The Effect of Soil Conductivity on Nest Site Selection in Northern Diamondback Terrapins

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ABSTRACT:

An *in situ* study on the effect of soil conductivity on nest site selection of northern diamondback terrapins was conducted. It was hypothesized that nesting terrapins are able to use cues for soil conductivity detect differences, thus should nest in areas of lower conductivity. To test this hypothesis, three areas on N. Sedge Island were designated, with each having three different types of plots: control (with no enhancement to the soil), high conductivity (simulating a storm surge event), and medium conductivity (a mixture of rainwater and high conductivity treatments). The soil conductivity, soil moisture and nest temperatures were recorded and significance was determined by using basic statistical analysis. Trends in nest site selection patterns for female terrapins that nested multiple times were observed. My results indicated that terrapins do not select nest sites based on soil conductivity. This study was the first of its kind as there has been no previous work in how soil conductivity affects nest site selection in terrapins. Also, with sea level rise, it is important to assess terrapin nesting sites and how the influence of salt water inundation affects nesting areas.

INTRODUCTION:

The northern diamondback terrapin (*Malacleymys terrapin terrapin*) is one of seven subspecies of terrapin that can be found throughout the east and Gulf coasts of the United States in brackish water (Northern Diamondback Terrapin 2015). These are the only species of turtles endemic to estuaries in the western hemisphere. Diamondback terrapins exhibit nest site fidelity, returning to the same nesting territory every year as reported by Burger and Montevecchi when terrapins returned to Little Beach, New Jersey each nesting season (Burger and Montevecchi 1975). Nesting females will lay eggs, ranging from 2 – 20 eggs per clutch, from early June through mid-July. Sandy beaches and upland areas that are made up of gravel and rise above the high tide line are preferred nesting habitat (Burger and Montevecchi 1975).

Within nesting habitats, there has been limited research how microenvironments affect nest site selection and conditions. Some of these conditions include soil moisture availability to the eggs and developing embryos, as well as nest temperature and soil particle composition. In terms of salt ions, increased ions can affect soil conductivity, thus moisture within the soil. In a previous study done by Dr. John Wnek it was determined that “high soil conductivity leads to 100% embryo mortality with no embryonic development past the first stage of development”

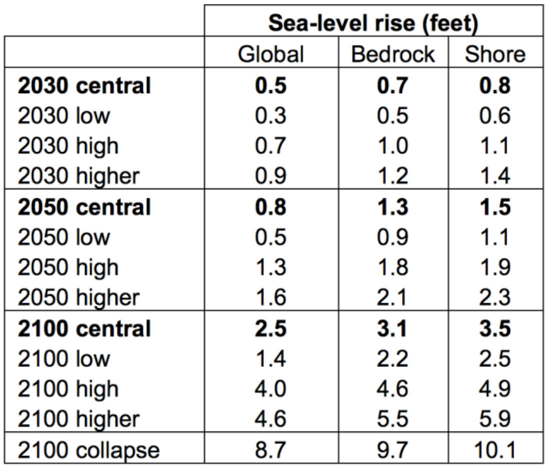
(Wnek 2010). It was also ascertained in areas of high conductivity that 66% of the eggs in the nests were desiccated, dried, whereas in areas of low soil conductivity only 16.7% of the eggs in nests were desiccated (Wnek 2010). Higher soil conductivity occurs when an area has been impacted by inundation events, like strong storms or higher tides (Foley 2006), when dredged material is added to a shoreline (Wnek 2010) and long term water exposure as a result of rising sea levels.

Barnegat Bay, located in Central New Jersey has been altered greatly by humans and shore development has sky rocketed since the mid-1990s. In Barnegat Bay alone nearly 36 % of shorelines have been altered (Wnek 2010). The expansion of human structures on bayside shorelines decreases viable nesting habitat for diamondback terrapins, and anthropogenic shore development is not the only threat to the diamondback terrapins and the Jersey Shore. Sea level rise (SLR) is a global threat with the melting of land based ice, such as the polar ice caps and the thermal expansion of sea water (Nicholls & Cazenave 2010; Church 2011; NOAA 2014). Studies indicate that there has been a consistent increase in sea level of 0.04 – 0.10 inches per year since 1990, and an increased rate of 0.12 inches per year since 1992 (Nicholls & Cazenave 2010; Church 2011; NOAA 2014). More prominent in New Jersey and most of the Mid-Atlantic is the effect of isostatic rebound and subsidence. Isostatic rebound is the slow downward movement of the North American continental plate due to the lost weight of the ice sheets from the beginning of the Quaternary glaciation (Huch, personal communication). Along with the subsidence, the compaction of the lose sands, which causes a sinking of the area (Huch, personal communication).

When these two factors combine, SLR is amplified in coastal New Jersey. SLR estimates are outline in Table 1, estimating almost double the rate of increase in coastal New Jersey (1.5

feet) than the global average (0.8 feet) by 2050 (Miller et al 2013). In figure 1, the effect of SLR on North Sedge Island is shown, at one foot increase alone, most of the island is inundated, along with many other parts of the Sedge Islands and much of the bay side of IBSP, prime terrapin nesting habitat. Once 4 feet of SLR occurs, the entirety of Sedge Islands are [covered] in water, gone from Barnegat Bay. Due to the loss of marshes and barrier islands, terrapins must nest in areas that are secondary to their primary sandy beaches and, in these different areas, microenvironmental factors, such as increases in soil moistures or changes in soil temperature, play a greater role in nest survival (Wnek 2010).

Table 1: The sea level rise is broken down into three categories. The global estimate is from the United Nations and IPCC report. The bedrock refers to the parts of the state that rest on bed rock, like northern parts of the state. Shore estimates are for our coastal areas (from Monmouth down to Cape May and back up the Delaware). (Miller et. al. 2013)



	Sea-level rise (feet)		
	Global	Bedrock	Shore
2030 central	**0.5**	**0.7**	**0.8**
2030 low	0.3	0.5	0.6
2030 high	0.7	1.0	1.1
2030 higher	0.9	1.2	1.4
2050 central	**0.8**	**1.3**	**1.5**
2050 low	0.5	0.9	1.1
2050 high	1.3	1.8	1.9
2050 higher	1.6	2.1	2.3
2100 central	**2.5**	**3.1**	**3.5**
2100 low	1.4	2.2	2.5
2100 high	4.0	4.6	4.9
2100 higher	4.6	5.5	5.9
2100 collapse	8.7	9.7	10.1

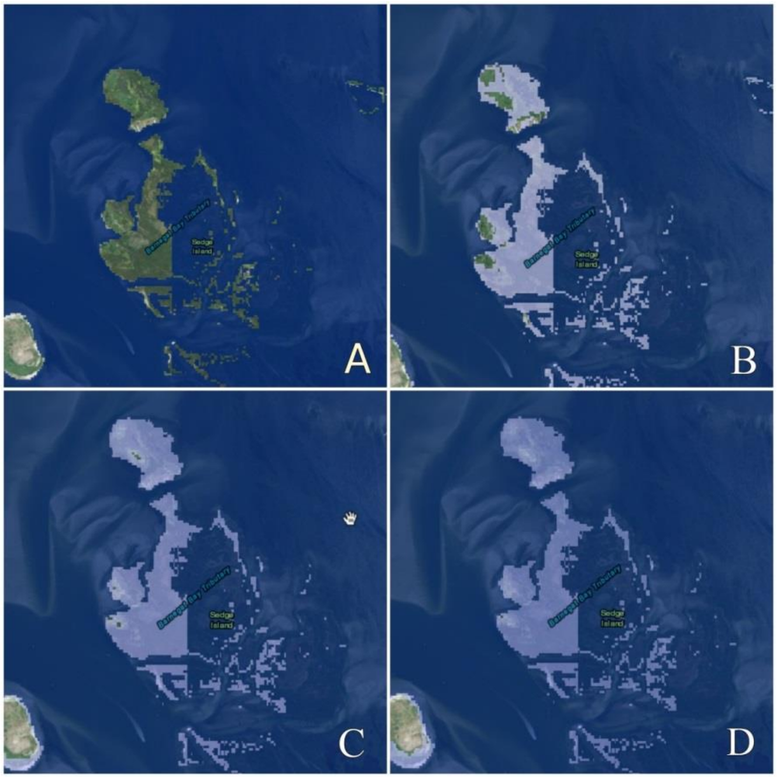


Figure 1: Map of Sedge Islands (N 39°47.43’ W 74°07.48’) with SLR for 1 foot (B), 3 feet (C), and 4 feet (D), where the islands become completely inundated (Rutgers 2013)

North Sedge Island, located in Barnegat Bay, is composed of predominately salt marshes with access to bay beaches on the north and east sides. Mature female terrapins utilize these bay beaches to gain access to nest on the Island (Figures 2). In the early 20th Century, 10% of the island was filled in with dredge material from the Barnegat Bay to create an area for a hunting shack residence. As a result, the area provided suitable habitat for diamondback terrapins to nest. A long-term terrapin nest site study was commenced in 2002 to assess nest site fidelity and nest site environmental condition on the Island, making it a suitable location to study the effect of soil conductivity on nest site. In this time, a return rate of 75-90% has been observed. There are some human disturbances on the Island that may affect terrapin nesting, such as the small Natural

Resource Education Center, where small groups stay for a few days at a time. However, this has not shown to impact the nesting frequency of females on the island (Cruz 2012).

Figure 2: Map of North Sedge Island (N 39°47.43' W 74°07.48'). Predominately composted of salt marsh, there are two human structures on the island with bay beach access on the east and the southwest sides of the island. The site of the study is denoted as the red star on the southwest side of the NREC house.

The objective of this study was to determine if the soil conductivity had an effect on nest site selection in Northern Diamondback terrapins. With SLR, it is important to assess terrapin nesting sites and how the influence of salt water inundation affects nesting areas. For example, in October 2012, the Jersey Shore was hit with one of the most powerful storms in recent history, Hurricane Sandy. The United States Geological Survey predicted "most of New Jersey coast was very likely to experience extensive beach and dune erosion and many areas were very likely to overwash" (Coastal Change Hazards 2012). In previous studies done on the Island, it was determined that the same number of female terrapins were landing on the Island in 2013 as they were in 2012; however a significant reduction in the number of nests dug in 2013 than in 2012. In 2014, the number of females and nests dug were the same as in 2012 previous to Sandy

(Wnek, personal communications). I wanted to determine if this lack of nesting was a result of changes in the nesting habitat or for other reasons.

QUESTIONS:

Do northern diamondback terrapins differentiate between a high soil conductivity area and an area of low soil conductivity in terms of nest site selection? |

Also, when nesting female terrapins are digging in areas of relatively high soil conductivity, can we observe certain cues to detect the conductivity and do they move to an area of lower conductivity?

This study is the first of its kind as there has been no previous work in how soil conductivity affects nest site selection in terrapins.

METHODS:

The Site: The study site was located on North Sedge Island, in Island Beach State Park NJ. Sedge Island is composed of predominately salt marshes with access to bay beaches to the southwest and east sides of the Island. Three areas along the southwest lawn of the Island were dug out, creating open nesting areas (Figure 3). In each of these areas (each 4 x 3 m), three treatment plots were created (1 m x 1 m); a plot of high soil conductivity, a plot of middle conductivity and a plot of low conductivity (Figure 3), placed 15 cm (6 inches) apart to buffer the treatments (Wnek 2010). To differentiate between plots, 5 x 5 x 30 cm (2 x 2 x 12 inch) stakes were driven flush into the group without interfering with the landscape, also to not cause tripping or mowing interference.

Figure 3: Study Area – Three similarly sandy areas are designated as one, two or three. Each area contains three treatment areas, one high conductivity (3000 – 7000 µS/cm) , medium conductivity (1500 – 3000 µS/cm) and control (70 – 400 µS/cm).

Data Collection of Conductivity: Soil conductivities (uS/cm) were measured by taking three random 30 mL samples from each plot from each treatment area. Each soil sample was mixed with two parts of distilled water (60 mL) and soil conductivity was measured using a YSI 30 multimeter (Rhoades et al. 1997). After a rainfall event and after a plot was treated the soil conductivity were measured. The conductivity values for the untreated nesting areas at Sedge ranged from 40 – 350 uS/cm, thus were considered control. Bay water (a conductivity of approximately 39.00 mS/cm) was added to the plots and given time to dry out so to not saturate the soil, until a conductivity of ranging from 3000 – 7000 uS/cm was obtained. For the medium conductivity, a dilution of bay water and rain water (the mixture was approximately 21.50 mS/cm) was added to the soil in the same fashion until a range of 1500 – 3000 uS/cm was reached. Rainwater was used in this experiment because it was an *in-situ* study and reflected the actual soil conductivity of the soils on Sedge Island (Wnek 2010). Also, mixing well water at Sedge would be problematic in that the water would provide multiple other variables that could not be controlled (i.e., sulfur, iron, etc…). Bringing in an outside source of water or using purified water would also be problematic in that it does not reflect the actual input of water in natural nests.

Data Collection of Terrapin Nesting: From early June to mid-July, terrapin nest site selection behavior was observed, including times of landing and nest site choice. The behavior of the terrapins in which plots they chose to nest in and if they moved from plot to plot after 'checking the sand' was recorded. Nesting terrapins were captured, identified, measured and marked if not previously done. Nests within the plots were moved to the hatchery already established on the Island to decrease predation and increase hatchling success, which was protocol for the ongoing study on the Island.

Thermochron I-buttons (DS1 model, +/- 1C) were used to record nest temperatures at 60 minute intervals in seven random nests throughout the incubation period. This data will give information on incubation temperatures and gender development for the 2015 season.

From late July to August, after the nesting season had ended, the data was analyzed. It is important to note that the focus of this research was on nest site selection, not hatchling success. The temperatures recorded were not significant in the soil conductivity but support an existing study at N. Sedge Island. Soil was analyzed to determine any significance on nest site selection in the terrapins.

Soil Analysis: Samples of the soil were taken and composition was determined using a gravimetric method and sieving. The percent of composition of particle sizes were determined using sieve analysis. I sieved soil samples taken from each treatment plot within each area, assessing the particle size distribution of the soil (Ingram 1971). Using a sieve shaker, each sample was shaken for three minutes. Sieve plates of varying wire mesh size were used and each number corresponded with different particle sizes, 4 (granule) 10 & 16 (very course sand), 30 (course sand), 45 (medium sand), 70 (fine sand), 170 (very fine sand), pan (silt and finer).

Soil Moisture Tension: The soil moisture was measured using a Delmhorst® Soil Moisture tension meter and recorded daily. This was used to check the soil tension and give a more detailed reading on the hydric conditions of the soil. The organic material of the soil was also determined by measuring 10.000 grams of a soil sample, heating the sample to 500 ^{o}C. The samples were then measured afterwards, to determine amount of organic lost, which resulted in a percentage of organic material.

RESULTS:

Terrapin Results: For six weeks from June 5th to July 19th 2015, 63 terrapins and 64 nests were observed on North Sedge Island. 54 active nests were observed and recorded, and an additional 10 nests were observed after predation. Of these 64 nests, 44 were found in my three treated areas, creating a sample size of 44. The location of each nest was observed and recorded (Figure 4).

The number of nests in the sample size was then broken down into which conductivity plot they had nested in, high, medium or control (Figure 5). Of the 44 nests, 18 were in control plots, 11 were in medium, 7 in high plots and 8 were outside of treatment areas. While more terrapins chose to nest in control areas, there was no statistical difference between the number of terrapins nesting in these areas (ANOVA; $F_{1,44}$=1.174603; $P > 0.05$).

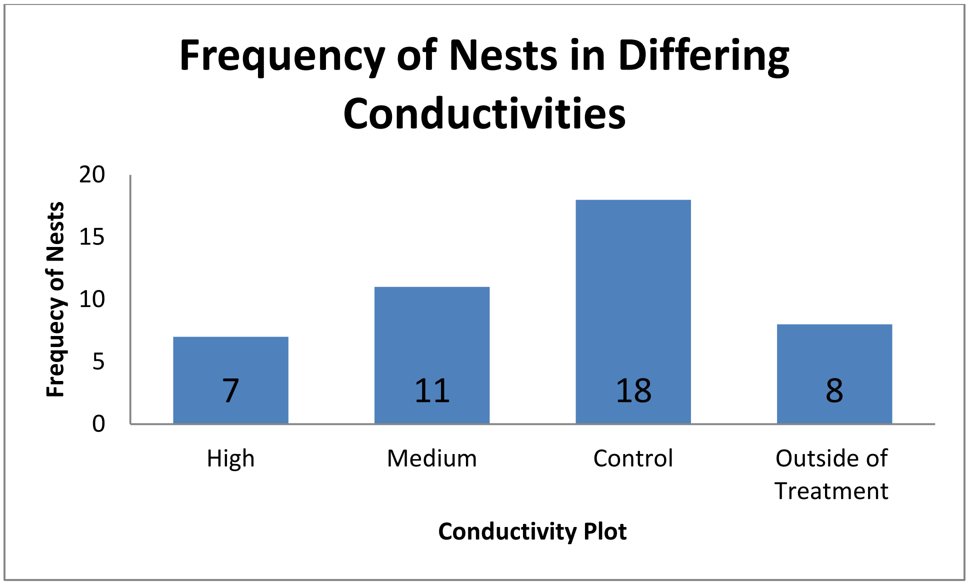


Figure 5: Frequency of Nests in Differing Conductivities: The sample size of 44 nests, were broken down into which treatment plot the terrapin nested in. There was found to be no statistical difference in which treatment area was chosen ($F_{1,43} = 174603$; $P > 0.05$).

Soil Samples: Soil samples were taken from nests starting from June 19th to the end of my sample period on July 19th, creating 24 data points. The conductivity of the soil samples were taken and recorded. The lowest recorded conductivity nested in was 73.7 uS/cm and was in Area 3, outside of the control plot, and the highest was 5680 uS/cm on the edge of a medium plot in Area 2. Although there was no statistical significance, 15 out of the 24 points were in areas of 300 uS/cm or lower conductivities, while only three nests were in conductivities of 3000 uS/cm or greater, and the remaining 6 nests ranging between 600 uS/cm to 2466 uS/cm.

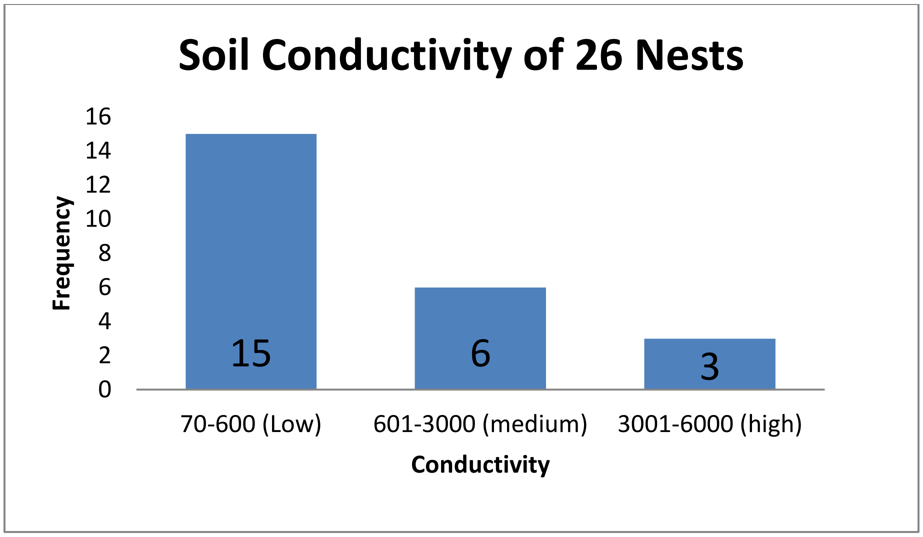


Figure 6: The soil conductivity for 26 terrapin nests was taken and broken down into three groups. The first group is low ranging from 70- 600 uS/cm, second group is medium ranging 601-3000 uS/cm and the final group of high ranging from 3001 uS/cm to the highest soil conductivity recorded at a nest site of 5680 µS/cm

Multiple Nesting Results: Six terrapins came up to nest more than once. The soil conductivities of where they nested each time was compared and recorded (Figure 7). Since our marked terrpain population have unique notch codes (Cagle 1952), we denoted our population by their alphabetical code marginal designation. Of the six terrapins that returned to my study areas multiple times four of them nested in areas of the same conductivity. Terrapins ABHIW and BCQW (nested three times) nested in areas of low conductivity each time. CKNWX nested in areas of medium conductivity both times. While NOVW nested in areas of high conductivity every time she nested. Only two of the six turtles, KNVW and KNQW (nested three times) nested in areas of differing conductivity. KNVW first nested in an area of medium conductivity on June 19th terrapin, while on July 17th, KNVW nested in a control plot and an area of low conductivity. The first two times that KNQW nested in areas of medium conductivity, but the third time she came up, KNQW nested in an area of low conductivity.

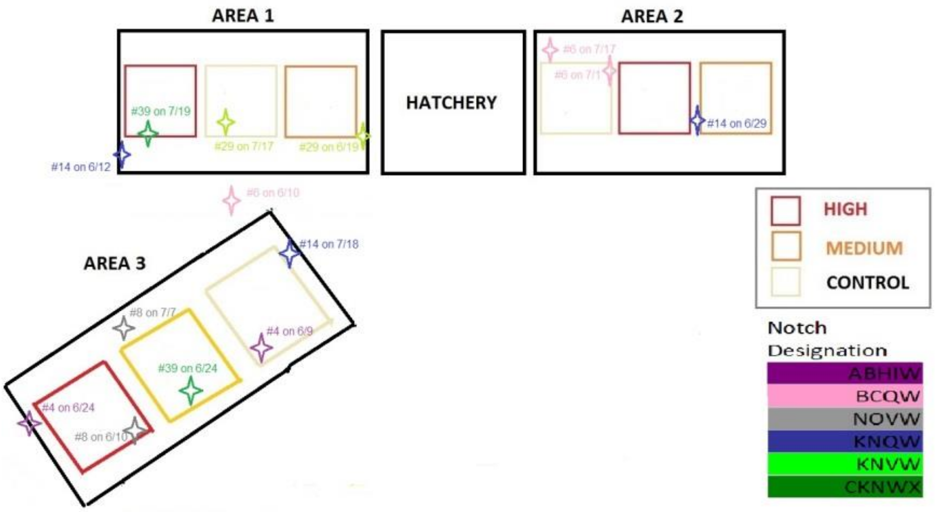


Figure 7: Diagram of nest sites of terrapins that nested multiple times during nesting season. Six terrapins nested more than once, four nested twice and two nested three times. Of the six terrapins that nested more than once, four nested in areas of the same conductivity each time they nested.

Soil Moisture Tension: The amount of moisture in the soil was measured using a Delmhorst® Soil Moisture tension meter. The treatment plots in Area 1 were measured, including a natural area close by. The high treatment plot had a significantly higher amount of moisture in the soil, than the other areas ($F_{1,79} = 73.23622$; $P < 0.05$).. Natural and control areas had the lowest amount of moisture in the soil (Figure 8).

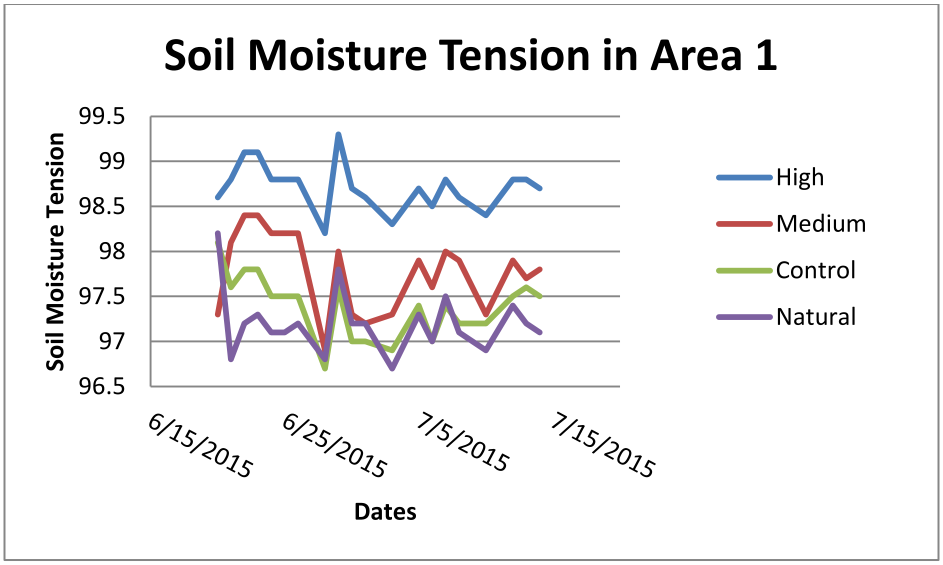


Figure 8: Soil Moisture Tension: Soil Moisture Tension was measured in treatment Area 1 from June 20th 2015 to July 14th 2015. The high treatment plot had the highest soil moisture tension, while natural and control had the lowest soil moisture tension ($F_{1,79} = 73.23622$; $P < 0.05$).

Soil Structure: From the sieve analysis samples were added together from 10, 16, 30, 45, 70 and 170 sieve plates depending on their mesh designation and sorted into gravel, sand, silt and clay. Each area and treatment plot saw 97 – 99% of the composition was sand and 1- 3% was silt or finer (Table 2). A textural triangle (Figure 10) was used and it was determined that all 9 treatment plots consisted of sandy soils.

Table 2: Soil Composition. Using sieve anaylsis the fraction of the composition of the soil was found in grams. There was statistical differences in the fraction of very course sand, medium sand, and fine sane between the different areas.

	Area 1			**Area 2**			**Area 3**		
Type of Particle	High	Medium	Control	High	Medium	Control	High	Medium	Control
Granule	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002
Very Course Sand	0.000	0.001	0.000	0.004	0.000	0.000	0.002	0.003	0.003
Course Sand	0.014	0.014	0.010	0.006	0.010	0.006	0.018	0.034	0.050
Medium Sand	0.098	0.109	0.102	0.055	0.076	0.059	0.167	0.238	0.391
Fine Sand	0.375	0.372	0.412	0.282	0.363	0.277	0.370	0.352	0.363
Very Fine Sand	0.492	0.477	0.430	0.623	0.537	0.632	0.423	0.354	0.186
Silt	0.020	0.026	0.024	0.019	0.014	0.024	0.019	0.017	0.010

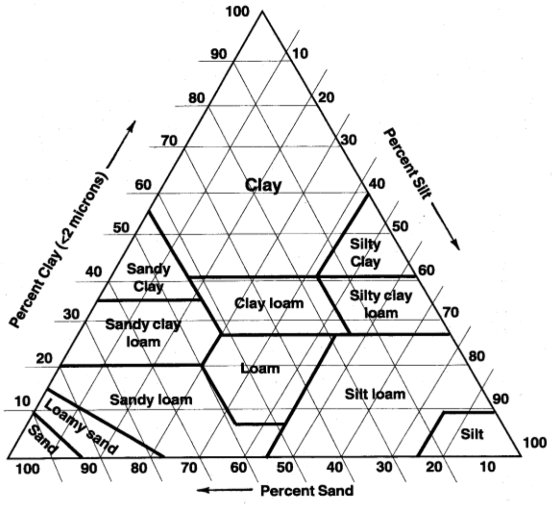


Figure 10: Textural Triangle. Using sieve analysis the, fractions were then taken and applied to find the composition of the different soil samples. . It was found that all the soil samples were composed of sandy soils.

The amount of organics were measured (Table 3) and it was found that Area 3 had a statistically significant lower amount of organics in the soil than Areas 1 and 2 ($F_{1,8} = 10.369$, $P < 0.05$). Of the nine treatment plots Area 3 high treatment had the lowest percent of organic material at 0.330%, while Area 1 high had the highest percent of organic material in the soil at 2.762%.

Table 3: Percent of Organic Material. The percent of organic material in each plot in each treatment area was found. Area 3 had a statistically lower amount of organic material than Area 1 and 2 ($F_{1,8} = 10.369$, $P < 0.05$).

	Area 1	Area 2	Area 3
High	2.762	2.650	0.330
Medium	2.601	2.760	1.210
Control	2.621	1.259	0.580

DISCUSSION:

Although there were a limited number of results, it was statistically found that the terrapins were selecting their nest site based on randomness rather than specific cause of a lower soil conductivity. This puts terrapins at higher risk when flooding events occur, because those events increase the soil conductivity and if a terrapin chooses to nest at a site that was once flooded, at least two-thirds (66.7%) of those eggs will become desiccated from the lack of moisture and die (Wnek 2010).

During this study, seven nests were laid in areas of high conductivity and the mean number of eggs laid in nests was 12.59. That is a total of 88 eggs, 66.7% of those, or 59 eggs, would not make it through incubation period because of lack of available moisture in the soil. Normally, there is only a 1% survival rate for hatchlings; therefore, lowering the chances an embryo can develop and successfully hatch can have a negative impact on sustaining terrapin populations. Diamondback terrapins are very important to salt marsh ecosystems and are an indicator of the health of the system (Silliman and Bertness 2002). They are an apex predator in the system and if they are removed the system becomes imbalanced, and not able to perform the important economic and ecological services.

Although there was a trend in the number of nests in each treatment area; seven in high, eleven in medium and eighteen in low/control, there was no correlation drawn as previously stated. While not statistically significant, of the soil conductivities recorded at the nest sites, 15 of 24 nests were in areas in which the conductivities were 300 uS/cm or lower. This shows a potential trend that with more research and a larger sample size could be further explored if this experiment was replicated.

The terrapins that also returned to the Island may be an indication that soil conductivity plays a role in the nest site selection. Four of the six that returned multiple times throughout the summer to nest, nested in areas of similar conductivity each time. KNWV, first nested in an area of medium soil conductivity and then came back and nested in an area of low soil conductivity. Terrapin KNQW nested three times during the nesting season. The first two times KNQW came up and nested in areas of high conductivity, but the third time KNQW nested in an area of low conductivity. This also notes a trend that they did not move to areas of higher conductivity.

Soil moisture tension showed how much moisture was in the soil. The high treatment plot had the greatest amount of moisture but due to the salt ions in the soil, that moisture is not available to things such as terrapin eggs or plant roots (Wnek, personal communication). While the natural and control had very similar soil moisture tension readings, that moisture was more available to things such as terrapin eggs because there is much less salt in the soil.

The composition of the soil also plays a large role in how much salt is in the soil (and how high the soil conductivity will be (USDA 2011). The smaller the soil particle size, the larger it’s attraction to the salt ions. Soils composed of predominately silt or clay will hold much more tightly to the salt ions and exhibit much higher soil conductivities while sandy and gravely soils have a less attraction and the salt ions are able to filtrate through the soil much easier (USDA 2011). This is good for the treatment areas in my study, because they were all sandy soils will predominately fine and very fine sand particles. This allowed the salt in the treatment areas to wash out more quickly than if the soil was made up of silts and clays.

Another important component of the soil is the amount of organic material in the soil. Organic material, much like smaller soil particles will hold onto the salt ions much more readily (USDA 2011). Meaning, the more organic material in the soil the higher the soil conductivity. It was found that Area 3 in all treatment plots had a much lower organic matter than Area 1 and 2. This was shown throughout the summer in the consistently lower soil conductivity readings than seen in the other two treatment areas. Despite the lower amount of organic material in the soil at Area 3, the number of nests were not different than those in Area 2 that had a higher organic composition. This may indicate that terrapins do not choose nest site selection based on organics.

The effect of soil conductivity is significant for not just terrapins but other shore nesters, because of the increasing risk of sea level rise, especially that estimated to impact the Jersey Shore (NOAA 2015). By the end of the century there will be a global increase of 2.5 feet, while the Jersey Shore will increase an estimated 3.5 feet (Miller 2013). As shown in figure 1, this has a huge impact on prime nesting habitat, and across the Barnegat Bay, not just Sedge Island.

CONCLUSION FOR MANAGEMENT OF TERRAPINS:

It was determined that diamondback terrapins do not differentiate between a high soil conductivity area and an area of low soil conductivity when selecting a nest site. It also indicates that nesting females do not use cues to detect the conductivity of the soil in relatively high soil areas, before they move to an area of lower conductivity.

The impact of sea level rise reaches beyond Sedge Island and the northern diamondback terrapins. Coastal areas are home to hundreds of millions of people, ranging from New York City, NY to Miami FL. They are integral to our economy and ecologically, especially salt marshes, which act as a sponge for flood waters, pollutants and excess nutrients. Diamondback terrapins are very important to salt marsh ecosystems and are an indicator of the health of the system (Silliman & Bertness 2002). They are an apex predator in the system and if they are removed the system becomes imbalanced, and not able to perform the important economic and ecological services. So when prime terrapin nesting habitat is being degraded (increased soil conductivity) through inundation events and SLR, we are losing an important component for their continued survival (Silliman & Berness 2002).

As a study that was first of its kind, it would be pertinent to continue research on the effects of soil conductivity in nest site selection to ensure its impact on this species, and that of other shore line nesting species. It is also imperative that there be continued education about shore nesters and the known threats they detect from SLR. We need to protect, enhance, and, sometimes, create more “natural” nesting areas for our shore nesters.

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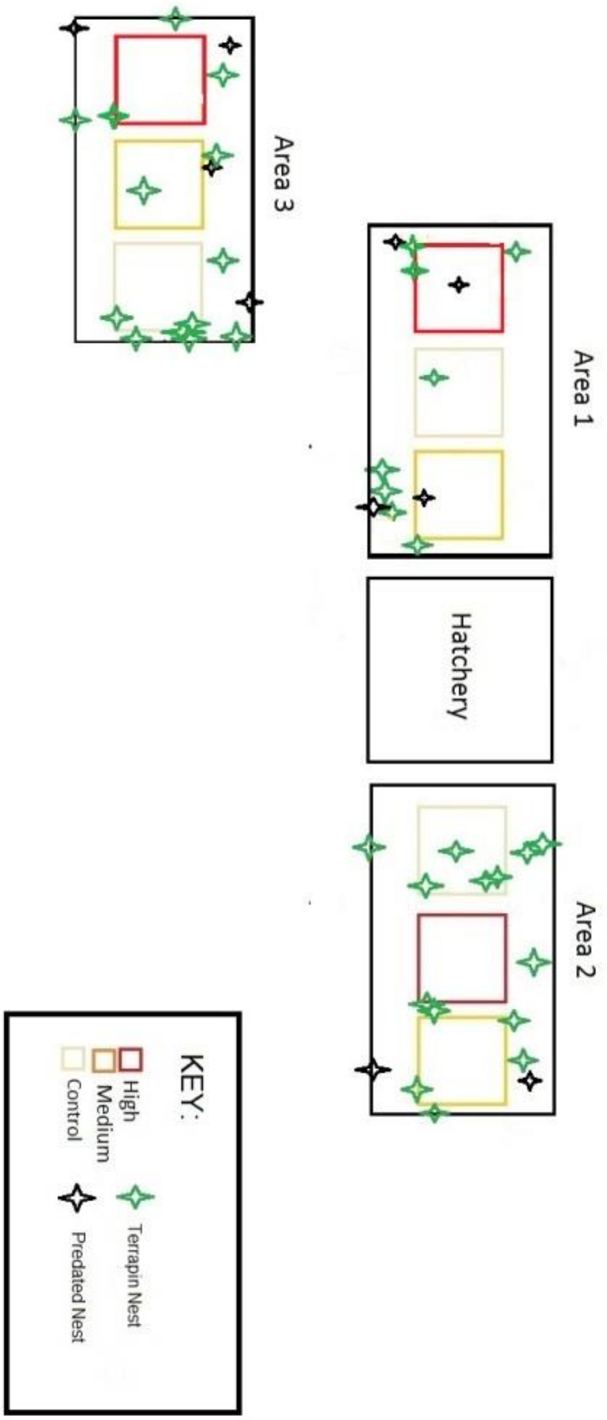

Figure 4: Locations of the 44 nests on North Sedge Island inside of the treatment areas from June 9th to July 19th, 2015. Green stars represent the 34 successful nests and the black stars represent the 10 predated nests.

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