AN ABSTRACT OF THE THESIS OF Marylou K. Staman for the Master of Science in Biology presented September 7, 2016.

Title: Nesting Patterns of the Green Sea Turtle (*Chelonia mydas*, *Cheloniidae*) on Andersen Air Force Base, Guam.

Approved: ______________________________
Terry J. Donaldson, Ph. D, Chair, Thesis Committee

Historically, two species of marine turtles have been observed foraging in Guam's waters, the green sea turtle (*Chelonia mydas*) and the hawksbill sea turtle (*Eretmochelys imbricata*). The conservation status of the green sea turtle species was recently reassessed and a ruling on this was published in the Federal Register. The new rule stipulated that the green sea turtle population within the Central West Pacific Designated Population Segment be up-listed from threatened to endangered based upon a lack of data from the region, including Guam. The purpose of this thesis research was to conduct a study at nesting sites on beaches located along the coast of Andersen Air Force Base (AAFB) in northern Guam. The goals of this study were to determine the number of sea turtle nests laid on the AAFB beaches over a 24-month period, identify preferred nesting sites, determine nesting phenology, and calculate mean emergence and hatching success rates. This study also initiated the use of methods for long-term monitoring of the AAFB sea turtle nesting beaches that could produce at least one year of consistent data.

During the February 2014 to January 2016 study period, 77 emergences resulting in 65 green sea turtle nests were discovered on the beaches of AAFB. All nesting activity fell between February and September, and the month with the highest mean number of

emergences was May ($\overline{X} = 9$). Eighty-three percent of emergences were in habitat characterized as shoreline vegetation, versus beach forest (10%) and open beach (6.5%). The habitat with the most false emergences was open beach habitat. The nests were laid in a significantly clustered spatial pattern, with a nearest neighbor ratio of 0.571449. The mean hatching (75.93%) and emergence (75.36%) success rates of nests during this study were highly correlated ($R^2 = 0.998$). These success rates were positively correlated with track width ($p<0.001$), in that larger sea turtles were producing more successful nests.

This data sets up the baseline for a long-term dataset could not only be used to help answer important questions about local and regional sea turtle biology, but it could also be used by resource managers charged with contributing to the recovery of this endangered species.

NESTING PATTERNS OF THE GREEN SEA TURTLE (*CHELONIA MYDAS*, *CHELONIIDAE*) ON ANDERSEN AIR FORCE BASE, GUAM

BY

MARYLOU K. STAMAN

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I would like to thank my family, friends, and committee for supporting me throughout my time at the UOG Marine Lab. I would like to thank NAVFAC Marianas and Andersen Air Force Base for their funding and guidance during the sea turtle project.

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number of times a female returns to nest each season varies geographically; however, females in Hawaii have been recorded laying as many as six clutches in one season (Balazs 1980). The remigration interval (the number of years between nesting) is not known for green sea turtles on Guam, however it has been estimated to be every 3+ years at a rookery at Ulithi Atoll, located 640km southwest of Guam in Yap State, Federated States of Micronesia (Cruce 2008). The eggs take approximately 50-80 days to develop (Ackerman 1997), during which time they are subject to a myriad of threats including poaching, predation, vegetation overgrowth, and erosion, flooding, and accretion caused by storm events. Once hatched, the hatchlings must face further predation as they leave the nest and hasten toward the water. Because of the high mortality rate between time of egg deposition and when hatchlings have aged one year, green sea turtles are characterized by a Type III survivorship curve in that their mortality rate is inversely related to their age (Iverson 1991).

The new ruling by the USFWS and NOAA-NMFS led to a revision of the current listings of endangered or threatened green sea turtle populations. The USFWS and NOAA-NMFS determined that the range-wide listing for green sea turtles should be changed into 11 distinct population segments (DPSs) with updated listings to reflect the status of green sea turtles in each segment (NMFS and USFWS 2015). The DPS that would include Guam is the Central West Pacific DPS, which also includes the Republic of Palau, Federated States of Micronesia (FSM), New Guinea, Solomon Islands, Marshall Islands, the Commonwealth of the Northern Mariana Islands (CNMI), and the Ogasawara Islands (Japan). The new rule stipulated also that the green sea turtle population within this DPS be up-listed from threatened to endangered based upon a lack of data from the

1. INTRODUCTION

Historically, two species of marine turtles have been observed foraging in Guam's waters, the green sea turtle (*Chelonia mydas*) and the hawksbill sea turtle (*Eretmochelys imbricata*). The conservation status of the green sea turtle species was recently reassessed and a ruling on this was published in the Federal Register by the National Oceanic and Atmospheric Administration-National Marine Fisheries Service (NOAA-NMFS) in conjunction with the U.S. Fish and Wildlife Service (USFWS) (81 FR 20057, 2016). This final rule identified the necessity of conducting a long-term, standardized monitoring project that addresses reproduction of green sea turtles on Guam. The purpose of this thesis research was to conduct such a study at nesting sites on beaches located along the coast of Andersen Air Force Base (AAFB), Guam.

The goals of this study were to determine the number of sea turtle nests laid on the AAFB beaches over a 24-month period, identify preferred nesting sites, determine nesting phenology, and calculate mean emergence and hatching success rates. This study also initiated the use of methods for long-term monitoring of the AAFB sea turtle nesting beaches that could produce at least one year of consistent data.

Green sea turtles have a rounded, smooth carapace that can reach a maximum straight length of 120cm. They can weigh up to 230kg in the Western Pacific and are distributed across all sub-tropical and tropical seas (Pritchard and Mortimer 1999) Green sea turtles reach sexual maturity at 30-35 years of age, have high nest site fidelity, and exhibit natal philopatry because females return to the location where they hatched to lay their own eggs (Heppell et al. 2003). Females select a nesting site above the high tide line and lay an average of 110-130 eggs per clutch (Pritchard and Mortimer 1999). The

the *Haggan Watch* program was disbanded and by 2011, only 12 island-wide surveys were conducted (Bonham 2014).

Through a Cooperative Ecosystem Studies Unit (CESU) agreement between the University of Guam (UOG), through its Marine Laboratory (UOGML), and the Naval Facilities Engineering Command (NAVFAC)-Marianas, a project was developed with the goal of improving sea turtle monitoring, protection, and educational outreach on AAFB. Research conducted as part of this project is the subject of this Master of Science thesis. By assigning the AAFB beaches to one monitoring team that coordinated with DAWR, this project aimed to increase survey effort in both quantity and consistency. Through the long-term implementation of data collection, managers may be able to detect major threats and temporal fluctuations in the ability and need to protect nests, and determine which factors influence the success of nests laid on the beaches of AAFB. The inter-annual variability in estimated resident numbers and their long-term trends may also eventually be detectable and utilized to design and implement future management plans that could lead towards the eventual recovery of the sea turtle population on AAFB.

In addition to meeting the four primary goals of this study, I was able to address several hypotheses relevant to sea turtle nesting on Guam. The first concerned nesting seasonality. Female sea turtles coming ashore to nest at AAFB may have preferred or peak nesting seasons that, based on nesting season data from nearby rookeries in Rota and Saipan, CNMI (Ilo and Manglona 2001, Maison et al. 2010), as well as historical data from Guam (NMFS and USFWS 1998), could have lasted from March through June each year. Alternatively, nesting could be year-round. Nesting season is defined here as the duration between the first and the last nest laid during a calendar year. I predicted that region. More specifically, the rule lists data gaps in historical baseline and in-water density data, insufficient long-term and standardized monitoring, and challenges to genetic sampling as a few of the factors contributing to overall data deficiency. Specific threats to the Central West Pacific DPS were identified as habitat destruction, over-utilization (harvesting), disease, predation, inadequate regulatory mechanisms, and other factors including pollution, climate change, natural disasters, and bycatch. These threats are exasperated by the DPS's relatively small insular nesting sea turtle population being spread across a massive area with limited suitable coastal nesting habitat that is being simultaneously strained by human population growth. While most of the population trends within the Guam DPS are unknown, some areas have been shown to have declining nesting populations (Seminoff et al. 2015).

Two years after the U.S. Endangered Species Act of 1973 was signed, the Government of Guam Department of Agriculture and Wildlife Resources (DAWR) began a Guam-wide nesting marine turtle monitoring program. Shortly after, the local government passed its own Endangered Species Act in 1979. While sea turtle education, enforcement and survey efforts increased, nesting beach areas lacked consistent monitoring and protection efforts. In 2000, through a grant from NOAA, DAWR initiated the Guam Sea Turtle Recovery Program to perform baseline population studies on Guam's green sea turtles. DAWR established the volunteer program *Haggan Watch* in 2005 (Wusstig 2014) to increase nesting beach monitoring throughout Guam. "*Haggan*" is the word for turtle in Chamorro, the native language of the Chamorro people who are indigenous to the Mariana Islands. Sea turtle surveys increased until 2007, when a record 326 surveys were conducted island-wide. However, due to limited funding and staffing the sex and survivorship of her clutch (Bjorndal and Bolten 1992). These data are also important from a management perspective because they can inform AAFB resource managers charged with overseeing recreational and development projects being conducted in different beach habitat types, including activities such as vegetation clearing or All-Terrain Vehicle (ATV) use.

The third hypothesis was that the distribution of sea turtle nests at AAFB would exhibit a non-random or non-uniform spatial pattern. Alternatively, the pattern of distribution of the nests would be random or uniform. Based on a study of a *C. mydas* nesting population on Ascension Island in the Central Atlantic that found that sea turtles "clumped" their nesting activity around uneven beach topography (Hays et al. 1995), I predicted that the females on AAFB would have nests distributed in clusters defined by the patchy nature of the distribution of preferred nesting habitat. I tested this hypothesis by using nesting spatial data collected during consistent daytime shoreline surveys. These data are important from a biological perspective because a female's nest spatial distribution can have direct consequences on the survival of her clutch when repeated nesting events in close proximity to one another might lead to older clutches being prematurely excavated and destroyed. These data are important from a management perspective because they can be used by AAFB resource managers charged with allocating resources to manage different nesting sites, or when designating temporary beach closures.

The last hypothesis concerned hatching and emergence of juvenile sea turtles. Here, hatching and emergence success rates of nests at AAFB should not vary significantly throughout the duration of the nesting season because factors that typically

C. mydas would have a preferred or peak nesting season on the beaches of AAFB. This hypothesis was tested by using nesting phenology data collected during consistent daytime shoreline surveys. This information is important from a biological perspective because nesting periodicity data for *C. mydas* on AAFB is relatively scarce and inconsistent. Making this data available for comparison with data from other well-documented rookeries in the region will add an important piece of the puzzle for local turtle recovery programs. This information is important from a management perspective because it can be utilized by AAFB resource managers charged with allocating funds and monitoring or enforcement personnel to nesting beaches, or designating temporary beach closures that prohibit recreational activities or military operations.

The second hypothesis considered beach habitat preferences of nesting females. Three specific and one assortment of habitat types were present at AAFB sites: These were identified as shoreline vegetation, open beach, beach forest, and other. I hypothesized that nesting sea turtles would prefer a single habitat over others. Alternatively, nesting sea turtles would utilize all available beach habitats randomly. Previous studies reported that *C. mydas* females tended to nest in both open beach habitats (Tortuguero, Costa Rica; Bjorndal and Bolten 1992) and shoreline vegetation habitats (Suriname; Whitmore and Dutton 1985). I predicted that the females on AAFB preferred the beach habitat characterized by shoreline vegetation over other types of habitat because of the wide extent of vegetation cover already present at this location. The null hypothesis was tested by using nesting habitat data collected and characterized during consistent daytime shoreline surveys. These data are important from a biological perspective because a female's nest-site selection can have significant consequences on coconut tree, *Cocos nucifera*. While connected naturally, the beach coastline has been separated artificially into five beaches: Tarague (0.7km), Scout (1.72km), Sirena (0.53km), Pati (0.15km), and Explosive Ordnance Disposal (EOD) beach (2.0km) (Figure 1). Four of the beaches (Scout, Sirena, Pati, and EOD) are located within the Pati Point Preserve, a Government of Guam Marine Protected Area (MPA) and four of the beaches (Tarague, Scout, Sirena, and Pati) are part of the USFWS-AAFB Overlay Refuge Unit. These five beaches represent the only available sea turtle nesting habitat on AAFB.

affect nest success rates would act equally regardless of the time of year. Alternatively, these rates should fluctuate, exhibiting variable success rates throughout the season. Based upon a study conducted on loggerhead sea turtles (*Caretta caretta*) in Japan that found that there was no seasonal trend in hatching success rates (Matsuzawa et al. 2002), I predicted that the hatching and emergence success rates of AAFB nests would be similar throughout the duration of the nesting season. I tested this hypothesis using clutch data collected during nest inventories. These data are important from a biological perspective because the average success rates of a nesting beach, whether increasing or decreasing, can be indicative of the general health of the AAFB *C. mydas* nesting population. These data are important also for determining the suitability of AAFB beaches as an incubation system for *C. mydas* eggs.

2. MATERIALS AND METHODS

2.1. Study Site

Guam (13°28' N, 144°47' E), with an area of 549 square kilometers, is the largest and southernmost island in the Mariana Islands. Guam is a U.S. Territory supporting various military installations that comprise approximately 29% of the island's total land area. One such installation, AAFB, is located on the windward northern tip of Guam and has approximately 15.6km of coastline. The northwest edge of AAFB, protected by an embayment backed by a 180-meter tall cliff line, is comprised of approximately 4.8km of sandy beaches bordered by a limestone forest. The beaches range from approximately 3 to 15 meters wide and are bordered by coastal strand dominated by vegetation that includes *Heliotropium foertherianum* (formerly *Tournefortia argentea)*, *Scaevola taccada*, *Pandaus tectorius*, *Sophora tomentosa*, *Casuarina equisetifolia* and the common was acquired through a cooperative agreement between the University of Guam and the Guam DAWR.

2.3. Field Methods

The following methods for sea turtle monitoring are consistent with those described in Eckert et al. (1999) and the Department of the Navy (2010), as well as those used by the Guam DAWR (K. Bonham, personal communication, March 2014) and the USFWS (J. Cruce, personal communication, October 2013).

In order to meet the four primary goals of this study, two different methods of data collection were utilized: a) daytime shoreline surveys and b) nest inventories.

2.3.1. Daytime Shoreline Surveys

The first three primary goals of this study were to use existing daytime shoreline survey data to determine the number of sea turtle nests laid on the beaches of AAFB, identify the preferred location, and establish the phenology of this nesting population. Surveys of sea turtle nesting were conducted at a frequency of 3-5 days per week when nesting was present, and 2-3 days per week when no nesting was observed. A higher frequency of surveys during a nesting season allowed for greater accuracy when determining nest lay dates, nest incubation periods, and female inter-nesting intervals. Almost all surveys were conducted between 05:00-11:00H in order to minimize the risk of weather and human-use disturbances obscuring signs of any sea turtle activity prior to data collection. EOD beach was not surveyed from February to October 2014 due to restricted access.

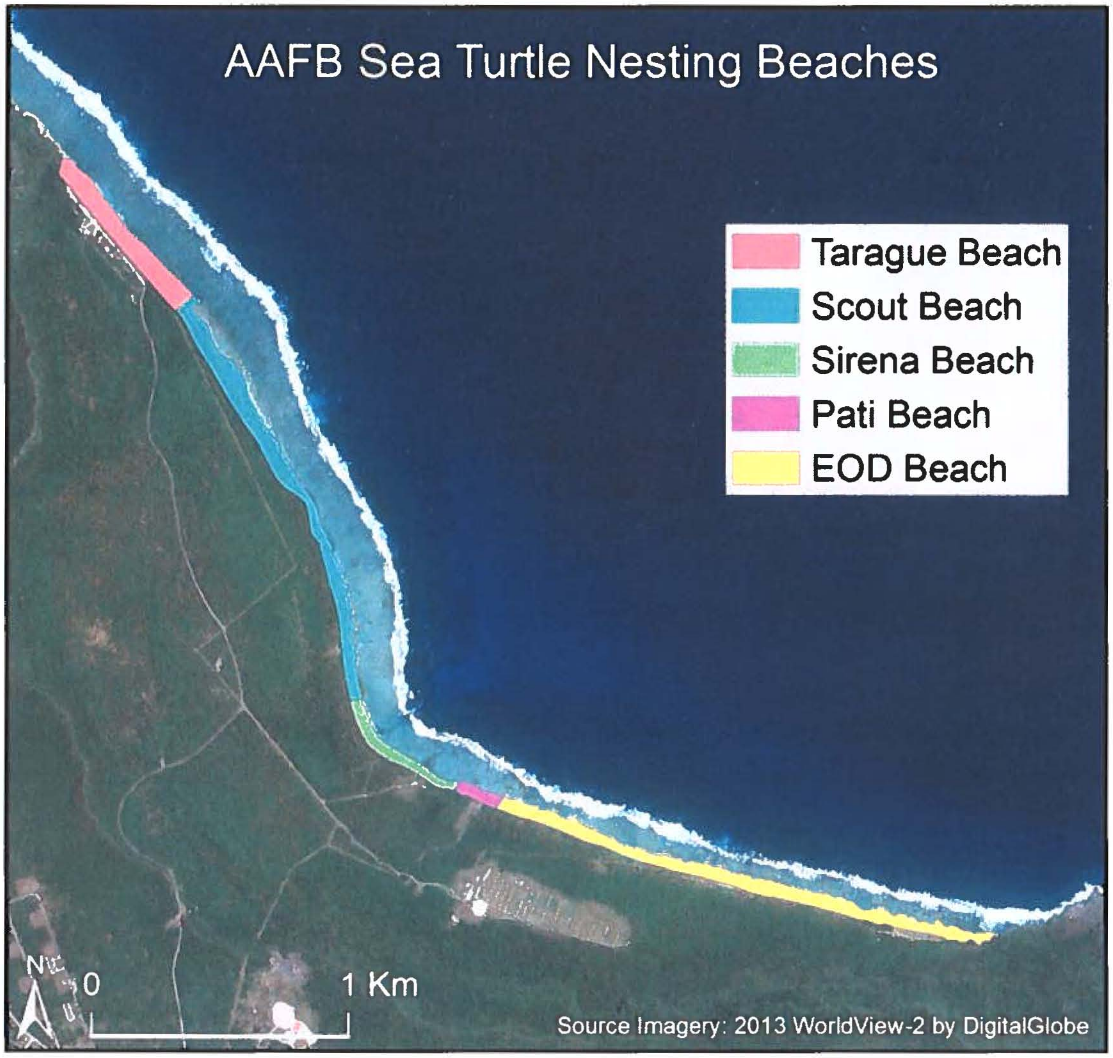

Figure 1. Study Site on Andersen Air Force Base, comprised of five artificially-separated beaches.

2.2. Study Timeline & Permitting Process

This study utilized data collected during a 24-month time frame stipulated by the CESU project, from February 2014 through January 2016. Given the current endangered status of green sea turtles on Guam, a permit from the USFWS was required to conduct research that involves handling turtles and disturbing nests. The permit for this project period. To address this goal, data from nest inventories were collected and then analyzed using the hatching and emergence success rate formulas found in "Determining clutch size and hatching success" (Miller 1999). Because of the relatively low abundance of sea turtles nesting on AAFB, and Guam in general, every nest that was laid during the study period was inventoried. Clutch data were obtained by making observations of signs of turtle hatching 45 days after the nest was laid until the nest had hatched or when the nest had been incubating for over 70 days. Nests that were marked previously and then located successfully, either after the emergence of hatchlings or after 70 days of incubation, were excavated and the contents inventoried. Actual hatching events occurred at night and were therefore not viewed in person, however infrared trail cameras were installed on many nests to record hatching, as well as predation or misorientation events as hatchlings attempted to make their way to the ocean.

During excavation, the contents of the nest were defined by the following categories as described by Miller (1999):

- S = empty shells in nest;
- L = hatchlings alive in nest;
- D = hatchlings dead in nest;
- UD = unhatched eggs with no obvious embryo;
- US = unhatched eggs with obvious embryo;
- UHT = unhatched full-term embryo in egg shell or pipped;
- P = depredated open shells containing egg residue.

Data were recorded on pre-printed waterproof paper and then transferred to a MS-Excel spreadsheet for later analysis.

Signs of sea turtle activity included the presence of adults or hatchlings, crawl tracks, or signs of body pitting, and nesting. Once activity was discovered, it was characterized (i.e., age of activity measured in days, species identification, and nesting vs. non-nesting "false" emergences), and the need for further action (e.g., nest protection and monitoring) was determined. To determine the nesting females' preferred nesting locality, two different types of data were collected during surveys. First, the location of the nest was categorized into different habitat types: open beach, shoreline vegetation, beach forest, or other. Because the five named beaches are actually comprised of one long, connected beach, these habitat types were used to analyze location preference for nesting females. Second, the Global Positioning System (GPS) coordinates of each nest were recorded and mapped with the mapping software ArcMap 10.2.2. This spatial data was used in later analysis of nesting patterns to determine if nests were laid randomly, uniformly, or in clusters. To determine the female sea turtle's preferred time of year for nesting, the dates of all nesting events were recorded during surveys and plotted by month using the graphing function of statistical software JMP (version 12.2.0, 2016). During previous surveys, each nest was marked with flagging tape so that it could be monitored and then excavated after the eggs hatched or passed an incubation period of 70 days. Additional data on lunar phase, tides, and weather conditions were also recorded. Data were recorded on pre-printed waterproof paper and then transferred into an MS-Excel spreadsheet for later analysis.

2.3.2. Nest Inventories

The fourth goal of this study was to determine the emergence and hatching success rates of all nests laid within the Tarague Embayment during the 24-month study dispersed, or clustered. The total area of the five AAFB beaches (289,310m^2) was used as the study area size for analysis. The ArcGIS-generated Nearest Neighbor Summary Report was referenced for distribution type and significance.

3.4. Hatching and Emergence Success

To determine the success of nest incubation, two calculations (Miller 1999) were used. The first was used to estimate the percentage of hatchlings that successfully emerged from their shells (i.e., the average hatching success rates of the nests):

$$\text{Hatching Success (HS, \%)} = \frac{\#S}{\#S+\#UD+\#UH+\#UHT+\#P}$$

The second calculation was used to estimate the number of hatched turtles that emerged from the nest (i.e., the average emergence success rate of the nests):

$$\text{Emergence Success (ES, \%)} = \frac{\#S-(\#L+\#D)}{\#S+\#UD+\#UH+\#UHT+\#P}$$

See section 2.3.2 for explanation of variables.

These calculations were used to determine what percentage of total eggs laid resulted in live, fully-functional young. The success rates garnered from these calculations were then compared against each other using standard least squares linear regression to determine the strength of the correlation between hatch success and emergence success. This information can be used by resource managers to assess the overall reproductive potential of AAFB's nesting population.

After the clutch data was used to calculate the hatching and emergence success, they were then averaged by month and compared against nest habitat, track width, and weather conditions using one-way ANOVAs.

3. DATA ANALYSIS

3.1. Nesting Peak Season

Once the number of nests and non-nesting emergences that occurred during the study period had been tallied, events were binned by month and used to evaluate whether nesting events occurred evenly throughout the nesting season. Results were separated by emergence condition (true, false, or unknown) and mean emergences by month were graphed using JMP statistical software.

3.2. Nesting Habitat Type

After each nest was categorized by substrate type (open beach, shoreline vegetation, beach forest, other), the data were averaged and graphed using JMP statistical software. The habitat type was then compared against emergence condition, clutch size, nest depth, and nest hatching success rates using one-way analysis of variance (ANOVA) followed by Tukey's post hoc tests. The level of significance (alpha) was set at $p<0.05$. All ANOVAs and Tukey's tests for this study were calculated using 95% confidence interval.

A chi-squared test was also used to compare categorical data (emergence condition and habitat type). This information can be used by resource managers to asses which habitat types correlate with more successful hatching rates.

3.3. Nest Spatial Patterns

All of the nests recorded during the study period were mapped with ArcGIS software and their spatial patterns were analyzed using Average Nearest Neighbor spatial statistical analysis to determine whether their distribution was random, uniformly

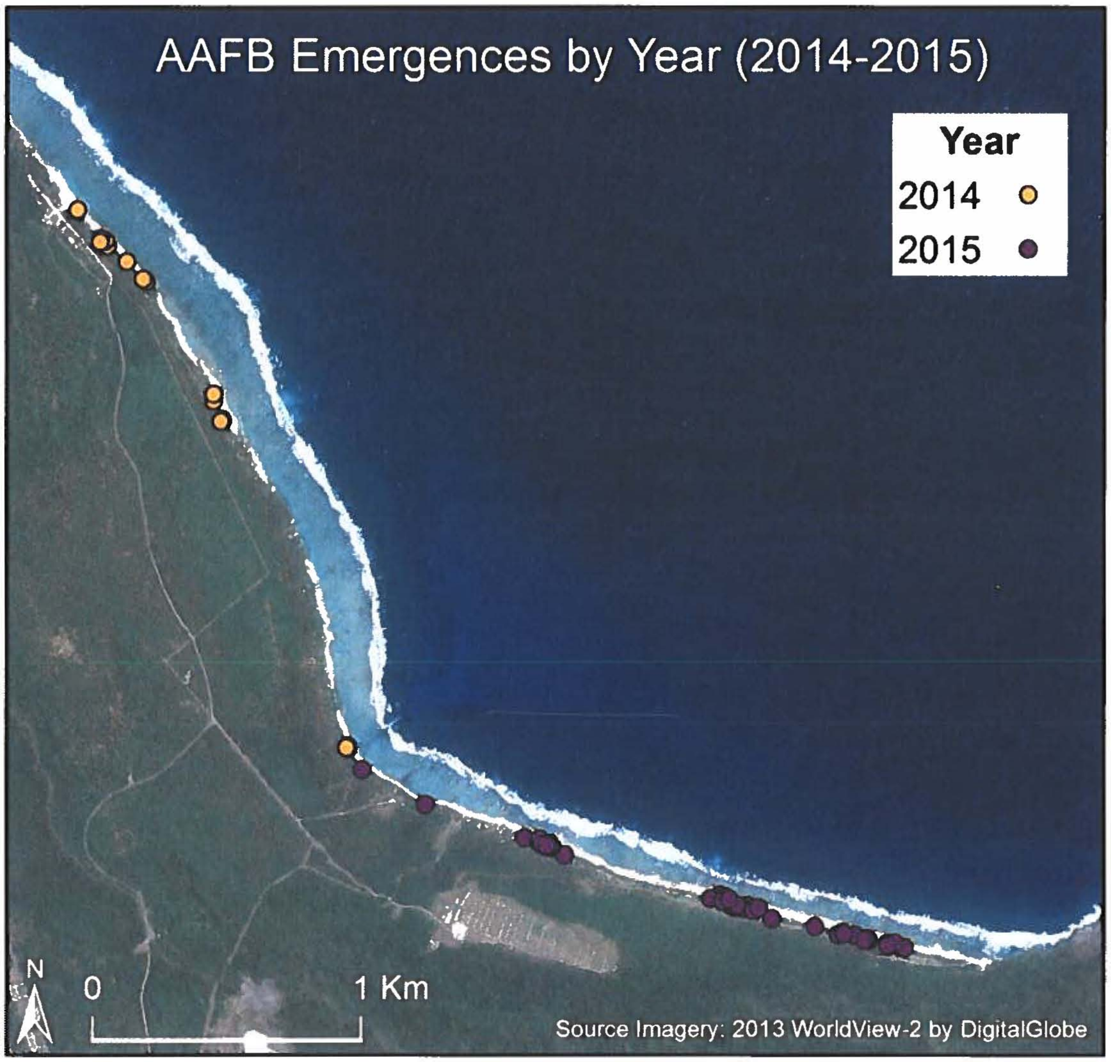

Figure 2. Map with the locations of all emergences on AAFB in 2014 (orange) and 2015 (purple).

4.1. Nesting Peak Season

The first emergence of the 2014 sea turtle nesting season was estimated to have been on February 18th, while the last emergence occurred on June 10th. The first emergence of the 2015 nesting season was on February 17th, while the last emergence took place on September 18th. There were no emergences in 2016 as of January 2016. The month with the greatest number of emergences in 2014 was April (n = 6). The month

4. RESULTS

During February 2014 to January 2016 study period, 1,164 surveys totaling over 628 hours of effort were made to record the nesting behavior of *C. mydas*. Eighteen emergences resulting in 15 green sea turtle nests were discovered on the beaches of AAFB in 2014, while 59 emergences resulting in 50 nests were discovered in 2015 (Figure 2). Although the length of the nesting season for each year differed greatly (4 months in 2014 versus 7 months in 2015), they both began in mid-February and represented the combined activity of at least five nesting females per year.

with the greatest number of emergences in 2015 was June (n=16) (Table 1, Figure 3). The month with the highest mean number of emergences during the study period was May ($\bar{X}$ = 9) (Figure 4).

Table 1. Number of emergences by month in 2014 (N=18), 2015 (N=59), and 2016 (N=0).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2014	-	2	4	6	5	1	0	0	0	0	0	0	**18**
2015	0	1	2	5	14	16	12	7	2	0	0	0	**59**
2016	0	-	-	-	-	-	-	-	-	-	-	-	**0**
Total	**0**	**3**	**6**	**11**	**19**	**17**	**12**	**7**	**2**	**0**	**0**	**0**	**77**

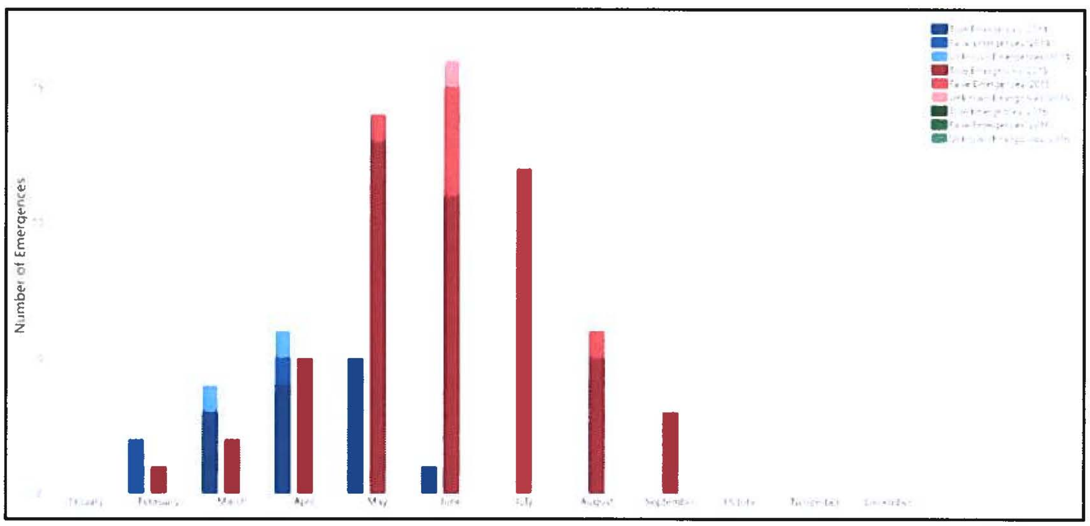

Figure 3. Total number of emergences in 2014 (blue, n=18), 2015 (red, n=59) and 2016 (green, n=0).

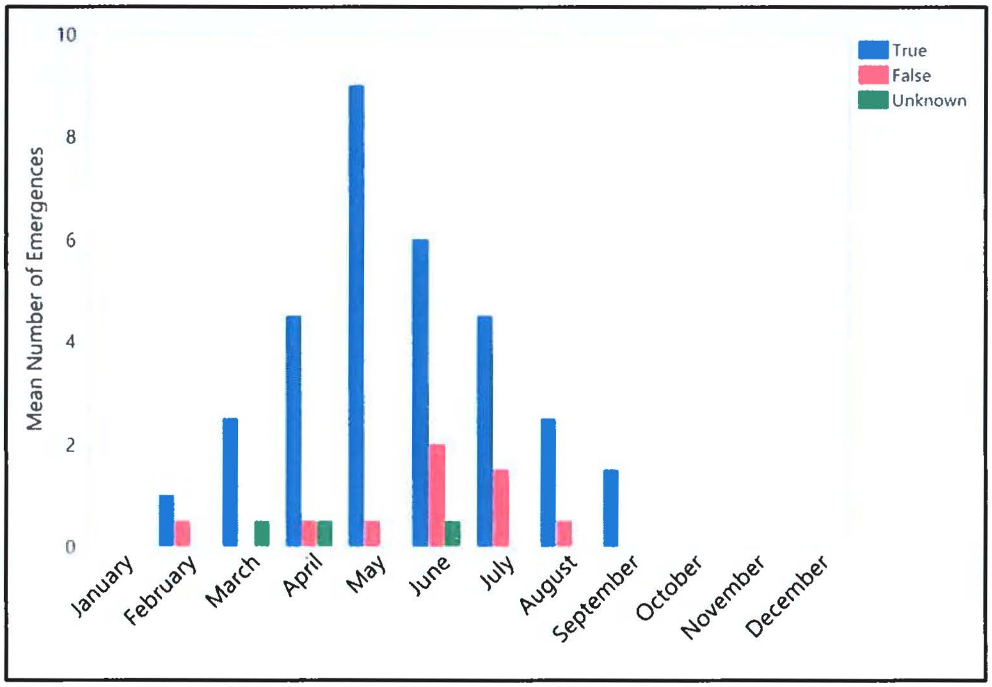

Figure 4. Mean number of emergences on the beaches of AAFB between February 2014 and January 2016.

4.2. Nesting Habitat Type

Of the 77 emergences encountered between February 2014 and January 2016, 64 were in habitat characterized as shoreline vegetation (Table 2, Figures 5, 6). The habitat with the highest percentage of false emergences was open beach habitat (40.0%, n=5). A one-way ANOVA revealed a significant relationship between nest habitat type and mean percent hatch success rate (p=0.0047), followed by a Tukey's post-hoc test. Open beach habitat had significantly lower hatch success rates than the beach forest (p=0.0032) and shoreline vegetation habitats (p=0.0084) (Figure 7).

A chi-squared test showed no relationship between emergence condition and habitat type (X^2 (N=77) = 4.462, p=0.35), however, the results of this test may not be reliable given the small sample sizes for beach forest (n= 8) and open beach (n=5).

Based on the results of a one-way ANOVA, clutch size did not vary significantly by habitat type (p=0.17), although the mean clutch sizes for beach forest and shoreline vegetation habitats were each greater than twice the mean of clutch sizes in open beach habitats (Figure 8). For each habitat type there were no significant differences between nest depths (one-way ANOVA, p=0.16).

Table 2. Number of emergences in each habitat type, by condition.

	True Nests	False Nests	Unknown	Total
Shoreline Vegetation	53	9	2	64
Open Beach	3	2	0	5
Beach Forest	8	0	0	8
Other	0	0	0	0
Total	64	11	2	77

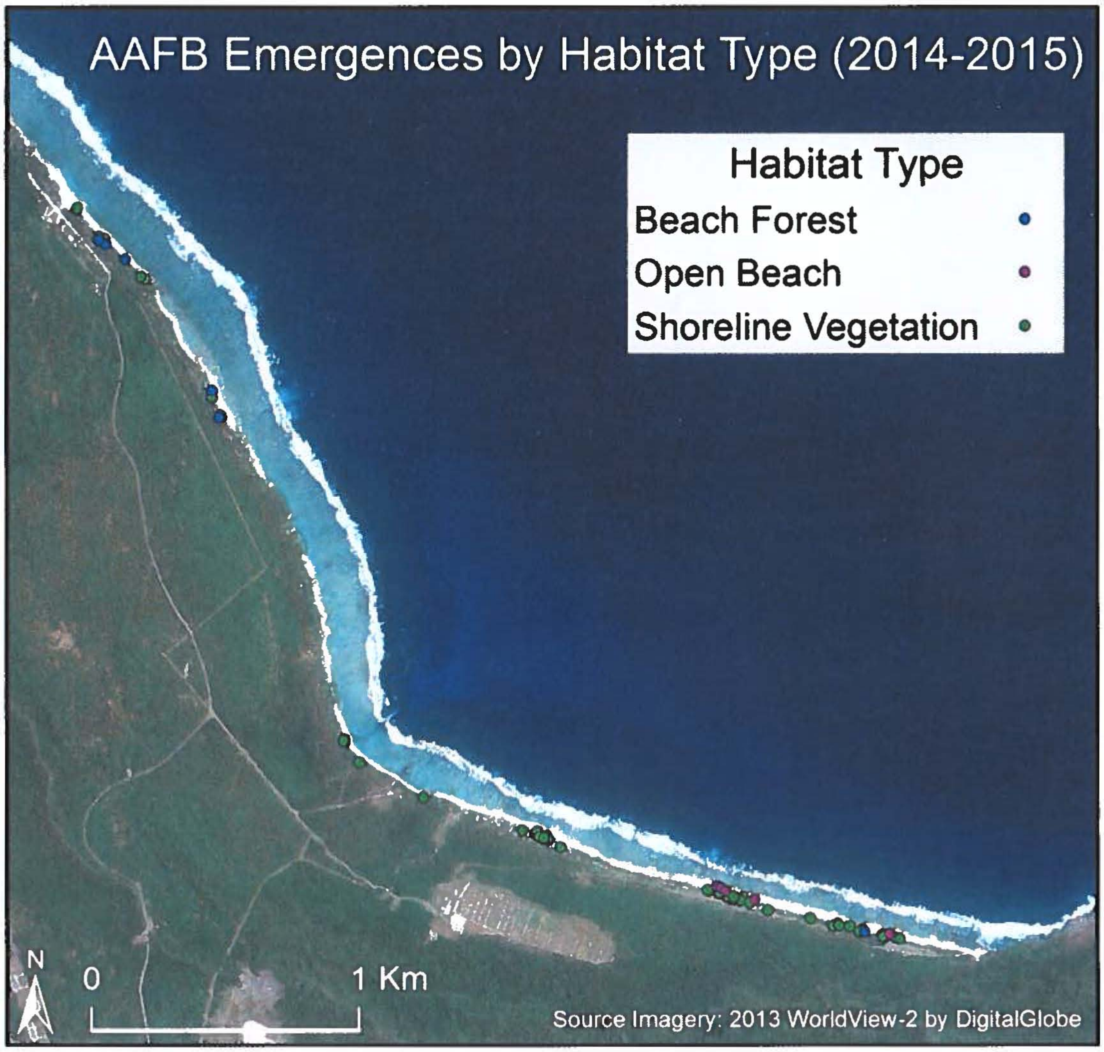

Figure 5. Map with the locations of all emergences on AAFB in 2014 and 2015, displayed by habitat type (beach forest = blue, open beach = purple, shoreline vegetation = green).

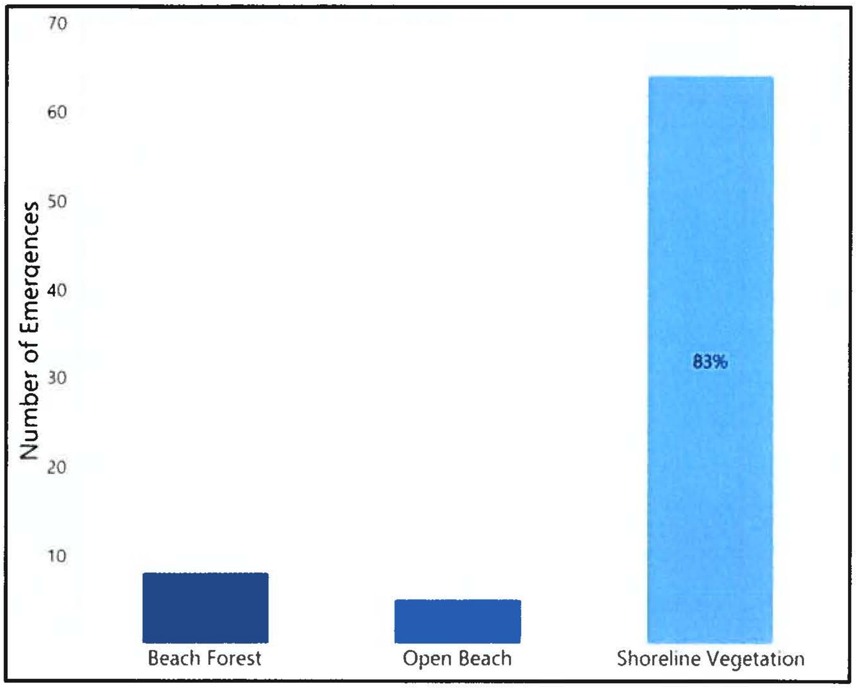

Figure 6. Number of emergences in each habitat type.

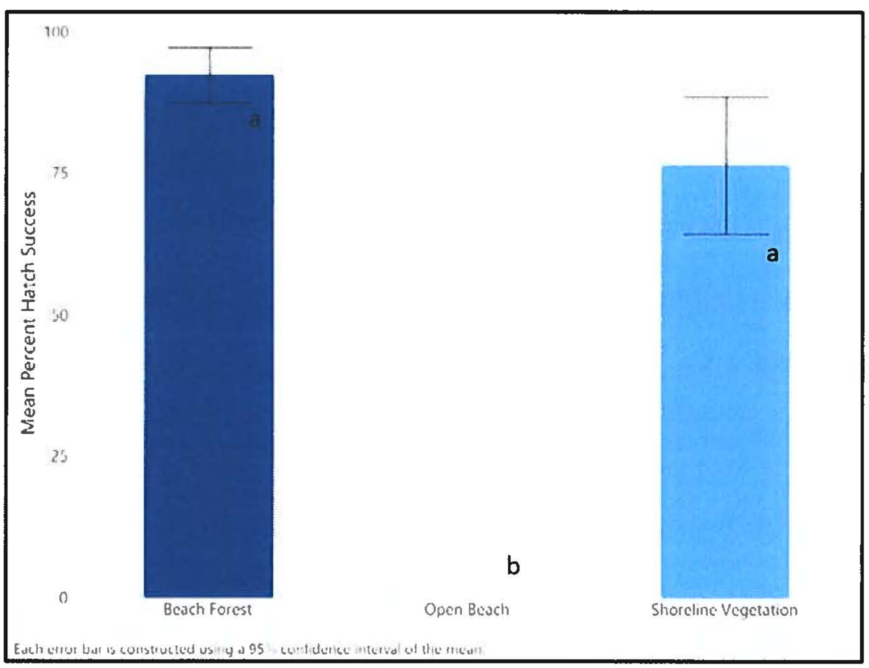

Figure 7. Mean percent hatch success by habitat type with confidence interval bars and connecting letters report.

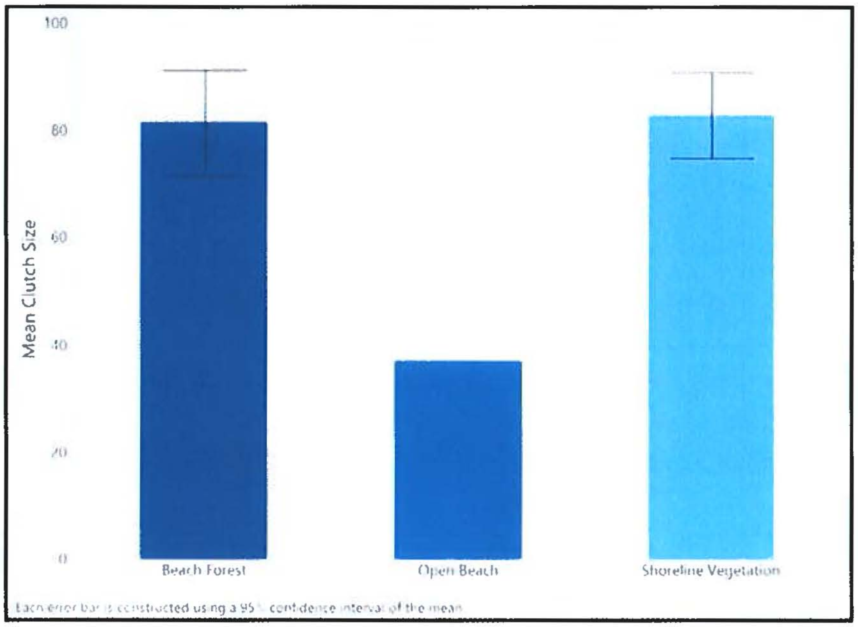

Figure 8. Mean clutch size of nests in each habitat type with confidence interval bars.

4.3. Nesting Spatial Patterns

The ArcGIS Nearest Neighbor spatial statistic tool determined that the emergences from the 2014-2016 study period were significantly clustered and not random or uniformly dispersed. The observed mean distance between emergences was 17.5139m, while the expected mean distance (given the study area) was 30.6483m. The index, or Nearest Neighbor Ratio, was 0.571449, $z = -7.194133$, and $p = 0.00$ (Figure 9).

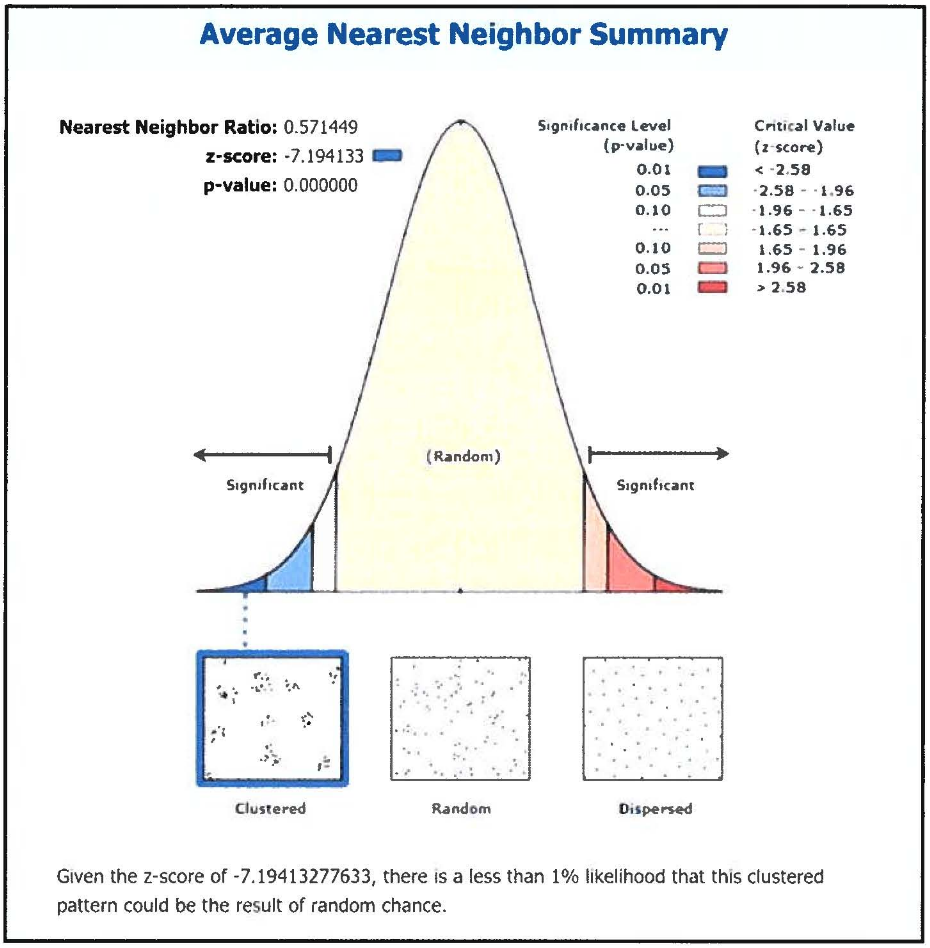

Figure 9. Average Nearest Neighbor analysis summary, showing nests laid on AAFB in 2014 and 2015 were significantly clustered (ArcGIS 10.2.2).

4.4. Hatching and Emergence Success

The mean of all hatching success data collected during the study period was 75.93% and the mean emergence success was 75.36%. There is a very strong correlation between emergence success and hatching success (R^2 of 0.998 and $p < 0.001$; linear regression, standard least squares) (Figure 10). Because of their strong correlation, only one variable (hatching success) was used to compare to other data.

The strongest association detected was the significant positive linear relationship between hatching success and track width ($Y=27.71+0.4505*X$, $R^2=0.042$, $p<0.001$)

(Figure 11). Hatching success was found to have little correlation with mean monthly precipitation (R^2=0.019, p=0.67) and maximum monthly precipitation (R^2=0.040, p=0.53).

As stated above, open beach habitat has a significant relationship with nest hatch success but this is negative with open beach nests having lower hatch success rates. Nest hatch success rate did not vary significantly by month (one-way ANOVA, p=0.49) (Figure 12).

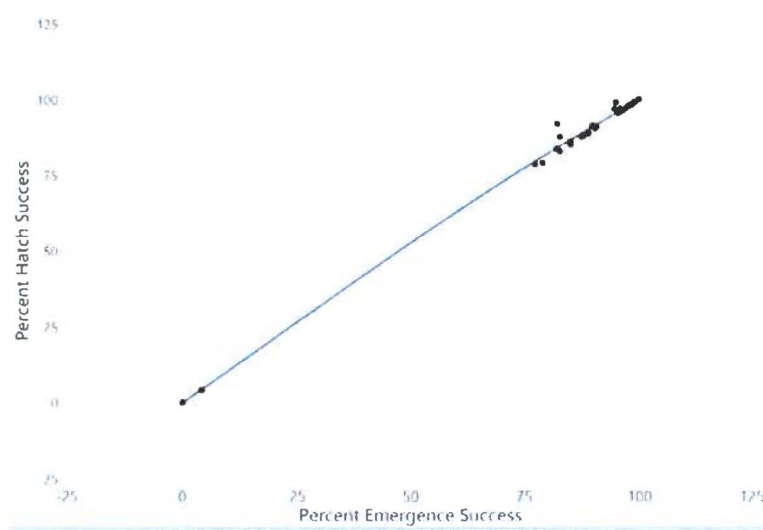

Figure 10. Linear regression model for percent emergence success rate by percent hatch success rate (R^2=0.998, p<0.001).

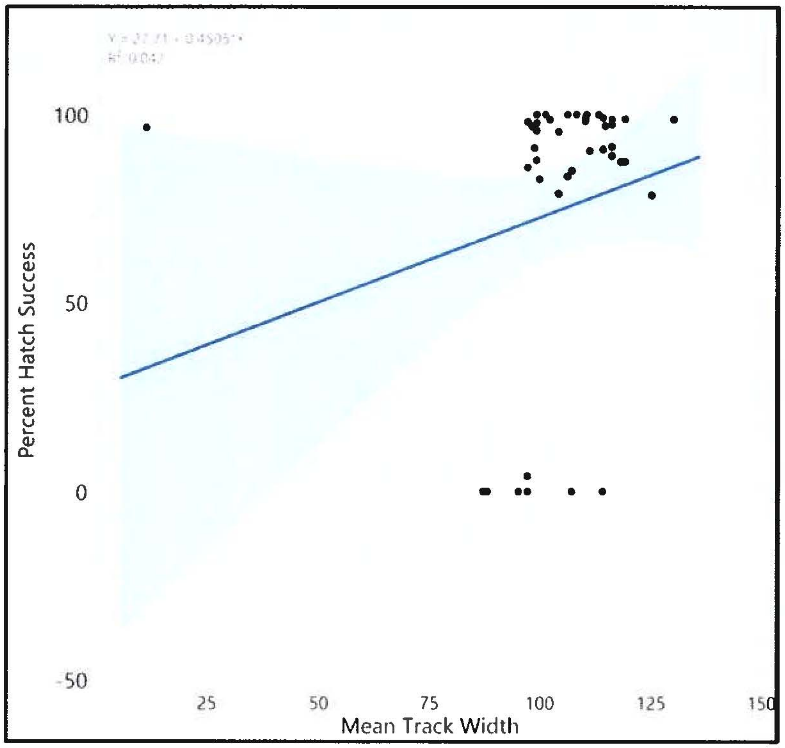

Figure 11. Percent hatch success rate versus average track width. Percent hatch success has a positive linear correlation to average track width ($Y=27.71+0.4505*X$, $R^2=0.0420$, $p<0.001$).

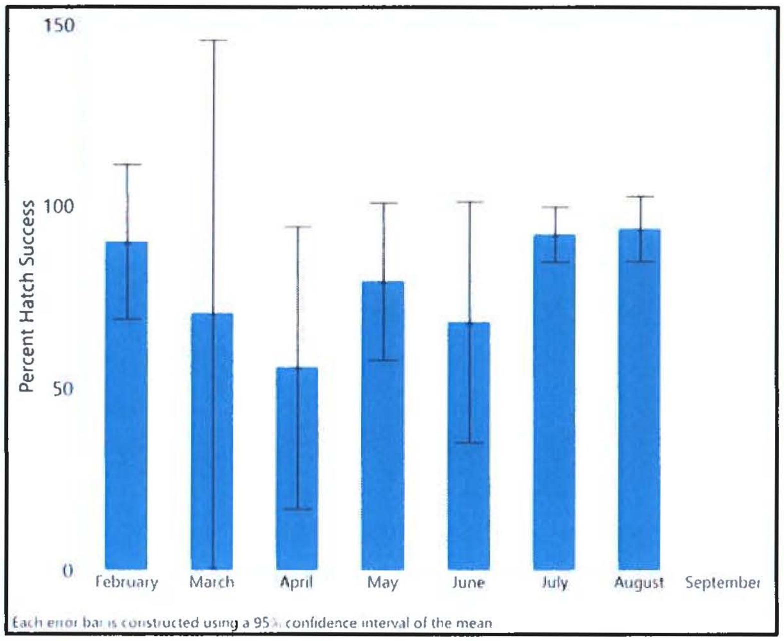

Figure 12. Mean percent hatching success rate by month when nest was laid, with confidence interval bars.

5. DISCUSSION

Because of sea turtle life history and the large annual variation of environmental conditions affecting sea turtle nests, long-term trends may not be detectable until 20-25 years of data has been collected (Chaloupka 2007). This study, however, was successful in meeting several goals of the CESU sea turtle project and laid a foundation upon which long-term monitoring and data analysis at AAFB can be built.

5.1. Nesting Peak Season

During the study period, all *C. mydas* nests were laid between February 17th and September 18th, with the highest mean number of nests occurring in May. In 2014, nesting season took place over approximately four months between February 18th and June 10th, with most emergences occurring in April. In 2015, nesting season took place over approximately seven months between February 17th and September 18th, with most emergences occurring in June. In 2016, there was no nesting in January. The difference in length of nesting seasons (almost doubling 2014 in 2015) is most likely attributed to sampling error in that there was lack of access to EOD Beach from February to October 2014. During 2015, all but two emergences took place on EOD Beach. This suggests that a large proportion of nests was most likely missed during the 2014 season. The AAFB nesting season between February and September closely matched that of a relatively nearby (690km) rookery of Ulithi Atoll, Yap State, FSM (Cruce 2008).

5.2. Nesting Habitat Type

Nesting females utilizing AAFB beaches during the study period favored nesting in shoreline vegetation habitat over open beach and beach forest habitats. While shoreline vegetation and open beach habitats are present throughout the AAFB embayment, beach forest habitat is limited to a short stretch of Scout Beach, located on the public half of the embayment. The mean width of the reef flat (the distance between the beach and reef crest) adjacent to the public beaches (Tarague, Scout, Sirena, and Pati) is approximately twice the distance (180m) as the mean width of the reef flat adjacent to EOD beach (90m), and may be partially responsible for beach (and therefore habitat) selection.

A significant correlation between open beach habitat and clutch size was not possible given the sample size of n=1. However, the one clutch size (37) in open beach habitat was considerably lower than the mean clutch sizes in the beach forest ($\overline{x}$=81.38) and shoreline vegetation ($\overline{x}$=81.65) habitats. More data from nests laid in open beach habitat would be needed to determine whether this result is a trend or an anomaly. Smaller clutch sizes are correlated with smaller carapace lengths of females (Broderick et al. 2003). Smaller carapace lengths may also be indicative of a younger nesting female, whose inexperience could lead to nesting in the open beach habitat closer to the high water mark.

Nests laid in open beach habitats were more likely to have lower hatching success rates. Because the open beach habitat is closer to the high water mark, nests laid in this habitat were more likely to be inundated by storm surge events or extreme high tides, thus increasing nest mortality and lowering hatching success. Because of the differences in mean distance to the high water mark of open beach nests (versus shoreline vegetation and beach forest nests), other parameters, such as distance from nest to high water mark, should be considered in the future to assess the true effect of habitat selection on incubating nests.

5.3. Nesting Spatial Patterns

The ArcGIS Nearest Neighbor spatial statistic tool confirmed that sea turtle nests laid on AAFB during the study period were significantly clustered. Clustering could be indicative of females showing a preference during nest-site selection, either towards habitat type or lighting conditions. It could also indicate avoidance of perceived threats such as predators, bright lights, or beach structures or barriers (Witherington et al., 2011). Several years of data may reveal other spatial constraints influencing sea turtle nest-site selection, such as beach access (i.e. nearshore bathymetry).

While not as certain a method as physically encountering a nesting female, inter-nesting intervals and mean track widths were used during this study to estimate the number of nesting females and predict which nest was laid by which female. From this imprecise data it was gleaned that females typically returned to nest in the same general area where they had already laid nests previously that season. In the future, more night surveys and tag-return data may reveal that nests are not only clustered relative to other nests but also relative to other nests laid by the same female.

5.4. Hatching and Emergence Success

The similarity between hatching and emergence success rates of nests successfully excavated during the study period can be attributed to a lack of nest damage by vegetation roots that can significantly impact the emergence success of hatchlings because of entanglement. In 2014, several nests on Cocos Island, Guam suffered lowered emergence success rates when hatchlings that had hatched successfully were then entangled in encroaching vegetation roots (K. Bonham, personal communication).

Biometric data from each nesting female was not collected because of limited resources during the duration of this study. During daytime shoreline surveys, however, several measurements of female track width were collected and averaged. While not as accurate as measuring a turtle (because of differences in sand composition, sand wetness, and weather conditions), average track widths were useful for distinguishing between turtles with larger body size differences (i.e. a 90cm width versus a 150cm width). Larger track widths may be correlated with high nest hatching success rates because larger, more experienced females have higher reproductive output (Broderick et al. 2003) and appear better at selecting sites that are more successful for incubation compared to smaller, younger females.

5.5. Weather Considerations

Prior to 2015, Guam had not experienced typhoon-force winds since super typhoon Pongsona in December, 2002. During the 2015 nesting season, however, the beaches of AAFB were altered significantly by three large storms that passed near or over Guam (Typhoon Dolphin in May, Tropical Storm Bavi in March, and Tropical Storm Chan-hom in July). The width of open beach (between vegetation at the top of the beach and the high water mark) was changed drastically, and even doubled in many places, after storm surge removed vegetation closest to the high water mark. Sea turtles that emerged after these storm events, however, crawled further from the water to nest in the shoreline vegetation habitat. This suggests that habitat type has a greater influence in nest-site selection than distance from the high water mark.

In an effort to quantify storm effects for comparison with nesting data, weather and oceanographic variable data (i.e. monthly maximum and mean precipitation, wave height, and sea surface temperature) were gathered from the NOAA National Weather Service, AAFB, and the Pacific Islands Ocean Observing System (PacIOOS) wave buoys deployed in the waters around Guam. Large gaps in the buoy wave data (presumably due to the storms) during the months with storm activity hindered these efforts, however. Sea surface temperature appeared constant throughout the study period, and although varied, monthly maximum and mean precipitation had little correlation to nest success. Impacts from weather and oceanographic variables may be more apparent if mean values are obtained strictly from the length of incubation period for each nest rather than estimated from lay dates. For this study, it was not possible to detect hatching events for many of the nests, even with game cameras, because of either survey frequency or weather conditions; almost all signs of hatch activity typically faded away within 24 hours on account of the beaches' exposure to windward conditions. Without specific hatch dates it was impossible to estimate incubation periods of each nest and relate them to weather variables.

5.6. Conclusion

With this 24-month study I was able to determine that female sea turtles emerged 77 times on AAFB and nested 64 times, that AAFB appears to have a sea turtle nesting season that peaks in May, that the habitat a female nests in could impact the hatching success of those eggs, that an unknown mechanism is driving females to nest in clustered spatial patterns, and that larger females produce nests with higher nest hatching success rates. The results of this study are important as a baseline assessment of sea turtle nesting on AAFB, however, additional data spanning many years will be necessary to support these findings. A long-term dataset could not only be used to help answer important questions about local and regional sea turtle biology, but it could also be used by resource managers charged with contributing to the recovery of this endangered species.

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