not have tags attached. Standard morphometric measurements and biological (blood and tissue) samples were collected from all turtles (Figure 8; Tables 3-4). Data collected with USGS and NPS funding are not included in this report.



Figures 9A and 8B. Maps showing trawling tracks and capture locations for all turtles (A), and SSM locations for loggerhead (panel B), May 2019

Ship Shoal is outlined in red.

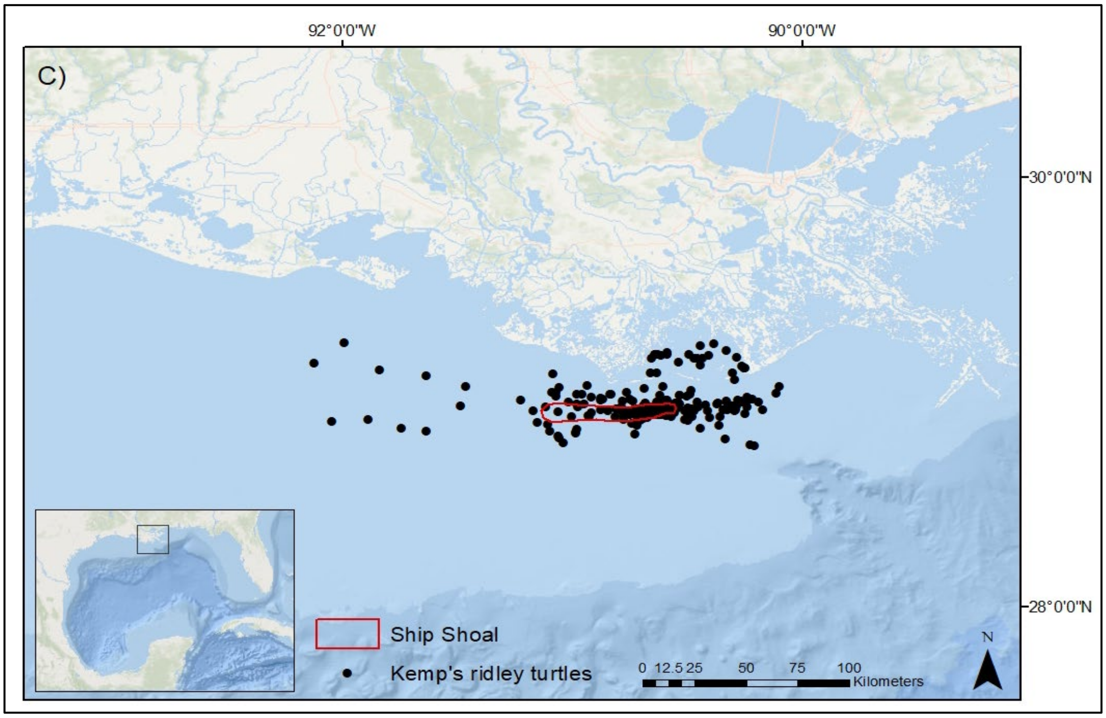


Figure 8C. Maps showing d Kemp's ridley turtles captured and satellite tagged during USGS directed trawling at Ship Shoal, Louisiana, Gulf of Mexico, May 2019

Ship Shoal is outlined in red.

1.12.1 Site Fidelity and Turtle Movements

Both loggerhead and Kemp's ridley release locations were on average 7.3 km from their capture location (Figure 9). Loggerhead home ranges were 0.0 to 6.0 km from capture and release locations; one turtle had a home range that overlapped with the capture location and the other took up residence about 6 km away. Both turtle home ranges overlapped with release locations. Kemp's ridley home ranges (95% KDE) were also on average similar distance to their release locations (4.58 km) as to their capture locations (4.79 km; Figure 10). Those that took up residence within 2 km of capture locations did so usually within a day; those that took up residence within 2 km of the release location did so on average 2.8 days later (range 0–14 days).

All 10 Kemp's ridleys showed site fidelity and all had enough mean daily locations (MDLs) for KDE analysis. We generated a total of 946 MDLs from 5835 filtered locations to use in KDE analysis for Kemp's ridleys. Locations for home ranges covered May–Sept 2016 for a total of 968 days. Overall home ranges (95% KDEs) ranged from 89.21–1902.04 km^2 (mean $\pm$ SD = 1067.73 $\pm$ 582.05 km^2) and core-use areas (50% KDEs) ranged from 14.53– 78.68 km^2 (mean $\pm$ SD = 234.2 $\pm$ 126.9 km^2; Figure 10). KDE centroids were in waters with an average depth of -12.2 m and were on average 18.4 km from shore (Figure 11). Eight of the ten Kemp's ridleys home ranges intersected the Louisiana Borrow Area.

The two loggerheads at Ship Shoal both displayed site fidelity and had enough MDLs for KDE analysis. From 1278 filtered locations, 288 MDLs were generated for these two turtles for KDE analysis. Locations for home ranges covered June–Dec 2016 for a total of 320 days. Home ranges (95% KDEs) were 886.6 and 4646.7 km^2 and core-use areas (50% KDEs) were 162.6 and 1001.4 km^2 for the two turtles, respectively. KDE centroids were in waters shallower than -20 m and were all within 22.3 km of shore (Figure 11). The tracks of one of the two tagged loggerheads tagged at Ship Shoal intersected the Louisiana Borrow Area.

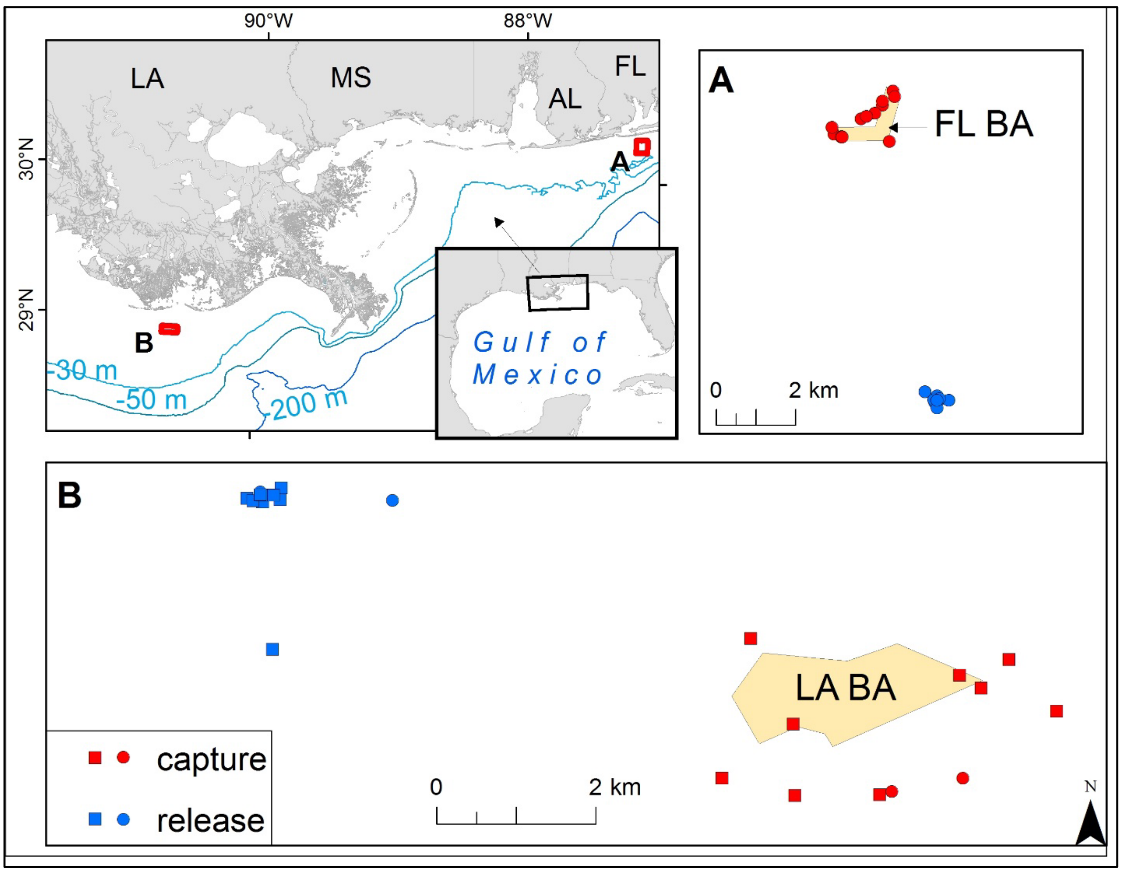


Figure 10. Borrow areas and capture/release locations for loggerheads (circles) and Kemp's ridleys (squares). Spatial analysis of distances moved from borrow areas

FL BA = Florida Borrow Area off Pensacola Beach, Florida; LA BA = Louisiana Borrow Area at Ship Shoal, Louisiana.

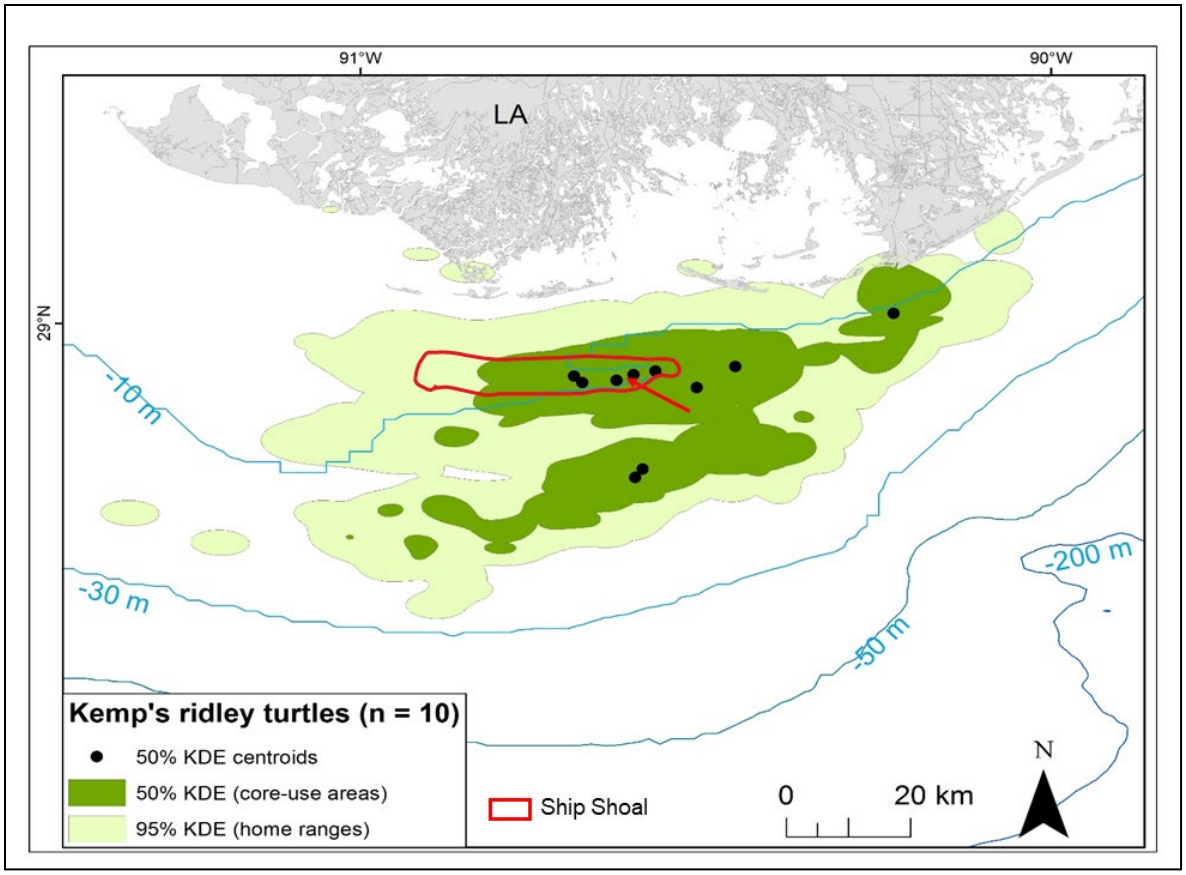


Figure 11. Kemp's ridley home ranges in spatial analysis of borrow site usage at Ship Shoal
Red arrow points to borrow area.

The two loggerhead turtles tagged at the Ship Shoal Louisiana site had centroids 29.6 km apart. Distances to the nearest Kemp's ridley centroids at the Ship Shoal Louisiana site ranged from 1.6–23.4 km (mean $\pm$ SD = 5.1 $\pm$ 6.7 km; Figure 11).

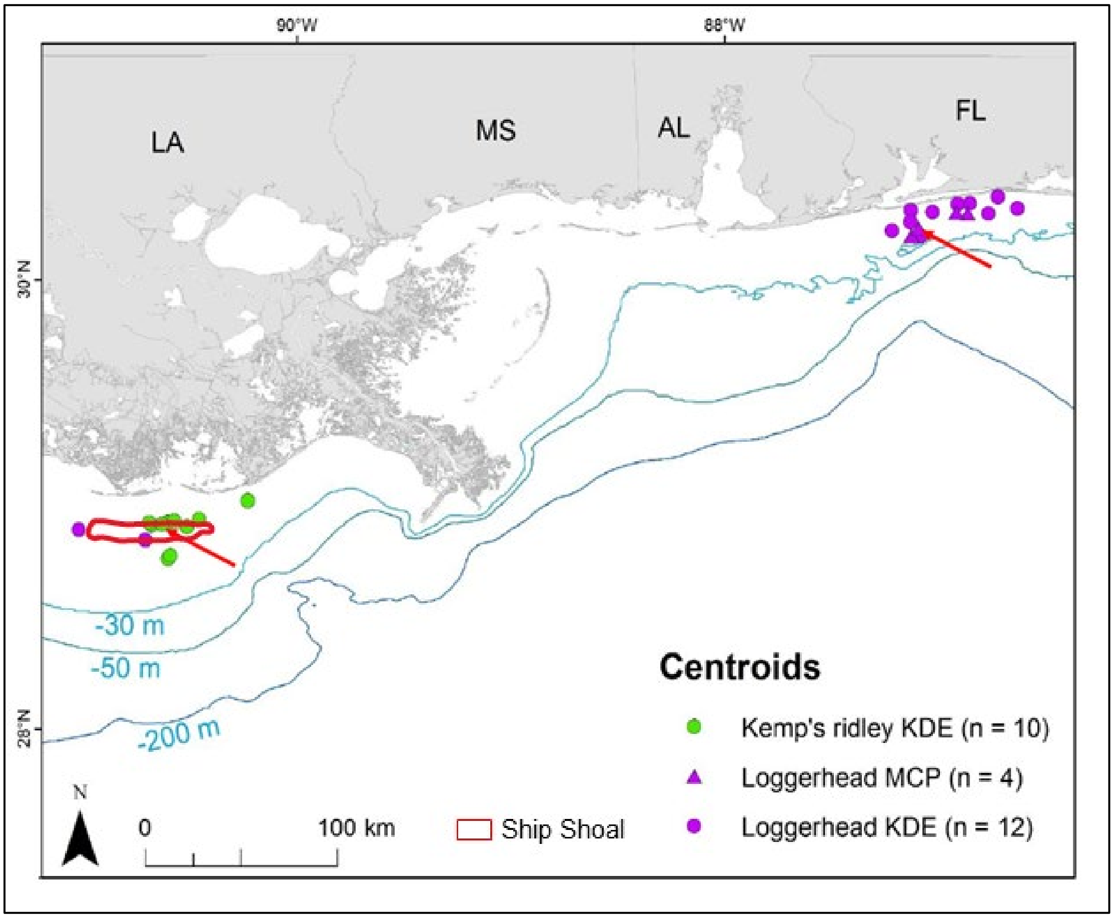


Figure 12. Centroids of turtles in spatial analysis of relocation trawling

Red arrows point to borrow areas in Florida and Louisiana.

Of the 14 loggerheads at Pensacola, 10 displayed site fidelity and had enough MDLs for KDE analysis. The other four either did not pass site fidelity tests or had < 20 MDLs and so their locations were used to make MCPs. We generated a total of 1028 MDLs from 5399 filtered locations to use in KDE analysis. Locations for home ranges covered July–Dec 2016 for a total of 1081 days used for KDEs. Overall home ranges (95% KDEs) ranged from 90.76–783.1 km^2 (mean $\pm$ SD = 379.1 $\pm$ 240.3 km^2) and core-use areas (50% KDEs) ranged from 13.58–165.7 km^2 (mean $\pm$ SD = 68.9 $\pm$ 48.6 km^2; Figure 12). KDE centroids were in waters with an average depth of -22.1 m and were on average 7.3 km from shore (Figure 12).

A total of 1245 filtered locations were used for MCPs across 3–127 days per turtle (mean $\pm$ SD = 42.5 $\pm$ 57.9 days). Only one turtle's locations (out of four) passed site fidelity tests but this turtle was only tracked for three days. The in-water area for MCPs ranged from 22.91–2407.98 km^2 (mean $\pm$ SD = 738.9 $\pm$ 1121.4 km^2). MCP centroids were in waters with an average depth of -25.3 m and were an average 11.0 km from shore (Figure 11). Nine of 14 loggerhead home ranges intersected the Floride Borrow Area.

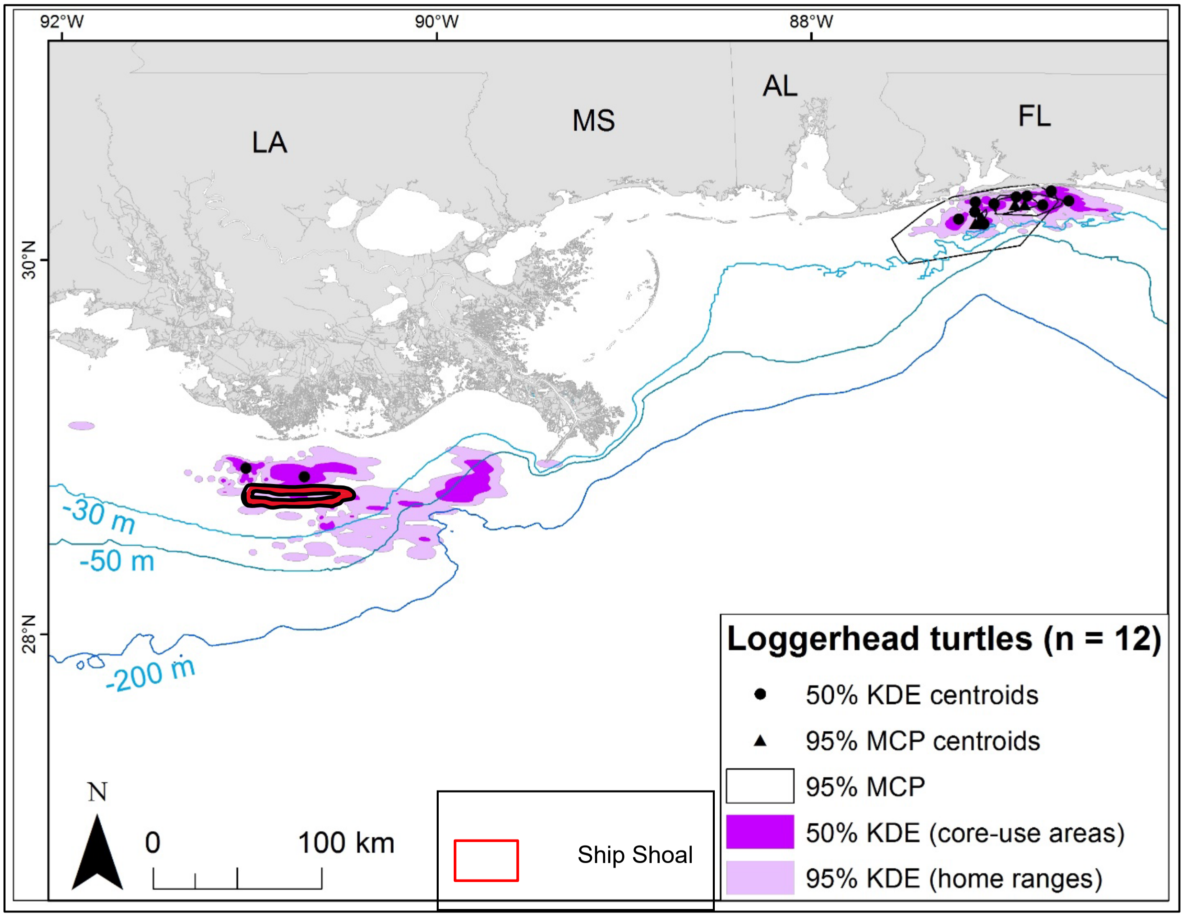


Figure 13. Loggerhead home ranges for turtles included in the borrow site analysis
Ship Shoal added in red off Louisiana.

At Pensacola, loggerhead release locations were on average 7.2 km from their capture location. Loggerhead home ranges were on average similar distances from capture and release locations (1.6 km and 1.8 km, respectively). Turtles that took up residence within 2 km of the capture or release location did so on average in 1.1 days, and sometimes in less than a day, with only one turtle taking longer (5 days) to be within 2 km of the capture location. For the 14 loggerheads tagged at the FL site, the distances to the nearest loggerhead centroid (both KDE and MCP centroids) ranged from 3.9–10.3 km (mean $\pm$ SD = 6.3 $\pm$ 2.4 km; Figure 11).

Depth use data showed that loggerheads in these two study sites used slightly deeper waters than Kemp's ridleys, as 35% of loggerhead dives were in 20–25 m of water and 43.5% of Kemp's ridley dives were in 10–15 m of water (Figure 13).

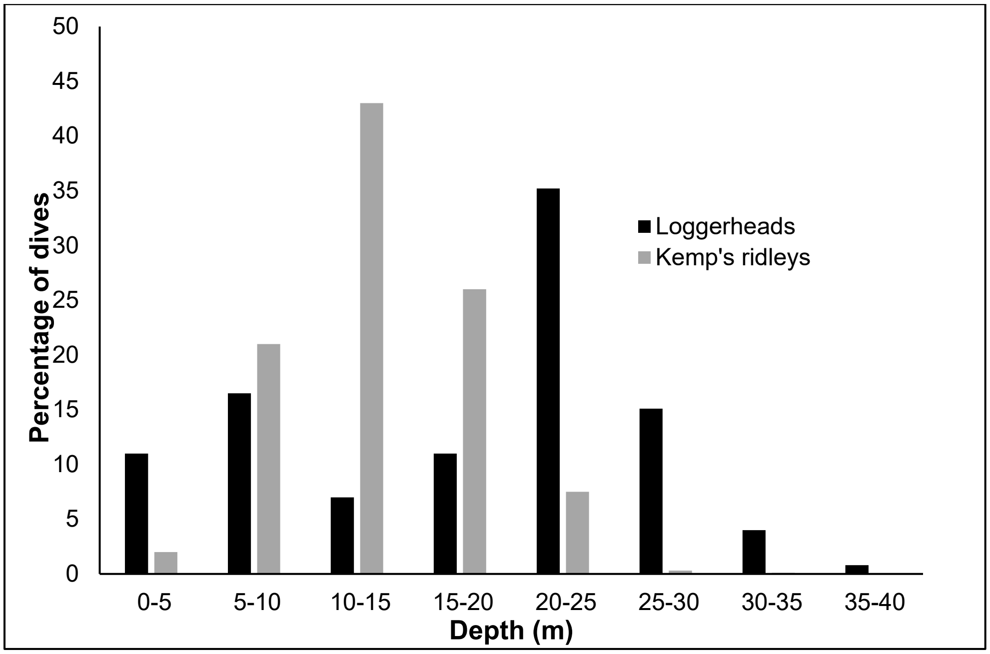


Figure 14. Percentage of total dives by depth bin

For depths between 40–100 m time spent was less than or equal to 0.1 and so not shown on figure.

Dive depth and duration varied by species and time of year. On average, dive time of loggerheads was primarily in 15–30 minute bins (46%), whereas Kemp's ridley dive time was primarily in 0–15 minute bin (43%); Figure 14.

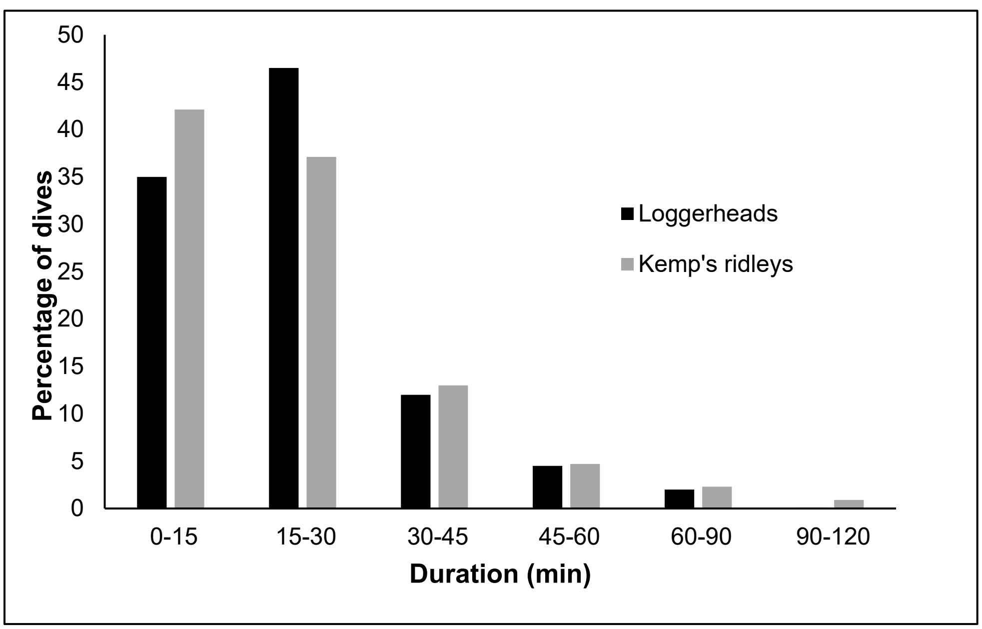


Figure 15. Percentage of total dives logged by duration bin for loggerheads and Kemp's ridley turtles

For duration between 120 and 210 min time spent was less than 0.05 and so not shown on figure.

1.13 Satellite Tracking: All Turtles

1.13.1 Tag Duration

For the 50 BOEM funded tags deployed on turtles in the northern GOM during this project, individual loggerhead tracking durations ranged from 10–281 days (mean = 142.0, SD 70.9, excluding two "failures"; Figures 21 and 22, Table 3) and individual Kemp's ridley tracking durations ranged from 53–275 days (mean = 128.5; SD 60.6; Figures 15 and 16, Table 3).

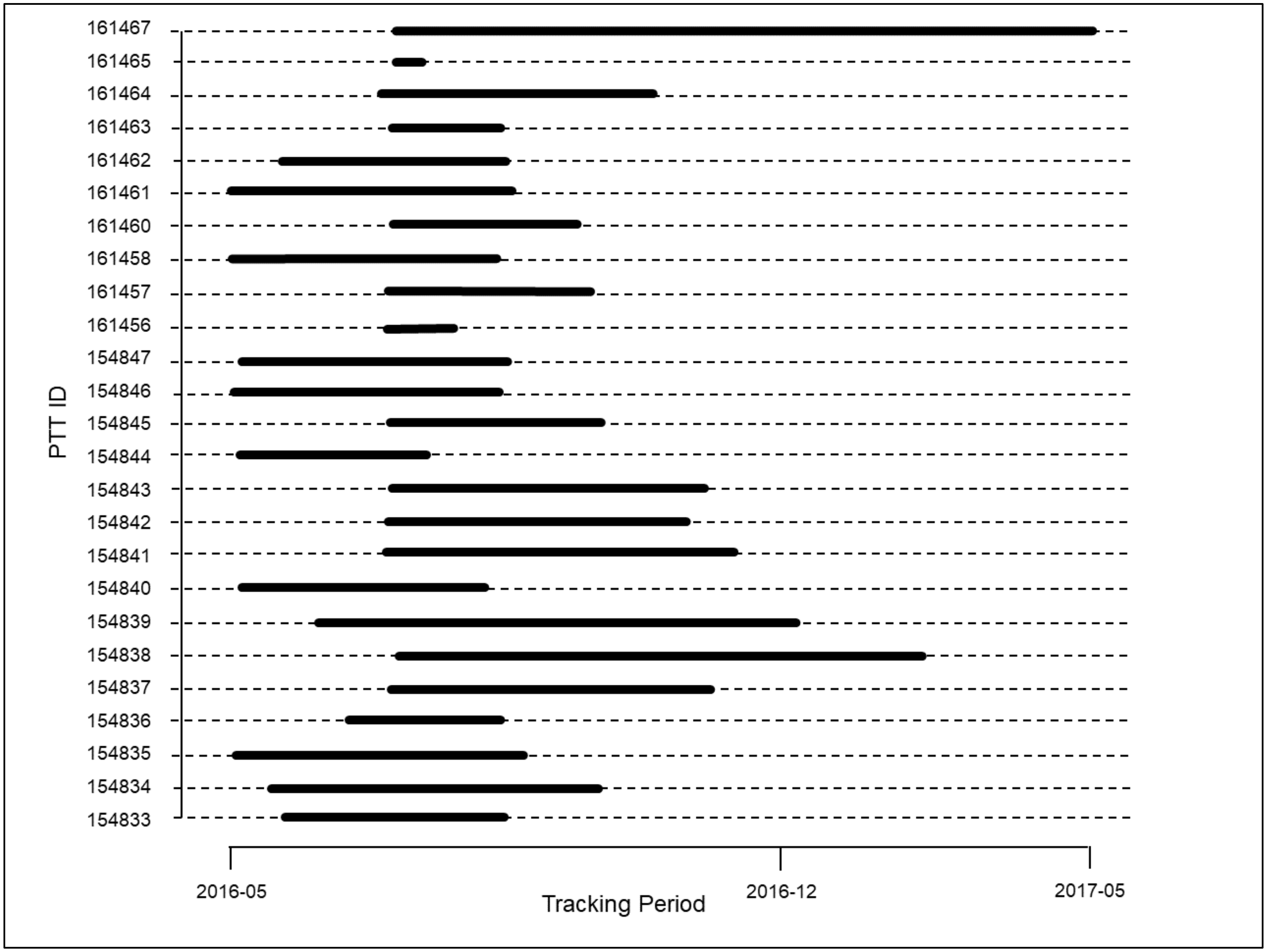


Figure 16. Summary of tag durations for tags tracking from May 2016 to May 2017

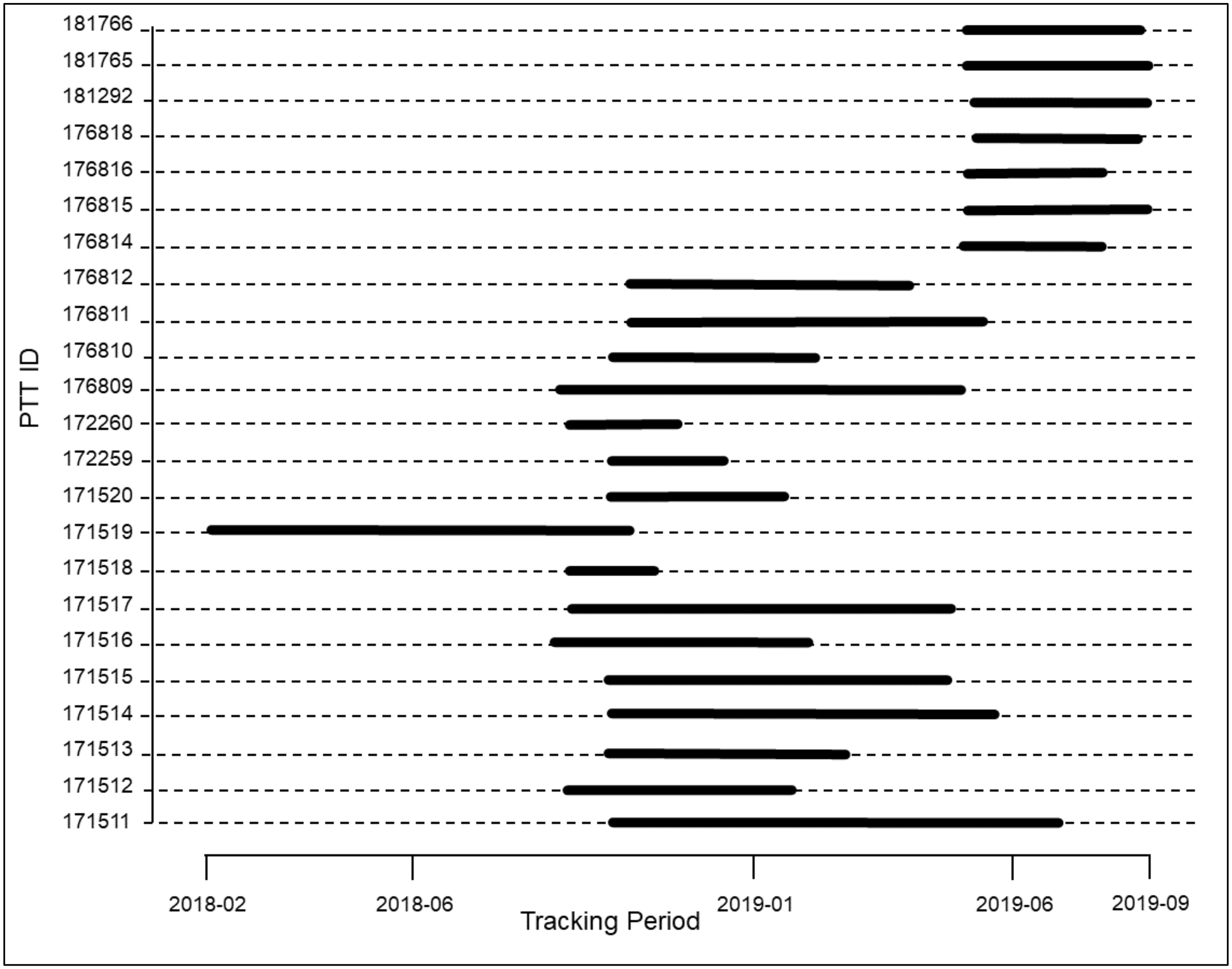


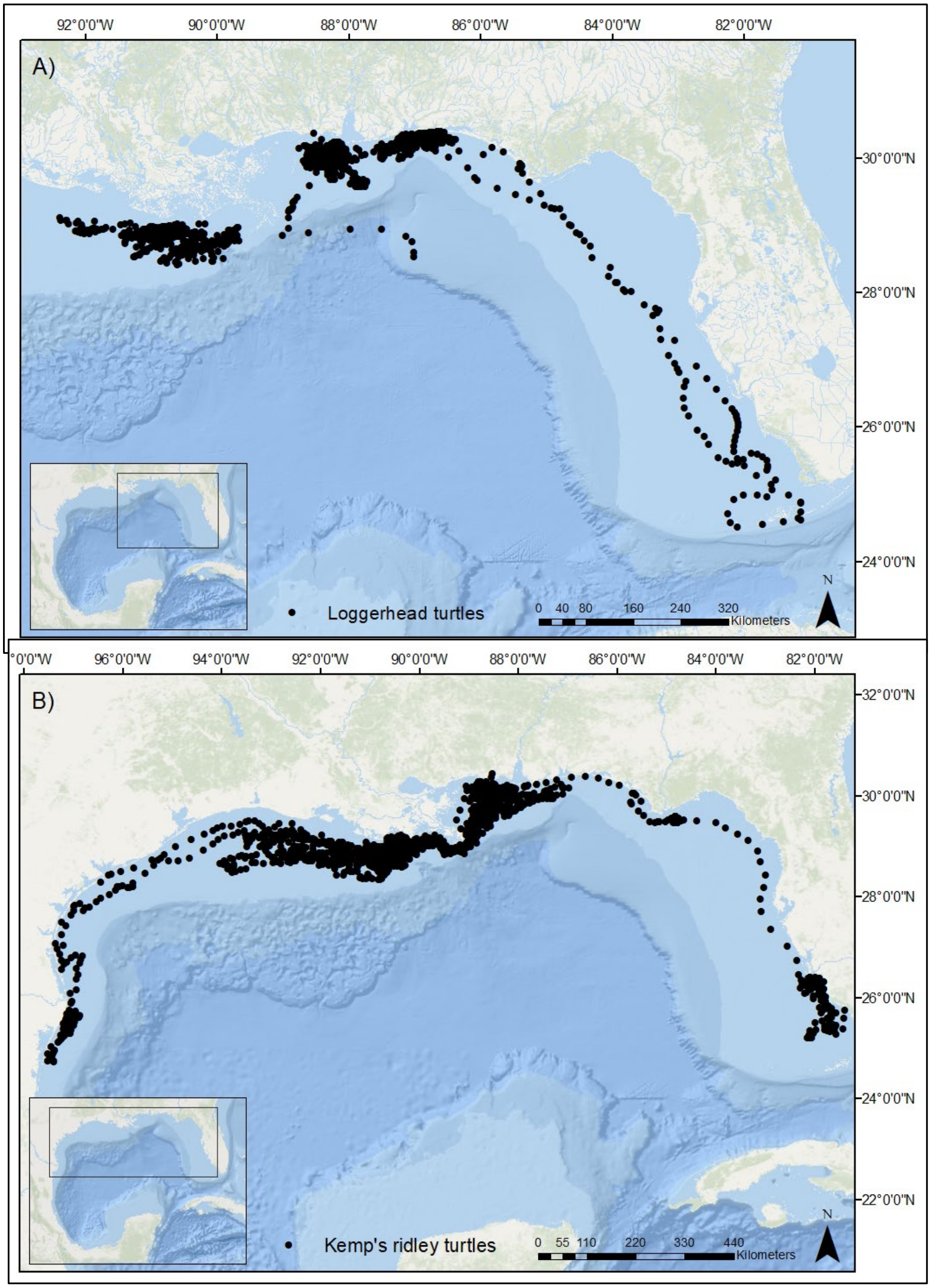
Figure 17. Summary of tag durations for tags tracking from February 2018 to August 2019

1.13.2 General Movements and Site Fidelity

Site fidelilty was high for the majority of turtles, as indicated by concentrated or clustered daily locations. Further exploration of behavioral states or modes (below) was warranted to decipher habitat-use patterns in spatial data. Several turtles moved across the GOM, migrating after tagging (see Figures 17 and 18). None of the turtles left the GOM, though several departed the immediate northern GOM.

1.13.3 Habitat Use and Behavioral State

Using a switching state space model (SSM) allowed us to interpret fine-scale behavioral information within the turtle tracks and examine these patterns at the species level (Figure 17). After fitting the switching SSM to individual turtle tracks, we identified locations where turtles were in transit (i.e., migration) or area-restricted search (ARS or foraging) mode (Figure 18). Over 90% of the observations resulting from the SSM indicated that turtles were in ARS (i.e., foraging) mode (91% ARS, 9% migration). Turtles tagged in 4 of the 5 sampling locations (Caminada, Pensacola, Chandeluer Islands, and Ship Shoal) stayed in very close proximity to their tagging locations throughout tracking (Figure 18).



Figures 18A and B. SSMs locations for all loggerhead (panel A) and Kemp's ridley (panel B) turtles tagged in the GOM 2016–2019

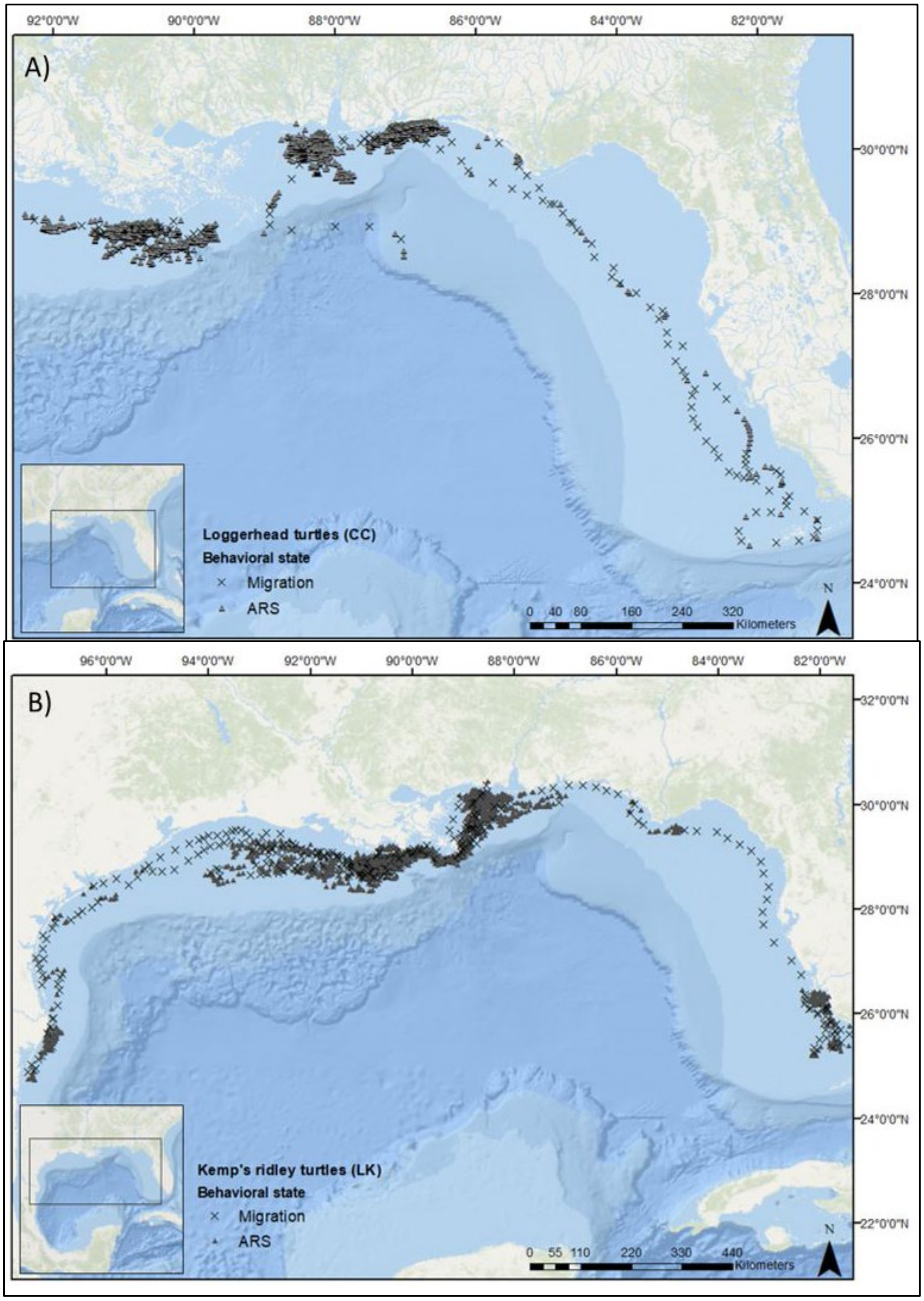


Figure 19. SSMs locations for all loggerhead (panel A) and Kemp's ridley (panel B) turtles tagged in the GOM separated by behavioral state (i.e., migration compared to area-restricted search)

1.13.4 Dive Patterns by Behavioral Mode

Advanced modeling algorithms, such as SSM, now allow for deciphering movement modes during animal tracking periods. We observed variations in turtle dive patterns by mode (foraging or area restricted search [ARS] compared to migration or transiting). However, for the majority of time during tracking, turtles were in foraging or ARS mode, as individual turtle were tagged at foraging sites and only performed short-term transiting movements, not true animal migration (i.e., as an adult female would perform post-nesting). Still, observed differences in mode for dive depth (Figure 19), dive duration (Figure 20), and time at depth (Figure 21) may affect time at surface calculations, so how to incorporate turtle behavioral mode should be a part of future generalized additive mixed modeling (GAMM) efforts that are ongoing as part of GOMMAPPS.

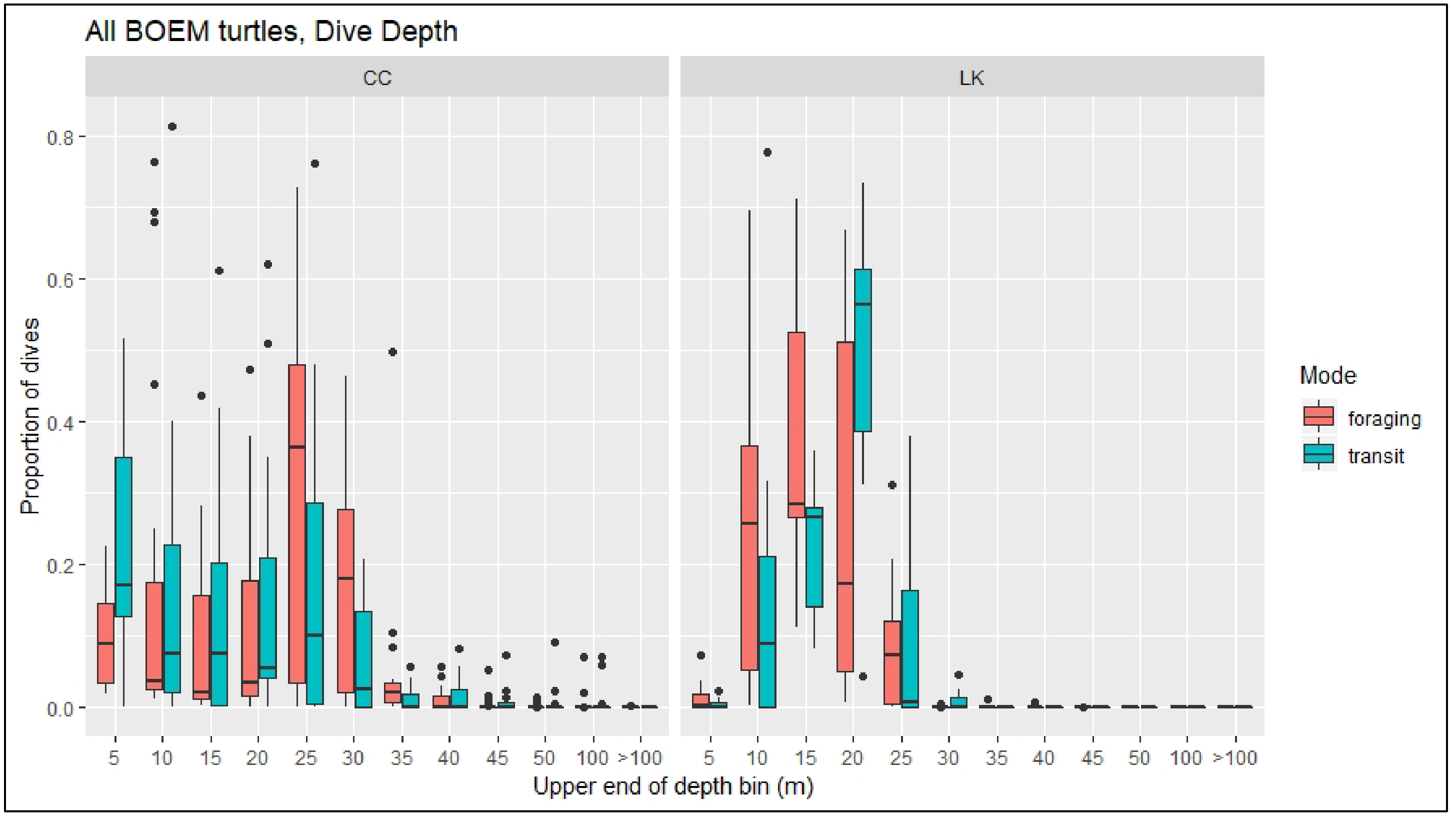


Figure 20. Boxplots for dive depth for loggerhead (CC) and Kemp's ridley (LK) turtles by mode in the GOM

Proportions of dive depths represent per turtle and per mode values with the dives per bin divided by the total dives for that mode. Samples sizes for the data presented are (CC foraging = 22, transit = 14; LK foraging = 13, transit = 7). Boxplots show median and inter-quartile range, and black dots are outliers that can be interpreted as those turtles with a higher or lower average proportion value for that dive bin than what is plotted for the other turtles.

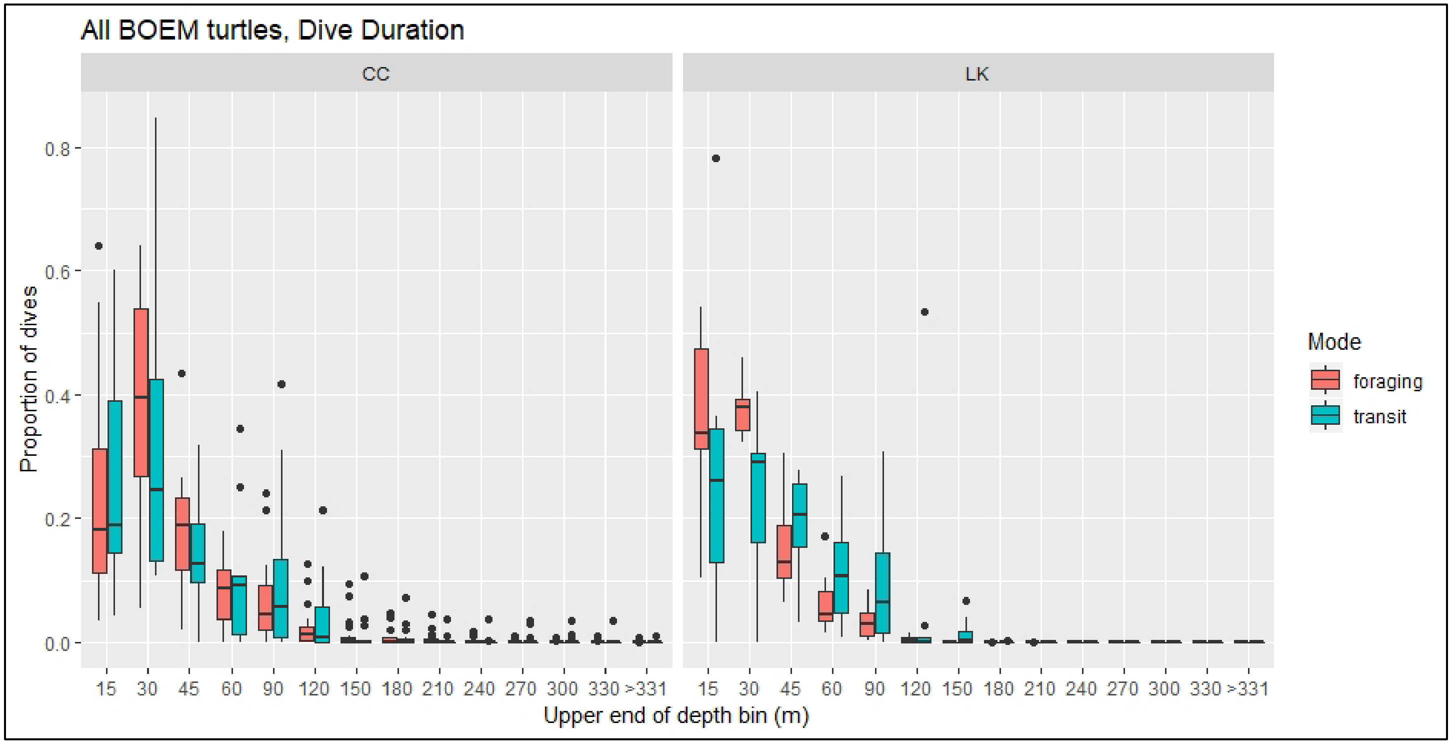


Figure 21. Boxplots for dive duration histograms for loggerhead (CC) and Kemp's ridely (LK) turtles by mode in the GOM

Proportions of dive durations represent per turtle and per mode values with the dives per bin divided by the total dives for each mode. Samples sizes for the data presented are (CC foraging = 22, transit = 14; LK foraging = 13, transit = 8). Boxplots show median and inter-quartile range, and black dots are outliers and can be interpreted as those turtles with a higher or lower average proportion value for that dive duration bin than what is plotted for the other turtles.

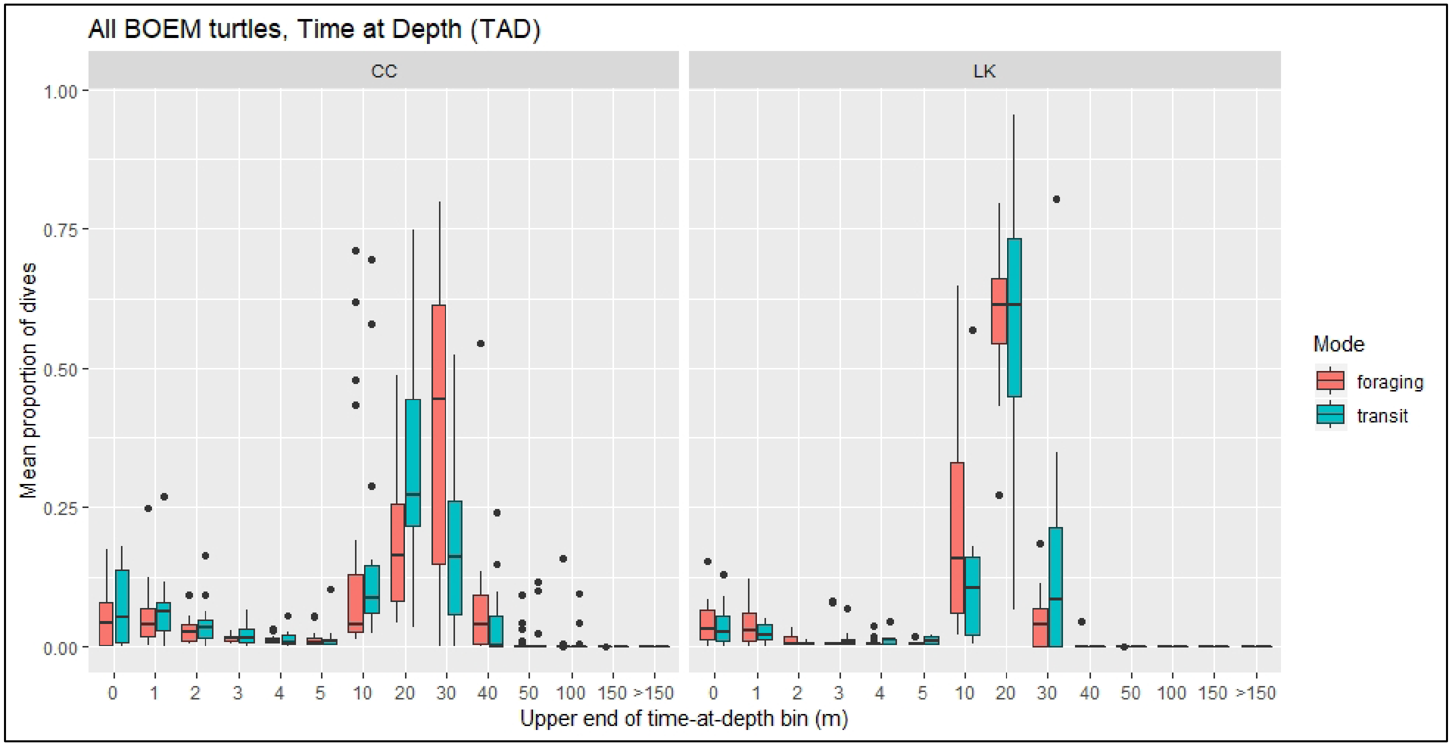


Figure 22. Boxplots for the proportion of time-at-depth (TAD) for loggerhead (CC) and Kemp's ridley (LK) turtles by mode in the GOM

Values in TAD bins represent the percent of time a turtle spent in a depth bin for the summary period (e.g., 24 hours). We then averaged the values per bin within dates for each behavioral mode. Samples sizes for the data presented are (CC foraging = 22, transit = 14; LK foraging = 13, transit = 8). Boxplots show median and inter-quartile range, and black dots are outliers and can be interpreted as those turtles with a higher or lower average proportion value for that time at depth bin than what is plotted for the other turtles.

Because of relatively short tracking durations (i.e., months, not years), dive information was obtained for unequal numbers of turtles across months of the year (Figure 22).

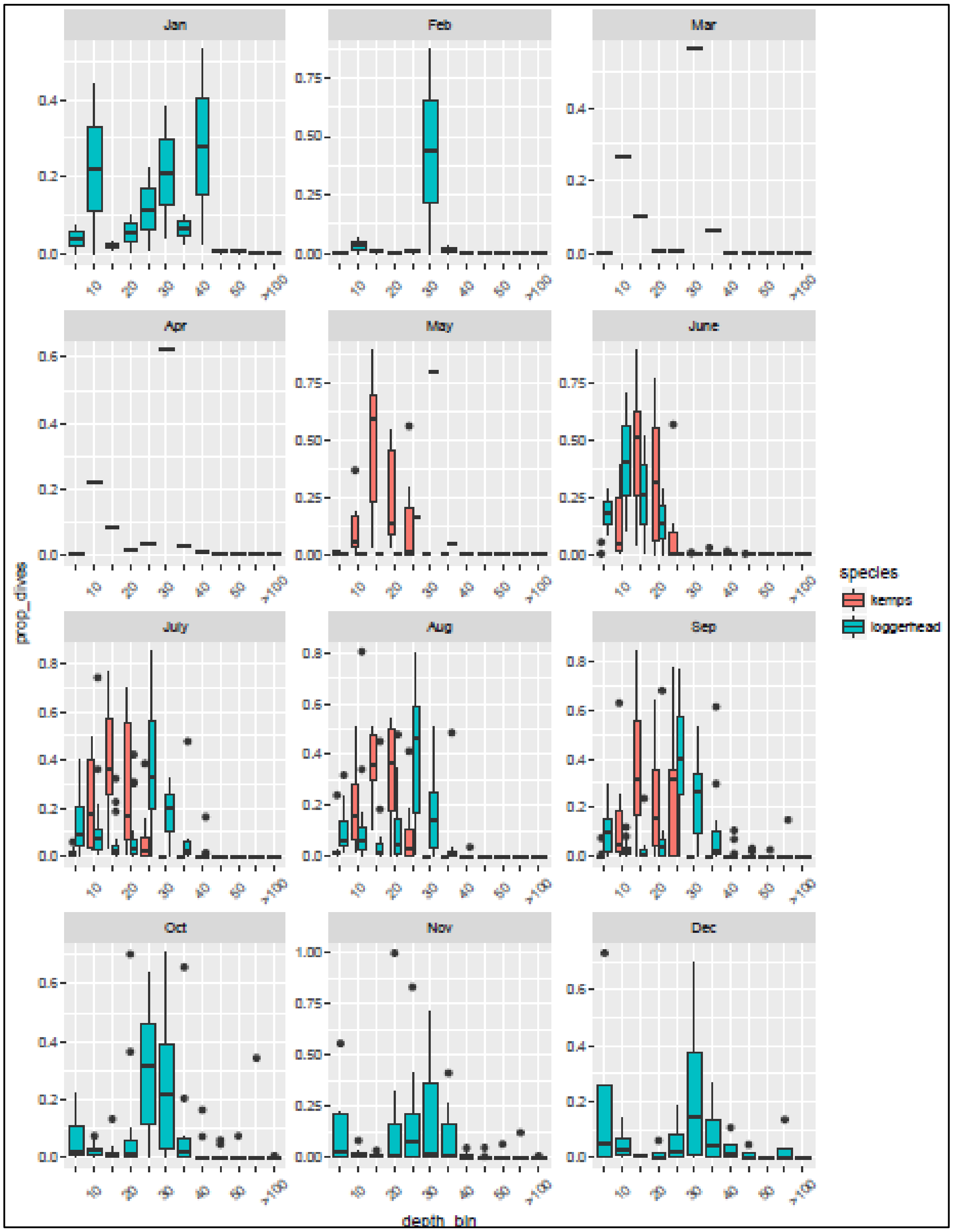


Figure 23. Monthly dive information for loggerhead and Kemp's ridley sea turtles

However, the patterns for proportion of time at depth for loggerheads and Kemp's ridleys with dive-logging tags were clear; loggerheads spent a mean 16.0% (±9.4 SD) time at the surface (0–2 m) and Kemp's ridleys spent a mean 10.0% (±6.0 SD) time at the surface (Table 5).

Table 5. Time at depth (TAD) for each turtle with percent of time at surface (0–2m)

PTT ID	TAD_surface (Mean proportion)	Percent time at surface (0–2 m)
Loggerheads		
154834	0.1	10.0
154837	0.2	17.2
154838	0.1	12.3
154839	0.2	19.5
154841	0.2	24.0
154842	0.1	5.9
154843	0.3	28.9
154845	0.2	23.1
161456	0.3	34.3
161457	0.2	20.7
161460	0.1	6.9
161463	0.1	9.3
161464	0.1	8.9
161465	0.2	18.6
161467	0.0	0.6
min		0.6
max		34.3
mean		16.0
SD		9.4
Kemp's ridleys		
154833	0.1	6.6
154835	0.1	10.9
154836	0.1	11.5
154840	0.1	14.3
154844	0.2	19.9
154846	0.2	15.9
154847	0.0	0.2
161458	0.1	7.4
161461	0.0	3.9
161462	0.1	12.3
min		0.2
max		19.9
mean		10.0
SD		6.0

1.14 Turtle Population Structure

1.14.1 Mitochondrial Genetic Analyses

A total of seven mitochondrial control region haplotypes were identified among the loggerhead turtle samples (Table 6). Five of these have previously been described from nesting populations in Florida or the adjacent Caribbean Sea (Shamblin et al. 2012). A single individual carried haplotype CC-A17.1. The only known nesting population for this haplotype is the Cape Verde loggerhead rookery in the eastern Atlantic (Monzón-Argüello et al. 2010). This haplotype was recovered in a Ceará, Brazilian bycatch sample (Reis et al. 2009), but, to our knowledge, this is the first detection of this haplotype in the western Atlantic besides this Brazilian record. The remaining haplotype has never been previously described. It contained the diagnostic position for CC-A44.1 as well as the G to A transition that splits haplotype CC-A12 from CC-A10. Haplotype CC-A44.1 is also an "orphan" haplotype of unknown origin, but given the other mutation, this individual likely represents a Caribbean Sea nesting population, possibly in Cuba or Mexico. The northern GOM turtles are not solely representative of the proximal Northern Gulf Recovery Unit (NGRU) nesting population, but rather contain a mixture of turtles from GOM and adjacent Caribbean Sea nesting populations.

Four mitochondrial control region haplotypes were recovered from the Kemp's ridley samples (Table 7). All four have previously been described from both the Texas nesting population and the juvenile foraging aggregation in the northeastern US. The frequencies of the two most common haplotypes, Lk4.1 and Lk6.1, from our sample are consistent with those from the Texas nesting population and in the foraging aggregation from the Atlantic Coast. These suggest that the haplotype frequencies are likely similar in the primary nesting population at Rancho Nuevo, Mexico, as well. Baseline data from the Mexican nesting population would provide more context.

Table 6. Summary of mitochondrial control region haplotypes for loggerhead turtles captured in the northern Gulf of Mexico (NGOM)

Published haplotype frequencies from the northern Gulf Recovery Unit (NGRU), Dry Tortugas Recovery Unit (DTRU), and Quintana Roo, Mexico (MEX) nesting populations from Shamblin et al. (2012) are included for comparison.

Haplotype	LA	MS	FL	NGOM	NGRU	DTRU	MEX
CC-A1.1	1	2	4	9	94	1	
CC-A1.4	1			1	2	1	13
CC-A2.1	3		8	14	12	28	64
CC-A2.3			1	1			6
CC-A2.5	1		1	2			10
CC-A3.1					1		3
CC-A8.1	1						7
CC-A9.1					1	2	8
CC-A17.1	1			1			
CC-A27.1					1		
CC-A59.1					1		
others							57
New		1		1			

Table 7. Summary of mitochondrial control region haplotypes for Kemp's ridley turtles captured in the northern Gulf of Mexico

Published hapltyope frequency data from the Texas nesting population (TX) and the northeastern United States foraging juvenile aggregation (NEUS) from Frandsen et al. (2020) are included for comparison.

Haplotype	NGOM	TX	NEUS
Lk1.1	1	1	2
Lk2.1	1	3	2
Lk3.1		1	6
Lk4.1	8	20	32
Lk5.1		1	
Lk6.1	3	13	15
Lk6.2		1	
Lk7.1		1	
Frandsen 3		1	
Frandsen 8			1

1.14.2 Isotopes

Fifty individual tutles were sampled for carbon and nitrogen isotopes with BOEM funding (Table 8) and 26 with funding from other projects (Table 9). Several of the turtle's samples did not yield reliable results for all three tissue types, so sample sizes were not equal across all samples (Tables 8 and 9). Analysis of stable carbon and nitrogen values revealed that mean values from carapace and whole blood were similar, differing from flipper tissue samples which were less depleted in carbon regardless of species or sex (Table 10). However, nitrogen values were more variable between species and sexes (Table 10). The lowest carbon isotope values were from green turtles, followed by Kemp's ridley, then loggerheads regardless of tissue. However, nitrogen isotopic values were highest for Kemp's ridley, then loggerhead, followed by green turtles.

Table 8. Individual turtle isotope results of all turtles captured through relocation or USGS directed trawling in the northern GOM, May 2016–May 2019 that received a BOEM funded satellite (SPOT) or depth-logging (SPLASH) satellite tag

NA values = not enough material for analysis or calculation. Species abbreviations are CC = loggerhead, LK = Kemp's ridley; F = female; M = male.

					Flipper Tissue		Whole Blood		Carapace	
#	Species	RF Flipper	Sex	Capture Location	c13	n15	c13	n15	c13	n15
1	CC	UUS161	F	Ship Shoal, LA	-14.64	11.03	NA	NA	-17.05	13.31
2	CC	UUS170	F	Ship Shoal, LA	NA	NA	NA	NA	-17.73	14.16
3	CC	MMC759	F	Pensacola, FL	NA	NA	-18.03	11.38	-17.97	12
4	CC	MMC757	F	Pensacola, FL	-14.89	10.06	-18.23	10.53	-18.18	10.99
5	CC	MMC761	F	Pensacola, FL	-14.75	10.36	-17.82	11.51	-17.87	11.61

					Flipper Tissue		Whole Blood		Carapace	
#	Species	RF Flipper	Sex	Capture Location	c13	n15	c13	n15	c13	n15
6	CC	MMC763	M	Pensacola, FL	NA	NA	-15.88	11.14	-18.73	10.17
7	CC	MMC766	F	Pensacola, FL	-13.81	10.88	-18.17	8.63	-18.75	8.25
8	CC	LLY494	F	Pensacola, FL	-13.85	10.69	-18.08	8.63	-18.68	8.47
9	CC	MMC769	F	Pensacola, FL	-15.09	9.58	-18.21	8.44	-18.83	8.18
10	CC	MMC771	M	Pensacola, FL	-15.13	10.39	-18.13	8.65	-18.67	8.67
11	CC	MMC774	F	Pensacola, FL	-14.54	11.05	-18.39	11.07	-18.68	10.59
12	CC	MMC773	F	Pensacola, FL	-15.82	10.63	-17.51	12.04	-17.4	11.64
13	CC	MMC777	F	Pensacola, FL	-18.24	11.24	-18.29	10.77	-18.25	10.64
14	CC	MMC781	F	Pensacola, FL	-14.97	10.6	-17.9	10.92	NA	NA
15	CC	MMC779	F	Pensacola, FL	-18.46	10.68	-19.24	10.65	-18.93	10.14
16	CC	MMC783	M	Pensacola, FL	-15.98	12.07	-18.04	10.37	-15.84	10.28
17	CC	BSC2004	F	Ship Shoal, LA	-14.61	13.39	-15.61	13.47	-15.58	13.44
18	CC	MMX297	F	Pascagoula, MS	NA	NA	-17.17	13.56	-16.48	13.63
19	CC	MMX907	F	Pascagoula, MS	-14.91	14.46	-16.68	13.51	-16.16	13.4
20	CC	MMW950	F	Pascagoula, MS	-15.17	12.37	-16.93	13.5	-16.69	12.93
21	CC	KKH802	F	Pascagoula, MS	-14.88	12.09	-17.46	11.85	-18.23	10.38
22	CC	BSC1256	UNK	Ship Shoal, LA	-15.31	12.28	-16.77	13.06	-17.51	14.66
23	CC	BSC1608	F	Ship Shoal, LA	-14.92	12.12	-16.49	14.07	-16.85	14.66
24	CC	BSC1610	F	Ship Shoal, LA	-15.26	11.64	-16.68	13.34	-16.3	14.5
25	CC	BSC1676	F	Ship Shoal, LA	-15.13	12.19	-16.66	13.39	-16.69	12.91
26	CC	BSC1258	F	Ship Shoal, LA	-14.75	12.55	-16.32	13.76	-16.21	13.81
27	LK	UUS146	M	Ship Shoal, LA	-17.07	12.95	NA	NA	-18.37	11.63
28	LK	UUS137	F	Ship Shoal, LA	-16.79	12.16	NA	NA	-18.34	12.34
29	LK	UUS135	F	Ship Shoal, LA	NA	NA	NA	NA	-18.12	11.95
30	LK	UUS142	F	Ship Shoal, LA	NA	NA	NA	NA	-18.25	12.52
31	LK	UUS139	M	Ship Shoal, LA	NA	NA	NA	NA	-17.72	13.49
32	LK	UUS144	F	Ship Shoal, LA	NA	NA	NA	NA	-18.28	12.68
33	LK	UUH366	M	Ship Shoal, LA	-14.22	13.48	NA	NA	-18.3	12.05
34	LK	UUS162	M	Ship Shoal, LA	-15.25	14.28	NA	NA	-18.07	12.06
35	LK	UUS164	F	Ship Shoal, LA	NA	NA	NA	NA	-16.64	12.07
36	LK	UUS168	F	Ship Shoal, LA	NA	NA	NA	NA	-18.5	12.47
37	LK	MMX983	F	Pascagoula, MS	NA	NA	-17.41	11.04	NA	NA
38	LK	MMX985	F	Pascagoula, MS	-16.01	14.18	-17.74	13.88	-17.42	12.87
39	LK	MMX905	M	Pascagoula, MS	-16.69	14.46	-18.5	13.48	-17.85	12.74
40	LK	MMX991	F	Pascagoula, MS	-15.79	14.52	-18.91	13.59	-18.7	12.9

					Flipper Tissue		Whole Blood		Carapace	
#	Species	RF Flipper	Sex	Capture Location	c13	n15	c13	n15	c13	n15
41	LK	MMW948	F	Pascagoula, MS	-15.26	11.68	-17.65	10.76	-17.01	11.96
42	LK	MMW962	F	Pascagoula, MS	NA	NA	-18.67	11.17	-17.92	11.37
43	LK	MMZ914	F	Pascagoula, MS	-17.3	13.98	-19.93	12.78	-18.93	11.9
44	LK	MMW964	F	Pascagoula, MS	-15.84	13.43	-19.08	13.78	-18.58	13.03
45	LK	MMW916	F	Pascagoula, MS	-15.31	13.8	-18.31	13.82	-18	12.52
46	LK	KKH809	F	Pascagoula, MS	-16.57	13.76	-18.98	13.23	NA	NA
47	LK	KKH813	F	Pascagoula, MS	-15.99	14.4	-18.76	13.25	-19.82	12.07
48	LK	BSC1606	F	Ship Shoal, LA	-14.92	13.78	-17.85	12.81	-19.09	13.2
49	LK	BSC1614	F	Ship Shoal, LA	-16.58	12.81	-19.03	12.87	-19.13	12.43
50	LK	BSC1264	M	Ship Shoal, LA	-16.22	12.66	-19.36	12.64	-19.87	11.44

Table 9. Individual turtle isotope results of sea turtle captures that did not receive a satellite tag or had a non-BOEM funded satellite tag attached NA values = not enough material for analysis or calculation

Species abbreviations are CC = loggerhead, LK = Kemp's ridley, and CM = green turtle; F = female; M = male; UNK=unknown.

					Flipper Tissue		Whole Blood		Carapace	
#	Species	RF Flipper	Sex	Capture Location	c13	n15	c13	n15	c13	n15
1	CC	BSC2002	F	Chandeleurs, LA	-15.58	12.36	-17.07	13.47	-16.69	13.57
2	CC	KKH803	UNK	Pascagoula, MS	-15.93	9.49	-18.72	9.15	-18.06	9.38
3	CC	MMX920	F	Pascagoula, MS	-14.77	12.77	-16.75	13.99	-17.86	13.99
4	CC	MMW967	F	Pascagoula, MS	-16.47	10.9	-18.13	10.85	-17.46	11.29
5	CC	BSC1678	F	Ship Shoal, LA	-15.08	12.15	-16.49	13.24	-17.05	14.22
6	CC	BSC1260	UNK	Ship Shoal, LA	-15.17	11.16	-17.25	11.08	-17.8	13.43
7	CC	BSC1222	F	Ship Shoal, LA	-14.23	12.59	-16.25	13.89	-15.76	13.92
8	CM	KMH974	UNK	Chandeleurs, LA	-14.78	11.28	NA	NA	-15.74	10.93
9	CM	KMH812	UNK	Ship Shoal, LA	-17.09	11.25	-19.04	10.62	-19.44	10.98
10	LK	MMX987	F	Pascagoula, MS	-16.54	13.5	-18.5	13.36	-18.4	11.67
11	LK	MMX989	F	Pascagoula, MS	NA	NA	NA	NA	-18.95	12.24
12	LK	MMX995	F	Pascagoula, MS	-15.93	12.21	-19.12	12.92	-18.76	12.33
13	LK	MMX993	F	Pascagoula, MS	-16.09	13.92	-18.78	13.33	-18.61	11.54
14	LK	MMW923	F	Pascagoula, MS	-14.45	10.12	-17.21	10.1	-17.22	10.92
15	LK	KKH815	F	Pascagoula, MS	-14.52	11.29	-17.52	10.82	-17.85	9.73
16	LK	KKH811	F	Pascagoula, MS	-17.22	13.52	-19.63	12.54	-20.48	12.16
17	LK	KKH817	F	Pascagoula, MS	-15.05	10.5	NA	NA	-19.19	11.83

					Flipper Tissue		Whole Blood		Carapace	
#	Species	RF Flipper	Sex	Capture Location	c13	n15	c13	n15	c13	n15
18	LK	KKH821	F	Pascagoula, MS	-13.95	10.99	-17.36	11.28	NA	NA
19	LK	MMW921	F	Pascagoula, MS	-14.99	12.09	-18.72	12.57	-18.81	12.24
20	LK	KKH829	F	Pascagoula, MS	-16.09	12.13	-18.92	11.25	-18.49	11.17
21	LK	KKH831	F	Pascagoula, MS	-15.52	11.36	-18.05	11.05	-18.28	11.82
22	LK	KKH833	F	Pascagoula, MS	-18.92	11.45	-19.52	12.13	-19.18	11.24
23	LK	BSC1612	UNK	Ship Shoal, LA	-16.78	13.47	-19.14	12.93	-18.03	13.54
24	LK	BSC1680	F	Ship Shoal, LA	-16.16	12.79	-19.69	12.74	-19.76	11.66
25	LK	BSC1240	F	Ship Shoal, LA	-14.61	13.18	-18.79	13.21	-19.32	11.82
26	LK	BSC1236	F	Ship Shoal, LA	-14.84	11.89	-18.6	12.94	-19.46	11.12
27	LK	BSC1238	F	Ship Shoal, LA	-15.44	14.16	-18.18	13.38	-18.54	12.27

Table 10. Summary stable carbon and nitrogen values for turtles sampled in the NGOM by gender and tissue type

CC = loggerhead, CM = green turtle, LK = Kemp's ridley. "." = no SD for n=1 sample.

Species	Sex	Tissue Type	n	mean C13	SD C13	mean N15	SD N15
CC	Female	Carapace	26	-17.40	1.01	12.18	1.98
CC	Female	Flipper Tissue	24	-15.20	1.12	11.60	1.15
CC	Female	Whole blood	25	-17.38	0.88	12.02	1.78
CC	Male	Carapace	3	-17.75	1.65	9.71	0.90
CC	Male	Flipper Tissue	2	-15.56	0.60	11.23	1.19
CC	Male	Whole Blood	3	-17.35	1.27	10.05	1.27
CC	UNK	Carapace	3	-17.79	0.28	12.49	2.76
CC	UNK	Flipper Tissue	3	-15.47	0.40	10.98	1.40
CC	UNK	Whole Blood	3	-17.58	1.02	11.10	1.96
CM	UNK	Carapace	2	-17.59	2.62	10.96	0.04
CM	UNK	Flipper Tissue	2	-15.94	1.63	11.27	0.02
CM	UNK	Whole Blood	1	-19.04	.	10.62	.
LK	Female	Carapace	32	-18.56	0.82	12.00	0.70
LK	Female	Flipper Tissue	27	-15.80	1.06	12.73	1.27
LK	Female	Whole Blood	27	-18.55	0.75	12.47	1.11
LK	Male	Carapace	6	-18.36	0.78	12.24	0.76
LK	Male	Flipper Tissue	5	-15.89	1.16	13.57	0.79
LK	Male	Whole Blood	2	-18.93	0.61	13.06	0.59
LK	UNK	Carapace	1	-18.03	.	13.54	.
LK	UNK	Flipper Tissue	1	-16.78	.	13.47	.
LK	UNK	Whole Blood	1	-19.14	.	12.93	.

Analysis of carbon and nitrogen isotopes signatures showed values for each tissue type in the range of expected values from the previously published literature. Across tissue types, turtles sampled at Ship Shoal had the largest range of carbon values, with considerable overlap in values between all sites. Overall mean carbon values were lowest in Pascagoula compared to Pensacola and Ship Shoal. Flipper tissues were significantly lower in carbon values than blood or carapace samples, which were similar (Figure 23).

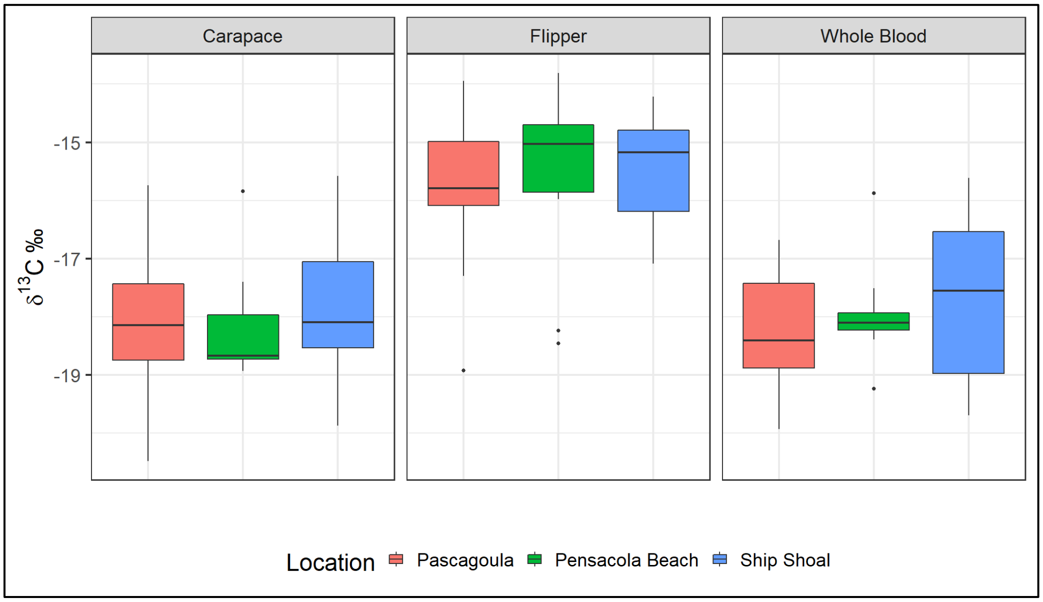


Figure 24. Carbon isotope results by capture site location and tissue type, all species combined
Note Pensacola Beach samples contain only loggerhead turtles.

Turtles sampled from Pacagoula and Pensacola Beach had considerably larger ranges of values than those sampled from Ship Shoal, with the exception of flipper tissue at Pensacola Beach. Mean nitrogen values differed between locations with Pensacola < Pacagoula < Ship Shoal. This pattern was consistent across tissues (Figure 24).

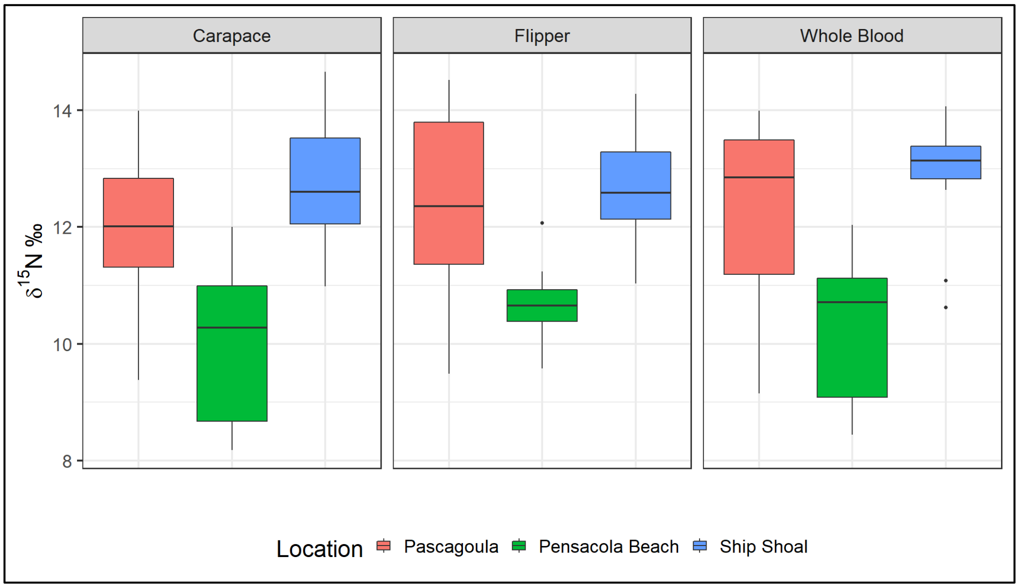


Figure 25. Nitrogen isotope results by capture site location and tissue type, all species combined
Note Pensacola Beach samples contain only loggerhead turtles.

The ranges of carbon isotope values for Kemp's ridely and loggerhead turtles overlapped; however the means differed. Green turtles carbon isotope values were more similar to values calculated for Kemp's ridley's than those for loggerhead turtles (Figure 25).

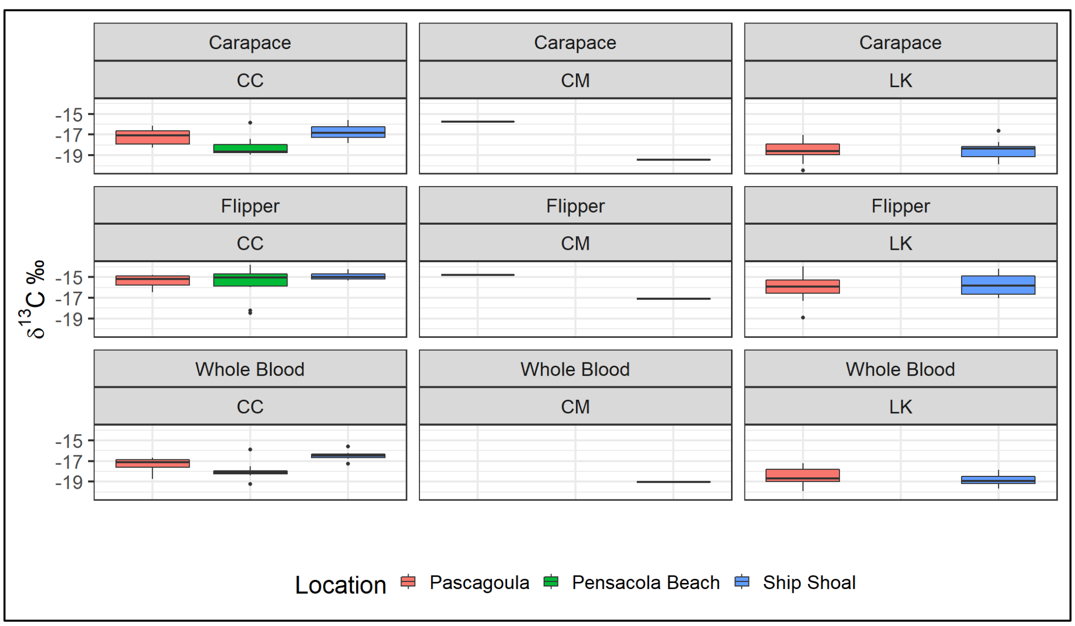


Figure 26. Carbon isotope results by capture site location and tissue type, with each species shown separately
CC = loggerhead, CM = green turtle, LK = Kemp's ridley.

Loggerheads and Kemp's ridley turtles had similar nitrogen isotope values, but values for green turtle were different. Nitrogen isotope values for turtles sampled at Pensacola Beach were significantly lower than for turtles sampled at both Pascagoula and Ship Shoal. Turtles captured off Pascagoula exhibited the largest range of nitrogen isotopes values (Figure 26).

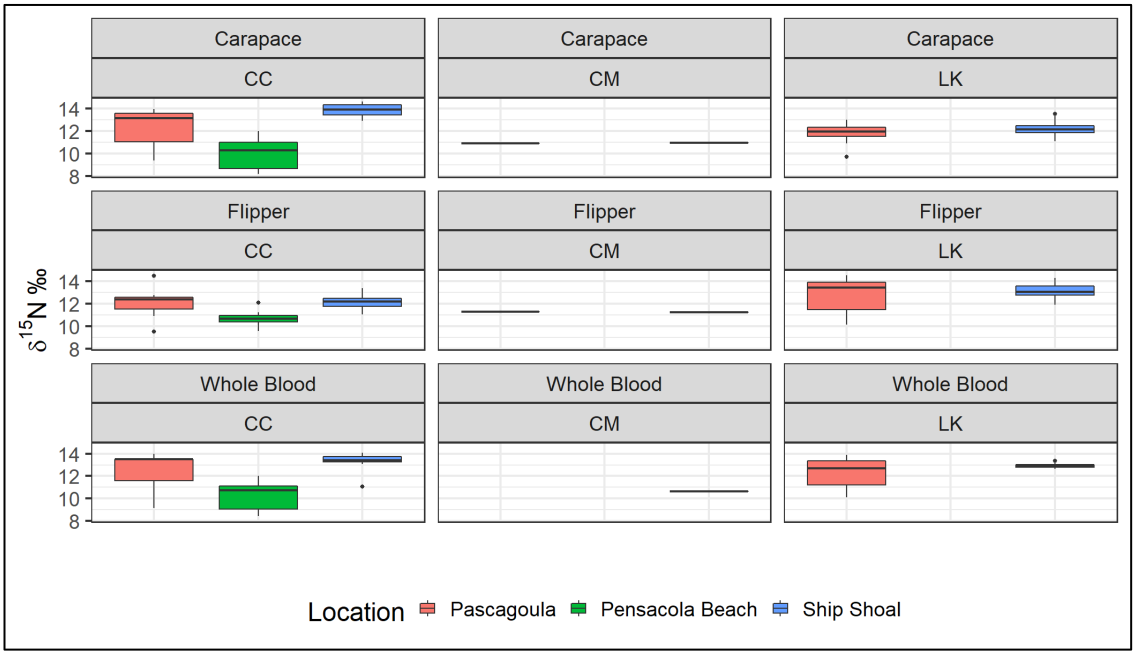


Figure 27. Nitrogen isotope results by capture site location and tissue type, with each species shown separately

CC = loggerhead, CM = green turtle, LK = Kemp's ridley.

There appears to be more overlap in resources used between loggerhead and Kemp's ridley sea turtles in Pascagoula. But in Ship Shoal, it appears there may be some separation between the two species, with loggerheads consuming less carbon depleted food sources than Kemp's ridleys or green turtles. Off Pascagoula there is the largest range of nitrogen values for both loggerhead and Kemp's ridleys, possibly indicating foraging across trophic levels (Figure 27).

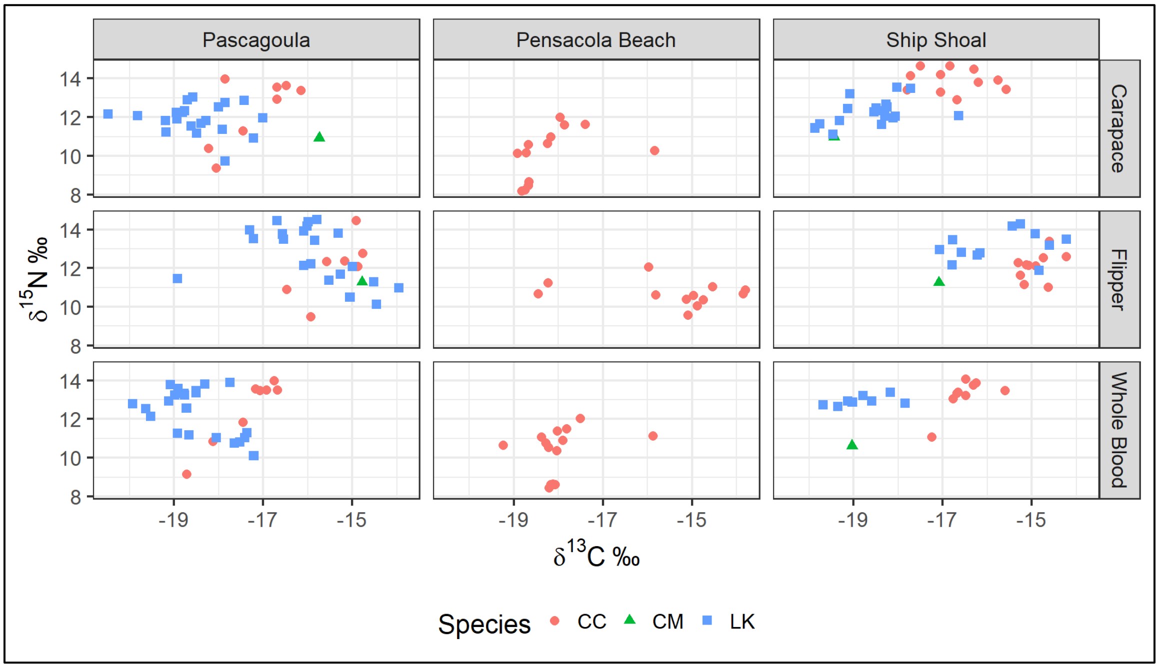


Figure 28. Carbon and nitrogen bi-plots by capture site, tissue type, and species
CC = loggerhead, CM = green turtle, LK = Kemp's ridley. Note CM from Pascagoula was captured in Chandeleurs.

Results of parsing the data by sex showed that there were no differences in foraging behaviours between sexes. However, small sample sizes of males and immatures precludes much inference about isotopic patterns in foraging strategies (Figure 28). Unknown turtles were too small to sex, so were considered immature or juvenile life stage.

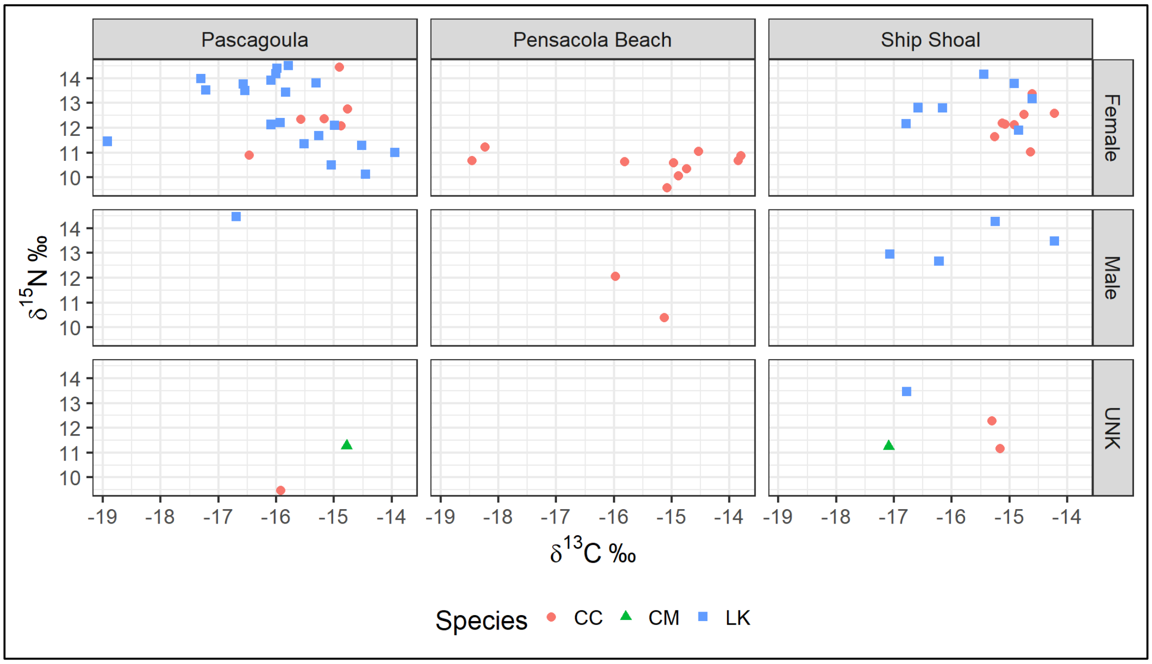


Figure 29. Carbon and nitrogen bi-plots by capture site, species, and sex

CC = loggerhead, CM = green turtle, LK = Kemp's ridley. Note: shown are tissue values, and CM from Pascagoula was captured in Chandeleurs.

Discussion

1.15 Satellite Tracking

In-water captures of 50+ turtles was achieved through highly coordinated relocation trawling efforts and direct US Geological Survey (USGS) trawling trips in various sites along the northern Gulf of Mexico (GOM). The subset of turtles captured in the water includes indivduals of both sexes, various life stages, and several species. This unique dataset expands on the knowledge base that exists on the spatial ecology of adult nesting females previously captured and tagged by the principal investigators (PIs) and others in the GOM (see Hart et al. 2013 and 2014; Foley et al. 2013; Garrison et al. 2019). In particular, the capture and successful tracking of turtles in this study shows that the methods used do provide access to understudied sea turtles (i.e., males, large subadults) in the GOM.

1.15.1 Site Fidelity and Movements

Overall, tracking revealed site fidelity to the northern GOM region for months. Despite optimized programming schedules for saving battery life and transmissions when satellite coverage was ideal, fouling played a role in the relatively short tracking durations obtained (see Hart et al. 2021; Reeves et al. 2018). Thus, fall and winter captures are necessary to obtain spatial habitat use information during winter months. Because weather can be challenging to perform fieldwork during winter months, this lack of data remains a gap even though we deployed a number of tags in the fall.

1.15.2 Habitat Use and Behavioral State

Most turtles tagged at dredging sites during this study remained in the area, which appeared to represent their foraging home range (e.g., 90% of individuals were in foraging mode). Dredging can generate noise and turbidity (McCook et al. 2015), although turtles appear to adjust to these disturbances over time and perhaps even use the dredged areas for foraging and predator avoidance (McCook et al. 2015, Whittock et al. 2017). Satellite tracking of flatback turtles in Australia showed that they increased their use of dredging areas while dredging was occurring (Whittock et al. 2017). The turtles in our study undertook longer and deeper resting dives during dredging and used the deeper waters created in the dredged areas. Although our results show fidelity of turtles to dredging areas, fine-scale data are needed to better understand how they are interacting with the habitat during dredging.

1.15.3 Dive Depth and Duration

The results here provide the first estimates of time at surface for northern GOM turtles tagged in the water that remain in the northern GOM. Garrison et al. (2019) previously tagged a portion of their turtles in the northern GOM, yet because many turtles left northern GOM waters, dive data logged in that study was derived from turtles outside the northern GOM areas of interest. In Garrison et al. (2019), the overall average percentage of time spent at the surface for loggerhead turtles was 11.45% (95% confidence interval: 8.59–14.31), but it was higher for Kemp's ridleys at 15.14% (95% confidence limit: 10.44–19.84%). Our mean values of 16.0% ±9.0 SD for loggerheads and 10.0% ± 6.0 SD for Kemp's ridleys represent an improvement in estimates of time spent at the surface for turtles in the water in the NGOM, which are key data used in aerial survey correction analyses. However, as in Garrison et al. (2019), winter dive times and time at surface is still lacking in our dataset.

Data from these tags showed that, on the shoals, loggerheads used slightly deeper waters and undertook longer dives than Kemp's ridleys. This behavior was evident for all tracked turtles, not just those on the shoals, and the pattern remained consistent for both species across seasons. However, we did observe a slight peak in the proportion of time Kemp's ridleys spent at the surface in February and October. Increased sample sizes would help confirm whether this slight increase is statistically significant or biologically relevant. Robinson et al. (2020) found similar dive patterns for juvenile loggerheads and Kemp's ridleys released after rehabilitation in New York: loggerheads dove deeper and longer than Kemp's rideys. Dive duration was also similar for male loggerheads in the Atlantic Ocean (mean = 27 min; Arendt et al. 2012). Spending more time on the bottom may make loggerheads more susceptible to dredge and trawler capture than Kemp's ridleys.

1.16 Turtle Population Structure

1.16.1 Genetic Structure

Loggerhead turtles foraging in the northern GOM represent a mixed stock of individuals that represent not only the proximal NGRU population nesting in northwest Florida and Alabama, but likely also nesting populations along Florida's coasts and in Mexico. Loggerhead turtle population boundaries in the Greater Caribbean region are defined on the basis of haplotype frequency differentiation, because most nesting sites in Florida share the common haplotypes CC-A1.1 and CC-A2.1 (Shamblin et al. 2012). Frequency differentiation is informative for inferring demographic structuring among nesting sites with respect to female recruitment. But this haplotype sharing creates challenges for interpreting dispersal and migratory connectivity. Larger sample sizes are required for robust mixed stock analyses that estimate relative contributions from potential nesting populations of origin.

Baseline nesting population data for Kemp's ridley turtles are currently available only from the Texas nesting population. However, the relative frequencies recovered from the northern GOM foraging Kemp's are reflective of these females and inwater samples from the northeastern US (Frandsen et al. 2020), suggesting that they are likely similar to those in the major nesting aggregation in Rancho Nuevo, Mexico. Should the haplotype frequencies from Rancho Nuevo prove to be undifferentiated from the Texas nesting population, it will be difficult to clarify the origin of Kemp's ridley turtles individually or even as a sampled cohort using the control region as a marker.

1.16.2 Isotopes

Many of the recent advances in understanding stable isotope ecology for marine turtles have come from integrating satellite tracking with isotope data. Several studies (Ceriani et al. 2014; Tucker et al. 2014; Vander Zanden et al. 2016) have focused on nesting females that were tagged on nesting beaches and then tracked to specific foraging sites. The values of carbon and nitrogen stable isotopes were calculated for each turtle and then compared to values calculated for untracked females also sampled on the nesting beach. Through modeling approaches with training data sets (tracked turtle + isotope values), untracked females were assigned a predicted foraging site based on their isotopic signatures. Though this integrated approach is an exciting development, methodologically, our data represents individuals tagged at foraging sites, thus a unique dataset for "matching" or assigning foraging grounds based on isotopic signatures (i.e., isoscapes). Satellite tracking is expensive, so more development of this tool by refining the expected range of isotopic values observed in specific foraging turtles, such as those in the northern GOM, is useful for a range of research questions, including ongoing work to assess damages to sea turtles and their habitat from the *Deepwater Horizon* oil spill (see Vander Zanden et al. 2016; Reich et al. 2017).

1.17 Other Leveraged Projects and Future Directions

1.17.1 Gulf of Mexico Marine Assessment Program for Protected Species (GOMMAPPS)

Simulataneous to this study, another BOEM-funded study (NSL# GM-16-09d) was being conducted on sea turtles in the GOM. As part of GOMMAPPS project, dive tags were also deployed on sea turtles in BOEM's Central and Western planning areas. Combining data from dive tags deployed in this study with that derived from tags deployed under the GOMMAPPS project is allowing for increased sample sizes for analyses of time at the surface for sea turtles across the GOM. In sum, the GOMMAPPS dive analyses includes data from depth-logging satellite tags deployed from 2010 to 2019; 38 of the 136 depth-logging tags are from this project.

Currently, in the ongoing GOMMAPPS analyses, 136 depth tags are being analysed; these were deployed on three species of marine turtles: loggerhead (n = 59), Kemp's ridley (n = 63) and green turtle (n = 14). All turtles were tagged in GOM sites in Texas, Louisiana, Mississippi, Alabama, and Florida. Mean tracking duration across all species was approximately 130 days. Our primary analysis in GOMMAPPS involves calculating the proportion of time spent in the top 2 meters of the water column (hereafter referred to as the surface of the water) and determining how this proportion is influenced by environmental attributes. To accomplish this, we are using generalized additive mixed modeling (GAMMs) with 10 remotely sensed covariates: sea surface temperature; sea surface temperature anomaly; sea surface salinity; sea surface height; bottom depth; distance to shore; distance to continental shelf break; current strength; current direction; frontal density. Turtle ID is specified as a random effect in the model. Models are currently separated by species, as each species is known to have unique distributions, feeding behavior and movement patterns.

Preliminary results indicate that Kemp's ridleys spent on average 17% of the time at the surface across all years of data and all spatial locations. This average time barely fluctuated when we further examined this proportion by season. While this analysis is ongoing, preliminary results from the GAMM suggest that Kemp's ridley dive behavior, specifically the time they spend at the surface, is influenced by their spatial location in the GOM, water depth, and the distance to the continental shelf. Loggerheads spent on average approximately 16% of time at the surface. This average was slightly lower for the Western planning area defined by BOEM, likely due to a lack of tracking data for this species as most tagged individuals hugged the Florida coastline and only moved as far west as Louisiana. Loggerhead time at surface also dropped slightly during the winter months and peaked during April–August, which coincides with the general timing of the nesting season. Preliminary results from the GAMM suggests that sea surface temperature anomaly, distance to the shelf, depth, and salinity are all significant environmental co-variates that influence loggerhead dive behavior in the GOM. Though there is a much lower sample size for green turtles, the data show that this species has a slightly higher mean time at the surface compared to the other two species (19%). Also, the range for time at surface for green turtles is wider when examined across all individuals. Time spent at surface peaked in summer, July specifically, which coincides with green turtle nesting season activity. Proportions were similar in other seasons. GOMMAPPS analyses will include experimenting with different statistical approaches to model green turtle dive behavior in relation to environmental covariates due to a limited sample size.

1.17.2 Acceleration Data Logging Project

Despite the information now available on sea turtle diving and movements, little is still known about their fine-scale activities and behavior. Satellite tags are capable of logging dive data, but only provide relatively coarse depth-bin data summaries, such as those provided here. The fine-scale dive profiles and activity budgets for these imperiled species are critical, especially where dredging operations occur. Acceleration data loggers (ADLs) now provide a way to assess turtle behavior at a much finer scale than dive data alone, allowing scientists to empirically measure body movements and orientation. The high-resolution data collected by an ADL can be used to identify and quantify specific behaviors (e.g., various types of swimming behavior based on their flipper-beat frequency and amplitude). When coupled with ADL- collected environmental data (e.g., depth and temperature) and location data collected from an attached satellite tag, ADL data are particularly informative. However, an ADL poses a logistical challenge because the logger stores information to memory; to obtain the data, the ADL must be recovered directly from the animal.

To gather finer-scale data on dive profiles for immature and mature endangered Kemp's ridleys and threatened loggerheads of both sexes, USGS is funded on a separate but related project through the BOEM Environmental Studies Program (Agreement M19PG00003). The work in that project is to develop and test a pop-off package that can be retrieved at-sea after having been affixed to sea turtles for a defined period of time. Data collected from the ADL will be analyzed to decipher behavioral patterns of diving, surfacing, and general activity levels over the course of several days. This information will be paired with location data derived from satellite tags affixed to the same individuals to interpret animal movement patterns in specific locations, characterize dive profiles and areas used by sea turtles throughout the year, and identify and assess physical and biological features of high-use habitats, especially those that overlap with proposed BOEM dredging sites.

This work lays the foundation for a long-term capture-mark-recapture study to determine turtle abundance and distribution in critical segments of the GOM study area. These data will advance the knowledge of what sea turtles are doing in the marine environment, where they are often unobservable to humans. Combining fine scale dive information with genetic analyses, population demographics, health, and foraging studies will allow BOEM to address information gaps as identified through the National Environmental Policy Act (NEPA) process and further Environmental Species Act Section 7 consultations. These data could be used to inform management decisions related to protected species monitoring and significant sediment resource extraction mitigation operations.

1.17.3 Recommendations for Future Work and/or Remaining Gaps to be Filled

BOEM is tasked with minimizing adverse environmental effects related to project-specific dredging operations through deliberate planning efforts and the implementation of relevant and effective mitigation measures. Historically, the US Army Corps of Engineer (USACE), dredging industry, academia, and other partners have contributed to improving protective measures and Best Management Practices, by principally focusing on dredging windows, the use of sea turtle deflecting dragheads, dredging operational parameters, and relocation trawling.

Based on the available literature and feedback recently gathered directly from experts in the sea turtle research and dredging industry community (Ramirez et al. 2017), the priority factors that need more data to improve analysis of entrainment risk included temporal and spatial relationship of sea turtle behavior within the water column (e.g., foraging, migrating, etc.) relative to draghead operating parameters and borrow area design relative to turtle deflecting draghead efficacy. Our results can help inform both of these priorities and fill information gaps.

Based on the results of this study, we recommend future work to fill data gaps:

1) Additonal dive-logging tags could be deployed to fill spatial, temporal gaps for all species. This would include additional in-water tagging efforts on all species, at additional sites and shoals (such as Sabine Pass off of Texas).
2) Fall deployments of depth-logging satellite tags could be performed to obtain fall and winter dive patterns and turtle movements. Results of this study showed that several months was the maximum transmission duration; for example, to obtain January to April dive and spatial data on turtles, December tagging would be necessary. Difficult weather for trawling in the late fall and early winter complicates filling this data gap, but future work to obtain winter dive times for all species of turtles would be valuable.
3) Deployment of popoff ADLs on turtles before, during and after active dredging operations. Planning and conducting such a study could help to answer questions that remain about whether the act of dredging itself attracts or concentrates turtles at the sites, or instead deters them.
4) GAMM modeling as per GOMMAPPS, incorporating as many dive tags with comparable setup files as possible, including consistent day and/or night programming to infer diel differences in dive patterns.

Data collected in this project will be used by importing it into a recently-developed BOEM decision support tool, Analyzing Sea Turtle Entrainment Risk (ASTER, see Ramirez et al. 2017). One significant factor impacting how and when coastal restoration projects are conducted is the potential for entrainment and mortality of federally protected sea turtles when using trailing suction hopper dredges. BOEM seeks to minimize adverse environmental effects related to project- specific dredging operations through deliberate project planning efforts and implementation of relevant and effective mitigation measures. The ASTER tool is a standardized geographically and temporally based decision support tool for use by practitioners in the US Atlantic and GOM regions to assess project-specific dredging entrainment risk for sea turtles within a common framework. ASTER tool users can define biological and environmental parameters for candidate dredging areas, including suitable benthic habitat, bottom type, bathymetry, and sea turtle presence and/or density; our data will be used to update the sea turtle presence maps currently in the tool. The final output of the ASTER tool includes a report informing the user of the relative risk to sea turtles at sites within the selected area of interest, thus providing resource managers a documented process of the mitigation factors considered for site specific projects. The ASTER tool will be used to guide future mitigation planning decisions within marine mineral resource areas, so that better informed decisions may minimize impacts to sea turtle species.

Conclusions

The Outer Continental Shelf Lands Act and associated laws authorize the Bureau of Ocean Energy Management (BOEM) to lease sediment resources from the OCS for shore protection, beach nourishment, and wetlands restoration for public works projects. BOEM conducts studies and employs vigorous environmental oversight to understand and mitigate potential impacts from the removal of OCS sediment. BOEM is the only federal agency authorized to convey marine minerals from the OCS. The program also responds to commercial requests for OCS minerals, such as gold, manganese, or other hard minerals, through competitive leasing procedures. BOEM is responsible for managing OCS sediment resources; the need and importance of these critical resources is clear. Known reserves of OCS sediment resources have become increasingly scarce due to ever-increasing requests for sand, resulting from depletion of nearshore and inland sand, major storm impacts, and sea level rise. Multiple-use conflicts sometimes develop from overlapping interest in and uses for OCS sediment resources. The data and findings presented here will help BOEM further develop a proactive program to meet future challenges associated with the spatial overlap of protected species and key resources to be extracted.

Project goals included identifying sea turtle dive patterns and habitat use at shoals and other areas where dredging occurred. The project study sites provided a mix of dredged areas for ongoing regional restoration plans. Leveraging ongoing relocation trawling allowed funding dispersed in the project to be maximized and provided spatial coverage of several rather than one site (e.g., Ship Shoal). The extent of seasonal movements could not be evaluated across the year because the majority of satellite tags transmitted for only four months, on average. This is an artifact of the northern Gulf of Mexico (GOM) high fouling rates (see Reeves et al. 2018), rather than failure of tagging equipment or tag attachment procedures. Thus, during tracking periods, high site fidelity to the capture locations was observed, with only southern GOM movements documented for a small proportion of tagged turtles. Finally, though future work on anti-fouling sensors may help to improve tracking durations, wintertime captures and tracking will be necessary to obtain winter movements and dive patterns.

This project provides a foundation for capture-mark-recapture work in these study sites, which could contribute to future research towards determination of species-specific vital rates and population abundance. The genetic signature of turtles captured at our study sites, which represent mixed-stock foraging grounds, highlighted connections to known nesting beaches, including a rare Cape Verdean link. Isotopic signatures highlighted food web resource use levels, against which changes can be measured in the future should resources available in the study sites shift or be perturbed. Future work with additional captures of subadult and adult turtles would be valuable to increase understanding of the origins of turtles living in these sites of interest because of sand resources.

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