EPIBIONTS OF HAWKSBILL SEA TURTLES IN SOUTHEAST FLORIDA

by

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This thesis was prepared under the direction of the candidate's thesis advisor, Dr. Jon Moore, and has been approved by members of her supervisory committee. It was submitted to the faculty of The Honors College and was accepted in partial fulfillment of the requirements for the degree of Bachelor of Science in Liberal Arts and Sciences.

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ABSTRACT

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Sea turtles, like all marine vertebrates, can host considerable populations of epibionts, i.e., externally-attached symbiotic organisms on the skin and shell. These organisms can form facultative, obligate, and sometimes endemic commensal relationships with sea turtles, whose outer surface provides an insular, mobile substrate for their colonization and dispersal. Juvenile hawksbill turtles, *Eretmochelys imbricata*, living off Florida's east coast can develop considerable epibiotic growth. I analyzed 236 photographs of 213 hawksbill turtles from SE Florida to document colonization patterns, relative abundance, and ecology of macroscopic commensals, including sea turtle barnacles (*Chelonibia* spp.), fire coral (*Millepora* spp.), and sponges (Porifera). I found that the epibionts increased significantly in overall abundance with turtle size. Hawksbill epibionts may reflect turtle movement and dispersal and can serve as a model for studying successional processes of epibiotic colonization.

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INTRODUCTION

The hawksbill turtle, *Eretmochelys imbricata*, one of seven sea turtle species, is distributed throughout tropical and sub-tropical oceans, living primarily in near shore coral reefs, coastal seagrass, and hardbottom habitats (Mortimer and Donnelly 2008). Post-hatchling hawksbills in the Atlantic and Caribbean have a pelagic stage where they drift with ocean currents, but eventually return to coastal reef habitats as juveniles around 20-25 cm (SCL) (Musick and Limpus 1997). In the Caribbean, hawksbills primarily feed on sponges but have been reported to eat jellyfish, other invertebrates, and marine plants (Bjorndal 2017; Blumenthal et al. 2009). Hawksbill turtles are currently listed as critically endangered on the IUCN Red List as a result of "over-exploitation of adult females and eggs at nesting beaches, degradation of nesting habitats, take of juveniles and adults in foraging areas, incidental mortality relating to marine fisheries, and degradation of marine habitats" (Mortimer and Donnelly 2008). Due to their decreasing numbers, it is imperative to study and protect these organisms not only to ensure the species will survive, but also to promote biodiversity. Hawksbills increase biodiversity through their trophic and daily interactions by proving a biogenic habitat for epibionts (Frick et al. 2003; Borkhanuddin et al. 2008).

Sea turtles are known to host an assortment of epibiotic organisms that settle on the exterior shell and skin (Frazier et al. 1984; Canine 1986; Frick et al. 1998). The habitat range of each turtle determines the epibionts that can colonize them (Canine 1986; Frazier et al. 1991; Schärer 2001). This factor can be used to elucidate the environmental distribution of an individual turtle as well as their relative life stage. Hawksbill sea turtles have been noted to host an array of epibionts that are associated with coastal reef ecosystems including algae, mollusks, annelids, crustaceans, sponges, corals, tunicates, gastropods, bivalves, and bryozoans (Frazier et al. 1985; Frazier et al. 1991; Frazier et al. 1992; Schärer 2001). There are currently over 100 epibionts that are known to have associations with hawksbill sea turtles globally (Frazier et al. 1985; Schärer 2001, Frick et al. 2003). One unique feature of hawksbills is that their keratin scutes overlap, which increases surface area for epibionts to settle (Schärer 2001). These overlaps also provide protection for more delicate epibionts, such as sponges and corals, that do not have as advanced physiological developments for attachment compared to other sessile organisms like barnacles.

One group of epibionts common to all sea turtles are barnacles of the genus *Chelonibia*. The commensal relationship between turtle barnacles and sea turtles has been documented in fossils dating back to the late Miocene (Ross 1963). *Chelonibia* is currently considered to be comprised of two extant species, *Chelonibia testudinaria* and *Chelonibia caretta.* The genus was previously thought to have consisted of four extant species, *C. caretta, C. testudinaria, C. patula, and C. manati* (Figure 1). However, Zardus et al. (2014) found that *C. testudinaria*, *C. patula*, and *C. manati* are genetically indistinguishable despite their distinctive morphological differences (Zardus et al. 2014). More research is needed to clearly delineate the species within the genus *Chelonibia*. *Chelonibia testudinaria* (*C. testudinaria*, *C. patula,* and *C. manati*) have been observed on a variety of host organisms including manatees and horseshoe crabs (Zardus et al. 2014). There has been only one documented occurrence of *C. testudinaria* (previously thought to have been *C. patula*) on an inanimate object, floating sea debris (Frazier et al. 1990).

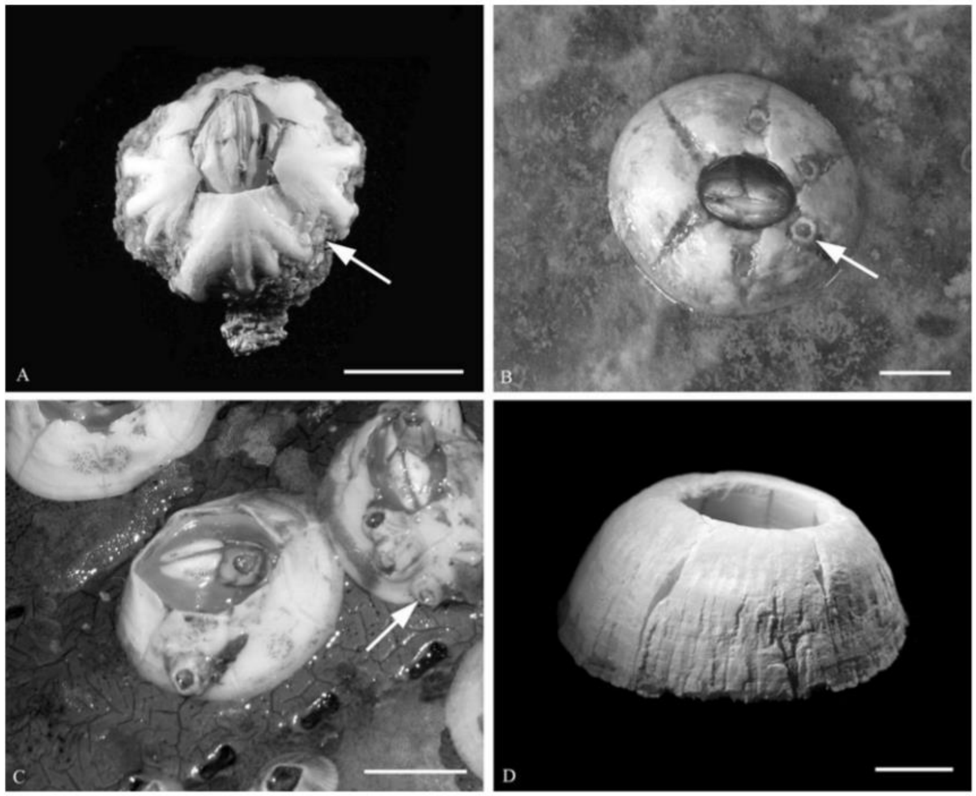

Fig. 1 The four extant described species of chelonibiid barnacles from various hosts. *Arrows* indicate attached conspecific complemental males. **a** *Chelonibia manati* removed from a manatee. **b** *Chelonibia testudinaria* on a green sea turtle. **c** *Chelonibia patula* attached to a horseshoe crab. **d** *Chelonibia caretta* taken from the carapace of a hawksbill sea turtle (*scale bar* 1 cm)

Figure 1. Types of Chelonibia, C. caretta, C. testudinaria, C. patula, *and* C. manati. *Arrows point to the much smaller male barnacles (From Zardus et al. 2014).*

Epibionts of sea turtles can be used to understand behavioral traits (Pfaller et al. 2014) and health (Bunkley-Williams et al. 2008) of the host (Robinson et al. 2016). The relationship between *Chelonibia* spp. and sea turtles can not only provide insight into these factors, but can also be used for individual identification. By studying the spatial dispersal and recruitment of *Chelonibia* on hawksbill turtles, more information about the development, dispersal, and behaviors of both organisms can be obtained.

MATERIALS AND METHODS

Data Collection

The data collected for this project was gathered between 2004-2017 by the Florida Hawksbill Project of the National Save the Sea Turtle Foundation (Wood et al. 2013). The study site spanned from Jupiter to Key West, Florida and included near shore reefs and off shore ledges (Figure 2). Individual hawksbill turtles were captured by hand in a depth range of 2-90ft using either SCUBA or snorkel (all turtles were captured under the permits FWC077, NMFS 18136-03). Once the turtles were brought on board the boat, the following catch data and measurements were taken: GPS coordinates, depth, substrate, and standard morphometrics including straight carapace length from the center notch of the nuchal scute to the tip of the longest pygal scute (Wyneken and Witherington 2001). Any epibionts present were drawn onto the capture data sheet as well as any abnormalities of the carapace, plastron, or extremities (Figure 3). Photographs of the turtle were taken with a small label placed near the turtle for identification of the carapace, plastron, face, cloaca, and any abnormalities or unique features were also taken for each turtle. Before release, metal tags were placed on the trailing edge of each front flipper and a “microchip” PIT tag

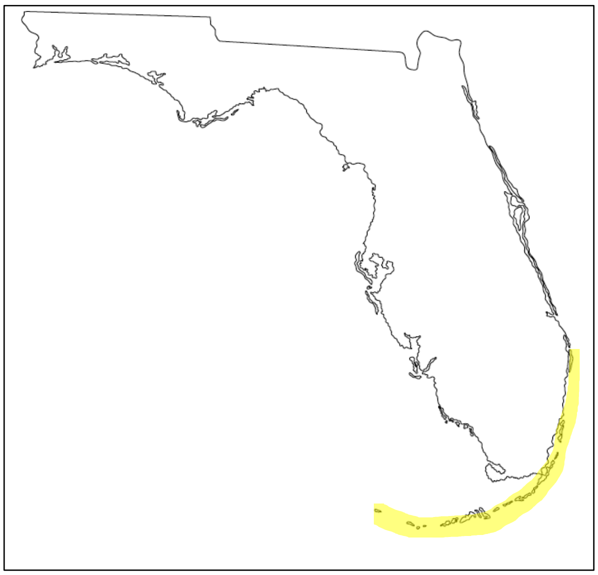

Figure 2. Map of Florida. The highlighted area depicts the span of the study area.

was inserted in the shoulder for future identification. After all the measurements were taken and the turtle was tagged, it was released back into the water.

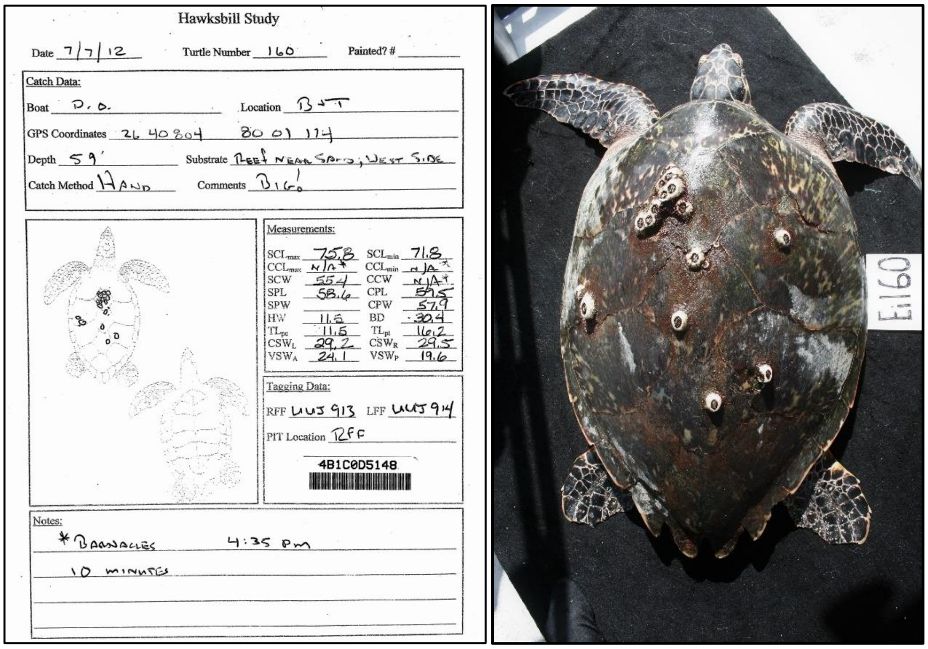

Figure 3. Capture Data sheet and photograph of turtle diagramed on the data sheet

Data Processing

The photographs of the captured turtles were used to quantify and identify the epibionts settled on the carapace. Each turtle was given a unique number based on the chronology of each capture. Using the Windows 10 photo application editing and drawing feature, the number of *Chelonibia* spp. was counted by hand and a red dot was drawn over the barnacle (Figure 4). The number of *Chelonibia* spp. present was recorded in an excel spread sheet. The presence of all other identifiable epibionts including algae, cnidarians, or poriferans were recorded on the spread sheet.

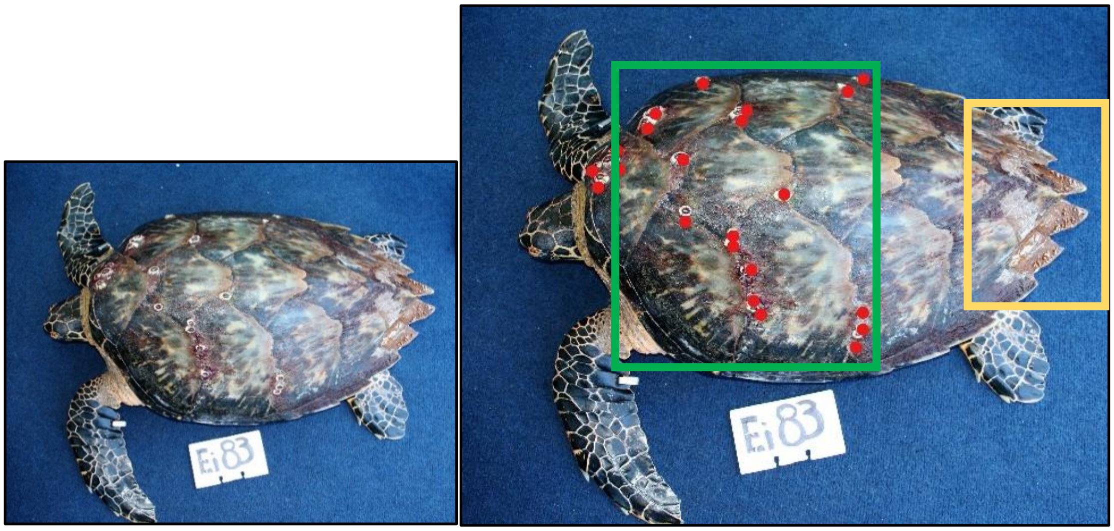

Figure 4. Photograph of Ei83. Red dots drawn over individual Chelonibia spp. *The yellow square highlights fire coral coverage and the green square highlights algae coverage.*

The SCL_{max} for each individual was inserted into the excel spread sheet. The SCL_{max} was used to standardize the size of all of our turtles. The SCL_{max} measurements for each turtles were separated into three size classes: 25-44 cm, 45-64 cm, and 65-84 cm. The size classes were created based of the range of all SCL_{max} measurements of the captured individual turtles. The three size classes allowed for the creation of relative size ranges of our turtles to help delineate between life stages.

For individual sea turtles captured more than once, separate size classes were created. Only the first and second captures were used in this analysis for consistency. The midpoint of the SCL_{max} between the captures was calculated and used to standardize the growth of the turtles since each turtle had differences in the time between captures. Using the range of the calculated midpoints, a new size class breakdown was made for these turtles; 40-54 cm, 55-69 cm, and 70-85 cm.

For individual turtles that were captured more than once, the difference in the number of *Chelonibia* spp. present on the carapace was calculated. The differences were then used to calculate the rate of *Chelonibia* spp. recruitment.

Statistical Analysis

The measurements of SCL_{max} for all individual turtles were used to calcualte the mean size of all turtles captured. A linear regression test was then performed on excel between the abundance of *Chelonibia* spp. and the SCL_{max} of all captured turtles. A One-Way ANOVA was performed in Excel to examine the statistical difference between the three size classes of all turtles captures (excluding recapture data).

A paired, two-tailed t-test was performed on excel between the days between captures and the change in barnacle abundance for all turtles that were captured more than once (N=26). Rate of change was calculated for the average rate of *Chelonibia* spp. recruitment over time per day and per year.

A polynomial regression analysis was run on Excel to examine the change in barnacle colonization rate between the number of days between captures and the change in barnacle abundance between captures.

A linear regression test was run on excel between the number of *Chelonibia* spp. and SCL_{max} to analyze the correlation between barnacle recruitment rate and turtle size.

To analyze the presence of coral growth on the carapace, the percentage of turtles with coral observed on the carapace was calculated. The range and mean SCL_{max} of turtles with a presence of coral on the carapace was calculated to illustrate the relative life stage at which coral begins to colonize on the carapace.

RESULTS

I analyzed photographs of 204 individual turtles. Twenty seven of the 204 turtles were captured more than once. The total number of captures that had photos usable to identify epibionts was 236 turtles. SCL_{max} was recorded for 226 captured turtles.

A variety of epibionts were observed on the hawksbill carapaces. The epibionts included filamentous red and green algae, calcareous red algae, red sponge, *Millepora* sp. (fire coral), and *Chelonibia* spp. (turtle barnacle) (Figure 5). The filamentous red and green algae had the largest overall spatial coverage observed, and often clumped around the base of the settled barnacles. *Chelonibia* spp. was observed most commonly in the upper third of the carapace. Red sponge was most commonly found growing underneath the posterior scutes. *Millepora* spp. was observed growing primarily on the lower third of the carapace, particularly the posterior scutes.

Figure 5.

Calcareous red Algae growing on posterior scutes

Millepora *spp. (fire coral) colonizing around multiple* Chelonibia *spp.*

Red and green filamentous algae growing around two Chelonibi*a spp.*

Red sponge growing underneath scute overlap.

Size Distribution

The size distribution of the 226 turtles with recorded SCL_{max} had a standard bell curve distribution (Figure 6). The SCL_{max} measurements for all captured turtles had a range of 28.4-83.9 cm with a mean SCL_{max} of 55.93 cm. The abundance of turtle barnacles found on the carapace for all captured turtles (N=226) ranged from 0-65 barnacles. The average number of individual barnacles on the carapace for all captures turtles was 11.87 (N=226, μ=11.87).

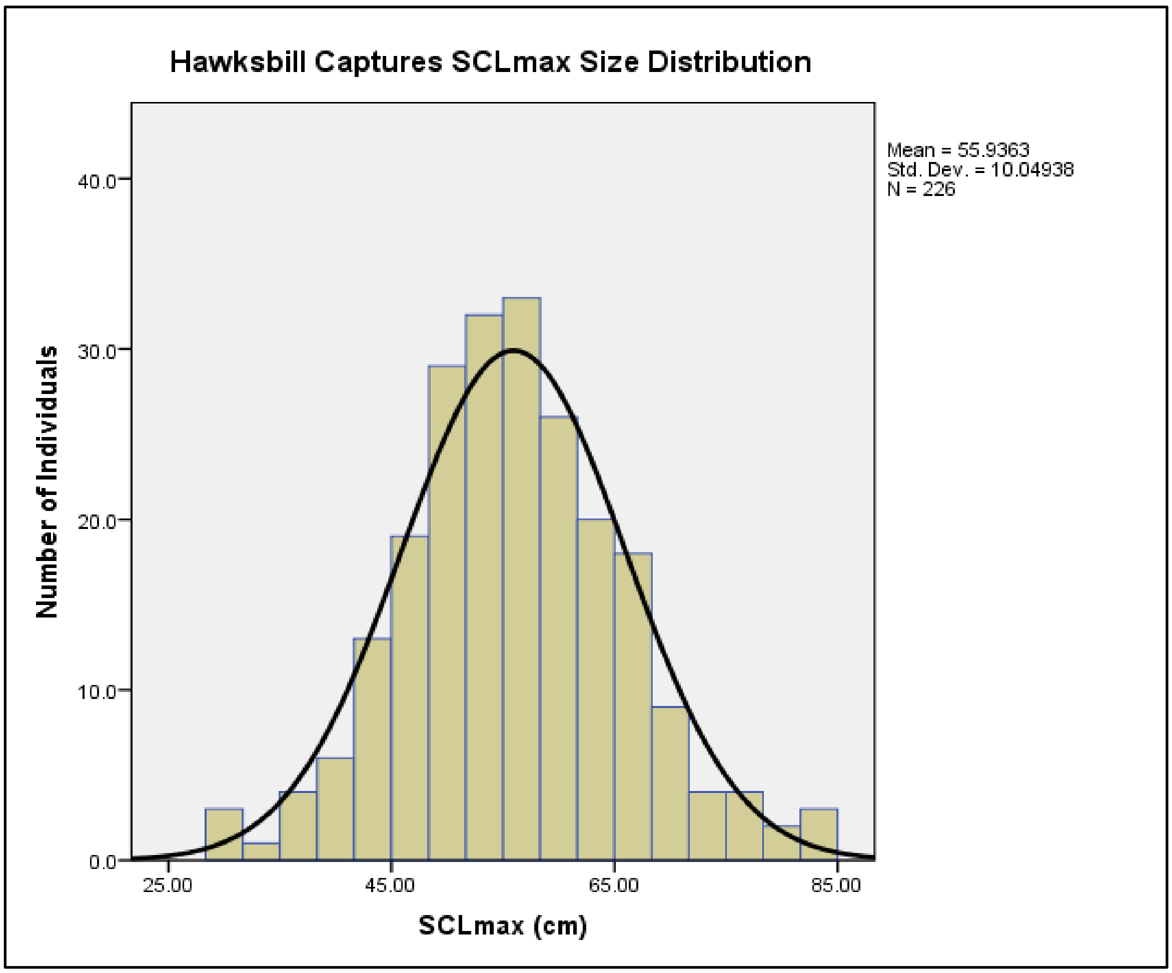

Figure 6. Hawksbill size distribution bell curve

Barnacle Abundance vs. Carapace Size

The resulting R^2 value was 0.2228 and the p-value was significant, rejecting the null hypothesis that the number of barnacles is equal to the SCL_{max} (N=226; R2= 0.2228; regression p-value= 9.74×10^{-16}) (Table 1). This suggests that there is a positive correlation between the number of barnacles present and the size of the turtle shell. When the data was graphed with a logarithmic regression line of best fit, the graph displayed a positive trend with a slight tapering off as the SCL_{max} increased (Figure 7).

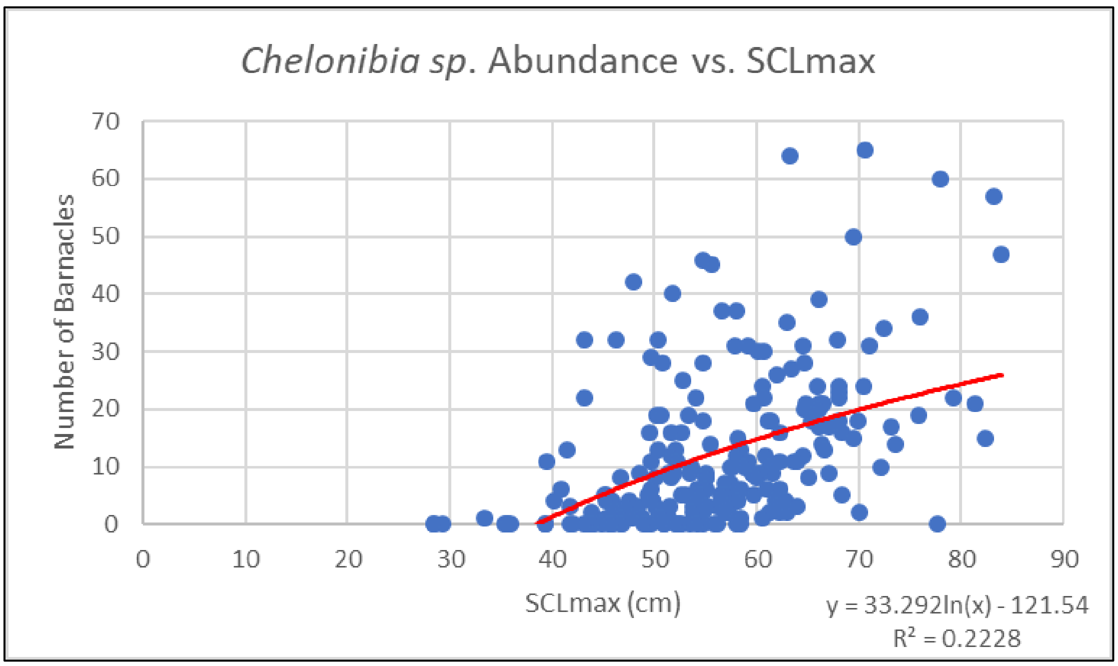

Figure 7. Number of Chelonibia *spp. Barnacles vs. Straight Carapace Length (cm).*

Table 1. Summary of Regression test statistics for barnacle abundance and SCL_{max}

Regression Statistics					
Multiple R	0.494913				
R Square	0.244939				
Adjusted R Square	0.241656				
Standard Error	11.3896				
Observations	232				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	9678.787	9678.787	74.61113	9.74E-16
Residual	230	29836.31	129.7231		
Total	231	39515.1			

Figure 8 shows that the average number of barnacles increases with increasing size: Size class 1: (24-44 cm) N=27 and μ=3.5, Size Class 2: (45-64cm) N=159 and μ=10.3, Size Class 3: (65-84 cm) N=40 and μ=23.5.

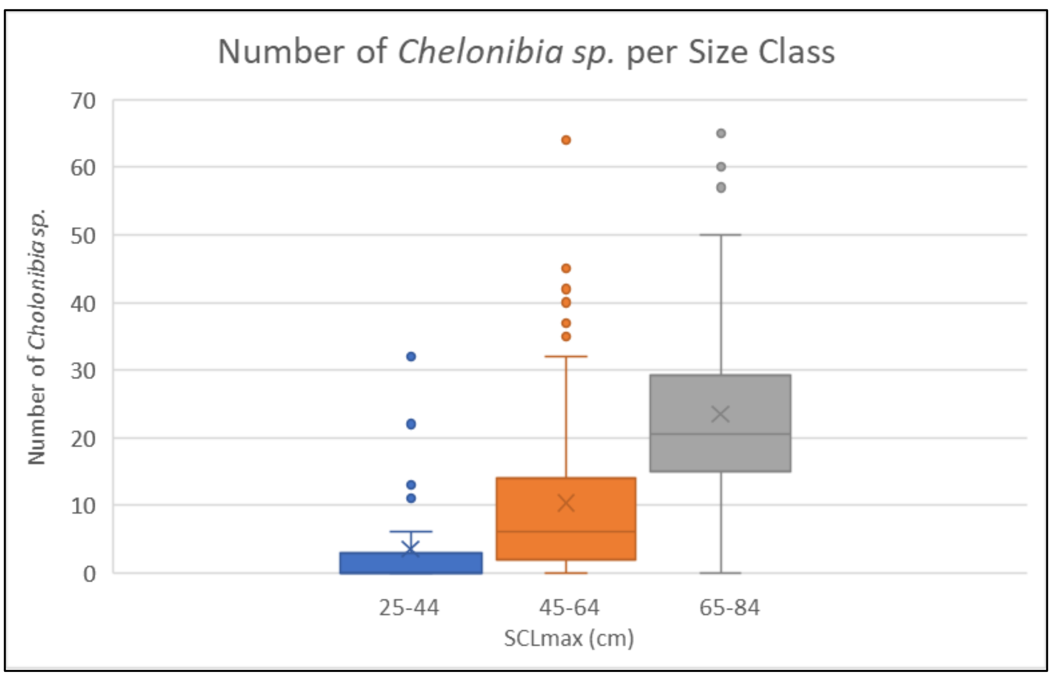

Figure 8. Box and whisker plot of barnacle abundance compared to SCL_{max} per size class.

The data from recaptured turtles was excluded from this test. The test resulted in a significant p-value of 1.61 x e^{-10} (α=0.05, N_1=24, N_2=140, N_3=32) (Table 2). These results suggest that the mean of each size class is statistically significant from each other.

Table 2. Summary of One-Way ANOVA analysis of compared means between the numbers of barnacles found in each size class.

SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	24	94	3.916667	65.03623
Column 2	140	1323	9.45	134.4507
Column 3	32	768	24	200

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6944.226	2	3472.113	25.39818	1.61E-10	3.042717
Within Groups	26384.48	193	136.7072			
Total	33328.71	195				

Barnacle Recruitment Rate

To analyze barnacle recruitment over time, photographs of turtles that were captured more than once were analyzed and compared. Using the number of days between captures and the change in barnacle numbers between captures, average rate of *Chelonibia* spp. recruitment on the carapace was calculated to be 2.6839 barnacles per year (N=26). The results of the paired, two tailed T-test between the days between captures and the change in barnacle abundance rejected the null hypothesis (P-value= 0.000104, N=26, df=25, α=0.05). This suggests that there is a significant difference between the number of days between captures and the increase in barnacle abundance.

The polynomial regression analysis between the number of days between captures and the change in barnacle abundance between captures resulted in a R^2 value of 0.0658 (Figure 9). The polynomial line in the regression graph indicates an initial increase in barnacle recruitment but eventually levels out as the days between captures increases (Figure 9).

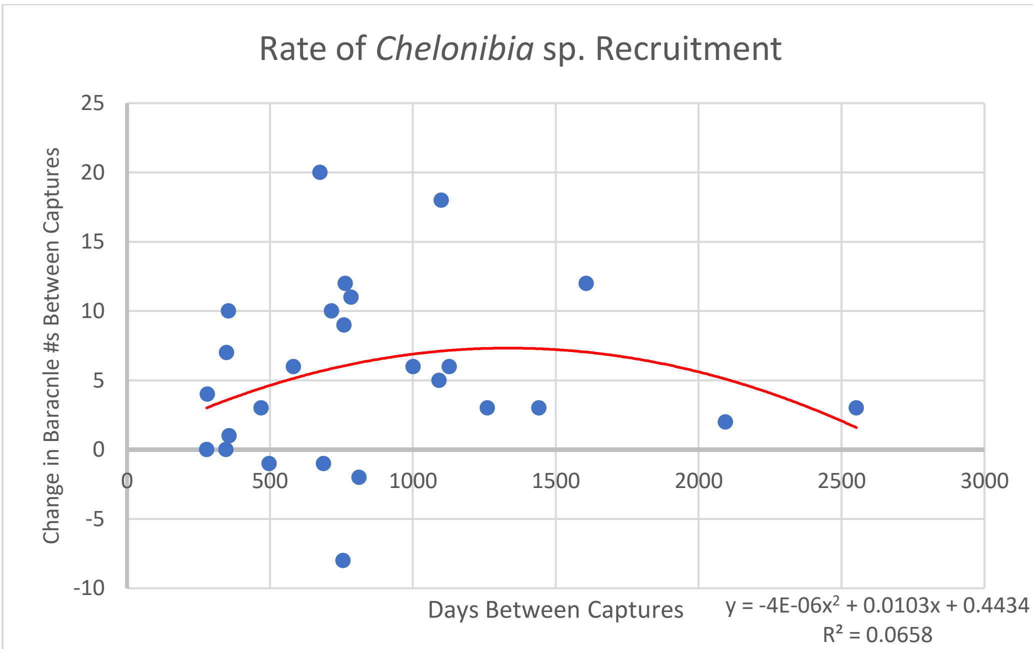

Figure 9. Polynomial regression graph of days between captures and the change in the number of barnacles between captures.

Barnacle Recruitment Rate vs. Carapace Size

The liner regression test between the difference in *Chelonibia* sp. present between captures and the calculated midpoint of SCL_{max} between the two captures resulted in a R^2 value of 0.145 and a p-value of 0.06 (N=25) (Table 3). The scatter plot of the data shows a positive trending line of best fit (Figure 10). These results suggest that there is a marginally significant difference between the number of recruited barnacles and the midpoint size of the turtle

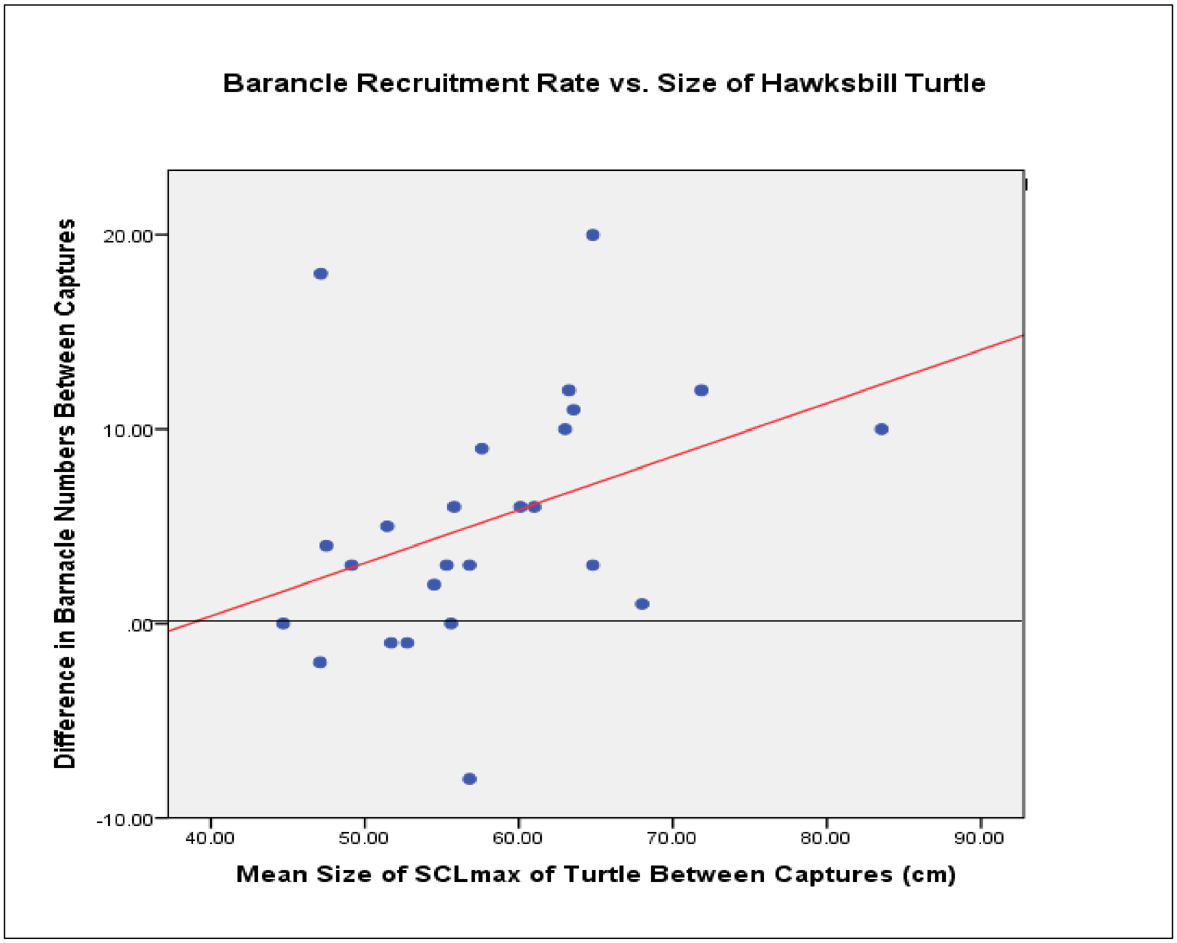

Figure 10. Change in Chelonibia *spp. abundance vs. straight carapace length (cm), reported as the mean size between captures.*

Table 3. Summary of regression test statistics for mean size of SCL_{max} of captured turtles in days and the difference in barnacle abundance between captures.

Regression Statistics					
Multiple R	0.380249				
R Square	0.144589				
Adjusted R Square	0.107397				
Standard Error	6.028089				
Observations	25				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	141.2694	141.2694	3.887665	0.060787
Residual	23	835.7706	36.33785		
Total	24	977.04			

The calculated SCL_{max} midpoints between the first and second captures ranged from 44.7 cm – 83.55 cm. The size classes created based off of that range was 40-54 cm, 55-69 cm, and 70-85 cm. There were 8 individuals in the first size class, with an average difference in barnacles between captures being 3.25 barnacles. The second size class had 15 individuals and 5.6 as the mean difference in barnacles between captures. The third size class, which consists of adult hawksbills, had 2 individuals and a mean difference in barnacle recruitment of 11 barnacles (Table 4).

Table 4. Table of number of individual and the mean difference in barnacles between captures per size class.

Mean Difference in* Chelonibia *sp. between Captures per Size Class			
Size Class	***40-54 cm***	***55-69 cm***	***70-85 cm***
Number of Individuals	*8*	*15*	*2*
Mean of Barnacle # differences	*3.25*	*5.6*	*11*

Coral Presence

A total of 236 individual turtles had photographs that were analyzed to record the presence of *Millepora* spp. (fire coral) on the carapace. 46 individuals had a presence of fire coral on the carapace, which is 20% of turtles in the sample. The size range of turtles that had a presence of fire coral was 46.7 cm – 79.2 cm SCL_{max} with a mean of 61.6 cm. The fire coral was most commonly observed colonizing on the posterior end of the carapace, particularly the two pygal scutes (Figure 11).

Figure 11. Fire coral growth on the lower third of the carapace.

DISCUSSION

Sea Turtle Barnacle Colonization

Sea turtle barnacles settle on a variety or sea turtle species and other organisms (Zardus et al. 2014). For hawksbill sea turtles, I found that *Chelonibia* spp. is commonly found on the carapace and significantly increases in abundance as the turtle's SCL_{max} size increases. I suspect that there is an increase in barnacle recruitment with size because there is a larger area for barnacles to settle. Since barnacles are broadcast spawners (Zardus and Hadfield 2004), the odds of barnacle larva landing and settling on a host turtle is higher with larger carapace size. This idea can also be applied to smaller turtles and why they have a lower average number of barnacles; because the odds of barnacle larvae settling on the shell is lower.

For turtles that were captured more than once, the data showed that *Chelonibia* spp. colonization rate initially increases but eventually plateaus and begins to decrease with an increase in time between captures. Figure 9 shows a polynomial line of best fit that illustrates this trend. *Chelonibia* spp. recruitment rate is marginally significant and has a positive correlation with turtle size over time between captures.

Coral Presence

Corals have been noted to grow on Hawksbills in other places in the Caribbean and were also found primarily on the posterior scutes like what was observed in this study (Schärer 2001; Frick et al. 2003). Corals have also been documented on the carapace of loggerhead sea turtles in the western Gulf of Mexico (Perrault et al. 2015). However, this genus of coral has not been previously documented on hawksbills in the Atlantic or Caribbean. This study may be the first to document and identify fire coral as an associated epibiont of hawksbills in the western Atlantic and Caribbean.

Fire coral occupies multiple niches as both a sessile organism on reefs and on mobile substrates such as the Hawksbill carapace. The colonization of *Millepora* sp. on the carapace of turtles may help increase the biodiversity and range of the species. By studying the growth of coral on itinerant substrates one could gain insights into the ecology and settling, growth, and reproductive behaviors of this species.

Diversity and Colonization of Epibionts

Hawksbills found in Southeastern Florida accumulate a variety of epibionts on their carapaces including red and green filamentous algae, calcareous red algae, *Chelonibia* spp., red sponge, and *Millepora* spp. (fire coral). Other studies of hawksbill epibionts in the Caribbean have recorded a greater diversity of epibionts. Using epibiont samples from 105 wild hawksbills captured off Mona Island, Puerto Rico, Schärer (2001) recorded an epibiont diversity representing 13 phyla of animals and 4 groups of algae. Since physical samples were not collected in this study, more detailed observations of organisms were limited by photo clarity and quality. Greater sampling of epibionts in the field are needed to create a more complete list of present carapace epibionts.

Our SCL_{max} measurements suggest that Southeast Florida is primarily populated by sub-adults and servew as a developmental habitat before the turtles migrate to nesting beaching throughout the Caribbean. As a result, the data primarily reflects epibiotic associations with sub-adult to young adult turtles. The results show that overall carapace diversity increases over time for hawksbills. As juveniles, hawksbills have generally clear shells with little to no epibionts, but as the turtles grow into the sub-adult phase more epibionts began to appear. As adults (70+ cm SCL_{max}), 95% of sampled turtles (N=21) had a presence of epibionts on their carapaces. Though more analysis needs to be done, there appeared to be a succession of colonizers on the carapace. The barnacles and filamentous algae began recruiting at the smallest size turtle with an SCL_{max} of 28.4 cm. Encrusting coralline algae did not appear until a size of 40.5 cm $SCL_{max.}$ Finally, coral did not appear on any carapace less than 43.9 cm. This data suggests that hawksbills are not exposed to encrusting epibionts, such as coralline algae and coral, until they reach about 40 cm, which is about the time they migrate to habitats where these organisms are present. The size class progression of epibionts successional colonization can be explained by the migration and movement patterns of juvenile hawksbills.

The specific spatial colonization of these epibiotic organisms observed on the carapace may be indicative of each species' preference for space. These preferences can provide insight into ecological roles, tolerances, and inter-species competition. Unlike stable environments, such as a rocky shore line, that may have consistent tidal patterns and temperature ranges, the recruitment, behavior, and well-being of epibionts on hawksbills are largely dependent on the behavior of their host.

While the host's behavior is a factor, it is also important to note the density of hosts and their proximity to each other. Southeast Florida has a high population of migrant sea turtles that travel to these beaches annually to nest between March and October (Brost et al. 2015). Primarily these nesting turtles are loggerheads, greens, or leatherback turtles, but all share similar epibionts with hawksbills. The population increase during this nesting season may allow for an increase of epibionts abundance and biodiversity.

Similar to terrestrial pollinators like bees, hawksbills have the potential to influence the movement of various epibiotic organisms between habitats (Frick et al. 2003; Borkhanuddin et al. 2008). As individuals forage, rest, and interact with other hawksbills, the transfer of both mobile and sessile epibionts may occur, such as snapping shrimp and brittle stars which have both been documented on hawksbills (Frick et al. 2003; Borkhanuddin et al. 2008). The transfer of organisms between hosts and habitats, especially for a global and highly migratory species like hawksbills, may have a role in maintaining biodiversity for a variety of ecosystems.

The biodiversity of hawksbill epibionts may explained through the consideration of the island biogeography theory. Island Biogeography Theory, developed by E.O Wilson and Robert MacArthur, describes the colonization patterns of islands, stating that proximity to other islands and the island's size determines rate of species colonization, rate of species extinction, and population and species abundance (Wilson and MacArthur 1967). This theory could be applied to the colonization of hawksbills by epibionts, as they are essentially mobile islands. The biogeography of epibionts on mangrove prop roots in Belize was found to have a similar log-log plot slope as those found in island communities described by the theory of island biogeography (Farnsworth and Ellison 1996; Wilson and MacArthur 1967). Although there are many factors involved in epibiont colonization on hawksbills, the results of this study and other hawksbill epibiont studies could possibly be explained in part by the island biogeography theory.

In Southeast Florida, the Gulf Stream runs parallel with the shoreline and transports warm waters from the Caribbean and Gulf of Mexico. This current may play a role in transporting larvae of organisms such as barnacles and corals (Norcross and Shaw 1984). *Chelonibia testudinaria* has a nine-day, seven stage larval phase, consisting of a planktonic period where they feed, develop, and search for a host substrate to settle on (Zardus and Hadfield 2004). In addition, since the larval phase is only nine days, the host turtles must be inhabiting an area with sufficient population densities and for a long enough period of time for the larvae to undergo a full development cycle (Zardus and Hadfield 2004). These factors of dispersal of larvae in barnacles can have similar applications to coral epibionts. *Millepora* spp. sexual reproduction occurs seasonally and has a planktonic medusa life stage (Lewis 2006). The Gulf Stream may play a role in transporting barnacle and coral larvae during the planktonic phase, ultimately effecting the diversity and abundance of epibionts colonizing on hawksbill turtles in Southeast Florida.

Hawksbill epibiont diversity and abundance is also controlled by symbiotic cleaner species (Sazima et al. 2010). Cleaner fish and shrimp have been documented to prey on epibionts of hawksbills (Sazima et al. 2004; Grossman et al. 2006). These predatory species limit the growth of epibionts on hawksbills and also provides space for new recruits to settle on the shell.

Hawksbills incidentally rub their shells against the reef during daily behavioral activities, which disturbs the epibiont community on their shell. As these turtles grow larger, it becomes more difficult to avoid epibionts being rubbed off when foraging on reefs. This suggests that as the turtles grow larger, the number of epibionts may be limited more due to the increased likelihood that the epibionts would be rubbed of. It has also been noted that barracudas will rub on the carapace of hawksbills as a scratching surface to possibly rid the fish of external parasites (Grossman et al. 2009). These external forces acting on the hawksbills carapace disrupts and damages the epibionts occupying the substrate. Ultimately, just like the predatory species, this creates new inhabitable space for epibionts and restricts the abundance of epibionts on the carapace.

Hawksbill epibionts are also subject to anthropogenic forces. Freshwater inputs from inlets may be a stressor on epibionts. Beach renourishments can cause silting which has been noted to be deleterious to barnacles and coral growth (Tomilixsox 1969; Pillai 1975). Human interactions may play a role in limiting epibioints on hawksbills.

Future studies

Further investigation is needed to fully assess the biodiversity and ecology of epibionts on hawksbill sea turtles. Spatial distribution and rate of colonization of epibionts should be evaluated in order to examine the rate of growth on the carapace as well as spatial preferences. This study only recorded macro-epibionts, but future studies should identify micro-epibionts on hawksbills. Robinson et al. has identified over 18 taxa of diatoms that were present on every species of sea turtle (Robinson et al. 2016). The data could also be expanded to create criteria for health assessments of wild turtles by using the abundance of epibionts abundance and coverage as an indicator that an individual requires medical assistance (Lazo-Wasmen et al. 2007, Flint et al. 2009).

CONCLUSIONS

A variety of epibionts were identified through the analysis of photographs from 236 wild hawksbill sea turtles captured between 2004-2017 in Southeast Florida. These epibionts included filamentous red and green algae, calcareous red algae, red sponge, *Chelonibia* spp. (turtle barnacle), and *Millepora* sp. (fire coral). The presence of *Chelonibia* spp. was found to increase significantly with an increase in turtle size (SCL_{max}). *Chelonibia* spp. recruitment over time increases initially but begins to decrease as the turtle reaches adult size (~70 cm). This trend may be explained through the theory of island biogeography. Coral colonization by *Millepora* spp on hawksbills may be the first recorded occurrence of this species as an epibiont growing on the carapace of hawksbills. More research is needed to fully identify the biodiversity of epibionts on hawksbill sea turtle carapaces. Overall epibionts are important to study as they maintain a functioning ecosystem on the exterior of organisms to which they may be endemic. Epibionts can be used to provide insight into the habitat use, migration, and ecological influence of the host animal.

APPENDIX

A. Table of turtles with a presence of coral and their SCL_{max}

Turtle	SCLmax
Ei07	67.9
E108	66.3
Ei13	57.9
Ei15 (3)	64.5
Ei15 (4)	67
Ei17 (2)	
Ei18 (2)	69.5
Ei18 (3)	69.9
Ei22	61.3
Ei22 (2)	64.7
Ei33	68.1
Ei34	46.7
Ei36	57.4
Ei37(2)	54.1
Ei38 (3)	61.1
Ei39	68.1
Ei39 (2)	68
Ei50	60.1
Ei63	53.5
Ei64 (2)	63.6
Ei66	56.6
Ei69	62.2
Ei71	67
Ei71 (2)	75.4
Ei83	60.6
Ei90	55
Ei99	60.7
Ei107	47
EI120	57.2
Ei126	50.8
Ei127	71
Ei129	56.9
Ei140	79.2
Ei142	59.2
Ei144	58
Ei145	54.7
Ei147 (4)	
Ei163	68
Ei168	
Ei175	61
Ei175 (2)	66.1
Ei176	57.3
Ei178	56.9
Ei178 (2)	65.1
Ei189	54.6
Ei190	58.5

B. Table of capture dates, barnacle counts, and SCL_{max} for turtles captured more than once.

Turtle	Capture 1 date	Capture 2 date	Barnacle #s Capture 1	Barnacle #s Capture 2	days 1-2	size1	size 2	mean size	Barnacle difference 1-2
Ei05	6/11/2004	7/14/2006	2	14	763	70.1	73.6	71.85	12
Ei15	7/5/2004	8/3/2006	3	12	759	54.3	60.9	57.6	9
Ei17	7/25/2004	8/26/2017	11	18	4780				7
Ei18	7/26/2004	12/18/2008	3	15	1606	57	69.5	63.25	12
Ei22	8/12/2004	7/28/2006	10	20	715	61.3	64.7	63	10
Ei23	8/20/2004	7/31/2008	2	5	1441	61.2	68.4	64.8	3
Ei28	5/12/2005	4/25/2006	17	24	348				7
Ei37	7/20/2005	7/23/2008	4	22	1099	40.2	54.1	47.15	18
Ei38	7/21/2005	4/26/2006	32	32	279	43.1	46.3	44.7	0
Ei39	7/21/2005	7/13/2006	23	24	357	68	68	68	1
Ei40	8/2/2005	10/23/2007	3	1	811	41.8	52.4	47.1	-2
Ei56	5/26/2006	10/5/2007	2	1	497	46	57.4	51.7	-1
Ei59	6/16/2006	7/17/2009	5	11	1127	49.4	62.2	55.8	6
Ei61	6/28/2006	6/23/2009	5	10	1091	45.3	57.6	51.45	5
Ei62	6/28/2006	7/22/2008	45	37	755	55.6	58	56.8	-8
Ei64	7/13/2006	2/15/2008	5	11	582	56.6	63.6	60.1	6
Ei67	7/24/2006	6/10/2008	19	18	687	50.7	54.8	52.75	-1
Ei79	9/15/2006	7/21/2008	30	50	675	60.1	69.5	64.8	20
Ei104	6/27/2007	6/16/2008	47	57	355	83.9	83.2	83.55	10
Ei119	7/31/2008	5/8/2009	0	4	281	45.2	49.8	47.5	4
Ei132	8/10/2009	8/5/2016	0	3	2552	46.7	63.9	55.3	3
Ei154	9/29/2011	6/23/2017	22	24	2094	43.1	65.9	54.5	2
Ei171	4/19/2013	9/20/2016	1	4	1260	50.8	62.8	56.8	3
Ei175	7/28/2014	9/19/2016	6	17	784	61	66.1	63.55	11
Ei178	9/8/2014	6/5/2017	2	8	1001	56.9	65.1	61	6
Ei185	6/19/2015	9/20/2016	0	3	469	46.8	51.5	49.15	3
Ei189	6/24/2016	6/5/2017	5	5	346	54.6	56.6	55.6	0

C. Table of raw data of epibiont presence

Turtle	date captured	SCLmax	*Chelonibia testudinaria*, barnacles	Coral	algae	Sponge
Ei02	4/5/2004	41.8	0			
Ei04	5/28/2004	61.8	4			
Ei05	6/11/2004	70.1	2			
Ei05 (2)	7/14/2006	73.6	14			
Ei06	6/11/2004	62.2	2			
Ei07	6/11/2004	67.9	32	X, 12 C. Tes.	X, red	
Ei08	6/17/2004	66.3	21	X 1 C. Tes	X, red	X
Ei09	6/23/2004	62.3	6		X, red	
Ei10	6/25/2004	50.1	3			
Ei10 (2)	8/4/2010	70.6	25			
Ei11	6/25/2004	54.7	0			
Ei12	6/25/2004	51.8	40		X, green	
Ei13	6/30/2004	57.9	31	X, 5 C. tes	X, red	
Ei14	6/30/2004	57.5	10			
Ei15	7/5/2004	54.3	3			
Ei15 (2)	8/3/2006	60.9	12		X,red	
Ei15 (3)	2/8/2008	64.5	12	X, fire, 2 C.test	X, red	
Ei15 (4)	7/27/2009	67	9	X fire coral	X, red	
Ei16	7/21/2004	82.3	15			
Ei17	7/25/2004	59.2	11			
Ei17 (2)	8/26/2017		18	X fire coral, multiple colonies		
Ei18	7/26/2004	57	3		X, red	
Ei18 (2)	12/18/2008	69.5	15	X fire	X, red and green	
Ei18 (3)	6/12/2009	69.9	18	X, fire	X,red	
Ei19	7/26/2004	48.4	3			
Ei20	8/5/2004	77.7	0			
Ei21	8/5/2004	50.2	19			
Ei22	8/12/2004	61.3	10	X, fire	X, red	
Ei22 (2)	7/28/2006	64.7	20	X, fire	X,red	
Ei22 (3)	6/8/2007	66	21	X, fire	X, red	
Ei23	8/20/2004	61.2	2		X,red	
Ei23 (2)	7/31/2008	68.4	5		X, red and green	
Ei24	8/26/2004	59.5	9			
Ei24 (2)	1/17/2007	62.2				

Ei25	1/7/2005	61.6	9		X, red	
Ei26	2/16/2005	47.5	4			
Ei27	4/21/2005	54.3	1			
Ei28	5/12/2005	73.2	17		X,red	
Ei28 (2)	4/25/2006		24		X,red	
Ei29	5/12/2005	63.2	64			
Ei30	6/3/2005	68.4	16		X, red	
Ei31	6/3/2005	66.3	14		X,red	
Ei32	6/15/2005	49.6	11		X,red	
Ei33	6/15/2005	68.1	22	X, fire?	X,red	X
Ei34	6/22/2005	46.7	8	X, fire	X, red	
Ei35	6/22/2005	52.1	13		X, red	
Ei36	7/6/2005	57.4	7	X, fire?	X, red, green	
Ei37	7/20/2005	40.2	4			
Ei37(2)	7/23/2008	54.1	22	X, fire	X, red	
Ei38	7/21/2005	43.1	32		X,red	
Ei38 (2)	4/26/2006	46.3	32		X,red and green	
Ei38 (3)	8/20/2009	61.1	18	X, fire	X, red, green, pink calc	
Ei39	7/21/2005	68.1	23	X, fire	X, red, green	
Ei39 (2)	7/13/2006	68	24	X, fire	X red	
Ei40	8/3/2005	41.8	3			
Ei40 (2)	10/23/2007	52.4	1		X, red, corraline	
Ei41	8/3/2005	51.7	8			
Ei42	8/5/2005	48.8				
Ei42 (2)	2/5/2008	62.3	9		X,red	
Ei42 (3)	1/6/2009	64.3	11		X, red	
Ei42 (4)	9/6/2010	67.7	12		X,red maybe coraline	
Ei43	8/5/2005	66.5	21		X,red	
Ei44	8/5/2005	70.6				
Ei45	8/10/2005	59.7	5		X,red	
Ei46	8/12/2005	62.1	3			
Ei47	8/15/2005	64.5	31		X, red	
Ei48	8/17/2005	45.3	1		X, red	
Ei49	8/19/2005	56.1	0		X, red	
Ei50	8/19/2005	60.1	9	X, fire small	X, red	
Ei51	8/31/2005	55.8				
Ei52	9/14/2005	64.9				
Ei53	9/30/2005	58.5				
Ei54	10/12/2005	49				
Ei54 (2)	10/6/2009	58.5	13		X, red and green	
Ei55	5/24/2006	52.7	16			

Ei56	5/26/2006	46	2		X, red coraline
Ei56 (2)	10/5/2007	51.4	1		X, red coraline
Ei57	6/7/2006	35.7	0		
Ei58	6/16/2006	66.7	13		X, red and green
Ei59	6/16/2006	49.4	5		X, red
Ei59 (2)	7/17/2009	62.2	11		X, red
Ei60	6/21/2006	81.3	21		
Ei61	6/28/2006	45.3	5		
Ei61 (2)	6/23/2009	57.6	10		X, red
Ei62	6/28/2006	55.6	45		X, red
Ei62 (2)	7/22/2008	58	37		X,red
Ei63	6/28/2006	53.5	9	X, fire	X, red and green
Ei64	7/13/2006	56.6	5		X, red
Ei64 (2)	2/15/2008	63.6	11	X,fire	X,red
Ei65	7/14/2006	41.4	13		X,red, red coraline alage
Ei66	7/24/2006	56.6	37	X,fire	X,red , red coraline
Ei67	7/24/2006	50.7	19		X,red
Ei67 (2)	6/10/2008	54.8	18		X,red
Ei68	7/28/2006	70.6	65		
Ei69	8/7/2006	62.2	16	X, fire	
Ei70	8/10/2006	78	60		X,red
Ei71	8/16/2006	67	17	X,fire	
Ei71 (2)	9/16/2008	75.4		X,fire	
Ei72	8/21/2006	54.7	28		X,red and green
Ei73	8/21/2006	54.8	46		X, red
Ei74	9/7/2006	51	0		
Ei75	9/7/2006	58.1	*14		
Ei76	9/13/2006	60.1	*12		
Ei77	9/13/2006	69.5	*1		
Ei78	9/15/2006	58.4	15		X, red
Ei79	9/15/2006	42	30		X, red and green
Ei79 (2)	7/21/2008	54.2	50		X, red
Ei80	9/22/2006	60.6	0		
Ei81	9/22/2006	53.6	0		X,red
Ei82	9/25/2006	50.4	6		X,red
Ei83	9/25/2006	64	24	X,fire	
Ei84	9/27/2006	53.3	10		X,red
Ei85	9/27/2006	60.7	32		X,red, coraline
Ei86	10/2/2006	39.5	11		X,red
Ei87	10/2/2006	55	19		X, red
Ei88	10/2/2006	43.8	22		X, red

Ei89	12/1/2006	40.9	11		X, red green corrlaine	
Ei90	12/4/2006	64.6	9	X, fire	X,red	
Ei91	12/29/2006	62	2		X, red	
Ei92	12/29/2006	56.4	6		X, red	
Ei93	1/3/2007	60.5	28		X, red	
Ei94	1/24/2007	48	26		X, red	
Ei95	2/9/2007	51.3	5		X, red, pink coraaline	
Ei95 (2)	9/17/2008	47.8				
Ei96	3/8/2007	60.7	42		X red, coraline	
Ei97	5/11/2007	48.8	9		X, red	X, red sponge
Ei98	6/6/2007	72.8	1		X, red, pink coraaline	
Ei99	6/6/2007	76	30	X,fire	X, red	X, red sponge
Ei100	6/15/2007	51.7	1			
Ei101	10/19/2007	83.9				
Ei102	6/20/2007	83.2	36			
Ei103	6/25/2007	55.1	12		X,red green	
Ei104	6/27/2007	51	47			
Ei104 (2)	6/16/2008	47	57			
Ei105	7/2/2007	43.4	8		X,red	
Ei106	7/11/2007	52.2	0		X,green	
Ei107	8/29/2007	53.5	1	X, green unidentified coral		
Ei108	10/26/2007	50.3	90			
Ei109	12/6/2007	58.5	11		X,red	
Ei110	6/10/2008	72.1	0		X,red	
Ei111	6/18/2008	70.5	13		X,red and green	
Ei112	6/24/2008	51.6	6		X,red and green	
Ei113	7/17/2008	45.1	10			
Ei114	7/23/2008	62.9	24		X,red	
Ei115	7/29/2008	46.7	16		X,red	
Ei116	7/29/2008	48.5	5		X,red	
Ei117	7/29/2008	45.6	2		X,red and green	
Ei117 (2)	7/3/2017	49.8				
Ei118	7/29/2008	57.2	9		X,red and green	
Ei119	7/31/2008	45.9	0		X,red and green	
Ei119 (2)	5/8/2009	52.6	4		X,red and green	
EI120	8/4/2008	53.8	4	X,fire	X,red	
Ei121	9/17/2008	63	4		X,red and green	

Ei122	12/19/2008	64.8	5		X,red	
Ei123	5/7/2009	50.8	3		X,red and green	X,red sponge
Ei124	5/7/2009	71	35		X,red and green	
Ei125	6/18/2009	72.4	21		X,red	X,red sponge
Ei126	6/18/2009	56.9	28	X,fire	X,red and pink coralline	
Ei127	7/10/2009	59.6	31	X,fire	X,red and green	
Ei128	7/16/2009	49.3	34		X, red, green, pink calc	
Ei129	7/17/2009	46.7	7	X,fire	X,red, green, pink calc	
Ei130	8/5/2009	63.9	9		X,red	
Ei131	8/10/2009	44.9	0		X,red	
Ei132	8/10/2009	60.4	0		X,red, green pink calc	
Ei132 (2)	8/5/2016	45.3	3		X,red green, pink calc	
Ei133	8/28/2009	55.5	0		X,red	
Ei134	9/17/2009	61.4	9		X,red and green	
Ei135	9/23/2009	52.7	4		X,red and green	
Ei136	9/25/2009	53	14		X,red	
Ei137	10/6/2009	79.2	18		X, red and green	
Ei138	10/9/2009	47.3	0			
Ei139	5/20/2010	59.2	5		X,red and green	
Ei140	6/16/2010	56.5	22	X, fire, green?	X,red, green, red calc	
Ei141	6/17/2010	58	3		X,red	
Ei142	7/1/2010	54.7	31	X,fire	X,red	
Ei143	7/1/2010	50.4	3		X,red	
Ei144	8/16/2010	43.9	12	X,fire	X,red	
Ei145	10/20/2010	49.5	2	X,fire	X,red, pink calc	
Ei145 (2)	9/28/2012	55				
Ei145 (3)	5/18/2013	52.5				
Ei146	10/22/2010	50.1	1			
Ei147	7/25/2011	51.9	0			
Ei147 (2)	7/31/2012	53.7				
Ei147 (3)	7/23/2013	43.1				
Ei147 (4)	6/18/2017	65.9	8	X,fire	X,red, pink calc	
Ei148	8/18/2011	57	16			

Ei149	8/19/2011	55.9	8		X,red	
Ei150	8/19/2011	54.2	0		X,red calc ?	
Ei151	9/1/2011	46.8	8		X,red and green	
Ei152	9/1/2011	49.6	9		X,red	
Ei153	9/29/2011	75.8	2		X,red and green	
Ei154	9/29/2011	58.8	22		X,red green, pink calc	
Ei154 (2)	6/23/2017	56.8	24		X,red	
Ei155	1/21/2012	68	5		X,red, red calc	
Ei156	3/25/2012	56.2	0		X, red	
Ei157	3/31/2012	52.8	0		X, red	
Ei158	6/17/2012	54.7	1		X, red and green	
Ei159	7/3/2012	58	6		X,red	
Ei160	7/7/2012	44	19		X,red	X,red sponge
Ei161	7/16/2012	55.1	10		X,red, green	
Ei162	7/24/2012	44	4		X,red and pink calc	
Ei163	8/4/2012	50.8	18	X,frire coral	X, red	
Ei164	8/14/2012	62.8	3		X, red	
Ei165	9/9/2012	49.7	25		X,red	
Ei165 (2)	9/23/2013	60				
Ei165 (3)	5/7/2014	63.4				
Ei166	9/9/2012	61	0		X, pink calc	
Ei167	9/21/2012	66.1	0		X, red and green	
Ei168	3/29/2013	57.3		X, Fire coral		
Ei169	3/29/2013	49.6	6		X,red	
Ei170	4/7/2013	56.9	0		X, red green and pink calc	
Ei171	4/19/2013	65.1	1		X, red	
Ei171 (2)	9/30/2016	58.2	4		X,red	
Ei172	4/26/2013	57.2	29		X,red, pink calc	
Ei173	5/12/2013	43.6	8			
Ei174	6/27/2013	66.1	27		X red	
Ei175	7/28/2014	60.6	6	X,fire		X,red sponge
Ei175 (2)	9/19/2016	49.8	17	X, Fire coral		
Ei176	8/8/2014	46.8	2	X,fire	X,red	
Ei177	9/6/2014	51.5	0		X, red and green	
Ei178	9/8/2014	57.2	2	X,fire	X,red, pink	

Ei178 (2)	6/5/2017	66	8	X,fire	X, red, pink calc	
Ei179	9/8/2014	49.7	4		X, red	
Ei180	11/14/2014	54.6	4		X,red	
Ei181	12/15/2014	56.6	0		X, red and green	
Ei182	12/19/2014	58.5	39		X,red	
Ei183	6/8/2015	54.5	1		X,red	
Ei184	6/14/2015	59.7	4		X,red and green	
Ei185	6/19/2015	45.8	0		X,red and green	
Ei185 (2)	9/30/2016	49	3		X,red	
Ei186	8/14/2015	52.2	3		X,red and green	
Ei187	8/21/2015	39.3	20		X,red and green	
Ei188	9/4/2015	39.3	6		X,red and green	
Ei189	6/24/2016	55.2	5	X,fire	X,red	
Ei189 (2)	6/5/2017	50.8	5		X, red and green	
Ei190	7/25/2016	45.8	1	X,fire	X,red and green	
Ei191	8/4/2016	29.3	5		X,red and green	
Ei192	8/4/2016	35.4	21		X,red and green	
Ei193	8/17/2016	52.1	0			
Ei194	8/19/2016	36	0			
Ei195	8/20/2016	35.5	0			
Ei196	8/20/2016	65.3	0			
Ei197	9/3/2016	43.4	0			
Ei198	9/4/2016	43.1	3			
Ei199	9/16/2016	28.4				
Ei200	12/8/2016	33.4				
Ei201	7/10/2017	28.4	1		X,red and green	X, red sponge
Ei202	7/20/2017	39.8	0			
Ei203	7/20/2017	37.9	0			
Ei204	7/21/2017	56.2	0		X,red	
Ei205	7/23/2017	48.9	0		X,red	
Ei206	7/23/2017		0		X,red	
Ei207	7/24/2017		0		X,red	
Ei208	7/30/2017		18		X,red	
Ei209	8/16/2017		0		X,red , pink calc	
Ei210	8/17/2017		0			
Ei211	8/19/2017		0		X,red green	
Ei212	8/20/2017		1		X,red	
Ei213	8/20/2017		0		X,red	

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