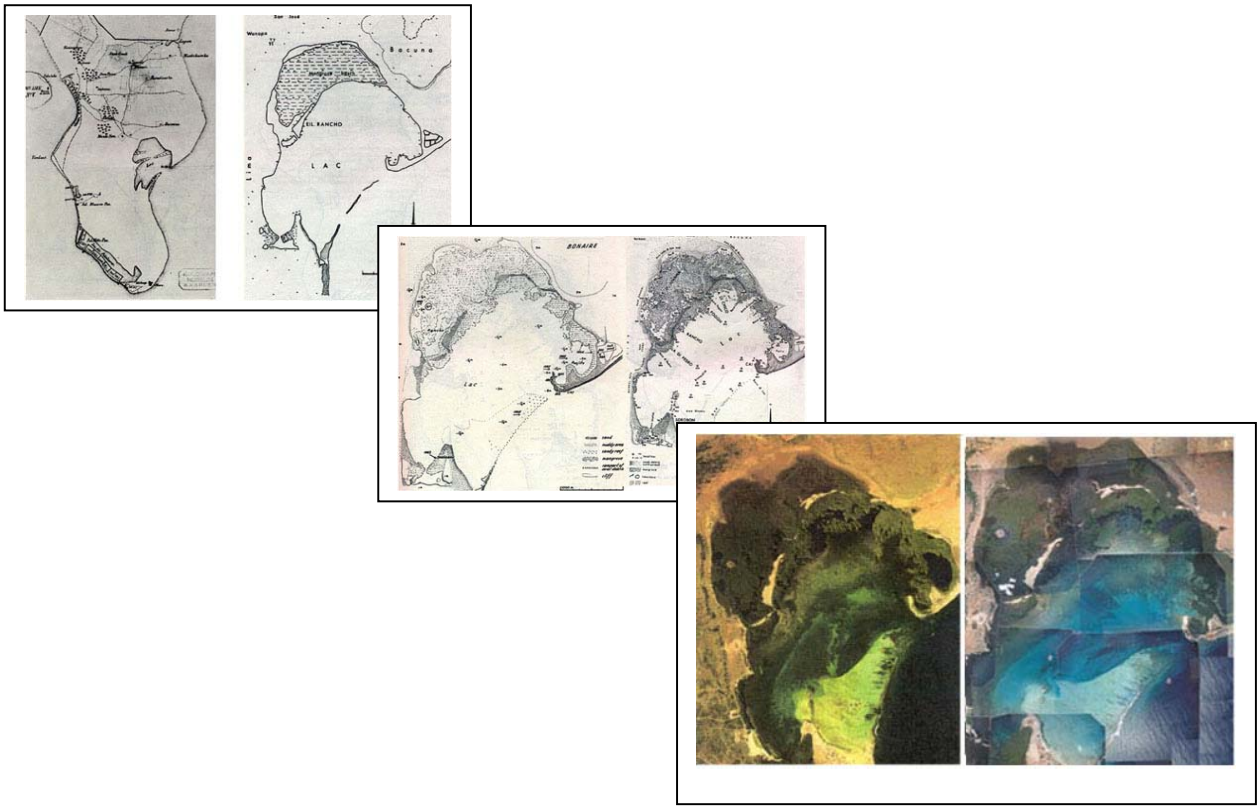
Lac Bay: Then and Now…

A Historical Interpretation of Environmental Change During the 1900s

A Site Characterization of Lac Bay
for
Resource Managers and Naturalists



prepared for
Bonaire Marine Park
by
Environics, N.V.
Cynthia E. Lott, Environmental Consultant
Final Edition
October 2001

Lac Bay Then and Now
A Historical Interpretation of Environmental Change During the 1900s

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For
Resource Managers and Naturalists

By

Cynthia E. Lott
Environmental Consultant

Bonaire, Netherlands Antilles
Final Edition
October 2001

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This Work is dedicated…

In the fondest memory of
My beloved friend, Dick Harrison, who encouraged me to believe in myself.

God Bless Us Every One….

Foreword

by Boi Antoin, Editor of EXTRA, Bonaire's Daily Newspaper, and respected local historian

LAC

No tin duda ku Lac ta un sitio, un bahia, ku nos mester trata na protehá i konservá na tur manera. E historia, kultura i naturalesa di Lac hamas por bai pèrdí. Asina importante e lugá aki tabata I ta pa Boneiru.

Despues di investigashonnan arkeológiko i ekológiko ku a tuma lugá di Lac, tabata nesesario, na mi konsepto, pa a bini ku un investigashon mas profundo i sientífiko di e área bunita aki.

Mi ta realmente kontento, komo un persona ku stima Boneiru di henter su kurason, ku a bini un investigashon asina, hasí pa Cindy Lott, ku no a spar ningun esfuerso pa investigá e naturalesa di e region di Lac. Ta trata aki di un dokumento ku un peso grandi, sigur kaminda e investigadó ta hasi sierto rekomendashon I ta menshoná puntonan di akshon ku e ta kere ku mester tuma pa konservá Lac pa Bonerianonan mes.

Ta di spera ku e instansianan kompetente lo usa e rapòrt aki komo un hèrmènt pa duna e protekshon ku ta nesesario asina tantu pa Lac, evitando asina ku ta hasi mas daño ku a hasi kaba na e region aki.

Boi Antoin, EXTRA
Bonaire, N.A.
October 28, 2001

LAC

There is no doubt that Lac is a place, a bay, which we must protect and conserve at all cost. The history, culture and nature of Lac may never be lost.

After archaeological and ecological research that took place of Lac it became necessary, in my opinion, to conduct a deeper and more scientific investigation of this beautiful area. I am very pleased, as a person that loves Bonaire wholeheartedly, that such an investigation has taken place, performed by Cindy Lott, who made every effort to investigate the nature of the region of Lac. We are dealing here with

a very important document, especially where the investigator makes certain recommendations and mentions points of action that she believes must be done to conserve Lac for the Bonairians themselves.

It is to be hoped that the authorities will use this report as a tool to give the necessary protection to Lac, thereby avoiding more damage to this area than has already be done.

Boi Antoin, EXTRA
Bonaire, N.A.
October 28, 2001

Acknowledgements

The 1999 Lac Bay environmental assessment project has been carried out on behalf of the STINAPA Bonaire National Marine Park, and the people of Bonaire, for managing and sustaining Lac Bay as "Perfectly Pure" as possible, for the future enjoyment of Bonaire.

It was made possible by the co-sponsorship of the following:

- *World Wildlife Fund, Netherlands*, who funded the overall Lac Bay program, and*;*
- *The Bonaire National Marine Park,* manager Kalli DeMeyer (former manager of this writing), whose idea this was anyway and put me through "hopi trabou" ("much work" - more than the four weeks she originally offered, now 2 years later, are we finished yet?); and the park program that also provided the logistical support that enabled me to conduct the benthic survey work;
- *DROB* [Dienst Ruimtelijke Ordening en Beheer], Bonaire, who provided the aerial photographs (Wing Group, N.V. Curacao 1998/Dec) for photointerpretation processes;
- *VOMIL* [Ministerie van Volksgezondheid en Milieuhygiene], Curacao, who partially funded the conch stock and seagrass assessment project.

I am especially honored for the Foreword recognition of my work, by the contribution of:

- *Mr. Boi Antoin*, Bonaire's well-respected historian, author of the primer, "Lac Historia di un bahia" ("Lac Story of a Bay"), Editor of the local daily newspaper, the EXTRA, and Television host for the local program, "Herensia di Siglo 20".

In the following, I would like to recognize the written contributions of my Florida colleagues, who joined me here to examine Lac through field investigations:

- *Allen Burdett, Wetlands and Mangroves Specialist, Florida Dept. of Environmental Protection, Submerged Lands Division, Tampa, Florida,* who trekked with Kalli and I for seemingly miles in the mangroves of Lac, carrying a Trimble Pathfinder GPS Unit on his back, allowing us to record elevation data for our mapping purposes, as well as providing his countless observations of the mangrove ecosystem processes found in Lac;
- *Randy Cooper, Hydrological Engineer, Florida Dept. of Environmental Protection, Submerged Lands Division, Tampa, Florida*, who provided technical insights on the sheet flow blockages and other hydrology issues, and recommendations for improving the circulation in the mangrove sub-basin areas of Lac; and finally,
- *Rob Patten, Coastal Restoration Consultant, Coastal Dunes Inc., Sarasota, Florida*, who examined the sand removal issues and provided restoration recommendations for the nearshore degradation problems at the Sorobon area;

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- *Claudia DeKort*, *STCB (Sea Turtle Club Bonaire)*, student intern, Holland, for her comprehensive treatise of association of sea turtles with seagrass in Lac Bay;

- *Caren Eckrich*, *Sea and Discover, Bonaire*, and marine biologist who conducted her graduate thesis research work on the mechanical degradation of seagrass by human activities;

And many special thanks for the hard work and dedication to the cause, by the local volunteers:

- *Barry Gassert*, the Bonaire Underwater Research Assistants (BONURA) project co-ordinator, whose time and detail management for the accomplishment of the bay surveys, and his drive to get it done, made the project successful; as well as

- *Nolly Thode*, marine park ranger, who captained the boat, affectionately known as "the yellow banana", and provided all other logistical support, including laying out all 17 grids with GPS navigation precision, and hauling divers in and out of the banana;

- *Linda Richter*, (NetTech), who produced the underwater survey forms and visual aide references for quality assurance data management and species identification cheat sheets;

- *Jessie Armacost*, BONURA data manager and photographer, who entered and manipulated all the "minutiae" into computer spreadsheet form, so that the author wouldn't go insane while attending to other layers of the Lac monitoring programme, and also provided underwater photos to illustrate this writing;

- *Donna Gassert*, BONURA scientific diver and field assistant, who trekked with me in and out of any area, filled with enthusiasm and a note pad, to record our scientific discoveries for this report;

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- *Elvis Martines*, STINAPA board member who represents the local fishing community, for assisting with fishermen interviews of past and present Lac;

- *Jerry Ligon*, Bonaire naturalist, for his birds sightings list of Cai area*;*

With special thanks to the following academic program for supporting my mapping needs of Lac:

- *Duke University Landscape Ecology Laboratory* at Raleigh, North Carolina, especially graduate student *Phyllis Dermer* and *Dr. Patrick Halpin*, for producing the Geographical Information Systems (GIS) interpretation maps of all the Lac Bay monitoring data;

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- The Bonaire Underwater Research Assistants (BONURA) who donated their talents, time and labor:

Donna Gassert	*Carla Hall*	*Chris and Jessie Armacost*
Coen Voss	*Carl Look*	*Rocky Valentine*
Daniel DeAnda	*Julie Burns*	*Minco Coenraad*
Renate Rietman	*Claudia de Kort*	*Valeria Brette*
Maarten Shuit	*Mary Ann*	*Sabine Engel*
Ben and Laura Buchbinder	And *Bill, The Tourist*, wherever you are!!	

Thanks, you guys, for your hard work, trust and support in the project and me.

And in my upmost respect to the People of Bonaire:

This volume is my gift to you – Bonaire - that you will refer to this volume of the Lac research – past and present – completed by visiting scientists, as well as myself. Through our studies, we have hoped to know the natural ways of Lac, investigated its environmental problems, and offered solutions for the bay to co-exist in the growing progress of Bonaire. This work is for you, and your generations to come. Please hold Lac Bay forever dear.

Sincerely,

Cindy

Cynthia E. Lott, Director *
Environics, N.V. Consultants,
Bonaire, Netherlands Antilles
October, 2001

[Environics, N.V. is a private environmental consulting business based in Bonaire, whose business plan is to provide scientific support to managing bodies, such as the Bonaire Marine Park, or private clients requiring environmental assessments,. Environics, N.V. provides expertise in research and monitoring; environmental impact assessments; environmental education; training programs for resource management personnel, naturalists, and teachers; and planning and maintenance programs for management infrastructures, such as marine park moorings and zonation marker buoys].

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Addendum: I would also like to thank Dr. Godfried van Moorsel, (June 2006), for his kind review of my work, providing me comments, suggestions, questions and corrections for this final version of my research.

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Executive Summary

This Site Characterization report provides a comprehensive coverage of past and present scientific research that had been conducted and recorded in Lac Bay during the 20th Century.

Elements of environmental change are evaluated in this writing by comparing information from the prior studies, and drawing implications from them against recent data collected from a year long ecological monitoring series that were conducted throughout 1999 by Environics, N.V. Consulting. Additional implications were based on ground-truthing a series of aerial photographs that were completed over the years.

The consultant activities were proposed to the Bonaire Marine Park and VOMIL to respond to the management needs listed in the Bonaire Marine Park Terms of Reference LAC001/98, by investigating the following research questions:

- *What is the current health and status of the bay area and surrounding environs, and how has it changed from the past to present, as determined through the interpretation of aerial photographs, scientific research and local historical knowledge?*
- *What is the status of the globally endangered species, the queen conch (Strombus gigas), which inhabit Lac Bay?*
- *How is the bay currently being used by marine life, wildlife, and by humans?*
- *Are there indications of threats on the bay's natural carrying capacity?*

These would begin to provide relevant data in which to support decisions pursuant to the associated public concern issues of the following that are addressed in Section 9 of this report:

- *Opening channels to "refresh" the dying mangrove wetlands;*
- *Extracting sand materials from the Sorobon site; and*
- *Fisheries exploitation of the queen conch.*

The following key environmental problems were found in the research:

- **Conch Population Decline**

Field monitoring activities determined that the conch population size class distribution of a 51,000-m^2 area found approximately 111 conch individuals, with an average age of 2.5 years old. No adult conchs were found in Lac Bay. In brief, the statistical results indicate that for both conch and

invertebrate species in general, the spatial distribution patterns for conch locations in the bay, are found to be in clumps, implying potential constraints on the population. For conch, fishing pressure may be likely, as the mapping results show the remnant conch population is located in the deeper bay channel or boat routes, where the species have least potential accessibility by people fishing for conch. Evidence of juvenile conch species being fished out before reaching adult reproduction size can also be found in the discarded conch piles at Cai, re-enforcing the field data that no adult conch exist in Lac. Taking juveniles may contribute to the extinction of conch in Lac Bay.

- **Mangrove Die-off and Hydrology**

Hydrological monitoring in the mangrove sub-basin areas found that annual salinities ranged from 44 $^{0}/_{00}$ to 180 $^{0}/_{00}$ throughout the area (normal bay salinity averages 44 $^{0}/_{00}$). Two main feeder channels that circulate bay water from the Lac lagoon, into the mangrove sub-basin areas occur in the Kreek di Pedro and Kreek di Coco areas. A third, less regular tide water delivery channel occurs across the Isla di Chico during high water events. Annual tidal flooding and draining phenomena occur during the March and September solstice periods that influences the environmental conditions in the mangroves wetlands. During the March solstice, the tidal waters drain rapidly, depleting the oxygen balance in the natural system, and fish kills frequently occur during this annual event. This dynamic process is part of a natural annual cycle that is typical for the mangrove environment at Lac.

Fresh water flow has been altered over history by building levees, such as at Mona Lisa levee, as well as ill-designed road construction and failing culverts. Periodic fresh water flow into the mangroves is a part of the natural system that provides balance for mangrove viability; it has been grossly altered at the mangrove sub-basin areas, and no longer functions.

- **Sedimentation Processes in Lac**

Sedimentation processes occur due to deposition of sands that are carried in from currents crossing over the coral “dam” that naturally separates the Lac from the coastal oceans. Sedimentation creates the Awa Blanku area. The circulatory patterns in the bay move in a clockwise pattern, that also diverge into the feeder channels that provide water into the mangrove sub-basin areas of the north, depositing sand in the process. In addition, sedimentation occurs in an ephemeral time scale in the area behind the Isla di Pedro. Historical interpretation of maps since the 1961 aerials, show sand deposition in 1961, no sand deposition in 1991, but sand deposition again in 1998 aerials. This again appears to be a natural cycle of the ecosystem rhythm, which occurs in Lac.

- **Management Recommendations**

After analyzing the GIS mapping results for seagrass habitat abundance, etc., a zonation plan of the bay is recommended to demarcate a sanctuary preservation area to replenish for viable conch and other wildlife habitats, as well as to designate multi-purpose recreational use areas. The map products include a GIS zonation map of the natural communities of Lac Bay in Section 3, with management recommendations for the greater bay area found in Section 10.

An example of a recommended zonation plan is found in Section 10. Thereafter, a fisheries management program could be implemented, enforced through issuance of permits and size class catch limits is recommended, that would sustain conch population and commercial fisheries, as well as for local family consumption.

Outside mangrove, shoreline restoration experts, as well as a hydrology engineer were invited to examine the "environmental" problems at Lac, and provide management recommendations in Section 9. The conclusions of environmental symptoms, stressors and biological responses to stress that were identified through scientific research are contained in the final Section 10. In addition, community stakeholders who are concerned for Lac met a consensus on how best to manage Lac; the comprehensive evaluation is provided in Section 10.

The following is a summary list of final management recommendations, as identified by scientific experts and community stakeholders for Lac Bay:

- Permit local, artesinal fishing practices in Lac only with catch quantity and size limits strictly enforced
- Issue permits to control fishing, netting or taking conch
- Initiate a 5-year moratorium against taking conch, and monitor every 3 years for size class distribution for the species in Lac Bay
- Enforce strict size limits of conch to protect taking of juveniles
- Enforce existing legislation to ban taking turtles, protect eggs and nests
- Legally exclude non-Bonaire registered boats to use Lac Bay waters
- Strictly prohibit sand extracting in Lac
- Support water quality standards at Cai

- DROB upgrade Cai road culverts to improve water circulation capabilities
- Disallow cutting of mangroves
- Monitor water quality standards at established sites around bay area
- Sorobon Beach Resort erosion can be safeguarded by removal of lower sections of the groin fence that are below the mean high water line that would greatly help the beaches to the north, without compromising privacy.
- Control car traffic and parking along beach strand of Cai; park outside of Cai area on hard limestone surface
- Establish an environmental education kiosk system throughout the Lac area to explain environmental processes, problems and solutions to promote community self-management and self-regulation.

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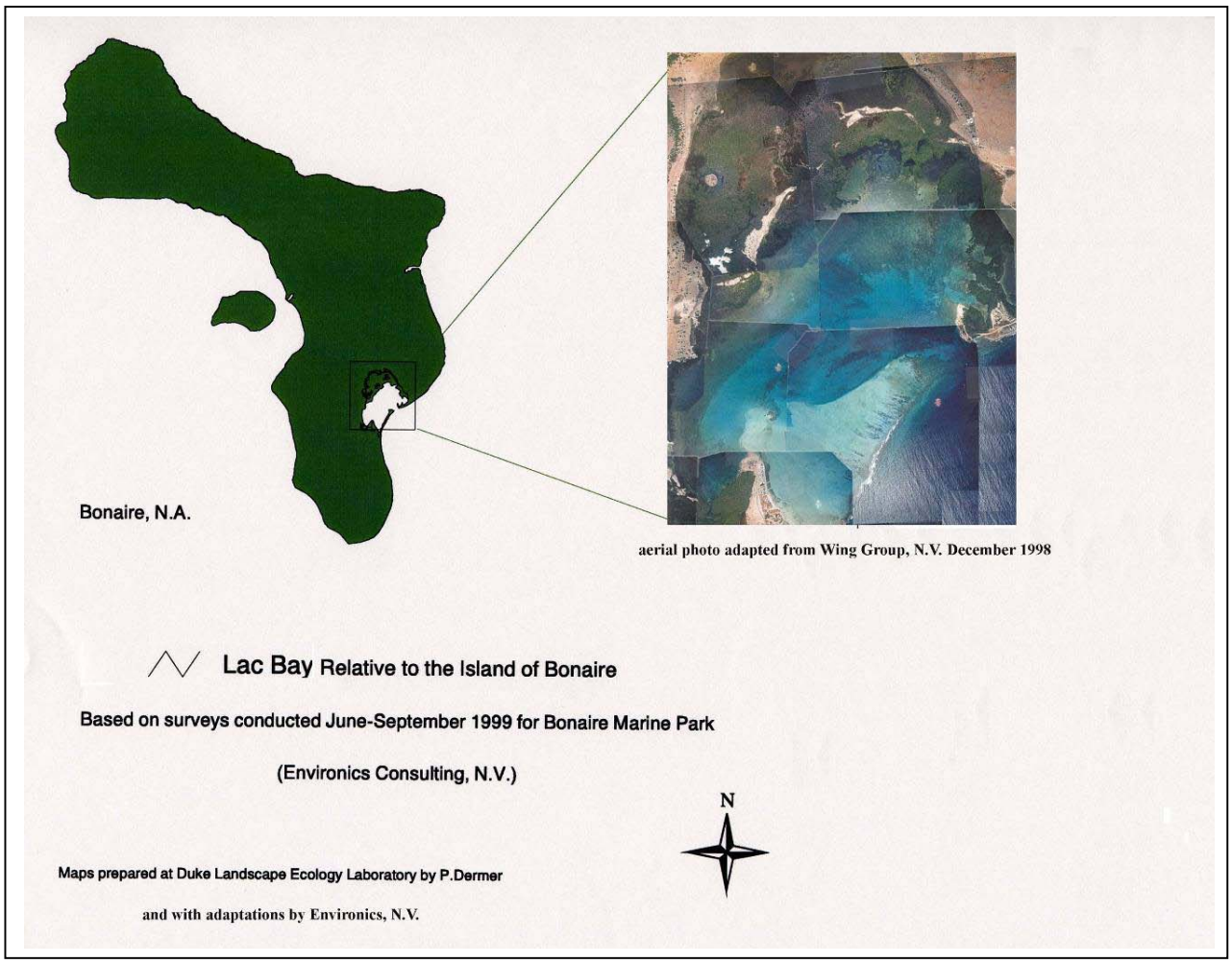
1. Introduction

1.1 Lac Bay Site Location

Lac Bay is geographically located on the southeast coast of Bonaire, and is the greatest lagoon in the Netherlands Antilles. The bay's map corner co-ordinates are located on the North at 12^0 07' 35.6", South at 12^0 05' 30.3", and on the West at 068^0 14' 30.3", and East at 068^0 12' 51.1". The entire Lac area, including the mangroves, is approximately 3.9 km north-south and 3.0 km east-west, with an overall standing water surface area of approximately 7.5 km (van Moorsel en Meijer 1993; Map 1).



Map 1 Location of Lac Bay relative to the island of Bonaire

Map prepared by Duke University Landscape Ecology Laboratory by P. Dermer and Environics, N.V. 2000

Lac is described as an approximately 3-km wide basin, also called a lagoon, that is positioned on the windward side of Bonaire (Map 1). Mangrove forests surround the Lac lagoon area. The lagoon

bottom is primarily covered by seagrasses, calcareous macro-algae, and sand mounds which are created by marine worms, burrowing shrimp, and the burrowing sea cucumber (Mohr 1972, Lott 2000)). The mouth, or opening of Lac is becoming isolated from the Caribbean Sea, due to the accumulation of sand and coral debris that create ridges along an adjacent submarine terrace. This physical separation of Lac from the sea influences hypersaline water conditions inside the Lac area. Many other coral rubble ridges frequently occur on similar submarine terraces that rim the islands in the Aruba, Bonaire, and Curacao region. These are a result from the windward conditions creating high energy, and therefore battering the east coasts of these islands by the constant strong wind and wave forces. Broken corals, and other calcareous organisms, continue to breakdown, and the weathered debris eventually collects into the offshore, deeper underwater ridge shelves (Mohr 1972; Bandoian and Murray 1974).

1.2 Project Background

The Lac Bay ecosystem is unique, as it is "…*the Netherlands Antilles' largest and as yet almost unspoiled lagoon*…" (Hummelinck and Roos 1969). Lac also holds international wetlands recognition, awarded during the 1970's with the status as a RAMSAR site. Thus, as described by van der Meulen (1998), a management program to safeguard Lac is vital:

> "Lac has important values for nature conservation, for the local population and for tourism. These values are at risk because of rapid increase of uses in Lac, both at the water and at the land.
>
> Main problems and threats:
>
> - plans for sediment extraction from Lac
> - plans for extraction of water from Lac
> - coastline erosion, at the peninsulas of Cai and Sorobon
> - erosion of dunes at Sorobon
> - waste, waste water and eutrophication at Sorobon and Cai
> - dying -off of mangroves
> - over-exploitation of conch and turtles
> - casual fishing by fishermen from outside Bonaire
> - conflicts for different users of the water (boating, surfing, snorkeling, kayaking, fishing, swimming)..."

A key goal of the Bonaire Marine Park 1999 Agenda was to focus on activities that would address these environmental problems and issues, and prioritise them as they related to needs for integrating a comprehensive management plan for Lac Bay. These activities were described under the following core elements:

- **research and monitoring:**
  - involves the need for the implementation of management and zoning plans for Lac Bay, and
  - conduct site characterization and monitoring activities for Lac Bay.

Working objectives were included for the project's core elements, as follows:

Objective 10: Establish research and monitoring programs to monitor the health of the system and effectiveness of the management plan

Activity 10.1: Design of an easy to implement but effective monitoring program for Lac to include hydrographic and biological data

Activity 10.2: Collection of baseline data

Activity 10.3: Monitoring of seagrass and mangrove ecosystems

Activity 10.4: Monitoring of conch and turtle populations

Activity 10.5: Monitoring of permitted uses and their impact on the environment

Activity 10.6: Research into productivity of mangrove and seagrass ecosystems

Activity 10.7: Implementation of research programs as identified in the management plan, i.e. function of Lac as a breeding/foraging ground for aquatic species

Output 10: Regular ongoing monitoring and research in Lac for support of management.

This Site Characterisation Report attempts to address the needs of Objective 10, attending to the Activities. The report includes a physical features site description, as well as a historical perspective of environmental change based on a comprehensive literature review of prior research of the Lac Bay environs. It also contains the results of the 1999 Lac Bay ecological monitoring activities (Lott 2000) for both the benthic assessments of the bay, and the hydrological and circulation processes of the bay's mangrove sub-basin areas, that includes:

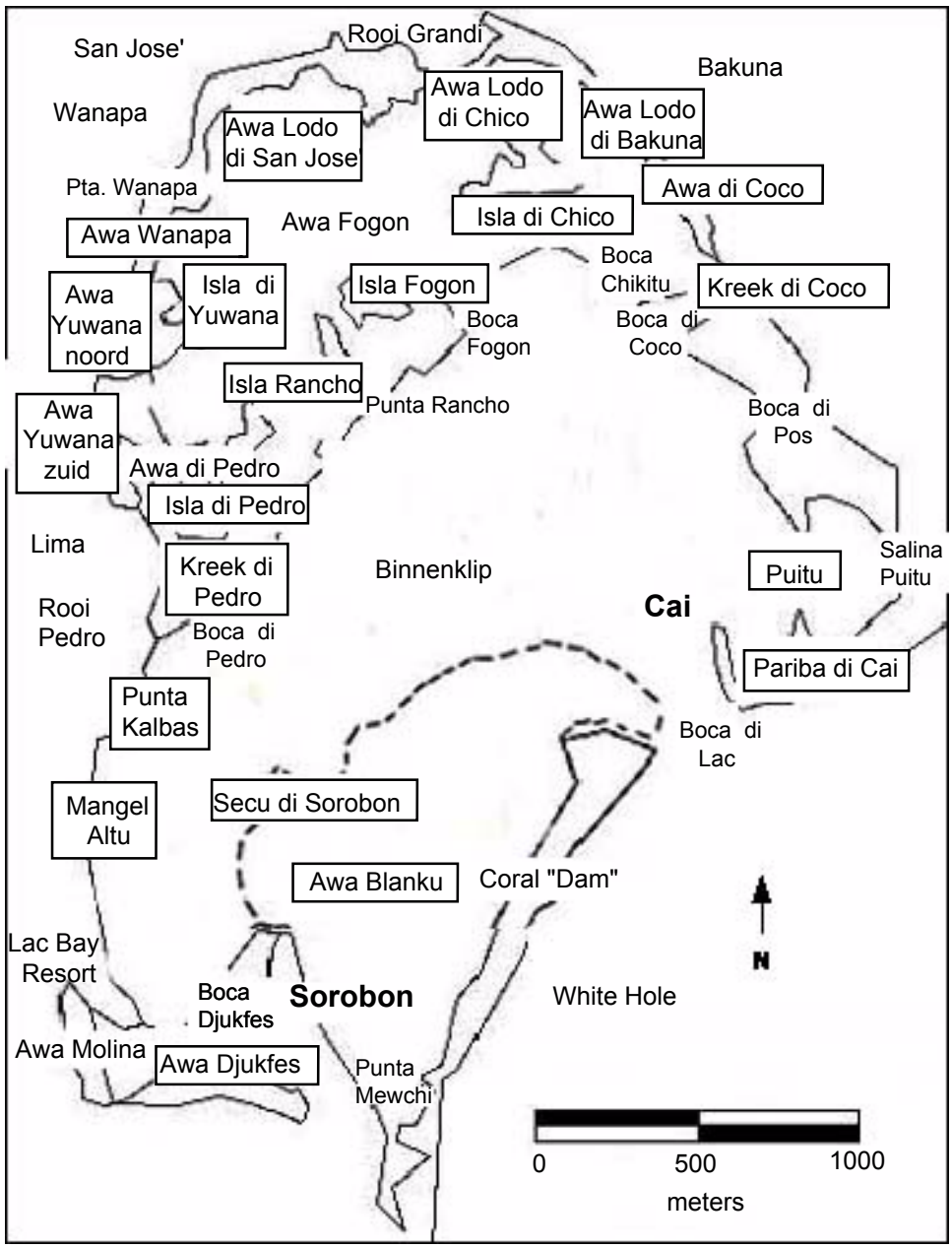
- the seagrass health and abundance in the bay;
- the size class and distribution of the commercially important species, the queen conch, Strombus gigas;
- representative invertebrate species and other substrate lifeform presence/absence inventory;
- hydrology and circulation monitoring results of the mangrove sub-basins of the bay;
- Lac Bay benthic ecology monitoring procedures; and

- management recommendations for Lac Bay derived by the implications found from this site report synthesis, and the ecological monitoring activities.

These are contained in the following volume that serves as a product for addressing the Activities of the above working Objective 10 and Output 10.

2. Places of Lac: An Introduction

The places of Lac are appropriately named for each of their physical features, in relationship to the natural communities where they are found (please refer to Map 2 and Map 3 for reading this section).



Map 2 Locations in Lac Bay

(adapted from van Moorsel en Meijer 1993)

2.1 Awa Blanku and the Coral "Dam"

Awa Blanku (Water White) is named for a reflective white and featureless carbonate sediment bottom that forms a shallow plateau across the southeastern section of Lac Bay. It is situated adjacent to a seaward *Coral "Dam"*. This coral " dam" forms a natural, physical reef barrier between the eastern seacoast of Bonaire, thus dividing the actual Lac Bay area from the open sea (Map 2). The dam is composed primarily of thickets of Acroporid branching corals, mainly the *Acropora cervicornis* species, commonly called stag horn coral. Smaller branching corals, known as finger corals (*Porites* spp.), are also common. At low tide, the branches of these rapidly growing Acroporids often are exposed above water. The effects of the breaking waves and the weight of these type coral species, cause the bottom layer of such thickets to be constantly crumbling into " coral reef rubble" (Colin 1978; Meer Mohr 1972). The cycle of the coral growth and the mechanical breakdown of the corals into rubble by wave and wind action, continue to provide the coarse, white sediment materials that make up the *Awa Blanku* area (Kobluk and Lysenko 1984).

Today, this firm and shallow bottom area is the recreational area for the windsurfing concessions located at Sorobon.

2.2 Secu di Sorobon

The *Secu di Sorobon* (Dry Sorobon) location is named for its shallow and emergent ridge formation. This ridge is a natural structure made by a conglomeration of red coralline (of calcium carbonate) macro-algae species. The ridge is composed of primarily *Lithothamnion*, as well as scattered, densely branching red algal balls, called "rhodolites". Other calcareous macro-algae species, such as *Goniolithon strictum, G. alsidii,* and *G. spectabile,* appear to look like a mass of miniature red branching corals. These species have sharp, calcified criss-crossing structures which become easily entangled with other green calcareous algae species, especially *Halimeda*, and the seagrass, *Thalassia testudinum* (Kobluk and Lysenko 1984).

The red algae group (Phylum Rhodophyta) often exceeds corals as important reef-building organisms, because, like corals, many members of this group are also calcareous, secreting calcium carbonate as they grow. They often form an algal ridge, that functions to absorb wave energy and thereby protect the more delicate organisms, such as invertebrates, fleshy algae, and sponges, that inhabit sheltered lagoons and back-reef habitats, such as found around Secu di Sorobon (Littler et al.1989). Here at Secu di Sorobon, this " red coralline algal reef" provides prime habitat for juvenile forms of the

Mithrax spider crab, Caribbean spiny lobster, and many juvenile reef fish species. Microscopic observation will reveal other interesting marine creatures that go unnoticed by the casual observer, such as Pycnogonid sea spiders; Amphipods, the Southern Gribble isopod (*Limnoria tripunctata*, a 7-pair legged crustacean); and numerous species of Polychaete worms, to name a few. These miniature marine species spend their entire life cycle secretly dwelling in these types of protective environments, but can be viewed by use of a simple magnifying glass.

2.3 Mangel Altu and Punta Kalbas

At *Mangel Altu* (Tall Mangrove) and *Punta Kalbas* (Point Kalbas), the red mangrove species, *Rhizophora mangel*, grows in its most luxuriant condition. Lacking any influence of fresh water from either a river, or periodic inundation from fresh water sheet flow into Lac, this rare growth condition can be viewed as "relatively fragile" (van Moorsel en Meijer 1993).

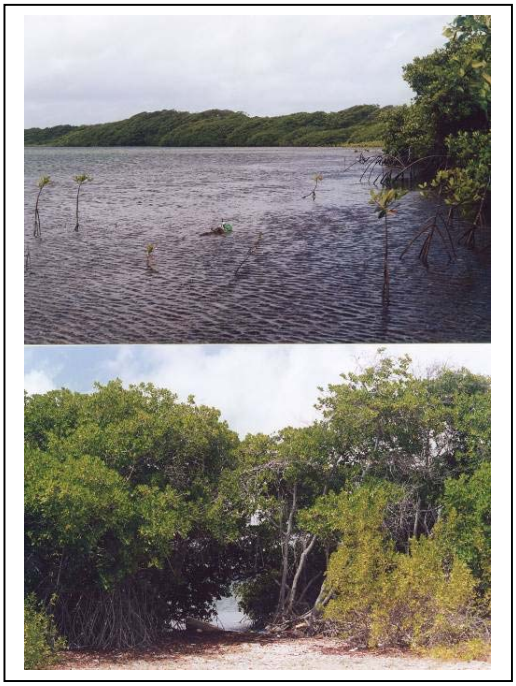


Figure 1 Mangel Altu and Punta Kalbas

Mangel Altu* is named for its large strand of impressive red mangrove (*Rhizophora mangel*) trees. These approximately 8 to 18 meters and higher mangroves are the tallest trees found in Lac Bay. They have successfully taken "root" along Lac's western shore, which once was a lengthy white sand beach, called *Playa di Palu Kalbas* (Kalbas Tree Beach). This beach was recorded to exist since 1949 to 1967, when the mangrove seedlings began to successfully encroach, developing the Mangel Altu that we know today (van Moorsel en Meijer 1993). Over the years, the beach has disappeared beneath these "walking" red mangrove roots, leaving only a peeping hole to view the bay, located at *Punta Kalbas

(photos by Environics, N.V. 2000)

Around 1949, there was no red mangrove growth at all along the border at *Punta Kalbas* (Figure 1). Instead, there was a long beach, that even as late as 1967, its fine, white sandy shore extended along the length of *Mangel Altu* and northward, from *Punta Kalbas* to *Boca di Pedro*. Today, the area is ingrown by a thriving red mangrove forest, towering to 18 meters in height (van Moorsel en Meijer 1993).

2.4 Lac's Mangrove Sub-basins: The Awa Lodo di San Jose' and the Awa Lodo di Chico

The northernmost region of Lac features a vast, shallow hypersaline pond area called *Awa Lodo di San Jose* and *Awa Lodo di Chico*. These salty and muddy ("lodo" in papiamentu) pond environments are in a state of a recurring mangrove die-off. Because of living in such extreme wet/dry seasonal conditions, these trees, especially the black mangrove, tend to grow in a dwarfed form, reaching from only 3 to 10 meters in height. The salinity values in this area ranged from 45 $^{0}/_{00}$ to 102 $^{0}/_{00}$ (parts per thousand salt content) when measured during the March 1999 – March 2000 monitoring period (normal salinity in the Lac Bay lagoon is approximately 40 $^{0}/_{00}$ to 45 $^{0}/_{00}$). Thus, the extreme salinity ranges in pond areas may influence adverse water quality conditions for tree growth at certain times of the year (Lott 2000).

The *Awa Lodo di San Jose* sub-basin features large debris areas of dead mangrove tree stumps and trunks. The exterior shores of this shallow (less than 1/2 meter deep) pond area contours along the adjacent dry kunuku ("country" in papiamentu) lands of the *Wanapa*, *San Jose*, and *Rooi Grandi*. Large stands of former red mangrove trees have died off here, and the decayed woody remains make a ghostly appearance (Figure 2). It was concluded through aerial photo-interpretation by the researchers Hummelinck en Roos during their 1969 studies, that this dying off process was already taking place during that time. In addition, Hummelinck (1969) recalled that during his earliest visit as a graduate student during the 1930s, in the area north of *Isla di Chico*, one could already see dead crowns of mangrove trees in the canopy. At one time, these former trees reached approximately 16 meters in height (van Moorsel en Meijer 1993).

The *Awa Lodo di Chico* sub-basin is also shallow, and although less than 1 meter deep even during periods of high water, it is teeming with life. Fish species such as killifish (*Cyprinodon*), mojarra (*Eucinostomus, Gerres,* and *Eugerres* spp.), and juvenile barracuda (*Sphyraena barracuda*) frequent these waters. A dense black mangrove swamp encircles this pond area, creating an enclosed haven for foraging aquatic birds, including flamingos, which feed on the fish life. The black mangrove trees here grow in a dwarfed height, approximately 4 meters tall, surviving in the rich detritus material soils that are boggy and low in oxygen. Seasonal water salinity values in the *Awa Lodo di Chico* location ranged from 44 $^{0}/_{00}$ to 81 $^{0}/_{00}$ during the March 1999 – March 2000 monitoring period (Lott 2000). These ranges provide adequate water quality conditions for fish life to inhabit here. In addition, a small gastropod species, the *Melongena melongena*, which resembles a miniature conch, thrives throughout the muddy pond bottom. This web of life attracts large numbers of several varieties of herons and egrets, as well as the flamingos,

frigate birds, ducks, long necked stilts and oystercatcher birds. Thus, on a seasonal basis, the area provides important wildlife habitat value, to both migratory, as well as resident species of bird life, which utilize these shallow, hypersaline areas for feeding in the pond, as well as roosting in the mangrove trees.

Figure 2 Lac's mangrove sub-basin region at Awa Lodo di San Jose'.

The Awa Lodo di San Jose area features what appears to be a large die-off of former red mangrove (*Rhizophora mangle*) trees. The successful growth of these red mangroves, over time, eventually re-claimed land by the process of the trees' roots trapping sediments with decayed vegetation. Other occurrences may also have contributed to the die-off, as a result of the construction of the road and the Mona Lisa levee, which altered periodic fresh water drainage into the area. Lacking these fresh water sources, maximum sea tide levels now generally flow into the "lodo" areas during the fall solstice periods, high winds, and/or increase during rainy season. At these times, the water levels are able to flood and circulate further into this far region of Lac Bay. During the remainder of the year, evaporation and poor water circulation patterns create hypersaline and muddy water conditions (Hummelinck en Roos 1969; van Moorsel en Meijer 1991; Lott 2000). However, these conditions are suitable for the growth of the black mangrove (*Avicennia germinans*) which are now sprouting new tree recruits, and eventually this black species may replace the former red mangroves as seen in this photo (Lott 2000). (photo: Environics, N.V. 1999)

2.5 The Five Islands of Lac

An almost continuous physical barrier of ridge islands divides and separates the Lac Bay basin from the posterior mangrove sub-basin region. These ridge islands were geologically formed on a limestone terrace created during the Pleistocene period of changing sea levels. During times of air and

sun exposure above sea level, carbonate sediments and marine algae would accumulate and harden along these geologic ridges, eventually forming the islands found in Lac today (Van Veghel 1997; Kobluk and Lysenko 1984). This "sediment trapping" process is ongoing, whereby the Lac islands have built up over time, and have eventually become vegetated with mangroves and succulent ground cover plants. The islands today are comprised primarily of a mixed mangrove tree community of the red (*Rhizophora mangle*), black (*Avicennia germinans*) and white (*Laguncularia racemosa*) mangrove species, with a fourth upland variety, the Buttonwood (*Conocarpus erectus*), that survive in a dynamic, and often extreme, wet/dry seasonal cycle.

The black mangrove *(Avicennia germinans*) is the predominate salt-tolerant tree that provides the major canopy of Lac Bay's islands. These trees grow in dwarfed form, due to poor soil conditions. Two forms of the fourth mangrove species, the Buttonwood tree (*Conocarpus erectus)* also flourish around these unique islands. This Buttonwood tree form, as well as an unusual bushy, silver leafed form (*C. erectus var. sericeus*) is common in this type of tropical terrain (Lott 2000; Patterson and Stevenson 1977).

Further beyond these islands are expansive and shallow, hypersaline muddy ponds, called "lodos". The westernmost pond is called *Awa Lodo di San Jose*, named for the adjacent upland kunuku area, and the easternmost pond is called *Awa Lodo di Chico*.

Figure 3 Typical scenery in the Lac mangrove sub-basin environs at the *Awa Lodo* areas.
(photo by Environics, N.V., 2000)

There are five islands that separate the Lac lagoon from the northern Awa Lodos ponds region. They are the *Isla di Pedro*, *Isla di Yuwana*, *Isla Rancho, Isla Fogon*, and *Isla di Chico* (Maps 2, 3). In addition, these islands further divide into western and eastern mangrove sub-basin sectors, with a boggy, central creek cutting along the eastern shore of the *Awa Lodo di Chico* (see Figure 37). This creek runs in a south/north direction and its presence forms another physical dividing line that separates the two mangrove sub-basin areas. The western sub-basin area is comprised of the islands, *Isla di Pedro, Isla di*

Yuwana, *Isla Rancho*, and *Isla Fogon*, while the eastern sector is comprised of the *Isla di Chico*, which includes an additional narrow creek, called the *Boca di Chikitu*.

2.6 Awa Yuwana and Awa Wanapa

The *Awa Yuwana zuid* and *Awa Yuwana noord* areas, as well as the *Awa Wanapa* area, occur in the north-west border of Lac (Maps 2, 3). Here, environmental conditions can be extremely dry, or wet, depending on the season and the wind force, and annually there are fish kills here during severe drought conditions. Seawater feeds into this area at different levels throughout the year, via the *Kreek di Pedro* channel. During periods of high water, the boggy, detritus laden soils provide a rich feeding ground for foraging aquatic birds of all kinds: herons, egrets, ducks, long necked stilts, and flamingos (Figure 4). During these wet conditions, killifish thrive in this area, providing food for the aquatic birds.

(photo by Environics, N.V., 2000)

Figure 4 The Yuwana areas

Flanking the northwestern border of this mixed mangrove swamp lies the *Awa Yuwana noord* and *Awa Yuwana zuid* as well as the *Awa Wanapa* areas. These 1-to1 1/2 meter deep areas, when flooded with baywater, provide a feeding ground for flamingos.

2.7 Awa Lodo di Bakuna and Awa di Coco

Bordering along the eastern perimeter of Lac's mangrove sub-basin region, are the *Awa Lodo di Bakuna* and *Awa di Coco* environs (Maps 2, 3; Figure 5). The waters here are received primarily from the *Kreek di Coco*, which connects from the open Lac lagoon, and delivers fresh bay water into these far reached extremities. In the more boggy soil areas, black mangroves grow in 4-meter high dwarfed sizes, while in the slightly better water circulation and aerobic soil conditions, mixtures of red, black and white mangroves persist together.

Figure 5 Awa di Coco

The black mangrove persists at Awa di Coco as the predominant tree, where the tree's pneumatophores, or snorkel-like roots, can breathe for oxygen through physical projections that grow upward out of the boggy soils of this area, respiring fresh air exchange.

(photo by Environics, N.V., 2000)

2.8 Kreek di Coco

On the northeast border of Lac, lies the *Kreek di Coco* (Maps 2, 3). The creek here is the only remaining opening that is maintained by fishermen, and in more recent times, kayakers, who enter the bay from the road to *Cai* access of Lac. *Kreek di Coco* thus provides a "feeder channel" from the open Lac lagoon water to flow in and out, which refreshes the *Awa Lodo di Bakuna* and *Awa di Coco* mangrove systems (Figure 6).

In the *Boca di Coco* creek bed, the water quality is clear and good, ranging from 40 $^{0}/_{00}$ to 45 $^{0}/_{00}$ salinity over the March 1999 – March 2000 monitoring period and thus shows its direct connection to the Lac bay basin. During high water events, the movement of water from the bay, and into the feeder channels is swift, and also swift at the reversal of the low tide events. When the water moves swiftly, the gastropod*, Melongena melongena*, can be seen in great numbers, sliding along the creek bed, moving into the direction of the incoming current. Other common marine life species that inhabit this area include mojarras, numerous varieties of juvenile grunts and snappers, and a type of Portunid crab (*Callinectes* sp.).

Figure 6 The Kreek di Coco "feeder channels"

Kreek di Coco is considerably important, as it provides a direct access of seawater from the Lac Bay basin. The creek allows the tidal exchange to flow into the mangrove sub-basin's eastern region, thus maintaining a "feeder channel" for seawater circulation into Lac's eastern border areas.

(photo by Environics, N.V., 2000)

2.9 Puitu and Cai : Lac's Cultural History

Cai, the name originated from the Spanish word for small island, "cayo", is termed "*Lac Cai*" in the Papiamentu language. This geographic point of Lac, is a part of the main opening to the bay, called "*Boca di Lac*"(Map 2). Lac Cai is significantly noted for being the home of the Soliana family, who were its first Bonairian settlers. Some members of this notable family continue to live and fish there up to today (Martines, personal communication 2000).

The following is a contribution by Boi Antoin, noted local historian of Bonaire and author of the book, *Lac Historia di un bahia*, which summarizes the past lifestyles of Lac by the first settlers of Bonaire:

2.9.1 Informashon Riba Importansia Históriko Di Lac

E region di Lac semper tabatin su importansia pa Bonerianonan, spesialmente pa loke ta trata peska. E promé Bonerianonan kaba, esta e Indjannan Caquetio ku a yega Boneiru 2.500 aña pasá for di Kòrsou, a deskubrí den Lac un fuente di alimento importante. Pa hopi aña nan a saka nan alimento diario, piská, karkó, tortuga I kokolishi for di e laman di Lac.

Prueba di presensia di e Indjannan aki den e área di Lac ta e diferente artefaktonan ku arkeologonan, spesialmente Dr. Jay Haviser, a enkontrá alrededor di Lac, for di Brua Wesu. Situá banda di Sorobon, te na Wanapa, kaminda a deskubrí te asta evidensianan di un pueblo chikitu di Indjan.

Atrabes di añanan, despues ku e poblashon boneriano a meskla ku Oropeo I personanan di origen afrikano, Lac a sigui ta un fuente importante di alimento pa Boneiru. Asina importante te asta ku diferente Boneriano a disidí di bai biba den e área di Lac.

Den e kuadro aki por menshoná prinsipalmente famia Soliana. Un famia di Antriol Pabou ku a disidí di okupá Cai, un parti di Lac, kaminda nan a konstruí nan ranchonan. E patriarka di e famia Soliana bibá na Lac tabata Martins Soliana. Anke e famia aki tabatin su kas na Antriol Pabou, ta na Lac nan a parti e parti di mas grandi di nan bida. E yu hòmbernan di Martins i su esposa, Chi Anita, a bira hopi konosí na Cai. Tabata trata aki di Celestijn, Pedro I Ramon. Te den e ultimo añanan di su bida ainda Ramon a bina na Cai.

Banda di famia Soliana por menshoná Dochi Martis, ku tambe tabatin su rancho na Cai, no mashá leu for di e ranchonan di famia Soliana.

Pa hendenan di Nikiboko tambe e area di Lac tabatin su importansia. Hopi piskadó di e barionan aki a piska den Lac. Nòmber di algun di nan ainda a keda mará na sierto partinan di e bahia aki, manera Boka di Coco, Boca di Taco I isla di Chico, ku ta referí na Chico Rosario di Tera Kòrá.

Papiando di e islanan aki, ta asina ku nan tabata lugá importante pa kimamentu di kalki. Un tempu Shon Pechi Beukenboom tabatin konsenshon di gobièrnu pa kima kalki riba e islanan ei, manera riba Isla Fogon, Isla Yuana I Isla di Pedro.

Lac ademas tabata lugá kaminda nos grandinan a usa e palunan di mangel pa traha nan kasnan di bara, tambe pa tam liña pa piska I traha makutu pa uso doméstiko.

Na entrada di Cai tabatin antes tambe un kas di warda, na unda militarnan tabata hasi warda, spesialmente den temporada di guera. Esaki pa kontrolá laman riba barkunan enemigu.

Boi Antoin, EXTRA
Bonaire, N.A.

October 28, 2001

Information On The Historical Importance Of Lac

The region of Lac always was very important for Bonairians, especially in the field of fisheries. The first Bonairians, the Caiqueto Indians, that arrived on Bonaire 2500 years ago from Curacao, discovered in Lac an important food source. During many years they got their daily food, fish, conch, turtle and kokolishi shells from the sea of Lac.

Proof of the presence of these Indians in the area of Lac are the different artefacts that archaeologists, especially Dr. Jay Haviser, found around Lac from Brua Wesu. Evidence of a small Indian village was found near Sorobon, up to Wanapa.

Through the years, after the Bonairian population was mixed with people of European and African descent, Lac remained an important source of food for Bonaire. It was so important that several Bonairians decided to live in the area of Lac. Here we must mention especially the family Soliana. It was a family from Antriol Pabao that decided to occupy Cai, a part of Lac where they constructed their ranches. The patriarch of the Soliana family that lived at Lac was Martins Soliana. Although this family had their home in Antriol Pabao, it was at Lac where they spent most of their time. The sons of Martins and his wife Chi Anita became very well known in Cai. They were Celestijn, Pedro and Ramon. Up to his last days Ramon stayed in Cai.

Besides the family Soliana we can mention Dochi Martis, who also had his ranch at Cai, not far from the ranches of family Soliana. Lac also had its importance for the people of Nikiboko. Many fishermen of this district fished in Lac. The name of some of them is still tied to certain parts of this bay, such as Boka di Coco, Boca di Taco and Isla di Chico, which refers to Chico Rosario of Tera Kora.

These islands were important areas for the burning of lime. There was a time that Shon Pechi Beukenboom had a concession from the government to burn lime on the islands, such as Isla Fogon, Isla Yuana and Isla di Pedro. Moreover, Lac was the place where our forefathers used the Mangrove trees to build their houses, called "bara", also used the mangrove tannin, called "tam", to treat their fishing lines, and used mangrove to make baskets for domestic use. There used to be a guardhouse at the entrance to Cai where the military stood on guard, especially at times of war. These were checking the sea for enemy ships.

Boi Antoin, EXTRA
Bonaire, N.A.

October 28, 2001

Figure 7 Lac Cai of Yesterday and Today

At Cai, the scattered mounds of broken conch shells leave behind a visual story of a long ago time at Lac when fishing was bountiful.

(left photo from Hummelinck en Roos 1969; right photo Environics 2000)

The *Puitu* and *Cai* areas are steeped in the social history of the Lac. *Puitu*, a small mangrove enclosed embayment, originally was more opened to the coast (Maps 2, 3), and subsequently provided a boat anchorage for the adjacent "*Salina Puitu*" (Antoin 1999). Though the salina was of little economic importance to the country of Bonaire, the salt it produced helped to preserve fish. It was abandoned around the year 1907 (van Moorsel en Meijer 1993). Today to enter Puitu, there are narrow mangrove passages that are explored by snorkelers and kayakers, who enjoy the natural beauty of this area (Figure 9).

Figure 8 Boca di Pos, the wells of Pariba di Cai

Boca di Pos, the wells of Pariba di Cai, provide a glimpse of the cultural history, which pervades in the Lac area. For the first Bonairians, the Soliana family who once lived in Cai, water was a scarce, but necessary commodity. Three wells were located in the north Lac area, one was natural and provided a good quality of sweet water, "dushi dushi" (Antoin 1999).

Figure 9 The Puitu mangrove channels

Several small mangrove channels lead into Puitu, a small embayment of Lac. In years past, these were once larger passages that allowed sailing craft entrance into the Puitu anchorage. Now enclosed by mangroves, except for a few tunnel entrances, the area has become a favorite snorkelling haven for visitors who enjoy seeing the natural Lac, such as Puitu's mangrove habitat. Here nature lovers can drift in the currents of the Puitu mangrove channel, and view the variety of sponges and oyster mangroves that perch colorfully on the mangrove roots.

(photos by John Thielgard 2000)

Today, at Cai, the culture of Bonaire continues to pervade. Weekends will find locals and tourists alike enjoying the natural ambience of Cai, and the local "snak" concessions providing food, drink and music. Snorkelers and kayak enthusiasts enjoy the natural settings at Lac Cai, observing juvenile barracuda and other reef fish who find safe haven in the seagrasses; while kayakers enjoy bird life, such as the magnificent frigate that often roosts in the surrounding mangrove trees (Figure 10).

Figure 10 Frigate birds roosting in Puitu mangroves

Today, the small mangrove enclosed bay (embayment) at Puitu is a paradise for the kayakers and the naturalists. Upon finally entering into the Puitu, the nature lover can enjoy an uncommon sight, because Puitu is a roosting place for frigate birds.

(photo by Environics, N.V. 1999)

3. Environmental Setting: Lac's Natural Communities and Zonation Patterns

The grandfather of Lac environmental research, Dr. P Wagenaar Hummelinck, first visited Lac as a graduate student from Utrecht, Holland, during the 1930s. He again returned to conduct comprehensive environmental research in the late 1960s, with his colleague, Dr. P. J. Roos. Their general description of the Lac environs is as follows:

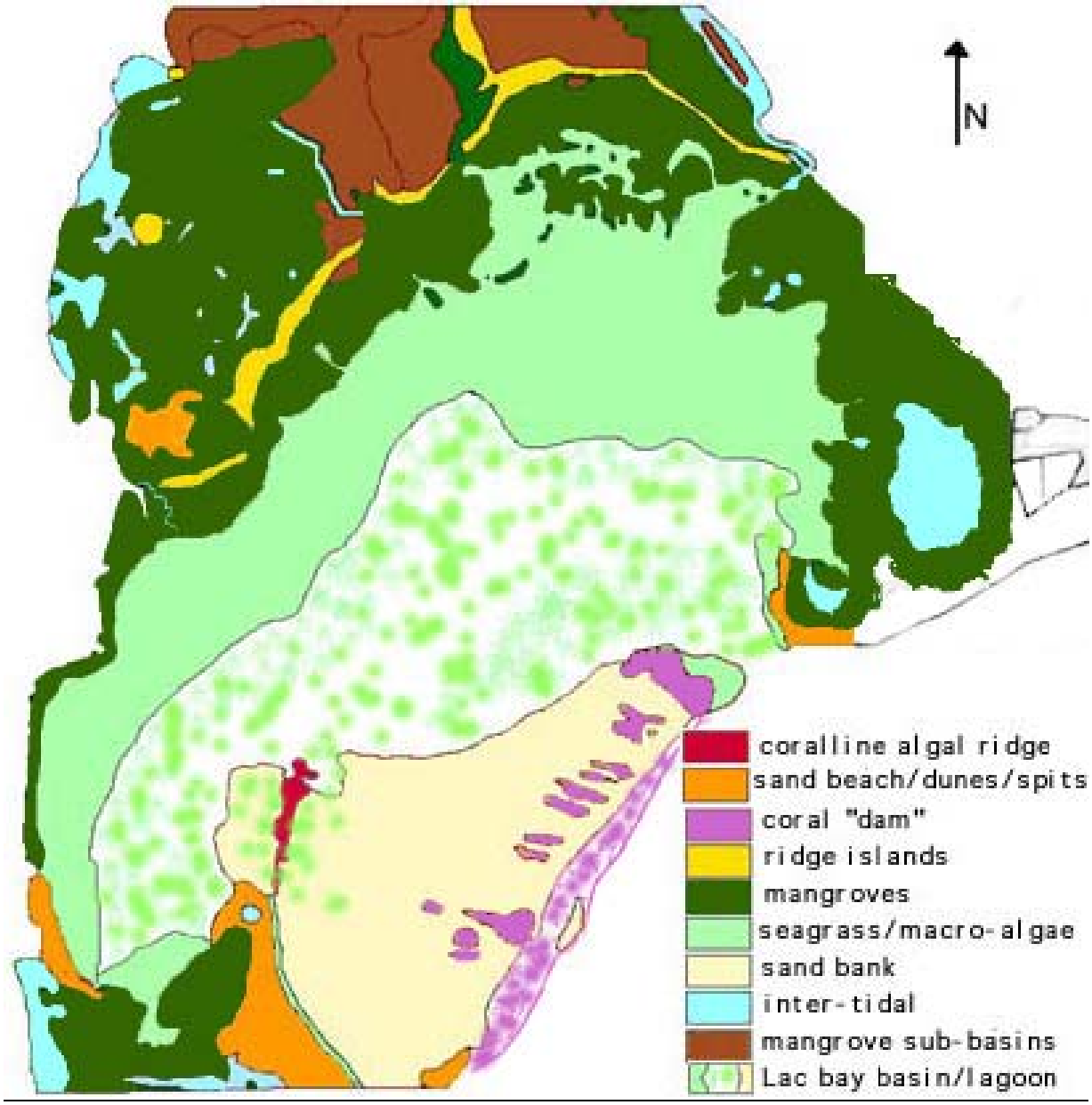
"…Lac is one of the seldom lagunes of clear water of this side of the South Caribbean, which can be compared with the lagunes of the Greater Antilles, Florida and the Bahamas…The clear water is remarkable when we compare it with the Piscadera baai in Curacao. In the Lac one can see with ease everywhere still to the bottom, while in the Piscadera inland basin one cannot literally see a hand before his eyes. Clear water signifies, however, not only few floating elements, but also few organic material and thus also less food. We may admit that the water of Lac is exceedingly poor of nutrition. Possibly this is the striking fact that there are here nowhere mangrove oysters to be found, that acorn shells are only found on a few places, and that many other sorts of animals which are present in great numbers in the Piscadera baai, are found in a quite few numbers in the Lac, or are totally missing. Also in the algae flora we find great differences.

It goes without speaking that on the other hand, good possibilities for existence are offered to organisms that feel not at home in muddy waters. We should be able to say, that the clear and nutrition-poor Lac is qualitatively rich, but quantitatively poor (many sorts but in few quantity), and the muddy but rich of nutrition Piscadera baai is qualitatively poor, but quantitatively rich. We shall have to take this in account when we go to lose ourselves in the possibilities of development of the Lac"…

(Hummelinck en P.J. Roos 1969; English to Dutch text translation by Carmita Santiago 1999).

The Lac Bay basin area is a depauperate, clear water shallow bottom lagoon system, comprised of several typical coastal marine communities (Hummelinck en Roos 1969). In general, over the years the lagoon of Lac has reached a maximum depth of 3 meters (Mohr 1972), or 8 meters (Hummelinck en Roos 1969), or 5 meters (Lott 2000). It is flanked by red mangrove forests in the bay's interior region, and by shallow bank reefs on its seaward side. The open bay basin is predominated by lush seagrass meadows. This environs maintains salinity values similar to that of the adjacent Caribbean Sea, while in the further reaches behind the lagoon, dense mangrove growth creates a hypersaline environment. This mangrove

sub-basin system includes numerous muddy, detritus-laden creeks, shallow lakes and salt ponds (Maps 3,) (Hummelinck en Roos 1969, Mohr 1972, van Moorsel en Meijer 1993, Lott 2000).



Map 3 Lac Bay's Natural Communities and Zonation Patterns

(Map adapted from aerial photograph by Wing Group, N.V. 1998. Zone rendering prepared by Duke University Landscape Ecology Laboratory by P. Dermer and Environics, N.V. 2000)

Dense seagrass and mixed macro-algae meadows flourish inside the open bay basin. This typical bay, or lagoon community consists of the predominant seagrass species, *Thalassia testudinum* (turtle grass), mixed with the predominant calcareous green algae, the *Halimeda* species, as well as other representatives of the macro-algae phyla. Occasional patches of the seagrass, *Syringodium filiforme*

(manatee grass) are also found, but uncommon. The seagrass, *Ruppia maritima*, occurs in the hypersaline environment of the muddy lakes of the interior. The inshore perimeter of this basin is flanked by red and black mangrove intertidal wetlands (Lott 2000).

Red mangrove propagule seedlings **Green calcareous algae, *Halimeda* species**

Figure 11 ***Halimeda* shoals: Sand producers and stabilizers**

***Halimeda* shoals are an important part of the bay's shallow shoreline bottom (right photo). These shoals are composed primarily of two green calcareous macro-algae species, *Halimeda incrassata* and *H. opuntia* that trap sediments, and provide substrate for the young cigar-shaped seedlings, called propagules, of red mangroves to anchor for propagating a new tree (left photo). In this process, they expand and stabilize fine sands and thus, reclaim land.**

(photo by Environics, N.V. 1999)

3.1 The Open Bayshore

The extensive, inner shoreline encircling the open bay, from Awa Djukfes to Cai, is dominated by a dense growth of the red mangrove trees (dark green zone Map 3). Directly beneath the mangrove canopy, layers of leaf detritus also contribute to this soft sediment bottom composition that is suitable for the settling of young red mangrove propagule seedlings. The red mangrove is termed a "pioneer " species because they are able to grow seaward by stretching out their prop roots and sinking them into the shallow bay bottom, that is composed primarily of the remains of two green calcareous algae species, *Halimeda incrassata* and *H. opuntia.* Here, the prop roots of red mangroves are able to anchor, where they can trap and stabilize these finer, settling sands. Their growth continues to encroach seaward, thus expanding the mangrove environment In general, a land reclamation process occurs in the Lac due to this sand circulation and settlement process (Figure 11) (Mohr 1972; van Moorsel en Meijer 1993).

The sands in the lagoon are a composite of degraded *Halimeda* species and other algal vegetation, and coral debris (Lott 2000). ***The origin of the sand found in the lagoon basin has been swept up by bottom currents against the submerged rubble ridge, forming a substantial sandspit, and on other places, minor spits are isolating subsidiary embayments from the lagoon*** (Mohr 1972*)*. These sands are of a coarse consistency, and are also of rubble forms while being deposited across the sand bank zone.

Offshore, along the windward seaside, a bank reef slope occurs, composed of Milleporid hydrocorals, Acroporids corals, gorgonians and scleractinians. In addition, isolated patch coral heads that are predominated by Acroporids, or branching corals, occur in a continuous border, stretching along the seaward edge of the bank reef. This high energy wave action zone, called the "dam" on old maps, is layered over a hard limestone substrate, with coarse calcareous sediments and coral rubble that deposits particles across the sand bank plateau, in a continuous deposition process (pale and dark pink zone Map 3) (Mohr 1972).

Due to it's physical position on the island, Lac is strongly exposed to the predominate easterly tradewinds. The winds, as well as a natural wet/dry annual seasonal condition, drives a dynamic hydrological cycle of inundation/dehydration, resulting in a flux of extreme salinity and water level conditions in the posterior portions of the bay area. In this sub-basin system, mixed dwarf red, black and white mangroves, including buttonwood, contribute to stabilising the islands of Lac. These islands have geologic origin, being originally Pleistocene limestone ridge formations. Now, in modern times, these ridges have trapped moving sediments and tree seedlings, thus changing into the Lac bay islands (dark yellow zone Map 3). There are five of these islands, and they have physically separated the greater clear water Lac lagoon apart from this muddy mangrove environs.

Figure 12 Upside down jellyfish, *Cassiopeia* spp.

Two species of the upside down jellyfish, *Cassiopeia xamachana* and *C. frondosa*, carpet the bottoms in the quiet waters of small embayments found throughout Lac Bay. These type jellyfish, members of Phylum Cnidaria, "farm" food with the symbiotic relationship of micro-algae, which harbors within the organism's tissues. This relationship, therefore, no longer requires toxic stinging tentacles for the jellyfish to capture food. (photo by Jessie Armacost 1999)

Additional ridges have been developed at the southeast Sorobon, and northwest Cai sectors, where sand deposits and withdraws, in an ongoing, ephemeral cycle (dark yellow zone Map 3). Dense mangroves have encroached in all these areas, limiting circulation and creating hypersaline conditions. As a result, these mangrove embayments contain shallow, soft muck bottoms. Here, the upside down jellyfish species, *Cassiopeia xamachana* and *C. frondosa*, abound in these quiet waters (Figure 12).

Studies completed by Lott (2000) determined that the greatest density of seagrasses occur along this inner perimeter of the Lac basin, extending from the south-west shores of Sorobon, and up to the Cai area (pale green zone Map 3) (Figure 13). The studies determined that these expansive seagrass meadows are suitable nursery habitat to support the commercially important queen conch, *Strombus gigas*, as well as juvenile phases of snapper and grunts, and the Caribbean spiny lobster.

(photo by Jessie Armacost 1999)

Figure 13 Seagrass Meadows in Lac Bay

Seagrass meadows thrive in a mixed macro-algae community, and flourish in the bay bottom. This typical shallow water, soft sediment marine community grows luxuriantly along the border of the bay's red mangrove forest shoreline, and blankets the bay bottom out into depths of approximately 3 meters.

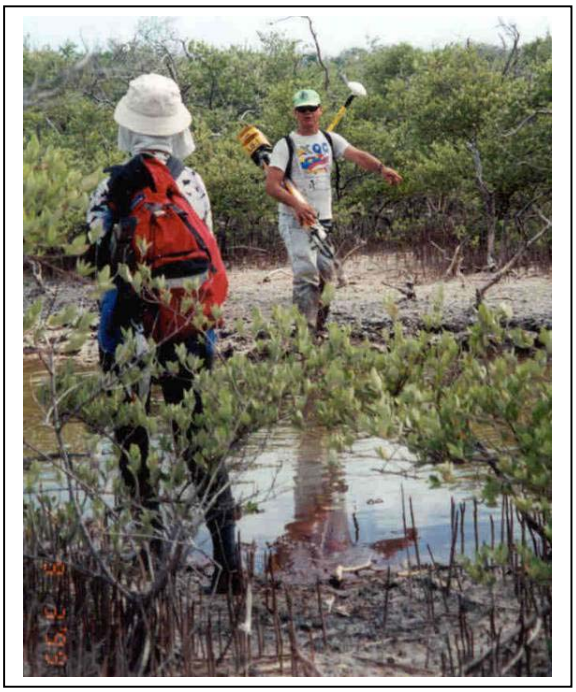
The seaward edge of the Lac basin is composed primarily of an open sparse sandy bottom (pale pink zone Map 3). Here the bottom composition is packed with coarse calcium carbonate materials, with some sponges and patch corals. This hard bottom plateau is divided from the seagrass area by a deeper (3 to 5 meter) channel, which is used by fishing boats coming in and out of the Sorobon docks area.

3.2 The Mangrove Environment

The zonation patterns of the mangrove environs in Lac Bay are rather typical in the locations of where each species group occurs. A pioneer species, the red mangrove, *Rhizophora mangle*, is the predominant tree that flourishes around the expansive inner shoreline of Lac bay, where the sea water salinity ranges are favorable for their growth, at approximately 35 $^{0}/_{00}$ to 45 $^{0}/_{00}$ (parts per thousand). Thriving further behind the red mangrove zone, is the black mangrove species, *Avicennia germanins*, that is the predominant tree of the interior mangrove ecosystem (dark brown zone Map 3) (Figure 14).

Figure 14 Mangrove Zones of Lac

The red mangrove is the most important mangrove of Lac's shoreline (above), where its prop roots reach out into the bay, and stabilize soft sediment.



Meanwhile, the black mangrove (right) is the most important interior species. The pneumatophore roots of the black mangrove (foreground of right photo) acts like a "snorkel", protruding up out of the muddy soils to allow the black mangrove to respire, or breath.

(photo by Environics, N.V., 2000)

Water quality conditions here are hypersaline, ranging from 45 $^{0}/_{00}$ to 100 $^{0}/_{00}$ (parts per thousand) over a year period, and soils can be anaerobic due to poor seawater circulation. The black mangrove can tolerate this less than suitable conditions by virtue of the tree's ability to "breathe" through its root apparatus, called the pneumatophores. These unusual roots work like a snorkel, pushing up out of the mucky, anaerobic soils, to respire above ground. Thus, in Lac Bay, the red mangrove is the most important mangrove of the shoreline, while the black mangrove is the more important interior species (Figure 14) (van Moorsel en Meijer 1993).

Sometimes mixed in with the red and black mangroves, but usually located more inland, is found the white mangrove species, *Laguncularia racemosa*. Finally, upland and on drier land is found a type of mangrove, called the buttonwood tree species, *Conocarpus erectus* (Hummelinck en Roos 1969; van Moorsel en Meijer 1993; Lott 2000). In Lac Bay, two variations of buttonwood species are found.

Growing on the interior islands of Lac is found the silvery, soft leafed buttonwood, *Conocarpus erectus* variation *sericeus* (Patterson and Stevenson 1977; Lott 2000). This silver leafed variation occurs as small bushes growing throughout the higher elevation and drier bay islands. The larger, typical green shiny leaf buttonwood tree of Lac Bay, *Conocarpus erectus*, is distributed landward, with the white mangroves, along the banks of the feeder channels, and the mangrove sub-basin inter tidal zones (bright blue zone Map 3) (Lott 2000).

3.3 The Black Mangrove Zone

Located behind the open bay in the northern direction are found the salt pond and black mangrove forest environments (dark brown zone Map 3). These two environs are separated away from the open bay basin by the dense shoreline growth of red mangroves. Here there is little regular tidal exchange.

In the past ten years, the red mangroves have become so successful that their growth now severely limits the water circulation from the open bay passages into the back shallow salt ponds (van Moorsel en Meijer 1993). On the higher elevation areas located in the north, the basins are further being transformed into large muddy mangrove graveyard areas. Skeletons of the formerly majestic red mangrove trees demonstrate that this mangrove dying off process is very slow.

(photo by Environics, N.V., 1999)

Figure 15 The mangrove's food web begins with anaerobic bacteria and diatoms

Though these mangroves seem ominous that little life prevails here, during rainy season they are filled with numerous species of aquatic birds, such as herons, ducks, egrets and flamingos. At that time, the refreshed waters become alive with a food web not seen by the human eye, or appreciated by the uneducated spectator. Diatoms drive the richness of the area, while bacteria produces anaerobic layers in the muds that compose this noxious environment. It becomes the basis of the food web of Lac.

However, this complex microcosm further brings to life crustaceans, worms, molluscs and small fish, such as the predominant killifish that thrive in this muddy pond environment, and provide food for

the foraging birdlife. In addition, below the skeletal remains of the once majestic mangroves, young new red and black mangrove seedlings are beginning to establish a new generation of growth (Figure 15).

Figure 16 Creek bed at Isla Fogon

Creek openings that once fed water into this mangrove sub-basin region no longer function, due to the dense vegetation growth that limit the water exchange between the open bay and the north mangrove sub-basin. Photo upper left and right show water flowing in creek from bay area near Isla Fogon, however the lower right and left photos show where the water flow dead ends.

(photo by Environics, N.V,. 1999)

Inside the black mangrove creeks and ponds of Lac's interior islands, these mangroves grow in a dwarf size, in response to the water quality conditions that prevail there. With the successful, but dwarfed growths of these trees, the tree density alone limits the tidal flow incoming from the main lagoon. Thus, salinity values of the water far exceed what is in the greater bay area, and due to poor circulation, the dissolved oxygen is quickly utilized. Referring to old aerial photographs of this area, one could still see clearly the creeks that functioned along both sides of the Isla Fogon, exchanging the open bay water into the back mangrove. But now, many creek passages to the bay are completely enclosed by mud and vegetation, and come to a dead end (Figure 16) (Lott 2000).

3.4 Lac's Interior Ridge islands

In Lac's northern interior area, there are numerous small islands composed of built-up sands that have been trapped by the mangrove roots. These isles are termed "ridge " islands (dark yellow zone Map 2) (see Section 3 defining "ridge "). The dry lands of these islands are covered with typical succulent beach plant species (Figure 17).

Plant vegetation found within the islands consists mainly of the two succulent ground covers, *Batis maritima*, and *Sesuvium portulacastrum*, that thrives on the higher elevation levels of these island terrain. A salt tolerant grass, *Sporobolus pyramidatus*, also carpets the ground throughout these bay islands. A form of spike rush, *Fimbristylis spathacea*, also is a common ground cover that carpets the shorelines along the feeder channels of the outside boundaries around Lac (Figure 17).

Figure 17 Ground vegetation in the islands of Lac

The predominant ground vegetation in the mangrove sub-basin bay islands includes from left to right: saltwort (*Batis maritima*); salt marsh grass (*Sporobolus pyramidatus*) - the smaller grass like plant in center photo; and sea-purslane (*Sesuvium portulacastrum*). Also in the center photo is the larger, bushy salt marsh plant called *Fimbristylis spathacea*.

(photo by Environics, N.V., 2000)

3.5 Marine algae and the mangrove sub-basin environment

Marine algae and seagrasses form the ecological foundation of Lac's marine system food web; like plants on land, they are primary producers, converting the sunlight energy and nutrients into edible plant materials (Littler et al. 1989). They therefore provide food, oxygen, as well as habitats in either a direct or indirect way, for most other inhabitants in the greater Lac marine environment.

Figure 18 Primary productivity in the Lac mangrove sub-basins provides habitat value

A significant partnership exists between the decaying mangrove leaf litter (left), and the blue-green algal bacteria, which flourish in the muddy waters of Lac's mangrove sub-basin. First, the blue-green bacteria begin to reproduce and layer on the stems and leaves, and begin breaking down the plant fiber materials into edible substances, called "detritus".

These blue-green "algal mats" of Lac (right) belong to the species, *Microcoleus*, (van Moorsel en Meijer 1993) and are closely related to bacteria. Thus, they can reproduce quickly, and provide a high level of primary productivity (food energy) in this seemingly hostile environment. Crustaceans, fish and worms digest this detritus material further, while aquatic birds feast on these marine creatures, and the circle of life goes on.

The cyano-algal mats dry out during the dry season, or when water levels are low, forming a black crusty veneer layer over the ground. It will remain in this condition until rainy season, or when water levels are high again. At that time, the biological productivity of the algal mats will commence, thus again beginning the dynamics of the complex and mysterious food web cycle of the mangroves and muddy environments found in mangrove sub-basin Lac.

(photos by Environics, N.V., 2000)

The *Cyanophyta,* phylum, commonly called the blue-green algae, holds an important significance in the mangrove sub-basin salt ponds. As the individual cells reproduce in the extreme environment of these shallow salinas, their cell densities can color the water column into a turbid green that will obstruct sunlight penetration. Thus, little other marine plant life can live beneath these backwaters that have elevated temperatures and salinities during certain times of the year. During the dry season, when the salt ponds dry up, these same cells desiccate in the baking sun, and leave behind dense, black crusty mats of filaments on the parched ground (Figure 18) (Lott 2000).

These blue-green "algal mats" of Lac belong to the species, *Microcoleus*, (van Moorsel en Meijer 1993) and are closely related to bacteria (Figure 15). Thus, they can reproduce quickly, and provide a high level of primary productivity (food energy) in this seemingly hostile environment. These cells, therefore, provide a first order of food energy transfer to crabs, shrimps, etc, that then become food to the wading bird which forage in the Lac backwaters, and are also a delight for birdwatchers to observe.

The primary productivity of the blue-green algae holds a special significant partnership of food energy transfer with the dying mangroves in the Lac mangrove sub-basin environment (Figure 18). The organic matter deposited in the shallow waters from the dying mangrove tree's leaves and wood, form a great contribution to the complex food web of Lac. However, these plant fiber materials cannot actually be directly consumed by any other organism. First the blue-green bacteria begin to reproduce and layer on the stems and leaves, and begin breaking down the plant fiber materials into edible substances, called "detritus". The detritus forms a substrate for a rich bacterial and algal growth, which, in turn, serves as an important food source for various herbivorous (plant eating) crustaceans, worms and fishes (Nybakken 1982) that are inhabiting the Lac mangrove sub-basin environment. These, in turn, become food for the foraging wading birds of Lac, such as herons and flamingos. ***Thus, although the mangrove mangrove sub-basin of Lac appears to be "dying", the net transfer of food energy far exceeds that which occurs in the Lac Bay basin.***

The Lac mangrove and salt pond environment, therefore, holds significant wildlife habitat value, when perceived in terms of the transfer of food energy derived via the presence of the blue-green algal and detritus productivity.

Of the simple marine macro-algae plants found in Lac Bay, researchers inventoried 65 types since 1969, as follows (Appendix A: Species List):

Macroalgae Phyla	Wagenaar, Hummelinck en Roos (1969)	van Moorsel en Meijer (1993)	Lott (2000)
Chlorophyta (green)	3 species	31 species	24 species
Phaeophyta (brown)	1 species	8 species	10 species
Rhodophyta (red)	0 species	24 species	14 species
Cyanophyta (blue-green)	0 species	1 species	1 species

Table 1 Comparison of numbers of algae species found by researchers in Lac bay.

3.6 Rare Status of the Mangroves and Lac's Geology

Lac's ability to promote mangrove growth was described by Thom (1984 in van Moorsel en Meijer 1993), and classified the bay's geomorphologic platform structure, as follows:

"… Setting 7: a carbonate environment behind a mobile but protective sand or shingle barrier…"

This type of mangrove system globally is relatively rare due to the absence of a river, or other fresh water inundation. Optimal conditions for mangroves are found in tropical estuaria where there is a strong regular rainfall occurring over the course of a yearly period (Balsco 1984 in van Moorsel en Meijer 1993). Thus, due to the absence of any fresh water influence, mangrove growth around Lac is defined as rare, and relatively fragile.

Hummelinck en Roos (1969) describe the uniqueness of this geologic infrastructure in Lac, that combined with years of substantial top layering of peat, provides optimum conditions for mangroves and seagrasses to thrive in this fragile ecosystem:

"…The coral and shell sand is often mixed with lagune mud, peat of mangroves, or sand that consists for the greater part of remains of lime-algae. Further we may admit that the vast underground, the plateau of limestone of southern Bonaire, is nearly everywhere present at a slight depth…

In the whole Caribbean territory seaweed pastures are found – a more or less linked up vegetation of Thalassia testudinum [turtlegrass] *– in lagunes or other undeep waters, where they promote sedimentation and supply considerable contribution to the biological and physical cleaning of the environment. They create is these manner favorable life conditions…"*

(Hummelinck en P.J. Roos 1969; English to Dutch text translation by Carmita Santiago 1999).

Beneath its lagoon, mangrove creeks and shallow muddy lakes, Lac is underlain by a karst limestone platform (Mohr 1972). Karsts are terrain usually characterised by barren, rocky ground, caves, sinkholes, underground rivers, and the absence of surface streams and lakes (www.britannica.com). At Lac, this geologic platform is considered to be a multi-terraced, Pleistocene age calcium plateau. This plateau features three terraces, that gradually slope downward in a west to easterly direction, towards the windward seacoast. One of the higher terrace slope lines can easily be discerned at the Lac Bay resort area. The degrees of angle of these three geologic profiles are 0.65^0, 0.82^0, and 1.21^0, and each terrace platform covers a distance of approximately 42 to 52 meters across (van Moorsel en Meijer 1993).

Today, at Lac lagoon, these type geologic understructures are all heavily overlaid with the decaying vegetative matter of mangrove detritus, and heavy deposits of the calcium carbonate remains of marine plants and other marine organisms, as well as from the sedimentation build-up of coral rubble. Lac is bound up in all areas by these limestone platform terraces (Hummelinck en P.J. Roos 1969). For example, when one walks in the inter-tidal areas of the Awa Yuwana area (bright blue zone Map 2), one's feet will ooze down through the plant detritus layers, and often trip into the early age karst limestone holes that riddle the bottom (Figures 19, 20, 21, 22).

Figure 19 Geologic structures of Lac

Lac is an environmental demonstration of how early geologic infrastructures give way to present day physical features (arrows in photo). The ridges of the middle Pleistocene terraces produced a barrier rift that in modern times became a sediment trap, thus forming the sand "ridge " islands of the Isla Rancho, Isla di Pedro, Isla Fogon and the Isla di Chico regions. These geologic origin ridges that are now transformed as ridge islands, are stabilised through the development of mangrove growth.

In the western Lac region, minor geologic dome-like structures explain the circular circumference of the Isla di Yuwana, and the Punta Wanapa features.

(photo adapted from Wing Group, N.V. December 1998)

Figure 20 Natural features of present day Lac originated from geologic ridge formations

Elongated fissure formations running along the eastern edge of the lower terrace explain the long shallow ponds found at the Awa Molina area (left arrow in photo). At Sorobon, a limestone ridge gives way to a submerged terrace at Binnenklip (right arrow in photo). Today, it is overlain with sediments, and conglomerated with calcareous algae species, forming an important limestone reef in the bay.

(photo adapted from Wing Group N.V. December 1998)

Figure 21 Sorobon area and Wowo di Lahan

(photo adapted from Wing Group, N.V. December 1998)

The lower-most geologic terrace extends due south of the Lac lagoon area, below where is now Sorobon. It levels at this location to form a horizontal plateau, and its platform is also riddled with fissures. In the Awa Djukfes pond, a complex limestone underground system permeates the bottom of this embayment area, containing numerous limestone fissures and caves (bottom arrow in photo).

At points where many of these fissures converge together, they have formed a "Wowo di Laman", or "Eye of the Sea" in this small bay. The Wowo di Laman is an underground conduit that leads out to the offshore coastal sea environment. One such "eye" can easily be seen at Sorobon beach (top arrow in photo), where this hole floods and drains at the will of the ocean's tides (Hummelinck en P.J. Roos 1969; van Moorsel en Meijer 1993).

Figure 22 Boca Djukfes

Reef fish, such as snapper and mangrove grunts, will use these Wowo di Laman, such as the one occurring in Boca Djukfes, like an underwater tunnel, to enter into this small mangrove bay to forage for worms and crabs that inhabit the mangrove environment.

(photo by Environics, N.V., 1999)

4. Environmental Landscape Changes of Lac

Lac is an ever changing or dynamic natural ecosystem, when perceived in the context of an environmental landscape. The environmental story of Lac is best described through the interpretation of its historic cartographic maps, and through the photointerpretation of modern aerial photographs. As Hummelinck en Roos (1969) exclaimed of the environmental sensitivity known of Lac:

"…When we see the Lac from the sky, we see behind the white strip of sand, not a smooth green cover of mangrove with here and there dark lagunes, but a pot-marked green cover with holes and greyish spots, which looks unhealthy compared with the fresh green strip of mangrove which surrounds the basin of Lac. These pot-marked holes seem to be muddy plains, and the greyish spots are places, where the mangrove bush is dead or nearly died off. What is happening with Lac…"

(Hummelinck en P.J. Roos 1969; English to Dutch text translation by Carmita Santiago 1999).

4.1 Sea level changes in Lac over time

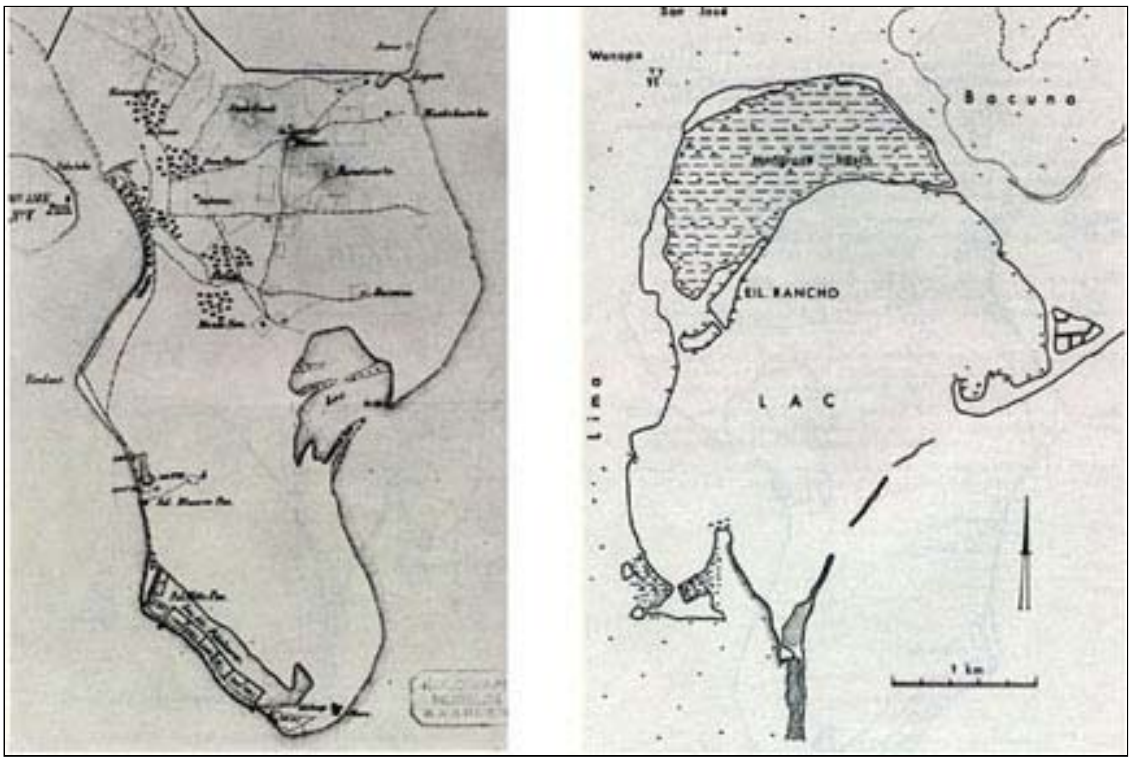
Lac can be described as a product of the fluctuations of sea level change (Mohr 972; Hummelinck en P.J. Roos 1969; van Moorsel en Meijer 1993). The sea level constantly changes at every locality with the changes in tides, atmospheric pressure, and wind conditions. Longer-term changes in sea level are influenced by the Earth's changing climates, and thus suggest implications for the state of the environment in Lac today (see Section 3.6).

At a time when the sea level stood several meters lower than it does in present day levels, Lac was of lower elevation, and situated as part of the limestone platform terrace of southern Bonaire. As sea level rose to its present day depths, however, the configuration of Lac was influenced by this change (see Figures 19, 20, 21).

4.2 Historical Maps Interpretation

The earliest map showing the configuration of Lac Bay was dated in the year 1866, followed by a second cartographic map produced in 1911 (Maps 4, 5). The rendering of the 1866 map of Lac showed little mangrove forestation in any area of Lac. However, the open bay basin lagoon was already being physically separated from the posterior sub-basin by some island development. Antoin (1999; personal

communication 1999) describes that this opening between the main lagoon and the separate lagoon at the top of the Lac, was very important for the movement of boat craft, that would enter into this "second" bay system to anchor, for transporting goods ashore. Hummelinck en Roos (1969) theorized that these "sandwall" divisions, as illustrated in the 1866 map, came into being at a time when the beach hook island



Year 1866 **Year 1911**

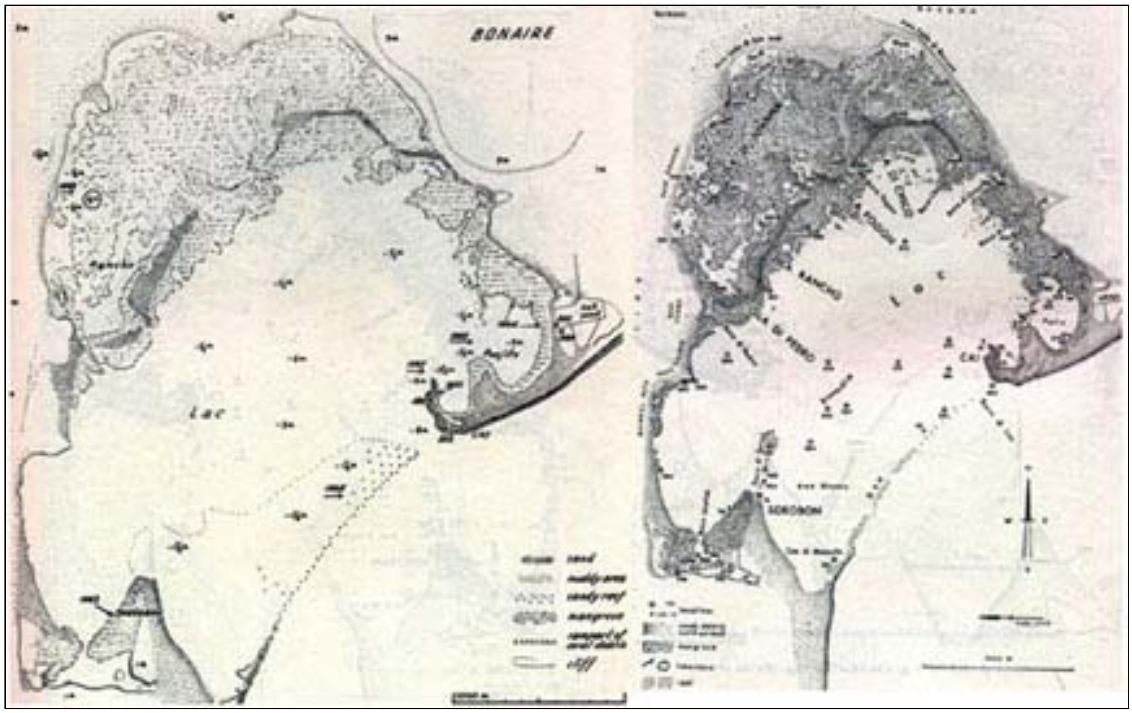
Map 4 Early historical cartographic maps of Lac

(adapted from Hummelinck en Roos 1969)

of Cai did not exist, as shown 1911 Map (hooked beach formation at right side of 1911 map). The researchers suggested that the vast passage opening as seen in the 1866 map, would have allowed greater sea circulation, and so also the successful importation and deposition of sediments and mangrove seedlings to enter via incoming sea currents.

In addition, boat craft would enter into the basin area located above the hooked beach formation, to anchor for collecting salt from the nearby salina (Antoin 1999). The 1911 map shows the open bay area extended to the shores of these salinas. Meanwhile, the first expansive growth of the mangrove bush

in the north mangrove sub-basin of Lac, is also clearly documented in the 1911 map. In addition, more mangrove growth is documented in the bottom sector of the map.



Year 1949 **Year 1967**

Map 5 Early historical cartographic maps of Lac
(adapted from Hummelinck en Roos 1969)

By the years 1949 through 1967, the Maps 4 document that the sediment trapping processes occurring along the old geologic ridge edge, had successfully created the four central islands of mangrove sub-basin Lac, as previously described in Section 3. The successful forestation of mangroves around the inner basin perimeter of Lac is also well detailed in both the maps. The mangrove wetlands are encroaching from the central lagoon islands, with growth extending to the hook shaped beach of the west shore, at where is now Cai. Also, the formerly opened anchorage area near the salt pans above the hooked beach is showing increased mangrove growth. Another mangrove embayment is being developed at the bottom of the map, where is now Boca Djukfes. That area is also beginning to fill and encroach away from the main Lac basin through mangrove development.

Year 1961 **Year 1998**

Map 6 Aerial photographic maps of Lac

(Year 1961 adapted from Hummelinck en Roos 1969; Year 1998 adapted from Wing Group, N.V. December 1998)

More accurate interpretation of physical processes can be realized through the remote sensing techniques of aerial photography. The 1961 aerial view of Lac shows dense mangrove growth throughout the inner perimeter of Lac, as well as in the mangrove sub-basin, above the ridge islands that separate the open Lac from mangrove wetlands (left photo, top white arrow). A central creek passage is visible at the point of the white arrow, where open bay water can feed into the mangrove sub-basin bay environment. In addition, for the first time, an accurate representation of the benthic, or bay bottom coverage can be interpreted. Seagrass coverage is extensive, except in the stark white zone of the aptly named, Awa Blanku region, that is located in the bottom of the bay.

The more recent 1998 aerial photograph clearly documents the gradual die-off phenomenon that is occurring in the mangrove wetlands in the upper bay area (right photo, top white arrow). The brown coloration of the mangrove die-off is in contrast to the green coloration living mangrove wetland areas. In addition, the central creek passage is no longer visible at the point of the top white arrow, due to increased growth of the mangroves, and the creek is hidden from view under the canopy of mangrove trees in that area. Ground-truthing activities conducted by Lott (2000) confirmed this observation, and further confirmed that the creek no longer functions, due to overgrowth and stoppage by vegetation (see Figure 16).

The seagrass density has also shown change in bottom coverage, comparing the 1961 and 1998 images. The 1961 aerial (left photo, bottom arrow) shows denser bottom coverage than in the 1998 aerial (right photo, bottom arrow). Overall, there appears to be more bottom coverage throughout the bay in the 1961 image. In addition, a defined border has developed along the edge of the seagrass bed in the 1998 view.

The ephemeral quality of sedimentation (filling as well as withdrawing) can be seen at the point of the central arrows in the two photographs. The 1961 image (left map, center arrow) shows sedimentation filling an extensive length of a creek bed behind the Isla Pedro area. The 1998 image (right map, center arrow) shows the sedimentation has shortened in the creek bed, but the remaining sediments appear more dense.

4.3 Physical Feature Changes and Hydrological Alterations in Lac

Aerial photographs taken during 1961 showed a visible channel connection between the Awa Yuwana and Awa di Pedro (Wagenaar, Hummelinck en Roos1969), that created better water exchange from open Lac through two openings at Kreek di Pedro (Figure 23). These researchers reported a difference in high tide occurring from open Lac to Kreek di Pedro of approximately 1 hour and 15 minutes. Later, data from van Moorsel en Meijer (1993) indicated for the same location, the tide time difference had grown to 2 hours and 34 minutes. They noted that this connection had grown closed. (Also note in the 1961 photo, signs of sedimentation occurring behind the Isla di Pedro).

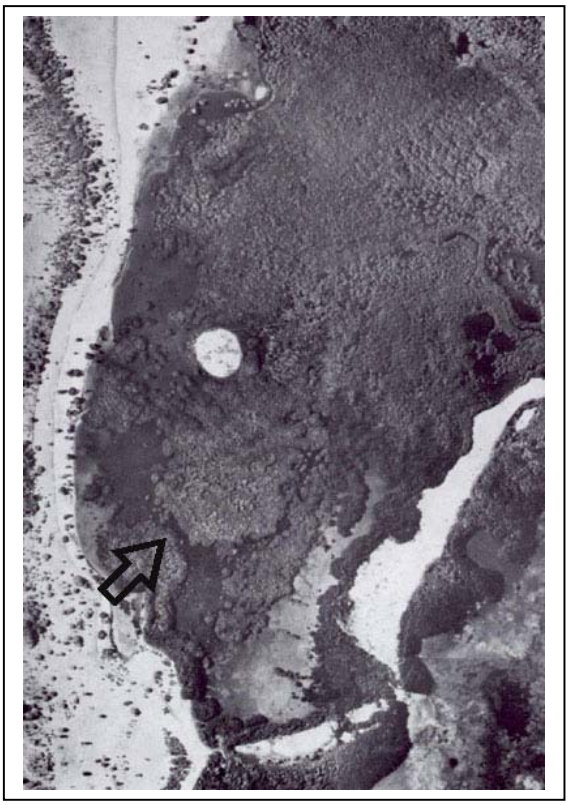


Figure 23 Sedimentation fluctuates in areas of Lac Bay

The Kreek di Pedro channel passage opening to Awa Yuwana is clearly visible in this 1961 aerial photograph.

In addition, note the sedimentation build-up occurring in the pond located behind the Isla di Pedro. Over the course of years, sediments build and recede on an "ephemeral" basis at various sand locations throughout Lac.

(aerial photo adapted from Hummelinck en Roos 1969)

Though the researchers observed a longer time delay in tide delivery of this area, and suggested the area had become closed, circulation does occur. Based on March 1999 – March 2000 monitoring

activities (Lott 2000), the average annual salinity values range from 46.8 $^{0}/_{00}$ to 79.6 $^{0}/_{00}$ from the Awa di Pedro, to the Awa Yuwana noord area, respectively, with the upper values occurring during the drier season (Section 4.5).

A further comparison between two recent aerial photo records at the Awa di Pedro sub-basin area, also demonstrates sedimentation occurring behind the Isla di Pedro. Note in Map 7, the left photo showed no sedimentation in 1991, while there is a build up of sediments in the right photo during 1998.

1991 **1998**

Map 7 Sedimentation processes in Lac

Sedimentation build-up occurred in the area of Kreek di Pedro since the 1991 aerial, to 1998 aerial. Compare effects with Year 1961 (Map 6, Figure 23) in which the same area contained sediments. This condition of sediments appearing and disappearing in the same map locations over the years, shows that the sedimentation processes in Lac are of an ephemeral nature. It also shows the value of remote sensing techniques to detect environmental change through aerial photography.

(left map courtesy Cargill Salt Company; right map adapted from Wing Group N.V. Curacao 1998)

4.4 Cultural Impacts on Physical Change of Lac Bay

Cultural changes have also influenced the physical feature changes in Lac. Referring to the below comparison (Figure 20), a 1967 photograph of Kreek di Pedro (Hummelinck en Roos 1969) showed an open exposure to the open bay basin, with a large mound of cracked conch shells sitting out in the creek. This area was frequently used by fishermen to enter and exit the bay, through the mangrove creek in this eastern sector of Lac. The recent year 2000 photograph shows the same area enclosed by a dwarf red mangrove forest, indicating a cultural change, and non-use of this passage, with the subsequent physical encroachment of mangroves.

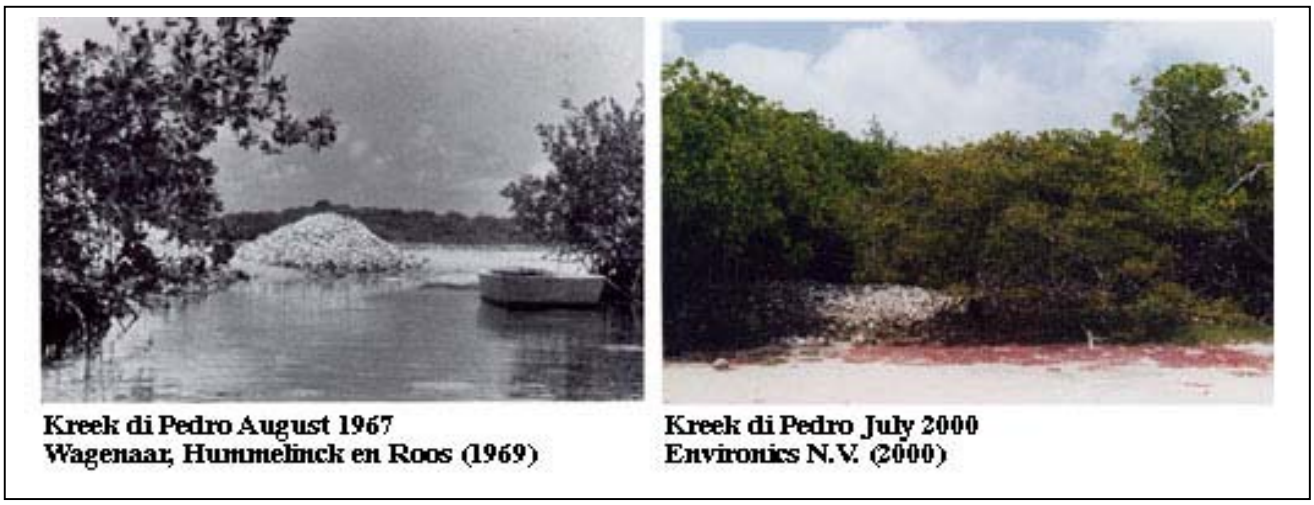


Figure 24 Changes of human cultural use in Lac and implications for mangrove growth in some areas

Comparison of mangrove channel opening at Kreek di Pedro, from 1967 to 2000, shows encroaching of mangroves and land reclamation over mound of conch shells in creek bed, as a result of non-usage of creek by fishermen. In certain cases at Lac, environmental change is effected by human cultural use change of the natural resources.

(left, Hummelinck en Roos 1969; right, Environics, N.V. 2000)

In the interior islands of Isla di Rancho and Isla di Chico, the Buttonwood tree, *Conocarpus* species was once harvested for charcoal. In addition, the Acroporid branching corals were frequently burned to derive a limestone building material (Antoin 1999; Newton, personal communication 1999), and the charred mounds are still visible reminders of those days (Figure 25). The Soliana family at Cai also utilized the mangrove roots to weave baskets for domestic use, and also to make fish traps. The mangrove roots were also burned to produce smoke that served as an insect repellent (Antion 1999).

Figure 25 Signs of days gone by in Lac, and changes in cultural use of its resources

In Isla di Rancho, the area was formerly used by fishermen to (top left to bottom right in photo) to crack conch, fish, and burn buttonwood for charcoal, and also burned Acroporid corals to get a limestone building material (Antoin 1999, Newton, personal communication 1999)

(photos by Environics, N.V. 1999)

At a meeting held on May 5, 1994, the four local fishermen who knew Lac well, Vicente Soliana, Gilbert Soliana, Buchi Martis and Silvio Domacasse, described how through the years they maintained the passages of certain creeks in Lac. They explained how they cut away the roots, and removed young sprouts that would eventually close up openings, and discourage boat passage. They would remove the vegetative debris and burn it. They argued that now since this method is no longer practiced, that the Lac has grown in, with poor seawater circulation that has created stench soils, and ultimately the death of the mangrove wetlands (Antoin 1999).

A recent survey of local fishermen who have used Lac for the past 25 to 50 years (Martines 2000) also explained that the Lac was growing smaller due to the encroachment of the mangroves. They still utilize traditional fishing practices in the bay, with handline or fish trap, and indicate they catch the same species of fish as before in the past. They have indicated that there still are large karko (conch >25 cm) in the bay, but you must know where to look, although in the past they would catch hundreds, and now very few. Most surveyed indicated that they no longer take their boats in through the mangroves, as the area

has grown up with trees, and is impassable. They all agreed that they would abide by any management policies initiated for the natural resource protection of Lac.

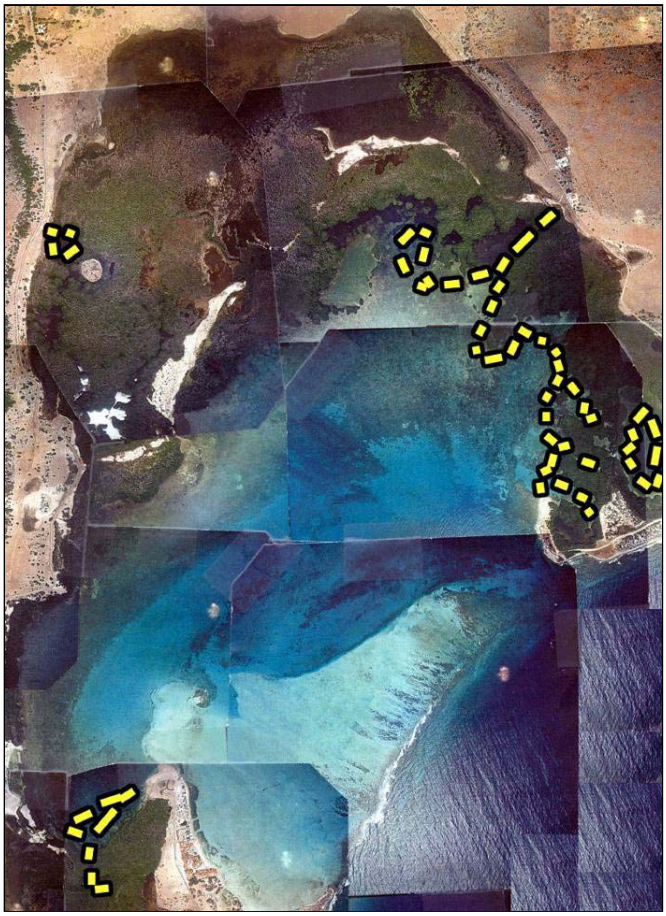


Figure 26 Recreational use of Lac has changed the face of cultural use for the bay

Tourism and recreational use of Lac by kayaking, windsurfing, swimming, and leisure time relaxation are now taking over more in the place of traditional fishing practices in Lac.

The left photo shows the map of popular trails used by local naturalists who guide tourists and nature lovers on kayak and snorkel tours of the mangroves in Lac.

Photo adapted from Wing Group N.V. Curacao 1998

Cultural change in Lac means ultimately environmental change in Lac, based upon the impacts that are given on the natural environment by the users of the resources. Be it fishermen who maintain creek passages for their boats, or windsurfers and kayakers who use the bay waters for sport and nature, each will leave a short or long-term effect on the natural physical features and ecological processes of the Lac.

4.5 Upland Alterations Changing Rainwater Sheet Flow Drainages into Lac

Up until approximately 1951, Cai was known to be inaccessible during the rainy season. Sheet flow movements of rainwater, draining from the higher elevations of San Jose, Rooi Grandi, Wanapa, and Bakuna, into the Lac mangrove sub-basin areas, all contributed to fresh water inundation during the periodic rainwater events. This "sweet water" sheet flow eventually entered into the Awa Lodo di San Jose and Awa Lodo di Chico areas; and also flooded any land passage access to the Cai area. After the

1951 time period when the road was constructed, as well as the creation of the "dam" or levee at Bakuna, these structures blocked the inundation of any further major rainwater sheet flowage into the Lac mangrove sub-basin sub-basin areas (van Moorsel en Meijer 1993).

Prior to the road and levee construction, the potential of yearly drainage of rainwater from the upland Lima area, was estimated at 1 x 2 km. x 500 mm = 10^6 square meters per year of sweet water, that flowed into the Lac mangrove sub-basin mangrove environment. From the upland Bakuna area, the sheetflow drainage was estimated to be even greater, at 2.4 x 1.3 km x 500 mm = 1.5 x 10^6 square meters per year of sweet water, that flowed into the mangrove environment of Lac. Thus, the dam construction alone has blocked, or limited the supply of approximately 40% freshwater sheet flow into the mangrove sub-basin mangrove environment of Lac (van Moorsel en Meijer 1993).

Since the supply of the fresh rainwater drained from the Bakuna in the first place, and then flowed into the two Awas di Lodos ponds, the dam is a very important issue for this area. In regards to all of Lac, the blockage by a dam means the reduction of a fresh water supply of a maximum 30% delivery to the entire bay environs. It is now assumed that no rainwater gets into the bottom at Bakuna any longer, including no rainwater flooding over the side areas of the dam, that were designed to allow water to cross over into Lac. These areas built into the sides of the dam are at the same level of the culverts at the "terra cora delta" so that an excess of fresh water could still flow to the Awa Lodo di San Jose (van Moorsel en Meijer 1993). However, whether they function to allow fresh water sheet flow across into the Lac, is questionable.

5. Physical Processes and Hydrology of Lac

The hydrology and sea circulation patterns inside Lac Bay are strongly influenced by spatial and temporal scale physical processes. The hydrologic cycle of the greater Lac Bay region includes an overall movement of water that is influenced and delivered from both offshore and coastal currents, tidal action, wind-driven surface currents, and evaporative processes (Map 8). Temporal and meso-scale processes (1 – 1000 kilometers influence), primarily tidal events and wind-driven surface currents, also influence the water masses and circulatory patterns that cycle within the bay's intra-regional mangrove sub-basin system. High water events occur during the September solstice period, that coincides with the rainy season, and low water events occur during the March solstice period, that coincides with the dry season (Mohr 1972; van Moorsel en Meijer 1993; Gielen, DeAnda personal communication 1999). These processes strongly influence the overall annual dynamics of seawater circulation patterns inside the Lac Bay basin, and the resultant distribution of shallow-water benthic communities throughout the system. In addition, these processes strongly affect the water levels that result in the extreme water quality conditions of the mangrove sub-basin areas.

Map 8 Lac's Circulation Process

This process creates the clockwise circulation patterns that cycle inside the main Lac Bay basin, and also influences movements of water into the interior mangrove sub-basins. This steady movement of coastal currents also transports sediments up from the lower reef sandy slope terraces, and moves and deposits these biogenic materials across the reef "dam". This process thus sustains the shallow calcareous bottom in the Awa Blanku sandy plateau, by providing a continuous build-up of sediments and coral rubble. These same currents then flow towards the Sorobon area, and afterwards turns more northward to the Boca Fogon area of open Lac, to finally flow outward again from the Cai passage into the open sea.

(adapted from van Moorsel en Meijer 1993)

Environmental change in these sub-basin areas is clearly related to the overall circulation variability within the system. This hydrological variability repeats itself over an annual period (van Moorsel en Meijer 1993; Gielen, personal communication 1999; Lott 2000).

5.1 Lac Basin Depths and Sedimentation Processes

The depth configuration in the Lac Bay basin was mapped by the Lott and BONURA team, during extensive benthic assessment activities that were conducted from June to September 1999 (Map 9). Divers surveyed approximately 51,000 square meters of bay bottom, and recorded depths by using various models of underwater depth computer gauges. A Garmin 12 GPS unit was used to record map positions. All maps were produced by the Landscape Ecology Laboratory at Duke University, Raleigh, North Carolina., in which the GPS data were interpolated with GIS ArcView computer software.

The expansive Awa Blanku and Secu di Sorobon area, located in the southeastern region of Lac, is virtually devoid of submerged vegetation, and is a shallow, sandy bottom plateau extension of the Lac Bay basin. Awa Blanku acts as a depository from the sediment-laden coastal currents, which continually bathe over this plateau. This shallow, 1 to 1 1/2 meters deep expanse at Awa Blanku, eventually grades away to the nearshore, bank coral reef system (Map 9, 11).

Hummelinck en Roos (1969) describe this area as follows:

"...Lac shows big contrasts: There are not only vast pastures of seaweed [sic: meaning seagrass], *but also shining white sand plains. The ground between the Dam and the Secu di Sorobon offers no possibilities for supplement for the seaweed. This is one big white plain of sandlime that is carried away over the Dam and it now forms a knee-deep tableland which slopes steep down in the north and west to the two meter lagune bottom that lays lower. A part of the sand goes, however, farther away, still at the beach of Mangel Altu that cuts off the western part of Boca Djukfes in the south, as a white spit of land.*

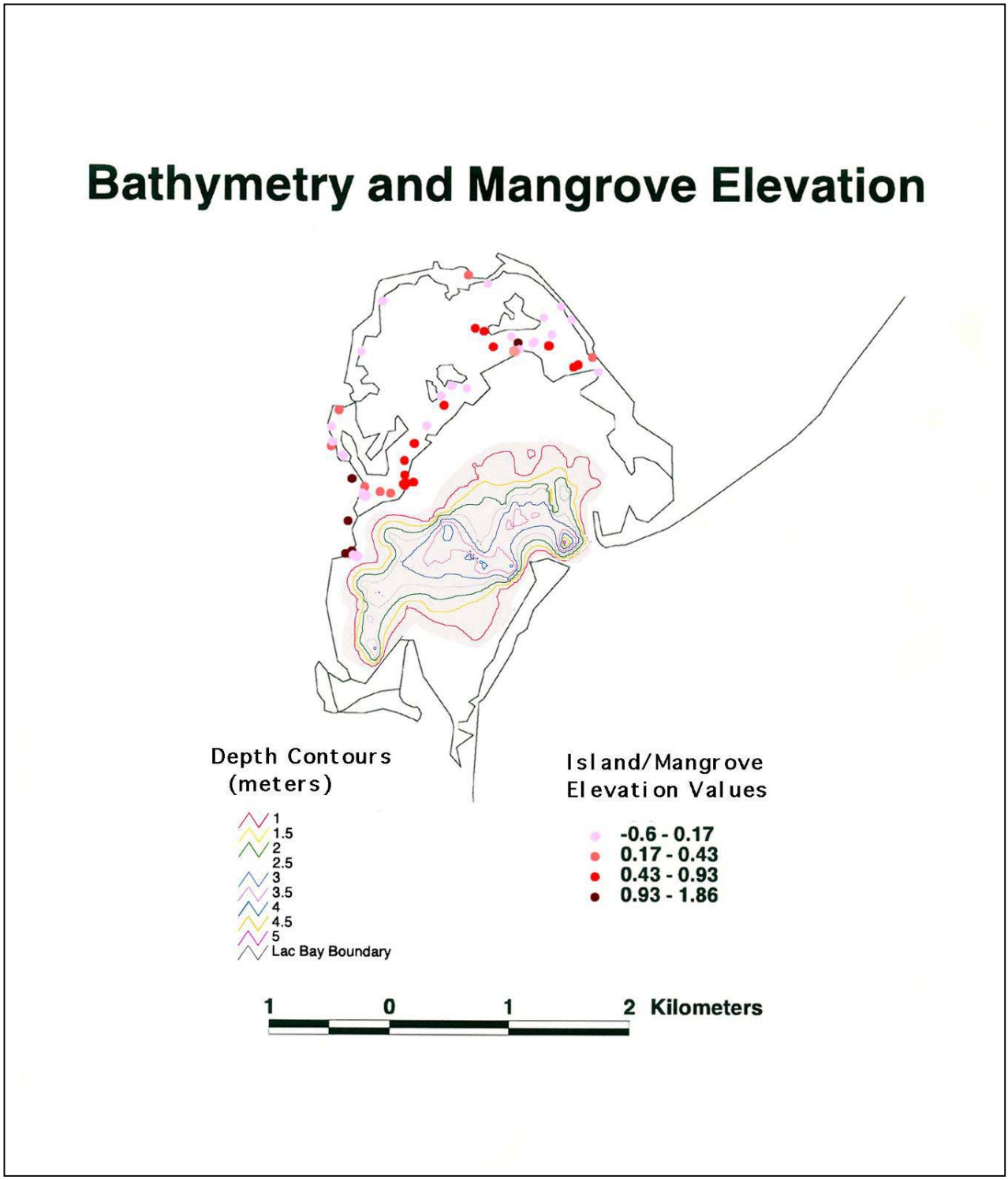
You should have an understanding since long that we have here the biggest supply of sand of the Lac, which is placed at our disposal. Many loads of trucks of sand have been taken away from here. This sand is of a totally other quality than the much more coarse sand, mixed up with shell-grit and pieces of coral of the older part of the Cai spit of land, from where several cart-loads have been carried away some years ago. It is good not to cherish great expectations of the supply of sand of Lac…"

(Hummelinck en P.J. Roos 1969; English to Dutch text translation by Carmita Santiago 1999).

The Lac bay bottom contour has changed very little over the past fifty years. Referring to the 1949 map (Map 9) (Wagenaar, Hummelinck en Roos 1969), the inner perimeter depths were 1/2 meters deep, while the 1999 surveys recorded 1 meter depths in similar areas (Map 10). The Boca di Lac, or bay opening of Lac to the sea, was 8 meters deep in according to the 1949 map, while the 1999 surveys recorded 5 meters deep in similar areas.

Map 9 Depths Map of Lac Bay 1949

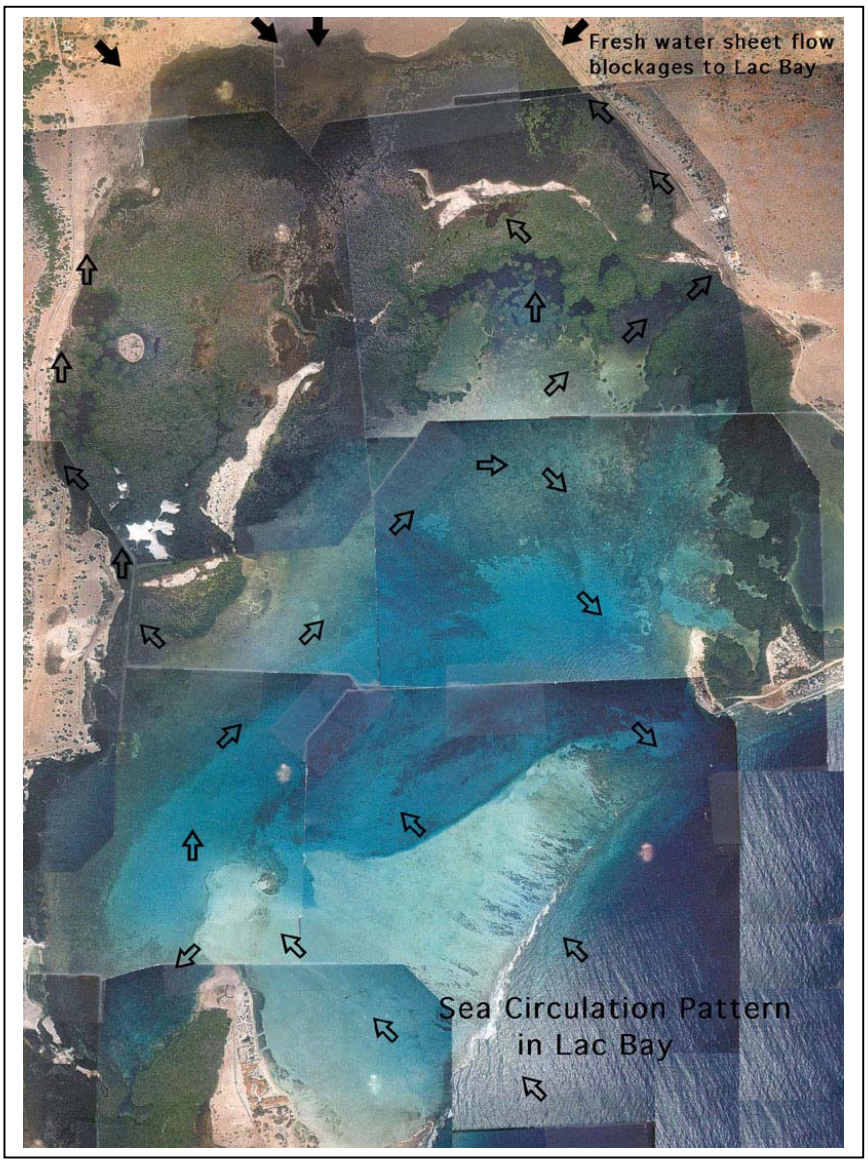
(adapted from Wagenaar, Hummelinck en Roos 1969)



Map 10 Depth Contours of Lac Bay and Physical Elevation of the Ridge Islands

(Maps prepared at Duke University Landscape Ecology Laboratory by P. Dermer)

The plateau area maintains its bottom composition of coarse calcareous sediments and coral rubble fragments, and its shallowness, due to the sediment transportation and deposition processes that occur there (Mohr 1972; van Moorsel en Meijer 1993). This sedimentation process originates as a result of the passage of adjacent coastal ocean water currents that carry suspended sediments from nearshore submerged terraces, and dumping materials over the reef plateau that divides the open Lac bay from the sea (Maps 11). In the perimeter areas around the main open Lac basin, the depths maintain shallow, less than 1 – 2 meter depths, where dense seagrass beds act to trap and stabilize the suspended sediments, and develop thick seagrass meadow patches. Then, the central area inside the Lac bay basin grades into depths of approximately 5 meters. The deepest areas, of course, occur in the Cai passage areas, that flow outward again into the nearshore reef zone (Map 9, 10, 11).



Map 11 Sea circulation patterns in Lac Bay by nearshore ocean currents. (van Moorsel en Meijer 1993; photo adapted from Wing Group, N.V. December 1998)

5.2 "Feeder Channels" of the Awa Yuwana and Awa di Chico areas

This clockwise direction flow cycle of the Lac currents also creates a diversion, and delivers seawater flow into the mangrove sub-basin Lac mangrove sub-basin areas through two main feeder channels:

- Boca di Pedro, through Kreek di Pedro, that continues to flow through the northwestern Lac border, along the Yuwana areas; and
- Boca di Coco, through Kreek di Coco, that continues to flow through the northeastern Lac border, along the Awa di Coco and Awa Lodo di Bakuna areas.

In addition, during high water events, a third diversion occurs at the Isla di Chico area, where water is pushed across the island elevation, and mixes into the muddy waters of Awa Lodo di Chico, subsequently refreshing this area's salinity values (Figure 27).

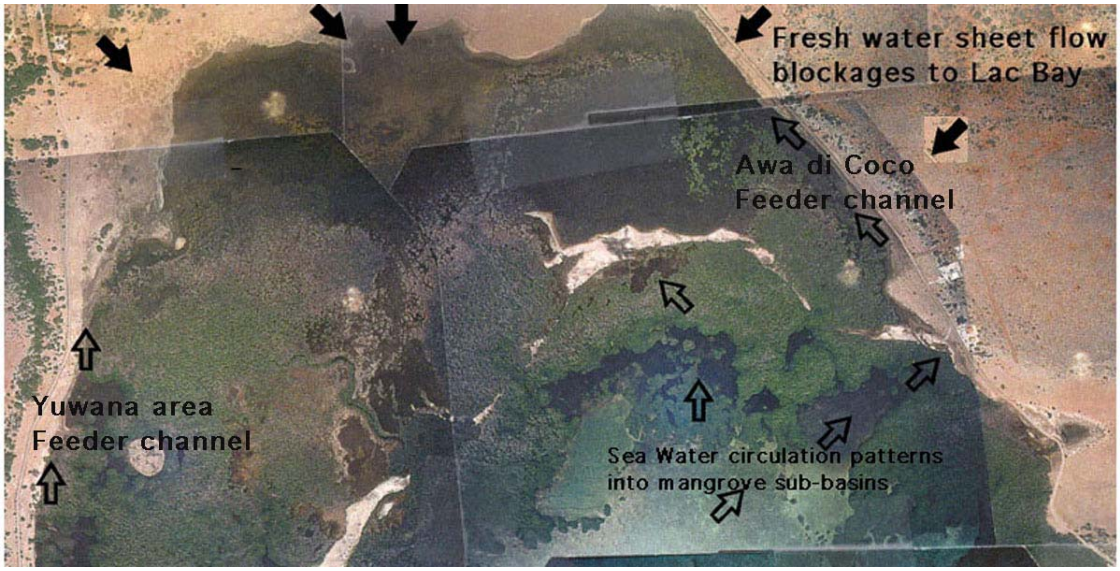


Figure 27 Diversion patterns of open Lac Bay seawater circulation

The open arrows indicate where cycling processes force bay water into the two primary feeder channels: via the west side through Boca di Pedro and into the Yuwana area, and at the east side through the Boca di Coco opening, into the Awa di Coco area. These openings from Lac bay deliver water further into the mangrove sub-basin region, through the Awa Yuwana and Awa di Coco feeder channels.

During high water events, water also passes across the central region at Isla di Chico, and fills fresh bay water into the Awa Lodo di Chico sub-basin.

(van Moorsel en Meijer 1993; photo adapted from Wing Group, N.V. December 1998)

5.3 Tidal Regimes in the Lac Mangrove Sub-basins

The tide delay differences were measured from the open bay basin, into the Lac mangrove sub-basin mangrove sub-basins by the prior researchers, van Moorsel en Meijer (1993) and Wagenaar, Hummelinck en Roos (1969). They estimated the tide levels at approximately a maximum 30-cm tidal height difference. In addition, the time delay differences of tide delivery from the open Lac into the mangrove sub-basin mangrove region is approximately 18-32 minutes, that are, among other reasons, often dependent on wind driving forces of surface chop, that pushes bay water further towards the interior during extreme wind conditions.

However, according to Wagenaar, Hummelinck en Roos (1969), the Awa Lodo di Bakuna no longer reacts to the tide. Studies by van Moorsel en Meijer (1993) found minimal tide levels variations ranging from 6 – 11 cm in this area, indicating that the limited openings from the open Lac results in restricted seawater exchange, and tide level fluctuations. But van Moorsel en Meijer (1993) observed that during their March 1993 research period, the waters of Awa Lodo di Chico and the Awa Lodo di San Jose were in contact with the open Lac, via the feeder channel of Kreek di Coco.

Figure 28 "Tidal overwash" of bay water into mangrove sub-basin region during high water events

Ground-truthing activities of aerial photographs, Lott (2000) determined that during high water events, the diversion of bay water floods across the central island of Isla di Chico. In those conditions, bay water mixes with the higher salinity waters in Awa Lodo di Chico. Salinity values were measured to be near open bay water levels, ranging from 44 $^{0}/_{00}$ to 61 $^{0}/_{00}$, over a year's monitoring activities.

(photo adapted from Wing Group, N.V. December 1998)

In addition, recent field ground-truthing activities by Lott (2000), observed a third source of sea water, flowing from the open Lac and across the central areas of Isla di Chico, feeding into Awa Lodo di Chico (Figure 28). Salinity values measured during an annual March 1999 – March 2000 monitoring period, indicated a 44 $^{0}/_{00}$ – 61 $^{0}/_{00}$ salinity range, on both the bay and shore sides of the island. These

observations revealed that during certain hydrological events, bay water also feeds through the central mangrove swamps of the Lac, flooding across the land barrier of Isla di Chico, as well as through the main feeder channels of Kreek di Coco and Kreek di Pedro.

Obviously, the limited physical openings of Lac from the open bay basin can result in restricted water level fluctuations. The daily water level differences can be as little as 1.5 cm to 24 cm over a weeklong period (van Moorsel en Meijer 1993). These extreme water level fluctuations in Lac Bay in such a short time window can be influenced by several natural factors:

- by forces of strong southeasterly trade winds that blow directly into the bay, and
- by seasonal water level fluctuations caused during the geographical and time scale solstice periods,

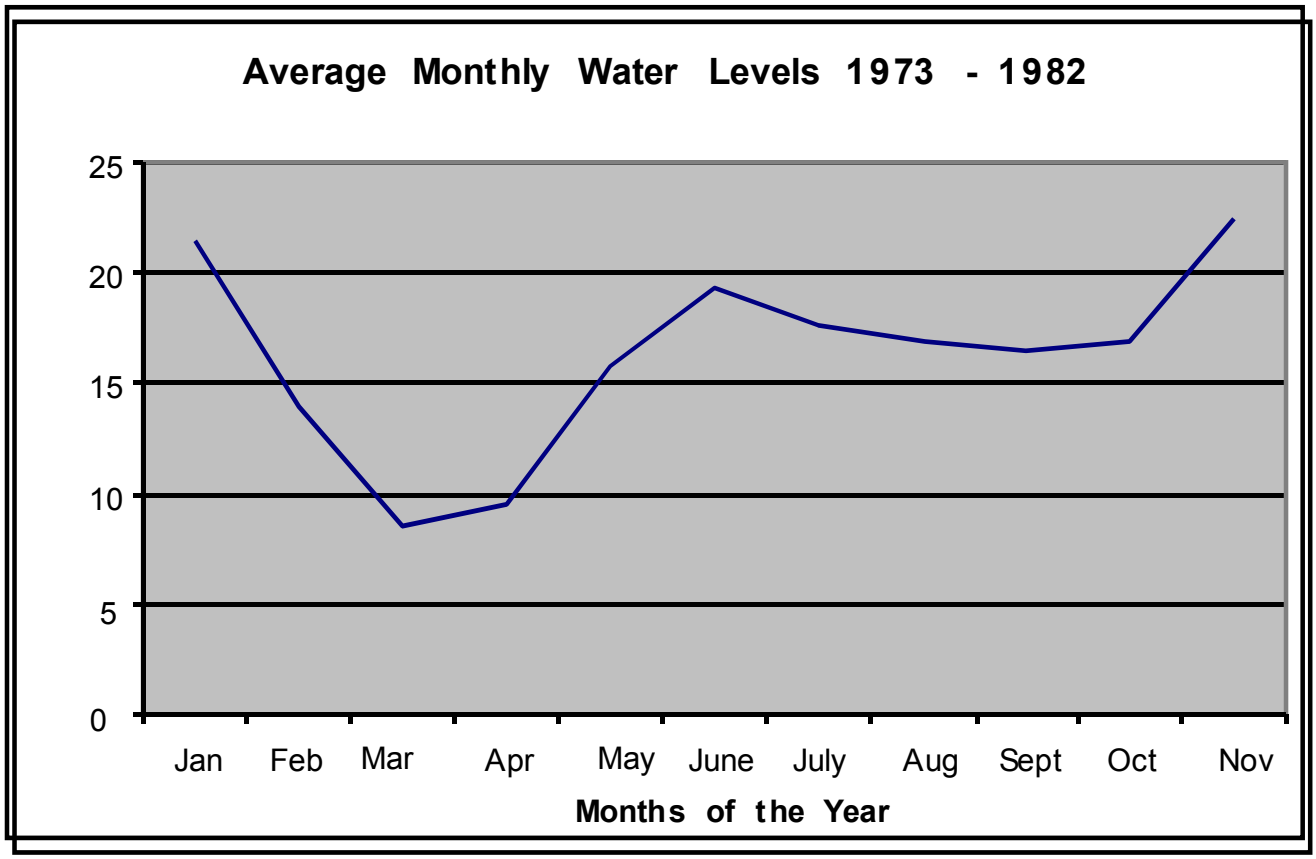
that are compounded

- by the annual rainy and dry season periods of Bonaire.

5.4 High water vs. low water level seasonal scale events into Lac

Possibly the physical separation between the open Lac and the mangrove sub-basin has a sea water level delivery threshold, which can be explained during rapid high water events that occur into the back sub-basin areas. These high tide water-flooding conditions can be explained based on a temporal scale event that occurs yearly around the September solstice period. As rapidly as the bay's tidal level rises and flows through the main feeder channels of Kreek di Coco and Kreek di Pedro, the seawater can just as rapidly withdraw and drain out of the bay again, around the March solstice period. It is also a coincidence that this high water scale event also occurs during the rainy season, while the low water scale event occurs during the dry season period. These also greatly influence the amount of water that occurs in Lac's mangrove sub-basin areas. But it should be noted that these tide level changes are not directly caused by the rainy/dry season periods, but they do confound the incoming and outgoing tidal level fluctuations during the solstice phenomena.

For the lower physical elevation levels of Bonaire, that are located at the south-eastern areas and at Lac Bay, this fluctuating tidal level phenomena seems to coincide around the bi-annual changes of the solstice periods. This timing, therefore, influences Lac's tidal level changes based on some magnitude of geographical scale. These hold implications for seawater flooding into the flatter land areas located at Bonaire, and Lac Bay (Figure 27, 28).



Graph 2 10-year trend of average monthly incoming/outgoing tidal levels that occur in the Akzo Salt Works pond areas, located adjacent to Lac Bay basin.

(Gielen, personal communication 1999)

High and low seawater levels were recorded by Jan Gielen, plant manager of Cargill Salt Company (former Akzo) over a 10-year period (personal communication 1999). The Graph 2 represents the average monthly tide water level data recorded by Gielen during the years of 1973 to 1982 at Akzo Salt Company, which is located adjacent to Lac Bay and residing on similar physical elevations. The data showed a peak during the fall/winter solstice months, when tide water levels would begin to increase, and higher levels of seawater flowed naturally over the dikes and into the salt works ponds. The flow would be so high, that according to Gielen, the company would turn off their seawater intake pumps to avoid flooding. Then during the spring/summer solstice periods, the seawater level would decrease and withdraw, so much that the company would be required to turn on their seawater intake pumps again, to deliver seawater back into the salt works pans.

According to the data recorded by Gielen, and based on his observations of the seasonal influences that effect the high and low water fluctuations, he predicted that at least every year a period of very high and very low seawater level processes would occur in the Salt Works basin areas. However, Gielen indicated that one could not exactly predict the date of time when it would occur, although it is strongly influenced by the changes caused by the solstice periods (Gielen, personal communication 1999).

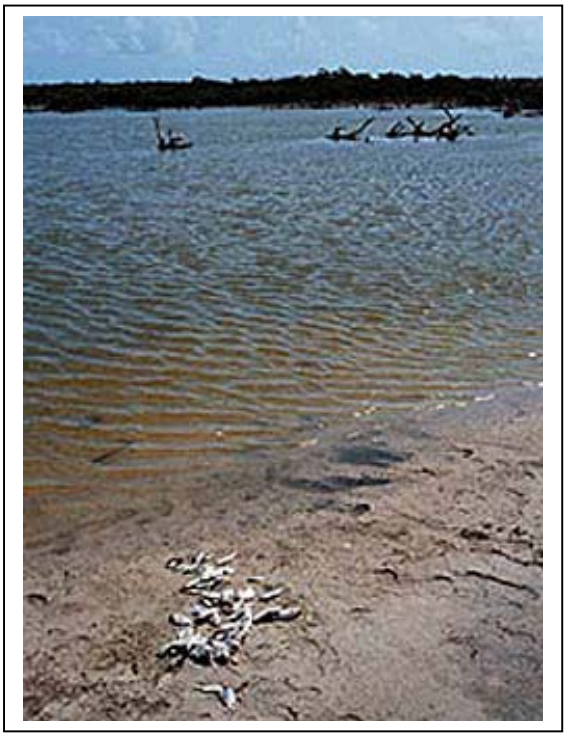


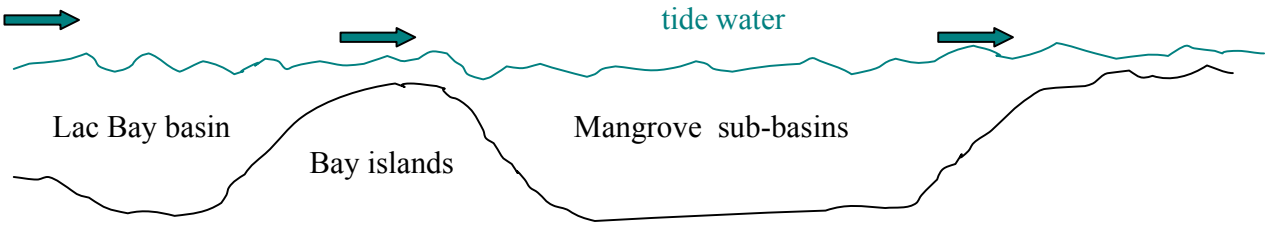
Figure 29 Low water events and fish kills

Each year, during the month of March at the beginning of the dry season, and coinciding with the spring solstice period, tidal levels begin to withdraw in the mangrove sub-basins of Lac bay. Often the withdrawal of water is rapid, and at the same time temperatures elevate, creating changes of dissolved oxygen and respiration rates in the natural system. Fish become stranded and "suffocate" in the mucky and anaerobic conditions, resulting in fish kills (van Moorsel en Meijer 1993, Lott 2000).

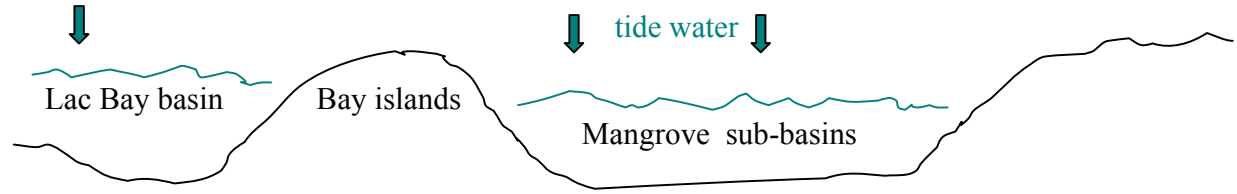
(photo by Environics, N.V. 1999)

Figure 30 Diagram of tidal fluctuations based on seasonal scale influences in Lac Bay

1. High water event floods over ridge islands, lowering salinity to 45 $^{0}/_{00}$–65 $^{0}/_{00}$
(coincides with September solstice period and rainy season, and/or high winds)



2. Low water events becomes trapped/evaporates, salinity elevates to 102 $^{0}/_{00}$-180 $^{0}/_{00}$
(coincides with March solstice period and dry season, and/or least winds)



High and low water events in Lac Bay

High water events occur when seawater moving into open Lac Bay has sufficiently high tide levels to flow over/around the ridge islands, and subsequently floods into the mangrove sub-basin areas located in the adjacent north Lac region. This temporal scale phenomenon typically coincides around the September solstice periods that are coincidental with the rainy season months. Flooding also occurs during prolonged periods of high winds that drive tides towards the mangrove sub-basins. The overall result is higher tides and greater seawater volumes that circulate and reside in the mangrove sub-basin areas of Lac Bay, during certain times of the year. Salinity values refresh to near bay levels, from 45 $^{0}/_{00}$ to 65 $^{0}/_{00}$.

Low water events occur when seawater moving into open Lac Bay recedes, resulting in low tide levels that are below the elevation of the ridge islands. Residing water becomes trapped, and settles. During this long water residency time, the volume eventually evaporates. The pre-cursor of this event typically occurs during the month of March and coincides with the spring solstice period. This initial tidal withdrawal event is usually swift, resulting in changes of respiration rates (oxygen use) by bacteria that are decomposing mangrove debris into consumable food energy, called “detritus”, that is the basis of the food web in the mangrove ecosystem. The oxygen levels in the water become quickly depleted due to the bacterial decomposition and increased water temperatures, and as a result, fish die-offs due to strandings and suffocation occur. This temporal scale phenomenon also subsequently occurs with the dry season, when increased sunlight and evaporation are at its greatest. Salinity ranges elevate from approximately 45 $^{0}/_{00}$ to 180 $^{0}/_{00}$.

(Ian Gielen, plant manager, Cargill Salt Company, personal communication 1999; Daniel DeAnda, manager, SeaHatch personal communication 1999; van Moorsel en Meijer 1993).

Similar tidal phenomena were anecdotally reported by the nearby Maricultura and SeaHatch facility over the years (van Moorsel en Meijer 1993; DeAnda, personal communication 2000). In March 1992, the water level reached so low that the sea grasses in the bay were exposed, and barely enough water was available for pumping into the intake channel of the facility for use.

These data and observed seasonal variations of incoming tide water levels, have similar implications for seawater circulation patterns in Lac Bay. During the winter solstice period, when the incoming tide levels that circulate into Lac bay are high enough, flooding occurs throughout the mangrove sub-basin areas, and subsequently refreshes the muddy lakes of the Awa di Lodo areas. Alternately, during the spring solstice period, when the tide levels begin to subside, and coincide with the evaporation effects of the dry season, these muddy sub-basins begin to dry out. Fishes, mainly mojarra, barracuda and killifish, which enjoyed the higher tidal levels, become trapped, and massive strandings occur during this annual natural event, usually during the month of March (Figure 29) (van Moorsel en Meijer, 1993; Lott 2000).

This annual fish kill phenomenon is a simple biological response to the changes in the rate of decomposition that is occurring in the mangroves, during this time of year. As the tidal levels drop in the Awa Lodos areas, the amount of organic debris is concentrated in the lower water levels. The respiration rate (use of oxygen) increases as the bacteria is working to decompose the mangrove debris and convert it into consumable "detritus", that serves as a food pathway for other organisms. The dissolved oxygen levels in the water become quickly taken up by this increased microbial respiration activity (Lugo and Snedaker 1974). Elevated water temperatures also influence the decrease of the oxygen level. The overall oxygen depletion can result in fish kills, as observed in Lac Bay around the low tide events that annually occur during the month of March (Figure 29).

5.5 Salinity as an indicator of water resident time in the mangroves of Lac

To test the circulation and quality of water that resides in the mangrove sub-basin region, Lott (2000) set up 12 monitoring sites in the mangrove areas for a one-year duration. The sites reached from Kreek di Pedro on the western Lac border, to Kreek di Coco on the eastern side, and monitoring occurred on a full and new moon monthly cycle, from a March 1999 to March 2000 time period. Salinity values were chosen as an indicator for the water resident time; and the Kreeks di Pedro and Coco served as "control" stations, being the two direct openings from the open bay into the Lac mangrove sub-basin. The salinity values closest to that of the control sites, indicated shorter water resident times and greater

circulation or flushing, while the salinity values exceeding that of the bay, indicated a longer water resident time, and subsequently implied the least circulation and flushing.

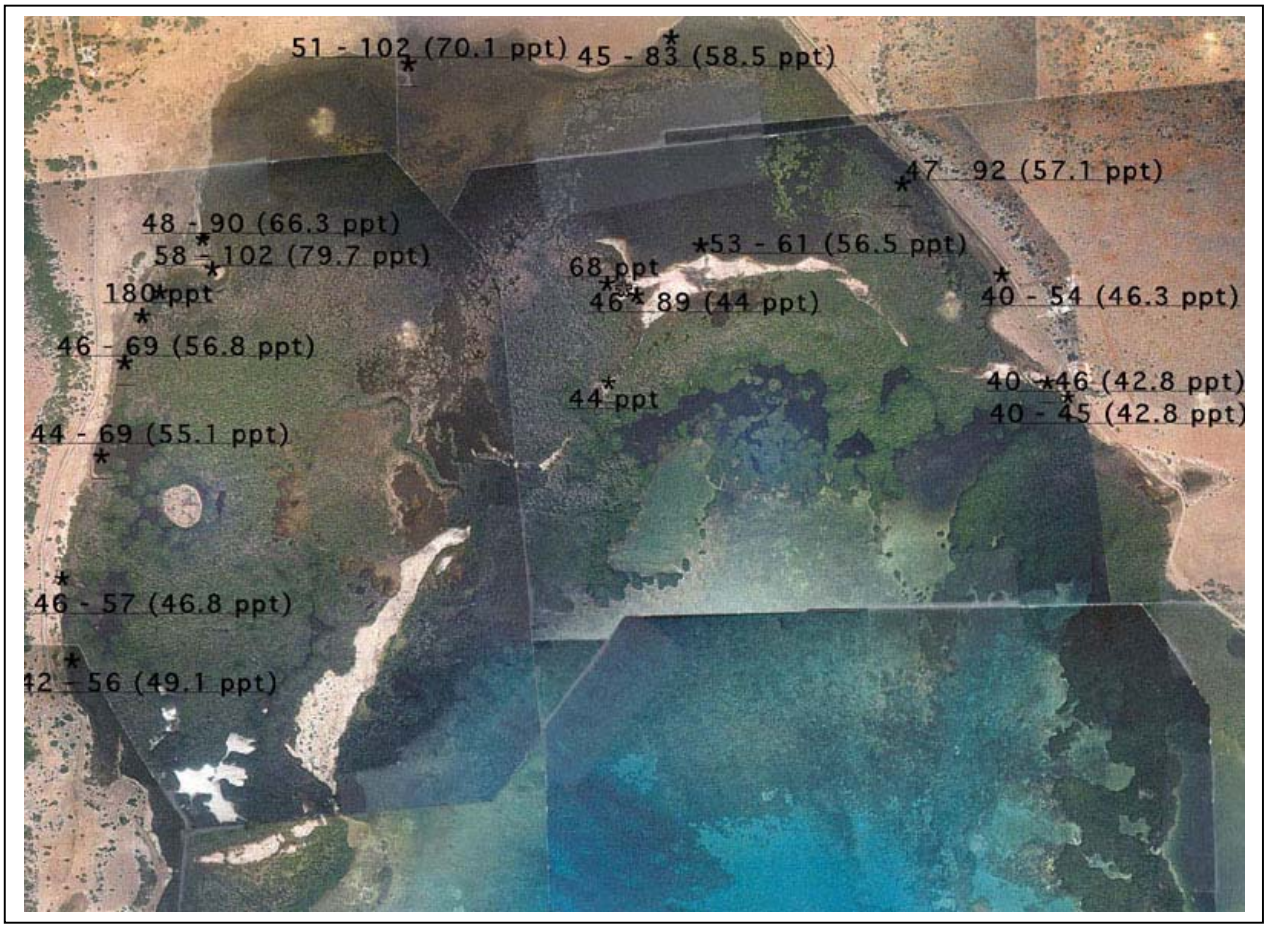


Figure 31 Salinity value ranges over a one-year period in the sub-basin regions of Lac Bay

Salinity values ranged from 40 $^{0}/_{00}$ to 180 $^{0}/_{00}$ in Lac bay over a one-year monitoring period, March 1999 to March 2000. Monitoring stations that were in near proximity of the two main feeder channels, at Kreek di Pedro and Kreek di Coco maintained a range of values of 40 $^{0}/_{00}$ to 46 $^{0}/_{00}$, while areas more remote had higher ranges at 55 $^{0}/_{00}$ to 102 $^{0}/_{00}$. During the March 1999 tide withdrawal, the salinity spiked to 180 $^{0}/_{00}$ at Pt. Wanapa, and a massive stranding of small fish resulted in a fish kill at that location (Lott 2000).

(map adapted from Wing Group, N.V. 1998)

The Figure 30 shows the monitoring sites and the resulting one-year time period salinity ranges. The monitoring sites situated closest to the two main feeder channels, at Kreek di Pedro on the west, and Kreek di Coco on the east, maintained a salinity range with values beginning at 44$^{0}/_{00}$ to 55 $^{0}/_{00}$ and 65

$^{0}/_{00}$. The monitoring stations in more remote locations away from the two main feeder channels, experienced increases in salinity values up to 102$^{0}/_{00}$ in the Awa Lodo di San Jose sub-basin, and 180 $^{0}/_{00}$ in the northwest corner of Awa Yuwana. These areas experience the least circulation. In addition, the salinity values occurring in the Isla di Chico area assumed 44 $^{0}/_{00}$ to 55 $^{0}/_{00}$ during periods of high water or winds, when water was able to flush over the land feature of that area, and refresh the Awa Lodo di Chico.

5.5.1 *Ruppia maritima* species as a plant indicator of fluctuating salinity conditions

A different species of seagrass, commonly called widgeon grass (*Ruppia maritima*) was observed growing in the greater Awa Lodo di San Jose, Awa Lodo di Chico, and the Awa Lodo di Bakuna sub-basins during wet conditions throughout the March 1999 – March 2000 monitoring period (Lott 2000). In addition, the salt pond monitoring stations formerly established by van Moorsel and Meijer (1993) were also dominated by the *Ruppia maritima* species. Other researchers (Adams and Bate 1994; Davis and Tomlinson 1974; McMimillan and Moseley 1967) have reported that various *Ruppia* species can tolerate living in salinity conditions over 100 $^{0}/_{00}$ (i.e. hyper-saline lakes), although the species prefers living in brackish water conditions. The *Ruppia maritima* seagrass species are able to survive here in the "awa lodos" extreme salty and muddy water conditions, because the shallow depths of these ponds allow for adequate sunlight penetration to promote growth. *Ruppia,* therefore, can be a good plant indicator that would signal a fluctuating, or wide salinity range (45 $^{0}/_{00}$ to > 100 $^{0}/_{00}$) of water quality conditions (Berns, personal communication, Florida Fish and Wildlife Conservation Commission 2001). This low to high salinity tolerance range thus allows *Ruppia* to persist in Lac's pond areas throughout the changing seasonal cycles. During the van Moorsel and Meijer (1993) study, the researchers reported that during dry season, *Ruppia maritima* had a 50% bottom coverage assessment, but the species would flourish to 100% bottom coverage during rainy season, showing a growth preference for lower salinities. The researchers also observed that the green macro-algae, *Batophora oerstedi*, occurred as the dominant simple plant (macro-alga) species growing in the ponds during their 1993 studies. The March 1999 - March 2000 monitoring stations established by Lott (2000) recorded that the salinity values throughout the pond areas ranged from 40 $^{0}/_{00}$ to 102 $^{0}/_{00}$. In addition, Lott (2000) observed that the *Ruppia* seagrass species coverage occurred only in patches following a year's observation, thus showing a change in lower abundance since the van Moorsel and Meijer (1993) study. However, the green macro-algae, *Batophora oerstedi*, continued to be the dominant simple plant coverage, perhaps also serving as an indicator of fluctuating salinity conditions.

6. Wildlife Habitat Value of Lac

6.1 Nursery Function Importance of Lac for Fish

Studies of tropical bays and lagoons containing seagrass beds and mangroves describe that these types of environs can harbor high densities and a richness of coral reef fishes, during their early developmental stages. Thus, these habitats are generally considered as "nursery" in their ecological function. The function of a nursery habitat has many dimensions (Nagelkerken 2000):

- provides shelter for juvenile species to avoid predators;
- provides an abundance of food based on the detritus-based food and energy web; and
- provides a location of interception where fish and invertebrate larvae, while in the floating planktonic stage, arrives in incoming currents for settlement.

Although in the Caribbean area, the importance of these biotopes (individual natural communities, such as the seagrass habitat) as a nursery habitat is well documented, the question remains for Lac Bay? Do the mangroves and seagrasses of Lac fulfill the nursery function that is so often attributed to these type environs? Several research studies in Lac had been conducted to answer these types of research questions.

A comprehensive survey list of the fishes using Lac was completed in the ecological base-line study by van Moorsel en Meijer (1993), and the list is reproduced in the species appendices of this report (Appendix A: Table 7). These researchers suggested that a full year study of the utilization of fish species in the nursery resources at Lac would be beneficial, to determine what fish actually use the area for breeding, and for nursery purposes. In this respect, two studies have been conducted that examined the importance of Lac Bay as a nursery habitat, conducted by van der Velde et al (1992), and Nagelkerken (2000).

The earlier study by van der Velde et al. (1992) found that the mangroves and seagrasses do hold a valuable habitat importance for some fish species during specific phases of their life. In this study, the researchers investigated the utilization of the various biotopes of Lac by fish fauna, as these environs are linked in providing critical habitat during the life history phases of a species. The study thus focused on the relative habitat importance value to the mangroves, the *Thalassia* seagrass beds, and the shallow and deep reef environs, for the utilization by nursery and juvenile fishes during unique phases in their life history.

The habitat value comparisons by van der Velde et al. (1992) revealed the following importance in the various Lac Bay biotopes for the juvenile and nursery phases of fish species:

I. Seagrass habitat:
- French grunt *(Haemulon flavolineatum)*
- Bluestriped grunt *(H. sciurus)*
- Yellowtail snapper *(Ocyurus chrysurus)*
- Stoplight parrotfish *(Sparisoma viride)*
- Doctor fish *(Acanthurus chirurgus)*

II. Mangrove habitat:
- Schoolmaster (*Lutjanus apodus*)
- Gray snapper (*L. griseus*)
- Great barracuda (*Sphyraena barracuda*)
- Foureye butterfly (*Chaetodon capistratus*)

III. Shallow reef:
- Smallmouth grunt (*Haemulon chyrsargyreum*)
- Mahogany snapper (*Lutjanus mahogoni*)
- Sergeant major (*Abudefduf saxatilis*)
- Ocean surgeon (*Acanthurus bahianus*)
- Blue tang (*A. coeruleus*)

And, for other fish species, van der Velde (1992) could not make further conclusions due to too few data.

The following Table 3. summarizes the results of the van der Velde et al. (1992) research:

Table 3 Functional habitat importance of various biotopes for life history phases of juveniles and nursery fish species in the Lac Bay environs

Fish Species	Juveniles				Nursery	
Common Name	Mangroves	Thalassia	Shallow Reef	Deep Reef	Lac Nursery	Reef Nursery
French grunt	xx	Xxx	x	-	-	xx(x)
Bluestriped grunt	-	Xxx	-	-	-	xxx
Caesar grunt	-	-	-	-	-	-
Smallmouth grunt	-	-	xx	-	-	-
Black margate	-	-	-	-	-	-
Gray snapper	xxx	Xx	-	-	xxx	(x)
Schoolmaster	xxx	Xx	-	-	xxx	x
Mahogany snapper	-	X	xx	-	-	x
Yellowtail snapper	(x)	Xxx	-	-	-	xxx
Great barracuda	xxx	Xx	-	-	xxx	xx
Sergeant major	(x)	-	xx	-	-	x
Foureye butterfly	xxx	Xx	x	x	-	xx(x)
Ocean surgeonfish	-	X	xx	-	-	x
Doctorfish	(x)	Xxx	x	-	-	x
Blue tang	(x)	X	x	x	-	x
Stoplight parrotfish	-	Xxx	x	x	-	xx

Values: - not important; () doubtful; x minor importance; xx medium importance ; xxx major importance

(adapted from van der Velde et al. 1992)

The second study conducted by Ivan Nagelkerken (2000) found that the presence of mangroves and/or seagrass beds in bays has significant habitat value for the life history of the fish. In general, he found that the presence of both types of biotopes together, i.e. seagrass beds with adjacent mangrove environs, diversifies the habitat available in the bays for a wider range of species, more than if there was only one biotope available. In Lac Bay, where there are seagrasses, mangroves, and a shallow coral reef area, the researcher focused on how a selected number of reef fishes utilize the various areas during a 9-month study. The following list summarizes the study by Nagelkerken (2000) of the various habitat used by fish in Lac Bay as a nursery biotope, which has a remarkable similarity to the conclusions by van der Velde during his 1992 Lac Bay study:

I. Seagrass habitat:

- French grunt *(Haemulon flavolineatum)*
- Bluestriped grunt *(H. sciurus)*

- Yellowtail snapper *(Ocyurus chrysurus)*
- Stoplight parrotfish *(Sparisoma viride)*
- Doctor fish *(Acanthurus chirurgus)*

II. Prop roots of the red mangrove (*Rhizophora mangle*):

- Schoolmaster (*Lutjanus apodus*)
- Gray snapper (*L. griseus*)
- Great barracuda (*Sphyraena barracuda*)
- Foureye butterfly (*Chaetodon capistratus*)

III. Shallow reef (4 depth zones: 0-3-m; 3-5-m; 10-15-m; and 15-20-m):

- Smallmouth grunt (*Haemulon chyrsargyreum*)
- Mahogany snapper (*Lutjanus mahogoni*)
- Sergeant Major (*Abudefduf saxatilis*)
- Ocean Surgeon (*Acanthurus bahianus*)

In addition, Nagelkerken (2000) found that the juvenile Blue Tang fish species (*Acanthurus coeruleus*) utilized all biotopes, including all depth zones in the shallow reef. He also observed that 2 fish species which did not use any of the biotopes in Lac Bay were the juvenile Black Margate (*Anisotremus surinamensis*), and the juvenile Caesar grunt (*Haemulon carbonarium*). These species were not found utilizing any biotope during the study.

Further, he found that although the fishes had a particular nursery habitat preference, as listed above, they often utilized more than one habitat simultaneously, because all provided suitable shelter. However, it was observed that the deeper 5 to 20-m reef zone was almost completely absent of juvenile fish, showing that juveniles prefer the shallow-water biotopes as a nursery. The 9-month study also allowed the researcher to conclude that a shift was observed at a particular life stage for the fish. As the fish matured from the juvenile stage, the species would change its habitat preference from the nursery biotope (i.e. mangroves, seagrass beds, and/or reef at 0 to 3-m depth) to the deeper (>3-m depth) reef.

An interesting conclusion was noted by Nagelkerken (2000) among the use of the biotopes by the more closely related fish species, such as the families Haemulidae (Grunts), Lutjanidae (Snapper), and the Acanthuridae(Surgeonfish). The data indicated that the different size classes (ages) within the same species would utilize separate biotopes, suggesting avoidance of competition among them for food and shelter.

In conclusion, the similarity in the results of the two research studies conducted in 1992, and later in 2000 in Lac Bay suggest that the mangroves and seagrass beds are important nurseries for at least seventeen reef fish species. The researchers emphasized that environmental impacts on these nursery biotopes may negatively affect the fish species densities on the reef. Not only this, but they indicated that many of the juveniles which utilize Lac for nursery, are of commercial importance to the reef fisheries and diving industry. On an ecosystem management approach, the researchers point out that there is a critical linkage of the fishes among the biotopes, and these linkages are important for sustaining the reef fish stocks.

A two hour snorkel inventory conducted by Environics, N.V. (July 2000) revealed an impressive list of juvenile and initial adult phases of fishes utilizing the seagrasses at Sorobon, as follows:

Table 4 Lac Bay Fish Census Representative Species

Site: Sorobon Date: July 14, 2000

Common Name	Family: *Genus species*	Abundance Code/fish phase
Smooth trunkfish	Ostraciidae*: Lactophrys triqueter*	S adult
Foureye butterflyfish	Chaetodontidae: *Chaetodon capistratus*	F juvenile
Barred cardinalfish	Apogonidae: *Apogon binotatus*	F adult
Beaugregory	Pomacentridae: *Stegastes leucostictus*	M juvenile/adult
Cocoa damselfish	Pomacentridae: *Stegastes variabilis*	M juvenile
Dusky damselfish	Pomacentridae: *Stagastes fuscus*	M juvenile
Longfin damselfish	Pomacentridae: *Stegastes diencaeus*	M adult
Threespot damselfish	Pomacentridae: *Stegastes planifrons*	S juvenile
Yellow goatfish	Mullidae: *Mulloidichthys martinicus*	M juvenile
Bridled goby	Gobiidae: *Coryphopterus glaucofraenum*	M adult
French grunt	Haemulidae: *Haemulon flavolineatum*	M juvenile/adult
Striped grunt	Haemulidae: *Haemulon striatum*	M juvenile
Tomtate	Haemulidae: *Haemulon aurolineatum*	M juvenile
Bar jack	Carangidae*: Caranx ruber*	S adult
Blue parrotfish	Scaridae: *Scarus coeruleus*	S juvenile
Redband parrotfish	Scaridae: *Scarus aurofrenatum*	M initial
Stoplight parrotfish	Scaridae*: Sparisoma viride*	F juvenile

Common Name	Family: *Genus species*	Abundance Code/fish phase
Striped parrotfish	Scaridae: *Scarus croicensis*	M juvenile
Mahogany snapper	Lutjanidae: *Lutjanus mahogoni*	F juvenile
Schoolmaster	Lutjanidae*: Lutjanus apodus*	M juvenile
Yellowtail snapper	Lutjanidae: *Ocyurus chrysurus*	M juvenile
Blackbar soldierfish	Holocentridae: *Myripristis jacobus*	F adult
Reef squirrelfish	Holocentridae: *Holocentrus coruscum*	F adult
Squirrelfish	Holocentridae: *Holocentrus adscensionis*	F adult
Blue tang	Acanthuridae: *Acanthurus coeruleus*	M juvenile
Ocean surgeonfish	Acanthuridae: *Acanthurus bahianus*	M juvenile
Bluehead wrasse	Labridae: *Thalassoma bifasciatum*	A juvenile/initial

Yellowhead wrasse	Labridae: *Halichoeres garnoti*	F juvenile/initial
Mojarra, yellowfin	Gerreidae: *Gerres cinereus*	M adult
Mojarra, flagfin	Gerreidae: *Eucinostomus melanopterus*	M adult
Mojarra, silver jenny	Gerreidae: *Eucinostomus gula*	M adult
Silversides	Atherinidae, Clupeidae, Engraulididae	A adult
Goldspot eel	Ophichthidae: *Myrichthys ocellatus*	S adult

Abundance Code: S (single) F (few 2 -10) M (11 - 100) A(abundant>100)

(Environics, N.V., 2000)

6.2 Habitat Value Importance of Lac for Migratory and Resident Bird Life

The birds reported by van Moorsel en Meijer (1993) were based on casual observations, and they noted that no systematic inventory of the bird species of Lac have ever been done. These researchers acknowledged that many types and appearances of the birds in Lac are on a seasonal basis, so a greater number of species seen do migrate, making many birds noted in Lac as temporary residents. However, this factor alone deems Lac with an important habitat value for bird life, by utilizing the bay and mangrove area for feeding and roosting during their migratory patterns. This includes the flamingo, an important species of Bonaire.

Thus, Lac is of great importance for flamingos, stilt walking species, and several herons, and other birds that are tied to the water, finding habitat preference in the extensive muddy water areas of Lac's quiet lagoons. Voous (1983, in van Moorsel en Meijer 1993) also noted other bird species that give Lac important habitat value, such as such as raptors, and others stilt walkers. This researcher also observed the rare *Amazona barbadensis*. In addition, van Moorsel en Meijer (1993) reports other bird observations by Frater Candidus that they themselves did not observe, as follows:

Scientific name	Common Name	Location/Activity
Tringa melanoleuca		Boca Djukfes
Ceryle alcyon		
Elaenia martinica	berry eating small grey flycatcher	
Tyrannus dominicensis	the great grey fly catcher	
Columba squamosa	large blue pigeon (rare in Antilles)	breeds in west Lac in high trees

Frater Candidus (in van Moorsel en Meijer 1993) also observed the following general accounts about flamingos in Bonaire:

"…From 1983-1986, there was constant breeding of the species, with approximately 2300 adult birds, and 1200 juveniles. In 1988–1990, there were approximately 3000-3400 adults, with 3100 juveniles, but the numbers decreased in 1991 to approximately 600-1800 adults. During January and February 1992, the amount of them further decreased on the terrain of the salt company to a minimum level of 250 (perhaps due to the dry weather); and in the Gotomeer there were approximately 100 young birds. Again, in 1992, this observation of young hatchlings on the Gotomeer took place. It was the first time since 1958-1960 to see this phenomena at Gotomeer…"

The summary of observed birds during March 20 – 27, 1992 by van Moorsel en Meijer (1993) includes the below additional notes as follows:

The great Caribbean flamingo, *Phoenicopterus ruber*, is the trademark of Bonaire, where this island is the only breeding place of the species for the south Caribbean population. Thus, this makes Lac also an important habitat value of providing foraging ground for this species, which breeds just south of Lac in the sanctuary preserves of the salt company, Cargill. In March 1991, the numbers of flamingos observed in Lac varied from 140-264, indicating flamingos as the largest group of birds utilizing Lac as a wildlife habitat area.

The appearance of flamingos in Lac is due to the food availability to them: they feed on the *Ephydra* larvae; the bacteria found in the shallow pond muds of the Lodos; and the Cyprinodon, or killifishes. The birds are found mostly in those areas where the salt tolerant seagrass, *Ruppia*, is found, that together with the snails that forage on the grass, could be a primary part of the flamingo "food chain".

The American frigatebird, *Fregata magnificens*, roosts frequently in the mangroves of Puitu. Though the species does not breed in Bonaire, pairing rituals have been noted.

One of the most striking appearances of Lac, are the numerous species of herons. These waders prefer the quiet shorelines of sheltered shallow ponds, and thus, can be viewed along the perimeter roads of Lac, making the species an enjoyable tourist past time for drive-by auto windshield bird observations. Many herons are found in the numerous dead mangroves of the mangrove sub-basin throughout Lac, the location where also 3 heron species breed (Voous 1983, in van Moorsel en Meijer 1993):

- little green heron*, Butroides striatus;*

- tricolor heron*, Egretta tricolor;*
- rufus, or reddish heron*, Egretta rufescens.*

Because the little green heron is well camouflaged, its numbers are grossly underestimated. However, it makes a loud, hectic scream if disturbed, which makes it finally easy to be seen. The *Egretta thula*, the small silver or little blue heron, is quickly agitated and will fly away, while the *E. rufescens* is less timid, and will allow itself to be approached by observers. The great silver heron, *E. alba*, is mostly solitary, and could be mistaken for the white phase American blue heron, *Ardea herodias*.

The fish bird of prey, osprey (*Pandion haliaetus*) generally is always in the vicinity. There appears to be a constant migration of the species between the south end of Bonaire, at the salt works, to the dead mangroves of north region Lac, which is a suitable hunting area for the osprey to consume fish from the shallow lodos.

The black-winged stilt, *Himantopus himantopus*, is noted as being second to the flamingo in the numbers observed in Lac; because they have about the same food as the flamingo; the grass species, *Ruppia,* and small snails.

The following is a Bird List compiled by local naturalist Jerry Ligon, while leading birding group from the Cruise ship Yorktown Clipper:

Location: Lac Cai Date: March 3, 1999

Common name	Numbers observed	Comments
Brown Pelican	6	
Magnificent Frigatebird	3	
Green Heron	2	
Little Blue Heron	2	
Tricolored Heron	12	
Reddish Egret	17	
Snowy Egret	20	
Great Egret	14	
Great Blue Heron	7	
Greater Flamingo	49	
White-cheeked Pintail	6	
Blue-winged Teal	4	
Osprey	2	
Peregrine Falcon	1	
Black-necked Stilt	15	
Sanderling	2	
Stilt Sandpiper	2	(we had difficulty identifying this)
Greater Yellowlegs	12	
Lesser Yellowlegs	17	
Ruddy Turnstone	12	
Laughing Gull	2	(first of the year for this species which usually comes back to Bonaire in March)
Royal Tern	7	

Bare-eyed Pigeon	
Common Ground Dove	7
Grey Kingbird	3
Tropical Mockingbird	3
Yellow Warbler	7
Bananaquit	18

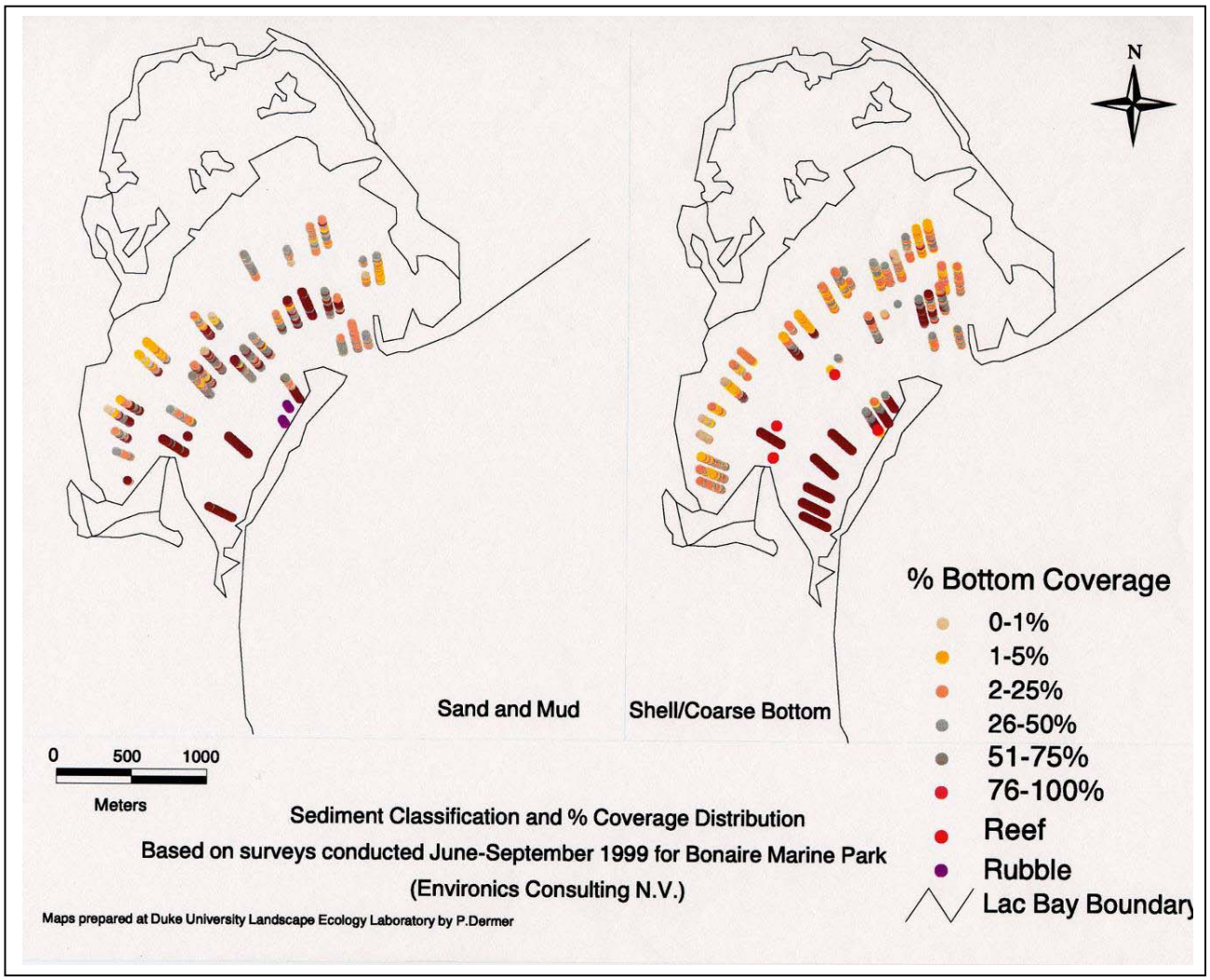
7. GIS Zonation Features and Management Implications

A series of Geographical Information Systems (GIS) maps were produced to visually interpret the ecological monitoring (Lott 2000) data points, and can serve as an analytical tool for establishing resource management zones. These % coverage data for seagrass, macro-algae, corals, sponges and sediment classification provide spatial pattern depictions of Lac in 1999, and can be used for interpreting environmental change over time. In addition, for zonation purposes, the ranges of values are individually defined when interpreted in color sequences on GIS depictions, in order to determine what areas to apply the appropriate management strategies.

7.1 Bottom sediment classification of Lac

The bottom characterization for fine sand/mud, shell/coarse sand, rubble, reef and sponges are depicted in Map 12. The maps show that the fine sand and mud distribution patterns occur typically in the inner perimeter mangrove/seagrass region of the bay, while the coarse sand and shell bottoms occur along the seaward flank areas. The interior of Lac, beginning around Secu di Sorobon and moving in a clockwise manner inside the bay area, has a fine sand and mud bottom composition. Meanwhile, the Awa Blanku area has a bottom composition with a moderate shell and coarse sand component. These depictions may imply that, for example, a wind surfer activity zone may require utilizing the coarse sediment bottom areas of the bay, such as existing in the Awa Blanku area.

Since the deployment area of the windsurf centers are along the Secu di Sorobon beaches area, special care should be made so that fine silt bottom found in this location is not chronically suspended by the impact of windsurfboards (Refer to Section 9.4 regarding shoreline erosion at Sorobon Beach). In addition, the Map 13 for seagrass coverage and lifeform living on the substrate bottom shows that the least marine life organisms actually distribute, or live in this area. This area would be suitable for recreation, as it would assume less environmental impact by windsurfing activity.



Map 12 Sediment Classification and % Coverage Distribution of Lac Bay

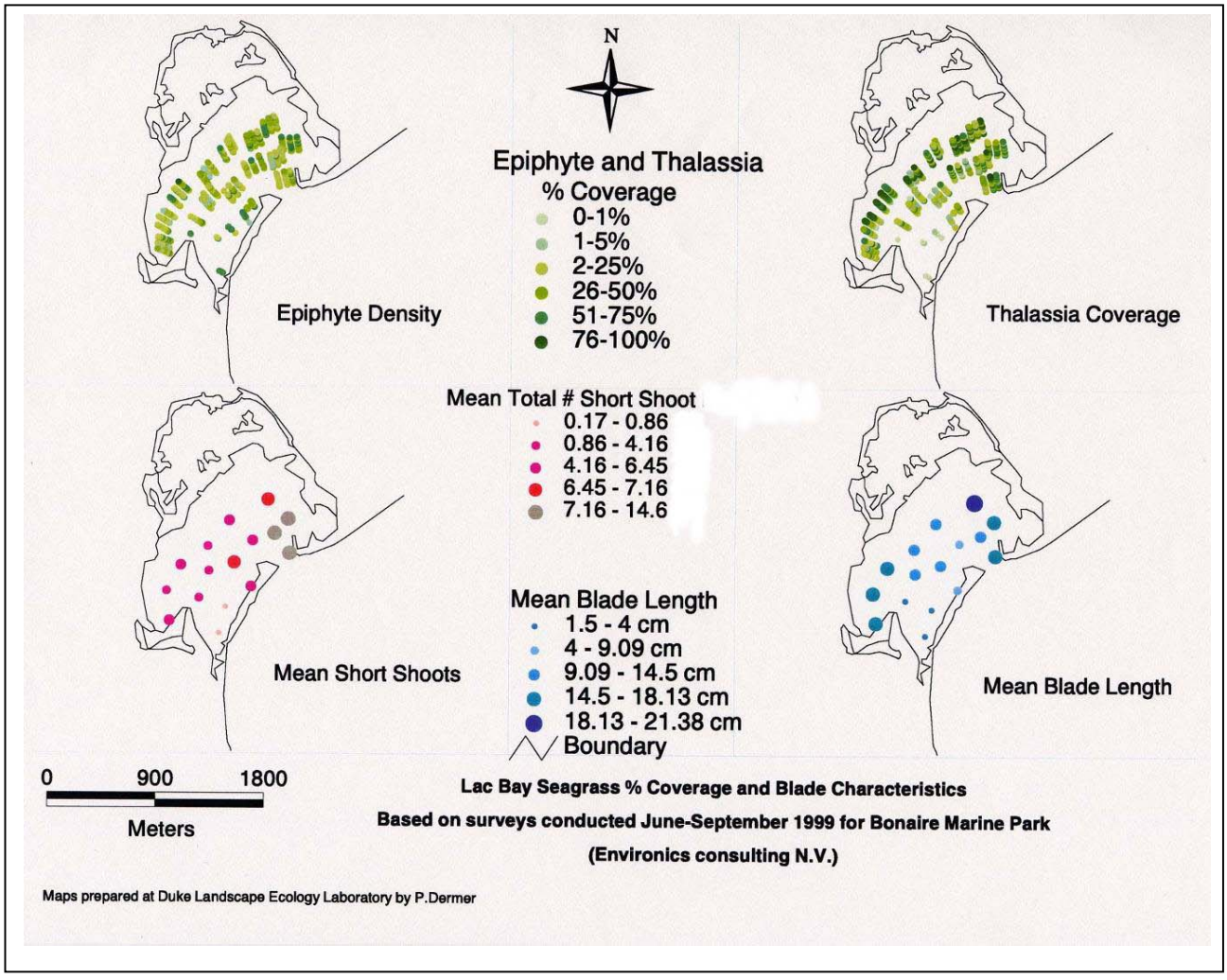
(Environics, N.V., 1999)

Maps prepared at Duke University Landscape Ecology Laboratory by P. Dermer

7.2 Seagrass and epiphyte coverage

The greatest % coverage range (26 – 75%) of *Thalassia*, turtle grass, occur along the nearshore inner perimeters of Lac Bay, from the south-west mangrove area, following the bay's interior nearshore contours, clockwise to the Puitu and Cai areas. According to the depths contours of Lac (see Map 9), these are also the shallowest areas of the bay, ranging from 1 - 3-m in depth only. In addition, the seagrass and epiphyte coverage, Map 13, show that the greatest short shoot seagrass density, and greatest

seagrass blade sizes occurs in the south-west area, located between the Sorobon Pier and Lac Bay Resort areas; and in the north-east area of the bay, that is adjacent to the Puitu and Cai. These areas may be considered for sanctuary preservation and wildlife habitat reserves, and be demarcated accordingly on a management zone map. They are suitable for conch nursery as they feature moderate epiphyte % coverage, which fouls, or grows, on the seagrass blades. The epiphyte material is consumed by the juvenile conch while it is undergoing shell development. Thus, these areas would serve as a conch replenishment zone, and could be marked with buoys indicating a restricted area for marine life.



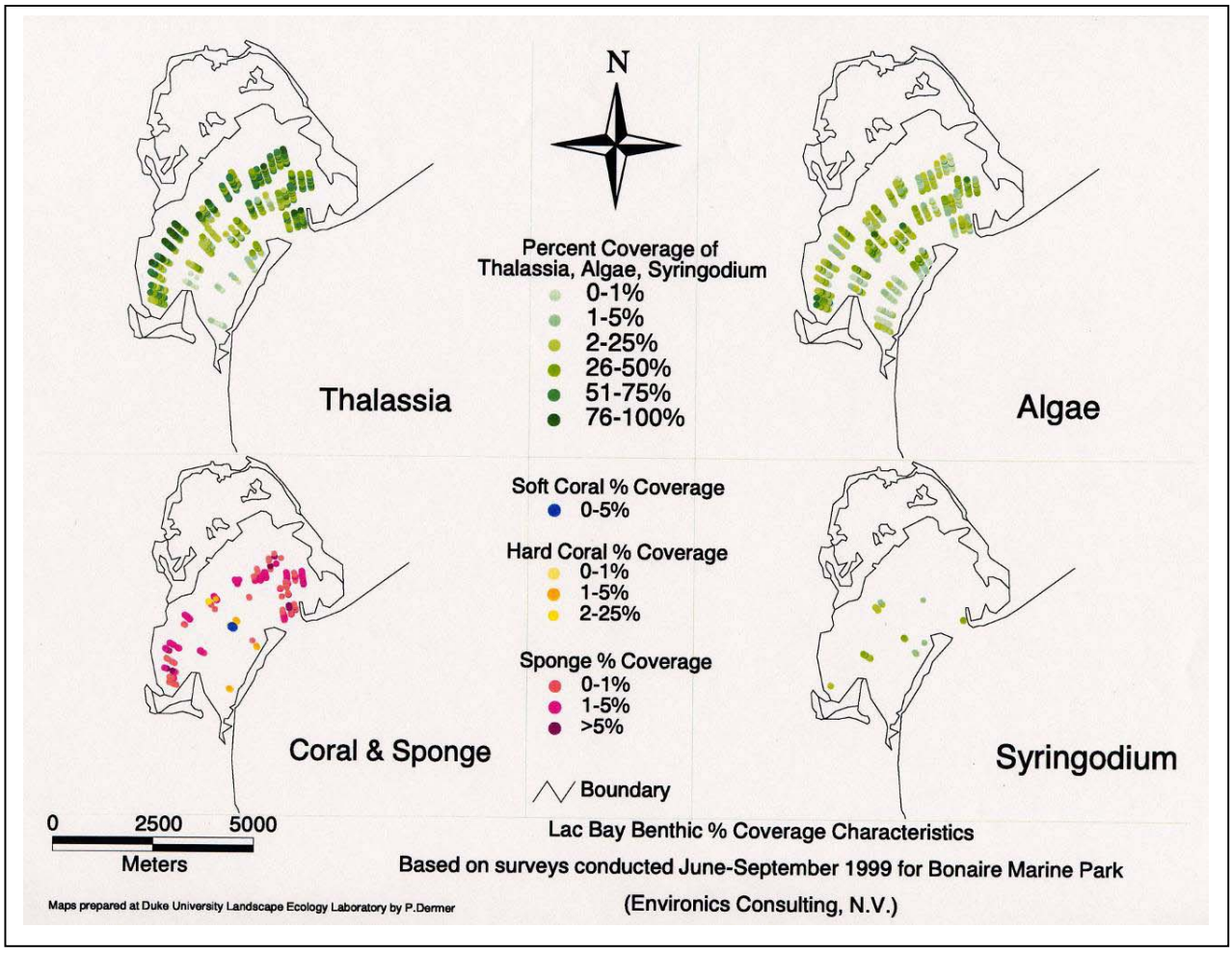
Map 13 Lac Bay Seagrass % Coverage and Blade Characteristics

(Lott 2000)

Maps prepared at Duke University Landscape Ecology Laboratory by P. Dermer

7.3 Benthic substrate lifeform % coverage

The Map 14 illustrates the % coverage of the seagrasses, *Thalassia* (turtle grass) and *Syringodium*, (commonly known as manatee grass). It also shows the marine algae species % coverage; as well as coral and sponge % coverage in relation to how these particular marine organisms are distributed on the bay bottom at Lac and how dense is their individual coverage.



Map 14 Lac Bay Benthic Substrate Lifeform % Coverage Characteristics

(Lott 2000)

Maps prepared at Duke University Landscape Ecology Laboratory by P. Dermer

The seagrass, *Syringodium*, is infrequent in the bay as shown in the lower right map in Map 14. On the other hand, the *Thalassia*, is the common seagrass for Lac Bay, and grows most abundantly nearer to the shallow zones, adjacent to the mangrove fringes inside Lac. The marine alga also grows in similar

patterns of abundance as the turtle grass, often binding together. This serves to stabilize the very soft sediment, which occurs in these dense seagrass areas. The sponges (pink circles in lower left map) grow in small mounds on the bottom in and amongst the seagrass and algae. Combined together, these benthic organisms provide homes for various invertebrate animals (See Species List, Appendix B). Small colonies of branching corals, i.e. *Porites* and *Acropora*, inhabit the coarse sediment areas of Awa Blanku, shown as yellow circles in the Map 14.

Due to the density and distribution of the seagrasses, and concurrent soft sediments which occur in these areas, they should be considered as sanctuary preservation areas, or replenishment zones for marine life. Increased human activity, such as windsurfing, would displace the bottom-attached organisms; as well as destabilize the soft sediment bottoms, that would promote erosion (See Section 9.5).

7.4 Total species present in Lac Bay, including Invertebrate distribution patterns

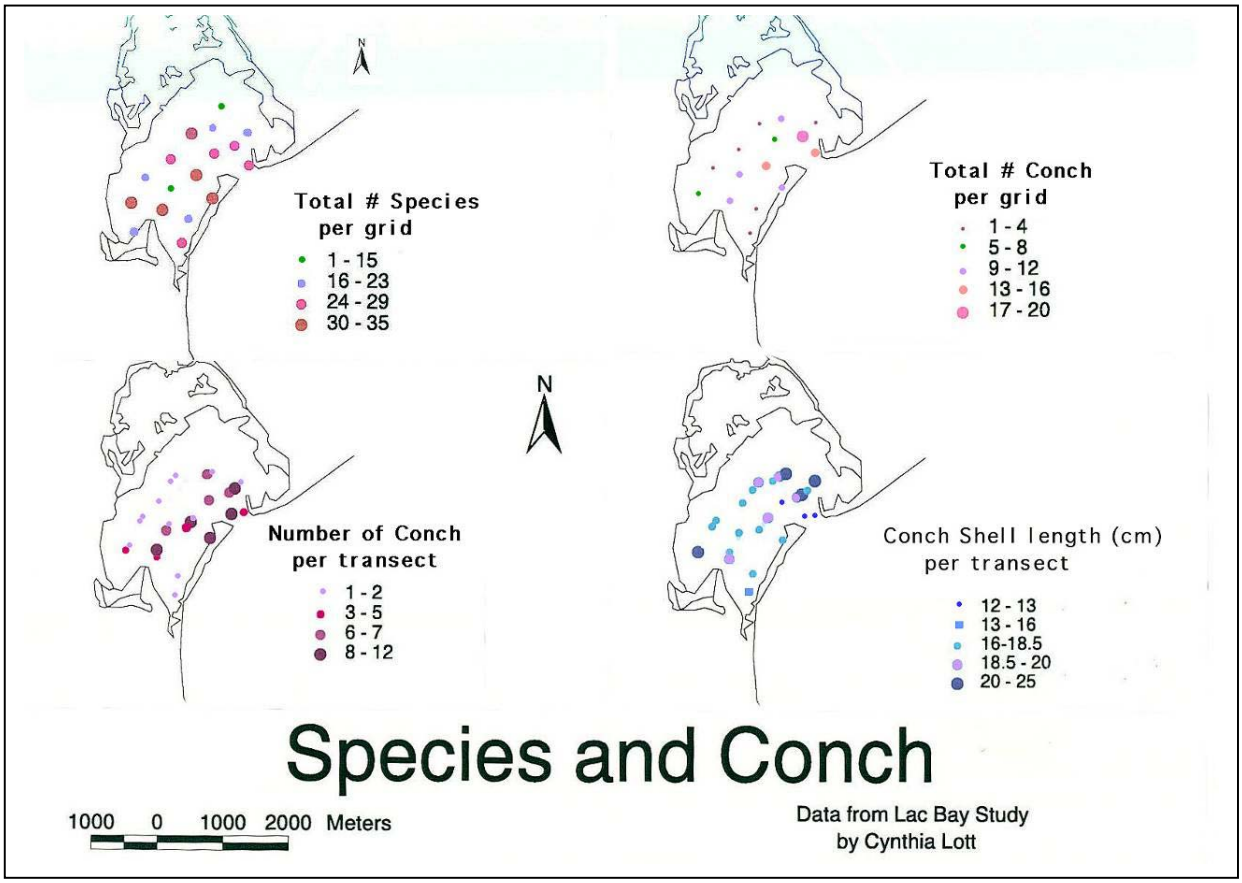
A total of 35 representative benthic species were surveyed as present, in addition to conch, during the 1999 monitoring activities. These included the members of the macro-algae phyla, as well as other bottom dwelling individuals found in the taxa groups for invertebrates, sponges, and corals. The comprehensive lists of those found present in Lac (Lott 2000) are contained in Appendix B.

The species distribution of all benthic representative species, including conch is presented in the below series of Maps 15 and 16. Due to the extensive bottom coverage of soft sediments in Lac, the most common benthic species assemblage found was members who thrived in great numbers in this type seagrass habitat, including the following organisms (listed in order of abundance):

- Caribbean sea anemone*, Condylactis gigantea;*
- U-shaped burrow worm*, Arenicola crisata;***
- Upside down jellyfish*, Cassiopeia species;*
- Donkey dung seacucumber*, Holothuria mexicana*
- Queen conch*, Strombus gigas; and*
- Pin cushion starfish*, Oreaster reticulata.*

**(Please note: the diagnostic fine mud/sand mounds of this seagrass soft sediment substrate area is typical for the burrowing worm, which consumes interstitial foods from around the sand grains. It is

frequently misidentified as that of the Ghost Shrimp, *Callianassa* species. The shrimp leaves a tale-tale pile of rod-shaped pellets at the tip of its mound, while the lugworm does not (Kaplan 1988). If one fans the top of the lugworm sand mound, a fine cloud of silt will settle once again, clean of other excrement. In addition, the Ghost shrimp prefers more coarse sediments in which to burrow, and likely if further surveys are taken in the greater Awa Blanku region, perhaps the mound of this species may become apparent).

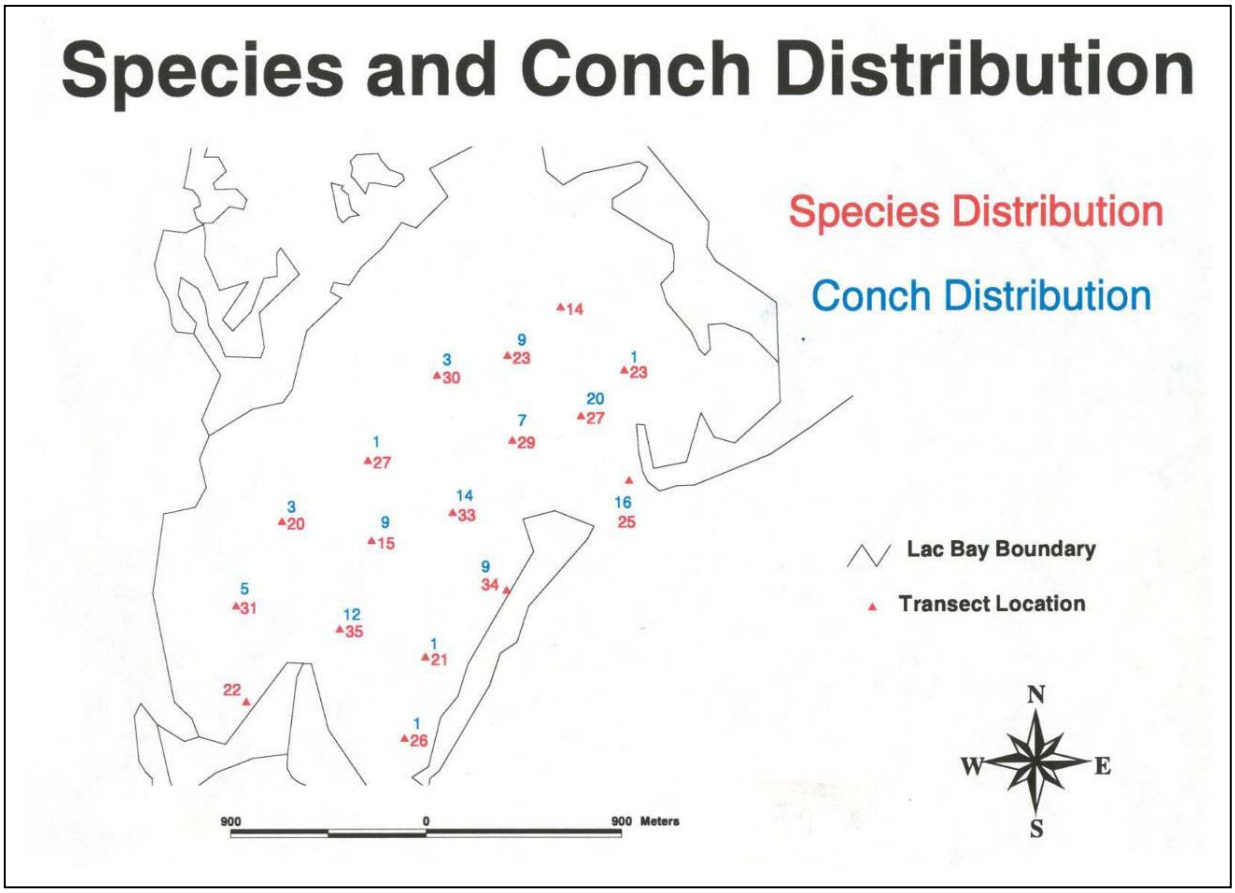


Map 15 Total Epibenthic Species Presence and Species Distribution Patterns in 17 study grids (200-m^2) at Lac Bay (Lott 2000)

Upper left: Total number of invertebrate species distributions in each grid size 200- m^2
Upper right: Total number of queen conch distributions in each grid size 200- m^2
Lower left: Total number of conch along the 3 transects lines inside each grid
Lower right: Range of conch shell lengths (cm) measured along the 3 transect lines inside each grid

Maps prepared at Duke University Landscape Ecology Laboratory by P. Dermer

The two Maps 15 and 16 illustrate the distribution of invertebrate species, including queen conch, encountered during the June - September 1999 benthic surveys at Lac Bay. The distributions were surveyed among the 17 grid sites used to determine the species abundance and density in Lac Bay. Each grid was laid out with 3 transect rope lines, each in 200-m length. Two divers swam and counted along a 2.5-m wide area on each side of the transect line, noting all invertebrate species and conch in the full 5-m wide area per single line (surveying 3 transects per grid). This provided a total 51,000-m^2 bottom assessment of Lac Bay (See Appendix B for Species List).



Map 16 Total Invertebrate Species and Queen Conch Distribution Patterns in 17 study grids (200-m^2) at Lac Bay (Lott 2000)

Total numbers of invertebrate species (red numbers) and queen conch (blue numbers) found in each of the 17 grid areas surveyed in Lac Bay

Maps prepared at Duke University Landscape Ecology Laboratory by P. Dermer

8. Environmental Threats: Identifying Symptoms and Stress in Lac Bay

8.1 An overview of ecosystem functions and environmental threats in Lac Bay

The following Sections 8 and 9 will review the natural ecosystem functions of the various marine communities, i.e. the mangroves sub-basin region, the seagrass meadows of the lagoon, and coastal beaches found at Lac Bay, and attempt to identify the environmental threats and issues that are associated with them. In this way, it would bring about an understanding for determining the conservation status of an ecosystem, through facilitating an awareness of "…how necessary, yet delicate, is the interplay of the biological and physical forces among coastal ocean, land and atmosphere…"(Alongi 1998). The ecosystem interplay in Lac Bay has "…far-reaching consequences for making informed management decisions…" (Alongi 1998).

This report has already discussed the notion that the organisms, species and communities in Lac are closely linked between the physical processes (sea currents and tidal circulation, winds, dry and rainy seasonal changes) with the biological processes (primary productivity in the seagrass and mangrove communities). The physical and biological linkages underlie the exchange of energy and biomass within the ecosystem (Sullivan et al. 1996). This linkage also begins to illustrate the "big picture concept" for holistic ecosystem processes that have dire implications for designing conservation strategies. For example, mangrove growth is retarded in more hypersaline areas where tidal circulation or fresh water input is negligent, or slow. In those type conditions, certain mangrove species may die out, or become "senescent", while other more salt tolerant mangrove species will eventually recruit to replace the former species. Or, during high water events and/or rainy season the cyano-bacteria "activates" which, in turn, provides a rich biological basis by breaking down the mangrove vegetation into a complex web of life found in the mangrove sub-basins of Lac. As a result, during certain physical, and/or temporal scale events that occur in Lac over an annual period, bird and fish life would abound in the mangrove sub-basin regions. As higher order members of the food web, they feed on invertebrates that feed on the proteins provided by the bacteria that are breaking down the decaying mangrove leaf litter, called "detritus". The products of seagrass or mangrove primary productivity come to full circle during such physical and temporal scale events in Lac Bay, where energy is passed through the food web.

Therefore, depending on the size of the ecosystem, its biological species components, and the kind of environment it is, the structure and functioning of the community may or may not be sensitive to external influences, whether caused by human or natural occurrences. And in turn, if there are any

sensitivities, they may or may not affect, or link influences to other surrounding ecosystems in a significant way. This is a particular useful concept in the management of mangroves that are located at the interface between land and sea. They are influenced by both terrestrial and marine factors (Pernetta 1993; Ludgo and Snedaker 1974).

In the study of mangrove ecosystem function in Lac, the patterns of surface hydrology and tidal dynamics are important topographical controls on mangrove distribution and density (Lugo and Snedaker 1974). For example, the five ridge islands of Lac originated during Pleistocene time during changes in sea level, and continue to change the configuration and ecosystem functions of Lac today, as plants and soils stabilize the area (see Section 9.2 - Burdett 1999; Meer Mohr 1972). These islands not only physically partition the mangrove sub-basins regions from the Lac lagoon, but also influence the changes in sea circulation flow patterns over long-term cycles (see Section 4).

A key to the environmental health in the mangrove areas found in Lac is the area's natural hydrological patterns - the timing, the distribution, and flow of waters (Sullivan et al. 1996). These sea circulation flow patterns fluctuate over a short-term cycle: diurnal, tidal, or over a one year temporal period in response to annual seasonal changes, and periods of high or low winds, or during natural disturbances, such as storms and hurricanes. Thus, according to such influences there are changes in the physical-chemical characteristics of water (salinity, temperature, dissolved oxygen content, etc.), as well as fluctuating tidal levels in the Awa Lodo areas of the bay over the course of one year. The physical changes ultimately causes biological shifts in species abundance and density, as well as fluctuations in the foraging patterns of species, as well as the productivity in the mangrove sub-basin region of Lac (Sullivan et al. 1996). For example, the black mangrove species that can tolerate more extreme water quality characteristics (higher salinity, anaerobic soils) is "succeeding" (replacing) the former red mangrove community that once flourished in the sub-basin areas.

Therefore, it is most important on a conservation perspective to become aware, that these dynamics, or changes in an ecosystem, *are parts of the normal functioning of the system*. One should be cautious that often "conservation fixes" may not take these dynamics into account (Alongi 1998; Sullivan et al. 1996; Pernetta 1993).

With these concepts in mind, the following will examine the ecology of the individual natural communities in Lac Bay, in order to begin to evaluate threats and sources of stress on these environments, and issues for attending to them.

8.2 The ecological importance of the mangroves community and stress factors

Mangrove is a term, which describes an ecological group of halophytic or salt-tolerant species of plants. A second definition for mangrove refers to the complex of plant communities found fringing on sheltered tropical shores; which would include growing below the high tide mark. Mangroves may also occur above the high tide mark, towards the uplands, or on coasts with no tides. Various species tend to occur based on the ability to withstand the frequency of inundation of sea water, or on the content of salinity in the soils (Lugo and Snedaker 1974; Alongi 1998).

There are world wide approximately eight families of mangroves. Lac claims four families of mangrove growing in its environs, and they are as follows:

Family Rhizophoraceae, Genus species *Rhizophora mangle*, the red mangrove tree, primarily occurs between high and below low tide, fringing along the bay shores of the Lac lagoon;

Family Avicenniaceae: Genus species *Avicennia germinans*, the black mangrove tree, primarily occurs in the muddy, intertidal areas of the five bay islands, as well as in the sub-basin areas at the Awa Lodos region;

Family Combretaceae, Genus species *Laguncularia racemosa*, the white mangrove tree, primarily occur along high tide and drier land elevations of the Lac Bay islands; and

Family Meliaceae, Genus species *Conocarpus erectus*, the Buttonwood tree, and *C. erectus var. sericeus*, the Buttonwood bush variety; primarily occur with the white mangrove in drier elevations, as well as along the land/road perimeters that surround Lac Bay.

Early writings concerning mangroves in 1888 first postulated that the broad ecological roles for mangroves are “building islands” and “extending shorelines”. Later in 1969, other studies revealed the dependence of sport and commercial fin fisheries, in which nursery fishes feed in the food web provided by the leaf detritus breakdown in the red mangrove forests. Additional energy exchange is provided by the micro-flora and micro-fauna which physically grows or lives on the mangrove tree roots underwater,

such as mangrove oysters and marine worms, that provides additional food sources to other marine life, as well as aquatic birds (Figure 30) (Lugo and Snedaker 1974).

Of economic importance in Bonaire, historically mangroves had been valued for firewood for fuel, timber for construction, and use of the tanbark, extracting the tannin acids from the reddish mangrove bark. Tanbark was used for treating mangrove branch sprouts to make rope, by rubbing the tanbark or "tam over the tender mangrove branches while twisting and stretching them. The process is called “pa tam lina” in Papiamentu, for making line for traditional fishing practices, and weaving fish baskets (Antoin 1999).

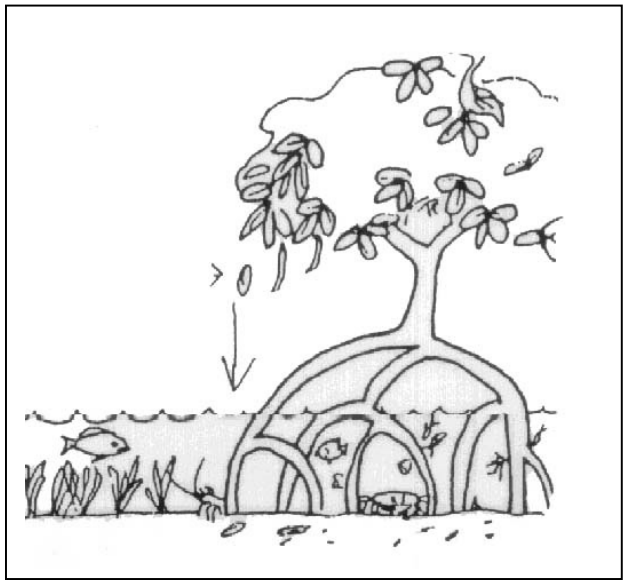


Figure 32 Mangrove Primary Productivity

Mangroves trees provide above ground structures of branches and leaves that transfer energy by primary production through sun photosynthesis. Birds roost and nest in these structures. Leaves fall and decay in the muds, and these "detritus" forms the basis for the food and energy web. Biologically, the mangrove roots provide respiration with aerobic and anaerobic processes in the muds and assist in recycling of mineral nutrients. Tidal exchange provides the exportation of vital minerals and organic matter into other nearby ecosystems (seagrass beds). Physically, the roots stabilize bottom areas, trap and build up soils through collection of sediments and decayed vegetation that protect and buffer shorelines from erosion (Lugo and Snedaker 1974). The roots also provide hiding and nursery habitat for reef and resident fishes, crabs and lobsters. Diagram by Cindy Lott 1987

Six potential stress factors that may affect the mangrove ecosystem are noted as follows (Lugo and Snedaker 1974):

- Channelization and Drainage - the organic materials produced in the mangrove basins that are exported by tides and sea currents into other nearby receiving ecosystems can be stopped or can be modified by channelization. The inputs into the mangrove system by incoming fresh water sheet flow from upland areas can be modified or stopped by drainage alteration activities;

- Siltation, harvesting and trimming- recycling of nutrients can be diverted by siltation, which obstructs the exchange of gases and mineral nutrients across the mud surface; while mass harvesting for utilitarian products, or large scale trimming activities for real estate development purposes is a drain on the above ground mangrove forest structure, as well as frequently a disruption in roots growth and stability;

- Hurricanes and storm events, or chemical application of herbicides are capable of converting the aboveground mangrove tree structures into broken down vegetation, that would be exported away or recycled in proportion to any remaining intact structures, disrupting primary productivity processes; and

- Thermal loading, would accelerate rates of respiration at elevated temperatures, and influence the respiration of the products of photosynthesis, caused by dumping thermal effluents into mangrove areas.

8.2.1 Is mangrove land reclamation a threat in Lac Bay?

The red mangrove species, *Rhizophora mangle*, in particular has been described as a "pioneer" species, referring to its ability to settle along the shores of a sheltered coastal area, in intertidal or below tide line levels. Other species, such as the black mangrove, *Avicennia germinans*, and the white mangrove, *Laguncularia racemosa*, tend to settle and grow behind the red mangrove, in intertidal areas to above the high tide level, or on upland banks. These species can be classified a "climax" species, because their growth may lead to successional processes via root and soil accumulation, thereby becoming a landward, terrestrial forest. Thus, some studies indicate that mangroves tend to grow in "zones" representing the ability for each species to withstand salinity and accumulate soils. Classical mangrove "zonation", therefore, occurs mainly when there is sufficient physical slope, or increasing gradients from the sea to land (Figure 33) (Lugo and Snedaker 1974).

Other studies indicate that the mangrove ecosystem establishes itself and grows out in response to external forces (changes in sea level, tidal circulation and fresh water input) rather than on sequences

initiated by the plant themselves (Pernetta 1993; Lugo and Snedaker 1974). These studies indicate that the appearances, and/or the disappearances, of certain mangrove species may be a result of these external sources acting on a particular locality, such as can be observed in the mangrove sub-basin areas of Lac Bay. It could be noted that during drought periods, or low water events with decreasing tidal energy, or geologic periods of lower sea levels and climatic change, the mangroves advance toward the sea, and die-out in landward zones (Pernetta 1993). (The one hundred year cycle of mangrove forestation and die-out

Figure 33 Mangrove Species Zonation

Classical mangrove "zonation" occurs when there is a physical slope, or increasing bottom gradients from the sea to land. In this situation, the red mangroves "pioneer", growing seaward by using "prop" roots to stabilize into the bay bottom (right tree), while the black mangrove tend to settle behind the red mangroves in muddy, low intertidal circulation conditions, using "pneumatophores", snorkel-like roots that protrude above the ground for respiration (middle tree). Upland, above high tide, are the white mangrove and buttonwood trees, burying their roots into the ground, and stabilizing soils along higher and drier landward elevations (left trees).

Graphic by Cindy Lott 1999

processes in the Awa Lodo areas could be influenced by this large temporal scale, long term phenomena (see historical maps interpretations Section 4.2). On the other hand, during high water events, or high winds pushing tidal circulation into the sub-basin areas, (or if there is adequate fresh water input by rainy season or sheet flow drainage), the mangrove growth flourishes and migrates inland. Signs of both these external physical phenomena have influenced the history of mangrove forestation in Lac Bay (see Section 5).

It is the nature of mangroves to reclaim land, through the stabilizing strategies of anchoring their prop roots into muds and shoals (Kaplan 1988). Hummelinck en Roos (1969) reported that already in the 1930's,the mangroves of Lac were expanding inland from a seaward direction, as discussed in the zonation growth habits of the different species. These researchers predicted, however, that this growth was of little consequence towards making a difference or harm in the water flow of the region.

In the first half of the 20th century, Lac's mangrove wetlands had the most important coverage of mangrove forest. However, during the latter half of the 20th century, this mangrove sub-basin environment have been experiencing a large mangrove die-off, transforming the area into large shallow, muddy water sub-basins (Hummelinck en Roos 1969; van Moorsel en Meijer 1993; Lott 2000). However, it has become known that during the earlier 25 to 50 years, the fishermen had been maintaining the creeks (see Section 2.8; 4.4). A recent survey indicated that they no longer continue this practice with regularity as done in past years.

Figure 34 Feeder channel in the Awa Yuwana area

Both the mangroves and water quality are in moderate saline conditions (relative to the Lac lagoon) in waters west of Isla di Rancho and Isla di Pedro, and in the south area of Isla Yuwana. These locations experience frequent tidal exchange from open Lac through the Kreek di Pedro.

Photo by Environics, N.V., 1999

However, there is a difference in tidal circulation in the Awa Lodos region of almost half of what has been measured in open Lac. Fallen trees and broken branches and the closures of canals and mouths of the "kreeks", form a threat of keeping those mangrove canals open, obstructing fresh bay water exchange in this area (Hummelinck en Roos 1969; van Moorsel en Meijer 1993).

Prior studies have shown that these basins lack daily tide water exchange, and as a result are appropriately called *lodos*, or muddy waters (Figure 35). At one time the mangroves here thrived, and reached 16 meter in height. Surrounding and separating the two major Awa di Lodo di Chico, and Awa Lodo di San Jose, there are now dwarfed black mangroves, of only less than 3 m height growing in the exterior, with red mangroves growing from 5 – 7 m height growing near to the Lac lagoon basin.

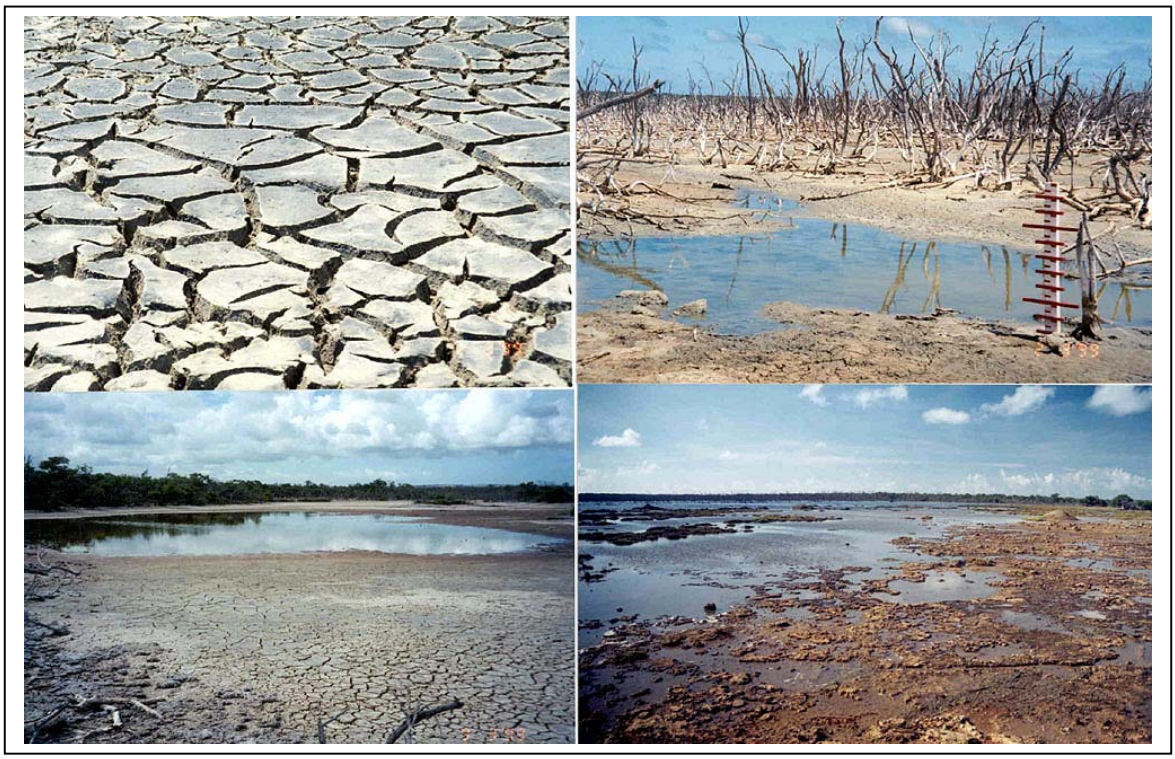


Figure 35 Mangrove sub-basins of Lac during dry and rainy season conditions

Views of the Awa Lodo di Sand Jose and Awa Lodo di Chico during low water events and dry season. The lower right photo shows Awa Lodo di San Jose during high water events, and rainy season conditions, where tidal and rain waters flood and mix extensively across the flat pond surfaces of the Lodos areas.

(photo by Environics, N.V., 1999

Figure 36 Awa Yuwana region during high water events

Views of the Awa Yuwana noord and Awa Yuwana zuid areas during high water events. High water typically occurs during periods of high winds, rainy season, or during September solstice periods (refer to Section 5). During these events, bird life utilizes the area for feeding, where the waters activate the energy pathway of the food web.

Photos by Environics, N.V., 1999

However, at the Boca Chikitu, the mixed stands of black and red mangroves are thriving to approximately 8-meter height. In addition, at the Boca Fogon area, these trees are so successful that they are impassable and impenetrable. They have expanded to reaching a height of 12 to 15 meters. Thus, their growth is separating Isla Rancho away from Isla Fogon towards the west to east and the open bay from the posterior bay, towards the south to north. A central creek further separates the sub-basin areas (Figure 37).

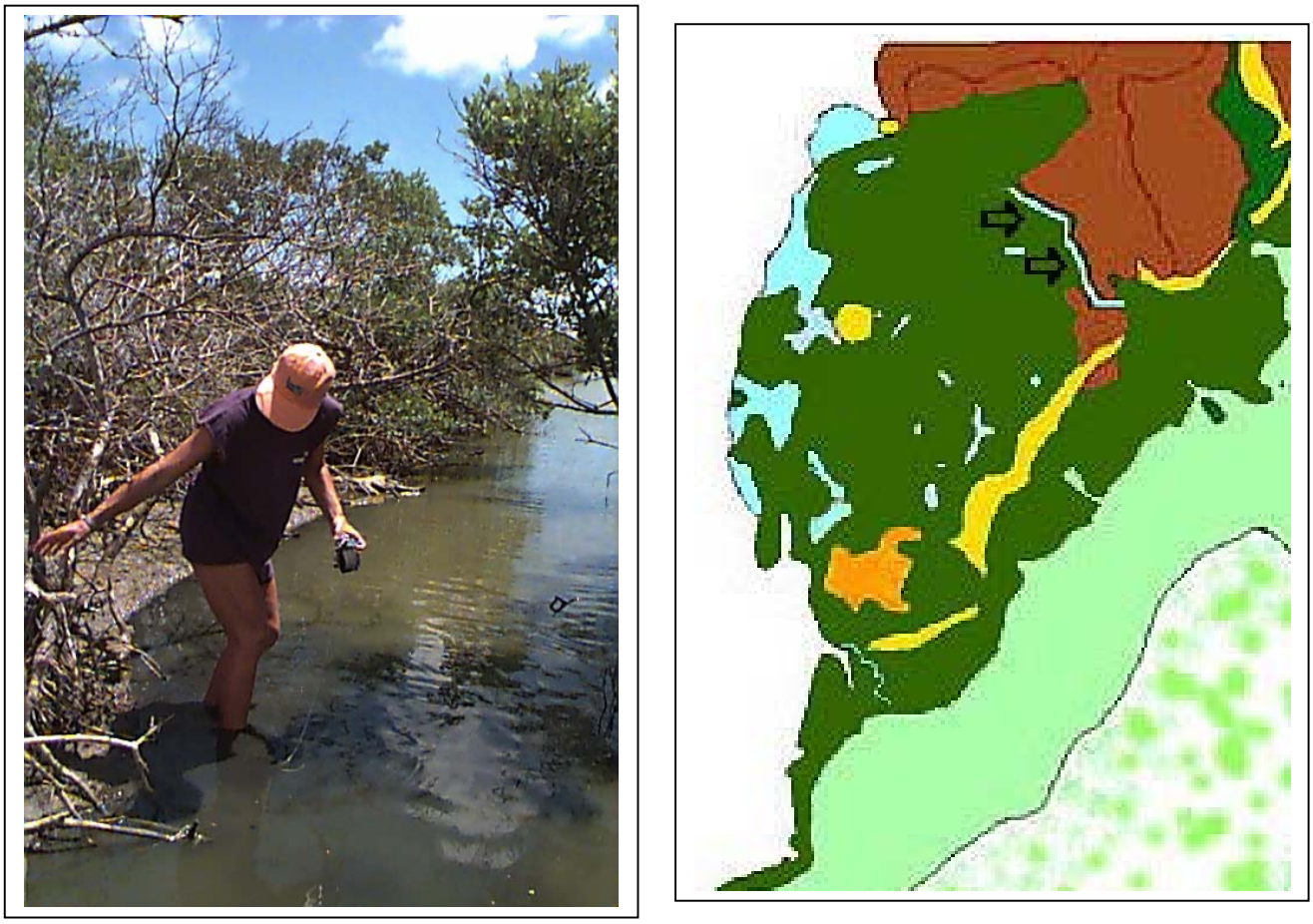


Figure 37 A central creek divides the mangrove sub-basin areas of Lac

A central creek that runs from a southeast to northeast direction physically divides the two mangrove sub-basin areas of Lac (black arrows above map). The successful growth of the mixed stands of black and red mangrove trees separates the Isla Rancho (long yellow island below the creek) away from Isla Fogon (shorter yellow island above the creek). Mangrove growth is dense at the juncture between the creek and the two islands.

Photo by Environics, N.V., 1999

8.2.2 Mangrove community "types" that persist in Lac Bay

Thus, mangroves are strongly controlled by local tidal regimes as well as fresh water input from terrestrial surface drainage (sheet flow), or periodic fresh water inundation during rainy season. At Lac, the mangrove growth sequences respond not only to these physical processes, but also to the configuration of the slope gradients and island elevations along Lac (Figure 33). In this respect, the mangrove communities in Lac Bay persist accordingly, and can be characterized under several definitions. A "*fringe mangrove forest*" is found growing along the lagoon, or bay shores, with an "*overwash mangrove forest*" found in the islands of Lac in the sub-basin regions, while a "*dwarf mangrove forest*" growth can be found in the more harsh condition, and low nutrient exchange environments at Lac.

The *fringe forest* is typified by growth in the protected shorelines of a shallow depth lagoon, where a density of red mangroves will "fringe" along the shore configurations of a bay, or lagoon. In this situation, the mangrove species are zoned according to the elevations described in Figure 33. The low velocities of tides occurring beneath the mangrove prop roots deposit and entrap all but the smallest organic debris, thus building up soils and stabilizing the bay shore (Figure 38)(Lugo and Snedaker 1974).

Figure 38 A "fringe mangrove forest" of Lac Bay

The *fringe forest* is typified by growing in the protected shorelines of a shallow depth lagoon, or bay. Here, at Puitu, red mangrove trees "fringe" along the configuration of the bayshore, and develop passages through the bay. The bottom is very soft sediment that is trapped by the mangrove root growth.

Photo by Environics, N.V., 1999

The smaller bay islands enclosed with mangrove growth are typical for an "*overwash mangrove forest"* type. An *overwash mangrove forest* features processes where the positions and alignments of the islands are stabilized with mangrove vegetation. Together these obstruct tidal flow and as a result this area is overwashed primarily at high tide, or during high water events due to winds or rainy season (see Section 5; Figure 28). The incoming tidal velocities are high enough to carry with them any loose organic

debris that is dropped in the inner sub-basins where the tidal velocity finally decreases, but the debris is not carried back out, thus depositing soils and building up the island (Figure 39) (Lugo and Snedaker 1974).

Photo by Environics, N.V. 1999

Figure 39 "Overwash Mangrove Forest" at Isla di Chico

An *overwash mangrove forest* features processes where the positions and alignments of the islands, obstruct tidal flow and as a result this area is overwashed primarily at high tide, or during high water events due to winds or rainy season (see Section 5).

Finally, a "d*warf mangrove forest*" persists in some areas of the Awa Yuwana, Awa di Chico and along the road to Cai regions (Figure 40). In these conditions, the forest is limited to a flat, low elevation level, and exists in an environment lacking external nutrient sources. These communities of either red, black or white mangroves grow in less than 2-m height, and their development may be nutrient limited (Lugo and Snedaker 1974).

In conclusion, mangroves represent a dominant soft bottom plant community in the Lac Bay area. Depending on the physical processes that occur in a given area, variations of mangrove density and growth patterns are fully represented throughout the Lac Bay region: ranging from climax growth at Mangel Altu, to dwarfed growth in the Awa Lodo regions. Die-off patterns of mangroves in the hypersaline pond areas of Awa Lodo di San Jose typify a stage of "successional, or dynamic change," according to the ecology of mangroves. In this condition, the less salt tolerant red mangrove species are eventually being replaced by new recruits of the more salt tolerant black mangrove species in the response to the physical processes as described in this section.

Photo by Environics, N.V., 1999

Figure 40 "Dwarf Mangrove Forest" at Cai

A "d*warf mangrove forest*" is typified growing along the edges of the Awa Yuwana, Awa di Chico and the road to Cai regions. In these conditions, the forest is limited to a flat, low elevation level, and exists in an environment lacking external nutrient sources.

At this location at Cai, the dwarf mangroves are primarily the white mangrove species, *Laguncularia racemosa*.

These dynamic differences of mangrove growth that are occurring throughout Lac in response to the local physical processes occurring in a particular area, *are part of the normal functioning of the system*. On a management perspective, one should carefully evaluate all the ecosystem interplay as described, when determining conservation strategies for the mangrove ecosystem processes in Lac Bay (Alongi 1998; Sullivan et al. 1996; Pernetta 1993).

8.3 Chronic low level fishing impacts on Queen Conch abundance

The Bonaire Marine Park 1999 Agenda recognized that inconclusive conch surveys in seagrass beds in Lac Bay implied that conch are low in abundance. Previously, a short term, rapid reconnaissance of conch stocks in Lac Bay were conducted by B.M.P. in March 1998, utilizing four surveys: snorkel transect swims, tows across the bay, and a random swim survey. Results showed eighteen live, and sixteen dead conch. The reconnaissance also noted the shell sizes were concentrated in certain areas around the seagrass, although details of this observation were not provided in the survey. Various conch size/age classes will disperse and aggregate into subpopulations accordingly in the seagrass ecosystem, relative to food preferences/location as they mature (personal observation, 1987, 1991; Berg, 1976; Appeldoorn, 1984).

To examine in detail the size/age class distribution of conch that settle in Lac Bay, a long term monitoring program for conch was initiated at seventeen permanent stations in Lac Bay, that covered approximately 51,000 m^2 area. First-time baseline data was collected during July to September 1999 by the BONURA research team (Lott 2000). The program was developed to provide detailed abundance and distribution data, and determine management replenishment zones for the queen conch species in Lac Bay (deMeyer, 1998; B.M.P. Agenda, 1999). The long term monitoring would also provide input regarding environmental change, as well as evaluation relative to whether management strategies for conch are working.

8.3.1. Ecological relationship of seagrass meadows and conch

Seagrass meadows serve as a primary nursery habitat for the early growth phases of the queen conch, *Strombus gigas*, a commercially important fishery resource. In this respect, the seagrass meadow provides favorable circumstances for the early development of conch in the following ways (Berg 1976; Brownlee and Stevely 1981; Hensen 1982; Appeldoorn 1984):

- The seagrass density provides for the yearling conch habitat, shelter and protection from predators while undergoing shell and early developmental stages. Yearling and juvenile conch lifestyle occurs primarily under the protection of night. During the day, both young and adult conch wholly, or partially bury themselves in the soft sediments that are typical in a seagrass environment;

- The seagrass blade surface provides a significant food source for yearling conch to forage on the epiphytes and epibiotic organisms that live attached upon the blades (see Figure 35). *Strombus gigas* are herbivores, and graze on the micro-life which are attached on the seagrass blades, as well eat microscopic algae, which are incorporated on sand particles. Thus, they consume considerable quantities of sand as a waste product;

- The seagrass meadow abundance and density also provides minimum competition for food and space for the juvenile conch. Generally conch occur in shallow water where there is adequate light penetration that supports the growth of seagrass and algae, which sustains the energy needs of the conch. Conch have also been reported in deeper water (30 - 70-m), especially in Bonaire, where there is little shallow seagrass and sand bank environment found; and

Figure 41 Conch, *Strombus gigas*, Life Cycle

Much of the life cycle of the conch species, or "karko" in papiamentu, is dependent on the seagrass meadows, such as in Lac Bay. The adult conch comes into the shallow seagrass and sandy banks to breed and deposit egg masses; as many as 500,000 eggs can consist in one mass (left photo). The "veliger" (center photo) hatches about four days later and floats in a pelagic, sea going stage for about three weeks. During this floating stage, the veliger will metamorphose into a "protoconch" (right photo), and will eventually swim down into a seagrass meadow in order to settle as a yearling conch. The conch undergoes its juvenile stages of life living and feeding in the seagrass beds for approximately 3 to 4 years, until when it reaches adult hood. Adult conch frequently migrate out into deeper sand ledges of the coral reef, to feed on a different variety of algal species than found in the seagrass meadows.

photos Environics, N.V., 1987 and SeaHatch Bonaire 1999

- The soft sediments typically found in seagrasses provide a "bed" for the conch to build and strengthen its shell, while extracting mineral ions from the water column, such as calcium. Yearling conch (less than 6 cm) remains buried in the soft sediments during the day, secreting calcium to strengthen their shells, while being protected from predators. In addition, adult conch move from deeper reef habitat into shallow sand areas to mate and deposit egg masses. In the Bonaire area, these breeding activities occur primarily during the July to November months.

8.3.2. Evaluating seagrass beds as a sustainable conch nursery habitat

To assess seagrass condition and its viability to sustain a conch nursery habitat in Lac Bay, the following parameters were included in the benthic assessments to make this determination (Lott 2000):

- seagrass/macro-algae percent substrate coverage,
- short shoot density,
- estimated epiphyte and epibiotic coverage loaded on the grass blades,
- *Thalassia* leaf width and length measurements, and
- classify the bottom sediment types.

Figure 42 Mixed seagrass and macro-algae community comprise the bay bottom

Typical views of mixed red, green and brown macro-algae species and turtle grass, *Thalassia testudinum* , that were assessed for % coverage found in a one meter square bay bottom area, to examine suitability as conch nursery habitat.

(photo by Jessie Armacost 2000)

The percent coverage of seagrass, macro-algae, sponge, coral and sediment features per m^2 were scored as one of six possible cover classes:

Bottom Coverage Codes:

+ = few coverage	3 = 26-50% coverage
1 = less than 5% coverage	4 = 51-75% coverage
2 = 5-25% coverage	5 = 76-100% coverage.

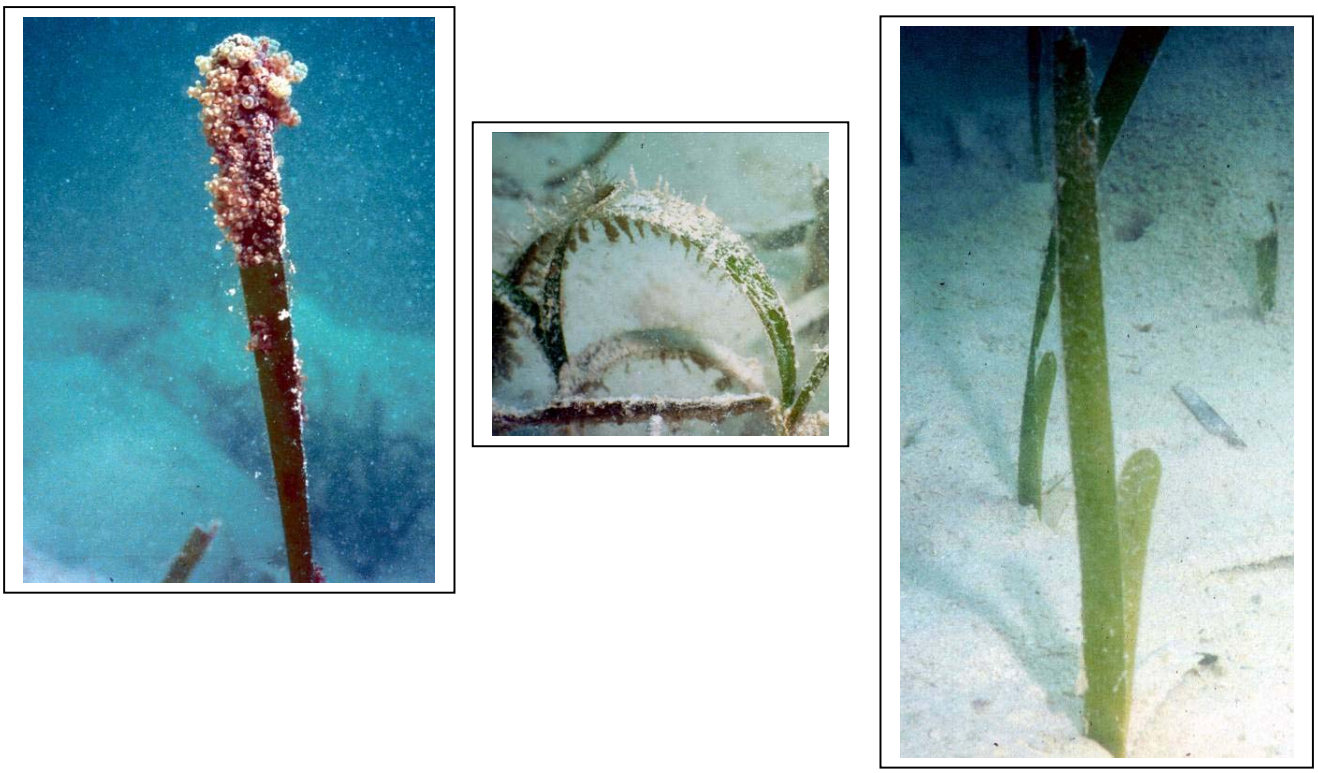


Figure 43 Epiphytes and Short shoots of the seagrass, *Thalassia testudinum*.

Seagrass assessments included estimating the density of epiphytes that grow on seagrass blades. The epiphytes provide food for early juvenile stage conch, which have recently settled out of the plankton to feed and grow-out in moderately dense seagrass beds. In Lac Bay, these epiphytes include the stinging mangrove anemone, *Bunodeopsis antilliensis* (left photo), algae and other micro-organisms that encrust on the actual seagrass blade (center photo).

Short shoots of the seagrass blades are the young blades growing up from the rhizome of the seagrass plant. The numbers of short shoots within a given area provide an estimation of seagrass productivity (right photo).

(photos by Jessie Armacost 2000)

Epiphyte density, the micro-life that lives upon seagrass, was determined by visually evaluating the coverage of microscopic epifauna and epiphytes observed fouled on the individual *Thalassia* species seagrass blades. Density was estimated in 25-cm^2 units. A single value code was designated to represent the overall average coverage of epiphyte fouling on the seagrass blades, by applying the following classification codes:

Epiphyte Coverage Codes

1 = clean blade
2 = light coverage
3 = moderate coverage
4 = heavy coverage.

Substrate Lifeform % Coverage in Lac Bay

Category	Code Range	Code Mean	% Coverage	Code Mean (excluding Awa Blanku grids)	% Coverage
Thalassia	0.3 – 4.1	2.7	5 – 25% /m^2	3.1	25-50% / m^2
macro-algae	0.9 – 2.7	1.9	~5 –25% /m^2	2.0	5-25% / m^2
sand/mud	0.9 – 4.1	1.8	~5 –25% /m^2		
shell/coarse	0.4 – 4.2	2.0	5 –25% /m^2		
epiphyte density	1.1 – 3.3	2.4	moderate %/ 0.125-m^2	2.5	moderate %

Seagrass Blade Measurements (cm) and Short Shoot Count Results

Category	Unit Range	Unit Mean	Unit Mean (excluding Awa Blanku grids)	% Coverage
blade length (cm)	3.0 – 21.4	12.6 cm	14.0 cm	
blade width (cm)	0.7 – 1.6	1.3 cm	1.5 cm	
total # short shoots	0.2 – 14.6	6.3 shoots per 25-cm^2 area	7.9	per 25-cm^2 area

Table 5 Summary of results of substrate lifeform % coverage in Lac Bay

Results of bay bottom assessments in Lac, for the estimation of % coverage of macro-algae and seagrass, sediment classification, and seagrass blade features, including epiphyte density as they exist in the bay (Lott 2000).

The Table 5 presents the results of the bottom assessments for Lac Bay. The average, or mean % coverage of the predominant seagrass, *Thalassia testudinum*, has a overall code value of 2.7, equal to a 5 – 25% coverage/m^2 in Lac bay. However, this value increases to an overall code of 3.1, or a 25 - 50% overall coverage of seagrasses in Lac bay, if the data for the sandbank, Awa Blanku, is omitted. This area is devoid of gross vegetation features, and the seagrass data in this area are not applicable. The overall epiphyte density on seagrass blades in Lac bay has a "moderate coverage" (see photo in Figure 43). There are an average number of 7.9 total short shoots in a 25 cm^2 area (Lott 2000). Conch biology research indicates that juvenile conch have a seagrass habitat preference for "moderate density" coverage, which allows mobility in amongst the vegetation.

Belt transect census for conch stock and size/class distribution, including species presence/absence inventories, were assessed in 17 grids that measured 3,000–m^2 area per grid. The grids covered a 51,000-m^2 total sampling unit area. The conch stock census data (Table 6) concluded that overall, a total of 111 conch were found in this large sampling area. These equals to 7 conch found per 3,000 m^2 area, or approximately 0.0021 conch individuals per m^2 in the total 51,000 m^2 sampling area.

Studies of growth rates for conch indicate shell lengths for associated size/age class is as follows:

- Yearling conch ranges from 7.6-10.8-cm;
- Two year olds range from 12.6-17.0-cm; and
- Three year olds from 18.0-20.5-cm.

The average annual growth rate is 52-mm/year; and mean longevity is about 6 years old. The reproductive maturity is reached at 3-4 years old (Berg 1976; Hensen 1982).

Of the total 111 conch found in Lac Bay, the shell length measurements ranged from 14.3 - 20.0-cm in length. The mean, or average shell length size was 17.8 cm, indicating the average age class of conch inhabiting Lac bay are approximately 2.5 years old, and are thus classified as sub-adult size/class, not yet reaching sexual maturity.

The statistical analysis of how the conch are distributed in the bay area for food and habitat indicate they are found in "clumps", showing that there is some restraints on the environment in which they live (Table 6). The seagrass habitat analysis indicates there is suitable environment conducive as a conch nursery habitat. Therefore, the "clumped" pattern of distribution may lead to the conclusion that conch may be under chronic, low level fishing pressure. This pressure occurs in the easy access areas,

where the water is shallow and clear, to allow easy taking. Thus, conchs are found *not* to be distributed in a random pattern, and *not* filling these available and sustainable environmental niches (Map 17). The Map 17 shows the mean, or average shell size/age class distribution of conch surveyed in Lac Bay , including the quantities found at the various depths in the seagrass habitat.

Photo by Jessie Armacost 2000

Figure 44 Juvenile conch inhabit shallow seagrass areas

The juvenile and sub-adult stages of conch use the shallow, less than 3-m deep seagrass beds as nursery habitat. These areas are prone to fisheries exploitation as easy access areas, and thus may have contributed to the collapse of the conch population in Lac Bay (Lott 2000).

Table 6 Spatial Pattern Analysis of Queen Conch, *Strombus gigas*, population in Lac Bay, Bonaire

Based on June - September 1999 surveys for Bonaire Marine Park by Environics, N.V.

Density of Queen Conch in 17 Grid Sites
111 total # Conch/51000 m^2
0.0021 conch/m^2 distribution
[compare to 0.42 conch/m^2 distribution
in the Los Roques managed area]

Sample Mean size class	**Size Class Range**
17.8 cm shell length	14.3 cm - 22.0 cm
11.1 cm shell width	**Sample Mean Age Class**
6.7 cmshell whorl	2.5 years old

SPA* of Conch in 17 Grid Sites in Lac Bay

Grid Sample Mean:	Std. Dev.	Variance
7 conch/3,000m2	6.2	35.9

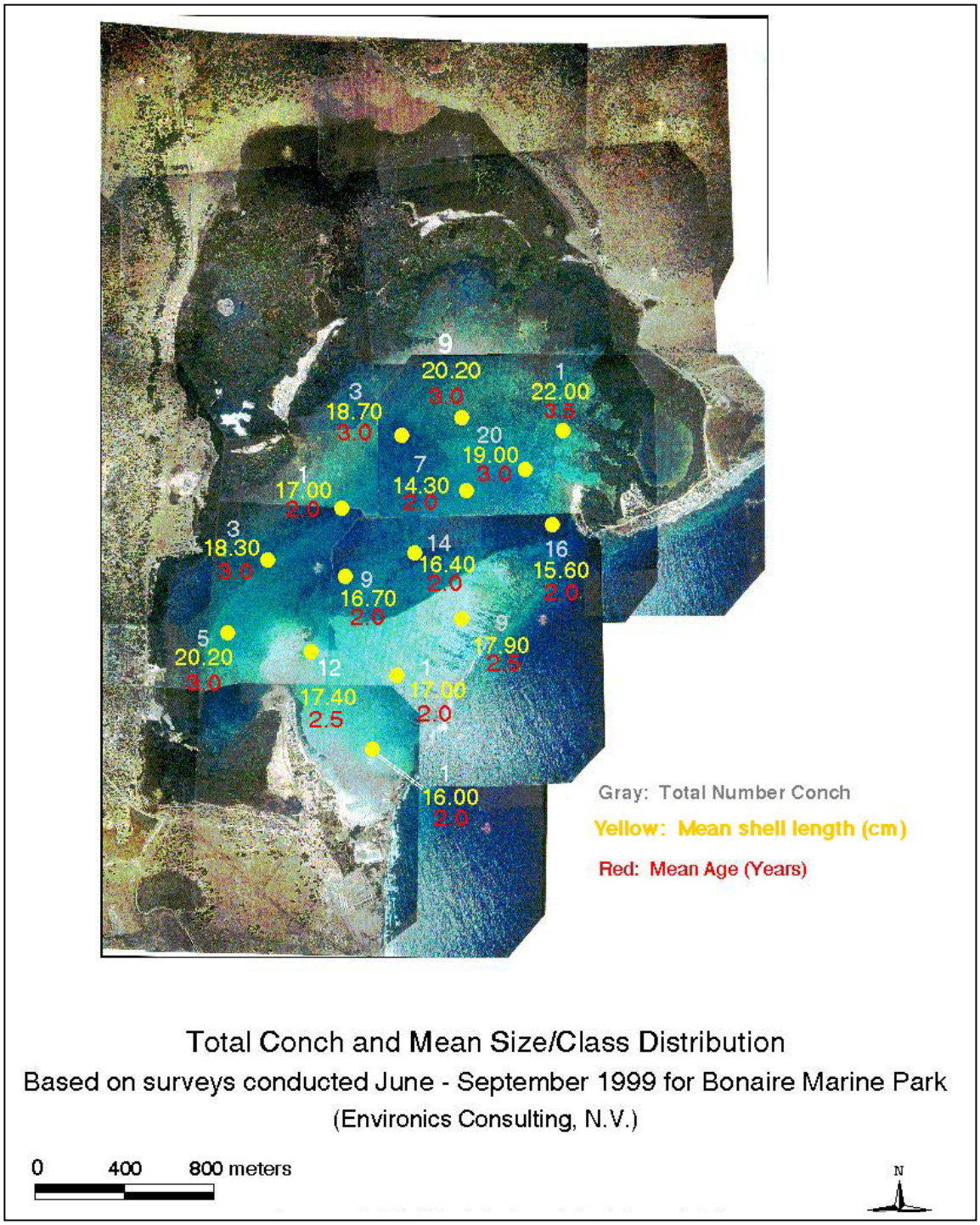
Conch Spatial Distribution Pattern - Clumped

Overall results indicate both conch and species presence in general are spatially distributed in Lac Bay in Clumped or Uniform patterning, implying there are some constraints on the system as described below:

Species Distribution based on Types of Spatial Patterns:
Random (mean=variance): Individuals are located independently of each other; implies environmental homogeniety, and/or non-selective behavior patterns;

Clumped (mean<variance): Individuals tend to be located together in clusters; implies environmental heterogeniety, some constraints on system exist, and aggregation to more favorable parts of the environment;

Uniform (mean>variance): Individuals are regularly spaced; some constraints on the system exist, negative interaction between individuals, competition for food or space



Map 17 Total Conch and Mean Size/Age Class Distribution in Lac Bay (Lott 2000)

Map prepared at Duke University Landscape Ecology Laboratory by P. Dermer

The general relationship between queen conch with turtle grass *Thalassia testudinum* is well known; and there is an observed association between juvenile conch densities with macrophyte, or epiphyte coverage and short shoot biomass. Juvenile queen conchs are important grazers of seagrass epiphyte, algae, and detritus, and conch densities may be limited by food abundance (Stoner and Waite, 1990).

Summary data in Lott (2000) for seagrass coverage concur with other studies that this area can support juveniles and sub-adult size classes for nursery and grow-out habitat (Table 5). The data also indicates appropriate total short shoots, epiphyte density coverage, and seagrass blade measurements that would support conch nursery habitat (Brownlee, W.N. and J.M. Stevely 1981; Stoner and Waite, 1990).

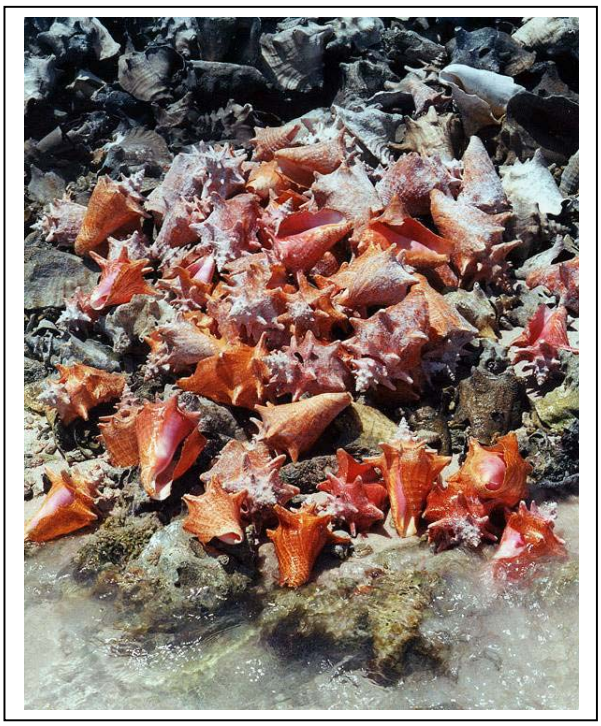


Photo by Environics, N.V. 2000

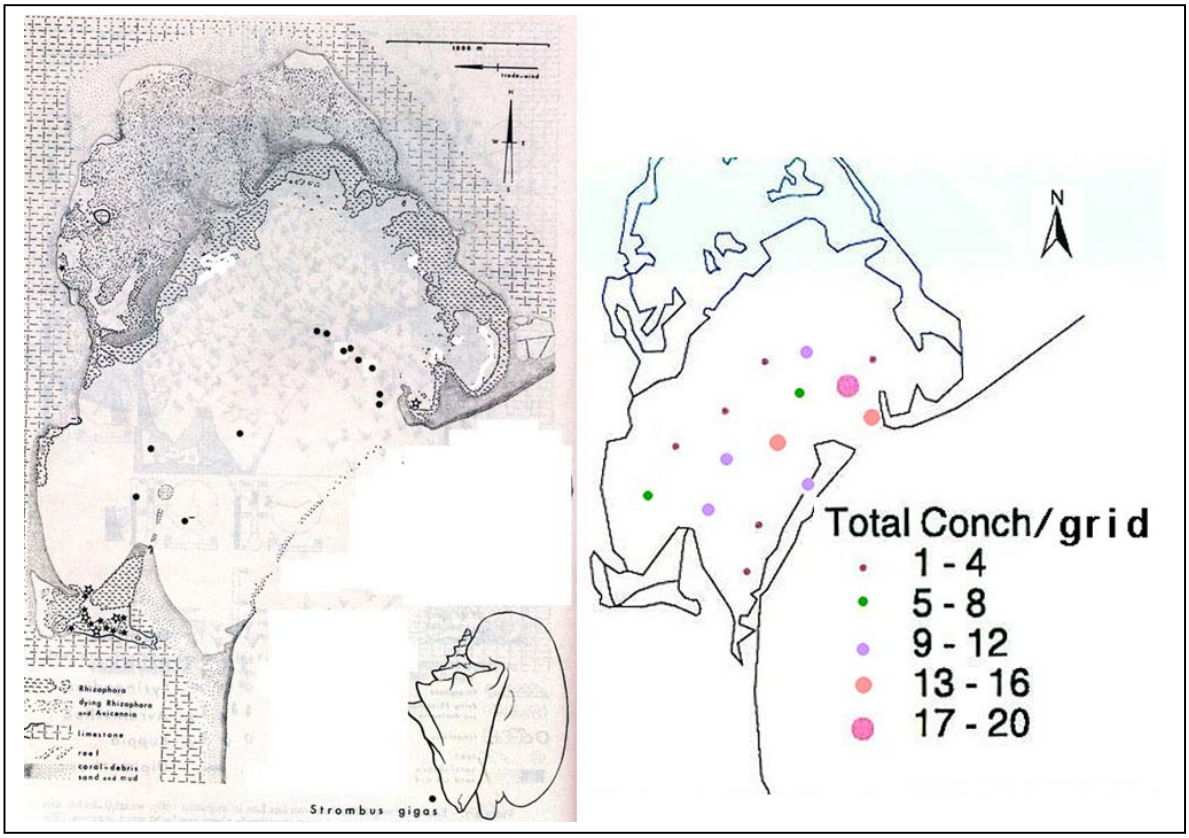
Figure 45 Signs of juvenile conch fishery exploitation at Lac Bay

Results of the recent monitoring by Lott (2000) found that although Lac has suitable habitat for conch, the population is low, which is likely due to "chronic, low level" exploitation of the juvenile and sub-adult size classes.

This photo shows juvenile size class conchs that were discarded at Cai, after being fished from Lac Bay. The habitat preference for them would be in the shallower (<3-m deep) seagrass areas of the bay, where they can be easily accessed for taking. (Note: These conch shells do not have the flared lip, as do mature adult conch shells, indicating this size class is not sexually mature conch).

8.3.3. Historical Change of Conch Distribution Patterns in Lac Bay

Historical interpretation from prior research conducted by Wagenaar, Hummelinck en Roos (1969) reveals that little has changed for the conch, seagrass and macro-algae benthic distribution patterns. Maps completed by the prior researchers when compared with the present day research reveal remarkable historical similarities in how the conch species are found to be distributed in Lac Bay (Map 18).



1969 Research **1999 Research**

Map 18 **Historical and Present Day Research of Conch Distribution Patterns in Lac Bay**

Historical (1969) and recent (1999) conch distribution patterns of Lac Bay are similar. Although the historical study did not give quantities, it did report the locations of conch beds in 1969. The 1999 research shows that the greatest conch densities found fall into the similar locations as found for 1969. These similar conch distribution patterns over the years may support the implications for fisheries exploitation of conch in the shallow, easy take locations of the bay (1969 and 1999 maps shows less conch found in shallower zones of Lac).

(maps adapted from Hummelinck en Roos 1969, left; Wing Group, N.V. 1998 right)

The Wagenaar, Hummelinck en Roos (1969) maps indicate that the conch distribution patterns were found to be along the boat channel area of the Boca di Cai, as well as the deep water borders that

flank the Secu di Sorobon and Awa Blanku region. These same distribution patterns for conch are similar in both the historical and present day research, as illustrated in Map 18.

Thus, the present day conch stock distribution patterns in Lac Bay are strikingly similar and seem unchanged over time, when compared with prior research. These similarities between the 1969 and 1999 research observations and conch distribution patterns in the bay, may imply likely conclusions for fisheries exploitation of the species (Figure 45, Map 18). The 1999 survey results for conch size class data for individuals smaller than 17.8-cm in length, found they are noticeably missing in the shallower (<3-m) seagrass areas that would support them (Lott 2000). These missing juvenile size classes, and the overall low abundance of conch in Lac Bay, may imply that the greatest densities of conch surveyed remain in habitat areas that are least accessible to "low level, chronic anthropogenic disturbances" (The Nature Conservancy 1999), where a remnant population persists in slightly deeper and less clear water.

9. Controversies and Conservation Issues

9.1. Conch fisheries exploitation and management

The results from the 1999 Lac Bay monitoring activities (Lott 2000) provide scientific documentation that the Lac Bay environs sustains suitable conch nursery habitat components (refer to Section 8.3). However, the low conch stock numbers as noted on Table 6, and the clumped distribution patterns of the species are remarkably similar to the prior studies conducted by Hummelinck en Roos during 1969 (refer to 1969-1999 conch distribution comparison on Map 18). This clumped distribution pattern of the species that has persisted over a thirty year time period may imply that the conch population in Lac Bay is scarce in the shallow depths due to "low-level, chronic anthropogenic disturbances" (Sullivan and Chiappone, 1993), such as by human fishing pressure. Data in the Lott (2000) monitoring report showed few juvenile conch were found in the typical shallow water nursery habitat area of Lac Bay, which also provides easy fishing access to collect the species.

Bonaire is located in the down-stream sea currents of the Los Roques Archipelago that features a vast shallow bank ecosystem that support large conch stock populations. In addition, in Los Roques, scientists Weil and Laughlin (1984) have shown that conch juveniles tend to occur in primarily shallow (< 1 meter depths) seagrass beds during the summer months. They reported that replenishment of conch stock into depopulated areas appear to be very rapid and capable in suitable habitat. It may be likely that due to its limited shallow seagrass meadow areas in Bonaire (for sustaining adult conch breeding grounds during mating season), a majority of Bonaire's conch juveniles may also originate as larval recruits from the Los Roques region, rather than locally from Bonaire waters.

During October 1999, Environics, N.V. visited the Venezuelan Enparques management program at Los Roques, and observed the results of their six-year conch moratorium that is currently in operation. Early population recovery data (Weil and Laughlin 1984) showed a stock density of 0.42 conch/m^2 distribution in the Los Roques managed area (compare to 0.0021 conch/ m^2 surveyed in Lac Bay by Lott in 1999). During the visit impressive numbers of conch were seen dispersed throughout the shallow seagrass beds. By casual observation, it appeared that Los Roques is currently enjoying a near recovery of the previously collapsed conch fisheries stock. It is likely that much of the conch larvae which settles into Lac Bay is derived via sea currents from the Los Roques conch fisheries resource. In this respect, Bonaire is benefiting from an upstream, managed fisheries resource, and should follow suit to manage the

stock replenishment in its own waters. Thus, it would benefit Bonaire to manage these species accordingly in Lac Bay, as is being done with success in the neighboring Los Roques Archipelago.

Environics, N.V. strongly recommends reviewing the Los Roques conch moratorium strategy and management model, as currently being instigated in that area, and adopting it in the Bonaire region. This strategy would also serve as a practical outreach mechanism that would drive community support of the Bonaire people during the implementation of such a moratorium program, through identifying from peer experience of a nearby neighbor. Environics, N.V. is currently networked with the Los Roques management program and would assist Bonaire Marine Park to develop strategies in this line for conch stock recovery in the Lac Bay area for management and education.

Figure 46 Los Roques Archipelago

The nearby Los Roques archipelago suffered an almost near collapse of the conch fisheries. Now with a six-year moratorium implemented through a strong enforcement policy and public education program, the species is successfully recovering, and large, breeding size adults can be found in shallow (< 1meter) waters throughout the area.

(photo by Environics, N.V. 1999)

During a moratorium, enforcement with penalties for poaching is imperative. Following a successful moratorium for conch, Environics, N.V. recommends strong fisheries management policies that are strictly enforced by the use of issuing fishery permits for conch, with allowable size and catch limits, and consequential fines with confiscation of equipment, in the case of violations, following the Los Roques model for conch management.

9.2. Mangrove "Die-off" and Hydrology

Contribution by Allan Burdett, Mangrove Environmental Specialist, Florida Dept. of Environmental Protection, Submerged Lands and Environmental Resources, Tampa, FL, March 1999

9.2.1. Overall Goal for Lac Bay: World Wildlife Fund for Nature Netherlands

The overall goal is to protect the natural environment of Lac together with the naturally occurring species from degradation, and preserve the aesthetic appeal of Lac as an unspoiled and undeveloped area promoting day recreational use.

Special Protection Required:

- To safeguard the integrity of the mangroves and seagrass beds by protecting them from physical damage and ensuring that they continue to function as important breeding, foraging and nursery grounds for birds, fish and invertebrates.
- To safeguard water quality within the Bay by preventing pollution and nutrient enrichment.
- To protect endangered species within the bay, e.g. conch, turtle, seastars from poaching and overfishing.
- To preserve the integrity of Lac and maintain its aesthetic appeal as a natural and undeveloped area and thereby ensure its continuing appeal to local people and tourists.
- To improve facilities for visitors at Cai and Sorobon in an ecologically and aesthetically sensitive fashion and provide signage and interpretative materials.
- To improve water circulation to the mangroves and thereby encourage growth in senescent areas.

9.2.2. Succession and Climax Cyclic Growth Phenomena of Mangroves

A stated Lac Bay Project Objective 8 (WWF/BMP 1998):

- *Maintain/improve water circulation within the Bay*

Management of Natural Systems requires an understanding and appreciation of mangrove succession and cyclic climax phenomena, "Mangrove Die-off", and its role in maintaining habitat diversity for fisheries, wading birds, shore birds and ducks.

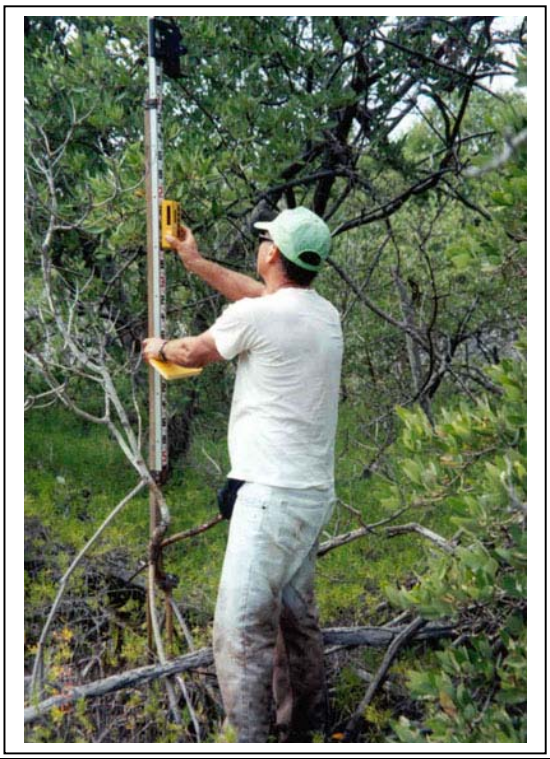


Figure 47 Evaluating mangrove growth

Under natural conditions, the successful growth and spread of mangroves may lead to cyclic or catastrophic climax, in which portions of the mangrove forest may thin or die-off due to ponding, drought, flooding, hypersalinity or a combination of factors. Red mangroves may decline in areas as salinity and hydrological conditions change and provide site conditions in which black mangroves are better adapted.

In this photo, Allan Burdett, mangrove expert and contributing author of this reading, measures the black mangrove growth in the Awa Fogon region.

Photo by Environics, N.V. 1999

As mangroves grow waterward into shallow basins and tidal creeks, sediment and organic matter can accumulate and tidal exchange can become greatly reduced. The edges of tidal basins often become levied. Thus, tidal waters can become trapped and remain somewhat perched as the tide recedes. As tide waters are trapped, persistent high water and subsequent drying of the basins can lead to hypersalinity, all of which can contribute to mangrove die-off. However, mangrove die-off and the establishment of mud flats, salinas, and shallow open waters, provide habitats beneficial to fisheries, shore birds, egrets, ducks, herons and flamingos.

9.2.3. Channelling Issues to improve tidal circulation in mangroves

Channelization to improve tidal circulation can result in excessive drainage and a loss of open shallow water habitats which are dependent upon ridges, vegetation or sand bars to retard run-off and help provide open ponding areas. Channelization may also increase the growth and spread of mangroves; however, this would also reduce the availability of open water areas for flamingos.

For example, efforts to channelize mangrove wetlands in the vicinity of Little Redfish Creek, in Tampa Bay, Florida, resulted in the drainage of a shallow water basin, which then became colonised with mangroves. Dredging of this small basin was then executed to restore fisheries habitats, which had

suffered a net loss in the area. The dredging was an expensive operation, which benefited fisheries while having adverse impacts to killifish, wading and shore bird habitats.

The costs and consequences of altering natural succession in an area as large as Lac Bay need to be carefully evaluated. Even small channelization projects may have long term consequences that may be adverse both to fisheries and to flamingos. Although large areas of mangroves have died in the upper Lac Bay, mangroves are continuing to grow and expand in these same shallow waters. Mangroves located on islands and fronting on the open waters of Lac Bay are continuing to expand their growth waterward.

The tidal creek, Kreek di Pedro, continues to provide drainage and tidal circulation to the backwaters of Lac Bay, and mangrove expansion is occurring concurrently with some mangrove die-off. Aerial photography shows the mangrove canopies are expanding throughout Lac Bay where tidal exchange occurs, however, some mangrove thinning and die-off is also occurring within the interior of the fringing mangrove forests.

9.2.4. Mangrove Management: Discussion and Options

Except for the mangrove die-off in areas of upper Lac Bay, recent and old aerial photographs show an overall increase in mangroves. Geologic processes such as uplift/subsidence in relationship to sea level rise, also need to be understood in evaluating long term management plans.

The salinas, mangroves and the upland vegetation along the northern perimeter of Lac Bay, are subjected to the impacts of grazing, browsing and erosion. A herd of sixteen goats were seen emerging along the north shore of Awa Wanapa where browse lines were quite evident. The fencing of some areas along the road to Cai may help to document and demonstrate the impacts of grazing/browsing.

Some of the off road vehicle traffic is also contributing disturbances to this area, and there is evidence of driftwood harvesting, particularly on the ancient buttonwoods.

Fisheries utilisation of the salinas and mangrove backwaters of upper Lac Bay was quite evident as observed during the second week of March 1999. Fish kills occurring during this low water period, helped dramatise the presence and importance of fisheries and wildlife relationships. During this low water period, numerous flamingos, egrets and herons were observed feeding, particularly in Awa Lodo di Chico.

Salinities ranged from 35 ppt (parts per thousand salt) at Punta Kalbas on March 8, 1999 to 180 ppt at Awa Wanapa on March 12, 1999. Even though salinities measured up to 180 ppt, a large number of killifish were observed dead along the banks. This provides evidence of their ability to thrive in high salinity waters. In Awa Lodo di Chico, or "Flamingo Bay", dead fish such as mojarra (*Diapterus plumeri*) and many small barracuda, were observed in waters where salinities were measured at 89 ppt on March 10, 1999. In the mangrove lagoon, Awa Yuwana Noord, numerous fish, such as mangrove snapper and blue crabs were observed on March 8, 1999 where water salinity was 44 ppt.

The environment of upper Lac Bay needs to be appreciated and evaluated for what it is, a rugged and evolving wilderness. The past and the present are vividly portrayed in aerial photography and on the ground. Perhaps trails, boardwalks, and overlooks may give visitors a glimpse of the area as ecotourism gains popularity.

9.3 Hydrology Alteration: The Importance of freshwater runoff to Lac Bay

Contribution by Randy Cooper, Hydrology Engineer, Florida Dept. of Environmental Protection, Submerged Lands and Environmental Resources Program, Tampa, FL September 19, 1999

9.3.1. Detrimental Effects of Freshwater Flow Alteration

The alteration of surface water runoff into Lac Bay, whether deliberate or inadvertent, may be causing detrimental effects to mangroves and marine life in the upper portion of the bay. Freshwater from rain falling directly into the bay, and flowing indirectly from upland runoff, is needed by the estuarine ecology to counter the effects of evaporation and to bring in valuable nutrients. While the restoration of surface water flow may be beneficial to the bay, future development and poor farming practices within the surrounding drainage basin could cause uncontrolled discharge of pollutants and excessive sedimentation.

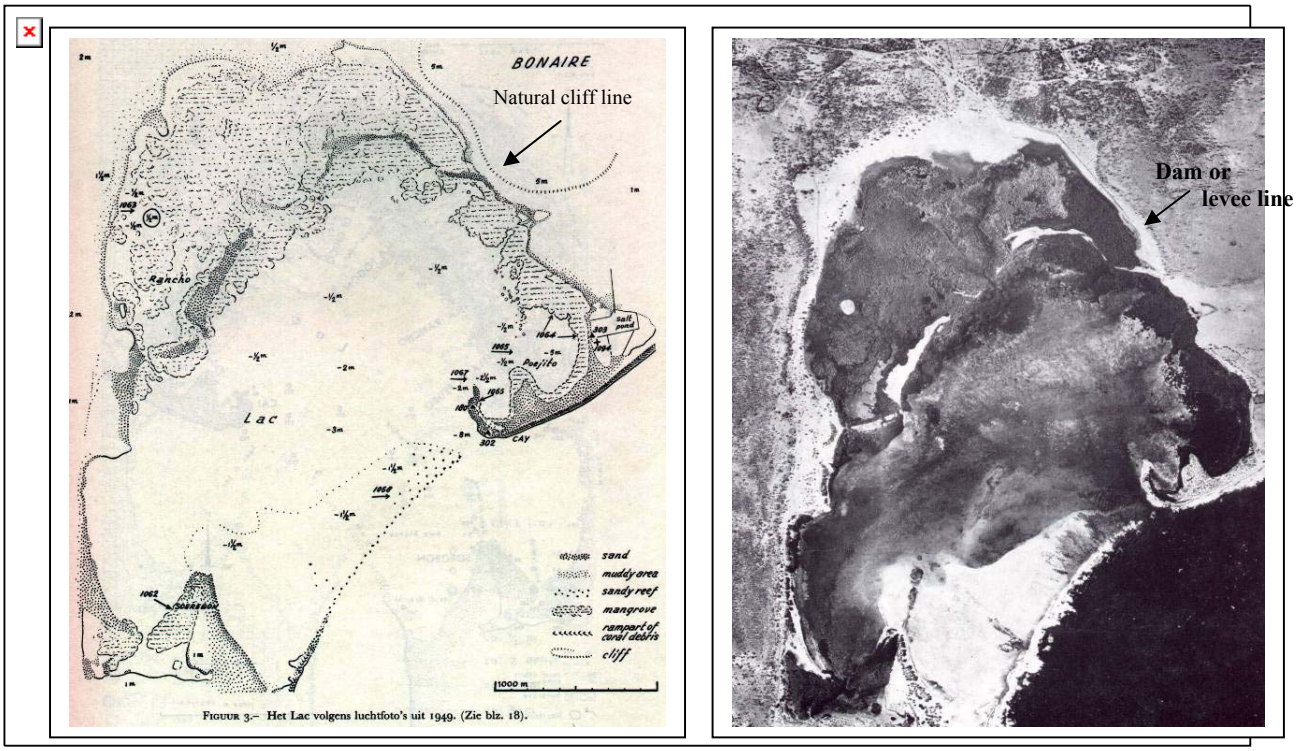
The loss of freshwater from an estuary environment can affect plant and marine life. In the state of Florida, regulations are in place to restrict the alteration of surface water in order to protect wetlands and estuaries. An example of what happens when no consideration is given to surface flow is the Tamiami Trail (U.S. Highway 41) along the west coast of Florida. It was constructed during the early 1950's through the Big Cypress Swamp and still impedes the free flow of surface water to the Everglades, despite the presence of a few culverts.

Two major causes of freshwater alteration from Lac Bay are:

- the construction of dams in the upland areas around the northern drainage basin, and
- the fill for the unimproved road that leads to Cai.

In his 1969 report, Wagenaar Hummelinck seemed to be aware of the importance of freshwater to the bay and stated *"After the rains, the plains north of the Lac would overflow and sweeten the Awa Lodo."* (translated version of the report by Carmita Santiago 1999).

Fill used to create roadbeds can also unintentionally act as a dam and impound the natural flow of water. This can cause detrimental effects to the watershed both upstream and down of the impoundment. Ponding and flooding of water occurs on the upstream side while evaporation and evapo-transpiration can lead to hypersalinity conditions in the downstream waterbody. Overall there are several areas along the unimproved road to Cai, which act as a dam and prevent runoff from entering into the bay. With the



Lac Bay 1949 **Lac Bay1961**

Map 19 Natural cliff alteration into dam, or levee at Rooi Grandi

Apparently the dams began to be constructed around the late 1950's or early 1960's. A large dam at Rooi Grande is clearly visible in the April 1961 aerial photo, as described in Hummelinck (1969) report, but is not visible in the 1949 map. Other dams can also be seen while driving around the area, such as at the Mona Lisa Passage.

(maps adapted from Hummelinck en Roos 1969)

exception of a ±50 foot (±15 meter) long concrete flume constructed within the roadway, few allowances were made for drainage along this road. Judging by the large delta which has formed in to the Awa Lodo di Chico portion of the upper bay, this flume seems to be the main drain for runoff from the Rooi Grande area. While the flume allows for relatively unimpeded flow of water over the road surface, it is somewhat hazardous to any motorist that may be driving along during a rain storm event (see Map 6, page 37).

Kaminda Sorobon, the paved road to Sorobon located along the western edge of the bay, was built with drainage in mind. There are several culverts installed that allow for surface water to drain under the road. However there is a restriction to flow from a cross-drain, which flows directly into the back yard of a single-family residence, located just south of the intersection of Kaminda Sorobon and the road to Cai.

The homeowner appears to be redirecting flows around the yard and into a dam constructed on the property. In addition to this alteration, a large impoundment of water can be seen directly west of Sorobon, as seen in a recently taken aerial photograph.

The impounding of surface water runoff in the northern drainage basin probably has more of an adverse effect on the bay that the damming caused by the Cai road. But to better understand the importance of runoff to the bay, more drainage analysis is needed. It is typical to use topographic maps to identify and delineate drainage basins. These maps should be readily available from a map publisher or the local surveyor's office. When the basin divides are identified on the maps, and also field verified, the quantity of runoff flowing to the bay can be more accurately estimated. Surveyors would be helpful in order to provide details of drainage patterns. Meanwhile, park rangers and volunteers should be encouraged to look for standing and flowing water during and after rainstorms. This is a good and inexpensive way to determine local drainage patterns.

9.3.2. Recommendations to restore freshwater flow around Lac Bay

The following is a brief listing of some projects that may provide some immediate freshwater to the bay and relief to vegetation affected by road fill:

1. Water stains and cracking of drying mud and sediment along the northern side of the road is evidence that runoff is being held back in the Bakuna portion of the Cai road (from the concrete flume to about where the small collection of homesites begins, adjacent to Kreek di Coco). The installation of multiple culverts along the portion of road or even lowering of the roadway surface would help to ensure proper drainage to the bay. Because of safety reasons to motorists, the installation of culverts is preferred over construction of a concrete flume at grade. The number and actual location(s) of culverts would need to be determined after field verification of low areas.

2. Just south of the homesites, roughly between Boca di Coco and Boca di Pos, is a small unnamed depressed area which appears to have been cut-off from the bay by road fill. A 1949 photo from the Hummelinck report (Map 17) shows that this area was previously connected to the bay. A strategically placed culvert would allow for this mini-salina to have a two-way inundation of tidal and freshwater to and from the bay. Just south of this area and north of the abandoned salt works is an area (Awa 'D'), containing dwarf mangroves that also appears to be cut-off from the bay. Although freshwater drainage contributions to the bay appear to be minimal in this area, one or two culverts under the road in

this vicinity would help to allow for the two-way exchange of water to areas previously severed by the road construction.

3. The abandoned salt works adjacent to Awa Puitu also holds back surface water. In consideration to the large number of flamingos, which feed at this site, the area should not be allowed to completely drain to the bay. When walking around the area one can see evidence that excess runoff fills up the surrounding area before eventually overtopping the road. One way to prevent erosion of the road and allow some replenishment of freshwater in the salt works and Awa Puitu is to simply provide a pop-off at an elevation lower than the road surface. A drainage study would be needed in order to determine the exact location and elevation for this control structure and culvert.

9.4 The Sorobon Area: Shoreline assessment and recommendations

Contribution by: Rob Patten, President, Coastal Dunes, Inc., Sarasota, FL, February 24, 2000

9.4.1. Introduction

Coastal Dunes, Inc. was asked by the Bonaire Marine Park to:

1) review current shoreline conditions at Sorobon and Cai beaches at Lac Bay,
2) make recommendations for the future management of these areas, and
3) review and comment on existing restoration and landscaping plans.

After reviewing historical information and park records and discussions with local scientists and residents, site visits to Lac Bay were conducted with park and government personnel during the week of February 7 – 14, 2000. The following are our conclusions and recommendations:

9.4.2. Sorobon Beach

The beaches of Sorobon are under considerable environmental pressure. Native coastal vegetation has been removed, the beach is eroding and attempts at shoreline protection (seawalls, sandbags, etc.) appear to create more problems than they solve. Erosional tendencies will continue at Sorobon unless some remedial measures are taken

First, use of the Northwest beach area for sand mining and extraction should be discontinued. Removal of sand at this updrift location most likely creates a sediment 'sink' and disrupts the littoral, or shore parallel, drift of sand that would naturally nourish or 'feed' the downdrift beaches.

Attempts at halting erosion at Sorobon are evidenced by the presence of sandbags and seawalls at the Sorobon Beach Resort and the construction of small rock groins and wooden retaining walls at the (windsurfing places). In most cases, these shoreline stabilisation structures only exacerbate the erosional pressures on the beaches, as they trap sand on the updrift (or south) side of the structures, thereby creating sand deficits on the downdrift (or north) sides of the structures.

The placement to two large wooden privacy fences into the water at the Sorobon Beach Resort has had the unintentional effect of negatively affecting the beaches of its neighbors to the north.

Figure 48 Sandbagging at Sorobon

Attempts at halting erosion at Sorobon are evidenced by the presence of sandbags and seawalls at the Sorobon Beach Resort.

Photo by Sorobon Beach Resort 2008 Internet

Figure 49 Barrier

Removal of the lower sections of fence that are below the waterline would greatly help the beaches to the north [for sand renourishment].

Photo by Coastal Dunes, Inc. 1999

The north fence, in particular, is having the effect of a shore-perpendicular groin and effectively traps sand that would otherwise be made available to the downdrift beaches. Removal of just the lower sections of the fence that are below the mean high water line would greatly help the beaches to the north, without compromising privacy.

One other factor contributes to the shoreline erosion at Sorobon, namely the removal or inadvertent destruction of near-shore seagrass beds. Seagrass beds serve to stabilise the nearshore, sub-tidal beach by binding sediments with their roots. When these beds are removed the nearshore environment becomes progressively unstable and sand is lost to the system. The existing windsurfing businesses have designated pathways through the grasses in front of their areas in an attempt to minimize the damage, and this is to be commended. However, more needs to be done. The remaining seagrass areas should be clearly marked with buoys or floating line to guide windsurfers from the beach to the launch area.

Figure 50 Seagrass destruction

Seagrass areas should be clearly marked with buoys or floating line to guide windsurfers from the beach to the launch area.

Photo by Coastal Dunes, Inc. 1999

9.4.3. Management recommendations for protecting and restoring the beaches of Sorobon

- Discontinue the extraction of sand from the beaches and nearshore areas south of the Sorobon Beach Resort.
- Remove the lower section of the two wood privacy fences to allow an uninterrupted flow of sand to downdrift beaches. Removal of only those fence sections below the mean high water line would have a very positive impact on downdrift beaches.
- Remove the sandbags and fill from around the landward terminus of the dock at Sorobon Beach Resort and rebuild that portion of the dock as a pile-supported structure. This would allow for a natural movement of sand and tend to reduce the need for constant sand renourishment at this beach.
- Clearly mark the boundaries of the remaining nearshore seagrass beds to prevent further destruction.
- Protect the remaining native beach and dune vegetation. Dunes act as a reservoir of sand that is available to renourish the beach after large storms. Native vegetation traps and accumulates wind-blown sand and serves to stabilise and build the dune. Removal of this vegetation will destroy the dune and eventually jeopardize the stability of the beach.

The beaches of Sorobon are a valuable resource to the Bonaire community and I am hopeful that these recommendations can be implemented to protect them. Thank you for contacting Coastal Dunes, and feel free to call should you have any questions.

9.5 Seagrass ecology and predation by Green Turtles, Chelonia mydas *in Lac Bay*

Contribution by Claudia de Kort , Bonaire Sea Turtle Club Student Intern, Amsterdam, Holland

9.6.1. Sea grass

Sea grass communities are very important ecosystems. They provide not only food, shelter, breeding- and nursery grounds for a variety of marine organisms, but they also play an active role in stabilizing the sediments (Zieman et al 1997). Sea grass ecosystems are among the most productive in the world. They usually can be found in relatively shallow waters (McRoy and McMillan 1977). Throughout the world, approximately 57 species of sea grasses have been recorded (McCook 1998).

Sea grasses are true flowering plants that have adapted to living in submerged marine environments. Flowering plants (Angiospermae) have true roots, stems, flowers and leaves. Sea grasses usually live together in seagrass beds or seagrass meadows. Sea grass beds are the dominant tropical shallow water marine community worldwide. Important sea grasses in the Caribbean coastal ecosystems include: *Thalassia testudinum* (turtle grass), *Syringodium filiforme* (manatee grass), *Halodule beaudettei* (shoal grass).

The anatomy of a sea grass is similar to that of any other grass. The horizontal rhizome anchors in the stem and grass blades that push up through several centimetres of sediment. The rhizomes anchor the plant in soft sediment, and often intertwine to form dense mats. The growth of sea grass is dependent on the sediment depth. As the sediment depth increases, the sea grass bed elevation will increase to form a bank, the leaf density (leaves per unit area) will increase and the leaf length will increase.

Within sea grass communities, a variety of benthic algae, phytoplankton and epiphytic algae growing on the sea grass blades can be found. Epiphytes are organisms living on the stems and leaves of sea grasses. Older leaves may be completely covered with epiphytic algae. A variety of animal species use the sea grasses as food source, like the Queen conch (*Strombus gigas*), sea urchins, fishes, dugongs, manatees and sea turtles (Sullivan et al 1991).

In the Caribbean, the two most abundant species of seagrass are *Thalassia testudinum* (turtle grass) and *Syringodium filiforme* (manatee grass). Other species of seagrass also exist but are not as common (Den Haring and Renshoff 1999).

On Bonaire, important sea grass areas are Lac Bay and Lagoen, both bays at the east side of the island (Valkering et al 1996). Both bays are believed to be important foraging areas for Green turtles (*Chelonia mydas*). Numerous Bonairian fisherman and volunteers of the STCB have reported sightings of foraging Green turtles in Lac Bay (Valkering et al 1996, Den Haring and Renshoff 1999). The dominant sea grass species in Lac Bay and Lagoen is *Thalassia testudinum* (Den Haring and Renshoff 1999).

9.5.2. Green turtles (Chelonia mydas)

For the conservation of a species, it is important to know more about the foraging behaviour of the species. This is the closest interaction of an organism and its environment. If we want to try to understand the role of sea turtles in marine ecosystems, we need to understand the quantitative aspects of the diet selection, digestive processing and nutrition and we need to try to elucidate how nutrition acts as regulating mechanisms in the reproduction of sea turtles (Lutz and Musick 1998).

Hatchling and post-hatchling Green turtles, like other marine turtles, are chiefly carnivorous (Hirth 1997). During this life stage, they feed on jellyfishes, small molluscs, crustaceans, sponges and other tiny creatures (Ripple 1996). When green turtles reach a carapace length of 20-25 cm, they leave their pelagic life phase and return to coastal water (near shore and estuarine habitats) (Zug and Glaor 1998). They switch to a predominantly vegetarian diet, which they will keep throughout their adult lives (Ripple 1996). The main diet of juvenile and adult Green Turtles is benthic algae and sea grasses (McCook 1998, Hirth 1997, Work and Balazs 1999) and therefor, they spend most of their lives in shallow bays and near-shore areas where these plants are present (Balazs 1980, Bjorndal 1985, Balazs et al 1987, Bjorndal et al 1991, Collazo et al 1992, Morreale et al 1992, Ripple 1996). The turtles have significant effects on the nutrient cycling and community structure of the seagrass beds they forage upon (Thayer et al 1982, Thayer et al 1984). Besides the seagrasses and algae, Green turtles are also known to consume animal matter including jellyfishes, salps and sponges (Mortimer 1981, 1982).

The lower jaw of Green turtles is serrated, which makes it more suitable for tearing the sea grasses (Ripple 1996, Lehrer 1990). Most studies on the diet of green turtles are examinations of stomach contents of large individuals (Hirth 1997).

In Kaneohe Bay, Hawaii, Green Turtles forage on several kinds of benthic algae, including *Acanthophora*, *Hypnea, Codium, Amansia*, as well as *Halophila hawaiiana*, the sole sea grass in the Hawaiian Islands (Balazs et al 1998). Green turtles in the Torres Strait eat both algae and sea grass. The algae appear not to have a higher nutritional value compared to sea grass (Garnett et al 1985).

The sea grass, *Thalassia testudinum,* is the primary diet species for the green turtle in the Caribbean (Bjorndal 1980, Bjorndal 1982, Lutz and Musick 1997). In a study on the stomach contents of 202 Green turtles, captured at the Caribbean coast of Nicaragua, 87% of dry mass was *T. testudinum*. Five percent of the stomach contents were other sea grasses, including *Syringodium filiforme* and *Halodule wrightii* (Mortimer 1976). Fourteen turtles studied near the Cuban coast, foraged primarily on the sea grass *T. testudinum* and on the sponge *Chondrilla nucula* (Acevedo et al 1984). In a lagoon in Florida, the main diet components were the sea grasses *S. filiforme* and *H. wrightii*. The sea grass *Halophila engelmanni* and some red and green algae were also found in smaller amounts (Mendonca 1983).

The turtles usually feed on the young, short leaves of the sea grass. These contain more nitrogen (an important nutrient) and less lignin compared to old leaves. Lignin is an indigestible plant constituent and lowers the digestibility of other structural elements in the plants. Green turtles establish and maintain grazing plots, recropping plots of *T. Testudinum* that they previously grazed (Bjorndal 1980, Ripple 1996). Therefor, feeding patches of green turtles in a bay can be recognised by the short leaves of the sea grass (Bjorndal 1980). This foraging behaviour can be evolved by the turtles to avoid the epiphytic carbonate of the upper regions of sea grass leaves (Zieman et al 1984). However, in a stressed pasture in the Virgin Islands, Williams (1988) observed that the green turtles ate all accessible *T. testudinum*. Foraging habits of Green turtles can be determined by the relative abundance of different sea grass species and feeding selectivity of the turtles (Balazs 1980). While slowly moving over sea grass beds and algae patches, Green turtles visually scan the potential foraging area. This scanning behaviour and differences found between sea grass and algae species available and consumed can be an indication that Green turtles feed selectively (Sazima and Sazima 1983). Diet selection of the turtles will not only be influenced by the availability of species, but also by the presence of microbial communities in their digestive tract. These microbial communities play an important role in the digestion of seagrasses and algae (Bjorndal 1980, 1985).

The average intake of sea grass of green turtles with a weight ranging from 7 to 68 kg., is 24 to 214 gram dry mass per day per turtle (Bjorndal 1980, Williams 1988). The studied turtles were mainly feeding on *T. testudinum* and were foraging in the Greater Caribbean. Green turtles at a *T. testudinum* site

in the Bahamas consume the equivalent of about 0.24% to 0.33% of their body weight every day (Bjorndal 1980). The carrying capacity of a *T. testudinum* feeding pasture in the Caribbean was estimated at one turtle per 72 m^2 (Bjorndal 1982). In a stressed *T. testudinum* pasture in the Caribbean, Williams (1988) estimated a carrying capacity of one turtle per 669-3,946 m^2.

The foraging behaviour of Green turtles is characterised by numerous short dives (4-8 min.) in shallow water (<3 m.) with short surface intervals (few seconds). Resting periods are characterised by longer dives (20-117 min.) in deeper water (4-14 m.) with long surface intervals (average 2.8 min.) (Balazs 1980, Rice et al 1998).

In Bonaire, the green turtles swim into Lac Bay during the night and feed on the sea grasses there. In the morning, they swim out of the bay again and reside on the reef nearby during the rest of the day (Van Eijck 1994). The turtles might prefer to forage at night in Lac Bay, because of the less disturbance by boat traffic in the bay at night. In other studies, green turtles were also observed to feed at night (Bjorndal 1980, Ogden et al 1983, Balazs et al 1987). In a research of Brill et al (1995) is shown that Green Turtles in Hawaii prefer to stay in shallower water, where sea grass beds are abundant, at night, compared with their submergence depth in the daytime. However, Balazs et al (1987) found that the tidal cycle is more important in determining foraging times of Green turtles in Hawaii, than is the diurnal cycle. Furthermore, Hirth (1997) concluded in his literature study on Green turtles, that juvenile and adult green turtles have been recorded feeding at all hours of the dial cycle, but daytime records predominate (Hirth 1997). Rice et al (1998) state that the green turtles in Hawaii foraged primarily at night before they were protected by law in 1978. After they became protected, they begun to feed primarily during the daytime (Rice et al 1998).

9.5.3. Lac Bay project Bonaire Marine Park (BMP)

In 1999, Bonaire Marine Park (BMP) initiated a research and monitoring program for the distribution and abundance of the Queen Conch (*Strombus gigas*) and seagrass characterization in Lac Bay . The complete program was under supervision of marine biologist, Cindy Lott (Lott 2000). STCB participated in this program, with special interest in the research on the seagrass in the bay. Detailed information on the complete program can be found in Lott (2000). Whenever encountered during a survey, the presence of turtles and their characteristics were noted. Grid surveys were conducted from July till September 1999.

-Lac Bay project STCB

Lac Bay is thought to be an important feeding area for Green turtles in Bonaire. In the bay the seagrass species *Thalassia testudinum* (Turtle grass) is abundant. Green turtles recrop the same area of sea grass over and over again (Bjorndal 1980, Ripple 1996). Therefor, feeding areas of Green turtles should be recognized by sea grass beds with short, cut off leaves, compared to sea grass beds with long leaves with a smooth edge (De Meyer pers. comm.). Snorkel surveys, with a manta tow, were carried out by STCB in Lac Bay to found out if areas of sea grass with obvious short leaves were present. In these areas, the sea grass is very likely preyed upon. However, a lot of organisms live in Lac Bay, who are possible predators on sea grass, including rays, conch and sea turtles (Den Haring and Renshoff 1999; Lott 2000).

9.5.4. Results

-presence

In total, 532 sightings of Green turtles were reported to STCB in 1999. Along the main island of Bonaire, 416 turtles were observed at 62 different sites. A top ten was made of the dive locations, where Green turtles were most frequently were sighted, after a correction on the data was made. In Table 1 the top ten is listed.

Table 1: Top ten dive sites, where Green turtles are most frequently sighted along the coast of the main island of Bonaire in 1999.

Number	Dive site
1	White Hole
2	Margate Bay
3	Baby Beach
4	Pink Beach
5	Andrea I
6	Windsock
7	Plaza resort
8	Marcultura
9	Andrea II
10	Small Wall

Around Klein Bonaire, 116 sightings of Green turtles were reported to STCB in 1999. The turtles were observed at 21 different dive sites. After a correction on the data was carried out, a top five of the dive sites was made where Green turtles were most frequently seen in 1999. The top five list is shown in Table 2.

Table 2: Top five dive sites at Klein Bonaire, where Green turtles were most frequently reported in 1999.

Number	Location
1	Jerry's Reef
2	Sampler
3	Ebo's reef
4	No Name
5	Leonora's Reef

-observations

About 125 surveys were carried out by STCB. In total, 526 sightings of Green turtles were reported to STCB via the sighting sheet network. Five percent (26) of them were reported to be foraging. Only one adult Green turtle with an estimated carapace length of >100 cm. was observed foraging. The food item this turtle was eating was undetermined. Nine juveniles or sub-adults with an estimated carapace length between 50 and 100 cm. were sighted foraging and fifteen juveniles with an estimated carapace length between 20 and 50 cm. Of one foraging turtle, the size is not known.

Sightings of foraging turtles were reported at all times of the day, between 9:00 and 16:30. The Green turtles were observed foraging at various depths between three and 35 m., with an average of eleven m. Turtles were reported foraging at different locations, primarily at the south-west coast of Bonaire. The turtles were never seen foraging in Lac Bay.

The food item the turtle was eating, was undetermined in 46% (12) of the observations. Nineteen percent (5) of the observed foraging turtles were reported to eat something on a coral and twelve percent (3) to eat coral. Two Green turtles were observed eating algae and two eating dead coral. Once, a Green turtle was sighted eating a purple tube sponge and once eating a sea anemone. Green turtles were never reported eating sea grasses.

-Lac Bay project BMP

In Table 3, an overview is given of the average measured data per grid. Results of grid 5, 6 and 17 are printed in italic, because these data were excluded for the analysis. Grids 5, 6 and 17 (near Secu di Sorobon and Awa di Blanku areas) are primarily all bare sandy bottom with no seagrass benthic coverage.

Thalassia testudinum (turtle grass) is the most abundant seagrass in Lac Bay. The average coverage of *T. testudinum* in the fourteen analyzed grids is 26-50% coverage per m^2. The macro-algae in the bay have a mean coverage of 5-25% per m^2. Mean densities for epiphyte cover on the seagrass blades

were estimated between light and moderate. The mean seagrass blade length measured was 14,0 cm. and the mean seagrass blade with was 1,0 cm. On average, 7,9 short shoots were counted per 0.125 m^2 within the sampling area (Table 3).

Table 3: Average coverage of *T. testudinum* and macro-algae, average epiphyte-density, blade length, blade with and number of short shoots, per grid.

Coverage code: 0=0-1%, 1=1-5%, 2=5-25%, 3=26-50%, 4=51-75%, 5=76-100%.
Epiphyte density code: 1=none, 2=light, 3=moderate, 4=heavy.
Results of grid 5, 6 and 17 are printed in italic, because these results are excluded for the analysis.

Grid	Average coverage		Epiphyte density	Blade length	Blade with	# of short shoots
	T. testudinum	Macro algae		(cm)	(cm)	(per 0,125 m^2)
1	3,1	2,7	2,6	16,7	1,2	6,0
2	3,2	2,2	2,0	16,4	1,2	4,2
3	4,1	1,8	2,7	18,1	0,9	6,2
4	2,0	2,6	2,1	14,5	0,6	3,5
5	*0,3*	*0,9*	*1,3*	*1,5*	*0,3*	*0,2*
6	*0,8*	*1,4*	*2,2*	*3,0*	*0,4*	*0,9*
7	2,1	2,5	3,1	9,1	0,8	6,4
8	2,5	2,4	2,8	12,4	1,6	6,9
9	3,1	1,6	2,4	13,2	1,0	3,4
10	3,7	2,2	2,5	13,9	1,1	6,1
11	4,0	1,8	3,0	15,9	1,2	10,1
12	4.0	1.5	3.3	21.4	1.0	1.2
13	1,4	0,9	1,1	8,0	0.9	5,7
14	2,8	1,8	2,1	11,7	0,8	10,7
15	3,7	2,4	3,1	17,8	1,3	12,1
16	3,6	1,9	2,3	16,2	1,0	14,6
17	*1,0*	*1,9*	*1,6*	*4,0*	*0,7*	*3,3*
Mean:	3.1	2.0	2,5	14	1,0	7,9

During the surveys in Lac Bay, no foraging turtles were encountered.

-Lac Bay project STCB

During snorkel surveys in Lac Bay with a manta tow, several areas were discovered with short sea grass blades. Three recropped sea grass areas were marked with a buoy, so they could easily be found back. The area of the three marked places was approximately ten m^2.

Because financial lost and shortage of time, STCB decided to cancel the excluding experiment with the cages and to carry out only the biomass study and the productivity study, according to the CARICOMP method. Then, a comparison could be made with the results of last year. However, these

studies were postponed for several times due to extreme bad weather, including a hurricane, which resulted in a shortage of time. Therefor, the biomass and productivity studies according to the CARICOMP method could not be carried out.

9.5.5. Discussion

-presence

Sightings of Green turtles were reported to STCB in 1999 at various different places along the west and south-east coast of the main island of Bonaire. However, in Table 1, a top ten list is shown of locations where Green turtles were most frequently encountered in 1999. When the different locations are related to the map of Bonaire, four hot spots can be determined:

- south east coast (including White Hole, Marcultura and Baby Beach)
- south west coast (including Margate Bay and Pink Beach)
- Airport-area (including Windsock and Plaza resort)
- mid-west coast (including Andrea I, Andrea II and Small Wall)

The south east coast appears to be the most important hot spot for Green turtles. The location where Green turtles were most frequently is White Hole, near Lac Bay. Lac Bay is thought to be an important feeding area for Green turtles (Valkering et al. 1996). During a one hour snorkel survey by STCB at White Hole, eighteen different Green turtles were observed. The large number of Green turtles sighted at White Hole near Lac Bay, supports the hypothesis that Green turtles rest during the daytime just outside Lac Bay (Van Eijck 1994). At Baby Beach, the maximum number of Green turtles encountered during a survey, was nine. Lagoen is also considered to be an important feeding area for Green turtles (Valkering et al 1996). Only two dives were made in 1999. On one dive, seven different Green turtles were observed. At all other locations around Bonaire, the maximum number of Green turtles sighted during one survey was four.

In Table 2, the top five is shown of dive sites where Green turtles were most frequently sighted in 1999 around Klein Bonaire. All five dive sites are next to each other, at the north east coast of Klein Bonaire. Hot spot for Green turtles at Klein Bonaire appears to be from Jerry's Reef to Leonora's Reef. Most Green turtles were spotted at the east coast, at Jerry's Reef.

Locations where Green turtles are most frequently seen are not necessarily important feeding sites. However, it is very likely that turtles will be observed close to the place where they find their food.

According to the sighting sheets returned to STCB in 1999, Green turtles were encountered along almost the complete coast of Bonaire main island and all around Klein Bonaire.

-observations

Green turtles were never observed foraging in Lac Bay by STCB in 1999. In 1998, one Green turtle was observed foraging in Lac Bay by STCB. This turtle was heavily afflicted by FP tumors. The disease appeared to seriously affect the (foraging) behavior of the turtle (Den Haring and Renshoff 1999). However, Lac Bay is believed to be the most important feeding area for Green turtles in Bonaire, since large sea grass beds can be found there. Local fishermen have reported sightings of foraging Green turtles in the bay in the past (Den Haring and Renshoff 1999). All surveys in 1999 in Lac Bay were carried out in daytime. The turtles are thought to enter the bay at night for foraging and leave the bay in the morning, to rest on the reef in daytime (Van Eijck 1994). This hypothesis can not be validated yet, because no surveys were carried out at night.

Turtles were observed foraging at various times during day time. No observations were reported to STCB during the night, probably because very few dives are made at night in Bonaire. Therefore, it can not be concluded from the data gathered that Green turtles only forage in daytime. Green turtles were observed foraging at various depths ranging from three to 35 meters. However, Green turtles appear to forage mainly in shallow waters (<3m.) (Balazs 1980, Brill et al 1995, Rice et al 1998).

Most of the sightings of foraging Green turtles were reported to STCB by tourists via the sighting sheet network. Tourists can easily mistake the food item they think the turtle is foraging on. For example, when a turtle was reported to be eating coral, it is more likely that the turtle was eating algae growing on the coral. In 1999, Green turtles were never reported to be observed eating sea grass. However, sea grass is believed to be the most important diet component of Green turtles in the Caribbean (Bjorndal 1980, Bjorndal 1982, Lutz and Musick 1997).

-Lac Bay project BMP

Sea turtles are expected to be foraging in Lac Bay in area with dense sea grass beds, thus with a high percentage of *T. testudinum* coverage. Grids with a high *T. testudinum* coverage are grid 3, 10, 11, 12, 15 and 16 (Table 3). Grids 10, 11, 12, 15 and 16 are close to each other in the northern area of the bay. The grids are all near the channel where turtles enter the bay. Blade lengths and epiphyte density in these grids are relatively high. When turtles forage in dense seagrass beds, they feed in the same areas for

several times in order to feed on fresh, young seagrasses (Bjorndal 1980, Ripple 1996). These feeding areas are likely near the dense seagrass areas, but with less density of seagrass beds, short leaves and low epiphyte density. Grid 13 and 14 are in the middle of grids 10, 11, 12, 15 and 16. These grids have seagrass with shorter blade lengths and low epiphyte density (Table 3). Therefor, it might be possible that this area is an important feeding area for turtles, resulting in shorter seagrass blades and low epiphyte coverage. The density of *T. testudinum* is low in grid 13 and 14. It might be that grid 13 and 14 had dense seagrass beds in the past like the surrounding grids, but because of repetitive preying of the turtles, the density decreased.

Besides, grid 13 and 14 are in the same area as where STCB has found recropped seagrass beds. Because locations where the surveys of STCB were carried out were not exactly positioned with the help of GPS, it is difficult to compare the results of the BMP study with the results of the STCB study on seagrass in Lac Bay.

The low density of seagrass and the shorter blades lengths in grid 13 and 14 could also be caused by high current in the area. The grids are close to the channel. However, lower density and blade lengths are then also expected in grid 16, next to the channel. Grid 16 has a high seagrass density and long seagrass blades. The current appears to have little or no influence on the growth of seagrass.

The density of seagrass beds in grids 1, 2, 4, 7, 8, and 9 and low compared to grids 10, 11, 12, 15 and 16. However, the blade lengths and epiphyte coverage in these grids are high, which does not point to a low density because of predation.

In areas predated by sea turtles, relatively more young fresh leaves might be expected, due to recropping of the sea turtles on seagrass beds. Therefor, next to a lower density and shorter leaves in a foraging area of turtles, a higher number of short shoots and a less blade width of the seagrass might be expected. The number of short shoots in the northern part of the bay appears to be higher compared to the southern part of the bay. However, no correlation could be found between the density of the seagrass beds and the number of short shoots. In grids 13 and 14 no extreme numbers of short shoots were found. It is not known what influences the number of short shoots in the seagrass beds in Lac Bay. The blade width is very diverse in the bay. No conclusions can be drawn from the measurements of blade width of seagrass blades in Lac Bay.

-Lac Bay project STCB

Several areas were found in Lac Bay with short, green sea grass leaves of *Thalassia testudinum*. Although it is very likely that the grass is preyed upon by Green turtles (Van Eijck 1994, Den Haring and Renshoff 1999), this could not be proven. In 1999, a Green turtle was never observed foraging in Lac Bay. And because the excluding experiment could not be completed, no evidence was found experimentally either.

9.5.6. Recommendations

-presence

Locations where most Green turtles are seen around Bonaire, are probably (close to) important feeding areas for the turtles. Therefor, it is important to determine hot spots, where Green turtles are most frequently seen.

In the present study, sightings of Green turtles around Bonaire are corrected with a correction factor related to the number of sighting sheets collected by different dive shops in 1999. It might be better to correct the sightings of Green turtles with a correction factor related to the popularity of the dive-site. To determine the popularity of different dive sites, a questionnaire can be held among divers on Bonaire. In this questionnaire, the divers can be asked which dive sites they visited, why they visited these dive sites (for example randomly or recommended by somebody), if they visited (or are planning to visit) some dive sites more than once and if they liked the dive sites they visited (and why; many fishes, many corals, etc.).

When the answers of this questionnaire are analyzed, a popularity index can be given to each dive site. The number of sighting sheets returned for each dive site, can be corrected in relation to the popularity of each dive site. In this way, one sighting of a Green turtle at a popular dive site has less value compared with a sighting at a non-popular dive site. An effort is made to reduce the value of different sightings of the same turtle at the same location.

At the east coast of Bonaire, seagrasses are more abundant compared to the west coast of Bonaire. Especially Lac Bay and Lagun have large seagrass beds. It is likely that the majority of Green turtles live at the east coast of Bonaire. More surveys need to be carried out at the east side of Bonaire to confirm the hypothesis that most Green turtles live at the east coast. Surveys should not only be carried out near Lac Bay, but also near Lagun and other locations at the east side. Whenever possible, a survey could be carried out near, for example, Playa Chikitu. In 1999, an adult female Green turtle was observed at Playa Chikitu making a nest attempt (see “Beach Surveys).

-observations

Green turtles are thought to forage in Lac Bay and Lagun on Bonaire. They are believed to enter the bays at night for foraging and leave the bays in the morning to rest outside the bays on the reef (Van Eijck 1994). In 1999, surveys were only carried out in Lac Bay in the daytime. Surveys could be carried out very early in the morning (sunrise). The turtles are thought to leave Lac Bay through a channel, near Lac Cai. Therefor, the very early surveys could be carried out near this channel. Turtles, which have been foraging in the bay at night, may be encountered on their way out of the bay back to the reef. If possible, surveys could be carried out at night, to be able to observe the turtles while foraging upon the sea grass in Lac Bay. However, precautions should be made, not to disturb the animals while feeding. Besides surveys near and in Lac Bay, surveys could also be carried out near Lagun and maybe more locations at the east coast of Bonaire.

-Lac Bay project BMP

The cooperation between BMP and STCB has been very well. Due to the cooperation, a more extended study could be carried out in Lac Bay. The research in Lac Bay resulted in valuable data for both organizations. If possible, it is good for future STCB students to work together with other organizations.

-Lac Bay project STCB

By carrying out snorkel surveys in Lac Bay systematically, all areas with recropped sea grass blades can be determined. The areas of all these locations could be measured. By comparing the total area of the different recropped sea grass locations with the total area of Lac Bay, the percentage area of sea grass beds foraged upon in Lac Bay can be determined.

The excluding experiment could be done again. With the excluding experiment, the possible predators, e.g. the Green turtles, on the sea grass could be determined. It is not sure whether the cages in the 1999 project were stolen or washed away. Therefor, the cages need to be attached to the sediment very tightly, so they can not wash away. Furthermore, other users of Lac Bay, including local fishermen, should be informed about the cages in the water.

If possible, a camera could be attached to (one of) the cages. The direct environment of the cages could be filmed and maybe a foraging turtle near a cage could be caught on film. The excluding experiment could be carried out as described in Materials & Methods. A sea grass biomass study can aid

in determining the relative 'health' for a sea grass community. Measurements that can be done on the sea grass in the different treatments are:

- mean number of shoots per unit area
- mean number of blades per unit area
- mean number of blades per shoot
- mean (maximum) blade length (cm)

Before a field survey can be started, the size of the sea grass site should be determined, as well as the placement of line transacts, quadrate size and number of quadrates that will be sampled. Information that needs to be collected in a sea grass biomass survey: Name of the site, date, transact #, quadrate #, sea grass species, number of shoots, number of blades, maximum and/or average blade length per shoot (cm) and/or quadrate. (Sullivan et al 1991).

With the help of the biomass and productivity study, according to the CARICOMP method, the amount of sea grass per m^2 eaten by the predators could be determined. Green turtles studied in the Greater Caribbean, foraged mainly upon *T. testudinum*. These turtles, with a body weight ranging from 7 to 68 kg. were found to eat 24 to 214 grams of dry mass per day per turtle (Bjorndal 1980, Williams 1988). At a *T. testudinum* site in the Bahamas, Green turtles were found to consume 0.24% to 0.33% of their body weight every day (Bjorndal 1980).

With the determined area of sea grass beds which is foraged upon in Lac Bay and with the data of the amount of sea grass eaten per day per m^2 in Lac Bay, an estimation could be made of the number of turtles foraging in Lac Bay. Besides studying the sea grass in Lac Bay, also algae could be studied. The presence of algae can for example be compared in undisturbed sea grass areas and recropped sea grass areas.

Most of the research on the foraging behavior is done in Lac Bay. However, at other locations, including Lagun, surveys should also be carried out. By doing more surveys at different locations along the (east) coast of Bonaire, more areas could be discovered with large sea grass beds. At these locations, surveys could be conducted to determine the possible presence of recropped sea grass areas. Similar research as described for Lac Bay, could be carried out in these areas.

10. Summary of Environmental Management Recommendations for Lac Bay

10.1 Evaluating environmental symptoms and stress to establish a conservation strategy

This Site Characterization study of Lac Bay was conducted for the Lac Bay project (De Meyer 1998) to fulfil the Objective 10:

> *Establish research and monitoring programs to monitor the health of the system and effectiveness of the management plan*,

The method to complete this objective was accomplished first, through summarizing all scientific research literature and monitoring programs that were conducted about the Lac Bay area, over the course of the 20th Century. This strategy provided a historical perspective in order to assess environmental change in Lac Bay over approximately 100 years. Second, the results of these prior studies were evaluated by comparing them with the recent environmental monitoring and assessments that were conducted in Lac Bay during March 1999 – March 2000 by the author of this report. These comparisons have provided clues for detecting *symptoms* of environmental change over a long-term window of Lac Bay, based on visible or measurable changes observed by scientists. The results of this environmental evaluation of change have been discussed in details throughout this report. Some of the symptoms found may or may not be linked to human activities. Regardless of the *source*, each places an effect upon the biological function of the system, or the organism. Clearly, natural phenomenon, such as the September and March solstice effects on the tidal circulation in the mangrove sub-basin areas, can impart significant changes in the coastal ecosystem. Therefore, the information in this report does reflect observations of apparent change in the ecosystem structure and function of Lac Bay, i.e. in the seagrass, mangrove and sandy beach communities, with an evaluation of the symptoms that are effecting them.

The *symptoms*, the *sources*, the *stressors*, and the resulting *biological response* to them on a natural community or marine resource in Lac have been set up in categories in the following Table 7. The *stressors* listed in the Table 7 summarize the impacts resulting from either human activities or natural causes, which, in turn, affect organisms and ecological processes. They were derived from the implications of scientific study that have been explained throughout this report. [Further identification of

these symptoms and stressors were discussed by additional experts in Section 9, who participated in the March 1999 - March 2000 field studies with the author].

In defining symptoms and stressors on an ecosystem, the human dimension must be factored into the evaluation process. Humans are also a part of the landscape that often results in "…adverse changes to the environment…" (Sullivan et al. 1996). The impacts of human activities on an environment can result in acceleration, slowing or short-circuiting of a natural process, or the complete removal of a natural process (Sullivan et al. 1996; Lugo and Snedaker 1974). For example, the effects of road construction and the development of the Mona Lisa levee have implications for the alteration of the periodic fresh water sheet flow that once drained into Lac's mangrove sub-basins. Wind surfing or snorkelling activities in the soft sediment, shallow seagrass beds may cause "trampling" effects in the seagrass community, and the displacement of marine life requiring that habitat. Thus, the rate and intensity of human activities on an environment may also influence an ecosystem function, and are a consideration in determining appropriate conservation strategies (Alongi 1998; Lobban and Schefter 1997).

However, often the potential human effects on a natural system are difficult to segregate because these human disturbances may persist as "…low level, chronic stressors…" (Sullivan et al 1996). This means that there may not be sufficient immediate human impacts to significantly degrade a natural process. But when factored together over time with natural disturbances, they may combine enough to effect changes in organism and community distributions, or ultimately, alter ecological processes (Alongi 1998; Lobbana and Schefter 1997; Sullivan et al 1996). For example, the daily, low level trampling on seagrasses by windsurfers or snorkelers may appear insignificant, but cumulatively, may contribute to re-contouring the bay bottom, that not only causes erosion effects, but changes near shore current regimes. Or, the occasional but chronic and indiscriminate taking of nursery conch may, over the years, change the species abundance and density of adult conch populations, or eventually contribute to the complete extinction of the conch species in Lac Bay altogether.

Ecosystem Community Marine Resource	Environmental Stressors	Sources of Stress	Biological Responses to Stress
Mangrove Community	• Water quality degradation, hypoxia • Fresh water starvation • Hypersalinity during dry season • Elevated temperatures during dry season • Sedimentation	• Hydrological alteration • Road construction/poor drainage mechanisms • Upland dam/levees obstructing fresh water periodic flow • Decreased sea tidal flow • Physical/temporal scale events	• Mangrove species show "senescent" conditions in some areas • Mangrove species show "successional" change in some areas • Decreased mangrove productivity • Seasonal fish strandings and fish kills • Habitat fragmentation in some areas • Organic bacterial decomposition rate changes • *Ruppia* grass % coverage decreased
Seagrass Meadows Soft sediment bay bottom communities	• Mechanical trampling on the bottom • Removal of marine life from their environment • Injury to sessile, attached marine organisms • Sedimentation/erosion	• Recreational impacts by wind surfers, snorkelers, swimmers, etc. • Collecting marine life • Net fishing and net seining practices	• Habitat fragmentation in some areas • Weakening of root/rhizome system • Decreased short shoot productivity • Decreased biomass • Change in species assemblages • Alteration of food web trophic structure • Displacement of marine species
Beaches and Dunes	• Destabilization effects along shoreline and intertidal areas • Alteration of coastal currents, sea flow pattern • Shoreline erosion	• Sand mining and beach material extraction • Placement of sand bags, sea walls, physical barriers in littoral zone • Recreational impacts by wind surfers, snorkelers, swimmers, etc.	• Degradation of inter-tidal seagrass and macro-algae community • Disruption , displacement and loss of littoral zone marine species • Loss of native coastal vegetation
Conch, "karko" (*Strombus gigas*) Bay fishes and lobster	• Chronic, low level removal of juvenile and sub-adult size/age class • Taking of juveniles with nets • Taking undersized lobster and egg bearing females	• Commercial, local fisheries practices • Shell collecting practices • Indiscriminate net fishing practices • Mask/snorkel selective fishing practices	• Population mortality of size classes • Reduced reproductive success • Decline in population due to taking juveniles • Reduced reproductive success
Green sea turtle (*Chelonia mydas*)	• Overharvesting of species • Disease	• Local fishing practices • Fibropapilloma tumors	• Turtle physical debilitation, declining health, organ dysfunction • Turtle strandings • Reduced reproductive success

Table 7 Examples of sources (human and environmental), stressors (impacts from them) and the biological responses, or stress on a natural community or organism in Lac Bay

10.2 Individual and Community Actions: Stakeholders of Lac Bay

Scientists are often requested to provide environmental management recommendations, based on a systematic evaluation of the environment. It is the work of the scientist to investigate environmental problems and provide conclusions concerning the symptoms and sources of environmental change, founded on the sound, scientific information gathering approach (Table 7). However, when determining a remedial action, or *solution* to resolve the environmental problem, it becomes an issues-based process. Therefore, the process of drafting a management plan that would be supported by the community, or by the resource users, is best conducted through a consensus building forum, shared by stakeholders who hold a common interest for the environment in question. A key concept to successfully manage natural resources is that it cannot be accomplished by a single agency or entity, but must be the concern of everyone, in the practice that stewardship of a resource is a collective responsibility (Sullivan et al 1996; Ludwig et al 1993). In this context, the Table 8 provides an overview of a citizenry who are pro-active in formulating and enacting solutions for managing the environmental integrity of Lac Bay. These individuals served in a citizen advisory capacity to provide input for drafting a Lac Bay management plan (De Meyer 1998).

Citizen advisory meetings were conducted throughout the month of October 1998, for the purpose of receiving input from the community about their perceptions of the ecosystem processes at Lac Bay, and the issues and proposed solutions for them. These individuals served as a force of stakeholders who have a vested interest in the future of Lac, and represented the following special interest groups among the community of Bonaire: the island government and their advisors; the fishermen who utilize Lac for subsistence; the non-government organizations (NGO's); SELIBON, DROB, LVV; tourism interests, and users and commercial interests groups in Lac.

The Table 8 lists whom the stakeholders represent, the issues of their concern, and the solutions they perceive as viable for managing Lac Bay that would sustain both the ecosystem processes and community interests for utilizing Lac's natural environment.

Community/Stakeholder Group	Issues and Concerns of Lac	Recommended Remedial Action
Island Government, represented by: • Commissioner R.C.M. Beukenboom • Eric Newton, DROB • Coen Voss, DROB	• Environmental values of Lac • Safeguard local fishing interests • Collapse of conch fisheries • Endangered green turtle species • Problem of non-Bonairian fishing boats in bay • Beach sand extraction problem • No development (hotels, restaurants, etc.) at Lac • Cai remain "fiesta" atmosphere and provide dry toilet facilities for users	• Support values w/Nature Policy Plan • Permitting system for local fishing, but monitor for catch/fishing pressure • 5-year moratorium on taking conch • No fishing of turtle allowed in Lac • Subsidize fishermen loss of income, pay as local guides for Lac nature tours • Legally exclude non-Bonaire registered boats to use Lac Bay waters • Strictly prohibit sand extracting in Lac • Support water quality standards at Cai
Local Fishermen, represented by: • R. Emers (LVV) • E. Newton (DROB) • D. Diaz • Elvis Martines • Gibi • T. Martinus • Papi Cecilia • Rufo • Imre Esse (Sea Turtle Club Bonaire)	• Poor water circulation at Cai/Puitu • Mangrove die-off at Awa di Lodo, area an eyesore/unattractive • Sedimentation at Awa di Mewchi, sand extraction possibilities? • Absence of large fish than before, belief that use of nets could be a major cause, and non-local fishing/poaching • Overfishing conch by non-fishermen who casually take them without knowledge to manage stock and sizes • Fishermen are not taking turtle, very few people are still trying to catch turtle; they should be "farmed" to increase their survivorship	• DROB upgrade Cai road culverts to improve water circulation capabilities • Disallow cutting of mangroves • Monitor water quality standards at established sites around bay area • Controversy against extracting sand in areas which has historic accumulations • Legally exclude non-local registered fishing boats in Lac Bay waters • Issue permits to control fishing, netting or taking conch • Enforce strict size limits of conch to protect taking of juveniles • 5-year moratorium on taking conch • Enforce existing legislation to ban taking turtles, protect eggs and nests • Consider offering small mesh nets in exchange for large mesh nets which could catch turtle

Table 8 Results of Community Meetings held during October 13, and 16, 1998 with Island Government and Local Fishermen representatives who hold an interest in a Lac Bay Environmental Management Program (De Meyer 1998)

Community/Stakeholder Group	Issues and Concerns of Lac	Recommended Remedial Action
Non-Government Organizations, represented by: • Rene Hakkenberg (Tene Boneiru Limpi) • Christie Dovale (Amigu di Tera) • Leiske Koekens (Magazina di Rey) • Coen Voss	• Threats to mangroves, they are fragile • Fisheries problems – fewer sharks; lower fish populations; net fishing should have a validation process; conch on brink of collapse • Non-locals fish the bay out, and take land crabs • Undesirable uses of the bay – jetskis, sand extraction • Outreach mechanisms – Conservation Education Officer could produce school box about Lac; Fishermen trained as local nature guides; Clean up campaign to educate users about trash on shores, in water	• Work with natural forces of the bay to preserve mangrove ecosystem • Enforce strict size limits for taking conch; restrict numbers of conch fishing permits • 5-year moratorium on taking conch • Ban conch on restaurant menus • Enforce ban on jetskis in Lac • Continue to prohibit extraction of sand • Develop tour guide certification and training programs • Develop education brochures, and on-site visitor information points at Lac • Organize a Lac clean up day
SELIBON and DROB, represented by: • H. Kwidama • Eric Newton and Coen Voss (DROB) • B. Oleana • O. Christina • H. Strevkerk • Leito (SELIBON)	• Sand extraction, find long-term alternative to this activity, legally the sand is owned by Central Govt. • Danger of uncontrolled private development, expansion of existing developments	• Illegal to harvest sand through the Verordening Marien Milieu • Adopt a land use plan, proposal 1. 50-100-m - prohibit building 2. 100-250-m - allow minimum land clearance 3. 250-500-m – allow control of land use to ensure that it is compatible with Lac's designation as a National Park

Table 9 Results of Community Meetings held during October 19 and 20, 1998 with Non-Government Organizations, SELIBON, and DROB representatives who hold an interest in a Lac Bay Environmental Management Program

(De Meyer 1998)

Community/Stakeholder Group	Issues and Concerns of Lac	Recommended Remedial Action
Tourism Sector, represented by: • T. Rondon (Lac Bay Resort) • Bruce Bowker (Carib Inn) • E. Oleana (Sorobon Beach Resort) • Tourism Corporation, absentee • CURO, absentee • Bonhata, absentee	• Concept of Tourism Cycle of Evolution with regard to Lac – Grave concerns of future development around Lac w/hotels and condos • Lac Bay resort, no plans for expansion in next 5 years • Sorobon Beach Resort, happy to be next to a future National Park • Sand extraction, the resort is suffering from beach erosion, need to replenish beach with sand despite having a retaining wall due to rapid erosion	• Petition for land use plan • Ratify the Nature Policy Plan through DROB and island govt. • Petition for National Park status for Lac • Prohibit sand extraction from Lac, the current practices by Sorobon Beach Resort may be influencing further erosion processes elsewhere (See Section 9.4)
Users of Lac, represented by: • E. Vliet (Jibe City) • Elvis Martines (The Place) • Andre Nahr , Malin (Sand Dollar Dive & Photo) • F. Peerenboom • Ann (Aqua Speed) • Gerard Van Eps (Bonaire Boating) • Jack Chalk (CURO)	• Windsurfing facilities increasing: from 1988 – 1998 board users rose from 10/day, to 80/day • Aqua Speed holds 4-5 races per year • Windsurfing education needs • Kayaks users increasing, began with only one facility, now many • Kayakers want to tour more areas in mangroves • Facilities for users, concrete boat slip at Sorobon used by fishermen and jetskiers • Boat mooring needed for F. Peerenboom	• Carrying capacity for windsurfing facilities reached limit with 2 commercial centers and the windsurf club, Aqua Speed • Limit 60 boards/day on the bay • Public access to windsurf via the centers or the club • Centers will provide education brochures, use of sign boards • Aqua Speed will inform/educate users, control activities during events • Install infrastructures – one BMP boat mooring;, tie offs for windsurf boards, turn markers, danger markers • Remove concrete boat slip as fishermen don't use it • Explore legal possibility for excluding all non-Bonaire registered boats

Table 10 Results of Community Meetings held during October 20, 1998 with the Tourism sector, and Users of Lac representatives who hold an interest in a Lac Bay Environmental Management Program (De Meyer 1998)

10.3 Human values play a role in effective resource management

Regardless of the role of scientific knowledge, human values also play a dominant role in affecting ecosystem management goals (FDEP 1995). Effective resource management strategies are built from the bottom up: from individuals to communities to the governing bodies (Sullivan et al 1996; FDEP 1995).. In the management of tropical small island ecosystems, such as found in Lac Bay, it is necessary to study not only the biological resources, but also the methods and relevant customs and values of native people who use them (Sections 2.9; 4.4). The misapplication of prescribing management strategies that would work in continental cultures may "fall flat" if applied on an island scale by well-meaning, but uncomprehending expatriate resource managers (Johannes and Hatcher 1986). Thus, management objectives must be culturally as well as environmentally sensitive. Grassroots citizenry group inputs such as listed in Table 8 are integral in achieving a workable management program. Secondly, management is doomed to failure when conservation mechanisms are not highly regarded among people whose basic economic and nutritional needs are not being met. Lastly, a critical concept to promote conservation and environmental management in developed, as well as developing countries, is that expanded, culturally specific educational programs are vital to motivate people to conserve their natural resources (Johannes and Hatcher 1986).

The following Table 9 is a summary of beliefs and values held by the stakeholder groups who met during the October 1998 for the problem solving and decision making processes of formulating a management plan for Lac Bay. Though they represented different interests as individual stakeholder groups (who are detailed in Table 8), they proved to share a common knowledge about Lac Bay, and how the area has changed over the years, and ultimately, share a common vision for Lac. Therefore, these shared beliefs and values are presented for review in the Table 9. In essence, they are representative of the local community of Bonaire - politicians, fishermen, tourism and commercial industry, environmental advocacy groups, and everyday users who visit and enjoy Lac.

In conclusion, this cross-section of representatives, or stakeholders, would serve as the general consensus for the people of Bonaire. Their grouped beliefs and values for what they envision to be the Lac of today, and for tomorrow, can provide a firm foundation for drafting a final management plan for Lac Bay. These are presented in the Table 9 that follows.

Stakeholders Belief Statements for Lac Bay	Values of Stakeholders Beliefs for Lac
• Lac should remain as it is	• Environmental/Preservation
• Private and commercial development of Lac and its environs is highly undesirable	• Environmental/Aesthetic
• Fish, wildlife and flora should be protected, especially conch and turtles	• Conservation
• Provision should be made for current users of the bay (facilities)	• Environmental/Cultural/Aesthetic
• Fishing by non-locals should be restricted or prohibited	• Cultural/Ethical/Economical
• Sand extraction should not be permitted	• Environmental/Conservation
• Steps should be taken to preserve water quality	• Environmental/Preservation
• Educational sites should be developed where visitors can learn about Lac and what people are doing to protect it	• Educational/Conservation/Cultural

Table 11 Consensus of Beliefs and Values among local Stakeholder Groups who hold a common interest for the management of Lac Bay

Based on Oct. 1998 citizen group meetings held by Bonaire Marine Park (De Meyer 1998)

10.4 Elements of Management Planning for Lac Bay

The summaries provided by the stakeholders in Table 9 are a critical first step toward achieving a successful product – the managed ecological integrity for Lac Bay. These belief statements and values can begin to be formulated into the working goals and objectives for the management of Lac, through the elements of devising the actual "business plan" (Lowe and Sealey 1999) for Lac. The elements are as follows:

1. Devise a clear mission statement that creates a vision for Lac based on the beliefs and values of the stakeholders and user groups, as well as the resource management team, and that the mission is widely understood among them;

2. Draft working goals and objectives that would systematically achieve the stated mission for Lac. Outline them in a business plan format – goals show what the plan will accomplish, objectives describe in more detail how the goals will be reached in some time frame. Provide a public forum opportunity for the stakeholders to review the draft plan, and prioritize them, to conclude with a final consensus-based management plan;

3. Develop a realistic financial plan, with an income source, to uphold and match the costs for putting the objectives into action;

4. Establish an organizational management structure that clearly illustrates staff responsibilities and duties for implementing all the components of the business plan; and lastly,

5. Create an evaluation process to provide measures of success, on a regular schedule. Benchmarks could be for short-term and long-term achievements in environmental monitoring, and resource user success through education.

10.5 Implementing the management plan for Lac through a zonation perspective

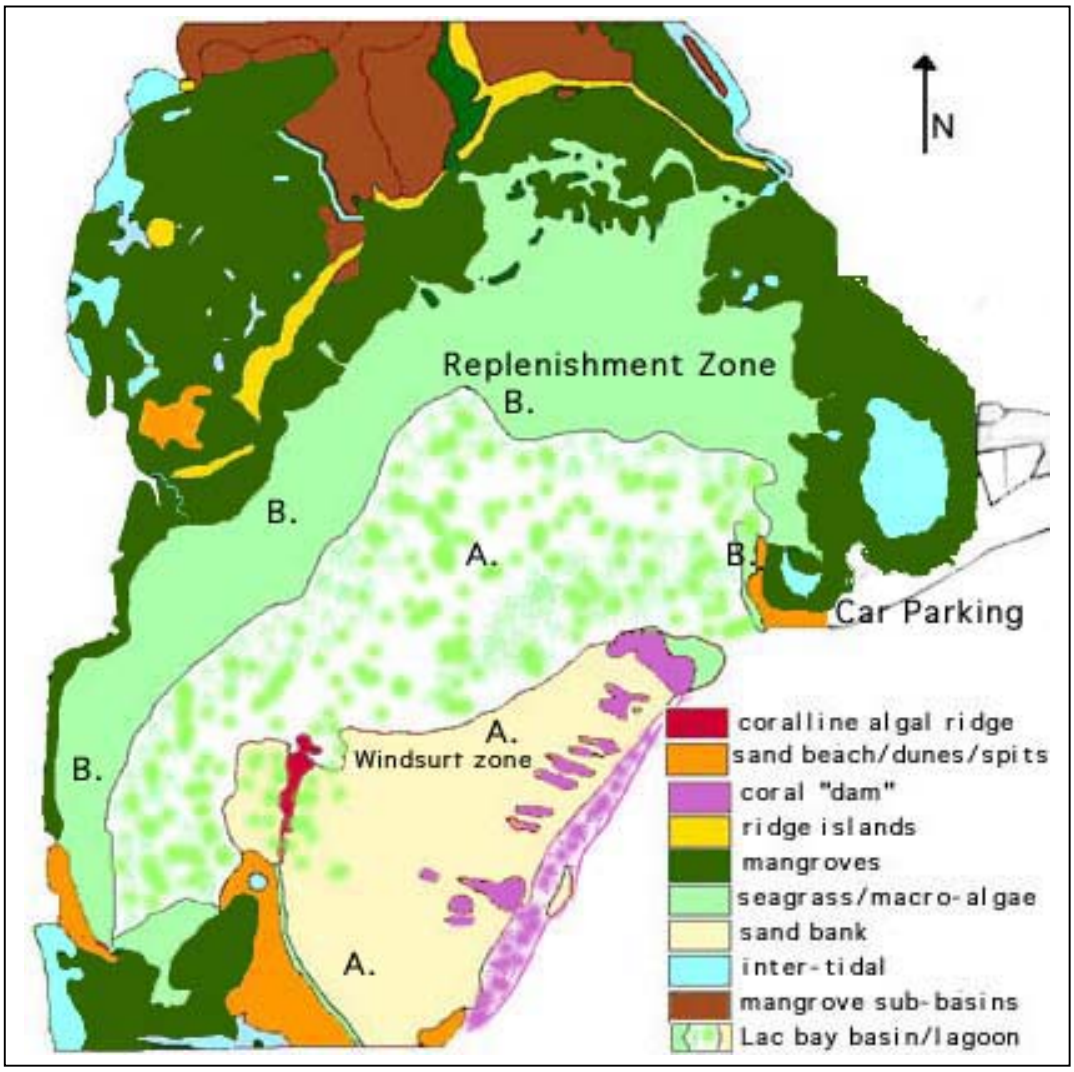
A successful management strategy used by marine protected areas throughout the world is often supported through a zonation program. Establishing zones is a very common-sense approach of evaluating the protected area landscape in question, and determining how and where the resources that lie within its boundaries can be used in a long-term and sustainable manner (Lowe and Sealey 1999). Thus, a final, but integral element for devising a management plan would include:

6. Establish zones and boundaries to contain the business plan, publicize the plan to derive support, including financial.

This perspective quickly provides a view of what is being managed, and how, so that partitioned areas for protection and uses are clearly defined in a visual way. These purposes and uses would include (Lowe and Sealey 1999):

- Defining the natural communities in Lac, and associated species requiring protection;

- Providing opportunities for non-consumptive uses of resources such as swimming, snorkelling, kayaking, windsurfing, boating, etc.; and
- Preserving commercially valuable stocks, such as for conch or lobster, through the establishment of a Replenishment Zone (in this case, nursery zones to protect yearling and juvenile stages of marine organisms).



Map 20 Example of a Zonation Map of established use areas for the management of Lac Bay

Map Key:
A. Hard bottom or relatively deep bottom area suitable for windsurfing activity;
B. Dense seagrass areas suitable for conch nursery habitat, take precaution for use, and prohibit fishing;
C. Car Parking location at Cai stationed outside beach area to preserve beach front
Mangrove zone preserved intact with special use provisions as a Wildlife Sanctuary Zone

(Based on March 1999 - March 2000 environmental assessments in Lac Bay by Environics, N.V)

The Map 19 is an example of a zonation map. It partitions Lac in an elementary way to support the management concepts as explained in this Section. Detailed zonation analysis is provided in Section 7 with specific environmental resource layout maps that are interpreted by Geographical Information Systems (GIS) technology. The natural resource GIS maps were completed by Environics, N.V. through bottom surveys at Lac during the March 1999 - March 2000 environmental assessments. The data in these GIS maps provide a detailed analysis for establishing exact zonation patterns for the marine protected areas in Lac Bay, based on ground truthing activities to interpret aerial photographs, and scientific data collection through field assessments. A final zonation map would be derived based on the collective consensus among the stakeholders and resource management team.

10.6 Concluding Remarks

This Site Characterization Report for Lac Bay is a comprehensive review of all environmental research that has been conducted throughout the Lac Bay area in the course of the 20th Century. These studies were evaluated in order to detect environmental change over the years as found in natural Lac by scientists. Those studies were compared for further analysis through the additional environmental assessments that were conducted during March 1999 - March 2000 by the author of this report. The results of the evaluation for detecting environmental change in Lac based on scientific environmental research were discussed throughout this report.

These works were two years in the making, for a two-fold purpose:

1. To provide accurate scientific information for the development of a management plan for Lac Bay. All information provided in this report are based on documented studies and field data monitoring activities that were completed by professional field scientists, including the author. (References are contained in the following Section 11); and

2. To provide accurate interpretative information for naturalists who serve as nature and tour guides in the Lac Bay, as well as for the on-site environmental education interpretation series at Lac.

The contents of this report are invaluable to serve as a reference and compendium about natural Lac, for all persons requiring them for their individual, or collective purposes: for management and environmental education. In this respect, Environics, N.V. is readily available to continue to serve in a

consulting capacity for the needs of Lac Bay, and can be contacted at 717-3976, Bonaire, Netherlands Antilles.

Thank you for this opportunity to serve the community of Bonaire. Environics, N. V.

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12. Appendix A: Species List (van Moorsel en Meijer 1993)

Naamlijst organismen waargenomen tijdens base-line study Lac Bonaire

Wetenschappelijke naam	Engelise naam	Papiamentu	Nederlandse naam
ALGAE	SEA WEED		ALGEN
Chlorophyta	green algae		Groenwieren
Acetabularia calyculus			
Acetabularia crenulata		Piteseli di lamen	
Avrainvillea nigricans			
Avrainvillea rawsonii			
Batophora oerstedii			
Caulerpa cupressoides var. cupressoides			
Caulerpa cupressoides var. lycopodium			
Caulerpa mexicana			
Caulerpa racemosa var. racemosa			
Caulerpa sertularioides f. farlowii			
Caulerpa sertularioides f. sertularioides			
Caulerpa verticillata			
Chaetomorpha spec.			
Cladocephalus luteofuscus			
Cladophora spec.			
Cladophoropsis macromeres (?)			
Codium intertextum			
Codium repens			
Dictyosphaeria cavernosa			
Emodesmis verticillata			
Halimeda incrassata			
Halimeda monile			
Halimeda opuntia			
Penicillus capitatus			
Pencillus dumetosus			
Penicilus pyriformis			
Udotea flabellum			
Udotea oxidentalis			
Ulva lactuca	Sea Lettuce		
groenwier indet.			
microscopisch groenwier indet.			
Phaeophyta	Brown Algae		Bruinwieren
Dictyota ciliolate			
Ductyota dichotoma			
cf. Dictyota divaricata			
Dictyota sp.			
Hydroclathrus clathratus			
Padina sanctae-crucis			
cf. Sargassum platycarpum			
Stypopodium zonale			
Rhodophyta	Red algae		Roodwieren
Acanthophora spicifera			
cf. Amphiroa fragilissima			
cf. Amphiroa rigida var. antillana			
Asparagopsis taxiformis			
Bostrychia tenella			
Ceramium sp.			
cf. Centroceras clavulatum			
cf. Champia parvula			
Chondria sp.			
Galaxaura subverticillata			
cf. Griffithsia sp.			
Hypnea cervicornis			
cf.Laurencia intricata			
Laurencia papillosa			
Laurencia poirei			

Laurencia sp.
Neogoniolithon spectabile

Wetenschappelijke naam	Engelise naam	Papiamentu	Nederlandse naam
Neogoniolithon strictum			
cf. Peyssonnelia sp.			
Polysiphonia sp. (P. subtilissima?)			
Spyridia filamentosa			
Wrangelia argus			
(microscopisch) roodwier indet.			
kortsvormig roodwier indet.			
Cyanophyta	Blue-green algae		Blauwieren
Schizothrix calcicola			
Entophysalis deusta			
ANGIOSPERMAE			BEDEKTZADIGEN/BLOEMPLANTEN
Cactaceae			
Cereus repandus	Candle cactus	Kadushi	Zuilcactus/Boomcactus
Lemaireocereus griseus	Candle cactus	Datu	Zuilcactus
Melocactus		milon di seru	
Opuntia wentiana	Prickly Pear	Tuna / Infrou	Spaanse juffer, Schijfcactus
Chenopodiaceae			Ganzevoetfam
Salicornia ambigua	glasswort		zeekraal
Amaranthaceae			Amarantachtigen
Lithophila muscoides		Yerba di kusinchi	
Aizoaceae			Ijskruidfam.
Sesuvium portulacastrum	Seaside purslane/samphire	Banana di rif, Bembe di baka	
Batidaceae			
Batis maritima	Saltwort	Banana di rif	
Euphorbiaceae			Wolfsmelkfam.
Hippomane mancinella	Manchineel	Manzaliña	
Fabaceae			Vlinderbloemenfam.
Haematoxilon brasiletto	Logwood	Brasil/Brasia	Stokvishout
Rhizophoraceae			Mangroven
Rhizophora mangle	Red mangrove	Mangel tan	Rode mangroven
Combretacea			
conocarpus erecta	Buttonwood, Grey mangrove	Manguel blanku, Romangel	Grijze mangel, Mangel
Laguncularia racemosa	White mangrove	(Manguel blanku)	
Tiliaceae			Lindefam.
Corchorus hirsutus			
Simaroubaceae			Hemelboomfam.
Suriana maritima	Bay cedar		
Convolvulaceae			Windefam.
Ipomoea pes-caprae	Beach morning glory / Sea vine		Strandiaan
Boraginaceae			Ruwbladigen
Tournefortia gnaphalodes	West Indian/ Seaside lavender	Tabaku di piskadó	
Theophrastaceae			
Jacquinia barbasco	joewood	Mata di Piscá, Palu huku	Steenhout,Stielgom
Verbenaceae			IJzerhardfam.
Avicennia germinans	Black mangrove, Saltpond tree	Manguel blanku	Witte mangrove
Burseraceae			
Bursera simaruba	Red saddle tree	Palu di sia korá	
Rubiaceae			
Enithalis fructicosa	Black torch	Lumbra blancu	
Randia aculeata		Palu di lele	
Hydrocharitaceae			Waterkaardefam.
Thalassia testudium	Turtls grass	Yerba di kania	
Potamogetonaceae			Fonteinkruidfam.
Ruppia maritima	Widgeon grass, Ditch grass		Snavel ruppia
Cymodoceaceae			
Syringodium filiforme	Manatee grass		
Cyperaceae			Cypergrassen
Fimbristylus spathacea	sedge		
Gramineae			Grassenfam.
Sporobolus pyramidatus			

Wetenschappelijke naam	Engelise naam	Papiamentu	Nederlandse naam
PORIFERA	SPONGES		SPONZEN
Demospongia			Hoomsponzen
Aplysina fistularis	Yellow tube sponge		
Aplysina sp.			
Amphimedon compressa	Red finger sponge		
Chondrilla nucula	Chicken-liver sponge		
Spheciospongia vesparia	Common loggerhead sponge		
CNIDARIA			NETELDIEREN
Hydroidea	Hydroids/sea fans		Hydroidpoliepen
Abietinaria ap.			
Myrionema hargiti			
Millepora	Fire coral		Brandkoraal
Scyphozoa	Jellyfish	Luna di awa	Kwallen
Cassiopeia	Upside-down jellyfish		lagunenkwal
Anthozoa			Bloemdieren
Gorgonacea			Hoornkoralen
Gorgonia sp.	Sea fan	Waya di awa	Waalerkoraal
Eunicea sp.	Sea rod		
Actiniaria	Sea amenomes		Zeeanemonen
Phymanthus crucifer	Beaded sea snemone		
Bunodosoma	Warty anemone		
Condylactis gigantea	Giant Caribbean anemone		
Aiptasia pallisa	Pale anemone		
Bartholomea annulata	Ringed anemone		
Stoichactis helianthus	Sun anemone		
Scleractinia	Stony corals		Steenkoralen
acropora cervicornis	Staghorn coral		Hertegeweikoraal
Porites porites	Thick finger coral		
Porites astreoides	Mustard hill corl		
Porites brannen	Blue crust coral		
Favia fragum	Golfball coral		
Siderastrea radians	Lesser starlet coral		
Montastrea annularis	Boulder star coral		
Diploria labyrinthiformis	Depressed brain coral		
Diploria strigosa	Common brain coral		
Agaricia agaricites	Lettace coral		
Agaricia humilis	Low-relief lettace coral		
PLATYHELMINTES			
			Zwart, pelagisch
NEMERTINA	RIBBON WORMS		
ANNELIDA			RINGWORMEN
Polychaeta - Errantia			Borstelwormen - vrijevend
Nereidae			zeeduizendpoot
Typosylis sp.			
Hermodyce	Fire worm	Lisinbein di awa	
Arenicola crisata	Lugworm		wadpier
Polychaeta - Sedentaria			Borstelwormen - vastzittend
Spionidae			
Sabella melanostigma	Banded fanworm		
Loimia medusa	Medusa worm		
Branchiomma nigromaculata	Black-spotted fanworm		
Sabelidae sp.			
Sabelidae sp.			
MOLLUSCA			WEEKDIEREN
Bivalvia		Paluli	Tweekleppigen
Pinna carnea	Flesh pen shell		steekmossel
Pinctada radiata (fossiel)	Atlantic / Scaly pearl oyster		
codakia orbicularis (dood)	Atlantic tiger lucine		

Laevicardium laevigatum	Egg cockle		
Periglypta listeri	Lister's venus		
Tagelus divisus	Purplish tagelus		
Wetenschappelijke naam	Engelise naam	Papiamentu	Nederlandse naam
Tellina mera	Mera tellin		
Tellina caribaea	Cribbean tellin		
Chione sp.	Chione		
Gastropoda		Kokolishi	Slakken
Opistobranchia (Nudibranchia)	Sea slugs		Voorkieuwigen (zeenaaktslakken e.a.)
Tridachia crispata	Lettuce sea slug		
Prosobranchia			Achterkieuwigen
Cerithidea costata	Costate horn shell		
Cerithium literatum	Lettered horn shell		
Cerithium variabile	Variable horn shell		
Cittarium pica (fossiel)	Magpie shell/ West India top shell	Kiwa	
Epitonium sp.	wentle trap		wenteltrap
Littorina angulifera	Mangrove periwinkle		
Melongena melongena	West Indian crown conch		indianenschelp
Natica? Eikapsel	sandcollar		
Olivella minuta	Minute dwarf olive		
Strombus gigas	Queen Pink conch	Karkó	
Voluta musica	Music volute		
Pulmonata Euthyneura			Longslakken
Melampus coffeus	Coffee-bean snail		
Cerion uva		kokolishi di kalakuna	Bijenkorfje
Tudora aurantia			
Cephalopoda			Inktvissen
Octopus vulgaris	Common octopus		oktopus
Sepiateuthis sepiodea	Reef squid	sekat bulado	pijlinktvis
CRUSTACEA			KREEFTACHTIGEN
Cirrinpedia	barncales		zeepokken
Chtalamus angustitergum	Mangrove star barnacle		
Isopoda			Pissebedden
Amphipoda			
Gammaridea			Volkreeftjes
Ampithoe sp.			
Caprelildae			Spookkreeften
Stomatopoda			Bidsprinkhaankreeft
	mantis shrimp		bidsprinkhaankreeft
Decapoda			
Natantia-Caridea			Garnalen
Stenopus hispidus	Banded coral shrimp		kappersgarnaal
Alpheus armatus	Red snapping shrimp		Pistoolgarnaal
Aplheus sp.	snapping shrimp		Buldozergarnaal
Processa sp.			
Repantia-Macrura			
Panulirus argus	Caribbean spiny lobster	Kref	langoest
Repantia-Anomura			
Paguristes sp.			
Petrochirus diogenes	Red hermit crab		heremetkrab
Coenobita clypeatus	land hermit crab	Soldachi	landheremetkrab
Reptantia-Brachyura	Crabs		Krabben
			landkrab
	mangrove crab		mangrove krab
Stenorhynchus seticornis	Arrow crab		
Percnon gibbesi	Urchin crab		
Callinectes sp.	Blue crab	Panicrak	Blauwe zwemkrab
Microphrys bicornutus	Spotted decorator crab		spinkrab
CHELICERATA			
Insecta			
Odonata			libellen
Corixidae			duikerwants
			waterkever elytra met gaten

			waterkever elytra glad
Trochopus plumbeus			schaatsenrijder
BRYOZOA	SEA MATS		MOSDIERTJES
Wetenschappelijke naam	Engelise naam	Papiamentu	Nederlandse naam
ECHINODERMATA			STEKELHUIDIGEN
Asteroidea			Zeesterren
Oreaster reticulatus	Cushion sea star		kussen zeester
Echinoidea	Sea urchins	Seapel	Zeeëgels
Diadema philippi	Long-spined black urchin	Seapel pretu	Zwarte zeeëgel
Tripneustes esculentus	West Indian sea egg	Seapel blanku	
Meoma ventricosa	Sea pussy		
Clypeaster subdepressus (+)	Flat sea biscuit		
Echinometa lucunter	Red rock urchin		
Lytechinus variegatus	Variable urchin		
Holothuriodea	Seacucumbers	Lolo di awa	Zeekomkommers
Holothuria mexicana	Donkey dung sea cucumber		
Holothuria arenicola	Burrowing sea cucumber		
Ophiuroidea	Brittle star		Slangsterren
CHORDATA			CHORDADIEREN
Ascidacea			Zakpijpen
Botrylus planus			sterretje
Cephalochordata			
Asymmetron lucayanum	Amphioxus		Lancetvisje
			Kraakbeenvi ssen
Ginglymostoma cirratum	Nurse shark	Tribon incente	Verpleegsterhaai
Dasyatis americana	Southern sting ray	Chuchu rok	Stekelrog
Teleostomi	Bony fishes	piska	Beenvissen
Albula vulpes	Bonefish	Hermanchi	
Gymnothorax moringa	Spotted moray	Kolebra bobo	Geviekte murene
Gymnothorax funebris	Green moray	Kolebra berde	Groene murene
Ophichthidae?	Snake eel		
Rivulus marmoratus	Marmored killyfish		
Poecilia sphenops	Molly	Marchuri	
Antherinomorus stipes (?)	Hardhead silverside	Piskechi	koornaarvisje
	Halfbeak (?)	Boca targu	
Belonidae	Needlefish (?)	Guepie	
Aulostoma maculatus	Trumpetfish (?)	trómpèt	Trompetvis
	…Pipefish gevangen door Alex Ploeg		zeenaaid
Adioryx coruscus	Reef squirrelfish		eekhhoornvis
Adioryx vexillarius	Dusky squirrelfish		eekhhoornvis
Holocentrus ascencionis	Longjaw squirrelfish	Kandelchi/ Kora di Spada	eekhhoornvis
Holocentrus rutus	Squirrelfish	Kandelch'i spada	
Myripristis jacobus	Blackbar soldierfish	Wow'i boyo	Soldatenvis
Mycteroperca rubra	Comb grouper		
Serranus baldwini	Lantern bass		
Serranus tigrinus	Harlequin bass	Piska 'i spons	
Apogon maculatus	Flamefish		
Caranx ruber	Bar Jack	Yaru	
Caranx fusus	Blue runner	Yaru	
Caranx latus	Horse-eye jack	korkobá blanku	
Lutjanus apodus	Schoolmaster	Bers	
Lutjanus mahogoni	Mahogany snapper	Kalala	
Lutjanus griseus	Grey/Mangrove snapper	karañitu	
Lutjanus analis	Mutton snapper	Carpitan	
Ocyurus chysurus	Yellowtail snapper	Grastèlchi ‘i pieda	
Eucinostomus havana	Bigeye mojarra		
Eucinostomus lefroyi	Mottled mojarra		
Eucinostomus argenteus	Spotfin mojarra	Cabicuchi	
Gerres cinereus	Yellowfin mojarra	Bersia / Cabicuchi	
Eugerres plumieri	Striped mojarra		
Haemulon flavolineatum	French grunt	robèki	
Haemulon chrysargyreum	Smallmouth grunt	Traki traki	
Haemulon melanurum	cottonwick		

Mulloidichthys martinicus	Yellow goatfish	Barbi	barbeel
Pseudopeneus maculatus	Spotted goatfish	Barbi shouru	barbeel
Pempheris schomburgki	Glassy sweeper	Babalochi	
Chaetodon striatus	Banded butterfly	Makamba marinir	Gestreepte koraalvlinder
Chaetodon capistratus	Foureye butterfly	Makamba kulu berdè	Vieroogkoraalvlinder
Pomacanthus paru	French angel (juv)	Sheu	Zwarte keizersvis
Microspatodon chrysurus	Yellowtail damselfish	Rey pandu	Juweelvis
Eupomacentrus paritus	Bicolo damselfish	Ladronchi	
Wetenschappelijke naam	Engelise naam	Papiamentu	Nederlandse naam
Eupomacentrus leucostictus	Beaugregory	Ladronchi	
Abudefduf saxatilis	Sergeant major	Katabòli	Sergeant majoorvis
Abudefduf taurus	Night sergeant		
Halichoeres radiatus	Puddingwife	Pepchi berdè	lipvis
Halichoeres garnoti	Yellowhead wrasse	Pepchi pinta	lipvis
Halichoeres pictus	Rainbow wrasse		lipvis
Halichoeres poeyi	Blackear wrasse		lipvis
Thalassoma bifasciatum	Bluehead	Pepchi blou	blauwkop lipvis
Scarus guacamaia	Rainbow parrotfish		regenboog papegaaivis
Scarus vetula	Queen parrotfish	Gutu berde	papegaaivis
Scarus taeniopterus	Princess parrotfish		papegaaivis
Sparisoma viride	Stoplight parrotfish	Gutu promente/ G. rab'i gai	papegaaivis
Sparisoma rubripinne	Yellowtail parrotfish		papegaaivis
Sparisoma radians	Bucktooth parrotfish		papegaaivis
Mugil curema	White mullet	Aidu	harder
Sphyraena barracuda	Barracuda	Piku	Barrakuda
Ophioblennius atlanticus	Redlip blenny	Pega pega	Slijmvis
nes longus	Orangespotted goby		grondel
Coryphopterus glaucolfraenum	Bridled goby		grondel
Lophogobius cyprinoides	Crested goby	Brant	grondel
Bothus lunatus	Peacock flounder	Sobrá 'i Dios	
Balistes vetula	Queen triggerfish	Pishiporko rav 'i gai	trekkevis
Acanthurus chirurgus	Doctorfish	Kleinfeshi blanku	doktersvis
Acanthurus coeruleus	Blue tang	Kleinfeshi blou	doktersvis
Acanthurus bahianus	Ocean surgeonfish	Kleinfeshi pretu	doktersvis
Lactophrys triqueter	Smooth trunkfish	Ka'i morto	koffervis
Lactophrys bicaudalis	Spotted trunkfish	Chapin	koffervis
Lactophrys trigonus	Buffalo trunkfish		koffervis
Sphoeroides spengleri	Bandtail puffer	Blas largu	ballonvis
Diodon hystrix	Porcupine fish	Djinda	egelvis
Sauria	Lizards	Lagadishi	Hagedissen
Cnemidophorus murinus	Whiptail lizard	Blausana	Hagedis
Iguana iguana	Iguana	Yuana	Leguaan
Anolis bonairensis			
	Birds	para	Vogels
Aves			
Sula leucogaster	Brown booby	Bubi	Bruine boebie
Pelecanus occidentalis	Brown pelican	Pelicano / Ganshi	Bruine pelikaan
Fregata magnificens	Magnificent frigatebird	Macuacu	Amerikaanse fregatvogel
Nyctanassa violacea	Yellow-crowned night heron	Krabechi	Geelkruinnachtreiger
Butorides striatus	Striated / Green heron	Galiña di awa/ Caw-caw	Groene reiger
Egretta caerulea	Little blue heron		Kleine blauwe reiger
Egretta tricolor	Tricolored heron	Garabet	Witbuikreiger
Egretta rufescens	Reddish egret		Roodbruine reiger
Egretta thula	Snowy egret	Garza blanca	Amerikaanse kleine zilverrirger
Egretta alba	Great white egret	Garza blanca	Grote zilverreiger
Ardea herodias	Great blue heron		Amerikaanse blauwe reiger
Phoenicopterus ruber	Greater Flamingo		Grote of Caraibische flamingo
Anatidae	ducks	patu	Eenden
Pandion haliaetus	Osprey	Gabilan di laman	visarend
Falco columbarius	Merlin		Smelleken
Haematopus palliatus	American oystercatcher	Kibra kokolishi /Shon piet	Amerikaanse scholekster
Himantopus himantopus	Black-winged stilt	Macamba / Redado/ Caweta di patu	Steltkluut
Calidris pusilla	Semipalmated sandpiper	Snepi	Kleine grijze strandloper
Numenius phaeopus	Whimbrel		Regenwulp
Tringa flavipes	Lesser Yellowlegs	Snepi	Kleine geelpootruiter
Arenaria interpres	Ruddy turnstone	Verfdo di boto	Steenloper

Columbia corensis	Bare-eyed pigeon	Ala blanca / Paloma di mondi	Naaktoogduif
Columbigallina passerina	Common ground dove	Totolica	Musduifje
Larus atricilla	Laughing gull	Cahela	Lachmeeuw
Sterna maxima	Royal tern	Bubi chiquitu	Koningsstern
Aratinga pertinax	Caribbean parakeet	Prikichi	West-Indische parkiet
Caprimulus cayennensis	White-tailed Nightjar	Palubrua	Witstaartnacntzwaluw
Hirundinidae	Swallows and Martins		Zwaluwen
Mimus gilvus	Tropical mockingbird	Chuchubi	Caraibische spotilijster
Dendroica petechia	Yellow warbler	Para di misa	Gele znger

13. Appendix B: Benthic species present in Lac Bay (Lott 2000)

(Benthic species based on surveys conducted during July to September 1999 in Lac Bay)

Invertebrates	**Genus**	**species**
U-shape burrow worm	*Arenicola*	*crisata*
upside - down jellyfish	*Cassiopeia*	*xamachana*
Caribbean sea anemone	*Condylactis*	*gigantea*
burrowing sea cucumber	*Holothuria*	*arenicola*
donkey dung sea cucumber	*Holothuria*	*mexicana*
whitish-green sea urchin	*Lytechinus*	*variegatus/williamsi*
West Indian crown conch	*Melongena*	*melongena*
sea pussy/ cake urchin	*Meoma*	*ventricosa*
pincushion starfish	*Oreaster*	*reticulata*
white short spine sea egg	*Tripneustes*	*ventricosa*
sun carpet anemone	*Stoichactis*	*helianthus*
milk conch	*Strombus*	*costatus*
queen conch	*Strombus*	*gigas*
unknown invertebrate	*unknown color/shape*	
Angiospermae		
shoal grass	*Halodule*	*beaudettei*
manatee grass	*Syringodium*	*filiforme*
turtle grass	*Thalassia*	*testudinum*
Green Algae (Chlorophyta)		
mermaids wine glass	*Acetabularia*	*crenulata/calyculus*
fan algae	*Avrainvillea*	*elliottii/longicaulis/ nigricans*
spongy fingers	*Avrainvillea*	*rawsonii*
long shag carpet	*Batophora*	*oerstedii*
cactus algae	*Caulerpa*	*cupressoides*
green pea caulerpa	*Caulerpa*	*racemosa*
round feather algae	*Caulerpa*	*sertularoides*
flat feather algae	*Caulerpa*	*taxifolia/mexicana*
green steel wool algae	*Chaetomorpha*	*linum*
short shag carpet algae	*Dasycladus*	*vermicularis*
turf ball algae	*Derbesia*	*sp.*
big green bubble algae	*Dictyosphaeria*	*cavernosa*
little green bubble algae	*Dictyosphaeria*	*ocellata*
oatmeal disc bush	*Halimeda*	*incrassata/monile*
clumpy oatmeal flake algae	*Halimeda*	*opuntia*
calc. Green ringed algae	*Neomeris*	*annulata*
merman's shaving brush	*Penicillus*	*capitatus/dumetosus/ pyriformis*
green pine cone algae	*Rhipocephalus*	*phoenix*
green cup-like algae	*Udotea*	*cyathiformes*
ringed fan algae	*Udotea*	*flabellum/occidentalis*
green glass marble algae	*Ventricaria*	*ventricosa*
tear drop marble algae	*Valonia*	*macrophysa*
marble algae	*Valonia*	*utricularis*

Brown Algae (Phaeophyta)

olive-brown y-branching	*Dictyota*	*cervicornis*
small brown y-branching	*Dictyota*	*divaricata/linearis*
largest brown y-branching	*Dictyota*	*mertensii/jamaicensis*
brown ruffle leaf algae	*Lobophora*	*variegata*
potato chip roll edge algae	*Padina*	*gymnospora/ sanctae-crucis*
sarcasm weed	*Sargassum*	*fluitans/hystrix/natans/ platycarpum*
brown trumpet algae	*Turbinaria*	*tricostata/turbinata*
potato chip flat edge algae	*Stypopodium*	*zonale*
unknown algae	*unknown color/shape*	

Red Algae (Rhodophyta)

sticker spur branch	*Acanthophora*	*spicifera*
calcareous branching	*Amphiroa*	*fragilissima/rigida/ tribulus/brasiliana*
red band fine filament	*Ceramium*	*spp.*
swollen rubber epiphyte	*Champia*	*parvula/salicornioides*
wiry iridescent blue turf	*Coelothrix*	*irregularis*
grande tough spine branch	*Eucheuma*	*isiforme*
wiry/rubbery purple turf	*Gelidium*	*pusillum*
cylindrical rubber branch	*Gracilaria*	*spp.*
hook half y branching algae	*Hypnea*	*cervicornis/musciformis*
stubby branch algae	*Laurencia*	*intricata/poitei*
stalked clusterballs	*Laurencia*	*papillosa*
white gooey branch	*Liagora*	*mucosa/pinnata*
thick branch calc red	*Neogoniolithon*	*spectabile/strictum*
purplish fuzzy turf algae	*Wrangelia*	*argus*
unknown algae	*unknown color/shape*	
	brown shaped like chain crunchy	

Sponge SP

chicken liver sponge	*Chondrilla*	*nucula*
heavenly blue sponge	*Dysidea*	*etheria*
fire sponge	*Tedania*	*ignis*
red/orange finger sponge	*Amphimedon*	*compressa*
unknown sponge	*unknown color/shape*	
	Black tube -Ircinia?	
	Black stringy - Haliclona?	
	Bread Crumb sponge?	
	Mustard color tube sponge	
	Short soft purple stubby tube sponge	

Cyanophyta

blue-green algae/bacterium	*Lyngbya sp.*

Cnidaria: Anthozoa

staghorn coral	*Acropora cervicornis*
starlet coral	*Siderastera radians*

14. Appendix C: Glossary of Terms

GLOSSARY OF TERMS

algae reef - conglomerated area composed of calcareous marine macro-algal species

algal mats - veneered surface composed of micro-algae species, primarily blue-green bacteria

anthropogenic - influenced by human activity

awa di lodo - papiamentu term for muddy waters

bank reef - shallow, hard bottom area composed of low relief corals

benthic - of or pertaining to marine life that lives on the bottom

belt transects - a measuring line width a specific length and width, usually 20-m long x 2.5 or 5 meters, for conducting assessments of flora and fauna

blue-green algae - clusters of microscopic algal filaments that often appear bluish-green

biogenic - originating from a living organism

calcareous algae - algae which secretes calcium carbonate, much like a coral

canopy - an overhead growth above the ground line, much as a tree provides a canopy of shade

carbonate environment - a physical condition in which calcium carbonate, primarily limestone, pervades

conglomerated - a mixture or embedding of various forms of life that are ingrown together

cyano-mat - a layer of blue-green algae, often covering an intertidal bottom area

depauperate - lacking of, poor in

desiccate - dried out

detrital, detritus - decayed vegetation

ecosystem - all of the organisms in a given place interacting with other non-living entities

ecotones: areas of transition, or boundary zones between adjacent communities where species gradually drop out and others come in (example, red, black and white mangroves grow in particular zones that separate due to salinity and aerobic soil conditions)

embayments - a semi-enclosed body of water

environment - the total physical, chemical and biological surroundings

epifauna - animal life which lives upon another organism, usually microscopic, or macroscopic in size

epiflora - plant life which lives upon another organism, usually microscopic, or macroscopic in size

estuaria, estuaries – juncture where a fresh water body converges with a marine environment, such as at the mouth of a river emptying into the sea

geomorphological platform structure - a geologically formed body, such as a coral reef, or coastal zone area

green algae - an alga composed of chlorophyll

GPS - global position satellite system to designate positions on earth

herbivores - consumes plant materials, a vegetarian

hypersaline - composed of high salt content

Karst limestone - layers of materials composed of calcium carbonate

kunuku - papiamentu for country side

macro-algae - marine algae that is a simple plant, and non-microscopic

mangrove ecosystem - an environment in which certain species of trees which can persist in salt water for periods of time

meso-scale – processes occurring on the order of 1 – 1000 kilometers, as in wind-driven currents and tidal currents

mega-scale – processes occurring on the order of thousands of kilometers, as in ocean basin circulation

phylum - a major division representing a line of organisms having similar traits

physical processes - interactions which drive an ecosystem, such as wind, currents

primary productivity - a first level in which energy is converted from the sun into usable food by other organisms

propagule - a seedling of a red mangrove

salinity $^{0}/_{00}$ (parts per thousand) – the mass of dissolved salts in a given volume of seawater

scale: temporal, spatial - relating to a magnitude of time or space

sea level - position of the air-sea interface, to which all terrestrial elevations and submarine depths are referred. The sea level constantly changes at every locality with the changes in tides, atmospheric

pressure, and wind conditions. Longer-term changes in sea level are influenced by the Earth's changing climates. Consequently, the level is better defined as mean sea level, the height of the sea surface averaged over all stages of the tide over a long period of time.
silt - a particle of sediment which is fine grain and remains suspended in a body of water due to its light weight composition

solstice: Either of two times each year that the sun reaches the highest Latitude (23.5° north or south of the Equator). The earth is tilted on its axis about 23.5° from vertical. As the earth orbits the sun, one hemisphere tilts toward the sun and receives more direct sunlight. That hemisphere is in summer, while the other is in winter.

Tides: The twice-daily rise and fall of the Oceans, caused by the pull of gravity from the moon and sun. As the earth spins, each part of the Ocean is under the moon once about every 24 hours. The water bulges toward the moon, creating a high tide. Halfway between them are the low tides. There are two high tides and two low tides each day.

wowo di awa - a papiamentu term for "eye of the sea", in which there are subterranean conduits that move seawater

zonation patterns - life style trends whereby organisms conduct specific habits in their daily activities, such as juvenile fish tend to zone themselves in shallow bay areas

15.Appendix D: Trampling effect by recreational activity and seagrass degradation

Contribution by Caren Eckrich, Sea and Discover, Bonaire, Netherlands Antilles

15.1. A research design to examine trampling effects by resource users in seagrass meadows

The contributing author of this section, marine biologist Caren Eckrich, examined the implications of resource use impacts on seagrass beds, such as found in the Lac Bay area. . The following contains excepts from the study that served as her graduate research thesis (1995-1998 Dept. of Marine Science, University of Puerto Rico at Mayagüez, M. S. in Biological Oceanography) and is currently in review for publication as:

> Eckrich, C. and J. Holmquist. In Review. Trampling on the Seagrass *Thalassia testudinum*: Direct Effects, Response of Associated Fauna, and the Role of Substrate Characteristics. Submitted to Marine Ecological Progress Series.

Eckrich observed that with the increased popularity of outdoor recreation in natural areas, managers know surprisingly little about the most basic consequences of this usage. High-use coastal areas usually have soft substrates and are often vegetated. These conditions thus pose special management concerns about the potential environmental impacts of swimmers, snorkelers, kayakers, windsurfers, etc. on these type areas.

The study used the beds of the seagrass species, *Thalassia testudinum* (turtlegrass), to experimentally examine trampling on vegetated aquatic substrates and indirect effects on mobile fauna. The research sought to answer some elements of the following research questions:

- What happens at the shoreline where walking becomes wading?
- Are these substrates more susceptible to damage than terrestrial or hard substrates?
- How does trampling affect mobile fauna?, and
- Are all "footprints" the same, or is trampling disturbance mediated by substrate characteristics such as sediment composition?

Eckrich (In review) found documentation on trampling effects in a number of other ecosystems, as follows:

- In terrestrial assemblages, damage to flora is directly related to the amount of foot traffic, with different plant species showing differential resistance and recovery to trampling;
- Damage documented in terrestrial plants includes reduced height, cover, and biomass;
- Human trampling can also change community composition of flora and fauna;
- Trampling experiments on coral reef flats resulted in direct breakage and/or mortality of coral colonies and reduced live coral cover; and finally
- In addition to damaging corals directly, frequent trampling resuspends sediment, which may also cause moderate stress to adjacent corals.

However, in her scientific literature review, Eckrich (In review) found that the effects of trampling by educational groups and individuals on seagrass assemblages are unknown, although damage of seagrass beds via moorings and propellers had been documented. Her research and findings are as follows:

"…Seagrasses, unlike terrestrial grasslands, have no history of trampling pressure by large herbivores and therefore may not have the resistance to trampling as some terrestrial flora. Seagrasses grow in saturated substrates, which may cause them to be more prone to trampling damage than terrestrial flora growing in soils that are drier and more compact. *Thalassia* also lacks some of the supportive tissues that are present in most terrestrial grasses (Cronquist 1981). For these reasons, *Thalassia* may be less resistant to trampling than terrestrial grasses.

- *The first objective of this study was to provide a detailed account of the response of Thalassia to trampling.*

Thalassia testudinum beds are highly productive communities and serve as habitat for a diverse assemblage of flora and fauna, including commercially important species of conch, lobsters, crabs, and fishes (Wood et al 1969; Hooks et al 1976; Zieman 1982; Lewis 1987; Virnstein and Howard 1987; Holmquist et al 1989; Sogard, et al 1989). Furthermore, *Thalassia* traps and binds sediments and damps

water motion (Ginsburg and Lowenstam 1958; Fonseca and Fisher 1986), which may aid in erosion control and influence water circulation patterns.

Thalassia short shoots (a short shoot is a cluster of blades within a sheath branching up from the rhizome) regenerate relatively quickly following a minor disturbance to the standing crop, i.e., above-ground biomass (Dawes et al 1979). However, regeneration is slow when *Thalassia* rhizomes are disturbed (Walker et al 1989; Holmquist 1997). Even if tramplers do not directly damage rhizomes, damage to seagrass standing crop may affect the rhizomes.

Although it is known that human trampling reduces vegetation cover in terrestrial communities (Bayfield 1979; Cole 1995a), there is little knowledge of how trampling affects mobile fauna associated with vegetation that is destroyed by trampling in any system. The high diversity and abundance of animals living within seagrass beds is maintained via the habitat selection and refugium from predation provided by the complexity of the seagrass habitat (Stoner and Lewis 1985; Sogard et al 1987; Edgar and Shaw 1995).

- *A second objective of this study was to determine how a disturbance such as trampling, which damages the vegetation of certain habitats, affects the mobile fauna associated with this plant structure.*

Abundances of mobile epifauna (animals living on the blade and sediment surfaces) and fishes are generally greater in seagrass than in sand, because seagrass habitats have more structural complexity and heterogeneity than sand habitats (Lewis 1984; Edgar 1990; Edgar and Shaw 1995). Although many observational studies positively correlate epifauna and fish abundances with seagrass cover and biomass (Stoner and Lewis 1985; Edgar 1990; Edgar and Shaw 1995), this relationship is not always observed. Experimental research on fish abundances has found no clear relationship between fish abundances and seagrass cover, leaf height, and density (Bell and Westoby 1986a, b; Connolly 1994). Trampling may thin or eliminate seagrass, which could negatively affect the abundances or percent composition of some species of mobile fauna while positively affecting other species.

An important emphasis of previous trampling studies has been the resistance of different plant species to this form of disturbance (Cole 1985; Cole 1995b). In terrestrial habitats, herbaceous plant species that are low-growing, have tough leaves, and form mats or tufts are generally more resistant to trampling than other growth forms (Cole 1988; Cole 1995b). Also, certain habitat types are more resistant than others to trampling. For example, terrestrial grasses are more resistant to trampling than

some forest plant species, such as leafy, stemmed forbs (Cole 1985). Although responses of different plant species and habitat types to trampling have been documented extensively, very little is known about how habitat characteristics, such as substrate quality, mediate the trampling disturbance**.** Knowledge of assemblage resistance to trampling as a function of varying habitat characteristics may help resource managers and educators determine areas to set aside for intensive usages such as camping or hiking. In a broader sense, this type of knowledge may also aid in the understanding of how organisms living in areas with varying habitat characteristics respond to perturbation.

- *A third objective was to investigate whether habitat characteristics, including sediment composition and substrate penetrability, are related to the response of Thalassia to trampling.*

This study reports the results of a multi-level, short-term trampling experiment on seagrass beds in La Parguera, Puerto Rico. I tested the null hypotheses that human trampling does not damage *Thalassia* shoots or rhizomes and does not alter the abundance or composition of associated fauna. Further, sediment composition and substrate penetrability were examined as potential mediators of trampling disturbance.

15.2. Experimental Methods

The study area was located near La Parguera, in south-western Puerto Rico (17° 58' N, 67° 03' W). This area has nearshore and offshore coral reefs with extensive turtlegrass beds throughout the inner insular shelf. The shallow seagrass beds in the area are comprised mainly of *Thalassia testudinum* but are sometimes interspersed with or bordered by *Syringodium filiforme* and *Halodule wrightii.* Calcareous green algae (*Halimeda, Penicillus, and Udotea* spp.) and unattached red and brown algae (particularly *Acanthophora* and *Dictyota* spp.) are common in the areas chosen for study. Zoanthids (small, anemone-like cnidarians that are generally colonial and attach to the substrata) often grow among *Thalassia* blades, sometimes forming dense mats. Most of the study sites were located behind coral reef crests or shallow rubble cays, while several of the study sites closer to the coast were behind mangrove islands with limited coral reef development.

The experimental design consisted of ten randomized blocks, each with three experimental trampling "lanes" (Figure 1). Trampling lanes were used so that the results could be compared with experimental trampling studies in terrestrial grasslands that examine trail usage. The lanes were wider than some experimental lanes used in terrestrial studies (Cole and Bayfield 1993), and were chosen in seagrass beds of a depth <1-m where no known trampling had occurred.

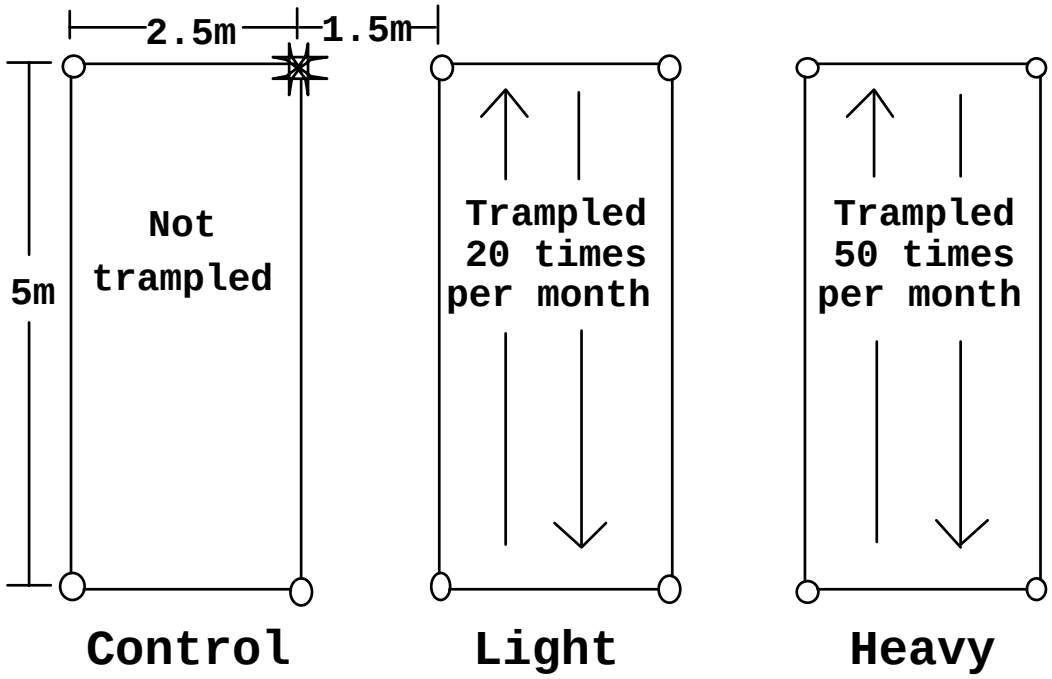

Figure 1. Treatment lanes A control with no trampling, a lightly-trampled lane that was trampled twenty times per month for four months, and a heavily-trampled lane (trampled fifty times per month for four months) Arrows indicate the direction of trampling

Each site had three 5 x 2.5-m lanes marked with PVC stakes: one as a control, one with low intensity trampling and one with high intensity trampling. The lanes were separated by 1.5-m so that the treatment applied to one lane would presumably not affect the other lanes. Seagrass-associated crustaceans are highly mobile and are capable of small scale (meters) redistributions within a day (Howard 1985; Holmquist 1997). The buffer zone was 1.5-m wide so that redistribution of fauna after trampling treatments would be possible, but the lanes would still be spaced close enough to minimize the effect of the natural heterogeneity of the shallow seagrass beds in this study.

In the low and high intensity trampling lanes, a 57-kg person wearing rubber-soled shoes walked to the end of the lane and back 20 and 50 times, respectively. The trampling was applied evenly across each lane (i.e. the trampler began trampling back and forth on the left side of the lane and slowly worked her way to the right side and so on from one side to the other). Treatments were applied once a month for

four months. Trampling intensities were based on observed patterns of educational and recreational usage in La Parguera. In this locale, it is not uncommon to have 500 people or more trampling areas of shallow seagrass (approximately 10 x 30-m) every month. These people often spend part of the day wading and repeatedly trample the same area of seagrass. For an area 2.5-m wide (such as my trampling lanes), 50 passes a month does not exaggerate the observed amount of trampling. I chose 20 passes a month for the low intensity trampling treatment, because this level of trampling would not be as intense a disturbance as the heavy trampling, but it would have detectable effects as demonstrated by the pilot studies.

I trampled five sites from March through July 1996 and five other sites from September 1996 through January 1997. Measurements were taken from each lane before trampling, two and four months after trampling began, and seven months after the last trampling treatment (the latter to assess recovery).

15.3. Experimental Results

Seagrass

In general, seagrass biomass decreased as trampling intensity increased and as trampling treatments were applied through time. After four months of trampling (before-after), Leaf Area Index, short shoot density, canopy height, and standing crop, all decreased in the heavily-trampled. Whereas, only canopy height and Leaf Area Index decreased in the lightly-trampled lanes. Declines were greater in the heavily-trampled lanes.

Trampling resulted in decreased seagrass and zoanthid (colonial anemones) cover, and increased sand cover. Percent cover of seagrass decreased in both types of trampled lanes and declined more in the heavily-trampled lanes than in the lightly-trampled lanes. Percent cover of sand increased in the heavily-trampled lanes and to a lesser extent in the lightly-trampled lanes. Zoanthid cover decreased in the trampled lanes, but algal cover did not.

Two out of the ten heavily-trampled lanes (2.5 x 5-m; trampled 50 times for four months) had large sand patches. In the pilot study, the lane with the most intense trampling (1 x 2-m; trampled once, 125 times) resulted in 77% sand cover, as compared to an average of 42% sand cover after four months of trampling in the heavily-trampled lanes, and had not recovered six months after the trampling treatment.

Rhizome biomass decreased in the heavily-trampled lanes. Study sites lost between 0-72% of their rhizome biomass (except one site that had a 5% increase) and 0-81% of their standing crop (except one site that had a 23% increase) in the heavily-trampled lanes.

The plots did not completely recover to pre-experiment conditions in the seven months following the last trampling treatment. Leaf Area Index, short-shoot density, and canopy height of the trampled lanes were still below the levels of the controls and the pre-trampling levels of the treatment lanes. At several of the study sites, the reduced seagrass cover in the heavily-trampled lanes was visually distinguishable from the surrounding seagrass 14 months after trampling ended.

Fauna

A total of 2614 shrimps composed of 18 species and 175 fishes composed of 11 or more genera were collected across all treatment categories. Ninety-seven percent of the total abundance of shrimps was accounted for by seven species: *Hippolyte zostericola/pleuracanthus* (40%), *Thor manningi* (23%), *Latreutes fucorum* (11%), *Alpheus normanni* (10%), *Periclimenes americanus* (8%), *Processa bermudensis* (3%), *Metapenaeopsis goodei* (2%).

Ninety-five percent of the total abundance of fishes was accounted for by four genera and one family: *Malacoctenus* (31.5%), *Sparisoma* (31.5%), *Bathygobius* (16.4%), Sygnathidae (12.1%), and *Haemulon* (3.6%).

After four months of trampling (before-after), shrimp abundances decreased in both the heavily and lightly-trampled lanes. Abundances of *Thor manningi*, when compared with the other shrimp species, decreased after four months in the heavily-trampled lanes. However, the abundance and mean percent abundance of *Processa bermudensis* increased in comparison with the other shrimp species after four months in the heavily-trampled lanes. Shrimp species richness decreased in the trampled lanes as well as in the controls. Overall abundances of fishes did not change after four months of trampling. In addition, the abundances and percent composition of individual fish species did not change significantly between treatments or time intervals. In the controls, shrimp abundances decreased from an average of 72 shrimp/m^2 to an average of 41 shrimp/m^2 and fish abundances increased from an average of 1.8 fish/m^2 to 3.3 fish/m^2 during the four months of trampling.

Just as human trampling reduces height, cover, and biomass of terrestrial plants, such trampling reduces the short shoot density, leaf-area index, standing crop, canopy height and cover of marine meadows. Intense levels of trampling also resulted in reduced rhizome biomass, an aspect of plant biomass that, to my knowledge, has not been measured in trampling studies. *The amount of damage to Thalassia from trampling is relatively proportional to the intensity and duration of foot traffic, which is also true for some plants in terrestrial communities* (Cole 1988; Taylor et al 1993).

Seagrass may be less resistant to trampling than terrestrial grasses. In general, grasslands are more resistant to trampling than forested habitat types (Cole 1988; Graydon and Hanson 1997). In a Montana grassland, it is estimated that one hundred hikers passing one-way on a 30-cm wide trail (not previously trampled) would flatten vegetation and result in short-term loss of forbs, but that this level of activity would recover completely by the following year (Cole 1988). I attempted to compare the impact of trampling on seagrass with that of the grassland in Cole's study. One hundred passes on a trail 30-cm wide is roughly equivalent to 800 passes on a trail 2.5-m wide, which was the size of the trampling lanes of this study. If this amount of trampling is divided among four months, we have about 200 passes per month, which is greater than the amount of trampling that was applied in heavily-trampled lanes (50 people; 100 passes) in the present study. Seagrass trampling lanes subject to 100 passes a month lost an average of 58% of their Leaf Area Index (relative to the controls) and 33% of their seagrass percent cover (relative to the controls) and had not recovered 14 months after trampling ended (pers. obs.). Although these are rough estimates and the fescue grassland may not be representative of common terrestrial grasslands, *Thalassia* would appear to be less resistant to trampling than terrestrial grasses.

Although *Thalassia* is grazed by large vertebrates such as manatees and sea turtles, this seagrass has not been subjected to the trampling pressure associated with grazing in terrestrial grasslands. Unlike most terrestrial grasses, *Thalassia* does not have sclerenchyma tissue, which helps prevent breakage of rhizomes, roots, and leaves (Cronquist 1981; Raven 1986). In addition, *Thalassia*, being submerged, grows in saturated sediment which may lead to less resistance to trampling relative to terrestrial grasses growing in relatively dry soils. Susceptibility of grasslands to livestock trampling is greater in wet soil conditions than dry soil conditions (Robinson and Alderfer 1952; Edmond 1966). Substrates saturated with water are generally softer than dry substrates, and trampling in saturated substrates is more likely to lead to substrate break-throughs and subsequently cause rhizome damage than trampling in dry substrates. Rhizome density may also influence the probability of substrate breakthroughs, although I did not collect sufficient data to test this relationship. It has been suggested that very soft sandflats are more sensitive to the impacts associated with trampling than more compact sandflats (Wynberg and Branch 1997). In my study, sites that had softer substrates had greater losses in rhizome biomass as a result of trampling. Substrate hardness influences the susceptibility of seagrass to trampling and perhaps other disturbances such as propellers and anchors. Habitat factors may also influence the time necessary for recovery of plant assemblages (Hylgaard 1980). *The present study supports the contention that environmental factors, such as substrate quality, play a role in an organism's response to perturbation*.

The depth of trampling or wading may also be an important factor, perhaps as important as substrate quality, in determining the amount of damage received by *Thalassia*. Depth is a potentially useful mitigating factor not present in terrestrial assemblages. A person would exert less force on the substrate in one meter of seawater than in 50 cm of seawater because of the buoyancy of the water. Unfortunately, the majority of waders tend to concentrate their activities in the shallowest, most easily damaged areas.

The maximum intensity of use that an area can continue to support under a particular management regime without inducing a major change in the biotic environment maintained by that management has been termed the "recreational carrying capacity" (Goldsmith 1974; Fletcher and Frid 1996). My study suggests that even relatively low levels of trampling may be non-sustainable and therefore exceed the recreational carrying capacity of Thalassia seagrass beds. Continued trampling treatments, even at low intensities, may increasingly damage the seagrass and result in sparse seagrass or bare sand. In temperate and sub-tropical regions, where seagrasses experience a shorter growing season and even annual defoliation, the effect of human trampling may be more pronounced than reported in this study.

Unlike most previous trampling studies, this study evaluates the response of mobile fauna to trampling disturbance. Direct trampling effects have been implicated in reductions of sessile invertebrate abundances and cover (Kay and Liddle 1989; Povey and Keough 1991; Brosnan and Crumrine 1994), but indirect effects, via damage to the seagrass canopy, may best expLeaf Area Indexn the observed shifts in the mobile invertebrate assemblage. Frequently trampled areas in rocky shore communities generally have lower densities of invertebrates than areas that are rarely trampled (Beauchamp and Gowing 1982). Observational studies conducted in seagrass habitats have found that epifaunal abundances generally decrease with decreasing seagrass structural complexity (Lewis 1984; Stoner and Lewis 1985; Edgar and Shaw 1995). Seagrass patches from which blades were experimentally removed have exhibited lower abundances of epifaunal invertebrates than uncut controls (Leber 1985; Connolly 1994; Connolly and Butler 1996). Decreased grass-shrimp abundances, particularly for *Thor manningi*, in response to trampling, were probably the result of the decrease in seagrass physical complexity. As trampling slowly thinned the seagrass, shrimps probably emigrated to denser seagrass outside of the trampling lanes or failed to immigrate into the trampling lanes rather than suffering direct mortality (see also Holmquist 1997). Conversely, shrimps of the Family Processidae are often associated with bare patches in seagrass meadows (Holmquist, pers. obs.), and this habitat preference may account for the increased abundance

and percent composition of *Processa bermudensis* in response to trampling. Trampling effects on the fish assemblage were not as pronounced. Organisms that are more mobile may be less likely to be sensitive to boundary and patch structure at a given spatial scale (Kareiva 1983; Wiens et al 1985; Kotliar and Wiens 1990), and this generalization appears to hold for at least some grassbed fauna (Holmquist, in press). *The comparatively mobile fishes using these grassbeds may not respond to the patch or scale (2.5 x 5-m lanes) produced by trampling in this study.*

Studies often find declining fish abundances with decreasing seagrass physical complexity (Sogard et al 1987; Connolly 1994; Edgar and Shaw 1995). However, there are contradictory findings (Bell and Westoby 1986b; Connolly 1994). Fourteen days after removing seagrass canopy from 5.5 x 5.5-m plots, Connolly (1994) found that fish abundances were not significantly different between treated and control plots. Bell and Westoby (1986a) found that fish abundances changed significantly when leaf height and density were manipulated at the scale of 25-m^2 within a seagrass bed. The same authors (Bell and Westoby 1986b) found that 15 of the 23 significant species responses found in their small scale study (within a seagrass bed) were not repeated at a larger scale (among seagrass beds). Whether fishes are attracted to seagrass because of its greater prey abundance or because of its physical complexity that serves as a refugium from predation is still unclear, but heavy trampling reduces both of these factors.

Human trampling is damaging to *Thalassia* standing crop and rhizomes and also decreases seagrass-associated shrimp abundances. Additionally, *Thalassia* beds recover very slowly after trampling has occurred. *Thalassia* was just beginning to recover seven months after trampling ended, and many trampled lanes were still distinguishable from surrounding seagrass fourteen months after trampling ended. Educators and managers can minimize this impact with alternatives such as underwater viewers, snorkeling, and interpretive aquaria. If group wading is unavoidable, I recommend concentrating activities in small areas of waist-deep seagrass with firm substrate. Terrestrial guidelines recommend diffusing trampling use in pristine areas (Graydon and Hanson 1997). However, concentration may be a better strategy in seagrass beds because of the long recovery time and because concentrated educational use minimizes the direct mortality of echinoderms, crabs, and zoanthids living within the seagrass canopy (pers. obs.)…"

15.4. Eckrich Seagrass Study Literature Cited

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