Task-by-Task Final Report to the Texas Coastal Management Program:
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Assessment of Optimal Sea Turtle Nesting Sites Along the Texas Coast

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Project Background

Sea turtles are tied to coastal beach habitats due to their need to return to land and lay eggs in a nest. This behavior demonstrates their terrestrial origins; although they are adapted for the sea, their ancestors were completely terrestrial. Although species-specific differences exist, in general the iteroparous reproductive behavior of all sea turtles is similar. Eggs are laid in nests high on a sandy beach. There is an involved process of emerging, digging, laying, filling-in, and returning to the sea (Bustard et al., 1975; Miller, 1997). After 50-60 days of incubation, hatchlings pip out of the eggs, emerge from the nest cavity and enter the sea in a swimming frenzy (Wyneken and Salmon, 1992; Miller, 1997; Gatto and Reina, 2020). Hatchlings that survive the high mortality during the path from nest to water make their way from coastal water to oceanic currents and develop in this environment. Following this oceanic stage, which can take decades, subadult turtles recruit back to coastal neritic habits. Individuals may spend time in developmental habitats, growing and developing sexually. However, there is much variation in this life history pattern (reviewed by Bolton, 2003). Eventually, sea turtles move into their foraging habitat and when they become sexual mature will migrate to reproduction habitats to mate. Gravid females will return to locations near their natal beach (Bjorndal et al., 1985; Limpus et al., 1992; Miller, 1997) to lay their clutch of eggs and the cycle repeats.

The location of nests on the beach, the type and quality of sand, elevation, slope, depth of nests, and distance from shoreline all play a role in hatching success of the entire clutch, individual fitness, and ultimately the success of the population and species (Horrocks & Scott, 1991; Wood & Bjorndal, 2000; Zavaleta-Lizarraga & Morales-Mavil, 2013). The selection of nesting habitat and specific sites is not random, but thought to be in response to both abiotic and abiotic factors (Weishampel *et al.*, 2006; Zavaleta-Lizarraga & Morales-Mavil, 2013).What constitutes suitable or even optimal nesting habitat likely varies from species to species, population to population and globally.

Sea turtles play an important and interesting role in terrestrial coastal ecosystems. Substantial energy acquired in marine systems by females turtles is transferred to coastal beach ecosystems (Bouchard and Bjorndal, 2000; Bjorndal and Jackson 2002). Sources of energy include non-viable eggs, eggs shells from pipped sea turtles, as well as the hatchlings themselves. Sea turtle nests are often consumed by a variety predators prior to hatching. Once hatchlings begin to emerge from a nest they experience high mortality due to predation by birds, crabs and a multitude of mammals. Many marine birds will synchronize their reproductive cycle with that sea turtle species, using the energy derived from sea turtle hatchlings to insure the success of their own offspring. Posthatching, eggshells, non-viable eggs and hatchlings that were not successful contribute to the bacterial, interstitial, and invertebrate coastal community ecosystem.

Natural and anthropogenic changes to coastal beach habitats greatly impact the hatching success of sea turtle nests, both positively and negatively. Beach re-nourishment and dune restoration projects can directly impact the quality of sea turtle nesting habitats. Negative changes can manifest in the form of changes in the beach profile, loss of elevation, and decrease in slope that then enable high tides to inundate eggs. Large grain size of grain or the use of other material to re-nourish a beach such as shell hash can increased compactness and hardness of the beach surface that constrains or preclude the excavation of the nest chamber (Ackerman, 1997). Incorporation of undesirable material in the sediment, such as clay, may change the moisture level of the substrate and promote mold or bacterial growth on eggs, or even changes in the thermal environment of nests. The nest environment, such as gas exchange, moisture, and temperature must satisfy the requirements of embryonic development; non-ideal conditions will reduce hatch success rate and increase hatchling mortality rate (Miller, 1985; Mortimer, 1990; Ackerman, 1980, 1997; Maloney et al., 1990; Packard and Packard, 1988). Embryonic mortality is higher in drier sand conditions, but also when nests are inundated with saltwater for more than several hours (Kaufman, 1968; Miller 1997). Although some recent work has been conducted, what comprises optimal sea turtle nesting habitat in Texas is still poorly understood. Recent work by Culver et al. (2022) has begun to address the impact of geomorphology on nest site selection for Kemp's ridley sea turtles.

Elevation, distance from shoreline, maximum dune slope, and average beach slope were found to be the drivers of nest selection in this species in the Padre Island regions. However, much more work needs to continue including comparative data on nest temperatures.

Sea turtle hatchling sex is determined by nest temperature. In general, nest temperatures in the range of 30-32ºC produce males, whereas nest temperatures in the range of 33-35ºC produce females (Mrosovsky and Yntema 1980; Limpus et al., 1985; Miller, 1997). Some regions of the world are experiencing increasing nest temperatures due to climate change (Hawkes et al., 2009; Hays et al., 2003; Glen and Mrosovsky, 2004). Accumulating evidence shows that nest site, sand composition, nest depth are all implicated in obtaining optimal nest temperature for development (Hawkes et al., 2009). Increased nest temperature is concerning since it has the potential to skew population sex ratio toward females. At first this might appear beneficial to an endangered or threatened population, but skewed sex ratios within a population will ultimately result in population decrease. Furthermore, sustained temperatures above these narrow ranges (>35ºC) will ultimately result in embryonic death.

Kemp's ridley sea turtles are the most critically endangered species in the world and are endemic to the western Gulf of Mexico. The Upper Texas Coast has seen a steady increase in nesting Kemp's ridley sea turtles since 2002. However, the combination of extensive erosion and beach/dune restoration have negatively impacted sea turtle nesting sites in this region. Furthermore, as the coastal spine project appears to gain traction, it is critical that project managers consider nesting sea turtles when re-engineering the beaches of the Upper Texas Coast. This research begins fills an important data gap and will serve as a guide to understand what nesting sites sea turtles on the Upper Texas Coast are selecting so that future beach restoration projects in this region can use the best available data to maintain or improve nesting habitat. This line of research will provide additional data to inform policymakers to ensure that optimal nesting habitat is provided for endangered Kemp's ridley (*Lepidochelys kempii*) and other sea turtle species. Understanding the variables that determine optimal nesting habitat is key to the conservation and restoration of Texas sea turtle populations.

The objectives of the study were to: 1) characterize the geomorphology and sand grain size distribution of beaches on the Bolivar peninsula (BP), Galveston (GI) and Follets Islands (FI), and 2) measure the temperature regime within simulated, experimental Kemp's ridley sea turtle nests at these same sites, where sea turtles are known to have nested.

Task 1 Summary: Project Planning. Six sites on the Upper Texas Coast and one reference site in Nueces County Park, adjacent to Padre Island National Seashore (PAIS), were identified as ideal locations since there are records of Kemp's ridley nests being laid at these sites. The Nueces County Park was chosen over PAIS since the National Park Service was not able to provide a permit to use the park in a timely matter that coincided with our research objectives. However, this area is adjacent to the PAIS boundary, has the same beach characteristics, is monitored by PAIS staff for nesting, and is a known common nesting site.

We ordered 105 HOBO MX data-loggers and 21 HOBO ProV2 temp/RH dataloggers. A single HOBO MX datalogger was buried with each nest and a single HOBO ProV2 temp/RH datalogger was buried in each of the three transects per nest site (3 per site x 7 sites = 21 dataloggers). We also ordered materials to fabricate 11,500 artificial eggs to be used in the 105 experimental nests. Each egg was filled with saltwater to mimic the density of a real sea turtle eggs. The inexpensive ping-pong balls ordered mimicked the size of real Kemp's ridley eggs well.

Two new graduate students were recruited during the time of this project, Justin Wilson (Marshall - M.S. student), Madelyn Rupp (Marshall - Ph.D. student). In addition, three undergraduate students (Eliza

Perez, Carolyn Pope and Brady Rich– Marshall lab) and one postdoctoral scientist was recruited and spent time with data analysis (Nathalie Jung – Dellapenna lab). Significant contributions were made by two M.S. level graduate students in the Dellapenna lab, Nick Wellbrock and Christena Holschler. Graduate students Nick Diaz (drone operator) as well as Wei Xing and Penj Lin (sediment analyses) assisted in the project. Two Gulf Center for Sea Turtle Research program assistants (Kari Howard and Theresa Morris) also assisted in this project.

Fig. 1. Simulated Nest Sites on the Upper Texas Coast and near Padre Island National Seashore

Fig. 2. HOBO MX data-loggers and HOBO ProV2 temp/RH dataloggers

Figure 3. Justin Wilson and Eliza Perez fabricating experimental sea turtle eggs

Tasks 2: Data Collection and Analyses

Simulated nests were placed prior to the height of Kemp's ridley nesting season on the Upper Texas Coast. Although nesting spans from April 1st to July 15th; in this region our first nest is laid early to mid-May. Simulated nests were placed between May 4-18th and remained *in situ* until ~50 days past the last potential nesting date (July 15th). Dataloggers and simulated nests were retrieved between September 22 and October 9th. Retrieval was delayed by Hurricane Nicholas, which made landfall in Surfside TX on September 13th, 2021. Due to the inundation of all sea turtle nests and the loss of some nests during to Hurricane Nicholas, no data from the HOBO ProV2 temp/RH dataloggers were retrieved. This was due to either total loss of dataloggers or disruption of datalogger function due to inundation by seawater. While the HOBO MX data-loggers are waterproof, the HOBO ProV2 temp/RH dataloggers were only water resistant not intended to function after water inundation. The inundation events were not expected *a priori*, but do serve as important events and study result. An unmanned aerial system (UAS), commonly referred to as drone, was used to photogrammetrically scan the simulated sea turtle nesting sites. Specifically, a real-time-kinematic (RTK) enabled drone known as the DJI Phantom 4 RTK. This RTK enabled drone connects to 15+ GNSS/GPS satellites maintaining positional and mapping accuracies of +2 cm horizontal and +5 cm vertical. Prior to flight operation, pre-flight preparations and planning was necessary. This included Federal Aviation Administration (FAA) airspace unlock requests and creation of flight plans. During flight operation, the drone executed the transects established in the flight plans of the nesting sites. Along the mowing-the-lawn transects, the drone captures hundreds of overlapping (70% overlap), offset images, or structure-from-motion imagery. Time to execute flight plans for each nesting site was less than fifteen minutes. Ground control points (GCPs) were established using United States Geological Survey (USGS) elevation data and National Oceanic and Atmospheric Administration (NOAA) Geodetic Survey markers in addition to implementing RTK-enabled post-processing kinematic (PPK) corrections. For each simulated nest, a surface sediment sample and a sample at the base of each simulated nest were collected. Grain size distribution and water content were determined for each collected sample, for a total of 186 samples. Samples were run through a 2 mm sieve to separate sand from coarser fractions. The coarser than sand fraction was set aside for sieve analyses, described below. For the sand and finer fraction (< 2 mm), samples were homogenized in 0.05 M sodium metaphosphate solution prior to the determination of the grain size distribution (63 µm to 2 mm, 4 µm to 63 µm and 0.01 µm to 4 µm) using a Malvern Mastersizer 2000 particle analyzer. This device separates the grain sizes (from clay to sand-sized particles) using laser diffraction. Samples (10 g) collected when the cores were sampled and were immediately placed in pre-weighed aluminum tins and kept in an oven at 50°C for at least 24 hours, and then re-weighed to determine water content. The porosity was calculated from the water content by estimating the salt content, using an average sediment density of 2.65 g cm^{-3}.

Fig. 4. Experimental nests being placed, sediment samples being collected, and final nest with datalogger placed depicted.

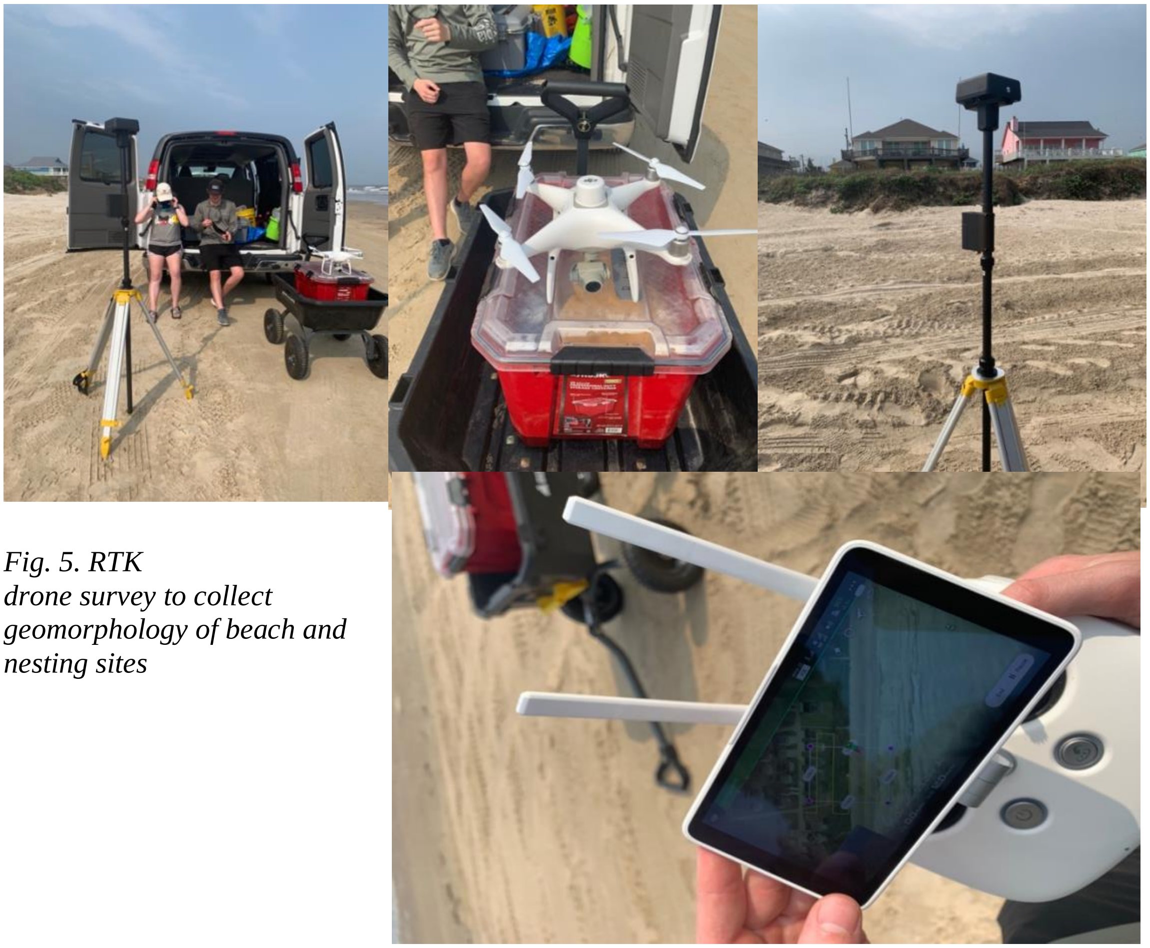

Fig. 5. RTK drone survey to collect geomorphology of beach and nesting sites

Fig. 6. Retrieval of Dataloggers

Statistical analyses were conducted in JMP Pro 16 (Cary, NC, USA). All temperature data derived from the dataloggers were tested for normality using the Shapiro-Wilk test. We explored the data using one-way ANOVAs to explore the effect of independent, categorical variables (row, column, grid location within a nest as well as site) on our dependent variables (mean, maximum, and minimum nest temperatures). We used a MANOVA and Tukey postdoc tests to evaluate mean nest temperature differences in row, transects, column transects, and individual nest grid location within each nesting site, and across all nesting sites. Furthermore, we conducted a step-wise regression model to determine which variables (row, column, grid location, and site) best explained the variation in mean, maximum, and minimal nest temperatures. The criterion for statistical analyses, which were conducted in JMP Pro 16 (Cary, NC, USA) was $p < 0.05$.

Task 3: Data Dissemination and Outreach

The project was featured on our GCSTR website (https://www.tamug.edu/GulfCenterforSeaTurtleResearch/research.html#Nesting-Sites)

Thirteen presentations that included a summary of this project have given to a variety of stakeholders. These groups include: Galveston Bay Chapter of the Texas Master Naturalists, Sea Turtle Saturday (Galveston, TX), Willowbrook Rotary Club (Houston, TX), TAMUG Administrative Executive Team, Galveston Island State Park, Friends of the State Park Galveston Park Board, Galveston Rotary Club, Sea Aggie Mom's Federation (a national group), Mitchell Lake Audubon Nature Center, Succeeding in Science at TAMUG, HDR, Dow, and Marathon.

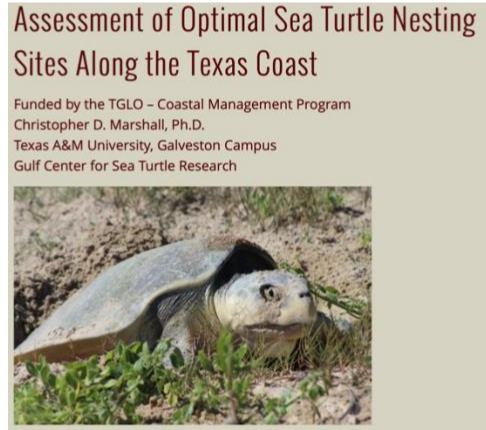

Fig. 6. Screenshot of the GCSTR website summarizing this work.

We intended to present an oral talk at the South-East Regional Sea Turtle Meeting in Orange Beach, AL the first week of February 2022. However, due to the rapid and widespread rise in the Omicron variant of COVID-19 that meeting has been postponed until February 2023. We still plan on presenting the work at this meeting. Additionally, the work will be presented at the Annual Meeting of the Society for Comparative and Integrative Biology, in Austin, TX January 3^{rd}, 2023. In addition to presentations, we are submitting a draft manuscript that Dr. Dellapenna and I will continue to craft for submission to Frontiers in Marine Science.

Two graduate students have been recruited during the time of this project, Justin Wilson (Marshall - M.S. student), Madelyn Rupp (Marshall - Ph.D. student), two undergraduate students (Eliza Perez and Carolyn Pope– Marshall lab), one postdoctoral scientist was recruited and spent time with data analysis (Nathalie Jung – Dellapenna lab). Significant contributions were made by two M.S. level graduate students in the Dellapenna lab, Nick Wellbrock and Christena Holschler. Graduate students Nick Diaz (drone operator) as well as Wei Xing and Penj Lin (sediment analyses) assisted in the project. Gulf Center for Sea Turtle Research program assistants (Kari Howard and Theresa Morris) also assisted in this project. As listed above in *Task 4: Data Dissemination*, thirteen presentations that included a summary of this project have been given to a variety of stakeholders. We intended to present an oral talks at the South-East Regional Sea Turtle Meeting in Orange Beach, AL the first week of February 2022. However, due to the rapid and widespread rise in the Omicron variant of COVID-19 that meeting has been postponed until February 2023. We still plan on presenting the work at this meeting. Additionally, the work will be presented at the Annual Meeting of the Society for Comparative and Integrative Biology, in Austin, TX January 3^{rd}, 2023.

Task 4: Project Monitoring and Reporting

We have made multiple presentations to local stakeholders in the region, posted to our GCSTR website, and provided the required deliverable reports to GLO-CMP. The data and detailed analyses can be found in the draft manuscript also submitted with this task-by-task report.