AN EVALUATION OF SEAGRASS COMMUNITY STRUCTURE AND ITS ROLE IN GREEN SEA TURTLE (*CHELONIA MYDAS*) FORAGING DYNAMICS IN THE LOWER LAGUNA MADRE

A Senior Scholars Thesis

by

TRACY FISHER WEATHERALL

Submitted to the Office of Undergraduate
Texas A&M University
in partial fulfillment of the requirements for the designation as

UNDERGRADUATE RESEARCH SCHOLAR

April 2010

Major: Marine Fisheries

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Approved by:

Research Advisors:	Anna R. Armitage
	André M. Landry, Jr.
Associate Dean for Undergraduate Research:	Robert C. Webb

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ABSTRACT

An Evaluation of Seagrass Community Structure and its Role in Green Sea Turtle (*Chelonia mydas*) Foraging Dynamics in the Lower Laguna Madre. (April 2010)

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Satellite tracking data of juvenile and subadult green turtles captured and released by Texas A&M University at Galveston's Sea Turtle and Fisheries Ecology Research Lab (STFERL) from the lower Laguna Madre indicate green sea turtles (*Chelonia mydas*) exhibit high fidelity to seagrass communities where they can be found year-round. Population growth is prerequisite to eventual down listing of this endangered species to a threatened status and its subsequent recovery. The role Texas' green turtle population will play in this recovery will depend, in part, on the ability of seagrass communities in the lower Laguna Madre to sustain continued growth of this population. Seagrass community structure was characterized during 7-8 March 2009 to determine if foraging grounds in the lower Laguna Madre can sustain green turtle population growth. Differences in seagrass community structure influencing foraging potential between high fidelity sites (Region 1) were compared to adjacent areas in which green turtles have not been captured and tracked by the STFERL (Region 2). Seagrass samples were taken from six seagrass communities to characterize seagrass and invertebrate community parameters. In addition, three standardized and randomized bag seine collections of nekton, invertebrates and plant debris were conducted within the six seagrass communities. Family richness and abundance of fishes and invertebrate fauna were assessed from the standardized bag seine collections. Seagrass species including *Thalassia testudinum* (turtle grass), *Syringodium filiforme* (manatee grass), *and Halodule wrightii* (shoal grass) were found in Region 1 whereas *T. testudinum* and *H. wrightii* were found in Region 2. Total seagrass biomass from Region 1 was significantly greater than that from Region 2 implying a healthier seagrass community. Seagrass beds in Region 2 were highly patchy and sparse. Family richness and faunal density collected with the bag seine in Region 1 were significantly higher than those in Region 2 suggesting seagrass habitat complexity was higher in Region 1. These data suggest a trend toward increased seagrass habitat quality and community complexity in Region 1 which, in turn, may contribute to a healthier seagrass environment that serves as an optimal foraging area for green turtles in the lower Laguna Madre.

DEDICATION

to

my family and friends who have encouraged and supported my decision in pursuing my lifelong dream.

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I wish to thank the Coastal and Wetland Ecology Lab for their assistance with my seagrass samples and for giving me resources for identifying the many invertebrates I found in my collection. Thanks also for the use of their lab and equipment therein. I also want to express my gratitude to the Sea Turtle and Fisheries Ecology Research Lab for the use of their boat, sampling equipment and many resources.

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NOMENCLATURE

CITES	Convention on International Trade and Endangered Species
CPUE	Catch-Per-Unit Effort
ESA	Endangered Species Act
IUC	World Conservation Union
NMFS	National Marine Fisheries Service
SCL	Straight Carapace Length
STFERL	Sea Turtle and Fisheries Ecology Research Lab
TPWD	Texas Parks and Wildlife Department
USFWS	United States Fish and Wildlife Service

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CHAPTER I

INTRODUCTION

Green sea turtles (*Chelonia mydas*) are distributed worldwide in tropical and subtropical regions (generally between 30° North and 30° South) where they occupy three habitat types: high-energy coastal beaches, pelagic convergence zones, and shallow benthic foraging areas in protected waters (Renaud et al., 1995; National Marine Fisheries Service [NMFS],1991 and United States Fish and Wildlife Service [USFWS], 1991). Green turtles are the only herbivorous marine turtle species and are listed as threatened and endangered under the Endangered Species Act (ESA) of 1973. They are internationally recognized as endangered by the World Conservation Union (IUC) and protected by the Convention on International Trade and Endangered Species (CITES) (Spotila, 2004).

As subadults and adults, green turtles forage on brown, green and red algae (Bjorndal, 1985) and three seagrass species: *Halodule wrightii* (shoalgrass), *Syringodium filiforme* (manatee grass) and *Thalassia testudinum* (turtle grass), with the latter species being their primary nutrition source (Mortimer, 1981; Coyne, 1994; Fuentes et al., 2006). In south Texas, green turtles approximately 20-25 cm SCL (Straight Carapace Length) recruit from open waters of the Gulf of Mexico to algae-laden jettied habitats at Brazos

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This thesis follows style and format of the journal Copeia.

Santiago Pass (Landry and Metz, 2009) of the lower Laguna Madre (Appendix A, Figure 1) where they remain for approximately 6 years (Musik and Limpus, 1997; Zug and Glor, 1998; Landry and Metz, 2009) or until reaching 35-40 cm SCL. A second ontogenic shift occurs when these individuals move to adjacent seagrass meadows where they remain (National Marine Fisheries Service [NMFS], 1991; Landry and Metz, 2009) until reaching sexual maturity. Like their counterparts in other tropical regions (Bresete et al., 1998; Makowski et al., 2006), green turtles in the lower Laguna Madre exhibit high fidelity to jetty and seagrass habitats (Landry and Metz, 2009). Satellite tracking data of subadult conspecifics captured and released by Texas A&M University at Galveston's Sea Turtle and Fisheries Ecology Research Lab (STFERL) suggest green turtles exhibit year-round fidelity to seagrass communities where they are commonly found (Landry and Costa, 1999; Landry and Metz, 2009). Arms (1996), as well as Landry and Metz (2009), also reported that juvenile green turtles display high fidelity to seagrass communities near Brazos Santiago Pass.

Recent in-water data suggest green turtle abundance in the lower Laguna Madre has increased (Landry and Metz, 2009) exponentially since 1991 (Appendix A, Figure 2). Population increases of the magnitude of those in the lower Laguna Madre are likely to result in an intensification of foraging pressure on algae and seagrass beds upon which this herbivorous species depends. An assessment of the associated seagrass ecosystem quality in the lower Laguna Madre is crucial to determining if constituent seagrass and algae habitats can sustain this growing green turtle assemblage and, if so, contribute to down listing this endangered species to a threaten status and advance population recovery.

Seagrass meadows are among the most complex and biologically productive marine ecosystems in the world (Mateo et al., 2006). As a subtropical habitat, seagrass beds have many diverse roles within the coastal environment (TPWD, 1999). They provide shelter and critical nursery habitats for commercially- and recreationally-important fishes, shrimp, crabs and countless invertebrates, and are direct food sources for waterfowl, fishes, and green turtles. (Zieman, 1982; Phillips, 1984; Thayer et al., 1984; Kenworthy et al., 1988; Zieman and Zieman, 1989; TPWD, 1999). The lower Laguna Madre complex has the greatest coverage of seagrass [latest estimate 480 km^2 (185 mi^2)] in Texas (Pulich et al., 1997; Pulich and Calnan, 1999; Withers, 2002). Although species diversity has increased over the past 30 years, information voids exist as to species composition and the ability of constituent species to support green turtle foraging. *Halodule wrightii* (shoalgrass) historically dominated the system but *Syringodium filiforme* (manatee grass) is now the dominant species. *Thalassia testudinum* (turtle grass) was once confined mostly to the southern areas of the lagoon near passes and to South Bay but since 1988 has become more widespread (Quammen and Onuf, 1993; Withers, 2002).

The fact that the lower Texas coast has been identified as developmental feeding grounds for immature green turtles moving among foraging areas as they grow

(National Marine Fisheries Service [NMFS], 1991; Coyne, 1994; Shaver, 1994; Renaud et al., 1995; Landry and Costa, 1999) provides an excellent opportunity to assess this species' dependence on constituent sea grass habitats and the ability of these habitats to sustain population growth needed for species recovery. However, it is unknown if foraging habitat use patterns by these green turtles are related to the health and diversity of the seagrass beds or other factors. Are specific seagrass habitats disturbed with poor water quality such as high/low salinity or high sediment coverage? The ultimate question remains: Why do green turtles choose foraging grounds within particular seagrass communities when they could easily move to other seagrass habitats nearby? Will these unused habitats eventually attract greens as their population continues to increase? Will the lower Laguna Madre ecosystem complex be able to sustain a growing sea turtle population?

The overall objective of my research is to identify biotic (living) and/or abiotic (nonliving) parameters within seagrass ecosystems in south Texas, specifically the lower Laguna Madre, that influence use and fidelity of green sea turtles to constituent habitats. Results of this research are used to determine if seagrass community structure (i.e., seagrass species composition; seagrass biomass; epiphyte; animal fauna; and dissolved oxygen content, salinity regime; turbidity; temperature) where green turtles are known to forage differ significantly from that of nearby seagrass habitats where green turtles have not been observed or captured. Understanding the quality of seagrass habitat composition as it relates to the feeding ecology of green sea turtles in the lower

Laguna Madre is essential for successful recovery of constituent stocks and determining if the ecosystem can sustain its growing increasing assemblage of conspecifics. This knowledge could eventually lead to the implementation of management decisions that protect and maintain essential green turtle habitats and, in doing so, aid in the down listing of green sea turtles from an endangered species status to a threatened status.

CHAPTER II

METHODS

Study site

The Laguna Madre, by encompassing 445 km of coastline extending from Corpus Christi Bay, Texas, USA, in the north, to Rio Soto la Marina, Mexico, in the south, is the largest hypersaline lagoonal system in the world (Tolan et al., 1997). It is separated by the Río Grande Delta into north and south lagoons, the Laguna Madre of Texas and Laguna Madre of Tamaulipas, respectively (Appendix A, Figure 3) (Tolan et al., 1997; Tunnell, 2002). The Laguna Madre of Texas is the State's largest estuarine system (Diener, 1975; Tunnell, 2002) and is bordered by Padre Island (a long and narrow barrier island) that separates it from the Gulf of Mexico (Tolan et al., 1997). Texas' Laguna Madre is divided into upper and lower halves of somewhat similar in size, 76 km long by 6 km wide and 91 km long by 8 km average width, respectively (Tunnell, 2002). These upper and lower counterparts are separated by a land bridge (Land Cut) extending approximately 45 km across the entire width. Both upper and lower lagoons are extremely shallow, averaging 1 m in depth. The lower Laguna Madre is primarily comprised of submerged patchy seagrass communities separated by large areas of sand and emergent wind-blown tidal flats (Tunnell, 2002; Withers, 2002).

Seagrass habitats were characterized 7-8 March 2009 in the lower Laguna Madre to determine if seagrass communities where green sea turtles have shown high habitat fidelity differ significantly from beds nearby where green turtles have not been observed or captured. Two geographically-diverse study areas were established in lower Laguna Madre to conduct this characterization: Region 1) lagoonal seagrass habitats adjacent to South Padre Island and Brazos Santiago Pass where green turtles demonstrate high habitat fidelity (Appendix A, Figure 4); and Region 2) lagoonal seagrass habitats adjacent to the mouth of the Arroyo Colorado and nearby spoil islands where green turtles have not shown foraging fidelity (Appendix A, Figure 5). Three sampling sites were randomly selected within each of these study areas. Region 1 was comprised of Site D (26° 03’ 47.5” N, 97° 11’ 51.9” W) which exhibited dense, short *Thalassia testudinum,* calcareous green algae and red algae; Site E (26° 03’ 3.4” N, 97° 10’ 58.8” W) was dominated by dense, long *Syringodium filiforme* and sparse, short *H. wrightii*; and site F (26° 02’ 13.8” N, 97° 10’ 10.8”W) typified by sparse, short, calcareous green algae, and red algae. Region 2 included two sites characterized by sparse, short H. wrightii and various species of calcareous green algae: Site A (26° 22’ 04.7” N, 97° 19’ 25.8” W) and Site B (26° 23’ 27.1” N, 97° 20’ 16.4” W). Site C (26° 21’ 12.1” N, 97° 19.12’ W) was comprised of sparse, short *T. testudinum.*

Abiotic conditions

Physical parameters (dissolved oxygen content, water temperature, turbidity, and salinity) were recorded to determine differences in abiotic conditions among all sites.

Seagrass habitat sampling

Seagrass species composition, biomass, and associated in- fauna (e.g., penaeid shrimp and blue crab larvae, gastropods and copepods) were characterized at the six sampling sites in the lower Laguna Madre. Seagrass was sampled along a 30-m long transect at each study site. Three locations were randomly chosen along a transect line within each study site. A 0.25 m^2 quadrat was used to assess seagrass species composition. All seagrass and associated fauna were removed from within each quadrat and frozen for subsequent analysis. Visual analysis of seagrass species composition and percent coverage could not be determined due to poor water visibility at all sampling sites.

Seagrass samples were washed in the lab through a 0.5 mm sieve. Fauna was separated from plant and debris, identified to the lowest practical taxonomic level, and enumerated. Seagrass leaves were removed from each stalk and gently scraped with a razor blade to remove epiphytic growth. Seagrass leaves and epiphytes were then dried at 60 °C to determine dry weight. Due to seagrass patchiness in Region 2 (Site C), seagrass and associated animal fauna were not collected in QC2 and QC3. Also, time limitations prevented seagrass analysis for study sites QF2 and QF3 of Region 1.

Animal collections

Fauna associated with shallow (<1M) seagrass habitats from six lagoonal sampling sites within the lower Laguna Madre was assessed via standardized and randomized tows of a 12.2-m long bag seine with 0.6-cm mesh. Three standardized (~30 m-long x

3.05 m) tows were conducted at each of the six sampling sites during daylight hours. These standardized data provided quantitative information used to generate the following: abundance (catch-per-unit effort or CPUE), family diversity, family richness and life history parameters (post larval through adult life stages and size composition) of fishes and other animal fauna occupying seagrass habitats at the time of sampling. Three randomized tows of variable lengths were conducted (usually within 30 minutes) throughout the sampling sites subsequent to standardized tows. These randomized data were used to obtain qualitative information (description) pertaining to family richness, diversity and life history stages of fishes and other animal fauna within a sampling site. All associated epifauna and benthic and/or floating debris taken in bag seine tows were immediately placed into 10% formalin and held for subsequent analysis. Nekton and epifauna were separated from plant, benthic sediment, and debris in the laboratory. Fishes were identified to the family level, enumerated and measured for standard length (SL/mm). All other animal fauna was identified to the family level and counted to determine differences in composition of constituent communities housed in seagrass habitats. Although standardized bag seine effort was actively deployed within study sites F2 and F3 of Region 1, there were no fishes collected.

Statistical analyses

The Shannon-Wiener diversity index (H′), was calculated for all animals where $H' = \Sigma(p_i)(\ln p_i)$ and p_i was the proportion of the faunal community belonging to the *i*th species (Krebs, 1994). Family evennesss E (equitability of abundance among species) was calculated per study site and between study areas, where $E = H' / H'_{max}$. For all response variables (density, diversity, evenness, richness…), differences between Region 1 and Region 2 were examined with t-tests ($\alpha = .05$).

CHAPTER III

RESULTS

Environmental parameters

Unpaired t-tests (α = 0.05) were used to compare hydrographic values between Region 1 (green sea turtle high fidelity foraging ground) and Region 2 (where green turtles have not been captured and tracked). There were no significant differences ($p>0.05$) in abiotic environmental characteristics [temperature (°C), salinity (‰), turbidity (m), and dissolved oxygen content (mg/L)] between Region 1 and Region 2 (Appendix B, Table 1).

Seagrass

Overall mean seagrass biomass (g/m^2) within each region was compared by an unpaired t-test (α = 0.05) and found to be significantly higher in Region 1 than in Region 2 ($p<0.05$) (Appendix B, Table 2). In general, seagrass biomass in Region 1 was consistently high whereas it was low and highly patchy in Region 2 (Appendix A, Figure 6). There were no significant differences ($p>0.05$) in mean biomass (g/m^2) constituent seagrass species (*Thalassia testudinum, Syringodium filiforme,* and *Halodule wrightii*) between the two regions (Appendix B, Table 2). *Thalassia testudinum*, *Syringodium filiforme,* and *Halodule wrightii* occurred in Region 1 with *T. testudinum* having more biomass than the other two species. *T. testudinum* and *H. wrightii* were found in Region 2 with *H. wrightii* higher in biomass. Epiphyte relative abundance was not significantly different between regions ($p>0.05$) (Appendix B, Table 2). Mean seagrass blade length between Region 1 and Region 2 was not statistically different ($p> 0.05$) (Appendix B, Table 2).

Animals collected by standardize bag seine

Unpaired t-tests ($\alpha = 0.05$) were used to compare epifaunal densities between Region 1 and Region 2. There were significantly more number of epifauna individuals (invertebrates and fishes) collected by the bag seine in Region 1 and Region 2 ($p<0.05$) (Appendix B, Table 3; Appendix A, Figure 7). Similarly, there were significantly more invertebrates in Region 1 than in Region 2 ($p<0.05$) (Appendix B, Table 3; Appendix A, Figure 8). A total of 15,465 animals (invertebrates and fishes) from 38 families were collected by a standardized bag seine from both regions. Region 1 samples yielded 14,600 animals compared to 865 animals collected from Region 2. The four taxa with the highest number of animals collected from Region 1 were copepods (6,521 individuals), gammarid amphipods (2,409 individuals), crab larvae (1,442 individuals), and polychaete worms (1,100 individuals). The animals with the greatest number of individuals collected from Region 2 were gammarid amphipods (240 individuals) and polychaete worms (108 individuals). Note: Time limitations restricted a complete analysis of invertebrate fauna from Region 1 (study sites E3, F1-F3).

The number of fishes collected by standardized bag seine was not significantly different ($p>0.05$) between the two regions (Appendix B, Table 3). A total of 530 fishes from 12 families were captured by standardized bag seine tows in both regions. Tows in Region 1 were comprised of 377 fishes in 8 families while those in Region 2 yielded 153 fishes from 10 families. Standardized and randomized bag seine tows determined family richness for ichthyofauna. There were 9 families collected from Region 1 and 10 families from Region 2. The Family Sparidae dominated abundance both regions (Appendix A, Figure 9).

Animals collected within 0.25m^2 quadrats

Epifauna collected within 0.25m^2 quadrats were not significantly different ($p>0.05$) between regions (Appendix B, Table 3). A total of 3,980 animals were collected within quadrats from both regions. There were 1,777 animals in 27 families collected from Region 1 and 2,203 individuals in 19 families were collected from Region 2. The most abundant animals collected within quadrats from Region 1 were gastropods (941 individuals) and gammarid amphipods (601 individuals). In Region 2, the most abundant animals were gammarid amphipods (1500 individuals), caprellid amphipods (197 individuals), and polychaetes worms (192 individuals). Note: Due to time limitations, animal analysis for QF3 of Region 1 and QA3 of Region 2 was not completed in the lab.

Animal richness, evenness, and diversity

Family richness (S) for animals (invertebrates and fishes) was significantly different ($p< 0.05$) between Region 1 and Region 2 (Appendix B, Table 4). Number of families in Region 1 averaged 29 compared to 19 in Region 2. Conversely, there were no differences ($p>0.05$) in evenness (E) and diversity (H') of animals (invertebrates and fishes) collected by standardized bag seine tows in Region 1 and Region 2 (Appendix B, Table 4). Similarly, there were no significant differences ($p>0.05$) in family richness (S), diversity (H'), and evenness (E) for fauna collected within $0.25m^2$ quadrat seagrass plots (Appendix B, Table 4).

CHAPTER IV

SUMMARY

Green turtle assemblages in Texas' lower Laguna Madre have grown exponentially since 1991 and, as a result, are likely creating increased foraging pressure on algae and seagrass communities on which this herbivorous species depends. The ability of these seagrass communities to sustain continued growth of this population is dependent, in part, upon the associated foraging habitat quality. Competition for seagrass resources or perusal of preferred seagrass communities may eventually drive some turtles to less beneficial foraging grounds (Landry and Metz, 2009). In this study, community structure of seagrass habitat in which green turtles were found foraging and to which they exhibit high fidelity (Region 1) was compared to adjacent areas in which green turtles have not been captured and tracked by the STFERL (Region 2).

Seagrass species composition varied between the two regions. Three species were found in Region 1 (*T. testudinum, S. filiforme, and H. wrightii*) compared to two species (*T. testudinum* and *H. wrightii*) in Region 2. Greater overall seagrass biomass in Region 1 suggests this region may offer green turtles habitat of higher quality foraging potential. Valentine and Duffy (2006) define healthy seagrass habitats as those which are characterized by high seagrass biomass and shoot density. Quantity and quality of seagrass foraging habitat probably play a major role in the disparate distribution of green turtles in the lower Laguna Madre (Landry and Metz, 2009).

André et al. (2005) reported green turtles feed selectively while targeting some seagrass species and avoiding others. Fuentes at al. (2006) examined the gut content from 76 green turtles from Australia and concluded the diets of most turtles consisted of *T. testudinum* despite the broad range of food items consumed. Mortimer (1981) determined *Thalassia sp*. to be the most important food item consumed by greens they examined from Nicaragua. However, Coyne (1994) reported *H. wrightii* the dominate species consumed by subadult green turtles in the lower Laguna Madre despite *H.wrightii* being the least abundant species. This study found *T. testudinum* occurring more often and in greater biomass In Region 1 than in Region 2.

Reduced foraging habitat quality in Region 2 could be a reason, in part, green turtles exhibit fidelity to Region 1. Seagrass habitat heterogeneity, specifically patchiness in seagrass cover, strongly affects community dynamics of seagrass ecosystems (Maciá and Robinson, 2005). Highly variable spatial structure of seagrass communities (Duarte et al., 2006) and patchy seagrass vegetation are often an indication of recovery processes from disturbances (Bell et al., 2006). Habitat disturbances are known to remove larger, slow growing species from a habitat, thus creating dominance by smaller, fast growing and opportunistic species that colonize and change community structure (Watling and Norse, 1998; Peterson et al., 2001; Duffy, 2006). *Halodule wrightii* has been described as a pioneer species in seagrass succession and, as such, can thrive in abundance in disturbed areas and withstand frequent perturbations in shallow coastal environments (Williams, 1990; Filho, 2004). *H. wrightii* patches were more frequent in Region 2 and may be an indicator of an area historically or recently disturbed. This may account for limited biomass of *T. testudinum* (not fast growing) in Region 2 and be the basis for low green turtle occurrence in this area.

Eutrophication (nutrient loading) could be another cause of patchy and poor quality seagrass beds in Region 2. Although there were no statistical differences in water parameters between Regions 1 and 2, water column nutrient concentration was not directly measured and may have varied between regions. Change in water quality due to increased eutrophication is one of the most widely reported causes of anthropogenic seagrass decline (Den Hartog and Phillips, 2000; Cardoso et al., 2004, Ralph et al., 2006). Study sites in Region 2 (Appendix A, Figures 4 and 5) are adjacent to the mouth of the Arroyo Colorado distributary channel (Tunnell, 2002). Despite its importance to the overall productivity of the LLM, the channel serves as drainage for irrigation of crops, municipal waste water returns, and as a floodway during heavy precipitation in the lower Rio Grande Valley. High inputs of phosphorus compounds entering the channel can result in the formation of algae blooms (Lingo, 2007). It is a commonly observed that nutrient enriched conditions replaces slow growing species with more opportunistic fast growing ones in marine habitats (Duarte, 1995; Valiela et al., 1997; McGlathery, 2001, Armitage et al., 2005) as well as terrestrial (Bargali, 1997) and freshwater (Craft and Richardson, 1997). This increased nutrient loading can also create algal proliferations that permeate and displace aquatic vegetation (Duarte, 1995, Valiela et al., 1997; Hauxwell et al., 2001; McGlathery, 2001; Armitage et al., 2005) and is a serious threat to seagrass ecosystems throughout the world (Short and Wylie, 1996; Duarte, 2002; Kenworthy et al., 2006; Valentine and Duffy, 2006). In addition to eutrophication, turbidity is a concern for seagrass health. Although there was no significant difference in turbidity between the two study regions it's worth mentioning that the Arroyo Colorado is a dredge maintained channel that, while being dredged, can cause fine sediments to be continually re-suspended and re-deposited over time. Increased attenuation of light (due to turbidity) over time can deplete seagrass of carbon reserves or, in extreme cases, inhibit photosynthetically-produced oxygen which can lead to sediment anoxia ultimately kill seagrasses (Tunnel, 2002). Historically, dredging events of the Gulf Intracoastal Waterway also caused major declines in seagrass coverage within the lower Laguna Madre during the mid 1960's to 1998 (Quammen and Onuf, 1993; Pulich and Calnan, 1999; Onuf, 2007, Landry and Metz, 2009). Thus, seagrass disturbances in Region 2 may be more frequent than Region 1 and recovery from these events are most likely temporally slower as well.

Seagrasses are foundation species (such as corals, kelps and mangroves) that have large rhizome and root structures belowground and dense, leaf canopies aboveground (Hughes et al., 2009). Constituent species provide shelter and nutrition for a wide range of organisms that are either permanent inhabitants of the community or transients (van Tussenbroek et al, 2006). Family richness and animal fauna density collected by bag seine within Region 1 were significantly higher than fauna collected in Region 2. These data suggest a trend toward increased seagrass habitat quality and community complexity in Region 1 which, in turn, may contribute to a healthier seagrass environment that serves as an optimal foraging area for green turtles. Increased structural complexity of seagrasses enhances epifaunal production and abundance (Heck and Orth, 1980, 2006; Duffy, 2006). Healthy seagrass beds provide nutrition for many organisms by supplying food in the form of seagrass tissue, epiphytes, detritus, or associated fauna (Greenway, 1995; Schwamborn and Criales, 2002; Kirsch et al., 2002; van Tussenbroek et al., 2006). In turn, aquatic and marine herbivores are often favorable for the abundance and productivity of vegetation (Porter, 1973, 1977; Lynch and Shapiro, 1981; Lewis, 1985; Vanni, 1987' Mallin and Pearl, 1994; Valentine and Heck, 1999). For example, mesograzers (small grazing invertebrates) can be beneficial for *T. testudinum* growth through herbivory on the leaf tissue (Valentine et al., 1997; Sluka and Miller, 2001; van Tussenbroek et al., 2006) and/or cropping of epiphytic growth (Heck et al., 2000; van Tussenbroek et al., 2006) by eliminating competition for light and nutrients (Valentine and Duffy, 2006). Also, green turtles in the Caribbean graze mostly on *T. testudinum* by selecting and cropping young, actively growing tissue at the base of the leaves allowing the older blades to float away (Audubon, 1897; Bjorndal, 1980; Moran and Bjorndal, 2005). In response to intensive grazing on *T. testudinum* by green turtles, Thayer et al. (1984) suggested blade growth increases with its tissue higher in nitrogen content and lower in lignin content than ungrazed blades (Moran and Bjorndal, 2005). Valentine et al. (1991) observed *T. testudinum* in summer months can survive extreme grazing pressure and can rebound to either equal or exceed the standing crop of non-grazed *T. testudinum* beds. Further, continual elevated nutrient composition from consistent blade productivity of *T. testudinum* is sustainable for long periods of repeated recropping pressure from green turtles (Moran and Bjornadal, 2005). Valentine and Heck (1999) concluded that sea urchin grazing can also increase shoot density during the summer months and most likely is the reason *T. testudinum* continues to thrive in habitats in the northeastern Gulf of Mexico. However, Moran and Bjornadal (2005) made it clear that over grazing can stress the plant and may eventually lead to a decrease in blade production (Moran and Bjornadal, 2005). Seagrass habitat heterogeneity and fragmentation (formation of remnant patches and edges) of seagrass beds (Region 2) are known to reduce fauna diversity and density (Duffy, 2006). Declining biodiversity, in theory, should reduce community productivity and resource use, change trophic interactions and decrease a system's stability (Duffy, 2006). Seagrass distribution in Region 2, as discussed previously, was highly patchy and most likely the reason animal density was extremely low.

Although there were significant differences in animal fauna collected with the bag seine, there were no statistical differences in animal density collected within the $0.25m^2$ seagrass plots of Regions 1 and 2. Animal densities collected within the plots were extremely heterogeneous, thus indicating a need for increased sampling replications to better reflect the faunal community. Also, animals may have been lost through the process of hand collecting the seagrass. A more efficient experimental design for collecting seagrass samples should be incorporated in future studies of this kind.

The larger abundance of individuals in Region 1 is, most likely, a result of seagrass habitat complexity. Structural complexity components (blade length and width, shoot density, and above-and below-ground biomass) of seagrass habitats influence abundance, growth and survival of fauna (Gillanders, 2006) and is likely to increase fish density due to a reduction in predation (Heck and Thoman, 1981; Orth et al., 1984; Minello, 1993; Rooker et al., 1998; Peterson et al., 2001; Stunz and Minello, 2001; Orth and van Montfrans, 2002; Gillanders, 2006). Low predation rates are often accompanied by, high survival and increased abundance (Gillanders, 2006). Region 2 seagrass communities were patchy and sparse whereas seagrass beds in Region 1 were more complex. Increased temporal repetitions of samples at each study site within both regions are prerequisite to a clearer representation of community structure. Due to time limitations, standardized bag seine tows (3) were only taken once for each study site. A clearer understanding of seagrass ecosystem structure requires sampling constituent study sites several times within a year.

Seagrass communities examined in Region 2 are clearly unlike those in Region 1 and may not support a growing green sea turtle population if anthropogenic caused disturbances continue. Long-term analysis of seagrass communities in both regions is prerequisite to determining if these critical habitats can sustain a growing green turtle population and other economically-and recreationally-important fauna. Continued in-water sea turtle research of both regions is necessary to fully understand this growing turtle population. Green turtle population dynamics in Region 2 remain unclear and must be characterized in an effort to understand distribution patterns for this species in the lower Laguna Madre. Additionally, it would be beneficial to satellite tag subadult turtles in Region 2 to determine if they will remain within the area where tagged and released or if they ultimately move to Region 1. Further, more research should be conducted from the Santiago Pass jetty to determine if juvenile green turtles, during their second ontogenetic shift, only recruit to Region 1 or if they move to other areas before establishing fidelity to a chosen habitat. Ultimately, conservation management plans must be established in Texas to protect these critical complex seagrass habitats in the lower Laguna Madre and, in doing so, contribute to potential down listing of the green sea turtle from an endangered species to a threatened status and eventual population recovery.

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APPENDICES

APPENDIX A

FIGURES

Figure 1. Map illustrating jetties at Brazos Santiago Pass and proximity to Region 1.

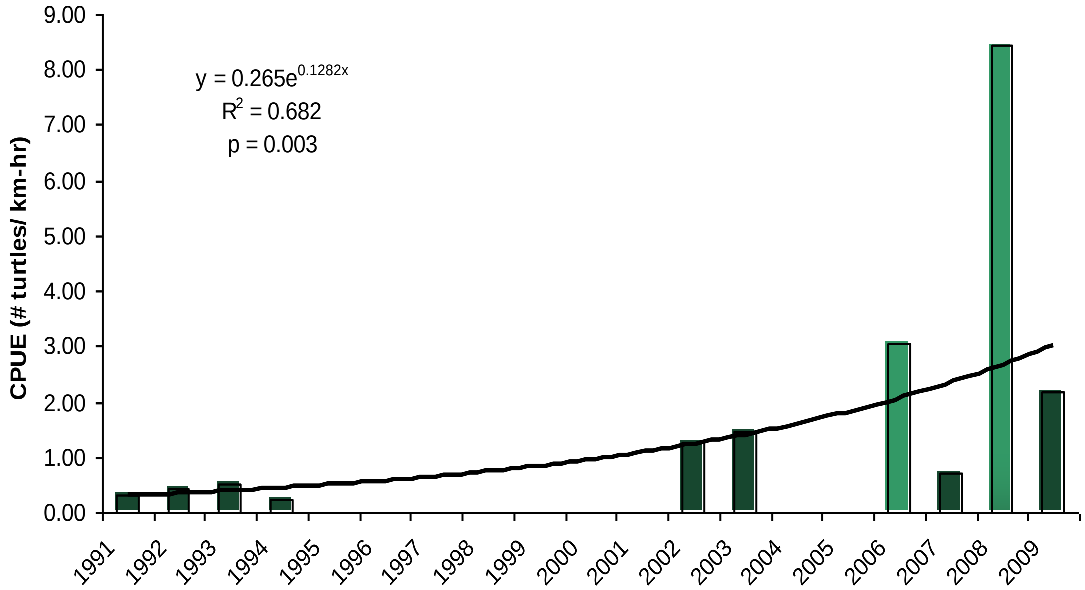

Figure 2. Exponential growth in annual green turtle catch-per-unit effort (CPUE) from the Mexiquita Flats area (Region 1) of lower Laguna Madre, 1991-2009 (Landry and Metz, 2009).

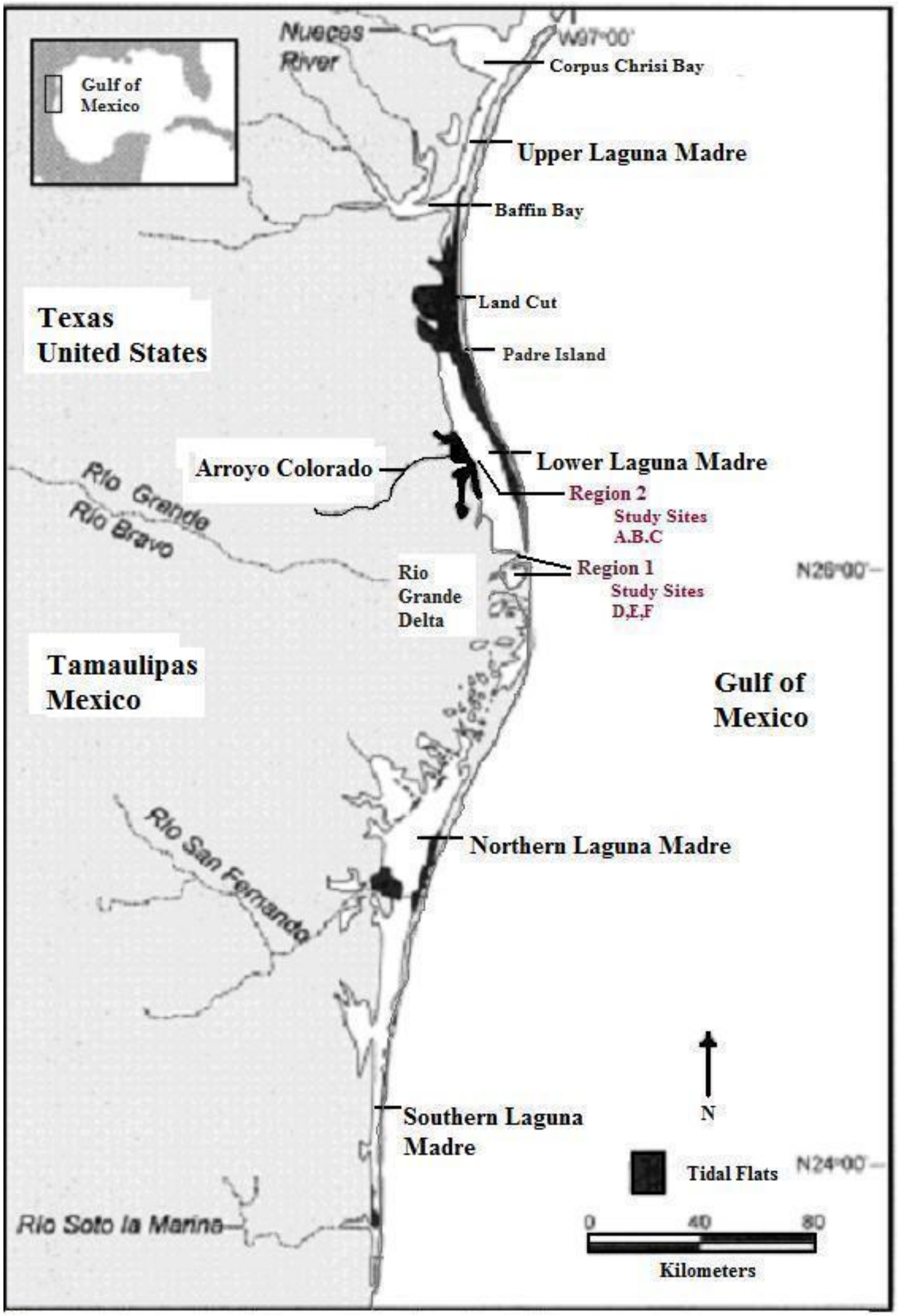

Figure 3. Laguna Madre of Texas and the Tamaulipas (modified with permission from Tunnell, 2002).

Figure 4. Lower Laguna Madre – Region 1.

Figure 5. Lower Laguna Madre – Region 2.

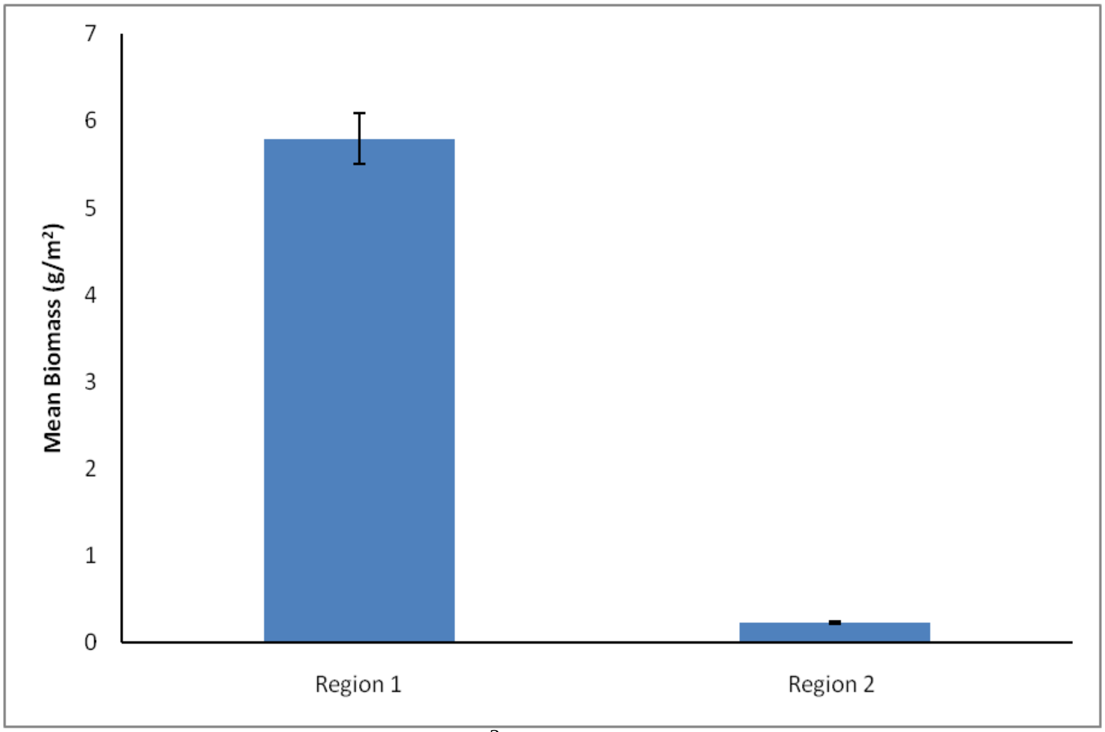

Figure 6. Mean seagrass biomass (g/m^2) illustrating significant differences between Region 1 (high fidelity foraging area) and Region 2 (where green turtles have not been captured and tracked).

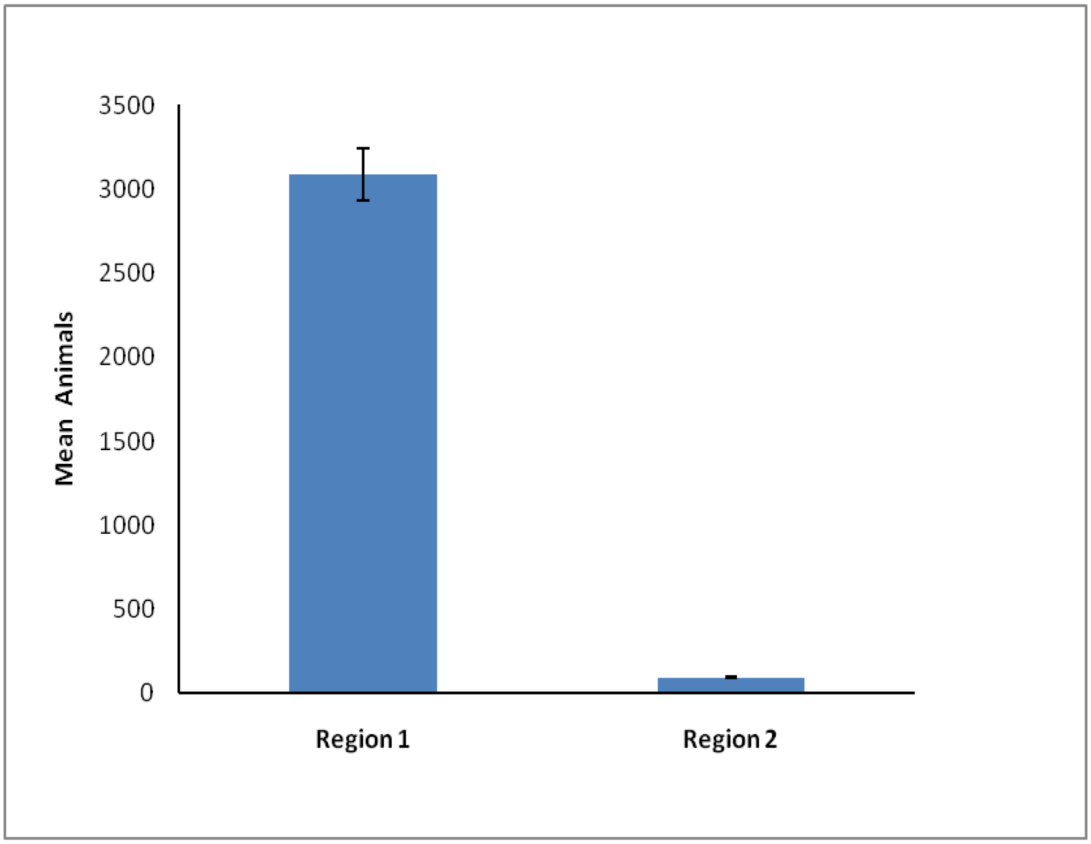

Figure 7. Mean number of animals (invertebrates and fishes) collected with standardized bag seine tow from Region 1 (high fidelity foraging area) and Region 2 (where green turtles have not been captured and tracked).

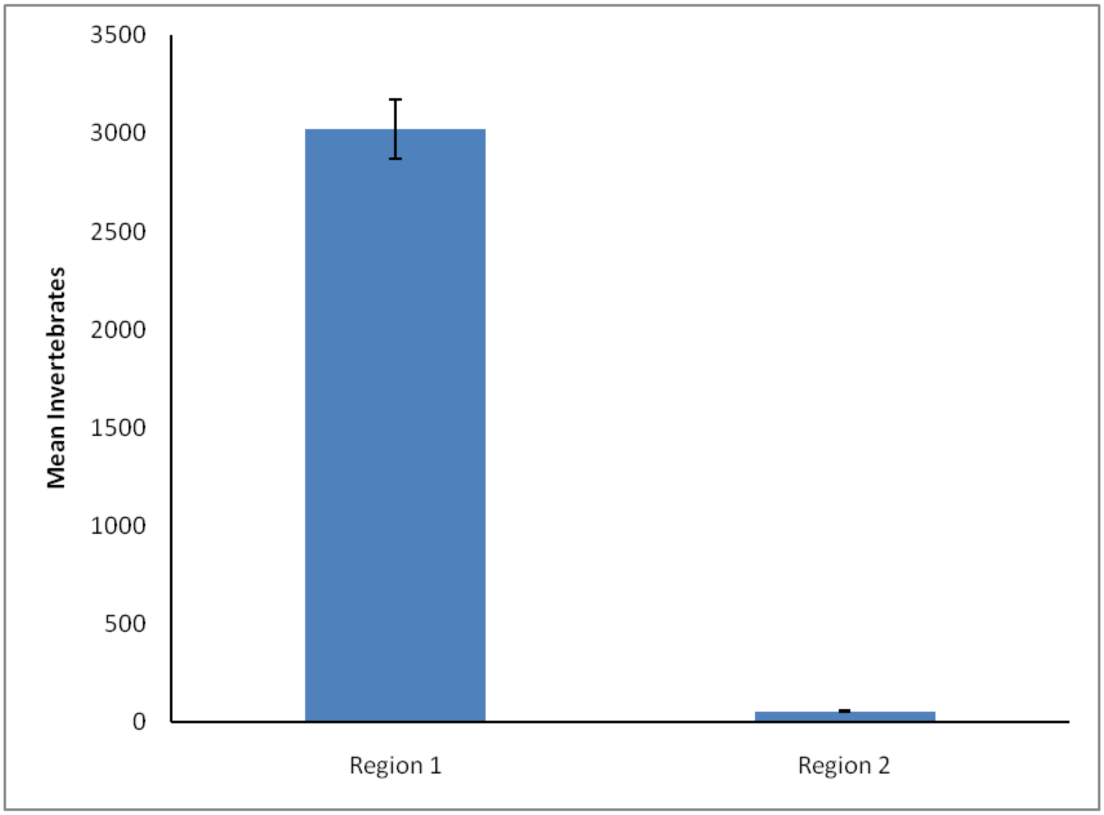

Figure 8. Mean invertebrates collected with standardized bag seine tows from Region 1 (high fidelity foraging area) and Region 2 (where green turtles have not been captured and tracked).

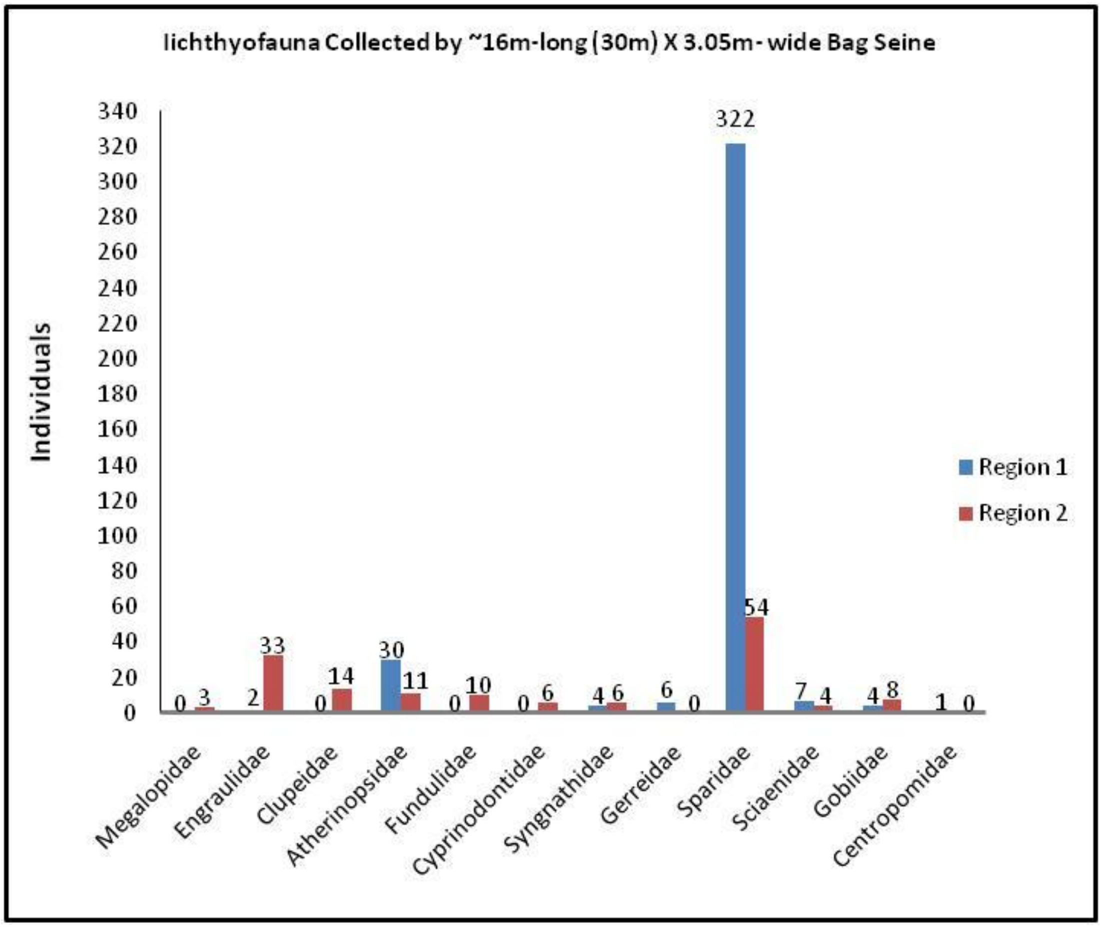

Figure 9. Ichthyofaunal comparison between Region 1 (high fidelity foraging area) and Region 2 (where green turtles have not been captured and tracked).

APPENDIX B

TABLES

Table 1. Mean environmental parameter comparison between Region 1 (high fidelity foraging areas) and Region 2 (where green turtles have not been captured and tracked). Unpaired t-test (α = 0.05) results are listed. An * signifies that the P-value was significant.

	Region 1		Region 2		
Parameter	**Mean**	**SE**	**Mean**	**SE**	**P-value**
Temperature (°C)	23.53	1.35	22.20	0.25	0.39
Salinity (‰)	34.37	0.07	31.50	1.70	0.17
Turbidity (m)	0.04	0.07	0.28	0.09	0.25
Dissolved oxygen (mg/L)	7.28	0.93	7.19	0.07	0.93

Table 2. Mean seagrass biomass (g/m^2), epiphyte biomass (mg/g seagrass), and overall blade length comparison between Region 1 (high fidelity foraging areas) and Region 2 (where green turtles have not been captured and tracked). Unpaired t-test (α = 0.05) results are listed. An * signifies that the P-value was significant.

	Region 1		Region 2		
Parameter	**Mean biomass (g/m^2)**	**SE**	**Mean biomass (g/m^2)**	**SE**	**P-value**
Overall Seagrass	5.80	0.76	0.23	0.09	0.017*
H. wrightii	0.11	0.20	0.08	0.14	0.81
T. testudinum	2.37	2.34	0.04	0.06	0.38
S. filiforme	1.97	1.97	0.00	0.00	0.38
Epiphyte	0.04 mg/g	0.01	1.41 mg/g	0.67	0.11
Blade length (mm)	80.50	25.90	57.00	13.52	0.41

Table 3. Mean animal fauna collected for Region 1 (high fidelity foraging area) and Region 2 (where green turtles have not been captured and tracked). Unpaired t-test ($\alpha = 0.05$) results are listed. An * indicates that the P-value was significant.

Parameter	Region 1 Mean Individuals	Region 1 SE	Region 2 Mean Individuals	Region 2 SE	P-value
Animals (invertebrates and fishes) collected with standardized bag seine.	3090.00	0.99	96.33	12.25	0.03*
Invertebrates collected with standardized bag seine.	3021.50	927.50	57.00	23.50	0.02*
Fishes collected with standardized bag seine.	33.67	17.70	16.33	7.86	0.42
Animals collected within $0.25m^2$ quadrat.	203.67	77.50	351.00	279.90	0.64

Table 4. Mean Family Richness (S), Evenness (E), and Diversity (H') for Region 1 (high fidelity foraging areas) and Region 2 (where green turtles have not been captured and tracked). Unpaired t-test ($\alpha = 0.05$) results are listed. An * indicates that the P-value was significant.

Parameter	Region 1 Mean Richness (S)	Region 1 SE	Region 2 Mean Richness (S)	Region 2 SE	P-value
Animals (invertebrates and fishes) collected with standardized bag seine.	29.00	0.00	19.00	1.00	*0.0045
Animals collected within $0.25m^2$ quadrat.	17.00	4.00	11.67	2.60	0.33
Parameter	**Region 1 Mean Evenness (E)**	**SE**	**Region 2 Mean Evenness (E)**	**SE**	**P-value**
Animals (invertebrates and fishes) collected with standardized bag seine.	0.54	0.04	0.71	0.05	0.09
Animals collected within $.25m^2$ quadrat.	0.63	0.03	0.46	0.09	0.15
Parameter	**Region 1 Mean Diversity (H')**	**SE**	**Region 2 Mean Diversity (H')**	**SE**	**P-value**
Animals (invertebrates and fishes) collected with standardized bag seine.	1.70	0.10	1.84	0.11	0.43
Animals collected within $0.25m^2$ quadrat.	1.48	0.24	0.96	0.22	0.19

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