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Nesting Trends in a Regionally Significant Green Turtle (Chelonia mydas) Rookery in St. Croix USVI



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# Nesting Trends in a Regionally Significant Green Turtle (*Chelonia mydas*) Rookery in St. Croix USVI

A Thesis submitted in partial satisfaction of the requirements
for the degree Master of Science

in

Marine Biology

by

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Kelly Stewart

2022

The Thesis of Paige Kauffman is approved, and it is acceptable in quality and form for publication on microfilm and electronically.

University of California San Diego

2022

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Lastly, thank you to my parents and my family for their continued love, support, and encouragement.

ABSTRACT OF THE THESIS

Nesting Trends in a Regionally Significant Green Turtle (*Chelonia mydas*) Rookery in St. Croix USVI

by

Paige Kauffman

Master of Science in Marine Biology

University of California San Diego, 2022

Professor Carolyn Kurle, Chair

Sandy Point National Wildlife Refuge (SPNWR), located in St. Croix U.S. Virgin Islands (USVI), is a known hotspot for nesting sea turtles; however, a full analysis of green turtle (*Chelonia mydas*) nesting trends has not been conducted until this study. Green turtle nesting activities have been documented since the start of the sea turtle monitoring effort at SPNWR in the early 1980s. These data were digitally entered, compiled, and standardized before being analyzed. Primarily using generalized additive models, *Chelonia mydas* activities were analyzed to determine trends over time by looking at three time periods of data collection: the entire time frame of 1982-2020, 2005 to 2020, and peak season (August and September) counts for all years. In addition, chi-squared tests were conducted to determine if green turtles have location preferences for nesting and overall activities. Over all examined time periods, increasing trends in both nests and total activities were noted, demonstrating the possible effectiveness of conservation efforts. The North Beach at SPNWR had the highest numbers of activities and nest counts, as well as the highest nesting success rate of the three beaches (North, West, South), likely due to its relative physical and geological stability. Although a small population, Sandy Point's nesting trends are increasing significantly more than those of similar nesting beaches in the region. Overall, the observed increasing nesting trends demonstrate that SPNWR's green turtle population seems to be recovering in numbers; however, conservation efforts must continue in order to see these trends persist.

# CHAPTER 1 INTRODUCTION

Sea turtles are facing an increasing number of threats, resulting in all species being listed as Endangered or Threatened (Lutz et al., 2002). As a result, many conservation efforts have been put in place to encourage population growth of sea turtle species, as many populations are decreasing (NRC, 1990). One of the most important ways to monitor these efforts is to estimate nesting trends, which allows insights into population trends over time, with subsequent realignment of conservation measures and priorities.

## *1.1 Green Turtle Background*

One such vulnerable species is *Chelonia mydas*, the green sea turtle, which is currently listed as Endangered (Seminoff, 2004). Green turtles are found throughout the world in tropical and subtropical waters (Jensen et al., 2019). In United States waters, the green turtle is found along both the west coast and east coast. Within the Atlantic, the species commonly nests in the U.S. Virgin Islands (USVI) and along the U.S. east coast from Massachusetts to Texas - with Florida being a particularly important nesting habitat (NMFS & USFWS, 1991). This species, like other sea turtles, typically occupies different habitats at different life stages (Hawkes et al., 2006; Lahanas et al., 1998; McClellan & Read, 2007), with adults usually found in coastal waters and hatchlings/juveniles in offshore waters (Bolten, 2003; Plotkin, 2003; van Buskirk & Crowder, 1994). After hatchlings spend several years in pelagic waters (Carr & Meylan, 1980; Musick & Limpus, 1997; Seminoff et al., 2015), they venture to shallow coastal waters until they reach the age of maturity, which may be about 25 to 35 years for females in the Caribbean (Avens & Snover, 2013; Frazer & Ladner, 1986; Phillips et al., 2021). Then, every two to five years, mature green turtles migrate to nesting beaches, typically in the same location they hatched earlier (Bjorndal, 1980; Lohmann et al., 2013; Meylan et al., 1990). In the Caribbean U.S. waters, green turtle nesting season usually begins in late spring (Johnson & Ehrhart, 1996; Valiulis & Mackay, 2011; Weishampel et al., 2003). Nesting typically happens at night, with females crawling up the beach and laying their eggs near the vegetation line. Green turtles will lay several clutches, usually about 2 weeks apart, over the course of a season, with each clutch generally consisting of over 100 eggs (Bjorndal & Carr, 1989; Broderick et al., 2003; Cheng et al., 2008). At the conclusion of the nesting season, the females return to their foraging grounds, which are widely distributed throughout the Caribbean and beyond (Carr et al., 1978). The eggs then incubate in the sand for around two months until the eggs begin to hatch. Once they emerge from their eggs, hatchlings make their way to the ocean by crawling toward the illuminated horizon, ideally the skyline over the ocean, during which time they must navigate obstacles and various predators (Ehrenfeld, 1968; Fowler, 1979). Those that make it to the water then travel offshore into the open ocean (van Buskirk & Crowder, 1994).

*1.2 Threats*

Green turtles have a long history of exploitation, especially in the Caribbean (Godley et al., 2004). The species has long been used by people for a variety of reasons, including consumption as well as for commercial purposes; however, the eighteenth century European expansion into the region resulted in a heavily exhausted population of *Chelonia mydas* (Rieser, 2012). Even over a century later, green turtles were still valued for their shells and leather (Chaloupka et al., 2008; Fleming, 2001; Lagueux, 2001). Furthermore, humans also indirectly threaten the species via terrestrial and oceanic habitat degradation and loss (Heppell et al., 2003; Matz, 2015; University of Exeter, 2017). Artificial lighting on or near nesting beaches may also be a threat and may cause disorientation of hatchlings that may ultimately lead to death

(Witherington, 1992). Moreover, human activity in any form on nesting beaches, especially at night - when green turtles primarily nest, disturbs nesting females (Lutcavage et al., 1997). In the water, green turtles are often caught as bycatch and are also struck by recreational and commercial boats (Gray & Diaz, 2016; Hazel et al., 2007). Climate change is becoming an additional concern for *Chelonia mydas* as well. Particularly, increasing temperatures may result in more female hatchlings (Blechschmidt et al., 2020; Jensen et al., 2018), as well causing the production of smaller, weaker, and slower green turtle hatchlings (Cavallo et al., 2015).

In addition to anthropogenic forces, Caribbean green sea turtles face a number of natural threats. On land, nests and hatchlings often succumb to predators, such as birds, crabs, ants, and small mammals like the mongoose and racoon (Fowler, 1979; Tomillo et al., 2010). The hatchlings that successfully make it to the water also must avoid predators like large fish and sharks, some of which can even prey on adult turtles (Heithaus, 2008). Natural erosion and other alterations of the beach can damage or destroy nests, as can burial or sand compaction (Ackerman, 1997; Grain et al., 1995; NMFS & USFWS, 1991).

### *1.3 Conservation Efforts*

Historically, there have been varying opinions on how to best approach sea turtle conservation efforts and management; however, as more information is understood about these animals, better plans may be implemented. Typically, green turtles (like other sea turtles) are most vulnerable as hatchlings, with only around 1 out of 1,000 surviving to reach maturity (Pritchard, 1980; Frazer, 1986). Therefore, focusing on nesting and hatch success on the nesting beach may be an important first step in protecting *Chelonia mydas* and increasing their numbers. Focusing on land-based nesting conservation efforts is also more feasible, compared to focusing on adult turtles in pelagic waters; however, large juveniles and breeding adults are vital to increasing sea turtle populations (Crowder et al., 1994). The Recovery Plan for the U.S. Population of Atlantic Green Turtle (NMFS & USFWS, 1991) emphasizes protecting and managing habitats, protecting and managing populations, increasing information and education, and increasing international cooperation.

There have been conservation-based success stories documented at green turtle nesting locations (Mazaris et al., 2017; Hays, 2004; Godley et al., 2020). For example, Tortuguero, Costa Rica saw an increase in nesting of over 400% over a study period of 1971 to 2003 (Troëng & Rankin, 2005). This dramatic increase has been largely attributed to the monitoring and overall conservation focus on the species in the area, which began in 1955 (Troëng & Rankin, 2005). Similarly, increases have been documented in the South Atlantic. At Ascension Island, over a span of 36 years, researchers recorded that the number of green turtle nests increased by approximately six times over numbers from the start of monitoring efforts. The researchers attributed this population increase to decades of legal protection and the banning of commercial harvesting (Weber et al., 2014).

### *1.4 This Study*

A population of green turtles, belonging to Regional Management Unit (RMU) 47 (Wallace et al., 2010) and the South Atlantic Distinct Population Segment (DPS) (NOAA, 2018), nests within the Sandy Point National Wildlife Refuge (SPNWR) in St. Croix - one of the U.S. Virgin Islands (Figure 1.1). In fact, SPNWR has one of the largest nesting populations of green turtles in the Northern Caribbean and in the Leeward and Windward Islands, as over 1,000 crawls are now documented annually (Eckert & Eckert, 2019). However, nesting trends have never been assessed for this population of green turtles. Therefore, this study on historical green turtle trends is the first study of its kind regarding SPNWR, and results from this study will provide much needed long-term green turtle trends for the area and will serve as an important baseline for future monitoring and recovery efforts.

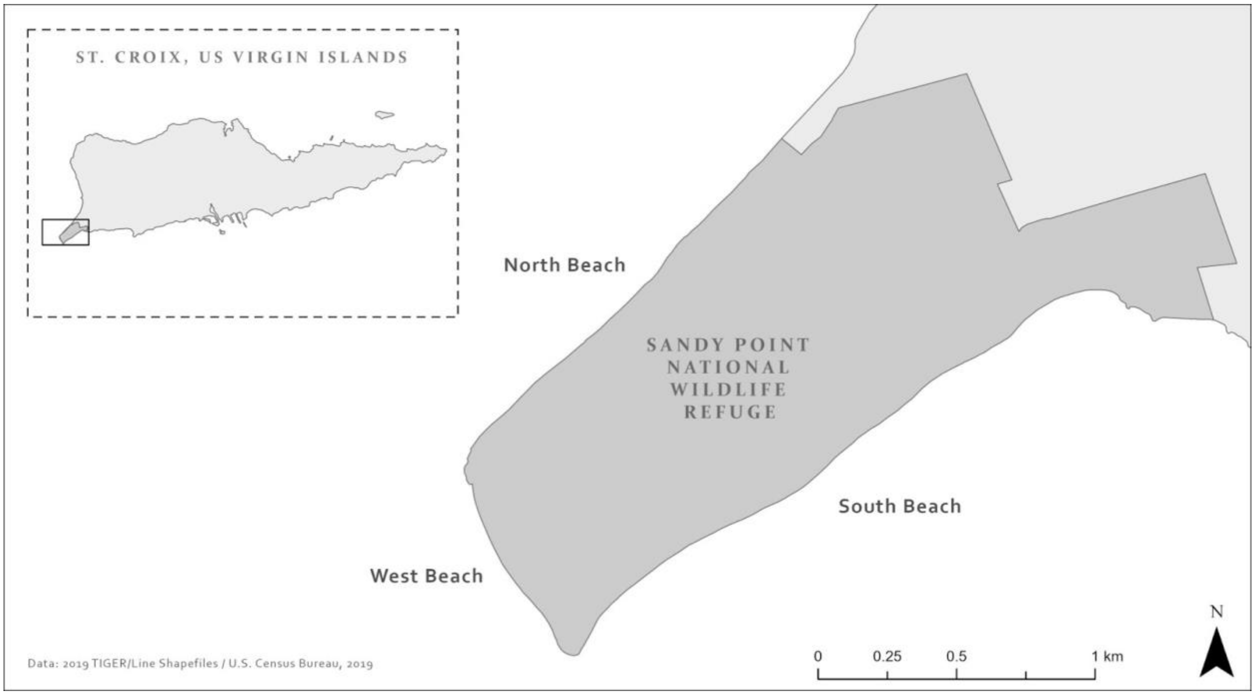


Figure 1.1.
The location of Sandy Point National Wildlife Refuge in St. Croix, U.S. Virgin Islands and the three beaches within the refuge.

In this study, the numbers of documented green turtle nests and overall activities (nests and false crawls) within Sandy Point National Wildlife Refuge over the past several decades were examined and analyzed. Data were sorted and separated by year and statistically analyzed to determine long-term trends starting with the beginning of the green turtle monitoring efforts. Furthermore, this analysis provides information necessary for addressing the objective of protecting and managing populations, as outlined in the Recovery Plan for the U.S. Population of Atlantic Green Turtle (NMFS & USFWS, 1991).

# CHAPTER 2 METHODS

## *2.1 Field Site*

All fieldwork was conducted at Sandy Point National Wildlife Refuge (SPNWR), which encompasses a 4.5-km beach located on the southwest peninsula of St. Croix, U.S. Virgin Islands (Fig. 1.1). Sandy Point provides long stretches of open sandy beaches that back up to a coastal forest. The refuge, managed by the U.S. Fish and Wildlife Service, was initially established in 1984 to protect the habitat of leatherback sea turtles (*Dermochelys coriacea*) that nest there; however, the refuge also protects habitat for other sea turtles, including the Threatened green turtle (*Chelonia mydas*) - the focus of this study (USFWS, 2017), and the Critically Endangered hawksbill turtle (*Eretmochelys imbricata*). Over time, green turtle nesting has become more frequent, resulting in green turtles becoming a focus of conservation and monitoring efforts, with nesting counts performed each year since 1994 (Valiulis & Mackay, 2011).

The beach is closed to public access seasonally from April to September (Evans, 2010). While this is primarily to protect leatherback nests, this time frame also encompasses some of the green turtle nesting season. Furthermore, once the beach is open for public access, people are only permitted on the beach during daytime hours (10 am to 4 pm). In addition, umbrellas and other objects that penetrate the sand are not authorized on the beach. This is to ensure that any nests on the beach are as protected as possible during the nesting months when people are allowed on the beach.

Observers at Sandy Point have noted that green turtles typically make their nests along the vegetation line - where the open beach sand meets the dense greenery - or even a bit into the vegetation fringing the sand. The vegetation serves as a dark background to the sandy beach and the ocean, allowing the turtles to better orient themselves and find their way back to the water after nesting, by shielding any background light and allowing the turtles to solely focus on the light of the horizon over the water (Salmon, 2003; Vandersteen et al., 2020; Varela-Acevedo et al., 2009; Witherington, 1997).

Along the beach within SPNWR, there are numbered stakes placed every 20 m on the vegetation line. The stake numbers start at 1 at the easternmost part of the refuge and increase in number, ending with 255 at the refuge boundary. Therefore, the entirety of the beaches within SPNWR have specific locations labeled, allowing for easy and accurate recording of turtle activity locations. Furthermore, SPNWR may be split up into three sections or “beaches,” depending on location. Generally, the South Beach is the length of beach from stake 0 to 139 and has little open sand or nesting habitat. The West Beach extends from stake 140 to 169, with landscape characteristics somewhat in between those of the South Beach and North Beach. The North Beach is the stretch of beach from stake 170 to the boundary of the refuge, at stake 255. The North Beach has a large, wide open stretch of sand before the vegetation line. While the physical landscape of the beaches changes over time, especially with storms, these are the standard attributes of each of the beaches.

*2.2 Data Collection*

Data used in this study were collected within the boundaries of SPNWR and include statistics from 1982, before the establishment of the refuge, up until 2020. The data collected for all species includes the date of the turtle activity, species, the activity - either nest or false crawl (non-nesting activity), the beach marker stake location, and other information not pertinent to this study (turtle tag information, vegetation information, recorded turtle injuries, etc.). During peak season, SPNWR sends out daily patrols where observers make note of any new activities on the beach. Each morning, observers cross out any tracks they have observed so that tracks will not be counted again during the next patrol. In addition, during the peak season, nightly patrols are often conducted, allowing observers to directly record turtle activity. Night patrols and daily morning patrols are the most accurate way to record activities; however, this is not always feasible, and, in the beginning and end of the nesting season when nesting activity is slow, patrols are conducted three days per week and nest dates may be estimated. In rare cases where nests went unrecorded at the time of deposition, the activity date for green turtles may be established at 50 days before nest emergence (the first date hatchlings emerge from the nest). As always, observers on patrol strive to be as accurate in their estimates as possible. Once the date has been established, observers record whether the activity is a nest or a non-nesting activity (false crawl). The location of the activity is also documented by beach marker stake and sometimes by triangulation.

*2.3 Data Compilation and Standardization*

Since there were no previous efforts to analyze nesting trends for *Chelonia mydas*, the first step of the analysis was to find and compile all the data from the past. As the data spans such a large frame and started in the 1980s, nearly all data found was in the form of hard copies, ranging from data sheets to notes scribbled on the back of papers - which was often the case in the earlier years when the focus was more on leatherback nesting. Therefore, the first step was to find all mentions of *Chelonia mydas*. Once all green turtle data were found and organized, it was manually entered into the database. Then, all the data were standardized to ensure the same structure and language was used throughout and to make for easier statistical analysis.

### *2.4 Statistical Analysis*

Total activity numbers were summed for each month and year, as were nest counts. The data were also sorted by beach section to investigate the possibility of location preference. Nesting success was calculated as the proportion of nests to false crawls (nest count divided by total activity count) and this was done for each year and each beach.

Three distinct timeframes were considered as well, to account for consistency of effort and peak season. First, all data (1982-2020) were analyzed to get an overall idea of trends since the start of green turtle data collection for the entire year. Second, the time period of 2005 to 2020 was examined, as this 15-year stretch had more regularly collected data. The year 2005 was chosen as the start date because nest surveys became more consistent in the early 2000s, as did efforts focusing on green turtles. However, data remain missing for 2003 and 2004, so it was determined 2005 would be the best starting point to conduct in-depth analyses. Lastly, data from green turtle peak season (August and September) was analyzed for each year to detect any possible differences in trends while only considering peak months of nesting, as this was the most consistent effort time frame for green turtles and when they would be most likely to be observed and counted.

#### *2.4.1 Nesting Trends: Generalized Additive Model*

It was determined that a generalized additive model (GAM) was the best way to analyze the majority of the data, as this model can create a regression line with more flexibility, allowing for a dataset that is less than linear. To create this model, the gam() function was used in R (R Core Team, 2019). This model works well for this study, as there were gaps in surveys over time and nonparametric data. Ultimately, statistical analysis using GAM was done for all green turtle activities within SPNWR to determine trends. Additionally, the same analysis was done just for nests. While the generalized additive model was used for the first two datasets, when analyzing the peak season nests from 2005 to 2020, an exponential regression linear model was used.

#### *2.4.2 Location Preference: Chi-squared Test*

The possibility of location preference was another topic of interest. SPNWR nesting habitat is often considered three separate beaches (North, South, West). To investigate if there was a preferred beach (North, South, West) for green turtle nesting, Pearson's chi-squared tests were set up with the null hypothesis that the number of green turtle activities was independent of location - in this case the "beach." The alternative hypothesis was therefore that the number of activities was different for different beaches and thus the two variables were not independent. Two chi-squared tests were performed: considering total activity counts and considering just nests. For each test, expected values were calculated, taking into account the proportional length of each beach, and a $p < 0.05$ was used when testing for significance.

In addition, nesting and activity density was calculated for each beach. Using the length of each beach, coupled with the activity counts for each beach, an estimate of the number of activities per stake (20 m) was calculated.

### *2.5 Effort*

Patrol efforts at SPNWR have varied over time. Originally, leatherbacks were the main focus of survey efforts at the refuge. Therefore, patrols were typically conducted during the leatherback season, starting in March/April and ending in July or August (see Table 1). As a result, most recorded green turtle activities were those that took place within the window of leatherback patrols. However, there were also periodic surveys for green and hawksbill turtles throughout the years; these surveys increased as time went on. Starting in 1994 however, daytime patrols were conducted seasonally, especially during peak season during August and

September to identify nesting activities (Valiulis & Mackay, 2011). While work was still concentrated on leatherbacks and their nesting season, patrols continued, although less consistently, after the last leatherback nest each year. Based on SPNWR activity data, the majority of *Chelonia mydas* activities took place from July to October, with a peak in August and September.

Table 1.
Start and end dates (mm/dd) of patrols at Sandy Point. These dates were determined using data for all three sea turtle species at SPNWR, so the start and end dates are based on the first and last nests recorded for any species.

| Year | Start date | End date |
|---|---|---|
| 1982 | 03/30 | 09/07 |
| 1984 | 03/26 | 09/07 |
| 1986 | 03/30 | 08/05 |
| 1988 | 02/28 | 08/02 |
| 1989 | 02/25 | 07/31 |
| 1990 | 03/27 | 08/14 |
| 1992 | 03/05 | 08/06 |
| 1993 | 04/02 | 12/04 |
| 1994 | 03/26 | 12/27 |
| 1995 | 01/06 | 12/31 |
| 1996 | 03/11 | 11/20 |
| 1997 | 03/09 | 12/12 |
| 1998 | 01/08 | 11/01 |
| 1999 | 04/01 | 08/11 |
| 2000 | 02/23 | 10/09 |
| 2001 | 03/11 | 12/14 |
| 2002 | 01/04 | 10/20 |
| 2003 | 01/19 | 08/21 |
| 2004 | 04/01 | 08/27 |

| Year | Start date | End date |
|---|---|---|
| 2005 | 03/01 | 12/19 |
| 2006 | 03/22 | 08/28 |
| 2007 | 03/12 | 11/27 |
| 2008 | 02/12 | 08/20 |
| 2009 | 04/01 | 12/07 |
| 2010 | 02/25 | 10/14 |
| 2011 | 02/05 | 12/24 |
| 2012 | 02/18 | 12/09 |
| 2013 | 03/12 | 12/18 |
| 2014 | 01/08 | 12/02 |
| 2015 | 02/24 | 12/22 |
| 2016 | 01/15 | 12/27 |
| 2017 | 01/11 | 12/21 |
| 2018 | 01/05 | 12/17 |
| 2019 | 03/02 | 12/10 |
| 2020 | 01/11 | 12/31 |

*2.6 Error*

Due to the nature of this study and the fact that the majority of the data were collected before the digital age, there is most likely error present throughout the various steps of this process. There were some changes in effort over the years, as there were fewer green turtles early on; however, in most years (apart from 1986-1992, 1999, 2003-2004, 2006, and 2008, when the last activity was recorded in August or the end of July), surveys were conducted nearly daily through August and September. In all likelihood, there was also missing data, whether it was lost or not collected due to hurricanes or storm events. There may also exist errors because data was manually entered and some assumptions had to be made when interpreting written notes; however, the effect was considered negligible given the volume of activity data. The numbers represented in the data are considered the minimum number of nests.

# CHAPTER 3 RESULTS

*3.1 Historical Trends*

Data from 35 years were included in this study, from 1982 to 2020. In this time, 29,502 *Chelonia mydas* activities were recorded. Of the 29,502 activities, 10,900 resulted in nests. Of the total activities, 20,288 occurred during peak green turtle season - August and September, and 7,239 of these were nests.

In the first year, 1982, one activity (a nest) was recorded, and in the final year, 2020, 5,728 total activities were recorded; 1,682 were nests. This is a major increase that needed a more detailed examination. On average, when including all years starting with 1982, there was a 26% increase in activities (including both nests and false crawls) each year. From 2005 to 2020, there was an average increase in activities of 23% per year. When only considering nests, there was an average increase in nests of 22% annually when looking at all years and of 19% from 2005 to 2020. In green turtle peak season, there was an average annual increase in nests of about 20% over the entire period examined. From 2005 to 2020, there was an increase in nests of 17% per year on average.

Overall, there was an increasing trend in *Chelonia mydas* activities over the study period (see Figure 3.1). The generalized additive model (GAM) resulted in an $R^2$ value of 0.8644 and

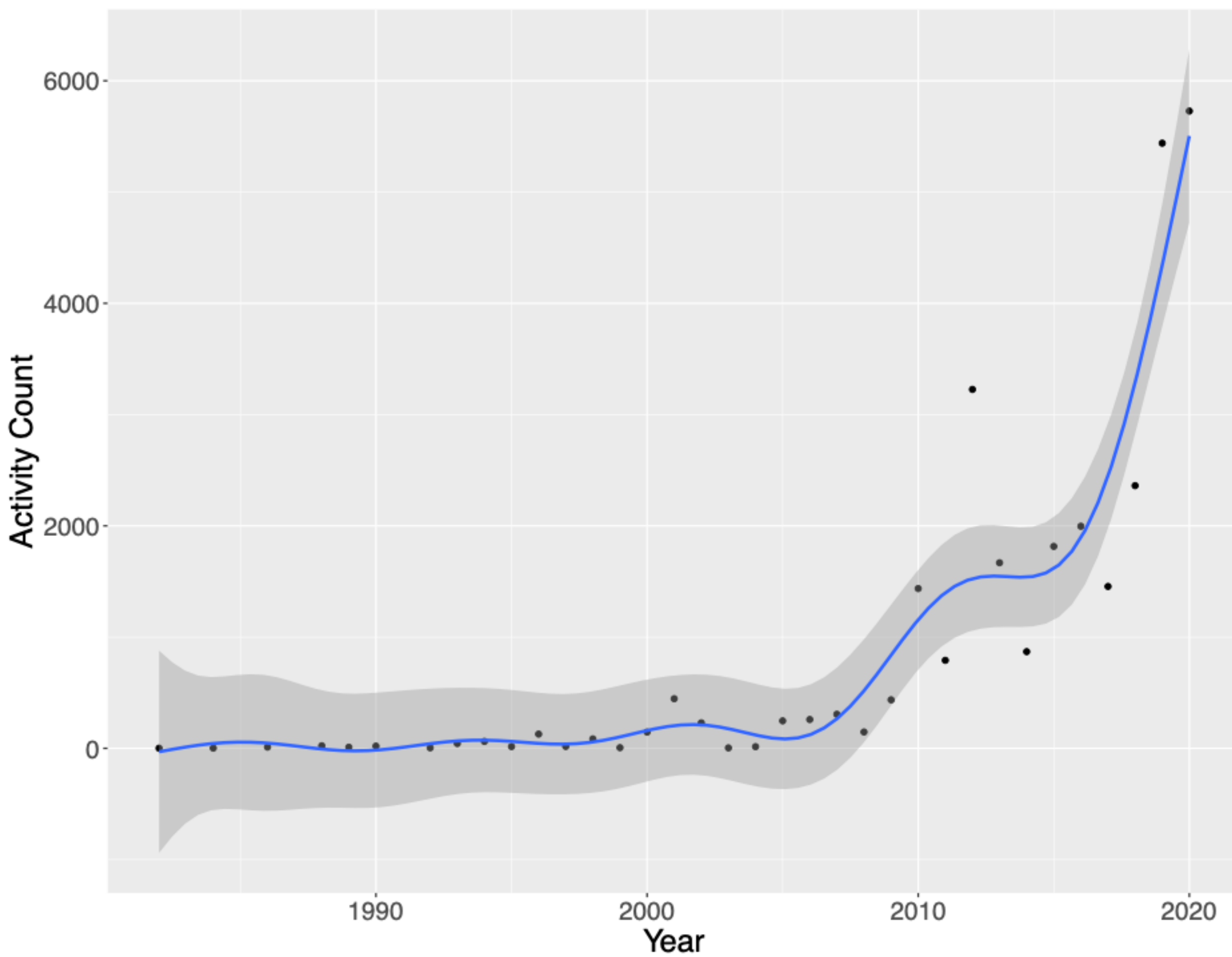


Figure 3.1
Generalized additive model of all *Chelonia mydas* activities from 1982-2020. The gray areas around the line indicate the confidence intervals.

To further investigate historical trends, the same analyses were used to look at total activities from 2005 to 2020. The GAM produced an $R^2$ value of 0.804, and the model explains 85.6% of the deviance in the data. In addition, the p-value of the smoothing function is 8.61e-05, demonstrating that the model is statistically significant.

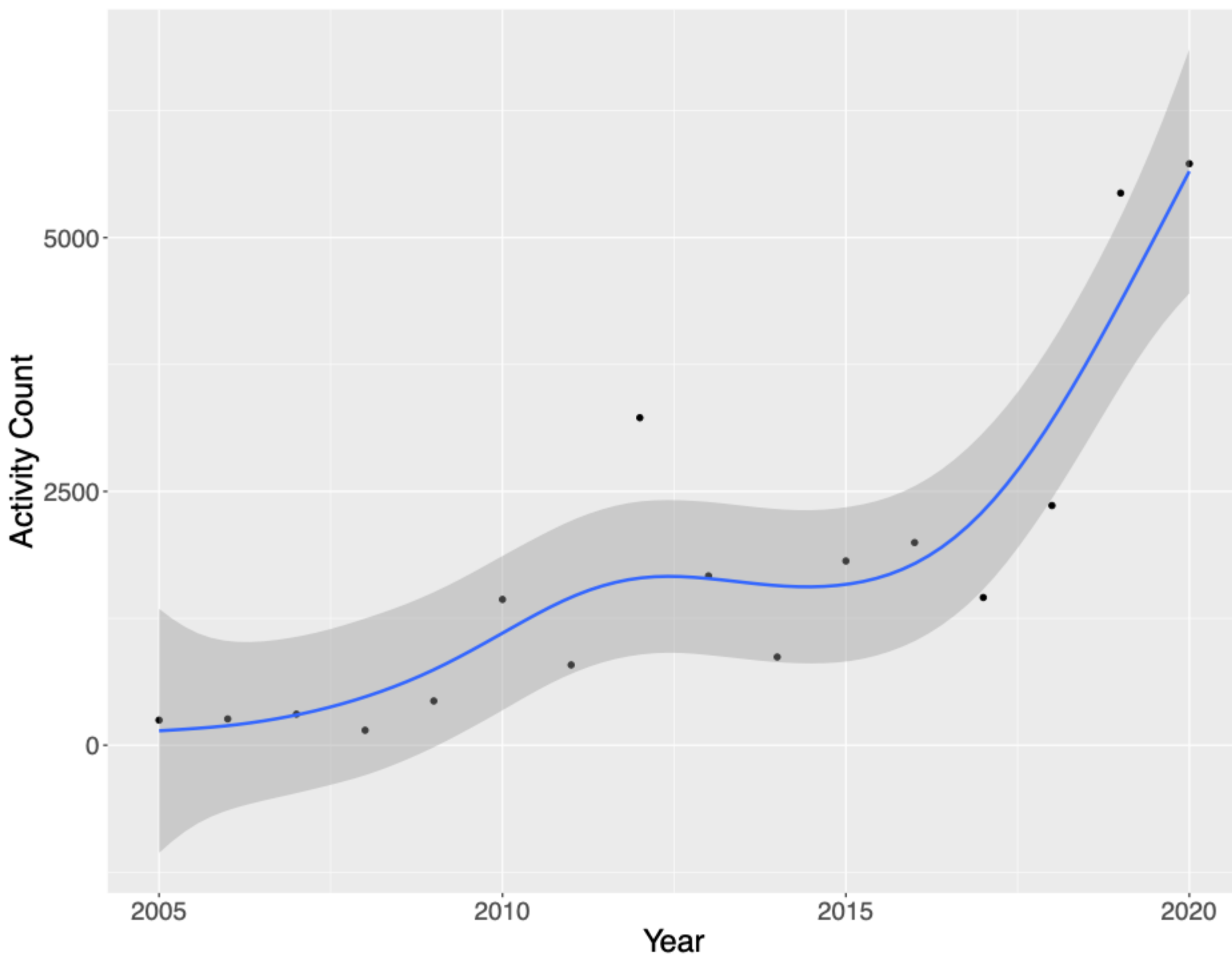


Figure 3.2
Generalized additive model of all *Chelonia mydas* activities from 2005 to 2020 with the gray representing the confidence intervals of the model

When the same model was used to analyze nest counts over the years, similar increasing trends resulted (see Figure 3.3). The GAM gave an $R^2$ value of 0.7790 with 80.4% deviance explained.

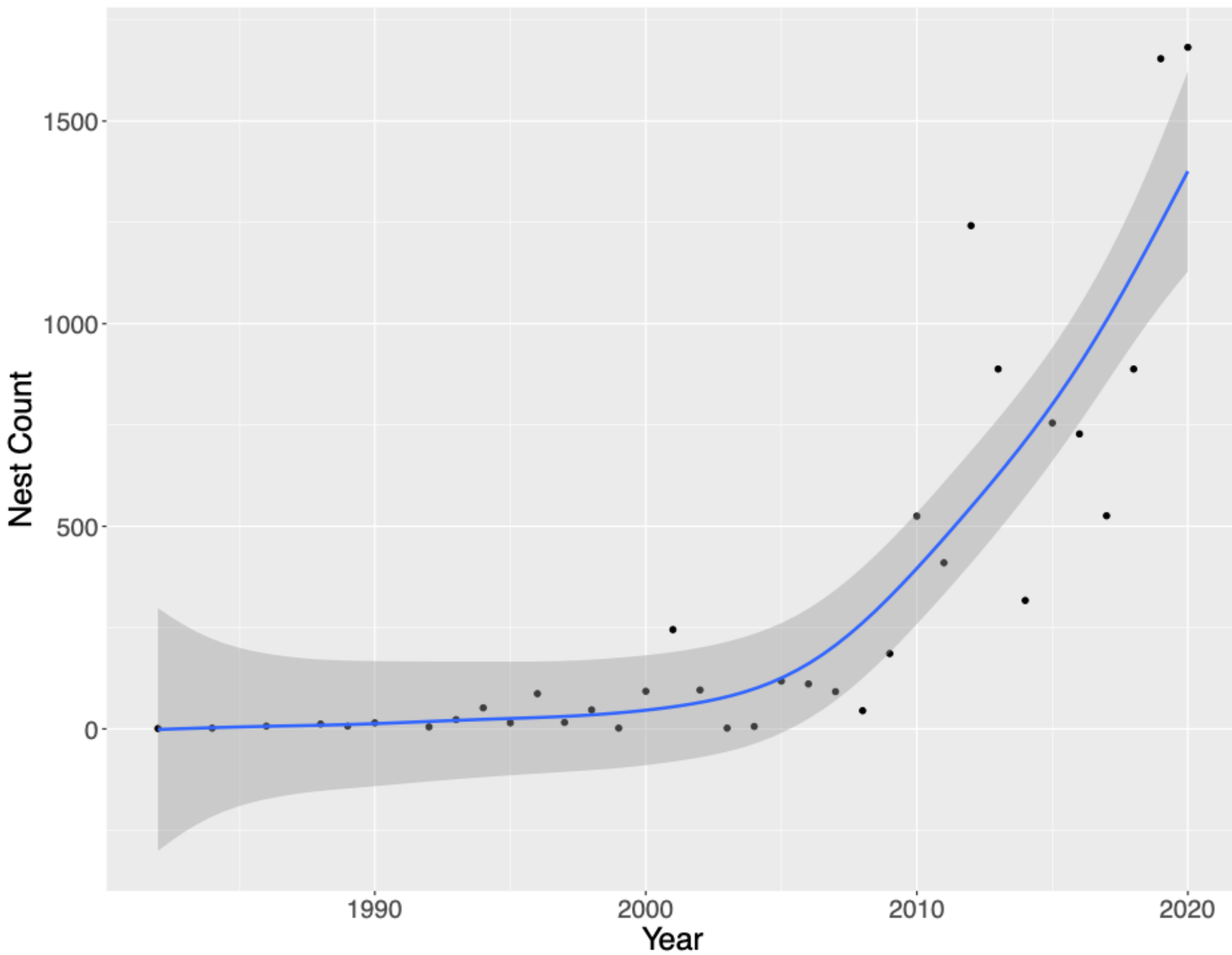


Figure 3.3
Generalized additive model of green turtle nests over all years (1982-2020) with the gray representing the confidence intervals

When examining nest numbers from 2005 to 2020, an increasing trend is seen (see Figure 3.4). This GAM results in an $R^2$ value of 0.754 with 81.6% deviance explained. The p-value of the smoothing function is 0.98e-07, indicating significance.

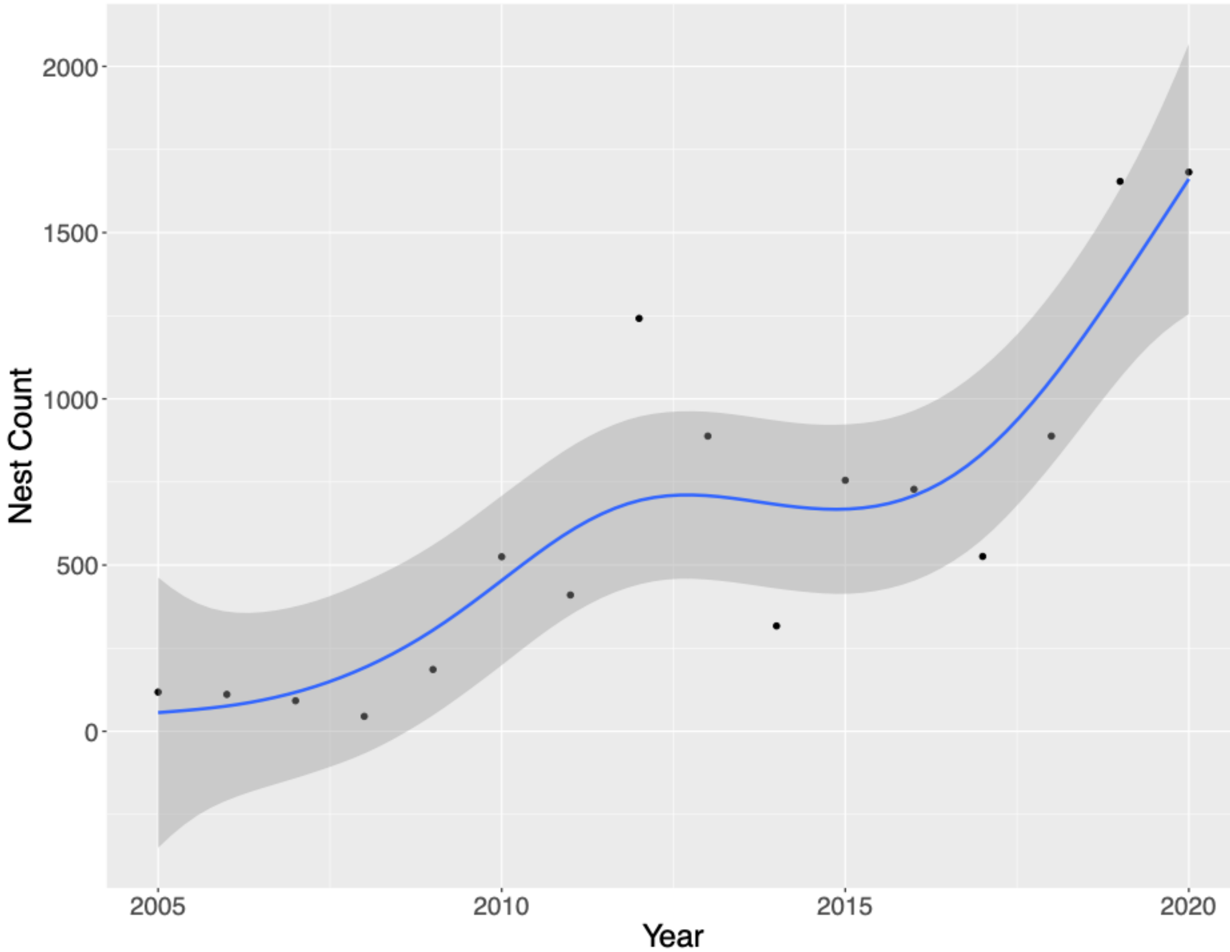


Figure 3.4
A generalized additive model of green turtle nests over 2005 to 2020, and the gray represents the confidence intervals

Trends were also analyzed using data from the green turtle peak season (see Figure 3.5).

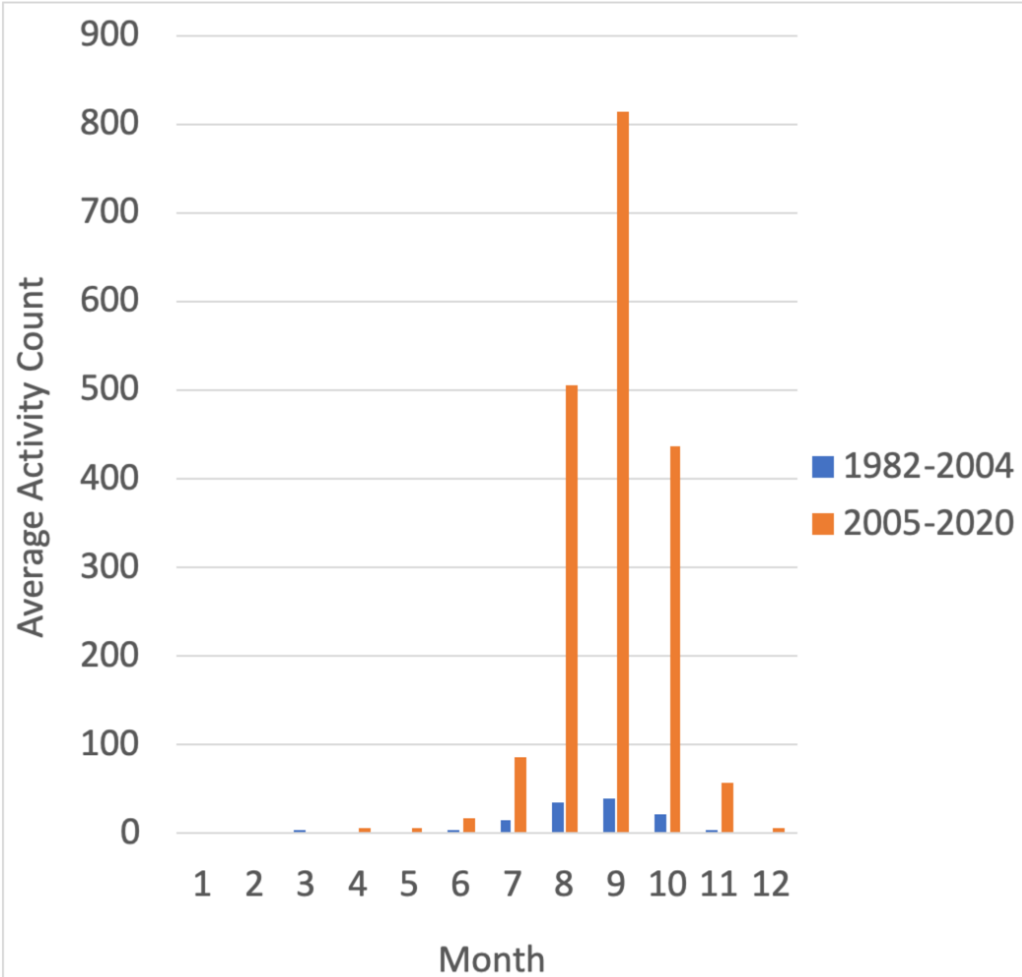


Figure 3.5
A histogram of the average activity count per month, which was calculated for the period before 2005, as well as for the period of 2005-2020. For both time-frames, the peak season occurs in August and September

When a GAM was created for the peak season nest data (see Figure 3.6), the $R^2$ statistic of the model was 0.720, accounted for 74.6% of data variance, and resulted in a p-value of 1.27e-10.

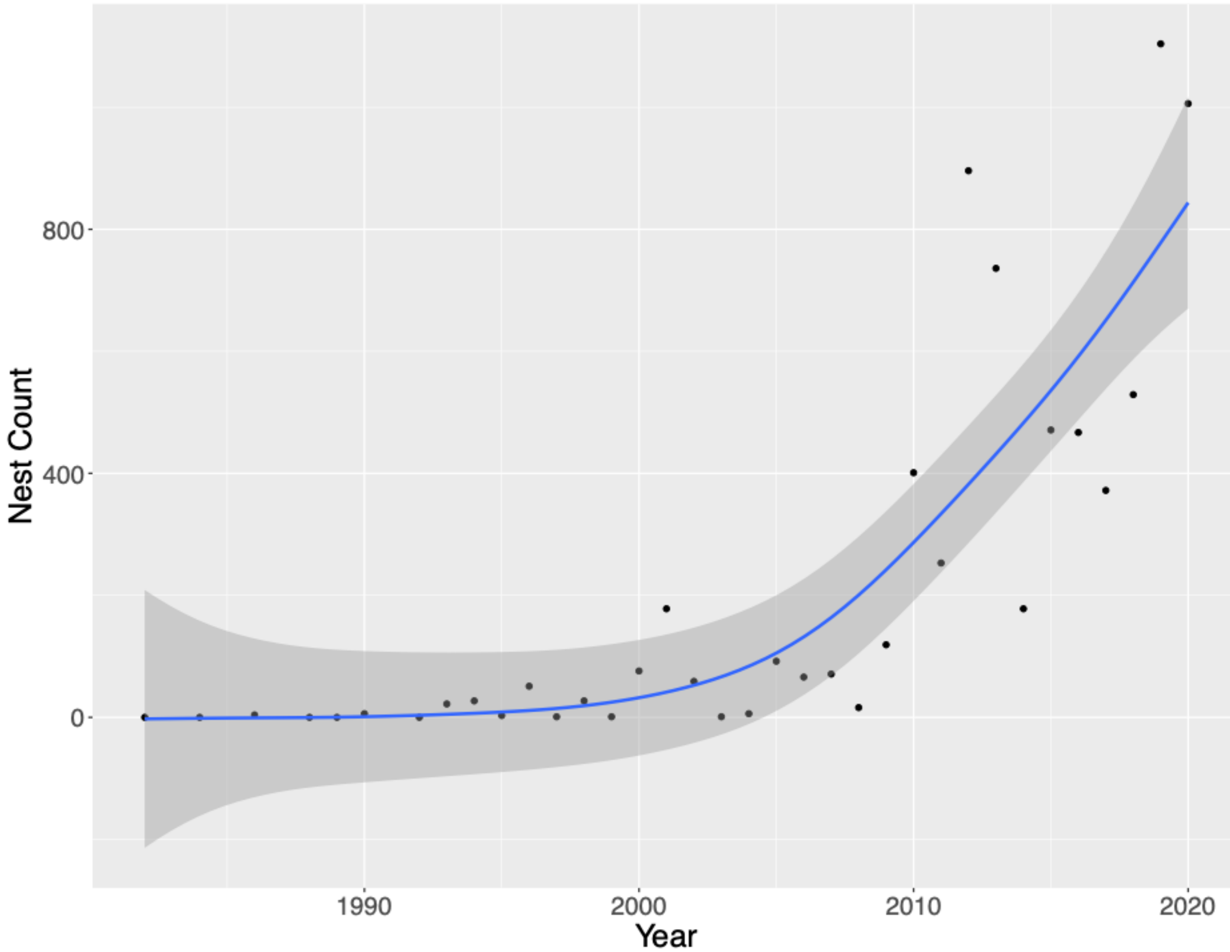


Figure 3.6
Generalized additive model of green turtle nests during peak season (August and September) annually from 1982 to 2020. The gray represents the confidence intervals of the model

Peak season nest trends were also examined for the time period of 2005 to 2020. In this case, the model with the best fit was an exponential model, not a GAM. The exponential trendline (see Figure 3.7) produced an $R^2$ value of 0.6039 (which was higher than the $R^2$ of the GAM) and a p-value of 0.0003967. The trendline equation had an exponent of 0.1942, thus indicating significant positive exponential growth.

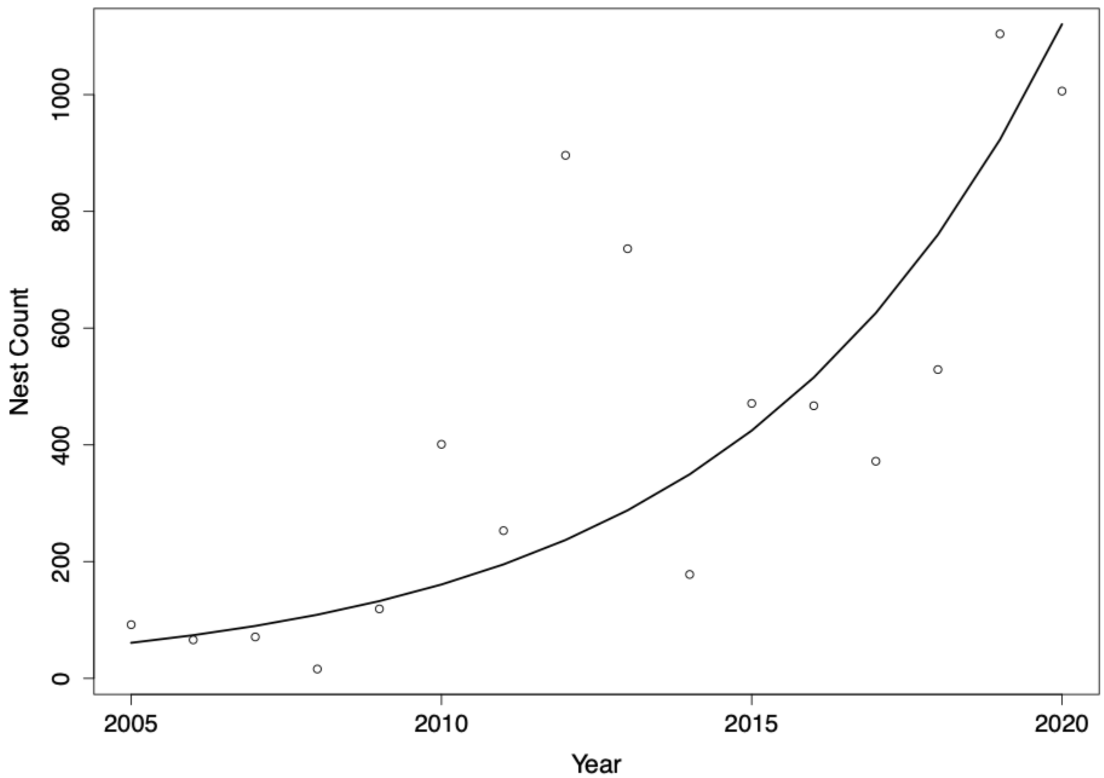


Figure 3.7
Nest counts in peak season (August and September) from 2005 to 2020 with an exponential trendline.

Nesting success - the proportion of nests to total activities - was also calculated for each year (see Figure 3.8). When a linear regression line was added to the plot, a slope of -0.0159 is given, demonstrating that there was a slight decline in nesting success over time. The $R^2$ value of this line is only 0.601.

When considering all years with data, the average nesting success was 0.5473 or almost 55%. Essentially, for about every 2 activities, one resulted in a nest, if looking at the average success over the entire timespan.

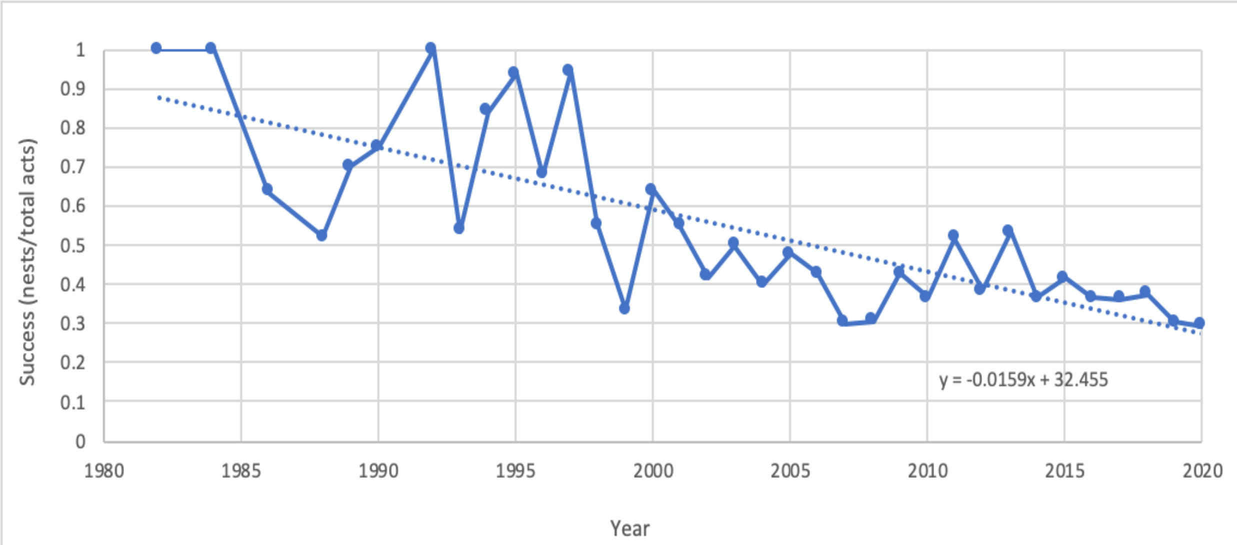


Figure 3.8
Nesting success (calculated as the proportion of nests compared to total activities) by year with a linear trendline.

Trends in nesting success were also investigated for the time period of 2005 to 2020 (Figure 3.9). Over these years, the average nesting success was about 39%. When a linear regression is fit to the plot, the resulting slope is -0.0052, demonstrating that nesting success was fairly consistent over these years.

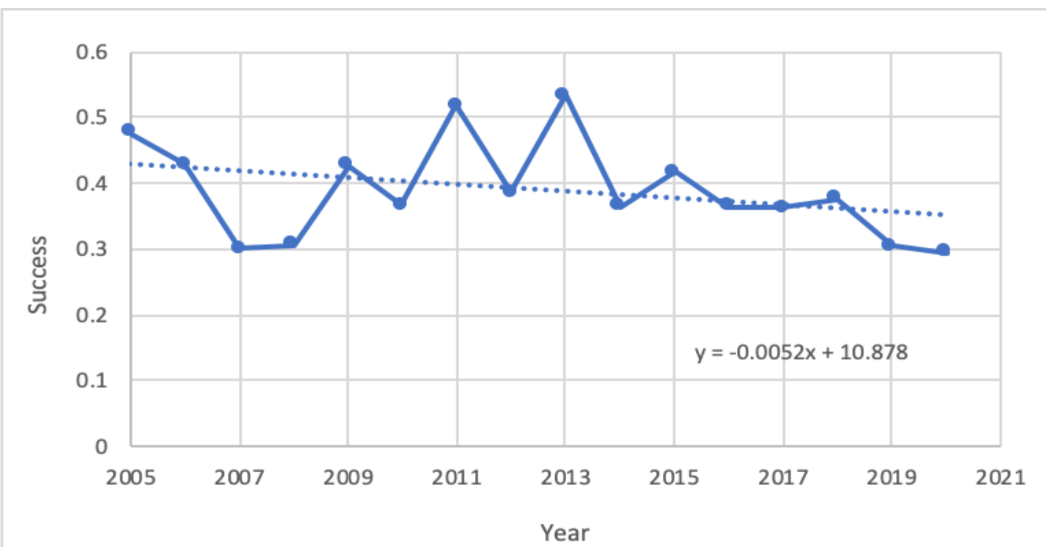


Figure 3.9
Nesting success (number of nests divided by the number of total activities) from 2005-2020. A linear trendline was added.

Success based on peak season data was also analyzed. Over peak season (August and September), the average nesting success rate was almost 53%. When only considering peak seasons from 2005 to 2020, the average success rate was about 38%.

Additionally, success by location was also calculated. Considering the entire time frame of data (the entire season for every season from 1982 to 2020), the North Beach had the highest nesting success at 39%, followed by the South Beach with 36% and then the West Beach with 35%.

*3.2 Location*

The Pearson's chi-squared test indicated that there was a significant difference in activity numbers on each of the three beaches, $X^2$ (2, $N$ = 29,158) = 160.13, $p$ = 5.99. Therefore, there does not exist equal activity on all three beaches. When considering nests alone, the chi-squared test indicated that there was a significant difference in the number of nests per beach, $X^2$ (2, $N$ = 10,770) = 124.77, $p$ = 5.99. Thus, for both green turtle activities and for nests, there exists partiality in some form.

When looking at total activities, the South Beach had 115 activities/stake, the West Beach had 93 activities/stake, and the North Beach had the highest activities/ stake with 122. If only considering nests, the South Beach had 41 nests/stake; the West Beach had 33 nests/stake; and the North Beach had the highest number of nests 47 nests/stake.

## CHAPTER 4 DISCUSSION

The goal of this study was to quantify the trends for green turtle nesting at Sandy Point National Wildlife Refuge. The resulting positive trend in historical nest counts with rapidly increasing annual totals may result in SPNWR becoming a significant *Chelonia mydas* nesting beach in the Caribbean region, much like Florida and several Central and South American sites. While Sandy Point has not been considered as such in the past due to low nests numbers and lack of trend analysis, nesting rates are rapidly increasing, and if they continue, promise nest numbers on par with those of other important nesting beaches in the region.

*4.1 Statistics*

Overall, both total *Chelonia mydas* activities and *Chelonia mydas* nests have been increasing over time. Reasonably, the cause may be increased effort during the calendar year, although in most years peak season was covered. One important change is that sea turtle management strategies have been implemented and enforced (Evans, 2010). Since the establishment of SPNWR in the 1980s, research has expanded, endangered species laws were enforced, and outreach efforts have improved. While there is still a small risk of illegal poaching and extraction, law enforcement combined with outreach has led to a sense of greater appreciation and respect for the green turtle, resulting in fewer documented poaching activities (Alexander et al., 2003; Eckert & Eckert, 1985; Eckert et al., 1982; McDonald et al., 1991; Valiulis & Mackay, 2011). Additionally, because SPNWR offers beaches free of coastal development and human disturbance, more females may choose to nest here rather than on other, less protected, beaches.

Specifically, after 2005, the increasing trend in green turtle activities and nests accelerated. This may be due to the fact that many conservation efforts began in the 1980s, and because the green turtle is such a long-lived species, the results of these changes were not seen until the 2000s.

Furthermore, 2012 resulted in an exceptionally high number of green turtle nests and activities at SPNWR. A possible explanation may be a surge in nests or survival decades prior. In the USVI, the age of sexual maturity is estimated to be approximately 27 to 33 years (Frazer & Ladner, 1986); however, sexual maturity is more dependent on size rather than age (Goshe et al., 2010). Taking this into account, perhaps there were exceptionally large numbers of successful nests two to three decades prior to 2012. In fact, 1984 to 1987 saw higher than average numbers of nesting females at Union Creek in the Bahamas (Bjorndal et al., 2005). Therefore, around 25 to 28 years before the spike in 2012 at Sandy Point, there were abnormally large numbers of nesting turtles in the Bahamas - 144 to 155 in comparison to the 20-70 recorded in previous years (Bjorndal et al., 2005). Other green turtle nesting beaches had similarly high numbers during the mid to late 1980s. For example, Tortuguero, Costa Rica had a particularly high estimated number of nests in 1986 (Troëng & Rankin, 2005). Florida also had a high nest count during this period, especially in 1985, when over 700 green turtle nests were documented, compared to the 100-300 common of that time (Conley & Hoffman, 1987). Perhaps a high number of nests were laid these years, resulting in an influx of juveniles, and 2012 was a year many of these green turtles matured and returned to nest. A previous thought was that some of these recruits possibly came to nest at SPNWR; however, green turtles tend to nest at their natal beaches, as shown by strong evidence for the natal homing hypothesis (Meylan et al., 1990). While some areas may have higher than average immigration rates, turtles typically go back to nest at their own beaches (Allard et al., 1994), so it's more likely that high survival rates from nests in the 1980s, perhaps in combination with good food resources and possibly a shorter time to maturity as a result, caused an increase at many of these nesting beaches.

Although overall activities and nest numbers show a definite increasing trend over time, it appears that nesting success has been decreasing. However, while this may seem in contrast to all the positive trends seen otherwise in this study, nesting success may not actually be decreasing or decreasing as much as shown. In the early years of Sandy Point patrols, there were little to no *Chelonia mydas* activities. As time went on and more green turtles frequented SPNWR, data became more consistently collected and possibly more accurate as to nest and false crawl distinctions, and this resulted in more typical nesting success statistics. According to data from other Atlantic green turtle nesting areas, nesting success rates are typically around 50%. In Broward County, Florida, 2015 nesting success was 51% (Burkholder & Slagle, 2015). This estimate is further supported by data from Tortuguero, Costa Rica, which estimated nesting success at 53% (Haro & Harrison, 2007). When considering all years, SPNWR data reveals green turtles have had an average nesting success of about 55%, which closely matches rates typically seen in the Caribbean. The slight decline in nesting success over time at Sandy Point may be a consequence of high-density nesting on Sandy Point's beaches, as well as a result of habitat loss due to hurricanes. Additionally, density-dependent factors, such as competition and increased predation can reduce overall success (Tiwari et al., 2006). Higher density of nesting females can also lead to increased disturbances, as females may run into one another, resulting in abandoned nesting attempts and false crawls (NMFS & USFWS, 1991). Yet, more and more female turtles still arrive, further undermining the habitat and increasing competition for space. Further adding to the degradation of suitable habitat, in 2017, Hurricane Maria washed away and removed much of the nesting habitat, particularly on the South Beach. As a result, females may do more false crawls before they find an ideal nest site. This is the most likely explanation for the lower average nesting success rate of 39% seen between 2005 and 2020.

Overall, Sandy Point is seeing increasing numbers of green turtle nests and activities, as are other important nearby nesting sites in the Caribbean, including Aves Island, Venezuela; Ascension Island; and Tortuguero, Costa Rica. On Aves Island, Venezuela, a generally increasing trend in green turtle activities has been noted, with particularly high numbers from 2005 to 2010 (García-Cruz et al., 2015). Ascension Island in the South Atlantic has seen their green turtle nest numbers increase over six times from 1977 to 2013 (Weber et al., 2014). Researchers there estimated almost 24,000 nests in 2013, compared to less than 4,000 when the study period began. Tortuguero, Costa Rica also has extraordinarily increasing trends. Over a study period of around 30 years, researchers saw an increase in nesting of over 400%, with 2003 numbers of nesting females estimated to be around 17,000 to 37,000 (Troëng & Rankin, 2005). When looking at a similar 30 year time-frame - 1990 to 2020, SPNWR nest numbers seem to have increased by over 11,000%, which is a much higher growth rate than seen at these other locations. However, SPNWR also has lower overall numbers: upwards of about a thousand nests, compared to tens of thousands documented at these aforementioned sites. To illustrate, Ascension Island has an area similar to that of SPNWR, with nesting beaches adding up to about 5,600m in length compared to SPNWR's 5,100m stretch (Weber et al., 2014). In 2012, the last year of the Weber et al. study, Ascension Island had a nest density of about 4.2 nests/m, while SPNWR had a density of only .2 nests/m. Consequently, SPNWR has lower nest density than many other beaches and most likely has more room for growth than these other locations.

Other global populations of *Chelonia mydas* also seem to be increasing. Over a period of 25 years, several global nesting beaches have shown increasing linear trends in population growth (Chaloupka et al., 2008). Archie Carr National Wildlife Refuge (ACNWR), Florida saw an increase of approximately 14% per year; Chichi-jima, Japan had an annual growth of almost

7%; East Island, Hawaii populations grew by about 5.7% a year; and the Heron Island, Australia rookery grew by nearly 4% annually (Chaloupka et al., 2008). In addition, at Aldabra Atoll, Seychelles, researchers recorded an increase of 500-800% in nests over a period of 40 years (Mortimer et al., 2011).

### *4.2 Location*

Sandy Point's North Beach is stable with wide stretches of open sand typically free of debris. The West Beach is characterized by dynamic erosion cycles, as the beach erodes annually with longshore current patterns and is replaced by the currents early in the year. Both the West Beach and South Beach have more wave action and denser vegetation. The South Beach customarily has the least amount of open sand habitat. Furthermore, Hurricane Maria in 2017 greatly impacted the South Beach's beach and vegetation line.

When considering total activities, as well as only nests, the North Beach had the highest density of *Chelonia mydas* activities, followed by the South Beach and then the West Beach. As green turtles generally prefer to lay their nests in areas where they can safely dig and deposit eggs in sand above the high water line (NMFS & USFWS, 1991), it is reasonable to expect them to favor the North Beach, as it is a stable habitat and provides large expanses of sand.

The nesting success rate for each beach was also calculated, and the North Beach had the highest success, which was as expected, due to its stability. The West and South Beaches have less stable beaches, and subsequently, *Chelonia mydas* females that emerge from the water onto these beaches lay nests less often.

*4.3 Conservation Outlook*

Based on the increasing trend in green turtle total activities and nests at Sandy Point National Wildlife Refuge, it can be concluded that the *Chelonia mydas* population is increasing at a rapid pace.

This increase is possibly attributed to expanded conservation efforts. The protections offered by these changes increased patrols, efforts, and safeguards, perhaps leading to a higher number of hatchlings making it to sexual maturity and returning to nest, as well as lower mortality rates during some life stages. In St. Croix, local conservation efforts include the establishment of Sandy Point National Wildlife Refuge in 1984 and community programs to increase awareness of the refuge's sea turtle species (U.S. Fish & Wildlife, 2017). Notably, SPNWR closes public access to the beach April through August due to nesting season. Although these closures protect only part of the green turtle's nesting season, the refuge is closed at night when green turtle nesting primarily takes place. Additionally, education efforts appear to help conservation and decrease poaching. Turtle Watch, which began in 1997, brings local community groups of adults and children to SPNWR and allows them to firsthand see turtles and learn about their importance (U.S. Fish & Wildlife, 2017). This program allows those in St. Croix to better understand sea turtle conservation and become personally involved and invested in the success of these species. Additionally, in the USVI, a law was established prohibiting the disturbance or take of any sea turtle (V.I. Code tit. 12, § 318, 2019). On a national level, the green sea turtle was listed under the Endangered Species Act in 1978 and in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), prohibiting trade of the species (NMFS & USFWS, 1991). It is possible that these efforts, combined with active law enforcement, have led to decreased poaching of turtles and nests, allowing greater numbers of turtles to survive.

Similar regulations exist in many surrounding regions as well (Weber, 2014; Troëng Rankin, 2005; Taft, 1998). However, while some areas have taken steps to increase conservation, others remain without protections for green turtles and still allow legal harvest, such as the nearby British Virgin Islands (McGowan et al., 2008). Although green turtles are a highly migratory species and are not safe in the entirety of the region, perhaps they benefit from the increased safety offered in nearby areas.

Increasing trends similar to those at SPNWR have been documented at other important *Chelonia mydas* nesting beaches and are also believed to be the result of conservation efforts. In Tortuguero, Costa Rica, increasing nest numbers are mainly due to the 1963 ban on egg and turtle collection and the designation of Tortuguero as a national park in the 1970s (Troëng & Rankin, 2005). However, there is still illegal poaching and capture of green turtles despite the laws and protections in place. Furthermore, as nearby Nicaragua and Panama are recorded foraging habitats for Tortuguero's nesting turtles, regulations and enforcement in these areas greatly affect green turtle numbers and survivorship (Troëng & Rankin, 2005). In addition, the *Chelonia mydas* rookeries examined by Chaloupka et al. (2008), such as Archie Carr National Wildlife Refuge in Florida, East Island, Hawaii, and Heron Island, Australia, all saw increasing trends. The documented growth was primarily due to protections designed to decrease prior exploitation and safeguard nesting turtles, mainly by making it illegal to harvest eggs or turtles (Chaloupka et al., 2008). The population growth of Aldabra Atoll is credited to the 1968 Green Turtle Protection Regulations, after which poaching dramatically declined, resulting in better survivorship of all life stages. Additionally, the 1994 Turtle Protection Regulations and the 1983 appointment of Aldabra Atoll as a UNESCO World Heritage Site boosted awareness and conservation (Mortimer et al., 2011).

Within a global perspective, SPNWR is considered part of Regional Management Unit (RMU) 47; this is the Southern Caribbean RMU that includes the Lesser Antilles (Wallace et al., 2010). However, it appears that Sandy Point data may fill a large information gap for RMU 47 as SPNWR's green turtle numbers have never been fully reported and the trends seem to be in contrast to those reported for this RMU. According to Wallace et al. (2010), RMU 47 has been decreasing in recent years (the long-term trend is listed as unknown). Yet, according to SPNWR data, there should be an increasing trend in the short-term as well as over a greater timespan. Either the trends seen at Sandy Point are opposite from the rest of the areas included in the RMU, or, more likely, RMU 47 is simply lacking data and, with the addition of SPNWR's data, might show increasing trends.

While there are 17 *Chelonia mydas* RMUs (Wallace et al., 2010), there are only 11 distinct population segments (DPSs) listed under the Endangered Species Act (81 FR 20057). Of these, the green turtles nesting at SPNWR are considered part of the South Atlantic DPS, which is listed as Threatened (NOAA, 2018). While RMUs are important in a global context, DPSs are designated through the ESA, which is a U.S. law. Therefore, the U.S. government likely uses DPSs when assessing species under U.S. jurisdiction, including green turtles at SPNWR.

Data from Sandy Point National Wildlife Refuge in St. Croix, the subject of this study, has revealed an average annual increase in nests of around 257% when considering the entire time period of nearly 40 years. Over the time period of 2005 to 2020, there has been an average increase of around 165% per year. The trends over this time period more likely reflect the true increase at SPNWR, as there was consistent effort and overall documentation of the whole beach. Similar to these other *Chelonia mydas* rookeries, it is believed that this growth is the result of protections put in place. Overall, trends at SPNWR (and abroad) look promising. The South Atlantic DPS seems to be recovering fairly well, as many nesting sites are seeing increasing numbers; however, some sites are only remaining stable or simply do not have enough data to determine any trend (Seminoff et al., 2015). The DPS has relatively low risk factors overall, resulting in a very low extinction risk (Seminoff et al., 2015). While this is great progress, the future remains uncertain, especially as the full effects of global warming and sea level rise have yet to be known. Therefore, even though South Atlantic populations seem to be on the rebound, the DPS still has progress to make before being considered for delisting.

In the Recovery Plan for the U.S. Population of Atlantic Green Turtle, four main ideas were outlined: protect and manage habitats, protect and manage population, information and education, and international cooperation (NMFS & USFWS, 1991). While steps have been taken to address each of these, improvements still must be made. Further work and research should be done regarding mature green turtles, habitat use and loss, and lighting regulations near nesting beaches. Additionally, better monitoring and enforcement is needed, as it was determined that the law enforcement in the U.S. Virgin Islands is inadequate (Eckert & Eckert, 2019). There should also be more outreach and education on how human disturbances negatively affect turtles, especially nesting females. Concerning the last goal of international cooperation, stricter regulations need to be adopted, and many countries still lack any real measures safeguarding sea turtles. For example, the legal turtle fishery in Turks and Caicos takes more than a thousand green turtles annually (Seminoff et al., 2015). Illegal catch of turtles is also an ever-present issue, whether it is deliberate or as bycatch, and stricter requirements need to be established and enforced. Overall, protections need to be in place throughout the green turtle's entire range, as this species is highly migratory and thus needs to be protected at each life stage.

Conservation must be long-term in order to see true effects on green turtle populations, and, according to this data, efforts seem to be working. With that in mind, *Chelonia mydas* research and conservation must continue.

# CHAPTER 5 CONCLUSION

This study provided the first comprehensive analysis of *Chelonia mydas* activities and nests within Sandy Point National Wildlife Refuge. Increasing trends were noted over the study period of nearly 40 years (1982-2020), both for total green turtle activities and for nest counts. These results demonstrate the effects of increased conservation efforts, the presence of law enforcement, improved outreach and possibly improved survival and recruitment, as similar cases throughout the world have demonstrated.

While green turtle nest counts are rapidly increasing, SPNWR is far from reaching carrying capacity. Based on a study conducted on the green turtles nesting on East Island of Hawaii's French Frigate Shoals, carrying capacity was approached at about 2.6 to 3.9 nests per square meter (Tiwari et al., 2010). Assuming SPNWR has the same general beach and resource conditions, the refuge would begin to reach carrying capacity when around 13,260 to 19,890 nests are recorded each year. As only 1,682 nests were laid in 2020, Sandy Point's green turtle nesting population still has opportunities for growth before reaching the carrying capacity of the habitat.

Based on the compiled data and the fact that the green turtle population is expected to continue to increase, SPNWR is becoming an emerging nesting hotspot for *Chelonia mydas*, both in the U.S. Virgin Islands and in the greater Caribbean. It should be recognized as a regionally significant nesting population and serve as an index nesting beach for the region. In particular, Sandy Point has the potential to greatly contribute to U.S. green turtle populations, and the data provided in this study should aid in improving domestic conservation efforts and strategies.

## REFERENCES


Ackerman, R.A. (1997). The Nest Environment and the Embryonic Development of Sea Turtles. In P.L. Lutz & J.A. Musick (Eds.) *The Biology of Sea Turtles*, 83-106. CRC Press.

Alexander, J., Garrett, K., Conrad, J., & Coles, W. (2003). Tagging and Nesting Research on Leatherback Sea Turtles (*Dermochelys coriacea*) on Sandy Point, St. Croix, U.S. Virgin Islands, 2003. *U.S. Virgin Islands Department of Planning and Natural Resources, Division of Fish and Wildlife, St. Croix, USVI*.

Allard, M.W., Miyamoto, M.M., Bjorndal, K.A., Bolten, A.B., & Bowen, B.W. (1994). Support for Natal Homing in Green Turtles from Mitochondrial DNA Sequences. *Copeia*, *1994*(1), 34-41. https://doi.org/10.2307/1446668

Avens, L., & Snover, M. (2013). Age and Age Estimation in Sea Turtles. In J. Wyneken, K.J. Lohmann, & J.A. Musick (Eds.) *The Biology of Sea Turtles*, 3, 97–134.

Bjorndal, K.A. (1980). Demography of the Breeding Population of the Green Turtle, *Chelonia mydas*, at Tortuguero, Costa Rica. *Copeia*, *1980*(3), 525-530. https://doi.org/10.2307/1444530

Bjorndal, K., Bolten, A., & Chaloupka, M. (2005). Evaluating Trends in Abundance of Immature Green Turtles, *Chelonia mydas*, in the Greater Caribbean. *Ecological Applications*,*15*(1). http://www.jstor.org/stable/4543354

Bjorndal, K.A., & Carr, A. (1989). Variation in Clutch Size and Egg Size in the Green Turtle Nesting Population at Tortuguero, Costa Rica. *Herpetologica*, *45*(2), 181–189. http://www.jstor.org/stable/3892160

Blechschmidt, J., Wittmann M.J., & Blüml, C. (2020). Climate Change and Green Sea Turtle Sex Ratio-Preventing Possible Extinction. *Genes*, *11*(5), 588. https://doi.org/10.3390/genes11050588

Bolten, A.B. (2003). Variation in Sea Turtle Life History Patterns: Neritic vs. Oceanic Developmental Stages. In P.L. Lutz, J.A. Musick, & J. Wyneken (Eds.) *The Biology of Sea Turtles*, *2*, 243-257.

Broderick, A.C., Glen, F., Godley, B.J., & Hays, G.C. (2003). Variation in Reproductive Output of Marine Turtles. *Journal of Experimental Marine Biology and Ecology*, *288*(1), 95-109.

Burkholder, D. & Slagle, C. (2015). Broward County Sea Turtle Conservation Program 2015 Report. *Nova Southeastern University*.

Carr, A., Carr, M.H., & Meylan, A.B. (1978). The Ecology and Migrations of Sea Turtles, 7. The West Caribbean Green Turtle Colony. *Bulletin of the American Museum of Natural History, 162*(1).

Carr, A., & Meylan, A.B. (1980). Evidence of Passive Migration of Green Turtle Hatchlings in Sargassum. *Copeia*, *1980*(2), 366–368. https://doi.org/10.2307/1444022

Cavallo, C., Dempster, T., Kearney, M.R., Kelly, E., Booth, D., Hadden, K.M., & Jessop, T.S. (2014). Predicting Climate Warming Effects on Green Turtle Hatchling Viability and Dispersal Performance. *Functional Ecology, 29*(6), 768-778. https://www.jstor.org/stable/48576992

Chaloupka, M., Bjorndal, K.A., Balazs, G.H., Bolten, A.B., Ehrhart, L.M., Limpus, C.J., Suganuma, H., Troëng, S., & Yamaguchi, M. (2008). Encouraging Outlook for Recovery of a Once Severely Exploited Marine Megaherbivore. *Global Ecology and Biogeography, 17*(2), 297-304. https://doi.org/10.1111/j.1466-8238.2007.00367.x

Cheng, I.J., Dutton, P.H., Chen, C.L., Chen, H.C., Chen, Y.H., & Shea, J.W. (2008). Comparison of the Genetics and Nesting Ecology of Two Green turtle Rookeries. *Journal of Zoology*, *276*(4), 375-384.

Conley, W.J. & Hoffman, B.A. (1987). Nesting Activity of Sea Turtles in Florida, 1979-1985. *Florida Scientist*, *50*(4), 201–210. http://www.jstor.org/stable/24320175

Diez, C.E., López, R., & Alvarez, A. (2015). Progress Report: In-water Surveys of Green Sea Turtles at Culebra Archipelago, Puerto Rico. *Programa de Especies en Peligro de Extinción, Departamento de Recursos Naturales y Ambientales, Estado Libre Asociado de Puerto Rico.*

Eckert, K.L. & Eckert, S.A. (1985). Tagging and Nesting Research of Leatherback Sea Turtles (*Dermochelys coriacea*) on Sandy Point, St. Croix, U.S. Virgin Islands, 1985. *U.S. Virgin Islands Department of Planning and Natural Resources, Division of Fish and Wildlife, St. Croix, USVI*.

Eckert, K.L. & Eckert, A.E. (2019). An Atlas of Sea Turtle Nesting Habitat for the Wider Caribbean Region. Revised Edition. WIDECAST Technical Report No. 19. Godfrey, Illinois. 232 pages, plus electronic Appendices.

Eckert, S.A., Eckert, K.L., & Boulon, R.H. (1982). Tagging and Nesting Research of Leatherback Sea Turtle (*Dermochelys coriacea*), Sandy Point, St. Croix, U.S. Virgin Islands, 1981/82. *U.S. Virgin Islands Department of Planning and Natural Resources, Division of Fish and Wildlife, St. Croix, USVI*.

Ehrenfeld D.W. (1968). The Role of Vision in the Sea-Finding Orientation of the Green Turtle (*Chelonia mydas*). 2. Orientation Mechanism and Range of Spectral Sensitivity. *Animal Behavior, 16*(2). 281–287. https://doi.org/10.1016/0003-3472(68)90010-9

Evans, M.A. (2010). Sandy Point, Green Cay and Buck Island National Wildlife Refuges Comprehensive Conservation Plan. *U.S. Department of the Interior, Fish and Wildlife Service Southeast Region*.

Fleming, E.H. (2001). Swimming Against the Tide: Recent Surveys of Exploitation, Trade, and Management of Marine Turtles in the Northern Caribbean. *TRAFFIC North America.*

Fowler, L.E. (1979). Hatching Success and Nest Predation in the Green Sea Turtle, *Chelonia mydas*, at Tortuguero, Costa Rica. *Ecology*, *60*(5), 946–955. https://doi.org/10.2307/1936863

Frazer, N.B. (1986). Survival from Egg to Adulthood in a Declining Population of Loggerhead Turtles, *Caretta caretta*. *Herpetologica, 42*(1), 47-55.

Frazer, N.B., & Ladner, R.C. (1986). A Growth Curve for Green Sea Turtles, *Chelonia mydas*, in the U.S. Virgin Islands, 1913-14. *Copeia*, *1986*(3), 798–802. https://doi.org/10.2307/1444963

García-Cruz, M.A., Lampo, M., Peñaloza, C.L., Kendall, W.L., Solé, G., & Rodríguez-Clark, K.M. (2015). Population Trends and Survival of Nesting Green Sea Turtles *Chelonia mydas* on Aves Island, Venezuela. *Endangered Species Research, 29*(2). https://doi.org/10.3354/esr00695

Godley, B.J., Broderick, A.C., Campbell, L.M., Ranger, S., & Richardson, P.B. (2004). An Assessment of the Status and Exploitation of Marine Turtles in the UK Overseas Territories in the Wider Caribbean. Final Project Report for the Department of Environment, Food and Rural Affairs and the Foreign and Commonwealth Office. 253pp.

Godley, B.J, Broderick, A.C., Colman, L.P, Formia, A., Godfrey, M.H, Hamann, M., Nuno, A., Omeyer, L.C.M., Patrício, A.R., Phillott, A.D., Rees, A.F., & Shanker, K. (2020). Reflections on Sea Turtle Conservation. *Oryx, 54*(3), 287-289.

Goshe, L.R., Avens, L., Scharf, F.S., & Southwood, A.L. (2010). Estimation of Age at Maturation and Growth of Atlantic Green Turtles (*Chelonia mydas*) Using Skeletochronology. *Marine Biology, 157*, 1725–1740. https://doi.org/10.1007/s00227-010-1446-0

Grain, D.A., Bolten, A.B., & Bjorndal, K.A. (1995). Effects of Beach Nourishment on Sea Turtles: Review and Research Initiatives. *Restoration Ecology, 3*(2), 95-104.

Haro, A. & Harrison, E. (2007). Report on the 2006 Green Turtle Program at Tortuguero, Costa Rica. *Caribbean Conservation Corporation*, 1-49.

Hays, G.C. (2004). Good News for Sea Turtles. *Trends in Ecology and Evolution, 19*(7), 349-351.

Hazel, J. & Lawler, I.R., Marsh, H., & Robson, S.K.A. (2007). Vessel Speed Increases Collision Risk for the Green Turtle *Chelonia mydas*. *Endangered Species Research, 3*. 105-113. 10.3354/esr003105

Heithaus, M.R., Wirsing, A.J., Thomson, J.A., & Burkholder, D.A. (2008). A Review of Lethal and Non-lethal Effects of Predators on Adult Marine Turtles. *Journal of Experimental Marine Biology and Ecology*, *356*(1-2), 43-51. https://doi.org/10.1016/j.jembe.2007.12.013

Heppell, S.S., Snover, M.L., & Crowder, L.B. (2003). Sea Turtle Population Ecology. In P.L. Lutz, J.A. Musick, & J. Wyneken (Eds.) *The Biology of Sea Turtles, 2*, 275-456. CRC Press.

Jensen, M.P., Allen, C.D., Eguchi, T., Bell, I.P., LaCasella, E.L., Hilton, W.A., Hof, C.A.M., & Dutton, P.H. (2018). Environmental Warming and Feminization of One of the Largest Sea Turtle Populations in the World. *Current Biology, 28*(1), 154-159.

Jensen, M.P., FitzSimmons, N.N., Bourjea, J., Hamabata, T., Reece, J., & Dutton, P.H. (2019). The Evolutionary History and Global Phylogeography of the Green Turtle (*Chelonia mydas*). *Journal of Biogeography, 46*(5), 860-870.

Johnson, S.A., & Ehrhart, L.M. (1996). Reproductive Ecology of the Florida Green Turtle: Clutch Frequency. *Journal of Herpetology, 30*(3), 407–410. https://doi.org/10.2307/1565180

Lagueux, C. (2001). Status and Distribution of the Green Turtle, *Chelonia mydas*, in the Wider Caribbean Region. *Marine Turtle Conservation in the Wider Caribbean Region: A Dialogue for Effective Regional Management*, 32-35.

Lahanas, P.N., Bjorndal, K.A., Bolten, A.B., Encalada, S.E., Miyamoto, M.M., Valverde, R.A., & Bowen, B.W. (1998). Genetic Composition of a Green Turtle (*Chelonia mydas*) Feeding Ground Population: Evidence for Multiple Origins. *Marine Biology, 130*, 345-352.

Lohmann, K.J., Lohmann, C.M., Brothers, J.R., & Putman, N.F. (2013). Natal Homing and Imprinting in Sea Turtles. In J. Wyneken, K.J. Lohmann, & J.A. Musick (Eds.) *The Biology of Sea Turtles*, *3*, 59-78. CRC Press.

Lutcavage, M.E., Plotkin, P., Witherington, B., & Lutz, P.L. (1997). Human Impacts on Sea Turtle Survival. In P.L. Lutz & J.A. Musick (Eds.) *The Biology of Sea Turtles*, 387-404. CRC Press.

Lutz, P.L., Musick, J.A., & Wyneken, J. (2002). *The Biology of Sea Turtles, 3*. CRC Press.

Matz, H. (2015). Current Threats to Coastal Seagrass Ecosystems. *University of Miami Shark Research*, 1-6.

Mazaris, A.D., Schofield, G., Gkazinou, C., Almpanidou, V., & Hays, G.C. (2017). Global Sea Turtle Conservation Success. *Science Advances, 3*(9), e1600730. https://doi.org/10.1126/sciadv.1600730

McClellan, C.M. & Read, A.J. (2007). Complexity and Variation in Loggerhead Sea Turtle Life History. *Biology Letters, 3*, 592–594. http://doi.org/10.1098/rsbl.2007.0355

McDonald, D., Dutton, P.H., & Boulon, R.H. (1991). Tagging and Nesting Research on Leatherback Sea Turtles (*Dermochelys coriacea*) on Sandy Point, St. Croix, U.S. Virgin Islands. *U.S. Virgin Islands Department of Planning and Natural Resources, Division of Fish and Wildlife, St. Croix, USVI*.

McGowan, A., Broderick, A.C., Frett, G., Gore, S., Hastings, M., Pickering, A., Wheatley, D., White, J., Witt, M.J., & Godley, B.J. (2008). Down but Not Out: Marine Turtles of the British Virgin Islands. *Animal Conservation*, *11*(2), 92-103.

Meylan, A.B., Bowen, B.W., & Avise, J.C. (1990). A Genetic Test of the Natal Homing versus Social Facilitation Models for Green Turtle Migration. *Science*, *248*(4956), 724–727. https://doi.org/10.1126/science.2333522

Mortimer, J.A., von Brandis, R.G., Liljevik, A., Chapman, R., & Collie, J. (2011). Fall and Rise of Nesting Green Turtles (*Chelonia mydas*) at Aldabra Atoll, Seychelles: Positive Response to Four Decades of Protection (1968–2008). *Chelonian Conservation Biology, 10*(2), 165-176. https://doi.org/10.2744/CCB-0872.1

Musick, J.A., Limpus, C.J. (1997) Habitat Utilization and Migration in Juvenile Sea Turtles. In P.L. Lutz & J.A. Musick (Eds.) *The Biology of Sea Turtles*, *1*, 137-163. CRC Press.

National Marine Fisheries Service and U.S. Fish and Wildlife Service. (1991). Recovery Plan for the U.S. Population of Atlantic Green Turtle. National Marine Fisheries Service, Washington D.C.

National Research Council (NRC). (1990). Decline of the Sea Turtles: Causes and Prevention. *National Academy Press*.

NOAA Fisheries. (2018). Green Turtle Distinct Population Segments Map. *National Oceanic and Atmospheric Administration, Office of Protected Resources*.

Phillips, K.F., Stahelin, G.D., Chabot, R.M., & Mansfield, K.L. (2021). Long-term Trends in Marine Turtle Size at Maturity at an Important Atlantic Rookery. *Ecosphere, 12*(7), e03631.

Plotkin, P. (2003) Adult Migrations and Habitat Use. In P.L. Lutz, J.A. Musick, & J. Wyneken (Eds.) *Biology of Sea Turtles*, *2*, 225-241. CRC Press.

Pritchard, P.C.H. (1980). The Conservation of Sea Turtles: Practices and Problems. *American Zoologist*, *20*(3), 609-617. https://doi.org/10.1093/icb/20.3.609

R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Rieser, A. (2012). The Case of the Green Turtle: An Uncensored History of a Conservation Icon. *The Johns Hopkins University Press*. 338pp.

Salmon, M. (2003). Artificial Night Lighting and Sea Turtles. *Biologist, 50*, 163–68.

Seminoff, J.A. (2004). *Chelonia mydas*. *The IUCN Red List of Threatened Species*. https://dx.doi.org/10.2305/IUCN.UK.2004.RLTS.T4615A11037468.en

Seminoff, J.A., Allen, C.D., Balazs, G.H., Dutton, P.H., Eguchi, T., Haas, H.L., Hargrove, S.A., Jensen, M., Klemm, D.L., Lauritsen, A.M., MacPherson, S.L., Opay, P., Possardt, E.E., Pultz, S., Seney, E., Van Houtan, K.S., & Waples, R.S. (2015). Status Review of the Green Turtle (*Chelonia mydas*) Under the U.S. Endangered Species Act. NOAA Technical Memorandum, NOAA- NMFS-SWFSC-539. 571pp.

Taft, C. (1998). *International Agreement for the Conservation of Caribbean Sea Turtles Signed by Central American Presidents*. Sea Turtle Conservancy. https://conserveturtles.org/policy-initiatives-central-american-issues/

Tiwari, M., Balazs, G.H., & Hargrove, S.K. (2010). Estimating Carrying Capacity at the Green Turtle Nesting Beach of East Island, French Frigate Shoals. *Marine Ecology Progress Series, 419*, 289-294.

Tiwari, M., Bjorndal, K.A., Bolten, A.B., & Bolker, B.M. (2006). Evaluation of Density-dependent Processes and Green Turtle *Chelonia mydas* Hatchling Production at Tortuguero, Costa Rica. *Marine Ecology Progress Series, 326*, 283-293.

Tomillo, P.S., Paladino, F.V., Suss, J.S., & Spotila, J.R. (2010). Predation of Leatherback Turtle Hatchlings During the Crawl to the Water. *Chelonian Conservation and Biology, 9*, 18–25. doi:10.2744/CCB-0789.1

Troëng, S. & Rankin, E. (2005). Long-term Conservation Efforts Contribute to Positive Green Turtle *Chelonia mydas* Nesting Trend at Tortuguero, Costa Rica. *Biological Conservation*, *121*(1), 111-116. https://doi.org/10.1016/j.biocon.2004.04.014

University of Exeter. (2017). *Marine Turtles Dying After Becoming Entangled in Plastic Rubbish.* Science Daily. https://www.sciencedaily.com/releases/2017/12/171218154235.htm

U.S. Fish & Wildlife. (2017). *About the Refuge*. Sandy Point National Wildlife Refuge, U.S. Virgin Islands. https://www.fws.gov/refuge/Sandy_Point/about.html

Valiulis, J. & Mackay, A. (2011). Saturation Tagging and Nest Management of Leatherback (*Dermochelys coriacea*), Hawksbill (*Eretmochelys imbricata*) and Green (*Chelonia mydas*) Sea Turtles at Sandy Point National Wildlife Refuge, St. Croix, U.S. Virgin Islands. *Geographic Consulting*.

van Buskirk, J., & Crowder, L.B. (1994). Life-History Variation in Marine Turtles. *Copeia*, *1994*(1), 66–81. https://doi.org/10.2307/1446672

Vandersteen, J., Kark, S., Sorrell, K., & Levin, N. (2020). Quantifying the Impact of Light Pollution on Sea Turtle Nesting Using Ground-Based Imagery. *Remote Sensing*, *12*(11), 1785. https://doi.org/10.3390/rs12111785

Varela-Acevedo, E., Eckert, K.L., Eckert, S.A., Cambers, G., & Horrocks, J.A. (2009). Sea Turtle Nesting Beach Characterization Manual. In *Examining the Effects of Changing Coastline Processes on Hawksbill Sea Turtle (Eretmochelys imbricata) Nesting Habitat*, 46-97.

Wallace, B.P., DiMatteo, A.D., Hurley, B.J., Finkbeiner, E.M., Bolten, A.B., Chaloupka, M.Y., Hutchinson, B.J., Abreu-Grobois, F.A., Amorocho, D., Bjorndal, K.A., Bourjea, J., Bowen, B.W., Dueñas, R.B., Casale, P., Choudhury, B.C., Costa, A., Dutton, P.H., Fallabrino, A., Girard, A., Girondot, M., Godfrey, M.H., Hamann, M., López-Mendilaharsu, M., Marcovaldi, M.A., Mortimer, J.A., Musick, J.A., Nel, R., Pilcher, N.J., Seminoff, J.A., Troëng, S., Witherington, B., & Mast, R.B. (2010). Regional Management Units for Marine Turtles: A Novel Framework for Prioritizing Conservation and Research across Multiple Scales. *PLoS One*,*5*(12): e15465. https://doi.org/10.1371/journal.pone.0015465

Weber, S.B., Weber, N., Ellick, J., Avery, A., Frauenstein, R., Godley, B.J., Sim, J., Williams, N., & Broderick, A.C. (2014). Recovery of the South Atlantic's Largest Green Turtle Nesting Population. *Biodiversity Conservation, 23*, 3005-3018. https://doi.org/10.1007/s10531-014-0759-6

Weishampel, J.F., Bagley, D.A., Ehrhart, L.M., & Rodenbeck, B.L. (2003). Spatiotemporal Patterns of Annual Sea Turtle Nesting Behaviors along an East Central Florida Beach. *Biological Conservation*, *110*(2), 295-303.

Witherington, B.E. (1992). Behavioral Responses of Nesting Sea Turtles to Artificial Lighting. *Herpetologica*, *48*(1), 31-39. http://www.jstor.org/stable/3892916

Witherington, B.E. (1997). The Problem of Photopollution for Sea Turtles and Other Nocturnal Animals. In J.R. Clemmons & R. Buchholz (Eds.) *Behavioral Approaches to Conservation in the Wild*, 303-328. Cambridge University Press.