A study of nesting diamondback terrapins (*Malaclemys terrapin*) at three locations in coastal New Jersey

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Chapter 1: Introduction

The Northern Diamondback Terrapin (*Malaclemys terrapin terrapin*)

Seven subspecies of terrapins (*Malaclemys terrapin* sp.) are found from Massachusetts to the Gulf of Mexico (Feinberg and Burke 2003) and the northern subspecies, *M. terrapin terrapin*, is found from Cape Code to North Carolina (Carr 1952; Palmer and Cordes 1988; Lovich and Gibbons 1990; Gibbons et al. 2001). Northern diamondback terrapins are medium sized turtles (adults males are approximately 10-14 cm and adult females are approximately 15-23 cm) with light silver-grey skin, dotted with black spots, and carapaces with smooth vertebral keels and distinct dark concentric rings (Carr 1952). *M. terrapin terrapin* have three life stages (Carr 1952; Ernst et al. 1994; Wnek 2010): Stage 1 is from a hatchling to year 1 where terrapins go form terrestrial ecosystem to the edges of brackish waters and are typically 25-38 mm Straight Carapace Length (SCL). Stage 2 as a juvenile is from 1-8 years in the open brackish water and typically 38-80 mm SCL. And finally Stage 3 is as a sexually mature adult from 5-40 years at 110-171 mm SCL and can live in the open brackish water and shorelines during reproductive seasons. Diamondback terrapins have not only a wide latitudinal range but also a wide and varied diet. Diamondback terrapins are omnivores whose diet includes bivalves, smaller fish, crabs, shrimp and marsh plants (Carr 1952; Roosenburg 1990). Northern diamondback terrapins are a sexual dimorphic species (Lovich and Gibbons 1990). Female terrapins are much larger than males in size and mass (Lovich and Gibbons 1990; Seigel 1984; Tucker et al. 1995). Female size ranges 150 mm-230 mm in SCL and male size ranges from 100 mm-140 mm (Ernst et al. 1994). Previous studies have stated a mean female mass of 705 g and a male mean mass of 242g with a 2.91 female to mass ratio (Lovich and Gibbons 1990). Females reach sexual maturity later than males, around 6 to 8 years of age at approximately 13.2 cm-17.6cm. Males reach sexual maturity around 3 to 5 years of age at 9 cm (Lovich and Gibbons 1990; Wnek 2010).

Habitat Use and Annual Reproductive Patterns

Malaclemys terrapin sp. are the only known turtle species to inhabit brackish water exclusively (Burger 1976). Terrapins can be found in estuaries, tidal marshes, wetlands and lagoons. In the study area of Barnegat Bay, New Jersey salinity ranges from 8 ppt – 32 ppt (Kennish 2001), but terrapins are commonly found in salinities from 11.3 ppt -31.8 (Sheridan 2010). Diamondback terrapins are habitat generalists that utilize both the terrestrial and aquatic habitat of an estuary for foraging, mating, nesting and hibernating (Sheridan 2010). Terrapin behavior is typically observed during the warmer months, when terrapins begin to emerge from hibernation in the spring (Yearicks et al. 1981). *M. terrapin terrapin* are usually observed out of hibernation between April and October, with nesting occurring from late May- August (Wood and Herlands 1997; Feinberg and Burke 2003), and hibernation occurring from November to March. However, terrapin annual activity cycle varies with latitudinal range (Ernst et al. 1994;

Bauer 2004) and as such hibernation and nesting activity times may differ, usually with terrapins being more active for longer periods of time in more temperate locations.

Nesting Behavior and Reproduction

Terrapins utilize terrestrial habitats within estuaries for basking as well as nesting. Nesting times can vary among the subspecies with the farther northern species nesting later than southern species (Burger and Motevecchi 1975; Seigel 1980; Roosenburg 1990). Although nesting behaviors may vary throughout their range (Roosenburg 1994) female terrapins typically nest in areas with high sand composition (Roosenburg 1990). Female diamondback terrapins often nest in areas of little vegetation and direct sunlight, sometimes associated with disrupted sites or residential areas (Kolbe and Janzen 2002). During nesting season it is important for terrapins to nest above the mean high tide line to avoid inundation of the nest with water (Burger and Montevecchi 1975; Roosenburg and Place 1995). Weather and time of day may influence emergence times of nesting terrapins (Feinberg and Burke 2003). *Malaclemys terrapin* sp. exhibits a high probability to return to the same nesting habitat within a single nesting season or over multiple seasons and years (Burger 1977; Roosenburg 1990).

Clutch Size and Number

Adult female terrapins may nest multiple times within one season (Burger and Montevecchi 1975; Feinberg and Burke 2003; Wnek 2010) and may lay up to three clutches per season (Roosenburg and Dunham 1997). Studies have discussed the reproductive characteristics of *M. terrapin* sp. through female morphometrics (body size), clutch size, and hatching success (Burger 1977; Wnek 2010). Mating in terrapin populations has not been studied as extensively as nesting but it is thought that mating occurs in early spring (Seigel 1984; Zimmerman 1992). Female terrapins have a low reproductive rate as they only lay one or up to a few clutches per nesting season (Burger 1977; Roosenburg 1990; Sheridan 2010) and the number of eggs per clutch vary among subspecies (Roosenburg 1990; Allman et al. 2012). Typically egg size decreases with increasing latitude but mean clutch size increases (Seigel 1980). Previous studies in New York reported the mean clutch size of 10.9 eggs (Feinberg and Burke 2003), in NJ the mean clutch size was 9.76 eggs (Burger and Montevecchi 1975) and in Florida the mean clutch size was 6.7 eggs (Seigel 1980). Recent studies have reported larger clutch sizes in NJ (Wnek 2010) and in Maryland (Roosenburg and Dunham 1997) indicating more studies are needed to determine reproductive variations geographically. *M. terrapin* sex determination is temperature dependent where females are produce in temperatures above 25°C (Roosenburg and Place 1995). In nests eggs exchange water, heat, carbon dioxide and oxygen with other eggs and with the sand (Ralph et al. 2005). Egg size among clutches within a population varies although there is little variation within a clutch (Roosenburg and Dunham 1997). Hatching success is defined has the number to hatchlings to successfully survive in the nest (Burger 1977). Hatching success of terrapin nests is affected by gas exchange, temperature, rainfall, inundation, and predation (Roosenburg and Kelley 1996; Wnek 2010). The hatching success of relocated nests depends on how quickly and cautiously the nest is moved and to where the nest is relocated (Wnek 2010). Hatching emergence occurs in the late summer to early fall typically (Burger 1976) with a mean emergence of 76.2 days for eggs laid in NJ (Burger 1977). Some hatchlings may overwinter in nests and emerge the following spring (Wnek 2010).

Terrapin Predation and Mortality

In coastal and island systems the influence of certain predators may by exaggerated due to additional food sources accompanied with human activities, such as food waste, and land use (Leighton et al. 2008). Predation upon terrapins occurs throughout their lifecycle. Turtle species typically congregate in small areas to nest and predators take advantage of these seasonal resources (Marchand 2002; Rodewald and Gehrt 2014). Terrapins are preyed upon by a wide range of fauna within the species' geographical range (Hackney et al. 2013). Nests and hatchlings are predated upon by flies (*Tripanurga importuna*), birds such as the American Crow (*Corvus brachyrhynchos*), and mammals such as foxes (*Vulpes vulpes*) and raccoons (*Procyon lotor*). Within nests eggs are at risk to vegetation and fungi (Auger and Giovannone 1979; Zimmerman 1992; Roosenburg and Place 1995; Butler et al. 2004). Although vegetation on sand dune habitats acts to stabilize substrate it increases the possibility of roots penetrating eggs (Burger and Montevecchi 1975). Generalist predators such as the raccoon prey upon all terrapin life stages and are considered the most impactful predator of turtles in North American (Ernst et al. 1994). Female terrapins have a higher mortality rate than males as they must travel to mate and nest. These actions expose them to not only predation but to capture and road mortality (Hackney et al. 2013). Anthropogenic actions that lower survival rates or fitness of adult terrapins are capture and death in crab traps (Seigel 1984; Tucker et al. 1995; Roosenburg et al. 1997; Wood and Herlands 1997), mortality on roads (Boyle and Samson 1985; Szerlag and McRobert 2006, 2007, 2009) and habitat alteration or loss (Wood and Herlands 1997; Sheridan 2010). Turtle populations are slow to react to predation and anthropogenic disturbance due to their high juvenile mortality and late maturity.

Human and Terrapin Conflicts

In the 1800s to early 1900s diamondback terrapins were considered a popular delicacy and populations greatly declined (Graham 2009). Today diamondback terrapins face other human threats such as morality due to human recreation and vehicles, and habitat fragmentation or destruction (Joyal et al. 2001; Taylor and Knight 2003; Szerlag and McRobert 2006, 2007, 2009). Human recreation has been observed to impact the behavior of a variety of tax and influences nesting behavior of turtles (Boyle and Samson 1985; Taylor and Knight 2003; Kerlinger et al. 2013). The highest boating densities occur in estuaries and since terrapins live exclusively in brackish water this poses threats to terrapin populations (Lester et al. 2011). Lester et al. reported that terrapins generally do not behavior respond to boating sounds which may impact their survival in areas of high boating (2011). Terrapins that inhabit these areas are vulnerable to female biased wildlife-vehicle collisions or road mortalities (Szerlag and McRobert 2006; Crawford et al. 2014). The natural configuration of coastal shorelines is being altered by beach raking, recreational activities, beach nourishing, pollution, coastal development and engineering and climate change (Defeo et al. 2009; Wnek et al. 2013).

Rationale and Objectives

For diamondback terrapins adult survival and fitness are extremely important in maintaining a population. Diamondback terrapins were a delicacy in the late 1800s and early 1900s (Carr 1952) and populations were severely depleted. It is uncommon now for people in the United State to harvest terrapins for cuisine it is common for them to be collected for the pet trade (Avissar 2006). Although terrapin populations have since begun to increase many states list their protection or game status differently (Wnek 2010). Listings range from no listing to game listing, Species of Special Concern, Threatened, or Endangered. NJ lists the terrapin as a Species of Special Concern, but also as a game species. As of March 2015 the NJ Department of Environmental Protection closed terrapin harvesting season but there is still deliberating about what the species should now be classified under (NJDEP 2015). Habitat alteration and loss is the primary cause for the loss of biodiversity worldwide and presents overwhelming conservation issues at numerous ecological levels (Sheridan 2010). Terrapins have been studied in NJ since the 1970’s it is still difficult to estimate the population size. Additionally terrapins have never been formally studied on Long Beach Island until this study.

Study Area

Along the coast of Ocean County, NJ is Barnegat Bay, an estuary and largest body of water in the state. Barnegat Bay is approximately 70 km long and its watershed is 660 square miles (SBB 2015). Throughout Barnegat Bay terrapins are found in habitat areas undisturbed by human influences and in residential areas (Epperson 1990). Terrapins that are found in these undisturbed habitats are typically protected from development by local, state and federal parks, refuges, and reserves. However, the NJ coast consists of barrier island peninsulas that serve as vacation destinations for thousands of people each year and terrapins often nest in areas influenced by development. During the summer months Barnegat Bay, NJ has one of the highest densities of recreational boating in the world (BBNEEP 2002) and the lack of behavioral responses to human activities is potentially very hazardous as terrapins are commonly injured or killed by motorized vehicles and boats (Lester and Avery 2011). Although it has been reported that terrapin emergence is not influenced by human presence it is known that terrapin nesting location is. Nesting females will attempt to emerge at their fidelic nest sites however, when these sites are altered it causes a change in nesting behavior (Winters 2013).

Barnegat Bay contains three separate ecological locations: Long Beach Island (LBI), North Sedge Island (NSI) and the Edwin B. Forsythe National Wildlife Refuge (EBFNWR). Terrapins are known to live and nest in each of these regions (www.terrapinnestingproject.com; Sheridan 2010; Wnek 2010; Basile et al. 2011; Winters 2013). However, as habitat fragmentation increases within Barnegat Bay the available nesting habitat is decreasing (Sheridan 2010; Winters et al. 2015). LBI is approximately 30 km long, heavily developed and is a popular vacation area. LBI is home to over 20,000 year round residents and over 100,000 residents during the summer months (SOCCC 2014). NSI is a larger island within the Sedge Islands Wildlife Management Area. It is managed by the NJ Division of Fish and Wildlife within the Marine Conservation Zone. NSI is comprised primarily of salt marsh with bay access on the north and east sides. NSI is comparatively untouched by humans except for small groups that visit the island for educational or recreational activities. EBFNWR is located in southern NJ on the inland side of Barnegat Bay. EBFNWR is located on the inland side of Barnegat Bay and includes more than 47,000 acres of southern NJ coastal habitats (USDOI 2015). While it is known that terrapins live in each of these regions, there is little documentation of nesting habits and reproductive outputs of these terrapin populations.

M. terrapin may be impacted by anthropomorphic influences (Blanvillain et al. 2007; Basile et al. 2011), such as dredging and filling of marsh habitat, human development on terrestrial nesting habitat, shore line stabilization projects (i.e. bulkheading) along the edges of terrestrial nesting and marsh habitat, and boat traffic in aquatic habitats (BBEP 2001, 2002, 2003; Sheridan 2010). Due to the presence of anthropogenic influences on LBI and NSI, and the lack of anthropogenic influences on EBFRNWR, as well as the presence of *M. terrapin*, these sites were selected for this study. It has been documented that the life history characteristics of *M. terrapin* varies throughout their geographical range (Burger 1977; Seigel 1984; Lovich and Gibbons 1990). Differences in body size, nesting behavior, and reproductive output have all been identified throughout different latitudes in the United States (Zimmerman 1992; Tucker et al. 1995; Bowen and Janzen 2008; Graham 2009; Wnek 2010). Terrapins are vulnerable to human impacts due to their longevity and low reproduction rates and as such it is important to conduct more studies about local populations in order to better understand their life history traits (Burger 1976). It is unknown whether life history characteristics of terrapins in NJ differ with latitude exposure to varying levels of anthropogenic influences. Identifying differences between populations will allow for more focused monitoring efforts in high density nesting areas and improved management practices for future researchers.

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Chapter 2: Northern Diamondback Terrapin (*Malaclemys terrapin terrapin*) Population Study on Long Beach Island, NJ

Abstract

The northern diamondback terrapin, *Malaclemys terrapin terrapin* has been documented nesting on barrier islands throughout the state of New Jersey. Long Beach Island (LBI), a barrier island peninsula in Ocean County, NJ has known terrapin nesting sites that are in both natural and residential areas. LBI is a vacation destination for tens of thousands of people each summer, which coincides with terrapin nesting season. However, until the present study, there was no formal documentation or data concerning nesting females, nesting behavior, or habitat use on LBI. This study collected descriptive data on *M. terrapin terrapin* populations at the north and south ends of LBI. We identified 125 females; 90 of which were newly identified. Landing dates ranged from June 8 - July 18 and occurred between 1000h and 1300h. On north LBI the mean distance of a nest to the center-line of a road was 31.7 m (± 13.7) and the mean distance of a nest to the nearest point of water was 76.0 m (± 11.1). On south LBI the mean distance of a nest to center-line of a road was 86.7 m (± 7.8) and the mean distance of a nest to the nearest point of water was 365.94 m (± 22.0). We determined that most nesting occurred where terrapins had land access associated with a soft shoreline. On north LBI the mean clutch size was 13.04 (± 0.25) eggs with a 91% hatching success rate. On south LBI the mean clutch size was 11.78 (± 0.35) eggs with a 95% hatching success rate. There was a significant difference between clutch sizes of north and south but not for hatching

success. Morphometric measurements were only recorded for females on the north end of LBI where there was a mean straight-carapace length (mm) of 197. 23 (± 2.02), a mean plastron length (mm) of 174.89 (± 1.65), and a mean mass (g) of 1156.15 (± 25.5).

Introduction

The northern diamondback terrapin, *Malaclemys terrapin terrapin* is the only turtle species known to inhabit brackish water exclusively (Burger 1976). *M. terrapin terrapin* is an estuarine emydid turtle with a geographical range from Massachusetts to the Gulf of Mexico (Feinberg and Burke 2003). Terrapins nest on barrier islands or habitat patches that accumulate sand (Burger and Montevecchi 1975; Roosenburg 1994), and they have also been known to nest on anthropogenically impacted areas such as the sides of roadways, construction sites and residential areas (Epperson 1990; Szerlag and McRobert 2007; Wnek 2010). Long Beach Island (LBI) (Figure 1), a barrier island peninsula in Ocean County, NJ has known terrapin nesting sites that are in both natural and residential areas (Figure 2). As previous studies throughout the state of NJ have assessed and demonstrated that distinct *Malaclemys terrapin terrapin* populations exist and may be influenced by human development, Long Beach Island (LBI), halfway down the coast of NJ, was an ideal research site to learn more about terrapin nesting and how it is influence by the surrounding environment. LBI is a vacation destination for tens of thousands of people each summer, which coincides with terrapin nesting season. However, until the present study, there was no formal documentation or data concerning nesting females, nesting behavior, or habitat use on LBI. For these reasons, this study sought to characterize nesting females on LBI by measuring the following variables: (1) female body size and mass, (2) mark and recapture rates, (3) peak nesting activity, (4) nesting sites and (5) clutch size and hatching success. This work will set the stage by establishing a baseline so that future work can determine the magnitude of affects that human activity may have on *M. terrapin terrapin* habitat and behavior.

Terrapin size varies with geographical latitude (Carr 1952; Burger and Montevecchi 1975; Burger 1977; Palmer and Cordes 1988; Lovich and Gibbons 1990; Roosenburg and Place 1995; Roosenburg and Kelley 1996; Gibbons et al. 2001; Kolbe and Janzen 2002; Feinberg and Burke 2003; Wnek 2010). Northern diamondback terrapin female size ranges from 150 mm to 230 mm in straight-carapace length (SCL) (Ernst et al. 1994). A study in Tuckerton, NJ found a mean SCL of 175 mm and straight-plastron length (SPL) of 158 mm (Szerlag and McRobert 2006). Female terrapins in South Carolina have a reported a SPL of 148 mm and a mean mass of 242 g (Lovich and Gibbons 1990).

Nest site fidelity is another important attribute of the terrapin population under examination. Based on several mark-recapture studies, it has been shown that terrapins exhibit nest site fidelity (Roosenburg 1996; Szerlag and McRobert 2007; Wnek 2010). *Malaclemys terrapin terrapin* exhibits a six-week nesting season from June to July (Burger and Montevecchi 1975). Factors that are believed to influence nest site selection are soil particle sizes, presence of vegetation and solar exposure (Feinberg and Burke 2003). Previous studies have reported terrapin nesting occurring during maximum sun exposure (Burger and Montevecchi 1975). Female diamondback terrapins typically nest in areas of little vegetation and direct sunlight usually associated with disrupted sites or residential areas (Kolbe and Janzen 2002). Diamondback terrapins are habitat generalists that utilize both the terrestrial and aquatic habitat for foraging, mating, and nesting (Sheridan 2010). Although nesting behaviors may vary throughout their range (Roosenburg 1994) female terrapins characteristically nest in areas with high sand composition, soft shore line, and may lay multiple clutches within one season (Burger and Montevecchi 1975; Feinberg and Burke 2003; Wnek 2010; Winters 2013). Variations in clutch size have been documented in different terrapin populations. Additionally, a single female will typically lay one clutch but not more than a few per nesting season, causing a very low reproductive rate (Burger 1977; Sheridan 2010). Specific clutch laying frequencies vary with location. *M. terrapin terrapin* may lay up to three clutches in a single season (Roosenburg 1991) although *M. terrapin terrapin* individuals in New York have been observed to lay only two clutches per season (Feinberg and Burke 2003). Typically, egg size decreases with increasing latitude but mean clutch size increases (Seigel 1980). Previous studies in New York reported the mean clutch size of 10.9 eggs (Feinberg and Burke 2003), while in NJ, the mean clutch size was 9.76 (Burger and Montevecchi 1975). Recent studies have reported larger clutch sizes in NJ (Wnek 2010) and in Maryland (Roosenburg and Dunham 1997), indicating more studies are needed to determine reproductive variations geographically. Hatching success is defined as the number of hatchlings to successfully survive in the nest (Burger 1977). Variation in nest survivorship (Burger 1976; Butler et al. 2004) and hatching success (Wnek 2010) may be affected by temperature and rainfall. Sand is an ideal substrate as different volumes of water are retained in different substrate and soil types thus affecting gas and water exchange between the eggs (Packard et al. 1987; Packard and Packard 1988b; Cagle et al. 1993). Nests are at risk of vegetation growing into eggs, fungi using the eggs are a nutrient source, and predators such as sarcophagid flies (*Tripanurga importuna*), crows (*Corvus brachyrhynchos*), foxes (*Vulpes vulpes*), and raccoons (*Procyon lotor*) (Auger and Giovannone 1979; Zimmerman 1992; Roosenburg and Place 1995; Butler et al. 2004).

Terrapins are vulnerable to human impacts due to their longevity and low reproduction rates (Burger 1977; Seigel 1984; Lovich & Gibbons 1990; Zimmerman 1992; Tucker et al. 1995; Bowen and Janzen 2008; Graham 2009; Wnek 2010; Winters 2013) and as such it is important to conduct more studies about local populations in order to better understand their life history traits (Burger 1976). Information on their status in NJ is very limited, and nesting areas and threats to their survival have not been fully identified. We sought to bridge this gap in knowledge by characterizing nesting females on LBI. Specifically, the objectives of our study were to measure the following variables: (1) mark and recapture rates, (2) female body size and mass, (3) peak nesting activity, (4) nesting sites and (5) clutch size and hatching success.

Materials and Methods

Study sites and field sampling methods

Data were collected from field sites located along the coast of LBI, NJ (Figure 1.0). LBI is approximately 30 km long and is located on the southern portion of the barrier islands of NJ. It separates the Atlantic Ocean from Barnegat Bay. The Atlantic side is developed for residential use and the bay side has residential development, commercial marinas and boat ramps. Terrapin nesting was monitored on LBI in two areas where locals have documented nesting activity: 1) the northern end in Barnegat Light and

2) the southern end in Holgate. At LBI, data were obtained during the 2014 nesting season from late May through late September. Daily surveys were conducted simultaneously and continuously during daylight hours at LBI. Two separate patrol groups were employed, one in each of the designated areas. Each group followed nesting females at a distance to minimize the potential of disturbing individuals. Investigator location and terrapin activity were recorded continuously. To obtain more detailed information regarding the nesting female terrapins a set number were captured by hand. Dates, times (EST) and landing locations for all captured terrapins were recorded. Females were palpated to determine if they were gravid at time of capture. Data were recorded on standardized data sheets and collected daily. The handing of turtles was in accordance with the permits allocated to Dr. Wnek by the NJ Division of Fish and Wildlife and all turtles were released at the site of encounter.

Mark-Recapture

Upon encountering nesting females, each was identified using a pre-established carapace notch code which was checked for the presence of a Passive Integrated Transponder (PIT) using a BioMark® portable reader. If no notches were observed the marginal scutes on all female terrapins were notched as an additional form of identification (Cagle 1939; Wnek 2010; Gibbons 1990). If no tag was detected at the time of capture then individuals were injected with 12 mm PIT tags that contained nine or ten alphanumeric characters (Wnek 2010; Buhlmann and Tuberville 1998). The dual method of identification aids in determining the presence of injuries or of previous injuries (Szerlag and Mcrobert 2006).

Morphometric Measurements

Morphometric measurements were taken from each captured nesting female to determine weight, carapace length and width, and plastron length only at the north LBI site. Terrapins were weighed (g) using an Ohaus® digital balance (model 2000, ± 1g). Straight line carapace length (mm), carapace width (mm), carapace height (mm) and plastron length (mm) was measured using a 40 cm tree caliper (Wnek 2010; Gibbons et al. 2001).

Nest Location

Nesting site was recorded using a Global Positioning System (GPS) device. Before a nest was relocated the GPS coordinates were recorded on a datasheet. A description of the surrounding environment was also obtained.

Nest Relocation and Nest Excavation

Terrapin nests that were laid in areas with high human activity (i.e., walking areas, kayak launch locations, and residences) were excavated and relocated to hatcheries with a sand substrate. The hatcheries on LBI are steel framed dog kennels with closing doors. On LBI the northern hatcheries are 3x3m and on the southern end the hatchery is 3x1.5m. When relocating a nest the number of eggs was recorded. Eggs were transported in containers with sand without changing egg orientation. Clutch relocation followed the protocol previously described by the Terrapin Nesting Project 2013. During nest excavation, the presence of hatchlings and undeveloped eggs were determined. Nests that have not hatched after incubating for 60 days within hatcheries were under constant watch. If a hatchling was seen on the surface, it was immediately removed. If a nest had the presence of sarcophagid flies (*Tripanurga importuna*) it was immediately excavated.

Predators to species were identified when possible, using direct observation, tracks, nest scars, or scat (Feinberg and Burke 2003).

Statistical Analysis and GIS

Data from the 2014 nesting season for LBI were analyzed and mapped. Nests that were depredated, missing data or in which the excavation results were unclear were excluded from data analysis. As there is a possibility that *M. terrapin* individuals may be encountered in all areas on maps generated, these data shows only the nests that were identified during surveys. Survey techniques and location protocols would not affect results. Sampling methods were unbiased in terms of body and clutch size as all encounters occurred once a terrapin had landed on shore and surveyors were witness to a natural process.

Statistical Analysis

Statistical analysis was performed using IMB© SPSS© Statistics Version 21. Means and standard errors were calculated for Straight-carapace-length (SCL) and straight-plastron-length (SPL) were compared to clutch size using a linear regression. Clutch size of North and South LBI were compared using t-test and all assumptions of normality and heteroscedasticity were met.

GIS

Geographic Information Systems (GIS) were used to document patterns of nest placement on LBI. GIS was additionally used to identify areas where nests might be clustered, particularly if those areas are close to altered coast lines, human structures or were at risk from tidal inundation due to the effects of tropical storms and hurricanes. Maps were developed using NJ Department of Environmental Protection Geographic

Information System digital data, but this secondary product has not been verified by NJDEP and is not state-authorized. A GIS a label was assigned to each occurrence that describes the occurrence type (i.e. nest, sighting or road mortality).

In order to analyze the results, the study defines the following variables for statistical analysis. For this study 'Nest' is defined as an area of known nesting by evidenced of egg(s), egg shell fragments, or by the presence of actively ovipositing females. 'On Road' is defined as individual(s) observed on a road and 'Occupied Habitat' is defined as a sighting of a live individual(s) or physical evidence of deceased terrapins. The distance to the nearest water and road centerline (the road layer used is based on line features, which are typically located at the center of the road, so the true distance to the road edge is less than the figure provided) was calculated by the GIS tool 'Near'. 'Near' was also used to calculate distances of point to shoreline types. 'Shoreline Types' are defined as follows; 'Beach' included waterfront areas as comprised of 100% sand, 'Bulkhead' included man-made structures at the water's edge, after the rip-rap, which were designed to hold back water and protect the adjacent areas from erosion, 'Earthen Dike' are structures which served as natural barriers between the land and the water, 'Erodable' included any soft shoreline other than beach, rock, marsh, or earthen dike, which were vulnerable at the water's edge, 'Marsh' is classified as areas of natural marsh edge, and 'Open water' was used in areas where the shoreline plot crossed over creek and canal entrances. To determine land ownership, land use/land cover, and description of land use/land cover at the location of the point feature the GIS tool 'Identify' was used.

The GIS data used in this study came from the The Land Use/Land Cover 2012 Update, Edition 20150217, is the fifth in a series of land use mapping efforts that was begun in 1986. Revisions and additions to the initial baseline layer were done in subsequent years from imaging captured in 1995/97, 2002, 2007 and 2012. This present 2012 update was created by comparing the 2007 LU/LC layer from NJDEP's Geographic Information Systems (GIS) database to 2012 color infrared (CIR) imagery and delineating and coding areas of change. Work for this data set was done by Aerial Information Systems, Inc., Redlands, CA, under direction of the NJ Department of Environmental Protection (NJDEP), Bureau of Geographic Information System (BGIS). LU/LC changes were captured by adding new line work and attribute data for the 2012 land use directly to the base data layer. All 2007 LU/LC polygons and attribute fields remain in this data set, so change analysis for the period 2007-2012 can be undertaken from this one layer. The classification system used was a modified Anderson et al., classification system. An impervious surface (IS) code was also assigned to each LU/LC polygon based on the percentage of impervious surface within each polygon as of 2007. Minimum mapping unit (MMU) is 1 acre (NJDEP 2/17/2015).

The NJDEP Shoreline Typing for Coastlines of NJ Along Its Atlantic and Inland Bays shoreline type project involved the identification and coding of the entire NJ shoreline within the Coastal Areas Facilities Review Act (CAFRA) zone from Keyport to Hieslerville (NJDEP 1993). The data were used to delineate different shoreline classifications based on particular landforms.

NJDEP State Owned, Protected Open Space and Recreation Areas in NJ dataset (Version 200812) contains protected open space and recreation areas owned in fee simple interest by the State of NJ Department of Environmental Protection (NJDEP). Types of property in this data layer include parcels such as parks, forests, historic sites, natural areas and wildlife management areas. The data were derived from a variety of source maps including tax maps, surveys and even hand-drafted boundary lines on USGS topographic maps. These source materials vary in scale and level of accuracy. Due to the varied mapped sources and methods of data capture, this data set is limited in its ability to portray all open space lands accurately, particularly the parcels purchased prior to 1991(NJDEP 1995).

Road Centerlines of NJ, NJ State Plane NAD83 data set was provided by the NJ Office of Information Technology (OIT) and Office of GIS (OGIS) which has enhanced the previously published NJ Department of Transportation (DOT) Roadway Network GIS dataset to create a fully segmented Road Centerlines of NJ feature class. This dataset includes fully parsed address information and additional roadway characteristics. It provides the geometric framework for display and query of relevant non-spatial data published as separate tables that can be joined to the feature class. The enhancement process included integration of multiple data sets, primarily those developed and maintained by county agencies in NJ and the US Census Bureau (NJOIT and OGIS 2015)

Results

Mark-Recapture

A mark-recapture study was conducted to identify nesting female terrapins. The mark-recapture study observed 128 females on LBI (Table 1) and noted 140 confirmed nests. Of these 107 females on North LBI were included in the mark-recapture study (Table 1). In the population of the 128 females studied, there were 35 previously tagged females and 90 newly tagged females in the 2014 season. Out of the 35 previously tagged individuals, three were encountered on the island more than once. Out of the 90 newly tagged females, seven were known to have returned to LBI during this nesting season. These seven females were all encountered on the north end of LBI. No newly tagged females on the southern end were encountered more than once. Notably, 15 females on the north end and three females on the south end had injuries, or evidence of previous injuries typically associated with boat encounters (Lester et al. 2013). On north LBI out of the 140 nests (Figure 3), 117 nests were relocated into the hatcheries for protection. When all space was occupied within the hatcheries, nests were placed outside the hatcheries in the surrounding sand; this was done for the remaining 23 nests. Comparing the observed population on North LBI of 110 nesting females to the 140 nests implies that there were some individuals who nested more than once, or some females who nested were not tagged by this study. Our mark-recapture study females identified in the north were never observed or encountered in the south and vice versa. This may indicate that on LBI the nesting female terrapins identified in this study are from two distinct populations but further studies must be conducted each year and over a longer period of time to account for travel time between sites.

Nest Timing and Location

Landing dates on LBI ranged from June 8 through July 18, 2014 (Figure 4). The most terrapin encounters occurred on June 26, with other peak encounter days being June 13, June 30, and July 3. Nesting peaks occurred on or around the full and new moons. Most terrapin encounters occurred between 1000 h and 1300 h (Figure 5), with peak encounter time being 1245 h. The earliest time a female was encountered was 0700 h and the latest time a female was encountered was 1700 h.

On north LBI GPS points were obtained from a total of 136 confirmed nests. On north LBI the mean distance of a nest to center line of roads was 32.7 m (± 5.0). The mean distance of a nest to the nearest point of water on north LBI was 79.6 m (± 4.0) (Figure 6). When analyzing land use/land cover, 113 nests occurred on residential properties (Figure 7). Four occurred on beach or waterfront areas comprised of 100% sand. Two nests occurred in marsh area, one in a dredged lagoon, and two on NJ Parks and Forestry land. On the north end of LBI the highest nesting density occurred along Bay View Avenue (between 26th Street and 23rd street) and on Sunset Blvd (Figure 12; Appendix Figure 1; Appendix Figure 2). When analyzing the nearest shore line type, 54 nests occurred on shorelines classified as erodible (Figure 8). There were 41 nests in areas classified as natural marsh edge, 33 nests that were on beach and water front areas, and 8 nests were closest to bulkhead areas.

On south LBI there were a total of 46 confirmed nests where GPS points were obtained. On the south LBI the mean distance of nests to the center line of roads was 27.3 m (± 2.4). On the south end of LBI the mean distance of a nest to the nearest point of water was 110.5 m (± 6.9) (Figure 9). When analyzing land use/land cover, 36 nests occurred on residential properties (Figure 10). Seven nests occurred on areas classified at salt marsh. All encounters occurred on private land. The area on the south end of LBI that had the highest nesting density was between Nelson Ave. and W Marshall Ave. (Figure 12; Appendix Figure 3). When analyzing the nearest shore line type 29 nests occurred closest to bulkhead areas. Four nests occurred on beach and 13 nests occurred on erodible shore line (Figure 11.0). There was no significant difference between north and south in the nesting distance to roads (n=182, p=0.781, $U_{0.64, 2147.6}$ =32140.0, $p > 0.05$, Mann-

Whitney U-test) but there was a significant difference between north and south in the nesting distance to water (n=182, *p*=0.000, $_{F\ 0,259.0}$=.646, $p < 0.01$, Independent Samples t-test).

Clutch Size and Hatching Success

The mean clutch size at LBI was 12.1 (± 0.21) eggs. The north (n=114) had a mean clutch size of 13.0 (± 0.25) eggs and the south (n=46) had a mean clutch size of 11.8 (± 0.35) eggs (Table 2). There was a significant difference between clutch sizes of north and south LBI (n= 160, *p*=0.005, $F_{7,21}$=.628, $p < 0.01$, Independent Samples t-test). On the north end of LBI 15 nests were depredated, six of which were depredated by crows. Eggs and hatchlings were also depredated by *Tripanurga importuna* (pers. obs). On the north end of LBI 129 eggs had maggots present. This value is unknown for southern LBI nests. Despite the depredation on eggs and hatchlings, the northern hatcheries had a 91% hatch success rate, and the south hatchery had a 95% hatching success (Table 3). There was no significant difference in between north to south (n=160, *p*=1.0, Fishers Exact Test).

Morphometric Measurements

Morphometric measurements were only recorded for females on the north end of LBI. There was a mean straight-carapace length (mm) of 197. 23 (± 2.02), a mean plastron length (mm) of 174.89 (± 1.65), and a mean mass (g) of 1156.15 (± 25.5) (Table 4). The smallest female that nested on LBI had a mean SCL of 156 mm, a SPL of 138 mm and weighed 522 g. There were positive correlations between Straight Plastron Length (mm) to mass (g) (n=100, $p < 0.001$, $F_{502.78,\ 1650.3}$= 293.99, r^2 =0.75m, linear regression), Straight Plastron Length (mm) to clutch size (n= 66, $p < 0.01$, F78,204=

7.479, $r^2 = 0.105$, linear regression), and Straight Carapace Length (mm) to clutch size (n=66, $p < 0.05$, $F_{156,280} = 2.522$, $r^2 = 0.038$, linear regression).

Discussion

Terrapin nesting

Although the north and south populations on LBI are 30 km apart on land, it is possible for the females to travel throughout the bay separating LBI from the main land. Our mark-recapture study showed there was no overlap in individuals encountered between the north and south ends of LBI. This is strong evidence that the females encountered are from two different nesting populations. Previous studies in NJ have demonstrated that females travel great distances (i.e., > 1 km) among areas within the same estuary system and may be encountered throughout, but only nest in specific areas (Wnek 2014; Winters et al. 2015). A terrapin's nest fidelity is what distinguishes populations apart, even if females travel within other population ranges (Tucker et al. 2001). There may be more than just these two populations on LBI as other nests were observed along the island but were not able to be included in this study (Appendix Table 1). We believe there are many more terrapin landings than identified in this study as evidence was found of depredated nests and reports of terrapins in locations outside our study areas.

Previous studies have shown that terrapins nest in higher elevations, typically above the mean high tide line, with sand substrate and limited vegetation (Burger and Montevecchi 1975; Kolbe and Janzen 2002). Interclutch nesting ranged from 14 (n=1) to 18 days (n=1). Encounter occurrence ranged from 5 days (n=1) to 31 days (n=1). The most terrapin encounters occurred on or around the full and new moons when tides were the highest. Our data is consistent with previous studies that documented the most terrapins landing occurring during 1100h and 1200h (Roosenburg 1994; Wnek 2010). However, on LBI there is a lack of sand dunes or isolated sandy beaches which results in terrapins nesting in residential areas or along sides of roads (Figure 3). Nest site selection and human impacts that may degrade nesting habitat play an important role in the future of terrapins (Roosenburg 1996; Szerlag and McRobert 2006). If site fidelity occurs, then the closure of a nesting site due to human development may have significant outcomes on individual reproductive output. Previous studies have shown that females travel greater distances to find suitable habitats when nesting areas are limited by human fragmentation (Winters 2013). This traveling increases terrapin mortality rates due to terrapin-human interactions, i.e. boat or road encounters. Limiting access to nesting habitats may decrease overall population fitness (Sheridan et al. 2010).

Terrapin Size and Hatching Success

Our data suggest that SPL (mm) varied regionally throughout the estuary system adjacent to LBI. Previous studies (Lovich & Gibbons 1990; Ernst et al. 1994; Tucker et al. 1995; Wnek 2014) have found larger clutch sizes than in this study, supporting the hypothesis that clutch size may vary geographically. These studies have reported differences in mean SPL (mm) of nesting female terrapins. Although North LBI had a greater mean SPL than length than Little Beach, NJ (39°29’ N, 74°21’W; 154.4 ± 9.9 mm SD; n=221; Burger and Montevecchi 1975) our data was not consistent with an increase in length with higher latitudes when comparing LBI to nearby North Sedge Island, NJ (39^{o}47’ N, 74^{o}07’W 172.7 ± 0.8 mm SD; n=180; Wnek 2014). The minimum plastron length for a nesting female on north LBI was 78 mm and the maximum was 204 mm. On

LBI (n=160) the minimum clutch size was 7 and the maximum clutch size was 21. There was a decrease in clutch size from north LBI to south LBI which coincides with the literature that among geographic areas there may be differences in clutch sizes (Goodwin 1994; Feinberg 2000; Feinberg and Burke 2003; Wnek 2010). On North Sedge Island there was a mean clutch size of 12.9 (± 0.8) (Wnek 2010) and on Little Beach there was a mean clutch size of 9.7 (± 2.6 SD) (Montevecchi and Burger 1975). Larger turtles typically produce larger clutch sizes than smaller turtles within the same species (Bobyn and Brooks 1994; Iverson et al. 1997). The positive correlations between SCL (mm) and SPL (mm) to clutch size at LBI is consistent with previous data (Iverson et al. 1997). Differences in clutch size may be due to variations in available resources and the metabolic costs of reproduction (Wnek 2010). The higher hatching success on south LBI may be due to less of a presence of the fly species *Tripanurga importuna*.

Conservation Implications

Estuaries with marsh or wetland ecosystems provide habitat and breeding areas for multiple species (Araujo 2002). Shoreline fauna such as piping plovers (*Charadrius melodus*), oystercatchers (*Haematropus palliates*), black skimmers (*Rynchops niger*), fiddler crabs (*Uca pugilator*), and diamondback terrapins (*Malaclemys terrapin*) rely on barrier islands for breeding (Burger 1975; Bertness 1985, Burger 1987; Lauro and Burger 1989). Barrier islands are dynamic ecosystems influenced by waves, tides, and currents. Coastal erosion causes a reduction in the size of barrier islands; major storm events can cause damage to areas that are subject to flooding (Gutierrez et al. 2009). In this study all terrapin encounter and nest sites were within the 100 year flood zone (http://www.njfloodmapper.org/). These coastal environments are highly threatened in the United States as shorelines in NJ are also utilized by humans causing further need for stabilization projects (Greenberg et al. 2006). The natural configurations of coastal shorelines are being altered by engineering, development, and recreational activities (Defeo et al. 2009; Winters 2013). Coastal engineering projects such as bulkheading try to prevent erosion; however this method prevents wetland ecosystems from functioning properly (Titus et al. 2009). Over 70% of the bay shoreline near or around LBI has been altered by residential development, commercial marinas, boat ramps and bulkheading (BBEP 2001-2003). Despite prevention methods erosion still occurs (Lathrop and Love 2007). The loss of coastal habitat contributes to declining populations of shoreline nesters (Jones and Strange 2008). Jones and Strange (2008) reported that on Holgate Beach on south LBI there was a decrease in nesting black skimmer (*Rynchops niger*) populations from 1985 to 1995 and observed a similar trend in other species of bird throughout the region. Although many studies have been conducted on nesting bird species not much is known about how nesting terrapins are influenced by development on LBI. More than 95% of structures on LBI are residential homes that were built before 1960 (Titus 1990). Previous studies have demonstrated terrapin populations are negatively impacted by loss of shorelines from human development (Feinberg 2000; Gibbons et al. 2001; Szerlag and McRobert 2006) although none have been conducted on LBI. Human activities surrounding residences or recreational sites have been known to affect nesting behavior in many species (Lafferty 2001; Moore and Seigel 2006) including terrapins (Roosenburg et al.2003). On LBI our study demonstrated that diamondback terrapins have nest site fidelity with most nesting occurring less than 190.5 m from water.

These results confirm the common belief of environmental nesting factors and also demonstrate that adult female terrapins are exposed to altered nesting habitats. Areas where there is bulkheading or inaccessible land have caused a decrease the amount of nesting activity. This study highlighted areas where females emerge and travel distances to nest, creating an increase in vulnerability due to different anthropogenic influences. Human disturbances that are thought to be must disruptive to terrapin nesting are motorized boats, kayaks, and bulkheading at nesting beaches (Winters 2013). Winters (2013) reported human activities, such as boating or kayaking, did not have a statistically significant effect on timing of terrapin emergence. This lack of behavioral response may be due to habituation or inability to perceive human threats. It is believed that due to the constant and high rate of coastal development within Barnegat Bay, NJ (BBNEP 2001), terrapins have been exposed to anthropogenic activities for so long that they no longer respond or perceive human presence as a threat. This is potentially hazardous as terrapins are commonly found as road kill or injured by boats (Lester and Avery 2011).

Knowing the environmental conditions that cause terrapin emergence will be a vital part in determining the regulation of human activities around terrapin nesting sites (Winters 2013). Monitoring possible changes in populations' nesting areas and knowing where major encounter areas are will allow for improved management practices. Szerlag and McRobert (2007) demonstrated that by identifying terrapin nesting areas it allows for more focused monitoring efforts towards terrapin movement and protection. It was recommended that high density nesting areas should have increased observations and limited human activity during high encounter times. Using this approach will allow future managers to more accurately predict terrapin nesting activity based on environmental variables. On LBI, further research is necessary to determine other high terrapin nesting density areas. Human activities on LBI should be limited (i.e. motorized boats should be restricted to areas a sufficient distance from known terrapin nesting beaches) to protect female terrapins during the summer and to reduce disturbances in nesting areas both spatially and temporally. This study highlighted important areas to focus monitoring efforts and to allow future researchers to continue to observe nesting trends on LBI. More efforts should be taken to create sandy areas on residential properties or LBI should incorporate living shoreline initiatives to encourage safe nesting habitat (Appendix 2; http://www.delawareestuary.org/living-shorelines). Identifying environmental triggers, high density nesting areas, restricting human activity, and potentially creating artificial nesting areas are avenues for further research which will aid in conservation efforts.

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Figures and Tables

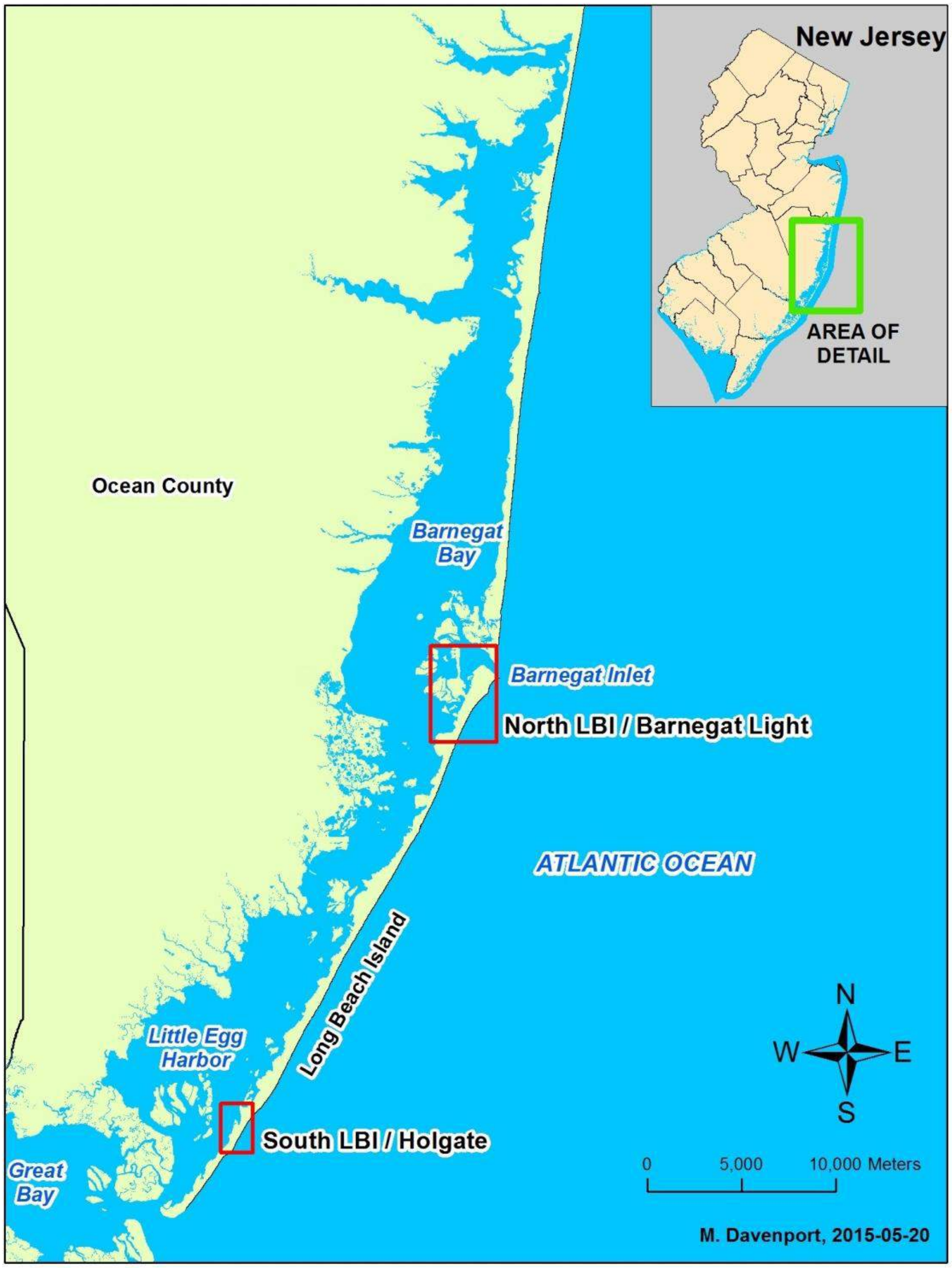

Figure 1. Long Beach Island (LBI), New Jersey survey sites.

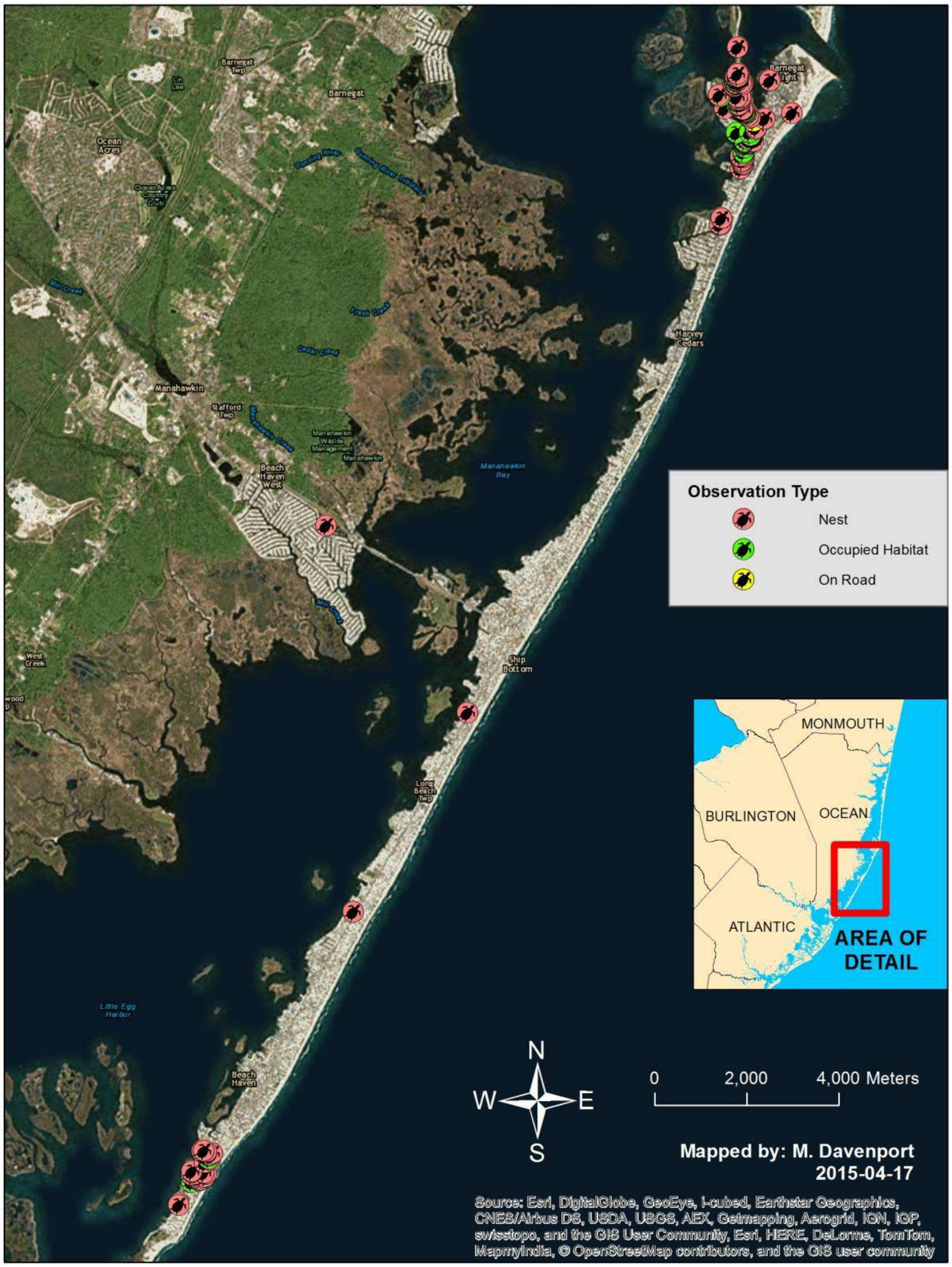

Figure 2. Occurrence type and location of nesting females along LBI during the 2014 nesting season. Nest is area of known nesting as evidenced by egg(s), egg shell fragments, or a female actively depositing eggs. On Road is defined as individual(s) observed on a road and occupied habitat is a sighting of a live individual(s) or physical evidence.

Table 1. Mark and recapture data of female terrapins landing on Long Beach Island, Barnegat Bay New Jersey during the 2014 nesting season. Nesting females were considered those that landed on the Island. Three females were encountered but were not identified on north LBI.

Location	No. New Females Captured	No. Observed Females from Previous Year(s)	Total No. Females Observed
North LBI	75	32	110
South LBI	15	3	18

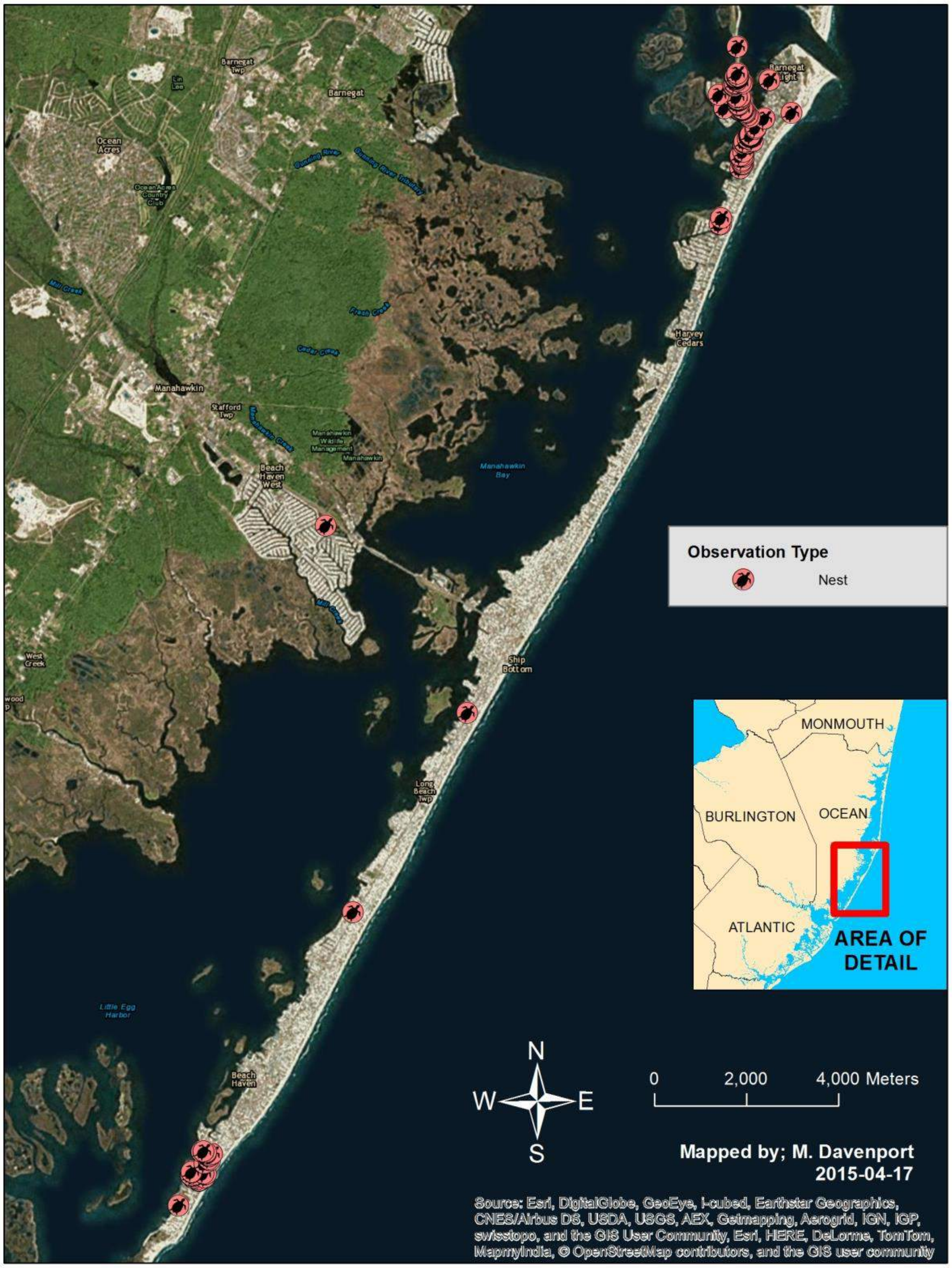

Figure 3. Confirmed *Malaclemys terrapin terrapin* nests on LBI, New Jersey during 2014.

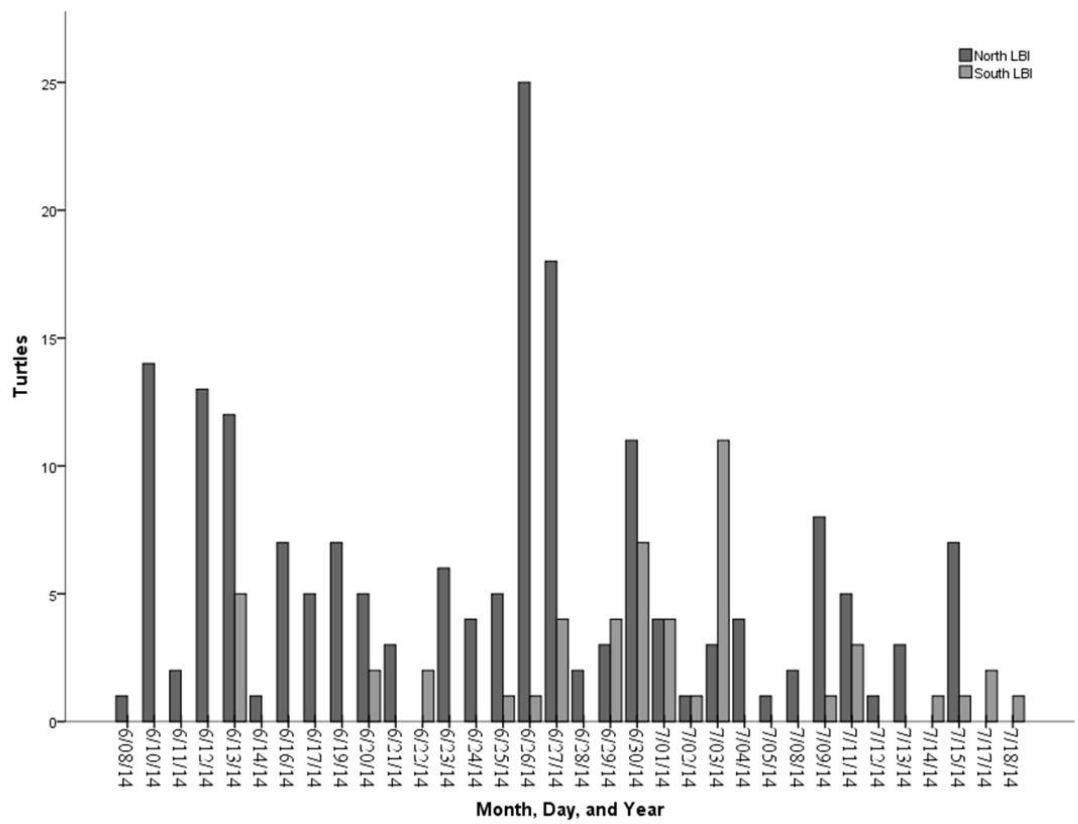

Figure 4. Date and month for the frequency of nesting female *Malaclemys terrapin terrapin* on LBI, New Jersey during the 2014 season.

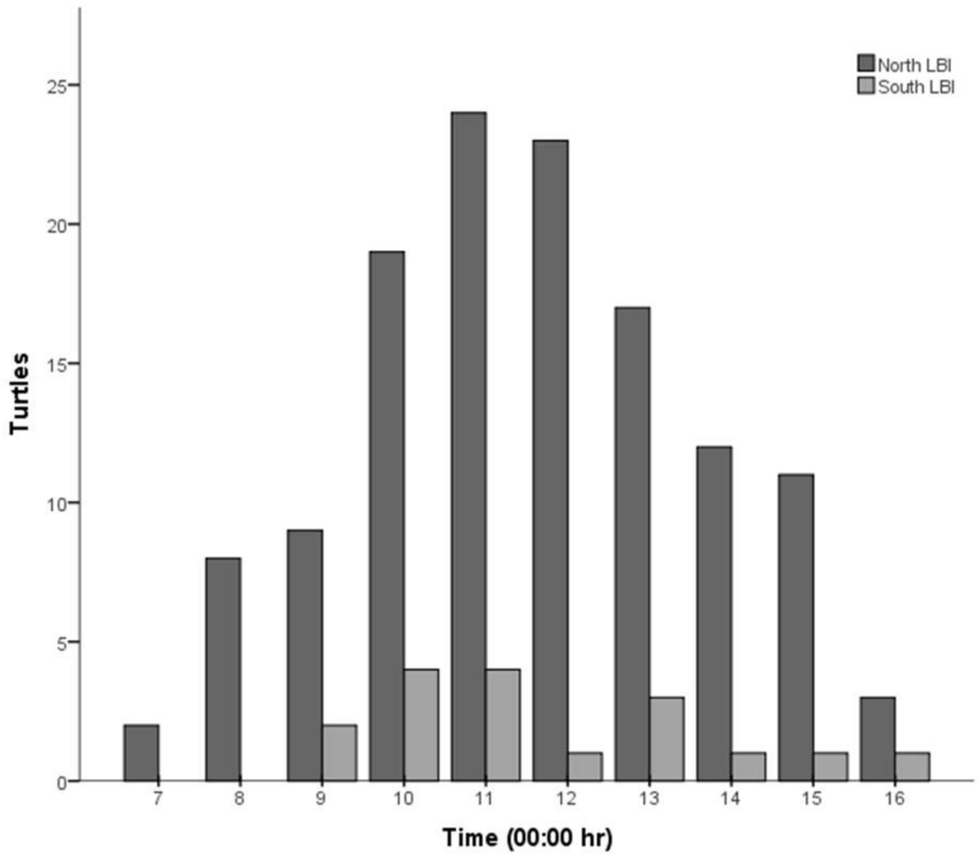

Figure 5. Time (h) EST of encounters of nesting *Malaclemys terrapin terrapin* on north LBI, New Jersey in 2014.

Figure 6. Confirmed *Malaclemys terrapin terrapin* nests on north LBI, New Jeresey during the 2014 nesting season.

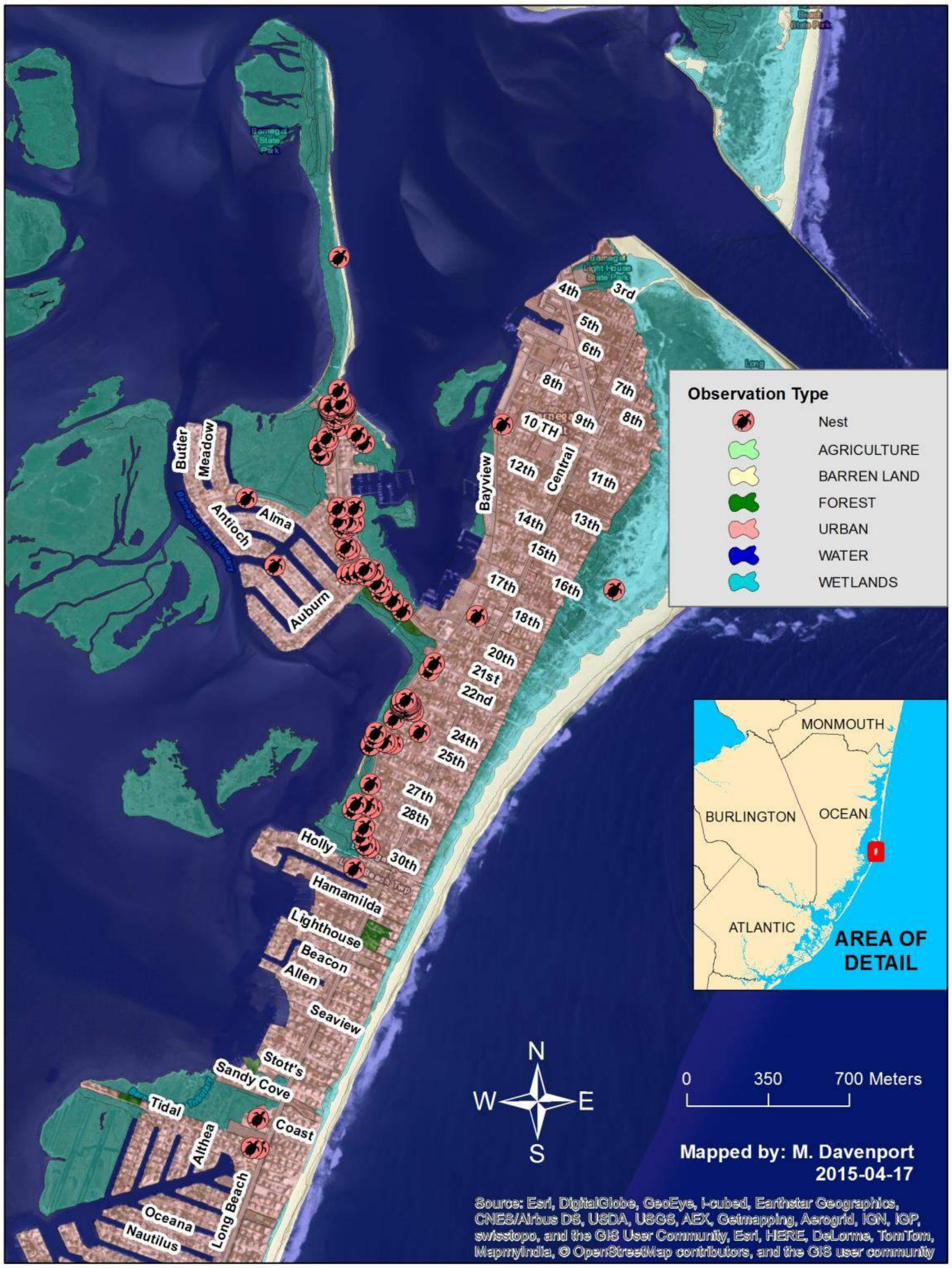

Figure 7. Land Use Land Covered on north LBI with confirmed nests shown. GIS data from the Land Use/Land Cover 2012 Update, Edition 20150217 from the NJ DEP was used.

Figure 8. Shore Types of north LBI, New Jersey. The GIS tool 'Near' was used to calculate distances of point to shoreline types. 'Shoreline Types' are defined as follows; 'Beach' included waterfront areas as comprised of 100% sand, 'Bulkhead' included man-made structures at the water's edge, after the rip-rap, which were designed to hold back water and protect the adjacent areas from erosion, 'Earthen Dike' are structures which served as natural barriers between the land and the water, 'Erodable' included any soft shoreline other than beach, rock, marsh, or earthen dike, which were vulnerable at the water's edge, 'Marsh' is classified areas of natural marsh edge, and 'Open water' used in areas where the shoreline plot crossed over creek and canal entrances.

Figure 9. Confirmed *Malaclemys terrapin terrapin* nests on south LBI, New Jersey during the 2014 nesting season.

Figure 10. Land Use Land Covered of south LBI, New Jersey with confirmed nests shown. GIS data from the Land Use/Land Cover 2012 Update, Edition 20150217 from the NJ DEP was used.

Figure 11. Shore Type south LBI, New Jersey. The GIS tool 'Near' was used to calculate distances of point to shoreline types. 'Shoreline Types' are defined as follows; 'Beach' included waterfront areas as comprised of 100% sand, 'Bulkhead' included man-made structures at the water's edge, after the rip-rap, which were designed to hold back water and protect the adjacent areas from erosion, 'Earthen Dike' are structures which served as natural barriers between the land and the water, 'Erodable' included any soft shoreline other than beach, rock, marsh, or earthen dike, which were vulnerable at the water's edge, 'Marsh' is classified areas of natural marsh edge, and 'Open water' used in areas where the shoreline plot crossed over creek and canal entrances.

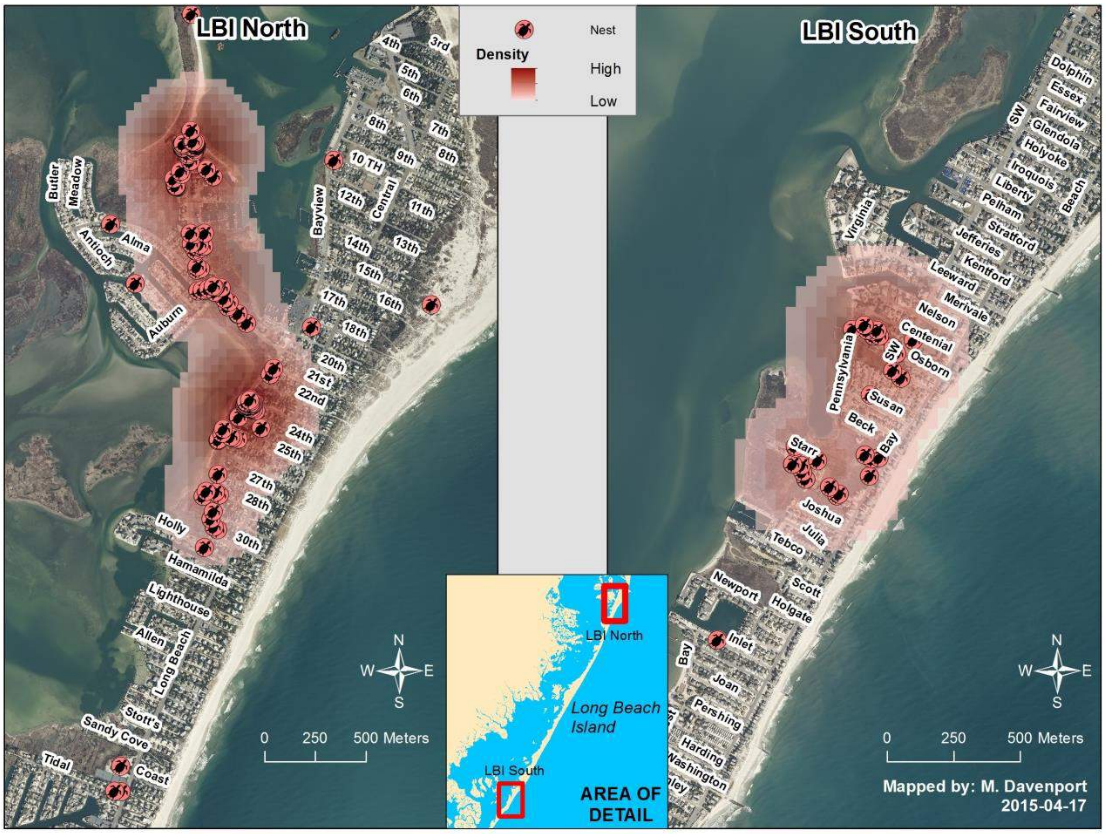

Figure 12. Nesting densities on north and south LBI during the 2014 nesting season. The Kernel Density GIS tool was used to calculate areas of high and low densities.

Table 2. Summary of clutch size within clutches on LBI, New Jersey. (n=the number of clutches laid included in the mean calculation)

Location	n	Mean clutch size	SE
North LBI	114	13.04	± 0.25
South LBI	46	11.78	± 0.35

Table 3. Summary of hatching success on LBI, New Jersey for the 2014 nesting season.

Location	# of eggs relocated to hatchery	# of live hatchlings released	Hatchling Success
North LBI	1973	1789	91%
South LBI	502	476	95%

Table 4. Mean morphometric data measures (± SE) for females encounter from the north end of Long Beach Island 2014 nesting season (n=the number of females for which morphometric data were taken).

Measurement	n	Mean ± SE	Minimum	Maximum
Straight Carapace Length (mm)	107	197.23 ± 2.02	156	280
Plastron Length (mm)	105	174.89 ± 1.65	78	204
Carapace Width (mm)	107	148.88 ± 2.82	73	168
Carapace Height (mm)	107	89.27 ± 2.23	60	194
Mass (g)	105	1156.15 ± 21.16	522	1727

Chapter 3: Regional Comparison of Northern Diamondback Terrapin (*Malaclemys terrapin terrapin*) Population Studies in New Jersey

Abstract

Barnegat Bay Estuary in New Jersey is a diverse ecosystem that is home to many species including the northern diamondback terrapin (*Malaclemys terrapin terrapin*). The increase in human activity along the NJ Shore, especially during the summer months (coinciding with the nesting season), may have a negative impact on terrapin nesting behavior. Population data on nesting females from North Sedge Island (NSI), Long Beach Island (LBI) and the Edwin B Forsythe National Wildlife Refuge (EBFNWR) are compared to one another. Field sites were patrolled to encounter and identify all nesting females. We examined female morphometrics along with information on proximity of sightings and nests to water access, roads, and human structures. Morphometric measurements on nesting females, as well as details on each clutch were recorded. For nesting females at NSI, mean straight-carapace length was 194.9 mm (±1.2) and mean clutch size of 12.7 eggs (±2.31). Females at LBI had a mean straight-carapace length of 197.2 mm (±2.0) and a mean clutch size of 13.0 eggs (±0.25). Females located at EBFNWR had a mean straight-carapace length of 189.2 mm (± 1.7) and a mean clutch size of 11.4 eggs (± 2.81). On the northern end of LBI out of 173 sightings all but two females were all encountered or nested less than 190.5 m from water access. On NSI out of 99 sightings 75 were encountered or nested less than 22.9 m from water access. On EBFNWR all 945 sightings were less than 82.3 m from water access. Our results show

that there were higher nest densities in areas where land was more accessible to females. Simple precautions like limiting boat traffic near nesting areas can be undertaken to improve long-term viability of NJ *M. terrapin* populations.

Introduction

In the state of NJ, the largest body of water is Barnegat Bay. Barnegat Bay is an estuary located along Ocean County, NJ and is influenced by tides and protected by barrier islands (NJDEP 2015). Throughout Barnegat Bay a species of estuarine emydid turtle, the northern diamondback terrapin (*Malaclemys terrapin terrapin*), can be found in undistributed habitat patches and in residential areas (Epperson 1990). Long Beach Island (LB), North Sedge Island (NSI), and the Edwin B. Forsythe National Wildlife Refuge (EBFNWR) are all located within Barnegat Bay (Figure 1). *M. terrapin* is the only turtle species known to inhabit brackish water exclusively and exhibits latitudinal variations in body size, nesting activity, and reproductive output (Burger 1976; Wnek 2010).

Reproductive output in terms of clutch size is believed to differ throughout *M. terrapin* sp.'s range. Female terrapins have a low reproductive rate as they only lay one or up to a few clutches per nesting season (Burger 1977; Roosenburg 1990; Sheridan 2010) and the number of eggs per clutch also varies among subspecies (Roosenburg 1990; Allman et al. 2012). It has been documented that mean clutch size increases with increasing latitude (Seigel 1980). Studies in New York reported the mean clutch size of 10.9 eggs (Feinberg and Burke 2003), in NJ the mean clutch size was 9.76 eggs (Burger and Montevecchi 1975) and in Florida the mean clutch size was 6.7 eggs (Seigel 1980). Recent studies have reported larger clutch sizes in NJ (Wnek 2010) and in Maryland (Roosenburg and Dunham 1997) indicating more studies are needed to determine reproductive variations geographically.

M. terrapin sp. is a sexually dimorphic species where females are much larger than males in size and mass (Lovich and Gibbons 1990; Seigel 1984; Tucker et al. 1995). Female size ranges 150 mm-230 mm in SCL and male size ranges from 100 mm-140 mm (Ernst et al. 1994). Previous studies have stated a mean female mass of 705 g and a male mean mass of 242g with a 2.91 female to mass ratio (Lovich and Gibbons 1990). *M. terrapin* has a geographical range from Cape Cod to the Gulf of Mexico (Feinberg and Burke 2003). Seven subspecies of diamondback terrapin exist across this range but the northern subspecies *M. terrapin terrapin* is found from Massachusetts to North Carolina (Carr 1952; Palmer and Cordes 1988; Lovich and Gibbons 1990; Gibbons et al. 2001). *M. terrapin terrapin* reportedly has larger body sizes and clutch sizes than southern terrapins like *Malaclemys t. ornata* located in Florida. Previous research has shown that nesting behaviors and nest site selection vary throughout the species' range (Roosenburg 1994). Factors that are believed to influence nest site selection are soil type, tidal stages, vegetation occurrence and solar exposure (Feinberg and Burke, 2003).

There are also morphometric, behavioral and reproductive output variation within local geographical areas. Information on the health and size of terrapin populations in NJ is very limited; nesting areas and threats to their survival have not been continuously studied. This study compares data collected on gravid females from NSI, LBI and the EBFNWR in order to determine differences between populations within the same estuary system. Specifically this study compared the following variables: (1) mark and recapture rates, (2) female body size and mass, (3) peak nesting activity, (4) nesting sites and (5) clutch size.

Materials and Methods

Study sites and field sampling methods

Data was collected from field sites located along the coast of NJ. Field sites were along Long Beach Island (LBI), North Sedge Island (NSI), and the Edwin B. Forsythe National Wildlife Refuge (EBFNWR) (Figure 1). LBI is approximately 20 miles long and is located on the southern portion of the barrier islands of NJ (SOCCC 2014). It separates the Atlantic Ocean from Barnegat Bay. The Atlantic side is developed for residential use and the bay side has residential development, commercial marinas and boat ramps. LBI serves as a vacation destination for tens of thousands of people each summer season, which coincides with terrapin nesting season. NSI is located in Barnegat Bay. NSI is a larger island within the Sedge Islands Wildlife Management Area. It is managed by the NJ Division of Fish and Wildlife within the Marine Conservation Zone. NSI has mostly salt marsh with bay beach access on the north and east sides. NSI is comparatively untouched by humans except for small groups that visit the island for educational or recreational activities. NSI has historically high levels of nesting activity (Wnek 2010). Terrapin nesting was monitored at LBI in two areas where locals have documented nesting activity, the northern end in High Bar Harbor and the southern end in Holgate. At LBI and NSI data was obtained during the 2014 nesting season from late May through late September. Daily surveys were conducted simultaneously and continuously during daylight hours at LBI and NSI. On LBI there were two separate patrol groups, one on the northern end in and one on the southern end. In this study only data from the northern end of LBI is included. Investigators would follow nesting females at a distance to minimize the potential of disturbing individuals. All observations were recorded of investigator locations and terrapin activity. Nesting female terrapins were captured by hand when required. Dates, times (EST) and landing locations for all terrapins encountered were recorded. Females were palpated to determine if they were gravid at time of capture. Data was recorded on a standardized data sheets and collected daily by myself or other trained personnel in times of my absence. The handing of turtles was in accordance with the permits allocated to Dr. Wnek by the NJ Division of Fish and Wildlife and all turtles were released at the site of encounter.

The Edwin B. Forsythe National Wildlife Refuge (EBFNWR) is located in southern NJ on the inland side of Barnegat Bay. EBFNWR protects more than 47,000 acres of southern NJ coastal habitats (USDOI 2015). EBFNWR is specifically managed for the protection of wildlife and wildlife habitat. Data from the EBFNWR was obtained from unpublished survey conducted by Drexel University. Sampling occurred between June and September 2012. Terrapins were trapped using hoop nets, fyke nets, dip nets, and hand capture (Sheridan 2010; Lester et al. 2013). To determine total clutch size x-radiography was used on gravid females and egg-laying was induced via interperotineal injection with 10-30 IU/kg Oxytocin (Ewert and Legler 1978). Different location protocols and sampling techniques would not influence the outcome of terrapin morphometrics or nesting choices.

Mark-Recapture

A mark-recapture study was conducted to identify nesting female terrapins and determine how often they nest, or their inter-nesting frequency. Upon encountering nesting females, each was identified using a pre-established notch code and checked for the presence of a Passive Integrated Transponder (PIT) using a BioMark® portable reader. If no notches were observed the marginal scutes on all female terrapins were notched as an additional form of identification (Cagle 1939; Gibbons 1990; Wnek 2010). If no tag was detected at time of capture individuals were then injected with 12 mm PIT tags that contained nine or ten alphanumeric characters (Buhlmann and Tuberville 1998; Wnek 2010).

Nest or Encounter Location

This study examined where female terrapins came up to nest and where they actually nested. Within the northeast corridor, NJ has the highest human population density which may impact the exact locations of nest sites (Pulispher and Pulsipher 2005). *M. terrapin* may attempt to nest several times before selecting a nest site location (Burger 1977). When a turtle was observed it was indicated on the data sheet if nesting occurred. Every known site where a female has nested was recorded using a Global Positioning System (GPS) device. Before a nest was relocated the GPS coordinates were recorded on the datasheet. The surrounding environment and where visually the nest was located were also indicated on the data sheet.

Nest Relocation and Nest Excavation

Terrapin nests that were oviposited in areas with high human activity (i.e., walking areas, kayak launch locations, and residences) were excavated and relocated to hatcheries with a sand substrate. Different volumes of water are retained in different substrate and soil types which affects gas and water exchange between the eggs and the sediment (Packard et al. 1987; Packard and Packard 1988; Cagle et al. 1993). The hatcheries on LBI are steel framed dog kennels with doors. On LBI the northern hatcheries are 3m x 3m and on the southern end the hatchery is 3m x 1.5m. The hatchery on NSI is wooden framed and approximately 3m x1.5 m in length. When relocating a nest the number of eggs was recorded. Eggs were transported in containers with sand without changing egg orientation. Clutch relocation followed the protocol of the Terrapin Nesting Project 2013.

Morphometric measurements

Morphometric measurements were taken from each nesting female to determine female weight, carapace length and width, and plastron length. Terrapins were weighed (g) using an Ohaus® digital balance (model 2000, + 1g) to establish weight. All terrapins were measured using a 40 cm tree caliper to determine straight line carapace length (mm), carapace width (mm), carapace height (mm) and plastron length (mm) (Gibbons et al. 2001; Wnek 2010).

Statistical Analysis and GIS

Data from the 2014 nesting season for LBI and NSI were analyzed and mapped. Data from the 2012 nesting season of EBFNWR were analyzed and mapped. Nests that were depredated, missing data sheets or in which the excavation results were unclear were excluded from data analysis. As there is a possibility that *M. terrapin* individuals may be encountered in all areas on maps generated, this data shows the nests that were only identified during surveys. Survey techniques and location protocols would not affect results. Sampling methods were unbiased in terms of body and clutch size. Only gravid females were included in data analysis.

Statistical Analysis

Statistical analysis was performed on IMB© SPSS© Statistics Version 21. The means, standard error, and Pearson Correlation coefficients of all measurements were calculated. All assumptions of normality and heteroscedasticity were met. A linear regression was used to compare SPL (mm) to mass (g) adjusting for site. Assumptions of homogenated variance were met. ANOVA was run to determine if there was a difference in clutch size between LBI, NSI, and EBFNWR. A Bonferroni post-hoc test was then used to determine which sites differ.

GIS

Geographic Information Systems (GIS) was used to document patterns of nest placement on LBI, NSI and EBFNWR. GIS was used to identify areas where nests might be clustered, particularly if those areas are close to altered cost lines, human structures and are at risk from tidal inundation due to the effects of tropical storms and hurricanes. Maps in this publication were developed using NJ Department of Environmental Protection Geographic Information System digital data, but this secondary product has not been verified by NJDEP and is not state-authorized. When generating maps using GIS a label was assigned to each occurrence that describes the occurrence type (i.e. nest, sighting or road mortality).

For this study 'nest' is defined as an area of known nesting by evidenced of egg(s), egg shell fragments, or a female actively ovipositing. 'On Road' is defined as individual(s) observed on a road and 'occupied habitat' is defined as a sighting of a live individual(s) or physical evidence. The default feature label if more specific information is not known. Distance of point to nearest water and road centerline (the road layer used is based on line features, which are typically located at the center of the road, so the true distance to the road edge is less than the figure provided) was calculated by the GIS tool 'Near'. 'Near' was also used to calculate distances of point to shoreline types. 'Shoreline Types' are defined as follows; 'Beach' included waterfront areas as comprised of 100% sand, 'Bulkhead' included man-made structures at the water's edge, after the rip-rap, which were designed to hold back water and protect the adjacent areas from erosion, 'Earthen Dike' are structures which served as natural barriers between the land and the water, 'Erodable' included any soft shoreline other than beach, rock, marsh, or earthen dike, which were vulnerable at the water's edge, 'Marsh' is classified areas of natural marsh edge, and 'Open water' used in areas where the shoreline plot crossed over creek and canal entrances. To determine land ownership, land use/land cover, and description of land use/land cover at the location of the point feature the GIS tool 'Identify' was used.

The Land Use/Land Cover 2012 Update, Edition 20150217 GIS data used the 2012 LU/LC data set is the fifth in a series of land use mapping efforts that was begun in 1986. Revisions and additions to the initial baseline layer were done in subsequent years from imagery captured in 1995/97, 2002, 2007 and 2012. This present 2012 update was created by comparing the 2007 LU/LC layer from NJDEP's Geographic Information Systems (GIS) database to 2012 color infrared (CIR) imagery and delineating and coding areas of change. Work for this data set was done by Aerial Information Systems, Inc., Redlands, CA, under direction of the NJ Department of Environmental Protection

(NJDEP), Bureau of Geographic Information System (BGIS). LU/LC changes were captured by adding new line work and attribute data for the 2012 land use directly to the base data layer. All 2007 LU/LC polygons and attribute fields remain in this data set, so change analysis for the period 2007-2012 can be undertaken from this one layer. The classification system used was a modified Anderson et al., classification system. An impervious surface (IS) code was also assigned to each LU/LC polygon based on the percentage of impervious surface within each polygon as of 2007. Minimum mapping unit (MMU) is 1 acre (NJDEP 2/17/2015).

The NJDEP Shoreline Typing for Coastlines of NJ along Its Atlantic and Inland Bays shoreline type project involved the identification and coding of the entire NJ shoreline within the Coastal Areas Facilities Review Act (CAFRA) zone from Keyport to Hieslerville (NJDEP 1993). The data was used to delineate different classifications of shoreline based on particular landforms.

NJDEP State Owned, Protected Open Space and Recreation Areas in NJ (Version 200812) dataset contains protected open space and recreation areas owned in fee simple interest by the State of NJ Department of Environmental Protection (NJDEP). Types of property in this data layer include parcels such as parks, forests, historic sites, natural areas and wildlife management areas. The data was derived from a variety of source maps including tax maps, surveys and even hand-drafted boundary lines on USGS topographic maps. These source materials vary in scale and level of accuracy. Due to the varied mapped sources and methods of data capture, this data set is limited in its ability to portray all open space lands accurately, particularly the parcels purchased prior to 1991(NJDEP 1995).

Road Centerlines of NJ, NJ State Plane NAD83 data set was provided by the NJ Office of Information Technology (OIT) and Office of GIS (OGIS) which has enhanced the previously published NJ Department of Transportation (DOT) Roadway Network GIS dataset to create a fully segmented Road Centerlines of NJ feature class. This dataset includes fully parsed address information and additional roadway characteristics. It provides the geometric framework for display and query of relevant non-spatial data published as separate tables that can be joined to the feature class. The enhancement process included integration of multiple data sets, primarily those developed and maintained by county agencies in NJ and the US Census Bureau (NJOIT and OGIS 2015)

Results

Mark-Recapture

NSI had a total of 74 females visit the island, 68 of which were previously tagged (Table 1). On NSI 37 previously tagged and four newly tagged females were encountered only once. Each female that had repeat sightings were seen at least twice. One female, HIJWX, was encountered four times. Females BCHW and AIPW were encountered three times. On NSI a total of 47 nests were laid. The mark-recapture study on the north end of LBI recorded a total of 109 individuals (Table 1). There were 73 newly tagged females and 36 previously tagged females. Out of the 36 previously tagged individuals two were encountered on the island more than once. Out of the 73 newly tagged females seven individuals were known to have returned to LBI during the nesting season. During the 2012 nesting season a total of 57 gravid females were encountered in EBFNWR. There were 15 females that were previously identified and 42 newly captured females (Table 1). All gravid females encountered were only observed once.

Encounter Timing and Location

Landing dates on NSI ranged from June 8 through July 22, 2012 (Figure 2). Peak encounter days on NSI were June 16, June 17, and July 3. Landing dates on LBI ranged from June 8 through July 18, 2014 (Figure 3). The most terrapin encounters occurred on June 26. Other peak encounter days were June 13, June 30, and July 3. The full moon was on June 13 and July 12, 2014. During 2012, EBFNWR saw a peak in activity the number of females encountered on June 15, July 1, and July 3. June 15, 2012 was four days after the third quarter moon and July 3, 2012 was the full moon (Figure 4).

On NSI all nests (Figure 5) are on property owned by NJ Fish and Wildlife and classified as marsh (Figure 6). NSI is labeled as urban low density residential single unit, where all nests are between 1979.3 m and 2115.3 m away from the nearest road (Figure 7). The closest nest to water was 3.73 m away and the further nest from water was a distance of 41.6 m (Figure 7). On the north end of LBI the mean distance of nests to the center line of roads was 31.7 m and the mean distance to the nearest point of water was 76.0 m (Figure 8). When analyzing land use/land cover 135 encounters out of a total of 173 encounters occurred on residential properties (Figure 9). When land ownership was identified at encounter sites 15 encounters occurred on the property of the Borough of Barnegat Light, six on Ocean County property, six on the road, and two on NJ Parks and Forestry land. On the north end of LBI the highest nesting density occurred along Bay View Avenue (between 26th Street and 23rd street) and on Sunset Blvd (Appendix Figure 1; Appendix Figure 2). Observations were made in relation to shoreline type. When analyzing the nearest shore line type 71 nests occurred on shore line classified as erodadble (Figure 10). Erodable included any soft shoreline other than beach, rock, marsh, or earthen dike, which were vulnerable at the water's edge. There were 41 nests that occurred on beach or waterfront areas as comprised of 100% sand. There were 51 nests occurred on areas classified as natural marsh edge. Ten nests were closest to bulkhead areas which included man-made structures at the water's edge, after rip-rap, which were designed to hold back water and protect the adjacent areas from erosion. Gravid females at EBFNWR (Figure 11) were encountered in the water (0 m) and as far as 77.4 m from the closest shore line (Figure 12). All encounters at EBFNWR but two which were on beaches were classified as water or wetlands. The two encounters that occurred on beaches are classified as barren land (Figure 12). Gravid females were encountered as close as 14.7 m to the centerline of a road and as far away as 2963.5 m (Figure 13). Throughout EBFNWR 27 gravid females were encountered in low marsh habitat, 22 gravid females were found in tidal rivers, inland bays, and other tidal waters, two gravid females were encountered on recreational land, two females were encountered on beaches, and one female was found behind a bulkhead (Figure 13).

Clutch Size

On NSI (n=41) the mean clutch size was 12.66 (± 2.31), on LBI (n=114) the mean clutch size was 13.044 (± 0.25), and at EBFNWR (n=54) the mean clutch size was 12.54 (± 2.70) (Table 5.0 and Table 6.0). Clutch size was positively and significantly correlated to SCL (mm) (n=144, Pearson Correlation p=0.000), SPL (mm) (n=144 Pearson Correlation p=0.011), and mass (g) (n=141, Pearson Correlation p= 0.000) at all three sites (Table 6). The results of the ANOVA showed that there was a significant difference over all (p=0.01) (Table 2). A Bonferroni post-hoc adjustment was used to account for multiple tests and there was a significant difference between LBI and EBFNWR (Bonferroni post-hoc p=0.001).

Morphometric Measurements

Morphometric measurements were compared between individuals of the LBI, NSI and EBFNWR populations (Table 3). The smallest female that nested on LBI had a mean SCL of 156 mm, a SPL of 138 mm and weighed 522 g. The smallest female that nested on NSI had a mean straight carapace length (SCL) of 163 mm, a straight plastron length (SPL) of 151 mm and weighed 891 g. The smallest female encountered in EBFNWR had a mean SCL of 160 mm, a SPL of 155 mm and weighed 749 g. Correlation coefficient calculations (Table 4) demonstrated the strength of the linear relationship with a significance level of $P < 0.05$. A strong positive correlation was observed between SCL (mm) and straight plastron length (SPL) (mm) (n=234, Pearson Correlation, r^2=0.418, p=0.000) and clutch size (n=144, r^2= 0.326, p=0.000, Pearson Correlation). A small positive correlation was observed between SCL and mass (g) but there is not enough evidence to suggest a significant correlation in the sampled population (n=227, r^2= 0.127, Pearson Correlation P=0.056). There was also a positive correlation to SPL (mm) and mass (g) (n=144, r^2= 0.081, Pearson Correlation P=0.011). Linear regression analyses of SPL (mm) and mass (g) were conducted to select for geographical location (Figure 14). It was found at NSI (n=74, $p < 0.001$, $F_{821.98,\ 1738.43}$= 214.48, $r^2 = 0.7487$) and LBI (n=100, $p < 0.001$, $F_{502.78,\ 1650.30}$ =293.99, $r^2 = 0.75$) that as SPL (mm) increased it was a significant predictor for an increase in mass (g). However, at EBFNWR SPL (mm) was not a significant predictor for an increase in mass (g) (n=52, $p > 0.05$, $F_{1045.49,\ 1272.91}$ =4.28, $r^2 = 0.088$).

Discussion

This study illustrated differences between nesting populations within Barnegat Bay. Our data suggests that there are latitudinal geographical variations in mean straight plastron length (mm) for adult female terrapins with an increased mean plastron length in higher latitudes (Wnek 2010). The mean plastron length found at NSI (39^{o} 47’ N, 74^{o} 07’W, 175.9± 1.1 mm) was greater than the mean length exhibited at LBI (39°45'28.7"N 74°06'22.3"W, 174.9 ± 1.7 mm). The mean plastron length (mm) of LBI was greater than adult female terrapins at EBFNWR (39°42'22.4"N 74°10'53.4"W, 153.9 ± 5.2 mm). Typically, within the same species, larger turtles produce larger clutch sizes than smaller turtles (Wnek 2010). Therefore, the finding that plastron length varies not only by individual size but by location highlights the importance of the natural environment on the sources of variation that come into play in species evolution. Consistent with expectations, this study reported variation in plastron length across females in a given location.

The number of potential offspring per female was another variable across both female size and habitat location; the number of offspring per female is an additional source of variation available to natural selection, which is essential to a species life history (Roosenburg and Dunham 1997). Additionally, the study confirmed that female terrapins have strong nest site fidelity. Ecological studies have shown nesting females return to the same nesting site repeatedly over different nesting seasons (Auger and Giovannone 1979; Roosenburg 1996; Gibbons et al. 2001; Tucker 2001); understanding the level of fidelity will enable conservation efforts to target appropriation locations

However, the findings at EBFNWR were less conclusive and may indicate sampling error or less fidelity for the particular location.

In addition to confirming annual site fidelity, this study revealed similar clutch frequencies at the locations studied as those previously reported for terrapins in Maryland and Florida (Wnek 2010); clutch frequencies of up to three nests per year were observed at LBI and NSI. However, there was a notable variation in clutch size not previously commented on in the Maryland and Florida studies. The geographic clutch comparisons from LBI, NSI, and EBFNWR (Table 6) showed that there was a general decrease in mean clutch size from the north to south. Variability in multiple clutches within a nesting season may be a result of available food resources, energy acquisition and stored energy (Wnek 2010). Examining differences of individuals at different geographic locations will help establish distinct nesting populations and future studies should be conducted to determine the gene flow and genetic diversity of these populations.

This study also determined the peak nesting times for female terrapins in Barnegat Bay. Female terrapins in Barnegat Bay were encountered from early July through late July, which is consistent with previously reported nesting times in NJ (Burger and Montevecchi 1975; Wood and Herlands 1997; Szerlag and McRobert 2007; Wnek 2010). A large body of evidence, including the findings of this study, establishes the summer months as key to terrapin nesting, and should enable conservation and education efforts to support terrapin environments. Overall, the observations of this study demonstrate that female terrapins select to nest in areas of soft shore line, specifically in marsh or wetland habitat. Notably for the potential impact on future nesting populations, in estuaries, human development inhibits new marsh from forming (Titus 1991). Human development therefore results in reduced access to suitable coastal habitat. Coupled with the fact that current anthropogenic disturbances predispose terrapins to population fragmentation; this is a major concern for this species. As habitat fragmentation increases within Barnegat Bay, available nesting habitat is decreasing (Sheridan 2010). Research towards better understanding diamondback terrapin nesting behavior in Barnegat Bay, both in natural areas and in relation to human coastal development is vital towards better understanding the impact of human barriers upon estuarine wildlife.

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Figures and Tables

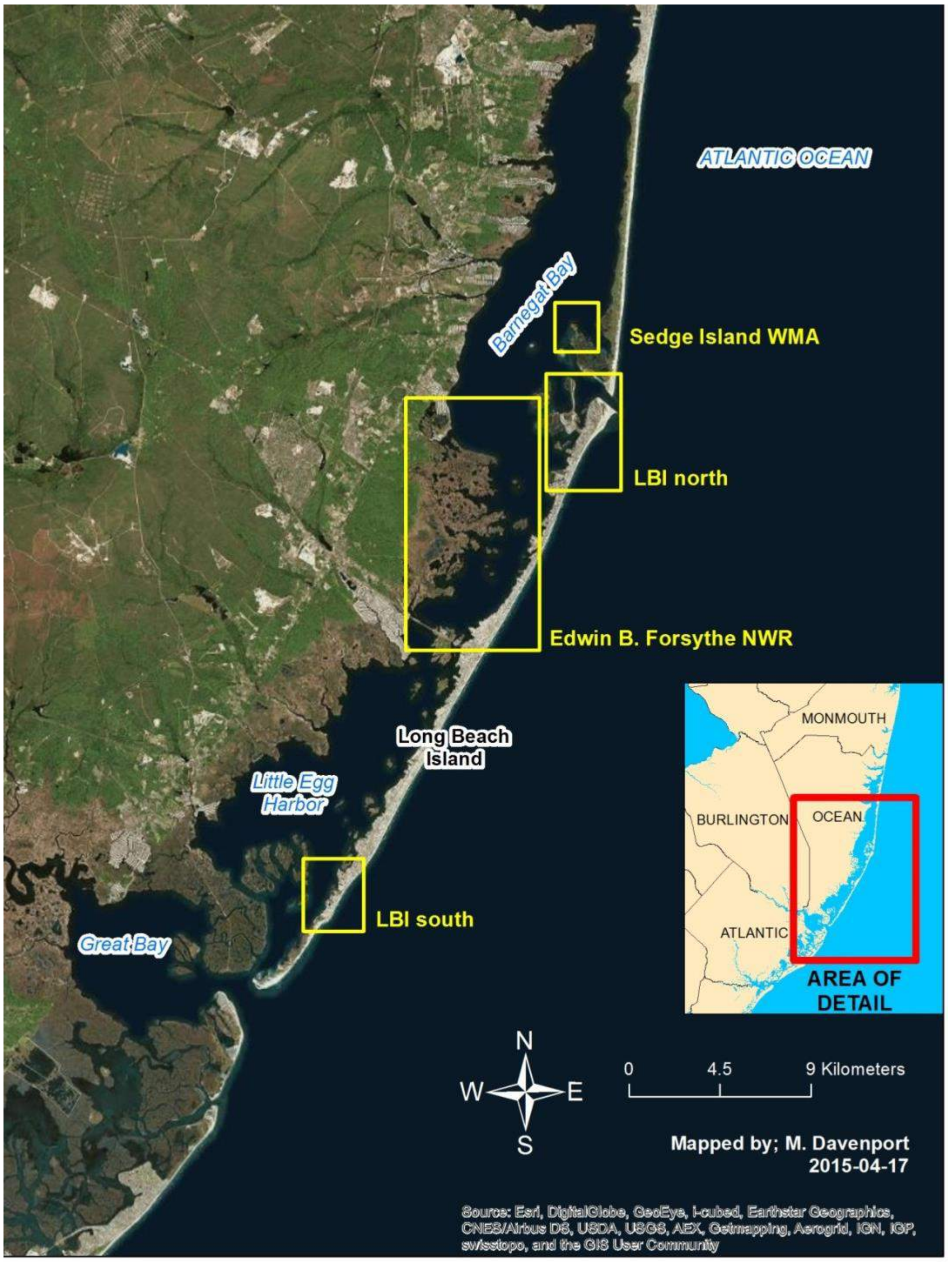

Figure 1. Survey site within Barnegat Bay, New Jersey. Female terrapins were encountered at all sites with yellow rectangles: Long Beach Island (LBI), North Sedge Island (NSI), and the Edwin B. Forsythe National Wildlife Refuge (EBFNWR).

Table 1. Mark and recapture data of female terrapins in Barnegat Bay, New Jersey. Data from NSI and LBI were obtained during the 2014 nesting season. Date from EBFNWR was obtained from an unpublished survey by Drexel University in 2012.

Location	Year	No. New Females Captured	No. Nesting Females from Previous Year(s)	Total No. of Gravid Females Observed
NSI	2014	6	68	74
LBI	2014	73	36	109
EBFNWR	2012	42	15	57

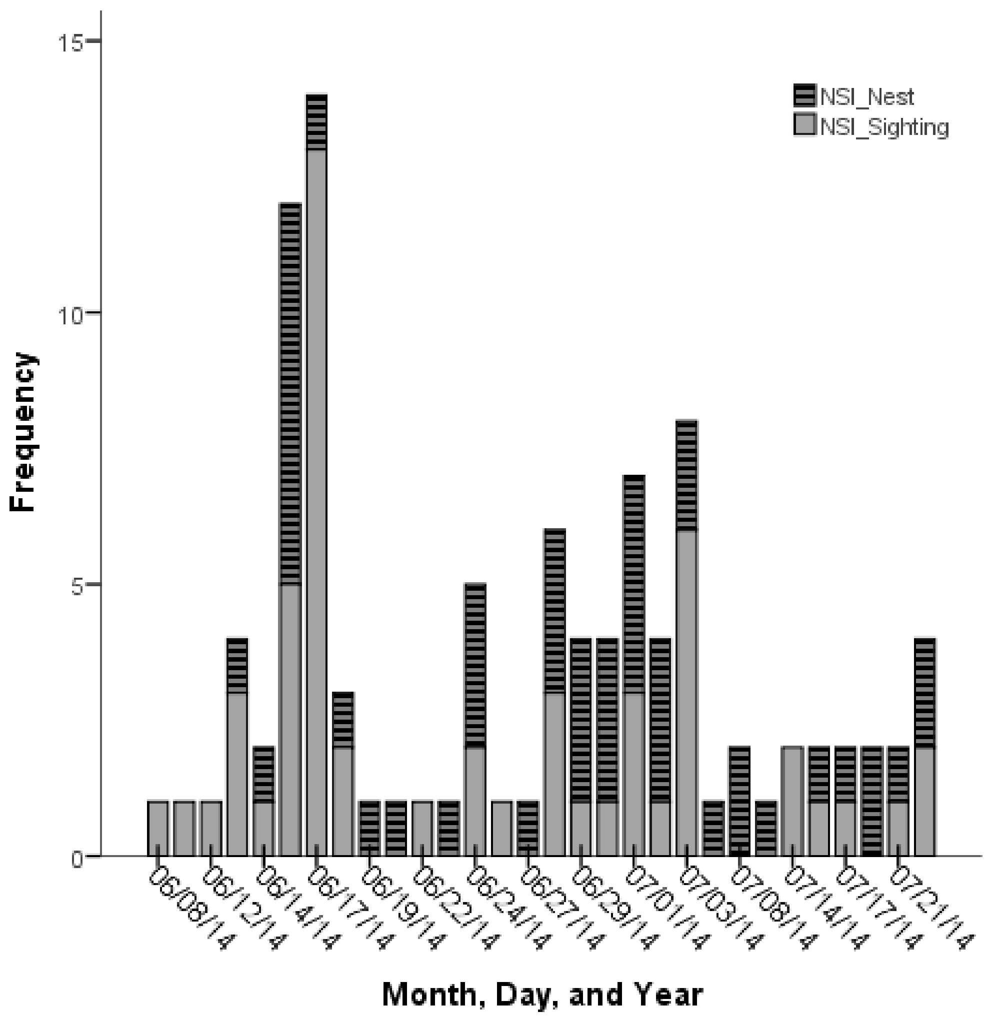

Figure 2. Date and month for the frequency of nesting female *Malaclemys terrapin terrapin* on NSI, New Jersey during the 2014 season.

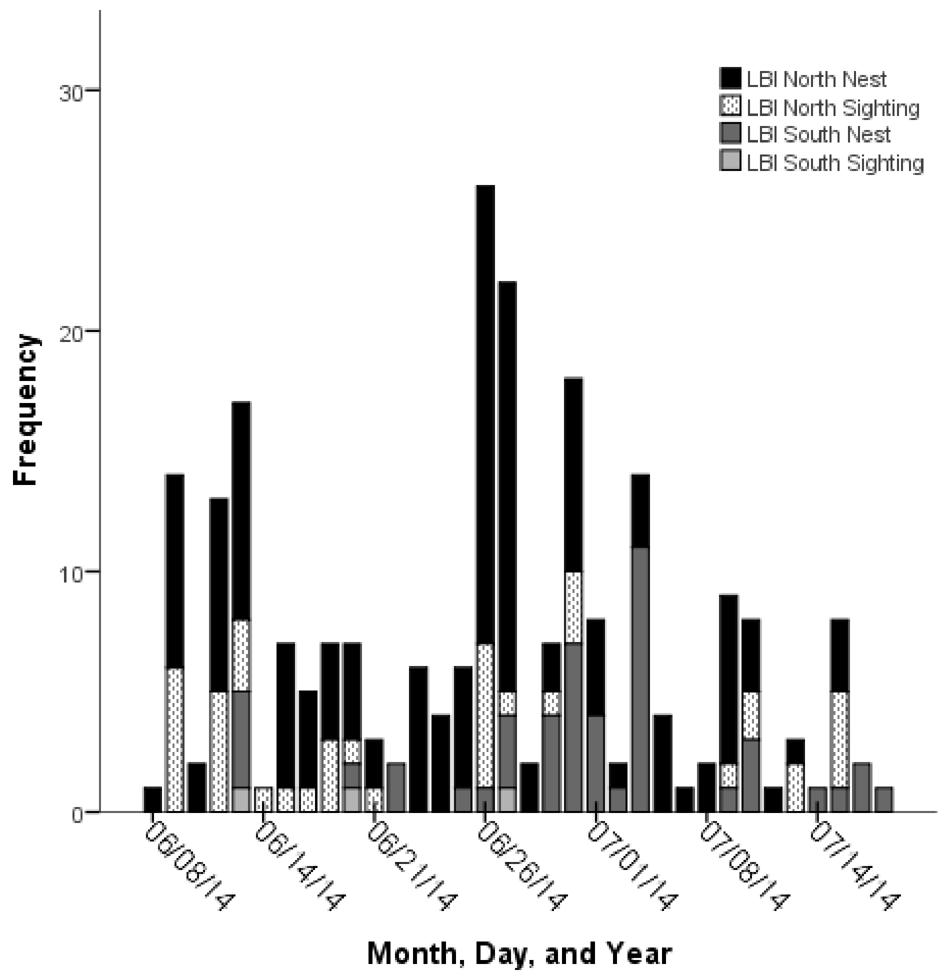

Figure 3. Date and month for the frequency of nesting female *Malaclemys terrapin terrapin* on LBI, New Jersey during the 2014 season.

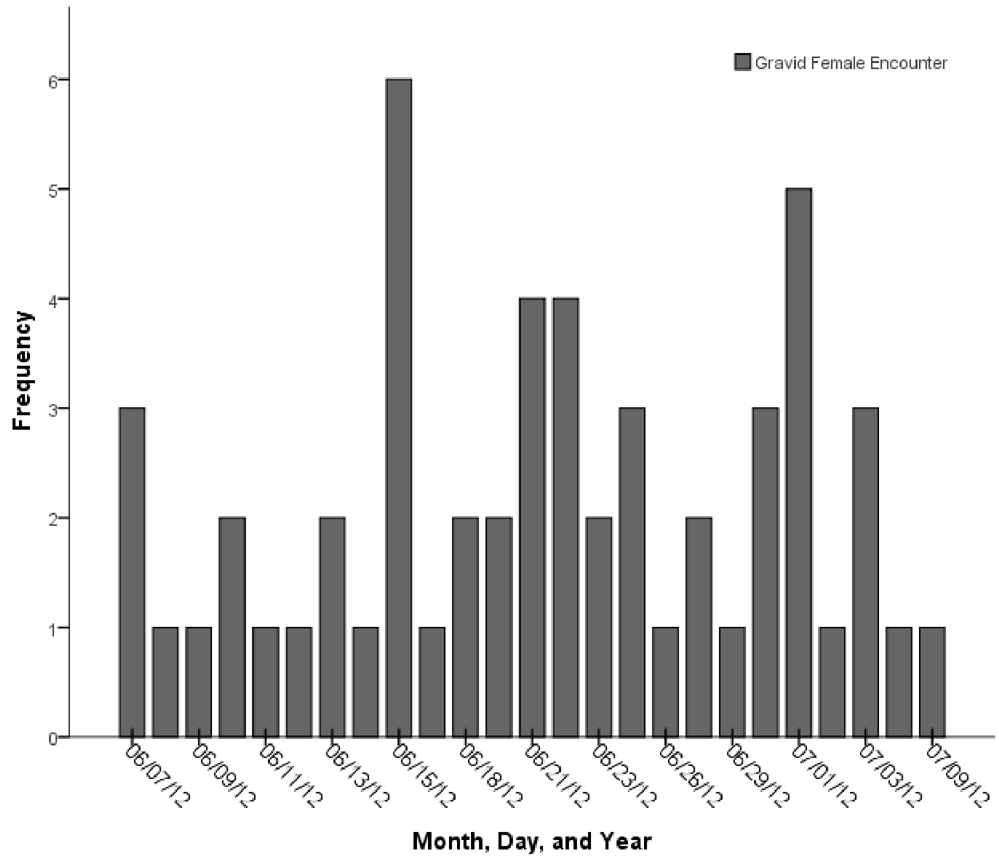

Figure 4. Date and month for the frequency encounters of gravid female *Malaclemys terrapin terrapin* on EBFNWR, New Jersey during the 2012 season.

Figure 5. Occurrence type and location of nesting females along NSI, New Jersey during the 2014 nesting season. Nest is area of known nesting as evidenced by egg(s), egg shell fragments, or a female actively depositing eggs. On Road is defined as individual(s) observed on a road and occupied habitat is a sighting of a live individual(s) or physical evidence.

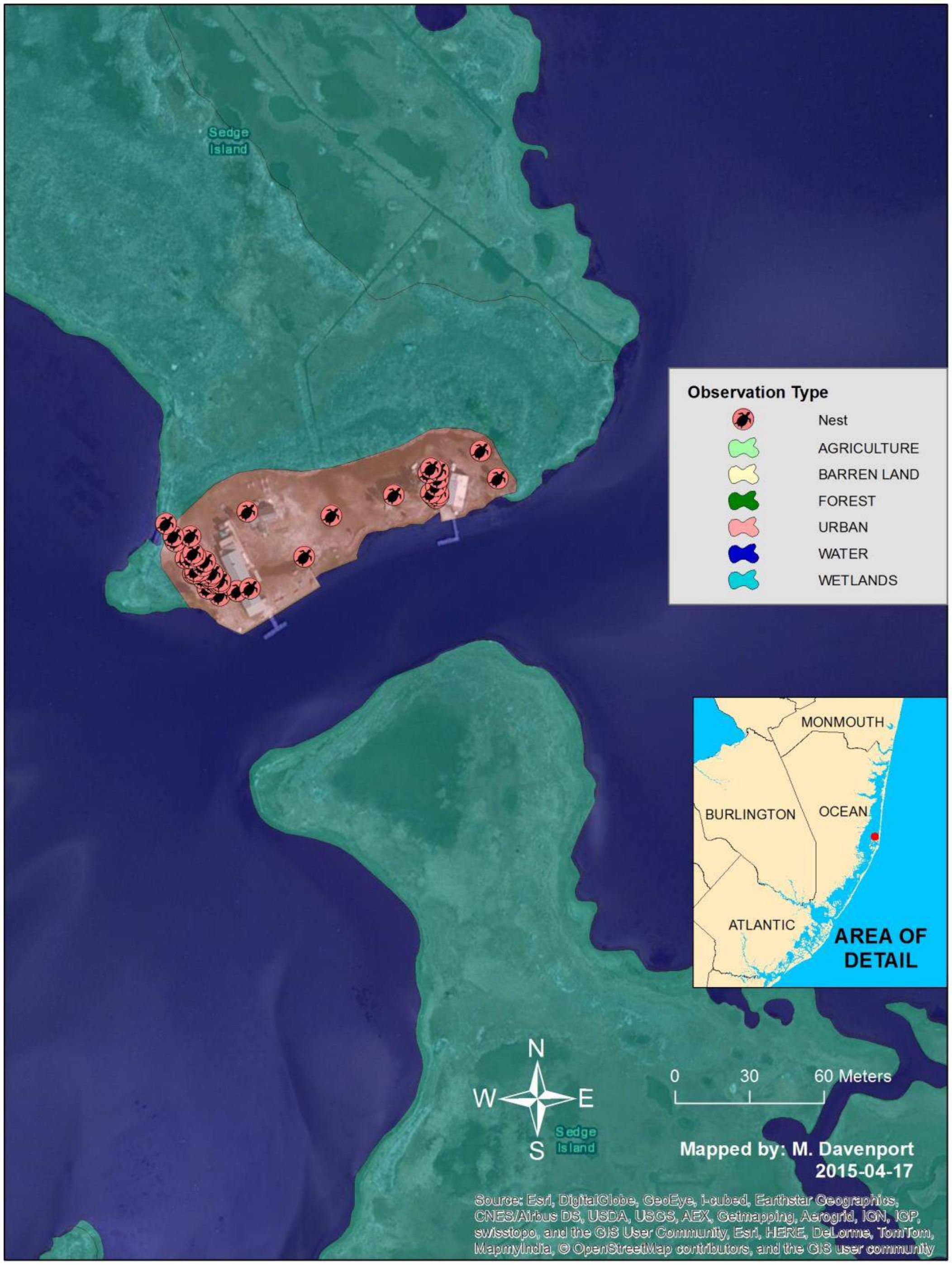

Figure 6. Land Use Land Covered of south NSI, New Jersey with confirmed nests shown. GIS data from the Land Use/Land Cover 2012 Update, Edition 20150217 from the NJ DEP was used.

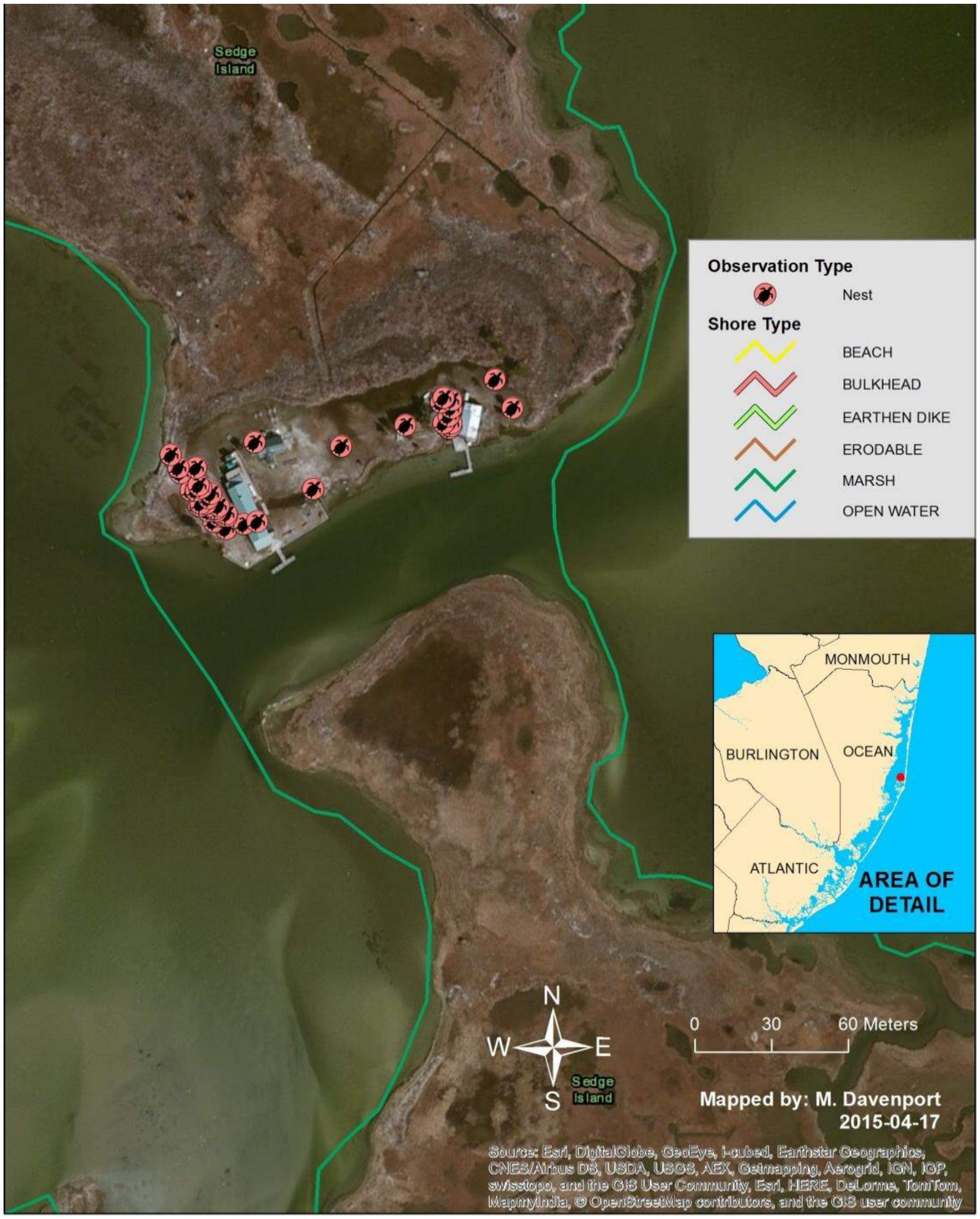

Figure 7. Shore Type south NSI, New Jersey. The GIS tool 'Near' was used to calculate distances of point to shoreline types. 'Shoreline Types' are defined as follows; 'Beach' included waterfront areas as comprised of 100% sand, 'Bulkhead' included man-made structures at the water's edge, after the rip-rap, which were designed to hold back water and protect the adjacent areas from erosion, 'Earthen Dike' are structures which served as natural barriers between the land and the water, 'Erodable' included any soft shoreline other than beach, rock, marsh, or earthen dike, which were vulnerable at the water's edge, 'Marsh' is classified areas of natural marsh edge, and 'Open water' used in areas where the shoreline plot crossed over creek and canal entrances.

Figure 8. Occurrence type and location of nesting females along north LBI, New Jersey during the 2014 nesting season. Nest is area of known nesting as evidenced by egg(s), egg shell fragments, or a female actively depositing eggs. On Road is defined as individual(s) observed on a road and occupied habitat is a sighting of a live individual(s) or physical evidence.

Figure 9. Land Use Land Covered on north LBI with confirmed nests shown. GIS data from the Land Use/Land Cover 2012 Update, Edition 20150217 from the NJ DEP was used.

Figure 10. Shore Types of north LBI, New Jersey. The GIS tool 'Near' was used to calculate distances of point to shoreline types. 'Shoreline Types' are defined as follows; 'Beach' included waterfront areas as comprised of 100% sand, 'Bulkhead' included man-made structures at the water's edge, after the rip-rap, which were designed to hold back water and protect the adjacent areas from erosion, 'Earthen Dike' are structures which served as natural barriers between the land and the water, 'Erodable' included any soft shoreline other than beach, rock, marsh, or earthen dike, which were vulnerable at the water's edge, 'Marsh' is classified areas of natural marsh edge, and 'Open water' used in areas where the shoreline plot crossed over creek and canal entrances.

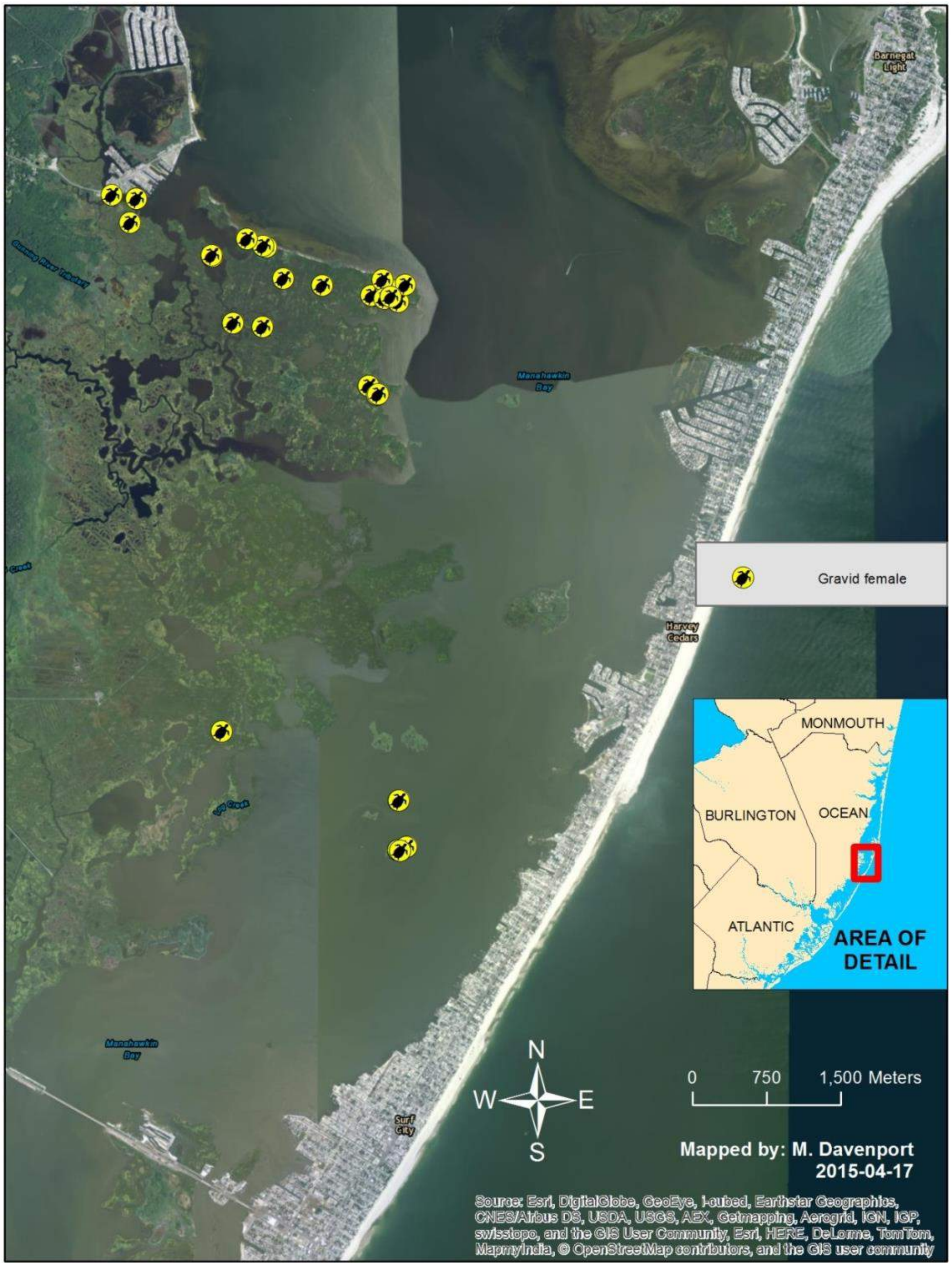

Figure 11. Encounter locations of all females (gravid and non-gravid) encountered throughout sampling sites in the EBFNWR, New Jersey during the 2012 nesting season.

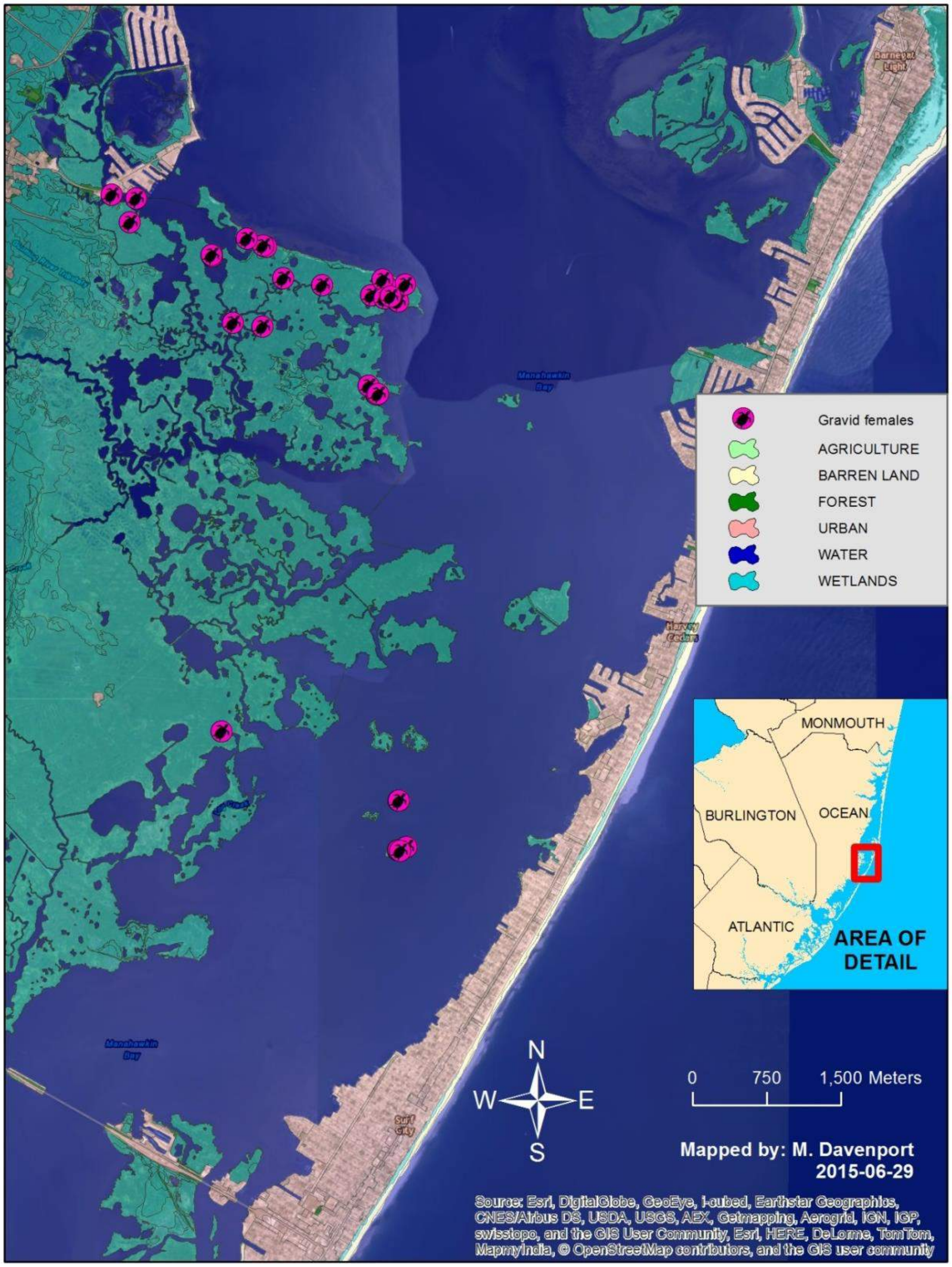

Figure 12. Land Use Land Covered of female terrapin encounters in EBFNWR, New Jersey. GIS data from the Land Use/Land Cover 2012 Update, Edition 20150217 from the NJ DEP was used.

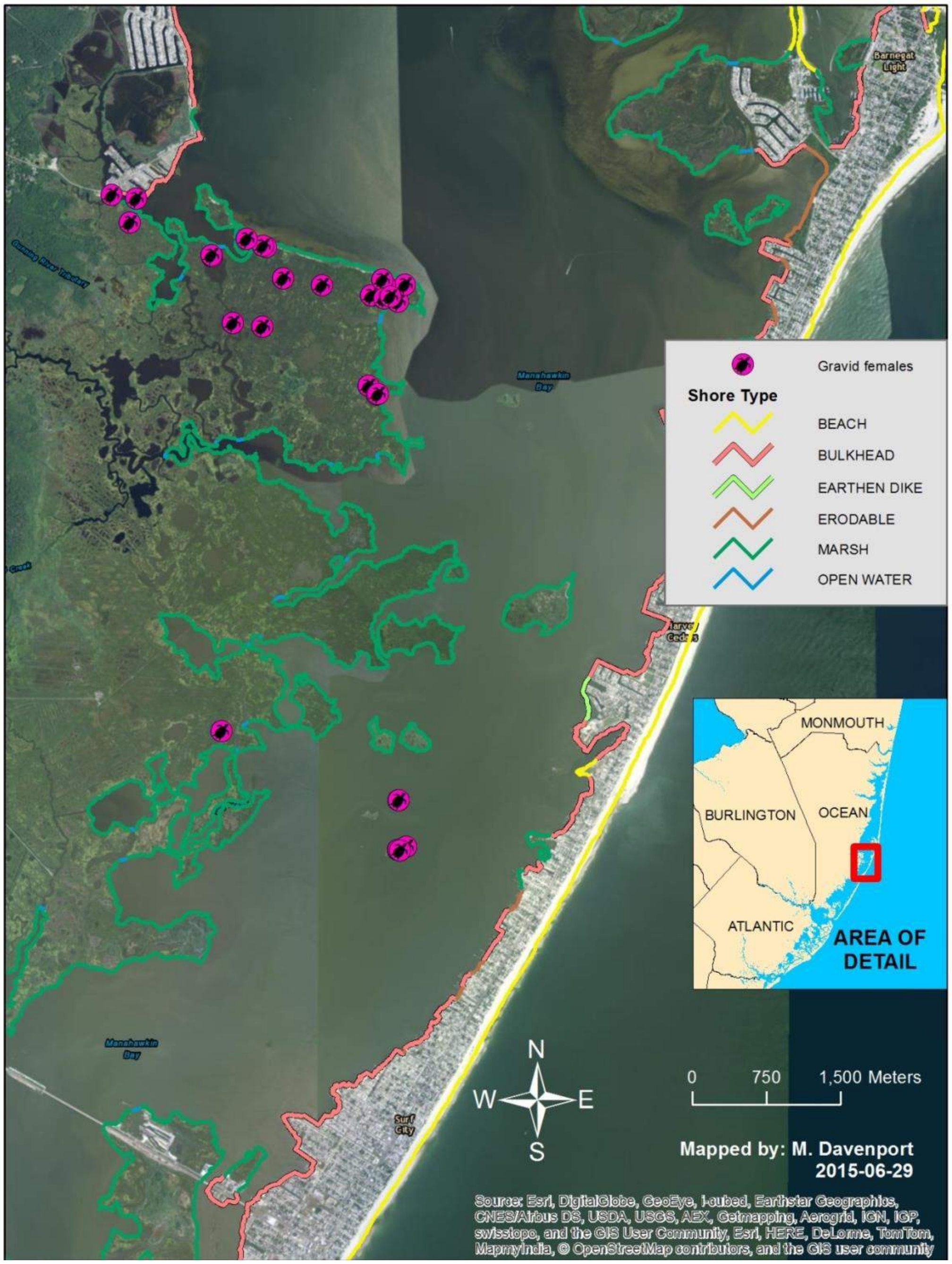

Figure 13. Shore Types of EBFNWR, New Jersey. The GIS tool 'Near' was used to calculate distances of point to shoreline types. 'Shoreline Types' are defined as follows; 'Beach' included waterfront areas as comprised of 100% sand, 'Bulkhead' included man-made structures at the water's edge, after the rip-rap, which were designed to hold back water and protect the adjacent areas from erosion, 'Earthen Dike' are structures which served as natural barriers between the land and the water, 'Erodable' included any soft shoreline other than beach, rock, marsh, or earthen dike, which were vulnerable at the water's edge, 'Marsh' is classified areas of natural marsh edge, and 'Open water' used in areas where the shoreline plot crossed over creek and canal entrances.

Table 2. Overall statistics of *in situ* clutch size variation among *M. terrapin* gravid females between sites in New Jersey (NSI, LBI, and EBFNWR). Values given are the total number of females or nests samples (n), mean ± standard error (SE), minimum number of eggs laid in a single clutch, maximum number of eggs laid in a single clutch, and p-value. Clutch size was determined from naturally deposited nests at LBI and NSI, and by x-radiographs at EBFWNR. ANOVA found a significant difference among sites ($p < 0.01$). ANOVA found a significant difference among sites ($p < 0.01$). A Bonferroni post hoc analysis ($p < 0.05$) was used to determine significant difference between sites indicated by the * with a 95% Confidence Interval.

Location	Year	n	Mean ± SE	Minimum # Eggs	Maximum # Eggs
NSI	2014	41	12.66 ± 2.31	7	17
LBI*	2014	114	13.044 ± 0.25	7	21
EBFNWR*	2012	54	11.39 ± 2.81	7	20
Total		209	12.54 ± 2.7	7	21

Table 3. Mean gravid female *M. terrapin* straight carapace and plastron length, carapace width and height and mass between sites in New Jersey (NSI, LBI, and EBFNWR). Clutch size was determined from naturally deposited nests at NSI and LBI, and by x-radiographs at EBFWNR. Values given are the total number of females or nests samples (n), mean ± standard error (SE), and minimum and maximum measurements.

Source		Year	n	Mean ±SE	Minimum	Maximum
Straight Carapace Length (mm)	NSI	2014	75	194.9 ± 1.2	163	220
	LBI	2014	107	197.2 ± 2.0	156	280
	EBFNWR	2012	54	189.2 ± 1.7	160	222
Plastron Length (mm)	NSI	2014	75	175.9 ± 1.1	151	200
	LBI	2014	105	174.9 ± 1.7	78	204
	EBFNWR	2012	54	153.9 ± 5.2	68	201
Carapace Width (mm)	NSI	2014	75	148.4 ± 2.1	128	186
	LBI	2014	107	146.3 ± 1.3	73	168
	EBFNWR	2012	54	144.9 ± 2.2	51	165
Carapace Height (mm)	NSI	2014	75	83.5 ± 1.6	70	193
	LBI	2014	107	89.3 ± 2.9	60	194
	EBFNWR	2012	54	95.1 ± 4.8	60	185
Mass (g)	NSI	2014	75	1283.7 ± 24.7	843	1815
	LBI	2014	105	1156.2 ± 25.5	522	1727
	EBFNWR	2012	52	1190.5 ± 30.1	749	1820

Table 4. Correlations *M. terrapin* straight carapace (SCL), straight plastron length (SPL), mass and clutch size for all sites (NSI, LBI, and EBFNWR). Clutch size was determined from naturally deposited nests at NSI and LBI, and by x-radiographs at EBFWNR.

		SCL (mm)	SPL (mm)	Mass (g)	Clutch Size
SCL (mm)	Pearson Correlation	1	.418**	.127	.326**
	Sig. (2-tailed)		.000	.056	.000
	N	236	234	227	144
SPL (mm)	Pearson Correlation	.418**	1	.081	.212*
	Sig. (2-tailed)	.000		.227	.011
	N	234	234	226	144
Mass (g)	Pearson Correlation	.127	.081	1	.386**
	Sig. (2-tailed)	.056	.227		.000
	N	227	226	232	141
Clutch Size	Pearson Correlation	.326**	.212*	.386**	1
	Sig. (2-tailed)	.000	.011	.000	
	N	144	144	141	209

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

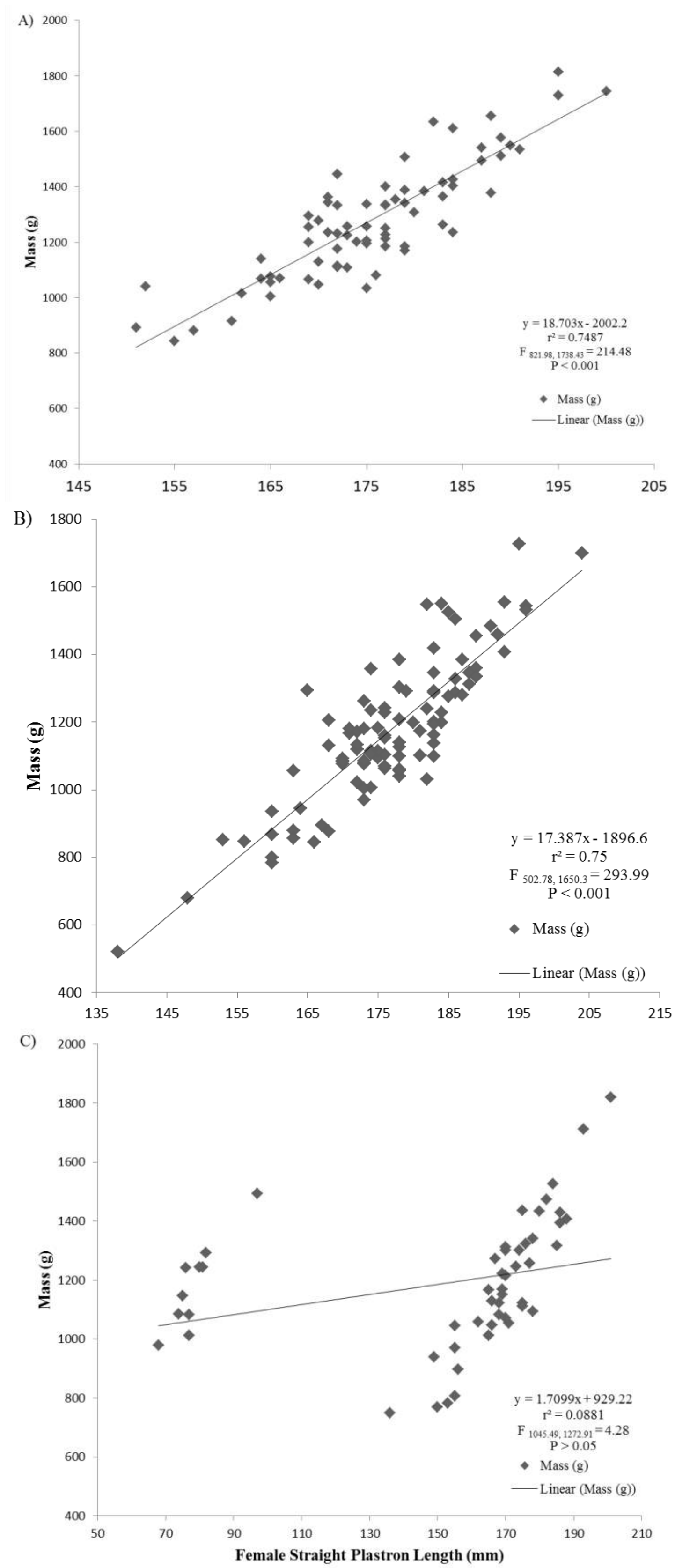

Figure 14. Regression analysis of the straight plastron length (mm) and mass (g) of terrapin encounters at A) NSI, New Jersey (n=74), B) LBI, New Jersey (n=100) and C) EBFNWR, New Jersey (n=52). There was a significant correlation between plastron length and mass for all terrapin captured at LBI and NSI ($P < 0.001$) but not at EBFNWR ($P > 0.05$).

Appendix

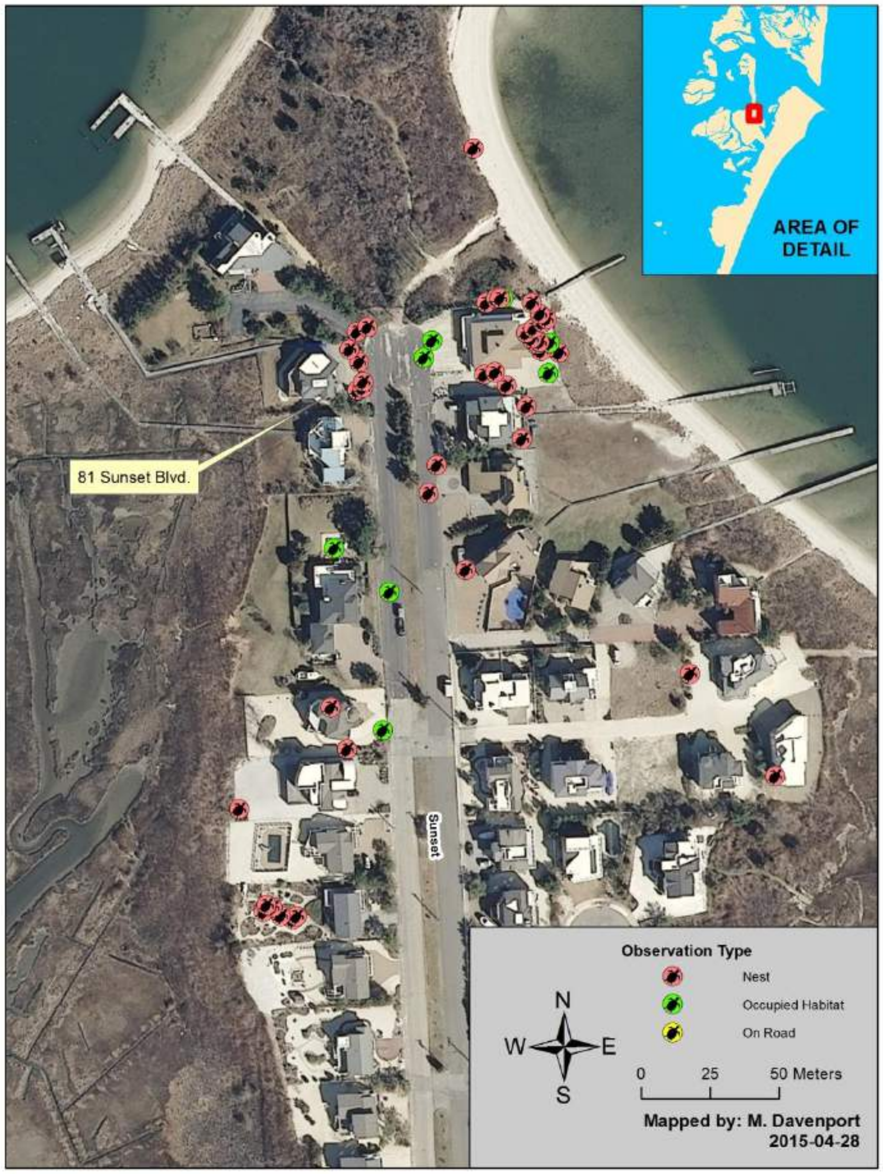

Figure 1. Occurrence type and location of nesting females on Sunset Blvd., LBI during the 2014 nesting season. Nest is area of known nesting as evidenced by egg(s), egg shell fragments, or a female actively depositing eggs. On Road is defined as individual(s) observed on a road and occupied habitat is a sighting of a live individual(s) or physical evidence.

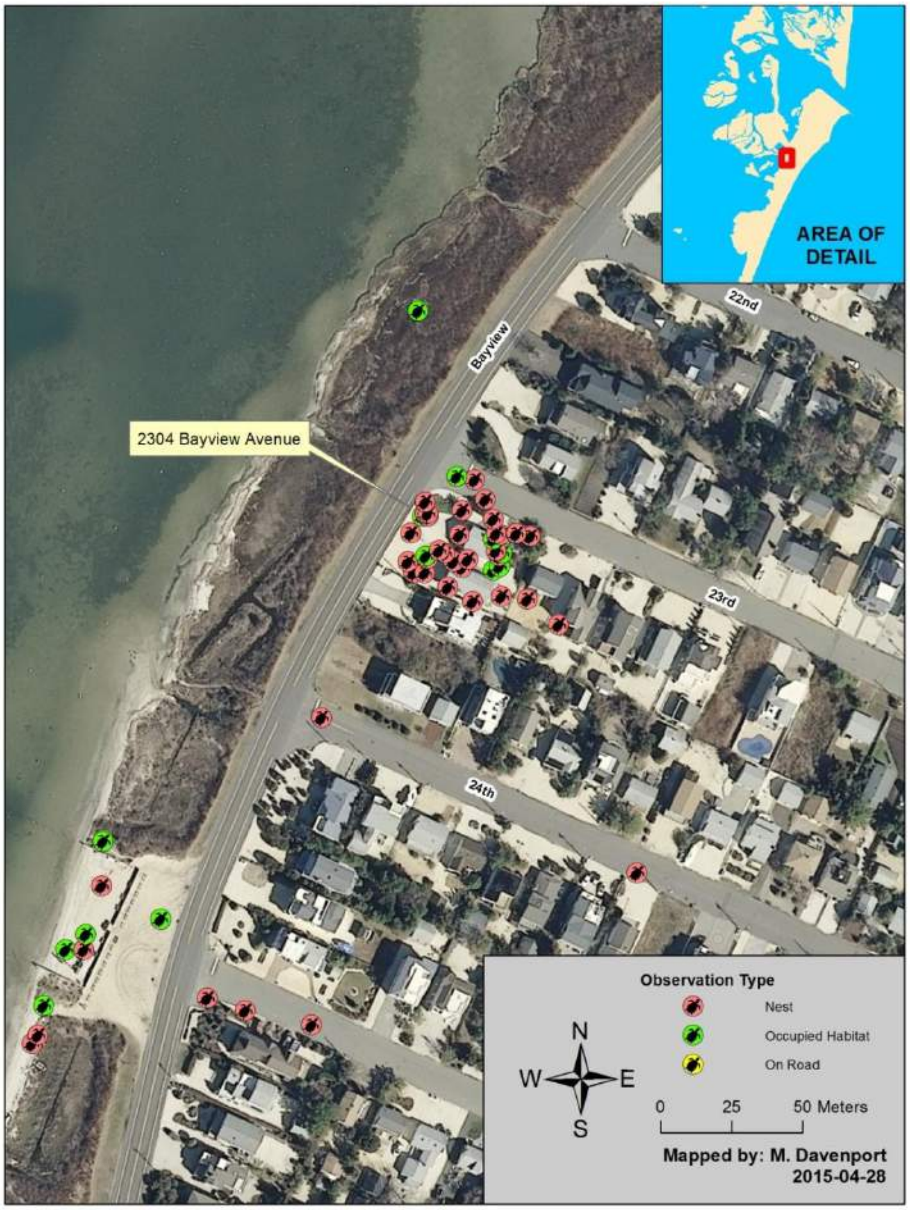

Figure 2. Occurrence type and location of nesting females along Bayview Ave., LBI during the 2014 nesting season. Nest is area of known nesting as evidenced by egg(s), egg shell fragments, or a female actively depositing eggs. On Road is defined as individual(s) observed on a road and occupied habitat is a sighting of a live individual(s) or physical evidence.

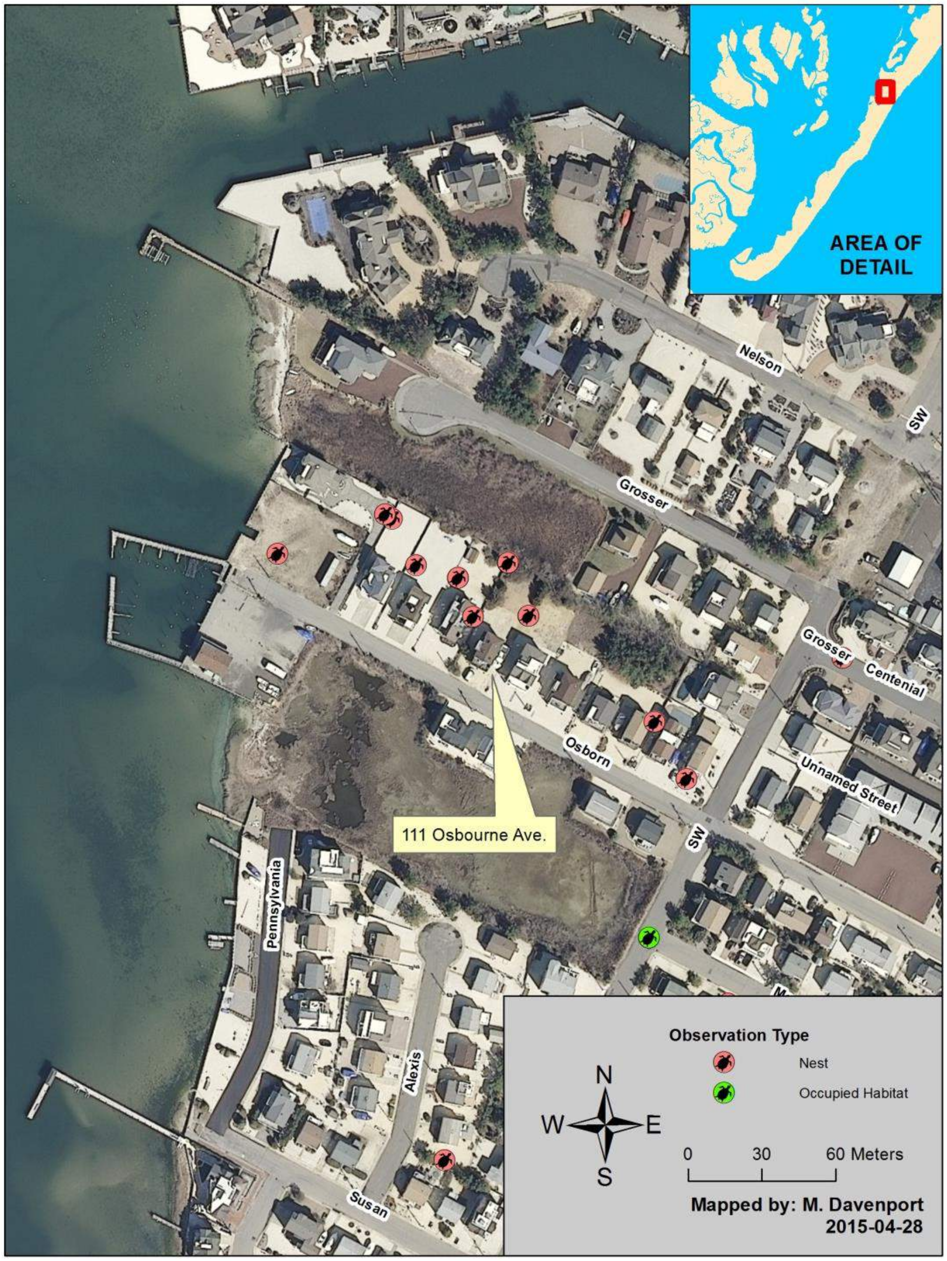

Figure 3. Occurrence type and location of nesting females on south LBI during the 2014 nesting season. Nest is area of known nesting as evidenced by egg(s), egg shell fragments, or a female actively depositing eggs.

Table 1. Confirmed nests found on LBI during 2014 that were not included in this study.

Type	Date	Location	Predator
Confirmed Nest	17-Jun	Arnold Blvd	-
Confirmed Nest	13-Jun	Arnold Blvd	-
Confirmed Nest	30-Jun	Arnold Blvd	-
Confirmed Nest	30-Jun-03-Jul	Arnold Blvd	-
Confirmed Nest	30-Jun-03-Jul	Arnold Blvd	-
Confirmed Nest	9-Jun	Arnold Blvd	-
Confirmed Nest	12-Jul	Arnold Blvd	-
Confirmed Nest	30-Jun	Arnold Blvd	-
Confirmed Nest	30-Jun-03-Jul	Arnold Blvd	-
Confirmed Nest Depredated	Unknown	Arnold Blvd	Unknown
Confirmed Nest Depredated	3-Jul	Arnold Blvd	Unknown
Confirmed Nest	14-Jun	Arnold Blvd	Unknown
Confirmed Nest	22-Jun	Arnold Blvd	-
Confirmed Nest Depredated	12-Jul	Albright Road	-
Confirmed Nest Depredated	12-Jul	Albright Road	Unknown
Confirmed Nest Depredated	Unknown	Antioch Road	Unknown
Confirmed Nest Depredated	Unknown	Antioch Road	Unknown
Confirmed Nest Depredated	Unknown	Tidal Drive	Unknown
Confirmed Nest Depredated	Unknown	Tidal Drive	Unknown
Confirmed Nest Depredated	Unknown	Tidal Drive	Unknown
Confirmed Nest Depredated	Unknown	Tidal Drive	Unknown
Confirmed Nest Depredated	Unknown	Tidal Drive	Unknown
Confirmed Nest Depredated	Unknown	Tidal Drive	Unknown
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Confirmed Nest Depredated	Unknown	Tidal Drive	Unknown
Confirmed Nest Depredated	Unknown	Tidal Drive	Unknown

Confirmed Nest Depredated	Unknown	Tidal Drive	Unknown
Confirmed Nest Depredated	Unknown	Tidal Drive	Unknown
Confirmed Nest Depredated	Unknown	Tidal Drive	Fox
Confirmed Nest Depredated	Unknown	Tidal Drive	Fox
Confirmed Nest Depredated	Unknown	Tidal Drive	Fox
Confirmed Nest Depredated	Unknown	Tidal Drive	Crow
Confirmed Nest Depredated	Unknown	Tidal Drive	Crow
Confirmed Nest Depredated	Unknown	Tidal Drive	Fox
Confirmed Nest Depredated	Unknown	Tidal Drive	Unknown
Confirmed Nest Depredated	Unknown	Tidal Drive	Fox
Confirmed Nest Depredated	Unknown	Tidal Drive	Fox
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Confirmed Nest Depredated	Unknown	Tidal Drive	Fox
Confirmed Nest Depredated	Unknown	Tidal Drive	Fox
Confirmed Nest Depredated	Unknown	Tidal Drive	Fox
Confirmed Nest Depredated	Unknown	Tidal Drive	Crow
Confirmed Nest Depredated	Unknown	Tidal Drive	Unknown
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