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Impact of Increased Green Turtle Nesting on Loggerhead Fitness

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by

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ABSTRACT

Marine turtles exhibit strong fidelity to their nesting beaches, making the conservation of nesting beaches important for ensuring successful sea turtle populations. Conservation of these nesting beaches involves understanding how species interact with the environment and each other, and understanding how environmental change and population growth can affect the suitability of the nesting habitat. The Archie Carr National Wildlife Refuge (ACNWR) is unusual in its high density of sea turtle nesting by two species: green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) turtles. The ACNWR in Melbourne Beach, Florida was established in 1991 due to the high density of loggerhead nesting, but in the time since it was established there has been a significant increase in green turtle nesting, from fewer than 50 nests in 1982 to over 15,000 in 2017. With such a high density of these two species in one relatively small area (21 kilometers of beach), the two species may compete for space. This is especially true for green turtles, which disturb large amounts of sand during their nesting process; in 2017, we observed 338 loggerhead clutches disturbed by nesting females during nesting surveys, nearly all of which were disturbed by green turtles. Using observed spatial and temporal nesting patterns for both green turtles and loggerheads on the ACNWR, I examined the effects these species may have on each other's nests now and in the future. Additionally, green turtles and loggerheads nest in different densities along the length of the ACNWR, with green turtles more concentrated in the southern portions of the Refuge. Finally, green turtle nesting begins and peaks approximately one month later on the ACNWR than loggerhead nesting. For each of these metrics, there is both considerable overlap and distinct separation between the two

species. By using these metrics in a modeling approach, I estimated the probability of nest disturbance by a subsequently nesting female, ranging from 0 to 0.105, and how these probabilities are predicted to change over time with a growing green turtle population. Evaluating the carrying capacity of this beach is important in the context of habitat disturbance, including climate change and an increase in storm frequency, and informing adaptive management strategies for effective conservation.

DEDICATIONS

For my parents, thank you for always supporting me unconditionally. For all the educators and role models in my life, thank you for inspiring my passion for science and research.

ACKNOWLEDGMENTS

I would like to thank the UCF Marine Turtle Research Group lab members for all their support, guidance, and feedback; I would like to thank the Burnett Honors College, Office of Undergraduate Research, and the Student Government Association for providing scholarships and travel funding that supported this project. A special thanks to Katrina Phillips and Chris Long for all the support, effort, and time you contributed to this research. Thank you to Dr. Kenneth Fedorka for serving on my committee and providing me valuable feedback. Thank you to Dr. Kate Mansfield for serving as my thesis chair and all your support, guidance, and feedback throughout this process.

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INTRODUCTION

The impact of competition dynamics on past and future extinctions is poorly understood because complex mechanisms involving the interaction of species within communities, such as local resource competition and individual space use have not been studied in depth (Buchmann 2012). Interspecific competition results in adverse effects to growth or survival due to the interaction between individuals of different species, driven by the indirect competitive mechanism, where a common resource is scarce or being over-utilized too quickly (Allaby 1999). If the resources are not scarce, then competition results when the involved species harm each other while trying to obtain or utilize the resource (Birch 1957). Competition induces the separation of similar species, achieved spatially, temporally, or ecologically, explained by the competitive-exclusion principle stating that ecological niches will not be shared by species (Gause 1934). No two resource-limited species with identical patterns of resource use can coexist in a stable environment because one species will inevitably out-compete the other (Allaby 1999). Interspecific competition has been observed in freshwater fish (sunfish, trout), marine systems (fishes, corals), terrestrial plants (grasses, spruce trees), and terrestrial animals (spiders, rodents) (Schoener 1983). In this study, we examine an instance of interspecific competition between green turtles (*Chelonia mydas*) and loggerheads (*Caretta caretta*) in nesting habitat.

Coastal areas are becoming more populated by humans and are therefore experiencing an increase in the development of housing and other structures (Burak et al. 2004). Coastal development leads to a reduction in the available beach area and can disrupt nesting sea turtles or hatchlings as they move between the beach and offshore habitats (Witherington & Bjorndal 1991). A reduction in available beach habitat can increase interspecific competition for viable nesting area. Beach development on the Archie Carr National Wildlife Refuge (ACNWR) experienced a 160 percent increase from 1986 to 2006 (Ehrhart 2013). When there is new development on the dune, beaches are unable to retreat inland to counter sea level rise (Ehrhart 2013). This increase in development in conjunction with issues such as sea level rise and coastal squeeze can affect the competitive ability of both species as density-dependent effects become more prominent, and females are forced to nest in smaller areas (Fuentes et al. 2010). It has been estimated that the total area of beach on the ACNWR would change from 0.99 million meters squared to about 0.57 million meters squared in 2050, which predicts a 43% reduction in available nesting habitat due to sea level rise (Ehrhart 2013). Understanding these human-created threats is especially important on beaches with high-density nesting.

Sea turtles are of interest to conservation biologists because they are an international species and all seven species of turtle are considered either threatened or endangered globally by the IUCN (IUCN Red List). Under the U.S. Endangered Species Act (ESA), loggerheads have four distinct population segments that are listed as Threatened, including the northwest and south Atlantic, and five that are listed as Endangered (ESA). For green turtles, eight distinct population segments are listed as Threatened, including the North and South Atlantic, while three are listed as Endangered (FWS 2016, NOAA 2016) and categorized as Endangered on the IUCN Red list (Engeman 2005). It is important to understand the aspects and effects of these species' competition for resources to aid in the recovery of their populations.

There are various protections, both federal and international, in place for marine turtle species, to include the Endangered Species Act (NOAA 2014, FWS 2016) and the Inter-American Convention (IAC), which is an intergovernmental treaty that provides a legal framework for countries to protect sea turtles (NOAA 2016). The measures involved include prohibited poaching of eggs, contact with turtles, appropriate fishing practices, designation of protected areas for critical habitat, restriction of human activities that can harm turtles, and promotion of research and education of sea turtles (NOAA 2014). Marine turtles also face the threat of anthropogenic climate change affecting nesting habitat through temperature increases, sea level rise (Fish 2005, Reece 2013), beach erosion, increased storm frequency, and coastal squeeze (Mazaris 2009). Successful conservation needs to involve an understanding of interspecies relationships, their environment, and factors contributing to distribution in the face of these threats posed by climate change (Reece 2013). With an increase in human activities and these threats to habitat, sea turtles' ability to respond to climate change has been reduced (Mazaris 2009).

Sea turtle nesting sites are the most accessible to study and implement protections for, as opposed to other, offshore and foraging sea turtle habitats (Nel et al. 2013). As a result, there are many studies involving nesting behavior and biology. In all marine turtle species, available terrestrial habitat is an important factor ensuring successful reproduction (Hawkes et al. 2009). Nest site selection on the beach has an impact on the outcome of the nest, the sex ratio of hatchlings, and the survival of hatchlings, therefore influencing the fitness of the population (Wang 1999). The general nesting process is similar in all species of sea turtles: a mature female emerges from the water, makes an ascent up the beach, selects and clears a nesting site, excavates a body pit and egg chamber, deposits eggs, covers the eggs with sand, camouflages the body pit, and returns to the water (Miller 1997). A significant difference is green turtles dig proportionally deeper body pits and also have longer hind flippers, allowing for a deeper egg chamber that extends forward more than most other species (Miller 1997). Due to the more massive, deeper body pits, green turtles throw more sand and disturb a larger area than loggerheads (Miller 1997).

Image 1. Green turtle nest laid on the ACNWR with Amanda Carmichael shown for scale. Green turtles disturb much larger areas of sand than loggerheads when nesting.

Image 2. Loggerhead nest. Loggerheads disturb a much smaller area when nesting than green turtles.

Loggerheads typically require between one to two hours to go through the nesting process (Hirth 1980) and lay an average of 110 eggs per clutch (Miller 2003). Green turtles require two to three hours (Hirth 1971) and lay an average of 128 eggs per clutch (Brost et al. 2015). Each season, green turtles lay between three and seven clutches with ten to fifteen days between laying (Hirth 1971, Dodd 1988), and loggerheads lay between two to four clutches, or about one every 14 days (Witherington et al. 2006). Loggerhead nesting tends to begin earlier than green turtle nesting, but there is still considerable overlap in Florida (Engeman 2005), with loggerhead nesting typically beginning in mid- to late April and green nesting not starting until late May. Loggerheads tend to nest in open, bare sand on Florida beaches, while green turtles tend to nest in vegetated areas behind open sand (Whitmore 1985) and on platforms of sand that are 1 – 3 meters higher than the mean high-water line (Johannes 1984).

Clutch disturbance, where clutches and eggs are dug up by subsequent nesters or predators is recorded at nesting beaches globally (Hirth 1971). Documented predators of marine turtle nests include various species of fire ants (Wetterer 2007), ghost crabs (Peterson 2013), raccoons, armadillos, bobcats, and humans (Engeman 2005). In addition, nesting sea turtle females can become interference competitors with each other. In Ostional National Wildlife Refuge (ONWR), olive ridley sea turtles (*Lepidochelys olivacea)* exhibit large mass nesting referred to as arribadas (Bezy et al. 2016). During these arribadas, intraspecific clutch disturbance and nest destruction from other nesting females occur (Hughes 1974). Intraspecific clutch disturbance is also observed in a study by Bustard and Tognetti (1969) on green turtles in the Great Barrier Reef. They suggest the nest destruction is a mechanism that takes place when a population increases to stabilize the population; however, in a species that is constantly overexploited, this mechanism may become absent (Bustard 1969). This being a group selection argument, it is more likely that nest destruction is a side effect of intraspecific competition. While there are various studies of intraspecific clutch disturbance (Bezy et al. 2016, Tiwari 2010), there are few data on interspecific clutch disturbance.

Peninsular Florida has large numbers of loggerhead nesting along its coast (96,886 nests in 2017; FWCC 2017). The Archie Carr National Wildlife Refuge (ACNWR) is located in Brevard County, Florida, and is a globally important nesting beach for loggerheads and increasingly for green turtles (Ehrhart et al. 2014). The University of Central Florida Marine Turtle Research Group (UCFMTRG) began surveys in Melbourne Beach, Florida in 1982 and recorded as few as 50 green turtle nests a year (Shamblin et al. 2014). However, green turtle nest numbers have increased significantly in peninsular Florida, from approximately 12,000 in 2011 to 53,902 nests in 2017, and Brevard County currently accounts for 43 % of green turtle nesting and 30% of loggerhead nesting in Florida (FWCC 2017). In 2017, the UCFMTRG documented 15,763 green turtle nests, breaking the record as the highest nesting green turtle year, and in 2016, documented the second highest loggerhead nesting year at 17,192 nests (UCF MTRG data). Due to the alternating cycle of foraging and nesting in marine turtles, there tend to be alternating high and low years of nesting in green turtles (Hirth 1971). As seen in Figure 1 and 2, the loggerhead nest counts show lower annual variation than green turtles, with green turtles having the highest year on record in 2013, 2015, and again in 2017. With the vast increase in green turtle nesting, the density gradients across the stretch of beach are experiencing change and loggerheads, and green turtles are increasingly competing for space.

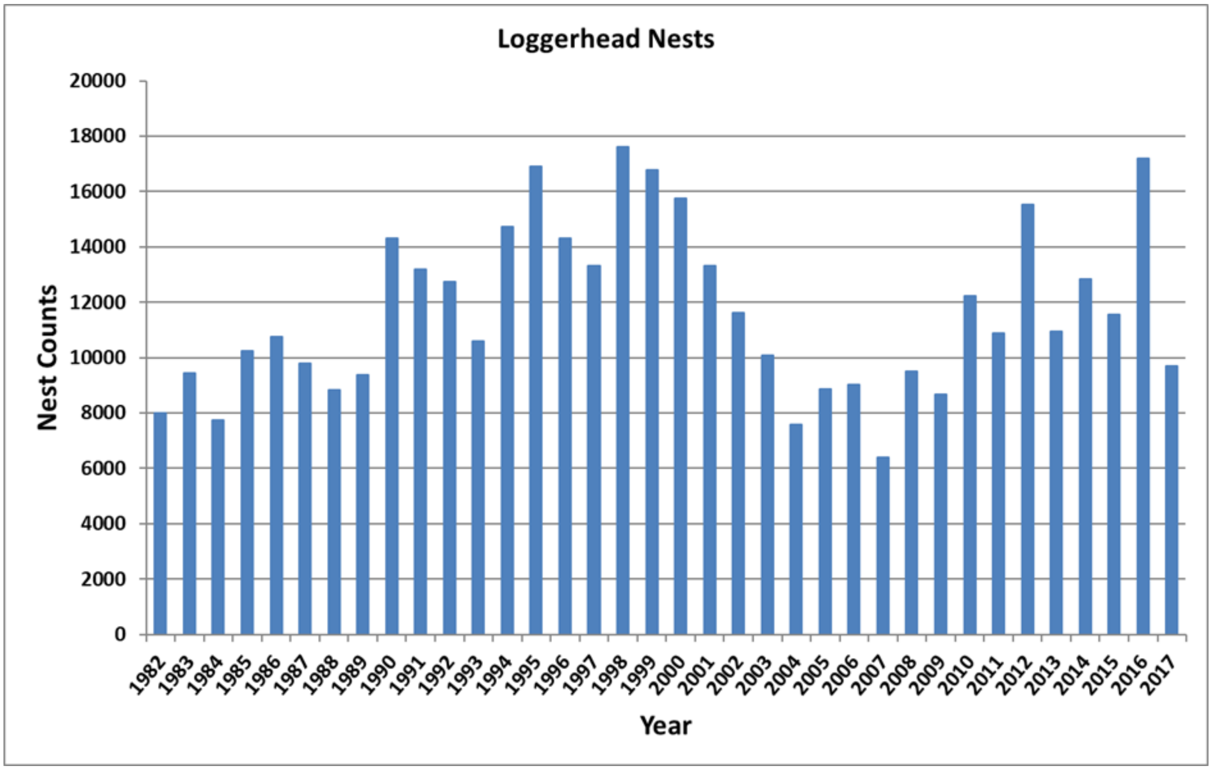

Figure 1. Number of loggerhead nests deposited on the ACNWR from 1982 to 2017.

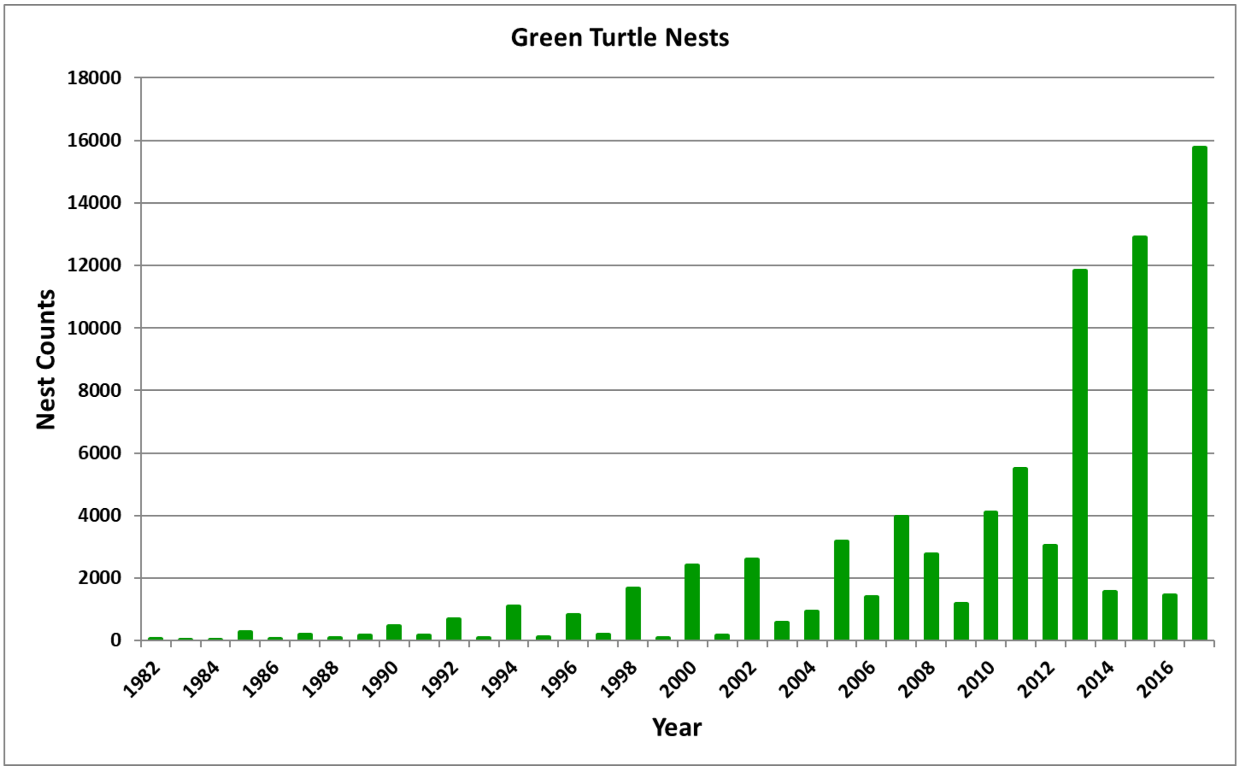

Figure 2. Number of green turtle nests deposited on the ACNWR from 1982 to 2017. Green turtles exhibit an alternating pattern of high and low density nesting years. High years have been record-breaking for 2013, 2015, and 2017.

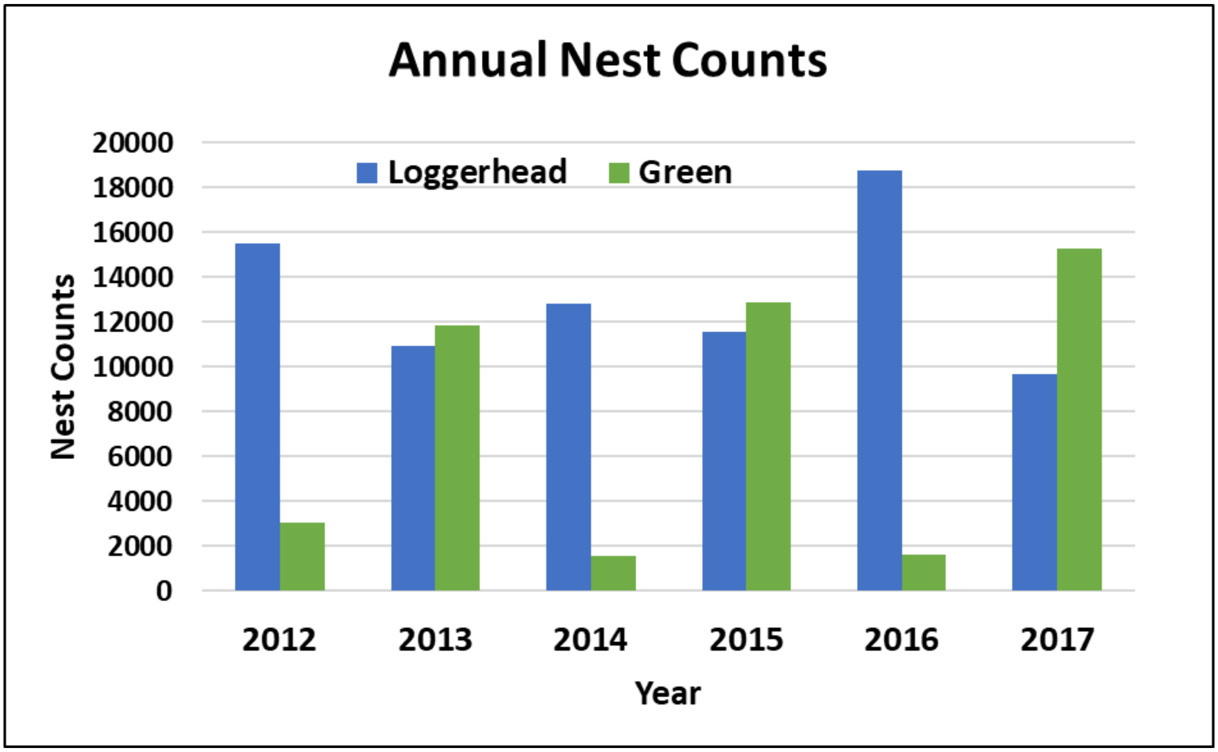

Figure 3. Annual nest counts at the Archie Carr National Wildlife Refuge in Florida. Green turtles exhibit alternating high and low nesting seasons.

My study aimed to estimate and predict: (1) the impact that an increasing population of green sea turtles is having on loggerhead nests and fitness; and (2) if coastal threats such as coastal squeeze, beach erosion, and sea level rise will enhance effects from these green turtles. To address these objectives, my study examines the following research questions: (1) What is the probability of loggerhead nest disturbance due to increased green turtle nesting over time; and (2) Will threats such as coastal squeeze, beach erosion, coastal development, and sea level rise increase nest disturbance by green turtles?

METHODS

Study Site

The site used in this study was the stretch of beach in the Brevard County portion of the ACNWR on the Atlantic Coast of Florida. The beach extends 21 kilometers from southern Melbourne Beach to the northern boundary of Sebastian Inlet State Park (Ehrhart et al. 2014). The study site is divided into half-kilometer zones that are marked using landmarks and referenced for data collection.

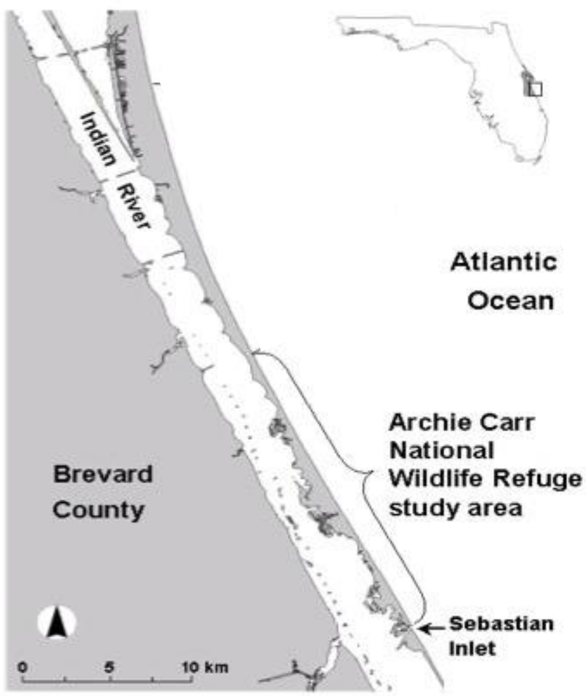

Figure 4. Location of the Archie Carr National Wildlife Refuge (ACNWR)

Nesting Beach Surveys

The UCFMTRG conducted annual morning surveys three days a week beginning on March 1st and continued daily surveys from April 1st through October 31st. During these surveys, the entire stretch of 21 kilometers was driven using all-terrain vehicles (ATV) at sunrise, and all nests and false crawls (non-nesting emergences) were tallied for every half kilometer. All nests and were differentiated by species. Tire tracks were purposefully placed over all turtle tracks to prevent old tracks from being recounted the following morning. All observed instances of clutch disturbances were recorded by surveyors, with data collected regarding clutch location, amount of eggs disturbed, species of eggs, and species of predator. I used data collected in this manner from 2012-2017 for subsequent analyses.

Marked Nests

The study site was monitored every night throughout the season by UCFMTRG researchers. A predetermined spatiotemporal distribution based on the previous five years of nest distributions is used to select a subset of nests to "mark" nests every season by the UCFMTRG. To mark a nest, a researcher would locate an emerging female turtle, and staying at a safe distance, would wait until the female began laying her clutch on the beach. Once the female completed the laying process, researchers were allowed to approach the female and record various measurements from that located clutch. These measurements included distance from clutch to dune and distance from clutch to high tide.

Temporal and Spatial Analysis

I analyzed temporal nest overlap of green turtle and loggerhead nests using the number of nests on the beach per day for both species. Survey nest counts do not account for hatching and emergences throughout the season. The number of nests present on the beach per day was estimated using the following equation (Tiwari 2010):

$$Nests_{t} = Nests_{(t-1)} + N_t - H_t,$$

Where *t* represents each day, *N* represents the number of nests deposited each day, and *H* represents the number of nests hatched. This equation was used for every day throughout the nesting season, beginning March 1st – October 31st, for each year from 2012 – 2017. By presenting these nest calculations graphically, I observed the difference and overlap in nest timing for both species over the season. I looked at a high green year and low green year for temporal overlap. I evaluated spatial overlap using the distance from clutch to dune measurements from the marked nest data of both species from years 2012 – 2017. These distances allowed me to view where the nests of both species were placed on the beach and determine any overlap in certain areas. Due to the marked nest distribution, nests from all zones of the beach were included. I graphed these distances for both species to determine the overlap of nests based on placement on the beach relative to the dune. The base of the dune is defined as a change in slope and a significant increase in vegetation, with transition being the area 1 meter South of the base of the dune and 1 meter North of the base of the dune. This analysis allowed for the identification of areas with the most overlap and most frequent interspecific competition.

Nest Distributions and Densities

I calculated nest distributions by dividing the survey nest counts per day by the total nest counts for the season for every beach zone. Once calculated, I took the average nest distributions of each year to find the annual average nest distributions of all years for both species. Using these averages, I examined the proportion of nesting for both greens and loggerheads graphically. The nest distributions do not take into account beach width or nest emergences. I calculated the densities of loggerheads for the 2012 – 2017 seasons. Density is calculated by dividing $Nests_t$ by beach width. I estimated beach width by adding the measured distance from clutch to dune and distance from clutch to high tide taken from the marked nests. For each season, 150 green turtle nests and 150 loggerhead nests were marked, giving a total sample size of 900 green turtle nests and 900 loggerhead nests. I calculated the area available for nesting per zone using the beach width and half-kilometer zones. I found the average nest densities of both species for all years and presented the annual averages graphically. I calculated the standard error for all averages used in my figures.

Probabilities of Clutch Disturbance

For my study, I define nest disturbance by nesting females as the displacement or damaging of eggs. The following equation represents the expected probability of an existing clutch being disturbed by another nesting female (Tiwari 2010):

$$F_t = 1 - e^{-AD}.$$

In this equation, F_t represents the probability of a nest being destroyed by nesting females on day t; A represents the area of disturbance from a green turtle when nesting; and D represents the nest density on the beach at the time of disturbance. I applied this equation to loggerheads using the respective calculated densities. The estimate for the area of disturbance by green turtles is estimated as two meters squared for all nests (Tiwari 2010, Mazaris 2009). I calculated areas of disturbance using the following measurements, with the assumption that green turtles are the main contributors to clutch disturbance; we assumed nest disturbance by loggerheads was negligible due to their relatively shallow body pits and less disruptive nests. A green turtle pit is about 1.5 m by 1.2 m and 45 centimeters deep, while the round egg chamber is dug about 40 centimeters deeper than the body pit (Bustard 1969). The depth to the bottom of the chamber in loggerhead nests is approximately 60 cm (Carthy et al.). With the clutch disturbance data collected from surveys, the estimation of nest disturbance can be compared to the observations being made by researchers. I found the probability that a nest would not be dug up by a green turtle using:

$$P = (1 - (1 - e^{-AD}))^{G}$$

Where G = the number of green nests laid on the beach on that day. Subtracting that probability by one again gave the probability that a nest would be dug up by a green turtle.

$$P = 1 - (1 - (1 - e^{-AD})^{G})$$

After simplifying, I was able to incorporate the effect of green turtles using the equation:

$$P = (1 - e^{-AD})^{G}.$$

I found the averages of these probabilities for each year and represented them graphically per beach zone and per day. In addition, I took the average for the probabilities of the three high green nesting years (2013, 2015, 2017) and the three low green nesting years (2012, 2014, 2016) and included them on the graph. I calculated the standard error for all averages, represented with error bars on each figure.

Altered Scenarios

I addressed the second research question using analyses to manipulate factors including beach area and green turtle nesting. I analyzed the probabilities of clutch disturbance when the beach area is reduced by half, when the green turtle nest counts were doubled, and the combination of the two. These analyses are theoretical but can show the possible impacts in the near and far future. To reduce the beach by half, I recalculated densities with half the beach area and subsequently redid all the probability calculations. To double the green turtle nest counts, I multiplied all counts by two and recalculated probabilities with the new values. For the figure with the combination of both, I redid all the calculations with both changes. I recreated the graphs to match the original probability graphs, taking new averages of the annual probabilities and including the standard error in the figures.

Correlations

I examined correlations between variables and average probabilities to determine the importance of each variable in determining the probability of clutch disturbance. The variables correlated included the half kilometer zones, loggerhead nest counts, green nest counts, average loggerhead densities, and beach areas. The calculated correlations provided R values, and I represented those values in a table.

RESULTS

Nest Depredation

In 2016, 83 nests, and in 2017, 338 nests were disturbed by green turtles. A higher portion of loggerhead nests were disturbed during a high green year than in a low green year. The depredation data were not recorded for years 2012 through 2015.

Temporal Overlap

Loggerheads begin nesting earlier in the season than green turtles (Figure 5). Loggerheads begin nesting in late April or early May, while green turtles start nesting in late May or early June. Due to this difference in timing, there are already a large number of loggerhead nests on the beach when the greens begin nesting in the area. In 2014, there were already 2,084 loggerhead nests present on the beach when green turtles began nesting and in 2015, there were 1,201 loggerhead nests when green turtles started nesting. The temporal overlap between species is higher in high green turtle nesting years (Figure 6).

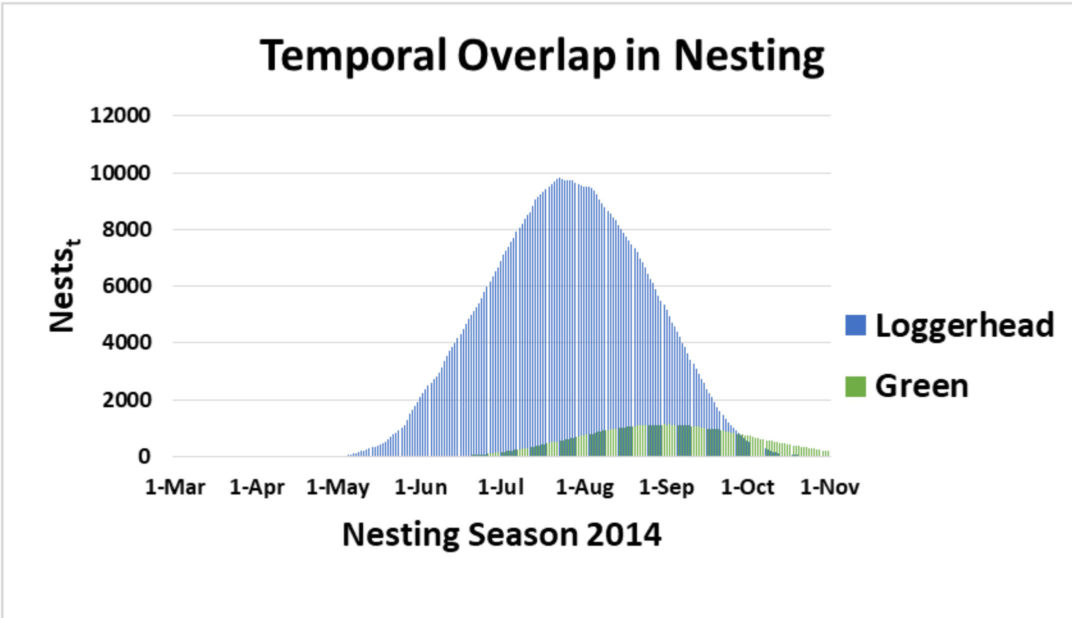

Figure 5. Temporal overlap of green turtle and loggerhead nesting in 2014, a low green nesting year, using the nests present on the beach on any given day (Nests$_t$).

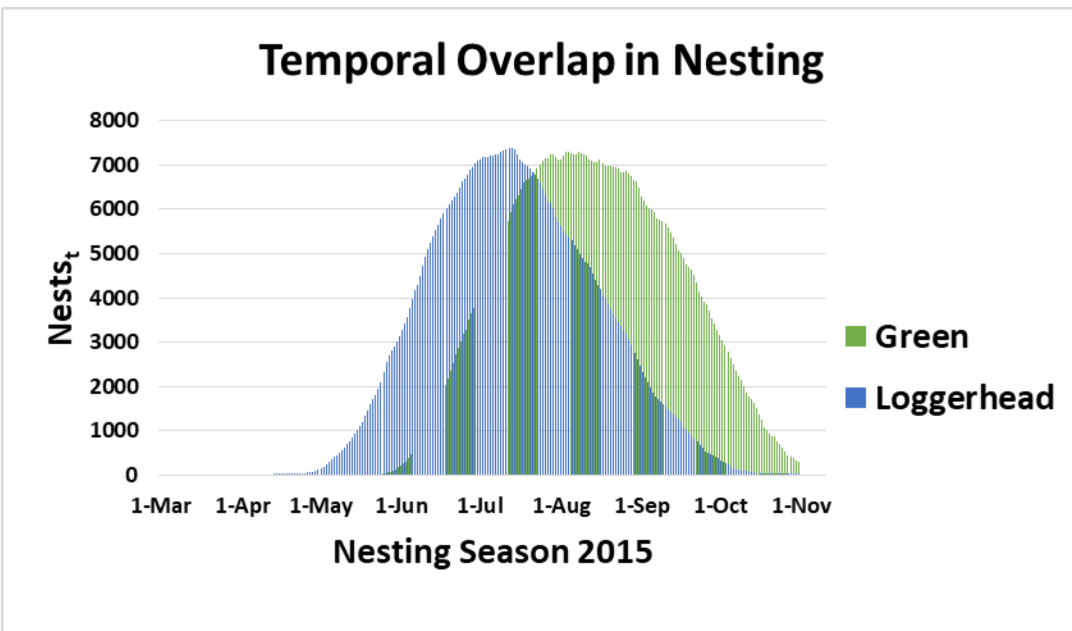

Figure 6. Temporal overlap of green turtle and loggerhead nesting in 2015, a high green nesting year, using the nests present on the beach on any given day (Nests$_t$).

Spatial Overlap

Green turtles tend to nest on the dune or in transition of the dune (Figure 7). Loggerheads also exhibit most of their nesting on the dune or in transition of the dune but have higher nesting on open beach than the green turtles do (Figure 7). The portion of beach with the highest green and loggerhead nesting is the same for both species, between 0 – 1 meters to the dune.

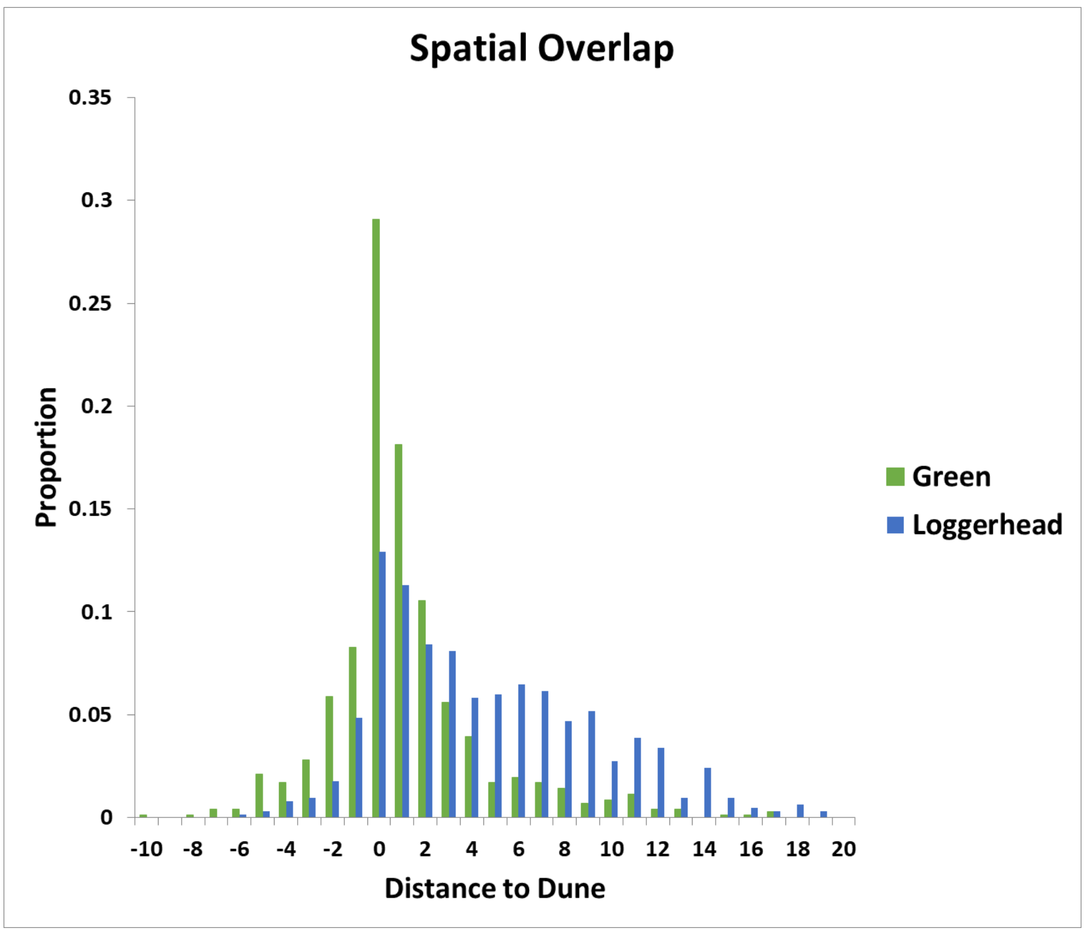

Figure 7. Spatial distribution of loggerhead and green turtle nests.

Nest Distributions

On average, loggerheads nest in higher proportions on the North end of the refuge, seen in Zones 1 – 21 in Figure 8. Although green turtles show high variability among beach zones, with the highest proportions being between zones 31 and 36, they do not show any trends from north to south. Nesting for both species occurs in the lowest proportions at the very South end of the refuge, zones 41 and 42. Nest proportions do not take into account the beach width or emergence of nests, only the survey count totals per species.

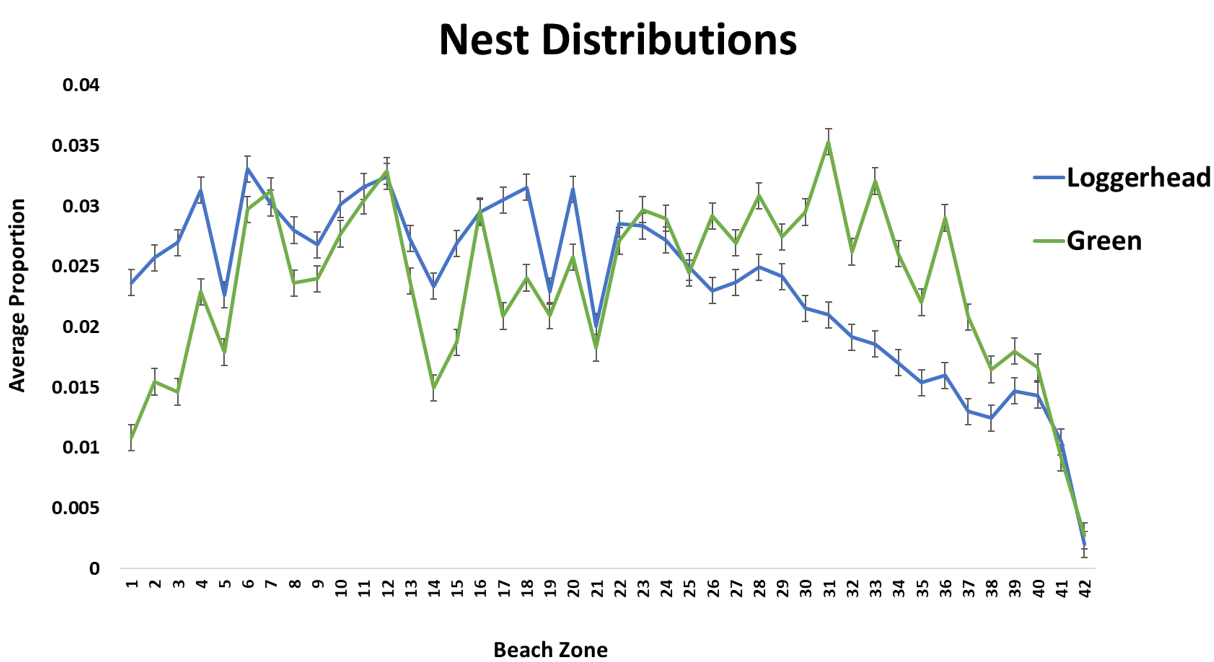

Figure 8. Average annual proportion of loggerhead and green turtle nests in each half-kilometer beach zone from 2012 – 2017. In general, a similar proportion of species' nests occur between zones 5 – 25. Standard error represented by error bars.

Nest Densities

Nest densities were calculated using $Nests_t$ and beach area for each half kilometer, therefore differing from nest distributions. Overall, loggerheads on average nest at higher densities across the majority of the refuge. Loggerheads exhibit the highest densities in zones 18 and 23, while greens exhibit the highest densities in zones 30 and 36 (Figure 9). The densities are more similar between both species in zones 34 through 38.

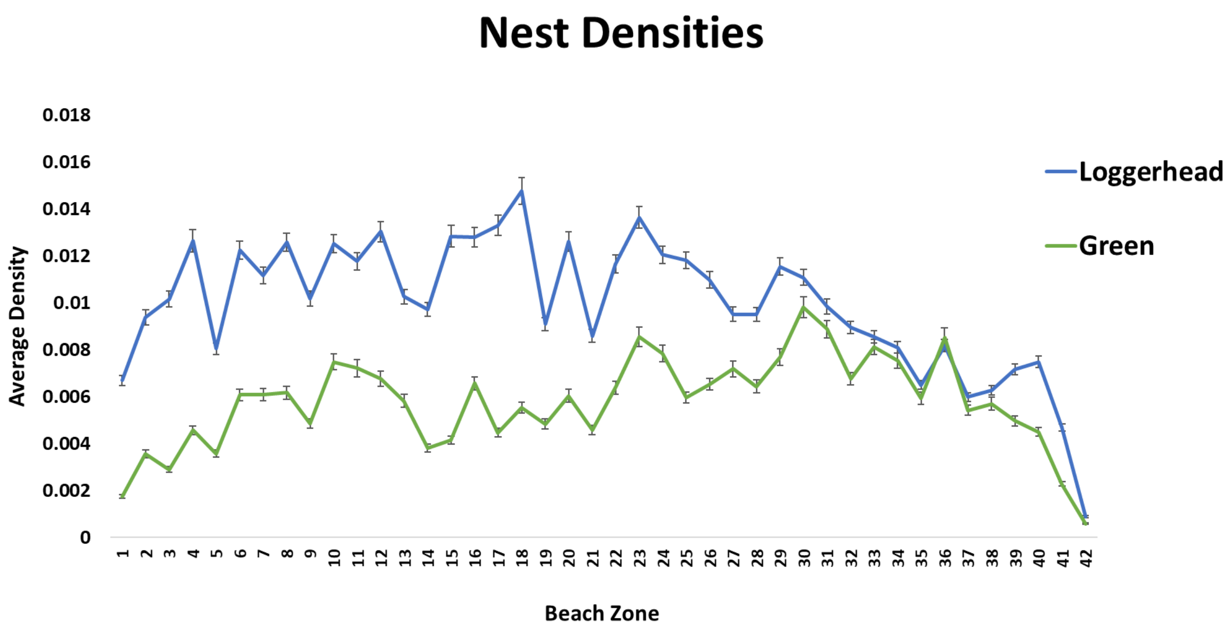

Figure 9. Average annual density of loggerhead and green turtle nests in each half-kilometer beach zone from 2012 – 2017. Loggerheads nest at higher densities with variation in both species across the Refuge. Standard error represented by error bars.

Probabilities of Clutch Disturbance

In years with high green turtle nesting (i.e., 2013, 2015, and 2017), the overall probability of clutch disturbance was higher than in low years, with the average probability being 0.042 in high years and 0.011 in low years (Figure 11). The highest probabilities occurred in 2017, with 0.105 being the highest (Figure 10). Due to the low density in beach zones 41 and 42, the probability of clutch disturbance remained very low in that section. The highest probability was around 0.1 during a high year, and the lowest probability was 0 (Figure 11). The probabilities in the high years and low years differed by as much as 0.06 in some zones. The probabilities of clutch disturbance are higher when observed per day versus per beach zone (Figure 12). Temporally, the peaks in the probability of nest disturbance occur in the high-density nesting months, July and August, with a probability as high as 0.305 in late July 2017 (Figure 12).

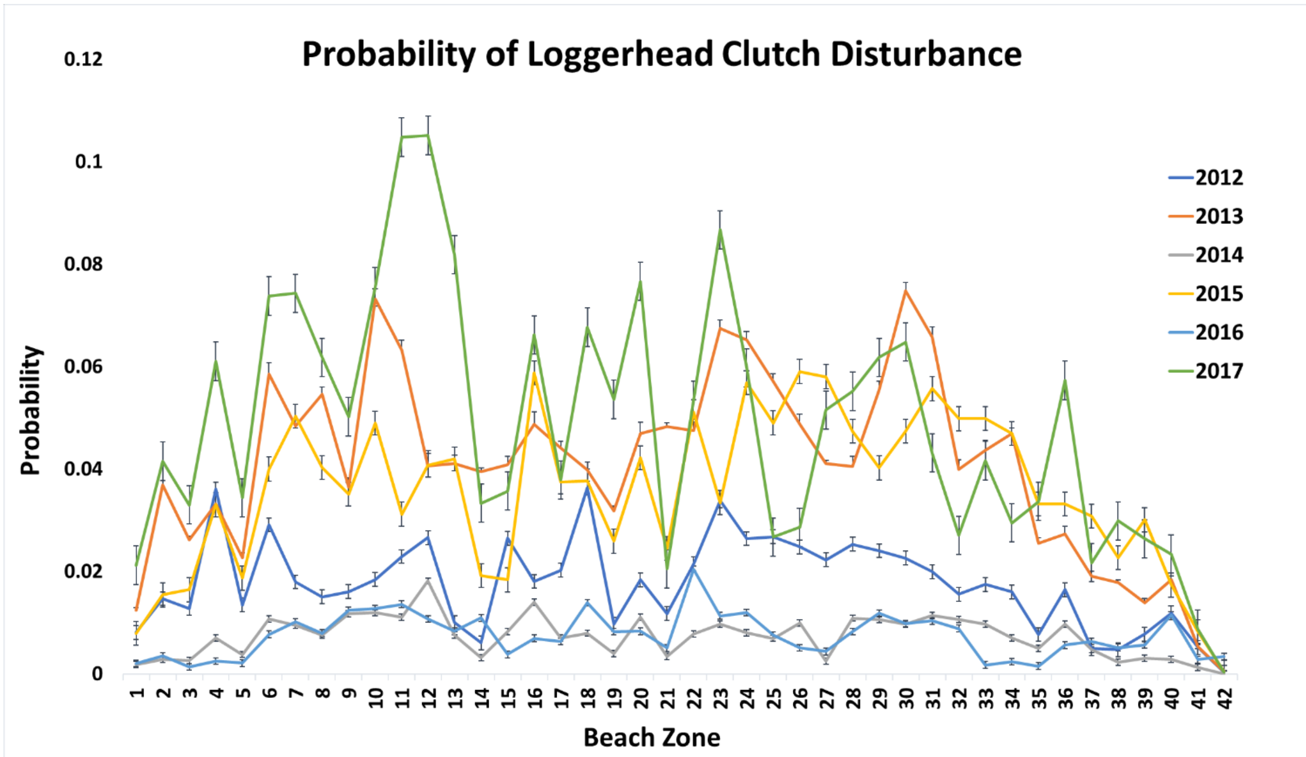

Figure 10. Average annual probability of a loggerhead nest being disturbed by a nesting green female. Standard error represented by error bars.

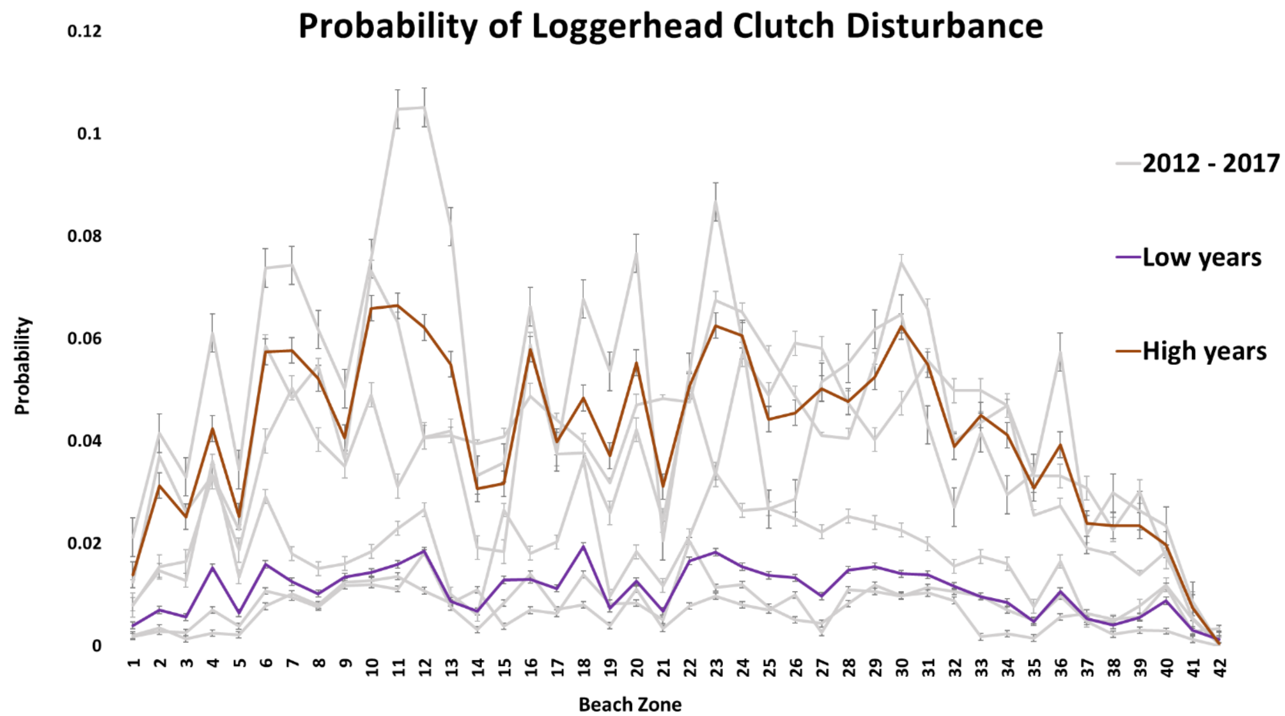

Figure 11. Average probability of a loggerhead nest being disturbed by a nesting green turtle. High years represent high-density green turtle nesting (2013, 2015, 2017) and low years represent low-density green turtle nesting (2012, 2014, 2016). Standard error represented by error bars.

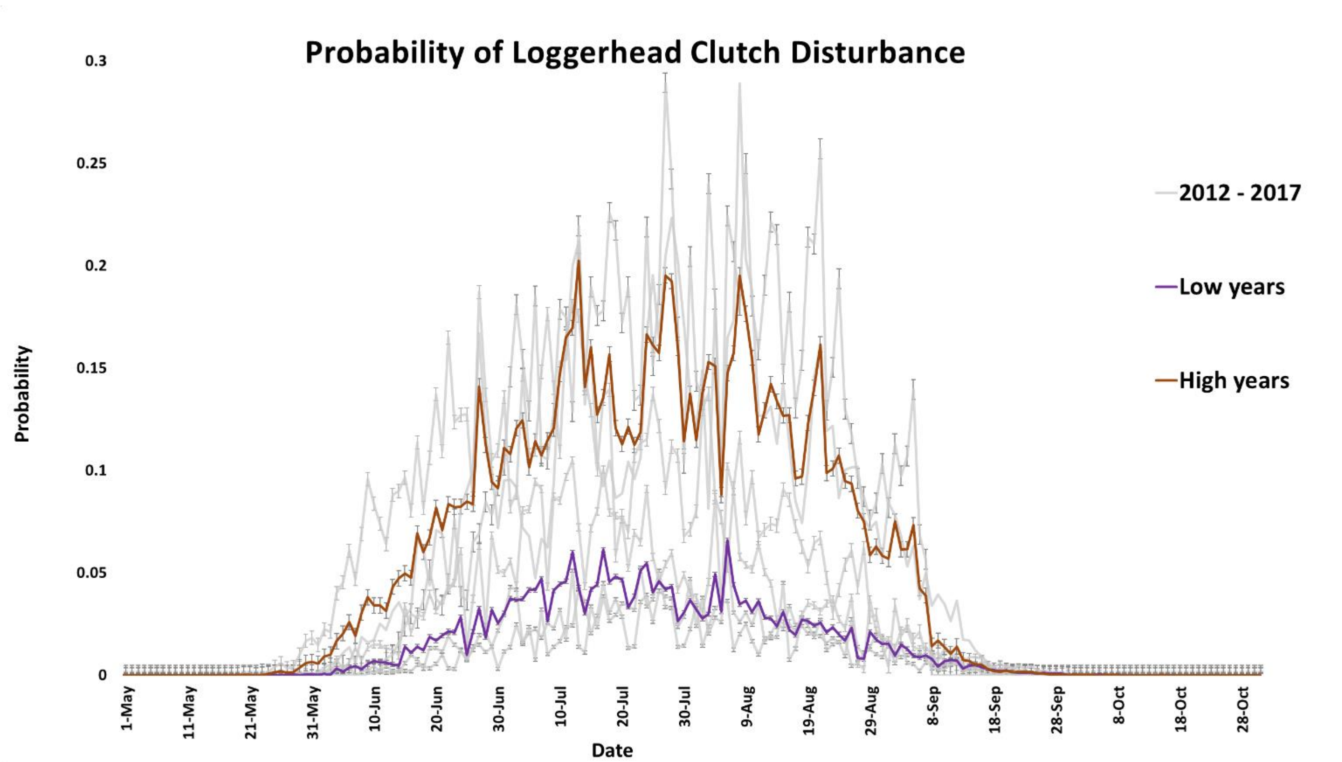

Figure 12. Average probability of a loggerhead nest being disturbed by a nesting green turtle per day. High years represent high-density green turtle nesting (2013, 2015, 2017) and low years represent low-density green turtle nesting (2012, 2014, 2016). Standard error represented by error bars.

Altered Scenarios

The probabilities of loggerhead clutch disturbance when the beach area per half-kilometer has been cut in half and when the green nests are doubled, as they have the same effect, with the high green turtle nesting years continuing to have the highest probabilities (Figure 13). The low years remain at fairly low probabilities despite the doubling. Figure 14 shows the new probabilities when both beach area and green turtle nest counts are manipulated. The average probabilities for the low years and high years vary between the scenarios. The low and high year average probability when the beach area is reduced by half or the green nests are doubled are 0.021 and 0.0745. The low and high year average probability when the beach area is reduced by half and the green nests are doubled are 0.0372 and 0.124. The probabilities are the highest in Figure 14, with the peak being almost 0.25. The peak probabilities remain in the same areas of beach but experience an overall increase.

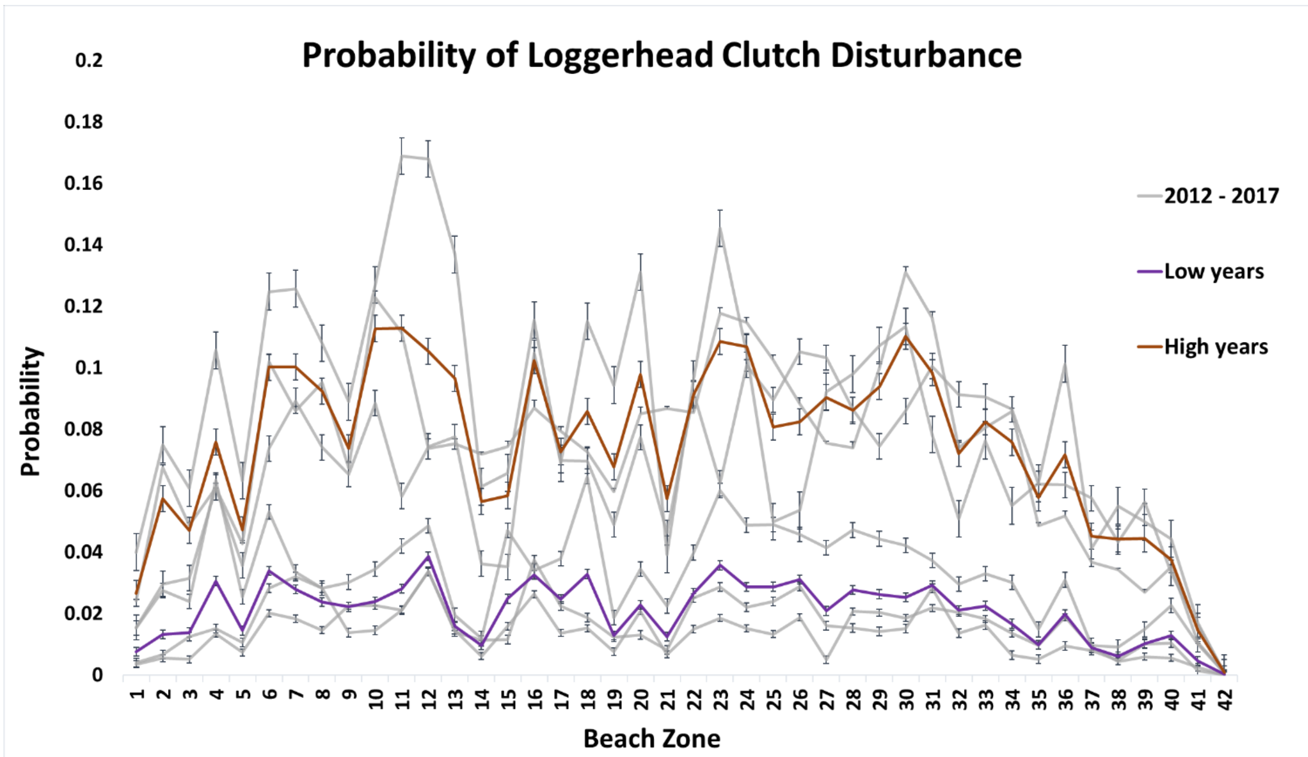

Figure 13. Average probability of a loggerhead nest being disturbed by a nesting green turtle when the beach area is reduced by half or the green nest counts are doubled. Standard error represented by error bars.

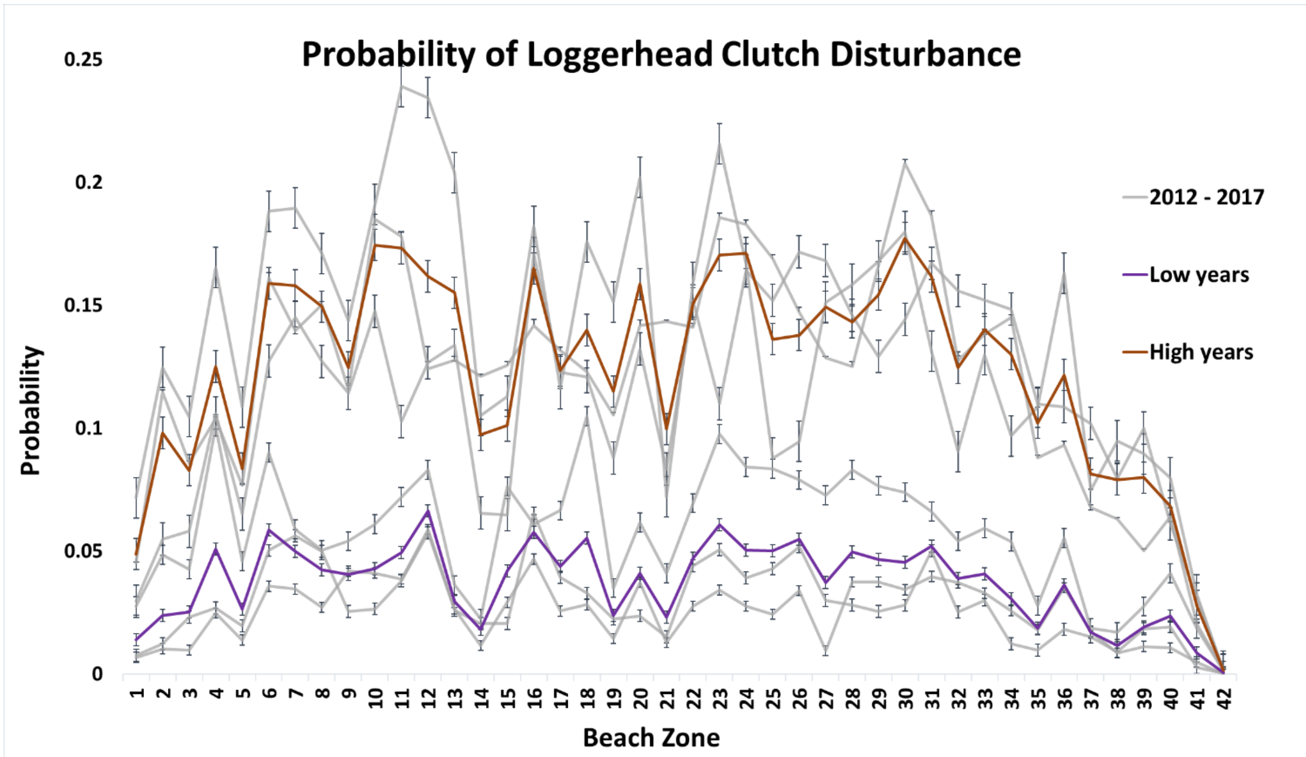

Figure 14. Average probability of a loggerhead nest being disturbed by a nesting green turtle when the beach area is reduced by half, and the green turtle nest counts are doubled. Standard error represented by error bars.

Correlations

Using the R values, I plotted the correlation coefficients for both green nests and beach areas, as I expected these to be the most important. The variable with the greatest measure of correlation to average probability is the green nest counts with an average R value of 0.837 (Table 1). Loggerhead densities also had a high measure of correlation with an average R-value of 0.827 (Table 1). The correlation coefficients with the lowest measures of correlation were the kilometers and the beach areas. Beach area did not correlate with average probability, with the average R-value being -0.301, suggesting there may be a negative relationship between beach area and the probability of clutch disturbance (Table 1). The green nests' correlation coefficient has a linear correlation whereas the beach area does not show any definitive linear correlation (Figure 15, Figure 16).

Table 1. R values of variables correlated with average probability of nest disturbance.

Year	Kilometer	Loggerhead Nests	Green Nests	Loggerhead densities	Beach Areas
2012	-0.305	0.735	0.714	0.839	-0.376
2013	-0.266	0.675	0.754	0.837	-0.517
2014	-0.193	0.658	0.879	0.792	-0.359
2015	0.0458	0.562	0.893	0.838	-0.323
2016	-0.330	0.727	0.900	0.779	-0.009
2017	-0.445	0.720	0.884	0.874	-0.238
Average	**-0.249**	**0.679**	**0.837**	**0.827**	**-0.301**

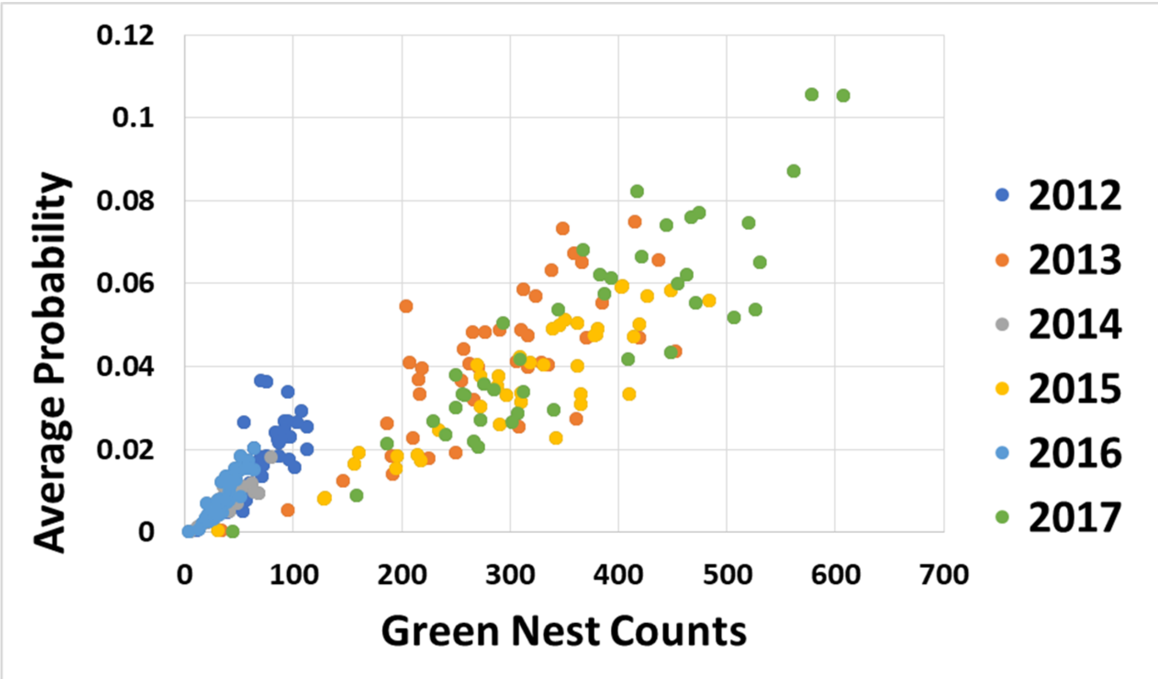

Figure 15. Correlation between green turtle nest counts and the average probability of nest disturbance. Green nest counts are highly correlated with the average probability of nest disturbance, meaning they are the driving force behind this nest disturbance.

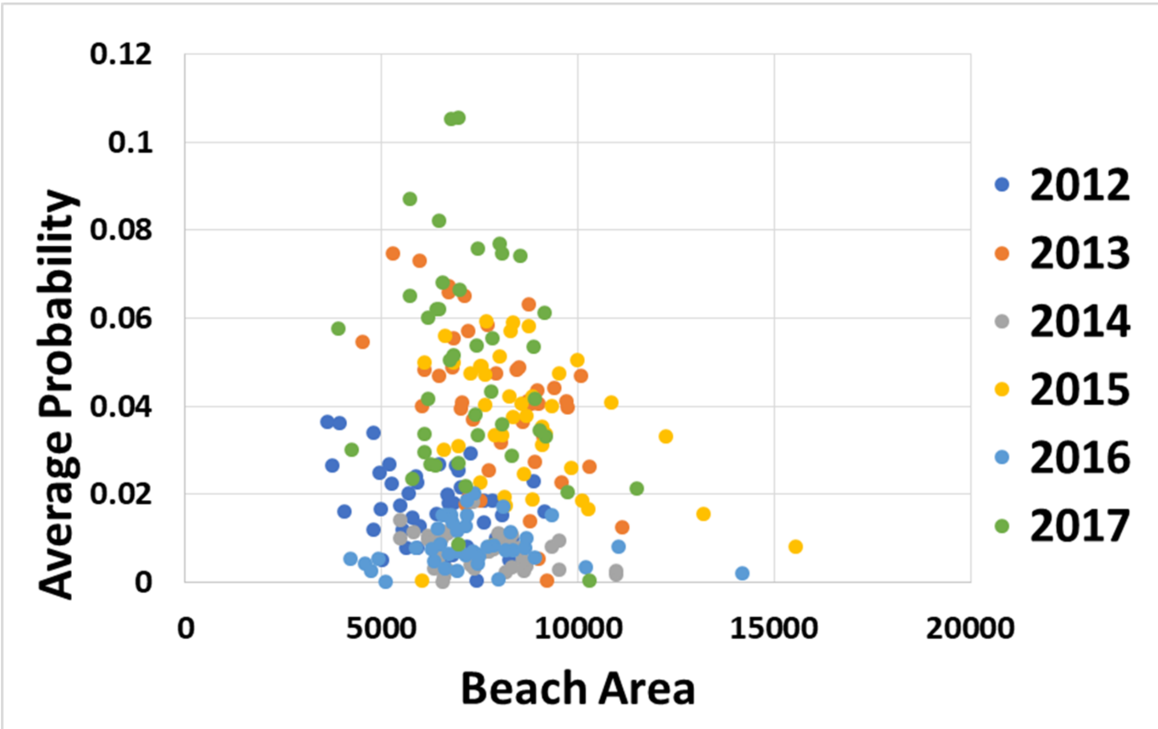

Figure 16. Correlation between beach area and the average probability of nest disturbance. Beach area is not correlated with the average probability of nest disturbance, meaning it is not having an impact on average probability.

DISCUSSION

While not a large overall impact, green turtles and their increased nesting on the ACNWR are having an impact on loggerhead nesting. If the green turtle populations and their corresponding nesting continue to increase, it is likely that the overlap will become greater and more loggerhead nests will be disturbed. However, the impact that green turtles are currently having on loggerheads is not as high one might expect. While there is a very high density of nests, especially in high green years, the highest probability of clutch disturbance is a 10 percent chance. This suggests that it would take a large reduction in beach habitat and another huge population increase for the impact to become significant for the species. This is further supported by the correlations drawn between the green nests and average probabilities. Green nests were highly correlated with the probability of clutch disturbance, indicating they are the most important variable regarding probability of nest disturbance. This matched my expectations of high green turtle nesting years having higher probabilities of nest disturbance than low green turtle nesting years. I expected the beach area also to be highly correlated; however, that was not the case. This does not mean that beach area does not play a role, as the availability of beach area is important in the sustainability of the numbers of greens nesting on the beach.

In order to evaluate carrying capacity of the nesting beach, carrying capacity has to be defined. This can be difficult, as there are many different definitions used in the primary literature (Mazaris 2009, Tiwari 2010). Carrying capacity can be defined biologically as the number of individuals of a certain species that an environment can sustain with limiting factors being brought into consideration, including resources and competition. Mazaris (2009) defines the carrying capacity as the maximum amount of nests that can be arranged within their defined beach area polygons. A study that evaluated carrying capacity, defined as the maximum amount of nests that are possible on the nesting beach, of the ACNWR, found that the beach can theoretically hold 136,720 green and leatherback nests and 476,395 loggerhead nests (Ussa 2013). However, Ussa's study defined carrying capacity as nests that would fit on the beach and did not consider any other factors. She did not take into account the emergence of nests, temporal analysis, or spatial analysis. Based on the calculated probabilities, the beach is a long way off from reaching any sort of capacity. These are not realistic numbers currently or in the near future. However, further work to reduce the loss of beach habitat is something that can be controlled to try and prevent this from becoming an issue. While the overall beach is not approaching carrying capacity currently, it is possible that some sections of beach with higher nest densities are closer to capacity and there will either be a further increase in clutch disturbance or migration of turtles to other sections of the beach.

The probability of clutch disturbance increases when the beach area is halved and when the green turtle population is doubled (Figure 13, Figure 14). When these two effects are combined, the probabilities of clutch disturbance increase even more, illustrating how these two changes could affect loggerheads in combination. With constantly expanding coastal development, increased storm events, and implementation of sea walls in addition to natural processes, beach erosion is continuously occurring. If large green turtle populations are the goal and would likely not represent a conservation issue if the beach were able to migrate landward naturally, it is best to focus on the factors affecting the nesting beach itself as something that can be controlled. As sea level rises and the beach continues to erode, available nesting habitat will continue to shrink. While the beach this study was conducted on is not particularly narrow, impacts like this will affect narrow beaches far more rapidly. As seen in Figures 13 and 14, beach habitat plays a major role in the outcome of interspecific competition between greens and loggerheads.

Green turtle populations are increasing in many places around the world (Seminoff 2015). With more beaches experiencing population recovery and further conservation work being done to encourage this, it is important to begin considering the other side of things. While on this beach it appears that it will take a while before green turtles start regulating loggerhead populations, on beaches with small areas and high densities, such as arribada nesting beaches, this could already be a problem or become a problem more rapidly. Knowing now that green turtle nest counts have the largest correlation with probabilities of nest disturbance, it is even more important to understand their effects and trends. This warrants further monitoring and research to observe the effects of green turtle population recovery on these nesting beaches.

My analyses were conducted after the conclusion of the nesting season, meaning many improvements could be made during future nesting seasons. All of the data in this study were pulled from the long-term data set and it would be useful to have data collected specifically for this study's approach. The area of a green nest used in this study is a conservative two meters squared when in reality many green nests are much larger than this estimate. Measurements should be taken of a subset of green nests to provide a more accurate measure of the area of disturbance. Measurements of loggerhead nests should also be taken to determine the average area a loggerhead nest occupies on the ACNWR. In addition, it would be helpful to take beach measurements in each section of the beach, as the beach width was calculated using distance to the dune and high tide data from sub-sampled marked nests. It would also be helpful to measure the beach at different times throughout the nesting season, as the beach width fluctuates in those months. A subset should be taken of the location of green and loggerhead nests relative to the dune to develop a more accurate idea of spatial overlap of the nests. My study also focuses on the impact of green nests, but does not factor in the effect of green false nesting attempts and body pits. A green turtle can abandon a nesting attempt at various stages in the nesting process and multiple times in one night. If body pits were added to the analysis, it could increase the probability of disturbance. While interspecific competition is examined here, intraspecific competition is not yet considered. There could be an impact on fellow green turtle nests as well. Lastly, this beach also experiences nesting from leatherback sea turtles, which were excluded from this study because they tend to nest the earliest and at a very low density on the ACNWR.   Future studies could be conducted to compare the impact of green turtle population recovery on other beaches with varying densities and areas.

With consistent increases in green turtle populations and nesting, we expect to see an increase in interspecific clutch disturbance. Conservation of marine turtles is based largely on protecting nesting beaches (Witherington 2003), and to properly conserve these turtles, the interaction of species and their distribution needs to be better understood. In the wake of posed threats such as beach erosion, coastal squeeze, and sea level rise, it is important to fully understand the overall habitat and what is happening within it. As green turtle populations continue to recover, it is also important to put management in place to control the beach habitats in order for these greater populations to be supported. If the populations continue to rise with a continued reduction in beach habitat, then the probabilities of nest disturbance will continue to increase.

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