Analysis of Loggerhead & Green Sea Turtle Nesting Densities & Nest Site Probability in Relation to Topographical Features

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I. Abstract

As the impacts of climate change and habitat loss increasingly threaten marine turtle species, it is important to examine less understood aspects of their behavior, as well as identify any alternative management strategies. The behavior surrounding beach selection in sea turtles is well understood, but nest site selection itself has not been well examined. Using loggerhead and green sea turtles as case species, the relationship between nest site locations and topographical features on the Canaveral National Seashore were analyzed using logistic regression. The results indicate that these sea turtle species are using topographical features as cues in nest site selection. These results can be used to create a predictive model to help aid in sea turtle conservation.

II. Introduction & Background

Being able to understand and predict an organism's habitat use patterns and identify the corresponding threats can be very helpful when making conservation decisions, which are frequently made with somewhat little information (Reece *et al.* 2013). The effectiveness of conservation strategies is particularly important as the planet experiences elevated species extinction rates so significant as to be characterized as its sixth mass and first modern extinction (Barnosky *et al*. 2011, Reece *et al*. 2013). Furthermore, climate change adds to the already existing threats faced by species and increases the risk of extinction by compromising species' abilities to adapt in a timely manner to new stressors. The global conservation status of both the loggerhead sea turtle *Caretta caretta* and the green sea turtle *Chelonia mydas* helps to emphasize the importance of understanding more about how a species' behavior patterns can affect their vulnerability (Mazor *et al*. 2013). As the conservation strategies for these species are considered, a more complete understanding of habitat suitability is required (Yamamoto *et al*. 2012).

The coupling of climate change and urban development in coastal areas has created an especially unsuitable environment for vulnerable native species. Anthropogenic pressures such as tourism and trade negatively impact biodiversity worldwide, and these pressures are particularly strong in coastal zones (Mazor *et al.* 2013). However, our ability to analyze the effect of these anthropogenic pressures on the environment is constantly improving, and allows us to better explore the combined impacts on threatened species (Kerr and Ostrovsky, 2013). One particularly notable consequence of climate change is the increased rate of global sea level rise, which is expected to intensify coastal erosion, flooding, and the inundation of low lying areas (Katselidis *et al*. 2014). These impacts put coastal species at an increased risk of habitat loss, threatening species like sea turtles that nest on low-lying beaches. Six out of the seven sea turtle species are listed as threatened or endangered, and only a few of their populations have shown signs of recovery since being listed with the US Endangered Species Act of 1973 (Witherington *et al.* 2011).

In the face of these changes, it is clear that effective conservation strategies will be key to ensuring that biodiversity is well maintained. Species such as sea turtles, however, can be quite difficult to manage, as their habitat range is so extensive. Management strategies almost exclusively focus on breeding areas, but for sea turtles and many other species, these are different from locations where the species forage (Hart *et al*. 2012). Sea turtles spend the majority of their adult lives out at sea foraging in seagrass beds, only returning to beaches to lay eggs when they are reproductively mature (Hart *et al*. 2012). One unique aspect of sea turtle nesting behavior is that the majority of species display philopatry, meaning nesting turtles almost always return to the beach from whence they hatched (Mazor *et al.* 2013). While there is some variation in the degree of this site specificity (Garmenstani *et al*. 2000), the accepted range is

~10km – 50km. The causes for this behavior are still poorly understood (Mazor *et al* 2013). Some have argued that sea turtles merely emerge on a beach, travel an indeterminate meaningless distance beyond the water, and lay their clutch - suggesting that females have a very limited ability to assess their nesting environment (Garmenstani *et al.* 2000). Recent studies, however, have found that nest distributions are shifting northward, potentially due to increased coastal development and warmer temperatures (Reece *et al.* 2013). This suggests that females may actively evaluate their available nesting habitat and seek out areas having the necessary conditions.

The temperate and tropical beaches that provide endangered sea turtle populations with crucial nesting habitat are constantly changing through natural processes. For instance, intensive winter storms create seasonal erosion and accretion, which continuously changes the profile of the beach. This group of species has had to adapt to such changes over multiple generations, suggesting a level of resiliency intrinsic to sea turtle species (Katselidis *et al*. 2014). There remains considerable debate within the scientific community as to whether or not sea turtles will be able to respond to the accelerated rate of these consequences due to climate change, as sea level rise threatens to alter their breeding habitats considerably (Katselidis *et al*. 2014).

If females are indeed selecting where to nest based on the available habitat, it becomes important to understand the basic requirements of a good nesting site. In most temperate areas, nesting can take place between late spring and early fall (Witherington *et al.* 2011). Studies suggest that an ideal nesting site is easily accessible from the sea, but high enough to protect nests from high tides and water tables, with a preference for beaches that are continuously exposed to wave energy from warmer water (Witherington *et al.* 2011). The sand must facilitate gas diffusion while also being damp and fine enough to easily construct a nest (Garmenstani *et* *al*. 2000, Hays *et al*. 1995). Additionally, the action patterns of nesting behavior defined by Witherington *et al*. 2011 are: 1) emerge from the sea; 2) prepare the nest site(s) by digging a body pit; 3) dig an egg chamber within the pit; 4) deposit the eggs within the chamber; 5) fill pit and cover eggs with sand; 6) camouflage the nest; 7) return to the sea. These action patterns determine a number of critical nest factors, including its elevation, suitability, depth of the eggs, and how attractive the nest may appear to predators (Witherington *et al*. 2011).

One of the most important impacts of nest location is its ability to strongly influence the gender ratio of the clutch, as the sex of sea turtles is determined by the incubation temperature of the nest (Hays *et al*. 1995). Cooler incubation temperatures lead to more males, while warmer incubation temperatures lead to more females (Katselidis *et al.* 2014). This temperature dependent sex determination has the potential to skew gender ratios as temperatures continue to rise due to climate change. An increase in temperature can also alter sea surface temperature cues, which females use to determine when and where to nest (Reece *et al*. 2013).

The position of the nest can also impact offspring survival (Hays *et al.* 1995). One of the most pressing causes of egg mortality is drowning of the eggs due to inundation, as well as exposure to pathogens (Witherington *et al.* 2011). Sea level rise increases the extent of coastal erosion, and furthermore, climate change stands to increase the intensity and number of storms that occur in coastal areas (Reece *et al*. 2013). Both of these consequences can lead to higher nest inundation rates, and thereby decrease hatching success. These impacts can also prevent females from nesting at adequate elevations, and instead they nest where the clutches would be more susceptible to storm inundation (Katselidis *et al.* 2014). Even a subtle change in nest elevation can greatly affect nesting success (Witherington *et al*. 2011).

Considering the impact that the nest site can have on multiple aspects of sea turtles' reproductive success, it is important to understand the behaviors that influence nest site selection itself. While the impacts of sand characteristics have been widely studied, the influence of larger beach characteristics, such as topographical features, are less well known (Garmenstani *et al*. 2000). Beach characteristics in particular have the potential to be more important when determining nest site selection patterns (Yamamoto *et* al. 2012). Although these characteristics have clear individual impacts, the ability of these factors to influence nest site selection in combination with one another can better help to explain why sea turtles nest on particular beaches more than others, as well as nesting patterns within beaches themselves (Garmenstani *et al*. 2000).

Determining which topographical features to analyze is a key consideration. It has been posited that several of the sea turtle species prefer to nest at a mean elevation of at least 1m above sea level, regardless of the beach type or location, because the slope of the beach can influence the likelihood of nest washout (Katselidis *et al*. 2014, Reece *et al*. 2013). Steeper beaches require less energy from the female sea turtle to locate an ideal nesting habitat above the high water line (Reece *et al*. 2013). Hence, turtles should prefer to nest on beaches with steeper slopes. Beach slope is clearly an important factor in nest site selection, but this behavior appears well established (Katselidis *et al*. 2014).

Other topographical features, such as vegetation, dunes, and the distance from the high tide line have not previously been closely analyzed in relation to loggerhead or green sea turtle nesting densities. However, there have been early indications in scientific literature that these features may play a key role. For instance, general observations have found that nests tend to be clustered towards areas closer to vegetation (Whitmore & Dutton, 1985; Hays *et al.* 1995;

Garmenstani *et al.* 2000). Another study has specifically suggested that the vegetation zone adjacent to beaches may act as a potential cue for sea turtles (Garmenstani *et al.* 2000). While these studies have presented preliminary theories, concrete connections between vegetation and nest site selection still need to be made. There is also evidence that sea turtles have the ability to analyze uneven beach topography in order to find the path of least resistance (Garmenstani *et al*. 2000), suggesting that the presence of dunes and distance from the high tide line will impact nest site selection as well.

To determine if loggerhead and green sea turtles are in fact using these topographical features to help with nest site selection, the correlation between nesting densities and the distances from vegetation, mean high tide line, and dunes can be analyzed (Garmenstani *et al.* 2000). It is important to note that these variables are all correlated based on the beach profile, which indicates using a multivariate statistical analysis (Dean, 1991).

In the context of climate change and sea level rise, it is important to focus on areas that will become relevant in the future, as well as the movement corridors among them, rather than just areas being utilized now (Reece *et al*. 2013). Additionally, successful conservation strategies must incorporate a sufficient understanding of the relationships between species and their environment, and how climate change might affect their behavior and distribution (Reece *et al*. 2013). Current management strategies primarily focus on protecting habitats that are now deemed as important, rather than thinking pf changes over the longer team. Assessing the areas that could have future ecological importance is the challenge (Katselidis *et al*. 2014). This discourse in management strategies' time horizons is more relevant as species inhabiting coastal areas are increasingly threatened (Katselidis *et al*. 2014).

With regards to sea turtles specifically, determining whether or not the beaches currently protected will be suitable into the future is critical (Reece *et al*. 2013). To do that, however, nest site selection must be better understood. Even though nest site selection may be a complicated process, habitat cues and topographic variables along the beaches may help in understanding this behavior (Hays *et al*. 1995). Furthermore, recent studies have suggested that onshore beach characteristics are important beyond simply serving to control the emergence pattern of sea turtle, allowing for more accurate nest density predictions (Yamamoto *et al*. 2012, Reece *et al*. 2013). Through two main hypotheses and corresponding objectives, this project seeks to identify the degree to which topographical variables are being used, and develop the necessary model to help in conservation management using loggerhead and green sea turtles as case species. As such, the hypotheses are as follows: 1) Loggerhead & green sea turtles use topographical features to select nest sites, and 2) A statistical model can accurately predict the spatial distribution of nest locations in the 2015 breeding season.

III. Methods

Study Site

The Canaveral National Seashore US National Park is a protected area containing sea turtle nesting beaches located in Volusia County and Brevard County, Florida. It is 90.1 square miles (233.4 km2) and is primarily made up of coastal barrier islands. These barrier islands provide protection to both people and wildlife, and are critically important nesting habitat for several different species of sea turtles (National Park Service). Off the coast of Florida, its 24-mile-long beach ranges between 30 to 50 yds. wide depending on the tide, and with an easterly facing aspect. It falls within both loggerhead's and green sea turtle's ranges, as shown in Figures 1 and 2,

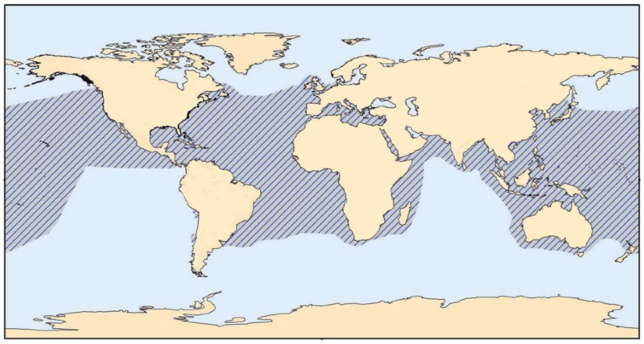


Figure 3: (Above) Range of loggerhead sea turtles (NOAA) (NOAA)

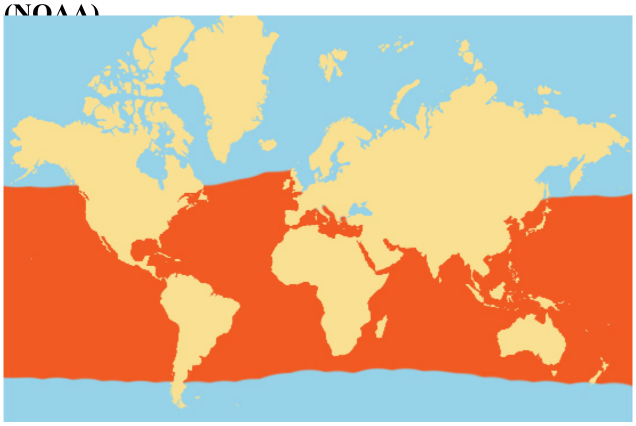
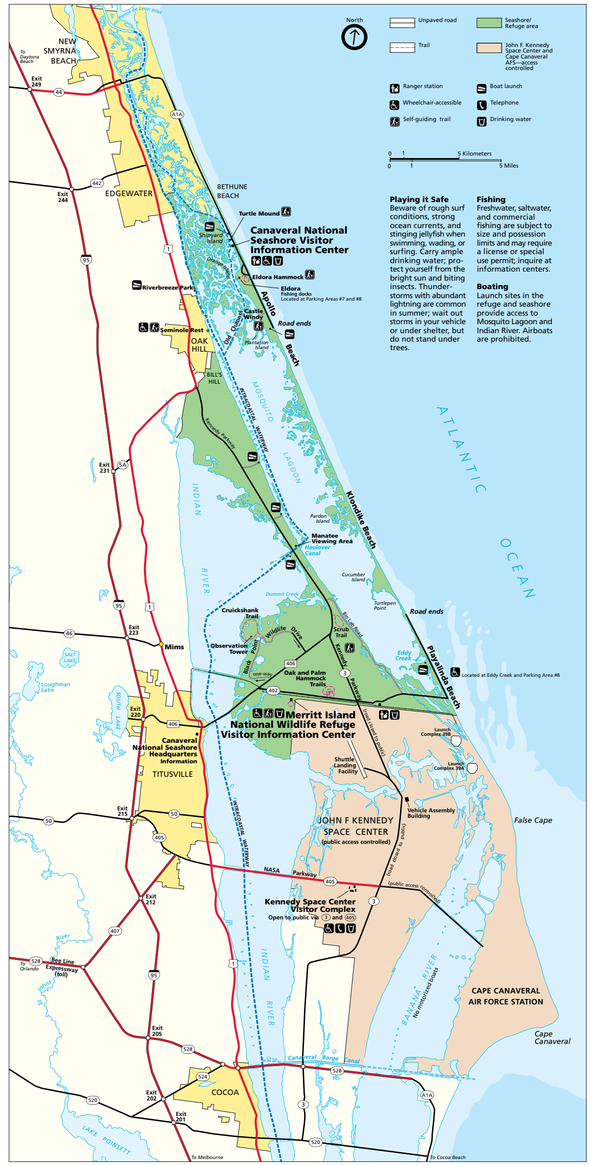


Figure 2: (Above) Range of green sea turtles (DOF).

Figure 1 (Right) Map of the three different nesting sites used in this study: Playalinda, Klondike, and Apollo. All three beaches are within the Canaveral National Seashore National Park, an area protected and closely monitored by the US National Park Service.



Data Collection & Analysis

I tested whether green and loggerhead sea turtles select nest sites based on vegetation, dune location, and the high tide line, and whether these relationships can predict nesting locations across space and time. Nest site locations along the coastline of Canaveral National Seashore US National Park were recorded by the National Park Service for each loggerhead and green sea turtle nest during the 2013, 2014, and 2015 breeding seasons. GPS coordinates were determined using a Garmin GPSmap 62s (Canaveral National Seashore, Office of Resource

Management). Specifically, there were a total of 7,889 nests recorded in 2013 – a record high nesting season – and 3,743 nests recorded in 2014, a total of over 11,600 data points to analyze, creating a very robust dataset. Prior to analysis, recorded nest locations were examined and suspect points were filtered from the dataset. These nest site locations included GPS coordinates located in deep water or on hard impervious surfaces, such as concrete.

Next, the three beach features under consideration, vegetation, dunes, and wrack line, were digitized in ArcGIS using visual interpretation of a 2013 georeferenced aerial photography map with a 1m resolution, provided by the National Park Service Southeast Region GIS Coordinator/Geographer. The vegetation line was defined as the first existence of vegetation on the open beach, and measurements of the dunes stop at the vertical face (Garmenstani et al. 2000). Additionally, the distance to the mean high water mark was determined by measuring to the middle of the highest high tide line visible on the beach. This is designated by the wrack line, which is marked by a fine line of deposited debris (Reece et al. 2013). This was done in tandem with the staff at the National Park Service, and an average wrack line was estimated for the three years in question, as there was no large storm during the study period to affect the beach profile. Euclidean distances of nest locations from each of these features were measured in ArcGIS, with distances down the beach being negative and up the beach being positive, relative to the location of the feature.

Logistic regression was used to assess the strengths of relationships between sea turtle nesting locations and distance from beach characteristics. This method was selected based on the predictive (rather than purely descriptive) focus of this project, which narrows the statistical method choices down to logistic regression or a kernel density estimator. A large drawback to a kernel density estimator is that one must create a set of arbitrary choices about what type of smoothing to use, rather than working with data in its original form (Parzen, 1962). Because of this, a simple logistic regression was selected.

I assessed specifically how distances from beach features affect the probability of a nest occurring in a given location. Since these beaches are sampled exhaustively for sea turtle nests, a set of randomly generated points represented locations without nests. In all models, the sample of non-nest sites was equal to the number of nest locations. The set of no nest points was bounded spatially by the low tide line and the inland edge of beach vegetation. For each of the 2013 and 2014 breeding season, and each focal species (loggerhead and green sea turtles) we constructed a logistic regression model of nest site locations and evaluated the ability of the model to predict the spatial distribution of nest locations using split-sample validation. Eighty percent of observations were used to train the model, with twenty percent selected randomly to be held out for validation. The importance of terms in the training model was evaluated based on their statistical significance. Training models were also checked for multicollinearity of predictors, but variance inflation factors <4 indicated no problems with collinearity (Allison, 1999). Subsequent to this analysis, the training model was used to predict observations in the test set. A location in the test set was predicted to be a nest site if the training model assigned it >0.5 probability of being used as a nest. The accuracy of model predictions was evaluated based on the total accuracy, sensitivity, and specificity (Fawcett, 2016).

To evaluate the ability to predict sea turtle nest locations through time, composite models were developed for each species from the 2013 and 2014 data. These were tested on their accuracy in predicting nest locations in the 2015 breeding season. Composite models were constructed by averaging the coefficients from the 2013 and 2014 models. I used simple, unweighted means because model performance, measured by prediction accuracy, was essentially equal between years (see Results section below). Prediction accuracy for 2015 nest site locations was again evaluated based on total accuracy, sensitivity, and specificity.

IV. Results

2013

Overall, there were statistically significant results for each of the three variables, regardless of the year or species. Considering at the training model for green sea turtles in 2013, the coefficients for the wrack line, dunes, and vegetation were 0.18, -0.286, and -0.119 respectively. Negative values indicate that the probability of a nest is more likely going down the beach, and positive values indicate that the probability of a nest is more likely going up the beach, relative to the feature being analyzed. Down the beach implies being closer to the water, whereas up the beach indicates being closer to the vegetation, or father inland. All variables had a *p*-value of <0.001 (Table 1). The model produced a total accuracy of 84.7%, with sensitivity being 91.1%, and specificity being 78%. Sensitivity measures the proportion of positive values that are correctly identified as such, whereas specificity measures the proportion of negatives that are correctly identified as such. The confusion matrix (Table 2) indicated that the model slightly overestimated the number of nests in an area, rather than underestimated.

Predictor	**Coefficient**	**Standard Error**	***p*-value**
Intercept	6.926	0.227	<0.001
d(wrack)	0.181	0.007	<0.001
d(dunes)	-0.286	0.011	<0.001
d(veg)	-0.119	0.012	<0.001

Table 1: 2013 Green Sea Turtle Analysis Results. Model coefficients and statistical significance from logistic regression.

	Reference	
Predicted	**No nest**	**Nest**
No nest	629	75
Nest	177	767

Table 2: Confusion Matrix for the 2013 Green Sea Turtle analysis.

The loggerhead 2013 data had similarly significant results. the coefficients for the wrack line, dunes, and vegetation were 0.139, -0.365, and 0.040 respectively. As with the green sea turtles, all *p*-values were found to be significant, with the wrack line and dunes at <0.001 and vegetation at 0.003 (Table 3). These results gave us a total accuracy level of 83.2%, with sensitivity being 86.3% and specificity being 80.1%. Also similar to the green sea turtles, this model overestimated the number of nests in an area rather than underestimating them (Table 4).

Predictor	Coefficient	Standard Error	*p*-value
Intercept	5.201	0.227	<0.001
d(wrack)	0.139	0.007	<0.001
d(dunes)	-0.365	0.012	<0.001
d(veg)	0.040	0.013	0.003

Table 3: 2013 Loggerhead Sea Turtle Accuracy Assessment.

	Reference	
Predicted	**No Nest**	**Nest**
No Nest	596	103
Nest	148	646

Table 4: Confusion Matrix for the 2013 Loggerhead Sea Turtle analysis.

2014

Using the same three variables as before, the 2014 training model for green sea turtles yielded coefficients of 0.152 for the wrack line, -0.221 for the dunes, and -0.185 for the vegetation. As with the 2013 green sea turtle model, all three *p*-values were <0.001 (Table 5). This resulted in a total accuracy of 86%, with the sensitivity being 78.4% and the specificity being 92.8%. As shown in the confusion matrix for this model (Table 6), this model once again over predicted nest locations, rather than under predicted.

Predictor	Coefficient	Standard Error	*p*-value
Intercept	6.352	0.702	<0.001
d(wrack)	0.152	0.021	<0.001
d(dunes)	-0.221	0.033	<0.001
d(veg)	-0.185	0.039	<0.001

Table 5: 2014 Green Sea Turtle Accuracy Assessment.

	Reference	
Predicted	**No Nest**	**Nest**
No Nest	58	6
Nest	16	77

Table 6: Confusion Matrix for the 2013 Green Sea Turtle analysis.

Following the same procedure, the 2014 loggerhead coefficients for the wrack line was 0.130, -0.386 for the dunes, and 0.082 for vegetation. All three *p*-values were <0.001 (Table 7). This resulted in a total accuracy of 83.5%, with a sensitivity of 85.4% and a specificity of 81.7%. As with all the others, this model over predicted nest locations (Table 8).

Predictor	Coefficient	Standard Error	*p*-value
Intercept	4.758	0.238	<0.001
d(wrack)	0.130	0.007	<0.001
d(dunes)	-0.386	0.013	<0.001
d(veg)	0.082	0.015	<0.001

Table 7: 2014 Loggerhead Sea Turtle Accuracy Assessment.

	Reference	
Predicted	**No Nest**	**Nest**
No Nest	592	93
Nest	126	543

Table 8: Confusion Matrix for the 2014 Loggerhead Sea Turtle analysis.

Overall, the following correlation coefficients were found using Spearman Correlation methods, shown below (Table 9).

	d(wrack)	d(dunes)	d(veg)
Green 2013	0.3395	0.3557	0.3979
Loggerhead 2013	0.3295	0.3210	0.3495
Green 2014	0.3456	0.3524	0.3931
Loggerhead 2014	0.3126	0.3134	0.3271

Table 9: Correlation values for each year analyzed for each species.

2015

Averaging the results of the 2013 and 2014 green sea turtle data gave us coefficients of 0.167 for the wrack line, -0.249 for the dunes, and -0.152 for the vegetation (Table 9). This resulted in a total accuracy of 85.5% when predicting the green sea turtle 2015 nest site locations, with a sensitivity of 95.6% and a specificity of 75.9%. For the loggerheads, the model averaged coefficients were 0.134 (wrack line), -.0375 (dunes), and 0.061 (vegetation). These predicted 2015 loggerhead nest site locations with 86.7% accuracy (Figure 4). The sensitivity and specificity of the 2015 loggerhead nest location predictions were 92% and 81.3%, respectively, and both models over predicted nest site locations (Tables 10 & 11). Additionally, there was no difference in results when using the pooled data for 2013 and 2014 to compute the coefficients *verses* using the average coefficient values for the two years.

	Reference	
Predicted	**No Nest**	**Nest**
No Nest	2688	155
Nest	852	3385

Table 10: Confusion Matrix for the 2015 Predicted Green Sea Turtle Nests.

	Reference	
Predicted	**No Nest**	**Nest**
No Nest	3162	310
Nest	727	3579

Table 11: Confusion Matrix for the 2015 Predicted Loggerhead Sea Turtle Nests.

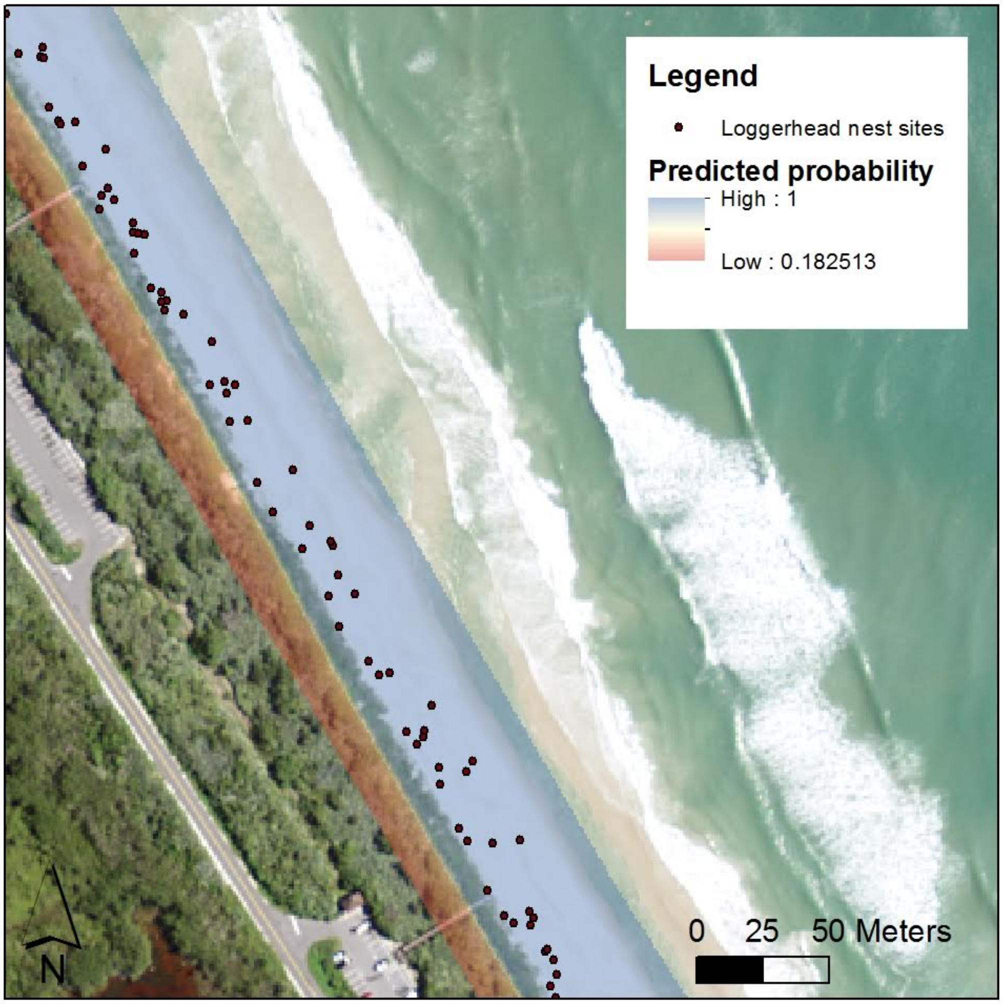


Figure 4: Visual representation of predicted probability found for Loggerhead sea turtles in comparison with observed 2015 data.

V. Discussion

These results indicate that both loggerhead and green sea turtles use topographical features to make decisions regarding available nesting sites, which contradicts initial conjectures that sea turtles emerge from the sea onto a beach with a very limited ability to assess their nesting environment (Garmenstani *et al.* 2000). These results suggest a more complex nest site selection process than originally suspected (Schultz, 2016). They further indicate that these species could be resilient to climate change and shifting nesting grounds by using microhabitat cues to select suitable for nesting, should such habitat remain available (Perez *et al.* 2016).

Additionally, using the trends determined from both years of the loggerhead and green sea turtle nesting data, one we can accurately estimate the probability of a nest site location based on topographical features with an average of 86% accuracy, using the 2015 nesting season as a test case. This model can be applied to beaches currently sensitive to climate change and other anthropogenic impacts to help better identify important regions, as well as to beaches that are not yet used by turtles now but that may enter their range in the future (Reece *et al*. 2013). The model consistently overpredicts the number of potential nest sites, which should be valuable when designing conservation policies. This would not only ensure that significant future areas are protected, but would also serve to predict whether or not a beach has capacity for additional nesting.

Most recent studies addressing climate change effects on marine species have suggested that the current biodiversity strategies in place do not sufficiently consider the future habitat requirements of many threatened species (Katselidis *et al*. 2014). The IUCN has all of the seven sea turtle species listed as threatened or endangered, including both loggerhead and green sea turtles. As their role as a keystone species in their marine environment is better understood, sea turtle conservation is considered increasingly important (IUCN). While maintaining high levels of biodiversity is always a key goal of conservation, the roles that sea turtles play in their ecosystem increases their significance (IUCN).

Today, global loggerhead and green sea turtle numbers are greatly reduced from historic levels according to IUCN estimates. These declines can be explained due to habitat loss, interactions with fisheries, as well as pollution and disease (Hart *et al*. 2012). These threats and declining populations have led to the elevation of protection levels for sea turtle species in the United States (Hart *et al*. 2012), and while sea turtle populations are now protected, the species still face great challenges when it comes to climate change.

Under conservative estimations for sea level rise of roughly 0.2m over the next 100 years, one can anticipate a loss of 38% of total nesting beach area worldwide. This is compounded by a loss of stand producing the loss of an average of 13% diminution of current nesting areas (Katselidis *et al*. 2014). Global sea levels will continue to rise due to the thermal expansion of water, as average mean global temperatures have been increasing at a rate of 0.02°C per decade (Von Holle *et al.* 2010). A predicted global sea level rise of even 0.6m over the next 100 years is quite plausible, especially when the melting of ice sheets and glaciers is considered (IPCC, 2013).

Sea level rise has several different implications on the nesting success of marine turtles. As the sea level rises and the beach narrows, the total available nesting area will become more and more constricted (Katselidis *et al*. 2014). This may cause nests to be laid more closely together, having a detrimental effect on nesting success (Katselidis *et al*. 2014). As the available area decreases, one could expect an increase in the amount of nests accidentally dug up by other turtles, increased nest infections due to closer avenues of diffusion for pathogens, or simple overheating of nests (Katselidis *et al*. 2014). Additionally, clusters of nests are at a greater predation risk (Katselidis *et al*. 2014).

Sea turtles have two possible responses to the temperature and sea level increases being experienced now and those expected into the future (Reece *et al*. 2013). Species may shift their nesting attempts upslope in elevation, which is often not an option, or they may shift farther north in latitude (Reece *et al*. 2013). A northward shift in nesting density has already been observed, along with an earlier nesting season corresponding to warmer temperatures (Reece *et al*. 2013). It is reasonable to assume that this trend will continue. The critically important habitats protected today may not be the habitats needing protection in the future. By following the northward trend in nesting and determining which beaches are suitable habitat, we can determine the ranges to which sea turtles may adapt. The improved understanding of nest site selection provided by this study, in tandem with projections of sea level rise, could play a key role in future conservation strategies (Fujisaki and Lamont, 2016).

It is important to understand that this model predicts nesting abundances based on microhabitat topographical features, and that other variables at sea could also play a key role (Katselidis *et al*. 2014). If sea turtles are unable to reach a particular beach, it will not matter if the potential abundances can be predicted. Additionally, it is difficult to determine at this stage whether or not these results are due to proximate or ultimate causation, meaning there could be underlying factors not yet identified (Mayr, 1988). Separating proximate from ultimate causation can be helpful when examining a system in question, but from a conservation standpoint, this is less of a concern (Hildén, 1965). If used in combination with other predictive measures, this model could play an important role in conservation efforts by addressing a large component of a sea turtle's ability to respond to climate change.

Using this model, one has the ability to potentially safeguard future nest sites and consider these locations in management efforts. This model can also help increase flexibility and reinforce the effectiveness of manual protection strategies, including nest relocation (Katselidis *et al*. 2014). Most importantly, while this study focuses on nesting sea turtles, these methods can be applied to other species, especially ones with similar nesting behaviors (Mazor *et al*. 2013).

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