APPENDIX I

THE STATE OF PUERTO RICAN CORALS: AN AID TO MANAGERS

Report
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I. Introduction
- A. Background
- B. Phylogenetic divisions of corals
  - 1) Hydrozoa
  - 2) Antipatharia
  - 3) Octocorallia
  - 4) Scleractinia

II. Socioeconomic and ecological importance of corals
- A. Ecological importance
- B. Socioeconomic importance
  - 1) Production of pharmacological compounds
  - 2) Prevention of coastal erosion and storm damage
  - 3) Nutrition
  - 4) Recreation
  - 5) Extraction of atmospheric carbon dioxide
- C. Age of Puerto Rican and Virgin Island coral reefs

III. General biology
- A. Reproductive biology
- B. Feeding
- C. Biological interactions and ecological relationships
- D. Capacity for reef formation

IV. Stressors
- A. Natural stressors
- B. Anthropogenic stressors
  - 1) Oil pollution
  - 2) Siltation from upland vegetation clearing
  - 3) Sewage discharge
  - 4) Dredging
  - 5) Thermal pollution
  - 6) Anchoring
  - 7) Scientific activities
  - 8) Ship grounding
  - 9) Overfishing and commercial collection of reef biota for aquaria
- C. Tolerance of corals to stressors and capacity to recover from disturbances
  - 1) short term
  - 2) long term

V. Abundance and present condition of the coral reef resource in Puerto Rico and the U.S. Virgin Islands

- A. Species distribution
- B. Present condition
  - 1) Puerto Rico
  - 2) offshore islands
    - a) Vieques
    - b) Culebra
    - c) Mona and Monito
    - d) Caja de Muertos
  - 3) U.S. Virgin Islands
    - a) St. Croix
    - b) St. Thomas
    - c) St. John
- C. Habitat threats
- D. History of exploitation
- E. Habitat requirements
- F. Habitat information needs

VI. Management recommendations

- A. Identification of critical areas
- B. Most susceptible species
- C. Collection
  - 1) commercial
  - 2) touristic
  - 3) scientific
- D. Cultivation
- E. Monitoring
- F. Probable future condition

VII. References

I. Introduction

A. Background

This work attempts to give an overview of the biology, taxonomy, distribution and state of corals in Puerto Rico, the U.S. Virgin Islands and adjacent islands. It is intended for the general public interested in corals, for managers that wish to evaluate proposed development within the context of the presence of the important ecosystems created by particular types of corals and for the beginning student that will hopefully soon contribute to the better understanding of these interesting animals. This document does not pretend to review all the literature on any of the topics discussed but will hopefully provide the raw material from which a management program for corals will be prepared.

B. Phylogenetic division of corals

Strictly speaking all extant corals belong to the Order Scleractinia of the Class Anthozoa (Phylum Cnidaria). Flexible usage of the word "coral", however, also includes other taxa within and in addition to Anthozoa. Octocorals (O. Gorgonacea and O. Alcyonacea) and black corals (O. Antipatharia) are other anthozoan orders including "corals". Hydrocorals, instead, belong within Class Hydrozoa. In this report the word "coral" will refer only to the Scleractinia and the rest will be noted as: a) octocorals, b) black corals or antipatharians and, c) hydrocorals or calcium secreting Hydrozoa. Details of the most common species are given below.

1) Class Hydrozoa (Cnidaria)

Hydrocorals (Phylum Cnidaria; Class Hydrozoa) are distantly related to the rest of the skeleton forming cnidarians and fall within two orders: the Milleporina and the Stylasterina. The Milleporina (commonly known as fire corals) are colonial and more than one type of polyp inhabits a single colony with specialization for feeding (gastrozooids) and defense (dactylozooids). These polyps protrude through cupless pores that can be easily seen in the skeleton with a magnifying glass and their digestive cavities are interconnected, as in other colonial, skeleton forming cnidarians. They posses stinging cells (nematocysts), generally more powerful than those of other Cnidaria, that enable them to paralyze and capture prey. Hermatypic hydrocorals play a significant role in coral reef construction, particularly in shallow, windward substrates, and their importance will be considered within this context when coral reefs are discussed. In brief, hydrocorals are capable of growing in shallow waters (being emergent during low tides) and, because of their buffering effect, contribute substantially to the protection of coastal lands during times of high seas. The Stylasterina are also colonial but do not contain zooxanthellae. They form small, fragile and cryptic colonies that are usually colorful (pink, purple or red) and branch in one plane. Stylasterines have been used frequently as ornamental pieces and as such may deserve fisheries management. Common species of both orders are included in Appendix 1. and brief descriptions are given in Colin (1978), Cairns (1982) and Kaplan (1988). It is emphasized that these tables do not necessarily include all species but only those usually encountered.

2) Antipatharia (Cnidaria; Anthozoa)

Black corals are typically deep sea, colonial anthozoans usually occurring under ledges possibly because their larvae is negatively phototactic (Grigg, 1965). The axial skeleton is black, spiny and scleroproteinaceous and is secreted in concentric layers around a hollow core. The polyps overlay the horny skeleton, are interconnected and possess six non retractile, unbranched tentacles. They usually contain a diverse array of internal and external unstudied "commensals" that include palaemonid crustaceans, lichomolgid copepods and pilargiid polychaetes (Goenaga, 1977; Humes and Goenaga, 1978).

Black corals are slow growing and their entire colonies are harvested for artisanal purposes in some regions of the Caribbean. In 1970 the local precious coral jewelry industry (black and pink coral) was estimated to have a retail value of more than 4 million dollars. Their axial skeleton is polished and attains considerable thickness in some species, rendering them commercially valuable in the jewelry trade to humans. Species that do not branch are bent for making necklaces.

The ecology and life history of these organisms is, for the most part, unknown but the available evidence suggests that recruitment is infrequent (Grigg, 1976). Therefore, populations of commercially important species can decline rapidly if overharvested. Their taxonomy, to a large extent, is also unknown.

In Puerto Rico and the Virgin Islands commercial harvesting is apparently uncommon but is known to occur. Thick stemmed, branched and large (i.e., potentially important economically) black corals (e.g., Antipathes spp.) occur in water depths below 50 m in La Parguera, Puerto Rico (Goenaga, 1985) although unbranched, thin stemmed species (e.g., Stichopathes spp.) are present at depths of 20 m (Goenaga, 1977). Both genera can also occur sparsely in very shallow, turbid waters off Mayaguez, western Puerto Rico and in La Parguera, southwestern Puerto Rico. The same situation has been observed in Jamaican individuals of Antipathes pennacea (Oakley, 1988). I have observed an individual of Antipathes sp. above depths of 8 m south of Arrecife La Gata, La Parguera, indicating that adult colonies of these species do not require deep waters. In the Virgin Islands, these species are most common at depths exceeding 30 m but can be found on the north shore of St. Croix and north of St.John (e.g. Haulover Bay) at depths of less than 20 m. Some of these colonies have been observed to have been harvested over a several year period which would indicate either cautious harvesting (some of these areas being within the V.I. National Park) or personal collecting for low level jewelry production. Antipatharians commonly settle on sloped surfaces, on the underside of plate-like scleractinians or in crevices, suggesting that the larval stages are susceptible to sediment bed load, to settling sediments, and/or to competition by encrusting organisms that require high light levels such as scleractinians.

Black corals may prove to be important as sclerochronological tools. As stated above they are known to produce growth rings although their periodicity is not well known. If the temporal cycle is defined they may be important assets in the elucidation of environmental variations in deeper habitats (i.e., below the thermocline) where hermatypic corals are absent or rare.

Appendix 1 includes species reported from the Caribbean. For the most part it is likely that most will be present in Puerto Rico and the U.S. Virgin Islands. The source for each record is included.

3. Octocorallia (Cnidaria; Anthozoa)

These cnidarians form soft, flexible colonies that may be bushlike, fanlike or rodlike, depending on the species. The polyps occupy cups within the skeleton and have 8 branched tentacles that are easily seen upon close inspection. In addition to the number of tentacles per polyp these plant-like animals differ from the also plant-like black corals in their capacity to retract the polyps within their skeletons. Their skeleton is internal as in hydrocorals and antipatharians and consists of a central axis composed of a collagenous protein (i.e., gorgonin) and of an abundant meshwork of calcium carbonate spicules embedded within a mass of tissue (i.e., coenenchyme) that surrounds the axial skeleton. This axial skeleton is absent in some species.

Soft corals include members of two orders within the Subclass Octocorallia: Gorgonacea and Alcyonacea. Alcyonacea includes species with skeletons consisting of spicules but no axial skeleton; Gorgonacea includes octocorals with axial skeletons composed of gorgonin (Muzik, 1982). Appendix 1 includes species observed in Puerto Rico and the U.S.V.I.. Reports are based on Yoshioka and Yoshioka (1989a) and personal observations.

Gorgonians are conspicuous members of coral reef ecosystems in the West Indies and can be very abundant in some sites where scleractinian corals apparently are unable to proliferate. The causes for these wide variations in population densities, however, remain to be answered. Valuable insight suggesting water motion and substrate relief as important factors is given by Yoshioka and Yoshioka (1989a and 1989b).

Gorgonians contain large amounts of chemical compounds (e.g., prostaglandins) with no obvious functions (Cierezco and Karns, 1973; Tursch et al., 1978; Fenical, 1982). The hypothesis that these compounds may be used for chemical defense against predators has been postulated by Bakus (1974). This hypothesis has been supported by experimental studies (Gerhart, 1984). This feature of gorgonians has made them the subject of intense collection in southwestern Puerto Rico and to a lesser extent in some areas on the south side of St. Thomas. The ecological effect of this extraction remains unassessed.

4. Scleractinia (Cnidaria; Anthozoa)

Scleractinians are calcium secreting, anemone-like animals that can form colonies comprised of many physically and physiologically linked polyps or else can be solitary or consisting of one polyp. Tentacles occur in multiples of six and the digestive cavities are divided by partitions (sclerosepta and sarcosepta) that radiate from the center of the polyp. In contrast to anemones they produce calcium carbonate, aragonitic skeletons that can reach considerable sizes (e.g., over 5 m in diameter and height in individuals of Montastrea annularis). The skeleton is internal, in contrast to other skeleton forming cnidarians. Many coral species possess annual growth bands, related to variable skeletal densities, that can be used to infer past environmental variations.

Corals can be divided ecologically into those that are capable (hermatypic corals) and those that are not capable (ahermatypic corals) of forming reefs. Reef building corals differ from non reef building species in that the former, and not the latter, contain algal endosymbionts (Dinoflagellata) commonly referred to as zooxanthellae. Zooxanthellae promote fast growth rates and enable hermatypic corals to form large colonies. These colonies accumulate over time and form the largest biogenically produced calcium carbonate buildups on Earth. These buildups are commonly known as coral reefs. Coral reefs are an important asset to nations that possess them. Their socioeconomic importance will be discussed below.

The fact that reef corals are capable of forming coral reefs sets them apart from the other types of corals. Reef forming corals are habitat generating organisms and this aspect poses important management considerations. While management of the first three skeleton forming cnidarians may focus on the individuals, management of the reef building corals will need to focus on the habitat. In other words, a valid management practice for black corals may be to control their collection or to culture them, because it is through collection that they are mainly affected. To effectively manage reef corals it is essential to control all the numerous human activities that are capable of damaging them, either directly or indirectly. This means the control of upland deforestation with its resultant soil destabilization and sediment input into the ocean, sewage outfalls, industrial outfalls, military activities, anchoring practices, and others. In summary, it means managing the coral reefs themselves.

We are of the opinion that the four groups should be included in a management plan but this report refers mainly to the principal coral reef builders, the Scleractinia. This order contains the most endangered corals in Puerto Rico and the U.S.V.I.. For reasons that will be mentioned below this group also contains some of the most fragile or sensitive taxa.

II. Socioeconomic and ecological importance of corals

The importance of hydrocorals, black corals and gorgonians to Homo sapiens has been mentioned in the section Phylogenetic division of corals. As stated above the emphasis of this manuscript is on reef building corals and their importance will be discussed in more detail. First, a brief background on the main products of reef corals: coral reefs.

Coral reefs are tropical and subtropical ecosystems that flourish at temperatures between 25 and 29 degrees centigrade in insular and continental platforms. Within the Wider Caribbean they occur from the Gulf of Mexico south to Panama and Tobago and north to the Bahamas and represent 9 % (1,000 km2) of the total area covered by these ecosystems in the world (Smith, 1978). Bermuda and northern Brazil (Recife) contain the northernmost and southernmost coral reefs, respectively, in the Atlantic Ocean. These regions are related biogeographically to Caribbean reefs but are impoverished in terms of reef related species. The reefs off Brazil exhibit relatively high endemicity (Margarida, 1982).

The principal building blocks of coral reefs are reef corals that accumulate through many centuries. These ecosystems are mainly known for their natural beauty and high biological diversity. The biological diversity in coral reef ecosystems has no parallel on Earth except for tropical rain forests (Connell, 1978). The ecological and socioeconomic importance of coral reefs is given in what follows.

A. Ecological importance

Coral reefs shelter a wide array of plants and animals and, at the same time, generate the oceanographic conditions that permit the establishment of other ecosystems. Seagrass meadows and mangrove forests, for example, occur in waters that are sheltered by the presence of coral reefs. These associated habitats shelter, in turn, many organisms that include commercially important as well as endangered species many of which contribute to the biodiversity of coral reefs as adults. Given this diversity of habitat and biota, coral reefs are important scenarios or natural laboratories where ecological hypotheses concerning or related to the coexistence of species can be tested.

B. Socioeconomic importance

1) Production of pharmacological compounds

A large diversity of chemical compounds may have resulted as a consequence of complex interactions between species in the coral reef. Some of these substances are highly active biocompounds whose applications in medical research are just now being discovered. These include antimicrobial, antileukemic, anticoagulant and cardioactive properties (Fenical, 1982; Rinehart et al., 1981; Salm and Clark, 1982). Coral reef organisms have been used as tools in the elucidation of physiological mechanisms (e.g., sea hare), fertilization (e.g., sea urchin), regeneration and cell association (e.g., sponges) and mechanisms of drug action (e.g., squids)(Angeles, 1981).

2) Prevention of coastal erosion and storm damage

This is particularly important for regions with low lying coastal plains. Coral reefs also contribute to the formation of sandy beaches and sheltered harbors. Beaches of touristic importance in Puerto Rico, such as Luquillo Beach, and many beaches in the U.S.V.I. are protected by offshore coral communities from direct wave action. These communities, although not necessarily structural coral reefs (i.e., do not contain a solid, structural framework formed by corals) are inhabited by corals and other sessile, benthic organisms that protect the underlaying structure, possibly eolionite, and contribute to its growth. The structural complexity of the surface of these reefs produces a baffle effect, which acts to reduce the wave energy.

The importance of the maintenance of healthy coral reef growth to reduce coastal erosion is underscored by the observed sea level rise in the last decades (Etkins and Epstein, 1982; Gornitz et al., 1982). Coastal erosion is likely to be felt more in areas where coral reefs are degenerated since large waves are capable of penetrating more easily in the absence of these natural barriers (Cubit et al., 1984).

3) nutrition

Coral reefs are among the most productive habitats of the world (Lewis, 1977). Fisheries in the Caribbean can be defined, with few although significant exceptions (e.g., upwelling zones and shrimp fisheries), as coral reef fisheries (Munro, 1983). Reef fishery products are often the primary source of dietary protein for coastal and island people. According to the Caribbean Fisheries Management Council (National Ocean and Atmospheric Administration, U.S. Department of Commerce) 59 % of the total fisheries consumed in Puerto Rico and the Virgin Islands come from coral reefs. The fisheries potential of many Caribbean reefs has been impaired in the last decades partially due to overfishing (e.g., Appeldorn and Lindeman, 1985) and, possibly, to habitat degradation (e.g., Bouchon-Navarro et al., 1985).

4) recreation

Tourism on many Caribbean islands is based on reef related activities and on the aesthetic and recreational value of reefs. An example is the underwater trail in Trunk Bay, St. John, which is utilized daily by hundreds of tourists. The National Park on St. John has documented annual increases of visitors to Trunk Bay beach from 20,000 people in 1966 to almost 170,000 people in 1986 (Rogers and Teytaud, 1988). This trend in visitation and impact is seen throughout the Caribbean (Rogers, 1985). Likewise, thousands of residents don masks, fins and/or SCUBA gear and dive on nearshore coral reefs for recreation. Tourism and recreation thus can provide powerful economic arguments for management and can play an important role by educating users about the nature of reef environments and their sensitivity, thus creating a large basis of informed support for continuing reef protection (Kenchington, 1988; Robinson, 1982). This type of development, however, requires close supervision and a parallel educational process about the fragility of component reef organisms. Without these considerations touristic activities can be detrimental to these fragile ecosystems (e.g., Salm, 1985).

5) extraction of atmospheric carbon dioxide

Coral reefs constitute about 0.17 % of the world ocean area and about 15 % of the shallow sea floor within the 0-30 m depth range (Smith, 1978). These ecosystems play an important role in the marine carbon budget primarily through the deposition of aragonitic calcium carbonate. Surface tropical waters, which are stratified by a permanent thermocline, are supersaturated with respect to calcium carbonate. The inorganic transfer of atmospheric CO_2 across the air-sea interface is, therefore, limited. By extracting $CaCO_3$, coral reef organisms provide a way of bringing more CO_2 into the ocean system. Reported rates of $CaCO_3$ deposition by coral reefs demonstrate that these ecosystems are an important buffer in the Earth's CO_2 cycle (Barnes et al., 1986). Coral reefs may contribute about 0.05% of the estimated net CO_2 fixation rate of the global oceans (Crossland et al., 1991). This aspect of coral reefs means that their importance transcends the national level and escalates to aspects of global significance.

C. Age of Puerto Rican and U.S.V.I. coral reefs

Modern coral reefs have deposited on Pleistocene erosional surfaces that flooded when sea level rose after the end of last glaciation. Sea level was about 100 m below present at the peak of the last glaciation and started rising about 18,000 years before present (ybp). At about 8,000-9,000 ybp, Caribbean shelves flooded and reef construction began over topographic highs of the platform. This means that the oldest reefs on our shelves, namely those at the insular shelf edge, are about 8-9,000 years old with those further inshore being younger (i.e., about 4-5,000 years old). In conclusion, even though corals arose as a group in the Triassic (200-230 million ybp; Rosen, 1981)) present coral reefs are relatively young. These assumptions are based on the work of Adey (1978) for St. Croix, U.S. Virgin Islands.

III. General biology

A. Reproductive biology

Corals can reproduce sexually and asexually. Sexual reproduction, usually hermaphroditic (of which several possibilities exist; for a review see von Moorsel, 1983; Szmant, 1984; Szmant, 1986), always result in the formation of minute larvae (called planulae) that spend a variable amount of time in the water column as plankton (from days to weeks) and eventually settle on an appropriate substrate (or die if one is not found). Alternatively, larvae can be brooded within the gastric pouch of its parent and let loose when ready for settling. Larval capacity for substrate selection is unknown for most species but is likely to vary among them. After settling, larvae develop a skeleton and, if colonial, start budding additional polyps that will eventually form an adult colony. Natural selection probably acts more intensely during initial larval recruitment (Crisp, 1977) and is probably the reason for production of vast numbers of gametes. Individuals of some species delay sexual reproduction and use the their available energy for asexual growth until a colony size safe from predation has been attained (Szmant, 1985).

Forms with branching morphology and high growth rates (e.g., Acropora palmata and A. cervicornis) can disperse through breakage during storms (e.g., Highsmith, 1982). Resulting fragments can, although not always do, recruit onto the substrate and form a new colony.

Most corals have well defined seasonal patterns of sexual reproduction (Szmant, 1986). Energy allocated to reproduction can be considerable even in those species in which sexual recruitment is rare. For example, even though Montastrea annularis is one of the most abundant corals off La Parguera and in many reefs off Mayaguez, I (CG) have never observed juvenile colonies of this species. The same can be said for other sites in the Caribbean (e.g., Bak and Engel, 1979; Hughes, 1985). Very small colonies of this species can be frequently observed in La Parguera. Upon close inspection, however, it can be seen that these are remnants of larger colonies that have undergone partial mortality and the rest of their skeleton have been covered by other organisms such as filamentous algae. While this is generally true for the V.I. as well, very small, apparently juvenile colonies have been observed in certain localities (e.g. Salt River submarine canyon (Boulon, 1979; Beets, pers. comm.)).

Different coral species have different colony turnover (Loya, 1976) but, as a whole zooxanthellate corals are more like trees, tortoises and elephants in being remarkable for their longevity (Rosen, 1981). In the La Parguera area, for example, there are corals of the species Montastrea annularis, which form colonies that can reach more than 5 m in diameter and height. Considering growth rates of slightly less than one cm per year (Goenaga and Winter, unpublished data), these corals are many hundreds of years old.

Rosen (1981) has remarked that "there is no real information on what constitutes the life span of most coral species, nor even how this concept applies to corals".

B. Feeding

Cnidarian, skeleton forming animals are well equipped to capture and eat living animal prey. They possess tentacles loaded with batteries of nematocysts. These are stinging cells that serve to paralyze and kill zooplankton. Hermatypic corals (scleractinians and, possibly, hydrocorals and gorgonians), however, are considered polytrophic organisms (Muscatine and Porter, 1977). This means that they can feed at multiple levels in the food web. These modes of feeding include: a) dissolved and suspended organic matter (auxotrophic), b) photosynthetates from zooxanthellae (primary consumers) and, c) zooplankton (secondary consumers). In addition, their capacity to photosynthesize, as a symbiotic unit with zooxanthellae, makes them a very special case of primary producer in which production exceed consumption in many cases.

Hermatypic gorgonians have abundant zooxanthellae in their tissues. The extent to which different species depend on their zooxanthellae for nutrition is, to a large extent, unknown (Muzik, 1982).

Black corals do not contain zooxanthellae. Their tentacular muscles are not well developed and tentacular contraction and retraction are slow. Even so, when presented in the laboratory with living zooplankton they exhibit an efficient preying response. Living food is rapidly engulf with the aid of ciliary currents inflowing through the pharynx into the gastrovascular cavity.

C. Biological interactions and ecological relationships

Reef corals represent a peculiar situation since, in most cases, they are the main constructors of their own habitat, the coral reef. Therefore, their condition reflects the condition of their habitat. If corals are dead or dying, the coral reef is likely to degenerate sooner or later.

Many other organisms, however, do depend to different extents on the condition of the coral reef. These include commercially important species that utilize corals, directly or indirectly, for shelter, food and as spawning sites.

Although the vertical structure (i.e., habitat created by the upward and lateral growth of corals that is capable of sheltering fish, molluscs, crustaceans, among others) of a coral reef is retained for some time after the death of the reef corals, as is the case of Arrecife Algarrobo off Mayaguez, ultimately, bioerosion, formerly counteracted by construction, will possibly flatten the habitat thereby diminishing the available shelters. The associated biota is likely to migrate elsewhere or die.

The biological composition of organisms living in and on the surface of coral reefs depends on many factors, many of which are still not well understood. Littler and Littler (1985) have proposed a model, based on prevailing nutrient concentration, wave energy and grazing pressure, to describe the predominant organisms living on coral reefs. The model fits many of our observations for Puerto Rico and the Virgin Islands and is discussed briefly here. Although Littler and Littler refer mainly to variations among reefs, the concepts can also be applied to trends observed to occur within reefs. Under this model corals gain primacy where there is: 1) intensive herbivory, 2) moderate levels of wave shear, and, 3) low nutrient concentrations. With an increase in the amount of nutrients, the growth of short lived filamentous and leafy algae is favored. Coralline algae, another important component in coral reefs, are generally not inhibited by moderate to high levels of nutrient enrichment but predominate in areas of moderate to heavy grazing, as in shallow, reef front habitats of La Parguera reefs prior to the 1984 Diadema antillarum die off (Vicente and Goenaga, 1984). These also predominate under heavy wave shear. The latter conditions are unknown in Puerto Rico but result in extensive algal ridges or algal crests elsewhere in the Caribbean. Adey and Burke (1976) have described algal ridges and boiler reefs from southeastern St. Croix. Eutrophic waters, where grazing and wave ripping are low, tend to favor large standing stocks of frondose macroalgae that can overgrow and kill both coralline algae and corals. Areas in which nutrient levels are low and grazing activity low to moderate are usually dominated by microfilamentous algae with greater surface area to volume ratios. However, these also appear opportunistically in any system where physical disturbances make space available.

We have also observed that the lower bathymetric limit of predominant photosynthetic reef organisms is, to a large extent, correlated with average water turbidity. Thus, major reef building coral species, such as Montastrea annularis are capable of growing down to 60 m in clear, shelf edge habitats off both north and south coasts of our islands but are limited to depths above 4-5 m in nearshore, turbid waters off Mayaguez. As it is well known, light accelerates calcium carbonate deposition in hermatypic corals and this light enhancing effect results from zooxanthellar photosynthesis. In the absence of adequate solar energy, corals are likely to be under competitive disadvantage.

D. Capacity for reef formation

Coral reefs are marine promontories or mounds that: 1) are capable, in part, of resisting wave action, 2) bind sediments, 3) grow vertically and horizontally by biological and physical processes, 4) are capable of generating hydrodynamic and chemical environments different from adjacent ones, and, 5) provide shelter for a large diversity of vertebrate and invertebrate taxa. The surface or outer layer of coral reefs is colonized and veneered by organisms of many phyla, the most notable ones being corals, octocorals, hydrocorals, anemones, sponges, and algae. Coral reef frameworks, however, are built mainly by reef corals (and infilled by coralline algae, calcareous algae, foraminiferans and molluscs).

The formation of coral reefs is a result of the relationship between scleractinians and zooxanthellae. This relationship allows the symbiotic unit to grow faster and, possibly more important, to grow uninterruptedly over long time periods. In these organisms, as in other colonial organisms, the probability of dying decreases with age (Jackson, 1979). Therefore, coral colonies accumulate over time in the tropics and generate the largest calcium carbonate buildups known in our planet.

The extent to which these buildups are a product of coral growth, however, is not uniform. Many generations of reefal organisms can build significant portions of the relief over which they live (in which case a coral reef is termed "structural" or, "true coral reefs"). In contrast they can overlie topographic highs unrelated to biogenic growth, such as cemented sand dunes (formed during lower sea stands in Pleistocene times). The former is probably the case of many reefs in the Puerto Rican southern coast while the latter is probably the case of many coral communities on the north coast and in the Virgin Islands. This is speculative and confirmation of the dominant process will be possible only after drilling through reef frameworks, determination of framework thickness and dating the underlying substrata.

IV. Stressors

A. Natural stressors

Damage to Puerto Rican and Virgin Island coral reefs due to natural phenomena has been documented on several occasions. Mass mortality of Millepora complanata was observed during heavy rains on the east coast (Goenaga and Canals 1979). Heavy mortality of echinoids and other reef flat organisms was found to be related to extreme low water exposure at mid-day (Glynn 1968).

Hurricanes can modify substantial portions of shallow reefs. Hurricane Edith caused extensive destruction of branching corals in 1963 (Glynn et al. 1965; see account for La Parguera). Two tropical storms in 1979 (David and Frederic) caused extensive damage on the outer east coast and southern coastal reefs. Damage was most obvious in the shallow Acropora palmata zone where colonies were ripped off and overturned causing damage to adjacent massive corals (Goenaga and Cintron 1979). These hurricanes caused damage to the reefs off the eastern point of Vieques (Raymond and Dodge 1980). The more exposed south coast was most severely affected, with most Acropora palmata stands destroyed and Porites beds affected. On the north coast, A. palmata was damaged in the fore reef area and some Porites beds were crushed by broken A. palmata branches, Long Reef experiencing the greatest effect.

Storms have undoubtedly caused the greatest destruction to coral reefs off the south side of St. John in the Virgin Islands (Rogers and Teytaud 1988). Hurricanes David and Frederic (1979), are known to have caused considerable damage to reefs off St. Croix (Rogers et al. 1980) and are most likely responsible for the widespread fragmentation of the dominant branching coral species seen in Fish Bay, Reef Bay, Coral Bay and other southside beaches on St. John. Tropical storm Klaus (1984) caused considerable physical damage to corals in Fish Bay (Rogers and Zullo 1987). Hurricane Hugo caused a significant reduction in total living cover by scleractinians on coral reefs on the south side of St. John (Rogers, et al. In Press). No measurable recovery of live corals occurred in the 12 months following the initial post-storm survey.

Based on frequency of hurricanes in the last decades it has been suggested that the so called "Acropora palmata zone" may not be the prevailing biota in shallow reef fronts in Jamaica (Woodley, 1989) and Puerto Rico (Goenaga, 1990). Instead, if Acropora spp. takes several decades to repopulate these areas, it is likely that this zone is more frequently devoid of branching coral species.

It must be mentioned that although hurricanes appear to be detrimental to coral reefs the opposite seems to be true (in the absence of additional stresses). By displacing large numbers of fast growing, predominant branching coral species that monopolize the substrate, large amounts of space is freed and made available for slower growing, massive species. The net effect appears to be an increase in species diversity (see Connell, 1978). These climatological phenomena have been also postulated to be important in terms of reef growth. Highsmith et al (1980), for example, postulated that hurricanes redistributed large amounts of calcium carbonate from reef corals that were incapable of further vertical growth because of their nearness to the water surface.

As elsewhere in the Caribbean, coral diseases, borne about by different pathogens, are known to attack reef corals in Puerto Rico and the Virgin Islands. The white band disease, for example, has caused drastic population declines in A. palmata. Peters (1983) has suggested that bacteria may be responsible but no causal agent has been specifically identified. The vector of this disease is yet unknown and its incidence in St. Croix is thought to be related to human activities (Gladfelter, personal communication). Vast stretches of living and healthy A. palmata observed in Cayo Largo, Fajardo, in 1979, have been severely decimated possibly as a consequence of this disease. A large portion of the affected colonies remain in growth position. This disease has affected over 5 ha of the A. palmata reef at Buck Island National Monument, St. Croix (Gladfelter 1982) and various other reef areas on St. Croix. Davis et al. (1986) has recorded a rate of advance of 4-5 mm/day for the disease. Many cases of white band disease have been reported from St. Thomas and St. John as well.

The black band disease, caused by a cyanobacteria (Peters, 1984), has been observed to affect corals in Puerto Rico (Peters, 1984) but it is still not as abundant as, for example, in Looe Key, Florida. This disease generally attacks massive, hemispherical corals, mainly Diploria spp. and Montastrea spp. I have observed a limited number of affected colonies in reefs of La Cordillera, Fajardo, and at the El Negro reef off the west coast of Puerto Rico. This disease has also been observed on corals in the Virgin Islands National Park on St. John and Buck Island, St. Croix (Rogers and Teytaud, 1988).

The recent, massive die offs of the black sea urchin, Diadema antillarum, throughout the Caribbean has also contributed to modify corals and the coral reef habitat. Individuals of this species act as bull dozers cleaning the substrate of fast growing fleshy and filamentous algae where coral larvae can settle and grow. Algal biomass within coral reefs has increased after the urchin die offs and other hervibores have not appeared to increase concomitantly. The increase in algal biomass, in turn, is likely to increase the availability of algal propagules that can settle on injuries inflicted to reef corals by various organisms such as fish (e.g., scarids) and molluscs (e.g., Coralophyllia sp.). This situation is possibly worse in artificially eutrophied areas (i.e., where nutrients are dumped into the ocean) where algal growth is likely to be further stimulated.

Another source of stress are the recent, massive coral bleachings (i.e., expulsion of zooxanthellae or their in situ degeneration) in which growth rates are slowed down and their capacity to heal from wounds is possibly impaired. Events of this nature have occurred Caribbean wide in 1987 and 1990 (Williams et al., 1987; Goenaga et al., 1989; Goenaga and Canals, 1990). Studies elsewhere in the Caribbean suggest that bleachings were more severe in polluted areas. National Park staff on St. John observed bleaching of several hard coral species and Palythoa in October of 1987 but not as severe as reported for Florida. D. labyrinthiformis and D. strigosa were most affected and Agaricia lamarki colonies as deep as 27 m were observed bleached (Rogers and Teytaud, 1988). M. annularis colonies were observed bleached at 60 m on the south shelf edge of St. Thomas (R. Boulon, pers. obser.).

B. Anthropogenic

Tropical shallow water communities are subject to many of the same anthropogenic stresses as communities from high latitudes (Hatcher et al., 1989), but the relative importance of these differ and attempts to extrapolate the results of studies from higher latitudes to the tropics have been unsuccessful. For example, dissolved nutrient concentrations are usually much lower in tropical surface waters than in temperate waters. The elevation of phosphate concentrations by 0.75 uM in New England waters would result on the average in doubling of phosphate concentration there, whereas in the eastern Caribbean it would constitute an approximately 40-fold increase (Hatcher et al., 1989).

For these reasons it is essential that we develop tropical guidelines to manage our marine resources. In this section we review the impact of human activities on coral reefs. Included are only those activities that are known to have impacted Puerto Rican and Virgin Island coral reefs at one time or another. Those activities that are capable of damaging coral reefs but that are unlikely to happen in our islands are not discussed. For a brief review of anthropogenic activities that damage coral reefs elsewhere in the Caribbean the reader is referred to Goenaga (1991).

1) Oil pollution

Oil pollution has been known to impact coral reefs in Puerto Rico several times. One instance was when the Zoe Colocotrini ran aground southwest of La Parguera, near Margarita Reef in the early 1970's. Recently (1991), a oil cargo ship sunk in the eastern Caribbean and, after a few days, the oil plume impacted coral reefs in eastern Puerto Rico, particularly those of Isla Culebra. The extent and nature of the impact, however, remains unassessed. Oil spills resulting from leaking oil barges and sunken vessels have impacted coral reefs around all three Virgin Islands and offshore cays at one time or another. An oil spill from a sunken barge off St. Martin reached St. John in early 1991 and affected reefs on the east end of the island. The long-term affects of these oil spills remains unknown.

Although the effects of oil on reef corals in their natural environment is controversial and poorly understood (Loya and Rinkevich, 1980; Brown and Howard, 1985) many coral reef scientists have expressed their apprehension concerning the harmful effects of oil spills (e.g., Bak and Elgershuizen, 1976). Degradation of some Caribbean coral reefs have already been attributed to chronic oil pollution. Chavez et al. (1985), for example, noted that the reef biota at Cayo Arcas, a group of islands off Yucatan (Mexico) that hold an oil pumping station, has been subjected to considerable environmental stress. Specifically, they attributed the disappearance of dense Acropora cervicornis thickets at this site to "activities related to the oil industry".

Bak and Elgershuizen (1976) have suggested that the water soluble fraction of oils in seawater is more harmful to corals than their direct contact with oil. Rutzler and Sterrer (1970) suggested that corals escaped observable damage from an oil spill in Panama because they were continuously submerged. Detergents, however, can disperse oil and its toxic fractions into deeper waters affecting the biota that otherwise would not come in contact (Cerame-Vivas, 1969; Cintron, 1981). Nevertheless, direct field evidence of these effects are generally wanting.

Data from laboratory experiments show that colonies of the scleractinian Madracis mirabilis were more affected by mixtures of various crude oils and Shell dispersant (LTX type) than by either the crude oils or the dispersant separately (Elgershuizen and de Kruijf, 1976). These investigators hypothesized that the observed non additive effects were related to a higher solubility of the toxic oil fraction in sea water after emulsification by the dispersant. Active ingestion of oil drops by corals do not occur and it is unlikely that oil is adsorbed to living coral tissue (Bak and Elgershuizen, 1976).

Mucus produced by corals, however, can trap drops of oil that may be incorporated into the reef food web via the mucus-eating fish and crustaceans (Elgershuizen et al., 1975). Zooxanthellae from the Caribbean scleractinian Diploria strigosa exhibit reduced photosynthesis after eight hour exposure to dispersed oil in concentrations of 19 ppm (Cook and Knap, 1983). Although recovery was rapid, long term effects were not looked at. Also, most of these experiments simulate the effect of episodic, acute oil spills. The effect of chronic, long term oil pollution remains unassessed to our knowledge.

Shinn (1972) observed that the scleractinian Montastrea annularis can survive two hours total immersion in Louisiana crude oil and that Acropora cervicornis, exposed for two hours to a mixture of seawater containing one part crude to 6-12 parts seawater, caused immediate retraction of polyps although recovery was complete after 24 hours. Based on these observations he remarked that "it would seem safe to conclude then that crude oil spills do not pose a significant threat to Atlantic reef corals". However, as Johannes (1975) has noted, this statement is premature since Shinn reported no subsequent observations on these corals. Dodge et al. (1985) determined experimentally that corals treated with chemically dispersed oil at concentrations of 20 ppm showed no depression in calcification. Once again, it is unknown whether long term impairment of vital functions, such as reproduction or maintenance, had occurred in individuals of these species. Also, Shinn's own experiments illustrate the importance of interspecific response to oil. Evidence of pathological responses, including impaired development of reproductive tissues, atrophy of mucous secretory cells and muscle bundles, has been observed in colonies of the shallow water Caribbean coral Manicina areolata during exposure to water accommodated fractions of No. 2 fuel oil (Peters, et al., 1981). This atrophy may help explain the decreased capacity of corals to recover from injuries after subject to oil pollution reported in Panama by Guzman and Jackson (1989). Gooding (1971) also documented an extensive destruction of reef associated biota, other than corals, by an oil spill in Wake Island. Guzman, et al. (1991) studied the short term effects of a major oil spill on the Caribbean coast of Panama in 1986. Their results showed that a large, nearshore oil spill can adversely affect individuals and communities of subtidal reef-building corals, and suggest that the effects may be long lasting.

Other effects of oil and the use of dispersants on coral reefs are the alteration of the physical properties of the reef surface (which inhibits larval settlement), the impairment of oxygen exchange across the air-water interface (Blumer, 1971; Kinsey, 1973) and the interruption of light penetration by surface oil films (Mergner, 1981). These have not been documented in the Caribbean.

A long-term, chronic situation may exist where corals and other shallow water marine invertebrates are increasingly being exposed to oil in the marine environment. This situation is occurring wherever boats are pumping their bilges. Most bilge water contains various amounts of oil and these slicks can be observed wherever the increasing numbers of pleasure and commercial vessels are anchored or moored. I (RHB) have observed up to half a dozen slicks moving downwind from Francis Bay on St. John at any one time from the dozens of boats anchored there. These slicks end up along the north shore of St. John where many reefs are found. The long-term effects of this low level but chronic exposure to oil will be hard to assess.

2) Siltation from upland vegetation clearing

Together with eutrophication this is probably the most significant anthropogenic activity in Puerto Rico and the Virgin Islands having a long term, detrimental effect on reef corals and their associated biota. It is noteworthy that despite recurrent warning to governmental authorities of the effect of upland deforestation on coral reefs (by coral reef scientists including ourselves) and despite multiple examples of the effect on our islands there is apparently little perception of the problem. To say the least, no action is taken. Abundant literature (and abundant examples in our islands and elsewhere) reveal the detrimental effects of the removal of upland vegetation without considering appropriate land conservation practices (e.g., utilization of siltation ponds, stabilization of unconsolidated sediment, reforestation programs and others). Similar problems exist in the Virgin Islands but resource management agencies and the public seem to understand the correlation between upland clearing and loss of sea life due to sediment runoff. This results in less problems of this nature than exist on Puerto Rico.

Siltation of coral reefs results from upland vegetation clearing and is generally considered an important factor controlling reef corals. It can limit reef corals by: 1) increasing water turbidity (Jerlov, 1968) and, thus, affecting the photosynthetic output of zooxanthellae, 2) causing energy expenditure in particle rejection (Lasker, 1980), 3) increasing the potential for bacterial infection (Ducklow and Mitchell, 1979; Peters, 1984), 4) abrasion (Wein, 1962; Storr, 1964), 5) creating conditions unsuitable for larval settlement (Maragos, 1972), 6) reducing feeding periods (personal observations) and/or altering heterotrophic and autotrophic feeding efficiencies (Dodge and Szmant, in press), 7) affecting planktonic food supply (Bak, 1978), and, 8) shifting the relative abundance of fish and promoting the survival of those that graze on the benthos (Galzin, 1981). The removal of mangrove stands, generally accompanying upland deforestation on developed coastal areas, magnifies the problem of siltation. These stands act as natural barriers for runoff due to precipitation. In the Puerto Rican southwestern coast it is not uncommon to observe large sediment plumes after heavy rains where the mangroves have been removed and replaced with stilt houses (CG, pers. obser.). These are located within the coastal zone and many dump raw sewage into the water.

Although coral reefs are known to occur under silt laden and/or eutrophic waters (Goenaga, 1988), it is unknown whether these are in the process of disappearing or whether the component biota is or will be capable of adapting to these conditions. The available evidence suggests that at least some of the biotic components which depend more upon sunlight die in deeper, although are able to persist in shallower, portions of reefs (Morelock et al., 1979; Acevedo, 1986; Goenaga, 1988).

3) Sewage discharge

Reef corals live in waters that are usually oligotrophic or with generally low nutrient concentrations. It has been suggested that the predominance of symbiotic relationships in coral reefs, such as that between zooxanthellae and corals, has evolved in response to low nutrient concentrations (Muscatine and Porter, 1977; Taylor, 1981). This symbiosis has resulted in an efficient recycling of nutrients between host and hostess. Under eutrophic conditions (high nutrient concentration in the water column) organisms with faster growth rates and capable of rapid transformation of nutrients into biomass, such as fleshy and filamentous algae, will usually outcompete or displace the slower growing corals (Johannes, 1975). High nutrient concentration in the water column is also known to stimulate bioerosion (i.e., the biochemical erosion of the vertical, calcium carbonate structure produced by corals by boring sponges, boring annelids and sipunculids) (Highsmith, 1981). The dynamic interplay between CaCO3 accretion (i.e., by coral growth) and destruction (i.e., by bioerosion) of coral reefs is, therefore, strongly influenced by nutrient availability. Examples illustrating this relationship are known from the fossil record (Hallock, 1988). In addition, cnidarian larval settlement, including those of corals, is precluded where the substrate has dense algal growth (Sammarco, 1980). Coral planulae need clean substrates that are free of algae to develop. The most probable outcome in eutrophic areas, as observed elsewhere around Puerto Rico (e.g., Ponce; C. Goenaga and V.P. Vicente, personal observations) and in the Caribbean, is a relict reef in which the vertical CaCO3 structure may, for some time, be preserved but in which the main reef building organisms, namely corals, become an inconspicuous element of the new community. This new community, dominated by fleshy and filamentous algae, is incapable of producing the structure necessary to maintain reef growth.

Sewage discharge into coastal waters may affect coral reef communities by 1) causing nutrient enrichment and enhancing the growth of algae at the expense of corals (Marszalek, 1981), 2) depressing oxygen levels (Wade et al., 1972), and 3) by introducing toxic substances such as chlorine (cf. Muchmore and Epel, 1973). Coral morbidity and mortality under experimental conditions is apparently the result of competition for space with algae and light and not directly related to effluent toxicity (Marszalek, 1981). Sewage is known to stress reefs in Barbados, Curacao, Florida Keys, Guadeloupe, Jamaica, Martinique, St. Kitts and British and U.S. Virgin Islands (Rogers, 1985).

The classical example of the effects of eutrophication on coral reefs is Kaneohe Bay in Hawaii. Twenty six to ninety nine percent of the local coral reefs here were destroyed by overgrowth of corals with the green alga Dictyosphaeria cavernosa due to cultural eutrophication (Maragos, 1972). Partial regeneration of the reef habitat has occurred six years after diversion of sewer discharges from the ocean (Maragos et al., 1985). In Puerto Rico, coral reefs growing close to sanitary discharges also show proliferations of green algae, namely, Ulva sp., Enteromorpha sp. and Dictyosphaeria sp. (V. Vicente and C. Goenaga, personal observations). These tend to colonize corals from their bases, eventually overgrowing them. Recent mass mortalities of the black sea urchin, Diadema antillarum, in the Caribbean make the situation worse. This urchin is a voracious omnivore that continually grazes on fleshy and filamentous algae covering the substrate. The head of the Environmental Protection Agency in the Caribbean, Pedro Gelabert, has recently stated that "...45% of the Puerto Rican coasts are too polluted to swim in them..." (El Nuevo Dia, 13 March, 1991; page 29) and point to raw sewage discharge as one of main pollutants. In the Virgin Islands, the proliferation of residential septic tanks has resulted in high soil loading which, during large rainfall events generates nutrient rich runoff into the sea. This has caused short term eutrophic conditions in various bays around St. Thomas and St. Croix. Faulty ocean outfalls from municipal sewage plants have resulted in severe eutrophication in several areas, notably off the airport in St. Thomas and the south shore on St. Croix. In these areas, algal overgrowth is very evident (RHB, pers. obser.).

4) Dredging

Dredging is a common practice in many embayments of our island. It is usually carried out to increase the depth of ship routes close to shore and for the construction of marinas. While options to minimize the effect to marine ecosystems are available (e.g., screens) these are not always nor thoroughly utilized. Supervision of dredging activities by appropriate government agencies is usually wanting. Dredging of inland lagoons and the devastation of a coral reef community near San Juan is discussed later.

The impact of dredging on coral reef communities are of three basic types: 1) mechanical damage (resulting in breakage of coral and octocoral colonies, many of which subsequently die), 2) sediment loading or siltation (i.e., rapid deposition of coarse silt and sand size sediments resulting from sediment laden water leaking from the dredge pumps) resulting in burial and death of colonies, and, 3) increased turbidity resulting in bleaching, excessive mucus secretion or death in scleractinians. Also, waters over dredged areas have significantly more bacteria than neighboring seawater (Galzin, 1981). This seems related to the suspension of fine sand particles that are utilized as a substratum by the bacteria and may result in the elimination of certain benthic faunal and floral species and the proliferation of tolerant species. Galzin (1981) also found that sand dredging in Guadeloupe, French West Indies, resulted in a decline of the abundance of the fish fauna and a reduction of species equitability.

An additional, usually ignored effect is the resuspension of toxic materials into the water column during dredging. Metals may be detrimental to corals by impairing their physiological processes and possibly by weakening the structure of the aragonite skeleton (Howard and Brown, 1984). This can be the case when dredging near marinas or boat haulout facilities (e.g. Benner Bay, St. Thomas) where toxic metals from antifouling paints have leached into the water and adsorbed onto bottom sediments.

5) Thermal pollution

Activities generating thermal pollution, mainly related to the energy industry, are known to be maintained in the vicinity of Caribbean coral reefs. The effect of this type of pollution on reef corals has not been documented for the Caribbean but it is known that increased water temperatures retard growth or cause mortality in scleractinians and also prevent larval recruitment into thermally enriched areas of reefs of Guam (Neudecker, 1981). Maximum ambient temperatures were found to be close to lethal temperatures for corals in Guam (Mayor, 1918). Mayor noted that the temperature at which the feeding reactions and normal metabolic processes cease are more significant than death temperatures. For example, three species of coral ceased to feed at temperatures 1.5-3.0_C lower than their lethal temperatures. The effect of thermal stress has been thoroughly studied in Hawaii (Jokiel and Coles, 1977; Jokiel and Coles, in press).

It is becoming increasingly important to assess the effect of thermal pollution in light of the proposed coal plant in Mayaguez. The thermal outfall will discharge in the vicinity of coral communities that are already stressed by organic enrichment and siltation. It is plausible that thermal pollution may be the "touche" for these communities. While it has been stated that reef fish proliferate in these stressed coral reefs (suggesting that the integrity of the structural reef components are not essential to the maintenance of, at least, some associated biota) this may turn out to be an understatement. Many reef fish utilize the structure generated by coral growth as shelter. When corals die this calcium carbonate structure (i.e., the coral skeletons) remains in growth position for some time. After a time period which is likely to vary according to prevailing physical and chemical factors the structure collapses due to bioerosion. It is then that reef associated biota will probably migrate elsewhere or die.

6) Anchoring

Anchoring on top of coral reefs can represent considerable disruption to coral reef communities. Davis (1977), for example, estimated that this activity has damaged nearly 20 % of staghorn communities in the Fort Jefferson National Monument, Florida. Tilmant and Schmahl (1981) found a significant linear correlation of reef use and incidence of physical damage. Standing and walking over coral and coral collecting can also ruin large portions of reefs (Goenaga, personal observations). Although this damage appears to be localized and inconsequential in the long run its' cumulative effects may not be so, especially where usage is intense.

Between January and March 1987, Rogers, et al. (1988) studied anchor damage in several northern and northwestern bays on St. John. Of the 186 boats surveyed, 32% were anchored in seagrass and 14% were anchored in coral with the rest on sand, mud or pavement. With an estimated 30,000 anchors being dropped in Park waters each year, this can result in considerable damage. Anchor chains can do more damage than the anchors as they drag across the bottom when the boat swings to wind and current shifts. In 1989 a 440 foot sailing cruise ship, the “Wind Spirit” dropped its anchor on a reef off northern St. John and destroyed some 300 m^2 of coral reef. The case is still pending as the V.I. National Park is seeking $350,000 in damages from the company for reef damage.

However, touristic sightseeing of coral reefs, if well planned and with adequate supervision, seems to be highly compatible with the preservation of these ecosystems and can be highly productive in terms of education and in terms of the employment generated. The economy of many Caribbean islands depend to a large extent on external tourism. The promotion of this activity for internal tourism seems equally important since it is likely to create an awareness of this important natural resource on islanders.

7) Scientific activities

Curiously, scientists are capable of inflicting considerable, although localized, damage to coral reefs. This is particularly so whenever, for example, collection is done carelessly. Reef corals are vulnerable to tissue injuries and these represent sites where algal infection can proceed.

8) Military activities

Military maneuvers near coral reefs are practiced in Vieques, off eastern Puerto Rico. The results from this activities can be quite significant. It seems particularly important to discuss the impact of military activities given that several authors (consultants to the armed forces) have stated that military activities are inoffensive to coral reefs and this notion may be utilized to justify further maneuvers elsewhere.

In 1982, Antonius and Weiner concluded that the "military impact of the Viequen reefs was negligible when compared to natural damage caused by storm- generated wave action". These conclusions are based on comparisons made between the reefs from Vieques and those in the eastern coast of St. Croix (presumably not subject to military activities) with which they found no differences. A close look at their section on Materials and Methods, however, reveals that, in their work, "the emphasis was on shallow water communities". It is widely known and has been extensively documented (e.g., Woodley et al., 1981; Graus et al., 1984; among many others) that damage to coral reefs by storms occurs mainly in shallow waters. It is at these depths that corals with the highest growth rates predominate (e.g., Acropora palmata and A. cervicornis). This is one reason why hurricanes have minimal long term effects on coral reefs (Graus et al., 1984). Deeper portions of coral reefs, where slower growing, massive corals predominate, are not affected as heavily by storms. However, military activities do not discriminate between shallow and deeper portions of the reef and bombs drop in shallow and in deep substrates affecting them equally. It seems reasonable, therefore, to question why Antonius, a consultant for the U.S. Navy, did not investigate the deeper portions of the reefs in Vieques. The same criticism applies to the work by Raymond and Dodge (1980).

In another work, Dodge (1981) also concluded that "...a general similarity between (bombing) range and control stations..." in Vieques, together with "...quantitative coral abundance and diversity data of others (namely, data by Antonius and Weiner, 1982) indicate a lack of anomalous and adverse sedimentation/turbidity conditions affecting coral on reefs near the range area". However, several comments must be made. Reef corals, as well as other organisms, need energy for processes other than growth, namely reproduction and maintenance. The effects of the presence of the range on these two other processes were not assessed. Coral colony fragmentation, a process acknowledged by Antonius and Weiner (1982) and Dodge (1982) to occur in Vieques, is, in fact, known to severely limit the reproductive potential of some species (Szmant-Froelich, 1985). An example of one of this species is Montastrea annularis, the very same species utilized by Dodge (1981) in his study.

Aerial photographs of eastern Vieques do show extensive cratering resulting from bombing activities on land as well as in the sea. Craters range in diameter from 5 to 13 m and the effects extend beyond the extent of direct disruption (Rogers et al., 1978). These reefs are littered with artillery and air-delivered exploded and unexploded ordnance (metal fragments, flare casings, parachutes) which have caused extensive damage. Damage to reefs in Vieques has been categorized by Rogers et al. (1978) as follows: 1) damage by direct hits and by shock waves which shear colonies near the site of impact, 2) damage due to abrasion by steel and rock fragments generated by the blasts, 3) damage by fragments that come to rest on top of living coral tissue, 4) fracturing and weakening of reef structure by blasts and direct hits, 5) dislodgement of colonies which can be transported by heavy seas causing greater damage, 6) deposition of coarse sediments on top of living corals, 7) damage by flare parachutes which drape around soft and stony corals, and others.

Large numbers of unexploded ordnance in these reefs limit their future utilization as fishing and/or touristic centers. It is hard to estimate the costs involved in the restoration of such damage. We can only hope that leaching substances from oxidizing and degenerating ordnance do not further pollute marine life in these areas.

9) Ship grounding

Ship grounding in coral reefs can abrade, fracture or overturn reef biota and hull breakage can result in the spill of hazardous substances. Also, alteration of the hydrodynamic regime while the ship is grounded over the reef can generate sediment plumes that increase water turbidity and smother corals downcurrent. Direct damage by ship grounding is more localized than that of storms but may alter the reef contour and relief to a much greater extent (Smith, 1985).

Curtis (1985) described how portions of Molasses Reef, Florida, was crushed and resembled a "graded roadbed covered with a veneer of coralline debris" when the M/V WELLWOOD grounded. He found that the damage was significant but that it depended on depth, location and afflicted taxa. Additional consequences of this grounding included damage by cable drag, propeller wash scour and shading. In Bermuda, ship groundings have obliterated topographical features of coral reefs creating flat, barren areas with deposits of boulders and rubble and sparse surviving corals (Smith, 1985). Damage to coral reefs by ship grounding has also occurred on other important marine reserves such as Mona Island, Puerto Rico (H. Ferrer, G. Cintron and R. Martinez, Department of Natural Resources, Commonwealth of Puerto Rico, personal communication).

In the Virgin Islands there are few known cases of large ship groundings on coral reefs. Of more widespread concern are the many groundings of pleasure craft, primarily by bareboat (no licensed captain aboard) charter boats. One case is that of Windswept Reef on the north shore of St. John. For several years, before the Park Service installed marker buoys, an average of five boats per week (from 10 to 60 feet in length) were striking this reef (RHB, pers. obser.). The reef was covered with shattered coral heads and fragments of branching corals. Live corals had numerous scars and patches of antifouling paint. Since bouy emplacement, observed groundings have been reduced to less than one per month. Reef recovery will take many years, if it occurs at all. This reef is an extreme example due to its location but similar groundings occur every day in some part of the Virgin Islands.

10) Overfishing and commercial collection of reef biota for aquaria

The manner in which overfishing may affect coral reefs is uncertain but it is likely that the community structure is modified. For example, overfishing of predator species in St. Croix was suggested to be the cause of unusual abundances of the echinoid Diadema antillarum in 1973 (Ogden et al, 1973). Diadema antillarum can locally overgraze bottom vegetation and corals and its abundance has been directly linked to the frequency of recruitment of reef corals (Sammarco, 1980). The community structure of coral reef fish has been dramatically altered as a result of intensive overfishing and this is believed by many scientists to have caused imbalances in the coral reef communities as well.

Massive collection of juvenile fish for aquaria is an established practice in Puerto Rico, particularly in the southwestern and western coast. While the effect of this activity is unknown it is conceivable that there are significant changes in the community structure after selective and intense removal of fish species, many of which are juveniles of commercially caught species. The aquarium trade is usually accompanied by the removal of additional taxa. The removal of, for example, the banded cleaning shrimp (Stenopus hispidus), a species widely collected in southwestern and western Puerto Rico, may have important consequences. This species is a well known parasite cleaner of fish and the effect of lowering its population densities may be important. Furthermore, these collectors usually utilize chemicals to collect fish whose effect on benthic life is unknown or uncertain. It is urgent and of outmost importance to analyze the aftermath of these activities so that they can be regulated.

C. Tolerance of corals to stressors

Degraded reef corals can recover by regeneration of partially damaged colonies or fragments or through recolonization by larval settlement. Factors which can influence coral recolonization include the extent of damage and its location, the availability of coral larvae, the requirement for a "conditioning" period of the substratum before corals can settle, the availability and diversity of microhabitats for settlements and survival, the role of grazers, and competition with other organisms such as algae and soft corals (Pearson, 1981).

The available evidence suggests that coral communities may recover from major natural disturbances after several decades but are likely to suffer irreversible changes from man-made disturbances (Weiss and Goddard, 1977). Full recovery from man-made disturbances may be prolonged or prevented altogether because of permanent change to the environment or a continuation of chronic, low level disturbances (Pearson, 1981). In 1975 Johannes reviewed the known effects of pollution on coral reef communities. He pointed out that reef corals are central to the integrity of the reef community and when these are selectively killed, migration or death of much of the other reef fauna ensues. Accordingly, the environmental tolerance of the reef community as a whole cannot exceed that of its corals.

At this point it is necessary to mention that non-structural coral communities have the same practical importance as coral reefs in terms of coastal protection, nutritional importance, and others. Coral communities differ from coral reefs essentially in the thickness of the biogenic framework. The former form thin veneers over preexisting structures, such as cemented sand dunes, that drowned after sea level rose during the last glacial period. Coral reefs, in contrast, have a thicker framework which, to a larger extent, have been the product of biogenic (i.e., versus physicochemical) activity. Non-structural coral communities give integrity to the underlying structure and prevent its physical or chemical erosion and eventual destruction.

The importance of habitats neighboring coral reefs, such as seagrass beds and mangrove forests, has been stressed by Ogden and Zieman (1977). Seagrass beds are important feeding grounds for nocturnal feeding fishes, such as grunts and snappers, which shelter on reefs by day. When they return to the reef these fishes deposit organic compounds in the form of feces that become available to detritivores and are introduced to the reef food web. Mangroves provide nurseries for juveniles of certain reef fish (chaetodontids, scarids, lutjanids)(Boulon, 1991) and are also feeding grounds for fish that shelter on reefs; mangroves also introduce fixed nitrogen and organic detritus into the trophic system of reefs as do reef flats and seagrass beds. Consequently, damage to these neighboring communities can potentially have an effect on nearby coral reefs. Fishermen on the south shore of St. Croix tell of the marked decrease of fish caught on reefs after the dredging and filling of Kraus Lagoon, an extensive mangrove nursery area. This can only have had serious consequences for the ecological balance of the reefs.

V. Abundance and present condition of the coral reef resource in Puerto Rico and the U.S. Virgin Islands

A. Species distribution

Coral abundance in Puerto Rico, the Virgin Islands and elsewhere is highly variable and dependent on the local conditions. As stated above, the relative abundance of coral species vary naturally both within and among coral reefs. Generally, along many portions of the Puerto Rican north coast reef forming corals are represented by small, sparse colonies with low vertical relief. Coral diversity is also low with tolerant species, such as Siderastrea siderea and Montastrea cavernosa, predominating. In turbid, silted reefs under the influence of river discharge reef corals may be dying or dead below depths of a few meters. For example, at Escollo Rodriguez, Mayaguez, corals below 4 m are scarce and many heads over 100 yrs. old of Siderastrea siderea are over 80% dead with only small patches of living tissue remaining. Colonies living in shallower waters, however, are surprisingly healthy, at least until 1988. Generally, the further offshore, the more healthy and abundant are corals. Similar species distributions occur in the Virgin islands with the exception of coral mortality due to rivers and the heavy discharge of upland sediments. In general north coast reefs in the Virgin Islands are adapted to the annual periods of heavy wave energies during the winter months. South shore reefs are generally more protected but have suffered from the passage of tropical storms and hurricanes, which have a higher frequency of passage to the south of our islands.

Species within all taxa that have been observed in Puerto Rico and the Virgin Islands are listed in Appendix 1. Species that have been observed elsewhere in the Caribbean are expected to occur in Puerto Rico and the Virgin Islands since they belong to the same biogeographic province. These are marked with an asterisk. It should be noted that Brazilian species do not necessarily occur in the Caribbean and are, therefore, not included.

With few exceptions the distribution of stony corals is homogeneous among the coral reefs of Puerto Rico and the Virgin Islands (i.e., most species occur in most reefs) although their relative abundance may differ among reefs. Some species are distributed in relation to physical factors prevailing in different reefs or different coastlines. For example, the hydrocoral Millepora squarrosa tends to have a higher relative abundance where water movement, related to wave energy or currents, is high and may be absent where water movement is low. This species is common on the outer, exposed reefs off La

Parguera and also in the north coasts of our islands. As another example, the scleractinian Agaricia lamarcki and the antipatharian Stichopathes spp. occur in reefs that possess deep or turbid waters. Substrate below turbid waters, as well as that of deep waters, receive reduced solar radiation. The shelf edge reefs off of La Parguera and St. Croix, for example, contain abundant individuals of both species below depths of 20 m. These species, however, also inhabit inshore, shallow (i.e., less than 10 m deep) reefs off Mayaguez.

Differential species distributions also occur within reefs along physical gradients (e.g., depth). Factors such as wave energy, water currents, light intensity and light quality, covary with depth and their effects upon the coral reef biota are difficult to separate. Differential species distribution along physical gradients is often called "zonation" and is exhibited by several species inhabiting the coral reef. The elkhorn coral, Acropora palmata, for example, inhabits only the shallow portions of coral reefs and are rarely found below 5 m. Likewise, in many reefs off of La Parguera, Stephanocoenia michelini is generally (although not always) restricted in the deeper reef substrates. More often, however, coral species are distributed throughout the depth gradients and it is their shape or relative abundance that may differ among microhabitats. The epitome of this situation, called phenotypic plasticity (or variation in growth form according to habitat), are individuals of one of the major coral reef building species: Montastrea annularis (star coral). Colonies of this species vary both in shape and size in relation to the depth gradients. Whereas in shallow, well lit environments it may form colonies that exceed 5 m in diameter and in height, in deep (or turbid) waters it forms plates that rarely exceed 1 m in diameter and few centimeters in height. The latter is also true for sloped surfaces.

In addition to variations related to the depth gradient, conditions are markedly different between areas windward and leeward of the shallowest region of emergent coral reefs: the reef crest. The reef crest, generally but not invariably with abundant colonies of Millepora spp., breaks and baffles wave energy and promotes calm water conditions on the leeward portion of coral reefs. Branching species of Porites generally form extensive, quasi monospecific, beds in the reef lagoon, just leeward of the reef crest. These so called Porites biotopes shelter a large number of other invertebrates and algae. For reasons that are not clear but that may be related both to natural (i.e., storms) and anthropogenic (e.g., eutrophication) causes, the extent of these biotopes has declined sharply within the last two to three decades in the La Parguera embayment and in the outer channels of the Mangrove Lagoon in St. Thomas.

B. Present condition

1) Puerto Rico

The information that follows provides information on the distribution of coral reefs and, therefore, of reef corals and associated biota. It is extracted in part from the coral reef inventory by Goenaga and Cintron (1979) and additional information by Wells (1988). Additional information from unpublished information by V.P. Vicente and myself is included. Information by other observers is credited as such. At present I am gathering additional data that will form part of a more extensive document on the coral reefs of Puerto Rico.

Many reefs in Puerto Rico have suffered considerable damage from human activities. Extensive coral reef degradation has been observed at the following sites: 1) all reefs from San Juan to Las Cabezas de San Juan, 2) inshore Fajardo reefs, 3) Humacao reefs, 4) annular reef off Puerto Yabucoa, 5) inshore Ponce reefs, 6) all reefs off Bahia Guayanilla and Bahia de Tallaboa, 7) all reefs off and fringing Guanica, 8) all west coast inshore reefs from Boqueron to Rincon, 9) reefs off Arecibo, and 10) reefs off Dorado.

Corals grow in most Puerto Rican coasts but differing physical conditions among platform segments result in localized reef formation. Reef development in this document is defined in terms of: 1) biotic cover, 2) cover of the major reef builders, namely reef corals, and 3) vertical structure or substrate heterogeneity.

In general, reef development on the western two thirds of the north coast is limited, except for patchy coral growth. This is possibly due to the presence of large river discharges that generate turbid water and promote unstable substrate unfavorable for larval settlement. As stated earlier siltation is an important factor affecting the distribution of corals.

East of San Juan lies a discontinuous chain of poorly developed and heavily stressed coral communities trending in an east-west direction and extending 1.5 km offshore. These probably consist of thin coral veneers over shallow, eolianitic platforms which, in some cases (e.g. Isla Piedra and Isla Cancora), rise above water (Kaye 1959). Mound-like patch reefs off Punta Las Marias rise to within a couple of meters of the surface. The tops of these mounds contain head corals with Acropora palmata, the elkhorn coral, on the periphery. Gorgonians tend to increase in abundance in the lower slopes.

A well-developed reef system laid in clear waters northwest of Boca de Cangrejos with extensive coral growth from the surface to 10 m depth was virtually destroyed by sedimentation from extensive dredging, and organic pollution from sewage treatment plants in Torrecilla Lagoon (Cintron, personal communication). Currently, almost no living coral is found deeper than 1.5 m. However, an apparently well developed reef occurs northeast of Boca de Cangrejos (Goenaga and Vicente, unpublished observations). Montastrea annularis, the small star coral, has a high estimated relative abundance in these reefs. Although this area is frequently subjected to the inflow of silt laden waters derived from the Torrecillas-San Jose lagoon system, prevailing Atlantic swells apparently do not permit the outflow of these waters over the reef (local fishermen, personal communication).

Off Punta Vacia Talega, stony corals veneer beach rock platforms mainly as encrusting forms. Millepora complanata is the most abundant coral near the surface, and Diploria spp. and Isophyllia rigida are common in deeper areas. Soft corals tend to be more abundant in sheltered areas. Scattered patch reefs that break the surface occur between Punta Iglesias and Punta San Agustin; these do not form a continuous barrier, but provide an effective wave energy absorbing structure. Water visibility is usually low and patches adjacent to the shore are dead, probably as a result of siltation. Water visibility improves offshore but corals are common only in depths of 1-3 m on the outermost reefs.

To the east, fringing coral communities, about .5 km wide, are found on the north and west side of Punta Miquillo and on the north and east side of Punta Picua. Punta Miquillo and Punta Picua were probably once sand cays, but are now connected to the mainland by a broad marsh, the former now severely decimated by construction activities. Both reefs, especially that at Punta Miquillo, have low coral cover. Benthic communities on the Punta Miquillo reef were damaged after a channel was dredged parallel to the shoreline in the 1960's. Punta Percha, farther east, had a slightly higher living coral cover in 1979. Ensenada Comezon has numerous, small patch reefs (about 2 m high) that lack distinct biotic zonation. Algae are dominant there but a number of small coral colonies also occur. Two roughly circular (300-500 m diameter) patch reefs occur offshore from the mouth of Rio Mameyes, each with a periodically exposed shoal of coarse sand. Coral diversity is low, probably due to siltation from the river.

East of this reef system is a complex of bank barrier, fringing and patch coral communities that protect and probably nourish Luquillo Beach at Punta Percha. The fringing reefs surrounding the northern and eastern end of the beach show degradation on the seaward edge where growth is limited to shallow waters. East of Luquillo, water transparency increases gradually and the reefs exhibit slightly higher living coral cover. East of Rio Juan Martin are a series of patch and fringing reefs with low coral diversity, that have been described by Torres (1973). Siltation appears to be the main factor limiting coral growth.

Reef development increases towards the east as river discharge diminishes east of Rio Espiritu Santo. Well developed reefs are common in Siete Mares (Fajardo). The only gross difference between these and other north coast coral communities appears to be the absence of the influence of river discharge in Siete Mares. M. annularis, as well as other scleractinians, are abundant (cover above 16%) in the reef front of the reef outside and west of the northernmost tip of Bahia Las Cabezas. This reef is emergent on its eastern portion and submerged to the west. Gorgonians are more abundant in deeper waters where there are large incrustations of the sponge Anthosigmella varians. The sands at the reef base is coarse and apparently well oxygenated. The brown alga, Dictyota sp., is moderately abundant at the shallow reef portion and unidentified red macroalgae forms dense algal carpets that cover most of the available hard substrates not colonized by benthic organisms. "Isoyake" surfaces (i.e., bare hard substrate) caused probably by grazing are common in shallow waters.

High reef development on the northeast coast occurs in the fringing reef system around the islets situated on La Cordillera but these have never been studied systematically, except for Icacos (Pressick, 1970) and an effort to preliminarily characterize the area by the DNR (Goenaga and Vicente, 1990 unpublished report available upon request). In general these reefs contain patchy, but diverse and abundant coral cover, particularly on their leeward sections. Between these offshore islands and the mainland there are other islets with high reef development on their windward shores (Mckenzie and Benton, 1972). Reef development is apparently directly related to distance from the mouth of Rio Fajardo. Isleta Marina and Cayo Ahogado have been formed by wave deposited sand and coral fragments atop the reef platform, and have a maximum altitude of less than 3 m. They undergo wave erosion periodically.

On the mainland, south of Las Cabezas de San Juan, an extensive but dying reef fringes the coast from northeast Cabo San Juan to the north end of Punta Sardinera, protecting the entrance to Bahia Las Croabas. From Playa Sardinera to Punta Barrancas there are no coral reefs, presumably because of the influence of Rio Fajardo. Narrow coral reefs, however, project eastward about 450 m from Punta Barrancas and Mata Redonda. There is a shallow reef in the northern Bahia Demajagua, but reef development is not extensive (McKenzie and Benton 1972).

Further south on the east coast, Isla Pineros, off Media Mundo, Ceiba, has moderate coral growth on its north and east coasts. Cabeza de Perro, an islet in the same area, was used by the U.S. Navy for bombing practice and lacks marine benthic life. South of this point to Punta Lima, the coast is mainly fringed by Thalassia testudinum beds with occasional small fringing and patch reefs. Some of these east coast fringing reefs probably rest near sand or mud formations, judging from their location at the edge of swamps (Kaye, 1959). Most of them have formed on a 6-7 m deep platform. Many patch reefs that do not reach intertidal level occur off this stretch of coast.

Southwest of Punta Lima coastal waters become turbid as a result of sediment laden rivers and creeks. Several islets such as Cayo Santiago and Cayo Batata occur here and have some coral growth especially in shallow waters and in south facing areas open to the sea. Surprisingly dense 90% living A. palmata stands intermingle (in 1979) with gorgonian and head corals close to the surface. Submerged shoals with sparse coral growth also occur occasionally off Humacao, such as Bajo Parse which consists of numerous gorgonians, small head corals and extensive patches of an encrusting sponge (Anthosigmella varians).

There is little coral growth in Yabucoa Bay (further south) apart from an annular reef in the southern part of the bay with few living corals possibly due, in part, to river runoff (Diaz-Piferrer 1969; Seiglie 1969). About 5.5 naut. mi. east of Yabucoa Bay is the reef La Conga, probably part of the submerged barrier reef bordering a large portion of the southern shelf of Puerto Rico.

A fringing reef extends almost continuously for four miles along this coast between Cabo Mala Pascua to Puerto Patillas which is exposed at low tide and protects a low sand apron at the foot of the Sierra de Guardarraya. A similarly stressed reef is responsible for the seaward protection of Punta Figueras. Arrecife Guayama, lying 0.6-0.9 km off Punta Figueras and nearly 5 km in length, is well developed, but now affected by siltation. The A. palmata zone has low coral cover and many dead colonies. West of this reef are the Corona and Algarrobo patch reefs which appeared relatively healthy and little affected by siltation in 1979.

Arrecife Las Mareas, south of Las Mareas, Guayama, is almost devoid of living coral and extensively colonized by fleshy algae. Southwest of Punta Pozuelo, a fringing barrier reef, Cayos Caribe extends for about 2.5 km. Cayos de Barca and Cayos de Pajaros are part of the same system although shallow channels divide them. The system forms an arc that protects the entrance of Bahia de Jobos. On the lee side of the reefs are a number of narrow sand cays fringed by mangrove vegetation. Living coral cover is moderate and tends to increase westward.

Numerous offshore keys occur off Salinas, Santa Isabel and Ponce (e.g., Unitas). About 2.5 km south of Ponce, an area of prolific gorgonian growth, particularly in shallow waters, is found at Bajo Tasmanian. This consists of a two-tiered platform, the northern level 6-12 m deep, and the southern level 18-24 m deep. Acropora cervicornis is common on the deeper portions. Large shingle-like growths of various massive corals occur in the shelf edge (Beach 1975). Las Hojitas reef, east of Punta Cucharas, is a perfect example of a dead coral reef. There are extensive dead coral colonies in the reef front whose outline can be easily seen but that are covered by extensive algal and sponge cover possibly due to increased nutrient content of the waters originated by the discharge of sewage treatment plants. South of Punta Cuchara lies Arrecife Ratones. Its deep reef front consists of an irregular bottom with silty sand at the base of the reef and among depressions. Topographic relief is high and generated primarily by scleractinian corals. Cover of sessile benthos is dominated by this taxa with Agaricia agaricites, M. annularis and M. cavernosa being the most abundant species (living coral cover about 5%). Large dead scleractinians, however, are often observed. Gorgonians are common to abundant. The surface of dead corals and substrate not colonized by zoobenthic organisms is covered by a thin, coralline algal tuft overlain by fine sediment.

Further west off Tallaboa living coral cover and diversity are low, due possibly to the industrial development of the area. Isolated heads of Acropora palmata and Millepora complanata occur on the seaward side of Arrecife Guayanilla. The reef off Punta Verraco has an extensive Thalassia and Syringodium bed on its reef flat. Stony coral cover in the shallow front reef is very reduced. The deeper fore reef has an extensive communities of gorgonians. Arrecife Unitas, northeast of Arrecife Guayanilla, exhibits low scleractinian cover and low gorgonian density. Off Punta Ventana, southwest of Guayanilla, is a submerged reef with moderate cover by scleractinians. Gorgonians are abundant and the reef, in general, seems to be well developed, in relation to those off Guayanilla and Tallaboa bays.

An extensive submerged reef surrounds the coast east of Punta Ventana to Punta Vaquero, where it breaks the surface. This reef protects Playa Tamarindo, Bahia de la Ballena and Playa de Cana Gorda on the coast of Guanica and has low living coral and huge carpets of the fast-growing colonial anemones Zoanthus and Palythoa lie over the predominately dead coral framework of the reef front. Patchy coral growth, with occasionally large colonies, occurs on the more protected, leeward reef sections.

West of Punta Jorobado, reefs become more prolific and complex in the area of La Parguera. This region is considered to have highest development of coral reefs in Puerto Rico. The coral reefs of La Parguera as well, as those elsewhere, are undergoing modifications mainly by proliferation of filamentous and fleshy alga (Vicente, 1987; Goenaga, 1988). The causes are unclear and may be related both to anthropogenic and natural causes.

Off La Parguera is a submerged (i.e., it does not break the water surface) barrier reef at the edge of the insular shelf. This reef is diverse and biological cover of benthic organisms is high in many areas (Boulon, 1980; Weinberg, 1981). The reef extends to the east towards Guanica and Guayanilla, where cover and diversity are reduced, and also towards the west. The geology of a portion of this system was studied by Quinn (1972) who concluded that, as other submerged shelf edge reefs of the Caribbean, it had been formed when sea level was low about 12,000 years ago after the end of the last glaciation.

Bahia Sucia, east of the Cabo Rojo lighthouse, contains a submerged coral reef, Rock-ola, with large colonies of M. annularis and abundant fish. In Bahia Salinas, west of the Cabo Rojo lighthouse, patches of coral alternate with Thalassia testudinum grass beds, and are described in Almy and Carrion-Torres (1963). Nearshore, between Cabo Rojo and Mayaguez there is high water turbidity, unusually slight wave action and heavy land drainage. The broad bank that lies immediately offshore minimizes wave action and probably limits water circulation and the removal of land drainage pollution. The coral patches and assemblages generally have few stony corals but dense stands of gorgonians occur there. Living stony corals are partially covered by mats of macro algae in some areas (Kolehmainen, 1974).

Offshore reefs include Escollo Negro and Arrecife Tourmaline, Las Coronas, Escollo Rodriguez, Cayo Fanduco, Manchas Interiores, Manchas Exteriores, Arrecife Peregrina and Gallardo and many other submerged banks with coral communities. These reefs are distinct from those of La Parguera and others in the south coast in that generally there is no well developed reef front. The substrates have reduced slopes and patchy coral growth with abundant gorgonians. North of El Negro, near but south of the shelf edge, there are deep reef sections that have abundant cover of platelike colonies of M. annularis over a medium relief substrate that results in an extensive and complex system of crevices and caves inhabited by abundant fishes. This habitat is quite unique and has been observed only off southern Vieques (I. Sadovy, personal communication), in addition to the Mayaguez platform. Las Coronas is a shallow (2-4 m) sand shoal colonized principally by large sized gorgonians and occasional massive corals. Manchas Interiores, Manchas Exteriores and Arrecife Peregrina have low relief spur and groove systems sloping more or less abruptly westward where inhabited by black coral (Antipatharia) and deeper water fauna. Encrusting coral growth with large pillar corals and gorgonians dominate the shallow depths. Escollo Rodriguez, about 1.6 km west of Cano Corazones consists of a series of elongated patch reefs. There is abundant fish life but the reefs appear to be affected by siltation from the Guanajibo River (Schneidermann and Morelock 1973; Goenaga, 1988). Much of the scleractinians inhabiting waters below 4 m are dead or dying. Shallow waters, however, contain surprisingly healthy and large colonies of M. annularis. Bajo Gallardo is a well-developed, relatively untouched reef about 13 km west of Punta Aguila, Cabo Rojo, with luxuriant elkhorn coral growth and abundant fish life. Other reefs in Mayaguez Bay exhibit signs of eutrophication and are described by Goenaga (1991, unpublished report).

North of Arrecife Peregrina to Punta Higuero, the insular shelf is less than 1 km wide and has coral communities on the outer edge where the bottom slopes steeply. Stony corals, unusual gorgonians, and black corals are abundant at depths of 15+ m but water transparency is quite variable, being influenced by river discharge. Poorly developed fringing reefs, consisting mainly of partially dead Acropora palmata and scattered gorgonians occur on the north side of the Rincon peninsula from Punta Higuero to Punta del Boqueron. There are a series of submerged coral communities about .3 km north of the Culebrinas river mouth, west of the town of Aguadilla. A large portion of the substrate of these reefs are covered by dense algal mats dominated by the articulated coralline algae Jania sp. and Amphiroa sp. Coral cover is generally low but can be higher than 10% in some patches. Coral colonies are generally small but abundant locally. Off Punta Tamarindo there are exceptionally large colonies of Acropora palmata in shallow waters. These colonies are approximately round in outline and inhabit a substrate where other corals are small and uncommon.

An underwater cave system occurs off Bajura, Isabel, which has dense coral growth, mainly agariciids, on the outer walls and ledges. The biota in these caves, about 1 to 6 m deep, has never been studied in detail. Some inner portions contain what appears to be fossilized A. palmata colonies. Surfaces of inner walls often contain extensive patches of the ahermatypic coral Tubastrea aurea.

Submerged patch reefs occur off Camuy and Puerto de Tortuguero and several minor coral assemblages are present in Arecibo. North of Dorado, is an extensive but highly stressed reef fringing the shore. The reef flat (1-3 m deep) has abundant gorgonians (e.g., Gorgonia spp.), and the predominant corals are Diploria strigosa and D. clivosa (brain corals). The reef front has many dead corals overgrown by algae and other corals and very high densities of Gorgonia flavellum (?). Seaward of this reef are small patch reefs at 25 m with abundant fish life.

2) offshore islands

a) Vieques

Numerous reefs are found around the coast of Vieques. Reefs off the eastern end are well known as a result of series of studies carried out in relation to a law suit by the government of Puerto Rico to the U.S. Navy in relation to environmental damage by military activities there (see discussion on the effect of Military activities in the section on Anthropogenic stressors). The area is used as a practice range for air dropped bombs and ships gunnery, but includes reefs at Punta Este on the eastern point, Penasco Fosil, Punta Gato, Gato Afuera, Isla Yallis and Punta Icacos on the north coast and Cerro Indio, Pena Roja, Bahia Salinas, Punta Salinas, Cerro Matias and Roca Alcatraz on the south coast.

Raymond and Dodge (1979) carried out an ecological survey of the shallow reefs fringing the promontories on the eastern, western, and northern shores of Bahia Salinas del Sur. The fringing reef off the west side of the bay consists of a well-developed Acropora palmata community. Banks and mounds of Porites porites have developed around two distinct promontories on the north coast (MacIntyre et al. 1983). The fringing reef on the eastern side of the bay consists of coral heads of the genera Montastrea, Siderastrea and Diploria. Another reef with a shallow reef front dominated by A. palmata and deeper head corals extends out from the promontory. The seaward slope levels off at 8 m, grading into the sediment floor of the bay. The back reef shoreward of the reef crest is composed of large colonies of M. annularis on rubble and pavement. MacIntyre et al. (1983) describe the results of core drilling and give estimates of accumulation rates for this reef. Roca Alcatraz, an island 1 km south of the bay is surrounded by A. palmata colonies.

b) Culebra and Culebrita

Ensenada Honda on Culebra has been described by Cintron et al. (1974). Communities of Porites furcata are found along the southeast coast (Glynn, 1973) and are extensive off Puerto del Manglar off the eastern coast (Goenaga, 1983). These corals form extensive monotypic stands that extend from the leeward reef through the reef crest and into the reef front. This is quite uncommon in other reefs where large, monotypic stands of this coral are restricted to the leeward reef sections.

c) Mona and Monito

Coral reefs or coral communities fringe most of the southeastern, southwestern and western sections of Mona. These lie at the zoogeographic center of the Caribbean Basin and contain maximum species richness for Caribbean coral reefs.

Cintron et al. (1975) described coral community zonation for Playa de P†jaros, Punta Caigo o No Caigo, Playa Uvero, El Capitan to Punta Arenas, Cabo Barrionuevo and the east and southeast cliffs of Monito. They conclude that the main coral communities habitat types were: 1) spur and groove, 2) the "drop off" at Carabinero, 3) the submarine caves at Carmelitas and, 4) the submarine cliffs of the north coast. They observed a total of 22 species and one hydrozoan. Coral abundance was said to be minimal along the vertical faces of the cliffs on the northern shore of the island where sponges and gorgonians are predominant zoobenthos. Coral communities are abundant from Cabo Barrionuevo on the northwest side to Punta Este on the east coast. Encrusting and solitary coral colonies scattered over hard bottom occur on the Carabinero and Playa Uvero shelf. Weinberg (1980) made a quantitative study on the "drop off" at Carabinero and he found a general impoverishment of species along the fore reef and down the drop off. Canals et al. (1983) report percent living coral cover at Playa de Pajaros, Playa Sardinera and Las Carmelitas. These range from 2.2% to 90.0%.

d) Caja de Muertos

Canals et al. (1980) describe the coral reefs of Caja de Muertos. Reef development is highest in the northeast coast of this island. The southern and western coasts contain patchy coral growth. These are small and underdeveloped reefs. Goenaga and Cintron (1978) documented the complexity and diversity of the lagoon of the eastern fringing reef.

3) the U.S. Virgin Islands

a) St. Croix and Buck Island

The St. Croix shelf is very different from the northern islands' shelf in that it is much narrower and shallower, which produces a compression of reef types and also allows less extensive areas of deep reef communities.The proximity and shallowness of the north shore shelf edge reefs has enabled them to be studied relatively extensively whereas the shelf edge reefs on the north sides of St. Thomas and St. John have not been studied at all. The shelf edge reef on St. Croix's north shore is similar in structure and community composition to the shelf edge reef described south of La Parguera, P.R.. This reef system runs fairly continuously from Butler Bay on the west coast to the western end of Long Reef on the north coast. The shelf edge reef along this shore ranges from several hundred meters to a little over a half a kilometer from the coastline. Just seaward of the coastline along this shore lies a zone of hard carbonate pavement followed by mostly dead reef patches encrusted with living coral (Multer, 1974). These have produced an irregular and broken series of wave resistant spurs. The dominant coral on these structures is A. palmata with scattered growths of A. cervicornis, P. astreoides, P. porites, D. strigosa, M. complanata and others. The shelf edge reef is dominated by M. annularis with varying amounts of A. agaricites, P. astreoides, P. porites, M. cavernosa and other species of hard corals. This reef has developed spurs made up of M. annularis sometimes also having shingle-like layers of A. agaricites. These spurs alternate with sediment chutes floored with coarse sand which is being transported off the shelf via these chutes. Coral growth ends at 60 to 70m and framework builders are replaced by sclerosponges such as Ceratoporella nicholsoni. The main stress on the shelf edge reef is the frequent anchoring of dive vessels. Several dive operations and sport divers come here to see the well developed reef, the many fish and experience the spectacular wall dive.

Near the eastern end of this system is Salt River submarine canyon. The two walls of the canyon differ markedly in coral cover, possibly the result of differences in vertical profile and substrate type (Boulon, 1979). The east wall ranged from less than one percent coral cover in the inner portion to 25 percent coral cover near the shelf edge. The most common species were Mycetophyllia sp., M. Annularis, D. strigosa, Agaricia sp. and M. cavernosa. The west wall is much steeper with solid substrate and ranged from 22 to 59 percent coral cover with the most common species being M. cavernosa, Agaricia sp., Porites sp. and S. siderea. Increases in sedimentation from upland sources have undoubtedly decreased coral growth and cover since this survey was made.

Long Reef extends eastward to Fort Louise Augusta and is described as an emergent bank barrier reef with an extensive back reef lagoon. The reef is dominated by A. palmata, M. annularis, Millepora sp., P. porites and others (Diamond Development, 1988). The reef is covered by high densities of algae probably due to eutrophication from human activities in Christiansted. This and channel dredging activities have reduced the living reef to less than 30% of the surface. Seaward of this reef the shelf slopes out to the edge with Agaricia lamarki in large formations perpendicular to the reef and separated by sand channels. The eastern part of Long Reef and Round Reef are described as in a less than “healthy” state (VIPA, 1983). Live coral cover is low (6 - 23%) as compared to other reefs in the area (18 - 65%). The authors were unable to ascertain whether this is the result of a less than optimal natural physical environment or human impact. Although, the combination of extremely low live coral coverage, the prevalence of small colonies and large amounts of sediment on the deeper reef at the edge of the Christiansted Canyon all suggest that sedimentation is a major factor limiting reef growth in this area.

Most of the shoreline east of Long Reef to Teague Bay is fringing reef with scattered bank reefs dominated by M. annularis. The Teague Bay reef is about 5km long and is considered the most extensive bank barrier reef on St. Croix (Ogden, 1974). The reef encloses a lagoon about .25 mile wide and averaging 5m deep. The back reef is dominated by M. annularis, P. porites and A. palmata. The reef crest receives heavy wave energy and has a distinct zone of M.complanata mixed with A. palmata. The fore reef slopes to the sand channel separating St. Croix from Buck Island. The fore reef is primarily composed of P. porites, A. cervicornis, M. annularis and Diploria spp. Main impacts to this reef system are from coastal and upland development and the increase in sediment input into the ocean. Anchor damage and boat groundings have also caused reef degradation.

Due to the prevailing wind and wave directions, the east end of St. Croix receives abundant clean water. This has resulted in producing well developed coral reefs with little human impact except for overfishing. Nearshore are numerous fringing reefs dominated by A. palmata and M. annularis. Offshore the shelf extends eastwards for about 20km and averages 20-30m deep. A submerged reef complex rises to about 10m in depth along the seaward edge and is known as Lang Bank. The bank is mostly cemented pavement with scattered sponges, gorgonians and coral heads. Dominant corals here are Porites spp., Diploria spp., Montastrea spp. and A. cervicornis.

The southeastern shore from East Point to Vagthus Point contains discontinuous bank barrier reefs enclosing shallow bays between rocky points. To the west of Vagthus Point large buttresses, as much as 5m in height, stand near to shore and reach to just below the surface (Palm Shores, 1987). These buttresses contain large D. labyrinthiformis heads with diameters over one meter. A. palmata is also found along with M. alcicornis, M. complanata, M. annularis, P. astreoides,P. porites, D. cylindrus and A. agaricites. Offshore of these structures lie a series of rubble reefs. All of the above listed corals with the addition of A. cervicornis occur on these rubble reefs.

The southwestern shore from Hess Oil to Sandy Point once contained relatively good reef development but the dredging of Krauss Lagoon and numerous dredgings of ship channels have killed most of the nearshore and bank reefs. The shelf is widest at this part of the island and there are numerous, scattered large patch reefs on the outer portions dominated by M. annularis.

The west end of St. Croix is a sand plain with scattered inshore areas of raised pavement supporting communities of hard corals mixed with gorgonians and sponges. North and west of the Frederiksted pier are scattered patches of corals dominated by M. annularis. The shelf edge reef system starts off Butler Bay and extends north towards Hams Bluff.

The Buck Island National Monument is located 2km north of Teague Bay on St. Croix. A barrier reef starts near shore at the southernmost point of Buck Island

(Anderson, et al., 1985). This reef forms an arc around the east end of the island, roughly paralleling the north shore. The crest of this reef is dominated by Millepora spp. The reef then grades into a contiguous series of patch reefs to the northwest of the island. This system of patch reefs extends approximately 2km northwest of the west tip of the island. A. palmata is a major constituent of this reef system. North and east of the barrier reef system is an extensive coral/gorgonian flat, nearly continuous to the shelf edge. Several massive A. palmata reefs are emergent at low tide. Although these reefs are composed of 100% A. palmata, less than 20% of the coral is actually alive. The evidence of impact from white band disease on this species is strong (Davis, et al., 1986), having reduced once world famous reefs to literal skeletons of their former selves.

While the types of communities surveyed by Davis, et al. (1986) have not changed since the original descriptions in 1977 (Gladfelter, et al., 1977), the condition of many of the communities has been dramatically altered. The lagoon area behind the barrier reef had a rich, live A. prolifera population in 1977 and now is consolidated A. prolifera rubble with an algal veneer. The A. palmata reefs show a reduction in live coral cover from nearly 100% in 1977 to only 20% in 1985. The cause or causes resulting in these dramatic changes are still not well understood.

b) St. Thomas and offshore cays

St. Thomas and St. John have extensive shelf habitats with the shelf being approximately 8 miles wide on the south and 20 miles wide on the north. Little to no work has been done on the shelves or the shelf edge. Observations from the Johnson Sea-Link have shown significant shelf edge reef development on the south side where the shelf edge is better defined. On the north, the shelf gradually slopes off into deep water. The shelf edge south of Saba Island was observed to occur at approximately 60m and at one site it was comprised of 80 to 100 percent living coral cover (R. Boulon, pers. obser.). The predominant coral appeared to be M. annularis. On this particular dive (Jan. 1990) a number of colonies exhibited varying degrees of coral bleaching. From benthic charts, the shelf edge south of St. Thomas and St. John appears to be similar to the shelf edge off southwestern Puerto Rico but at a slightly greater depth.

Saba Island and Flat Cay are small uninhabited islands SSW of the St. Thomas airport. Flat Cay has very good reef development off its windward (eastern) shore (Rogers, 1982). Saba Island has a coral reef off its eastern shore. From 1978 to 1981 a monitoring study indicated a significant decrease in living coral cover at Flat Cay, probably due to filling activities at the airport runway extension and Hurricanes David and Frederic (August 30 - September, 5, 1979). Extensive physical damage to A. palmata was observed about two weeks after these storms.

Around Range Cay and along the eastern shore of Brewers Bay are found scattered corals on pavement. The western shore has a fringing coral reef and an extensive coral reef is found in the western and central portions of the bay. Seaward of the grass bed in eastern Brewers are sparse coral communities on areas of raised pavement. Brewers Bay has been stressed by sand extraction, dredging and some sewage effluent from the treatment plant located near the airport. The runway extension for the new airport partly closed the bay and has resulted in reduced flushing rates.

Perseverance Bay is to the west of Brewers Bay and is the largest bay on the southwestern coast of St. Thomas. Fringing coral reefs exist along the western shore and extreme eastern shore near Black Point (Nichols and Towle, 1977). The seaward reefs faces are dominated by A. palmata, Diploria, Montastrea, Porites, Meandrina and Agaricia. Signs of stress and attrition were evident in 1977 in the shallower reef platforms and shoreward portions of all the reefs. The lowered water quality observed by Nichols and Towle (1977) has improved with stabilization of bottom sediments in Brewers Bay and may presently be allowing for healthier communities.

To the west of Perseverance Bay and around the west end of St. Thomas, including Kalkun Cay, West Cay and Salt Cay, coral communities occur predominantly as scattered corals on submerged rocks or nearshore carbonate pavement. Most corals in these communities are small head corals like Montastrea, Diploria, Siderastrea, etc.. Savanna Island has several fringing reefs along its shoreline and probably also has some deeper reef formations.

From Botany Point to Stumpy Point on the northwest coast of St. Thomas there is considerable development of both fringing and deeper bank reefs. Little to no work has been done here so descriptions of these reefs is limited to knowledge of the present conditions and what stresses may be impacting them. The primary natural controlling agent on reef structure in this area is the occurrence of large swells during the winter months. This level of energy limits coral growth to encrusting and head forms. Little human induced stresses in this area allow for relatively healthy reef communities.

Most of the bays along the north coast of St. Thomas contain varying amounts of fringing reefs and hard bottom communities with scattered corals. The rocky coastlines between the bays support scattered corals growing on the submerged rocks. Varying degrees of exposure to wave energy from the north determine the coral types and growth forms present at different sites along this coast. Many of the inshore reefs along this coast are suffering from sediment runoff and/or nutrient loading from septic runoff during large rainfall events. The wide insular shelf along this coast can be characterized as being mostly composed of algal and sand plains with occasional raised carbonate ridges containing coral/gorgonian communities.

Inner Brass Island has been relatively well studied as a result of potential development on the island (Williams, et al., 1990). Much of the island is surrounded by either hard bottom with sparse, mixed coral zones comprised of A. palmata, Diploria P.

astreoides and Millepora. The northwest part of the island has several areas of good coral development where the slope is steep and deep water forms of Montastrea, Diploria and others are abundant. The east side of the island receives considerable wave energy. Tyre Bay contains a mostly dead A. palmata reef that most likely was killed when the Navy blasted a channel through this reef in the 1940's. Outer Brass Island is surrounded by deep water and coral growth is limited to subtidal rock surfaces and some hard bottom.

To the east, Hans Lollik Island has received considerable attention due to a very large proposed hotel/residential resort development (Tamarind Resort Assoc., 1991). Reefs surrounding this island include deep water, fringing and patch reefs. An extensive fringing reef system borders almost the entire eastern shoreline, while the inner portion of Tamarind Bay contains small patch reefs. Along the eastern shore of the island, the fringing reef has created a channelized deep reef and reef wall, with a narrow lagoon inshore that is full of patch reefs and A. palmata flats. The northwest side of the island is mostly corals growing on subtidal bedrock and mixed coral/gorgonian flats. Deep bank reefs occur along the outer edge of the gorgonian flats on the southwest portion of the island. They also occur extensively on the fringe of the eastern gorgonian flats and extend to the north tip of Little Hans Lollik and Pelican Cay. Around the island, subtidal bedrock communities are dominated by Diploria spp., Favia and Millepora spp.. The patch reefs are comprised of M. annularis, M. cavernosa, P. porites, Agaricia spp., Diploria spp., I. sinuosa, Favia, S. radians, and D. stokesi. The deep bank reefs here are described as being mostly composed of gorgonians with few hard corals (Diploria spp., Montastrea spp., Favia and A. cervicornis). Little Hans Lollik and Pelican Cay are surrounded primarily by coral encrusted subtidal bedrock and gorgonian flats.

Magens Bay on the north coast is a deeply indented bay. Extensive buttressed fringing reefs on the south side of the bay are mostly dead (RHB, pers. obser.). This is most likely due to sediment runoff and septic loading of the soil which leaches into the water during large rainfall events. Residential development on the north shore of St. Thomas has skyrocketed during the past twenty years. The north side of Magens Bay has scattered reef development on carbonate benches along the shore. Some of these reef areas are very healthy with the predominant corals being M. annularis, Diploria spp., Porites spp. and some A. cervicornis. These areas do not appear to have been affected much by the water conditions on the other side of the bay.

Mandahl Bay, to the east of Magens Bay, has suffered some of the consequences of dredging and groin construction in the late 1960's. Present day reefs include a hard bottom area off the mouth of the channel created by the groins. This area has scattered A. palmata, A. cervicornis, Montastrea spp. and others (Mandahl Bay Villas, 1990). The western part of the bay contains scattered small corals on rocky ledges. We can only speculate that coral development was quite good in this bay prior to dredging and groin construction based on what is left.

Most of the shoreline east of Mandahl Bay to Sapphire Bay is composed of rocky coastline with a few beaches. Coral communities along this stretch are limited to growth on subtidal bedrock or scattered corals on carbonate pavement. Several Porites patch reefs in southern Water Bay were destroyed by dredging activities in the 1960's and 1970's (D. Hubbard, pers. comm.).

A line of islands stretch to the northeast and include Thatch, Grass, Mingo, Lovango and Congo Cays and Carvel Rock. The north sides of these islands are bordered by deep water and only support scattered coral colonies on the subtidal bedrock. The south sides have several deeper fringing reef areas and scattered corals on carbonate pavement. A submerged rock formation to the east of Lovango Cay has a relatively healthy veneer of corals growing on it. Strong currents here provide clean, food rich water for these benthic organisms.

Sapphire Bay (Red Bay) once had a very healthy reef around Prettyklip Point but was destroyed by dredging and removal of beachrock which has resulted in increased water turbidity. Broken shafts of A. palmata up to eight feet long are now cemented into the existing reef (Sapphire Beach Hotel and Marina, 1984). Small Acropora spp. and Diploria spp. occur offshore on submerged bedrock outcrops.

Red Hook Bay on the east end of St. Thomas has fringing reefs along the north side of the bay. These reefs are composed of M. annularis, D. labyrinthiformis, Porites spp., A. agaricites, S. siderea and A. cervicornis. Many dead Montastrea and Diploria skeletons are found here with live coral cover being less than 10% (V.I. Port Authority, 1988).

A long history of dredging in this bay and heavy vessel traffic have taken a serious toll on these reefs. The south side of Red Hook Bay has coral growth on subtidal bedrock around Cabrita Point. Great Bay on the south side of Cabrita Point has scattered fringing reefs which are relatively healthy but increasing development in this bay will almost certainly have an effect on them. The south side of the bay near Current Cut has extensive reef growth on pavement. Large colonies of M. annularis and Diploria spp. predominate. The channel between St. Thomas and Great St. James Island is composed of dense coral/gorgonian communities due to strong tidal currents flowing between the islands. Most of the coral communities around The St. James islands and Dog Island are scattered corals on subtidal bedrock with some hardbottom areas. Whelk Rocks to the east of the channel between the St. James islands and Cow and Calf Rocks south of Deck Point, St. Thomas are boulder piles with encrusting corals.

Except for the barrier reef areas between Cas Cay and Patricia Cay and Patricia Cay and Long Point, most of the south shore of St. Thomas is scattered coral communities on carbonate pavement. Most of these occur adjacent to shore but some occur as raised patches off Benner Bay and south and east of Dog Island. Coral encrusted boulder reefs occur at Triangle reefs east of Charlotte Amalie harbor. Several small fringing reefs occur at Bolongo Bay and around Green Cay. The barrier reefs which form the southern arm of the Benner Bay Mangrove Lagoon have suffered storm damage but still have relatively high live coral cover. The reef crests are emergent at low tides and extensive backreef habitat is present. The upper fore reefs are composed primarily of A. palmata. The channel between Patricia Cay and Long Point has the remains of once healthy Porites reef flats. Dredging for sand extraction in the 1960's may have killed this reef.

Buck Island is mostly surrounded by coral encrusted subtidal bed rock. The north side of the island has some relatively well developed deeper fore reef. This area is used by the Atlantis Submarine for its underwater tours. It is not known what effect, if any, this may be having on the reefs here.

Charlotte Amalie Harbor has nothing in the way of reef development. If it ever did, it would be long dead due to dredging, sewage disposal, cruise ships, etc.. There are some deeper coral communities along the south and west shores of Hassel Island which appear to be just out of the turbid water conditions inside the harbor.

Water Island has little in the way of coral reefs around it. Most of the coastline is rocky with scattered hard coral attached to the subtidal portions of the rocks. However, along the southeastern shoreline, from approximately five meters to 20m in depth, there is a deep, buttressed reef formation with high living coral cover (V. Vicente, pers. comm.). The dominant coral on the buttresses is M. annularis.

c) St. John and offshore cays

Approximately 56% of St. John's land area is a National Park (Dept. of the Interior). Along with this, 5,650 acres of submerged lands are also owned and managed by the National Park. While this has provided some protection for the marine resources, inholdings and nearby development have produced sedimentation in several of the bays under NPS jurisdiction (Hubbard, et al., 1987). Continued fishing, diving and heavy boating activities, including anchoring and groundings, have resulted in continued degradation of NPS marine resources. Until the NPS takes serious, drastic measures to protect its resources, the decline will continue. From 1983 to 1985 the NPS contracted with a number of local agencies to survey the marine resources within NPS waters. These projects resulted in fairly detailed reports on the benthic invertebrate and associated fish assemblages (Beets, et al., 1986; Boulon, 1986). Descriptions for coral reefs and communities within the NPS will rely considerably on these reports along with personal observations by RHB.

Cruz Bay is the principal harbor and port of entry for St. John and as such is the most heavily utilized bay on the island. A shallow, mostly dead reef extends from the southern point (Gallows Point) and provides considerable protection for the bay. This reef has been killed due to sedimentation and vessel groundings. Thirty years ago, this reef was very healthy and good for snorkeling. Remains of A. palmata stands can still be seen. The north side of the bay contains some coral growth on subtidal bedrock with live cover <5%.

Solomon and Honeymoon Bays have subtidal bedrock off the points with coral cover of 5-10%. The predominant corals are P. porites, A. palmata, A. cervicornis, S. radians, S. siderea, M. annularis, C. natans, D. clivosa and D. strigosa. A small patch of dead upper fore reef is off the southern point of Honeymoon Bay. A few small patches of A. palmata are surviving among many dead ones. Other corals are present with a live coral cover of 20-25%.

Caneel Bay and Scott Beach have patches of subtidal bedrock with low coral cover (<5%). Towards the northern point of Scott Beach the coral cover increases to 40-50% with Millepora sp. becoming dominant. Turtle Bay has a similar distribution of coral cover on subtidal bedrock with coral cover increasing towards the points.

The Durloe Cays (Henley, Ramgoat and Rada) have varying amounts of coral cover around them on subtidal bedrock. The exposed northeast parts have higher cover (40-60%) which then decreases towards the southern parts. Some large colonies of A. palmata exist and D. cylindrus is unusually common around these cays. Other corals here include D. strigosa, D. labyrinthiformis, D. clivosa, C. natans and P. porites. Southeast of Henley Cay are carbonate ridges with high coral cover (60-80%) with M. annularis being dominant. Surrounding all the Cays in deeper water is a zone of gorgonian/coral pavement with coral cover around 5%.

Hawksnest Bay is a deeply indented bay with several types of coral assemblages. The eastern and western shores are dominated by subtidal bedrock with low coral cover (5-10%). Four large patches of upper fore reef exist in the southern part of the bay. These are dominated by A. palmata which provides about 10% live cover. These reefs have been impacted by sediment runoff from the St. John clinic at the top of the watershed and boat groundings. The western part of the bay has areas of pavement with low coral cover (5-10%). These areas are bordered on the seaward side by lower fore reef having coral cover of 25-30%.

Dennis Bay and Perkins Cay have considerable reef development between them and off the beach. Large stands of A. palmata exist on the east and west sides of the beach with many of the colonies dead and low coral cover (5-10%). To the west and northeast of Perkins Cay the coral cover is higher(15-20%) with the dominant corals being P. astreoides and A. palmata. There is a narrow lower fore reef zone dominated by M. annularis and 20-30% coral cover.

Jumbie Bay has moderate sized patches of A. palmata dominated upper fore reef on the east and west sides of the bay. There is high mortality of A. palmata in this reef which has resulted in low live cover (5-15%). White band disease is evident here which may explain the mortality. A band of head coral colonies stretches between the upper fore reef patches and is dominated by M. annularis.

Trunk Bay and Trunk Cay have little coral growth. Most of it is present on subtidal bedrock around the cay and eastern point. An underwater trail is located on the western side of the cay and has suffered from breakage and abrasion from swim fins and collection of “souvenirs” by tourists. This trail is an example of the cumulative impact of many individuals over a long period of time.

Johnson’s Reef is an extensive nearly emergent bank reef complex located north of Trunk Bay. The reef crest is dominated by Millepora sp. (30-40% coral cover) with small dead colonies of A. palmata, probably from storm damage. The upper fore reef is impressive with 40-50% coral cover dominated by moderate to large colonies of A. palmata. White band disease has been observed but not common. P. astreoides is abundant in patches. This reef sustains considerable damage from boat groundings. The lower fore reef is a narrow band around the platform with M. annularis being dominant and coral cover of 30-40%.

Windswept Beach is located on an exposed point protected by a large fringing reef. The reef is dominated by A. palmata in relatively good condition. Storm and vessel damage is evident. During the years from 1982 to 1985 an average of 3 boats per week were grounding on this reef. After the NPS installed buoys marking the reef, fewer than one boat per month were observed to hit this reef. Total coral cover here is 30-40% with many small colonies of A. palmata growing in the nearshore parts of the reef.

The bays east of Windswept to Mary’s Point (Peter, Little Cinnamon, Cinnamon, Maho, Little Maho and Francis) have little in the way of reef development. Peter Bay has a small patch of healthy A. palmata reef at the western end but other coral growth in these bays is on subtidal bedrock or carbonate pavement with low coral cover (<5%). Mary’s Point to Leinster Bay is all subtidal bedrock with low coral cover except for one area of carbonate ridges off the central part of the north shore of Mary’s Point that has higher coral cover (probably 20-30%). Whistling Cay off the west end of Mary’s Point has a small pavement area off the south side with scattered corals. The rest of the cay is mostly subtidal bedrock with corals growing on it.

Mary’s Point Creek has several small reef areas at its mouth that have small stands of A. palmata and scattered other corals. Leinster Bay and Waterlemon Cay have several areas of carbonate pavement with scattered corals. Waterlemon Cay has several large colonies of A. palmata and P. porites on its northwestern side with 10-20% coral cover. The coast east to Brown Bay is mostly subtidal bedrock with encrusting corals. Just east of Threadneedle Point and just east of Brown Bay are small, narrow patches of fringing reef dominated by A. palmata and Millepora spp..

Mennebeck Bay has fringing reefs extending from both points and forming a semi-enclosed bay. Reef development is diverse and healthy. The reef crests are dominated by Millepora spp. and the upper fore reef by A. palmata with 25-30% coral cover. The lower fore reef is dominated by M. annularis and P. porites with 35-40% coral cover. Haulover Bay has well developed reefs on the western side and a series of deep (22m+) patch reefs in the middle of the bay. These patch reefs have high scleractinian diversity and large numbers of antipatharians with Antipathes atlantica, an unidentified species and Stichopathes lutkeni being present. The unidentified species forms large colonies of 3-4m in crown diameter. There is evidence of some collection of these corals.

From the eastern point of Haulover Bay around East End to Red Point are some of the best developed, healthiest reefs left in the Virgin Islands. This stretch of coast includes Newfound Bay, East End Bay, Privateer Bay and several small unnamed bays. These bays all have well developed fringing reefs and extensive areas of lower fore reef seaward of them. The fringing reefs are dominated by A. palmata, Millepora spp. and Porites spp.. The lower fore reefs are dominated by Montastrea spp., Diploria spp., Agaricia spp. and others. Some of these reefs were affected by the oil spill that originated off St. Marten in 1991 but are not known to have suffered any mortality. Recent subdivision work in Privateer Bay threatens to produce sediment runoff which could affect these relatively pristine coral reefs. Flanagan Island, southeast of Privateer Point, is fringed by subtidal bedrock with encrusting corals.

Round Bay has little in the way of coral reefs. The shoreline has varying amounts of subtidal bedrock with encrusting corals. Out in mid-bay are a number of raised patches of carbonate pavement with scattered corals and other organisms. From Hurricane Hole to Lagoon Point coral growth is limited to growth on subtidal bedrock at the points. These bays are deeply indented with substantial amounts of red mangrove development. Lagoon Point was once a well developed fringing reef with an extensive backreef lagoon. There are still some stands of A. palmata but storm damage and a few boat wrecks have reduced much of this reef to rubble. The lower fore reef is still relatively healthy with fairly high coral cover composed of Montastrea spp., Diploria spp., Agaricia spp. and others.

John’s Folly Bay has a fringing reef extending off both points. This reef has also suffered considerable storm damage and has few large stands of A. palmata left. There is a relatively expansive lower fore reef seaward of this bay with good coral cover. Le Duck Island east of John’s Folly is mostly subtidal bedrock and carbonate pavement, both of which have only scattered corals. Eagle Shoal lies south of Le Duck Island and comes to about 2m from the surface. This shoal contains many grottos and caves in the boulders that create this structure. Coral cover is good with head corals predominating. To the west of Eagle Shoal lies Drunk Bay. This bay is mostly cobble and large subtidal bedrock boulders. However, there is a fringing reef along the north side of the bay dominated by A. palmata and having 25-30% coral cover. The east side of Ram Head is predominately subtidal bedrock and carbonate pavement with some lower fore reef along the edge.

The west side of Ram Head is mostly cobble bottom inshore with a lower fore reef having spur and groove formations offshore. Saltpond Bay has low coral cover (<5%) in the bay with high Millepora cover (30-35%) on the rocks at the mouth of the bay. Booby Rock has an extensive, tiered lower fore reef northwest of it with high coral cover (30-40%). Many large colonies of M. annularis and C. natans are present.

Coral communities in Kiddle and Grootpan Bays are primarily on carbonate pavement with generally low coral cover (<5%). The west side of Grootpan Bay has an area of higher cover (up to 20-25%) with several large colonies of M. annularis, C. natans and D. cylindrus. Kiddle Bay has a patch of lower fore reef in the middle of the bay with 20-30% coral cover of which M. annularis predominates. Off the western point of Kiddle Bay is a bank patch reef with low relief and total coral cover of 20-50%. M. cavernosa is the dominant coral.

Little and Greater Lameshur Bays contain considerable amounts of subtidal bedrock with coral cover ranging from <5% inshore to 10-20% near the points. Millepora spp. dominate near the points. Shallow carbonate pavement areas in both bays contain low coral cover (<5%). Little Lameshur has a small area of lower fore reef on the western side with a coral cover of 15-20% dominated by P. porites and M. annularis. In Greater Lameshur a large area of lower fore reef occurs on the eastern side near the sites of the Tektite I and II programs during 1969-1971. Coral cover is 15-20% and is primarily M. annularis. The west side of Yawzi Point, which separates the two bays, coral cover is from 20-25% in mid reef and 30-40% near the edge with M. annularis dominant. The east side of the point is a coral garden with coral cover of 35-40%. M. annularis predominates with large colonies often forming continuous complexes. Several large colonies of C. natans and P. porites are also present. Greater Lameshur Bay had extremely high abundances of Diadema antillarum prior to the 1983 die-off.

Europa Bay is mostly subtidal bedrock on the points with low coral cover (<5%). Some small colonies of A. palmata are present but this species is the main contributor to the storm rubble present throughout this bay. There is a narrow reef crest composed of eroded carbonate mounds with few corals on their tops. The sides are colonized by Diploria spp., Montastrea spp., Colpophyllia spp., Porites spp. and F. fragum. A patch of lower fore reef is off the western shore and is dominated by M. annularis.

Reef Bay is the largest bay on the south side of St. John. Both sides of the bay have exposed reefs which form an incomplete barrier for the shore and back reef zones. All reef zones in this bay are in relatively good condition except for reef crest and upper fore reef zones which were severely damaged during hurricanes David, Frederick and Hugo. The reef crests are ramparts of A. palmata fragments, the amount of which suggests a previously extensive A. palmata zone. The western side of the bay is currently experiencing sedimentation due to residential development using improper construction methods. The back reef on the eastern side of the bay is wide and contains large, healthy stands of P.

porites which have grown to low mean water. The western back reef is very narrow but healthy with high coral cover (30-40%) of P. porites and P. astreoides. The fore reef zones in this bay are primarily carbonate pavement with mounds containing large colonies of M. annularis, D. strigosa and S. siderea. A. palmata rubble is abundant. There are several large offshore bank patch reefs in this area. Just south of White Cliffs is a large patch reef that rises to about 15m from the surface from a sand plain at about 25m. This reef has scattered corals on top with good coral cover near the edge. Large head corals predominate. South of the western end of Reef Bay lie several smaller bank patch reefs having low vertical relief but high coral cover (50-60%). A. agaricites is predominant with scattered large colonies of M. annularis and C. natans. Numerous other species are also present in small amounts.

Eastern Fish Bay is an extension of the western Reef Bay fringing reef system. The reef crest and upper fore reef exhibit similar types and amounts of storm damage as at Reef Bay. The upper fore reef is barren pavement with all A. palmata having been stripped off. A few large M. annularis colonies are still present.The lower fore reef is oriented as a series of spurs and grooves with high coral cover (40-60%). The western side of Fish Bay has an extensive lower fore reef with high coral cover (30-40%) dominated by A. agaricites.

Rendezvous Bay extends from Dittlif Point on the east to Bovocoap Point on the west. Most coral communities in this bay occur as scattered corals on carbonate pavement or on subtidal bedrock with low coral cover. The western side of Rendezvous Bay has a considerable amount of lower fore reef with moderate coral cover dominated by M. annularis. This zone extends around Bovocoap Point to Devers Bay. Extending southwest from Bovocoap Point are a series of raised carbonate ridges with extensive ledges around the edges. These ridges have low coral cover (<5%), most of which is composed of plate-like colonies of several species of head coral.

The shoreline from Devers Bay to Cruz Bay is mostly subtidal bedrock and nearshore carbonate pavement with low coral cover. Off Moravian Point are several patches of subtidal bedrock which are emergent at low tide. They contain scattered corals with Millepora spp. predominating. There is some lower fore reef associated with these patches. Stevens Cay to the west has extensive carbonate pavement surrounding it and a wide zone of lower fore reef further offshore. The lower fore reef has moderate coral cover with varying amounts of M. annularis, A. cervicornis and Agaricia spp..

C. Habitat threats

Possibly the most important threat to corals in Puerto Rico and the Virgin Islands is inland deforestation, particularly (although not necessarily restricted to) that adjacent to fringing and platform coral reefs. Sediments derived from inland deforestation are detrimental to reef corals and, therefore to coral reefs, in ways mentioned above (see section on Anthropogenic stressors). Additionally our coral reefs are also stressed, although to generally unknown extents, by chemical pollutants, indiscriminate and careless commercial and scientific collection of living corals, collection of "live rock" (coral reef portions frequently containing endolithic biota as well as living postlarval, juvenile and/or adult corals) and commercial collection of both juvenile and adult reef fish. The latter is largely responsible for unbalances in our reef systems resulting in low or no recruitment and a gradual degradation of these once productive systems.

The corals most likely to be affected are those inhabiting fringing reefs (i.e., those closest to shore) which are generally under the direct influence of human activities (Goenaga, 1986). Those that presumably are least affected by anthropogenic effects are those farthest from land (e.g., shelf edge reefs). Shelf edge reefs and bank barrier reefs (those in mid portions of insular platforms) are also subject to siltation by dredging and by fishing activities as well as by ocean outfalls.

D. History of exploitation

Collection for commercial purposes of reef corals and hydrocorals is presently uncommon in our islands. In the past, it was a common activity particularly off the east coast of Puerto Rico (Fajardo). Most vendors, mainly local fishermen, were stopped from their activities by implementing the regulation for the extraction of corals prepared by the PRDNR. The CZM Act of 1978 prohibits the taking of coral and sand in the U.S.V.I..

More importantly, has been the collection of corals and associated biota by scientists. This activity, sometimes as destructive or even more destructive than commercial extraction, is, to my knowledge (CG), unregulated (although according to Miguel Canals, forest keeper of the Guanica Forest Biosphere, coral extraction for any purpose within a natural reserve is restricted and regulated). In the U.S.V.I. this is regulated by Act 5665 which requires permits for any collection of indigenous species, marine or terrestrial.

Black corals, to our knowledge, have not been systematically harvested for commercial purposes in the past nor in the present. Gorgonians, on the other hand, are intensively collected, at least in the La Parguera, PR area, for scientific/commercial purposes, namely for the assessment of pharmacologically important compounds. Similar, though not as intensive, collections have been made off the southwest coast of St. Thomas. The impact of this activity, intensive only for short time spans, is unknown and needs to be assessed, particularly in relation to the abundance and ecology of target species.

As stated elsewhere, commercial collection of reef associated biota (e.g., juvenile reef fish, anemones, brittle stars, cleaning shrimps and others) is common and intense in the west and southwest Puerto Rican coast and to a lesser extent in the VI and its effect on reef corals and other biota needs to be assessed urgently. It is at this moment unknown whether irreparable damage is being done to the environment.

E. Habitat requirements

Generally, optimum development of reef corals occurs in clear, oligotrophic sea water that is unpolluted, relatively free of terrigenous sediment input and not subject to temperatures above or below that in which they originally developed. Wide shelves are apparently also important or correlated to the formation of extensive and complex reef habitats. In Puerto Rico and the VI these conditions (except that related to the width of the insular shelf) are met with increasing frequency as distance increases from the coast or on offshore islands. A high incidence of dead or dying reef corals is usually observed on inshore habitats. Examples of this situation are Mayaguez, Guanica, Guayanilla, Yabucoa, many sites along the north coast of PR and numerous sites around the VI.

F. Habitat information needs

It is essential that the appropriate government agencies, namely the Puerto Rico Department of Natural Resources, the Virgin Islands Department of Planning and Natural Resources and others, update coral reef inventories so that careful evaluation of unexplored sites is made possible. Inventories need to focus on particularly critical sites. For example, very old, unusual colonies of Montastrea annularis (possibly around one thousand years old) inhabit submerged banks southeast of La Parguera. It is extremely important to characterize this area and give it special protection. Assessment of shelf edge reefs east of La Parguera, north of St. Croix, south of St. Thomas/St. John and of offshore islands also needs to be made. Shelf areas also need to be surveyed for the presence of bank reefs and other habitat critical for the survival of coral reef fish and the source of recruitment for many of our inshore reefs.

V. Management recommendations

A. Identification of critical areas

The following areas are considered critical because of the presence of extensive coral reefs and abundant reef corals and need to be assessed in detail. It must be emphasized that there is urgent need to update inventories and detailed descriptions of many of these areas. Further information of interest in this context is given in Wells (1988).

1. Puerto Rico

a. La Cordillera (the coral reefs of La Cordillera have been assessed recently by DNR personnel) -northeast coast from east of Cabezas de San Juan to nearCulebra

b. Bahia°a de Jobos and adjacent platform reefs-south coast; south of the municipalities of Salinas and Guayama

c. Cayo Ratones-south coast; about 1 km south of Ponce

d. Caja de Muertos and Cayo Berberia -south coast; south of Ponce

e. La Parguera -south coast; off the municipality of Lajas

f. Sergeant Ree -southeast coast; 0.3 km southeast of Punta Tuna

g. Tourmaline and El Negro reefs -west coast; approximately 10 km west of Punta Ostiones

h. Reefs south of La Cancora, near Punta Boca de Cangrejos -north coast; north of San Juan

i. Submarine caves off Jobos, Isabela -north coast; north of the municipality of Isabela

j. Vieques -18 km east of eastern Puerto Rico

k. Culebra-north of Vieques

l. Mona and Monito -halfway between Dominican Republic and western Puerto Rico in the Mona Passage

m. Caja de Muertos

2. U.S. Virgin Islands

a. Buck Island -north of St. Croix

b. Shelf edge reefs north of St. Croix -from Hams Bluff east to Christiansted on north shore

c. St. Croix barrier reefs -south coast from East Point to Vagthus Point -north coast from Teague Bay to East Point

d. Shelf edge reefs south of St. John/St. Thomas -from south of the east end of St. John west to south of Sail Rock

e. Reefs associated with the Mangrove Lagoon, St. Thomas -Long Point to Deck Point and including Cow and Calf Rocks

f. All reefs within the V.I. National Park on St. John -north and south coasts of St. John

g. East end reefs on St. John -Haulover Bay to Red Point, St. John

h. Stevens Cay and Moravian Shoal -west end of St. John

B. Most susceptible species

The most susceptible species is probably Acropora palmata given the high incidence of the disease known as "white band disease" caused by an unknown agent. Populations of this species and its congeneric A. cervicornis have been drastically reduced within the last decade. Collection of this species should be completely banned and scientific studies requiring handling of specimens should be made under close supervision of competent personnel. Species that are subject to intensive scientific collection, be it whole or portions of the colonies, are also in need of urgent regulation.

C. Collection

1) commercial and touristic

Commercial collection of skeleton forming cnidarians should be strictly prohibited at least until information on growth rates are thoroughly analyzed in the context of possible exploitation. This includes collection of reef rock (i.e., "live rock") which, in addition to generating disturbance in the coral reef, is likely to contain larvae or juvenile coral recruits that are not visible to the naked eye. Tourists should neither be allowed to collect until sustainable yield data are available.

2) scientific

Bonafide, justifiably scientific collection of skeleton forming cnidarians or portions of them, should be regulated. It is necessary that government agencies supervise the collection or extraction of these animals. As mentioned earlier this activity can cause extensive damage to coral reefs. Collection methods that are damaging to corals and associated biota should be banned.

D. Anthropogenic reduction of water quality

Efforts must be made to educate the general public, government officials, developers and special interest groups on the effects of terrigenous sediment input and the discharge of untreated sewage and petroleum products into our coastal waters. These inputs and discharges must be eliminated to the most practical extent possible.

E. Fishing

Fishing effort on coral reef fish must be reduced to allow for a restoration of naturally balanced reef systems which will result in stony coral recovery.

F. Anthropogenic destruction of habitat

Education and enforcement must target the problems of anchor and vessel grounding damage to coral reefs. The provision of moorings in popular anchoring sites and marking of reefs with buoys will significantly reduce damage to corals.

G. Cultivation and transplantation into degraded habitats

Cultivation of skeleton forming cnidarians is a possibility that could be explored considering the commercial demand for this resource. Cultivation is possible from "nubbins" and, possibly, from sexually produced larvae. There is ample, available literature from which this issue could be assessed and resolved.

Transplantation to degraded habitats is also an option to be considered. Its implementation, however, would be fruitful only if factors producing the degradation are simultaneously curbed (i.e., in those cases where these are recurrent). There is existing literature also that would help in the assessment of this possibility.

H. Monitoring

Monitoring of degraded and healthy habitats need to be implemented, particularly near recent sources of pollution and or other detrimental activities. Photographic documentation of selected reefs can lead to very valuable information on short to medium term changes in the community structure. The resources needed and the time to be spent to carry on this activity are minimum for the quality of the information obtained.

I. Probable future condition

The future condition of reef corals depends on the: 1) extent that concerned government agencies (i.e., PR Department of Natural Resources, VI Department of Planning and Natural Resources, PR Environmental Quality Board, PR Planning Board, Environmental Protection Agency, Corps of Engineers) decide to properly manage the coastal zone of PR and the VI in benefit of these valuable resources and, 2) frequency of further "natural" disturbances. The second we cannot control if, in fact, these disturbances are Homo-independent. The first is up to government authorities and is to a large extent related to education beginning in the lower grades (the Departments of Education are largely responsible for this). In the absence of quick changes in the policies related to coastal zone management coral reefs will most likely undergo further degradation. It is not unreasonable to state that this degradation will be irreversible in terms of human generations. Aspects related to the recovery of coral reefs are discussed above (section on Tolerance of corals to stressors and capacity to recover from disturbances).

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Appendix 1.

Phylum Cnidaria
- Class Hydrozoa
  - Order Milleporina
    - Millepora alcicornis Linnaeus
    - Millepora complanata Lamarck
    - Millepora squarrosa Lamarck
  - Order Stylasterina
    - Stylaster roseus (Pallas)

- Class Anthozoa
  - Order Antipatharia
    - Antipathes pennacea Pallas @, @@
    - A. tanacetum Pourtales @
    - A. furcata Gray @
    - Stichopathes spp. @@@

  - Subclass Octocorallia
  - Order Alcyonacea
    - Family Anthothelidae
      - Erythropodium caribaeorum (Dushassaing and Michelotti)
    - Family Anthothelidae
      - Iciligorgia schrammi Duchassaing
    - Family Briareidae
      - Briareum asbestinum (Pallas)
    - Family Telestacea
      - Telesto riisei (Duchassaing and Michelotti)

  - Order Gorgonacea
    - Family Gorgoniidae
      - Gorgonia mariae Bayer
      - G. ventalina Linnaeus
      - G. flabellum Linnaeus
      - Pseudopterogorgia acerosa (Pallas)
      - P. americana (Gmelin)
      - P. bipinnata (Verrill)
      - P. rigida (Bielschowsky)
      - P. albatrossae Bayer
      - Pterogorgia anceps (Pallas)
      - P. citrina (Esper)
    - Family Plexauridae
      - Eunicea mammosa Lamouroux

Appendix 1 (cont.)

E. succinea (Pallas)
E. laxispica (Lamarck)
E. mammosa Lamouroux
E. succinea (Pallas)
E. fusca Duchassaing and Michelotti
E. laciniata Duchassaing and Michelotti
E. touneforti Milne Edwards and Haime
E. clavigera Bayer

Family Plexauridae
E. knighti Bayer
E. calyculata Ellis and Solander
Muricea atlantica (Kukenthal)
M. muricata (Pallas)
M. pinnata Bayer
M. laxa Verrill
M. elongata Lamouroux
Muriceopsis sp.
M. sulphurea (Donovan)
M. flavida (Lamarck)
Plexaura flexuosa Lamouroux
P. homomalla (Esper)
Pseudoplexaura porosa (Houttuyn)
P. flagellosa (Houttuyn)
P. wagenaari (Stiasny)
P. crucis Bayer
Plexaurella dichotoma (Esper)
P. nutans (Duchassaing and Michelotti)
P. grandiflora Verrill
P. grisea Kunze
P. fusifera Kunze
Family Ellisellidae
Ellisella spp.

Order Scleractinia
Family Astrocoeniidae
Stephanocoenia michelinii Milne Edwards and Haime
Family Pocilloporidae
Madracis decactis (Lyman)
M. mirabilis (Duchassaing and Michelotti)

Appendix 1 (cont.)

Family Acroporidae

- Acropora palmata (Lamarck)
- A. cervicornis (Lamarck)
- A. prolifera (Lamarck)

Family Agaricidae

- Agaricia agaricites (Linnaeus)
- A. fragilis Dana
- A. tenuifolia Dana
- A. lamarcki Milne Edwards and Haime
- Leptoseris cucullata (Ellis and Solander)

Family Siderastreidae

- Siderastrea siderea (Ellis and Solander)
- S. radians (Pallas)

Family Poritidae

- Porites astreoides Lamarck
- P. porites (Pallas)
- P. branneri Rathbun
- P. divaricata Lesueur

Family Faviidae

- Favia fragum (Esper)
- Diploria clivosa (Ellis and Solander)
- D. strigosa (Dana)
- D. labyrinthiformis (Linnaeus)
- Manicina areolata (Linnaeus)
- M. mayori Wells
- Colpophyllia natans (Houttuyn)
- Cladocora arbuscula (Lesueur)
- Montastrea annularis (Ellis and Solander)
- M. cavernosa (Linnaeus)
- Solenastrea bournoni Edwards and Haime

Family Rhizangiidae

- Phyllangia americana Milne Edwards and Haime*
- Astrangia solitaria (Lesueur)*

Family Meandrinidae

- Meandrina meandrites (Linnaeus)
- M. meandrites forma brasiliensis (Edwards and Haime)
- Dichocoenia stokesi Milne Edwards and Haime
- D. stellaris Edwards and Haime
- Dendrogyra cylindrus Ehrenberg

Family Mussidae

- Mussa angulosa (Pallas)
- Scolymia lacera (Pallas)
- S. cubensis (Milne Edwards and Haime)

Appendix 1 (cont.)

Isophyllia sinuosa (Ellis and Solander)
Isophyllastrea rigida (Dana)
Mycetophyllia lamarckiana Milne Edwards and Haime
M. aliciae Wells
M. danae Milne Edwards and Haime
M. ferox Wells

Family Caryophyllidae
Eusmilia fastigiata (Pallas)
Tubastrea aurea (Quoy and Gaimard)*

Family Oculinidae
Oculina diffusa Lamarck

* ahermatypic
@ source: Opresko, 1974
@@ source: Oakley, 1988
@@@ source: Noome and Kristensen, 1976; Goenaga, 1977