CHARACTERIZATION OF HABITAT FOR HAWKSBILL TURTLE (*Eretmochelys imbricata*) IN LOS ROQUES ARCHIPELAGO NATIONAL PARK, VENEZUELA

A Thesis

by

LUCIANA ESTELA HUNT

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2009

Major Subject: Geography

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Chair of Committee,	William D. Heyman
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August 2009

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ABSTRACT

Characterization of Habitat for Hawksbill Turtle (*Eretmochelys imbricata*) in Los Roques Archipelago National Park, Venezuela. (August 2009)

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Information on the locations for feeding, reproductions, and resting, are essential to effectively protect sea turtle populations and implement conservation efforts. This type of ecological information is critically important for hawksbill turtle conservation in Los Roques Archipelago National Park (LRANP) where turtles have been declining in spite of habitat protection efforts. The goal of this research was to produce a benthic habitat map of LRANP employing *in situ* visual surveys, remote sensing and geographic information system techniques, and to spatially characterize sea turtle occupancy and patterns of usage by habitat type. Between June and August of 2008, turtle behavior and habitat use were recorded during 159 h of observation, comprising 46 sighting events (n = 20 juveniles, n = 26 female adults). Observed activities were grouped into 4 categories: foraging, resting, swimming, and reproductive behavior. The benthic habitat at each turtle sighting was recorded as one of three categories: coral reef, sand or marine vegetation. Results suggest that the population of turtles within LRANP is comprised primarily of female adults and juvenile individuals and that coral reef is the most important habitat for this species. The most important foraging area in the atoll is a coral

patch reef that connects Dos Mosquises Sur and Dos Mosquises Norte. The data in this thesis have been made available in digital and map form to the managers of LRANP for management purposes.

DEDICATION

To Mom and Dad

To Carter

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Heyman, and my committee members, Dr. Fitzgerald, Dr. Liu, and Dr. Posada for their guidance and support throughout the course of this research.

Thanks also go to my friends and colleagues and the department faculty and staff for making my time at Texas A&M University a great experience. I also want to extend my gratitude to the L.T. Jordan Institute for International Awareness, which partially financed my Master's thesis field work in Venezuela, and to Los Roques Scientific Foundation which provided local transportation, food, and room for me and my assistants.

My deep admiration to Pablo Segundo Mata, Moncho, Carlos and Humberto, who dedicate their lives to take care not only of the turtles that Los Roques Scientific Foundation rescues, but of the different ecosystems and species that live within the Archipelago.

Finally, thanks to my mother and father for their encouragement and to my husband for his patience and love.

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CHAPTER I

INTRODUCTION

Exploited for centuries, primarily for its carapace scutes (tortoiseshell or bekko), the hawksbill turtle, *Eretmochelys imbricata*, is considered critically endangered throughout its range (Baillie & Groombridge 1996, Hilton-Taylor & Mittermeier 2000, Mortimer & Donnelly 2008). There exist significant threats to the survival of the species in Asia, Central America and the Caribbean region (Fleming 2001, Chacón 2004, Campbell 2007, Buitrago et al. 2008). Serious threats to the hawksbill turtle include illegal take in large part to support the tortoiseshell trade, destruction of foraging and nesting habitats, incidental capture in fishing gear, and continued subsistence use of meat and eggs in many countries (IUCN 2008). Despite of international agreements, trade of hawksbill's products persists in Asia, Central America and the Caribbean (Fleming 2001, Chacón 2004). Hawksbill turtles are still caught in many countries in the Caribbean (Meylan & Donnelly 1999), with Cuba currently permitting the largest legal catch of 500 hawksbill turtles per year (Carrillo et al. 1999).

E. imbricata is a medium-sized marine turtle with a circumtropical distribution. The life history of hawksbill turtles remains poorly understood, but involves several stages

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This thesis follows the style of Marine Ecology Progress Series.

and appears to be geographically complex (Diez & van Dam 2002). Coral reefs are considered critical habitats throughout the development of juvenile, sub-adults, and adult hawksbill turtles. This habitat association is undoubtedly related to the diet choice of hawksbills, which is based on high selectivity for certain species of sponges and on a variety of invertebrates (Meylan 1988, van Dam & Diez 1997a, Leon & Bjorndal 2002, Spotila 2004). Hawksbills are found around rocky outcrops and high-energy shoals, which are optimum sites for development of coral reefs and sponges (Carr 1952, Leon & Bjorndal 2002). This is one of the reasons why coral reefs are priority places for hawksbill conservation (Sisak et al. 1998, Bjorndal 1999).

Juvenile *E. imbricata* tend to forage during the day and exhibit a pattern of rest diving during the night (van Dam & Diez 1996, Sisak et al. 1998). Sisak et al. (1998) also demonstrated that these turtles utilize a restricted geographical area between 4 and 8 meters depth. Van Dam and Ten (1996) observed that the overall mean foraging depth for juvenile hawksbills was 4.7 m, while resting dives had a mean depth of 6.8 m. Other studies have confirmed that resting dives are deeper and longer than the foraging dives (van Dam & Diez 1996, van Dam & Diez 1997b, Houghton et al. 2008). Though diurnal activity, depth differences, and general habitat preferences have been described, no significant differences have been established between the sites preferred by turtles of different life stages (Buitrago & Guada 2002a) nor between specific habitat types and types of turtle activity.

Hawksbills can have a positive indirect effect on corals by grazing on coral competitors, as well as effects on overall benthic biodiversity in reef areas by making prey species more vulnerable to predation by other organisms (Leon & Bjorndal 2002, Gulko & Eckert 2004, Spotila 2004). Being primarily spongivores, *E. imbricata* can also affect reef diversity and succession indirectly by influencing space competition, which may influence succession and diversity of reef communities (Meylan 1988, Leon & Bjorndal 2002). At a time when coral reefs are among the most endangered ecosystems on the planet (Wilkinson 2000), successful conservation and management of hawksbills may be an important contributor to coral reef ecosystem restoration (Spotila 2004, Mortimer et al. 2007).

Studies of sea turtle population trends have largely been based on long-term monitoring of the seasonal beach nesting activity of adult females. Unfortunately, observing only female nesting activity provides insufficient information for stock assessment because adult females may not nest every year. Also, no information is provided on the demographic structure of the population because the immature, adult male and non-breeding female individuals are not sampled (Chaloupka & Limpus 2001).

Hawksbill turtle is one of five marine turtle species found in the waters of Venezuela along with Green turtle (*Chelonia mydas*), Loggerhead turtle (*Caretta caretta*), Olive Ridley turtle (*Lepidochelys olivacea*), and the Leatherback turtle (*Dermochelys coriacea*). The legislation of Venezuela has completely protected the hawksbill turtle since 1979. In addition Venezuela has signed several international agreements that contain specific language about the protection of marine turtles and their habitats (Buitrago & Guada 2002b). Despite these local and international conservation efforts, hawksbill populations are still declining around the world (Spotila 2004, Buitrago et al. 2008, Mortimer & Donnelly 2008). Nonetheless, data collected between 2002 and 2006 indicate that the hawksbill population in Los Roques is stable or increasing (FCLR 2007, de los Llanos 2002). Los Roques Archipelago National Park (LRANP) is considered the most important reef in Venezuela and one of the best preserved in the Americas. It also possesses large areas of marine phanerogams or flowering plants- one of the most important natural habitats for feeding, resting and reproduction activities of marine turtles (FCLR 2007, de los Llanos 2002, Vernet 2001). These areas are especially important for adult, juvenile and pre-adult hawksbill turtles (Buitrago & Guada 2002, de los Llanos 2002, Guada & Solé 2000). Between 1978 and 2006 there were a total of no less than 200 turtle nests each year in Los Roques and 60 – 77% of those nests each year were of *E. imbricata* (Buitrago 1987, Guada & Vernet 1992, de los Llanos 2002, FCLR 2007). Spotila (2004) estimates a population of 50-500 nesting female hawksbills in Venezuela per year. The generation of ecological information, such as the distribution and characterization of the critical habitats (feeding, resting and reproduction domains), is given primary importance for hawksbill conservation in LRANP.

Geographic Information Systems (GIS) are useful tools for resource managers and scientists and can be used to illustrate spatial dynamics, general distribution of ecosystems, and smaller scale habitats within reef communities. Satellite remote sensing techniques are being increasingly used as useful tools for environmental evaluations of coastal and marine environments (Green et al. 2000, Schweizer et al. 2005, Mishra et al. 2006, Wright & Heyman 2008). The spatial resolution of these systems ranges from 30 m for the Landsat Thematic Mapper (TM), to 4 m for the IKONOS multispectral data, and down to 2.44 m for Quickbird multispectral data.

Benthic habitat characterizations for LRANP have been previously conducted by Posada et al. (2007) and Schweizer et al. (2005) using aerial photographs and visible bands of the Thematic Mapper (TM) sensor aboard the Landsat 7 satellite. These researchers defined eight different bottom types spectrally: sand, dispersed communities over sand, dense seagrass, disperse seagrass, meadows over sand, reef communities, mixed vegetation over muddy bottom, and lagoons. They concluded that seagrass meadows predominate in LRANP.

The goal of this study is to characterize the spatial and temporal patterns of habitat use by *E. imbricata* in Los Roques Archipelago National Park using remote sensing, GIS, and *in situ* visual survey techniques. A subsidiary goal is to ground-truth a newly updated benthic habitat map (Lazo 2008) of the Archipelago. To do so, the study has three specific objectives:

1. Evaluate hawksbill turtles' behavior and distribution around Los Roques Archipelago, Venezuela.
2. Examine the biotic and physical characteristics of preferred turtle habitat using GIS, remote sensing and underwater visual survey techniques.
3. Identify key habitats for hawksbill turtles using variables identified in the previous objectives.
4. Evaluate the accuracy of Lazo's (2008) benthic habitat map from *in situ* observations. Since this is a subsidiary objective, and is not included in the analysis of turtle habitat distribution, it is included in an appendix, rather than the main body of the thesis.

CHAPTER II

MATERIALS AND METHODS

Study area

Field surveys of benthic habitat and *E. imbricata* distribution and behavior were conducted within Los Roques Archipelago National Park (LRANP) during the peak of Hawksbill nesting season for this area which is between June and August 2008 (Chacón 2004, FCLR 2007). LRANP is an atoll located 160 km north of the Venezuelan coast between 11°45' - 11°59' N and between 66°33' - 66°58' W (Schweizer et al. 2005); Figure 1, Appendix A). This site was chosen because it is the most important coral reef ecosystem in Venezuela and provides good potential habitat for *E. imbricata* (de los Llanos 2002, FCLR 2007). The atoll is comprised of more than 40 coralline keys with fringing reefs, hundreds of patch reefs, over 200 sand banks, and extensive mangrove forests and sea grass beds (Weil & Jorge 2003). The archipelago was declared a national park in 1972 due to the great diversity of marine habitats and ecosystems it contains (Schweizer et al. 2005). Because of the presence of four species of marine turtles within the Park (*Dermochelys coriacea, Eretmochelys imbricata, Caretta caretta and Chelonia mydas*), LRSF has worked with turtles since 1976 and has implemented the Integral Conservation Program for marine turtles since 1999 (Buitrago 1987, FCLR 2007) with a research center located on Dos Mosquises Sur.

Turtle observation

Two techniques were used for observing turtles (snorkeling surveys and Manta tows). A third technique was used for benthic habitat assessments. Since some turtles were sited during the benthic habitat assessments, this was considered a third turtle survey technique. Daytime snorkeling surveys were conducted by two observers around most of the coastal marine areas of LRANP with depths of 15 m or less. Transects lasted an average of 65 minutes (min = 23 min, max = 167 min, SD = 33.4, n= 56). For each transect observers swam parallel to the shoreline along with the prevailing ocean current, remaining within eye contact with one another. Manta Tow surveys were conducted by 2 on-boat observers and a snorkel diver towed behind the boat at a constant speed of approximately 4 km hr^{-1} along randomly selected shore-parallel transects. To obtain random transects, the starting points were created with the option Data Management > created random points in ArcInfo software. Manta tow surveys lasted up to 60 minutes, depending on the depth water visibility, currents and weather conditions. Tows varied from 24-65 min with a mean of 56 $\pm$ 10.1 min (n = 16).

The following data were recorded at the beginning of each transect: (1) date and time of day; (2) location (reef name and GPS data); (3) observer names; (4) observation platform (in water or boat); (5) start time and end time of each transect; (6) weather (S: sunny, C: cloudy, R: rainy, W: windy); and (7) in-water horizontal visibility (1: <6m; 2: 6-12 m; 3: 12-18 m; 4: >18 m).

In cases of *E. imbricata* sightings, the observer made a hand or visual signal to alert the others while keeping the animal in sight. Next, a picture of the turtle was taken, and the following data were recorded on the white board connected to the waist of one of the observers: (1) type of turtle behavior observed (foraging, swimming or resting); (2) life stage of turtle (juvenile or adult); (4) sex of turtle; (5) GPS location of the first sighting; (6) dominant benthic form (coral, sand or marine vegetation); (7) photographs of the turtle and the substrate; and (8) the depth (m) at which the observed behavior occurred (Tables 1 and 2). Start, route and end points were recorded with a Garmin GPSMAP 60CSx unit that was placed inside a dry case that was attached on a buoy that was attached to the waist of one of the divers, as well as a white board where all the data was collected. Photographs were taken with a Sony CyberShot DSC-W130 digital camera with an underwater housing. Bathymetric data were collected with a Hondex PS-7 Handheld Depth Sounder, a Speedtech Depthmate Portable Sounder and with a leadline.

Benthic habitat map accuracy assessment

Boat surveys were conducted by 2 to 3 observers from a 10 m fiberglass skiff, equipped with two 40 HP outboard engines. Transects started at randomly generated sites generated as mentioned above, within the archipelago and lasted an average of 72 minutes (min = 48 min, max = 206, SD = 27.5, n= 69). Twenty points were selected every two minutes along each transect. Characteristics of the benthic habitat and bathymetry were recorded for each point when the boat stopped.

Analyses

To test the hypothesis that *E. imbricata* were distributed randomly within the study area, I quantified the amount of each benthic habitat available within the Archipelago (using Lazo's 2008 benthic habitat map), then calculated expected frequencies of hawksbill's sightings according to the surface area of each benthic habitat available. A chi-square test was used to test for differences between observed and expected habitat use. Prior to statistical analysis I tested the data for normality and homogeneity of variances.

To evaluate the possible confounding effects of survey technique on *E. imbricata* encounter rates, I quantified the amount of time spent for each technique, then calculated expected frequencies of observation for each technique according to the time spent. A chi-square was used to test differences between observed and expected turtle sightings for each survey technique used. Finally, a chi-square test was also used to identify the relationship between turtle behavior and benthic habitat type. A Mann-Whitney test was used to evaluate differences between mean turtle depth (m) for each of the three main observed behaviors – swimming, resting or feeding. The results were regarded as significant at $p < 0.05$. SPSS 14.0 (SPSS Inc., Chicago, Illinois, USA) statistical package was used for all statistical analyses.

Applied correspondence analysis was used to evaluate how turtle behavior (foraging, swimming and resting) was related to habitat type (coral, sand and marine vegetation) as well as the relationship between these variables to turtle's life stage. Correspondence analysis is a statistical visualization method for picturing the associations between the levels of a two-way and multi-way contingency table containing some measure of correspondence between the rows and columns (Hirschfeld & Wishart 1935). Pearson chi-square statistic is computed for cross tabulation in order to assess the significance of the association (or similarity) between the row and the columns variables (Greenacre & Blasius 1994). The relationships are determined by the angle formed between variables where smaller angles indicate stronger relationships, and were 0° is a positive correlation and 180° is a negative correlation. Angles near 90° and 270° show no relationship between variables (Houser in press).

CHAPTER III

RESULTS

Turtle distribution

Between June and August 2008, the distribution, life stage, behavior and benthic habitat use by *E. imbricata* were evaluated in Los Roques Archipelago using three different survey techniques. A total of 46 turtles were documented during 159 hr of monitoring (n = 20 juveniles, n = 26 female adults). Hawksbill turtles were not randomly distributed within the Archipelago.

E. imbricata were most commonly sighted in two areas in the western part of the archipelago. The area surrounding the Dos Mosquises cayes (Dos Mosquises Norte, Dos Mosquises Sur, Herradura Dos Mosquises and Pelona Dos Mosquises) had 30 turtles (61.2% of all turtles sighted during the survey), and nine near Cayo de Agua and Bequeve Islands (BQV-CA) (18.5%) (Figure 3, Apendix A). Dos Mosquises was the area were the most survey time was spent (31.3% of total survey time), followed by Laguna Central (24.9%), Isla Larga (18.6 %) and Cayo de Agua (17.4 %).

The distribution of *E. imbricata* was dependent on the benthic habitat ($\chi^2 = 116.75$, df = 4, $p < 0.0001$). *Eretmochelys imbricata* were most commonly sighted in coral reef habitats (67%, n=33) (Figure 3, Appendix A) despite the relatively low proportion of coral within the archipelago (15%) (Table 3). Sand bottom covers the greatest area of the Archipelago (43%), followed closely by marine vegetation (42%) but only nine *E.*

imbricata (19%) were sited over sand and only four (8%), were sighted over marine vegetation (Table 3).

On average, 0.51 sightings hr^{-1} were made using snorkel surveys (n = 31), 0.08 sightings hr^{-1} were made using boat surveys (n = 7), and 0.53 sightings hr^{-1} were made using manta tow surveys (n=8). In-water surveys (manta tow and snorkeling surveys) appeared to be more suitable for sea turtles surveying ($\chi^2 = 31.348$, df = 2, $p = < 0.0001$) than on-boat survey techniques (Figure 2, Table 4 in Appendix A).

Behavior and habitat use as a function of life stage

Hawksbill behavior was significantly associated with benthic habitat type when all turtle's life stages were analyzed together (χ^2_4=12.529, p< 0.05). Coral reef habitat was widely used for foraging (100%, n=14), swimming (61.5%, n=16), and resting (33.3%, n=3). In contrast, sand habitat was used just for swimming (23.1%, n=6) and resting (33.3%, n=3) as was marine vegetation habitat, which was used for swimming (7.7%, n=2) and resting (22.2%, n=2) (Table 5).

The majority of adult female turtles were sighted on coral reef habitat (73%, n = 19), followed by sand (15%) and marine vegetation (12%). Juveniles were found mostly using coral reef habitat (70%, n = 14) and sand habitat (25%). Just one juvenile *E. imbricata* was sighted over marine vegetation (5%).

Fourteen turtles were observed foraging (29%), 24 were swimming (53%) and 8 were resting (18%). Adult female *E. imbricata* were observed swimming (n=12, 44%)

foraging (n=10, 37%) and resting (n=5, 19%) (Table 5). Juvenile turtles were observed mainly swimming (64%, n=12), but also resting (12%) and foraging (12%).

The correspondence plot shows that foraging behavior is closely related to coral habitats and resting behavior to marine vegetation. Swimming behavior was related to sand. Adult hawksbills were more related to foraging behavior within coral reef habitats. The strongest relationship was between juvenile hawksbills and swimming behavior. Adult and juvenile behavior are not closely related, in fact it is shown that their behavior, in relation to the habitat where behaviors were observed, was completely opposite (angle in between variables is 180°) (Figure 4 in Appendix A).

I found significant differences in between mean depths between behaviors. The mean depth (±1 SD) for each behavior is shown together with range and sample size in Table 6. Resting depths were 66% deeper than foraging depths (p = 0.005) and 46.8% deeper than swimming depths (p = 0.013). Mean swimming depths were 36% deeper than foraging depths but this difference was not statistically significant (p = 0.429).

CHAPTER IV

DISCUSSION

Information on the location for feeding, reproduction and resting are essential to effectively protect sea turtle populations and implement conservation efforts. This type of ecological information is critically important for hawksbill turtle conservation in Los Roques Archipelago National Park, which is considered as the most important nesting area for *Eretmochelys imbricata* in Venezuela (de los Llanos 2002, FCLR 2007). Between June and August 2008, the distribution, life stage, behavior and benthic habitat use by *E. imbricata* were evaluated in Los Roques using three different survey techniques.

The distribution of *E. imbricata* in Los Roques is dependent on benthic habitat type ($\chi^2 = 116.75$, df = 4, $p < 0.0001$, Figure 2, Table 3 in Appendix A). Reef environments provide important components of *E. imbricata* diet, especially certain species of sponges and marine invertebrates (Meylan 1988, van Dam & Diez 1997b, Leon & Bjorndal 2002, Spotila 2004). Indeed, my data support previous claims that the distribution of Hawksbill turtles is strongly linked to coral reef habitat (Table 1, Figure 4 in Appendix A). These habitats are used not only for foraging, but also for resting and swimming (Table 6). The findings here therefore reinforce the important role of coral reef ecosystems for all Hawksbill life stages, as well as the ecological role of *E. imbricata* as a sponge grazer in these ecosystems and thus influencing coral reef succession and overall diversity (Leon & Bjorndal 2002, Gulko & Eckert 2004, Spotila 2004). In terms of habitat utilization, the difference in depth in between foraging and resting sites was of great interest. Particularly, the turtles appeared to select resting sites of greater depth than the foraging grounds they chose (Table 7). These foraging areas were entirely covered by different species of coral as stated before by van Dam & Diez (1997) and Houghton (2003).

Both female adults and juvenile hawksbill turtles were sighted within the Archipelago during 76 hr of intensive in-water and 83 hr of boat-based surveys (Table 2). Although the monitoring was done during the peak of the nesting season (FCLR 2001, 2007), neither male adults nor hatchlings were observed. These findings contrast with the results of previous research in Los Roques Archipelago National Park such FCLR (2007) that found adults (female and male), juveniles, and hatchlings within the Park, and de los Llanos (2002) also found adults (female and male) and juveniles there. In both studies, the majority of *E. imbricata* turtles encountered were juveniles and females outnumbered males. In the current study however, only females were encountered. In addition, adults were encountered more frequently than juveniles. This difference in the results might be related to the period of time when the survey was carried out as well as differences on depth preference in between adult females and males. Adult male hawksbills might be selecting sites of greater depths, although additional data would be required to test this.

Adult hawksbills are more likely than juveniles to be encountered foraging in coral reef habitats. Juveniles are more likely to be exhibiting swimming behaviors. Interestingly, the relationship between juvenile hawksbills and swimming behavior is the most pronounced in this study (Table 6, Figure 4 in Appendix A). This might be related to fear by juveniles as a response to the presence of researchers under the water. Adult turtles were less disturbed by our presence. Every time we found adults foraging, we were able to approach to within a meter of them before noticing alteration of their behavior. After observing them for more than 5 minutes, either we left after taking all the data necessary or they finished eating and swam away.

The different survey techniques utilized in this study affected turtle behavior in different ways. Manta tow technique demonstrated more efficiency for turtle sighting than either snorkel surveys or on-boat surveys (χ^2 = 31.348, df = 2, p = < 0.0001, Table 2). With manta tow technique the observer has a greater field of vision, and thus a larger observational area, than with the other two techniques. It therefore offers a higher probability of sea turtle sighting. The problem with this technique is that the turtles respond nervously to the sound of the boat and they tend to swim in the opposite direction. This technique is therefore better suited to sighting the turtles than it is to assessing their behavior. In boat surveys, the researcher remains above water. This technique, while much quicker and easier for the researchers, suffers the same limitations as the manta tow for turtle monitoring, namely the sound of the motors scares the turtles. This technique has further problems with observation of the turtles being severely inhibited by water visibility, depth of the turtle, and sea level. Boat surveys do have the advantage of being able to cover larger areas. For properly assessing turtle behavior and habitat use, snorkeling surveys are the most efficient technique. The limitation of this method is the area covered is much less, water visibility remains an issue, and ocean currents can easily pull snorkelers off track. These techniques were chosen based on the time and resources available. The utilization of all three different types of surveys minimized their individual shortcomings while yielding a richer range of data related to *E. imbricata* distribution, behavior and habitat use within LRANP.

As a result of this research, I conclude Dos Mosquises and Bequeve-Cayo de Agua to be areas of high conservation priority during the nesting season. These two, relatively small areas accounted for 80% of the turtle sightings. Sightings in the area the Herradura, which is a patch of coral reef within Dos Mosquises that connects Dos Mosquises Norte with Dos Mosquises Sur, ranged between 1 and 12 turtles/observation day. In other sites, never more than two turtles were observed in any given observation day despite a comparable amount of monitoring time spent in the different locations (Figures 2 and 3 in Appendix A). The coral reef patch of la Herradura Dos Mosquises thus appears to be the most important foraging area for *E. imbricata* within LRANP whereas Bequeve-Cayo de Agua represent important feeding and resting areas for Hawksbill turtles for all life stages. This supports the previous hypotheses of de los Llanos (2002) related to the Herradura Dos Mosquises as a potential foraging area for Hawksbills. The preference for these sites demonstrated by *E. imbricata* is likely due to the expanse and quality of coral reef habitat and the proximity to high quality nesting beaches (FCLR 2001, FCLR 2007).

The LRSF's research station in Dos Mosquises Sur Island maintains a turtle conservation program that entails protecting nests that are in danger of being poached and raising hatchlings until they are big enough to face the challenges that they will encounter in the ocean. None of the turtles observed were wearing tags. Van Dam and Diez have been studying immature Hawksbill turtles at Mona and Monito Islands (Puerto Rico) since 1992 and found that they appear to remain sedentary for long period of time (van Dam &

Diez 1998). This may also partially explain the density of turtles in around the Herradura coral patch. Juvenile hawksbills frequenting the Herradura coral patch could come from the frequent releases of immature hawksbills form the Research Center at Dos Mosquises by LRSF staff. Additional studies with extensive tagging programs and genetic surveys are necessary to clarify existing ambiguity concerning movements, migrations and precedence of the turtles distributed not only in this precise location but also around the archipelago.

The fact that the majority of turtles were found in Dos Mosquises and BQV-CA areas is also of importance since both areas are daily frequented by tourists. Fortunately, tourists boats arrive at Dos Mosquises Sur from the west side of the Island, the Research Center and a Center of Marine Turtle Project. The Herradura is located to the East of this Island. Furthermore, the Herradura coral patch is monitored daily for mischievous activities by LRSF staff. It is virtually impossible for turtles to be illegally harvested at that location. This could be another reason why this area is highly populated by *Eretmochelys imbricata*. Further explanation of the density of hawksbills in this location could come from future studies of habitat health and richness. For example, when sufficient resources are available, turtles may develop affinities to specific areas for their foraging and resting activities, as noted for nesting behaviors.

CHAPTER V

CONCLUSIONS AND SUMMARY

- Los Roques Archipelago National Park is an important foraging and resting site for *Eretmochelys imbricata* during it nesting season.
- The population of hawksbill in June-August 2008 was comprised mainly of adult females and juvenile turtles.
- Hawksbills select resting sites of greater depth than foraging ones.
- Female mature turtles are mostly foraging in coral reef habitats whereas juveniles are found mostly swimming on sandy areas.
- Snorkel surveys technique is more efficient for assessing turtle behavior and it habitat use.
- The coral reef patch of la Herradura Dos Mosquises is the most important foraging area for *E. imbricata* within the LRANP.
- Bequeve and Cayo de Agua represent important feeding and resting areas for Hawksbill turtles of all live stages.

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APPENDIX A

TABLES AND FIGURES

Table 1 Benthic forms and turtle behavior variables.

Benthic Forms			Turtle Behavior		
C	=	coral (soft and hard coral)	**F**	=	foraging
S	=	sand	**S**	=	swimming
MV	=	marine vegetation (sea grass and algae)	**R**	=	resting

Table 2 Classification of life stages for *E. imbricata*

stage	hatchling **I**	juvenile **II**	adult **III**
carapace length	4 cm - 7 cm	12 cm - 70 cm	> 70 cm
secondary sexual characteristics	without secondary sexual characteristics		*males* have longer prehensile tail with a terminal nail, larger and recurved claws on the front flippers; and more concave plastra.

Table 3 The number and proportion of observed *E. imbricata* as related to the total available area and proportion of each benthic habitat type (coral, sand, and marine vegetation). Benthic habitats are all ≤ 10 m in depth and are based on Lazo's (2008) benthic habitat map for Los Roques Archipelago.

	Habitat availability		*E. imbricata*	
	Proportion	Area (km^2)	Proportion	n
Coral	0.15	66.4	0.72	33
Sand	0.43	187.2	0.19	9
Marine vegetation	0.42	185.7	0.09	4
Total	1	439.3	1	46

Table 4 Survey effort (hours and percentage), *E. imbricata* encounters (number and percentage of total number observed), and *E. imbricata* encounter rate (sighting · hr^{-1}) as a function of survey technique.

Survey Techniques	Total time		*E. imbricata* encounters		Encounter rate
	hr	%	n	%	sighting · hr^{-1}
Manta Tow	15	10	8	17	0.53
Snorkelling	61	38	31	67	0.51
Benthic habitat surveys	83	52	7	15	0.08
Total	159	100	46	100	0.29

Table 5 Frequency of observations of *E. imbricata* in each habitat type (coral, sand, or marine vegetation) according to behavior (foraging, swimming, or resting) and life stage (juvenile or adult). Reported values are the number of turtles observed.

Behavior Category	Life stage	Benthic habitat	Number of sighting events
Foraging	Juvenile	Coral	4
		Sand	0
		Marine vegetation	0
	Adult	Coral	10
		Sand	0
		Marine vegetation	0
Swimming	Juvenile	Coral	8
		Sand	3
		Marine vegetation	1
	Adult	Coral	8
		Sand	3
		Marine vegetation	1
Resting	Juvenile	Coral	2
		Sand	2
		Marine vegetation	0
	Adult	Coral	1
		Sand	1
		Marine vegetation	2

Table 6 Frequency of observations of *E. imbricata* in each habitat type (coral, sand, or marine vegetation) according to life stage (juvenile or adult), and behavior (foraging, swimming, or resting). Reported values are the number of turtles observed followed by percentage of total.

Life stage	Habitat						Behavior					
	Coral		Sand		Marine Vegetation		Foraging		Swimming		Resting	
	n	%	n	%	n	%	n	%	n	%	n	%
Adult	19	41	4	9	3	7	10	22	12	26	4	9
Juvenile	14	30	5	11	1	2	4	9	12	26	4	9
Total	33	72	9	20	4	9	14	30	24	52	8	17

Table 7 Mean depth (±1 SD), range and sample size of depth data collected for each behavior.

Activity	Mean depth (m)	Range of depths (m)	Sample size (N)
Foraging (F)	1.6 (0.5)	0.6 - 2.7	14
Swimming (S)	2.5 (0.7)	1.0 - 4.0	23
Resting (R)	4.7 (1.2)	1.7 - 7.6	8

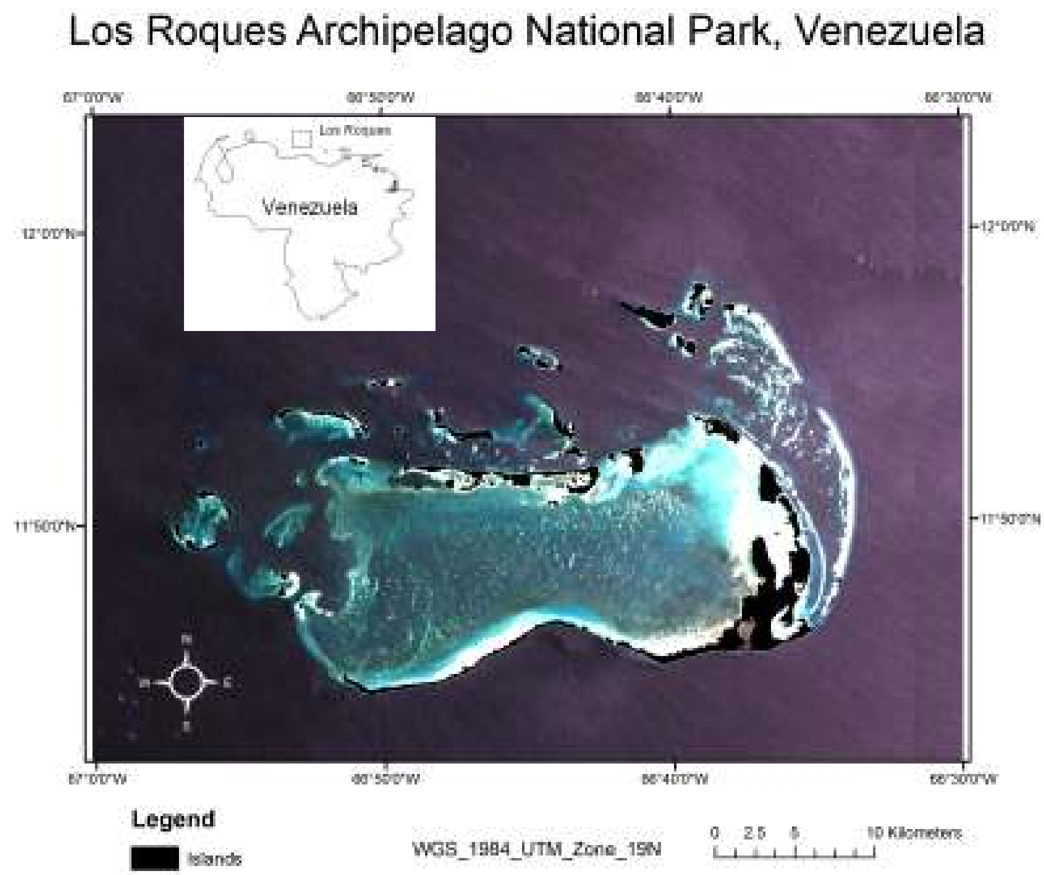

Figure 1 Map of the study area: Los Roques Archipelago National Park, Venezuela.

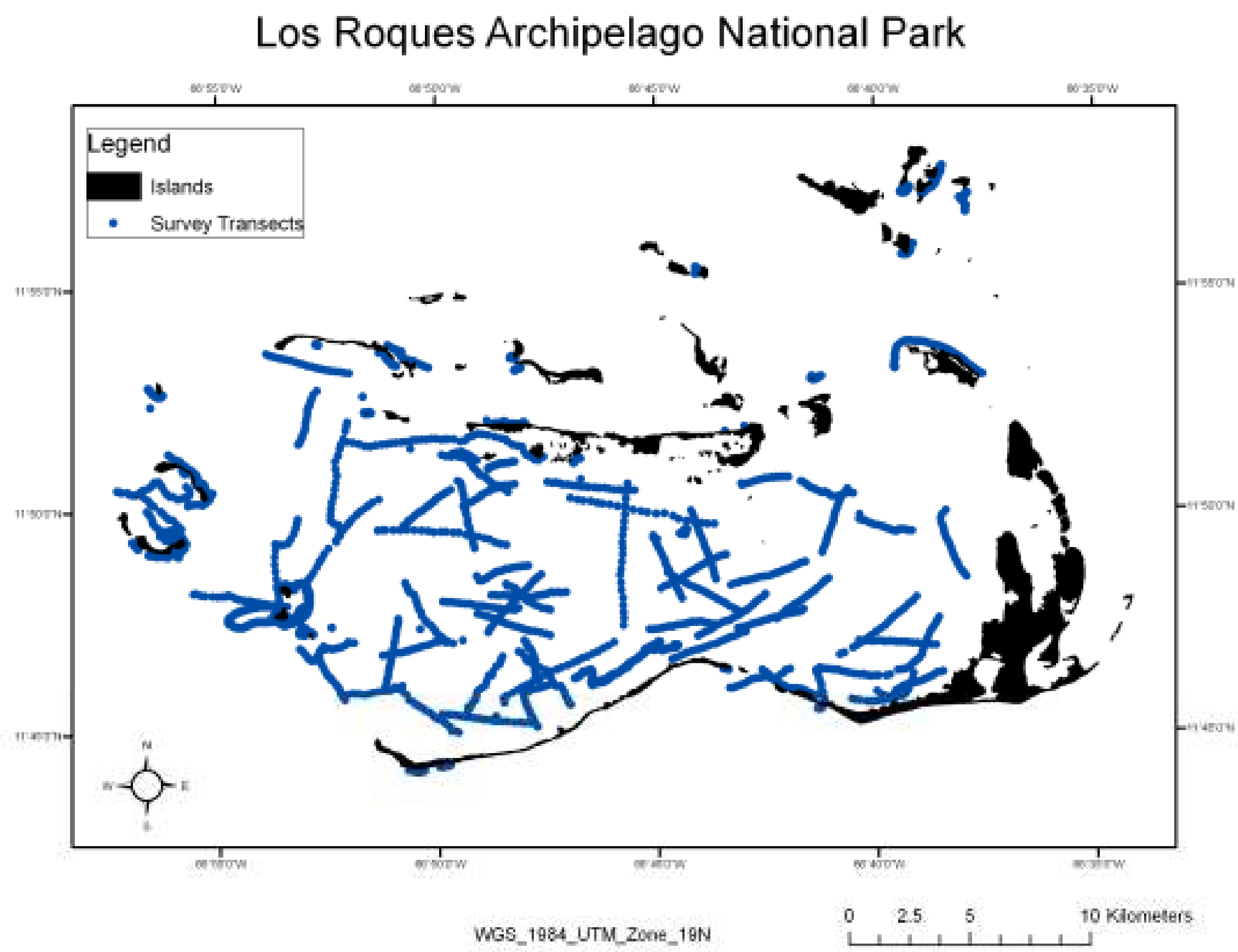

Figure 2 Distribution of all survey transects conducted within Los Roques Archipelago, June-August 2008.

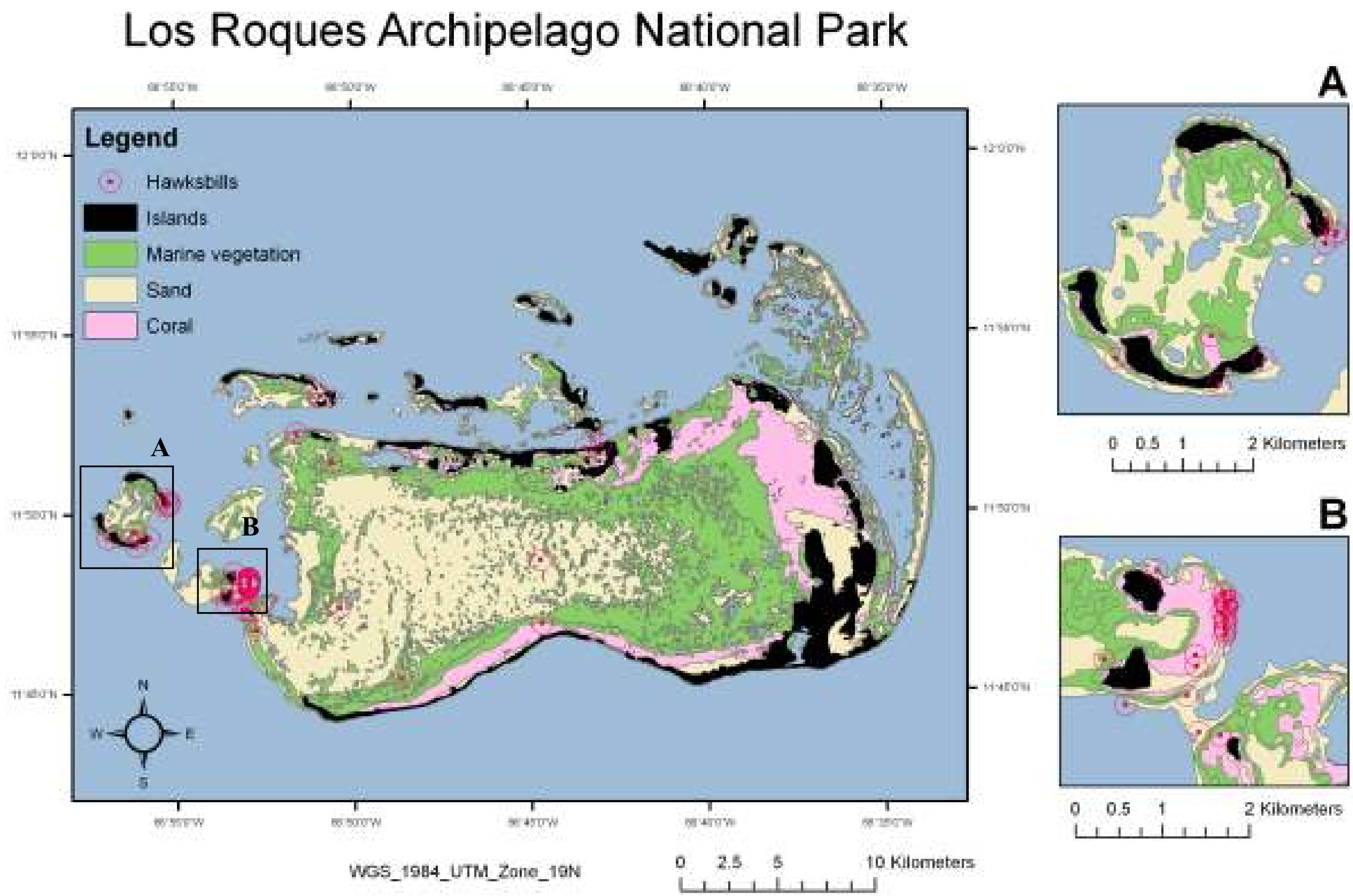

Figure 3 Distribution of *E. imbricata* observations within Los Roques Archipelago overlaid on Lazo's (2008) benthic habitat map. A. Bequeve-Cayo de Agua area (BQV-CA), B. Dos Mosquises area (DM).

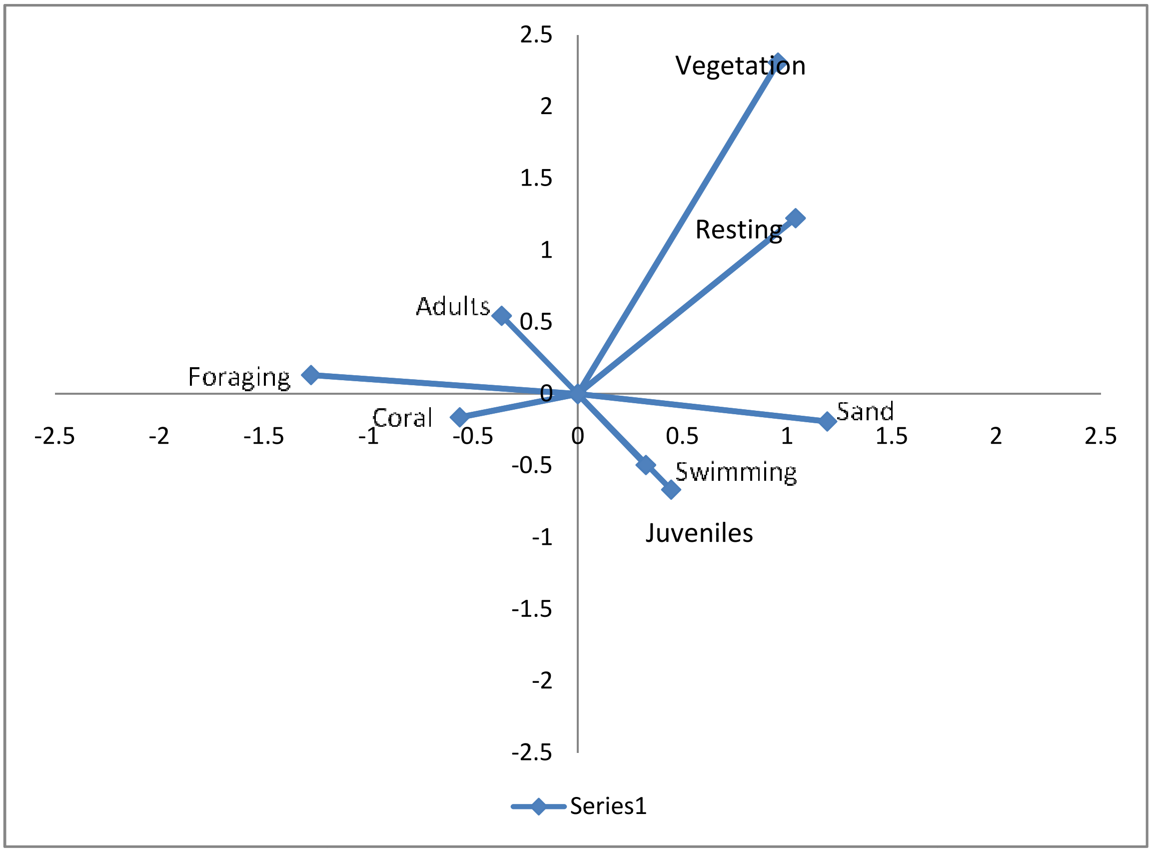

Figure 4 Correspondence analysis provides a graphical summary of the analysis of all the variables: turtle behavior (foraging, swimming and resting), bottom type habitat (coral, sand and marine vegetation) and turtle lie stage (adults and juveniles).

APPENDIX B

HABITAT MAPPING ACCURACY ASSESSMENT

Lazo (2008) created a benthic habitat map for LRANP using data from a Landsat Thematic Mapper image, but without intensive field verification. The map was used to identify and measure the total area covered by each benthic habitat type (Jensen 2005, Congalton & Green 1999). I performed a quantitative accuracy assessment of the Lazo (2008) benthic habitat map that was based on field-collected benthic habitat data. This "procedure" involved pairwise comparisons between remotely-sensed data for a set of sites on the map and *in situ* information for each of those same sites. Seventy five reference points per benthic form (coral, sand and marine vegetation) were selected out of the transects points obtained from the boat surveys (Jensen 2005). The reference or *in situ* data were assumed to be correct. An error matrix (Table 3) of the classification map was computed as well as a Kappa analysis, which is a discrete multivariate technique measure of accuracy between the remote sensing-derived classification map and the reference data (Jensen 2005).

The Coefficient of Agreement (K_{hat}) was based on the standard normal deviation and was asymptotically distributed. The coefficient of agreement was computed as:

$$K = \frac{N \sum_{i=1}^{k} x_{ii} - \sum_{i=1}^{k} (x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^{k} (x_{i+} \times (x_{+i})}$$

where

$$\sum_{i=1}^{k} x_{ii} = n_{11} + n_{22} + n_{kk}$$

$$\sum_{i=1}^{k} (x_{i+} \times x_{+i}) = (n_{1+} \times n_{+1}) + (n_{2+} \times n_{+2}) + (n_{k+} \times n_{+k})$$

When K values > 0.80 (i.e., 80%) strong agreement is represented. Values between 0.40 and 0.80 represent moderate agreement and values < 0.40 represent poor agreement (Jensen 2005).

APPENDIX C

ERROR MATRIX

Mathematical example of an Error Matrix

		j=columns (reference)			row total
		1	2	k	$\mathbf{n_{i+}}$
i=rows	1	$\mathbf{n_{11}}$	n_{12}	n_{1k}	n_{1+}
(classification)	2	n_{2+}	$\mathbf{n_{22}}$	n_{2k}	n_{2+}
	k	n_{k1}	n_{k2}	$\mathbf{n_{kk}}$	n_{k+}
column total	$\mathbf{n_{+j}}$	n_{+1}	n_{+2}	n_{+k}	**n**

Overall Accuracy = $(n_{11} + n_{22} + n_{kk})/ n$

Producer's Accuracy	**User's Accuracy**
$1= n_{11}/n_{+1}$	$1= n_{11}/n_{1+}$
$2= n_{22}/n_{+2}$	$2= n_{22}/n_{2+}$
$3= n_{k1}/n_{+3}$	$3= n_{k1}/n_{3+}$

Error Matrix for Lazo's map

		Ground Reference Test Information			
	Class	Coral	Sand	Marine Vegetation	**Row Total**
Remote Sensing Clasification	Coral	**25**	13	25	63
	Sand	2	**51**	13	66
	Marine Vegetation	3	24	**45**	72
	Column Total	30	88	83	201

Overall Accuracy = (25+51+45)/201 = 121/201 = 60.2 %

Producer's Accuracy

Coral= 25/30 = 83%

Sand= 51/30 = 58%

Marine Vegetation= 45/83 = 54%

User's Accuracy

Coral= 25/63 = 40%

Sand= 51/66 = 77%

Marine Vegetation= 45/72 = 63%

VITA

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