OCS Study
BOEM 2023-064

# Gulf of Mexico Marine Assessment Project for Protected Species: Sea Turtles

**US Department of the Interior**
**Bureau of Ocean Energy Management**
**Gulf of Mexico Regional Office**
**New Orleans, LA**

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# Gulf of Mexico Marine Assessment Project for Protected Species: Sea Turtles

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## ABOUT THE COVER

An adult female Kemp's ridley that was captured via trawler in Mississippi Sound in November 2017 and then recaptured while nesting on Rancho Nuevo, Mexico in April 2018. Photo credit: US Geological Survey.

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# Contents

## List of Figures



## List of Tables

## List of Abbreviations and Acronyms

| Short Form | Long Form |
|---|---|
| BLM | Bureau of Land Management |
| BOEM | Bureau of Ocean Energy Management |
| BSEE | Bureau of Safety and Environmental Enforcement |
| CCL | curved carapace length |
| CCW | curved carapace width |
| DNA | deoxyribonucleic acid |
| FTA | Flinders Technology Associates |
| FWC | Florida Fish and Wildlife Conservation Commission |
| GOMMAPPS | Gulf of Mexico Marine Assessment Program for Protected Species |
| Gulf | Gulf of Mexico |
| IACUC | Institutional Animal Care and Use Committee |
| KDE | kernel density estimate |
| MMS | Minerals Management Service |
| NEPA | National Environmental Policy Act |
| NMFS | National Marine Fisheries Service |
| NOAA | National Oceanic and Atmospheric Administration |
| OCS | Outer Continental Shelf |
| OCSLA | Outer Continental Shelf Lands Act |
| PCR | polymerase chain reaction |
| PIT | passive integrated transponder |
| SCL | straight carapace length |
| TAS | time at surface |
| USFWS | US Fish and Wildlife Service |
| USGS | US Geological Survey |
| WARC | Wetland and Aquatic Research Center |

## Introduction

Globally, all sea turtle species, except the olive ridley (*Lepidochelys olivacea*) are considered imperiled. Although sea turtles are generally a well-researched taxon, knowledge gaps persist with respect to reproductive biology, conservation status, and threats (Rees et al. 2016). Filling these gaps is difficult for wide-ranging marine species such as sea turtles as they have a complex life-history that involves several ontogenetic shifts in habitat use (Bolten 2003). Advances in technology such as satellite telemetry help refine our understanding of spatial ecology but are typically conducted on regional scales. A broad-scale, basin-wide understanding of sea turtle distribution requires interdisciplinary and collaborative studies (Wildermann et al. 2019).

Sea turtles use a variety of habitats throughout their lives, including sandy beaches, open ocean, coastal bays, and nearshore waters. Once they reach reproductive maturity, females migrate sometimes thousands of kilometers from nearshore foraging areas to nesting beaches every 3–5 years to deposit eggs. The eggs incubate and hatchlings emerge onto those sandy beaches before they enter the ocean, swim rapidly offshore and take refuge in offshore *Sargassum* habitat for 1–3 years. As juveniles, sea turtles move into nearshore habitats and coastal bays where they will forage until they reach sexual maturity. Adult turtles also establish foraging home ranges in nearshore waters and those home ranges may overlap with juvenile foraging areas (Lamont et al. 2015). Broad-scale, multi-seasonal and multi-year surveys are necessary to derive density estimates as life-stages overlap and variations in movements occur.

The Gulf of Mexico (Gulf) is one of the most biodiverse ocean basins in the world (Costello et al. 2010). The rich variety of invertebrate species provide the prey for many higher trophic level species, including sea turtles. Five sea turtle species, all listed under the US Endangered Species Act, inhabit the northern Gulf including the threatened loggerhead (*Caretta caretta*), critically endangered Kemp's ridley (*Lepidochelys kempii*), threatened green turtle (*Chelonia mydas*), threatened leatherback (*Dermochelys coriacea*), and endangered hawksbill (*Eretmochelys imbricata*). Gulf nearshore waters and coastal bays provide sea turtle foraging habitat (Hart et al. 2013, 2014; Lamont and Iverson 2018). Additionally, sandy beaches across the northern Gulf support green sea turtles (Lamont et al. 2023), leatherbacks (NMFS and USFWS 1992), and a genetically distinct group of nesting loggerheads (Shamblin et al. 2012) and represent the only historic nesting habitat for Kemp's ridleys in the world (Bevan et al. 2016; Shaver et al. 2016).

Although the Gulf contains some of the highest levels of species per unit area in the world, it is also one of the most threatened habitats. Overfishing, habitat loss, and pollution rank as some of the top threats to marine biodiversity in the Gulf (Costello et al. 2010). Additionally, in April 2010, over three million barrels of oil leaked into northern Gulf waters after the *Deepwater Horizon* drilling rig exploded (Malakoff 2015). These stressors may impact sea turtle species and life-stages disproportionally depending on species-specific trends in habitat use and locations of migratory pathways. For example, juvenile Kemp's ridleys are captured at least 2.5 times more frequently in commercial fishing activities than juvenile green turtles (Putman et al. 2023). Additionally, while some activities are limited to one general region, most, such as vessel traffic and commercial fishing activities, occur across the entire ocean basin. Therefore, knowledge of sea turtle distribution and habitat use basin-wide in the Gulf across life-stages and species would aid in management and conservation of the species (Sequeira et al. 2018).

Data on sea turtle movements and distribution in the Gulf have only recently become available. Adult female loggerheads forage predominately along the West Florida Shelf and off Mexico (Girard et al. 2009; Foley et al. 2014; Hart et al. 2014; Ceriani and Meylan 2015), while adult Kemp's ridleys primarily use foraging areas in the western Gulf (Shaver et al. 2017). Overlap in home ranges between the two species occurs in the northern Gulf (Hart et al. 2018a). Green turtles nest in low numbers in the northern Gulf ; those females establish foraging areas in the southern Gulf including the Florida Keys (Lamont et al. 2023). Juvenile loggerheads, Kemp's ridleys, and green turtles forage in coastal bays (Lamont and Iverson 2018) and nearshore waters throughout the Gulf, often in similar areas (Lamont and Iverson 2018; Wildermann et al. 2018; Lamont and Johnson 2021). Although leatherbacks do not nest in large numbers on Gulf beaches, individuals from Central America forage in the northern Gulf (Sasso et al. 2021).

One important and persistent knowledge gap in sea turtle ecology in the Gulf, and globally, is an understanding of sea turtle dive behavior. This is particularly significant as sea turtles demonstrate the longest reported breath-hold dives of all marine animals and spend more than 90% of their time underwater (Hochscheid et al. 2010; Hochscheid 2014; Iverson et al. 2019). Dive behavior is impacted by environmental and oceanographic variables and can vary seasonally, by activity (e.g., migration vs foraging), by species and by life-stage (Hochscheid et al. 2014; Iverson et al. 2019). Dive patterns provide information on sea turtle time-on-bottom and time-at surface (TAS) defined as the top two meters of the water column. These times impact aerial surveys and are when sea turtles are most vulnerable to threats (e.g., vessel strikes, trawling, see Thomson et al. 2013; Hochscheid et al. 2014; Fuentes et al. 2015; Hart et al. 2018b; Fuentes et al. 2021; Hart and Lamont 2022). There are few dive data sets for turtles in the Gulf of Mexico so limited information on sea turtle surface time exists.

The primary method used to assess broad-scale density and distribution for marine animals, including sea turtles, is aerial surveys which utilize line transect sampling (Epperly et al. 1994; Fuentes et al. 2015). However, a primary assumption of this method is that all animals on the transect line are detected and this assumption cannot be met when surveying marine animals (Buckland et al. 1993) as some proportion of individuals will be underwater when the survey aircraft passes above. This assumption can be mitigated by correcting the survey data for reduced probability of detection for those underwater individuals, however the usefulness of those correction factors depends on the accuracy of the detection probabilities. Generating detection probabilities is particularly challenging for sea turtles as they spend such a small proportion of their time at the surface (Okamura et al. 2006; Fuentes et al. 2015). The first step towards generating species-specific correction factors for aerial surveys is to determine which environmental drivers influence surface intervals.

This study builds upon two previous studies (Garrison et al. 2019; Hart and Lamont 2022) and provides information on turtle dive behavior, specifically TAS, for juvenile and adult (male and female) loggerhead, Kemp's ridley and green turtles in the US Department of the Interior's Bureau of Ocean Energy Management (BOEM) Eastern, Central, and Western planning areas (Figure 1). These results will contribute to broad-scale spatially explicit density models that incorporate environmental and oceanographic parameters and will improve aerial survey counts. Furthermore, the model output can be used by various management and regulatory agencies in decisions that may impact the Outer Continental Shelf (OCS) habitats as well as for critical habitat designations.

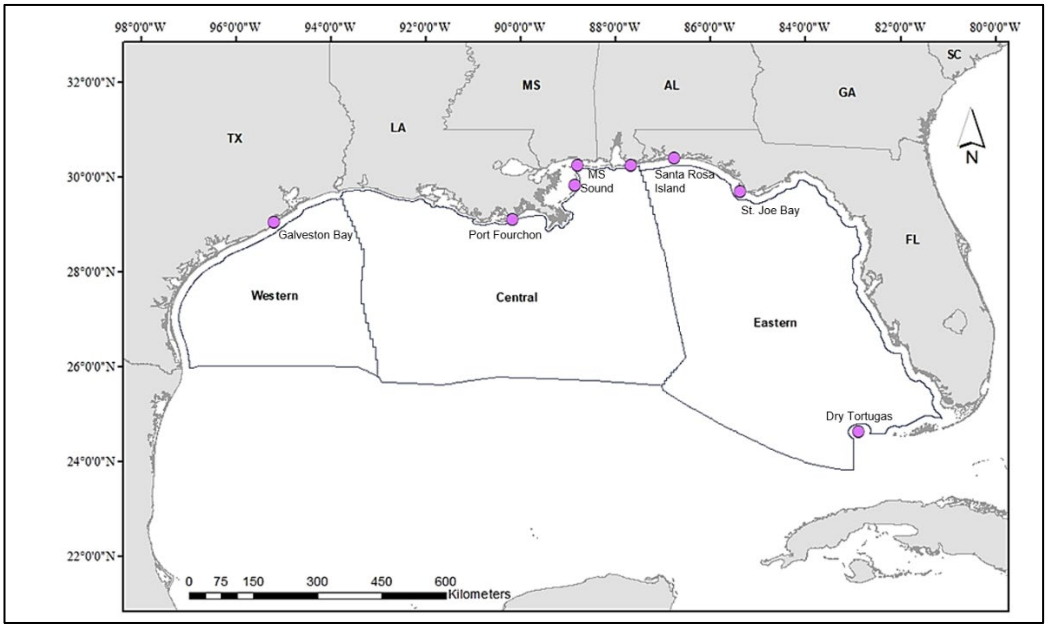


**Figure 1. Locations (purple dots) where sea turtles were captured and tagged along with boundaries of BOEM's Eastern, Central and Western planning areas across the US Gulf of Mexico.**

## 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. The OCSLA Amendments of 1978 (92 Stat. 629) established a policy for the management of oil and natural gas on the OCS and for protection of the marine and coastal environments. The amendments authorized the Secretary of the Interior to conduct studies in areas or regions of sales to ascertain the "environmental impacts on the marine and coastal environments of the OCS and the coastal areas which may be affected by oil and gas development" (43 USC 1346).

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. To meet its responsibilities, BOEM has four priority goals for OCS leasing: (1) orderly resource development to meet the Nation's energy needs; (2) protection of the marine and coastal environments; (3) receipt of fair market value; and (4) preservation of free-enterprise competition.

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 assessments, studies that acquire and analyze marine environmental data, literature surveys, socioeconomic-analysis studies, public conferences, and special studies (toxicity studies, spill-trajectory analyses, etc.).

## 1.2 BOEM and USGS Relevance and Benefits

The US Geological Survey Wetland and Aquatic Research Center (WARC) conducts relevant and objective research, develops new approaches and technologies, and disseminates scientific information for management, conservation and restoration of aquatic species and their habitats throughout the U.S. and the world. Founded in 2009, the WARC was created to bring together scientific experts in biology and ecology throughout the Southeastern US and Caribbean. WARC's roots lie in US Fish and Wildlife Service and National Park Service research units that were brought into the USGS as the Biological Resources Division in 1994. The WARC continues to support the Department of the Interior mission by providing state-of-the-art, accurate scientific information to the public and resource managers.

For this study, the US Geological Survey (USGS) and BOEM collaborated with the US Fish and Wildlife Service (USFWS) and the National Oceanic and Atmospheric Administration (NOAA) to design a project that would provide spatially-explicit density and distribution information for sea turtles, marine mammals, and seabirds in the Gulf , with a particular focus on under-studied life-stages, species, and geographic locations. TAS data for sea turtles in the northern Gulf will enable generation of accurate density and abundance estimates from aerial survey data, particularly for previously understudied life-stages, species, and geographic locations. Filling these knowledge gaps will enhance decision-making abilities for BOEM related to OCS activities including exploration of oil and gas, decommissioning of energy platforms, renewable energy development, and marine mineral development (e.g., dredging).

## 1.3 USGS Objectives and Goals

The overarching goal of the Gulf of Mexico Marine Assessment Project for Protected Species: sea turtles (GOMMAPPS) study was to collect broad-scale information on the distribution and abundance of sea turtles in the Gulf to inform seasonally- and spatially-explicit density estimates for priority species. GOMMAPPS represents a multi-agency partnership between BOEM, USFWS, NOAA, and USGS, all of whom collect information on large marine vertebrates to provide improved spatially-explicit density distributions for multiple management objectives. Though GOMMAPPS is intended to provide broad-scale information, specific locations identified for satellite tagging targeted regions of highest oil and gas activity (i.e., in the Central and Western Gulf of Mexico).

The objectives of the USGS role in GOMMAPPS were to:

1. Provide TAS data to NOAA for sea turtle density estimates that will be generated from broadscale aerial surveys conducted by NOAA and USFWS throughout US Gulf neritic waters over multiple years (see Figure 2).
2. Use satellite telemetry and state space modeling to identify spatial distribution, home ranges, dive patterns and TAS for hard shelled turtles in BOEM's Central and Western planning areas.
3. Use genetic analyses to describe sea turtle stock of origin.

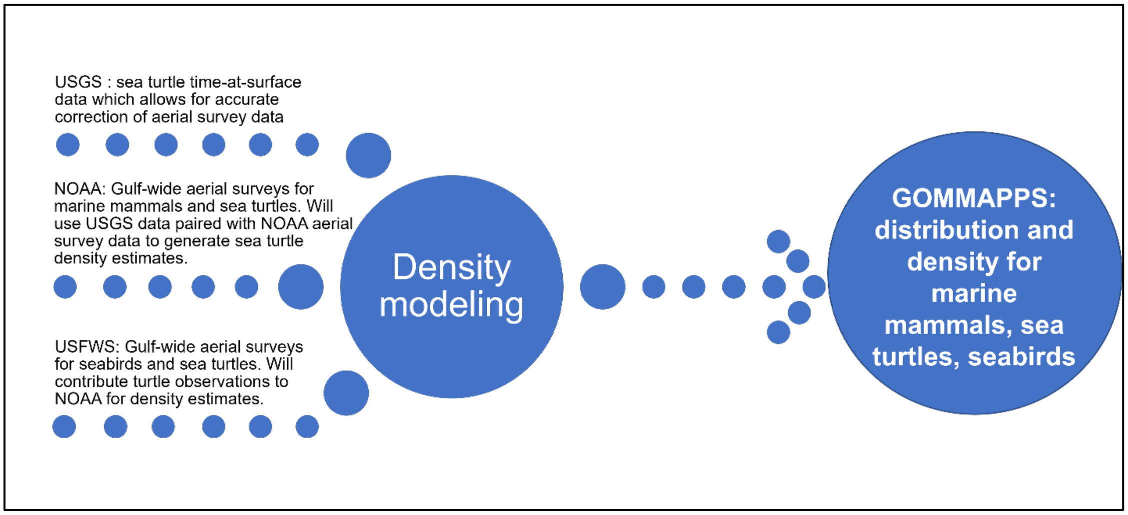


**Figure 2. Contributions to the overall GOMMAPPS objective of generating distribution and density estimates for marine mammals, sea turtles, and seabirds in the Gulf of Mexico.**

# 2 Methods

This project included three primary tasks undertaken by USGS: satellite tracking, TAS estimation (defined by the top 2 m of the water column), and genetic analyses. In addition, Gulf-wide sea turtle density and distribution data were gathered during aerial surveys conducted as part of the marine mammal (NOAA) and seabird (USFWS) portions of the GOMMAPPS program (see Rappuci et al. 2023; Gleason et al[1]).

Turtles were captured at in-water sites throughout the Gulf (Figure 1) using a variety of methods including tangle net, hand capture, and trawling. In addition, a subset of GOMMAPPS satellite tags were deployed on adult green turtles captured on nesting beaches in Northwest Florida. Biological samples were collected for mitochondrial DNA analyses at the University of Georgia.

Turtle captures for GOMMAPPS focused on BOEM's Central Planning Area, with a few select individuals (e.g., adult male green turtles) tagged in the southern portion of the Eastern Planning Area (Figure 1). Turtles were captured primarily at in-water sites that ranged from Northwest Florida to Galveston, Texas to Dry Tortugas National Park, Florida. In addition, satellite tags were deployed on adult female nesting green turtles at two beaches in Northwest Florida. Aerial survey data collected during marine mammal (NOAA) and seabird (USFWS) surveys were conducted over the entirety of the US Gulf of Mexico coast during 2017–2018 (Figure 3).

[1] Gleason JS, Sussman AL, Davis KL, Haney JC, Hixson KM, Jodice PGR, Lyons JE, Michael PE, Satgé YG, Silverman ED, Zipkin EF, and Wilson, RR. In review. Gulf of Mexico Marine Assessment Program for Protected Species (GOMMAPPS): seabird surveys in the Northern Gulf of Mexico, 2017–2020. New Orleans (LA): US Department of the Interior, Bureau of Ocean Energy Management. Interagency Agreement No.: M17PG00011. Report No.: OCS Study BOEM 2023-xxx.

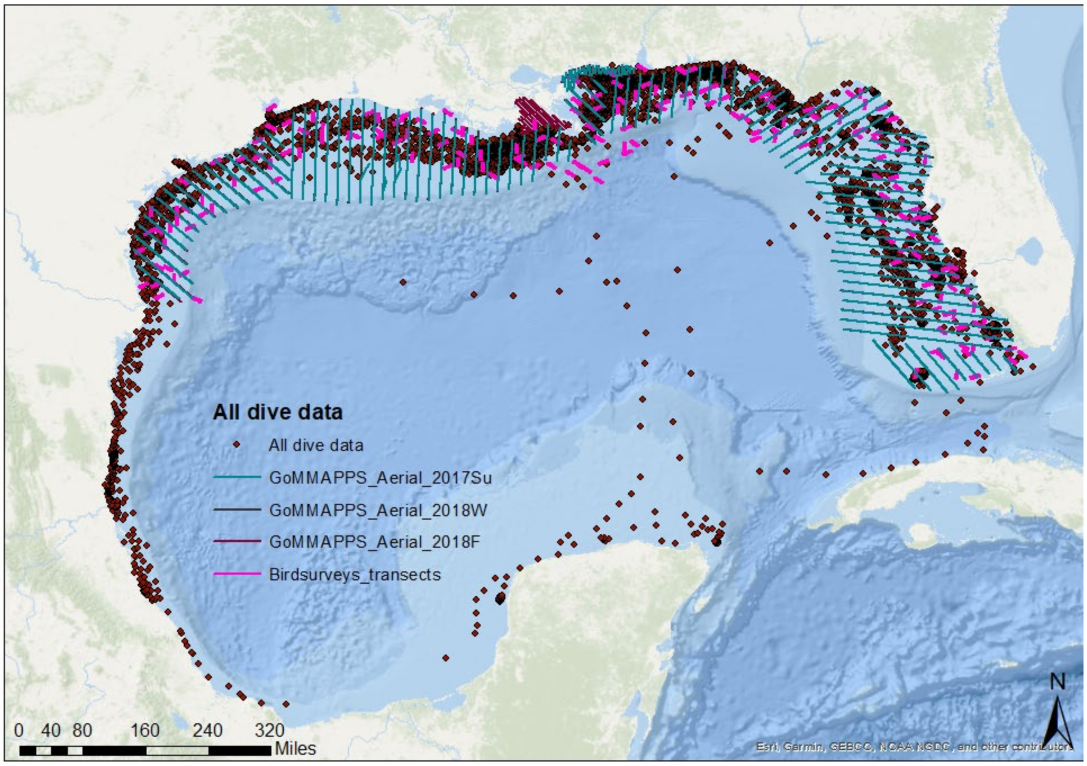


**Figure 3. Sea turtle depth locations, NOAA aerial survey tracklines (GoMMAPPS aerial) and USFWS aerial survey (Birdsurveys) tracklines.**

Combined, these data will contribute to density estimates for marine mammals, sea turtles, and seabirds across the Gulf of Mexico.

## 2.1 Training and Permitting

All turtle handling was conducted in accordance with permit requirements identified in NOAA permits 17304 and 21366, Louisiana Department of Wildlife and Fisheries (LNHP-18-006 and WDP-19-006), MS State Permit SRP-037-17, Dry Tortugas National Park permit DRTO-2018-SCI-0007, and FWC permits 118 and 176. All activities complied with NMFS approved methods (Stokes et al. 2008) and USGS Animal Care and Use Committee (IACUC; USGS/WARC/GNV 2019-15) standards.

## 2.2 Turtle Capture and Sampling

Turtle capture and tagging was opportunistic and followed the methods described in Hart and Lamont (2022) and protocols (NMFS and USFWS 2008) approved by the USGS's Institute for Animal Use and Care Committee (IACUC). Turtles were captured between July 2017 and October 2019 using set net, dip net, hand capture, or trawling methods. Relocation trawling involved 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 involved a contracted trawler operating 12 hours a day along tracks pre-determined by the USGS research team unrelated to hopper dredge operations. Turtles captured by relocation trawlers were released approximately 13 km from capture sites, whereas turtles captured by directed trawling were released at their capture sites. Tow times were limited to 30 min and were conducted at between 3 and 6 km/hr.

All captured turtles were individually marked with a metal Inconel tag placed along the trailing edge of each front flipper and a passive integrated transponder (PIT) tag placed subcutaneously. Turtles were measured using two methodologies: (1) straight carapace length (SCL) and width (SCW) using calipers, and (2) curved carapace length (CCL) and width (CCW) using a flexible tape measure. Tissue samples were collected from the rear flipper of each captured turtle using sterile 6 mm biopsy punches, and 2 ml of whole blood was collected from the dorsal cervical sinus (Owens and Ruiz 1980). Samples were separated 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. Additionally, a portion of each blood sample was placed onto FTA cards (Whatman, Inc.) and kept dry at room temperature until processing.

## 2.3 Satellite Tracking

Sea turtle capture, tagging, and tracking techniques are well-developed (see Hart et al. 2013, 2014; Lamont et al. 2018) for documenting movement and habitat use areas. Satellite tags (called platform transmitter terminals or PTTs) were adhered using slow-curing epoxy (two-part Superbond epoxy; see Hart et al. 2021). Several types of Wildlife Computers PTT models were selected for the project: SPLASH10-309A (7.6 cm x 5.6 cm x 3.2 cm, mass 125 g), SPLASH10-238A-AF (10.5 cm x 5.6 cm x 3.0 cm, mass 213 g), SPOT6-375 (9.9 cm x 5.5 cm x 2.1 cm, mass 152 g), SPOT5-287 (7.0 cm x 4.0 cm x 2.3 cm, mass 72 g), SPLASH10-F-344 (8.6 cm x 8.6 cm x 2.8 cm, mass 231 g), SPLASH10-F-351 (8.6 cm x 5.5 cm x 2.5 cm, mass 149 g), MK10-PAT (1.2 cm x 3.8 cm, mass 61 g), and MK10 (8.4 cm x 5.2 cm x 2.2 cm, mass 201 g) tags. We 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).

### 2.3.1 Home Range Analyses

We used the satellite-based Argos system to collect turtle location data, and accuracy estimates were assigned using Kalman filtering (Kalman 1960; CLS 2015). Satellite locations with location class (LC) Z were excluded. Using the satellite data as our input, we applied Bayesian hierarchical state space modeling (SSM; Jonsen 2016) in R (R Core Team 2020) to estimate location and behavioral mode for each turtle at consistent time intervals, following model specifications in Hart et al. (2020) and Benscoter et al. (2022) in the R packages "bsam" (Jonsen 2016; Jonsen et al. 2005; Jonsen et al. 2017) and "rjags" (Plummer 2016). We omitted temporal gaps >20 days, and split track sections with <50 locations (Hart et al. 2020; Benscoter et al. 2022*)*. We ran the SSM with a 24 h time step and spatially compared SSM outputs to the satellite locations for quality assurance. The SSM categorized each location into one of two behavioral modes that were defined as "area-restricted searching" (ARS) or "transiting," which we deemed migration (Jonsen et al. 2007, 2013). Briefly, ARS was characterized by relatively tortuous tracks and slow swim speeds; and transiting was characterized by relatively straight tracks and fast swim speeds (see Hart et al. 2020; Benscoter et al. 2022). The end of migration and start of foraging was determined by identifying the asymptote of the cumulative distance vs. deployment duration and a corresponding SSM mode switch from migration to ARS and no further movement away from the foraging grounds. Prior to analysis, SSM locations on land were filtered out, as well as those that represented speeds >5 kph. The R package "geosphere" (Hijmans 2019) was used for distance calculations, and ArcGIS 10.8.1 (ESRI 2020) was used for mapping and depth calculations. The Global Self-consistent, Hierarchical, High-resolution Geography Database shoreline layer was used (GSHHG; Wessel and Smith 1996), and the ETOPO1 Bedrock cell-registered bathymetry (Amante and Eakins 2009) was used for calculating water depth.

### 2.3.2 Foraging

For turtles with ≥20 days of SSM locations for foraging mode, kernel density estimation (KDE; Worton 1995; Keating and Cherry 2009) was used with filtered SSM locations following methods in Hart et al. (2020); the 50% and 95% KDE represented the core use area and the overall home range, respectively (Hooge et al. 2001). When <30 SSM locations were available, KDE estimation was not possible. All KDEs were calculated using the R package "adehabitatHR" (Calenge 2006), and the in-water area ($km^2$) for each KDEand depth at each 50% KDE centroid (geometric center) was the distance to shore from each centroid (km) was calculated in ArcGIS 10.8.1 (ESRI 2020). For individuals with multiple KDE activity centers, summary values reported were for the largest activity center.

### 2.3.3 Dives

Though this analysis is specifically focused on time at surface, tags were programmed tags to collect time-at-depth (TAD) in the following bins: 0, 1, 2, 3, 4, 5, 10, 20, 30, 40, 50, 100, and 150 m. Tags were programmed to collect data for a full 24-hour period and summarize all data every 12 hours.

The proportions of time turtles spent at the surface (top 2 meters of water column) was summarized, therefore, we calculated the total proportion of time spent in the top three bins for each dive observation. This information was then used to examine patterns across species, season, and spatial location.

## 2.4 Genetic analyses

Tissue and blood samples collected from turtles were sent to the University of Georgia for mitochondrial DNA analyses that included DNA extractions, PCR amplifications, and sequencing (Shamblin et al. 2012). There, 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 (University of Florida) for haplotype assignment. The resulting haplotype profiles were compared with available published data from nesting and foraging populations in the region.

# 3 Results

## 3.1 Data Collection and Tag Deployment Schedule

From July 2017 to October 2019, 48 turtles were captured, sampled, and outfitted with satellite tags funded by BOEM for GOMMAPPS (Table 1). Most turtles (n=29) were captured in the Eastern Planning Area, whereas 23 were captured in the Central Planning Area and 1 was captured in the Western Planning Area. Loggerheads ranged in size from 58.4 to 105.6 cm CCL (mean 75.5 cm), Kemp's ridleys ranged in size from 40.3 to 67.8 cm CCL (mean 57.8 cm) and green turtles ranged in size from 37.9 cm to 109.1 cm CCL (mean 80.3 cm).

**Table 1. Summary of all turtles captured as part of the GOMMAPPS project**

PTT = platform transmitter type; Cm = green turtle, Lk = Kemp's ridley, Cc = loggerhead; juv = juvenile; U = unknown sex, F = female, M = male; SRI = Santa Rosa Island, Florida; MS = Mississippi Sound; Fourchon = Port Fourchon, LA; SJB = St. Joseph Bay, Florida; SJP = St. Joseph Peninsula, Florida; SJB = St. Joseph Bay, Florida; DRTO = Dry Tortugas National Park; AL = Alabama; CCL = curved carapace length.

| PTT ID | PTT type | Species | Age class | Sex | Location | Method | CCL (cm) | Capture date | Total tracking days |
|---|---|---|---|---|---|---|---|---|---|
| 172681 | SPOT6 | Cc | adult | F | Chandeleurs | trawl | 80.0 | 1/25/2018 | 434 |
| 175694 | MK10 | Cc | juv | U | MS | trawl | 61.0 | 10/6/2018 | 62 |
| 175697 | MK10 | Cc | adult | F | MS | trawl | 82.4 | 10/16/2018 | 126 |
| 172669 | MK10 | Cc | juv | F | MS | trawl | 63.0 | 10/19/2018 | 58 |
| 175691 | Mk10-PAT | Cc | juv | U | MS | trawl | 69.9 | 5/13/2019 | 82 |
| 181792 | SPOT6 | Cc | juv | U | AL | hand | 58.4 | 8/5/2019 | 42 |
| 172679 | SPOT6 | Cc | juv | U | SRI | hand | 85.6 | 8/23/2018 | 169 |
| 172680 | SPOT6 | Cc | juv | U | SRI | hand | 71.2 | 9/19/2018 | 330 |
| 172672 | Mk10-PAT | Cc | adult | F | SJP | nesting | 88.0 | 7/17/2018 | 253 |
| 172683 | SPOT6 | Cc | juv | U | SJB | hand | 76.5 | 7/27/2018 | 438 |
| 181793 | SPOT6 | Cc | adult | M | SJB | hand | 105.6 | 8/30/2019 | 676 |
| 172667 | Mk10-PAT | Lk | adult | F | MS | trawl | 57.7 | 11/2/2017 | 80 |
| 172668 | Mk10-PAT | Lk | adult | F | MS | trawl | 67.6 | 11/4/2017 | 229 |
| 172673 | MK10 | Lk | adult | F | MS | trawl | 60.2 | 9/8/2018 | 51 |
| 172666 | MK10 | Lk | adult | F | MS | trawl | 67.8 | 9/9/2018 | 54 |
| 172675 | MK10 | Lk | adult | F | MS | trawl | 66.0 | 9/9/2018 | 2 |
| 175695 | MK10 | Lk | adult | F | MS | trawl | 57.6 | 10/6/2018 | 126 |
| 172674 | MK10 | Lk | adult | F | MS | trawl | 65.5 | 10/15/2018 | 139 |
| 175696 | MK10 | Lk | adult | F | MS | trawl | 57.5 | 10/15/2018 | 594 |
| 175693 | MK10 | Lk | adult | F | MS | trawl | 66.1 | 9/8/2019 | 29 |
| 176036 | SPOT6 | Lk | juv | U | SRI | tangle | 40.3 | 8/8/2018 | 110 |
| 176032 | SPOT6 | Lk | juv | U | SRI | tangle | 54.3 | 9/14/2018 | 92 |
| 176035 | SPOT6 | Lk | juv | U | SRI | tangle | 40.8 | 9/14/2018 | 172 |
| 172676 | SPOT6 | Lk | juv | U | SJB | hand | 52.9 | 8/22/2018 | 73 |
| 172671 | SPLASH10 | Lk | juv | U | SJB | hand | 54.6 | 9/26/2018 | 15 |
| 172678 | SPOT6 | Cm | juv | U | Texas | tangle | 54.5 | 7/16/2018 | 354 |
| 172670 | MK10 | Cm | juv | U | Fourchon | dip net | 54.4 | 12/5/2017 | 175 |
| 175689 | SPLASH10 | Cm | juv | U | Fourchon | dip net | 57.9 | 12/3/2018 | 256 |
| 175690 | Mk10-PAT | Cm | juv | U | Fourchon | dip net | 60.0 | 12/3/2018 | 77 |
| 172685 | SPOT6 | Cm | juv | U | Fourchon | dip net | 48.4 | 12/4/2018 | 295 |
| 172684 | SPOT6 | Cm | juv | U | Fourchon | dip net | 46.5 | 12/6/2018 | 478 |

| PTT ID | PTT type | Species | Age class | Sex | Location | Method | CCL (cm) | Capture date | Total tracking days |
|---|---|---|---|---|---|---|---|---|---|
| 175688 | SPLASH10 | Cm | juv | U | Fourchon | dip net | 56.6 | 4/26/2019 | 110 |
| 142659 | SPOT5 | Cm | juv | U | MS | trawl | 37.9 | 11/3/2017 | 214 |
| 181790 | SPOT6 | Cm | juv | U | AL | tangle | 42.0 | 10/14/2019 | 141 |
| 161466 | Mk10-PAT | Cm | adult | F | SRI | nesting | 112.7 | 7/15/2017 | 47 |
| 142658 | SPOT | Cm | juv | U | SRI | tangle | 41.5 | 9/20/2017 | 172 |
| 181795 | MK10 | Cm | adult | M | SRI | hand | 100.0 | 6/27/2019 | 64 |
| 181806 | MK10 | Cm | adult | F | SRI | nesting | 102.7 | 6/30/2019 | 112 |
| 175692 | SPLASH10 | Cm | adult | F | SJP | nesting | 100.8 | 6/14/2019 | 265 |
| 172677 | SPOT6 | Cm | adult | F | SJP | nesting | 105.8 | 6/29/2019 | 80 |
| 181803 | MK10 | Cm | adult | F | SJP | nesting | 103.6 | 7/6/2019 | 158 |
| 181807 | MK10 | Cm | adult | F | SJP | nesting | 102.2 | 7/9/2019 | 215 |
| 181802 | MK10 | Cm | adult | F | SJP | nesting | 109.1 | 7/15/2019 | 437 |
| 175686 | SPLASH10 | Cm | adult | F | DRTO | hand | 102.3 | 8/15/2018 | 494 |
| 175685 | SPLASH10 | Cm | adult | F | DRTO | hand | 103.2 | 8/16/2018 | 230 |
| 175687 | SPLASH10 | Cm | adult | F | DRTO | hand | 105.3 | 8/16/2018 | 425 |
| 175699 | SPLASH10 | Cm | adult | F | DRTO | hand | 95.0 | 8/14/2018 | 268 |
| 175698 | SPLASH10 | Cm | adult | M | DRTO | hand | 104.3 | 8/17/2018 | 848 |

Of those 48 tags deployed, 21 provided depth data; these tags were deployed on 10 green turtles, 8 Kemp's ridleys, and 3 loggerheads. Depth-tagged turtles ranged in size from 54.4 cm CCL (green turtle) to 112.7 cm CCL (green turtle).

## 3.2 Satellite telemetry

All turtles (n=48 tags) were tracked for a total of 2,286 days and mean tracking durations for all turtles was 130 days. Species-specific differences in tracking duration were observed, as loggerheads were tracked for 310 days with a mean tracking duration of 156 days; they were tracked most frequently into the Eastern and Central Planning Areas. Kemp's ridleys were tracked for 559 days with a mean tracking duration of 100 days; they were tracked most frequently into the Western Planning Area.

Green turtles were tracked for 1,417 days with a mean tracking duration of 163 days; they were tracked most frequently into the Eastern and Central Planning Areas.

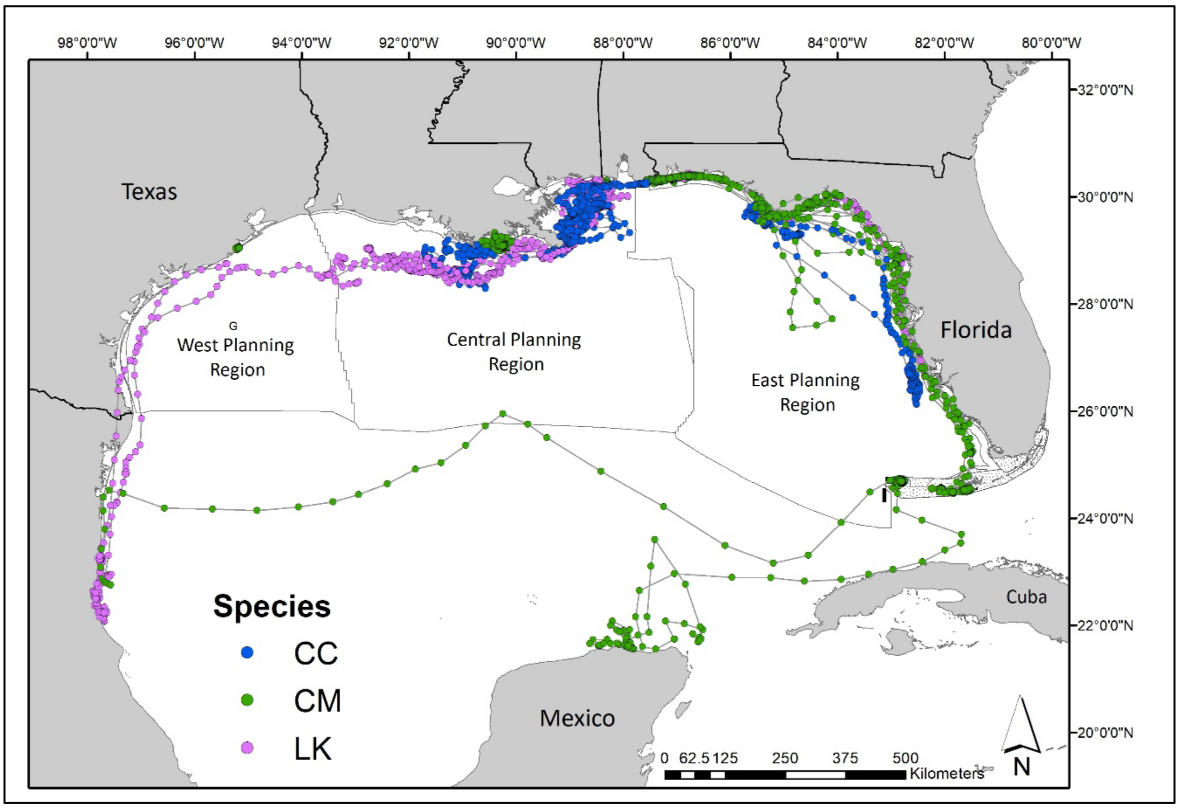


**Figure 4. SSM tracks per BOEM planning area from satellite tags deployed during the GOMMAPPS project on loggerheads (CC), Kemp's ridleys (LK) and green turtles (CM).**

Several individuals of all three species crossed international boundaries and used waters off Mexico and/or Cuba (Figure 4).

Foraging KDEs were calculated for 28 individuals including 10 loggerheads, 3 Kemp's ridleys and 15 green turtles (Table 2, Figure 5); for large adult green turtles summary, see Lamont et al. (2023). Where KDE was not possible, fewer than 30 SSM locations were predicted.

**Table 2. Foraging home range details (KDE area and period, depth of 50% KDE) for GOMMAPPS turtles**

Note "_" indicates track split, but same turtle denoted with PTT id. Note U = unknown, F = female, M = male. Location abbreviations are as in Figure 1.

| PTT ID | Species | Life stage | Sex | Tagging location | Start date KDE | End date KDE | Depth at 50% KDE centroid (m) | Area of 50% KDE (km2) |
|---|---|---|---|---|---|---|---|---|
| 172669 | CC | Juvenile | F | Mississippi | 10/21/2018 | 12/8/2018 | 13 | 48.7 |
| 175691 | CC | Juvenile | U | Mississippi | 5/13/2019 | 8/3/2019 | 10 | 495.4 |
| 175694 | CC | Juvenile | U | Mississippi | 10/31/2018 | 12/7/2018 | 13 | 332.4 |
| 175697_1 | CC | Adult | F | Mississippi | 10/17/2018 | 12/1/2018 | 11 | 351.6 |
| 175697_2 | CC | Adult | F | Mississippi | 12/6/2018 | 1/10/2019 | 39 | 853.7 |
| 175697_3 | CC | Adult | F | Mississippi | 1/17/2019 | 2/19/2019 | 34 | 220.9 |
| 181792 | CC | Juvenile | U | Alabama | 8/7/2019 | 9/16/2019 | 6 | 70.8 |
| 172679 | CC | Juvenile | U | Navarre | 9/26/2018 | 12/14/2018 | 8 | 1145.5 |
| 172680_1 | CC | Juvenile | U | Navarre | 10/23/2018 | 12/1/2018 | 1 | 597.6 |
| 172680_2 | CC | Juvenile | U | Navarre | 12/8/2018 | 1/7/2019 | 24 | 555.8 |
| 172681 | CC | Adult | F | Chandeleurs | 1/25/2018 | 7/12/2018 | 15 | 767.6 |
| 172683 | CC | Juvenile | U | SJB | 7/27/2018 | 12/8/2018 | 1 | 26.9 |
| 181793 | CC | Adult | M | SJB | 9/1/2018 | 11/4/2018 | 3 | 14.6 |
| 172666 | LK | Adult | F | Mississippi | 9/9/2018 | 11/1/2018 | 5 | 60.4 |
| 175695 | LK | Adult | F | Mississippi | 10/11/2018 | 12/2/2018 | 16 | 135.1 |
| 175696 | LK | Adult | F | Mississippi | 12/17/2018 | 1/26/2019 | 33 | 3460.3 |
| 142659 | CM | Juvenile | U | Mississippi | 11/3/2017 | 7/3/2018 | 7 | 250.5 |
| 181790 | CM | Juvenile | U | Alabama | 10/14/2019 | 3/3/2020 | 7 | 352.0 |
| 172678 | CM | Juvenile | U | Texas | 7/18/2018 | 12/2/2018 | 1 | 6.9 |
| 142658 | CM | Juvenile | U | SRI | 9/22/2017 | 3/9/2018 | 15 | 271.4 |
| 172670 | CM | Juvenile | U | Fourchon | 12/5/2017 | 5/28/2018 | 1 | 2.0 |
| 172684 | CM | Juvenile | U | Fourchon | 12/8/2018 | 3/27/2020 | 1 | 74.1 |
| 172685 | CM | Juvenile | u | Fourchon | 12/5/2018 | 9/25/2019 | 1 | 6.1 |
| 175688 | CM | Juvenile | U | Fourchon | 4/26/2019 | 8/13/2019 | 1 | 1.8 |
| 175689 | CM | Juvenile | U | Fourchon | 12/3/2018 | 8/15/2019 | 1 | 94.7 |
| 175690 | CM | Juvenile | U | Fourchon | 12/3/2018 | 2/12/2019 | 1 | 10.8 |
| 175685 | CM | Adult | F | Dry Tortugas | 8/17/2018 | 3/15/2019 | 10 | 9.1 |
| 175686 | CM | Adult | F | Dry Tortugas | 8/16/2018 | 12/22/2019 | 9 | 6.8 |
| 175687 | CM | Adult | F | Dry Tortugas | 8/17/2018 | 5/27/2019 | 10 | 5.6 |
| 175699 | CM | Adult | F | Dry Tortugas | 8/15/2018 | 5/9/2019 | 11 | 1.4 |
| 175698_1 | CM | Adult | M | Dry Tortugas | 8/18/2018 | 4/12/2019 | 10 | 3.3 |
| 175698_2 | CM | Adult | M | Dry Tortugas | 5/27/2019 | 7/14/2019 | 3 | 920.1 |
| 161459 | CM | Adult | F | SRI | 7/14/2017 | 10/11/2017 | 2 | NA |
| 161466 | CM | Adult | F | SRI | 7/18/2017 | 8/31/2017 | 5 | NA |
| 181806 | CM | Adult | F | SRI | 7/6/2019 | 10/20/2019 | 4 | 277.7 |
| 175692 | CM | Adult | F | SJP | 6/14/2019 | 1/16/2020 | 4 | 25.5 |
| 172677 | CM | Adult | F | SJP | 6/29/2019 | 9/19/2019 | NA | NA |
| 181803 | CM | Adult | F | SJP | 7/6/2019 | 9/28/2019 | 2 | 25.0 |
| 181807 | CM | Adult | F | SJP | 7/9/2019 | 1/16/2020 | 11 | 33.8 |
| 181796 | CM | Adult | F | SJP | 7/11/2020 | 9/22/2020 | NA | NA |
| 181800 | CM | Adult | F | SJP | 7/15/2020 | 10/9/2020 | 1 | 64.0 |
| 181805 | CM | Adult | F | SJP | 7/17/2020 | 8/16/2020 | 5 | NA |
| 181798 | CM | Adult | F | SJP | 7/25/2020 | 9/12/2020 | 2 | 115.9 |
| 181797 | CM | Adult | F | SJP | 7/26/2020 | 8/15/2020 | NA | NA |

In this study, mean size of core-use foraging areas (50% KDE) for loggerheads was 421.7 $km^2$ (±356.1 $km^2$) with average depth of 13.7 m (±11.9 m). Mean size of core-use foraging areas for Kemp's ridleys was much larger and more variable, 1218.6 $km^2$ (±1941.8 $km^2$) with average depth of 18.0 m (±14.1 m). Mean size of core-use foraging areas for in-water captured green turtles was much more confined, 126.0

km$^2$ (±240.5 km$^2$) with average depth very shallow (5.6 m, ±4.8 m). See Lamont et al. (2023) for additional summary of nesting turtles with depth tags and for details on nesting green turtle tracking data.

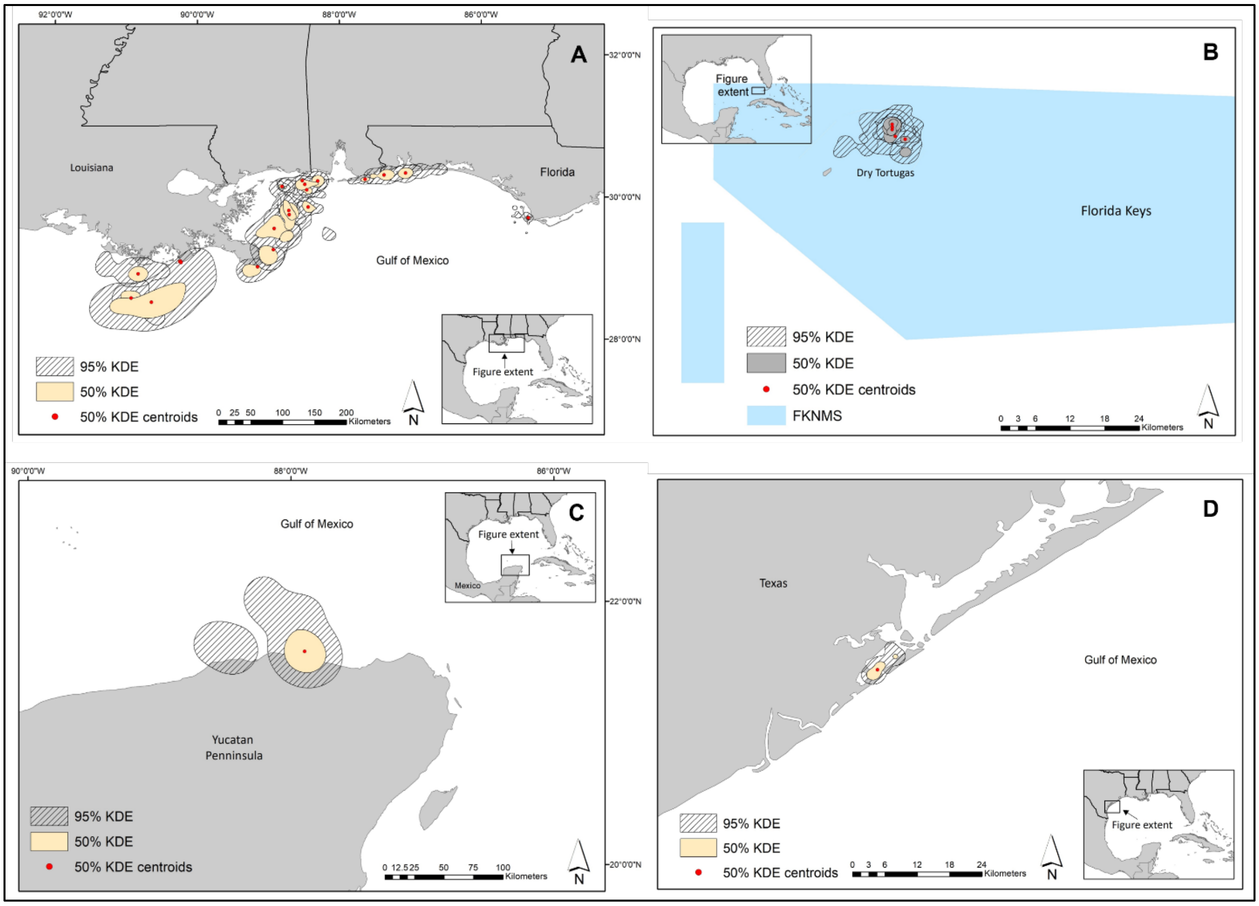


**Figure 5. Foraging home ranges (KDE 95%) and core use areas (KDE 50%) for loggerheads, Kemp's ridleys and green turtles in the northern Gulf of Mexico.**

(A) Dry Tortugas, (B) Mexican coast, (C) and within Galveston Bay, TX (D). See Table 2 for estimates of core-use areas for nesting green turtles.

### 3.2.1 Dive Profiles and Time at the Surface

Of the 21 tags that provided dive data for this project, mean proportion of time spent in the top two meters of the water column for all individuals was 19.4%. Green turtles spent a greater proportion of time in the top two meters (26.7%) compared to Kemp's ridleys (14.3%) or loggerheads (8.4%).

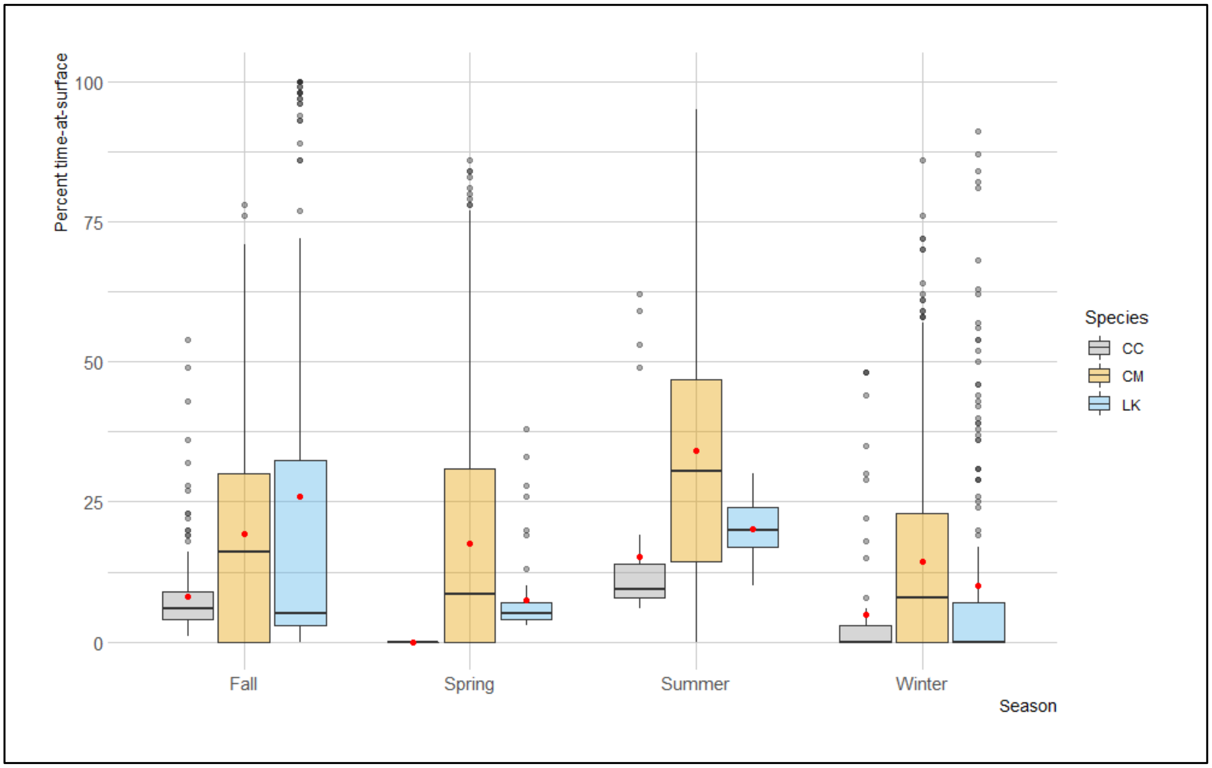


**Figure 6. Percent time at the surface per species by season.**

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

Within-species dives in the 0–2 m depth bins varied by individual for all three species. Green turtle TAS reached 65%, Kemps ridley TAS reached 54%, and loggerheads reached 9%. The TAS for all species was greatest in summer (Figure 6). TAS for loggerheads and green turtles did not differ between the Eastern and Central BOEM Planning Areas (neither were tracked into the Western Planning Area; Figure 7) however, Kemp's ridleys spent more time at the surface in the Western Planning Area than in the Central Planning Area (no Kemp's ridleys were tracked into the Eastern Planning Area; Figures 5 and 7).

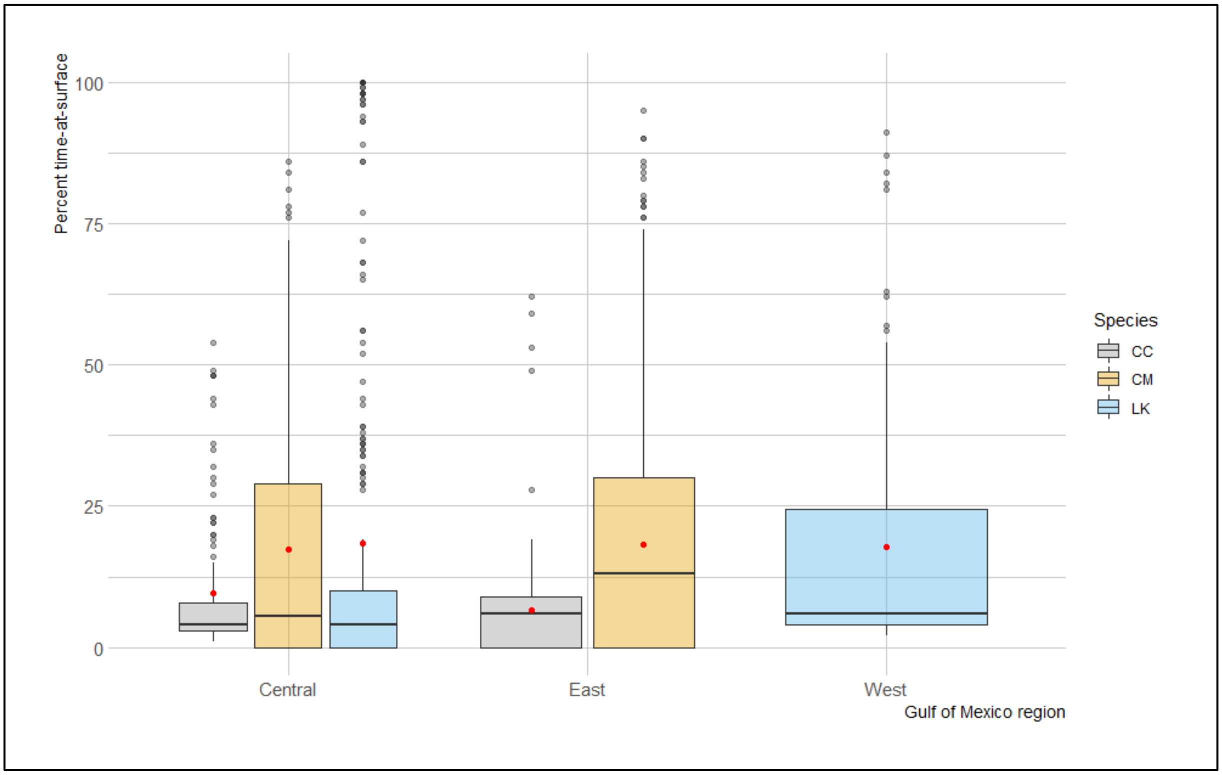


**Figure 7. Percent time at the surface per species in BOEM's Central, Eastern and Western Planning Areas.**

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

## 3.3 Genetics

Northern Gulf beaches support a genetically distinct group of nesting loggerheads (Table 3). Frequency of the CC-A1.1 is greater in those individuals than from loggerheads that use other nesting beaches in the southwest or southern Gulf of Mexico. Secondary, in Northern Gulf loggerheads is the CC-A2.1 haplotype. Interestingly, CC-A1.3 is found more frequently in loggerheads from the southern Gulf of Mexico and southeast Florida.

**Table 3. Summary of mitochondrial control region haplotypes for loggerhead turtles captured in the northern Gulf of Mexico**

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 | GOMMAPPS | NGRU | DTRU | MEX |
|---|---|---|---|---|
| CC-A1.1 | 1 | 94 | 1 | 0 |
| CC-A2.1 | 3 | 12 | 28 | 64 |
| CC-A1.3 | 1 | 0 | 0 | 0 |

The relative haplotype frequencies recovered from the northern Gulf foraging Kemp's ridleys are reflective of nesting females from Texas and from the main nesting aggregation at Rancho Nuevo, Mexico, with Lk4.1 dominating (Table 4; Frandsen et al. 2020; Lamont et al. 2021). They also reflect similar frequencies as juvenile Kemp's ridleys found from in-water samples from the same region (Northwest Florida; Lamont et al. 2021) and the northeastern US (Frandsen et al. 2020). Interestingly, haplotypes Lk1.1 and Lk2.1 were found in Kemp's ridleys nesting in TX and foraging in the northern Gulf (this study and Lamont et al. 2021) but not in nesters from Rancho Nuevo, Mexico. This may reflect the low sample sizes from Rancho Nuevo; additional genetic analyses are necessary to better understand the genetic diversity of Kemp's ridleys both on nesting beaches and at foraging sites throughout the Gulf of Mexico.

**Table 4. Summary of mitochondrial control region haplotypes for Kemp's ridley turtles captured in the northern Gulf of Mexico**

Published haplotype frequency data from the Texas nesting population (TX), northeastern United States foraging juvenile aggregation (NEUS), and Northwest Florida juvenile foraging aggregation are included for comparison (Frandsen et al. 2020; Lamont et al. 2021).

| Haplotype | GOMMAPPS | TX nesters | Rancho Nuevo | NEUS | NW FL |
|---|---|---|---|---|---|
| Lk4.1 | 2 | 20 | 10 | 32 | 78 |
| Lk6.1 | 5 | 13 | 6 | 15 | 34 |
| Lk3.1 | 0 | 1 | 2 | 6 | 6 |
| Lk2.1 | 0 | 3 | 0 | 2 | 2 |
| Lk1.1 | 0 | 1 | 0 | 2 | 2 |
| Haplotype 11 | 0 | 0 | 0 | 0 | 1 |
| Haplotype 12 | 0 | 0 | 0 | 0 | 1 |

Juvenile green turtles across the Gulf are strongly structured with an apparent transition occurring between the western group and eastern group in Northwest Florida (Table 5). Our results followed those patterns with haplotypes CM-A1.1 and CM-A3.1 found most frequently in turtles sampled during GOMMAPPS. Most of the juvenile green turtles in the Gulf, including those sampled during GOMMAPPS, originate from Mexican nesting beaches with a much smaller contribution from nesting beaches on Florida's east coast (Shamblin et al. 2023).

**Table 5. Summary of mitochondrial control region haplotypes for green turtles captured in Louisiana, Northwest Florida, and the Dry Tortugas**

Published haplotype frequency data from sites across the Gulf of Mexico including St. Joseph Bay, Florida; Santa Rosa Island, Florida; Port Fourchon, Louisiana (LA), and Dry Tortugas National Park (DRTO) are included for comparison (Shamblin et al. 2015, 2023).

| Haplotype | GOMMAPPS | St. Joseph Bay | Santa Rosa Island | LA | DRTO |
|---|---|---|---|---|---|
| CM-A1.1 | 6 | 48 | 22 | 79 | 0 |
| CM-A1.2 | 1 | 9 | 0 | 2 | 3 |
| CM-A3.1 | 5 | 80 | 16 | 31 | 14 |
| CM-A5.1 | 1 | 4 | 1 | 2 | 4 |
| CM-A58.1 | 2 | 0 | 0 | 3 | 0 |
| CM-A28.1 | 0 | 0 | 0 | 0 | 1 |

Although frequency differentiation is informative for inferring demographic structuring among nesting sites with respect to female recruitment, this haplotype sharing with all three species 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 and for questions regarding gene flow, range expansion, and diversity.

# 4 Discussion

The species, life-stages, and locations of turtles captured and tagged during this study helps fill gaps in the general knowledge about sea turtle dive patterns, TAS, and distribution in the Gulf. Although GOMMAPPS focused on in-water turtles, this study also included data on green turtles nesting in the northern Gulf of Mexico (Lamont et al. 2023). The tags deployed opportunistically on large adult female green turtles provided the first spatial data for green turtles nesting in the northern Gulf and are contributing to critical habitat designations for the species, as well as an understanding of their TAS, timing of post-nesting movements, and locations of migratory corridors. The dive-surface behavior data collected during GOMMAPPS can be applied to improve the accuracy and precision of abundance estimates for sea turtles derived from visual survey data, in particular aerial surveys (Pollock et al. 2006; Eguchi et al. 2007).

## 4.1 Time at the Surface

The TAS estimates documented during GOMMAPPS are similar to many of the TAS estimates generated for these three species elsewhere (Sasso and Witzell 2006; Garrison et al. 2019; Wildermann et al. 2019; Robinson et al. 2020). However, the TAS for loggerheads and Kemp's ridleys in GOMMAPPS differed from what was documented during Hart and Lamont's (2021) BOEM-funded study in the northern Gulf where loggerheads (n=15) spent more time at the surface (16.0%) than Kemp's ridleys (n=10; 10.0%). The differences in TAS documented during both studies may simply reflect individual variation in turtles captured. However, it may also reflect differences in capture methods, turtle sizes, or behaviors (e.g., migration, foraging). Loggerheads (mean 86.4 cm CCL) and Kemp's ridleys (mean 63.6 cm CCL) in Hart and Lamont (2021) were captured via trawler and were slightly larger than those captured in this study (loggerhead mean 76.5 cm CCL, Kemp's ridley mean 57.8 cm CCL). Turtles in the GOMMAPPS dataset were captured using multiple methods including trawlers, but also hand capture, tangle netting, dipnetting, and while on the nesting beach. All of the Kemp's ridleys tagged during GOMMAPPS were captured from August to October whereas Kemp's ridleys in Hart and Lamont (2021) were captured throughout the year. Capturing and tagging turtles in winter or spring allows tracking of those individuals during the nesting season whereas tags applied in late summer or fall (i.e., GOMMAPPS) may have ceased transmitting by the start of summer nesting. Seasonal variations in TAS have been documented in the Gulf of Mexico (Garrison 2019) and Atlantic Oceans (Turtle Expert Working Group 2009; Braun-McNeill et al. 2010; NEFSC and SEFSC 2011). In fact, studies have demonstrated a great deal of variability in TAS (TEWG 2009; Braun-McNeill et al. 2010, NEFSC and SEFSC 2011, Garrison et al. 2019) and suggested much of this variability is likely related to migratory patterns and sea surface temperatures. In the northern Gulf, loggerheads migrate away from nesting beaches between mid-July and early August (Hart et al. 2013) and Kemp's ridleys migrate to foraging grounds from late May through August (Shaver et al. 2016). Tracking turtles over winter and spring seasons, like we did during GOMMAPPS, reduces the chances of gathering TAS data during the post-nesting migratory period for these species.

### 4.1.1 Green turtles

The green turtle has a circum-tropical distribution that is listed as endangered by the International Union for Conservation of Nature (IUCN; Seminoff 2004). The species is divided into 11 distinct population segments with those nesting in the North Atlantic (including the eastern United States) considered threatened (Lamont et al. 2023). Although historically a tropical species that was severely exploited, populations appear to be rebounding and expanding (Valdivia et al. 2019).

Green turtle nesting density was relatively low in Florida through the early 1980s and then began to increase on both the Atlantic and Gulf coasts (Chaloupka et al. 2008; Witherington et al. 2009; Weishampel et al. 2016). The densest nesting in Florida occurs along the Atlantic coast in the Archie Carr National Wildlife Refuge (Shamblin et al. 2015) and along Gulf beaches in southwest Florida. Nesting in the northern Gulf occurs in low but consistent numbers (Shaver et al. 2020; Lamont et al. 2023). Because of these low numbers, very little information has been available on green turtles that nest in the northern Gulf.

As part of GOMMAPPS, data was gathered from nesting turtles to supplement the in-water work on this species that occurred near Port Fourchon, Louisiana and Dry Tortugas, Florida (see below). In this project, 14 satellite tags were placed on 13 green turtles (one female was tagged twice) after they nested in Northwest Florida. Turtle tracking revealed use of nearshore northern Gulf habitat during the breeding season, use of migratory pathways that included stopover areas in seagrass habitat along the eastern Gulf of Mexico, and residence at foraging areas located primarily in the Florida Keys (see Lamont et al. 2023). Home ranges for nesting green turtles (mean 50% KDE = 118 $km^2$, range 25.0 to 277.7 $km^2$) were similar in size to juvenile green turtles tracked during GOMMAPPS (Mean 50% KDE = 107.0, range 1.8 to 352.0 $km^2$; see Table 2). These females spent inter-nesting periods in the northeastern Gulf near the tagging sites and across the northern portions of Florida's Big Bend region. Migration took a mean of 22 days to complete and, except for one female who traveled across deep water to the Yucatan Peninsula, Mexico, most females migrated in relatively shallow water. Five of the 13 turtles undertook foraging stopovers during migration which lasted an average of 16 days. Most (64%) foraging home ranges were established in the Cape Sable region of Southwest Florida which represents an emerging hotspot for post-nesting green turtles (Hart et al. 2021; Sloan et al. 2022).

Juvenile green turtles tagged at Port Fourchon used very shallow coastal areas, with small foraging home ranges (Figure 5A) and -1m depth (see Table 2). However, these juvenile turtles were resident year-round at the northern Gulf study site, an area with heavy boat traffic.

Larger green turtles tagged in the Dry Tortugas in the southern Gulf of Mexico used areas fairly restricted in size (Figure 5B) and in 3–11 m depth (see Table 2). These subadult and adult turtles, all captured in the water, were tracked across winter months, so their TAS data includes periods of winter-time southern Gulf in-water green turtles surfacing behaviors at foraging sites.

In the Atlantic, Robinson et al. (2020) found that, after release from rehabilitation centers in the region, loggerheads were the deepest diving of the three species, Kemp's ridleys were intermediate, and green turtles were shallowest, which is similar to our findings in the Gulf of Mexico. However, Wildermann et al. (2019) found maximum surface durations of juvenile green turtles tagged off of Crystal River, Florida in the eastern Gulf were significantly lower than surface durations for Kemp's ridleys and loggerheads, which is in direct opposition to our findings in which green turtles had the highest TAS (26%) among the three species.

### 4.1.2 Loggerheads

Loggerhead marine turtles in the Northwest Atlantic are listed as threatened under the US Endangered Species Act. The species exists as five subpopulations (Turtle Expert Working Group 2009) and 10 management units (Shamblin et al. 2011; Shamblin et al. 2012) based on mitochondrial DNA analyses. The subpopulations in the Dry Tortugas and northern Gulf of Mexico are the two smallest, with individual nesting subpopulation estimates of 258–496 females (50 percentile distribution=331) and 323–634 females (50 percentile distribution=432), respectively (Richards et al. 2011).

Previous satellite tracking efforts with adult female loggerheads have shown that northern Gulf of Mexico loggerheads exhibit relatively low nesting site fidelity both within (i.e., inter-nesting) and among (i.e., remigration) nesting seasons (Hart et al. 2013; Hart et al. 2014). The satellite-tracked females remained in the northern and northeastern Gulf during the inter-nesting period, moving as far as 2,837 km during that approximately two-week time-period and depositing successive nests that were more than 400 km apart (Hart et al. 2013). After completing the nesting season, all tracked females remained within the Gulf with most traveling to foraging locations in Southwest Florida and the northern Gulf (Hart et al. 2014). Because a relatively large proportion of females establish foraging areas in the northern Gulf, there is potential for spatial overlap with post-nesting Kemp's ridley females (Hart et al. 2018a; Fujisaki et al. 2020). These foraging areas also have potential to overlap with several anthropogenic activities including shipping vessels, oil and gas platforms, shrimp trawlers, and deepwater aquaculture (Hart et al. 2018b; Farmer et al. 2022).

Dive data and time-at-surface information for loggerheads in the Gulf was previously limited. However, recent work by Hart and Lamont (2022), Garrison et al. (2019), and Iverson et al. (2019) reported that satellite tracked adult female loggerheads from northern Gulf nesting beaches spent a mean 10% of their time at the surface. Our information further refines these values and covers a larger spatial area. The only information for male loggerheads was previously derived from a study on the Atlantic coast where Arendt et al. (2012) captured males in South Carolina; turtles spent <4% of the time at the surface in that location.

### 4.1.3 Kemp's ridleys

The only historic nesting sites for Kemp's ridleys in the world are found along the Gulf coast of northern Mexico (Shaver et al. 2016). Kemp's ridley nesting declined significantly between the 1940s and the mid-1980s (Marquez et al. 2005). Because of this decline, in the 1970s the National Park Service established the binational Kemp's ridley recovery project. This project's aims included protection of nesting turtles and nests at the primary nesting beach of Rancho Nuevo, Mexico and formation of a secondary nesting colony at Padre Island National Seashore (PAIS), Texas (Shaver and Caillouet 1998, 2015; Shaver 2005; Caillouet et al. 2015). Previous satellite tracking efforts of adult female Kemp's ridleys from the PAIS nesting beach showed these individuals remained off northern Mexico and Texas during the inter-nesting period (Shaver et al. 2017), traveling as far as 369 km during that time. Post-nesting females traveled nearly 800-km on average to foraging areas established in shallow waters throughout the Gulf but primarily along the southern Louisiana coast (Shaver et al. 2013).

Variation in dive behavior in sea turtles has been documented relative to body size (Hays et al. 2004) and geographic location. Sasso and Witzell (2006) found that juvenile Kemp's ridleys in the Ten-thousand Islands, Florida spent 94% of their time submerged, which is a much greater proportion of time than was documented during GOMMAPPS for the relatively larger Kemp's ridleys tagged in the northern Gulf of Mexico (54%). Along with the habitat type, body size of Kemp's ridleys differed between turtles tracked for GOMMAPPS (mean 57.8 cm, range 40.3–67.8 cm CCL) and those tracked in Sasso and Witzell (2006; mean 46.2, range 40.2–54.1). The Ten-thousand Islands is a chain of islands and mangrove islets along the Southwest Florida coast characterized by shallow water and soft-bottom habitats, whereas the Kemp's ridleys tracked for GOMMAPPS were primarily captured and tracked in deeper waters of the open Gulf. Larger turtles may have greater lung capacity thereby allowing them to remain submerged longer and dive deeper than smaller turtles (Hays et al. 2004).

The TAS data for all three species in this study adds additional information to the results presented in Hart and Lamont (2022) and Garrison et al. (2019). Roberts et al. (2022) recently integrated the depth-logging tag data from these studies with GOMMAPPS results into one analysis (see Roberts et al. 2022; see section 4.1). With data from 136 satellite tags attached to loggerheads, Kemp's ridleys, and greens, behavioral switching state-space modelling was used with a generalized additive model to determine which environmental parameters influenced the proportion of time turtles spent at the surface. In that paper authors examined the influence of 11 remotely sensed parameters that have been shown to influence sea turtle dive behavior: sea surface temperature, sea surface temperature anomaly, sea surface salinity, sea surface height, bottom depth, distance to shore, distance to shelf, current strength and direction, frontal gradient magnitude-color fronts, and frontal gradient magnitude-thermal fronts. Roberts et al. (2022) found that species-specific differences occurred in TAS relative to location, season, and environmental and oceanographic features. For example, both loggerheads and green turtle TAS was influenced by frontal features whereas TAS for Kemp's ridleys was not. These results will be used to improve NOAA's density estimates for sea turtles across the Gulf of Mexico which are being calculated using aerial survey data (see Rappucci et al. 2023).

### 4.1.4 TAS

The TAS results suggest seasonal variations in dive behavior occur. Although sample sizes were very small, loggerhead TAS dropped slightly during the winter months and peaked during April-August, which coincides with the general timing of the nesting season. A similar pattern was observed with green turtles where TAS peaked in summer, July specifically. However, a slight peak was observed in the proportion of Kemp's ridley TAS in February and October. It is possible that during winter, when SST falls, sea turtles alternate relatively short periods of resting on the seafloor with longer periods of basking in the sun and warmer surface waters (Lamont et al. 2018). However, additional wintertime data is needed in the Gulf. During winter in the Mediterranean, loggerheads at temperate sites spend several hours resting on the bottom while making occasional trips to the surface for gas exchange (Hochscheid et al. 2005). These winter behaviors could complicate comparisons of TAS estimates. On one hand, we may expect TAS to be longer as turtles bask at the surface but on the other hand, TAS may be shorter due to the prolonged periods of submergence. These behaviors are most likely also affected by varying temperatures with submergence times increasing as temperatures decrease. This gap is particularly important for the northern Gulf which can experience periods of extreme cold relative to the tropical regions of the southern Gulf (Lamont et al. 2018; Osland et al. 2021).

## 4.2 Gulf-wide distribution and density modeling

The main goal of the GOMMAPPS project was to assess the abundance and distribution of marine mammals, sea turtles, and seabirds throughout the US Gulf of Mexico and to place them in an ecosystem context. Data from the sea turtle component of the larger project is being used in broader efforts to develop spatially-explicit models linking environmental and oceanographic variables to sea turtle, marine mammal, and seabird distributions in partnership with NOAA and USFWS. The first stand-alone sea turtle paper was published (see Roberts et al. 2022).

Continued collaborations with the NOAA and USFWS partners will explore multi-species density and distribution models.

## 4.3 Contributions to Additional Projects

Simultaneous to this study, another BOEM-funded study was being conducted on sea turtles in the northern Gulf (Hart and Lamont 2021). As part of this project, Argos and dive-capable telemetry tags were deployed on sea turtles captured during relocation or USGS-directed trawling efforts from southern Louisiana to Pensacola, Florida. These tags were deployed to assess turtle movements and behavior post-capture from trawling vessels in the northern Gulf. Additionally, genetic and stable isotope analyses were conducted on skin samples collected from each captured turtle to provide information on population connectivity and diet. Tagged turtles showed fidelity to dredging areas and provided similar information as GOMMAPPS regarding time-at-surface for loggerheads and Kemp's ridleys. Together, this study and GOMMAPPS resulted in the tagging of 136 sea turtles across the northern Gulf which provides unprecedented data on movements and dive behavior which contribute to spatially explicit density models for use by management and regulatory agencies in the Gulf of Mexico.

Sand resources on the OCS are collected using trailing suction hopper dredges and used for beach nourishment and coastal construction. Hopper dredges also have the potential for entrainment and mortality of federally listed marine species including sea turtles. To minimize that risk, BOEM developed the Analyzing Sea Turtle Entrainment Risk Decision Support Tool (ASTER; Ramirez et al. 2017) which is a standardized geographically and temporally based decision support tool for the Atlantic and Gulf regions that will be used to assess project-specific dredging entrainment risk within a common framework.

Before the GOMMAPPS project, no information was available on movement patterns and habitat use of adult green turtles that nest on beaches in the northern Gulf. From 2017 to 2019, 12 females were encountered on nesting beaches in Northwest Florida and satellite transmitters were attached to their carapace (Lamont et al. 2023). Results of this study highlighted the use of interesting areas in the northern Gulf and stopover sites along migratory pathways. These stopover sites were in areas of dense seagrass, suggesting turtles were foraging during migration. Finally, foraging areas were established in the Florida Keys National Marine Sanctuary and in an unprotected area off Cape Sable, Florida which lies outside the boundaries of the Sanctuary and Everglades National Park. These data provide the first movements for green turtles nesting in the northern Gulf and, in addition to contributing to GOMMAPPS, these data are also being used by NOAA for Atlantic green turtle critical habitat designations.

## 4.4 Recommendations for Future Work

Improved information is needed on living marine resource abundance, distribution, habitat use, and behavior in the Gulf to properly mitigate and monitor for potential impacts of human activities, including those related to the oil and gas industry. The Gulf is a heavily used and industrialized basin, supporting oil and gas exploration and development, commercial and recreational fishing, shipping, military operations, and tourism. Given the highly mobile nature of many protected species in the Gulf, an ecosystem approach to monitoring and managing these species is most effective. While GOMMAPPS provided a substantial foundation for addressing this need, gaps remain for all involved taxa (see Rappucci et al. 2023; Gleason et al.[2]).

For sea turtles, despite focused work to obtain TAS data through GOMMAPPS, and integration with turtle dive data in Hart and Lamont (2022), and Garrison et al. (2019), gaps remain in our general understanding of sea turtle distribution and dive patterns in the Gulf of Mexico. These knowledge gaps limit Gulf-wide density and distribution modeling estimates for all species.

Through GOMMAPPS, we have identified the following needs for future work:

1. TAS estimates during winter months for loggerheads, Kemp's ridleys, and green turtles;
2. TAS estimates in BOEM's Western Planning Area for for loggerheads and green turtles;
3. Impact of behavioral state on TAS estimates for all species;
4. Time at bottom for all species to inform trawling surveys and to assess impacts from sand and gravel extraction;
5. Spatial distribution data for leatherbacks, which were not included in this GOMMAPPS study.

[2] Gleason JS, Sussman AL, Davis KL, Haney JC, Hixson KM, Jodice PGR, Lyons JE, Michael PE, Satgé YG, Silverman ED, Zipkin EF, and Wilson, RR. In review. Gulf of Mexico Marine Assessment Program for Protected Species (GOMMAPPS): seabird surveys in the Northern Gulf of Mexico, 2017–2020. New Orleans (LA): US Department of the Interior, Bureau of Ocean Energy Management. Interagency Agreement No.: M17PG00011. Report No.: OCS Study BOEM 2023-xxx.

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