Seasonal Habitat Use of Diamondback Terrapins (*Malaclemys terrapin*) in North Inlet, Winyah Bay, Georgetown, South Carolina

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SEASONAL HABITAT USE OF DIAMONDBACK TERRAPINS
(*MALACLEMYS TERRAPIN)* IN NORTH INLET, WINYAH BAY,
GEORGETOWN, SOUTH CAROLINA

By

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ABSTRACT

There is a lack of knowledge on Diamondback Terrapins (*Malaclemys terrapin)* seasonal movements and habitat use during the transitional period into overwintering. Observations of male and female Terrapins during late summer (August/September) and fall (October/November) were compared to determine if habitat use and distance traveled are influenced by season. Observed locations were also analyzed to determine if water depth and distance to shore could be used to predict Terrapin presence. Movements were tracked using radio telemetry and observed coordinates were inputted into ArcGIS for analysis. Total distance traveled and the maximum distance traveled were calculated for each Terrapin using Global Positioning System (GPS) coordinates. To address seasonal habitat preferences, we recorded observations in three macrohabitats: main tidal creek, secondary tidal creek, and a submerged sandbar. A mixed effect logistic regression was used to determine if water depth and distance to shore predicted Terrapin location.

Distance traveled decreased for males and females during the month of November; in males this decreasing trend of movement was observed September through November. In contrast, there was a trend towards increased female movement in October. Overall, distance traveled was greater for females compared to males. In late summer, Terrapins primarily occupied areas in secondary tidal creeks whereas in fall Terrapins were found in main tidal creeks especially associated with a shallow sandbar. For example, 70% of observations during late summer occurred in smaller side channels. In the fall, 60% of observations were in a main tidal creek and the remaining 40% associated with a submerged sandbar. I was unable to discriminate between randomly selected pseudo-absence points and the observed Terrapin locations. The observed habitat use and decreased movement during November suggests that the sandbar could be the chosen overwintering site for this Terrapin population.

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INTRODUCTION

Seasonal variation in basking sites, prey abundance, overwintering sites, and reproductive behaviors are important determinants of habitat selection in turtles (Beaudry et al. 2009, Hart and Lee 2006, Harden et al 2007). Because turtles are ectotherms, they are dependent on access to a range of thermal environments to aid in digestion and other metabolic processes (Hart and Lee 2006). Accordingly, turtle habitat selection may vary seasonally due to changing physiological demands associated with feeding, courtship, mating, and overwintering (Akins et al. 2014, Harden et al. 2007). For example, Spotted Turtles (*Clemmys guttata*) prefer wetland microhabitats based on the amount of sun exposure and the proximity to hibernation sites, choosing wetlands with high sun exposure in the fall season (Beaudry et al. 2009). In Diamondback Terrapins (*Malaclemys terrapin)*, reproductively mature Terrapins often exploit a wider range of habitats and exhibit behavioral changes such as increased movement compared to non-reproductive Terrapins (Millar and Blouin-Demers 2011, Roosenburg et al., 1999, Tulipani 2013). For example, increased movement by gravid female Terrapins may be associated with travel to nesting areas (Sheridan et al. 2010).

As temperatures decrease in fall, thermoregulatory requirements and food sources may influence turtle macrohabitat selection. Spotted Turtles (*Clemmys guttata*), leave shaded upland areas to reach their overwintering wetland by mid-October and some as early as late September (Beaudry et al. 2009). Diamondback Terrapins typically start overwintering as early as mid-October and as late as late-November, showing a preference for shallow, mud microhabitats from November to March (Akins et al. 2014, Yearicks et al. 1981, Hart and Lee 2006). When Terrapins emerge from overwintering, they must immediately increase their body temperature to increase their metabolic rate, and they may choose overwintering sites to better facilitate these needs (Beaudry et al. 2009). Food resources are also an immediate need for energy for growth and reproduction after emerging from overwintering (Beaudry et al. 2009). In the fall, turtles that preferred deeper waters in the warmer months now seek microhabitats that allow them to raise their body temperatures on warmer days when preparing for overwintering (Plummer 1977). These observations suggest that turtles may show preference for overwintering sites being within close proximity to microhabitats that aid in thermoregulation.

The Diamondback Terrapin (*Malaclemys terrapin*) is a unique salt marsh specialist, endemic to estuarine habitats of the eastern and Gulf coasts of the United States and are listed as vulnerable according to the IUCN Red List (IUCN 2019). In South Carolina, Terrapins are designated as an “at risk” species listed as a “high priority” for conservation in the Comprehensive Wildlife Conservation Strategy (South Carolina Department of Natural Resources 2015). Consequently, research on ecology and natural history of South Carolina Terrapin populations is necessary to prevent further decline of the species within the state.

In South Carolina and elsewhere, Terrapins are threatened by crab pots, boat traffic, nest predation, and habitat destruction (Harden and Williard 2012, Gibbons et al. 2001, Butler et al. 2004, Gibbons et al. 2000). Adult survival is one of the most important factors contributing to growth rate in turtle populations (Bowen et al. 2004). Turtle populations recover slowly following loss of sexually mature individuals due to life history traits such as delayed sexual maturity and low offspring recruitment (Heppell

1998, Feinberg & Burke 2003). Diamondback Terrapins are sexually size dimorphic, with mature females weighing about 667 g and adult males about 242 g (Gibbons et al. 2001). As a consequence of this large difference in body size, male and female Terrapins exploit different food resources and likely different habitat resources as well. Despite the widespread interest in Terrapin ecology and conservation, there is a paucity of research on spatial ecology and habitat use of Terrapins in general and whether Terrapins use a different suite of habitats across seasons. Particularly of interest, with limited research to date, is the transitional period into overwintering, as a majority of studies focus on earlier season movements influenced by reproductive behaviors. Quantifying these fundamental ecological characteristics will help to inform management decisions regarding human activities that may impact Diamondback Terrapins.

The goal of this study was to quantify seasonal movement patterns and habitat use of Diamondback Terrapins in North Inlet, SC, and determine preferred macrohabitat characteristics. Investigating changes in late-season movement patterns and habitat use will provide much needed information on macrohabitat preferences as temperatures gradually decrease and Terrapins locate overwintering sites. My two objectives for this study were to determine if Terrapins display seasonal differences in habitat use and to identify variables to predict Terrapin presence in North Inlet. In order to gain a better understanding of seasonal habitat use, Terrapin movement patterns (maximum distance and total distance traveled) and macrohabitat preferences were studied comparing late summer to the fall season.

METHODS

Terrapin collection and Radio-telemetry

Terrapin movements were tracked in order to identify locational information on the habitat characteristics at the observed coordinates. Diamondback Terrapins were captured in North Inlet-Winyah Bay National Estuarine Research Reserve, Georgetown County, SC, using a hand-towed seine during July- September 2019 (Figure 1). Town, Bly, and Old Man Creeks were the main tidal creeks surveyed in this study. The hand-towed seine method required two researches to walk along the edges of the secondary tidal creeks with the net fully in contact with the bottom substrate. These requirements ensure that the net was used properly and the Terrapins would not be able to escape capture. Therefore, this method could only succeed at lower tide levels in smaller secondary tidal channels. Until all Terrapins were captured all surveys took place during seining trips. Due to these logistical constraints, we were unable to conduct surveys equally across all tidal stages and hence surveys were biased towards low tide conditions. Once all individuals were captured, tracking was then able to be conducted over a wider range of tidal conditions. In total, I conducted nine surveys at low tide, three surveys at high tide, seven at rising tide, and four surveys at outgoing tide.

Immediately after capture, transmitters (Wildlife Materials, Inc, Murphysboro, IL) were fitted to each individual’s posterior carapace using 5-Minute General Purpose Epoxy (Starbrite) for use in tracking via radio telemetry. Transmitters were attached to the posterior carapace to minimize any interference while swimming. Radio-telemetry is an effective method for monitoring broad-scale Terrapin movement patterns and habitat use (Harden et al. 2007, Roosenburg et al. 1999). Under optimal conditions, radio-tagged Terrapins with antennas exposed to air can be detected at distances of at least 1 km (S.L.

Parker, personal observation). Individuals were temporarily housed in dry 38 L plastic containers for five minutes to allow epoxy to dry. Weight of transmitters (24 g) was < 10 % of body weight for all individuals (Beaupre et al. 2004). At the end of the study 7 individuals were captured, three males and four females, resulting in a total of 121 observations that ranged from July-November and 7 observations in February.

I tracked radio-tagged Terrapins using a Lotek Biotracker VHF receiver (Lotek Wireless Inc, Seattle, WA) and a Yagi double element antenna. Each Terrapin was assigned a unique frequency for use as an identifier. Surveys were conducted for radio-tagged Terrapins every two to five days between 0800 – 1500 h from August to November, 2019. The study period was defined as two seasons, late summer (August and September) and fall (October and November). One final survey was conducted in February. Because Terrapins were often submerged and therefore difficult to pinpoint visually, we narrowed their location and marked latitude and longitude of radio-tagged Terrapins within an approximately 3 m radius using a handheld GPS device (GPSmap 62s, Garmin International Inc., Olathe, KS). For each Terrapin location we recorded habitat (submerged or exposed), macrohabitat (main channel, side channel, or submerged sandbar), water depth of tidal creek, distance to shore, creek width (<3m, 3-5m, 5-8m, 8m+), and tidal height (NOAA, Clambank Station, North-Inlet). Side channels were defined as the smaller tidal creeks (3-20m wide) branching off of the larger main tidal creeks (100-300m wide). Water was continually present in the main tidal creeks, whereas water was often absent in the smaller tidal creeks at low tide with the exception of isolated pools. Additionally, I identified a sandbar in Old Man Creek where Terrapins congregated in November. I defined approximate dimensions of the sandbar by marking latitude and longitude associated with depth measurements of radio-tagged terrapins.

Spatial and Statistical Analysis

To map and visualize our Terrapin location dataset we imported longitude and latitude data for each observed location (n=128) into the ArcMap module of ArcGIS (Environmental Systems Research Institute, Redlands, CA). An individual vector dataset was created for each Terrapin which included all observed locations collected during the study. Spatial data was used to provide characteristics of the geographic environment within the study area. Using ArcGIS, I was able to visualize the data and assign habitat characteristics to each individual Terrapin point.

For seasonal movements, total distance and maximum distance moved was calculated using the inputted coordinates in ArcGIS. In-water distances were calculated from the latitude-longitude coordinates of each relocated Terrapin. Maximum distance moved (m) for each individual, was calculated as the distance between the farthest two marked locations. Total distance moved (m), was the aggregate distance measured from point of capture through the last observed location at the end of the study in November. Total and maximum distance traveled was also calculated in ArcGIS on a monthly basis for each individual Terrapin. This was completed by isolating observations based on month. The calculated distances between male and female Terrapins over season were compared.

To identify relationships between Terrapin presence/absence and habitat characterization, we identified and obtained additional spatial data sets representing environmental conditions within the study area to use in GIS. To identify the land cover type in which Terrapins were observed we used a land cover dataset (NLCD 2016 land cover CONUS). This dataset provides a standardized classification of land cover type. With our longitude/latitude coordinates and the land cover dataset we then assigned a value of land cover type to each Terrapin observation. Terrapin locations were also compared with bathymetry data from public government GIS databases (NOAA Digital Coast, USGS, and NHD). The scope of this study did not allow for personal collection of high spatial and temporal resolution bathymetry data. For water depth measurements, pre-existing public datasets were utilized (NOAA LIDAR 2019). Geospatial data, from a public dataset, provides a snapshot of conditions when that data was collected. The values are limited to the conditions at that specific time. Inclusion of additional variables beyond water depth was not possible due to the resolution in available datasets. Geospatial data was used to assign characteristics to determine if Terrapins selected particular habitat types relative to the habitats available.

A chi-squared test was used to determine if there was a relationship between Terrapin habitat and season (August/September versus October/November, n=120). Macrohabitat characteristics were defined as main tidal creek, secondary tidal creek, or submerged sandbar. Alpha values of ≤ 0.05 were considered significant.

Water depth and distance to shore values to were assigned to each observation in ArcGIS. To include additional areas that could be potential Terrapin habitat, the study area was extended 1km from the furthest North, South, East, and West observed Terrapin point. Grids (3x3m) were created within the entire study area using the fishnet function in ArcGIS. The study area was reduced to water only grids as all observed Terrapin points were located in the water. As a result all random points were generated in the water. Values in each individual grid included distance from shore and water depth. To determine water depth, a preexisting dataset (2019 NOAA LIDAR digital elevation model) was used. To determine distance to shore values, a raster was created to differentiate water from land. The boundaries of this distance to shore raster indicated the shoreline. Therefore, the measured distance from the Terrapin points to the end of the raster determined the distance to shore values. Terrapin points were then assigned water depth and distance to shore values based on the determined grid values in which they were located. To assign these values, zonal statistics was completed in ArcGIS. After completion, a water depth and distance to shore value was assigned to every Terrapin point and pseudo-absence point.

Mixed effects logistic regression was used to determine habitat associations, with water depth and distance to shore as fixed factors and Terrapin ID as a random factor. Pseudo-absences were used and generated at random over the study area (Engler et al. 2004). Pseudo-absences (n = 1000) were generated using the random points function in ArcGIS, with random points set ≥ 3m to adjacent random points. The pseudo-absence points represented random locations where Terrapins could be present but were not located during this study. This provided information on total available habitat within the study area (Phillips et al. 2009, Fill et al. 2015). The values for the 1,000 random points and the 128 Terrapin points were used for the logistic regression. Incorporating these randomly selected pseudo-absences allowed for the most effective distribution model for this analysis, yielding the most reliable distribution results (Barbet-Massin et al. 2012). RStudio was used for the logistic regression, using the lme4 package within the glmer function (RStudio 1.3.959). Logistic regression was used to determine if the variables, distance to shore and water depth, could influence Terrapin presence.

RESULTS

Movement Patterns

In total, we recorded 128 observations for the seven captured Terrapins. Overall movement, measured as maximum distance and total distance moved, by both male and female Terrapins decreased from August to November. Females, exhibited a trend of increased movement from September to October followed by a decreased movement from October to November (Figure 2). For males, a trend of decreased movement was observed from September to November (Figure 2). The only similar trend observed between males and females was the decreased movements noted during November. Maximum and total distance moved decreased 30-60% during the month of November, with female movement tending to decrease more dramatically than males. On average, maximum distanced traveled by females was 1,383 m and total distance traveled was 3,850 m. For males, they traveled on average a maximum distance of 944 m and a total distance of 3,056 m.

Seasonal differences in habitat association

Habitat use by Diamondback Terrapins differed as a function of season. The majority of late summer (August/September) Terrapin observations occurred in secondary tidal creeks compared to fall observations (October /November) which all occurred in Old Man creek (main tidal creek) or near a submerged sandbar located within this creek (χ^2=78.38, df=2, *p*- = < 0.0001, Figures 3 and 4). Out of a total of 62 observations in Old Man, Bly, and Town creeks, 51 occurred during the fall (Figure 3b). Frequency of Terrapin observations in main tidal creeks was nearly five times higher during the fall compared to late summer (Figure 4). During the late summer, there were nearly twice as many observations in the side channels compared to the main tidal creeks (Figure 4). All observations in the fall were located in Old Man Creek, and 33 out of 120 observations in November were associated with a shallow submerged sandbar (Figure 3).

Results from mixed effects logistic regression indicated that there was no association between depth and distance to shore and Terrapin presence (Table 1, Figure 5). On average, males were found at a water depth of 1.2 m (±0.85) and females were found at 1.4 m (±0.82). Males were found on average 33.9 m (±27.1) from shore with females located on average 42.1 m (±31.5) from shore.

DISCUSSION

Trends in movement patterns

The results suggest that over the duration of the study, females tend to move greater distances than males, independent of month. These results parallel those of previous studies where females traveled greater distances than males (Hart and Lee 2006, Sheridan et al. 2010, Szerlag-Egger and McRobert 2007, Lamont et al. 2021). The decreased movement in November is likely due to cooler water temperatures and Terrapins settling into overwintering sites (Hart and Lee 2006). A small sample size was a constraint limiting our analysis hence comparison between movement patterns of males and females could not be analyzed statistically. An underlying reason for the observed differing trends in distance traveled between sexes may be due to the sexual size dimorphism present between males and females (Lamont et al. 2021, Hart and Lee 2006, Sheridan et al. 2010, Szerlag-Egger and McRobert 2007, Tucker et al. 1995). Another explanation may be the location of preferred prey items (Gibbons et al. 2001, Tucker et al. 1995, Butler et al. 2012). For example, diet of male Terrapins encompasses smaller prey such as periwinkles and fiddler crab, whereas females can consume a larger range of prey including blue crab (*Callinectes sapidus*) which commonly reside in large tidal creeks (Ramach et al. 2009). These size-related dietary preferences decrease resource competition between sexes which leads to a divergence in habitat selection (Tucker et al. 1995, Herrel et al. 2017).

Seasonal differences in habitat association

A notable change in Terrapin habitat use was observed between late summer and fall. In this study, Terrapins were observed in small tidal creeks during late summer, however, Terrapins were increasingly found in main tidal creeks in the fall. Secondary tidal creek observations took place only in late summer (August and September), with zero side channel observations in the fall (October and November). These side channels provide shallower water and could provide an increase in prey availability and protection from common threats such as boat traffic (Lester et al. 2012) and other human impacts (Gibbons et al. 2001, Hart and Lee 2006, Castro-Santos et al. 2019). The majority of main tidal creek observations (82%) took place during October and November. Interestingly, by November the majority of Terrapins were associated with a sandbar in the channel of Old Man Creek that was adjacent to one of the side tidal creeks occupied earlier in the season. In contrast to my findings, Terrapins have been found to spend more time in shallower marsh habitats than open water habitats (Harden et al. 2007). Over the whole duration of our study, roughly 80% of the observations were located by the submerged sandbar or in the main tidal creek in deeper waters.

Preference for the submerged sandbar in the fall may indicate selection of an overwintering site. Terrapins from populations ranging from Cape Cod to Texas select mud beds for overwintering (Yearicks et al. 1981, Hart and Lee 2006, Hurd et al. 1979). Similar to our sandbar observations, hundreds of Terrapins may gather and overwinter in similar smaller locations such as a shallow mud creek (Hart and Lee 2006). These behaviors differ those in spring and summer where the Terrapins are more dispersed in a variety of habitats (Hart and Lee 2006). The submerged sandbar may provide a shallower habitat in close proximity to basking sites which aid in thermoregulation (Seebacher et al. 2004, Akins et al. 2014, Beaudry et al. 2009). Other factors that may be important in overwintering sites are moderate salinities (13.6 – 20.0 ppt) and tidal action for water circulation (Hart and Lee 2006). Terrapins are effective osmoregulators and are capable of maintaining water balance in seawater (Gilles-Baillien 1970), however they drink freshwater when available (Hart and Lee 2006 and Williard et al 2019). Terrapins avoid drinking water that has salinity above 27.7 ppt (Hart and Lee 2006). Salinity of tidal creeks were not obtained during this study, however future research should investigate salinity of water in the vicinity of Terrapin overwintering sites.

Terrapins have high site fidelity, remaining near, or returning to specific tidal creeks (Harden et al. 2007, Gibbons et al. 2001, Sheridan et al. 2010). The preference for specific tidal creeks could be influenced by resource availability, with Terrapins choosing to stay close to locations with high productivity and prey abundance (Lamont et al. 2021). Tidal creek preference could be due to other factors as well such as, reproductive behaviors, basking, and temperature fluctuations (Beaudry et al. 2009, Lamont et al. 2021, Akins et al. 2014). Terrapins in the present study displayed site fidelity, staying mostly within one larger tidal creek for the duration of the study.

No association was found between Terrapin preference and water depth or distance to shore. We were unable to discriminate between locations where Terrapins were present from the randomly selected pseudo-absence points due to minimal amount of variability among the observed and random points, resulting in inflated standard errors. A larger Terrapin sample size and increased number of Terrapin observations in a variety of habitat types is necessary to generate models capable of predicting habitat features associated with Terrapin presence. Because of limitations in resolution of publically accessible spatial data of the study area, I was unable to characterize small-scale variation in Terrapin habitat use. In particular, assignment of water depth to observed Terrapin locations was difficult because many subtidal creeks were shallow and subject to large tidal fluctuations. Accordingly, water depth measurements obtained from GIS layers were highly variable and may not have consistently depicted water depth at the time of Terrapin observation.

Implications for conservation

Understanding seasonal habitat use by Diamondback Terrapins is essential for developing plans for mitigating potential impacts on the species. During the summer, Terrapins are most likely impacted by incidental capture in crab pots and potentially by boat strikes as individuals travel along major tidal creeks (Harden and Williard 2012, Gibbons et al. 2001, Butler et al. 2004, Gibbons et al. 2000). Human impacts on terrapins may also occur during the winter in South Carolina, because aggregations of multiple Terrapins in one area, as reported by this study and others, could make them vulnerable to activities such as boat traffic (Lester et al. 2012) and dredging (Castro-Santos et al. 2019). Future research expanding on these findings would help improve understanding of late season movements and habitat areas that require protection. Although the results of this study show fall and winter habitat preferences, more research on male and female movements during the transition period into overwintering will need to be conducted to aid future management decisions.

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Table 1. Results of logistic regression analysis of Terrapin presence as a function of water depth (depth (m)) and distance to shore (distance (m)). Randomly selected pseduo-absences were incorporated into the model to represent locations where Terrapins were not observed but potentially could occur. No significant relationship was found due to low variability between observed and pseudo-absence points. Data presented in Figure 5.

Mixed effects logistic regression model for habitat characteristics					
Fixed Effects	**Estimate**	**SE**	**95% CI**	**z value**	**Pr (>|z|)**
Intercept	17.67	9.52	3.7x10^-1, 5.9x10^15	1.856	0.0635
Depth	-0.44	6.15	3.7x10^-6, 1.1x10^5	-0.071	0.9432
Distance	-0.01	0.18	6.9x10^-1, 1.4x10^0	-0.066	0.947
Random Effects		**Variance**	**±SD**		
Turtle ID (n = 128)		14362	119.8		

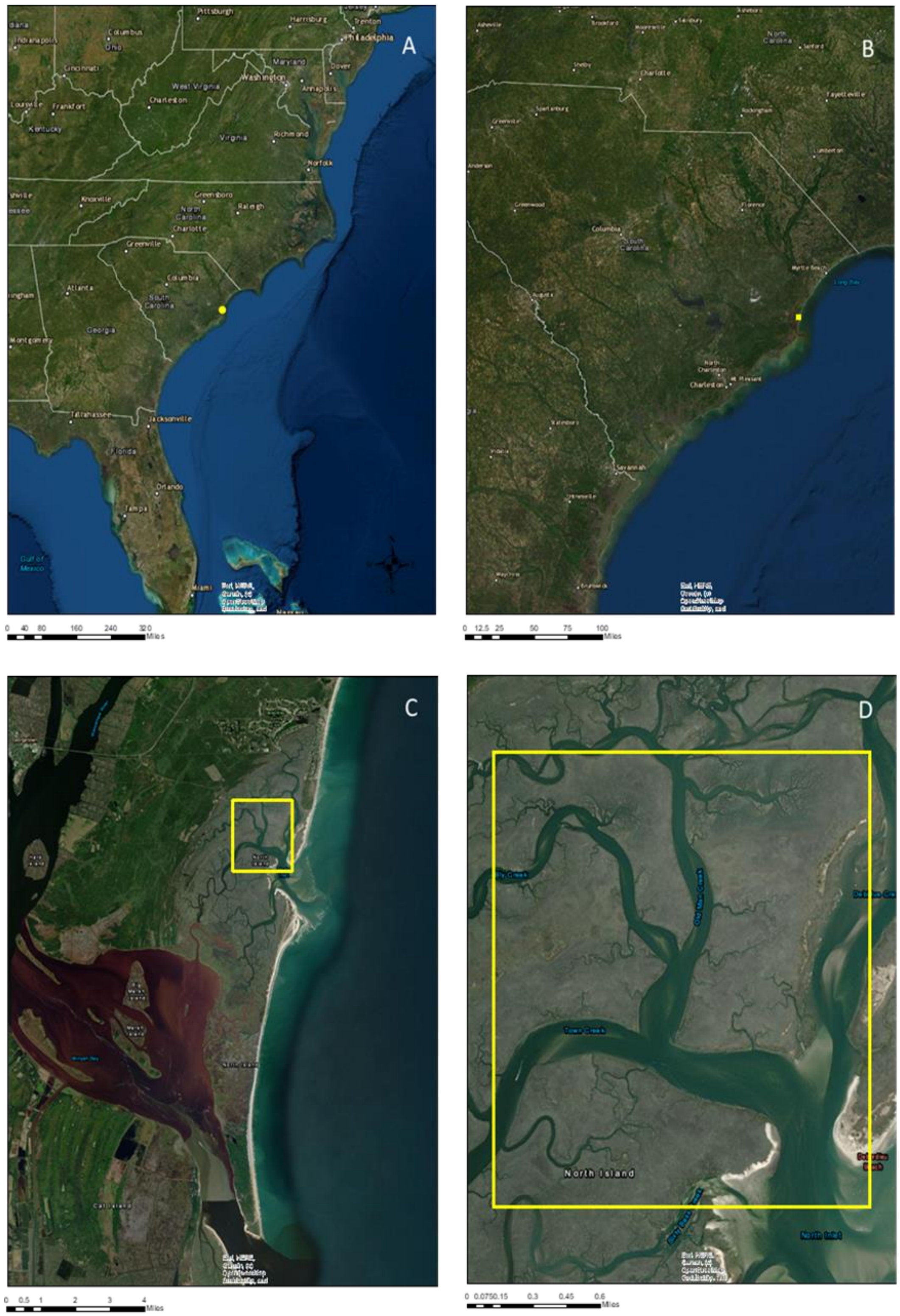
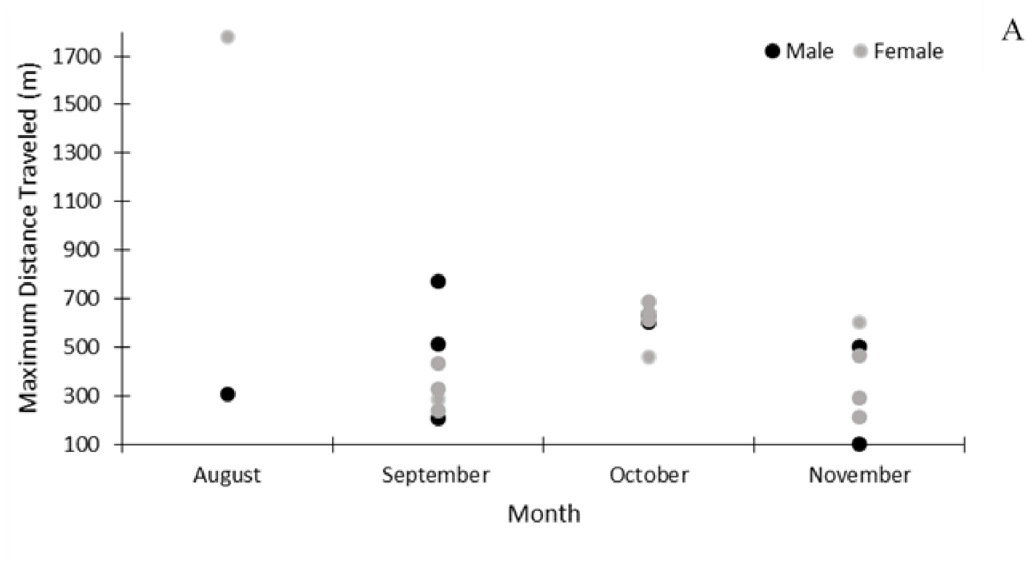


Figure 1. Study area located in North Inlet, Winyah Bay, Georgetown, South Carolina (A-D).



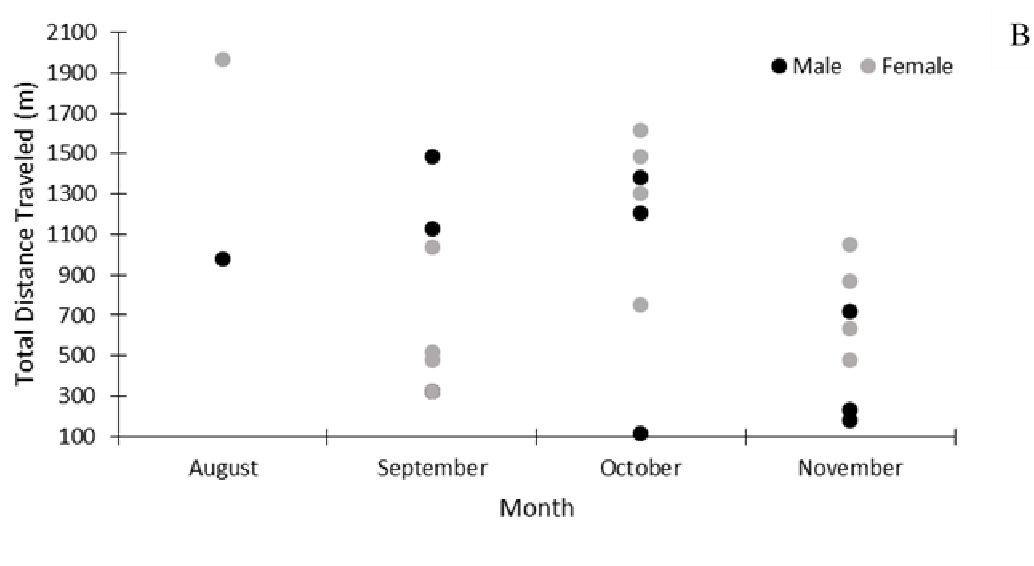


Figure 2. Maximum distance traveled (A), calculated as the distance between the farthest two marked locations, and total distance traveled (B), calculated as the distance measured from the first observation until the last observed location, through the months of August and November of males and female Terrapins (n=7) in North Inlet, Winyah Bay, Georgetown, SC.

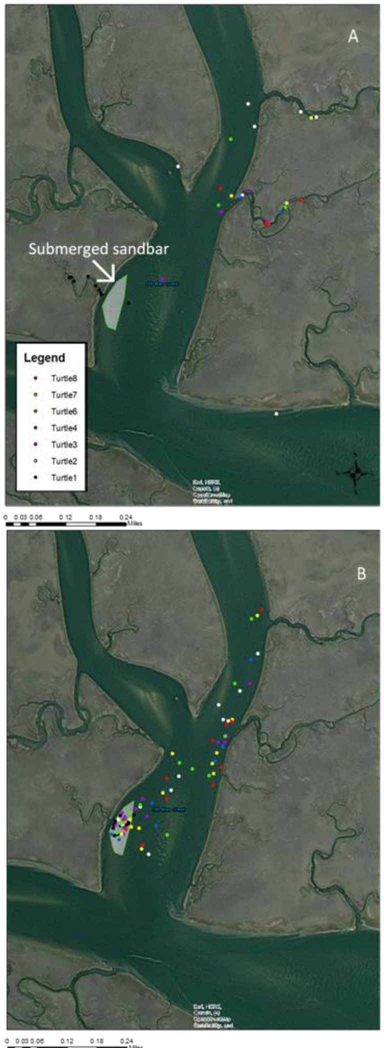


Figure 3. Locations of radio-tagged Diamondback Terrapins (*Malaclemys terrapin*) (n=120 observations) in North Inlet, Winyah Bay, Georgetown, South Carolina during August/September (A) (n = 36) and October/November (B) (n = 84). Colored circles indicate location of individual radio-tagged Terrapins (n = 7). Locations of three microhabitats were observed (main tidal creek (n = 62), secondary tidal creek (n = 25), and the sandbar (n = 33)). Location of submerged sandbar noted with polygon (A). No sandbar observations noted in late summer (A) and no secondary tidal creek observations noted in the fall season (B). A majority (n = 51) of main tidal creek observations were during the fall season (B).

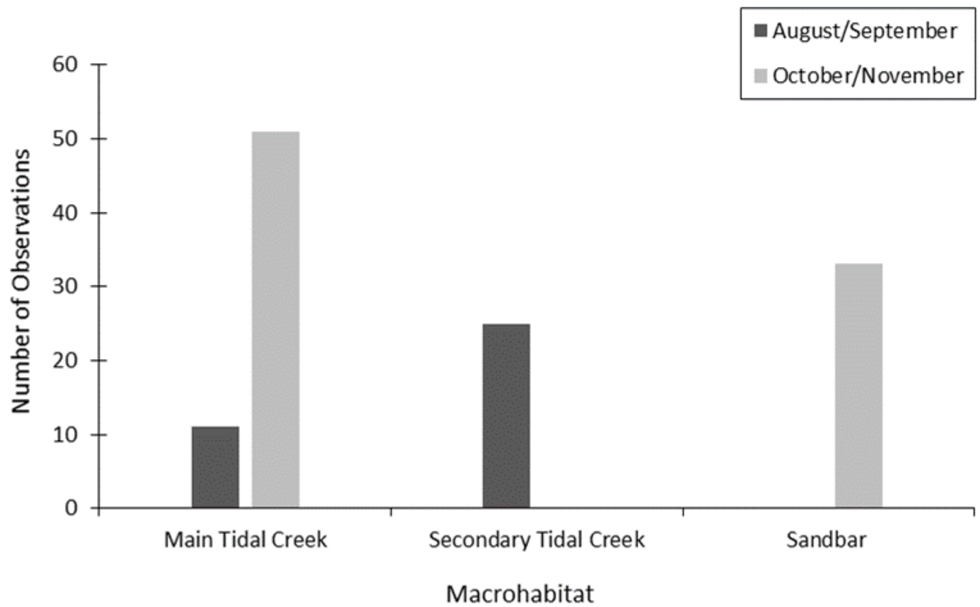


Figure 4. Frequency of observations of radio-tagged Diamondback Terrapins (*Malaclemys terrapin*) as a function of macrohabitat (main tidal creek, secondary tidal creek, and sandbar) and season (August/September and October/November) in North Inlet, Winyah Bay, Georgetown, South Carolina. The frequency of observations differed between seasons (χ^2 = 78.37, *df* = 2, *P* = <.0001), with the majority of Terrapin observations in October/November occurring in main tidal creeks and a submerged sandbar compared to August/September where the majority of observations were in secondary tidal creeks.

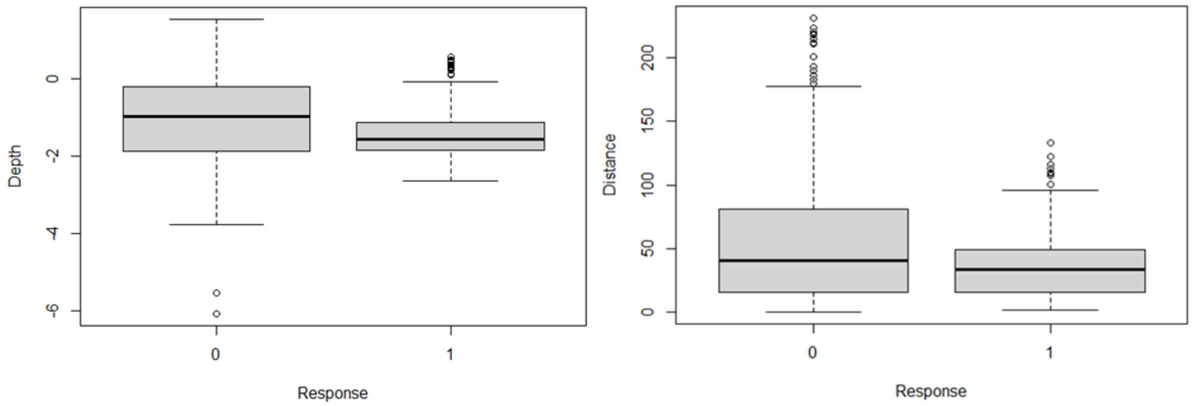


Figure 5. Terrapin presence as a function of water depth (depth) and distance to shore (distance). All Terrapin locations were included in this analysis regardless of month. For response, 0=pseudo-absence (n=1000) and 1=presence (n=128). Large standard errors and low variability were observed, resulting in no significant relationship.