Identifying Diamondback Terrapin Nesting Habitat in the Mission-Aransas Estuary, Texas

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Table of Contents

List of Figures

List of Tables

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Executive Summary

This project attempted to locate nesting areas for the Texas diamondback terrapin in the Mission-Aransas Estuary, Texas. The project occurred from May-July 2017. Sites were chosen based on a nesting habitat characterization from the Nueces Estuary and walking surveys and digital game cameras were employed to determine whether these areas were used as nesting beaches. Eight, of eleven, locations were shown to serve as nesting sites for diamondback terrapins. A total of 32 nests were located over the course of the study. All nests had been raided by predators prior to discovery. Data was collected for each nest, including distance from water, slope, vegetative cover, nest depth, and sediment grain size. Predated adult females were discovered on multiple nesting beaches. One dead female was found that had been struck by a boat, and a live female was discovered on land near a nesting beach. The results of this study agreed with what has been shown for the Nueces Estuary in that nesting beaches must be located above the mean high tide line and have adjacent marsh habitat. Nests were also found in areas of high vegetative cover, which differs from studies from outside of Texas. Actions such as nesting beach restoration/enhancement, predator removal, and education outreach could serve to increase nesting success, and subsequently augment local terrapin numbers.

Introduction

As the only brackish water turtle in North America, diamondback terrapins (*Malaclemys terrapin*) inhabit a narrow band of estuarine habitats from Cape Cod, MA to Corpus Christi, TX. The Texas subspecies (*Malaclemys terrapin littoralis*) occurs in marshes, tidal creeks, and embayments from western Louisiana to Oso Bay, just south of the City of Corpus Christi, TX. In Texas, this species is listed as S1S2 (imperiled/critically imperiled) by the Texas Parks and Wildlife Department. Terrapins are a long-lived species and are slow to reach sexual maturity, taking up to 8 years in females and 4 years in males (Brennessel 2006). It should be noted that sexual maturity relates more to size than age and that southern populations may achieve maturity faster than those at northern latitudes (Seigel 1984).

Mating occurs in early spring once water temperatures rise above 24° C. There is some evidence to suggest that terrapins form mating aggregations during this time (Seigel 1980). Females often mate with multiple males and have the ability to storm sperm for several years. Once a female has been fertilized, egg development continues internally until the female is ready to nest. Nesting is perhaps the best understood aspect of terrapin reproduction and multiple studies have been conducted throughout their range. Female terrapins exhibit nest site fidelity, or philopatry, meaning that they return to the same nesting areas each year. A female may lay multiple clutches in one nesting season, which normally lasts from May through July. Warmer, or colder, than normal conditions may advance or delay the start and end of nesting.

Like all turtles, terrapins nest on land. In most states, terrapins seem to prefer to nest in sandy areas with little, to no, vegetation, although they are limited by the available habitat and substrate type. Nesting occurs above the normal high tide line, although above normal rainfall, or tidal events may result in the inundation of normally exposed nesting sites. Nesting may occur both day and night and appears to be population dependent. Females often make several nesting forays before actually depositing eggs (Brennessel 2006). These aborted nesting attempts may be the result of a disturbance, the presence of a predator, or may occur for no obvious reason.

Terrapins begin digging a nest by "sniffing" at the ground and then using their forelimbs to move the substrate. The turtle then begins digging in an alternating fashion using her rear limbs to dig out a nest. Nests are flask shaped and usually 14-16 cm deep (Butler 2000). Nest depth is important as shallower nests are prone to desiccation, erosion, and temperature related stress (Brennessel 2006).

Once satisfied with the excavated nest chamber, the female positions its cloacal opening over the nest and deposits between five and twelve soft, oval shaped eggs into the nest. There does appear to be a correlation between the size of the female and clutch size, with larger females producing more eggs (Montevecchi and Burger 1975). Once nesting has ended, females use their hind limbs to cover the nest cavity. The complete process takes approximately 30 minutes, and upon completion, the female re-enters the water.

Egg development continues in the nest for 60 to 90 days. The incubation time is directed by temperature with higher temperatures inducing faster development. Temperature also plays a role in determining sex, with higher nest temperatures (>30° C) producing more females and lower temperatures (<28° C) producing more males. During this time, the nest remains vulnerable to predation and it is not unusual for over 90% of nests to be depredated by raccoons, birds, and ghost crabs (Feinberg and Burke 2003). The majority of nests are raided within the first 24-48 hours after the eggs are deposited and predators likely use a cue, such as scent, to locate the nests (Butler et al. 2004; Brennessel 2006).

If a nest remains intact, hatchlings will begin to emerge once incubation is complete. Not all hatchlings exit the nest, as some may choose to overwinter within the nest only to emerge the next spring. Emergence from the nest may bring on a second wave of predation, and the majority of hatchlings quickly leave the nest in search of cover (Brennessel 2006). Unlike other turtle species, terrapin hatchlings do not seek open water, instead choosing to move into vegetated marshes. This completes the nesting cycle for diamondback terrapins.

Access to nesting beaches is the most vital component of the nesting process therefore it is imperative that these areas remain accessible. Nest site disturbances, including development and shoreline hardening, can destroy entire nesting colonies or force them to nest in less suitable areas such as roadsides or parking lots. This can lead to an increase in vehicular mortality and an overall decline in numbers. Without knowing the exact location of these nesting sites, it is impossible to ensure their continuance as functional nesting habitat. Therefore it is imperative that these sites be identified throughout the state of Texas.

While numerous studies have been conducted on all stages of terrapin reproduction, there is virtually nothing known about this process in Texas. A United States Geological Survey (USGS) technical report includes one observation of a nesting terrapin on South Deer Island in Galveston Bay on an exposed shell hash beach (Hogan 2003). Rachel George (2014) attempted to locate nesting habitats in Galveston Bay, Texas, and while no actively nesting terrapins were observed, she did capture gravid females during her study. In 2015, Baxter identified specific terrapin nesting sites in the Nueces Estuary, Texas and characterized these areas based on substrate, elevation, slope, and vegetative cover. That study found that terrapins in the Nueces Estuary utilized shell hash beaches above the mean high tide. These areas possessed a high degree of vegetative cover and always bordered a marsh. The purpose of this study was to document terrapin nesting sites in the Mission-Aransas Estuary, Texas by applying the nesting habitat characterization from the Nueces Estuary, Texas.

Materials and Methods

Study Area

The Mission-Aransas Estuary is located on the South Texas coast between San Antonio Bay and Corpus Christi Bay (Fig. 1). The Mission-Aransas Estuary consists of several embayments including Aransas Bay, Mesquite Bay, Redfish Bay, St. Charles Bay, Port Bay, Mission Bay, and Copano Bay (Armstrong 1987, Britton and Morton 1989). The estuary is directly connected to the Gulf of Mexico by way of Cedar Bayou and Aransas Pass on the north and south ends of San Jose Island, respectively (Chen 2010, Bittler 2011). The Mission-Aransas Estuary receives freshwater inflow from the Mission River, Aransas River, and Copano Creek (Fig. 2). These sources of freshwater are not utilized to supply drinking water to municipalities and none are restricted by manmade diversions such as dams or other structures (Evans et al. 2012). Salinity typically ranges from 25–35 ppt in Redfish Bay, 20-30 ppt in Aransas Bay and

Figure 1. Location of the Mission-Aransas Estuary, Texas (modified from Google Earth Pro).

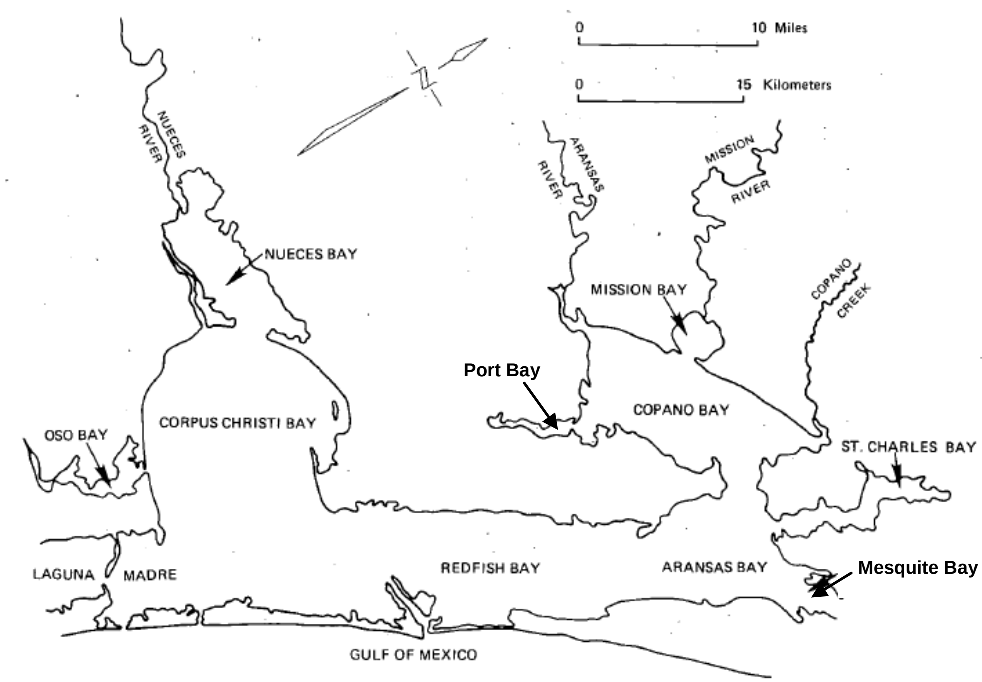

Figure 2. Map of the Mission-Aransas Estuary, Texas (Modified from Texas Department of Water Resources 1981).

Mesquite Bay, and 10–20 ppt in St. Charles Bay, Copano Bay, Port Bay, and Mission Bay (Chen 2010). These salinities are variable and are dependent on rainfall to maintain their characteristic profile.

Site Locations

Eleven sites were surveyed for diamondback terrapin nesting (Table 2). These sites were chosen based on past data collected from outside of Texas, as well as information gathered from George (2014) and Baxter (2015). A description of each site can be found below.

Table 2. Diamondback terrapin nesting study sites, including abbreviations, in the Mission-Aransas Estuary, Texas.

Location	**Abbreviation**
Bayside Marsh	BSM
Blackjack Point	BJP
Copano Creek Mouth	CCM
Goose Island State Park	GISP
Mission Bay Mouth West	MBMW
Mission Bay Mouth East	MBME
Port Bay Mouth	PBM
Rattlesnake Point	RSP
Redfish Point	RFP
Big Island	BI
Copano Bay Causeway	CBC

Bayside Marsh

This site is located near the town of Bayside, Texas off of SH 136 (Fig. 3). This area is popular for recreational fishing activities and has a small, defunct boat ramp that is used only during times of high water. There is a large amount of trash present along the shoreline as a result of heavy human use and the prevailing southeasterly winds. The shoreline consists mainly of shell hash and averages 10 m wide. Vegetation consists of native species, such as sea ox-eye daisy (*Borrichia frutescens*), sea purslane (*Sesuvium portulacastrum*), and saltwort (*Batis maritima*). There are also a small number of invasive saltcedar (*Tamarix* sp.) trees located there. The shoreline is bordered by Copano Bay to the east and by salt marsh to the west. The Aransas River empties into Copano Bay near this site, as well.

Figure 3. Bayside Marsh site, represented by the red “x”.

Blackjack Point

Located on the Aransas National Wildlife Refuge (ANWR) and east of Goose Island State Park (GISP), Blackjack Point consists of a narrow shoreline made up of shell hash that gives way to marsh (Fig. 4). The shoreline ranges from 2 m to 10 m in width and is bounded by Aransas Bay to the south and an extensive marsh complex to the north. The vegetation present along this shoreline consists of native species including sea ox-eye daisy (*B. frutescens*), Carolina wolfberry (*Lycium carolinianum*), sunflower (*Helianthus* sp.), and saltgrass (*Distichlis spicata*). While there is little human presence on Blackjack Point, the shallow waters surrounding the area experience heavy traffic from both air, and motor, boats at all times of the year. Prevailing southeasterly winds make this a high-energy shoreline and trash, that has been washed ashore, is common.

Figure 4. Blackjack Point site, represented by the red “x”.

Copano Creek Mouth

The Copano Creek Mouth site is located north of Holiday Beach, Texas and just south of where Copano Creek flows into the northeast corner of Copano Bay (Fig. 5). There is salt marsh directly adjacent to this site. The shoreline consists mainly of sandy sediments with a lesser degree of shell hash and is extremely narrow. The shoreline vegetation consists mainly of honey mesquite (*Prosopis glandulosa*), saltgrass (*D. spicata*), and sea ox-eye daisy (*B. frutescens*). The site is privately owned and signs of public use were absent.

Goose Island State Park

Goose Island State Park is located on the Lamar Peninsula across the Copano Bay Causeway from Fulton, Texas (Fig. 6). The GISP site is located on the far west end of the park and is not readily accessible to park visitors. The shoreline is made up of shell hash and is quite narrow and is bordered by Aransas Bay on one side and salt marsh on the other. Vegetation consists of sea ox-eye daisy (*B. frutescens*), cordgrass (*Spartina alterniflora*), and sea purslane (*S. portulacastrum*).

Figure 5. Copano Creek Mouth site, represented by the red “x”.

Figure 6. Goose Island State Park site, represented by the red “x”.

Mission Bay Mouth West

This site is located at the mouth of Mission Bay where it empties into Copano Bay (Fig. 7). The Mission River serves as a source of freshwater to this area. This shoreline is gently sloping, relatively wide and bordered by Copano Bay to the south and a large salt marsh to the north. Consisting mainly of shell hash, the shoreline is dominated by prickly pear cactus (*Opuntia engelmannii*). As a high-energy shoreline, windblown trash is common to this site.

Figure 7. Mission Bay Mouth West site, represented by the red “x”.

Mission Bay Mouth East

Although situated directly northeast of the Mission Bay Mouth West site, this location differs drastically in offering only 500 m of shell hash shoreline before transitioning into a steep bluff (Fig. 8). Although appropriate nesting habitat is limited, there is a small marsh directly adjacent to it. The remainder of the shoreline is heavily grazed by cattle and consists of introduced grass species and honey mesquite (*P. glandulosa*).

Port Bay Mouth

This site is situated at the mouth of Port Bay where it empties into the south end of Copano Bay (Fig. 9). It consists of a narrow shell hash shoreline and is bounded by Copano Bay on one side and salt marsh on the other. Characteristic plant species include saltgrass (*D. spicata*), sea ox-eye daisy (*B. frutescens*), sea purslane (*S. portulacastrum*), and saltwort (*B. maritima*). This site is located near a privately owned mariculture facility and public access appears to be minimal.

Figure 8. Mission Bay Mouth East site, represented by the red “x”.

Figure 9. Port Bay Mouth site, represented by the red “x”.

Rattlesnake Point

This site is located near the confluence of Port Bay and Copano Bay (Fig. 10). It exists as a long, narrow spit that reaches out approximately 1,500 m into the water. There is a single roadway on the point that terminates at the privately owned Redfish Lodge. The shoreline is composed mainly of shell hash and is proximate to a small salt marsh. Plant species such as saltbush (*Atriplex* sp.), dodder (*Cuscuta* sp.) and sea ox-eye daisy (*B. frutescens*) are common along the shoreline. Because the land is privately owned, there is little human disturbance.

Figure 10. Rattlesnake Point Site, represented by the red "x".

Redfish Point

Located on the west side of the Copano Bay Causeway just outside of Fulton, Texas, this parcel of land is held by Ducks Unlimited under a conservation easement (Fig. 11). The shoreline consists mainly of shell hash and is sandwiched between Copano Bay and an extensive salt marsh. Shoreline vegetation consists of prickly pear cactus (*O. engelmannii*), saltgrass (*D. spicata*) and sunflower (*Helianthus* sp.). Although recreational fishing is common in the waters surrounding Redfish Point, posted signs warn "No Trespassing" and human activities appear to be minimal on the actual shoreline.

Figure 11. Redfish Point site, represented by the red "x".

Big Island

This site is located south of Cedar Bayou on the backside of the privately owned barrier island known as San Jose Island (Fig. 12). While not an actual island, this site consists of a shell hash shoreline with typical vegetation, such as cordgrass (*S. alterniflora*), sea ox-eye daisy (*B. frutescens*), sea purslane (*S. portulacastrum*), and prickly pear (*O. engelmannii*). There are also isolated honey mesquite (*P. glandulosa*) present. Although, San Jose Island is privately owned by the Bass family, human traffic is quite common along the shoreline and in the back lakes within the interior of the island.

Copano Bay Causeway

The Copano Bay Causeway site is situated at the base of the south end of the bridge and consists of an isolated shell hash beach with an adjacent salt marsh (Fig. 13). The area is popular for recreational fishing and is proximate to a heavily used boat ramp. Vegetation includes the invasive saltcedar (*Tamarix* sp.), cordgrass (*S. alterniflora*), and sea purslane (*S. portulacastrum*).

Figure 12. Big Island site, represented by the red “x”.

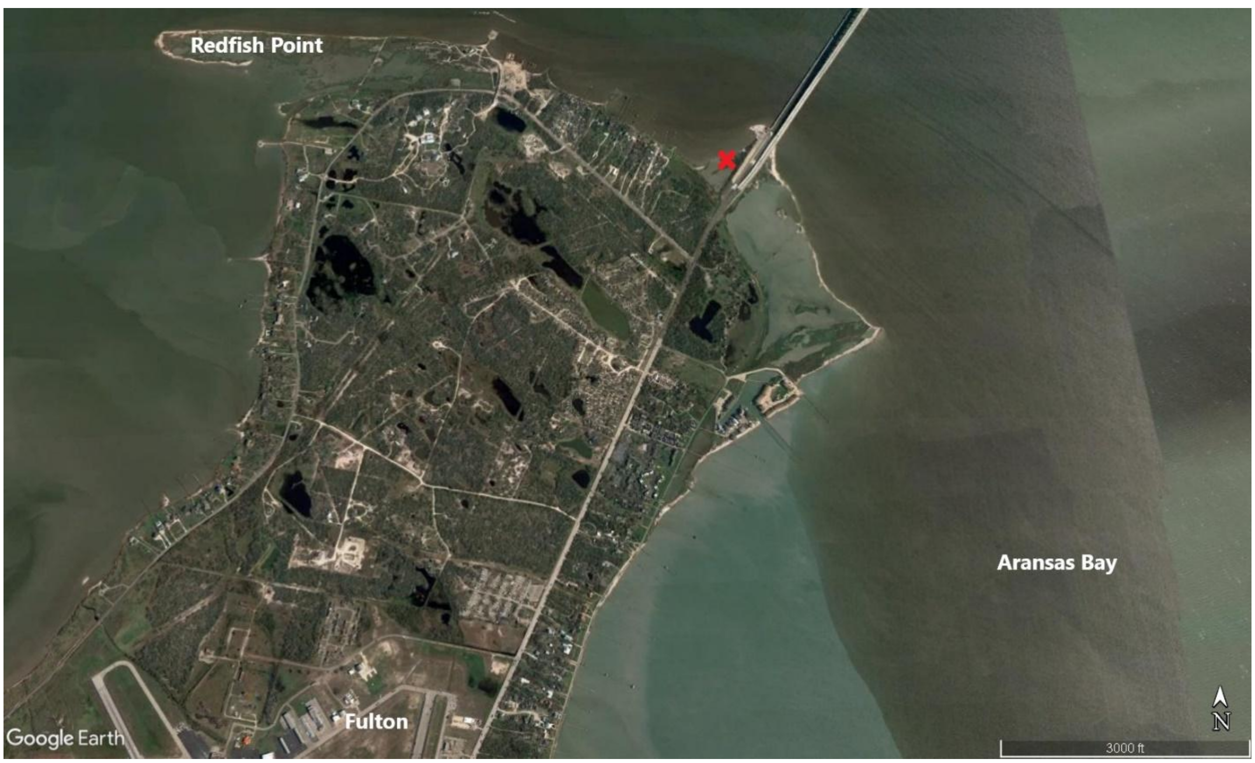

Figure 13. Copano Bay Causeway site, represented by the red “x”.

Field Sampling

Several approaches were utilized during this study to identify diamondback terrapin nesting beaches in the Mission-Aransas Estuary, Texas. Walking surveys and digital trail cameras were employed as well as nest site characterizations when actual nests were discovered. Before leaving to sample, a Garmin GPSMap78SC handheld GPS unit was used to mark a known survey benchmark on the Texas A&M University-Corpus Christi campus. This was done to attain a measure of accuracy for the handheld GPS unit used in the field. A detailed description of each sampling approach is included below.

Walking Surveys

Surveys were conducted in areas that were likely to contain suitable terrapin nesting habitat. Using the findings of Baxter (2015) for the Nueces Estuary, Texas, similar areas were sought out for walking surveys during this study. Stop and start times were recorded for each survey, as were latitude and longitude for each start and stop point. Surveys were completed for each field day and consisted of slowly walking the area while looking for evidence of terrapin nesting. Signs of terrapin nesting could include aborted nesting attempts, actively nesting terrapins, and predated terrapin nests. Whenever evidence of nesting was observed, a latitude and longitude was recorded using a Garmin handheld GPS unit. Further analysis of located nests is included in the *Nest Collection* portion of this section.

Digital Game Cameras

Game cameras were utilized from May 1, 2017 through July 29, 2017. Cameras were attached to t-posts driven into the ground. Figure 14 shows the locations of digital game cameras over the course of this study. Cameras were placed in areas that appeared appropriate for nesting, but showed no evidence of such during walking surveys. If walking surveys later showed nesting to occur in a particular location where cameras were set, they were promptly removed and relocated. The cameras used were Bushnell TrophyCam models 111636 and 119836. These cameras possess a time lapse function that allowed for the capture of one photograph every minute that the camera was deployed. In addition, the standard motion detection function was employed to capture additional photographs in these areas.

Nest Collection

In the event that a nest was located, pictures were taken immediately before any other data collection occurred. Recorded data for each nest included: latitude/longitude, nest depth (mm), distance from water (m), vegetative cover (%), slope (%), and sediment grain size (%). Each method is discussed in detail below.

Latitude and longitude were acquired using a handheld Garmin GPSMap78SC. These locations were logged on the GPS unit and also written on field data sheets. Nest depth was recorded as the distance between the surface of the ground and the bottom of the nest chamber. Distance from water was measured as a straight line from the nest to the nearest area of open water. Vegetative cover was estimated using a 1 m^2 quadrat placed directly over the nest. Vegetative species present within the quadrat were also recorded on the field data sheet.

Figure 14. Locations of digital game cameras within the Mission-Aransas Estuary, Texas.

Slope was determined using the tape and level method (Fig. 15). Instructions for this method are as follows:

1. Lay a board of known length perpendicular to the slope to be measured.

2. Place a carpenter's level on the board.

3. Raise the board until it is level (bubble on carpenter's level will be centered).

4. Use a tape measure to determine the board's distance from the ground.

5. Fill in the values and calculate % slope using the following formula.

   % Slope = Rise/Run x 100 = Distance from ground/Length of Board x 100

6. Repeat steps 1-5 four more times.

7. Take the average of all five calculated % slopes

8. Record this average as the % slope for the grade in question.

Figure 15. Example of the tape and level slope method (www.watershedmanagement.vt/gov).

When a nest was located, sediment samples were collected and returned to the lab. Samples were dried, sorted, and weighed in order to determine the proportion of variously sized sediments within the sample (TCEQ 2012). Table 1 shows the criteria used to classify nest sediments.

Table 1. Criteria for sorting sediment into classes based on grain size.

Grain Size	Classification
2 mm and larger	Gravel
.0625 - 2 mm	Sand
.002 - .0625 mm	Silt
.002 mm and smaller	Clay

Meteorological Data

In addition to the above methods, meteorological data were collected twice daily when conducting field work, using a Kestrel 3500 multi-parametric anemometer. Data was collected immediately upon arrival to the first sampling area and then a second time, upon departure from the final site. Data collected included air temperature (°C), relative humidity (%), wind intensity (mph), wind direction, cloud cover (%), and present weather. Tide stage was recorded using the MANERR Station #1 (Copano West) or MANERR Station #2 (Copano East) depending on which station was most proximate to the sites being sampled. These stations can be accessed at www.cbi.tamucc.edu/dnr/station. A map of these station locations is shown below (Fig. 16).

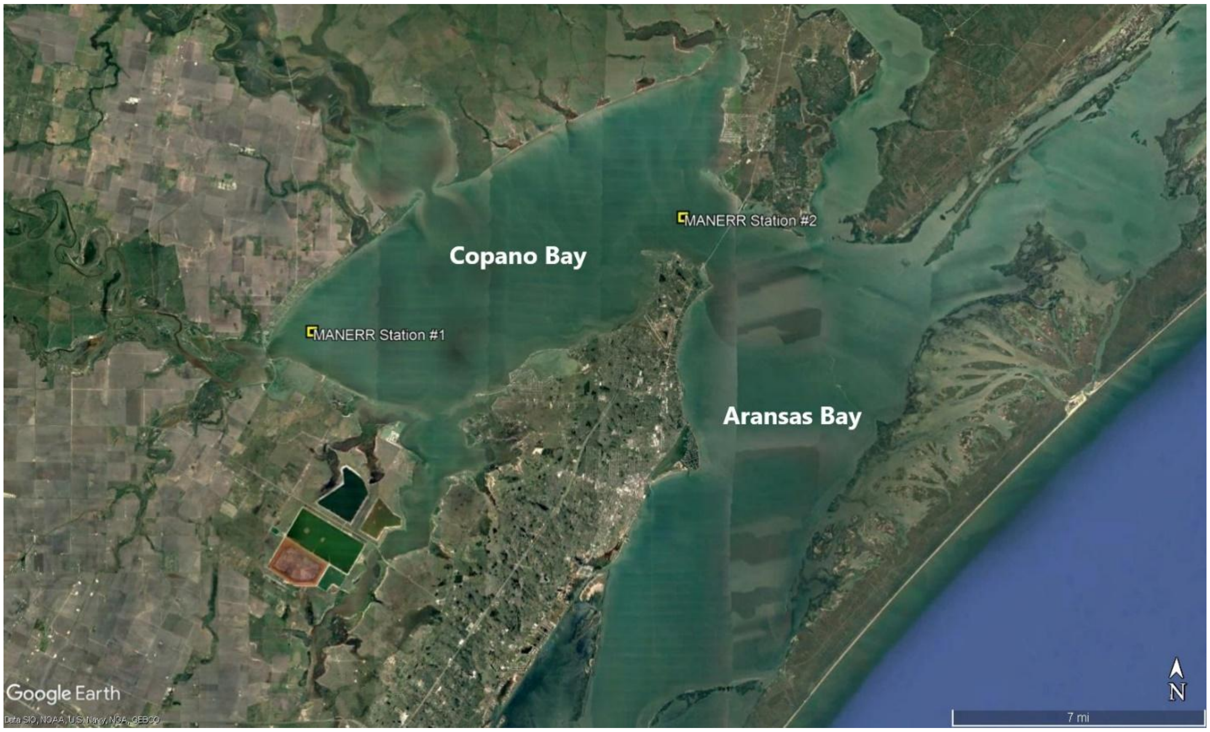

Figure 16. Map showing the location of the two MANERR station used to acquire tidal data for this study.

Results

Walking Surveys

Eighteen days of walking surveys occurred in the study area between May 1, 2017 and June 29, 2107. Eleven separate areas were surveyed over the course of the study. A list of those sites, along with their abbreviations, can be found in Table 2. Of those 11 sites, all were shown to be terrapin nesting beaches with the exception of MBME, BI, and CBC.

Figure 17 shows the location of each site surveyed within the Mission-Aransas Estuary, Texas. Survey efforts resulted in the identification of 32 terrapin nests (Fig. 18). All identified nests had been predated prior to discovery. An example of a raided nest is show in Figure 19, including the excavated nest cavity and unconsumed eggshells.

Figure 17. Locations of sites surveyed for diamondback terrapin nesting in the Mission-Aransas Estuary, Texas.

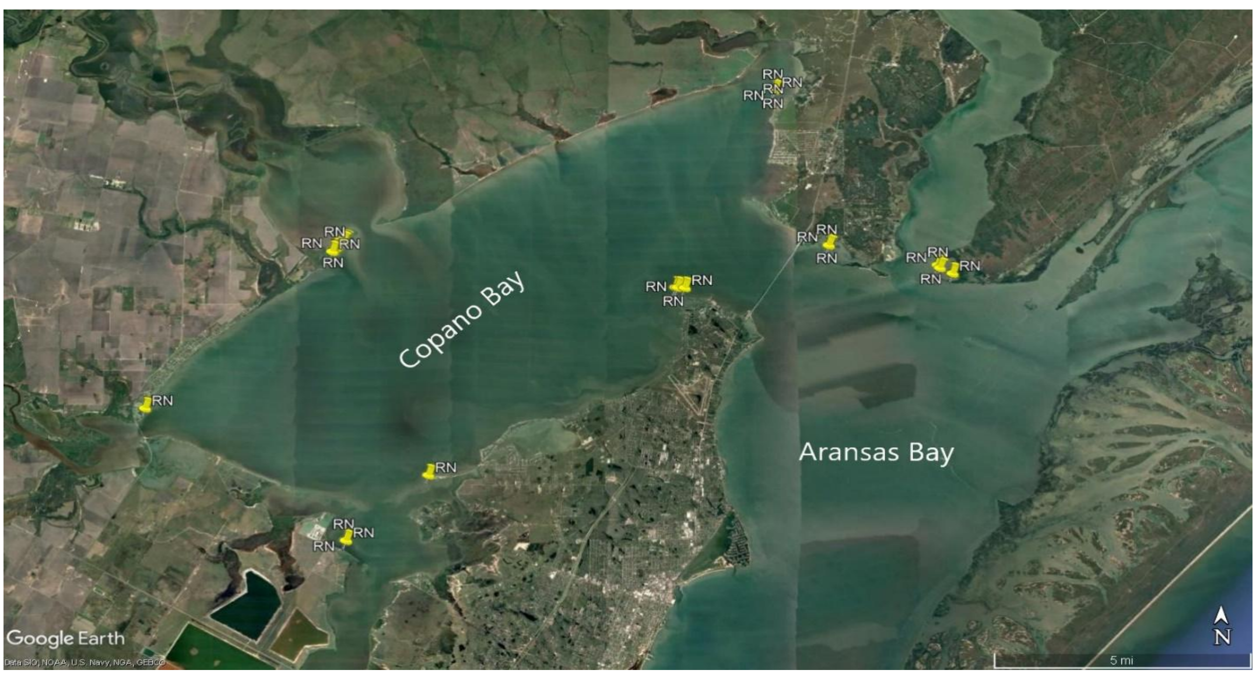

Figure 18. Locations of raided nests (RN) observed during walking surveys in the Mission-Aransas Estuary, Texas.

Figure 19. Example of a predated diamondback terrapin nest, showing the excavated nest cavity and unconsumed egg shells.

During these walking surveys, dead female terrapins were observed on multiple occasions. These individuals were of a size to be considered sexually mature. Figures 20 and 21 show a deceased, mature female diamondback terrapin that was located on a nesting beach at the Bayside Marsh (BSM). The absence of the head and posterior region suggests the terrapin was predated on the way to, or from, a nest site. Figure 22 shows a deceased, mature female terrapin located along a nesting beach on the Blackjack Peninsula (BJP). It appeared that this individual was struck by an outboard motor boat, possibly while attempting to reach the nesting beach.

One live, mature female terrapin was located during a walking survey at the Bayside Marsh (BSM) and is pictured in Fig. 23. This individual was located moving through the low marsh vegetation. It appeared that this female had recently been to the nesting beach, as evidenced by the shell hash on its carapace, and may have been returning to open water after nesting.

Figure 20. A deceased, mature diamondback terrapin located at BSM during a walking survey in the Mission-Aransas Estuary, Texas.

Figure 21. Alternate view of deceased, mature female terrapin located on nesting beach at BSM, Mission-Aransas Estuary, Texas.

Figure 22. A deceased, mature female terrapin located on BJP during a walking survey in the Mission-Aransas Estuary, Texas.

Figure 23. A live, mature female terrapin located at BSM with shell hash on the anterior and posterior carapace.

Evidence of predators was also documented during walking surveys and included signs of digging, rooting, tracks, and the presence of scat. The photograph below shows evidence of rooting along a nesting beach by feral hogs (Fig. 24).

Figure 24. Photograph showing the results of feral hog rooting along a nesting beach at BJP in the Mission-Aransas Estuary, Texas.

Digital Game Cameras

Game cameras provided over 500,000 photographs over the course of the study and proved effective out to 14 m during daylight hours and out to 7 m at night. While no terrapins were captured on digital game cameras over the course of this study, the presence of known nest predators was well documented. Raccoons were the most common predator over the course of the study, although other potential predators, including coyotes and large birds, were also photographed (Fig. 25 and Fig. 26).

Nest Collection

A total of 32 raided terrapin nests were collected during this study from eight separate locations within the Mission-Aransas Estuary, Texas. Nest data from each location were averaged and is presented in Table 3. Plant species present at nesting sites for specific sampling locations is given in Table 4. It is important to note that the nest at BSM was located under a saltcedar (*Tamarix* sp.) although vegetative cover was reported as 0%, as there was no vegetation growing under the tree.

Figure 25. Digital game camera photograph of a raccoon (*Procyon lotor*) on a terrapin nesting beach in the Mission-Aransas Estuary, Texas.

Figure 26. Digital game camera photograph of a coyote (*Canis latrans*) on a terrapin nesting beach in the Mission-Aransas Estuary, Texas.

Table 3. Averaged nest data for eight nesting locations within the Mission-Aransas Estuary, Texas.

	BSM	BJP	CCM	GISP	MBMW	PBM	RSP	RFP
Distance from water (m)	5.5	4.5	4.9	7.4	13.1	5.3	2.0	6.0
% Clay	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% Silt	0.1	1.0	0.8	0.5	0.4	0.4	0.1	0.2
% Sand	3.5	35.0	67.9	66.1	31.3	39.3	13.7	53.2
% Gravel	96.4	64.0	31.3	33.4	68.3	60.3	86.2	46.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Slope (%)	7.7	11.1	0.0	3.8	12.7	10.9	16.9	5.4
Vegetative Cover (%)	0.0	48.0	94.2	75.0	22.6	65.0	100.0	73.3
Nest Depth (cm)	10.0	16.1	14.2	10.7	13.1	11.0	12.0	11.3

Table 4. List of plant species present at nest sites for sampling locations in the Mission-Aransas Estuary, Texas.

Location	% Veg Cover	Plant Species Present
BSM	0.0	Saltcedar
BJP	48.0	Sea Ox-eye Daisy, Carolina Wolfberry, Sunflower, Saltgrass
CCM	94.2	Honey Mesquite, Saltgrass, Sea Ox-eye Daisy
GISP	75.0	Cordgrass, Sea Ox-eye Daisy, Sea Purslane
MBMW	22.6	Prickly Pear Cactus
PBM	65.0	Saltgrass, Sea Ox-eye Daisy,
RSP	100.0	Dodder, Saltbush, Sea Ox-eye Daisy
RFP	73.3	Saltgrass, Sunflower

Discussion

Nesting beaches were often located at the confluence of two water bodies, including places where rivers/creeks meet a bay and where smaller bays emptied into larger bays (Fig. 17). A few examples included the BSM site, where the Aransas River meets Copano Bay, the CCM site where Copano Creek empties into Copano Bay, the MBMW located at the mouth of Mission Bay where it discharges into Copano Bay, and the PBM and RSP sites, which both occur towards the distal end of Port Bay where it meets Copano Bay.

Walking Surveys

Walking surveys proved to be the most effective method for locating diamondback terrapin nesting sites, resulting in the discovery of numerous raided nests, several dead female terrapin, one live female terrapin, and the presence of predators on nesting beaches. Walking surveys also documented the presence of terrapin predators along nesting beaches. Sign such as scat, tracks, and rooting were common along all surveyed shorelines. The majority of this sign were left by raccoons, but the presence of coyotes, feral hogs, and large wading birds were also present.

The finding of a partially consumed, mature female at BSM points to the issue of predation during nesting forays. That the head, posterior, and internal organs of the turtle were absent, suggests it was killed and partially consumed while exhibiting nesting behavior. Seigel (1980) reported an eye-witness account of raccoon predation on an adult female terrapin on Merritt Island, Florida. The raccoon created an opening in the posterior of the animal by which it was able to remove the internal organs of the terrapin. He also reports finding 24 dead, adult females within a .5 km area of the local nesting beach. Although predation of these individuals was not observed, Seigel provides evidence that raccoons were likely responsible. All dead terrapins were surrounded by raccoon tracks and showed similar damage to the observed predation. Second, there was nothing to suggest a natural death for these individuals, as there were no signs of dehydration or overheating. He also points out that this phenomenon appeared to be seasonal, as adult terrapins rarely make overland forays outside of nesting season. He estimated that at least 10% of the adult female population at the study site were killed by raccoons over the course of one year. Seigel (1993) also reported on a long-term decline in terrapin populations at the Kennedy Space Center, Florida and attributed this decline to predation of adult females by raccoons.

Ner (2003) also reported predation of seven adult females by raccoons. Each individual was discovered laying upside down and raccoon scat was found near each dead terrapin. The dead terrapin in Figure 20 was also discovered laying upside down in the fashion described by Ner (2003). Raccoon scat and tracks were observed daily during walking surveys over the course of this study.

The presence of feral hogs along nesting beaches is alarming, as these animals are known to pose a threat to reptiles. Jolley *et al*. (2010) reported that 3,000 feral hogs consumed 3.16 million reptiles in one year. This species is known to excavate and consume turtle eggs, including those of sea turtles (Lewis et al. 1996). It is safe to assume that terrapin nests are at risk. Feral hogs pose threats to terrapins in other ways, as well. Activities such as rooting, physically alter habitats and reduce plant cover (Barrios-Garcia and Ballari 2012). Changes to these areas could render them inappropriate as nesting habitat and cause them to be abandoned as a nesting beach.

Predators are not the only threat to terrapins when accessing nesting beaches as evidenced by the individual observed at BJP (Fig. 22). The damage to the carapace is indicative of a boat strike and likely occurred when the terrapin was in shallow water near the nesting area. Boat strike injury, or mortality, is a well-established threat to terrapins (Lester 2013). During the nesting season, females tend to aggregate near nesting beaches (Baxter 2015). This could lead to an increase in boat strikes in the waters adjacent to nesting areas. The shallow waters adjacent to the BJP nesting site experience heavy boat traffic throughout the year and terrapins within this particular population show a higher rate of boat strike injury than in other locales (Baxter unpublished). With advances in bay boat design, has come the ability to operate in water less than a 0.3 m deep. At these shallow depths, terrapins have little, to no, means to escape and are often struck.

The one live, female terrapin observed was seen at BSM and was moving over thick marsh vegetation consisting mainly of saltwort (*B. maritima*) and glasswort (*Salicornia virginica*). Initially unaware of a human presence, the turtle continued to move freely towards open water. Once the terrapin became aware of the presence of humans, it stopped forward movement and slowly worked its way under the marsh vegetation. Once removed from under the vegetation, the presence of shell hash on both the anterior, and posterior, portions of the shell suggested that this turtle had recently forayed to the nesting beach and was returning to open water (Fig. 23). That this behavior was observed at 1015 h suggests that daytime nesting occurs at this location.

Digital Game Cameras

Although this method proved effective in the Nueces Estuary for documenting nesting beaches (Baxter 2015), no terrapins were photographed on land during this study. This is likely the result of modifications in methods for the current project. For this study, cameras were only set in areas that contained appropriate nesting habitat, but did not show any signs of terrapin nesting during walking surveys. The lack of terrapins photographed on land, combined with a lack of evidence gathered from walking surveys, suggests that these particular areas are not used as nesting habitat in the Mission-Aransas Estuary.

Over the course of this study, predators were documented for each day the cameras were in operation. The majority of these predators were raccoons, although coyotes and grackles were also documented. Raccoons are known to be a threat to terrapins at several life stages. The females are preyed upon during the nesting process, eggs are readily consumed, and hatchlings are often eaten after emergence. While coyotes have not been positively shown to raid terrapin nests, it seems likely that an opportunistic species such as this, would indeed take a terrapin nest if it were readily accessible.

Nest Collection

The two most important factors for whether an area was used for nesting appeared to be sites possessing an elevation above normal high tide and an adjacent marsh. It is important that the nesting beach remains dry throughout the incubation period and for this reason, areas with proper elevation are preferred as nesting habitat. Upon emergence from the nest, terrapins spend the first several years of their lives in the marsh, therefore this type of habitat is a prerequisite for nesting to occur in a given area.

A comparison of nesting areas for the Nueces and Mission-Aransas estuaries is found in Table 5. The two systems show some similarities, but also differ in important ways. A slight slope seems to be preferred by individuals from both estuaries. Palmer and Cordes (1998) reported an ideal slope of ≤ 7°. For this study, the average slope of 8.6 % converts to 4.8° and is well within the nesting habitat suitability index (Palmer and Cordes 1998). Digging and laying may be easier in areas with low slope as the terrapin must hold itself at a 30°-40° angle while laying. This position would be difficult to hold on higher slopes (Burger and Montevecchi 1975). Low slope also reduces the amount of wind erosion preventing eggs from becoming exposed.

Table 5. Comparison of diamondback terrapin nest site characteristics for Nueces Estuary and Mission-Aransas Estuary, Texas.

	Nueces	Mission-Aransas
Distance From Water (m)	5.4	6.1
Slope (%)	10.02	8.6
Vegetative Cover (%)	90	59.8
% Clay	0	0
% Silt	1.4	0.4
% Sand	17	38.8
% Gravel	81.6	60.8
Nest Depth (cm)	9.16	12.3

While vegetative cover was, on average, lower in the Mission-Aransas Estuary, there was still a relatively high percentage of vegetation at most nest sites (Table 3). This was also seen in the Nueces Estuary (Baxter 2015). On average, sites in the Mission-Aransas Estuary had a higher percentage of sand, compared to the Nueces Estuary, although the majority of sediments from both systems were classified as gravel, represented as shell hash.

There is conflicting data surrounding the issue of preferred substrate type and ideal vegetative cover for terrapin nesting. Generally, terrapins have been shown to prefer flat to softly sloping sandy beaches with little to no vegetation (Seigel 1980; Palmer and Cordes 1988). Of course, there are exceptions and in some areas terrapins nest in partially vegetated areas or in non-sandy substrates (Auger and Giovannone 1979; Feinburg and Burke 2003). These differences may be easily explained, as terrapins must nest in the substrate(s) available. In Nueces Bay, there are no areas of elevated, exposed sand. Instead there is only river silt and shell hash available. Silt particles are too fine and do not allow gas exchange to occur in the eggs, making it an inappropriate nesting substrate. The terrapins in Nueces Bay nest in shell hash because it is the only option. In contrast, several sites within the Mission-Aransas Estuary possessed a high percentage of sand. Other sites within the Mission-Aransas Estuary contained almost all shell hash and very little sand, similar to what was found in the Nueces Estuary (Baxter 2015). While sandy substrates may be preferred, it is of little relevance when there are no sandy beaches available.

It has been suggested that isolated shell-hash islands may be a preferred nesting habitat for terrapins in Texas (Guillen et al. 2015). This assumption was made based on two things: data from nesting in Galveston Bay and a nesting habitat suitability index (HSI) from Halbrook (2003). Nesting in Galveston Bay occurs on an island known as South Deer Island. This island is unique for Texas bays, as it is large enough to contain a marsh habitat within its interior. A survey of current satellite imagery shows few other islands that contain both elevated shorelines and marsh habitat. There is little evidence, outside of the Deer Island complex, that isolated islands are preferred nesting habitat. The nesting HSI formulated by Halbrook (2003) for the Nueces Estuary included five islands located in the west end of Nueces Bay. She concluded that four of these five islands were suitable as nesting habitat. Baxter (2015) surveyed these islands and found no evidence that nesting was occurring there. These islands are small in size and contained no marsh habitat. The nearest marsh was located across the open waters of Nueces Bay and there is no evidence of hatchlings making forays across open water to reach this habitat. The results from this study, and the Nueces Estuary (Baxter 2015), show no evidence of nesting on shell hash islands. Instead, mainland shorelines were used exclusively for nesting in these two Texas estuaries.

A high degree of vegetation suggests heavy root biomass, which can lead to infiltration of eggs and nest failure. However, nests in areas with no vegetation risk increased desiccation and wind erosion (Brennessel 2006). Palmer and Cordes (1988) suggested an optimum nesting habitat as having 5% - 25% vegetative cover. In the Mission-Aransas, vegetative cover on nesting beaches was variable, but it was common to have a relatively high percentage of vegetation. While average vegetative cover was lower in this study than for the Nueces Estuary, there were individual sites within the Mission-Aransas Estuary that showed a high degree of vegetation. There did not appear to be preferred plant species for nesting sites as vegetation varied from location to location. Raided nests were often found directly adjacent to the base of a shrub, tree, or cactus. On one occasion, four raided nests were found on opposite sides of the same honey mesquite (*P. glandulosa*). While these areas may lead to increased egg loss due to root infiltration, there is perhaps a trade-off when compared to nesting in non-vegetated areas. By nesting in heavy vegetation, terrapins may avoid avian predators such as grackles and laughing gulls. Perhaps nest survival is higher in vegetated areas due to the hot, dry climate that is typical of the Mission-Aransas Estuary. Plant growth provides shade and retains moisture which may prevent eggs from overheating or dessicating during development.

Conclusions and Recommendations

That nesting beaches were easily located for this project is evidence that the habitat characterization provided from the Nueces Estuary can be applied to other Texas estuaries. This is important as it reduces effort in locating these areas, and by identifying them, they can be preserved as functional nesting habitat. Fortunately, a few of these sites occur within the boundaries of state, or federal, lands or on conservation easements (BJP, GISP, RFP). It should be noted that this is not true for all nesting sites for the Mission-Aransas Estuary, and is likely untrue for other estuaries along the Texas coast. As coastal development increases, it is essential to protect these areas so that they remain accessible for nesting. Shoreline hardening, road building, and habitat fragmentation are all parts of the development process and all have the capacity for restricting access to historical nesting sites for diamondback terrapins.

As seen in the Nueces Estuary, the presence of predators may strictly limit nest survival in most, if not all, of these areas. If nest success is low for an extended period of time, recruitment will be limited, and the population may become unstable to the point of extirpation. Traditionally, terrapin nests have been protected using exclusion fences that prevent predators from accessing nests. Unfortunately, the substrate in the Mission-Aransas is such that nest presence is only known once a predator has raided it, and these types of fences are not feasible.

Instead, the removal or relocation of predators during nesting season may be a more desirable option for increasing nest survival. The seasonal trapping and removal of raccoons and feral hogs from nesting areas from May-July could drastically reduce the number of terrapin nests that are depredated, resulting in higher nesting success for these populations. It is difficult to estimate nesting success for these populations due to the substrate in which nesting occurs, but it can be assumed that by removing raccoons and feral hogs from nesting sites, that nesting success would increase as a result. Raccoon removal has been shown to be effective, lowering nest predation by over 60% in a single year (Munscher et al. 2012). When raccoons were not removed the following year, nest predation returned to previously high levels. The same logic would imply that the removal of feral hogs would increase nest survival, as well.

Another method for increasing nest success for terrapins in the Mission-Aransas Estuary is the restoration and enhancement of existing nesting habitat. Burger (1977) showed that areas of high-density nesting were more heavily predated than more dispersed nests. Because suitable nesting habitat is limited in the Mission-Aransas Estuary, terrapins are forced to nest in high densities, allowing predators to locate a high percentage of total nests within a small area. If these narrow bands of elevated shell and sand were made wider, it would increase the available nesting habitat and allow terrapins to nest in lower densities within a given area. Substrate type (sand, shell) does not appear to be a limiting factor for nesting to occur, therefore a wide range of sediment sizes would be appropriate when enhancing/restoring these areas and could be attained from a variety of sources.

That current nesting habitat occurs as a thin strip of land between the open bay and marsh raises the issue of erosion. These beaches often occur on high energy shorelines resulting in the loss of nesting habitat due to erosive wave action. In order to ensure the existence of these nesting areas, erosion prevention measures could be enacted. Living shoreline stabilization methods should be utilized and could include oyster reef and cordgrass (*S. alterniflora)* placement. Hardened shorelines (bulk heading, rip rap, etc.) limit access to nesting areas and should be avoided.

Another experimental method being utilized with varying degrees of success is the creation of new nesting habitat. Diamondback terrapins exhibit nest site fidelity and there have been questions regarding the possibility of creating new terrapin nesting habitat and whether it would be used as such. Initial results have shown that terrapins will indeed utilize created nesting habitats and will exhibit site fidelity in future years (Brennessel pers com). These generated nesting sites are referred to as “terrapin gardens” and have been used as mitigation for development projects along the east coast. Terrapin gardens are also being installed by homeowners whose properties occur in areas of historic terrapin nesting (Lacey pers com). It appears that the highest nesting success occurs when these areas are created where known terrapin nesting activity intersects with the newly constructed nesting habitat (Egger pers com). There are some concerns regarding the artificial concentration of terrapin nests in terrapin gardens and increased accessibility to known terrapin predators, although initial results show this as an effective strategy to increase terrapin nesting habitat.

In late August of 2017 the Mission-Aransas Estuary sustained a direct hit from Hurricane Harvey, a category 4 storm, which devastated local towns and wreaked havoc on the environment. Several terrapin nesting beaches were affected and may have been permanently altered in a fashion making them no longer suitable for nesting. These areas should be restored to ensure that functional nesting habitat is available and recruitment to local populations is not reduced, or even eliminated.

Many of the shorelines used by terrapins as nesting beaches experience heavy boat traffic, which may also contribute to decreased nesting success. Females tend to show site fidelity during the nesting season and are often present in large numbers in the shallow waters adjacent to these areas during nesting season. Because of advances in boat design, access to these shallow waters has increased and could lead to increased boat strike injuries, or mortalities, to the breeding adult population. The survival of mature females is imperative to the success of this species and should be protected whenever possible. Signage requiring boats to run in deeper water, away from shorelines, could reduce the number of terrapins killed in these areas, therefore increasing the number of nesting females. Also, an education/outreach effort should be made to inform the public of this risk to terrapins.

Finally, the data gathered at known nesting beaches in the Mission-Aransas Estuary should be applied in other Texas estuaries where the location of nesting beaches is currently unknown. With coastal development on the rise, it is imperative to locate these areas and to preserve them as functional nesting habitat.

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