EXAMINING NEST SITE DISTRIBUTION AND ABUNDANCE IN A POPULATION OF NORTHERN DIAMONDBACK TERRAPINS (Malaclemys terrapin terrapin)

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Abstract

The diamondback terrapin (*Malaclemys terrapin*) is a unique aquatic turtle because it can inhabit estuarine environments. The species is endangered in Rhode Island, with only one confirmed nesting area located at the Douglas Rayner Wildlife Refuge at Nockum Hill in Barrington, RI. Relatively little is known of the nesting behaviors of diamondback terrapins, and few studies have investigated nesting within the Rhode Island population. The goal of this research was to examine the distribution and abundance of terrapin nests in the Douglas Rayner Wildlife Refuge. The number of nests present in nine areas of the refuge was compared. Physical properties of nesting areas were examined, including soil temperature, distance from the water, soil density, soil grain size, and vegetative cover. Only vegetation cover was found to have a significant relationship with the number of nests in each area. Terrapins were found to prefer areas of 0-50% vegetative cover. Predation was examined by distinguishing between nests that were found destroyed and those that were found intact within each area. Predators appeared to be more likely to feed on nests in areas with 25-50% vegetative cover. Extensive nesting was discovered in the meadow, an area previously considered to be used sparingly by nesting females. Population estimates were also performed using mark and recapture data, showing a population increase from 166 to 288 terrapins from 2000 to 2010. The results of this study have improved our understanding of habitat use by diamondback terrapins in Rhode Island, and will therefore aid in future conservation efforts for the species.

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INTRODUCTION

Habitat selection, a universal activity in animals, is an important ecological factor that shapes much of an animal's life history (Orians and Wittenberger 1991). Most animals are known to quickly make decisions regarding habitat quality based on general environmental factors (Orians and Wittenberger 1991). In addition, animals typically prefer habitats in which they have the greatest survivability and reproductive success (Orians and Wittenberger 1991). Therefore, habitat selection can have profound effects on the survival of individuals. This includes maternal nest site selection, which can impact the survival and fitness of the offspring (Kolbe and Janzen 2002).

While nest site selection has been studied extensively in insects, less is known about this topic in reptile populations, and few studies have investigated how nest site selection may impact the nest success of reptiles (Kolbe and Janzen 2002). Maternal effects on offspring survival and phenotype have been observed in a population of the snapping turtle, *Chelydra sepentina* (Kolbe and Janzen 2002). In this population of turtles, nest location influenced the survival of the nest, and temperature of the nest was shown to influence sex ratios (Kolbe and Janzen 2002). Because of these maternal effects, knowledge of what drives the choices an individual makes regarding its habitat can be useful for species conservation. The diamondback terrapin, (*Malaclemys terrapin*) is a species whose conservation could be aided by an increased understanding of the factors influencing nest site selection.

The diamondback terrapin is an estuarine turtle whose range covers the Atlantic coast of North America, from Texas to Massachusetts (Brennessel 2006). Across its range, the species is divided into seven subspecies based on differences in body size and coloration (Brennessel 2006). Diamondback terrapins spend the majority of their time in the water, leaving only to bask, or in the case of females, to lay their eggs. The diamondback terrapin is biologically unique in that it is the only species of North American turtle that can live its entire life in brackish water. In addition, the species exhibits high levels of sexual dimorphism, with males being around 50% smaller than females. The unique biology of diamondback terrapins, combined with their striking coloration, makes them attractive to both scientists and non-scientists.

However, due to past impacts of human hunting and increasing habitat loss, the future of the diamondback terrapin is uncertain. Loss of salt marsh habitat due to increasing coastal development has destroyed much of the nesting, feeding, and basking habitat of the species (Brennessel 2006). As habitat is altered and developed for human use, subsidized predators such as raccoons may find their way into terrapin habitat and may prey upon terrapins or their eggs (Marchand and Litvaitis 2003). Human hunting, which intensified in the 1800's, nearly drove the diamondback terrapin to extinction by the early 20th century (Brennessel 2006). Although terrapin consumption in North America is largely a thing of the past, there is still a demand for turtle meat in ethnic markets, and many diamondback terrapins are harvested each year as a result. Many more drown in commercial and recreational crab traps as bycatch, or are killed by automobiles while searching for nest sites. As a result of the combined effects of these threats, they are now protected on various levels throughout their range (Brennessel 2006).

The imperiled status of diamondback terrapin populations is particularly apparent in Rhode Island, where it is listed as a state endangered species (RINHS 2006). There is only one confirmed population of northern diamondback terrapins (subspecies *M. terrapin terrapin*) within Rhode Island, and the exact number of individuals within this population is unknown. In addition it is believed that this population nests only at the Douglas Rayner Wildlife Refuge, located at Nockum Hill in Barrington, Rhode Island. Nockum Hill is a 20 hectare peninsula jutting out from the north shore of the Barrington River, an estuarine body of water surrounded by salt marsh habitat (Goodwin 1994). The upland sections of the peninsula are covered mainly with mixed forest habitat, sandpits, meadows, agricultural land and early successional fields. In 1992, the land was designated as a wildlife refuge due to its significance as a nesting area for the local terrapin population (Goodwin 1994). Nockum Hill has nine different areas that terrapins are known to nest in (Figure 1). The most noticeable difference between these areas is the percent of vegetation cover.

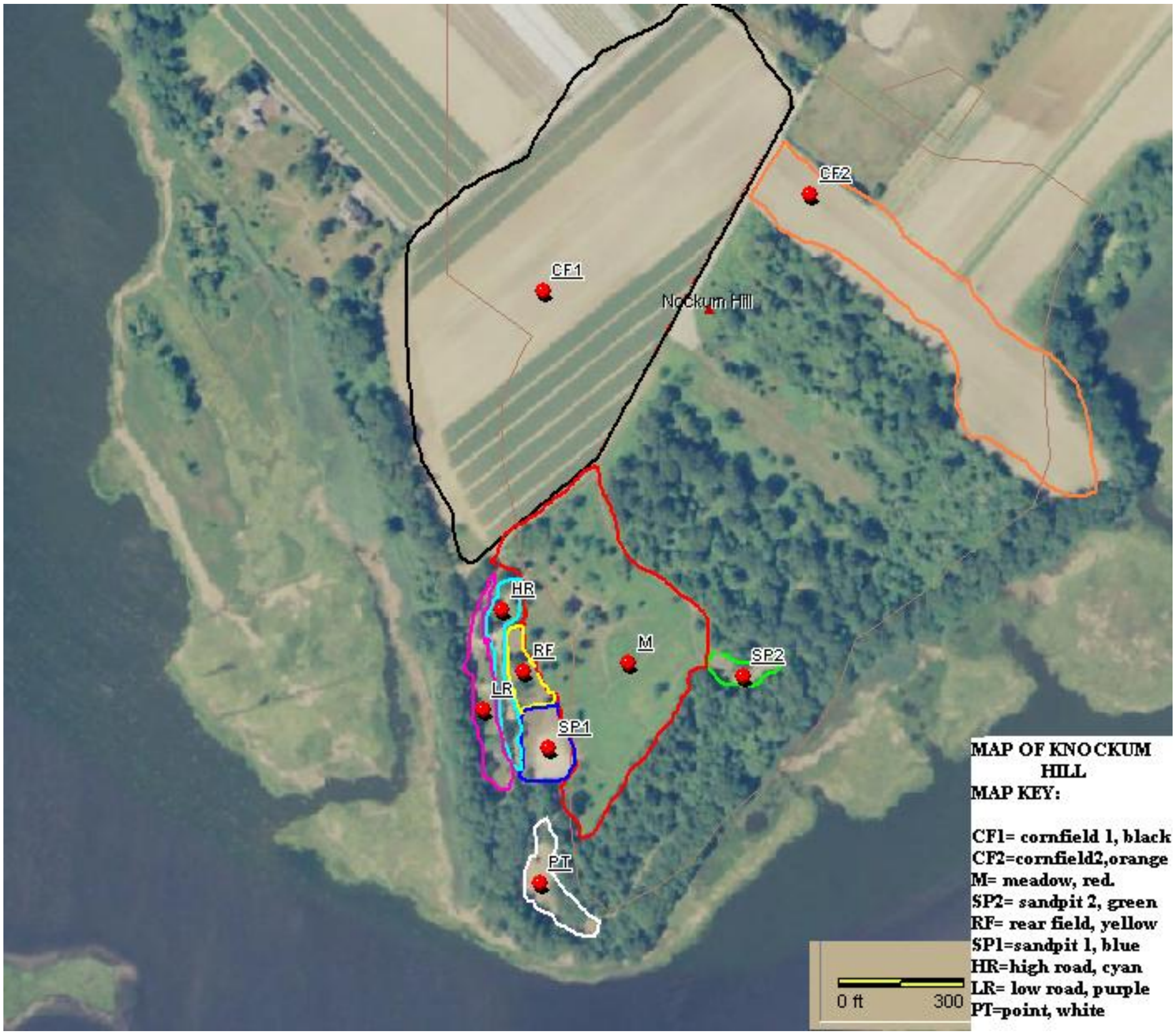

Figure 1: *The nine sections of Nockum Hill where terrapins are known to nest.*

Since 1990, nesting females have been studied using mark and recapture techniques. This research is headed by Charlotte Sornborger, a volunteer researcher from the Barrington Land Trust, who has amassed 20 years of data about female terrapins nesting at the wildlife refuge. In addition, since predation of nests by raccoons, coyotes, and domestic dogs is a constant threat, researchers from the

Barrington Land Trust also attempt to protect nests using predator excluders in an effort to ensure the persistence of the population. Despite the length of this study, little is known about the basic ecology of the terrapins that nest at Nockum Hill. For example, although the areas where turtles nest within the refuge are known, few attempts have been made to determine the distribution and abundance of nests or the factors that influence habitat selection.

Although a wealth of information about nesting ecology is known for many terrapin populations, many aspects of diamondback terrapin reproduction are thought to vary throughout the terrapins' geographic range (Feinberg and Burke 2003). Terrapins are known to prefer nesting only on clear days in some areas of their range, such as Nockum Hill, while in other regions they actively nest at night and in the rain (Brennessel 2006). Additionally, terrapins are often observed probing the substrate with their snouts when searching for a nest site, apparently tasting or sniffing the soil (Brennessel 2006). It is unknown why they engage in this behavior, and what information about a potential nesting site it allows them to gain. From these observations it can be hypothesized that terrapins are making nesting decisions based on physical characteristics of the site, although the specific parameters that influence those decisions remain unknown.

It is generally accepted that diamondback terrapins prefer nesting in sparsely vegetated, sunny, open areas with sandy substrate (Feinberg and Burke 2003). However, since other aspects of diamondback terrapin nesting ecology at Nockum Hill differ substantially from those at other, better researched locations, generalizations regarding nest site preference cannot be assumed to apply to terrapins at Nockum Hill. For example, at Nockum Hill diamondback terrapins have never been observed nesting at night, whereas in populations from Little Beach Island, New Jersey, nocturnal nesting is often observed (Brennessel 2006). Variations in other factors, such as climate and topography of nesting areas throughout the diamondback terrapin's range also make generalizations about nesting behavior less useful. As a result of such differences, site specific research is required to gain a basic understanding of what variables affect nest site selection and the distribution of terrapin nests at Nockum Hill.

This study was designed to unearth more information about terrapin nesting patterns at Nockum Hill. The main goals of this research were to determine which areas appear to be preferred and what factors might influence nest site selection by female diamondback terrapins and subsequent nest success. It was hypothesized that diamondback terrapins at Nockum Hill prefer to nest in areas close to the water, with low vegetative cover, higher soil temperatures, relatively coarse soil texture, and low soil compaction. Although finding definitive answers to the question of what influences nest site selection would take years of research, it is hoped that this project can form a baseline for future research on the terrapin population at Nockum Hill. Such research is important because it will provide further insight into the basic ecology and life history of diamondback terrapins within Rhode Island. Ecological information gained from this study may contribute to the successful conservation of the species within Rhode Island, because it will allow researchers to know what areas are preferred by female terrapins. Knowledge of terrapin nest site preferences could serve as a guide for future management decisions that would allow proper nesting habitat to be maintained at Nockum Hill, possibly allowing Rhode Island terrapin populations to increase or persist indefinitely.

METHODS

This study contained two components: a field based portion to determine what areas are frequently chosen by nesting terrapins, and a laboratory based component which examined the factors contributing to that distribution. The field based component involved collecting GPS coordinates of terrapin nests during June 2010. Nesting females were observed, and their nests were cataloged as soon as possible after nesting was completed to increase the chances of actually locating the nest. In some rare cases, intact nests were found while patrolling Nockum Hill some time after the nests were dug .The coordinates of each nest were plotted onto a satellite map of Nockum Hill. An effort was made to patrol each nesting area equally and as many nests as could be located within the study period were plotted. The number of nests in each of the nine areas of the peninsula was recorded. The areas were delineated based on differences in vegetation type, as well as differences in terrain. The number of nests per square meter was calculated. A distinction was made between nests that were destroyed by predators and those that were discovered intact, and they were plotted on the map as points of different colors. This allowed potential trends in nest predation to be observed. After collecting these data, the results were compared to determine which area showed the highest nesting activity.

The second part of the study focused on the factors that may be responsible for the distribution of nests observed. The characteristics of each of the nine different areas were examined. The specific characteristics that were investigated are vegetative cover, soil temperature, soil texture, the bulk density of the soil, and the distance of each area from the water. Results for these parameters are shown in table 3. Vegetative cover was examined using a scale of 1-4 as an index of percent vegetation cover (Figure 4). On this scale, 1 is defined as an area with 0-25% vegetation cover, 2 as 25-50% cover, 3 as 50-75% cover and 4 almost entirely covered with vegetation (75-100% cover). The spatial differences in vegetative cover throughout the refuge are shown in Figure 2. The number of nests found in each level of vegetation cover was recorded and these data were analyzed using a Chi Square test (Zar 2010). This test was also used for the number of depredated nests found within each vegetation class. All statistical analyses were evaluated using a significance of 5%.

***Figure 2**: A map showing generalized percent vegetation cover of the 9 sections at Nockum Hill.*

***Figure 3:** Shows the vegetation scale used in estimating percent cover. From left to right: 0-25%, 25-50%, 50-75%, and 75-100% cover.*

Soil temperature was measured using an 18 cm soil thermometer. Measurements were taken at 18 cm and at 5 cm to obtain readings both near the surface and at depth. All measurements were taken over the course of three days of clear weather, with temperatures ranging from 29-31 degrees Celsius. Three sites within each area were chosen for temperature readings, with an effort made to sample across the variety of cover and soil types in a given area. The three readings from each depth at a given area were averaged and the correlation between the temperatures at each depth was determined using regression analysis (Zar 2010).

Soil texture was also determined for each area. Three sites were selected to account for differences in vegetation cover and soil type within an area. Soil samples were taken from each of those three sites using a hand trowel. Roughly one liter of soil was collected from each site and stored in a sandwich bag. This was repeated at three sites in each of the nine areas. The samples were separated into 2000, 850, 425, 180, 63, and 50 micron size classes using sieves. To accomplish this, approximately 200 grams of the sample were dry sieved for 1 minute using a motorized shaker. The original weight of the sample used was recorded before sieving began. All fractions were weighed, summed and the total weight was subtracted from the original mass of sample that was placed in the sieve set. This difference represented sediment of a fine grain size that may have been lost during the sieving process. From these data and the total mass of the sample, the percentage by mass of each grain size class was calculated. The decimal forms of the percentages were then multiplied by their respective grain sizes, and the results were summed. This sum represents the average grain size of the sample. The results from the 3 sample sites in each area were averaged, to give the average grain size of soil from the area. The average grain size from each area was plotted against the number of nests per square meter to determine if there was any correlation between soil grain size and the number of nests found in that area.

To determine if the compaction of soil influences nest site selection by female terrapins, average bulk density was determined for each of the nine areas of Nockum Hill. This was done using a 100 cubic centimeter PVC soil core sampler. Three soil cores were taken for each area of the study site. Each core was dried at 60 degrees Celsius for 48 hours and weighed, and bulk density was calculated. These bulk density values were averaged for each area.

The distance from nesting sites to the water was measured from five randomly selected nests in each of the nine areas. If an area did not have five nests, all nests that were observed in that area were used. The distances were measured from the nearest shoreline to each of these points. These distances were then averaged.

Averaged data from bulk density analysis, 5 cm depth temperature readings and distance from the water measurements were analyzed using regression to determine the relationship between nest density and each of these variables (Zar 2010). The distribution of nests among the different vegetation cover groups was analyzed using Chi Square. A one-way ANOVA was used to determine if temperature at 5 cm depth was different in areas of differing vegetation cover, and the correlation between soil temperature at 5cm and temperature at 18 cm was tested using regression (Zar 2010).

Size estimates were also made for the population of female terrapins that nest at Nockum Hill. This was done using mark and recapture data collected by the Barrington Land Trust over the past 20 years. The estimates were calculated using the Schnabel method for estimating population size from mark and recapture data (Chapman and Overton 1966).(Equation 1).

Equation 1. $N = \left(\frac{(M+1)(C+1)}{R+1}\right) - 1$

<u>Where:</u>

N= Estimate of population size

M=Total number of animals marked on first visit

C= Total number of animals captured on second visit

R= Total number of marked animals recaptured on the second visit.

Two estimates were performed using this method: one from the data obtained during the 1999 and 2000 seasons, and another from the data obtained during the 2009 and 2010 seasons. These years were chosen because they are a decade apart, and this allowed long term changes in population size to be observed.

RESULTS

The distribution of nests observed in the 2010 season showed that the highest numbers of nests were found in sandpit 1, the rear field, and the point (Figure 4). These areas also had the highest nest density (Table 1). The distribution does not appear to be random, since clustering is observed in various areas. A high number of nests was also found in the meadow (n=12), an area previously considered to be a relatively unimportant nesting area for terrapins at Nockum Hill. The distribution map showed terrapin nests to be a minimum of 53.0 meters and a maximum of 347.3 meters from the nearest shoreline. However, no relationship was found between nest density and the distance of an area from the water (Figure 5).

Table 1: Raw number of nests and nest density observed in each area

Location	**# of Nests**	**Nests/ m^2**
Sandpit 1	38	$2.3x10^{-2}$
Point	16	$1.1x10^{-2}$
Rear Field	26	$2.6x10^{-2}$
High Road	8	$5.3x10^{-3}$
Low Road	2	$1.1x10^{-3}$
Cornfield	5	$8.6x10^{-5}$
Cornfield 2	2	$1.3x10^{-4}$
Meadow	12	$6.1x10^{-4}$
Sandpit 2	1	$1.4x10^{-3}$

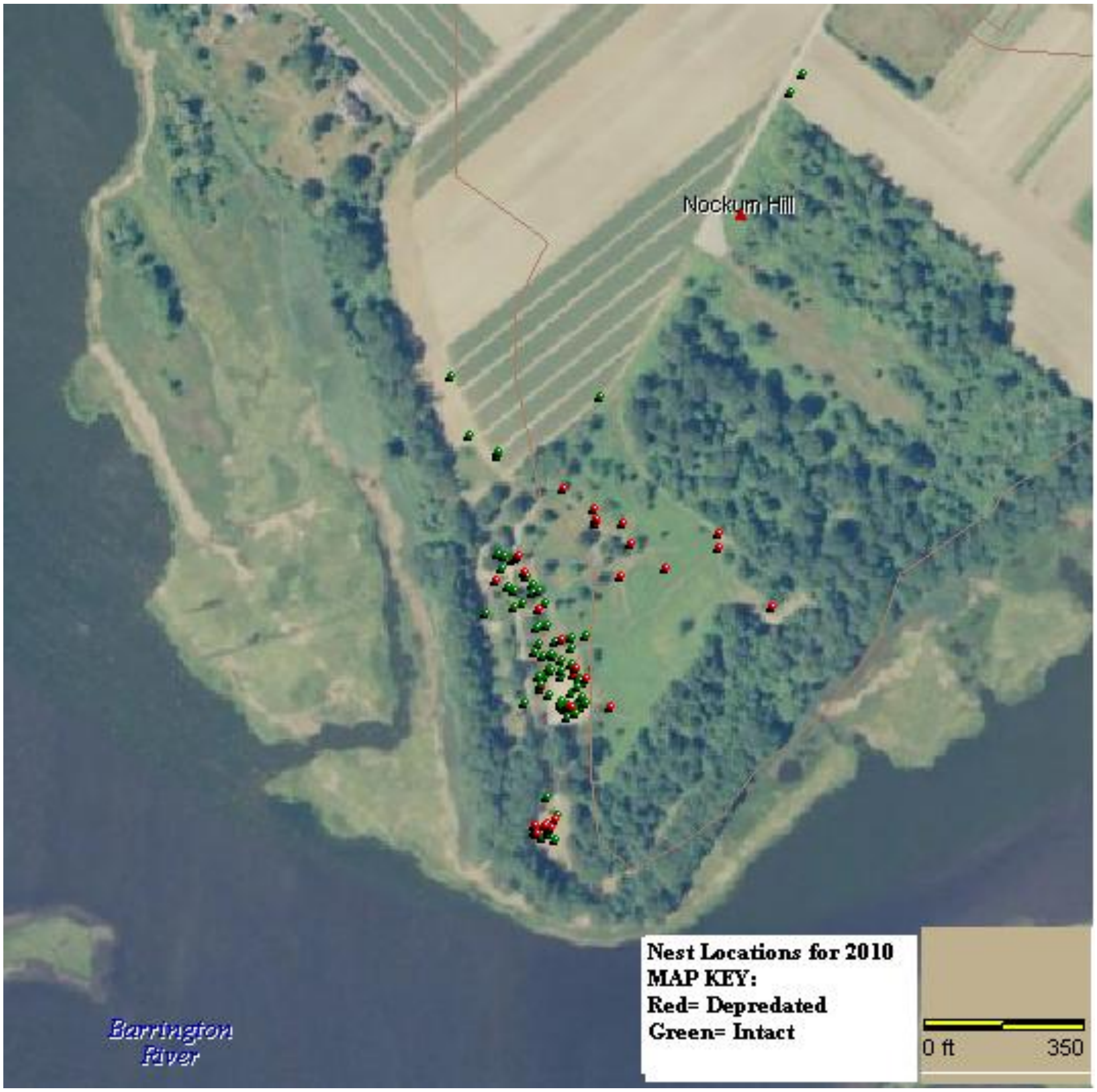

Figure 4. *Observed distribution of depredated and intact diamondback terrapin nests at Nockum Hill.*

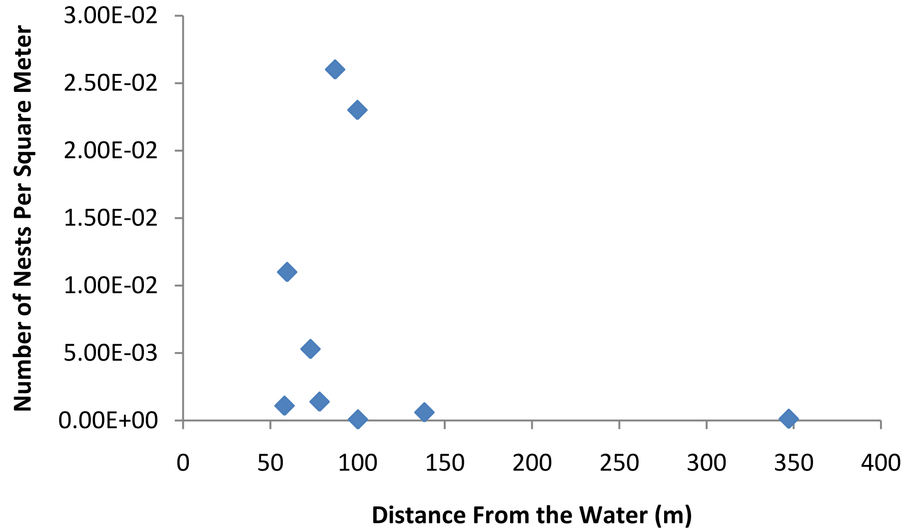

Figure 5. *The average distance of nests from the water in each area plotted against the number of nests per m^2 observed in each area of the hill, showing no relationship between the variables. For any area with greater than five nests, n=5. For any area with a number of nests less than five, data for all observed nests were averaged.*

Significantly more terrapin nests were found in areas of less than 50% vegetative cover than were found in areas of denser vegetation (Chi Square analysis: ($0.01<p<0.025$) (Table 2). A comparison of the number of nests in each area with the map of vegetation cover at Nockum Hill showed that areas where nests were observed in the highest abundance fit generally within this vegetation cover range, although some of these areas were partially covered with denser vegetation. Other areas existed that had large tracts of bare ground, yet they exhibited fewer nests.

Table 2: Number of nests observed listed by percent vegetation cover.

Vegetation Cover	Number of Nests
0-25%	41
25-50%	56
50-75%	12
75-100%	1

A significant positive correlation was found between soil temperatures at 5cm depth and temperatures observed at 18 cm depth ($p < 0.0005$) (Figure 6). However, no correlation was found between nest density and the soil temperature at 5 cm ($p>0.05$) (Figure 7). Similarly, no correlation was found between the number of nests per square meter and soil bulk density ($p>0.05$) (Figure 8). In addition, no difference was found among temperatures at 5 cm in areas of differing vegetation cover ($p=.0904$).

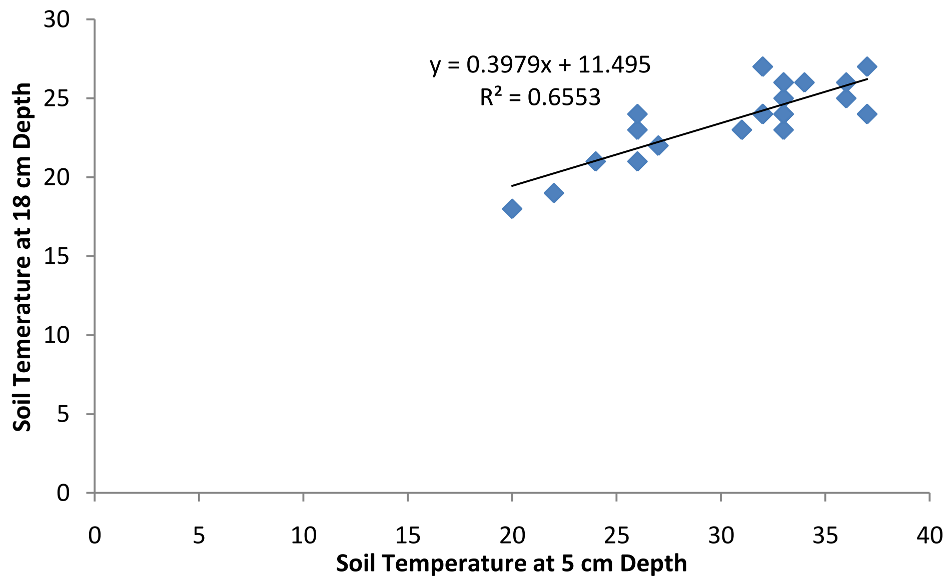

Figure 6. *Average soil temperatures (n=3) observed at 18 cm versus average soil temperatures (n=3) measured at 5 cm. A positive correlation was observed, suggesting 5 cm soil temperatures influence temperatures seen at 18 cm depth.*

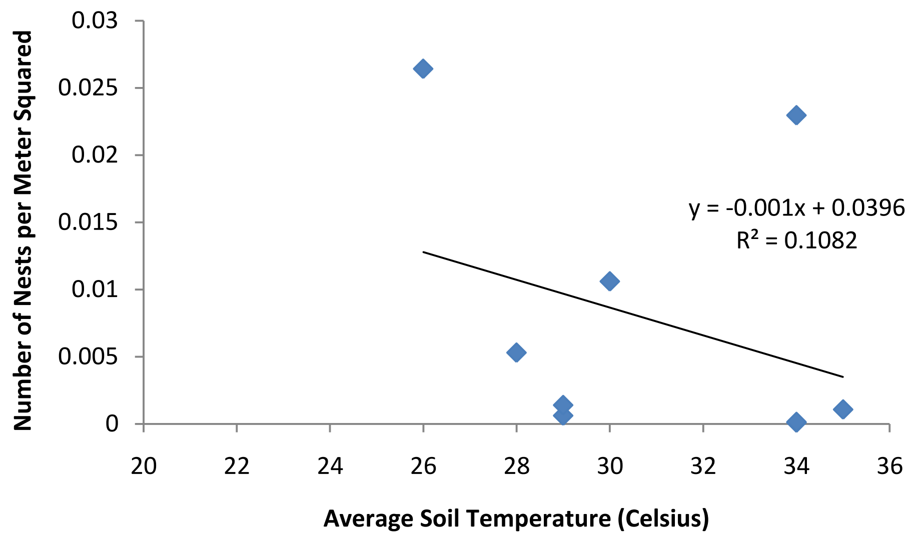

Figure 7. *Average soil temperature (n=3) for each area versus the number of nests observed per square meter, showing no significant relationship between the variables.*

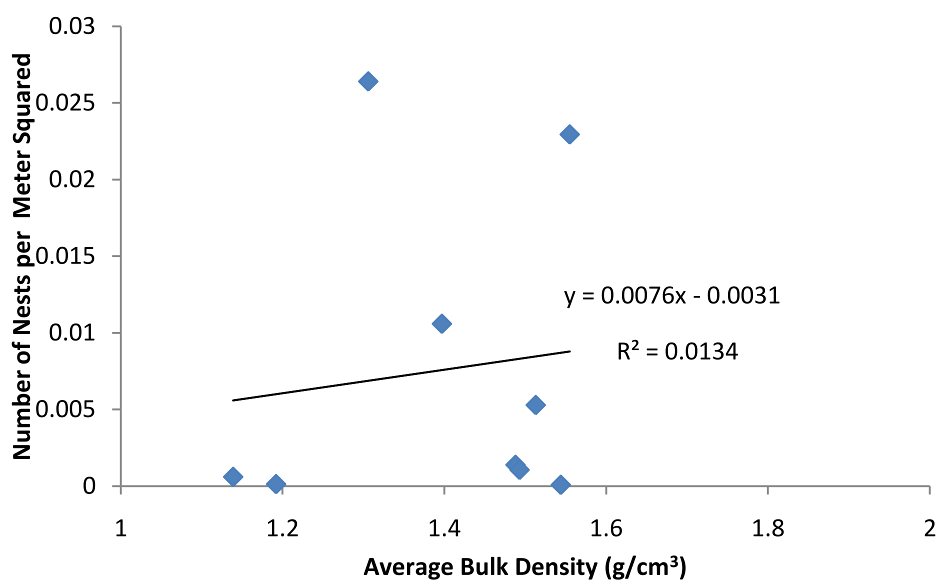

Figure 8. *Average bulk density (n=3) of each area versus the number of nests per square meter found in each area. No significant relationship was found.*

Sandpit 1 had the finest average grain size, while cornfield 2 had the coarsest grain size; falling into the coarse sand range on the Wentworth scale (Table 3). Although some areas had coarser sediment than others, all areas except cornfield 2 had an average grain size that fell within the medium sand classification on the Wentworth scale (Souren 2010). Regression analysis suggested that there was no significant relationship between the number of nests per square meter and the soil grain size of the area (p>0.10) (Figure 9).

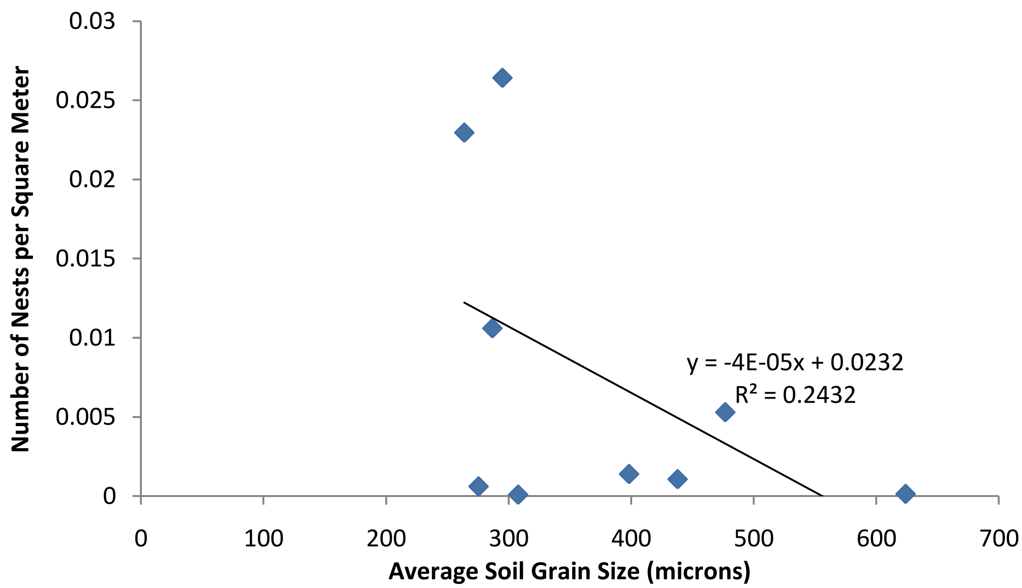

Figure 9*. Average grain size for each area versus nest density in each area. No relationship was found, however the stacking of points observed around 300 microns suggests a stronger relationship could be seen if smaller mesh sizes were used when sieving.*

Comparison of the number of depredated nests observed in each area showed that predation appeared to be concentrated largely in sandpit 1, the meadow, the point, and the rear field (Table 4). Thirty-one (28.2%) of all nests observed were depredated. Of those, 22 were located in areas of 25-50% vegetation cover (Table 5). This is significantly more than the number of depredated nests observed in areas of greater or lesser vegetation cover (p<0.001).

Table 3: Results for measurements of physical characteristics of each area.

Area	Average Soil Temp. (Celsius)	Average Bulk Density(g/cm)	Distance From the Water (m)	Average Soil Grain Size (microns)	Wentworth Soil Class
Cornfield 1	34	1.544	100.2	307.82	Med. sand
Cornfield 2	34	1.192	347.2	623.98	Coarse sand
Meadow	29	1.139	138.3	275.51	Med. sand
Sandpit 1	34	1.555	99.9	263.89	Med. sand
Sandpit 2	29	1.488	78.2	398.31	Med. sand
Rear Field	26	1.306	87.1	295.02	Med. sand
High Road	28	1.513	73	476.84	Med. sand
Low Road	35	1.493	58.1	437.94	Med. sand
Point	30	1.397	59.6	286.8	Med sand

Table 4: The number of depredated nests by area as well as the percent depredation by area.

Region	Depredated Nests	Total Number of Nests	% Depredated
Meadow	10	12	83.33
Sandpit 2	1	1	100.00
Sandpit 1	7	38	18.42
Cornfield 1	0	5	0.00
Cornfield 2	0	2	0.00
Point	7	16	43.75
Rear Field	5	26	19.23
High Road	0	8	0.00
Low Road	1	2	50.00
Total	31	110	28.18

Table 5: The number of depredated nests found in each vegetation class, as well as the percentage of nests in that class that were depredated.

Vegetation	Depredated Nests	Total Number of Nests	% Depredation
0-25%	2	41	4.88 %
25-50%	22	56	39.29 %
50-75%	6	12	50.00 %
75-100%	1	1	100.00 %

The calculation of population size using data from 1999 and 2000 resulted in a population estimate of 166 female terrapins present in the year 2000. The calculation of population size using data from 2009 and 2010 gave an estimated population of 288 female terrapins .

DISCUSSION

Little work has been done to uncover patterns in diamondback terrapin nest site selection, however information on habitat selection has important implications for the conservation of the species. Such information would be especially useful in Rhode Island, where the species is listed as endangered. Therefore, this study investigated the distribution of terrapin nests in the Douglas Rayner Wildlife Refuge, as well as factors that may affect nest site selection.

Based on the clustered distribution of nest sites observed during the study, non-random nest site selection appears to be occurring at Nockum Hill. The nest site distribution map showed three distinct areas with high numbers of terrapin nests: sandpit 1, the point, and the rear field. These areas are similar in that they are large open tracts of land with relatively little vegetative cover. The majority of sandpit 1 had less than 25% vegetation cover, with smaller sections near the sandpit's edges that had up to 50%

vegetation cover. The majority of the point and rear field were covered with areas of 25-50% vegetation cover, although the point also contained some areas with less than 25% cover, and the rear field has some portions that have up to 75% vegetation cover.

Overall, there were significantly more nests in areas with 0-50% vegetation cover, suggesting that terrapins prefer nesting in areas that are either bare or have sparse vegetation. Interestingly, about half of the nests (56 out of 110) were located in areas that had 25-50% vegetation cover. This could be explained in two different ways. One is that terrapins actually prefer nesting near some sort of vegetative cover rather than nesting in the bare ground. Perhaps some vegetation helps conceal the nest location from predators, although the predation trends observed do not support that idea. Alternatively, it may be that there is simply more area of Nockum Hill covered with sparse vegetation than there is bare ground. This would increase the chances of a terrapin nesting in an area with 25-50% cover.

The map of vegetation cover, however, shows that the majority of Nockum Hill and the surrounding area are bare. Despite this, the largest patches of bare ground in the cornfields north of the refuge showed little use by female terrapins. This seems to suggest that vegetation cover alone cannot account for the observed distribution of nests. Although no significant relationship was found between nest density and distance from the nest to the water, soil temperature, bulk density, or grain size, it may be possible that these variables can only account for the observed distribution when examined together using multivariate statistics. It could also be that there are other variables that impact nest site selection, such as historical use of certain areas of Nockum Hill by humans. For example, while the farm fields may have characteristics that make them suitable for terrapin nesting, the fact that they are often plowed using loud machinery may discourage nesting attempts, and may diminish the reproductive success of those terrapins that choose to nest there since their eggs may be destroyed by farm machinery. This could lead to the cornfields seeing less use than would be predicted by simply examining the physical characteristics of the areas, especially if hatchling terrapins at Nockum Hill are exhibiting nest site fidelity.

A study of nest distribution similar to this research project was performed by the Barrington Land Trust in 1990 (Bush and Auger 1990).The distribution of terrapin nests that Bush and Auger observed was quite similar to the one observed during this study, albeit with fewer total nests located. Bush and Auger found large total numbers of nests in sandpit 1. They also observed many nests in the low road, something that was not seen during this study. Two nests were observed in the cornfield as opposed to the five that were observed in the current study. The major difference between the 1990 and 2010 distributions is that in 1990 five nests were observed on the beach just above the high tide mark (Bush and Auger 1990). No nests were found on the beach in 2010. While this could be accounted for by sampling error during the current study, it is likely that in the 20 years since Bush and Auger examined terrapin nesting at the hill there has been significant coastal erosion at Nockum Hill (C. Sornborger, personal observation). Such erosion could have changed the shoreline enough that the beach is not as suitable of a nesting area as it may have been 20 years ago, forcing females to move further inland to nest.

One interesting observation is that there were many more nests in the meadow than expected. This section of the hill was previously considered to be an area that did not have much nesting activity, since few nests were found there in the 20 years of the mark and recapture study, and no nests were observed there during the 1990 study (Bush and Auger 1990). This was assumed to be due to the prevalence of tall grass and high levels of vegetative cover. However, twelve depredated nests were found here in the 2010 season, typically in small bare patches or areas of short but dense vegetative cover. These findings, combined with observations of females entering and exiting the meadow, suggest that nesting does take place in this area. From data collected in this study, it seems that there is currently more activity occurring in the meadow than in the low road, which was previously found to be a major nesting area at the hill (Bush and Auger 1990). Perhaps the low road has become more overgrown in recent years and the vegetation in the meadow has been more thoroughly mowed by refuge staff. This would lead to the meadow becoming a more favorable nesting area since there would be a lower percent vegetation cover throughout the area. Likewise, the increased growth of vegetation on the low road could make it less suitable nesting habitat and account for its lessened use. Regardless, the results of this study suggest that the meadow should not be ignored when collecting data for the mark recapture study, nor should it be discounted when protecting terrapin nests in future seasons.

Although the results for soil texture analysis did not show a significant relationship between the coarseness of the sediment and the number of nests in the area, it seems that cornfield 2, the area with the coarsest sediment, had very low nesting activity. Likewise, the area with the finest sediment, sandpit 1, had very high nest densities. While the differences are not statistically significant, these observations are notable since they may suggest that terrapins prefer nesting in areas of finer sediment. In addition, the graph of grain size versus nest density shows a distinct stacking of points at the fine end of the soil texture scale. This suggests that if the samples were reexamined using sieves of finer mesh, a stronger relationship between nest density and soil texture could have been observed. As a result, the relationship between sediment size and nest density should be examined in greater detail in the future.

Similarly, a significant relationship was not found between soil bulk density and nest density (Figure 8). This suggests that soil compaction is not a factor that affects nest site selection. However, bulk density may not be the best proxy for soil compaction under the conditions at Nockum Hill. This is because high amounts of organic material were found in the core samples from areas such as the meadow, and this must be removed to obtain accurate measurements of bulk density. The removal of the organic material leaves the core samples it was taken from with very low masses, and thus low bulk densities. However, areas with large amounts of organic material present in the core samples typically exhibited high percentages of vegetation cover. As a result, the soil was actually very compact, so much so that core samples were difficult to obtain from these areas. It can be assumed that a terrapin may have more difficulty digging through this type of substrate than it would when digging in loose sand, but this information cannot be inferred by looking at the bulk density data. Therefore, compaction should not be ruled out as a potential factor influencing nest site distribution in diamondback terrapins at Nockum Hill without further study.

There was also no significant relationship between the distance of a given area from the water and the nest density observed in that area (Figure 5). This was not expected, as the majority of terrapins were predicted to select the closest suitable nest site to minimize energy expenditure. Instead, it appears that if distance from the water plays any role in guiding nest site selection, it is secondary to other factors that may be driving nest site selection by terrapins at Nockum Hill, and that terrapins will seek nest sites that have low vegetative cover regardless of how far the nest is from the water.

The temperature of the nest can have important effects on the development of hatchlings. Diamondback terrapins exhibit temperature based sex determination, where males develop at lower temperatures and females result from higher temperatures (Brennessel 2006). The temperature of the nest may also influence other factors in development, such as hatchling size (Kolbe and Janzen 2002). Therefore, temperature was considered as a variable that may influence nest site selection. However, the temperature of the substrate did not correlate significantly with the number of nests observed per square meter in each area (Figure 7).Temperature readings were taken on one occasion for each site. It may be more useful to use temperature loggers to obtain long term temperature averages that may allow researchers to better explain terrapin nest site selection. Additionally, temperature readings from 5 cm below the surface correlated positively with the 18 cm temperatures; this showed that it would be possible for terrapins to use the temperature within the top layer of soil to estimate the temperature below (Figure 6).

Soil temperature should be influenced by a variety of factors, one of which is the percent of vegetation cover. The higher the degree of cover, the cooler the soil temperature should be (Brennessel 2006). However, this trend was not observed in the data obtained during this study. There was no significant difference in soil temperature among sites with differing degrees of vegetation cover, although it is possible a relationship could be seen if the study was repeated and long term temperature data were obtained.

Of the 110 nests observed during the study, 31 (28.2%) were depredated (Table 4). Of these depredated nests, the majority were in the sandpit, the meadow, and the point. The high predation on the point and in sandpit 1 could be due to the fact that in this section of the hill there are a high number of nests in a small area. This could make it easier for predators to move from one nest to another, and depredate nearly all nests within relatively large areas. It is also possible that any chemical cues that predators can use to locate terrapin nests may be more easily detected when nest density increases.

The fact that all but one of the nests observed in the meadow were depredated may be inconsequential, since these were all found on the last day of sampling, and this area was isolated from other major nesting sites, making it hard to track female terrapins. In addition, female terrapins passing through this area often disappear into sections of tall and dense grass making them easy to lose. Therefore, the data obtained in the meadow may not be representative of the true degree of predation or total nesting occurring in this part of the refuge.

Of the 31 nests found depredated, 22 of them were located in areas of 25-50% vegetative cover, significantly more than were found in other vegetation classes. This large number suggests that there is likely some relationship between vegetation cover and nest depredation. In a similar study, Burger found that terrapin nests closest to vegetated areas were most susceptible to mammalian predation (Burger 1977). It may be possible that terrapins digging in areas of high vegetative cover dig shallower nests, which predators can locate and destroy easier. Although the raw number of depredated nests was not as high in areas of greater than 50% cover, these areas showed the highest percentages of depredated nests (Table 4). This fact supports the idea that nests in thicker vegetation are easier to depredate.

In addition, proximity to habitat edges has been known to play a role in predation of turtle nests; this may be due to the fact that many animals that prey on nests are edge predators (Temple 1987). Research by Temple showed that predation rate increased with proximity to an edge (Temple 1987). Conversely, research involving simulated painted turtle nests showed that increased proximity to habitat edges lead to a decrease in predation (Marchand and Litvaitis 2003). It is possible that proximity to habitat edges may influence predation at Nockum Hill, however this factor was not considered in this research. There may be an interaction between the effects of a nest's proximity to habitat edge and vegetation cover, especially since it is likely that vegetation cover will be higher near habitat edges. It is also known that snapping turtles, ornate box turtles, and blanding's turtles appear to prefer nest sites far from edges, perhaps in response to selective pressures from nest predation (Temple 1987). The distance of nests from habitat edges would therefore be a variable to consider closely in future research.

The reason that the majority of depredated nests were found within 25-50% vegetation cover could be that there were more of these nests, making them easier to locate. However it is possible that nests with greater than 50% cover may also be so obscured by vegetation that they are hard to dig into. This could make preying on nests with very high percent vegetation cover less profitable, especially when there is an abundance of nests that are easier to reach.

Since nests are typically cryptic and the female terrapin rarely leaves a visible trace behind, it is believed that predators use olfaction to locate nests (Brennessel 2006). If predators primarily locate nests using olfaction, the depth of a nest may influence their ability to find it. Depth of a nest could be influenced by the amount of vegetation surrounding it, since the presence of plant roots may make digging a nest more difficult and result in shallower nests. Therefore, nests that are in substrate with less than 25% vegetation cover could be deeper underground and less easily found by way of chemosensory detection. If these nests are deeper, the increased depth may also increase the handling time of the nest, since the predator must dig for a longer period to reach the eggs. This could account for the very low percentage of depredated nests observed in areas of 0-25% cover. To determine if these explanations can account for the trend observed in the data, further research on nest predation should be conducted that takes the depth of the terrapin nest into account as well as the percent vegetation cover above and around it.

When examining predation trends, it should be noted that the year this study was performed was considered an abnormal year by the researchers who have been observing these animals for the past 20 years (C. Sornborger, personal observation). Based on general observation, the 2010 season saw a late onset of nest predation when compared to previous years. Predation at Nockum Hill usually begins within a few days of nesting; however in this case it took weeks for evidence of predation to be found. General observations indicate that the type of predation was also different; the predators responsible appeared to have a much lower success rate than they had the previous year .This could suggest that the predators were largely inexperienced or perhaps a different species of predator than has been seen in the past. The species of the predators from the 2010 season were never confirmed. However, coyotes were seen in the area during the course of the study and the feces and tracks of a large canid were observed. Also, raccoons are known predators of turtle nests (Ner and Burke 2008), and their tracks were found near nesting sites during the study.

Working alone or with the help of a pair of volunteers made it difficult to locate every nest, and presented a particular problem for areas of Nockum Hill that are more isolated, such as the meadow and sandpit 2. The fact that these areas were isolated, in combination with the lack of significant manpower, may have contributed to the lower number of intact nests found in these locations. This is because a single researcher can run into significant problems when attempting to keep track of 15 or more nesting terrapins at once. Inevitably, in these situations not all of the nests are found, especially since nests can be quite cryptic if enough time has passed since they were dug. Further research on this topic should utilize large teams of researchers to ensure data accuracy. This change would ensure that more nests are located, and that their locations can be more accurately determined and represented.

Although the data obtained during this study have shed some light on factors that may be influencing terrapin nest site selection at Nockum Hill, much more can be gained by the long term continuation of this study. Despite the fact that few significant relationships were found in this initial study, if long term data is collected it is possible that new relationships between physical variables and nest site selection could become apparent. Therefore, it is important that this research be continued, and perhaps be adopted by the Barrington Land Trust to allow data to be collected annually. If this project is to be continued, future research on the physical properties of nesting sites should include the use of a penetrometer to determine soil compaction in place of the bulk density method used in this study. Temperature loggers should also be used to gather temperature data throughout the season. Root density of nest sites should be measured, since plant roots have been known to destroy terrapin nests and their presence may make the nest digging process more difficult (Brennessel 2006). Also, comparisons of physical traits of nesting sites to random locations within each of the nine areas should be made, since this will allow patterns in nest site selection to be more easily identified (Kolbe and Janzen 2002).

The results of this research could have a variety of practical conservation implications. From the map of nest locations, it has been shown that terrapins nest in the meadow more than was originally believed. This is very interesting, considering the fact that much of the meadow is covered by thicker vegetation than other areas within the wildlife refuge. The large number of nests observed here suggests that this area should not be excluded from conservation activities at Nockum Hill despite the fact that it is covered with relatively dense vegetation.

The majority of nests at Nockum Hill were located in areas of less than 50% vegetation cover, suggesting that these sparsely vegetated areas are important habitat for nesting terrapins. The potential importance of these areas becomes even more obvious when these nesting preferences are examined alongside the observed predation trends. As discussed previously, increased vegetative cover appears to make terrapin nests more susceptible to predation. However, predators appear to specifically prefer nests of 25-50% cover. Interestingly, the majority of terrapin nests observed during the study were found in this vegetation class. This observation can be interpreted in two ways. The first is that if terrapins prefer to nest in slightly vegetated areas, animals that prey upon their eggs may have learned to associate these areas with potential food sources. Therefore, these predators might search areas of the refuge with 25-50% cover more diligently than they would other regions. The second potential explanation is that factors that are currently unknown are preventing terrapins at Nockum Hill from taking full advantage of nest sites with less than 25% cover. This could be due to successional processes that result in the area of densely vegetated ground increasing throughout the refuge, or simply because these areas do not exhibit the optimal conditions for nesting.

Further research should be done in an attempt to explain this observation, but regardless of the reason for this trend it is important knowledge for those working to conserve diamondback terrapins at Nockum Hill. Knowing that terrapins choose to nest primarily in areas of less than 50% cover, and that high vegetation cover may make a nest more likely to be depredated, researchers at Nockum Hill can attempt to maintain the nesting areas so that vegetation cover remains less than 50%, or more preferably, below 25% over a large area. This could potentially limit predation, and will also provide more optimal nesting conditions for female terrapins.

The current conservation methods that are being employed appear to be working. According to estimates of the population based on mark and recapture data, there are currently 288 female terrapins at the hill. The population estimate from 2000 was only 166 female terrapins, suggesting that the population is growing. In 2003, it was determined that there were 188 female terrapins in this population, suggesting further increases more recently. According to Mitro, this number was not as low as it seemed and the population should be large enough to withstand stochastic events that may otherwise cause the extirpation of terrapins at Nockum Hill (Mitro 2003). If the findings from this research are valid and the vegetation cover at the refuge is maintained at 0-25%, it is possible that the size of the terrapin population could remain at the current level or increase further.

Studies of the nesting ecology of other aquatic turtle species have shown similar trends to those observed during this study. Kolbe and Janzen engaged in a 4 year study on snapping turtles, investigating the impact of nest site selection on nest success and nest temperatures in natural and altered habitats (Kolbe and Janzen 2002). The snapping turtle, *Chelydra serpentina*, is similar to the diamondback terrapin in that it is an aquatic turtle with similar life history characteristics. Kolbe and Janzen found that snapping turtles preferentially nested in areas with low vegetation cover, and there was a tendency for them to nest in sandy patches, which had significantly higher soil temperatures (Kolbe and Janzen 2002). They also found that predation was lower in regions of low vegetative cover (Kolbe and Janzen 2002). Therefore, the results of Kolbe and Janzen's research support the findings of this study, since low vegetation cover was correlated with increased nesting and decreased predation in both studies. Interestingly, Kolbe and Janzen observed a significant negative correlation between temperature and vegetation, and noted that most nests were in areas of higher temperatures (Kolbe and Janzen 2002). This was not observed in the current study. Given the similarities between the results of the two studies, this difference suggests that the effects of temperature on nest site selection by terrapins at Nockum Hill should be reexamined in the future.

In conclusion, the results of this study suggest that diamondback terrapins at Nockum Hill prefer nesting in locations with less than 50% cover, and that temperature, distance from the water, soil grain size, and soil density are not significant factors that independently affect nest site selection. However, it is possible that all of these factors interact to influence nest site selection at Nockum Hill. It appears that terrapins use sandpit 1, the point and the rear field as their prime nesting sites, with nest density being highest in the rear field. In addition, the rate of predation appears to be highest in areas of above 25% vegetation cover, perhaps due to decreased nest depth in vegetated areas, although further research is needed to verify this. The results of this study will allow for improved conservation of terrapins within Rhode Island, a state in which their fate has been questionable. In addition, understanding the habitat selection process rather than simply knowing what habitats are selected will allow habitat use to be predicted in other areas as well (Harvey and Weatherhead 2006). This study therefore has the potential to serve as a baseline for future research on diamondback terrapin nesting ecology, not only within the state of Rhode Island but throughout the species' range. In order to effectively conserve the species for the long term, an improved understanding of diamondback terrapin life history and habitat selection is necessary, and studies such as this one will contribute to that understanding. Perhaps with the knowledge gained by this and similar studies, the diamondback terrapin can be successfully conserved for future generations.

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