Final Report
SPATIAL DYNAMICS AND DISTRIBUTION OF THE TEXAS DIAMONDBACK TERRAPIN (*MALACLEMYS TERRAPIN LITTORALIS*) ALONG THE MIDDLE TEXAS GULF COAST



Prepared for the Texas Comptroller of Public Accounts
Contract #23-7615BG
(Principal Investigators: Shawn F. McCracken, Daniel Coffey, and Loretta Battaglia)

by

Shawn F. McCracken[1], Daniel Coffey[1], Loretta Battaglia[1], Garrett Guzoski[1], and Tyler Bowling[1]

[1]Department of Life Sciences
Texas A&M University - Corpus Christi
6300 Ocean Dr., Corpus Christi, Texas 78412

TABLE OF CONTENTS

TABLE OF CONTENTS **2**

EXECUTIVE SUMMARY **3**

ACKNOWLEDGEMENTS **4**

CHAPTER I: BACKGROUND INFORMATION **5**

CHAPTER II: HISTORICAL AND CONTEMPORARY DISTRIBUTION OF TEXAS DIAMONDBACK TERRAPIN ACROSS THE TEXAS COAST, WITH A FOCUS ON THE NORTHERN PORTION OF THE UPPER LAGUNA MADRE (INCLUDING BAFFIN BAY) **9**

METHODS *9*

RESULTS *14*

CHAPTER III: CREATION OF INATURALIST PROJECT AND CITIZEN SCIENCE CAMPAIGN TO ACQUIRE CONTEMPORARY RESEARCH-GRADE TEXAS DIAMONDBACK TERRAPIN OBSERVATIONS THROUGHOUT TEXAS **23**

METHODS *23*

RESULTS *24*

CHAPTER IV: IDENTIFY MOVEMENT PATTERNS AND HABITAT USE OF TEXAS DIAMONDBACK TERRAPIN IN THE TEXAS MIDDLE GULF COAST SYSTEM **26**

METHODS *26*

RESULTS *29*

CHAPTER V: DATA PUBLISHING **49**

CHAPTER VI: DISCUSSION **50**

REFERENCES **58**

APPENDIX A **62**

EXECUTIVE SUMMARY

This report documents the status, distribution, and movement ecology of the Texas diamondback terrapin (*Malaclemys terrapin littoralis*) along the Texas Gulf Coast. The species is present in Texas from Oso Bay near Corpus Christi to the Texas-Louisiana border, but contemporary records are patchy, concentrated in a few estuaries, and still insufficient to define full population status or habitat needs.

A statewide observation database, field surveys, and citizen science records were used to fill major data gaps. An iNaturalist project greatly expanded research-grade observations and added new locality records, while head-count surveys, trapping, eDNA, and camera traps provided complementary but uneven detection across sites.

GPS telemetry and mark-recapture work in the Nueces Estuary showed that terrapins use riverine, bay, and marsh habitats and likely make seasonal movements tied to local environmental conditions. However, transmitter performance was inconsistent, reinforcing the need for continued refinement of telemetry methods in this species.

Overall, the study found that the Texas diamondback terrapin remains present along the Texas Gulf Coast, but its distribution, abundance, and habitat requirements are still incompletely understood. The findings support continued long-term monitoring, expanded citizen science participation, and a multi-method survey strategy to better define occupied habitat and inform conservation planning. Future work should prioritize repeated surveys in historically occupied areas, continued telemetry efforts, and protection of connected estuarine and nesting habitats that support the species' persistence in Texas.

ACKNOWLEDGEMENTS

We thank Texas Parks and Wildlife Department (TPWD), and U.S. Fish and Wildlife Service (USFWS) for issuing permits. All handling methods were approved under TAMU-CC IACUC protocols.

CHAPTER I: BACKGROUND INFORMATION

Identifying movement patterns and the historical and contemporary range of a species is imperative to understanding critical habitat needs and the threats to species of conservation concern (Litzgus and Mousseau 2004; Bodkin 2015). This type of research is consequential to species dependent on coastal wetlands and estuaries that require shoreline habitat for physiological and reproductive requirements, and that are negatively impacted by human disturbance and sea-level rise (Hopkinson *et al.* 2008; Vitousek *et al.* 2017: Lyons *et al.* 2020; Lamont *et al.* 2021). The diamondback terrapin (*Malaclemys terrapin*) is a small to medium sized (maximum carapace length: female = 23.8 cm; male = 14.0 cm) emydid turtle that lives in coastal wetlands and estuaries along the United States Atlantic coast, from Cape Cod, Massachusetts to Corpus Christi, Texas in the Gulf of Mexico (Ernst and Lovich 2009; Roosenburg and Kennedy 2018); their distribution includes a disjunct population found in Bermuda (Brennessel 2006; Ernst and Lovich 2009). Seven subspecies of *Malaclemys terrapin* have been identified and are classified based on their morphological characteristics and geographical distributions. Within Texas, the subspecies *Malaclemys terrapin littoralis* (common name, Texas diamondback terrapin) is found from Sabine Lake (Orange County) in the north to Baffin Bay (Kleberg County) in the south although only a few records exist beyond Nueces Bay (Dixon and Hibbits 2013). Texas diamondback terrapins are listed as a 'T3 Vulnerable Subspecies' on the IUCN Red List with declining population trends across much of their range due to human development, transportation, habitat disturbance/loss, pollution, oil and gas drilling, drowning in crab traps, pet trade, invasive species, disease, and climate change (Crawford *et al.* 2014; Roosenburg *et al*. 2019). In Texas, they are listed as 'S2 Imperiled' by the Texas Parks and Wildlife Department (TPWD) and are a Species of Greatest Conservation Need (TPWD 2012). This designation means this species is at high risk of extirpation in the jurisdictional range, has few populations or occurrences, recent and widespread steep declines, and severe threats to their population status. Thus, the clear recommendation was for more research and monitoring of this species. It is also illegal to possess the species without a scientific, educational or zoological permit (Malik 2022).

Diamondback terrapins are the only brackish water estuarine species of turtle found in North America. Their primary habitat includes salt marshes, tidal creeks, and mangroves; preferring areas with freshwater inflows (Mohrman 2022). Closely related to freshwater turtles, diamondback terrapins have developed several unique adaptations throughout their evolutionary history that allow them to be the only species of turtle tolerable of a wide range of salinities (Wood 1977; Brennessel, 2006; Hart and Lee 2006; Coleman 2011). As adults, diamondback terrapins exhibit sexual dimorphism. Females can weigh three to four times more than males and tend to have larger heads (Hart and Lee 2006; Roberge 2012). Sexual maturity occurs later in females than males, around six years of age rather than three or four (Davenport 1992; Hart and Lee 2006). Female diamondback terrapins exhibit nest site fidelity, or philopatry, meaning that they return to the same nesting areas each year (Harden *et al.* 2007). In the spring and summer

months, female terrapins travel through salt marshes to reach sand dunes or narrow strips of sandy beach in eastern populations or shell hash in far western populations (e.g., Texas coast) to lay one or more clutches of 5-12 eggs each (Davenport 1992; Hart and Lee 2006). As the embryos develop, the sex of each one is determined by the temperature in the nesting chamber, which is termed temperature-dependent sex determination or TSD (Jeyasuria *et al.* 1994; Hart and Lee 2006; Coleman 2011; Roberge 2012). In general, warmer temperatures (≥31°C) give rise to females while cooler temperatures (≤27°C) produce males (Jeyasuria *et al.* 1994). During incubation, there is often a high chance of nest depredation by predators and the risk of predation remains high as hatchlings emerge (Davenport 1992). Therefore, it is important to have a variety of available nesting areas to ensure adequate numbers of each sex and increase the probability of nesting on a beach isolated from predators (Hart and Lee 2006; Coleman 2011; Roberge 2012).

The diamondback terrapin's role in estuarine food webs is complex, making it a valuable species for conservation studies of tidal ecosystems and a sentinel of changing climate. They are a tertiary consumer within these coastal communities, preying upon snails, crabs and fish (Brennessel 2006). An important constituent of marsh food webs, adult terrapins can also have a direct influence on densities of the salt marsh periwinkle snail, *Littorina irrorata* (Hauswaldt and Glenn 2005; Mohrman 2022). As periwinkle snails impact primary production by grazing upon periphyton, the extirpation of terrapin from the saltmarsh food web could generate a trophic cascade and indirectly cause an overall decline in primary producers at the base of many Gulf Coast food webs (Brennessel 2006).

Knowing the geographic range of a species establishes the foundation for further studies to investigate the species status and requirements so that management and conservation strategies can be developed (Politi *et al.* 2021). Diamondback terrapin surveys along the Texas Gulf Coast over the past decade have been scattered with variable levels of effort (Guillen *et al.* 2015; Baxter 2017). The lack of statewide surveys and a long-term population monitoring program in Texas has resulted in little being known about the distribution, population status, habitat preferences, and general ecology of the Texas diamondback terrapin (Guillen *et al.* 2015; Baxter 2017; Mohrman 2022). The contemporary range of diamondback terrapins in the middle Texas Gulf Coast system and the western extent of their range is currently unknown, along with current nesting habitat use and availability (Baxter 2017; Mohrman 2022). Although a few historical records exist west of Nueces Bay in the upper Laguna Madre and into Baffin Bay, no recent observations (*e.g.*, iNaturalist) or survey efforts have occurred in the area (Dixon and Hibbits 2013; Guillen *et al.* 2015).

The Conservation Action Plan for diamondback terrapins in the Gulf of Mexico (CAP) specifically recommends filling gaps in the geographic range data in Texas (Mohrman 2022). To address these gaps, a database of Texas diamondback terrapin distribution data should be created, including historical and contemporary observations. While multiple sources are required to build such a database, new technological resources like the iNaturalist citizen science platform can play a critical role in generating interest in the species and aid collection of recent observations of research grade quality. Social media platforms also serve as a useful tool to

direct potential contributors to an iNaturalist project. Finally, trapping, headcount surveys, and environmental DNA (eDNA) assay survey methods (Fields *et al.* 2024) are proven methods to identify the current status of diamondback terrapin presence/absence.

Research on diamondback terrapins has primarily been focused on the Atlantic coast populations (Roosenburg 1994; Harden and Williard 2012; Winters *et al.* 2015; Woodland *et al.* 2017). The lack of data for the Gulf of Mexico was highlighted by Hart *et al.* (2014) in their region-wide genetic study and more recently in the diamondback terrapin CAP in the Gulf of Mexico (Mohrman 2022). The majority of research from the Gulf of Mexico has focused on demography and nesting threats; with much of these data gathered outside of Texas (Selman and Qualls 2008; Coleman *et al.* 2011; Butler and Heinrich 2013; Selman *et al.* 2014; Pearson and Wiebe 2018; Mohrman 2022). Knowledge on the spatial ecology of diamondback terrapins along the Texas Gulf Coast is sparse, including current nesting habitat use and availability (Baxter 2017; Mohrman 2022). Historic through current data indicate that diamondback terrapins' home range, defined as the area traversed by an animal during normal daily activities excluding migrations or erratic movements, and site fidelity (e.g., using the same foraging habitat) are variable across the range of the species (Bailey 1984; Guillen *et al.* 2015). Although, as mentioned previously, it is reported that females exhibit high nest site philopatry (Harden *et al.* 2007). Again, this is further complicated by the fact that most previous studies were conducted on the Atlantic coast. In a North Carolina estuary, a home range of 305.4 ± 64.5 ha for females was calculated (Spivey 1993); in northeast Florida a home range of 54.33 ± 54.80 ha was calculated (Butler 2002); in Texas, a home range estimate between 2-30 ha was calculated in Galveston Bay (Guillen *et al.* 2015), and in Nueces Estuary near Corpus Christi an average distance between recaptures was 0.4 km (Baxter *et al.* 2013). These studies used traditional capture-mark-recapture methods, radio telemetry, or acoustic tracking data, which are inherently known to result in limited location observations (Godley *et al.* 2008; Lamont *et al.* 2015). Recently, Lamont *et al.* (2021) placed Argos satellite tags on two female diamondback terrapins in northwest Florida and reported a home range of 6,980 ha with a maximum distance travel from capture site of 11.3 km for the first individual, and a home range of 16,730 ha with a maximum distance travel from capture site of 49.6 km for the second individual. These home range estimates and long-distance movements are an order of magnitude larger from previous research and reveal a large disparity in what is understood about the spatial dynamics and habitat requirements for diamondback terrapins across their range.

In Texas, identifying nesting sites and the level of philopatry, as well as suitable nesting habitat, across their range is critical to preserving this imperiled diamondback terrapin population. To understand the extent of estuarine wetland and nesting habitats that need critical protection for Texas diamondback terrapins consistent with CAP recommendations (Mohrman 2022), it is imperative to have improved data on the spatial dynamics of this species. The use of state-of-the-art long-term GPS satellite tracking technology could serve as a tool for identifying the movement patterns and habitat use of Texas diamondback terrapins occupying the Texas Middle Gulf Coast. These high-resolution data would allow for a better understanding of

movement and home ranges, and the identification of nesting and foraging habitats required by diamondback terrapins (Lamont *et al.* 2021). Studies of this type may reveal a paradigm shift in our knowledge of diamondback terrapin spatial dynamics that will require larger areas of conservation and restoration to ensure recovery of this species. Thus, this type of research will inform vulnerability assessments and adaptive management and conservation strategies to be implemented that help preserve this unique and imperiled species.

Given the large data gaps described above and recent recommendations for future research, the objectives of the proposed study were to 1) identify the historical distribution across the Texas coast and confirm the contemporary status of Texas diamondback terrapin occupying the northern portion of the Upper Laguna Madre, including Baffin Bay; 2) create an iNaturalist project page and science campaign on social media to attract and acquire contemporary research grade observations of Texas diamondback terrapin throughout Texas; and 3) identify the movement patterns and habitat use of Texas diamondback terrapin (*Malaclemys terrapin littoralis*) occupying the Texas Middle Gulf Coast system, including sex-specific estimates of home range, nesting and foraging habitat, and the spatiotemporal variation in seasonal behaviors.

CHAPTER II: HISTORICAL AND CONTEMPORARY DISTRIBUTION OF TEXAS DIAMONDBACK TERRAPIN ACROSS THE TEXAS COAST, WITH A FOCUS ON THE NORTHERN PORTION OF THE UPPER LAGUNA MADRE (INCLUDING BAFFIN BAY)

This chapter addresses Task 1 of the contract. Task 1: Agency will identify Texas diamondback terrapin historical distribution across the Texas coast and confirm contemporary status in the northern Upper Laguna Madre, including Baffin Bay.

METHODS

Terrapin observation database

To identify the distribution of Texas diamondback terrapins in Texas, we conducted a comprehensive literature and museum database review to identify the geographic extent of observations available for Texas diamondback terrapin (*Malaclemys terrapin littoralis*) in Texas. Historic observation data from unpublished sources (i.e. Baxter et al. data held at TAMU-CC) was processed first. Next, available literature with detailed location data was processed and then compared with records from online databases (Global Biodiversity Information Facility [includes VertNet], Texas Natural Diversity Database, and iNaturalist [compiled as part of Task 2]) to prevent duplication of geographic records. Finally, we included additional observations collected during this study. Only location data with GPS coordinates or map figures that could be manually georeferenced were included in our database. We considered observation records prior to the year 2016 to be historical and all those in 2016 through 2026 to be current or contemporary locality data for terrapins. To limit the spatial clustering of historical points, we used the reported maximum home range of 0.9 km radius to create a buffer between points (Spivey 1993). It was assumed that all records of diamondback terrapins in Texas were the subspecies *Malaclemys terrapin littoralis*, based on its published range encompassing the entire Texas Gulf Coast from Baffin Bay eastward to Sabine Lake (Dixon and Hibbits 2013).

These observation points were used to inform our survey locations in combination with manually classified potential nesting site locations that were generated as part of a previous project (McCracken 2025, 2026). Using a combination of geographic data sources, primarily current and historic satellite imagery, potential survey sites were identified with a category range from 1-3, with category 1 equal to highest probability for nesting and category 3 being the least. Category 1 sites must meet all three criteria for a nesting site – shell beach, adjacent wetland habitat, and near freshwater outflows. Category 2 sites will have a shell beach but wetland habitat may not be immediately adjacent, or it is far from freshwater outflows. Category 3 sites will have a shell beach but wetland habitat and freshwater outflows are at a distance. For the current project we only used sites classified as Category 1 or 2 (e.g., Figure 1).

We classified observations from 2016 to 2026 as contemporary or current, and all those before 2016 as historic. The data compiled from the methods described above, our survey data

(described below), and observations collected by the iNaturalist project (Task 2) were used to create a georeferenced spreadsheet of Texas diamondback terrapin observations and to produce various maps of these observations.

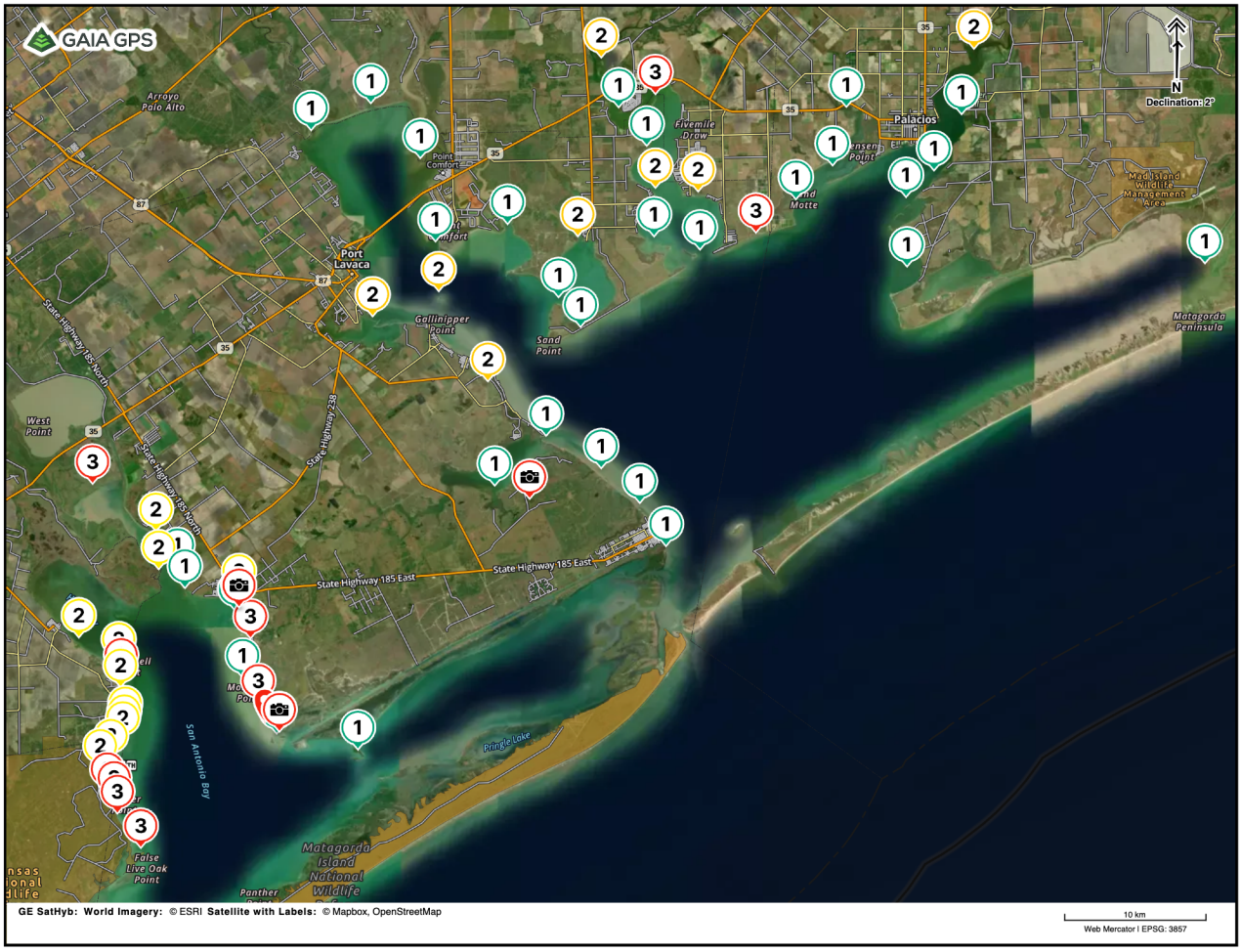


Figure 1. Map of San Antonio and Matagorda Bay systems with manual classification points of potential nesting locations for Texas diamondback terrapin. Waypoint icon numbers indicate potential nest site probability with a category range from 1-3, with category 1 equal to highest probability for nesting and category 3 being the least. Category 1 sites that must meet all three criteria for a nesting site – shell beach, adjacent wetland habitat, and near freshwater outflows; Category 2 sites will have a shell beach but wetland habitat may not be immediately adjacent or it is far from freshwater outflows; and Category 3 sites will have a shell beach but wetland habitat and freshwater outflows are at a distance.

Terrapin surveys

We conducted one or more sampling techniques (*i.e.* headcount surveys, environmental DNA (eDNA) sampling, traditional trapping, and camera trapping) to confirm presence/absence of terrapins and to fulfill objective 3 (Task 3) throughout the Texas mid-coast region with a particular focus on Baffin Bay, Oso Bay, Nueces Bay, and Aransas Bay. All terrapins were trapped and handled in accordance with TAMU-CC Institutional Animal Care and Use Committee (IACUC) animal use protocols (TAMU-CC-IACUC-2023-0019) and Texas Parks and Wildlife Scientific Research Permit (SPR-1021-162).

Head-count surveys for terrapins have been demonstrated to be an efficient method for identifying occupied habitat (Breininger et al. 2019). We performed headcount surveys independently and during each eDNA sampling event. Once the boat is stationary or anchored at the survey location, two observers use a rangefinder to measure distances to nearby solid objects to calibrate their distance estimates. We searched for terrapins within an approximate 60 m radius of the boat. Observers position themselves to scan opposite sides of the boat, covering 180 degrees in a 60 m radius. Observers are looking for a turtle head(s) sticking out of the water, binoculars are used as needed to confirm identification. Each survey was conducted for 10 minutes and all terrapin observations were recorded. We performed headcount surveys across the mid-coast from Matagorda Bay to Baffin Bay.

For environmental DNA (eDNA) sampling, at each site we collected water at both the surface (0m) and below the surface (~0.5m). Each sampling site had water collected with two sterile 1L Nalgene bottles for eDNA analysis. Before starting sampling, wearing new nitrile gloves, bottles were labeled and two blanks will be made using distilled water for a total volume of 2L of distilled water. At each sampling site, wearing new nitrile gloves, bottles were labeled and water samples collected with two sterile 1L Nalgene bottles for a total volume of 2L of water. Samples were immediately placed in an ice filled cooler. Nitrile gloves were replaced between every sampling site to prevent cross-site contamination. Before leaving each site, bottle lids were checked, and the cooler was verified as secure. Post sampling, samples were transported within the cooler to TAMU-CC for processing. Water samples were transferred to refrigerated storage at 2° C. We attempted to filter all samples within 48 hours of collection, but if we knew this was not possible the samples were frozen and stored at -20° C. Any frozen samples were thawed at room temperature in the dark and immediately filtered. Each 1L sample was filtered through a sterile, 0.45 Micron, 47mm, Nitrocellulose Mixed Ester (MCE) Membrane filter using peristaltic pump. Filters are dried and placed in a labeled mylar bag with silica beads and kept in a -80° C freezer for long-term storage or until transferred to the Marine Genomics Laboratory at TAMU-CC. All laboratory analysis of eDNA samples were conducted by the Marine Genomics Laboratory at TAMU-CC. This lab developed an eDNA qPCR assay protocol to detect diamondback terrapins in water samples that researchers could easily collect (Fields *et al.* 2024). A quarter of each filter is excised, cut into strips and DNA extracted using a modified Qiagen Blood and Tissue Kit extraction protocol. Extracted DNA samples are cleaned for

impurities and then purified. The optimized multiplex qPCR assay protocol is then performed on the samples.

Traditional trapping used modified commercial crab traps with a “chimney” that extends above the water’s surface to allow terrapins to surface for air once caught in the trap (Figure 2). We identified potential trapping sites based on previous observation records and proximity to manually classified suitable potential nesting sites. We deployed 4 traps at each site and traps were baited primarily with mullet (*Mugil cephalus*) caught by cast netting in local waters or purchased from local fish markets. Trapping was done in a 2-day period, with the first day for baiting and setting traps and the second day for checking for terrapin captures. Traps were set in the morning of day 1, between 8:00 – 11:00 AM and were set with ~ 25-50 mm of the trap sticking out above the water, not inclusive of the chimney. Traps were checked on the second day, approximately at the same time traps were set the day before and any captured terrapins were recorded and processed. Processing terrapins included using standard calipers to measure the carapace length (CL), carapace width (CW), plastron length (PL), plastron width (PW), and body depth (BD) at the greatest distance for each parameter. Weight was also recorded using a digital fish scale that gave measurements in increments of 10g. Terrapins were notched for identification purposes following the Schwartz system (Figure 3), where the turtle is notched on their marginal scutes. Terrapins were photographed, and then a blood sample was taken by accessing the subcarapacial or brachial vein. Only three attempts were made to collect a blood sample in accordance with our IACUC protocol. PIT tags (passive integrated transponder) were injected into the right hind limb of turtles for secondary identification purposes. Once all data were recorded and procedures performed, they were released in the same location where they were captured.

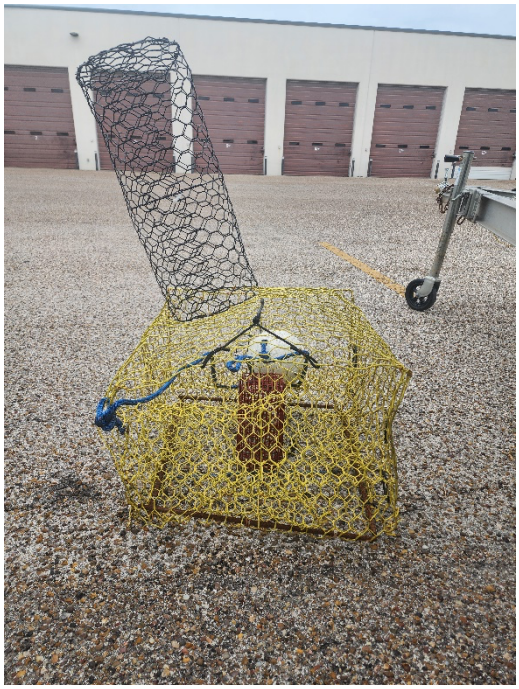


Figure 2. Image of a modified crab trap. The chimney attached to the crab trap allows terrapins to climb up to fresh air in the event the tides rose over the sampling period (photo by Garrett Guzoski).

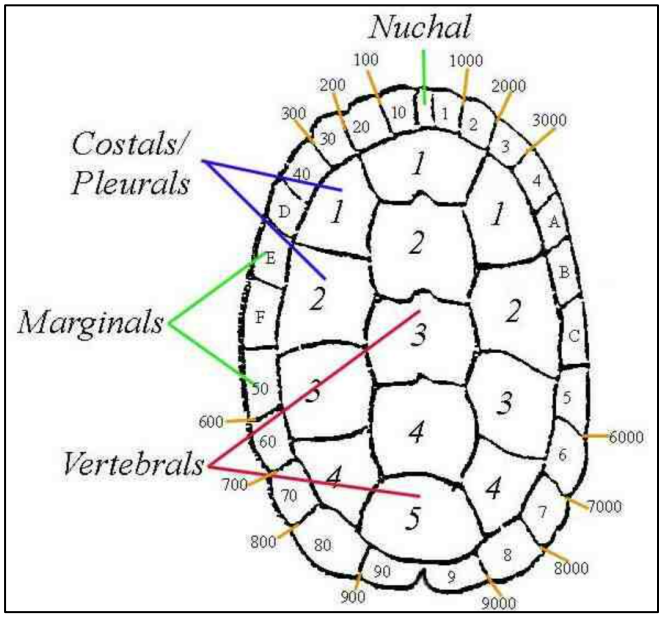


Figure 3. Image of Schwartz system for terrapin shell notching. The notches on marginal scutes are used to identify individual terrapins. The notching sequence begins with the first marginal scute to the right of the nuchal scute as #1 and follows down the marginal scutes skipping the bridge (A, B, C) (image by Don Lewis, Wellfleet Bay Wildlife Sanctuary).

Camera traps were deployed to detect terrapins nesting. Cameras were mounted on t-posts driven into the ground and secured with a cable lock to a 24-inch screw anchor in the ground to deter theft (Figure 4). Cameras were placed just above the high-water line with a view of the shell hash beach area. Cameras were set to hybrid timelapse mode, taking a picture every 5 minutes while also being able to trigger with movement.



Figure 4. Image of camera trap at potential nesting site on Oso Bay.

RESULTS

Terrapin observation database

We identified a total of 404 site observations (separated by approximately 0.7 km, see methods) for Texas diamondback terrapins (Figure 5). A total of 32 sites represent terrapin observations between 2016 and 2026 (Figure 6), with the remaining 372 sites representing where terrapins were last observed before 2016 (late 1800s through 2015) (Figure 7). The western and southernmost site on South Padre Island, Texas represents two observations of hatchlings found on the surf side of the beach in March 2019 (Guadiana *et al.* 2020). While it is possible that these came from a nearby hatching event from an introduced or dispersed terrapin, it is also possible that these were from a pet terrapin and dumped on the beach. The nearest voucher specimen

(MVZ 257690) and other historical and contemporary observations documented in this study are from nearly 200 km northeast in Nueces County, Texas. The northern and easternmost site is in Sabine Lake on the Texas and Louisiana border. This site location is from observations in the mid-1980s (Mabie 1987); however, there is a current population just south of here in the vicinity of Sabine Pass, Texas. A spreadsheet of compiled terrapin observation data is available in the Figshare project for the study.

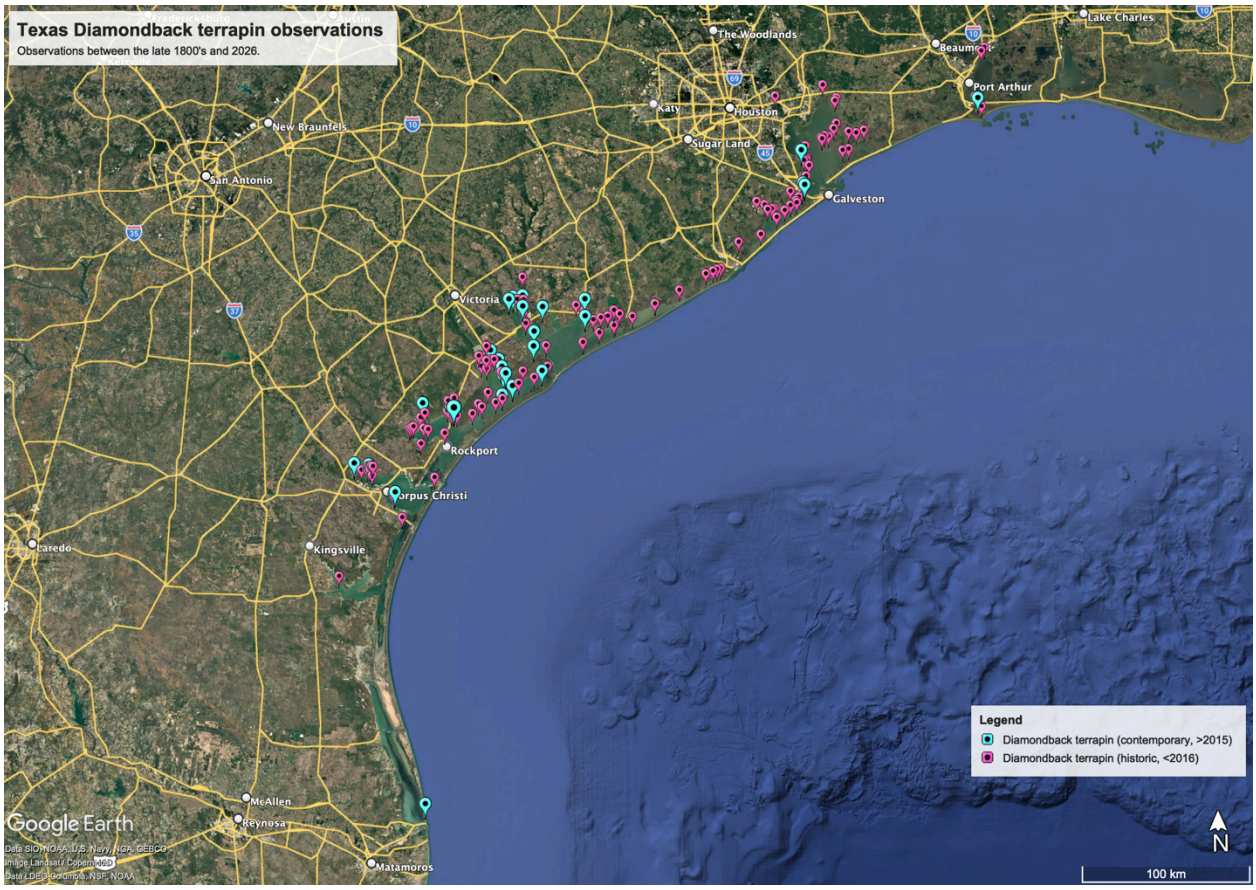


Figure 5. Map of all observation sites for the Texas diamondback terrapin (*Malaclemys terrapin littoralis*) in Texas. Observations date from the late 1800s through May 2026. Magenta points represent terrapin observations prior to 2016, and the light blue points are observations ≥2016 that are considered contemporary observations.

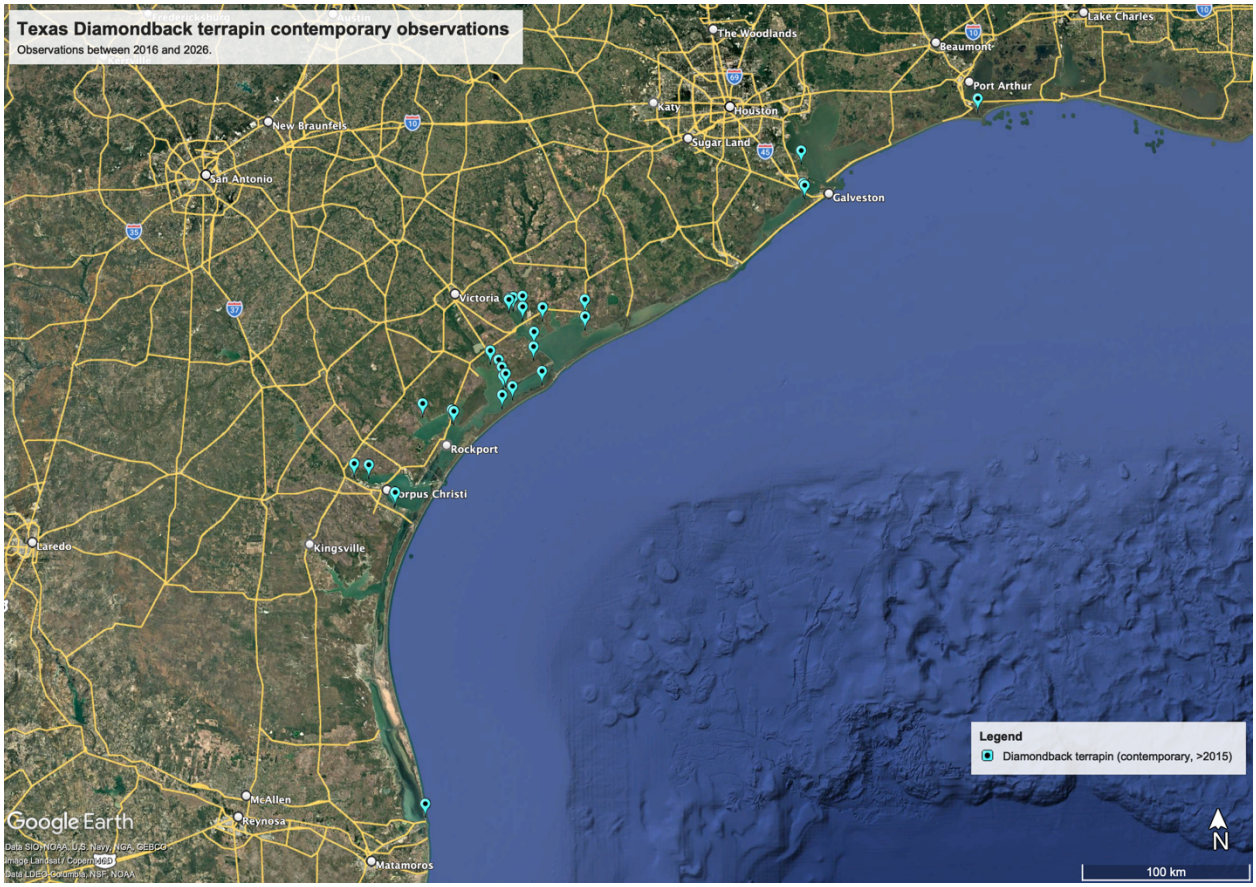


Figure 6. Map of recent observations for the Texas diamondback terrapin (*Malaclemys terrapin littoralis*) in Texas. Observations date from 2016 through May 2026.

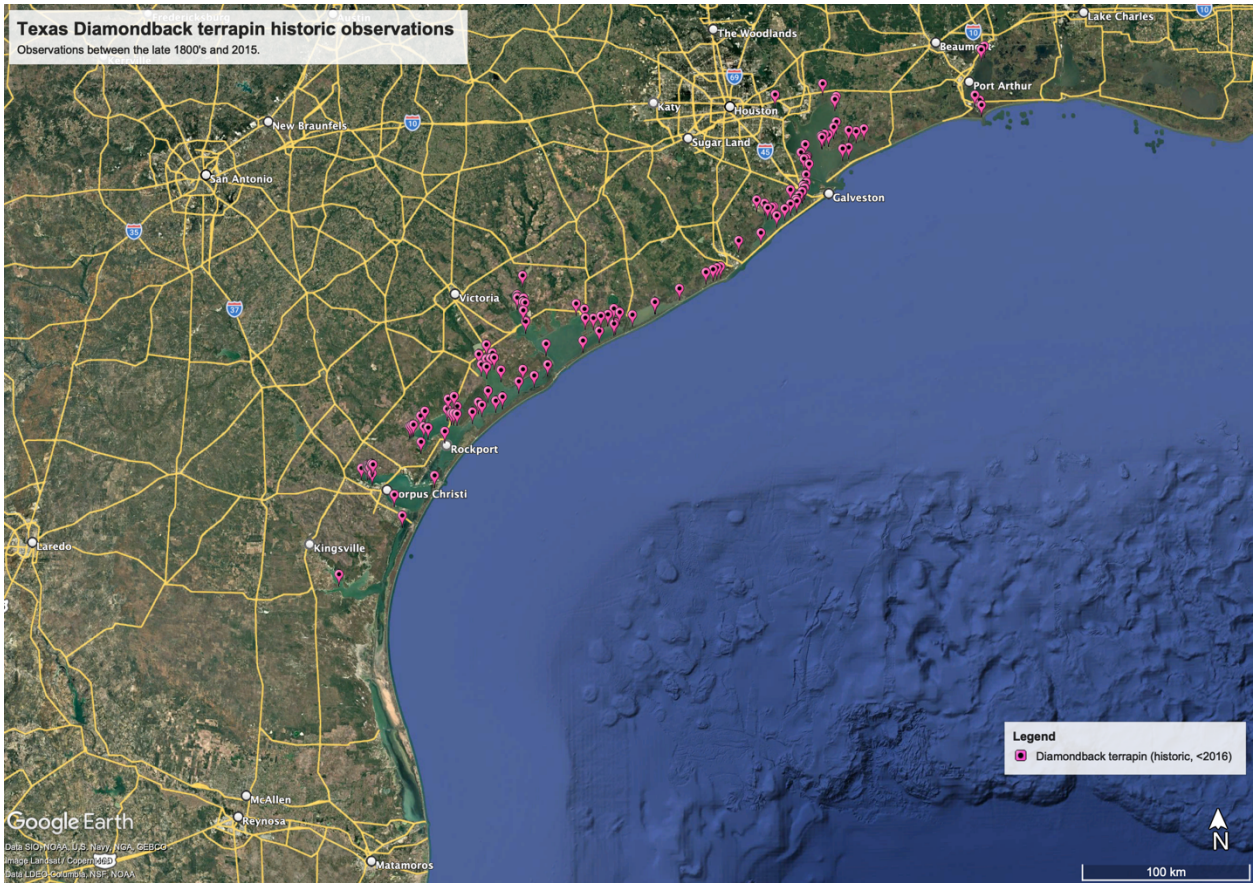


Figure 7. Map of historic observations for the Texas diamondback terrapin (*Malaclemys terrapin littoralis*) in Texas. Observations date from the late 1800s through 2015.

Terrapin surveys

In 2023, as part of a concurrent terrapin distribution and nesting site study, we conducted up to six head-count surveys at sites in San Antonio Bay. Texas diamondback terrapins were only detected at a single location, site 011 (site ID: Dbt_nest_1_35 in other study) (Figure 8), twice out of 6 surveys, with a maximum of 5 individuals observed. The shell hash beaches of two islands near site 011 were searched for evidence of nesting on June 15, June 22, and July 10 of 2023, but none were identified. At site 011, we used 8 modified crab traps baited with mullet to trap terrapins (August 16-17, 2023, and September 7-8, 2023), but no terrapins were captured during these trapping events. On March 6, April 5, August 8, and August 22 of 2024, head-count surveys were conducted at 20 eDNA sites in San Antonio Bay (Figure 8). A single terrapin was observed again at site 011 (eDNA site ID: 011) on April 5, 2024, but all other sites were negative for terrapin heads during surveys. From the Fall of 2024 through February of 2026, we conducted head-count surveys on 7 occasions during deployment and retrieval of traditional traps in Baffin Bay (Figure 9). No terrapin heads were observed during these surveys. In the spring of 2025, we began performing head-count surveys during eDNA sampling events. We surveyed a total of 96 sites from San Antonio Bay south to Baffin Bay, most of which were surveyed three times over the course of one year (Figure 10). Two terrapins were observed on November 12,

2025 in Copano Creek at site 077 (Figure 10). No other terrapins were observed during the 2025-2026 headcount surveys, including site 011.



Figure 8. Head-count and eDNA survey sites in San Antonio Bay and Matagorda Bay. The yellow icon represents the positive detection of terrapins during head-count surveys.



Figure 9. Head-count and trapping survey sites in Baffin Bay. Orange diamond marks the location of a historic observation reported by commercial trappers in a survey by Mabie (1987).



Figure 10. Head-count and eDNA survey sites from San Antonio Bay to Baffin Bay (n=96). Yellow icons represent head-count positive sites.

Environmental DNA (eDNA) survey samples were collected from March 2025 through February 2026 at a total of 96 sites (Figure 10) as a part of this project and another project sponsored by the Coastal Bend Bays and Estuaries Program. Samples collected from March through August of 2025 were all negative for terrapins, and the remaining samples are awaiting processing at the Marine Genomics Lab at TAMU-CC.

Traditional trapping was generally unproductive, except in Nueces Bay and the Nueces River. No terrapins were captured in Baffin Bay, Oso Bay, or St. Charles Bay (vicinity of fish cleaning station at Goose Island State Park where terrapins are regularly observed congregating) using modified crab traps (Table 1). Using a cast net, at the Goose Island State Park (GISP) fish cleaning station, one female terrapin was captured on November 5, 2025, two (females) on April 17, 2026, and two (one male, one female) on May 29, 2026. All of these terrapins had Telemetry Solutions GPS transmitter tags attached. As part of a concurrent mark-recapture research study, we conducted an aggressive trapping campaign in Nueces Bay and the Nueces River from August 2, 2023, to August 30, 2024. A winter gap occurred from mid-November to mid-March, when no trapping was conducted because water temperatures dropped below 20°C and terrapins were no longer captured; it was presumed they were brumating. A total of 105 individuals were captured, of which 7 were fitted with GPS transmitter tags. In Chapter IV, we report the results of this study regarding the movement patterns and habitat use of terrapins in this system.

Table 1. Terrapin trapping events across bay systems.
(Note: Does not include trapping events in Nueces River or Bay.)

Date	Bay System	Trap type	Terrapins Captured
9/5/24	Baffin	modified crab trap	0
10/22/24	Baffin	modified crab trap	0
5/9/25	Baffin	modified crab trap	0
5/28/25	Baffin	modified crab trap	0
7/29/25	Oso	modified crab trap	0
7/30/25	Oso	modified crab trap	0
8/7/25	St. Charles	modified crab trap	0
7/31/25	St. Charles	modified crab trap	0
9/1/25	Baffin	modified crab trap	0
10/8/25	St. Charles	modified crab trap	0
10/9/25	Oso	modified crab trap	0
10/10/25	Oso	modified crab trap	0
10/13/25	St. Charles	modified crab trap	0
10/14/25	St. Charles	modified crab trap	0
10/17/25	St. Charles	modified crab trap	0
10/23/25	St. Charles	modified crab trap	0
10/28/25	St. Charles	modified crab trap	0
10/29/25	St. Charles	modified crab trap	0
10/30/25	St. Charles	modified crab trap	0
10/31/25	St. Charles	modified crab trap	0
11/5/25	St. Charles	cast net	1
11/18/25	Baffin	modified crab trap	0
2/16/26	Baffin	modified crab trap	0
4/17/26	St. Charles	cast net	2
5/29/26	St. Charles	cast net	2
Total	**-**		**5**

Initial camera trap efforts began in April 2023 with the installation of a test unit on the Powderhorn Wildlife Management Area near Port O'Connor, Texas (Figure 11). This pilot deployment was designed to evaluate field protocols prior to broader implementation across Matagorda Bay. By late May, we planned to expand to additional sites; however, no terrapin activity was captured at the Powderhorn WMA site, and concurrent field surveys in San Antonio Bay detected only a single location positive for terrapins. As a result, further camera installations were postponed while survey efforts shifted toward first identifying active terrapin populations before deploying nesting observation methods (e.g., walking surveys and camera traps) in adjacent suitable habitats. When we returned in November 2023 to retrieve the initial camera, it

had been stolen. Over the winter, a new camera security system was designed and tested for shoreline deployment. In spring 2024, two new cameras were installed along Powderhorn Lake, near locations with prior terrapin observations on iNaturalist. These cameras remained in place throughout the season, confirming the effectiveness of the new security measures, but again no terrapin nesting activity was recorded. Significant disturbance from cattle was observed, with animals rubbing against the cameras and bending t-posts, misdirecting camera views away from the shoreline. Reinforcing the posts did not prevent damage, leading to a recommendation against deploying game cameras in areas with cattle unless robust mounting structures (e.g., bollards) are available. In spring 2025, we installed cameras on Matagorda Bay near sites where hatchlings had been recently reported on iNaturalist. One of these sites was near Indianola, about 6 kilometers south of where the hatchling was observed; and the other was near Palacios, about 8 kilometers west of where the hatchling was observed. The cameras were placed at these locations as they were in the closest suitable nesting habitat that we could access and were relatively secure from human disturbance. These cameras ran until mid-July; no terrapins were observed. We were unable to locate suitable sites for camera deployment on Baffin Bay.

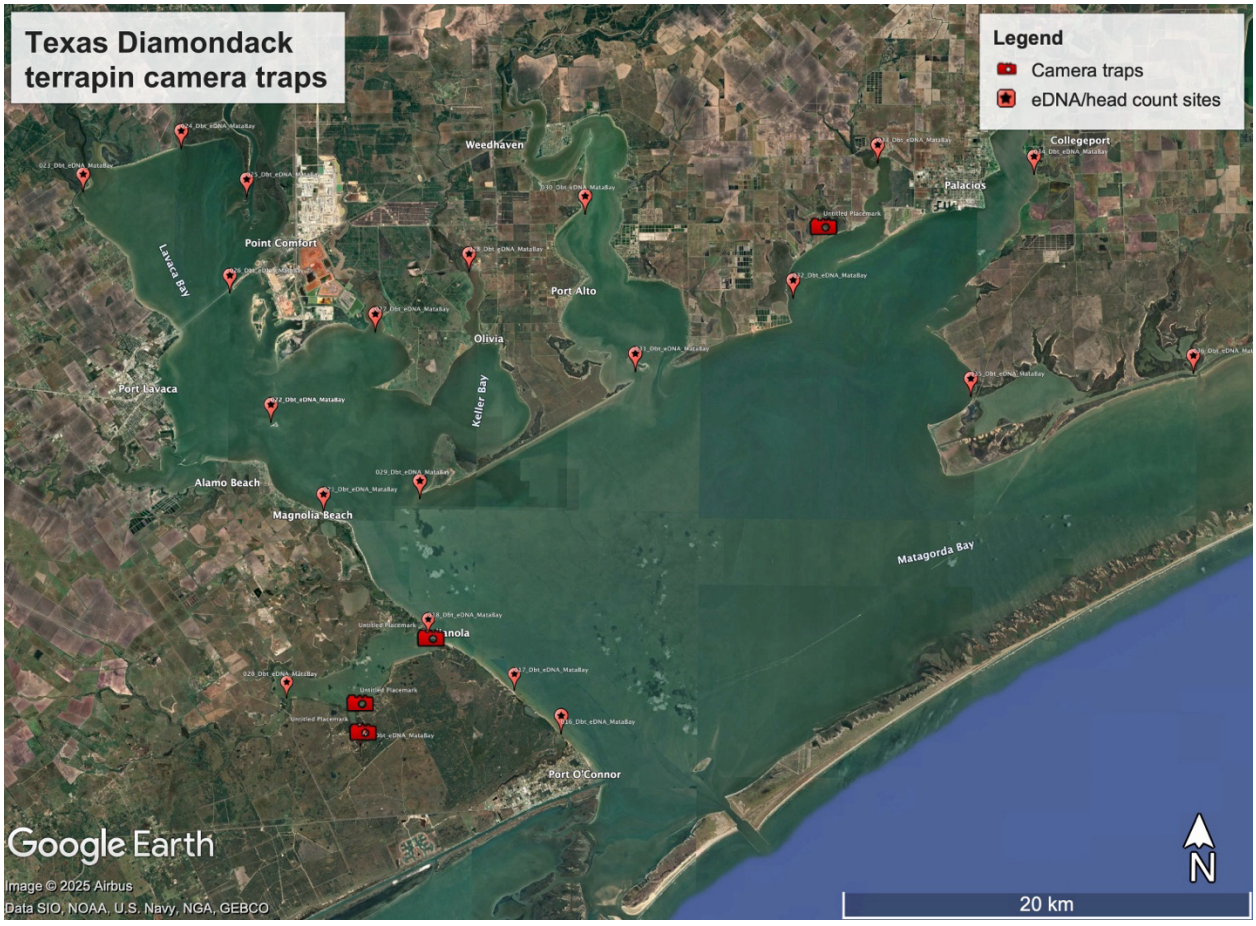


Figure 11. Camera trap installation sites to detect terrapin nesting activity. Two western sites were deployed in 2023 and 2024. The other two sites to the east and northeast were deployed in 2025.

CHAPTER III: CREATION OF INATURALIST PROJECT AND CITIZEN SCIENCE CAMPAIGN TO ACQUIRE CONTEMPORARY RESEARCH-GRADE TEXAS DIAMONDBACK TERRAPIN OBSERVATIONS THROUGHOUT TEXAS

This chapter addresses Task 2 of the contract. Task 2: Agency will generate an iNaturalist project and citizen science campaign to acquire contemporary research-grade Texas diamondback Terrapin observations throughout Texas.

METHODS

Creation of iNaturalist project and outreach efforts

To assist us in acquiring contemporary research-grade observations and identify undocumented diamondback terrapin populations in Texas we began by creating an iNaturalist project called, "Texas diamondback terrapin Task Force" (link - https://www.inaturalist.org/projects/texas-diamondback-terrapin-task-force). Project parameters are set to gather observations of taxa identified as diamondback terrapin (*Malaclemys terrapin*) or Texas diamondback terrapin (*Malaclemys terrapin littoralis*) and restricted to the geographic extent of the state of Texas. In the description of the project we include a statement that handling or possessing the Texas diamondback terrapin is illegal. Since diamondback terrapins are a threatened species, iNaturalist automatically obscures the geolocation data of observations to protect the species from poaching. However, the submitting user can join as a member of the Texas diamondback terrapin Task Force project. This allows the owner and assigned administrators of the project to see the true GPS coordinates for the observation. Therefore, we monitor the project for new observations from non-members and send them a direct message through iNaturalist asking them to join the group and provide them instructions on how to do so. Our messages include a statement that handling or possessing the Texas diamondback terrapin is illegal without appropriate permits.

We have also created outreach media and presented our research to several groups to encourage citizens to report their observations of diamondback terrapins. Recently, we created an ArcGIS Survey123 form where we can send citizen observers directly to share their observations and upload photos without needing to register or signup for an account. This creates an alternative to iNaturalist that requires multiple steps for the user to be able to share unobscured coordinates with our research group. While we have not deployed the form yet, we will do so before the end of July 2026. Link to observation form - https://survey123.arcgis.com/share/4ee4735d499c4817964e640c10135cee.

RESULTS

Creation of iNaturalist project and outreach efforts

The Texas diamondback terrapin Task Force - iNaturalist project now has 174 Research Grade observations, doubling the number of observations since the start of the project (Figure 12). The majority of these observations have come from the fish cleaning station at Goose Island State Park on St. Charles/Aransas Bays or from West Bay near Galveston, TX. We continue to contact the observers (78 total as of May 10, 2026) on the project to ask them to grant us access to their observations so that location coordinates can be unobscured. A total of 25 observers have joined the project allowing their GPS coordinates to become available to us.

The iNaturalist project has resulted in five new locations for terrapin observations: 1) in between Magnolia Beach and Indianola on Matagorda Bay (Dbt_00062, found dead on beach 12/15/2025), 2) near Oyster Lake Park on Matagorda Bay (Dbt_00292, near a historic site from the 1980s); 3) Palacios Bay Beach on Tres Palacios Bay (Dbt_00061, hatchling likely from Turtle Bay area); 4) east side of Lavaca Bay Causeway (Dbt_00391, found dead on road, user is TXDOT employee who finds them in the area occasionally); and 5) two observations on northeast side of Oso Bay (Dbt_00389 and Dbt_00394, both observed exiting upland vegetation areas and walking across beach area back into the water, likely nesting events).

Educational outreach has included a formal presentation to the TAMU-CC Anglers Club (2024), which trained participants on terrapin identification and reporting methods. A public presentation was given at the Calallen Public library in the fall of 2024 that highlighted the need for terrapin research and conservation. Specialized PowerPoint slides were also developed for the Texas Sea Turtle Stranding and Salvage Network (STSSN) to help responders identify Texas diamondback terrapins and submit verified reports to the McCracken Lab or the iNaturalist project (Appendix A). We have also created flyers that we have posted with permission at boat ramps and share opportunistically with boaters, kayakers, and fishing guides, directing them to the iNaturalist project (Appendix A). Project updates, fieldwork highlights, and educational content have been regularly disseminated through the McCracken Lab and Center for Coastal Studies social media platforms, maintaining continuous public engagement throughout the project.

The project's visibility and professional engagement were further strengthened through conference and invited presentations. In 2025, Dr. Shawn McCracken and postdoctoral researcher Dr. Tyler Bowling presented "Distribution and Movement Ecology of the Texas diamondback Terrapin (*Malaclemys terrapin littoralis*) and Habitat Use and Environmental Tolerances of diamondback Terrapins in the Southwestern Gulf of Mexico" at the 10th Triennial diamondback Terrapin Workshop in Cape May, New Jersey. Earlier that year, PI McCracken presented "Casting a Wide Net: An Array of Techniques to Identify Nesting Habitats of the

Texas diamondback Terrapin" at the Gulf of Mexico Alliance Business Advisory Council Meeting and "Distribution of diamondback Terrapins in Texas and Identification of Nesting Habitats" at the Gulf of Mexico Alliance All-Hands Meeting.

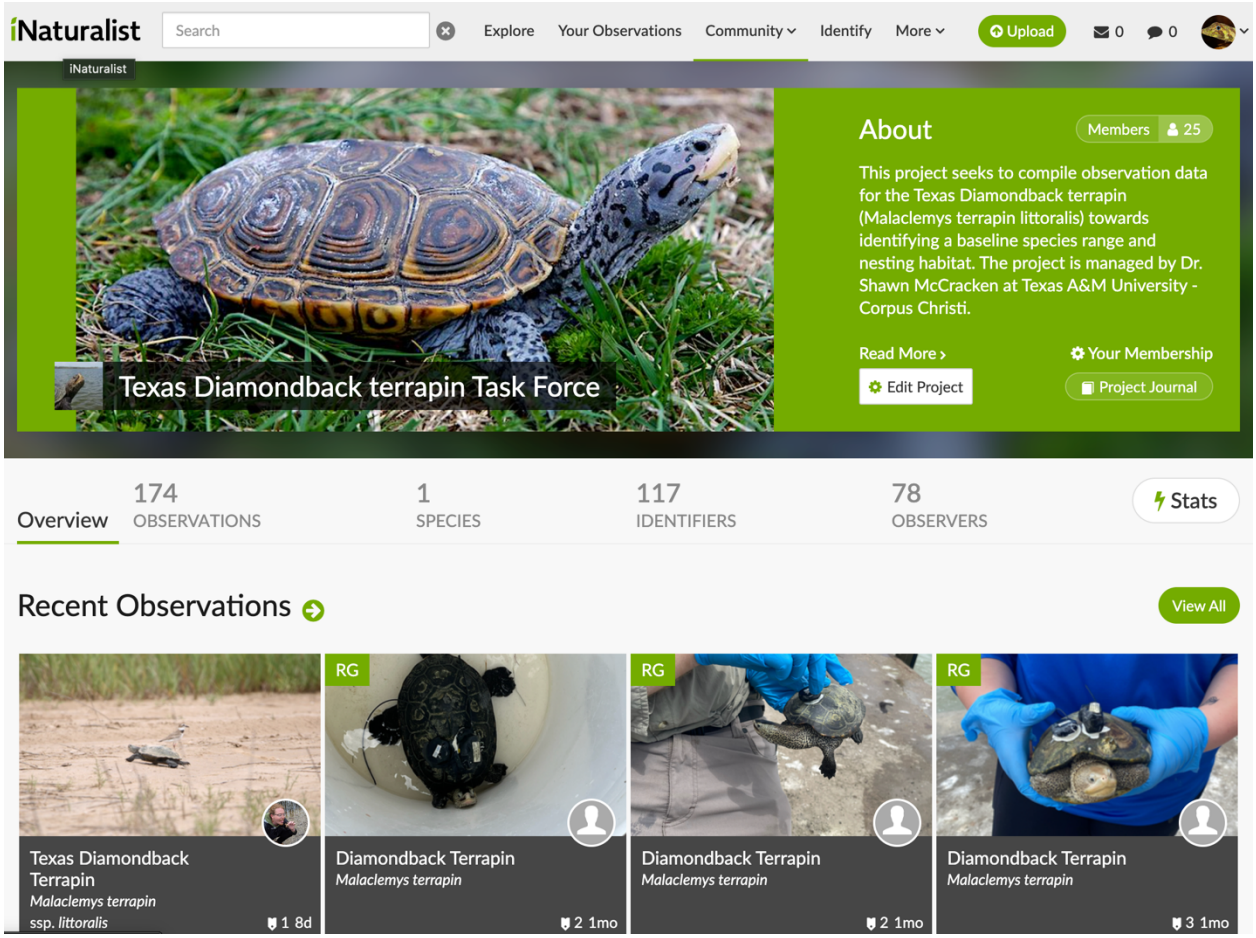


Figure 12. Landing page for the Texas diamondback terrapin Task Force – iNaturalist project showing summary statistics and recent observations.

CHAPTER IV: IDENTIFY MOVEMENT PATTERNS AND HABITAT USE OF TEXAS DIAMONDBACK TERRAPIN IN THE TEXAS MIDDLE GULF COAST SYSTEM

This chapter addresses Task 3 of the contract. Task 3: Agency will identify movement patterns and habitat use of Texas diamondback Terrapin in the Texas Middle Gulf Coast system. Due to the potential challenges of attaching GPS transmitters to small turtles in a marine environment, we also conducted a mark-recapture study in the Nueces Estuary to assess how salinity and water temperature influence terrapin movement and habitat use.

METHODS

Terrapin trapping and GPS transmitter mounting

For details of trapping methods, refer to the Methods section of Chapter II (page 12). All terrapins were trapped and handled in accordance with TAMU-CC Institutional Animal Care and Use Committee (IACUC) animal use protocols (TAMU-CC-IACUC-2023-0019) and Texas Parks and Wildlife Scientific Research Permit (SPR-1021-162).

Selected terrapins for GPS transmitter mounting were observed to be in good health and of appropriate size for transmitters. Only terrapins ≥440 g were tagged to ensure sexual maturity, and that the GPS transmitter did not exceed 5% of the terrapin's total body weight. GPS transmitters were attached using JB Weld Marine Epoxy slightly posterior to the peak of the terrapin's carapace to reduce drag and allow acquisition of GPS locations when a submerged terrapin surfaces for air or is basking (floating) near the surface. Preparing terrapins to be mounted with transmitters included gently smoothing out the area on the carapace with a sanding sponge. After the area was smooth, it was cleaned with isopropyl alcohol and then rinsed with deionized water. The epoxy was mixed until firm, then placed on the bottom of the transmitter and pressed onto the carapace. Once hard, JB Weld Water Weld epoxy was used to surround the base of the transmitter and was kneaded in to ensure no air bubbles were beneath the transmitter. Total set time for mounting the transmitters was approximately 1 hour. Terrapins were then released in the same location where they were captured.

Terrapin trapping and mark-recapture study

The study site was located in the Nueces Estuary, specifically the tidal segment of Nueces River and Nueces Bay located north of Corpus Christi, TX. The study site consisted of 6 sampling locations in Nueces River and Nueces Bay. Five of the sampling locations were in the river which were named starting at the most upstream location: River 1, River 2, River 3, River 4, and River 5 (hereafter referred to as R1, R2, R3, R4, and R5, respectively) and one location in Nueces Bay (hereafter referred to as Bay). The entire length of the study site is ~20 km with each site being ~4 km apart (Figure 13).

Trapping methods were similar to those described in Chapter II (page 12); however, we deployed 4 crab traps at each of the 6 sampling locations for a total of 24 crab traps deployed per session.



Figure 13. Study site map illustrating the 6 sampling sites. The study area is made up of the terminal ~20 km of Nueces River leading into Nueces Bay with ~4 km spaced between sites.

Movement analyses

Spatial location data were imported into R and organized by individual, date, and coordinate accuracy. Erroneous or low-confidence GPS fixes were filtered out. The cleaned dataset was then plotted to visualize movement paths and assess spatial clustering. To identify activity centers, a k-means spatial clustering approach was used to group locations (point coordinates) in close proximity that represented distinct activity areas, such as foraging or nesting sites. These clusters were visualized and evaluated to determine the number and location of primary activity centers. Home range was estimated using a 95% minimum convex polygon (MCP), which encompasses the outermost 95% of recorded locations and provides a standard measure of the area used by the individual. The polygon was calculated for each terrapin and visualized to show the spatial extent of their range. Step length, defined as the distance between consecutive GPS fixes, was calculated to quantify movement distances between time steps. Distances were computed using planar coordinates, and the resulting step lengths were summarized to characterize movement patterns.

For the mark-recapture study, R was used to perform a one-way ANOVA to test for differences in salinity and water temperature across all 6 sample sites. A Tukey HSD test was

performed to identify the differences among the 6 sampling sites. A density curve for both salinity and water temperature were created in R to visualize the distribution of terrapin captures. A binary logistic regression with a quadratic term was performed in R to test whether the probability of terrapin occurrence was significantly related to salinity and water temperature.

Salinity and temperature measurements

Data collection for salinity and temperature began in September 2023 and ended in August 2024. Salinity and temperature measurements for the R1 and Bay stations were collected from two permanent data collection stations owned and operated by the Conrad Blucher Institute at Texas A&M University - Corpus Christi. The two stations are named Salt 03 and Salt 05 and data for these stations can be accessed at their website: https://www.conradblucherinstitute.org/data. For the other 4 sites, HOBO saltwater conductivity/salinity data loggers were used to record salinity and temperature measurements. The loggers were placed inside of a 50 mm diameter PVC tube that was cut to 300mm long. A PVC cap was glued to the bottom and the top had a screw on PVC cap for access to the loggers in the field. The PVC piping that housed the loggers were then attached to a cinder block using zip ties (Figure 14). The loggers were submerged at each of the 4 locations and were set to record salinity and temperature every 12 hours. Data were collected every 2 weeks from the loggers using the HOBO waterproof shuttle.



Figure 14. Image of HOBO logger set up. The HOBO logger was placed inside a PVC tube that had holes drilled in it for water flow. The PVC tubing was then zip-tied to a cinder block and placed at the 4 sampling sites (R2, R3, R4, and R5) in the Nueces River.

RESULTS

GPS transmitters and movement

Initially, we proposed using GPS loggers from Telemetry Solutions to track Texas diamondback terrapins. These loggers require a base station for data download transfers from GPS loggers deployed on terrapins. They also have a limited battery life span of about 160 days when scheduled to acquire a GPS location twice daily. Recently, other cellular-based GPS loggers with small solar panels for charging batteries have become available, and prices had come down to within our budget range. These GPS loggers transmit data via cellular networks, which can then be retrieved through an online portal. This technology presented the opportunity to more easily acquire GPS location data for terrapins and to provide a longer battery life (resulting in more data points). It was decided to test cellular devices from two manufacturers: Cellular Tracking Technologies and Advanced Telemetry Systems.

We started with two ES-420 GPS cellular trackers from Cellular Tracking Technologies. On August 17, 2023, we deployed the first unit on a female diamondback terrapin weighing 1060 grams caught at our trapping location in Nueces Bay (see Bay site in Figure 13). On 8/17/2023 at 1700h, we received a single position fix (27.853550, -97.482870) for the terrapin that was approximately 50 meters from the original capture and release site. We can see on the data portal that several unsuccessful data transmission attempts were made up to 9/11/2023, with no further connection attempts or data received from this terrapin. On 9/8/2023, we deployed the second unit on a female diamondback terrapin weighing 940 grams caught at the same location in Nueces Bay. We can see on the data portal that several unsuccessful data transmission attempts were made up to 11/1/2023, with no further connection attempts or data received from this terrapin. In talking with the manufacturer, there were two suspected issues that occurred: 1) the solar panel was not exposed to enough sunlight to keep the battery sufficiently charged, and 2) data transmissions failed because the unit was not out of the water long enough to establish a cellular connection and transmit a full data packet. Despite continued trapping at this site, we did not recapture either terrapin.

In late October 2023 we received two L20 Solar-cell glue-on GPS trackers from Advanced Telemetry Solutions. These units have a water switch that signals to the GPS receiver when it is out of the water and should attempt a GPS fix or data transmission. They also have a VHF transmitter to allow for traditional telemetry tracking. On 11/9/23, we deployed both units on terrapins caught in the Nueces River at site R3 (Figure 13). Both were females, weighing 1490 grams and 1140 grams. We only received two GPS points from each of these transmitters. We believe these terrapins must have emerged from winter brumation and likely spent time out of the water during this timeframe to recover and acclimate. On the first unit, we received the first position at one of the Nueces Bay island sites (on 2/24/24 @ 1612h) and the second position at an adjacent island (on 3/13/24 @ 2045h) (see Bay site in Figure 13), but on a few occasions, we detected a VHF signal. The VHF signal was coming from the salt marsh area adjacent to the Nueces River; however, we were unable to track it down due to a weak, intermittent signal

(likely from the terrapin submerging) and difficult access to the habitat. For the other unit, we received location data for two days in early March 2024. The first location (on 3/9/24 @ 1908h) was approximately 2.2 km downstream from where it was originally trapped at site R3, and the second position (on 3/13/24 @ 2005h) was approximately 3.55 km downstream from the original trap location. Both positions appear to be at the edge of the river. We had considerably fewer VHF signal detections from this terrapin, and efforts to track and relocate these terrapins for hand capture failed. We suspect that the water switch on these units was not drying out enough to signal that a position fix should be taken or data uploaded over the cellular network. No further GPS points were received from either unit.

In April 2024, we received three Q4000ER GPS with VHF transmitters from Telemetry Solutions. These are the original units we had proposed using, and they also have a water switch and a VHF transmitter. The manufacturer worked with us to customize the layout of the units to ensure the electrodes for the water switch were optimally positioned for proper function, and that all antennas were angled properly for optimal performance. Each of these transmitters was programmed slightly differently to test whether forcing GPS position attempts (regardless of the water switch position) or relying on the water switch to take GPS positions worked better. The reasoning for testing this is that forced GPS attempts use more power than checking the water switch and would result in less runtime. These units require a base station to receive data uploads. The base station was deployed during the third week of June on a water quality monitoring station owned by the Conrad Blucher Institute adjacent to our Nueces Bay trapping site (see Bay site in Figure 13). We moved the base station to a signpost near the River 3 site at the beginning of September 2024 in an effort to collect data from any terrapins that remained in the river portion of the system.

On 4/17/2024, we deployed one unit on a female terrapin weighing 1280 grams caught in Nueces Bay near the larger western island of our Bay trapping site (see GMG0053 in Figure 15). On 5/15/2024, we deployed the other two units on terrapins caught in the Nueces River at the River 3 site (Figure 13). Both were females, weighing 900 grams and 940 grams. Of the three terrapins tagged with GPS transmitters from Telemetry Solutions, only one produced accurate GPS fixes (n=29) from April to July 2024. The program settings for this transmitter were configured to a mix of forced GPS fix attempts (0550h and 1750h) and water switch checks. On 4/29/2024, the first GPS point after initial capture placed this individual in the shallow marsh area to the north of the Nueces River discharge point on the western side of Nueces Bay, likely a foraging area. GPS points indicate that this individual remained in the vicinity of this marsh until late May. On 6/1/2024, a GPS point indicates she traveled approximately 4 km NW into the marshes, possibly to nest (Figure 15). Available points indicate she spent a minimum of four days (6/1/2024-6/4/204) in this area before the next point on 6/6/2024 places her back at the previous foraging location at the mouth of the river. A series of points indicates she was in this area until at least 6/24/2024. On 6/29/2024, a point shows she relocated to the bay islands area where she was originally captured. The last GPS point collected from this individual occurs on 7/24/2024 at the eastern island in the bay (for movement over time see Figure 16). Home range

was determined with a 95% Minimum Convex Polygon (MCP) to be 459 ha (4.59 km2) (Figure 17). Due to the high level of clustering Figure #18) of the minimal points, additional analysis did not produce reliable results.

In August 2025, we received 8 additional Q4000ER GPS with VHF transmitters from Telemetry Solutions. The base station was mounted to a light post (at ~4.5 m) at the Goose Island State Park boat ramp where we planned to trap terrapins that frequent the fish cleaning station at this location.

On 11/5/2025, we deployed one unit on a male terrapin weighing 620 grams caught from the boat dock at the Goose Island State Park boat ramp with a cast net. We had a manufacturer recommended programming schedule that relied solely on the water switch drying to activate the GPS unit. The frequency for checking the water switch was set to every second with the idea that this would result in more GPS fixes. The data downloaded to date has not resulted in any attempts to take a GPS position for this individual. We have observed this individual at the GISP fish cleaning station and attempted to recapture it with a cast net to reprogram the transmitter, but these attempts have been unsuccessful.

Four of the remaining units from Telemetry Solutions were deployed on 4/17/26 (2 female) and 5/29/26 (1 female, 1 male). No data has been downloaded from these individuals as of the writing of this report.



Figure 15. GPS positions for a female terrapin captured and tagged on 4/17/2024 in Nueces Bay (GMG0053 capture location). The yellow circles represent the GPS points collected by the Telemetry Solutions logger.

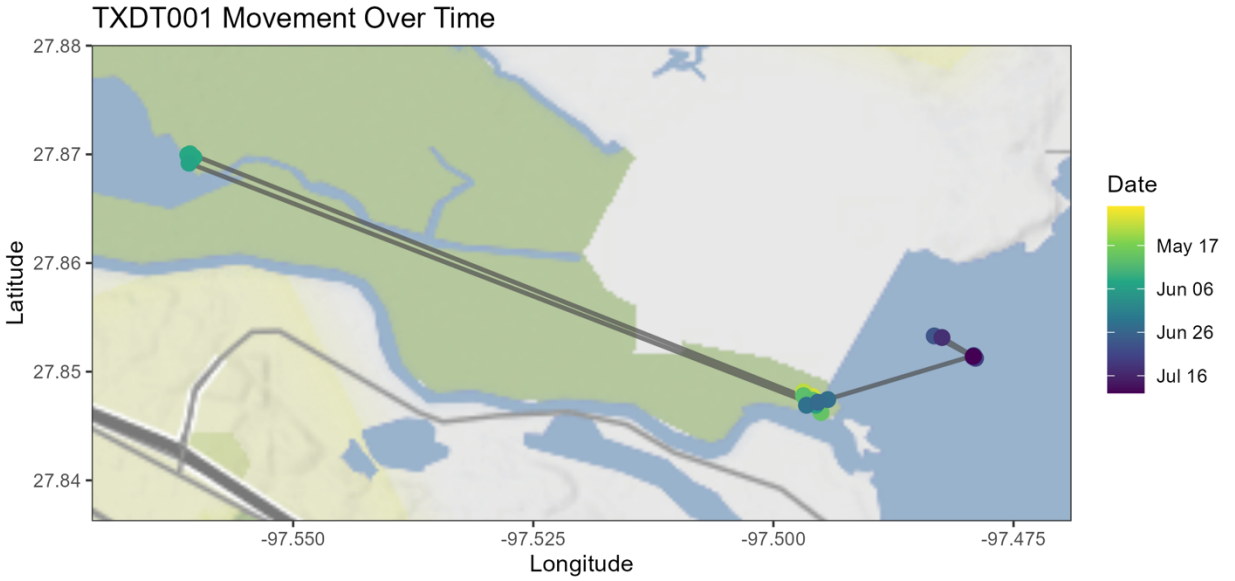


Figure 16. Movement over time for a female terrapin captured and tagged on 4/17/2024 in Nueces Bay (GMG0053). The first GPS point collected after release was on 4/29/2024 and the final point was collected on 7/24/2024.

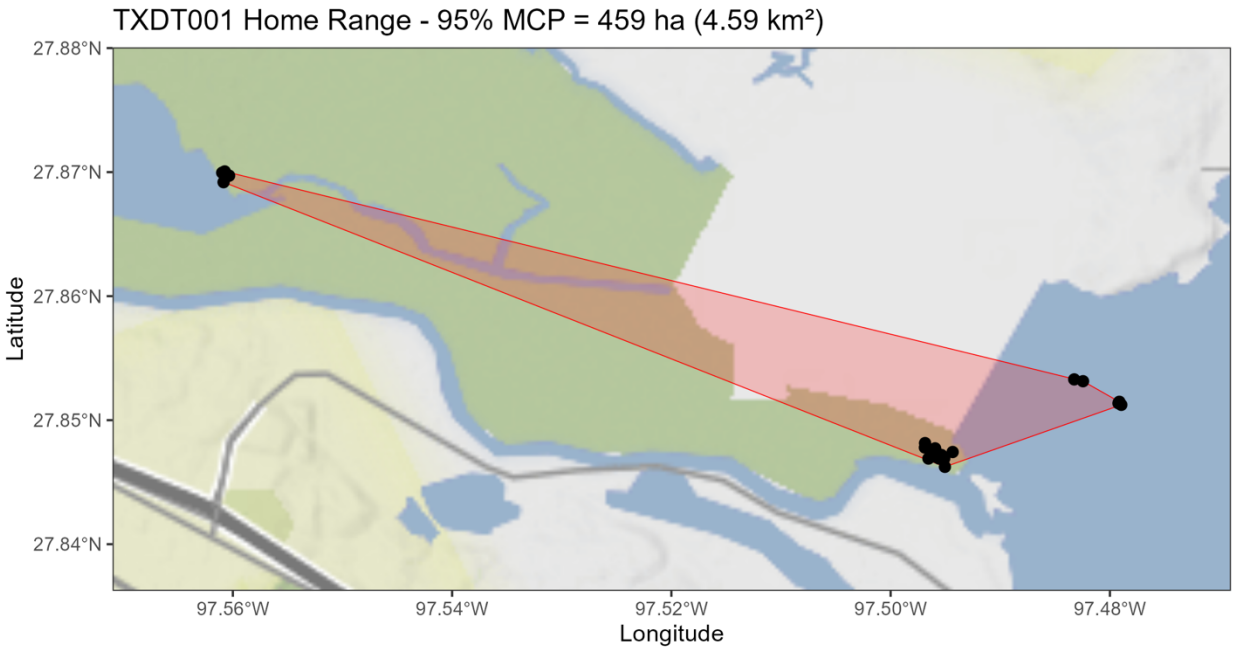


Figure 17. Home range map for a female terrapin (GMG0053) captured and GPS tagged in Nueces Bay.

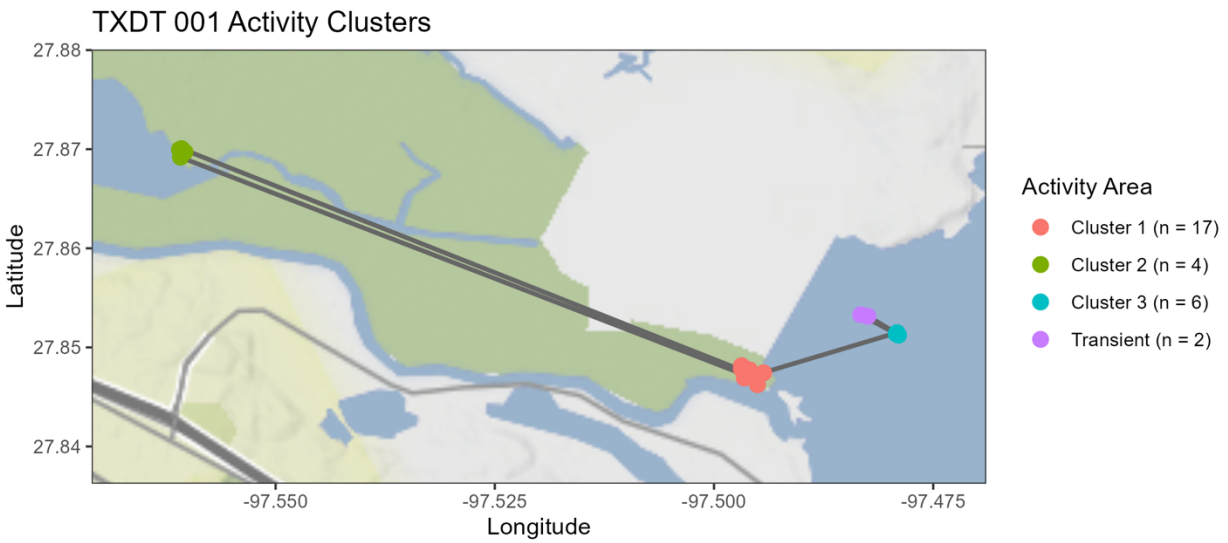


Figure 18. Activity cluster map for a female terrapin (GMG0053) captured and GPS tagged in Nueces Bay. The number of GPS points collected at each cluster are in parentheses.

Mark-recapture study

Terrapin trapping began in September 2023 and was conducted weekly, weather permitting, through August 2024. During the winter months, December to March, trapping was done monthly due to terrapin's inactivity during their brumation phase. Over 33 trapping events, 25 yielded at least 1 terrapin capture. Total number of terrapin captures was 105, with 5 being recaptures. Female terrapins were larger than males (Table 2) and weighed more than 2 times that of males. Of the 105 captures, 82 were female and 23 were male for a sex ratio of 3.6:1 (F:M). Between September and November 2023, 23 terrapins were captured before entering their brumation period over the winter months, during which no terrapins were captured (Figure 19). After emerging from brumation in late March 2024, 56 terrapins were captured in the spring with 37 being recorded in April, the most active month. Over the summer months of 2024 less terrapins were captured in comparison to the spring with 26 captures being recorded between June – August suggesting activity peaks in spring and lessens as the year progresses. Captures were also recorded at 5 of the 6 sampling sites (Figure 20). Terrapins remained absent throughout the year at the most upstream site, R1. The R3 site was the most successful location with 56 captures being recorded. Other species captured as bycatch varied between sites. Bycatch species included: *Callinectes sapidus* (blue crab), *Clibanarius vittatus* (thinstripe hermit crab), *Menippe mercenaria* (stone crab), *Aurelia aurita* (moon jelly), *Trachemys scripta elegans* (red-eared slider), *Paralichthys lethosstigma* (southern flounder), *Pogonias cromis* (black drum), *Sciaenops ocellatus* (red drum), *Ariopsis felis* (hardhead catfish), and *Hypanus americanus* (southern stingray).

Table 2. Mean (± SE) morphometric measurements of captured terrapins. Measurements include carapace length (CL), carapace width (CW), plastron length (PL), plastron width (PW), body depth (BD), and weight. Female terrapins were larger overall and weighed more than twice that of male terrapins.

Sex	**Measurement**					
F (n=82)	**CL (mm)**	**CW (mm)**	**PL (mm)**	**PW (mm)**	**BD (mm)**	**Weight (g)**
Mean ± SE	181.1 ± 2.3	129.7 ± 1.6	162.2 ± 2.1	114.1 ± 1.8	76.8 ± 1.1	984.8 ± 34.3
Range	120 – 215	86 – 156	107 – 197	70 – 143	47 – 94	250 – 1570
M (n=23)						
Mean ± SE	139.7 ± 2.7	100.4 ± 1.9	122.7 ± 2.5	90.0 ± 2.5	55.7 ± 1.3	421.7 ± 24.9
Range	126 – 164	86 – 115	106 – 147	64 – 113	50 – 68	280 – 620

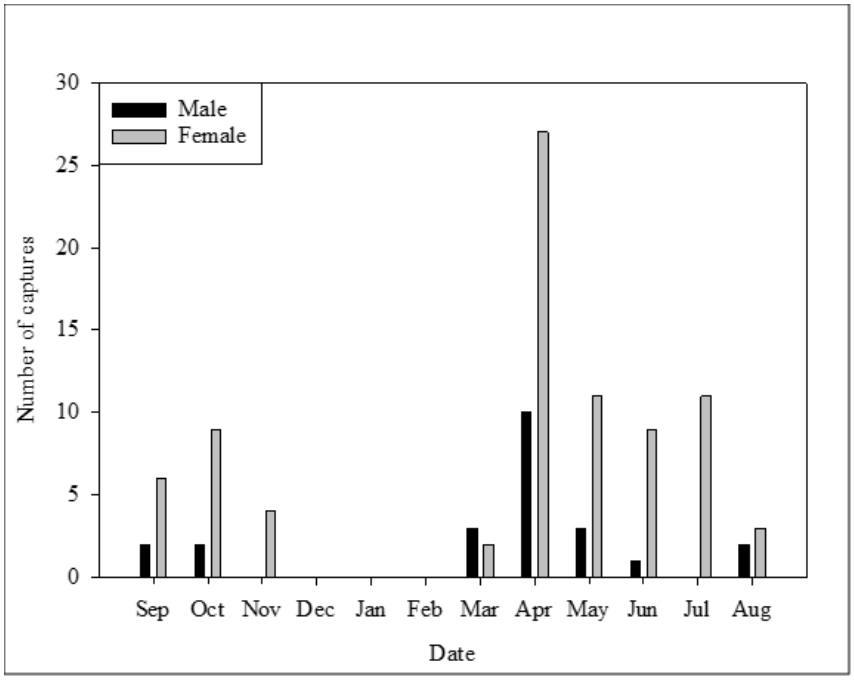


Figure 19. Terrapin captures by month. Most captures recorded were in spring 2024, with April having the most captures (n=37) while the fall and summer months recorded less captures. No terrapins were captured over the winter months (Dec-Feb).

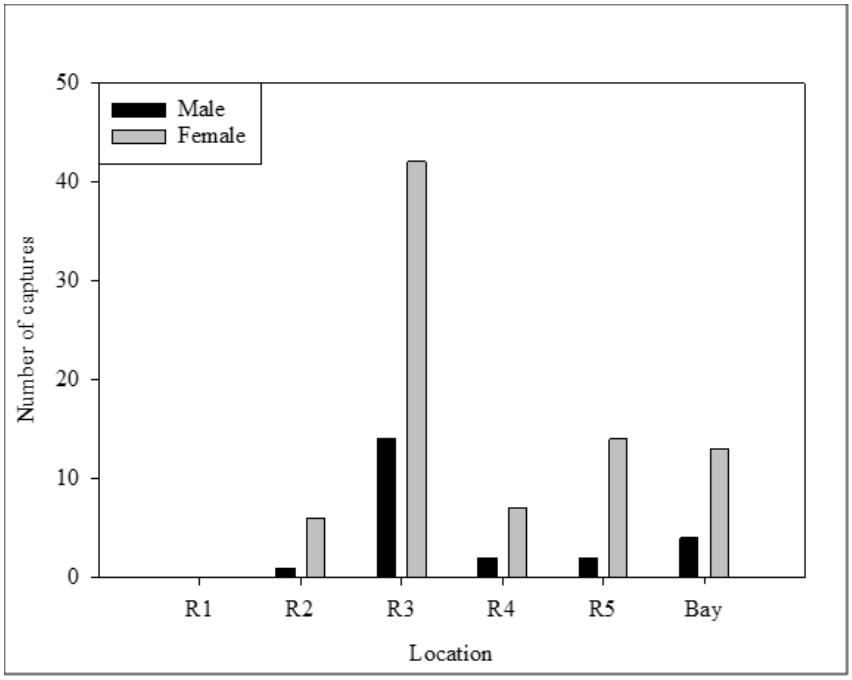


Figure 20. Terrapin captures by location. An absence of terrapins at the most upstream site, R1, was recorded while R3 had the most captures (n=56) of all sites. More females were captured at all successful sites than their male counterparts.

Salinity varied greatly during data collection between September 2023 and August 2024 (Figure 21). When data collection began in the fall of 2023, a salinity gradient was obvious with the most upstream site, R1, being the least saline and the bay site being the most saline. Overall, the bay site maintained the highest salinity (34.33 ± 0.15 psu, mean ± SE), while the R1 site had the lowest salinity (12.24 ± 0.36 psu, mean ± SE). During the summer of 2024, the R1 site shifted to the most saline with a measurement of 41.8 psu on 6/12/24 displaying characteristics of a reverse estuary with higher salinity than downstream sites and the bay site. The lowest salinity recorded was at the R2 with a measurement of 0.1 psu on 7/1/24. A one-way ANOVA showed significant differences in salinity across sampling sites throughout sampling days (df =5, F=57.85, p<0.0001, Figure 22). Post-hoc Tukey HSD test (Table 3) showed the bay site was significantly different than all river sites (p=<0.00001). Sites R1, R2, R3, and R4 showed no significant differences throughout the sampling events. Water temperature during data collection showed less variation between sites than salinity did. Monthly mean temperatures (Figure 23) showed no significant variance between sites via a one-way ANOVA (df=5, F=1.031, p=0.401).

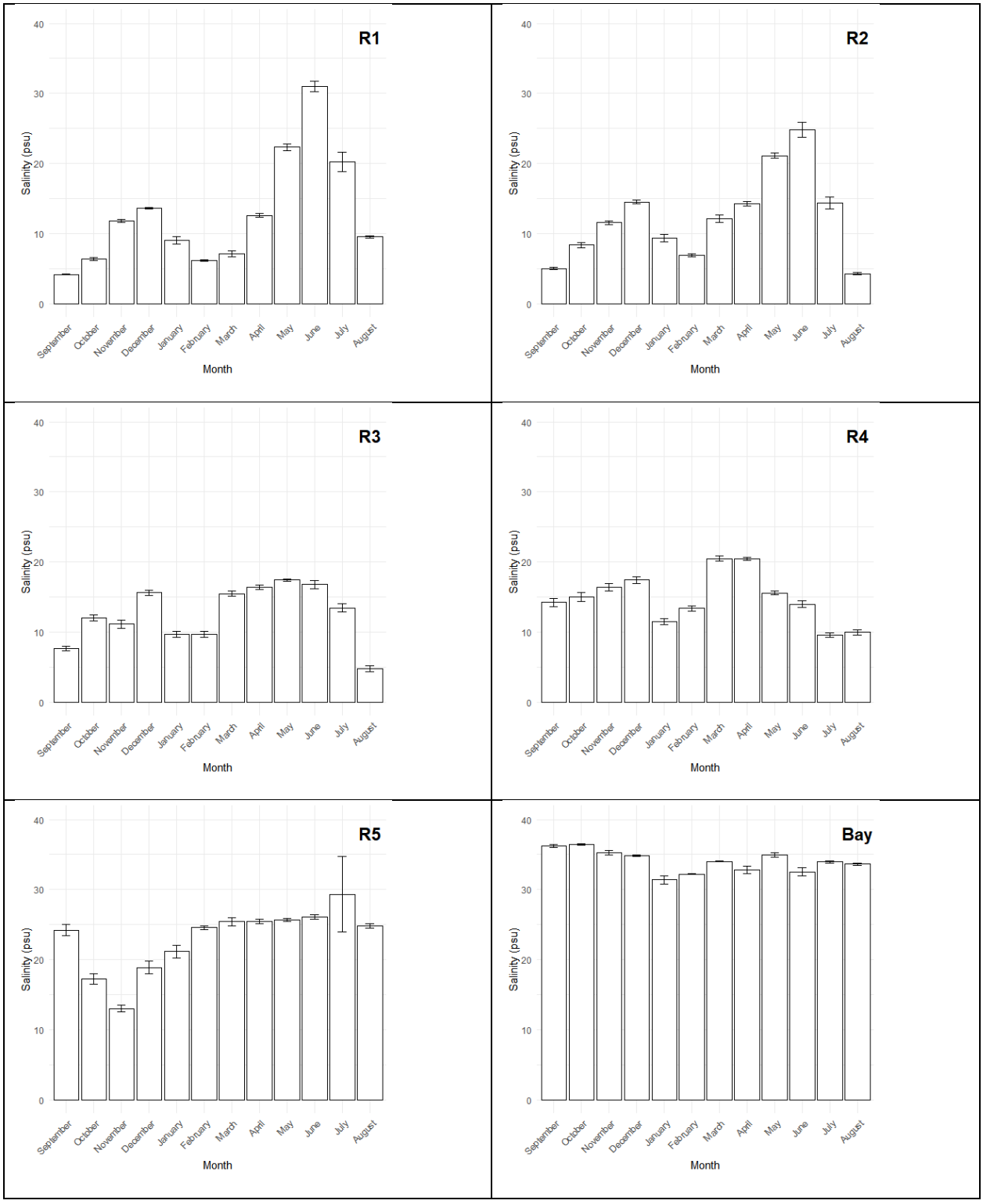


Figure 21. Mean monthly salinity from September 2023 to August 2024. The R1 site shows the most variation in salinity with mean monthly lows under 5 psu and a peak above 30 psu. The bay site showed the least variation in salinity with all months having a mean above 30 psu while also peaking above oceanic salinity (35 psu) at times.

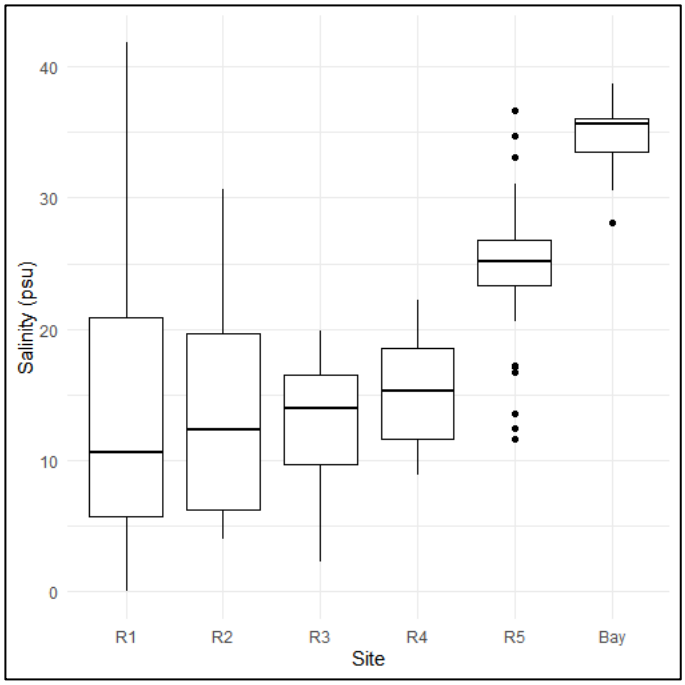


Figure 22. One-way ANOVA for salinity across 6 sampling sites. Sites R1, R2, R3, and R4 showed the most similarity between sampling sites, while the bay site was significantly different from all the other locations.

Table 3. Tukey HSD results for salinity of all six sampling sites. The table shows the difference in means, 95% confidence intervals, and p-values, while significant values are shown in bold.

Comparison	Difference	Lower CI	Upper CI	P value
R1 – Bay	-21.06484	-25.76422	-16.36546	**<0.001**
R2 - Bay	-20.97613	-25.67551	-16.27675	**<0.001**
R3 - Bay	-21.87065	-26.57002	-17.17127	**<0.001**
R4 - Bay	-19.47935	-24.17873	-14.77998	**<0.001**
R5 - Bay	-10.26935	-14.96873	-5.56998	**<0.001**
R2 - R1	0.08871	-4.61067	4.78809	1.00000
R3 - R1	-0.80581	-5.50518	3.89357	0.99634
R4 - R1	1.58548	-3.11389	6.28486	0.92628
R5 - R1	10.79548	6.09611	15.49486	**<0.001**
R3 - R2	-0.89452	-5.59389	3.80486	0.99402
R4 - R2	1.49677	-3.20260	6.19615	0.94162
R5 - R2	10.70677	6.00740	15.40615	**<0.001**
R4 - R3	2.39129	-2.30809	7.09067	0.68641
R5 - R3	11.60129	6.90191	16.30067	**<0.001**
R5 - R4	9.21000	4.51062	13.90938	**<0.001**

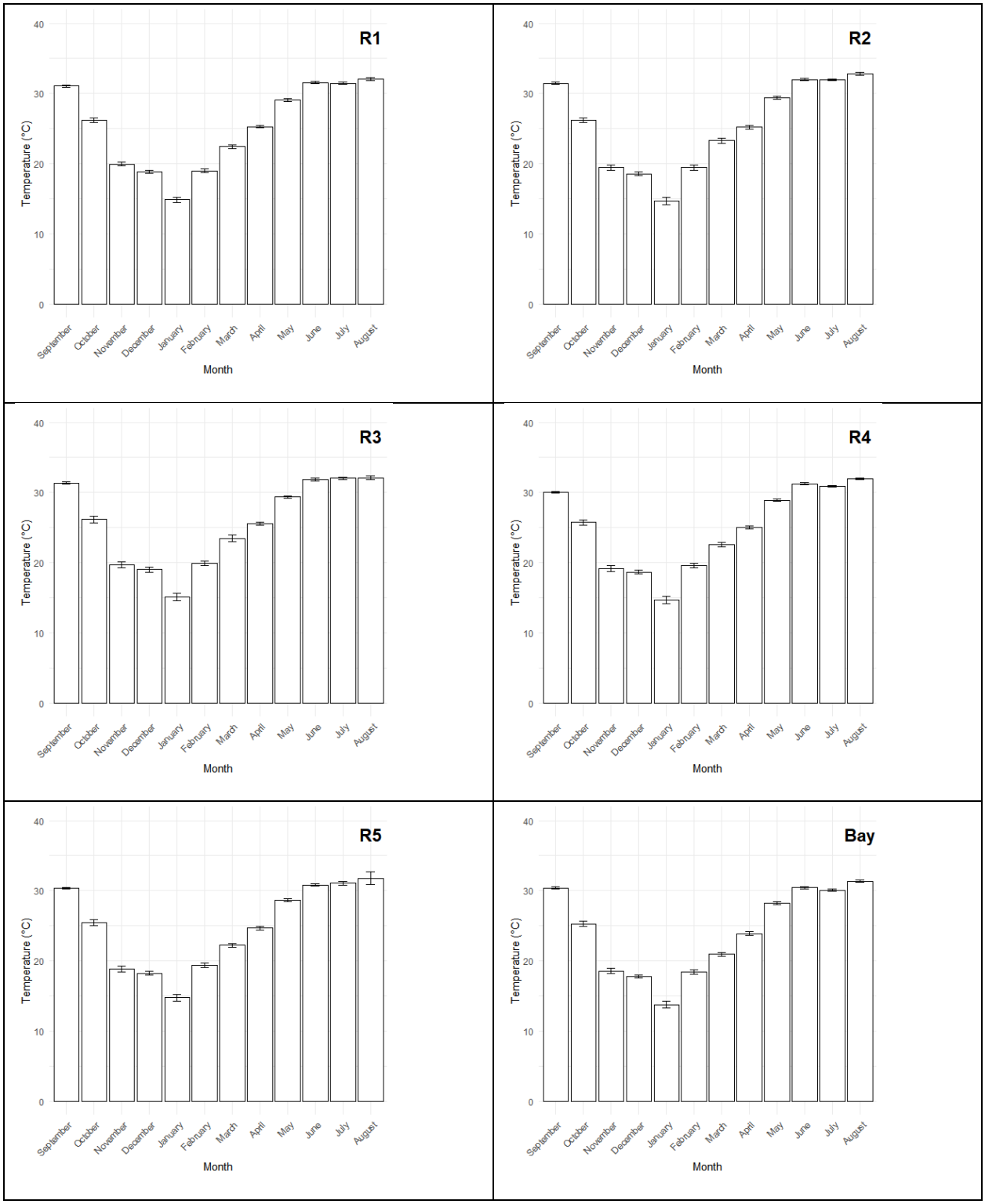


Figure 23. Mean monthly water temperature from September 2023 to August 2024. Water temperature remained consistent throughout sampling sites throughout the sampling period. Highest temperatures were recorded in August while the lowest was in January.

Terrapin captures occurred in a range of salinity from 9.37-37.15 psu. A density curve for captures by salinity (Figure 24) displayed a bimodal distribution showing two favored ranges of salinity. The first peak (~16 psu) belongs to the mesohaline estuarine zone while the second,

smaller peak (~34) belonging to the euhaline estuarine zone. The predicted probability of presence for *M. terrapin littoralis* showed a significant nonlinear relationship with salinity (χ^2 = 21.28, df=1, p < 0.001; Figure 25). Predicted probability of occurrence peaked at 24.1 psu with a peak probability of presence at 0.458 (95% CI = 0.340-0.580), falling between the two peaks of the density curve. The single peak weighs the two peaks from the raw data and represents the estimated optimum for a preferred range. The probability was at 0 for freshwater and oligohaline zones and approached 0 as salinity passed the oceanic salinity levels.

Terrapin captures by temperature ranged from 19.70-33.94 °C. The density curve for captures by temperature (Figure 26) also shows a bimodal distribution, suggesting two favored ranges of temperature. The first peak occurs at ~26 °C and the second peak occurs at ~31°C. The predicted probability of presence for *M. terrapin littoralis* showed a significant nonlinear relationship with water temperature (χ^2 = 5.88, df=1, p = 0.015; Figure 27). Predicted probability of occurrence peaked at 26.8 °C with a peak probability of presence at 0.315 (95% CI = 0.223-0.424) which correlates with the first density curve peak.

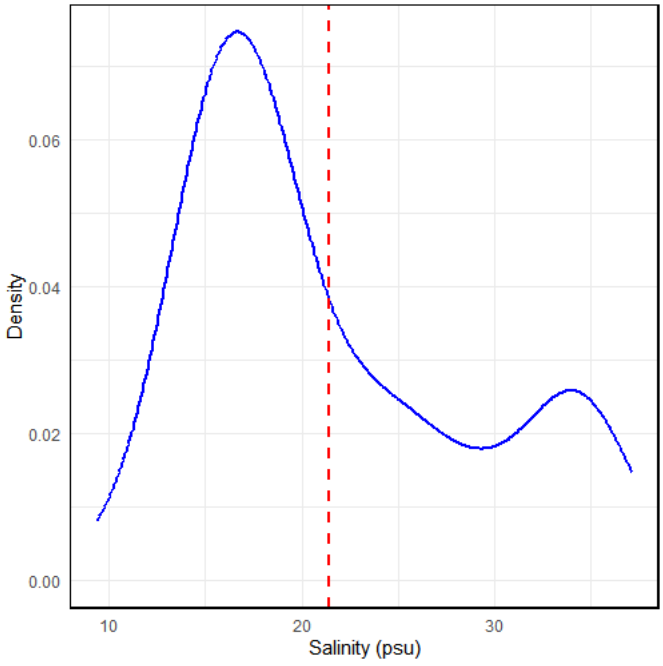


Figure 24. Density curve for salinity by captures. Mean salinity of captures (red dashed line) occurred between the two peaks at 21.38 ± 0.71 psu (mean ± SE). Density curve (blue line) shows two peaks occurring at ~16 psu and ~34 psu. The two peaks suggest terrapin densities are greatest around these two salinity levels.

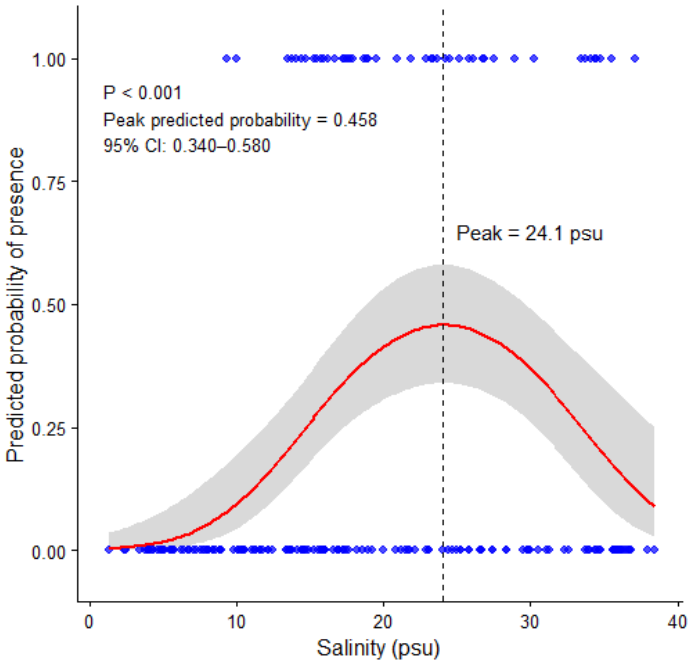


Figure 25. Predicted probability of *M. terrapin littoralis* occurrence in relation to salinity. Blue dots represent presence (1) and absences (0) of terrapins, the red line shows the predicted probability of presence, and the gray shaded area represents the 95% confidence interval. Predicted probability of presence peaked at 24.1 psu. Salinity had a significant nonlinear relationship with terrapin occurrence ($\chi^2 = 21.28$, df=1, $p < 0.001$).

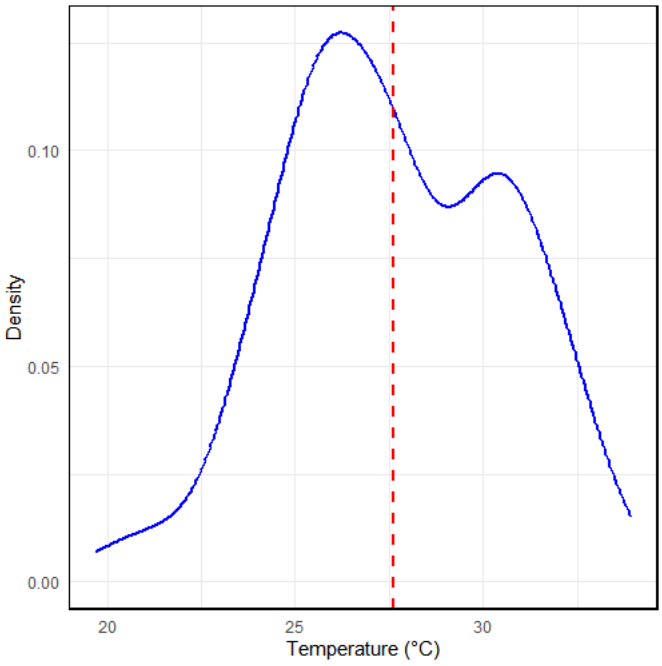


Figure 26. Density curve for temperature by captures. Mean temperature of captures (red dashed line) occurred between the two peaks at 27.52 ± 0.61 (mean ± SE). Density curve (blue line) shows two peaks occurring at ~26 °C and ~31 °C. The two peaks suggest terrapin densities are greatest around these two temperatures.

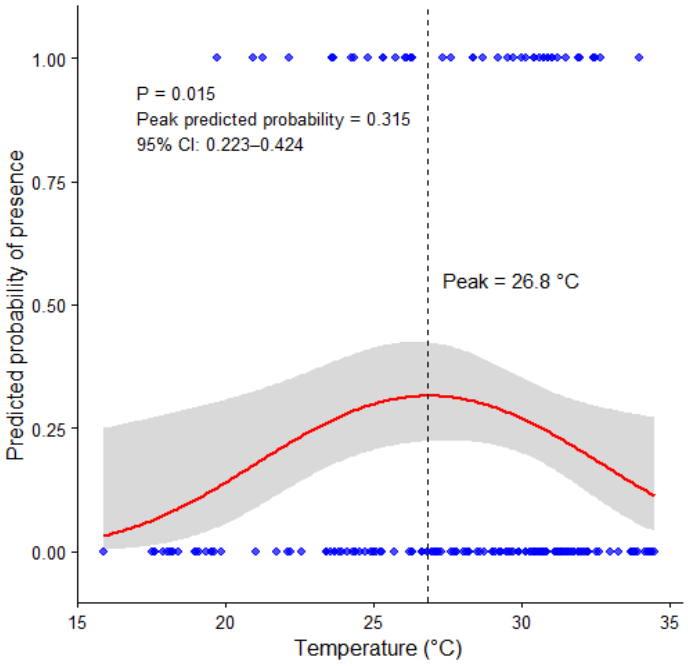


Figure 27. Predicted probability of *M. terrapin littoralis* occurrence in relation to water temperature. Blue dots represent presence (1) and absence (0) of terrapins, the red line shows the predicted probability of presence, and the gray shaded area represents the 95% confidence interval. Predicted probability of presence peaked at 26.8 °C. Water temperature had a significant nonlinear relationship with terrapin occurrence ($\chi^2 = 5.88$, df=1, p = 0.015).

Of the five recaptures, one male terrapin was recaptured twice while three females were recaptured once. Each of the terrapins recaptured had traveled to an area with higher salinity than their previous locations. Terrapin #10 (Figure 28) was first captured at R3 and was recaptured 7 months later at R4 for a salinity difference of +1.38 psu. Terrapin #16 (Figure 29) was first captured at R3 and recaptured 1 week later at the same site, then recaptured 2 weeks later at R5, approximately 8 km downstream for an overall salinity difference of +22.86 psu. Terrapin #49 (Figure 30) was first captured at R3 and was recaptured 3 weeks later at R2 for a salinity difference of +5.99 psu. Terrapin #64 (Figure 31) was first captured at R2 and was recaptured 2 months later at the bay site for the longest distance of approximately 16 km and a salinity difference of +7.3 psu. Although the recapture sample size is small, all recaptures occurring in areas of greater salinity, including near oceanic salinity, could indicate that higher salinity is not a deterrent for their movements.

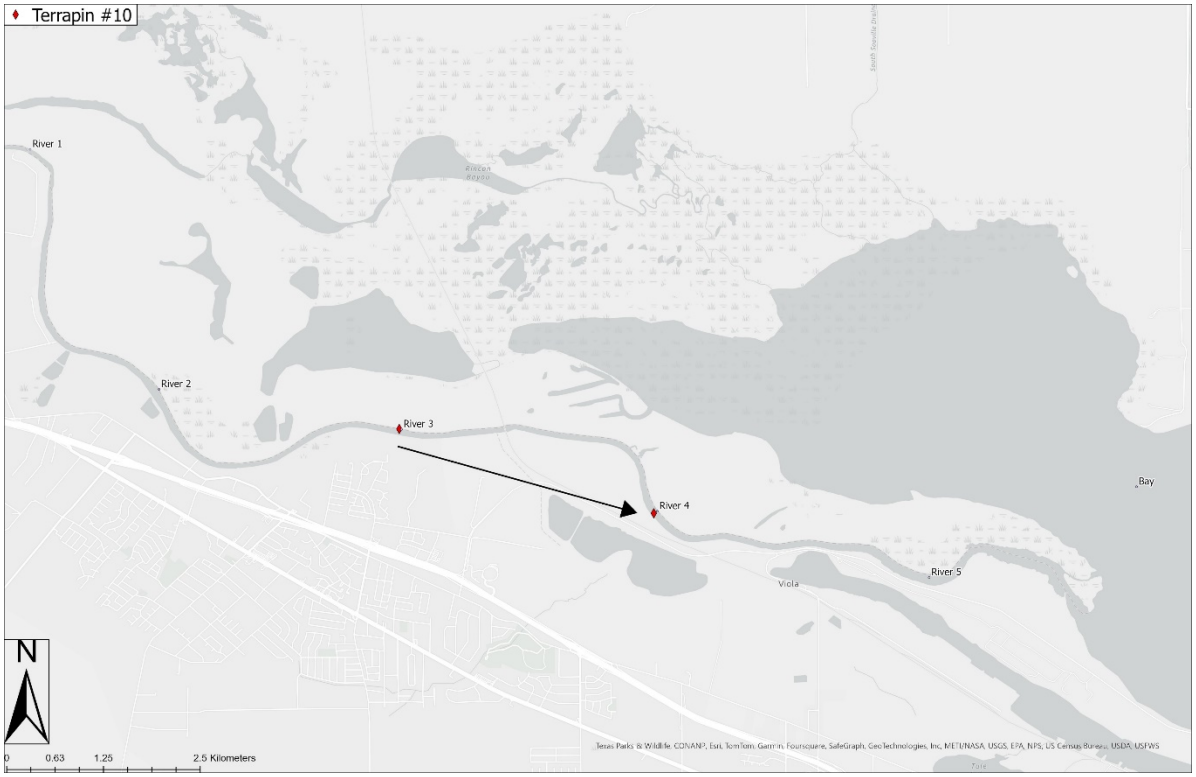


Figure 28. Movement of terrapin #10. Terrapin #10 was first captured on 11/9/23 and again on 6/12/24. Terrapin #10 had traveled approximately 4 km downstream from R3 to R4 where salinity was higher by 1.38 psu.

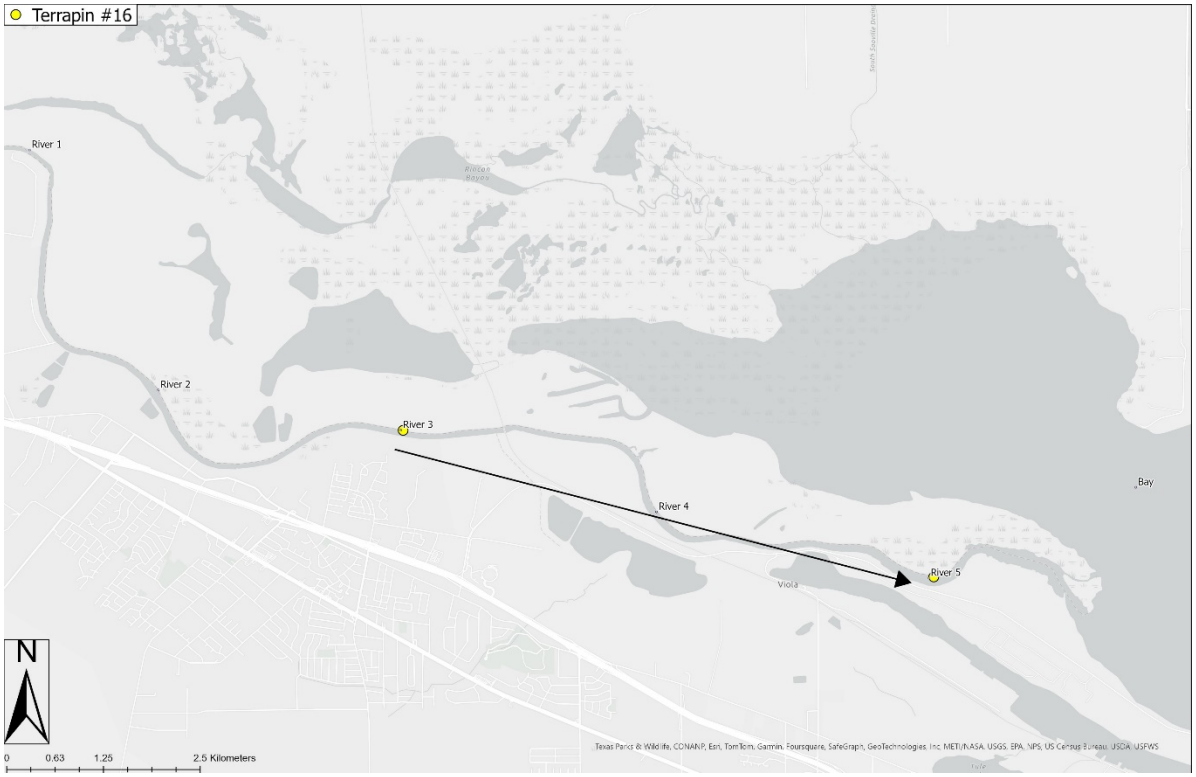


Figure 29. Movement of terrapin #16. Terrapin #16 was first captured on 4/4/24, and again in the same location, R3, on 4/9/24, and a 3rd time on 4/17/24. Terrapin #16 had traveled ~8km downstream from R3 to R5. The difference in salinity between captures was +7.3 psu between the 1st and 2nd captures, +15.6 psu between the 2nd and 3rd captures, with an overall difference between 1st and 3rd captures of +22.86 psu.

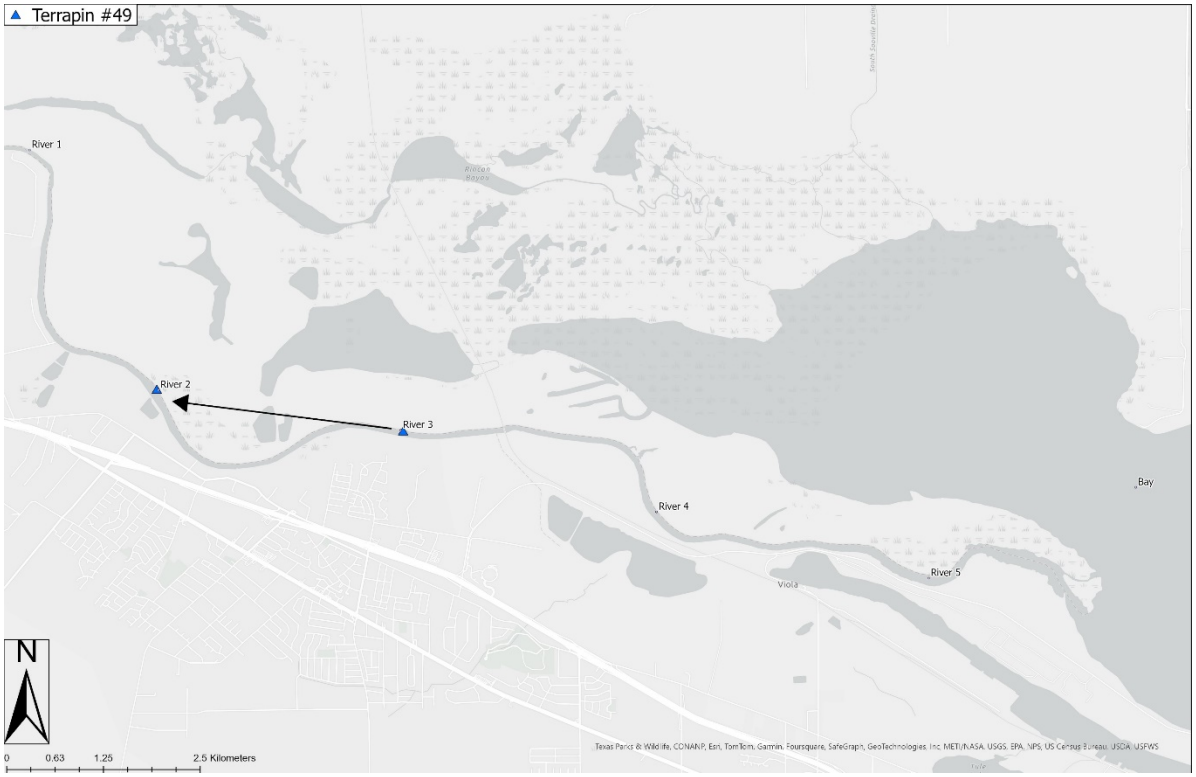


Figure 30. Movement of terrapin #49. Terrapin #49 was first captured on 4/25/24 and again on 5/15/24. Terrapin #49 had traveled approximately 4 km upstream from R3 to R2 where salinity was higher by 5.99 psu.

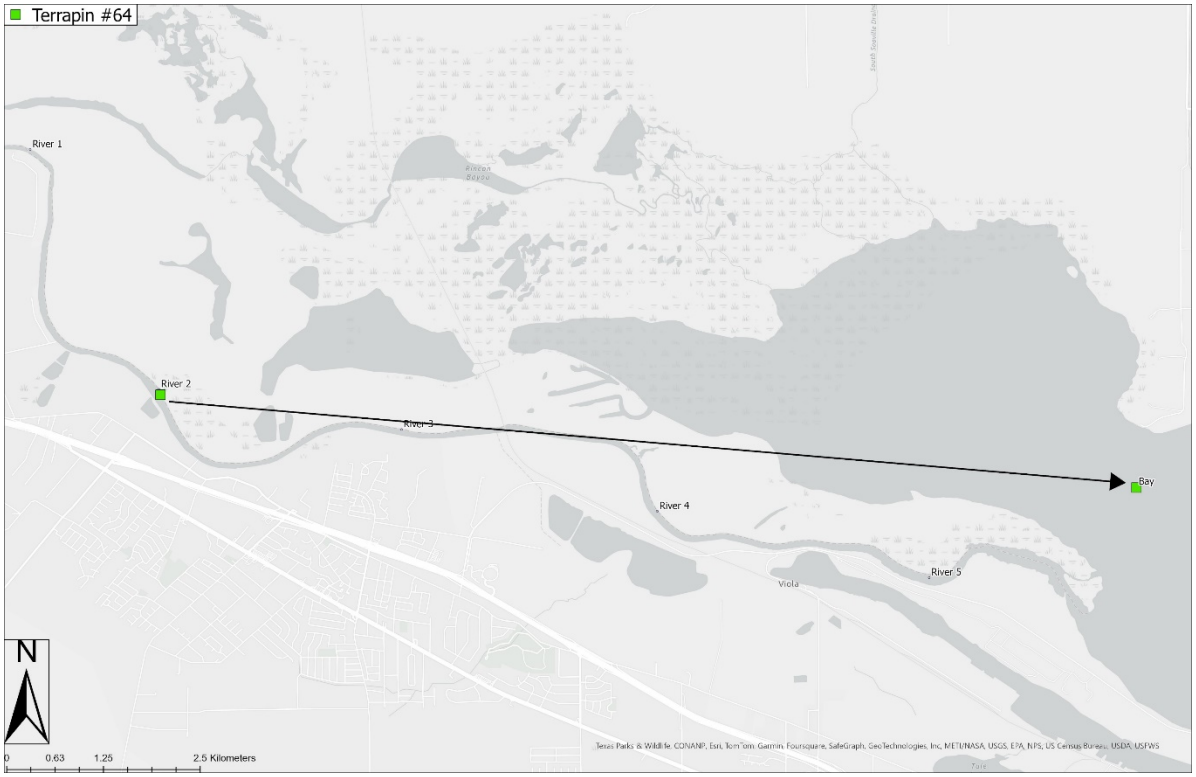


Figure 31. Movement of terrapin #64. Terrapin #64 was first captured on 6/5/24 and again on 7/30/24. Terrapin #64 had traveled approximately 16 km downstream from R3 to the bay site where salinity was higher by 7.3 psu.

Terrapins occupied a large portion of the Nueces River and the central part of Nueces Bay. Terrapins ranged from upstream of the Nueces River, near the R2 site, and continued downstream to the bay site. Terrapin densities (Figure 32) were highest in the central point of the study area, near the R3 site, with an average of approximately 9-13 terrapins per 25 m^2. Salinity at the R3 site was 12.9 ± 0.22 psu (mean ± SE) throughout the study period, well below the optimal range of salinity which was 24 psu. This site was located adjacent to the discharge site of a water treatment facility. The bay and R5 sites had the second highest densities, averaging approximately 3-5 terrapins per 25 m^2. Salinity at these sites were 21.5 ± 0.29 and 34.3 ± 0.15 psu (mean ± SE) respectively. Salinity for R5 was closest to the optimal range while the bay site had a salinity similar to that of the second peak of the salinity density curve. The R2 and R4 sites had the lowest densities, averaging approximately 1-3 terrapins per 25 m^2 with salinities of 12.6 ± 0.32 and 15.4 ± 0.20 (mean ± SE), respectively.

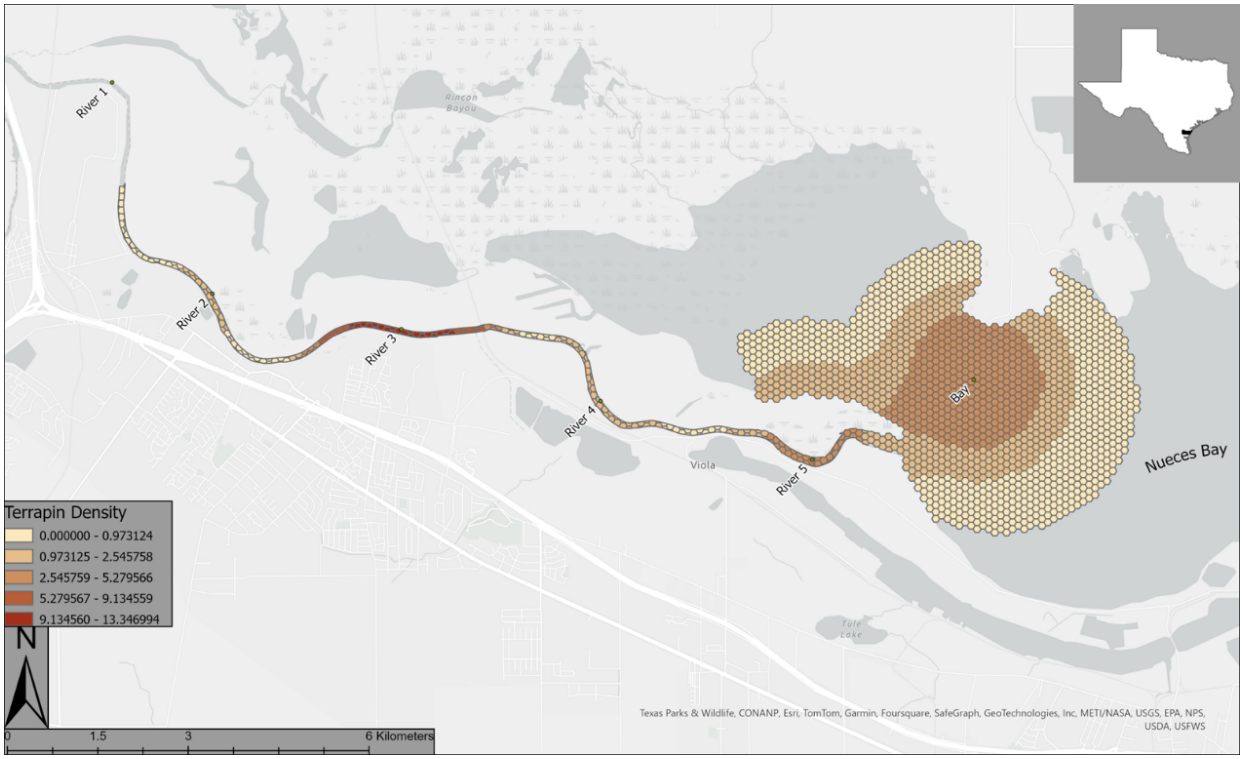


Figure 32. Terrapin population densities for Nueces River and Nueces Bay. Each hexagonal plot represents an area of 25 m^2; densities reflect trap-based estimates aggregated across sessions. Highest terrapin densities are seen near the River 3 site with approximately 9-13 terrapins per 25 m^2. Lowest densities are at the R2 and R4 sites with approximately 1-3 terrapins per 25 m^2. The R5 and Bay sites had densities in the intermediate range of approximately 5-9 terrapins per 25 m^2.

CHAPTER V: DATA PUBLISHING

This chapter addresses Task 4 of the contract. Task 4: Data Publishing

A project has been created on the Figshare public data repository for the research project data. The project can be accessed at this link: https://figshare.com/projects/_b_SPATIAL_b_b_DYNAMICS_AND_DISTRIBUTION_OF_THE_TEXAS_DIAMONDBACK_TERRAPIN_MALACLEMYS_TERRAPIN_LITTORALIS_ALONG_THE_MIDDLE_TEXAS_GULF_COAST_b_/275400

CHAPTER VI: DISCUSSION

Distribution and Status

The Texas diamondback terrapin persists along the Texas coast in all major bay systems east of Oso Bay, but its distribution is spatially fragmented and unevenly documented. Historical records suggest a broader coastal occurrence, whereas contemporary detections are concentrated in a limited number of localities, including Oso Bay, Nueces Bay and River system, Mission-Aransas Bay system (including Copano Bay and Creek), San Antonio Bay, Matagorda Bay system, Galveston and West Bay, the Sabine River south of Sabine Lake. Large gaps exist when comparing historical and contemporary observations (2016 to present), particularly in eastern Galveston Bay, between West Bay and Matagorda Bay, and between and within the San Antonio Bay and Mission-Aransas Bay system (Figures 5-7). This pattern is consistent with previous assessments that identified major information gaps in the species' Texas range and emphasized the need for more comprehensive statewide monitoring (Guillen *et al.* 2015; Mohrman 2022). The historical assessment of terrapin observations conducted in this study updates the work of Guillean et al. (2015) and partially fulfills the recommendation to "Characterize historic populations" in the Conservation Action Plan for Diamond-backed terrapins in the Gulf of Mexico (Mohrman 2022).

The extensive survey work conducted as part of this study did not detect terrapins in Baffin Bay. There have also been no observations of terrapins on iNaturalist south of Oso Bay, including the entire Upper Laguna Madre and the Baffin Bay system. The historic observation of terrapins near Riviera Beach in Baffin Bay is from a 1984 survey mailed to commercial fishing boat operators by Texas Parks and Wildlife biologist David Mabie in 1984 (Mabie 1987). No other historical observations were found for Baffin Bay, and researchers never confirmed the presence of terrapins in this area; our study yielded the same result. It is suspected that there may have been a misidentification by the respondents (e.g., sea turtles), or that this observation was of terrapins translocated from another population, either by humans or a major weather event.

In 2019, two hatchlings were observed on the surf side of South Padre Island, Texas. The authors hypothesize that the observations resulted from a nearby hatching event by an adult that was either introduced or dispersed, possibly by a hurricane (Guadiana et al. 2020). It is also possible that these were from a pet terrapin and dumped on the beach. No other terrapin observations have been reported from this area.

The results of this study indicate that the terrapin population in the Nueces Bay/River system represents the westernmost population of Texas diamondback terrapins, while the Oso Bay population is the southernmost extent. The eastern extent for the subspecies remains somewhere near the Texas-Louisiana border (Glenos 2013).

Survey Approach

The population status of the diamondback terrapin is difficult to ascertain due to its ecology and the limited effectiveness of standard sampling methods (Levasseur et al. 2019). This study employed a broad range of survey techniques to both identify where terrapins occur along the Texas coast and to attach GPS tracking devices to study their movement ecology.

Head-count surveys have been the recommended method for determining the population status of terrapins (Harden et al. 2009, Levasseur et al. 2019). The application of head-count surveys has focused on the Atlantic Coast and Florida populations of terrapins and has proven to be an effective and efficient method of assessing the presence/absence of terrapins (Harden et al. 2009, Butler and Heinrich 2013, Levasseur et al. 2019). However, head-count surveys performed during this study yielded few new localities for terrapins along the middle Texas Gulf Coast. This could be a limitation of survey site selection, which prioritized sites based on proximity to potential nesting habitat and freshwater outflows (McCracken et al. 2025, 2026), and of the relatively large distances between most of the survey locations. It could also be the result of a low density of terrapins at these survey sites, which precluded our detection.

Environmental DNA (eDNA) surveys are a promising technique for detecting rare and elusive species in aquatic environments (Jerde et al. 2011). While the lack of terrapin detections using a published methodology for the species is disappointing, the relatively small volume of water collected (2 L) at each site may be a contributing factor. The same concerns mentioned above for head-count surveys not yielding many observations may play a role in eDNA survey success as well.

Traditional trapping with modified crab traps remains a reliable method for capturing terrapins where known populations exist. The lack of captures in Oso Bay was somewhat surprising, as terrapins have been regularly reported in this bay on iNaturalist and verbally in angler interactions. While trapping efforts in Oso Bay were limited for this particular research project, it is probable that reduced freshwater inflows from the water treatment facility and the ongoing drought may play a role in what habitat terrapins are utilizing in the system. Continued survey efforts are needed to determine the status of the Oso Bay terrapin population. No captures of terrapins at the Goose Island State Park fish cleaning station on St. Charles Bay are likely due to the presence of a reliable food source from anglers discarding unwanted parts of their catch, and terrapins not needing to enter a baited trap to access a meal. Using a cast net at this site to capture terrapins has been highly productive since using a custom net with a wider mesh (0.75”) and heavier weights, allowing it to sink faster and prevent terrapins from escaping. Overall, these findings indicate that trap success is strongly context dependent and that continued site-specific monitoring is necessary to better evaluate terrapin occupancy and capture probability across estuarine habitats.

Previous use of camera traps to detect nesting terrapins has been successful in the Nueces Estuary, where a large terrapin population occurs (Baxter 2015). However, another previous study using camera traps in areas deemed suitable nesting habitat for terrapins recorded no detections (Baxter 2017). While no terrapins were detected during camera trap deployments in this study, improved security measures to prevent theft were developed, and site-specific

attributes were identified to ensure proper camera performance. Recommended security measures include bolting a camera-specific security box to the metal t-post and screwing a large auger anchor into the ground to attach the security box, then securing it with a cable lock. Site attributes for camera performance include locating the camera away from wave action that may create heavy airborne water droplets that can settle on the camera lens, obscuring the view, and ensuring that the camera is located where cattle or horses do not have access to prevent them from rubbing against t-posts and bending them. Camera traps remain a useful tool for identifying nesting areas, and future deployments should build on the improved security and site-selection measures developed in this study to maximize detection success and minimize equipment loss. The use of camera traps also has utility for monitoring nest predators (e.g., raccoons and coyotes) and for monitoring nest success in the future.

A central outcome of this research is that no single survey technique was sufficient to characterize terrapin occupancy across the study area. Head-count surveys were effective at confirming presence in a few locations, eDNA expanded the spatial reach of sampling but did not detect terrapins, trapping was productive in some estuarine settings but not others, and camera traps were constrained by disturbance and presumed low detectability at nesting sites. These findings support a multi-method monitoring framework for detecting terrapins, given their cryptic nature, seasonal variation in detectability, and distribution across heterogeneous coastal habitats (Mohrman 2022).

Citizen science

The creation of the Texas diamondback Terrapin Task Force iNaturalist project substantially improved efforts to collect contemporary, research-grade observations across Texas. Because Research Grade observations require a photo, date, georeference, and community agreement on identification, the platform provided a practical mechanism for generating observations that were both verifiable and useful for distributional analyses. For a cryptic estuarine species with incomplete range coverage, this approach is especially valuable because it expands detection capacity beyond conventional field surveys (Whitmer et al. 2025).

Public outreach was an essential component of the project's success. Presentations, flyers, social media posts, and direct engagement with anglers, boaters, kayakers, and fishing guides helped raise awareness of terrapin identification and reporting procedures, while also reinforcing legal and conservation messaging. This broad outreach strategy likely contributed to the growth of project participation and to the increasing number of observers willing to share records on iNaturalist and through direct communication. However, one of the greatest challenges when working with a threatened species, whose exact locations are often obscured on public platforms, is communicating with observers to obtain precise location data. By creating an alternative reporting pathway, such as Survey123, a flexible framework for collecting public observations can be established while retaining research utility.

The new localities documented in this study have direct research value because they expand the set of areas warranting follow-up surveys, nesting-habitat assessments, and long-term

monitoring. Several of these records occurred in areas with either limited prior documentation or historical records that had not been recently confirmed, indicating that citizen science can reveal occupied habitat that might otherwise remain undetected. Records from Matagorda Bay, Tres Palacios Bay, Lavaca Bay, and Oso Bay suggest that terrapin occupancy extends into multiple estuarine systems where population status remains poorly resolved. The concentration of many observations at Goose Island State Park and West Bay also suggests that some areas support particularly visible or accessible populations, while other estuaries remain under-documented and require further targeted survey effort.

The iNaturalist project contributed to the study by generating new contemporary records, improving public awareness, and identifying sites that warrant further survey effort. Citizen science has proven useful in Texas for detecting rare reptiles and expanding distributional knowledge, and the terrapin project appears to have served the same purpose here (McCracken 2025). In practical terms, these observations helped fill range gaps that would have been difficult to address through field surveys alone. The iNaturalist project, combined with alternative reporting pathways and continued outreach, will continue to produce new observations and inform where to conduct further research to identify terrapin populations along the Texas coast.

GPS logger-based movement ecology

The various GPS logger trials in this study revealed the challenges of deploying small telemetry devices on aquatic turtles in marine environments (Lamont et al. 2023). Several deployed units with new battery charging and data transmission technologies yielded few or no fixes, likely due to limited solar charging, short surfacing intervals, water-switch behavior, or incomplete cellular transmission. Ultimately, the initially proposed GPS loggers from Telemetry Solutions provided the most robust movement data set. The most effective programming for these units was set to force a GPS fix attempt at 0550h and 1750h, and to check the water switch every 5 minutes, triggering a GPS fix attempt if the switch was dry. These settings resulted in approximately 69% of successful GPS fixes coming from the timed forced attempts and the remaining 31% resulting from water switch triggered GPS fixes. These settings are now being used on Telemetry Solutions GPS loggers attached to terrapins at Goose Island State Park, and the manufacturer's mobile application indicates they are collecting GPS data.

The movement data suggest that terrapins in the middle Texas coast may use habitats more dynamically than earlier Texas studies implied (Clarkson et al. 2010). Earlier research and regional syntheses have shown that terrapin movements and home range estimates vary substantially with study design and tracking intensity, and more recent telemetry studies have revealed much larger movement potential than traditional methods captured (Lamont et al. 2021; Lamont et al. 2023). Lamont et al. (2023) reported that the seasonal space use area was between 3.1-14.8 km^2 for 95% MCP for diamondback terrapins (n=10) in the Florida panhandle on the Gulf of Mexico. In the current study, the tracked female terrapin had a 95% MCP of 4.59 km^2, which is on the low end of the results reported by Lamont et al. (2023). However, compared to other previous studies where MCP's ranged between 0.0031-1.079 km^2 (including Clarkson et

al. 2010 at South Deer Island in Galveston Bay, Texas), the limited movement data from a single individual in this study is more than 4x those previous home range estimates (Spivey 1998; Butler 2002). The most likely explanation for this outcome is the use of GPS logger telemetry technology, which provides more location data with greater accuracy. The home range estimate in the present study is for a single terrapin that was tagged in mid-April, approximately 1.5 months after terrapins were finished brumating for the winter. We detected two terrapins, fitted with GPS loggers in the Fall of 2023, during the last week of February and the second week of March in 2024, respectively. Based on the location where these individuals were tagged in the Nueces River (see R3 in Figure 13) and where the two GPS points received for each individual came from, it appears that these terrapins brumated in the river over the winter, coming out of brumation once the water warmed to approximately 20 °C, and then moved downstream towards the bay. One of these individuals moved from R3 to the bay islands area between GPS tagging in the late Fall of 2023 and the end of February 2024, a distance of approximately 9.5 km. Therefore, it is likely that the home range size for the single individual in this study is underestimated but may also be skewed by the large movement (~4 km) recorded during what is thought to have been a nesting event. While overall GPS tracking had limited success in this study, it did help identify a GPS tracking system that outperforms others for terrapins and approximate the time of year and water temperature at which terrapins exit brumation along the middle Texas coast. Continued successful GPS tracking of terrapins following this study will provide a clearer picture of the size and habitat used, as well as any movement patterns.

Mark-recapture study movement ecology

Salinity throughout the Nueces River and Nueces Bay was highly variable over the course of this study and did have an influence terrapin occurrence. The highest recorded salinity (41.8 psu) during this study occurred at the most upstream sampling site (R1), where no terrapins were captured, while the lowest salinity (0.1 psu) was recorded at the R2 location. During the summer of 2024, Nueces Estuary displayed reverse estuary characteristics with greater salinity values observed in the upstream segment of the river. Although salinity spiked during the summer of 2024, terrapins remained absent from the most upstream location, possibly due to fluctuations in water conditions, which were outside of the terrapin's preferred range of salinity. Altered freshwater flows as experienced in Nueces Estuary can have significant impacts on estuarine and coastal species such as mortality, growth, and movement (Gillanders and Kingsford, 2002).

Salinity and water temperature both influenced the occurrence of diamondback terrapins in Nueces River and Nueces Bay. Only one terrapin was captured in salinity below 10 psu which leads to the assumption that terrapins require some moderate levels of brackish water in their natural habitat. Freshwater avoidance corresponds with the findings of Ashely et al. (2021) where juvenile terrapins immediately leave freshwater to find brackish water in a controlled environment. Although terrapins captured during this study were adults, the results show a difference in salinity preference to the juveniles from Ashley et al. (2021) where juvenile

terrapins favored lower salinity waters, around 10 psu. The findings of the current study showed a preference for the upper mesohaline and the polyhaline estuarine zones, with a high number of terrapins captured at ~17 psu and a preferred range near ~24 psu. Several terrapins were even captured at or above oceanic salinity, with the highest salinity at which a capture occurred being 37.15 psu. Peak captures and preferred range occurred in water temperatures of ~26 °C and only one terrapin was captured in waters under 20 °C (19.7 °C). In this study, terrapin brumation in the Nueces Estuary begins when water temperature drops below 20 °C, and they emerge from brumation when water temperature reaches a constant ~22 °C. However, the limited data from GPS loggers used in this study indicate that emergence occurred at water temperatures of approximately 20 °C. The last terrapins caught before winter 2023 were recorded on 11/9/2023 in waters around 25 °C. The next trapping event occurred when the water temperature reached ~19 °C, and terrapins were absent, as no captures were recorded. Terrapins were not captured again until late March 2024, when water temperatures had risen to ~22 °C. The slight discrepancy in water temperatures triggering terrapin emergence from brumation may result from terrapins not immediately seeking a meal, but rather acclimating to conditions after brumation and moving towards more favorable environmental conditions. Terrapin brumation sites were not identified during this study, but brumation cycles vary by region due to climate factors across their distribution (Brennessel, 2006). Terrapin brumation in South Texas begins later than that of northern species, such as the terrapins in North Carolina, which begin their brumation in October (Brennessel, 2006). Some subspecies are even thought to skip brumation and be active year-round, such as terrapins located in the Florida Keys (Brennessel, 2006). As global temperatures are expected to rise between 1.0-5.6 °C (IPCC, 2021), there is increased potential for alterations in terrapin brumation cycles and unbalanced hatchling sex ratios, which could impact terrapin population dynamics (Lamont et al., 2024). Unbalanced hatchling sex ratios have already been observed in other reptilian species, such as *Chelonia mydas* (green sea turtle) in eastern Australia, which is skewing towards female dominance with warmer temperatures (Jensen et al., 2020).

Terrapin occurrences indicated a “sweet spot” for salinity at ~24 psu. Although terrapins were observed occupying salinity outside of the “sweet spot”, the zone of tolerance for terrapins in Nueces Estuary should be considered to be 10-37 psu. Although terrapins can tolerate waters above oceanic salinity; it does not appear to be a preferred salinity level for terrapins and may induce further stresses as well as reduce total mass and carapace length in juveniles as reported by Ashley et al. (2021). The “sweet spot” for water temperature was determined to be ~26 °C, with little difference between the probability of occurrence and the density curve of actual captures, both peaking around 26 °C. The mean water temperature at the bay islands area was slightly lower during the summer months than at other monitored locations during this study. GPS data from the single individual in this study showed that she relocated to the bay island area around July, when water temperatures began to climb to their annual high. The movement to this area also provides access to deeper water, where temperatures are cooler, and terrapins can thermoregulate by diving deeper in the water column to access varied temperatures.

Of the 5 recaptures during the study, all occurred in areas of higher salinity than previous captures. The greatest difference in salinity was from a male terrapin (notch #16) that was first caught in a salinity of ~10 psu, then again at ~17.5 psu and lastly captured at a salinity of ~33 psu. It was caught in the same location the second time and traveled 8 km downriver, where it was captured a third time. A female terrapin (notch #64) moved from an area with a salinity of ~27.5 psu to an area with a salinity of ~34.8 psu. Movement into areas where salinity approaches oceanic levels supports the idea that higher salinity is not a deterrent to terrapin movement. Although the sample size is small relative to recaptures, the absence of recaptures at lower salinity levels than in previous captures indicates their resilience to higher salinities.

Conclusions

This study shows that the Texas diamondback terrapin persists across the middle and upper Texas coast, but its distribution remains patchy, incompletely documented, and concentrated in a limited number of occupied estuarine systems. Historical records, contemporary survey data, and citizen science observations together show that substantial gaps remain in knowledge of local occupancy, nesting habitat, and population status.

In this study, no single survey method was sufficient to characterize terrapin presence, habitat use, and movement ecology. However, the combination of survey efforts, GPS telemetry, and mark-recapture evidence indicates that terrapins occupy a mosaic of bay, marsh, and riverine habitats and may shift among them in response to seasonal conditions, salinity gradients, and resource availability. As a result, the most reliable approach for future monitoring is an integrated strategy that combines these methods rather than relying on a single technique. The iNaturalist project and outreach campaign substantially improved the number and geographic spread of contemporary observations. Incorporating a citizen science component proved to be a meaningful complement to field surveys and a practical tool for identifying areas that warrant follow-up investigation. The GPS telemetry component provided useful insight into terrapin movement and seasonal behavior, even though device performance was inconsistent and only a small number of tags yielded location data. Testing several manufacturers' GPS logging devices was an important step in identifying the tracking technology that works best for a small turtle species in a challenging marine environment. The home range of Texas diamondback terrapins was found to be up to 4x larger than in previous studies, likely due to increased location data and accuracy made available by current GPS tracking technologies. These results underscore the importance of connected estuarine habitats that include nesting substrate, adjacent marsh, and freshwater inflows. This is important because the conservation action plan for Gulf terrapins identifies shoreline development, habitat loss, and bycatch in crab traps as persistent threats, and these pressures are especially relevant in the fragmented landscapes examined here (Mohrman 2022). The study also reinforces the broader regional recommendation that terrapin conservation in the Gulf of Mexico requires coordinated monitoring, habitat protection, and threat reduction, especially in areas affected by coastal development and crab-trap mortality (Mohrman 2022).

Future Research Recommendations

Future work should focus on refining detection protocols and habitat type selection. Expanding head-count survey coverage in poorly sampled stretches of coast where historical records exist but recent confirmations are lacking is particularly needed. Also, eDNA sampling protocols need to be evaluated to determine the appropriate water volume required to sufficiently sample for terrapin DNA under our site conditions along the Texas coast. Increasing awareness of terrapins in Texas bays and estuaries through outreach and by promoting the use of citizen scientist reporting platforms like iNaturalist are likely the most effective tools for identifying the contemporary occurrences of terrapins in Texas. However, these occurrences must be verified by researchers through field surveys. A greater number of individuals with GPS logging data spanning seasons will help refine home range estimates and provide greater resolution of seasonal movements and habitat use, particularly in identifying nesting sites. Establishing a longer-term monitoring program would substantially improve inference about range limits, nesting distribution, and movement ecology, providing the baseline needed for adaptive management.

REFERENCES

Ashley, E., Davis, A., Terrell, K., Lake, C., Carden, C., Head, L., Choe, R., Maerz, J.C. 2021. Effects of salinity on hatchling diamond-backed terrapin (*Malaclemys terrapin*) growth, behavior, and stress physiology. *Herpetologica* 77: 45-55.

Bailey, J.A. 1984. Principles of wildlife management. Wiley, New York, NY.

Baxter, A.S. 2015. Identifying diamondback terrapin nesting habitat in the Nueces Estuary, Texas. Technical Report No. TAMU-CC-1503-CCS for Coastal Bend Bays and Estuaries Program. Corpus Christi, Texas. 29 pp.

Baxter, A. S. 2017. Identifying diamondback terrapin nesting habitat in the Mission-Aransas Estuary. Coastal Bend Bays and Estuaries Program. Publication Number CBBEP-117. 33 pg.

Baxter, A., Hill, E.M., and Withers, K. 2013. Population assessment of Texas diamondback terrapin (Malaclemys terrapin littoralis) in the Nueces Estuary, Texas. *Texas Journal of Science* 65: 51-63.

Bodkin, J.L., 2015. Historic and contemporary status of sea otters in the North Pacific. In *Sea otter conservation* (pp. 43-61). Academic Press.

Breininger, D.R., Stolen, E.D., Breininger, D.J., and Breininger, R.D. 2019. Sampling rare and elusive species: Florida east coast diamondback terrapin population abundance. *Ecosphere* 10: e02824.

Brennessel, B. 2006. *Diamonds in the Marsh: a natural history of the Diamondback Terrapin*. University Press of New England, Lebanon, NH.

Butler, J. A. 2002. Population ecology, home range, and seasonal movements of the Carolina diamondback terrapin, *Malaclemysterrapin centrata*, in northeastern Florida. Florida Fish and Wildlife Conservation Commission Project Report NG96-007

Butler, J.A., and G.L. Heinrich. 2013. Distribution of the ornate diamondback terrapin (*Malaclemys terrapin macrospilota*) in the Big Bend region of Florida. *Southeastern Naturalist* 12: 552-567.

Calenge, C. 2006. The package adehabitat for the R software: a tool for the analysis of space and habitat use by animals. *Ecological Modelling* 187: 516–519.

Clarkson, E., Marlow, A., and G. Guillen. 2010. Site Fidelity and Range of an Island population of Diamondback Terrapin (*Malaclemys terrapin*) in West Galveston Bay, Texas. Poster presented at the Diamonback Terrapin Working Group Triennial Workshop, Chauvin, Louisiana, USA.

Coleman, A.T., T. Wibbels, K. Marion, D. Nelson, and J. Dindo. 2011. Effect of by-catch reduction devices (BRDS) on the capture of diamondback terrapins (*Malaclemys terrapin*) in crab pots in an Alabama salt marsh. *Journal of Alabama Academy of Science* 82: 145–157.

Crawford, B.A., J.C. Maerz, N.P. Nibbelink, K.A. Buhlmann, and T.M. Norton. 2014. Estimating the consequences of multiple threats and management strategies for semi-aquatic turtles. *Journal of Applied Ecology* 51: 359-366.

Davenport, J. 1992. The biology of the diamondback terrapin *Malaclemys terrapin* (Latreille). *Testudo* 3: 1-5.

Dixon, J. R., and T. J. Hibbits. 2013. *Amphibians and Reptiles of Texas: With Keys, Taxonomic Synopses, Bibliography, and Distribution Maps, 3rd edition*. Texas A&M University Press, College Station, TX.

Ernst, C. H., and J. E. Lovich. 2009. *Turtles of United States and Canada, 2nd edition*. John Hopkins University Press, Baltimore, MD.

Fields, A.T., Hunt, E.P., Lanoue, K. Baxter, A.S., Sebby, R.S., Tarkington, W.J., and D.S. Portnoy. 2024. Development, verification, and implementation of an eDNA detection assay for emydids with a case study on diamondback terrapins, *Malaclemys terrapin*, and red eared slider, *Trachemys scripta elegans*. *Conservation Genetics Resources* 16: 147–157.

Gillanders, B. M. and Kingsford, M. J. 2002. Impact of changes in flow of freshwater on estuarine and open coastal habitats and the associated organisms. *Oceanography and Marine Biology, an Annual Review* 40: 233-309.

Glenos, S. M. 2013. A comparative assessment of genetic variation of diamondback terrapin (*Malaclemys terrapin*) in Galveston Bay, Texas in relation to other northern Gulf Coast populations.

Godley, B.J., J.M. Blumenthal, A.C. Broderick, M.S. Coyne, M.H. Godfrey, L.A. Hawkes, and M.J. Witt. 2008. Satellite tracking of sea turtles: where have we been and where do we go next? *Endangered Species Research* 4: 3-22.

Guadiana, C.J., P.S. Robinson, M.S. Schalk, and D.R. Davis. 2020. New county records of amphibians and reptiles from South Texas, USA. *Herpetological Review* 51: 799-803.

Guillen, G., M.L. Gordon, J. Oakley, M. Mokrech, B. Alleman, R. George, and D. Bush. 2015. Population survey of the Texas diamondback terrapin, *Malaclemys terrapin littoralis*, in San Antonio Bay, Matagorda Bay, and Sabine Lake. *EIH Report 15-001*. 194 pp.

Harden, L.A., N.A. Diluzio, J.W. Gibbons, and M.E. Dorcas. 2007. Spatial and thermal ecology of diamondback terrapins (*Malaclemys terrapin*) in a South Carolina salt marsh. *Journal of the North Carolina Academy of Science* 123: 154-162.

Harden, L.A., and A.S. Williard. 2012. Using spatial and behavioral data to evaluate the seasonal bycatch risk of diamondback terrapins (*Malaclemys terrapin*) in crab pots. *Marine Ecology Progress Series* 467: 207-217.

Hart, K.M., and D.L. Lee. 2006. The diamondback terrapin: the biology, ecology, cultural history, and conservation status of an obligate estuarine turtle. *Studies in Avian Biology* 32: 206-213.

Hart, K.M., M.M. Lamont, A.R. Sartain, and I. Fujisaki. 2014. Migration, foraging, and residency patterns for northern gulf loggerheads: Implications of local threats and international movements. *PLoS ONE* 9.

Hauswaldt, J. S., and T. C. Glenn. 2005. Population genetics of the diamondback terrapin (*Malaclemys terrapin*). *Molecular Ecology* 14:723-732.

Hopkinson, C.S., A.E. Lugo, M. Alber, A.P. Covich, and S.J. Van Bloem. 2008. Forecasting effects of sea-level rise and windstorms on coastal and inland ecosystems. *Frontiers in Ecology and the Environment* 6: 255-263.

IPCC. 2021. Climate Change 2021: The physical science basis. Contribution of working group I to the sixth assessment report of the Intergovernmental Panel on Climate. 2391 pp.

Jerde, C.L., Mahon, A.R., Chadderton, W.L. and Lodge, D.M. 2011. "Sight-unseen" detection of rare aquatic species using environmental DNA. *Conservation Letters* 4: 150-157.

Jeyasuria, P., Roosenburg, W.M., & Place, A.R. 1994. Role of P-450 aromatase in sex determination of the diamondback terrapin, *Malaclemys terrapin*. *Journal of Experimental Zoology* 270: 95-111.

Jonsen, I.D., McMahon, C.R., Patterson, T.A., Auger-Méthé, M., Harcourt, R., Hindell, M.A., & Bestley, S. 2019. Movement responses to environment: fast inference of variation among southern elephant seals with a mixed effects model. *Ecology* 100: e02566.

Lamont, M.M., Johnson, D., and Catizone, D.J. Home ranges and Movements of Two Diamondback Terrapins (*Malaclemys terrapin macrospilota*) in Northwest Florida. *Estuaries and Coasts* 44, 1484–1491 (2021).
Lamont, M.M., Price, M.E. & Catizone, D.J. Satellite telemetry reveals space use of diamondback terrapins. *Anim Biotelemetry* 11, 42 (2023).
Lamont, M. M., Osland, M. J., Baustian, M. M. 2024. Salt marsh habitats and diamondback terrapins in a rapidly changing climate: a review. *Estuaries and Coasts, 48.*
Litzgus, J. and T.A. Mousseau. 2004. Home range and seasonal activity of Southern Spotted Turtles (*Clemmys guttata*): implications for management. Copeia 2004: 804-817.
Lyons, M.P., B. von Holle, M.A. Caffrey, and J.F. Weishampel. 2020. Quantifying the impacts of future sea level rise on nesting sea turtles in the southeastern United States. *Ecological Applications*: 30: p.e02100.
Malik, S. 2022. Turtle Bay: Diamondback terrapins have benefitted from recent protections. *Texas Parks and Wildlife Magazine*. March issue.
McCracken, S.F. 2025. Distribution of diamondback terrapins in Texas and Identification of Nesting Habitats. Final report to Gulf of Mexico Alliance, Grant #GSG-122232. 27 pp.
McCracken, S.F. and Bowling, T. 2026. Environmental DNA Assessment of the Texas Diamondback Terrapin (*Malaclemys terrapin littoralis*). Final report to Coastal Bend Bays & Estuaries Program, Contract No. 2503. 9 pp.
Mohrman, T. 2022. *Conservation Action Plan for Diamondback terrapins in the Gulf of Mexico*. 49 pp.
NEPARC. 2019. *Turtle PIT Tagging Protocol for the Northeastern U.S.* Developed by: NEPARC Turtle Working Group in partnership with the Spotted Turtle Working Group, the Collaborative to Combat the Illegal Trade in Turtles (CCITT), and the Northeast Wood and Blanding's Turtle Working Groups.
Pearson, S.H., and J.J. Wiebe. 2018. Considering diamond-backed terrapin (*Malaclemys terrapin*) nesting habitat and reproductive productivity in the restoration of Gulf of Mexico coastal ecosystems. *Ocean and Coastal Management* 155: 8-14.
Politi, N., L. Rivera, S. Martinuzzi, V.C. Radeloff, and A.M. Pidgeon. 2021. Conservation prioritization when species distribution data are scarce. *Landscape and Urban Planning* 210: 104067.
Roberge, T. 2012. Evaluating the reproductive ecology of the diamondback terrapin in Alabama saltmarshes: implications for the recovery of a depleted species. *Thesis. The University of Alabama at Birmingham.*
Roosenburg, W.M. 1994. Nesting habitat requirements of the diamondback terrapin: a geographic comparison. *Wetland Journal* 6: 8-11.
Roosenburg, W.M. and V.S. Kennedy (eds.). 2018. *Ecology and conservation of the diamond-backed terrapin*. Johns Hopkins University Press, Baltimore, MD. 277 pages.
Roosenburg, W.M., Baker, P.J., Burke, R., Dorcas, M.E. & Wood, R.C. 2019. *Malaclemys terrapin. The IUCN Red List of Threatened Species 2019*: e.T12695A507698. https://dx.doi.org/10.2305/IUCN.UK.2019-1.RLTS.T12695A507698.en. Accessed on 04 November 2022.
Selman,W., and C. Qualls. 2008. The impacts of Hurricane Katrina on a population of yellow-blotched sawbacks (*Graptemys flavimaculata*) in the Lower Pascagoula River. *Herpetological Conservation and Biology* 3: 224-230.

Selman, W., B. Baccigalopi, and C. Baccigalopi. 2014. Distribution and abundance of diamondback terrapins (*Malaclemys terrapin*) in southwestern Louisiana. *Chelonian Conservation and Biology* 13: 131-139.

Spivey, P.B. 1998. Home range, habitat selection, and diet of the diamondback terrapin (*Malaclemys terrapin*) in a North Carolina estuary. M.S. Thesis, University of Georgia, Athens, GA.

Texas Parks and Wildlife Department (TPWD). 2012. *Texas Conservation Action Plan 2012 – 2016: Statewide/Multi-region Handbook*. Editor, Wendy Connally, Texas Conservation Action Plan Coordinator. Austin, Texas.

Vitousek, S., P.L. Barnard, C.H. Fletcher, N. Frazer, L. Erikson, and C.D. Storlazzi. 2017. Doubling of coastal flooding frequency within decades due to sea-level rise. *Scientific Reports* 7: 1-9.

Whitmer, M., E. Pinnix, S. Finn, J. Jarvis, H. Sutton, and A. S. Williard. 2025. Use of Community Science Data to Assess Factors Associated With Diamond-Backed Terrapin (*Malaclemys terrapin*) Sightings in Coastal Marshes of Southeastern North Carolina, USA. Ecology and Evolution 15, no. 6: e71526.

Winters, J.M., H.W. Avery, E.A. Standora, and J.R. Spotila. 2015. Between the bay and a hard place: altered diamondback terrapin nesting movements demonstrate the effects of coastal barriers upon estuarine wildlife. *Journal of Wildlife Management* 79 (4): 682–688.

Wood, R.C. 1977. Evolution of the emydine turtles Graptemys and Malaclemys (Reptilia, Testudines, Emydidae). *Journal of Herpetology* 1: 415-421.

Woodland, R.J., C.L. Rowe, and P.F.P. Henry. 2017. Changes in habitat availability for multiple life stages of diamondback terrapins (*Malaclemys terrapin*) in Chesapeake Bay in response to sea level rise. *Estuaries and Coasts* 40: 1502-1515

APPENDIX A

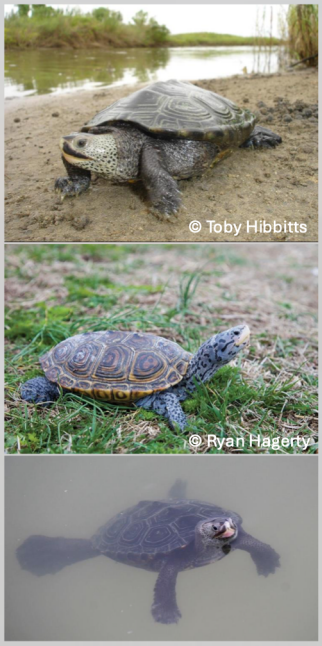
Specialized PowerPoint slides developed for the Texas Sea Turtle Stranding and Salvage Network (STSSN) to help responders identify Texas diamondback terrapins and submit verified reports to the McCracken Lab or the iNaturalist project.

Texas Diamondback terrapins (*Malaclemys terrapin litoralis)*

Distinguishing characteristics

- Shell length
  - Males: 4-5.5 inches
  - Females: 6-9 inches
- Diamond-shaped scutes (plates that form the carapace)
- Dark carapace (upper shell)
- Pale plastron (lower shell),
- Webbed feet
- Back feet larger than front
- Skin speckled

- More information: https://tpwd.texas.gov/huntwild/wild/species/terrapin/



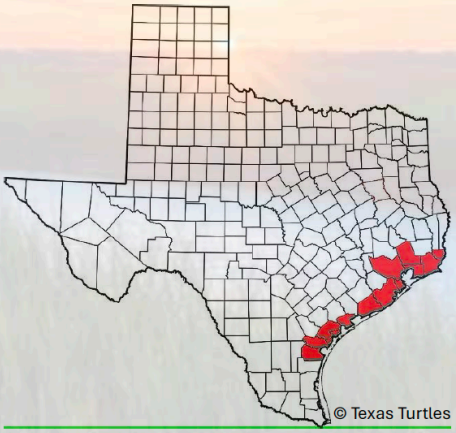
Texas Diamondback terrapin (*Malaclemys terrapin littoralis)*

Habitat

- Brackish or salt water
- Only turtle species found in estuaries, tidal creeks, and saltwater marshes

Life History

- Mating season is in the spring
  - Nest in sand above the high-tide line and lay 4-18 eggs
  - Eggs incubate 60 to 100 days, temperature dependent
  - Warmer temperatures produce more females
- Live up to up to 40 years
- May dig into the mud to hibernate over the winter months
- Diet: Crustaceans, bivalves, fish and insects



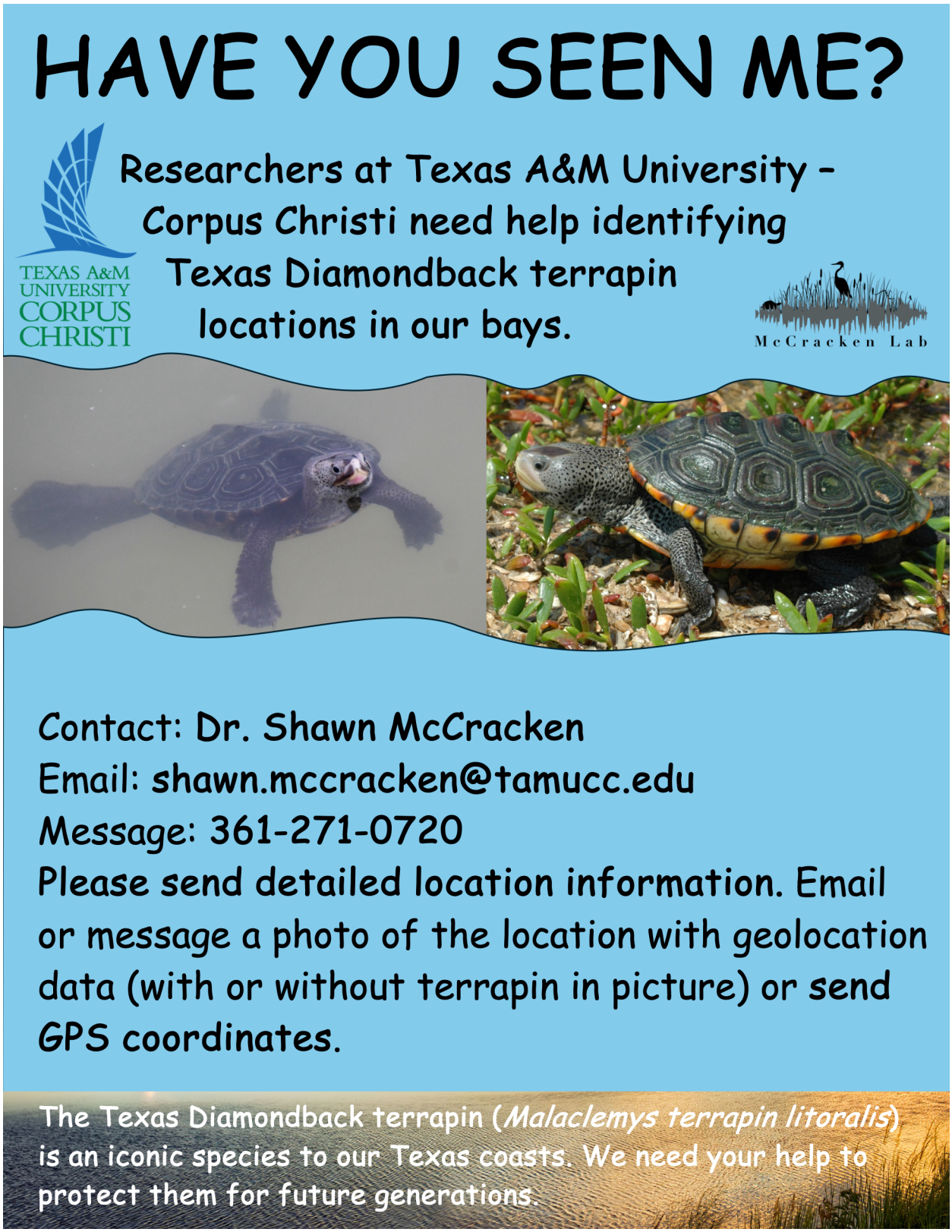
Texas Diamondback terrapin (*Malaclemys terrapin littoralis)*



- Researchers at Texas A&M Corpus Christi need help finding Texas Diamondback terrapins (*Malaclemys terrapin litoralis)* in our bays! Please help us protect this iconic Texas coast species for future generations.
- Please report sightings to our iNaturalist project (Texas Diamondback terrapin Task Force) linked at the QR code. Join the project and unobscure the data for our project admins.
  - or
- Contact Dr. Shawn McCracken directly with GPS coordinate data and any photos.
- Email: shawn.mccracken@tamucc.edu
- Message: 361-271-0720

McCracken Lab

Wanted flyers that we share opportunistically with boaters, kayakers, and fishing guides, directing them to the iNaturalist project.



TEXAS A&M UNIVERSITY CORPUS CHRISTI

Have you seen me?

Researchers at Texas A&M Corpus Christi need help finding Texas Diamondback terrapins (*Malaclemys terrapin litoralis*) in our bays! Please help us protect this iconic Texas coast species for future generations.





Please report sightings to our iNaturalist project linked at the QR code. Join the project and unobscure the data for our project admins.

or

Contact Dr. Shawn McCracken directly with GPS coordinate data and any photos.

- Email: shawn.mccracken@tamucc.edu
- Message: 361-271-0720

McCracken Lab