PUERTORICAN REEFS : research synthesis, present threats and management perspectives

Jorge R. Garcia, Jack Morelock, Roberto Castro, Carlos Goenaga and Edwin Hernandez

Abstract

This work provides a synopsis of scientific research undertaken in characterization of coral reef systems from Puerto Rico. A data set on the sessile-benthic community structure and coral taxonomy from 52 reefs surveyed with quantitative sampling protocols over a 15 year period (1984-1999) is here included. These data are analyzed in the context of the contrasting oceanographic conditions of the puertorrican shelf and the history of man-induced and natural environmental stressors potentially affecting the ecological condition of reefs at the sites studied. A total of 93 coral taxa, including 43 scleractinian (stony) corals, 42 octocorals (gorgonians), 4 species of black coral (anthipatharians) and 4 hydrocorals have been reported from puertorrican waters. Coral reefs from La Parguera (Turrumote, Media Luna, Shelf-edge), offshore Mayagüez Bay (Tourmaline Reef), Naguabo (Algodones Reef), and La Cordillera de Fajardo (Cayo Diablo, Cayo Palominitos) showed the highest live coral cover (>30 %). These reefs lie on protected sections of the shelf, upstream from large riverine discharges and are the ones farthest from shore. *Montastrea annularis* was the dominant coral taxa among reefs with high live coral cover. Hard-ground and rock reefs with very low coral cover are exposed to very strong wave action (*i.e*. Caja de Muertos) and/or receive heavy loads of sediments from large riverine discharges (e.g. Morrillos, Boca Vieja, Mameyal, Cerro Gordo).

Montastrea cavernosa, Porites astreoides and *Diploria strigosa* were the most abundant corals from reefs under heavy sediment stress. Dead coral reefs (Hojitas, Guayanilla, Rio, Algarrobo) are associated with a history of combined impacts such as dredgings, ship traffic, domestic sewage and industrial (mostly organic) discharges in semi-enclosed environments (*i.e*. Guayanilla Bay, Ponce Bay, Mayagüez Bay). Designation of coastal areas with high coral development as Natural Reserves, with prospective plans for establishment of closed fishing regulations within reserve areas stands as the main strategy for protection and management of coral reefs in Puerto Rico. At present, several monitoring programs are in place to document changes in the community structure of coral reefs in Puerto Rico.

Research Background

Research on the puertorrican coral reefs started in the 1960's and has proceeded at a slow pace until present. Initial qualitative surveys by Almy and Carrión Torres; [1] Glynn *et al*. [2] and Glynn [3] provided taxonomic accounts of corals and guidelines for their identification, which stimulated research on aspects of their ecology during the 1970's. The vertical zonation of coral species on reefs from the north and south coasts were reported by Pressick [4] and Szmant-Froelich, [5] respectively. In his analysis of Western Atlantic coral reefs, Glynn [6] noted the low diversity of scleractinian corals in Puerto Rico relative to other regions in the Caribbean. One of these descriptions included the reef flat biotope from Laurel Reef in La Parguera. [7] Loya [8] performed studies relating the community structure of hermatypic corals to sedimentation and established the first quantitative assessments of coral cover and diversity patterns from puertorrican reefs. The relationship between live coral cover and sedimentation stress was further examined by Rogers. [9] Her work also included the first measurements of community metabolism for Puerto Rican coral reefs. [10] Acevedo and Morelock [11] expanded knowledge on coral degradation and sedimentation stress in their studies of coral reefs from the south and southwest coasts, providing at the same time further characterizations of community structure for several reefs in the region.

The first geographical inventory of puertorrican reefs was prepared by Goenaga and Cintrón. [12] This work, along with subsequent qualitative surveys of reef geomorphology and community structure [13, 14, 15, 16] established criteria for designation of marine areas with coral reef development as Natural Reserves by the government of Puerto Rico. With this initiative, the government of Puerto Rico recognized the exceptional ecological value of coral reef systems, but provided feeble mechanisms for their protection and management. Intensified utilization of the coastal zone stimulated problem oriented research involving coral reef communities, which allowed further quantitative characterizations during the late 1970's, 80's and 90's. Rogers *et al*. [17] evaluated the impacts of military operations on the coral reefs of Vieques and Culebra, on the northeast coast. Rogers [18] associated the degradation of western Atlantic and Caribbean coral reefs to the decline in reef fisheries. Subsequent characterizations of coral reef communities in shallow reefs around Puerto Rico have included fish assemblages as an integral part of the reef community. [19, 20, 21, 22, 23] Positive correlations between fish species diversity and live coral cover were reported from belt-transect surveys in shallow reefs around Puerto Rico. [24] Unfortunately, these studies have been unable to evaluate shifts in fish community structure over time for any particular reef. A preliminary assessment of the decline in coral reef associated fisheries was prepared by Appledoorn *et al*. [25]

During the last decade, coral reef research in Puerto Rico has largely focused on community characterization and monitoring programs, marine reserve feasibility studies, environmental impact assessments, coral diseases and mitigation programs. For example, CARICOMP [26] is a Caribbean-wide coral reef monitoring program set up to examine changes in the ecological health of coral reefs and associated ecosystems (*i.e*. fringing mangroves, seagrass beds) across a network of laboratories and marine reserves (including the puertorrican site of La Parguera). As part of the U. S. Coral Reef Initiative Program for P. R. (from NOAA) a series of coral reefs in Natural Reserves of Puerto Rico have been recently selected as priority sites for establishment of characterization and monitoring programs. Baseline characterizations of coral reef communities based on quantitative sampling protocols are available for Jobos Bay, La Parguera, Guanica, La Cordillera de Fajardo, El Tourmaline Reef, and Caja de Muertos. [21, 26, 27] Other initiatives have included characterization efforts in support of the coral reefs occurring within the Rio Espiritu Santo Natural Reserve, [28] Isla de Mona Natural Reserve [16, 29] and La Cordillera de Fajardo Natural Reserve. [30]

At least two major efforts were launched during the 1990's to protect coral reef associated fishery resources and the ecological integrity of important coral reef systems. A feasibility study for establishment of a Marine Fishery Reserve in La Parguera, [31] southwestern Puerto Rico included a baseline characterization of sessile benthic and fish communities of the Turrumote, Media Luna and San Cristobal Reefs. More recently, on the northeastern side of the island, Hernández-Delgado *et al*. [32] described the marine biological resources associated with the coral reef at the Isla de Culebra Fishery Reserve. Additional quantitative and qualitative characterizations of reef communities have been included as part of environmental impact studies related with the submarine outfall discharges of Regional Wastewater Treatment Plants of the P. R. Aqueducts and Sewers Authorithy from 11 sites around the island of Puerto Rico. [19] Other characterizations of coral reef communities were performed in relation to operations of thermoelectric power plants in Jobos Bay, [5] San Juan Bay [33] and Guayanilla-EcoElectrica. [20, 34]

Mass mortalities of corals and related reef organisms have also received research attention in Puerto Rico. Vicente and Goenaga [35] reported on the mass mortality of the black sea-urchin, Diadema antillarum, around the coastline of Puerto Rico, and provided a general description of dying specimens from direct observations in the field. A series of reports of massive coral bleaching from the waters of Puerto Rico were produced in the late 1980's. [36, 37, 38, 39, 40] These studies evidenced permanent damage by the bleaching phenomena on reef corals and associated the periodic bleaching events to elevated sea surface temperatures.

Oceanographic Features of the Puertorrican Shelf

Corals grow throughout most of the insular shelf of Puerto Rico, yet the physical, climatic and oceanographic conditions that affect coral reef development vary markedly among insular shelf segments. The north and northwest coasts are narrow (< 3 km) and shallow communities are subjected to high wave action during winter, as cold fronts from the North Atlantic reach the Caribbean Antilles. The north and west coasts also receive substantial sediment and nutrient loading from the discharge of some of the largest rivers in Puerto Rico.

The north coast features abundant formation of sand dunes, some of which are now submerged eolianites. Others fringe the coastline, forming rocky beaches with rich intertidal communities (*i.e*. Isabela, Arecibo, Loiza). The northeast coast has a wider shelf, partially protected from wave action by a chain of small emergent rock reefs aligned east- west between the main island and the Island of Culebra. The northeast coast is upstream from the discharge of mayor rivers resulting in more appropriate conditions for coral reef development. The east coast is characterized by extensive unconsolidated sand deposits which limit coral reef development, but scattered rock formations within this shelf section have been colonized by corals. Isla de Culebra and Isla de Vieques lie at the eastern boundary of the puertorrican shelf.

The south coast is a coastline of lower wave energy and the insular shelf is generally wider than at the north coast. Rivers with smaller drainage basins discharge on the southeast coast and only small intermittent creeks discharge on the southwest coast, which has been classified as a semi-arid forest. The south coast also features a series of embayments and submarine canyons. Small mangrove islets fringe the south coast and many of these provide hard substrate for coral development. The shelf-edge drops off at about 20 meters with an abrupt, steep (almost vertical) slope. At the top of the shelf-edge lies a submerged coral reef formation [41] which gives protection to other reefs, seagrass and mangrove systems of the inner shelf.

The southwest coast is relatively wide and dry, with many emergent and submerged coral reefs that provide adequate conditions for development of seagrass beds and fringing mangroves. Toward the central west coast lies Mayaguez Bay, one of the largest estuarine systems of the island and partially influenced by wave action from North Atlantic swells during winter. Mona and Desecheo are oceanic islands between Puerto Rico and the Dominican Republic which belong to Puerto Rico. The northern sections of the islands are strongly affected by wave action and their insular platforms are virtually reduced to steep walls, whereas the southern coastal sections of these islands are more protected and have wider platforms where coral reefs develop. There are no rivers in either of the islands, which are surrounded by waters of exceptional transparency. [13]

Types of Reefs and Geographical Distribution

Modern shelf-edge reefs formed in Puerto Rico some 8,000 yrs bp. Inner reefs, formed on top of submerged banks and sandy bottoms of the flooded shelf are believed to be about 5,000 years old. [42] The rise in sea level associated with the last Pleistocene glaciation (Wisconsin) flooded the lower limestone ridges of the shelf, providing appropriate sites for coral growth and subsequent reef development. Cross-shelf seismic profiles provided by Morelock *et al*. [41] support the theory of Kaye, [43] which state that reefs on the southwest coast developed on drowned calcarenite cuestas formed as eolianite structures parallel to the coastline during the Wisconsin glacial period. Proper substrate, depth, and water transparency conditions in the southwest coast allowed for extensive development of coral reefs during the mid-Holocene period. [12] At least three mayor types of reefs are recognized within the puertorrican shelf, although different coral reef formations have been reported. [12, 22, 41] The distribution of the major reef types as updated from different sources is shown in Figure 1.

Figure 1. Types of reef and their distribution

Rock reefs

These are submerged hard substrate features of moderate to high topographic relief with low to very low coral cover, mostly colonized by turf algae and other encrusting biota. Coral colonies are abundant in some cases (*i.e. Diploria spp., Porites astreoides, Acropora palmata, Dendrogyra cylindricus*) but grow mostly as encrusting forms, providing minimal topographic relief. These types of reefs fringe the west and northwest coastlines of Rincon, Aguada, Aguadilla, Isabela and Quebradillas. Also lie between Dorado and San Juan on the north coast, to the northeast off Fajardo forming a chain of reefs between Fajardo and Isla de Culebra, and on the East Coast off Yabucoa and Humacao. These are coastlines subjected to high wave energy, abrasion and sedimentation stress. Rock reefs are important habitats for fishes and macroinvertebrates since they are usually the only available structure providing underwater topographic relief in these areas. Some have developed atop of submerged rocky headlands and are characterized by the development of coralline communities adapted for growth under severe wave action and strong currents. Examples of these include the granodiorite rock reefs located between Humacao and Yabucoa, off the southeast coast. A second type of "rock reef" is formed atop of basaltic extrusive rocks. [45] Most of these are fairly shallow (1-6 m), not extending more than 10-50 m horizontally and showing moderate to steep irregular slopes. Examples include the reefs of Cabezas de San Juan at Fajardo and Cabeza de Perro Island at Ceiba. There are deeper basaltic rock reefs, such as the submerged outcrops of the Culebra Island archipelago, which forms an extensive and complex system of slabs, boulders, overhangs, crevices, cracks and channels. These structures may support deeper reef coral fauna (e.g. red corals, *Icilligorgia schrammi*, and black coral, *Anthipathes* spp.) in waters as shallow as 10-12 m (Hernández-Delgado, personal observation). In other cases, rocky bottoms form long and narrow ridges parallel to the shelf-edge, arising from depths of 22 to 40 m which support some coral growth, but these systems have not been studied yet.

Hard Ground Reefs

Hard grounds are mostly flat, eolianite platforms ranging in depth from 5 to 30 meters largely covered by turf algae, encrusting sponges and scattered patches of stony corals. Coral colonies are typically encrusting forms, perhaps an adaptation to the extremely high wave energy that prevails seasonally on the north coast. Many of the encrusting coral colonies grow over vertical walls in crevices among the hard ground. The barrel sponge, *Xetospongia muta*, is usually abundant in hard ground reefs, where it represents one of the main features contributing topographic relief. Low-relief sand channels aligned perpendicular to the coast cut through the hard ground platform in many areas providing topographic discontinuities. The sand is generally coarse and mostly devoid of biota, evidencing short deposition times and highly dynamic movements across the shelf due to the high wave action. These systems are found off the central north (off Arecibo) and northeast coastlines.

Coral Reefs

Coral Reefs are mostly found as fringing, patch, bank and shelf-edge formations in Puerto Rico. Fringing coral reefs are by far the most common. These are located throughout most of the northeast, east and southern coastlines associated with erosional "rocky" features of the shelf. Coral is not the main component of the basic reef structure, but its development has significantly contributed to its topographic relief, influencing the sedimentology of adjacent areas and providing habitat for a taxonomically diverse biological assemblage that is consistent with a coral reef community. Examples of these fringing reef types include the formations along the leeward side of the Cordillera de Fajardo reefs. One of the best developed fringing reefs along that chain is Cayo Diablo, where a dense growth of coral is present, including very large colonies of massive and branching coral growth types. These reefs show a variable spur-and-groove growth pattern which is probably most evident at the reef off the southeast section of Isla Palominitos, where the distance between the top of the "spurs" and the bottom of sand channels at the "groove" can exceed 6-7 meters. Examples of fringing reefs in the west coast include those at Mayaguez Bay (Manchas Interiores, Manchas Grandes, Rodriguez and El Negro Reefs) and Cabo Rojo (Isla Ratones, El Ron, Boquerón and other smaller ones).

On the south coast, coral reefs fringe many small islands or keys, such as those of La Parguera, Guánica, Guayanilla, Ponce, Guayama and Salinas, or may be found as fairly extensive coral formations associated with the shoreline at the mouths of coastal embayments (Guánica, Guayanilla, Peñuelas). In some instances, coral growth has been primarily responsible for the formation of emergent island reefs, or keys, such as the reefs off La Parguera. In these keys, well developed coral formations typically fringe the windward (forereef) section of the islet and a reef flat colonized by a *Porites porites* biotope is generally found with intermixed turtle seagrass (*Thalassia testudinum*) and scattered coral colonies of small size and low relief. [7] Development of the reef flat leads to establishment of red mangrove growing towards the water, with its aquatic root system providing habitat for a diverse assemblage of juvenile reef fishes and invertebrates. The reef grows continuously as wave action brakes up coral colonies and fragments and deposits them on the emergent section of the reef. These keys grow notoriously during hurricanes, as abundant coral fragments are detached from the substrate and deposited on land.

Fringing reefs are also found off the northeast coast at Rio Grande, Luquillo, Fajardo, Culebra and Vieques. Many of these systems resemble barrier reefs, but according to the strict definition of barrier reefs (emergent reefs separated from the shoreline by a wide and deep lagoon), these are not barrier reefs because only shallow (< 20 m depth) lagoons separate these reefs from the shoreline. [12] Northern fringing reefs are characterized by the presence of shallow (0.5-3.0 m depth) back-reef communities dominated by Porites porites biotopes and scattered colonies of different species.

Shelf-edge reefs the best developed (but least studied) coral reef ecosystems in Puerto Rico. An extensive reef formation is found at the shelf-edge off the south coast, from Guayanilla to Cabo Rojo. This reef displays the typical "spur-and-groove" growth pattern with sand channels cutting through the shelf perpendicular to the coastline. Off La Parguera, the reef starts at a depth of about 18 meters and continues down the shelf slope to depths of at least 35 meters. Optimal development is found just at the shelf-break, at a depth of 20 meters. Another less extensive system, but very well developed is the shelf-edge reef at the northern Tourmaline Reef off Bahía Mayaguez. This reef begins at a depth of about 10 meters, increasing the height of its "spurs" towards the shelf-edge. Both of these shelf-edge reefs grow in waters of moderate to high transparency. Perhaps the best developed reef within Puerto Rican waters is the shelf-edge reef found off the southwestern section of Isla de Mona. Although limited quantitative data is available to characterize this reef in terms of its live coral cover, [13, 16] it is evident that extensive sections surpass 60 % of live coral cover. The waters that surround this oceanic reef receive minimal terrigenous inputs.

Reef Community Structure, Coral Taxonomy and Distribution

Puertorrican coral reefs were initially described in terms of their taxonomic composition by Almy and Carrión Torres. [1] This initial survey identified a total of 35 species of scleractinian corals from La Parguera, southwest coast of Puerto Rico. Later surveys have been reported by Mckenzie and Benton, [44] Rogers et al., [17] Hernandez-Delgado, [22, 29, 30] Hernandez-Delgado and Alicea-Rodriguez [46, 47] and Hernandez-Delgado *et al*. [48, 49] A compendium of coral taxa from puertorrican waters was prepared from different sources. [12, 38, 44, 50, 51, 52] Table 1 presents a taxonomic listing of 93 species of coral taxa, including octocorals and hydrocorals from puertorrican reefs.

Table 1. Annotated list of coral taxa reported from Puertorrican waters.

Phylum Cnidaria
Class Hydrozoa
Order Milleporina
Millepora alcicornis
Millepora complanata
Millepora squarrosa

Order Stylasterina
Stylaster roseus

Class Anthozoa
Order Antipatharia
Antipathes pennacea
A. tanacetum
A. furcata
Stichopathes sp.

Subclass Octocorallia
Order Alcyonacea
Erythropodium caribaeorum
Iciligorgia schrammi
Briareum asbestinum
Telesto riisei

Order Gorgonacea
Gorgonia mariae
G. ventalina
G. flabellum
Pseudopterogorgia acerosa
P. americana
P. bipinnata
P. rigida
P. albatrossae
Pterogorgia anceps
P. citrina
Eunicea mammosa
E. succinea
E. axispica
E. fusca
E. laciniata
E. touneforti
E. clavigera
E. knighti
E. calyculata
Muricea atlantica
M. muricata
M. pinnata
M. laxa
M. elongata
Muriceopsis sp.
M. sulphurea
M. flavida
Plexaura flexuosa
P. homomalla
Pseudoplexaura porosa
P. flagellosa
P. wagenaari
P. crucis
Plexaurella dichotoma
P. nutans
P. grandiflora
P. grisea
P. fusifera
Ellisella sp.

Order Scleractinia
Stephanocoenia michelinii
Madracis decactis
M. mirabilis
Acropora palmata
A. cervicornis
A. prolifera
Agaricia agaricites
A. fragilis
A. tenuifolia
A.lamarcki
Leptoseris cucullata
Siderastrea siderea
S. radians
Porites astreoides
P. porites
P. branneri
Favia fragum
Diploria clivosa
D. strigosa
D. labyrinthiformis
Manicina areolata
M. mayori
Collpophyllia natans
Cladocora arbuscula
Montastrea annularis
M. cavernosa
Phyllangia americans
Astrangia solitaria
Meandrina meandrites
Dichocoenia stokesi
Dendrogyra cilindricus
Mussa angulosa
Scolymia lacera
S. cubensis
Isophyllia sinuosa
Isophyllastrea rigida
Mycetophyllia lamarckiana
M. aliciae
M. danaana
M. ferox
Eusmilia fastigiata
Tubastrea aurea
Oculina diffusa

Quantitative assessments of sessile-benthic reef communities were performed during the period between 1985 and 1999 on 54 reefs around the island of Puerto Rico. Characterizations were performed using various techniques rendering information of the percent cover by reef substrate categories. These included continuous measurements along 10 m linear transects, [8, 53] phototransects, and 1.0 m^2 standard quadrat techniques. Data on reef community structure and coral taxonomic composition has been separated into three depth strata (1 - 5 m; 6 - 12 m; 15 -25 m) representing different reef types and physiographic zones within a given reef. Only live coral cover and taxonomic composition is available for the deeper reefs studied (15 - 20 m). Percent cover data are means from replicate line transects or quadrat surveys (n = 4 or 5) on each reef.

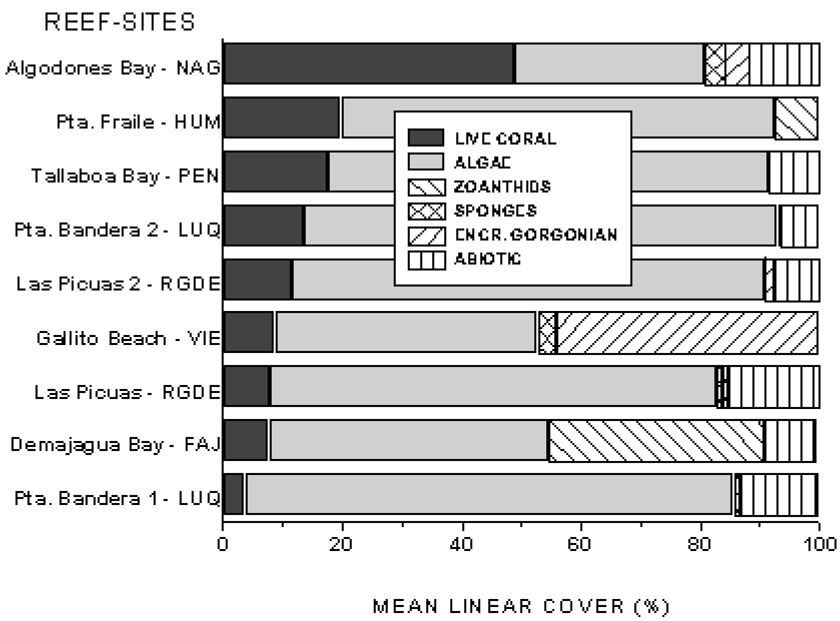

Figure 3. Mean linear cover by sessle benthic substrate categories – reef depth: 1-5 meters

Percent cover by sessile-benthic substrate categories at shallow reefs (1 - 5 meters) are presented in Figure 2. Algae was the dominant substrate type in terms of percent cover in seven out of the nine reefs surveyed, ranging in cover between a minimum of 31.8 % at Algodones Reef in Naguabo, and a maximum of 82.1 % at Pta. Bandera Reef in Luquillo. The mean cover of algae on shallow reefs was 65 %. Live coral at shallow reefs varied between a maximum of 48.9 % at Algodones Reef and a minimum of 3.7 % at Pta. Bandera Reef (Fig. 2). Mean live coral cover was 15.5 %. Shallow reefs with live coral cover of 20 % or higher were both from the southeast coast (Algodones and Pta. Fraile), whereas reefs with live coral cover below 10 % were all from the northeast coast, including the island of Vieques. The taxonomic composition of stony corals at shallow reefs was characterized by a mixed assemblage of species (Figure 3). Between four and 10 species of corals were intercepted by linear transects at each reef. The *Porites astreoides, P. porites, Siderastrea radians, S. siderea* assemblage represented more than 50 % of the total coral cover at shallow reefs surveyed. *Porites astreoides* and *Siderastrea radians* were present at all reefs surveyed in the 1 - 5 m depth range. Other common taxa included *Diploria* spp. and the hydrocorals, *Millepora* spp. The encrusting octocoral, *Erythropodium caribbaeorum*, was present in five out of eight reefs surveyed with maximum cover (44 %) at Gallito Beach Reef in Vieques (Fig. 2). Zoanthids, particularily the encrusting, colonial form *Palythoa caribbea*, and sponges were the other main biotic components of the shallow reef benthos. Abiotic cover (sand, holes, overhangs, etc.) averaged 8 % at shallow reefs.

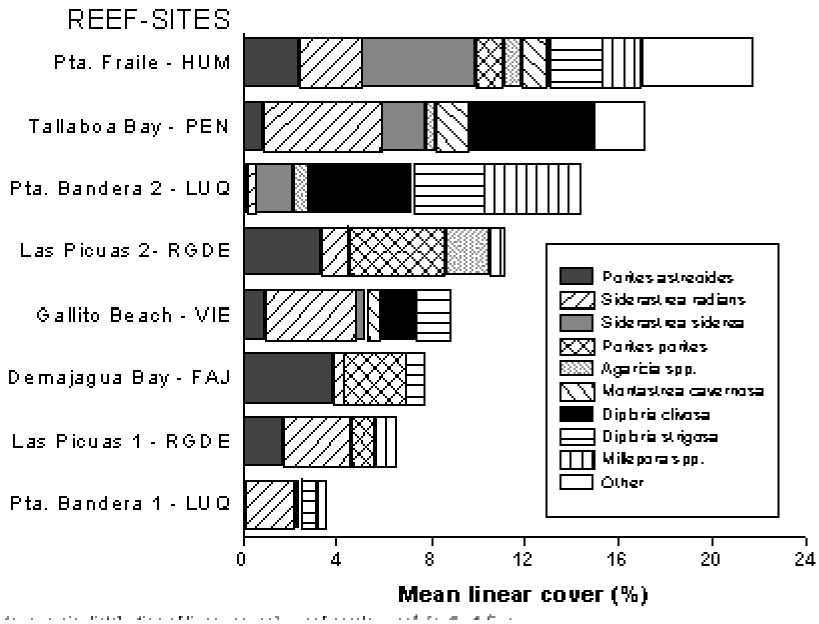

Figure 3. Taxonomic distribution of linear cover by reef corals – reef depth: 1-5 meters

Live coral cover varied from 0.6 % to 49.1 % at reefs surveyed in the intermediate depth range (6 - 12 m). Mainland reefs from the north and northeast coastlines (Mameyal, Bajíos, Boca Vieja, Morrillos, Siete Mares, Pta. Candelero) evidenced low coral cover (Figure 4). Las Cabezas Reef in Fajardo was the only mainland reef from the northeast coastline with live coral cover above 10 %, ranking 15th among reefs studied at intermediate depths. Hard-ground and rock reef communities of the north coast are subject to very strong wave action and heavy loads of sediment from large river plumes. Reefs from the south coast located close to shore in Ponce Bay (*i.e*. Hojitas) and Guayanilla Bay (*i.e*. Guayanilla, Cayo Río, Cayo Unitas) also ranked very low in terms of live coral cover. These are inshore coral reefs in advanced state of degradation. An increasing pattern of live coral cover associated with distance from shore was observed in Mayagüez Bay, where a series of dead coral reef structures, such as Algarrobo Reef and other submerged patch reefs (not included in this survey) are found close to shore. Mid-shelf reefs in Mayagüez Bay varied in live coral cover between 10.6 % at Media Luna and 29.3 % at Las Coronas. Tourmaline Reef, in the outer shelf of Mayagüez Bay showed the highest live coral cover of all reefs studied (*i.e*. 49.1 %). Turrumote and Media Luna Reefs in the southwest coast (La Parguera), and Cayo Diablo and Isla Palominitos reefs from the northeast island chain (Cordillera de Fajardo Reefs) followed Tourmaline Reef in terms of live coral cover. The reefs of the Cordillera de Fajardo are subject to very strong wave action during winter, but are located upcurrent from major rivers and do not receive large sediment loads. Well developed coral reef communities have developed along the protected (leeward) sections of the chain of islets.

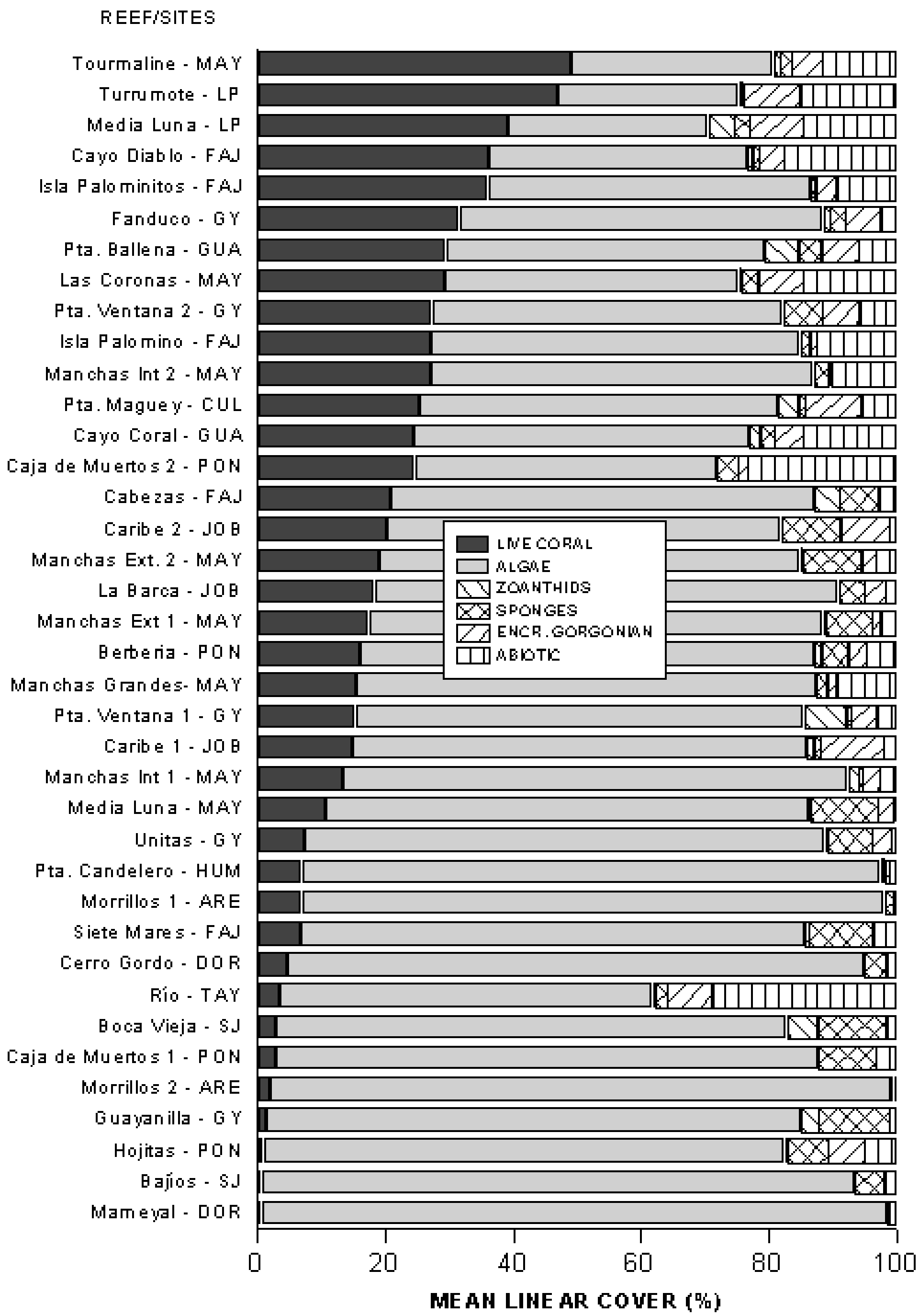

Figure 4. Mean linear cover by sessle benthic substrate categories – reef depth: 6-12 meters

Algae was the dominant substrate on 35 out of the 38 reefs studied at intermediate depths, ranging in cover from 28.2 % in Turrumote to 98.0 % at Mameyal Reef. A mixed assemblage of short filamentous algae, forming an "algal turf" was the most common type of algal cover, although substantial fleshy algae was observed at La Barca and Cayo Caribes Reefs from Jobos Bay, and at Mameyal and Cerro Gordo reefs in Dorado. Calcareous algae (mostly *Halimeda* sp.) was an important component of the algal cover at Cayo Rio and Guayanilla Reef. The encrusting octocoral, *Erythropodium caribbaeorum*, was observed in variable percent linear cover at 29 reefs surveyed at intermediate depths (6-12 m). The highest cover was observed in the Caribes Reef at Jobos Bay (9.9 %) and Pta. Maguey in Isla Culebra (8.7 %). Conversely, encrusting gorgonian was absent from the high energy hard ground and rock reef communities from the mainland north coast (Fig 4). Zoanthids (*Palythoa caribbea*) and sponges were the other main biotic components of the reef benthos at intermediate depths. Abiotic cover (sand, holes, overhangs, etc.) ranged from 0 - 26.8 %.

The taxonomic composition of corals at reefs of intermediate depth (6 - 12 meters) is presented in Figure 5. *Montastrea annularis* was the predominant scleractinian coral at 19 of the 22 reefs with highest live coral cover within this depth range. Conversely, *M. annularis* was absent in 12 out of the 13 reefs with lowest live coral cover among the reefs surveyed. *Montastrea cavernosa* and *Porites astreoides* occurred in more reefs than any other coral taxa and were the main components of the live coral assemblage of highly degraded reefs, such as Mameyal, Cayo Río, Morrillos, and Guayanilla Reef.

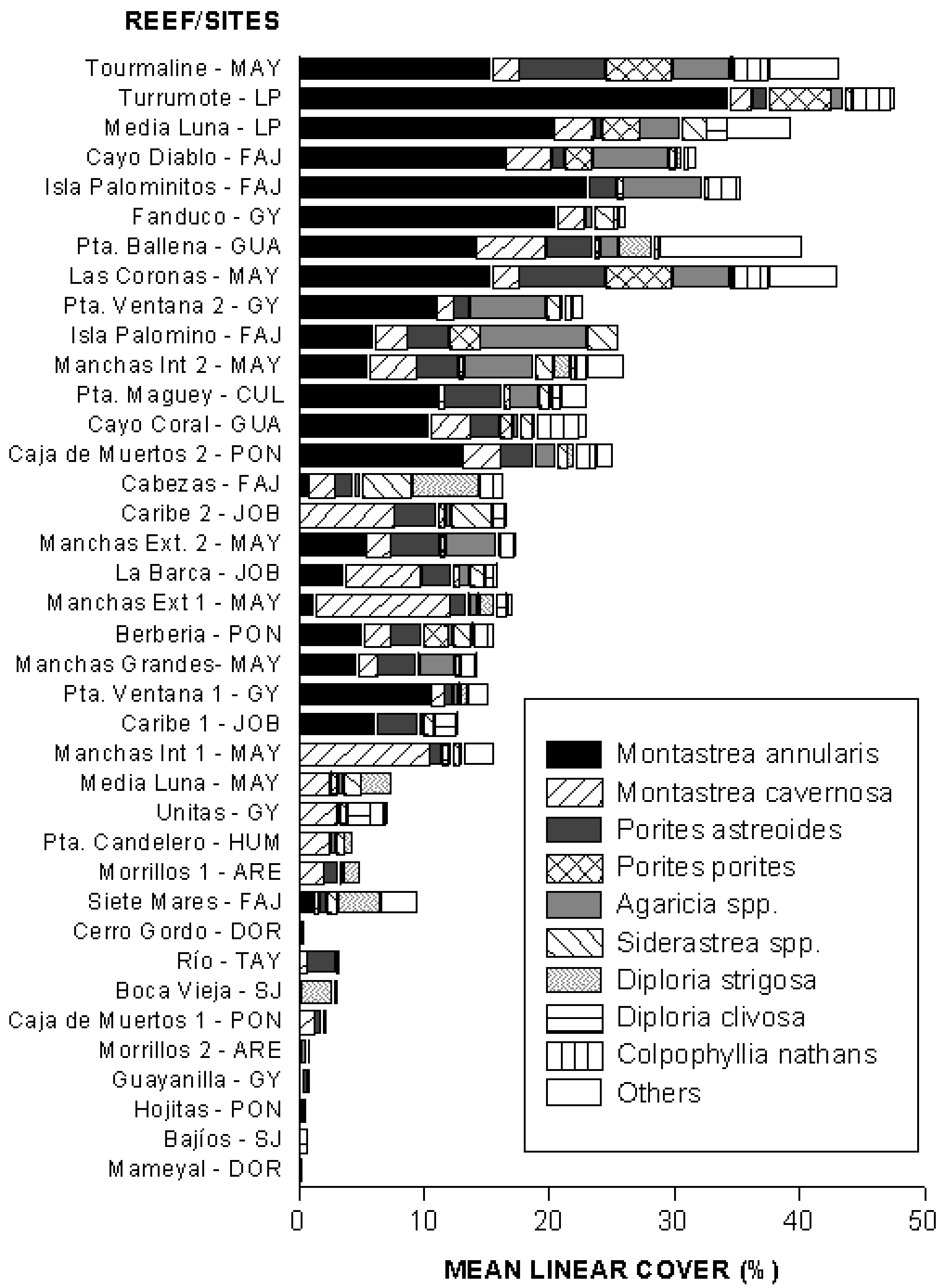

Figure 5. Taxonomic distribution of linear cover by reef corals – reef depth: 6-12 meters

Live coral cover at the deeper reefs studied (15 - 25 m) was highest at the shelf-edge reef off La Parguera (44 %). Other reefs from the southwest coast (Penuelas, Turrumote) surveyed at depths between 15 and 25 m depths ranged in live coral cover from 16 to 27 %. Manchas Interiores, Manchas Exteriores and Manchas Grandes Reefs at the middle-shelf of Mayaguez Bay presented live coral cover ranging between 0 and 7 % (Fig 6). *Montastrea annularis, M. cavernosa, Porites atreoides* and *Agaricia* spp. were the most common coral taxa at the deeper reefs studied.

Environmental Stressors of Coral Reefs in Puerto Rico

The present status of Puerto Rican coral reefs may be one of the most critical in the Caribbean. [54] This is perhaps a result of our highly accelerated urban and industrial coastal development during the last four decades and (still) the lack of effective management policies to protect the ecological integrity of these resources. Superimposed on this local scenario are global and regional stressors presently affecting coral reefs. On a local scale, anthropogenic activities, such as the massive deforestation of mangroves in the north coast, dredging of our principal bays for ocean cargo, runoff from large scale agricultural developments in the coastal plain, deforestation of large river watersheds for urban development, raw sewage disposal into rivers and establishment of thermoelectric power plants on the north and south coasts represented an important combination of factors acting as potential stressors to coral reefs in the 1950's. One decade later, the first (taxonomic) observations on coral reef systems were undertaken. [1] Two decades later, the first inventory of puertorrican coral reefs was performed. [12] Thus, no one really knows what the "pristine" condition of our coral reefs ever was.

In absence of baseline data on live coral cover, massive overgrowth by algae and other encrusting biota of coral skeletons has been used as an indication of "reef degradation" in Puerto Rico. Mackenzie and Benton [44] were the first to document the massive algal cover and low live coral in reefs of the north coast. Sedimentation and high turbidity has been associated with coral reef degradation in a variety of reef systems in Puerto Rico by different authors. [19, 20, 21, 28, 33, 43, 46, 48] In their qualitative inventory of reefs, Goenaga and Cintrón [12] noted the high sedimentation affecting reefs of the north coast and those in the south and west coasts in bays used for ocean cargo (e.g. Guayanilla, Mayagüez). Acevedo and Morelock [11] provided a quantitative assessment of sediment impact on south coast coral reefs by measuring reductions of live coral cover from reefs located close to sediment point sources.

Combined contamination sources, perhaps with synergistic effects, have been a major threat to coral reefs in Puerto Rico. Dead coral reefs with massive colonies completely overgrown by algae and other encrusting biota are found in Ponce, Guayanilla and Mayagüez Bays. These systems share a combination of environmental stressors that probably acted together as causal factors of the irreversible damage to coral reefs in these bays. Before any large scale manipulations of drainage basins by man, coral reefs co-evolved with riverine runoff discharges into these bays. But, sediment loads probably increased dramatically when river drainage basins were deforested for urban development. Furthermore, these bays were dredged repeatedly in order to allow large ship traffic inside the bays. It is possible that the magnitude of sediment stress alone could have killed the reefs in these bays, but it is uncertain at this point. In addition to the stress associated with sediment abrasion and increased turbidity, primary treated domestic sewage and industrial (mostly organic) waste water from tuna factories were discharged into the inner sections of Ponce and Mayagüez Bays for many years, which promoted the process of eutrophication. It is to be inferred that the increased productivity further limited water column light penetration in these bays and perhaps favored growth of algae and other encrusting biota over corals. Other major anthropogenic activities that have been associated with reef degradation in Puerto Rico include

- oil spills [55]
- anchoring of large oil cargo vessels [Hernández-Delgado, personal observations]
- uncontrolled recreational activities [22, 29]
- eutrophication [43]
- mechanical destruction by ship groundings [7, 56]
- thermal pollution [22]
- overfishing [25]
- military bombing activities, particularly at Vieques and Culebra Islands [17, 57]

In the particular case of Culebra and Vieques islands, historical bombing during military training activities have caused severe destruction of coral reef fisheries and reef frameworks. [17] A total of 76% of the surface of Vieques Island has been part of a U.S. NAVY training facility since 1941. Most coral reefs located in the eastern half of the 35 km long Vieques Island are still suffering from the impacts of military training activities. For the last two decades, there had been no reliable monitoring records of ecological changes in Vieques easternmost coral reefs, although 8 to 50% declines in coral cover from coral reefs located within maneuver areas in Vieques have been reported. [57] Such decline in coral mortality has been attributed to hurricanes, concluding that the impact of bombing in the coral reef was negligible. [57] Unfortunatelly, deep reef sections that are typically unaffected by hurricanes were not included in the assessment of bombing effects.

Natural factors that have been associated with coral reef degradation include:

- hurricanes [2]
- coral bleaching [38, 39, 40, 47]
- coral diseases (*i.e.*, white band disease, black band disease, white plague and seafan fungus disease [58]
- predation by territorial pomacentrid fishes, mostly *Stegastes planifrons* [40, 46]
- the Caribbean-wide massive mortality of the sea-urchin *Diadema antillarum* [35, 39]

The decline in abundance of large fishes along with the massive mortality of the black sea-urchin represents a major shift in the community structure of puertorrican reefs. It can be hypothesized that the reduction of grazing pressure by the black sea-urchin has promoted algal overgrowth of corals and other hard ground substrates. The absence of large fish predators includes parrotfishes, which are important herbivores in the coral reef system and carnivores, which consume small fishes. Some authors believe that the lack of large fish predators has stimulated a proliferation of small fish farmers, such as damselfishes (e.g. *Stegastes planifrons*) which bite and kill coral polyps to promote new growth of algae to feed their young. Likewise, the persistent and ever increasing fishing pressure over spiny lobster (*Panulirus argus*) has reduced substantially the abundance of this predator from shallow reefs. Consequently, there has been a proliferation of one of its favorite prey, corallivorous gastropods. The increased abundance of these gastropods is having large scale coral predation effects on *Acropora palmata* in La Parguera. [Bruckner, personal communication]

Management Approach to Coral Reef Resources

The presence of well developed coral reef communities stands as one of the main criteria in designation of coastal areas as Natural Reserves by the Department of Natural Resources of the Commonwealth of Puerto Rico. Natural Reserves which present coral reef systems include:

1. Espíritu Santo River Estuary Natural Reserve, Río Grande
2. Cabezas de San Juan Natural Reserve, Fajardo
3. La Cordillera Natural Reserve, Fajardo
4. Mosquito Bay Natural Reserve, Vieques
5. La Parguera, Lajas
6. Caja de Muertos, Ponce
7. Mona Island
8. Tourmaline Reef
9. JOBANERR, Salinas

All of these Natural Reserves are under the jurisdiction of the Puerto Rican government. There are also protected lands owned by the United States federal government (*i.e.* Culebra National Wildlife Refuge, which protects many of the coastal lands and cays in the Culebra Island archipelago. Natural Reserves bring only a minor degree of protection to coral reefs, but effective management is limited by the lack of laws regulating fishing activities and recreation. There are at present other candidate sites for the establishment of Natural Reserves and Marine Fishery Reserves. These include El Covento Beach Candidate Natural Reserve, Turrumote Marine Fishery Reserve, and Culebra Island Marine Fishery Reserve (MFR).

Management perspectives for protection of coral reef resources must address integral ecosystem approaches including permanent fishing closure inside critical reef sections as part of the management strategy. The decline of large fishes from puertorrican reefs represents a major threat to the integrity of the reef ecosystem and has been shown to have direct consequences upon live coral cover. It may be argued that due to the offshore larval dispersion patterns of most coral reef fishes [60, 61, 62, 63] closed fishing areas would not have any fishery enhancement effects on local scales. Ramirez and García [64] have shown that important predatory fish families, such as Lutjanids, have mostly neritic larval dispersion patterns, and as such, present good potential for self-recruitment. Many other reef fish families have shown neritic larval cycles and could benefit directly from an expected increment in parental stock biomass due to closed fishing laws in coral reefs. Also, direct escape of large fishes and lobsters from closed fishing areas could benefit adjacent areas open to reef fisheries. The abundance of large fishes increases the recreational value of coral reefs for ecotourism which, in turn, serves to support the local economy. With establishment of closed fishing areas in selected reef areas of already designated Natural Reserves, a network of protected areas could allow for an additional level of connectivity that some reef fishes and lobsters need for replenishment of their populations. [63] The next step would be the establishment of such management policies on a larger, regional (northern Caribbean) scale. Public awareness is the driver for these initiatives to become reality.

Click in this box
to return to
coral reef papers

Literature Cited

1) C.C. Almy, Jr., & C. Carrión Torres. Carib. J. Sci. 3 (1963.) 133.
2) P.W. Glynn, L.R. Almodóvar, & J. G. González. Carib. J. Sci. 4 (1964) 335.
3) P.W. Glynn. Mar. Biol. 1(1968) 226.
4) E. C. Pressick. Carib. J. Sci., 10 (1970) 137
5) A. Szmant-Froelich. Annual Report, PRNC-162 (Puerto Rico Nuclear Center-DOE) Environmental Studies. 50 p.
6) P.W. Glynn, In: O.A. Jones, & R. Endean (eds.). Biology and Geology of Coral Reefs, Vol. 2. Academic Press, Inc., New York, N.Y. (1973)
7) P.W. Glynn. Marine Geology, V. 20 (1973) 297
8) Y. Loya. Bull. Mar. Sci. 26 (1976) 450
9) C. S. Rogers. Mar. Poll. Bull. 14 (1983) 378.
10) C. S. Rogers. J. exp. Mar. Biol. Ecol. 41 (1979) 269.
11) R. Acevedo, and J. Morelock. Proc. 6th Int. Coral Reef Symp., Australia, 2 (1988) 189.
12) C. Goenaga, and G. Cintrón. Inventory of the Puerto Rican Coral Reefs. Department of Natural

Resources, San Juan, P.R. Report (1979).190 p
13) G. Cintrón, J. Thurston, J. Williams and F. MacKenzie. Department of Natural Resources, San Juan, P.R. - Proceedings 2nd Symposium DNR (1975), San Juan, P. R. p. 69
14) P. Colin. Caribbean Reef Invertebrates and Plants. T.F.H. Publications. 1978.
15) M. Canals and H. Ferrer. Los arrecifes de Caja de Muertos. Department of Natural Resources, San Juan, P. R. Report (1980).
16) M. Canals, H. Ferrer, and H. Merced. Proceedings 8th Symposium, Department of Natural Resources, San Juan, P. R. (1983), San Juan, P. R. p. 1-26
17) C. S. Rogers, G. Cintrón, and C. Goenaga. The impact of military operations on the coral reefs of Vieques and Culebra. DNR, San Juan, P.R. Report (1978)
18) C. S. Rogers. Proc. 5th Int. Coral Reef Congr. 6 (1985) 491
19) J. R.García, C. Goenaga, and V. Vicente. Characterization of marine communities in the vicinity of PRASA submarine outfalls. Report. (1985) Metcalf & Eddy, Inc.
20) R. Castro and J. R. García. Characterization of marine communities associated with reefs and seagrass/algal beds in Guayanilla and Tallaboa Bays. Report (1996) EcoElectrica/Gramatges and Associates, Inc. 171 pp
21) J. R. García, and R. L. Castro. Characterization of coral reef, seagrass beds and mangrove root communities at the Jobos Bay Natural Estuarine Research Reserve JOBANERR-DRNA Report (1997) 69 p.
22) E.A. Hernández-Delgado. 1992. Coral reef status of northeastern and eastern Puerto Rican waters: recommendations for long-term monitoring, restoration and management. Caribbean Fishery Management Council , Hato Rey, P.R., (1992) 87 pp.
23) R. P. Webb, D. Collar, W. C. Schwab, C. Goenaga, J. R. Garcia and R. Castro.
U. S. G. S., Water Resources Investigations Report 98-XXXX. (1998) San Juan, P. R. 73
24) J. R. García, and R. L. Castro. International Conference on Scientific Aspects of Coral Reef Assessment, Monitoring and Restoration. NCRI. Florida. (1988).
25) R. Appeldoorn, J. Beets, J. Bohnsack, S. Bolden, D. Matos, S. Meyers, A. Rosario, Y. Sadovy, and W. Tobias. NOAA Technical Memorandum NMFS-SEFSC-304 (1992)
26) J. R. García, C. Schmitt, C. Heberer, and A. Winter. La Parguera, Puerto Rico, USA. In: B. Kjerfve (ed.) CARICOMP - Caribbean Coral Reef, Seagrass and Mangrove Sites, UNESCO (1988), Paris 195 p.
27) J. R. García, R. Castro and J. Sabater. Coral reef communities from Natural Reserves in Puerto Rico. Vol. 1. Isla Caja de Muertos, Bosque Seco de Guanica, Bahía de Mayaguez, Cordillera de Fajardo. (Report) DNR-PR/USCRI (1999).
28) E.A. Hernández-Delgado. Inventario preliminar de las comunidades coralinas de la costa de Río Grande, incluyendo la Reserva Natural del Estuario del Río Espíritu Santo. (Informe) Junta de Planificación, San Juan, P.R. (1995).
29) E.A. Hernández Delgado. National Marine Sanctuary Site Nomination: Mona and Monito Islands. National Oceanic and Atmospheric Administration, Washington, D.C., (1994)
30) E.A. Hernández-Delgado. Preliminary inventory of the coral reef systems and hardground communities from La Cordillera Natural Reserve, Puerto Rico. Project Reefkeeper, Miami, FL (1994)
31) J. R. García. La Parguera Marine Fishery Reserve. (Report) Sea Grant (1996)
32) E.A. Hernández-Delgado, A.M. Sabat, L. Alicea-Rodríguez, J.E. Martínez-Suárez, A.L. Ortiz-Prosper, E.O. Rodríguez-Class, C.G. Toledo-Hernández, & R.N. Ginsburg. Proceedings XXIII Symposium Department of Natural Resources, San Juan, P. R. (1988)
33) J. R. García and R. Castro. Characterization of marine communities associated with reefs and seagrass/algal beds in San Juan Bay and Ensenada Boca Vieja, Palo Seco. (Report) Grammatges and Associates, Inc. (1995)
34) J. R. García and R. Castro. Pre-construction survey of marine communities associated with coral reefs and seagrass/algal bed habitats in Guayanilla and Tallaboa Bays, southwestern Puerto Rico. (Report) Grammatges and Associates. (1998).
35) Vicente, V. and C. Goenaga. Mass mortalities of the sea-urchin *Diadema antillarum* in Puerto Rico.

Center for Energy and Environment Research. CEER-M-195 (1984).
36) L. Bunkley-Williams and E. H. Williams. Oceanus 30 (1987) 71.
37) L. Bunkley-Williams, J. Morelock, and E. H. Williams. Journal of Aquatic Animal Health. 3 (1991) 242
38) C. Goenaga, V. P. Vicente, and R. A. Armstrong. Carib. J. Sci., 25 (1989) 59
39) E. H. Williams, Jr. and L. Bunkley-Williams. Sea Frontiers, March-April. (1988) p. 81-87
40) E. H. Williams, Jr. and L. Bunkley-Williams. Proc. 6th International Coral Reef Symposium, Australia 3 (1989) 313
41) J. Morelock, N. Schneiderman and W. R. Bryant. Studies in Geology, 4 (1977) 17 42) W.H. Adey. Science, 202 (1978) 831
43) C. Kaye. Shoreline features and quaternary shoreline changes, Puerto Rico. U. S. Geological Survey. Prof. Pap. 317-B. (1959)
44) F. Mckenzie and M. Benton. Biological inventory of the waters and keys of north-east Puerto Rico. Department of Natural Resources, San Juan, P.R. Report (1972) 90 pp.
45) H.A. Meyerhoff . Sci. Surv. Porto Rico and the Virgin Islands. 4 (1927) 145
46) E. A. Hernández Delgado and L. Alicea Rodríguez. Estado ecológico de los arrecifes de coral en la costa este de Puerto Rico: I. Bahía Demajagua, Fajardo, y Playa Candelero, Humacao. Proceedings XII Symposium of the Caribbean Fauna and Flora. University of Puerto Rico, Humacao, (1993) 2.
47) E. A. Hernández Delgado and L. Alicea Rodríguez. Blanqueamiento, pérdida de pigmentos y recuperación en los cnidarios de la costa este de Puerto Rico entre el 1992 y 1993. Proceedings XII Symposium of the Caribbean Fauna and Flora. University of Puerto Rico, Humacao, (1993) 73
48) E. A. Hernández-Delgado, E.O. Rodríguez-Class and J.E. Martínez-Suárez. Evaluación biológica del arrecife Cayo Ahogado, Bahía Algodones, Naguabo, Puerto Rico Environmental Quality Board of P. R., San Juan, P.R., Report (1996) 41 pp.
49) E. A. Hernández-Delgado, L. Alicea-Rodríguez and J.E. Martínez-Suárez. Las comunidades coralinas de Playa Los Gallitos, Vieques, Puerto Rico: I. Descripción cualitativa. Unión de Protección del Medio Ambiente de Vieques. Report (1996) 24
50) C. Goenaga. M. S. Thesis. University of Puerto Rico, Mayaguez (1977).
51) C. Goenaga. Assessment of precious coral fisheries potential south of Guanica Bay, Puerto Rico, using the submersible RV Johnson Sea Link. National Marine Fishery Service, NOAA. (Report)1985.
52) C. Goenaga. Ph. D. Dissertation, University of Puerto Rico, Mayaguez. (1985) 215 pp.
53) J. W. Porter. Ecology, 53 (1972) 745
54) C. Goenaga and R.H. Boulon, Jr. The State of Puerto Rican and U.S. Virgin Islands Corals. Caribbean Fishery Management Council, Hato Rey, P.R. Report (1991) 66 pp.
55) M. J. Cerame-Vivas. Sea Frontiers, 15 (1969) 224
56) E. A. Hernández-Delgado, A.L. Ortiz-Prosper and L. Alicea-Rodríguez. Characterization of damage and recovery patterns of the coralline community impacted by the Caribe Cay grounding at Palominitos Island, Puerto Rico. (Unpublished Report)
57) A. Antonius and A. Weiner. Mar. Ecol. 3 (1982) 255
58) A. W. Bruckner. Ph. D. Dissertation, University of Puerto Rico, Mayaguez (1999)
59) H. A. Lessions, D. R. Robertson and J. D. Cubit. Science, 226 (1984 335
60) R. E. Johannes. Envir. Biol. Fish. 3 (1978) 65
61) J. Leis and J. M. Miller. Mar. Biol. 36 (1976) 359
62) P. F. Sale. Oceanogr. Mar. Biol. A. Rev. 18 (1980) 367
63) C. M. Roberts. Science, 278 (1997) 1454
64) J. Ramirez-Mella and J. R. García. Proceedings 47th Annual Meeting of the Gulf and Caribbean Fisheries Institute, Isla Margarita, Venezuela, 1994 (in press).