Population Survey of the Texas Diamondback Terrapin in San Antonio Bay, Matagorda Bay, and Sabine Lake

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SECTION 1. EXECUTIVE SUMMARY

The Diamondback Terrapin, Malaclemys terrapin, is the only naturally occurring endemic estuarine species of turtle found in the United States. Within Texas the subspecies Texas Diamondback, Malaclemys terrapin littoralis, ranges from Sabine Lake to Baffin Bay although recent records indicate Nueces Bay represents the last established population, and is considered the western edge of the distribution of the species. Within Texas estuaries, terrapin have been found over a range of habitat types including brackish to high salinity coastal marshes, tidal flats and creeks, shell islands, intertidal oyster reefs, and lagoons. Due to their relatively small size, amphibious existence, and association with intertidal wetlands accurate estimates of their density and abundance have been difficult to establish. Various techniques ranging from transect surveys, head counts, and use of both passive and active gear including modified crab pots, fyke nets and seines have been used to estimate their abundance within their range.

Currently little is known about the population status, habitat preferences, distribution, and general ecology of terrapin in Texas. This is primarily due to the lack of any comprehensive statewide survey of terrapin and the absence of an established population monitoring program that incorporates methods that target this species. The Texas terrapin has been identified as a species of concern by the Texas Parks and Wildlife Department (TPWD) and the U.S. Fish and Wildlife Service (USFWS) (Connally 2012; Texas Parks and Wildlife Department 2011). Additional population and demographic data is needed to effectively manage and conserve this species.

The primary objective of this study was to assess the current distribution and density of Texas Diamondback Terrapin populations within un-surveyed portions of the Texas coast. The study area included three major bay systems in the mid to upper Texas coast: San Antonio Bay, Matagorda Bay, Sabine Lake and adjacent waters. Information on the distribution of terrapin in other estuaries is also included. However portions of several estuaries including the upper Laguna Madre, Baffin Bay, and portions of Galveston Bay have not been comprehensively surveyed.

A second objective of the study was to determine critical factors that may affect the distribution of terrapin in Texas. Candidate factors that were evaluated included the presence of critical habitat features such as emergent and submerged vegetation, substrate type, elevation, and presence of human disturbance (e.g. man-made shoreline modification, boat traffic, and blue crab fishing effort). These factors have been identified by other investigators as important factors that may limit the distribution of terrapin in all or portions of its range.

In order to obtain the information necessary to accomplish each objective we used three complementary data collection approaches. These methods included a review of available published information, collection of third party observations, and new field surveys in the study area. Included with this report is a comprehensive geodatabase containing information on the density, local population size (when possible), demographics (sex, size, and relative age), distribution, and habitat associations of terrapin captured during this study and from various data sources for the surveyed estuaries and remaining portions of the Texas coast. The primary conclusions and deliverables provided by this study are listed below.

1). All sightings both past and present from multiple studies have been archived and are available in georeferenced electronic format. In most cases these data represent specific locations where terrapin have been captured or observed. This includes data from this study, past EIH studies, records from TPWD coastal fisheries monitoring, other published studies, reported sightings from biologists, fishermen and the public, the TPWD abandoned crab trap program, and questionnaire responses.

2). First documented occurrence of diamondback terrapin in Jackson County is reported.

3). Based on past studies, historical records, and personal observations the primary factor causing declines in terrapin prior to the 1930's was overharvest of the species for the terrapin soup market in the northeast. Following that period the shell dredging industry became active and was responsible for the widespread loss of both above tidal, intertidal and subtidal oyster shell throughout the Gulf coast. Accounts and official records indicate that much of the terrapin's former preferred nesting beaches and protected isolated islands were completely destroyed by the early 1970's.

4). Two of the largest concentrations of terrapin in Texas are found in the Nueces Bay and West Galveston Bay. Both of these areas contain numerous small oyster shell islands often associated with colonial waterbird aggregations. Previous studies on the Nueces and Aransas Bay populations indicate that multiple oyster shell islands are likely providing suitable nesting habitat.

5). The only records of terrapin nesting in Texas is on shell beaches located on South Deer Island and near Moses Lake in the Galveston Bay system.

6). Terrapin home range estimates range between 0.2 and 0.9 km radius (12.5 to 254 hectares).

7). The limited home range (< 0.9 km radius; 254 hectares, 2.54 km2) and breeding site philopatry exhibited by female terrapin makes this species exceptionally susceptible to local extirpation risk. Therefore it is critically important to identify all major nesting shorelines in Texas.

8). Habitat suitability curves for nesting terrapin developed for Atlantic coast populations include multiple variables such as % canopy cover as shrubs (V1), % canopy cover of grasses (V2), and mean substrate slope (V2) (Palmer and Cordes 1988). These curves need to be seriously reevaluated and modified to take into account the habitat associations observed in Texas terrapin. For example, data collected by our laboratory and others suggest that other variables such as degree of isolation, the amount of shell hash substrate, and the presence of adjacent wetlands which provides cover to hatchlings are also very important in both nesting and hatching success.

9) Based on a review of the literature and recent studies in Texas terrapin are seldom found when air temperature drops below 15 ºC in land or water. Furthermore, it appears that terrapin are seldom found when air or water temperature exceeds 35 ºC. During these periods terrapin are usually found burrowed in sediment and during the winter are in a state of brumination.

10) One of the primary factors that have been identified in the limiting the distribution of terrapin is elevated salinity. The distribution of terrapin occurrences spans a large salinity range from 0.2 to 47 psu. However, the majority of terrapin occurrences range between 10 and 34 psu. Although terrapin possess a salt secreting gland, it is not as efficient as those found in true sea turtles. Therefore terrapin must occasionally obtain freshwater to drink. This can be from rainfall or freshwater inflow. Based on the distribution of historical terrapin captures and observations the southern extent of terrapin in Texas is likely limited to Nueces Bay or nearby estuarine waters due to the lack of rainfall and reliable freshwater sources further south in the Laguna Madre.

11) Many past studies have relied exclusively on carapace dimensions to describe the size of terrapin. It is recommended that in the future investigators incorporate measurements of carapace, plastron, and the head region at a minimum to describe individuals and fully evaluate the growth and development of members of the species.

12). Based on our examination of historical data collected by past studies in Nueces Bay and adjacent water bodies there is a statistically significant size difference in both male and female terrapin between the upper and lower coast of Texas. Terrapin from the upper Texas coast were in general both longer and heavier than those form the south coast of Texas. The reduced size may reflect higher energy use for metabolism due to higher salinities and more stressful conditions at the extreme end of their distribution.

13) Estimates by Guillen and Oakley (2013) and Hogan (2003) suggest the population size of insular populations of terrapin is around 327 ± 50 terrapin/29 hectares. A population size of 327 terrapin on a 29 hectare island would translate into an estimated density of 11 terrapin /hectare, or 2,991 terrapin /mi2. Estimated population sizes and density were lower along the lower Texas coast. The average population size of Nueces Bay was 322 terrapin. The surface area of Nueces Bay is 6940.97 hectares (26.79 mi2). Using this value the extrapolated density of terrapin would be 12 individuals / mi2. The areas used for Nueces Bay do not take into account the fringing marsh and islands found in that system. The estimated population abundance and density of terrapin at the South Deer Island complex if correct is most likely the most abundant local population of terrapin in Texas. If the estimated numbers provided by each study is approximately correct this would imply that insular wetlands isolated from the mainland

inherently have a higher carrying capacity for terrapin. This may be due to reduced predation. In addition, the Nueces Bay population is located near the edge of the distribution of this species and may be encountering strong selection pressure against further growth.

14). There is a need to collect additional data on habitat features in support of the development of a wetland carrying capacity model for terrapin. Guillen and Oakley (2013) reported that Texas terrapin captured on land are found more frequently in Spartina alterniflora stands and in vegetation exhibiting a canopy height of 20-60 cm. Although terrapin can be found over the entire spectrum of vegetation cover they are most frequently encountered in 40-60% vegetation cover.

15). Based on historical data obtained from South Deer Island, the average growth rate of female terrapin between the ages of 3 to 7 is 10 mm per year. Male terrapin appear to grow much faster at an earlier age and then experience slower growth ranging from 1 to 2 mm per year up to the age 8.

16). Maintenance of a balanced ratio of male and female organisms is often considered essential for population viability although in some cases the distribution can be skewed. The populations of terrapin at South Deer Island have been maintaining a 1:1 ratio of males and females since the early 2000's (Guillen et al. 2011; Hogan 2003). In contrast Halbrook (2003) reported a skewed ratio favoring females, 2.91:1 female: male, in the Nueces Bay area.

17). One of the major risks to terrapin population viability is bycatch mortality associated with the commercial blue crab fishery of Texas. Based on information obtained from crabbers, past information surveys, TPWD fishery independent surveys and ongoing work by our institution and others it appears that the risk of bycatch mortality increases substantially whenever crabbers operate near areas of high terrapin density such as the Nueces and Aransas Bay systems, East Matagorda Bay system and interconnecting waterways, and the West Bay-Deer Island complex. Currently the Gulf States Marine Fisheries Committee (GSMFC) and member states are investigating the need to implement regulations that would require blue crab fishermen to install bycatch reduction devices (BRD). The highest risk from bycatch mortality would be from accessible areas (e.g. open water, deeper tidal creeks) which allow high blue crab fishermen to deploy pots close to terrapin nesting and foraging areas.

The combination of physical isolation, suitable habitat and abundant prey has led to the relatively high population levels observed at the South Deer Island complex. The lack of boat access to commercial fisherman and most recreational vessels, the apparent lack of terrestrial predators, and the beneficial protection terrapin share by inhabiting the island with federally protected colonial waterbirds, has no doubt led to the establishment of these large island populations on South and North Deer Island and adjacent wetlands located on mainland at Greens Lake and on the bay side of Galveston Island. Similarly the Nueces Bay terrapin population apparently utilizes the wetlands and remote oyster shell islands in that bay system for foraging and the islands for nesting. It is clear that terrapin rely on a mosaic of habitats including tidal creeks and saltmarshes for foraging and oyster shell or sand beaches for nesting. Other factors such as isolation from predators and commercial blue crab fishing effort contribute to their long term population viability. Due to individual longevity, delayed maturity, and long generation times, long-term studies are critically needed to monitor the dynamics and trends in terrapin populations in Texas.

SECTION 2. INTRODUCTION AND BACKGROUND INFORMATION

Section 2.1. Life History

Section 2.1.1. Range

The Diamondback Terrapin[1], *Malaclemys terrapin,* is the only naturally occurring endemic estuarine species of turtle found in North America (Brennessel 2006; Ernst and Lovich 2009). Worldwide terrapin are only found in the United States and Bermuda (Ernst and Lovich 2009). Seven recognized subspecies occur from Cape Cod Massachusetts around the Florida Keys to Baffin Bay (Brennessel 2006). An additional isolated population of terrapin has also naturally colonized the island of Bermuda (Parham et al. 2008). Within Texas the subspecies *Malaclemys terrapin littoralis* is found from Sabine Lake (Orange County) to Baffin Bay (Kleberg County) although only a few records exist beyond Nueces Bay (Dixon and Hibbits 2013). Currently Dixon and Hibbits (2013) does not report any occurrences of terrapin in Jackson county.

The Texas subspecies is defined by having a deep carapace with terminal knobs on the median keel; a very pale plastron and having a head with a dorsal surface that light colored (Brennessel 2006). Hartsell (2001), conducted an analysis of the phenotypic characteristics of all subspecies of terrapin and concluded that *M. terrapin littoralis* is nearly impossible to distinguish from *M.* terrapin pileata and recommended combining the two in one subspecies, *M. t. pileata*. We have also found many specimens in Galveston Bay that have many features that give them the appearance of *M. t. pileata.*

The validity of current subspecies designations continues to be evaluated. (Forstner et al. 2000) concluded that based on their analysis there was sufficient evidence to maintain the current subspecies designations. However, more recent genetic studies have called into the question these designations. Hauswaldt and Glenn (2005), found that there was no population structure within or among adjacent estuaries along the east coast. They further concluded that terrapin northeastern Atlantic coast estuaries were more genetically similar to specimens from Nueces Bay Texas than they were with specimens from the southeastern Atlantic coast estuaries. They attribute this pattern to extensive translocation of terrapins during the early 20thcentury to replenish diminished population and to provide turtle farms with stocks. Terrapin collected in Texas were especially sought for shipment to the northeastern US because of their larger size (Hauswaldt and Glenn 2005). (Hart 2005) found that six management units that did not exactly parallel existing subspecies boundaries were warranted based on data collected using microsatellite DNA analysis. She concluded that a Gulf of Mexico management unit consisting of all Gulf States is supported by current genetic data. Later analyses suggested that a management unit consisting of terrapin from Texas (*M.t. littoralis*) and Louisiana (*M.t. pileata*) is warranted (Hart et al. 2014). They concluded that additional sampling is needed to refine these management units especially in southern states.

[1] Henceforth interchangeably referred to as unless noted otherwise as just “terrapin” in this report

Coleman (2011), conducted genetic population studies using microsatellite DNA and concluded that *M.t. pileata* and *M.t. littoralis* can be grouped into one management unit (MU). However, he cautioned that more samples are needed to discriminate the differentiation between this MU and the populations of *M.t.macrospilata* in the eastern Gulf of Mexico. Most recently Glenos (2013) in her study of northern Gulf of Mexico terrapin using microsatellite DNA found that terrapin within Texas, Nueces Bay and Galveston Bay were genetically more similar than terrapin from Louisiana and Alabama and recommended that each remain a distinct management unit. She noted however that her samples for Louisiana were biased since specimens were lacking from western portion of the state similar to past comparative studies (Coleman 2011; Glenos 2013; Hart et al. 2014).

Section 2.1.2. Description

Terrapin is a moderately sized turtles exhibiting distinctive sexual dimorphism in size and morphology (maximum carapace length (CL_{max}) females = 23.8 cm; CL_{max} male = 14.0 cm) (Ernst and Lovich 2009)(Figure 1). Smaller specimens can be sexed by examining the shape of the their head (broader in females), type of tail (thick and large in males versus small in females) and the position of the cloaca, which is outside the margin of the plastron in males and not so in females (Brennessel 2006). Terrapin shells are characterized by concentric markings and grooves on the vertebral and pleural scutes and gray to black skin with dark flecks, blotches, spots or stripes (Figure 2). The carapace is oblong; its posterior marginal scutes may be curled slightly upward and slightly serrated. A vertebral keel is present and may be low or knobby and very prominent. The variety of colors and patterns have made terrapin popular pets in recent years for classrooms and educational programs (Chew and Lee 2008).

Section 2.1.3. Habitat Associations and Movement

Terrapin inhabit estuaries including coastal marshes, intertidal oyster reef, mangrove swamps, tidal mudflats, tidal creeks, lagoons and sounds behind barrier islands (Brennessel 2006; Bulhmann et al. 2008; Ernst and Lovich 2009; Nemec 1995). There are no records of terrapin living in freshwater systems or open ocean (Bulhmann et al. 2008). Within estuaries terrapin have been observed foraging and/or basking in intertidal wetlands, oyster reef, isolated oyster reef and sand islands, mangroves, tidal creeks, ocean facing beaches, and open water. Nesting habitat, which will be discussed later, occurs in a range of habitats including sandy beaches and oyster shell hash berms with relatively little vegetation. In the northeast it is not unusual for terrapin to attempt to lay eggs in yards within neighborhoods which were formally nesting beaches (Brennessel 2006).

Figure 1. Illustration of sexual dimorphism in adult terrapin size and morphometrics. Larger female with wider head on left, smaller male on right.

Figure 2. Terrapin exhibiting various color patterns and morphology.

Within Texas estuaries, terrapin have been found over a range of habitat including brackish to high salinity coastal marshes, tidal flats or creeks, shell islands, intertidal oyster reef, and lagoons (Halbrook 2003; Haskett 2011; Koza 2006). Estuaries are one of several aquatic ecosystems considered most at risk across Texas (Connally 2012). Due to the unique dependence of terrapin on estuaries terrapin might be a suitable sentinel or indicator species for this ecosystem (Tabor and Aguirre 2004; Zacharias and Roff 2001).

Recent studies conducted along the upper Texas Coast and Galveston Bay suggests that terrapins show a greater association with intertidal salt marshes and upland areas in contrast to the Atlantic coast subspecies which appear to spend a larger amount of time in subtidal environments including intertidal creeks (Clarkson 2012; Haskett 2011; Haskett and Guillen 2010). It is unknown whether this same pattern is true along the lower Texas coast since limited comparative research on the distribution of terrapin between has been conducted in the Nueces and Aransas Bay systems and those studies did not investigate the differential role of terrestrial and intertidal systems as nesting and foraging habitat (Halbrook 2003; Koza 2006).

Non-nesting terrapin habitat selection is largely influenced by sexual dimorphism and diet. The considerable large difference in gape size between males and females promotes gender-based resource partitioning. In a South Carolina study, the females' large gape size facilitated a diet of large and small *Littorina littorea* (periwinkle snail), as well as crabs and scavenged fish (Tucker et al. 1995).. The smaller gape size of males restricted them to a diet of smaller periwinkle snails and other species (Tucker et al. 1995). Since larger periwinkle snails inhabited less dense vegetation at higher elevations further from creeks, it was more common to find females foraging in these areas (Tucker et al. 1995). High tides and marsh flooding enabled easy access into the marsh above the creeks and therefore increased foraging opportunities for female terrapin. Males were constricted to foraging on the smaller periwinkle snails that inhabit the thick, tall vegetation adjacent to creeks (Tucker et al. 1995). However, these trends have only been observed on the Atlantic coast, and no research has been done in Texas on tidal influence on prey availability and habitat selection. Due to the reduced tidal amplitude in the Gulf of Mexico, these patterns in use of intertidal wetlands may not be as pronounced.

Sexual size dimorphism is also strongly correlated with open water habitat use. Larger females have been found to swim further into open water, and distance from shore is positively correlated with plastron length (Roosenburg et al. 1999) (Roosenburg et al 1999). They proposed that this may also have to do with gender-based resource partitioning. In the Chesapeake Bay, larger clams are found further from shore, and terrapin may require greater crushing strength associated with larger jaw size to feed on these clams. Roosenburg et al (1999) also found a higher abundance of female terrapin in the upper reaches of the marsh, while male terrapin were found more commonly along the edges of the marsh and channels. This distribution supports the gape size limitation hypothesis proposed by Tucker et al. (1995).

Terrapin display variable levels of home range and site fidelity. Previous studies have found that on a larger scale, high site fidelity can limit terrapin's ability to re-colonize abandoned creeks (Tucker et al. 2001). Gibbons et al. (2001), estimated a 5.7% migration rate for local populations with a maximum range of 0.7 km. Several studies have found that female migration rates and range are higher than males (Butler 2002; Gibbons et al. 2001; Hogan 2003; Tucker et al. 2001). Migration rates are most likely correlated with dietary needs, reproduction, and habitat selection, and are ultimately limited by the habitat available and ease of movement. Spivey (1993), calculated a home range of 305.4 ± 64.5 ha for female terrapins in a North Carolina estuary using the minimum convex polygon method. Butler (2002), calculated a home range of 54.33 ± 54.80 ha in Northeastern Florida. Clearly, estimates of home range vary between regions and studies, and needs to be researched further. These previous studies were conducted on the Atlantic coast. More data is needed on home range of Terrapin Texas. Preliminary data from our ongoing research shows our home ranges estimate ranging between 2 and 30 ha (Guillen and Oakley 2013). However these estimates are based primarily on terrapin from and insular population and may not be an appropriate comparison to larger marsh associated populations. Baxter et al. (2013), reported average distances between recaptures to be 0.4 km.

Section 2.1.4. Seasonality

The annual activity of diamondback terrapins varies with latitude (Brennessel 2006; Ernst and Lovich 2009). Along the Gulf coast and Texas the active season extends from late February to November along the upper coast and from early February to December along the lower coast of Texas (Halbrook 2003; Haskett 2011; Hogan 2003). In Texas, during the dormant period terrapin will brumate in burrows either in creek banks or within the marsh (Haskett 2011). There is limited evidence that during milder winters the period of dormancy may be smaller.

As temperature decreases in November through January, terrapin become less active and must select locations to brumate. This process involves cessation of foraging, a drop in metabolism, and a retreat into tidal creeks (Brennessel 2006). During hibernation, they burrow in the bottom of deep creeks and in the side of creek banks. Burrowing can either be singular or communal (Yearicks et al. 1981). In a 1997-2000 radiotelemetry study in a Florida salt marsh, a radio-tagged female was found burrowed in 3-5 cm of mud in low areas near creeks that were flooded at high tide. From November until January, her burrowing location varied, but from January through February, she remained burrowed in one spot (Butler 2002).

In Texas, our continuing study in Galveston Bay we have found active terrapins (walking and swimming) year round, although the vast majority of terrapin burrow in late November until late February. Burrowing sites vary in vegetation cover and location, as we've found terrapins burrowed in creeks, creek banks, and terrestrial marshes with up to 100% vegetation cover and vegetation height of half a meter or more. However, some terrapin remain active. In one case a single female terrapin swam a distance of approximately 2.3 km between two sites (South Deer to North Deer) in February, with water temperatures near 18^{o} C. Limited data collected in Texas also suggests that during the summer months terrapin may reduce their activity in response and burrow more frequently due to high temperatures (Haskett 2011; Hogan 2003).

Section 2.1.5. Salinity and Osmoregulation

As a species terrapin are found exclusively in estuaries including mudflats, seagrass beds, saltmarshes, intertidal oyster reef, and mangrove forests (Brennessel 2006; Texas Parks and Wildlife Department 2011). Terrapins can survive in freshwater, but no natural populations exist in purely freshwater habitats (Bulhmann et al. 2008). Dunson (1970), found that terrapin collected from Maryland to Florida occurred in salinities between 11 and 32 psu. The terrapin's ability to survive in estuaries is closely associated with various physiological and behavioral adaptations that allow it to survive in varying salinity.

The Diamondback terrapin possess a pair of lachrymal glands that secrete salt in the form of "salty tears". These glands function as an extra kidney, but their salt secretion capacity as well as activity is much lower than that in sea turtles and is not sufficient for complete osmoregulation in 100% sea water (32 ppt) (Brennessel 2006)(Cowan 1990). To compensate for this, terrapin exhibit osmoregulatory behaviors such basking, reduced feeding on marine invertebrates, and drinking fresh water that floats on top of the more dense saltwater or has accumulated in depressions during rainfall events (Bels et al. 1995; Davenport and Macdeo 1990; Davenport and Magill 1996). This usually takes no longer than 15 minutes to rehydrate and can be accomplished with just a small film of water. During past studies on South Deer Island, Texas we have witnessed terrapin rapidly emerging from burrows and thick vegetation to locate puddles of freshwater accumulated on plants and the ground after rainstorms. Davenport and Macdeo (1990), observed terrapin responding to the vibration caused by falling rain drops by seeking out films of water in mesocosm experiments. They also observed terrapin opening their mouths and orienting their head upward during heavy downpours.

Terrapin also utilize behavioral osmoregulation when fresh drinking water is unavailable by increasing their basking activity, which prevents additional salt influx that can occur during immersion in salt water while concurrently increasing salt excretion rates (Davenport and Magill 1996). Terrapins also effectively may minimize salt intake through their diet by engaging in hyperphagia, during which they consume a large amount of food in times of high freshwater inflow so that they can fast during periods of high salinity (Davenport and Ward 1993). During periods of prolonged exposure to high salinity terrapin will also reduce consumption of prey items (e.g. invertebrates) containing high salt content (Davenport and Ward 1993).

Although the presence of lachrymal glands and behavioral adaptations enables terrapin to exist in saline conditions for a long time it appears that eventually they must secure sufficient freshwater from rainfall events or a surface water source. This is the most likely explanation for the apparent geographic limitation and absence of terrapin in most of the Laguna Madre. While terrapins have often been routinely observed in Nueces Bay, which has the last significant freshwater river tributary, they have rarely been observed in south of Kleberg County including South Padre Island, the mainland, or the adjacent lagoon system. It is highly probable that terrapin cannot tolerate the prolonged high salinity observed in the Upper Laguna Madre during times of extended drought. This represents a significant ecological barrier to movement between Nueces Bay and points further south (Duran 2004). The combined physiological and behavioral osmoregulation would also explain the somewhat paradoxical distribution of the mangrove terrapin, which is found in nearshore marine habitat in southern Florida (Hart and McIvor 2008; Wood 1981). However, this area also receives considerable annual rainfall and likely possesses complex topography capable of capturing rainfall and creating puddles of freshwater. Also, terrapin can skim the surface of a waterbody and extract the thin layer of overlying freshwater that forms initially.

Section 2.1.6. Trophic Interactions and Pathogens

Terrapin are predators of many small invertebrates and fish in wetland habitats. Past studies have shown that a terrapin's diet consists of invertebrates such as marsh periwinkle snails (*Littorina irrorata*) and various crab species (*Sesarma* spp., Uca spp., *and Callinectes sapidus*) (Butler et al. 2012; Davenport et al. 1992; Tucker et al. 1997). Cagle (1952), reported the presence of small clams in intestinal contents of Louisiana terrapin. Tucker et al. (1995) found similar prey items in fecal samples. Tucker et al. (1995), found that the smaller sized males consume smaller and different prey items than females. Hatchling have been seen eating tiny fiddler crabs (Bulhmann et al. 2008).

Diamondback terrapin may function as a keystone predator foraging on major salt marsh grazers which in turn reduces herbivory (Sierra and Burke 2007). Based on experimental manipulation of the dominant marsh grazer (the periwinkle, *Littorina irrorata*) and two of its common consumers (e.g., blue crabs, *Callinectes sapidus*, terrapins, *Malaclemys terrapin*) Silliman and Bertness (2002) demonstrated that saltmarsh plant biomass and production is largely controlled by grazers and their predators. They concluded that periwinkle grazing can convert a saltmarsh wetland into a barren mudflat within 8 months if predators were removed. Thus, top-down control of grazer density is a key regulatory determinant of marsh grass growth and density. The discovery of this simple trophic cascade implies that over-harvesting of snail predators (e.g., terrapin) may be an important factor contributing to the massive decline in salt marshes across the southeastern United States (Silliman and Bertness 2002). The diet of Diamondback terrapin in Texas is unknown. We have observed several terrapin eating periwinkle snails during past field investigations on Deer Island in West Bay. Currently Mr. Bryan Alleman at the University of Houston Clear Lake is investigating the diet of terrapin in Galveston Bay.

Multiple species have been known to prey upon terrapin eggs and hatchlings including raccoons, gulls, coyote, ghost crab, herons, crows, shrikes, boat-tailed grackles, hogs, rats, muskrats, foxes, armadillo, skunks, mink and river otter (Butler et al. 2004; Ernst and Lovich 2009). Crows and gulls are effective daytime predators of eggs (Burger 1977). Draud et al. (2004), found that brown rats if present can cause considerable mortality on hatching terrapin after they leave their nest. Burger (1977), found that that following predators destroyed the corresponding percentages of nests red foxes 34%, raccoons, 48%, laughing gulls 8%, and crows 6%.

Lazell and Auger (1981), reported that invasion of beach grass (*Ammophila breviligulata*) roots into terrapin nests destroyed eggs by bursting infertile eggs and or by surrounding the incubating eggs. Stegmann et al. (1988), documented that the infiltrating roots will absorb nutrients from terrapin eggs. They hypothesized that this was adaptation by beach grass to live in mineral poor sand dunes. They also found that other plants are capable of this type of "predation" including saltwort (*Batis maritima*), seashore saltgrass (*Distichlis spicata*), worm wood (*Artemisia campestris*) and bayberry (*Myrica pensylvanica*) (Butler et al. 2004; Feinberg 2004; Feinberg and Burke 2003). It is possible that other plants in coastal areas can also cause mortality in eggs through root infiltration (Feinberg and Burke 2003).

Mortality in adult terrapin due to terrestrial predators has been observed less frequently than in the juvenile and egg stage. However, some predators, such as raccoon, have been show to kill adult nesting female terrapin (Brennessel 2006; Feinberg and Burke 2003; Seigel 1980b). Predation by raccoons is considered is one of the greatest threats to long-term local terrapin population viability. Predation of egg, juvenile and adult terrapin by raccoons has resulted in local extirpation of populations (Seigel 1993). These local extirpations usually occurred after an increase in raccoon numbers caused by the removal of physical obstacles which previously prevented their access into nesting areas. Although not considered a significant source of mortality, predation by wading birds and bald eagles has been documented (Brennessel 2006; Bulhmann et al. 2008).

Multiple aquatic organisms that have been identified as potential predators of juvenile and adult terrapin include alligator, crocodile, dolphin, sea turtle, sharks and large bony fish (Brennessel 2006; Bulhmann et al. 2008; Ernst and Lovich 2009). Alligators have been identified by (Mann 1995) and (Gunter 1981) as likely predators of terrapin based on a inverse relationship between terrapin and alligator abundance. They found that terrapin abundance generally declined in areas experiencing increasing alligator populations. The likelihood of alligator feeding on terrapin where their ranges overlap is highly plausible given a documented diet that includes many freshwater turtles and is considered an opportunistic generalist predator (Ouchley 2013; Wolfe et al. 1987).

Frick (1997) documented two records of adult and juvenile terrapin being consumed sea turtles along the Georgia coast. In 1993 a necropsy of a 62.5 cm CCL (curve carapace length) stranded

Kemp's Ridley (*Lepidochelys kempi*) yielded one adult (12.2 cm CCL) and one juvenile terrapin. In 1996 a necropsy of a 72 cm CCL loggerhead (*Caretta caretta*) yielded the partial remains of two juvenile and one adult terrapin.

Bottlenose dolphin (*Tursiops truncatus*), have been observed capturing terrapin by sliding up banks and grabbing adult terrapin along the North Carolina coast (Fertl and Fulling 2007). Lovich and Gibbons (1990), observed that 12% of females and 8% of males in their South Carolina study population were missing limbs as a result of encounters with predators. Within Texas we have received reports of hatchling terrapins being carried away by gulls in Galveston County, and also adult terrapin being found in the stomach of a red drum (*Sciaenops ocellatus*) in Orange County, Texas. We have also personally observed terrapin in Galveston Bay with scars along the edge of their carapace, missing limbs and scars on their head that appear that could have been caused by a bite from a large predator (Marlow and Guillen 2011). They found that 7-13% of the females and 5-8% of the males collected between 2008 and 2011 exhibited injuries due to multiple sources (natural predators and boat collisions), which is similar to values reported by (Lovich and Gibbons 1990)(Figure 3).

Terrapin is occasionally fouled with attached barnacles (*Balanus eburneus, Chelonibia manati, C. testudinaria*) Eastern oysters (*Crassostrea virginica*), and slipper snail (*Crepidula plana*)(Ross and Jackson 1972; Seigel 1978). If these fouling organisms grow to large and are located near the back of a female it can impede or prevent nesting (Ernst and Lovich 2009). Internal parasites are rare or nonexistent in wild terrapins based on samples from Massachusetts to the Florida Keys (Werner 2005).

Section 2.1.7. Reproduction

Sexual maturity in terrapin is usually attained in 4-8 years for females and even less (2-5 years) for males along the southeastern and Gulf coast (Brennessel 2006; Ernst and Lovich 2009; Nemec 1995). However, maturity is often more closely correlated with size than age. Females mature at a plastron length of approximately 14 cm, while males mature at 8 to 10 cm (Brennessel 2006; Nemec 1995). It is also common for southern populations of terrapin to reach sexual maturity at a younger age than northern populations. Females in North Carolina and New Jersey have been found to mature at around 13.5 centimeters in plastron length at approximately 7 years of age, while females in Florida have been found to mature at approximately 4-5 years of age. Similarly, males have been shown to reach maturity at approximately 9.0 cm and 5 years of age in North Carolina, while attaining maturity at 9.5 cm and 2-3 years of age in Florida (Siegel 1984).

Figure 3. Example of injuries observed at the South Deer Island, West Bay site (Marlow and Guillen 2011).

The small size in males is indicative of sexual selection pressures. In a species in which the males are small, such as the terrapin, female sexual selection based on size and aggressive mate defense are not likely. It is more likely that the smaller size of males is due to a higher investment of energy and resources into sexual reproduction and mating rather than aggression and mate defense (Brennessel 2006). There is limited data on sexual maturity in Texas terrapin. Data obtained from captive studies suggest that female terrapin in Texas attain sexual maturity at 6-7 years of age at plastron lengths of 14-16 cm (5.6-6.4 inches), while males attain maturity at 3 years of age and plastron lengths of 9-10 cm (3.6-4.0 inches) (Ernst and Lovich 2009; Hildebrand 1932; Nemec 1995). The sexes are difficult to distinguish until they reach these sizes (Hildebrand 1932).

Courtship and mating of terrapin usually occurs in tidal creeks and in open water in aggregations during late March in Florida (Seigel 1980a). Courtship starts with the female floating at the surface. She is then pursued by one or more males who attempt to copulate with her. If successful the terrapin will copulate up to two minutes.

Section 2.1.8. Nesting

While terrapin utilize many habitats over the course of their life, including tidal creeks and salt marshes, nesting habitat is regarded as one of the most important habitats for their life cycle, and losing just a small part of this habitat could cause the decimation of their population (Brennessel 2006). Terrapin exhibit environmental sex determination (ESD) that is heavily influenced by temperature. A constant incubation temperature of 28.5^{o}C to 29.5^{o} C is required to produce mixed sex ratios, while temperatures outside this range produce mono-sex clutches (Roosenburg and Place 1995). Maintaining appropriate sex ratios may be difficult for terrapins due to the large daily variation (2-12^{o} C) in the terrapin nest temperature (Burger 1976b). Female terrapins therefore require a wide variety of nesting microhabitat to choose from in order for sex ratios to be balanced (Roosenburg 1994). Consequently, obtaining a healthy sex ratio is very dependent on nesting site selection.

Terrapin nesting habitat is also more variable compared to sea turtles, and includes dike roads, sand dunes, and shell hash beaches (Roosenburg 1994). A habitat suitability index (HSI) model for diamondback terrapin nesting was produced for the Atlantic coast (Palmer and Cordes 1988). The model assumes ideal nesting habitat is above normal high tide in upland areas and is characterized by having ≤ 25% canopy cover of shrubs, between 5 and 25% canopy cover of grasses, and ≤ 10º slope (Palmer and Cordes 1988). Although this model was developed for the Atlantic coastline, the authors claim that it could be modified and applied to other locations including the Gulf coast. Halbrook (2003) used the HSI model in the Nueces Bay area to evaluate the suitability of islands for nesting terrapin. She concluded that four of the five islands surveyed in Nueces Bay appear to be suitable habitat for nesting terrapin.

Only two terrapin nests have been documented recently in Texas, and so nesting habitat is poorly documented but assumed to occur in high elevated shell hash (George 2014; Hogan 2003)(Figure 4 and 5). These two recent records are supported by early observations of fishermen and citizens in Galveston Bay who found terrapin nesting in and around shell islands in the late 1800's and early 1900's (Gallaway 2001). Borden and Langford (2008) citing a personal communication (D.H. Nelson, pers. com) noted that nesting beaches in the Northern Gulf of Mexico are located almost exclusively on small and widely distributed islands (Nelson and Best 2004). Borden and Langford (2008) noted that unlike Atlantic coast nesting beaches, beaches in Alabama are largely composed of oyster shells, which prevents locating turtles and their nests via female crawls, the typical method described by Feinberg and Burke (2003) for sand beaches. In summary it appears that the Atlantic subspecies of terrapin appear to prefer sandy beaches for nesting in contrast to Texas and other Gulf coast estuaries where isolated islands containing shell-hash mounds may be preferred (Borden and Langford 2008; Hackney et al. 2013; Hogan 2003; Palmer and Cordes 1988).

Based on limited historical nesting data it is very likely that the current Atlantic model will need to be modified for optimal use in Texas. This is based on several observations including the presence of relatively large population of terrapin on South Deer Island, Aransas Bay, and Nueces Bay (Halbrook 2003; Haskett 2011; Koza 2006). These sites and historical nesting locations consist of isolated shell hash islands that provide suitable elevation and isolation from predators.

Figure 4. Terrapin nesting on Shell Island next to Moses Lake, Texas. Photo credit: Amanda Hackney *in* (George 2014).

Figure 5. Female Diamondback terrapin covering her nest site on South Deer Island, Texas. Source (Hogan 2003).

Guillen and Oakley (2013), recommended future development of an HSI model for nesting habitat in Texas that incorporates a measure of isolation and sediment type as two additional attributes. They also recommended collection of additional data on habitat, nesting activity and hatching success to support additional model development and testing.

The nesting season of terrapin extends from April through July depending on location along the Atlantic and Gulf coast (Ernst and Lovich 2009). The two nesting events observed in Texas occurred in April and May (George 2014; Hogan 2003). Also, possible terrapin scrapes were observed on June 6, 2013 on South Deer Island by (George 2014). Based on this limited data we can conclude that the nesting season in Texas extends from April to June and possibly July.

Terrapin will begin looking for a suitable nesting site by sniffing the substrate. Lazell and Auger (1981) described terrapin sand sniffing and theorized they were "sniffing" to avoid areas of high plant rhizome density. Once a suitable area site is located, they dig the nest by scooping out sand or shell hash with their back feet. The digging behavior is similar to that described for the green sea turtles (Burger 1977). The eggs are deposited in triangular or flask-shaped nest cavities dug and then covered by females (Brennessel 2006; Ernst and Lovich 2009; Nemec 1995). Total depth of nests (from soil surface to bottom of egg compartment) ranges from 11 to 20 cm (4-8 inches) (Nemec 1995).

Section 2.1.9. Early Life History

Very little is known about the first few years of the Diamondback terrapin's life (Gibbons et al. 2001). Juveniles and hatchlings appear to be absent from habitats in which most adults are found, suggesting a difference in hatchling habitat preference (Gibbons et al. 2001). Terrapin hatchlings consistently appear to move directly into heavy marsh vegetation and tidal wrack upon hatching (Burger 1976a; Coleman et al. 2014; Lovich et al. 1991; Muldoon 2010). Recent studies have found hatchlings under *Spartina patens* and *Distichlis spicata* in the intertidal zone of the upper marsh (Draud et al. 2004). Natural predators of hatchling terrapin include birds and raccoons (Draud et al. 2004).

Section 2.1.10. Growth and Survival

Terrapin exhibit a type III survivorship curve with a clutch size averaging 12 eggs (Roosenburg and Dunham 1997) and a maximum life span of approximately 30-50 years (Roosenburg 1990; Tucker et al. 2001), although an average life span closer to 5.7 years based on instantaneous mortality rates in a South Carolina estuary has been documented by (Tucker et al. 2001). A type III survivorship denotes a life history where an organism typically experiences high mortality during the early life stages in contrast to later life stages (Molles 2005). Roosenburg (1990), estimated that in order to replace herself as a hatchling, a female Diamondback terrapin needs to undergo three years of maximum reproduction. This specific life history leaves terrapin extremely susceptible to local population depletion or extirpation. Females that have survived to reproductive maturity are highly valuable to the population as the limiting factor in offspring production, and their mortality can decimate populations. Furthermore, the time required to reach maturity (generation time) may prevent Diamondback terrapin from being able to quickly adapt to changing environments, which makes the terrapin especially susceptible to loss due to habitat alteration (Roosenburg 1990).

Section 2.2. Man-made Sources of Mortality

Section 2.2.1. Historical Accounts of Terrapin and Commercial Harvest

There are numerous historical accounts of terrapin by early settlers of the east coast extending back to the 1585 (Schaffer et al. 2008). Based on anecdotal accounts, terrapin were believed to extremely numerous prior to the late 1800's (Schaffer et al. 2008). There were tales of terrapin in Chesapeake Bay being so great in number that slaves and indentured servants complained about the frequency of turtles in their diets (Schaffer et al. 2008).

Historical documentation of terrapin in Texas are scarce and what little we know of the early exploitation and biology of terrapin is largely limited to early accounts in Galveston Bay (Gallaway 2001). One of the earliest accounts of terrapin in Texas is provided by (Hooten 1847). The English author Charles Hooten wrote a book based on his journal account of a visit to Texas in 1841. Mr. Hooten was considered a self-styled naturalist and tried to capture every detail of the flora and fauna as he traveled Galveston Island and Edward's Point, the San Leon area of the western shore of Galveston Bay. This excerpt from St. Louis' Isle, or Texiana is the earliest information that was found by (Gallaway 2001) in her research of historical occurrences of the Diamondback Terrapin in Galveston Bay. The quoted material below illustrates the detailed observations captured by Mr. Hooten in his journal.

Hooten (1847) reported, *"In front the view consisted entirely of a vast expanse of bay studded with numberless little islands, or banks, composed of nothing but shells ... [Red Fish Bar) ...*

Three Spaniards ... arrived on an expedition for the catching of the terrapin [on their nesting ground], - a small kind of sea tortoise, which is used in Texas for the manufacture of soup. They had engaged to supply one of the hotels [in Galveston] with, / think, two thousand, and the fishing was engaged to come off on the following morning...

The sky was wholly cloudless, the sun burning hot, and the water beautifully calm, as we rowed amongst the little shell-islands before mentioned. The noses of many terrapins were seen sticking out of the water…, and our Spaniards, aided by the Doctor and Bill immediately set to work...

By five 0 'clock, nearly three hundred terrapins of various sizes were taken, besides a great quantity of red and other fish, and we returned home."

This previous passage by Hooten (1847) provides a glimpse of the abundance of terrapin and their unique association with intertidal oyster reef and associated islands. Interestingly enough today the two documented areas in Texas still containing high number of terrapin are located in West Bay and Nueces Bay which have either shell islands and/or extensive intertidal oyster reef (Halbrook 2003; Hogan 2003).

The next documentation of terrapins swimming or nesting in Galveston Bay system also occurred along the Red Fish Bar complex, specifically a bar on the east side of the bay off of Smith Point, directly opposite Edward's point. Edward's Point is now called Eagle Point. The information as described in Gallaway (2001) and Henson (1993) based on the memoirs of Forest McNeir who was born August 16, 1875 and grew up at Smith Point area (McNeir 1956). McNeir (1956), provides an account of the distribution of nesting terrapin near Smith Point. He states as quoted in (Gallaway 2001) and (Henson 1993)

"*One summer when I was nine or ten years old my mother and Mr. Le Bert,and Paschal and I took our little sailing skiff and went down to the shell reefs [the east part of Red Fish Bar] … On one of the larger islands we found a lot of diamond back terrapins getting ready to lay their eggs, and we caught as many as we could carry in the skiff, about ten dozen, I think We sent them to Galveston on the mail boat, and to our great surprise got four dollars a dozen for them. That was a fortune. I never saw any more diamond back terrapins when I got older*".

This quote provides additional information about the association of terrapin with oyster reefs and shell islands for both nesting and foraging habitat.

(Gallaway 2001) provides a glimpse at the dawn of the terrapin fishery in Galveston Bay in her review of (Hayes 1974). She quotes Charles W. Hayes who wrote a book in 1879 about the early history of Galveston that was posthumously published almost a hundred years later. He gave detailed reports of the imports and exports from the port at Galveston in his book about Galveston written in 1879, and seafood and turtles were not on any of the reports. However at the same terrapins were being sold at the local seafood markets at Galveston and Houston and restaurants and hotels where purchasing directly form the local fishermen. Doughty (1984) reported a total of 2,000 pounds of sea turtles sold in Galveston in 1890. This total was taken from (Stevenson 1891).

Diamondback terrapin were historically harvested for food and to supply local restaurants. Commercial harvesting of diamondback terrapins began in the late 1800's and did not wane until the economic collapse of the Great Depression. Accounts by Stevenson (1891) provides a description of the commercial fisheries of Texas including information on terrapin landings. He described how terrapin were occasionally taken in the bay with seines by fishermen attempting to capture various species of fish and shellfish. He specifically mentioned incidental landings in Galveston Bay and Aransas Bay.

In 1895 Texas legislature passed a law prohibiting the harvest of terrapin and other species of fish and marine turtles during the months of April through September by drag seine or set net for selected waters of Texas running from Nueces County to Galveston Bay (State of Texas Legislature 1895). In 1897, C. H. Townsend listed 34,800 total pounds for Galveston in his report, "Statistics of the Fisheries of the Gulf States" for the United States Commission of Fish and Fisheries (Townsend 1899). The last report of turtles sold in Galveston by Doughty was 4,300 pounds for 1902 which was based on his consolidation of state and federal fisheries reports on landings (Doughty 1984).

Hay (1904), reported securing up to 250 terrapin in Rockport circa 1904. It is unclear whether these were collected in the field or whether they were purchased at a fish market. He goes on to state that “they are said to occur southward as far as Brownsville, at least and northward as far as Galveston”. This is one of the few references of terrapin occurring past Baffin Bay which has never been confirmed. He also references 4 specimens collected by an investigator named “Maxmilian” earlier in Texas but did not provide a date or full reference (Hay 1904).

During the early 1900’s, in the mid-Atlantic and New England states, diamondback terrapins became the main ingredient in a gourmet turtle soup craze which used sherry as another essential ingredient (Coker 1920; Martin 1989; Morrise 2010; Schaffer et al. 2008). At the time, diamondback terrapins were so plentiful that fishermen considered them a nuisance because they sometimes were unable to haul in their fishing nets due to the weight of the creatures. Unfortunately, larger females were targeted in response to the new demand for what was considered luxury cuisine, and it was not long before local Atlantic populations began to crash. Populations near large cities were locally extirpated (Morrise 2010). The downturn in local landings of terrapin on the east coast resulted in increased imports form other estuaries and an interest in developing commercial terrapin production. As early as 1902 terrapin from Texas were being transported to the east coast, including Maryland and North Carolina for evaluation in artificial propagation studies along with other subspecies (Barney 1922; Hay 1904). The importation of Texas terrapin continued as the price of terrapin increased to support the demand for terrapin stew (Hildebrand 1928; Hildebrand 1932; Hildebrand 1933). Texas terrapin were particularly in demand for culturing since it was believed they grew faster and larger. At the height of its popularity, terrapin stew was considered a status symbol among members of the upper class. The prices paid for terrapin averaged $90/dozen in 1920, reflecting the stew’s appeal as a luxury item (Martin 1989).

There is strong evidence that the passing of Prohibition helped save terrapins (Texas Parks and Wildlife Department 2007b). When Prohibition laws made possessing sherry wine illegal, turtle soup fell out of favor and thousands of trapped turtles were released into the ocean (Martin 1989). An attempt was made to create culture farms with some success, but by the end of World War I, markets declined because of lack of product (Coker 1920; Morrise 2010). Finally, during the Great Depression made the dish too expensive for many people to purchase. It is believed that during subsequent years terrapin populations gradually began to recover as a result (Morrise 2010).

Prior to the mid 1980's there have been no formal studies or assessments of terrapin in Texas. Anecdotal data suggests however that terrapin were much more common prior to the 1970's. Data on these recent historical sightings of terrapin primarily from Galveston Bay were compiled by Gallaway (2001) and later expanded by Wilson (2009). These accounts which were documented in Gallaway (2001), provides potential clues as to the apparent scarcity of terrapin during the late 20th century. We have included all of these sightings and locations in our database of occurrences.

Gallaway (2001) conducted an interview with Frank Dick in 1998 about the cattle industry around Galveston Bay during the early part of the 20th century. Mr. Dick described a diamond back terrapin-nesting site he was familiar with in the late 1930s to the late 1960's. It was located on the western shore of Galveston Bay, called Dollar Point. It is south of the floodgate at Moses Lake in Texas City (Dick 1998). Some notable comments from Mr. Dick about his observations in the 1930's include:

"*Well for a long stretch there for about a half a mile was nothing but gravel, shell gravel and sand. Man it was from here to that wall across there, gravel, see real deep gravel. Gravel was put there by the bay, you know over hundreds of years. And little old diamond-backed turtles was about this long, and about that wide and it had three humps to them, you know it wasn't a solid round shell. It had three humps you know it'd be one here in the middle and one here, and right on top of that middle of that hump was a diamond like, you know upside down diamond Dad told me he use to make a lot of soup. But they wasn't but about that long you see about that wide. Man during egg laying season, you go along that shoreline and there will be hundreds upon hundreds of little heads just sticking up out of the water….*

They stay out there treading water till dark see, and they all came in today their eggs deep in that gravel. Hundreds and hundreds of heads! Not a one is left, that's it, they built the levy there, it's all gone, there's no sand, no gravel, and no turtles….

Big turtles, big turtles, when they dug that levy one of these days I might, check the papers on what it cost. They destroyed the only nesting ground I know on this whole part of this coast. I *never seen a diamondback over at Virginia Point and I've been down in here all my life. The only nesting area I know was that place right there on Dollar Point….*

Yeah they laid their eggs you know about that deep, the coyotes dig out a lot of them, you know, They can, they smell them you know, the eggs, because you'll find them where they were dug out. One time the coyotes or the wolves had just started to dig them out, but I know they just started because I got out and always walked that bay shore you see looking, looking you know for some signs in the gravel. I found this nest dug down to and them little turtles were comin out of them wet shells. It was deep under the shell where it got sandy….

….don't ever recall a turtle being around except the nesting season. I don't know, but I never caught one in my crab traps or on the fishing lines at Virginia Point. I've never seen one and I was born and raised out there. I only saw the diamond-backed turtle during nesting season at Dollar Point" (Dick 1998; Gallaway 2001).

Gallaway (2001) argues that Mr. Dick's description to the nesting habitat was very similar to both (Hooten 1847; McNeir 1956). The locations of these nesting sites were all in the mid region of Galveston Bay where the largest concentration of shell gravel was found before the shell was heavily mined out of the bay from the late 1930s to the late 1960s.

Gallaway (2001), also interviewed long time shrimpers in the area to determine if they had noticed any trends in terrapin occurrence in Galveston Bay based on their incidental catch or knowledge of the area. She reasoned that since Mr. Dick gave Dollar Point as a large nesting site for the terrapin it was reasonable that early Texas City Shrimpers would also be able to supply information about terrapins in that area. She spoke with Mack Wilson who fished in the Dollar Point area from the 1940's until the late 1070's (Wilson 2001). He was also one of the shrimpers known to trawl in Moses Lake and Swan Lake while it was open to shrimping. He told her that they would pull their nets up the little bayous that fed into the lakes as far as possible. It was in the area of Silo Bayou that they caught the largest concentration of terrapins. At times the terrapins were so numerous that they filled the nets (Gallaway 2001).

Mr. Wilson went on to state that "*anytime they drug their nets close to the shore, from Moses Lake to Swan Lake, that they would catch terrapins in their nets*". He further stated that "*Because their drags were relatively short, most of the turtles survived. The turtles sometimes weighed 8 or more pounds and were considered a nuisance to the shrimpe*rs". He stated that there was no market for terrapins at that time. He went on to say that terrapins were most plentiful in the 1940's and 1950's (Gallaway 2001).

Based on an interview with rancher Todd Furnace, Gallaway (2001) documented the past occurrence of large populations of terrapins feeding in the marshes of West Bay. Mr. Furnace worked cattle along the salt grass range of Galveston and Brazoria Counties. He stated that he observed "*hundreds of terrapins and thousands of crabs in the salt marshes from Chocolate Bayou to the Galveston Causeway*" the year west Galveston County and Brazoria marshes froze during a heavy snowstorm in late December of 1924 and January of 1925 (Furnace 2000). The presence of stressed terrapin and crabs during this cold snap would represent one of the few documented occurrences of high natural mortality in terrapin.

Section 2.2.2. Habitat Loss and Historical Shell Dredging

Habitat which terrapin use for foraging and nesting has declined significantly from the 1700's through the early 2000's. Two key habitat features that we will discuss include intertidal wetlands, and intertidal oyster reef and shell-hash islands/beaches. As noted earlier these two habitat types have been documented as key features supporting diamondback terrapin populations along the Gulf coast (Borden and Langford 2008; Hogan 2003).

Battaglia et al. (2012), described the unique relationship of terrapin and intertidal saltmarshes along the Gulf coast. The loss of intertidal saltmarsh which is critical to terrapin in Texas and along the Atlantic and Gulf coasts has been documented by various sources (Dahl 2000; Dahl 2006; Frayer et al. 1983; Liu and Cameron 2001; Moulton et al. 1997; Pulich and White 1991). The loss of intertidal wetlands has been caused by various sources including navigation dredging, wetland filling, marina and coastal development, flood control levee construction, and subsidence due to oil and gas and freshwater extraction (Mitsch and Gosselink 2007). The loss of intertidal saltmarsh has likely had a major impact on the carrying capacity of estuaries for terrapin.

Structures such as bulkheads or fencing can destroy entire nesting colonies because female terrapins return to the same locations to nest each year (Connally 2012; Texas Parks and Wildlife Department 2011). Therefore the construction of levees, bulkheads, fences and similar structures in areas that formally supported nesting terrapin is considered a major factor that limits the long-term viability of this species.

Oyster reefs have supported a commercial fishery for oysters along the Gulf coast including Texas since the late 1800's (Galstoff 1931; Henson 1993; Hoffstetter 1977; Tucker 1929). Due to overharvest, creation of navigation channels and the harvest of oyster shell for road base the depth and coverage of oyster reefs in Texas estuaries has been reduced from historical base conditions. For example, in the early 1900's public reefs in Galveston Bay supplied around 40,000 barrels (4,540 m3 of oysters per year) (Hoffstetter 1977). Bay the late 1930's the annual harvest had dropped below 5000 barrels (480 m3). In 1949 no harvest was reported and in 1950 only 60 barrels were recorded suggesting that the reefs had become so depleted that they could no longer supported a fishery. Today with the exception of Sabine Lake, most estuaries contain less than 1-10% of the biomass of historical (1885–1915) oyster reefs in Texas (Philine et al. 2012).

The Gulf coast has a long history of the use of oyster shell for road base. Early settlers in the developing towns around Galveston Bay and other Texas estuaries used the shell from the Native American middens as a substitute for gravel (Doran 1965; Gallaway 2011). A shell midden or shell mound is an archaeological feature consisting mainly of mollusk shells. A midden, by definition, contains the debris of past human activity, in contrast to wind or tide created beach mounds. With the coming of the railroads, the midden shell became a major resource, since rocks and gravel for paving materials were absent from the coastal prairies. When railroads proposed to cross the wet prairies on the western shore of Galveston Bay, a ballast material had to be found for the base of the tracks. From the mid 1800s until the late 1890s, shell middens on the western shore of Galveston Bay were heavily mined for this purpose (Gallaway 2011).

The shell of the middens was insufficient to meet demand for construction material and shell mining expanded to the oyster reefs and islands in the bay. The mining of oyster shell (mud-shell) began in 1905 when large quantities of shell were removed from the Galveston Bay system for industrial and construction purposes (Gallaway 2011). For example, cattle were driven across Redfish Bar in Galveston Bay, the prominent land bridge between Eagle Point and Smith Point, until the 1880s. The bar was completely dredged away before 1950 (Gallaway 2011). Recall that this was the same bar is where 100's of terrapin had been observed nesting and swimming at the turn of the century (Hooten 1847).

New industrial processes after World War II greatly increased the value of the shell as a feedstock for chemical processes and the volume of shell removed in Galveston Bay increased from about 2,500 acre-feet per year in 1945 to over 5,000 acre-feet per year in the mid 1960s (Gallaway 2011; Henson 1993). Across the Gulf states shell production during this period had increased from 468,000 short tons in 1912 to a peak of 21,230,116 short tons in 1967 (Arndt 1976). During 1967 the proportion of the total Gulf states shell mined in Texas alone was 10,776,368 short tons (50.7%)(Arndt 1976). This increase in dredging raised environmental concerns that resulted in more stringent regulation of the industry by TPWD (Gallaway 2011). At the time, the primary concern of this activity was the increased siltation and damage to nearby oyster reefs (Hopkins and McKinney 1976). By 1969 shell dredging had been banned from Galveston Bay, although it continued into the early 1980's in other bay systems (Benefield 1976; Crowe 1984; Gallaway 2011; Garcia 1979; Hofstetter 1960). Today shell dredging is normally only allowed pursuant to a federally permitted navigation channel dredge project (31 TAC chapters 69, subchapter H; and Texas Parks & Wildlife Code chapter 86.).

Section 2.2.3. Boat and Vehicle Mortality

Injuries to terrapin due to vessel collisions and propeller cuts are not uncommon and may be significant source of mortality in some populations (Burger and Garber 1995; Gibbons et al. 2001; Lester 2012; Roosenburg 1992; Tucker et al. 2001). Controlled studies have shown that terrapin do not seem to exhibit a flight response to noise generated by outboard motors (Lester 2012). Roosenburg (1990) found that motorboat collisions was a significant source to female terrapin and concluded that the frequent habit of large congregations of terrapin floating in open water makes them particularly vulnerable to vessel collections. Tucker et al. (2001) estimated that more than 1% of the total population of terrapin in South Carolina were probably killed by boat collisions. Cecala et al. (2008), during their study of patterns of limb loss and major shell injuries over a 24 year period at Kiawah Island, South Carolina found that shell injury rates have increased temporally and suggested that this may be due to increasing levels of watercraft activity. They also found that terrapins with major injuries had lower survivorship rates than uninjured terrapin. We have observed signs of vessel collisions in our study of populations of terrapin in West Bay near Galveston Island. Marlow and Guillen (2011), found that female terrapin found on South Deer Island had higher injury rates (13% island, 7% mainland) from all sources than the males (5% island, 8% mainland) in the same area. They hypothesized that nesting females have to travel to nest, which puts them at greater risk of injury or death by motor boats as well aquatic predators. Some of the injuries (e.g. diagonal carapace slashes) were attributed to impacts with propeller.

Along the east coast terrapin mortality due to automobile collisions is considered a significant source of mortality in many states (Brennessel 2006; Nemec 1995; Wood and Herlands 1995). Many of the fatal collisions involve terrapin moving from open water to nesting sites located across busy road ways. Avissar (2006), observed significantly lower average carapace sizes of in terrapins and a lower frequency of adult females compared to an earlier (12-14 years) survey of a tidal creek and attributed this to road mortality of nesting females. We were not able to find any historical data on automobile collisions with terrapin in Texas. However it is feasible that terrapin might be impacted by automobile collisions on roads crossing near wetlands.

Section 2.2.4. Fishery Bycatch

Bycatch by the blue crab *Callinectes sapidus* pot fishery has been documented throughout the range of diamondback terrapin (Bishop 1983; Brennessel 2006; Butler and Heinrich 2004; Butler and Heinrich 2007; Crowder et al. 2000; Dorcas et al. 2007; Ernst and Lovich 2009; Grosse et al. 2009; Guillen and Oakley 2013; Guillory and Prejean 1998; Hart and Crowder 2011; Lukacovic et al. 2005; Morris 2003; Nemec 1995; Rook et al. 2010; Roosenburg 2004; Roosenburg and Green 2000; Roosenburg et al. 1997; Valdez 2005; Wood 1997; Wood and Herlands 1995). The degree of how much blue crab fishery bycatch affects the overall population of terrapin range wide, by subspecies, and local isolated populations varies. Several studies have documented that where crabbing effort overlaps areas where terrapin are found, extensive mortality can result, sometimes leading to local extirpation.

Detailed studies of a terrapin population in South Carolina spanning 16 years recorded a decline in one part of the study area coincident with the construction of a public boat dock that facilitated increased recreational blue crab fishing access in an area where terrapin resided (Tucker et al. 2001). Eventually the population was virtually extirpated. They attributed this to the high level of site fidelity of terrapin which limits their recolonization rate and reduces the likelihood of repopulation in a reasonable period of time. In addition, the reduced life span of females precluded many of them reaching sexual maturity (Tucker et al. 2001). Dorcas et al. (2007), hypothesized that because male and small female terrapins are most susceptible to mortality in crab traps, population declines should coincide with shifts in the age and size distributions of the population and a shift to a more female-biased sex ratio, if the blue crab fishery was causing size selective bycatch mortality. They used twenty-one years of mark-recapture data (>2800 captures of 1399 individuals) from a declining diamondback terrapin population in South Carolina to test the prediction that the decline is the result of mortality in crab traps. They found that since the 1980s, the modal size of both male and female terrapins has increased substantially and the proportion that are females is higher than in earlier samples (Dorcas et al. 2007).

Recently (Wolak et al. 2010) who were studying terrapin affected by the blue crab fishery found a dramatic shift to a younger male age structure, a decrease in the length of time to terminal female carapace size, a 15% increase in female carapace width, and an increase in sexual dimorphisms in Chesapeake Bay. Their results are one of the first to implicate a fishery in the selective *increase* in size of a reptilian bycatch species. They concluded there is strong pressure in the form of a constant trap entry size opening that should select for terrapins that grow fast enough to a sufficient size that cannot enter the crab pot. This evolutionary trend has implications for population viability that needs to be considered when developing conservation strategies.

The reduction of crab pot mortality was ranked as a high priority by various experts attending the Diamondback Terrapin Working Group meeting in 2004 (Butler et al. 2006). One measure that has attracted considerable attention as a means of reducing terrapin bycatch is the requirement to install bycatch reduction devices (BRD) on commercial and recreation crab pots. Since the early 2000's BRDs have been tested by many investigators and have been shown to reduce the catch rates of terrapin but also smaller crabs (Baxter 2013; Butler and Heinrich 2004; Butler and Heinrich 2007; Coleman et al. 2011; Cuevas et al. 2000; Guillen and Oakley 2013; Upperman et al. 2014). At least three states have implemented the use of BRDs for either commercial or recreational crabbing (Watters 2004).

Two principal commercial fisheries in Texas that have captured terrapin include the bay/bait shrimp and blue crab fishery. Of the two it is believed that the blue crab fishery is believed to cause more mortality since the shrimp fishery is prohibited from operating in many secondary bays and/or cannot access the small tidal creeks and intertidal oyster reef areas. According to the Texas Parks and Wildlife Department "today most terrapins are killed by speeding cars or become trapped in baited blue crab traps and drown" (Texas Parks and Wildlife Department 2007b).

Recently two investigators have investigated the potential impacts on the blue crab fishery on Texas terrapin (Baxter 2013; Guillen and Oakley 2013). Both investigators reported reduced bycatch rates of terrapin when BRDs were used, however catch rates of blue crab were reduced and average size was increased. However, Guillen and Oakley (2013) conclude that it is difficult to determine if bycatch from the commercial blue crab fishery is a serious risk since the interaction of fishing effort and accessible habitat may influence the likelihood that terrapin will be exposed to this source of mortality. The highest risk from bycatch mortality would be from areas accessible (e.g. open water, deeper tidal creeks) to blue crab fishermen that are located adjacent to suitable terrapin habitat. In addition, terrapin are often very active during the spring months during mating so this would potentially expose them to crab pots as well. In contrast, many areas where terrapin are numerous are also located in locations which are very inaccessible (isolated islands, shallow water, oyster reef) to blue crab fishermen. These areas would provide protection from blue crab fishing pressure and potential bycatch mortality. Despite over 10 years of sampling the number of dead terrapin observed in abandoned crab pots in Texas has remained relatively low (Morris 2003). However, these abandoned pots are retrieved in February after several months have passed when terrapin are active. Consequently many of the trapped terrapin may have completely decomposed leaving no evidence behind.

Section 2.3. Research Need

Within Texas, terrapin are considered to be imperiled or critically imperiled because of rarity due to very restricted range, few populations, steep declines, or other factors making them vulnerable to extirpation (Connally 2012). The Texas terrapin has been identified as a species of concern by the Texas Parks and Wildlife Department (TPWD) and U.S. Fish and Wildlife Service (USFWS) (Connally 2012; Texas Parks and Wildlife Department 2011).Based on the SGCN table and State Conservation Plan, the primary management concerns and related information needs for terrapin are that the subspecies is believed to be either imperiled or critically imperiled because of rarity due to 1) very restricted range, 2) very few populations, 3) steep declines, or 4) other factors making it very vulnerable to extirpation (TPWD 2011 and 2012).

Factors that may make terrapin populations vulnerable to extirpation include 1) structures such as bulkheads or fencing which can destroy entire nesting colonies because terrapins cannot return to the same locations where they nest each year; 2) road vehicle and boating mortality, 3) crab traps (primarily drowning in lost or abandoned traps), and 4) power plant intakes. Although not listed, another major threat to local terrapin populations identified in other states as documented in previous State Plans included elimination or fragmentation of wetlands by urbanization, resort and secondary development, dredging, and habitat degradation (TPWD 2005; Butler et al. 2006).

In order to establish a baseline population estimate and evaluate the risk to the long term persistence and viability of local populations of terrapin in Texas more information is needed on the distribution and density of foraging and nesting terrapin along with associated habitat. The first step of this effort is the collection of demographic data and habitat associations. Once sufficient data is collected Habitat Suitability Index (HSI) models need be constructed and used to spatially map the availability of suitable habitat along the entire Texas Gulf Coast (Palmer and

Cordes 1988). This information and resulting empirical model can then be used to identify important habitat needed to support this species and prioritize future habitat conservation and restoration actions.

Currently little is known about the population status, habitat preferences, distribution, and general ecology of terrapin in Texas. This is primarily due to the lack of any comprehensive statewide survey of terrapin and the absence of an established population monitoring program that incorporates methods that target this species. The Texas Parks and Wildlife Department (TPWD) Coastal Fisheries Division is responsible for conducting a long-term fisheries independent monitoring programs that consists of biological sampling utilizing bag seines, trawls and experimental gill nets (Martinez-Andrade et al. 2005). The TPWD monitoring program has used a probabilistic sampling design since the mid 1970's (American Fisheries Society 2005). As a result over the period of record the program has collected data from most of the Texas coast. The program although very effective at sampling open water organisms does not monitor intertidal wetlands or smaller tidal streams and rivers where terrapin are known to congregate.

Very few targeted population studies have been conducted on Texas terrapins, and all of these investigations have been focused on the Galveston, East Matagorda/Cedar Lakes, and Nueces Bay systems (Guillen et al. 2011; Guillen and Oakley 2013; Halbrook 2003; Haskett 2011; Hogan 2003; Koza 2006). Historical data which includes sightings from the general public, biologists, and agency monitoring suggest a more expansive range in Texas (Gallaway 2001; Mabie 1987; Stevenson 1891). However, official records and published data are sporadic and limited (Clarkson 2012; Dixon and Hibbits 2013; Halbrook 2003; Haskett 2011; Haskett and Guillen 2010; Koza 2006; Raun and Gehlbach 1972). Recent studies by Selman and Baccigalopi (2012) in southwestern Louisiana suggest that large populations of terrapin may exist in the extensive wetlands located within the Rockefeller Wildlife Refuge and areas bordering Sabine Lake. According to the authors, they believe the high number of terrapin present within the refuge is due to the ban on commercial harvest of terrapin and crabs and the presence of extensive mid to high salinity wetlands which occur through the region.

Section 2.4. Study Objective

The primary objective of this project was to assess the current distribution and density of Texas Diamondback Terrapin populations within un-surveyed portions of the Texas coast. The study area included three major bay systems in the mid to upper Texas coast: San Antonio Bay, Matagorda Bay, Sabine Lake and adjacent waters. A secondary objective was to determine critical factors that may affect their distribution. Based on a review of the literature candidate factors that we evaluated included the presence and availability of saltmarsh and other habitat, salinity regime, and human disturbance (e.g. man-made shoreline modification, boat traffic, blue crab fishing effort). These factors have been identified by other investigators as important variables may limit the distribution of terrapin in all or portions of its range.

This data is critically needed to establish baseline population estimates and support development of future overall population estimates including development of conservation and management practices for this species. Data from this study will be combined with other data sets, and published studies to develop 1) an initial estimate of terrapin distribution in previously un-surveyed bay systems in Texas; 2) density and/or population estimates and 3) identification of habitat associations in support of development of future habitat suitability models. This data will also provide the essential baseline information, when combined with other past studies in Texas in Nueces and Galveston Bay to develop overall population and range estimates for the entire Texas coast in future studies.

The primary conservation benefit of this project is the completion of the first comprehensive baseline assessment of the status of population numbers and distribution of terrapin within Texas. The development and implementation of effective conservation actions requires that state natural resource managers and their partners have data available to them that answer specific resource management questions related to species and habitats, and the threats to them (AFWA 2011). It is our belief that baseline population data for terrapin in Texas provided by this study is necessary for State and Federal natural resource agencies to develop effective conservation and management strategies and tools. This study is a critical first step in the development of a robust monitoring and data collection program that can supply the needed critical information to manage this species. Furthermore it builds upon other work conducted by the principal investigator and other researchers in Texas.

SECTION 3. METHODOLOGY

Section 3.1. Historical Data Compilation

An exhaustive review of literature from various media sources, agency reports, fishing reports, biological monitoring databases, and peer reviewed sources was conducted. This included data from the Texas Parks and Wildlife Department Coastal Fisheries Monitoring Program and Abandoned Blue Crab Trap removal program. When possible the geographic coordinates of terrapin were extracted from published reports and sightings. When only generic data was provided (e.g. saw terrapin in Port Bay) the approximate centroid of the waterbody is provided. The resulting database provides sufficient metadata on the source and accuracy of each coordinate. Data were classified into four categories including 1) primary literature reports (agency or peer reviewed literature which may include secondary reports from questionnaires), 2) secondary literature (agency planning documents, park/wildlife refuge inventories) not providing specific location data, 3) previous reports from citizens, biologists, and eye witness observations by EIH staff 4) TPWD Coastal Fisheries Division Fishery Independent monitoring data and 5) the TPWD abandoned crab trap database. Literature citations that appear in this report were included and compiled into an EndNote™ library (Appendix A). Historical data from agency and other databases were compiled into a comprehensive Texas terrapin Excel database and associated Google Earth layer (Appendix B). The distribution of terrapin sightings was also plotted in Google Earth Pro.

Section 3.2. Online Questionnaire

Section 3.2.1. Questionnaire Development

A questionnaire developed and run with LimeService's (www.limeservice.com) on-line survey software was used to gather information about terrapin observations along the Texas coast. The questionnaire format was approved by the UHCL Committee for the Protection of Human Subjects (CPHS) prior to solicitation. A complete example of the survey is included in Appendix C.1; the following is a brief description of the survey design.

The first section of the questionnaire was optional and consisted of multiple short text fields for respondents to provide their contact information and affiliation. The second section was for species verification. The third section consisted of a map of the Texas Gulf Coast highlighting the eight bay systems (Sabine Lake, Galveston Bay, Matagorda Bay, San Antonio Bay, Aransas Bay, Corpus Christi Bay, Upper Laguna Madre and Lower Laguna Madre). Respondents were asked to select all the bay systems in which they have observed diamondback terrapins. In the fourth section, only the bay systems that were previously selected were included. One page for each bay system was populated and included four items: an interactive map allowing the respondent to pinpoint the location of the observation and two questions pertaining to the number of terrapin observed and the season of the observation. Additionally, respondents were given the option to report another sighting (up to 10 per bay system). The final section of the questionnaire consisted of a mandatory question related to general trends in terrapin observations over time and an optional comment section.

Section 3.2.2. Participant Selection and Solicitation Process

An extensive list including name, contact information, and agency affiliation for bay partners, CCA chapter members, coastal fisheries biologists, refuge biologists, commercially licensed fishermen, recreational fishermen, eco-tourism guides, university research groups, rehabilitation and stranding staff and volunteers, zoo staff and veterinarians, state and local biologists, and master naturalists was developed for questionnaire distribution.

Questionnaire links were sent to all contacts twice, once at the beginning of the survey period and once towards the end of the survey period as a reminder for completion. The questionnaire was made accessible from May-August of 2014.

In addition to the online questionnaire links emailed to the compiled list of individuals, fliers were posted in local bait shops, local newspapers, and dispersed at professional meetings advertising links to the questionnaire and requesting any additional information.

Section 3.2.3. Questionnaire Follow-up and Additional Responses

Questionnaire data were downloaded after the end date in September 2014. All data were compiled in an Excel database (0). Personal information (first name, last name, phone, and e-mail) were removed from the database prior to submission with this report.

After reviewing the results from completed questionnaires, it was determined that a follow up question to each of the respondents was required. Each respondent was emailed at the address provided to determine approximately how long ago terrapin observations occurred. Time scale was categorized into the following: (1) 0-5 years ago, (2) 5-10 years ago, (3) 10-20 years ago, and (4) > 20 years ago. Results from each respondent were then correlated to each observation in the questionnaire results. Some respondents also elaborated on their observations, providing photographs and more detailed descriptions than originally reported in the questionnaire. Additional information from these respondents is documented in Appendix C.3.

Section 3.3. New Field Data Collection and Analysis

Section 3.3.1. Field Site Selection Process

Sample sites were randomly generated using ArcMap 10 software. Routes were mapped based on accessibility from boat ramps, main channels, and water depth around each bay system. While mapping routes around each bay system, variables relevant to viable terrapin habitat were taken into consideration including water depth, salinity (distance from the Gulf pass), and habitat type. Routes were also mapped through areas with a lower probability of terrapin captures (based on salinity, habitat type, etc.). A geometric layer was clipped along these routes encompassing a distance of 50m to either side of the route line generating a 100m "thoroughfare" for randomized site distribution.

In Sabine Lake (Figure 6), 60 sites were randomly generated based on the above listed parameters. One-hundred sites were generated in both Matagorda (Figure 7) and San Antonio bays (Figure 8). Sites were then grouped into clusters based on similarities in habitat types and various environmental parameters. During field surveys, sampling events were attempted for at least one site per cluster but, in some instances, a few clusters were unable to be sampled (i.e. no trespassing/posted signage in sample area, distance too far away from accessible boat ramp, private landowner denied access to property, etc.). Appendix D lists all randomly generated sites as well as notes pertaining to each visit or sampling attempt.

Figure 6 Randomized field sites produced in Sabine Lake (n = 60). Red icons = sample site locations.

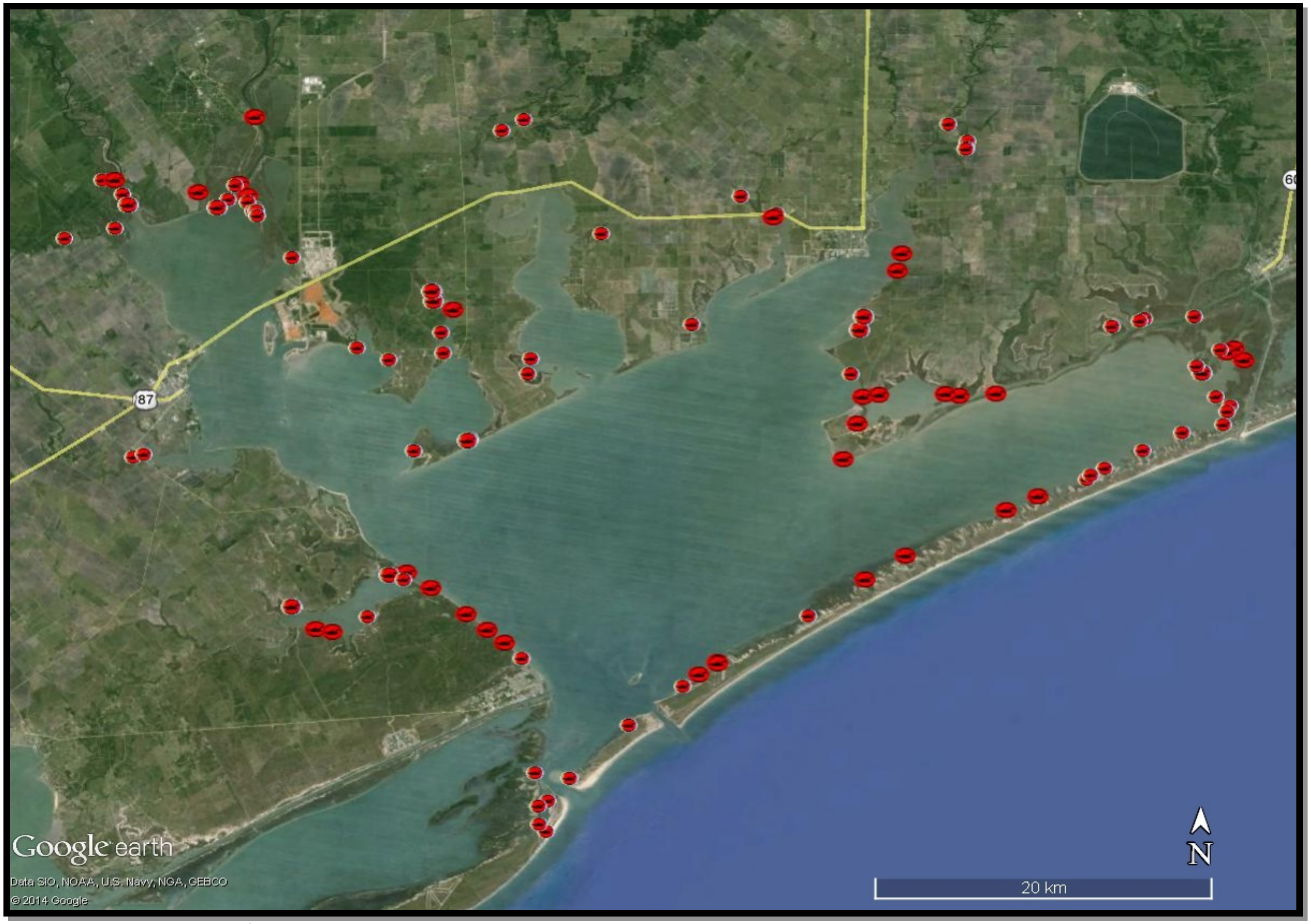

Figure 7 Randomized field sites produced in Matagorda Bay (n = 100). Red icons = sample site locations.

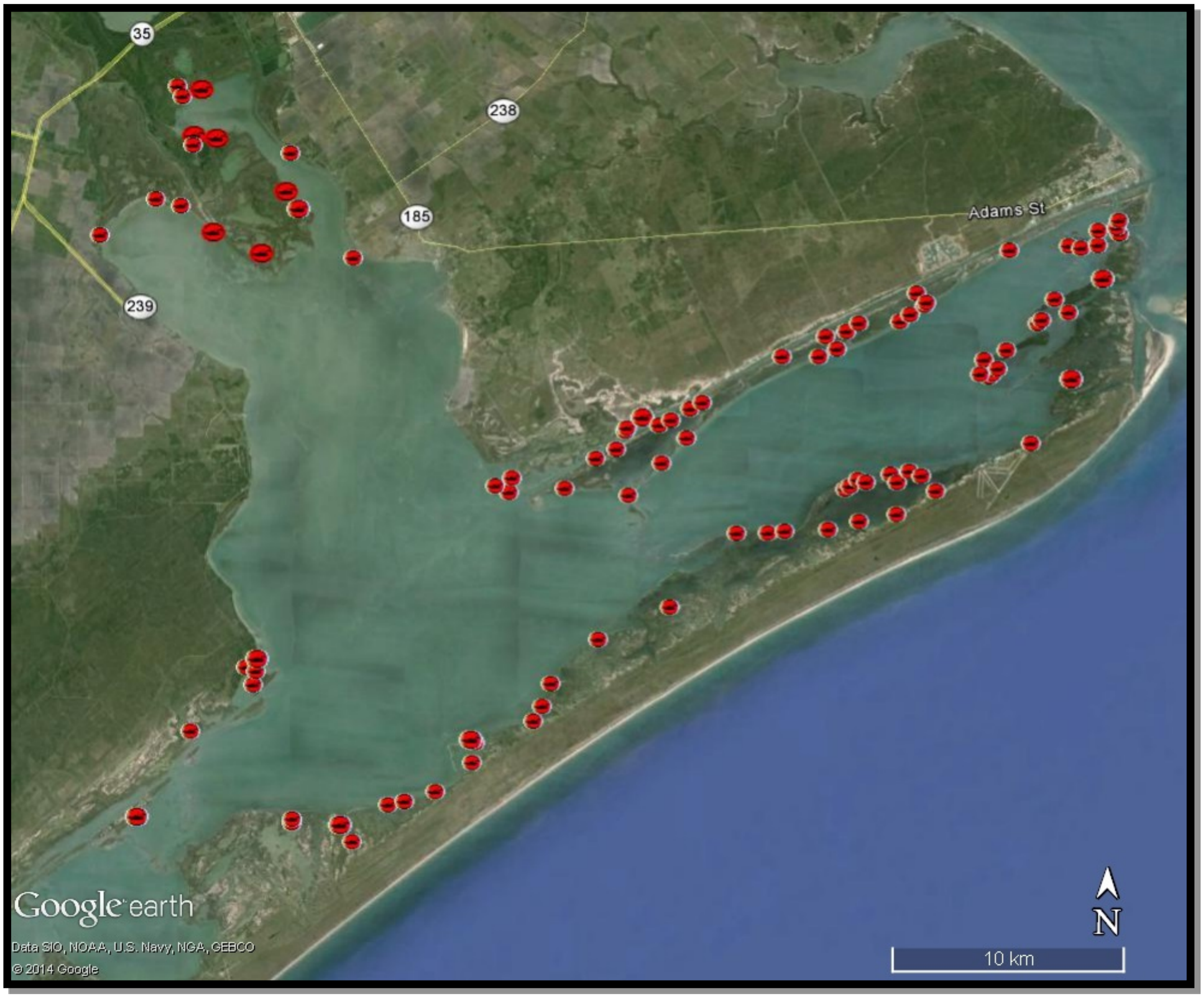

Figure 8. Randomized field sites produced in San Antonio Bay (n = 100). Red icons = sample site locations.

The final list of sampled sites is provided in (Table 1). These sites were selected based on accessibility and ability to perform all three sample methods. All field sampling was conducted within the guidelines stipulated by Texas Parks and Wildlife Department State Scientific Collection Permit #SPR-0504-383, Louisiana Department of Wildlife and Fisheries State Scientific Collection Permit #SCP73, Louisiana Department of Wildlife and Fisheries State Louisiana National Heritage Program Collection Permit #LNHP-014-036, and U.S. Fish and Wildlife Service Special Use Permits #R2014-012, #21530-14-11-DI, and #14-006 (Southwest Louisiana National Wildlife Refuge, Aransas National Wildlife Refuge [including Matagorda Wildlife Management Area], and Texas Point/McFaddin National Wildlife Refuge, respectively). Additionally, landowner permission was obtained for sites populated on private lands or for access to boat ramps located on private lands.

Table 1 Final list of sample sites with all three sampling methods employed organized by bay system. Bolded rows represent sites that were revisited.

Bay System	Site Name	Visit	Latitude	Longitude	Refuge
Sabine Lake	SAB-01	Initial	29.87448	-93.77601	Sabine NWR
	SAB-37	Initial	29.83537	-93.77258	
	SAB-43	Initial	29.71401	-93.84919	
	SAB-50	Initial	29.74249	-93.99646	
	SAB-52	Initial	29.75149	-93.95279	
	SAB-55	Initial	29.70303	-93.86733	Texas Point NWR
	SAB-55	Revisit	29.70303	-93.86733	Texas Point NWR
	SAB-56	Initial	29.70931	-93.88669	Texas Point NWR
	SAB-56	Revisit	29.70931	-93.88669	Texas Point NWR
	SAB-58	Initial	29.69876	-93.85380	
	SAB-58	Revisit	29.69876	-93.85380	
Matagorda Bay	MAT-09	Initial	28.49119	-96.55557	
	MAT-12	Initial	28.51022	-96.49654	
	MAT-14	Initial	28.66937	-96.47169	
	MAT-14	Revisit	28.66937	-96.47169	
	MAT-21	Initial	28.58866	-96.44994	
	MAT-27	Initial	28.72247	-96.60407	
	MAT-34	Initial	28.72349	-96.65839	
	MAT-81	Initial	28.63148	-96.00452	
	MAT-94	Initial	28.65496	-96.21277	
	MAT-94	Revisit	28.65496	-96.21277	
San Antonio Bay	SAN-09	Initial	28.42841	-96.77157	
	SAN-18	Initial	28.18527	-96.83899	Aransas NWR
	SAN-20	Initial	28.24891	-96.78701	Aransas NWR
	SAN-32	Initial	28.34702	-96.61914	
	SAN-54	Initial	28.40424	-96.41784	Matagorda Island WMA
	SAN-63	Initial	28.36418	-96.43117	Matagorda Island WMA
	SAN-90	Initial	28.21779	-96.69268	Matagorda Island WMA
	SAN-98	Initial	28.18313	-96.74957	Aransas NWR

Section 3.3.2. Field Site Surveys

Several capture techniques were employed to maximize effectiveness and minimize bias associated with any single method (Hurd et al. 1979) including head count surveys, use of modified crab traps, and walking transect surveys. All site visits followed a similar sampling timeline: perform head count survey on arrival, set modified crab traps, collected water quality and site characteristic data, perform walking transect surveys, compile additional site notes, check and remove crab traps. See descriptions below for details of each sampling method.

Section 3.3.2.a. *Head Count Surveys*

Head count surveys were performed during each site visit upon arrival at the sampling area. Head count surveys were performed in a linear manner following the shoreline (if in open bay; Figure 9A) or through the center of the creek (if in tidal creek or narrow bay; Figure 9B) in a modified version of that described by Harden et al. (2009). At approximately 500m from the site, the head count survey was started (distance from the site was determined using a hand held GPS unit). Head count surveys were completed once the vessel reached a distance of approximately 500m past the site coordinates (~1000m total transect distance).

One team member ("1" in Figure 10) would sit on the bow of the vessel facing the port side (red triangle) while the other team member ("2" in Figure 10) would sit on the bow of the vessel facing the starboard side (blue triangle). The operator ("3" in Figure 10) would primarily scan towards the front of the vessel (green triangle) searching the area directly in front of the vessel, but, would on occasion survey areas 360° around the vessel.

Parameters recorded during all head count surveys included site number, date, observer and view, start time, starting coordinates, end time, ending coordinates and elapsed survey time. Periodically during the survey, one observer would record width (if the survey was performed in narrow tidal creeks or bays) or distance from shore (if the survey was performed in very wide creeks or bays) using a handheld rangefinder. An average width or distance from shore was calculated and also recorded. The operator of the vessel attempted to maintain a constant speed while under way and an average speed was recorded for the duration of the head count survey.

If any observations were made during head count surveys, each observer would record the GPS coordinates of the sighting, the species sighted (if possible), time of the observation, approximate distance of the observed specimen from the vessel, the number of heads observed, and (if the observed organism was a terrapin) the activity of the observed individual. Activity was divided into one of 3 categories: 1) swimming in open water; 2) basking; or 3) other. Any additional notes about conditions, observed organisms, etc. were also made during head count surveys.

Figure 9. Head count survey transect (red line) with start and end points (red filled circles). Trap locations indicated by white squares. Actual site coordinates represented by yellow bubble. (A) Head count survey following open shoreline; (B) head count survey following tidal creek.

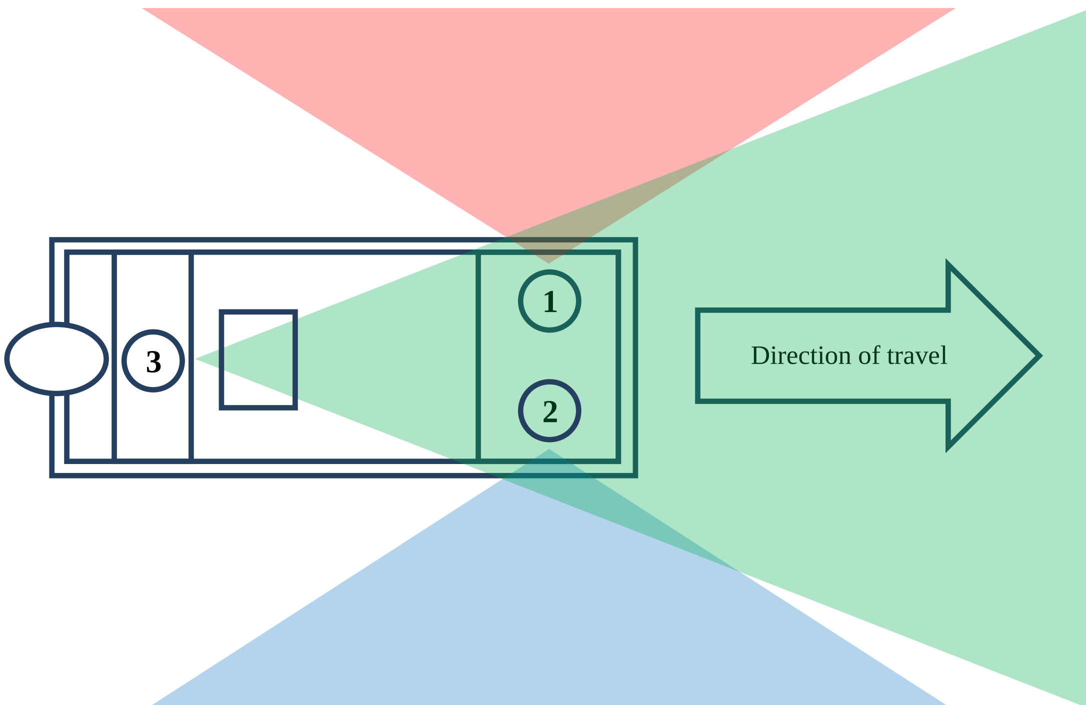

Figure 10. Schematic of head count survey positions. Black ellipse = motor (stern of vessel); red triangle = observer 1 field of view (bow); green triangle = observer 3 (operator) field of view; blue triangle = observer 2 field of view (bow).

Section 3.3.2.b. *Modified Crab Trap Effort*

At each sample location, five modified crab traps were deployed for a minimum of 3 soak hours (180 minutes) with a few exceptions (see Section 4.3.1 for more details). All traps were modified with a chimney to allow captured terrapin access to air until the trap was checked (Figure 11). Traps were set 100m apart following the shoreline or tidal creek shape (Figure 9). Traps were equipped with a variety of bait, depending on availability from local fish markets and bait shops, including: chicken pieces (primarily necks and thighs), various fish fillets (typically catfish), shrimp, menhaden, and mullet (cut and uncut). Any captured terrapin were processed using the protocol described in Section 3.3.2.f. By-catch was also documented and crabs were measured for size and sexed (when possible). Total soak time for each trap was calculated in minutes and overall trapping times were recorded for each site.

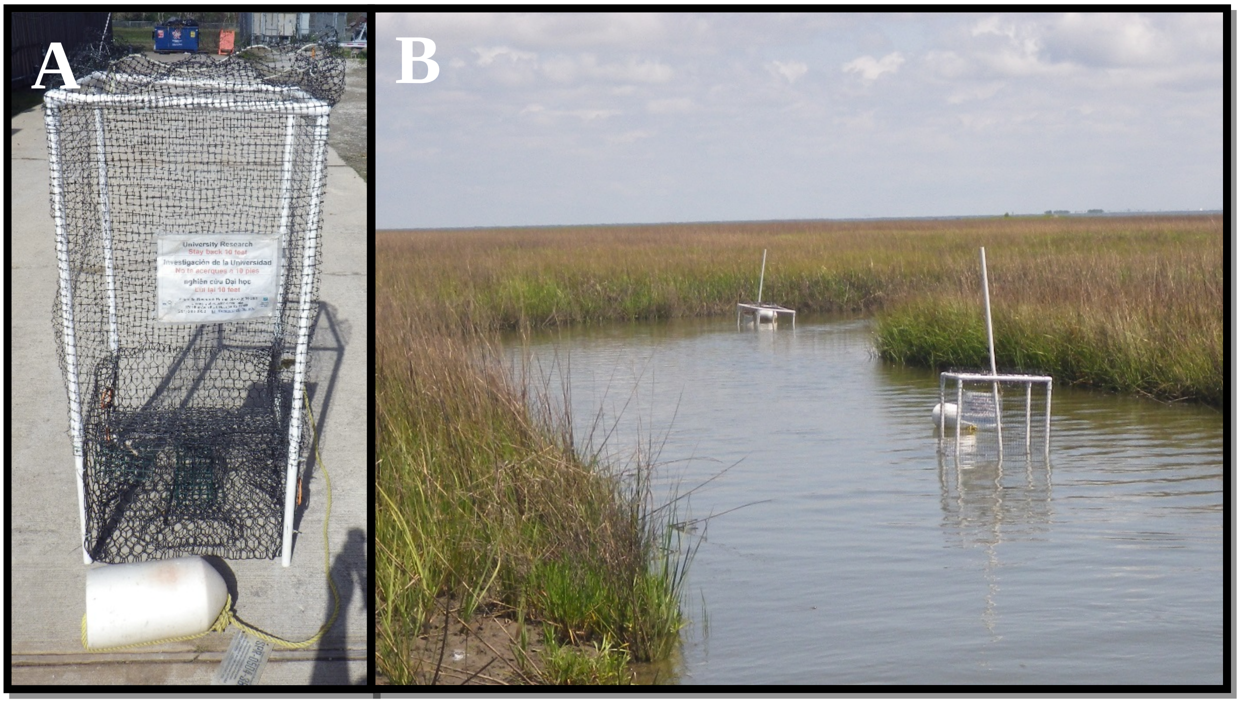

Figure 11 (A) Modified crab trap with chimney fully extended. (B) Crab traps deployed in tidal creek (anchored by 5m PVC pole).

Section 3.3.2.c. *Environmental and Hydrological Data Collection*

During each visit, air temperature (°C), water temperature (°C), salinity (ppt), Secchi depth (m), and wind speed (mph) were recorded prior to performing walking transect surveys. Days since last significant rainfall (DSLR) were determined using the closest weather station data available through Wunderground.com. Significant rainfall was determined as 0.10" within a 24 hour period.

Section 3.3.2.d. *Walking Transect Surveys*

Upon arrival at the sampling location, after collecting environmental and hydrological data, one team member would silently divide the horizon into equal portions. Within each portion one landmark along the horizon was selected and silently assigned a number. Searchers randomly selected numbers and were assigned the corresponding landmarks. If no landmarks were available along the horizon, compass headings were used. Once transects were determined, searchers surveyed in a straight line toward their reference on the horizon (or following their compass heading). Once an impassable barrier, edge of island, marked no trespassing area, critical avian nesting habitat or other point of no forward progress was met, the searcher turned 135° to the right and continued on a new transect.

Each searcher was equipped with a stopwatch, and his or her effort was timed in minutes during transect surveys. If for any reason an observer left his or her transect, or took a break from searching, the stopwatch was paused until the transect search was resumed. Additionally, if a terrapin was captured, the stopwatch was paused during processing. Total search effort for each individual was recorded at the end of the survey period.

Section 3.3.2.e. *Partial Sampling*

In addition to the fully sampled sites, partial surveys were conducted at other sites. At these sites full surveys were not possible for various reasons which are provided later in the report. In some cases valuable partial information was still obtained on the occurrence of terrapin.

Section 3.3.2.f. *Terrapin Processing and Data Collection*

When a terrapin was encountered ("captured") in the field, time of capture was recorded as well as GPS coordinate and elapsed search time. Habitat within a $1m^2$ area around the terrapin was assessed for vegetative cover (%), average height (cm), and species composition. Types of prey within the $1m^2$ area were also documented including number of fiddler burrows present, types of prey available and, if present, marsh periwinkle snails (*Littorina irrorata*) were counted and length and width measured (mm, $n \leq 20$).

For terrapin captured on land, air temperature at human breast height (°C), air temperature at ground level (°C), soil surface temperature (°C), carapace temperature (°C), soil temperature at depth (if burrowed, °C), and body temperature (°C) were recorded using a Kestrel 3000 Pocket Wind Meter and Metris Instruments Infrared Laser Thermometer (model EC400L1), respectively. If a terrapin was captured in water, emergent vegetation cover (%) and type were documented within a $1m^2$ area (if present), and air temperature (°C), water temperature (°C), water depth (m), and creek width or distance from shore (if in open water, m) were recorded.

All environmental, habitat, and prey data were recorded prior to handling the terrapin in order to limit total handling time and reduce stress to the individual. All terrapin were initially scanned with AVID Mini-TracKer I RFID Reader (AVID, Norco, CA, USA) to ensure no pre-existing PIT tags were present and scanned for any previously made external markings or tags. Using Haglof Mantax sliding calipers (40-cm), 11 straight measurements (mm) were recorded for each individual: carapace length along the mid-line (SCL_{min}), maximum carapace length (SCL_{max}), plastron length along the mid-line (SPL_{min}), maximum plastron width (SPL_{max}), carapace width at the second vertebral suture (SCW_{min}), maximum carapace width (SCW_{max}), plastron width at the bridge (SPW_{min}), plastron width along the carapace-plastron suture (SPW_{max}), body depth at the second vertebral suture (SD_{min}), maximum body depth at the tallest keel (SD_{max}), and maximum head width (HW_{max}; Figure 12 and 13). Body weight (kg; W_{max}) was also recorded using a Pesola Macro-Line 5-Kilo hanging scale fitted with a mesh, drawstring bag (tared for bag weight).

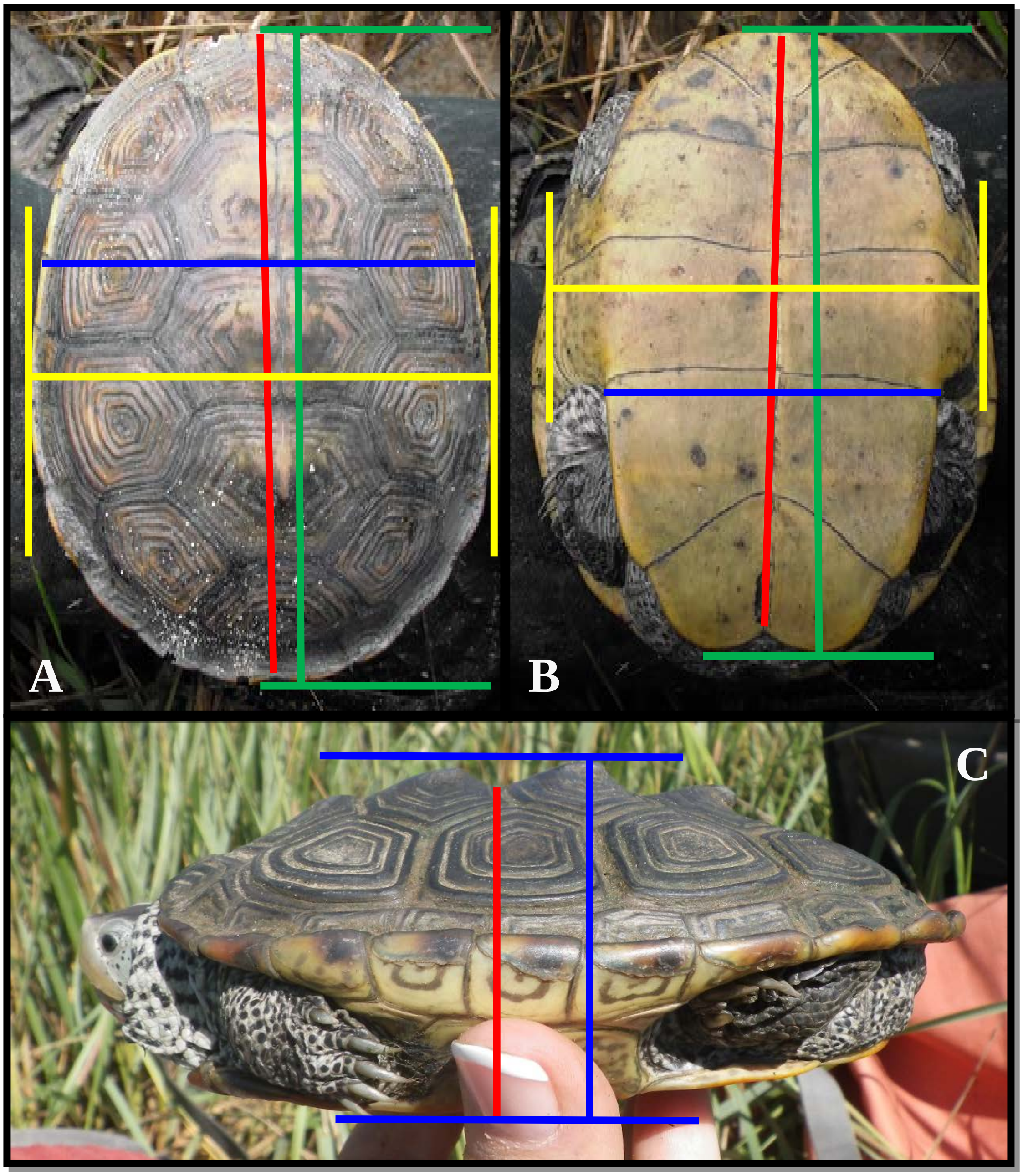

Figure 12 Straight line measurements (mm) recorded for each terrapin. (A) Carapace length (red = SCL_{min}; green = SCL_{max}); carapace width (blue = SCW_{min}; yellow = SCW_{max}); (B) plastron length (red = SPL_{min}; green = SPL_{max}); plastron width (blue = SPW_{min}; yellow = SPW_{max}); (C) body depth (red = SD_{min}; blue = SD_{max}).

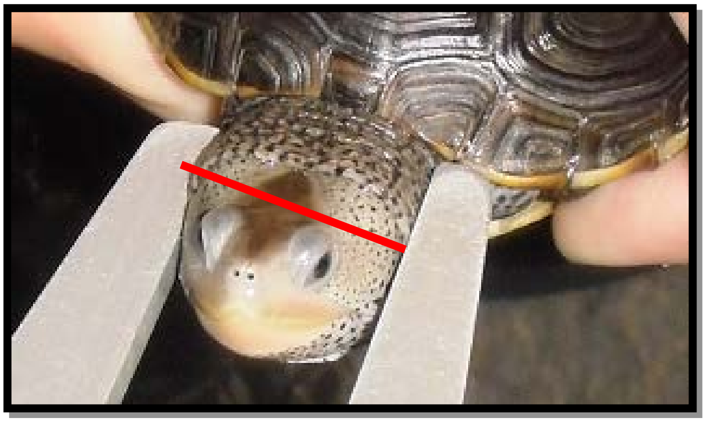

Figure 13 Maximum head width (mm; HW_{max}).

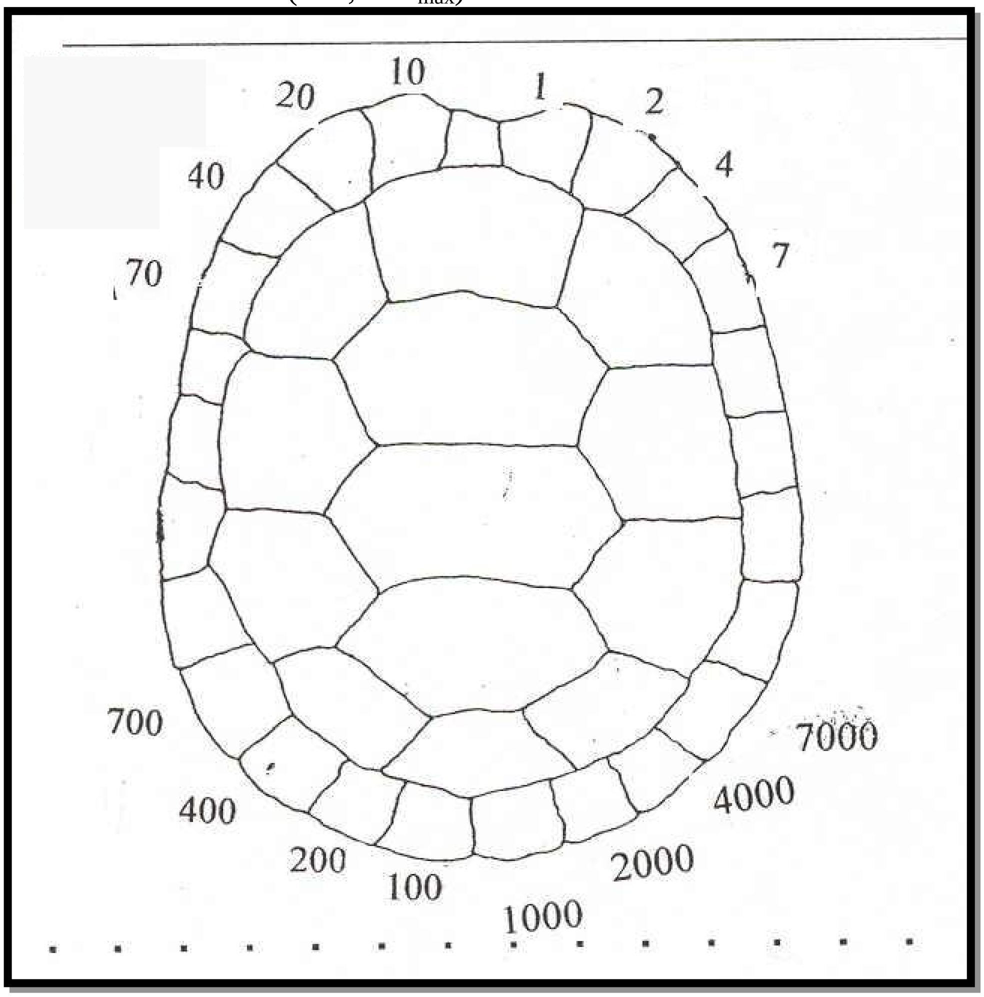

Figure 14 External marking pattern modified from Cagle (1939) used to uniquely identify each terrapin.

Each terrapin was marked with two methods of identification. Marginal scutes on the carapace were externally notched using a Nicholson 6" black diamond triangular file in a modified version of Cagle (1939) system for unique markings (Figure 14). Because notches are not permanent and will grow out after a few months or years (*pers. obs.*), terrapin were also injected with AVID MUSICC Chip PIT tags. The injection site was cleansed using cotton balls soaked in 70% isopropyl alcohol for 1 minute before injecting the PIT tag. A sterile, 12-gauge needle was used for each individual injection. After injection, the site was covered for 60 seconds with a cotton ball soaked in a 10% povidone-iodine antiseptic solution. Finally, the injection site was closed using New-Skin® liquid bandage, which was allowed to dry completely before releasing the leg.

Section 3.3.2.g. *Additional Site Notes*

In addition to initial environmental and hydrological data, any observations made about habitat, vegetation, prey availability, predator evidence, and anthropogenic factors were recorded for each site, regardless of terrapin captures. This data is reported as presence/absence of each parameter in the final field database supplied in Appendix E.

Section 3.3.3. Field Data Analysis

Field data was compiled into an Excel database. SigmaPlot 13.0, and MiniTab 17 software packages were used to run statistical analyses. A combination of t-tests and one-way ANOVA's were used to determine significant relationships in body size between sites, body size between capture methods, and body size between sexes, respectively. Statistical significance was set at $\alpha = 0.05$, unless otherwise noted. All values are represented as mean ± 1 standard error (SE), unless otherwise noted.

Section 3.4. GIS Analysis and Habitat Characteristics

GPS coordinates for terrapin captured by EIH from 2008-2014 along with capture coordinates from this study were analyzed for habitat type using the National Wetland Inventory (NWI) (USFWS) and 2010 Coastal Change Analysis Program (C-CAP) Land Cover (NOAA) datasets. Table 2 provides descriptions of C-CAP class codes used in this study. Table 3 provides descriptions of the NWI classes used in this study. All coordinates were verified for accuracy and coordinates with obvious discrepancies were removed prior to analysis (i.e. generated in deep open water, on well-developed land away from marsh habitat, etc.).

Each observation was analyzed for habitat type using circular buffers at three radii distances: maximum daily movement observed on South Deer Island in Galveston Bay (0.2 km radius = 0.126 km^2; (Clarkson 2012), average daily movement observed using radiotracking in Galveston Bay (0.1 km radius = 0.031 km^2; (Guillen and Oakley 2013)) and maximum home range reported in the literature (0.9 km radius = 2.545 km^2; (Spivey 1993)).

Individual capture observations in combination with their respective 0.9 km circular buffers were then divided into 17 clusters (Table 4 and Figure 15) based on spatial distribution and expert judgment of "natural barriers" between clusters (i.e. proximity between captures, geomorphic features, water depth, etc.).

Table 2. Class code descriptions for C-CAP Land Use dataset.

Class Code	Class Description	Class Code	Class Description
2	Developed, High Intensity	13	Palustrine Forested Wetland
3	Developed, Medium Intensity	14	Palustrine Scrub/Shrub Wetland
4	Developed, Low Intensity	15	Palustrine Emergent Wetland
5	Developed, Open Space	17	Estuarine Scrub/Shrub Wetland
6	Cultivated Crops	18	Estuarine Emergent Wetland
7	Pasture/Hay	19	Unconsolidated Shore
8	Grassland/Herbaceous	20	Bare Land
9	Deciduous Forest	21	Open Water
10	Evergreen Forest	22	Palustrine Aquatic Bed
11	Mixed Forest	23	Estuarine Aquatic Bed
12	Scrub/Shrub		

Table 3. Descriptions for NWI land cover classes used in study.

Class	Description
1	Estuarine and marine Deepwater
2	Estuarine and marine wetland
3	Lake
4	Freshwater emergent wetland
5	Freshwater Forested/Shrub Wetland
6	Freshwater pond
7	Other (may include riverine class below in analyses where number of sites classified as riverine is infrequent)
*8	Riverine (may be included in “Other” category for this study, due to low number of sites classified as riverine)

Table 4 Descriptions of "site" clusters used in habitat analysis (based on circular buffers applied to historical and recent terrapin capture locations).

Cluster #	**Description**	**Bay System**
1	Green's Lake	Galveston Bay
2	East Goat Island	Galveston Bay
3	North Goat Island	Galveston Bay
4	North Texas Point NWR (SAB-56)	Sabine Lake
5	East Texas Point NWR (SAB-55 & SAB-58)	Sabine Lake
6	San Bernard NWR	Galveston Bay
7	East Matagorda Bay	Matagorda Bay
8	Tres Palacios Bay (MAT-94)	Matagorda Bay
9	Keller Bay (MAT-14)	Matagorda Bay
10	Mud Island	Galveston Bay
11	Dalehide Cove	Galveston Bay
12	Sportsmans Marsh	Galveston Bay
13	North Deer Island	Galveston Bay
14	South Deer Island	Galveston Bay
15	Melager Cove	Galveston Bay
16	Sweetwater Marsh	Galveston Bay
17	Shell Island	Galveston Bay

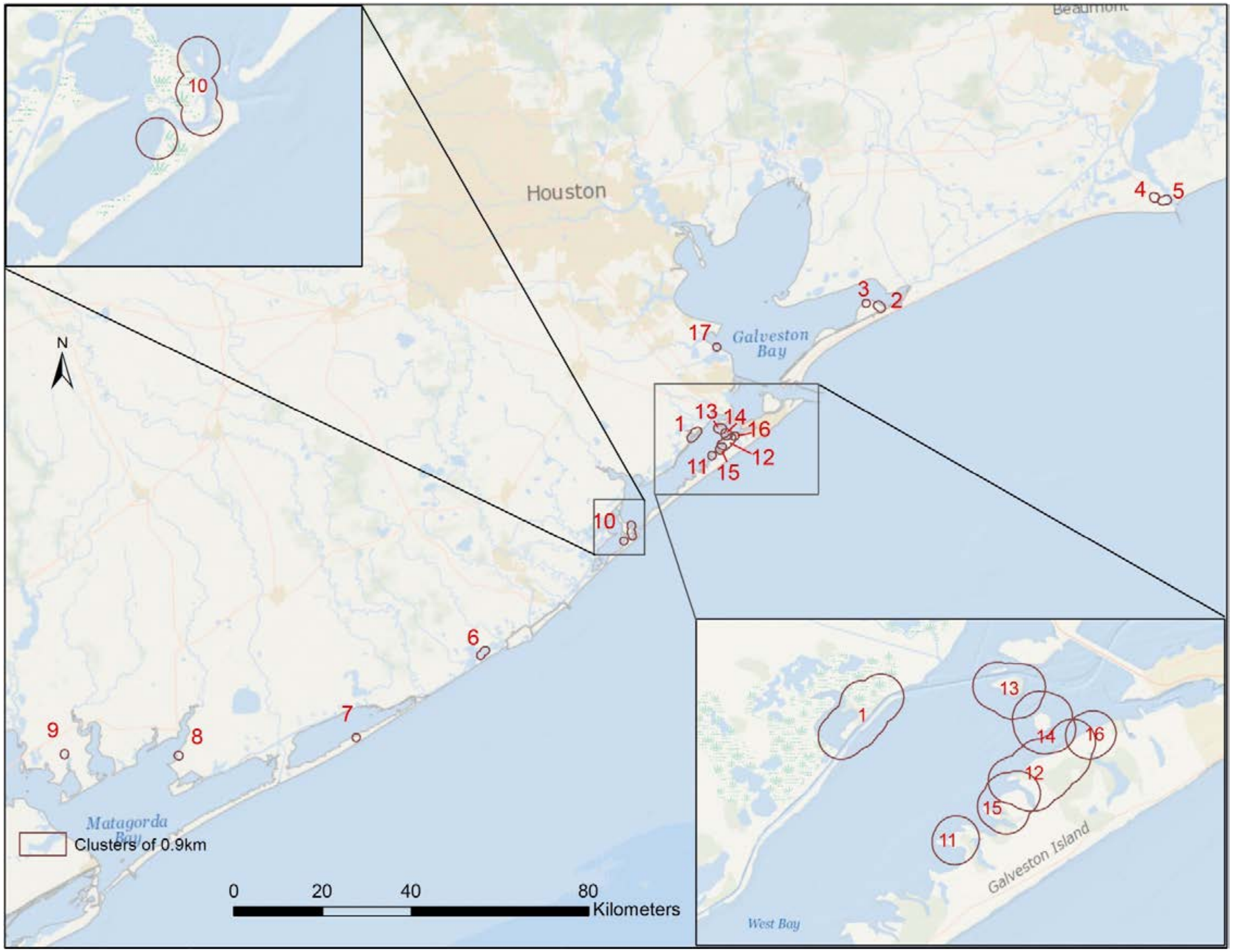

Figure 15 Map of 17 “site” clusters constructed using 0.9 km buffers using historical capture coordinates and capture coordinates from this study. See Table 4 for cluster descriptions.

The GIS technique used to facilitate the creation of these clusters involved creating composite overlays of the individual overlapping 0.9 km terrapin “home ranges”. The original boundaries between polygons of adjacent overlapping individual terrapin home ranges (= polygons in GIS terminology) are then removed (*dissolved*). The attributes of the newly formed polygon will be the sum of the component parts. The resulting layer is called for the purposes of this report a “cluster”. In summary these clusters represent large concentrations or populations of potentially interacting terrapin that were created in GIS by dissolving the original individual circular boundaries and *merging* them into a composite boundary (de Smith et al. 2015; Wade and Sommer 2006) (de Smith et al. 2015 available online at http://www.spatialanalysisonline.com /HTML/index.html).

These clusters were then used to conduct overall habitat assessments of terrapin “sites”; areas in which known terrapin populations exist. For the purpose of this study, a 0.9 km circular buffer was also applied to the starting location at each sample site in which no terrapin were captured (Table 5 and Figure 16). The habitat type within this buffer was also analyzed for comparison between habitats where terrapin were observed and where no terrapin were encountered and potentially absent.

Table 5. No capture site numbers and associated codes for GIS analysis.

Bay System	Site ID	GIS ID
Matagorda Bay	MAT-09	1
Matagorda Bay	MAT-12	2
Matagorda Bay	MAT-21	3
Matagorda Bay	MAT-27	4
Matagorda Bay	MAT-34	5
Matagorda Bay	MAT-81	6
Sabine Lake	SAB-01	7
Sabine Lake	SAB-37	8
Sabine Lake	SAB-43	9
Sabine Lake	SAB-50	10
Sabine Lake	SAB-52	11
San Antonio Bay	SAN-09	12
San Antonio Bay	SAN-18	13
San Antonio Bay	SAN-20	14
San Antonio Bay	SAN-32	15
San Antonio Bay	SAN-54	16
San Antonio Bay	SAN-63	17
San Antonio Bay	SAN-90	18
San Antonio Bay	SAN-98	19

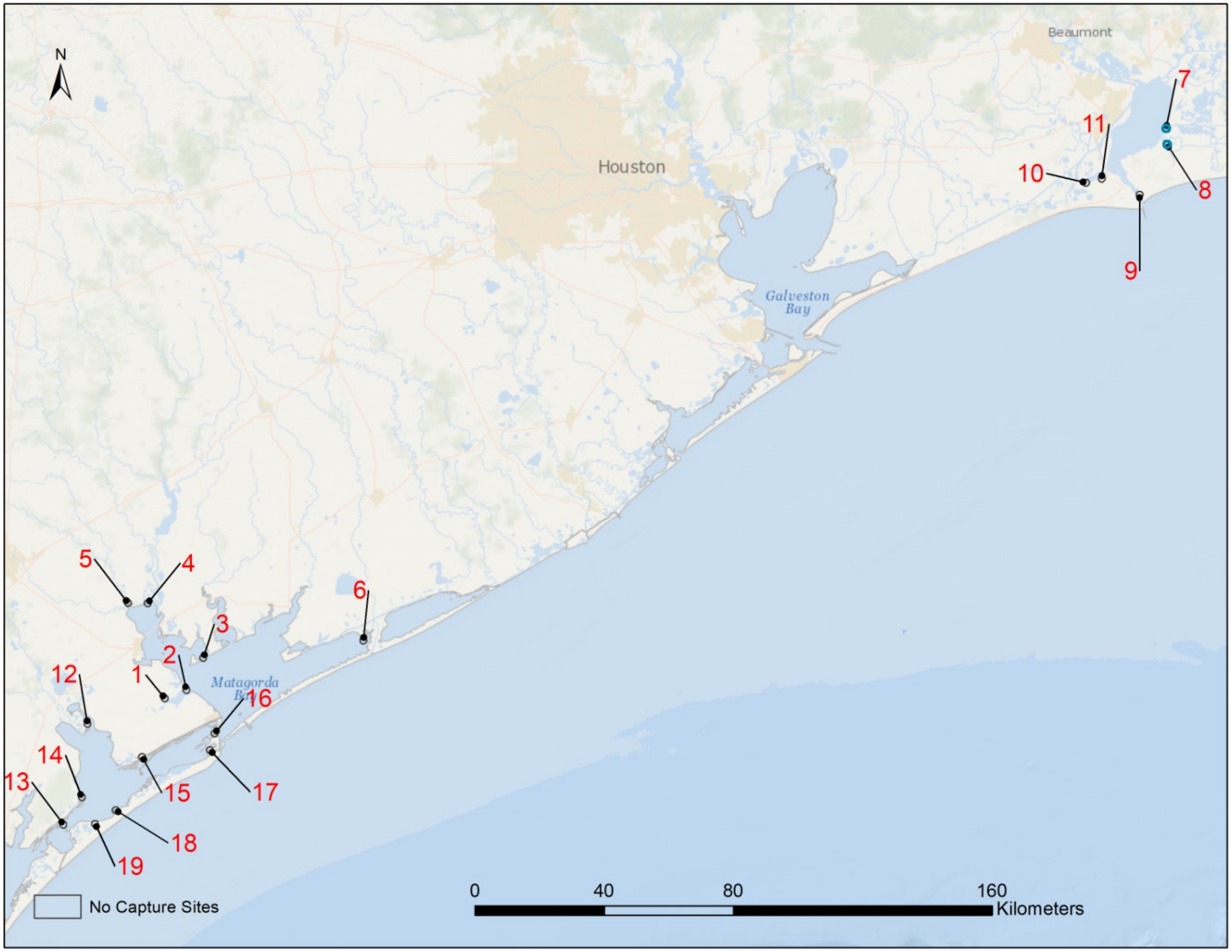

Figure 16 Map of sites with no captures. Sites 7 and 8 were excluded from the analysis due to lack of C-CAP data for those areas. See Table 5 for no capture site IDs.

SECTION 4. RESULTS

The previously discussed locations of terrapin sightings and harvest in the late 1800's described by (Gallaway 2001) are depicted in Figure 17. This area includes the location of the former Redfish bar which contained numerous oyster reefs and associated shell hash islands (Figure 17 and 18). At that time 100's of terrapin were sighted floating in the bay and nesting on shell islands located on Redfish bar. The bar was removed or reduced to subtidal depths during the early 1900's by oyster fishermen, mud shell dredging and navigation channel construction (Gallaway 2011). During 1900 to early 1970's terrapin appeared to be common in portions of Galveston Bay but not sufficiently numerous to support a fishery and or there was no longer a demand after prohibition (Figure 19). As stated earlier in the introduction, during the period 1924-1925 there was evidence of hundreds of terrapin in the mainland saltmarshes from Chocolate Bayou to Galveston Island Causeway (Gallaway 2001). Not included in the map is an early collection of 250 terrapin in Rockport circa 1904 by (Hay 1904). It appears that terrapin populations plummeted from large noticeable congregations throughout Galveston Bay and elsewhere to a status of rare encounters after the 1960's despite a cessation of commercial harvesting for over 35 years. It appears that other natural or man-made mechanisms continued to reduce terrapin populations in Texas.

Multiple published sources were used to develop the record of historical occurrence of terrapin occurrences across the Texas coast from the 1970's till the present (Clarkson 2012; Guillen et al. 2011; Guillen and Oakley 2013; Halbrook 2003; Haskett 2011; Haskett and Guillen 2010; Heffernan 1971; Hogan 2003; Huffman 1997; Koza 2006; Mabie 1987). Several studies include information gathered from formal questionnaires of and informal reports by citizens, fishermen and biologists (Guillen and Oakley 2013; Huffman 1997; Mabie 1987). The dates of when individuals reported seeing or capturing terrapin ranged from the 1970 to 2014. One of the earliest records of terrapin being captured by the TPWD coastal fisheries independent monitoring program was reported by (Heffernan 1971). He collected a terrapin with a shrimp trawl during the time period from December 1970 to November 1971 in Port Bay, a tributary of Copano Bay. This record was not included in their electronic database of recent captures.

Mabie (1987), conducted a questionnaire of biologists, game wardens and fishermen during 1983 and 1984 to determine the distribution of terrapin in Texas (Figure 21). He also collected additional data in Nueces and Lavaca Bay using crab pots. He recorded 58 reports extending from Baffin Bay to Sabine Lake and extending from the 1973 to 1984. Terrapin were present in every major bay system except the Laguna Madre. His records suggest that terrapin were present in the upper portions of Sabine Lake, Trinity Bay, Lavaca Bay, Hynes Bay, Guadalupe Bay, Copano Bay, Nueces Bay and Baffin Bay during this time period. These sites represent a wide range of potential salinity regimes extending from the least saline to most saline bay system. The highest frequency of sightings occurred from San Antonio to Galveston Bay.

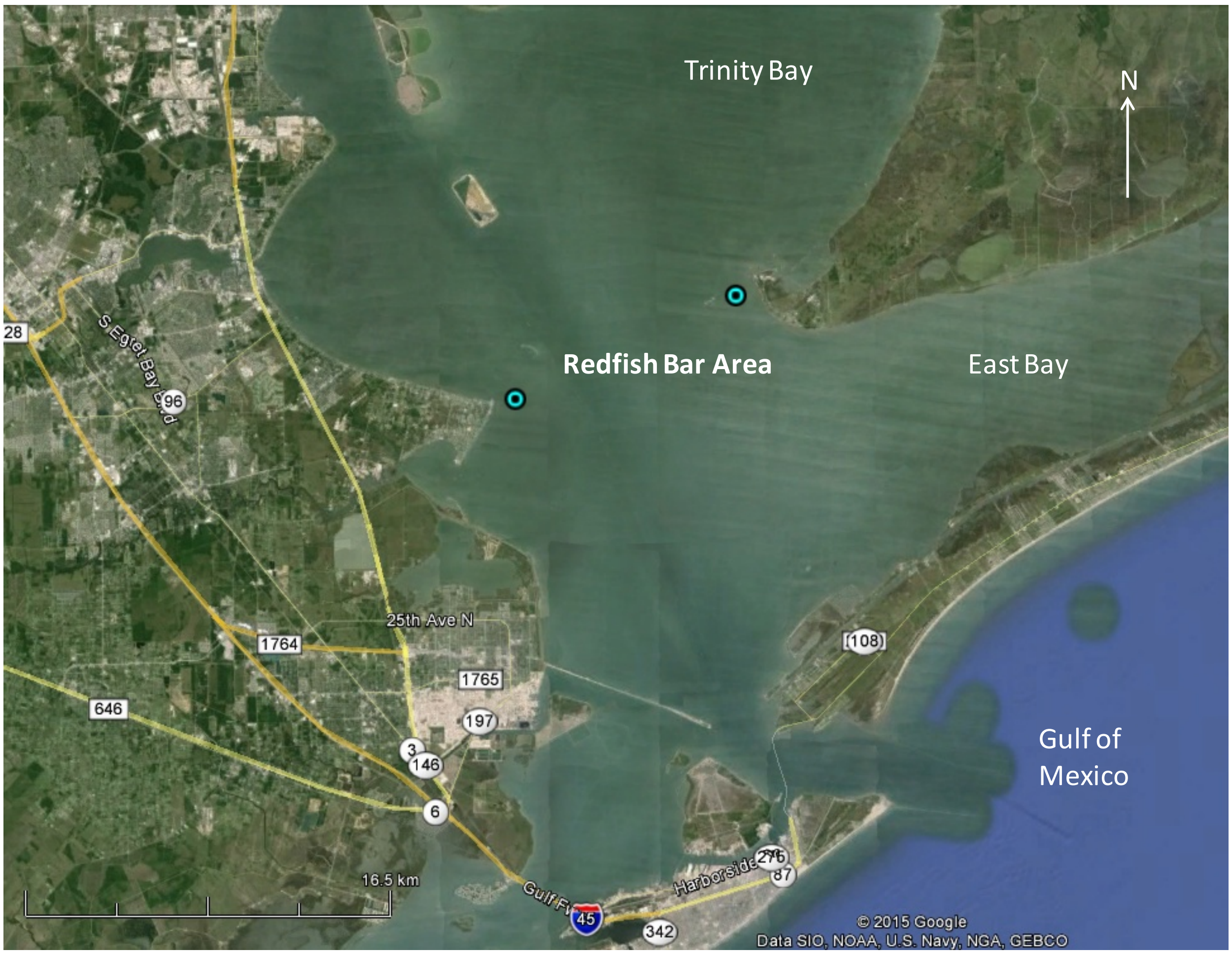

Figure 17. Location of historical sightings in the late 1800's based data summarized by (Gallaway 2001).

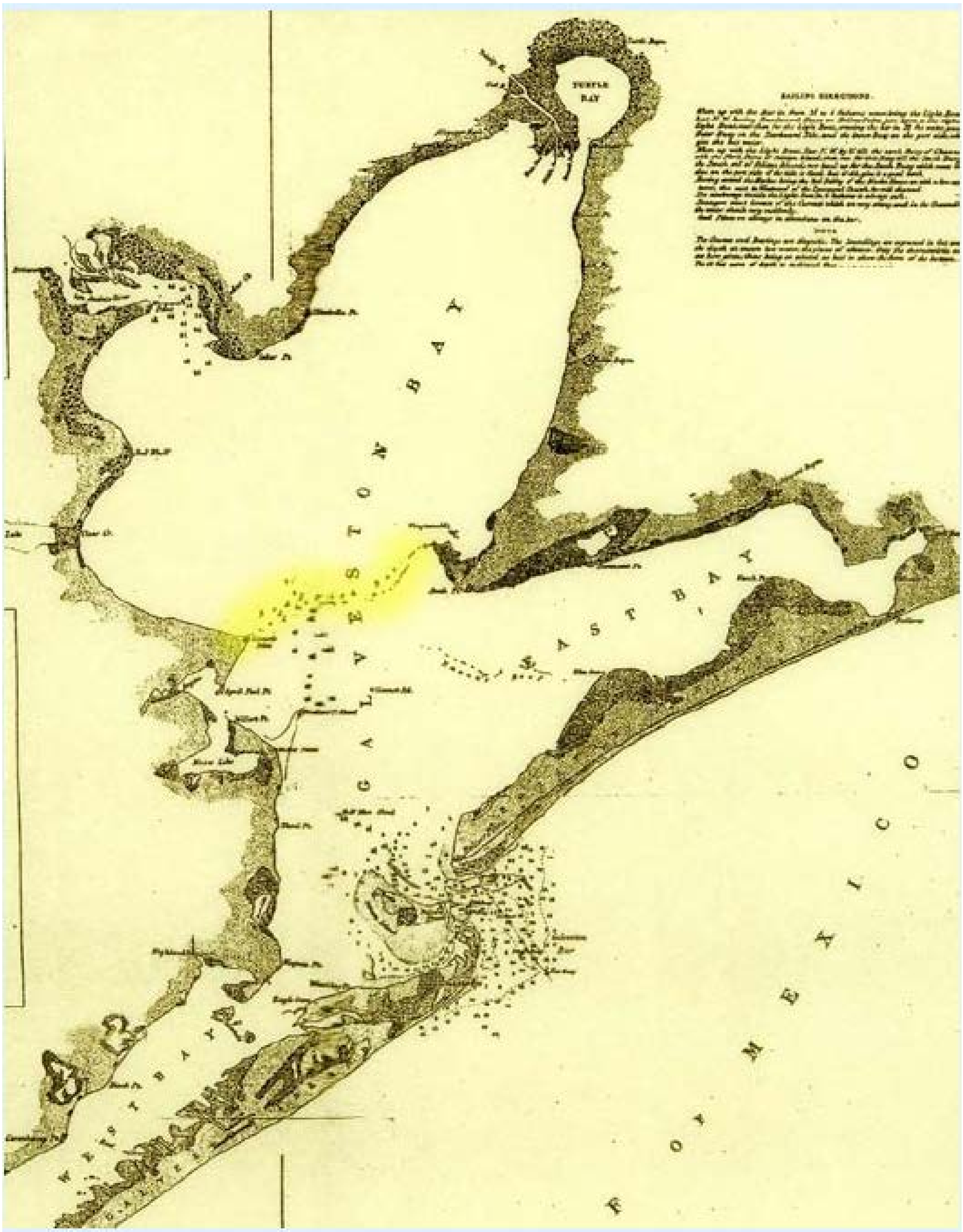

Figure 18. An 1851 map of Galveston bay with Redfish Bar highlighted in yellow. Image courtesy National Archives *in* (Gallaway 2011).

Figure 19. Location of sightings reported in (Gallaway 2001) during 1900-1970. Blue dots represent specific landmarks mentioned while the red line designates areas where terrapin where generally seen or captured.

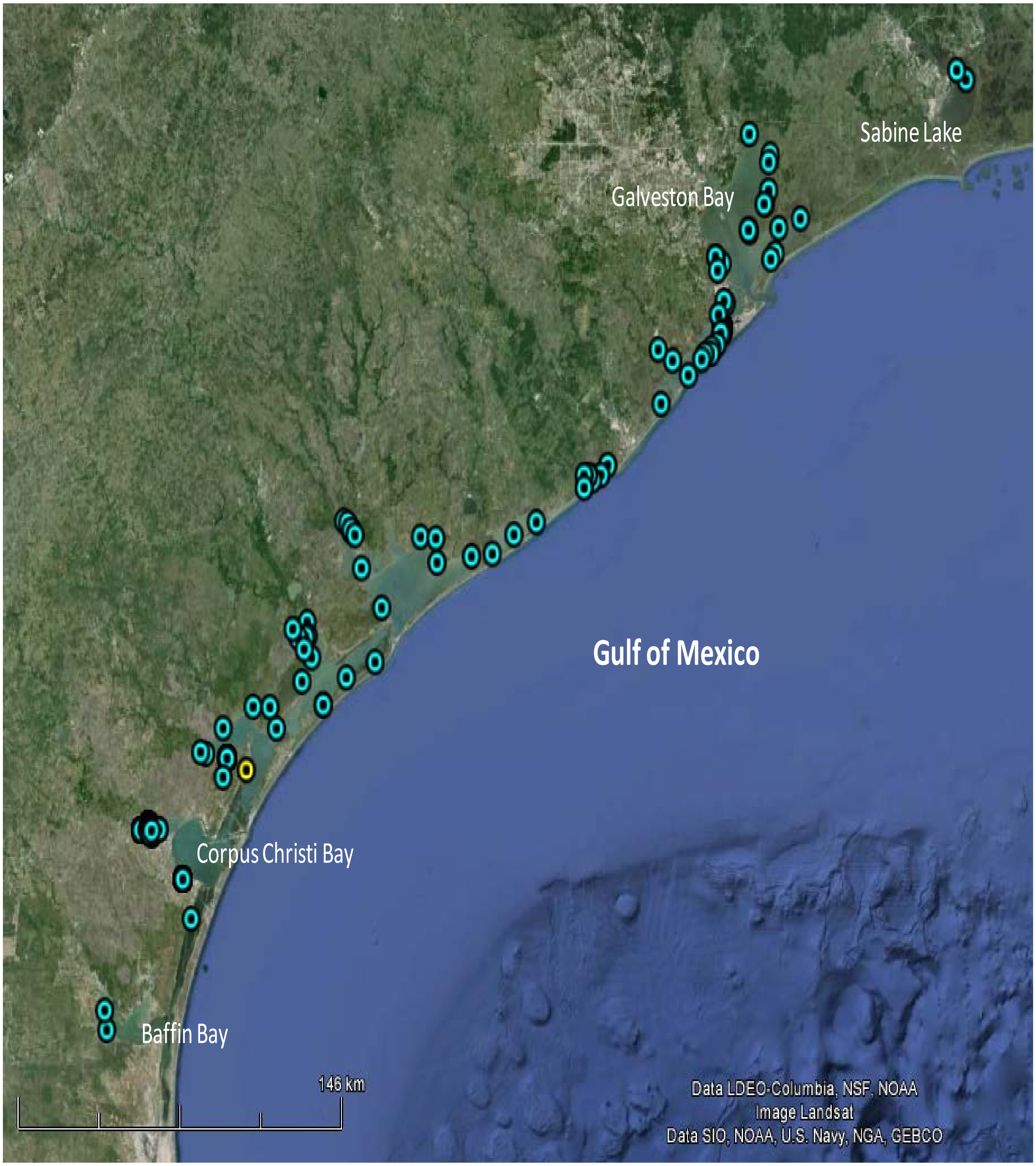

Figure 20. Sightings of terrapin in Texas based on multiple studies conducted from 1984 to 2013, reporting on sightings primarily from 1973 to 2014 (Clarkson 2012; Guillen et al. 2011; Guillen and Oakley 2013; Halbrook 2003; Haskett 2011; Haskett and Guillen 2010; Heffernan 1971; Hogan 2003; Huffman 1997; Koza 2006; Mabie 1987). Sightings denoted with blue circles with exception of yellow circle that depicts an early pre 1904 report by (Hay 1904).

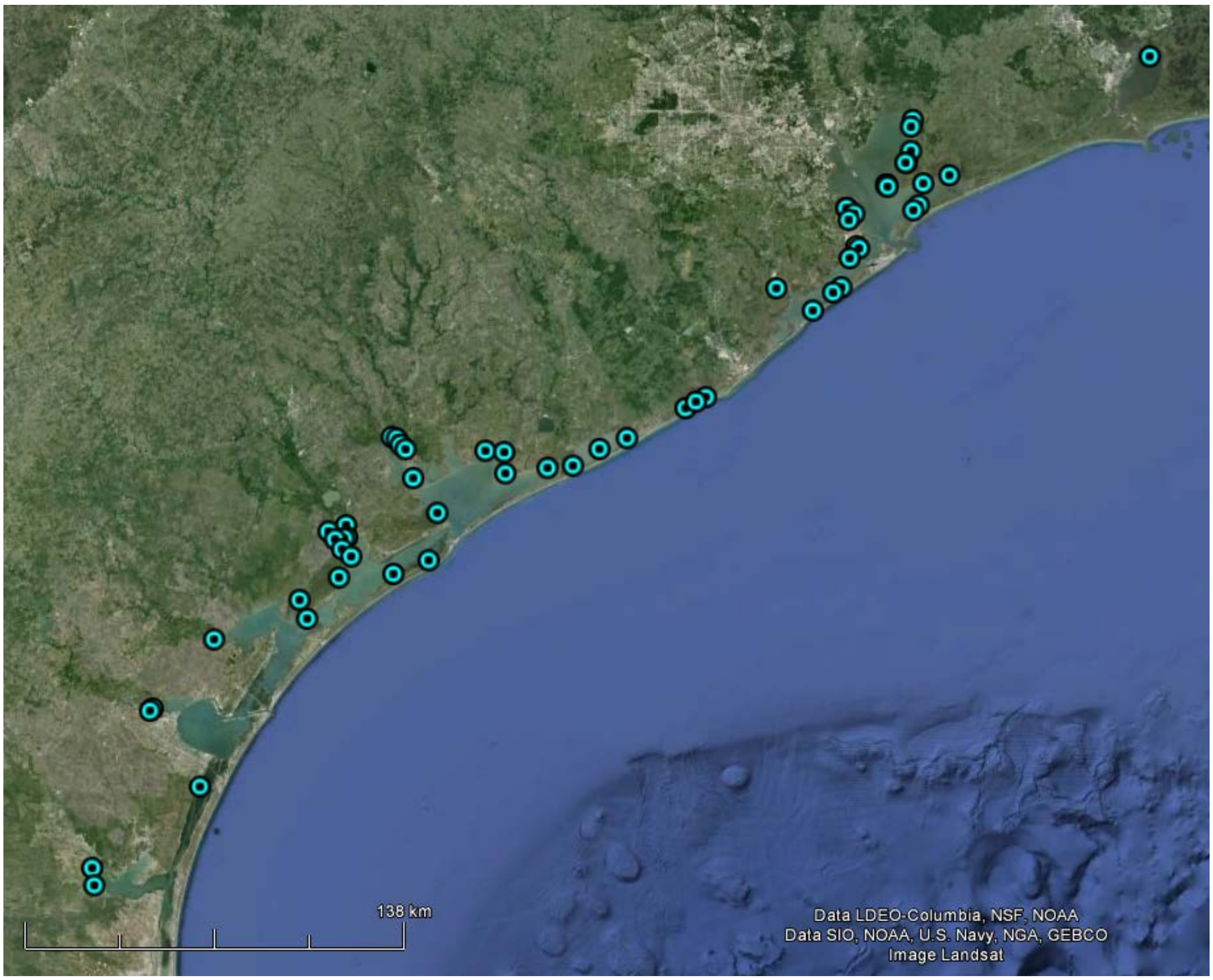

Figure 21. Sightings of terrapin in Texas based on (Mabie 1987) for the time period 1973 to 1984. Blue circle denote locations of sightings or captures.

Mabie (1987), reported the most southern known occurrence of terrapin in Texas. He reported that trappers had observed terrapin at Riviera Beach in Baffin Bay during 1984 (Mabie 1987). The approximate location extends from one marker to the next in the map depicting the area where terrapin were observed (Figure 21).

In the fall of 1997 Huffman (1997) conducted a trap survey in West Bay, to investigate reports of terrapin in that area. Due to low catch rates he also compiled an updated listing of sightings based on interviews and data obtained from various biologists and reports in Galveston Bay. He found the most prevalent reports of terrapin in the saltmarshes around the middle portion of Galveston Island (Figure 22). He also received reports of terrapin sightings in the Chocolate Bayou and Trinity River delta.

During 2003-2007 two graduate theses (Halbrook 2003; Koza 2006) and one agency report (Hogan 2003) were published that investigated terrapin populations in Nueces Bay, Corpus Christi Bay, Copano Bay, San Antonio, Lavaca and Galveston Bay (Figure 23-25). All three of these studies appeared primarily utilized modified and baited crab pots which were deployed in areas within 200 meters of either a saltmarsh or isolated spoil islands consisting of high levels of shell hash. Nueces Bay consists of multiple dredge spoil areas containing shell hash and mud located in the upper delta region of the bay. Many of these islands are isolated from the mainland. A total of 144 terrapin were captured during 29 trapping days from June 1997 to August 1999 (Halbrook 2003). Sufficient positional data (latitude and longitude) data was available for 135 terrapin to plot their occurrence on the map depicted in Figure 23. Almost of these terrapin were captured within 30 meters of isolated shell has islands or nearby saltmarshes. Using mark recapture methodology she estimated the population of Nueces Bay to be 322 terrapin during her study period. Average salinity ranged between 8.1 and 22.3 psu during her study period. She only reported one deployment when terrapin was not collected.

Koza (2006), collected 154 terrapin from four bay systems using modified baited crab traps from March to November 2003. He found that terrapins were primarily captured off of spoil islands near river deltas in oligohaline waters over shell hash substrates (Figure 24). During his study, terrapins were captured in salinities ranging from 0.30 to 25.36 ppt. He concluded that optimal salinities for *M. t. littoralis* were determined to lie between 0.3 and 15.9 psu (which accounted for 86.0% of total data collected).

Hogan (2003), studied the insular population of diamondback terrapin on South Deer Island during July 2001 to May 2002. She primarily utilized modified crab pots with some supplemental wading and basking surveys. She recorded a total of 135 capture events (116 individuals, 19 recaptures) during the study period (Figure 25). The highest number of terrapin was captured during April–May 2001 and April–May 2002. During her study she reported that maximum salinity ranged between 19.7 and 32.2 psu. Minimum and average values were not reported. She also reported a nesting terrapin on a shell hash berm on the south side of the island during April 2001.

Figure 22. Terrapin sightings and captures reported in (Huffman 1997). Blue circle denote locations of sightings or captures.

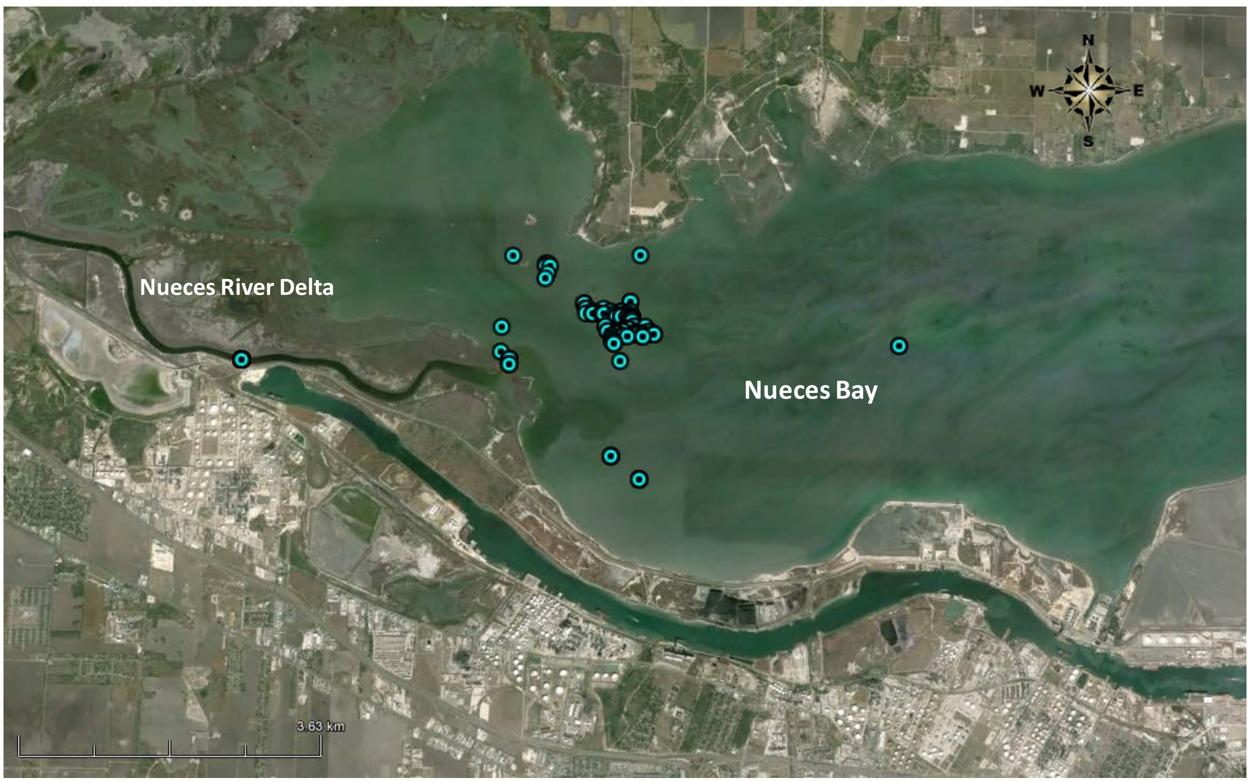

Figure 23. Location of collected terrapin in Nueces Bay by (Halbrook 2003). Blue circle denote locations of sightings or captures.

Figure 24. Location of terrapin collected by (Koza 2006). Yellow circle denote locations of sightings or captures.

Figure 25. Location of captured terrapin collected by (Hogan 2003). Blue circle denote locations of sightings or captures.

The TPWD Coastal Fisheries Independent monitoring program utilizes experimental gillnets, seines and trawls to capture fish and shellfish for stock assessment and monitoring. Gillnets and seines are used to sample shoreline fish assemblage, whereas trawls are used to monitor in water > 1 meter deep. Since it is a coast wide monitoring program that utilizes a probabilistic sampling design it is the only possible standardized index of terrapin abundance. TPWD provided data on the occurrence of terrapin captures by any of their gear for the period of 1983 to through 2013. The earliest and most recent recorded instance of a terrapin being captured occurred in May 1983 and November 2013. A total of 72 terrapin were captured by from 1983 to 2013 (Figure 26). The majority of terrapin were collected with gillnets with much lower but equivalent numbers collected with bag seines and shrimp trawls. This implies that terrapin are more commonly associated with shoreline habitat versus deeper water (Figure 27).

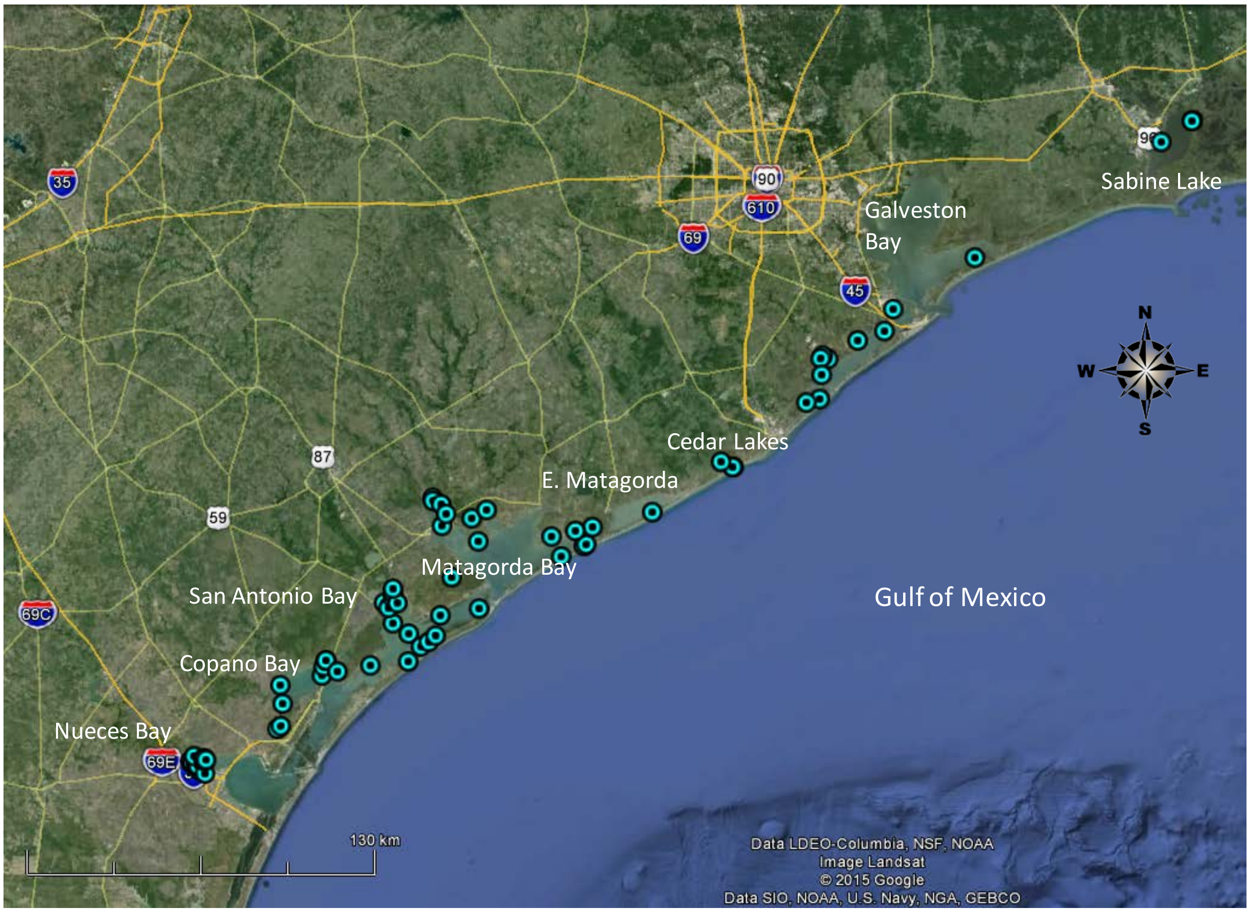

Figure 26. Occurrence of diamondback terrapin in Texas in TPWD coastal fisheries samples obtained from monitoring gear during 1983 to 2013. Blue circle denote locations of sightings or captures.

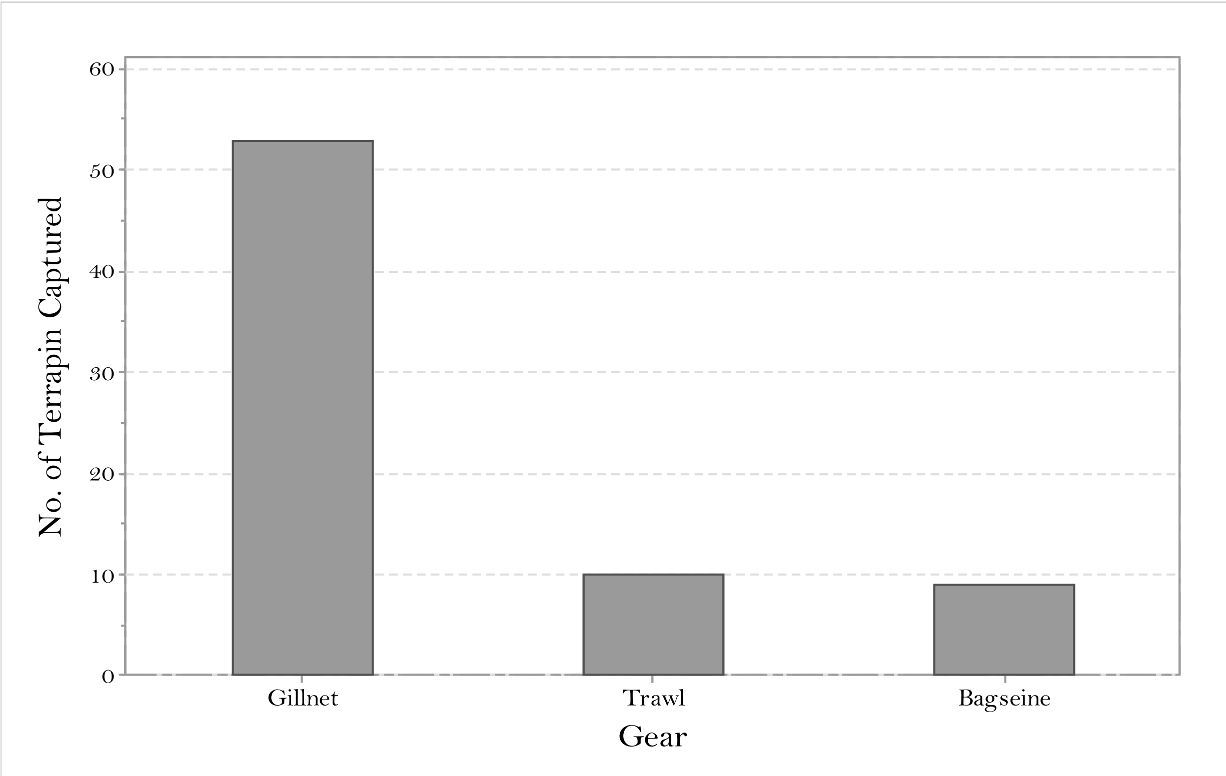

Figure 27. Frequency of terrapin capture by TPWD sampling gear in Texas 1983-2013.

There has been a slight upward trend in numbers of terrapin captured by TPWD, although the overall numbers are still very low and rare when one considers the hundreds of samples collected each year (Figure 28). The actual *catch per unit effort* (CPUE) based on historical sampling effort for all years combined was calculated as 0.4 terrapin/gillnet set, 0.01 terrapin/unit effort of trawling, and 0.001 terrapin per unit effort of seining (Martinez-Andrade et al. 2005). The maximum, average and minimum salinity that was measured during TPWD terrapin collections was 0.0, 20.32 and 42.50 psu. Examination of the cumulative distribution of salinity when terrapin were captured indicates that the majority (80%) of terrapin were captured at salinity levels between 7.3 to 32.7 psu. The maximum, average and minimum water temperature measured during terrapin captures was 32.4, 26.7 and 9.4 C respectively. Ninety percent of the terrapin captures occurred when water temperature was above 20 C. The maximum, average, and minimum carapace length of captured terrapin was 251, 185 and 27 mm respectively.

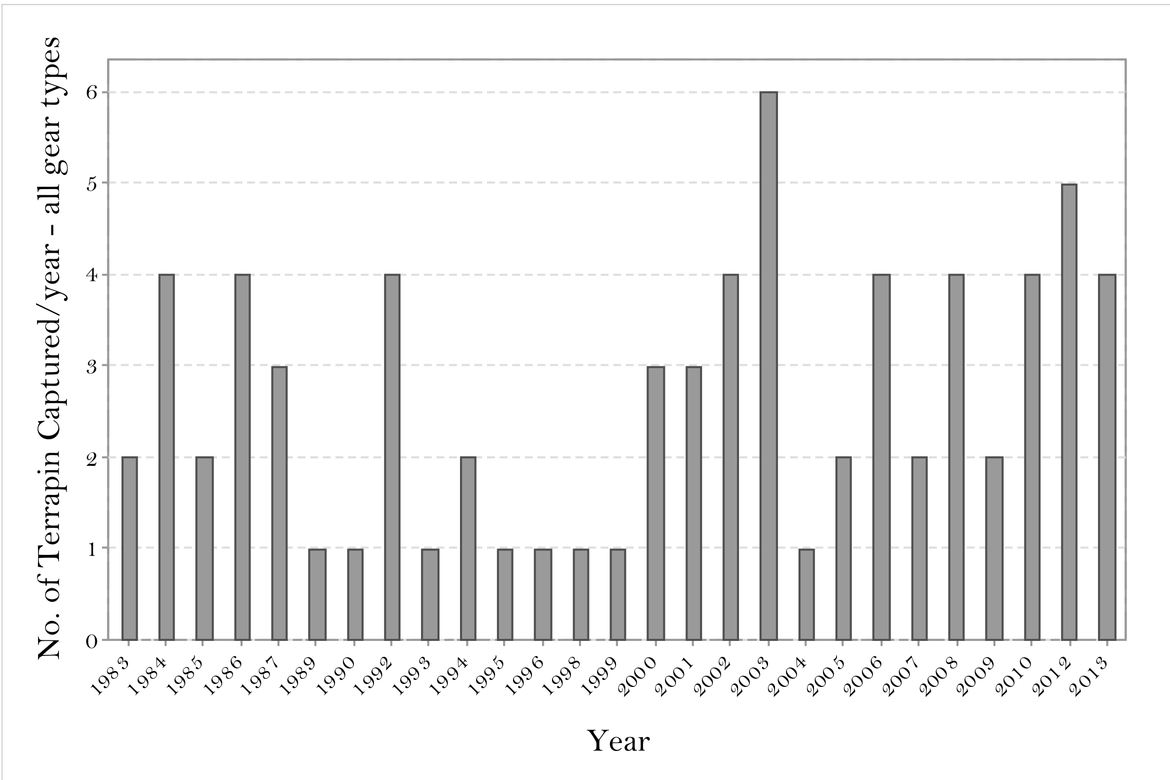

Figure 28. Terrapin catch per year for all TPWD gear types combined.

Each year since 2002, during the month of February the TPWD has sponsored a derelict blue crab pot pickup across the Texas coast (Morris 2003). Data is collected by volunteers on the presence of bycatch organisms in abandoned crab pots. This database is maintained by TPWD (Morris 2003). All past data was provided to us to determine the rate of terrapin occurrence (both live and dead remains) in collected traps. It should be noted that this data is likely biased low in regards to bycatch rates since only recent bycatch of terrapin would be visible to the collector. The older remains would mostly likely decompose rapidly or be scavenged. Based on our review of their database it appears that reported bycatch rates have been relatively low since 2005 (Figure 29 and Table 6). Only nine incidents have been reported since 2002. The largest bycatch was the capture of 20 terrapin within one crab pot in East Bay near the Anahuac National Wildlife Refuge in 2006.

Table 6. Summary of terrapin bycatch associated with abandoned traps compiled by the annual TPWD abandoned crab trap removal program.

Diamondback terrapins observed during TPWD Abanonded Crab Trap Removal Program 2002-2013					
Year	**Live**	**Dead**	**Total**	**Bay**	**Comments**
2002	2	0	2	Sabine Lake	Observed in trap study
2003	1	0	1	Sabine Lake	Observed in trap study
2005	0	22	22	Galveston Bay	Observed during trap removal - 20 found in 2 traps
2006	0	4	4	East Galveston Bay	Observed during trap removal - all found in 1 trap
2008	0	1	1	San Antonio Bay	Observed during trap removal
2009	0	1	1	Galveston Bay	Observed during trap removal
2011	0	1	1	Galveston Bay	Observed during trap removal
2013	0	1	1	Lavaca River	Observed during trap removal - Cason and Hartl
2014	0	1	1	Galveston Bay	Observed during trap removal
* 2004, 2007, 2010, 2012 - no terrapin reported					

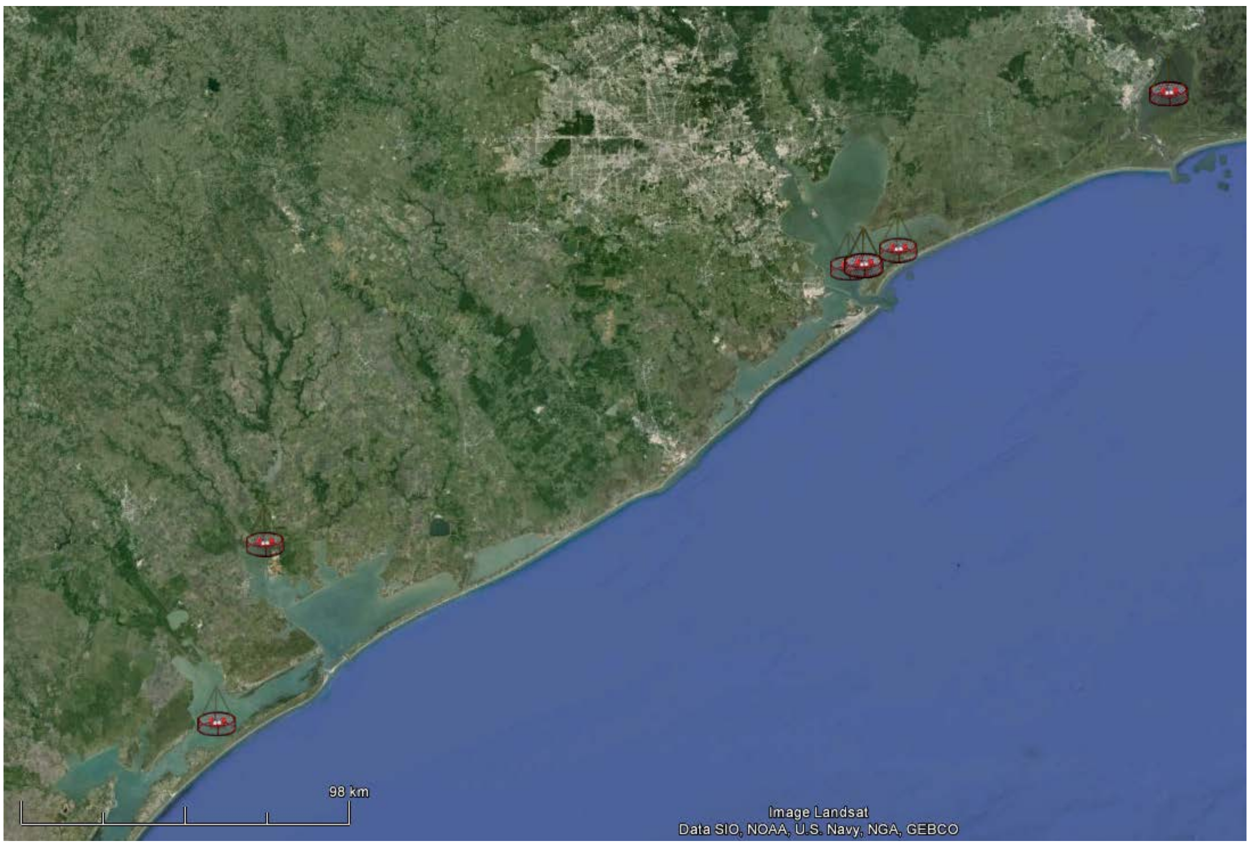

Figure 29. Location of terrapin bycatch associated with abandoned crab pots from 2002-2014.

The Environmental Institute of Houston (EIH) has compiled data from past limited studies of the mid-coast (Guillen et al. 2011), questionnaires sent out to crabbers as part of bycatch reduction (BRD) device study (Guillen and Oakley 2013), ride-along trips with crabbers also part of the BRD study, and sightings by fishermen, biologists and lay public that have been reported to EIH over the last 5 years. Based on these sources, 76 observations of terrapin are plotted in Figure 30. This data includes data from a unique stranding event involving 14 hatchling terrapin. These hatchlings washed up on Mustang Island in October 2008, after Hurricane Ike flooded coastal wetlands in the Galveston Bay area and flushed out a variety of dead and living organisms that subsequently drifted at sea and was transported with a large debris field down the coast. The period of record in the case of the recollections of some crabbers extend back 10-20 years (Guillen and Oakley 2013). The remaining data on terrapin was primarily collected between 2010 and 2014.

In addition to the observational data collected by the public and volunteers and staff we also conduct regular monitoring of key locations within the Galveston Bay system using line transect methods on land and modified and baited crab pots in aquatic environments. We began monitoring terrapin using a combination of modified crab traps and land searches (transects) on South Deer Island in 2008 (Haskett and Guillen 2010). We continue to collect demographic data on terrapin in the same area and adjacent bay systems including West Bay, Trinity Bay, East Bay, Christmas Bay, during various specific studies and routine monitoring (Guillen et al. 2011; Guillen and Oakley 2013; Haskett 2011; Hogan 2003). Data from specific surveys associated with the South Deer Island complex and other routine monitoring sites (Sportsmen Road, Greens Lake, West Bay, East Bay, Moses Lake, and North Deer Island is presented in Figure 31.

Secondary resource documents including oil spill response planning, wildlife management area checklists and park planning documents which indicate the likely presence of terrapin were also used to evaluate the potential range of terrapin in Texas (Figure 32). In most cases only general information was provided without any specific coordinates. One notable report was the San Jacinto Monument area which does not have any previous sighting data.

Based on examination of the distribution of data collected by EIH staff and reported by others it is clear that the area around Moses Lake, North and Sound Deer Island and the bay side of the west end of Galveston Island, Bolivar Peninsula and the Cedar Lakes areas support sufficient terrapins to be noticed by both biologists, citizens and commercial and recreational fishermen. These areas have isolated shell hash islands and/or extensive saltmarshes bordered by expansive shallow waters overlying extremely soft tide flats. These attributes provide terrapin with some measure of protection from mainland predators and from the blue crab fishery which would have a difficult time accessing some of these areas to shallow depths and/or hazardous (reef) bottom conditions.

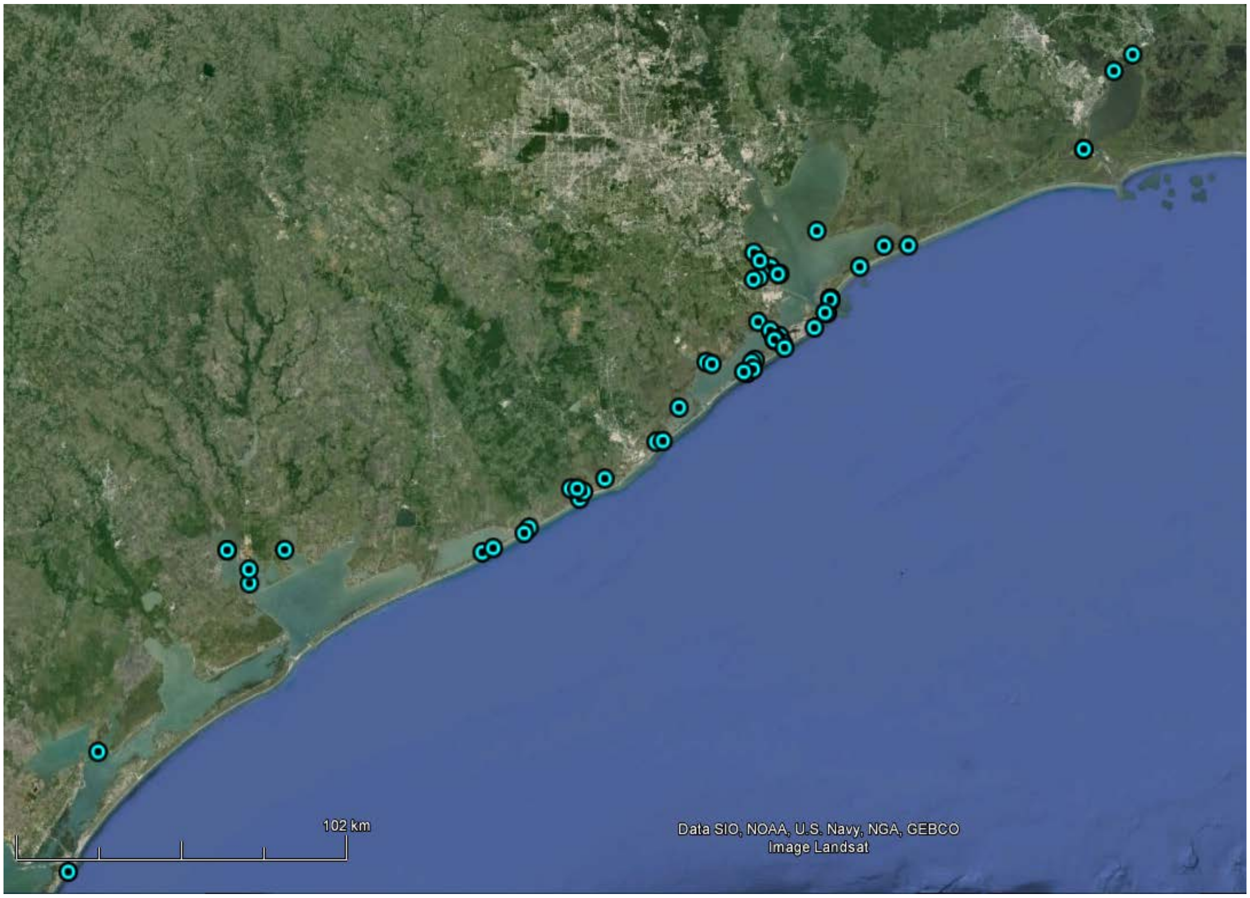

Figure 30. Sightings or collections of terrapin by EIH staff including mid-coast studies (Guillen et al. 2011) reports received by public sources, and through the bycatch study questionnaire results in (Guillen and Oakley 2013).

Figure 31. Locations of positive captures or terrapin sightings collected through past EIH studies.

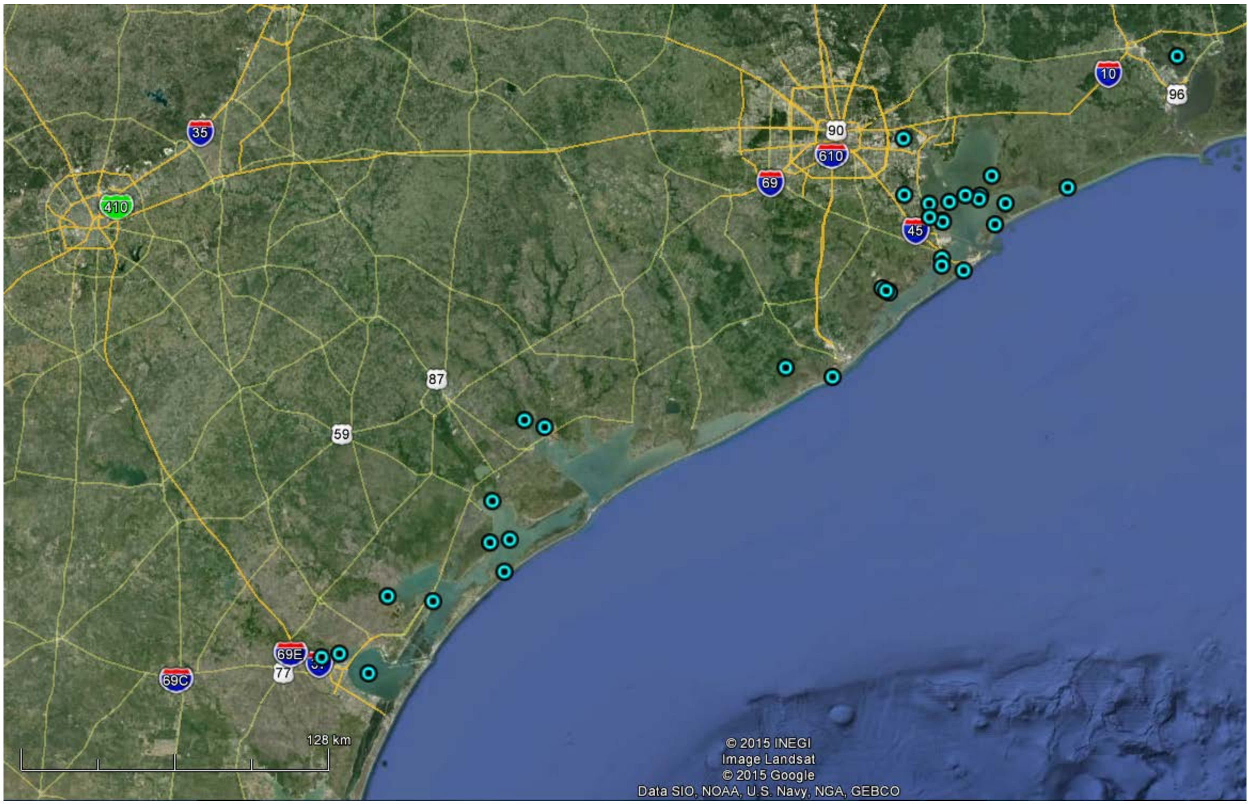

Figure 32. Secondary references including wildlife management area, park and oil spill response planning documents, and past studies that indirectly reference the probably presence of terrapin.

We have also provided information on sites where no terrapin were found or captured by either EIH or other investigators. This included observations by volunteers, ongoing studies, and monitoring and other published studies which provided information on locations where sampling effort failed to locate terrapin. This data was combined and presented in Figure 33. Based on examination of these "zero catches" it is evident that there is considerable overlap with sites where terrapin have been captured. In some cases the same site on different dates or times failed to yield terrapin. This may be due to subsequent mortality, low numbers or seasonal changes in their behaviour (e.g. burrowing vs. swimming), or emigration from the area.

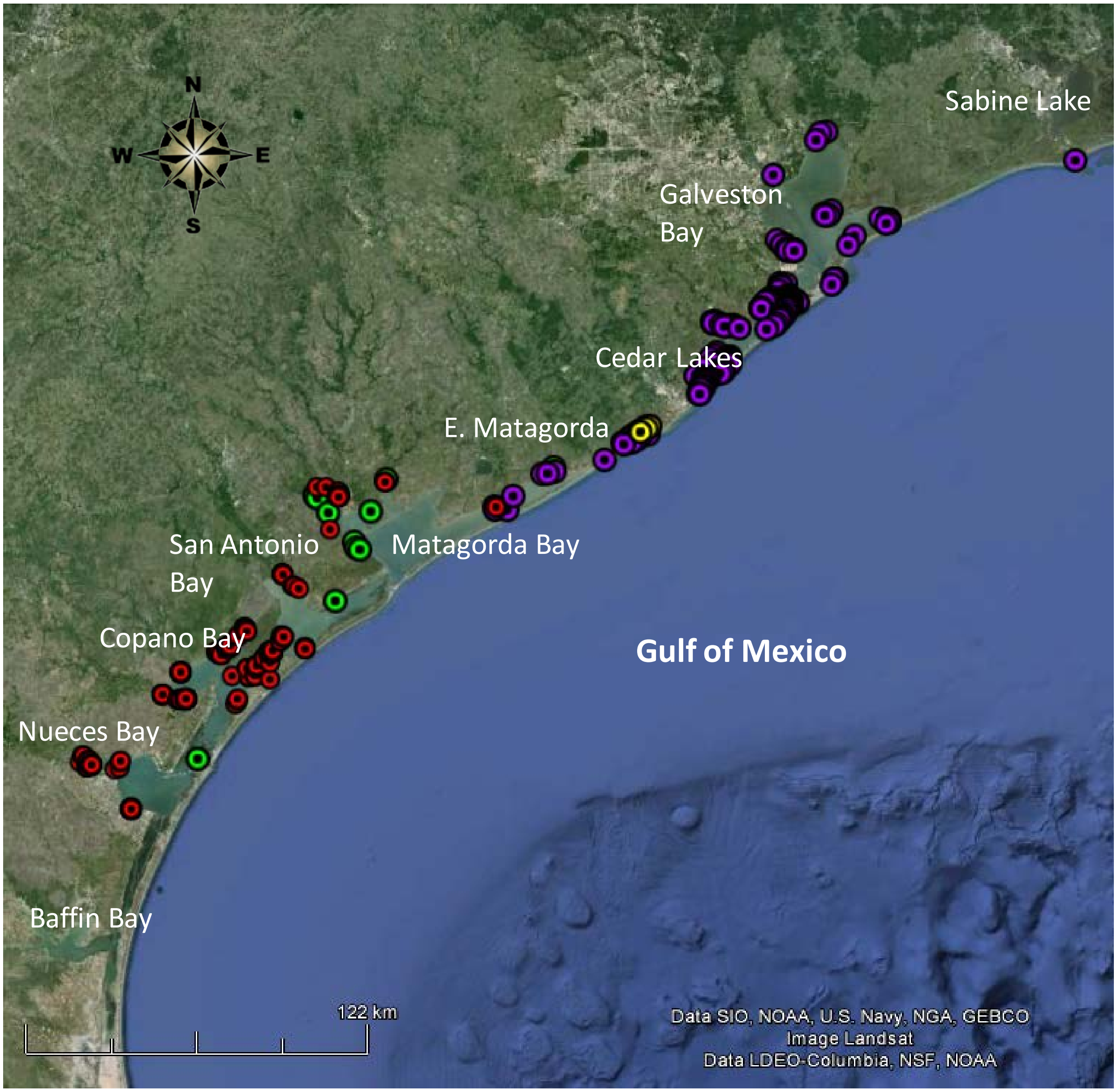

Figure 33. Sites where terrapin were not detected during surveys, crab pot deployment, or other search method. Data source: EIH ongoing terrapin surveys – purple disk; Guillen et al. (2011) – yellow disk; Koza 2006 – red disk; Volunteer reports - green disk.

Section 4.2. Online Questionnaire

In total, 210 links to the online questionnaire were emailed with 70 (33.3%) completed surveys returned. Twenty-three surveyors (15.8%) reported no observations of terrapin while 123 reports of terrapin (*n* = 877) occurred in all bay systems except the Lower Laguna Madre (Table 7). One terrapin was reported in the Upper Laguna Madre, though no GPS coordinate was generated for that observation or any additional information from the respondent.

Table 7 Number of terrapin observations reported and number of terrapin reported from online questionnaire for Texas bays.

Bay System	Number of Terrapin Observations Reported	Total Number of Terrapin Reported
Sabine Lake	8	147
Galveston Bay	37	125
Matagorda Bay	26	80
San Antonio Bay	18	72
Aransas Bay	22	108
Corpus Christi Bay	11	344
Upper Laguna Madre (ULM)	1	1
Lower Laguna Madre (LLM)	0	0
TOTAL	**123**	**877**

Terrapin were observed most commonly in the summer (53.7% of responses, *n* = 66), second most commonly in the spring (34.6%, *n* = 43) and fall (18.7%, n = 23) and least commonly in the winter (1.6%, *n* = 2). Seventeen respondents (13.8%) were unsure of the season in which their observations occurred (Figure 34).

Twelve respondents (9.7%) reported an overall trend of increasing terrapin numbers, while 8 (6.5%) reported decreasing numbers of terrapin and 31 (25.2%) reported no observable change. The majority of respondents (n = 72, 58.5%) responded as unsure about any observable changes in terrapin observations.

Thirty-nine respondents provided email addresses while completing the questionnaire. These respondents were emailed with a follow-up question pertaining to the time during which their particular observations occurred. Of the 39 respondents emailed with a follow up, 33 (84.6%) replied, representing 106 total terrapin observations (86.1% of the original 123 observations reported). Forty-nine (46.2%) of the 106 observations were reported as being within the last 0-5 years, 24 (22.6%) within the last 5-10 years, 8 (7.5%) within the last 10-20 years, and 2 (1.9%) occurring greater than 20 years ago.

The most recent report of a terrapin observation was made during the follow-up component and consisted of an additional observation made in San Antonio bay on 19 November 2014, after the questionnaire had closed for public access. The earliest terrapin observation reported by the questionnaire survey was near Sabine Lake in 1974 off the Gulf shore of McFaddin National Wildlife Refuge. All and recent (≤ 10 years) reported sightings are depicted in Figure 35 and 36.

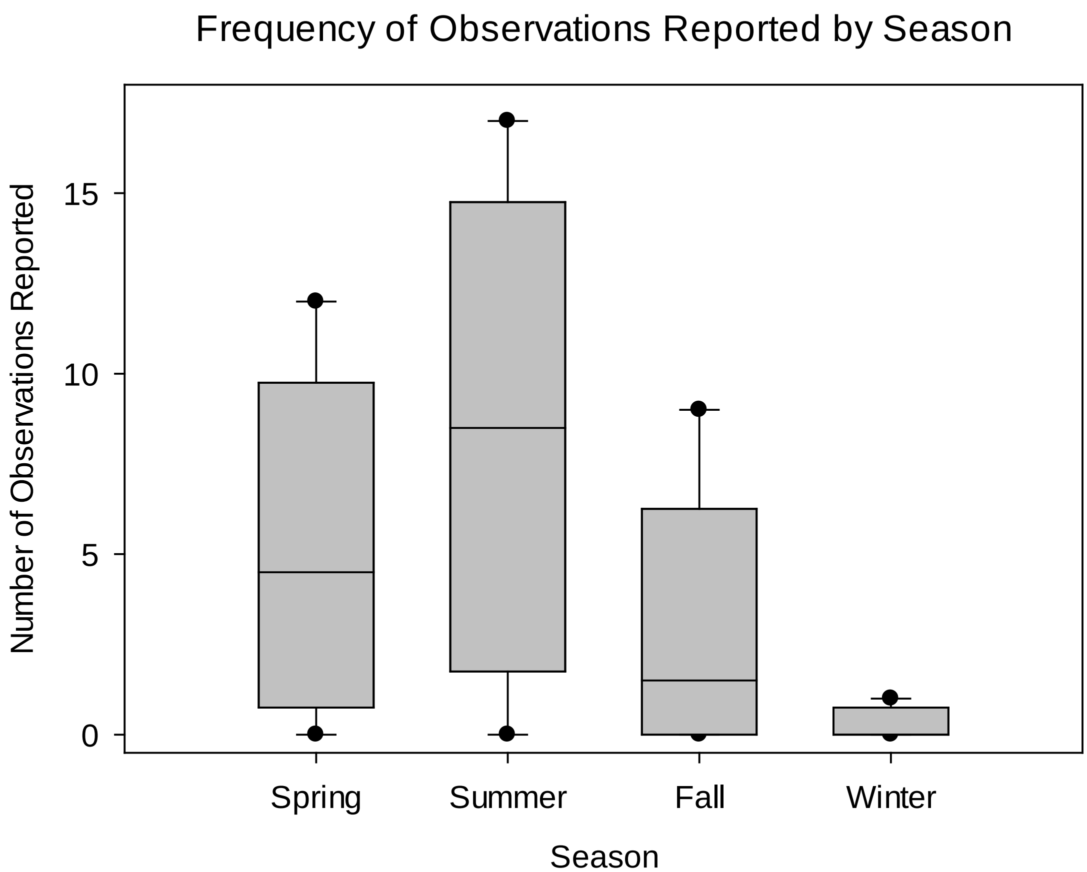

Figure 34 Frequency Boxplot of terrapin observations reported by questionnaire respondents plotted by season.

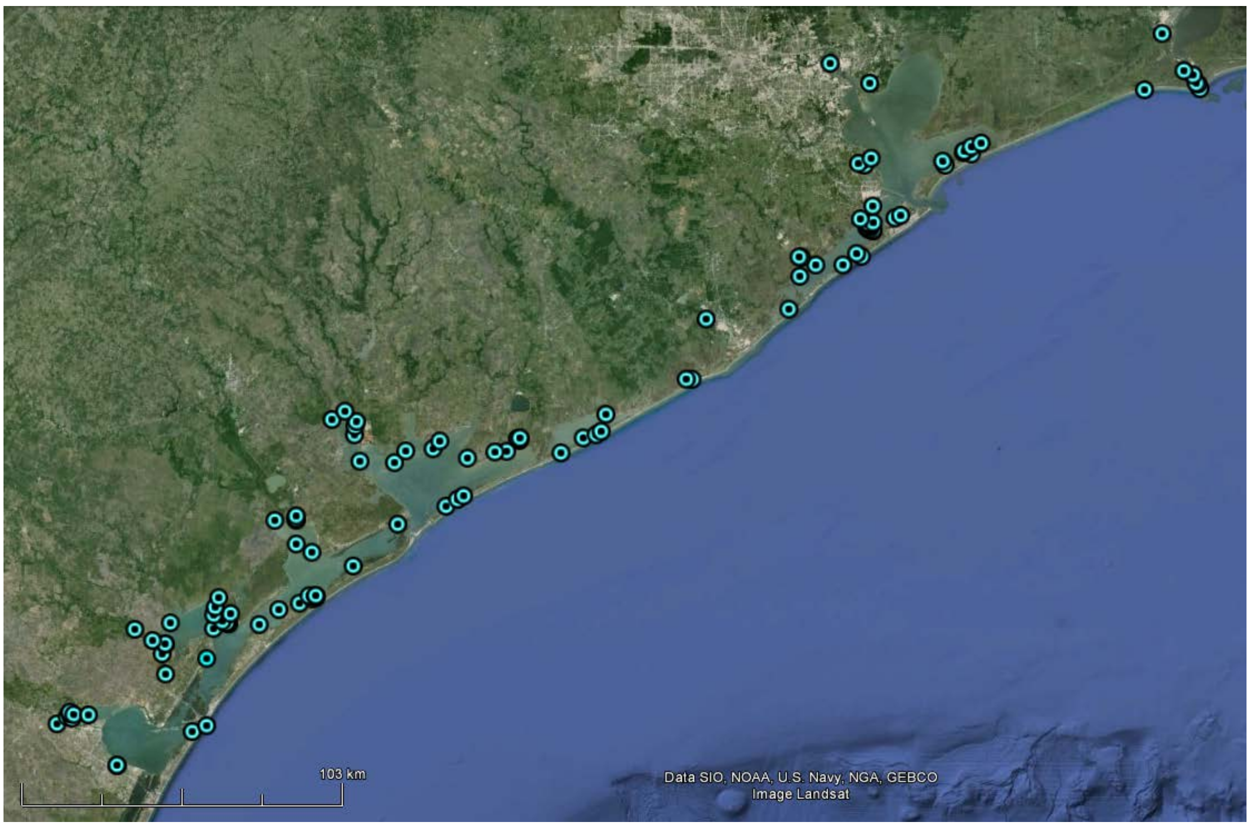

Figure 35. Location of all terrapin sightings obtained by the study questionnaire.

Figure 36. Location of all recent (10 year) terrapin sightings obtained using the study questionnaire.

During follow up questioning, two respondents supplied photographs of terrapin observed. One citizen, seeing a newspaper article pertaining to the questionnaire, emailed in a report of two terrapin (one male and female) on the Gulf side of Matagorda peninsula, across from East Matagorda Bay. All photographs from respondents can be found in Appendix C.3.

Section 4.3. New Field Data Collection

Section 4.3.1. Site Descriptions, Environmental Data, and Search Effort

Twenty four randomly generated selected sites were fully sampled (all three methods employed) during this study (8 per bay system). The location of all sampling sites, sites where terrapin were captured, and sites were no terrapin were observed are depicted in Figure 37- 39.

Environmental conditions observed during site visits are provided in

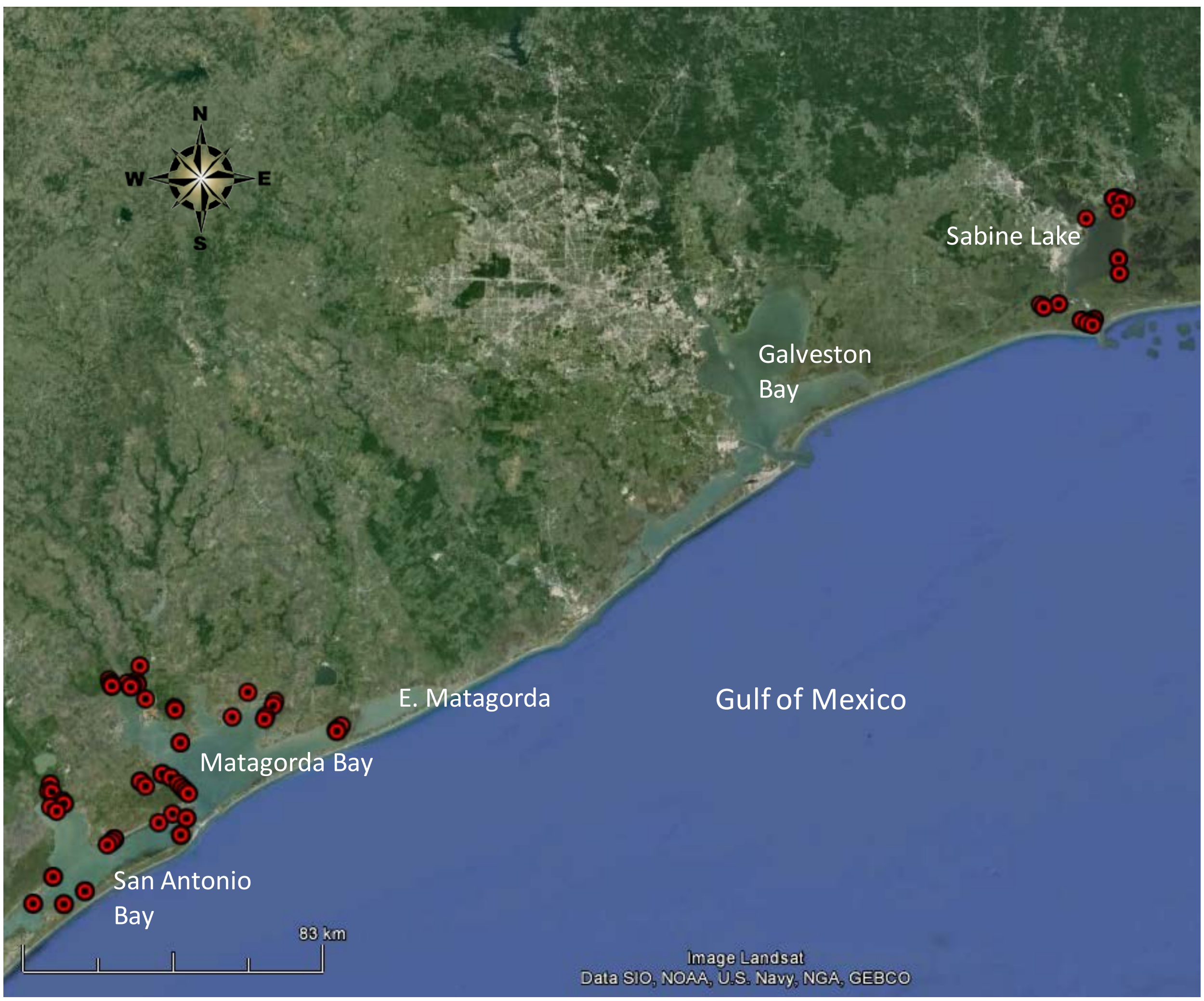

Figure 37. Sites in San Antonio Bay, Matagorda Bay, and Sabine Lake where terrapin sampling was conducted during 2014.

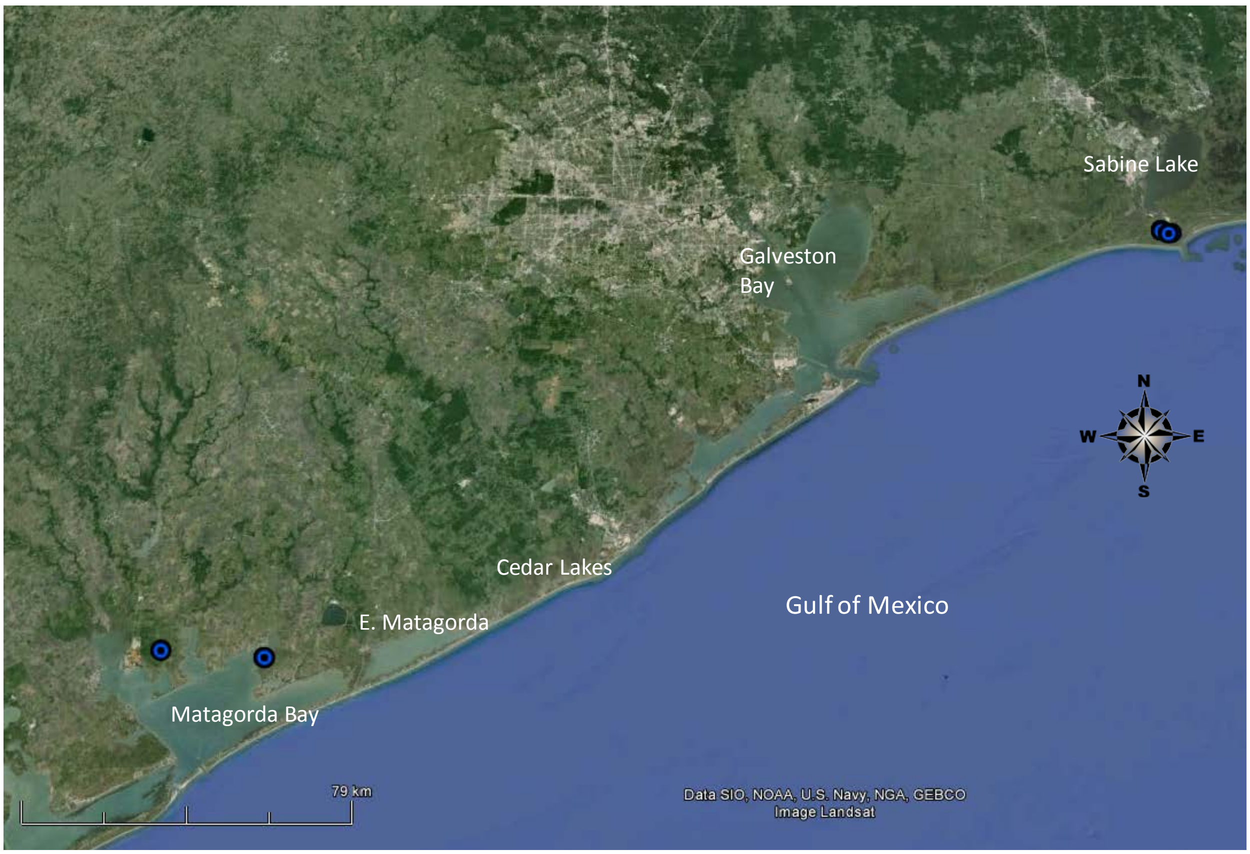

Figure 38. Sites where terrapin were in captured in Matagorda Bay and Sabine Lake during 2014.

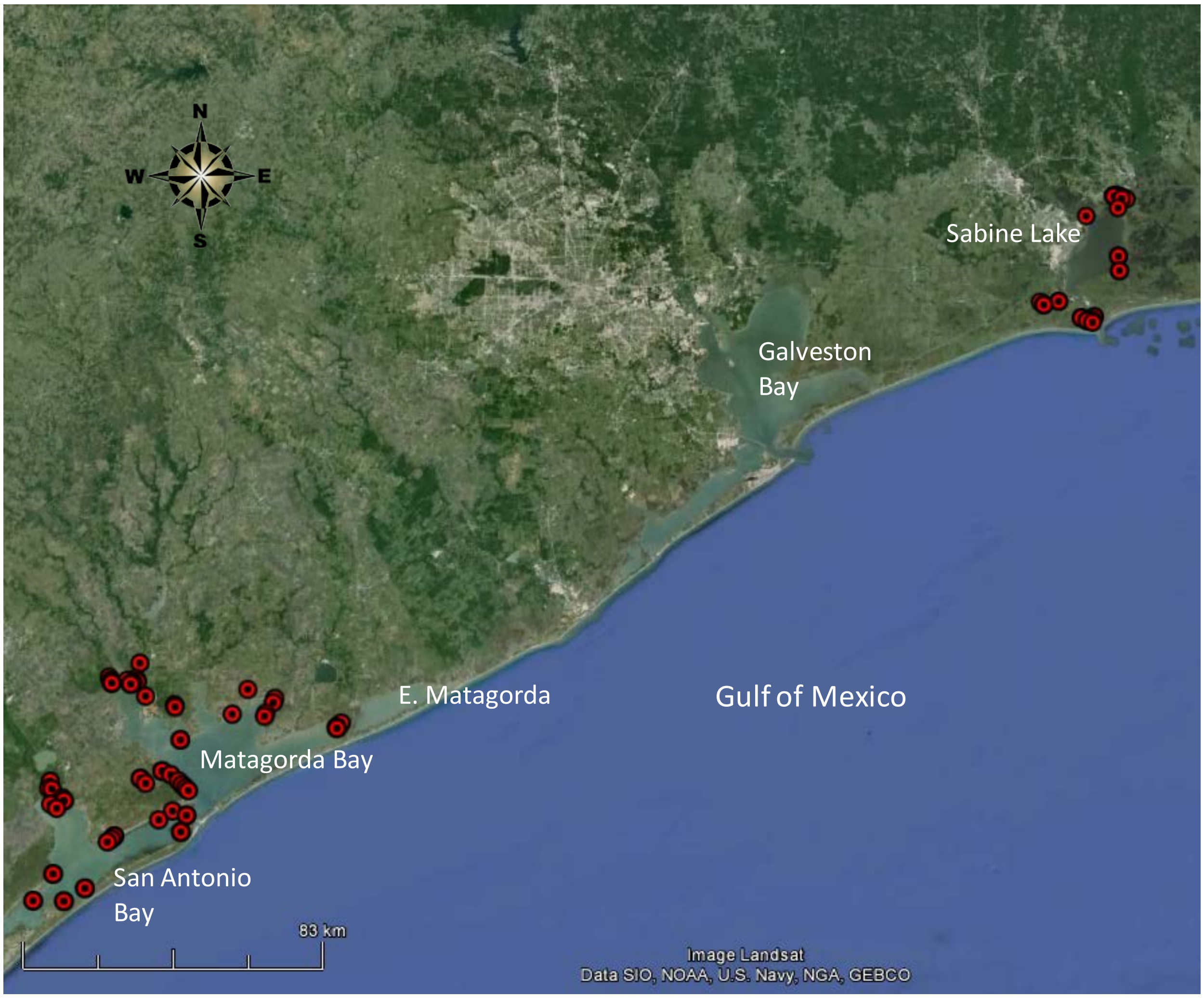

Figure 39. Sites where terrapin were not captured in San Antonio Bay, Matagorda Bay and Sabine Lake during 2014.

The average days since last significant rainfall for all sites sampled was 10.0 (range: <1-27). Mean air temperature and water temperatures for all sites sampled were 26.8°C and 24.4°C, respectively (range: 19.2-32.6°C and 17.5-33.5°C, respectively). The average salinity for all sites sampled was 27.5 ppt (range: 8-36 ppt). The mean Secchi depth for all sites sampled was 0.284 m (range: 0.052-0.073 m). The mean wind speed for all sites sampled was 8.0 mph (range: 1.5-13.4 mph).

Total biological sampling effort is summarized in Table 9. The mean head count survey time was 13.3 ± 0.95 minutes across all sites. Mean crab trap soak time was 1294.1 ± 244.83 minutes across all sites. The mean transect survey time was 338.4 ± 15.96 minutes across all sites. The crab traps were placed approximately 18.9m from shore (range: 0.5-150.0m) depending on depth (average = 0.62m, range = 0.06-1.07m) and accessibility. Crab trap effort was calculated and followed the sampling protocol described in Section 3.3.2.b with the following exceptions.

1) At site SAB-37 only one trap was set due to high wind conditions

2) At site SAB-58 the average crab trap soak times for the first visit was 1183 minutes and during the second visit it was 1211 minutes. The soak time was extended because head count surveys were unable to be performed due to lack of navigable water.

3) The average soak time was reduced to 143 minutes due to inclement weather approaching at site MAT-81.

4) At site SAN-18 the average soak time was reduced to 152 minutes due to the presence of nuisance species.

The following section of the report provides descriptions of dominant habitat, observed evidence of predators, prey, and other observations made at each fully sampled site.

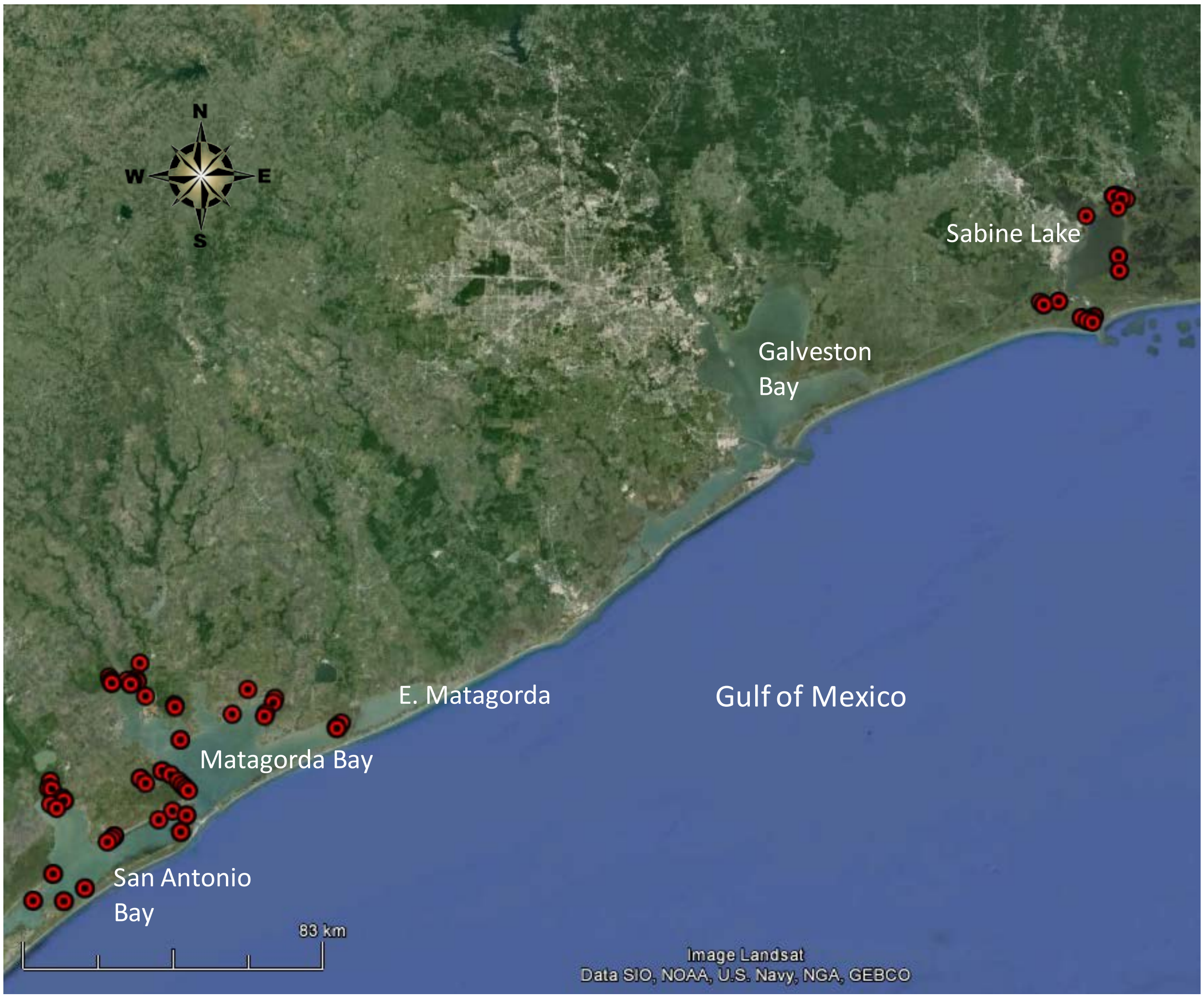

Figure 37. Sites in San Antonio Bay, Matagorda Bay, and Sabine Lake where terrapin sampling was conducted during 2014.

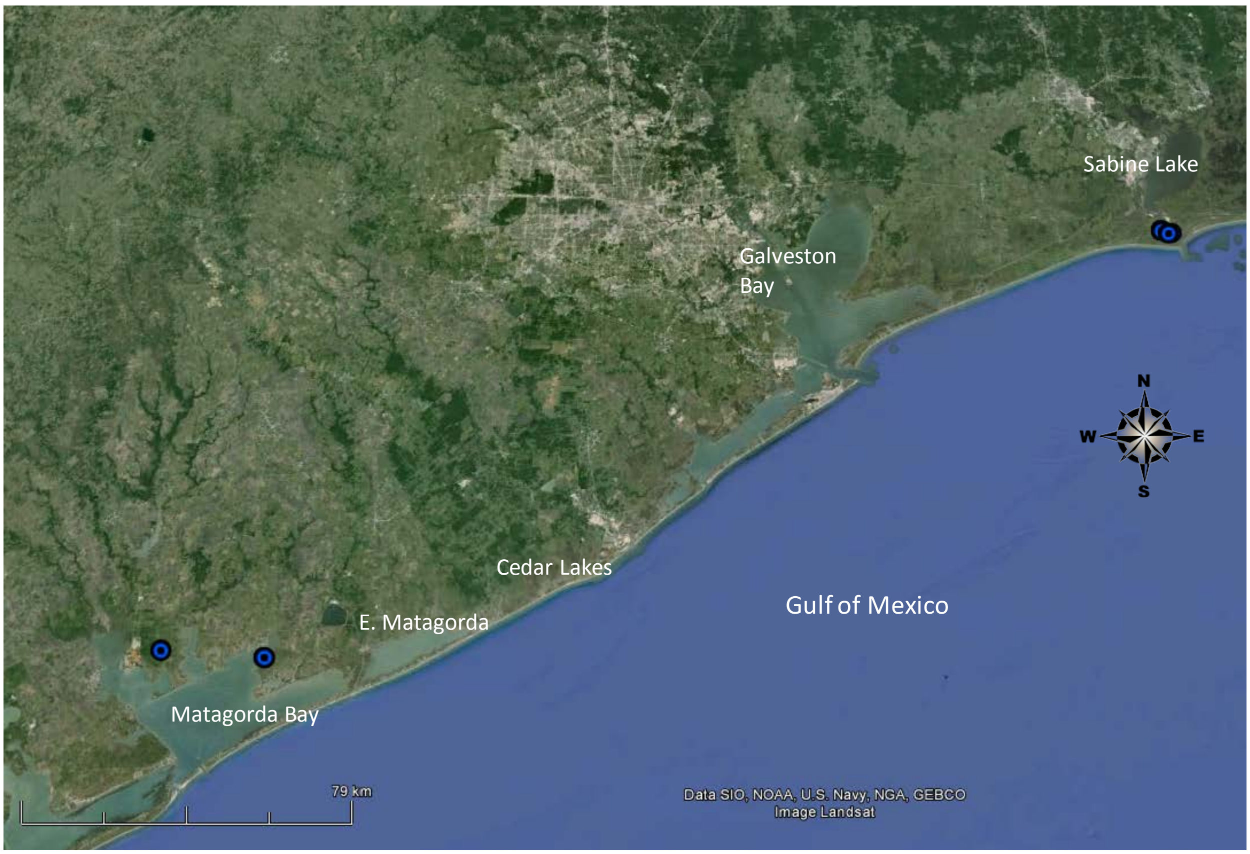

Figure 38. Sites where terrapin were in captured in Matagorda Bay and Sabine Lake during 2014.

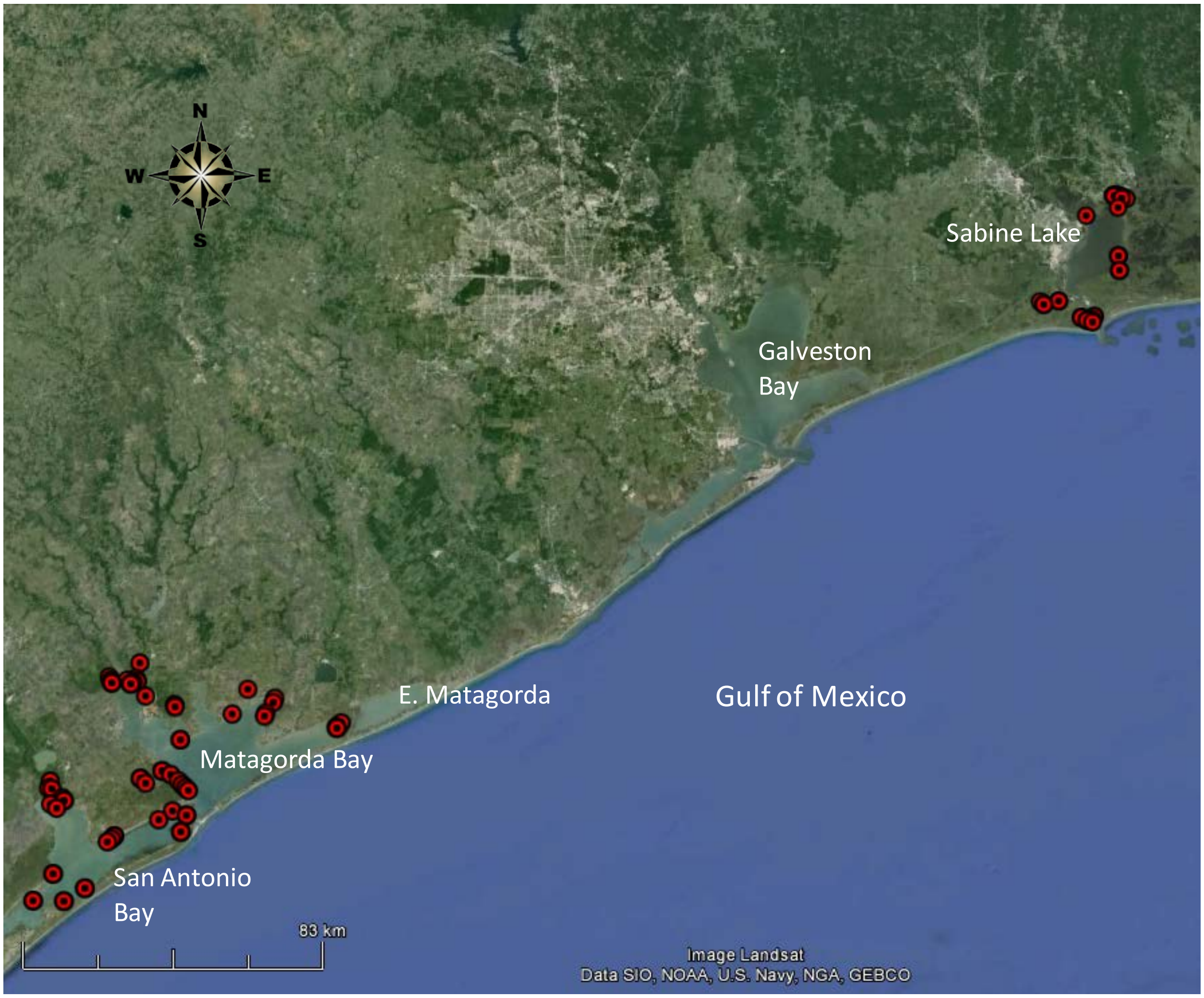

Figure 39. Sites where terrapin were not captured in San Antonio Bay, Matagorda Bay and Sabine Lake during 2014.

Table 8. Summary of environmental conditions observed during each sampling event. *Significant rainfall: > 0.10" (based on rain gauge data from nearest weather station on Wunderground.com). Bolded rows represent site revisits.

Site Name	Sample Date	DSLR*	Air Temp. (°C)	Water Temp (°C)	Salinity (ppt)	Secchi Depth (m)	Wind Speed (mph)
SAB-01	4/12/14	16	23.8	21	10	0.274	10.2
SAB-37	4/12/14	16	26.1	25.1	8	0.164	9.1
SAB-43	4/11/14	14	22.1	18.5	27	0.16	10.3
SAB-50	4/10/14	13	30.4	21.5	12	0.362	6.8
SAB-52	5/12/14	27	26.8	25	26	0.4	7
SAB-55	5/16/14	3	24	20.5	23	0.222	8.2
SAB-55	**6/17/14**	**21**	**32.3**	**29**	**15**	**0.184**	**4.9**
SAB-56	5/15/14	2	21.7	18	26	0.182	1.5
SAB-56	**6/16/14**	**20**	**32.1**	**29.5**	**15**	**0.202**	**9.3**
SAB-58	5/13/14	<1	24.8	24.5	30	0.322	7.9
SAB-58	**6/18/14**	**22**	**30.4**	**30.5**	**23**	**0.106**	**10.2**
SAB Mean ± SE		14.0 ± 2.63	26.8 ± 1.18	23.9 ± 1.33	19.6 ± 2.33	0.234 ± 0.0280	7.8 ± 0.81
MAT-09	4/18/14	4	19.2	17.5	33	0.29	7.5
MAT-12	4/18/14	4	29.6	22.5	32	0.73	3.9
MAT-14	4/28/14	14	27.9	25	35	0.3	3.7
MAT-14	**5/20/14**	**7**	**27.5**	**24**	**35**	**0.136**	**8.2**
MAT-21	5/21/14	8	27.6	27	33	0.362	10.1
MAT-27	4/25/14	11	23.4	22.5	32	0.542	3.4
MAT-34	4/27/14	13	27	24	32	0.19	11.8
MAT-81	4/17/14	11	20.3	19	30	0.362	11.2
MAT-94	4/24/14	10	27.5	25	32	0.514	8.9
MAT-94	**5/19/14**	**6**	**26.1**	**25**	**32**	**0.098**	**7.2**
MAT Mean ± SE		8.8 ± 1.12	25.6 ± 1.10	23.2 ± 0.92	32.6 ± 0.48	0.352 ± 0.0623	7.6 ± 0.98
SAN-09	4/20/14	6	22.7	20.5	23	0.224	4.9
SAN-18	6/11/14	1	30	33.5	33	0.052	10.5
SAN-20	6/12/14	2	32.1	29	34	0.142	11.9
SAN-32	6/9/24	13	30.4	28	32	0.209	13.4
SAN-54	4/19/24	5	25.4	21.5	34	0.192	9.5
SAN-63	4/19/24	5	23.6	20.5	32	0.642	3.8
SAN-90	6/11/24	1	30.1	29	32	0.53	6.2
SAN-98	6/10/24	13	32.6	30.5	36	0.132	10.1
SAN Mean ± SE		5.8 ± 1.72	28.4 ± 1.37	26.6 ± 1.78	32 ± 1.38	0.265 ± 0.0733	8.8 ± 1.22
Overall Mean ± SE		**10.0 ± 1.31**	**26.8 ± 0.70**	**24.4 ± 0.79**	**27.5 ± 1.51**	**0.284 ± 0.0317**	**8.0 ± 0.55**

Table 9. Summary of search and trap times observed during each sampling event. Bolded rows represent sites that were revisited. *SAB-37, only one trap was able to be deployed due to weather conditions; **SAB-58, crab traps were left to soak overnight to accommodate for the inability to perform head count surveys.

Site Name	Sample Date	Head Count Survey Time (min)	Total Trap Soak Time (min)	Total Transect Search Time (min)
SAB-01	4/12/2014	17	903	360
SAB-37*	4/12/2014	10	197	429
SAB-43	4/11/2014	14	906	336
SAB-50	4/10/2014	13	998	344
SAB-52	5/12/2014	11	941	360
SAB-55	5/16/2014	13	1062	363
SAB-55	6/17/2014	13	1048	373
SAB-56	5/15/2014	11	1668	370
SAB-56	6/16/2014	7	1164	395
SAB-58**	5/13/2014	0	5917	361
SAB-58**	6/18/2014	0	6057	345
SAB Mean ± SE		9.9 ± 1.66	1896.5 ± 618.33	366.9 ± 7.86
MAT-09	4/18/2014	13	909	363
MAT-12	4/18/2014	17	902	345
MAT-14	4/28/2014	17	998	364
MAT-14	5/20/2014	15	951	362
MAT-21	5/21/2014	17	910	376
MAT-27	4/25/2014	14	928	371
MAT-34	4/27/2014	10	901	365
MAT-81	4/17/2014	10	716	247
MAT-94	4/24/2014	16	1209	457
MAT-94	5/19/2014	15	1076	415
MAT Mean ± SE		14.4 ± 0.85	950.0 ± 40.62	366.5 ± 16.81
SAN-09	4/20/2014	14	908	45
SAN-18	6/11/2014	9	764	127
SAN-20	6/12/2014	23	977	334
SAN-32	6/9/2014	20	928	388
SAN-54	4/19/2014	18	898	185
SAN-63	4/19/2014	19	910	361
SAN-90	6/11/2014	16	902	351
SAN-98	6/10/2014	15	880	322
SAN Mean ± SE		16.8 ± 1.51	895.8 ± 21.40	264.1 ± 45.04
Overall Mean ± SE		**13.3 ± 0.95**	**1294.1 ± 244.83**	**338.4 ± 15.96**

Section 4.3.1.a. *Sabine Lake*

Eight sites in Sabine Lake were fully sampled with terrapin captured at three (*n* = 19): two sites within Texas Point National Wildlife Refuge and one site nearby the refuge (Figure 40 and 41). Terrapin were not captured at site SAB-58 during the initial visit, but extensive evidence of terrapin along with observations of heads in ponds throughout the site dictated a revisit during the second sampling round. Head count surveys were unable to be employed during both visits to site SAB-58 due to lack of navigable water ways and access to the site only from the road.

Sabine Lake Sites Visited But Not Searched

In addition to the fully sampled sites, 10 sites in Sabine Lake were also visited. Full samples were not performed at these sites due to various reasons outlined in Table 10. In some cases valuable partial information was still obtained on the occurrence of terrapin.

SAB-01

Site SAB-01 (Figure 42) was visited on 12 April 2014. The site primarily consisted of *Spartina patens* with patches of *Juncus* spp., *S. alterniflora, Scirpus* spp., and *Distichlis spicata*. Substrate was primarily soft mud with a few stagnant pools throughout the walking transect area. *Littorina* spp. snail was observed near creek edges and along the shoreline and fiddler crab burrows persisted throughout. Little evidence of predators was observed, though, muskrat nests (*n* = 5) were documented as well as various marsh bird species. No evidence of terrapin was observed during the search.

SAB-37

Site SAB-37 (Figure 43Figure 43) was visited on 12 April 2014. The site primarily consisted of *S. patens* with patches of *Scirpus* spp. Additionally, patches of highland vegetation lined with hog trails were found throughout the sample area. Substrate was primarily firm mud covered in vegetation >0.5 m tall. A few stagnant pools and holes persisted throughout the walking transect area but there was no evidence of tidal creeks or recent inundation. No prey sources were readily observed. Muskrat nests as well as coyote and boar evidence were observed during walking transects. The shoreline consisted of a thin strip of mixed shell hash and mud. No evidence of terrapin was readily observed during the search. During the site visit, only one trap was able to be set at this site due to high wind conditions. Search time was increased per searcher to partially accommodate for the loss of trap effort.

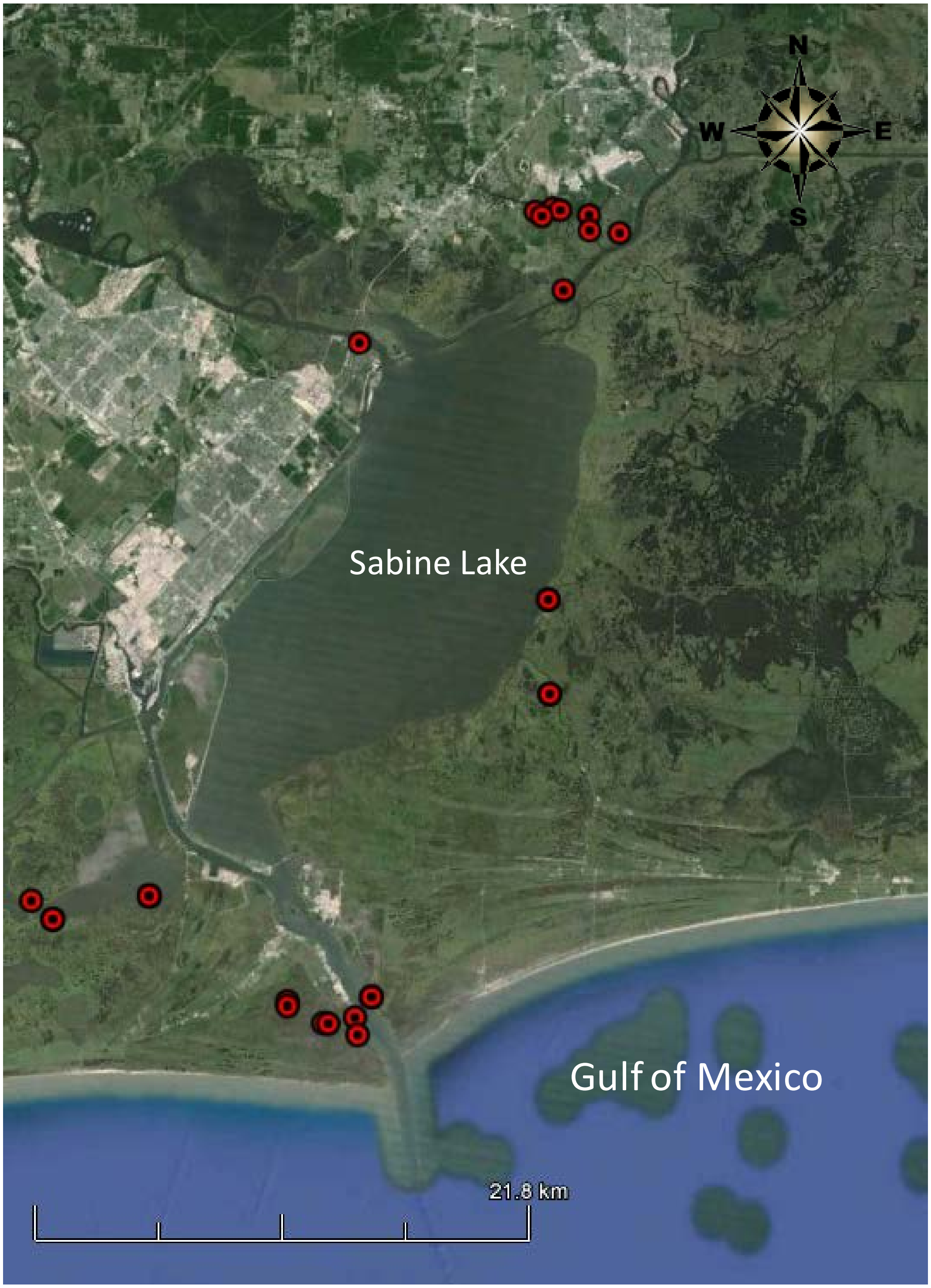

Figure 40. Location of all sampling locations in Sabine Lake during 2014.

Figure 41. Location of terrapin captured during 2014 in Sabine Lake.

Table 10 Sabine Lake sites visited but not sampled[2]. *Significant rainfall: > 0.10" (based on rain gauge data from nearest weather station on Wunderground.com).

Site	Date	DSLR*	Salinity (ppt)	Air Temp (°C)	Water Temp (°C)	Secchi Disk (m)	Wind Speed (mph)	Head Count Time (min)	Reason for Not Sampling
SAB-17	4/13/2014	28	4	22.6	20	0.272	8.6	16	No access; dense vegetation
SAB-18	4/13/2014	28	3						Posted
SAB-19	4/13/2014	28	4	23.3	20	0.27	5.1	14	Limited walkability
SAB-20	4/13/2014	28	3	23.9	21.5	0.332	7.2	14	Dominant freshwater vegetation
SAB-21	4/13/2014	28	4	23.3	20	0.27	5.1		Limited walkability
SAB-23	4/13/2014	28	3	23.9	21.5	0.332	7.2		No access
SAB-24	4/13/2014	28	3						Posted with no access
SAB-26	4/13/2014	28	5						Dangerous access
SAB-30	4/13/2014	28	7						No access; dominant upland vegetation
SAB-48	4/10/2014	13	15	21.4	19	0.058	14.5	12	Dangerous access

[2] At each of these sites, only some environmental data were recorded and photographs were taken, if possible. These sites were not fully sampled for various reasons, including: issues with accessibility (i.e. steep or cliff-like banks, no access from water or roadways, etc.); posted “No Trespassing” areas or areas clearly marked as private property; issues with walkability (i.e. very soft sediment, thick or impassable vegetation, etc.); dominance of upland or non-saltmarsh vegetative species (i.e. Alligator weed [*Alternanthera philoxeroides*], Palmetto [*Sabal minor*], Sawgrass [*Cladium jamaicense*], etc.); similarity to other previously sampled sites; and lack of time to complete site visit. A full database including all parameters and observations documented for each site is included in Appendix E.

AB-01

Figure 42. Photograph of SAB-01 habitat taken during field survey on 4/12/14.

Site SAB-01 (Figure 42) was visited on 12 April 2014. The site primarily consisted of *Spartina patens* with patches of *Juncus* spp., *S. alterniflora*, *Scirpus* spp., and *Distichlis spicata*. Substrate was primarily soft mud with a few stagnant pools throughout the walking transect area. *Littorina* spp. was observed near creek edges and along the shoreline and fiddler crab burrows persisted throughout. Little evidence of predators was observed, though, muskrat nests (n = 5) were documented as well as various marsh bird species. No evidence of terrapin was readily observed during the search.

SAB-37

Figure 43. Photograph of SAB-37 habitat taken during the field survey on 4/12/14

Site SAB-37 (Figure 43) was visited on 12 April 2014. The site primarily consisted of *S. patens* with patches of *Scirpus* spp. Additionally, patches of highland vegetation lined with hog trails were found throughout the sample area. Substrate was primarily firm mud covered in vegetation >0.5 m tall. A few stagnant pools and holes persisted throughout the walking transect area but there was no evidence of tidal creeks or recent inundation. No prey sources were readily observed. Muskrat nests as well as coyote and boar evidence were observed during walking transects. The shoreline consisted of a thin strip of mixed shell hash and mud. No evidence of terrapin was readily observed during the search. During the site visit, only one trap was able to be set at this site due to high wind conditions. Search time was increased per searcher to partially accommodate for the loss of trap effort.

SAB-43

Figure 44. Photograph of SAB-43 habitat taken during the field survey on 4/11/14.

Site SAB-43 (Figure 44) was visited on 11 April 2014. The site primarily consisted of *Batis maritima* mixed with patches of *Salicornia* spp., *S. alterniflora*, and *Juncus* spp. The site was located approximately 1 km north of the transect survey start point, a tidal creek lined with *S. alterniflora* marsh cut through the sample area. This area was inaccessible by boat due to low tide and searchers only made it to the edge of the marsh area before returning during transect surveys. The substrate was primarily firm mud. Fiddler crab burrows were found throughout the walking transect sample area and *Littorina* spp. were observed near the aforementioned tidal creek. No evidence of predation was readily observed. No evidence of terrapin was readily observed during the search. It should be noted that traps were set along the shoreline immediately off of the Sabine Pass ship channel and heavy barge traffic knocked the traps over while they were soaking. This wave action from barge traffic has also caused heavy erosion along the shoreline with some ledges >1 m in vertical height.

SAB-50

Figure 45. Photograph of SAB-50 habitat taken during the field survey on 4/10/14.

Site SAB-50 (Figure 45) was visited on 10 April 2014. The site primarily consisted of tall (>0.5 m tall) *S. patens* with patches of *Scirpus* spp., *D. spicata*, and *S. alterniflora*. Small, stagnant ponds were found throughout the sample area. Additionally, a small tidal creek and pond system with *Littorina* spp. scattered throughout was searched during transect surveys, but, no evidence of terrapin or other prey sources were readily observed during the search. This site contained little to no evidence of predator presence. No evidence of terrapin was readily observed during the search.

SAB-52

Figure 46. Photograph of SAB-52 habitat taken during the field survey on 5/12/14.

Site SAB-52 (Figure 46) was visited on 12 May 2014. The site primarily consisted of *S. alterniflora* mixed with tall (>0.5 m) patches of *D. spicata*, *B. maritima*, *Iva* spp., *Scirpus* spp., and *S. alterniflora*. Seagrasses and submerged vegetation were present in some small ponds throughout. *Littorina* spp. was observed along the fringes of the marsh area as well as blue crab remains and *Geukensia* spp. was scattered throughout. Muskrat nests as well as coyote and raccoon droppings were observed during transect surveys. No evidence of terrapin was observed during the search. Additionally, a tidal creek was observed ~ 300 m south of the starting point that was lined with submerged crab pots.

SAB-55

Figure 47. Photograph of SAB-55 habitat taken during the field survey on 5/16/14. This site was revisited on 6/17/14 under similar conditions as those depicted (see Table 8 for actual site conditions during each sampling event).

Site SAB-55 (Figure 47) was initially visited on 16 May 2014 and revisited on 17 June 2014. The site primarily consisted of thick *S. alterniflora* stands with patches of *Juncus* spp. and *D. spicata*. Substrate was primarily mud covered in thick stands of vegetation with pocket mud flats along one observer's transect. *Littorina* spp. was observed throughout along with fiddler crabs and *Geukensia* spp. Raccoon tracks were observed during transect surveys but no other signs of predators were readily observed. Four terrapin were captured during the initial site visit and one terrapin was captured during the revisit. See Section 4.3.2 for more information on terrapin captures and observations across all sites.

SAB-56

Figure 48. Photograph of SAB-56 habitat taken during the field survey on 5/15/14. This site was revisited on 6/16/14 under similar conditions as those depicted (see Table 8) for actual site conditions during each sampling event).

Site SAB-56 (Figure 48) was initially visited on 15 May 2014 and revisited on 16 June 2014. The site primarily consisted of a thick mixture of *S. alterniflora* and *S. patens* with patches of *Juncus* spp., *B. maritima, D. spicata, Scirpus* spp., and *Borrichia frutescens*. Substrate was similar to that described for site SAB-55. *Littorina* spp. and fiddler crabs were observed throughout. Raccoon tracks and coyote scat were also observed. During the revisit, water levels were elevated compared to initial conditions and all substrate was inundated. Ten terrapin were captured during the initial site visit and two terrapin were captured during the revisit. See Section 4.3.2 for more information on terrapin captures and observations across all sites.

SAB-58

Figure 49 Photograph of SAB-58 taken during field survey on 5/13/14. This site was revisited on 6/18/14 under similar conditions as those depicted (see Table 2 for actual site conditions during each sampling event).

Site SAB-58 (Figure 49) was initially visited on 13 May 2014 and revisited on 18 June 2014. The site primarily consisted of a thick mixture of *S. alterniflora*, *Juncus* spp., *Scirpus* spp., *B. maritima*, *Salicornia* spp., and *B. frutescens*. Substrate was similar to that described for sites SAB-55 and 56. In addition, submerged and emergent vegetation persisted throughout ponds during both visits. Most creeks and ponds were covered in surficial layers of *Sargassum* spp. *Littorina* spp., small fish, blue crabs and fiddler crabs were observed throughout. A raccoon was observed during transect surveys and the site housed various horseflies, mosquitoes, and gnats. This site was located directly off a gravel road with no water bodies large enough for head count surveys to be performed. Instead, crab traps were left to soak overnight during both visits to accommodate for the loss of head count survey sampling. No terrapin were captured during the initial site survey although heads were observed in small tidal ponds during transect surveys. Two terrapin were captured during the second visit.

Matagorda Bay

Two of the eight sites in Matagorda Bay that were fully surveyed yielded terrapin (*n* = 5 terrapin) (Figure 50-53). Terrapin were captured in Keller Bay and Tres Palacios Bay. In addition to the fully sampled sites, 20 sites in Matagorda Bay were also visited. Full surveys were not performed at 13 of these sites due to various reasons outlined in Table 11. Seven of the 20 additional sites visited appeared to have potential terrapin habitat, but were not sampled due to various reasons outlined in Table 12.

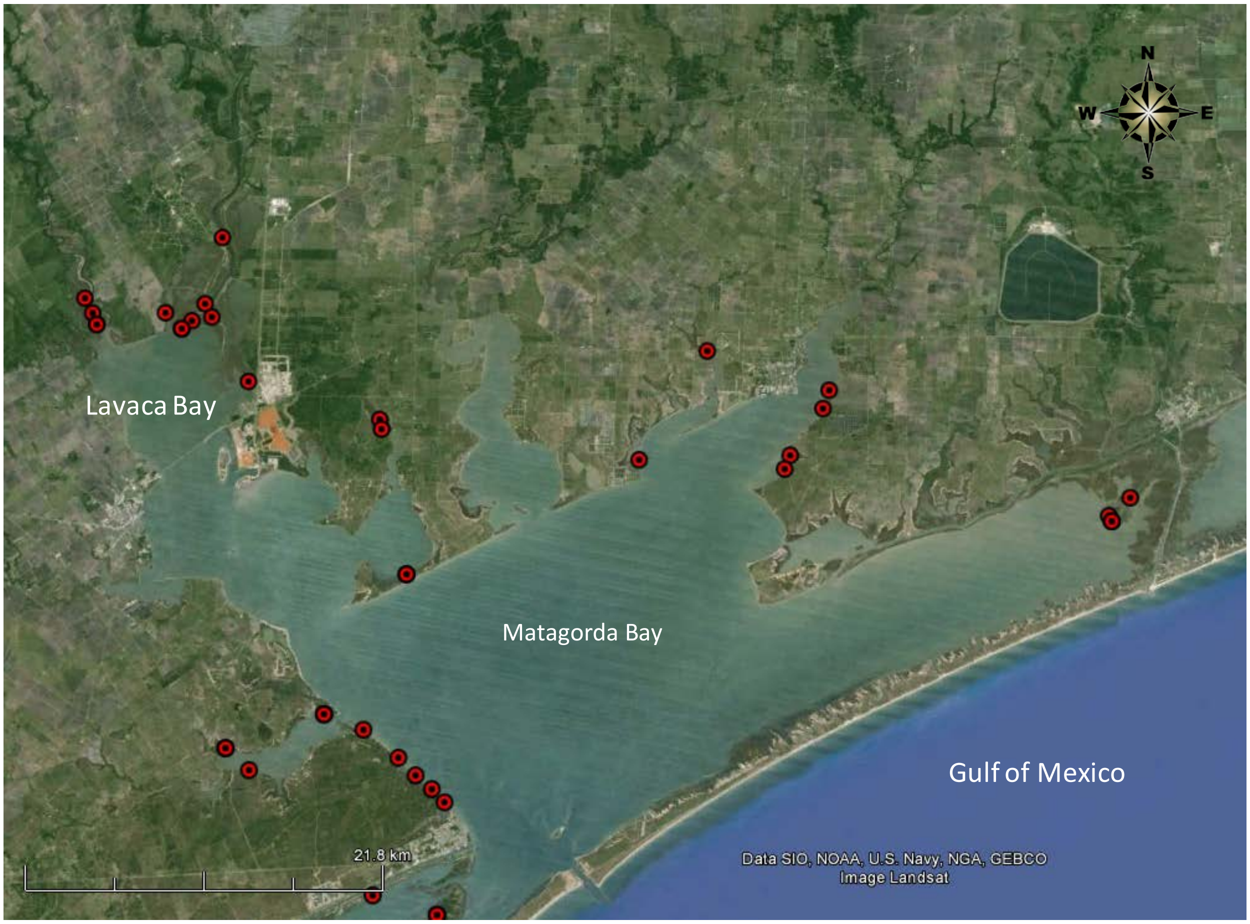

Figure 50. Location of sites sampled in Matagorda Bay during 2014.

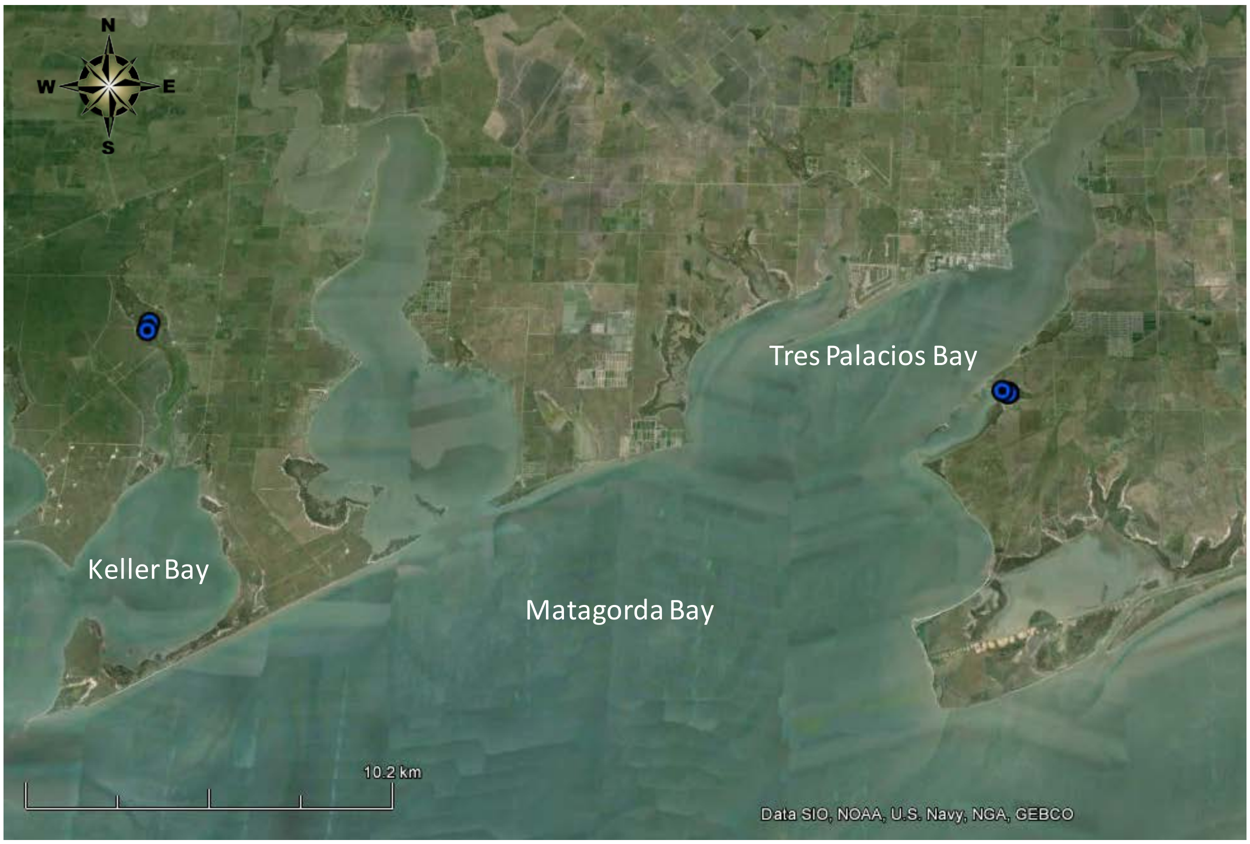

Figure 51. Locations of sites in Matagorda where terrapin where captured in 2014.

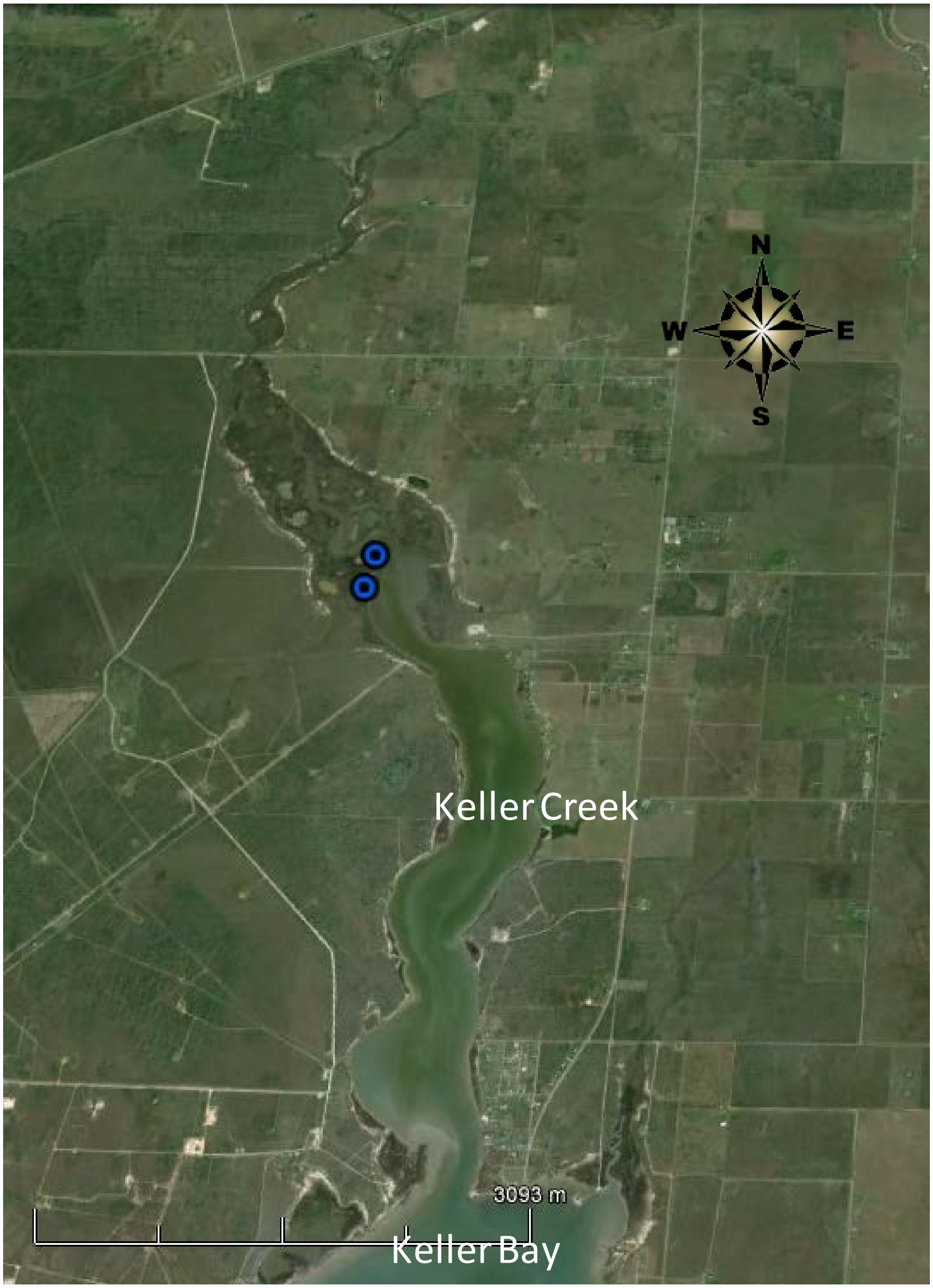

Figure 52. Location of captured terrapin collected in Keller Bay north of Matagorda Bay.

Figure 53. Location of captured terrapin collected in 2014 in Coon Island Bay, a tributary to Tres Palacio Bay and Matagorda Bay.

Table 11. Matagorda Bay sites visited but not sampled. *Significant rainfall: > 0.10" (based on rain gauge data from nearest weather station on Wunderground.com).

Site	Date	DSLR*	Salinity (ppt)	Air Temp (°C)	Water Temp (°C)	Secchi Disk (m)	Wind Speed (mph)	Head Count Time (min)	Reason for Not Sampling
MAT-03	4/26/2014	12	33		24.5				No access; dense vegetation
MAT-04	4/26/2014	12	32	24.9	24	0.68	5.5		Heavy pollution
MAT-06	4/26/2014	12	32		25				Posted; dense vegetation
MAT-07	4/18/2014	4	32	24.3	20.5	0.312	2.6	22	Dominant upland vegetation
MAT-11	4/26/2014	12	34	25.1	24.5	0.372	12		Posted
MAT-31	4/25/2014	11	26						Dense vegetation
MAT-32	4/25/2014	11	26						Private; dominant upland vegetation
MAT-38	4/25/2014	11	26						Private property
MAT-40	4/25/2014	11	22						Private property
MAT-47	4/21/2014	7	32	22.3	21	0.22	10.9		Private property
MAT-50	4/21/2014	7	34	22.7	22.5	0.137	10.8	13	Dense vegetation
MAT-84	4/24/2014	10	31	25.7	24	0.338	6.5		No access; dominant upland vegetation
MAT-85	4/24/2014	10	31	25.7	24	0.338	6.5		No access; dominant upland vegetation

Table 12 Matagorda sites that were not sampled but may provide suitable habitat for terrapin. Sites not sampled due to not being randomly selected, weather conditions, or similarity to sites sampled nearby[2]. *Significant rainfall: > 0.10" (based on rain gauge data from nearest weather station on Wunderground.com).

Site	Date	DSLR*	Salinity (ppt)	Air Temp (°C)	Water Temp (°C)	Secchi Disk (m)	Wind Speed (mph)	Reason for Not Sampling
MAT-10	4/26/2014	12	32	24.9	24	0.68	5.5	Habitat and accessibility good
MAT-26	4/27/2014	13	33	27	24.5	0.35	7.4	Similar to MAT-34 (sampled)
MAT-33	4/25/2014	11	32					Juncus marsh with small creeks
MAT-35	4/25/2014	11	32					Similar to MAT-27 (sampled)
MAT-37	4/27/2014	13	33	27	24.5	0.35	7.4	Conditions no conducive to sampling
MAT-86	4/17/2014	11	30					Habitat good, accessibility difficult
MAT-93	4/17/2014	11	30					Similar to MAT-81 (sampled)
	Average ± SE	**11.7 ± 0.36**	**31.7 ± 0.47**	**26.3 ± 0.70**	**24.3 ± 0.17**	**0.460 ± 0.1100**	**6.8 ± 0.63**	

MAT-09

Figure 54. Photograph of MAT-09 habitat taken during field survey on 4/18/14.

Site MAT-09 (Figure 54) was visited on 18 April 2014. The vegetation at the site primarily consisted of *S. alterniflora* mixed with *D. spicata*, *B. maritima*, *Salicornia* spp., *Juncus* spp., and *S. patens*. The topography of the sample area transformed from marsh to upland habitat with bobwhite quail heard by searchers during surveys. Smooth snails, *Littorina* spp., and fiddler crab claws were observed. The site appears to be used as hunting land with duck blinds, shotgun shells, and tractor/ATV tire marks observed. Little evidence of predator presence was documented, although, unidentified scat, hoof prints, and human footprints were observed. No evidence of terrapin was observed during the search.

MAT-12

Figure 55 Photograph of MAT-12 taken during field survey on 4/18/14. Also visible are structural remains from a house located within the walking transect search area.

Site MAT-12 (Figure 55) was visited on 18 April 2014. The site primarily consisted of marsh mixed with *Salicornia* spp., *B. maritima*, *Avicennia germinans* and small stands of *S. alterniflora*. The sample area contained deep tidal creeks and ponds distributed throughout. *Littorina* spp., various fish species, hermit crabs, oysters and other prey sources were observed during walking transects. High levels of human recreation were documented during surveys with kayakers, wade fishermen, children swimming, and boat traffic all observed. Little evidence of predator presence was documented. Evidence of terrapin was lacking during the site survey, though habitat looked to be ideal at the time of sampling.

MAT-14

Figure 56. Photograph of MAT-14 taken during field survey on 4/28/14. This site was revisited on 5/20/14 under similar conditions as those depicted (see Table 8 for actual site conditions during each sampling event).

Site MAT-14 (Figure 56) was initially visited on 28 April 2014 and revisited on 20 May 2014. The site primarily consisted of a thick mixture of *S. alterniflora*, *Juncus* spp., *S. patens*, *B. frutescens*, *B. maritima*, *D. spicata*, *Salicornia* spp. and *Iva* spp. Substrate was firm, inundated mud with some ponds and creeks throughout the sample area. *Littorina* spp., smooth snails, small fish, horn snails and fiddler crabs were observed throughout. Raccoon tracks, coyote scat, and game trails were also observed during transect surveys. One terrapin was captured during the initial visit and one during the revisit, though multiple heads were observed in creeks, ponds, and open water during each sampling event. See Section 4.3.3 for more information on terrapin captures and observations across all sites.

MAT-21

Figure 57 Photograph of MAT-21 taken during field survey on 5/21/14.

Site MAT-21 (Figure 57) was visited on 21 May 2014. The vegetation at the site was primarily composed of *B. maritima* and *Salicornia* spp. mixed with small pockets of *S. alterniflora*. Most of the sediment consisted of dry, cracked mud with smaller pockets of ponds and marsh areas. We documented little to no prey resources at the site. Evidence of predators was generally lacking although, game trails, large hoof prints, and 4-wheeler tracks were observed. No evidence of terrapin was observed during the search.

MAT-27

Figure 58 Photograph of MAT-27 taken during field survey on 4/25/14.

Site MAT-27 (Figure 58) was visited on 25 April 2014. The site consisted of mixed marsh including *B. maritima*, *Salicornia* spp., *S. alterniflora*, *D. spicata*, *Juncus* spp., *Iva* spp., and *S. patens*. Throughout the sample area, most of the sediment consisted of dry, cracked mud with small pockets of pond and marsh areas. As walking transects extended away from shore, sediment became softer and less dry. *Geukensia* spp., horn snails, and *Littorina* spp. were observed during surveys. Coyote scat, game trails, and raccoon evidence were also documented. No evidence of terrapin was readily observed during the search.

MAT-34

Figure 59 Photograph of MAT-34 taken during field survey on 4/27/14.

Site MAT-34 (Figure 59) was visited on 27 April 2014. The site primarily consisted of thick, tall (>0.5 m) stands of *Juncus* spp. with patches of *B. maritima, S. alterniflora, Iva* spp., and *D. spicata*. High wind conditions pushed water into the site inundating sediment. Smooth snails, *Littorina* spp., and fiddler crabs were observed. There was little evidence of potential terrapin predators at the site although unidentified scat, many large wading birds, and a marsh snake were observed. Evidence of terrapin was lacking during the site survey.

MAT-81

Figure 60 Photograph of MAT-81 taken during field survey on 4/17/14.

Site MAT-81 (Figure 60) was visited on 17 April 2014. The site primarily consisted of *S. alterniflora* with patches of *B. maritima* and *Salicornia* spp. Sediment was a mixture of sand and mud. *Littorina* spp., *Geukensia* spp., horn snails, and clams were observed. There was little evidence of predators at the site although some areas appeared to have been excavated by small mammals. No evidence of terrapin was observed during the search. Sampling effort (walking transect time and total trap soak time) was reduced due to inclement weather entering the area towards the end of sampling.

MAT-94

Figure 61. Photographs of MAT-94 taken during field surveys. The bottom right (4/24/14) depicts conditions at the original site coordinates. During the revisit (5/19/14, top right), sampling at the site was shifted 883 m north-northeast (left) to a pocket marsh nearer to terrapin captures from 4/24/14.

Site MAT-94 (Figure 61) was initially visited on 24 April 2014 and revisited on 19 May 2014. During the first site visit, the site primarily consisted of small stands of *S. alterniflora*, *Juncus* spp., *B. maritima, D. spicata,* and *Salicornia* spp (lower right image of Figure 61). Substrate was firm, and exposed throughout much of the sampled area. Little to no evidence of prey sources was observed. Deep cow tracks were found throughout and, in many areas, sediment under these tracks was soft and deep. North of the projected sample site coordinates exists a thin strip of *S. alterniflora* dominated marsh. Terrapin was captured by trap at the mouth of a creek entering this marsh area and during walking transect surveys. Biologists also observed swimming terrapin “heads” in tidal ponds and creeks along the marsh. During the revisit the starting coordinates for searches and head count surveys was moved approximately 883m north of the original site location in order to expand and include more of the marsh area (upper right image of Figure 61). Within this "new" search area, fiddler crabs, small insects, and other potential prey sources were observed throughout the study area. Searchers observed multiple heads of turtle swimming in creeks and ponds. Additionally, one terrapin was captured by trap during the second survey at the site. See Section 4.3.3 for more information on terrapin captures and observations across all sites.

Section 4.3.1.b. *San Antonio Bay*

Eight sites in San Antonio bay were fully surveyed with no terrapin captured (Figure 62). In addition to the fully sampled sites, 10 sites in San Antonio Bay were also visited. Full surveys were not performed at these sites due to various reasons outlined in
Table 13. The majority of these sites were considered freshwater tidal wetlands which typically across the range of terrapin do not harbor large populations of the species (Brennessel 2006).

Table 13 San Antonio Bay sites visited but not sampled[2]. *Significant rainfall: > 0.10" (based on rain gauge data from nearest weather station on Wunderground.com).

Site	Date	DSLR*	Salinity (ppt)	Air Temp (°C)	Water Temp (°C)	Secchi Disk (m)	Wind Speed (mph)	Head Count Time (min)	Reason for Not Sampling
SAN-05	4/20/2014	6	25						No access (shallow depth)
SAN-06	4/20/2014	6	26						Posted
SAN-08	4/20/2014	6	20						No access
SAN-12	4/20/2014	6	4	24	22.5	0.08	6.4	9	Dominant freshwater vegetation
SAN-13	4/20/2014	6	10	25.6	22	0.172	4.5	15	Dominant freshwater vegetation
SAN-14	4/20/2014	6	3						Dominant freshwater vegetation
SAN-28	5/21/2014	8	31	26.3	25.5	0.152	6		Dominant upland vegetation
SAN-38	5/21/2014	8	35	25.6	24	0.24	7.8		Dominant upland vegetation
SAN-41	5/21/2014	8	34	26	24	0.238	9.9		Dominant upland vegetation
SAN-44	5/21/2014	8	32	26.2	26	0.22	9.5		No access

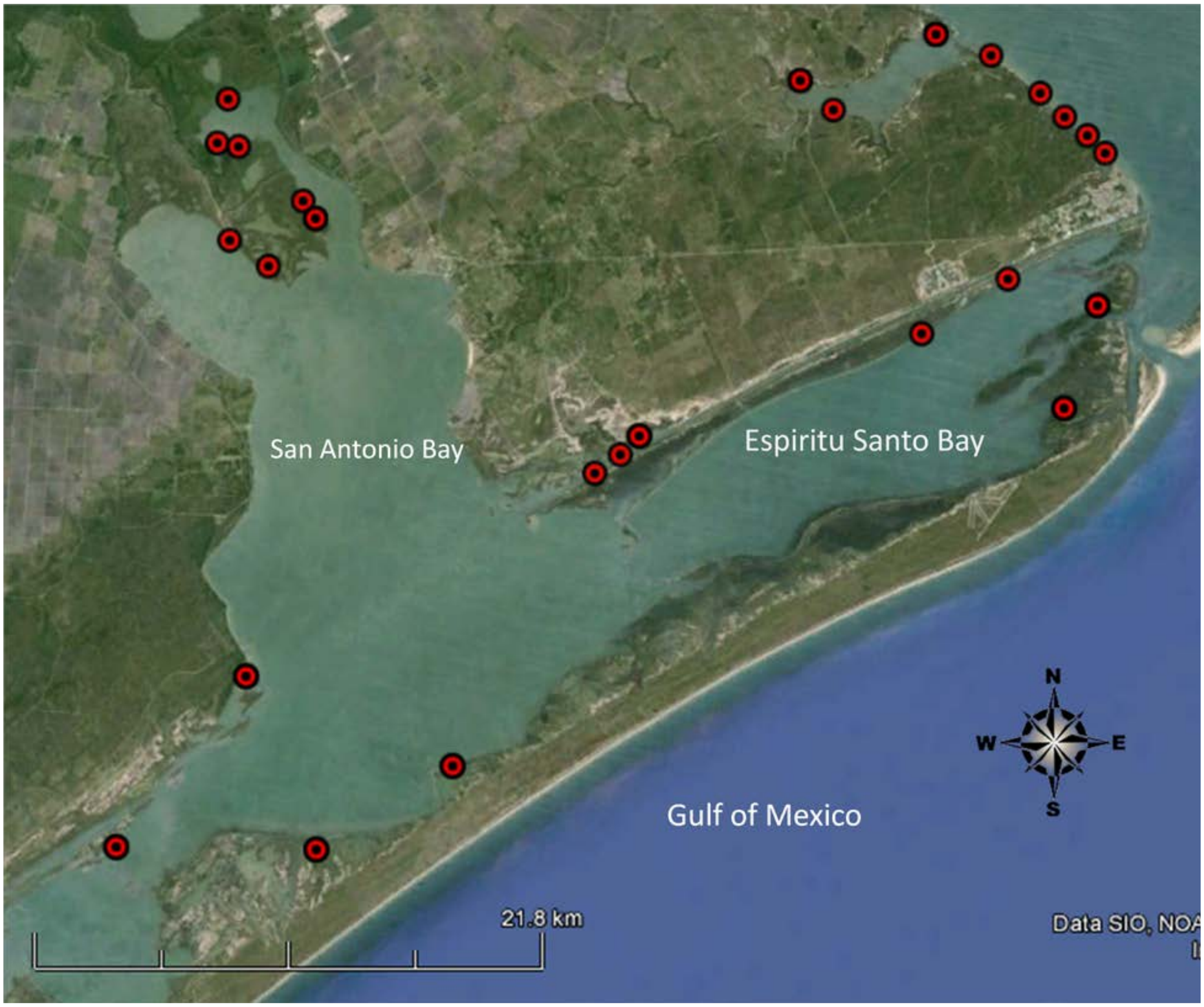

Figure 62. Site searched for terrapin in the San Antonio Bay complex.

SAN-09

Figure 63 Photograph of SAN-09 taken during field survey on 4/20/14.

Site SAN-09 (Figure 63) was visited on 20 April 2014. The site primarily consisted of upland, freshwater plants, including, *Baccharis halimifolia* and *Phragmites australis*. Most of the sediment consisted of dry, cracked mud. Terrapin prey resources were not observed. Game trails were observed throughout the site and hogs heard rustling through brush. No evidence of terrapin was readily observed during the search. Walking transect time was greatly reduced due to presence of heavy concentrations of biting and stinging insects and lack of "ideal" terrapin habitat (i.e. dense dominant freshwater vegetation; firmly packed sediment).

SAN-18 – Not Photographed

Site SAN-18 was visited on 11 June 2014. The site primarily consisted of thick stands of *A. germinans* with surficial mix of *B. maritima* and *Salicornia* spp. A thin strip (<10 m) of *S. alterniflora* lined the shore of the site, but did not persist throughout. Most of the sediment consisted of dry, cracked mud. Searchers were able to cover the extent of the island within less than 130 minutes of total search time. No prey sources were observed and no evidence of predator presence was documented. Additionally, no evidence of terrapin was observed during the search. Nuisance insect species were prevalent throughout the search area. No photographs were taken at the time of this visit.

SAN-20

Figure 64 Photograph of SAN-20 taken during field survey on 6/12/14.

Site SAN-20 (Figure 64) was visited on 12 June 2014. The site primarily consisted of mixed marsh including *B. maritima, Salicornia* spp., *D. spicata, B. frutescens, A. germinans,* and *S. alterniflora* lining tidal creeks and ponds. Sediment was moist mud, with pockets of higher, dry, cracked mud flats. *Littorina* spp., fiddler crabs, and horn snails were observed throughout the search area. Coyote tracks and scat as well as hog trails and 2 piglets were also observed. Additionally, observation towers and decks were present approximately 350 m north of the search location. Evidence of terrapin was lacking at this site during the survey period.

SAN-32

Figure 65. Photograph of SAN-32 taken during field survey on 6/9/14.

Site SAN-32 (Figure 65) was visited on 9 June 2014. The site primarily consisted of mixed marsh including *B. maritima, Salicornia* spp., *D. spicata, B. frutescens, A. germinans,* and *S. alterniflora*. Also present along creek edges and shorelines were patches of Black Mangrove (*A. germinans*) and patches of submerged sea grasses. Sediment was primarily mud, with large areas of higher, dry, cracked mud flats. Only fiddler crabs and small snails were observed throughout the search area. Coyote tracks and scat, raccoon tracks, and cattle trails were observed throughout. A dolphin was observed feeding in the shallow water off the shore line (<1m deep). Evidence of terrapin was not observed during the survey.

SAN-54

Figure 66. Photograph of SAN-54 taken during field survey on 4/19/14.

Site SAN-54 (Figure 66) was visited on 19 April 2014. The site primarily consisted of thick stands of Black mangrove (*A. germinans*) with interspersed patches of *Salicornia* spp. and *S. alterniflora*. Much of the vegetation was thick, and difficult to navigate through. Sediment was primarily mud, with areas of high, dry, cracked mud flats. Fiddler crabs, hermit crabs, larval blue crabs and *Littorina* spp. were observed throughout the search area. Coyote tracks and scat were also documented. Walking transect surveys were terminated due to large quantities of nesting migratory shorebirds. No evidence of terrapin was observed during the search.

SAN-63

Figure 67 Photograph of SAN-63 taken during field survey on 4/19/14.

Site SAN-63 (Figure 67) was visited on 19 April 2014. The site primarily consisted of mixed marsh with stands of Black mangrove (*A. germinans*), *B. maritima*, *Salicornia* spp. and *S. alterniflora*. Seagrasses were also present throughout the trap set area. Sediment was primarily sand and inundated throughout. Fiddler crabs, hermit crabs, larval blue crabs and *Littorina* spp. were observed throughout the search area. Coyote tracks were documented along with either deer or hog trails throughout. Human footprints were also observed with heavy boat traffic and fishing in surrounding creeks and waterways. Duck blinds were present on surrounding islands. Evidence of terrapin was not observed during the search.

SAN-90

Figure 68. Photograph of SAN-90 taken during field survey on 6/11/14.

Site SAN-90 (Figure 68) was visited on 11 June 2014. The site primarily consisted of *B. maritima* with patches of *Salicornia* spp., *S. alterniflora, D. spicata, B. frutescens,* and short, A. germinans. Sediment was primarily sand and was firm throughout. Fiddler crabs, horn snails, and *Littorina* spp. were observed throughout the search area. Large quantities of jellyfish and some seagrasses were present within surrounding waterbodies. Coyote scat and raccoon tracks were also documented. No evidence of terrapin was observed during the search.

SAN-98

Figure 69. Photograph of SAN-98 taken during field survey on 6/10/14.

Site SAN-98 (Figure 69) was visited on 10 June 2014. The site primarily consisted of *B. maritima* with small patches of short *A. germinans* and interspersed *Salicornia* spp., *B. frutescens*, and *S. alterniflora*. Sediment was a mixture of mud and sand and very firm throughout. Fiddler crabs, larval blue crabs, and horn snails were observed throughout the search area. Coyote tracks and scat, boar tracks, and small deer trails were also documented. Oyster beds were present along connected waterways and large quantities of mullet and bait fish were observed swimming in pools. No evidence of terrapin was observed during the search.

Section 4.3.2.a. *Catch Per Unit Effort (CPUE)*

Terrapin were captured at five of the 24 sites surveyed during both initial and subsequent sampling events (Table 14, Figure 38, 41, 52 - 53). No terrapin were recaptured during the course of this study. Only male terrapin were captured in Matagorda Bay (*n* = 5)(Table 14). In contrast both male (*n* = 6), female (*n* = 11) and unknown (*n* = 2) terrapin were captured in Sabine Lake (Table 14). In Matagorda Bay, two terrapin were captured by hand at MAT-94 (0.263 terrapin/search-hr). Trap CPUE values in Matagorda Bay averaged 0.06±0.002 terrapin/trap-hr. In Sabine Lake, hand capture CPUE averaged 0.447±0.28 terrapin/search-hr while trap CPUE averaged 0.07±0.03 terrapin/trap-hr. During processing, holding time averaged 31±2.1 minutes.

Table 14. All captures made during field sample period from April - June 2014. *Hand = captured during transect survey; Trap = captured in modified crab trap.

Site Name	Capture Date	Notch #	Sex	Capture Latitude	Capture Longitude	Capture Method*
SAB-55	5/16/2014	874	M	29.70296	-93.87152	Hand
	5/16/2014	875	F	29.70238	-93.86795	Trap
	5/16/2014	876	M	29.70282	-93.86722	Trap
	5/16/2014	877	U	29.70282	-93.86722	Trap
	6/17/2014	881	U	29.70324	-93.86925	Trap
SAB-56	5/15/2014	864	F	29.71054	-93.88843	Hand
	5/15/2014	865	M	29.71046	-93.88869	Hand
	5/15/2014	866	F	29.71086	-93.88740	Hand
	5/15/2014	867	M	29.71211	-93.88939	Hand
	5/15/2014	868	F	29.71029	-93.88821	Hand
	5/15/2014	869	F	29.71019	-93.88761	Hand
	5/15/2014	870	F	29.71251	-93.88983	Hand
	5/15/2014	871	F	29.71029	-93.88802	Hand
	5/15/2014	872	M	29.70889	-93.88763	Trap
	5/15/2014	873	F	29.70922	-93.88651	Trap
	6/16/2014	879	F	29.71027	-93.88911	Hand
	6/16/2014	880	F	29.71128	-93.88586	Trap
SAB-58 (revisit only)	6/18/2014	882	F	29.70607	-93.85941	Hand
	6/18/2014	883	M	29.70343	-93.85812	Trap
MAT-94	4/24/2014	861	M	28.66183	-96.20807	Hand
	4/24/2014	862	M	28.66214	-96.20792	Hand
	5/19/2014	878	M	28.66253	-96.20987	Trap
MAT-14	4/28/2014	863	M	28.67183	-96.47231	Trap
	5/20/2014	899	M	28.67398	-96.47192	Trap

Section 4.3.2.b. *Habitat Type at Capture Location*

Eleven terrapin (45.8%) were captured in traps. Individuals captured by hand were found in a mix of *Spartina* dominant marsh (n = 3), mud flat (n = 3), creek edge (n = 3), mixed marsh (n = 2), open water (n = 1), and secondary creek (n = 1) habitats (Figure 70). This pattern is consistent with past studies in our area, where terrapin have been known to exploit and utilize both terrestrial and aquatic habitat (Clarkson 2012). Those terrapin found in secondary creeks and open water were captured while actively swimming. Six (46.2%) terrapin were found burrowed in the aforementioned habitats. Five (41.7%) of the terrapin captured on land were found in areas with vegetation ranging from 0-20 cm in height (Figure 71). Terrapin were also captured in areas with vegetation ranging from 40-60 cm (n = 4), 20-40 cm (n = 2) and 60-80 cm (n = 1). Eighty-three percent of terrapin were captured in areas with vegetation comprising less than 40% total cover (Figure 72). Saltmarsh cordgrass (*Spartina alterniflora*) was present in 100% of captures on land and dominated vegetative cover while *Distichlis spicata* was present at only one capture location in Sabine Lake.

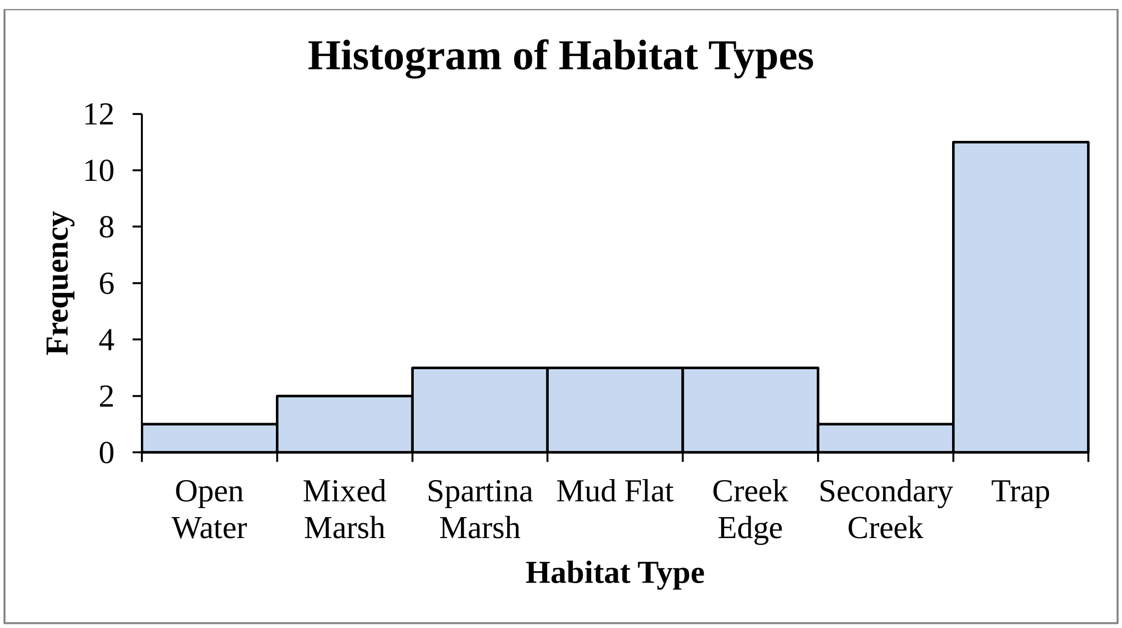

Figure 70. Histogram showing frequency of terrapin captures by habitat (n = 24).

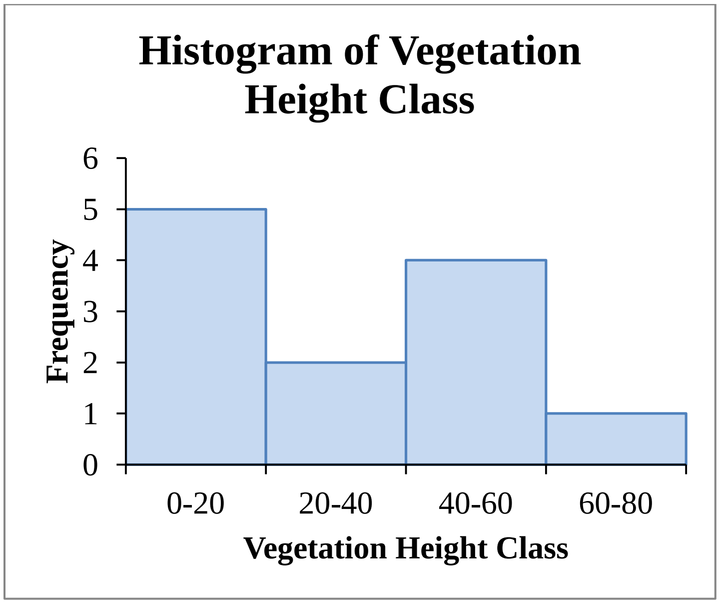

Figure 71. Histogram showing frequency of terrapin captures in habitats classified by differing vegetation height classes (in cm). Representative of both males and females captured on land by hand (*n* = 12).

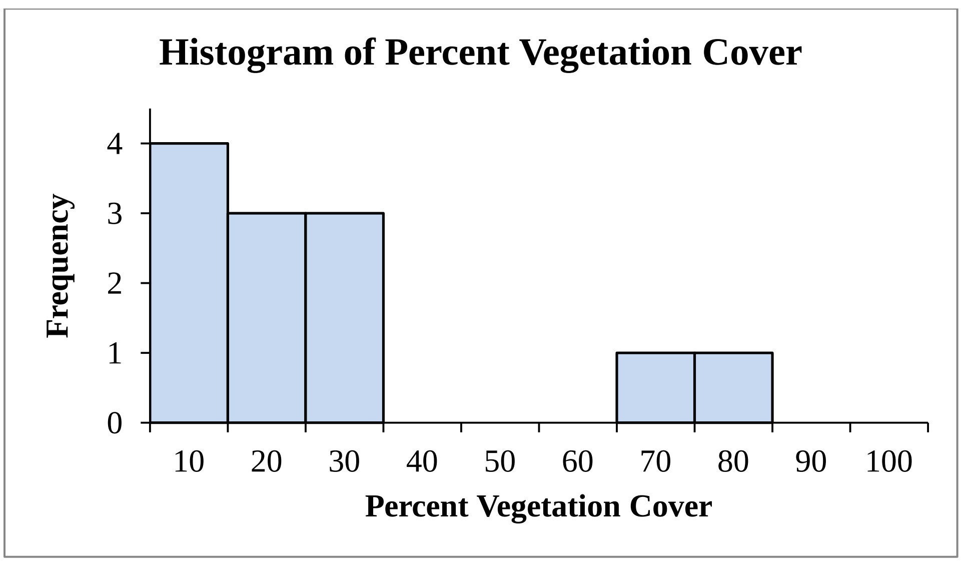

Figure 72. Histogram showing frequency of terrapin captures in habitats classified by varying percent vegetation cover. Representative of both males and females captured on land by hand (*n* = 12).

Section 4.3.2.c. *Past Studies on Habitat Use*

During their recent study Guillen and Oakley (2013) collected habitat preference data for each of the 316 capture events occurring from July 2011-October 2012. Analysis of this data showed that habitats selected by terrapins are characterized mostly by vegetation that ranges in height from 20-60 cm (Figure 73).

They found that terrapins showed no significant trend in selection of vegetation cover (Figure 74). Their data showed a high variability in both vegetation height and percent cover, and these preferences may also change seasonally. The histograms below display the frequency of captures in each vegetation height class, varying vegetation covers, and varying dominant vegetation species. Terrapin were recaptured most often in close proximity to saltmarsh cordgrass (Figure 75).

Section 4.3.2.d. *Prey Availability at Capture Location*

Only two major prey species were sufficiently common to present information on their abundance in relation to the presence of terrapin. The potential “common” prey items included the marsh periwinkles (*Littorina irrorata*) and fiddler crabs (*Uca* spp). Due to the low sample size (n = 12) it is very difficult to assess spatial patterns in prey availability at point of capture (Figure 76). However, higher numbers of marsh periwinkles appear to be present more often when females are captured in contrast to males (Figure 77). Female terrapin are documented as being able to feed on larger periwinkles (Tucker et al. 1995). Therefore females may try and locate areas containing higher amounts of larger prey.

Section 4.3.2.a. *Environmental Parameters at Time of Surveys*

The environmental variables that were evaluated included air and water temperature, days since last significant rainfall (DSLR), salinity, wind speed, and Secchi disk transparency. Individual measurements related to specific surveys sites were previously reported in Table 8. Summary statistics of environmental variables measured at sites where full surveys were conducted are presented in Table 15. During the study period the average air temperature was 26.8 ºC with individual values ranging between 27 and 32.6 ºC. Average water temperature was 24.4 ºC with individual values ranging from 17.5 to 33.5 ºC. Highest terrapin capture rates occurred when air and water temperatures where 21.7 and 18.0ºC (Figure 78 and 79). However there was not consistent relationship between air or water temperature and catch rates.

During the study period the average DSLR was 9.97 days with individual values ranging between 1 and 27 days (Table 15). Highest terrapin capture rates occurred when salinity was 2-3 DSLR (Figure 80). However, there did not appear to be any linear relationship between the variables since zero catches were recorded above and below 2-3 DSLR. Terrapin were not captured or observed when salinity was below 12 psu.

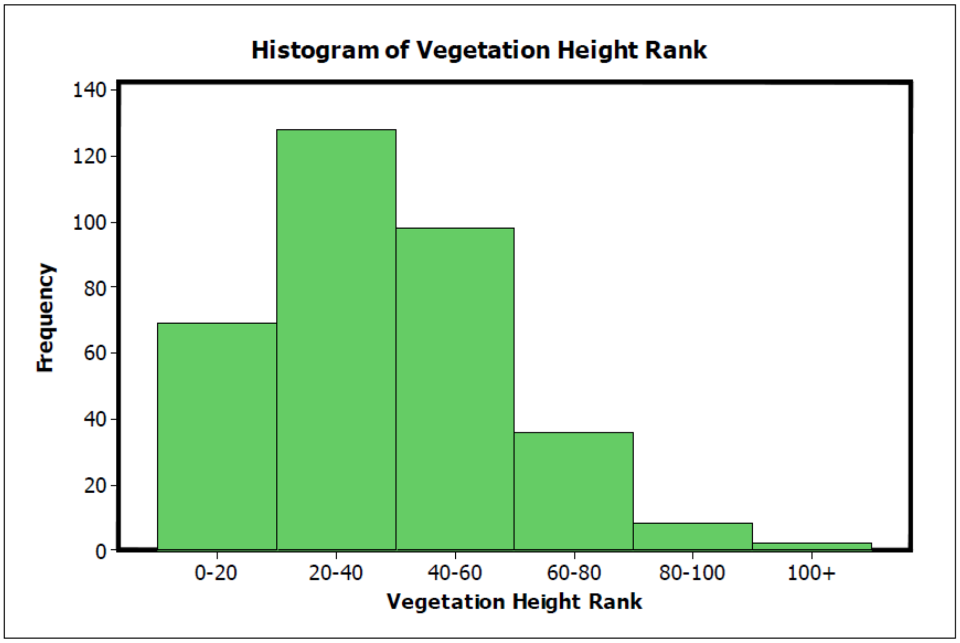

Figure 73. Histogram showing frequency of terrapin capture in habitats classified by differing vegetation height, in cm. Based on data collected on male and female terrapin from 2011 to 2013. Source: Guillen and Oakley (2013).

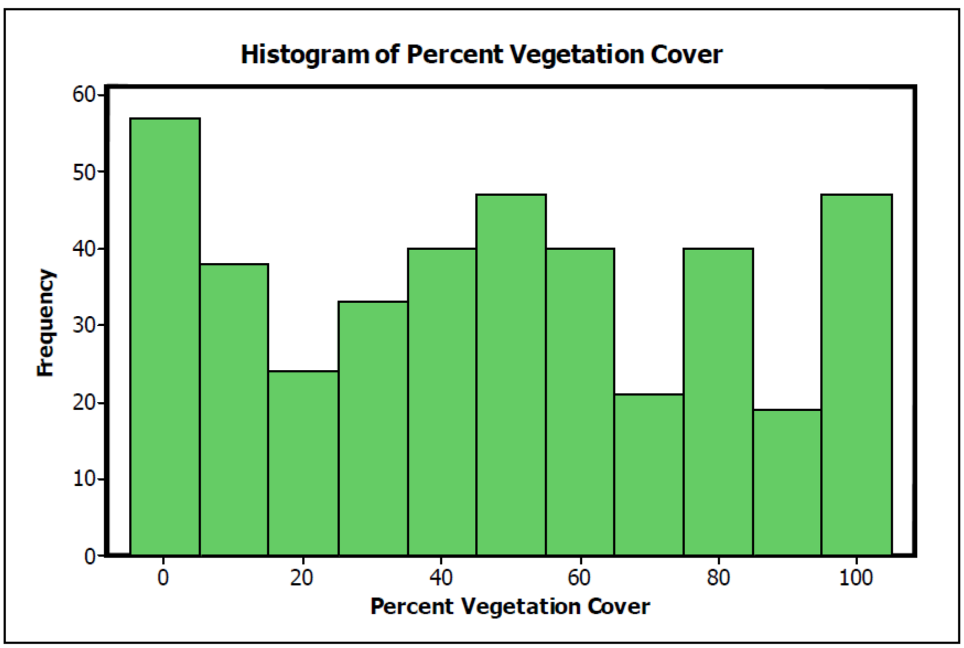

Figure 74. Histogram showing frequency of terrapin capture in habitats classified by varying percent vegetation cover. Based on data collected on male and female terrapin from 2011 to 2013. Source: Guillen and Oakley (2013).

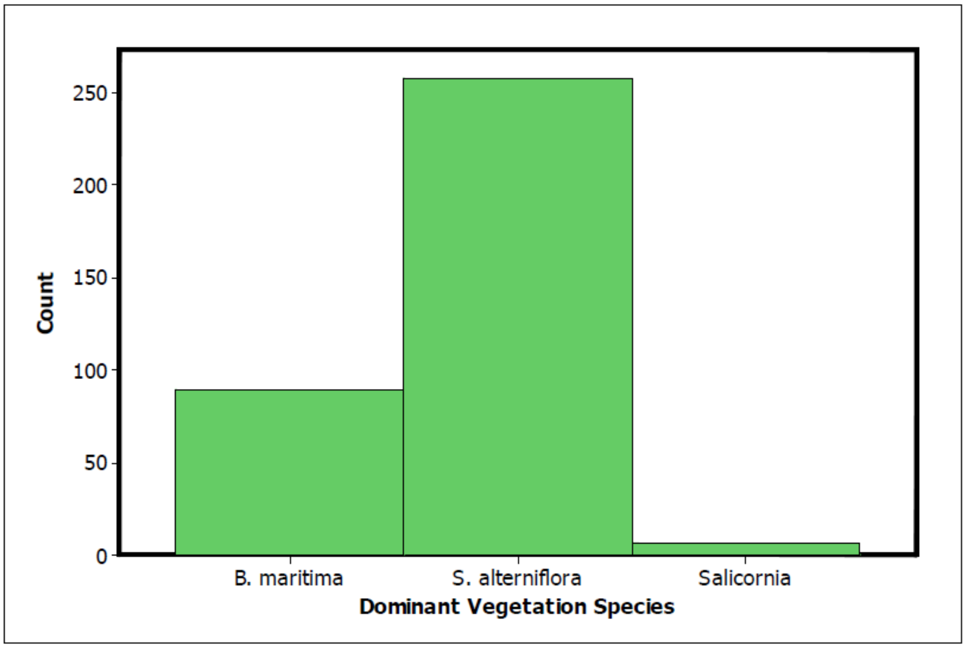

Figure 75. Histogram showing the number of terrapin captures events that occurred in habitat dominated by either *B. maritima, S. alterniflora*, or *Salicornia* spp. Based on data collected on male and female terrapin from 2011 to 2013. Source: Guillen and Oakley (2013).

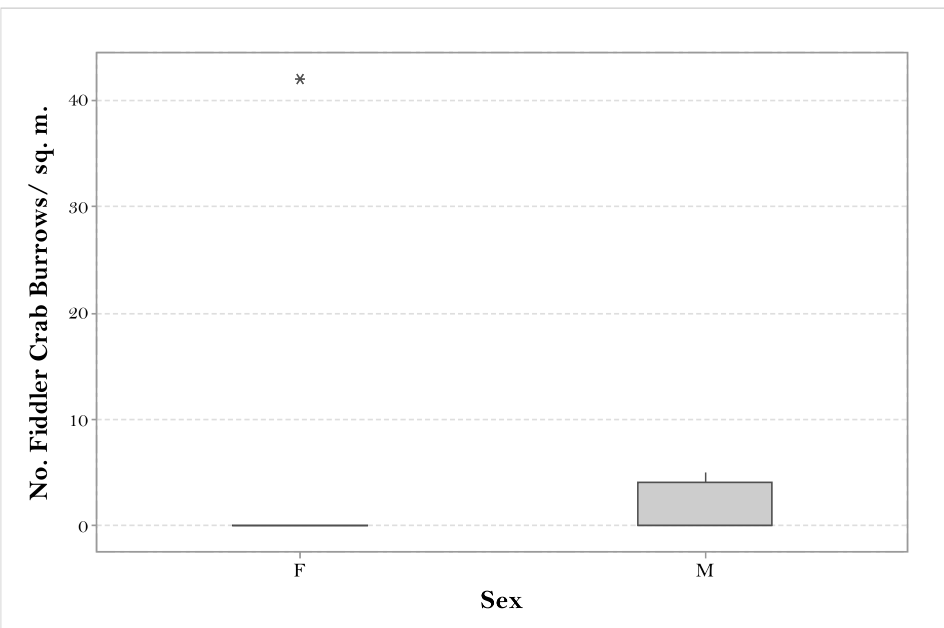

Figure 76. Boxplot depicting the number of fiddler crab burrows observed within a square meter of a female versus male terrapin occurrence.

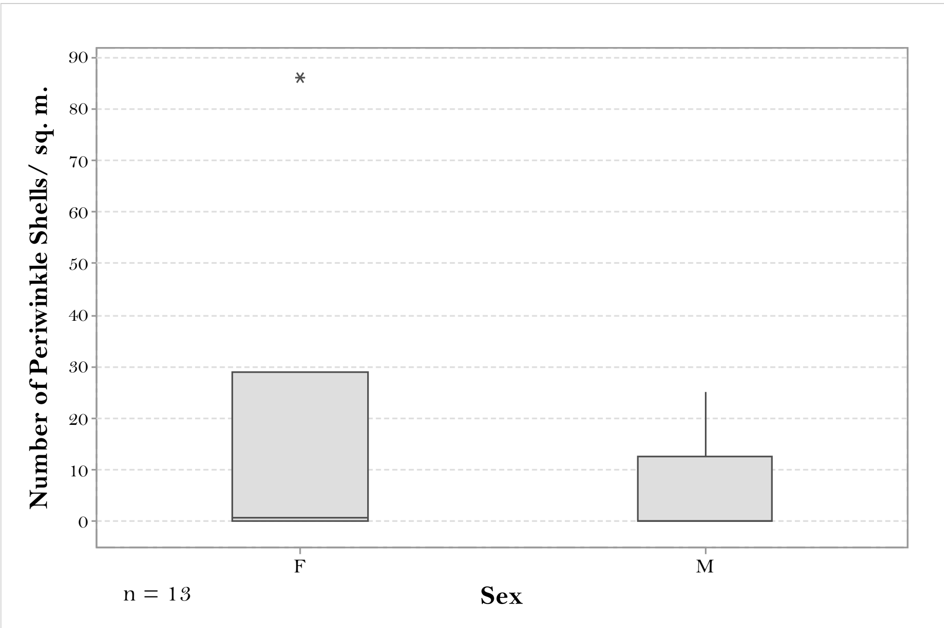

Figure 77. Boxplot depicting the number of marsh periwinkle shells observed within a square meter of a female versus male terrapin occurrence.

Table 15. Summary statistics for environmental variables measured during the full surveys.

Variable	Mean	Minimum	Median	Maximum
DSLR	9.9	1	10	27
Air Temp ºC	26.8	19.2	27.0	32.6
Water Temp	24.3	17.5	24.5	33.5
Salinity	27.4	8	32	36
Secchi	0.28	0.05	0.22	0.73
Wind Speed	7.9	1.5	8.2	13.4

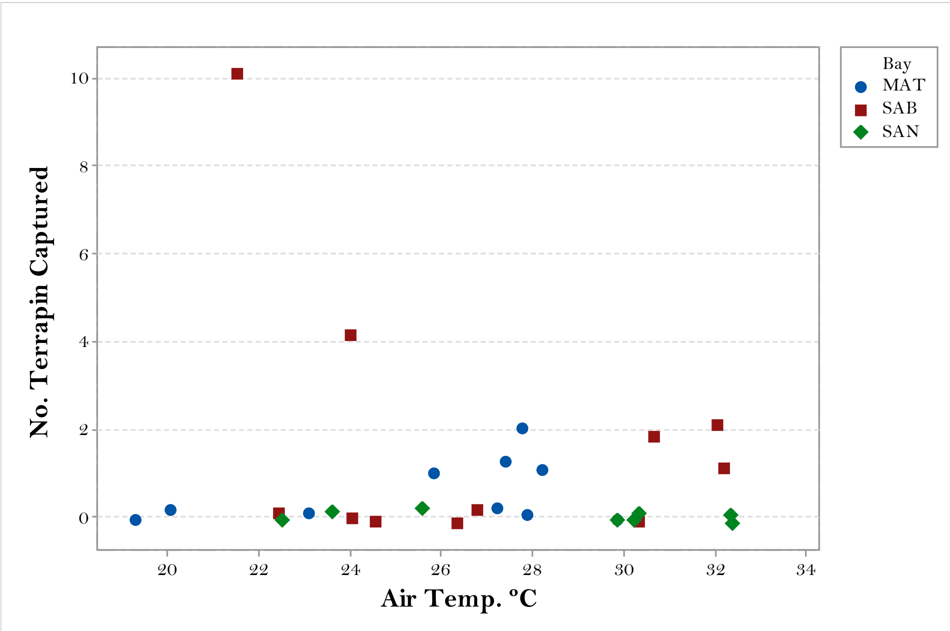

Figure 78. Relationship between air temperature and number of terrapin captured during 2014 surveys.

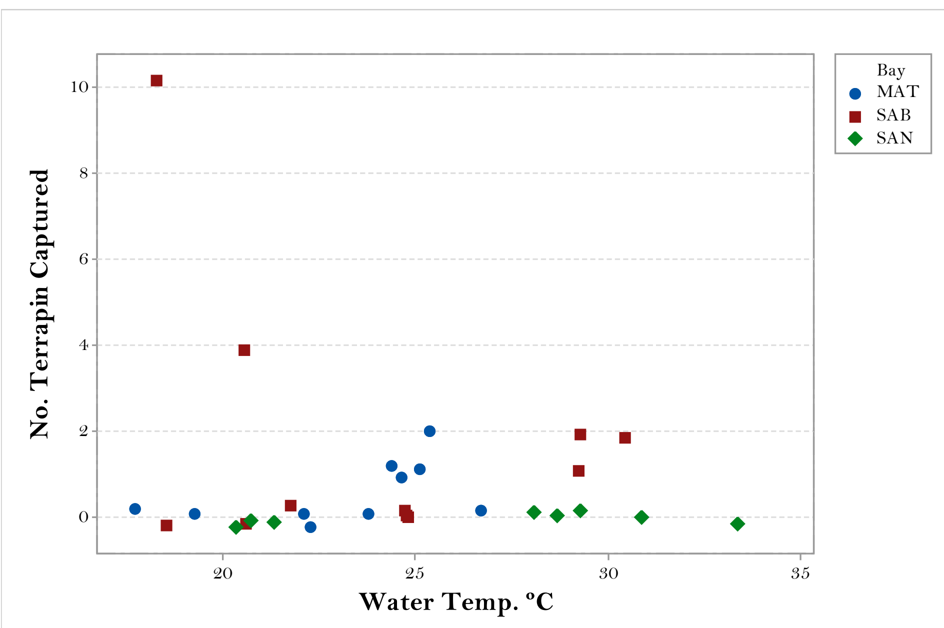

Figure 79. Relationship between water temperature and number of terrapin captured during 2014 surveys.

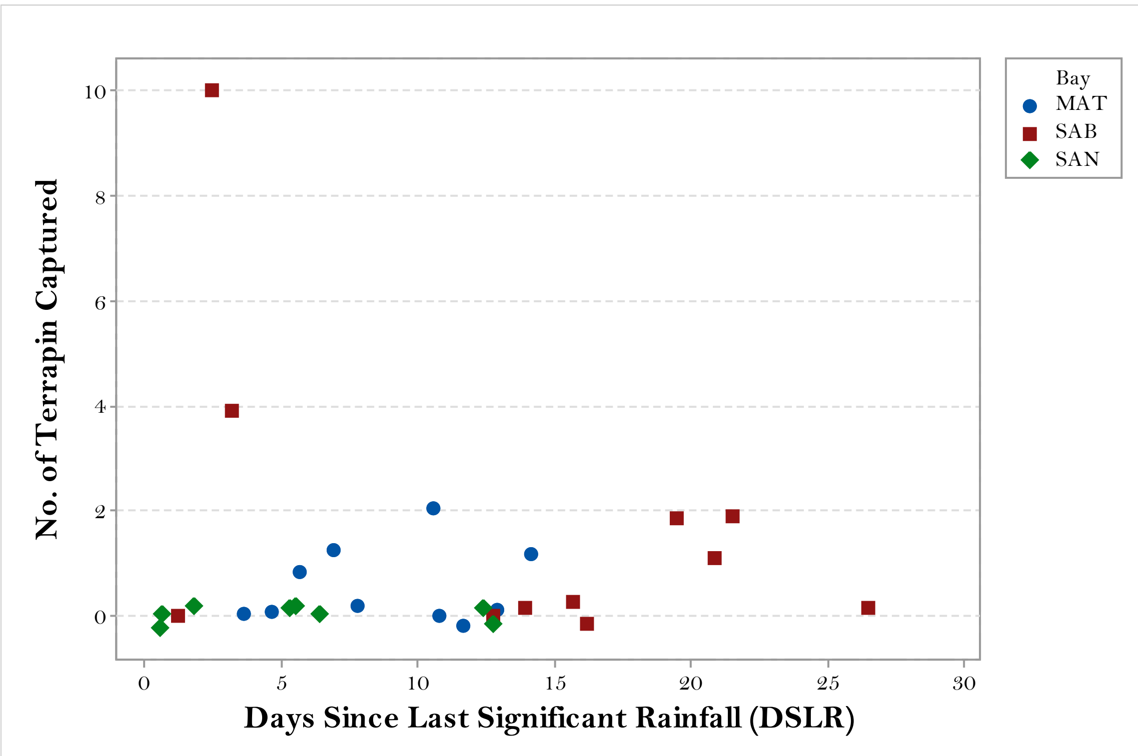

Figure 80. Relationship between DSLR and number of terrapin captured during 2014 surveys. Significant rainfall: > 0.10"/day.

During the study period the average salinity was 27.5 psu with individual values ranging between 8 and 36 psu (Table 15). Highest terrapin capture rates occurred when salinity was 23-26 psu (Figure 81). There did not appear to be any linear relationship between the variables since zero catches were recorded above and below 23-26 psu. The response appeared to be more of a unimodal distribution of terrapin centered on moderate salinity values. Terrapin were not captured or observed when salinity was below 12 psu.

During the study period the average wind speed was 7.9 mph with individual values ranging between 1.5 and 13.4 m (Table 15). Highest terrapin capture rates occurred when wind speed was 1.5 mph (Figure 82). There did not appear to be any linear relationship between the variables since zero catches were recorded over the entire range of wind speeds measured.

During the study period the average Secchi disk transparency was 0.28 m with individual values ranging between 0.05 and 0.73 m (Table 15). Highest terrapin capture rates occurred when Secchi disk transparency was 0.18 m (Figure 83). There did not appear to be any linear relationship between the variables since zero catches were recorded above and below 0.18 m. Terrapin were not captured or observed when Secchi disk transparency was below 0.09 psu or above 0.64 psu.

Environmental and habitat measurements, day of year (DOY) when captured, sex, carapace length (CL), and prey availability when terrapin were captured were recorded and analyzed using principal components analysis to evaluate potential gradients in the distribution of captured terrapin and identify which combination of factors appear to be most correlated with the distribution of captured terrapin (Gotteli and Ellison 2004). Data from trap captured and land searches were combined prior to analysis. For trap and water catches percent total cover and by vegetation types was assumed to be zero. The number of fiddler crab burrows and number of periwinkles were also assumed to be zero. Males were given a score of 1, females 0 and unknown 0.5. The resulting two principal components that represent linear combinations of the original variables represented 52.3% of the variability in the data. The resulting equations are listed below:

Eq. 1) Principal component 1 (x-axis) = 0.193 DOY + 0.296 DSLR + 0.277 Air Temp + 0.297 water temperature - 0.120 salinity + 0.057 Secchi disk + 0.262 wind speed + 0.063 terrapin CL - 0.062 sex (female = 0, male =1) – 0.253 water (water = 1, land = 0) + 0.348 (marsh = 1, non-marsh = 0) + 0.302 vegetation class (rescaled 0-4) + 0.303 % *Distichlis spicata* cover +0.196 % *Spartina alterniflora* cover + 0.333 total cover +0.054 distance from shore – 0.016 fiddler crab burrows + 0.311 marsh periwinkle count. PC 1 Proportion of variation explained = 29.3%

Eq. 2) Principal component 2 (y-axis) = 0.374 DOY + 0.299 DSLR + 0.300 Air Temp + 0.292 water temperature - 0.269 salinity - 0.241 Secchi disk + 0.182 wind speed - 0.071 terrapin CL - 0.014 sex (female = 0, male =1) + 0.251 water (water = 1, land = 0) - 0.178 (marsh = 1, non-marsh = 0) - 0.281 vegetation class (rescaled 0-4) + 0.029 % *Distichlis spicata* cover - 0.369 % *Spartina alterniflora* cover + 0.263 total cover - 0.161 distance from shore – 0.114 fiddler crab burrows - 0.084 marsh periwinkle count. PC 2 Proportion of variation explained = 23.0%

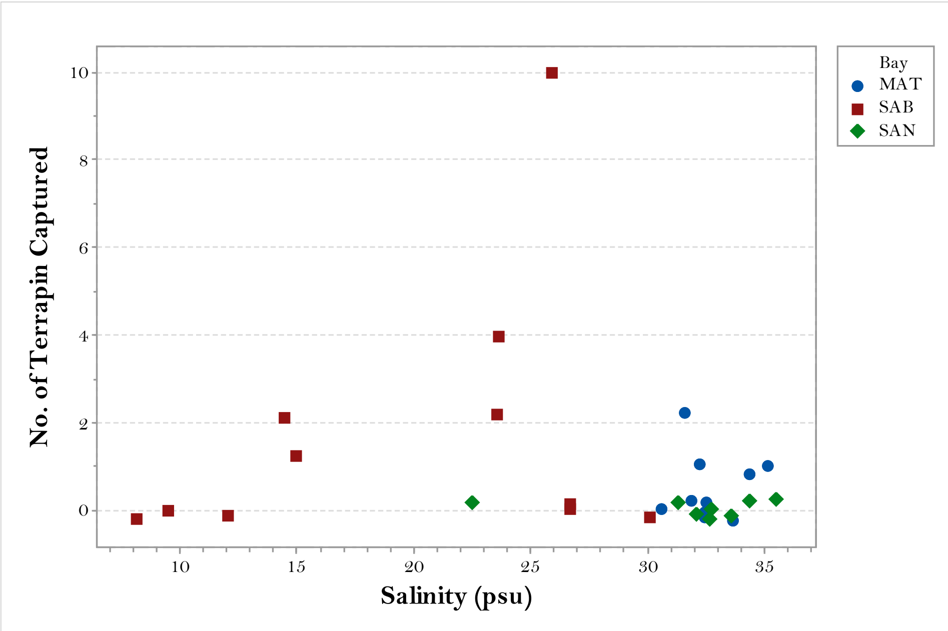

Figure 81. Relationship between salinity and number of terrapin captured during 2014 surveys.

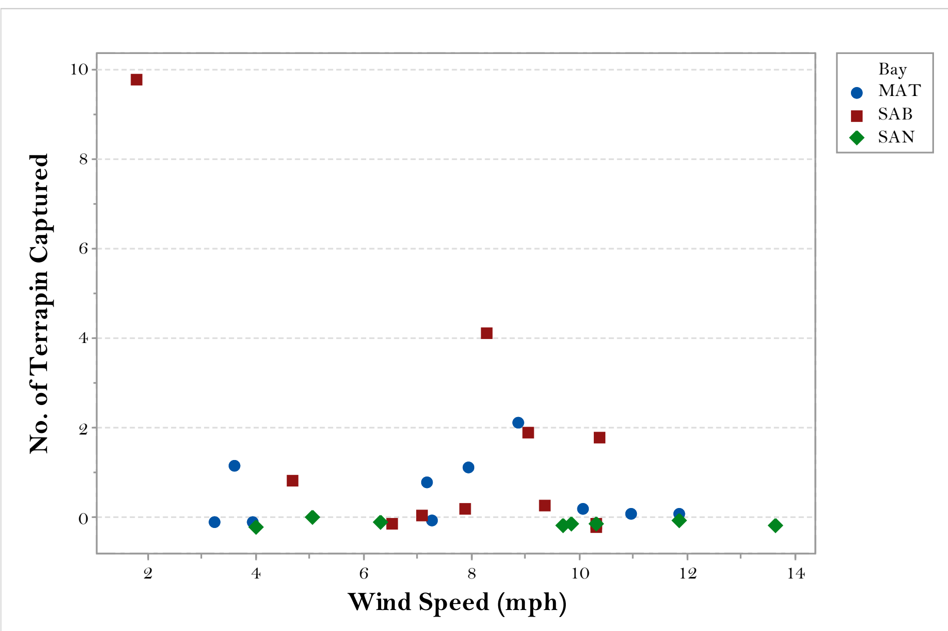

Figure 82. Relationship between wind speed and number of terrapin captured during 2014 surveys.

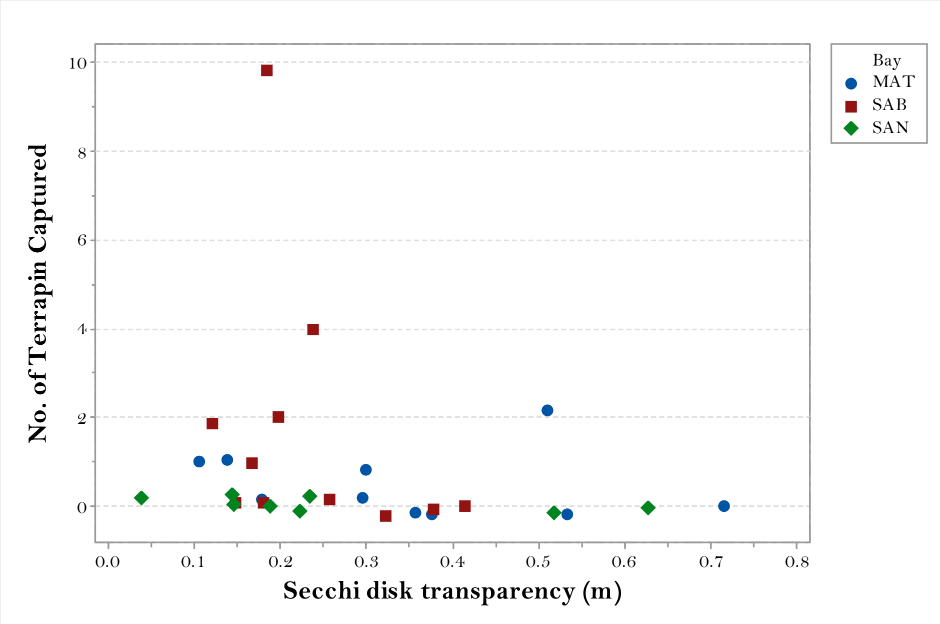

Figure 83. Relationship between Secchi disk transparency and number of terrapin captured during 2014 surveys.

Based on PCA it appears that the variables that best describe the distribution of sites where terrapin were captured along the PC1 axis were whether the terrapin was captured in open water, marsh or mudflat, vegetation height (class), and percent cover (Figure 84). The loading coefficients document the opposite influence of the classification of each site as either open water or marsh that has an opposite influence on the classification and ordination of sites. Along the PC2 axis salinity, DOY, DSLR, air and water temperature, Secchi disk transparency and percent cover as *Spartina alterniflora* were the most important (large negative or positive loading coefficient) variables. The distribution of sites based on their PC1 and PC2 scores are depicted in Figure 85. Although terrapin captured at the same site usually were grouped closer together reflecting the similarity of conditions, this did not always occur at the same site which usually reflected differences in habitat used (e.g. open water vs. marsh). Differences between terrapin captured on different dates of collection (e.g. SAB 55-1 and 55-2) usually reflected changes in environmental conditions related in part to seasonality.

Section 4.3.2.b. *Distribution of salinity values from past EIH studies and current study when terrapin where collected.*

We also combined the salinity data from past studies with our 2014 results and plotted a cumulative distribution curve reflecting the distribution of salinity collected when at least one terrapin had been captured. The distribution of terrapin occurrences spanned a large salinity range from 11 to 47 psu (Figure 86). The majority (90%) of terrapin were captured between 21 and 34 psu.

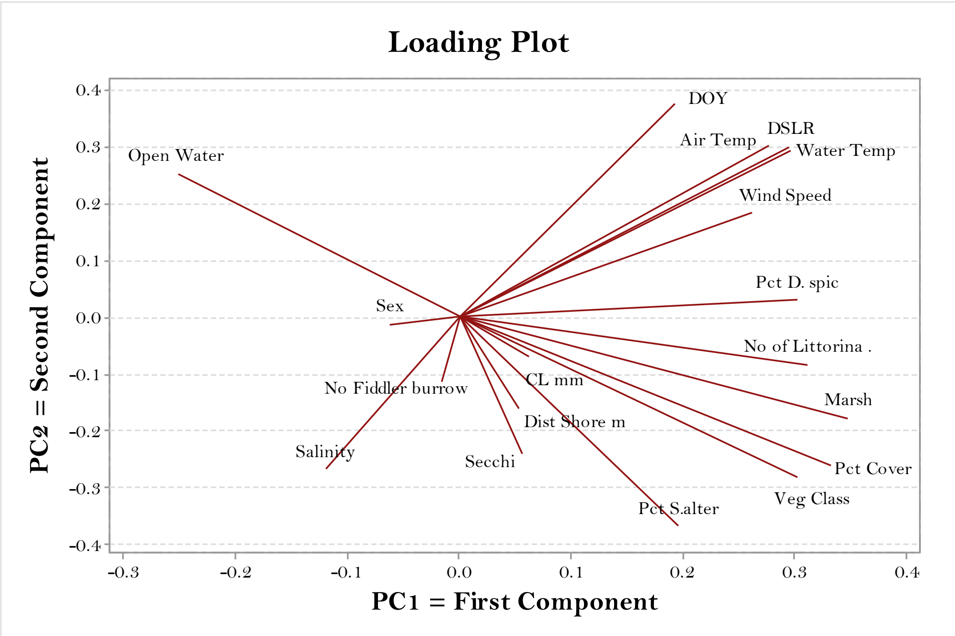

Figure 84. Principal components analysis loading plot denoting loading coefficients for each variable used in the first two components. Principal components 1 and 2 explained 29.3% and 23.0% of the data variability.

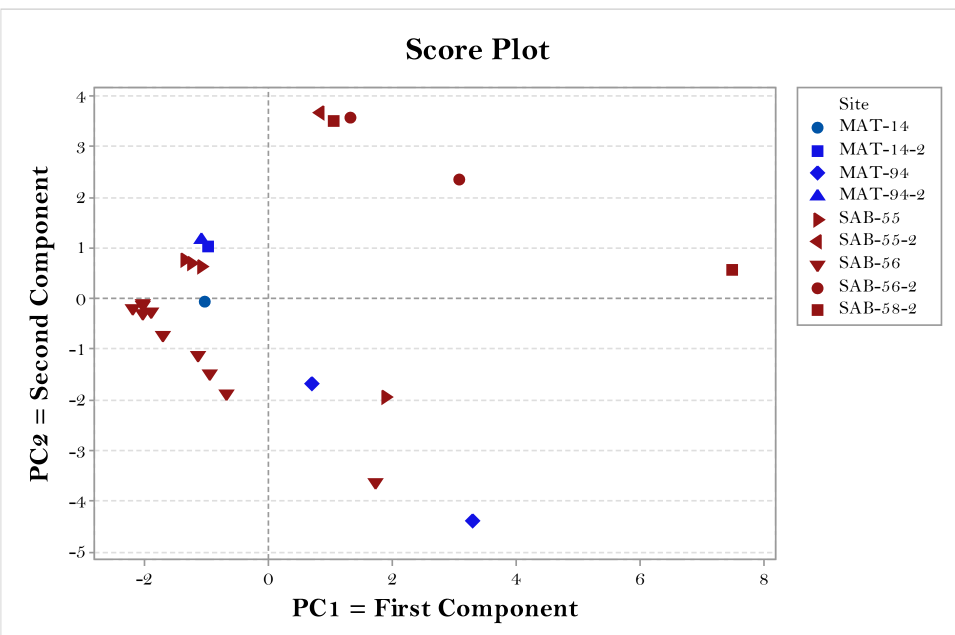

Figure 85. Principal components analysis score plot denoting composite scores for each site where terrapin where captured. Principal components 1 and 2 explained 29.3% and 23.0% of the data variability.

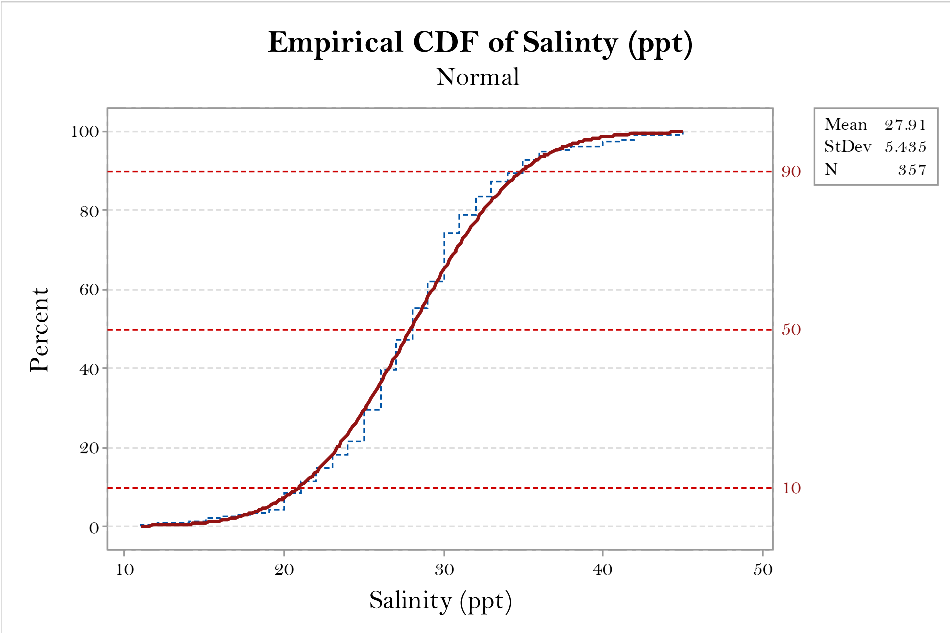

Figure 86. Cumulative distribution of salinity for all EIH and recent 2014 terrapin collections when at least one terrapin was caught.

Section 4.3.2.a. *Terrapin Morphometrics*

Measurements for male terrapin from Matagorda Bay did not significantly differ from males captured in Sabine Lake (t-test: $t_{(9)}$ range= -1.28-1.23, $p > 0.05$), therefore, all males are grouped for the following morphometric analyses. Additionally, there were no significant differences (t-test: $t_{(22)}$ range = 1.47-2.03, $p > 0.05$) in any measurements between terrapin captured by hand (males = 5; females = 8) or trap (males = 6; females = 3; unknown = 2), therefore, all terrapin were grouped by sex, regardless of capture method, for the following analyses.

Female terrapin (*n* = 11) collected during this study were significantly larger (one-way ANOVA: $F_{(2,21)}$ range = 19.48-36.68, $p < 0.001$) than males (*n* = 11) for all 11 measurements (Figure 87). Females were also significantly larger than unknowns (*n* = 2) for carapace length, carapace width, plastron length (mid), and plastron width (suture) based on Fisher LSD *post hoc* analyses. This dimorphism is consistent with other literature (Ernst and Lovich 2009).

Female SCL_{min} averaged 169.5 ± 5.5 mm (range: 140-208 mm) and SCL_{max} averaged 172.8±5.8 mm (range: 141-213 mm) while males averaged 131.5±3.7 mm (range: 104-146 mm) and 132.7±3.8 mm (range: 104-147), respectively. Female SPL_{min} averaged 153.6±4.8 mm (range: 126-183 mm) and SPL_{max} averaged 158.5±4.8 mm (range: 129-189 mm) while males averaged 110.5±2.3 mm (range: 96-120 mm) and 114.7±2.6 mm (range: 98-126 mm), respectively (Figure 87).

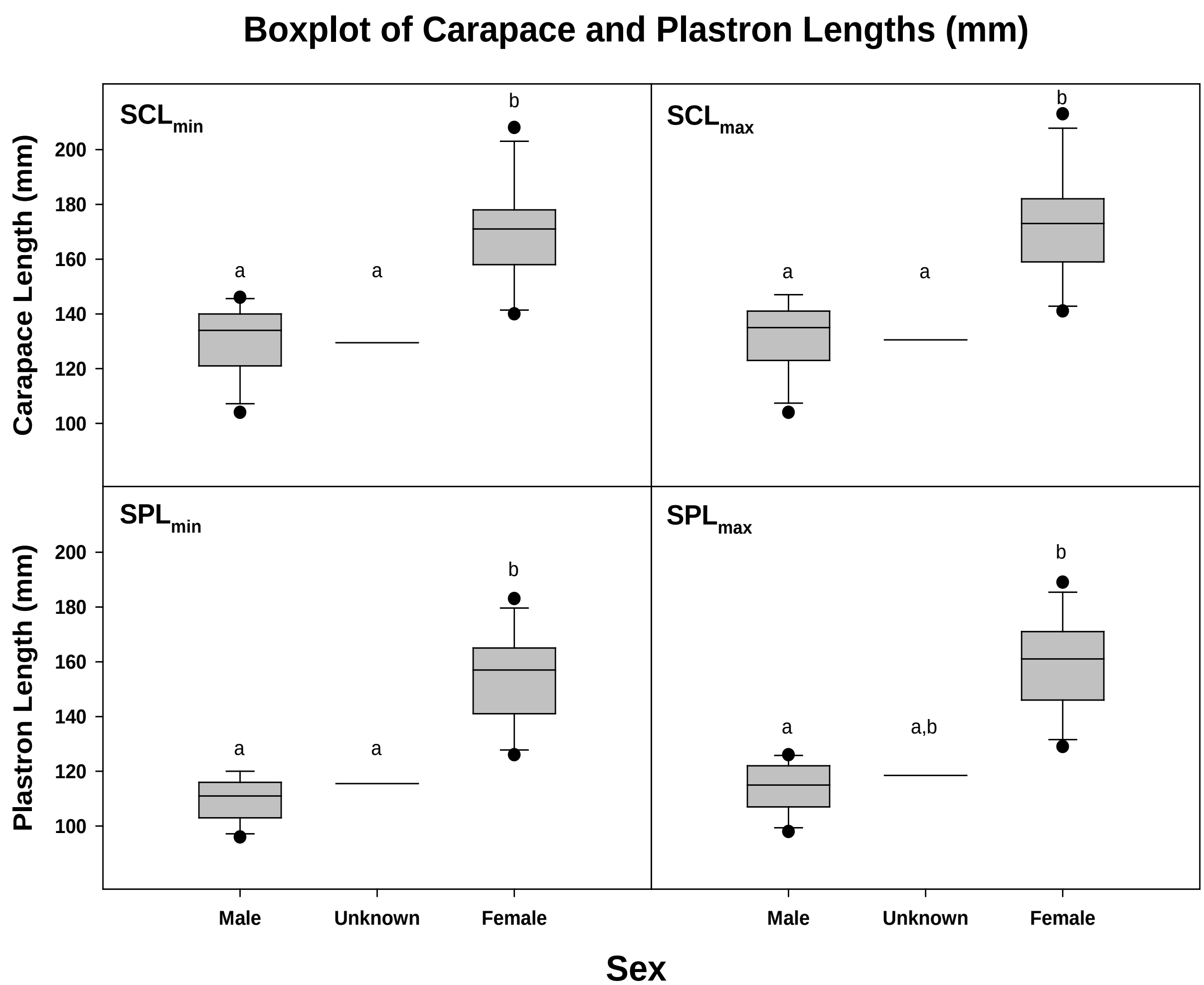

Figure 87. Boxplot of carapace and plastron lengths. Females were significantly larger than males in all measurements (one-way ANOVA: $F_{(2,21)}$ range = 19.48-36.68, $p < 0.001$). Letters above boxplots indicated statistically significant groups.

Female SCW_{min} averaged 122.2±4.1 mm (range: 99-149 mm) and SCW_{max} averaged 125.0±4.1 mm (range: 102-152 mm) while males averaged 94.5±2.3 mm (range: 78-106 mm) and 96.9±2.5 mm (range: 79-107 mm), respectively. Female SPW_{min} averaged 78.5±3.0 mm (range: 60-92 mm) and SPW_{max} averaged 111.4±3.9 mm (range: 90-138 mm) while males averaged 58.4±1.4 mm (range: 50-65 mm) and 85.6±2.2 mm (range: 71-94), respectively (Figure 88).

Female SD_{min} averaged 65.3±2.1 mm (range: 54-78 mm) and SD_{max} averaged 67.7±2.0 mm (range: 57-79 mm) while males averaged 48.5±1.1 mm (range: 40-52 mm) and 50.8±1.0 mm (range: 44-56 mm), respectively (Figure 86). Females captured in this study exhibited megacephaly as compared to males with head widths (HW_{max}) averaging 38.2±2.2 mm (range: 28-54 mm) and 23.0±0.3 mm (range: 20-24 mm), respectively (Figure 89). Females were also heavier than males (0.8±0.08 kg, range: 0.45-1.41 kg; 0.2±0.02 kg, range: 0.21-0.45 kg) and were, on average, older than males based on carapacial growth ring counts (4.9±1.0 rings, range: 0-9; 1.9±0.7 rings, range: 0-5)(Figure 90).

Length weight models were constructed using straight mid-line plastron length (SPL) and maximum straight plastron length (SPL_{max}) versus weight using non-linear models (Figure 91 and Figure 92). Both models provided excellent fits $r^2 > 0.97$. The larger data points (>150 cm) were exclusively populated by females reflecting the sexual dimorphism observed in the species by others (Brennessel 2006; Guillen et al. 2011; Guillen and Oakley 2013; Halbrook 2003; Hogan 2003; Koza 2006).

Section 4.3.2.a. *Sexual Dimorphism – Other Studies*

Due to the low numbers of terrapin collected during the 2014 study we collected archived and published data produced by (Guillen and Oakley 2013; Halbrook 2003; Hogan 2003; Koza 2006). Comparison of the 2207 individual terrapin measurements identified a distinct latitudinal gradient in female adult size (Figure 93 and 94). To remove the influence of sex we separated out the specimens by sex and ran a one way ANOVA with a Tukey's multiple comparison test for each attribute (weight and length) for each sex.

Based on the ANOVA and multiple comparison results, female terrapin exhibited significant difference in midline carapace length between study sites (Figure 95 and Table 16). Females terrapin collected by EIH was significantly larger than those collected by Halbrook (2003) and Koza (2006). Female terrapin collected by both Hogan (2003) and SWG female terrapin were also significantly longer than terrapin collected by Koza (2006). In contrast female terrapin collected by EIH, this SWG project and Hogan (2003) was significantly heavier than those collected by Halbrook (2003) and Koza (2006)(Table 17 and Figure 96).

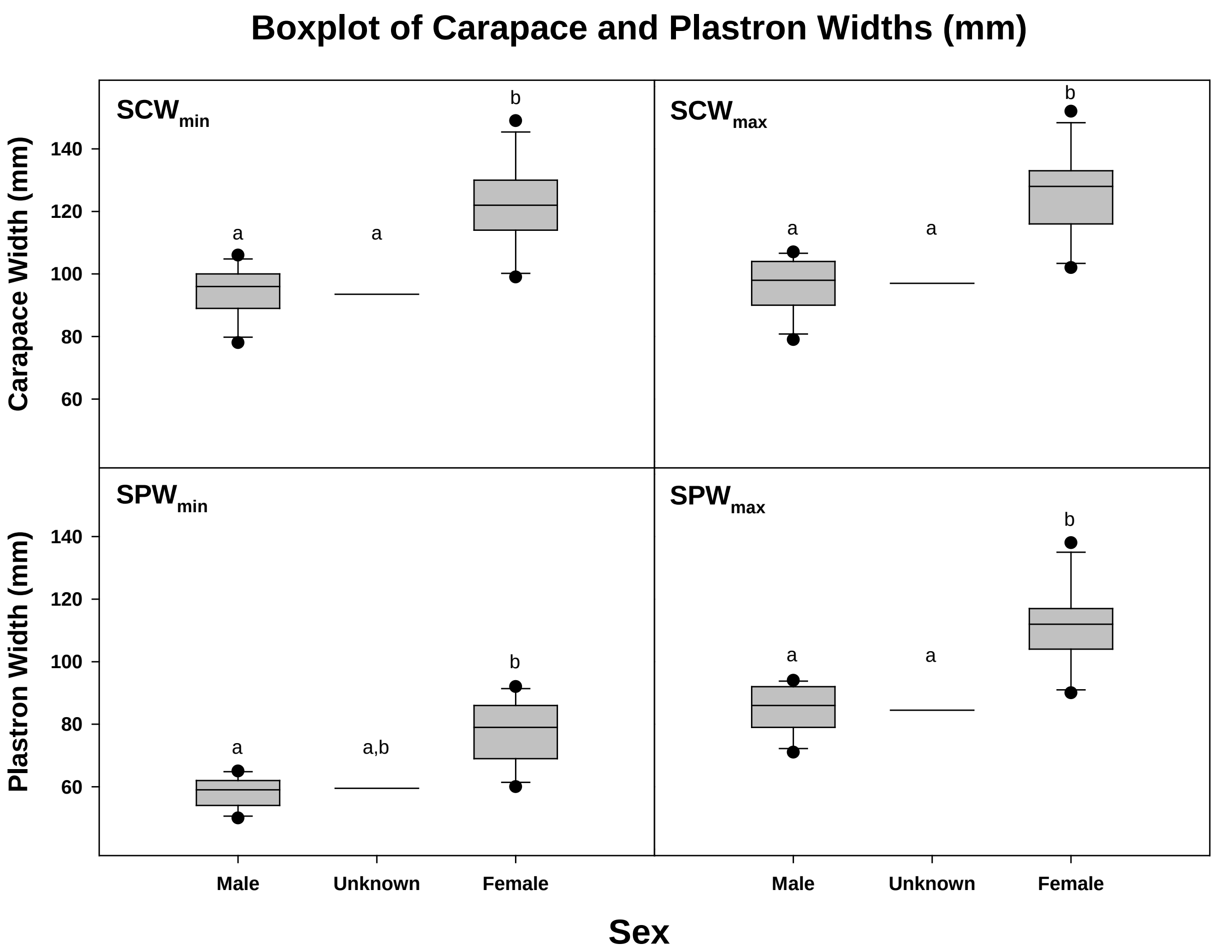

Figure 88. Boxplot of carapace and plastron widths. Females were significantly larger than males in all measurements (one-way ANOVA: $F_{(2,21)}$ range = 19.48-36.68, $p < 0.001$). Letters above Boxplots indicated statistically significant groups.

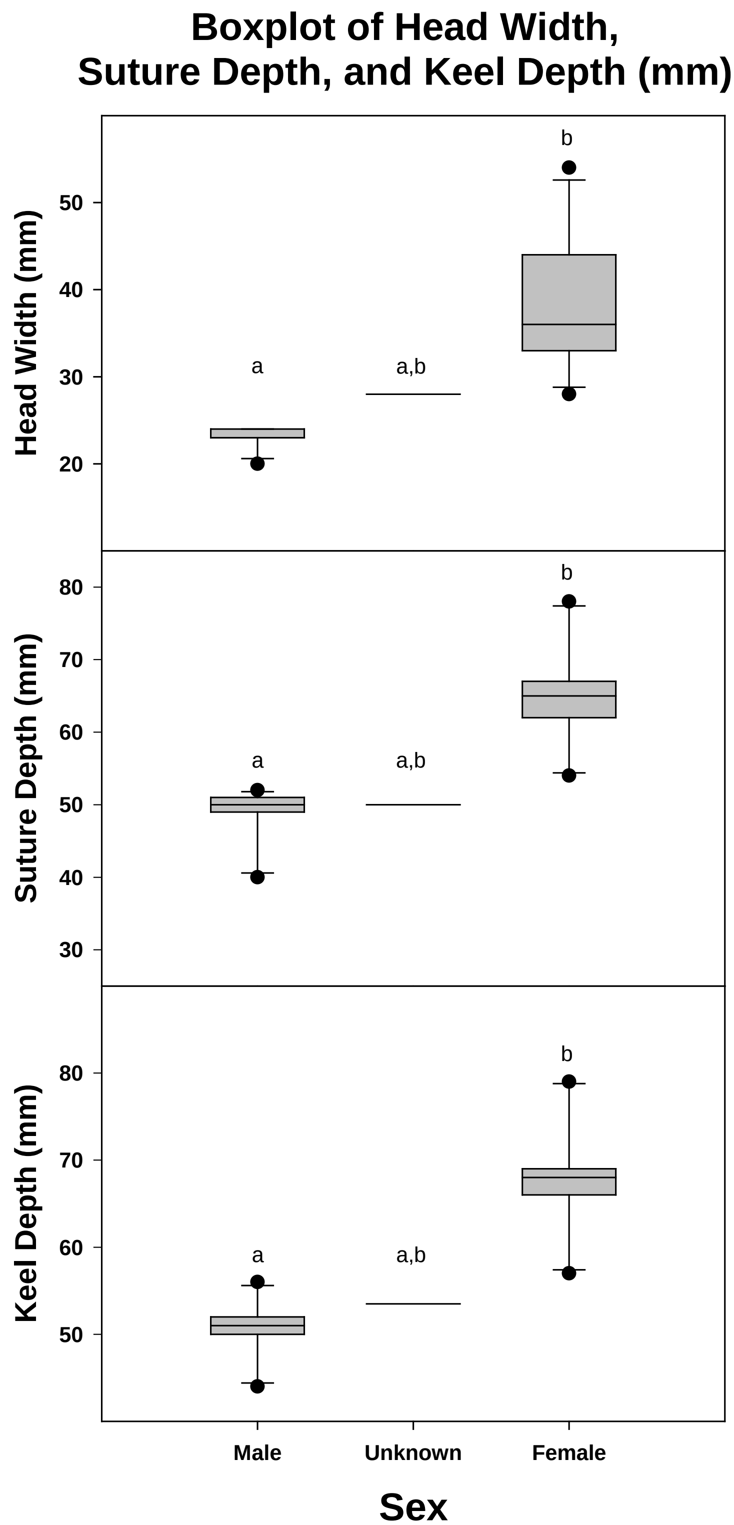

Figure 89. Boxplot of head width and body depth measurements. Females were significantly larger than males in all measurements (one-way ANOVA: $F_{(2,21)}$ range = 19.48-36.68, $p < 0.001$). Letters above Boxplots indicated statistically significant groups.

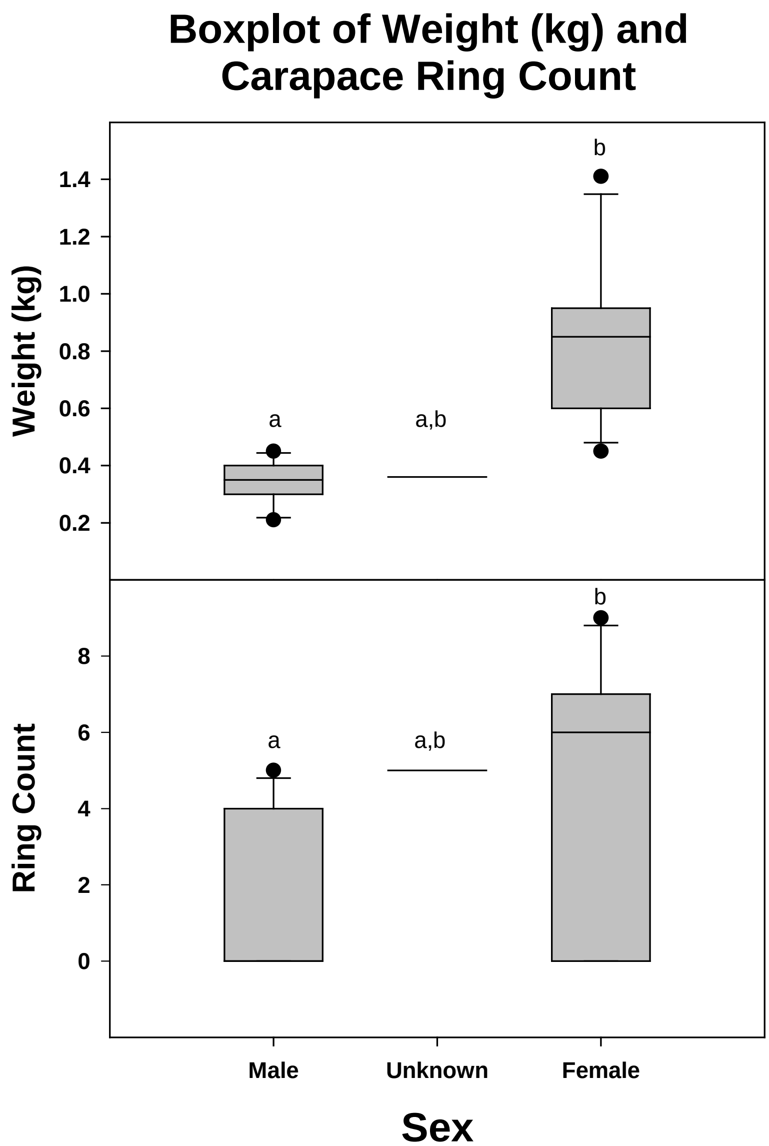

Figure 90. Boxplot of weight and carapacial ring count. Females were significantly heavier than males in all measurements and significantly older based on ring counts (one-way ANOVA: $F_{(2,21)}$ range = 19.48-36.68, $p < 0.001$). Letters above Boxplots indicated statistically significant groups.

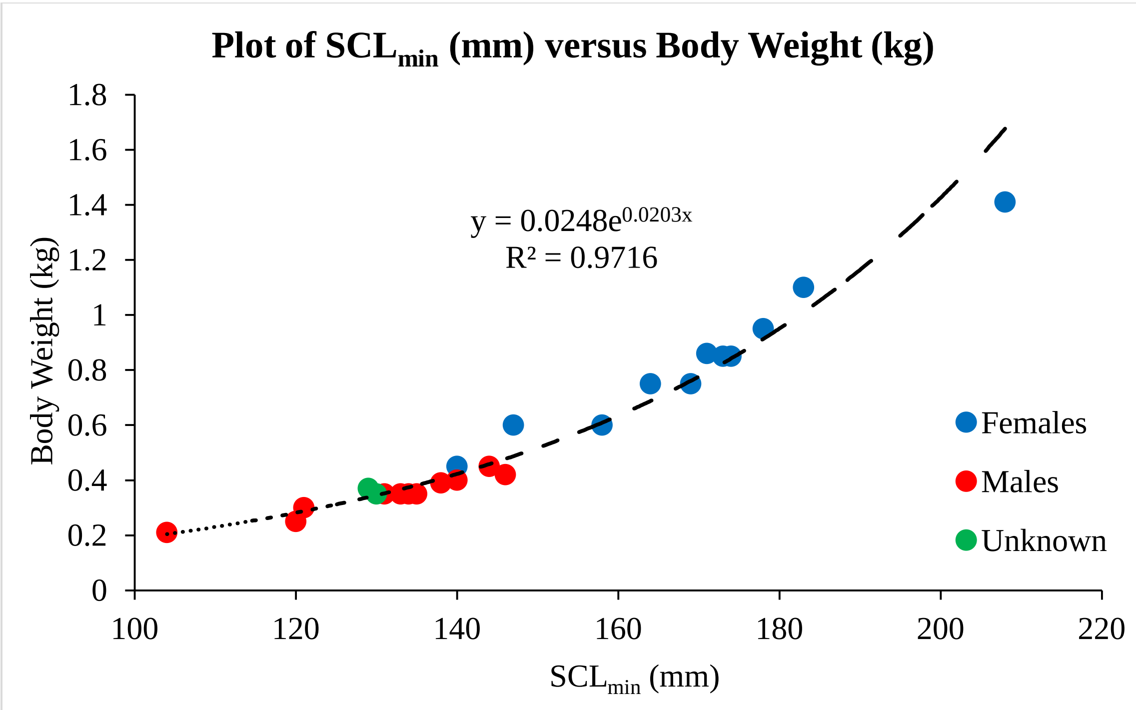

Figure 91 Relationship of body weight and straight carapace length along the midline (SCL_{min}) of terrapin captured in this study (R^2 = 0.9716).

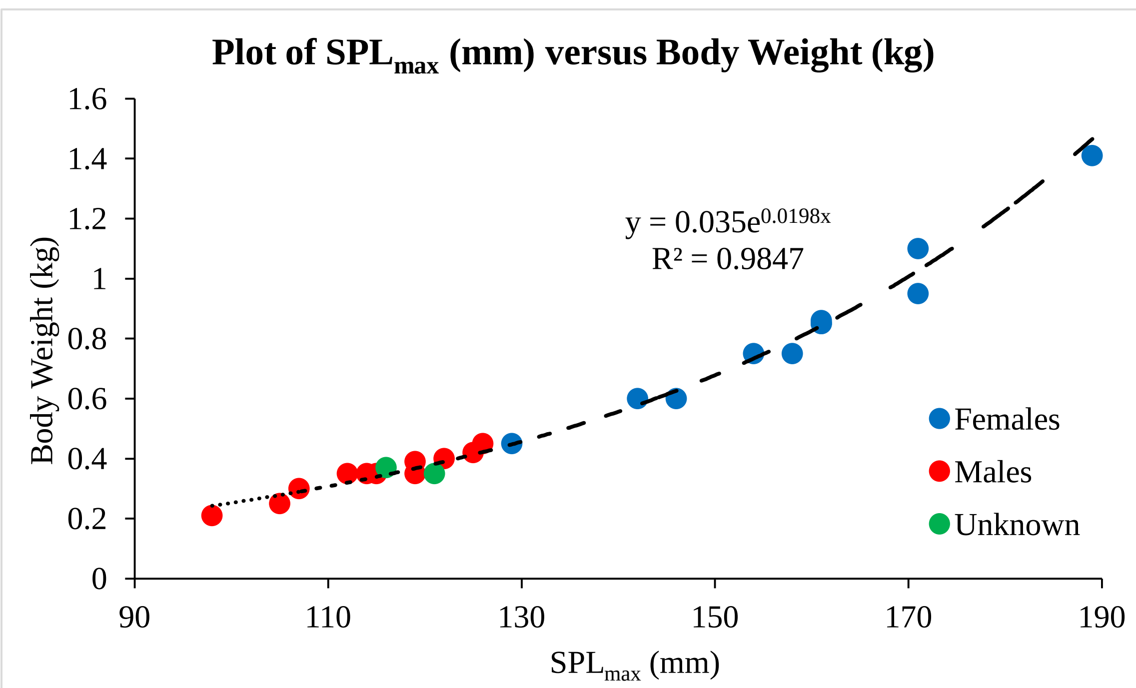

Figure 92 Relationship of body weight and maximum straight plastron length (SPL_{max}) of terrapin captured in this study (R^2 = 0.9847).

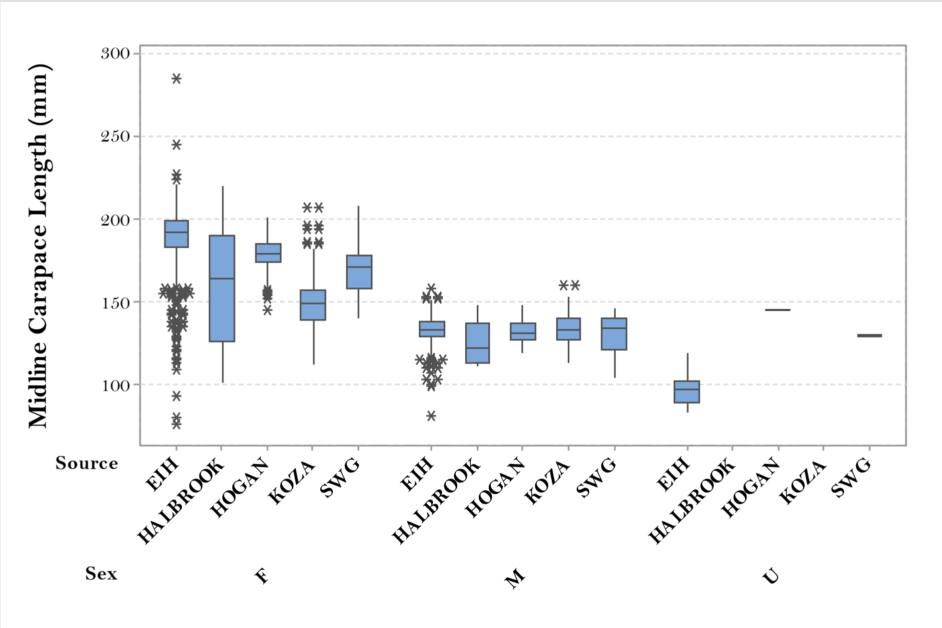

Figure 93. Comparison of male and female terrapin midline carapace length collected during several studies and using additional archived data from EIH.

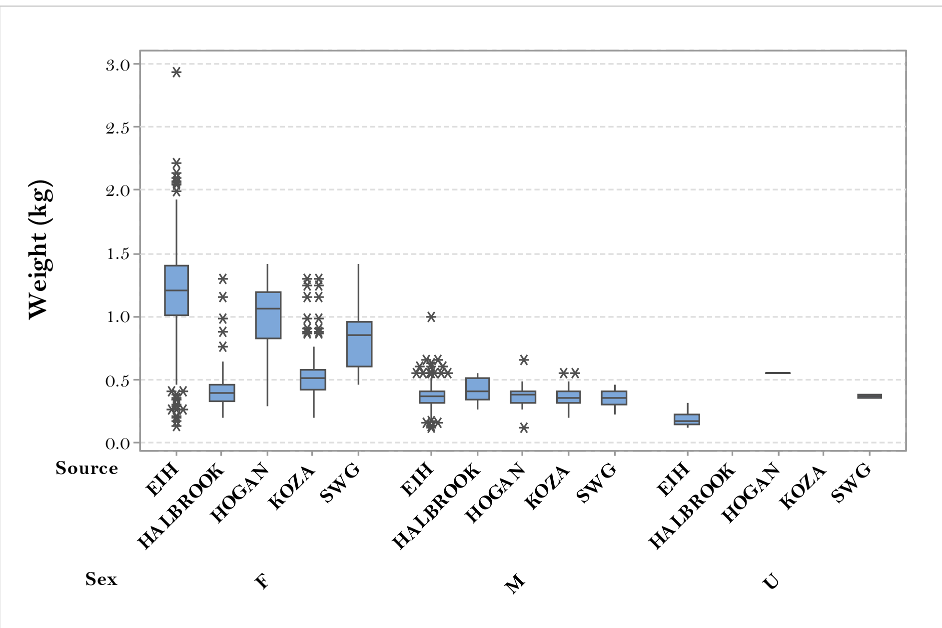

Figure 94. Comparison of male and female terrapin body weight collected during several studies and using additional archived data from EIH.

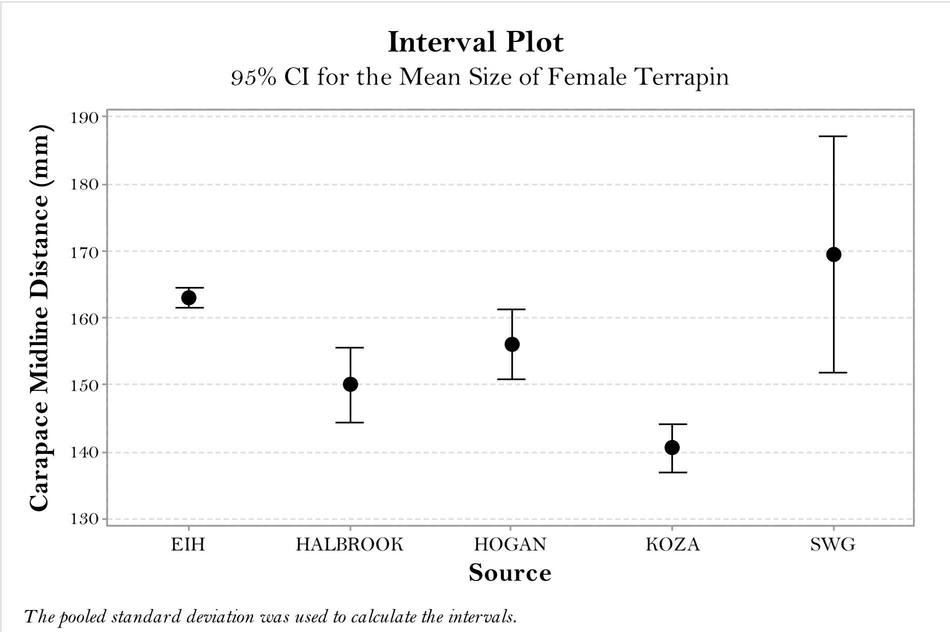

Figure 95. Confidence interval plot of carapace midline length of female terrapin by study.

Table 16. Results of ANOVA and Tukey's pairwise comparison test for female carapace midline distance across multiple studies and regions.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Source	4	127853	31963.2	35.57	0.000
Error	2004	1800985	898.7		
Total	2008	1928838			

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Source	N	Mean	Grouping
SWG	11	169.55	A B
EIH	1489	163.124	A
HOGAN	131	156.13	A B
HALBROOK	107	150.05	B
KOZA	271	140.608	C

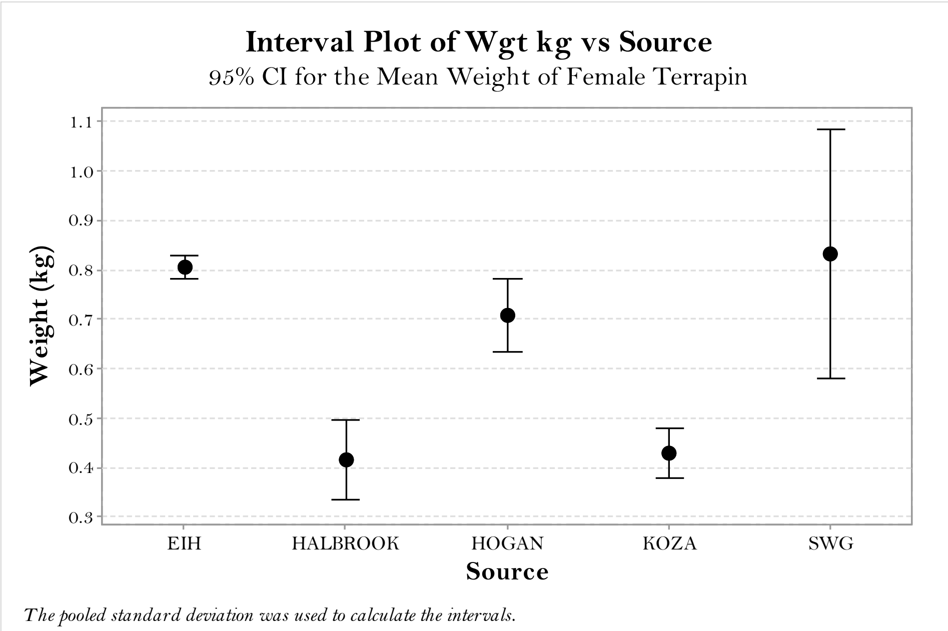

Figure 96. Confidence interval plot of weight of female terrapin by study.

Table 17. Results of ANOVA and Tukey's pairwise comparison test for female terrapin weight across multiple studies and regions.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Source	4	43.08	10.7702	59.83	0.000
Error	1874	337.35	0.1800		
Total	1878	380.44			

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Source	N	Mean	Grouping
SWG	11	0.8336	A
EIH	1362	0.8061	A
HOGAN	128	0.7099	A
KOZA	271	0.4284	B
HALBROOK	107	0.4172	B

Male terrapin carapace length exhibited significant differences between studies (Figure 97 and Table 18). Male terrapin collected by EIH were significantly longer than those collected by Hogan (2003), Halbrook (2003), SWG 2014 collections, and Koza (2006). With the exception of SWG collections all other terrapin were significantly longer than those collected by Koza (2006).

Male terrapin weight exhibited significant differences between studies (Table 19 and Figure 95). Male terrapin collected by EIH were significantly heavier Halbrook (2003), SWG 2014 collections, and Koza (2006). With the exception of SWG collections the Halbrook (2003 and Koza (2006) terrapin were significantly smaller than EIH or Hogan (2003) terrapin. The trend of heavier and longer terrapin being found along the upper coast is most likely related to less metabolic stress associated with less frequent prolonged periods of drought that occur more frequently along the lower coast which likely stresses terrapin more often.

Section 4.3.2.b. *Age and Growth*

Due to the low number of terrapin captured we utilized data from (Guillen and Oakley 2013). Using their data for South Deer Island they were able to provide crude estimates of annual growth for females. Females on South Deer Island between the ages of 3 and 7 appear to exhibit a mean growth rate of 10 mm per year (Figure 99). They found that male terrapin appear to grow much faster at an earlier age and then experience erratic but slow rates possibly not more than 1 or 2 mm per year up to the age 8. They proposed that more energy is placed in males growing faster and becoming sexually mature in males. In contrast the slower growing female, in terms of percentage of total maximum size, is more likely due to the higher metabolic costs associated with egg production

Section 4.3.2.c. *Sex Ratio*

Due to the low number of captures obtained during the 2014 survey we have instead provided an analysis of population data obtained from three published sources. Guillen and Oakley (2013), evaluated recent terrapin demographic data collected from 2009 through 2012. They found that the sex ratio of adult terrapin was 1:1 at three locations in West Bay including South Deer Island, Galveston Island marsh at Sportsmen Road, and North Deer Island area (Figure 100). This suggests that sex biased mortality or survival is not occurring in adult terrapin. Of the 135 individual terrapins captured from July 2011-October 2012, 66 were females and 70 were males. This slightly male-biased sex ratio was present at every site. Hogan (2003), also found earlier in 2001 that the sex ratio on South Deer Island was 1:1. In contrast Halbrook (2003) found that terrapin in Nueces bay exhibited a female to male sex ratio of 2.9:1.

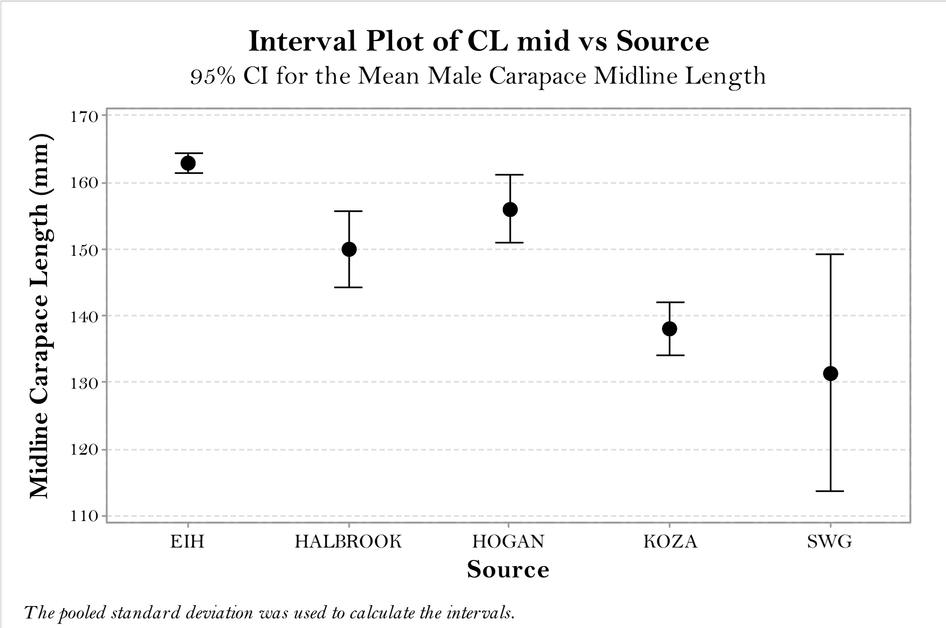

Figure 97. Confidence interval plot of carapace midline length of male terrapin by study.

Table 18. Results of ANOVA and Tukey's pairwise comparison test for male carapace midline distance across multiple studies and regions.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Source	4	139870	34967.4	38.49	0.000
Error	1953	1774234	908.5		
Total	1957	1914104			

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Source	N	Mean	Grouping
EIH	1489	163.124	A
HOGAN	131	156.13	A B
HALBROOK	107	150.05	B
KOZA	220	138.050	C
SWG	11	131.45	B C

Means that do not share a letter are significantly different.

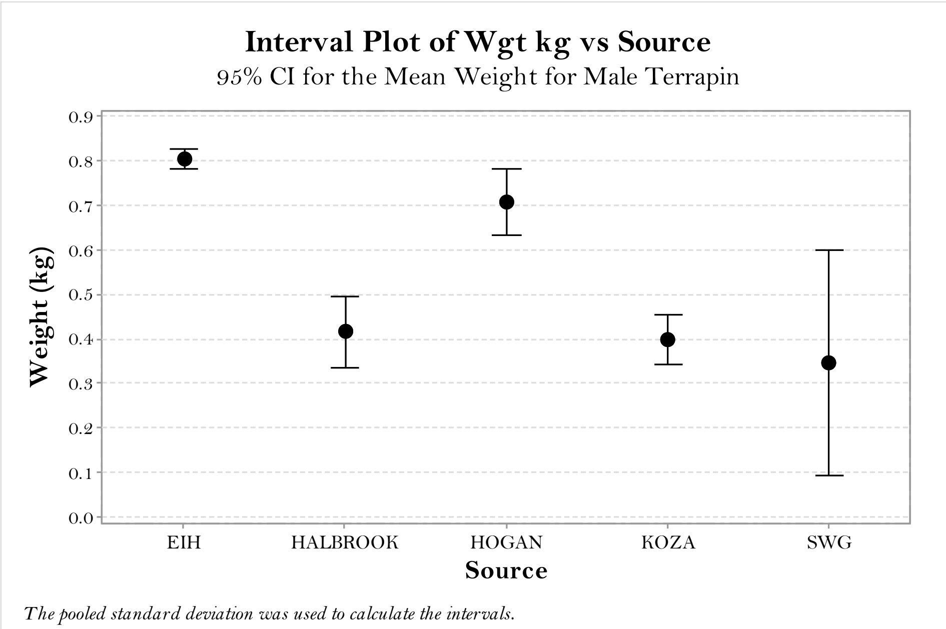

Figure 98. Confidence interval plot of weight of male terrapin by study.

Table 19. Results of ANOVA and Tukey's pairwise comparison test for female terrapin weight across multiple studies and regions.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Source	4	43.80	10.9501	59.93	0.000
Error	1823	333.10	0.1827		
Total	1827	376.90			

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Source	N	Mean	Grouping
EIH	1362	0.8061	A
HOGAN	128	0.7099	A B
HALBROOK	107	0.4172	C
KOZA	220	0.4009	C
SWG	11	0.3473	B C

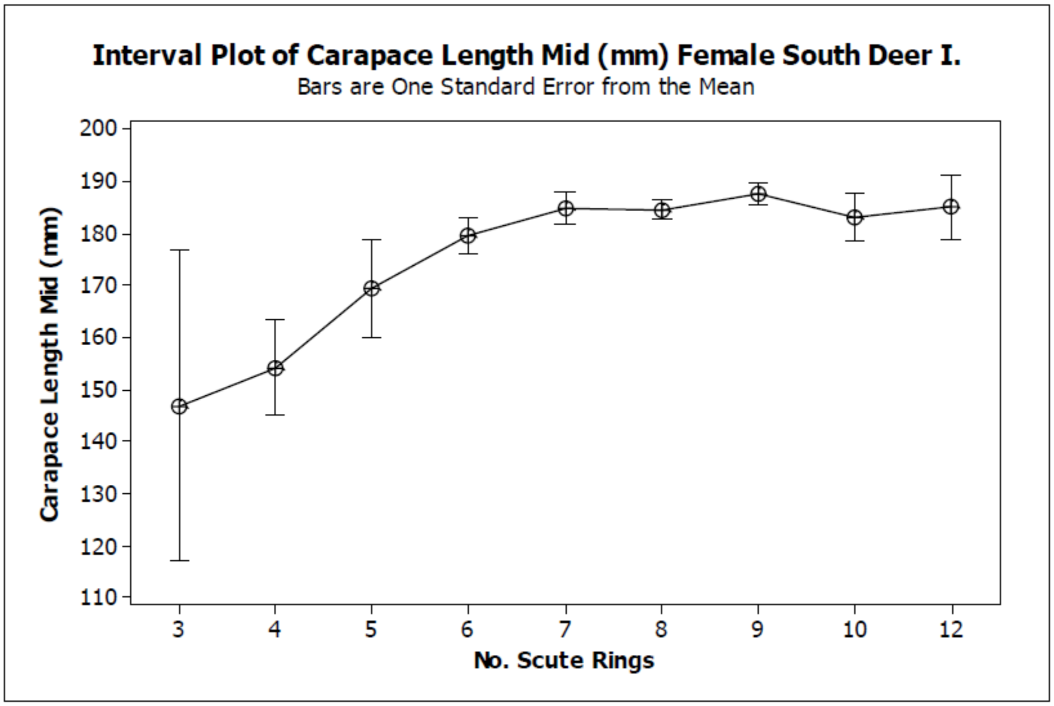

Figure 99. Size at age for age 3 to 12 female terrapin captured at South Deer Island during 2008 to 2013 (Guillen and Oakley 2013).

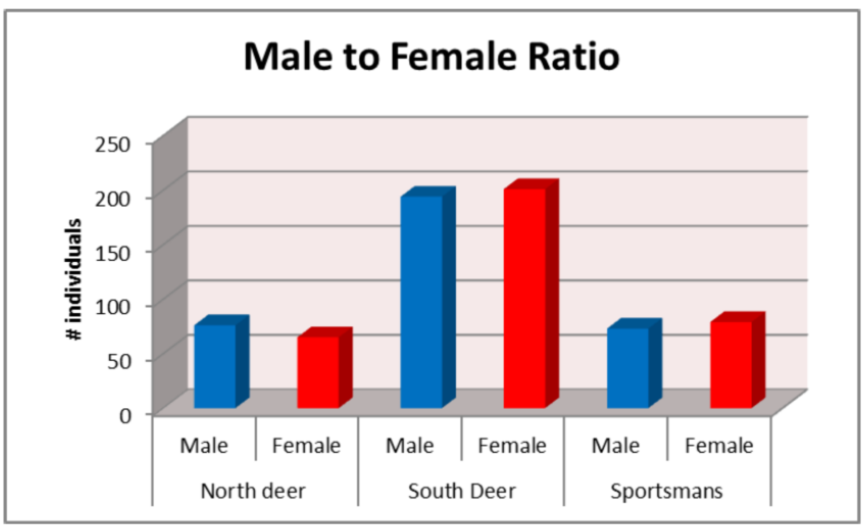

Figure 100. Sex ratios of captured terrapin during the study period (February 2009- August 2012) (Guillen and Oakley 2013).

Section 4.3.2.a. *Population size and density*

Due to the relatively low catch rates observed during the study estimates of population size were not attempted due to insufficient numbers of marked and recaptured terrapin (*n* for all sites = 0). Past studies conducted and summarized by (Guillen and Oakley 2013) have provided estimates of the population size of terrapin on South Deer Island based on Jolly Seber model output (Krebs 1999; PISCES Conservation 2009). They estimated an average and 95% confidence interval for South Deer Island to be 327 ± 50 terrapin (Figure 101). The point estimate however varied between 957 to 27 terrapin through this period indicating wide confidence intervals. Assuming a population size of 327 terrapin on this 29 hectare island we would then estimate a density of 11 terrapin/hectare or 2,991 terrapin/mi^2.

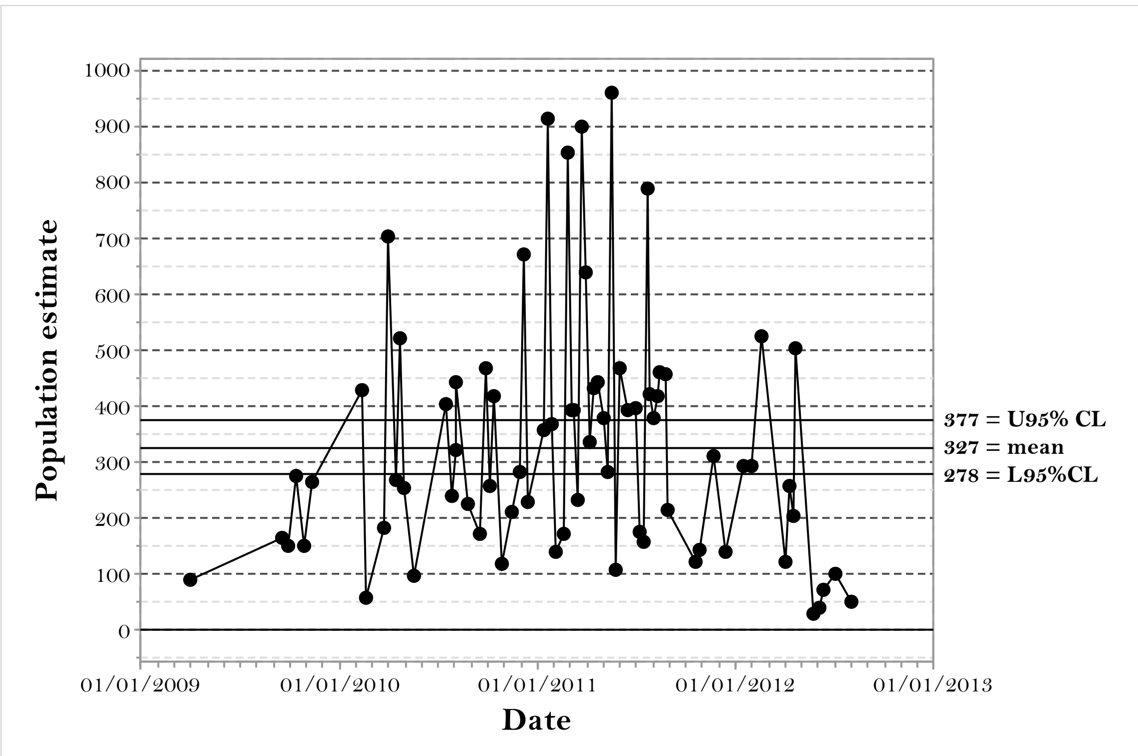

Figure 101. Result of Jolly Seber mark recapture estimates from March to August 2012 (Guillen and Oakley 2013).

Halbrook (2003), using mark recapture methodology estimated the average population size of Nueces Bay was 322 terrapin. The surface area of Nueces Bay is 6940.97 hectares (26.79 mi^2). Using this value the extrapolated density of terrapin would be 12 individuals / mi^2. Baxter et al. (2013), presented an estimate of the population size of 438 terrapin in Nueces Bay. This abundance would yield a density of 16 terrapin / mi^2. The areas used for Nueces Bay do not take into account the fringing marsh and islands found in that system. Based on a cursory examination of the surrounding marshes we estimated that there is likely 2,390 additional hectares (9.22 mi^2) of wetlands. Converting the estimates above into numbers per wetland would yield approximately 35-47 terrapin/mi^2 of marsh. The estimated population abundance and density of terrapin at the South Deer Island complex if correct is most likely the most abundant local population of terrapin in Texas.

Section 4.4. GIS Analysis and Habitat Characteristics

Section 4.4.1. Analysis of land cover composition for 2008-2014 data

We conducted two analyses of the habitat associations for terrapin. The first analysis includes a more a comprehensive analysis of geographic coordinates for the period extending from 2008 to 2014 including past data collected by EIH and the recent study. The second analysis included only more recent data from 2010 to 2014. As described earlier results are presented for 0.2 km radius (0.126 km^2), 0.1 km radius (0.031 km^2) and 0.9 km radius (2.545 km^2) from the collection point of each terrapin or centroid of each cluster formed by overlapping home ranges. More detailed analyses are provided for the site clusters formed by the analysis of 0.9 km radii (Figure 15 and Table 4).

Section 4.4.1.a. *Analysis of land cover data for 2008-2014 capture sites*

The more extensive (2008 to 2014) analysis included the geographic coordinates for 1,932 terrapin previously captured and georeferenced using GPS by EIH investigators from 2008-2014. These data were combined with the 24 coordinates obtained from terrapin captured in this study and analyzed to determine possible association with specific habitat types as defined by the National Wetland Inventory (USFWS) and C-CAP Plant Cover Data (NOAA) national datasets and modified classification schemes.

Land cover within the varying buffer sizes based on the C-CAP land cover data show consistent patterns of association with high percentage of ‘Estuarine Emergent Wetland’ and ‘Unconsolidated Shore’ land cover classes (Figure 102 and Table 2). As the estimated home range areas considered were increased, values for the ‘open water’ class (class code 19) also increased. A similar pattern of increasing percentages of aggregated ‘Estuarine and Marine Deepwater’ habitat was observed when the constructed buffers constructed around terrapin capture locations were compared using the National Wetland Inventory data (Figure 103 and Table 3). Although there was some variation between sites and clusters the overall pattern of habitat use was fairly consistent with overall patterns described above (Figure 104 and 105).

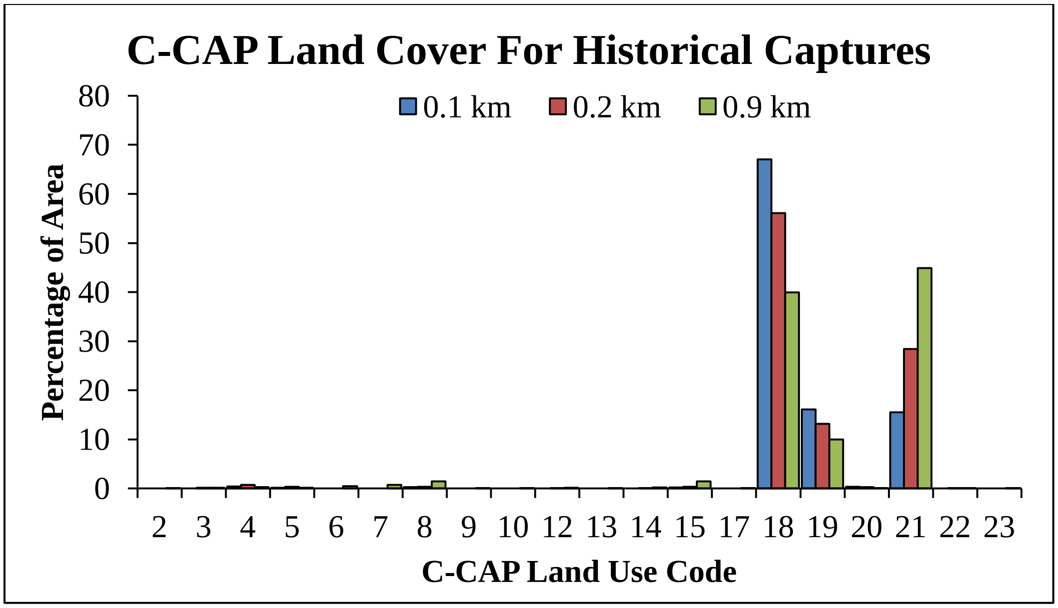

Figure 102. Percentage of C-CAP land cover types within 0.1 km (blue), 0.2 km (red), and 0.9 km (green) areas of capture locations (2008-Present). See Table 2 for code descriptions.

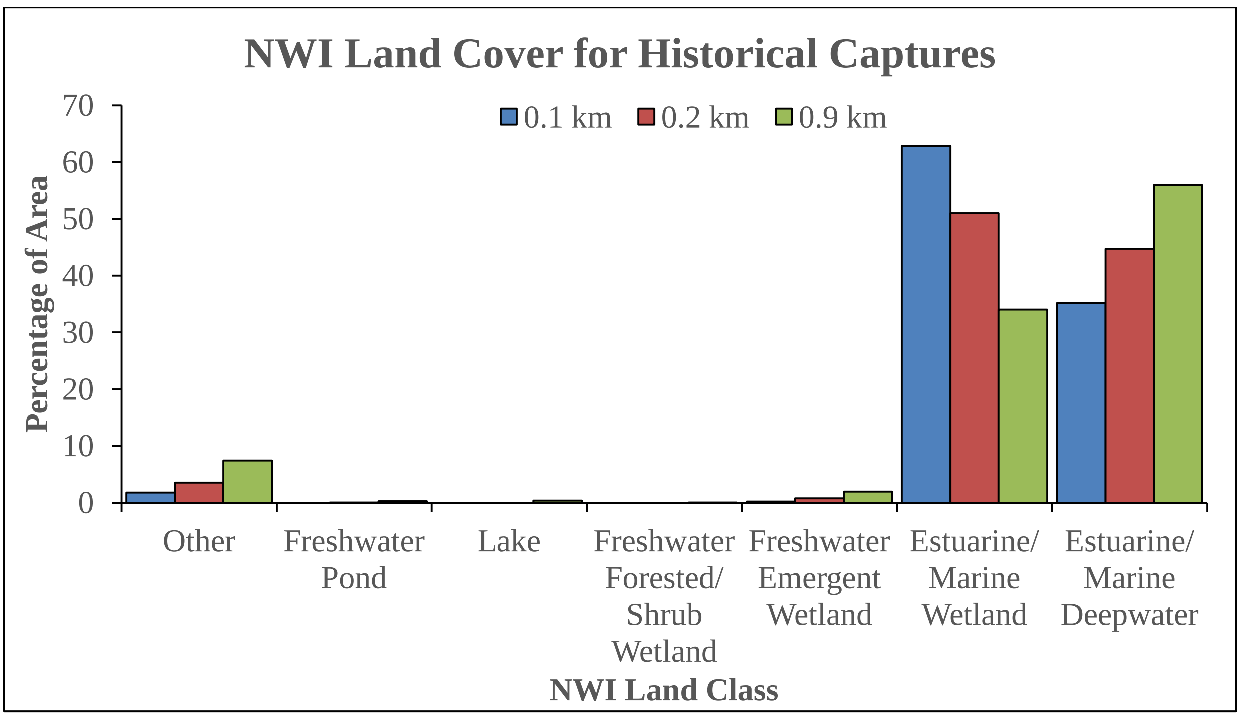

Figure 103. Percentage of NWI land cover classes within 0.1 km (blue), 0.2 km (red), and 0.9 km (green) areas for all capture locations combined (2008-Present).

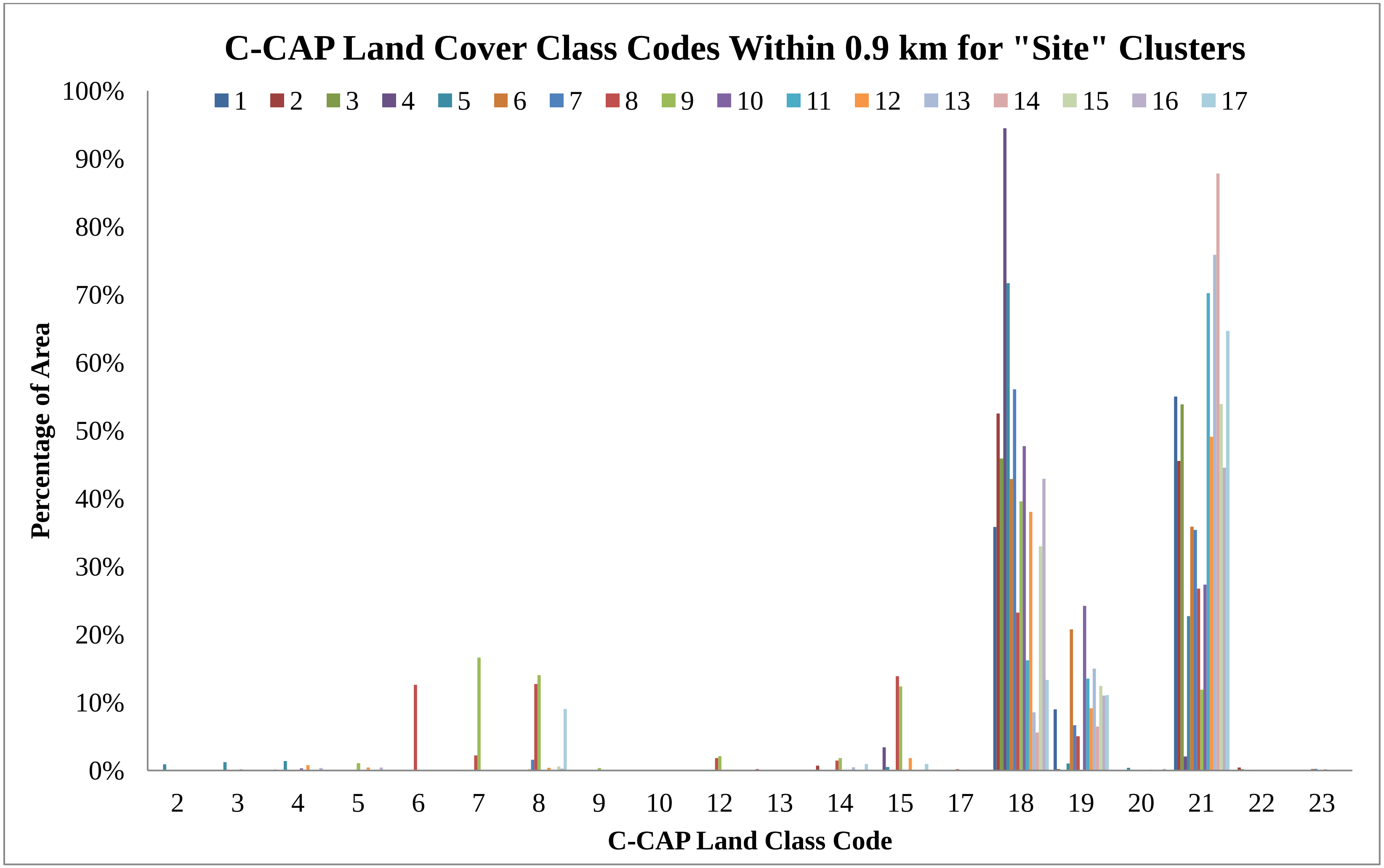

Figure 104 Percentage of C-CAP land cover classes within 0.9 km radius of 17 historical (2008 - 2014) EIH terrapin population clusters. See Table 2 for class code descriptions of land use.

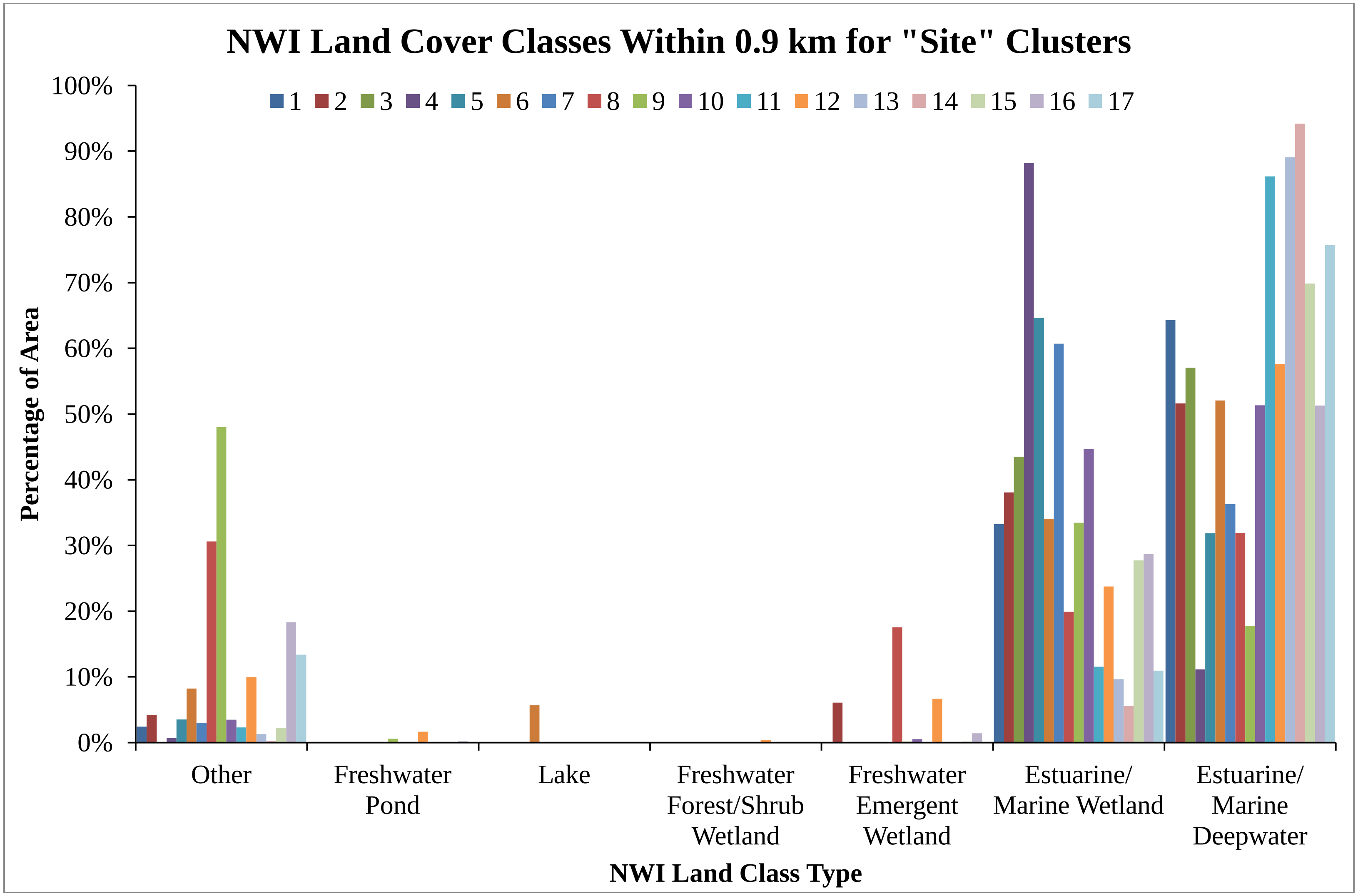

Figure 105. Percentage of NWI land cover within major land class groups within 0.9 km radius of 17 historical and recent (2008 - 2014) EIH individual terrapin and group clusters. See Table 3 for listings of NWI land cover.

Interestingly enough the highest number of captures when the 0.9 km radius was used did not occur in areas dominated by saltmarsh but instead at locations containing a high percentage of open water, specifically in clusters 13, 14, 12 and 15 near and including South Deer Island (Figure 106).

In summary, terrapin were seldom found far from an open source of water and highest counts were associated with wetland areas located adjacent to extensive open water. This association most likely is due open water mating, foraging and escape of predators. In addition, expansive open water areas surrounding islands provides a barrier to predators. The next area exhibiting high densities that was not analyzed as part of our dataset was Nueces Bay. This site contained similar amounts of open water habitat with isolated islands (Figure 23- 24 and 26).

Section 4.4.1.b. *Analysis of land cover data for 2014 non-capture sites.*

In addition to characterizing the land cover and vegetation types at sites where terrapin were captured we also attempted to randomly select sites that in some cases were not ideal habitat as documented in the literature. The reason for this approach to sampling is to provide an assessment of all types of habitat in order to contrast sites where terrapin were captured versus random and opportunistic samples of estuarine habitat.

A total of 19 sites mainly around Sabine Bay, Matagorda Bay and San Antonio Bay were surveyed during this study with no observation of terrapins were recorded (Table 5 and Figure 16). These sites were investigated in regard to land cover composition using both the C-CAP land cover dataset and the National Wetland Inventory dataset. As noted earlier, sites 8 and 9 were excluded from the analysis against the C-CAP data due to a gap in this dataset (Table 5 and Figure 16). The analysis used regular circular buffers of 0.9 km (i.e. maximum home range reported) to analyze the land cover composition. Figure 107 - 109 show proportions between 19 - 63% of the ‘Estuarine Emergent Wetland’ land cover class, and up to 45% of the ‘Unconsolidated Shore’ land cover class when the C-CAP data was examined. Examination of National Wetland Inventory data for these sites (Figure 109) shows a range between 19-90% of the aggregated ‘Estuarine and Marine Wetland’ class.

Section 4.4.2. Analysis of land cover composition for 2010-2014 data

An additional GIS analysis was conducted on 46 sites (Figure 110) where terrapins were reported during the last 5 years in order to identify land cover composition patterns. The time frame of 5 years was used to provide more consistent analysis with regard to the 2010 C-CAP land cover dataset. The maximum reported home range of 0.9 km was used to create buffers around these sites, which overlapped at many sites as shown in Figure 1. These buffers were given ID numbers from 1 to 46 and then intersected with both the C-CAP land cover data and the National Wetland Inventory dataset to calculate the percentages of land cover classes and wetland types.

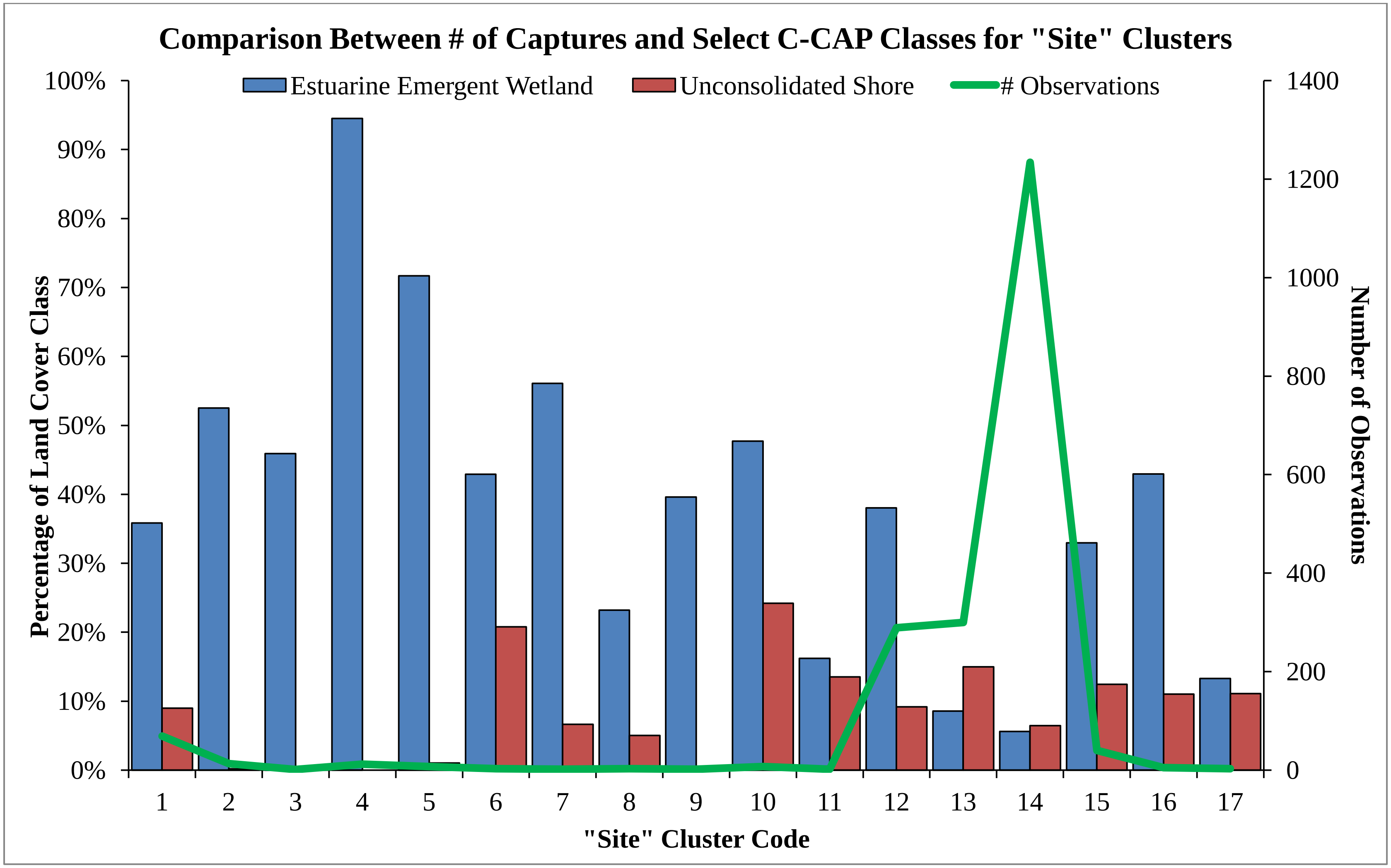

Figure 106 Comparison of number of terrapin captures (green line) and the C-CAP land cover composition within each “site” cluster using the most prevalent land use types at 0.9 km buffer: "Estuarine Emergent Wetland" (blue) and "Unconsolidated Shore" (red). See

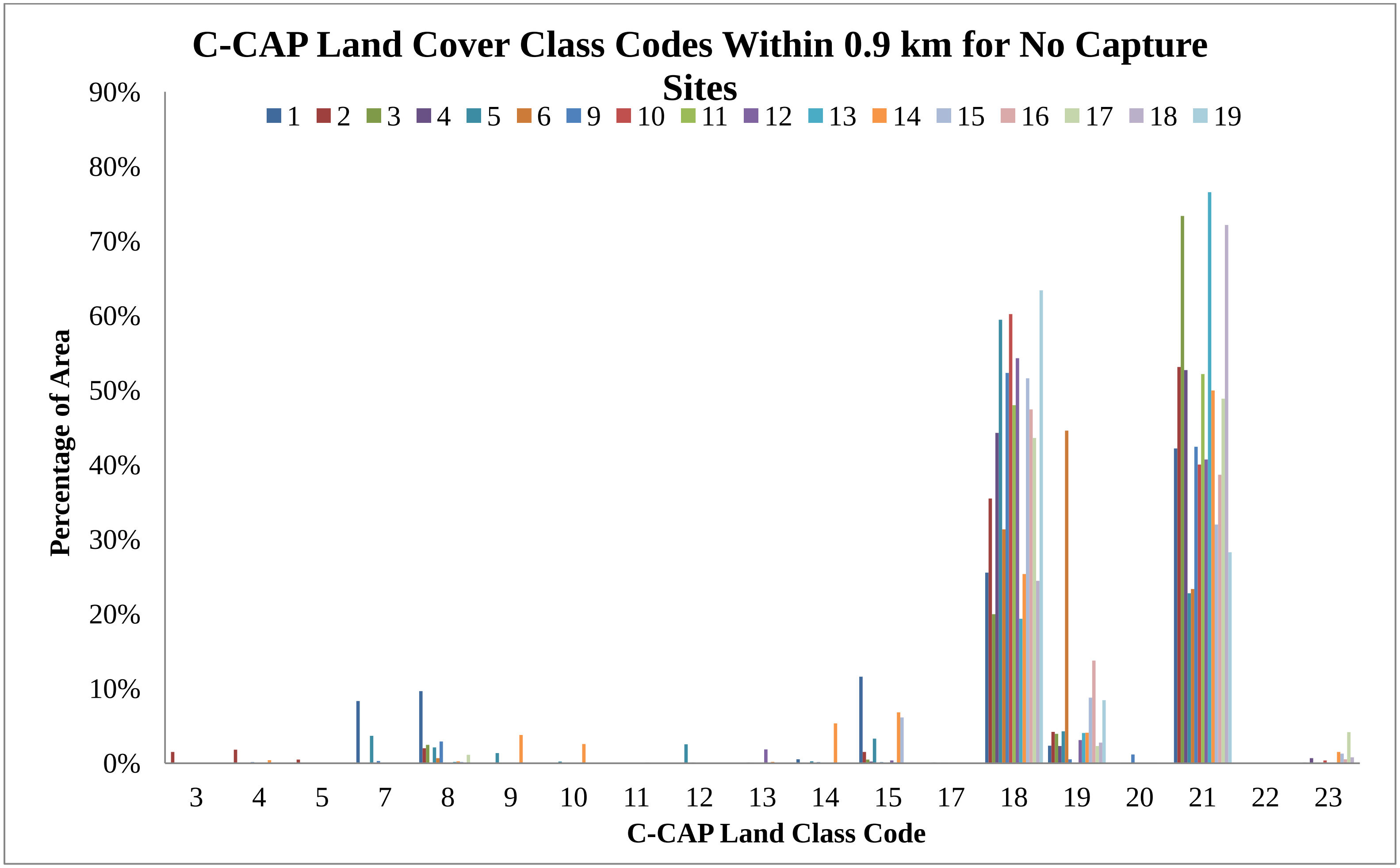

Figure 107 Percent of C-CAP land cover classes at sites with no terrapin captures. See Table 2 class code descriptions of land use.

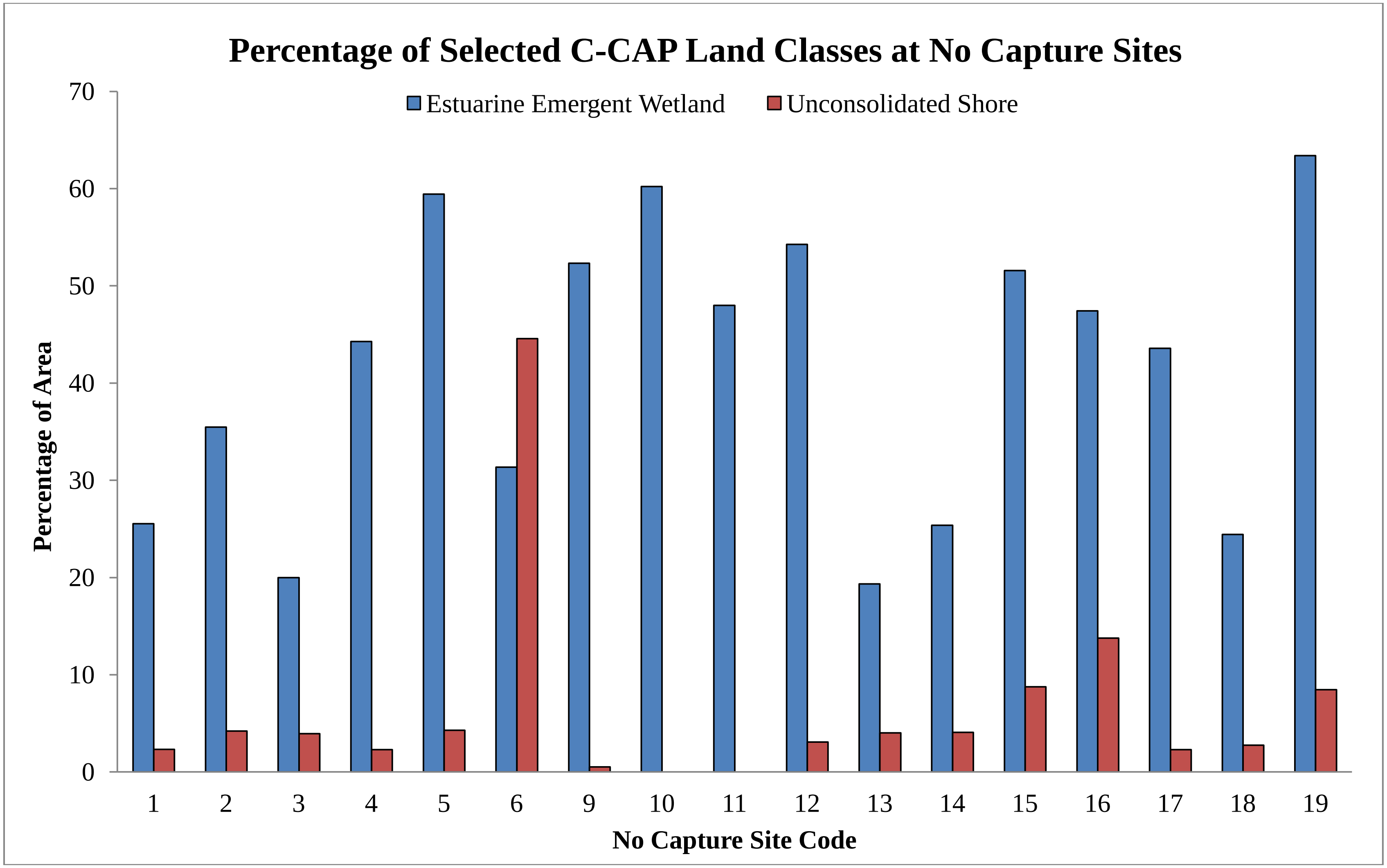

Figure 108 Percent of C-CAP land cover for estuarine emergent wetland (blue) and unconsolidated shore (red) land class types at sites were no terrapin were captured. Sites 7 and 8 in Sabine Lake were not included due to lack of C-CAP land cover data for those areas. See Table 4 for site descriptions and bay locations.

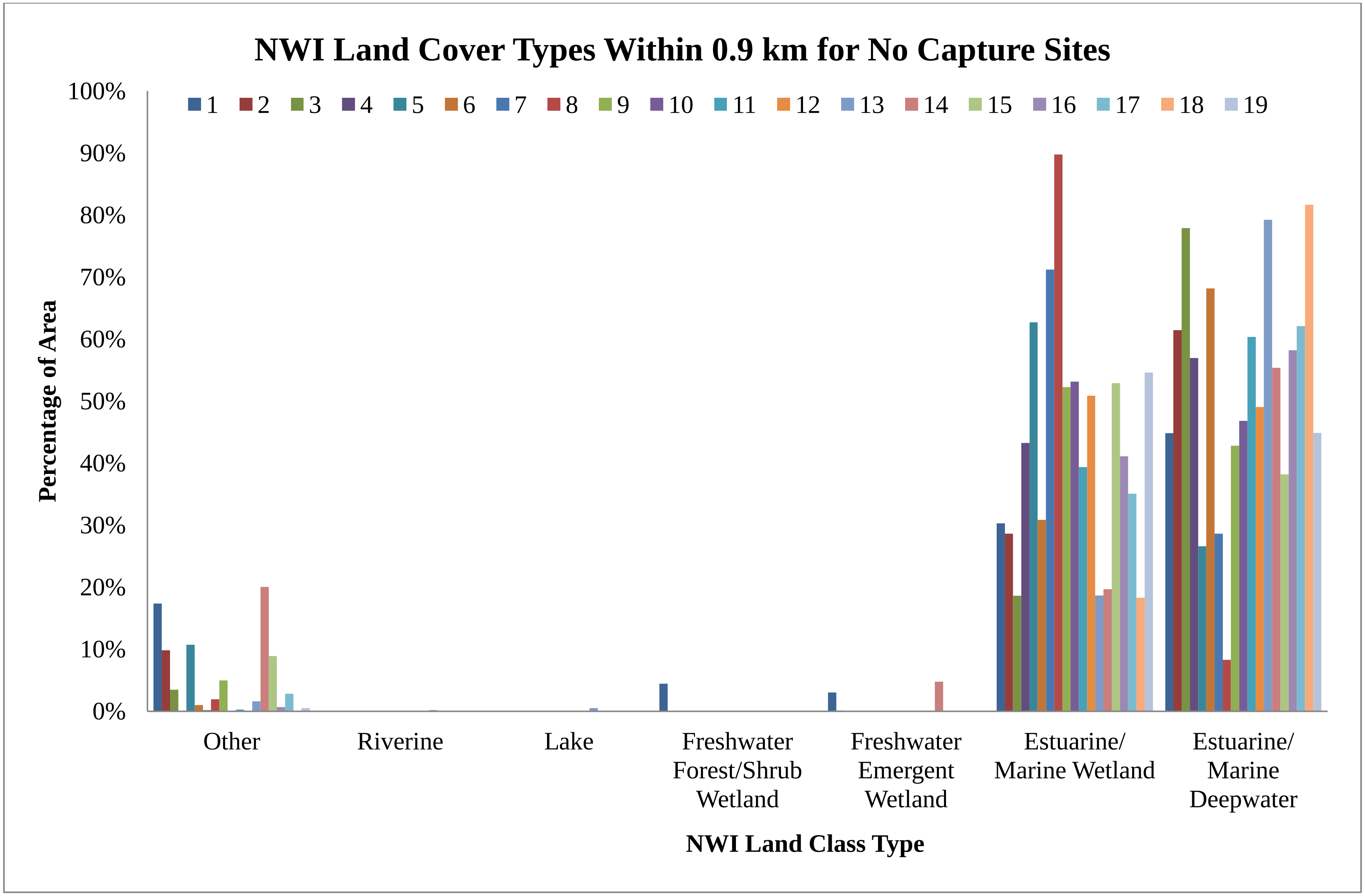

Figure 109 Percent of NWI land cover classes at sites with no terrapin captures. See Table 5 for no capture site descriptions.

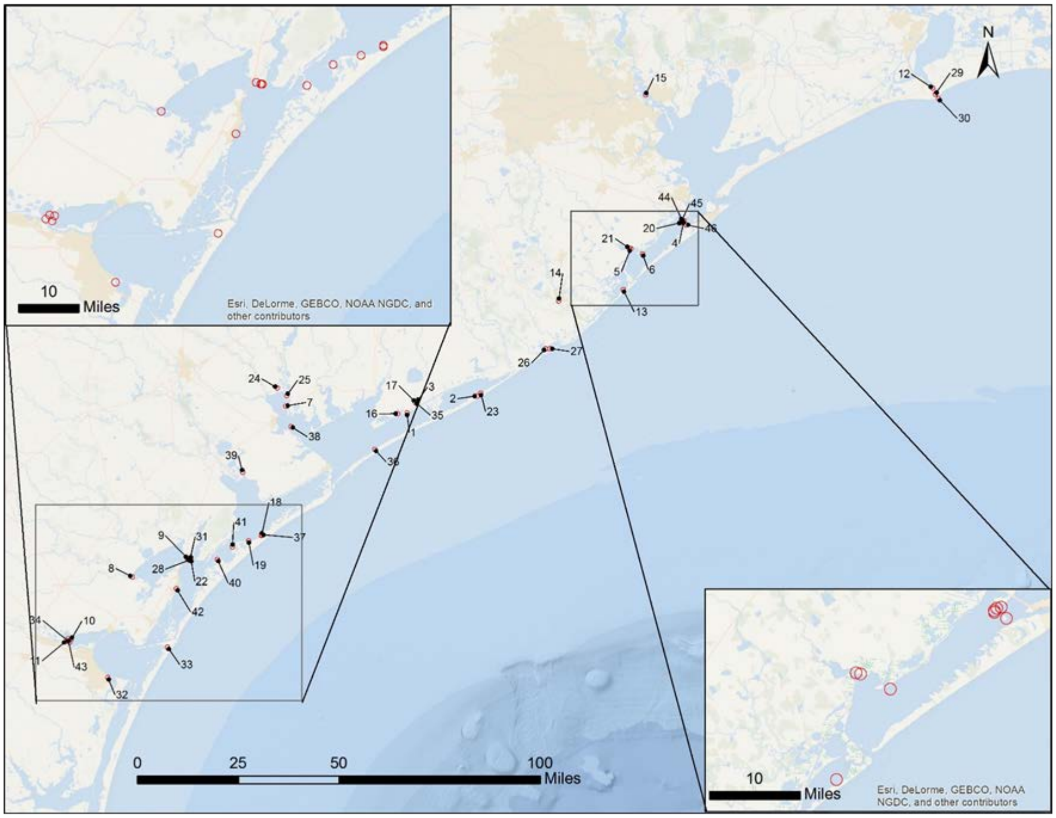

Figure 110. Map of 46 sites (using buffers equal to 0.9 km) where terrapins were reported during 2010-2015.

In general the analysis shows similar patterns of land cover composition to what have been seen previously at the 2008-2014 capture sites. In regard to the National Wetland Inventory data, wetland types were aggregated into major classes as shown in Figure 111. The summary statistics indicate that ‘Estuarine and Marine Wetland’ exists at 24% on average and it may reach up to 63% in some sites. The high percentages of the ‘Open Water’ and ‘Estuarine and Marine Deepwater’ are mainly due to the regular circular buffers used in this analysis. In the case of the C-CAP land cover data, the land composition includes up to 70% of ‘Estuarine Emergent Wetland’ and up to 47% of ‘‘Unconsolidated Shore’ (Figure 112). The average percentages of these two classes are 25% and 8% respectively. In summary, the analyses conducted with more recent data yielded similar results to the 2008-2014 analysis. Terrapin appear to utilize open water areas extensively along with wetland areas based on predicted home ranges.

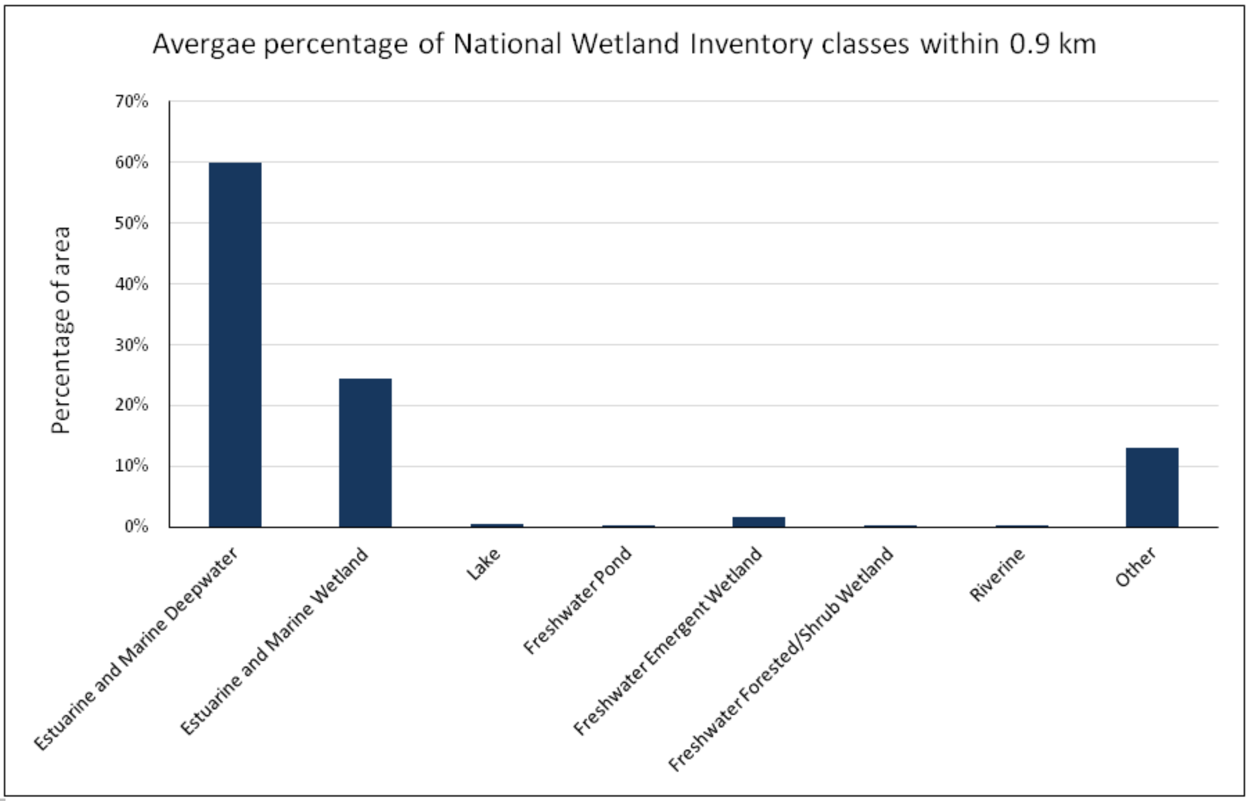

Figure 111. Average percentages of aggregated National Wetland Inventory classes within 0.9 km (maximum home range reported) at 46 sites where terrapins were reported during 2010-2014.

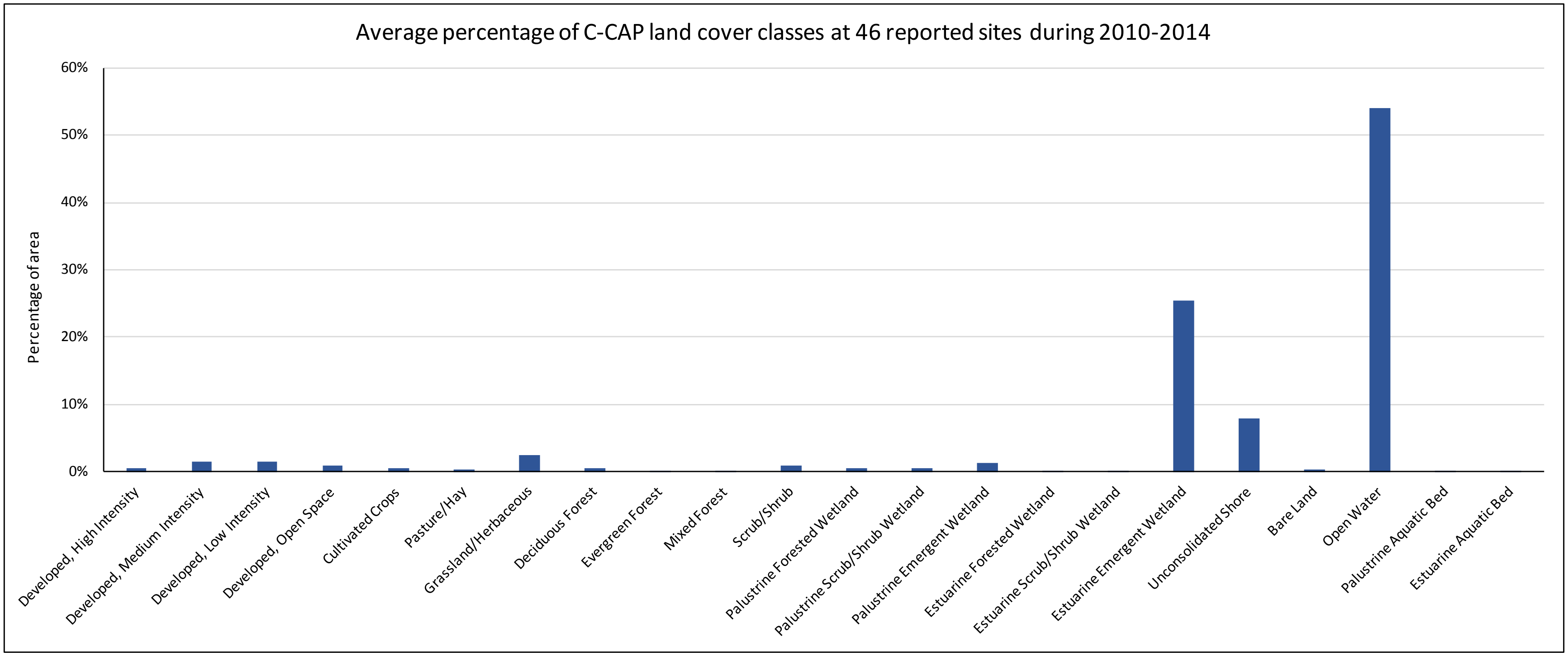

Figure 112. Average percentage of C-CAP land cover classes reported at terrapin capture sights during 2010-2014.

SECTION 5. DISCUSSION

This study provides new information on the distribution of terrapin along the middle coast extending from San Antonio Bay up to Sabine Lake. This was accomplished by combining the results of new field studies in Galveston Bay, Cedar Lakes Creek and East Matagorda Bay which included previously unpublished data. Furthermore a thorough analysis of historical data and studies in Nueces, Aransas, Corpus Christi and other minor bays conducted during the period 1997-2006 provides coast wide coverage of most bay systems. However, significant gaps exist along the middle coast that will require additional surveys. The primary conclusions and deliverables produced by this project include.

1). All sightings both past and present from multiple studies have been archived and are available in kml, ArcGIS and Excel format. In most cases these data represent specific locations where terrapin have been captured or observed. This includes data from this study, past EIH studies, records from TPWD coastal fisheries monitoring, other published studies, reported sightings from biologists, fishermen and the public, the TPWD abandoned crab trap data, and questionnaire responses.

2). First reported occurrence of diamondback terrapin in Jackson County is provided. Based on this occurrence we can now conclude that terrapin occurs or has occurred in all coastal Texas counties from Sabine Lake down to Baffin Bay (Dixon and Hibbits 2013).

3). Based on past studies, historical records, and personal observations the primary factor causing declines in terrapin prior to the 1930's was overharvest of the species for the terrapin soup market in the northeast. Following that period the shell dredging industry became active and was responsible for the widespread loss of both above tidal, intertidal and subtidal oyster shell throughout the Gulf coast. Accounts and official records indicate that much of the terrapin's former preferred nesting beaches and protected isolated islands were completely destroyed by the early 1970's.

4). Two of the largest concentrations of terrapin in Texas are found in the Nueces Bay and West Galveston Bay. Both of these areas contain numerous small oyster shell islands often associated with colonial waterbird aggregations. Previous studies on the Nueces and Aransas Bay populations indicate that multiple oyster shell islands are likely providing suitable nesting habitat.

5). The only records of terrapin nesting in Texas is on shell beaches located on South Deer Island and near Moses Lake in the Galveston Bay system.

6). Terrapin home range estimates range between 0.2 and 0.9 km radius (12.5 to 254 hectares).

7). The limited home range (< 0.9 km radius; 254 hectares, 2.54 km^2) and breeding site philopatry exhibited by female terrapin makes this species exceptionally susceptible to local extirpation risk. Therefore it is critically important to identify all major nesting shorelines in Texas.

8). Habitat suitability curves for nesting terrapin developed for Atlantic coast populations include multiple variables such as % canopy cover as shrubs (V1), % canopy cover of grasses (V2), and mean substrate slope (V2) (Palmer and Cordes 1988). These curves need to be seriously reevaluated and modified to take into account the habitat associations observed in Texas terrapin. For example, data collected by our laboratory and others suggest that other variables such as degree of isolation, the amount of shell hash substrate, and the presence of adjacent wetlands which provides cover to hatchlings are also very important in both nesting and hatching success.

9) Based on a review of the literature and recent studies in Texas terrapin are seldom found when air temperature drops below 15 ºC in land or water. Furthermore, it appears that terrapin are seldom found when air or water temperature exceeds 35 ºC. During these periods terrapin are usually found burrowed in sediment and during the winter are in a state of brumination.

10) One of the primary factors that have been identified in the limiting the distribution of terrapin is elevated salinity. The distribution of terrapin occurrences spans a large salinity range from 0.2 to 47 psu. However, the majority of terrapin occurrences range between 10 and 34 psu. Although terrapin possess a salt secreting gland, it is not as efficient as those found in true sea turtles. Therefore terrapin must occasionally obtain freshwater to drink. This can be from rainfall or freshwater inflow. Based on the distribution of historical terrapin captures and observations the southern extent of terrapin in Texas is likely limited to Nueces Bay or nearby estuarine waters due to the lack of rainfall and reliable freshwater sources further south in the Laguna Madre.

11) Many past studies have relied exclusively on carapace dimensions to describe the size of terrapin. It is recommended that in the future investigators incorporate measurements of carapace, plastron, and the head region at a minimum to describe individuals and fully evaluate the growth and development of members of the species.

12). Based on our examination of historical data collected by past studies in Nueces Bay and adjacent water bodies there is a statistically significant size difference in both male and female terrapin between the upper and lower coast of Texas. Terrapin from the upper Texas coast were in general both longer and heavier than those form the south coast of Texas. The reduced size may reflect higher energy use for metabolism due to higher salinities and more stressful conditions at the extreme end of their distribution.

13) Estimates by Guillen and Oakley (2013) and Hogan (2003) suggest the population size of insular populations of terrapin is around 327 ± 50 terrapin/29 hectares. A population size of 327 terrapin on a 29 hectare island would translate into an estimated density of 11 terrapin /hectare, or 2,991 terrapin /mi^2. Estimated population sizes and density were lower along the lower Texas coast. The average population size of Nueces Bay was 322 terrapin. The surface area of Nueces Bay is 6940.97 hectares (26.79 mi^2). Using this value the extrapolated density of terrapin would be 12 individuals / mi^2. The areas used for Nueces Bay do not take into account the fringing marsh and islands found in that system. The estimated population abundance and density of terrapin at the South Deer Island complex if correct is most likely the most abundant local population of terrapin in Texas. If the estimated numbers provided by each study is approximately correct this would imply that insular wetlands isolated from the mainland inherently have a higher carrying capacity for terrapin. This may be due to reduced predation. In addition, the Nueces Bay population is located near the edge of the distribution of this species and may be encountering strong selection pressure against further growth.

14). There is a need to collect additional data on habitat features in support of the development of a wetland carrying capacity model for terrapin. Guillen and Oakley (2013) reported that Texas terrapin captured on land are found more frequently in *Spartina alterniflora* stands and in vegetation exhibiting a canopy height of 20-60 cm. Although terrapin can be found over the entire spectrum of vegetation cover they are most frequently encountered in 40-60% vegetation cover.

15). Based on historical data obtained from South Deer Island, the average growth rate of female terrapin between the ages of 3 to 7 is 10 mm per year. Male terrapin appear to grow much faster at an earlier age and then experience slower growth ranging from 1 to 2 mm per year up to the age 8.

16). Maintenance of a balanced ratio of male and female organisms is often considered essential for population viability although in some cases the distribution can be skewed. The populations of terrapin at South Deer Island have been maintaining a 1:1 ratio of males and females since the early 2000’s (Guillen et al. 2011; Hogan 2003). In contrast Halbrook (2003) reported a skewed ratio favoring females, 2.91:1 female: male, in the Nueces Bay area.

17). One of the major risks to terrapin population viability is bycatch mortality associated with the commercial blue crab fishery of Texas. Based on information obtained from crabbers, past information surveys, TPWD fishery independent surveys and ongoing work by our institution and others it appears that the risk of bycatch mortality increases substantially whenever crabbers operate near areas of high terrapin density such as the Nueces and Aransas Bay systems, East Matagorda Bay system and interconnecting waterways, and the West Bay-Deer Island complex. Currently the Gulf States Marine Fisheries Committee (GSMFC) and member states are investigating the need to implement regulations that would require blue crab fishermen to install bycatch reduction devices (BRD). The highest risk from bycatch mortality would be from accessible areas (e.g. open water, deeper tidal creeks) which allow high blue crab fishermen to deploy pots close to terrapin nesting and foraging areas.

The combination of physical isolation, suitable habitat and abundant prey has led to the relatively high population levels observed at the South Deer Island complex. The lack of boat access to commercial fisherman and most recreational vessels, the apparent lack of terrestrial predators, and the beneficial protection terrapin share by inhabiting the island with federally protected colonial waterbirds, has no doubt led to the establishment of these large island populations on South and North Deer Island and adjacent wetlands located on mainland at Greens Lake and on the bay side of Galveston Island. Similarly the Nueces Bay terrapin population apparently utilizes the wetlands and remote oyster shell islands in that bay system for foraging and the islands for nesting. It is clear that terrapin rely on a mosaic of habitats including tidal creeks and saltmarshes for foraging and oyster shell or sand beaches for nesting. Other factors such as isolation from predators and commercial blue crab fishing effort contribute to their long term population viability. Due to individual longevity, delayed maturity, and long generation times, long-term studies are critically needed to monitor the dynamics and trends in terrapin populations in Texas. Currently with the exception of a few areas like Nueces Bay and South Deer Island there is not sufficient baseline data to monitor the response of terrapin to future management actions (e.g. BRD implementation).

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Appendix A. EndNote Library

Electronic Supplement

Appendix B. Historical TPWD Data

Electronic Supplement

This appendix includes a compilation of all historical data provided to EIH through Texas Parks and Wildlife's Resource Monitoring Program (1983-2013) as well as the Abandoned Crab Trap Removal Program (2002-2013).

Appendix C. Online Questionnaire Format & Supplemental Information

Appendix C.1. Example Online Questionnaire

Start Screen: Statement of Intent and disclaimer.

Figure 113 Start screen for online questionnaire. Includes statement of intent, thank you, and disclaimer.

Section 1: Contact information (optional).

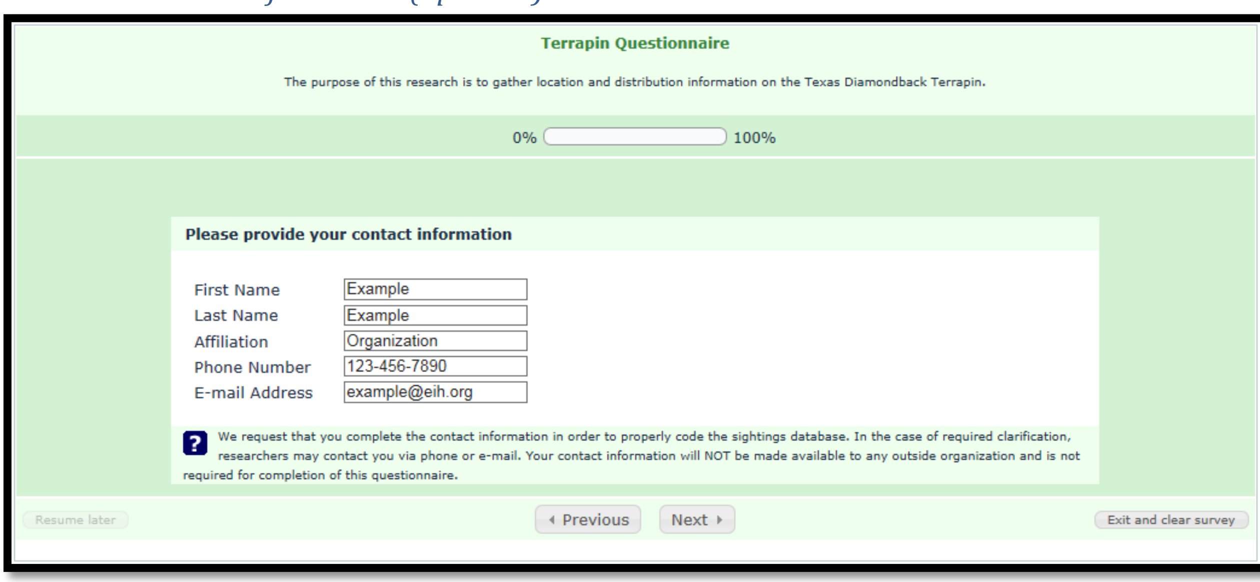


Figure 114 Contact information screen for online questionnaire. Includes short text fields for First Name, Last Name, Affiliation, Phone Number, and E-Mail Address. All fields were optional for respondents.

Section 2: Species verification (required).

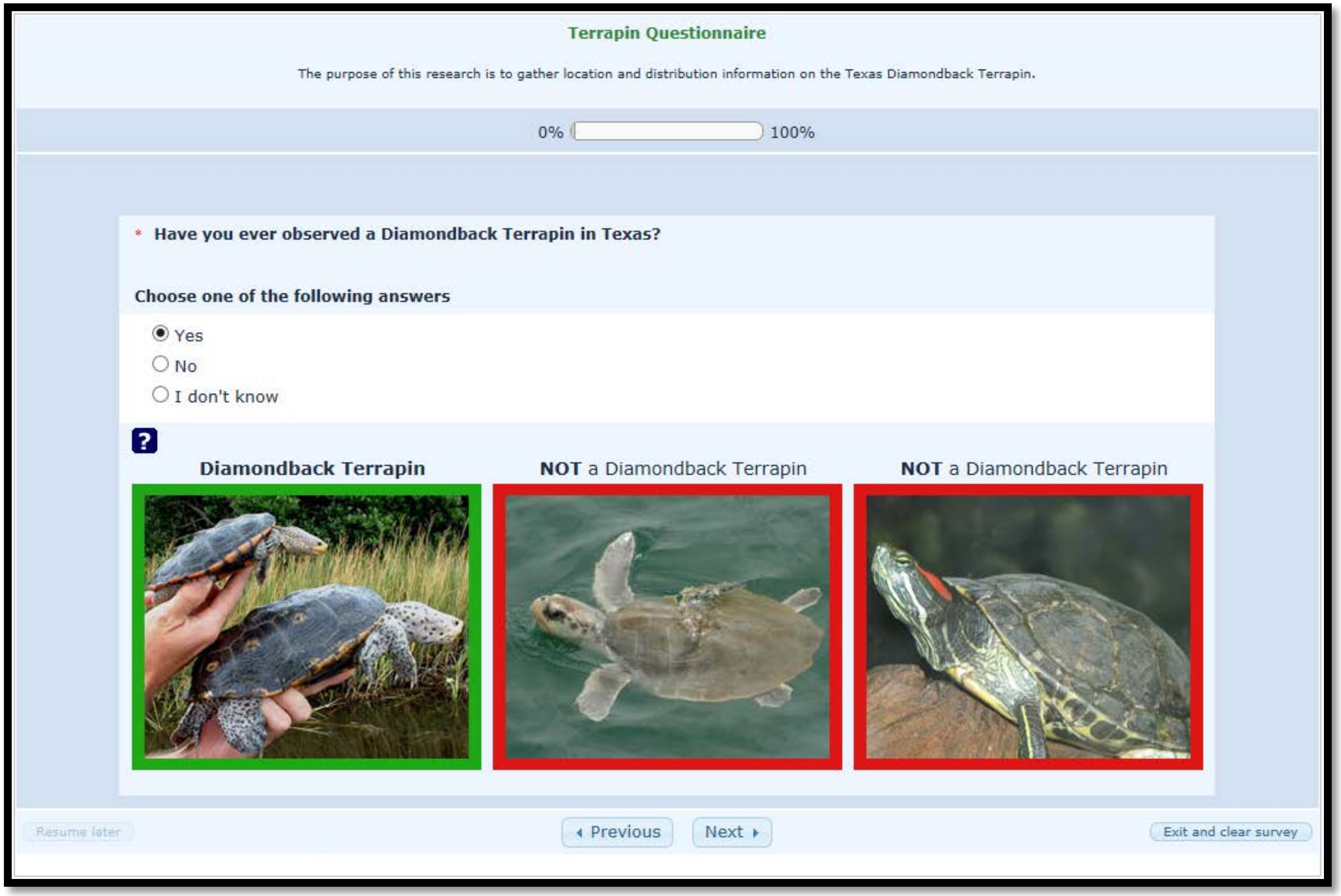
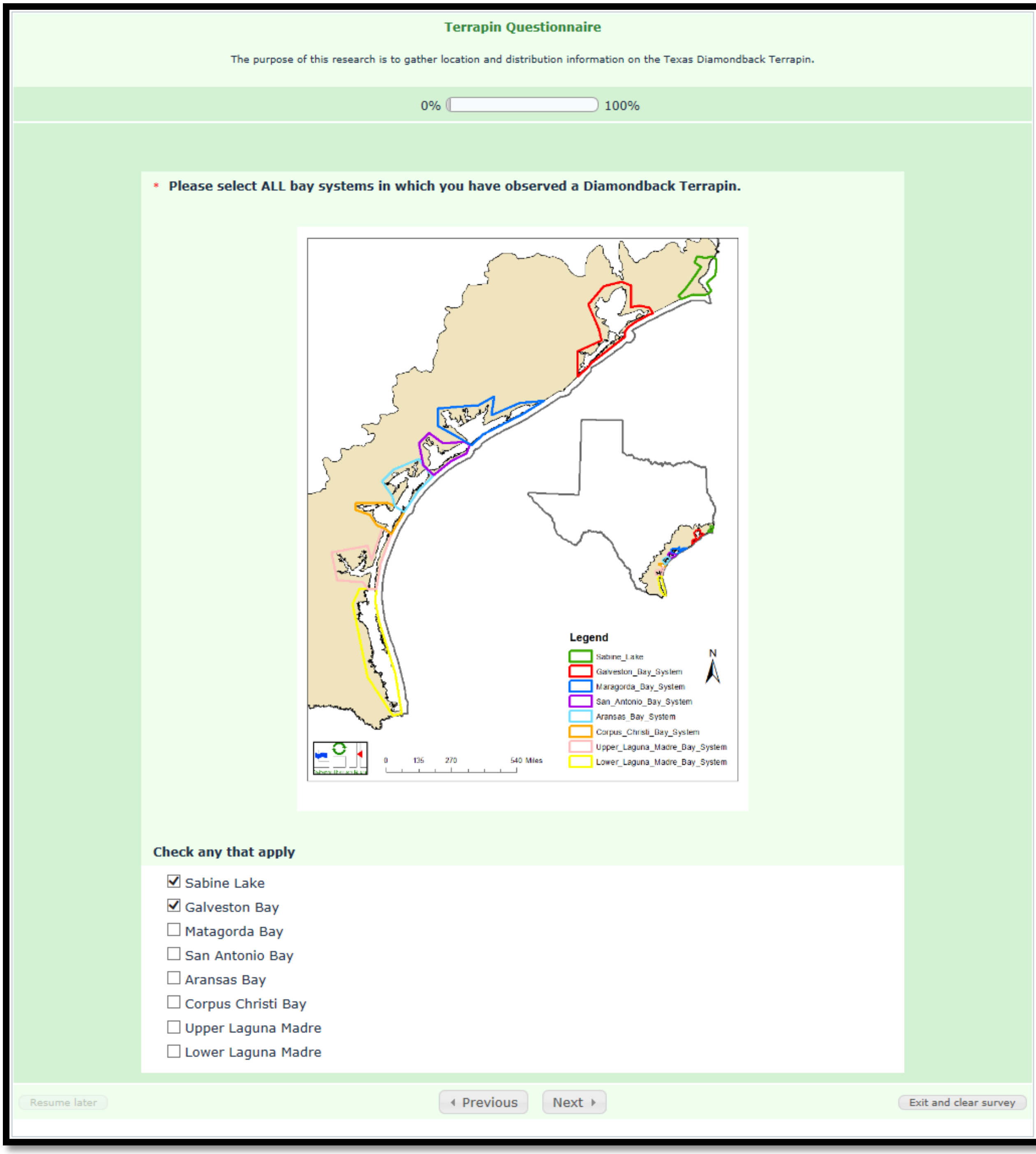


Figure 115 Species verification screen. If respondent answered "no" or "I don't know" to this question, sections 3-4 were skipped and the respondent was brought to the end of the survey.

Section 3: Bay Selection (required).



Terrapin Questionnaire

The purpose of this research is to gather location and distribution information on the Texas Diamondback Terrapin.

0% 100%

* **Please select ALL bay systems in which you have observed a Diamondback Terrapin.**

Check any that apply

- ☑ Sabine Lake
- ☑ Galveston Bay
- ☐ Matagorda Bay
- ☐ San Antonio Bay
- ☐ Aransas Bay
- ☐ Corpus Christi Bay
- ☐ Upper Laguna Madre
- ☐ Lower Laguna Madre

Resume later | ◂ Previous | Next ▸ | Exit and clear survey

Figure 116 Bay selection screen. This screen included a map of the Texas Gulf Coast with each of the 8 major bay systems highlighted. Respondents could select any and/or all of the major bays in Texas where a terrapin observation had occurred. In this example, Sabine Lake and Galveston Bay were both selected.

Section 4: Interactive Map and Observation Specific Questions (required).

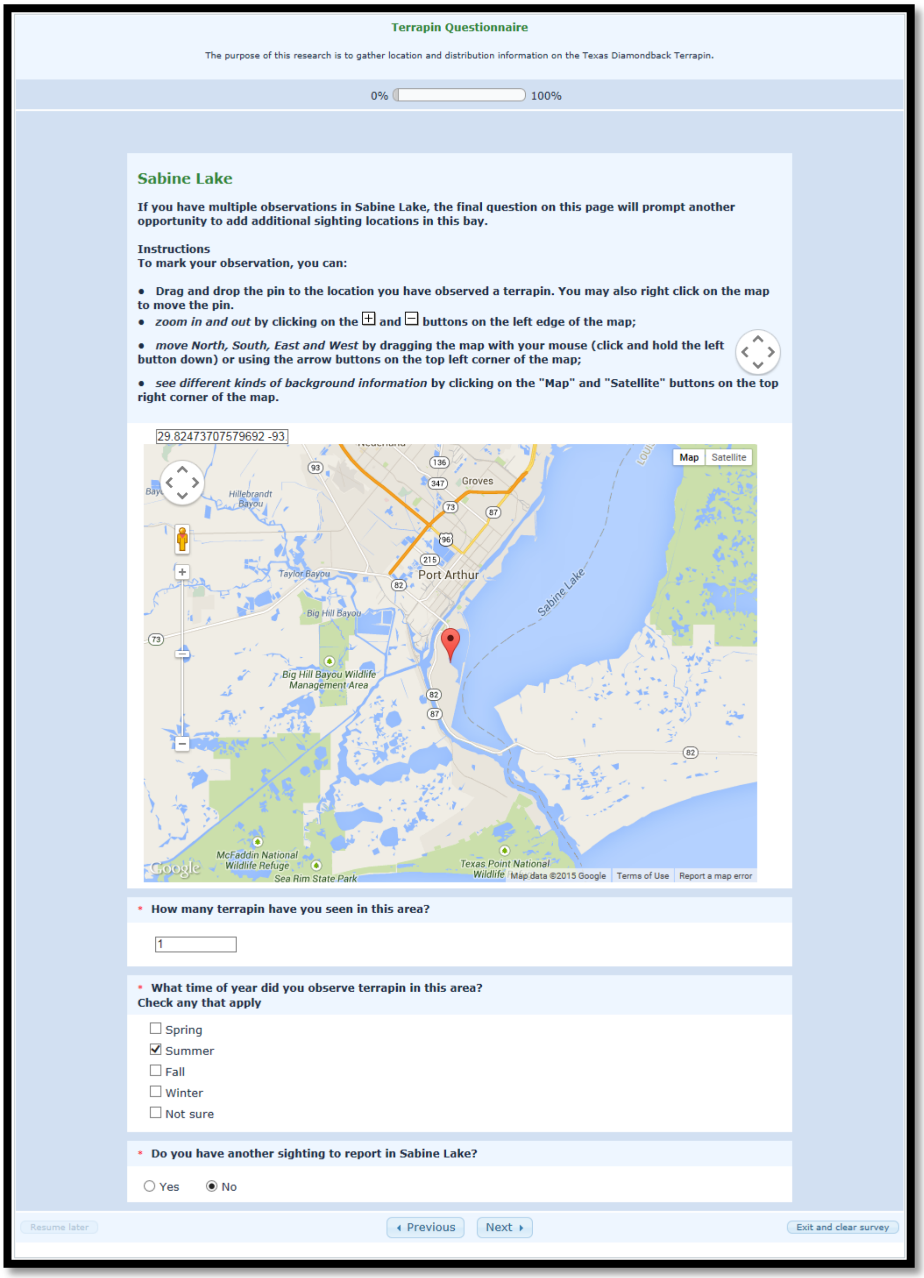
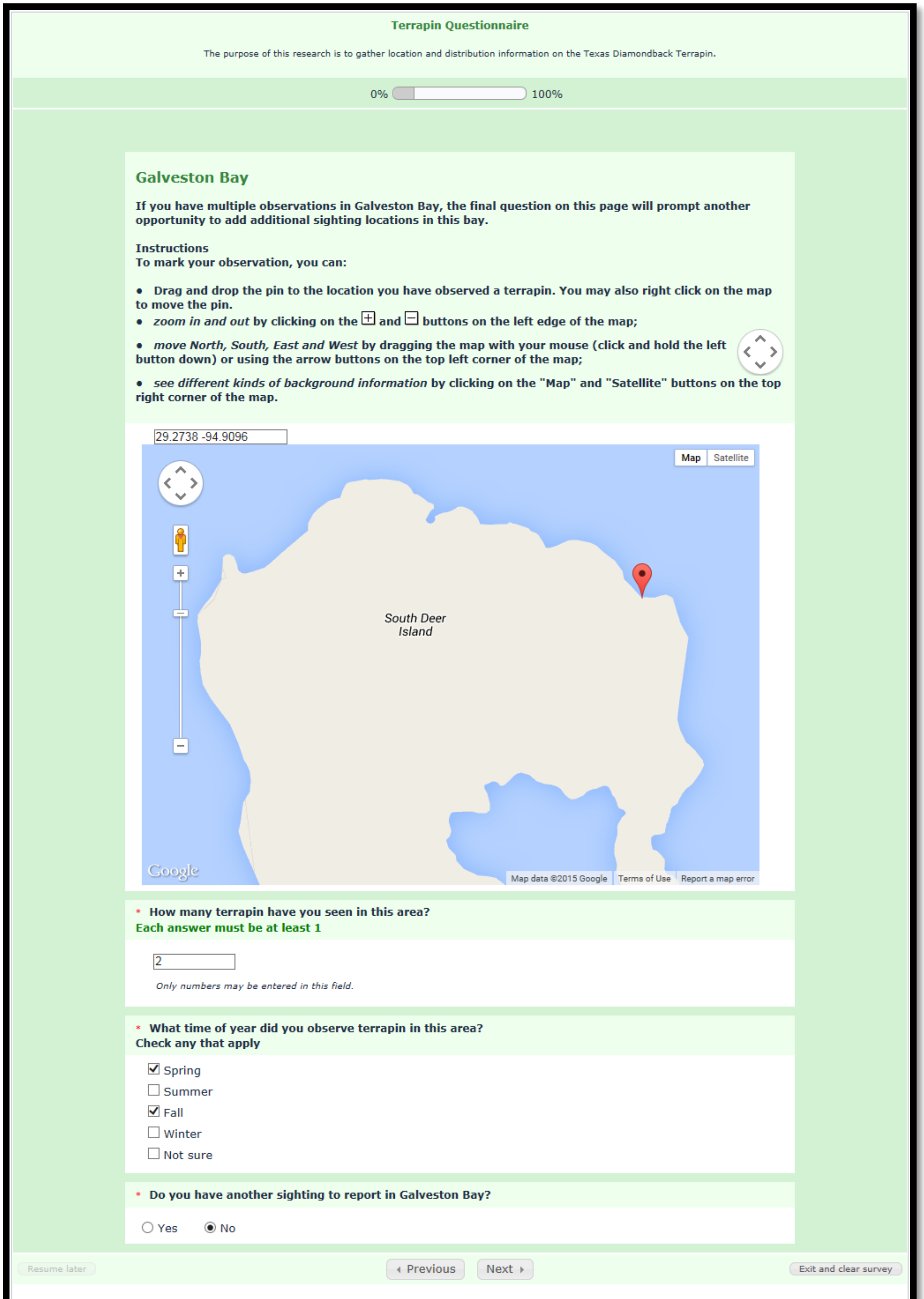


Figure 117 Interactive map and observation specific questions screen.

Respondents were provided an interactive map automatically populated based on their selections in Section 3 (Figure 114). Here, respondents were able to zoom in or out as needed and could place a marker on the map to indicate location of their observation. Additionally, respondents were required to answer two questions specific to the observation: number of terrapin observed and season in which observation occurred. Finally, respondents were able to indicate additional observations. By selecting "Yes", the survey generated another map within the same bay system (up to 10 total observations per system). By selecting "No", the survey would generate a map within another bay system (Figure 115), if selected in Section 3, or bring the respondent to the end of the survey (Figure 117).



Terrapin Questionnaire

The purpose of this research is to gather location and distribution information on the Texas Diamondback Terrapin.

0% 100%

Galveston Bay

If you have multiple observations in Galveston Bay, the final question on this page will prompt another opportunity to add additional sighting locations in this bay.

Instructions
To mark your observation, you can:

- **Drag and drop the pin to the location you have observed a terrapin. You may also right click on the map to move the pin.**
- ***zoom in and out* by clicking on the ⊞ and ⊟ buttons on the left edge of the map;**
- ***move North, South, East and West* by dragging the map with your mouse (click and hold the left button down) or using the arrow buttons on the top left corner of the map;**
- ***see different kinds of background information* by clicking on the "Map" and "Satellite" buttons on the top right corner of the map.**

29.2738 -94.9096

* **How many terrapin have you seen in this area?**
Each answer must be at least 1

2

Only numbers may be entered in this field.

* **What time of year did you observe terrapin in this area?**
Check any that apply

- ☑ Spring
- ☐ Summer
- ☑ Fall
- ☐ Winter
- ☐ Not sure

* **Do you have another sighting to report in Galveston Bay?**

○ Yes ◉ No

Resume later | ◂ Previous | Next ▸ | Exit and clear survey

Figure 118 Additional bay map generated when selecting multiple bays in Section 3.

Section 5: Trends in observations (required).

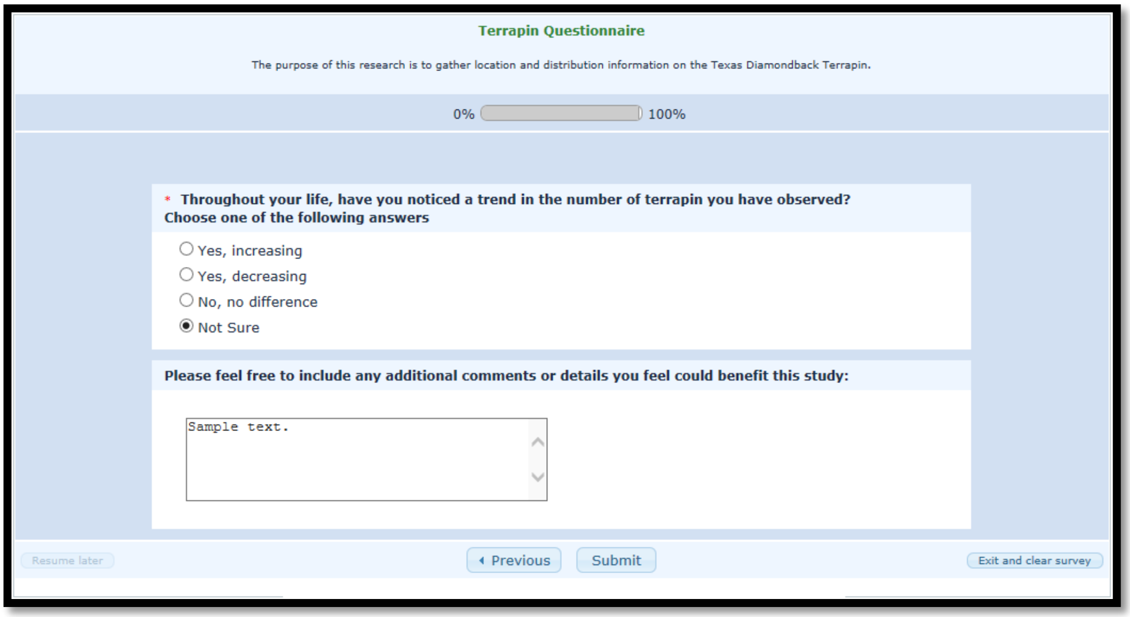


Figure 119 Trend and comment screen. Respondents were able to select one of four options relating to general trends observed with terrapin sightings. Respondents were also provided space for additional comments.

End Screen: Thank you, EIH contact information, share on social media (optional), and information on EIH Adopt-a-Terrapin program.

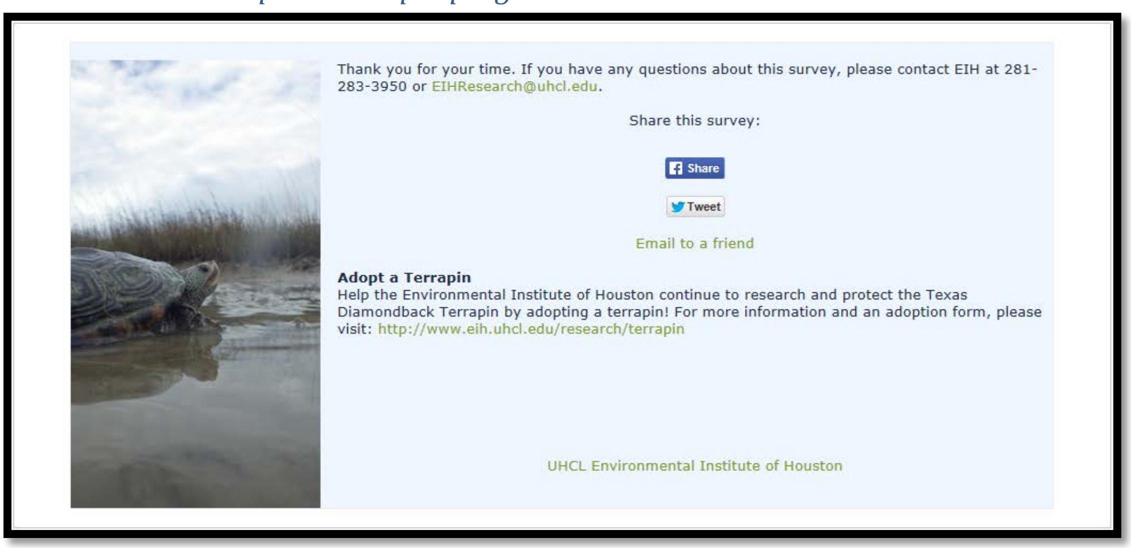


Figure 120 End screen of questionnaire. Contained contact information for EIH, optional links to share the survey on social media or through email, and information about the EIH Adopt-a-Terrapin program.

Appendix C.2. Questionnaire Database

Electronic Supplement

Appendix C.3. Supplemental Responses from Respondents

Figure 121 Five diamondback terrapin observed in Oso Bay (offshoot of Corpus Christi Bay) basking with a slider (*Trachemys scripta*, red circle) and soft shell (*Apalone spinifera*, blue circle) near a freshwater outflow from waste water treatment facility (27.71117, -97.33561). Photo credit: C. McIntyre (4/13/2009).

Figure 122 (A) Two male and one female terrapin collected during derelict crab trap removal program in Galveston Bay (n = 10 total observations for day). Note female missing both front legs; (B) Sexual size dimorphism between male and female terrapin captured during derelict crab trap removal program in Galveston Bay. Photo credit: S. Tompkins (2/1/2006).

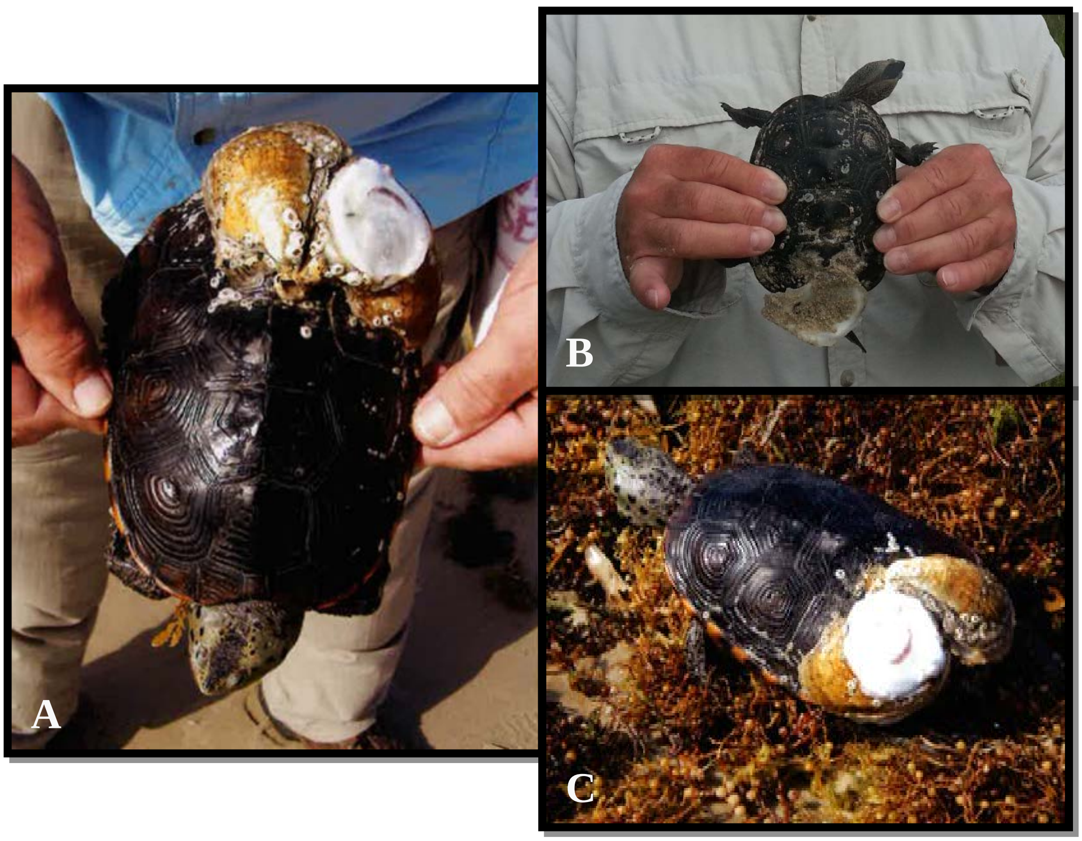


Figure 123 Photographs of male (B) and female (A and C) terrapin collected on Gulf side of East Matagorda Bay walking through *Sargassum* spp. mats in swash zone with oysters affixed to posterior portion of carapace. Photo credit: A. Rammer and M. Burnett (5/15/2013).

Appendix D. Comprehensive List of Randomly Generated Sample Sites

The following is a comprehensive list of all sites randomly generated for this project. Comments were made when sites were either inaccessible due to being posted, dropped based on desk recon (with explanation in parentheses), and if sites were fully sampled (including revisit sites)

Site Name	**Latitude**	**Longitude**	**Site Visit Comments**	**Date Visited**
MAT-01	28.48586	-96.50951	POSTED	4/18/2014
MAT-02	28.51178	-96.48607	DROPPED (site generated directly off launch in open water)	Desktop
MAT-03	28.50298	-96.47116		4/26/2014
MAT-04	28.47168	-96.42616		4/26/2014
MAT-05	28.50763	-96.48788		
MAT-06	28.48799	-96.44956	POSTED	4/26/2014
MAT-07	28.47836	-96.54087	HEAD COUNT ONLY	4/18/2014
MAT-08	28.47687	-96.53072		4/18/2014
MAT-09	28.49119	-96.55557	FULL SAMPLE	4/18/2014
MAT-10	28.46265	-96.41565		4/26/2014
MAT-11	28.47901	-96.43670	POSTED	4/26/2014
MAT-12	28.51022	-96.49654	FULL SAMPLE	4/18/2014
MAT-13	28.63946	-96.46549		
MAT-14	28.66937	-96.47169	FULL SAMPLE	4/28/2014
MAT-14	28.66937	-96.47169	FULL SAMPLE; REVISIT	5/20/2014
MAT-15	28.66456	-96.45964	DROPPED (site generated in middle of private, mowed lawn)	Desktop
MAT-16	28.64187	-96.51792		
MAT-17	28.65133	-96.46694		
MAT-18	28.58245	-96.48263		
MAT-19	28.63514	-96.49846		
MAT-20	28.58981	-96.44848		
MAT-21	28.58866	-96.44994	FULL SAMPLE	5/21/2014
MAT-22	28.57702	-96.65328		
MAT-23	28.57869	-96.64681		
MAT-24	28.70361	-96.69706		
MAT-25	28.72086	-96.58029		
MAT-26	28.72958	-96.66200		4/27/2014
MAT-27	28.72247	-96.60407	FULL SAMPLE	4/25/2014
MAT-28	28.72077	-96.58226		
MAT-29	28.73778	-96.67453		
MAT-30	28.72582	-96.58570		
MAT-31	28.73131	-96.61582		4/25/2014
MAT-32	28.72937	-96.58546		4/25/2014
MAT-33	28.69385	-96.55813		4/25/2014
MAT-34	28.72349	-96.65839	FULL SAMPLE	4/27/2014
MAT-35	28.72723	-96.59764		4/25/2014
MAT-36	28.71797	-96.57973		
MAT-37	28.73789	-96.66701		4/27/2014
MAT-38	28.73651	-96.59100		4/25/2014
MAT-39	28.70981	-96.66628		
Site	**Latitude**	**Longitude**	**Site Visit Comments**	**Date**

Name				Visited
MAT-40	28.77534	-96.58196		4/25/2014
MAT-41	28.73549	-96.59343		
MAT-42	28.63660	-96.41227		
MAT-43	28.62774	-96.41396		
MAT-44	28.70951	-96.37032		
MAT-45	28.76888	-96.43156		
MAT-46	28.77538	-96.41824		
MAT-47	28.65729	-96.31478		4/21/2014
MAT-48	28.72189	-96.26411		
MAT-49	28.73195	-96.28587		
MAT-50	28.71988	-96.26586	HEAD COUNT ONLY	4/21/2014
MAT-51	28.77484	-96.15998		
MAT-52	28.76040	-96.14930		
MAT-53	28.76495	-96.14828		
MAT-54	28.76129	-96.14910		
MAT-55	28.37701	-96.40459		
MAT-56	28.36648	-96.40407		
MAT-57	28.36235	-96.39981		
MAT-58	28.38011	-96.39891		
MAT-59	28.39632	-96.40682		
MAT-60	28.42455	-96.35038		
MAT-61	28.39336	-96.38587		
MAT-62	28.58624	-96.04025		
MAT-63	28.56919	-96.07413		
MAT-64	28.45429	-96.30812	DROPPED (site too close to airport; access dangerous/restricted)	Desktop
MAT-65	28.55112	-96.12276	DROPPED (outside range of fuel tank)	Desktop
MAT-66	28.44739	-96.31782		
MAT-67	28.51021	-96.20800	DROPPED (outside range of fuel tank)	Desktop
MAT-68	28.57178	-96.07167		
MAT-69	28.52426	-96.18362	DROPPED (outside range of fuel tank)	Desktop
MAT-70	28.60156	-95.99144		
MAT-71	28.61237	-95.98736		
MAT-72	28.55923	-96.10353	DROPPED (outside range of fuel tank)	Desktop
MAT-73	28.46172	-96.29683	DROPPED (site too close to airport; access dangerous/restricted)	Desktop
MAT-74	28.46079	-96.29692	DROPPED (site too close to airport; access dangerous/restricted)	Desktop
MAT-75	28.59680	-96.01638		
MAT-76	28.48885	-96.24225		
MAT-77	28.60922	-95.98902		
MAT-78	28.57578	-96.06328		
MAT-79	28.61619	-96.21036	DROPPED (outside range of fuel tank)	Desktop
MAT-80	28.66276	-96.03984		
MAT-81	28.63148	-96.00452	FULL SAMPLE	4/17/2014
MAT-82	28.66420	-96.00952		
MAT-83	28.65815	-96.05951		
MAT-84	28.69954	-96.18750		4/24/2014
MAT-85	28.68947	-96.19012		4/24/2014
MAT-86	28.64500	-95.99367		4/17/2014

Site Name	Latitude	Longitude	Site Visit Comments	Date Visited
MAT-87	28.61864	-96.12962	DROPPED (outside range of fuel tank)	Desktop
MAT-88	28.61741	-96.20066	DROPPED (outside range of fuel tank)	Desktop
MAT-89	28.61770	-95.99602		
MAT-90	28.64349	-95.98951		4/17/2014
MAT-91	28.57991	-96.22187	DROPPED (outside range of fuel tank)	Desktop
MAT-92	28.61724	-96.15191	DROPPED (outside range of fuel tank)	Desktop
MAT-93	28.63532	-96.00790		4/17/2014
MAT-94	28.65496	-96.21277	FULL SAMPLE	4/24/2014
MAT-94	28.65496	-96.21277	FULL SAMPLE; REVISIT	5/19/2014
MAT-95	28.64576	-95.98500		4/17/2014
MAT-96	28.66143	-96.04274		
MAT-97	28.60059	-96.21357	DROPPED (outside range of fuel tank)	Desktop
MAT-98	28.61818	-96.16028	DROPPED (outside range of fuel tank)	Desktop
MAT-99	28.62931	-96.21784		
MAT-100	28.63902	-95.97899		4/17/2014
SAB-01	29.87448	-93.77601	FULL SAMPLE	4/12/2014
SAB-02	29.86472	-93.78019		
SAB-03	29.81034	-93.84044		
SAB-04	29.82689	-93.81130		
SAB-05	29.93580	-93.76230		
SAB-06	29.80842	-93.84029		
SAB-07	29.97911	-93.78280		
SAB-08	29.82661	-93.81696		
SAB-09	29.97150	-93.75779		
SAB-10	29.99740	-93.72045		
SAB-11	29.99675	-93.75582		
SAB-12	29.98353	-93.71234		
SAB-13	30.00474	-93.74450		
SAB-14	29.98540	-93.71690		
SAB-15	30.00507	-93.73874		
SAB-16	29.99972	-93.82622		
SAB-17	30.02443	-93.74741	HEAD COUNT ONLY	4/13/2014
SAB-18	30.02539	-93.76104	POSTED	4/13/2014
SAB-19	30.03398	-93.77573	HEAD COUNT ONLY	4/13/2014
SAB-20	30.03137	-93.78465	HEAD COUNT ONLY	4/13/2014
SAB-21	30.03459	-93.77891		4/13/2014
SAB-22	30.00444	-93.83524		
SAB-23	30.03297	-93.78724		4/13/2014
SAB-24	30.03206	-93.76192	POSTED	4/13/2014
SAB-25	30.00284	-93.83645		
SAB-26	30.00049	-93.77281		4/13/2014
SAB-27	30.00325	-93.84007		
SAB-28	29.99576	-93.92325		
SAB-29	29.98711	-93.92100		
SAB-30	29.97741	-93.86805		4/13/2014
SAB-31	29.99448	-93.92533		
SAB-32	29.99096	-93.92395		

Site Name	Latitude	Longitude	Site Visit Comments	Date Visited
SAB-33	29.98956	-93.90514		
SAB-34	29.98674	-93.89507		
SAB-35	29.99166	-93.91082		
SAB-36	29.83850	-93.77157		
SAB-37	29.83537	-93.77258	FULL SAMPLE	4/12/2014
SAB-38	29.80280	-93.75546		
SAB-39	29.80521	-93.75567	DROPPED (site populated in middle of parking lot)	Desktop
SAB-40	29.79032	-93.75007	DROPPED (site populated on edge of boat ramp)	Desktop
SAB-41	29.75460	-93.88457	DROPPED (site located on LNG terminal; access dangerous/restricted)	4/11/2014
SAB-42	29.72008	-93.84343		
SAB-43	29.71401	-93.84919	FULL SAMPLE	4/11/2014
SAB-44	29.72191	-93.83946		
SAB-45	29.70310	-93.83964		
SAB-46	29.79164	-93.94633		4/11/2014
SAB-47	29.78900	-93.95059		4/11/2014
SAB-48	29.74991	-94.00754	HEAD COUNT ONLY	4/10/2014
SAB-49	29.75038	-93.96639		
SAB-50	29.74249	-93.99646	FULL SAMPLE	4/10/2014
SAB-51	29.80097	-93.95478	DROPPED (site in ship channel; access dangerous/restricted)	Desktop
SAB-52	29.75149	-93.95279	FULL SAMPLE	5/12/2014
SAB-53	29.74131	-93.89119	DROPPED (site in middle of oil rig)	Desktop
SAB-54	29.69743	-93.87753		
SAB-55	29.70303	-93.86733	FULL SAMPLE	5/16/2014
SAB-55	29.70303	-93.86733	FULL SAMPLE; REVISIT	6/17/2014
SAB-56	29.70931	-93.88669	FULL SAMPLE	5/15/2014
SAB-56	29.70931	-93.88669	FULL SAMPLE; REVISIT	6/16/2014
SAB-57	29.70038	-93.87849		
SAB-58	29.69876	-93.85380	FULL SAMPLE	5/13/2014
SAB-58	29.69876	-93.85380	FULL SAMPLE; REVISIT	6/18/2014
SAB-59	29.70697	-93.87765		5/15/2014
SAB-60	29.70292	-93.90168		
SAN-01	28.42905	-96.82349		
SAN-02	28.43164	-96.83455		
SAN-03	28.47674	-96.82563		
SAN-04	28.45062	-96.77553		
SAN-05	28.41055	-96.78757		4/20/2014
SAN-06	28.41869	-96.80893	POSTED	4/20/2014
SAN-07	28.40914	-96.74724		
SAN-08	28.43528	-96.77716		4/20/2014
SAN-09	28.42841	-96.77157	FULL SAMPLE	4/20/2014
SAN-10	28.47267	-96.82350		
SAN-11	28.45338	-96.81848		
SAN-12	28.47555	-96.81499	HEAD COUNT ONLY	4/20/2014
SAN-13	28.45616	-96.80815	HEAD COUNT ONLY	4/20/2014
SAN-14	28.45719	-96.81805		4/20/2014
SAN-15	28.41699	-96.85892		
SAN-16	28.23857	-96.78867		

Site Name	Latitude	Longitude	Site Visit Comments	Date Visited
SAN-17	28.24398	-96.78755		
SAN-18	28.18527	-96.83899	FULL SAMPLE	6/11/2014
SAN-19	28.24552	-96.79195		
SAN-20	28.24891	-96.78701	FULL SAMPLE	6/12/2014
SAN-21	28.21974	-96.81596		
SAN-22	28.34609	-96.60673		
SAN-23	28.31596	-96.62502		
SAN-24	28.39406	-96.49527		
SAN-25	28.34400	-96.61194		
SAN-26	28.38636	-96.50681		
SAN-27	28.35065	-96.59838		
SAN-28	28.33043	-96.63949		5/21/2014
SAN-29	28.31658	-96.67736		
SAN-30	28.31839	-96.65299		
SAN-31	28.38919	-96.50234		
SAN-32	28.34702	-96.61914	FULL SAMPLE	6/9/2014
SAN-33	28.33902	-96.59978		
SAN-34	28.37200	-96.54216		
SAN-35	28.33422	-96.63057		
SAN-36	28.34273	-96.62607		
SAN-37	28.31909	-96.68349		
SAN-38	28.39288	-96.49599		5/21/2014
SAN-39	28.39773	-96.49959		
SAN-40	28.37514	-96.53427		
SAN-41	28.41521	-96.45904		5/21/2014
SAN-42	28.35323	-96.59313		
SAN-43	28.38552	-96.52482		
SAN-44	28.34142	-96.62668		5/21/2014
SAN-45	28.32230	-96.67617		
SAN-46	28.38002	-96.53930		
SAN-47	28.38221	-96.53021		
SAN-48	28.37188	-96.55838		
SAN-49	28.32894	-96.61063		
SAN-50	28.38620	-96.44625		
SAN-51	28.42229	-96.41083		
SAN-52	28.37545	-96.45983		
SAN-53	28.42756	-96.41109		
SAN-54	28.40424	-96.41784	FULL SAMPLE	4/19/2014
SAN-55	28.36796	-96.46361		
SAN-56	28.36593	-96.46590		
SAN-57	28.42343	-96.42010		
SAN-58	28.41763	-96.42021		
SAN-59	28.41638	-96.42760		
SAN-60	28.41723	-96.43298		
SAN-61	28.38763	-96.44459		
SAN-62	28.36574	-96.47134		
SAN-63	28.36418	-96.43117	FULL SAMPLE	4/19/2014

Site Name	Latitude	Longitude	Site Visit Comments	Date Visited
SAN-64	28.36466	-96.46744		
SAN-65	28.39070	-96.43279		
SAN-66	28.37149	-96.46965		
SAN-67	28.42463	-96.41211		
SAN-68	28.39586	-96.43898		
SAN-69	28.32499	-96.49664	DROPPED (outside range of fuel tank)	
SAN-70	28.30236	-96.55625	DROPPED (outside range of fuel tank)	
SAN-71	28.30322	-96.53721	DROPPED (outside range of fuel tank)	
SAN-72	28.32324	-96.52438	DROPPED (outside range of fuel tank)	
SAN-73	28.24059	-96.65800		
SAN-74	28.30162	-96.56364	DROPPED (outside range of fuel tank)	
SAN-75	28.30664	-96.52367	DROPPED (outside range of fuel tank)	
SAN-76	28.32228	-96.50721	DROPPED (outside range of fuel tank)	
SAN-77	28.32555	-96.51016	DROPPED (outside range of fuel tank)	
SAN-78	28.31908	-96.49018	DROPPED (outside range of fuel tank)	
SAN-79	28.27163	-96.60625		
SAN-80	28.31938	-96.52988	DROPPED (outside range of fuel tank)	
SAN-81	28.32220	-96.52088	DROPPED (outside range of fuel tank)	
SAN-82	28.25842	-96.63747		
SAN-83	28.32063	-96.52785	DROPPED (outside range of fuel tank)	
SAN-84	28.32679	-96.50190	DROPPED (outside range of fuel tank)	
SAN-85	28.30957	-96.50732	DROPPED (outside range of fuel tank)	
SAN-86	28.30136	-96.57733	DROPPED (outside range of fuel tank)	
SAN-87	28.33843	-96.44870	DROPPED (outside range of fuel tank)	
SAN-88	28.19144	-96.72874		
SAN-89	28.19695	-96.70804		
SAN-90	28.21779	-96.69268	FULL SAMPLE	6/11/2014
SAN-91	28.19286	-96.72156		
SAN-92	28.17652	-96.74433		
SAN-93	28.18372	-96.77087		
SAN-94	28.20869	-96.69211		
SAN-95	28.21664	-96.69084		
SAN-96	28.18526	-96.77075		
SAN-97	28.22553	-96.66546		
SAN-98	28.18313	-96.74957	FULL SAMPLE	6/10/2014
SAN-99	28.23147	-96.66172		

Appendix E. 2014 Field Database

Electronic Supplement