Establishment of Seagrass Decline and Causative Mechanisms in Pearl Lagoon, Nicaragua through use of Traditional Ecological Knowledge, Sediment Coring and Direct Visual Census

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For the people of Pearl Lagoon Basin, Nicaragua, especially the children.

ABSTRACT

Seagrass beds are declining in all ecosystem types around the world. Members of a community-based resource management project in Pearl Lagoon (RAAS, Nicaragua) initiated interest into the loss of seagrass in Pearl Lagoon. The desire was to know if and why seagrass beds have been disappearing from the shallow littoral zone throughout the entire 60 km long lagoon. The loss, in a region where human population is rapidly increasing, could have drastic affects for the local shrimp and fish industry as well as a loss of major feeding grounds for the West Indian manatee. The use of Traditional Ecological Knowledge (TEK) to inform the development and execution of this project allowed the expansion from a high resolution study of a small area to include a low resolution study of the entire lagoon. Direct visual census via collaborative field work established the present distribution of seagrass beds. Visual census of seagrass beds obtained significant baseline information: (a) identification of the two species *Ruppia maritima* and *Najas guadalupensis*, (b) present locations of patches throughout the lagoon and (c) a rough measure of seagrass abundance. The results of semi-directive interviews were expected to provide a 30 year time course of seagrass abundance. Sediment coring for shells of a seagrass habitat-specialist gastropod species provided an empirical indicator of historical seagrass presence and enabled the determination of confidence limits around TEK responses. TEK definitively established that significant seagrass coverage has disappeared, perhaps to the extent of 75% over the last three decades. Interview responses and empirical evidence suggested that loss of seagrass patches is mainly in response to hurricane disturbances coupled with point (dredging) and non-point source (sedimentation) anthropogenic changes. While the grass might have been able to recover from each of these disturbances individually, the cumulative effect may have been fatal. The incorporation of TEK into an ecological study is essential in information poor areas which are often impoverished regions. The use of TEK provides otherwise unavailable information and through participation empowers local people.

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Foreword

This paper is the ultimate product of an enlightening two year adventure. Moving between Toronto, Ontario; Pearl Lagoon, Nicaragua and Antigonish, Nova Scotia the journey was both spatial and metaphysical. What is presented in this paper is mainly the product of field work in Nicaragua. However, the topic selected and methodology used while in the field is a synthesis, that for me partially reconciles two different worldviews. I believe that all human beings have the right to equality, justice and a comfortable standard of living as do 'nature', wildlife and wilderness areas have an equal right to an unthreatened existence. The subject of this paper, seagrass decline, represents my concern with the natural world. The context, a community-based project in Pearl Lagoon, Nicaragua and the incorporation of traditional ecological knowledge reflect my deep sense of caring for people. My MES courses are varied and diverse, yet my focus has always been the natural world and the reactions of people to this source. The main component of my learning has been ecological theory and methodology. The other two components include the theory and practice of community-based resource management and the theory of community transformation. Throughout my field seasons I grappled with issues of community "development" and actively participated in resource management. The experience that was the research and the writing of this paper drew on aspects from all three of these components. The following chapters present my investigation of seagrass dynamics in Pearl Lagoon. This research has answered many basic ecological questions and inspired many more. Perhaps the most important offshoot of this research is the interest it kindled in many young people in Pearl Lagoon. The interest in and ownership of the new knowledge we created is the best reward I could ever have.

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CHAPTER 1
Introduction

1.1 Pearl Lagoon

Pearl Lagoon (12°15'N-12°50'N, 83°30'W, Nicaragua, surface area = 52 000 ha) is one of the largest lagoons on the Atlantic coast of Central America (Christie et al. 2000). The lagoon drains water from a watershed extending westward to the beginning of the central mountain range (Fig.1.1). Until recently, Pearl Lagoon had one natural outlet to the Caribbean Sea; that in its southern range. In 1978-79 two canals were built: one in the extreme south and one 60 km farther north connecting the northern end of the lagoon to the Rio Grande de Matagalpa. This created a second, indirect, outlet to the sea. Pearl Lagoon's climate is classified as tropical humid receiving annually 2000-6000 mm rain, most of which falls during the wet season (May – October, (Brenes-R. 2001). The lagoon's bathymetrics is such that the majority of the lagoon is two to three meters deep. Salinity varies significantly from 2-36 ‰ on multiple spatial-temporal scales, in part, because of the high input of freshwater during the rainy season flushed through a relatively shallow profile (Brenes-R. & Castillo-V. 1999).

The high spatio-temporal salinity variability physiologically stresses species living in the lagoon. Despite this, some seagrasses species have managed to succeed in this estuarine ecosystem, and thus became the dominant primary producer in Pearl Lagoon. Most seagrasses are salt tolerant (e.g., *Ruppia maritima* is tolerant to high and low salinities) but some species, such as *Najas guadalupensis*, are primarily freshwater, limited to salinities below 10 ‰ (Haller 1974, Kantrud 1991). Seagrass beds of *R. maritima* and/or *N. guadalupensis* perform important functions in Pearl Lagoon. They are home to juvenile white shrimp (*Penaeus schmitti*) and other juvenile crustaceans and fish that use the beds as aquatic nurseries (Schuegraf & Cassanova - unpublished data, Fonseca et al. 1996, Arrivillaga & Baltz 1999). Seagrass beds also provide grazing habitat for the West Indian manatee (*Trichehus manatus*). Both shrimp and manatee provide food and/or economic income to local people. In addition, seagrass beds trap sediments thus reducing turbidity; and provide a large surface area that contributes to the oxygenation of water.

Historically, Pearl Lagoon and the whole Nicaraguan Atlantic Coast were sparsely populated by indigenous peoples. Spanish influence was resisted by these indigenous peoples whose main experience with colonialism was through British traders (Freeland 1988). Sustained contact with Europeans began in the early 1600s and, as has happened in most indigenous cultures, signaled the beginning of overharvesting of natural resources for trade in the market economy. The population of green turtle (*Chelonia mydas*) on Nicaragua's Atlantic Coast, for example, suffered from British sailors' desire for a portable, fresh meat source (Nietschmann 1973). In the 1700s Creole people from Jamaica or Belize, and the Garifunas (Black Caribs) both settled along these coastal shorelines (Freeland 1988). Costeños (as they call themselves), although distinct in cultural traditions, share a respect and appreciation of their natural environment. Today, Pearl Lagoon is home to twelve Miskito, Creole and Garifuna communities (Fig. 1.1), all having lived sustainably for hundreds of years [1]. Today these people live largely through subsistence farming, fishing and hunting - traditional knowledge is still passed from generation to generation through word of mouth.

Since the early 20th century deteriorating economic situations forced Pacific Coast Mestizos, people of mixed Spanish and Amerindian origin, to colonize the Nicaraguan Atlantic coastal regions. During the 1980s Sandinista armies from the Pacific invaded the Atlantic region, and as a result, some people remained in the area when the war was over. Simultaneous with the end of the war, landless Mestizos from the Pacific began moving further east. .This "Contra War" had the unanticipated effect that from the early 1980s through to the 1990s people were afraid to leave their communities to farm (Nickerson & White 1996) consequently there was little large scale environmental impact. On a positive note, the lack of security discouraged

[1] THE TOTAL POPULATION OF THE AREA IS 6250, EACH VILLAGE VARIES FROM 85-1500 INDIVIDUALS. (1995 GOVERNMENT CENSUS, 1992 NGO SURVEY IN CHRISTIE *ET AL.* 2000).

international companies from resource extraction – thus leaving the Pearl Lagoon watershed as a relatively pristine ecosystem. In the 1990's, however, the agricultural frontier finally reached the Pearl Lagoon watershed (Bradford 2002). Further, a population explosion began (demographic studies suggest an annual 8% increase; Christie *et al.* 2000) extorting ever increasing demands on the natural resources.

Indigenous cultures in Pearl Lagoon until recently practiced agroforestry with little direct impact on the forests, and with few chemicals (personal communication) By comparison the newly arrived Mestizos practice Spanish-style cattle farming clearcutting large tracts of forest to plant large cattle pastures whereby the soil quickly (in 2 or 3 years) is eroded away. Many of the rivers in indigenous territories that carry water into Pearl Lagoon are now colonized by Mestizos (Bradford 2002). In addition to destruction of forests for cattle pastures, logging is known to occur in the Pearl Lagoon watershed. Since the creation of the Atlantic Coast Autonomy Law in 1987 contracts for resource extraction must now be approved not only by the federal government but also by the Regional Council–finally giving the Coast control over its own resources (Freeland 1988). This law, however, is blatantly circumvented. That is, to avoid detection logging companies illegally remove significant lumber reserves by transporting the lumber overland to the Pacific Coast. This shipping process demands the creation of a road network significantly contributing to the sedimentation problems of Pearl Lagoon (Hodgson 1997).

The advance of the agricultural frontier, presence of illegal logging, and increasing human populations, simultaneous with an expectation for higher standards of living, all contribute to increased sedimentation, eutrophication and chemical poisoning in lagoon waters. Seagrasses are particularly sensitive to variations in light transmittance, requiring high light intensities (Longstaff & Dennison 1999). Any mechanism that decreases light transmittance is likely to have significant impacts on plant coverage. In the summer (rainy season) water depth increases 30 cm, whereas Secchi depth decreases from 160 + cm to 35 cm (Schuegraf, unpublished data). Outside of these seasonal cycles, assumed long-term turbidity increases occur because of the significant sheet erosion found during the land clearing processes.

Increasing surface runoff not only contributes to sheet erosion, but such runoff also picks up unabsorbed fertilizer and other nutrients (e.g., organic sewage, fertilizers, soil nutrients from burning or clear-cutting) (Brush & Hilgartner 2000). Excess nutrient loads contribute to increased turbidity levels via phytoplankton blooms – a leading cause of eutrophication (Longstaff & Dennison 1999, McGlathery 2001). Aquatic epiphytes and phytoplankton take advantage of high nutrient levels maximizing growth rates. Eutrophication is exacerbated by increasing human population as human wastes enter the water untreated (Hemminga & Duarte 2000, Kennish 2002). As epiphytes and phytoplankton become the dominant primary producers seagrass beds succumb in coverage and density from light starvation (Frankovich & Fourqurean 1997, McGlathery 2001).

A third consequence the advancing agricultural frontier is likely to have had on Pearl Lagoon is the introduction of chemical poisons including pesticides and herbicides. Most aquatic plants including the seagrasses *R. maritima* (Kantrud 1991) and *N. guadalupensis* (Dierberg et al. 2002), absorb nutrients through their leaves. This makes these plants highly susceptible to herbicides used to kill persistent terrestrial weeds. Seagrass patches in Pearl Lagoon were historically found at the mouths of rivers – the first places herbicide runoff is likely to impact. Unfortunately, to measure the presence of herbicides in the water was beyond the capabilities of this research project, and therefore not considered.

1.2 CAMP-Lab – Recognition of the Seagrass Problem

CAMP-Lab (Coastal Areas Monitoring Project and Laboratory) is a community-based Pearl Lagoon environmental protection and resource management project recently created to monitor and educate the people of Pearl Lagoon about their environment. One initial contribution CAMP-Lab made was the creation of a community-based resource management plan2 for the entire Pearl Lagoon watershed (Christie 1993). CAMP-Lab now has a committee in most

[2] This management plan was, after many years of trying, in May 2003 ratified by the Pearl Lagoon municipal government.

communities surrounding the lagoon, whose mandate it is to help identify and solve environmental problems. It was during one of the field trips with CAMP-Lab members that the lack of seagrass beds in the lagoon was identified as an issue. Research assistants – also CAMP-Lab members – showed surprise and confusion when seagrass was not present where expected. CAMP-Lab staff became curious – they initiated their own investigation by asking questions before this present research was even proposed. Their earlier and present efforts became the impetus behind my research project.

Loss of seagrass beds is likely to cause severe stress on Pearl Lagoon's ecosystem dynamics (Short & Wyllie-Echeverria 1996). Although not unique to Pearl Lagoon loss of seagrass has been documented in temperate (Giesen et al. 1990, Olesen 1996, Knapton & Petrie 1999, Seymour et al. 2002), sub-tropical (Larkum & West 1990, Brush & Hilgartner 2000, Meehan & West 2000, Kendrick et al. 2002) and tropical climates (Robblee et al. 1991, Quammen & Onuf 1993). Seagrass decline is attributable to both natural and anthropogenic causes. Natural causes include overgrazing by herbivores, disease, earthquakes and hurricanes. In Pearl Lagoon herbivore abundance is decreasing – through inference this suggests overgrazing is not likely to be of issue (Nickerson & White 1996, Jimenez 2002). Similarly, no diseased plants have been observed, nor is there memory of any history relating to earthquakes. However, Pearl Lagoon has experienced three hurricanes in the last 15 years. These hurricanes are likely to have impacted Pearl Lagoon in some way, for example, through flooding, physical scouring of leaves, and uprooting of rhizomes (Kalbfleisch & Jones 1998). Hurricanes are also known to increase sediment and nutrient loads thus may contribute to increased turbidity and eutrophication as described above – but a hurricane is a single point source stress (Valiela et al. 1998), and seagrass beds destroyed by hurricanes usually recover within two years or less (Valiela et al. 1998).

The observed loss of seagrass beds in Pearl Lagoon is therefore likely a direct result of human impacts. Such impacts can be acute point-source events, for example, dredging (Quammen & Onuf 1993) or use of explosives (Meehan & West 2000), or chronic non-point stresses such as sedimentation (from land clearing), eutrophication, or chemical poisoning as described above. The increasing population and consequent land use changes in and around Pearl Lagoon I suspect have exacerbated such non-point sources of anthropogenic pollution (Bradford 2002). Indeed, if this is the case, then it remains to be seen whether all seagrass loss can be contributed to a single mechanism. But first, it remains whether seagrass loss has indeed occurred as the peoples of Pearl Lagoon suspect. It is this latter issue I wish to resolve first. If such a loss can be quantitatively demonstrated, then I aim to identify the specific mechanism of action that may have caused such loss to occur.

1.3 Chapter outlines

The goals of this thesis are to obtain an understanding of seagrass loss in Pearl Lagoon. Specifically, I aim to determine whether the seagrass has declined in recent years, and if so, to postulate a mechanism of action that is likely to have caused the decline to occur. In Chapter 1, I introduce Pearl Lagoon to the reader summarizing the historical background of today's environmental issues. This chapter briefly describes the CAMP-Lab project required to put the research into context. In Chapter 2, I detail the methods used in this research study. I employ direct visual census to identify the current distribution of seagrass beds in Pearl Lagoon. I use traditional ecological knowledge (TEK) to generate historical distributions of seagrass coverage – supported by sediment cores to obtain appropriate confidence limits. I develop a model of the seagrass habitat niche in an attempt to help identify mechanisms of action that may have contributed to the seagrass decline. In Chapter 3, I present the results of this work, and contributing references that help the reader understand seagrass ecology. In Chapter 4 I offer a synthesis, that is, my interpretation of seagrass dynamics in Pearl Lagoon. Specifically I present evidence for and against each of the potential causes expanded in this chapter. I then suggest research directions and questions related to these topics. A short description of how the results of this thesis are to be given back to the community follows. This chapter ends with a summary and conclusion of the research.

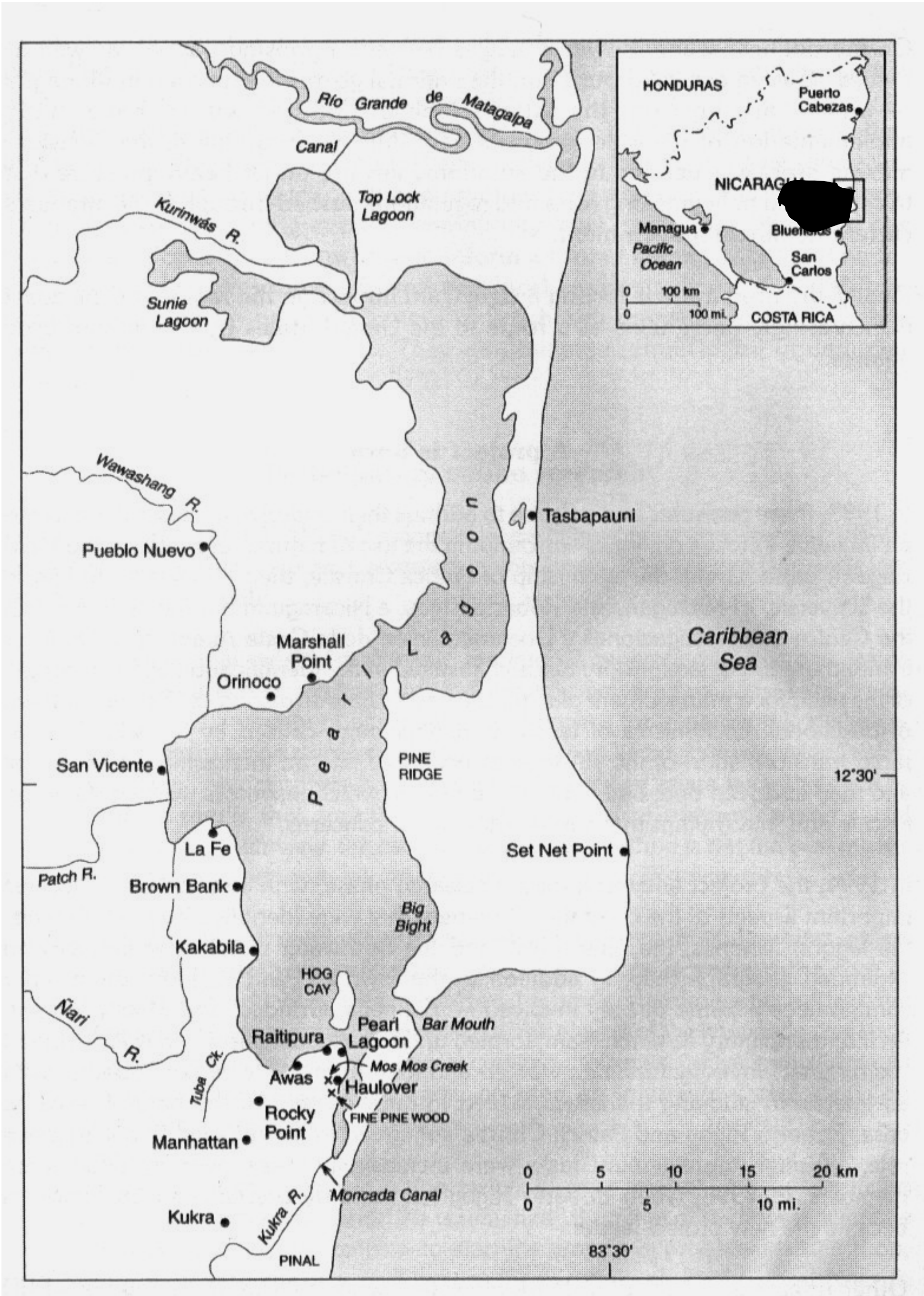

FIGURE 1.1 PEARL LAGOON, ATLANTIC COAST, NICARAGUA. NOTE THE CANALS AT NORTHERN AND SOUTHERN EXTENTS, ALSO NUMEROUS RIVERS DRAINING INTO THE LAGOON. THE MANY COMMUNITIES SURROUNDING THE LAGOON ARE IDENTIFIED. SHADED AREA IN INSET IS APPROXIMATE AREA OF WATERSHED (MODIFIED FROM CHRISTIE 2000).

CHAPTER 2
Materials and Methods

2.1. Introduction

My research goals are to obtain an understanding of seagrass dynamics in Pearl Lagoon. Specifically, I aim to determine whether the seagrass has declined in recent years, and if so, to postulate the mechanisms of action that are likely to have caused the decline to occur. Pearl Lagoon is a poorly studied ecosystem: only one hydrographical and several commercial fishery studies have been published in the past 10 years (DIPAL). Thus to determine if seagrass has indeed declined I compare present abundance (direct visual census: Section 2.2.1, below) to earlier seagrass coverages based on local knowledge from the peoples of Pearl Lagoon. People's local knowledge, known as "traditional ecological knowledge" (TEK: Section 2.2.2, below), is expected to generate a 30-year temporal sequence of seagrass abundances to compare to present coverage. However, reliance on TEK alone may bias the results due to fading memories, and thus its accuracy is difficult to ascertain. This weakness I minimize by correlating TEK responses to known associations of invertebrate/seagrass community organization, and then tracking this association back through time using sediment cores (Section 2.2.3, below). To help identify possible mechanisms that may have contributed to the seagrass decline I develop a habitat profile model that seeks change in environmental variables correlated with seagrass disappearance (Section 2.2.4, below).

2.2 Methods

Three exploratory pilot studies were made in Pearl Lagoon, Nicaragua, in June, August and October, 2002: primary research data was collected from February to May, 2003. Each study included at least two people, myself and a driver/research assistant – although we were frequently accompanied by several volunteers. The study plots were located in the more easily accessible southern zone of the lagoon, which by coincidence contains the highest abundance of seagrass patches in present times. Because of the readily available seagrass patches in close proximity to the lab a small portion of the southern lagoon was studied at high resolution. I identify this portion of the southern lagoon as the "intensively studied" zone. Sixteen field trips were made to this zone to acquire primary data. Separately, two field trips were made to the northern half of Pearl Lagoon in late February and mid-May. The latter northern trip permitted an opportunity to recheck if seagrasses were growing in previously visited locations, and to obtain answers to specific questions that had been unanswered or controversial during the first trip. Thus data was collected from the lagoon at effectively two scales of resolution - one encompassing the entire lagoon (low resolution) and the second as a subsystem detailed in higher resolution.

2.2.1 Direct Visual Census

I used direct visual census to establish locations in the lagoon where seagrasses are currently present. With these observations I gained further insight into the seasonal cycle and typical seagrass habitat found in Pearl Lagoon. Seagrass dynamics were observed on the three pilot trips in June, August and October 2002, and continuously from early February to early May, 2003. For each site seagrass samples were collected and species identified. Nearby vacant sites were monitored to determine if and when the initial appearance of seagrass occurred, and the subsequent species composition. Visible changes in the succession or health of a patch were identified using indicator variables such as coverage, and presence or absence of flowers and seeds. Present locations of seagrass patches (GPS) were used to make a map of present seagrass distribution throughout Pearl Lagoon.

2.2.2 Traditional Ecological Knowledge (TEK)

The body of traditional ecological knowledge encompasses ecological information used everyday by native peoples and communities. This knowledge is employed daily for doctoring, hunting, farming and fishing. Indigenous knowledge matures over hundreds of years through observing the environment, ecosystems and their interactions (Berkes et al. 2000, Pierotti & Wildcat 2000). TEK is most representative of phenomena that are tangible and physically possible to observe. Knowledge is passed from generation to generation, most often orally, in the form of stories or while learning traditional methods. Accessing and using this knowledge only improves an ecological study by providing perspectives and information that might otherwise be lacking (Calheiros et al. 2000). Recent trends in the use of TEK, especially in the North American arctic, incorporate TEK into all environmental assessment or resource management plans. Integrating TEK is now a legal requirement in the Canadian North (Abele 1997) and has necessitated great interest in and use of TEK by ecologists.

For my own TEK analysis I conducted 25 interview sessions to discern the historic distributions of seagrasses growing in Pearl Lagoon (all respondents were from communities local to Pearl Lagoon). The question design (Appendix A) was influenced by the oral culture of Pearl Lagoon residents to maximize research flexibility. On occasion, very specific questions were asked to some respondents in order to elicit key insights. Not all questions were asked to all people, and additional questions arose as conversation progressed. Interviews usually started by asking the respondent a general question such as "I want to know more about the grass that grows in the water, the 'mananti grass', would you mind telling me what you know about it?". From this starting point further questions were asked expanding on the initial information obtained. Questions covered various themes including:

(1) animal use of seagrass beds
(2) when seagrass is present in the lagoon (life history),
(3) the presence of flowers/seeds on the seagrass,
(4) a physical description and/or a drawn picture,
(5) where the seagrass grows/used to grow (occasionally maps were drawn, or patches identified on a map),
(6) specific memories describing seagrass patches
(7) reasons for the disappearance or decrease in seagrass abundance.

During the interview process, I believe, translation barriers were minimal because I, the interviewer, am almost 100% fluent in Creole, the first or second language of Pearl Lagoon inhabitants. A cultural difference was present between myself and the interviewees but after 7 months living in the watershed these differences were not expected to impart bias during the interview process.

Interviewees were classified into four groups. The first group, "Group 1 - Expert" I assumed were knowledgeable about seagrasses as these respondents were typically ex-manatee hunters (Ferguson & Messier 1996, Mymrin 1998), some who periodically check to see if the seagrass is present. Other expert respondents were those who participated in active research within the lagoon itself (e.g., local ecologists) combining TEK with their understanding of ecological processes. The second class of respondents I classified as "Group 2 - Better" - these included fishers who were active, or had been in the last 15 years, and who were likely to have traveled frequently in areas where seagrass has been known to grow. Interviewees who wanted to talk about the seagrass, and CAMP-Lab members that did not fall into above categories I classified as "Group 3 - General" respondents. "Group 4 - Synthesis" respondents were those interviewees who were either more educated, or involved from the conception through to the execution of the project helping to interpret the results of the coring, observation and interviews. Efforts were made to minimize (a) interviewee discomfort (Ferguson & Messier 1996), and (b) prebias in the interviewee responses (Chambers 1994, Huntington 2000).

Responses were ordered into groups paralleling the question themes, and summarized by calculating the percentage of respondents that provided similar answers. A low resolution map of historical coverage of seagrass patches for the entire lagoon was created by placing every patch mentioned by any person on the map – thus creating a best-scenario map. By comparison, at the higher resolution intensively studied zone the coverage map was created by combining maps drawn by each respondent. If the respondent was confident in remembering patch coverage areas then these areas were marked on the map; if the respondent was unsure, the location was not identified on the map unless supported by another respondent. The difference in techniques between the two scales reflect changes in sampling methodologies as field lessons learned were integrated back into the research design.

2.2.3 Sediment Coring

Sediment coring contributed to two objectives. The first objective was to derive confidence limits around the TEK results (Poizat & Baran 1997). The second objective was to provide insight as to why seagrass may no longer be growing in historical TEK locations. Confidence limits surrounding the TEK results were derived by correlating TEK responses to the presence or absence of periwinkle/seagrass, species-specific community associations found in the sediment cores. The assumption is that seagrass communities are home to a diverse community of macro-benthic invertebrates, some of which are habitat-specialists (Kolasa 1989) found uniquely within seagrass patches (Edwards 1978, Edgar et al. 1994, Creed 2000). In Pearl Lagoon two gastropods "periwinkles" (Fig. 2.1), the first understood to belong to Family Cerithiidae and the second *Neritina virginea* (Kaplan 1988), are thought to show such habitat-specialist associations. Thus, evidence of the slow-to-decay periwinkle shells found within sediment cores would suggest past presence of seagrass beds. Such correlation was first field-tested at Big Shoal using a quadrat size equal to 0.16 m2 (nquadrats =15). The density of live species *A* gastropods in a mature seagrass bed was 95 ± 46 per m2, the density of live species *B* gastropods was 23 ± 15 and the combined density was 109 ± 48. By comparison, for habitat absent of seagrass (i.e., bare mud/sand substrate) no live periwinkles were found (nquadrats =15). These results support the view that periwinkles are locationally dependent on seagrass (Z-test p<0.001).

With the above periwinkle/seagrass association clearly demonstrated it is possible to obtain a degree of confidence limits around the TEK responses. That is, for each sediment core, presence (scored a "1") of either shell supports the idea that seagrasses were present in the historical past. Absence of both shells (scored a "0") supports the idea that seagrasses were absent in the historical past. TEK interviewee responses were coded similarly, that is, a "1" was assigned to assumed historical presence, and a "0" was assigned to assumed historical absence. The frequency of congruency between "1's" and "0's" between the sediment cores and TEK responses defined the confidence limits used.

Sediment cores were sampled using a piece of PVC pipe (d = 11 cm, h = 100 cm) was used to remove a sediment core (~ 40 cm deep) in locations where TEK responses suggested seagrass was suspected to have occurred (Edgar 1994). Most cores were completed in the "intensively studied" part of the southern zone, permitting a detailed analysis. Sampled point locations were identified using an Eagle Explorer GPS unit. Sediments were removed from the pipe, divided into 8 cm segments and sieved. Shells from each segment were identified and categorized. Sediment cores were collected from Tasbapouni south in presently found seagrass beds, and in locations where seagrass beds were thought to have occurred (Fig 2.2).

At the higher resolution scale of the "intensively sampled" zone I used a chi-square test to test the null hypothesis that there is no correlation between the presence "1" and absence "0" of gastropod shells as derived from sediment coring, with the presence "1" and absence "0" obtained from TEK. For this higher resolution analysis each core I used as a statistical replicate thus permitting the generation of a 2x2 contingency table (i.e., (1/0), (1/1), (0/1) and (0/0)). Hence, as in the random flipping of a coin, the expected frequency of congruency is 50% (i.e., (1,1) & (0,0)). Significant deviation from 50% suggests either the results are much more congruent than would be expected by chance (thus increasing the level of confidence around the TEK results), or the results are much less than congruent (thus suggesting either TEK or the core sampling methodologies are heavily biased). The ?2 statistic was compared at a = 0.05 with one degree of freedom allowing a decision on whether or not the two sets of results were independent.

At the lower resolution scale of the whole lagoon sampling methodology for TEK generated only positive "1" data. I therefore used a proportional analysis to test the null hypothesis that the frequency of sediment coring agreeing with TEK responses is random (P=0.5) because out of the two possible matchings of TEK and coring results (e.g., (1/1), (1/0)) only one demonstrates congruency (i.e., (1/1)).

2.2.4 Habitat Profile

I developed a seagrass "habitat profile" for present seagrass locations. The "habitat profile" identifies the multidimensional niche of environmental variables that includes sediment coarseness, sediment oxidation, depth, salinity, epiphyte loads, and nitrate levels. Changes in these variables within a sediment core, or between locations may provide some insight into historical influences that have changed seagrass coverage in Pearl Lagoon. Seagrass success (biomass – wet weight) was quantitatively measured with an Ohaus Digital Balance. Depth I measured using a standard inch-calibrated yard stick. Salinity I measured using a "NEW S-100 JAPAN 8905 A-155" refractometer internally calibrated to function at 20°C. A calibration curve (r2=0.939) using standards for 29°C corrected for the more realistic temperature in Pearl Lagoon. Sediment coarseness and oxidative state I measured by classifying texture and colour of sediment cores. Sediments I classified as anoxic if grey or black, and oxygenated if a brown colour was present. Sediment coarseness I measured by creating a texture-based scale (Fig. 2.3). Epiphyte load, one measure of nutrient levels (Frankovich & Fourqurean 1997), I classified from 0 (i.e., no epiphytization) to 5 (i.e., heavily epiphytized; Fig. 2.4). Nitrate levels I measured (at river mouths, near towns, and in isolated areas) using Acquamarine© Salt Water Nitrate Indicator Strips sensitive to 0, 10, 20, 40, 80 and 200 ppm.

FIGURE 2.1. SEDIMENT CORES WERE SIEVED FOR SPECIES (A) BELONGING TO FAMILY: CERITHIIDAE AND (B) *NERITINA VIRGINEA*.

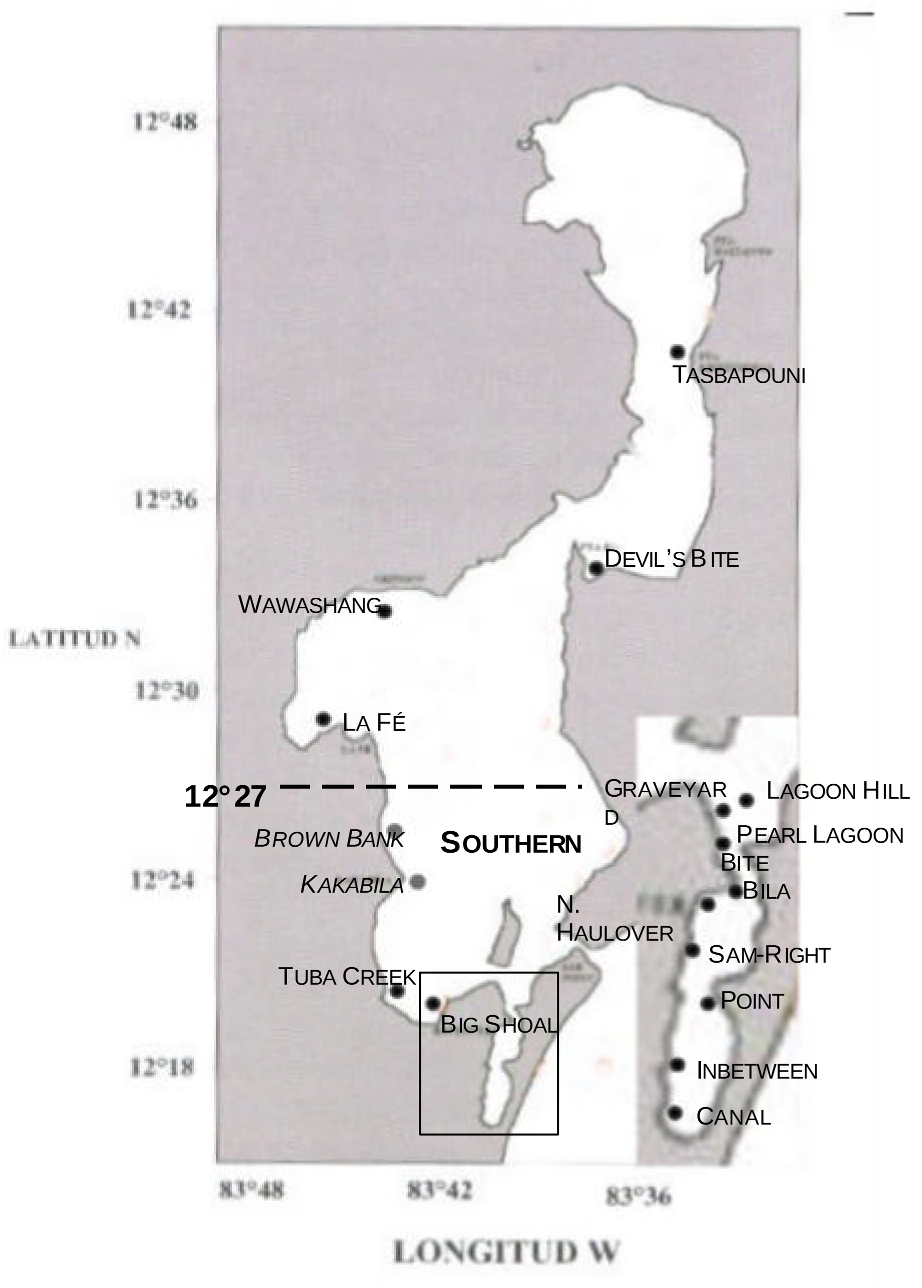

FIGURE 2.2 DIAGRAM OF PEARL LAGOON SHOWING ALL CORE SAMPLING SITES. ITALICIZED SITES WITH GREY CIRCLES WERE INVESTIGATED BUT NOT CORED. LATITUDE 12°27' N IS THE DIVISION BETWEEN NORTHERN AND SOUTHERN ZONES. THE "INTENSIVELY STUDIED" ZONE IS BOXED (MODIFIED FROM BRENES-R. & CASTILLO-V. 2001).

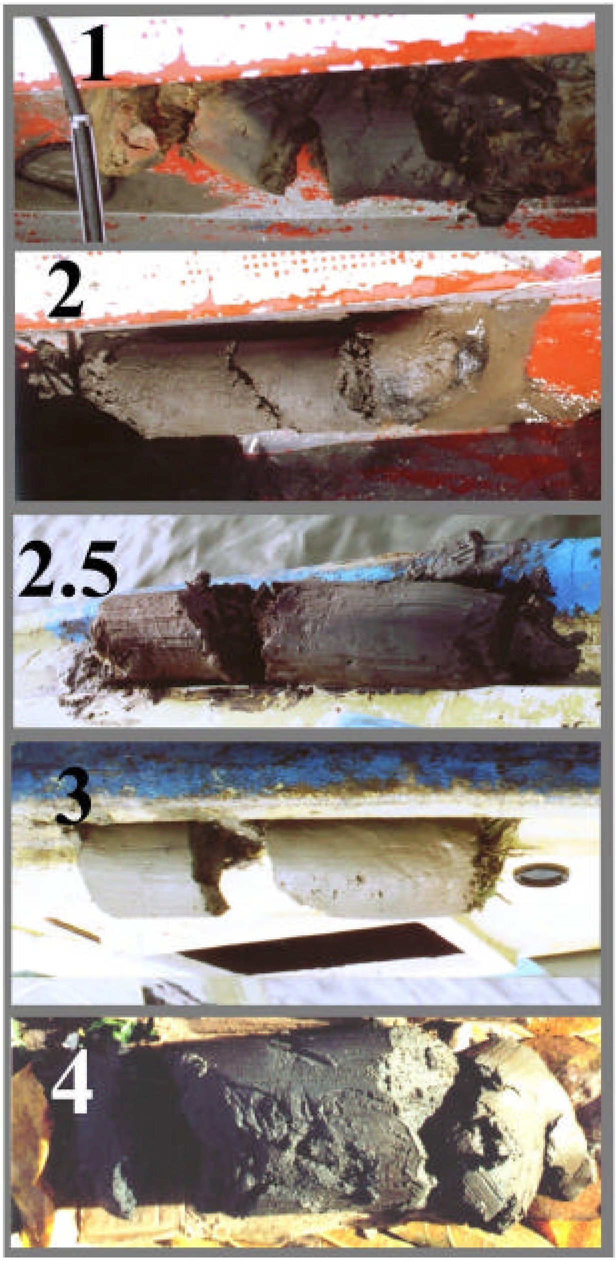

FIGURE 2.3. THE SEDIMENT COARSENESS SCALE RANGES FROM 1 TO 7 (1 = CLAY, VERY FINE SEDIMENTS; 2 = BLACK MUD (LIQUID) AND SILT, FINE SEDIMENT; 3 = MIXTURE OF MUD AND SAND ; 4 = FINE SAND; 5 = COARSE SAND; 6 = FINE SEDIMENT CONTAINING PEBBLES; 7 = FINE SEDIMENT CONTAINING LARGE NUMBER OF PEBBLES AND/OR ROCKS). PHOTOS SHOW THE VALUES 1 TO 4 INCLUSIVE.

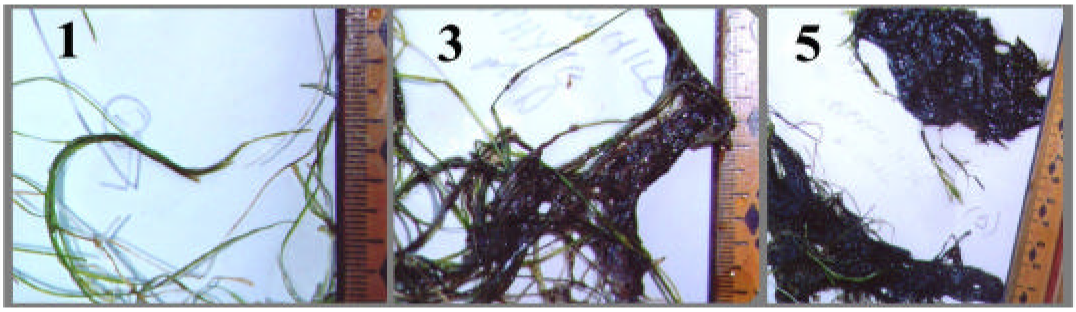

FIGURE 2.4 EPIPHYTE LOAD RANGES FROM 0 = NO EPIPHYTES, TO 5 = HIGHLY EPIPHYTIZED. PHOTOS FOR VALUES 1, 3 AND 5 ARE SHOWN.

CHAPTER 3
Results

3.1 Introduction

The present research suggests that seagrass coverage has indeed declined in Pearl Lagoon. The purpose of this chapter is to show the results that support this claim. However, to begin the chapter I first place Pearl Lagoon seagrasses into a local context based on my own field observations (Section 3.2.1, below). I then review the TEK responses that assert the decline to have occurred (Section 3.2.2, below). In Section 3.2.3. I offer evidence through sediment coring that shows that although TEK is adamant about the decline, the specificity of TEK responses regarding where, when, and why the decline occurred is highly variable. In Section 3.2.4 I compare and contrast habitat profiles that provide insight into mechanisms of recent seagrass losses.

3.2 Pearl Lagoon Seagrasses

There is much debate over the taxonomic definition of seagrass (Les et al. 1997), thus, the norm is to identify seagrasses as a community of benthic macrophytes, instead of by specific species. Benthic macrophytes typically cited as belonging to the seagrass community include (a) marine seagrasses such as turtle grass (*Thalassia testudinum*), shoal grass (*Halodule wrightii*) and manatee grass (*Syringodium filiforme*) (Quammen & Onuf 1993), and (b) salt-tolerant freshwater plants such as the naiads (*Najas* spp.) and pondweeds (*Potamogeton* spp.) (Sculthorpe 1967, Kautsky 1988) and *Ruppia maritima* (Kantrud 1991). Most literature on seagrass on Nicaragua's Atlantic Coast discuss oceanic species only (Phillips et al. 1982, Ryan 1992, Bradford 2002). However, one report by (Marshall et al. 1995) identifies *R. maritima* and *H. wrightii* as growing in some coastal lagoons in the Northern Atlantic Region (RAAN). In Pearl Lagoon seagrass beds are comprised of two species: the more common *Ruppia maritima* (Fig. 3.1) (Edwards 1978, Marshall et al. 1995, Bortolus et al. 1998) and the less common *Najas guadalupensis* var. *guadalupensis* (Fig. 3.2) (Haynes & Wentz 1973, Haynes 1979, Lowden 1986, Stevens et al. 2003). Future references to "*Najas*" and "*Ruppia*" will refer to the above species respectively.

3.2.1 Direct Visual Census

Ruppia maritima was the most common species of seagrass found in Pearl Lagoon (i.e., observed in 8/9 locations; Fig. 3.3). By comparison, *Najas* grew in only two of the nine locations sampled in the lagoon. All seagrass beds were monospecific except one patch of mixed *Najas* and *Ruppia* in the southern end at Big Shoal.

Ruppia dominated seagrass beds undergo cyclical variation. In the dry season waters clear (i.e., decreasing turbidity) and seagrass grows profusely; during the rainy season high water input containing nutrients and/or sediments causes high turbidity and the seagrasses die (Edwards 1978, Flores-Verdugo et al. 1988, Dunton 1990) In Pearl Lagoon, three 'Group 1 - Expert' respondents attributed the cyclical seasonal loss of seagrass to decreased light penetration. Seagrasses regenerate when light intensity reaches a level capable to support growth. (Dunton 1990, Burd & Dunton 2001). A cycle similar to that found in other tropical lagoons was reported by most respondents of Pearl Lagoon. The seagrass was said to grow quickly in March and April, and to be floating in May. During the intense rains of June and July seagrass plants are uprooted and lost from the seagrass patch. Recolonization occurs from November through to February. Some stages of this cycle were observed during my field trips: in June 2002 *Ruppia* began to die, by August it was completely gone; nonetheless, the seagrass returned from October to February, depending on the depth of the patch. I observed *Ruppia* patches to flower and bear seeds abundantly from February (Big Shoal and Pearl Lagoon Bite) through to April; after which, the rhizomes began to shrivel and the crop began to decay. Highest biomass of *Ruppia* (956.8 g/m2 wet weight) occurred shortly before plant decay.

In the southern location I observed *Najas* to grow in October and bear seeds by early February. In late March signs of decay became observable, and by early May coverage had reduced to zero. Highest biomass of *Najas* was obtained in mid February (557 g/m2 wet weight). In the northern location *Najas* was present in late February and absent in mid-May. In Pearl Lagoon both *Ruppia* and *Najas* are believed to reproduce primarily by seed because very little stored underground biomass is found when the seagrasses are absent (personal observation).

3.2.2 Traditional Ecological Knowledge

Thirty interviews were made encompassing 41 people from nine different communities. Of this group four people were interviewed twice. Twenty-two interviewees were from communities in the northern zone. The smallest category interviewed was 'Group 4 - Synthesis' as this group only included two CAMP-Lab staff and my primary research assistant. There were six 'Group 1- Expert' respondents including three manatee hunters, two ecologists and one researcher. The largest respondent category was 'Group 2- Better' with 17, and the remaining 12 respondents were classified as 'Group 3-General'.

Six individuals (including one Group 1 – Expert) from the intensively studied zone provided high resolution data concerning time-lines as to when dieback in this zone and nearby areas occurred (Fig. 3.4). In contrast, only low resolution data was obtainable for the rest of the lagoon because interviews were dispersed over a large area. Except for discrete events (e.g., dredging in 1978/79, and Hurricane Joan in 1988) –responses were highly variable as to when and why seagrass declines occurred (Table 3.1). The most common thought was that, yes, seagrass decline had occurred (89% respondents); seagrass decline occurred between 8 and 10 years previous (44% respondents). In regards to decline in the last 10 years most people originally responded that the cause was unknown. When asked to guess numerous different hypotheses were given, three being equally common (24%): (1) some form of physical human destruction (i.e. propeller scarring, uprooting by handnets), (2) burial of seagrass beds and (3) sedimentation.

Figure 3.5 shows a best-scenario map of seagrass beds in the lagoon prior to any major disturbances. Patch size was approximated from TEK responses, when possible. Only one additional discrete event was associated with seagrass loss on the large scale (Fig. 3.5a). The loss of seagrass beds in the vicinity of the Top Lock canal was suggested by two Expert respondents to be the result of more saline waters accessing this previous isolated region.

3.2.3 Sediment Coring

Sixty-four sediment cores were collected. Table 3.2 identifies sediment core and shell association distribution patterns. Twenty one of the cores were sampled in seagrass patches. Core attempts were made in the Kakabila patch, but the pipe was lost in deep waters and could not be recovered. The patch of seagrass at Brown Bank was not found until the last day of the field season, and hence, was not sampled in time for this analysis.

At the high resolution scale of intensive sampling in the southern zone, the null hypothesis states that there is no correlation between the presence (1) and absence (0) of past periwinkle/seagrass associations, with the presence (1) and absence (0) of past seagrass locations derived from TEK. The results from a chi-square test (Table 3.3) show that the observations made by the two methods are not independent of each other, that is, there is high congruency among the results (?2calc = 5.892 > ?20.05,1 = 3.841). At the low resolution scale of the entire lagoon the proportionality test showed that sediment core sampling and TEK responses are 92% congruent (a -level significance ranged from 0.99 – 0.69). Together, both set of results suggest that for the purposes of this research project, map projections based on TEK responses are adequate to derive historical seagrass coverages.

3.2.4 Habitat profile

Environmental variables such as gradients in turbidity, depth, salinity, sediment texture, oxidation, and nutrient levels influence seagrass coverage and density. *Ruppia* was found growing over a range of depths from 0.2 – 1.3 m (Table 3.4): by comparison *Najas* patches were found within a range 25 and 50 cm only. *Ruppia* occurred, with no loss in coverage, at salinities from 14 – 41 ‰. *Najas*, on the other hand was present in salinities ranging from 7 – 36 ‰.

Although present at 36 ‰, *Najas* coverage was decidedly less than it was at lower salinities – visible evidence of decay was apparent.

Information on sediment coarseness and oxidative state came from extruded sediment cores (n=21); 18 of these were in *Ruppia* patches, the other 3 were dominated by *Najas* (Table 3.5). Nine of the 21 cores were made in the largest patch, Big Shoal. The distribution of cores was roughly proportional to the size of the seagrass patches. *Ruppia* was typically found growing in a mixture of fine sand and mud/silt with an inch or two of soft mud on the top. This 'typical' substrate was assigned a coarseness of 3; the mean from 18 cores was 3.0 ± 0.2. Sediment coarseness for *Najas* patches was 2.3 ± 1.3. For *Ruppia*, 10 of 17 cores showed a distinct oxidative layering effect (inset, Fig. 3.6): top 4cm was a light brown; below 4cm, the mud/sand mixture was black and assumed anoxic. The roots, however carried oxygen deeper into the substrate creating an oxygenated capsule surrounding themselves (Fig.3.6). The remaining seven were anoxic throughout. The two *Najas* cores from Big Shoal had the same characteristics as *Ruppia* patches, however the core from La Fe had black mud on the top and the rest was a red claylike substance.

Changes in the epiphyte community structure was evident throughout the observation period. High densities (highly epiphytized = 5) of the green cyanobacteria *Limbia* (personal communication – Garbary 2003) turned brown, broke down and disappeared as the field season progressed. The *Limbia* was typically replaced by a brown, encrusting epiphyte (mildly epiphytized = 2). Shallow areas appeared to carry the highest epiphyte load.

To model nutrient concentrations nitrate levels were measured at the mouths of the three major rivers, the Patch, the Nari and the Wawashang. Nitrates were also measured at the three of the largest communities, Pearl Lagoon, Orinoco and Haulover as well as three relatively isolated sites, Devil's Bite, Big Shoal and Point. For all sites, however, the lack of any reading suggests lack of sensitivity of the equipment used. As such, the model of nutrient levels in the lagoon is excluded from the final synthesis.

These results suggest that the ideal ranges of the multidimensional niche where seagrasses are most likely to grow include shallow, < 50 cm depths with a substrate composed of a sand and mud/silt mixture. For *Ruppia*, the salinity should be between 14-40‰, for *Najas* salinity should be between 5 - <20 ‰. It appears that water nitrate levels need not be high for growth of either plant. While this characterization could include much more information, it still enables classification of most sites as hospitable or inhospitable to growth.

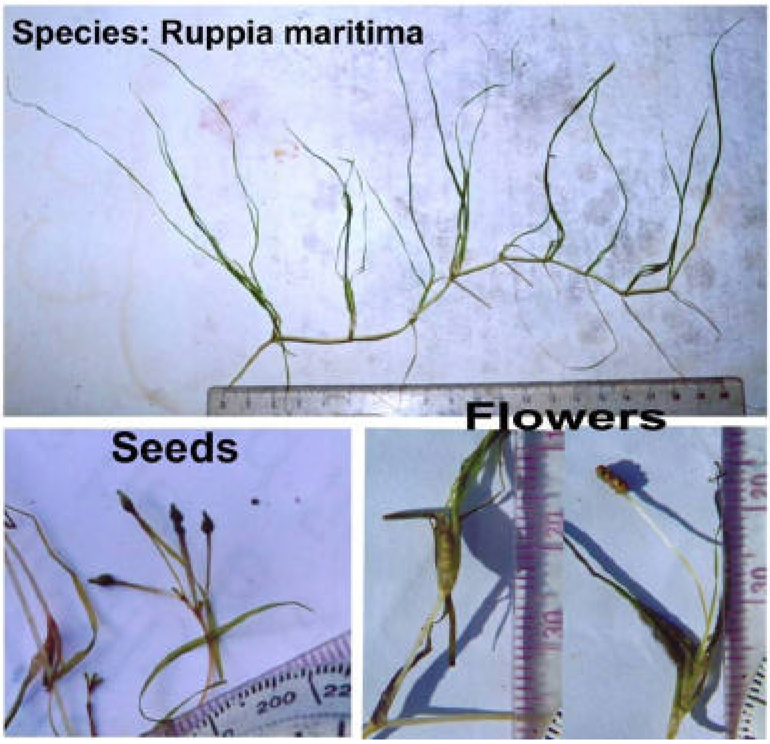

FIGURE 3.1. *RUPPIA MARITIMA* WITH DETAIL OF SEEDS AND FLOWERS. THE FLOWERS ARE SHOWN INSIDE THE SHEATH AND ATTACHED TO A SHORT PEDUNCLE.

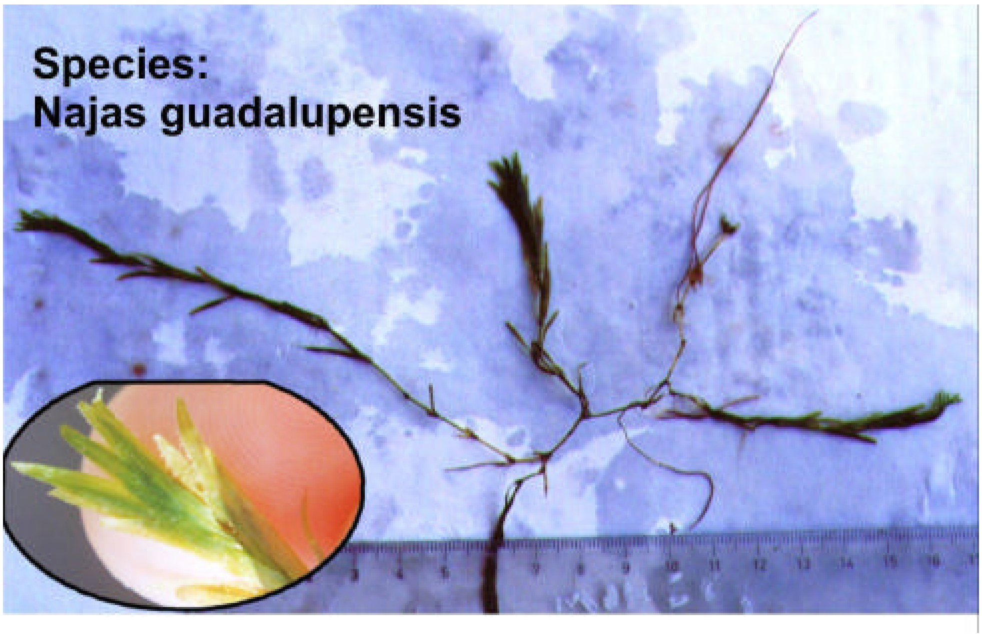

FIGURE 3.2. *NAJAS GUADALUPENSIS* VAR. *GUADALUPENSIS.* INSET: BARELY VISIBLE MINUTE TEETH TAXONOMICALLY USED TO DISTINGUISH SPECIES.

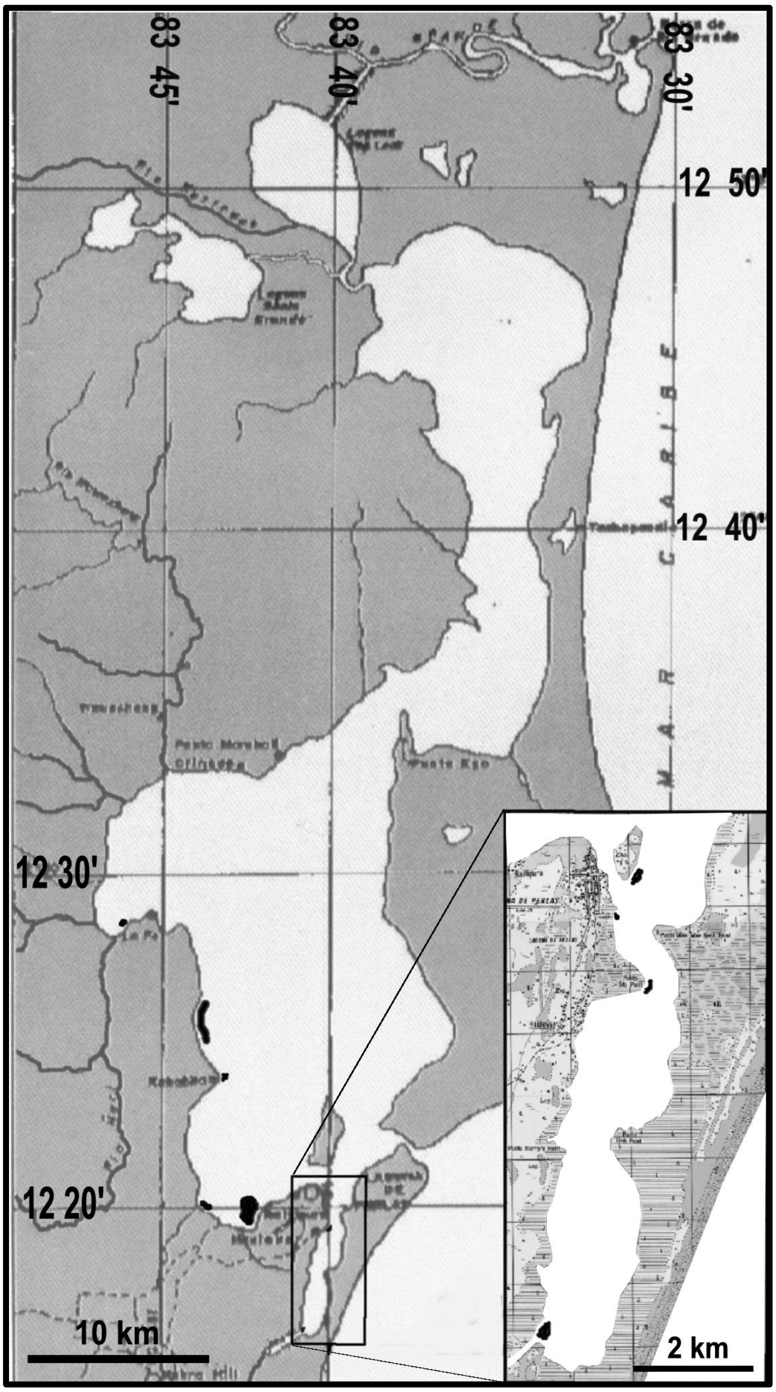

FIGURE 3.3. CURRENT DISTRIBUTION AND NAMES OF SEAGRASS PATCHES IN PEARL LAGOON. INSET: CLOSE UP OF EXTREME SOUTH END. ALL NINE EXTANT PATCHES ARE VISIBLE. THE PATCH AT LA FÉ WAS ENTIRELY *NAJAS GUADALUPENSIS* AND THE PATCH AT BIG SHOAL WAS MIXED *N. GUADALUPENSIS* AND *RUPPIA MARITIMA*. ALL OTHER PATCHES WERE *R. MARITIMA.* (MODIFIED FROM BRENES-R. & CASTILLO-V. 2001).

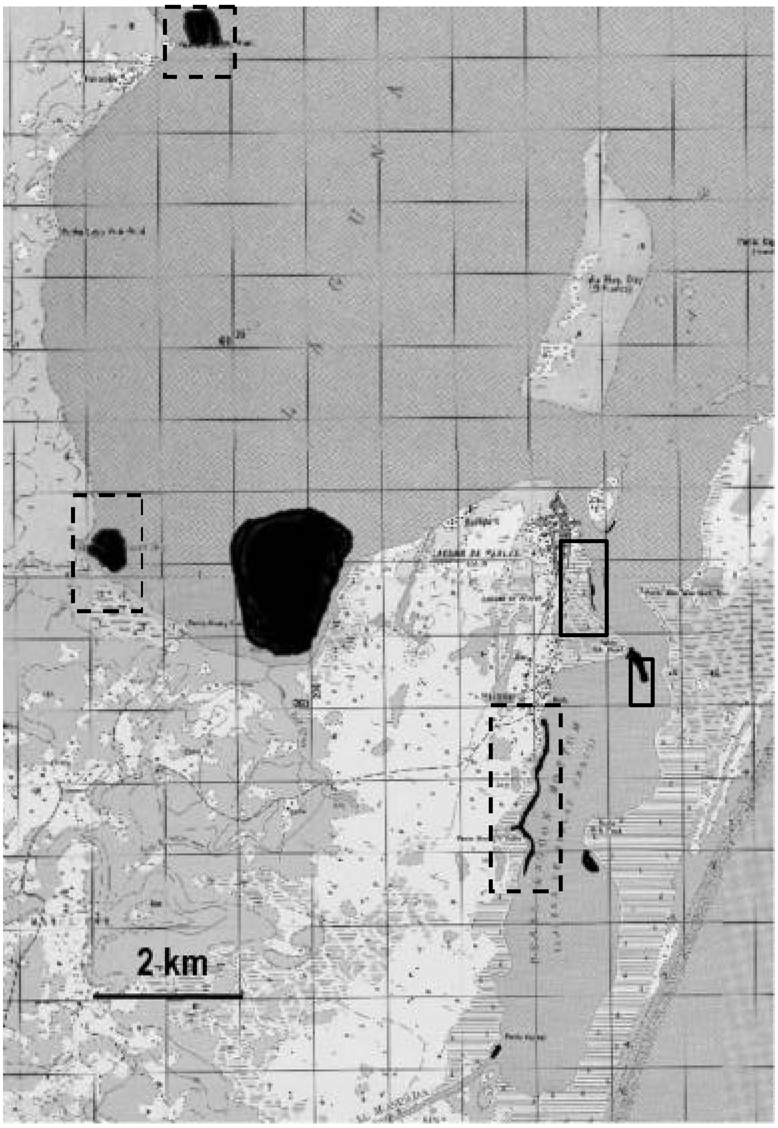

FIGURE 3.4. PRE-1978 DISTRIBUTION FOR THE INTENSIVELY STUDIED AREA OF THE SOUTHERN ZONE. (A) SOLID BOXES REPRESENT LOSS ATTRIBUTED TO DREDGING. (B) DASHED BOXES REPRESENT LOSS DUE TO HURRICANE JOAN. (MODIFED FROM INETER, NICARAGUA 1988)

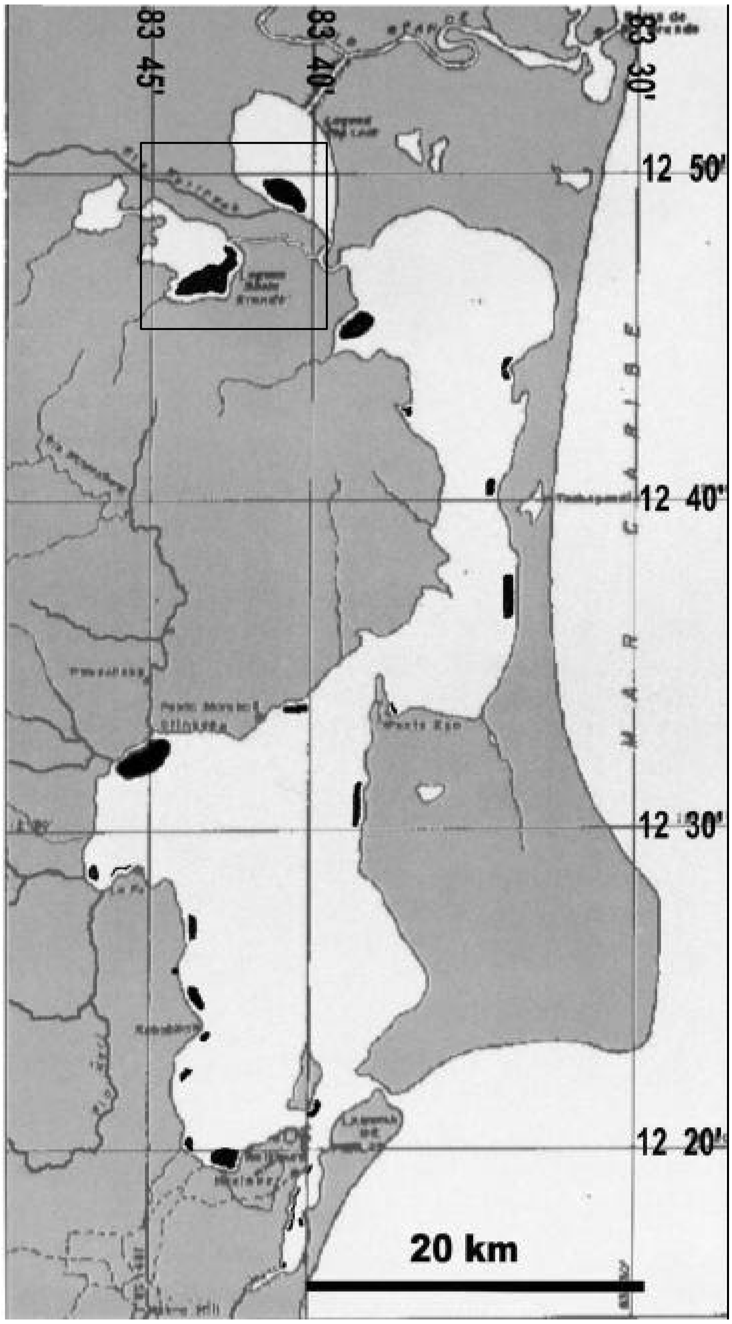

FIGURE 3.5. PRE-1978 SEAGRASS PATCH DISTRIBUTION. (A) BOX REPRESENTS LOSS DUE TO CREATION OF CANAL AND SUBSEQUENT SALINITY CHANGES. PATCH SIZE IS ESTIMATE ONLY. (MODIFIED FROM BRENES-R. & CASTILLO-V. 2001).

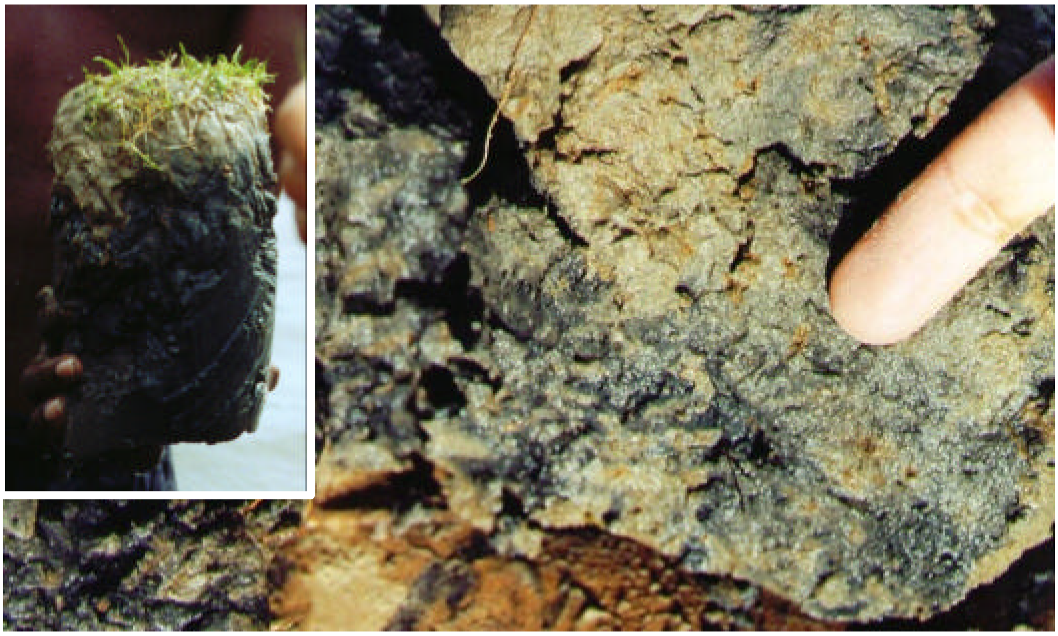

FIGURE 3.6. INSET: SEDIMENT CORE FROM BIG SHOAL, OCTOBER 2002, SHOWING DISTINCTIVE OXYGENATED LAYER IN THE TOP 4 CM OF THE CORE. NOTICE THE RHIZOMES AND ROOTS TRANSPORT OXYGEN INTO THE SOIL CREATING OXIDATIVE CONDITIONS AROUND THE ROOTS..

TABLE 3.1. THE REASONS, STATED BY INTERVIEW RESPONDENTS, THAT MAY HAVE HAD SOME INFLUENCE ON THE MOST RECENT DISAPPEARANCE OF THE SEAGRASS BEDS. REASONS ARE LISTED BY NUMBER OF RESPONDENTS THAT INDICATED A GIVEN REASON.

Reason for Disappearance	Number of respondents (ntotal = 17)
Burial	4
Physical Human Disturbance	4
Sedimentation	4
Salinity Change	3
Manatee Consumption	3
Hurricane	2
Herbicides	2
Increased Breeze	1

TABLE 3.2. DISTRIBUTION AND NUMBER OF SEDIMENT CORES AT FIELD SITES IN PEARL LAGOON, BY DECREASING LATITUDINAL VALUE. IF SHELLS WERE OBSERVED IN ANY CORES FROM A SITE A Y APPEARS IN THE TABLE. THE LAGOON IS DIVIDED INTO NORTHERN AND SOUTHERN SECTIONS, SUBTOTALS ARE IN BRACKETS NEXT TO DIVISION HEADINGS. THE INTENSIVELY CORED SECTION IS A SUBSECTION OF THE SOUTHERN PORTION.

Division	Location	Number	Shells observed
Northern (12)	Tasbapouni	2	n
	Devil's Bite	1	y
	Wawashang – mud	3	y
	Wawashang – sand	2	y
	La Fe	4	y
Southern (52)	Tuba Creek	5	y
Intensively Studied (47)	Big Shoal – far	2	n
	Big Shoal	15	y
	Lagoon Hill	1	y
	Pearl Lagoon Bite - grass	1	y
	Graveyard	4	y
	Pearl Lagoon Bite	4	y
	Bila	1	y
	Haulover North	6	y
	Sam-Right	4	y
	Point	4	y
	Inbetween	1	n
	Canal	4	y
Total	18	64	y=15, n=3

TABLE 3.3 CHI-SQUARE 2X2 CONTINGENCY TABLE USED TO DERIVE CONFIDENCE LIMITS AROUND TEK RESPONSES.

	Sediment Core	TEK	Total
Shell Presence	43	40	83
Shell Absence	3	13	16
Total	46	53	99

TABLE 3.4. SEDIMENT COARSENESS, OXIDATION, DEPTH AND SALINITY RANGE FOR ALL CORE SITES IN THE LAGOON. DEPTH AND SALINITY ARE QUANTITATIVE VARIABLES WHILE COARSENESS AND OXIDATION ARE QUALITATIVE.

Species	n	Mean ± 95% CL	range	Feb-May	Annual (DIPAL)	n	Mean ± 95% CL	range	Brown/	Black
Ruppia	18	0.7 ± 0.1	0.2 - 1.3	14-41	2-26	18	3.0±0.2	2-4	10	7
Najas	3	0.3 ± 0.2	0.3 - 0.5	5-39	2-22	3	2.3±1.3	1-3	2	0
No Grass	45	0.8 ± 0.1	0.4 - 1.5	7-26	0-26	44	3.1± 0.3	2-7	27	13
Total	66	0.8 ± 0.1	0.2 - 1.5	5-41	0-26	65	3.0±0.2	1-7	34	25

TABLE 3.5. LOCATION AND NUMBER OF SEDIMENT CORES IN SEAGRASS BEDS ACCORDING TO SPECIES OF SEAGRASS.

Location	Species	Number of Cores
Big Shoal	*Ruppia*	9
	Najas	2
Canal	*Ruppia*	1
Lagoon Hill	*Ruppia*	1
Bila	*Ruppia*	1
Tuba Creek	*Ruppia*	5
Kakabila -Mud	*Ruppia*	
Kakabila -Sand	*Ruppia*	
PL Bite	*Ruppia*	1
La Fe	*Najas*	1

CHAPTER 4
Discussion and Future Direction

4.1 Introduction

The goal of this research was to determine if seagrass coverage had declined in Pearl Lagoon, and if so, to postulate plausible mechanisms that may have led this to be. Incorporating local people into the scientific research process, and using traditional ecological knowledge were both successful in reaching this goal (Section 4.2). People of Pearl Lagoon warmly received the knowledge gained from this study – and, through infectious enthusiasm began to propose their own research questions. Most people's concern was the desire for a conclusive answer to the question "Why *is* the mananti grass disappearing?"

Decline is caused by both natural causes and anthropogenic disturbances. In Pearl Lagoon the only natural mechanism acting towards seagrass loss is disturbance by hurricanes. Substantive correlations are made between Hurricane Joan and seagrass loss (Section 4.3.1), but this is not so with more recent hurricanes (Section 4.3.2). To contrast, several anthropogenic influences were hypothesized by the people of Pearl Lagoon to have caused seagrass decline – with evidence strongly supporting some of these hypotheses (e.g., creation of a transport route in the North and South ends of the lagoon; Section 4.4.1), and less evidence found for others (e.g., sedimentation, Section 4.4.2; eutrophication, Section 4.4.3; and chemical poisoning, Section 4.4.4).

The true extent of peoples' ownership of this new knowledge is shown in their desire to continue the research and to begin restoration programs. Restoration of seagrass beds in Pearl Lagoon (Section 4.5) to their former coverage may hopefully be accomplished one day. I conclude this chapter showing how the new knowledge was presented to the people of Pearl Lagoon (Section 4.6): final conclusions are then made (Section 4.7).

4.2 Success of using Traditional Ecological Knowledge

Research in the lagoon was carried out at two different scales – first, the intensively studied zone was sampled at high resolution which generated consistent results with little variation. Second, the lower resolution scale, carried out for the entire lagoon that generated highly variable responses. The implication is that if time permits the ideal analysis should occur at high resolution for the entire lagoon. However, logistics are likely to prevent this from happening.

Interestingly the traditional ecological knowledge provided higher quality information (i.e., higher congruency) in areas closer to residential communities than further away. TEK was, however, used successfully in this research to increase the scale of observation to that of the lagoon as a whole thus minimizing the need for time consuming core sampling procedures. Senseless searching along the shorelines was avoided as volunteers knew the location of the nearest grass patches to their communities – however most respondents were not aware that these patches no longer existed. Absence of patches was observed by 'Group 1 - Expert' respondents whose knowledge was highly correlated with core samples. Such high correlations between the 'expert' responses and the core samples may occur because expert respondents generally have a vested interest in the resource under investigation as, for example, Inuit hunters and belugas (Mymrin 1998), Inuit hunters and caribou (Ferguson & Messier 1996) and Cree hunters and caribou (Berkes 1999). In Pearl Lagoon manatees feed in seagrass meadows and, subsequently, are hunted in this area. Most seagrass 'Experts' (75%) are manatee hunters [3]. One manatee hunter reported that he periodically checked for seagrass in the patch outside his community – to see if the seagrass is recovering. 'Expert' respondents thus contributed to higher

[3] TWO OF THE SIX 'EXPERT' RESPONDENTS WERE ECOLOGISTS FROM PEARL LAGOON, NOW LIVING IN BLUEFIELDS. OF THE FOUR ONSITE 'SEAGRASS EXPERTS', THREE WERE MANATEE HUNTERS. THE FOURTH SEAGRASS EXPERT WAS A MASTER FISHER DOING RESEARCH ON BLUE CRAB (*CALLINECTES SAPIDUS*) ABUNDANCE IN THE LAGOON. THESE CRABS FOUND IN SHALLOW WATERS ALONG THE SHORE AND COMMONLY INHABIT SEAGRASS PATCHES (EGGLETON ET AL. 1998, HOVEL ET AL. 2002).

accuracy of TEK responses (Calheiros et al. 2000). Another method that produced accurate and highly detailed information was the participation of community members in field work and as research assistants. Collaborative fieldwork has been found (Huntington 2000) to be one of the most effective information gathering methods.

4.3 Natural causes of seagrass decline

The only natural mechanism proposed to cause seagrass decline was the impact of hurricanes. In the last 30 years Pearl Lagoon felt the impact of hurricanes at least three times. In people's memories Hurricane Joan (1988) was distinctively followed by seagrass loss in the lower southwestern area of the lagoon. The connection to hurricanes Cesar (1996) and Mitch (1998) is much more tenuous (see below).

4.3.1 Hurricane Joan (1988)

Impossible to miss, Hurricane Joan reached a maximum windspeed of 230 km/h (Unisys 2001). Entire forests were leveled by the hurricane (Urquhart 1997). The seagrass beds at Kakabila and Tuba Creek were completely destroyed (Kakabila CAMP-Lab committee). The Sam-Right patch that ran from Haulover south towards the Canal also disappeared with the hurricane. An expert respondent stated that the last time he definitively remembered seagrass in this area was in 1983. However, regrowth of patches at Tuba Creek and Kakabila was noticed approximately five years after Hurricane Joan had passed. Evidence from the literature details hurricane-induced seagrass destruction and supports the quick return of patches (Pulich Jr. & White 1991, Kalbfleisch & Jones 1998, Valiela et al. 1998). Sediment cores showing an absence of periwinkle/seagrass associations from Tuba Creek and Kakabila areas may correlate with the five year seagrass absence and subsequent return of the seagrasses to an early successional stage.

Although hurricane Joan temporarily destroyed numerous seagrass beds in the lagoon's southern zone it's impact was not observed as severe in the northern zone (except Nickerson and White (1996) documented fish kills in the area of Orinoco). At issue is the observation that most seagrass loss in the northern zone occurred years *after* hurricane Joan past.

4.3.2 Hurricane Cesar (1996) and Hurricane Mitch (1998)

In the last 10 years the northern zone experienced two hurricanes – Cesar in 1996, and Mitch in 1998. Cesar, a minor hurricane reached a maximum windspeed of 129 km/h. Cesar passed through Pearl Lagoon causing slight flooding and damage in the northern region of the lagoon (Unisys 2001). In 1998 a major hurricane, Mitch, wrought disaster as it barreled through Honduras (Harborne et al. 2001). For three days Mitch raged as a force 5 hurricane with windspeeds as high 285 km/h. Mitch caused significant environmental impact. Although Pearl Lagoon did not experience the wind damage it did nonetheless receive extreme flooding carrying debris and mud from nearby swamps. The presence of wood chips in some sediment cores was theorized to be remnants of this debris field. Physical damage and subsequent recovery of hurricane-affected seagrass was observed, as expected (Patriquin 1975, Boucher 1990, Williams 1990, Duarte et al. 1997, Urquhart 1997). Provided with TEK estimates of seagrass disappearance from 4-16 years, and that the last hurricane was in 1998 (thus suggesting recovery should well have proceeded by now) it seems unlikely that any of the three hurricanes was responsible for the permanent loss of seagrasses as experienced today.

4.4 Anthropogenic influences in Pearl Lagoon

As a discrete event the building of canals in 1978-79 correlated with the first remembered seagrass losses in Pearl Lagoon. There is abundant circumstantial evidence relating this multi-faceted point disturbance to claimed seagrass losses. More recently however, three chronic anthropogenic disturbances - sedimentation, eutrophication and chemical poisoning - have been hypothesized to be primarily responsible. These mechanisms are discussed in detail below.

4.4.1 Digging and Dredging

The 1978-79 construction of a transport route through Pearl Lagoon influenced seagrass beds via burial, substrate, and salinity changes. The building of two canals – Moncada Canal in the south connecting Pearl Lagoon to the Rio Escondido, and Top Lock Canal in the north connecting Top Lock Lagoon to the Rio Grande de Matagalpa – and dredging a channel connecting the canals constituted a major physical disturbance. In the southern zone construction dredges deposited massive amounts of sand and mud on seagrass beds burying them indefinitely. New cays were readily observable following dredging. Respondents say that seagrass meadows were either buried or completely removed during the dredging process. Two studies (Larkum & West 1990, Onuf 1994) document seagrass loss due to dredging.

One expert group member suggested that a large patch of grass by the mouth of the Kurinwas river disappeared the year following the construction of the canal. The loss of this patch and the patch in Sunie Lagoon were not due to burial, but instead to changes in salinity made by connecting the previously isolated northern reaches of the lagoon directly to the Caribbean Sea. Historically, salinity must have been below 6 ‰ because the water hyacinth (*Eichornia crassipes*) cannot survive salinities above this and it similarly disappeared from Top Lock and Sunie Lagoons immediately following the construction of the canal (Dumailo 2001). Because of its low salinity preference this patch is likely to have been dominated by *Najas guadalupensis*. Quammen and Onuf (1993) document seagrass loss and changes in patch composition following salinity change.

4.4.2 Sedimentation

Sedimentation is responsible for the loss of seagrass in a number of different locales globally (Giesen et al. 1990, Larkum & West 1990, Onuf 1994, Olesen 1996, Kendrick et al. 2002). Sedimentation is frequently associated with dredging, and/or terrestrial erosion. Both contribute to increased turbidity – and ultimate change of benthic substrate type (Larkum & West 1990, Kendrick et al. 2002). Turbidity and substrate change are problems that occur in Pearl Lagoon. Evidence from direct visual census shows that *Ruppia maritima* patches at shallow depths (<20 cm) were actively reproducing in February while at greater depths seagrass was either not present or still in vegetative states. One expert stated that in some locations seagrass used to be present "green and good" all year. The first piece of evidence implies that more light allows earlier development of plants, while the second demonstrates that today's cyclic abundance of seagrass does not necessarily reflect original processes. Thus it appears there has been a shallowing of seagrass maximum depth possibly due to increased suspended inorganic sediment.

Seagrass beds are normally found on a sand/mud substrate, with sand being the main component. *Najas* appears to be able to colonize fine, sticky sediments (i.e. clay) that *Ruppia* cannot (Kantrud 1991). However, neither seemed capable of growing on a pure mud substrate[4]. Muddy substrate whereby a person sinks 50 cm was found at one historical site. Only two of the historical sites (from a sample size of n=7) currently maintain an appropriate sandy substrate on which seagrass may potentially grow. These observations suggest that the nature of sedimentation has changed in recent times. Finer clay particles are likely more prevalent today than they were in the past. Two lines of supporting evidence are suggested: (a) the accumulation of sediment at the mouths of the Top Lock Canal and Kurinwas Rivers (Fig. 4.1) is a recently new phenomenon, and (b) oyster reefs within Pearl Lagoon have effectively died. The decline of oyster reefs was previously correlated with sedimentation (Kirby 1994). Evidence for sedimentation abounds, yet conclusive evidence that the rate of sedimentation has increased is lacking.

One of two research efforts is required to determine whether indeed sedimentation rates are increasing. The first, to continue with the tradition of community participation, is to produce a photographic record of deforestation. Deforestation is directly correlated to increased sedimentation rates (Hodgson 1997). Thus, temporally sequenced satellite photos showing clear

[4] ONE SMALL PATCH OF GRASS AT KAKABILA WAS BEGINNING TO GROW ON MUD IN FEBRUARY. HOWEVER, TWO MONTHS LATER THIS PATCH HAD COMPLETELY DISAPPEARED.

cut areas of this region would permit an indirect estimate of when sedimentation rates may have started to increase (Mas & Puig 2001). Such satellite photos *do,* in fact, exist and I have attempted to acquire them for a number of months. A second research effort is to date sediment cores via pollen analysis (Brush & Hilgartner 2000), diatom analysis (Parsons 1998), radioactive lead dating (Verschuren et al. 2000) or carbon-nitrogen isotope analysis (Heikoop et al. 2000). The first two require detailed knowledge of historical environmental conditions and thus are probably not suitable. Both radioactive lead dating and carbon-nitrogen isotope analysis are capable of determining the origin and timing of sediment deposits.

4.4.3 Eutrophication

Eutrophication due to increasing coastal population sizes is the most pervasive culprit suspected to cause seagrass decline on a global scale (Giesen et al. 1990, Olesen 1996, Short & Wyllie-Echeverria 1996, Brush & Hilgartner 2000, Cerco & Moore 2001, Kendrick et al. 2002). The increasing population in the Pearl Lagoon watershed is similarly suspect to cause eutrophication within Pearl Lagoon proper (Kennish 2002). High nutrient levels caused by either organic sewage or fertilizer runoff trigger phytoplankton blooms which mask seagrasses of photosynthetic light – subsequently causing anoxic conditions when the blooms settle and decompose (Frankovich & Fourqurean 1997, Gacia et al. 1999, McGlathery 2001). However, dry season nitrate measurement at river mouths and in the vicinity of communities failed to register nitrate levels above 2.5 ppm. To complicate matters further grass patches were not distributed in a manner compatible to test for correlation between epiphyte load and proximity to rivers or villages. Thus key insights as to whether increased nutrient levels are occurring, or whether such levels exist along a spatial gradient from point sources was unattainable. Interestingly, it remains unknown whether the increased turbidity that is found during the rainy season is caused primarily due to phytoplankton blooms or to sediment load. The colour of seasonal 'flood' waters is commonly stated, by respondents, to be "red" – suggesting that turbidity is mainly due to inorganic sediment – not excessive nutrients.

One line of evidence suggesting that increased nutrients may indeed be present is the presence of a new macroalga. The filamentous green alga dubbed "mudgrass" was always found growing on at least 5cm of mud substrate. The mudgrass was observed in seven historical seagrass patches (out of a possible 19). At Big Shoal the mudgrass was growing in vast mats where it has almost successfully excluded *Ruppia*. The presence of the algae would not be significant if it were not for a key observation made by one expert respondent. Specifically, the expert respondent thought that the "mudgrass" presence was new for he had no recollection of mudgrass presence prior to 1997. Key research to discern whether the mudgrass presence is a response to increased nutrients, or whether it is an introduced species will help resolve the eutrophication issue.

4.4.4 Chemical Poisoning

Potential effects of chemical poisons were not measured in this research. Herbicides intended for terrestrial weeds can be leached from farmlands in the same way that nutrients and sediment are (Kennish 2002). Herbicides may be particularly harmful to aquatic plants that often absorb nutrients through their leaves (Hemminga & Duarte 2000, Dierberg et al. 2002). Two respondents mentioned that agro-chemicals might be carried by rivers and have an effect on seagrass beds. There is no specific observed evidence from TEK, sediment coring, or visual census to support this hypothesis. However, herbicides have been known to cause seagrass decline in other aquatic ecosystems (Short & Wyllie-Echeverria 1996, Bester 2000). By contrast, some aquatic macrophytes are known to be quite resistant to herbicides (Sculthorpe 1967). *R. maritima*, for example, is found growing in irrigation drainwater ponds with a large variety of herbicides concentrations (Kantrud 1991). Today, many herbicides are organic and breakdown within short half-lives (Skogerboe & Getsinger 2001). Thus it is unlikely that the herbicide concentrations in agricultural run-off entering Pearl Lagoon are high enough to cause seagrass death. Direct testing for herbicide concentrations in sediments, plant tissues, and the water column would help understand this phenomenon better.

4.5 Restoration

The recent loss of economically important seagrass beds from Pearl Lagoon is likely due to the compound effect of changes in salinity as a function of building the canal system, increased turbidity levels, and frequent hurricanes. The change in salinity levels and reduced light penetration are likely to have significantly weakened seagrass beds. The subsequent destruction from hurricane Mitch destroyed most remaining patches. Since hurricane Mitch the assumed increasing sediment load has made much previous habitat unsuitable for seagrass growth thus impeding successful recolonization.

The communities' desire to initiate restoration efforts is commendable, however, it should proceed with caution. My recommendation is that restoration of seagrass should be started on a small scale in locations where the substrate is still suitable, on the chance that seagrass can recolonize some areas. Further research is necessary (as outlined above) to confirm the primary cause of current seagrass loss. Without such research, large scale restoration efforts may be doomed to failure.

4.6 Reflections

This project cannot be truly understood outside the context in which it developed. The integral involvement of CAMP-Lab staff and members, and local research assistants resulted in the development of the question: Why are seagrass beds disappearing? This research was, in many ways, participatory:

- Community members were involved in the origin of the question.
- All research activities included local people.
- Insight and synthesis of information was assisted by local viewpoints.
- During CAMP-Lab committee meetings I was continuously asked with curiosity what I had discovered.

Thus in a very real way this research belongs to the people of the Pearl Lagoon communities. It became essential, therefore, that the product of this research be returned to the people in a form they could appreciate and understand. Dried and pressed specimens of both *Najas guadalupensis* and *Ruppia maritima* with herbarium labels were left with CAMP-Lab for students and future researchers. During my field season an hour long radio show on "Mananti grass" was broadcast on the CAMP-Lab radio program. This involved a live interview with me and the broadcasting of some of the recorded interviews I did with local people. The goal was to inform people about seagrass in the lagoon and about my research and early results. In addition an article (Appendix B) was written for the CAMP-Lab newsletter Awake. Awake is a popular communications newsletter written in the Creole language and distributed in all communities throughout the lagoon. This article was a summary of the results of the research and list of possible actions that could be taken by CAMP-Lab committees in regards to seagrass beds near their communities.

4.7 Conclusion

The range of knowledge and level of understanding obtained about seagrasses in Pearl Lagoon would have been impossible using any one method alone. The combination of sediment coring, visual census, and indigenous knowledge provided a past and present model of seagrass dynamics that is unique in caliber. In information poor, inhabited areas no ecological study can really be complete without the incorporation of indigenous, or local, knowledge.

That seagrass has been disappearing in Pearl Lagoon is without doubt. It remains to be seen if this trend will continue. The loss of seagrass patches I suspect is mostly in response to hurricane disturbances coupled with point (dredging) and non-point source (sedimentation) anthropogenic changes. While the grass might have been able to recover from each of these disturbances individually, the cumulative effect may be fatal. While grass is returning to some areas in Pearl Lagoon my prediction is that seagrass beds will continue to disappear. If increasing population trends and the eastward movement of the agricultural frontier are not slowed, the rate of seagrass loss is likely to increase as the stresses caused by increasing turbidity and eutrophication are realized to their full extent.

FIGURE 4.1 LANDSAT IMAGE OF PEARL LAGOON FROM NOVEMBER 5, 1999. NOTE SEDIMENT BUILDUP BY TOP LOCK CANAL AND THE KURINWAS RIVER (SOLID BOX). BLACK AREAS (DASHED BOXES) ARE BELIEVED TO BE NEW MUD/SILTSUBSTRATE (DASHED BOXES) DUE TO SEDIMENTATION.

APPENDIX A

Framework for Interview Questions

General Questions
1) I am interested to know more about the grass that grow in the lagoon, would you talk on the grass for me?

On the presence/absence of grass
Do you remember a time when the grass was different from now?
How many classes of grass do you know of in the lagoon?
Have you noticed that the grass is more or less grass now? Where?
When did you notice a loss?

On animals associated with seagrass beds
Do cockles only live where there is grass?
How do you call this animal? Does this animal, the "perenka" live only in the grass?

On logging and clearing upstream
Does the flood always come at the same time? Does it always last for the same amount of time?
Is there a time when it used to be different (less/more darker, last longer, less time?)
How far the nearest river?
Plenty people live up the river?
What they do up there?
Any companies that make logging up there?
When they come?
How long they stay?
How much they take out (number, species)?

On agriculture, use of fertilizers and herbicides
Where do your village farm?
Plenty farms? About how many manzanas?
These people use fertilizers, that make the plants grow good?
Do people use poisons, that kill bad plants?
How they use it, spray it?

APPENDIX B
Article for CAMP-Lab Awake Newsletter

What is Happening to the Mananti grass?: Past, Present and Future.
Monica Schuegraf

This is not really written only by me, but by all of CAMP-Lab around the entire lagoon. I would like to say a special thank you to all the CAMP-Lab committees who made me feel welcome, helped me looking grass, and sharing information. I also want to thank all the people who made interviews with me. I could never have written this without everybody's help. And especially like to thank those who came out with me looking grass again and again.

Mananti grass is the name most often given to the grass that grows in the lagoon. This grass is very important because plenty different animals live in it and use it, like: mananti, shrimps, fish, crabs and ducks. The mananti is a big animal that eats this grass. People used to kill mananti when they were feeding in the grass patches. The grass is used mostly by young shrimps and young fish when they growing up to hide from bigger fish that want to eat them, they also use the mangrove foots for this. Also ducks would come feed at grass patches. But mananti grass also does other things, when the grass is floating on the surface it makes the water keep calm, calm. Because the water is moving so slowly plenty pieces of small dirt drop out of the water onto the bottom in grass patches. These fields of grass then, help clean the water after storms or a stiff breeze. On land, trees produce oxygen that people and animals need to breathe, in the water mananti grass is one of the few plants that put oxygen in the water for fish and shrimp to breathe. Mananti grass is very important to the mananti, the fish and the shrimps so it is important to us too.

Mananti grass is what we call all the grass that grows inside the lagoon, but there are actually two class (what scientists call '*species*') of grass that grow in the lagoon. Both class of grass live where the ground is a little tough, usually in a mixture of sand and mud. One class favor the grass in picture 1 and its *species* name is *Najas guadalupensis*. This *species* doesn't like the water when it gets very salt and when the water gets too salt for it, it dies. It is not common. This second class of grass favors that in picture 2 and its *species* name is *Ruppia maritima.* This grass can live when the water gets very very salt or when the water is fresh. *Ruppia* is the grass that is most common and is found in most places where there is grass in the lagoon. This one can grow very tall, 4 or 5 feet high and also floats on top of the water. In most of the lagoon, mananti grass begins to grow in January and floats on top of the water any time from early April to May. Just after the grass floats new small grass plants begin come up. These plants probably do not get to grow too big as when the rains and the flood comes around July the grass dies. It digs up and drifts all over the lagoon. In January the grass starts to grow again. In places where the water is very shallow, like by Awas and the graveyard in front of Pearl Lagoon the grass may be there all year. It is definitely there from October until June

There used to be plenty grass growing everywhere in Pearl Lagoon. grass patches used to be found in places like, by the mouth of the Kurinwas River, in Top Lock Lagoon, in Sunie Lagoon, near the creek by Tasbapouni, in Devil's Bite, from the mouth of the Wawashang going right to Square Point, in front of Pine Ridge and below La Fé. Also above Brown Bank and below Brown Bank going to Kakabila, in front of Kakabila, by Tuba Creek mouth, Awas what they call Big Shoal, the south-east side of Hog Cay, in front of Haulover down to the Canal and across the other side to the Point. Now hardly any of these places have grass growing again. From Awas come round to Kakabila, in that bite has plenty grass, and from Kakabila go up to Brown Bank has a big patch too. Only by La Fé and in Awas we found a small patch of the *Najas* class of grass. All the other patches are only the *Ruppia* class of mananti grass. There are also small patches of grass in front of Lagoon Hill, Bila Point and by the Canal.

We know that there is very little grass left in Pearl Lagoon. We also know there are many reasons the grass has died. The grass that grew by the mouth of the Kurinwas is said to have died the year after the canal to the Rio Grande was complete. It is believed that this is because the water got too salt for the grass. The time when the grass disappears seems to be hard to find, I have received many different answers to this question ranging from 15 to 4, to even 1. And even, people keep saying that where there is grass, it is not as thick as it used to be. This might mean the grass has been disappearing slowly, becoming less and less each year until none is left. There are many possible reasons that might have caused the grass to disappear. A very important one of these is the hurricanes, Joann (1988), Cesar (1996) and Mitch (1998) that affected us in the last 15 years. The hurricanes may have dug up the roots of the grasses. And in fact, the CAMP-Lab committee in Kakabila says the grass disappeared for 5 or 6 years after Hurricane Joann, and then began to come back slowly, and mananti grass is present there now.

There are other possible reasons for the grass to have died, but these reasons are not easy to see, like hurricanes. One reason, particularly for the Wawashang area is that the rivers may be carrying runoff from farms up the rivers like, Patch, Nari and the Wawashang. This water might be carrying chemics like herbicides and insecticides that can poison and kill the grass. When we farm we must keep not using these sorts of chemics. Also the deforestation, both by logging companies and from all new farms and portreros causes soil and mud to go into the water. This dirt gets carried into the lagoon and may stop the sunlight from reaching to the bottom, and grass needs light to grow. It is also possible that grass is getting dug up from too many waves from all the pangas we have now, or that more people going dory are hauling out the grass in their nets. Maybe having too much nutrients in the lagoon is also causing the grass to die. By using toilets we stop too muc h nutrients from going in the lagoon. One last idea is that there might be a different kind of grass that is taking the places where the grass used to grow. I don’t know if this morass that grows on the mud, that almost looks like grass has always grown in this lagoon, or if it is new?

In most places the grass is dying, but in some areas of the lagoon, it may be coming back. It is important that the communities know what is happening to the grass in the lagoon. Because shrimp and fishing success depend a little bit on the existence of the grass patches. The CAMP -Lab committees or any interested people should try and monitor the places where grass used to grow throughout each year and write down if mananti grass is there or not. The best times to look for the grass are mid-February, when the grass is just beginning to grow, mid-April, when it should be floating, mid-June when it should be beginning to dig up and August, there should be none and October or November to see if it is beginning then when the water begins to come clear. This could be done when people go dory, or could be an activity planned by CAMP-Lab.

If the grass continues to die, or does not come back to more places in the lagoon we might lose all the grass. It is very important to protect the areas where the grass is growing. This could be done by making the grass patches into protected areas, like reserves. This would mean maybe people couldn’t fish there. But this protected area would be a place where fish and shrimp would always be able to grow up, and when they got big, leave and move into the rest of the lagoon. This way there would *always* be a place that could have new shrimps and fish coming from. Also the mananti grass would live there and make seeds and these seeds could be used to make grass grow back in other areas. It is very important to make sure that we still have patches of grass for our children to know and so they have a good future.

Note: Picture 1 is equivalent to Figure 3.2, and Picture 2 is equivalent to Figure 3.1.

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