Research and Monitoring Results for the Size Class Distribution and Abundance of the Queen Conch, *Strombus gigas*, and Seagrass Characterization in Lac Bay, Bonaire

prepared for
Bonaire Marine Park

by
Environics Consultants
Cynthia Lott, MSc 1994
February 2000

Executive Summary

This report provides a comprehensive coverage of accomplishments completed to date by Environics for the Lac Bay queen conch (*Stombus gigas*, known locally as "karko") monitoring project, which was completed over the period June - December 1999. The consultant activities were proposed to the Bonaire Marine Park and VOMIL in the Terms of Reference (May 1999, Appendix 1) 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?

For this report, the following activities were conducted to provide baseline information about the status of the conch population and also to describe the current health and status of the greater bay environs, through the process of the following:

- assessing change from the past to present with historical interpretation through prior literature search;
- conducting rapid ecological assessments of the bay benthos, including queen conch population status, seagrass abundance and epiphyte density, and
- detecting potential threats of the conch in the Lac Bay environs.

Field monitoring to determine the conch population size class distribution, in addition to characterization of the seagrass beds, were completed in seventeen 200 x 200 meter grid sites in the bay. Each grid contained three 5-m belt transects, to assess a total of 3,000-m^2 area per grid. The completed ecological assessment would result over coverage of 51,000-m^2 area. The sites were non-randomly selected for ground truthing extensive coverage from aerial photographs. Each transect start point was placed with compass rose headings, followed by assigning latitude/longitude coordinates on a line map of Lac Bay (grid map - Map 2). In the field, the grids and transect lines were located using a Garmin GPS unit to conduct the monitoring activities with trained volunteers. Rapid Ecologicial Assessment protocols were adapted from The Nature Conservancy Caribbean Program (1996), and the Southwest Florida Water Management District (1998) seagrass monitoring methods (adapted in the BMP volunteer monitoring draft manual in Westmacott, 1999). This project was completed through the scientific support of trained volunteers from the Bonaire Underwater Research Assistants (BONURA) group. Following mastery training skills, the resultant protocol and species identification training were field tested in Lac with the volunteers during June 1999; routine surveys were underway in July 1999. Monitoring activities were completed at the end of September 1999.

GIS map products of the survey results are currently being completed at Duke University, through the co-operation of the Dept. of the Environment, with graduate student Phyllis Dermer, under the supervision of Dr. Patrick Halpin. Draft maps are contained in this report.

The final map products will include a GIS zonation map, with management recommendations for the greater bay area.

In brief, the statistical results indicate that for both conch and invertebrate species in general, the spatial distribution patterns are clumped or uniform, implying potential constraints on the system. For conch, fishing pressure may be likely, as the map results show the remnant conch population is located in the deeper bay channel or boat routes, that have least potential for anthropogenic accessibility. The conch mean size class is approximately 17.8-cm, or approximately 2.5 years; no adults were found during this assessment period. In the 51,000-m^2 bay area surveyed, a total of 111 conch were found, averaging only 7.4 conch per 3,000-m^2 grid area. Surveys were conducted during the normal breeding period when adult conch usually migrate into shallow sandy areas to mate (personal observation, 1987, 1991; Stoner and Waite, 1990). Anecdotal reports in Bonaire indicate that adult conch remain on the deep reef sandy terraces to mate, at approximately 50-70-m depths, likey due to Bonaire's limited shallow water bank systems available for breeding purposes (personal communication, Newton, 1999).

A main resource for conch larval recruitment into Lac Bay may generate from upstream sea current sources that are located in the neighboring Aves Island and Los Roques archipelago region. During October 9–13, 1999, Environics visited Los Roques to observe the area's conch fishery management program, and its implications on conch fisheries for Bonaire. Approximately 6 years ago, the Los Roques archipelago also realized a near complete collapse of conch. They immediately initiated a "no-take" moratorium to manage the remaining stock, with strict consequences to poachers. Environics observed an impressive recovery, with many adult size conch concentrated in the shallow (<3-m) seagrass banks of Los Roques. In the Los Roques conch sanctuary areas, there were reported an estimated 0.42 individuals per m^2 in unfished areas (Weil and Laughlin, 1984). (Compare the Los Roques estimation to the Lac Bay estimation of 0.0021 individuals per m^2).

Los Roques Inparques marine management program is anxious to network with Bonaire, to share its program as a "peer demonstration model" with Bonaire the benefit from the Los Roques experience, to save the Lac Bay conch population.

Historical research conducted by Hummelinck and Roos (1969) described the discarded conch piles at Cai as changed very little since Hummelinck's prior study period that was conducted during the early 1930's. The reference inferred that the conch fishing pressures had been impacted approximately since this time, and the result of the conch distribution patterns are similar to this present day GIS map depiction for conch distribution - that remaining conch are found only in areas of least access by fishers.

The results of this study, and the historical research by Hummelinck and Roos (1969), lead to the conclusion that conch populations once were, and can be, viable in Lac Bay. In addition, according to conch size class and habitat viabilitiy studies (Stoner and Waite, 1990, 1991; Weil and Laughlin, 1984), Lac bay's abiotic conditions (bottom depths, temperatures), as well as its biotic features (seagrass habitat abundance, epiphyte density, short shoot abundance), are suitable to sustain conch stock. However, the results from this survey activity indicates that few, or no conch were found in the greater seagrass areas, but, as found in 1969, stock are still distributed in areas that may be least accessible to fishing pressure – in the deeper boat channels, or in shallower, high energy wave zones. However, moderate numbers of young conch (less than the mean 2.5 year size class found in this study) do persist in some areas of Lac, but are quickly taken out. Evidence shows the removal of young recruits due to fishing pressure, by the discarded piles of recent takes of brightly pink small (<17.5-cm) cracked conch shells found in the bushes near the shores of Sorobon.

Adult conch reach reproductive size during the 3 to 5 year size class (Berg, 1975). Therefore, a 6 year moratorium is recommended to support the Lac Bay conch population recovery, modeled after the Los Roques conch recovery program. Public education and outreach programs, supplemented with peer visits from the Los Roques park management team to describe their conch recovery program, is recommended, that would drive the local Bonairean community into supporting the Lac management program. 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 for viable conch and other wildlife habitats, as well as to designate mulit-purpose recreational use areas. 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.

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 provided the funding for the overall Lac Bay program, and;
- Kalli deMeyer, Bonaire Marine Park manager, who put the Environics/BONURA team together and gave us her blessings with the yellow banana, commanded by Nolly Thode, to get us out there to do the job; and
- VOMIL, Curacao, who partially funded the conch stock and seagrass assessment project.

And many special thanks to,

- Barry Gassert, the 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;
- Carmita Santiago, Rincon, who translated the Hummelinck and Roos (1969) scientific research from Dutch into English for my historical review of past studies in Lac Bay;
- Not forgetting the techno-team,
- Linda Richter, (NetTech), who produced the underwater survey forms and reference visual aids for quality assurance data management and species identification cheat sheets;
- Jessie Armacost, BONURA data manager, 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;

- Duke University at Raleigh, North Carolina, Dept. of the Environment, especially graduate student Phyllis Dermer and Dr. Patrick Halpin, for producing the GIS interpretation maps of Lac Bay survey data;

And last but not least,

- The following members of the Bonaire Underwater Research Assistants (BONURA) who donated their talents, time and labour:

Donna Gassert	Carla Hall	Chris Armacost	Coen Voss
Carl Look	Rocky Valentine	Daniel DeAnanda	Julie Burns
Minco Coenraad	Renate Rietman	Claudia de Keef	Valeria Bette
Maartin 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 me and the project :-)

Table of Contents

1. Introduction

1.1 Lac Bay Site Description

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 size is approximately 3.9 km North-South and 3.0 km East-West, with an overall highwater surface area of approximately 7.5 km (van Moorsel en Meijer, 1993; geographical map - Map 1).

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 northern posterior portions of the bay area. In this sub-basin system, mixed dwarf red, black and white mangroves, including buttonwood, flank the embayment area, that have trapped and created sand sill islands, and separated greater Lac apart from this posterior region's shallow, detritus and muck bottom salt ponds, or salinas.

The Lac Bay main basin area is a depauperate, clear water shallow bottom lagoon system, comprised of several typical coastal marine communities (Hummelinck and Roos, 1969). These include along the windward seaside, a fringing fore reef slope composed of milleporid hydrocorals, acroporids, gorgonians and scleractinians. The back coral patch reef is of similar species composition, but is situated in a shallower, high energy wave action zone, layered over a hard calcareous plateau bottom, that eventually grades into a sparse sandy bank. Dense seagrass and mixed macro-algae meadows flourish inside the main bay basin. The inshore perimeter of this basin is flanked by red and black mangrove intertidal wetlands.

1.2 Project Background

The Lac Bay lagoon ecosystem is unique in the Netherlands Antilles, and thus holds international wetlands recognition and the status as a RAMSAR site. Thus, as described by van der Meulen (1998), a management program to safeguard Lac is imminent:

> "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, 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 prioritize them as they related to needs for integrating a comprehensive management plan for Lac Bay. They were described under the following core elements:

- **research and monitoring**:

  a. involves the need for the implementation of management and zoning plans for Lac Bay, and
  b. conduct site characterisation and monitoring activities for Lac Bay.

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

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

Activity 10.1: Design of an easy to implement by effective monitoring programme 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 programmes 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 in support of management

In particular, this volume is a summary of all accomplishments to date, as proposed by Environics to the Bonaire Marine Park and VOMIL, in the Terms of Reference for Conch and Seagrass (May, 1999; Appendix 1). It address the needs for the following BMP Project code LAC001/98 objectives and activities:

a. Activities 10.2 & .3: Collection of baseline data and monitoring seagrass, and
b. Activity 10.4: Monitoring of conch populations.

1.3 Problem

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, 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).

Long term monitoring of conch at permanent stations would provide pertinent abundance and distribution data, and determine management replenishment zones for the species in Lac Bay (deMeyer, 1998; B.M.P. Agenda, 1999). For this study, assessment parameters would include:

- conch size class distribution;
- % benthic coverage of seagrass and macro-algae;
- species presence/absence inventories of invertebrates that utilize the seagrass habitat, and flora species;
- detection of indicator species, including presence of conch predators;
- depth;
- water quality analysis for salinity, turbidity and temperature;
- bottom sediment classification.

Data interpretation of the above biotic and abiotic baseline information would result in developing a zonation map for management purposes (The Nature Conservancy, 1996).

2. Methods and Materials

Two methods were used to implement the project:

a. recruiting and training volunteers to identify bay species, including technical exercises to perform scientific diving methods for gathering field data; followed by,
b. conducting the rapid ecological assessments for seagrass coverage and conch size class distribution, with the scientific support of the trained volunteers (The Nature Conservancy 1996; SWFWMD, 1998 in Westmacott, 1999).

2.1 Training Volunteers

All volunteer training activities were conducted at Lac Bay over a series of days. Mastery skill workshop sessions were utilized, through hands-on field interaction and repetitive drills. They included:

- Seagrass and macro-algae identification techniques
- Seagrass protocol and using field survey forms
- Transect and quadrat analysis scientific diving skills
- Data collection
- Data processing
- Use of Quality Assurance field assessment guide cards

Referring to the texts, handouts and the identification cards, through hands-on field experience, the training sessions included the classification of the seagrasses, and phyla of all macro-algae and invertebrates that would be surveyed.

For brevity's sake in this report, detailed explanation of the mastery skill training program is reserved to the above. Further inquiry into this topic may be found in the reference, *Companion to the BMP Lac Bay Volunteer Training Manual* (currently in production by Environics). However, the field assessment guide cards and sample field data sheets are presented in Appendix 2. They are self-explanatory.

2.2 Benthic Surveys Method for Seagrass

Seagrass and macro-algae assessments were conducted following the standardised protocol for visual estimation on a percent coverage scale, as introduced by the South West Florida Water Management District (SWFWMD, 1998). Environics completed a five day training workshop (1998) series for implementing this method in Florida during October 1998, and introduced the protocol to Bonaire Marine Park (in Westmacott, 1999).

The protocol provides for a comprehensive, yet rapid ecological assessment of seagrass monitoring method, that can be repetitive, to supplement resource management decisions based on field information. Repetitive data allows to record changes in seagrass growth, zonation and distribution over time, as well as in this study, characterise the overall health, or condition of seagrass meadows in the bay.

Thus, in addtion to the parameters listed in Section 1.3, to assess seagrass condition and viability for conch nursery habitat, the following parameters were included in the benthic assessments:

- seagrass/macro-algae percent substrata coverage,
- short shoot density,
- estimated epiphyte coverage loaded on the grass blades, and
- *Thalassia* leaf width and length measurements.

The method uses the botanical Braun-Blanquet visual estimations procedure (SWFWMD, 1998) that is evaluated within a meter square quadrat for seagrass % coverage, measures blade length, relative epiphytic loading, short shoot density and characterises the sediment along a transect (survey form, Appendix 2a). Details of the SWFWMD (1998) seagrass assessment protocol is available in the Lac Bay Volunteer monitoring manual (Westmacott, 1999).

3. Establishing Map Unit Polygons with Line transects

The procedure involved laying out seventeen 200 x 200 m map grid polygons (Boat Procedure, Appendix 3), and referencing the four corners and center point of each polygon with diver down floating flags and weights. For each grid, three 200-m length transect lines were laid out according to pre-determined compass rose headings, that would establish all transects in SE-NE mapping unit orientation. Each transect was also marked with GPS latitude/longitude coordinates, and placed on a reference map of Lac Bay. The polygons were conveniently selected so that data could be used to ground truth the aerial photographic map, and cover as much bay bottom areal extent as possible. The transects are also permanent via the starting point GPS map coordinates, and compass headings, so that the same map unit polygons can be re-surveyed in the future. These sites can then be monitored yearly to detect changes in the seagrass communities at several sites (Westmacott, 1999; survey grids - Map 2).

a. Marine Reconnaissance Survey Form

During each assessment period, the boat team setting up the grid map polygons also recorded oceanographic parameters including tide, time of day, Beaufort Wind Scale weather conditions, and at the mid-grid point, the sea surface temperature, salinity, and secchi disk turbidity readings were recorded (marine reconnaissance data summary – Table 2).

b. Estimation Procedure with Quadrats

The following sampling unit areas were surveyed during this project in order to assess for species densities and characterize the Lac Bay benthic environs (grid sampling unit areas - Table 1):

- belt transect census for conch stock and size/class distribution, including species presence/absence inventories, to assess a 3,000–m^2 area per grid, and a 51,000-m^2 total sampling unit area;
- 1-m^2 belt quadrat assessments for substrata and lifeform % benthic coverage, to assess a 126–m^2 area per grid, and a 2,142-m^2 total sampling unit area; and
- 25-cm^2 belt mini-quadrat assessments for seagrass analysis, including epiphyte density, short shoots counts, and seagrass blade size evaluations, to assess a 4.125–m^2 mini-area per grid, and a 70.125-m^2 total mini-sampling unit area.

The method of data acquisition for substrata and lifeform coverage is accomplished using a 5-m wide belt transect of 200-m length. To conduct the ground truth interpretation, each transect line was marked in 10-m increments, and used as a guide for the placement of a 1-m^2 quadrat for survey analysis (The Nature Conservancy, 1996). This served to conduct % coverage assessments for seagrass species, macro-algae, hard/soft corals and sediment characteristics. In addition, 25-cm^2 mini-quadrats were inserted at each 20-m increments, placed inside the lower corner of each 1-m^2 quadrat along the transect line. This served to conduct detailed assessments of seagrass/macro-algae % coverage, short shoot density, epiphyte % coverage, average *Thalassia* leaf width and length measurements, and sediment type characteristics, adapting the SWFWMD (1998) protocol.

Beginning at 0-m on the transect line, one diving buddy pair would swim side by side, to assess the 2.5-m width section along each side of the transect line per diver. While swimming along the entire length of the 200-m long belt transect, the surveyors conducted census counts for conch stock (including recording shell length/width measurements), and species presence/absence inventories for invertebrates and substrate lifeform. At every 10-m increment, each diver conducted benthic assessments by placing the 1-m^2 belt quadrat to estimate substrata and lifeform % coverage. In addition, at every 20-m increments, the surveyor would place the 25-cm^2 mini-quadrat inside the 1-m^2 quadrat to estimate for epiphyte density, total short shoot counts, and turtle grass blade length and width measurements (SWFWMD, 1998; oceanographic and biological parameters summary - Table 2; field assessment data summary – Tables 2 and 4).

3.1 Scoring System for Species Abundance and Density

Percent coverage of substrata and lifeform features per m^2 are scored as one of six possible cover classes:

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

Epiphyte density was determined by visually evaluating the coverage of microscopic epifauna and epiflora observed fouled on the individual *Thalassia* species seagrass blades. Density was estimated per 0.125-m^2 belt mini-quadrats. A single value code was designated to represent the overall average coverage of fouling, by applying the following classification codes:

- 1=clean
- 2=light
- 3=moderate
- 4=heavy

The Appendix 2b survey sample sheets contains the reference cards for estimating the different cover classes in the 1-m^2 and the 25-cm^2 mini-quadrats, according to the Braun-Blanquet method, and the epiphyte density coverage codes (The Nature Conservancy, 1996; SWFWMD, 1998).

Preliminary surveillance of typical Lac Bay substrata allowed to establish category descriptions for bottom sediment type (The Nature Conservancy, 1996), and was thus classified for % coverage scoring as follows:

Sand-mud: this category is defined as within the lower limit of fine sand, clays and muds (grain size 0.12 –0.2-mm, or has powdery texture or tends to stick to the fingers);

Shelly/coarse sand: coarse biogenic material, derived from calcareous algae, such as Halimeda species, or pulverized coral and shell fragments (grain size 0.5-2-mm);

Coral rubble: includes coarse coral reef materials that are moveable (>5-mm-1-m);

Hard reef: defines the eroded hard pavement bottom, any rocky platform or any consolidated bottom with less than 3-cm of sediment overlaying it.

3.2 Conch, Invertebrate and Species Presence/Absence Monitoring Procedures

Species presence/absence inventory data is the collection of information on the occurrence of conspicuous flora and fauna in marine benthic communities. This type of species inventory allows for the analysis of multiple sample sites based on overall species composition. It can quantify the overlap of species composition among and within mulltiple sites, on a spatial or temporal scale (Sullivan and Chiappone, 1993; Sullivan et al, 1994; The Nature Conservancy, 1996).

In this project, species presence/absence inventories were assessed to determine baseline information, as well as to discern how the species are distributed throughout the bay environs, to ultimately develop a resource management zonation map. Although inventory data of this type are only semi-quantitative, it can be a powerful tool in characterising and differentiating community types, such as defining zones for a mixed seagrass/macro-algae community, or patch reef/sponge sandy community. Thus, this type information serves as a valuable management tool to provide vital biodata for developing marine zonation maps (The Nature Conservancy, 1996).

A non-random, systematic survey method was used, in order to assess as much of bay bottom as possible. The belt transect method allowed to visually conduct representative flora and fauna species census counts, while swimming a 2.5-m wide distance along each side of a transect line. This method required the least amount of time (about 1-2 hours to complete one 200-m x 5-m belt area), with a moderate amount of expertise, aided by the use of underwater species identification cards (survey identification cards - Appendix 2b). As each diver swam along the length of the transect, he/she scanned a 2.5-m wide area of the bottom, noting all species present that included echinoderms, sponges, seagrasses, macro-algae and conch. When a conch shell was encountered, it was noted on the conch survey form as live, or empty (and noting with our without holes) to discern the population of live, fished or natural cause of death. The live conch were measured for total shell length, body whorl length and body whorl width (conch census data summary – Table 3). This vital data (assessing a total 51,000 –m^2 area) could be used for spatial analysis purposes to assess age classification of the individual, and note distribution patterns of age class sub-populations in the Lac Bay area for mapping interpretation needs (The Nature Conservancy, 1996).

While swimming the length of the transect line, other representative invertebrate fauna were also noted and quantified for mapping purposes, to distinguish distribution patterns as well as population numbers. Species noted included the pin cushion star fish, *Oreaster reticulata*; the donkey dung sea cucumber, *Holothuria mexicana*; upsidedown jellyfish, *Cassiopeaa* spp., and several typical bay anemones and sea urchin species. These species data will not be presented in this report, but can be reviewed in the final Site Characterization Report for Lac Bay (presently in progress by Environcs).

4. Data Analysis and Results

For substrata and lifeform distribution, data was reported as relative percent coverage values, as described above. It is presented in this report in table, graph and map forms. Georgraphical Information System marine mapping depictions were produced to analyse gross overall distribution of the seagrass components coverage, bottom sediment compostion and depth, total species inventory and conch distribution. Those parameters interpreted in this fashion are of valuable importance for developing final marine management zonation maps. The maps presented in this report are draft copies, final map products are currently in production at the time of this writing, and will be submitted later in an Addendum to this report. The zonation map can be produced following review of this report by management, and with further consultation with Environics. Additional summaries and analyses of the Lac

Bay benthic assessments can be reviewed in the final Site Characterization Report for Lac Bay (presently in progress by Environcs).

It should be noted at this time, that this method of monitoring for substrata and lifeform coverage may be used effectively for ground-truthing aerial photographs for developing benthic community baseline zonation maps for management purposes, as is the primary objective in this project. Otherwise, this type of characterization is of limited use, as there are no statistical tests that can be easily applied to the data to determine levels of significance in viewing spatial and temporal change. The most powerful use of area measurements is for examining spatial patterns of natural communities, as well as for the comparison of mean coverage per m^2 over time, and examining the size-frequency distributions of individuals over time (Sullivan and Chiappone, 1993). The use of similarity dendrograms can be applied for future comparative analysis that can detect spatial change of substrata and lifeform coverage over time within and among study sites. Therefore, for management and environmental decision making, the methodology used in this study is a valuable survey instrument for the qualitative review of community structure. It can provide for a rapid detection of the effects and changes caused by larger-scale episodic events, such as storm events, or other natural phenomena, such as benthic algal-blooms, in addition to detecting anthropogenic disturbances in an area. Therefore, as done in this survey, the method must be employed at a large number of study sites that are dispersed throughout the ecosystem of interest (Sullivan and Chiappone, 1993; Sullivan et al, 1994; The Nature Conservancy, 1996).

a. Spatial Pattern Analysis

Spatial pattern analyis is a simple statistical application to interpret community ecology in two aspects, for:

- Describing or discovering a dispersal pattern, and
- Explaining the reason for the dispersal patterns.

In community ecology, we want to understand trends for:

- Spatial patterns – what are the community types in Lac bay; and
- Temporal patterns – how do these communities change:
    - seasonally,
    - with management or use of policies,
    - due to catastrophic events, such as hurricanes.

(Sullivan et al, 1991).

Natural communities exist under condtions of multivariate control, that is, no one factor (biotic or abiotic) would account for 100% of the patterning (Sullivan et al, 1991). Biotic factors, such as food resources, predation, competition, coupled with abiotic factors, such as temperature and substrate, contribute to control natural communities' patterning. We need to understand the patterning of communities, and how they change naturally, in order to evaluate man's impact on the system, for applying appropiate management strategies.

Patterns in natural communities are interpreted in several ways:

a. Random, implies environmental homogeniety, and/or non-selective behavior patterns, where all individuals are located independently of each other;

b. Clumped, implies environmental heterogeniety, where individuals tend to be located together in clusters, by aggregating to more favorable parts of the environment; or

c. Uniform, implies negative interaction between individuals, where individuals are regularly spaced in relation to competition for food or space.

Those non-random patterns (b. and c.) imply that some types of constraints on the system exist. Those spatial patterns may be a result of a number of factors:

- Vectoral factors – wind and currents,
- Reproductive factors – settlement and recruitment fragmentation,
- Social factors – territories and home ranges,
- Coactive factors – competition, and/or
- Stochastic factors – random variation

(Sullivan et al, 1991).

4.1 Spatial Pattern Analysis of Conch Species Distribution in Lac Bay

A simple statistical spatial pattern analysis was calculated to assess for the queen conch population distribution in Lac Bay. In order to evaluate the dispersal patterns of a population, the range of "intensity" is examined for changes in relative population density in an environment. These intensity patterns are then used as a sensitivity index to assess clumping (Sullivan et al, 1991). From each 200-m^2 grid sampling unit area, a mean number of conch organisms per area, and a variance, were calculated to derive at the following indices:

a. Random: sample mean = variance;
b. Clumped: sample mean < variance ; and
c. Uniform: sample mean > variance.

Table 3, Chart 6 and Maps 3a, b and c presents the results of the data summaries for the queen conch stock census count and the corresponding distribution within Lac Bay. Overall results indicate that conch species are spatially distributed in Lac Bay in a clumped or uniform pattern, implying there are some constraints on the system as previously described. The clumped or uniform spatial depiction patterns are evident in Map 3b.

The results show that there are approximately 111 total conch found in the 51,000 m^2 grids total sampling unit area, with a mean population density of 7 conch per 3,000 m^2, or a density of 0.0021 individuals per m^2. The sample shell lengths ranged from 14.3 cm to 20.2 cm, with a mean total shell length of 17.8 cm; according to Brownlee and Stevely (1981) this size class equates to an approximately 2.5 year old juvenile conch. No adult conch were found in this study, although the assessment period was conducted during the typical Caribbean adult queen conch aggregation and mating time, that occurs during April to late November (Weil and Laughlin, 1984).

4.2 Seagrass Abundance and Epiphyte Density Analysis for Conch Habitat Viability in Lac Bay

The substrata and lifeform characteristics for Lac Bay were calculated based on the mean score of each category's relative percent coverage, using the coverage scale codes as described in section 2.4. For each grid, first the mean score value of each benthic category was derived, then the mean of all grid means for each category was calculated to obtain a final estimated value. Table 4. describes the "mean of means" for *Thalassia*, macro-algae, and sediment characteristics for the Lac Bay benthos.

Thalassia has an estimated gross mean score code of 2.7, or approximately ranging in the estimated 5 – 25% coverage per m^2 within the 2,142-m^2 sampling unit area. Macro-algae has a gross mean score code of 1.9, sand/mud scored 1.8, and shell/coarse sand scored 2.0; or all categories (nearly) ranging into the estimated 5 – 25% coverage per m^2 within the 2,142-m^2 sampling unit area. When re-calculating seagrass and macro-algae coverage by excluding grids 5, 6, and 17 (in locations at Seco di Sorobon and Awa di Blancu areas, which are primarily all bare sandy bottom, with little or no seagrass benthic coverage), the*Thalassia* mean score value increased to 3.1, or 26 – 50% coverage per m^2, and macro-algae increased to a mean score value of 2.0, or 5 – 25% coverage per m^2 (abundance and density summary - Table 4).

Relative mean densities for epiphyte loadings on the turtle grass blades were estimated as between light and moderate, with a gross mean score of 2.4 density code per 0.125-m^2 within the 70.1-m^2 mini-sampling unit area. Mean turtle grass blade lengths were estimated as 12.6-cm, while blade widths were estimated as approximately 1.3-cm, and there was estimated a total of 6.3 short shoots per 0.125-m^2 within the sampling area. Again, when eliminating grids 5, 6, and 17 as described above, values increased for epiphytes to 2.5, seagrass blade length to 14.0-cm, seagrass blade width to 1.5-cm, and total number short shoots increased to 7.9 per 0.125-m^2 within the sampling area.

Each benthic category mean score code had a wide range of values, due to the variations of substrata in the bay benthos. The summary range of score code values (see above or Table 4 for area and code details) are as follows:

Thalassia	0.3 – 4.1
macro-algae	0.9 – 2.7
sand/mud	0.9 – 4.1
shell/coarse	0.4 – 4.2
epiphyte density	1.1 – 3.3
blade length (cm)	3.0 – 21.4
blade width (cm)	0.7 – 1.6
total # short shoots	0.2 – 14.6

5. GIS Zonation Features and Management Implications

[Please note: The maps in this report are draft versions, and final maps will be submitted at a later date in an Addendum to this report].

A series of Geographical Information Systems (GIS) maps were produced to visually interpret the survey data points, and can serve as an analytical tool for establishing resource management zones. The above score codes are mean summary values per category for all items surveyed among all seveteen grids, and are necessary for spatial pattern analysis. However, for zonation purposes, the ranges of values are individually defined when interpreted in color sequences on GIS depictions.

The bottom characterization for fine sand/mud, shell/coarse sand, rubble, reef and sponge are depicted in Maps 4a, 4b, and 7. 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 shelly bottoms occur along the seaward flank areas.

The Charts 1 and 3 depict the relative % coverages breakdown of the sediment composition in the bay area. Grids 5 and 6 (refer to the grid location Map 2) have a mean score code value of 4.2 and 3.3 (26 – 75% coverage), respectively for shell and coarse sand bottom composition, and are located in the Awa Blancu area, as seen in Maps 4a and 4b. In addition, Grid 17 has a mean score code value of 4.1 (51 – 75% coverage) for fine sand/mud and it is located in Secu di Sorobon.

The draft bathymetry Map 5 (depths in feet on this version), and the mean depths Chart 2, show that the depths in the Grids 5, 6, and 17 are relatively shallow compared to all other grid sites, less than 6 feet (< 2-m). However, Grid 17 has a fine sand and mud bottom composition, while Grids 5 and 6 bottom composition has a moderate shell and coarse sand component. These data may imply that, for example, a wind surfer activity zone may require to exclude the Grid 17 area, so that fine silt is not chronically suspended by impact of windsurfboards. In addition, the *Thalassia* % coverage map (Maps 6 and 7, Charts 3 and 4) shows the least seagrass distribution in this area, with a mean score code value range of 0.3 to 1.0 (less than 5% coverage).

The draft bathymetry Map 5 and Chart 2 shows that the Grids 8, and 13 occur in deeper water (12 feet, or 3.4 m), and features <25% coverage of seagrass (Map 6, Charts 3 and 4). Based on the GIS interpretation and the charts data, a windsurfer activity use zone could be extended from the shores of the concession facilities, across Awa Blancu crossing Grids 5, 6, 7, 8, and 13. These areas feature the least seagrass densities. Although Grid 8 has a 3.6 mean score code for sand/mud (26 – 50% coverage, Chart 1), is a mixed algal/seagrass community (2.5 and 2.4 mean score code values for seagrass and macro-algae, respectively. It is also located in relatively deeper water (3.1 m, Chart 2) than any other grid area.

The greatest % coverage range (26 – 75%) of *Thalassia* occur along the nearshore inner perimeters of Lac Bay, from the southwest mangrove area, following the bay's interior nearshore configuration, to the Puitu and Cai areas (Grids 1, 2, 3, 9, 10, 11,12,14, 15 and 16). The bathymetry Map 5 indicates these are also the shallowest areas of the bay, ranging from 1 to 9 feet (< 3-m). In addition, the seagrass and epiphyte coverage Maps 7 and 8, and Charts 3, 4 and 5 concur that the greatest short shoot seagrass density, and greatest seagrass blade length and width data occurs in the Grids 1, 2, 3 in the southwest area, Grids 11, 12, 14, 15, and 16 located in the northeast and the Puitu and Cai areas. These areas may be considered for sanctuary preservation and wildlife habitat reserves, and be demaracted accordingly on a management zone map.

5.1 Historical Interpretation, including prior research maps

Historical interpretation from prior research conducted by Hummelinck and Roos (1969) reveals that little has changed for the conch and seagrass/macro-algae benthic distributions. Maps completed by the prior researchers (historical maps – Map 9a, b) when overlapped with this study's draft maps reveal remarkable similarities in species distribution patterns (*Thalasssia* – Map 6; conch distribution – Map 3 a, b).

Seagrass benthic coverages appear to distribute in similar zonal patterns in both the Hummelinck and Roos (1969) maps, and this report's maps. In addition, conch distribution patterns were depicted in the boat channel area of the boca of Lac Bay near Cai, as well as along the deep water borders that flank the Secu di Sorobon and Awa Blancu region in both the historical and present day maps. Stoner and Waite (1990, 1991) indicate that following early juvenile conch size class, conch individuals prefer 4-m to 8-m depths which contain suitable food resources. Data from this study concur with these findings (*Thalasssia* – Map 6; conch distribution – Map 3 a, b).

Prior scientific research conducted by Hummelinck and Roos (1969) indicates that the piles of conch at Cai have existed since his early research visits during the 1930's, but when he returned to continue his research again in 1969, "…the white shell hills do not grow anymore…". He also reported that "in the course of the sixty years" (prior to 1930), based on his calculation of the amount of shell piles at Cai, "…an average of five hundred karko a month…" were available for taking. He observed that conch were no longer abundant in Lac Bay beyond the year 1930, implying the conch fisheries may have already collapsed. Hummelinck (1969) also indicated that during those years, the conch stock in the shell may have been transported away by boat to Curacoa, as well as taken away to be made into shell lamps, that were being produced near that time period.

Comparing the 1999 GIS mapping against the Hummelinck mapping conducted during 1969 (Historic Maps – 10a,b), the live conch stock distribution patterns in Lac Bay are strikingly similar and unchanged. These similarities between the 1969 and 1999 conch distribution mapping in the bay, and research observations, may imply likely conclusions. Where conch size class data (for individuals in the less than mean 17.8-m) are noticeably missing in the shallower (<3-m) seagrass areas that would support conch, may imply that in Lac Bay, conch have been able to survive in habitat areas that are least accessible to "low level, chronic anthropogenic disturbances" (The Nature Conservancy, 1999).

5.2 Implications for Management

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 conch are important grazers of seagrass detritus, and conch densities may be limited by food abundance (Stoner and Waite, 1990).

Results of experiments by Stoner and Waite (1990, 1991) have shown that juvenile queen conch size class (7.5-10.0 cm and 12.5 – 15.0 cm shell length) are proficient at choosing suitable habitat with seagrass present over baresand, and moderate seagrass density was selected over low or high-density seagrass. In addition, the researchers noted that larger size class conch appear to prefer habitat with higher short shoot density, while adult conch have less specialized food preferences. Also, 90% of conch, regardless of size classes, were associated with moderate density seagrass plots. Stoner and Waite (1990) indicated this may be due to mobility limiations of juvenile conch in thicker, denser stands of seagrass. The researchers further explained that these selective habitat preferences by juvenile conch may therefore be a function for food response, and predator avoidance. These experimental studies were conducted in depths of less than 3-m during the months of February and July, in the Bahamas.

Summary data in this report for seagrass and other benthic coverage, support the Stoner and Waite (1990) findings that the larger size class conch habitat preference is in higher short shoot density areas. For example, the Map 8, Table 3, and Chart 5 results show that in the northwest region of Lac at Grids 11, 12, 14, 15, and 16, feature a relatively high mean value for seagrass total short shoots, epiphyte density coverage, and seagrass blade measurements. The conch Map 3b, Chart 6 concur this same area to support a larger conch shell size class (> 20-cm).

Further findings by Stoner and Waite (1990; 1991) indicate that juvenile conch survivorship may lie in the production of preferred food items, such as seagrass detrtitus rather than live standing crop seagrass, with additional nutrition derived from macro-algae and/or interstial organisms deposited on sediments. The benthic percent coverage ranges found in this assessment show a composition relative to suitable conch nursery habitat in this regard. However, the summary conch stock census data concluded that there is only approximately 0.0021 conch individuals per m^2 found in the 51,000 m^2 sampling area. Studies conducted by Weil and Laughlin (1984) report that in the neighboring Los Roques archipelago management area, there are an estimated 0.42 per m^2 individuals in unfished and managed areas.

6. Conclusions and Recommendations

The data in this report, though qualitative in description, have implications based from the above references by Stoner and Waite (1990, 1991) and by Weil and Laughlin (1984) that the Lac Bay environs do feature suitable conch nursery habitat benthic components. However, the low conch stock numbers and clumped distribution patterns found in this survey, are remarkably similar to the prior historical research conducted by Hummelinck and Roos (1969). This clumped spatial patterning may imply that the limited conch distribution patterns prevailing in the Lac Bay area may be attributed to low-level, chronic anthropogenic disturbances by fishing pressure on juvenile conch in shallow, easy access zones (Sullivan and Chiappone, 1993). Data in this report show few juvenile conch found in the nursery area.

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 the neighboring Los Roques archipelago, Weil and Laughlin (1984) have indicated that recruitment of conch juveniles tend to occur in primarily shallow (< 1-m 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 meadows areas in Bonaire (for sustaining adult conch breeding grounds during mating season), a majority of Bonaire's conch juveniles may also originate as larval recruitments from the Los Roques region, rather than locally.

During October, 1999, Environics visited the Enparques management program at Los Roques, and observed the results of the six year conch moratorium currently in operation. Although no recent data is available, during the 1999 visit impressive numbers of conch were seen dispersed in the seagrasses, more than the 0.42 per m^2 individuals found in the unfished areas previously cited by Weil and Laughlin (1984). Personal observation indicates that Los Roques is currently enjoying a full recovery of the previously collapsed conch fisheries stock.

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

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

The results from this project also provide sufficient mapping tools to develop a resource management zonation map, to establish preservation sanctuary boundaries with appropriate policies, as well as to delineate zones for human recreational activities. The results provide sound scientific information that would support policy and management strategies when developing a management plan. Further final version GIS maps are now, and can be produced for these purposes, through the gracious co-operation of Duke University Dept. of Environmental Management, in Durham, North Carolina.

Environics requests to assist Bonaire Marine Park to design and implement the above recommendations with a proposed plan that is attached with the submission of this report.

6.1 References

Appeldoorn, R.S. 1984. The effect of size on mortality of small, juvenile conchs (*Strombus gigas* Linne and *S. costatus* Gmelin). *Journal of Shellfish Research*. 4:37-43.

Berg, C.J. Jr. 1976. Growth of the queen conch, *Stombus gigas*, with a discussion of the practicality of its mariculture. Marine Biology 34:191-199.

Brownlee, W.N. and J.M. Stevely 1981. The biology, fisheries, and managemnt of the queen conch, *Stombus gigas*. *Marine Fisheries Review*, 43:1-12.

Hummelinck, P.W. and P.J. Roos 1969. Een natuurwetenschappelijk onderzoek gericht op het behoud van het Lac op Bonaire. *NWNA*. No. 18. 25 pp

<u>Manual of Assessment and Monitoring methods Parque Nacional del Este, Dominican Republic. March 1966.</u> The Nature Conservancy Florida and Caribbean Marine Conervation Science Center, University of Miami, Coral Gables, FL

SouthWest Florida Water Management District Summer 1998 Results. Seagrass Monitoring Protocol. Prepared by Scheda Ecological Associates, Inc.

Stoner, A.W. and J.m. Waite 1990. Distribution and behavior of queen conch, *Stombus gigas*, relative to seagrass standing crop. *Fishery Bulletin*, U.S. 88:573-585

Stoner, A.W. and J.m. Waite 1991. Trophic biology of *Stombus gigas* in nursery habitats: diets and food sources in seagrass meadows. *Journal of Mollusc Studies*, 57:451-460

Sullivan, K.M., M.Chiappone and C. Lott 1991. Marine Mapping Course. School for Field Studies, South Caicos, Turks andCaicos Islands. British West Indies.

Sullivan, K.M. and M.Chiappone 1993. Hierarchical methods and smapling design for conservation monitoring of tropical marine hard bottom communities. *Aquatic Conservation: marine and Freshwater Ecosystems*, Vol. 3:169-187

Sullivan, K.M., M.Chiappone and C. Lott 1993. Abundance patterns of stony corals on platform margin reefs of the Caicos bank. *Bahamas Journal of Science*, Vol.1, No.3.

G.W.N.M. van Moorsel en A.J.M. Meijer August 1993. Baseline ecological study van het Lac op Bonaire. Bureau Waardenburg BV, Adviseurs voor milieu en ecologie. Nederlands.

Weil, E.m. and R. Laughlin 1984. Biology, population dynamics, and reproduction of the queen conch, *Stombus gigas* Linne' in the Archipelago De Los Roques National Park. *Journal of Shellfish Research* Vol. 4, No.1:45-62.

Westmacott, S. 1999. Lac Bay monitoring manual for Volunteers. Bonaire Marine Park, Bonaire, N.A.

Workshop on Subtropical and Tropical Seagrass Management Ecology: Responses to Environmental Stress. October 14 – 16, 1998, Ft. Myers, Florida. Hosted by Florida Center for Environmental Studies, South Florida Water Management District, Florida-Mississippi-Albama Sea Grant Consortium.

7.1 Appendix 1: Terms of Reference

The Conch, *Strombus gigas,* and Seagrass Benthic Survey of Lac Bay
Terms of Reference for Lac Bay Management Program Proposal to Bonaire Marine Park
For Research and Monitoring, Education and Outreach Activities for
the Conch, Strombus gigas, and Seagrass Abundance of Lac Bay

Problem:
* inconclusive surveys of seagrass beds indicate that conch are low in abundance

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, 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. Conch size/age classes will disperse and aggregate subpopulations accordingly in the seagrass ecosystem relative to food preferences/location as they mature (personal observation, 1987, 1991; Berg 1975; Appledoorn 1985). Long term monitoring of conch at permanent stations would provide pertinent abundance and distribution data and determine management replenishment zones for the species in Lac Bay.

Proposal: Phase I

- establish monitoring stations and volunteer monitoring activities for conch stock assessment and size/class distribution in Lac Bay, and seagrass assessments in the bay (DeMeyer 1998; B.M.P. Agenda 1999; SWFWMD 1998).

- use rapid ecological assessments of bay benthos to determine conch size/class distribution and abundance, and mating aggregations, including seagrass (as conch viable habitat) monitoring protocols (refer to Appendix containing Conch Stock Assessment protocol by The Nature Conservancy 1996; Seagrass Monitoring protocol by SWFWMD 1998).

Results:

Conch size class distribution and other substrate lifeform distribution of invertebrates utilizing the seagrass habitat; seagrass/algae % coverage of benthos; developing species presence/absence inventories; detection of indicator species, including presence of conch predators; water quality analysis, and bottom sediment analysis would provide up to date baseline information for developing a zonation map, and subsequent management plan for conch stock, and seagrass beds as viable habitat for conch and other invertebrate species (The Nature Conservancy 1996).

Product: Marine Communities Zonation Map

Phase II Year 2000: Conch Larval recruitment and settlement processes in Lac Bay

- Conch veliger cycling in Lac Bay through presence/absence of conch veliger through planktonic field investigations;
- Investigation of upstream recruitment sources and viable habitat conditions (literature review of neighboring conch programs) in source sinks such as Los Roques, Aves Island, Venezuela.

Background

This report provides an overview of accomplishments completed to date by Environics for the Lac project over the period July - September 1999. The consultant activities respond to the research questions and management needs as found in the Terms of Reference LAC001/98 (refer to Preliminary Progress Report - Appendix 1).

The activities are to provide baseline information about the current health and status of the greater bay environ, by:

- assessing change from the past to present with historical interpretation through prior literature search and conducting artisanal fisher interviews;
- conducting rapid ecological assessments of the bay benthos, including queen conch population status, seagrass and epiphyte abundance, species presence inventories, with anecdotal human use surveys of the bay, and
- detect potential threats of the Lac Bay environs.

The consultant activities respond to the following research questions and management needs as found in the Terms of Reference LAC001/98 (Appendix 1):
The following are the tasks proposed by Environics to address the above research questions for the Lac Bay project (proposal - Appendix 2):

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, and scientific research?
What is the status of the two globally endangered species, green sea turtle (Chelonia mydas), and 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?

Pursuant to the Terms of Reference for Project code LAC001/98 (DeMeyer 1998 - Appendix 1), the above tasks address the following objectives that are contained in the project code:

Objective 10: Establish research and monitoring programmes to monitor the health of the system and effectiveness of the management plan
Activity 10.1: Design of an easy to implement by effective monitoring programme 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 programmes as identified in the management plan, i.e. function of Lac as a breeding and foraging ground for aquatic species
Output 10: Regular ongoing monitoring and research in Lac in support of management

The following report outlines and describes all activities completed to date for the above tasks, which encompasses the BMP Project code LAC001/98 objectives and activities.

Task 1: Historical Interpretation for Characterizing Lac Bay Environs:

a.
interpret all past research conducted in the bay, synthesized into one easy to read layman's booklet, including historical fisher interviews to discern what was known in the past of the bay's fisheries resources, mangrove forests and bay water environments
Appendix 3 lists all literature found;
b.
interpret and characterize the bay environment by groundtruthing aerial photographs, followed by environmental monitoring to establish what we know now, resulting in a zonation map

The completed historical interpretation series, or "*Site Characterization of Lac Bay Environs*", will also include sections containing current bay area baseline data that are now being investigated through monitoring activities with Environics serving as chief scientist, and training volunteers to provide scientific support. The prior literature research provides a historical interpretation of Lac, serving as a foundation to detect any change noted during the baseline monitoring. These two sections of the report will provide to the marine park manager important decision making tools: "what was known" and "what we know now", in order to interpret how has the bay historically changed over time, and what needs to be known now? These ingredients form a basis from which a management plan can be finalized - information based on sound scientific evidence. Future monitoring activities of "what needs to be known now" can then be the key measuring devices, that will gauge whether Lac's final management plan is successfully attending to key environmental problems and issues effecting the bay, when the plan is implemented and underway.

Conch size class distribution, turtle sightings and habitat preference, and seagrass productivity status are also currently being monitored at 17 newly established 200 x 200 meter grid sites in the bay (map and protocol - Appendix 7). The sites were randomly selected and placed with compass rose headings, and labeled with latitude/longitude coordinates on a map of Lac Bay; in the field, the actual sites are being located using a Garmin GPS unit, for monitoring activities by trained volunteers. Monitoring protocols were adapted from the BMP volunteer monitoring draft manual (Westmacott 1999), as well as from The Nature Conservancy Caribbean program, and the Southwest Florida Water Management district student and volunteer rapid ecological monitoring methods. The resultant protocol and species identification training were field tested in Lac with a Corp of volunteers during June 1999; routine surveys are now underway. Completion of the monitoring is anticipated by the end of September 1999. The final product will be a GIS zonation map, with management recommendations for the greater bay area. The GIS map will be produced through the University of Miami biology department labs of Dr. Kathleen Sullivan, near the completion of the project.

The baseline monitoring activities in the bay area were completed in mid September for providing current ecological assessment for the "Site Characterization of Lac Bay Environs". Works were completed through the scientific support of trained volunteers from the Bonaire Underwater Research Assistants group. (The training and implementation of these monitoring strategies will be contained in the final volunteer manual).

An overview of the results (map – Appendix 3; tables - Appendix 5; species presence/absence inventory Appendix 6) indicate for both conch and species in general, the spatial distribution patterns are clumped or uniform, implying potential constraints on the system. In the case of conch, fishing pressure may be likely, as the map results show most conch remaining are located in the bay channel or boat routes, where fishing pressure is least. Conch size class is approximately 2.5 years; no adults were found in this assessment activity. Recruitment of these juveniles may be from upstream sources, such as Aves Island or Los Roques. During October 9 – 13, Environics will visit Los Roques to observe the area's conch fishery management program, and its implications on conch fisheries for Bonaire.

7.2 Appendix 2a. Survey forms
Appendix 2b. Color underwater identification reference cards

7.3 Appendix 3. Boat Procedure

Materials

The boat: Hard bottom, inflatable with adjustable tilt motor. Capacity seating for 6 divers, 2 team members and captain. The boat had adequate workspace for materials and provided ease and safety.

Grid materials:

3 – Transect reels of polypropylene ¼ inch line, 200 meters in length, with loops at each end and at 100-meter mark of line, surveyor tape strips at each 10 meter interval (marked clearly with the meter location for underwater surveyors), weighted at each 20 meter interval with minimum 8 ounce weights. A length of wooden dowel that will fit through the center hole of the reel and extending beyond each side for handholds should be obtained.

6 – Dive flags, weighted with floats, each with a maximum depth (plus) line attached, looped at end.
1 – Float (Center) with maximum depth (plus) line attached, looped at end.
3 – Float (Clorox bottle) attached to a long line with a 1 kg weight.
8 – Iron ring weights, minimum 3 kg.
3 – Heavy weights (coral rock), minimum 5 kg. Tie line around the weight with a stringer of 45 cm.
1 – Reel or spool of line, 2 to 3 mm in diameter, 100 meter length, with 1 kg weight attached end.
1 – GPS
1 – Thermometer
1 – Refractometer
1 – Clip board, with grid data sheet, map of grids and grid GPS locations.
1 – Knife
1 – Compass, boat
1 – Secchi Disk
Water
Sun Protection Lotion

Grid – Transect Line Process

Each grid consists of 3 – 200 meter transect lines spaced 100 meters apart, creating a 200 meter square grid. The following steps of this process have proved to be both time efficient and easy to follow. Each step will be detailed initially, but each repetition of that step will be assumed the detail was followed.

Find the first GPS location of lower left grid point. Working at the stern of the boat, Team Member 1 should attach a 5 kg weight with the 45 cm stringer to the loop of the 0-meter end of Spool 1 and the dive flag. Drop the weight with the dive flag and transect line attached at this GPS point. Team member 2 should be holding the spool with the dowel as handholds, facing the rear of the boat. The captain should go into the compass bearing (previously set on the map and grid chart) at a low speed. Team Member 2 should prepare a ring weight for the center mark of 100 meters and should attach same when that point of the transect line 1 is reached. The captain should regulate speed accordingly during this part. Team Member 2 should prepare a ring weight and dive flag for the 200-meter mark. Both should be attached to the loop at 200 meters. This completes Transect 1. The captain should return to the first point of that transect.

At this time the 100 meter line with the 1 kg weight should be attached to the float with 2 kg weight that is dropped at 0 meter mark of Transect 1. The captain should maintain a compass bearing heading plus 90 degrees to the original Transect 1 compass bearing while Team Member 1 is controlling the line to be released. Team Member 2 should be prepared to drop the float (Clorox bottle) with a 1-kg. weight when the end of the 100 meter line is reached. This marks the 0-meter mark of Transect 2. Team Member 2 should have prepared the 5-kg weight and dive flag to the 0-meter loop on Transect 2. When ready, the Transect 2 line, with weight and flag should be dropped and the captain again follows the pre-designated compass bearing. At the 100-meter mark of Transect 2, the center float should be attached to a ring weight and in turn attached to the loop at 100 meters. This is the center of your grid and where all measurements will be taken. Continue with laying out Transect 2 in the same manner as Transect 1. Return to the 100-meter line, still in the water. Reel it up while the captain returns to Transect 1. Return to Transect 2 and repeat the 100-meter line process and the Transect 3 process. At the end of Transect 3, return and reel up 100-meter line and remove all Clorox bottle floats. This total process can take up to 45 minutes to complete, therefore start 45 minutes before divers will enter water.

Diver (Volunteer) Process

There are now 3 transects with a dive flag at zero and 200 meter marks, with a float in the center. Pickup your divers. Each transect gets 2 divers dropped at the zero meter mark. Assure that each diver knows the grid number and transect number before they get into the water.

The divers will be down approximately 45 minutes or more. It is the captain and team members' responsibility to assure no boats are within the grid. The safety of the divers must be the paramount responsibility of the boat personnel. Any diver who surfaces must be attended to as fast as possible. As divers surface, they should be picked up quickly. Assure that all data sheets are on board.

Data Collection - Boat

It is also the responsibility of the boat members to obtain and record the water clarity, temperature, and salinity at the center point of the grid. This is a strategic point to observe and protect the divers or snorkelers. GPS readings at each zero meter point for each transect line should also be recorded during this time. If possible and advisable, go to the next Grid GPS point. Mark it with a Clorox bottle. This will save considerable amount of time on the next Grid.

Grid Breakdown

The collection of the weights, flags, and transect lines can be done at any convenient time. After some practice, it will take approximately 12 minutes to reel up the line. Plan accordingly if you still have divers in the water. You want to get them out of the water as soon as they surface.

Starting at the 200-meter end of the transect line, Team Member 1 prepares the empty reel with dowel, while Team Member 2 lifts out the flag, weight, and transect line end. This end is fastened to the reel. The method of reeling up the line is a 3-person operation. Team Member 1 sits facing the front of the boat, forward of the captain. Team Member 2 sits facing the other Team Member (facing the stern). The captain slowly goes forward, pulling in the line, while Team Member 1 reels in the line and Team Member 2 maintains tension on the reeled in line. The captain goes at a speed suitable to reel in the line and collect the weights, floats, and flags. Stow all materials neatly while moving to the next transect line. Anticipate a minimum of 45 minutes to collect the equipment.
NOTE: If there is heavy tidal flow or currents, heavier weights would be recommended.

8.1Map 1 – Map of Lac Bay and Environs

8.2 Map 2 –Benthic Survey Grid Sites

8.3 Map 3A,B,C – Total number of species and total number of conch

8.4 Map 4A – Bottom characterization
Map 4B - Sediment classification and % coverage distribution

8.5 Map 5 – Bathymetry and mangrove elevation

8.6 Map 6 – Thalassia % coverage

8.7Map 7 – Seagrass and epiphyte coverage

9.1 Chart 1 – Sediment composition characteristics in Lac Bay

9.2 Chart 2 – Mean depths of grids

9.3 Chart 3 – Lac Bay benthic % coverage composition

9.4 Chart 4 – Relative % coverage of seagrass abundance and epiphyte density

9.5 Chart 5 – Turtle grass, *Thalassia testudinum*, mean blade size and short shoots density

9.6 Chart 6 – Estimated conch size/age class and total

10a Historic seagrass and algae distribution map (Hummelinck and Roos, 1969)

10b Historic conch and invertebrate distribution map Hummelinck and Roos, 1969)

11. Conch Data: Tables 1, 2, 3, 4