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Assessing the Impact of Urban Sprawl on *Rhizophora mangle* in Puerto Rico:

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6 May 1999

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Abstract

This study examined the affects of urban sprawl on the mangrove ecosystems of Puerto Rico. Data on urban sprawl, water quality, mangrove leaves, and mangrove distribution were analyzed statistically and with GIS software. The data indicated a correlation between urban sprawl and increased water pollution levels. Increased hydrocarbons were found to harm mangrove tree health. Urban expansion greatly reduced mangrove tree distribution until the 1970's. Since, mangrove trees have crept into protected and undeveloped areas and their distribution has increased.

Table of Contents

List of Tables

List of Figures

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This report is the product of an education program, and is intended to serve as a partial documentation for the evaluation of academic achievement. The report should not be construed by the reader as a working document.

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Executive Summary

This project, prepared for the National Sea Grant Program in conjunction with the University of Puerto Rico at Rio Piedras, is an evaluation of the effects of urban sprawl on coastal wetlands in Puerto Rico. The focus of this study is on the mangrove ecosystems found in the Laguna San Jose in San Juan, Isla Magueyes in La Parguera, and Bahia Jobos in Central Aguirre. We found pollution in the Laguna San Jose and Isla Magueyes, then identified correlations between water quality and mangrove health. We also looked at historic trends in the water quality of Laguna San Jose and found high fecal coliform and ammonia levels. Further, we analyzed mangrove distribution around the lagoon and found mangrove distribution has recently increased.

Traditionally, mangrove trees have been unpopular. Scientist paid little attention to them until the early 1970s. Around this time, biologists began to realize the importance of these unique species: they are a highly productive ecosystem, they trap and use excess nutrients, they provide homes for diverse groups of fish, amphibians, lizards, and birds, and they protect against erosion.

There are extensive federal and Puerto Rican laws which regulate the direct discharge of pollutants into the commonwealth's waters, but these laws are not fully effective in preserving water quality due to non-compliance and unregulated non-point source pollution. Laws have also been enacted which make it illegal for an individual to cut down mangroves, but these laws do not apply to mangrove clearing for development. Through this direct assault, urban

development continues to be a major threat to mangrove distribution in the San Juan Metropolitan Area.

We analyzed the effects of urban sprawl on mangrove ecosystems by looking at the components of the ecosystem separately and as a whole. Land-use maps and literature on historical land uses revealed minor changes in development around the Laguna San Jose. The watershed around the lagoon is almost entirely urbanized with a ring of mangroves around the lagoon. An analysis of aerial photographs, land use maps, and inventories on mangrove distribution showed mangroves declined from the 1930s until the 1970s. However, since the 1970s the distribution of mangroves has increased.

We compared water quality in the Laguna San Jose from 1974 to 1997. We compared this data to parameters for water quality in a healthy mangrove forest and to average levels of nutrients in a mangrove. The data indicates that nutrient levels and pH are close to average, ammonia levels are slightly high, and fecal coliform levels are extremely high. We suggested that the fecal coliform levels needed to be lowered, and that the high ammonia levels should be further investigated. We also measured the water in the Laguna San Jose, Isla Magueyes, and Bahía de Jobos. Low levels of dissolved oxygen correlated with development around the Laguna San Jose, and low levels of dissolved oxygen varied with oil contamination at Isla Magueyes.

Chapter 1: Introduction

Urban development has put an increasing strain on wetlands in the San Juan metropolitan area. This study evaluates how these pressures have affected the valuable coastal ecosystems. The project focuses on the mangrove forest ecosystems along the Caño Martin Peña, Laguna San José, and Suarez Canal. It includes a review of historical water quality data in the lagoon, evaluation of urban sprawl in San Juan, and analysis of field data.

The project was commissioned and funded by the Sea Grant Program at the University of Puerto Rico at Mayaguez. The project team worked closely with Dr. Angel David Cruz and Dr. Maritza Barreto of the Department of Geography at the University of Puerto Rico at Río Piedras.

Our results will be useful to a variety of organizations and researchers. Sea Grant will be able to incorporate this study into its libraries containing information concerning the quality of coastal resources in Puerto Rico. Academic researchers will be able to access Sea Grant's databases and have access to our data. Government agencies such as the United States Geological Survey and the San Juan Bay Estuary Program will be able to incorporate our findings into their research. It is essential that our results and recommendations also be made available to local lawmakers concerned with water resource management, as policy changes may be necessary to ensure the health of Puerto Rico's coastal ecosystems.

We applied a variety of research methods to collect data on urban sprawl and ecosystem health. An important part of our task was confirming that urban growth was taking place. We examined recent and archived land use maps, aerial photographs, and census information to ascertain this impression. We also analyzed the health of the mangrove trees and the water quality in our areas of study. An assessment of the *Rhizophora mangle* health was accomplished by sampling and examining their leaves. The evaluation of water quality included a review of historical data recorded by USGS since 1974 as well as an analysis of water quality in samples we collected. To further evaluate the effects of urban development, we compared data from our test site in San Juan to mangrove forests in La Parguera and Central Aguirre. La Parguera and Central Aguirre, which are located on Puerto Rico's southern coast, are less impacted by development.

This study is an Interactive Qualifying Project (IQP), a graduation requirement instituted at Worcester Polytechnic Institute in 1972. The IQP was designed to make graduates aware of the social impact of their technical careers. The aim of each project is to investigate a technological area or issue and its effects on a societal structure or institution. Urban sprawl is the direct result of human development, and it has been shown to have detrimental effects on surrounding ecosystems, particularly wetlands. Coastal wetlands are of tremendous value to society, and therefore their destruction is a degradation of the common good. Social pressures are the essential factor preventing change in environmental policy. Therefore, we are examining how the urban social mechanism depletes its own valuable resources by investigating how development affects the coastal wetlands in San Juan.

Chapter 2: Literature Review

This project contains a review of literature on wetland ecosystems and urban sprawl. It presents theories and evidence on the effects of sprawl on mangroves and the social forces that drive this interaction. Laws concerning water pollution and their effectiveness are reviewed. The literature review also focuses on water quality research, which is an important component of our fieldwork. The review explains the Global Positioning System and Geographic Information Systems and their applications. It then deals with specific maps and mapping.

2.1 Wetlands

There is no single accepted definition for wetlands among politicians, environmental managers, or even ecologists. This ambiguity stems partly from the fact that most wetland definitions are written to fit an agenda and partly because wetlands themselves can be highly variable (Dennison & Berry, 1993). However, one commonly referenced definition, the one used by the United States Environmental Protection Agency (EPA), appears under Section 404 of the Clean Water Act (33 CFR Section 323.2, and 40 CFR Section 230.3):

> The term 'wetlands' means those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions.

To be officially classified as a wetland, therefore, a particular area must meet at least three requirements: it must have surface water or saturation near the surface at least part of the year, it must support wetland plants, and at least periodically it must have oxygen poor soil resulting from inundation with water (Dennison & Berry, 1993; Kent, 1994).

We were specifically concerned with mangroves, a type of coastal wetlands. Coastal wetlands fit the same definition as other wetlands but have the added condition of being adjacent to the ocean and have some level of salinity (Kent, 1994).

2.1.1 Functions of Wetlands

There are many types of wetlands, all with unique characteristics, but all coastal wetlands, particularly mangrove forests, serve similar natural functions. Some of these functions include mediation of flooding, groundwater replacement, sediment entrapment, and decontamination of toxic chemicals (Kent, 1994). Wetlands are efficient at removing excess nutrients (Bramwell & Prasad, 1995), and preventing eutrophication of other clean water resources. Eutrophication of aquatic systems is caused by a dramatic increase in the level of macronutrients nitrogen, potassium, and phosphorus, and is characterized by algal blooms that render the water inhospitable to fish, animal, and human use. Wetlands were tested in Louisiana for use as natural wastewater treatment utilities at a savings of $785 to $34,700 per acre used over conventional wastewater treatments (Breaux et al, 1995).

Wetlands also have significant ecological importance. They have an extremely high primary productivity in that large amounts of energy are converted into plant mass for the support of various consumers in the food chain. They not only provide energy for their own food chain, but energy in the form of plant mass can leave the system through migratory grazers like birds and insects or by flowing out with water currents as organic debris known as detritus (Kent, 1994).

2.1.2 Mangroves

The term mangrove has two meanings. Mangroves can refer specifically to mangrove trees, a tree that is adapted to aquatic environments. It can also refer to clusters of mangrove tress and the complex plant and animal communities that form within the mangrove clusters. This meaning is synonymous with tidal forest (Lugo and Snedakar, 1974).

Mangrove trees belong to eight different families and twelve genera. All of these species spend some time partially submerged in water. The most common mangrove species in Puerto Rico are the *Avicennia germinans* (Black mangrove), the *Conocarpus erectus* (Buttonwood), the *Laguncularia mangle* (White mangrove), and the species we studied, *Rhizophora mangle* (Red mangrove) (Lugo and Snedaker, 1974). The common names may vary from nation to nation. The common names above are used in the United States and their Spanish translations are used in Puerto Rico.

Mangrove forests are complex ecosystems that can be extremely sensitive to pressure from development (Lugo and Snedakar, 1974). Mangrove trees are adapted to life in a shallow aquatic environments (Wolanski et al, 1997) making them particularly susceptible to water pollution.

Mangroves often grow in dense forests. They can be found commonly in tropical estuaries and tropical marine flood plains. They thrive along protected shallow shorelines with lots of sediment, no frost, and active currents that circulate the water. Mangroves dominate the shoreline in Puerto Rico, covering 60 to 70 percent of the shoreline in tropical climates (Cintron, 1979). They grow best around 23 degrees north and south of the equator in areas protected from high waves, but can flourish anywhere in the tropics (Lugo and Snedakar, 1974).

2.1.3 Ecology, Man, and Mangrove

Mangroves have always provoked curiosity. The first written account of a mangrove forest in western literature comes from the Chronicle of Nearchus, written about ancient Greek mariners around 320 b.c. They were intrigued by many of the same characteristics which arouse interest today, such as mangroves adaptation to a saline environment, their above ground roots, and their neumatophores, the root like structures that project out of the water to aid in respiration (Lugo and Snedaker, 1974).

Historically, human interest in mangroves has not translated into an affinity for them. In 1667, the French explorer Du Terte warned his fellow travelers of "wild boars and other savage beasts... who lie and wait to surprise men [in mangroves]". Mangrove popularity had not improved by 1951 when a Florida newspaper blamed a "mangrove root gas" for the death of two men. Even within the scientific community, mangroves once had few fans. J.H. Davis, a mangrove expert in the 1930s and 40s, referred to mangrove trees as "freaks," and W.E. Odum of the University of Miami called the mangrove forest "a form of wasteland" in 1969. Mangroves form dark swamps, which can take on an ominous feel. They are often too dense and wet for people to walk through. These factors help to explain people's historic apathy or even contempt for them (Lugo and Snedaker, 1974).

The Puerto Rican opinion of mangrove forest is perhaps no exception. Many San Juan residents feel that the trees are an unsightly nuisance. The route of the *Acuaexpreso*, a boat that is used for public transportation in San Juan, passes through mangrove forests, and the mangroves are blamed for some of the unpopularity of this form of public transportation (Dr. Angel David Cruz, personal communication). Mangrove forests often have to compete with developers. With shorefront land being so valuable, the mangroves are often sacrificed for development (Lugo and Snedaker, 1974).

Recently, scientists and environmentalists have discovered the value of mangrove forests. Mangroves are unique ecosystems, which provide people with an important resource. They produce enough organic material to feed neighboring communities. Mangroves provide safe habitats for fish and juvenile crustaceans. They are home to a large and diverse group of amphibians, reptiles, invertebrates, and microorganisms. They also combat wave erosion, and process excess nutrients. For these reasons, mangroves must be protected.

Mangroves are extremely productive ecosystems. They feed neighboring ecosystems such as off shore coral reefs and beaches while creating enough organic materials to sustain their own ecosystems. The biomass levels in mangrove forests are high (Wolanski, 1997). Biomass estimations for mangroves in Puerto Rico in dry weight per hectare are 7,780 kg in leaves, 12,740 kg in stems and branches, 27,960 kg in wood, 14,370 kg in prop root, and 49, 970 kg in subsurface roots. The total above ground biomass is 62,850 kg dry weight per hectare (Lugo and Snedakar, 1974). Mangrove forests are the breadbaskets of the tropical wetland, and if they are harmed the wetlands and local ocean ecosystems could starve.

Mangrove forests produce nutrients for the microorganisms within the mangrove forest and in surrounding bays, coral reefs, and in deeper off shore waters. At the lowest end of the food chain, fungi decompose fallen mangrove trees, leaves, and branches (Gordon, 1993). The biomass that was once in the trees fuels populations of microscopic decomposers. Mangroves produce high amounts of organic materials for these decomposers. In La Paguera, Puerto Rico, mangroves add 8.2 m^3 day in organic materials to the ecosystem (Lugo and Snedaker, 1979). The dinoflagulates, which produce the light show in La Paguera's bioluminescent bay, depend on the nutrients and vitamin B_{12} produced by the mangroves (Dr. Maritza Barreto, personal communication).

Mangrove forests control the physical structure of the ecosystem. The trees change existing ocean currents. Within the forests, the trees divert the water in complex mazes of eddies, jets, and stagnated zones. These currents control the distribution of the pollutants as well as organic material, fungi, and microorganisms that inhabit the floor of swamp waters. The many of the microorganisms are adapted to life in the channels produced by the trees and have difficulty surviving without them (Wolanski et al, 1997). Marine larvae and insects feed on the microorganisms and follow the microorganisms currents push them (Gordon, 1993). The currents also push the larvae closer to their prey (Wolanski et al, 1997).

The mangrove trees affect prawn, shrimp, and larger commercial fish as well. They follow the larvae and insects along these currents to feed on them (Wolanski, 1997). Young crustaceans have soft-shells making them vulnerable to fish. Juvenile crustaceans seek shelter from predators in exposed portions of the mangrove root systems (Gordon, 1993). Shrimp and other commercial crustaceans can grow to their full size while safely hidden in an underwater matrix of roots and neumatophores. Tropical fisheries need the mangroves to be healthy so the mangroves can provide a habitat for the wildlife that the commercial fish feed on and a habitat for the commercial fish themselves.

Many bird species prey on the fish in waters around the mangroves. Because the fish get nutrients either directly from mangrove trees or from other organisms that consume organic material from the mangroves, the birds are inextricably linked to mangrove forest. Birds also make their nests in the branches of the mangrove and rest on their limbs. Some species found commonly in the Laguna San José are the *Coereba flavela* (Bananaquit), the *Seivras noveboracesis* (migrant Northern Waterthrush), and the *Butoarides striatus* (Green Heron). Two endangered species can also be found in the lagoon, the *Pelecanus occidentalis* (Brown Pelican) and the *Agelaius xanhomus*

(Yellow Shouldered Blackbird) (Ceer, 1988). Without healthy mangrove forests, species like these cannot exist.

Mangroves can slow erosion. Waves are the main agent of coastal erosion. The roots systems of the trees slow wave erosion by binding sediments and anchoring the shoreline. The Army Corps of Engineers have successfully used mangroves to slow erosion in Florida and Georgia. Mangroves growing below the high water mark weaken the force of oncoming waves, which also combats erosion (Woodhouse et al, 1962; Dennison and Berry, 1993).

Mangroves can trap and process enormous amounts of untreated sewage, landfill and street runoff, and agricultural runoff. Nutrient pollutants from runoff increase the amount of organic compounds and macronutrients in a body of water. Other sources of organic materials include decaying natural vegetation and decaying animals and microorganisms. Increases in inorganic nutrients such as nitrogen, potassium, and phosphorous can cause algae blooms. Algae blooms occur when algae populations multiply far beyond their normal levels because of the high amounts of macronutrients. When the algae die, microbes decompose them using aerobic respiration, which depletes the water's oxygen supply. Lowering oxygen levels effects all forms of life in the ecosystem including large fish that often cannot survive in water with low oxygen levels (Andrew and Greenway, 1998). The algae blooms can become so thick that they block sunlight from reaching the bottom of the water, further devastating the wildlife. Algae blooms can grow so dense that the dead microorganisms can displace the water and extend the shoreline. The filling in of bodies of water is known as eutrophication. This process occurs naturally but algae blooms speed up the process. The water displacement can fill in lagoons, lakes, and streams. If the mangroves are cut off from the water, they will suffer. Because mangroves process many of the pollutants that cause algae blooms, mangroves can protect against them.

Tides and fresh water inputs mix with the water in the mangrove forest. This process, referred to as flushing, eventually carries the water into the ocean. The quicker a mangrove forest is flushed the sooner it can recover from contamination (Andrew and Greenway, 1998). Stagnant bodies of water are particularly vulnerable to pollution including sewage and industrial byproducts (Andrew and Greenway, 1998). The Laguna San José is poorly flushed. Water exits through two slow moving canals, the Suarez and the Martin Peña and enters primarily through land runoff and two small streams. The entrance to the Caño Martin Peña is partially blocked by trash and sediment build-up. Salt water leaches in through the banks that separate the lagoon from the ocean but this does little to flush the lagoon (Andrew and Greenway, 1998).

2.1.4 *Rhizophora mangle*

The *Rhizophora mangle* goes by many names in Puerto Rico. These names include Mangle Colorado, Mangle Rojo, Mangle Zapatero, and Mangle de Chifle. *Rhizophora mangle* can be identified by its characteristic prop root system, which can rise to a meter off the ground before merging into a unified trunk. Red mangrove reach an average height of four to ten meters. In Puerto

Rico, they are commonly found along side *Conocarpus erectus, Avicennia germinans,* and *Laguncularia mangle.* *Rhizophora* can be distinguished from these species by its longer wider leaves. The leaves have an average length of eight to ten centimeters and an average width of four to five centimeters (Cintron, 1985).

Rhizophora has a characteristic seed dispersal method. The seeds germinate from the small flowers, which grow on the end of the tree's branches. The seed matures in two to three months and the embrion remains on the tree for eleven to twelve months. After this time, the top portion drops the base of the seed into the water. Currents carry the seeds until they are deposited on the shore and can grow into a new tree (Cintron, 1985).

Natural stresses that the *Rhizophora* encounter, include hurricanes, increased salt concentrations during times of drought and low flushing, and the natural growth and regression of the coastline. These stresses physically remove and/or destroy biomass.

Some of the manmade stresses that *Rhizophora* encounter are channeling, dam building, artificial lakes, road construction, sedimentation, nutrient overloading, and thermal loading. Channeling, dam building, road construction, and artificial lakes isolate the mangroves from nutrients. Thermal discharges, nutrient overloading, and sedimentation stress the mangroves by increasing their respiration (Lugo and Snedakar 1974). *Rhizophora* can process more nitrogen than most mangrove species making it particularly resilient to nutrient overloading and algae blooms (Richard Webb, personal communication).

The author of an extensive body of literature on Puerto Rican natural resources, Gilberto Cintrón, argued water depth, salt concentration, and differing abilities to endure the force of waves control the distribution of mangrove species. *Rhizophora* prefer lower salt concentrations of a quarter that of the sea, or 9 parts per thousand. Young plants develop best at a salinity of 10-20 parts per thousand. *Rhizophora* can survive in salinity as high as 50-55 parts per thousand, but the high salinity stunts their growth. Shallow water has higher saline concentrations because it is flushed less. This poor flushing enables the salt to build up, as water evaporates. *Avicennia germinans* and *Languncluaria mangle* can tolerate high salt concentrations and prefer weaker waves, and therefore are found further in land (Cintron, 1985). *Conocarpus erectus* is not nearly as rugged the species related to it; *Conocarpus* grows almost entirely out of the water.

The *Rhizophora* is particularly good at protecting shorelines from erosion. Their root system is extremely strong allowing them to grow in deeper waters than *Conocarpus, Avicennia,* and *Laguncularia* (Cintron, 1985). This adapatation enables *Rhizophora* to withstand high waves and hurricane strength winds making it the frontline against wave erosion. *Rhizophora* takes up, and then evaporates more water than it can store. This adaptation, which helps the trees grow in aquatic environment, also makes them useful in reclaiming land lost to erosion (personal communication, Richard Webb).

Salt concentrations greatly effect mangrove height. A healthy *Rhizophora* can grow to a maximum height of 20 meters. Mangroves this large are found more commonly on the northern coast of Puerto Rico. Mangroves on the south coast are stunted 3.7 m on average by an increased salt concentration (Cintron et al, 1979).

On the northern coast, we worked with the *Rhizophora mangle* found in two sub groups of mangrove ecosystems called riverine forests and basin forests. Riverine forests grow in flood plains along rivers, while basin forests grow in drainage basins, lakes, and lagoons. The shoreline cuts off both systems from total contact with the ocean except where the river meets the ocean. The river currents and the tidal flux control flushing in basin and riverine forests. Land runoff is a primary water input in these ecosystems and it greatly increases nutrients levels and lowers salinity in them (Lugo and Snedakar, 1974).

On the southern coast, we worked with mangroves found in overwash and fringe forests. In overwashed forests, high tides submerge part of the mangrove forests. The entire forest is in contact with the ocean. They are commonly found on the "finger-like projections" that jut out from the mainland and on low standing islands (Lugo and Snedakar, 1974). They divert incoming tides, which carry organic debris into the sea. Because overwash forests are below the high tide mark, *Rhizophora* clearly dominates the other species (Lugo and Snedakar, 1974).

Like overwash forests, fringe forests are exposed to the ocean. However, fringe forests grow behind protective beaches above the mean high tide. They are not directly exposed to the tide, but saline water seeps through the beach and into the mangroves. Therefore, they retain more of the organic materials they produce. Species other than *Rhizophora* grow in these relatively dry conditions. Since fringe forest and overwash forests are found so close to the ocean, they are exposed to high winds (Lugo and Snedakar, 1974).

2.1.5 A *Rhizophora mangle* Forest: Case Study

David I. Griggs, Robert P. Van Eepoel, and Robert Brody conducted a study on Benner Bay and a nearby lagoon, both on St. Thomas, one of the American Virgin Islands adjacent to Puerto Rico. The *Rhizophora mangle* dominated the coastline. A nearby marina severely stressed the local ecosystem and damaged the mangroves. Griggs described the impact of the marina as "biologically devastating" (Griggs et al, 1971). The boats dumped unburned hydrocarbons and exhaust into the water. Areas where the currents are weak are prime locations for docks, and this is where docks were built in St. Thomas. Unfortunately, in areas of low flushing water is particularly susceptible to pollution because the slow water exchange allows harmful toxins to build up in the water (Griggs et al, 1971).

The researchers collected field data at eleven sites from the shoreline of the lagoon to the point where the bay emptied into the ocean. The data they collected included measurements of water temperature, salinity, dissolved oxygen, water clarity, and pH. The study was conducted from February to May (Griggs et al, 1971).

The water temperature ranged from 24°C too 33°C. The average temperature in February was 27.5°C. It increased to an average temperature of 29.5°C by May. The researchers found that the water temperature fluctuations were higher in the more shallow areas near the shore. They expected to find a spectrum of high temperature fluctuation going to lesser fluctuations as the water got deeper and they found this gradient. Smaller volumes for water hold their thermal energy less than larger volumes (Griggs et al, 1971.)

The Griggs study found dissolved oxygen levels to be related to water temperature, plant and animal life, and water circulation. Without the influence of any manmade or biological factors, the water will remain one hundred percent saturated. When plants grow in unpolluted water, the plants raise the oxygen levels above saturation during the day by releasing oxygen created by photosynthesis. At night, plants respire and deplete the water below the saturation level. The researchers found that pollution disrupted this cycle in Benner Bay and the mangrove forest. They found that dissolved oxygen fluctuations were less than expected. They ranged from 8.2 mg/L to 4.6 mg/L of oxygen averaging 6.5 mg/L of oxygen. The highest levels of oxygen in the water were in March when the water was coolest because cool water can hold more dissolved gasses than warm water (Griggs et al, 1971).

Salinity varied both spatially and temporally. Shallow areas had higher amounts of salt than areas closer to the open ocean, unless there had been a heavy rain. Rain reversed the trend causing shallow water closer to the land to have a lower salinity than the sea. As along Puerto Rico's the southern coast, there are few rivers on St. Thomas. The water either penetrates the carst shore, or runs directly into the ocean without being channeled through a river. In one site near the shore the salinity decreased dramatically from 37.5 ppt to 4.0 ppt after a heavy rain. Without rain's affect, the salty levels ranged from around 28 ppt near the ocean to 37 ppt closer to the land (Griggs et al, 1971).

The researchers found the pH to be between 8.2 and 8.4. They expected more variation in pH from such a polluted site. During the day, pH goes up because of higher plant metabolic activity (Griggs et al, 1971).

The water clarity in Benner Bay was poor. The area near the marina was particularly bad. Heavy rains stirred up the *Thalassia* sediments in the water and added sediments picked up by the land runoff. Four to five days after a heavy rain, mortality among the plant and animal life increased. Some of the wildlife could not survive when the salt concentrations decreased. The casualties of the low salt concentrations include native grasses, algae, and hydroids found in the mangrove roots (Griggs et al, 1971).

The color of the water indicated the type of flora on the bottom of the bay or lagoon and the level of suspended particulate matter (SPM). A brown opaque color showed that there were large amounts of suspended microorganisms and sediment. The researchers found that clear greenish blue water, getting more blue as the water got deeper, was a sign of more pure water. Transparent water indicated that the water was relatively unpolluted and covered with a sandy bottom. Transparent water also showed that the water was flushed quicker making it more homogeneous (Griggs et al, 1977).

2.2 Regulations on Water Quality

The power to enforce laws applying to water pollution and wetland conservation is mostly reserved for the state governments. Puerto Rico, as a United States territory, falls under the category of a state with regard to environmental law. Therefore, the regulations on water quality and wetlands are unique to that island. However, many of these measures are subject to federal EPA review, and must be in accord with national laws to receive federal funding (Flatt, 1997). Overall, Puerto Rico's water quality laws reflect the desire of the commonwealth to promote water resource conservation. This began in 1945 with the Water Protection Act. This act protected watersheds and called for the conservation and recreational use of coastal-terrestrial zones. The following sections review the major federal and local laws concerning water quality in Puerto Rico.

2.2.1 Clean Water Act

In 1972, the United States Congress passed a set of amendments to the Federal Water Pollution Control Act in order to mandate more effective water quality laws. These amendments became collectively known as the Clean Water Act (CWA). Some of the highlights of CWA were that: (1) it banned discharge of any pollutants into navigable U.S. waters, (2) it established fish and wildlife protection as a national priority, (3) it included a flat ban on discharge of harmful levels of toxic pollutants, and (4) it empowered the Environmental Protection

Agency (EPA) Administrator to set guidelines for water quality (Flatt, 1997). The states retained the authority to enforce water quality specifications, but those specifications would be subject to federal EPA review in order to secure national funding for the states.

2.2.2 Puerto Rico Water Pollution Control Law

Section 595 of the Puerto Rico Water Pollution Control Law makes it unlawful for an person, corporation, or entity, to discharge into the water any organic or inorganic material capable of polluting or placing water quality outside of the minimum standards of purity. "To pollute" is defined in Section 591 as to make a body of water harmful to human, animal, or plant health, or to make it ill-smelling or impure according to the proper standards of purity. This ban on discharging pollutants, according to Section 596, includes those activities that may have started before the enactment of the law.

Section 597 requires a person to obtain authorization by the Secretary of Health of Puerto Rico before discharging any sewage or industrial waste, constructing any facility for discharging wastes, or altering any existing facilities for discharging such wastes.

The Secretary of Health is also given the power to set maximum levels of pollution tolerance in the water according to Section 599. The actual tolerances are listed in Article 3 of the Puerto Rico Water Quality Standards, summarized later.

Section 601 provides for the Penalties for violating the Water Pollution Control Law. For each day a person is in violation of the law after receiving a final notice to cease the activity, that person will be fined between 100 and 1000 dollars, and/or spend between 90 days and 1 year in jail.

2.2.3 Puerto Rico Harmful Spills Law

The Puerto Rico Harmful Spills Law mandates that an emergency clean-up plan be implemented in the incidence of a spill of pollutants from a truck, ship, pipeline, or other source. It gives the Board of Environmental Quality the power to acquire the necessary equipment to handle such a spill and to require a contribution from those who transport pollutants to fund the equipment purchases.

2.2.4 Puerto Rico Water Resources Act

The Puerto Rico Water Resources Act states that it is the policy of the Puerto Rican Commonwealth to maintain water purity and to insure water resources are used for their most beneficial and reasonable public use.

Section 1505 of this act gives a detailed assignment of the functions of the Secretary of the Department of Natural Resources. These functions, listed in abbreviated form here, reflect the aim of the Department to:

(a) prepare, adopt, and maintain a water conservation plan
(b) establish a water area classification system
(c) adopt proper regulations and a permit system for water use and land use around water resources
(d) adopt special regulations for critical water areas

(e) circulate reasonable use criteria for water resources
(f) carry out technical research and surveys in conjunction with U.S. agencies
(g) recommend development standards to the Planning Board
(h) recommend a declaration of emergency to the Governor when water supply or quality is in jeopardy
(i) regulate the design, construction, and operation of wells, and
(j) perform inspections on the bodies of water in Puerto Rico

Anyone who utilizes a water resource or constructs a water connection system without the proper permit, according to Section 1523, shall be punished with a fine of no more than $500.00 or by no more than 6 months in jail.

Rules 113 and 114 of this act provide compliance plans and monitoring provisions for underground injection facilities which discharge sewage into the ground, as in a leach field. Hazardous wastes are not allowed to be discharges through underground injection facilities. Rules 115 and 116 provide parameters for water pollution control systems and water treatment facilities as well as measures to be taken at time of malfunction or non-compliance.

2.2.5 Effectiveness of Laws

The first problem reducing the effectiveness of laws is compliance. If people do not obey a set of laws, then those laws are unable to perform their function. An excellent example of noncompliance is the development on the Martin Peña Canal. Considerable amounts of illegal development has occurred in this area (Cruz, personal communication). A low-income residential area has ignored laws governing development and waste discharge on that canal and have caused a staggering increase in trash and sewage discharge into the water.

Another problem is that the regulations mentioned in the sections above largely govern point source pollution. The regulations ban the direct dumping or piping of pollutants into bodies of water. While these laws are quite necessary considering past discharge practices, and effective when obeyed, they neglect non-point source pollution which can also be detrimental to nearby bodies of water. Because of its non-specific nature, there are currently no laws which deal with non-point source pollution.

2.2.6 Point and Non-Point Source Pollution

Pollution is commonly grouped into two broad categories, point source pollution, and non-point source pollution. These categories are based on how the pollution enters the environment.

Point source pollution refers all types pollution that enter the environment through a single point. This form of pollution includes anything coming from a pipe. Carol Browner, editor of The EPA Water Quality Inventory, cites industrial facilities, municipal wastewater treatment facilities, and pipes that dump street run-off into natural bodies of water as key producers of point source pollution. Since the 1970's, the American government has passed legislation to regulate point source pollution. According to Browner, these regulations have been largely followed and have controlled point source pollution (Browner 1992).

Non-point source pollution refers to pollution that originates from a source too large and dispersed to be stopped by simply plugging up a pipe. Browner cites atmospheric deposition, and any land use that creates contaminated run-off including agriculture, construction, mining, and logging as major contributors of non-point source pollution to natural ecosystems. Browner also argues that, today, non-point source pollution has far more detrimental effects on the environment than point source pollution. Non-point source pollution is harder to identify, and expensive to stop. By definition, non-point source pollution is dispersed over a large area. Natural ecosystems can process low concentrations of non-point source pollution, but if concentrations rise to an intolerable level, they can cripple life in large tracts of land (Browner 1992).

We are primarily concerned with non-point source pollution. One of the causes of non-point source pollution is urbanization, and as cities spread out into neighboring regions, they bring their polluting runoff.

2.3 Urban Sprawl

Urban sprawl is a type of development that involves the encroachment of cities into their surrounding area. It is characterized by commercial strips, usually along heavily traveled roads, large expanses of sparsely populated sections separating the residential neighborhoods from commercial sectors, and increasingly scattered development extending from an urban center (Pelley, 1999). The term generally refers to the expanding regions around cites.

Urban sprawl has been linked to a variety of environmental problems. In some areas these problems degraded the surrounding ecosystems enough to catch the attention of city officials. The Pennsylvania Environmental Commission has linked urban sprawl to the degradation of air and water quality, the increase in pollution from cars, the loss of open space, and even decay of the inner cities (Pelley, 1999).

As people choose to live further from their work, they are forced to drive more, which can cause many problems. Air quality analyst for the EPA, Geoffrey Anderson investigated this issue. He found that while the American population has risen only 1 percent per year between 1970 and 1996, the number of vehicle miles traveled has increased 3 percent, and the number of miles traveled per person has risen 41 percent. He also estimates that 1/4 of the nitrogen oxide pollutants, 1/4 of the carbon dioxide, and 1/4 of the volatile organic compounds produced by Americans each year comes from their cars (Pelley, 1996). These statistics suggest that urban sprawl has serious environmental repercussions. They serve to highlight the importance of studying the effects of urban sprawl.

2.3.1 Alternative Development Options

Some authors suggest that limiting suburban development can work. In 1970, Portland Oregon passed a law strictly limiting the boundaries of the area in which development could take place. In the following thirty years, jobs in the city center increased from 50,000 to 105,000. They have not had an air quality violation since 1987, while before 1970 they averaged 100 violations per year (Pelley, 1999). Curbing suburban development does not deserve all of the credit for Portland's success, but it does show that limiting urban sprawl can be successful and practical.

A less restrictive development policy would be to limit building near mangrove forests or other wetlands. A policy like this would likely have less opposition than one similar to Portland's, while avoiding wetland problems associated with urban sprawl.

2.3.2 The Economics of Wetlands and Urban Development

Wetlands have thriving ecosystems, which can be harnessed to bolster local economies. However, misuse of these ecosystems can be damaging to them and economically harmful. The cost of the degradation of the wetland must be determined to calculate a project's total impact on the economy. The effects of use and urban development of wetlands are not just felt by the ecosystems themselves or through long term hazards, but they can have short-term economic consequences. Since the turn of the century, half of the world's wetlands have disappeared. According to Barbier (1994), the economic value of much of this land in its natural state was not considered before it was destroyed.

Barbier (1993) suggested a system to measure the impact development would have on an ecosystem. The first step in his system is to determine how a development is affecting the environment. Then, the ramifications of these changes on local markets must be uncovered, and the benefit of the project must be compared to the cost on the environment. In his system, human health effects, effects on wildlife that are not commercially valuable and the effects on the entire ecosystem are not included in the figures. These factors are impossible to quantify according to Barbier.

Barbier (1994), Dixon and Hutschmidt (1986), and Dixon et al. (1988) did a study on the commercial impacts of the development of a Geothermal plant along two Philippine rivers, the Bao and the Mahio. They predicted an increase in the water temperature would profoundly harm local rice farming and fishing. Fish are adapted to oxygen levels in their surrounding waters. When water temperatures increase, the water can hold less oxygen, and fish can suffocate. The study predicted that the cost to local economies along the Bao River would amount to 41 percent of the total cost of the project. This impact could devastate local economies (Dixon and Hutschmidt in Barbier, 1993).

Another study conducted by Hodgeson and Dixon (1988) predicted costs comparable to the studies cited above. A logging project was planned in the Bacuit Bay, also on the Philipino islands. The study projected the local fishing industry would lose 40 million dollars over a ten year span if the logging project proceeded. To a fishing economy in a developing nation, a lose this large would be catastrophic. The logging company wanted to cut trees that covered a coral island, which would cause sedimentation. Increased sedimentation of the reef would drive the fish away. (Dixon and Hutschmidt's in Barbier, 1993). These studies show that the impact of development on wetlands can cripple local economies.

2.4 Water Quality

In order to determine the health of the *Rhizophora mangle* ecosystem, we studied the water near the trees. When studying water in the environment, it is important to understand the different processes that water undergoes in the environment. A water sample that is taken from a lake, lagoon, river, or ocean, will not be pure water. Almost all of the water in nature has other elements dissolved in it. Vaporized water, rising into the atmosphere, is the purest form of water in nature. When this vapor condenses in the clouds, it picks up small traces of oxygen, nitrogen, carbon dioxide, nitrous oxides, ozone, and argon. The carbon dioxide in the droplets of water causes rain to act as a very weak acid. As rain falls it continues to pick up gases from the atmosphere. When the rain hits the ground it is slightly acidic. This causes the water to react with alkyline or basic compounds such as calcium, magnesium, iron, zinc, and other metals. The alkylinity of these metals causes the water to reach a more neutral pH (Renn, 1968).

A fundamental test for water quality is the measurement of Suspended Particulate Matter (SPM) which comprises of any material that floats in the water. These materials might be sediments, organic material, algae, or other microorganisms. Suspended particulate matter can be measured by taking samples of water from a particular area and measuring the turbidity of that sample. A more efficient way is to use sophisticated equipment such as a Calibrated Airborne Multi-spectral Scanner (CAMS). Information received using this equipment can then be interpreted to produce maps that show the concentration of SPM in various locations. Researchers in 1990 monitored the SPM in Puerto Rico, particularly Mayaguez Bay. They concluded that human activity affected the coastal productivity or water quality by altering sediment and nutrient concentrations. This occurs because suspended sediments and excessive algae block the sunlight from reaching photosynthetic organisms that are not close to the surface. The team also developed useful techniques to monitor short-term and long-term changes in water quality. These changes are directly related to the changes in the spatial distribution of SPM.

The pH test measures water's corrosiveness. Distilled water (pure water) has a pH of seven, which is neutral. A pH lower than seven is acidic and one higher than seven is basic. An average pH range for water in nature is 5.0 to 8.5. Water having a pH out of this range is most likely polluted. Seawater has a pH of about 8 because of its salt content (Renn).

The dissolved O_2 test measures the amount of dissolved oxygen in the water sample. Oxygen in the air dissolves into water. Underwater photosynthetic plants contribute oxygen to water as well. The concentration of dissolved O_2 does not change the pH of water (Renn). Oxygen is removed by plant and animal respiration along with the aerobic decomposition of organic matter. Low concentrations of dissolved O_2 are a result of a few processes. High SPM blocks sunlight from photosynthetic organisms, which produce the oxygen. Large concentration of oxygen-consuming pollutants also cause low levels of oxygen. Therefore, low concentrations of dissolved oxygen are an indicator of pollution. In the absence of these oxygen-consuming pollutants, the temperature of the water determines the concentration of dissolved oxygen. This is why the temperature of the water must be determined. As the temperature of the water rises, less oxygen can be dissolved into it. Water that is full of nutrients also contains little oxygen because the oxygen is used up by the aerobic decomposers. These decomposers grow excessively as a result of excess nutrients such as carbon, nitrogen, hydrogen, oxygen, sulfur, phosphorus, potassium and other minerals are found in different concentrations in a natural ecosystem. Excess nutrients can be a direct effect of agricultural runoff.

Ammonia and hydrogen sulfide are gases with a foul odor, which are poisonous in high concentrations. Nitrogen is converted into ammonia and sulfur is converted to hydrogen sulfide after anaerobic decomposition (TextB). Ammonia is then transformed into nitrate and nitrite by bacteria using aerobic respiration (Renn, 1968). Methane also has a foul smell and is a product of the anaerobic decomposition of carbon (TextB).

Pollution occurs when biological wastes and mineral nutrients are not processed as quickly as they enter a system. Water pollutants can be divided into four main categories. Pathogens are organisms that can cause disease. The primary causes for these pathogens are human sewage and/or animal manure getting into the water. These pathogens can cause diseases such as typhoid, hepatitis, and cholera. Nutrients and biodegradable organic matter include the remains of animals and plants, including feces, leaves, wood waste, fat, and debris from food-processing plants. Physical agents are heat and suspended solids. The final category of pollutants is the toxic chemicals. These are chemicals, which are poisonous to organisms. These include metals such as lead and mercury, pesticides, waste products from the petrochemical industry, and radioactive waste. Coliform bacteria such as *Escherichia coli* originate in the intestines of humans and animals. The coliform bacteria enter the ecosystem by means of human and animal feces. Therefore, the presence of coliform bacteria in water is an indicator that the water contains sewage (TextB),

2.5 Ground Water

The water table around the San Jose Lagoon is extensive. This ground water has a specific quality depending on the composition of the earth strata from which it is taken. A shallow well receives water that has recently infiltrated the soil and its quality will vary with the season and the rainfall. Deeper wells will have less variation in water quality because the surface water has to travel a long distance through the soil and will the cleansed in the process.

A study done in The Chesapeake Bay shows how seasonal and tidal variations in ground water discharge, influence the coastal waters around the bay. Ground water lies beneath the ground and serves as a base flow to tributaries or flow directly to the sea. This movement of water displaces nutrients from agricultural lands and also displaces toxins contained in pesticides and waste materials from agricultural lands and residential septic tanks towards the coastal waters. These factors affect certain properties of water quality that can be tested (Robinson, 98).

The Chesapeake Bay researchers measured the ground water level in correlation with sea level using an electrical water probe, which is accurate to 0.3 cm. Using this equipment, they were also able to determine the direction in which the water was flowing. They found the ground water flow parallel to the shoreline. In their conclusion they expressed that the maximum distance of tidal influenced ground water was between 36.7 m and 401.1 m (Robinson, 94). This information tells us that in a coastal habitat, if the ground water within the range of tidal influence is contaminated, it will affect the coastal waters around it (Robinson, 98).

The drainage basin for the Laguna San Jose is quite extensive. To the north of the lagoon, the basin extends from Santurce to Isla Verde. A large portion of Carolina, and a small section of Rio Piedras is included in the basin. The Caño Martin Peña has a separate drainage basin. There is a close interaction between the waters of the channel and the lagoon with its drainage basin. Steep topography and urbanization causes flooding and fast-moving rainfall-runoff from the basin into the lagoon, the channel, and their respectively tributaries.

2.6 The Global Positioning System (GPS)

The Global Positioning System, or GPS, was developed by the US Department of Defense as a means to provide US military forces with a simple, precise position readout anywhere on or above the surface of the earth (Hurn, 1989). It has since been released for civilian use, which today accounts for more than 90 percent of its use (Parkinson, 1996). This system was used during the project to obtain geodetic locations of each water and mangrove leaf sample location

2.6.1 Principles of Operation

The satellite constellation that GPS relies on is a group of twenty-four active satellites in a high Earth orbit (Hurn, 1989; Parkinson, 1996). Several reserve satellites also exist. The twenty-four active satellites constantly broadcast information on two separate frequencies. One signal is highly precise and encrypted for military use, and the second is available to the public, although intentionally degraded to reduce accuracy (Parkinson, 1996; Fair, 1999). Both civilian and military systems rely on the same principle to operate. A GPS receiver must have a clear path to at least three satellites to be able to determine an approximate location. With four satellites, a GPS receiver can calculate a highly accurate position, in the absence of intentional degradation to be discussed later (Parkinson, 1996; Fair, 1999).

2.6.2 Signal Characteristics

Encoded in the signal each satellite broadcasts is a unique series of pulses, known as a pseudorandom noise code. This code both identifies an individual satellite and provides a baseline with which to measure the delay between the signal's departure from the satellite and its arrival at the receiver (Parkinson; 1996).

2.6.3 Position Calculation

Each satellite also has four precisely accurate atomic clocks on board. Exact time and satellite position data are likewise encoded in the satellite broadcast. A GPS receiver calculates the distance to each transmitter based on the time a signal takes to arrive from each respective satellite (Parkinson, 1996). Because each satellite also broadcasts its approximate position, the intersection of the signals can then be calculated (Fair, 1999). Although only three satellites are required to calculate an approximation of this intersection, a fourth corrects for any error in the receiver's internal clock, providing a position reading accurate to within twenty-five meters (Fair, 1999). The use of a fourth satellite allows a GPS receiver to utilize an inexpensive quartz oscillated clock, similar to that in a wristwatch, instead of the expensive atomic standard used aboard the satellites (Parkinson, 1996; Fair, 1999).

2.6.4 Positioning Errors

When GPS was released for public use, the military intentionally reduced the accuracy of the signal. This practice is known as selective availability, and was designed to prevent the military use of GPS against the United States (Hurn, 1989; Parkinson, 1996). Under selective availability, however, a receiver's location calculation randomly drifts around the true position measurement. Nevertheless, with selective availability, a GPS receiver can typically calculate its position to within 100 meters (Parkinson, 1996; Fair, 1999).

2.6.5 Error Correction

Soon after the release of GPS to the public, means were developed to work around this erroneous signal. Selective availability affects all receivers within a relatively close vicinity with very much the same error. If a GPS base station receiver is located at a known position, an error correction signal can be calculated and broadcast in real-time to other receivers in the area. This practice, known as differential GPS (DGPS) can increase accuracy to with 1 meter if the receiver is within 100 kilometers of the base station, and within 1 centimeter if only a 10 kilometer separation exists (Fair, 1999).

If real-time calculations are not required, stationary receivers can determine position to within 1 millimeter over a few hours or days (Parkinson, 1996; Fair, 1999). Selective availability, as described above, causes a receiver's position estimate to drift over a spherical volume of a nearly uniform radius. If the receiver remains stationary for a period of time, the center of the sphere can be calculated to this millimeter accuracy (Parkinson, 1996; Fair, 1999).

2.7 Geographic Information Systems (GIS)

Geographic Information Systems, or GIS, is a type of graphical computer database system capable of a wide variety of functions related to surveying and managing areas of the environment. GIS can combine numerous types of data, such as population, natural resources, pollution levels, and other quantifiable information onto a multiple layer database capable of displaying one or many such levels (Wolf, 1994). This data is spatially referenced, meaning information compiled into each data layer has to be carefully surveyed and related to geographic reference points, such as coordinates obtained from GPS or other surveying techniques. Layers then can be overlaid with map data to provide a graphical representation of their corresponding information in relation to the terrain (Wolf, 1994). This data layering ability was useful in examining and comparing experimental results and historic data with the geographic features and population of the areas of study.

GIS is not limited to topographic display of data, however. It is capable of processing data using a wide array of numerical analysis methods such as statistical and deterministic modeling (Lyon 1995). In addition to map data, GIS is also capable of displaying data in spreadsheet form. Because the two are dynamically linked, data in either of the presentation formats can be used to access data in the other. Data can also be updated using either method (Environmental, 1997).

2.8 Maps

Several types of maps were useful for this study. Basic geographical maps were often used as a general reference for determining areas of study. This type of map is also the base level in GIS software. Information such as urban development, mangrove distribution, and water quality can be overlaid on the geographical map.

Topographical contour maps were used early on to analyze water shed areas around the bodies of water of interest. Topographical maps display isobars to represent elevation and make land contours easy to determine. By looking at the land contour around the San José Lagoon, we could see that the lagoon receives extensive runoff from the land.

One of the most important types of map we used was the land use map. Land use maps are geographical maps, which contain sections and borders that represent types of development, bodies of water, or ecosystems. The land uses are determined by examining aerial photographs and ground truthing. Through examination of different land use maps of the same area over a period of time, we were able to determine the nature of developmental changes that occurred.

Chapter 3: Methodology

3.1 Background Research

We began our research at the WPI and Clark University libraries in Worcester, Massachusetts. We found information on water quality, wetlands, GIS and GPS, and general information on mangroves. Information that pertains directly to mangroves of Puerto Rico was scarce. Federal and Puerto Rican law codes protecting wetlands were obtained from the Library of Congress.

Laws pertaining specifically to mangroves in Puerto Rico were reviewed at the University of Puerto Rico, Rio Piedras campus library. We obtained information on land use around the San José Lagoon at *Inventorio Scientifico* through aerial photographs and through interviews. We found information on past land uses at the San Juan Bay Estuary Program and on maps provided by Professor Angel David Cruz of the University of Puerto Rico. Alexi Dragoni of the Natural Resources Department provided us with GIS data on land use, and the Altoonian IQP provided us with population data.

Information on the *Rhizophora mangle* in the San José Lagoon was found at the San Juan Bay Estuary Program, the U.S. Geographical Survey, the University of Puerto Rico library, and the Natural Resources library. Data from previous years on water quality in the lagoon was provided to us by the U.S. Geological Survey.

3.2 Location of Study

The San José Lagoon and its adjacent canals, the Martin Peña and the Suarez, were chosen for two reasons. First, both the canals and the lagoon have a considerable population of *Rhizophora mangle* trees. The area was also particularly interesting because one half of the land around the lagoon was urbanized and the other was not. Section 4.0 describes the development in that area.

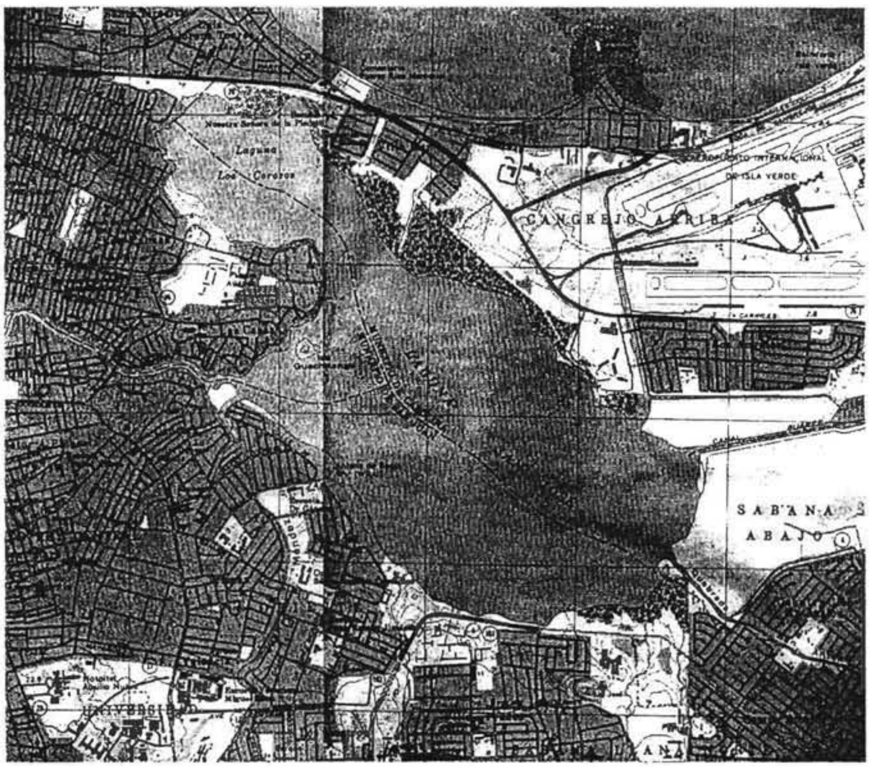

Figure 3.1: Laguna San José and surrounding area

In order to evaluate the relative health of the mangroves around the lagoon, we needed to compare them to mangrove forests in less urbanized areas. The areas of comparison would also have to be dominated by *Rhizphora mangle*. The first area we chose was Magueyes Island in La Parguera, in the southwestern part of Puerto Rico.

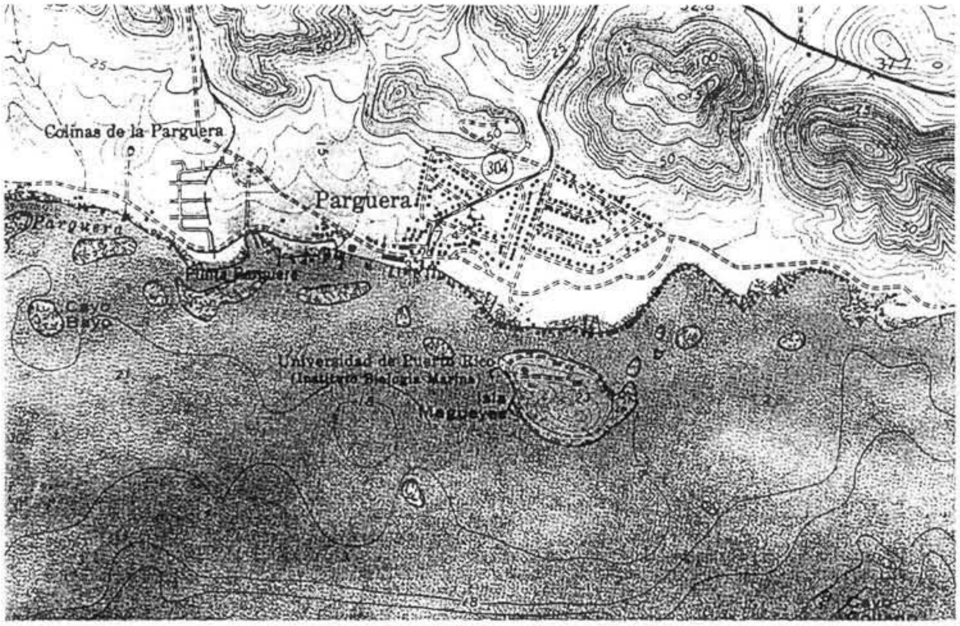

Figure 3.2: Isla Magueyes and surrounding area

The second area of study was Bahía de Jobos in Guayama, also on the southern coast of the island. Both of these areas were in far less developed areas than the San José Lagoon, and served as a control for our water quality and leaf size comparisons.

Figure 3.3: Bahía de Jobos, Cayos Caribes, and surrounding area

3.3 Water Sampling

In order to determine the health of the body of water around the red mangrove, water quality tests were conducted. The samples were taken using a systematic unaligned system of random sampling because this system proved to be time efficient and served our purpose well. This system is a combination of planned traverses and random point sampling. We planned the sampling transects to be sampled and chose sampling stations that would give us a good representation of the area. Between 6 and 15 water samples were taken from each area.

Various tests were conducted on these samples. The reason the following tests were chosen was that they could be performed on-site. Water quality results become skewed if the sample is allowed to sit for a period of time. These tests were also chosen because the results can be compared to historical data. Also, for consistency with historical data from USGS, all samples were taken at a depth of 1 foot.

The tests conducted were the following: salinity, pH, dissolved oxygen, dissolved solids, nitrates, nitrites, phosphates, and ammonia nitrogen. The test for salinity and suspended solids was performed using a LaMotte conductivity/ total dissolved solids meter. Conductance was measured in UMHOS/cm and TDS was measured in PPM. Litmus paper was used in order to determine the pH of the samples. The tests for nitrates, nitrites, phosphates, and ammonia nitrogen were all conducted in the same fashion. The concentration of the respective nutrients was determined by introducing one or more chemical reagents into the sample. The chemicals react with the sample and cause a change in color. The color change is analyzed using an Axial Reader in order to measure the concentration of that particular material. The amount of dissolved oxygen in the water sample was determined using the titration method. All of these tests result in units of ppm.

3.4 Leaf Ratio and Size

The first aspect of the *Rhizophora mangle* leaf morphology we measured was the length to width ratio. Speaking with mangrove expert Dr. Oscar Luguillo, we learned that environmental contaminants may affect the length to width ratio of the leaves. To see if we could demonstrate a correlation between leaf ratio and pollution levels, we sampled leaves at Laguna San José, Isla Magueyes, and Bahía de Jobos. Mature leaves were gathered from trees in each of these areas. Approximately thirty leaves per tree were collected from three trees in each of the various sampling stations. The leaves gathered in San Juan were compared to those gathered in Bahia de Jobos and La Parguera.

We also compared the leaf size between the test locations and between sites within each location. Different types of pollution and other environmental factors have been shown to affect the leaf size of red mangrove trees. High water temperature, high salinity, and oil pollution reduce the leaf size, while excess nutrients make the leaves larger (Lugo, 77). We considered all these factors when determining the probable causes for the differences we observed.

3.5 Locating Sample Positions

To accurately pinpoint the locations at which we collected water samples, we used the global positioning system. Because a differential global positioning system was not available over the course of this project, two standard GPS receivers were used. Coordinate readouts from both a Magellan GPS 4000 XL and an Eagle Explorer were compared at a known location before each set of samples was collected. The more accurate device was used to record locations of each point in the sample set using the Universal Transverse Mercator (UTM) format and the NAT 27 datum standard. Through analysis of aerial photographs and maps, we determined approximate test locations needed to provide an accurate sampling of the study areas. The corresponding geodetic coordinates of these locations were then programmed into the GPS receiver. Samples were collected from stations near these locations, as well as from random points from within the sample area. In each case, the coordinates of the sampling stations were recorded along with the sample results. We also observed and recorded locations of possible point source pollution from available data and inspection, as well as other visible pollution sources and indicators, and recorded those as well.

3.6 Analysis Using Global Information Systems

After the data collection process, the sampling areas were digitized and georeferenced using Atlas GIS. The resultant digital map was then overlayed in Surfer with data collected during sampling. This aided in visualizing trends and correlations between water quality, mangrove distribution, and urbanization. IDRISI and Thematic Mapper were also used to analyze infrared spectral imagery and aerial photographs.

3.7 Statistical Analysis

The leaf size and ratio data that we collected needed to be statistically analyzed in order to determine whether the sample groups were statistically different or not. Analysis of variance, or ANOVA, was used as an initial assessment of whether there were statistical differences between groups. This test, however, does not reveal within which groups the differences lie. For this function, we used the t-test assuming unequal variances. This test told us whether samples had statistically different means. Statistical significance was displayed on bar graphs representing sample means. All of these statistical and graphing functions were performed with Microsoft Excel.

3.8 Aerial Photograph Interpretation

Aerial photographs were taken with both visual spectrum and infrared imaging. We also used these to analyze the effect of urbanization on the areas around San José Lagoon. From visual band aerial photos, we were able to compare and quantify mangrove distribution around the San José Lagoon over time. Using infrared imagery, boundaries between developed areas, water features, and vegetation were easily distinguishable. Aerial photography in both paper and digital format was used.

Chapter 4: Results

4.1 Population

San Juan and Carolina are two cites bordering the Laguna San José. San Juan is located west of the lagoon and Carolina to the south and east. The lagoon divides the two cities. Both San Juan and Carolina are in the San Juan metropolitan area. The population of San Juan grew tremendously in the 1940s and 1950s, jumping from 169,247 people in 1940 to 451,658 by 1960. Carolina's population followed this growth trend in the 1960s and 1970 (figure 4-1).

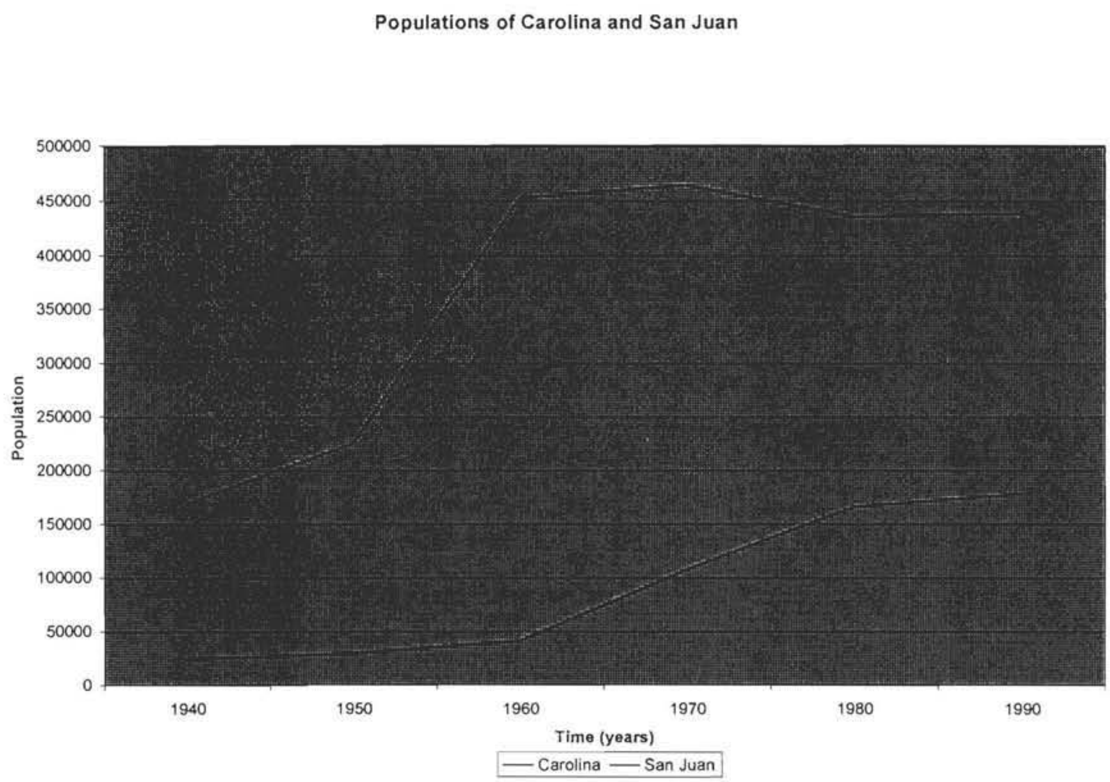

Figure 4-1: The populations of both San Juan and Carolina grew dramatically this century. The population of San Juan increased in the 1940s and1950s. The population of Carolina grew, later, in the 1960's and the 1970's.

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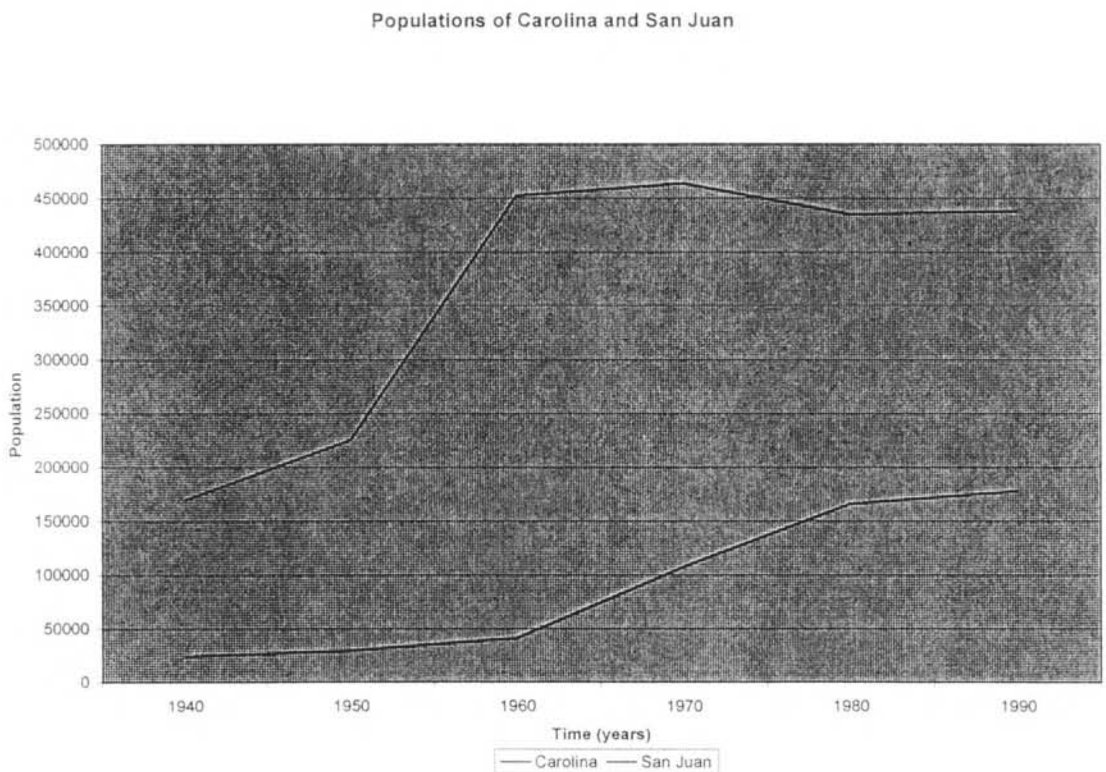

Figure 4-1: The populations of both San Juan and Carolina grew dramatically this century. The population of San Juan increased in the 1940s and1950s. The population of Carolina grew, later, in the 1960's and the 1970's.

In the 1950's, the American government rushed to develop Puerto Rico's industry. Much of the industrial development took place in the San Juan metropolitan area. A program designed to develop manufacturing called Operation Bootstrap was centered in San Juan. Agricultural workers migrated to San Juan to work in factories as Puerto Rico's sugar industry declined. The train to San Juan stopped west of Laguna San Jose. Many of the immigrants did not travel far from this stop and a shanty town developed around it. After San Juan's population exploded, people began to move south to Carolina and thus its population grew after San Juan's.

4.2 Development and Land Use Around the San José Lagoon

The areas in San Juan from which we collected water and red mangrove leaf samples were the San José Lagoon and its adjoining tributaries, the Suarez Canal to the east and the Martin Peña Channel to the west. Together, the three bodies of water are bordered by a system containing both developed and undeveloped areas. The San José Lagoon itself is an area of interest because it has different development patterns on its eastern and western shores.

Our first water samples were taken from the Suarez Canal. This canal flows through a largely undeveloped area and is bordered on both sides by mangrove forest. Just beyond the strip of mangroves north of the canal is a high density residential area that extends for between 500 and 800 meters. The San Juan International Airport lies beyond this development. A large area of dense residential development lies to the south of the canal, but 800 meters of undeveloped and recreational land lies between it and the water.

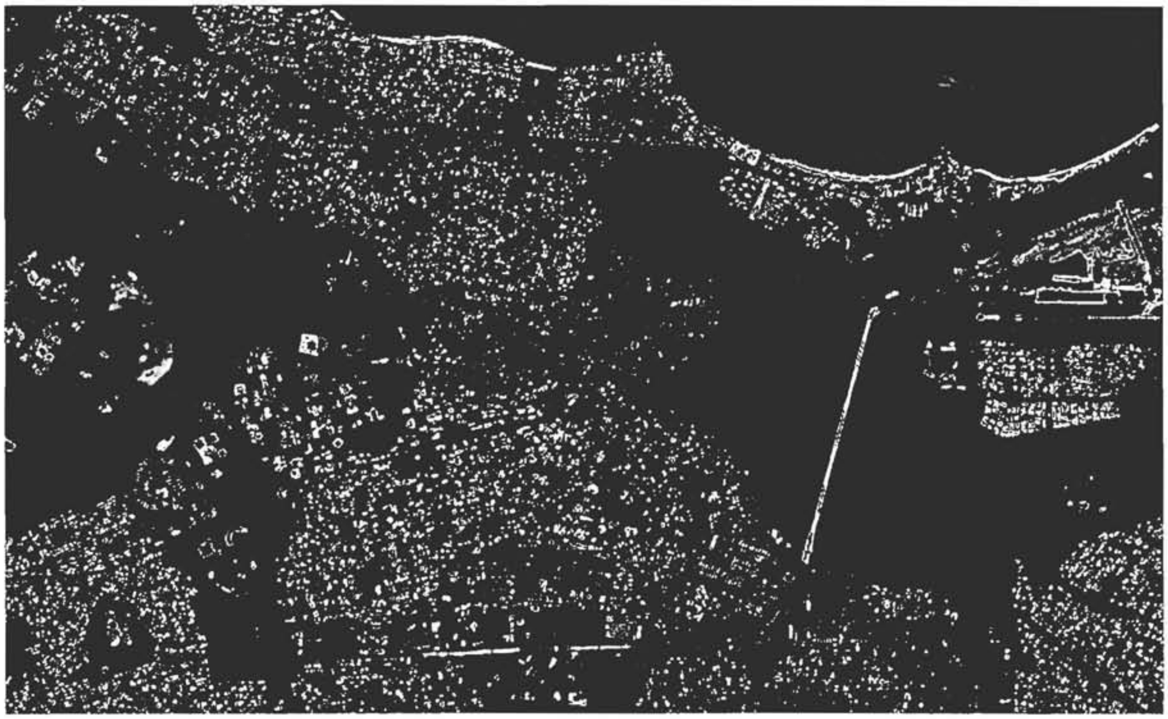

Figure 4-2: 1995 spot imagery of the Laguna San José area from Thematic Mapper

The eastern shore of the San José Lagoon is comprised completely of mangrove forest. In the northeast section of the lagoon, including Laguna Los Corozos, mangrove coverage extends from the shore to between 100 and 400 meters inland. Beyond that, the land is mostly high density development with some sections left undeveloped. Highway 26 runs outside the northeast shore of the lagoon, coming as close as 100 meters in one spot and as far as 750 meters in another. To the south and east of the lagoon lies mostly undeveloped land, mangroves, and mixed forest. However, about 400 meters southeast of the water is a large section of dense residential development that extends for over two kilometers away from the lagoon.

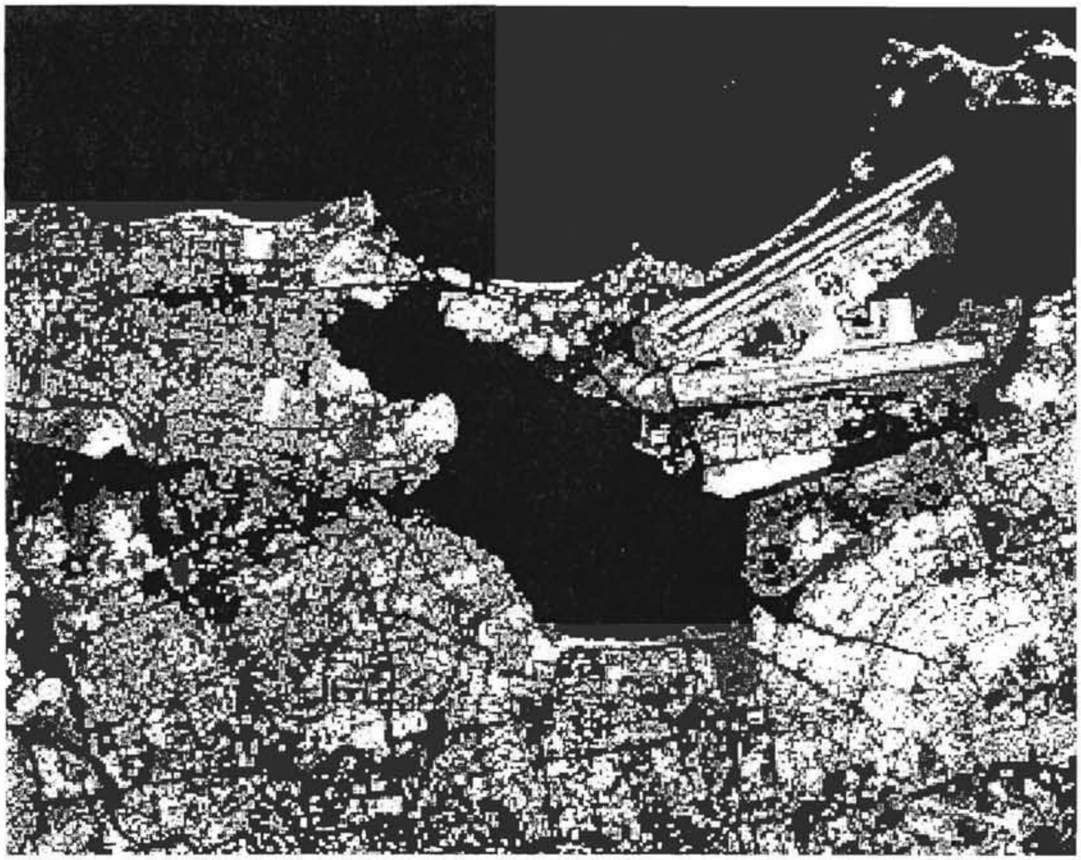

Figure 4-3: 1986 infrared imagery of the Laguna San José area from IDRISI. Development is depicted by shades of yellow and brown, while vegetation appears violet and light blue.

The lagoon's western shore is densely developed. The shoreline is comprised largely of substandard type development, some mangrove stands, and a few small undeveloped sections. The land, which is found further inland, is primarily characterized by high-density residential development, which stretches for kilometers. Small commercial patches of land are interspersed in the residential area along with bits of public use land, recreational areas, and streets.

The Caño Martin Peña connects the San José Lagoon with San Juan Bay. It flows through highly urbanized sections of San Juan. The eastern half of the channel is bordered predominantly by shanty type development. Mangrove stands occur mostly at the two mouths of the channel and along the western half of the channel. Considerable stretches of undeveloped land occur on the western end. The inland area, to the north of the channel, is a mixture of high-density residential and commercial development. The south side, to the east, is very similar but with more residential development than commercial. The western areas south of the channel are mostly undeveloped. A large industrial park, however, lies about 500 meters south of the channel in that area. Major highways cross the Caño Martin Peña Canal at four places. These are highways 2, 22, 1, 25, and 40. Highway 1 turns and one runs parallel to the northern shore of the channel, three hundred meters away in the northwestern quarter.

The water system of the San José Lagoon, Caño Martin Peña, and Canal Suarez is an interesting case for a water quality study. From the most urbanized areas around the Martin Peña to the unspoiled mangroves of the eastern bank of the lagoon and the Suarez Canal, there is a substantial difference in land use patterns. We chose this area with the following question in mind: will the development trends be reflected by water quality trends, or will the water quality be similar across the connected system?

To determine land use changes around the San José Lagoon, we examined land use maps from the years 1971, 1977, and 1987. These maps provided a valuable insight into recent development trends. The 1987 map was the most recent map made of this type, so we recognize that some changes may have occurred since that map was published.

The Suarez Canal has undergone some changes since 1971. The area north of the canal changed from a low-density residential area in 1977 to a high-density area in 1987. A recreational area developed 300 meters south of the canal between 1971 and 1977. The developments around the lagoon and on the northern and southern banks of the Caño Martin Peña have had little variation. A large public park had developed since 1971 near the San Juan Bay to the north of the Martin Peña, replacing undeveloped land. To the south of the middle of the channel, considerable high-density residential development occurred after 1977. North of the channel, near the intersection of highways 1 and 22, an area of shanty development has disappeared, and an area of dense residential development has appeared near it. Other than these changes, the land use has been consistent between 1971 and 1987.

4.2.1 History of the San Juan Bay Estuary System

The San Juan Bay Estuary System includes the San Juan Bay, Caño de San Antonio and the Laguna del Condado, Caño Martin Peña, the Laguna San José, the Canal Suarez, the Laguna La Torecilla and the Laguna de Piñones. This system is found on the northern coast of Puerto Rico. Mangroves and herbaceous wetlands covered most of the area in 1936. The mangroves totaled 4,978 acres (2,015 hectares) of coverage in the estuarine system. Since that time the amount of mangrove coverage has decreased. The San Juan Bay

Estuary Program made an ecological assessment of the San Juan Bay Estuary System in 1997. They looked at the biological community and habitats of all of the areas in the San Juan Bay Estuary System. The areas most pertinent to our study are the Martin Peña Channel, the Laguna San José, and the Canal Suarez. They compared mangrove distribution from the years 1936 and 1995 and found a huge decrease in mangrove coverage. They found the mangroves to decrease by a total of 66.8% around the Caño Martin Peña and 53.5% around the Laguna San José and Canal Suarez. In conclusion, they proposed projects for mangrove restoration on the north and south shores of the Martin Peña Channel and of an area immediately north of the tidal basin of the Canal Suarez (Janicki 97). Our group analyzed aerial photographs of the years 1962, 1971, 1977, and 1987. We also used land use maps from the years 1971, 1977, and 1987. Using this data in conjunction with the data obtained from the Jancki study in 1997, we put together a history of the Caño Martin Peña, Laguna San Jose, and Canal Suarez. We also compiled a mangrove inventory from the years 1936, 1962, 1971, 1977, 1987, 1995.

4.2.2 History of the Caño Martin Peña

The Martin Peña Channel connects the San José Lagoon to the San Juan Bay. In the 16th century, mangroves dominated the habitat around the Martin Peña Channel. Herbaceous wetlands grew just beyond the mangrove stands about half way up the channel. This has since changed dramatically. In 1936, mangroves bordered the channel on the north and south side. The total coverage of the mangroves was about 1,028 acres (416 hectares). In the 1950's, slums developed along the northern border of the channel on government land. The development of these slums proved to be one of the most destructive events for the mangroves on the Caño Martin Peña. Many of the dwellings were built directly over the water. Raw sewage was dumped into the channel and garbage was used as fill material. This reduced the amount of mangrove coverage and polluted the water. Later, in 1960, one hundred acres (40 hectares) of mangroves were filled south of Kennedy Avenue (PR-2) with the establishment of the San Juan Landfill. There were 135.82 acres of mangroves left, most of which were found on the southern shore of the channel in 1962.

In 1965, the western end of the channel had been straightened. This created a small island near the mouth of the channel, just east of where the Parque Central is found today. The affect of the slums on the channel led to the effort put forth by the Urban Renewal Program in the 1960's. This program played an integral part in building of public housing so that squatters could be moved away from the channel. Dense residential areas were developed near the area where the slums were found, north of the channel and east of the Highway 22. By 1971, many of the slums were eradicated and there were 15.29 acres of mangrove cover left on the area they occupied, most of which was on the southern shore.

By 1974, 160 acres (65 hectares) of mangroves could be found along the Martin Peña Channel. By 1977, this number had changed to 168.34 acres. In 1979, the Parque Central and the Parque Ecuestre were built. Most of the slums along the channel were eliminated by 1982. Only the Tokio area remained along the southeastern edge in 1983. Mangrove coverage around the channel had increased to 204 acres (83 hectares) by 1984. The San Juan Municipal Landfill covered 150 acres (61 hectares) by the early 1980's. Man-made activities in 1987 included the depositing of fill for temporary access and construction to improve the docking facilities along the channel (Janicki 97). The mangroves covered an area of 206.62 acres in 1987. Although their numbers have been increasing it is still a far cry from the original 1,028 acres.

4.2.3 History of the Suarez Canal

The Suarez Canal was built between 1840 and 1900 in order to connect the Laguna San José to the Laguna La Torrecilla. The area around the canal was populated primarily by mangroves in 1936. The mangroves extended eastward from the northeastern and southeastern shores of the Laguna San José to about halfway between the Laguna La Torrecilla and the northeastern bend of the canal. The total mangrove coverage around the canal including the mangroves around the Laguna San José, at this time, was 642 acres (260 hectares). The Suarez Canal was narrow and shallow until the years between 1962 and 1967 when it was widened and deepened. Forty-nine acres (20 hectares) of mangrove were removed and then filled in to 1.5 m (5ft) above mean water level. This took place on the western bank of the canal, west of the PR-26 highway. Near this area, dredging occurred to allow for a future yacht basin on the north side of the canal. This increase in volume of the Canal Suarez resulted in the Canal Suarez becoming the primary outlet of water from the Laguna San

José. This made the flushing of the Laguna San José through the Caño Martin Peña poor. Industrial chemicals were discharged into the canal from the mid-1970's until the construction of the Carolina Waste Water Treatment Plant in Vacia Talega in the early 1980's (Janicki 97). The mangrove distribution along the canal has decreased immensely. Only spots of mangroves can be found on the banks of the canals. From 1962 to 1987, the mangroves decreased from 399.54 acres to 187.83 acres respectively (Sect F).

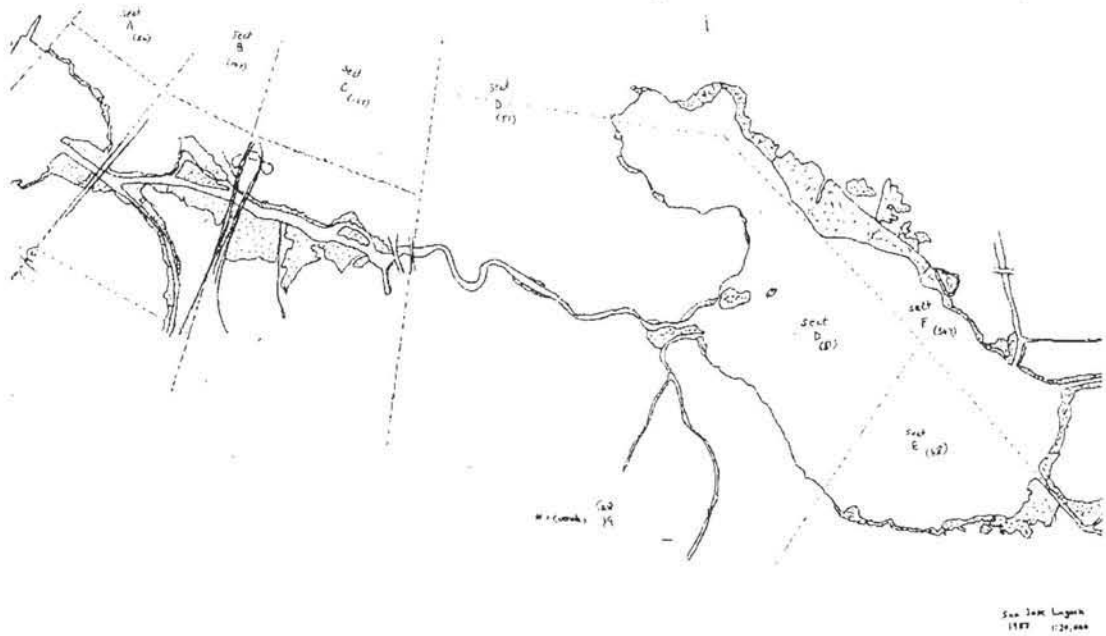

Figure 4-4: 1987 composite trace of aerial photographs and mangrove coverage

4.2.4 History of Laguna San José and Laguna Los Corozos

The Laguna San José had been at one time lined with extensive stands of mangroves totaling a cover of about 642 acres (260 hectares). These mangroves also bordered the Suarez Canal, and the Laguna Los Corozos, which is a small lagoon connected to the north bank of the Laguna San José. These two lagoons share the same water and in the 1950's had a volume of 10.2 million cubic meters. The surface area of these lagoons was 1,352 acres (547 hectares) with a maximum depth of 2.5 meters (8.2) feet.

Dredging of a possible drainage canal for Luis Muñoz Marin International Airport was completed by 1951. The mangrove coverage in 1962 was 444.81 acres. In 1967, the southeastern shore of the lagoon was being dredged to a depth of 11m (36 feet). The dredged material was possibly being used as fill for the development occurring around the lagoon. All dredging and filling operations ended in 1971. In this year, the mangroves covered an area of 178.65 acres. A public housing project had been constructed on a fill area along the western shore of the lagoon, north of the mouth of the Martin Peña Channel. The volume of the Laguna San José had increased to 13.2 million cubic meters by 1974. The water in the lagoon was greatly influenced by the discharge of chemicals and sewage into the neighboring Caño Martin Peña and the Canal Suarez. In 1974, the mangrove coverage along the lagoon was 166 acres (67 hectares). This decreased to 157.85 acres in 1977, then increased to 230.66 in 1987 and to 385 acres (156 hectares) in 1989 (Janicki).

4.3 Mangrove Coverage around the Study Area

The mangrove coverage has been dramatically reduced in this century. The mangrove stands, which border the Caño Martin Peña have been reduced by 66.8%. The stands around the Laguna San José have been reduced by

53.5% and those around the Canal Suarez have been reduced by over 80%. All of this destruction in mangrove coverage started in the 1950's. After analyzing the land use maps, the mangrove inventory data, and the aerial photographs, we found that many mangroves were lost to urban development. The development of slums and the building of the Canal Suarez were the cause of the mayor loss in mangrove coverage. Since this initial destruction, the mangrove population has been rising. This was due to the elimination of the slums and the implementation of laws that protect the mangroves from being cut down.

Although the mangrove population is rising, there is still a concern with new urban development, which often times continues in mangrove areas. An example of this urbanization is the new Urban Train and new National Security Building. The Urban Train tracks are being constructed so that the train will travel above ground at a higher elevation than the streets. The area of mangroves cut for this project was not very large. The train travels over the mangroves along the Caño Martin Peña. The elimination of these mangroves is a threat to the natural environment. The National Security building, which is currently under construction, appears that it will contain docks at the rear for small boats. The dock is right on the bank of the Martin Peña. The travelling of these boats will most likely further pollute the channel.

Urbanization impacts the mangroves and the ecosystems in which they are found in other ways. Altering the input and output of runoff is one such example. We were unable to determine the mortality rate of the mangrove trees by means of the aerial photographs, therefore we cannot accurately determine if any loss in mangrove coverage could be attributed to pollution.

4.4 Observations

All of the sites had noticeable differences in amounts of trash, smell and turbidity of the water, and fauna. Quantifying all of this information was beyond the scope of this project. We did not have the resources in many cases. However, our observations helped guide our analysis and may aid the reader. The water in the Laguna San José and in the Caño Martin Peña appeared to contain the most pollution. The water at Isla Magueyes was the second most polluted water, and the water at Bahía de Jobos appeared to be the cleanest

Rhizophora line the pedestrian walkway along the Caño Martin Peña. The trees grow densely along the channel, their leaves are full and green, and the some of the trees have grown extremely tall. There is no development directly on the banks of the channel; mangroves dominate the shore on both sides except where the highways pass over the channel. There were animals and plants both on the trees and in the surrounding waters. A dark green fuzzy coat blanketed the nematophores of the Black Mangroves. This substance resembled moss. Tiny white insects lived on the underside of the *Rhizophora* leaves. They appeared to be in a larval stage; they were in white balls, without defined features. When the leaves were disrupted, by touching the balls or bending the leaves, tiny white flies emerged. Wings on their backs were identifiable, but the insects did not fly. They walked around the underside of the leaf. Small lizards, a few fish, and several bird species, including the white egret, were noticed frequently along the canal. We also observed an iguana swimming in the canal. According to Oscar Laguillo, pollution can cause albinism in mangroves. No albino mangroves were observed in the Martin Peña or in any of the other sites.

We observed more signs of oil and fecal pollution in the water on the eastern side of the walkway. Oil was clearly visible in the water and the area's smell resembled feces. This strong odor was present intermittently along the pedestrian walk, but it was never as powerful as it was on the eastern side. Mangroves, on the side opposite the walkway on the eastern end of the canal, suffered most from the effects of hurricane George, which hit last year. Broken limbs and debilitated trees were visible. Trash was present all over the canal with a large concentration on the western side. Visibility within the water is extremely poor. The Caño Martin Peña appeared to have the worst pollution of the sites we sampled, but housed a surprising amount of wildlife.

Mangroves surround the Laguna San José, creating a wall of trees. A thin, strip of trees grow between the development on the western edge and the water. On the eastern and northern shores, the mangrove forest is deeper. The same green moss like substance observed in the Martin Peña was apparent on the trees of the lagoon. The lagoon had an odor similar to the channel, but it was weaker and more evenly dispersed in the lagoon, as supposed to the pockets of scent found in the channel. Suspended solids blocked clear visibility in the water. Trash was scattered on the banks of the lagoon. The entrance to the Caño Martin Peña is blocked by trash accumulation. *Rhizophora* have spread onto trash piles and appear to be growing steadily on them. Some of these *Rhizophora* have been cut and houses have been built were they once were. No albino mangroves were noticed in the Laguna San José.

The mangrove trees appeared to be shorter at Isla Magueyes. This observation was confirmed by the Luego and Snedakar's (1974) findings. Trees on the western side of the island appeared to be healthy. The trees on the eastern shore had not entirely recovered from the hurricane. Some of the branches were broken and a trail that once circled the island was cut off by fallen trees on the western side. The roots of the *Rhizophora* were more red at Isla Magueyes than at the other sites. The roots were also covered with yellow fungi. Mangroves formed an unbroken ring around the island.

There was once a zoo at the site in Isla Magueyes. When the zoo was changed into a research station, many of the animals were left on the island. Cuban iguanas, some up to four feet long, were one of the species left on the island and are prevalent today. Many species of birds and smaller lizards were also observed on the island.

The water appeared to be cleaner at Isla Magueyes than it had been at the San José Lagoon and the Caño Martin Peña. The water lacked the high amounts of suspended particles, making the water extremely clear. It also lacked the fecal and oil odors found at the San Juan sites. There was a boat dock on the southern coast of the island, where we saw a small trace of oil in the water. There were houses along the mainland, and the waters around the station are popular locations for boating and for riding jet skies, which leave unburned hydrocarbons in the water.

All of the samples taken at Bahía de Jobos were taken from the trees located in the water. We traveled 3,000 meters, out to the Cayos Caribes to take our samples. Trees at station F were noticeably affected by hurricane George. They had broken branches and smaller leaves. The trees exhibited no signs of pollution damage; the trees had full green leaves and were of normal size. Small lizards inhabited the islands in the bay. We also observed at least four dolphins in the bay.

The water was the cleanest in the Bahía de Jobos. Recreational boating is not as popular there as it is in Isla Magueyes, and the Bahía de Jobos lacks the odor found in the Laguna San José and the Caño Martin Peña. The water is not as clear as in Isla Magueyes but that is not necessary an indication that it is polluted. There were many large energy-producing plants on the mainland side of the bay, but most of them have been shut down for many years. We sampled trees with 3,000 meters of open bay between them and the old power plant so the effects of the plant was minimal.

4.5 Water Samples

Throughout the course of this project, several water quality assessments were made within the Laguna San José, Isla Magueyes, and Bahía de Jobos. Testing equipment was provided by the Sea Grant College of UPR Mayaguez. Included were chemical test kits for nitrates, nitrites, ammonia nitrogen, phosphate, and dissolved oxygen. At the majority of sample locations, the levels obtained using the chemical test kits were below measurable levels for all but the dissolved oxygen titration test. Neither the conductivity meter for dissolved solids nor the meter for salinity testing functioned properly, although the salinity meter did provide enough information the make a comparative analysis between test locations. Because the pH meter consistently registered high acid values of three or less, litmus paper was used for pH testing instead. The results of our water sampling are found in Appendix B.

4.5.1 Historical Water Quality in the Laguna San José

The USGS has monitored water quality in the Laguna San José from 1974 to the present. They take water samples at a site 0.3km east of the Caño Martin Peña and 200m south of the Isla Guachinango. This site is in the southern portion of the lagoon; it has a latitude value of 18°25'50" and a longitude of 66°02'12". The pH and temperature levels were within the ranges mangroves grow best in. Fecal coliform levels were higher than the normal level of fecal coliform in a mangrove forest. Dissolved oxygen, nitrates, nitrites, and phosphates were close to average levels in a mangrove ecosystem.

The range of pH preferred by mangroves is between 4.8 and 8.8 (Cintron, 1985). The mean pH in the Laguna San José was 8.3. The pH fluctuated in and out of the healthy range until 1989-1990. At this time, the pH dropped into the healthy range and has remained there through 1997 (figure 4-5). In 1996, it approached the high end of the range but did not exceed it, and pH has been declining since then.

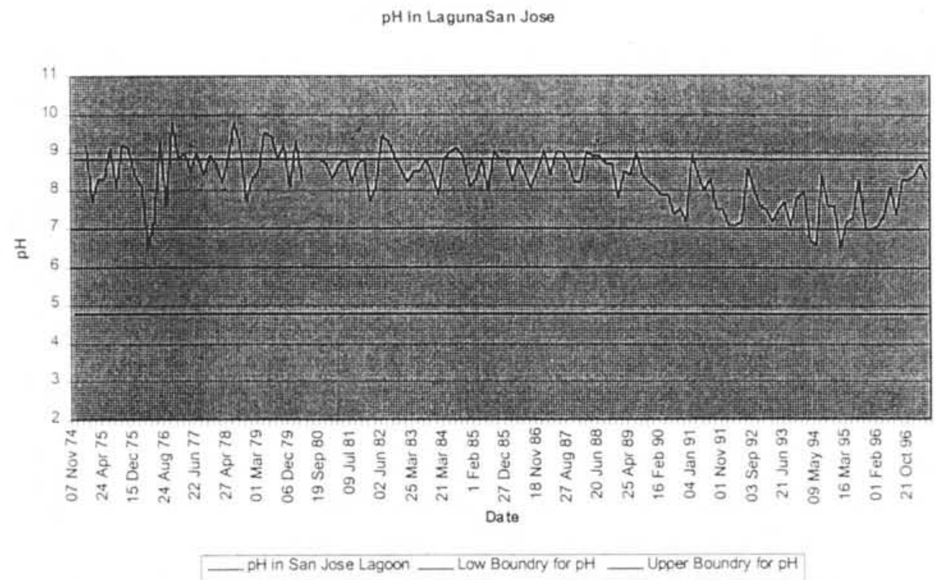

Figure 4-5: The pH in Laguna San Jose moved from a highly basic level to a normal level in the early 1990s.

The Laguna San José exceeded the pH range considered to be healthy for a mangrove forest intermittently between 1974 and 1989, during this period the water was highly basic. Alkalinity can be harmful to plant life because it transforms harmless ammonia ions into ammonium hydroxide, which is toxic to some plants (Webb and Gomez-Gomez, 1995). Ammonia ions are abundant in the lagoon making this transformation possible. At a pH of seven, ammonia and ammonium hydroxide exist in 300:1 ratio. At a pH of 9.5, the ammonia to ammonium hydroxide ratio plummets to 1:1 (Webb and Gomez-Gomez, 1995). The pH in the Laguna San José reached 9.8 on the dates of October 27, 1976 and July 27, 1978. Arial photographs from this period reveal that the mangroves survived in the basic water. However, they may have been harmed in other ways. The basic water could have stunted their development or production levels. It is also likely that the high pH harmed other types of plant life.

The temperature range considered to be adequate in a mangrove ecosystem is between 20 and 35 degrees C (Cintron, 1985). The water in the Laguna San José remained in this rage for the period studied (figure 4-6). The mean temperature was 28 degrees C. Many large industrial facilities and energy plants use water from nearby bodies of water to cool their machines. Several light industrial facilities are located along tributaries to the Laguna San José. Any increase to water temperature that these facilities cause is not substantial enough to raise water temperatures in the lagoon out of healthy ranges.

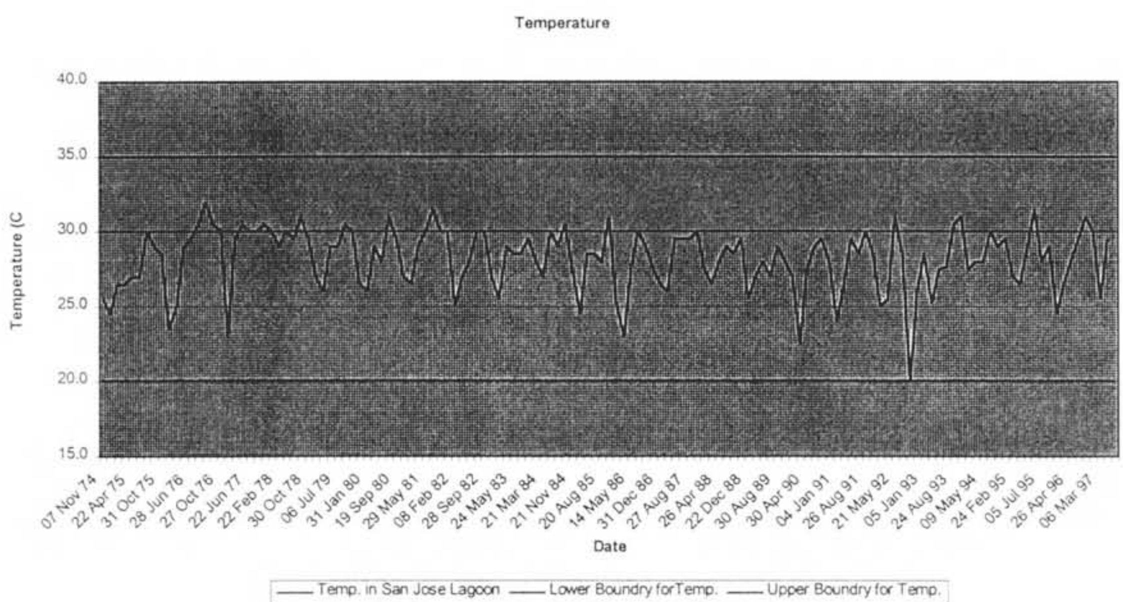

Figure 4-6: Temperature remained within the parameters for a healthy mangrove forest during the period studied.

The fecal coliform levels in the Laguna San José frequently and drastically exceed this mark (figure 4-7). The USGS measured fecal coliform without a filter from 1974 to 1979, with a 0.7 um-mf filter from 1978 to 1990, and with a 0.45 um-mf from 1990 to 1997. Data collected with different filters cannot be compared. However, data collected by the same filter appears to fluctuate dramatically and above average levels. The average level of fecal coliform in a mangrove forest is 600 col/100ml of water. The mean fecal coliform level found in the unfiltered water was 98,534.84col/100 ml with a standard deviation of 226,266.9. The mean fecal coliform level found with the 0.7um/mf filter was 76,053.5col/100 ml of water, and the mean fecal coliform level found with the 0.45um/mf filter was 2031 with a standard deviation of 24,623. Some of the highest recorded levels include 760,000col/100 ml on November 25, 1981, and on November 24, 1982 and November 21, 1981 (with the 0.45 um-mf filter). On October 30, 1978, with the 0.7 um-mf filter, the highest fecal coliform level ever was recorded at 1,200,000col/100 ml of water.

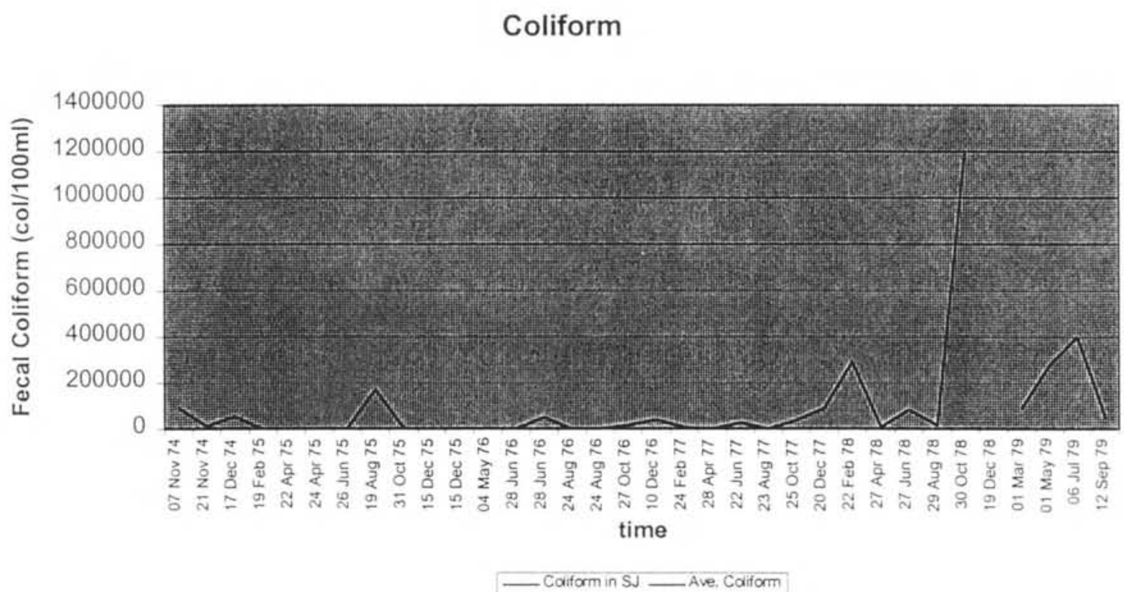

Figure 4-7a: Fecal Coliform levels often reach extremely high levels. It was measured using three different filters over three different periods. The average fecal coliform level is 600col/100ml. The levels get so high on the graphs that this average level does not appear.

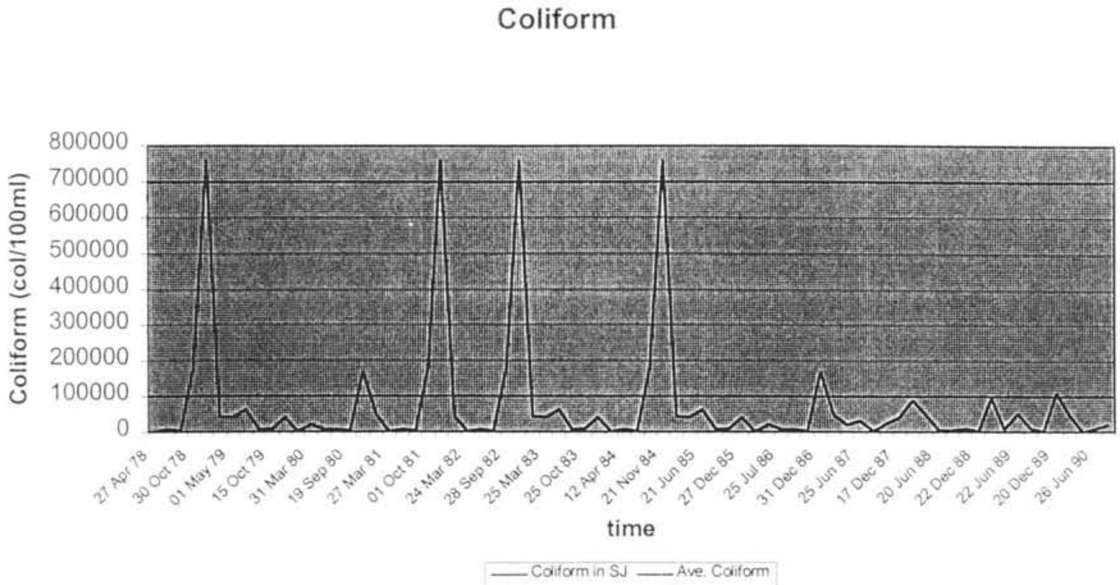

Figure 4-7b

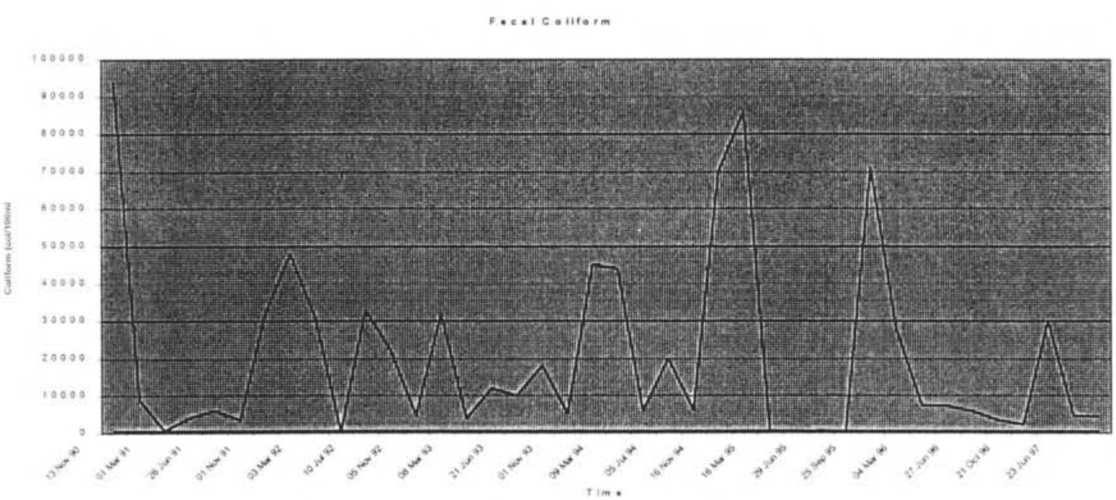

Figure 4-7c

The fecal coliform is an enteric bacteria that is found in feces and can be used to indicate how much feces is in a body of water. Human waste is by far the main contributor to fecal coliform levels in the lagoon. Fecal coliform has little direct effect on mangrove trees. However, human feces provides a breeding ground for organisms that can be pathogenic in humans. These pathogens often infect the human intestine. Excretion forces the pathogens out of the body into wastewater with fecal matter. Many of these pathogens continue to flourish in the contaminated water and can infect humans if the water is ingested. Typhoid, hepatitis A, cholera, and *E. coli*, can all be transmitted through water contaminated with feces.

Microorganisms break down fecal matter into simpler molecules. If fecal levels get too high and sufficient macronutrient levels are present, then microorganism populations can grow to levels that the ecosystem cannot handle and algae blooms can occur. Algae blooms deplete the water's oxygen supply and keep light from reaching the bottom. Because mangroves take in oxygen and sunlight through their leaves, algae blooms may not severely affect them. However, they are fatal to plants too short to break through the water's surface. Algae blooms can grow so dense that the dead microorganisms can displace the water and extend the shoreline. This water displacement can fill in lagoons, lakes, and streams. If the mangroves are cut off from the water, they will suffer.

Many of the homes in San Juan illegally connect their waste water pipes to street-water runoff pipes. Street water pipes are located above the waste water pipes to prevent contamination from the wastewater in the event of a leak.

It is easier and cheaper to connect wastewater to street runoff pipes because workers do not have to dig as deep to find the street water runoff pipes. This practice is common in San Juan (personal communication, Richard Webb), and may lead to the high levels of coliform in the lagoon. The shores of the Laguna San José are largely undeveloped, but the few houses there could be piping waste directly into the water. The banks of the tributaries that feed the lagoon are lined with development. They could also be dumping sewage into the canal, which would increase coliform levels in the lagoon. Sewage treatment plants pipe their processed waste out into offshore ocean waters, so they are not contributing to the fecal coliform levels in the lagoon (Ruben Gonzales, personal communication).

The average dissolved oxygen level in the Laguna San José was 7mg/L. The average dissolved oxygen level for a mangrove forest is 4mg/L (Cintron, 1985). The dissolved oxygen levels in the lagoon drop below this level for short periods, but are, for the most part, above average with a large spike between 1991 and late 1992 (figure 4-8). Mangrove growth is unaffected by oxygen rich water, and many fish and smaller plants may be helped by the high oxygen levels. High levels of dissolved oxygen are not expected in waters infected with algae blooms. The abundance of oxygen suggests that there is not a problem with algae blooms in the lagoon, despite the high fecal coliform levels.

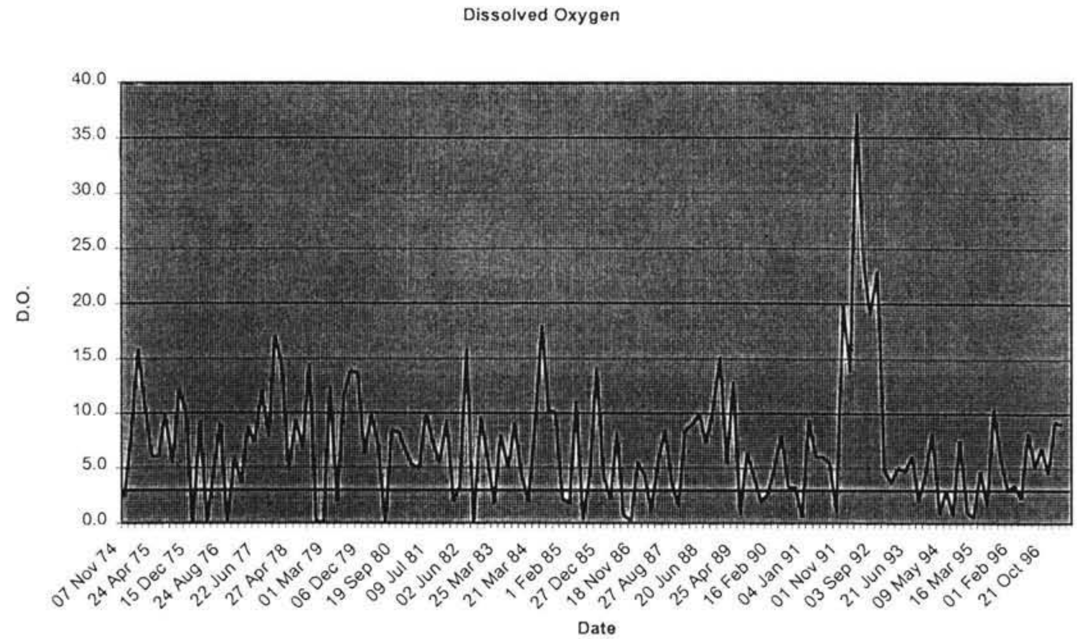

Figure 4-8: Dissolved oxygen has fluctuated within and above the average range, indicating the unlikelyhood of an algae bloom

The mean ammonia concentration is 0.87 mg/L. The average concentration of ammonia for mangroves is 0.073 (Cintron, 1985). Figure 4-9 indicates no increasing or decreasing trend, but does show a spike in the period between late 1994 and the summer 1996. As mentioned earlier, in the presence of a basic solution (like in the lagoon), ammonia combines with hydroxide ions to form ammonium hydroxide, a compound lethal to some plants. Ammonia concentrations in the lagoon could be harmful to mangroves and other plants in the ecosystem. Microbes process ammonia transforming it into nitrates and nitrites. The process is quick, and therefore high ammonia concentrations suggest the ammonia had been introduced recently and constantly if high concentrations persist. Livestock and industrial waste are two common contributors of ammonia in an ecosystem (Renn, 1968).

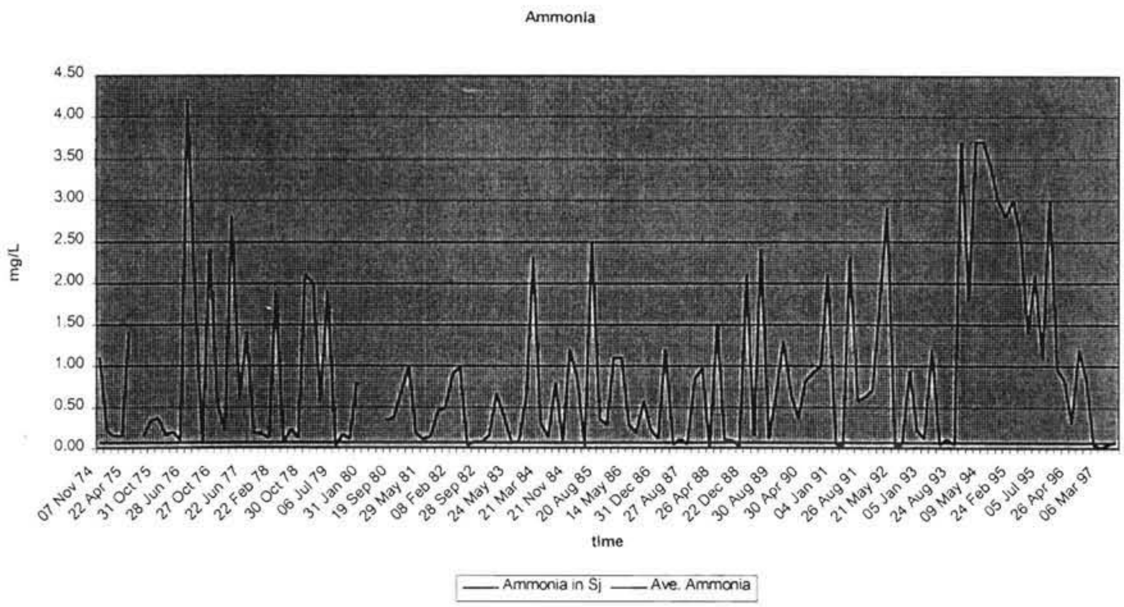

Figure 4-9: Ammonia levels exceed average values for a mangrove lagoon. Ammonia levels remain consistently high for in the early 1990s.

Nitrate and nitrite concentrations have mean levels of 0.030 mg/L and 0.026 mg/L, respectively. Average nitrate and nitrite levels are not far from the means in San José. The average nitrate level in a mangrove ecosystem is 0.01mg/L and the average level for nitrite is 0.003 (Cintron, 1985). Both graphs indicate a fluctuation above the average (figure 4-10). The USGS did not measure nitrates with every water sample so the nitrate data is incomplete.

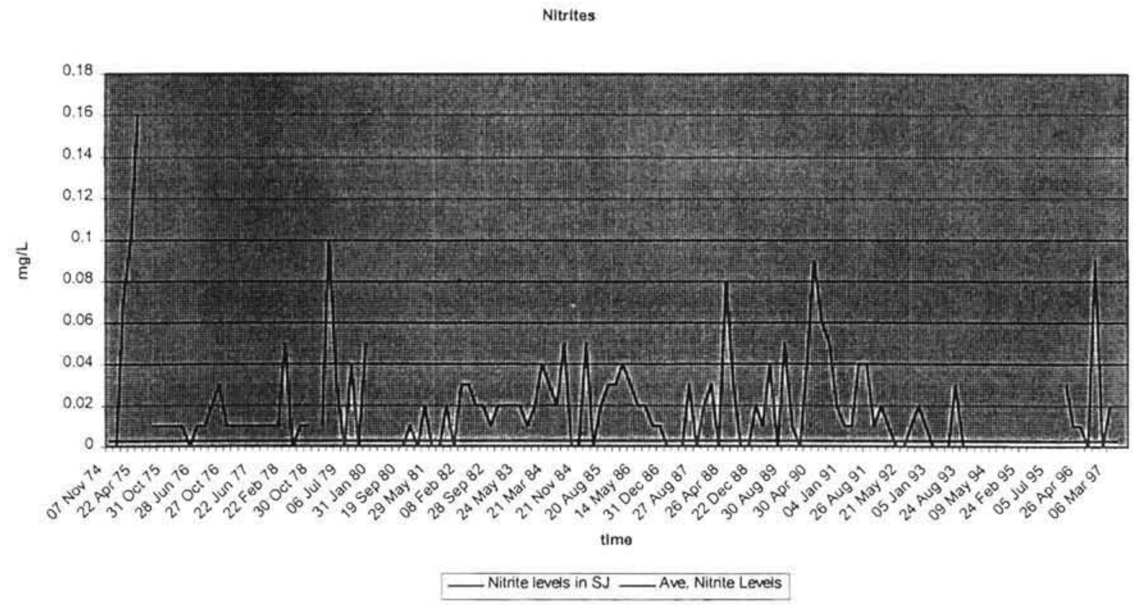

Figure 4-10a: Nitrates and Nitrites are above average values a mangrove lagoon.

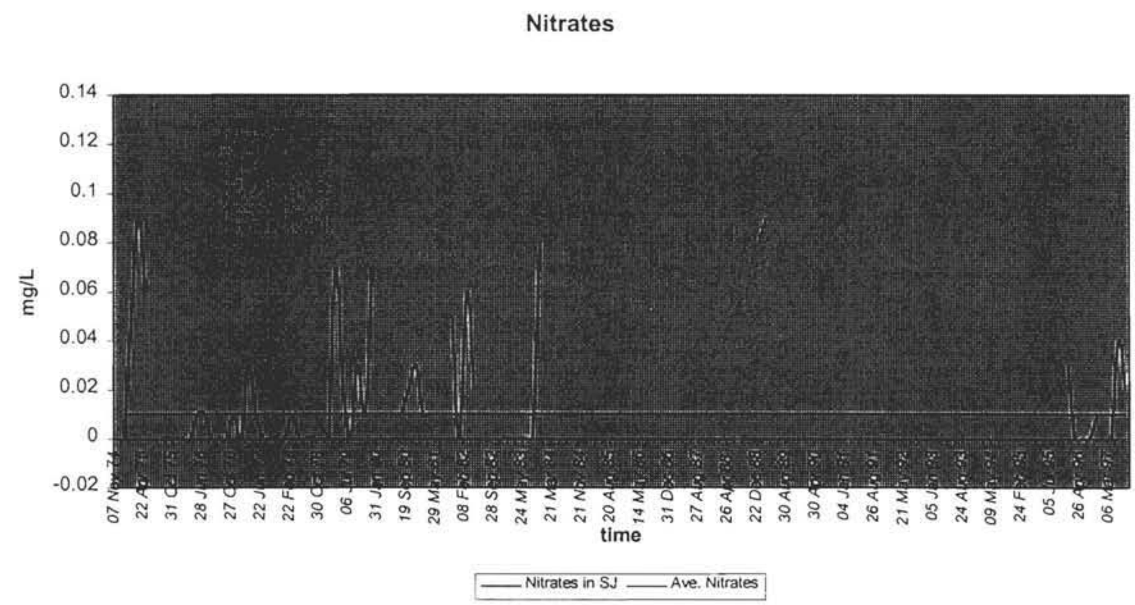

Figure 4-10b

Mangroves consume large amounts of nitrogen. If the nitrogen levels were below the average than the mangroves could be starving, but with the levels above average, the mangroves have an adequate supply of nitrogen. It is possible that high levels of nitrogen are getting into the lagoon and the mangroves are processing it so quickly the nitrogen does not show up in the water (Renn, 1968). Algae blooms could occur in water with high levels of nitrogen, but the dissolved oxygen levels indicate this is not the case. Agricultural runoff can cause increased nitrogen levels; nitrogen is a main ingredient in fertilizers. There is little agriculture in the area, which could keep nitrogen at a healthy level.

The mean phosphorous level was 0.579 mg/L. The average phosphorous level in a mangrove lagoon is 0.1 mg/L (Cintron, 1985). Phosphorous levels drop consistently throughout the period studied (figure 4-11). The since April 1996 the mean phosphorous level has been around 0.2 mg/L. Like nitrogen, mangroves feed on phosphorous. Unless phosphorous levels get so high that they create an algae bloom, it helps most plants. Agriculture is the main contributor of phosphorous to most lagoons. The lagoon is not exposed to too much agricultural runoff and has healthy phosphorous levels. Detergents in the United States used to contain phosphorous until the late 1970's when this became illegal (Kent Rissmiller, personal communication).

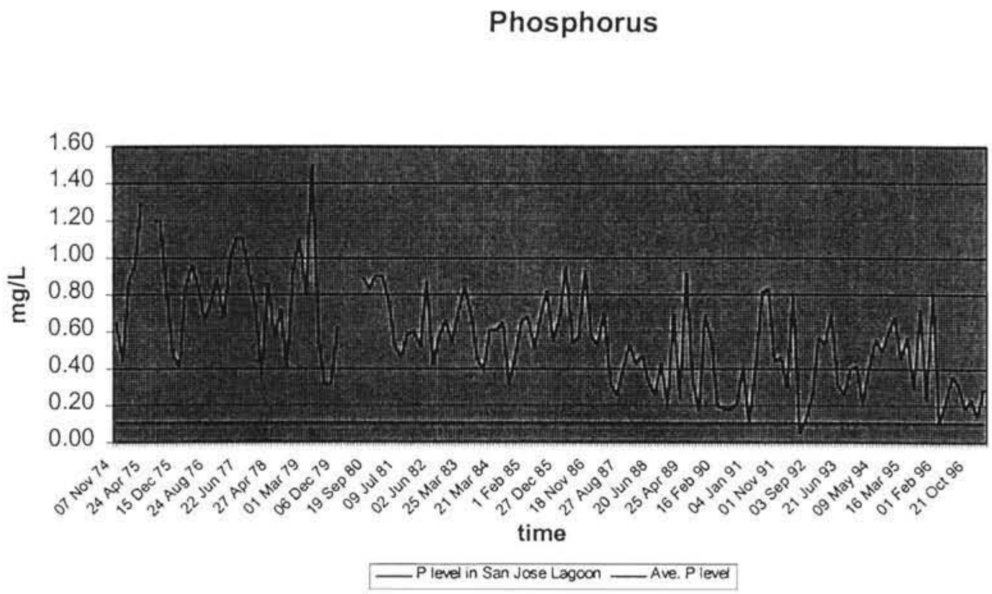

Figure 4-11: Phosphorus decreases throughout the period studied and got closet to the average.

4.5.2 Present Water Quality Data

We took water samples at Laguna San José, Caño Martin Peña, Isla Magueyes, and Bahía de Jobos. We measured nitrate, nitrite, phosphate, dissolved oxygen, pH, conductance, temperature, and ammonia. We found high levels of nutrients at the western end of the Caño Martin Peña. The conductance and pH meters did not function, and the data we collected with them was unusable. Temperature was within normal ranges at all locations. Dissolved oxygen was close to average levels at all sites indicating no algae bloom problem. However, dissolved oxygen did vary.

Dissolved oxygen in the Laguna San José increased going from west to east along the lagoon as depicted in figure 4-12. The western shore has the most development and the least mangroves. Without the mangroves, there is nothing to process the excess nutrients coming from the land. The excess nutrients on the western shore could cause a mild algae bloom which would lower the dissolved oxygen level. Oxygen is more soluble in colder water, but the temperature is lowest on the side with the lowest dissolved oxygen, indicating that the low levels cannot be attributed to high temperature.

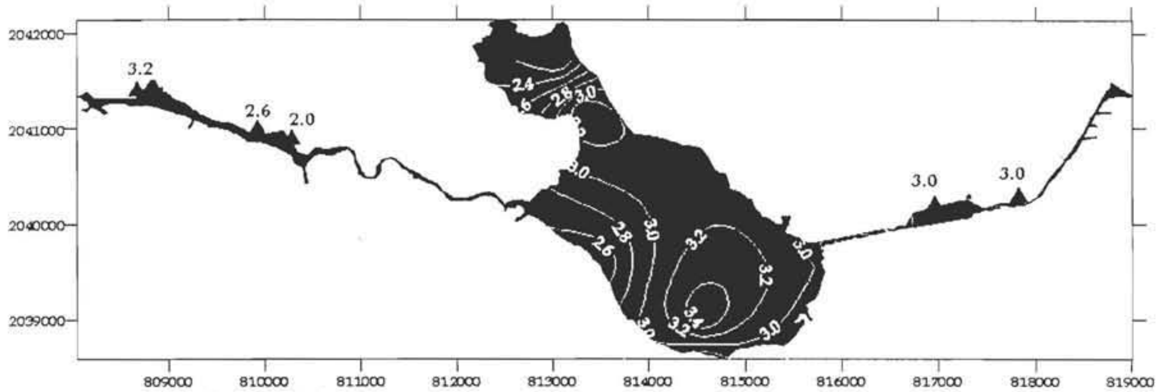

Figure 4-12a: Isobaric interpolation of dissolved oxygen in Laguna San José, Caño Martin Peña, and Canal Suarez. The indicated values should be doubled to expresss parts per million.

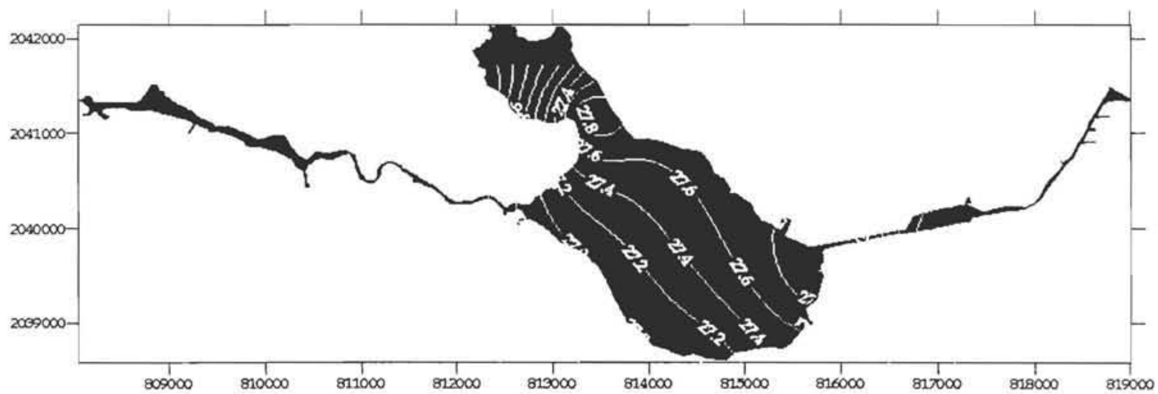

Figure 4-12b: Isobaric interpolation of temperature in Laguna San José, Caño Martin Peña, and Canal Suarez

At Isla Magueyes, dissolved oxygen was inversely related to oil pollution, suggesting the oil lowered dissolved oxygen levels. Dissolved oxygen levels were highest at sites 4 and 5. Sites 4 and 5 were subjected to the least oil contamination. Dissolved oxygen was lowest at sites 1, 2, 3, and 6. Sites 1 through 3 were located between the island and the mainland. The mainland is lined with the docks of large recreational boats parked next to houses. The boat dock for Isla Magueyes is located at site 6 (figure 4-13). These sites have the highest levels of oxygen and oil contamination.

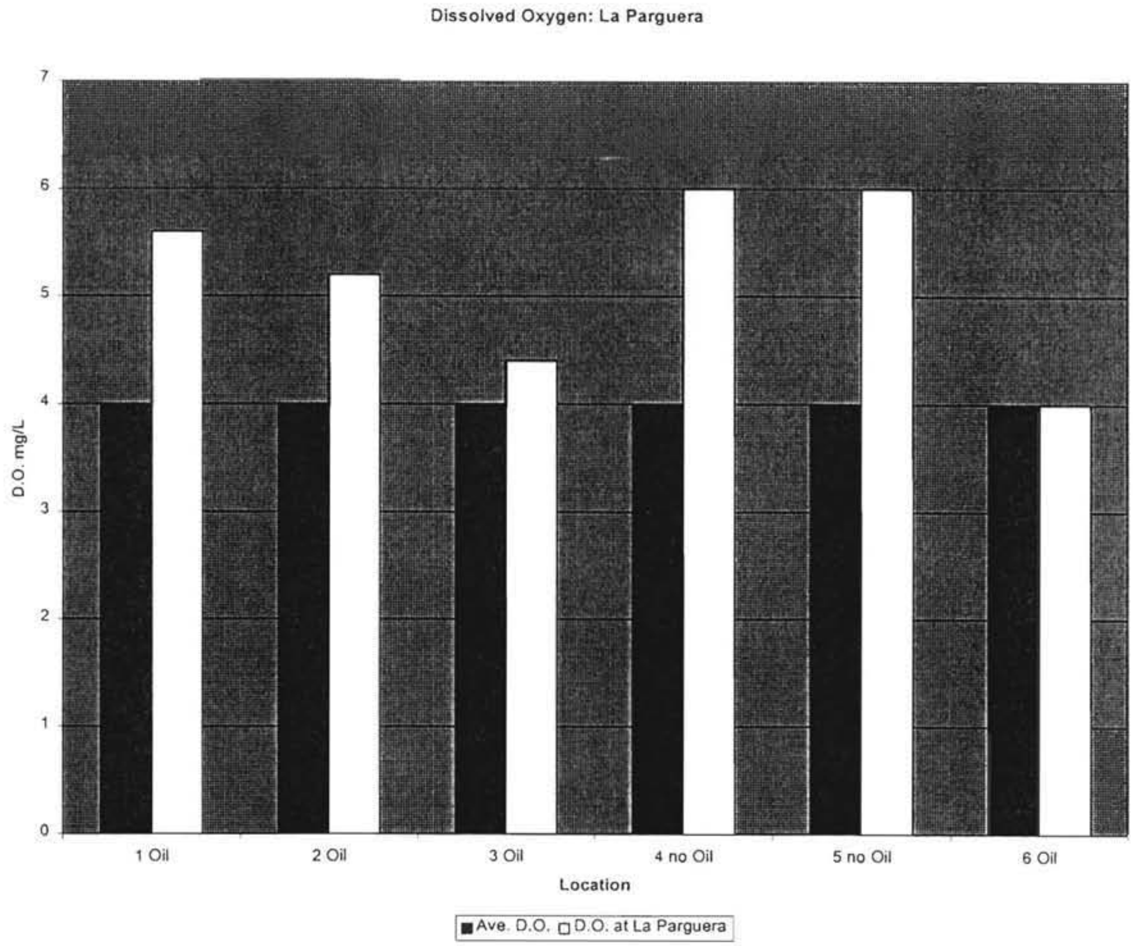

Figure 4-13: Dissolved oxygen levels within the sample sites on Isla Magueyes

There are three possible explanations for the correlation between low dissolved oxygen and visible oil contamination. Oil could be killing photosynthetic microorganisms, which produce oxygen, therefore lowering dissolved oxygen levels. Oil could also be harming the mangroves that produce organic material and inorganic nutrients for the photosynthetic microorganisms. As discussed later in the results, the leaves sampled at these sites were smaller than those at the unpolluted sites. This reduction in leaf size would lower the amount of biomass dropped in the water and therefore the amount of nutrients going to the photosynthetic algae, starving the algae, and lowering oxygen levels in the water. Dissolved oxygen could also be varying with changes in water temperature that randomly correlate with the polluted areas. The first two explanations suggest oil is altering the dissolved oxygen levels while the third suggests natural forces are altering oxygen levels.

The temperatures documented in La Parguera argue against the latter explanation. If higher temperatures were driving out the oxygen then higher temperatures should correlate with lower dissolved oxygen levels. This is not the case at Isla Magueyes. Site 3 has the lowest temperature and the lowest level of dissolved oxygen. High temperatures and low dissolved oxygen levels are not correlated at Bahía de Jobos providing further evidence that natural temperature fluctuations are not controlling the dissolved oxygen levels in these microclimates With increasing temperature, dissolved oxygen goes up at all sites, contrary to what would occur if only natural variation in temperature controlled the dissolved oxygen. As mentioned earlier, low temperature correlates with low dissolved oxygen in the Laguna San José as well. This evidence supports the first two theories—oil is affecting dissolved oxygen.

We found high nutrient levels at the far-western site on the Caño Martin Peña. The nitrite level at this site on the canal was 0.06mg/L, while the standard average is 0.003mg/L. The ammonia levels were 3mg/L and 4mg/L and the standard average level is 0.073mg/L, and the phosphates level was 1mg/L and the standard average level in a lagoon is 0.1mg/L. This site was located where the pedestrian walkway meets the land. The samples were taken from the land under the walkway. Adjacent to the end of the walkway is the Parque Central. The grasses are fertilized at the park and the runoff from the park most likely causes the unusually high levels of nutrients.

4.6 Leaf Samples

Leaf samples were collected at Caño Martin Peña in San Juan, Isla Magueyes in La Parguera, and the Cayos Caribe in Bahía de Jobos. These leaf samples were analyzed in two ways. The length to width ratio was measured based on the theory that pollutants can affect this ratio. The leaf sizes were also analyzed, as pollutants and salt are known to affect leaf size (Lugo, 1977).

4.6.1 Length to Width Ratios

Dr. Oscar Luguillo, an expert on mangrove genetics in Puerto Rico, communicated to us a hypothesis that pollution stresses can cause the leaves of a mangrove tree to deviate from their normal, healthy length to width ratio. More simply, pollution causes mangrove leaves to either become relatively thinner or wider. With this theory in mind, we analyzed the length to width ratios with respect to where they were taken from. Statistical significance was determined by performing t-tests assuming unequal variances. Tests which resulted in a p-value of less than 0.05 showed a significant difference in the means. Therefore, sample pairs with p-values above 0.05 were placed in the same significance group. Significantly similar groups were identified on the graphs by the same lowercase, italicized letter.

We did not see any discernable trends in the ratio data when analyzed by site. Figure 4-14 shows the mean length to width ratio for each site that we studied. The average ratios seem to vary without pattern from place to place. The data was also compiled into total averages for each of the three locations and is presented in Figure 4-15. This plot shows us that while each location has a significantly different mean length to width ratio, these ratios do not follow the pollution trends. Gilberto Cintron proposed that the average length to width ratio for a healthy red mangrove tree is around two. The location with the mean ratio closest to this ratio is Caño Martin Peña, by far the most polluted of our three study areas. Bahía de Jobos, the least polluted of the locations, has a mean ratio between those of Caño Martin Peña and Isla Magueyes. At Isla Magueyes, which has some oil pollution, but certainly not as much pollution as in Caño Martin Peña, the leaf ratio is highest. Therefore, although there is something affecting the length to width ratio of the leaves that we sampled, our data does not support a correlation between pollution levels and leaf ratio. This is could be due to the affect of the numerous variables involved; oil, salinity, and water temperature.

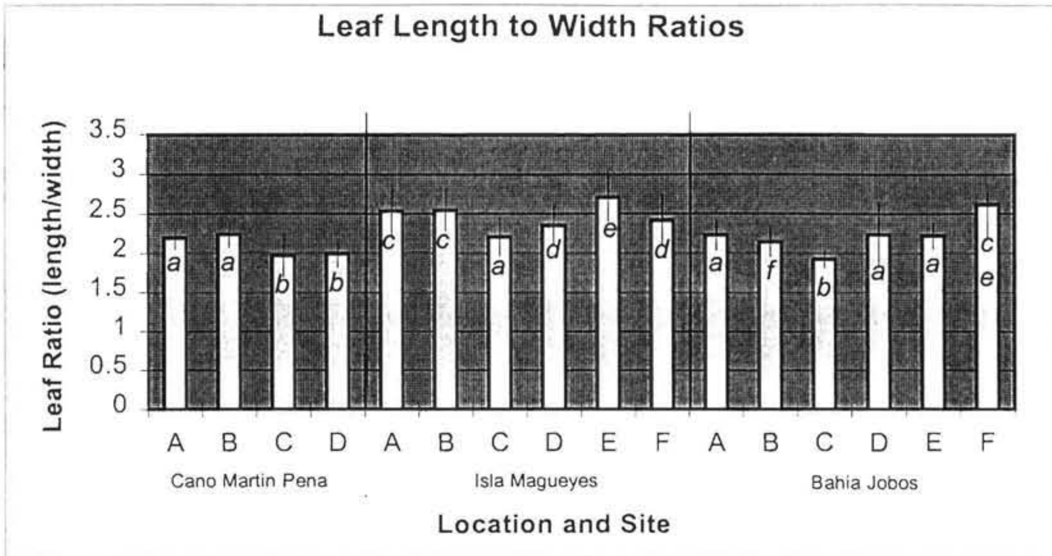

Figure 4-14: Leaf length to width ratio means presented by site. Means are represented by columns with lines showing the standard deviation. Significance is denoted by lowercase italicized letters.

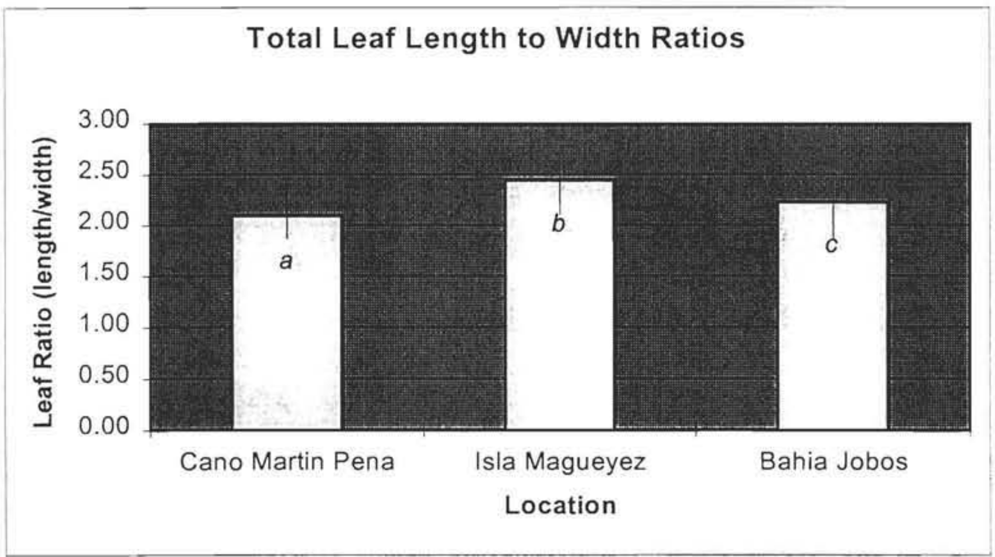

Figure 4-15: Leaf length to width ratio means presented by location. Means are represented by columns with lines showing standard deviation. Significance is denoted by lowercase italicized letters.

4.6.2 Leaf Size

With the length and width data we collected, we were also able to analyze the discrete leaf size in the areas we sampled. Leaf size is related to the health of the tree because a reduction in the surface area of the leaves reduces the trees ability to carry out photosynthesis, the essential function for their survival. In order to compare the lengths and widths between samples at the same time, we calculated a rectangular approximation of leaf area by multiplying the average length to the average width within each site. This calculation approximates an average surface area of the leaf. Statistical significance was determined between the overall lengths and the overall widths of the three sites. They are displayed in the same manner as with the ratio data.

We must consider a few factors that affect leaf size. The salinity of the water mangroves grow in has a direct effect on the leaf size. As the salinity increases, the size of the leaves decreases (Lugo, 1977). Oil also reduces the size of leaves (Chan, 1976). A small amount of oil can have a profound effect on the leaf size, while salinity needs a relatively large change for a noticeable difference (Lugo, 1977). Excess nutrients in the water causes mangrove trees to have larger leaves (Cintron, 1984). The primary source for nutrients is terrestrial runoff, therefore the San Juan systems should have higher nutrient levels than either Isla Magueyes or Bahía de Jobos, which receive very little runoff from the land. This assumption is supported by our water quality data. We considered all three factors—salinity, oil, and nutrients—in our analysis of the leaf size.

Figures 4-16 and 4-17 show that the leaves on the Caño Martin Peña are only slightly larger than the leaves at Isla Magueyes. Since the salinity is so much lower and the nutrients are much higher in Caño Martin Peña, we expected that the leaves would be much larger. The most likely reason for the reduction from that expected is oil pollution. We noticed considerable amounts of oil floating on the surface of the water. This observation was more obvious on some parts of the canal than others, as discussed later. From these findings, we conclude that oil is having a considerable effect on the health of the trees in the Caño Martin Peña.

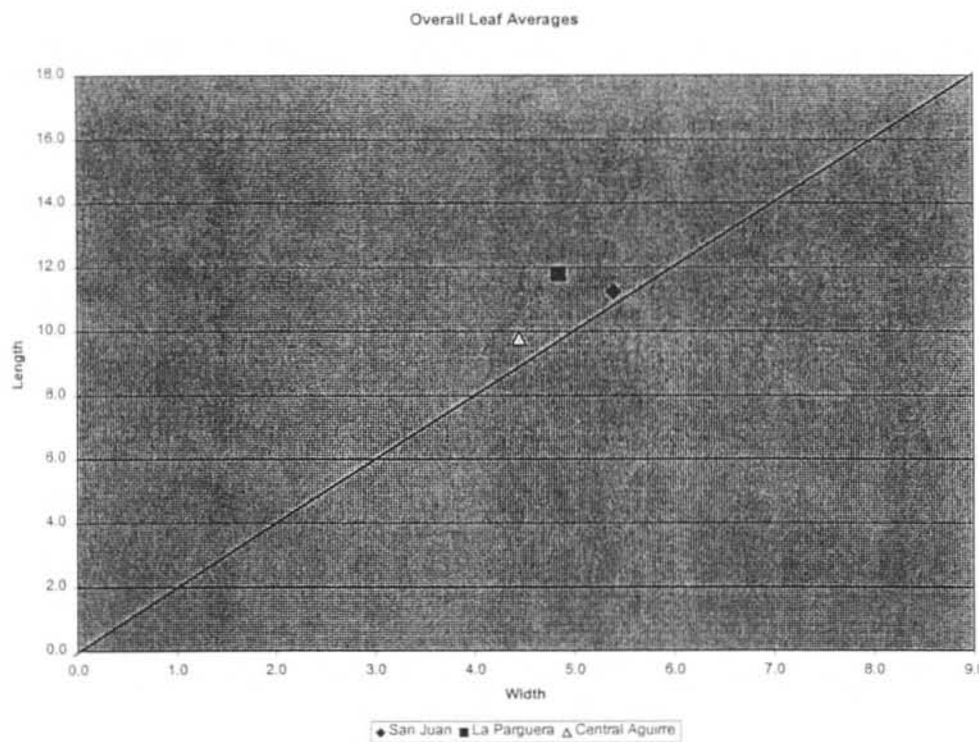

Figure 4-16: Scatter plot of overall mean leaf sizes for each of the three sample areas. The diagonal line represents a 2:1 length to width ratio.

Figures 4-16 and 4-17 also show a larger difference in leaf size between Isla Magueyes and Bahía de Jobos than the difference between Martin Peña and Isla Magueyes. Since Isla Magueyes and Bahía de Jobos have similar salinity and nutrient levels, we expected that the sites would have similar leaf sizes. The smaller leaf size cannot be attributed to oil, since Bahía de Jobos has the least noticeable oil pollution of all the sites. The reason for the difference is most likely sampling bias. The trees on Isla Magueyes were sampled on the inland side of the mangrove strip, while the Bahía de Jobos trees were sampled from a boat. We observed in the field that leaves collected on the waterline are smaller than leaves collected inland, therefore those two locations cannot be compared accurately either. This observation is supported by the data displayed in Figure 4-17, which shows that the rectangular approximation of area of leaves at Bahía de Jobos are much smaller than that at the other two sites.

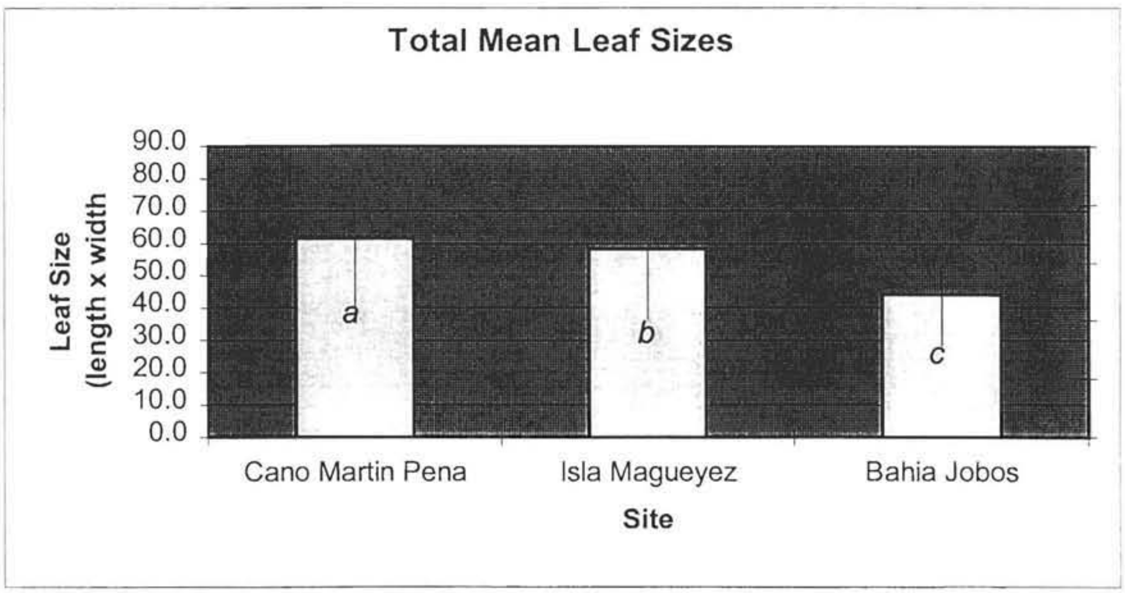

Figure 4-17: Mean rectangular approximated leaf size by location. Means are represented by columns with lines showing standard deviation. Significance is denoted by lowercase italicized letters.

The leaf sizes of each site within the Caño Martin Peña correlate with our observations. Figures 4-18 and 4-19 show that site A had the smallest leaves. This site is also where there was the largest amount of oil floating on the surface of the canal. As discussed earlier, oil pollution has been shown to cause a considerable reduction in leaf size.

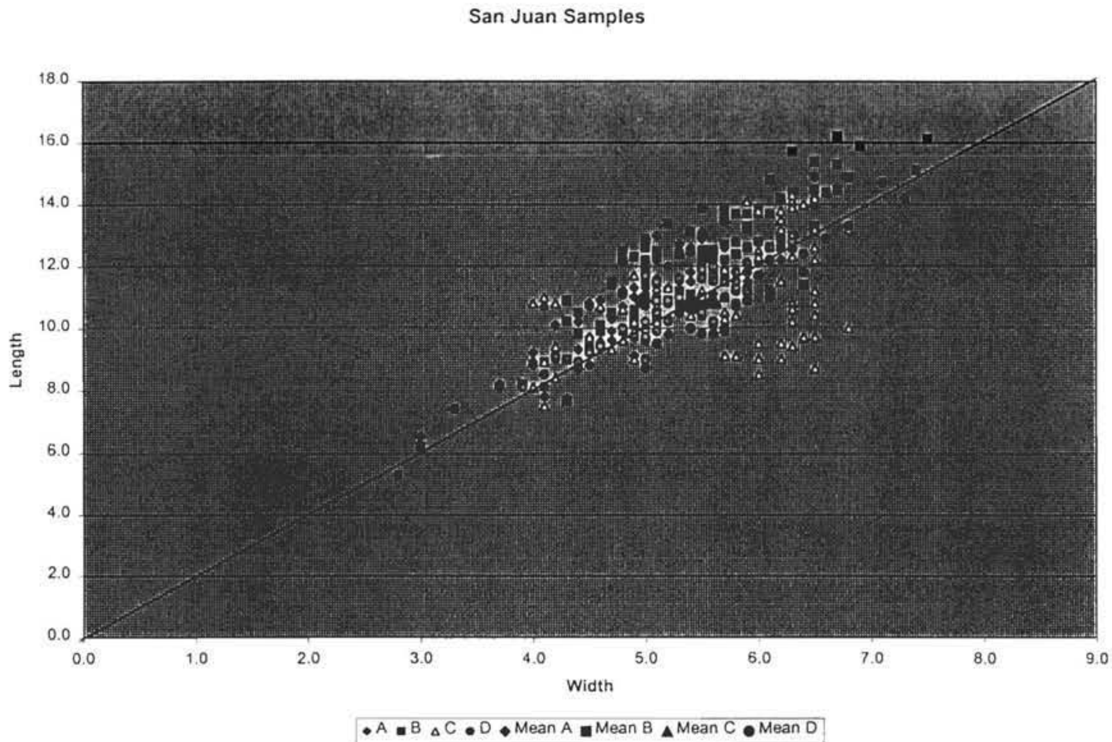

Figure 4-18: Scatter plot of leaf sizes within Caño Martin Peña. The diagonal line represents a 2:1 length to width ratio.

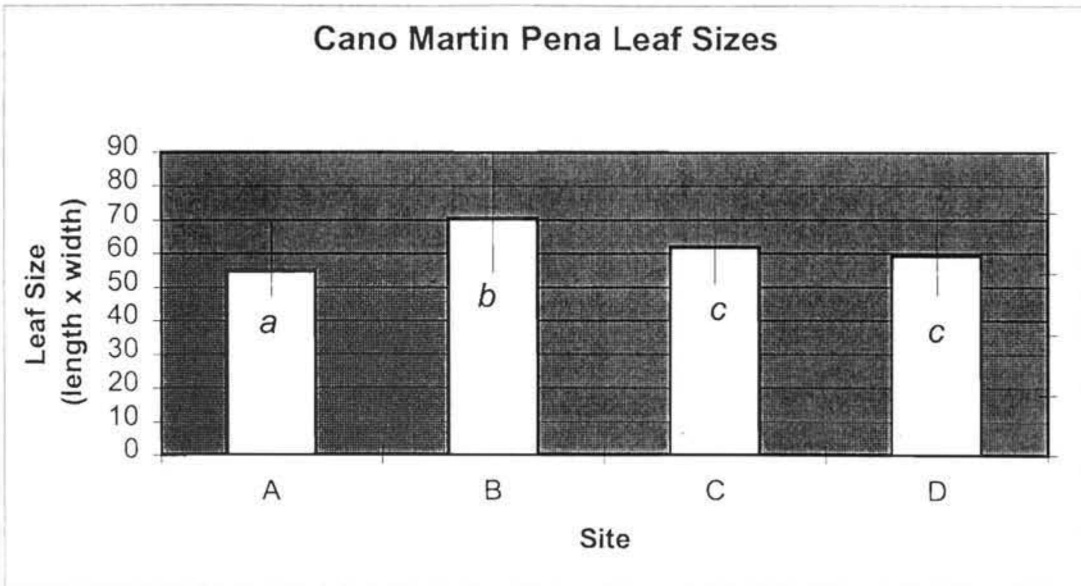

Figure 4-19: Mean leaf size indices by site on the Caño Martin Peña. Means are represented by columns with lines showing standard deviation. Significance is denoted by lowercase italicized letters.

The data for Isla Magueyes correlates very closely with observations around the island. Figures 4-20 and 4-21 show that the three sites with the smallest leaves are D, E, and F. Sites D, E, and F lie in or near the narrow channel between the island and the mainland, which is heavily traveled by boats. It is likely that oil exhaust from these boats is to blame for the smaller leaves as documented by Cintron (1985). Sites A, B, and C lie on the ocean side of the island, where the water is exchanged more readily. The water there, as we observed, was considerably clearer than in the channel. The larger leaf size observed at these areas is likely attributed to the cleaner water.

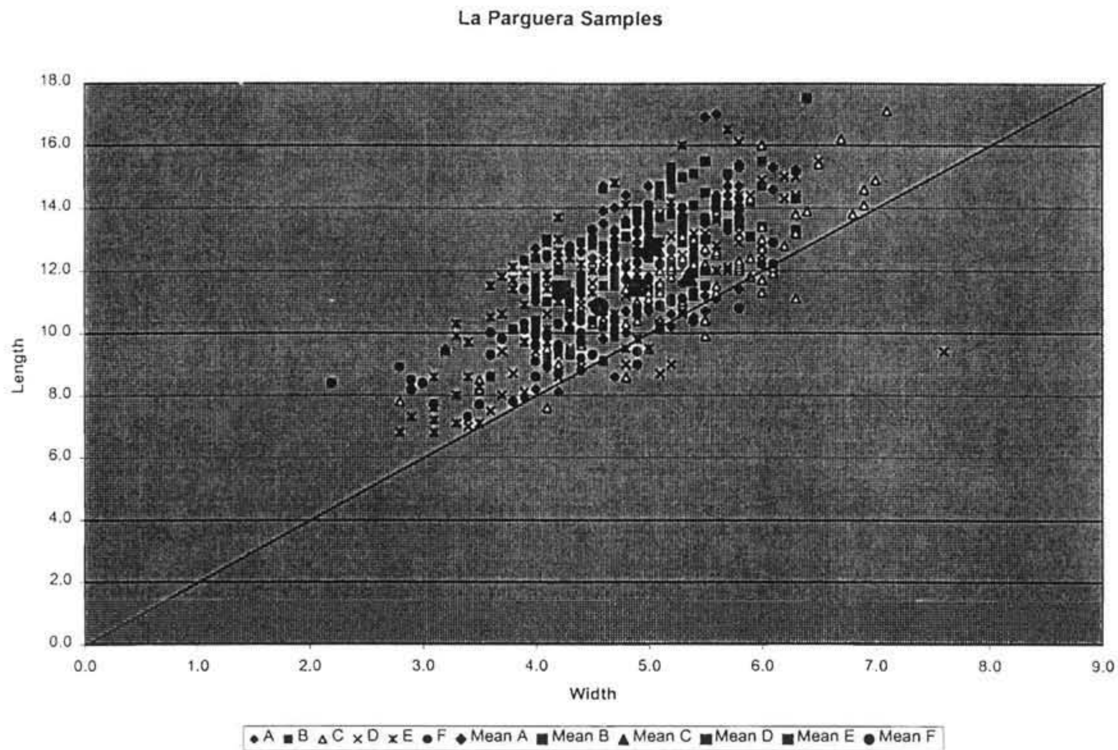

Figure 4-20: Scatter plot of leaf sizes on Isla Magueyes. The diagonal line represents a 2:1 length to width ratio.

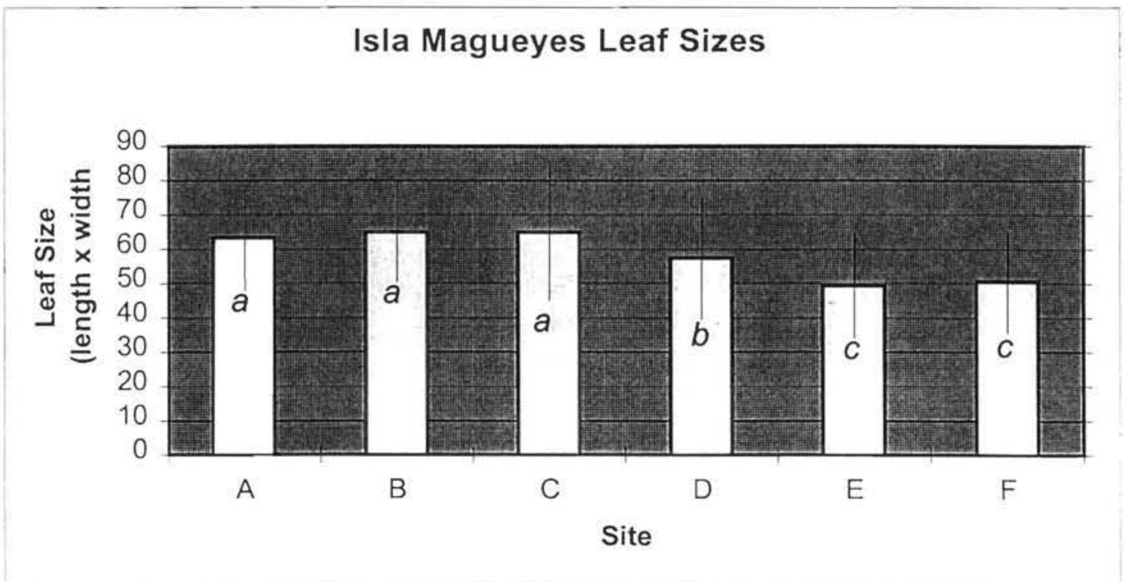

Figure 4-21: Mean leaf size indices by site for Isla Magueyes. Means are represented by columns with lines showing standard deviation. Significance is denoted by lowercase italicized letters.

It is difficult to discern trends in the data for Bahía de Jobos as displayed in Figures 4-22 and 4-23. The leaf size means rise and fall from site to site, and we are unable to correlate those changes with environmental observations. It is possible that the hurricane had different effects on each site due to their orientation to the storm. We think it is unlikely that oil or any other pollution has affected the leaves in Bahía de Jobos, since there is very little development around the bay and likewise little activity on the water. The electrical plant off the bay scaled back its operations years ago, and would not be discharging pollutants anyway, with the exception of some excess heat. We are unable to definitively explain the leaf size changes we observed between sites on the bay.

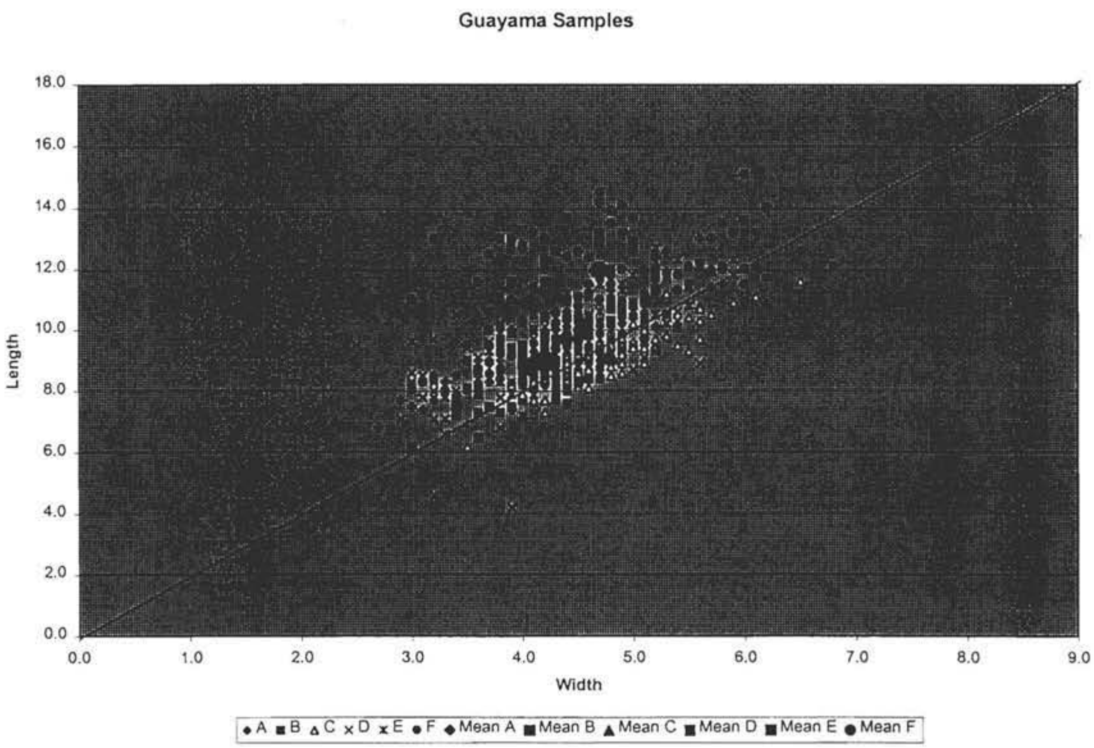

Figure 4-22: Scatter plot of leaf sizes on Isla Magueyes. The diagonal line represents a 2:1 length to width ratio.

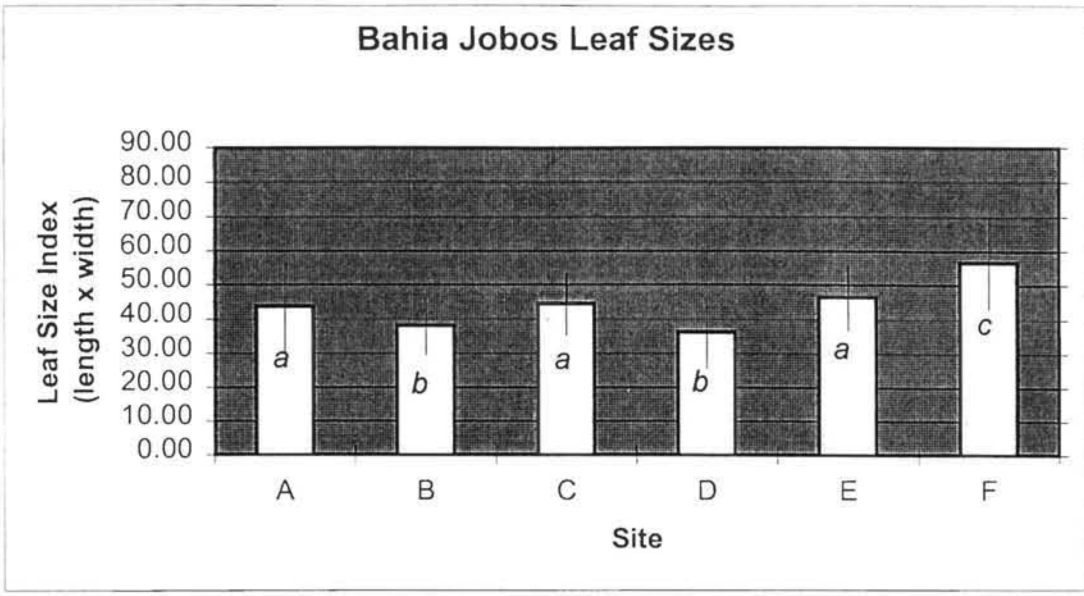

Figure 4-23: Mean leaf size indices for Bahía de Jobos. Means are represented by columns with lines showing standard deviation. Significance is denoted by lowercase italicized letters.

By comparing leaf size data between locations as well as analyzing the leaf size data within Caño Martin Peña and Isla Magueyes, we have determined that oil pollution is indeed reducing the size of leaves on the red mangrove trees. This morphological change reduces the ability of the trees to carry out photosynthesis and produce the energy they need. Therefore, oil is likely the most threatening form of pollution facing the mangrove populations in San Juan.

Chapter 5: Conclusions and Recommendations

In our analysis of the historical mangrove distribution data, we found that most of the loss in mangrove coverage can be directly attributed to urban expansion. The Governor, with the recommendation of the Secretary of Natural Resources, can declare commonwealth land as a commonwealth forest, which is protected from urban development. Although there are laws that protect the environment, if it is economically and socially more suitable for a piece of land to be urbanized, the Governor has the authority to deem a commonwealth forest as commonwealth land. The urge for continued expansion is putting great stress on the surrounding natural ecosystems. We found that laws do protect the mangroves, but ultimately they can be eliminated for the good of the commonwealth. We recommend that all further development around the Caño Martin Peña and the Laguna San Jose allow for a buffer zone between the shore and the urbanization. This zone would provide space for the mangroves to grow.

The data on water quality in Laguna San José from 1974 to 1997 indicates dangerously high fecal coliform levels. Fecal coliform tests measure the amount of human waste in a water sample. Human waste carries pathogens such as typhoid, hepatitis A, cholera, and *E. coli*. High levels of coliform put the public at risk of contracting these pathogens. According to Richard Webb of USGS, the waste-water pipes of some of the homes in the San Juan area are connected to the storm-water pipes, which empty into the lagoon, not the public waste-water pipes. Houses with wastewater pipes connected to storm runoff pipes must be identified and their pipes must be connected to the proper public sewage pipes. Some of the houses on the lagoon and along tributary streams may be dumping untreated sewage directly into the water. This practice needs to be further investigated. Other causes of the high coliform levels must also be identified and stopped.

Inorganic nutrient levels in Laguna San José are slightly above average. The main problem that could come from an increase in nutrients is an algae bloom. Algae blooms lower dissolved oxygen levels. The dissolved oxygen levels in the lagoon are above average, however, and we can conclude algae blooms and increased nutrient levels are not harming the lagoon. Ammonia levels in the water are also above average. Unlike nutrients, ammonia directly harms living organisms. We suggest an in-depth study of ammonia levels within the lagoon be done to determine if the effects of this toxin are harming the ecosystem.

The data on current water quality in the lagoon revealed that the dissolved oxygen levels near the western, more developed side of the lagoon, were lower than dissolved oxygen levels near the less urbanized areas of the lagoon. A study documenting long term changes in dissolved oxygen levels across the lagoon needs to be done in order to monitor changes in the oxygen levels in the water.

An analysis of the water quality tests conducted around Isla Magueyes in La Parguera demonstrated a correlation between oil pollution and low dissolved oxygen levels. The lowest dissolved oxygen levels at Isla Magueyes were above the mean oxygen level for a mangrove, however, further research on the effects of oil on dissolved oxygen levels couid help to save waters with low dissolved oxygen levels.

We analyzed the mangrove leaf length to width ratio data expecting to find a correlation either with salinity, oil pollution, or nutrient levels, or a combination of those factors. The data we collected, however, does not support the hypothesis as suggested by Dr. Laguillo. We did find significant differences in leaf ratios between the three locations we studied, but were unable to correlate these differences with any environmental factors. Perhaps the differences are simply do to the genetic variability of *Rhizophora mangle* from one part of the island to another (Laguillo, personal communication). We did, however, see a close grouping between leaf ratios within certain areas. Within one sample area, each grouping of three to four trees had a similar length to width ratio with respect to the rest of the area. Although we cannot find any correlation to environmental pollutants, we suspect there is something causing this distinction and a more focused study is viable. It is also possible that population genetic variability could have as much, if not more, effect on the leaf ratios than environmental conditions.

By analyzing leaf size data and pollution observations between the three locations of study, we determined that oil pollution is the major environmental threat to the mangrove forests. This conclusion is also supported by the leaf size data compared within each location. Sites within each area that had high levels of oil pollution showed statistically significant reductions in mean leaf size. We have therefore documented that oil pollution changes *Rhizophora mangle* leaf morphology and further postulate that this size change impairs the ability of the trees to carry out sufficient photosynthesis for growth. We found this to occur in the Caño Martin Peña of San Juan and at Isla Magueyes in Las Parguera. This shows that although the mangroves of the Paseo Linear are large and numerous, we cannot conclude that they are healthy due to the exposure to oil contamination. It has been shown that excessive and/or chronic oil contamination can devastate the distribution of a coastal mangrove forest (Lugo, 1977). We were unable to differentiate between the effects of deforestation and oil pollution when analyzing the historical reduction in mangrove distribution. That is to say that the mortality rate of the mangrove stands cannot be determined by analyzing maps and aerial photos that are more than five years apart. However, the effects of residual oil in the San Jan Bay Estuary System should be studied further.

Appendix A: National Sea Grant Program

The National Sea Grant Program is a network of research universities partnered with the National Oceanic and Atmospheric Administration (NOAA). They are dedicated to marine resource management, and strive to balance coastal development with conservation.

Congress passed the National Sea Grant College Program Act in 1966, which set up an alliance of 29 colleges and universities under the NOAA. The Sea Grant Program works with universities from the Great Lakes to Puerto Rico as well as schools on both coasts and Hawaii. Sea Grant is composed of a partnership between the government, academia, and industry. There are 29 Sea Grant programs working with over 200 universities around the country. The subdivision in Puerto Rico works with the University of Puerto Rico (Sea Grant Puerto Rico web page).

Sea Grant supports 450 graduate students each year along with small research projects (Altoonian et. al. 1998). To date, Sea Grant has supported the research of 12,000 graduate students. They also sponsor fellowships in marine policy in Washington DC, as well as private industry internships.

Sea Grant encourages the consciences management of coastal resources through research followed by education and public outreach. The organization conducts advanced research the results of which are often critical to the public, government officials, scientists, and the future of our marine resources. Sea Grant's research has lead to breakthroughs in AIDS and cancer research. The projects in Puerto Rico discovered a compound, which combats AIDS and cancer. The researchers found this compound in tropical marine sources. They also found an anti-inflammatory compound in tropical red algae. Sea Grant investigates local fisheries to determine optimal resource management strategies (Sea Grant Puerto Rico web page). Researchers at Sea Grant strive to gain a better understanding of marine biology and the environments relationship with society.

Sea Grant advances the general public's awareness of marine ecosystems by educating school children. They help developed curriculums for K-12 students in the marine sciences, and train elementary school teachers. Sea Grant also conducts open workshops and continued learning programs to further Educate the public.

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Rio Puerto Nuevo (Rio Piedras) Basin
Laguna San Jose No. 2 at San Juan, PR

Lat: 18□25'46"
Long: 66□02'10"

Date	Time	Depth at Sample Location (feet)	Specific Conductance (us/cm)	pH (Standard Units)	Water Temperature (Deg C)	Disolved Oxygen (mg/L)	Disolved Oxygen (Percent Saturation)	Nitrates (mg/L)	Nitrites (mg/L)	Ammonia Nitrogen (mg/L)	Phosphorus (mg/L)
07 Nov 74	1015	1	19800	xx	25.5	2.4		0.02	0	1.10	0.65
21 Nov 74	1010	1	11100	xx	24.5	8.0		0	0	0.21	0.44
17 Dec 74	1215	1	15000	9.2	26.5	15.8		0.05	0.07	0.15	0.87
19 Feb 75	1150	1	20000	7.7	26.5	10.6		0.09	0.1	0.15	0.96
22 Apr 75	1040	1	26200	8.3	27.0	6.1		0.06	0.16	1.40	1.30
24 Apr 75	1040	1	26200	8.3	27.0	6.1		xx	xx	xx	xx
26 Jun 75	1505	1	34500	9.1	30.0	10.0		0	0.01	0.16	1.20
19 Aug 75	1005	1	28000	8.1	29.0	5.4		0	0.01	0.34	1.20
31 Oct 75	1235	1	18000	9.2	28.5	12.2		0	0.01	0.37	0.81
15 Dec 75	1215	1	9800	9.1	23.5	10.0		0	0.01	0.17	0.47
15 Dec 75	1245	1	11000	8.4	25.0	0.0		0	0.01	0.20	0.41
04 May 76	1420	1	22500	8.1	29.0	9.2		0.01	0	0.09	0.84
28 Jun 76	1650	1	26000	6.5	29.5	0.0		0.01	0.01	4.20	0.96
28 Jun 76	1700	1	26000	7.2	30.5	4.8		0	0.01	1.80	0.84
24 Aug 76	1310	1	23000	9.3	32.0	9.0		0	0.02	0.08	0.66
24 Aug 76	1325	1	30800	7.6	30.5	0.0		0	0.03	2.40	0.76
27 Oct 76	1330	1	23000	9.8	30.0	6.0		0.01	0.01	0.54	0.89
10 Dec 76	1200	1	23000	8.8	23.0	3.6		0	0.01	0.22	0.67
24 Feb 77	1320	1	17500	9.0	29.5	8.7		0.03	0.01	2.80	1.00
28 Apr 77	1305	1	28000	8.5	30.5	7.3		0.01	0.01	0.61	1.10
22 Jun 77	1450	1	24000	9.0	30.0	12.0		0	0.01	1.40	1.10
23 Aug 77	1430	1	23500	8.4	30.0	7.8		0	0.01	0.18	0.92
25 Oct 77	1345	1	22000	8.9	30.5	17.0		0	0.01	0.18	0.74
20 Dec 77	1305	1	16000	8.7	30.0	14.4		0	0.01	0.13	0.37
22 Feb 78	1230	1	29500	8.2	29.0	4.8		0.01	0.05	1.90	0.86
27 Apr 78	1200	1	21500	8.8	30.0	9.3		0	0	0.07	0.57
27 Jun 78	1200	1	19800	9.8	29.5	6.8		0	0.01	0.23	0.72
29 Aug 78	1220	1	19200	9.2	31.0	14.4		0	0.01	0.13	0.41
30 Oct 78	1210	1	13000	7.7	29.5	0.2		xx	xx	2.10	0.93
19 Dec 78	1200	1	15500	8.3	27.0	0.0		0	0.01	2.00	1.10
01 Mar 79	1145	1	27000	8.5	26.0	12.4		0.07	0.1	0.58	0.80
01 May 79	1145	1	24400	9.5	29.0	2.0		0.02	0.03	1.90	1.50
06 Jul 79	1150	1	9660	9.4	29.0	11.5		0	<0.01	0.04	0.54
12 Sep 79	1310	1	11500	8.8	30.5	13.8		0.03	0.04	0.16	0.31
15 Oct 79	1235	1	9180	9.2	30.0	13.6		0.01	0	0.12	0.32
06 Dec 79	1040	1	7760	8.1	26.5	6.2		0.07	0.05	0.80	0.63
31 Jan 80	1025	1	12500	9.3	26.0	9.8		xx	xx	xx	xx
31 Mar 80	1320	1	20400	8.3	29.0	7.2		0.02	0.01	0.38	1.30
22 May 80	1515	1	27000	xx	28.0	xx		xx	xx	xx	xx
23 Jul 80	1050	1	27192	8.8	31.0	8.4		0.01	0	0.34	0.89
19 Sep 80	1120	1	27300	8.8	29.5	8.2		0.02	0	0.37	0.83
26 Nov 80	1505	1	20600	8.7	27.0	6.6		0.03	0.01		
30 Jan 81	900	1	22700	8.3	26.5	5.2		0.01	<0.01		
27 Mar 81	1200	1	22500	8.7	29.0	5.0		0.01	0.02		
29 May 81	1230	1	13700	8.8	30.0	10.0	131	0.01	<0.01		
09 Jul 81	1115	1	18100	8.2	31.5	7.4	100	xx	<0.01		
01 Oct 81	1145	1	19800	8.7	30.0	5.4	71	0.05	0.02		
25 Nov 81	1240	1	14400	8.8	30.0	9.2	128	xx	<0.01		
08 Feb 82	1235	1	12900	7.7	25.0	2.0	24	0.06	0.03		
24 Mar 82	930	1	20000	8.1	27.0	3.4	43	0.02	0.03		
02 Jun 82	1125	1	10600	9.4	28.0	15.8	200	xx	0.02		
03 Aug 82	1220	1	19100	9.3	30.0	0.0	0	xx	0.02		
28 Sep 82	1100	1	23000	8.9	30.0	9.6	126	xx	0.01		
24 Nov 82	945	1	26100	8.5	27.0	6.0	82	<0.01	0.02	0.16	0.54
08 Feb 83	955	1	23600	8.2	25.5	1.8	24	<0.01	0.02	0.66	0.71
25 Mar 83	1240	1	30500	8.5	29.0	8.0	115	<0.01	0.02	0.39	0.84
24 May 83	1010	1	11900	8.5	28.5	4.9	66	<0.01	0.02	0.08	0.69
25 Aug 83	1010	1	18800	8.8	28.5	9.0	123	<0.01	0.01	0.08	0.45
21 Nov 84	1310	1	14100	8.1	27.5	2.2	29		<.01	1.20	0.66
1 Feb 85	900	1	17200	8.3	24.5	1.8	23	0.05	0.05	0.84	0.68
25 Apr 85	850	1	26000	8.8	28.5	11.0	155		<0.01	0.03	0.51
21 Jun 85	1220	1	27700	8.0	28.5	0.3	4		0.02	2.50	0.69
20 Aug 85	850	1	22100	9.0	28.0	4.3	58		0.03	0.36	0.82

7 Nov 85	1310	1	10100	8.8	31.0	14.1	xx		0.03	0.29	0.55
27 Dec 85	900	1	14600	8.8	25.2	4.4	57		0.04	1.10	0.68
28 Feb 86	850	1	30700	8.2	23.0	2.2	29		0.03	1.10	0.95
14 May 86	1220	1	9500	8.8	27.5	8.2	108	0.08	0.02	0.29	0.54
25 Jul 86	850	1	24400	8.5	30.0	0.7	10		0.02	0.19	0.57
25 Sep 86	915	1	26200	8.1	29.0	0.2	3		0.01	0.57	0.93
18 Nov 86	1005	1	14000	8.6	27.5	5.5	73	0.09	0.01	0.22	0.57
31 Dec 86	830	1	16000	9.1	26.5	4.4	58	xx	<0.01	0.12	0.53
25 Feb 87	910	1	25000	8.4	26.0	1.2	16	xx	<0.01	1.20	0.70
30 Apr 87	920	1	13800	9.0	29.5	5.7	78	xx	<0.01	0.05	0.31
25 Jun 87	1030	1	11000	9.0	29.5	8.4	114	0.07	0.03	0.11	0.26
27 Aug 87	730	1	25000	8.7	29.5	3.6	51	xx	<0.01	0.05	0.40
23 Oct 87	1000	1	21000	8.2	30.0	1.6	21	xx	0.02	0.85	0.53
17 Dec 87	1005	1	14700	8.2	27.5	8.4	106	xx	0.03	0.97	0.43
25 Feb 88	1010	1	22000	9.0	26.5	9.0	112	xx	<0.01	<0.01	0.47
26 Apr 88	1050	1	11500	8.9	28.0	9.9	126	0.12	0.08	1.50	0.33
20 Jun 88	1015	1	23000	8.9	29.0	7.3	93	xx	0.03	0.11	0.26
19 Aug 88	1045	1	22300	8.7	28.5	10.1	128	xx	<0.01	0.10	0.43
20 Oct 88	1015	1	17000	8.7	29.5	15.1	197	xx	<0.01	0.03	0.20
22 Dec 88	1030	1	17800	7.8	25.5	5.4	65	0.08	0.02	2.10	0.70
27 Feb 89	1005	1	12500	8.5	27.0	12.8	157	0.09	0.01	0.16	0.24
25 Apr 89	905	1	25000	8.4	28.0	0.8	10	xx	0.04	2.40	0.92
22 Jun 89	945	1	22600	9.0	27.0	6.4	80	xx	<0.01	0.12	0.34
30 Aug 89	1045	1	13000	8.4	29.0	4.2	54	0.05	0.05	0.64	0.17
27 Oct 89	845	1	13000	8.2	28.0	2.0	25	xx	0.01	1.30	0.69
20 Dec 89	1030	1	9600	8.1	27.0	2.6	32	xx	<0.01	0.65	0.55
16 Feb 90	915	1	21000	7.9	22.5	5.0	56	xx	0.04	0.37	0.20
30 Apr 90	1055	1	26000	7.9	27.5	8.0	101	0.01	0.09	0.82	0.18
26 Jun 90	850	1	26500	7.4	29.0	3.3	42	xx	0.06	0.92	0.18
21 Aug 90	1015	1	24400	7.5	29.5	3.3	42	0.05	0.05	1.00	0.21
13 Nov 90	930	1	22400	7.2	28.0	0.6	xx	xx	0.02	2.10	0.41
04 Jan 91	910	1	18000	8.9	24.0	9.3	108	xx	0.01	0.05	0.10
01 Mar 91	1030	1	17700	8.4	26.5	6.1	74	xx	0.01	0.04	0.41
06 May 91	1145	1	22500	8.0	29.5	6.0	76	xx	0.04	2.30	0.81
26 Jun 91	930	1	27000	8.3	28.5	5.5	xx	xx	0.04	0.58	0.83
26 Aug 91	930	1	29000	7.5	30.0	1.0	13	xx	0.01	0.63	0.44
01 Nov 91	1005	1	32000	7.5	28.5	19.9	48	xx	0.02	0.71	0.46
02 Jan 92	910	1	23000	7.1	25.0	13.8	16	xx	0.01	1.70	0.30
03 Mar 92	825	1	26700	7.1	25.5	37.2	21	xx	<0.01	2.90	0.79
21 May 92	1230	1	22700	7.2	31.0	24.0	144	xx	<0.01	0.03	0.05
10 Jul 92	755	1	21000	8.6	28.5	19.0	69	xx	0.01	0.06	0.13
03 Sep 92	1215	1	24000	8.0	20.0	23.0	20	xx	0.02	0.94	0.26
05 Nov 92	800	1	13200	7.6	26.0	4.8	58	0.09	0.01	0.22	0.57
05 Jan 93	820	1	32000	7.5	28.5	3.7	48	xx	<0.01	0.12	0.53
08 Mar 93	1000	1	21000	7.2	25.2	5.0	59	xx	<0.01	1.20	0.70
04 May 93	930	1	12800	7.5	27.5	4.7	58	xx	<0.01	0.05	0.31
21 Jun 93	1025	1	14000	7.7	27.6	6.1	76	0.07	0.03	0.11	0.26
24 Aug 93	1045	1	22500	7.1	30.5	2.0	24	xx	<0.01	0.05	0.40
01 Nov 93	1100	1	10100	7.8	31.0	4.4	57	xx	xx	3.70	0.41
21 Dec 93	955	1	14600	8.0	27.5	8.2	108	xx	xx	1.80	0.21
09 Mar 94	1010	1	26800	6.7	28.0	0.9	1	xx	xx	3.70	0.41
09 May 94	945	1	34600	6.6	28.0	3.0	38	xx	xx	3.70	0.56
05 Jul 94	1020	1	24400	8.4	30.0	0.7	10	xx	xx	3.40	0.49
02 Sep 94	930	1	35400	7.6	29.0	7.5	96	xx	xx	3.00	0.59
16 Nov 94	950	1	28600	7.6	29.5	1.0	13	xx	xx	2.80	0.68
24 Feb 95	920	1	28600	6.5	27.0	0.5	7	xx	xx	3.00	0.45
16 Mar 95	845	1	32300	7.2	26.5	4.7	57	xx	xx	2.60	0.57
10 May 95	1020	1	30400	7.3	29.0	1.6	23	xx	xx	1.40	0.29
29 Jun 95	1120	1	23600	8.3	31.5	10.4	152	xx	xx	2.10	0.72
05 Jul 95	1020	1	32500	7.0	28.0	5.7	71	xx	xx	1.10	0.23
25 Sep 95	945	1	21700	7.0	29.0	3.0	41	xx	xx	3.00	0.81
01 Feb 96	920	1	18700	7.1	24.5	3.4	43	0.03	0.03	0.96	0.10
04 Mar 96	1000	1	27400	7.4	26.5	2.3	31	<0.01	0.01	0.83	0.21
26 Apr 96	1120	1	24200	8.1	28.0	8.2	112	<0.01	0.01	0.32	0.36
27 Jun 96	945	1	21500	7.4	29.5	5.1	66	<0.01	<0.01	1.20	0.31
30 Aug 96	1000	1	16500	8.3	31.0	6.9	97	0.01	0.09	0.82	0.18
21 Oct 96	1030	1	14900	8.3	30.0	4.5	58	xx	<0.01	0.04	0.23
06 Mar 97	945	1	16000	8.4	25.5	9.2	90	<0.01	0.02	0.02	0.14
23 Jun 97	1000	1	30000	8.7	29.5	9.0	117	0.40	0.02	0.05	0.29
09 Sep 97	1000	1	24000	8.3	31.0	10.2	137	0.02	0.02	0.08	0.36

Location: **Laguna San Jose**

Sample #	UTM Coordinates (WSG84)		Dissolved Oxygen	O_2 ppm	pH	Salinity		Nitrates	Nitrites	Phosphates	Ammonia Nitrogen	Temperature
	Longitude (E)	Latitude (N)				Conductivity	Salinity					
SJ001	19812333	2041464	2.1	4.2	6.0	72.1		< 0.2	< 0.02	< 1.0	1.0	26.0
SJ002	19813072	2041705	2.0	4.0	6.5	72.0		< 0.2	< 0.02	< 1.0	1.0	27.0
SJ003	19813316	2041209	3.4	6.8	6.5	73.0		< 0.2	< 0.02	< 1.0	< 1.0	28.0
SJ004	19813874	2040578	3.1	6.2	5.5	75.0		< 0.2	< 0.02	< 1.0	< 1.0	27.5
SJ005	19813493	2039573	2.4	4.8	6.5	72.0		< 0.2	< 0.02	< 1.0	< 1.0	27.0
SJ006	19813880	2038842	3.0	6.0	6.0	69.0		< 0.2	< 0.02	< 1.0	1.0	27.0
SJ007	19814577	2038587	2.6	5.2	6.0	72.0		< 0.2	< 0.02	< 1.0	< 1.0	27.0
SJ008	19814575	2038986	3.6	7.2	6.0	72.0		< 0.2	< 0.02	< 1.0	1.0	28.0
SJ009	19815763	2039532	3.0	6.0	6.0	72.0		< 0.2	< 0.02	< 1.0	1.0	28.0
SJ010	19816205	2039608	2.0	4.0	6.5	72.0		< 0.2	< 0.02	< 1.0	1.0	28.0
SJ011	19816918	2039796	3.0	6.0	6.0	72.0		< 0.2	< 0.02	< 1.0	< 1.0	27.0
SJ012	20183936	2039908	3.0	6.0	6.0	72.0		< 0.2	< 0.02	< 1.0	< 1.0	27.0

Location: **Cano Martin Pena**

Sample #	UTM Coordinates (WSG84)		Dissolved Oxygen	O_2 ppm	pH	Salinity		Nitrates	Nitrites	Phosphates	Ammonia Nitrogen	Temperature
	Longitude (E)	Latitude (N)				Conductivity	Salinity					
SJ013	19810388	2040518	2.0	4.0	6.0	86.0		< 0.2	< 0.02	1.0	4.0	27.0
SJ014	19810081	2040582	2.6	3.2	6.0	86.0		< 0.2	< 0.02	< 1.0	0.0	28.0
SJ015	19813316	2041209	1.0	2.0	7.0	88.0		0.06	< 0.02	1.0	3.0	27.5
SJ016	19813874	2040578	1.4	2.8	6.5	88.0		0.06	< 0.02	1.0	4.0	28.0

Location: **Isla Mayges**

Sample #	UTM Coordinates		Dissolved Oxygen	O_2 ppm	pH	Salinity		Nitrates	Nitrites	Phosphates	Ammonia Nitrogen	Temperature
	Longitude (E)	Latitude (N)				Conductivity	Salinity					
P001	19706957	1987855	2.8	5.6	7.0	81.0		<0.2	<0.02	0	<1	28.5
P002	19707088	1987819	2.6	5.2	7.0	82.0		<0.2	<0.02	0	<1	29.5
P003	19707331	1987658	2.2	4.4	7.0	82.0		<0.2	<0.02	0	<1	27.0
P004	19707032	1987554	3.0	6.0	7.0	84.0		<0.2	<0.02	0	<1	28.0
P005	19707119	1987547	3.0	6.0	7.5	80.0		<0.2	<0.02	0	<1	28.5
P006	19706869	1987676	2.0	4.0	7.0	82.0		<0.2	<0.02	0	<1	29.5

Location: **Bahla Jobos**

Sample #	UTM Coordinates		Dissolved Oxygen	O_2 ppm	pH	Salinity		Nitrates	Nitrites	Phosphates	Ammonia Nitrogen	Temperature
	Longitude (E)	Latitude (N)				Conductivity	Salinity					
G001	19795557	1984436	2.2	4.4	6.5	90		<0.2	<0.02	0	<1	28.0
G002	19795492	1984520	1.4	2.8	6.5	90		<0.2	<0.02	0	<1	27.0
G003	19795450	1984182	1.8	3.6	7	90		<0.2	<0.02	0	<1	27.5
G004	19795226	1984100	2	4.0	7	90		<0.2	<0.02	0	<1	27.5
G005	19795029	1984183	2	4.0	7	91		<0.2	<0.02	0	<1	28.0
G006	19794751	1983579	2.6	5.2	7.5	90		<0.2	<0.02	0	<1	29.0

Appendix D: Leaf Data

Martin Pena Canal: Area A — 1 Apr 99
Longitude: 19810388
Latitude: 2040518

Sampled Tree	Leaf Number	Leaf Length (cm)	Leaf Width (cm)	Ratio (Length/Width)
A1	1	11.5	5.0	2.30
A1	2	10.3	4.7	2.19
A1	3	10.8	4.5	2.40
A1	4	10.8	5.1	2.12
A1	5	11.1	5.0	2.22
A1	6	10.2	4.4	2.32
A1	7	11.3	4.9	2.31
A1	8	10.1	4.2	2.40
A1	9	10.7	4.8	2.23
A1	10	12.1	6.0	2.02
A1	11	11.3	5.0	2.26
A1	12	12.0	5.6	2.14
A1	13	9.1	4.9	1.86
A1	14	9.0	4.2	2.14
A1	15	10.7	4.8	2.23
A1	16	10.6	4.6	2.30
A1	17	10.0	4.8	2.08
A1	18	10.7	5.0	2.14
A1	19	10.4	4.9	2.12
A1	20	10.3	4.9	2.10
A1	21	9.3	4.2	2.21
A1	22	10.8	5.1	2.12
A1	23	12.6	5.4	2.33
A1	24	12.0	5.2	2.31
A1	25	6.5	3.0	2.17
A1	26	12.7	5.3	2.40
A1	27	10.9	5.4	2.02
A1	28	13.7	6.0	2.28
A1	29	9.8	5.2	1.88
A1	30	12.9	5.5	2.35
A2	1	10.3	4.7	2.19
A2	2	11.7	5.5	2.13
A2	3	10.2	4.4	2.32
A2	4	13.9	6.0	2.32
A2	5	10.9	5.2	2.10
A2	6	12.5	5.3	2.36
A2	7	8.2	3.7	2.22
A2	8	8.1	3.7	2.19
A2	9	12.2	5.6	2.18
A2	10	10.7	4.5	2.38
A2	11	10.9	4.6	2.37
A2	12	11.5	5.0	2.30
A2	13	11.2	4.8	2.33
A2	14	10.7	4.1	2.61
A2	15	9.2	4.0	2.30
A2	16	9.5	4.5	2.11
A2	17	12.2	6.2	1.97
A2	18	11.5	5.3	2.17
A2	19	11.9	5.7	2.09
A2	20	11.1	5.6	1.98
A2	21	8.8	4.5	1.96
A2	22	8.9	4.0	2.23
A2	23	11.5	5.6	2.05
A2	24	11.5	5.9	1.95
A2	25	11.5	5.4	2.13
A2	26	7.8	4.1	1.90
A2	27	11.0	5.1	2.16
A2	28	9.9	4.7	2.11
A2	29	11.3	5.2	2.17
A2	30	10.4	4.9	2.12
A3	1	12.2	5.1	2.39
A3	2	11.4	5.0	2.28
A3	3	11.6	5.1	2.27
A3	4	11.9	5.0	2.38
A3	5	11.8	5.4	2.19
A3	6	10.6	4.6	2.30
A3	7	13.1	5.5	2.38
A3	8	11.5	5.8	1.98
A3	9	12.4	5.8	2.14
A3	10	11.9	5.6	2.13
A3	11	9.0	4.3	2.09
A3	12	8.8	4.0	2.20
A3	13	11.0	4.9	2.24
A3	14	11.8	5.6	2.11
A3	15	13.0	5.1	2.55
A3	16	10.3	5.2	1.98
A3	17	11.0	5.1	2.16
A3	18	9.6	4.7	2.04
A3	19	12.6	5.7	2.21
A3	20	12.2	5.5	2.22
A3	21	12.4	5.6	2.21
A3	22	11.4	5.1	2.24
A3	23	12.5	5.5	2.27
A3	24	10.8	5.2	2.08
A3	25	10.1	4.9	2.06
A3	26	10.0	4.8	2.08
A3	27	9.7	4.5	2.16
A3	28	11.0	5.0	2.20
A3	29	9.3	4.4	2.11
A3	30	9.1	4.2	2.17
Median		10.9	5.0	2.19
Average		10.88	4.97	2.19
Std Dev		1.34	0.59	0.14
Coeff of Variation		0.1236	0.11855	0.06383

Martin Pena Canal: Area B — 1 Apr 99
Longitude: 19810081
Latitude: 2040582

Sampled Tree	Leaf Number	Leaf Length (cm)	Leaf Width (cm)	Ratio (Length/Width)
B1	1	12.6	5.9	2.14
B1	2	14.1	6.5	2.17
B1	3	16.1	7.5	2.15
B1	4	15.7	6.3	2.49
B1	5	13.7	6.1	2.25
B1	6	14.9	6.8	2.19
B1	7	15.3	6.7	2.28
B1	8	12.6	6.3	2.00
B1	9	12.6	6.2	2.03
B1	10	14.0	6.5	2.15
B1	11	13.0	6.3	2.06
B1	12	13.7	5.9	2.32
B1	13	13.2	5.9	2.24
B1	14	12.9	6.3	2.05
B1	15	11.4	6.4	1.78
B1	16	11.2	5.3	2.11
B1	17	15.9	6.9	2.30
B1	18	12.4	5.8	2.14
B1	19	13.0	5.5	2.36
B1	20	10.1	4.9	2.06
B1	21	9.9	4.6	2.15
B1	22	13.3	5.9	2.25
B1	23	12.3	5.5	2.24
B1	24	12.2	5.5	2.22
B1	25	11.6	5.7	2.04
B1	26	11.7	5.5	2.13
B1	27	10.1	4.6	2.20
B1	28	12.6	5.0	2.52
B1	29	12.2	5.0	2.44
B1	30	12.5	5.1	2.45
B2	1	12.3	4.9	2.51
B2	2	13.4	5.2	2.58
B2	3	14.5	6.7	2.16
B2	4	12.5	5.5	2.27
B2	5	10.7	5.5	1.95
B2	6	10.2	4.3	2.37
B2	7	10.9	5.5	1.98
B2	8	12.3	5.1	2.41
B2	9	12.2	5.7	2.14
B2	10	11.6	5.6	2.07
B2	11	12.8	6.0	2.13
B2	12	13.5	5.7	2.37
B2	13	12.7	5.7	2.23
B2	14	12.5	5.6	2.23
B2	15	12.6	6.1	2.07
B2	16	12.4	5.3	2.34
B2	17	14.8	6.1	2.43
B2	18	10.3	5.1	2.02
B2	19	13.1	5.4	2.43
B2	20	10.6	4.9	2.16
B2	21	15.4	6.5	2.37
B2	22	12.4	5.3	2.34
B2	23	12.5	5.4	2.31
B2	24	10.4	4.7	2.21
B2	25	12.0	5.0	2.40
B2	26	13.3	6.5	2.05
B2	27	12.2	4.8	2.54
B2	28	11.5	4.7	2.45
B2	29	11.4	4.7	2.43
B2	30	10.9	4.3	2.53
B3	1	8.2	3.9	2.10
B3	2	12.0	5.5	2.18
B3	3	15.1	7.4	2.04
B3	4	13.6	5.7	2.39
B3	5	16.2	6.7	2.42
B3	6	13.9	5.7	2.44
B3	7	11.0	5.4	2.04
B3	8	14.5	6.5	2.23
B3	9	11.1	5.4	2.06
B3	10	10.5	4.7	2.23
B3	11	12.5	4.8	2.60
B3	12	9.3	4.5	2.07
B3	13	15.1	7.4	2.04
B3	14	8.9	4.1	2.17
B3	15	14.4	6.3	2.29
B3	16	10.9	5.2	2.10
B3	17	13.7	6.0	2.28
B3	18	9.8	4.4	2.23
B3	19	9.0	4.3	2.09
B3	20	11.7	5.0	2.34
B3	21	9.9	4.8	2.06
B3	22	10.5	4.4	2.39
B3	23	14.4	6.6	2.18
B3	24	13.7	5.8	2.36
B3	25	12.9	6.2	2.08
B3	26	13.9	5.5	2.53
B3	27	12.9	5.0	2.58
B3	28	6.2	3.0	2.07
B3	29	10.8	5.3	2.04
B3	30	14.2	6.2	2.29
Median		12.4	5.6	2.23
Average		12.39	5.55	2.24
Std Dev		1.86	0.83	0.17
Coeff of Variation		0.14968	0.14859	0.07683

Martin Pena Canal; Area C — 1 Apr 99
Longitude: 19813316
Latitude: 2041209

Sampled Tree	Leaf Number	Leaf Length (cm)	Leaf Width (cm)	Ratio (Length/Width)
C1	1	14.3	6.5	2.20
C1	2	13.5	6.2	2.18
C1	3	14.1	5.9	2.39
C1	4	12.8	5.8	2.21
C1	5	14.0	6.4	2.19
C1	6	12.3	6.3	1.95
C1	7	14.1	6.3	2.24
C1	8	11.4	5.8	1.97
C1	9	9.9	4.9	2.02
C1	10	11.5	5.7	2.02
C1	11	14.2	6.5	2.18
C1	12	11.9	5.7	2.09
C1	13	14.3	6.3	2.27
C1	14	13.8	6.2	2.23
C1	15	13.9	6.3	2.21
C1	16	13.8	6.0	2.30
C1	17	12.5	6.0	2.08
C1	18	10.5	5.1	2.06
C1	19	9.1	5.7	1.60
C1	20	12.2	6.5	1.88
C1	21	8.9	4.1	2.17
C1	22	8.4	4.2	2.00
C1	23	8.1	4.0	2.03
C1	24	9.0	4.9	1.84
C1	25	13.0	6.3	2.06
C1	26	13.2	6.2	2.13
C1	27	12.3	6.0	2.05
C1	28	13.2	6.5	2.03
C1	29	13.2	6.8	1.94
C1	30	12.6	6.5	1.94
C2	1	10.4	5.4	1.93
C2	2	11.1	5.4	2.06
C2	3	9.6	4.6	2.09
C2	4	10.3	5.1	2.02
C2	5	10.2	4.9	2.08
C2	6	10.3	5.1	2.02
C2	7	10.7	5.4	1.98
C2	8	11.0	5.7	1.93
C2	9	10.6	4.8	2.21
C2	10	11.8	5.5	2.15
C2	11	10.7	4.6	2.33
C2	12	11.3	5.2	2.17
C2	13	10.0	5.0	2.00
C2	14	11.2	5.5	2.04
C2	15	9.7	4.5	2.16
C2	16	10.4	5.1	2.04
C2	17	11.3	5.1	2.22
C2	18	10.4	5.4	1.93
C2	19	9.4	4.2	2.24
C2	20	9.3	4.7	1.98
C2	21	10.9	5.1	2.14
C2	22	9.6	4.8	2.00
C2	23	10.2	5.1	2.00
C2	24	11.0	5.7	1.93
C2	25	11.8	5.6	2.11
C2	26	7.7	4.3	1.79
C2	27	11.6	5.8	2.00
C2	28	7.5	4.1	1.83
C2	29	10.8	5.4	2.00
C2	30	10.1	5.0	2.02
C3	1	10.8	6.5	1.66
C3	2	11.5	6.2	1.85
C3	3	11.2	5.9	1.90
C3	4	9.1	5.8	1.57
C3	5	9.7	6.4	1.52
C3	6	10.8	6.3	1.71
C3	7	10.8	6.3	1.71
C3	8	10.4	5.8	1.79
C3	9	10.2	4.9	2.08
C3	10	10.3	5.7	1.81
C3	11	10.4	6.5	1.60
C3	12	10.5	5.7	1.84
C3	13	10.6	6.3	1.68
C3	14	9.5	6.2	1.53
C3	15	10.2	6.3	1.62
C3	16	8.5	6.0	1.42
C3	17	9.5	6.0	1.58
C3	18	10.7	5.1	2.10
C3	19	10.3	5.7	1.81
C3	20	11.2	6.5	1.72
C3	21	11.0	4.1	2.68
C3	22	10.8	4.2	2.57
C3	23	10.8	4.0	2.70
C3	24	11.7	4.9	2.39
C3	25	9.4	6.3	1.49
C3	26	9.0	6.2	1.45
C3	27	9.0	6.0	1.50
C3	28	9.7	6.5	1.49
C3	29	10.0	6.8	1.47
C3	30	8.7	6.5	1.34
Median		10.9	5.6	2.01
Average		10.92	5.59	1.97
Std Dev		1.61	0.76	0.27
Coeff of Variation		0.1478	0.1354	0.13875

Martin Pena Canal: Area D — 1 Apr 99
Longitude: 19813874
Latitude: 2040578

Sampled Tree	Leaf Number	Leaf Length (cm)	Leaf Width (cm)	Ratio (Length/Width)
D1	1	14.7	7.1	2.07
D1	2	10.9	5.9	1.85
D1	3	11.8	6.4	1.84
D1	4	12.8	5.8	2.21
D1	5	12.8	6.3	2.03
D1	6	11.5	5.8	1.98
D1	7	10.7	5.8	1.84
D1	8	9.8	5.5	1.78
D1	9	14.9	6.5	2.29
D1	10	10.1	5.6	1.80
D1	11	9.7	4.9	1.98
D1	12	13.3	6.8	1.96
D1	13	14.2	7.3	1.95
D1	14	10.0	5.4	1.85
D1	15	10.0	5.7	1.75
D1	16	9.5	5.1	1.86
D1	17	9.8	5.6	1.75
D1	18	11.3	5.9	1.92
D1	19	11.0	6.1	1.80
D1	20	11.2	5.8	1.93
D1	21	12.6	6.1	2.07
D1	22	12.1	5.9	2.05
D1	23	10.2	5.6	1.82
D1	24	11.0	5.5	2.00
D1	25	12.2	6.1	2.00
D1	26	11.2	5.9	1.90
D1	27	11.7	6.0	1.95
D1	28	12.9	6.6	1.95
D1	29	12.4	6.4	1.94
D1	30	11.2	6.1	1.84
D2	1	11.8	5.9	2.00
D2	2	11.0	5.7	1.93
D2	3	10.8	5.8	1.86
D2	4	11.6	5.6	2.07
D2	5	11.1	4.8	2.31
D2	6	10.8	5.4	2.00
D2	7	11.0	5.1	2.16
D2	8	11.5	5.8	1.98
D2	9	11.0	5.1	2.16
D2	10	11.0	5.3	2.08
D2	11	10.5	5.3	1.98
D2	12	10.8	5.2	2.08
D2	13	10.4	4.7	2.21
D2	14	11.7	5.6	2.09
D2	15	9.9	5.7	1.74
D2	16	11.3	5.8	1.95
D2	17	10.5	5.1	2.06
D2	18	11.6	5.5	2.11
D2	19	11.9	5.6	2.13
D2	20	12.0	5.6	2.14
D2	21	10.4	5.5	1.89
D2	22	11.9	5.5	2.16
D2	23	9.5	4.6	2.07
D2	24	10.9	5.1	2.14
D2	25	11.8	5.8	2.03
D2	26	10.2	5.0	2.04
D2	27	10.0	4.8	2.08
D2	28	11.6	5.5	2.11
D2	29	11.4	5.1	2.24
D2	30	11.6	5.3	2.19
D3	1	9.0	5.0	1.80
D3	2	8.7	5.0	1.74
D3	3	9.2	4.5	2.04
D3	4	10.9	5.0	2.18
D3	5	9.9	5.1	1.94
D3	6	9.7	4.9	1.98
D3	7	9.0	4.3	2.09
D3	8	9.8	5.5	1.78
D3	9	11.1	9.8	1.13
D3	10	10.2	5.2	1.96
D3	11	11.7	5.0	2.34
D3	12	11.5	5.6	2.05
D3	13	8.5	4.1	2.07
D3	14	7.7	4.3	1.79
D3	15	8.9	4.4	2.02
D3	16	9.4	4.6	2.04
D3	17	9.6	5.0	1.92
D3	18	10.9	5.2	2.10
D3	19	10.5	5.3	1.98
D3	20	11.5	5.8	1.98
D3	21	11.5	5.1	2.25
D3	22	10.5	5.5	1.91
D3	23	9.1	4.2	2.17
D3	24	11.0	5.4	2.04
D3	25	8.7	4.4	1.98
D3	26	9.7	5.0	1.94
D3	27	8.1	3.9	2.08
D3	28	8.1	4.1	1.98
D3	29	5.3	2.8	1.89
D3	30	7.4	3.3	2.24
Median		10.7	5.4	1.99
Average		10.73	5.42	1.99
Std Dev		1.51	0.87	0.17
Coeff of Variation		0.14045	0.16062	0.08336

La Parguera Area A — 1 Apr 99 — Longitude 19707032 — Latitude 1987554

Sampled Tree	Leaf Number	Leaf Length (cm)	Leaf Width (cm)	Ratio (Length/Width)
A1	1	14.4	4.8	3.00
A1	2	14.7	4.8	3.20
A1	3	12.4	4.1	3.02
A1	4	12.5	4.3	2.93
A1	5	12.7	4.0	3.18
A1	6	12.4	4.7	2.64
A1	7	13.3	4.7	2.83
A1	8	14.7	5.0	2.94
A1	9	14.8	5.2	2.85
A1	10	13.5	5.3	2.55
A1	11	12.8	4.8	2.74
A1	12	12.5	4.7	2.66
A1	13	14.3	5.6	2.55
A1	14	13.7	4.9	2.80
A1	15	11.9	4.4	2.70
A1	16	13.7	5.0	2.74
A1	17	15.0	5.7	2.63
A1	18	13.2	4.8	2.69
A1	19	15.3	5.8	2.64
A1	20	11.8	5.3	2.18
A1	21	11.0	4.0	2.75
A1	22	13.5	5.5	2.45
A1	23	13.3	5.7	2.33
A1	24	14.7	5.7	2.58
A1	25	13.5	4.9	2.78
A1	26	10.1	3.9	2.59
A1	27	12.4	4.5	2.76
A1	28	12.6	4.4	2.86
A1	29	12.4	4.5	2.76
A1	30	13.6	4.8	2.83
A2	1	12.2	5.3	2.30
A2	2	12.3	4.9	2.51
A2	3	13.5	4.9	2.76
A2	4	10.9	4.5	2.42
A2	5	13.0	4.7	2.77
A2	6	14.7	5.8	2.53
A2	7	14.4	5.7	2.53
A2	8	12.8	4.3	2.98
A2	9	12.9	4.9	2.63
A2	10	14.0	4.7	2.98
A2	11	13.5	4.6	2.93
A2	12	14.0	4.7	2.98
A2	13	11.7	4.9	2.39
A2	14	11.4	4.9	2.33
A2	15	10.7	4.8	2.23
A2	16	15.2	6.3	2.41
A2	17	12.4	5.3	2.34
A2	18	15.5	6.0	2.58
A2	19	15.3	6.1	2.51
A2	20	14.4	5.6	2.57
A2	21	14.6	6.1	2.39
A2	22	13.7	5.3	2.58
A2	23	15.4	5.8	2.66
A2	24	12.0	4.2	2.86
A2	25	12.7	5.2	2.44
A2	26	13.9	4.6	3.02
A2	27	16.9	5.5	3.07
A2	28	17.0	5.6	3.04
A2	29	10.7	5.0	2.14
A2	30	10.8	5.0	2.16
A3	1	12.6	5.5	2.29
A3	2	10.2	5.2	1.96
A3	3	8.2	4.0	2.05
A3	4	8.8	4.7	1.83
A3	5	11.1	5.6	1.98
A3	6	10.6	5.2	2.04
A3	7	9.8	4.6	2.13
A3	8	11.4	5.8	1.97
A3	9	10.7	5.5	1.95
A3	10	7.9	3.9	2.03
A3	11	11.8	5.0	2.36
A3	12	8.9	4.1	2.17
A3	13	10.0	4.8	2.08
A3	14	9.2	4.1	2.24
A3	15	10.5	5.4	1.94
A3	16	9.1	4.7	1.93
A3	17	11.2	5.5	2.04
A3	18	10.1	5.1	1.98
A3	19			
A3	20			
A3	21			
A3	22			
A3	23			
A3	24			
A3	25			
A3	26			
A3	27			
A3	28			
A3	29			
A3	30			
Median		12.6	5.0	2.58
Average		12.58	4.99	2.53
Std Dev		2.01	0.58	0.35
Coeff of Variation		0.159948	0.117293	0.138839

La Parguera Area B — 1 Apr 99 — Longitude 18707119 — Latitude 1987547

Sampled Tree	Leaf Number	Leaf Length (cm)	Leaf Width (cm)	Ratio (Length/Width)
B1	1	13.4	5.3	2.53
B1	2	12.8	4.6	2.78
B1	3	15.1	5.7	2.65
B1	4	14.7	5.1	2.88
B1	5	14.6	5.2	2.81
B1	6	11.8	4.4	2.68
B1	7	13.5	4.8	2.81
B1	8	11.6	4.4	2.64
B1	9	12.4	5.0	2.48
B1	10	14.6	5.1	2.88
B1	11	13.8	4.9	2.78
B1	12	11.3	4.3	2.63
B1	13	13.0	5.5	2.36
B1	14	11.5	5.1	2.25
B1	15	12.4	5.4	2.30
B1	16	14.0	5.8	2.41
B1	17	11.5	4.4	2.61
B1	18	11.6	4.4	2.64
B1	19	12.0	5.2	2.31
B1	20	13.1	4.8	2.73
B1	21	13.2	5.3	2.49
B1	22	14.9	5.2	2.87
B1	23	13.4	5.3	2.53
B1	24	11.5	4.7	2.45
B1	25	13.6	5.5	2.47
B1	26	12.7	5.0	2.54
B1	27	14.3	6.3	2.27
B1	28	12.5	5.0	2.50
B1	29	15.1	5.4	2.80
B1	30	15.3	5.2	2.94
B2	1	10.1	4.7	2.15
B2	2	11.4	5.0	2.28
B2	3	13.4	6.0	2.23
B2	4	12.9	4.4	2.93
B2	5	12.9	5.3	2.43
B2	6	13.1	5.9	2.22
B2	7	13.6	5.8	2.34
B2	8	10.4	4.0	2.60
B2	9	13.7	5.3	2.58
B2	10	13.5	5.7	2.37
B2	11	10.2	4.6	2.22
B2	12	9.6	4.4	2.18
B2	13	9.1	4.6	1.98
B2	14	9.9	4.7	2.11
B2	15	9.9	4.4	2.25
B2	16	9.5	4.2	2.26
B2	17	12.6	4.9	2.57
B2	18	14.7	6.0	2.45
B2	19	13.3	6.3	2.11
B2	20	12.0	5.4	2.22
B2	21	9.4	4.3	2.19
B2	22	12.0	5.5	2.18
B2	23	11.8	5.4	2.20
B2	24	11.5	4.6	2.50
B2	25	12.2	5.2	2.35
B2	26	15.1	5.2	2.90
B2	27	17.5	6.4	2.73
B2	28	12.4	5.0	2.48
B2	29	14.1	5.7	2.47
B2	30	14.3	5.6	2.55
B3	1	12.0	4.6	2.61
B3	2	13.8	5.2	2.65
B3	3	13.0	5.4	2.41
B3	4	15.0	5.3	2.83
B3	5	14.2	5.9	2.41
B3	6	12.8	5.0	2.56
B3	7	13.8	4.9	2.84
B3	8	12.9	4.5	2.87
B3	9	14.0	5.0	2.80
B3	10	14.8	4.8	3.17
B3	11	12.0	4.6	2.61
B3	12	13.7	5.1	2.69
B3	13	14.1	5.4	2.61
B3	14	13.0	4.1	3.17
B3	15	14.5	5.1	2.84
B3	16	12.4	4.0	3.10
B3	17	15.5	5.5	2.82
B3	18	14.5	5.5	2.64
B3	19	10.1	4.0	2.53
B3	20	12.3	5.4	2.28
B3	21	11.0	4.1	2.68
B3	22	10.1	3.8	2.66
B3	23	9.5	4.2	2.26
B3	24			
B3	25			
B3	26			
B3	27			
B3	28			
B3	29			
B3	30			
Median		12.8	5.0	2.54
Average		12.77	5.04	2.54
Std Dev		1.70	0.58	0.26
Coeff of Variation		0.133007	0.115588	0.102607

La Parguera Area C — 1 Apr 99 — Longitude 19706868 — Latitude 1987678

Sampled Tree	Leaf Number	Leaf Length (cm)	Leaf Width (cm)	Ratio (Length/Width)
C1	1	11.1	6.3	1.76
C1	2	11.5	5.1	2.25
C1	3	12.2	5.4	2.26
C1	4	10.9	5.0	2.18
C1	5	9.0	4.2	2.14
C1	6	11.3	6.0	1.88
C1	7	11.7	6.0	1.95
C1	8	11.3	5.6	2.02
C1	9	11.4	5.1	2.24
C1	10	11.8	5.9	2.00
C1	11	12.0	5.8	2.07
C1	12	10.4	5.5	1.89
C1	13	11.9	6.1	1.95
C1	14	9.5	5.0	1.90
C1	15	12.3	4.2	2.93
C1	16	10.4	5.1	2.04
C1	17	10.4	4.9	2.12
C1	18	14.9	7.0	2.13
C1	19	11.6	5.0	2.32
C1	20	14.6	6.9	2.12
C1	21	12.7	6.0	2.12
C1	22	12.2	5.4	2.26
C1	23	10.4	5.1	2.04
C1	24	10.3	4.8	2.15
C1	25	9.9	5.5	1.80
C1	26	13.8	6.3	2.19
C1	27	12.1	6.1	1.98
C1	28	12.8	6.0	2.13
C1	29	12.1	5.8	2.09
C1	30	16.2	6.7	2.42
C2	1	11.0	5.3	2.08
C2	2	7.6	4.1	1.85
C2	3	11.2	5.4	2.07
C2	4	11.3	5.1	2.22
C2	5	9.8	4.4	2.23
C2	6	12.7	6.0	2.12
C2	7	12.7	5.5	2.31
C2	8	10.3	4.5	2.29
C2	9	17.1	7.1	2.41
C2	10	14.1	6.9	2.04
C2	11	16.0	6.0	2.67
C2	12	13.8	6.8	2.03
C2	13	13.4	6.0	2.23
C2	14	10.9	5.1	2.14
C2	15	9.5	3.2	2.97
C2	16	12.2	5.8	2.10
C2	17	15.4	6.5	2.37
C2	18	13.1	5.3	2.47
C2	19	13.9	6.4	2.17
C2	20	13.5	5.8	2.33
C2	21	13.2	6.3	2.10
C2	22	11.8	5.2	2.27
C2	23	12.3	5.3	2.32
C2	24	8.5	3.5	2.43
C2	25	7.8	2.8	2.79
C2	26	8.2	3.5	2.34
C2	27	8.6	4.8	1.79
C2	28	12.1	5.5	2.20
C2	29	10.1	4.3	2.35
C2	30	12.5	5.6	2.23
C3	1	12.0	5.2	2.31
C3	2	12.6	5.6	2.25
C3	3	11.1	5.0	2.22
C3	4	11.5	5.6	2.05
C3	5	12.2	5.5	2.22
C3	6	11.8	4.8	2.46
C3	7	11.0	4.9	2.24
C3	8	10.1	4.1	2.46
C3	9	9.5	4.1	2.32
C3	10	11.4	4.8	2.38
C3	11	12.4	5.9	2.10
C3	12	12.4	5.3	2.34
C3	13	12.8	6.2	2.06
C3	14	13.0	6.0	2.17
C3	15	12.8	6.2	2.06
C3	16	12.6	5.1	2.47
C3	17	14.3	5.9	2.42
C3	18	13.0	5.4	2.41
C3	19	11.8	4.7	2.51
C3	20	11.6	5.1	2.27
C3	21	12.0	5.1	2.35
C3	22	12.1	5.2	2.33
C3	23	10.1	4.3	2.35
C3	24	9.6	4.4	2.18
C3	25	11.3	5.0	2.26
C3	26	10.8	4.3	2.51
C3	27	12.3	5.8	2.12
C3	28			
C3	29			
C3	30			
Median		11.8	5.3	2.22
Average		11.79	5.35	2.22
Std Dev		1.79	0.85	0.22
Coeff of Variation		0.151152	0.159163	0.098983

La Parguera Area D — 1 Apr 99 — Longitude 19707088 — Latitude 1987819

Sampled Tree	Leaf Number	Leaf Length (cm)	Leaf Width (cm)	Ratio (Length/Width)
D1	1	12.1	5.7	2.12
D1	2	8.7	5.1	1.71
D1	3	12.9	5.6	2.29
D1	4	11.6	4.5	2.58
D1	5	8.1	3.9	2.08
D1	6	9.0	5.2	1.73
D1	7	11.0	4.1	2.68
D1	8	9.2	4.1	2.24
D1	9	9.0	4.8	1.88
D1	10	7.5	3.6	2.08
D1	11	12.9	5.8	2.22
D1	12	9.4	4.2	2.24
D1	13	11.1	4.4	2.52
D1	14	7.0	3.4	2.06
D1	15	9.5	4.3	2.21
D1	16	10.3	5.1	2.02
D1	17	11.5	5.5	2.09
D1	18	13.1	5.2	2.52
D1	19	10.7	5.3	2.02
D1	20	8.6	4.2	2.05
D1	21	12.0	5.7	2.11
D1	22	8.0	3.7	2.16
D1	23	9.5	5.0	1.90
D1	24	10.6	5.3	2.00
D1	25	9.4	4.0	2.35
D1	26	12.3	4.8	2.57
D1	27	12.5	5.3	2.36
D1	28	10.2	5.1	2.00
D1	29	11.0	4.3	2.56
D1	30	9.4	7.6	1.24
D2	1	12.6	5.4	2.33
D2	2	16.1	5.8	2.78
D2	3	14.9	6.0	2.48
D2	4	15.0	6.3	2.38
D2	5	15.0	6.2	2.42
D2	6	11.8	4.7	2.51
D2	7	8.9	4.4	2.02
D2	8	11.8	4.7	2.51
D2	9	11.2	4.8	2.33
D2	10	14.0	5.6	2.50
D2	11	13.2	5.5	2.40
D2	12	11.7	4.7	2.49
D2	13	9.1	4.1	2.22
D2	14	11.8	4.1	2.90
D2	15	9.3	4.2	2.21
D2	16	11.9	4.9	2.43
D2	17	10.2	3.9	2.62
D2	18	11.3	5.4	2.09
D2	19	9.7	4.1	2.37
D2	20	13.7	5.8	2.45
D2	21	11.3	4.9	2.31
D2	22	9.8	4.0	2.45
D2	23	8.7	3.8	2.29
D2	24	9.3	4.2	2.21
D2	25	9.3	4.3	2.18
D2	26	12.2	4.7	2.60
D2	27	11.8	4.9	2.37
D2	28	15.5	6.0	2.58
D2	29	13.2	5.4	2.44
D2	30	12.9	5.1	2.53
D3	1	10.4	4.0	2.60
D3	2	13.2	5.0	2.64
D3	3	8.8	3.8	2.39
D3	4	13.8	5.8	2.43
D3	5	14.3	6.2	2.31
D3	6	14.4	6.3	2.29
D3	7	13.2	5.8	2.28
D3	8	12.5	6.0	2.08
D3	9	10.8	4.1	2.59
D3	10	12.2	4.8	2.54
D3	11	14.1	5.6	2.52
D3	12	12.9	5.1	2.53
D3	13	11.6	4.5	2.58
D3	14	10.9	4.4	2.48
D3	15	10.1	4.1	2.46
D3	16	14.4	5.9	2.44
D3	17	15.5	6.5	2.38
D3	18	13.4	4.9	2.73
D3	19	13.8	5.1	2.71
D3	20	12.7	4.7	2.70
D3	21	11.5	4.2	2.74
D3	22	9.4	3.7	2.54
D3	23	10.8	4.1	2.59
D3	24	10.5	4.6	2.28
D3	25	12.1	4.9	2.47
D3	26	11.9	4.7	2.53
D3	27	12.8	5.4	2.37
D3	28	12.5	5.2	2.40
D3	29	11.8	5.0	2.37
D3	30			
Median		11.5	4.9	2.38
Average		11.47	4.90	2.35
Std Dev		2.02	0.79	0.27
Coeff of Variation		0.17634	0.161268	0.113059

La Parguera Area E — 1 Apr 99 — Longitude 19706957 — Latitude 1987855

Sampled Tree	Leaf Number	Leaf Length (cm)	Leaf Width (cm)	Ratio (Length/Width)
E1	1	11.6	4.0	2.90
E1	2	11.3	4.0	2.83
E1	3	11.1	4.0	2.78
E1	4	12.4	5.1	2.43
E1	5	10.4	4.0	2.60
E1	6	10.4	4.0	2.60
E1	7	11.2	4.2	2.67
E1	8	11.6	4.7	2.47
E1	9	13.5	5.0	2.70
E1	10	13.9	5.0	2.78
E1	11	14.1	4.8	2.94
E1	12	12.4	4.3	2.88
E1	13	11.4	3.8	3.00
E1	14	12.9	4.1	3.15
E1	15	9.8	4.0	2.45
E1	16	10.6	3.7	2.86
E1	17	11.4	4.0	2.85
E1	18	11.5	4.6	2.50
E1	19	12.3	4.5	2.73
E1	20	12.7	4.6	2.76
E1	21	9.4	3.2	2.94
E1	22	11.8	3.7	3.19
E1	23	14.8	4.7	3.15
E1	24	11.7	4.1	2.85
E1	25	13.1	4.7	2.79
E1	26	12.0	5.6	2.14
E1	27	11.0	4.7	2.82
E1	28	9.9	3.3	3.00
E1	29	12.8	4.2	3.03
E1	30	10.5	3.5	2.92
E2	1	11.7	3.8	3.08
E2	2	11.4	4.1	2.78
E2	3	11.2	4.0	2.80
E2	4	13.2	4.5	2.93
E2	5	14.4	5.9	2.48
E2	6	13.0	4.2	3.10
E2	7	11.5	3.6	3.19
E2	8	16.5	5.7	2.89
E2	9	14.2	5.2	2.73
E2	10	14.4	5.1	2.82
E2	11	12.9	4.1	3.15
E2	12	12.9	4.4	2.94
E2	13	12.2	4.4	2.77
E2	14	12.0	4.5	2.67
E2	15	16.0	5.3	3.02
E2	16	14.0	5.2	2.69
E2	17	12.1	3.8	3.18
E2	18	12.3	3.9	3.15
E2	19	12.4	4.0	3.10
E2	20	10.3	3.3	3.12
E2	21	12.8	4.5	2.84
E2	22	12.4	4.2	2.95
E2	23	13.5	5.0	2.70
E2	24	12.0	4.2	2.86
E2	25	9.7	3.4	2.85
E2	26	11.9	4.1	2.90
E2	27	11.9	3.9	3.05
E2	28	11.8	4.0	2.95
E2	29	7.3	2.9	2.52
E2	30	10.3	4.7	2.19
E3	1	6.8	2.8	2.43
E3	2	10.9	4.3	2.53
E3	3	10.4	4.5	2.31
E3	4	7.2	3.1	2.32
E3	5	7.6	3.1	2.45
E3	6	11.3	4.5	2.51
E3	7	7.1	3.2	2.15
E3	8	8.6	3.1	2.77
E3	9	7.1	3.5	2.03
E3	10	8.6	3.4	2.53
E3	11	10.2	4.7	2.17
E3	12	11.3	4.5	2.51
E3	13	10.9	3.9	2.79
E3	14	9.7	3.9	2.49
E3	15	8.3	3.5	2.37
E3	16	10.3	4.3	2.40
E3	17	9.8	4.9	2.00
E3	18	13.7	4.2	3.26
E3	19	12.7	5.4	2.35
E3	20	9.5	4.8	1.98
E3	21	11.7	4.0	2.93
E3	22	6.8	3.1	2.19
E3	23	10.5	4.3	2.44
E3	24	13.1	5.0	2.62
E3	25	10.6	4.7	2.26
E3	26	8.0	3.3	2.42
E3	27	12.8	5.4	2.37
E3	28			
E3	29			
E3	30			
Median		11.4	4.2	2.77
Average		11.40	4.22	2.71
Std Dev		2.04	0.67	0.31
Coeff of Variation		0.178812	0.158928	0.115178

La Parguera Area F — 1 Apr 99 — Longitude 19707331 — Latitude 1987658

Sampled Tree	Leaf Number	Leaf Length (cm)	Leaf Width (cm)	Ratio (Length/Width)
F1	1	11.3	5.4	2.09
F1	2	10.4	4.7	2.21
F1	3	12.7	4.3	2.95
F1	4	11.7	4.8	2.44
F1	5	13.7	5.8	2.36
F1	6	11.7	4.4	2.66
F1	7	13.2	4.9	2.69
F1	8	12.1	4.8	2.52
F1	9	11.3	4.9	2.31
F1	10	11.1	5.2	2.13
F1	11	12.0	4.6	2.61
F1	12	11.5	4.4	2.61
F1	13	11.7	5.0	2.34
F1	14	12.3	3.9	3.15
F1	15	11.4	3.9	2.92
F1	16	10.8	4.4	2.41
F1	17	11.0	4.3	2.56
F1	18	9.6	3.6	2.39
F1	19	12.8	4.7	2.72
F1	20	9.7	4.4	2.20
F1	21	14.0	5.3	2.64
F1	22	7.3	3.4	2.15
F1	23	14.1	5.0	2.82
F1	24	10.6	4.9	2.16
F1	25	13.5	5.0	2.70
F1	26	10.3	3.9	2.64
F1	27	12.5	4.1	3.05
F1	28	13.3	4.5	2.96
F1	29	10.9	5.1	2.14
F1	30	8.8	4.4	2.00
F2	1	12.2	5.1	2.39
F2	2	8.5	2.9	2.93
F2	3	9.0	4.9	1.84
F2	4	7.7	3.1	2.48
F2	5	8.4	3.0	2.80
F2	6	10.4	5.4	1.93
F2	7	8.2	2.9	2.83
F2	8	8.9	2.8	3.18
F2	9	10.8	5.0	2.16
F2	10	7.8	3.8	2.05
F2	11	10.0	3.6	2.78
F2	12	13.4	3.7	2.53
F2	13	9.1	4.0	2.28
F2	14	10.4	4.4	2.36
F2	15	10.5	4.3	2.44
F2	16	14.3	5.8	2.47
F2	17	9.3	3.6	2.58
F2	18	8.4	2.2	3.82
F2	19	11.3	3.3	2.15
F2	20	11.3	4.4	2.57
F2	21	8.7	4.2	2.07
F2	22	9.6	4.0	2.40
F2	23	13.7	5.5	2.49
F2	24	9.5	4.2	2.26
F2	25	12.2	6.0	2.03
F2	26	9.8	3.7	2.65
F2	27	9.9	4.0	2.48
F2	28	12.9	6.1	2.11
F2	29	12.0	4.7	2.55
F2	30	12.2	6.1	2.00
F3	1	10.8	4.9	2.20
F3	2	11.3	4.4	2.57
F3	3	11.1	5.3	2.09
F3	4	14.0	5.6	2.50
F3	5	9.2	4.4	2.09
F3	6	9.4	4.9	1.92
F3	7	11.1	5.2	2.13
F3	8	10.8	5.8	1.86
F3	9	9.6	4.2	2.29
F3	10	10.1	4.3	2.35
F3	11	12.0	5.5	2.18
F3	12	13.4	5.0	2.68
F3	13	11.1	5.3	2.09
F3	14	11.5	5.5	2.09
F3	15	13.5	5.8	2.33
F3	16	11.2	5.4	2.07
F3	17	9.9	4.1	2.41
F3	18	10.3	4.2	2.45
F3	19	9.3	4.5	2.07
F3	20	11.0	5.2	2.12
F3	21	10.4	4.5	2.31
F3	22	8.6	4.0	2.15
F3	23	7.7	3.5	2.20
F3	24	9.3	4.3	2.16
F3	25	10.5	4.7	2.23
F3	26	10.0	4.4	2.27
F3	27			
F3	28			
F3	29			
F3	30			
Median		10.8	4.6	2.36
Average		10.84	4.57	2.41
Std Dev		1.72	0.80	0.34
Coeff of Variation		0.158181	0.174751	0.141287

Central Aguirre Area A — 2 Apr 99 — Longitude 19795557 — Latitude 1984436

Sampled Tree	Leaf Number	Leaf Length (cm)	Leaf Width (cm)	Ratio (Length/Width)
A1	1	10.4	4.9	2.12
A1	2	12.6	6.5	1.94
A1	3	9.5	4.6	2.07
A1	4	9.0	3.7	2.43
A1	5	9.8	4.9	2.00
A1	6	9.6	4.9	1.96
A1	7	8.2	4.2	1.95
A1	8	9.4	4.6	2.04
A1	9	9.3	4.1	2.27
A1	10	11.2	5.1	2.20
A1	11	9.0	4.4	2.05
A1	12	11.8	5.4	2.19
A1	13	10.5	5.0	2.10
A1	14	10.2	4.9	2.08
A1	15	8.4	4.3	1.95
A1	16	9.9	3.9	2.54
A1	17	10.0	4.1	2.44
A1	18	8.7	3.8	2.29
A1	19	12.8	5.3	2.38
A1	20	13.0	5.8	2.22
A1	21	8.6	4.0	2.15
A1	22	7.9	4.3	1.84
A1	23	11.5	5.8	1.98
A1	24	12.2	5.8	2.16
A1	25	9.9	4.7	2.11
A1	26	11.4	5.7	2.00
A1	27	7.7	3.2	2.41
A1	28	10.1	5.2	1.94
A1	29	12.1	6.1	1.98
A1	30	8.9	4.8	1.85
A2	1	10.1	4.4	2.30
A2	2	8.5	3.2	2.66
A2	3	11.7	4.7	2.49
A2	4	9.1	4.1	2.22
A2	5	9.8	4.3	2.23
A2	6	12.0	5.7	2.11
A2	7	11.0	4.8	2.29
A2	8	9.5	5.1	1.86
A2	9	9.6	4.1	2.34
A2	10	12.0	5.8	2.07
A2	11	9.6	3.8	2.53
A2	12	9.0	4.3	2.09
A2	13	8.4	3.2	2.63
A2	14	9.2	4.0	2.30
A2	15	10.5	4.2	2.50
A2	16	10.3	4.5	2.29
A2	17	8.9	3.7	2.41
A2	18	10.0	3.9	2.56
A2	19	10.6	4.4	2.41
A2	20	11.4	5.2	2.19
A2	21	10.9	5.0	2.18
A2	22	9.2	4.9	1.88
A2	23	8.8	4.2	2.10
A2	24	6.8	2.7	2.52
A2	25	6.2	3.0	2.07
A2	26	12.1	5.2	2.33
A2	27	10.4	4.2	2.48
A2	28	11.1	5.1	2.18
A2	29	7.4	3.1	2.39
A2	30	8.5	3.4	2.50
A3	1	10.3	4.4	2.34
A3	2	7.5	3.0	2.50
A3	3	7.7	2.9	2.66
A3	4	10.5	5.3	1.98
A3	5	7.5	3.0	2.50
A3	6	9.6	4.3	2.23
A3	7	8.3	3.7	2.24
A3	8	8.0	3.3	2.42
A3	9	10.4	4.4	2.36
A3	10	10.8	4.3	2.47
A3	11	8.8	3.7	2.37
A3	12	7.4	3.9	1.90
A3	13	9.4	4.5	2.09
A3	14	9.2	3.9	2.36
A3	15	10.0	4.3	2.33
A3	16	9.5	4.4	2.16
A3	17	8.2	4.0	2.05
A3	18	9.7	3.8	2.29
A3	19	9.2	3.8	2.42
A3	20	8.8	4.0	2.20
A3	21	11.9	5.3	2.25
A3	22	9.3	3.8	2.45
A3	23	8.9	4.4	2.02
A3	24	9.8	4.3	2.23
A3	25	9.2	4.2	2.19
A3	26	8.3	3.3	2.52
A3	27	10.8	5.0	2.16
A3	28	10.4	5.0	2.08
A3	29	9.9	4.9	2.02
A3	30	9.8	4.4	2.23
Median		9.7	4.4	2.23
Average		9.70	4.39	2.23
Std Dev		1.40	0.78	0.20
Coeff of Variation		0.14473	0.177877	0.091747

Central Aguirre Area B — 2 Apr 99 — Longitude 19795492 — Latitude 1984520

Sampled Tree	Leaf Number	Leaf Length (cm)	Leaf Width (cm)	Ratio (Length/Width)
B1	1	9.8	4.6	2.13
B1	2	10.9	4.9	2.22
B1	3	8.6	4.2	2.05
B1	4	9.7	4.3	2.26
B1	5	9.4	4.3	2.19
B1	6	8.3	4.0	2.08
B1	7	9.2	4.0	2.30
B1	8	10.2	4.8	2.13
B1	9	11.9	5.7	2.09
B1	10	7.6	4.4	1.73
B1	11	7.3	3.6	2.03
B1	12	9.8	4.4	2.23
B1	13	9.0	4.3	2.09
B1	14	9.2	3.6	2.29
B1	15	10.7	4.8	2.23
B1	16	10.1	3.8	2.66
B1	17	10.6	4.9	2.18
B1	18	7.7	4.3	1.79
B1	19	8.0	4.4	1.82
B1	20	8.3	4.5	1.94
B1	21	8.4	4.6	1.83
B1	22	9.8	4.6	2.13
B1	23	7.7	3.4	2.26
B1	24	9.4	4.5	1.87
B1	25	9.0	4.5	2.00
B1	26	9.4	3.9	2.41
B1	27	8.7	4.2	2.07
B1	28	8.1	3.6	2.25
B1	29	9.3	4.0	2.33
B1	30	7.7	4.0	1.93
B2	1	7.3	3.8	1.92
B2	2	9.3	4.7	1.98
B2	3	8.8	4.1	2.10
B2	4	11.0	4.4	2.50
B2	5	7.8	3.4	2.24
B2	6	9.3	4.2	2.21
B2	7	7.2	3.4	2.12
B2	8	9.7	4.2	2.31
B2	9	10.9	4.8	2.27
B2	10	8.8	4.1	2.15
B2	11	8.1	4.4	1.84
B2	12	10.8	4.8	2.25
B2	13	11.8	5.2	2.27
B2	14	8.1	3.6	2.25
B2	15	8.8	4.0	2.20
B2	16	8.9	4.4	2.02
B2	17	9.1	4.6	1.98
B2	18	9.2	3.9	2.36
B2	19	8.7	3.8	2.29
B2	20	9.9	4.2	2.38
B2	21	8.8	4.0	2.20
B2	22	8.8	4.1	2.15
B2	23	8.1	4.1	1.98
B2	24	8.8	4.1	2.15
B2	25	9.5	4.0	2.38
B2	26	10.3	4.8	2.15
B2	27	9.8	4.6	2.13
B2	28	8.8	4.2	2.10
B2	29	7.5	3.7	2.03
B2	30	8.3	4.2	1.98
B3	1	8.4	3.2	2.63
B3	2	10.4	4.4	2.36
B3	3	9.4	4.8	1.97
B3	4	9.0	4.0	2.25
B3	5	9.0	4.0	2.25
B3	6	9.7	4.5	2.16
B3	7	8.7	3.8	2.29
B3	8	9.5	4.7	2.02
B3	9	7.5	3.9	1.92
B3	10	8.9	4.3	2.07
B3	11	6.2	3.0	2.07
B3	12	9.6	4.4	2.18
B3	13	9.4	4.3	2.19
B3	14	11.3	5.2	2.17
B3	15	8.5	4.1	2.07
B3	16	8.7	3.6	2.42
B3	17	6.5	3.6	1.81
B3	18	8.5	4.4	1.93
B3	19	9.2	4.2	2.19
B3	20	7.5	3.4	2.21
B3	21	10.4	4.5	2.31
B3	22	8.2	3.9	2.10
B3	23	7.8	3.4	2.29
B3	24	11.0	5.1	2.16
B3	25	8.3	4.5	1.84
B3	26	7.5	3.9	1.92
B3	27	8.8	4.4	2.00
B3	28	9.9	4.5	2.20
B3	29	8.1	3.5	2.31
B3	30	########	########	########
Median		9.0	4.2	2.15
Average		8.97	4.20	2.14
Std Dev		1.14	0.49	0.18
Coeff of Variation		0.127183	0.114911	0.084436

Central Aguirre Area C — 2 Apr 99 — Longitude 19795450 — Latitude 1984182

Sampled Tree	Leaf Number	Leaf Length (cm)	Leaf Width (cm)	Ratio (Length/Width)
C1	1	9.0	4.8	1.94
C1	2	10.8	5.6	1.93
C1	3	8.7	4.5	1.93
C1	4	8.6	4.9	1.76
C1	5	9.2	4.4	2.09
C1	6	9.3	5.5	1.69
C1	7	9.5	5.2	1.83
C1	8	7.7	4.2	1.83
C1	9	8.6	4.4	1.95
C1	10	6.2	3.5	1.77
C1	11	10.2	5.0	2.04
C1	12	10.5	5.7	1.84
C1	13	9.1	4.8	1.98
C1	14	9.9	4.9	1.82
C1	15	11.6	6.5	1.78
C1	16	8.8	4.7	1.87
C1	17	7.7	4.1	1.88
C1	18	10.9	5.8	1.85
C1	19	10.7	5.8	1.81
C1	20	8.8	4.8	1.83
C1	21	9.3	4.5	2.07
C1	22	9.8	5.3	1.85
C1	23	9.7	4.9	1.98
C1	24	10.1	5.4	1.87
C1	25	9.4	5.2	1.81
C1	26	9.4	5.2	1.81
C1	27	8.8	5.1	1.75
C1	28	8.6	4.1	2.10
C1	29	8.8	4.8	1.91
C1	30	9.1	4.8	1.90
C2	1	9.7	4.4	2.09
C2	2	11.4	5.5	2.07
C2	3	11.2	5.3	2.11
C2	4	10.2	5.0	2.04
C2	5	8.3	4.3	1.93
C2	6	9.2	4.5	2.04
C2	7	10.2	5.1	2.00
C2	8	9.3	4.5	2.07
C2	9	9.1	4.4	2.07
C2	10	9.1	4.7	1.94
C2	11	8.8	4.4	2.00
C2	12	9.1	4.7	1.94
C2	13	8.2	3.9	2.10
C2	14	8.8	4.4	1.95
C2	15	9.8	5.1	1.92
C2	16	8.1	4.6	1.76
C2	17	8.7	4.4	1.98
C2	18	8.2	4.9	1.88
C2	19	9.7	5.6	1.73
C2	20	8.8	4.5	1.96
C2	21	8.8	4.4	2.02
C2	22	8.9	4.7	1.89
C2	23	10.4	5.5	1.88
C2	24	8.4	4.2	2.00
C2	25	9.5	4.9	1.94
C2	26	8.2	4.3	1.81
C2	27	9.5	4.7	2.02
C2	28	8.7	4.6	1.89
C2	29	9.3	4.4	2.11
C2	30	9.8	5.0	1.92
C3	1	10.5	5.1	2.06
C3	2	9.2	4.8	1.92
C3	3	8.4	4.1	2.05
C3	4	7.7	4.2	1.83
C3	5	9.7	4.8	2.02
C3	6	9.5	4.6	2.07
C3	7	9.5	4.8	1.98
C3	8	8.5	4.7	1.81
C3	9	8.7	4.5	1.93
C3	10	9.4	5.0	1.89
C3	11	8.8	4.5	1.91
C3	12	9.8	4.7	2.04
C3	13	9.7	4.8	1.89
C3	14	8.6	4.3	2.00
C3	15	11.1	6.1	1.82
C3	16	10.0	5.1	1.96
C3	17	7.3	4.2	1.74
C3	18	8.8	4.7	1.83
C3	19	8.3	4.1	2.02
C3	20	9.5	5.4	1.78
C3	21	9.2	4.8	1.92
C3	22	7.2	4.0	1.80
C3	23	8.5	4.7	1.81
C3	24	8.5	4.8	1.77
C3	25	9.7	5.2	1.87
C3	26	8.5	4.7	1.81
C3	27	7.9	4.0	1.98
C3	28	9.4	5.1	1.84
C3	29	10.3	5.6	1.84
C3	30	########	########	########
Median		9.2	4.8	1.92
Average		9.17	4.79	1.92
Std Dev		0.94	0.52	0.11
Coeff of Variation		0.102163	0.108113	0.054975

Central Aguirre Area D — 2 Apr 99 — Longitude 19795226 — Latitude 1984100

Sampled Tree	Leaf Number	Leaf Length (cm)	Leaf Width (cm)	Ratio (Length/Width)
D1	1	9.7	4.8	2.02
D1	2	8.6	4.1	2.10
D1	3	9.8	4.2	2.33
D1	4	7.2	4.0	1.80
D1	5	9.5	2.5	3.80
D1	6	10.2	3.8	2.68
D1	7	8.4	4.4	1.91
D1	8	8.4	4.6	1.83
D1	9	9.6	3.0	3.20
D1	10	8.6	3.0	2.87
D1	11	9.6	3.8	2.53
D1	12	8.0	3.4	2.35
D1	13	10.1	4.2	2.40
D1	14	8.6	3.6	2.39
D1	15	10.1	4.2	2.40
D1	16	9.4	4.2	2.24
D1	17	9.4	4.5	2.09
D1	18	10.5	3.4	3.09
D1	19	8.2	3.3	2.48
D1	20	9.7	4.1	2.37
D1	21	10.8	5.4	1.98
D1	22	10.3	5.1	2.02
D1	23	8.5	4.3	1.98
D1	24	8.6	4.4	1.95
D1	25	9.4	4.9	1.92
D1	26	8.2	4.5	1.82
D1	27	7.7	3.4	2.26
D1	28	7.8	3.1	2.52
D1	29	7.9	4.1	1.93
D1	30	8.2	3.0	2.73
D2	1	8.3	3.0	2.77
D2	2	9.2	4.1	2.24
D2	3	9.4	4.3	2.19
D2	4	8.9	4.0	2.23
D2	5	9.2	4.3	2.14
D2	6	9.2	4.1	2.24
D2	7	8.5	4.3	1.98
D2	8	7.8	4.3	1.81
D2	9	9.1	5.1	1.78
D2	10	8.7	5.0	1.74
D2	11	10.3	5.4	1.91
D2	12	9.1	4.7	1.94
D2	13	9.6	3.8	2.53
D2	14	9.1	4.2	2.17
D2	15	6.8	3.8	1.79
D2	16	8.2	4.0	2.05
D2	17	8.1	3.6	2.25
D2	18	9.6	4.8	2.00
D2	19	8.3	3.2	2.59
D2	20	4.8	3.2	1.44
D2	21	7.1	3.3	2.15
D2	22	4.2	3.9	1.08
D2	23	7.1	2.9	2.45
D2	24	9.7	3.2	3.03
D2	25	9.1	3.6	2.53
D2	26	9.2	4.0	2.30
D2	27	8.5	3.8	2.24
D2	28	8.4	3.6	2.33
D2	29	10.7	4.5	2.38
D2	30	10.9	4.5	2.42
D3	1	9.4	3.5	2.69
D3	2	8.5	3.1	2.74
D3	3	8.9	3.6	2.47
D3	4	9.0	4.6	1.96
D3	5	9.0	4.1	2.20
D3	6	7.8	3.3	2.36
D3	7	7.8	3.8	2.05
D3	8	7.1	3.2	2.22
D3	9	8.6	3.7	2.59
D3	10	9.7	9.5	1.02
D3	11	8.1	3.0	2.70
D3	12	9.5	3.8	2.50
D3	13	8.4	3.7	2.27
D3	14	8.8	4.2	2.10
D3	15	8.5	3.1	2.74
D3	16	9.0	3.0	2.67
D3	17	8.0	3.2	2.50
D3	18	8.9	5.6	1.59
D3	19	9.5	3.8	2.50
D3	20	6.8	3.3	2.00
D3	21	10.0	4.1	2.44
D3	22	10.2	5.3	1.92
D3	23	9.5	5.0	1.90
D3	24	8.4	4.2	2.00
D3	25	9.3	5.2	1.79
D3	26	10.4	4.8	2.26
D3	27	7.5	3.9	1.92
D3	28	10.1	4.5	2.24
D3	29	9.8	4.3	2.23
D3	30	9.0	4.4	2.05
Median		8.8	4.0	2.24
Average		8.81	4.05	2.24
Std Dev		1.15	0.89	0.41
Coeff of Variation		0.130556	0.219108	0.185059

Central Aguirre Area E — 2 Apr 99 — Longitude 19795029 — Latitude 1984183

Sampled Tree	Leaf Number	Leaf Length (cm)	Leaf Width (cm)	Ratio (Length/Width)
E1	1	9.9	3.8	2.61
E1	2	10.2	4.0	2.55
E1	3	9.1	4.2	2.17
E1	4	10.3	4.6	2.24
E1	5	10.6	4.7	2.26
E1	6	8.6	4.0	2.15
E1	7	10.7	5.1	2.10
E1	8	10.4	5.1	2.04
E1	9	9.8	4.4	2.18
E1	10	9.3	4.4	2.11
E1	11	9.1	4.2	2.17
E1	12	9.9	3.9	2.54
E1	13	11.5	4.7	2.45
E1	14	9.5	4.4	2.16
E1	15	9.9	4.1	2.17
E1	16	9.2	4.3	2.14
E1	17	9.5	4.3	2.21
E1	18	9.3	4.5	2.07
E1	19	10.1	4.6	2.20
E1	20	7.9	3.6	2.19
E1	21	8.3	3.8	2.18
E1	22	9.6	4.2	2.29
E1	23	10.3	4.7	2.19
E1	24	11.3	4.9	2.31
E1	25	11.0	4.9	2.24
E1	26	11.4	5.5	2.07
E1	27	9.1	4.2	2.17
E1	28	9.9	4.5	2.20
E1	29	11.7	5.3	2.21
E1	30	12.3	5.9	2.08
E2	1	9.4	4.1	2.29
E2	2	10.7	5.1	2.10
E2	3	9.4	4.2	2.24
E2	4	9.7	4.4	2.20
E2	5	9.0	4.3	2.09
E2	6	8.8	4.3	2.05
E2	7	9.4	4.7	2.00
E2	8	9.0	4.3	2.09
E2	9	9.2	4.8	1.92
E2	10	9.3	3.7	2.51
E2	11	9.5	4.2	2.26
E2	12	10.5	5.3	1.98
E2	13	10.0	4.7	2.13
E2	14	11.1	4.8	2.41
E2	15	9.6	4.3	2.23
E2	16	11.0	4.4	2.50
E2	17	9.8	4.5	2.13
E2	18	8.0	3.6	2.22
E2	19	10.5	4.6	2.29
E2	20	8.3	3.9	2.13
E2	21	10.5	5.2	2.02
E2	22	9.4	4.5	2.09
E2	23	8.1	3.6	2.25
E2	24	7.9	3.9	2.03
E2	25	10.8	5.5	1.96
E2	26	10.4	4.2	2.48
E2	27	9.4	4.6	2.04
E2	28	9.8	4.2	2.33
E2	29	8.9	3.8	2.34
E2	30	10.4	4.3	2.42
E3	1	9.9	4.2	2.36
E3	2	11.8	5.9	2.00
E3	3	8.4	4.7	1.79
E3	4	11.2	4.8	2.33
E3	5	10.9	4.4	2.48
E3	6	10.6	5.0	2.12
E3	7	9.2	4.2	2.19
E3	8	10.0	4.8	2.08
E3	9	8.9	4.7	1.89
E3	10	12.3	5.4	2.28
E3	11	10.9	4.7	2.32
E3	12	10.8	5.0	2.16
E3	13	8.2	4.3	1.91
E3	14	11.8	5.0	2.36
E3	15	9.2	4.0	2.30
E3	16	11.1	4.5	2.47
E3	17	11.1	4.5	2.47
E3	18	12.7	5.2	2.44
E3	19	11.8	5.3	2.23
E3	20	12.0	4.8	2.50
E3	21	11.5	4.9	2.35
E3	22	9.7	4.7	2.08
E3	23	10.6	4.5	2.36
E3	24	10.2	4.7	2.17
E3	25	10.5	4.1	2.56
E3	26	11.2	4.4	2.55
E3	27	11.5	5.2	2.21
E3	28	12.1	5.6	2.16
E3	29	10.9	5.0	2.18
E3	30	10.5	4.9	2.14
Median		10.1	4.6	2.20
Average		10.08	4.58	2.22
Std Dev		1.12	0.51	0.17
Coeff of Variation		0.11118	0.110915	0.078571

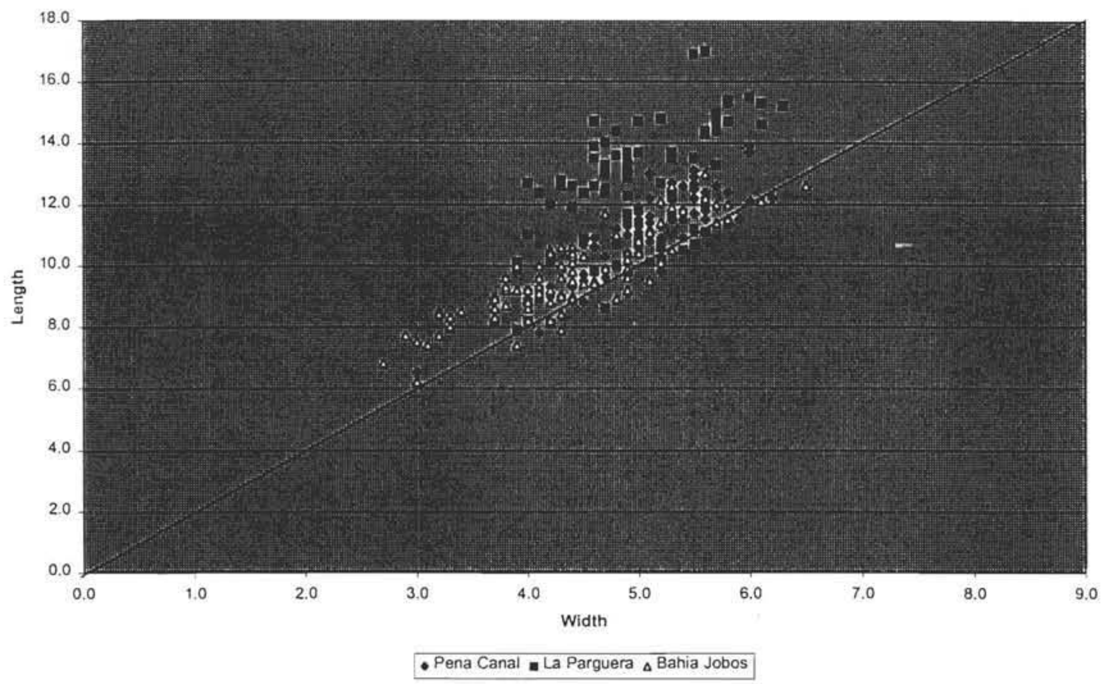
Central Aguirre Area F — 2 Apr 99 — Longitude 19794751 — Latitude 1983579

Sampled Tree	Leaf Number	Leaf Length (cm)	Leaf Width (cm)	Ratio (Length/Width)
F1	1	11.8	5.4	
F1	2	10.6	3.7	2.86
F1	3	11.1	3.8	2.92
F1	4	12.5	3.7	3.39
F1	5	12.0	6.0	2.00
F1	6	12.4	4.6	2.70
F1	7	10.0	3.7	2.70
F1	8	11.2	3.1	3.61
F1	9	8.3	3.1	2.68
F1	10	9.0	3.5	2.57
F1	11	13.0	3.2	4.06
F1	12	9.5	3.7	2.57
F1	13	12.8	3.9	3.28
F1	14	11.6	3.9	2.97
F1	15	12.7	4.0	3.18
F1	16	13.0	3.9	3.33
F1	17	11.8	4.9	2.48
F1	18	10.3	4.0	2.58
F1	19	11.5	4.6	2.50
F1	20	13.5	5.8	2.33
F1	21	11.1	4.5	2.47
F1	22	10.0	4.5	2.22
F1	23	9.4	4.3	2.19
F1	24	11.5	4.8	2.40
F1	25	15.1	6.0	2.52
F1	26	13.2	5.9	2.24
F1	27	12.8	4.0	3.20
F1	28	12.0	6.0	2.00
F1	29	13.2	6.1	2.18
F1	30	12.1	5.8	2.09
F2	1	11.5	6.0	1.92
F2	2	14.1	4.9	2.88
F2	3	10.8	4.5	2.40
F2	4	12.7	3.9	3.26
F2	5	11.3	5.4	2.09
F2	6	11.7	6.2	1.89
F2	7	12.4	5.7	2.38
F2	8	13.0	4.2	3.10
F2	9	11.2	4.6	2.43
F2	10	13.0	4.7	2.77
F2	11	12.0	4.8	2.50
F2	12	11.5	5.5	2.09
F2	13	12.1	5.5	2.20
F2	14	12.0	4.9	2.45
F2	15	10.1	5.4	1.87
F2	16	12.1	6.8	1.78
F2	17	10.8	4.9	2.20
F2	18	13.9	4.8	2.90
F2	19	12.0	4.2	2.86
F2	20	11.0	4.7	2.34
F2	21	12.4	4.4	2.82
F2	22	11.4	4.1	2.78
F2	23	13.7	5.0	2.74
F2	24	11.8	4.2	2.78
F2	25	8.7	4.2	2.07
F2	26	13.8	6.0	2.27
F2	27	9.7	5.1	1.90
F2	28	10.9	5.1	2.14
F2	29	11.1	4.6	2.41
F2	30	13.2	4.7	2.81
F3	1	9.5	3.5	2.71
F3	2	12.6	4.5	2.80
F3	3	12.3	4.7	2.93
F3	4	11.0	3.9	2.82
F3	5	13.2	4.7	2.81
F3	6	11.6	3.6	3.22
F3	7	14.0	6.2	2.26
F3	8	13.0	5.7	2.28
F3	9	12.0	5.2	2.31
F3	10	12.2	5.6	2.18
F3	11	13.1	4.7	2.79
F3	12	12.2	4.2	2.90
F3	13	8.4	3.8	2.21
F3	14	11.5	4.8	2.50
F3	15	10.2	4.3	2.37
F3	16	13.5	4.8	2.81
F3	17	13.2	4.1	3.22
F3	18	14.2	4.7	3.02
F3	19	12.8	5.0	2.52
F3	20	13.2	4.9	2.69
F3	21	14.5	4.7	3.09
F3	22	12.6	4.3	2.93
F3	23	13.7	4.4	3.11
F3	24	13.0	5.7	2.28
F3	25	12.3	5.8	2.07
F3	26	13.0	5.7	2.28
F3	27	11.0	3.0	3.67
F3	28	13.0	3.8	3.42
F3	29	12.8	4.7	2.72
F3	30	12.9	5.0	2.58
Median		12.0	4.7	2.57
Average		11.98	4.69	2.81
Std Dev		1.40	0.83	0.45
Coeff of Variation		0.116874	0.178204	0.173217

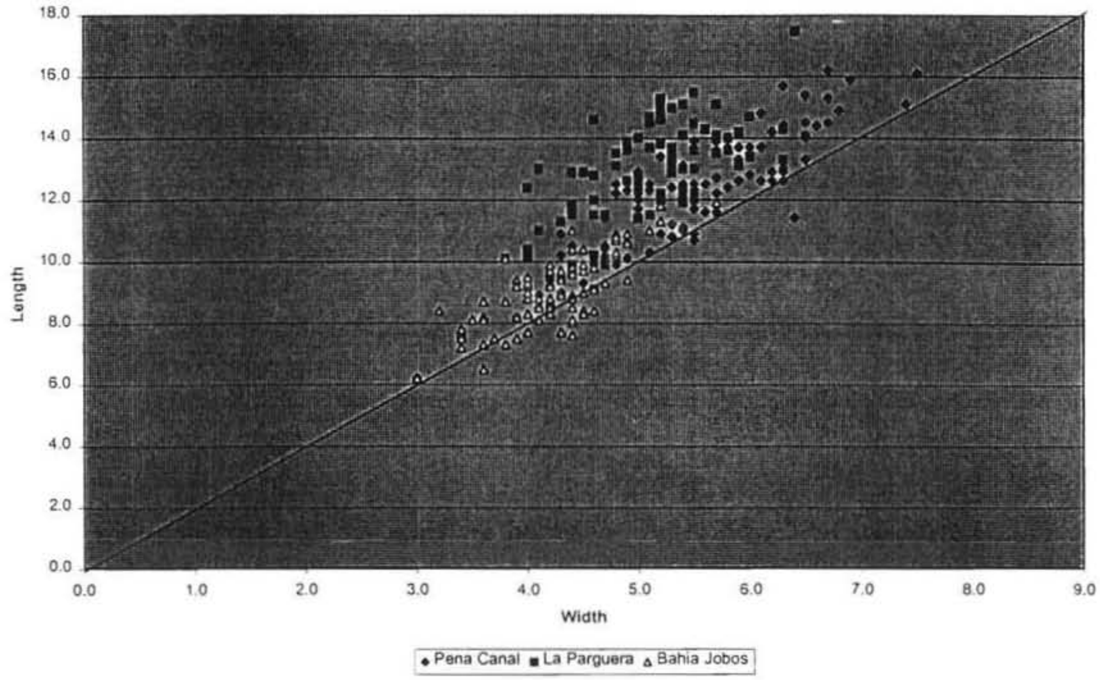
Appendix D: Leaf Data

On the following pages are graphical representations of the lengths and widths of leaf samples taken, presented by sample groups.

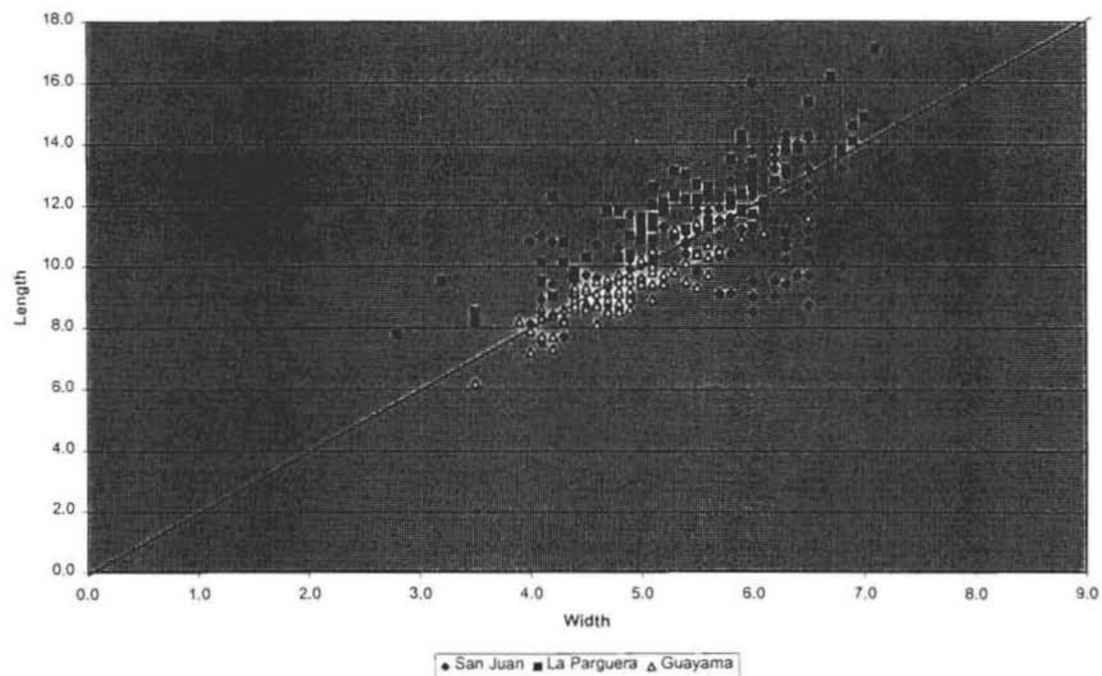
Sample A



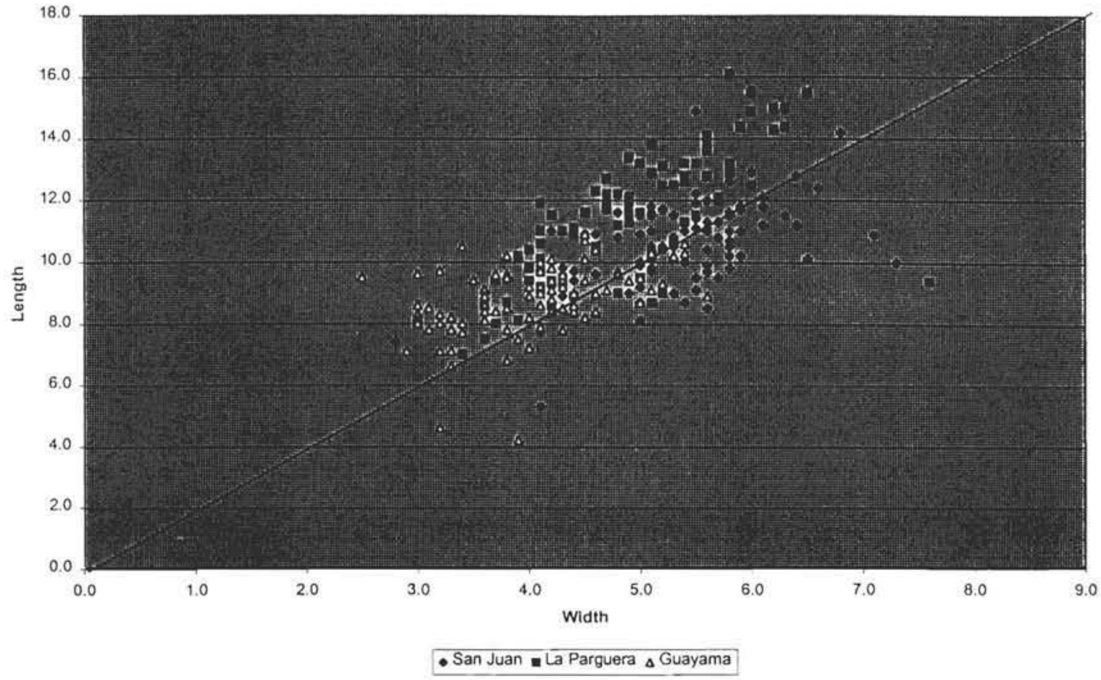
Sample B



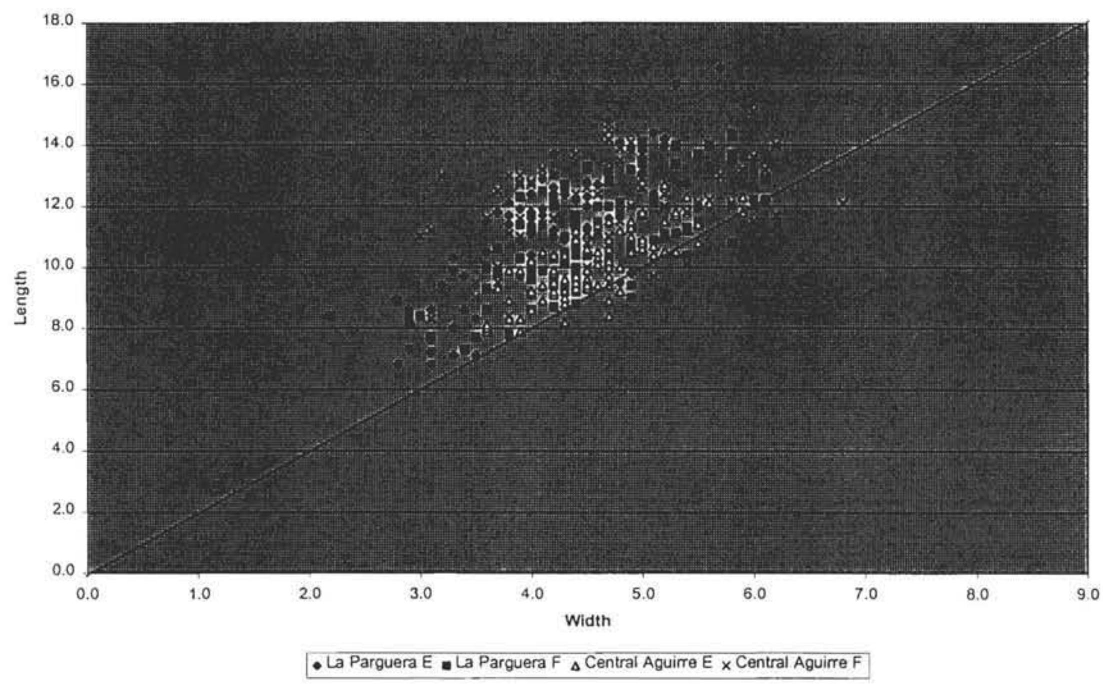
Sample C



Sample D



Samples E and F



Appendix E: Interview Summaries

Interviewee: Professor Richard Pete, Clark University
Date: 22 February 1999
Time: 1130
Interviewer: Mark Brito and Steve Schachterle
Recorder: Mark Brito and Steve Schachterle

We tried some planned questions in the beginning of this interview. Professor Pete openly admitted to knowing none of the answers to them. We were also told we would not be given much time so we tried to cover ground quickly. Steve made up the first question during the interview after the planned questions failed. Professor Pete went on at length to answer it and the rest of the interview became more of a conversation, which spun off the initial question. We taped the conversation, went back over, found the questions, and briefly summarized their answers. After a rough start, Professor Pete proved to be a convincing and gifted speaker.

Question: How could non point source pollution from industry effect wetlands in Puerto Rico?

Answer: Puerto Rico, like many developing areas, attempted to industrialize rapidly and at all costs. The American government brought in oil refineries and petrochemical industry in the 1960s with little consideration for the environment. They shipped oil up from Venezuela and began set up refineries in Puerto Rico. The government did little to monitor the industrialization. Environmental officials were often corrupt. Cancer rates escalated but with the desire for industrialization so great little was done to help the environmental problems. People moved close to the refineries, which harmed their health.

Question: What types of pollutants from the petrochemical and oil refining industry would cause the most harm?

Answer: Tar products, sulfur, and oil all would come out of that kind of development, but the worst are the organic compounds from ethylene production. Ethylene can be improperly stored and can leach out.

Question: What kind of problems do these organic compounds cause?

Answer: They interact with natural growth processes in and causes aberrations in growth. These growth problems are especially pronounced in children, but increase cancer levels in adults. It effect both plants and animals.

Question: How will coastal waters be effected by this type of pollution?

Answer: Some will be removed from the waters quickly, some will be their forever. Organic pollutants may be dispersed by the currents and diluted, but in the dispersal they will come in contact with many more organisms, which they can harm. It would be better to confine the damm things, and then they could be removed.

Question: What kind of measures could be taken to counteract organic pollutants.

Answer: Ending petroleum refining is the only way to completely rid the environment of the toxins. Besides that, you can scrub the shoreline--

Question: Do you mean physically scrub the rocks and stuff?

Answer: Yes. You can recycle the chemical, which requires a major investment, one that should be made by the American government.

Question: Is the condition of the waters surrounding industry worse in Puerto Rico than in the continental US?

Answer: Yes, it's worse. They have less regulation in Puerto Rico, a greater density of industry, and a tropical climate. The climate speeds up the process where by the chemicals get into the life.

Interviewee: Professor William L. Turner II, Clark University

Title:	Higgins Chair of the Environment and Society
Date:	22 February 1999
Time:	1600
Interviewer:	Mark Brito and Steve Schachterle
Recorder:	Mark Brito and Steve Schachterle

At Clark University we received information from Professor Peet, that professor B.L.Turner would be able to answer many of our questions. William Clark is an expert in Cultural and Human Ecology. He is also knowledgeable in the fields of third world agriculture and global change. He answered all of our planned questions and many probing questions. In the following interview, only the planned questions and a summary of the answers are included. Much valuable information was attained from this interview.

Question: Could you describe the geological structure and composition of the Puerto Rican Island?

Answer: Puerto Rico, like most islands and tropical areas is a carst environment. The land is primarily made of limestone with areas that are dissolved into sinkholes and is very flat. Generally water runs right through the limestone, as it is very porous.

Question: What types of agriculture might we expect to find in Puerto Rico?

Answer: Maize, sugar cane on a corporate scale. Plantations. Very few subsistent agriculture, and house gardens. Many commercial gardens.

Question: What types of pollution do these types of agriculture create?

Answer: Nitrogen, it does flow off according to the dynamics of the estuary. Water flow, elevation, etc... Eutrification, and build-up of nitrogen, potassium and phosphorous, NKP.

Question: Specifically, what types of agriculture cause some of the pollution we can expect to find?

Answer: Maize and sugar cane are very demanding of fertilizer. A lot of run-off of this fertilizer occurs.

Question: What effects will these pollutant have on the wetlands?

Answer: The excess fertilizer causes many problems. It affects the plants in the area. The animals who eat the plants and so on. Particularly, it can have a dramatic affect on the growth of algae in water. These algae grow and essentially suffocate the oxygen supply right out of the water. They also form a canopy over the water and don't allow sunlight to penetrate to the bottom of the water. This kills most life underneath.

Question: Will these pollutants have any affect on drinking water supplies?

Answer: Yes, especially near the coast where the carst area is thin. The surface water drains very easily through the porous limestone and contaminates the potable water supplies. Also, the ground water is not very deep.

Question: Do you think that pollution in the coastal ground water supplies can contaminate drinking water further inland?

Answer: Yes, it is possible. It also depends on the elevation of the land and the water table, also the flow of the water. The coastal ground water is largely interconnected with the sea water.

Question: What types of pollution could we find besides agricultural runoff?

Answer: Topospheric pollution is a possibility. Industrial regions as well as urban regions form a micro-climate around themselves where the temperature is about 1 to 2 degrees higher. Here nitrogen is reieased into the air and combines with ozone and then falls in rain to contaminate the soil. This is not acid rain. It is a different type. He was not completely sure of the details but told us that there are currently studies being done on this subject.

Question: Do the pesticides used in agriculture have an effect on coastal wetlands?

Answer: Yes, there are studies which do link pesticides to run-off to pollution in the environment.

Question: What markers could you look for in the land to determine if erosion from agriculture has effected the coast?

Answer: There are various things one can look for; Large nutrient build-up originating from agricultural topsoil, a large canopy setting (large trees as a result of the fertilizer), thin topsoil depth, and changes in the physical landscape, e.g. changes in tidal flux, and changes in elevation of water or soil.

Interviewee: Julio Morales Rivera
Occupation: Ranger at Parque Linear
Interviewer: Mark Brito
Recorder: Mark Brito
When: April 22 1999, at ~ 2:00pm
Where: Paseo Linear, Santurce, Puerto Rico

Julio Morales Rivera has lived near the Martin Pena Channel for over 20 years and has six years of experience working on the Paseo Linear. Before working on the walk, Sr. Rivera worked on the Perez Cia Dyke. The interview was conducted in entirely in Spanish and lasted approximately 45 to 50 minutes.

Question: As far back as you can remember, what was the mangrove coverage around this area? (Santurce area, near the west mouth of the Martin Pena Channel)

Answer: In 1964, when I was eight years old, I remember the mangrove forests in the area were enormous. The mangroves covered the banks of the Martin Pena from the San Juan Bay to where the Martin Pena stands lies now. These mangroves were eventually cut down for the development of slums. Where the Parque Central lies today, used to be all wetlands covered with mangroves. It was known by "Los Tablones", "La Veinte", and "El Fangito." It got the name " Los Tablones," because the people would travel through the area on wooden boards and other types of makeshift bridges. In fact, the mangroves were a good place to hide from the cops because it is very difficult to run through them. The area where the Acuaexpresso is right now, used to be all mangroves until the slums developed there as well. This area then became known as Tokio. The Milla de Oro (Gold Mile) was also an area in which the mangroves were destroyed.

Question: What were the slums like and how did they affect on the environment?

Answer: The slums caused a lot of pollution to the area. The houses were built right over the water using garbage as fill which polluted the waters. Because sanitation trucks could not get into the area, the people made latrines that emptied directly into the channel. This severely polluted the water as well. I remember swimming in the channel. I also played in the mangrove forests, fished the waters, made small rafts, and hunted large crabs. They were everywhere. You didn't even have to catch them outside the little holes they make in the ground. You could see them everywhere. The slums grew extremely fast. The train would stop right outside of the slums on the way to San Juan. Farmers looking for work would leave the rural areas and build a shack near the city. This continued to happen as Puerto Rico's economy changed from an agricultural one to more of an industrial one.

Question: How did all of this affect the mangroves?

Answer: Well, a lot of mangroves were cut down to make room for the houses. The mangroves also were very useful to the people. Many people used it for firewood. This actually become a way of income for some people of the area. They made charcoal out of the mangrove trees. This was sold locally and was called "chimba." People also used the mangroves as a hideout for the making of distilled rum called "caña," because the mangroves are difficult to walk through. The development eventually eliminated almost all of the mangroves until the government decided to get rid of the dwellings.

Question: What did the government do the remedy the situation?

Answer: The government moved as many people as possible into public housing projects. Many of these housing projects were built away from the channel. This left room for the mangroves to regenerate themselves. After everyone was moved out, the Channel was straightened, widened, and dredged to a depth of 14 ft.

Question: What are some of the stresses that the mangroves endure today?

Answer: Hurricanes affect the mangroves. When Hurricane George hit in September, all the mangroves were left without leaves. They resembled trees in wintertime up north. The mangrove trees here are very resilient. By December, three months later, all the leaves were back on the trees. There is still pollution going into the waters of the channel. I used to work on the Perez Cia Dyke. It is a huge dyke where boats are taken to be cleaned. The dyke is sixty feet deep with an elaborate lock system. Large boats from the San Juan Bay are brought in through the Martin Peña and into the lock system. The water around the boat is then drained and the boat is left suspended on large stands. The boat is cleaned inside and out. All of the exterior paint is stripped and replaced by five to six coats of new paint. The inside of the boats is also cleaned extensively. When I worked there, I did not notice any tanks or any other types of receptacles under the boat to catch all of the refuse. They might be there but I'm not sure that they are. The astounding thing is that this process takes place every three to four months per boat. That means that there are boats there constantly.

Las Tres Monjitas is a dairy plant where milk is taken to be processed. The plant is south of the Channel, in Hato Rey Norte. Two or three years ago, I saw a stream of white floating on the channel. I reported it to Natural Resources and their investigation found that it came from Las Tres Monjitas.

Apparently, they had dumped 100's of gallons of cut milk and processing chemicals into a small tributary of the channel. They were fined between three to five thousand dollars a day until the mess was cleaned up. Within a week, the plant hired someone to clean it. I also often find a stream of what appears to be oil at the beginning of the walk. There is a Shell gas station and two mechanic shops along a tributary to the Martin Peña. I cannot say whether the oil is coming from those sources, but it could be possible.

Question: What are the consequences of all this pollution?

Answer: Due to all of the pollution, boating and fishing has been banned. Only police boats are allowed in the channel. Fish kills have been noticed from time to time. I haven't seen large numbers of dead fish, but have had fellow workers tell me that they have seen large fish kills. During my shifts, I mostly see small dead fish. Perhaps the larger fish in the channel can withstand the pollution better. I feel that the oil is the worst pollutant. A lot of oil comes out of boat engines as well.

Question: Is there any current urbanization affecting the channel and the mangroves today?

Answer: The current construction of the Urban Train passes over some mangrove areas. There was some mangrove clearing for this project but I do not think that many mangrove trees where cut down for this project. Now, there was a large area of mangroves cleared for the future construction of the National Security Building. In the building will be the chiefs of police, fire, 911 will be there, and other offices that pertain to security. It also appears that they are constructing a dock behind the building. I just recently became aware of this. If they plan to put a dock there, that would mean that more boats would be travelling up and down the channel. I believe this will pollute the water even more.

Question: With what you have seen through the years, what o you feel to be the greatest danger to the mangroves and to the area's habitat?

Answer: The mangroves are resilient and can easily to adapt to their habitat. Cutting them down is their greatest stress. Since they have been left alone, they have flourished, although the pollution in the water is still a concern.