GENETIC ANALYSIS, MOVEMENT, AND NESTING PATTERNS OF THE GREEN SEA TURTLE (*CHELONIA MYDAS*) IN ST. CROIX, VIRGIN ISLANDS (USA): A REGIONAL ANALYSIS FOR THE CARIBBEAN

by

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GENETIC ANALYSIS, MOVEMENT, AND NESTING PATTERNS OF THE GREEN SEA TURTLE (*CHELONIA MYDAS*) IN ST. CROIX, VIRGIN ISLANDS (USA): A REGIONAL ANALYSIS FOR THE CARIBBEAN

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DEDICATION

This thesis is dedicated to my parents, Terry and Julie Schultz, who have done so much for me over the years and who continue to motivate and support me every day. Without their help I would be nowhere near the person I am today. Thank you for everything mom and dad!
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ABSTRACT

The green sea turtle *Chelonia mydas* is listed as endangered by the IUCN Red List of 2004. The Endangered Species Act now classifies the green turtle species into 11 distinct population segments (DPSs) with most segments being classified as threatened and only three (Mediterranean, Central West Pacific, and Central South Pacific) being listed as endangered. More information needs to be obtained about the foraging, nesting, and movement behaviors of the different green turtle rookeries worldwide to implement the best management practices. The main purpose of this study was to track internesting and post-nesting movements, categorize the benthic habitat types utilized during these periods, identify the dominant genetic haplotype, and provide summary statistics of female green sea turtles nesting on the East End beaches, including the beaches within Jack, Isaac, and East End Bays, of St. Croix, US Virgin Islands.

Seven Wildlife Computers™ SPOT-352A platform transmitter terminals (PTTs) were attached to female green sea turtles on the East End beaches of St. Croix in August and October 2015. The females were tracked using the Satellite Tracking and Analysis Tool (STAT) on seaturtle.org and movement patterns were mapped. Kernel density estimation (KDE) was utilized to calculate 50% core use and 95% activity areas during their internesting and post-nesting periods. Minimum convex polygons (MCPs) were created when KDE could not be completed. Habitat utilization was identified in the core use areas and MCPs. Tissue biopsies were collected from 60 nesting female green turtles on the East End beaches from 2012-2015. The ~820-bp mtDNA control region was sequenced to identify the haplotypes present within this rookery. Summary statistics were calculated for nesting data collected on the East End beaches from 2003-2015 to identify
some of the life history characteristics of the green turtle rookery on the East End beaches. Recommendations were provided for better ways to conduct long-term nesting surveys with uniformity, so that population estimation models can be applied.

Female green turtles were tracked between 16-241 d (mean=160.9±10.6) for a total of 1,126 PTT days transmitted before analyses were conducted. Kernel density estimation and a MCP could not be created when less than ten detections of the highest location class were received. Three females were residents of the waters around St. Croix, remaining within the same areas during both their internesting and post-nesting periods. Three females were classified as migrants as two transitioned to the waters near St. Kitts and Nevis during their post-nesting periods and one moved to the waters to the northwest of Vieques. The haplotypes identified on the East End beaches of St. Croix were CmA3.1, CmA5.1, and CmA5.2. The haplotype CmA5.1 was most common (91.4%, n=58). The average number of green sea turtle nests was 263.9±53.5 between 2003 and 2015. The mean clutch size was 107.9±3.4 eggs with an average hatching success of 86.7±2.0%. Nesting survey effort varied greatly over the survey period, which limited the power of the data collected.

The major finding of this study was that there are resident and migrant green turtles on the East End beaches of St. Croix. The dominant haplotype on the East End beaches was identified as CmA5.1. While a population estimation was not able to be calculated from the nesting beach monitoring data, significant knowledge was gained about the large rookery present on East End beaches, which will allow conservation managers to evaluate other ways to protect this population. Future researchers should utilize additional satellite transmitters equipped with depth recorders to monitor dive
profiles of both male and female green turtles throughout the Caribbean. Additional
genetic analyses should be conducted on the East End beach rookery to adequately
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Chapter 1: Using satellite telemetry to describe the internesting and post-nesting movement patterns and habitat utilization of female green sea turtles, *Chelonia mydas*, from the East End beaches of St. Croix, USVI
The green sea turtle, *Chelonia mydas*, is one of seven sea turtle species and lives in tropical and subtropical waters worldwide (Broderick and Godley, 1999). It is listed as threatened by the Endangered Species Act (1973) and endangered by the IUCN Red List of Threatened Species (2004). *Chelonia mydas* has a long maturation period, reaching sexual maturation between 20 and 50 y of age (Purnama et al., 2013). Although some researchers have found that females can produce clutches as early as 15-19 y after being released from the Cayman Turtle Farm (Bell et al., 2005). Frazer and Ehrhart (1985) used the von Bertalanffy and logistic models to estimate the maturation age between 18-27 y and 26-33 y, respectively. This long maturation time leaves these turtles vulnerable to several threats in the water at all life stages. Green turtle populations are also in danger because their nesting and foraging habitats are disappearing. Poaching and invasive species are other major concerns for conservation managers working to increase sea turtle populations around the world. It is estimated that only one in 1000 hatchlings survive to adulthood (TNC, 2011).

Once sea turtles reach the age of sexual maturation they return to the waters near where they were hatched to breed and nest, a phenomenon known as natal homing (Carr, 1967). Signals from the magnetic fields surrounding the Earth are believed to work in conjunction with other homing mechanisms to allow these animals to find their way back to near the same beach where they were born (Benhamou et al., 2011). Female green sea turtles are believed to use circular search patterns along with wind and current patterns to locate these beaches (Åkesson et al., 2003). They continue to return to these same waters to breed every few years. Male and female green turtles breed every one to four years.
depending on their location (Carr, 1964; Åkesson et al., 2003; Wright et al., 2012). The number of years between nesting seasons is referred to as the remigration interval (Alvarado and Murphy, 1999).

The internesting period is the time period between the first and last clutch laid by a female in a single nesting season (Sato et al., 1998). The number of days between the laying of one clutch and the laying of the next successive clutch is referred to as the internesting interval (Sato et al., 1998). The average green sea turtle internesting interval was 12.6±2.9 d (n=38) in July on Huyong Island, Thailand (Yasuda et al., 2006). The mean interval on Melbourne Beach, Florida was 12.9±1.59 d (n=165) (Johnson and Ehrhart, 1996). During the internesting period, female green turtles remained relatively close to their nesting beaches of Poilão, Guinea-Bissau (Godley et al., 2010); Rekawa Sanctuary, coast of Sri Lanka (Richardson et al., 2013); and Ascension Island (Hays et al., 1999). About 80% (n=7) of females spent their internesting period within an 80 km range of their nesting beach on Poilão, Guinea-Bissau (Godley et al., 2010). Females on Ascension Island had internesting ranges of approximately 0.7-2.4 km² (Witt et al., 2010) and spent significantly more time submerged during their internesting period than during migration (Hays et al., 1999). The average dive was 22.1 min during internesting periods and only 7.3 min during migration (Hays et al., 1999). This finding indicated that green turtle females primarily rest and do not move very long distances during their internesting period (Hays et al., 1999). It is hypothesized that female green sea turtles travel to foraging grounds in other areas after they have completed nesting because food is typically not abundant near the breeding and nesting sites (Hays et al., 2002c; Read et al., 2014). The remigration and internesting intervals of nesting female sea turtles have been
well studied using mark and recapture studies on important turtle nesting beaches (Yasuda et al., 2006; Wright et al., 2012).

Historically, flipper and PIT (passive integrated transponder) tags have been the most widely utilized tools to study the movement patterns of sea turtles. Long-term movement patterns of numerous individuals and the establishment of population estimates have been made possible with the use of flipper tags (Read et al., 2014). One potential disadvantage of flipper tags is that their short serial numbers are replicated; therefore, it is vital to ensure that sea turtle researchers on nearby beaches do not utilize the same series (Balazs, 1999). PIT tags, however, each have unique 10-digit ID numbers that are not duplicated by the manufacturers (Balazs, 1999). While PIT tags are unlikely to be lost because they are inserted into the turtle, they often do not provide as much data because a specialized scanner is needed to identify the ID number (Balazs, 1999). Flipper tags are clamped on externally and can be recorded by anyone who sees the turtle, but these tags have a much higher likelihood of detachment than PIT tags (Balazs, 1999). The major disadvantage of both of these tags is that the turtle must be physically captured or located on the beach after the initial tag attachment to confirm its actual location. This greatly limits the amount of information that can be gained from these tags because detecting locations in the open ocean is nearly impossible resulting in data generally only being collected when the turtles are on land.

Satellite telemetry is a more modern method of tracking the movement patterns of sea turtles and is becoming more widely utilized. The type of platform transmitter terminal (PTT) used can vary, but common models include:

Sirtrack™ (Yasuda et al., 2006; Rees et al., 2013; Richardson et al., 2013)
These PTTs can be programmed to send sorted data to satellites at specified time intervals. Fastloc® technology is now able to find locations within milliseconds with integrated GPS-like capabilities, making it more accurate than the Argos-based PTTs (Witt et al., 2010; Weber et al., 2013). However, the Fastloc transmitters are approximately three times as expensive as typical Argos transmitters. This additional cost can significantly reduce the sampling size if investigators have budget constraints. There are also additional costs for transmitting satellite data for both the Argos-based and Fastloc PTTs (Maxwell et al., 2011). Argos-based PTTs are the best tool for collecting the largest amount of sea turtle satellite movement data when project funding is limited.

Most investigators retrieve sea turtle tracking data using the Argos system and analyze it using the Satellite Tracking and Analysis Tool (STAT) on seaturtle.org (Godley et al., 2010; Rees et al., 2013; Richardson et al., 2013) along with the software program R and ArcGIS® 10.2 (ESRI, 2013) (Scott et al., 2012; Hart et al., 2014). Data can be retrieved directly from Argos through use of their Telnet network; however, only the last nine days of data are downloadable (Coyne and Godley, 2005). STAT is a web-based system that automatically downloads the data from the Telnet network and converts it to Generic Mapping Tools (GMT) grid format (Coyne and Godley, 2005). Editing options available on STAT allow users to filter data for maximum speed (calculated based on the distance between two consecutive points), Argos location class, and turning angle (Coyne and Godley, 2005). According to the Argos User’s Manual (2015) the location classes are ranked 3>2>1>0>A>B. The most accurate classes are 3 (<
250 m), 2 (250-500 m), and 1 (500-1500 m) (Hays et al., 1999 and Argos User’s Manual, 2015). Class 0 has an estimated error of < 1500 m and location classes A and B have unknown accuracy levels (Hays et al., 1999 and Argos User’s Manual, 2015). Hoener et al. (2012) found the 68th percentile spatial errors of location classes 0, A, and B to be 4.15, 10.19, and 9.24 km, respectively. The finalized, edited data from STAT can be downloaded in comma separated values (CSV) standard file format (Coyne and Godley, 2005). Mapping of the data can either be accomplished through the use of the Maptool on seaturtle.org or with other mapping software (Coyne and Godley, 2005). All maps created on seaturtle.org can be shared publicly or kept private (Coyne and Godley, 2005). The goal of seaturtle.org and STAT is to further the collaboration of researchers utilizing satellite telemetry to conduct their work (Coyne and Godley, 2005).

The biggest limitation of PTTs is that they can gather much more data than the capacity of the bandwidth needed to transfer the data (Hatase et al., 2006). Only 256 bits per message can be transmitted with the Argos system (Hays et al., 2007). Environmental conditions such as cloud coverage or waves can also block signal (Shillinger et al., 2012). PTTs can only send a successful signal when they are within range of satellites (Patterson and Hartmann, 2011). The PTTs are typically within the visibility range of a satellite for only about ten minutes during each pass and the number of satellite passes per day can vary with the location of the PTT (Argos User’s Manual, 2015). A PTT can also only send transmission signals when the antenna is above the surface of the water. The salt-water switch enables the PTT to register when it is in a “dry” state and able to send a signal (Wildlife Computers™, pers. comm.) If the salt-water switch malfunctions, then the PTT may continuously register a “wet” state and consequently, will never attempt to send
a signal, or in contrast will continuously register a “dry” state and will persistently attempt to send a transmission, which will severely limit the battery life (Hays et al., 2007). Typically, highly accurate locations are retrieved only when six or more signals are sent to the same satellite within a single pass (Ballorain et al., 2013). In an attempt to alleviate these issues, PTTs send the same signal multiple times (Patterson and Hartmann, 2011). Wildlife Computers™ (pers. comm.) recommends having the PTTs transmitting constantly when tracking sea turtles because of the diving behavior and short surface intervals of the turtles. Battery life also limits the length of time over which data can be collected (Patterson and Hartmann, 2011).

The adhesion process for PTTs requires several steps to ensure secure attachment. The PTTs are typically attached to the highest part of the carapace with marine-grade epoxy after any bio-fouling is removed (Hazel et al., 2013; Richardson et al., 2013). The epoxy is often smoothed to create a streamlined shape and to reduce the amount of frictional drag and/or the risk of entanglement (Hays et al., 2003). Loss of PTTs is one of the major drawbacks to using telemetry (Godley et al., 2010). PTTs can be lost and stop sending signals a few hours after the turtle is released (Godley et al., 2003). Scute shedding is thought to be one of the causes of PTT loss (Hazel et al., 2013). Wire and screws can be used to attach the PTTs by drilling into the shell of the turtle; however, ethical considerations regarding the value of the data collected versus the possible harm to the animal should be considered when utilizing this approach (Hazel et al., 2013). Salt-water switch failure and broken antennae are other issues associated with PTTs (Hays et al., 2007). A broken antenna may decrease the effectiveness of the signal sent by the PTT and result in an increase in incomplete messages (Hays et al., 2007). Godley et al. (2002)
suggest that attaching the PTT so that the antenna is facing the posterior end of the turtle gives it more structural protection if the antenna becomes bent. Use of anti-foulant paint around the switch is suggested as a method of decreasing the likelihood of salt-water switch malfunction; however, the paint cannot be directly applied to the switch (Hays et al., 2007). Ensuring proper adhesion of the PTTs is difficult, but vital for obtaining the most data from each PTT.

Satellite telemetry has allowed the in-water movements of sea turtles to be tracked, which has precipitated the discovery of novel life history characteristics of sea turtles from certain nesting beaches, especially in the wider Caribbean (Figure 1.1). The Wider Caribbean Region is defined as the marine environment of the Caribbean Sea, the Gulf of Mexico, and sections of the Atlantic Ocean south of 30° N latitude and within 200 nmi (370.4 km) of the Atlantic coasts of the states mentioned in article 25 of the UNEP (1983). The Wider Caribbean Region extends from as far north as Florida to as far south and east as French Guyana on the North Coast of South America. Green turtles in the Caribbean do not always make long-distance migrations from their nesting to foraging grounds as shown by Esteban et al. (2015). Two of the three female greens tracked from Zeelandia Beach, St. Eustatius remained within five and 47.3 km of their release site after being tracked for a total of 42 and 237 d, respectively (Esteban et al., 2015). This is believed to be the first documented case of green sea turtles in the Caribbean not migrating more than 50 km from their nesting grounds to forage (Esteban et al., 2015). One of the turtles tracked by Esteban et al. (2015) migrated to foraging grounds near El Macao, Dominican Republic, 606 km straight-line distance from her tagging location. All seven female green turtles tracked from their nesting beach in the
Cayman Islands migrated to foraging grounds ranging from 520-856 km straight-line distance from their nesting beach while being tracked for 67-281 d (Blumenthal et al., 2006). While there appears to be some dissimilarity in the movement patterns of female green turtles tracked in previous studies, all have remained within the Wider Caribbean Region for the duration of their tracking period. Not many satellite telemetry studies have been conducted on green turtles nesting in the eastern Caribbean and there is a need for more data regarding the movement patterns of both female and male greens once they leave the waters near the nesting beaches.

Satellite telemetry has helped scientists identify long-distance movement patterns of many sea turtle species. Identifying other analysis methods for Argos-based satellite tracking data has allowed researchers to gain more knowledge about the green turtle population than just the movement of individual turtles. One such analysis tool is kernel density estimation (KDE), which identifies areas of higher concentrations within larger utilized areas and is helpful when analyzing home range data (Worton, 1989). Home range or activity area is represented by 95% kernel density estimation (KDE) and core use area is denoted by 50% KDE (Schofield et al., 2010; Rees et al., 2013; Hart et al., 2014). Minimum convex polygons (MCPs), or the smallest polygons created from all points of movements of an animal, can also be used to estimate the size of the activity area of an animal when KDE cannot be performed on the data (Broderick et al., 2007; Hart et al., 2014).

Identifying where green turtles are moving during their internesting period and after the nesting season will give conservation managers information that can help them prioritize which environments should be protected in addition to the nesting beaches.
Determining the benthic habitats types in the core use or MCP areas of the satellite tracked green turtles will allow for identification of common habitat types being utilized by individuals of the green turtle population. Marine environments utilized by turtles during their internesting periods provide protection and possibly a food source between clutch laying (Hart et al., 2010). Benthic habitat mapping of the area utilized during the internesting period can provide insight to the types of benthic habitat types that are typically found in such areas (Hart et al., 2010). Locations of other ideal foraging habitats for green turtles may also be able to be identified using benthic habitat mapping.

Benthic habitat mapping was performed in 1999 for the waters around the US Virgin Islands and Puerto Rico utilizing visual analysis of aerial photos with the Habitat Digitizer in ArcView 3.1 (Kendall et al., 2001). Ground truthing revealed that this method was 93.6% accurate at detecting all habitat types and 100% accurate at detecting submerged vegetation (Kendall et al., 2001). The definitions of the habitat types were:

Seagrass classified as any area with 10% or more coverage of *Thalassia testudinum*, *Syringodium filiforme*, *Halodule wrightii*, or *Halophila baillonis* (Figure 1.2).

Macroalgae classified as any habitat with 10% or greater cover by red, green, or brown macroalgae (Figure 1.3).

Colonized pavement classified as flat rock covered by hard coral, macroalgae, or other sessile invertebrates (Figure 1.4).

Colonized pavement with sand channels classified as colonized pavement with alternating sand sections that are perpendicular to the shore (Figure 1.5).
Sandy areas classified as coarse sediment typical of high wave energy areas (Figure 1.6) (Kendall et al., 2001).

Benthic habitat mapping was also conducted near St. Kitts and Nevis in 2010 (Schill et al., 2011). Imagery from the IKONOS and QuickBird satellites, as well as transects with an underwater video camera were used in conjunction to produce the habitat maps for these areas (Schill et al., 2011). The definitions of the habitat types were:

Dense seagrass defined as greater than 50% coverage by *Thalassia testudinum* and *Syringodium filiforme* (Figure 1.7).

Sparse seagrass defined as sand areas with less than 50% seagrass cover (Figure 1.8).

*Acropora palmata* stumps defined as vast fields of mostly dead *Acropora palmata* coral (Figure 1.9) (Schill et al., 2011).

The number of nesting green sea turtles on the End East beaches of St. Croix, USVI, including the beaches within Jack, Isaac, and East End Bays (Figure 1.10) has increased greatly over the last few decades (Mackay, 2011). This increase in rookery size coupled with the lack of knowledge about the internesting and post-nesting movement behaviors of females from these nesting beaches provided justification for this study. The null hypotheses for this study were that the tracked females would remain within the Wider Caribbean Region (as shown in Figure 1.1) and that the majority of the dominant benthic habitat type would not differ in either the internesting or post-nesting periods.
MATERIALS AND METHODS

Researchers patrolled the East End beaches during August and October 2015 starting at approximately 20:00 in search of nesting female green turtles. Flipper tags were applied to the right front and rear left flipper of each untagged female located on the beach. A PIT (passive integrated transponder) tag was inserted into the left shoulder if the female was still in a trance-like state during the egg-laying process. A PIT tag was not inserted if the female was not located during the nest laying process. Triangulation of the nest location was performed and a wooden popsicle stick labeled with the date and flipper tag number of the female was placed in the nest if the nest chamber was still visible. The curved carapace width (CCW) and length (CCL), mating scars, and locations of any epibionts were recorded for each female following the nesting beach monitoring protocol of The Nature Conservancy (TNC). Only when the females had concluded nesting or had completed their false crawl and were heading back towards the water were they guided into a wooden corral (Figure 1.1). The second carapace scute of each turtle was scrubbed with 80-grit wet/dry sandpaper in multiple directions while saltwater was poured over the carapace. Ninety percent alcohol was poured over the attachment area and then wiped with paper towels until completely dry following the procedures by Hays et al. (2001) and Hart et al. (2012) to remove any substances that would prevent proper adhesion. Approximately 25 g of the SuperBond™ epoxy resin and 25 g of the SuperBond™ fast curing agent were vigorously mixed for three min. Electrical tape was used to cover the wet/dry sensors of the PTT during the attachment process to prevent accidental application of epoxy onto these sensors. Epoxy was applied to both the carapace and the underside of the PTT before the PTT was pressed down onto the
carapace with the antennae facing towards the rear of the animal as recommended by Godley et al. (2002). The remaining epoxy was concentrated around the sides of the PTT to create a more hydrodynamic shape as per Hays et al. (2003). Once the epoxy was dry and hardened enough so that a fingernail could not dent it (approximately one h), the wooden corral was removed and the female was released. Time and all tag information were recorded for each turtle (Table 1.1).

Seven Wildlife Computers™ SPOT-352A platform transmitter terminals (PTTs) were attached to green sea turtle females (see Appendix B-H) on the East End beaches of St. Croix, USVI, including the beaches within Jack, Isaac, and East End Bays (Figure 1.12). The PTTs constantly transmitted for 16-241 d, depending on the date of attachment and PTT signal termination. Five of the transmitters continued to transmit after data were collected for analyses for this study. Attaching the PTTs throughout the nesting season allowed for females to be tagged at different stages of nesting. The intention was to get a haphazard sample of the females nesting on the East End beaches. The time between attachments also allowed the attachment procedure to be reevaluation if signals from PTTs were lost before attachment on other females, as happened to Samantha (#146260) only 16 d after attachment. Rates available through the Joint Tariff Agreement were utilized to minimize the cost of satellite data transmission. The SPOT-352A PTTs were equipped with salt-water switches to conserve battery power, allowing the PTTs to shut off while the turtles were below the surface of the water (SPOT6 Users Guide, 2015). The PTTs were tested on land prior to attachment to ensure proper function, location orientation, and correct data delivery, as recommended by Argos and Wildlife Computers™ (pers. comm.).
The satellite data were collected using the Argos system with Kalman filtering. This filtering uses an algorithm that provides more accurate location class estimations than the previous least-squares location processing method utilized by Argos (Lopez et al., 2014). The Kalman filtering algorithm is now the default Argos data processing method and is likely to become the standard for satellite telemetry data analyses (Silva et al., 2014). The Satellite Tracking and Analysis Tool (STAT) on www.seaturtle.org was used to filter the location data (Coyne and Godley, 2005). Locations representing speeds of more than five kph, locations on land, and locations very spatially different (greater than 120 km) from the last valid location were removed following Godley et al. (2003), Hart et al. (2010), and Revuelta et al. (2015). Maps of the tracks of each of the turtles were available for the public to view on www.seaturtle.org following each attachment. More intensive filtering, sorting, and mapping of the telemetry data was conducted using Microsoft Excel, MATLAB R2015B, Geospatial Modeling Environment (GME) 0.7.4, and ArcGIS® 10.2 (ESRI, 2013). The best location, according to location class (ranked 3>2>1>0>A>B), from each day was selected as representative of the general location of each turtle on that day for mapping purposes following recommendations of Witt et al. (2010) and Richardson et al. (2013). When all of the location classes for a given day were the same, the first location from that day was selected for mapping purposes to maintain consistency. Locations that were obviously on land were removed, excluded from the analysis, and the next best location for that day was utilized following Esteban et al. (2015).

The movements of the tracked female turtles were divided into internesting, transition, and post-nesting periods and mapped accordingly using ArcGIS® 10.2 (ESRI, 2013). The Satellite Tracking and Analysis Tool (STAT) on www.seaturtle.org was used to filter the location data (Coyne and Godley, 2005). Locations representing speeds of more than five kph, locations on land, and locations very spatially different (greater than 120 km) from the last valid location were removed following Godley et al. (2003), Hart et al. (2010), and Revuelta et al. (2015). Maps of the tracks of each of the turtles were available for the public to view on www.seaturtle.org following each attachment. More intensive filtering, sorting, and mapping of the telemetry data was conducted using Microsoft Excel, MATLAB R2015B, Geospatial Modeling Environment (GME) 0.7.4, and ArcGIS® 10.2 (ESRI, 2013). The best location, according to location class (ranked 3>2>1>0>A>B), from each day was selected as representative of the general location of each turtle on that day for mapping purposes following recommendations of Witt et al. (2010) and Richardson et al. (2013). When all of the location classes for a given day were the same, the first location from that day was selected for mapping purposes to maintain consistency. Locations that were obviously on land were removed, excluded from the analysis, and the next best location for that day was utilized following Esteban et al. (2015).

The movements of the tracked female turtles were divided into internesting, transition, and post-nesting periods and mapped accordingly using ArcGIS® 10.2 (ESRI,
The internesting period was defined by the transmission of the highest location classes (3, 2, and 1), the apparent position of these locations near land, and the coincidence of the time interval between these transmissions with a reasonable internesting period (less than 14 d) per the methods from Tucker (2010), Maxwell et al. (2011), and Revuelta et al. (2015). The transition period was defined as 14 d directly following the last inferred nesting event. The post-nesting period began directly after the transition period ended and lasted for the remainder of the tracking duration. Satellite telemetry data utilized for the analyses in this study were collected until 28 March 2016. It should be noted that five PTTs continued to transmit after this date.

Kernel density estimation (KDE) was performed for both the internesting and post-nesting period utilizing the highest LCs (3, 2, and 1) following Rees et al. (2013). KDE was only calculated when there were >20 daily locations following Shillinger et al. (2010), Hoenner et al. (2012), and Hart et al. (2013). The 50% KDE represented the core use area and the 95% KDE describes the activity area for each turtle as defined by Schofield et al. (2010). The area within both the 50% core use and 95% activity areas was calculated for each female (Table 1.2). Minimum convex polygons (MCP) were created for turtles with 10-20 locations of LCs 3, 2, and 1 following Hart et al. (2014).

Benthic habitat maps obtained from Kendall et al. (2001) and Schill et al. (2011) were used to identify the major habitat type utilized during the internesting and post-nesting periods of these females. It should be noted that dense seagrass and sparse seagrass are individually classified by Schill et al. (2011), whereas the presence of 10% of more seagrass species is simply described as seagrass by Kendall et al. (2001). The dominant habitat type utilized for each turtle was determined to be the benthic habitat...
type that had the greatest percentage occupation within the core use areas or MCPs (if KDE could not be calculated for reasons described above). Land was removed from core use area during these analyses since the inclusion of land in the core use area of the turtles was likely a result of Argos LC errors. When benthic habitat mapping data were not available for the entire core use area or MCP, the habitat type for the unavailable sections were identified as unknown.

Based on movement patterns, females were defined as resident or migrant turtles. Resident females were identified as those that utilized the same areas during both their internesting and post-nesting periods following methods of Richardson et al. (2013). Migrant females were described as those that moved away from the waters that they occupied during their internesting period.

RESULTS

A total of 1,126 PTT days were received from the seven satellite tagged female green turtles in the current study. The female turtles were tracked between 16-241 d (mean=160.9±10.6 d) for a total of 12,941 PTT location detections transmitted before analyses were conducted (Table 1.3). Five of the PTTs continued transmitting after 28 March 2016 when the data were downloaded for analysis. All tracked turtles remained within the Wider Caribbean Region for the entire tracking duration. A combined movement map of all satellite-tracked turtles is displayed in Figure 1.13.

The PTT for Samantha (#146260) stopped transmitting after 16 d. Her movements before the signal ceased are showed in Figure 1.14. Core use area, activity area, and MCP
were not calculated for Samantha (#146260) because she did not have enough high LC detection locations before the PTT stopped transmitting.

Three of the tracked females, Savannah (#146259), Dionne (#146261), and Emily (#153482) utilized the same areas around St. Croix during both their internesting and post-nesting periods (Figure 1.13) and have all remained in the waters directly surrounding St. Croix after being tracked for 241, 237, and 157 d, respectively (Figures 1.15-1.17). Savannah (#146259) and Dionne (#146261) moved back and forth between the East End and southwest parts of the island during their internesting periods (Figures 1.18-1.19). The 50% core use area sizes of the internesting movements of Savannah (#146259) and Dionne (#146261) were 11.5 and 9.7 km² and their activity area sizes were 93.4 and 112 km², respectively (Figures 1.20-1.21). The dominant benthic habitat types within the internesting core use area of Savannah (#146259) and Dionne (#146261) were colonized pavement and seagrass, respectively (Figures 1.22-1.23). Dionne appears to have nested on the west end of St. Croix at Sandy Point National Wildlife Refuge during this time. Emily (#153482) remained in the waters closer to the East End during her internesting period (Figure 1.24) and had an internesting MCP size of 5.4 km² (Figure 1.25) that was dominated by seagrass (Figure 1.26). Savannah (#146259) and Dionne (#146261) no longer transmitted data indicative of nesting after 39 d and 65 d, respectively, which indicated that their transition periods had begun (Table 1.4) (Figures 1.27-1.28). Emily returned to the same area she utilized during her internesting period, just to the northeast of St. Croix, during her transition period (Figure 1.29). Savannah (#146259) and Dionne (#146261) had post-nesting areas in the waters on the southwest end of St. Croix (Figures 1.30-1.31), whereas Emily (#153482) stayed in the waters just
to the northeast of St. Croix (Figure 1.32). The 50% core use area sizes of the post-nesting movements of Savannah (#146259) and Dionne (#146261) were 4.8 and 7.6 km$^2$ and their activity area sizes were 20.3 and 20.5 km$^2$, respectively (Figures 1.33-1.34). The overwhelmingly dominant (86.1% and 96.9%, respectively) habitat type of the post-nesting areas of Savannah (#146259) and Dionne (#146261) was seagrass (Figures 1.35-1.36). Kernel density estimation and MCP analyses could not be conducted for the post-nesting period of Emily due to an insufficient number of high LCs. All three of these resident turtles remained in the same post-nesting areas until data were retrieved for analysis after 187, 158, and 119 d, respectively.

One tracked female, Victoria (#146262), remained within the waters closer to the East End beaches during her internesting period (Figure 1.37), but then transitioned approximately 120 km straight-line distance to the northwest of St. Croix to what appeared to be her foraging grounds near the waters on the northwest side of Vieques (Figures 1.38-1.39). The 50% core use area size of the internesting movements of Victoria (#146262) was 4.4 km$^2$ and her activity area size was 19.2 km$^2$ (Figure 1.40). The dominant benthic habitat type of her internesting period was colonized pavement (Figure 1.41). Victoria (#146262) remained in the waters near Vieques for 159 d until her PTT stopped transmitting (Figure 1.42). The 50% core use area size of the post-nesting movements of Victoria (#146262) was 5.6 km$^2$ and her activity area size was 21 km$^2$ (Figure 1.43). The predominant (98.3%) benthic habitat type of her post-nesting area was seagrass (Figure 1.44).

Another female, Annette (#146263), was satellite tagged on the East End of St. Croix, but did not lay a nest on the night of PTT attachment; however, it was assumed
that she nested on the East End beaches one day after PTT deployment. Annette then moved throughout the waters to the East of St. Croix (Figure 1.45) and appears to have nested on two different islands, including Antigua and St. Kitts, based on satellite telemetry data (Table 1.5). The large movements made by Annette (#146263) during her internesting period (Figure 1.46) resulted in her having a vastly larger internesting MCP area than all of the other females tracked in this study (52,923.9 km$^2$) (Figure 1.47). Annette (#146263) traveled to the southeast and eventually circled around to the waters around Nevis where she remained just over 200 km straight-line distance from her tagging location (Figure 1.48). Cheryl (#146264) nested on St. Croix on the same night of PTT attachment, but had no satellite transmissions indicative of nesting after that date. She transitioned directly to the waters near Nevis after PTT deployment (Figure 1.49). This may have been because Cheryl (#146264) was tagged later in the nesting season (23 October 2015). For this reason the movement patterns and benthic habitat utilization during her internesting period could not be identified. Cheryl (#146264) traveled in a direct route to the southeast approximately 200 km straight-line distance to the waters surrounding Nevis (Figure 1.50). Annette (#146263) and Cheryl (#146264) both remained near the waters surrounding Nevis during their post-nesting period having both been tracked for a total of 158 d (Figures 1.51-1.52). Annette (#146263) had a post-nesting MCP area of 1.5 km$^2$ (Figure 1.53), which was predominately (57.0%) dense seagrass (Figure 1.54). The 50% core use area and 95% activity area size of the post-nesting movements of Cheryl (#146264) were 4.0 km$^2$ and 14.5 km$^2$, respectively (Figure 1.55). The main benthic habitat type within the post-nesting core use area was dominated
(68.7%) by sand (Figure 1.56). Both turtles continued to transmit after analyses were conducted.

The three turtles (Dionne, Emily, and Savannah) that remained within the same waters surrounding St. Croix during both their internesting and post-nesting periods were identified as residents (Table 1.6). The three females (Annette, Cheryl, and Victoria) that moved away from St. Croix during their post-nesting period were defined as migrants. There was no statistically significant difference between resident and migrant females and their carapace measurements (CCL and CCW) with p-values of 0.91 and 0.97, respectively. Four neophytes were tagged in this study meaning the female was identified and tagged for the first time with no signs of previous tagging, such as a flipper scar (Table 1.6). Three remigrants were also tracked within this study meaning that these females had been previously tagged with a flipper or PIT tag.

The average 50% core use size during the internesting period for female turtles tracked in this study was 8.5±1.2 km². The internesting core use area sizes of female green satellite tracked from the East End beaches ranged from 4.4-11.5 km². The size of the 95% activity area during the internesting period ranged from 19.2-112 km² with a mean size of 74.9±16.4 km². The internesting MCP size ranged from 5.4-52,923.9 km². The two dominant habitat types utilized by these tracked females during their internesting periods were seagrass and colonized pavement (Figure 1.57; Table 1.7).

The average 50% core use size during the post-nesting period for female turtles tracked in this study was 5.5±0.5 km². The post-nesting core use area sizes of female green satellite tracked from the East End beaches ranged from 4.0-7.6 km². The size of the 95% activity area during the post-nesting period ranged from 14.5-21.0 km² with a
mean of $19.1 \pm 1.0$ km$^2$. The post-nesting MCP size ranged from 1.5-9.3 km$^2$. The majority (five out of six) of the dominant habitat type utilized during their post-nesting periods was seagrass or dense seagrass, dependent on which benthic habitat descriptions were utilized for analysis (Kendall et al., 1999; Schill et al., 2011) (Figure 1.58; Table 1.7).

DISCUSSION

The major finding of the current study was that there are resident and migrant female green turtles within the nesting rookery on the East End beaches of St. Croix. Some females remained in the waters directly surrounding St. Croix, whereas others moved to foraging grounds in other parts of the Caribbean. One female tracked within this study also nested on two beaches other than her original tagging location, providing evidence against the natal homing hypothesis. The findings of this study supported the hypothesis that tracked female green turtles remained within the Wider Caribbean Region. The dominant benthic habitat types utilized during the internesting periods were seagrass and colonized pavement, while seagrass was most dominantly utilized during the post-nesting periods.

The movement patterns identified in this study differ from the widely believed hypothesis that green turtles travel long distances between their nesting and foraging grounds. The turtles tracked in the current study do not demonstrate vastly large (>250 km) movements after nesting as observed by female green sea turtles that have nested in other parts of the world, such as on Ascension Island where turtles have been recorded as traveling over 2,000 km to their foraging grounds off the coast of Brazil (Hays et al.,
2002c). Green turtle foraging grounds have not been identified around Ascension Island; this is hypothesized as the reason turtles migrate so far from the nesting beach (Hays et al., 2002c). The green sea turtles nesting on Ascension Island have low body mass during their internesting period and gut content analyses provided evidence that they do not feed during this period (Hays et al., 2002a). Whereas it appears that the resident turtles of St. Croix may be foraging during their internesting periods as it was identified in this study that they utilized the same areas during both their internesting and post-nesting (foraging) periods. The benthic habitat analyses from the present study indicated that the resident females were utilizing seagrass beds and areas covered with macroalgae (colonized pavement) during their internesting periods (Figure 1.57). Use of PTTs with depth recorders in future satellite telemetry studies from the East End beaches may help to clarify this hypothesis by analyzing dive profiles of these animals during their internesting periods. Resident females tracked during this study traveled no more than 28 km straight-line distance away from their nesting beach on the East End of St. Croix. Similar results were found when Esteban et al. (2015) tracked two female green turtles moving no greater than 50 km away from their nesting beach on St. Eustatius. However, one green turtle tracked by Esteban et al. (2015) traveled 606 km straight-line distance from her nesting beach and was identified as a migrant breeder. All three green turtles tracked from their nesting beach on St. Eustatius settled in foraging grounds in St. Eustatius, St. Kitts, and Dominican Republic with shallow (10-25 m) seagrass beds (Esteban et al., 2015). Behavioral plasticity may exist in the movement patterns of female green sea turtles after the nesting season. This hypothesis is further supported by satellite telemetry studies of female green turtles nesting on the island of Poilão, Guinea-Bissau.
and identification of movements of over 1,000 km from their nesting to foraging grounds. However, some turtles remained within the Bijagos archipelago and were believed to have local residency in that area (Godley et al., 2010).

Three main behavior patterns described for green sea turtles released from Ceará, Brazil were: residency with high site-fidelity, medium-range movements (<100 km), and long-range movements (>100 km) (Godley et al., 2003). Three of the turtles (Dionne, Emily, and Savannah) tracked in the current study would be classified by the above described characteristics as having residency with high site fidelity, whereas the other three (Annette, Cheryl, and Victoria) would be described as displaying long-range movements. Female green turtles satellite tracked from their nesting beach in the Rekawa Sanctuary in Sri Lanka also demonstrated similar types of movement patterns to those observed in the present study (Richardson et al., 2013). Seven of the ten females moved to foraging sites over 300 km away from their nesting beach in Sri Lanka, whereas the other three utilized the same areas during both their internesting and post-nesting periods (Richardson et al., 2013). The turtles that remained within the same waters for foraging as they utilized during their internesting period were referred to as resident breeders (Richardson et al., 2013). Some female green turtles nesting on the East End beaches of St. Croix appear to forage in areas of seagrass beds near their nesting beach after the nesting season; whereas, others travel long distances (up to 250 km straight-line distance) possibly in search of other food sources. The majority of the dominant benthic habitat type utilized during the post-nesting period was seagrass or dense seagrass. It is likely that some turtles remained in the waters directly surrounding St. Croix as food resources are plentiful in the waters to the south and northeast of St. Croix (Figure 1.59). The areas
to the northwest of St. Croix are generally characterized by a short shelf (approximately 500 m) followed by a steep wall face. Green sea turtles typically do not utilize these areas as seagrass beds are not predominant there (Lewis, pers. comm.). Seagrass beds are, however, prevalent in the waters surrounding the island of Vieques (Figure 1.60). The waters surrounding Nevis also have large areas of seagrass beds and algae covered areas (Figure 1.61). The habitat availability of seagrass beds in certain areas may be the reason for the observed movement patterns of the tracked female green turtles within this study. The seagrass habitats surrounding St. Croix likely are not large enough to sustain the entire East End beach rookery, resulting in migration of some females to foraging grounds in other parts of the Caribbean.

It is hypothesized that female greens that do not migrate far from their nesting grounds to forage may have shorter remigration intervals (time between successive nesting seasons) because these females may not expend as much energy transitioning to their foraging grounds (Esteban et al., 2015). However, a female green sea turtle satellite tagged in the Cayman Islands was documented nesting in two consecutive years after moving to her foraging grounds in Guatemala, 855 km away (Blumenthal et al., 2006), indicating that some females may still make long migrations between nesting and foraging grounds and continue to have short remigration intervals. Turtles tagged in this study may be able to provide data to test this hypothesis in the future dependent upon PTT attachment, battery life, and movement patterns of each of the females.

One female tracked within this study nested on two beaches other than her original tagging location, providing evidence against the natal homing hypothesis. Annette (#146263) nested on St. Croix, Antigua, and St. Kitts before transitioning to her
foraging grounds near Nevis (Table 1.5). Evidence against the natal homing hypothesis within the Caribbean region also was documented by Esteban et al. (2015). Green turtles tracked from St. Eustatius were identified nesting on other islands up to 21.8 km away from their tagging location (Esteban et al., 2015). The close proximity of islands within the Caribbean may be a possible explanation for this behavior and gives support against the natal homing hypothesis within the Caribbean. The mean internesting interval for female green turtles tracked in the current study was 10.3±0.09 d. This average is consistent with female green turtles on St. Eustatius with internesting intervals ranging from 9-13 d (Esteban et al., 2015) and the mean interval on Huyong Island, Thailand being 12.6±2.9d (n=38) (Yasuda et al., 2006).

While there is evidence against the natal homing hypothesis, green turtles have shown high fidelity to their foraging grounds (Balazs, 1976; Broderick et al., 2007). Locations referred to as post-nesting in this current study may be labeled as foraging grounds following the classification used by Stokes et al. (2015), which identified foraging sites as fixed areas where satellite tracked turtles remained for greater than 27 d. All turtles in the current study demonstrated site fidelity and remained within the same foraging grounds that they initially traveled to for a range of 88-187 d (Table 1.4). The tracked females that nested on the East End beaches of St. Croix did not travel only to other areas throughout the Caribbean to forage, but some also remained in the waters directly surrounding St. Croix during the non-breeding and non-nesting seasons. This information is critical to conservation managers as it demonstrates the necessity to not only protect known sea turtle nesting beaches, but also conserve areas that are likely
foraging grounds. Since sea turtles show high fidelity to foraging grounds these areas can be identified as key habitats imperative to sea turtle conservation (Broderick et al., 2007).

The female green turtles tracked in the current study had relatively the same sized core and activity areas of female green sea turtle in previous studies; however, the extent of these areas may largely be variable based on habitat availability in different parts of the world. The mean sizes of the internesting core and activity areas within this current study were 8.5 and 74.9 km$^2$, respectively. A female nesting on Qaru Island, Kuwait had an internesting core use area of 3.8 km$^2$ (Rees et al., 2013). Hypothetically, green turtles do not forage during the internesting period (Hays et al., 2002a). Therefore, their movement during this time may not be limited by the size of the seagrass beds, whereas it likely restricts their movement during foraging. This provides evidence for why the mean sizes of the post-nesting core and activity areas (5.5 and 19.1 km$^2$, respectively) were smaller than those of the internesting core and activity areas (8.5 and 74.9 km$^2$, respectively) for the females tracked within this current study (Table 1.2). Three female greens that were satellite tracked by Rees et al. (2013) from Kuwait had a post-nesting core use and activity area smaller than 15 km$^2$ and 80.0 km$^2$, respectively. While the activity area of the females tracked in this study from the East End beaches of St. Croix were small in comparison to the 80.0 km$^2$ area from the female tracked from Kuwait, this may be a factor of the size of the foraging area (seagrass availability) within these different areas. A male green turtle was tracked traveling 691.9 km in what was believed to be his foraging ground in the East Pacific (Hart et al., 2015). Such a large foraging area was hypothesized to exist due to the lower food densities present in that region of the Pacific (Hart et al., 2015). However, such a large foraging area when compared to that of
females may also be indicative of sex-based differences in habitat utilization or food preference, but more satellite telemetry studies tracking male green turtles are needed to test these hypotheses.

Green sea turtles typically forage on *Thalassia testudinum* as well as some other species of seagrass and algae (Bjorndal, 1997). The majority of the dominant benthic habitat type identified during the post-nesting period of turtles tracked in the current study was seagrass. Godley et al. (2003) suggests that home range size may vary based on the main diet component of green turtles, with those having more algae-dominant diets having larger home ranges. The waters surrounding St. Croix, Nevis, and Vieques are more predominately covered with seagrass beds in areas that the tracked turtles utilized; therefore, this may be the reason that the turtles in this current study had slightly smaller home ranges than green turtles tracked in other parts of the world. The current study reveals a need for additional benthic habitat mapping throughout the Caribbean to identify critical habitat utilization areas, such as areas of large seagrass beds or large amounts of macroalgae. Protection of these foraging grounds is necessary as these areas are utilized by the turtles for the majority of their adult lives. Current sea turtle conservation efforts are mainly focused on monitoring sea turtle nesting habitats; however, vital marine environments also are crucial for protecting this species.

Identification of dominant habitat type becomes more critical when long-term site fidelity can be determined from specific animal movements. Successful long-term PTT attachment is important so that the largest amount of data can be collected during each satellite telemetry study. There is no explanation for why data stopped transmitting from the PTT on Samantha (#146260) after only 16 d in this study. It was hypothesized that
sand caught between the epoxy and PTT during the attachment process may have resulted in a weak attachment. Other possible causes of signal loss included broken antennae, scute shedding, saltwater switch failure, or PTT malfunction (Hays et al., 2007; Hazel et al., 2013). This early PTT detachment illustrated why all seven PTTs were not attached at the same time in this study. Project managers wanted to evaluate and where necessary, improve the attachment process before deploying all transmitters to minimize equipment loss.

Sea turtle researchers have utilized switching state-space modeling (SSM) to explicitly determine the start and end of internesting and foraging periods when analyzing satellite telemetry data (Jonsen et al., 2005; Hart et al., 2014). State-space modeling simulates the movements of each individual turtle utilizing errors specified by the Argos location classes with Markov Chain Monte Carlo (MCMC) in WinBUGS using the software program R (Jonsen et al., 2005; Hart et al., 2014). Switch state-space modeling could be utilized to support the classification of the internesting and post-nesting periods in the present study; however, because some turtles remained in the same regions during their internesting and post-nesting periods there may be an issue distinguishing these areas from one another as SSM determines its classification based on distance. Use of SSM may also be troublesome when females are utilizing nesting beaches that are separated by more than a few km, as was seen in the movements of Annette (#146263) in the present study (Figure 1.46). Utilization of SSM is also recommended by Maxwell et al. (2011) in combination with typical Argos data, when funding for Fastloc GPS transmitters is not available. Fastloc transmitters that are not retrieved are still limited by bandwidth for the amount of data that they are able to send over the Argos system.
(Maxwell et al., 2011). Argos-based locations with improved data filtering techniques are sufficient for interpreting large-scale movements of sea turtles (Witt et al., 2010). The large power requirements and shorter lifespans of the Fastloc transmitters do not currently make them any better than the Argos-based transmitters at tracking sea turtle movements (Witt et al., 2010). However, the combination of new satellite telemetry analysis methods as well as more accurate PTTs have allowed for the expansion of knowledge of sea turtle movements.

The most vital step when conducting a satellite telemetry study is ensuring a secure PTT attachment so that data can be collected for the entire lifespan of the PTT battery and so that the PTT does not prematurely detach. It is recommended that future researchers utilize an adjustable wooden corral as done in this current study when attaching a PTT on the beach. It is important that the corral is configured so as to confine each turtle as much as possible to avoid injury to the turtle and researchers, as well as ensure a secure attachment of the PTT. When some turtles in this study were not confined sufficiently in the corral, they were able to move their flippers, which resulted in the throwing of sand making the PTT application process more difficult. The more the turtles are able to move their flippers, the greater chance of personnel injury, as well. The wooden corral utilized in this study was adjustable and could change from 1.22-1.83 m on each side. A diagram with specific recommended dimensions for a wooden corral to confine an adult green sea turtle is included in Figure 1.11. Specialized corral dimensions should be utilized depending on the average adult size of the turtle species being confined. It is also recommended to cut handles into each section of the corral for easier handling while maneuvering the corral around the beach. Also, a confined turtle should
be given time (approximately five min) to settle down after it is captured before the adhesion process begins. This will help prevent sand from being flung onto the attachment site once the epoxy application begins. After the attachment process is complete, it is vital to remove the corral carefully and allow the turtle to find its way back to the water.

Different types of epoxies are recommended for use of transmitter attachment on different sea turtle species due to the unique compositions of the carapaces. Examples of other types of epoxies used are Sonic Weld™ (Ed Greene and Company; Sparta, Tennessee) and Fast Foil™ (Power Fasteners, Inc.; New Rochelle, NY) for Caretta caretta (Arendt et al., 2012); Foilfast (SFS Stadler, Cheltenham, UK) for Chelonia mydas (Godley et al., 2003); and Sika Anchorfix 3 (Lyndhurst NJ, USA) for Lepidochelys olivacea (Maxwell et al., 2011). It is vital to ensure that the epoxy utilized for attachment does not heat up too much as this can harm the turtle and may change the natural behavior of the turtle after release. The curing time is also an important aspect to keep in mind, as it is best to confine the turtle for as little time as possible, while still ensuring a secure attachment. The two-part epoxy (SuperBond™) used in this study had low heat activation and only took an hour to set. The type of epoxy utilized, the specific attachment protocols, and the type of PTT used can all impact the longevity of the PTT transmission (see Appendix Y).

The length of the PTT duration directly coincides with the amount of information that is gathered. This is very critical especially when small samples sizes are being utilized, which is often the case in satellite telemetry studies. Of course the small study size may limit the power of the findings, but when funding is limited, satellite tracking a
small number of individuals can still provide valuable insight on the movement patterns of females from specific nesting beaches. More than 40 tracked turtles are needed to draw conclusions about the movement patterns of turtles from a specific rookery (Shofield et al., 2013). Future studies should involve the satellite tracking of more female greens from East End beaches, as well as the satellite tracking of male greens from the mating grounds in the waters around St. Croix. Identification of male movement patterns after breeding would provide information about where and how these animals forage and if the post-breeding movements of males is different than that of female greens. Other researchers may utilize PTTs equipped with depth recorders to investigate diving behavior of these animals as well. Additional, more up-to-date benthic habitat mapping and ground truthing around St. Croix would also be helpful in identifying possible foraging grounds of these animals. Future studies should also incorporate a greater number of PTTs in order to enlarge the sample size and get a broader sense of many of the foraging areas that females that nest on the East End beaches of St. Croix are utilizing.

The use of seaturtle.org to map sea turtle movements all around the world and view them in one place has helped raise awareness and funds for sea turtle research worldwide. Individuals can “adopt a turtle” which helps to raise funds for the satellite telemetry costs and also gives people a reason to care about these animals and the marine environment that the turtles live in. Knowledge gained from satellite telemetry studies can help conservation managers determine where areas of protection need to be created for these animals. The coupling of satellite telemetry with other information (such as benthic habitat mapping) will enable future researchers to identify specific marine
environments being utilized by the species that are being tracked. Novel findings, such as the identification of different movement patterns of the green sea turtles, will help conservation managers better understand the extent of habitat that these turtles are utilizing. Protecting marine environments that are critical habitats for the green sea turtle species can be difficult because sea turtles cross international boundaries and can make it tough to manage one specific rookery. International cooperation will be required to help reestablish the population of green sea turtles all around the world.
LITERATURE CITED


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The Nature Conservancy’s St. Croix sea turtle monitoring and protection plan. 2011.


Table 1.1. PTT, flipper tag, and PIT tag information for seven female green sea turtles, *Chelonia mydas*, tagged on the East End beaches of St. Croix, USVI. Deployment release information for each individual female turtle. Carapace length (CCL) was measured notch to tip.

<table>
<thead>
<tr>
<th>Turtle name</th>
<th>PTT number</th>
<th>Carapace length (cm)</th>
<th>PIT tag number</th>
<th>RFF tag number</th>
<th>LRF tag number</th>
<th>PTT deployment date</th>
<th>Time of release</th>
<th>Deployment location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savannah</td>
<td>#146259</td>
<td>115.5</td>
<td>AVID<em>076</em>321*559</td>
<td>LLC237</td>
<td>LLC134</td>
<td>8/1/2015</td>
<td>0026</td>
<td>St. Croix</td>
</tr>
<tr>
<td>Samantha</td>
<td>#146260</td>
<td>118.5</td>
<td>AVID<em>076</em>299*058</td>
<td>LLC014</td>
<td>LLC015</td>
<td>8/4/2015</td>
<td>0005</td>
<td>St. Croix</td>
</tr>
<tr>
<td>Dionne</td>
<td>#146261</td>
<td>105.4</td>
<td>None - no lay</td>
<td>EEF314</td>
<td>EEF315</td>
<td>8/4/2015</td>
<td>2327</td>
<td>St. Croix</td>
</tr>
<tr>
<td>Victoria</td>
<td>#146262</td>
<td>110.7</td>
<td>None - no lay</td>
<td>LLC016</td>
<td>LLC017</td>
<td>8/5/2015</td>
<td>2310</td>
<td>St. Croix</td>
</tr>
<tr>
<td>Annette</td>
<td>#146263</td>
<td>115.2</td>
<td>None - no lay</td>
<td>LLC309</td>
<td>LLC308</td>
<td>10/22/2015</td>
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<td>St. Croix</td>
</tr>
<tr>
<td>Cheryl</td>
<td>#146264</td>
<td>103.7</td>
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<td>LLC406</td>
<td>LLC480</td>
<td>10/23/2015</td>
<td>0050</td>
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<tr>
<td>Emily</td>
<td>#153482</td>
<td>110.3</td>
<td>AVID<em>076</em>285*088</td>
<td>LLC476</td>
<td>RRN953</td>
<td>10/23/2015</td>
<td>0215</td>
<td>St. Croix</td>
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</tbody>
</table>
Table 1.2. Turtle, tagging, and tracking data for seven female green turtles, *Chelonia mydas*, satellite tracked from the East End beaches of St. Croix, USVI in 2015 and 2016. * means that PTT was still transmitting when the data were analyzed on 28 March, 2016. - means that there were not enough high LCs (3, 2, and 1) to calculate.

<table>
<thead>
<tr>
<th>Turtle name</th>
<th>PTT number</th>
<th>Tagging date</th>
<th>Tracking period (d)</th>
<th>Overall displacement (km)</th>
<th>Final detected location</th>
<th>Size of internesting core (km$^2$)</th>
<th>Size of internesting activity (km$^2$)</th>
<th>Size of post-nesting core (km$^2$)</th>
<th>Size of post-nesting activity (km$^2$)</th>
<th>Size of internesting MCP size (km$^2$)</th>
<th>Size of post-nesting MCP size (km$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savannah</td>
<td>#146259</td>
<td>8/1/15</td>
<td>241*</td>
<td>23</td>
<td>St. Croix*</td>
<td>11.5</td>
<td>93.4</td>
<td>4.8</td>
<td>20.3</td>
<td>175.1</td>
<td>5.9</td>
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<tr>
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<td>8/4/15</td>
<td>16</td>
<td>1</td>
<td>St. Croix</td>
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<td>-</td>
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<td>Dionne</td>
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<td>St. Croix*</td>
<td>9.7</td>
<td>112</td>
<td>7.6</td>
<td>20.5</td>
<td>1,067.3</td>
<td>4.6</td>
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<tr>
<td>Victoria</td>
<td>#146262</td>
<td>8/5/15</td>
<td>159</td>
<td>111</td>
<td>Vieques</td>
<td>4.4</td>
<td>19.2</td>
<td>5.6</td>
<td>21</td>
<td>6.6</td>
<td>9.3</td>
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<tr>
<td>Annette</td>
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<td>10/22/15</td>
<td>158*</td>
<td>215</td>
<td>Nevis*</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>52,923.9</td>
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<td>219</td>
<td>Nevis*</td>
<td>-</td>
<td>-</td>
<td>4.0</td>
<td>14.5</td>
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<tr>
<td>Emily</td>
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<td>10/23/15</td>
<td>157*</td>
<td>-</td>
<td>St. Croix*</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5.4</td>
<td>-</td>
</tr>
</tbody>
</table>

Mean size 8.5 74.9 5.5 19.1 10,835.7 5.5
SE 1.2 16.4 0.5 1.0 4,706.4 0.6
Table 1.3. PTT performance while attached to female green sea turtles, *Chelonia mydas*, tracked from East End beaches of St. Croix, USVI utilizing SuperBond™ epoxy resin and fast curing agent. Location class (LC) given with number of detections in each class (percentage of total detections). * means that PTT was still transmitting when analyzes were conducted on 28 March, 2016.

<table>
<thead>
<tr>
<th>Turtle name</th>
<th>PTT number</th>
<th>Tracking duration (d)</th>
<th>Location Classes</th>
<th>Total detections</th>
</tr>
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<tbody>
<tr>
<td></td>
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<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Savannah*</td>
<td>#146259</td>
<td>241*</td>
<td>11 (0.34%)</td>
<td>19 (0.59%)</td>
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<tr>
<td>Samantha</td>
<td>#146260</td>
<td>16</td>
<td>1 (0.79%)</td>
<td>5 (3.94%)</td>
</tr>
<tr>
<td>Dionne*</td>
<td>#146261</td>
<td>237*</td>
<td>26 (1.12%)</td>
<td>31 (1.34%)</td>
</tr>
<tr>
<td>Victoria</td>
<td>#146262</td>
<td>159</td>
<td>82 (3.98%)</td>
<td>65 (3.15%)</td>
</tr>
<tr>
<td>Annette*</td>
<td>#146263</td>
<td>158*</td>
<td>16 (0.99%)</td>
<td>23 (1.43%)</td>
</tr>
<tr>
<td>Cheryl*</td>
<td>#146264</td>
<td>158*</td>
<td>32 (1.59%)</td>
<td>30 (1.49%)</td>
</tr>
<tr>
<td>Emily*</td>
<td>#153482</td>
<td>157*</td>
<td>9 (0.56%)</td>
<td>8 (0.50%)</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td></td>
<td>1,126 (1.37%)</td>
<td>177 (1.40%)</td>
</tr>
</tbody>
</table>
Table 1.4. Last inferred nest dates, length of internesting period, and length of post-nesting period for green sea turtles, *Chelonia mydas*, satellite tracked from the East End beaches, USVI. Samantha (#146260) stopped transmitting after only 16 d and, therefore, was not tracked during her post-nesting period. It was determined that Cheryl (#146264) laid her last nest of the season on the East End beaches before the PTT was attached; therefore, Cheryl (#146264) was not tracked during her internesting period. * means that the PTT was still transmitting when the data were analyzed on 28 March, 2016.

<table>
<thead>
<tr>
<th>Turtle name</th>
<th>PTT number</th>
<th>Tag deployment date</th>
<th>Last inferred nest date</th>
<th>Length of tracked internesting period (d)</th>
<th>Start date of post-nesting period</th>
<th>Last detection date</th>
<th>Length of tracked post-nesting period (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samantha</td>
<td>#146260</td>
<td>8/4/2015</td>
<td>8/14/2015</td>
<td>10</td>
<td>-</td>
<td>8/20/2015</td>
<td>-</td>
</tr>
<tr>
<td>Victoria</td>
<td>#146262</td>
<td>8/5/2015</td>
<td>10/2/2015</td>
<td>58</td>
<td>10/16/2015</td>
<td>1/12/2016</td>
<td>88</td>
</tr>
</tbody>
</table>
Table 1.5. Inferred nest dates after PTT deployment. Displacement is the straight-line distance between origin of track and nest location. * means no nest was laid on the deployment date. ** means that it was a confirmed nest (observed female nesting on beach after PTT attachment). - means that value could not be calculated because there was no previous nesting data.

<table>
<thead>
<tr>
<th>Turtle name</th>
<th>PTT number</th>
<th>Tag deployment date</th>
<th>Inferred nests post-deployment</th>
<th>Internesting interval (d)</th>
<th>Location class</th>
<th>Nesting location (country)</th>
<th>Displacement (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savannah</td>
<td>#146259</td>
<td>8/1/2015</td>
<td></td>
<td></td>
<td></td>
<td>St. Croix</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8/11/2015**</td>
<td>10</td>
<td>3</td>
<td>St. Croix</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8/21/2015</td>
<td>10</td>
<td>2</td>
<td>St. Croix</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9/1/2015</td>
<td>11</td>
<td>1</td>
<td>St. Croix</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9/9/2015</td>
<td>8</td>
<td>3</td>
<td>St. Croix</td>
<td>0.4</td>
</tr>
<tr>
<td>Samantha</td>
<td>#146260</td>
<td>8/4/2015</td>
<td></td>
<td></td>
<td></td>
<td>St. Croix</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8/14/2015</td>
<td>10</td>
<td>2</td>
<td>St. Croix</td>
<td>0.6</td>
</tr>
<tr>
<td>Dionne</td>
<td>#146261</td>
<td>8/4/2015*</td>
<td></td>
<td></td>
<td></td>
<td>St. Croix</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8/7/2015</td>
<td>-</td>
<td>3</td>
<td>St. Croix</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8/14/2015</td>
<td>7</td>
<td>3</td>
<td>St. Croix</td>
<td>17.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8/23/2015</td>
<td>9</td>
<td>3</td>
<td>St. Croix</td>
<td>17.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9/4/2015</td>
<td>12</td>
<td>2</td>
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<td>0.9</td>
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<td>9/14/2015</td>
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<tr>
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<td></td>
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<td>9/26/2015</td>
<td>12</td>
<td>3</td>
<td>St. Croix</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10/8/2015</td>
<td>12</td>
<td>1</td>
<td>St. Croix</td>
<td>1.9</td>
</tr>
<tr>
<td>Victoria</td>
<td>#146262</td>
<td>8/5/2015*</td>
<td></td>
<td></td>
<td></td>
<td>St. Croix</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8/11/2015</td>
<td>-</td>
<td>3</td>
<td>St. Croix</td>
<td>0.3</td>
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<td></td>
<td></td>
<td></td>
<td>8/17/2015**</td>
<td>6</td>
<td>3</td>
<td>St. Croix</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8/26/2015</td>
<td>9</td>
<td>3</td>
<td>St. Croix</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9/6/2015</td>
<td>11</td>
<td>3</td>
<td>St. Croix</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9/19/2015</td>
<td>13</td>
<td>3</td>
<td>St. Croix</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10/2/2015</td>
<td>13</td>
<td>3</td>
<td>St. Croix</td>
<td>0.2</td>
</tr>
<tr>
<td>Annette</td>
<td>#146263</td>
<td>10/22/2015*</td>
<td></td>
<td></td>
<td></td>
<td>St. Croix</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10/23/2015</td>
<td>-</td>
<td>3</td>
<td>St. Croix</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>11/1/2015</td>
<td>9</td>
<td>3</td>
<td>Antigua</td>
<td>303.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>11/12/2015</td>
<td>11</td>
<td>2</td>
<td>St. Kitts</td>
<td>185.6</td>
</tr>
<tr>
<td>Cheryl</td>
<td>#146264</td>
<td>10/23/2015</td>
<td>No other nests</td>
<td>-</td>
<td>-</td>
<td>St. Croix</td>
<td>-</td>
</tr>
<tr>
<td>Emily</td>
<td>#153482</td>
<td>10/23/2015*</td>
<td></td>
<td></td>
<td></td>
<td>St. Croix</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10/24/2015**</td>
<td>-</td>
<td>3</td>
<td>St. Croix</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>11/4/2015</td>
<td>11</td>
<td>2</td>
<td>St. Croix</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>11/16/2015</td>
<td>12</td>
<td>1</td>
<td>St. Croix</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Mean 10.3
SE 0.09
Table 1.6. CCL (curved carapace length) and CCW (curved carapace width) measurements and resident/migrant and neophyte/remigrant classifications for each female green turtle, *Chelonia mydas*, tracked from the East End beaches of St. Croix, USVI.

<table>
<thead>
<tr>
<th>Turtle name</th>
<th>PTT number</th>
<th>CCL</th>
<th>CCW</th>
<th>Resident/ Migrant</th>
<th>Neophyte/ Remigrant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savannah</td>
<td>#146259</td>
<td>115.5</td>
<td>105.5</td>
<td>Resident</td>
<td>Neophyte</td>
</tr>
<tr>
<td>Samantha</td>
<td>#146260</td>
<td>118.5</td>
<td>104.4</td>
<td>-</td>
<td>Neophyte</td>
</tr>
<tr>
<td>Dionne</td>
<td>#146261</td>
<td>105.4</td>
<td>97.0</td>
<td>Resident</td>
<td>Remigrant</td>
</tr>
<tr>
<td>Victoria</td>
<td>#146262</td>
<td>110.7</td>
<td>103.0</td>
<td>Migrant</td>
<td>Neophyte</td>
</tr>
<tr>
<td>Annette</td>
<td>#146263</td>
<td>115.2</td>
<td>106.0</td>
<td>Migrant</td>
<td>Neophyte</td>
</tr>
<tr>
<td>Cheryl</td>
<td>#146264</td>
<td>103.7</td>
<td>94.0</td>
<td>Migrant</td>
<td>Remigrant</td>
</tr>
<tr>
<td>Emily</td>
<td>#153482</td>
<td>110.3</td>
<td>101.0</td>
<td>Resident</td>
<td>Remigrant</td>
</tr>
</tbody>
</table>
Table 1.7. Dominant benthic habitat types identified for female green sea turtles, *Chelonia mydas*, that were satellite tracked from the East End beaches of St. Croix, USVI during both their internesting and post-nesting periods. Benthic habitat type described as per the findings of Kendall et al. (2001) and Shill et al. (2011). * means that the PTT was still transmitting when the data were analyzed on 28 March, 2016. - means that there were not enough high LCs (3, 2, and 1) to calculate.

<table>
<thead>
<tr>
<th>Turtle name</th>
<th>PTT number</th>
<th>Length of tracked internesting period (d)</th>
<th>Internesting period dominant habitat</th>
<th>Length of tracked post-nesting period (d)</th>
<th>Post-nesting period dominant habitat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savannah</td>
<td>#146259</td>
<td>39</td>
<td>Colonized pavement</td>
<td>187*</td>
<td>Seagrass</td>
</tr>
<tr>
<td>Samantha</td>
<td>#146260</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Dionne</td>
<td>#146261</td>
<td>65</td>
<td>Seagrass</td>
<td>158*</td>
<td>Seagrass</td>
</tr>
<tr>
<td>Victoria</td>
<td>#146262</td>
<td>58</td>
<td>Colonized pavement</td>
<td>88</td>
<td>Seagrass</td>
</tr>
<tr>
<td>Annette</td>
<td>#146263</td>
<td>21</td>
<td>-</td>
<td>123*</td>
<td>Dense seagrass</td>
</tr>
<tr>
<td>Cheryl</td>
<td>#146264</td>
<td>-</td>
<td>-</td>
<td>145*</td>
<td>Sand</td>
</tr>
<tr>
<td>Emily</td>
<td>#153482</td>
<td>24</td>
<td>Seagrass</td>
<td>119*</td>
<td>-</td>
</tr>
</tbody>
</table>
Figure 1.1. Wider Caribbean Region map (source: ANCO Maritime Activities Ltd).
Figure 1.2. Image utilized to describe seagrass from aerial photos and ground truthing by Kendall et al. (2001).
Figure 1.3. Image utilized to describe colonized pavement from aerial photos and ground truthing by Kendall et al. (2001).
Figure 1.4. Image utilized to describe macroalgae from aerial photos and ground truthing by Kendall et al. (2001).
Figure 1.5. Image utilized to describe colonized pavement with sand channels from aerial photos and ground truthing by Kendall et al. (2001).
Figure 1.6. Image utilized to describe sand from aerial photos and ground truthing by Kendall et al. (2001).
Figure 1.7. Image utilized to describe dense seagrass from satellite images and underwater transect videography by Schill et al. (2011).
Figure 1.8. Image utilized to describe sparse seagrass from satellite images and underwater transect videography by Schill et al. (2011).
Figure 1.9. Image utilized to describe *Acropora palmata* from satellite images and underwater transect videography by Schill et al. (2011).
Figure 1.10. Map of the East End beaches within Jack, Isaac, and East End Bays on St. Croix, USVI.
Figure 1.11. Diagram of suggested measurements for an adjustable corral to restrain an adult green sea turtle while performing a transmitter attachment. Slits in the front and back panels slide into those on the side panels and allow for the corral to be easily adjusted based on the size of the turtle.
Figure 1.12. Map of satellite transmitter attachment locations for all seven female green sea turtles, *Chelonia mydas*, tracked from the East End beaches of St. Croix, USVI.
Figure 1.13. Combined movement map of all seven satellite tracked female green turtles, *Chelonia mydas*, from their nesting beach on the East End beaches of St. Croix, USVI in August and October 2015 until 28 March 2016.
Figure 1.14. Total movement map of the female green turtle, *Chelonia mydas*, Samantha (#146260) after 16 d of satellite tracking from the East End beaches of St. Croix, USVI. Green star represents tagging location and pink triangle represents last detection location.
Figure 1.15. Total movement map of the female green turtle, *Chelonia mydas*, Savannah (#146259) after 241 d of satellite tracking from the East End beaches of St. Croix, USVI. Green star represents tagging location.
Figure 1.16. Total movement map of the female green turtle, *Chelonia mydas*, Dionne (#146261) after 237 d of satellite tracking from the East End beaches of St. Croix, USVI. Green star represents tagging location.
Figure 1.17. Total movement map of the female green turtle, *Chelonia mydas*, Emily (#153482) after 157 d of satellite tracking from the East End beaches of St. Croix, USVI. Green star represents tagging location.
Figure 1.18. Internesting movement map of the female green turtle, *Chelonia mydas*, Savannah (#146259) after PTT attachment on the East End beaches of St. Croix, USVI. Green star represents tagging location.
Figure 1.19. Internesting movement map of the female green turtle, *Chelonia mydas*, Dionne (#146261) after PTT attachment on the East End beaches of St. Croix, USVI. Green star represents tagging location.
Figure 1.20. Map of 50% core use (red) and 95% activity areas (yellow) of the female green turtle, *Chelonia mydas*, Savannah (#146259) during her internesting period (39 d).
Figure 1.21. Map of 50% core use (red) and 95% activity areas (yellow) of the female green turtle, *Chelonia mydas*, Dionne (#146261) during her internesting period (65d).
Figure 1.22. Map of habitat utilization of the female green turtle, *Chelonia mydas*, Savannah (#146259) during her internesting period (39 d) including an outline of her 50% core use area (red). Pie chart shows percentages of each habitat type with less prevalent habitat types displayed in dark purple.
Figure 1.23. Map of habitat utilization of the female green turtle, *Chelonia mydas*, Dionne (#146261) during her internesting period (65 d) including an outline of her 50% core use area (red). Pie chart shows percentages of each habitat type with less prevalent habitat types displayed in dark purple.
Figure 1.24. Internesting movement map of the female green turtle, *Chelonia mydas*, Emily (#153482) after PTT attachment on the East End beaches of St. Croix, USVI. Green star represents tagging location.
Figure 1.25. Minimum convex polygon (MCP) for the internesting period movements of the female green turtle, *Chelonia mydas*, Emily (#153482). Green star represents tagging location.
Figure 1.26. Map of habitat utilization of the female green turtle, *Chelonia mydas*, Emily (#153482) during her internesting period (24 d) including an outline of her minimum convex polygon (MCP) for this period outlined in black. Pie chart shows percentages of each habitat type with less prevalent habitat types displayed in dark purple.
Figure 1.27. Movement map of the female green turtle, *Chelonia mydas*, Savannah (#146259) during her transition period after her last inferred nest.
Figure 1.28. Movement map of the female green turtle, *Chelonia mydas*, Dionne (#146261) during her transition period after her last inferred nest.
Figure 1.29. Movement map of the female green turtle, *Chelonia mydas*, Emily (#153482) during her transition period after her last inferred nest.
Figure 1.30. Post-nesting movement map of the female green turtle, *Chelonia mydas*, Savannah (#146259).
Figure 1.31. Post-nesting movement map of the female green turtle, *Chelonia mydas*, Dionne (#146261).
Figure 1.32. Post-nesting movement map of the female green turtle, *Chelonia mydas*, Emily (#153482).
Figure 1.33. Map of 50% core use (red) and 95% activity areas (yellow) of the female green turtle, *Chelonia mydas*, Savannah (#146259) during her post-nesting period (187 d).
Figure 1.34. Map of 50% core use (red) and 95% activity areas (yellow) of the female green turtle, *Chelonia mydas*, Dionne (#146261) during her post-nesting period (158 d).
Figure 1.35. Map of habitat utilization of the female green turtle, *Chelonia mydas*, Savannah (#146259) during her post-nesting period (187 d) including an outline of her 50% core use area (red). Pie chart shows percentages of each habitat type.
Figure 1.36. Map of habitat utilization of the female green turtle, *Chelonia mydas*, Dionne (#146261) during her post-nesting period (158 d) including an outline of her 50% core use area (red). Pie chart shows percentages of each habitat type.
Figure 1.37. Internesting movement map of the female green turtle, *Chelonia mydas*, Victoria (#146262) after PTT attachment on the East End beaches of St. Croix, USVI. Green star represents tagging location.
Figure 1.38. Total movement map of the female green turtle, *Chelonia mydas*, Victoria (#146262) after 159 d of satellite tracking from the East End beaches of St. Croix, USVI. Green star represents tagging location and pink triangle represents last detection location.
Figure 1.39. Movement map of the female green turtle, *Chelonia mydas*, Victoria (#146262) during her transition period after her last inferred nest.
Figure 1.40. Map of 50% core use (red) and 95% activity areas (yellow) of the female green turtle, *Chelonia mydas*, Victoria (#146262) during her internesting period (58 d).
Figure 1.41. Map of habitat utilization of the female green turtle, *Chelonia mydas*, Victoria (#146262) during her internesting period (58 d) including an outline of her 50% core use area (red). Pie chart shows percentages of each habitat type with less prevalent habitat types displayed in dark purple.
Figure 1.42. Post-nesting movement map of the female green turtle, *Chelonia mydas*, Victoria (#146262). Pink triangle represents last detection location.
Figure 1.43. Map of 50% core use (red) and 95% activity areas (yellow) of the female green turtle, *Chelonia mydas*, Victoria (#146262) during her post-nesting period (88 d).
Figure 1.44. Map of habitat utilization of the female green turtle, *Chelonia mydas*, Victoria (#146262) during her post-nesting period (88 d) including an outline of her 50% core use area (red). Pie chart shows percentages of each habitat type with less prevalent habitat types displayed in dark purple.
Figure 1.45. Total movement map of the female green turtle, *Chelonia mydas*, Annette (#146263) after 158 d of satellite tracking from the East End beaches of St. Croix, USVI. Green star represents tagging location.
Figure 1.46. Internesting movement map of the female green turtle, *Chelonia mydas*, Annette (#146263) after PTT attachment on the East End beaches of St. Croix, USVI. Green star represents tagging location.
Figure 1.47. Minimum convex polygon (MCP) for the internesting period movements of the female green turtle, *Chelonia mydas*, Annette (#146263). Green star represents tagging location.
Figure 1.48. Movement map of the female green turtle, *Chelonia mydas*, Annette (#146263) during her transition period after her last inferred nest.
Figure 1.49. Total movement map of the female green turtle, *Chelonia mydas*, Cheryl (#146264) after 158 d of satellite tracking from the East End beaches of St. Croix, USVI. Green star represents tagging location.
Figure 1.50. Movement map of the female green turtle, *Chelonia mydas*, Cheryl (#146264) during her transition period after her last inferred nest. Green star represents tagging location, which was also the location of her last inferred nest.
Figure 1.51. Post-nesting movement map of the female green turtle, *Chelonia mydas*, Annette (#146263).
Figure 1.52. Post-nesting movement map of the female green turtle, *Chelonia mydas*, Cheryl (#146264).
Figure 1.53. Minimum convex polygon (MCP) for the post-nesting period movements of the female green turtle, *Chelonia mydas*, Annette (#146263).
Figure 1.54. Map of habitat utilization of the female green turtle, *Chelonia mydas*, Annette (#146263) during her post-nesting period (123 d) including an outline of her minimum convex polygon (MCP) for this period outlined in black. Pie chart shows percentages of each habitat type with less prevalent habitat types displayed in dark purple.
Figure 1.55. Map of 50% core use (red) and 95% activity areas (yellow) of the female green turtle, *Chelonia mydas*, Cheryl (#146264) during her post-nesting period (145 d).
Figure 1.56. Map of habitat utilization of the female green turtle, *Chelonia mydas*, Cheryl (#146264) during her post-nesting period (145 d) including an outline of her 50% core use area (red). Pie chart shows percentages of each habitat type.
Figure 1.57. Habitat utilization charts representing benthic habitat types found within the core use areas (when >20 high LC points) or minimum convex polygons (<20 high LC points) of female green sea turtles, *Chelonia mydas*, during their internesting period after satellite tag deployment on the East End beaches of St. Croix, USVI. Benthic habitat type identified with data from Kendall et al. (2001) and Schill et al. (2011).
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Figure 1.60. Benthic habitat mapping around the island of Vieques conducted by Kendall et al. (2001).
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Chapter 2: Genetic stock structure analysis of female green sea turtles, *Chelonia mydas*,
nesting on the East End beaches of St. Croix, USVI: a regional analysis
INTRODUCTION

The natal homing of sea turtles in which these animals return to nest on the beach where they were hatched has been identified through the use of long-term flipper tag studies (Carr, 1967). This homing indicates that sea turtle population genetics are structured through female lineage (Bowen et al., 1992; Formia et al., 2007). Breeding site fidelity makes mitochondrial DNA (mtDNA), which is maternally inherited, an excellent tool for determining population structure in all sea turtle species (Bjorndal et al., 2006). Mitochondrial DNA can be utilized to investigate genetic phylogeny on many different sea turtles nesting beaches (Bowen et al., 1992; Formia et al., 2007). These different nesting aggregations are referred to as rookeries (Bjorndal et al., 2006). Control region sequencing has allowed for the identification of different haplotypes, specific genetic mutations that are typically inherited together, which can be used to conduct stock structure analyses. These analyses enable sea turtle conservation managers to identify specific management units (MUs) that should be managed separately to maintain the greatest genetic diversity within the population (Proietti et al., 2009).

Genetic analyses are being utilized to investigate the gene flow across populations of green turtles throughout the Caribbean and the rest of the world. Tissue biopsies (Bjorndal et al., 2006; Formia et al., 2006) or blood samples (Fitzsimmons, 1998; Shamblin et al., 2012a) are utilized to conduct these analyses. Eighteen haplotypes and two unique groups were identified within 147 females when the 510-bp control region of mtDNA was analyzed for one Mediterranean and eight Atlantic populations of green turtles (Encalada et al., 1996). The western Caribbean and Mediterranean groups shared ten haplotypes in common and the eastern Caribbean, South Atlantic, and West Africa
groups shared eight haplotypes, none varying by more than five mutations (Encalada et al., 1996). Green turtles nesting on Ascension Island had different mtDNA than most other Atlantic rookeries when a 481-bp fragment of mtDNA was utilized for analyses (Avise and Bowen, 1994). Seventy percent (n=168) of female green turtles in the Brazilian rookeries had the CmA8 haplotype (Bjorndal et al., 2006). The haplotypes CmA3, CmA4, CmA5, CmA20, and CmA21 were found in females nesting in Tortuguero, Costa Rica (Bjorndal et al., 2005). All 70 hatchlings sampled from the island of Poilão in Guinea-Bissau had only one mtDNA haplotype, CmA8, when analyzed with a 488-bp control region fragment (Godley et al., 2010).

Shamblin et al. (2012a) identified 20 polymorphic tetranucleotide loci from green turtles in the Indian River Lagoon in Florida. Shamblin et al. (2012b) sequenced the mitochondrial genome of female green turtles nesting on Buck Island, USVI; Aves Island, Venezuela; Galibi, Suriname; and Tortuguero, Costa Rica using 490-bp fragments of the mtDNA control region (Figure 2.1). On Buck Island, two haplotypes CmA5 (n = 45, 92%) and CmA16 (n = 4, 8%) were identified through the use of 490-bp mtDNA fragments (Shamblin et al., 2012b). Additional sequencing with the ~1050-bp fragment identified SNPs that were variants of previously known haplotypes on Buck Island (Shamblin et al., 2012c). These included CmA5.1.1 (n=23, 47.0%), CmA5.1.3 (n=21, 42.9%), CmA5.2 (n=1, 2.0%), and CmA16.1 (n=4, 8.2%) (Shamblin et al., 2012c) (Figure 2.2). The CmA5.1.1 and CmA5.1.3 lineages on Buck Island may have descended from the population on Aves Island (Shamblin et al., 2012b). The larger rookery on the East End beaches of St. Croix, including the beaches within Jack, Isaac, and East End Bays, is believed to be genetically linked to the rookery on Buck Island due to their close
proximity (Figure 2.3). This genetic linkage would indicate that these turtles are within the same management unit (Shamblin et al., 2012b). This idea was proposed by Shamblin et al. (2012b) and was investigated further in the present study. Being able to connect smaller rookeries to larger ones through genetic analysis will allow for a better understanding of the gene flow and relatedness of green turtles throughout the Caribbean (Shamblin et al., 2012b).

The green sea turtle has been classified into 11 distinct population segments (DPSs) under the Endangered Species Act (ESA) based on genetic analyses conducted all over the world (Figure 2.4). The Mediterranean, Central West Pacific, and Central South Pacific DPSs are listed as endangered and all other DPSs are listed as threatened. The US Virgin Island green turtle rookeries are classified within the South Atlantic DPS and therefore are listed as threatened (66 Federal Register 81, 2016). The division of the DPSs was based on haplotype distribution as well as known life history characteristics of breeding populations from around the world. Only a few genetic studies have been conducted to investigate the haplotypes of the green sea turtles nesting within this region of the Caribbean; therefore, further research is needed to better delineate the North and South Atlantic DPSs. The natal homing of these animals limits the amount of gene flow from rookery to rookery (Schroeder, 2008) and highlights the importance of the conservation of as many rookeries as possible to keep genetic variation within this species (Avise and Bowen, 1994). The purpose of this study was to identify the dominant haplotype present within the nesting female population on the East End beaches of St. Croix, USVI and identify which DPS classification is appropriate for this rookery.
MATERIALS AND METHODS

A total of 60 skin biopsy samples were collected from nesting female green sea turtles during the 2012-2015 nesting seasons by The Nature Conservancy (TNC) on the East End beaches of St. Croix. A 6-mm biopsy punch was utilized for collection during the egg-laying process and skin samples were stored in vials in a saline solution as described by Dutton and Balazs (1995). Each female turtle was identified with flipper or PIT tags to ensure that the same female was not sampled more than once. Samples were sent to the NOAA Southwest Fisheries Science Center Marine Mammal and Turtle Molecular Research Sample Collection (La Jolla, CA, USA) for analysis. DNA was isolated utilizing a Corbett CAS-1200 extraction robot (Corbett Robotics, San Francisco, CA; Dutton et al., 2008). An ~820-bp fragment was amplified at the 5’ end of the control region of the mitochondrial genome using the primers LCM15382 (GCTTAAACCCTAAAGCATTGG) and H950 g with polymerase chain reaction (PCR) procedures (Abreu-Grobois et al., 2006; Dutton et al., 2007). The 25 μL PCR reaction was comprised of 18 μL purified H2O, 2.5 μL of 10x Mg buffer, 1.5 μL DNTPs, 1 μL (20-50 ng) of template DNA, 0.75 μL of each primer, and 0.5 μL of Taq polymerase. The PCR was performed as follows: initial DNA denaturation at 94°C for two min, followed by 36 cycles of (1) DNA denaturation at 94°C for 50 sec, (2) annealing of primers at 52°C for 50 sec, and (3) extension of primers at 72°C for one min, and (4) extension of primers at 72°C for five min. In order to detect for contamination, negative controls were included in each PCR. The products were purified and sequenced utilizing procedures similar to Dutton et al. (2014). Haplotypes were identified and classified based on the publications on the Archie Carr Center for Sea Turtle Research website.
Analysis of molecular variance (AMOVA) was conducted utilizing both $F_{st}$ and $\phi_{st}$ measures in Arlequin v 3.5.1.2 (Excoffier and Lischer, 2010) using 10,000 permutations to test for population structure. The $F_{st}$ and exact test were used to calculate significance in genetic variation between the East End beaches and Buck Island rookeries.

RESULTS

The haplotypes identified on the East End beaches of St. Croix were CmA3.1, CmA5.1, and CmA5.2. The haplotype CmA5.1 was most common ($n=53$, 91.4%) and CmA3.1 ($n=4$, 6.9%) was the second most common. Only 58 out of the 60 tissue samples were analyzed as one was incorrectly collected from a hawksbill and another was a pseudoreplicate obtained from a female that had previously been sampled. Comparison of haplotypes that have been identified utilizing the ~800 bp mtDNA control region fragment within other Caribbean and Atlantic green sea turtle rookeries are listed in Table 2.1. The $F_{st}$ results indicated that there was no significant difference between the genetic variability of the Buck Island and East End beach rookeries; however, the exact tests results did reveal a significant difference between the two rookeries.

DISCUSSION

The major findings of this study were that the dominant haplotype on the East End beaches is CmA5.1 and the classification of this rookery into the South Atlantic DPS was correct. There was not complete evidence that the Buck Island and East End beach rookeries should be classified as two separate management units (MUs) because there
were differences in the $F_{st}$ and exact test results. Both the East End beaches and Buck Island nesting populations were both dominated by the CmA5.1 haplotype indicating that both of these rookeries were correctly classified into the South DPS. Mitochondrial DNA genetic analyses allow for conservation managers to identify and recognize certain rookeries that are more impacted by threats not on or near the nesting beach (Formia et al., 2006). It has been suggested that regional analyses of population threats be conducted to identify MUs in greatest need of conservation (Godfrey and Godley, 2008). Different temporal breeding between the northern and southern hemispheres likely limits genetic intersecting; however, there is year-round breeding in some rookeries (Naro-Maciel et al., 2014).

Even though the CmA3.1 haplotype was present in the East End beach rookery, it was relatively rare and did not provide enough evidence against the classification of the East End beaches rookery within the South Atlantic DPS. However, it is worth mentioning that the CmA3 haplotype is dominant in the Northwestern Caribbean. Analyses of additional tissue samples could identify the overall distribution of the CmA3.1 haplotype within the East End beach rookery. The amount of genetic variability within the East End beach rookery could then be more accurately compared to the variability within the Buck Island rookery. Maintaining genetic diversity within the green sea turtle population is vital for the conservation of this species. The marginal results of significance based on the $F_{st}$ and exact test results of genetic variability indicated that further analyses need to be conducted to conclusively state if two separate MUs exist in this region. The exact test is more sensitive, so there was some indication of differentiation between these rookeries, but it should be investigated further, with
additional samples from the East End beaches. The presence of the CmA3 haplotype at the East End beaches, but not within the Buck Island population indicated that there was some genetic differentiation between these rookeries. If additional analyses are able to identify these rookeries as separate MUs, this would be a significant finding as Buck Island and the East End beaches are separated by less than ten km and would be the first reported distinct MUs that are separated by such a small distance.

Sequencing outside of the 817-bp control region has found single nucleotide polymorphisms (SNPs) that allowed for the differentiation of the CmA5.1 haplotype into CmA5.1.1, CmA5.1.2, and CmA5.1.3 (Shamblin et al., 2012b). The haplotype CmA3.1 only represented 7% of the samples (n=67) analyzed at Aves Island utilizing the 817-bp control region (Shamblin et al., 2012b). Utilizing pairwise F_{ST} values when comparing the 817-bp control regions, significant differentiation was identified between the rookery at Tortuguero and those at Buck Island, Aves Island, and Galibi (Shamblin et al., 2012b). Shamblin et al. (2012b) recommended investigating these same CmA5.1 SNPs for genetic comparison to the greens nesting on the East End beaches of St. Croix. Utilizing SNPs to further delineate mtDNA haplotypes identified in other parts of the Caribbean would be the best way to visualize the connectivity of these populations (Shamblin et al., 2012b). Continued analysis of the tissue samples from the East End beaches rookery utilizing genetic struck analysis could identify whether the green turtle rookery on Buck Island should be classified as separate MUs.

Genetically different rookeries must be managed independently due to the maternal-basis for genetic diversity (Bowen et al., 1992). The distance between the nesting beaches plays a role, but does not appear to be the determining factor for
rookeries being classified as separate MUs. Rookeries in the Rocos Atoll and Fernando de Noronha (off the coast of Brazil) were found to be genetically different with the mtDNA sequencing of the 817-bp control region even though these rookeries are only 150 km apart (Shamblin et al., 2015a). Introduction of novel haplotypes to nesting beaches are not likely because of the natal homing behavior of female sea turtles (Bowen et al., 1992). In the Caribbean there may be more “leakage” (females utilizing other nesting beaches) than first thought by Bowen et al. (1992) due to the close proximity of the islands as noted by Esteban et al. (2015) and Schultz (unpublished data). Bjorndal et al. (2005) also mentioned these natal homing “mistakes,” but explains that genetic analyses have shown that these occurrences are rare. Genetics studies, in combination with traditional tagging (flipper and PIT tags) and satellite telemetry, will allow for conservation managers to understand the true movements and behaviors of turtles from specific rookeries. Genetic analyses will allow managers to identify which rookeries have lower genetic diversity and are therefore in need of greater conservation efforts.

The results of this study help to clarify the distinct population segment (DPS) boundaries for the green sea turtle population within the eastern Caribbean region. The US Virgin Islands green turtle rookeries have been classified into the South Atlantic DPS (66 Federal Register 81, 2016), but there have been relatively few genetic studies conducted within the Caribbean near the dividing line between the North and South Atlantic DPSs. It is vital to clarify this haplotype boundary to identify the genetic variability within this region and to ensure that the green turtles nesting on St. Croix are managed with other nesting populations of similar haplotypes. Rookeries of similar
genetic structure should be managed together to ensure that conservation measures are
distributed to all areas of genetic diversity.

Future work should utilize mitogenomic markers to separate out specific
haplotypes; since the Buck Island CmA5.1 haplotype breaks down into two variants with
additional mitogenomic markers. Conducting this analysis on the females nesting on the
East End beaches may provide more insight into the complexity of these rookeries.
Shamblin et al. (2012b) hypothesized that the CmA5.1.1 and CmA5.1.3 haplotypes
originated from the Aves Island rookery. The spread of genetic diversity is believed to be
a result of the erosion of Aves Island and the lack of proximity of other islands to this
nesting beach (Shamblin et al., 2012b). The closest islands to Aves Island are in the
Lesser Antilles, 175 km away (Shamblin et al., 2012b).

The identification of the dominant haplotype (CmA5.1) within the East End
beaches rookery is just the first step for completing a genetic stock analysis for this
rookery. Use of SNPs to further differentiate the CmA5.1 haplotype will help determine
if there is great enough genetic variability within these rookeries to definitively classify
them as two separate MUs. Identification of differences in genetic variability within such
a small geographic region would provide evidence that there may be more genetic
variability within the green turtle population than understood from current research and
that more studies need to be conducted to identify if this is occurring within other
rookeries around the world. Analyzes of additional samples from the East End beach
rookery will identify if there is enough genetic variation between this and the Buck Island
rookery to classify them as separate MUs. Further genetic analyses should also include
the truncation of the control region to ~400 bp to allow for better comparison of other
green turtle genetic analyses throughout the Caribbean. This study is the first step to better understanding the genetic variability present within the green turtle rookeries in St. Croix and additional analyses are needed to fully identify the diversity present in this region.
LITERATURE CITED


“Endangered and threatened wildlife and plants; final rule to list eleven distinct population segments of the green sea turtle (*Chelonia mydas*) as endangered or threatened and revision of current listings under the Endangered Species Act; final rule,” 81 Federal Register 66 (6 April 2016), pp. 20057-20090.


The Nature Conservancy’s St. Croix sea turtle monitoring and protection plan. 2011.
Table 2.1. Haplotype frequencies of the green sea turtle, *Chelonia mydas*, with ~800 bp fragment analyses of mtDNA from control region from within the Wider Caribbean Region.

<table>
<thead>
<tr>
<th>Haplotype</th>
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<th>Aves Island</th>
<th>Galibi</th>
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<td>-</td>
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<tr>
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<td>-</td>
<td>4</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Sample size</td>
<td>58</td>
<td>49</td>
<td>67</td>
<td>58</td>
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</tbody>
</table>

References

- Present study
- Shamblin et al. (2012b)
Figure 2.1. Haplotype frequency distribution of green sea turtles, *Chelonia mydas*, throughout the Caribbean region based on 490-bp control region haplotypes (source: Shamblin et al., 2015b).
Figure 2.2. Haplotype frequency distribution of green sea turtles, *Chelonia mydas*, throughout the Caribbean region based on 490-bp control region haplotypes (histograms), including mtDNA variations of the Cm-A5 haplotype (pie charts) (source: Shamblin et al., 2012c).
Figure 2.3. Map identifying Buck Island and the East End beaches, which are adjacent to East End, Isaac, and Jack Bay.
Chapter 3: Summary statistics of green sea turtle, *Chelonia mydas*, nesting data from the East End beaches of St. Croix, USVI and recommendations for long-term sea turtle nesting data collection and management
INTRODUCTION

The timing and length of the nesting season of green sea turtles, *Chelonia mydas*, varies worldwide (Yasuda et al., 2006). Green turtles lay nests year round in some areas, such as on Huyong Island, Thailand (Yasuda et al., 2006) and only during part of the year in others. Green turtles nest in the British Virgin Islands throughout the year, but have a primary nesting season between June and September with the largest peak in August (McGowan et al., 2008). In the Cayman Islands, green turtles nest from July through September with a peak in August (Aiken et al., 2001). At the largest green turtle rookery in the Western Hemisphere, Tortuguero, Costa Rica, nesting occurs primarily between June and November with a peak in August (Vander Zanden et al., 2012). *Chelonia mydas* nests year round on the East End beaches of St. Croix, including the beaches within Jack, Isaac, and East End Bays (Figure 3.1), but have a peak nesting period between July and September (TNC, 2011).

Sea turtle fisheries worldwide have contributed to the decline in sea turtle populations over the past few decades. Some legal sea turtle fisheries still exist in parts of the world and have reduced the number of adult sea turtles (Bell et al., 2005; McGowan et al., 2008). Up to 84 adult sea turtles can be legally captured each year in the turtle fishery in the Cayman Islands (Bell et al., 2007). Green sea turtles were the only species permitted for legal take in all of the 42 sea turtle fisheries investigated in a study by Humber et al. (2014). An estimated 42,000 sea turtles are captured each year in these legal sea turtle fisheries, with green turtles making up 80% of those catches (Humber et al., 2014). Most of these legal fisheries are concentrated in the Caribbean and Indo-Pacific region (Humber et al., 2014). Several illegal sea turtle fisheries also exist globally.
Sea turtle meat is considered a delicacy in some cultures, which is why these international fisheries still exist. However, the overharvesting and illegal take of green turtles may be contributing to their threatened and endangered status by creating unsustainable populations (McGowan et al., 2008).

Human development of beaches and pollution are other major threats to the green sea turtle population. Sea turtles have many threats as hatchlings and juveniles, but once full grown their only predators are sharks and humans (McGowan et al., 2008). Threats on the beach can limit the turtle population even before the hatchlings reach the water. The tropical fire ant, *Solenopsis geminata*, has been found to be a major threat to hatchlings as a single sting greatly decreases the chance of survival for a hatchling (Wetterer et al., 2010). These ants are been prevalent on the beaches on the west end of St. Croix, US Virgin Islands at Sandy Point National Wildlife Refuge (Wetterer et al., 2010). High human presence and lack of beach isolation were found to be the major negative influences reducing the number of green turtles nesting on a beach in Ras Al-Hadd, Oman between 1998 and 2000 (AlKindi et al., 2006). Both natural and anthropogenic threats have and continue to lead to the decline of sea turtle populations in many areas of the world.

The presence of *C. mydas* is vital to maintaining healthy beach and marine ecosystems. Eggshells and unhatched turtles provide nutrients to the vegetation, and robust vegetation prevents beach erosion (TNC, 2011). The nutrients left on the beach from sea turtle nesting provides great resources and habitats for small animals that live there (Madden et al., 2008). High-density nesting areas in Tortuguero, Costa Rica had significantly more nitrogen (248 kg/km) and phosphorus (14 kg/km) when compared to
areas of lower nest density (Vander Zanden et al., 2012). The green sea turtle is one of the few animals that feed on seagrasses (TNC, 2011). The presence of these turtles is vital for the survival of seagrasses, which need to be grazed upon to regenerate and grow (TNC, 2011). *Thalassia testudinum*, or turtle grass as it is more commonly known, provides vital habitat for at least 85 taxonomic groups in the Virgin Islands National Park, St. John, USVI (Bologna et al., 2008). Animals utilize these seagrass beds as breeding and nursery grounds (Bologna et al., 2008). Without the presence of sea turtles, the grasses would be unlikely to regenerate effectively, which may lead to a decline in the health of seagrass beds around the world. *Chelonia mydas* are essential parts of both the marine and beach environments and should be protected as such. Sea turtles are charismatic megafauna that are utilized by many to promote the restoration of the marine environment (Blumenthal et al., 2006). The conservation of the ocean protects the habitat of not only these turtles, but many other organisms as well. Sea turtle nesting beaches and areas where these turtles reside in the open ocean contribute largely to ecotourism in these areas. It is necessary to increase the threatened and endangered sea turtle populations around the world to maintain both healthy ecosystems and economies.

Actual population estimates of sea turtles are difficult to obtain because these animals spend the majority of their lives in the open ocean, with females typically only returning to beaches to nest. The life-history traits of sea turtles as well as unknown immature turtle survival rates make sea turtle population changes difficult to study. It has been predicted that sea turtles can live up to 100 years and likely do not reach maturity until between the ages of 18 and 33 (Frazer and Ehrhart, 1985). Night-time monitoring of sea turtle nesting beaches, including tagging nesting females and excavating nests, helps
researchers collect data on these species. Since nesting behavior can differ dependent on the species, location of the nesting beach, and each individual female, it is necessary to conduct monitoring on many sea turtle nesting beaches all around the world to gather as much data as possible for each individual species.

The number of eggs laid per nest (clutch size), number of nests laid by a single female in a season (clutch frequency), and the nest depth vary with each female. The clutch size ranged from 80 to 130 eggs on Huyong Island, Thailand (Gomuttapong et al., 2013). On Alagadi Beach in northern Cyprus in 1998, the average clutch size was 109.4 (SD=24.4, n=29) (Glen et al., 2005). Females typically lay two to eight nests each season (Weber et al., 2013), but average clutch frequencies range from four to seven clutches per season on Huyong Island, Thailand (Yasuda et al., 2006) and average 5.9±0.2 clutches per season on Ascension Island (Weber et al., 2013).

The incubation period and nest success rate can vary greatly from beach to beach. The incubation period of green turtle hatchlings ranged from 43-60 d on Alagadi Beach, Northern Cyprus (Broderick et al., 2000) to an average of 58 d on Huyong Island, Thailand (Gomuttapong et al., 2013). The average hatching success rate was 28% (SD=35, n=10) for green turtles in the Cayman Islands in 1998 (Aiken et al., 2001), whereas on Alagadi Beach in northern Cyprus the hatching success rate was 94% (n=71) (Broderick and Godley, 1999). Since sea turtle eggs are semipermeable, they can be impacted by the characteristics of the sand surrounding them, including temperature, grain size, and moisture level of the sand (Crain et al., 1995), all which can effect hatching success (the fraction of eggs hatched within a single clutch) (Miller, 1999).
The sex of sea turtles is temperature dependent, particularly during the middle third of the incubation period (Broderick et al., 2000; Godley et al., 2002). Higher temperatures produce females and cooler temperatures produce males (Broderick et al., 2000). Several studies have been conducted attempting to investigate the sex ratio of hatchlings. This is a very difficult process because no external features differentiate males from females at this young age, so sacrifice of the hatchling is typically the only method of ensuring correct sexing (Broderick et al., 2000; Godley et al., 2002). While sex ratios are difficult to determine, calculating population estimates using the number of nesting females within a rookery is an acceptable method of determining an approximate number of individuals within the population (Pfaller et al., 2013).

There have been a few studies conducted over the years investigating the overall population trends of *C. mydas*. However, there were issues with data analysis due to differences in survey effort and imperfect detection over the years (Bjorndal et al., 1999; Pfaller et al., 2013). The population growth rates were 6.8%, 5.7%, 3.8%, 13.9%, and 4.9%, respectively, for six major rookeries worldwide including Ogasawara, Japan; East Island, Hawaii; Heron Island, Australia; Archie Carr National Wildlife Refuge, FL, USA; and Tortuguero, Costa Rica from 1973 until 2003 (Chaloupka et al., 2008). Raine Island, Australia showed an increase in population size from 1973 through 1988 and then began to decrease (Chaloupka et al., 2008). Recording and analysis of nest detection probability is just as important as recording the nesting history during these long-term population surveys. Pfaller et al. (2013) had statistically significant evidence of an increase in the nesting population on Wassaw Island, GA until detection probability was added into the analysis.
The Nature Conservancy (TNC) has implemented several conservation practices on the East End beaches, including removing mongoose, documenting and tagging nesting female turtles, and reducing poaching activities by increasing nighttime beach presence. Poaching and the abundance of feral animals have been documented as the largest threats to hatchling success on the East End beaches of St. Croix, USVI (Harvey, 2008). The Javan mongoose, *Herpestes javanicus*, will dig up the nests and eat the eggs before hatching (Harvey, 2008). Traps have been put in place before the nesting season each year since 1994 in an attempt to reduce the abundance of this invasive species (Mackey, 2011). Since the establishment of the sea turtle monitoring program on the East End beaches in 1994, TNC has been working to prevent human poaching of sea turtle eggs for consumption (Harvey, 2008). The volunteers that monitor sea turtle nesting on the East End beaches bury wooden popsicle sticks labeled with the tag number of the mother and the nesting date to allow collection of nesting data, but not draw the attention of poachers to the nests (Harvey, 2008). The abundance of poachers has seemed to almost disappear thanks to nighttime presence of interns on the beach (Lewis, pers. comm.).

Long-term population studies are likely the only means to get an accurate population estimate for any sea turtle species. Godfrey and Godley (2008) suggest that regional analyses of population threats be conducted to identify which management units (MUs) are in greatest need of conservation efforts. The conservation efforts being implemented at the East End beaches of St. Croix, USVI have attempted to limit the number of threats to the sea turtles on these beaches (TNC, 2011). This study will provide summary statistics of the nesting population of green sea turtles on the East End...
beaches of St. Croix, USVI and provide recommendations for collecting and analyzing long-term nesting data.

MATERIALS AND METHODS

Green sea turtle nesting data were collected from 1994-2015 on Jack, Isaac, and East End beaches of St. Croix, USVI. The Division of Fish and Wildlife of the USVI Department of Planning and Natural Resources (DPNR), the West Indies Marine Animal Research and Conservation Service (WIMARCS), US Fish and Wildlife Service (USFWS), National Park Service (NPS), St. Croix Marine Turtle Conservation Project, and The Nature Conservancy (TNC) have funded or been a part of various aspects of the sea turtle nest monitoring project on the East End beaches of St. Croix over the past 21 years. One to three people monitored the East End beaches from approximately 2000 to 0300 five times a week from August until December 1994-2015. Data were collected on the total number of nesting female green sea turtles each season, carapace sizes, clutch size, and hatching success. Females were flipper tagged on the right front and left rear flippers, as well as PIT tagged in the left shoulder if the female was found before or while in a trance-like state during egg laying. A PIT tag was not inserted if the female was not located during the nest laying process. Curved carapace width (CCW) and length (CCL) were taken for each female. Triangulation of the nest was completed if the egg chamber was visible. A popsicle stick labeled with the date of nesting and female flipper tag information was placed in the nest if the egg chamber was still open. Hatched nests were excavated when located. Clutch size and hatching success were recorded upon excavation of the nests. Due to inconsistencies in data collection, population estimation modeling
could not be completed for this nesting data, particularly due to variability in nighttime monitoring effort. Changes in the types of data collected from year to year resulted in only partial sections of the data being summarized. Summary statistics were calculated for the total number of nesting females, clutch size, and hatching success.

RESULTS

The data collected by TNC between 1994-2015 varied greatly in terms of the consistency of effort. This consistency was dependent upon the source of funding, personnel, amount of funding, and unforeseeable events, such as inclement weather. No data were able to be obtained before 2003 and no data were collected for the 2011-nesting season. However, there did appear to be an overall trend of an increase in the number of nesting females over the entire duration of the monitoring project. The average number of confirmed green turtle nests was 263.9±53.5 between 2003-2015. The largest number of nests (612) was observed during the 2010 nesting season, but this may have been a factor of the varying survey effort over the years. Table 3.1 provides a summary of some of the nesting data that were collected on the East End beaches from 2003-2015. The mean clutch size was 107.9±3.4 eggs with an average hatching success of 86.7%±2.0%. Figure 3.2 is a suggested data sheet for collection of sea turtle nesting data on the East End beaches. Information collected from this data sheet would allow for population modeling to be conducted after several years of data collection. In addition to these data sheets, daily logs should be kept with how many total hours each beach was monitored every night. Figure 3.3 is a suggested data sheet for collection of nest excavation data.
DISCUSSION

The major findings of this study are that the East End beach rookery has approximately 263.9±53.5 green turtle nests each season with a mean hatching success rate of 86.7%±2.0%. The number of nesting females is relatively high for an area of beach approximately only two km in total length. The average clutch size of 107.9±3.4 eggs is consistent with other green nesting populations around the world. Generally the clutch size ranges from 80-130 eggs (Gomuttapong et al., 2013). The average hatching success of 86.7%±2.0% is generally greater than other nesting populations. Green turtle nests in the Galápagos had a mean hatching success of 46.0%±33.4% between the years 2004 and 2007 on a variety of different nesting beaches (Zárate et al., 2013). Average hatching success rates have been shown to vary from 28%-94% depending on the nesting beach location and season (Broderick and Godley, 1999; Aiken et al., 2001). The temperature, grain size, and moisture of the sand surrounding the clutch can all impact the hatching success of each individual nest (Crain et al., 1995). Therefore, it is difficult to compare hatching success across differing beaches if these factors are not measured and taken into consideration.

Long-term sea turtle nesting data are needed to understand the life history and population dynamics of this long-lived species. It is essential to have a long-term data analysis plan before establishing sea turtle nesting beach protocols. The amount of effort must remain consistent throughout the entire duration of the project, just as the data collection methods must remain the same for the data to be viable and well suited for statistical modeling. A 39-year data set collected on loggerhead nesting on Wassaw Island, GA, USA demonstrated the necessity of integrating detection probability into
models of long-term population trends (Pfaller et al., 2013). A significant positive increase was observed for the number of nesting loggerheads on Wassaw Island, but after incorporation of imperfect detection rates into the model, no significant change in abundance was identified (Pfaller et al., 2013). Changes in monitoring effort or site fidelity of nesting females could both explain trends observed in population estimate data; therefore, it is vital that detection probability remain the same for the entirety of the project (Pfaller et al., 2013). Accurate record keeping of the number of beach hours or distance patrolled is necessary for the establishment of an accurate model with tight confidence intervals. It is important to have similar start and end dates for monitoring each season, so as not to have a possible confounding variable in the data. When attempting to model a population and get an estimate of population size, it is best to gather information about the total number of nesting females and get an estimate of the total number of nests laid in each season, whereas it is less important to collect the greatest amount of data about each specific female or nest. It is also vital to conduct random nest inventories to calculate an average clutch size and hatching success for each season. However, things such as grain size, temperature, predation, or other natural events are variables that can all impact the hatching success (Crain et al., 1995).

The consistent application of flipper and PIT tags is the only way to visually identify each individual nesting female and obtain a reliable count of the total number of females nesting each season. Individual identification is also essential for calculating the average nesting frequency of females nesting in the survey area. It is necessary to have standard protocols with descriptive definitions for conducting nest excavations to get accurate measures of clutch size and hatching success. Often paper data sheets are
utilized to record nesting data while on the beaches, but it is vital that this information be digitized in a consistent format to allow for easy access, data manipulation, and analyses in the future. Training, data recording, and data processing should all remain the same throughout the entirety of the nesting beach monitoring project regardless of the project coordinator. The Sea Turtle Nest Monitoring System on seaturtle.org allows nesting data to be entered in a consistent format and statistics to be calculated for each season. Data including the total number of nests, number of false crawls, clutch size, and hatching success can all be entered into this online database on seaturtle.org.

The recommended data sheets in Figures 3.2 and 3.3 include the minimum amount of data that should be collected during each nesting season on the East End beaches to conduct population modeling after several years of data have been collected. Beach monitoring should always be conducted with a minimum of three people (one within each bay). If funding is limited for the project, duration of the beach monitoring, not the number of individuals monitoring the beaches each night, should be shortened. This will ensure that survey effort is not a confounding variable when creating the population estimation model. The portion of each season (number of days) that is monitored will then need to be taken into account when running the model. Tagging of each individual female should be the most important goal of the monitoring program in order to identify the total number of nesting females each season. The entire beach survey area needs to be covered thoroughly and no nesting female should be missed on a given night. These data will be vital when attempting to estimate the size of the rookery on the East End beaches. Identification of each nesting female will also allow for the calculation of average clutch frequency and remigration interval, which are also necessary for
modeling. Specific information about each individual female (such as carapace measurements) is not vital for model creation and therefore should only be conducted when additional funding allows for more personnel to be involved with the project.

Towards the end of the nesting season, focus should shift to collecting nest excavation data utilizing the data sheet in Figure 3.3. Information should primarily be collected on hatching success, clutch size, and predation rates. Hatching success data are necessary to model how the population of the rookery will change over time and predation rates are important for identifying the effect predation is having on the population.

Models created from long-term sea turtle nesting data can help managers establish population estimates and identify whether their efforts are effective in increasing sea turtle populations (Boulon and Frazer, 1990). The nesting green sea turtle population on Ascension Island is on the rise (Weber et al., 2014). The average number of clutches per year on Ascension Island increased from a mean of 3,752 nests between 1977-1982 to a mean of 23,724 nests between 2010-2013 (Weber et al., 2014). Local population estimates at specific nesting beaches allow different rookeries to be classified on scales of endangerment, so that rank of importance can be established for protection (Boulon and Frazer, 1990). The IUCN Red List, however, only classifies the overall green sea turtle population as endangered and does not divide this global population into smaller segments (Godfrey and Godley, 2008).

The green sea turtle, *C. mydas*, has been classified into 11 distinct population segments (DPSs) under the Endangered Species Act (ESA) based on genetic analyses conducted all over the world (Figure 3.4). The Mediterranean, Central West Pacific, and Central South Pacific DPSs are listed as endangered and all other DPSs are listed as
threatened. The US Virgin Island green turtle rookeries are classified within the South Atlantic DPS and therefore are listed as threatened (66 Federal Register 81, 2016).

Utilizing long-term nesting data is necessary to identify the number of individuals within a specific rookery and determine if it is in need of additional conservation efforts.

Sea turtle nesting data collection is necessary to create population estimates for individual rookeries, which can then be utilized to identify which populations are more threatened and endangered. The consistency of nesting data collection, however, is just as important because without consistency these population estimates are not likely to be accurate. Sea turtles are generally only encountered on land, so tagging studies and nesting data statistics are vital to collecting information about at least a little part of the life history of these threatened and endangered animals. Nest monitoring data are very valuable information, as this is generally the only time we usually encounter these animals, so we need to gather as much data as possible. Continued nesting beach monitoring on the East End beaches should utilize the data collection sheets in Figures 3.2 and 3.3 to focus primarily on accurately identifying the number of females nesting on these beaches each season and hatching success. Digitalizing and statistical comparisons of yearly data will allow for easier analyses after the data have been collected over several years. Overall this current study provided evidence of a large green sea turtle rookery on the East End beaches of St. Croix, USVI and identified key steps necessary to implement population estimation modeling for this rookery in the future.
LITERATURE CITED


The Nature Conservancy’s St. Croix sea turtle monitoring and protection plan. 2011.


<table>
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<th>Nesting season</th>
<th>Total number of females</th>
<th>Confirmed number of nests</th>
<th>Mean clutch size</th>
<th>Mean hatching success</th>
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Figure 3.1. Map of the East End beaches within Jack, Isaac, and East End Bays on St. Croix, USVI.
Female Nesting Data Collection Sheet - East End beaches

Date: ___________ Time: _______________

Observer: ___________

Species: Cm Ei

Beach: JB IB EEB

Tags:

PTT: ______________

LFF: ________ RFF: ___________

LRF: ________ RRF: ___________

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<td>Rear</td>
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Figure 3.2. Data sheet for collection of night-time monitoring data of nesting female sea turtles on the East End beaches of St. Croix, USVI.
Nest Excavation Data Collection Sheet - East End beaches

Date: ___________  Time: ___________

Observer: ______________

Species:  Cm    Ei

Beach:  JB   IB   EEB

Nest Predated: Yes  No

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<td>Dog</td>
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<tr>
<td>Other</td>
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<td>Mongoose</td>
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Total # of eggs (Clutch size): _______

# Hatched: ______________

# Dead: ______________

Figure 3.3. Data sheet for collection of sea turtle nest excavation data on the East End beaches of St. Croix, USVI.
APPENDIX A. Satellite Attachment Data Sheet

St. Croix Green Sea Turtle Field Work Data Sheet

Date: ________________________________

Attachment Start Time: ________________________

Release Time: ______________________________

Release Latitude: ____________________________

Release Longitude: __________________________

PIT Tag Number: _____________________________

RFF Tag Number: _____________________________

LFF Tag Number: _____________________________

Satellite Transmitter Number:

CCW: ________________  CCL: ________________

Photo Taken:  Yes  No

Tissue Biopsy Taken:  Yes  No

Comments:
APPENDIX D. The female green turtle, *Chelonia mydas*, Dionne (#146261) after PTT attachment on August 4, 2015. Note: Red light is from headlamps used on beach at night.
APPENDIX F. The female green turtle, *Chelonia mydas*, Annette (#146263) after PTT attachment on October 22, 2015.
APPENDIX H. The female green turtle, *Chelonia mydas*, Emily (#153482) after PTT attachment on October 23, 2015.
APPENDIX I. Adjustable wooden corral utilized in this study to restrain green sea turtles, *Chelonia mydas*, during the satellite transmitter attachment process.
APPENDIX J. Attachment of the PTT to the carapace of a green sea turtle, *Chelonia mydas*, with the use of a mixed 2-part epoxy (SuperBond™).
APPENDIX K. The female green turtle, *Chelonia mydas*, Victoria (#146262) entering water after completion of the PTT attachment process.
APPENDIX L. Minimum convex polygon (MCP) for the internesting period movements of the female green turtle, *Chelonia mydas*, Savannah (#146259). Green star represents tagging location.
APPENDIX M. Map of habitat utilization of the female green turtle, *Chelonia mydas*, Savannah (#146259) during her internesting period (39 d) including an outline of her 50% core use (red) and 95% activity areas (yellow).
APPENDIX N. Minimum convex polygon (MCP) for the post-nesting period movements of the female green turtle, *Chelonia mydas*, Savannah (#146259).
APPENDIX O. Map of habitat utilization of the female green turtle, *Chelonia mydas*, Savannah (#146259) during her post-nesting period (187 d) including an outline of her 50% core use (red) and 95% activity areas (yellow).
APPENDIX P. Minimum convex polygon (MCP) for the internesting period movements of the female green turtle, *Chelonia mydas*, Dionne (#146261). Green star represents tagging location.
APPENDIX Q. Map of habitat utilization of the female green turtle, *Chelonia mydas*, Dionne (#146261) during her internesting period (65 d) including an outline of her 50% core use (red) and 95% activity areas (yellow).

Internesting Period = PTT deployment date until last inferred nest
Transition Period = 14 d period after last inferred nest
Post-nesting Period = more than 14 d after last inferred nest
APPENDIX S. Map of habitat utilization of the female green turtle, *Chelonia mydas*, Dionne (#146261) during her post-nesting period (158 d) including an outline of her 50% core use (red) and 95% activity areas (yellow).
APPENDIX T. Minimum convex polygon (MCP) for the internesting period movements of the female green turtle, *Chelonia mydas*, Victoria (#146262). Green star represents tagging location.
APPENDIX U. Map of habitat utilization of the female green turtle, *Chelonia mydas*, Victoria (#146262) during her internesting period (58 d) including an outline of her 50% core use (red) and 95% activity areas (yellow).
APPENDIX W. Map of habitat utilization of the female green turtle, *Chelonia mydas*, Victoria (#146262) during her post-nesting period (88 d) including an outline of her 50% core use (red) and 95% activity areas (yellow).
APPENDIX X. Minimum convex polygon (MCP) for the post-nesting period movements of the female green turtle, *Chelonia mydas*, Cheryl (#146264).
APPENDIX Y. Table of PTT attachment durations for green sea turtles, *Chelonia mydas*, tracked in published studies with deployment location, PTT type, and epoxy utilized. * means that the same turtle was tracked again the next nesting season.

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