LOMA LINDA UNIVERSITY
School of Science and Technology
in conjunction with the
Faculty of Graduate Studies

Home Range and Foraging Ecology of Juvenile Hawksbill Sea Turtles Around Roatan, Honduras

by

Melissa Dawn Berube

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

September 2010

Each person whose signature appears below certifies that this thesis in his/her opinion is adequate, in scope and quality, as a thesis for the degree Masters of Science in Biology.

____, Chairperson

Stephen G. Dunbar, Associate Professor of Biology

____

William K. Hayes, Professor of Biology

____

Ernest R. Schwab, Associate Dean, School of Allied Health Professions

ACKNOWLEDGEMENTS

There are a number of people to whom I owe thanks. First is my mother Darlene Berube, whose support has carried me through the past three years. I owe a debt of gratitude to the members of my committee. Dr. Stephen G. Dunbar my advisor, for taking me on as graduate student and for his guidance, particularly in the last year during the writing process; Dr. William K. Hayes, for some of the best lectures I have ever attended, his expertise in statistics, and his support and guidance; Dr. Ernest P. Schwab for his thought provoking discussions, encouragement, and ability to make me realize the "bigger picture". I would also like to thank Dr. Jeff Seminoff for his willingness to discuss my research, for providing me with valuable insights and suggestions, and for inspiring me to continue on with sea turtle research. I would like to acknowledge the support of the owners and staff at Reef House Resort on Roatán. In particular, I would like to thank Larry and Carol Stevenson for graciously welcoming me into their family, and for providing a home away from home. I would also like to acknowledge the following individuals for their support and encouragement throughout my research: Ashley Register, Meredith Einsphar, David Nelsen, Bethania Siviero, Gerad Fox, Aaron Corbit, and the members of the Marine Research Group. Lastly, I would like to thank the Department of Earth and Biological Sciences for providing a well-rounded academic experience, and for encouraging open discussion and independent thought.

CONTENTS

TABLES

Tables Page

FIGURES

Figures | Page

ABBREVIATIONS

CITES	Convention on International Trade in Endangered Species of Flora and Fauna
CR	Critically Endangered
DD	Data Deficient
FKD	Fixed Kernel Density
GPS	Global Positioning System
h	Smoothing Factor
h_{cv}	Least-Squares Cross-Validation
HRE	Home Range Extention
h_{ref}	Reference Smoothing Factor
IUCN	World Conservation Union
MCP	Minimum Convex Polygon
MISE	Mean Integrated Square Error
SCL	Straight Carapace Length
TEDS	Turtle Exclusion Devices
UTM	Universal Transverse Mercator

ABSTRACT OF THE THESIS

Home Range and Foraging Ecology of Juvenile Hawksbill Sea Turtles
Around Roatán, Honduras

by

Melissa Dawn Berube

Master of Science, Graduate Program in Biology
Loma Linda University, September 2010
Dr. Stephen G. Dunbar, Chairperson

The hawksbill (*Eretmochelys imbricata*) is one of seven species of sea turtle. It is listed as critically endangered and has suffered population declines of 80 % worldwide, and 95 % in the Caribbean. The hawksbill has a circumglobal distribution in tropic and subtropic waters, and spends periods throughout its life in close association with coral reefs. Being the largest spongivore in the reef ecosystem, hawksbills play an important role in maintaining reef biodiversity.

Due to its precarious outlook, conservation efforts must be continued for the hawksbill and its habitats to aid its recovery. Understanding habitat use, migration routes, and foraging ecology are important for implementing management strategies. Home range estimates can provide knowledge of migration routes and core areas of activity, highlighting hotspots for protection of this sea turtle species. Foraging ecology offers insight into the diet of the hawksbill and allows for conservation efforts to be streamlined, focusing on the turtle and its primary dietary constituents.

My objectives were to determine the home range of juvenile hawksbills, the abundance of available dietary items in resident juvenile versus non-resident sites, and the diet of juvenile hawksbills on inshore reefs in Honduras. This study was initiated to determine if there is a link between home range size, food availability, and diet in juvenile hawksbills in Honduras.

Results indicated that the home range of juvenile hawksbills in the study area is small. Home range estimates for juvenile hawksbills in Honduras are similar to those reported for juvenile hawksbills in Puerto Rico, Japan, the Cayman Islands, and Yucatan, Mexico. The abundance of dietary items, *Pseudopterogorgia elisabethae*, *Pseudoptergoria* sp. and *Spirastrella coccinea*, differed significantly between resident versus non-resident juvenile sites. The results of compositional analysis to assess the difference between the availability of prey items in the turtle-occupied habitat and those consumed by the juvenile hawksbills, differed significantly using parametric testing, but did not differ significantly using randomization. The prey abundances ranked *Chondrilla caribensis* > *Geodia Gibberosa* > other species. Discriminate function analysis showed that the chosen predictors were able to differentiate between non-resident and resident sites and correctly classified non-resident sites 76.2 % of the time and resident sites 92.6 % of the time. The diet of juvenile hawksbills was mostly comprised of sponges, but also included small amounts of other organisms. I report for the first time the presence of the sponge, *Melophlus ruber*, in hawksbill diets. These findings indicate that juvenile hawksbills in the area of Roatán, Honduras are primarily, but not indiscriminately, spongivores. I conclude that the small home range size established by these juvenile hawksbills is likely the result of a large abundance of high quality prey items available in their foraging habitat.

CHAPTER ONE

INTRODUCTION

Sea Turtles

Proganochelys, the direct ancestor of modern-day sea turtles, was the earliest known fossil turtle and had a wide distribution by the Triassic. Examination of its limb structure indicates a marsh-living or terrestrial life style, giving sea turtles terrestrial origins (Gaffney 1990; Pritchard 1997). Marine turtles represent a sister group to the Diapsida (Gaffney and Meylan 1988), and the earliest turtles are evolutionarily close to pareiasaurs. Pareiasaurs are short, heavy-bodied terrestrial reptiles with large bony plates, known as osteoderms, embedded in the skin (Lee 1993). For sea turtles to inhabit marine environments, modifications in body form occurred resulting in forelimbs with elongated phalanges surrounded by tough connective tissue that gave them a rigid paddle-like appearance (Pritchard 1997). The carapace is streamlined with tapered edges, and the plastral lobes have expanded (Gaffney et al. 1987).

Sea turtles belong to the class Reptilia, order Testudines, and family Cheloniidae (Wagler 1830; Pritchard 1997). Pritchard et al. (1997) stated that, by the Cretaceous, four families of sea turtles had diverged: Protostegidae; Toxochelyidae; Dermochelyidae; and Cheloniidae. Protostegidae and Toxochelyidae are now extinct, while Dermochelyidae and Cheloniidae have extant representative species. The dermochelyids comprise large turtles with a secondary palate, no nasal bones, undifferentiated rhamphothecae, unridged tomial surfaces, jaws covered with keratin, prefrontal scales in contact dorsally, and parasphenoid overlain by pterygoids. The bones of the plastron and carapace in the Dermochelyidae family are greatly reduced. The plastral bones are reduced to narrow splints, the pleurals are reduced to endochondral ribs, the entoplastron of the plastron is missing, and the peripheral and neural bones of the carapace are lacking. This family also has limb bones, limb girdles, and vascularized cartilage in the vertebrae. The chelonids vary in size, a secondary palate is present, the skull is extensively roofed, the rhamphothecae are well-developed, and their head is non-retractile. The carapace is covered in scutes that vary in number depending on the species, the plastron is not cruciform with persistent fontanelles, and the posterior plastral lobe is wide and long (Pritchard 1997).

The two existing families of sea turtles include seven species. *Dermochelys coriacea* (leatherback) is the only marine turtle from the Dermochelyidae. The remaining six species, all belonging to Cheloniidae, are comprised of *Natator depressus* (flatback); *Caretta caretta* (loggerhead); *Lepidochelys olivacea* (olive ridley); *Lepiochelys kempii* (Kemp's ridley); *Chelonia mydas* (green); and *Eretmochelys imbricata* (hawksbill). Sea turtles can be found in tropical and subtropical waters, with the leatherback having the largest range in latitude due to adaptations that allow them to inhabit cold water (Frair et al. 1972; Greer et al. 1973; Pritchard 1997; Sherrill-Mix et al. 2008). Two species have limited ranges: the Kemp's ridley is located in the North Atlantic and Gulf of Mexico, whereas the flatback is found only off the coast of northern Australia (Pritchard 1997).

The conservation status of sea turtles is determined by the World Conservation Union (IUCN), which uses the Red List Programme (Seminoff 2004; Santos et al. 2006).

The status of sea turtle species ranges from Data Deficient (DD) to Critically Endangered (CR). The IUCN and the Convention on International Trade in Endangered Species of Flora and Fauna (CITES), have developed criteria for status listing. These criteria include global population numbers, population trends, and fragmentation of habitat and populations (Pritchard 1997). The listing status is not without its problems. The global status is not sufficient for representing trends in a particular geographical area. For example, in areas where there is a plethora of one species, there may be a diminished population of another, yet the less abundant species may be listed less critically on the Red List (Seminoff 2004). This is because the Red Listing takes into consideration the global population numbers, and does not categorize each species by region. The life history traits of sea turtles make them highly vulnerable to disturbances and, therefore, stochastic declines among local populations.

Sea turtles have a long life span that includes late onset of maturity and slow growth rates (Musick and Limpus 1997). These life history traits put sea turtles at risk for population losses. Loss of populations can be caused by invasive species, climate change and anthropogenic causes such as habitat loss or degradation, unsustainable exploitation, and pollution (Horrocks 1992; Wuethrich 1996; Gibbons et al. 2000). Adult turtles are often poached for their shells (Horrocks 1992) and meat (Horrocks 1992; Jaffe 1999). Large numbers of adult and juvenile turtles die by incidental catch in the long lines and gill nets of fishing fleets (Wuethrich 1996; Flam 2000; Hays et al. 2003). Wuethrich (1996) suggested that approximately 80 % of the catch in these nets is bycatch, including sea turtles. The United States now enforces the use of Turtle Exclusion Devices (TEDs) in these nets. The TEDs allow turtles to escape and avoid drowning, while the intended catch remains. Although enforced in the U.S., these nets are not mandatory in other countries, and because of the migratory nature of turtles, nets still pose a major problem (Henwood et al. 1987). Lewison et al. (2004) state that there has been little effort to determine the magnitude of bycatch of protected species. Consumption of sea turtle eggs as food by humans and animals, and destruction of nests by wild and feral animals, are large problems causing early mortality (Jaffe 1999; Flam 2000). Hatchlings are at risk due to beach pollution (Reeves 1989; Flam 2000), predation (Flam 2000), and beachfront development (Reeves 1989). Hotel development on beachfronts causes confusion for hatchlings which mistake the lights of hotels for lunar reflections off the sea surface and are directed inland rather than toward the sea (Reeves 1989).

To increase sea turtle populations, a worldwide conservation strategy was developed in 1995 by the IUCN (Weaver 1996). Two vital aspects of sea turtle recovery were proposed: protection of nesting and feeding areas, and protection of eggs and turtles (Eckert and Honebrink 1992; Eckert et al. 1992; Fuller et al. 1992; Wuethrich 1996). However, education about declining populations, and conservation efforts can play a tremendous role in recovery, as well (Eckert and Honebrink 1992; Eckert et al. 1992; Balazs and Chaloupka 2004). While population recovery may take decades, conservation programs focusing on nesting beaches and protection of adults have resulted in increasing numbers of turtles (Balazs and Chaloupka 2004; Hays 2004; Tröeng and Rankin 2005). For example, Balazs and Chaloupka (2004) reported a long term increase in abundance of green sea turtles in the Hawaiian Archipelago that resulted from a 30-year-long conservation effort that followed a ban on turtle harvesting. Policy regulation, in tandem with conservation efforts, aid in sea turtle recovery (Navid 1980; Eckert et al. 1992), but policy regulation is not consistently enforced (Anonymous 1988; Horrocks 1992).

Hawksbill Sea Turtle

The hawksbill turtle (*E. imbricata*) is easily distinguished from other sea turtle species by two pairs of prefrontal scales, a bony alveolar surface of the upper jaw, a narrow-elongated beak, no terminal teeth, and the mandibular symphysis is excavated (Pritchard 1997). The carapace is speckled in color, the nuchal scute is not in contact with the first costals, and the scutes are thick and overlapping (Pritchard 1997). In early studies, the hawksbill turtle had been grouped with Chelonia (Deraniyagala 1939 in Pritchard 1997) and Lepidochelys and Caretta (Carr 1942 in Pritchard 1997). Bowen et al. (1993), using analysis of mtDNA, discovered that the hawksbill is not a part of Chelonia but that it is more closely related to Carettinae. They suggested that the penchant of hawksbills for spongivory developed from a carnivorous, rather than an herbivorous, ancestral condition.

The hawksbill turtle is located mostly in Caribbean waters, and populations throughout the region have been greatly decimated (Marcovaldi 1999). Over the last 100 years, the numbers of hawksbills worldwide have declined by 80 % (Meylan and Donnelly 1999), and the numbers of hawksbills in the Caribbean have declined approximately 95 % (Bjorndal and Jackson 2003). Hawksbills have an average weight of 39.1 kg (Al-Merghani et al. 1996), a carapace length of over 91.4 cm in adulthood (Bruenderman and Terwilliger 1994), and can lay an average of 83.8 eggs per clutch (Al-Merghani et al. 1996). The main nesting season is between June and August. However, nesting can occur in all other months with the exception of February and March (Horrocks 1992). Along with threats that sea turtles face in general, the hawksbill is largely harvested for its shell, which, at one time, provided a large economic resource for several countries (Marcovaldi 1999; Meylan and Donnelly 1999). Between 1970 and 1986, approximately 251,660 Caribbean hawksbills were slaughtered and sold to Japan (Donnelly 1987). Hawksbills are now on the CITES list, which prohibits import and export of this species into and out of all countries (Donnelly 1987; Meylan and Donnelly 1999). Some countries, such as Cuba and Japan, have submitted proposals to have the status of the hawksbill downgraded so trade could be resumed (Marcovaldi 1999).

Hawksbills have a circumglobal distribution in subtropic and tropic waters (Meylan and Donnelly 1999; Tröeng et al. 2005). The preferred foraging habitat for hawksbills are coral reefs which, like hawksbill populations, have been greatly decimated in the past century (Meylan and Donnelly 1999; Gardner et al. 2003). Until recently, the role of hawksbills in coral reef ecosystems was not well understood. However, we now know that hawksbills spend their time closely associated with reefs, and play a critical role in maintaining biodiversity within this ecosystem (Hill 1998; Meylan and Donnelly 1999; Diez and van Dam 2002; Leon and Bjorndal 2002; Baillie et al. 2004; Tröeng et al. 2005; Cuevas et al. 2007; Blumenthal et al. 2009a). Hawksbills are the largest spongivores associated with reefs (Hill 1998), which makes them an important keystone species. Without their consumption of sponges, it is likely that the diversity and health of reef ecosystems would decrease due to sponge competition with corals for space (Hill 1998; Leon and Bjorndal 2002; Bjorndal and Jackson 2003; Tröeng et al. 2005).

Now that the link between hawksbills and reef ecosystems is better understood, it is recognized that to aid recovery of hawksbill populations, one must protect the turtle and its habitat (Lopez-Mendilaharsu et al. 2008). This requires an understanding of the turtle's migrations, diet, and habitat utilization on nesting and foraging grounds (Bjorndal 1997; Meylan and Donnelly 1999; Leon and Bjorndal 2002). Understanding the hawksbill's diet provides insight into the trophic ecology, digestive physiology, health, diet contaminants, energetics, and endoparisites of the turtle (Forbes 1999). Despite their usefulness, food selection and diet preferences of all sea turtles have been poorly studied (Lopez-Mendilaharsu et al. 2008).

In the past it was thought that hawksbills were indiscriminate omnivores, but it is now known that they are primarily spongivores (Meylan 1984; Meylan 1988; Anderes Alvarez and Uchida 1994; Broderick et al. 2001). Meylan (1988) demonstrated that approximately 95.3 % of food consumed by Caribbean hawksbills consisted of sponges. The sponges most often consumed are: *Chondrilla nucula; Geodia* sp*.; Suberities* sp*.; Ancorina* sp*.; Myriastra* sp*.; Chondrosia* sp*.; Placospongia* sp*.; Ecionemia* sp.; *Aasptos* sp.; *Tethya* sp.; and *Erylus* sp. (Acevedo et al. 1984; Meylan 1988; Hill 1998). Of all these species, *C. nucula* is most commonly consumed, and comprises the majority of sponge content reported in hawksbill diets (Meylan 1988; Vicente and Carballeira 1991; Vicente 1994; Hill 1998; Leon and Bjorndal 2002). Although primarily spongivores, hawksbills may also consume a variety of other prey species such as tunicates, marine plants, algae, soft corals, zoanthids, polychaetes, gastropods, holothurians, and anemones (Den Hartog 1980; Fraizer 1984; Bjorndal et al. 1985; Vicente and Carballeira 1991; Broderick et al. 2001; Cuevas et al. 2007; Dunbar et al. 2008).

The composition of prey species in hawksbill diets is a result of the turtle's habitat, selectivity by the turtle, and availability of food items (Bjorndal 1980; Garnett et al. 1985; Brand-Gardner and Limpus 1999). Selectivity of prey species is thought to be dependent on the abundance, nutrient content, and chemical defense system of the prey (Leon and Bjorndal 2002). For example, it is thought that *C. nucula* is selected because it is abundant and has high protein content (Meylan 1988; Leon and Bjorndal 2002), while *Spirastrella coccinea* is selected despite its low abundance, low protein content, and high chemical defense system, because it has a vital nutrient not obtainable from other species (Leon and Bjorndal 2002). Selectivity may also be based on the ability of that food item to provide protection to the intestinal epithelia (Meylan 1988). Hawksbills, unlike some spongivorous organisms, do not have special spicule compacting organs or masticatory structures that reduce damage to the digestive tract (Meylan 1988). Spongivorous fish have been shown to selectively feed on cnidarians for their mucus content, which may reduce damage to the intestinal epithelia caused by spicules (Randall 1983). It is possible that this may pertain to hawksbills, as well.

Gastric lavage is the preferred method of retrieving dietary samples from sea turtles, and involves flushing food from the upper esophagus and stomach (Forbes and Limpus 1993; Forbes 1999; Amorocho and Reina 2007). Lavages are a useful and safe method to obtain large amounts of undigested food for analysis, without causing harm to the turtle (Forbes 1999). While using samples obtained by gastric lavage is the ideal method to conduct dietary analysis, fecal matter can also be used (Legler 1977; Caputo and Vogt 2008). Fecal sampling is often used to obtain data on food material that is not easily lavaged (Caputo and Vogt 2008). However, studies using only fecal sampling

(Lima et al. 1997), or a combination of fecal sampling and gastric lavage (Seminoff et al. 2002) are uncommon.

The Concept of Home Range

A home range is defined as the area in which an animal conducts its daily activities, but excludes migrations and unpredictable movements (Burt 1943). Determining the home range of an animal requires repeated sightings over time, and estimations of home range are dependent on the amount of time an animal spends in a particular habitat (White and Garrott 1990).

Measures of size, shape, and structure of home ranges are common uses of range estimators (Kenward et al. 2001). Measurements of home range size may be needed for indices of movement within or between species, and for management purposes, such as reserve planning (Hulbert et al. 1996). Shape measurements may be important for indicating how social cohesion or territoriality affects conspecifics (Ims 1988), or how ranges conform to the landscape for security requirements and meeting resource needs (Redpath 1995). Measurements of structure rely on home range cores, and these cores may vary in extent of overlap with neighbors or in content (Poulle et al. 1994).

Aebischer et al. (1993), define habitat use as a part of a path within a habitat determined by the movement of an animal through space and time. Understanding habitat use is beneficial for examining seasonal differences, age class effects, and the relationship between home range size and food abundance. Habitat use is typically compared with available habitat in two stages; the overall study area is examined for home range selection, and specific use within the range is studied (Aebischer et al. 1993).

Radio-telemetry, which relies on obtaining relocation points is the most common method for determining habitat use (Kernohan et al. 1998). The compositional analysis of habitat use has many assumptions, the most important of which is that each location event provides an independent measure of use (Aitchinson 1986). Other assumptions include equal use of habitat between different animals, and that territoriality plays a role in establishing a home range (Aitchinson 1986).

Methods for estimating home range differ in several ways and include the ability to achieve stable shape and size estimates with a few locations per range, estimating shapes that conform to observed patterns of locations, distinguishing outer areas as well as core areas, and deriving statistics that describe the range structure (Kenward 1992; Robertson et al. 1998). The benefits of home range estimations are that they provide complete utilization distributions, biological independence of observations, and consideration of radio telemetry error (Kernohan et al. 1998).

The minimum convex polygon (MCP) is the area within a polygon formed by joining the outer-most sighting positions of the organism being observed (Burt 1943). This method assumes a bivariate normal distribution, but can be biased when there are multiple nuclei (Robertson et al. 1998; Kenward et al. 2001). MCP is a simple calculation that allows for comparisons between studies (Hooge et al. 1999), and gives a more accurate range when only a small number of locations are used (Boyle et al. 2009) if they are well spaced in time (Kenward 1987; Harris et al. 1990). However, the MCP is unable to define fine-scale movements within the polygon, and is sensitive to outlying observations (White and Garrott 1990).

Kenward et al. (2001), describe “nearest neighbor” as a method to define a core range while meeting the criteria for estimating size, shape, and structure of a home range. Nearest neighbor clustering excludes outlying locations. Outliers are excluded because movements within the core range may involve different activities than movements outside. Results from core range analysis may show differences in the number and extent of cores, as well as differences between range and population density, age, body mass, and food supply (Kenward et al. 2001).

The harmonic mean estimator is useful for determining core patches within a home range, and determining discontinuities in range use (Seaman and Powell 1996). The problem with the harmonic mean estimator is that it overestimates home range size because it is sensitive to outlying re-sightings (Seaman and Powell 1996).

Fixed kernel density (FKD) is useful for determining core patches within a home range. Unlike the harmonic mean estimator, it appropriately weighs outlying observations (Worton 1987). It is often used to analyze data that may have a non-normal or multimodal distribution (Seaman and Powell 1996). FKD is nonparametric (Silverman 1986), examines spatial distribution patterns of use (Worton 1995), and gives estimations with very little bias (Seaman and Powell 1996). By using FKD, the errors obtained from more generalized means of home range calculation are avoided.

Both fixed kernel density and harmonic mean estimator are used to interpolate contours between values of estimated density (Harris et al. 1990; Seaman et al. 1999). These contours form density isopleths that can depict multinuclear ranges within the outer range area. The isopleths can vary in both shape and size, but a minimum of 30 re-sightings are needed for calculation (Harris et al. 1990; Seaman et al. 1999). The type of estimator chosen will depend on sample size, how the animal is moving, and what the question is. There is no single best estimator (Kenward et al. 2001). The kernel methods assume independence among all observations (Harris et al. 1990).

When conducting spatial analysis, spatial autocorrelation is often a concern because locations within an animal's home range cannot be temporally or spatially independent of each other (Otis and White 1999). To avoid some of the temporal and spatial errors that occur using a fixed kernel method, smoothing parameters are employed (Worton 1989; Worton 1995). The choice of smoothing factor can greatly affect the home range calculation. The choice of kernel method is less important than the choice of smoothing factor, because the difference in home range size varies more with different smoothing factors than with kernel choice (Worton 1989; Wand and Jones 1995). The smoothing factor (h) calculates the spread of the kernel over individual observations (Rodgers and Carr 1998). A small smoothing parameter results in narrow kernels and may have an undersmoothed distribution (Rodgers and Carr 1998). A large smoothing parameter results in wide kernels and may have an oversmoothed distribution (Rodgers and Carr 1998). The reference smoothing factor (h_{ref}) is an optimum value with reference to a known standard distribution (Silverman 1986; Worton 1989; Worton 1995). The h_{ref} is often chosen when there is a concentrated group of points, and the distribution is unimodal (Worton 1995; Rodgers and Carr 1998). However, the h_{ref} tends to oversmooth the distribution and not show multiple centers of habitat use (Rodgers and Carr 1998). The least-squares cross-validation smoothing factor (h_{cv}) is a value that minimizes the mean integrated square error (MISE) (Worton 1995). The h_{cv} is used when the distribution is not unimodal (Worton 1989), and has a propensity to undersmooth the distribution and show trends in the data that are artifacts (Sain et al. 1994).

Utilization distribution provides a measure of space usage, and does not assume uniform use of areas (Katajisto and Moilanen 2006). In this method, contours are useful in eliminating inaccurate estimations of habitat use that may occur by elimination of points due to small sample or habitat size, and by misclassification of relocation points (Kernohan et al. 1998). Utilization distribution is also used because it smoothes locational data and is free of parametric assumptions (Worton 1989). Swihart and Slade (1985) list non-conformation to parametric assumptions as a problem of utilization distribution. Other problems include observations not being independent of the true distribution, and a two-dimensional distribution (Swihart and Slade 1985). Biases in utilization distribution data may occur when data is collected irregularly, as some areas may appear to be highly utilized because they were sampled more (Katajisto and Moilanen 2006). This can result in autocorrelation, but can be avoided if the data sampling occurs with a proper time interval between collections (Katajisto and Moilanen 2006).

Sea Turtle Home Range

Sea turtles are the only reptiles to undergo long distance migrations (Plotkin 2003). Adult sea turtles migrate at regular intervals between nesting and foraging areas, and these migrations can be from hundreds to thousands of kilometers (Horrocks et al. 2001; Plotkin 2003). Migratory behaviors of adults may vary if nesting grounds are transient or food sources become unreliable (Plotkin 2003). In order to migrate long distances, sea turtles need a mode of navigation. It is suggested that the navigation of sea turtles is directed by waterborne chemicals (Luschi et al. 1998; Papi et al. 2000), windborne information (Luschi et al. 2001), currents (Morreale et al. 1996; Papi et al.

2000), water temperature (Plotkin 1994), bathymetric features (Morreale et al. 1994), and biological compasses (Papi and Luschi 1996; Luschi et al. 1998). It is likely that the method of navigation varies both interspecifically and intraspecifically (Plotkin 2003). Unlike adults however, juvenile sea turtles typically do not undergo long distance migrations at seasonal intervals. Instead, juveniles recruit to developmental grounds establishing small home ranges in suitable foraging areas, thereby increasing their access to resources (Renaud et al. 1995; Musick and Limpus 1997; Seminoff et al. 2002; Avens et al. 2003; Makowski et al. 2006). Nonetheless, juveniles may undergo seasonal migrations if there is a change in population density, or food abundance (Bjorndal et al. 2000; Godley et al. 2003; Plotkin 2003). Juveniles in temperate zones are more likely to undergo seasonal migrations moving into lower latitudes in the winter, and higher latitudes in the summer (Musick and Limpus 1997). Young sea turtles in tropical zones are more limited in their movements, and usually do not undertake long migrations (Musick and Limpus 1997). Still, results from recent studies of juvenile hawksbill home ranges are inconsistent. Some studies conclude that juvenile hawksbills have long distance movements and large home ranges (Boulon 1989; Marcovaldi and Filippini 1991), while others conclude that juveniles show little movement and have small home ranges (van Dam and Diez 1998; Cuevas et al. 2007; Blumenthal et al. 2009b).

Migratory pathways, home ranges, and habitat use by sea turtles are determined by tracking studies. Tracking of sea turtles is conducted primarily through three methods of telemetry: satellite, radio, and sonic (Boarman et al. 1998; Makowski et al. 2006). The chosen telemetry method is dependent on the developmental stage of the turtle. Sonic and radio telemetry are useful in juvenile home range and tracking studies (Renaud et al.

1992; van Dam and Diez 1998; Seminoff et al. 2002; Makowski et al. 2006; Seminoff and Jones 2006), because they provide better accuracy for small ranges (Renaud and Williams 1997; Cuevas et al. 2008). Sonic and radio telemetry are limited because they do not provide information on vertical migration or underwater behavior, movements are shown in two dimensions, and they are labor intensive (Seminoff et al. 2002; Schmid et al. 2003; Seminoff and Jones 2006; Blumenthal et al. 2009b). Satellite telemetry has been used in juvenile home range and tracking studies (Polovina et al. 2000; Godley et al. 2003), but is more often used in adult home range and tracking studies because of the high cost, large size, and low positional accuracy (Blumenthal et al. 2009a).

Study Goal, Objectives, and Hypotheses

The goal of this study was to determine if there is a discernable link between diet, food availability, and home range size of juvenile hawksbills in the area of Roatán, Honduras. Some questions I intended to answer were: what are the sizes of home ranges established by juvenile hawksbills in this study area? Are home ranges smaller in areas where there is a high abundance of sponge and other primary prey items? What prey species do juvenile hawksbills consume most in the study area?

I hypothesized that:

1. Juvenile hawksbills in the area of Roatán establish small and localized home ranges on inshore reefs versus large, scattered home ranges
2. Common prey items of hawksbills are more abundant at resident juvenile home range sites versus sites at which juveniles are non-resident

3. The primary prey item in juvenile hawksbill diets is sponge, but other items may be present

To test my hypotheses I followed three main objectives:

1. Determine the spatial distribution of juvenile hawksbills by examining their home ranges
2. Conduct habitat assessments to compare the distribution of available food sources in resident and non-resident areas;
3. Obtain ingesta from gastric and fecal samples to determine the diet of juvenile hawksbills

In chapter 2, we detail home range, habitat assessment, and foraging ecology studies of juvenile hawksbill sea turtles in the Port Royal region of Roatán, Honduras and their implications for future conservation efforts. In Chapter 3, I summarize the main conclusions and limitations of this study, and discuss the implications of this study for future conservation efforts.

References

Acevedo, M., Gomez, O., and Berovides, V. 1984. Alimentacion de tres especies de quelonios marinos en la plataforma suroccidental de Cuba. Revista de Investigaciones Marinas. 5: 29.

Aebischer, N.J., Robertson, P.A., and Kenward, R.E. 1993. Compositional analysis of habitat use form animal radio-tracking data. Ecology. 74:1313-1325.

Aitchinson, J. 1986. The statistical analysis of compositional data. Chapman and Hall, London, England.

Al-Merghani, M., Miller, J.D., Al-Mansi, A., Khushaim, O., and Pilcher, N.J. 1996. The marine turtles of the Arabian Gulf. NCWCD studies 1991-1994. A marine wildlife sanctuary for the Arabian Gulf: environmental research and conservation following the 1991 Gulf War oil spill.

Amorocho, D.F., and Reina, R.D. 2007. Feeding ecology of the East Pacific green sea turtle *Chelonia mydas agassizii* at Gorgona National Park, Colombia. Endangered Species Research. 3:43-51.

Anderes Alvarez, B.L., and Uchida, I. 1994. Study of hawksbill turtle (*Eretmochelys imbricata*) stomach content in Cuban water. Ministry of Fishing Industry, Cuba.

Anonymous. 1988. Mexico's sea turtle program. Marine Fisheries Review. 50:70-72.

Avens, L., Braun-McNeill, J., Epperly, S., and Lohmann, K.J. 2003. Site fidelity and homing behavior in juvenile loggerhead sea turtles (*Caretta caretta*). Marine Biology. 143:211-220.

Baillie, J.E.M., Bennun, L.A., Brooks, T.M., Butchart, S.H.M., Chanson, J.S., Cokeliss, Z., Hilton-Taylor, C., Hoffmann, M., Mace, G.M., Mainka, S.A., Pollock, C.M., Rodrigues, A.S.L., Stattersfield, A.J., and Stuart, S.N. 2004. 2004 IUCN Red List of threatened species: a global species assessment.

Balazs, G.H., and Chaloupka, M. 2004. Thirty-year recovery trend in the once depleted Hawaiian green sea turtle stock. Biological Conservation. 117:491-498.

Bjorndal, K.A. 1980. Nutrition and grazing behavior of the green turtle *Chelonia mydas*. Marine Biology. 56:147-154.

Bjorndal, K.A. 1997. Foraging ecology and nutrition of sea turtles. In: Lutz, P.L., and Musick, J.A. (eds). The biology of sea turtles. CRC Press, pp 199-232.

Bjorndal, K.A., Bolten, A.B., and Chaloupka, M.Y. 2000. Green turtle somatic growth model: evidence for density dependence. Ecological Applications. 10:269-282.

Bjorndal, K.A., Carr, A., Meylan, A.B., and Mortimer, J.A. 1985. Reproductive biology of the hawksbill *Eretmochelys imbricata* at Tortuguero, Costa Rica, with notes on the ecology of the species in the Caribbean. Biological Conservation. 34:353-368.

Bjorndal, K.A., and Jackson, J.B.C. 2003. Role of sea turtles in marine ecosystems: reconstructing the past. In: Lutz, P.L., Musick, J.A., and Wyneken, J. (eds). Biology of sea turtles. CRC Press, pp 259-273.

Blumenthal, J.M., Austin, T.J., Bell, C.D.L., Bothwell, J.B., Broderick, A.C., Ebanks-Petrie, G., Gibb, J.A., Luke, K.E., Olyik, J.R., Orr, M.F., Solomon, J.L.,and Godley, B.J. 2009a. Ecology of hawksbill turtles, *Eretmochelys imbricata*, on a western Caribbean foraging ground. Chelonian Conservation and Biology. 8:1-10.

Blumenthal, J.M., Austin, T.J., Bothwell, J.B., Broderick, A.C., Ebanks-Petrie, G., Olyik, J.R., Orr, M.F., Solomon, J.L., Witt, M.J., and Godley, B.J. 2009b. Diving behavior and movements of juvenile hawksbill turtles *Eretmochelys imbricata* on a Caribbean coral reef. Coral Reefs. 28:55-65.

Boarman, W., Goodlett, T., Goodlett, G., and Hamilton, P. 1998. Review of radio transmitter attachment techniques for turtle research and recommemdations for improvement. Herpetological Review. 29:26-33.

Boulon, R. 1989. Virgin Island turtle tag recoveries outside of the U.S. Virgin Islands. In: Eckert, S.A., Eckert, K.L., and Richardson, T.H. (eds). Proceedings of the ninth annual workshop on sea turtle conservation and biology. NOAA Tech Memo NMFS/SEFC-232. pp 207-209.

Bowen, B.W., Nelson, W.S., Avise, J.C. 1993. A molecular phylogeny for marine turtles: trait mapping, rate assessment, and conversation relevance. Proceedings of the Natural Academy of Sciences. 90:5574-5577.

Boyle, S.A., Lourenco, W.C., da Silva, L.R., and Smith, A.T. 2009. Home range estimates vary with sample size and methods. Folia Primatologica. 80:33-42.

Brand-Gardner, J.M.L., and Limpus, C. 1999. Diet selection by immature green turtles, *Chelonia mydas*, in subtropical Moreton Bay, south-east Queensland. Australian Journal of Zoology. 47:181-191.

Broderick, A.C., Godley, B.J., and Hays, G.C. 2001. Trophic status drives interannual variability in nesting numbers of marine turtles. Proceedings of the Royal Society of London. 268:1481-1487.

Bruenderman, S., and Terwilliger, K. 1994. Swimming beyond boundaries: the uncertain future of Virginia's marine mammals and sea turtles. Virginia Wildlife. 55:11-27.

Burt, W.H. 1943. Territoriality and home range concepts as applied to mammals. Journal of Mammalogy. 24:346-352.

Caputo, F.P., and Vogt, R.C. 2008. Stomach flushing vs. fecal analysis: the example of *Phrynops rufipes* (Testudines: Chelidae). Copeia. 2:301-305.

Carr, A.F. 1942. Notes on sea turtles. Proceedings of the New England Zoological Club. 21:1-16.

Cuevas, E., Abreu-Grobois, F.A., Guzman-Hernandez, V., Liceaga-Correa, M.A., and van Dam, R.P. 2008. Post-nesting migratory movements of hawksbill turtles *Eretmochelys imbricata* in waters adjacent to the Yucatan Peninsula, Mexico. Endangered Species Research. 1-11.

Cuevas, E,. de los Angeles Liceaga-Correa, M., and Garduno-Andrade, M. 2007. Spatial characterization of a foraging area for immature hawksbill turtles (*Eretmochelys imbricata*) in Yucatan, Mexico. Amphibia-Reptilia. 28:337-346.

Den Hartog, J.C. 1980. Notes on the food of sea turtles: *Eretmochelys imbricata* (Linnaeus) and *Dermochelys coriacea* (Linnaeus). Netherlands Journal of Zoology. 30:595.

Deraniyagala, P.E.P. 1939. The tetrapod reptiles of Ceylon, Colombo Museum, Ceylon.

Diez, C.E., and van Dam, R.P. 2002. Habitat effect on hawksbill turtle growth rates on feedng grounds at Mona and Monito Islands, Puerto Rico. Marine Ecology Progress Series. 234:301-309.

Donnelly, M. 1987. Japanese trade in hawksbill shell from the wider Caribbean 1970-1986. Western Atlantic Turtle Symposium, Mayaguez, Puerto Rico.

Dunbar, S.G., Salina, L., and Stevenson, L. 2008. In-water observations of recently released juvenile hawksbils (*Eretmochelys imbricata*). Marine Turtle Newsletter. 121:5-9.

Eckert, K.L., and Honebrink, T.D. 1992. Sea turtle recovery action plant for St. Kitts and Nevis. Kingston, Jamaica.

Eckert, K.L., Overing, J.A., and Lettsome, B.B. 1992. Sea turtle recovery action plan for the British Virgin Islands. Kingston, Jamaica.

Flam, F. 2000. A turtle in trouble. Philadelphia Inquirer, Philadelphia. pp C1, C4.

Forbes, G., and Limpus, C. 1993. Non-lethal method for retrieving stomach contents from sea turtles. Wildlife Research. 20:339-343.

Forbes, G.A. 1999. Diet sampling and diet component analysis. Research and Management Teachniques for the Conservation of Sea Turtles. 4:1-5.

Frair, W., Ackerman, R.G., and Mrosovsky, N. 1972. Body temperature of *Dermochelys coriacea*: warm turtle from cold water. Science. 177:791-793.

Fraizer, J. 1984. Marine turtles in the Seychelles and adjacent territories. Junk Publishers. Hague, Netherlands.

Fuller, J.E., Eckert, K.L., and Richardson, J.I. 1992. Sea turtle recovery action plan for Antigua and Barbuda. Kingston, Jamaica.

Gaffney, E.S. 1990. The comparative osteology of the Triassic turtle Proganochelys. Bulletin of the American Museum of Natural History. 194:1-263.

Gaffney, E.S., Hutchinson, J.H., Jenkins, F.A., and Meeker, L. 1987. Modern turtle origins: the oldest known cryptodire. Science. 237:289-291.

Gaffney, E.S., and Meylan, P.A. 1988. A phylogeny of turtles. In: Benton, M.J. (ed). The phylogeny and classification of tetrapods. Clarendon Press, Oxford. pp 157-219.

Gardner, T.A., Cote, I.M., Gill, J.A., Grant, A., and Watkinson, A.R. 2003. Longterm region-wide decline in Caribbean corals. Science. 301:958-960.

Garnett, S.T., Pirce, I.R., and Scott, F.J. 1985. The diet of the green turtles, *Chelonia mydas* (L), in Torres Strait. Wildlife Research. 12:103-112.

Godley, B.J., Lima, E.H.S.M., Akesson, S., Broderick, A.C., Glen, F., Godfrey, M.H., Luschi, P., and Hays, G.C. 2003. Movement patterns of green turtles in Brazilian coastal waters described by satellite tracking and flipper tagging. Marine Ecological Progress Series. 253:279-288.

Greer, A.E., Lazell, J.D., and Wright, R.M. 1973. Anatomical evidence for a counter-current heat exchanger in the leatherback turtle (*Dermochelys coriacea*). Nature. 244:181.

Harris, S., Cresswell, W.J., Forde, P.G., Trewella, W.J., Woollard, T., and Wray, S. 1990. Home-range analysis using radio-tracking data - a review of problems and techniques particularly as applied to the study of mammals. Mammal Review. 20: 97-123.

Hays, G.C. 2004. Good news for sea turtles. Trends in Ecology and Evolution. 19:349-357.

Henwood, T., Stuntz, W., and Thompson, N. 1987. Evalutation of U.S. turtle protective measures under existing TED regulations, including estmates of shrimp trawler related mortality in the wider Caribbean. Fisheries Bulletin. 85:813-817.

Hill, M.S. 1998. Spongivory on Caribbean reefs releases corals from competition with sponges. Oecologica. 117:143-150.

Hooge, P.N., Eichenlaub, W.M., and Solomon, E.K. 1999. Using GIS to analyze animal movements in the marine environment. pp 1-21.

Horrocks, J.A. 1992. WIDECAST sea turtle recovery action plan for Barbados. Caribbean Environmental Technical Report. 12:61.

Horrocks, J.A., Vermeer, L.A., Krueger, B., Coyne, M., Schroeder, B.A., and Balazs, G.H. 2001. Migration routes and destination characteristics of post-nesting hawksbills turtles satellite-tracked from Barbados, West Indies. Chelonian Conservation and Biology. 4:107-114.

Hulbert, I.A.R., Iason, G.R., Elston, D.A., and Racey, P.A. 1996. Home-range sizes in a stratified upland landscape of two lagomorphs with different feeding strategies. Journal of Animal Ecology. 33:1479-1488.

Ims, R.A. 1988. Spatial clumping of sexually receptive females induces space sharing among male voles. Nature. 335:541-543.

Jaffe, M. 1999. Shell shocked. The Philadelphia Inquirer, Philadelphia. pp F1, F14.

Katajisto, J., and Moilanen, A. 2006. Kernel-based home range method for data with irregular sampling intervals. Ecological Modelling. 194:405-413.

Kenward, R.E. 1987. Wildlife radio tagging: equipment, field techniques and data analysis. London, UK.

Kenward, R.E. 1992. Tecniques for monitoring the behavior of Grey Squirrels by radio. Symposium of the Zoological Society of London. 49:174-196.

Kenward, R.E., Clarke, R.T., Hodder, K.H., and Walls, S.S. 2001. Density and linkage estimators of home range nearest neighbor clustering defines multinuclear cores. Ecology. 82:1905-1920.

Kernohan, B.J., Millspaugh, J.J., Jenks, J.A., and Naugle, D.E. 1998. Use of an adaptive kernel home-range estmator in a GIS environment to calculate habitat use. Journal of Environmental Management. 53:83-89.

Lee, M.S.Y. 1993. The origin of the turtle body plan: bridging a famous morphological gap. Science. 261:1716-1720.

Legler, J.M. 1977. Stomach flushing: a technique for chelonian dietary studies. Herpetologica. 33:281-284.

Leon, Y.M., and Bjorndal, K.A. 2002. Selective feeding in the hawksbill turtle, an important predator in coral reef ecosystem. Marine Ecological Progress Series. 245:249-258.

Lewison, R. L., Freeman, S. A., and Crowder, L. B. 2004. Quantifying the effects of fisheries on threatened species: the impact of pelagic longlines on loggerhead and leatherback sea turtles. Ecology Letters. 7:221-231.

Lima, A.C.D., Magnusson, W.E., and Da Costa, V.L. 1997. Diet of the turtle *Phrynops rufipes* in central Amazonia. Copeia. 216-219.

Lopez-Mendilaharsu, M., Gardner, S.C., Riosmena-Rodriguez, R., and Seminoff, J.A. 2008. Diet selection by immature green turtles (*Chelonia mydas*) at Bahia Magdalena foraging ground in the Pacific Coast of the Baja California Peninsula, Mexico. Journal of the Marine Biological Association of the United Kingdom. 88:641-647.

Luschi, P., Akesson, S., Broderick, A.C., Glen, F., Godley, B.J., Papi, F., and Hays, G.C. 2001. Testing the navigational abilities of ocean migrants: displacement experiments on green sea turtles (*Chelonia mydas*). Behavioral Ecology and Sociobiology. 50: 528-534.

Luschi, P., Hays, G.C., Seppia, C.D., Marsh, R., and Papi, F. 1998. The navigational feats of green sea turtles migrating from Ascension Island investigated by satellite telemetry. Proceedings of the Royal Society of London. 265:2279-2284.

Makowski, C., Seminoff, J.A., and Salmon, M. 2006. Home range and habitat use of juvenile Atlantic green turtles (*Chelonia mydas* L.) on shallow reef habitats in Palm Beach, Florida, USA. Marine Biology. 148:1167-1179.

Marcovaldi, M.A. 1999. Biology and status of the hawksbill in the Caribbean. Chelonian Conservation and Biology. 3:173.

Marcovaldi, M.A., and Filippini, A. 1991. Trans-Atlantic movement by a juvenile hawksbill turtle. Marine Turtle Newsletter. 52:3.

Meylan, A.B. 1984. Feeding ecology of the hawksbills turtle (*Eretmochelys imbricata*): spongivory as a feeding niche in the coral reef community. PhD. Zoology.

Meylan, A.B. 1988. Spongivory in hawksbill turtles: a diet of glass. Science. 239:393-395.

Meylan, A.B., and Donnelly, M. 1999. Status justification for listing the hawksbill turtle (*Eretmochelys imbricata*) as critically endangered on the 1996 IUCN Red List of Threatened Animals. Chelonian Conservation and Biology. 3:200-224.

Morreale, S.J., Standora, E.A., Paladino, F.V., and Spotila, J.R. 1994. Leatherback migrations along deepwater bathymetric contours. In: Schroeder, B.A., and Witherington, B.E. (eds). Proceedings of the Thirteenth Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memo, NMFS-SEFSC-341, Miami, FL. pp 109.

Morreale, S.J., Standora, E.A., Spotila, J.R., and Paladino, F.V. 1996. Migration corridor for sea turtles. Nature. 384:319-320.

Musick, J.A., and Limpus, C.J. 1997. Habitat utilization and migration in juvenile sea turtles. In: Lutz, P.L. and Musick, J.A. (eds). The biology of sea turtles. CRC Press. pp 137-163.

Navid, D. 1980. World conference on sea turtles. Environmental Policy and Law. 6:17-18.

Otis, D.L., and White, G.C. 1999. Autocorrelation of location estimates and the analysis of radiotracking data. Journal of Wildlife Management. 63:1039-1044.

Papi, F., and Luschi, P. 1996. Pinpointing "Isla Meta": the case of sea turtles and albatrosses. Journal of Experimental Biology. 199:65.

Papi, F., Luschi, P., Akesson, S., Capogrossi, S., and Hays, G.C. 2000. Open-sea migration of magnetically disturbed sea turtles. The Journal of Experimental Biology. 203:3435-3443.

Plotkin, P. 1994. Migratory and reproductive behavior of the olive ridley turtle, *Lepidochelys olivacea* (Eschscholtz, 1829), in the eastern Pacific Ocean. Dissertation, College Station, TX.

Plotkin, P. 2003. Adult migrations and habitat use. In: Lutz, P.L., Musick, J.A., and Wyneken, J. (eds). The Biology of Sea Turtles. CRC Press. pp 225-241.

Polovina, J.J., Kobayashi, D.R., Parker, D.M., Seki, M.P., and Balazs, G.H. 2000. Turtles on the edge: movement of loggerhead turtles (*Caretta caretta*) along oceanic fronts, spanning longling fishing grounds in the central North Pacific, 1997-1998. Fisheries Oceanography. 9:71-82.

Poulle, M.L., Artois, M., and Roeder, J.J. 1994. Dynamics of spatial relationships among members of a fox group (*Vulpes vulpes*: Carnivora). Journal of Zoology. 23:93-106.

Pritchard, P.C.H. 1997. Evolution, phylogeny, and current status. In: Lutz, P.L., and Musick, J.A. (eds). The Biology of Sea Turtles. CRC Press. pp 1-28.

Randall, J.E. 1983. Caribbean reef fishes. TFH Publications. Neptune City, NJ.

Redpath, S.M. 1995. Habitat fragmentation and the individual: tawny owls *Strix aluco* in woodland patches. Journal of Animal Ecology. 64:652-661.

Reeves, L. 1989. Sea turtles need help to survive. Underwater USA. 6:36-37.

Renaud, M.L., Carpenter, J.A., Manzella, S.A., and Williams, J.A. 1992. Telemetric tracking of green sea turtles (*Chelonia mydas*) in relation to dredged channels at South Padre Islands, Texas, July though September 1992. Southeast Fisheries Center. National Marine Fisheries Service. Galveston Laboratory.

Renaud, M.L., Carpenter, J.A., Williams, J.A., and Manzella-Tirpak, S.A. 1995. Activities of juvenile green turtles, *Chelonia mydas*, at a jettied pass in south Texas. Fishery Bulletin. 93:586-593.

Renaud, M.L., and Williams, J.A. 1997. Movements of Kemp's ridley (*Lepidochelys kempii*) and green (*Chelmonia mydas*) sea turtles using Lavaca Bay and Matagorda Bay 1996 - 1997. Environmental Protection Agency.

Robertson, P.A., Aebischer, N.J., Kenward, R.E., Hanski, I.K., and William, N.P. 1998. Simulation and jack-knifing assessment of home-range indices based on underlying trajectories. Journal of Applied Ecology. 35:928-940.

Rodgers, A.R., and Carr, A.P. 1998. HRE: The home range extension for ArcView, user's manual. Centre for Northern Forest Ecosystem Research, Ontario. Ministry of Natural Resources.

Sain, S.R., Baggerly, K.A., and Scott, D.W. 1994. Cross-validation of multivariate densities. Journal of American Statistical Association. 89:807-817.

Santos, K.C., Tague, C., Alberts, A.C., and Franklin, J. 2006. Sea turtle nesting habitat on the US Naval Station, Guantanamo Bay, Cuba: A comparison of habitat suitability index models. Chelonian Conservation and Biology. 5:175.

Schmid, J.R., Bolten, A.B., Bjorndal, K.A., Lindberg, W.J., Percival, H.F., and Zwick, P.D. 2003. Home range and habitat use by Kemp's ridley turtles in west-central Florida. Journal of Wildlife Management. 67:196-206.

Seaman, D.E., Millspaugh, J.J., Kernohan, B.J., Brindige, K.J., Raedeke, K.J., and Gitzen, R.A. 1999. Effects of sample size on kernel home range estimates. Journal of Wildlife Management. 63:739 - 747.

Seaman, D.E., and Powell, R.A. 1996. An evaluation of the accuracy of kernel density estimators for home range analysis. Ecology. 77:2075-2085.

Seminoff, J.A. 2004. Sea turtles, red listing, and the need for regional assessments. Marine Turtle Newsletter. 106:4-6.

Seminoff, J.A., and Jones, T.T. 2006. Diel movements and activity ranges of green turtles (*Chelonia mydas*) at a temperate foragng area in the Gulf of California, Mexico. Herpetological Conservation and Biology. 1:81-86.

Seminoff, J.A., Resendiz, A., and Nichols, W.J. 2002. Home range of green turtles *Chelonia mydas* at a coastal foraging area in the Gulf of California, Mexico. Marine Ecological Progress Series. 242:253-265.

Sherrill-Mix, S.A., James, M.C., and Myers, R.A. 2008. Migration cues and timing in leatherback sea turtles. Behavioral Ecology. 19:231-236.

Silverman, B.W. 1986. Density estimation for statistics and data analysis. Chapman and Hall. London, UK.

Swihart, R.K., and Slade, N.A. 1985. Testing for indenpendence of observations in animal movements. Ecology. 66:1176-1184.

Tröeng, S., Dutton, P.H., and Evans, D. 2005,. Migration of hawksbill turtles *Eretmochelys imbricata* from Tortuguero, Costa Rica. Ecography. 28:394-402.

Tröeng, S., and Rankin, E. 2005. Long-term conservation efforts contribute to positive green turtle *Chelonia mydas* nesting trend at Tortuguero, Costa Rica. Biological Conservation. 121:111-116.

van Dam, R.P., and Diez, C.E. 1998. Home range of immature hawksbill turtles (*Eretmochelys imbricata* (Linnaeus)) at two Caribbean islands. Journal of Experimental Marine Biology and Ecology. 220:15-24.

Vicente, V.P. 1994. Spongivory in Caribbean hawksbill turtles, *Eretmochelys imbricata*: data from standed specimens. In: Schroeder, B.A., and Witherington, B.E. (eds). 13th annual symposium on sea turtle biology and conservation. NOAA Tech. Memo.

Vicente, V.P., and Carballeira, N.M. 1991. Studies on the feeding ecology of the hawksbill turtle, *Eretmochelys imbricata*, in Puerto Rico. In: Salmon, M., and Wyneken, J. (eds). 11th annual workshop on sea turtle biology and conservation. NOAA Tech Memo NMFS-SEFSC-302, Miami, FL. pp 117.

Wagler, J.G. 1830. Naturliches System der Amphibien. 354.

Wand, M.P., and Jones, M.C. 1995. Kernel smoothing. Chapman and Hall, Ltd. London, UK.

Weaver, S. 1996. The Fiji sea turtle conservation strategy: a strategy to guide the next three years of research and management of turtles in Fiji, New Zealand.

White, G.C., and Garrott, R.A. 1990. Analysis of wildlife radiotracking data. Academic Press. New York.

Worton, B.J. 1987. A review of models of home range for animal movement. Ecological Modelling. 38:277-298.

Worton, B.J. 1989. Kernel methods for estimating the utilization distribution in home range studies. Ecology. 70:164-168.

Worton, B.J. 1995. Using Monte Carlo simulation to evaluate kernel-based home range estimators. Journal of Wildlife Management. 59:794-800.

Wuethrich, B.C. 1996. Into dangerous waters. International Wildlife. 26:44-51.

CHAPTER TWO

HOME RANGE AND FORAGING ECOLOGY OF JUVENILE HAWKSBILL SEA TURTLES (*ERETMOCHELYS IMBRICATA*) ON INSHORE REEFS OF HONDURAS

Melissa D. Berube [1,3,*], Stephen G. Dunbar [1,2,3,**], Klaus Rützler [4,***], and William K. Hayes [1,****]

[1]Department of Earth and Biological Sciences, Loma Linda University, Loma Linda, CA 92350;
[2]Protective Turtle Ecology Center for Training, Outreach and Research, Inc. (ProTECTOR),
[3]Turtle Awareness and Protection Studies (TAPS), Reef House Resort, Roatán, Honduras
[4]Smithsonian Institution, National Museum of Natural History
[*]Corresponding author: Melissa Berube mberube@llu.edu
[**]Second Author: Dr. Stephen G. Dunbar sdunbar@llu.edu
[***]Third Author: Dr. Klaus Ruetzler ruetzler@si.edu
[****]Fourth Author: Dr. William K. Hayes whayes@llu.edu

Address for first and fourth authors: Department of Earth and Biological Sciences, Griggs Hall, Loma Linda University, Loma Linda, CA, 92350
909-558-1000 ext 44530

Address for second author: Rm 120, Griggs Hall, Loma Linda University, Loma Linda, CA, 92350
909-558-1000 ext 48903

Address for third author: Department of Invertebrate Zoology, Smithsonian Institution, Washington, D.C. 20560-0163

Submitted to: Chelonian Conservation and Biology

Abstract

The hawksbill sea turtle is critically endangered and can be found in subtropical and tropical waters circumglobally. Worldwide numbers of hawksbills have been decimated, with Caribbean populations suffering an estimated decline of 95 %, indicating a precarious outlook for the species in this region. We tracked six juvenile hawksbills with radio telemetry off the coast of Roatán, conducted habitat assessments at 14 sites, and examined the diet of five juvenile hawksbills. Home ranges of all six turtles were small, with 100 % minimum convex polygons from 0.15 - 0.56 km^2, and a 50 % fixed kernel density for all animals pooled of 5.80 km^2. The habitat assessment showed that common prey items in hawksbill diets were abundant in areas where juvenile hawksbills were resident and in non-resident areas, with sponges (*Chondrilla* sp., *Geodia* sp.), and octocorals (*Pseudopterogorgia* sp.) being most prevalent. We found sponge to be the primary component in the diet, comprising 59 % of total ingesta. The most prevalent sponge species in the diet samples were *Melophlus ruber* and *Chondrilla caribensis*. While *C. caribensis* is a common constituent of hawksbill diets, the current study provides the first report of *M. ruber* as a component of hawksbill diets. This study represents an important step in implementing conservation efforts in Honduras, lending further support to suggestions that the southeastern coast of Roatán may be an important recruitment ground for juvenile hawksbills in this area.

Introduction

The hawksbill sea turtle is a critically endangered (Mortimer and Donnelly 2008a), medium sized turtle, with a circumglobal distribution in tropical and subtropical waters (Carr et al. 1966; Baillie and Groombridge 1996; van Dam and Diez 1998; Meylan and Donnelly 1999; Tröeng et al. 2005). The worldwide populations of hawksbills have been greatly reduced, with Caribbean populations suffering a decline of as much as 95 % since pre-exploitation, indicating a potentially precarious outlook for the species (Carr et al. 1966; Groombridge and Luxmoore 1989; Meylan and Donnelly 1999; Bjorndal and Jackson 2003; Tröeng et al. 2005). Hawksbills inhabit coral reefs throughout the main stages of their lifespan and, as large spongivores, play a critical role in maintaining reef biodiversity (Carr et al. 1966; Hill 1998; Leon and Bjorndal 2002; Blumenthal et al. 2009b). Hill (1998) and Leon and Bjorndal (2002) have shown that, without consumption of sponges by hawksbills, the diversity and health of reef ecosystems decreases due to competition for space between sponges and corals. With increasing coral reef degradation and declining hawksbill populations (Meylan and Donnelly 1999; Gardner et al. 2003; Blumenthal et al. 2009b), both the turtle and its habitat require protective measures. To implement appropriate conservation efforts, many factors, such as habitat use, migration corridors, foraging ecology, and the ecological role of hawksbills, require consideration (Bailey 1984; Seminoff et al. 2002; Godley et al. 2003; Seminoff and Jones 2006; Cuevas et al. 2007; Blumenthal et al. 2009a).

Horrocks et al. (2001) showed that adult sea turtles can make long distance migrations between nesting and foraging habitats, thus establishing large home ranges (Horrocks et al. 2001). In contrast, most juveniles establish small home ranges by recruiting to developmental grounds, distributing themselves among suitable foraging areas, and increasing their access to resources (Renaud et al. 1995; Musick and Limpus 1997; Seminoff et al. 2002; Avens et al. 2003; Makowski et al. 2006). However, if foraging abundance or population densities change, juveniles may undertake migrations as well (Bjorndal et al. 2000; Godley et al. 2003). A home range excludes migrations or unpredictable movements, and is defined as the area in which an animal conducts its daily activities (Bailey 1984). To determine the home range of any animal, repeated sightings must be obtained over time (White and Garrott 1990).

Home range is often calculated using a minimum convex polygon (MCP), which includes the area formed by connecting the peripheral sightings of an animal (Burt 1943; Makowski et al. 2006). MCPs are sensitive to outliers and do not delineate core areas of use by the animal (White and Garrott 1990; Griffin 2002). However, MCPs allow for comparisons between studies (Hooge et al. 1999), and can be more accurate than other methods when sample size is small (Boyle et al. 2009). To determine core areas of use, 50 % fixed kernel density (FKD) can be calculated (Griffin 2002; Seminoff et al. 2002; Makowski et al. 2006; Cuevas et al. 2008). FKD estimates are practical because they describe spatial use patterns (Worton 1995), have very little bias (Seaman and Powell 1996), and are less sensitive than MCPs to outliers (Worton 1987).

Home ranges are calculated by data provided from tracking studies, which may also highlight migratory pathways and habitat use of sea turtles, and are usually conducted through satellite, radio, and sonic telemetry (Boarman et al. 1998). The telemetry method employed typically depends on the developmental stage of the turtle. Satellite transmitters have been used for juvenile home range and tracking studies (Polovina et al. 2000; Godley et al. 2003), but their low positional accuracy, large size, and high cost, make them more appropriate for use in studies of adults (Blumenthal et al. 2009b). Radio and sonic telemetry have proven useful for juvenile home range and tracking studies (Renaud et al. 1992; van Dam and Diez 1998; Seminoff et al. 2002; Makowski et al. 2006; Seminoff and Jones 2006) because they provide better accuracy for small ranges (Renaud and Williams 1997; Cuevas et al. 2008). However, radio and sonic telemetry are limited in that they only show two-dimensional movements, they provide no information on underwater behavior or vertical migrations, and they are labor intensive. Results from previous studies of juvenile hawksbill home ranges are inconsistent, with some studies indicating little movement and a small home range (van Dam and Diez 1998; Cuevas et al. 2007; Blumenthal et al. 2009b), while others have documented long migrations and large home ranges (Boulon 1989; Marcovaldi and Filippini 1991). All studies using radio telemetry yield very few data points because the signal is only intermittently available when the turtle surfaces to breathe.

Ideally, home range studies of juvenile hawksbills should be conducted in tandem with foraging ecology studies that elucidate links between recruitment to particular foraging grounds and the sizes of home ranges established. Understanding the diet of sea turtles provides insight into trophic ecology, digestive physiology, health, dietary contaminants, energetics, and endoparisites (Forbes 1999). Despite the usefulness of understanding these parameters, food selection and diet preferences have been poorly studied for all sea turtle species (Lopez-Mendilaharsu et al. 2008).

Carr and Stancyk (1975) previously suggested that hawksbills are opportunistic omnivores. However, we now know they are primarily spongivores (Meylan 1984; Meylan 1988; Anderes Alvarez and Uchida 1994; Broderick et al. 2001), with sponges comprising approximately 95.3 % of the diet in the Caribbean. *Chondrilla nucula* is reported to be the most commonly consumed sponge, and comprises the majority of reported sponge content in hawksbill diets (Meylan 1988; Vicente and Carballeira 1991; Vicente 1994; Hill 1998; Leon and Bjorndal 2002); nevertheless the Caribbean population of this Mediterranean species has recently been recognized as genetically distinct and named *Chondrilla caribensis* (Rützler et al. 2007). Although hawksbills are primarily spongivores, their diet may also include a variety of other prey species, such as tunicates (Broderick et al. 2001), marine plants (Broderick et al. 2001), cnidarians (Leon and Bjorndal 2002), algae (Bjorndal et al. 1985), soft corals (Bjorndal 1997), zoanthids (Dunbar et al. 2008), polychaetes (Bjorndal et al. 1985), gastropods (Den Hartog 1980), holothurians (Vicente and Carballeira 1991), and anemones (Den Hartog 1980).

The purpose of this study was to examine the links between diet, food availability, and home ranges of juvenile hawksbills. Understanding these links can augment knowledge of the migratory behavior of hawksbills, highlight important foraging areas, and stimulate focused conservation efforts in the Caribbean.

Materials and Methods

Study Area

Roatán is located approximately 60 km off the north coast of Honduras (N16°20′24″, W086°19′48″), and is part of the Bay Islands. These islands form part of the Mesoamerican Barrier Reef complex, which consists of hard and soft corals interspersed with sponges, beds of *Thalassia testudinum*, and sandy substrate. The Port Royal area of Roatán is on the southeastern coast of the island, and experiences less commercial pressure than other parts of the island. The reef flat in the area is shallow (< 20 m) and slopes gently for approximately 2.2 km, until it reaches the reef crest where the wall drops more than 300 m (Dunbar et al. 2008). The upper portion of the reef slope is comprised mainly of turtle grass (*T. testudinum*) and sand beds. As the reef slopes towards the crest there is a mixture of hard corals of Faviidae, Milleporidae, and Pocilloporidae; soft corals of Gorgoniidae and Plexauridae; and sponges of Chondrillidae, Geodiidae, and Petrosiidae (Dunbar et al. 2008).

Turtle Capture and Transmitter Attachment

Juvenile hawksbills were incidentally captured by hand by local fisherman on the southeastern coast of Roatán, and brought to a holding pen for tagging and measurements. Upon delivery of each turtle, fishermen were interviewed to identify the capture location. This was done so that each turtle could be released as close as possible to its capture site to minimize disorientation.

Each turtle was tagged on the right front and right rear flippers with Inconel style 681 metal tags (Archie Carr Center for Sea Turtle Research, Gainsville, FL), measured for straight and curved carapace length and width (±0.1 cm), weighed (±0.1 kg), checked for epibionts, and digitally photographed prior to transmitter attachment. For each turtle in the study, two small holes were drilled into the lower right marginal scutes, and the AI-2 radio transmitter (Holohil Systems Ltd., Carp, ON, Canada) secured to the carapace (supported by rubber rings to prevent chafing against the scutes) with zip ties, and covered with Powerfast two-part marine epoxy. Care was taken to reinforce the base of the antenna and streamline the transmitter as much as possible. The placement and attachment of the transmitter did not restrict movement or affect swimming ability, and turtles had no problems with submergence subsequent to transmitter attachment.

Turtle Release and Tracking

We transported turtles by boat to the Port Royal area and released them in the approximate location of their capture. Upon release, in-water observations of each turtle were obtained, as reported by Dunbar et al. (2008), and each turtle was given a 24-hour acclimation period prior to the onset of tracking. Tracking occurred between the hours of 0600 and 1600, using a three-element Yagi antenna (Wildlife Materials, Murphysboro, IL) and Yaesu VY-500 portable receiver (Amateur Electronic Supply, Las Vegas, NV). We attempted re-sightings of each turtle daily, and with each re-sighting we recorded the latitude and longitude of the turtle's position with a Garmin 72 Global Positioning System (GPS). Re-sighting locations were taken at least 24 hours apart to reduce autocorrelation in the home range analysis (Schmid et al. 2002). We tracked turtles from June to September 2007 and from June to September 2008.

Home Range Analysis

Minimum convex polygon (MCP) and fixed kernel density (FKD) were calculated from the re-sighting coordinates using the HRE: The Home Range Extension for ArcView (Rodgers and Carr 1998), in ArcMap 9.3 (Environmental Research Systems Institute, Redlands, CA). We used 100 % MCP because of the low number of re-sightings for each turtle (Boyle et al. 2009), and because it allowed us to compare our results with other studies (Hooge et al. 1999). All re-sighting coordinates were combined for all turtles and FKDs calculated using the reference bandwidth (h_{ref}) as a smoothing factor. We reported only the 50 % FKD, which shows core areas of use (Worton 1989; Griffin 2002) and is less sensitive to outliers than other FKD isopleths (Yasuda and Arai 2005).

Survey Transects

We selected survey sites based on extensive prior knowledge (from our own observations and those of other fishermen and divers) of presence of juveniles in the area, and accessibility for frequent dive visits. A total of 14 sites was surveyed from June to September 2008, both in areas known to be inhabited by juvenile hawksbills (resident juvenile sites; n=8), and without recorded sightings of juveniles (non-resident juvenile sites; n=6) (Figure 1). Following methods by Dunbar (2006), we placed transects at random in each survey site, and obtained Universal Transverse Mercator (UTM) readings for both the start and end point of each transect. A 2-m wide swath on each side of the transect was surveyed for abundance of prey species (Dunbar et al. 2009). We conducted a total of 48 transects, with 27 transects in resident sites and 21 in non-resident sites.

We surveyed for specific sponge, soft coral, zoanthid, and anemone species reported in the literature from hawksbill diet studies (Meylan 1984; Meylan 1988; Leon and Bjorndal 2002; Cuevas et al. 2007). The number of each species per site was counted, and the mean abundance for each species in both non-resident and resident areas was calculated for comparison. All data are represented as mean ± standard error.

For comparisons of resident and non-resident sites, we closely examined the transect data for each of the 11 prey types. Data were sparse (encountered on < 25 % of surveys) for five prey types (*Ancorina* sp., *Anemonia sulcata, Chondrosia reniformis, Spirastrella coccinea,* and *Suberites* sp.) and largely failed to meet parametric assumptions of normality and homoscedasticity. Data were deemed adequate for the remaining seven prey types (*Chondrilla caribensis, Geodia gibberosa, Palythoa caribaea, Pseudopterogorgia elisabethae, Pseudopterogorgia* sp., *Sidonops neptuni,* and

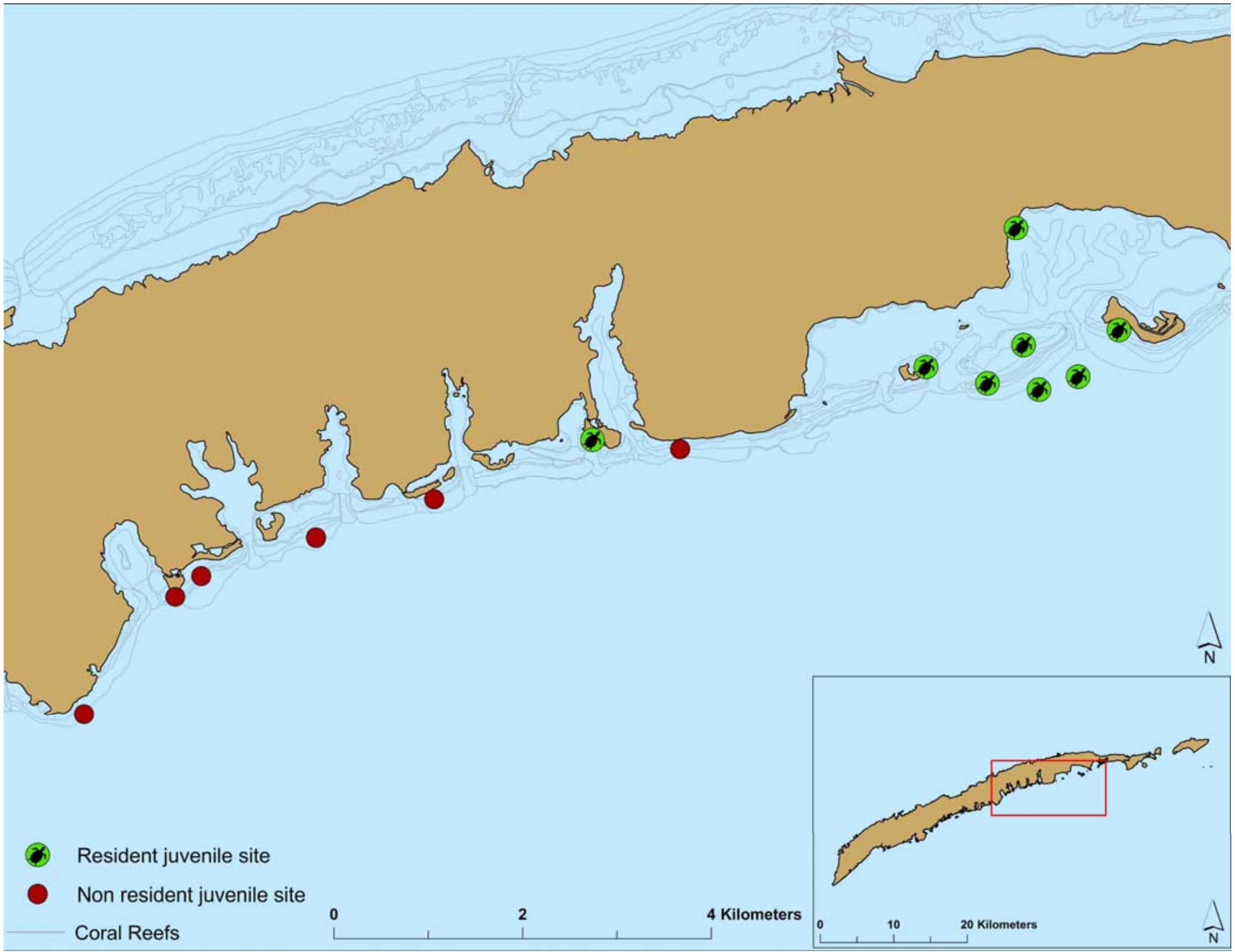

Figure 1: A map of Roatán, showing the 14 survey sites of habitat assessment, with resident and non-resident sites differentiated. Inset shows the entire island for reference.

Suberites sp.), of which six (all but *S. neptuni*) were rank-transformed to meet parametric assumptions. We compared abundance between resident and non-resident sites using a nonparametric Mann-Whitney test for the five sparsely-populous species, and independent *t*-tests for the seven populous species. The seven populous species were also included in a discriminant function analysis (including leave-one-out cross-validation) to evaluate distinctiveness of resident versus non-resident sites. We computed Cohen's *d* using pooled standard deviation (Hojat and Xu 2004) for each of the 11 prey types to determine effect size. Cohen's d values of ~ 0.5 are generally considered moderate and ≥ 0.8 large (Cohen 1988). All analyses (other than Cohen's *d*) were conducted using SPSS 13.0 for Windows, with alpha set at 0.05.

Dietary Analysis

This study was initially designed to address home range and habitat structure. However, after conducting the habitat assessment we determined that an examination of juvenile hawksbill diets should be included to make the study cohesive. Accordingly, the habitat assessment was carried out prior to determining the diet of juvenile hawksbills in this study. We carried out lavages on four turtles between April and November, 2009. Prior to lavages, turtles were measured, weighed, and tagged using the same methods described previously. The input and retrieval tubes to be used in the lavage were carefully cleaned, disinfected, sanded to remove sharp edges, and marked at 10-cm intervals. For lavages, we generally followed methods by Forbes (1999), but made modifications for smaller turtles. Animals were placed on their carapaces in the lap of an assistant, with the turtle held at a downward angle in a manner that inhibited free movement of the front flippers. Total lavage time required less than 5 minutes. In one case when stomach contents were not obtained, we obtained a sample of fecal matter (for turtle 086-09). Both gastric and fecal samples were stored in 40 % ethanol and refrigerated until analyzed.

Each lavage sample was viewed under a dissecting scope, sub-sampled, and separated into major taxa. Percent composition of a prey item was determined by comparing the dry weight of a species to the total dry weight of the sample. Sponges were isolated from the rest of the ingesta and identified to the lowest taxa possible by spicule type and spongin content.

We used compositional analysis (Aebischer et al. 1993) to assess the differences between select prey species consumed by the juvenile hawksbills and the availability of corresponding prey items in the turtle-occupied habitat. Prey species were categorized into three sponge groups (*C. caribensis, G. gibberosa*, and other) for both prey species consumed (used) and those available (available). The three categories were chosen based on which prey species were most abundant in the habitat assessment. Compositional analysis was conducted using R software 2.11.0, with an alpha set at 0.05 (Calenge 2006).

Results

Tracking

The overall results of our tracking study are presented in Table 1. We tracked six turtles (five in the first tracking season, one in the second) ranging in size from 28.7 - 35.6 cm (mean = 32.6 ± 1.1 cm) $SCL_{minimum}$ and in weight from 2.9 - 5.4 kg (mean = 4.2 ± 0.4 kg). Tracking duration ranged from 15 - 60 days (mean = 49.2 ± 7.5). Although we attempted one re-sighting for each turtle per day, the number of re-sightings per turtle ranged from 4 - 6 (mean = 5 ± 0.9). The number of times per turtle a transmitter signal was detected without re-sighting ranged from 3 - 11 (mean = 8.2 ± 1.3), and the number of days between signal reception, ranged from 1 - 23 (mean = 4.2 ± 0.6). While we attempted to re-locate each of the five turtles from the first tracking season during the second tracking season, none were found.

Home Range

The 100 % MCP of individual turtles ranged from 0.15 - 0.56 km2 (mean = 0.40 ± 0.08 km^2; Table 1), and all six turtles had overlapping home ranges established over inshore reefs (Figure 2). The 50 % FKD for all turtles combined was 5.80 km^2 (Figure 3).

Survey Transects

An area of approximately 11.5 km2 was surveyed during the habitat assessment. The potential dietary species with the highest total abundance in all survey sites were *G. gibberosa*, *P. elisabethae*, and *C. caribensis*. The species with the lowest total abundance in all sites were *Suberites* sp., *A. sulcata*, and *C. reniformis*. In non-resident areas, species

Table 1: Summary of data collected for each of the six turtles tracked, including estimated home range sizes, tracking information, and physical characteristics. Straight carapace lengthminimum (SCL) and weight were collected prior to release. Home range estimate of minimum convex polygon (MCP) was calculated using HRE: The Home Range Extension for ArcView.

Turtle ID	SCL (cm)	Weight (kg)	Tracking Duration (days)	Number of Sightings	Mean Duration Between Sightings (days)	MCP Area (km^2)	Number of days receptions were obtained without re-sighting	Range of days between reception without re-sighting
037-06	32.2	4.6	41	4	8.5	0.17	11	1 - 6
044-06	28.7	2.9	60	8	6.5	0.55	10	1 - 23
046-07	35.2	5.0	59	5	11.8	0.46	10	1 - 11
052-07	35.6	5.4	60	4	11.8	0.15	6	1 - 13
053-07	30.7	3.7	60	6	8.3	0.51	9	1 - 9
073-08	33.0	3.7	15	5	2.0	0.56	3	2 - 3

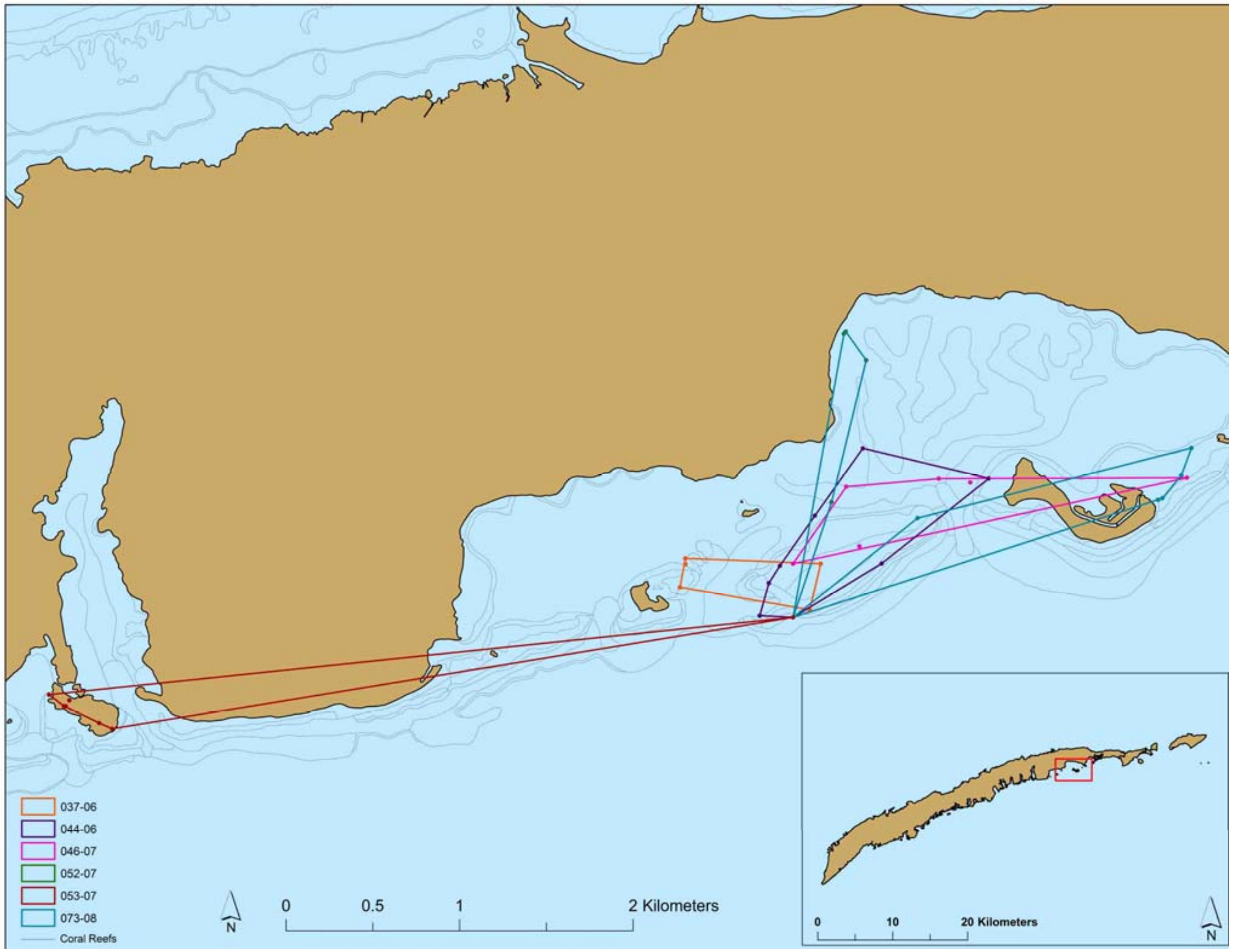

Figure 2: Minimum convex polygons (MCP) of the six juvenile sea turtles in this study. All MCPs overlap in the Port Royal area. Inset: Island of Roatán with the study area marked.

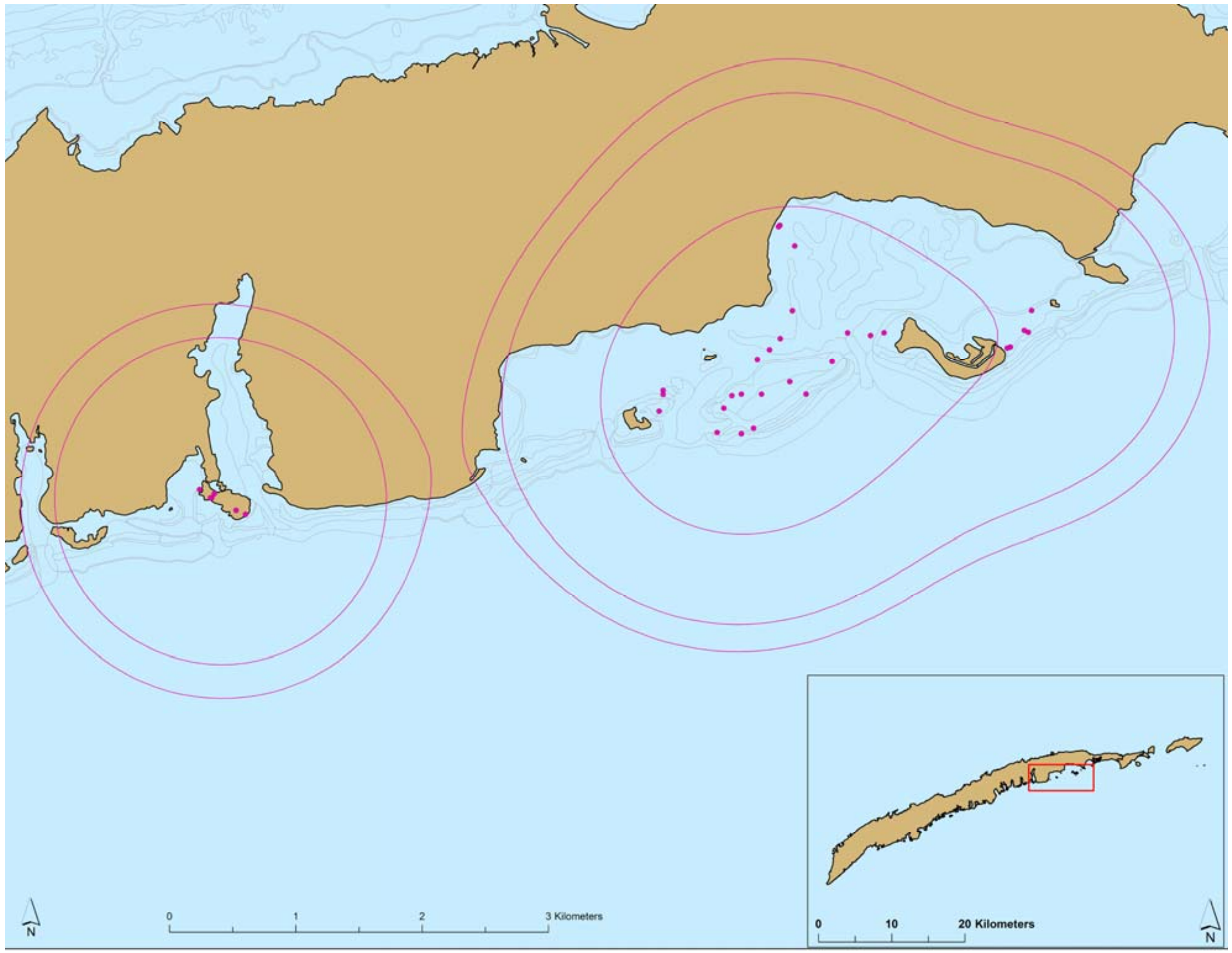

Figure 3: Fixed kernel density (FKD) isopleths of all juvenile hawksbill re-sightings. The innermost isopleth represents 50 % FKD, the middle isopleth represents 90 % FKD, and the outermost isopleth represents 95 % FKD. Inset: Island of Roatán with the study area marked.

with the highest mean abundances were *Pseudopterogorgia* sp., *G. gibberosa*, and *C. caribensis*, whereas species with the lowest mean abundances were *A. sulcata*, *Suberites* sp., and *S. coccinea.* In resident areas, the species with the highest mean abundances were *G. gibberosa*, *P. elisabethae*, and *C. caribensis*, while the species with the lowest mean abundances were *Suberites* sp., *A. sulcata*, and *Ancorina* sp. The three species to show a significant difference in mean abundance between resident and non-resident sites (Table 2) were *G. gibberosa*, *Pseudopterogorgia* sp. and *S. coccinea*.

The discriminate function analysis for the habitat assessment included seven of the 11 prey species. The overall Wilks' lambda was significant (Wilk's lambda = 0.48, χ^2 = 31.31, df = 7, P < 0.001), confirming the difference between resident and non-resident sites. Resident and non-resident sites correctly classified 92.6 % and 76.2 % of the time, respectively, with an overall predictive success of 85.4 %. Leave-one-out classification also revealed a high level of classification success (resident 81.5 %, non-resident 71.4 %, overall 77.1 %). Differences in abundance of *Pseudopterogorgia* sp. and *G. Gibberosa* provided the best discrimination between sites.

Diet Analysis

The five turtles in the lavage study ranged in size from 19.8 - 49.7 cm (mean = 29.06 ± 5.28 cm) $SCL_{minimum}$, and in weight from 1.6 - 14.5 kg (mean = 4.64 ± 2.47 kg) (Table 3). Lavage samples revealed that juvenile hawksbills at our study site consumed a variety of specimens, with sponges comprising the main dietary component. Approximately 59.0 % (Figure 4) of ingesta consisted of various sponges, with percent composition among various genera and species ranging from 0.3 % - 75.3 % (Table 4). The exception was turtle TIN075-08, whose primary dietary component was an unidentified alga. *M. ruber* and *C. caribensis* were the most prevalent sponge species found in the gut contents of examined turtles (Table 4), having high percent compositions in several of the lavage samples (Figure 4).

Compositional analysis revealed lack of preference for the three prey categories using randomization (Wilk's Lambda = 0.212, df = 2, P = 0.086), but suggested prey preference using parametric testing (P = 0.021). The ranking of prey item preference indicated *C. caribensis* > *G. gibberosa* > other.

Table 2: Comparison of mean abundance (± standard error) for 11 prey species between transects in resident (n = 27) and non-resident juvenile turtle sites (n = 21), including probability (P) of statistical difference between sites and effect size (Cohen's *d*).

Prey Species	Resident Site	Non-resident site	P	Cohen's d
Ancorina sp.	0.48 ± 0.20	0.67 ± 0.28	0.60 [b]	0.16
Chondrilla caribensis	30.48 ± 4.52	27.71 ± 6.31	0.38[a]	-0.11
Chondrosia reniformis	0.67 ± 0.40	0.38 ± 0.33	0.58 [b]	-0.15
Geodia gibberosa	58.93 ± 8.45	28.05 ± 8.20	0.002 [a]	-0.75
Sidonops neptuni	0.81 ± 0.41	1.52 ± 0.47	0.26 [a]	0.33
Pseudopterogorgia elisabethae	42.30 ± 10.69	12.57 ± 3.68	0.75 [a]	-0.69
Pseudopterogorgia sp.	16.81 ± 4.79	38.67 ± 6.22	<0.001[a]	0.82
Spirastrella coccinea	2.19 ± 1.05	0.19 ± 0.19	0.034 [b]	-0.48
Suberites sp.	1.22 ± 0.52	1.48 ± 0.44	0.20 [a]	0.11
Anemonia sulcata	-	0.26 ± 0.17	0.12 [b]	-0.40
Palythoa caribaea	3.07 ± 0.55	6.19 ± 1.44	0.13 [a]	0.64

[a] Independent *t*-test
[b] Mann-Whitney test

Table 3: Summary of data on physical characteristics collected for each turtle on which gastric lavages were performed. SCL represents the minimum straight carapace length.

Turtle ID	SCL (cm)	Weight (kg)
075-08	19.8	2.5
086-09	25.1	2.6
087-09	26.4	2.0
092-09	24.3	1.6
094-09	49.7	14.5

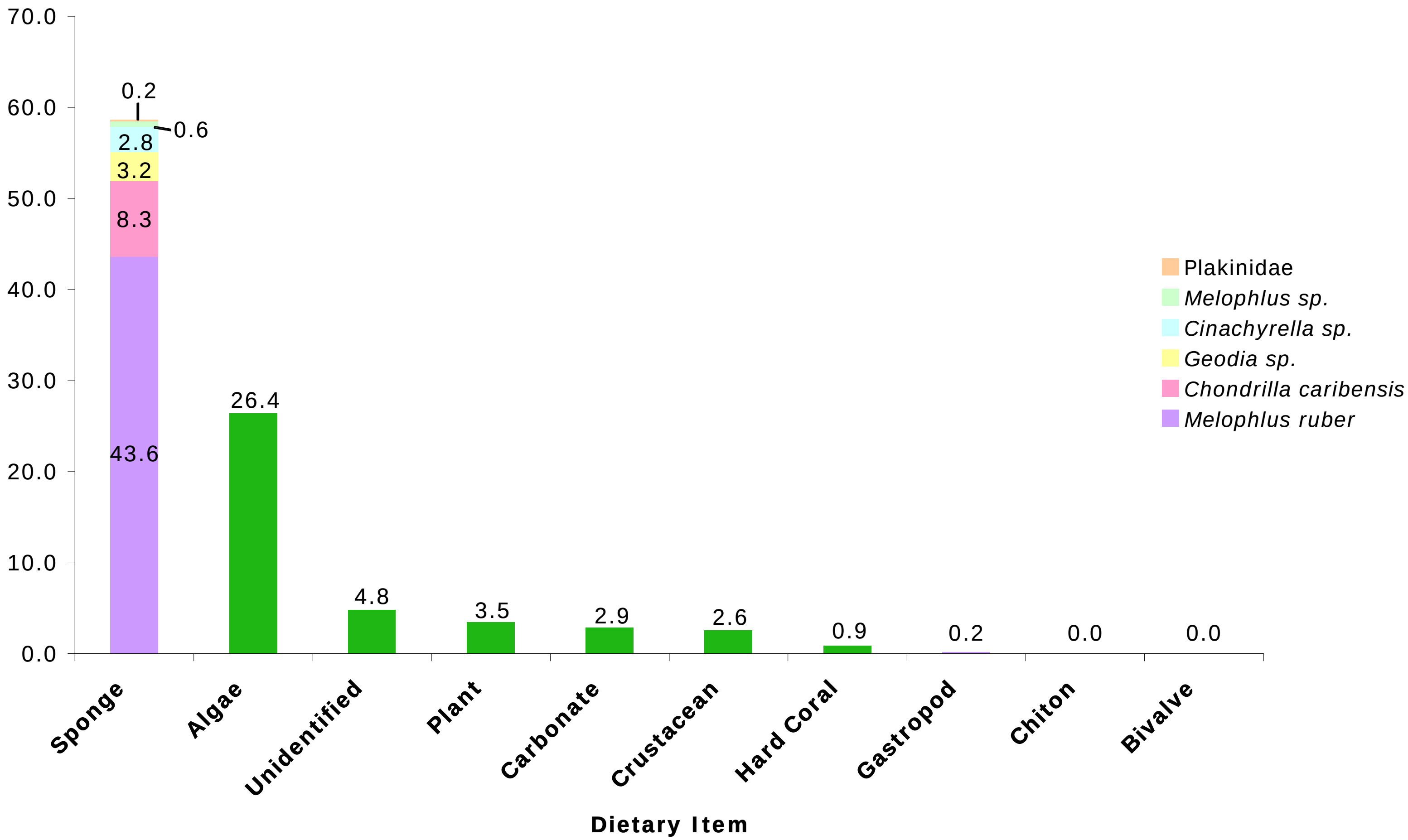

Figure 4: Diet composition of juvenile hawksbill sea turtles (n = 5), with sponges identified to genus and species, where possible.

Table 4: Sponge species identified in the diet of juvenile hawksbill sea turtles, the percent composition of each species to the sponge component of the diet, and the rank of each species.

Order	Family	Species	Percent Composition	Rank
Astrophorida	Ancorinidae	*Melophlus ruber*	75.30	1
	Chrondrosiidae	*Chondrilla caribensis*	14.14	2
	Geodiidae	*Geodia gibberosa* or *Sidonops neptuni*	5.42	3
Spirophorida	Tetillidae	*Cinachyrella* spp.	4.85	4
Homosclerophorida	Plakinidae	N/A	0.28	5

Discussion

Home Range and Foraging Ecology

Home ranges (MCP) of each of the six juveniles were less than 1 km^2 and the core area of activity (50 % FKD) for all juvenile re-sightings pooled was 5.80 km^2. Since MCP is a connection of the peripheral sightings, the estimated home ranges are likely exaggerated as the polygons cross small areas of land. In any case, these results are comparable to those of other studies. Blumenthal et al. (2009b) observed that juvenile hawksbills in the Cayman Islands had small daily home ranges, with displacement between capture and recapture sites ranging from 0.63 - 2.08 km. Cuevas et al. (2007) discovered that juvenile hawksbills in Yucatan, Mexico, also had small home ranges, with displacement averaging 1.2 km in diameter. Home ranges for juvenile hawksbills in Puerto Rico were even smaller, ranging from 0.07 - 0.14 km^2 (van Dam and Diez 1998), and in Japan, Okuyama et al. (2005) reported the home range for a single juvenile hawksbill to be less than 1 km^2. Similar results have also been obtained for juvenile green sea turtles. For example, the home ranges of juvenile greens in Oahu, Hawaii, were 2.62 km^2 (Brill et al. 1995). In Palm Beach, Florida, they ranged from 0.69 - 5.05 km^2 (Makowski et al. 2006), and in South Padre, Texas, they ranged from 0.22 - 3.11 km^2 (Renaud et al. 1995). In the current study, the high abundance of food resources on the inshore, shallow reefs, and the plethora of resting places likely explain the small home ranges.

We found that the home ranges for all six juveniles in the current study overlapped. Similar results were obtained in other studies. Seminoff et al. (2002) found overlapping home ranges for 11 of the 12 adult turtles in their study on neritic foraging grounds in Bahía de los Angeles, Gulf of Mexico, California. While their study was conducted on adults, and adult behavior likely differs substantially from that of juveniles, nevertheless, the home ranges overlapped on foraging grounds as did the home ranges in the current study. Schmid et al. (2003) reported that subadult Kemp's ridley turtles had home ranges that overlapped in a particular foraging area in west-central Florida. Similar findings were obtained in Palm Beach, Florida, by Makowski et al. (2006), who found that the home ranges of six juvenile greens overlapped, and concluded this was indicative of adequate resources in the developmental habitat shared by several turtles. They also proposed that site fidelity displayed by turtles in their study could be a more efficient means of exploiting available resources than random foraging, allowing turtles to reduce the energetic costs involved with more large scale movements (Makowski et al. 2006). In our study, the reef structure and overlapping home ranges may be an indication of the high quality habitat in this area, where other juvenile hawksbills are often sighted (Dunbar and Berube, 2008; Dunbar et al. 2009). In such a case, the suggestion by Dunbar et al. (2008), that the area may be an important recruiting and developmental ground, may have merit.

The size of a home range may depend on where it is established. Small home ranges in the Caribbean could result from high quality prey items at foraging sights. When Cuevas et al. (2008) undertook a study of post-nesting migratory movements of hawksbills, they showed that the hawksbill with the smallest home range foraged at a Caribbean site, while the hawksbill with the largest home range foraged at a Gulf of Mexico site. They proposed that Caribbean habitats might contain higher quality food items, allowing the turtle to occupy a smaller home range (Cuevas et al. 2008).

Since radio telemetry was used exclusively, it was often difficult to obtain a re-sighting for a single turtle on any given day, and often no re-sightings were obtained. If a transmitter signal was detected during a tracking attempt but the turtle was not sighted, the signal detection was recorded. Artisanal fishermen and divers reported observations of turtles with transmitters in the Port Royal area after the current study, usually with the antennae broken off. Unfortunately, individual turtle identities remained unknown.

Overall abundances of sponge species in both resident and non-resident areas demonstrated that *G. gibberosa, C. caribensis*, and *P. elisabethae* had the highest abundances. In non-resident sites, species with the highest mean abundances were *Pseudopterogorgia* sp. and *G. gibberosa*, while in resident sites species with the highest mean abundances were *P. elisabethae* and *G. gibberosa*. The three species showing a significant difference in mean abundance between resident and non-resident sites were *P. elisabethae*, and *Pseudopterogorgia* sp., and *S. coccinea.* Even though *G. gibberosa* and *Pseudopterogorgia* sp. where abundant in both resident and non-resident sites, with *G. gibberosa* showing a significant difference and *Pseudoptergorgia* sp. not showing a significant difference in abundance, the discriminate function analysis showed that these two prey species provided the best discrimination between resident and non-resident sites, with an overall predictive success of 85.4 % (77.1 % leave-one-out classification). This correlates well with results from other work showing that hawksbills have a preference for *Chondrilla* spp., *Pseudopterogorgia* spp. and *S. coccinea* (Leon and Diez 1999; Leon and Bjorndal 2002; Diez et al. 2003; Cuevas et al. 2007). It is possible that these prey species are some of the most abundant sponge and soft coral species located within the reefs around Roatán. Therefore we suggest hawksbills may be establishing their home ranges based on the nutrient content or defense systems of other prey items. Perhaps the sites that we considered to be non-resident sites were previously resident sites. There is also the potential that juveniles are currently present at non-resident sites and that we have not yet detected them.

We found hawksbill diets were comprised of a number of different taxa. However, 59.0 % of all food consumed by juvenile hawksbills consisted of sponge, with the most prevalent sponge species being *M. ruber* (44 % of total dry weight) and *C. caribensis* (8 % of total dry weight). The compositional analysis suggested that turtle preference for sponges was in the order *C. caribensis* > *G. gibberosa* > other. Our evidence suggests that hawksbills feed preferentially on certain sponge species. *M. ruber* was excluded as a category from the compositional analysis because it was not included in the habitat assessment for reasons previously noted. Had it been included in the habitat assessment, and therefore the compositional analysis, it is likely to have had a high preferential ranking. These findings suggest that juvenile hawksbills in the Port Royal region of Roatán are primarily, but not strictly, spongivores. In a study of hawksbills from seven different Caribbean countries, Meylan (1988) demonstrated that 95.3 % of their diet consisted of sponge, with *C. caribensis* (her *C. nucula*) having the highest rank (12.6 % average dry weight). In the Dominican Republic, Leon and Bjorndal (2002) noted sponge as the most frequent diet item, but the hawksbill's diet also contained large amounts of the corallimorpharian *Ricordea florida.* The most prevalent sponge species in the diet of Dominican Republic hawksbills was *Chondrilla nucula/caribensis* (59 % of volume at Bahía; 14 % at Cabo Rojo). In our study, *C. caribensis* was the second highest consumed species. It is a common diet item for hawksbills, and was highly abundant within the reefs of the study site. *Chondrilla* has few spicules, little silica, densely packed collagen fibrils, and both a high nitrogen and energy content (Meylan 1984). While *Chondrilla* is widely reported as a common dietary item for hawksbills, this report constitutes the first record of *M. ruber* as part of hawksbill diets. *M. ruber* (Ancorinidae, Astrophorida) was first described by Lehnert and van Soest (1998) from shallow to deep (0.2 - 88m) reef and framework-cave habitats in Jamaica. It is a dark red, vase-shaped sponge with a tough consistency and a robust siliceous skeleton. The genus has one other species, *M. sarasinorum* Thiele which has an Indo-Malayan distribution (Lehnert and van Soest 1998).

The varied diet of hawksbills in the current study suggests that juveniles are not indiscriminately feeding, but that their diet may be the result of available prey abundance and selectivity for certain species. In releases of other juvenile hawksbills in Roatán, we observed them feeding on the zoanthid *P. caribaea*, but this species was not identified in any of the gastric lavage samples. Similarly, hawksbills are known to distribute themselves on hard bottom sites where soft corals, such as *Pseudopterogorgia* sp., are prevalent (Cuevas et al. 2007). However, this species was absent from all gut samples we retrieved in our study. Therefore, hawksbills in Roatán may be showing selectivity for particular prey species, although other more abundant prey items are available.

Conservation

When evaluating conservation efforts for critically endangered sea turtles such as *E. imbricata*, both the turtle and its habitat are important factors for decision-makers and resource managers to consider. While the entire habitat range of a sea turtle species should be considered (Meylan and Donnelly 1999; Channell and Lomolino 2000; Bjorndal and Bolten 2010), James et al. (2005) recommend that high-use areas be the primary focus for conservation efforts, especially if there is high mortality of turtles in those areas. While adults are still the primary focus of many conservation efforts, it is becoming increasingly clear that protecting juveniles and subadults is also likely to result in long-term sustainability of sea turtles (Crouse et al. 1987; Griffin 2002; Schmid et al. 2003).

Home range and diet studies of juveniles are vitally important for focusing conservation efforts, since site fidelity and core areas can highlight hotspots where habitat characterization and use can be examined (Broderick et al. 2007; Cuevas et al. 2007; Blumenthal et al. 2009b). This can focus conservation efforts on specific areas of resources that are important for juvenile development (Makowski et al. 2006), particularly recruitment and development grounds.

By examining the diet of juveniles in the Port Royal area we have made the first determination of which species are key prey items for the population of juvenile hawksbills in the Caribbean waters of Honduras. The current study may be an important step in implementing more rigorous conservation efforts in Honduras. Dunbar et al. (2008) suggest that the Port Royal area may be a critical recruitment ground for juvenile hawksbills. In the current study, resulting small home ranges are likely a reflection of the high quality habitat in the Port Royal region. The nearshore, shallow reefs in this area have a high abundance of food resources, while the structure of the reef itself, may allow for sufficient resting areas under ledges, resulting in less travel between foraging and resting grounds, and less energy expenditure. Thus, the Port Royal area may require special consideration as a site for more intensive future research and conservation efforts, and should also be considered for special protection by both local and central governments in Honduras.

Acknowledgements

Logistical and financial support was provided by the Protective Turtle Ecology Center for Training, Outreach and Research, Inc. (ProTECTOR), the owners of the Reef House Resort, the Department of Earth and Biological Sciences at Loma Linda University, and the State of the World's Sea Turtles (SWOT). We thank the Honduras Natural Resources and Environment Secretariat (SERNA), and Dirección General de Pesca y Acuicultura (DIGEPESCA) for providing research permits for this work. Thanks to Dr. Rob van Soest for providing information about *Melophlus ruber*. We also thank Dr. Art Rodgers and Dr. Jeff Seminoff for their input on home range analysis, Dr. Anne Meylan for her insights into gastric lavages and hawksbill diets, and Aaron Corbit for his help with compositional analysis. This work was carried out under permit #DGPA/5428/2007 from the Secretariat of Agriculture and Ranching (SAG), and is in compliance with Loma Linda University IACUC protocol # 86004. This is contribution Number 2 of the Protective Turtle Ecology Center for Training, Outreach and Research, Inc. (ProTECTOR).

References

Aebischer, N. J., Robertson, P. A., and Kenward, R. E. 1993. Compositional analysis of habitat use from animal radio-tracking data. Ecology 74:1313–1325.

Anderes Alvarez, B.L., and Uchida, I. 1994. Study of hawksbill turtle (*Eretmochelys imbricata*) stomach content in Cuban water. Ministry of Fishing Industry, Cuba.

Anonymous. 1988. Mexico's sea turtle program. Marine Fisheries Review. 50:70-72.

Avens, L., Braun-McNeill, J., Epperly, S., and Lohmann, K.J. 2003. Site fidelity and homing behavior in juvenile loggerhead sea turtles (*Caretta caretta*). Marine Biology. 143:211-220.

Bailey, J.A. 1984. Principles of wildlife management. Wiley-Liss, New York.

Baillie, J., and Groombridge, B. 1996. IUCN Red List of threatened animals. IUCN, Gland, Switzerland.

Bjorndal, K.A. 1997. Foraging ecology and nutrition of sea turtles. In: Lutz, P.L., and Musick, J.A. (eds). The biology of sea turtles. CRC Press, pp 199-232.

Bjorndal, K.A., and Bolten, A.B. 2010. Hawksbill sea turtles in seagrass pastures: success in a peripheral habitat. Marine Biology. 157:135-145.

Bjorndal, K.A., Bolten, A.B., and Chaloupka, M.Y. 2000. Green turtle somatic growth model: evidence for density dependence. Ecological Applications. 10:269-282.

Bjorndal, K.A., Carr, A., Meylan, A.B., and Mortimer, J.A. 1985. Reproductive biology of the hawksbill *Eretmochelys imbricata* at Tortuguero, Costa Rica, with notes on the ecology of the species in the Caribbean. Biological Conservation. 34:353-368.

Bjorndal, K.A., and Jackson, J.B.C. 2003. Role of sea turtles in marine ecosystems: reconstructing the past. In: Lutz, P.L., Musick, J.A., and Wyneken, J. (eds). Biology of sea turtles. CRC Press, pp 259-273.

Blumenthal, J.M., Austin, T.J., Bell, C.D.L., Bothwell, J.B., Broderick, A.C., Ebanks-Petrie, G., Gibb, J.A., Luke, K.E., Olyik, J.R., Orr, M.F., Solomon, J.L.,and Godley, B.J. 2009a. Ecology of hawksbill turtles, *Eretmochelys imbricata*, on a western Caribbean foraging ground. Chelonian Conservation and Biology. 8:1-10.

Blumenthal, J.M., Austin, T.J., Bothwell, J.B., Broderick, A.C., Ebanks-Petrie, G., Olyik, J.R., Orr, M.F., Solomon, J.L., Witt, M.J., and Godley, B.J. 2009b. Diving behavior and movements of juvenile hawksbill turtles *Eretmochelys imbricata* on a Caribbean coral reef. Coral Reefs. 28:55-65.

Boarman, W., Goodlett, T., Goodlett, G., and Hamilton, P. 1998. Review of radio transmitter attachment techniques for turtle research and recommemdations for improvement. Herpetological Review. 29:26-33.

Boulon, R. 1989. Virgin Island turtle tag recoveries outside of the U.S. Virgin Islands. In: Eckert, S.A., Eckert, K.L., and Richardson, T.H. (eds). Proceedings of the ninth annual workshop on sea turtle conservation and biology. NOAA Tech Memo NMFS/SEFC-232. pp 207-209.

Boyle, S.A., Lourenco, W.C., da Silva, L.R., and Smith, A.T. 2009. Home range estimates vary with sample size and methods. Folia Primatologica. 80:33-42.

Brill, R.W., Balazs, G.H., Holland, K.N., Chang, R.K.C., Sullivan, S., George, J.C. 1995. Daily movements, habitat use, and submergence intervals of mornal and tumo-bearing juvenile green turtles (*Chelonia mydas* L.) within a foraging area in the Hawaiian Islands. Journal of Experimental Marine Biology and Ecology.185:203-218.

Broderick, A.C., Coyne, M.S., Fuller, W.J., Glen, F., and Godley, B.J. 2007. Fidelity and over-wintering of sea turtles. Proceedings of the Royal Society of Biological Sciences. 274:1533-1539.

Broderick, A.C., Godley, B.J., and Hays, G.C. 2001. Trophic status drives interannual variability in nesting numbers of marine turtles. Proceedings of the Royal Society of London. 268:1481-1487.

Burt, W.H. 1943. Territoriality and home range concepts as applied to mammals. Journal of Mammalogy. 24:346-352.

Calenge, C. 2006. The package “adehabitat” for the R software: A tool for the analysis of space and habitat use by animals. Ecological Modelling. 197:516-519.

Carr, A., and Stancyk, S. 1975. Observations on the ecology and survival outlook of the hawksbill turtle. Biological Conservation. 8:161-172.

Carr, A., Hirth, H., and Ogren, L. 1966. The ecology and migrations of sea turtles, 6 the hawksbill turtle in the Caribbean sea. American Museum Noviates. 2248:1-29.

Channell, R., and Lomolino, M.V. 2000. Dynamic biogeography and conservation of endangered species. Nature. 403:84-86.

Cohen, J. 1988. Statistical power analysis for the behavioral sciences, 2nd ed. Erlbaum Assoc., Hillsdale, New Jersey.

Crouse, D.T., Crowder, L.B., and Caswell, H. 1987. A stage-based population model of loggerhead sea turtles and implications for conservation. Ecology. 68:1412-1423.

Cuevas, E., Abreu-Grobois, F.A., Guzman-Hernandez, V., Liceaga-Correa, M.A., and van Dam, R.P. 2008. Post-nesting migratory movements of hawksbill turtles *Eretmochelys imbricata* in waters adjacent to the Yucatan Peninsula, Mexico. Endangered Species Research. 1-11.

Cuevas, E,. de los Angeles Liceaga-Correa, M., and Garduno-Andrade, M. 2007. Spatial characterization of a foraging area for immature hawksbill turtles (*Eretmochelys imbricata*) in Yucatan, Mexico. Amphibia-Reptilia. 28:337-346.

Den Hartog, J.C. 1980. Notes on the food of sea turtles: *Eretmochelys imbricata* (Linnaeus) and *Dermochelys coriacea* (Linnaeus). Netherlands Journal of Zoology. 30:595.

Diez, C.E., Velez-Zuazo, X., and van Dam, R.P. 2003. Hawksbill in seagrass beds. Marine Turtle Newsletter. 102:8-10.

Dunbar, S.G. 2006. Integrated watershed resources management. Standard 2.2.1: Rapid inventory of common hermit crabs in Roatán, Mesoamerican reef. United States Agency, International Development. Pp. 29.

Dunbar, S.G., and Berube, M.D. 2008. Hawksbill sea turtle nesting beach reconnaissance on Roatán, Honduras. United States Fish and Wildlife Services. Pp. 40.

Dunbar, S.G., Salina, L., and Stevenson, L. 2008. In-water observations of recently released juvenile hawksbils (*Eretmochelys imbricata*). Marine Turtle Newsletter. 121:5-9.

Dunbar, S.G., Salinas, L., and Berube, M.D. 2009. Activities of the Turtle Awareness and Protection Studies (TAPS) program under the Protective Turtle Ecology Center for Training, Outreach, and Research, INC (ProTECTOR) in Roatán, Honduras. Ministry of Environment, Honduras. Pp. 60.

Eckert, K.L., Overing, J.A., and Lettsome, B.B. 1992. Sea turtle recovery action plan for the British Virgin Islands. Kingston, Jamaica.

Forbes, G.A. 1999).Diet sampling and diet component analysis. Research and Management Teachniques for the Conservation of Sea Turtles. 4:1-5.

Gardner, T.A., Cote, I.M., Gill, J.A., Grant, A., and Watkinson, A.R. 2003. Longterm region-wide decline in Caribbean corals. Science. 301:958-960.

Godley, B.J., Lima, E.H.S.M., Akesson, S., Broderick, A.C., Glen, F., Godfrey, M.H., Luschi, P., and Hays, G.C. 2003. Movement patterns of green turtles in Brazilian coastal waters described by satellite tracking and flipper tagging. Marine Ecological Progress Series. 253:279-288.

Griffin, D.B. 2002. GIS analysis of inter-nesting habitat, migratory corridors, and resident foraging areas of the loggerhead sea turtle (*Caretta caretta*) along the southeast coast.

Groombridge, B., and Luxmoore, R. 1989. The green turtle and hawksbills (Reptilia: Cheloniidae): World status, exploitation, and trade. CITES Secretariat, Lausanne, Switzerland.

Hill, M.S. 1998. Spongivory on Caribbean reefs releases corals from competition with sponges. Oecologica. 117:143-150.

Hojat, M., and Xu, G. 2004. A visitor's guide to effect sizes. Advances in Health Sciences Education. 9:241-249.

Hooge, P.N., Eichenlaub, W.M., and Solomon, E.K. 1999. Using GIS to analyze animal movements in the marine environment. pp 1-21.

Horrocks, J.A. 1992. WIDECAST sea turtle recovery action plan for Barbados. Caribbean Environmental Technical Report. 12:61.

Horrocks, J.A., Vermeer, L.A., Krueger, B., Coyne, M., Schroeder, B.A., and Balazs, G.H. 2001. Migration routes and destination characteristics of post-nesting hawksbills turtles satellite-tracked from Barbados, West Indies. Chelonian Conservation and Biology. 4:107-114.

James, M.C., Ottensmeyer, C.A., and Myers, R.A. 2005. Identification of high-use habitat and threats to leatherback sea turtles in northern waters: new directions for conservation. Ecology Letters. 8:195-201.

Lehnert, H., and van Soest, R.W.M. 1998. Shallow water sponges of Jamaica. Beaufortia: Institute for systematics and population biology (zoological museum) University of Amsterdam. 48(5):71-103.

Leon, Y.M., and Bjorndal, K.A. 2002. Selective feeding in the hawksbill turtle, an important predator in coral reef ecosystem. Marine Ecological Progress Series. 245:249-258.

Leon, Y.M., and Diez, C.E. 1999. Population structure of hawksbill turtles on a foraging ground in the Dominican Republic. Chelonian Conservation and Biology. 3:230-236.

Lopez-Mendilaharsu, M., Gardner, S.C., Riosmena-Rodriguez, R., and Seminoff, J.A. 2008. Diet selection by immature green turtles (*Chelonia mydas*) at Bahia Magdalena foraging ground in the Pacific Coast of the Baja California Peninsula, Mexico. Journal of the Marine Biological Association of the Uniter Kingdom. 88:641-647.

Makowski, C., Seminoff, J.A., and Salmon, M. 2006. Home range and habitat use of juvenile Atlantic green turtles (*Chelonia mydas* L.) on shallow reef habitats in Palm Beach, Florida, USA. Marine Biology. 148:1167-1179.

Marcovaldi, M.A., and Filippini, A. 1991. Trans-Atlantic movement by a juvenile hawksbill turtle. Marine Turtle Newsletter. 52:3.

Meylan, A.B. 1984. Feeding ecology of the hawksbills turtle (*Eretmochelys imbricata*): spongivory as a feeding niche in the coral reef community. PhD. Zoology.

Meylan, A.B. 1988. Spongivory in hawksbill turtles: a diet of glass. Science. 239:393-395.

Meylan, A.B., and Donnelly, M. 1999. Status justification for listing the hawksbill turtle (*Eretmochelys imbricata*) as critically endangered on the 1996 IUCN Red List of Threatened Animals. Chelonian Conservation and Biology. 3:200-224.

Mortimer, J.A., and Donnelly, M. 2008. Hawksbill turtle (*Eretmochelys imbricata*): Marine Turtle Specialist Group 2008 IUCN Red List status assessment.

Musick, J.A., and Limpus, C.J. 1997. Habitat utilization and migration in juvenile sea turtles. In: Lutz, P.L. and Musick, J.A. (eds). The biology of sea turtles. CRC Press. pp 137-163.

Navid, D. 1980. World conference on sea turtles. Environmental Policy and Law. 6:17-18.

Okuyama, J., Shimizu, T., Abe, O., Yoseda, K., and Arai, N. 2005. Dispersal processes of head-started hawksbill turtles (*Eretmochelys imbricata*) in the Yaeyama Islands waters, Okinawa, Japan. Proceedings of the 2nd International symposium on SEASTAR2000 and Asian Bio-logging Science (The 6th SEASTAR2000 Workshop): 63-68.

Polovina, J.J., Kobayashi, D.R., Parker, D.M., Seki, M.P., and Balazs, G.H. 2000. Turtles on the edge: movement of loggerhead turtles (*Caretta caretta*) along oceanic fronts, spanning longling fishing grounds in the central North Pacific, 1997-1998. Fisheries Oceanography. 9:71-82.

Renaud, M.L., Carpenter, J.A., Manzella, S.A., and Williams, J.A. 1992. Telemetric tracking of green sea turtles (*Chelonia mydas*) in relation to dredged channels at South Padre Islands, Texas, July though September 1992. Southeast Fisheries Center. National Marine Fisheries Service. Galveston Laboratory.

Renaud, M.L., Carpenter, J.A., Williams, J.A., and Manzella-Tirpak, S.A. 1995. Activities of juvenile green turtles, *Chelonia mydas*, at a jettied pass in south Texas. Fishery Bulletin. 93:586-593.

Renaud, M.L., and Williams, J.A. 1997. Movements of Kemp's ridley (*Lepidochelys kempii*) and green (*Chelmonia mydas*) sea turtles using Lavaca Bay and Matagorda Bay 1996 - 1997. Environmental Protection Agency.

Rodgers, A.R., and Carr, A.P. 1998. HRE: The home range extension for ArcView, user's manual. Centre for Northern Forest Ecosystem Research, Ontario. Ministry of Natural Resources.

Rützler, K., Duran, S., and Piantoni, C. 2007. Adaptation of reef and mangrove sponges to stress: evidence for ecological speciation exemplified by *Chondrilla caribensis* new species (Demospongiae, Chondrosida). Marine Ecology. 28 (Suppl. 1):95-111.

Schmid, J.R., Bolten, A.B., Bjorndal, K.A., and Lindberg, W.J. 2002. Activity patterns of Kemp's ridley turtles, *Lepidochelys kempii*, in the coastal waters of the Cedar Keys, Florida. Marine Biology. 140:215-228.

Schmid, J.R., Bolten, A.B., Bjorndal, K.A., Lindberg, W.J., Percival, H.F., and Zwick, P.D. 2003. Home range and habitat use by Kemp's ridley turtles in west-central Florida. Journal of Wildlife Management. 67:196-206.

Seaman, D.E., and Powell, R.A. 1996. An evaluation of the accuracy of kernel density estimators for home range analysis. Ecology. 77:2075-2085.

Seminoff, J.A., and Jones, T.T. 2006. Diel movements and activity ranges of green turtles (*Chelonia mydas*) at a temperate foragng area in the Gulf of California, Mexico. Herpetological Conservation and Biology. 1:81-86.

Seminoff, J.A., Resendiz, A., and Nichols, W.J. 2002. Home range of green turtles *Chelonia mydas* at a coastal foraging area in the Gulf of California, Mexico. Marine Ecological Progress Series. 242:253-265.

Tröeng, S., Dutton, P.H., and Evans, D. 2005,. Migration of hawksbill turtles *Eretmochelys imbricata* from Tortuguero, Costa Rica. Ecography. 28:394-402.

van Dam, R.P., and Diez, C.E. 1998. Home range of immature hawksbill turtles (*Eretmochelys imbricata* (Linnaeus)) at two Caribbean islands. Journal of Experimental Marine Biology and Ecology. 220:15-24.

Vicente, V.P. 1994. Spongivory in Caribbean hawksbill turtles, *Eretmochelys imbricata*: data from standed specimens. In: Schroeder, B.A., and Witherington, B.E. (eds). 13th annual symposium on sea turtle biology and conservation. NOAA Tech. Memo.

Vicente, V.P., and Carballeira, N.M. 1991. Studies on the feeding ecology of the hawksbill turtle, *Eretmochelys imbricata*, in Puerto Rico. In: Salmon, M., and

Wyneken, J. (eds). 11th annual workshop on sea turtle biology and conservation. NOAA Tech Memo NMFS-SEFSC-302, Miami, FL. pp 117.

White, G.C., and Garrott, R.A. 1990. Analysis of wildlife radiotracking data. Academic Press. New York.

Worton, B.J. 1987. A review of models of home range for animal movement. Ecological Modelling. 38:277-298.

Worton, B.J. 1989. Kernel methods for estimating the utilization distribution in home range studies. Ecology. 70:164-168.

Worton, B.J. 1995. Using Monte Carlo simulation to evaluate kernel-based home range estimators. Journal of Wildlife Management. 59:794-800.

Yasuda, T., and Arai, N. 2005. Fine-scale tracking of marine turtles using GPS-Argos PTTs. Zoological Science. 22:547-553.

CHAPTER 3

CONCLUSIONS

Study

This study was conducted to determine the home range and foraging ecology of juvenile hawksbill sea turtles on the southeastern coast of Roatán, Honduras. Six juveniles were tracked using radio telemetry. Their home ranges, determined by minimum convex polygon (MCP), ranged from 0.15 - 0.56 km^2. When all turtle re-sightings were combined, the core area of activity was located in Port Royal, and had an area of 5.80 km^2.

A habitat assessment was conducted using survey transects to determine the abundance of common dietary items in resident versus non-resident juvenile hawksbill areas. The species with the highest mean abundances in resident turtle sites were *Geodia gibberosa*, *Pseudopterogorgia elisabethae*, and *Chondrilla caribensis*, while the species with the lowest mean abundances were *Suberites* sp., *Anemonia sulcata*, and *Ancorina* sp. The species with the highest mean abundances in non-resident sites were *Pseudopterogorgia* sp., *G. gibberosa*, and *C. caribensis*, while the species with the lowest mean abundance were *A. sulcata*, *Suberites* sp., and *Spirastrella coccinea*. The three species showing a significant difference in mean abundance between resident and non-resident sites were *P. elisabethae*, and *Pseudopterogorgia* sp., and *S. coccinea.*

Ingesta were obtained from four juvenile hawksbills by gastric lavage and from one juvenile by fecal sample. Sponge was the most prevalent dietary item, with 59.0 % of diet composition consisting of five different sponge groups. The two most common sponge species were *Melophlus ruber* and *C. caribensis*, which comprised approximately 8 % and 44 % of total percent composition, respectively.

Applications to Conservation

Hawksbill sea turtles are critically endangered and both populations worldwide and in the Caribbean have suffered large declines (Meylan 1984; Bjorndal and Jackson 2003). Hawksbills spend most of their lives associated with coral reefs, and their role in maintaining reef biodiversity is imperative. As the largest spongivores and a critical keystone species, they reduce the competition between sponges and corals for space, thereby increasing the health and diversity of reef ecosystems. Since most life stages of the hawksbill are linked to reef ecosystems, it is important that both the coral reefs and the turtles be considered when implementing conservation measures. While hawksbills are linked with reefs during foraging, their entire range must be considered (Meylan and Donnelly 1999; Channell and Lomolino 2000; Bjorndal and Bolten 2010). However, focusing primarily on foraging grounds or hotspots may be most advantageous, as mortality of turtles is highest in these areas.

Historically, adults and nesting beaches have been the main focus of conservation efforts. Further examination has stressed that long-term sustainability of sea turtles is more likely if subadults and juveniles are a main focus of conservation efforts (Crouse et al. 1987; Griffin 2002; Schmid et al. 2003). The question then becomes, how do we determine where these conservation efforts should be focused? I suggest that it may be best to allocate efforts to areas where subadults and juveniles are spending the majority of their time. This involves home range and foraging ecology studies of these life stages. Examining movements within ranges highlights hotspots and core areas, and ingesta can be obtained to determine primary dietary items. This can focus conservation on particular food items in foraging grounds, and areas that are important for development of the turtles.

Along with conservation efforts, policy regulation also plays an important role in turtle recovery (Navid 1980; Eckert et al. 1992). However, policies are often not regulated (Anonymous 1988; Horrocks 1992). Fishermen in Mexico are still allowed to capture olive ridleys (Anonymous 1988), and penalties for turtle poaching in other countries are not a deterrent, because the offense is often not viewed seriously (Horrocks 1992).

The current study is an important step towards implementing conservation efforts in Honduras. By tracking the movements of juveniles and determining core areas of activity, it is becoming increasingly clear that the Port Royal region of Roatán may be a hotspot and important foraging grounds for juvenile hawksbills. The small MCPs and overlapping home ranges indicate that this area may be a high quality habitat, including abundant food resources and resting places. The abundance of food resources and resting places allows for less travel between these areas, and therefore less energy expenditure. The high abundance of *C. caribensis* in the habitat assessment, and in percent composition of diet indicates that this sponge species is crucial to hawksbills diets. The discovery of *M. ruber* as the primary dietary component, the absence of reports of *M.*

ruber as a component of hawksbill diets in the literature, and its scarcity in the Atlantic (Lehnert and van Soest 1998), all indicate that conservation efforts towards this sponge species may be critical. The results of this study indicate that Port Royal should be considered when implementing conservation efforts on the island. Now that important dietary items are known, habitat assessments can be conducted around the entire island to determine future recruitment grounds and hotspots, and therefore protect these areas. Results from this study may be applicable not only to Roatán, but the other Bay Islands, and throughout the Caribbean region.

Limitations of This Study

While this study yielded relevant data on juvenile hawksbill home ranges, we recognize the need for further tracking studies around Roatán. It would be beneficial to extend the tracking period to examine if the movements of juveniles change in other seasons. However, it is felt that the main weakness in the current study was the use of radio telemetry as the sole means of tracking. Although beyond the scope of this study, it may have been advantageous to add sonic telemetry in tandem with the radio telemetry to increase the number of re-sightings. A larger number of re-sightings would likely have resulted in a more accurate home range size, and possibly illustrated other core areas of activity. However, since signals were obtained numerous times without directly observing the turtle, and the turtles have been re-sighted by divers and fishermen in later seasons in the same home range area, we are confident that the tracking results provide an accurate assessment of juvenile hawksbill home range.

It would have been beneficial to obtain gastric lavage samples from more turtles, as the sample size was small. However, since the species obtained are consistent throughout the samples, it is probable that the percent composition may not vary with greater sampling. However, the presence of species within the diet may vary. Another benefit would have been to obtain samples from stranded and deceased turtles (Dr. A. B. Meylan, personal communication). The amounts of ingesta obtained were small, and if the entire digestive tract were available, it is likely that the percent composition of species may be different. Despite its limitations, this study provides critical information on juvenile home ranges and diets in Honduras, an area where there is a paucity of reported data.

References

Anonymous. 1988. Mexico's sea turtle program. Marine Fisheries Review. 50:70-72.

Bjorndal, K. A., and Bolten, A. B. 2010. Hawksbill sea turtles in seagrass pastures: success in a peripheral habitat. Marine Biology. 157:135–145.

Bjorndal, K.A., and Jackson, J.B.C. 2003. Role of sea turtles in marine ecosystems: reconstructing the past. In: Lutz, P.L., Musick, J.A., and Wyneken, J. (eds). Biology of sea turtles. CRC Press, pp 259-273.

Channell, R., and Lomolino, M.V. 2000. Dynamic biogeography and conservation of endangered species. Nature. 403:84–86

Crouse, D.T., Crowder, L.B., and Caswell, H., 1987. A stage-based population model for loggerhead turtles and implications for their conservation. Ecology. 68:1412–1423.

Eckert, K.L., Overing, J.A., and Lettsome, B.B. 1992. Sea turtle recovery action plan for the British Virgin Islands. Kingston, Jamaica.

Griffin, D.B. 2002. GIS analysis of inter-nesting habitat, migratory corridors, and resident foraging areas of the loggerhead sea turtle (*Caretta caretta*) along the southeast coast.

Horrocks, J.A. 1992. WIDECAST sea turtle recovery action plan for Barbados. Caribbean Environmental Technical Report. 12:61.

Lehnert, H., and van Soest, R.W.M. 1998. Shallow water sponges of Jamaica. Beaufortia: Institute for systematics and population biology (zoological museum) University of Amsterdam. 48(5):71-103.

Meylan, A.B. 1984. Feeding ecology of the hawksbills turtle (*Eretmochelys imbricata*): spongivory as a feeding niche in the coral reef community. PhD. Zoology.

Meylan, A.B., and Donnelly, M. 1999. Status justification for listing the hawksbill turtle (*Eretmochelys imbricata*) as critically endangered on the 1996 IUCN Red List of Threatened Animals. Chelonian Conservation and Biology. 3:200-224.

Navid, D. 1980. World conference on sea turtles. Environmental Policy and Law. 6:17-18.

Schmid, J.R., Bolten, A.B., Bjorndal, K.A., Lindberg, W.J., Percival, H.F., and Zwick, P.D. 2003. Home range and habitat use by Kemp's ridley turtles in west-central Florida. Journal of Wildlife Management. 67:196-206.