RAPID ECOLOGICAL ASSESSMENT

PARQUE NACIONAL DEL ESTE, DOMINICAN REPUBLIC

by

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PREFACE

People around the world are beginning to realize that natural processes, people, animals, and living systems are interconnected in one way or another, and that humans are the main players in the downfall of many of our beautiful ecosystems and resources. The disappearance of corals and the collapse of fisheries has focused attention on the fragility of coastal marine resources. The protection of marine areas has finally become a primary concern to many countries, like the Dominican Republic, that rely heavily on tourism as a source of income. The sustainable management of our marine resources requires a basic understanding of the coastal processes and ecology as well as a careful assessment of threats and uses. The ecological "health" or status of marine natural communities is the first step in the process of developing a management plan. This ecological evaluation (REA) forms the basis for the development of a reasonable and feasible management plan for protected areas.

The purpose of this document is to summarize the scientific information gathered to guide a feasible management plan for Parque Nacional del Este (PNDE). This document was written for park managers and resource policy makers. It was produced in Spanish for the managers of the park and in English for the international community so that they can support and be well informed about the park. In this way the international scientific community can also give feedback on the status of PNDE.
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1. INTRODUCTION

A. WHAT IS A RAPID ECOLOGICAL ASSESSMENT?

A Rapid Ecological Assessment (REA) is a flexible process developed by The Nature Conservancy that uses integrated methodologies to obtain and analyze biological and ecological baseline information in a cost-effective manner for effective conservation and resource management decision-making. It has been developed in response to the need to carry out conservation planning in areas that are either expansive, poorly known, or are exceptionally diverse at a habitat or species level.

The REA integrates a hierarchy of increasingly detailed methods and analyses to produce maps of natural communities and descriptions of flora and fauna, and to define conservation priorities. The synthesis of this information is the basis for planning monitoring programs and carrying out a strategic plan of protection, management, and research needs of the protected area. "Rapid" is a relative term; the duration of these evaluations vary tremendously depending on the size of the area, availability of imagery and maps, and availability of data from previous studies done on the natural communities and flora and fauna of the area. Likewise, the objectives, rationale, and field procedures of an REA also vary from region to region. However, they usually focus on:

* initial descriptions of natural communities,
* development of marine community base maps,
* inventories of flora and fauna, and
* identification of potential or realized threats.

This information can be used to establish baseline information on the status of marine ecosystem components and provide the basis for the development of monitoring programs. Coupled with available historical and anecdotal information, the information produced by an REA may allow for the subsequent evaluation of resource management practices and conservation in marine protected areas.

An REA is based on analyses and ground-truthing of satellite images, aerial photographs, and maps, which enable the characterization of the biological, physical, and social components of the natural system, and allow the delineation of priority areas and potential threats. The field work builds up detailed biological and ecological information across the study area, and provides an efficient inventory approach that supports further analysis, monitoring, and planning needs. Before the field work begins, one should decide what the main objectives of the study are since these will vary for every area and every project. One should also gather as much background information as possible on the area to be assessed: previous studies done, oceanographic influences, geology, maps, aerial photographs, satellite images, etc. The goal of the field work itself is to bring together all the background information to characterize, assess, and establish guidelines for monitoring shallow-water marine communities. The sampling priorities should include at least one example of every community class or type, especially rare, endangered, or
sensitive community types in the area. In summary, the sampling priorities should be set to collect the minimum amount of information needed to ground-truth the original community base maps and assess the communities that are in the targeted area. It is essential to set these priorities when faced with limited resources, time, and personnel.

The Florida and Caribbean Marine Conservation Science Center (FCMCSC) of The Nature Conservancy (TNC) supports certain marine parks and protected areas in the tropical western Atlantic, in terms of remote sensing and GIS support for conservation management in these areas. The ability to track and improve stewardship for marine communities will push the database development to interact not only with GIS software, but also to interface with large numerical databases, particularly for water quality data. In the Caribbean the FCMCSC and TNC have provided technical and scientific support for marine conservation in many nations. Rapid Ecological Assessments have been successfully conducted in Montego Bay Marine Park, Jamaica (Grossman et. al., 1991), and in the Punta Ycacos Lagoon, Toledo District, Belize. The REA's have basically focused on in-country field training, the development of community base maps, and the subsequent development of restoration and monitoring programs for marine/terrestrial protected areas. The data gathered through REA's are also used to track marine biodiversity through the Biological and Conservation Database (BCD) of The Nature Conservancy’s Heritage Network. They use a method of information organization, computer databases, and maps which ranks species in terms of how threatened they are based on their ecological fragility and life history strategies within the different geographical areas. This information organized in the network allows for regional and local conservation priorities to be established (Sullivan et. al., 1994).

B. OVERVIEW OF PARQUE NACIONAL DEL ESTE

Parque Nacional del Este is located on the southeastern coast of the Dominican Republic. Topographically it lies between San Rafael de Yuma, La Granchorra, La Romana, and Mano Juan, and is bordered by San Rafael de Yuma on the north, the Bahía de Yuma to the east, and the Caribbean Sea to the south. It was declared a protected area in September of 1975 and consists of approximately 42,000 hectares of land (mainland and small islands) (Figure 1).

The land of the park consists largely of various terraces of Pleistocene coralline rock that emerged from the ocean, and whose present elevation varies between 15 and 60 meters above sea level. The coastal limestone is extremely porous and filled with cavities and casts of coralline fossil organisms (Benchmarks, 1973). There are two geologic normal faults; one is in the northeast near Boca de Yuma and extends for almost 20 kilometers from east to northeast. The other lies on the southeastern side near La Granchorra and extends for approximately 12 km. east to southeast (Cano, 1993).

The climate of the park is typically tropical. The mean annual air temperature is 26.5°C with very little annual variation (< 2°C). The humidity is very stable with an average of 79%. Rainfall averages 1000 mm per year with approximately 70% of the precipitation occurring between May and July, and September through October. The Northeast Trade Winds blow
almost continuously from the northeast and east (Benchmarks, 1973). An outstanding feature of the park is the absence of freshwater. There are no rivers, lakes, ponds, streams, or fresh water swamps (Towle et. al., 1973). However, there seem to be some sinkholes that accumulate fresh water in the area. The currents flow from east to west although there is evidence of many intricacies in the Mona Passage between Puerto Rico and the Dominican Republic (Metcalf et. al., 1977).

The geology, geomorphology, and hydrogeology of the park, combined with the humid tropical climate that characterizes it, all indicate that due to the high porosity of the coralline floor, there is a large flow of groundwater that is high in nitrogen towards the ocean (Cano, 1993).

The terrestrial flora and fauna of Parque Nacional del Este have been previously described (Benchmarks, 1973; Cano, 1993; Towle et. al., 1973), and an extensive REA was concurrently done on the terrestrial systems of Parque Nacional del Este. In summary, it seems that many different types of environments occur in Parque Nacional del Este. These include mangrove swamps, coconut plantations, moist subtropical deciduous forests, salt-resistant plant communities, and dry sub-tropical forests. The terrestrial fauna is typical of an oceanic island. There are many birds, both woodland and migratory waterfowl, and some are ecologically important due to their endangered status (e.g. Roseate Flamingo and Hispaniola Parake) or due to the fact that large breeding populations exist in the park (e.g. white-crowned pigeon and frigate bird). The rest of the terrestrial fauna includes various small mammals (e.g. hutia and solenodon) and reptiles (e.g. iguana) as well as insects. The results of the terrestrial ecological assessment are presented in a separate document.

The coastline of the park is varied, and consists of (1) white sandy beaches and relatively shallow waters on the western and southern portions of park mainland and around most of the southern portion of Saona Island; (2) predominantly rocky intertidal coasts and cliffs on the eastern side of the mainland and on the northeastern coast of Saona Island; and (3) well-developed varied mangrove forests in some places on the southern coasts of the mainland. Saona Island is also interesting because it is the only island in the country that has three saltwater lagoons.

C. PREVIOUS STUDIES DONE IN PARQUE NACIONAL DEL ESTE

Marine research studies conducted in Parque Nacional del Este are scarce. With a few exceptions, most of the information available for the park was obtained through the studies that were conducted as the basis upon which the area was declared a park, or for its subsequent management plan. All these will be briefly summarized and discussed here. These studies will also be referred to in the results and discussions sections of this document.

In 1973, a physical oceanographic study was conducted by Metcalf et. al. (1977) whereupon they released drift bottles that were later recovered in order to study the exchange of water between the Atlantic Ocean and the Caribbean Sea through the Mona Passage. A
similar study, but encompassing the entire Caribbean, was done by Brucks (1971). These studies are important because the system of currents that influence Parque Nacional del Este is responsible for much of the distribution of the marine fauna that rely on currents for the dispersal of their larvae. Equally or even more important is the fact that these strong currents can also carry with them a large number of pollutants that will surely affect the fauna and flora of the park: trash to the park shores, contaminants that will affect the health of the local fauna and flora, disease and viruses, oil and other mineral pollutants.

Metcalf et. al.'s (1977) study indicated the existence of "an extremely complex current condition in Mona Passage, with some bottles drifting from the Caribbean into the Atlantic Ocean and others in the opposite direction." (Metcalf et. al., 1977) (Figure 2). There seems to be a complicated pattern of tidal and residual currents. More importantly they recognized that "there is a very real danger that surface pollutants from the Mona Passage area would drift ashore to the Dominican Republic" (Metcalf et. al., 1977).

Gauge and Arnemann (1982) studied the coastal fisheries and their management in the Dominican Republic. They concentrated on independently estimating fisheries production, number and type of fishing vessels, and number of active fishermen in 73 different coastal areas, as well as evaluating the different fishing methods and catch per unit effort (C.P.U.E.) in each area. Saona Island was among the areas surveyed, and to our knowledge, this has been the only fisheries study done in Parque Nacional del Este. It is important because, as shall be discussed, overfishing and fishing methodology are two of the larger problems identified during the REA.

The only other documented marine research study in Parque Nacional del Este is that of Olivares (1984). This was a study of the composition, distribution, and abundance of the zooplankton community in Bahía de las Calderas on the southern coast of the park. Data on temperature, salinity, and depth of the area was also collected. This study is important because zooplankton studies provide the basis for the characterization of the productivity of an area.

Olivares (1984) found that there were no notable differences in the temperature readings throughout the area (due to its low depth), and that these did not significantly vary with tidal level either. Salinity did show a difference within the area and with tidal level. Salinity is high (37 and 38 ppt) in the bay and decreases to normal seawater (35 ppt) as one moves out of the bay. Both surface salinity and that at 1 meter depth decreased as tidal level increased, demonstrating that as the tide decreases there is an outflow of water from the Bahía de las Calderas accompanied by an increase of salinity. They found low salinity levels at a station outside the entrance of the bay. Later, as the tide rose, they found this low reading at the entrance to the bay and at stations moving towards the bay, possibly indicating a freshwater source somewhere near the entrance to Bahía de las Calderas that contributes freshwater to the bay itself.

The zooplankton analysis seems to indicate that the composition of the community remains fairly constant as the tide changes. There is, however, a significant difference in the dominance of certain groups with differences in tidal level. It seems that high tides can
concentrate some zooplankton species towards the northwestern end of the bay. It also seems that some groups lose part of their population as the water leaves the bay during low tide.

Prior to the declaration of the area as a park in September of 1975, three studies or surveys were made. These formed the basis for the actual declaration of the area as a park. In 1973, Benchmarks, Inc. was hired to produce a document that not only described and pointed to the values and special qualities of the natural and socio-cultural resources of the park, but also proposed some ideas for a management plan. Among the proposed ideas were some dealing specifically with the conservation of manatees, turtles, lobster, conch, flamingos, etc. In addition to the general descriptions of the flora, fauna, geology, and history of the area, the report also considered some problems to be met in the creation of the park such as the preconceived conflicts with fishermen and agriculturists. The study also offered some ideas on the development of marine-related ecotourism in the park, as well as how to go about staffing and educating the future rangers, and staff that would work in the park.

A far more complete, but complimentary study was done by various researchers from the Island Resources Foundation, Inc. in 1973 (Towle et. al., 1973). This study entitled Report on Terrestrial Wildlife, Marine Habitats and Management Aspects of Marine Oriented Recreation in the Proposed Parque Nacional del Este, Dominican Republic relied on ground-truthed aerial photograph interpretations and helicopter reconnaissance surveys, and offered the best documented descriptions of the marine habitats and life (inventories) around the park before the realization of the REA. They are therefore very useful for comparisons of dominant marine fauna and flora through time in different locations of the park.

This study also recommended specific management procedures for the conservation of endangered wildlife such as turtles, manatees, and flamingo; and of economically important species such as lobster and conch. They anticipated problem areas that may have arisen with the creation of the park, identified research needs, and suggested ecotourism ideas.

In 1975 a short underwater survey was conducted by Caboza and Pierce in marine areas adjacent to the present park, and in a few areas inside the park. Although it is simply a descriptive study and has no quantitative basis, this study does point out that there is a general lack of large fish and suggests spearfishermen to be responsible for this.

After the declaration of the area as a national park, the Dirección Nacional de Parques elaborated the Plan de Manejo del Parque Nacional del Este (Fahrenkrog, 1979). This management plan was the first in its class of all the parks in the Dominican Republic. The plan not only describes the park and its resources, but includes limited preliminary species lists of the marine fishes, marine reptiles and mammals, corals, marine molluscs, and marine seagrasses and algae, among others.

The management plan divides the park into zones according to the characteristics of the resources available and the intended use of each one. It also delineates the management plan including its administration and surveillance, as well as recreational, educational, and research
activities to be developed. Importantly, the management plan also proposed that the Catuano passage (Bahía de Catalinita) that separates Saona Island from the mainland be included in the park limits in order to conserve important nursery grounds for many marine animals. Furthermore, they proposed that a 500 m wide band stretching out from the coastline (both mainland and around Saona Island) also be included to protect natural resources and for research, educational, and recreational purposes.

In 1993 the Dirección Nacional de Parques (DNP), in conjunction with the Agencia Española de Cooperación Internacional (AECI), completed a project on the public use, protection, and recuperation of the wildlife of Parque Nacional del Este (Cano, 1993). This study gave a very complete description of the area including not only its natural (geology, geomorphology, hydrogeology, lagoons, topography, climate, vegetation, and fauna) and cultural resources (archeology and history), but also some specific characteristics such as use of land, access to the park, demography, and tourist and recreational services. It proposes well thought-out projects dealing with public use and associated infrastructure as well as with research, protection, and recuperation of wildlife. The authors, however, recognize that due to differences in methodology it was impossible to survey the marine areas together with their characteristic flora and fauna. They did, however, survey the intertidal and marine areas for molluscs, which is useful if only for the sole reason that it compliments surveys made during the REA.

Finally, one cannot forget to mention a series of studies done by dominican archaeologists in Catalinita and Saona Islands (Vega, 1987). In this study, the discovery of great conch piles called "conchales" or "concheros" demonstrates the economic importance of Strombus gigas for both the Taino indians and for modern fishermen. The tremendous number of conch in these piles provide the evidence that at one time conch stocks were quite plentiful. Vega notes "It is interesting to see how the places where the most numerous precolombian conch piles exist are the same places where, today, the fishermen still dedicate themselves to the same work and create "modern" parallel conch piles. The place in the country with the greatest modern conch piles is Catalinita Island, between Saona and Boca de Yuma."

One can easily conclude that although there have been studies done in the marine areas surrounding the park, these (with the exceptions of Olivares’ (1984), and the Island Resources Foundation (Towle et al., 1973) studies) have been limited to yielding species lists. No in depth study dealing with the ecology of the different marine habitats had been done. Nor had there ever been any type of effort to specifically identify threats to the marine environments and its inhabitants, or to deduce a management plan for them.

D. THE REA IN PARQUE NACIONAL DEL ESTE

As a Park in Peril, it was vital to conduct a Rapid Ecological Assessment in Parque Nacional del Este. Very little work has been done in the park, and what has been done can be described as dated information. An extensive survey of the marine communities was necessary if appropriate recommendations are desired to revise the management plan in order to make it more effective.
The REA conducted in Parque Nacional del Este consisted of three phases: the acquisition of background information and maps of the region, the acquisition of high resolution aerial photographs of the region, and finally an ecological evaluation of the area performed by three groups of scientists in more than 21 days of field work. The scientists were divided into groups in charge of:

* rocky intertidal and mangrove surveys,
* benthic surveys (soft sediment and hard bottom), and
* visual census of fish communities.

The purpose of the field work was to cover as much of the area of the park as possible, while collecting data to make an initial characterization of the different components of the park: mangroves, benthos, fish, and coastal systems. The field objectives of the REA in Parque Nacional del Este were:

1.) the compilation of species inventories and the characterization of substrate and lifeform cover in reefs and seagrass communities in the entire park,

2.) the realization of reef fish censuses to characterize the reef fish communities and to have a preliminary evaluation of the impact of fishing in the park, and

3.) the quantitative characterization of the mangrove and rocky intertidal communities.
II. METHODS

A. MANGROVE COMMUNITY

The technical objectives of the mangrove component of the Parque Nacional del Este project are:

1.) To provide a detailed characterization of mangrove communities that will:
   * allow for the assessment of areas for conservation of biodiversity, fisheries production, and potential as fisheries reserves areas.
   * establish baseline information on the patterns of estuarine and marine communities as related to undisturbed coastal watersheds and terrestrial communities.
   * provide an overview of mangrove community types as well as ecosystem diversity and function for the study area.

2.) To demonstrate innovative and applicable technologies in marine resource characterization, mapping, and monitoring using remote sensing and GIS modeling.

3.) To transfer information to people and institutions within the Dominican Republic willing and able to maintain diversity and ecosystem function as well as for conservation planning throughout coastal waters.

The assessment and mapping of mangrove communities (see Figure 3 for the survey sites) was accomplished through five major tasks. The project utilized both satellite and air-borne imagery to evaluate the entire area to both delineate mangrove communities and vegetation zones. The tasks completed include:

a.) Soil Analysis / Interstitial Water Analysis
The depth and accumulation of peat are important features in the descriptions of mangrove communities, and can help identify some trends (e.g. is this a stable mangrove forest or a progressive state following a past disturbance). Soil cores were collected throughout the park.

b.) Quantitative Plots
There are at least three reasons for completing quantitative plots:
   * to quantify the density, size, and species of mangroves that are identified as one "polygon" or community on the imagery (ground-truthing).

   * to establish potential monitoring sites that can be used to make quantitative comparisons between mangroves surveyed throughout the country (e.g. in the CARICOMP program).
* to document the diversity of mangrove community types, and to evaluate country-wide if this diversity is captured in the parks system.

c.) Photo Surveys
Photographs taken from photo-observation points document the "representativeness" of the plot site. Photos can help document the level of herbivory, and the health of the trees.

d.) Faunal Surveys
To add to our general information about the area, and to add to our community descriptions and assessment of wildlife habitat. Using check-lists and keys for the common molluscs and crustaceans, we can describe qualitatively the organisms associated with the mangrove communities.

e.) Mapping
Mapping the park accomplishes two objectives:

* to collect latitude/longitude of specific survey areas that we can correlate to areas on the imagery, and
* to collect latitude/longitude of prominent features across the image for geo-referencing the final image and maps. This will allow us to determine our accuracy and precision. GPS locations from survey points and landmarks were recorded.

To classify the community type, an analysis of the soil samples had to be conducted to determine the organic content of the soil. Vegetation community structures were determined by direct counts or the line transect method (belt-quadrat); the dominant species in the overstory determines part of the classification of the community. The coverage and height of the dominant species determines the physiognomic type of the community. Communities are further distinguished by their habitat. However, a problem with the classification of mangrove occurrences is the soil-type modifiers used in the community classification. The exact composition of the soil must be known; therefore, soil samples that were collected were analyzed. The soil modifiers (low peat, moderate peat and high peat) are based on the soil core analysis. The organic content of the soil determined which of the three designations the community received (<20% organic content = low; 20-50% o.c. = moderate; >50% o.c. = high).

In order to scientifically arrive at some consensus in a limited amount of field time, an attempt was made to obtain a maximum of information that could be related to strategic research monitoring plans as well as management actions. The different methodologies used for ground-truthing or data acquisition through field work are explained in the REA Methods Manual (Sullivan et. al., 1994). This manual includes data sheets, protocols, and references for the field methods.

B. ROCKY INTERTIDAL COMMUNITY
At the rocky intertidal stations, species (molluscs and algae) presence-absence inventories, and quantitative data were gathered. The quantitative data from the rocky intertidal surveys were used to:

1.) create shore profiles to determine the general slope of the rocky intertidal shoreline. This is important because the slope determines part of the initial community classification of a rocky intertidal community.

2.) characterize the communities in terms of dominant flora and fauna in plot surveys. This allows for potential monitoring sites to be established and assists in comparing intertidal communities.

These data were used to generate a summary table and a similarity matrix. Similarity was calculated using the Coefficient of Jaccard.

**C. BENTHIC and FISH COMMUNITIES**

In the benthic community stations surveyed, species (algae, sponges, octocorals, hard corals, and fish) presence-absence inventories, chain transects, quadrat surveys of the biotic (lifeform) and abiotic (substrate) components of the benthic communities, and community element occurrence surveys were done. A summary of these methods is given in the Technical Report.

The data obtained from the chain transect technique were used to create depth and physical relief profiles across the transects. These quantify the spatial or topographic complexity of the site, which may be important in dictating the abundance and diversity of the fish, invertebrate, and plant assemblages in the sites. This information can also be used as a monitoring tool for investigating changes in the physical and ecological structure of the reefs.

The data gathered from the substrate-lifeform surveys were used to:

1.) make frequency distribution graphs that show the distribution frequencies of the different coverage classes, be they either substrate (abiotic: nature of the bottom) or lifeform (biotic components). These are useful in ascertaining the dominant types of substrate and lifeforms in the different stations.

2.) make frequency distribution graphs showing the distribution frequencies of the different species of algae and seagrasses in the soft-bottom communities surveyed.

3.) create a summary table of the results from the seagrass biomass surveys. This information is important because it may be an indicator of the "health" of the seagrass community.
The frequency distribution graphs can be useful in comparing the gross changes in benthic composition over time and in comparing many reef communities.

Data gathered from the community element occurrence surveys were used to:

1.) make frequency distribution graphs of the variation in size of sponges and corals in the octocoral-dominated low-relief site where this type of survey (community EOR) was done.

2.) create summary tables of the results obtained from the community-level surveys (EOR's) in the sites where these surveys were done.

The Reef Environmental Education Foundation (R.E.E.F.) fish survey forms from the fish censuses were scanned and analyzed through a computer program, based in UNIX which processed the data and generated reports. Some species were eliminated from the data because they were observed less than 5% of the time (limit factor). These could be identification mistakes, or were seen so few times that more data is needed to include them in the list. In order to interpret the data in a more ecological manner, the fish species were divided into trophic feeding guilds. For practical purposes a list of the locally commercially important species was also made. The methods for interpreting the reports are well-defined in the Technical Report. Summarizing, these reports offer information on the frequency of observation of the fish species or guild (or both) and on the density of the species or guild when they were seen. Each report lists the species, families, and guilds for each site. These reports were generated to summarize the:

1.) the species seen on all the fish survey dives in Parque del Este, ranked by species, family, and guild.

2.) the species seen in each one of the survey sites in Parque del Este, ranked by species, family, and guild. If dives were made at different times (morning, afternoon, and night) in one sight, these were also divided, and summary reports were made for each division.

These data were then used to generate summary tables that point to differences in abundance and spatial and temporal species richness between the sites. A similarity matrix showing the Jaccard Coefficient and the Coefficient of Community was generated to compare the different sites in terms of species richness. Data from the summary reports were also used to generate visual representations of the importance of the trophic guilds in terms of relative abundance at the different sites in Parque Nacional del Este.
III. RESULTS AND DISCUSSION

A. MANGROVE COMMUNITIES

1. MANGROVE COMMUNITY DIVERSITY

The objective of this REA was to define methods to characterize and classify mangrove communities as a tool for tracking coastal biodiversity. Mangroves combine the vegetation strata features of terrestrial systems and also incorporate the geomorphological and oceanographic characteristics of marine and estuarine systems. The purpose of the proposed hierarchy (Figure 4) is to better identify and track ecological communities as units of natural diversity that persist under a unique interaction of physical, hydrological, and biological influences. The hierarchy compares the characterization of communities by combining vegetation strata with soil, hydrology, and invertebrate fauna (crustaceans and molluscs).

Mangrove communities were defined as having one of four vegetation structures. Vegetation structure is described by strata, and includes an assessment of both the height of the trees and the area of ground covered by the canopy (cover values).

Shrublands - Shrubs are 0.5 to 5 meters tall, and may cover 25 to 60% of the surface. Trees may be present, but they cover less than 25% of the surface. Herbs (seedlings) or non-vascular plants may be present as any cover value. Although the term "dwarf mangroves" is often used to describe mangrove shrublands, true "dwarf shrublands" are defined as growth forms less than 0.5 meters in height.

Scrub Thickets - Shrubs are 0.5 to 5 meters tall, and the majority of the shrub crowns are overlapping with 60 to 100% coverage. This would describe the densest mangrove shrub communities. Trees may be present, but cover less than 25% of the surface. Herbs (seedlings) and non-vascular plants can be present at any cover value.

Woodlands - Trees are over 5 meters tall, and tree cover is 25 to 60% of the surface. Shrubs, herbs, and non-vascular plants can be present at any cover value.

Forests - Trees are over 5 meters tall. The majority of the tree crowns are overlapping (60 to 100% coverage). Shrubs, herbs, and non-vascular plants may be present at any cover value.

Mangrove Community Types found in Parque Nacional del Este based on the characterization of strata and soil cores (see Figure 4 for a graphical representation).

MANGROVE SHRUBLANDS
*Red Mangrove Shrublands
*Black Mangrove Shrublands
*White Mangrove Shrublands
*Grey Mangrove Shrublands
Mixed Mangrove Shrublands

MANGROVE SCRUB THICKETS
*Red Mangrove Scrub Thicket
*Grey Mangrove Scrub Thicket

MANGROVE WOODLANDS
*None

MANGROVE FORESTS
*Red Mangrove Forest
*White Mangrove Forest

These nine types do not represent the high diversity of mangrove communities located in the park as it is impossible to sample every community type. Appendix I contains the community descriptions for all the community types listed above.

Similar studies have been conducted in Jamaica and Belize (Table 1). Montego Bay, Jamaica had 8 community types, Parque Nacional del Este, Dominican Republic had 9 community types, and Port Honduras, Belize had 7 community types; however, even though Belize had the fewest number of community types, the total area covered by mangroves is much greater than Jamaica and the Dominican Republic combined. In fact, the total area of mangroves is over 4.5 times greater in Belize than the other two countries combined.

2. MANGROVE SOILS

Table 2 shows the element abundances from the soil cores taken at the mangrove community sites. Red Mangrove Scrub Thickets and Shrublands have unusually high concentrations of lead (Pb); however, Grey Mangrove Scrub Thickets (which are located around Lago los Flamencos) have by far the highest concentrations of heavy metals. This community type also had the highest sediment fraction content. The pH of the soils are all very similar (slightly basic). Red Mangrove Forests had the highest % moisture and organic content values; this is to be expected as this community type's landform is usually fringing the sea. The high organic content can be explained by the fact that forests have a high production of leaves and twigs which decompose easily in the high heat and humidity; therefore, the soils of forests tend to be composed of peat which has a high organic content.

3. CRUSTACEAN FAUNA

During the mangrove community characterizations, 7 species of crustaceans from 6 genera and 5 families of the Order Decapoda, were sampled and identified (Appendix 1). These species were identified using Kaplan (1988), Williams (1984), Crane (1975), Abele and Kim (1986), and Voss (1976). Gross morphological features such as carapace shape, external surface features (i.e. spines, hairs, tubercles), and external mouthparts were used as the main identifying
characteristics. The species encountered were typical, and represent crustaceans that have been previously observed as mangrove community inhabitants.

The main groups of decapod crabs, the most abundant and most frequently encountered in Parque Nacional del Este, included one species of fiddler crabs from Family Ocypodidae, and three species of shore and marsh crabs from the Family Grapsidae. The rest of the species were encountered infrequently due to their specialized nature and specific habitat requirements. The ocypodid crabs, mainly from the genus *Uca*, were commonly found in burrows or walking in highly saturated muddy sediments in mangrove areas adjacent to water. The crabs from the genus *Uca* represent a group of closely resembling species that are difficult to identify in the field. Crabs of this genus are characterized by long eye stalks and a large claw in males. The grapsoid crabs, such as *Pachygrapsus transversus* (common shore crab) were found amongst mangrove prop roots in all types of communities.

4. MOLLUSCAN FAUNA

The study in the Parque Nacional del Este yielded 17 species of molluscs, distributed among 8 families and 2 classes (Appendix 1). There were 6 families of gastropods with 15 species, and 2 families of bivalves with 2 species. There were 2 species of gastropods (Family Potamididae) and 3 pulmonate snails which could not be identified to the species level using the sources at the University of Miami, Rosenstiel School of Marine and Atmospheric Science’s Invertebrate Museum.

The molluscan samples that were brought back from the Dominican Republic were identified by using the distinguishing shell characteristics of different species, and comparing them to the known species in the Invertebrate Museum. For example, the shape of the aperture, the presence/absence of the umbilicus, the number of whorls, the length of the spire, the distinctness of the sutures, and the shell markings are all defining characteristics of gastropods. Differences in these shell characteristics are key components in the identification of these molluscs. Bivalves have other shell features which distinguish species from one another. The exteriors of bivalve shells may have radiating, concentric or reticulate sculptures; the beak, umbo and lunule are also important deterministic features of bivalves. However, the most defining characteristics of bivalves are located on the interior of their shells. The location of the muscle scars, the hinge characteristics, and the attributes of the pallial sinus and pallial line are of the utmost importance in the identification of different bivalve species. Several guides (Warmke and Abbott, 1962; Morris, 1975; Abbott and Dance, 1982; Rehder, 1992) were used to help with the identification of the more common species as well.

The most common molluscs found at the survey sites were gastropods in the families Neritidae, Littorinidae, Potamididae, and Ellobiidae. Members of the family Neritidae are found in countries with warm waters; these herbivorous snails are mostly found in rocky intertidal areas or in mangroves. The periwinkles (Family Littorinidae) occur in the littoral zone of most parts of the world; however, most of the species that inhabit the Caribbean live above the high tide line in rocky areas or in mangroves, and like the nerites, are herbivorous. The horn shells
(Family Potamididae) are distributed in warm waters, occurring in large colonies in muddy environments. The salt-marsh snails (Family Ellobiidae) are pulmonate snails that spend most of their time out of water and are important macro-detritivores in mangrove forests.

5. CONCLUSIONS

As already stated, natural communities can be characterized by the assemblage of species that occur together. A characterization of faunal assemblages implies not only the presence or absence of a particular group of organisms, but their relative dominance and distribution within the community. For example, the species of crabs or snails found in a particular mangrove area are what makes one red mangrove forest community type unique. A fringing red mangrove forest may well have a different faunal assemblage from a hammock red mangrove forest based on differences in inundation and soil chemistry even though both communities are structurally similar. There is a great deal of species overlap between different mangrove communities because different landforms (e.g. fringing and hammock) are lumped together to form the mangrove community types. Thus, one can see the limitations of using a classification based on the structural components of the community (the actual mangrove trees) as opposed to its ecological components.

Coastal and tidal wetlands such as mangrove forests are considered harsh ecological environments as they are subjected to physical changes and disturbances. These disturbances can create new space for colonization or settlement, and often initiate competitive interaction among species. This interaction of organisms throughout the community is what determines the resilience and resistance of a community to change. The species biodiversity of a community is not simply an aesthetic characteristic, but a feature vital to the function of the community as a whole. In other words, every species is important to the function of a natural community. Assessment and monitoring of the health of a community in terms of function and production is tied to monitoring the status and trends in species diversity. Physical factors such as inundation class can be inferred from the biota; thus, changes in the biota indicate physical changes, particularly in the hydrology of the community. Vegetation structure alone appears much more plastic and less sensitive to physical change.

B. ROCKY INTERTIDAL COMMUNITIES

The importance of wave exposure to the distribution and abundances of intertidal populations is well known (Ricketts et. al. 1968; Dayton, 1971). The rocky intertidal stations in Parque Nacional del Este are characterized by either being on the leeward sides of the mainland and islands (Saona and Catalinita) and having moderate to high slopes, or being on the windward sides and having greater slopes or inclination. Fifteen sampling stations were surveyed throughout the park (Figure 5). Different species are found in these different environments, and they are each best adapted to the one they inhabit. According to the analysis done, a definite patterns emerges which makes possible the division of the species into four different groups depending on their distribution: (1) the generalist species, (2) species most commonly found in stations sheltered from high-energy wave action, (3) species most commonly
found in stations exposed to high-energy wave action, and (4) species that are found in only one or two stations.

The generalist species are those that are present in most of the stations. They can be commonly found throughout the park in many different types of rocky intertidal habitats. These include: * Nerita peloronta, N. tessellata, N. versicolor, Citarium pica, Echininus nodulosus, Littorina meleagris, L. ziczac, Tectarius muricatus, Purpura patula,* and *Acanthopleura granulata.* Some species are only found in the stations that are sheltered from the direct winds, currents, and waves. These stations (R1, R2, R3, R5, R7, R9, R12, R13, R14, and R15) are on the leeward sides of the mainland and Saona Island and have moderate to high inclinations. The species include: *Isognomon alatus, Brachidontes exustus, Neritina virginea, Nodilittorina tuberculata, Leucozonia ocellata,* and *Chiton marmoratus.*

Other species are found in the stations that are facing the incoming winds, currents, and waves. These stations are mostly on the windward side of the mainland and Saona Island and are characterized by high slopes (stations R4, R6, R8, R10, and R11). The species that were found in these stations are basically the generalist species listed above. The following species, however, must be added to this list because although they are only found in a few stations, these stations are mostly characterized by high wave energy: *Littorina mespillum, Chiton squamosus, Chiton tuberculatus,* and *Chiton sp. A.* Note, however, that although not characteristic of these habitats, these last species were also found in some stations on the leeward sides of the study area.

Other species seem to be truly rare in Parque Nacional del Este, are only found in one or two stations, and in relatively low numbers. These species include: *Acmaea leucopleura* (station R7), *Acmaea sp A.* (station R6), *Diodora dysoni* (station R14), *Diodora listeri* (stations R1 and R8), *Diodora viridula* (station R14), *Fissurella barbadensis* (stations R1 and R2), *Fissurella nodosa* (stations R14 and R15), *Fissurella rosea* (station R1), *Littorina angulifera* (station R9), *P shopperita pupa* (station R4 and R9), *Tegula excavata* (stations R7 and R15), *Astraea phoebea* (station R9), and *Ceratozona squallida* (station R14). These species have been reported previously in the park (Fahrenkrog, 1979; Cano, 1993), and are thus considered to be truly present. Two species seem to be rare, but have not been reported previously in the park: *Fissurella angusta* (stations R6 and R12), and *Acanthochitona pygmaea* (station R14). These observations would need further studies to ascertain their true presence.

The division of the most common species into groups depending on the type of habitat that they are most commonly found in represents the adaptations that each species possesses in order to survive (Table 3). Although each station has its own zonation pattern where there are places of higher physical stress (desiccation, wave energy) and areas of higher biotic competition and predation, the positioning of the station itself is also very important. Stations facing strong winds, currents, and wave energy are bound to have more vertical slopes, and the species listed under the category "high-energy, windward" must be adapted to life in these stations. They must be able to resist the constant pounding of the waves much more than the species listed under the category "low-energy, leeward." In addition to the "generalists," this list includes
chitons which are best adapted to high wave energy. The species included in the category "low-energy, leeward" are either excluded from the other habitats by competition or predation, or simply cannot cope with the strenuous physical environment found in the windward sides of the mainland and Saona Island.

1. SPECIES RICHNESS PATTERNS

The total mollusc species list compiled in the rocky intertidal stations on Parque Nacional del Este includes 13 families and 35 species (see Appendix 2). Four new species and two new families can be added to the previous lists provided by Fahrenkrog (1979) and Cano (1993). These are: *Isognomon alatus* (Isognomonidae), *Diodora dysoni*, *Fissurella angusta*, and *Acanthochiton pygmaea* (Acanthochitonidae). When compared with the study done in the central-western coast of Venezuela (Pérez, 1974), there are thirteen species common to both sites: *Brachidontes exustus*, *Cittarium pica*, *Diodora listeri*, *Fissurella barbadensis*, *F. nodosa*, *Littorina mespillum*, *L. ziczac*, *Nerita peloronta*, *N. tessellata*, *N. versicolor*, *Nodilittorina tuberculata*, *Tectarius muricatus* and *Purpura patula*. These species seem to have wide geographical ranges.

Data collected in the rocky intertidal stations in Parque Nacional del Este, are summarized in Table 4. It shows three of the variables measured in the rocky intertidal stations in the park, as well as the position of the stations in terms of their exposure to wave action.

As expected, species richness increased down each transect towards the waterline in all stations. Species richness is higher in the lower zones where the physical environment is less stressful than near the high tide level where exposure is greatest.

However, species richness varied substantially between stations (Table 4). For example, in stations R5, R6, and R3, for example, fewer than 10 species were present, while in stations R14, R15, and R9 more than 15 species were found. Stations R5 and R6 are on the southwestern side of Isla Catalinita. Their low species richness is probably due to the fact that these stations have a very small yellow zone. The size of the yellow zone is directly related to the abundance of nerites and chitons, and the small sizes of the yellow zones of these stations imply that many nerites and chitons are not numerous at these stations. Stations R14 and R15 are on the western and southwestern coasts of Saona Island respectively. Station R14 is actually located adjacent to a tourist beach. Its high species richness could be explained by the intermediate disturbance hypothesis. In natural areas, competition theory predicts that in the absence of disturbances a single or very small number of species will occupy most of the space. Physical disturbances are sufficient to prevent the monopolization of space by any one sessile organism. The impacts from tourists (walking on the coast, shell collecting) and other anthropogenic (i.e. trash) impacts could act on the dominant species, preventing it from occupying most of the space. Further studies including caging experiments could be done to see if this is the case.

2. SPECIES COMPOSITION
Analyzing the species composition at the different stations, the similarity matrix (Table 5) shows that in some cases, the highest similarity values (> 0.60 Jaccard’s Coefficient) are for stations that have the same characteristics in terms of the supposed wave energy (derived from observations and geographical position) and slope (measured). For example, stations R8 (Isla de Catalina) and R11 (Playa Guanábano) have the highest similarity index (0.87). They are both considered high-energy stations and have very high slopes (36.16° and 26.10°, respectively).

The similarity matrix, however, clearly points out that it is not only slope and wave energy that determines the species composition of a site. There are some instances where two stations are seemingly different in terms of physical characteristics and are quite similar in terms of species composition (high values for Jaccard’s coefficient). This is the case with stations R2 and R8 (Jaccard’s coefficient = 0.61), R9 and R10 (0.63), R10 and R12 (0.75), R2 and R11 (0.61), R9 and R11 (0.61), and R11 and R12 (0.60).

Other times stations have very low species similarities, but are quite similar in terms of the physical characteristics that were measured. This is the case with stations R1 and R5 (Jaccard’s coefficient=0.27), R1 and R7 (0.19), R1 and R14 (0.27), R3 and R7 (0.21), R5 and R7 (0.19), R3 and R9 (0.25), R5 and R14 (0.16), and R5 and R15 (0.24).

Some of these contradictions can be explained. For example, in the first group above, the high species similarity between stations R9 and R10 and between R9 and R11 can be explained by their closeness to each other. Although the R9 is on a leeward side and R10 and R11 on the windward side of the mainland, they are near each other, and one can conclude that the same factors that affect one site will also affect the others nearby. The high species similarity between two distant stations, R11 and R12, can also be explained in terms of their similarities in slope. Although they are quite distant from each other (R11 on the mainland, R12 on Saona Island) and one is characterized as a leeward community while the other is characterized as a windward community, both have similarly high inclination values (26.10° and 22.33°).

However, others cannot be explained as easily. Stations R2 and R8, for example, have a species composition similarity of 0.61, yet one is on the western leeward coast on the mainland and has a low inclination of 5.16°, while the other station is on the windward coast of a small island and has a slope of 36.16°. Clearly, one must look at other factors that are responsible for zonation patterns in the rocky intertidal. These include biotic factors such as predation and competition, as well as other abiotic factors (e.g. currents, oceanography, salinity, rainfall, etc.) that were not measured in this study.

3. VERTICAL ZONATION PATTERNS

The zonation patterns found in the stations are as expected. The zones are evidently the result of the varying responses of the different organisms to the environmental conditions that are related to the tide and wave exposure. In most stations, the white zone and gray zones (spray or splash zones), when present, are dominated by either Tectarius muricatus (stations R4,
R5, R6, and R8) or *Littorina ziczac* (stations R3, R9, R11, and R14), with *Echininus nodulosus* also present. Pérez (1974) similarly found that in the central western coast of Venezuela, littorinids (*Littorina ziczac*, *L. mespillum*, *L. nebulosa*, *Nodilittorina tuberculata*) were also the most abundant species in the high intertidal areas, followed by nerites (*Nerita versicolor*, *N. peloronta*, *N. tessellata*). In Venezuela, however, *Tectarius muricatus* was rarely found. Comparison of this study with the one in Venezuela shows that although littorinids in general seem to be best adapted to life in the high intertidal in most geographical areas, the species that is dominant varies with geographical location. This is in agreement with many other studies mentioned in section II of this report: although the species may vary geographically, certain genera or groups of similar organisms tend to occupy similar positions in the intertidal ecotones all over the world.

Desiccation is probably the most important physical factor determining the upper limit of species in rocky intertidal coasts. These three littorinids (Family Littorinidae) are well adapted to avoid or resist water loss and can live in the higher zones of the intertidal community. They have a relatively heavy shell, the opening of which is closed by a horny operculum. Littorinids are also known to cluster in depressions in the rock when humidity is low. This seems to be a behavioral adaptation which reduces air movement past the shell, and thus desiccation (Thomas et al., 1983). Their heavy shells and whitish color also protects them from the high temperatures which contribute to desiccation by interacting with evaporation. Limpets avoid high temperatures by evaporative cooling: they raise themselves off the substrate and the wind cools their bodies. This, however, also increases the risk of desiccation. In Parque Nacional del Este, the black zone is usually dominated by *Nerita* spp. as well as *Acanthopleura granulata* and the carnivorous *Purpura patula*. When found, *Littorina meleagris* and *Cittarium pica* occur in the gray or black zones. Pérez (1974) found that the lower intertidal coasts in Venezuela were dominated by *Cittarium pica*, *Purpura patula*, and other carnivorous snails of the genus *Thais*. He also found other more specialized limpets (*Fissurella* spp., *Diodora* spp., *Acmaea* spp.) and chitons that are adapted to strong wave action.

It has generally been assumed that the lower limits of intertidal species are determined mostly by biological factors such as interspecific competition for space and predation. Predators include the carnivorous snails, *Purpura patula* and *Leucozonias ocellata*, fish, crabs, birds, and humans. Predation on the top shell, *Cittarium pica*, was observed in station R7 as evidenced by shell piles. These gastropods are widely used as food and the beautiful shells are sold to tourists as souvenirs. These activities could represent predation or physical disturbance (stepping or walking over the rock platform) on spatial and temporal scales. The very few large individuals of top shells observed in all stations is evidence that predation by man is definitely a factor controlling the growth and abundance of this species. The fact that many top shell juveniles were found in various stations (R7, R14, R15, etc) provides some evidence that predation by the other predators mentioned above might not be a major limiting factor in this species. Keough et al. (1993) compared the size distribution of seven intertidal molluscs, half of which were used for food and bait and half of which were not, in protected (area used as a rifle range) vs. non-protected (frequently visited by humans) sites. The study found that the collected species were significantly (15-40%) larger and/or more abundant at the protected sites. Other studies reviewed by Keough et al. (1993) have corroborated these results. Furthermore,
Keough et. al. (1993) point out additional effects of the removal of the larger individuals from a community. For example, the intensity of intraspecific competition "may vary with the sizes of the individuals involved, so removal of these larger individuals could have disproportionate effects on the performance of smaller individuals." (Keough et. al., 1993). A reduction in the abundance of Cittarium pica, an important herbivore of the rocky intertidal, could allow the development of large macroalgal populations that may later be resistant to subsequent attacks by herbivores. The removal of large individuals may also be important if those individuals contribute disproportionately to the reproductive effort in a local population (for example, if gonad volume increases exponentially with length of the species) (Keough et. al., 1993).

Although the patterns that have emerged from the REA seem to be in accordance with the typical pattern of rocky intertidal community structure in the Caribbean, one must define and comprehend the physical factors (wave action, desiccation, temperature, light intensity, etc.) that affect the local populations, as well as the biotic factors or interactions between the species in the community in order to fully understand the community structure in the rocky intertidal areas around Parque Nacional del Este. Since none of these were measured in Parque Nacional del Este, a full understanding of the community is impossible at this point. With the ecological evaluation, trends have emerged and some hypotheses may be made, but in order to entirely comprehend the community structure of these coastal areas, specific studies (for example, caging, predator removal, for example) and measurements must be made at each site.

4. CONCLUSIONS

1. In general the rocky intertidal areas of Parque Nacional del Este have the expected species composition, richness, and zonation patterns which are comparable to most other Caribbean areas.

2. The species in Parque Nacional del Este may be divided into four different groups depending on their distribution, which is related to environmental conditions:
   (a) generalist species: present in most of the stations;
   (b) leeward species: most commonly found in the leeward, more sheltered (from wind, currents, and waves) stations;
   (c) windward species: most commonly found in stations exposed to high-energy wave action, mostly on the windward sides of the park, and
   (d) rare species: found in only one or two stations.

3. Species richness increases down each transect. Species richness varies substantially between stations. Some of the patterns in species richness can be explained simply by the geographic location of the station. However, others must be studied more closely to determine the factors responsible for the patterns observed.

4. High similarities (according to Jaccard’s Coefficient) in species composition between stations can be explained by similarities in wave energy and slope of the stations. It is obvious, however, that other factors are important in determining species composition.
5. The zonation patterns in most stations show that littorinids are dominant in the high intertidal (white, gray, or splash zone). They are well adapted to dealing with high temperatures and desiccation stress through morphological, physiological, and behavioral adaptations.

6. The black zones of Parque Nacional del Este are generally dominated by nerites, chitons, and the carnivorous snail *Purpura patula*.

7. The scarcity of large *Cittarium pica* is notable. It is suspected that this is due to anthropogenic stresses (collecting), as this species is used as a food source in the Dominican Republic. It is illegal to collect species smaller than 5 cm by law (Law 5914, Decree 312). The presence of this important herbivore of the lower rocky intertidal is related to the control of algal growth, and its absence could have many influences in community structure.

C. BENTHIC COMMUNITIES

A total of 19 benthic sites (Figure 6) were surveyed during the REA of Parque Nacional del Este. Fourteen of these were hard bottom sites, and the remaining five were soft-sediment sites. Substrate-lifeform surveys provide a signature of the community in the form of frequency-distribution curves for each site. Topographic relief, depth, and substrate-lifeform were used to classify each community type. An explanation on interpreting substrate-lifeform data is given in Sullivan and Chiappone (1993).

The hard bottom benthic community sites were divided into six categories based on their relief, depth, and dominant biota: low-relief spur and groove reef, flat reef, transitional reef, patch reef, low-relief hard bottom reef, and rocky coast or platform reef. Likewise, the soft bottom benthic community sites were divided into three categories depending on the dominant algae/seagrass species living there: *Syringodium*-dominated seagrass community, mixed seagrass community, and mixed seagrass/algae community. Detailed descriptions of these 6 different hard bottom and 3 different soft bottom community types and of each site belonging to them.

The information from the species presence-absence surveys done in the hard bottom communities were separated by reef category (low-relief spur and groove and reef flat, and patch, low-relief hard bottom, and rocky coast platform reefs), and by lifeform surveyed (algae, sponges, octocorals, hard corals). The information for soft bottom community types were separated in the same manner. This information has been summarized in Tables 6 and 7 below. Table 6 summarizes the data from the species presence/absence surveys, and is useful in comparing the species richness of the different categories into which all benthic community stations were placed. Table 7 is a summary of the data from the lifeform surveys done in all the benthic stations in Parque Nacional del Este. It shows the relative cover of the different biota in each of the stations in a comparative manner.

The reef community structure emerging from the study done in Parque Nacional del Este does not fit very well into the general model of reef zonation described in the reef section of this
document. The Catuano Passage is formed between the mainland and Saona Island, and water from the Mona Passage and the northeastern coast of the Dominican Republic is rapidly funneled through it from east to west. The easternmost portion of the Catuano Passage is characterized by shallow high wave energy reef flats, and small patch reefs. Farther along the channel, in the shallow areas, there are moderate to dense seagrass and algal communities. On the leeward western portions of the park, low-relief spur and groove and hard bottom communities are the types of bottom typically found. Unfortunately, ecological evaluations of the easternmost portion of the park as well as of the south-southeastern coast of Saona Island were not included in this study. It is recommended that these studies be done in order to fully comprehend the distribution, locations and dynamics of the community structure in Parque Nacional del Este.

A summary of the general results of the surveys done in each site followed by a discussion of the possible factors influencing the patterns found will follow below:

1. HARD BOTTOM BENTHIC COMMUNITIES

   a. Low-Relief Spur and Groove Communities

   Four of the benthic sites were characterized as belonging to the low-relief spur and groove community category: Parque Nacional and El Peñón, both on the west side of Parque Nacional del Este; Arrecife de Rubén on the western coast of Saona Island; and El Toro on the same Saona coast, but farther south. These sites are relatively protected from direct wave action by land barriers. They occur in approximately 15-25 meters depth of water, and have well-defined, but low relief (< 1m) spur and groove features. These do not appear to be actively accreting structures.

   The substrate in low-relief spur and groove communities is mostly hard reef, but crevices, depressions, and spaces (grooves) are filled with sediment. The lifeform data shows that these communities are characteristically dominated by algae, sponges, and octocorals, while hard coral cover is very low. Diversity of all lifeforms is high, and it is in this reef category that we find the sites with some of the greatest species richness in octocoral species (El Toro with 22 species), sponge species (El Peñón with 36 species), and hard coral species (El Peñón with 26 species). Most algae were calcareous (Halimeda) or turf algae, although Dictyota was also present. Octocoral and sponge individuals were characterized by large size. Corals, when found, were mostly Diploria labyrinthiformis, Siderastrea siderea, or Montastrea cavernosa. These sites were reminiscent of low-relief spur and groove communities in the Bahamas and the Turks and Caicos (Sullivan et al, 1994b; Sullivan et al, in press).

   b. Reef Flats

   Three reef flat communities which consisted of low-relief consolidated carbonate platforms were identified in Parque Nacional del Este: Pasa Grande, Arrecife del Tronco, and Arrecife de Fuertes Olas. All are in relatively shallow water (0.5-3.0 m.) and located on the eastern portion of the canal between the mainland and Saona Island. They are thus subjected
to heavy wave action and strong currents coming from the Mona Passage.

Despite these similarities, each of the three sites is different in its own way in terms of its substrate and lifeform characteristics. Pasa Grande has a hard reef substrate with some rubble and virtually no sediment; Arrecife del Tronco is a consolidated Porites reef with loose rubble and sediment; and the western portion of Arrecife de Fuertes Olas (only the western portion was characterized using substrate-lifeform survey) is mostly rubble with some sediment and small patches of hard substrate.

Lifeform characteristics in reef flats varied substantially. All are dominated by algal cover. Pasa Grande is dominated by algae (algal covers > 75% of the quadrat in 72% of them) although sparse hard coral colonies (Acropora palmata, Diploria clivosa, Porites astreoides, Porites porites) are also present. The greatest algal species richness, especially of phaeophytes, occurs in this station. The most important algae here are Dictyota, Turbinaria, Stypopodium, and Halimeda. Arrecife del Tronco is also dominated by algae although not as strongly as Pasa Grande. Here there was sparse to moderate sponge and hard coral (mostly Porites porites forma furcata) cover. Arrecife de Fuertes Olas is also strongly dominated by algae with some sparse hard corals and seagrasses present.

c. Transitional Reefs

The only station characterized as a transitional reef, El Faro #2, occurs in the southwestern coast of Saona Island. It is described as being very similar to those that occur in southern Florida, representing a drowned reef flat community that has been colonized by algae, hard corals, and octocorals. El Faro #2 is deeper (7-10 meters) than other stations, but has very low physical relief (even lower than the low-relief spur and groove communities). It consists mostly of a hard reef substrate with some rubble and sediment present in the crevices and depressions, and is dominated by algae and octocorals. Common algae include Halimeda, Dictyota, and Amphiroa. Hard corals and sponges are not dominant, yet occur sparsely throughout the station.

d. Patch Reefs

Three patch reef communities were identified in Parque Nacional del Este. Two of them, Arrecife del Angel #1 and Arrecife del Angel #2, occur on the eastern portion of the park in a deep channel between Saona and Catalinita islands. The other, El Faro #1, is on the southwestern coast of Saona Island next to the transitional reef, El Faro #2. Although these three patch reef communities are all relatively low-relief communities, they differ substantially in both physical and biological characteristics. Arrecifes del Angel #1 and #2 both have a relatively circular shape, and are surrounded by a sand halo and then a seagrass (Thalassia testudinum) bed. It has been shown that these sand halos can be caused by the nocturnal grazing activities of long-spined sea urchins which move out of their hiding places on the reef at night to feed on the adjacent seagrass beds (Vega, 1990).

Arrecife del Angel #1’s substrate consists of a non-consolidated rubble or cemented dead
Porites porites corals, with sediment increasing towards the periphery of the reef (Technical Report). Arrecife del Angel #2’s substrate is a mixture of hard reef, sediment, and rubble. El Faro #1 is a heterogeneous series of patches separated by sediments and rubble from Acropora cervicornis. The substrate itself consists of a consolidated reef platform with some coral heads.

The dominant biota in all three patch reefs are algae. In Arrecifes del Angel #1 and #2, alga covered > 50% of the quadrats in 72% of them. The alga Dicyota was very common in El Faro #1. Although sponges, octocorals, and hard corals occur in all three patch reefs, El Faro #1 and Arrecife del Angel #2 are also characterized by having a diverse octocoral and hard coral fauna. For example, El Faro #1 was the only place where Agaricia tenuifolia was found and where colonies of Millepora squarrosa were also common. This latter coral species was only found in this and the adjacent (El Faro #2) stations. Hard coral and octocoral species are also very common in Arrecife del Angel #2 where large colonies were abundant.

e. Low-relief Hard Bottom

Again, only one community was found that fit this category: Arrecife de los Cocos. This station is located less than one mile off the coast in a deep (3-4 m) channel, on the western side of the park. It is therefore relatively protected from heavy wave action. It has extremely low physical relief, and only distinct isolated coral heads are observed. It lies on a carbonate platform and has very small amounts of sediment and rubble. Its biota is dominated by algae and octocorals. This station has one of the greatest diversities of algae found in the park. This is specially true of Rhodophytes, or red algal species. Although sponge and octocoral cover is moderate, species richness is quite high. This station has the greatest abundance of octocoral species (28) of all stations surveyed in the park. By contrast, hard corals are very uncommon, and, when found, colonies are very small. Some hard corals found in this station were: Millepora alcicornis, Porites astreoides, Dichocoenia stokesii, and Diploria labyrinthiformis.

f. Rocky Coast Platforms

Two of the communities surveyed fit this category: Acantilado del Catuano and Puerto Catuano. Both of these stations are located in the northern coast of Saona Island, but Acantilado del Catuano is in the passage between the island and the mainland, while Puerto Catuano is farther to the southwest, away from the passage.

Acantilado de Catuano is the underwater continuation of a vertical rocky coast, and its subsequent levelling off into a platform. Its substrate is mostly a hard platform with some rubble throughout. Its biota is dominated by algae, although sparse sponge, octocoral, and hard coral communities are also found. The algal species assemblage is a combination of algal species typical of hard bottom and soft bottom communities. Not surprisingly, it is one of the stations with the highest algal species richness (29 species) in the park. Hard coral and octocorals are not very common, but their species richness is quite high. On the wall, Tubastrea, Madracis, and Agaricia were common, while on the platform Montastrea, Diploria, and Siderastrea were the species that were more commonly found.
The substrate of Puerto Catuano, like Acantilado del Catuano, is also mostly hard reef, but it has more sediment and less rubble than Acantilado del Catuano, by comparison. It is also dominated by algae, but is much poorer in terms of sponge, octocoral, and hard coral species than Acantilado del Catuano.

2. SOFT BOTTOM BENTHIC COMMUNITIES

The substrate of all soft bottom benthic communities surveyed in Parque Nacional del Este is composed mostly of sediment with small amounts of rubble and patches of hard reef.

a. Syringodium-Dominated Seagrass Communities

Hierba del Tronco is the only soft-bottom station whose biota is dominated by the seagrass Syringodium filiforme. Like Arrecife del Tronco beside it, it is located in the eastern portion of the passage between Saona Island and Catalinita Island, and is subject to heavy wave energy. As expected, its biota is mostly composed of seagrasses, although some patches of algae were encountered. A comparison of the relative cover and frequency of occurrence of the different seagrass species shows that although Syringodium is the dominant seagrass, Thalassia is also present in moderate amounts. The algal species richness here was surprisingly high with 25 species found. Most dominant of these algal species is Halimeda incrassata followed by Penicillus dumetosus and Udotea flabellum.

b. Mixed Seagrass Communities

The only station surveyed that fits this category, Pilas de Lambí, is located to the north/northwest of Catalinita Island, 5 miles from the coast of the mainland, where large white piles of dead Strombus gigas are clearly visible, hence the name of the site. Its biota is composed of moderate to dense cover by different seagrass species (Thalassia, Halodule, and Syringodium) with some algae dispersed throughout. Algal species richness is low, and no single species of algae is dominant in terms of cover, although Penicillus dumetosus individuals are quite numerous (it occurs in 84% of the quadrats).

c. Mixed Algae/Seagrass Communities

Three of the communities surveyed in Parque Nacional del Este fit this category: Los Manglecitos, La Ciudad de Penicillus, and Hierba de los Cocos. These communities are characterized by being in relatively shallow water (< 3 m) and by being co-dominated by seagrasses and algal species.

Los Manglecitos is less than 100 m from the southeastern coast of the mainland. It has a highly variable cover of both algae (Halimeda, Laurencia intricata, and Dictyota) and Thalassia testudinum. The most common (in terms of number) algal species are: Penicillus capitatus, P. dumetosus, and Laurencia intricata. In terms of cover; however, the dominant algal species are: Halimeda opuntia, Laurencia intricata, and Dictyota cervicornis.

Ciudad de Penicillus has the same characteristics in terms of dominant biota as Los Manglecitos, but there are more anemones and sponges present in this soft bottom community.
The dominant seagrass is *Thalassia testudinum*. The most important algal species in terms of cover are: *Penicillus dumetosus*, *Halimeda monile*, and *Halimeda incrassata*. In terms of number, the most important algal species are various species of: *Caulerpa*, *Halimeda*, *Penicillus*, and *Udotea*. It is interesting to note that the density of seagrass shoots and blades in Ciudad de Penicillus is lower compared to Hierba del Tronco, which is dominated by *Syringodium*, although the length of the blade is longer there.

Finally, Hierba los Cocos is dominated by the alga *Lobophora variegata*, although *Udotea* and *Avarainvitea* species are also common. Both *Thalassia testudinum* and *Syringodium filiforme* are found in this station.

3. DISCUSSION OF PATTERNS

Some of the patterns of diversity and coral cover (Tables 6 and 7 above) that have been found in the hard-bottom benthic communities in Parque Nacional del Este can be explained. In other cases, however, further studies are needed to ascertain the factors controlling these patterns.

There is a general consensus among scientists that coral species diversity increases with increasing depth. One can see that in Parque Nacional del Este this is generally true: coral species richness is relatively greater in the deeper sites (low-relief spur and groove and transitional reefs) than in the shallower ones (reef flats and low-relief hard bottom communities) (Table 6).

One of the notable observations in Parque Nacional del Este is the lack of considerable structural reef development at the visited localities. Spur and groove formations are typically underdeveloped with little physiographic relief. No high relief spur and groove features or highly developed acroporid communities were found. In general, hard coral cover is considered low in all sites (Table 7). The absence of high-relief spur and groove features may be caused by high sediment transport. Sediment particles smother reef organisms, and reduce the light available for photosynthesis. This was the case for the platform margin reefs in the Caicos Bank (Sullivan et. al., 1994b), where the influence of sediment transported from the shallow portions of the Caicos Bank to the fore reef slope as well as strong surge conditions in the windward sides resulted in decreased reef development along the slope environment offshore of tidal passes. Rogers (1990) also found degradation of coral reefs caused by sedimentation. Specifically, the study found that heavy sedimentation was associated with reduced coral diversity, live coral cover, coral growth rates, coral recruitment, calcification, net productivity of corals, and rates of reef accretion. Sedimentation can therefore negatively affect the reef organisms in a number of different ways, which could lead to changes in the interactions between fish and their reef habitats.

Another possibility for the restricted reef development found is that high-relief spur and groove communities are present, but were not surveyed. Studies need to be done in the reef slope in the eastern portion of the park as well as on the south-southeastern coast of Saona Island before any conclusions can be made regarding this.
The low or total absence of *Acropora* species is surprising since in many areas, *Acropora palmata* and *A. cervicornis* dominate many reef crests and the shallow and mid-water reef community structure in many Caribbean marine communities (Bak, 1977). In Parque Nacional del Este, they were only found in all three reef flat communities and in some patch and transitional reefs, but never in the typical large numbers or densities. It is interesting to note that most surveyed sites were below 30 ft. *A. palmata* is usually found above that depth. The importance of these species in community structure is widespread. According to Kojis and Quinn (1993); for example, only three coral species dominate present day coral reef community structure and the Pleistocene geological record: *Acropora palmata*, *A. cervicornis*, and the *Montastreaannularis* "complex." Some reefs in the northwestern Caribbean are described as being in low wave energy conditions and having a predominance of *Acropora cervicornis* as a major mid-depth reef builder (Sullivan et. al., 1994b). *Acropora* species are the fastest growing of the scleractinian corals (10-12 cms./yr.), offer protective hiding places for a large variety of organisms, and have an important role in protecting back reef areas from the effects of wave energy.

Their low numbers in Parque Nacional del Este can have various explanations. First of all, *A. palmata* is an environmentally sensitive species with narrow niche boundaries. It requires clear and well circulated water, a firm stable substrate for attachment, and moderate temperatures without extreme seasonal variations (Jaap et al., 1989). The virtual absence of *A. palmata* in the reefs surveyed in Parque Nacional del Este could be explained by turbidity or storm damage. These factors can reduce both immediate population size and subsequent recruitment since its principal mode of localized recruitment is vegetative propagation from fragments broken from a parent colony. Alternatively, the sediments could be unstable and dynamic, and not conducive to coral settlement, attachment, or long-term growth. Waves or speedboats could re-suspend sediments causing chronic stress (partial burial, tissue abrasion, recruitment inhibition) for acroporid corals. Secondly, in the last decades, white band disease has severely diminished *Acropora* populations in the Caribbean. According to Kojis and Quinn (1993), their dominance in the reef crest and their vegetative reproductive habit "may have resulted in low genetic variation and, along with very high abundance, greatly increased these species susceptibility to epidemic diseases." Additionally, their chance and patchy recruitment could also influence their inability to recover, and the populations may have to rely on self-seeding for new recruits.

Kojis and Quinn (1993) have hypothesized that damaged (by white band disease) scleractinian sites in the Caribbean are likely to be recolonized by soft corals. They hypothesized that soft corals are capable of rapidly recolonizing Caribbean reefs previously dominated by scleractinian corals and function as successional species in rebuilding the community structure of the reef. The high abundance of octocoral dominated communities in Parque Nacional del Este could be explained by this theory. Similar octocoral dominated reefs have been found in Turks and Caicos (Sullivan et al., 1994b) and in Curacao (Bak, 1977). Unfortunately, there are no previous descriptions of the reef communities in the park, which could be used to compare the communities in a temporal scale and substantiate this hypothesis.
The characteristic patterns of biota in the low-relief spur and groove communities, the transitional reef, and the low-relief hard bottom need to be discussed further. The low-relief spur and groove and hard bottom communities generally have a high cover of octocorals and sponges relative to hard corals, while the transitional reef is characterized by very high densities of octocorals. Gorgonians and sponges are important elements of marine ecosystems because they are hosts or serve as refuges for a large number of organisms, and because they may contribute to significant amounts of sediments, in the form of microscopic spicules, to the surrounding areas.

The octocoral assemblages in each of the communities could be analyzed individually if time and space permitted. Opresko (1973), in a study in Florida, divided octocorals into categories depending on their distribution and sighting frequency (restricted vs. general) and the habitat type where they were more commonly found (clear water patch reef vs. inshore). Additionally he identifies and discusses the environmental factors that are more likely to influence the distribution of species. These are temperature, salinity, illumination, sedimentation, and currents. Yoshioka and Yoshioka (1989b, 1991) also hypothesize that variations in sediment transport (and indirectly topographic variations) are the major factors influencing the distribution of shallow-water gorgonians.

The distribution and high cover of sponges and octocorals relative to that of hard corals in the low-relief spur and groove and low-relief hard bottom sites in Parque Nacional del Este (Table 7) as well as the tremendous cover by octocorals in the transitional reef could theoretically be explained by these factors. These communities are located on the western portions of the mainland and Saona Island. There, they are protected from strong wave action, to which these organisms are not well adapted. Additionally, in all these communities the substrate is mostly hard reef which ensures the successful recruitment and settlement of the planula larvae, and the attached living conditions of these organisms. In situ observations, oceanographic logistics, and the observation that sediments are only found in crevices and depressions, indicate that these sites are swept by currents which may transport food to the colonies. They also bring sediment, but it seems that its presence in these communities is not very durable. Rogers (1990) surveyed areas before and after dredging in Florida, and found that octocorals were the most tolerant of the reef benthos to sedimentation, mostly due to their morphology which prevented sediment accumulation. Octocorals are morphologically adapted to avoid sediment accumulation, and also have the metabolic adaptations to get rid of sediment particles through mucus (Opresko, 1973). Therefore, it seems that high densities of octocorals are found in these sites because they are better adapted to the living conditions there, specifically the sediment transport and strong currents, relative to hard corals. Additional measurements of sponge, hard coral, and octocoral density, abundance, and size were done in the low-relief hard bottom community, Arrecife Los Cocos. It was found that octocorals and sponges form characteristically very large colonies relative to hard corals. According to Opresko (1973), the "abundance of a species, its average size and weight in diverse habitats, and its abundance relative to that of other species occurring in the same habitat are indicative of how well the species is adapted to a given habitat." The results present further evidence that sponges and octocorals are much better adapted to these habitats than hard corals.

Furthermore, the fact that in many of these places the hard corals that were mentioned
as being relatively abundant (Diploria labyrinthiformis, Montastrea cavernosa, Siderastrea siderea) have all been hypothesized to be indicative of areas of relatively high sedimentation stress (due to their greater tolerance) also supports this hypothesis.

Although cover by hard corals is low in these sites, species richness is not. This too can be explained by the effects of sedimentation. Liddell and Ohlhorst (1987) found that sedimentation rates in Jamaica did not correlate with living hard coral cover or abundance, but were positively correlated with coral diversity. He hypothesized that sediments (in the amounts found in his study) could act as a small disturbance to increase species diversity through the intermediate disturbance hypothesis.

Finally, and by far the most remarkable of the observations made in Parque Nacional del Este is the high degree of algal cover found in most stations (Table 7). All hard bottom benthic communities are dominated by algae. High algal cover can be caused by several factors acting singly or together:

- lack of grazing by sea urchins and herbivorous fishes (scarids and acanthurids).
- high nutrient waters which enhances macroalgal competition with hard corals.

Herbivory is an important factor in the development and structure of macroalgal and reef communities, especially in the tropics where the intensity of herbivory is greater. Hypothetically this is because herbivorous fishes in the tropics have larger sizes, higher metabolic rates, more mobility, orientation behavior, and a range of sophisticated sensory cues that are increasingly damaging to macroalgal populations in the subtropical and tropical regions (Littler et al., 1986b). It is also a selective force in the evolution of plants and their anti-herbivory defense mechanisms. The defense mechanisms have been reviewed by Littler et al. (1983, 1986b). Summarizing, algal defense mechanisms may be morphological, chemical, nutritional, or behavioral. Defense associations against herbivores as another defense mechanism has been demonstrated in Belize, where some marine algae (Amphiroa tribulus, Jania adherens, Laurencia poitei, Digenia simplex, and turf algae) showed significant reduced probability of being discovered and eaten when they occurred in close proximity of one of the most toxic of marine algae, Stypopodium zonale (Littler et al., 1986a). Although some of these algae have certain defense mechanisms (Amphiroa tribulus is calcified, and Laurencia poitei and Digenia simplex have small degrees of toxicity), if there were no other alternatives present, the probability of their being eaten by herbivores and echinoderms would be higher than when they were near or associated with Stypopodium zonale.

If the statement that the "maximal limits [of] algal biomass on reef systems ... are generally set by nutrient levels ...., whereas, the actual standing crops present are determined by the more proximate controlling factor of herbivory" (Littler et al., 1986b) is true, then one can conclude that most reef zones in Parque Nacional del Este are influenced by high nutrients, and that herbivory is not well developed, unless a high proportion of the algae found in Parque Nacional del Este have strong defense mechanisms against herbivory. This last possibility will be discussed below.
Some of the algae that have been found to have efficient grazing defense mechanisms are: crustose coralline algae (such as *Hydrolithon boergesti*, *Neogoniolithon strictum*, *Peyssonnelia* spp., *Porolithon pachydermum*, and *Lithophyllum congestum*); jointed calcareous algae (such as *Amphiroa rigida* and *Halimeda* spp.); thick leathery species (such as *Sargassum polyceratium*, *Turbinaria turbinata*, and *Gracilaria debilis*); and *Dictyota cervicornis*, *Stypodium zonale*, and *Laurencia obtusa* which have strong chemical defenses. Some of the more susceptible algae are sheet algae (such as *Anadyomene stellata*, *Enteromorpha linga*, and Ulva lactuca) and filamentous algae (*Centroceros clavulatum*, *Ceramium niten*, and *Spyridia filamentosa*, for example) (Littler et al., 1983, 1986a).

Comparing the previous lists with the algae most abundantly found in the reefs in Parque Nacional del Este, one can see that the more commonly seen species are also included in the list of algae with efficient defense mechanisms. It seems that the nutritional requirements of the herbivores found in Parque Nacional del Este are satisfied by other more palatable algae. If, however, the herbivorous fish had fewer feeding options (or there was a greater number of them), then these macrophyte communities would theoretically not be so developed. The herbivores would have no choice, but to feed upon these algal species, as they supposedly do in most other Caribbean reefs where these large standing crops of macrophytes do not exist. This pondering leads to three options: (a) either herbivore feeding pressure is not strong enough and allows the large standing crops of macrophytic alga, or (b) the nutrient load in the area is large and allows for the development of these communities, or (c) both. These possibilities will be examined.

A weak grazing pressure could explain the high algal standing stocks in the reefs in Parque Nacional del Este. This is caused by low numbers and sizes of herbivores on the reefs. Littler et al. (1986b) noted a disproportionate abundance of herbivorous fishes, with exceptionally large parrotfish, in Looe Key, Florida. They attributed this to an increase in algal cover (due to increased eutrophication as a result of expanding human population). As will be discussed later in the section on fish communities in Parque Nacional del Este, the fish surveys show that although there are many herbivores on the reef, they are never the dominant feeding guild and that there is a general lack of large fish throughout the park. In the low-relief hard bottom, Arrecife Los Cocos, a high degree of red algal cover was found. Since many of these species (for example, *Jania* or *Acanthophora*) are highly palatable to herbivorous fish (M. Chiappone, pers. comm.), their presence could be explained by the absence of herbivores.

The high algal cover found in Parque Nacional del Este could also be caused by the restricted spatial heterogeneity these reefs show. Littler et al (1986b) have reviewed investigations that have shown that the lower the spatial heterogeneity, the lower the amount of protective cover available for fishes and sea urchins; therefore, the lower the grazing pressure. Thus, reasonably large standing stocks of macrophytic algae often develop. The remarkable low reef development found in Parque Nacional del Este has been previously discussed. This, together with the observation that very few *Diadema* were seen during the surveys, could partially account for the high algal cover found in the park.

Herbivory can have a dominant and direct control on algal standing stocks in the
surveyed benthic communities in Parque Nacional del Este; therefore, further studies need to be
done in this area. Algal inventories including information on abundance and density of some
species are needed. Comparative palatability and herbivory studies (placing different algal
species on lines in different habitats, for example), and manipulative studies of herbivore
populations (monitored enclosure cages, for example) are also recommended. These could be
coupled with experiments using nutrient diffusers to simulate upwelling or increased
eutrophication, and the results could be ultimately used for management purposes.

High nutrient waters could reach Parque Nacional del Este from different sources. The
lack of environmental pollution directly affecting the area precludes nutrient enrichment through
waste or sewage disposal (the small amounts of domestic sewage pollution occurring along the
coasts of Saona Island are considered insignificant). There are also no rivers in the park which
could contribute fertilizers, sewage, or other nutrient sources to the park. However, the Rio
Yuna farther east of the park as well as Rio Chavón and Rio Cumayasa to the west of the park,
could be important sources of nutrients and pollutants. They run through the Altagracia and
Romana provinces which are major producers of sugarcane and cattle. Many herbicides,
fertilizers, and other chemicals are used in this region and ultimately end up as river discharge.
If currents carry these towards the reef, seagrass, and mangrove communities in the park, they
have the potential of being causative agents of the high algal cover.

Alternatively, nutrients could arrive from distant sources such as Puerto Rico, or even
from South America via the Orinoco Plume. Large amounts of trash and tar, seemingly from
Puerto Rico and the oil spills that have occurred there, were found in the eastern coast of the
park while rocky-intertidal surveys were being conducted. High amounts of nutrients could
likewise be transported to the park.

Upwelling, the process through which high nutrient bottom waters are brought up to the
surface, is another possible source of nutrients to the park. Littler et al. (1986b) have pointed
out the possible importance of upwelled nutrients to the major coral reef systems of the world.
Although the importance of upwelling has not been demonstrated to date, it must be kept in mind
when studying the nutrient dynamics of reef systems.

Finally, groundwater seepage could also contribute significant amounts of nutrients
(nitrogen specifically) to reef areas. Many submarine springs that discharge throughout the
coasts of Parque Nacional del Este have been reported previously (Cano, 1993, Towle et al.,
1973). The same observations were made by the terrestrial team while they conducted their
investigations (Abreu, pers. comm.). Nitrogen enrichment by groundwater is probably not from
anthropogenic sources in Parque Nacional del Este. It may derive from decomposition of plant
litter (either mangrove or otherwise), from terrestrial nitrogen fixing organisms (NH₄ is oxidized
to NO₃ by nitrifiers), or from rainwater, which has been reported to be extremely variable in
nitrate concentration (D'Eliia et al., 1981). Deep oceanographic studies, surface salinity
sampling along the coasts of the park, as well as hydrographic or hydrological studies are needed
in order to assess the importance of this possible nitrogen source. The presence of nitrogen-rich
groundwater inputs to the park could have important management implications if these
communities are nutrient limited. For example, it has been suggested that the eutrophication
occurring in the Florida Reef Tract is caused by inputs of phosphorus to coastal waters of the eastern Gulf of Mexico which are then carried downstream by prevailing currents to the nitrogen-rich, phosphorus-limited waters of the Florida Reef Tract (Lapointe et al., 1993). This could mean that even modest enrichment of the park with domestic sewage, which is typically high in phosphorus, could initiate large eutrophication problems, given the existence of nitrogen-rich groundwater inputs, and the general tendency towards phosphorus limitation of algal growth in shallow, carbonate-rich waters (Lapointe et al., 1993). One must also take into account that an important source of phosphorus already exists in the park in the form of bird guano from the seabird rookeries in the Las Calderas region.

4. CONCLUSIONS

1. The benthic communities surveyed in this study in Parque Nacional del Este were:

   (a) shallow high wave-energy reef flats and small patch reefs in the easternmost (windward) portion of the surveyed area,
   (b) shallow moderate to dense seagrass/algae beds near the coast in the Catuano Passage, and
   (c) low-relief spur and groove and hard bottom communities on the western (leeward) portions of the park.

2. Most of the benthic surveys were done at moderate depths, and a general lack of considerable structural reef development was found. The possible causative factors for this are discussed.

3. On the western leeward portion of the park reef communities that were found were:
   - low relief spur and groove and hard bottom communities with a high cover by octocorals and sponges relative to hard corals.
   - transitional reef communities characterized by very high octocoral cover relative to sponges and hard corals.

   The relatively higher cover by sponges and octocorals, which are better adapted to and more tolerant of high sediment transport conditions (relative to hard corals), as well as the peculiar oceanographic conditions found in these areas, justify the necessity to conduct further studies that would explain the presence of these unique communities.

4. All sites surveyed are mostly covered with macrophytic algae. This may be due to the low amounts of grazing pressure; to nutrient enrichment; or to a combination of both factors. Low amounts of grazing pressure may be caused by low abundances of herbivores, restricted spatial heterogeneity of the area, or high anti-herbivore defense mechanisms in the algae. Well-defined herbivory studies are needed to assess the importance of this factor in shaping community structure in these areas.

5. Nutrient enrichment may derive from nearby sources such as local upwelling, groundwater seepage, various rivers, or from distant sources such as Puerto Rico or
South America. Since Parque Nacional del Este is highly influenced by waves, wind, and currents, further oceanographic and hydrological studies are needed to determine the importance of these factors in shaping community structure.

D. FISH COMMUNITIES

A total of 58 fish surveys were done in 6 different benthic substrate habitats in Parque Nacional del Este (Figure 7). The habitats were: low-relief spur and groove communities, transitional reef, patch reef, low-relief hard bottom communities, rocky coast communities, and mixed algae/seagrass communities. Figure 7 shows the geographical variation in sites surveyed; one can see that fish surveys were conducted mostly on the north and northwestern sides of Saona Island, and that no fish surveys were conducted on the eastern side of the park. There were more dives and more time spent conducting fish surveys around Saona Island than in the western side of the park.

1. SPECIES RICHNESS

The fish fauna sampled in Parque Nacional del Este are taxonomically and trophically diverse. A total of 122 fish species is reported for the park. Most of these have not been reported previously (Cano, 1993). The surveys show a variation in richness (by fish species and by family) between habitats, sites, and time of day. Several conclusions may be made from this limited field sampling:

- the greatest fish species richness (79 species) was found in Arrecife de los Cocos.
- there is no significant difference in fish species richness between Saona Island sites and those on the western side of the park.
- there is a significantly greater reef fish diversity at reef sites than at the algae/seagrass site.
- at the mixed algae/seagrass site there is no difference in species richness between morning and afternoon.
- there is greater richness of fish species in the morning than in the afternoon in the low-relief spur and groove, transitional reef, and low-relief hard bottom communities. This difference is most pronounced in the low-relief spur and groove community, Arrecife de Rubén, located on the western coast of Saona Island.
- at Arrecife de los Cocos on the western side of the park, where the only night fish survey was conducted, there is a significant difference in the species richness seen during the day (morning and afternoon) and the night. This is probably due to human error and more night dives must be conducted to ascertain this difference.
- there is no significant difference in fish species richness between reef habitats or between
sites in the same habitat.

The greater diversity in the reef areas compared to the seagrass/algae areas is understandable given the greater topographical complexity that the reef areas offer. It has been shown (Carpenter et al., 1981) that density and diversity of fishes increases as the structural complexity of an area increases. This, however, negates the last conclusion above. There should be differences in fish species diversity between reef habitats, the more structurally complex ones having the greater number of species. Perhaps this is due to the fact that no reef habitats showing high development and topographical complexity were surveyed, as will be discussed shortly.

2. SIMILARITY PATTERNS

As expected, community structure was found to be significantly more similar at different sites within than among reef type categories (Alevizon et al., 1985). If one analyzes the similarity matrix (Table 8), one can see that 3 of the 4 most similar (in terms of which species are present in each site) sites are: El Toro, El Peñón, and Arrecife de Rubén. This is expected since these are the three low-relief spur and groove sites, and should have very similar fish species assemblages. Also expected is the fact that the most dissimilar of all sites is the mixed algae/seagrass community. The following matrix (Table 8) shows similarities (Jaccard’s Coefficient and Community Coefficient) in total number of species between sites. Some relatively high similarities between sites of different benthic habitats, such as that between El Faro 1 (a patch reef) and El Faro 2 (a transitional reef) may be explained by their close geographic location. Likewise, some of the high similarities between Puerto Catuano, Acantilado de Catuano, and El Peñón with other sites of different benthic habitat is probably due to the fact that it is in these three stations that the highest fish species richness are found. These sites would be expected to have a high species similarity to all other sites since their species lists are the largest; therefore, species present at other sites have a higher probability of being part of their long list. Hierba los Cocos, the only soft-bottom community surveyed is very dissimilar to the other sites in terms of fish species. This too is expected. This site is also most similar to Arrecife de los Cocos, which is not surprisingly located beside it geographically. Unfortunately no data was taken on reef fish abundances or biomass, and no in-depth analysis can be made of the differences in fish community structure and/or assemblages in the different reef habitats, since analysis of presence/absence lists only (what was done in the park) minimize the between habitat differences (Alevizon et al., 1985).

3. GUILD ANALYSIS

A large amount of data can be analyzed via the UNIX summary reports. For the purposes of this ecological evaluation, the most useful data is the information available from the grouping of the species into trophic guilds. This interesting method of data organization has also been used by Sale and Guy (1992) and other authors (reviewed in Sale, 1991).

Table 9 numerically summarizes the guild information from the summary reports. It shows the percent sighting frequency (%SF) of each guild at each site. Thus, a 100% sighting
frequency means that at least one member of that guild was seen by all divers in that site. The same type of analysis could be made for species and family information available in the summary reports, but for our purposes the guild analysis is sufficient.

From this table, one can conclude that the most often seen guild is the planktivore guild. Russ and Alcala (1989) reviewed various authors who have also found that planktivores are the dominant group in terms of numbers and biomass in reef environments. This is probably due to the fact that these coral reefs are near land masses and are subject to large inputs of nutrients and organic matter; the area may therefore have a high productivity.

The data gathered also shows that the families Labridae and Pomacentridae are among the most frequently seen fishes. This may be due to reduced competition and predation caused by overfishing (as will be discussed below) since the members of these families are small, not commercially valuable, and do not get trapped in wire mesh fish traps.

4. DISCUSSION

Probably most important of all is the fact that during the dives, the observation that there were very few large fish individuals in the reefs in Parque Nacional del Este, when compared to other western Caribbean sites was made by all members of the team. This exact same observation was made in nearby reefs by Caboza and Pierce (1975). They reported that "there is a marked absence of large fish along the reef area of [Catalina Island, 15 miles west of the park]. It could actually be termed a void of fish life over the two pound class." In the present study, there is evidence for this lack of large fish (Appendix V). Appendix V clearly shows that the least frequently seen guild was the top predator guild. Table 9 also shows the same result, but in a more detailed manner: divided by site as well as by temporal surveys. The top predator guild, of course, would contain most of the larger fish species in the park.

The scarcity of large fish may be caused by:
- lack of food available to them at those sites
- unsuitability of the sites
- overfishing

Scarcity of food is a doubtful causative agent because it was available in most of the sites. Very few large parrotfish, for example, were seen in areas that had very high palatable algal cover. This was the case in Arrecife los Cocos which had high algal cover by palatable rhodophytes, yet no large parrotfish were seen, although many of the characteristically smaller species were abundant. This site had the highest total richness of fish species (79 species), yet the only top predators seen were some jacks (Caranx ruber), one barracuda (Sphyraena barracuda), and a few gray snappers (Lujanus griseus).

Unsuitability of the sites may be a reason for the lack of large fish in Parque Nacional del Este. Declines in tropical fisheries is at least partially a result of degradation of coral reefs, seagrass beds, and mangroves from sedimentation (Rogers, 1990). Samoilys (1988) has attributed the inability of a reef fish population in Kenya to recover after prohibiting of all fishing and collecting to heavy sediment influx from a river. As mentioned previously, in the
park, there is evidence that sedimentation may be a serious problem. It may not only destroy mangrove and seagrass beds which are important nursery grounds for a variety of fish and invertebrate species, but may also be responsible for the low reef development seen in the areas surveyed, as discussed previously. If there is low reef development, topographical relief, or structural complexity in any given area, there is also a scarcity of hiding places for fishes, and one finds a relative low number or absence of them there (Rogers, 1990). Deterioration of any of these ecosystems has led to declines in fish populations and fish diversity, and to collapse of the fisheries in many areas (Rogers, 1990).

The third alternative above is the most probable cause for the absence of large fish. The relatively small size of fishes observed suggests a general state of overexploitation. Unfortunately, no data was taken on approximate fish biomass, which has been shown to be the most useful measure when examining the effects of fishing pressure on coral reef fish assemblages (Samoilys, 1988). In their study in the Dominican Republic, Towle et al. (1973) seem to be in accordance with the hypothesis that the scarcity of large fish is mostly due to overfishing when they say that "the paucity of fish and lobster along the western coast of the peninsula and Bahia Catalina, where they were formerly plentiful, is directly attributable to heavy year-round spearfishing that has occurred." The best indicator of the effects of overfishing is the low abundance of large species (Russ and Alcala, 1989) or individuals of a species. At La Gonave, Haiti; for example, Ferry and Kohler (1987) found fish were relatively smaller at a highly exploited (by fishing traps) fringing reef compared to a structurally similar one that was not as heavily exploited. Fish species composition, total fish abundance, and numerical catch per unit effort, however, did not differ significantly between sites. Low densities or almost total absence of large fish has also been attributed to overexploitation by fishing in many other locations such as the Great Barrier Reef, Guam, Florida (all in Salvat, 1987), and Kenya (Samoilys, 1988). These studies and many more have been reviewed by Roberts and Polunin (1991) and Bohnsack (1982).

Fishing methods that have been specially implicated as causing reduced abundance and average size of large fish populations are trap fishing (Katnik, 1982; Koslow et al., 1988) and spearfishing (Bohnsack, 1982). According to the socioeconomic study conducted by Grupo Equis for this area (1994), both of these methods are used in the park (Table 10).

Although a fisheries survey has not been conducted for the park, the socioeconomic study (based on personal interviews) showed that fishing is the most important undertaking, occupying 40%, 30%, and 22% of the workforce in Saona Island, Bayahibe, and Boca de Yuma, respectively. Overall, 30% of all people living in the park area are fishermen. The study also shows that 80% of the fishermen have been fishing for at least 5 years, and that there are other fishermen from other zones that fish in the park as well. Fifty-seven percent of all fishermen surveyed fish daily or every other day (28% fish 3 times per week), and 82% fish for more than 6 hours daily. Additionally, the average catch per day for each fisherman is 50.3 lbs. Altogether, these results would seem to indicate that the fishing pressure is very high in the park. A complete fisheries study (biomass measures, species caught, fishing pressure, gear used, and selectivity) would determine the real status of the fisheries in the marine area of the park.
Whatever the cause for the low number of large fish individuals observed, their removal from the community causes changes in predator-prey relationships and in patterns of herbivory which may in turn strongly affect reef community structure and the fisheries itself because of the strong trophic linkages between fish, algae, and coral dynamics (Koslow et al., 1988). The kind of changes depends on the fishery. Predation, for example, controls reef fish populations and abundance. The removal of a significant portion of the biomass from coral reef ecosystems, which rely so heavily on tight nutrient-cycling to maintain their productivity, should cause definite changes in reef community structure. Additionally, the removal of an excess number of mature fish from reefs can have a serious effect on recruitment to local reefs or even other islands in the Caribbean Sea (Ferry and Kohler, 1987).

In a study done in Looe Key (Florida), Bohnsack (1982) compared reefs with low (due to heavy spearfishing) and large abundances of fish predators, and showed that the removal of piscivorous predators caused significant changes in the abundances of the rest of the fish species. Likewise, Goeden (1982) found that removal of keystone predator species in the Great Barrier Reef through fishing seemed to bring about species compositional changes in the entire community (relative abundances of the other large predatory fishes changed, etc.). In a more thorough study, Russ and Alcala (1989) found that the abundances of species targeted by fishermen (lutjanids, serranids, and lethrinids, and carangids) significantly decreased after protective management broke down in a marine reserve, and fishing with traps, hand lines, gill nets, spears, etc. was allowed. They also found a significant change in community structure which included decreases in density and diversity of the fish assemblages. They concluded that intense fishing pressure had both direct and indirect effects and far wider impact on the fish assemblage than the predicted significant decreases in abundance of the commercially valuable species targeted by fishermen. In a study in Jamaica, Koslow et al. (1988) found that overall catch rates declined significantly (82%) in some heavily exploited areas. Specifically they found that the fishes commonly caught in traps (lutjanids and large serranids and scarids), families particularly vulnerable to trap fishing (acanthurids and balistids), and other commercially preferred species groups (small serranids, haemulids, mullids) declined most consistently; while only commercially less desirable species (chaetodontids, holocentrids, and tetraodontiformes) increased in catch rate. Likewise, Russ (1985) found that a site with protective management (absolutely no fishing allowed) had higher abundance (number) of fishes, higher species richness, and higher abundance of species targeted by fishermen.

In summary, the many studies done seem to show that fishing pressure may bring about the following changes: decreases in the average size of target species; decreases in abundance of target species (mostly large carnivorous and piscivorous fish); decreases in abundance of non-target species (if non-selective fishing methods are used); decreases in the egg production of the community; genetic changes within populations; increases in abundances of non-target species; increases in the productivity of the fished population due to decreases in the amount of energy devoted to reproduction (because a larger proportion of the population is maintained in a phase of active growth instead of reproduction); destruction of benthic substratum and decreases in live coral cover, both of which affect abundances of target and non-target fish species; and decreases in diversity or species richness of large piscivores.
Fortunately, it also seems that recovery of large fish species may be rapid once harvesting pressure is reduced. For example, once the ban on spearfishing went into effect in Looe Key, Florida there was a logarithmic increase in predator abundance in the first two years (Salvat 1987). Roberts and Polunin (1991) have reviewed studies that have corroborated this conclusion.

5. CONCLUSIONS

1. Fish surveys were conducted in the different benthic habitat types and at different times of day, but only on the western side of the park including Saona Island. No fish surveys were done on the eastern side of the park or south and southeastern Saona Island.

2. The fish assemblage in the surveyed areas is taxonomically and trophically diverse. A total of 122 species of fishes (comprising 42 families) are reported for the park, the majority of which have not been previously reported for Parque Nacional del Este.

3. When compared by Jaccard’s Coefficient and by the Coefficient of Community, the surveyed reef communities showed no differences in fish species richness. Applying the same methods, a difference in species richness was found when surveys in reef communities vs. seagrass beds, as well as in the morning vs. the afternoon were compared. The difference in species richness found when different habitats (reef vs. seagrass bed) were compared could be explained by the topographical differences of these habitats.

4. Most fish species similarity patterns between sites may be explained by (a) similarity of habitats, or (b) geographical proximity.

5. From the guild analysis one can conclude that the most abundant feeding guild is the planktivore guild, followed in descending order by invertebrate bottom feeders, non-territorial herbivores, secondary predators, territorial herbivores, corallivores, spongivores, and lastly, top predators. These results indicate an apparently normal food chain structure, although the presence of top predators was less than would be expected.

6. The most frequently seen family of fishes were the labrids and scarids, followed by the holocentrids, acanthurids, and pomacentrids.

7. Very few large fish (both species and individual) were observed in this study. This is evidenced by observations (both in this study as well as previous ones) as well as by the fact that the least frequently seen feeding guild was the top predator guild, where most larger fish would be found. There are three major reasons why this pattern may be occurring:
   - overfishing,
   - lack of proper habitats, and
   - lack of proper food sources.

The scarcity of large individuals has been shown to cause important changes in reef
community structure including changes in predator-prey relationships, fish abundances and diversity, herbivory patterns, nutrient cycling and productivity, genetic fish size distributions, egg production in the community, etc.; all of which affect the fisheries of the zone and of adjacent areas. Further studies are needed to investigate this issue more closely.

8. The high number of small individuals as well as typically small fish species (labrids and pomacentrids), the low number of top predators, and the uncertainty of whether the high cover by algae documented for the benthic communities surveyed is due to the low numbers of large herbivores or to high nutrient loads highlight the need for further fisheries and oceanographic studies in the area.
IV. RECOMMENDATIONS

Coral reefs and associated shallow-water marine communities are extremely important coastal resources. Coastal marine systems protect the land margins from oceanic waves and storms energy. The productivity of coastal areas has sustained coastal human populations throughout the tropics for hundreds of years primarily through the harvest of reef fish, lobster, and conch. Despite the importance of these coastal ecosystems, the degradation of coral reefs, mangroves, and seagrass bed components is increasing at an alarming rate. Hazards to tropical shallow-water systems are largely due to three threats: 1.) the over-exploitation of target species, 2.) the degradation of water quality through diversion or pollution of freshwater run-off, and 3.) habitat destruction through mechanical damage, sedimentation, and dredging.

The indiscriminate use of coastal marine resources or unregulated human activities along the coast adversely affect these important ecosystems. The need for conservation management of marine resources is urgent and is recognized as a priority in the World Conservation Strategy (Kenchington and Hudson, 1988). Integrated Coastal Zone Management that combines sustainable resource use with marine protected areas and replenishment zones has become a priority because of the attention from the professional communities of ecologists and conservationists as well as local communities relying on these resources for their livelihood. There is a global realization that the survival of tropical coastal ecosystems with the associated reefs, fisheries resources, and tourism potential is in peril without effective management.

The establishment of marine parks and reserves in the tropical waters of the Caribbean and the world has accelerated in recent years (Clark et al., 1989). Some of the major reasons for the protection, management, and sustainable use of marine areas include: 1.) increased financial revenues from ecotourism, 2.) conservation of fish and invertebrate stocks, 3.) prevention of shore erosion, and 4.) coral reef protection. The dynamics and natural variability of coastal communities such as coral reefs are not completely understood; however, there are prudent management actions which can be taken to assure the protection of coral reefs (eg. limit, control, or allow the reparation of the damage caused by human use and sustain the high productivity associated with coral reefs which subsequently supports other neighboring biological communities).

Each area considered for potential conservation management has special considerations and is threatened or impacted by different factors. "The first requirement in identifying options for management is the practical assessment of the extent, impact, and feasibility of change or control of the human activities which affect or are likely to affect the area in question" (Craik et al., 1982). Through the Rapid Ecological Assessment carried out in Parque Nacional del Este, a resource analysis of the area was obtained. A better understanding of the dynamic processes influencing the marine areas of the park was gained, and the uses and potential threats to the park were identified. Table 11 shows these potential uses and threats to coral reefs in general and to Parque Nacional del Este in particular. This information, together with some fisheries information (analysis of uses) from the socioeconomic report (Grupo Equis, 1994) allows the determination of the value and economic importance of the area as a fisheries and tourist resource.

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Although Table 11 has been useful in formulating the following more specific recommendations, it must not be forgotten that the ultimate success of a management plan is determined by its relative acceptance of the users, the level of enforcement by managers, and the appropriateness of the plan to ensure the ecological sustainability of the park's ecosystems (Craik et al., 1982).

The results of this study have identified and set the stage for the development of management, research, and monitoring needs during the next few years. In terms of monitoring and research needs, four major areas may be identified: 1.) oceanographical studies and monitoring of water quality, 2.) monitoring of reefs and biological processes, 3.) fish ecology, and 4.) local community use of the park and local fisheries studies. The following recommendations can be made on the basis of this study as well as on the general knowledge that has been gained throughout the years of park and fisheries management around tropical regions of the world. These studies (Alcala, 1988; Alcala and Russ, 1990; Alcolado et al., 1993; Berkes, 1995; Bohnsack, 1993; Clark et al., 1989; Craik et al., 1982; Davis, 1981; Etchman, 1993; Gilmour and Craik, 1985; Hawkins and Roberts, 1993; Hellawell, 1991; Johannes, 1981; Kelleher et al., 1982; Kelleher and Duton, 1985; Kenchington, 1988; Plan Development Team et al., 1990; Polunin, 1990; Reese, 1993; Roberts et al., 1991; Salm, 1984; Salvat, 1987; Savina and White, 1986; Soulé and Simberloff, 1986; Tilmant and Schmahl, 1981; Usher, 1991; Van’t Hof, 1985; White, 1986a, 1986b, and many others) are numerous and demonstrate the different methods of achieving the best sustainable use of the resources for the benefit of all involved, which is the primary objective for the managers of Parque Nacional del Este.

A. RECOMMENDATIONS FOR MARINE PARK ESTABLISHMENT

The coastal systems of Parque Nacional del Este are unique for a large variety of reasons: 1.) the waters are relatively pristine for the island of Hispaniola, 2.) they represent many of the marine communities degraded or damaged in other parts of the country, and 3.) they include unique coastal mangrove systems. PNDE deserves special protection as well as inclusion in the park's management plan; therefore, the first and foremost action to be made is to include all the marine areas to the 100-meter bathymetry line or contour line as part of Parque Nacional del Este, since these areas are not included as such in the actual park legislation.

In the study by Benchmarks, Inc. (1973) it states "the values of the proposed park lie in its natural resources ... and in the special qualities inherent in the fascinating zone of contact where land and sea meet .... Many of the special resources are related to the sea, the coastal area, and the waters adjacent to the coast." Additionally, Towle et al. (1973) also argue in favor of the marine areas being included inside the park's boundaries for two strong reasons:

First, they point out that there are interdependencies between the park's subaqueous and subbenthic ecosystem. Natural and manmade terrestrial activities have impacts on marine areas, and vice versa. The role of the mangrove lagoon in Las Calderas and other lagoons, and productivity of the nearshore sublittoral zone is a case in point. The
terrestrial groundwater flow, coastal seepage rates, and equilibrium that exists in the peninsular aquifer is another natural example. The fact of interdependency argues for boundaries extending beyond the littoral highwater mark.

Secondly, Towle et al., like the Benchmarks group, are of the opinion that a strong reason for including the marine areas inside park boundaries is the fact that "marine assets comprise a valuable portion of the park’s natural interest, and will receive an initial focus by the anticipated use and associated development of the park’s beaches and coastal areas. It is advantageous to incorporate these areas into the planning and management framework."

Several authors (e.g. Benchmark’s Inc., 1973 and Towle et al. 1973) have already claimed that the most important value of Parque Nacional del Este lies in its natural resources and in the regulated and controlled use of its beaches and coastal areas. The present study corroborates this statement. A total of 122 species of fishes, 35 species of intertidal and rocky shore molluscs, 87 species of algae, 62 species of conspicuous reef sponges, 29 species of octocorals, and 38 species of hard corals were found in this study. These species were recorded from check-lists for conspicuous or common species; a complete species inventory of these or other taxa would reveal an even higher biodiversity for the area. The high biodiversity in both species and habitats present, the aesthetic beauty, and low human population density present in the park are reasons enough to encourage the protection of these waters and coastal systems.

The location of Parque Nacional del Este, on the southeastern tip of the Dominican Republic, make it an ideal site for conservation management. It is well known that invertebrates may depend almost entirely on other nearby reefs as sources of larval recruits (corals, fish, lobster, queen conch, etc.). The waters of Parque Nacional del Este are probably very important sources of recruits for important fishing areas farther down the southern coast of the Dominican Republic, including Parque Nacional Jaragua near Haiti. A study by Metcalf et al. (1977) shows that the Mona Passage is extremely important in regulating the surface water movements in and out of the Caribbean Sea because strong tidal currents are present throughout its 115km width. Their drift bottle study clearly shows that the waters that move along the southern coast of the Dominican Republic first go through Parque Nacional del Este. This means that anything that influences or happens in the Mona Passage and the waters of Parque Nacional del Este has the potential of affecting (both positively and negatively) the entire southern coast of the Dominican Republic and beyond.

B. MANAGEMENT RECOMMENDATIONS

If the previous recommendation of including the marine areas as part of the park are taken into account, the management recommendations cited below should be followed:

1. FISHING AND COLLECTING

Effective fisheries management in tropical coastal systems needs to have three important components: 1.) closed seasons to protect spawning stocks, 2.) size limits to protect juveniles and prevent over-exploitation, and 3.) marine protected areas or reserve zones that protect
populations and stock genetic diversity. From a regional perspective, if the park is to function as a marine fisheries reserve and conserve biodiversity, fishing will need to be restricted within the park boundaries. Fishing should be limited to hand-lines or hook-and-line fishing only at certain times of the year.

The park should include areas of "no-take" where it is prohibited to fish by any method or collect any marine organisms or shells. These areas of the park would be designated as reserves or refuges for flora and fauna. Initially, these areas should include Las Calderas, Paso del Catuano, and the shallow zones on the western coasts.

The prohibition throughout the entire limits of the park of the capture, fishing, and collection of species that the studies show could be endangered or threatened is recommended. Specifically, the west Indian top-shell (Cittarium pica), the queen conch (Strombus gigas), the spiny lobster (Panulirus argus), and the Spanish lobster (Panulirus guttatus). Furthermore, the collection of corals, molluscs (shells or the actual animal), sponges, and echinoderms, whether living or dead or whether underwater or on the coasts, should be prohibited to every person and for every purpose. It is recommended that the harassment, capture, or death of the following species should be prohibited throughout the park: all marine turtle species and sea birds (including their nests and eggs), as well as all marine mammals.

2. POLLUTION

Metcalf et al. (1977) warn that "there is a very real danger that surface pollutants from the Mona Passage would drift ashore to the Dominican Republic." This statement not only offers further pressure to attempt to regulate the activities in Parque Nacional del Este, but also calls for the inclusion of periodic assessments and chemical analyses of the surface waters, as well as periodic removal and examination of the trash found on the eastern coast of the park's mainland and on Saona Island.

Therefore, the discharge into and the use of the following products should be prohibited inside park limits and in adjacent areas: herbicides, pesticides, antifouling paints and agents, sewage, detergents, petroleum hydrocarbons, heated waters from industrial plant cooling, hypersaline waste water from desalination plants, heavy metals, radioactive wastes, and mining residues. In addition, the prohibition of the discharge of waters previously used in agriculture, domestically or industrially is recommended inside park limits, unless these waters have been previously treated and have reached safe potability limits.

3. SEDIMENTATION

It is recommended that any activity involving slash and burn of trees for any purpose be prohibited in the limits of the park. The construction of roads and/or trails should be prohibited inside the park unless the correct water and erosion control studies have been completed. Mining, dredging (of any type and for any purpose), and the extraction of sand from underwater and coastal sources should also be prohibited in the waters of the park.

4. TOURISM AND RECREATION
The tourism experience for PNDE should be a unique adventure and rare opportunity to see a natural area in its pristine state. There will be a carrying capacity or maximum number of tourists the park can support to maintain this quality experience. Specific anchoring areas should be designated and mooring buoys should be installed for the purpose of permanently eliminating the use of anchors by recreational boats in the park. In accordance with this, specific places should be marked for snorkeling and diving activities inside park waters.

It is recommended that free navigation be prohibited inside the limits of the park. Navigational routes should be established and marked. Limits to boat velocities, sizes, and number of boats in different areas of the park should be established as part of the overall establishment of carrying capacity.

C. RESEARCH RECOMMENDATIONS

Assessment of anthropogenic impacts often requires more than the anecdotal information recorded during the field observations. The placement and size of coastal protected areas are dependent on good baseline information on:

* biological diversity,
* relationships between coastal wetlands to upland and marine communities, and
* an evaluation of human threats or impacts that can be successfully addressed through management.

Although the coastal areas of Parque Nacional del Este do have a low human population density, human uses and impacts on the natural resources are significant. The fisheries and wildlife resources of the area are exploited and a significant number of tourists visit the area. The study area is complex in both its hydrology and geology, providing a diverse matrix of marine and coastal communities. Specific recommendations on work needed to complete a management plan include:

1. An intensive evaluation of the human uses of this area, specifically hunting and fishing. There is a need to document impacts on animal populations, changes to the ecosystem, and potential alternative uses of the resources that may be less destructive.

2. An extensive inventory of the plant diversity, especially bromeliads and orchids, is proposed as a research project for tropical botanists. The percent coverage and the range of associated species is also important. In addition, a survey and inventory of mammalian, reptilian, amphibian, and bird species utilizing the area would provide useful information for evaluating the impact of hunting practices.

3. It is recommended that ecological assessments of the marine areas not covered by this study (the south and southeastern coast of Saona Island and the eastern coast of the park) be made.

4. It is recommended that a field study be made to determine the placement of demarcation, anchoring, and navigational buoys.
5. A study should be made to determine the use of the various beaches in the park by nesting turtles. This study should be accompanied by an educational program on turtles for the local people.

6. Oceanographic and hydrological studies need to be done in the park to establish baseline information on water quality.

7. It is recommended that a water quality protection plan be developed that includes research and monitoring in the park.

8. A complete fisheries survey needs to be completed for the park.

9. It is recommended that a study be made to determine the possible spawning sites and seasons of commercially valuable fish and invertebrate species. Plankton studies should also be made to determine important recruitment areas for these species.

10. Productivity studies of seagrass beds in the park should be conducted in order to determine the nutrient flows that occur throughout the different areas of the park.

As has been discussed previously, fishing is potentially a major direct and indirect structuring force in coral reef environments. The indirect ecological effects of fishing, such as changing levels of predation and herbivory on reef community structure, have not been well studied. One of the main reasons for this is the lack of valid scientific control sites for the studies. "Marine fisheries reserves [areas with no fishing] offer the best chance to have scientifically valid controls in which the system can operate with minimal fishing interference." The establishment of a marine reserve in specific designated areas of Parque Nacional del Este would offer a means of distinguishing the effects of fishing from other factors impacting coral reef ecology and fish community structure.

Comparative fisheries and ecological studies done before and after reserve establishment would offer scientifically sound data and an excellent opportunity to study fishing effects, comparable to very few places in the world. This data would make an invaluable addition to the scientific knowledge about fisheries, fisheries management, and coral reef ecosystems in general.

**D. ECOTOURISM RECOMMENDATIONS**

It is recommended that boat captains be given courses and/or training on marine ecology. These courses should emphasize the damages caused by pollution, tourism, high boat velocity, etc. to the marine flora and fauna.

In addition, every visitor to the park (including the coastal and marine areas) should be given an orientation that explains the significance of his/her visit to Parque Nacional del Este, and that motivates him/her to act according to the conservation rules established for the park.
E. BUOY PLACEMENT RECOMMENDATIONS

There are various types of buoys, each physically different from the others and serving specific purposes. Mooring buoys are placed as a means of diminishing the physical and biological damage caused by careless anchoring. Presently, there are no buoys of any type in the park; therefore, mooring buoys should be placed at sites identified as popular diving and/or snorkeling spots, or sites that would want to be developed as such. Navigational buoys are specifically placed to serve as guides for boats. They may contain information about hazards (reefs, narrow channels, and sandy shoals) and instruct captains on how to avoid these dangers. Demarcation buoys are specifically designed to pinpoint important and sensitive ecological sites such as nesting marine birds, reefs, etc.

1. It is recommended that mooring buoys be placed in the following places:

   a. SCUBA Locations:
       Parque Nacional,
       El Toro,
       Arrecife de Rubén,
       El Penon,
       Guaragao, and
       El Faro.

2. It is recommended that navigational buoys be placed in the following places:

   a. in strategic places near the coastline in order to maintain the navigation of all boats at least 500m away from the edge of the coastline.

   b. in the Paso del Catuano, including mangrove canals.

3. It is recommended that demarcation buoys be placed to show nesting frigate bird colonies in Las Calderas Bay and any conch or lobster breeding, nursery, or recruitment areas.
APPENDIX I: THE MANGROVE COMMUNITY

1. Mangroves of the Caribbean

The term "mangroves" refers to woody plant assemblages with three key characteristics:
* these communities are composed of bushes, shrubs, or trees with salt tolerance,
* these communities dominate depositional coastal environments, and
* these communities are restricted to the tropics (Chapman, 1976).

Mangrove communities are located in structural habitats such as tree canopies or high-peat
muds, and dynamic habitats such as those caused by seasonal conditions; for example, salinity
and/or sedimentation regimes.

The new world mangrove communities of the tropical western Atlantic consist of
relatively few species (six). However, there are only four mangrove species that occur on the
Caribbean coast of Central America. These species can occur as shrubs or trees depending on
the environmental and geomorphological conditions for their growth. Mangrove communities
are characterized by their geomorphological setting, vegetation structure, species composition,
and soil type. The first step in understanding ecological processes is to describe the pattern of
communities that occur in a functioning system.

Thom (1984), and Cintron-Molero and Schaeffer-Novelli (1992) described a geological
basis for mangrove community distribution. Mangroves often grow in geomorphologically active
areas and can stabilize the landform following a sedimentation event. Each geological setting
is characterized by a landform type; for example, fringing, basin, overwash, hammock, riverine,
or scrub. Mangrove communities are further characterized by production, organic matter
export, and utilization patterns. All of these processes are dependent on the geomorphological
setting. The eight geomorphological settings that favor the establishment of mangrove
communities are in the Caribbean are:

1.) Low tidal range with ample sediment inputs - this setting is dominated by freshwater
input and a rapidly forming river delta.

2.) High tidal range with sediment input - this setting is typical of a broad mouthed
estuary with strong bi-directional tidal flow.

3.) High wave energy with low sediment input - this setting is typical of windward
islands, where shoreline processes are dominated by waves.

4.) High wave energy and high river discharge.

5.) Drowned river valley.

Three settings occur only in carbonate environments such as the Bahamian archipelago, the
Florida Keys or offshore cays in Belize:
6.) Low energy carbonate platforms.

7.) Coral rampart or protective sand barrier.

8.) Low energy embayments without protective barriers.

The specific characterization of mangrove communities completed in Parque Nacional del Este was aimed at identifying the parameters critical to documenting unique features of community diversity. Mangrove communities are, in fact, structured by trees; however, these plants are unique in their ability to grow at the ocean's edge and modify their growth form with changes in hydrology, tides, and sedimentation. The same species of tree can grow and mature as a sprawling short shrub of less than a meter in height or be a massive tree of over 30 meters. The plasticity of growth forms and the physiological tolerance to standing salt and brackish waters create unique coastal communities. These communities share some similarities with upland terrestrial plant communities, but also have some similarities to marine benthic communities. Mangrove communities occur under specific conditions of freshwater and sediment input at the land/sea interface (Thom, 1984). The specific combination of flora and fauna is an end-product of three interrelated processes: water column and soil productivity, biological interactions, and disturbances (e.g. hurricanes). Therefore, the study of mangroves as a coastal community has required an integration of both terrestrial and marine ecology. The gradation of physical parameters, such as salinity and inundation, produce a unique system of vegetation zones structured by the different mangrove tree species. The only comparable system in either marine and terrestrial systems may be the zonation seen in alpine plant communities which occur along unique gradients of aspect and altitude. The nature and scope of these physical gradients are produced by the geology, oceanography, and hydrology of the coastline.

The classification of natural communities has been an exercise and objective for terrestrial ecologists for over 70 years. Only recently have marine ecologists begun the task of community classification (Ray, 1975; Maragoes, 1991). Terrestrial ecosystems and larger biomes should be identified by the unique geomorphology and hydrology of an area, but "communities" have been historically designated by vegetation structure (e.g. grass lands, woodlands, forests, etc.). The confusion between the terms "vegetation classification" and "ecological classification" has made it difficult to distill a universal hierarchical concept of an ecological classification from terrestrial to marine systems. With the important exception of seagrass beds, most marine benthic communities are not structured by vegetation strata.

There is a wealth of scientific information about the structure, distribution, and production of mangrove systems; usually, these overviews have a regional emphasis (Odum et al, 1982; Lugo and Snedaker, 1974; Cintron-Molero and Schaeffer-Novelli, 1992). For example, an oil spill along the Caribbean coast of Panama provided a grim opportunity to evaluate the long-term impacts of oil contamination on mangrove systems (Keller and Jackson, 1991). There is a clear recognition of the importance of mangroves to coastal ecosystem function and fisheries production.
2. Mangrove Soils

Mangroves are able to persist in a variety of substrates, ranging from sand to peat. In locations where mangroves have been present for some time and low wave energy and depositional conditions persist, high amounts of peat soil formation and deposition will occur (Odum and McIvor, 1990). Peat soils are formed through an accumulation of partially decomposed woody or fibrous plant matter under reducing conditions. This peat soil formation is driven by the productivity and subsequent decomposition of large amounts of plant matter (e.g. leaves, wood, propagules, and flowers).

A soil classification system based on quantifiable soil properties was developed in 1975 in the United States (Soil Survey Staff, 1975; Brown et al., 1990). This system classifies soils in a hierarchical manner from the broadest category to the narrowest:
* order,
* suborder,
* great group,
* subgroup,
* family, and
* series.

Classification of soils is based on morphology as well as various physical and chemical properties. According to this system, peat soils are placed in the HISTOSOL group. This group is characterized by highly organic soils, consisting of peat or muck deposits, which accumulated in high moisture conditions over other types of soil (e.g. sand, marl). Histosol soils have at least one half, by volume, of the upper 80 cm stratum consisting of organic material (Rieger, 1983). Within the histosol group, peat soils are classified in the HEMISTS and SAPRISTS suborders. These suborders are distinguished by the level of decomposition of the accumulated organic matter. Hemists are histosols that are composed of organic matter that is not entirely decomposed beyond recognition, while saprists contain almost completely decomposed organic matter. Overall, peat soils are characterized by more than 75% moisture retention, less than 12% mineral matter in saturated natural deposits, low to neutral pH, and a limited amount of microbial breakdown (Cohen and Spackman, 1984).

Previous studies have characterized mangrove soils in south Florida, the Caribbean, and Central America. Cohen and Spackman (1984) described the different peat soils found in south Florida coastal swamps. Wanless (1974) described the geology of soils in south Florida mangroves. Woodroffe (1981) investigated the implications of mangrove soil stratigraphy on the history of the mangrove swamps in Grand Cayman, and compared these to mangrove soils on the Belize shelf. Thom (1967) described the geomorphology and ecology of mangrove soils in Tabasco, Mexico. Most of these studies have dealt mainly with the geological implications of peat accumulation in mangrove swamps, and have not considered the relationship between mangrove soils and their corresponding mangrove vegetation structure and associated invertebrate fauna.
Mangrove peat soils may convey useful information in mangrove community characterizations. For example, Woodroffe (1981) recorded calcareous sediments associated with mangrove peat soils. He found soil cores on Ambergris Cay that were identical to those from submarine cores in the Belize shelf (limestone bedrock overlaid by mangrove peat, and finally marine deposits). Knowing the peat depth and sequence of underlying sediments may indicate the age and history of seawater incursion and land formation of a mangrove community. In addition, by knowing the biochemistry and microbiology of mangrove peats, one may discover the state of microbial decomposition of the mangrove peats.

3. Crustacean Fauna of Mangrove Communities

Crustaceans are one of the most pervasive invertebrates found in marine environments and mangrove communities are no exception. Their diversity and abundance is due mainly to their high adaptability to varying conditions in marine communities. In mangrove communities, crustaceans can be found in all components of mangrove habitats; from the prop root community to the arboreal community. Evidence of their diversity and adaptability can be seen in the varied feeding forms found within mangrove communities, from detritivores to herbivores feeding on mangrove leaves. These feeding forms position crustaceans at the bottom of mangrove food chains; they are responsible for most of the nutrient recycling in these communities. Through their feeding on plant and organic matter, mangrove crustaceans are able to expedite the microbial decay and return nutrients back to the system quickly. Even though crustaceans, such as larval decapod shrimp, are abundant and diverse in waters associated with mangrove communities, crustaceans associated with mangrove mud flats and mangrove plants (arboreal community) are more easily recognized and characterized (Odum et al., 1982; Kaplan, 1988). These "intertidal" crustaceans have become adapted to varying physical conditions (eg. salinities and temperatures) close to the water’s edge, and include mostly crabs from the Order Decapoda.

Four main groups of decapod crabs are commonly found in the intertidal (exposed prop roots, mud flats, and arboreal communities) areas of mangrove communities. These are Families Grapsidae, Ocypodidae, Gecarcinidae, and Xanthidae.

**Family Grapsidae** includes shore or marsh crabs which are always found in shallow water or land near water. In mangroves, species such as *Aratus pisonii* (mangrove tree crab) are found on the branches of *Rhizophora mangle* where it finds shelter and feeds on leaves (Kaplan, 1988). Other grapsoid crabs, such as *Pachygrapsus transversus* (common shore crab) live amongst mangrove prop roots.

**Family Ocypodidae** includes the fiddler crabs from the genus *Uca*. These include many similar species that live in burrows in mud flats associated with mangrove communities. These crabs are scavengers, feeding on detrital matter; however, some ocypodid crabs have been found to feed directly on mangrove pneumatophores (Wada and Wowor, 1989).

**Family Gecarcinidae** includes the land crabs which have adapted to long periods away
from water. Land crabs such as *Cardisoma guanhumi* (great land crab) can be found in large burrows in sediments close to mangroves. These crabs are omnivorous, feeding on detrital matter and leaves (Kaplan, 1988).

**Family Xanthidae** includes mud and stone crabs that live in shallow waters. Species such as *Eurytium limosum* (mangrove mud crab) are found burrowing in muddy sediments in mangrove swamps below the high tide mark (Kaplan, 1988).

Occasionally, other decapod families that are mostly found in submerged marine communities may be found within mangrove communities. Crabs in the Family Portunidae, such as *Callinectes sapidus* (blue swimming crab), may enter mangrove tidal flats during high tide. Hermit crabs from the Families Diogenidae and Paguridae may also be found in waters adjacent to mangrove communities.

Characterizing the crustacean fauna found in mangroves is an important step in understanding the relationship between the vegetative structure and invertebrate diversity that is supported by this structure. Crustaceans in mangroves and other marine communities are closely linked to the substrate they inhabit, both using it as a shelter and as a food source. Since mangroves are depositional environments and are dependent on the delicate balance of physical and biotic factors affecting them, it follows that the presence or absence of mangrove crustaceans may reveal important information on the state of the community. For example, the absence of mangrove crabs may lead to the increase in the accumulation of organic matter. In addition, the diversity, high adaptability due to specialized morphologies, sampling ease in intertidal areas, and distinct taxonomy make crustaceans in mangrove communities excellent candidates as ecological indicators.

4. **Molluscan Fauna of Mangrove Communities**

The molluscan species that are found in mangrove swamps are important components of the ecosystem; in fact, molluscs account for a large portion of the biomass of the eulittoral zone, and are key components at all trophic levels (Morton, 1983). This has led scientists, such as Macnae (1963) and Morton (1983), to pose the question of whether there is a specific mangrove fauna. However, many of the species encountered in mangrove forests can be found in other habitats at an equivalent tidal level (Macnae, 1963). In general, the mangrove molluscan fauna can be described as species that are associated with tropical estuarine areas, that are able to survive in mangroves at the limit of their ecological range, and/or those species that have evolved within a specific mangrove ecosystem (Morton, 1983).

Although there may be no mangrove specific molluscs, there are species that are commonly associated with mangroves and were found in Parque Nacional del Este. For example, *Littorina angulifera* almost always lives on the prop roots (above the water line) of red mangroves and moves higher in the tree if there is high tidal fluctuations or strong wave action. In fact, in experiments where the snail is submerged, 50% of them die within two days.
Isognomon alatus is another species that almost always inhabits the nutrient rich waters of mangrove swamps. This bivalve lives attached to roots with a byssus, and is a filter feeder like all other bivalves. Also, Melampus coffeus is an important detritivore in mangrove communities as it accounts for a high percentage of the breakdown of mangrove leaf litter (Proffitt et al., 1993).

The mangrove molluscan fauna are important indicators of environmental quality or habitat changes in mangrove ecosystems, especially the bivalves. Branch and Grindley (1979) showed that a changing environment led to changes in the fauna of estuarine habitats; therefore, it would be prudent to monitor those species that occur in threatened habitats. Molluscs are also good indicator species of environmental change because of their secure taxonomic status, as the species that occur in mangrove communities are well documented and described. Since molluscs have diverse and specialized forms, they occupy varying levels in the trophic hierarchy of mangroves; this also makes them good indicator species. For example, Melongena melongena is a predator on bivalves; the absence of this key predator in a mangrove area may be because of dwindling food supply. This would lead to an investigation of why the bivalves that this species preys upon are reduced in number. The reasons for the reduction of a prey item may be over-hunting or it could be a changing environment.

The sampling required to monitor mollusc diversity or specific populations is not complex because the target molluscan species are often conspicuous. Molluscs are easy to collect and enumerate, further showing their worth as indicator species.

Previous studies on the molluscan fauna of mangroves have included such diverse subjects such as the regional differences in physiognomy of different shell characters (Vermeij, 1974) and the consumption of leaf litter by Melampus coffeus (Proffitt et al, 1993). In the past, authors such as Coomans (1969), Perez (1974), Morton (1983), and Rodriguez (1963) have determined which molluscs occur in different mangrove communities, and their distribution within the different zones of those mangrove communities. However, few studies on the molluscan assemblages of mangroves have used those assemblages as a way to classify mangrove communities. For example, Morton (1976) has illustrated that the zonation of a mangrove forest and the zonation of a rocky intertidal area are similar; however, Berry (1963) argues that the zonation of a mangrove swamp is more complex due to the varying physical conditions. The zonation of habitats defines what kind of organisms will be found there based on different physical and biological factors (eg. tides, wave exposure, competition, and predation). Molluscs can be used as important zoning organisms in the mangroves, just as in rocky intertidal habitats (Morton, 1983). In fact, a major component of characterizing rocky intertidal communities are the different species of molluscs that occur in each zone (Delgado and Chiappone, 1993). It would follow that a similar community characterization hierarchy could be devised for mangroves based on zonation and/or faunal composition rather than vegetation structure. Previously, the vegetation would determine the community features and the fauna would be a secondary characteristic of the forest or wetland. Few authors have used the association between the faunal assemblage and the mangrove community as a method of zoning and/or characterizing the community.
As stated before, the zonation of plants and animals in mangrove communities is produced by a combination of biotic and abiotic factors. Environmental factors such as the dynamics of the tides, exposure to wave action, and fresh water influence, along with competition and predation influence the zonation of coastlines. Different species have different tolerances to salinity, exposure, temperature, and sedimentation; therefore, crustaceans and molluscs can be used as important zoning organisms in mangrove communities (Berry, 1963; Sasekumar, 1974). Transects of mangrove communities, from inshore to the water's edge, can show the basic distribution patterns not only of the trees, but also of the associated mangrove fauna (Morton, 1983). Surveys done in this manner can also provide detailed information about the zonation and the abundance of mangrove fauna. However, environmental factors such as tidal range, climate, soil, and salinity must be taken into account. Mangrove ecosystems can be divided into five different zones, characterized by the fauna as opposed to the trees themselves (Figure 1.1).

1.) The **High Tree Zone** is characterized by the presence of *Littorina* spp.; thus, it is sometimes called the Littorine Zone.

2.) The **Lower Tree Zone** is characterized by other species of gastropods which can tolerate longer periods of inundation; for example, *Nerita* spp. The High and Lower Tree Zones both extend from the seaward fringe to the landward edge of the mangroves.

3.) The **Marginal Zone** occurs at the water’s edge, and is characterized by the presence of bivalves.

4.) The **Ground Zone** provides habitat for large populations of a number of crab species, most notably *Uca* spp.

5.) The **Burrower Zone** encompasses the coastal bank.

Berry’s ecologically based system acknowledges the importance of the mangrove community’s major invertebrate fauna. This classification system provides an alternative to vegetation classifications which base their system on the vegetation structure of the mangrove forest, and consider the fauna secondary.
5. Mangrove community descriptions from Parque Nacional del Este, Dominican Republic.

RED MANGROVE FORESTS (marine)

Red Mangrove Forests are characterized by the dominance of the red mangroves in the overstory. They can be distinguished from other red mangrove forests by the organic content of soil. Forests are defined as communities where the dominant trees have a coverage of 60-100% of the surface. Trees are over 5.0 meters tall. This community occurs along most of the coastline of Parque Nacional del Este, including Isla Saona. If the shoreline does not consist of a fringing red mangrove forest, then it is a rocky intertidal community, a beach, or a stand of coconut trees.

Soil analysis of the core samples showed that this community can grow in low, moderate, or high peat soils. The soils of the element occurrences of this community type are very similar. From 0-20cm down, the soil had a color of 2.5/2 and was composed of organic material (a red peat). From 20-70cm down, the soil was described as having lots of roots; rock was hit at the 70cm mark. The deeper the core went, the stronger the smell of hydrogen sulfide.

Hydrological influences on this community type can be quite variable. The areas where this community commonly occurs is usually flooded by all high tides. The overlying water at all the sites was seawater (mesosaline), with a temperature of 27°C. As most of the occurrences of this community are situated along the coast, they are influenced by oceanic processes as well. Currents may bring nutrients or cold water from offshore which may affect the flora and fauna of the community. The life zone is tropical moist. The shorelines where this community type occurs were described as smooth with small embayments or without inlets. The forests that were surveyed occurred along the leeward side of protected shallow lagoons (Las Calderas) or on the leeward side of islands (Isla Saona).

This community type is very homogenous. Red mangroves dominate every strata; no other mangrove species were found in this community type which is mostly located along the shore. This is due to the fact that red mangroves are the most salt tolerant of the four species of mangroves. The red mangrove forests can be sub-divided based on soil's organic content. The soil can be classified as low, moderate, or high peat. The three sub-types were encountered and surveyed in Parque Nacional del Este. There is no variability in the floral species composition of this community type.

Hurricanes, floods, and storm surges can cause extensive damage to this community type. There is usually intense herbivory on seedlings and smaller shrubs in these community types. There was evidence of termite activity at the sites as well. Unconsolidated (subtidal) beds, seagrass beds, hard-bottom communities, coconut stands, sand channels, patch reefs, salt ponds, stands of *Batis maritima* and other types of mangrove communities occurred nearby to the red mangrove forests.
Mangrove communities are used as a source of timber for wood products and for fuel; they can also be used for fishing as mangroves provide habitat for many species of juvenile fish. The mangroves of Las Calderas are especially important, as the lagoon provides a unique habitat for invertebrates and one of the few remaining nesting frigate bird colonies. Anthropogenic impacts are few here, but important as boaters disturb the nesting frigate birds. Feral animals also present a problem. On Isla Saona, trash that is washed up on shore due the flow of the currents presents a health problem. All sorts of garbage was found along the coast; for example, wood, plastic bottles, needles, tires, sandals, dolls, etc. If tourists are to visit the north coast of Isla Saona, a clean up operation should be undertaken.

WHITE MANGROVE FORESTS (estuarine)

White Mangrove Forests are characterized by the dominance of the white mangroves in the overstory. They can be distinguished from other white mangrove forests by the organic content of soil. Forests are defined as communities where the dominant trees have a coverage of 60-100% of the surface. Trees are over 5.0 meters tall. The only place where this community type was encountered was around the lake of Punta Cacon on Isla Saona due to the limited sampling. This community probably occurs elsewhere; probably around other saline lakes.

Soil analysis of the core samples revealed that white mangrove forests grow in low peat soils. The soils of this community type were described as quite deep (> 80cm and still did not hit rock), with a fairly strong hydrogen sulfide smell. The soil had a few roots, was very sandy and wet, and had a color described as 3/2. However, in some places rock was hit (calcareous) and the soil was composed of a sandy clay.

Hydrological influences on this community type can be quite variable; however, the area where this community occurred is flooded by heavy rain and/or storm surges. Overlying water analysis yielded a pH of 8, a temperature of 26°C, and a salinity of 21 ppt (mixosaline). The water of the lake was a reddish color (tannin stained) and the substrate was quite difficult to walk across as a person would sink into the mud/sand very easily. The life zone is tropical moist. The shoreline of the lake was described as smooth with small embayments. The lake lies behind a thick mangrove fringe which is probably the remnant of a larger mangrove fringe that extended to the coast. However, these mangroves have been removed to plant coconut trees behind a sandy beach for tourists.

This community was very homogenous; although there were red mangroves in the white mangrove dominated tree canopy. Surprisingly, red mangroves dominated the herbaceous layer, instead of the white mangrove. The white mangroves in the tree canopy were quite unusual in that they had pneumatophores. The white mangrove forests can be sub-divided based on soil’s organic content. Only the low peat sub-type was encountered in the Dominican Republic. Species composition was not very variable at this site as the white mangrove seemed to be the main tree in the dominant strata (tree canopy). Hurricanes, floods and storm surges can cause
extensive damage to this community type. There is usually intense herbivory on seedlings and smaller shrubs in these community types. There was evidence of termites at the site as well. Unconsolidated (subtidal) beds, seagrass beds, coconut stands, and other types of mangrove communities occurred nearby to the white mangrove forest.

In general, mangrove communities are used as a source of timber for wood products and for fuel; there was evidence of this activity even though the forest occurred within park boundaries. The mangroves of this lake provided an excellent habitat for various species of crabs (especially _Uca burgersi_) and many birds. However, the presence of a tourist beach directly in front of the lake is quite disturbing.

**RED MANGROVE SHRUBLANDS (estuarine)**

Red Mangrove Shrublands are characterized by the dominance of the red mangroves in the overstory. They can be distinguished from other red mangrove shrublands by the organic content of soil. Shrublands are defined as communities where the dominant tree forms are shrubs and the crowns cover 25-60% of the surface. Shrubs are 0.5 - 5.0 meters tall. This community type seems to occur most commonly behind large saline lakes or lagoons in Parque Nacional del Este. For example, an element occurrence of this community was rather prevalent behind Las Calderas. This community type was also seen adjacent to large saline lakes north of Punta Algabe.

Soil analysis of the core samples revealed that this community type grows in low peat soils, explaining their stunted growth. The soils of this community type were described as a wet clay with finger roots with a hydrogen sulfide smell; the color was 3/3. The deeper the core went the darker the clay got (more peat) and the stronger the hydrogen sulfide smell. However, not all sites were like that; one site’s soil was described as a sandy, dark algal laminate with no smell; color 6/1. Hydrological influences on this community type can be quite variable. The areas where this community commonly occurs are usually flooded by heavy rain; although one could have been flooded by storm surges as well. Most of the sites had no overlying water; but one site did. Water analysis yielded a pH of 5, a temperature of 36°C, salinity of 38 ppt and [O₂] of 3.9. The life zone is tropical moist. The shoreline of two of the element occurrences of this community were marshy, and the other was an embayment with only coastal drainage. The latter also had a tidal creek connection to the ocean.

Most EO’s of this community type were very homogenous; even though they were somewhat small. Red mangroves usually dominate all strata layers; however, there can be other species present, especially in the herbaceous layer. There is almost no variation in the floral species among the occurrences of this community. Red mangroves usually dominate every strata; the only strata where other species can be regularly found is in the herbaceous layer where _Avicennia germinans_ and _Laguncularia racemosa_ seedlings can be observed. Sometimes, there will be some species other than _Rhizophora mangle_ in the dominant strata, but there will not be enough of these trees to make the element occurrence a mixed mangrove community.
Red mangrove shrublands can be sub-divided based on soil’s organic content. The red mangrove shrublands in Parque del Este were growing in low peat soils.

Species composition is not very variable in these communities as the red mangroves dominate every strata. Hurricanes, floods and storm surges can cause extensive damage to this community type. There is usually intense herbivory on seedlings and smaller shrubs in these community types; however, these communities appeared to be quite healthy. This community type is distributed throughout Parque Nacional del Este; occurring along the edges of salt ponds, saline lagoons, and lakes. They can also occur as a dwarf red mangrove shrubland. Unconsolidated (subtidal) beds, seagrass beds, other types of mangrove communities (eg. Grey Woodlands and Red Scrub Thickets), salt ponds, saline lakes, expanses of Batis maritima, and upland hammocks occur nearby to red mangrove shrublands in the Dominican Republic.

In general, mangrove communities are used as a source of timber for wood products and for fuel; however, since they are protected within the park boundaries, no evidence of this activity was seen. Mangrove areas are also important as habitat for larval fish. The mangroves of Las Calderas are especially important, as the lagoon provided a unique habitat for invertebrates and one of the few remaining nesting frigate bird colonies. Human impacts are few, but important (eg. nesting frigate birds being disturbed by boaters); also, feral animals such as, dogs, cats, pigs and burros should be controlled.

**WHITE MANGROVE SHRUBLANDS (estuarine)**

White Mangrove Shrublands are characterized by the dominance of the white mangroves in the overstory. They can be distinguished from other white mangrove shrublands by the organic content of soil. Shrublands are defined as communities where the dominant tree forms are shrubs and the crowns cover 25-60% of the surface. Shrubs are 0.5 - 5.0 meters tall. This community type occurred only to the south of Lago los Flamencos in Parque Nacional del Este. More than likely, this was due to the fact that sampling was rather limited, as there are probably other white mangrove shrublands in the park.

Soil analysis of the core samples showed that this community grows in moderate peat soils. The soils of this community type were described as having no smell, color of 4/2 and having few roots. The mangroves were growing in very shallow soil as rock was hit after only 8cm. This would explain their somewhat stunted growth. Hydrological influences on this community seemed to be rather limited. The community could be flooded by heavy rain, by storm surges, or by abnormal (equinoctial) tides. The lagoon is a hypersaline (salinity is > > 100ppt; pH of 6; 28°C), stagnant body of water with a rather horrendous smell. The lagoon did not seem to support any life, except bacteria; although, there were many birds in the area. There was overlying rain water at the site which supported mosquito larvae, other insects, snails and crustaceans. Water analysis yielded a pH of 6, a temperature of 27°C, and salinity of 20 ppt. The life zone is tropical moist. The shoreline of the element occurrence of this community was described as smooth without inlets. The lagoon is covered by a blue-green algae mat, that
when broken apart reveals a squishy, black, jelly-like substance. The color of the water of the lagoon is a bright orange. The geology of the lagoon seems to be very interesting as the limestone has fossil corals and shells.

This community was composed of mostly white mangroves; however, there were red mangroves in the dominant strata, every strata for that matter, but not enough to make the occurrence a mixed shrubland. The grey mangrove or buttonwood was also interspersed throughout the site. *Rhizophora mangle* and *Conocarpus erectus* occurred at the community site; however, *Laguncularia racemosa* was the dominant species in every strata. The mangroves’ growth was stunted as they were living in a rather harsh environment. There was very little soil and the lagoon that the mangroves border is hypersaline. White mangrove shrublands can be sub-divided based on soil’s organic content. The moderate peat sub-type was surveyed in Parque Nacional del Este. Hurricanes, floods, and storm surges can cause extensive damage to this community type. There was some herbivory on all trees, but the trees appeared to be rather healthy even though their growth was stunted.

This community type occurred as a single stand in Parque Nacional del Este; however, there are probably more white mangrove shrublands in the park that were not sampled due to the limited time and scope of the surveys. Unconsolidated (subtidal) beds, seagrass beds, hard-bottom communities, other mangrove communities, hypersaline lagoons, stands of *Batis maritima*, beaches with stands of coconut trees, and upland hammocks occurred nearby to the white mangrove shrubland. In general, mangrove communities are used as a source of timber for wood products and for fuel; they are also used as fishing grounds in some areas; however, since this community is protected within park boundaries, no evidence of these activities were seen. Outside of the lagoon is a very nice beach; however, due to the horrific odor of the lagoon, tourists are not taken there. There are few anthropogenic impacts at this site due to the bad smell; however, feral animals still present a problem. There was evidence of cows and horses; a burro was seen and heard while the reconnaissance was being done.

**BLACK MANGROVE SHRUBLANDS (estuarine)**

These communities are characterized by the dominance of the black mangroves in the overstory. They can be distinguished from other black mangrove shrublands by the organic content of soil. Shrublands are defined as communities where the dominant tree forms are shrubs and the crowns cover 25-60% of the surface. Shrubs are 0.5 - 5.0 meters tall. This community type was encountered inland on the mainland, next to large, hypersaline lakes. As a point of reference, these communities occurred to the west of Playa Guanabano.

Soil analysis of the core samples revealed that this community type grows in low and moderate peat soils. Generally, the soils of this community type were very shallow (10-20cm deep). Most of the area where the mangroves were growing was exposed carbonate rock, with pockets of soil. One site was described as brown soil that had an "organic-plant" smell; color was 3/2. At another site, the soil was quite similar; the surface was covered with a blackish
clay (2.5/1), but underneath was a brown, marly, wet mud. The community could only be flooded by heavy rain. Both black mangrove shrublands that were surveyed bordered hypersaline ponds (>40ppt); one of which had a pH of 6.5, salinity of 64ppt, and a temperature of 40°C. Neither pond seemed to support any fish life, and the ankle high water was extremely hot. There was more water the previous week when the soil cores were taken. The water had dramatically receded during that time; many inundated areas had dried up and the lakes had shrunk. Interstitial water was analyzed at one of the sites and revealed water with a pH of 5.5, salinity of 75ppt, and a temperature of 28.5°C. The life zone is tropical moist. The communities were located far inland; however, the shoreline of the lakes were described as indented with islands, while the other had a marshy shoreline. The environments where these communities occurred could further be described as salt ponds with mangrove islands and/or embayments with only coastal drainage.

The floral species composition of the community was very homogeneous. The black mangrove shrublands surveyed were practically monospecific stands; there was one white mangrove at one of the sites. Red mangrove trees did occur just outside of one of the plots; however, it was a small stand and it would not have made the shrubland mixed. The mangroves’ growth was stunted as the trees were growing in a rather harsh environment. There was very little soil above the carbonate platform, and the temperature and salinity of the water they were growing in was extremely high. Black mangrove shrublands can be sub-divided based on soil’s organic content. There were two sub-types of black mangrove shrubland that were surveyed, low peat and moderate peat. The two black mangrove shrublands surveyed had different landforms; one was an overwash, while the other was a fringe.

Hurricanes and other storms can cause damage to this community type. There was limited herbivory on the trees. The trees appeared to be very healthy; however, there were dead or dying black and white mangroves in the area. The growth of the trees was also stunted due to the hostile conditions. This community type occurred inland in Parque Nacional del Este. Only two of these communities were sampled; however, there are probably more black mangrove shrublands in the park that were not sampled due to the limited amount of time for the surveys. Grey mangrove shrublands and scrub thickets, hypersaline lakes, and upland hammocks and/or forests are adjacent to these communities.

In general, mangrove communities are used as a source of timber for wood products and for fuel; they are also used as fishing grounds in some areas. At these particular community sites, large Cardisoma sp. were encountered, these crabs are eaten in the Dominican Republic. There were few anthropogenic impacts on the community sites surveyed because of the remote location; however, feral animals still present a problem. There was evidence of feral goats and/or horses in the area.

GREY MANGROVE SHRUBLANDS (estuarine)

These communities are characterized by the dominance of the grey mangroves in the
overstory. They can be distinguished from other grey mangrove shrublands by the organic content of soil. Shrublands are defined as communities where the dominant tree forms are shrubs and the crowns cover 25-60% of the surface. Shrubs are 0.5 - 5.0 meters tall. This community type was encountered inland on the mainland, next to a hypersaline pond. More than likely, this was due to the fact that sampling was rather limited, as there are probably other grey mangrove shrublands in the park.

Soil analysis of the core samples revealed that this community grows in moderate peat soils. The soils of this community type were described as having no smell, color of 4/1 (brown) and sandy. The mangroves were growing in shallow soil as rock was hit after only 20cm; most of the surface was exposed carbonate rock. This would explain their stunted growth, as the trees were quite old. The community could be flooded by heavy rain. The hypersaline pond (>40ppt) which the grey mangrove shrubland fringes had a pH of 6.5, salinity of 64ppt and a temperature of 40°C. The pond did not seem to support any fish life. Ten days before the actual survey of the site, a soil core was taken. The water dramatically receded during that time. Many inundated areas had dried up and the lake had shrunk. The life zone is tropical moist. The community was located far inland; however, the shoreline of the lake was described as indented with islands.

This community was composed of mostly grey mangroves; however, there were white and black mangroves in the area. There were dead black and grey mangroves found at the survey site. The floral species composition of the community can be variable. Grey mangrove shrublands could be monospecific stands or, as in this case, can have other species of mangroves growing in limited numbers in the area. The mangroves’ growth was stunted as the trees were growing in a rather harsh environment. There was very little soil above the carbonate platform. Grey mangrove shrublands can be sub-divided based on soil’s organic content. Only the moderate peat sub-type was encountered and surveyed in Parque Nacional del Este.

Hurricanes and other storms can cause damage to this community type. There was some herbivory on all trees. The trees did not appear to be very healthy as there was partial mortality and the trees were small (stunted growth). This community type occurred as a single stand in Parque Nacional del Este; however, there are probably more grey mangrove shrublands in the park that were not sampled due to the limited time and scope of the surveys. Other mangrove communities, hypersaline lakes, stands of Batis maritima, and upland hammocks and/or forests are adjacent to the survey site. In general, mangrove communities are used as a source of timber for wood products and for fuel; they are also used as fishing grounds in some areas. At this particular site, large Cardisoma sp. were encountered, these crabs are eaten in the Dominican Republic. There are few anthropogenic impacts at this site because of the remote location; however, feral animals still present a problem. There was evidence of cows and/or horses.

**MIXED MANGROVE SHRUBLANDS (estuarine)**
These communities are characterized by the co-dominance of the red and black mangroves in the overstory. They can be distinguished from other mixed mangrove shrublands by the organic content of soil. Shrublands are defined as communities where the dominant tree forms are shrubs and the crowns cover 25-60% of the surface. Shrubs are 0.5 - 5.0 meters tall. This community type occurred as a large band, running east to west, just north of Las Calderas. The mixed mangrove area was bounded to the north by six foot tall saw-grass and to the south by *Batis maritima*. Mixed mangrove shrublands probably occur in other locations, but were not encountered in Parque Nacional del Este.

Soil analysis of the core samples revealed that mixed shrublands grow in low peat soil. The soil of this community type, from 0-20cm, was described as a compactable sandy-clay with no odor. From 20-40cm, the clay was wetter (more compactable), had a bit of red color (6/1) due to the roots and some odor. At 40-60cm, the clay had a stronger odor and many more roots. After 60cm, carbonate rock was hit. The surface of the clay soil was covered with an algal laminate.

The community could be flooded by heavy rain. When the surveys were done, it had just rained and puddles were forming; however, there was no appreciable amount of overlying water. Water analysis revealed that interstitial water had a pH of 6, salinity of 55ppt, and a temperature of 26°C. The life zone is tropical moist. The community was located inland; the closest shoreline feature was Las Calderas, which can be described as having a semi-marshy shoreline and/or as smooth with small embayments.

This community was composed of mostly red and black mangroves; however, there were white mangroves in most of the strata layers. There were dead and dying grey mangroves found adjacent to the survey site; grey mangroves are not very salt tolerant and probably could not survive very well in the salty clay they were growing in. Mixed mangrove shrublands can be dominated by any two or more of the four species of mangroves. Therefore, they could be subdivided according to the co-dominant species. For example, this particular community could be named a mixed (red-black) shrubland. A different mixed mangrove shrubland could be named mixed (white-grey) shrubland.

The mangroves’ growth was stunted as the trees were growing in rather salty soil. Mixed mangrove shrublands can be sub-divided based on soil’s organic content. The low peat sub-type was encountered in the park. The floral species composition of the community can be very variable. Mixed mangrove shrublands are co-dominated by any two or more species of mangroves. In this case, the red and black mangroves were the dominant ones in the overstory. Hurricanes and other storms can cause damage to this community type. There was some herbivory on the seedlings, but the trees appeared to be healthy even though their growth was stunted a little; this was probably due to the high fluctuations in salinity that these trees experience. This community type occurred as a band to the north of Las Calderas in Parque Nacional del Este (see aerial photo). However, there must have been areas of mixed mangrove shrublands that were not sampled due to the limited time and scope of the surveys. Other mangrove communities such as red mangrove scrub thickets and shrublands, sawgrass fields,
upland forests, shallow marine lagoons (Las Calderas), and stands of Batis maritima are located adjacent to this community.

In general, mangrove communities are used as a source of timber for wood products and for fuel; they are also used as fishing grounds in some areas. No evidence for any of these activities was seen at this site. The mangroves of Las Calderas are especially important, as the lagoon provides a unique habitat for invertebrates and birds. For example, one of the few remaining nesting frigate bird colonies occurs here. There are few anthropogenic impacts; although they can be devastating. Nesting frigate birds are disturbed by boaters and are killed unintentionally. Also, there were reports that manatees used to congregate in the shallow lagoon to feed, but they have since been hunted out. Feral animals, such as dogs, cats, burros and goats can also present a problem.

**RED MANGROVE SCRUB THICKETS (estuarine)**

Red Mangrove Scrub Thickets are characterized by the dominance of the red mangroves in the overstory. They can be distinguished from other red mangrove scrub thickets by the organic content of the soil. Scrub thickets are defined as communities where the dominant trees have a coverage of 60-100%. The trees are 0.5 - 5.0 meters tall. This community type seems to occur throughout Parque Nacional del Este. However, this particular red mangrove scrub thicket was growing to the north of Las Calderas; therefore, it was not in a true marine environment.

Soil analysis of the core samples revealed that red mangrove scrub thickets grow in low, moderate, and high peat soils. The soils of this community type was very deep as rock was never hit. The soil from 0-20cm down was a clay with some roots, but still sandy-grey in color. From 20-40cm down, the clay had more roots in it when the clump was broken up (color 6/2), and it had a hydrogen sulfide smell. Greater than 40cm, the clay had even more roots (color 6/3), and a stronger hydrogen sulfide smell. The clay became wetter as the core went deeper.

The areas where this community occurred are flooded by heavy rain and/or storm surges. The survey site had no overlying water; in fact, it occurred about 50m inland. No interstitial water analysis was done; although the soil was moist. The life zone is tropical moist. The site was inland of a large lagoon (Las Calderas), which has a smooth shoreline with small embayments. The vegetation structure of red mangrove scrub thickets can vary quite a bit. Red mangroves can occur as a fringe, overwash, or basin community, and in Parque Nacional del Este there is a prevalent dwarf red mangrove scrub thicket community which occurs along the southern portion of the peninsula. These mangroves are dwarf because of the poor soils that they are growing in, yet they are completely viable plants. There is almost no variation in the floral composition of red mangrove scrub thickets. Red mangroves dominate every strata; however, the herbaceous layer usually has other species present. However, these seedlings do not survive as the red mangroves are more suited for the harsh environmental conditions associated with growing in high salinity water and/or soils. There is usually not much
physiognomic variation among the element occurrences of red mangrove scrub thickets. However, sometimes if the trees are tall enough, a scrub thicket can be confused with a forest, but trees must be over 5m tall to be considered a true forest. Red mangrove scrub thickets can be sub-divided based on the soil’s organic content. The soil can be classified as low, moderate, or high peat. All three sub-types were encountered and surveyed in Parque Nacional del Este.

Species composition is not very variable in these communities as the red mangroves dominate almost every strata. Hurricanes, floods and storm surges can cause extensive damage to this community type. However, there was no evidence of any damage as the trees appeared to be quite healthy even though they were growing in a harsh area. No herbivory was noted. Three dead *Laguncularia racemosa* were seen. This community type is distributed extensively throughout Parque Nacional del Este. Usually it occurs to the seaward side of other mangrove communities that are less salt tolerant; for example, black or white mangrove woodlands, and/or grey mangrove forests. Upland forests, salt ponds, hyper-saline lagoons, seagrass beds, other types of mangrove communities (eg. mixed mangrove shrublands), *Salsicornia/Batis* stands, and offshore reefs are adjacent to red mangrove scrub thickets.

In general, mangrove communities are used as a source of timber for wood products and for fuel (charcoal); however, no evidence of these activities were seen. Probably because these red mangrove scrub thickets are protected within the park boundaries. Mangrove areas can be used for fishing as they provide important habitat for juvenile fish. Mangroves have been cleared away to plant coconut trees. Mangroves are quite important, as they provide a unique habitat for invertebrates and birds, especially the mangrove communities in Las Calderas. One of the few remaining nesting frigate bird colonies occurs there; these birds are often disturbed by boaters which leads to their unintentional death. Anthropogenic impacts (eg. trash and sewage) seem to be few in red mangrove scrub thickets because of the remote locations of some of the sites. However, feral animals such as dogs, cats, pigs, goats and burros need to be controlled.

**RED MANGROVE SCRUB THICKETS (marine)**

Red Mangrove Scrub Thickets are characterized by the dominance of the red mangroves in the overstory. They can be distinguished from other red mangrove scrub thickets by the organic content of the soil. Scrub thickets are defined as communities where the dominant trees have a coverage of 60-100%. The trees are 0.5 - 5.0 meters tall. This community type occurs throughout Parque Nacional del Este. Survey sites included areas that were inland and areas adjacent to the shore. Most of the red mangroves that fringe the mainland are scrub thickets.

Soil analysis of the core samples revealed that this community grows in low, moderate, and high peat soils. The soils of these communities were quite deep (sometimes >75cm). The soils were generally described as containing high amounts of organic matter, making them quite peaty (color 3/1) with a hydrogen sulfide smell. Occasionally, there was a layer of litter and duff, or a coarse coral rampart/gravel above the soil.
The areas where this community occurred could be flooded by heavy rain, storm surges, spring high tides and/or all high tides. Most commonly, red mangrove scrub thickets are flooded by all high tides as they usually occur along the coast. For this same reason, red mangrove scrub thickets are also at the mercy of the currents and whatever they are carrying with them (eg. cold water, nutrients, etc.). However, one study site was inland, but it was located at a deep saline lake that had a tidal creek connection to the ocean. All the sites had overlying seawater (mesosaline, 30-40ppt); however, interstitial water analysis could be done at one of the sites. Interstitial water analysis revealed an [O₂] of 3.7ppm, a pH of 6, salinity of 34ppt, and a temperature of 28°C. The overlying water had an average [O₂] of 3.2ppm, salinity of 37ppt, a pH of 5.5 and a temperature of 33°C. The life zone is tropical moist. One site was inland, but occurred next to a saline lake with a connection to the ocean; therefore, it was an embayment with coastal drainage. The other sites were right on the shoreline, and were described as smooth with small embayments. The areas chosen for study were on the leeward side of the peninsula.

The vegetation structure of red mangrove scrub thickets can vary quite a bit. Red mangroves can occur as a fringe, overwash, or basin community, and in Parque Nacional del Este there is a prevalent dwarf red mangrove scrub thicket community which occurs along the southern portion of the peninsula. These mangroves are dwarf because of the poor soils that they are growing in, yet they are completely viable plants. There is almost no variation in the floral composition of red mangrove scrub thickets. Red mangroves dominate every strata; however, the herbaceous layer usually has other species present. However, these seedlings do not survive as the red mangroves are more suited for the harsh environmental conditions associated with growing in high salinity water and/or soils. There is usually not much physiognomic variation among the element occurrences of red mangrove scrub thickets. However, sometimes if the trees are tall enough, a scrub thicket can be confused with a forest, but trees must be over 5m tall to be considered a true forest. Red mangrove scrub thickets can be sub-divided based on the soil's organic content. The three sub-types of red mangrove scrub thicket were encountered and surveyed in Parque Nacional del Este. Species composition is not very variable in these communities as the red mangroves dominate almost every strata. Hurricanes, floods and storm surges can cause extensive damage to this community type. However, there was no evidence of any damage as the trees appeared to be quite healthy. Some herbivory was noted, especially on the seedlings and smaller shrubs. Termites were present as well. This community type is distributed extensively throughout Parque Nacional del Este. Usually it occurs to the seaward side (as a fringe) of other mangrove communities that are less salt tolerant; for example, black or white mangrove woodlands, and/or grey mangrove forests. Upland forests, salt ponds, hyper-saline lagoons, seagrass beds, hard-bottom communities, other types of mangrove communities (eg. mixed mangrove shrublands), Salicornia/Batis stands and offshore reefs are adjacent to red mangrove scrub thickets.

In general, mangrove communities are used as a source of timber for wood products and for fuel (charcoal); however, no evidence of these activities were seen. Probably because these red mangrove scrub thickets are protected within the park boundaries. Mangrove areas can be used for fishing as they provide important habitat for juvenile fish. Mangroves have been
cleared away to plant coconut trees. Mangroves are quite important, as they provide a unique habitat for invertebrates and birds, especially the mangrove communities in Las Calderas. One of the few remaining nesting frigate bird colonies occurs there; these birds are often disturbed by boaters which leads to their unintentional death. Anthropogenic impacts (eg. trash and sewage) seem to be few in red mangrove scrub thickets because of the remote locations of some of the sites. However, feral animals such as, dogs, cats, pigs, goats, and burros need to be controlled.

**GREY MANGROVE SCRUB THICKETS (estuarine)**

Grey Mangrove Scrub Thickets are characterized by the dominance of the grey mangroves in the overstory. They can be distinguished from other grey mangrove scrub thickets by the organic content of the soil. Scrub thickets are defined as communities where the dominant trees have a coverage of 60-100%. The trees are 0.5 - 5.0 meters tall. This community type seems to occur most commonly behind large saline lakes or lagoons in Parque Nacional del Este. A rather tall grey mangrove scrub thicket occurred north of Lago los Flamencos on Isla Saona, these trees were growing practically out of carbonate rock. Another community of grey mangrove scrub thicket was a true dwarf community as the trees were less than .5m tall; this community occurred to the west of Playa Guanabano. This occurrence was also growing practically out of rock, and what little soil there was, was very poor. Supposedly, there is a large stand of grey mangroves (unknown physiognomic type) on the west side of the peninsula, around the Bayahibe/Dominicus area; however, sampling did not reach that far north.

Soil analysis of the core samples revealed that this community grows in moderate peat soils. The soils of these communities were very shallow (only 5-10cm deep) with little or no smell. The site with the taller trees (Lago los Flamencos) had a clay-like soil with a color of 4/2; the soil had few roots. However, the true-dwarf scrub thicket had soil that was described as semi-moist, semi-crumble, but compactable, and it had a salty smell. Judging from the growth of the trees, this soil was very poor.

The areas where this community occurred are flooded by heavy rain and/or storm surges. None of the sites had overlying water; in fact, one site occurred far inland. No interstitial water analysis was done; although the soil was moist at the dwarf grey mangrove site. The salinity of the water of Lago los Flamencos was much greater than 100ppt. The life zone is tropical moist. One site was inland, but occurred next to a salt pond (marshy shoreline). The other shoreline was described as smooth without inlets.

The vegetation structure of the two EO's of this community type were quite different. Both communities were very old; however, one thicket had trees that were less than .5m tall while the other had trees that were 2-5m tall. This difference can be accounted for by the poor soil (it seemed to be saline) at the dwarf grey mangrove site. There is almost no variation in the flora between the occurrences of this community. Grey mangroves dominate almost every strata; however, the herbaceous layer at Lago los Flamencos was dominated by *Laguncularia*
*racemosa.* The physiognomic variation between the two community occurrences is quite obvious. One community is a true dwarf grey mangrove scrub thicket (due to the poor quality of the soil); the other community is almost a grey mangrove forest, but the trees are not quite tall enough as trees must be over 5m tall to be considered a forest. Grey mangrove scrub thickets can be sub-divided based on the soil’s organic content. The moderate peat sub-type was encountered in Parque Nacional del Este. Species composition is not very variable in these communities as the grey mangroves dominate almost every strata.

Hurricanes, floods and storm surges can cause extensive damage to this community type. However, there was no evidence of any damage as the trees appeared to be quite healthy even though they were growing in a harsh area. There was herbivory on all trees, but it was especially intense at the dwarf grey mangrove site. This community type has a patchy distribution in Parque Nacional del Este. It was only encountered at the edge of a salt ponds (mainland) and around a hyper-saline lagoon (Isla Saona). Upland forests, salt ponds, hyper-saline lagoons, seagrass beds, other types of mangrove communities and offshore reefs are adjacent to these grey mangrove scrub thickets.

In general, mangrove communities are used as a source of timber for wood products and for fuel; however, since these grey mangrove scrub thickets are protected within the park boundaries and the sites were particularly inaccessible, no evidence of this activity was seen. Mangroves are quite important, as they provide a unique habitat for invertebrates and birds. Human impacts seem to be few in grey mangrove scrub thickets, but feral animals such as, dogs, cats, pigs, and burros need to be controlled.
6. Systematic list of mollusc (Mollusca) and crustacean (Crustacea) species recorded from mangrove communities in Parque Nacional del Este; this list does not include three species of pulmonate gastropods which were found, but could not be identified. Taxonomic classifications are after Abbott and Dance (1982) and Vaught (1989) for molluscs, and after Bowman and Abele (1982) for crustaceans.

**PHYLUM MOLLUSCA**

Class Bivalvia
  Order Mytiloida
    Family Mytilidae
      *Brachidontes exustus* (Linnaeus, 1758)
  Order Pterioida
    Family Isognomonidae
      *Isognomon alatus* (Gmelin, 1791)

Class Gastropoda
Subclass Opisthobranchia
  Order Cephalaspidea
    Family Bulidae
      *Bulla striata* Bruguiere, 1792

Subclass Prosobranchia
  Order Archaeogastropoda
    Family Neritidae
      *Nerita tessellata* Gmelin, 1791
      *Nerita versicolor* Gmelin, 1791
      *Neritina virginea* (Linnaeus, 1758)
      *Pupera virginea* (Linnaeus, 1758)
      *Pupera virginea* form *tristis* (Orbigny, 1842)
  Order Mesogastropoda
    Family Littorinidae
      *Littorina angulifera* (Lamarck, 1822)
    Family Potamididae
      *Batillaria minima* (Gmelin, 1791)
      *Cerithidea* sp. A
      *Cerithidea* sp. B

Subclass Pulmonata
  Order Archaeopulmonata
    Family Ellibiidae
      *Melampus coffeus* (Linnaeus, 1758)
  Order Stylommatophora
    Family Cerionidae
      *Cerion yumaensis* Pilsbry & Vanatta, 1895
PHYLUM ARTHROPODA
Subphylum Crustacea
Class Malacostraca
Order Decapoda

Superfamily Grapsidoidea
Family Grapsidae
  Goniopsis cruentata (Latreille, 1802)
  Pachygrapsus transversus (Gibbes, 1850)
  Pachygrapsus sp. A
Family Gecarcinidae
  Gecarcinus lateralis (Freminville, 1835)

Superfamily Ocypodoidea
Family Ocypodidae
  Uca burgersi Holthuis, 1967

Superfamily Portunoidea
Family Portunidae
  Callinectes sapidus Rathbun, 1896

Superfamily Coenobitoidea
Family Coenobitidae
  Coenobita clypeatus (Herbst, 1791)
APPENDIX II: THE ROCKY INTERTIDAL COMMUNITY

The rocky intertidal zone is defined as the region of the coastline that is subjected to tidally controlled exposure and inundation by seawater. The rocky intertidal ecosystem; however, usually includes the littoral zone which is directly affected by the sea (including wave action). It is therefore a meeting place of marine and terrestrial communities. These are areas characterized by high physical heterogeneity, and high light and nutrient (supplied by both coastal runoff and the stirring of coastal sediments by waves) levels. There is generally higher diversity in tropical rocky intertidal systems than in temperate regions, although algal diversity is higher in temperate regions.

Studies in these areas have been numerous, partly due to habitat accessibility, and the presence of high diversity and densities of easily manipulated sessile or slow-moving organisms. Previous studies have played a key role in determining the relative importance of physical and biotic factors in determining community structure of rocky intertidal environments.

A universal feature of intertidal zones is the vertical zonation of organisms with respect to tidal height. Although the species vary geographically, certain genera or groups of similar organisms tend to occupy similar positions. There is a general agreement that the tides are mainly responsible for this zonation, although they are not the direct cause of it. The tides are caused by the combination of gravitational forces of the moon, sun, and other planets on the earth’s oceans, and the natural period of oscillation of the oceans and bays.

The movement of the tides results in a gradient of exposure to atmospheric conditions, which inevitably imposes gradients of other environmental factors on the organisms that live there. Differences in the organisms’ responses to these variables, and thus their adaptation potential to these physical factors, partly result in the zonation patterns we observe. Biotic factors such as competition, predation, and herbivory; however, also play important roles in defining these zonation patterns, and cannot be disregarded. Whittaker (1970) uses the term "community gradient" to describe the cline variation in population density and composition (community structure) along the environmental gradient.

The most important physical factors that control intertidal distributions include desiccation, temperature, salinity, and wave action. Desiccation potential and temperature both increase as one moves up the shore. Desiccation is a very important factor controlling the upper limit of many species, especially in the upper part of the shore. It has been shown to be the most important physical factor limiting the local distribution of most of the organisms in the sites studied on the Washington coastline of North America (Dayton, 1971). Species that colonize the upper rocky intertidal zones must be able to either avoid or resist drying out through morphological, behavioral, or physiological adaptations. These include having white shells (some barnacles and Littorina), heavy shells (some Littorina), opercula, and staying close to the substratum (chitons). In the central-western coast of Venezuela it has been shown that exposure has a strong effect on both the density and number of individuals. During high tides there were more organisms grouped together than during low tide, when the organisms occupied more
space. Grouping seems to be a behavioral adaptation to avoid getting washed away during high tides. Nevertheless, the study also documented a greater number of individuals at low tide than at high tides (Pérez, 1974).

Temperature can be an important factor in itself, but it also increases desiccation through an increase in evaporation. Adaptations to avoid the harmful effects of high temperatures include thick shells (Acmaea, Thais, and Littorina), and evaporative cooling (barnacles, isopods, limpets).

Salinity may be very variable: it may rise during periods of low tide when water in tide pools are prone to evaporation, and it may drastically fall during heavy rains and storms. Organisms that live in tide pools must be able to resist these gross and rapid salinity changes.

Wave action or exposure can act in several different ways. The direct physical effect on the shore is obvious since pounding breakers can exert very large forces on the shore and on the organisms that live attached to the substratum. Waves can act as disturbances and can prevent the monopolization of space by any one organism. Wave action can also increase the vertical area of the intertidal zone and decrease the effects of desiccation and temperature through waves, or indirectly through spray. Waves also have the potential of exposing subtidal organisms to air. Additionally, wave effects can be modified by fog, wind, slope of the shore, and nature of the substratum as described by Thomas et. al. (1983). Currents also have a strong influence on zonation and species densities since they are responsible for bringing in the supply of planktonic food and larvae. Barnacles, for example, have been shown to have faster growth rates and higher population densities in wave-exposed habitats than in similar more tranquil and sheltered habitats (Bierbaum and Zischke, 1979). Currents can also be responsible for the death of many organisms if they are laden with sediments that may suffocate them or pollutants that may harm them.

Biotic factors also play a definite role in the distribution of species. All species having lower limits below the extreme high water mark can certainly function normally subtidally. The reasons for the zonation patterns must then be mostly due to biotic interactions. Abrupt discontinuities in the distribution patterns of sessile populations are frequently considered to be the result of competitive interactions. It has been assumed that competition for space or food increases down the shore because growth is faster there, and this increases the rate of competitive processes such as shading, smothering, and crushing (Thomas et. al., 1983). Competition can lead to clear dominance hierarchies and zonation patterns (Dayton, 1971). It has also been shown to have other effects such as the decrease in the basal diameter of barnacle shells (Bierbaum and Zischke, 1979).

Predation can keep intertidal distributional limits of other species as there are many predatory snails, birds, and fish in these areas. Collecting by humans, for bait or food consumption, can also be considered a form of selective predation and can lead to changes in size and density of species. Keough et. al. (1993) showed that 3 of 4 species collected (for food, bait, or as souvenirs) were significantly (up to 47%) smaller in areas where they were
actively collected versus areas where they were protected. This study also showed that the
abundance of one species was significantly lower in the areas where collections were common.
Selective removal of the larger individuals can change the intensity of intraspecific competition
and can have disproportionate effects on the performance of smaller individuals. It can also be
important if those animals contribute disproportionately to reproductive effort in a local
population (Keough et. al., 1993).

Predation can also be responsible for maintaining a high species richness or diversity in
a habitat by selectively eliminating the competitively dominant space occupiers in the rocky
intertidal area and thus preventing the monopolization of space. Some researchers believe that
predation is the dominant factor controlling species diversity. "In the presence of predation,
competing species can coexist even when competition is unbalanced. Predation on the superior
species reduces the competition and allows the inferior species to survive" (Thorne-Miller and
Catena, 1991). Predation can influence not only the densities and number of species, but also
their size distributions. If predation is a very important factor in a community, such as when
there is a keystone predator, it can be the most influential control of community structure,
affecting the densities, sizes, and species present, as well as the overall diversity of the site.

Herbivores, such as periwinkles and limpets in the upper zones, and urchins and fish in
the lower zones, can have significant effects on the community structure and zonation patterns
of algae. Changes in algal cover will, in turn, affect other species since algal cover offers a
refuge from desiccation and high temperatures to a wide variety of organisms. Finally, it must
be mentioned that predation and herbivory on the newly settled invertebrate larvae and algal
spores are important factors that influence the zonation patterns of the resident species. Limpets,
for example, have been shown to have a negative effect on the recruitment (settlement and
establishment) of algae and barnacles (Dayton, 1971).

A rocky intertidal area can be divided into 5 general zones (Figure 2.1). Although these
are not absolutely universal and some areas may lack one or two zones, they have been accepted
worldwide and are known as the "general scheme of zonation" (Stephenson and Stephenson,
1950). A general description of these zones follows. The supralittoral, white, or gray zone is
the highest zone and basically maintains a biota of terrestrial origin such as lichens and vascular
plants. The bottom limit of this zone is defined by the upper limit of periwinkles (Littorina).

The supralittoral fringe follows the supralittoral zone and extends down to the upper limit
of barnacles. This zone is also referred to as the black zone because it is sometimes of a darker
tint than the others due to lichens and blue-green algae.

The midlittoral zone begins at the upper limit of the barnacles, and extends down to the
upper limit of the algal mat.

The fourth zone is the infralittoral fringe which follows the infralittoral zone and reaches
down to the extreme low water mark. This zone is characterized by red and green algae.
Finally, the infralittoral or sublittoral zone is the lowest zone and it begins at the extreme low water mark and has no bottom limit. This zone is below the influence of the tides.

The boundaries separating the different zones can be modified by many factors such as slope which may change zone positions, dominance patterns, and wave action (Thomas et. al., 1983).

The general agreement of many studies is that the upper limits of the species (especially above mean tide level) are controlled more by physical factors mentioned above, while the bottom limits of these species, and the upper limits of lower shore species are controlled by biological factors (Thomas et. al., 1983). It is also generally agreed that species diversity is higher in the lower zones, where the physical environment is less stressful, than near the high tide level, where exposure is greatest. Diversity then increases again, with the presence of vascular plants high up on the coast (Thomas et. al., 1983). The relative importance of the different physical factors and biotic interactions influencing zonation varies from one location to another. The ultimate goal of any study in the rocky intertidal environment is the definition and understanding of the biotic and physical factors which determine the population structure and zonation of that intertidal community. When one can show that the growth and regulation of the populations in a rocky intertidal community are affected in a predictable manner by physical disturbances and by interactions between organisms, one can truly say that an understanding of that community structure has been reached.

Rocky intertidal areas are subject to overharvesting, pollution due to runoff, and waste outfall from human development, and habitat alteration. The tides and currents bring in water laden with nutrients and larvae, but also laced with harmful heavy metals, petroleum, or toxic organics that lead to disease and deformation in some organisms. Larvae may not be able to find the chemical signals that make them settle, and the populations may therefore not be replenished. "Eventually, some species disappear and others lose genetic variation within their populations. The characteristic biological diversity is diminished; the system is weakened and becomes more vulnerable to further stresses" (Thorne-Miller and Catena, 1991). These threats and effects will intensify with the increase in coastal development and population growth. Unless these important areas are properly managed, the nature of rocky intertidal environments may be altered forever.
APPENDIX III: THE SEAGRASS COMMUNITY

Seagrass beds are worldwide conspicuous and important features of submerged coastal zones. They are among the most productive ecosystems in the biosphere. In the Caribbean they are composed of marine spermatophytes or flowering plants belonging to two families, Potamogetonaceae and Hydrocharitaceae. Two groups of species can be recognized: (1) shallow rooted forms which are able to colonize oxidized and unstable sediments, and (2) species that build a strong mat of rhizomes and form mature seagrass meadows (i.e Thalassia) (Longhurst and Pauly, 1987). Three species characterize most Western Atlantic seagrass beds: Thalassia testudinum (turtle grass) which belongs to the second group of species above, and Syringodium filiforme (eel grass) and Halodule wrightii (shoal grass), both of which belong to the first group (Figure 3.1).

Seagrass beds may be continuous stands of plants consisting of one or more species or a heterogeneous array of sandy and muddy areas interspersed across the vegetation. Drift and calcareous algae may be abundant. It must be remembered that each of these sub-habitats (e.g. sand, grass, algae) that are often collectively described as a seagrass bed may influence the way a species perceives and uses the surrounding environment (Orth et al., 1984).

1. Physical Requirements of Seagrass Beds

Seagrasses are rooted plants that depend upon photosynthesis, and therefore upon water depth and clarity. They occur in shallow waters (mostly < 20 m) where wave and tidal action are not excessive. A fourth species, Halophila sp., can be found in deeper (up to 35 m) sandy slopes or in highly disturbed or turbid conditions. Seagrasses also depend on nutrients from the sediments. If the sediments are too thin (< 3 cms) or disturbed by current flow or bioturbation, seagrass beds cannot establish themselves. Although no conclusions can be made, there is evidence (Tribble, 1981) that the distribution and zonation patterns of Thalassia and Syringodium are dictated by selective grazing by herbivores, primarily fishes (Tribble, 1981) or by light (turbidity, water depth, etc.) (Zieman et al., 1989).

2. Faunal Assemblages Associated with Seagrass Beds

The faunal assemblage associated with seagrass beds consists of a very diverse group of animals in terms of their life forms and ecological characteristics.

Infaunal species include burrowers and tube-dwellers as well as the animals that crawl over the sediment-water interface. The composition of the infaunal species that live in the substrate depends on the particle size of the sediments. The patterns of abundance and distribution of these species is also dictated by the structure of the sediment itself and therefore by the amount and type of rhizomes, roots, and shoots inside and arising from the sediments. The mat of roots and rhizomes protect animals from predation by fishes and crabs, but also
prevent larger burrowers from residing within the bed.

Epifaunal species live on the leaves and blades of seagrasses which provide substrates for attachment and feeding. They include micro and meiofauna, sessile fauna, creeping and walking fauna (i.e. gastropods), and swimming fauna. Mobile species live freely over and under the canopy of seagrasses and consists mostly of fishes. The species composition and abundance of these two groups seems to depend mainly on plant characteristics, such as leaf morphology, leaf standing crop, and density of shoots. It has been shown (Heck and Wetstone, 1977) that the diversity of animal species associated with seagrass beds increases with increasing plant biomass (Heck and Wetstone, 1977). Plants with more foliose leaves offer greater surface area per unit weight and should provide more protection than plants with simpler leaves and lower surface area per unit weight. The abundance of particular species associated with seagrass habitats is also affected by other factors, however, such as the characteristics of the prey and predator species themselves (e.g. camouflage), and the heterogeneity or patchiness of the vegetation. It has been suggested (Holt et al., 1983) that patchy areas with a high percentage of edges or "ecotones" may actually support a higher density of some mobile foraging species than homogeneous areas.

All in all the presence or absence of a species and its abundance in seagrass beds depends on the species' physiological tolerances, morphological constraints, habitat preferences, ability to avoid prey, and other biological interactions such as competition and predation; the heterogeneity or patchiness of the grass bed; as well as on the density and complexity of the grass shoots and rhizomes, the presence of toxic or inhibitory substances, plant biomass, leaf area, morphology and thickness, and proximity of the rhizome layer to the sediment surface (Orth et al., 1984; Thayer et al., 1984).

3. Important Characteristics of Seagrass Beds

Seagrass beds are characterized by a high biomass, productivity, and turnover rate of plant material, which makes them important benthic primary producers as well as store-houses of organic material that nourish detritus-based food chains of great complexity.

Frequently, they contribute large portions to the primary productivity of coastal ecosystems (Vicente et al., 1980; Thayer et al., 1984). Their production is also the basis for other secondary production since the plants, whether it be the blades themselves or their epibionts and macroalgae, are fed upon by a large number of consumers.

Seagrass blades also provide a habitat and shelter for small resident and juvenile fishes and invertebrates, as well as surface area for attachment by numerous sessile and motile epibionts.

Additionally, seagrass beds are prime sites for the settlement of juvenile fishes from the plankton (i.e. Diodon holocanthus), and act as nurseries for many economically and ecologically
important species such as certain reef fishes (eg. Acanthuridae, Holacanthidae, Mullidae, Ocyurus chrysurus) (Ogden, 1976; Ogden and Zieman, 1977), invertebrates (eg. Panulirus argus), and marine mammals (eg. manatees).

Furthermore, seagrass plants anchor and filter sediments, and act as accretion mechanisms for suspended sediments. This way, they lessen tidal and wave energy and contribute to water clarity and sediment deposition, as well as preventing shoreline erosion (Short, 1987).

Finally, seagrass beds play an important role in the cycling of coastal nutrients, accelerating nitrogen fixation and increasing diffusive nutrient flux to local waters. They can also absorb pulses of nutrients in runoff waters, thereby acting as important buffers zones in case of anthropogenic stresses (Morse et al., 1987; Short, 1987).

4. Interactions between Coral Reefs and Seagrass Communities

Coral reefs and seagrass beds are closely associated, and the relationships between these two important communities are numerous and varied. As will be seen below, the organisms that inhabit coral reefs are resource limited due to the tight recycling of energy characteristic of reefs. The proximity of seagrass beds, which are more open systems, provides a readily available source of food. Seagrass beds are trophically linked with coral reefs through the feeding forays of herbivorous and carnivorous (eg. Sphyraena sp., Scomberomorus sp., Caranx sp., etc.) fishes and echinoids and by movements of reef dwelling fishes (eg. Pomadasyidae, Lutjanidae, Holocentridae) which exploit the fish and invertebrate populations in seagrass beds at night. For example, the existence of halos of sand surrounding coral reefs and separating them from seagrass beds has been partly attributed to the diurnal and nocturnal feedings of fishes and sea urchins from reefs to grassbeds (Ogden and Zieman, 1977). This relationship could be so strong that it has been suggested (Ogden and Zieman, 1977) that the enhanced fish biomass characteristic of coral reefs near seagrass beds can be attributed to these feeding activities.

Extensive seagrass beds bridge the distances between coral reefs and mangroves which have widely different physical requirements. In terms of fisheries, recent investigations (Zieman et al., 1989) have suggested that seagrass beds in open environments and within mangrove-lined bays contain the densest populations of commercially important species such as some penaeid shrimp. For example, a clear association has been obtained between organism catch and seagrass cover. Furthermore, a study on the population dynamics of the commercially important spiny lobster, Panulirus argus, has shown that mature lobster appear to be more abundant near reef-grass flat boundaries, while juveniles are found in mangrove and seagrass habitats in St. John, U.S. Virgin Islands (Olsen et al., 1975).

Finally, the interactions between seagrasses and the carbonate sediments on which they grow are of particular importance in the cycling of nutrients in the Caribbean. Large amounts of organic material can be produced in seagrass beds and exported to the adjacent resource-
limited coral reef communities and the surrounding nutrient-poor waters of the Caribbean, enriching them. This cycle, the effects of sediment nutrients on seagrasses (reviewed by Short, 1987), and the effects of grazing on the seagrasses, other grazers and fauna, and chemical decompositional processes occurring within the seagrass community are very complex and not fully understood. Readers are referred to Morse et al. (1987), Thayer et al. (1984), and Orth et al. (1984) for their review.

5. How Seagrass Communities Respond to Stressors

Although there are few studies dealing with the responses of seagrass communities to stresses (both natural and anthropogenic), these seem to be quite numerous. Coastal changes such as those caused by dredging and filling operations, coastal erosion caused by the elimination of terrestrial vegetation, and sediment resuspension by boat traffic all lead to an increase in sediment particle suspension in the water column. The increase in turbidity causes a decrease in light penetration which limits the vertical distribution of the seagrass and causes them stress.

It has been shown (Vicente et al., 1980) that seagrasses decrease the biomass of total plant material (roots, rhizomes, stems, and leaves), as well as leaf production. This leads to decreases in the stability of the substrate, in the biotic viability of the plant, and in energy for the upper trophic levels (by decreasing primary productivity). More specifically, seagrasses also decrease blade density and leaf thickness. Leaf thickness has been used as an indicator of rhizome growth and of the overall state of vigor of Thalassia (Vicente et al., 1980).

Although highly productive, it seems that turtle grass beds are slow to recover following damage by natural or man-induced disturbances. Matthews et al. (1991) and Zieman (1976), for example, have studied the ecological effects of physical damage from motor boats and prop wash on Thalassia beds in Florida. Zieman (1976) found that when there is a disturbance of the rhizome system of the plants, such as that caused by motor boat propellers, the plants are extremely slow to recover, sometimes taking as much as five years to do so. In the tracks left by the propellers, the proportion of fine sediment components was reduced, and the pH and Eh are also reduced in comparison to the thriving surrounding grass bed.
APPENDIX IV: THE CORAL REEF COMMUNITY

Coral reefs have the greatest diversity of any marine ecosystem known today, comparable in diversity, productivity, and complexity to tropical rain forests on land (Connell, 1978). The inherent beauty of these natural communities and the increase in scuba diving facilities all over the world have led to a significant increase in the number of people wanting to learn more about coral reefs and the factors that govern their community structure.

1. Physical Requirements of Coral Reefs

Corals are living marine animals. These enormous wave-resistant formations have a thin lining of living tissue of many polyps (Figure 4.1) living together as a colony. Most corals live symbiotically with minute unicellular algae called zooxanthellae in their bodies. Coral shapes range from simple encrusting sheets, to massive mounds, to various erect branching or plate-like forms. They can propagate asexually by breaking into clonal fragments (branching corals) or by budding (colony growth), or sexually. Larvae can develop internally (brooding) or externally (broadcasting), this last method being by far the most common one. When broadcasting occurs corals throw eggs and sperm into the water column, and fertilization occurs in the ocean. Here they develop into planktonic larvae which later settle in appropriate places in the bottom if the physical conditions permit (Figure 4.2).

Tropical oceans are very poor in nutrients, and these corals depend upon the photosynthesis of their algae for part of their energy requirements. The algae, on the other hand, receive protection, oxygen, and nutrients from their hosts. A number of environmental conditions must be met in order for corals to survive (Figure 4.3). One must take into account not only the requirements and tolerances of the adult colonies, but also those of the coral planula larvae and of the symbiotic zooxanthellae living inside the coral colonies. Water must be warm (tropical) and the salinity not vary much from that of normal seawater (35 ppt). Typical salinities are between 34-38 ‰. Corals can therefore not survive in areas where cool water is upwelled from deep waters. Additionally, the water must be fairly transparent and thus free of sediments so that light can reach the zooxanthellae and photosynthesis can be accomplished. Low light levels in turbid inshore waters might be insufficient for the zooxanthellae of corals to maintain normal growth rates. Coral colonies which are frequently covered with sediment must be able to expend considerable energy towards the removal of that sediment and still maintain normal growth rates, or they must be morphologically adapted to avoid sediment accumulation (for example, Gorgonia ventalina). For the same reasons, reef corals that depend upon zooxanthellae cannot live in deep waters where light doesn’t reach them. Most living coral colonies live attached to a calcium carbonate structure that is composed mainly of the skeletons of older dead corals cemented together with calcareous algae. A hard substrate is also necessary for the coral larvae to settle. Currents can also affect and limit the distribution of coral species in many ways (Figure 4.4). Not only are they responsible for the transport of the larvae and nutrients, but can also be detrimental if they carry pollutants or are sediment-laden. If currents are too strong, they prevent the settlement of larvae and affect the growth form of the coral.
species. Vertical reef growth is controlled by rising sea levels, while wave action breaks away the reef and the damage is repaired by horizontal growth.

2. Competition Leads to Specialization

The conditions for reefs of high structural complexity, low levels of environmental fluctuations, clear and tranquil waters, and geological age, all lead to the development of a highly complex community with a high species diversity (Thorne-Miller and Catena, 1991). It is widely accepted that the species assemblages are highly organized and have co-evolved. Many organisms are mutually dependent, and commensalism and symbiosis have developed to a greater degree of complexity here than in any other ecosystem (Longhurst and Pauly, 1987). Most researchers believe that it is competition for space and food that is responsible for the evolution of such a large number of specialized species in reefs. For example, soft corals will compete for space, and avoid predation and overgrowth by hard corals by the chemical release of noxious substances that can cause necrosis in the tissues of hard corals. Hard corals, on the other hand, will compete for space using sweeper tentacles and mesenteric filaments. The overall natural diversity of a coral reef depends mostly on geographical location, chance recruitment and colonization, and intermittent natural disturbances, although other factors may be important locally.

3. Species Composition

Surprisingly, even with this great community complexity and diversity, there is a general uniformity of specific composition of reef-forming communities over very large areas within ocean basins compared with the very distinct differences between ocean basins (Longhurst and Pauly, 1987). This also occurs with reefs in the Indo-Pacific, and is in contrast with fish and other invertebrate groups inhabiting the reefs which show a pronounced endemism. This widespread homogeneity of coral species seems to be due to long generation times and the Pleistocene collapse in reef communities (Liddell and Ohlhorst, 1988). The Western Atlantic Reef Province (West Indies), of which the Dominican Republic is a part, therefore, tends to have similar species occupying the same ecological niches in all reef formations. Liddell and Ohlhorst (1988) collected the data available on studies of coral reefs in the Western Atlantic province, and found, that although the majority of the reefs were remarkably similar in terms of coral species present, they differed tremendously in relative abundance and diversity of coral species. They attributed the differences in coral abundance to differences in environments and stochastic processes. The observed differences in coral diversity exhibited distinct geographical trends which seemed to be largely mediated by temperature. Other factors thought to be important in these biogeographic differences include "regional differences in the extent and distribution of habitat suitable for reef development; prevailing climate and climatic extremes; nutrient input and primary production; and intensity of biologic interactions, including competition, predation, and disease" (Jackson, 1991).
4. Diversity Theories

Various theories exist to explain the maintenance of high diversity in reefs (Connell, 1978). The intermediate disturbance hypothesis suggests that high diversity at a single location is best maintained by disturbances (such as storms, hurricanes, freshwater floods, sediments, and invading groups of predators) that act to stop any one competitive dominant species from monopolizing the area. Thus, there is a balance between competitive exclusion of species by the best competitor and the processes of disturbance that prevent this monopolization. In the absence of this disturbance, diversity would be maintained at a lower level. According to this theory, keystone predators play an important role in maintaining high diversity. Diversity should be highest at middle levels of disturbance since at low levels the best competitor will take over, while at high levels, mortality is too frequent or severe for many species to survive. The fact that coral species diversity is highest at intermediate depths has been used as evidence for this theory: very rapid growth rates in higher light intensity outstrip the effects of disturbance, resulting in the competitive exclusion of the weaker species; factors of disturbance at greater depths dominate and this is a possible explanation for the increased diversity with depth (Thorne-Miller and Catena, 1991). Another example is that of Liddell and Ohlhorst (1987). In their study in Jamaica, they found that coral diversity increased with depth. They also found that light, sedimentation, turbulence, grazing/predation are highly correlated with depth and suggested that these parameters exert a strong influence on the biotic zonation of these reefs. They attribute the trend of low coral diversity at the shallow fore reef increasing towards the deeper fore reef as reflecting the transition from turbulence acting as a limiting factor to merely one of physical disturbance. The explanation of all these patterns is more complicated than what it seems since both resource availability (nutrients, light, zooplankton) and disturbance (water movement and sedimentation) decrease with depth. Another theory maintains that it is the interaction between disturbance and growth rates that determines diversity. Growth rates vary with colony form, branched corals having faster growth rates than more massive forms. Coral growth rate and mortality also decrease with depth.

5. Nutrient Cycling

A recurrent question is how coral reefs, which are highly productive structures, can survive in the oceanic deserts that they inhabit (Figure 4.5). It is generally agreed that nutrient availability, especially that of phosphorus and nitrogen, limits algal growth in coastal waters. Elevated nutrient concentrations can increase primary production, but sustained increases can lead to changes in community structure to an algae-dominated reef. The nitrogen cycle and dynamics of coral reef ecosystems have been studied by many authors (Wiebe, 1985). Being quite complex and ever-changing, nutrient cycles are only briefly summarized here. It has recently been discovered that many members of the coral reef ecosystem fix nitrogen (Wiebe, 1985) and that this fixation is partly controlled by the feeding activities of herbivores. Additional nitrogen is obtained through terrestrial runoff, groundwater sources, and through upwelling of cold, nutrient-rich waters. Fixation of nitrogen by many members of the reef ecosystem is a feature one would expect to find on (probably) all coral reefs except those that
are polluted with sewage or enhanced terrestrial runoff (Wiebe, 1985). Nitrates can be removed from seawater by plants and bacteria through assimilation or dissimilation. Denitrification can also be a source of nitrogen under conditions of anoxia or low oxygen concentrations such as that found in algal mats, *Thalassa* beds, or dead coral heads. Finally, it also seems possible that nitrification or the flux between organic nitrogen and ammonia can occur (such as it does in terrestrial ecosystems where this is the dominant pathway) although there is little data available on this and on nitrate assimilation. The dynamic processes of the nitrogen cycle in coral reef systems are still poorly understood. A new idea is now emerging: that these ecosystems are not really limited by nitrogen, phosphorus, or any nutrient. This is due to their ability to biologically produce it, to the tremendous flux of water around them, and to their ability to efficiently recycle the nutrients and keep them in their ecosystem. Further studies in nutrient cycling should clarify this dilemma and provide information for management decisions.

6. **Reef Zonation**

Although reefs around the world exhibit a great variety of shapes and sizes, all reefs have general morphological features that are the result of interactions between biological growth and physical factors such as water depth, wind, waves, and currents. All reefs can thus be divided into major habitat regions or zones, although all may not be present in every reef (Figure 4.6). A zone is defined as "an area where local ecological differences are reflected in the species association and signalized by one or more dominant species" (Liddell and Ohlhorst, 1987). The **reef front** or **reef slope** faces out to deep water and is the general drop-off of the ecosystem. Here we find a series of surge channels, called spur and groove formations (Figure 4.7), that present the most effective possible breakwater (Longhurst and Pauly, 1987). It is usually here that one finds the greatest number of sponges and fishes due to the great amount of places for them to find shelter and the abundant plankton immediately off the slope. The reef slope may be further divided into zones that correspond to reactions to illumination and wave action. Thus, the lower fore reef terrace-escarpment is the first part of the reef slope. In Jamaica and Mexico, it is usually dominated by the corals *Acropora cervicornis*, *Agaricia agaricites*, and *Madracis mirabilis* as well as crustose coralline algae, clionid sponges, and, to a lesser degree, filamentous and macroalgae. The upper fore reef slope is deeper than the lower fore reef terrace-escarpment. Here corals are by far the dominant category of organisms, although algae occur in the same numbers as in the former subzone. The dominant corals are *Montastrea annularis* and *Agaricia agaricites*. The third subzone of the reef slope is the lower fore reef slope. This zone is deeper and thus is dominated by plate-like corals such as some *Agaricia* species, as well as demosponges and macroalgae. The **reef crest**, sometimes called the **reef flat**, is a 0.5 to 5 m zone at the top of the reef slope. This is the place where the waves crash; thus, making it a high energy environment. It may or may not be capped off by an algal ridge. The organisms that live in this zone must be able to withstand the constant trampling of the waves. In many reefs, this zone is dominated by elkhorn coral, *Acropora palmata*, as well as crustose coralline algae and clionid sponges. The reef flat is usually the shallowest zone (1 m) and it is here that corals are most easily observed due to their near exposure at low tides. It is usually dominated
by filamentous and macroalgae (both calcareous and fleshy forms). Behind the reef crest, towards the shore is the rear zone or back reef. Sloping down from the reef flat to the lagoon is where the richest growth of corals usually occurs, with as much as half of the surface covered with coral colonies (Longhurst and Pauly, 1987). The lagoon or off-reef floor is the shallow zone around a reef. It is usually quite sandy and can support a healthy seagrass community; thus, providing an important foraging area for fishes.

7. Threats to Coral Reefs

In the last 20 years, coral reefs and their associated organisms have been inflicted with a variety of damaging impacts, both from natural and anthropogenic sources. Among the natural damages are the infestations of black and white band disease, invasions by Acanthaster planci and severe storms, in the Pacific, and the mass die-off of Diadema antillarum (very important herbivore) as well as coral bleaching, in the Caribbean.

In contrast to studies in the Pacific which show reefs rapidly recovering, the Caribbean reefs show little signs of recovery, and actually seem to be continuing to decline. In the 1970's, for example, white band disease decimated the Acropora populations in many reefs in the Caribbean. Today, Acropora show little signs of recovery and no other species seem to be taking their ecologically important place. Acroporids offer important protection from the full force of the incoming waves and storm activity. In the Caribbean there are also fewer fast-growing opportunistic species and larval recruitment rates (through growth, fragmentation, and regeneration) are generally an order of magnitude lower than in the Pacific (Kojis and Quinn, 1993). In addition, fertilization success may be very low in the Caribbean compared to the Pacific. All the evidence suggests that Caribbean reefs are less resilient than their Pacific counterparts.

Unfortunately, coral reefs are now threatened throughout much of their range, especially where there are large coastal populations or where tourism is economically important and unregulated. Threats include increased turbidity and sedimentation, abnormal inputs of nutrients and organic matter, pollution by toxic chemicals, thermal loading, changes in water circulation and wave exposure, direct physical damage and breakage, and the selective removal of organisms (Acevedo and Morelock, 1988). In the Philippines, for example, more than 60% of the original coral reef cover has been destroyed in the last twenty years (Longhurst and Pauly, 1987). In Jamaica there have been dramatic changes in the community structure of reefs in the last few decades (Hughes, 1993). Coral cover has declined from 77% in 1970 to less than 5% in 1993, while macroalgal cover has increased from 1-3% cover in 1983 to more than 90% in 1993. The species composition of coral, algal, and herbivore assemblages has also changed markedly. Coral reefs provide substrate and shelter for a wide variety of invertebrates and fishes. Damage to corals may result in the collapse of the complex community of organisms that are closely associated with them.

There are many factors which have contributed to the rapid degradation of coral reefs.
We might not be able to do anything about the natural storms and diseases that coral reefs confront year after year, but we can make a difference in controlling the anthropogenic factors. The response of corals to anthropogenic activities is poorly understood. Further studies on coral tolerance ranges and the effects of these stresses on coral reef communities are urgently needed in order to develop guidelines for their conservation. Below, the most important anthropogenic activities will be reviewed, but one has to be aware that they can also work in unison with each other and with the natural factors, making their additive and synergistic effects even more devastating.

Coral reef ecosystems are extremely sensitive to environmental perturbations since they have very narrow physiological tolerance ranges, and since the interactions of key reef species (plant-herbivore relationships, algae-coral competition, etc.) are susceptible to stresses. Any variation in physical-chemical conditions outside the tolerance ranges of corals could be harmful to their growth and survival (Pastorok and Bilyard, 1985). Humans can affect coral reefs in a wide variety of ways which can be divided into four large groups: coastal development, pollution, fishing and collecting, and recreational activities. Although river runoff is definitely an important detrimental agent to coral communities, many times its effects cannot be separated from the others mentioned above. Rivers discharge fresh water laden with sediments as well as pollutants (sewage, fertilizers, pesticides, etc) into coastal ecosystems. The effects of river runoff will therefore be included in the discussion below.

8. Coastal Development

Coastal development is a term used to describe a wide variety of activities. These may include construction of hotels and condominiums, roads, military installations, golf courses, mining, etc. Most of these activities involve the actual dredging or moving of sand, which is needed either as a construction material, or in order to create or replenish beaches. Dredging is also used to deepen navigational channels and harbors. Sedimentation and turbidity caused by dredging and from river runoff is probably the most important factor affecting coral biota and limiting coral reef community development and survival. Dredging and river runoff increase turbidity in the water and affect corals in three different ways. It may lead to the actual smothering of coral tissue, it alters the optical properties of the light available for photosynthesis by corals, and it increases the concentration of potentially irritating sediments on corals. These effects are not limited to the area directly dredged or smothered, but also to downstream areas where the currents take the suspended particles. Nor are the effects limited in time: continual resuspension and transport of the dredged sediments can cause reef degradation years after the dredging itself has ceased (Rogers, 1990).

If sedimentation is severe, or if sediment loading exceeds sediment removal, a sediment layer builds up on coral colonies which may become anoxic and kill the underlying tissue. This lesion will most probably be overgrown with filamentous algae which will, in turn, prevent the settlement of coral larvae recruits.
Hermatypic corals are dependent on light for their well being. The effluent from dredging of very dense coarse and fine particles, which absorb and scatter light, reducing the transmittance of light energy to deeper waters, and thus a vital source of energy for hermatypic corals. Light attenuation occurs at all wavelengths (Figure 4.8), but is critical at the shorter wavelength range which contains the energy used by photosynthetic organisms. This leads to a decrease in chlorophyll a concentration and thus a decrease in primary production. Water column turbidity may then change both the intensity and spectral quality of the ambient light from that which would be predicted on the basis of depth alone (Dallmeyer et. al, 1982). Corals have been found to reduce their production of oxygen and their chlorophyll content when exposed to peat sediments in the lab (Dallmeyer et. al., 1982). Turbidity has also been known to move the lower limit of coral growth to shallower depths. Acevedo and Morelock (1988) found a high abundance of Agaricia lamarckii, normally a deep-water species, in shallow water relative to its presence farther from the sediment source.

Corals remove sediments from their surface with their tentacles and cilia, by hydrostatic pumping, and by entrapping them in mucus which they produce and which later sloughs off. The active removal of sediment particles requires the time and energy of the coral which would have otherwise been used for food capture, growth, skeletal repair, or reproduction. This diversion of resources from other functions may account for reduced growth rates commonly found in corals living in highly turbid waters. Sediments on coral surfaces may also inhibit exchange of oxygen, carbon dioxide, and metabolites (Lasker, 1980). In the laboratory, corals have been found to increase respiration rates after being exposed to peat sediments (Dallmeyer et. al., 1982). Corals differ in their ability to reject and remove sediments, so sedimentation is likely to have effects on coral distribution, coral community composition, and reef zonation. In general, species inhabiting the seaward margins of a reef are less tolerant of sediment loads than species found in nearshore areas (Pastorok and Bilyard, 1985). More specifically, sea whips and other gorgonians are often the most tolerant of the reef benthos because their morphology accumulates little sediment (Rogers, 1990). Among hermatypic corals, it has been found that Montastrea cavernosa (Lasker, 1980; Acevedo and Morelock, 1988), Acropora cervicornis (Rogers, 1983), Diploria strigosa (Rogers, 1983), D. labyrinthiformis (Dodge and Vaisnys, 1977), Siderastrea siderea (Acevedo and Morelock, 1988), S. radians, Meandrina meandrites, Manicina areolata, and Isophyllia sinuosa (Rice and Hunter, 1992) among others are relatively more resistant to sedimentation than Montastrea annularis (Lasker, 1980), Acropora palmata (Rogers, 1983) (Acevedo and Morelock, 1988), and Diploria clivosa (Rogers, 1983). These findings should be taken with caution because the results of studies comparing species in terms of their ability to remove sediment particles and/or survive burial by sediments are conflicting (see review in Rogers, 1990). For example, Cook et. al. (1993) found that Diploria species (both D. strigosa and D. clivosa), of which D. strigosa is considered relatively resistant to sedimentation, were the most damaged and most slow to recover after the dredging for construction of an airfield in Bermuda. All in all, it seems that corals with larger polyps (Montastrea cavernosa), or with branched (Acropora cervicornis) or cylindrical (Diploria strigosa) morphologies are better adapted to higher sediment loads. This is probably due to the presumption that sediment removal resembles a random walk. Rounder and smaller corals would therefore have a higher chance of quickly removing particles than larger or older corals.
There is evidence that older age classes are less abundant in areas impacted by sediments (Dodge and Vaisnys, 1977).

Sedimentation could also act as a factor determining the distribution and abundance of coral species and reefs. For example, Hubbard (1986) found that extensive reef growth was limited to the west wall of a canyon in St. Croix, U.S.V.I., and that this could possibly be due to the fact that sediment moves into the canyon by the eastern margin, since only gorgonians and a few sediment-tolerant species were found there.

Additionally, sedimentation has also been known to specifically cause decreases in coral cover and coral species diversity in Puerto Rico (Acevedo and Morelock, 1988), Aruba (Eakin et. al., 1993), and many other locations. Coral cover and diversity increased with increasing distance from the sediment source. Other effects included coral bleaching, burial of coral colonies, and colonization of coral surfaces with filamentous algae. All in all, sedimentation seems to affect corals and coral reefs in a variety of different ways: decreased fertilization rates and success of larval development (Richmond, 1983), decreased photosynthesis and net productivity of the coral community, increased respiration rate of corals, decreased growth rates of corals, prevention of coral planulæ from settling (they cannot settle in shifting sediments), increased mortality of individuals, burial and death of colonies, decreased coral cover, decreased coral diversity, upward shift in depth zonation, decreased coral abundance, alteration of growth forms to more branching types, predominance of more resistant species, and alteration in age structure of coral reefs. However, one must remember that sedimentation is only one of the many stresses affecting reefs, which makes it very difficult to differentiate the responses to sedimentation from that to fresh water, sewage pollution, etc.

9. Pollution

There are many different forms of pollution: agricultural pollution includes pollution by herbicides, pesticides, and fertilizers; petroleum hydrocarbon or oil pollution; thermal pollution; sewage pollution; pollution by heavy metals; pollution by radioactive wastes; and pollution by trash. Most of these are increasing globally at an alarming rate. Space and time cannot permit the development of these topics in full. Suffice it to say that the effects of the different types of pollution have been well documented. A few examples will be given in order to give the reader an idea of the possible magnitude of these effects.

a. Petroleum Hydrocarbons or Oil Pollution

Until 1975, there was no evidence that crude oil floating on the surface of the ocean harmed coral reefs. Today, oil pollution in the oceans is a world-wide environmental problem, and concern for it is growing since the very existence of coral reefs is threatened by it. Recent evidence indicates a wide variety of detrimental effects of oil pollution on coral reproduction, growth rate, colonization capability, feeding, and behavioral responses (Loya and Rinkevich, 1980).
Coral populations in oil-polluted reefs in the Red Sea, for example, have been found to have a significant number of anomalies. These include higher mortality rates, decreased vitality, lower life expectancy and settlement rates of planulae on artificial objects, abnormal behavioral responses of corals and larvae, etc. Additionally, studies have documented a large number of reproductive anomalies associated with coral populations living in oil-polluted reefs, which include smaller numbers of breeding colonies, decreases in the average number of ovaria per polyp, smaller numbers of planulae produced per coral head, and premature extrusion of planulae larvae which decreases their viability and chances of successful settlement (Loya and Rinkevich, 1979, 1980).

In the Caribbean, the operation of an oil refinery off Aruba was shown to decrease the density, growth rates, and diversity of coral populations (Eakin et. al., 1993). Offshore drilling for oil involves the discharge of drilling fluids (used to remove drill cuttings and to lubricate drill bits). Although the effects of these toxic drilling fluids and the sedimentation brought about by the actual drilling are hard to separate, it has been shown that some corals alter their feeding behavior, disrupt the normal pattern of polyp expansion and retraction, change morphologically and physiologically, and die after being exposed to drilling fluids (Rogers, 1980). Experiments on the northwestern coast of Panama indicated that oil decreased the percent coverage of all organisms (plants and animals) and that little recovery was evident even 20 months after the oil spill (Dodge and Knap, 1993). It also seems that certain species, such as Acropora palmata, are highly sensitive to oil spills compared to others (Montastrea annularis) (Dodge and Knap, 1993). After the Galeta oil spill in Panama in 1986, there was extensive mortality reported for shallow subtidal reef corals. The total cover decreased by more than 50%, and sublethal effects included coral bleaching, tissue swelling, partial mortality, and tissue lesions (Dodge and Knap, 1993). Other detrimental effects on corals by oil demonstrated in the Caribbean include thinning of cell layers and disruption of cell structure, damage to tactile stimuli and normal feeding mechanisms, and excessive mucus secretion leading to enhanced bacterial growth and eventual coral destruction (Loya and Rinkevich, 1980).

The interacting factors that determine the nature and extent of the biological consequences of oil spills include: the type of oil, dosage, environmental physical factors, prevailing weather conditions, nature of biota, seasonal factors, prior exposure of area to oil spills, presence of other pollutant or stresses, and type of remedial action (Loya and Rinkevich, 1980). To make things worse, it seems that the widely used method to combat oil spills, the dispersion of crude oil emulsifiers, worsens matters since the emulsifiers facilitate the entry of the oil pollutants into animals, which might be adequately protected from the oil alone otherwise (Loya and Rinkevich, 1980). The reader is referred to Loya and Rinkevich (1980) for a very complete review of the studies done on the effects of oil pollution on the coral reef ecosystem.

b. Sewage Pollution

Unlike oil pollution, pollution by sewage has been recognized as harmful to coral reefs for a long time. Its effects have been documented worldwide. The potential impacts of sewage
effluent and the subsequent eutrophication on coral communities have been extensively studied by Banner (1974), Smith (1977), and Maragos et al. (1985) in Kaneohe Bay, Hawaii and by Acosta (1993) in Colombia. Today, coastal eutrophication resulting from anthropogenic influence is considered one of the most urgent environmental signals correlated with the global decline of coral reefs (Lapointe, 1993). The effects of sewage pollution and eutrophication have been reviewed and summarized by Pastoret and Bilyard (1985). They can be divided into three categories: nutrient enrichment, sedimentation, and toxicity.

Nutrient enrichment and the subsequent eutrophication of an area may be caused not only by sewage pollution, but also by increased tourism and industry development along the coast. Anthropogenic eutrophication has been defined as "a combined function of nutrient enrichment, sedimentation, and toxicity associated with the dumping of domestic and industrial wastes" (Tomasick and Sander, 1987). Historical data demonstrate a strong correspondence between the sudden growth of tourism and industry and the degradation of water quality, eutrophication, and demise of coral reefs in Barbados (Bell and Tomascik, 1993). Groundwater seepage and river runoff also magnify the effects leading to eutrophication. When it rains, water percolates through the soil and picks up nitrogen. This accumulates in the groundwater lens which later flows laterally and out to sea at certain points on the coast. Studies have shown that uncontaminated groundwater constitutes a significant source of nitrogen (but not phosphorus) for the reef ecosystem (Marsh, 1977; D’Elia et al., 1981), while contaminated groundwater is both a rich source of nitrogen and phosphorus (Marsh, 1977; D’Elia, et. al., 1981; Lapointe et al., 1993). Groundwater may be contaminated by industry, agriculture and sewage (from domestic households and tourist hotels that dispose of it through cess pits), and river runoff is usually highly contaminated with sediments, sewage, and agricultural wastes (Bell and Tomascik, 1993). The effects of groundwater seepage and river runoff are often the same or hard to differentiate, so they shall all be discussed in this and the following sections.

Direct effects of nutrient enrichment include the enhancement of primary production and increase in biomass of benthic algae and phytoplankton populations, and shifts in species dominance which often lead to blooms of nuisance algae (planktonic flagellates, benthic green or blue-green algae) (Tomasick and Sander, 1987; Marsh, 1977). Indirectly, elevated phytoplankton populations affect coral reefs because they reduce light penetration and/or alter spectral quality, which negatively affects coral zooxanthellae and thus coral nutrition, growth and survival. Phytoplankton blooms and organic loading from anthropogenic sources also increase the sedimentation of organic matter which may smother the corals, and which promotes the growth of filter feeders such as sponges and bryozoans which outcompete corals for space (Tomasick and Sander, 1987). Algae also overgrow corals, suffocating them and killing the underlying organisms by blocking light and increasing sedimentation (Banner, 1974; Maragos et al., 1985). Bacteria in coral mucus also increase and kill coral tissue. As a result of all these indirect effects, heterotrophic processes overwhelm autotrophic processes which results in net coral reef erosion. It has been shown that even low levels of eutrophication can restrict coral growth and reproduction (Bell and Tomascik, 1993). A reduction in coral diversity, through the direct elimination of certain species, and changes in species composition and zonation, has been demonstrated in Barbados (Tomasick and Sander, 1987). Furthermore, Hunte and Wittenberg
(1992) found that settlement and abundance of juvenile scleractinian corals (number or recruits and number of species recruiting) was negatively affected by eutrophication while colonization by other invertebrates (polychaetes, sponges, tunicates, bryozoans) was positively affected by it. This suggests that suitable coral settlement substrate may be limiting on eutrophic reefs (Hunte and Wittenberg, 1992). Nutrient enrichment can therefore affect community structure of coral reefs.

Sedimentation resulting from sewage can be divided into three categories depending on the source from which it originates: particles contained in the sewage effluent, particulate organic matter produced from the nutrient enrichment (already discussed above), and natural particles. The potential detrimental effects of these sediments have already been discussed. Because much of the sewage sediment is organic and is readily decomposed by microbes in the water column or in the sediment, there is a decrease in oxygen levels in the water. Corals and many other tropical organisms live at the limit of their oxygen tolerance, thus a decrease in oxygen level may constitute a significant stress.

Toxic substances in sewage effluent such as PCB’s, metals, chlorine, phosphate, pesticides, and petroleum hydrocarbons also affect coral reefs. They may act in an additive manner, synergistically, or antagonistically; therefore, the results may be very variable. Different toxic substances have been known to kill corals even at low concentrations and reduce reef calcification. Pesticides may be carried as sewage effluent or by river runoff and thus constitute a serious threat to coral reefs near agricultural areas. Pastorok and Bilyard (1985) described that corals had increased respiration rates and decreased photosynthesis rates when exposed to different pesticides. They concluded that the pesticides affected coral metabolism in such a way that their growth and maintenance were seriously compromised. In addition to the toxic substances in effluent, hydrogen sulfide in the bottom sediments near effluent also negatively affects coral reef communities. Hydrogen sulfide increases near sewage effluent due to the increase in organic content in sediments. There is evidence that hydrogen sulfide may cause coral mortality and decrease coral diversity (Pastorok and Bilyard, 1985). Acosta (1993) found that contamination (in general) decreased the reproductive effort of corals in Colombia.

The degree to which coral reef communities are affected by sewage effluent is determined not only by the quality and quantity of the effluent, but also by the physical factors in the surrounding water, previous exposure to stresses, and many other factors. Although only a few studies have been done on this subject, they have demonstrated that sewage effluent do indeed affect coral reef communities in a variety of different ways. Worse yet, it is hypothesized that Caribbean reefs with many sources of groundwater input are more sensitive to phosphorus enrichment and thus anthropogenic pollution than Pacific reefs (D’Elia et. al., 1981) since they provide a balanced nutrient supply needed to sustain nuisance algal blooms.

c. Pollution by Heavy Metals

Pollution by heavy metals has been extensively studied in temperate areas. In the tropics,
however, this topic has received relatively little attention. Mineral extraction, both at deep sea and at coastal sites, is increasing and the fact that the possible effects of mining and smelting on coral communities have not been properly documented is disturbing. A preliminary study on the subject was done in the vicinity of a tin dredging and smelting operation in Thailand (Brown and Holley, 1982). Apparently these activities decreased coral species diversity in an intertidal flat. Many invertebrate species and algae were found to have elevated concentrations of heavy metals. However, coral species did not, and dead coral cover was not significantly higher than in control areas. Apparently these coral species are not obviously affected by the levels of metals discharged at the site. Further studies are needed in this subject to corroborate these results.

d. Recreational Activities

The growth of tourism in many island countries and coasts, together with the development of safer scuba diving equipment and propaganda on marine life from television series, videos, movies, and magazine articles, have inevitably led to the use of the ocean for a wider variety of activities and by many more people. Coral reefs and their inhabitants no longer benefit from the isolation that once protected them, and are now plagued by scuba divers, underwater photographers, reef walkers, spearfishermen, snorkelers, hook and line fishermen, sailors, boaters, etc. Research studies on the impacts of these and other recreational activities on coral reef communities have not been numerous, yet there is growing recognition of the severity of damage associated with them, and a realization that tourism and resource protection are intrinsically interdependent (Rogers et. al., 1988). Tilmant (1987) found a "linear correlation between reef use and physical damage" and has recognized three major concerns for reef environments receiving intensive recreational use: boating impacts, diver impacts, and fishing impacts.

Boating impacts include groundings, anchor damage, and pollution. The effects of oil pollution by boats (mostly gasoline, diesel, and kerosene) have already been described above. Ship groundings and careless anchoring have been listed as the two most important man-made physical impacts threatening Florida reefs (Etshman, 1993).

Ship groundings can be quite numerous in heavily used reefs such as in Biscayne National Park where six groundings were observed in eight patch reefs within three years (Tilmant and Schmahl, 1981). In Bermuda thirteen major ship groundings have occurred since 1940, and these have destroyed approximately 1% of the outer reefs (Cook et. al., 1993). In the Virgin Islands National Park, single boat groundings have been reported to cause several square meters of destruction (Rogers et. al., 1988). Vessel groundings are generally caused by lack of knowledge of the local waters, night operation, and generally poor attention to safe navigational practices. This can cause severe damage to coral heads, especially massive corals. The high incidence of damage to these larger specimens may result in the loss of older large corals, and change the community structure brought about by the destruction of the hiding places used by many fish and other organisms (Tilmant, 1987). Cook et. al. (1993) reported that in Bermuda recovery and recruitment of corals at a major grounding site was very slow, and that
approximately 100-150 years are required to restore coral coverage and species diversity (with Diploria being particularly slow to recover). Gittings et al. (1993) studied the effects of the grounding of the 122 m freighter M/V Wellwood in the Key Largo National Marine Sanctuary. They found that damage occurred along the strip where the vessel made contact with the hard bottom along its inbound path, at the site where the vessel was finally hard ground, and during ship salvage efforts where the propwash and cables dragged on the bottom. Corals were broken, abraded, and toppled over, and where the ship finally came to rest nearly all the corals were destroyed in a 1500 m² flattened area. Additionally shading by the ship caused many corals to bleach. The coral reef community recovered substantially during the next five years, although coral colonies remained small and most recruits were from species that brood larvae. Gittings et al. (1993) suggested transplanting massive coral species that are broadcast spawners and generally have long planktonic stages, low recruitment rates, and low relative abundances in mature communities, in order to help restore previous community diversity and structure. Boat groundings have also caused extensive damage in seagrass beds in the Florida Keys (Matthews et al., 1991). These often leave denuded areas and can cause extensive damage if left for a long term.

Anchor damage has been documented extensively in Florida (Davis, 1977), where an estimated 20% of a zone of Acropora cervicornis was found destroyed in Fort Jefferson National Monument. Anchoring and groundings have been reported as being the most important disturbances in Abrolhos Marine Park on the east coast of Brazil, where breakage of coral heads and disturbances in sea grass beds have occurred (Leao et al., 1993). Anchor damage to seagrass beds has also been documented (Rogers et al., 1988).

Boating in general can also cause damage in soft sediment communities such as shallow seagrass beds (Matthews et al., 1991). Boats leave highly visible prop (propeller) scars which can destabilize grass beds. Secondly, they are responsible for prop (propeller) wash: the suspension of sediments caused when a motorboat, sailboat, or personal watercraft (jetski) runs into shallow water, but does not actually contact the bottom. "Repeated prop washing along one path has the potential to create a channel and cause shoals to form on the edge of that channel smothering existing seagrass. Extensive prop wash in the open areas will increase turbidity and may cause further destabilization of bottom sediments and erosion of seagrasses" (Matthews et al., 1991).

Diver and snorkeler impacts include coral breakage and disturbance of organisms. Many divers are inevitably drawn to corals and other reef organisms and touch, break off, or stand on them without knowing the effects these actions may have on the individual corals or on community structure in general (increased susceptibility to disease or of being overgrown with algae). Others accidentally break off parts of coral or kick up sediment which can weaken corals because they need to use energy to remove the sediment particles, or smother them if they are not able to cope with the sediment load. Eshman (1991) discussed that in Florida 1.4% of the divers end up breaking coral in a 30 minute dive period, and that in a two hour (two tank) dive, an average diver contacts the reef twenty one times! Many divers will also hand-feed fish. The extent to which fish are disrupted or have their behavior or relative numbers modified due to
frequent diver presence (some species are less tolerant to human presence and may be completely displaced) needs to be investigated.

Other recreational impacts on coral reef communities include reef walking, boat littering, and demand for marine curios as souvenirs. The latter may lead to a decrease in the number of target species that are in demand, which may, in turn, cause changes in reef ecology. For example, in Hurghada (Red Sea), the collection of pufferfish and triggerfish for sale as stuffed souvenirs is partly to blame for the sea urchin explosion in the 1980’s, which has caused extensive reef erosion in that area (Hawkins and Roberts, 1993). Reef walking has caused considerable damage to some areas (Rogers et. al., 1988). Recently there has been increasing concern over the tremendous amounts of rubber and plastic trash that is thrown overboard by pleasure boats. These articles are ingested by fish, birds, and turtles, causing their death, and wrap around coral heads suffocating the tissues underneath.

The precise extent to which these recreational activities affect coral reefs is unknown to date. Further studies need to be conducted to assess the effects of each of these activities and the extent to which they may be permitted without significantly altering the community.

Coral reefs are highly complex and diverse communities. They are also inherently beautiful and mysterious, and unavoidably attract a tremendous amount of visitors. Unfortunately, it also seems that coral reefs, perhaps due to their complexity or their limited physiological range, are very sensitive to changes in their environment. Sadly, sometimes it seems that their disappearance is unavoidable. Efforts to manage and monitor coral reefs, and to reduce the anthropogenic stresses that we know affect them must be increased worldwide. Only through the efforts of many will the magnificence of coral reefs be preserved for future generations to enjoy.
APPENDIX V: FISH (IMPORTANT COMPONENTS of CORAL REEF COMMUNITIES)

1. Reef Fish Ecology

The fish community associated with coral reefs is the most complex and diverse known, with approximately 30 to 40% of all fish species known associated in some way with coral reefs. Anywhere from 250 (northern Caribbean) to 2200 (western Indo-Pacific) species can be found in, on, or near a major reef complex (Moyle and Cech, 1988). However, there is a notable lack of quantitative information regarding the distribution and abundance patterns of reef fishes within reef systems, especially for Caribbean reefs (Alevizon et. al., 1985).

Interactions between species are very complex, thus making the overall structure of the fish community very difficult to comprehend. How this great number of fish species can live packed into these relatively small environments has long been the focus of studies concerning biological diversity. The fish communities associated with coral reefs therefore offer some of the best opportunities to study the factors and interactions that encourage the development and maintenance of highly diverse assemblages. The question as to what factors determine which species will occur in a particular place and what it is that gives different assemblages their particular composition is still unanswered. Although there are others available, two different viewpoints have emerged to explain reef fish community structure:

- the deterministic or equilibrium view and
- the stochastic or non-equilibrium view.

The deterministic view recognizes that the fish community is made up of specialized and adapted fishes (shape, color, behavioral patterns, etc. all reviewed in Smith, 1978) that interact in many different ways in order to subdivide and share resources (e.g. food and space), with predation allowing competitors to coexist in some cases. According to this view, reef fish communities are in a stable state of equilibrium and thus are predictable in terms of composition and structure, as long as the processes that govern them and the species interactions are understood.

The more modern stochastic view (Sale, 1980) argues that the basic composition of the fish community is governed by random processes such as destruction of reefs by storms and larval recruitment or colonization. Since fish larvae are constantly being produced and settling on vacant spots on the reef, and since these vacancies are unpredictable, then the species of fish landing on any given space is also unpredictable and random. This hypothesis states that if disturbed, fish species do not necessarily recolonize in the same assemblage. Sale and Douglas (1984) found that fish community structure is independent of any measured aspect of reef structure such as reef topography and substrate diversity, with the exception of reef size. Sale et. al. (1984) found further evidence for the stochastic theory in their study on the Great Barrier Reef where they found that the total number of recruits and species varied significantly among years and reefs despite the fact that differences among sites within reefs did not exist. Thus,
they hypothesized that the relative recruitment success among reefs varied spatially and temporally and that these random processes would lead to yearly differences in fish population composition and community structure. This view would also support Whittaker (1960) which suggested that similar habitats occurring in different geographical zones may exhibit different diversity because different fish communities are available to populate the habitat in each zone. Many other studies such as that of Talbot et. al. (1979) also agree with Sale's theory. They concluded that their assemblages "remained in a permanent, non-interactive, non-equilibria, non-climax state, with a structure heavily influenced by chance factors in recruitment, and continually varying through time." (Talbot et. al., 1979). The stochastic view is further supported by evidence which indicates that it is very hard to get repeatable surveys, and by the lack of groups of species that seem regularly associated with one another in a structured way.

Both views have problems. The stochastic view requires that larvae be constantly available and that space and/or food be limiting. Evidence exists that shows that some fish larvae are not produced continuously (Victor, 1983). In fact, it seems that some fish populations are limited by the availability of settling larvae. Discussion also exists on whether space is limiting or not because some recolonization studies show that after storms space is not limiting, while studies with artificial reefs shows that it is. Furthermore, and in contrast with the findings of Sale and Douglas (1984), Shulman (1984) has shown that recruitment and/or early survival is strongly limited by the number of refuges and therefore by reef heterogeneity. Bell and Galzin (1984) also demonstrated that there was a positive correlation between species density and diversity and live coral cover on reefs of otherwise comparable structural complexity. It seems as if there is a great number of studies correlating fish diversity and number with a gross index of substrate complexity, all of which negate the stochastic theory of fish community structure. The deterministic view, on the other hand, requires resources to be limiting some of the time and species composition to be predictable, neither of which is true all the time.

It seems that this area of ecology is under considerable controversy as evidence can be found for both views depending on the amount of area surveyed (Sale et. al., 1984; Sale and Douglas, 1984; Alevizon et. al., 1985) and the time intervals between surveys. Finally, Smith's (1977) view is a very interesting compromise of the two previous views. He considers that the final structure of the community is the result of stochastic processes of colonization with deterministic aspects of adaptation. It seems certain that a better understanding of the ecology of coral reef fishes and the processes which structure reef fish communities awaits considerable additions to the limited amount of applicable data available. Only through future research will one truly understand what is occurring in these complex; yet, fascinating systems.

2. Reef Fisheries

Reef fish comprise a major, if not the most important resource in the Caribbean, particularly in developing countries with large areas of coastline. The reef habitat associated with many Caribbean islands is limited, and the home range of many fishes associated with these reefs is highly restricted. This creates a concentration of fishes around these reef habitats, which makes artisanal fisheries in the region a viable and economically attractive way of life. Fishing
is widespread and can damage habitat, remove organisms, and indirectly alter community structure on coral reefs.

Reef fisheries usually exploit a large number of species simultaneously. Reef organisms tend to be vulnerable to overfishing because their life history characteristics are not adapted to the high adult mortality associated with fishing. Characteristics of particular concern are the sedentary post settlement of the life history stage, low natural mortality, slow growth, long life, multiple reproductions increased fecundity with size, and geographically restricted distribution associated with reef habitats. Larger individuals, often the top predators, are frequently targeted and are more vulnerable to fishing gear (Plan Development Team, 1990). Populations of reef fishes, specially those of these larger predators, can be rapidly depleted. Increased fishing pressure on certain key species can also cause permanent changes in fish community structure. Fishing has been shown to cause changes in species composition, reduce population abundances (catch rates decline in heavily exploited areas), and lower average fish size (Goeden 1982, Bohnsack, 1993). These large-scale changes of reef fish community structure may, in turn, affect the entire reef system, as well as the fisheries themselves, due to the close links between fish, algal, and coral dynamics. Changes in the patterns of predation and herbivory associated with overfishing of the larger individuals will bring changes in coral reef ecosystems due to the fact that these are strong structuring forces in the reef.

Despite the fact that fishing is the most important human exploitable activity on coral reefs in the world, few studies have documented the effects of fishing on coral reef fish communities, and general knowledge of the impact of fishing on communities of coral reef fishes is limited (Munro, 1983; Bohnsack, 1982). In their analysis of protective fisheries management (reserves), Roberts and Polunin (1991) reviewed the different studies that have dealt with changes caused by fishing in the fish populations themselves as well as in the reef community structure as a whole. It can be said that fishing activities impact coral reefs both directly and indirectly. The reader is referred to Bohnsack (1993) for a review of the studies documenting these impacts. In summary, direct fishing impacts include the removal of organisms (fishes, invertebrates, and turtles) from the reef habitats, and habitat damage resulting from destructive fishing practices. Destructive fishing techniques such as the use of explosives, chemicals, and bottom trawls or drive nets, for example, can directly damage reefs. In the Philippines and Indonesia, most aquarium fishes are taken with sodium cyanide (Ireland and Robertson, 1974). Not only will these fish not live for long, but this method of gathering is extremely harmful to corals, thus leading to serious and extensive destruction of coral reef habitats.

3. Threats to Fish Populations

Indirect fishing impacts can result from the removal of important components of the reef ecosystem, which can disrupt ecological relationships. Predation and herbivory are important structuring forces in coral reef ecosystems, and their alteration, through fishing practices, can bring about drastic changes in the structure of the coral reef and adjacent communities. The balance of competition for space between corals, sponges, and algae, for example, could be indirectly shifted by changes in the densities of herbivores from over-fishing of large predators

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The range of fishing methods used on coral reefs in the Caribbean is extensive. Nevertheless, all are size selective and most target larger individuals within a stock, so that fishing pressure inevitably leads to a decrease in the average size of fishes through the removal of the larger individuals (Roberts and Polunin, 1991). Populations of reef fishes, especially those of large predators, can be rapidly depleted through overharvesting. Additionally, some methods are particularly destructive to corals.

Fishing methods have been classified as being either active or passive. Active methods are those in which the fisherman needs to be physically engaged in the fishing activity in order to catch a fish (Hubert, 1983). Passive methods are those in which the movement of the fishes causes them to be caught in or by a device which is set by the fisherman and then left unattended for a period of time (Hayes, 1983). In general, passive methods tend to be less destructive than active methods because the vessels used in passive fishing are usually not anchored to or on the reefs, and because fishing gear is seldom dragged over the reefs. Both of these activities destroy and cause much damage, sometimes irreparable, to the reef and its ecosystem.

Passive fishing methods include:
- fish traps,
- gill or trammel nets, and
- bottom long lines.

Active fishing methods include:
- spearing (speargun),
- hook-and-line fishing,
- poisoning, and
- hand fishing.

Some of these methods, as well as the effects that each has been known to cause to the fish and reef communities will be discussed below.

a. Trap Fisheries

One of the most widely used artisanal fishing gear on coralline fishing grounds in the Caribbean is the wire mesh fish trap (Figure 5.1). These traps are usually hexagonal in shape (see Munro et al, 1971 for a complete description and drawings of the different types and designs of fish traps), and can be used over a wide depth range, being set at different depths to target different species assemblages. These traps lie on the bottom and capture a wide range of species of reef fish, some of which are not taken by other gear types. It has been calculated (Stevenson, 1978) that annual harvests from coralline shelves may vary from as low as 0.5 metric tons per km² to as much as 4.0 metric tons per km².

A major concern exists that fish traps may be too effective and may damage reef fish
stocks. For example, many noncommercial species and undersized commercial fishes injure themselves and may die in fish traps from attempting to escape from the traps, embolisms caused by the changes in water pressure as the traps are pulled up, stress and handling of the fish at the surface, and from predators such as morays which enter the traps and feed on the defenseless prey. Also, lost traps may continue to catch and kill fish until they finally degrade. Although fishermen usually set fish traps from open wooden boats, today entire reef communities are subject to unregulated exploitation due to increasing conversion to motorized boats.

The most striking characteristic of a fish trap fishery is the great variety of species and sizes of fish which are harvested. Katnik (1982) reported a reduction in the large size classes of parrotfishes (Scaridae), snappers (Lutjanidae), and surgeonfishes (Acanthuridae) when comparing heavily and lightly fished reefs. Trap fishing can also lead to changes in community structure. For example, in the same study Katnik (1982) reported that some fish of less economic importance became more abundant on heavily fished reefs. Likewise, Koslow et al. (1988) hypothesized that heavy trap fishing led to a series of changes in which larger (serranid, lutjanid, and scarid) and deeper bodied (balistid, pomacanthid, and acanthurid) fish species declined disproportionately after trap fishing was allowed in some reefs in Jamaica. It seems that these fish species are more susceptible to overexploitation by traps. Investigations of heavily fished reef flats in Guam have revealed similar impacts on the economically important species there.

One of the most important aspects of fisheries management and regulation is determining the optimum mesh size for a reef fishery. Adjusting mesh size can reduce the chances of overfishing by reducing unwanted by-catch and injuries to undersized fish, and optimize fishery resource production by reducing the mortality of the juveniles (Bohnsack et al., 1989).

b. Gill or Trammel Nets

Gill nets (Figure 5.2) are vertical walls of netting normally set out in a straight line. Capture of fish is based on fortuitous encounters with the net by the fish which become entrapped by the thin filaments, usually by the gills. Gill nets are generally considered shallow-water gear, although bottom sets may be made at depths exceeding 50 meters. The gill nets are among the most effective gear for collecting many species of fishes, and being non-selective in this process, may greatly reduce populations of many species as well as capture juveniles. Gill nets can also be destructive to the habitat if the setting involves excessive standing, walking, or handling of the reef. The overturning of boulders on shallow crests or the placing of hard objects on the reef may result in the crushing of juvenile coral polyps and small colonies, as well as extensive damage to the live tissue of corals, sponges, and other benthic reef biota.

c. Spearfishing

Except for the damage done by the divers (sediment movement, contact with corals, etc.), spearfishing is usually nondestructive of the habitat. However, it is regarded as one of the most damaging to fisheries and reef community structure due to the fact that it is a highly selective method of fishing, with regard to species and size. Spearfishermen particularly concentrate on
the larger predator species and individuals because of their greater food and sport value. Concentrated effort in spearing certain preferred species can reduce their abundance far below what is required to produce a reasonable sustainable yield.

Studies made by Bohnsack (1982) on the impacts of spearfishing on the reef fish populations on three reefs at the Looe Key National Sanctuary in Florida showed that, where spearfishing was popular, piscivorous populations were smaller, and there were significant differences in the overall community structure of the prey species. This was hypothesized to be caused by predator removal through spearfishing. Likewise, Antonius et al. (1978) reported that most large piscivorous predators were conspicuously absent from Looe Key due to spearfishing pressure.

d. Hook and Line Fishing

Fishing with hook and line has been shown to cause little change in reef fish abundance, size, or reef community structure (Tilmant, 1987). Although it may be one of the least damaging methods of fishing, further studies and analyses need to be done on this method in order to judge it correctly.

e. Fishing with Poison

The use of natural poisons is probably the oldest method of fishing known. It has been used by subsistence fishermen for thousands of years with no known adverse effects. However, the effects of today’s use of highly toxic modern chemicals that kill a broad spectrum of life forms on the reef, as well as the effects that these long-lived chemicals themselves might have on the natural ecosystem, have not been analyzed. Undoubtedly, they must adversely affect many elements of the reef community.

f. Collecting for Aquaria

During the last two decades the marine aquarium hobby has experienced a remarkable increase in popularity. This increase has resulted in the development of the aquarium fish industry, whereby many colorful tropical and subtropical marine fishes and selected invertebrate animals such as shrimps, anemones, and sea stars are trapped and sold to pet shops all over the world. The great majority of these marine aquarium trade fishes are coral reef species. This selective type of fish collecting from coral reef habitats may cause significant depletions in some species populations, particularly rare species which are highly prized. The methods utilized to capture the fish may also damage coral reefs because they often involve the close physical contact of the divers with the substrate, and the use of anesthetics.

Fortunately, it seems that fish species populations that have been overharvested by fishing and/or collecting have the ability to recover quite rapidly. Bohnsack (1993), for example, has shown a logarithmic increase in predator abundance in Looe Key, Florida in only two years after spearfishing was banned there.
APPENDIX VI: BENTHIC COMMUNITY MAPS

Using aerial photos and satellite imagery, the benthic community maps of the park were delineated and polygons were attributed. Ground truthing or field confirmation of the community polygons was accomplished by the belt quadrat method. Percent cover of the substrate and lifeform components of the bottom are scored as one of seven possible cover classes. Depending on both the size and geometry of a community, transect lines were oriented across the major axis of the polygon. This may conform with a depth gradient or some other type of variability across the polygon. Transect lines are marked in 1m increments and are used as a guide for the placement of 1m² quadrats, which are bisected by the line and sampled contiguously along the transect. The number of transect lines used at a site was dependent upon the size and heterogeneity of the area. Within each quadrat, the percent cover of substrate and lifeform features were estimated. This rapid habitat characterization accomplishes two goals:

- a quantitative assessment of benthic cover within the polygon, and
- a confirmation of the community designation originally determined from aerial and satellite imagery.

Two benthic community maps were created for Parque Nacional del Este. These maps are based on The Nature Conservancy's Marine Benthic Community Classification Hierarchy (Table 12; this table contains descriptions of each community type). The classification consists of eleven soft sediment or unconsolidated community types and nine hard substrate or consolidated bottom community types. In total, 19 of the 20 community types were encountered and mapped in PNDE; the total area of all the mapped marine communities is 11,416.7 Ha. Table 13 shows the area coverage (in hectares) and frequency of each community type. The community type that had the greatest area coverage was moderate to dense seagrass in sand-mud; while patch reefs were the most frequent community type.

The second benthic habitat map can be constructed by grouping similar community types together; this coarser classification relies on the type of substrate and lifeforms present while ignoring percent coverage. Within this classification, there are five soft sediment community types and four hard bottom community types (Table 12). The soft sediment community types are: 1.) Sand-Mud/Bare Bottom, 2.) Sand-Mud/Seagrasses, 3.) Sand/Bare Bottom, 4.) Sand/Seagrasses/Algal Canopy, and 5.) Rubble/Loosely Consolidated Hard Bottom. The hard bottom community types include: 1.) Algal Turf-Octocoral-Sponge Communities, 2.) Seagrass Communities, 3.) Coral Reef Communities, and 4.) Nearshore Platform/Rocky Intertidal Communities. All of the community types (nine) were encountered and mapped; table 14 shows the area coverage (in hectares) and frequency of each of the coarser community types. In parallel with the more detailed community map, Sand-Mud/Seagrasses had the greatest area coverage; but Hard Bottom/Coral Reefs were the most frequent community encountered.
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Table 6:

**Species Richness (# species) in the Different Benthic Communities in Parque Nacional del Este**

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Table 11:

Threats to Coral Reefs and Surrounding Environments

I. Fishing and Collecting
   - collecting of corals and shells by tourists
   - collecting of corals and shells for commercial purposes
   - spearfishing
   - commercial collecting (food, pharmacology, etc.)
   - collecting of reef materials for construction
   - commercial line fishing
   - trap fishing
   - fishing in mangrove habitats
   - fishing in river mouths
   - commercial trawling close to reefs
   - fishing with explosives
   - fishing with poison
   - use of muro-ami and Kayakas

II. Pollution
    - herbicides
    - pesticides
    - antifouling paints and agents
    - sediments and turbidity
    - sewage / detergents
    - petroleum hydrocarbons
    - heated water from industrial plant cooling
    - hypersaline waste water from desalination plants
    - heavy metals (mercury, cadmium, etc.)
    - radioactive wastes
    - mining

III. Siltation
     - logging
     - slash/burn agriculture
     - dredging
     - coastal mining
     - mangrove destruction

IV. Coastal Development
    - filling
    - sand extraction
    - dredging

V. Tourism / Recreation
    - anchoring
    - reef walking
    - snorkelling
    - diving
    - small boat damage

VI. Military Activity
    - bombing
    - atomic testing
Table 12:

**Soft Sediment / Unconsolidated Bottom Communities**

1A. Sand-Mud / Bare Bottom
   1.1. These communities include calcareous mud banks and flats, island moats, anchialine ponds, and mangrove channels or lagoons.

1B. Sand-Mud / Seagrasses
   1.2. Sparse Seagrass
   Physically similar to mixed algal turf areas with smaller sized sediment grains (.12 to .5mm), but seagrasses predominate (<30% coverage). Usually deeper than mixed algal turf, and can be adjacent to patch reefs or octocoral/sponge reefs.

   1.3. Moderate to Dense Seagrass Communities
   Described as a dense blanket (>30% coverage) of seagrass, typically *Thalassia testudinum* or *Syringodium filiforme* in deeper water or tannin stained mangrove channels. The bed area is extensive and forms a large mound of trapped sediment.

   1.4. Seagrass Patches on Matrix of Soft Sediment
   Described as small patches of moderate to dense seagrass, but each patch is separated by an area of bare sediment; usually found in shallow water. The spatial extent of this community can be quite large.

2A. Sand / Bare Bottom
   2.1. Sand Beaches
   Described as intertidal, calcareous sand beaches.

   2.2. Sandy Shoals and Sand Bars
   Calcareous sands or sandy shoals composed of coarse grain (.5 to 2mm) sand that is very uniform in size. These banks are actively precipitating sediments or oolites because of their round shape. These banks may be exposed at low tides, and have no conspicuous benthos.

2B. Sand / Seagrasses / Algal Canopy
   2.3. Sparse Seagrass
   Similar to sparse seagrass in sand-mud; however, the seagrass is rooted in sediment the size of sand grains. This community is usually found in shallow, nearshore waters.

   2.4. Sandy Algal Canopy
   Green, calcareous algas dominate.

   2.5. Mixed Algal Canopy
   These communities are composed of sparse seagrasses, red algae (such as *Laurentia intricata*), and green algae. Sediment size typically ranges from .5 to 2mm in diameter.

3. Rubble / Loosely Consolidated Hard Bottom
   3.1. Calcareous Rubble Beaches
   These beaches are intertidal, with cobblesized grains.

   3.2. Reef Rubble Communities
   These communities are usually located nearshore or adjacent to reefs, and consist of a predominately bare bottom with rubble sized sediment (>5mm) which can include large rocks that have weathered from the neighboring coast or reef.

**Hard Substratum / Consolidated Bottom Communities**

4A. Hard Bottom / Algal Turf-Octocoral-Sponge Communities
Hard bottom communities are described as having a combination of sponges, octocorals, and/or algae as the dominant benthos.

4.1. Sparse Hard Bottom Communities
Lifeforms cover < 30% of the consolidated substrate.

4.2. Dense Hard Bottom Communities
Lifeforms cover > 30% of the consolidated substrate.

4B. Hard Bottom / Seagrasses
4.3. Dense Seagrass Patches on a Matrix of Hard Bottom
Seagrasses comprise > 50% of the total area.

4.4. Hard Bottom Matrix with Dense Seagrass Patches
Seagrasses comprise < 50% of the total area.

4C. Hard Bottom / Coral Reef Communities
4.5. Patch Reefs
Every patch reef can be recognized in imagery, but groups of patch reefs make up unique communities. These groups will be lumped into one polygon, including the outside of the halo identifying each patch reef. There are two kinds of patch reefs: linear or bank patch reefs and domed or lagoonal patch reefs.

4.6. Platform Margin / Shelf Edge Reefs
These communities can be transitional reefs, reef crests, or spur and groove reefs.

4.7. Fringing Reefs
These reefs are similar to platform margin / shelf edge reefs; however, they occur offshore.

5. Hard Bottom Nearshore Platform / Rocky Intertidal
These communities occur along windward or leeward shore areas, and are characterized by sharp zones of algal and animal species with differing tolerances to heat and desiccation.

5.1. Windward Rocky Community

5.2. Leeward Rocky Community
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<td>Leeward Rocky Community</td>
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<td>Total Marine Benthic Communities</td>
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<td>BENTHIC COMMUNITY TYPE</td>
<td>AREA (Ha.)</td>
<td>FREQUENCY</td>
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<td>Land</td>
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<td>Sand-Mud / Bare Bottom</td>
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<td>Sand / Seagrasses/ Algal Canopy</td>
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<td>Rubble / Loosely Consolidated Hard Bottom</td>
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<td>Hard Bottom / Algae-Octocoral-Sponge Communities</td>
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<td>Hard Bottom / Seagrasses</td>
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<td>Hard Bottom / Coral Reef Communities</td>
<td>857.3</td>
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<tr>
<td>Hard Bottom Nearshore Platform / Rocky Intertidal</td>
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<tr>
<td>Total Marine Benthic Communities</td>
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<td>N/A</td>
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</table>
PARQUE NACIONAL DEL ESTE
EVALUACION ECOLOGICA RAPIDA
MAPA DE ESTACIONES EN MANGLARES

ESTACIONES
EN MANGLARES
M1 Punta Basura (Saona)
M2 Montaña de Caracoles
M3 Lago de Avicenia
M4 Lago de los Peces
M5 Palma Muerta
M6 Lago Salado
M7 Mangle Rojo Muerto
M8 Las Calderas (Norte I)
M9 Las Calderas (Norte II)
M10 Franja Roja (int.)
M11 Franja Roja (ext.)
M12 Mangles Enanos
M13 Lago los Flamencos (Sur)
M14 Lago los Flamencos (Norte)
M15 Lago Punta Cacón
PARQUE NACIONAL DEL ESTE
EVALUACION ECOLOGICA RAPIDA
ROCKY INTERTIDAL MAP

ROCKY INTERTIDIAL SITES
R1 Caseta de Guardia
R2 Caseta de Guardia
R3 Caseta de Guardia
R4 Punta del Cactus (Saona)
R5 Playa Mangle (Catalinita)
R6 Punto del Canal (Catalinita)
R7 Catalinita Sotavento
R8 Islita de Catalinita
R9 Orquidea Salvaje
R10 Punta Basura
R11 Playa Guanabano
R12 Costa Roja (Saona)
R13 Punta Botella (Saona)
R14 Catuano (Saona)
R15 Casa los Flamencos (Saona)
PARQUE NACIONAL DEL ESTE
EVALUACION ECOLOGICA RAPIDA
MAPA DE ESTACIONES BENTONICAS

ESTACIONES BENTONICAS
B1 Parque Nacional
B2 Pasa Grande
B3 Arrecife del Tronco
B4 Hierba del Tronco
B5 Arrecife del Angel #1
B6 Arrecife del Angel #2
B7 Arrecife de Fuertes Olas
B8 Pilas de Lambí
B9 Los Manglecitos
B10 Ciudad de Penicilus
B11 El Peñón
B12 Arrecife de los Cocos
B13 Hierba de los Cocos
B14 Acantilado de Catuano
B15 Arrecife de Rubén
B16 Puerto Catuano
B17 El Toro
B18 El Faro #1
B19 El Faro #2

km

0 2 4
Figure 1.1

NEAR-TERRESTRIAL ZONE

LITTORINA ZONE

NERITA ZONE

UCA ZONE

BURROWER ZONE
**Figure 3.1**

*Thalassia testudinum*

- Leaf
- Branch or Short Shoot
- Rhizome
- Rhizome Meristem
- Distance between branches (CM)

*Syringodium filiforme*  
*Halophila decipiens*  
*Halodule*
Free-swimming larva

Appetitive behavior
Alternate and phases

Delay Releaser

Random contact with a surface

Appetitive behavior
Crawling the surface

Releaser

Contact with pits and grooves

Releaser

Contact with a substance on the surface of another species

Releaser

Contact with adults of the same species

Appetitive behavior
- frequent flexion of the body

Attachment

Block in appetitive behavior
Contact with smooth, uncolonized surface

Block in appetitive behavior
Contact with crowded surfaces
Figure 4.8
Figure 5.1