The State of Coral Reef Ecosystems of the Commonwealth of Puerto Rico

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INTRODUCTION AND SETTING

Puerto Rico, the smallest of the Greater Antilles, is located in the north central Caribbean, between the U.S. Virgin Islands (USVI) to the east and the Dominican Republic to the west (Figure 5.1). Puerto Rico is an archipelago comprised of the main island; the oceanic islands of Mona, Monito, and Desecheo in the Mona Passage; Caja de Muertos Island on the south coast; Vieques Island; Culebra Island; and a series of smaller islets or cays known as the "Cordillera de Fajardo." The total area of the Puertorrican archipelago is 8,929,468 km^2.

The geological, climatological, and oceanographic features that affect growth and development of coral reefs vary markedly among insular shelf segments (García-Sais et al., 2003). The north and northwest coasts are narrow (<3 km) and shallow communities are subject to strong wave action during winter as large swells from the north Atlantic reach the Caribbean Antilles. The north and west coasts also receive substantial sediment and nutrient loading from the discharge of the largest rivers of Puerto Rico. Sand dunes are abundant along the north coast, some of which are now submerged eolianites. Others fringe the coastline, forming rocky beaches with rich intertidal communities. The northeast coast has a wider shelf, partially protected from wave action by a chain of emergent rock reefs (Cordillera de Fajardo) aligned east-west between the main island and the island of Culebra. The northeast coast is upstream from the discharge of large rivers, resulting in more appropriate conditions of light penetration for coral reef development. The east coast between Fajardo and Vieques is characterized by extensive sand deposits that provide unfavorable substrates for coral growth. However, scattered rock formations within this shelf section have been colonized by corals.

The south coast is an environment of relatively low wave energy and the insular shelf is generally wider than the north coast. Rivers with smaller drainage basins discharge on the southeast coast and only small 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 (Acevedo and Morelock, 1988). 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 m with an abrupt, steep (almost vertical) slope in many sections. At the top of the shelf-edge lies a submerged coral reef which gives protection to other reefs, seagrass and mangrove systems of the inner shelf (Morelock et al., 1977).

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. Coral reefs off Mayaguez Bay show a marked trend of deterioration toward the coastline, but the shelf-edge reef systems are in good condition. Farther north along the west coast is Rincón and coral reef systems are established throughout the relatively narrow shelf off Tres Palmas, including an elkhorn coral (*Acropora palmata*) biotope fringing the coastline that is probably the largest remaining stand in Puerto Rico. A series of patch reefs are distributed throughout the Rincón mid-shelf and there is a "spur-and-groove" coral reef formation at the shelf-edge. Off the northeast coast of Aguadilla, several small marginal coral reef systems are associated with rock outcrops at depths between 15-25 m. These reefs are strongly affected by intermittent river discharge (Culebrinas River) and wave action. East of Aguadilla, the influence of large river plumes, a prominent feature of the coastline, constrains coral reef development, but hard ground and rock reefs with live corals are present throughout.

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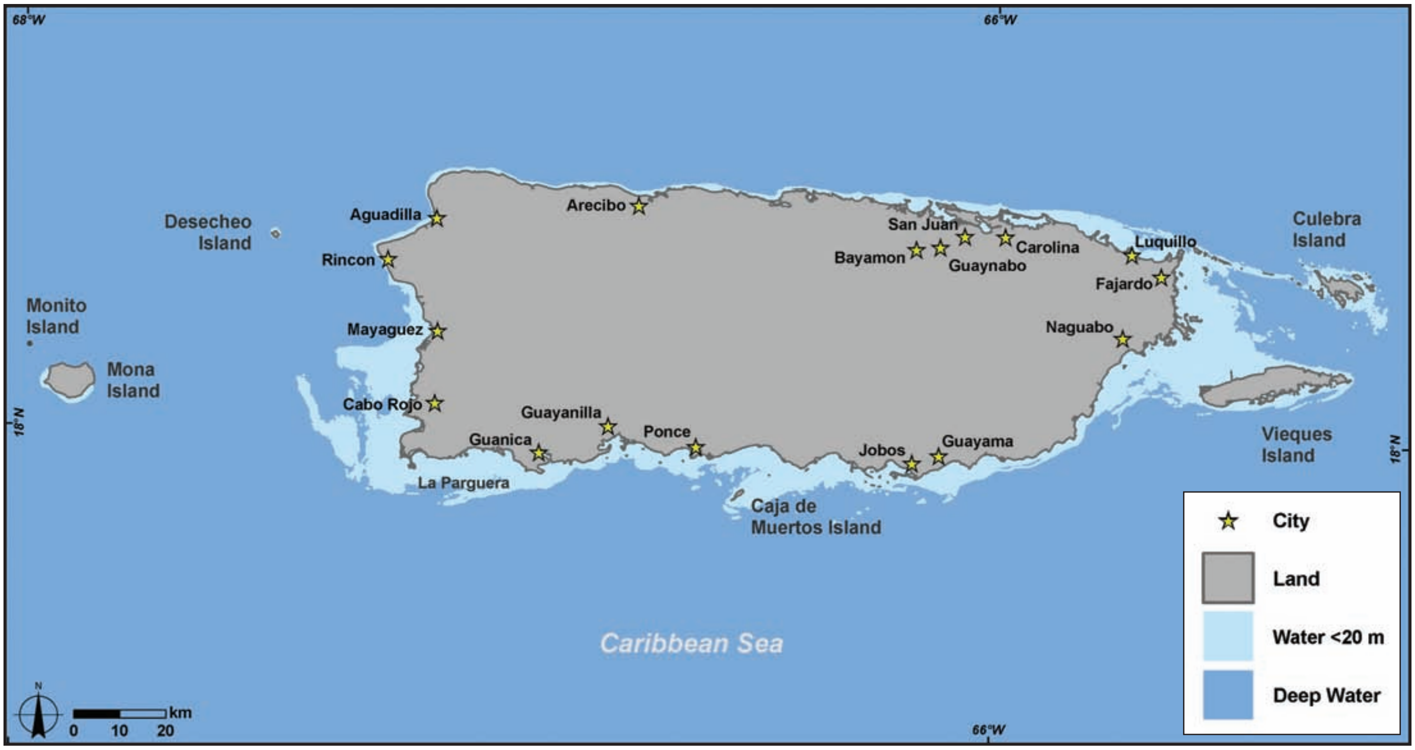

Figure 5.1. A map of Puerto Rico showing locations mentioned in this chapter. Map: A. Shapiro.

Mona and Desecheo are oceanic islands in the Mona Passage that belong to Puerto Rico. The northern sections of the islands are strongly impacted by wave action and their insular platforms are narrow, whereas the southern coastal sections of these islands are more protected and have wider platforms where coral reefs develop. There are no rivers on either of the islands, which are surrounded by waters of exceptional transparency (Cintrón et al., 1975). In Desecheo, the coral reef system is impressive at depths between 20-30 m with live coral cover exceeding 70% in many sections. The coral reef system off Puerto Canoas at Desecheo Island extends down to a depth of 40 m (García-Sais et al., 2004).

Modern shelf-edge reefs formed in Puerto Rico some 8,000 years ago (Adey, 1978). Inner reefs, formed on top of submerged banks and sandy bottoms of the flooded shelf are believed to be about 5,000 years old (Adey, 1978). 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 (Goenaga and Cintrón, 1979). Cross-shelf seismic profiles provided by Morelock et al. (1977) support the theory of Kaye (1959), which states 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 (Goenaga and Cintrón, 1979). At least three major types of reefs (rock reefs, hard ground reefs, coral reefs) are recognized within the Puertorrican shelf (García-Sais et al., 2003) although different coral reef formations have been reported (Goenaga and Cintrón, 1979; Hernández-Delgado, 1992; Morelock et al., 1977).

Rock reefs are submerged hard substrate features of moderate to high topographic relief with typically low to very low coral cover, mostly colonized by turf algae and other encrusting biota (Figure 5.2). Coral colonies are abundant in some cases (e.g., *Diploria* spp., *Siderastrea* spp., *Montastrea cavernosa*, *Porites astreoides*) but grow mostly as encrusting forms, providing minimal topographic relief. These types of reefs fringe the west and northwest coasts and are believed to be the main components of deep reef systems beyond the shelf-edge. 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.

There are deep basaltic rock reefs; an extensive and complex system of slabs, boulders, crevices; and vertical walls associated with the insular slope. The most extensive deep reef formation is the great southern Puerto Rico fault zone (Glover, 1967; Garrison and Buell, 1971), a submerged section of the Antillean Ridge that extends across the entire Mona Passage. The ridge rises from a mean depth of 4,600 m and includes the islands of Mona, Monito and Desecheo, as well as submerged seamount peaks that rise to depths of less than 100 m, such as Bajo de Cico and Bajo Esponjas

Hard ground reefs are mostly flat platforms ranging in depth from 5-30 m and largely covered by turf algae, encrusting sponges, and scattered patches of stony corals (Figure 5.2). Coral colonies are typically encrusting forms, 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, *Xestospongia 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 and provide topographic discontinuities. The sand is generally coarse and mostly devoid of biota, reflecting short deposition times and highly dynamic movements across the shelf due to the high wave action. These systems are found off the north central and northeast coastlines (García-Sais et al., 2003).

Coral reefs are mostly found as fringing, patch, 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 southwestern coastlines associated with erosional “rocky” features of the shelf. In most instances, coral is not the main constituent of the basic reef structure, but its development has significantly contributed to topographic relief, influencing the sedimentation of adjacent areas and providing habitat for a taxonomically diverse community that is consistent with a coral reef system (García-Sais et al., 2003). On the south coast, coral reefs fringe many small islands or keys, and are found as extensive coral formations associated with the shoreline at the mouths of coastal embayments. 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 (García-Sais and Sabater, 2004). Fringing reefs are also found off the northeast coast, mostly on the leeward section of the islets off Fajardo (in the Cordillera de Fajardo Natural Reserve).

Shelf-edge reefs are the best developed (but least studied) coral reef systems in Puerto Rico. An extensive reef formation is found at the shelf-edge off the southwest coast in La Parguera. This reef displays the typical “spur-and-groove” growth formation with sand channels cutting through the shelf perpendicular to the coastline (Figure 5.2). Also, the reef formations at the shelf-edge of Ponce (Derrumbadero), Guánica, and Desecheo and Mona Islands are characterized by structurally and taxonomically complex communities. The shelf break on the north coast is characterized by a more gentle slope than on the south coast and the substrate is generally sandy or a flat, hard ground with low relief. Scattered rock reefs occur throughout many sections of the north coast. Some are present down the insular slope and represent the main substrate for deep reef communities with live hermatypic and ahermatypic corals providing important physical habitat.

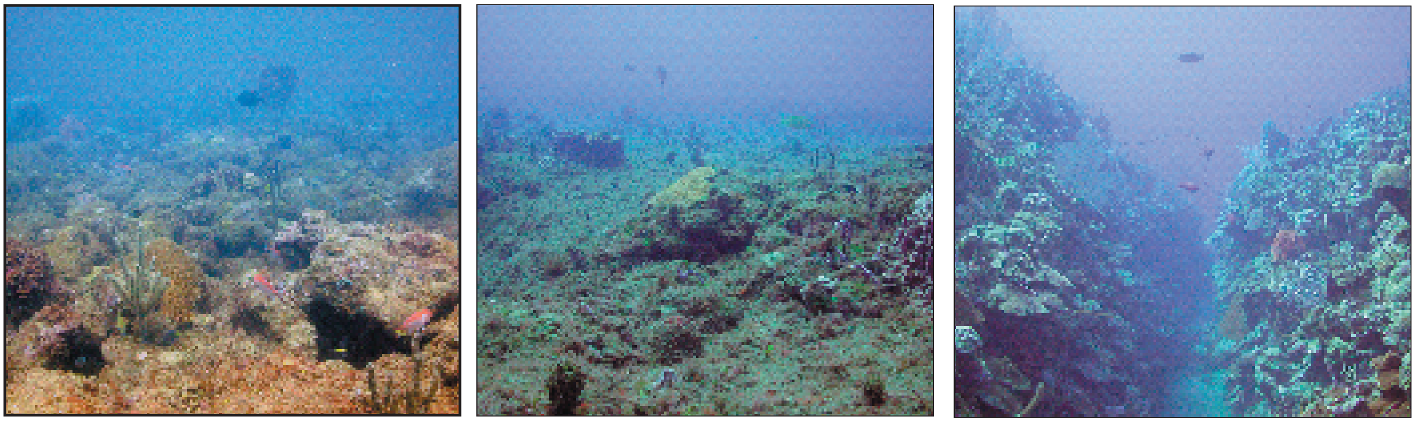

Figure 5.2. Left photo depicts rock reef habitat in the Aguadilla shelf, northwest coast. Center photo shows hard ground reef habitat in Arecibo, north coast. Right photo depicts a “spur and groove” coral reef formation in La Parguera, southwest coast. Photos: J. Sabater.

The Coral Reef Monitoring Program for Puerto Rico, which is sponsored by the National Oceanic and Atmospheric Administration (NOAA) and administered by the Puerto Rico Department of Natural and Environmental Resources (DNER), is now fully implemented and has achieved its initial goals in collaboration with Federal and local governmental agencies and marine scientists from research institutions. This chapter provides an assessment of the status of coral reef systems in Puerto Rico. A synopsis of scientific research undertaken in characterization of coral reefs is included, along with an evaluation of temporal and spatial trends of reef community structure and health, as suggested by the data emerging from ongoing monitoring programs. Quantitative baseline characterizations of sessile-benthic and fish communities at natural reserve sites and other sensitive coastal areas represent the basis for this assessment of Puertorrican coral reefs. Inferences derived from basic research on coral diseases, coral bleaching, mass mortalities and potentially relevant environmental and anthropogenic stressors, such as global warming, storms, eutrophication, fishing, sediment runoff, dredging activities and others are also presented. A description of the major ongoing programs on coral reef community characterizations and monitoring is included, along with a database on percent cover and taxonomic composition of live corals and fishes from reefs surveyed around Puerto Rico. Conservation management strategies that include active marine protected area (MPA) programs and revisions to fishing laws are presented and evaluated. Preliminary conclusions about the status of coral reefs and recommendations for management are also included in this chapter.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

Bleaching has been reported on Caribbean reefs since the 1940s (Goreau, 1964) and has been associated with localized events including marked changes in salinity, turbidity and extreme low tides (Winter et al., 1998). During the summer of 1987, a massive coral bleaching event was observed in Puerto Rico (Goenaga et al., 1989; Williams et al., 1987) and throughout the Caribbean (Williams and Bunkley-Williams, 1988).

Goenaga et al. (1989) reported extensive bleaching of zooxanthellate cnidarians from forereef environments in La Parguera that included scleractinians, zoanthids, encrusting and arborescent gorgonians, anemones and hydrocorals. A total of 64 species of coral reef photosymbiotic hosts were affected (Williams and Bunkley-Williams, 1989). Goenaga et al. (1989) associated the bleaching event to exceptionally calm seas coupled with high water transparency and increased water temperature. Vicente (1994b) found 22% of 326 corals monitored at Cayo Enrique Reef in La Parguera bleached in 1987 and 44% of those showed tissue necrosis. Goenaga et al. (1989) also found that bleaching was unrelated to depth and that the Boulder star coral, *Montastrea annularis*, had been most affected by the bleaching event in Cayo Enrique, La Parguera. Lingering effects of the 1987 mass bleaching of corals in La Parguera that lasted until late 1988 were reported by Bunkley-Williams et al. (1991). Williams and Bunkley-Williams (1990b, 2000) argued that beyond the initial damage, corals do not have sufficient time to recover between closely spaced major bleaching events and therefore the damage may be cumulative and ever increasing.

Velasco et al. (2003) tagged and observed 386 specimens of 23 species of corals off southwestern Puerto Rico after a bleaching event in 1998. They found 99% of coral colonies recovered from bleaching after three years, including the 15% that bleached again in 1999 (Velasco et al., 2003). Wilkinson (2003) and Williams and Bunkley-Williams (2000) suggested that the 1998 event in the northern Caribbean consisted of widespread, but only low to moderate bleaching. Wilkinson (2003) suggested that most susceptible corals had been killed by previous bleaching.

A number of bleaching studies have been conducted around Puerto Rico (e.g., Bunkley-Williams et al., 1991; Goenaga and Canals, 1990; Goenaga et al., 1989; Goreau et al., 1992; Hall et al., 1999; Hernández-Delgado and Alicea-Rodriguez, 1993; Velasco et al., 2003; Vicente, 1989, 1990, 1994a,b; Williams and Bunkley-Williams, 1988, 1989; Williams et al., 1987; Winter et al., 1998; Woodley et al., 1997). The nearshore reefs seem to have been damaged more by bleaching and have recovered less than the shelf-edge reefs in southwestern Puerto Rico (Williams and Bunkley-Williams, unpublished data). Many former inshore coral reefs have deteriorated to algal reefs. The reefs at Mona Island appear to have been damaged more than those on the main island of Puerto Rico, but this seems to be due more to diseases than bleaching, although bleaching may have had a precursor effect (Williams and Bunkley-Williams, unpublished data).

Winter et al. (1998) compared coral reef bleaching events at La Parguera to a 30-year (1966-1995) record of sea surface temperature (SST) for that location and found that the annual temperature indices of maximum daily SST, days >29.5°C, and days >30°C all predicted the years of severe coral bleaching in La Parguera corresponding to 1969, 1987, 1990, and 1995. However, no one simple predictor of the onset of a bleaching event within a single year may be applicable according to Winter et al. (1998).

Diseases

Coral disease, specifically black band disease (BBD), was first reported on reefs surrounding mainland Puerto Rico in 1972 (Antonius, 1981), with sporadic observations by other researchers over the last three decades (Williams and Bunkley-Williams, 1990b). A coral disease monitoring program established in 1994 has documented outbreaks of BBD in selected locations near La Parguera, Rincón, and Aguadilla, with isolated cases observed in other locations including the offshore islands of Desecheo and Mona (Bruckner, 1999). The prevalence of BBD has declined since Hurricane Georges (1998), although localized outbreaks in previously unaffected locations continue to occur. A recent Caribbean-wide survey reported an unusually high prevalence of BBD (6.8%) on Desecheo Island (Weil et al., 2002). On Mona Island, BBD has affected 1-11% of the brain corals (*Diploria strigosa* and *D. clivosa*) in reef crest and backreef environments since the mid-1990s, with infections occurring sporadically (<1%) among other massive (*M. faveolata, C. natans* and *S. siderea*) and plating (*Agaricia* spp.) corals in deeper forereef environments.

An outbreak of white plague was reported on reefs near La Parguera in 1997 (Bruckner and Bruckner, 1997), and again in 2003 at shelf edge localities which affected at least 16 species (Weil, unpublished data). An outbreak of white plague was also observed in 1999 on Mona Island that affected 14 species, with the highest prevalence among small, massive corals (*D. strigosa, D. stokesii*) many of which died within one to two weeks. Culebra Island's *Montastraea* spp. populations have also been affected by white plague since 2002, with the most recent outbreak observed in April 2004 (E. Herndandez-Delgado, pers. comm.).

White band disease (WBD), the leading cause of mortality to Caribbean acroporid populations, was first reported by Goenaga in the early 1980s with 20-33% of the *A. palmata* colonies affected on one reef near La Parguera (Davis et al., 1986). Isolated cases of WBD were observed between 1995-2003, including an outbreak that affected 15% of the standing colonies on a reef off the east coast of Mona Island (Bruckner and Bruckner, in press). WBD has also been observed among *A. cervicornis* populations near La Parguera in shallow nearshore locations and deeper shelf-edge reefs. A more virulent form of WBD was first documented among *A. cervicornis* colonies throughout Culebra in 2003, affecting 45% of all colonies on seven reefs (AGRRA, 2003). More recently, this has been reported among inshore *A. cervicornis* nurseries and in reef environments around Culebra (E. Hernandez-Delgado, pers. comm). Other conditions that have increased in abundance since 1999 on reefs near La Parguera, Desecheo and Mona Islands include yellow band disease (YBD) among *M. faveolata* and *M. annularis* and dark spots disease on *S. siderea* and other species (Bruckner, unpublished data; Weil, 2004).

The prevalence of diseases has been monitored annually on Mona Island since 1995, with emphasis on YBD. YBD was absent from these reefs in 1995 and was observed for the first time in 1996 among four colonies of *M. faveolata*. In 1999, YBD affected up to 50% of all *M. annularis* (species complex) colonies within permanent sites, including many of the largest (2-3 m diameter and height) and presumably oldest colonies. The highest prevalence of disease was recorded in shallow depths (3-10 m) off the protected west coast while fewer colonies were affected in deeper water (15-25 m) off the south coast. Measured rates of disease spread and tissue mortality has been slow (5-15 cm/year) compared to other diseases, although spatial, seasonal, and annual differences were observed. Individual colonies with a single YBD lesion have exhibited multiple infections on the colony surface over time. With exception of those colonies with YBD that died, most corals first affected by YBD between 1999 and 2001 were still affected in 2003, with colonies losing 50-100% of their tissue over this period. The prevalence of YBD progressively increased in deeper sites over the last four years and this disease is the greatest threat affecting the survival of *Montastraea* spp. populations.

Tropical Storms

Hurricanes are natural catastrophic events that have caused massive mortalities to coral reef and other coastal marine communities in Puerto Rico (Figure 5.3). In particular, hurricanes appear to be the main factor for the large-scale decimation of elkhorn coral (*Acropora palmata*) biotopes in Puertorrican reefs. The intense wave action, surge, and sediment abrasion stress associated with hurricanes cause the mechanical detachment and mortality of many benthic reef organisms, including corals in shallow reef zones. Coastal communities are also impacted by high sediment and nutrient loads from rainfall runoff during and several days after the pass of hurricanes.

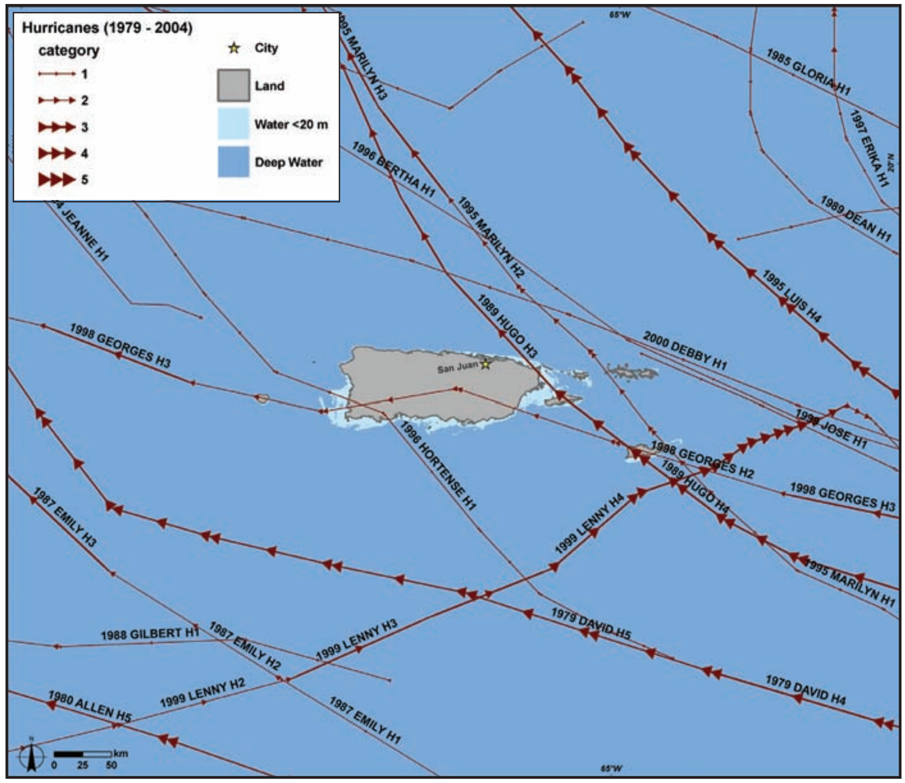

Figure 5.3. The path and intensity of hurricanes passing near Puerto Rico between 1979 and 2004. Year of storm, Hurricane name and storm strength on the Saffir-Simpson scale (H1-5) are indicated for each. Map: A. Shapiro. Source: NOAA Coastal Services Center.

The effects of Hurricane Edith (1963) on the shallow reefs of La Parguera were documented by Glynn et al. (1964). In addition to the massive mortality of reef benthic invertebrates and algae, destruction of the elkhorn coral biotope to the extent of 50% mortality was noted on inner reefs by Glynn et al. (1964). Based on aerial photoanalysis, Armstrong (1981) described the large-scale detachment and deposition of coral fragments, mostly elkhorn coral (*A. palmata*), finger coral (*Porites porites*), and fire coral (*Millepora* spp.) on the forereef of Cayo Enrique, La Parguera, after Hurricane David passed 340 km south of Puerto Rico during August 1979. The fringing red mangrove (*Rhizophora mangle*) also suffered significant damage from Hurricane David due to uprooting and scalding of the leaves (Armstrong, 1981). Extensive mass mortalities of benthic algae down to a depth of 17 m were reported by Ballantine (1984) after the pass of Hurricanes David and Allen one year later (in August 1980). Matta (1981) also noted a drastic decline in abundance and species richness of macroalgae in Cayo Turrumote, one of La Parguera's outer reefs.

Massive destruction of elkhorn coral biotopes off the northwest coast of Vieques Island reefs was reported by García-Sais et al. (2001d). These reefs appear to have been impacted by a high magnitude mechanical force, probably Hurricane Hugo in 1989. Large broken arms and other smaller coral fragments have been overgrown by benthic algae and other encrusting biota. This catastrophic phenomenon was highly significant for the north coast reef communities of Vieques in particular because of the relatively extensive area of the reef crest in relation to deeper reef physiographic zones. Re-colonization and growth of *A. palmata* colonies, as inferred from observations at La Parguera and Vieques reefs appears to be occurring at a very slow pace.

At a broader scale, hurricanes can change the biogeochemistry and productivity of coastal regions due to their influence upon river discharge and loading of sediments, nutrients, organic matter and other materials that affect phytoplankton primary productivity. Using a time series of remotely sensed imagery to analyze changes in ocean color, Gilbes et al. (2001) showed that after the pass of Hurricane Georges (September 21-22, 1998), phytoplankton biomass increased by at least two orders of magnitude, extending from coastal to adjacent oceanic regions more than 37 km offshore. Based on U.S. Geological Survey (USGS) stream flow measurements at 55 stations in 15 drainage basins, Gilbes et al. (2001) estimated that more than 1,000 metric tons of nitrate were discharged to the coastal waters of Puerto Rico during September 20-25, 1998 and concluded that this massive pulse of nutrients significantly increased phytoplankton productivity, generating a signal that was prominent in the SeaWiFS imagery.

Coastal Development and Runoff

Puerto Rico has a population of approximately 3.8 million people. The capitol city of San Juan is the main population center with 434,000 people, or 11.4% of the total population (2001 Census; http://www.censo.gobierno.pr/Centro_Datos_Censales.htm, accessed 1/20/05). Bayamón (224,000), Ponce (186,000), Carolina (186,000), Arecibo (100,000), Guaynabo (100,000), and Mayaguez (98,000) are the other main population centers. With the exception of Guaynabo, the remaining six cities (which combine for 1.23 million people or 32% of the total population) are located on the coast (Figure 5.1). San Juan, Bayamón, Carolina, and Arecibo are located on the north coast, where no significant development of coral reefs occurs. These are coastal areas with a narrow insular shelf that experience heavy wave action during the winter and are under the influence of major river runoff. Most coral reef systems in Puerto Rico are located in areas upstream of major rivers and away from population centers and terrestrial inputs, such as those in Cordillera de Fajardo, Vieques, Culebra, and the oceanic islands of Desecheo and Mona. Extensive coral reefs also exist along the protected southwest coast, from Guayanilla to La Parguera and Cabo Rojo.

Important coral reef systems are found along the Mayaguez and Ponce sections of the insular shelf. Coral reefs on these coastal sections developed under the influence of moderate (Ponce) to high (Mayaguez) seasonal runoff from river discharge and have experienced significant degradation, particularly in systems located close to the shoreline. These two cities share a history of coastal development that has been detrimental to coral reefs. Both are cities where dredging activities have been required to allow large ship traffic within the bays. Primary sewage was discharged inshore close to reef systems via submarine outfalls for several decades. Organic discharges from tuna factories were dumped through submarine outfalls in both bays for more than 20 years. Benthic habitats have been subjected to sedimentation caused by resuspension during ship docking activities and navigation within the bays. The result has been the loss of coral reefs within the inner shelf and a major shift of benthic community structure on mid-shelf sections, where soft corals have colonized hard ground benthic habitats (García-Sais and Castro, 1995). However, outer shelf reef systems at both bays, such as Tourmaline Reef in Mayaguez Bay and Derrumbadero Reef in Ponce Bay, rank among the best developed coral reefs in Puerto Rico, with live coral cover exceeding 40% at both sites.

Significant water quality restoration initiatives have been implemented during the last decade to prevent further deterioration of the marine habitats at both bays. In Mayaguez Bay, secondary treatment was mandated by the U.S. Environmental Protection Agency (EPA) for both domestic sewage and tuna factory discharges into the bay. At Ponce, the primary treated submarine sewage outfall was relocated to discharge at a depth of 150 m down the insular slope below the pycnocline. The tuna factory finished operations and moved out of Ponce Bay, but the proposed expansion of the Ponce port into the Megaport of the Americas poses relevant challenges to avoid further deterioration of coral reefs in the bay. Sediment re-suspension by large cargo ships and dredging represents the major threats to coral health. Concerns have also been raised in relation to potential impacts of the Ponce megaport operations on downstream coral reef systems at Guayanilla, Guánica and La Parguera. Guayanilla Bay is an important port that supported large scale industrial (petrochemical) operations between the 1960s and 1980s, and still harbors two large thermoelectric power plants (i.e., Costa Sur and EcoEléctrica) and several smaller coastal industries. As with Ponce and Mayaguez Bays, the inner coral reefs have been severely impacted, but those at the outer shelf appear to be in better condition. The coral reefs off Guánica Bay are mostly associated with the bay's entrance and the shelf-edge. Inside the enclosed bay, conditions are estuarine and unfavorable for coral reef development.

Coastal Pollution

Most industrial discharges are connected to Regional Waste Water Treatment Plants (RWWTP), which are administered by the Puerto Rico Aqueducts and Sewers Authority (PRASA). Five RWWTPs discharge disinfected (chlorinated) primary-treated effluent via submarine outfalls to the marine environment in compliance with the Federal Clean Water Act, Section 301(h). These include the five RWWTPs of Carolina, Bayamón-Puerto Nuevo, Arecibo, Aguadilla and Ponce. The location of these outfalls is shown in Figure 5.9 and discussion of the results of monitoring activities at outfall sites can be found in the 'Water Quality' section of this chapter.

Another potentially relevant source of pollution to the coastal waters of Puerto Rico results from the operation of thermoelectric power plants as large volumes of seawater are used to cool the machinery. The plants of San Juan (in San Juan Bay), Palo Seco (in San Juan), Aguirre (in Jobos Bay, Guayama), and Costa Sur (in Guayanilla Bay) are administered by the Puerto Rico Power Authority, whereas the EcoEléctrica Power Plant is privately owned. The power plants of Aguirre and EcoEléctrica have seawater cooling towers and do not discharge heated effluents to coastal waters. All power plants have to comply with EPA-mandated demonstration studies in compliance with Federal Clean Water Act, Section 316(a) to evaluate the effect of thermal discharge upon marine communities, including zooplankton entrainment and impingement of small fishes and invertebrates. An initial evaluation of thermal and entrainment impact by the Costa Sur power plant in Jobos Bay was prepared by the Puerto Rico Nuclear Center (PRNC, 1972). Significant impacts of the thermal effluent upon mangrove root and seagrass communities were observed within the mangrove fringed coastal lagoon in the immediate vicinity of the thermal discharge, also known as the "thermal cove" (PRNC, 1972). Entrainment of zooplankton affected mostly estuarine populations of copepods and larval stages of benthic invertebrates and fishes. Taxonomic assessments of fishes and invertebrates entrained by the power plant were not provided in the study by the PRNC (1972). Coral reef systems located in the outer bay section were not directly affected by thermal pollution associated with thermoelectric power plant operations in Jobos Bay. Potential indirect effects of larval mortality and/or recruitment failure of reef organisms with mangrove-related developmental stages were not quantitatively evaluated.

As part of the environmental baseline studies for establishment of the EcoEléctrica power plant in Guayanilla Bay, García-Sais et al. (1995) studied the taxonomic composition and temporal abundance patterns of zooplankton, including ichthyoplankton in the vicinity of the proposed plant's intake and outfall structure locations in the bay. Clupeiform (including anchovies and sardines) and Gobioidei (mostly Gobiidae) larvae and other estuarine types were the numerically dominant assemblage of larval fishes and zooplankton present within the inner- and mid-sections of Guayanilla Bay. Coral reef fish larvae, including snapper (Lutjanidae) and grunts (Haemulidae), were collected from the deeper sections of the mid- and outer-bay shelf-edge, where a submarine canyon connects the inner-bay (estuarine) environment with the outer bay's fringing reefs and adjacent offshore waters. The information on larval reef fish distributions was pursued with the objective of locating intake structures in areas that would minimize entrainment of reef fish larvae. An EPA-mandated monitoring program of reef benthic populations and zooplankton entrainment is ongoing in Guayanilla Bay.

Tourism and Recreation

The effect of tourism activities upon coral reef systems in Puerto Rico is not well known. According to the Puerto Rico Tourism Company (PRT, 2002), a total of 2.5 million rooms in hotels and "paradores" were occupied throughout the island during 2001-2002. The total room occupancy maintained a gradually increasing rate from 1992 to 2000 (1.08-2.63 million), and then declined slightly (2.51 million) during 2001 (Figure 5.4). Approximately 58% of the total room occupancy has been concentrated within the San Juan metropolitan area, where coral reefs do not occur. However, tourists staying in San Juan often travel to the northeast, south and southwest coasts to participate in scuba diving charters and other marine recreation activities. There is a generalized perception that passive recreational diving has minimal impact

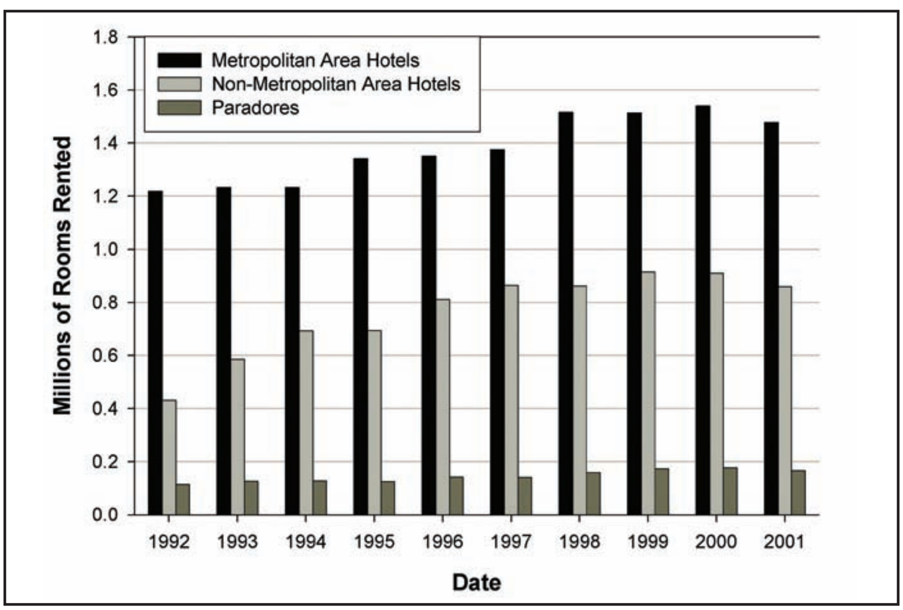

Figure 5.4. Annual occupancy rates for hotels and paradores in Puerto Rico from 1992-2001. Source: Puerto Rico Tourism Company, 2002.

upon coral reef systems. The diving charter industry is at the forefront in terms of coral reef protection policies and is active and highly visible in many activities organized for coral reef protection. In most instances, diving charters do not allow spearfishing during diving expeditions and emphasize coral reef protection. The effect of anchoring by relatively large diving vessels was a problem that has been significantly improved by the installation of mooring buoys by the DNER in the most heavily visited dive sites.

One of the main concerns regarding the ecological health of coral reefs in Puerto Rico is the unknown recreational carrying capacity of these systems. There has been an increasing trend of utilization of coastal resources by local and non-local tourists without consideration of the maximum level of resource utilization that the system can withstand. Between 1996-2003, the total number of boats registered in Puerto Rico increased almost 28%, from 44,050 units in 1996 to 60,911 units in 2003 (Figure 5.5). Coral reef areas are favorite destinations for recreational boat users because of the protected waters they create on the leeward side of reefs. For example, on holidays, over 200 boats can be anchored on a small reef in La Parguera. Concerns over reef health include many activities that are usually undocumented, such as the extra fishing pressure, damage of corals and seagrass during anchoring and propeller groundings, trampling on corals and seagrass during snorkeling activities, and the contamination of the water by garbage, engine fuel, and other substances.

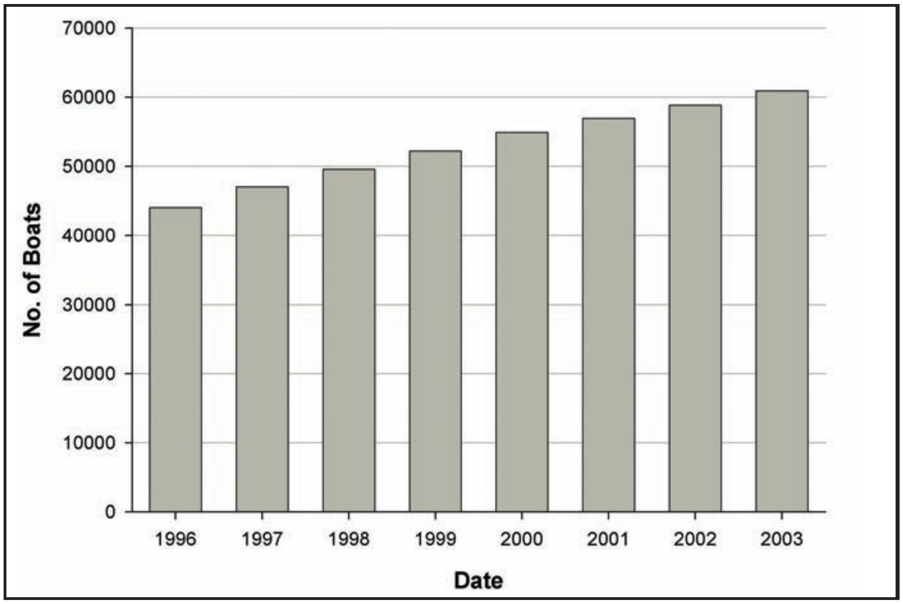

Figure 5.5. Number of boats registered in Puerto Rico between 1996 and 2003. Source: Matos-Caraballo et al., 2002.

There is a critical need to establish a maximum capacity of boats allowed per reef and orientation guidelines for best utilization of reef resources, including illustrative presentations of the underwater life and prepared underwater trails for recreational snorkeling that minimize damage and optimize resource utilization (García-Sais and Sabater, 2004).

Fishing

Reef fish are under intense pressure in Puerto Rico from a variety of user groups, including commercial fishers, recreational anglers, as well as ornamental organism collectors and exporters. Reef fisheries have plummeted during the last two decades and show the classic signs of overfishing: reduced total landings, declining catch per unit effort (CPUE), shifts to smaller fish, and recruitment failures. Commercial fish landings reported between 1979 and 1990 fell by 69% (Appeldoorn et al., 1992).

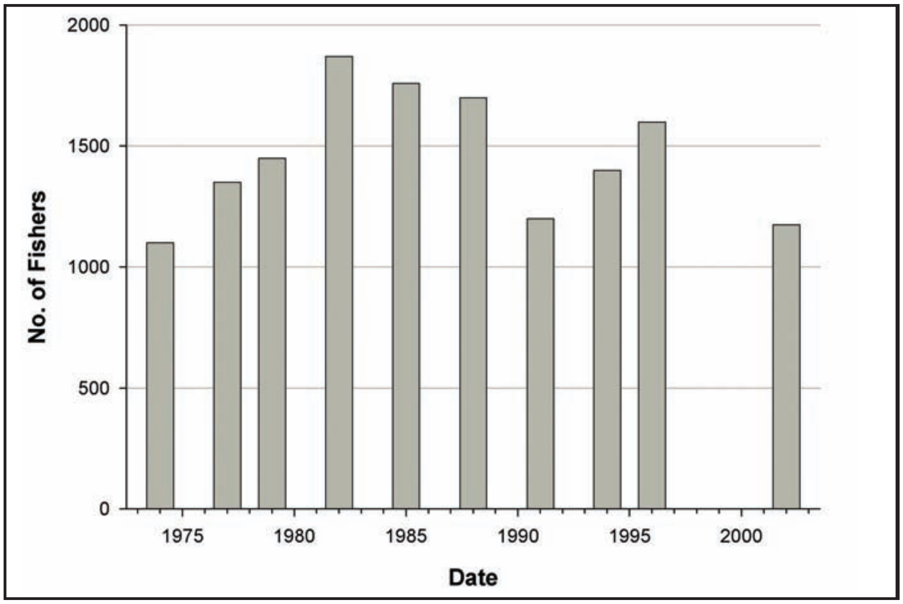

Figure 5.6. Number of active fishers in Puerto Rico since 1974. Source: Matos-Caraballo, 2004.

The latest commercial fishery census (Matos-Caraballo, 2002) reported 1,163 commercial fishers in Puerto Rico for 2002, a reduction of 38% since 1982 (Figure 5.6). The 2002 commercial fisheries data includes 956 fishing vessels, 10,372 fish traps, 2,774 lobster pots, 147 beach seines, 993 gill nets, 391 trammel nets, 1,267 cast nets and 12,310 fishing lines of different types. Among the different fishing techniques, 385 fishers practice skin diving and 225 practice scuba diving. An average of 3.07 million pounds of fish and shellfish per year were captured from 2001-2003 by the commercial fishery (Matos-Caraballo, 2004). Yellowtail, silk, lane, and mutton snapper were the four main species, collectively representing 32.2% of the total fish catch between 2001 and 2003 (Table 5.1). Landings of conch and lobster averaged approximately 574,000 pounds between 2001-2003, or 18.7% of the total commercial fisheries landings.

Reef associated fisheries represented 82% of the total commercial landings between 2001 and 2003, whereas deep water snappers (silk, queen, wenchman) and groupers (misty) represented 11.3% of the total catch. Large pelagic species, including dolphinfish, tunas, and wahoo, were 6.6% of the total landings. Between 2001 and 2003 notable catch reductions were observed for most reef fishes, particularly for mutton and yellowfin snappers which declined 72.6% and 46.3%, respectively (Table 5.1). The catch of silk snapper also declined markedly, from 291,722 pounds in 2001 to 169,826 pounds in 2003.

Until 2000, the only fishery statistics available in Puerto Rico relied on data collected by the commercial fishing industry. In January of 2000, NOAA Fisheries' Marine Recreational Fisheries Statistics Survey (MRFSS) reinitiated data collection in Puerto Rico, and has greatly increased the understanding of recreational fishing pressure on reef fish populations (Lilyestrom and Hoffmaster, 2002). On average, the angler population is comprised of approximately 200,000 residents and 40,000 non-residents.

Table 5.1. Total reported commercial fisheries landings (in lbs.) by species in Puerto Rico during 2001-2003. Source: Matos-Caraballo, 2004.

COMMON NAME	CATEGORY	2001	2002	2003	MEAN
Yellowtail snapper	Reef	328,998	291,024	176,569	265,530
Silk snapper	Slope	291,722	198,028	169,826	219,859
Lane snapper	Reef	186,225	184,630	123,150	164,668
Mutton snapper	Reef	291,722	91,842	79,980	154,515
Grunts	Reef	156,641	147,100	107,566	137,102
Queen snapper	Slope	107,671	110,058	126,999	114,909
Cero mackerel	Reef	84,711	117,869	80,897	94,492
Dolphinfish	Oceanic	111,075	100,622	64,848	92,182
Parrotfishes	Reef	99,255	107,543	69,590	92,129
Trunkfishes	Reef	77,814	79,110	58,596	71,840
Red hind	Reef	69,098	81,206	48,045	66,116
Hogfish	Reef	68,843	68,578	55,957	64,459
Ballyhoo	Reef	60,905	68,045	41,094	56,681
Mullets	Reef	61,129	57,023	42,846	53,666
Triggerfishes	Reef	60,929	56,694	35,998	51,207
Bar jack	Reef	50,845	63,137	37,085	50,356
King mackerel	Reef	101,572	28,053	16,946	48,857
Unid. groupers	Reef	54,180	46,837	31,709	44,242
Barracudas	Reef	19,888	53,546	41,997	38,477
Sharks	Reef	45,169	38,437	25,210	36,272
Skipjack tuna	Oceanic	38,391	38,443	30,655	35,830
Rays	Reef	3,637	53,326	35,624	30,862
Unid. jacks	Reef	38,168	30,117	23,074	30,453
Blackfin tuna	Oceanic	25,286	27,107	34,196	28,863
Vermilion snapper	Reef	44,891	23,135	15,835	27,954
Unid. snappers	Reef	60,114	9,495	9,943	26,517
Yellowfin tuna	Oceanic	35,392	19,303	23,467	26,054
Porgies	Reef	37,031	24,558	11,276	24,288
Snooks	Reef	11,830	37,836	20,900	23,522
Mojarras	Reef	19,445	20,995	17,411	19,284
Sardines	Reef	25,398	28,053	16,946	19,062
Goatfishes	Reef	22,475	19,004	12,785	18,088
Unid. tunas	Oceanic	26,147	11,055	14,818	17,340
Nassau grouper	Reef	18,706	18,708	10,217	15,877
Little tunny	Reef	20,323	14,486	11,704	15,504
Coney	Reef	16,091	19,038	11,002	15,377
Squirrelfishes	Reef	18,313	16,086	10,701	15,033
Wenchman	Slope	7,731	6,197	7,233	7,054
Misty grouper	Slope	6,222	5,679	5,861	5,921
Horse-eye jack	Reef	6,607	4,823	4,188	5,206
Yellowfin grouper	Reef	3,708	6,916	4,893	5,172
Wahoo	Oceanic	8,344	1,095	2,012	3,817
Tarpon	Reef	2,193	4,421	2,436	3,016
Yellow jack	Reef	3,934	3,215	827	2,659
TOTAL FISHES		**2,887,686**	**2,689,338**	**1,921,936**	**2,499,653**
Lobster	Reef	285,018	300,753	242,583	276,118
Conch	Reef	328,467	235,608	188,020	250,698
Octopus	Reef	33,939	28,561	26,476	29,659
Other shellfish	Reef	14,241	12,092	8,127	11,487
Land crabs	Reef	6,322	6,460	1,619	4,800
TOTAL SHELLFISH		**671,338**	**583,474**	**466,825**	**573,879**
TOTAL LANDINGS		**3,559,024**	**3,272,812**	**2,388,761**	**3,073,532**

Total annual fishing trips varied from a high of 1,411,943 in 2001 to a low of 1,098,420 in 2002. Total angler participation dropped from 249,869 to 216,861 in 2003. Trends in the recreational fishery indicate a decline in the use of traps and nets due to their high costs and relatively low yield, and an increase in the use of lines and scuba gear. The largest percentage (58-64%) of recreational fishing trips were made by shoreline anglers. Private boat trips accounted for 35-40% of trips and the remainder (1-3%) was charter fishing trips. Reef fish comprised 16-29% of the total catch. Most of the reef fish were caught by private boat anglers. Total recreational catch from 2000 to 2002 varied between 4,601,748 lbs. and 2,413,878 lbs (Lilyestrom and Hoffmaster, 2002). Overall CPUE declined an average of 40% per year over this same period. As for the commercial fisheries landings, consistent declines were noted in the catch of lane snapper, mutton snapper and silk snapper.

In an effort to convert the collapsing fishery into one which will be sustainable over time, the DNER has enacted new fishing regulations which will require recreational fishing licenses, prohibit recreational spearfishing with scuba gear, eliminate beach seines within three years, establish size limits and daily quotas on several species, require species-specific permits for high-value and sensitive species (i.e., spiny lobsters, queen conch, and land crabs), and create MPAs around Mona, Monito, and Desecheo Islands and the Condado Lagoon, among other measures. Compatibility with Federal fisheries management measures has been achieved to a high degree with these regulations.

Trade in Coral and Live Reef Species

According to Sadovy (1992) export of marine organisms from Puerto Rico for the aquarium trade began in the early 1970s with approximately 50 species. From the available data, reef fishes and motile megabenthic invertebrates comprise the bulk of the aquarium trade. The most commonly captured and exported fish species is the royal gramma (*Gramma loreto*), followed by yellowhead jawfish, blue chromis, redlip blenny and rock beauty, although over 100 species have historically been exported (Mote Environmental Services, Inc., 2002). Table 5.2 presents a list of the main fish and invertebrate species in the aquarium trade in Puerto Rico. There are approximately 12 ornamental organism collectors in Puerto Rico, and three main exporters who exported over 37,000 royal gramma and over 8,400 yellowhead jawfish between 1998 and 2000.

Table 5.2. Reef fish and invertebrate species exported in largest quantities from Puerto Rico for the aquarium trade during 1998-2000. Source: LeGore and Associates, 2002.

FISHES	
Common Name	**Species**
Royal gramma	*Gramma loreto*
Yellowhead jawfish	*Opistognathus aurifrons*
Blue chromis	*Chromis cyanea*
Redlip blenny	*Ophioblennius atlanticus*
Rock beauty	*Holacanthus tricolor*
Greenbanded goby	*Gobiosoma multifasciatum*
Blue tang	*Acanthurus coeruleus*
Horned blenny	*Hysoblennius exstochilus*
Bluehead wrasse	*Thalassoma bifasciatum*
Pygmy angelfish	*Centropyge argi*
Spanish hogfish	*Bodianus rufus*
Flame cardinal	*Apogon maculatus*
Redtail trigger	*Xantichthys ringens*
French angelfish	*Pomacanthus paru*
Neon wrasse	*Halichoeres garnoti*
INVERTEBRATES	
Blue leg hermit crab	
Pink tip anemone	
Turbo snail	
Serpent starfish	
Feather duster worm	
Rock anemone	
Curly cue anemone	
Flame scallop	
Sea cucumber	

Approximately 113 marine invertebrates have also been historically exported, with the top five species in terms of numbers exported being *Condylactis* spp. anemones, blue legged hermit crabs, feather dusters, serpent stars and turbo snails. A total of 7,500 blue legged hermit crabs and 3,600 *Condylactis* spp. were exported in the first five months of 2002. In addition to the quantified exports, there are unquantified sales to local aquarium shops and private collections for home aquariums. Efforts are underway to estimate the number of private marine ornamental organism collectors in Puerto Rico through the MRFSS telephone survey. A proposal has been submitted to provide a stock assessment and design management strategies for aquarium trade target species in Puerto Rico (Le Gore and Associates, 2002).

Ships, Boats, and Groundings

Since 2001 there have been seven reported ship groundings off Puerto Rico and the associated islands involving substantial coral reef injuries as well as a number of additional unreported incidents. Relatively few of these involved significant restoration efforts, although local scientists and volunteers have performed coral rescue operations to stabilize broken coral. The largest effort was undertaken in Vieques after a ferry grounding in November 2002, which involved reattachment of over 100 coral fragments using cement.

One of the largest restoration efforts undertaken in Puerto Rico to date is in response to the *M/V Fortuna Reefer* ship grounding. On July 24, 1997, the *Fortuna Reefer* ran aground on a fringing reef located off the southeast coast of Mona Island (18°02'N; 67°51'W), 65 km from Puerto Rico. The 326-foot freighter remained grounded for eight days within the island's largest remaining elkhorn coral (*Acropora palmata*) stand.

The grounding and subsequent removal of the *Fortuna Reefer* impacted 6.8 acres of shallow forereef. The reef substrate was crushed and fractured, and entire colonies of *A. palmata* and *D. strigosa* were dislodged and fractured along the direct path of the vessel, and hundreds of additional *A. palmata* branches were sheared off by the cables used to remove the vessel. Coral fragments (n=1,857) were reattached to the reef substrate or standing dead colonies using wire within three months of the grounding, and fragment survivorship and patterns of recovery have been monitored twice per year since 1999. More than half (57%) of the fragments were alive two years after the restoration effort, while the remainder died (26%) or were detached and removed from the site (17%; Bruckner and Bruckner, 2001).

Six years after the restoration, 20.3% (377) of the restored fragments were living (Figure 5.7). Many of these (58%) had produced new branches and 30% (114) had reattached to the substrate. Fragments had an average of 60% live tissue, although 33% had little or no mortality and 22% showed signs of re-sheeting over previously denuded skeleton. Each fragment had developed an average of four new 21 cm branches (maximum of 30 branches, up to 73 cm long per fragment), and branching patterns had the typical tree-like morphology seen on adult colonies. The most significant sources of mortality include overgrowth by boring *Cliona* spp. sponges, predation by *Coralliophila abbreviata* gastropods, and WBD, with partial mortality associated with algal interactions (primarily *Dictyota* and *Halimeda* spp.) and damselfish (*Stegastes planifrons*) algal lawns (Figure 5.8). In 2003, an outbreak of WBD affected 15% of the standing colonies within the grounding site and surrounding area, with a lower prevalence (4%) among restored colonies.

Reef fish communities appear to be recovering within the *Fortuna Reefer* grounding site, with an increase in abundance, species richness and diversity over the last four years. Mean fish abundance per transect (total area 60 m^2) has increased from 13.9 (± 5.17 standard error [SE]) to

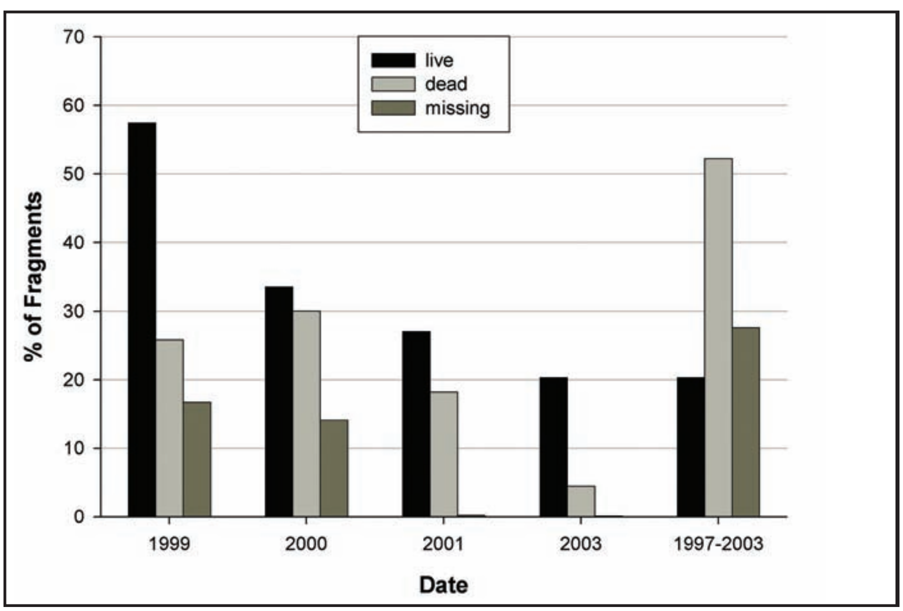

Figure 5.7. Status of restored fragments at the *Fortuna Reefer* site. Source: Bruckner and Bruckner, in press.

32.3 (± 4.8 SE) and the number of species has increased from 2.5 (± 0.54 SE) to 7.3 (± 0.332 SE). While the number of species per transect is similar inside and outside the grounding site, abundance outside of the site is nearly three times as high (mean=90.6). This difference in abundance may be due in part to the presence of large schools of acanthurids observed outside the grounding area.

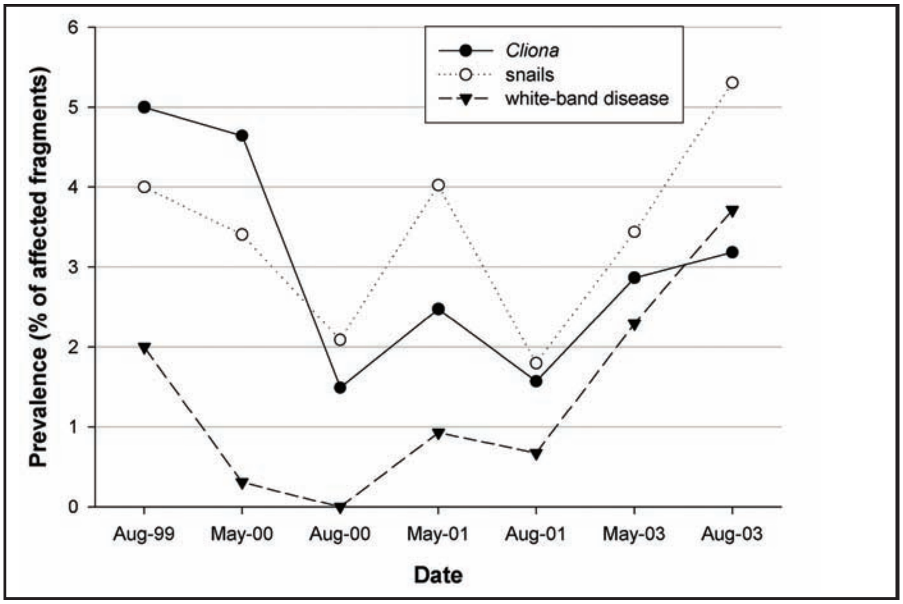

Figure 5.8. Sources of fragment mortality at the *Fortuna Reefer* site. Source: Bruckner and Bruckner, in press.

Marine Debris

Marine debris is has not been reported to be a significant problem affecting Puertorrican reefs.

Aquatic Invasive Species

A number of freshwater non-native/invasive/alien species have been introduced into Puerto Rico (Bunkley-Williams and Williams, 1994; Bunkley-Williams et al., 1994; Williams and Sindermann, 1992; Williams et al., 2001b). The Mozambique tilapia, *Oreochromis mossambicus* (Cichlidae), dominates in local brackish waters, but has not invaded coral reef areas. This species is known to utilize coral reefs in the Pacific and the reasons for its current limited distribution in the Caribbean are not known (Williams and Bunkley-Williams, unpublished data). The introduced jellyfish, purple sea mane (*Drymonema dalmatinum*) experienced a major population explosion in Puerto Rico in 1999 (Williams et al., 2001a) and a minor one in the Virgin Islands in 2003 (Williams and Bunkley-Williams, unpublished data). These outbreaks are not known to have caused much damage, but the potential for greater problems exists.

Williams and Bunkley-Williams (1990b; 2000) suggested that the 1983-1984 mass mortalities of the black long-spined sea urchin, *Diadema antillarum* Phillipi (Echinometridae), and later die-offs (Williams et al., 1991) were caused by a virus introduced from the Pacific region. These events changed the ecology of the reefs throughout the region, and neither the urchins nor the reefs have ever recovered. In addition, Juste and Cortés (1990) reported the presence of non-native clams including southern quahog (*Mercenaria campechiensis*), northern quahog (*M. mercenaria* and *M. mercenaria notata)* from five localities around Puerto Rico. The non-native clams are not considered a major threat to coral reefs.

Whitfield et al. (2002) reported red lionfish, *Pterois volitans* (Scorpaenidae) established along the Atlantic coast of the U.S. and in Bermuda. This species was recently observed in Puerto Rico (Williams et al., unpublished data), but it is not known if a reproductively viable population has been established. Widespread rumors of the escape and establishment of Indo-Pacific clownfishes (Pomacentridae) in Puertorrican waters (Williams et al., 1994a) are unconfirmed.

Williams et al. (1994a) suggested that the euryhaline leech, *Myzobdella lugubris* (Rhynchobdellida: Piscicolidae) was introduced from the continental U.S. to eastern Puerto Rico along with mariculture animals. It also occurs in western Puerto Rico (Williams and Bunkley-Williams, unpublished data).

Security Training Activities

The islands of Vieques, Culebra, and Desecheo have served as training ranges for the U.S. Navy since the 1940s. There is no published information regarding the impact of such training activities in Culebra and Desecheo Islands. Rogers et al. (1978) reported severe destruction of coral reefs in Vieques Island caused by bombing activities during military training. For the last two decades, there have been no reliable monitoring records for Vieques' easternmost coral reefs, although 8% to 50% declines in coral cover from coral reefs located within maneuver areas in Vieques have been reported (Antonius and Weiner, 1982). Decline in coral cover has been attributed to hurricanes, concluding that the impact of bombing in the coral reef was negligible (Antonius and Weiner, 1982). Unfortunately, deep reef sections that are typically unaffected by hurricanes have not been included in the assessment of bombing effects. Efforts to include the coral reef systems within the shooting range of eastern Vieques as part of the National Coral Reef Monitoring Program of NOAA have not been successful to date. However, a large biological baseline data set is now available for 11 reefs outside the shooting range in Vieques (García-Sais et al., 2001d).

Offshore Oil and Gas Exploration

There are currently no offshore oil and gas exploration activities occurring in Puerto Rico.

CORAL REEF ECOSYSTEMS- DATA GATHERING ACTIVITIES AND RESOURCE CONDITION

Puertorrican coral reefs were initially described in terms of their taxonomic composition by Almy and Carrión-Torres (1963). This initial survey identified a total of 35 species of scleractinian corals from La Parguera, on the southwest coast of Puerto Rico. Later surveys were reported by Rogers et al. (1978), Armstrong (1980), Goenaga and Boulon (1991), Hernandez-Delgado (1992, 1994a,b), and Hernandez-Delgado and Alicea-Rodriguez (1993a,b).

Goenaga and Cintrón (1979) prepared the first geographical inventory of Puertorrican reefs. This work, along with subsequent qualitative surveys of reef geomorphology and community structure (Cintrón et al., 1975; Canals and Ferrer, 1980; Canals et al., 1983), established criteria for designation of marine areas with coral reef development as natural reserves by the government of Puerto Rico.

During the last decade, coral reef research in Puerto Rico has largely focused on community characterization and monitoring programs, benthic habitat mapping, marine reserve feasibility studies, environmental impact assessments, coral diseases, and mitigation programs. As part of the U.S. Coral Reef Initiative Program for Puerto Rico (NOAA), a series of coral reefs located in natural reserves were recently selected as priority sites for characterization and monitoring programs. Other initiatives have included characterization efforts in support of the coral reef systems occurring within the Rio Espiritu Santo Natural Reserve (Hernández-Delgado,1995), Isla de Mona Natural Reserve (Canals et al.,1983; Hernández-Delgado, 1994a) and La Cordillera de Fajardo Natural Reserve (Hernández-Delgado, 1994b).

The purpose and priorities of the Coral Reef Monitoring Program for Puerto Rico were initially presented by the DNER to NOAA's U.S. Island Coral Reef Initiative in 1997. The main objectives of the program were to map the spatial distribution of coral reefs, produce a baseline characterization of priority reef sites and establish a monitoring program targeting selected high-priority reef sites. The monitoring program would provide information needed for effective resource management and public awareness, while contributing to a scientific database for long-term analysis of the coral reefs in natural reserves of Puerto Rico.

The DNER has identified the natural reserves of Mayaguez Bay, Desecheo Island, Rincón, La Parguera, Bahía de Jobos, Ponce Bay, Cordillera de Fajardo and the islands of Culebra and Vieques as high-priority monitoring sites. Baseline characterizations for these reef systems were prepared by García-Sais et al. (2001 a, b, c, d). The baseline characterization and monitoring for the Culebra Marine Reserve was prepared by Hernández-Delgado (2003). The baseline characterization of the newly-established MPA at Tres Palmas Reef in Rincón is ongoing. This report includes monitoring data from a total of 12 reef sites under the U. S. Coral Reef Monitoring Program funded by NOAA and two additional reef sites monitored since 1999 as part of EPA's 301(h) studies associated with operations of the submarine outfalls of the RWWTPs at Arecibo and Aguadilla, on the north and northeast coasts, respectively. La Parguera, on the southwest coast of the island, is the monitoring site within Puerto Rico for the Caribbean Coastal Marine Productivity Program (CARICOMP). The CARICOMP data base is available on-line at http://www.caricomp.com.

Additional quantitative and qualitative characterizations of reef communities were included as part of environmental impact studies related to the submarine outfall discharges of RWWTPs of PRASA from 11 sites around Puerto Rico (Figure 5.9; García-Sais et al., 1985). Other characterizations of coral reef communities were performed in relation to operations of thermoelectric power plants with thermal outfalls in Jobos Bay (Szmant-Froelich,1973), San Juan Bay (García-Sais and Castro,1995), and Guayanilla Bay (Castro and García-Sais,1996; García-Sais and Castro,1998). Table 5.3 provides a list of reef sites for which quantitative baseline characterizations were performed, along with geographic references and depths. Mass mortalities of corals and related reef organisms have also received research attention in Puerto Rico. Vicente and Goenaga (1984) 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 in the waters of Puerto Rico were produced in the late 1980s (Bunkley-Williams and Williams, 1987; Williams and Bunkley-Williams, 1989; Goenaga et al., 1989; Williams and Bunkley-Williams, 1990a,b). These studies highlighted the permanent damage of the bleaching phenomena on reef corals and associated the periodic bleaching events to elevated SSTs.

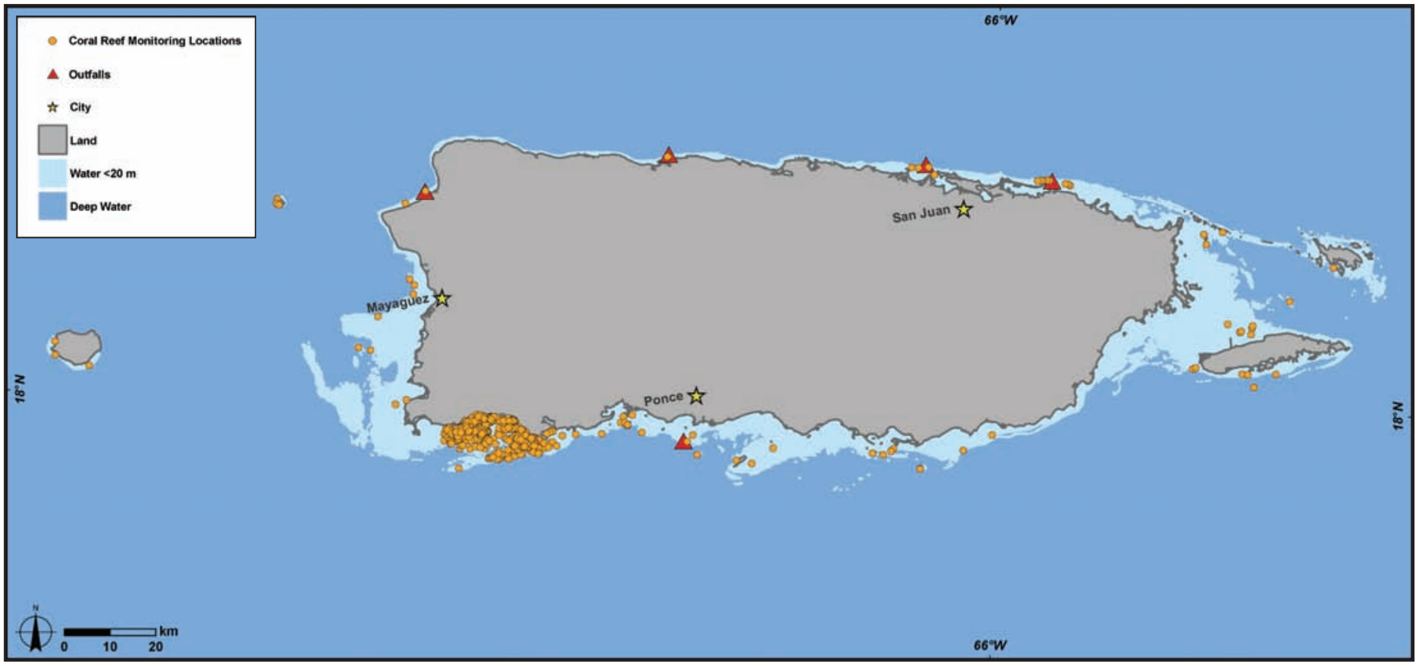

Figure 5.9. Coral reef monitoring sites around Puerto Rico. Map: A. Shapiro. Source: Garcia-Sais, pers. obs.; CCMA-BT, unpublished data.

Table 5.3. Geographic references, dates, and depths of reef habitats surveyed during baseline characterization and monitoring programs. Source: Garcia-Sais, pers. obs.

	DATES		GEOGRAPHIC REFERENCES		
REEF - SITE	**Baseline**	**Monitoring**	**Latitude**	**Longitude**	**DEPTH (m)**
Bajíos - SJ	1994	none	18° 27.900' N	066° 07.800' W	6.7
Guayanilla - GY	1995	none	17° 58.600' N	066° 45.800' W	3.6-5.5
Caja de Muertos 1 - PON	May-99	2001	17° 53.341'N	066° 29.810' W	9.1
Boca Vieja - SJ	93-94	none	18° 28.700' N	066° 09.800' W	6
Río - TAY	1995	none	17° 58.800' N	066° 44.700' W	3
Unitas - GY	1995	none	17° 57.900' N	066° 46.100' W	10.6
Media Luna - MAY	Jun-99	2001	18° 06.079' N	067° 18.731' W	10.6
Caribe 1 - JOB	Sep-96	none	17° 55.400' N	66° 12.300' W	4.0-6.0
Manchas Grandes- MAY	1997	none	18° 12.500' N	067° 12.100' W	10
Berberia - PON	May-99	2001	17° 55.190' N	066° 27.190' W	7.6
La Barca - JOB	Sep-96	2001	17° 54.635' N	066° 13.564' W	10
Manchas Ext. 2 - MAY	1997	none	18° 14.300' N	067° 12.600' W	10
Caribe 2 - JOB	Sep-96	2001	17° 55.094' N	66° 12.595' W	10
Caja de Muertos 2 - PON	May-99	2001	17° 53.701' N	066° 31.703' W	7.6
Cayo Coral - GUA	Jun-99	2001	17° 56.173' N	066° 53.303' W	7.6
Pta. Maguey - CUL	n/d	none	18° 17.600' N	065° 18.100' W	5.0-6.0
Manchas Int 2 - MAY	1997	none	18° 13.600' N	067° 12.000' W	10
Pta. Ventana 2 - GY	Jun-99	2001	17° 56.500' N	066° 48.400' W	12
Las Coronas - MAY	Jun-99	2001	18° 05.836' N	067° 17.225' W	10
Pta. Ballena - GUA	Jun-99	2001	17° 56.380' N	066° 51.633' W	10
Fanduco - GY	1995	none	17° 57.900' N	066° 45.600' W	6.1
Isla Palominitos - FAJ	Jul-99	none	18° 20.142' N	065° 33.944' W	10.6 - 7.6
Cayo Diablo - FAJ	Jul-99	2001	18° 21.602' N	065° 31.942' W	10.6
Media Luna - LP	1996	none	17° 56.200' N	067° 03.200' W	10
Turrumote - LP	1996	none	17° 56.100' N	067° 01.100' W	10
Tourmaline - MAY	Jun-99	2001	18° 09.794' N	067° 16.418' W	10.6
Pta. Maguey - CUL	n/d	none	18° 17.600' N	065° 18.100' W	5.0-6.0
Manchas Int 2 - MAY	1997	none	18° 13.600' N	067° 12.000' W	10
Isla Palomino - FAJ	Jul-99	2001	18° 21.333' N	065° 34.267' W	10.6
North Reef - DES	Jun-00	2001	18 ° 23.416' N	067° 29.229' W	11
Pto. Botes - DES	Jun-00	2001	18° 22.895' N	067° 29.316' W	17

Table 5.3, (continued). Geographic references, dates, and depths of reef habitats surveyed during baseline characterization and monitoring programs. Source: Garcia-Sais, pers. obs.

	DATES		GEOGRAPHIC REFERENCES		
REEF - SITE	**Baseline**	**Monitoring**	**Latitude**	**Longitude**	**DEPTH (m)**
Pto. Canoas - DES	Jun-00	2001	18° 22.699' N	067° 29.026' W	18
El Palo - CRO	May-00	2001	18° 00.034' N	067° 12.670' W	3
Resuellos - CRO	May-00	2001	17° 59.470' N	067° 13.987' W	8.2
South of Margarita Reef - LP	May-00	none	17° 52.068' N	067° 06.017' W	8.2
La Boya (Shelf edge) - LP	May-00	none	17° 53.304' N	066° 59.877' W	18.1
South of Turrumote - LP	Jul-00	none	17° 53.949' N	067° 01.108' W	13
Arrecife Las Mujeres - MON	Jun-00	none	18° 04.302' N	067° 56.215' W	18
Pajaros - MON	Jun-00	none	18° 03.168' N	067° 51.995' W	13.6
Carmelitas - MON	Jun-00	none	18° 05.923' N	067° 56.300' W	8.5
Boya 2 - PON	Aug-01	none	17° 55.815' N	066°37.814' W	16.1
Bajo Derrumbadero - PON	Aug-01	none	17° 54.237' N	066° 36.516' W	16.7
Bajo Tasmania - PON	Aug-01	none	17° 56.564' N	066° 37.147' W	9.1
Maria Langa Veril 50' - GY	Aug-01	none	17° 57.563' N	066° 45.255' W	15.2
Maria Langa 30' - GY	Aug-01	none	17° 57.630' N	066° 45.256' W	10
Tallaboa 35' - GY	Aug-01	none	17° 56.759' N	066° 43.480' W	10.6
Las Mareas 55' - GMA	Sep-01	none	17° 53.093' N	066° 08.956' W	16.7
Las Mareas 70' - GMA	Sep-01	none	17° 53.057' N	066° 08.947' W	21.2
Cayos de Barca 35' - GMA	Sep-01	none	17° 54.830' N	066° 14.866' W	10.6
Arrecife Guayama 45' - ARO	Sep-01	none	17° 55.353' N	066° 03.675' W	13.6
Punta Guilarte Shoal 33' - ARO	Sep-01	none	17° 57.219' N	066° 00.112' W	10
West Caballo Blanco - VIE	May-01	2004	18° 10.297' N	065° 28.126' W	4.5
Arrecife Mosquito - VIE	May-01	2004	18° 09.804' N	065° 29.632' W	10.6
Arrecife Comandante - VIE	May-01	none	18° 09.465' N	065° 28.227' W	5.5
Boya 6 - VIE	May-01	none	18° 10.711 N	065° 31.148' W	10.6
Arrecife Coronas - VIE	May-01	2004	18° 09.896' N	065° 29.454' W	10.6
North Caballo Blanco - VIE	May-01	none	18° 10.563' N	065° 28.029' W	3
Black Jack - VIE	May-01	2004	18° 03.319' N	065° 27.794' W	30.3
Canjilones Reef - VIE	Feb-01	2004	18° 05.380' N	065° 35.413' W	15.2
Puerto Ferro Reef - VIE	Feb-01	none	18° 04.845' N	065° 25.057' W	12
Pirata Reef - VIE	Feb-01	2004	18° 05.512' N	065° 35.011, W	15.2
Boya Esperanza Reef - VIE	Feb-01	2004	18° 04.832' N	065° 29.277' W	9.1
Capitan Reef - VIE	May-01	none	18° 04.766' N	065° 28.572' W	13
Bajo Holiday - VIE	May-01	none	18° 13.500' N	065° 23.500' W	18.2
Arecibo - AA1	Oct-99	2000-2004	18° 29.478' N	066° 40.878' W	16.1
Arecibo - AA2	Oct-99	2000-2004	18° 29.460' N	066° 40.974' W	21.2
Aguadilla - AGS2	Oct-99	2000-2004	18° 24.780' N	067° 10.878' W	13.9
Aguadilla - AGS3	Oct-99	2000-2004	18° 23.256' N	067° 13.350' W	10.9
Bayamon - B15	1999	2000-2004	18° 28.728' N	066° 10.632' W	11.5
Bayamon - B14	1999	2000-2004	18° 28.788' N	066° 08.538' W	11.5
Carolina - CC3	1999	2000-2004	18° 26.892' N	065° 50.934' W	9.1
Carolina - CC4	1999	2000-2004	18° 27.018' N	065° 51.156' W	9.7
Carolina - CC5	1999	2000-2004	18° 27.078' N	065° 51.534 ' W	9.7
Carolina - CC6	1999	2000-2004	18° 27.426' N	065° 53.514' W	7.3
Carolina - CC7	1999	2000-2004	18° 27.468' N	065° 53.826' W	10.3
Carolina - CC8	1999	2000-2004	18° 27.432' N	065° 54.294' W	10.3
Carolina - CC9	1999	2000-2004	18° 27.426' N	065° 54.552' W	10
Carolina - CC10	1999	2000-2004	18° 27.402' N	065° 55.002' W	9.7

WATER QUALITY

Water quality monitoring is conducted by several organizations in Puerto Rico and is under the official purview of the DNER. Most of its monitoring data were not available for inclusion in this report, but the data should be analyzed and incorporated in the next reporting effort.

Data analyzed in this section primarily comes from monitoring of industrial discharges associated with RWWTPs administered by PRASA. Five RWWTPs discharge disinfected (chlorinated) primary-treated effluent via submarine outfalls to the marine environment under EPA 301(h) waiver compliance programs. These include the RWWTPs of Carolina, Bayamón-Puerto Nuevo, Arecibo, Aguadilla, and Ponce, as shown in Figure 5.9.

Methods

Water quality monitoring of the effluent and receiving waters has been in effect for all of the above mentioned RWWTPs since 1999. The receiving water monitoring program analyzes of 171 water and sediment chemistry parameters including nutrients, suspended sediments, trace metals, pesticides, and bacteriology (CSA/CH2MHILL, 1999). Sampling is performed quarterly or biannually within the discharge zone, at one reference station, and at upstream and downstream far-field stations. Water samples are taken at 10%, 50% and 90% of the total station depth. Supporting data on ocean currents and biological assessments of infaunal and epibenthic invertebrates, fish, and coral reef communities are also included as part of the 301(h) monitoring programs for receiving waters of the RWWTPs (CSA/CH2MHILL, 1999). Secondary treatment plants discharge via submarine outfalls in the vicinity of Humacao, Barceloneta, Manatí, and Mayaguez Bay. All of the submarine outfalls discharging disinfected primary-treated effluent are located in the immediate vicinity of a large river.

Results and Discussion

In general, sediment and nutrient loading to the marine environment by RWWTPs submarine outfalls represents a small fraction of the river discharge. For example, the mean loading of total suspended solids (TSS) by the Aguadilla RWWTP submarine outfall from 2000 to 2002 was approximately 1.35% of the Culebrinas River loading for the same period (Table 5.4). Likewise, dissolved inorganic nitrogen (DIN) and total phosphorus (TP) loading by the RWWTP was 0.5% and 1.49% of the loading by the Culebrinas River, respectively. In terms of fecal coliform contamination of coastal waters, the RWWTP input was less than 1% (<0.1%) of the Culebrinas River input to Aguadilla Bay (Table 5.4). A similar pattern has emerged for other submarine outfalls in the north coast of Puerto Rico (CSA/CH2MHILL, 2000-2003), suggesting that rivers still represent the main pathways of sediment, bacteria and nutrient loading into Puerto Rico's coastal waters.

Table 5.4. Total suspended sediment (TSS), nutrient, and bacterial loadings from the Aguadilla RWWTP outfall, and the Culebrinas River into the coastal waters of Aguadilla. Source: CH2MHILL, 2000-2003; USGS hydrological data, http://waterdata.usgs.gov/nwis.

PARAMETER	2000		2001		2002		MEAN	
	RWWTP	River	RWWTP	River	RWWTP	River	**RWWTP**	**River**
Total Suspended Solids (10^6 kg/yr)	1.328	99.52	0.84	46.07	0.259	34.4	**0.81**	**60**
$NO_2 + NO_3 – N$ (10^6 g/yr)	0.67	250.54	0.69	219.59	1.07	207.61	**0.81**	**225.91**
Dissolved Inorganic N (DIN) (10^6 g/yr)	0.71	258.19	1.26	235.05	1.69	219.53	**1.22**	**237.59**
Total Phosphorus (TP) (10^6 g/yr)	0.38	60.59	0.81	42.33	0.93	39.77	**0.71**	**47.56**
Fecal Coliforms (10^{12} col./yr)	273.5	52505	15.05	44690	1.43	110549	**96.66**	**69.23**

BENTHIC HABITATS

U.S. National Coral Reef Monitoring Program in Puerto Rico

Methods

Quantitative assessments of sessile-benthic reef communities were performed on at least 79 reefs around Puerto Rico between 1985 and 2003 (Table 5.5). Scientists utilized various techniques to collect information on the percent cover by reef substrate (sessile-benthic) categories, including: continuous measurements along 10 m linear transects using chain links (CARICOMP, 1996), video-transects (CSA/CH2MHill, 1999), and 1 m^2 standard quadrat techniques (CSA/CH2MHill, 1999). Data on reef community structure and coral taxonomic composition were separated into three relative depth strata: shallow (1-5 m), intermediate (6-14 m) and deep (15-25 m), representing different reef types and physiographic zones within each reef. Mean percent substrate cover was calculated from replicate line transects or quadrat surveys (n=4 or 5) for each reef.

Results and Discussion

Percent cover by sessile-benthic substrate categories at shallow reefs (1-5 m) is presented in Figure 5.10. Benthic algae was the dominant substrate type in terms of percent cover in seven of the nine shallow reefs surveyed, ranging in substrate cover between a minimum of 31.8% at Algodones Reef in Naguabo, and a maximum of 82.1% at Punta Bandera Reef in Luquillo (García-Sais et al., 2003). 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 Punta Bandera Reef (Figure 5.10). Mean live coral cover was 15.5%. The two shallow reefs with live coral cover of 20% or higher were both from the southeast coast (Algodones and Punta Fraile), whereas reefs with live coral cover below 10% were all from the northeast coast, including Vieques Island. The taxonomic composition of stony corals at shallow reefs was characterized by a mixed assemblage of species (Figure 5.11). Between four and 10 species of corals were intercepted on linear transects at each reef. The *Porites astreoides, P. porites, Siderastrea radians,* and *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 caribaeorum*, was present in five of eight reefs surveyed, with maximum cover (44%) at Gallito Beach Reef in Vieques. Zoanthids, particularly the encrusting, colonial form *Palythoa* spp., and sponges were the other main biotic components of the shallow reef benthos. Abiotic cover (sand, holes, overhangs, etc.) averaged 8% at shallow reefs (García-Sais et al., 2003).

In the intermediate depth range (6-14 m), live coral cover varied from 0.6% to 51.9% at surveyed reefs (n=52). Mainland reefs from the north and northeast coastlines (Mameyal, Bajíos, Morrillos, Boca Vieja and Cerro Gordo) contained very low coral cover (<5%) (Figure 5.10). Las Cabezas Reef in Fajardo was the only mainland reef from the northeast coastline with live coral cover above 10%, ranking 19th 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 (e.g., Hojitas) and Guayanilla Bay (e.g., Guayanilla, Cayo Río, Cayo Unitas) also exhibited very low live coral cover (<5%). These are inshore coral reefs in an advanced state of degradation. An increasing pattern of live coral cover associated with distance from shore was observed in Mayaguez 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 Mayaguez Bay varied in live coral cover between 10.6% at Media Luna and 29.3% at Las Coronas (Figure 5.10). Tourmaline Reef on the outer shelf of Mayaguez Bay showed the highest live coral cover of all reefs studied with a mean of 51.9%. Turrumote and Media Luna Reefs in the southwest coast (near La Parguera); Cayo Diablo and Isla Palominitos Reefs from the northeast island chain (Cordillera de Fajardo Reefs); and Comandante, Mosquito and Boya Esperanza Reefs from North Vieques all presented live coral cover higher than 35% (Figure 5.10). In the case of the reefs of the Cordillera de Fajardo and Vieques, this may be related to their level of exposure and distance from river discharges. Both areas are subject to strong wave action during winter, but are located up-current from major rivers, and thus, do not receive large sediment loads. Well-developed coral reef communities exist along the protected (leeward) sections of the chain of islets.

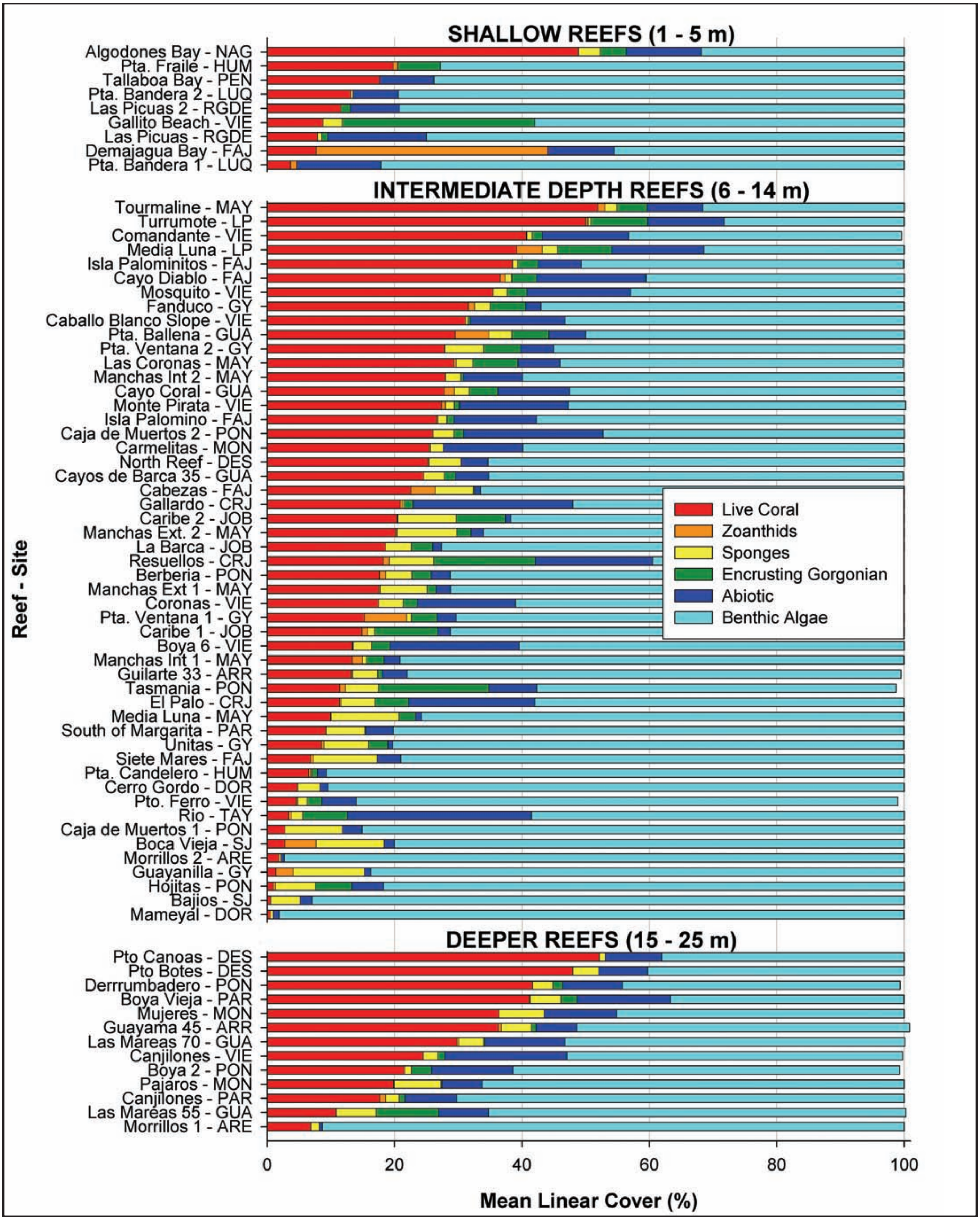

Figure 5.10. Mean linear cover by sessile-benthic substrate categories for various reef depths. Total cover may not equal 100% due to rounding within categories. Source: Garcia-Sais et al., 2003; Garcia-Sais et al., 2001d.

Benthic algae was the dominant substrate on 47 of the 52 reefs studied at intermediate depths, ranging in cover from 28.2% in Turrumote to 98% at Mameyal Reef (Figure 5.10). 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, as well as at Mameyal and Cerro Gordo Reefs in Dorado. Calcareous algae, (mostly *Halimeda opuntia*) was an important component of the algal cover at Cayo Rio and Guayanilla Reef. The encrusting octocoral, *Erythropodium caribaeorum*, was observed in variable percent cover at most reefs surveyed from intermediate depths (6-14 m). The highest cover was observed in the Tasmania Reef in Ponce (17.3%). Conversely, encrusting gorgonian was mostly absent from the high energy hard ground and rock reef communities of the north coast. Zoanthids (*Palythoa* spp.) and sponges were the other main biotic components of the reef benthos at intermediate depths. Abiotic cover (e.g., sand, holes, overhangs) ranged from 0-26.8%.

The taxonomic composition of corals at reefs of intermediate depth (6-14 m) is presented in Figure 5.11. *Montastrea annularis* was the dominant scleractinian coral in 19 of the 22 reefs with highest live coral cover and was absent from 12 of the 13 reefs with lowest live coral cover among the 52 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.

Live coral cover from the deeper reefs studied (15-25 m) was highest at Puerto Canoas and Puerto Botes Reefs in Desecheo Island (in the Mona Passage) with 52.2% and 48.8%, respectively (Figure 5.10). Puerto Canoas had extensive reef sections where live coral cover exceeded 80% and featured some of the largest live coral colonies of the Puertorrican coral reefs. Live coral cover at Puerto Canoas Reef peaked at depths between 22-25 m. The reef extended down the insular slope to a maximum depth of 40 m. Further down the insular slope, live coral cover declined sharply with increasing depth and sponges became the dominant sessile-benthic invertebrate taxa (García-Sais et al., 2003). Derrumbadero Reef in Ponce presented the third highest live coral cover among reefs studied in the 15-25 m depths with a mean of 41.8%. Derrumbadero Reef is a submerged seamount with a spectacular "spur-and groove" coral reef formation fringing the southern edge of the seamount top. The spurs rise about 5-6 m from their coralline sandy base and are colonized with corals and other encrusting biota on their top and at the walls, forming ledges and overhangs at the shelf-edge.

Among coral reefs associated with the mainland shelf-edge, La Boya Vieja Reef in La Parguera presented the highest live coral cover with a mean of 41.2% (Figure 5.10). Shelf-edge reefs in the south and eastern sections of the mainland (e.g., Boya 2 near Ponce, Maria Langa near Guayanilla, Las Mareas near Guayama) presented generally lower live coral cover (<30%). The shelf-edge reef at La Parguera, located in the southwest coast, is farther offshore and farther away from river plumes than shelf-edge reefs of the south and southeast coasts which are influenced by estuarine conditions that inhibit light penetration. Wave energy appears to be another relevant factor in the structural development of shelf-edge coral reefs in Puerto Rico. For example, the shelf-edge reef at Pájaros, located on the southeast coast of Mona Island, had a mean live coral cover of 19.9%, whereas the shelf-edge reef at Mujeres on the southwest coast averaged 36.4%. Likewise, the shelf-edge reefs established on the southwest coast of Desecheo Island (e.g., Puerto Botes, Puerto Canoas) had much higher live coral cover (48.0-52.2%) than at North Reef (on the north coast) which averaged 25.3% (Figure 5.10). The southwest coast is protected from the seasonally large swells that pound the north coast of Puerto Rico during the winter and from the extreme southeasterly swells generated by hurricanes traveling across the Caribbean Basin.

Montastrea annularis was the dominant coral in terms of substrate cover at reefs studied in the 15-25 m depth range (Figure 5.11). In general, the variability of live coral cover for the reefs studied within this depth range was associated with the variation in cover by *M. annularis*. As for reefs studied in the 6-14 m depth range, the deeper reefs with highest live coral cover consistently showed a high relative substrate cover for *M. annularis*. For example, *M. annularis* represented more than 55% of the total cover by stony corals in seven reefs with greatest live coral cover. Conversely, in the seven reefs with lowest overall coral cover (with the exception of Canjilones Reef in Vieques), *M. annularis* contributed less than 45% of the total coral cover. It has been reported that with increasing depth below the shelf-edge down to at least 70 m, the occurrence of *M. annularis* becomes increasingly dominant to the point that it may represent more than 90% of the total

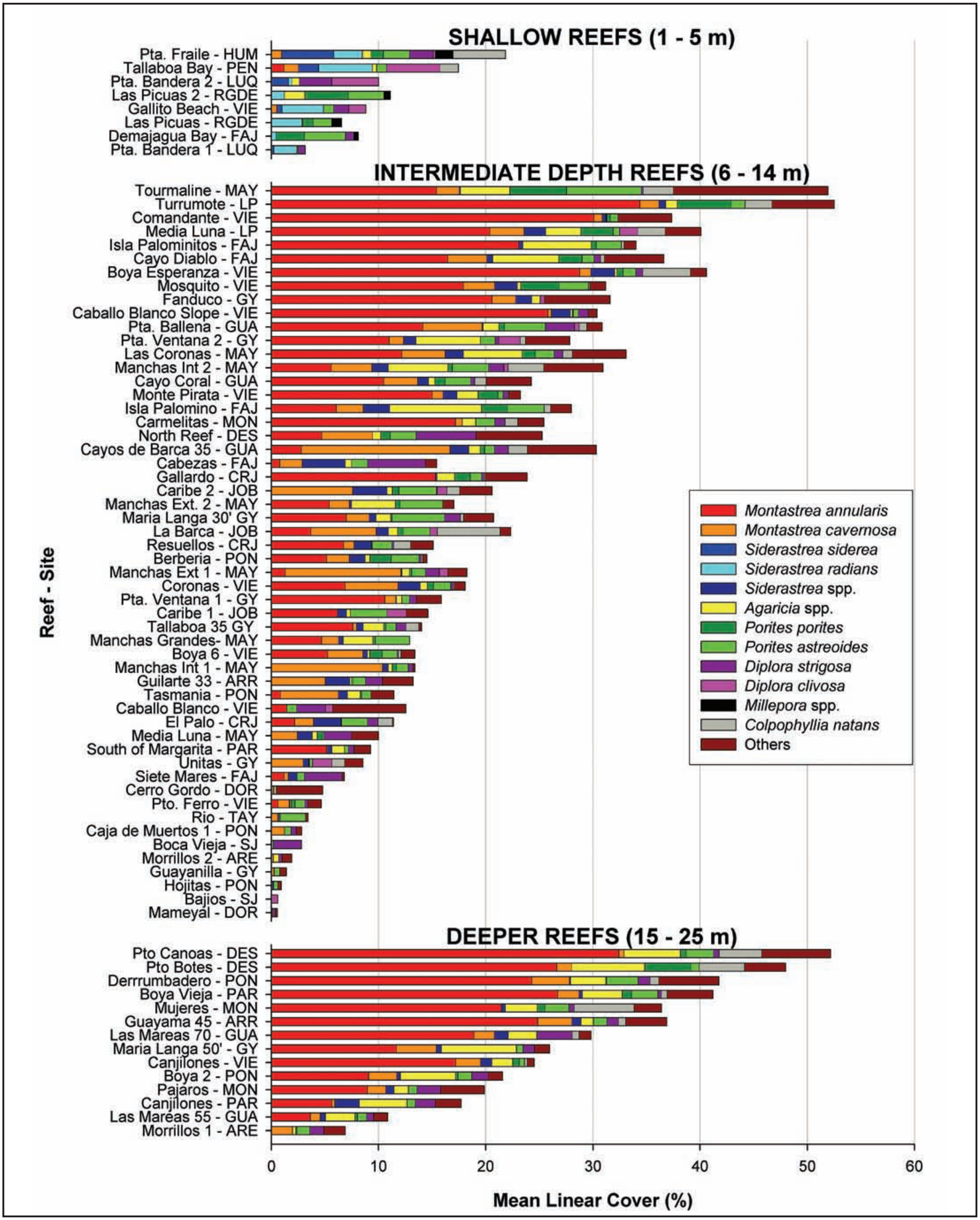

Figure 5.11. Mean linear cover by species for reefs at various depths. Source: Garcia-Sais et al., 2003; Garcia-Sais et al., 2001d.

substrate cover by live corals (García-Sais et al., 2004; R. Armstrong, pers. comm.). Other less prominent species of scleractinian corals present on the deeper reefs studied include *M. cavernosa*, *Porites astreoides,* and *Agaricia* spp. (Figure 5.11).

U.S. National Coral Reef Monitoring Program in Puerto Rico (NOAA), Natural Reserves

A series of coral reef systems located in natural reserves in Puerto Rico were selected as priority sites for biological characterization under the U. S. Coral Reef Initiative Program for Puerto Rico (NOAA) in 1999-2000. These included reef sites at Desecheo and Mona Islands, Fajardo, Guanica, Guayama, Guayanilla, La Parguera, Mayaguez, Arroyo, Cabo Rojo, Caja de Muertos, Ponce, and Vieques. Figure 5.9 shows the location of coral reef monitoring sites.

Methods

Quantitative and qualitative baseline characterizations of the reef community at these sites were reported by García-Sais et al. (2001a, b, c, d). Monitoring efforts by personnel from the DNER began on these reefs in 2001. Table 5.5 presents a summary of the quantitative data gathered during the 2001 monitoring effort for reefs included in the National Coral Reef Monitoring Program.

Table 5.5. Mean percent substrate cover by benthic categories for 18 monitored reefs. Source: DNER, unpublished data.

BENTHIC CATEGORIES	REEF SITES: Caribe-Guayama	Barca-Guayama	Coral-Guanica	Ballena-Guanica	Ventana-Guayanilla	Tourmaline-Mayaguez	Coronas-Mayaguez	Media Luna-Mayaguez	West-Caja de Muertos	Windward- Caja de Muertos	Berberia- Caja de Muertos	Norte-Desecheo Island	Botes-Desecheo Island	Canoas-Desecheo Island	Palominos-Fajardo	Diablo-Fajardo	El Palo-Fajardo	Resuellos-Cabo Rojo
Live Coral	14.9	18.7	19.4	29.2	23.4	59.7	30.4	8.8	24.9	2	17.6	23.1	45.3	52.5	26	36.8	12.8	21.5
Gorgonian	3.2	2.3	4	13.4	6.1	2.5	8.7	4	2.1	0.1	6.3	0.1	0	0	2.7	3.7	10.5	31.8
Turf Algae	54.9	34.9	55.1	42.5	50.3	22.6	40.2	78	59.7	83.6	31.5	29.8	29.1	12.9	57.7	41.1	52.2	33.6
Fleshy Algae	6.7	25.3	0	0	1	0	0.8	0.1	0.2	3.4	17.1	37.3	15	24.6	4.8	1.5	0.6	0
Encr. Algae	1	1.5	0.9	2.1	6.4	1.8	0.2	0.3	0.1	1.2	1.4	2.8	2.2	3	0.5	3	0.4	0.3
Calcareous Algae	8.8	5.1	1.8	0.5	2.6	2.8	12.7	0	0.2	1.5	20.6	0	0.2	0	0	0	4	0
Sponges	6.9	4.2	1.4	4.7	7.2	1.9	1.4	7.8	2.3	7.2	1.8	4.5	3.2	3.3	0.4	1.6	2.8	4.2
Zoanthids	0.7	0	1.1	3.7	0	0.7	0.1	0.1	0	0	0.4	0	0	0	0.2	0.3	0	0
Tunicates	0	0	0.1	0	0.1	0.1	0.2	0.1	0	0.4	0	0	0.2	0	0	0	0	0
Sand	0.1	2.8	3.8	1.7	0.9	0.2	1.4	0.7	1.2	0.5	0	2.2	0.7	1.1	1.2	7.5	0.9	0.3
Gravel / Rubble	0.5	0	4.6	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0	0
Dead Coral	0.2	0	0	0	0	3.6	0.4	0	2.3	0.2	0	0	0.1	0.1	0	0	0	0
Overhangs	2.2	5.2	7.6	2.2	1.9	3.9	3.2	0	7	0	3	0.2	4.1	2.3	5.9	4.5	15.4	8.3

Results and Discussion

At most sites, the percent cover of stony corals remained within 3% of baseline levels (Figure 5.12). Exceptions included the decline in coral cover at Cayo Coral in Guánica and at Cayo Caribes in Guayama. These changes may be related to small scale localized disturbances, since adjacent reefs (Ballena Reef in Guánica and Barca in Guayama) appeared relatively stable and varied very little from the baseline data. In addition, increases in coral cover that were detected at Tourmaline Reef were not detected at any other surveyed reefs within Mayaguez Bay (i.e., Coronas and Media Luna), which remained within 2% of the baseline data.

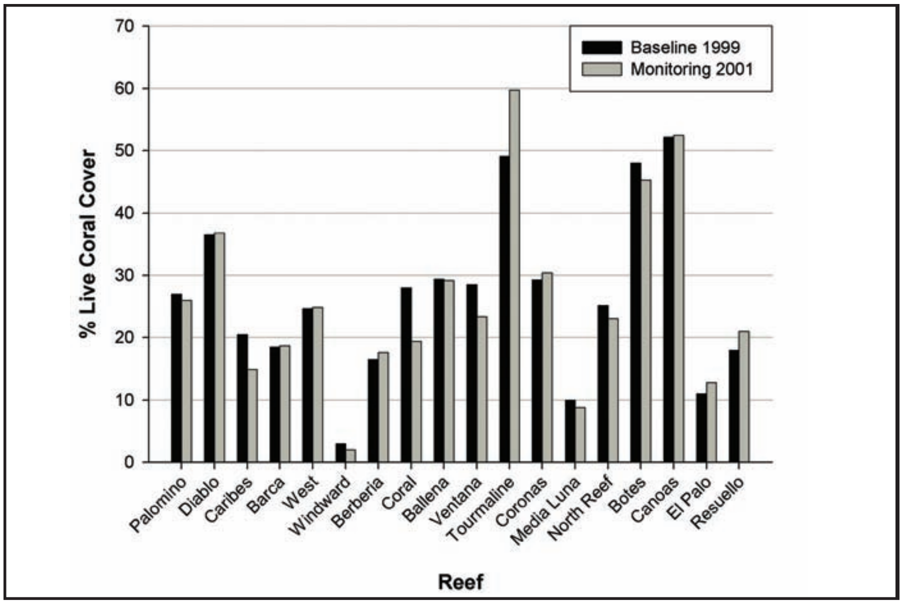

Figure 5.12. Comparison of percent live coral cover at 18 sites between baseline characterization in 1999 and first monitoring event in 2001. Source: DNER, unpublished data.

Caribbean Coastal Marine Productivity Program

The Caribbean Coastal Marine Productivity Program (CARICOMP) is a Caribbean-wide coral reef monitoring program established to examine changes in the ecological health of coral reefs and associated ecosystems (e.g., fringing mangroves, seagrass beds) across a network of laboratories and marine reserves, including the Puertorrican site of La Parguera (CARICOMP,1996). This program is directed in Puerto Rico by the University of Puerto Rico (UPR), Department of Marine Sciences and has been active since 1994. Dr. Ernesto Weil is currently the site director for the CARICOMP program in Puerto Rico. The CARICOMP Data Management Center is based in Kingston, Jamaica. Only limited CARICOMP monitoring results have been incorporated in this report, but should be included in the next reporting effort.

Methods

Monitoring methods can be found in Woodley et al., 1996.

Results and Discussion

Baseline characterization and early coral reef monitoring records for the site of La Parguera were presented at the 8th International Coral Reef Symposium in Panama (Woodley et al., 1996). The CARICOMP coral reef monitoring database includes available data for Media Luna Reef from Puerto Rico (CARICOMP, http://www.ccdc.org.jm/caricomp.html, Accessed: 12/29/04). Figure 5.13 shows the annual variation of mean cover by live corals at Media Luna Reef (10 m depth).

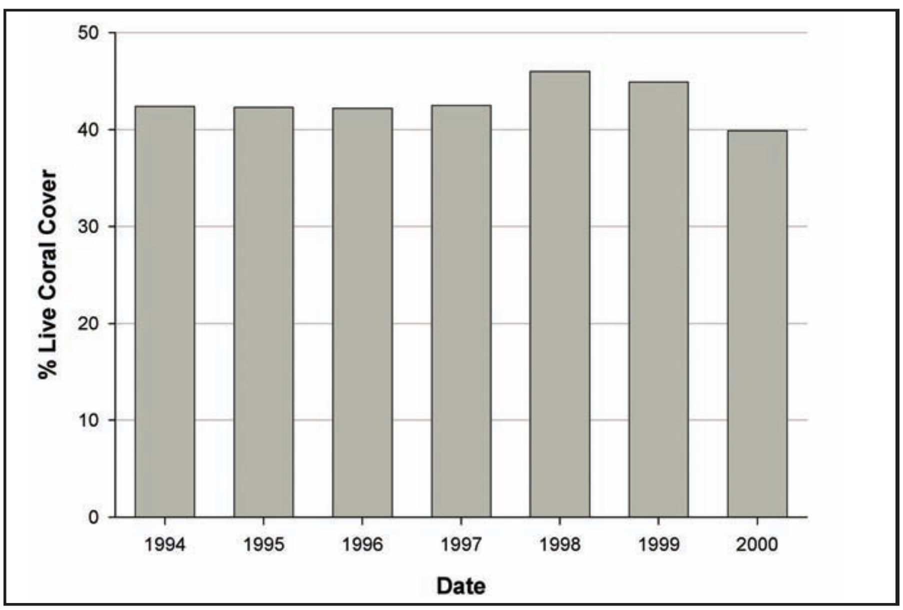

Figure 5.13. Annual variation of mean percent live coral cover (10 m depth) at Media Luna Reef in La Parguera, Puerto Rico from 1994-2000. Source: CARICOMP, unpublished data.

NOAA's Coral Reef Ecosystems Study

In 2002, NOAA's Coastal Ocean Program initiated a five-year program to address the continued decline of coral reef ecosystem health. Based at UPR-Mayaguez, the Coral Reef Ecosystems Study (CRES) is a collaborative research program involving five universities, one non-government organization (NGO), and two Federal agencies. The CRES program was developed to:

- Identify and evaluate factors critical to the decline of coral reefs;
- Evaluate effective management approaches;
- Develop tools to assist resource managers;
- Evaluate socio-economic concerns vital to management plans; and
- Integrate environmental studies, socioeconomic impacts, and modeling into a comprehensive ecological study.

The overall strategic assessment will address four major research focus areas: 1) relationships between watershed activities and coral reefs; 2) causes of ecological stress; 3) coral reef ecosystem integrity; and 4) evaluation and linkages of MPAs. The principal study area is the reef system off La Parguera, with additional work being conducted in conjunction with the Luis Peña Channel Marine Fishery Reserve (LPCMFR) on Culebra Island and the National Park on St. John, USVI. Figures 5.14 and 5.15 show preliminary results identifying watershed sources of sedimentation to the coastline in the natural reserve at La Parguera, Lajas.

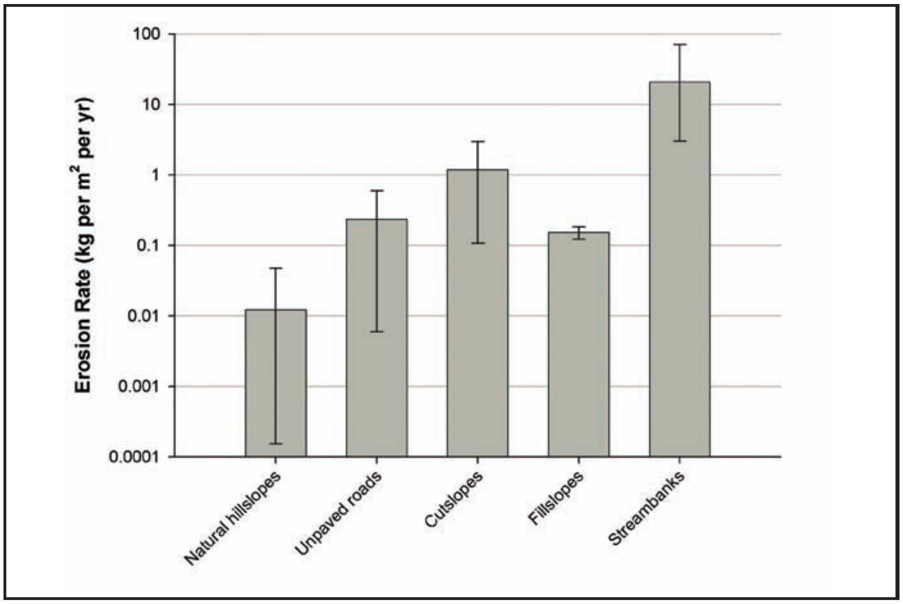

Figure 5.14. Measured erosion rates for different sediment sources in the watershed of La Parguera.

The CRES project has conducted only one full year of sampling, yet certain trends have become apparent. Detailed seasonal sampling has shown that the reef system is very dynamic, with large changes occurring over short periods of time. Some of these seem to be associated with seasonal variations (e.g., temperature, rainfall) while others may be indicative of increased nutrient stress (e.g., cyanobacterial overgrowths in La Parguera and Culebra).

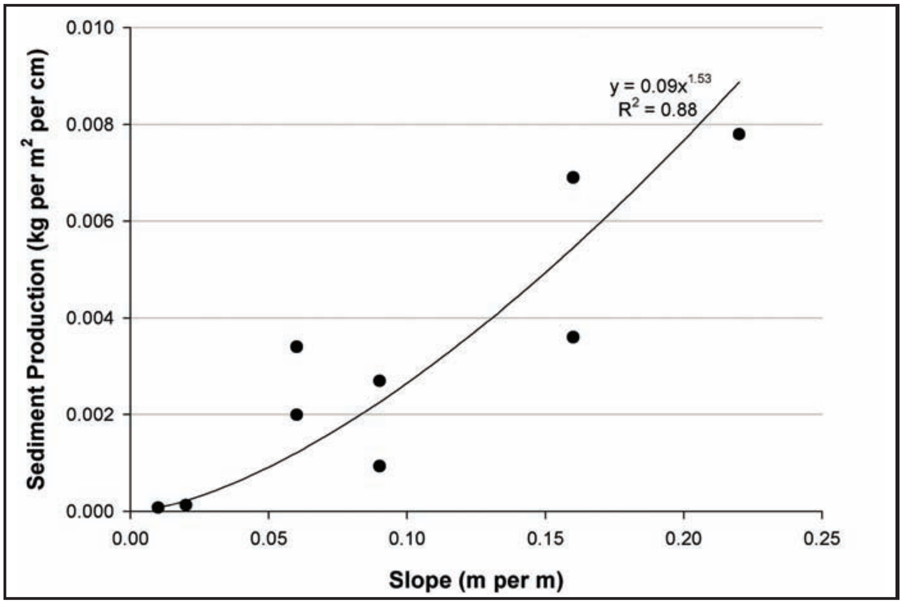

Figure 5.15. Rate of sediment production as a function of slope in disturbed areas of La Parguera watershed. Source: C. Ramos, unpublished data.

Coastal development, especially in hilly areas, is often a major cause of increased sedimentation. The unique environmental signal resulting from the intense rain event in November 2003 provided an opportunity to study the transport of nutrients and sediments into the La Parguera system. These studies showed the process to be complex and result from both nearshore and upstream processes that differentially act at various locations across the shelf. A combination of techniques (permanent data loggers, sediment traps, high spatial and temporal sampling) is necessary to fully understand how the system operates.

Diseases and bleaching continue to be a problem, with the worst bleaching event since 1988 occurring in 2003. While some progress has been made in identifying potential pathogens, new diseases were observed (e.g., of coralline algae) and the potential for disease reservoirs suggests that the causes and cycles of disease infection may be more complex that previously thought.

Luis Peña Channel Marine Fishery Reserve Monitoring (LPCMFR)

The Luis Peña Channel Marine Fishery Reserve (LPCMFR) was established on the west coast of Culebra by the government of Puerto Rico in May 1999. The main objective of this project is to monitor benthic organisms and fish at permanent stations within and outside of the reserve in order to determine the impact of protection.

Methods

Monitoring methods can be found in Hernández-Delgado, 2003

Results and Discussion

As in past years, fish biomass within the reserve has increased since closure. The most striking results are illustrated in Figure 5.16.

At one site within the LPCMFR, the data showed a decline in coral cover over time and then a more recent stabilization. This result may have followed the delayed but eventual increase in herbivores observed since the reserve was closed. The opposite trend to that of corals would represent the change in percent algal cover. However, as Figure 5.16 illustrates, the recorded increase in algae was due almost entirely to an increase in cyanobacteria. This strongly suggests that the increase in herbivorous fishes has mostly impacted fleshy macroalgae, while an increase in nutrient loading into the reserve (a trend supported by observed changes in nearby land use, resulting in runoff and increased turbidity) has allowed cyanobacteria to colonize the open space.

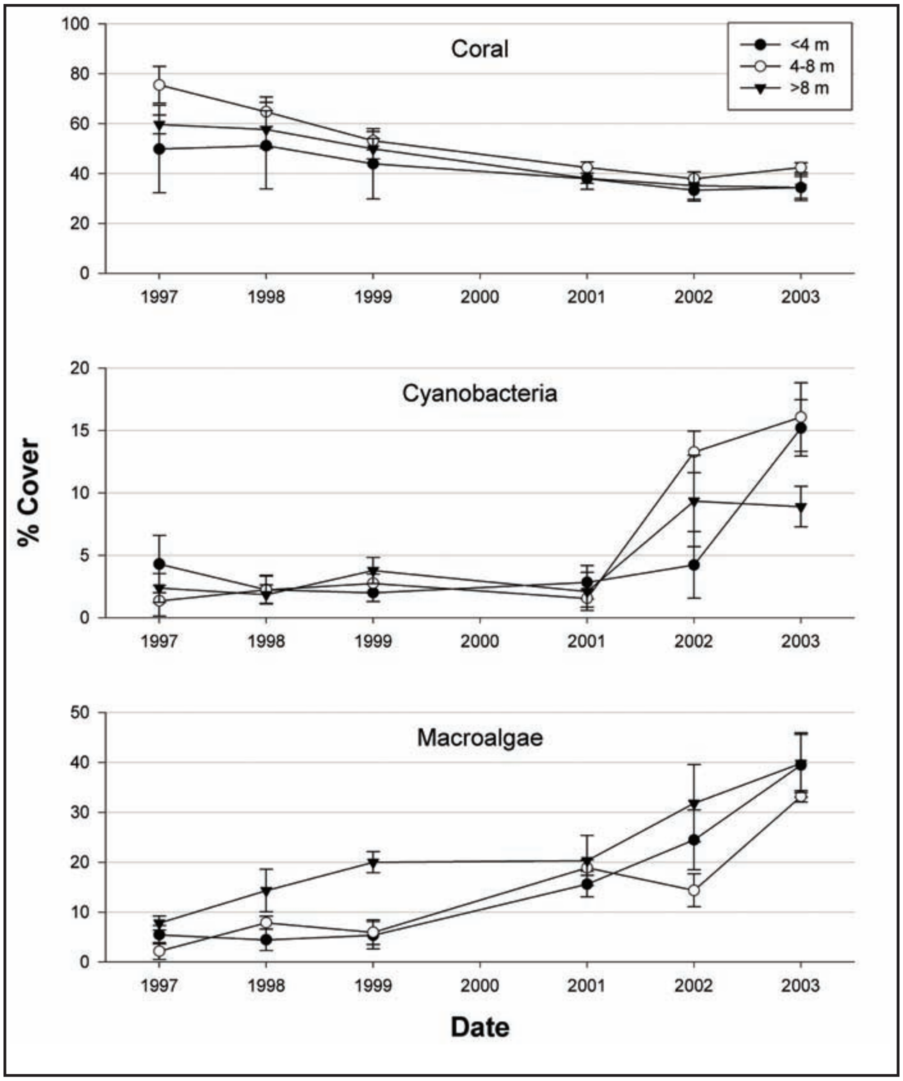

Figure 5.16. Decline in coral cover and increase in cyanobacteria cover within the Luis Peña Channel Marine Fishery Reserve, Culebra. Source: Hernández-Delgado, 2003.

PRASA Submarine Outfall Studies-301h Waiver Demonstration

Another ongoing, long-term monitoring of reef communities in Puerto Rico is associated with EPA's 301(h) waiver demonstration studies for the submarine outfalls of the PRASA RWWTPs. The location of these submarine outfalls in the north and south coasts of Puerto Rico are shown in Figure 5.9. Initial baseline characterization studies of marine communities in the vicinity of these submarine outfalls were prepared by García-Sais et al. (1985). Monitoring studies of water quality and currents, sediment chemistry, infaunal benthic communities, fish and epibenthic invertebrate communities, and coral reef communities started in October 1999 and have continued to the present at the RWWTPs of Carolina, Bayamón-Puerto Nuevo, Arecibo, Aguadilla, and Ponce. The 301(h) monitoring program for the Arecibo RWWTP submarine outfall includes monitoring of coral communities to assess whether effluent discharge has had any measurable impact on the maintenance of balanced indigenous populations of corals and associated fish and epibenthic invertebrate communities. Included in this report are summarized results for the RWWTPs of Arecibo and Aguadilla, which are being monitored by UPR-Department of Marine Sciences under the direction of Dr. Jorge (Reni) Garcia-Sais.

Methods

Sampling protocols and EPA-approved quality assurance/quality control manuals for the monitoring program were prepared by CSA Group/CH2MHill (1999). With the exception of Ponce, which is an ocean outfall 150 m deep, all other outfalls discharge within the insular shelf at depths ranging between 15-40 m on the north coast of Puerto Rico. From these sites, true coral reef systems are only present in the vicinity of the RWWTP submarine outfall in Aguadilla, but coral communities associated with rock and hard ground reefs are included in the monitoring program for all RWWTP submarine outfalls.

Two coral community monitoring stations were studied in the vicinity of the Arecibo outfall. Stations AA1 and AA2 were established on a hard ground reef habitat, located approximately 1 km and 0.8 km due east of the outfall, respectively. The insular shelf section located to the west of the outfall is under the direct influence of the Rio Grande de Arecibo plume and impractical for monitoring benthic communities due to the prevailing high turbidity of the water. Both coral stations AA1 and AA2 are sections of an extensive hard ground reef habitat found off the Arecibo coastline. Coral monitoring stations were located at similar distances due east of the outfall, but at different depths. AA1 reef was studied at a depth of 16 m, whereas AA2 was surveyed at a depth of approximately 21 m. The geographic coordinates of the alternative coral community stations are included in Table 5.3.

Monitoring of coral reef communities within the Arecibo RWWTP 301(h) program has followed a winter and summer cycle with sampling efforts usually occurring in February and July. The two Arecibo coral monitoring stations are located within a general area subject to extended periods of high wave energy (from October to March) and the influence of the Rio Grande de Arecibo plume.

Two coral community monitoring stations were established to the east and west of the Aguadilla RWWTP outfall. Aguadilla station AGS2 was established on a hard ground reef habitat, located approximately 0.93 km northeast of the outfall. Station AGS3 was established on a coral reef area approximately 4.26 km southwest of the outfall. The location of sampling stations is shown in Figure 5.9. Coral community monitoring stations were established at locations that characterized the typical reef communities present in the vicinity of the outfall. Station AGS2 is a submerged patch hard ground habitat that rises from a depth of approximately 18 m to a fairly even platform at 14 m. This station is close to the outfall and also under the influence of the Culebrinas River plume. Station AGS3 is located in a zone of abundant rock outcrops farther offshore than AGS2 and also farther from the influence of both the outfall and the Culebrinas River plume. The coordinates of the alternative coral community stations are included in Table 5.3.

Results and Discussion

Summarized monitoring data of coral benthic community structure for the Arecibo Reefs AA1 and AA2 are presented in Figure 5.20. As can be inferred from the percent cover of biota at these reefs, it is evident that benthic algae (both turf and fleshy growth) represent the dominant biological assemblage colonizing hard substrate at AA1 and AA2, and sponges represent the most prominent invertebrate taxa of the reef community. Live corals represent minor components of the reef community structure at both Arecibo sites and occur mostly as encrusting forms, providing low topographic relief and scarce habitat for fishes and other reef biota. The poorly developed state of these hard ground reefs is related to the strong wave and surge energy seasonally

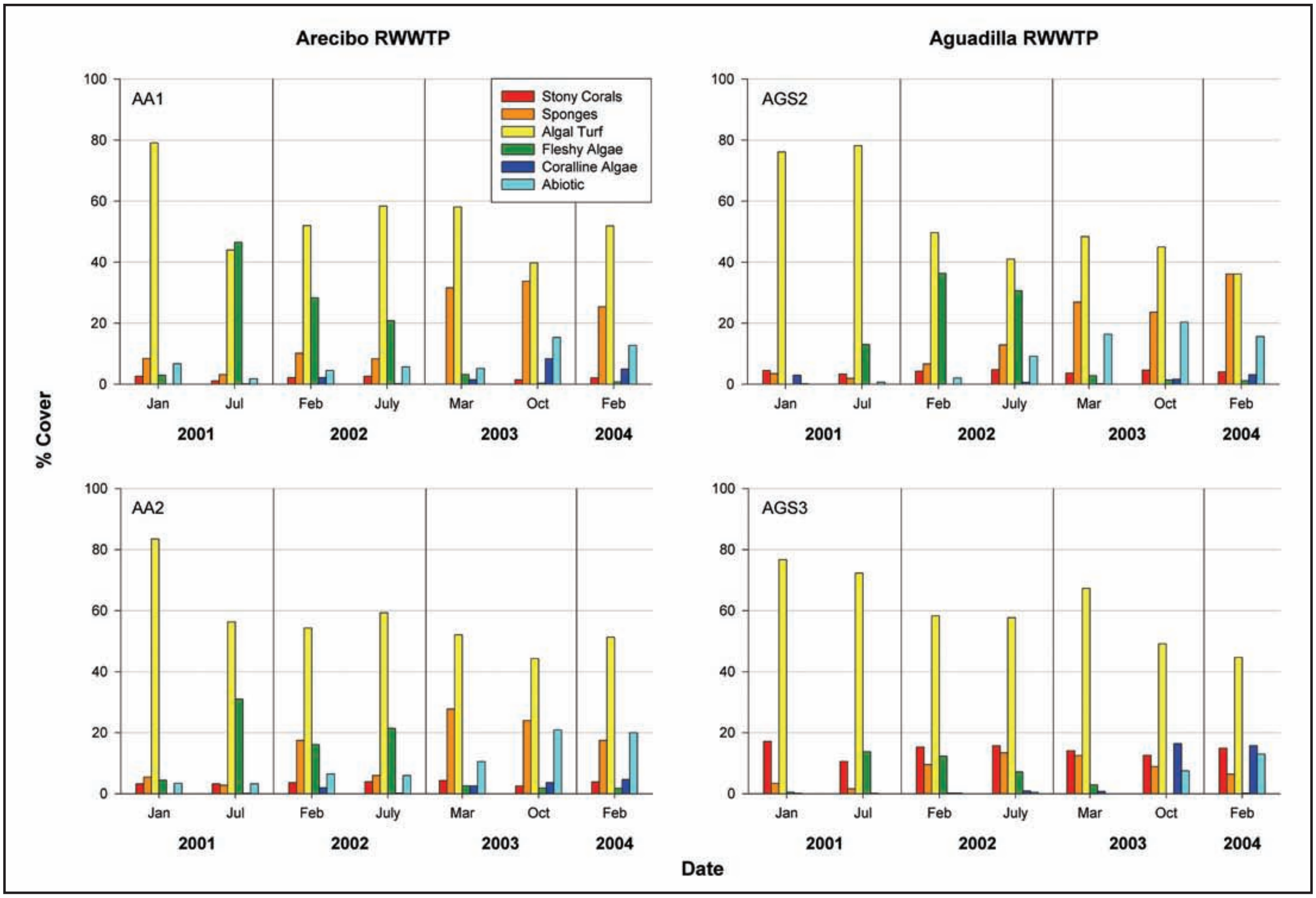

Figure 5.17. Percent cover by substrate categories at coral communities in the vicinity of the Arecibo and Aguadilla RWWTP outfalls, from 2001-2004. Source: EPA 301(h) Waiver Demonstration Monitoring Program.

affecting the north coast of Puerto Rico and the localized effect of large river plumes.

Summarized monitoring data on percent cover by substrate categories at Aguadilla reef community stations AGS2 and AGS3 also appear in Figure 5.17. Coral stations in Aguadilla are located in a high-energy environment and evidently under the estuarine influence of the Culebrinas and Guayabo River plumes. Coral communities in the study area are representative of the typical hard ground reef habitat that prevails on many sections of the north coast of Puerto Rico (e.g., AGS2), and of sparse and relatively small patch reef systems that have developed on top of rocky promontories (e.g., AGS3).

The higher taxonomic complexity and percent cover of live corals at AGS3, as compared to AGS2, may be related to a combination of factors, including the higher exposure to river runoff and associated sedimentation stress at AGS2; the deeper location of the reef at AGS2, with its implications for lower light availability for corals; differences of sediment types at the base of reefs between both stations; and the higher separation of the reef at AGS3 from the unconsolidated substrate at its base. The two latter differences have implications for higher propensity of AGS2 to sediment re-suspension effects, as compared to AGS3. The higher number of fish species and abundance at AGS3 are probably associated with the higher topographic relief (habitat heterogeneity) and availability of live coral habitats.

It is difficult to make an assessment of what has been the effect, if any, of the Aguadilla RWWTP discharge on coral reefs in this region due to the confounding effects of sedimentation stress, both from the strong wave and surge action and from the massive river runoff from the Culebrinas and Guayabo Rivers. Nevertheless, the hard ground coral community at AGS2 does not show any structural evidence of previous coral reef development, nor does AGS3 show any evidence of significant degradation of its standing coral structures. Records from permanent photoquadrats show that an active coral growth and recruitment process is taking place at the Alt-AGS3 reef station.

Benthic Habitat Mapping Project

NOAA's Center for Coastal Monitoring and Assessment, Biogeography Team (CCMA-BT), completed a nearshore benthic habitat mapping project for Puerto Rico in 2001.

Methods

Map development was based on visual interpretation of aerial photographs, which were used to delineate habitat polygons in a geographic information system (GIS). Habitat polygons were defined and described according to eight geomorphologic zones and a hierarchical habitat classification system consisting of 21 discreet habitat types within five major habitat categories. A detailed description of methods can be found in Kendall et al. (2001).

Results and Discussion

The mapping project was completed in 2001 and resulted in a series of maps encompassing 1,599 km^2 of nearshore habitat in Puerto Rico. The maps are currently being distributed on a CD-ROM and on-line at http://biogeo.nos.noaa.gov/products/benthic/. A summary map (Figure 5.18), where polygons have been aggregated into five major habitat categories, depicts the geographical distribution of reefs and other types of benthic habitats on the Puertorrican shelf (Kendall et al., 2001).

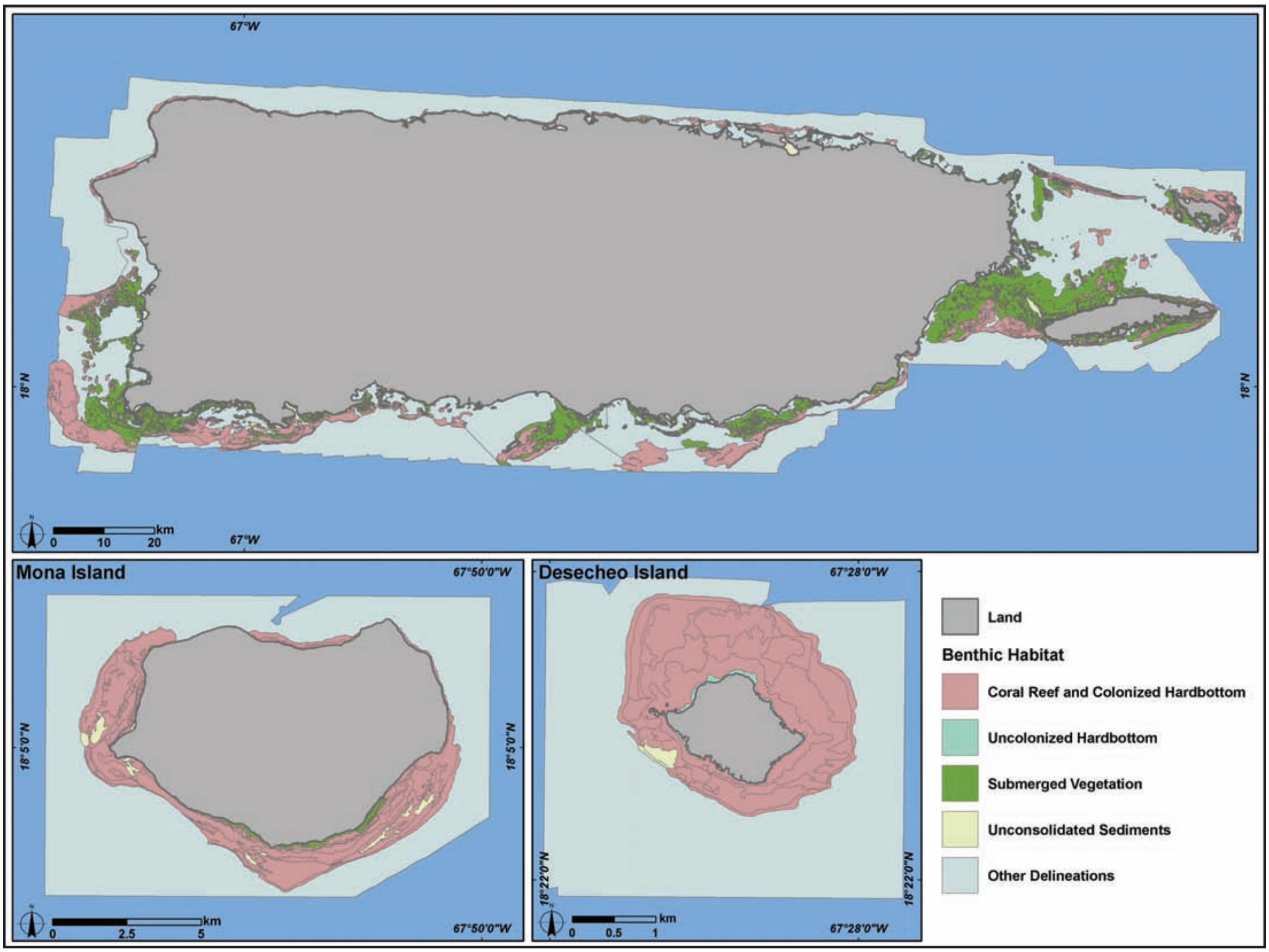

Figure 5.18. Nearshore benthic habitat maps were developed in 2001 by CCMA-BT based on visual interpretation of aerial photography and hyperspectral imagery. For more info, see: http://biogeo.nos.noaa.gov. Map: A. Shapiro. Sources: García et al., 2004; Kendall et al., 2001.

ASSOCIATED BIOLOGICAL COMMUNITIES

U.S. National Coral Reef Monitoring Program in Puerto Rico (NOAA), Reef Fish Monitoring

Methods

Quantitative and qualitative surveys of diurnal, non-cryptic reef fishes have been included as part of the biological baseline characterizations and monitoring of coral reef communities in Puerto Rico. Reef fishes were surveyed using a belt-transect technique. Transects 10 m long and 3 m wide (30 m^2 survey area) centered over the linear transects were used to characterize the reef benthic community. A total of five belt-transects were surveyed at each reef station.

Results and Discussion

The mean abundance of fishes ranged from 241.4 per 30 m^2 at Puerto Botes Reef at Desecheo Island to 22.0 per 30 m^2 at El Palo Reef in Boquerón (Table 5.6). Number of species was highest (29 per 30 m^2) at Puerto Canoas Reef in Desecheo and lowest (10 per 30 m^2) at Caña Gorda and Ballena Reefs in the Guánica area. The highest number of diurnal, non-cryptic fish species observed was also from Puerto Canoas Reef at Desecheo Island with a total of 54 species. The highest fish abundance was found at offshore island sites separated from the main island of Puerto Rico. Puerto Canoas and Puerto Botes at Desecheo Island were the only reefs surveyed with an average of 25 or more (non-cryptic) fish species per transect. Highest abundance (96.9 per 30 m^2) and number of species (22 per 30 m^2) of fish among the mainland reefs surveyed were found at Turrumote Reef in outer Mayaguez Bay.

Table 5.6. Mean abundance and species richness of reef fishes present within belt transects during baseline characterization surveys in 1999-2000. Source: Garcia-Sais et al., 2003; Garcia-Sais, unpublished data.

REEF/ SITE	MEAN ABUNDANCE / 30 m^2	TOTAL # SPP. / 150 m^2	MEAN SPP / 30 m^2
Puerto Botes - DES	241.4	49	25
Puerto Canoas - DES	208.6	54	29
Derrumbadero - PON	161.4	47	25.2
Playa Mujeres - MON	133	48	23
SE Cayo Diablo/99 - FAJ	128	49	21
North Reef - DES	127.4	38	21
Tourmaline - MAY	96.8	42	22
Playa de Pájaros - MON	89	40	19
Las Carmelitas - MON	86	42	22
La Barca - JOB	84.6	30	15.2
Maria Langa 15m - GUY	82.2	46	23
Cayo Puerca West - JOB	71	32	14.8
La Boya - PAR	70.4	38	24
Caribes - JOB	70.2	38	20.4
Boya Esperanzan - VIE	63.4	46	20
Corona - VIE	63.4	37	18
West Reef/99 - CMU	61.8	45	21
Mosquito - VIE	60.8	34	17
Punta Ventana/99 - GUA	60.4	34	16
Comandante - VIE	56	41	19
North Palomino/99 - FAJ	55	31	18
Palominos/01- FAJ	55	31	18
Cayo Puerca East - JOB	54.8	25	10.4
SE Palominitos/99 - FAJ	54.6	29	14
Tallaboa - GUY	50	38	17
Puerto Ferro - VIE	49.2	46	19
Punta Colchones West - JOB	48	24	12.8
Boya 2 - PON	47.8	34	17
Bajo Gallardo - BOQ	46.6	36	17
Canjilones - PAR	44	31	19
Media Luna/99 - MAY	43.2	26	13

Table 5.6 (continued). Mean abundance and species richness of reef fishes present within belt transects during baseline characterization surveys in 1999-2000. Source: Garcia-Sais et al., 2003; Garcia-Sais, unpublished data.

REEF/ SITE	MEAN ABUNDANCE / 30 m^2	TOTAL # SPP. / 150 m^2	MEAN SPP / 30 m^2
Boya 6 - VIE	43	40	19
Punta Colchones East - JOB	42.6	27	14.2
Maria Langa 10m - GUY	40.4	42	17
Monte Pirata - VIE	38.6	38	17
Canjillones - VIE	36.8	43	17
Windward Reef - CMU	36.8	19	13
Punta Ballena - GUA	36.5	20	10
Las Coronas - MAY	34.8	30	15
Margarita Hard Ground - PAR	33.4	27	15
Caballo Blanco Reef Crest - VIE	32	22	13
Caña Gorda - GUA	31.8	20	10
Berberia - CMU	28.8	26	11
Caballo Blanco Reef Slope - VIE	28.4	26	11
Resuellos - BOQ	28	32	15
Cayo Coral/99 - GUA	26.8	29	14
El Palo - BOQ	22	24	11
Tasmania - PON			

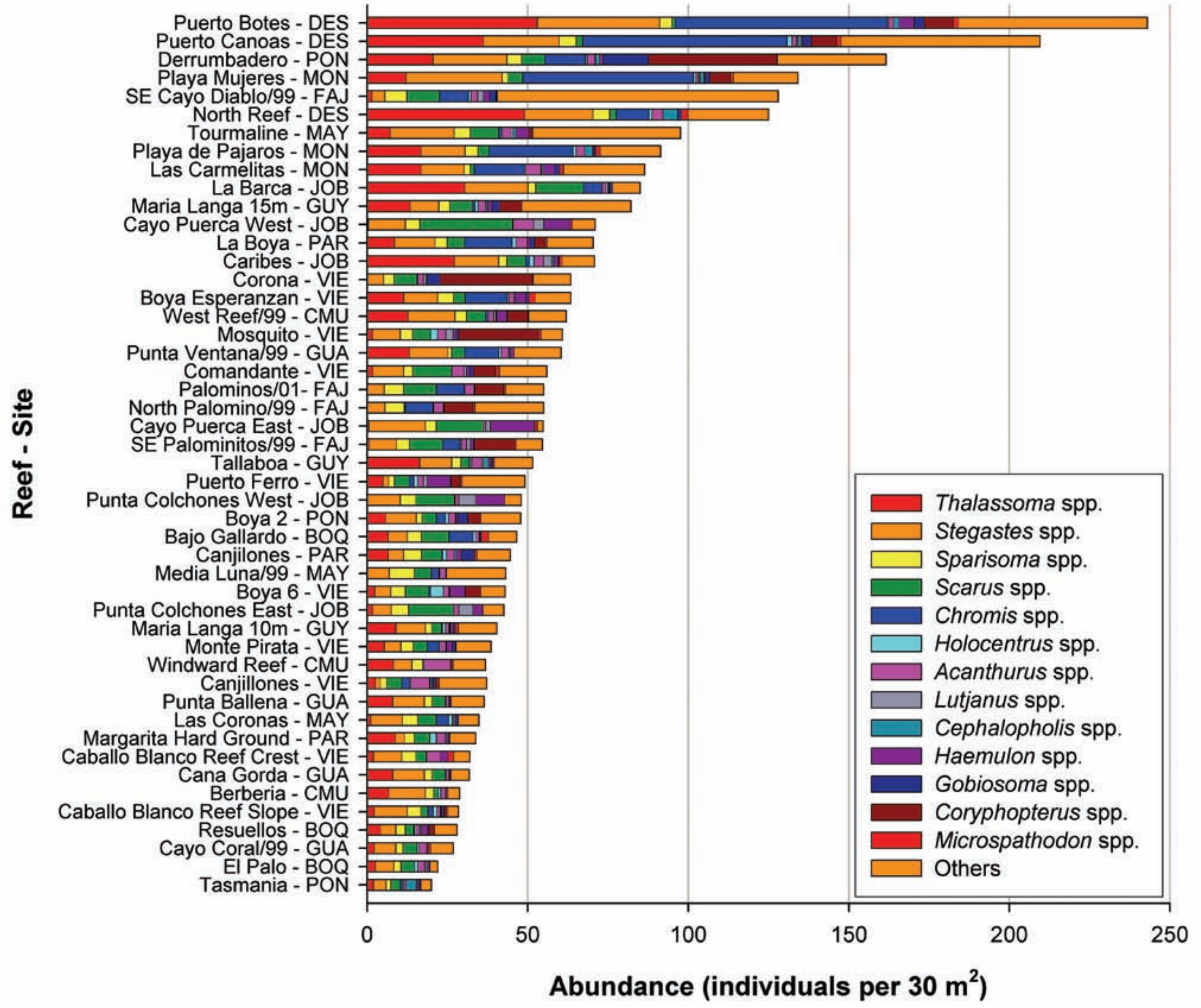

Figure 5.19. Taxonomic composition and abundance of numerically dominant fish taxa from belt-transect surveys performed during the USCRI-NOAA baseline characterization studies of Puertorrican reefs (1999-2001). Source: Garcia-Sais et al., 2003; Garcia-Sais, unpublished data.

Fish assemblages at offshore island reefs, particularly those surveyed at Desecheo and Mona Islands, were characterized by a high abundance of zooplanktivorous fishes, such as *Chromis* spp., creole wrasse (*Clepticus parrae*), bicolor damselfish (*Stegastes partitus*) and juvenile stages of Spanish hogfish (*Bodianus rufus*) (Figure 5.19). High live coral cover was associated with high abundance of the sharknose goby (*Gobiosoma evelynae*) and peppermint goby (*Coryphopterus lipernes*) that live on top of large coral colonies. Number of fish species was positively correlated (p<0.01) with live coral cover on reefs surveyed around Puerto Rico (Figure 5.20) and explained more of the variability than did rugosity. Reefs with low live coral cover and high benthic algal cover exhibited less diverse fish communities, typically with a high abundance of dusky damselfish (*Stegastes dorsopunicans*).

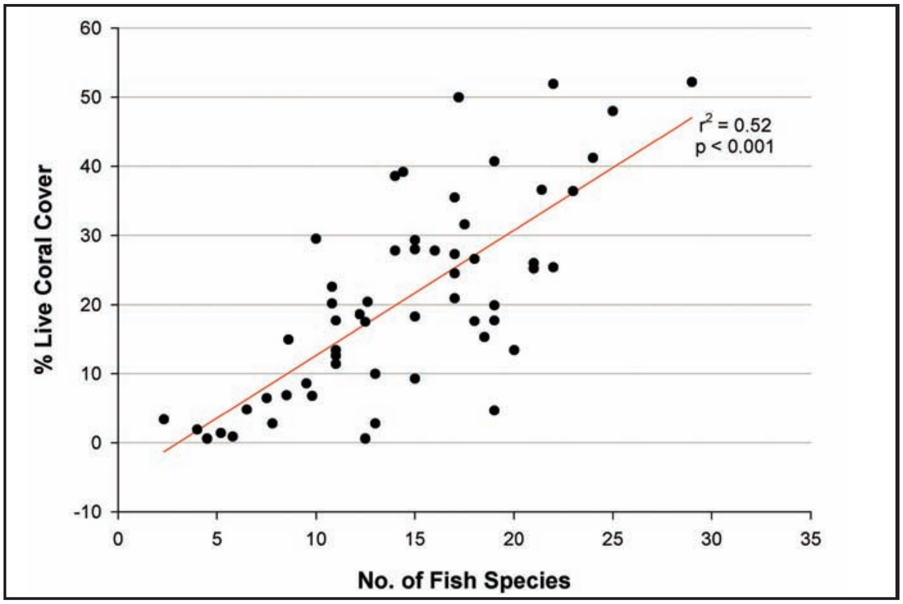

Figure 5.20. Positive correlation between fish species richness (no. of spp per transect) and percent of live coral cover on reefs surveyed around Puerto Rico. Source: Garcia-Sais et al., 2003; Garcia-Sais, unpublished data.

NOAA's Center for Coastal Monitoring and Assessment, Biogeography Team (CCMA-BT)

Since August 2000, NOAA's CCMA-BT has led a collaborative effort to monitor coral reef ecosystems throughout the U.S. Caribbean, including Puerto Rico. This regionally-integrated monitoring effort explicitly links observed fish distributions to shallow (<30 m) benthic habitat types recently mapped by CCMA-BT and its many partners (Kendall et al., 2001). Objectives of this work include: 1) developing spatially-articulated estimates of distribution, abundance, community structure, and size of reef fishes, conch, and lobster; 2) relating this information to in situ data collected on associated habitat parameters; and 3) using this information to establish the knowledge base necessary to implement and support "place-based" management strategies (e.g., MPAs) for coral reef ecosystems of the Caribbean, as well as to quantify the efficacy of management actions.

This regional monitoring program has been conducted in partnership with the UPR, U.S. National Park Service (NPS), USGS, and the Virgin Islands Department of Planning and Natural Resources, and provides standardized monitoring data for portions of U.S. Caribbean. Since the inception of this effort in August 2000, 628 surveys of reef fish populations and associated benthic habitats have been conducted in southwestern Puerto Rico (Figure 5.9). The foundation of this work is the near shore benthic habitat maps created by CCMA-BT in 2001. Using ArcView© GIS software, the benthic habitat maps are stratified before monitoring stations are selected along a cross-shelf depth gradient. Because the project was designed to monitor the entire coral reef ecosystem, CCMA-BT and its partners survey seagrass meadows, mangroves, and sand flats, in addition to coral reefs.

Methods

Survey sites are selected at random within each habitat stratum to ensure spatially comprehensive coverage of the study region. At each site, fish, conch, lobster, and benthic habitat information is collected using standard visual survey techniques (Figure 5.21; Christensen et al., 2002). Since 2003, CCMA-BT has also been collecting data on water quality and oceanographic characteristics at selected survey locations. These water quality data are not yet available, but will be provided in the next reporting effort.

Results and Discussion

By relating monitoring data to the habitat maps, CCMA-BT and its partners are able to map and model (predict) species and community level parameters throughout the seascape. Furthermore, by integrating this work with other concurrent studies on fish migration patterns, home range size, fish dispersal, and recruitment being conducted by partner groups, the program is in a unique position to answer questions about marine zoning strategies (e.g., placement of MPAs), and will be in a position to evaluate management efficacy as long-term monitoring continues.

Since August 2000, a total of 628 locations in southwestern Puerto Rico have been surveyed, resulting in abundance estimates for over 200 species of fishes, 50 species of coral, and 100 species of algae. The highlights of this section are the relationships observed between fish species and the habitats they occupy throughout their life histories, as well as changes in the observed patterns since the last reporting effort in 2002.

Measures of fish community structure (abundance, species richness, and species diversity) were markedly different among the habitat types sampled (reef, mangrove, and other substrates), with reefs exhibiting highest overall species diversity (r^2=0.50, $p<0.0001$) and richness (r^2=0.53, $p<0.0001$). Mangroves exhibited highest mean log-transformed abundance when compared to all other habitat types (r^2=0.42, $p<0.0001$), with relatively low average species diversity (Figure 5.22). When measures of community structure were compared among years for all coral surveys, no statistically significant differences were observed. The average total number of individuals per reef census, however, has declined since 2002, while species diversity during

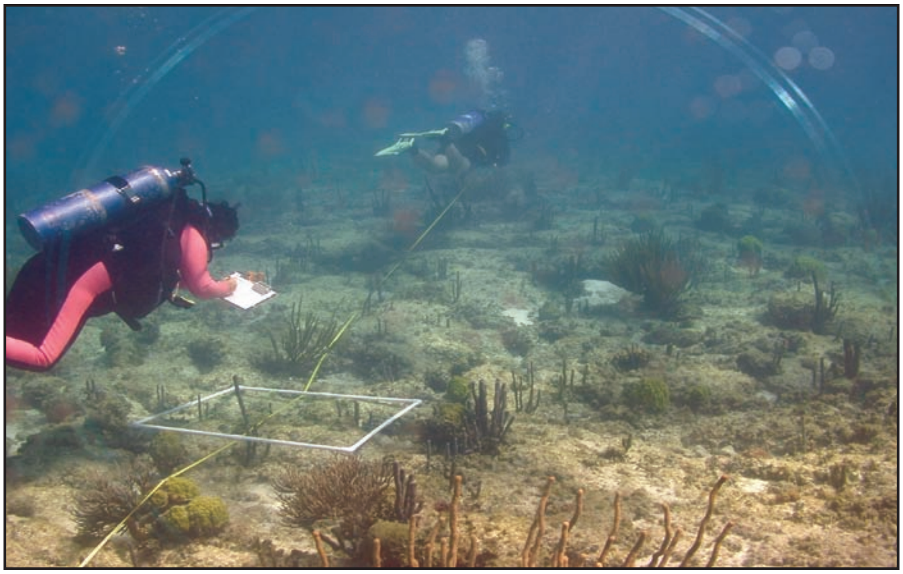

Figure 5.21. Divers collect data on fish communities and benthic habitat cover along a transect according to established protocols used by CCMA-BT scientists throughout the Caribbean. Photo: M. Kendall.

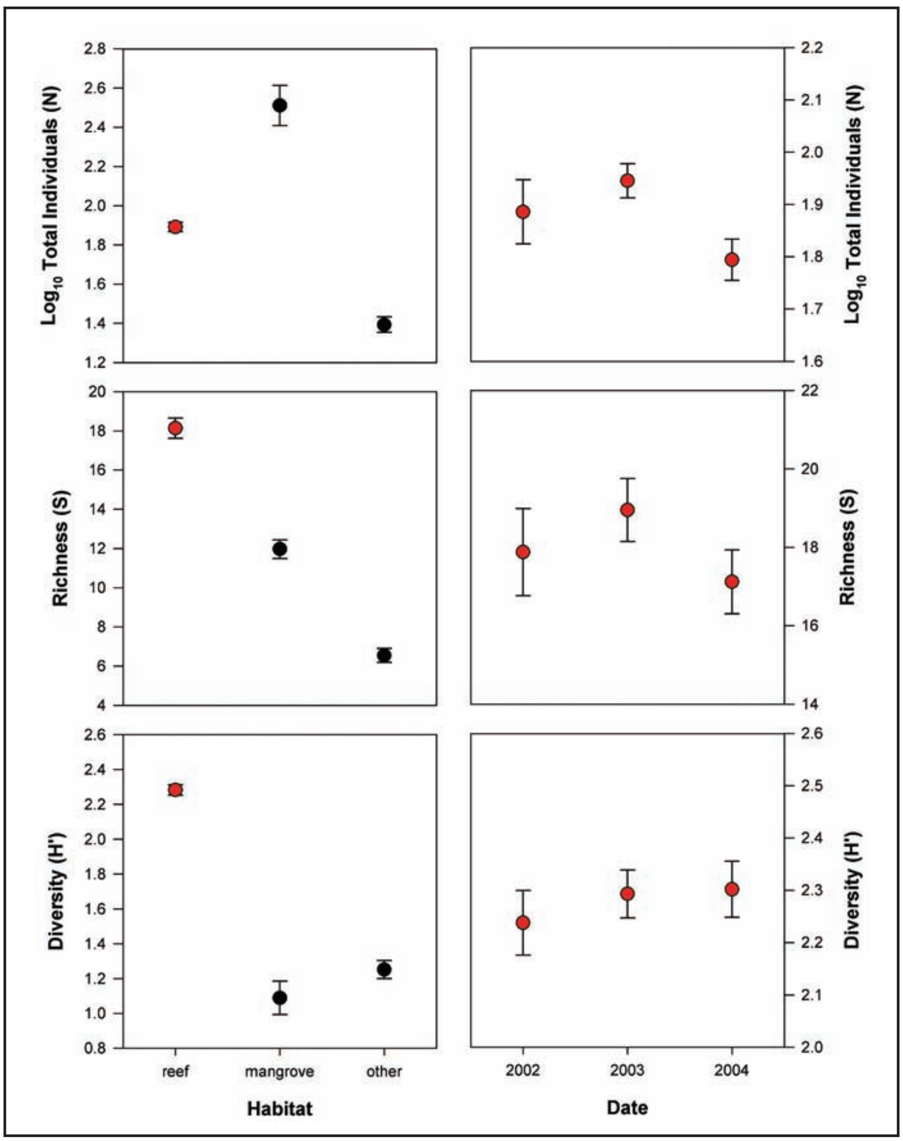

Figure 5.22. Comparison of fish community structure estimates by habitat type (left panels). Data collected in reef habitat is broken out by year (right panels). Source: CCMA-BT, unpublished data.

this same period has increased (Figure 5.22). This may indicate that the declining abundances of several once numerically dominant reef species (e.g., grunts; Figure 5.23), coupled with a relatively stable level of species richness, has resulted in increased diversity.

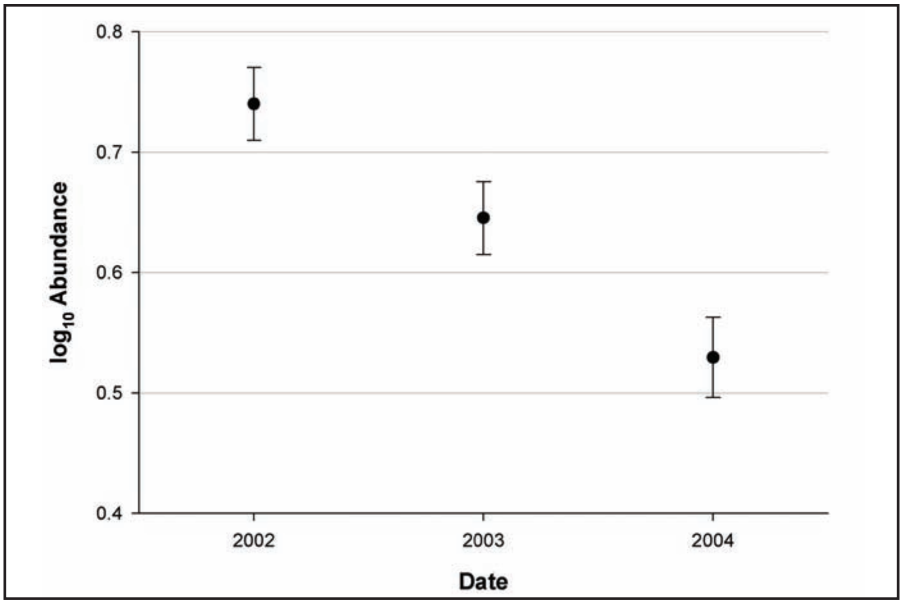

Figure 5.23. Comparison of log-transformed abundance of grunts (family Haemulidae) among years. Model is significant (p=0.02), with abundances in 2003 and 2004 lower than in 2002. Source: CCMA-BT, unpublished data.

Results of the CCMA-BT monitoring activities clearly indicate that fish community structure is different among the various habitats that comprise the coral reef ecosystem in southwestern Puerto Rico, and further corroborate findings by Christensen et al. (2002). It is important, however, to understand that many species in the region require several habitat types throughout their life-histories for growth and reproductive success. Furthermore, these data suggest that preserving a mosaic of habitats is critical to managing significant numbers of fish species that are associated with coral reefs as adults. An analysis of frequencies (correspondence analysis/reciprocal averaging) using data collected since 2002 indicated that many snapper (family Lutjanidae), grunt (family Haemulidae), and wrasse (family Labridae) species exhibit clear ontogenetic shifts in patterns of habitat utilization. For example, lane snapper (*Lutjanus synagris*) less than5 cm fork-length disproportionately inhabit seagrass meadows, and then move into the cover provided by mangrove prop roots (from 5-15 cm). *L. synagris* larger than 15 cm subsequently move from this refuge to reef sites along the entire shelf (Figure 5.24). This is just one of many examples that underscores the need for continued monitoring of reef fish populations in all component habitats of the coral ecosystem.

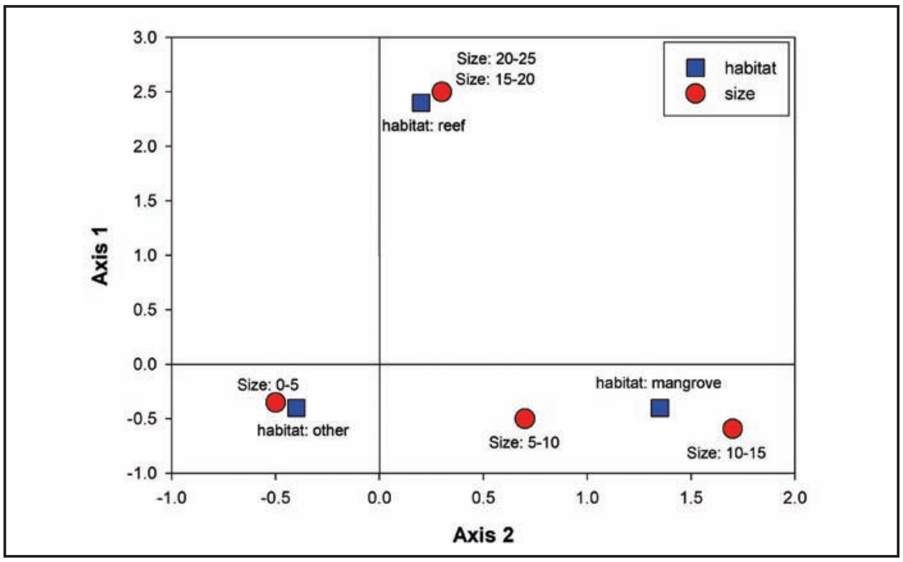

Figure 5.24. Results of correspondence analysis of lane snapper size class distributions among habitats monitored in southwestern Puerto Rico, 2002-2004. Source: CCMA-BT, unpublished data.

Coral reefs exhibited the highest number of species and the highest average diversity among all of the habitat types monitored. Measures of habitat characteristics, particularly topographic complexity (measured as rugosity) and percent live coral cover, were important determinants of fish abundance, richness, and diversity. Figure 5.25 shows the relationships between fish community structure and percent live coral coverage. Each parameter exhibited a statistically significant relationship (log_{10} abundance, r^2=0.48, p<0.0124; richness, r^2=0.69, p<0.0008; diversity, r^2=0.70, p<0.0044), with reef sites characterized by higher live coral cover having significantly higher parameters of fish community structure. It is important to note that the average percent live coral cover measured at 151 reef sites since 2002 is 3.22%, and has not changed significantly since then. A second component of reef habitat that appears to impact estimated parameters of fish community structure is rugosity. Figure 5.26 shows this strong correlation, which indicates that rugose (i.e., more structurally complex) reefs support more fish species (r^2=0.69, p<0001).

CCMA-BT coral reef ecosystem monitoring activities in southwestern Puerto Rico since 2002 indicate that parameters of fish community structure have not changed significantly over the past three years; however, several species of reef fishes have exhibited a decline in abundance (e.g., Haemulids). Community structure is significantly different among habitats within the seascape, and many species require one or more habitats for successful recruitment, growth, and reproductive success. As such, it is critical to consider the entire mosaic of habitats when managing coral ecosystems in Puerto Rico.

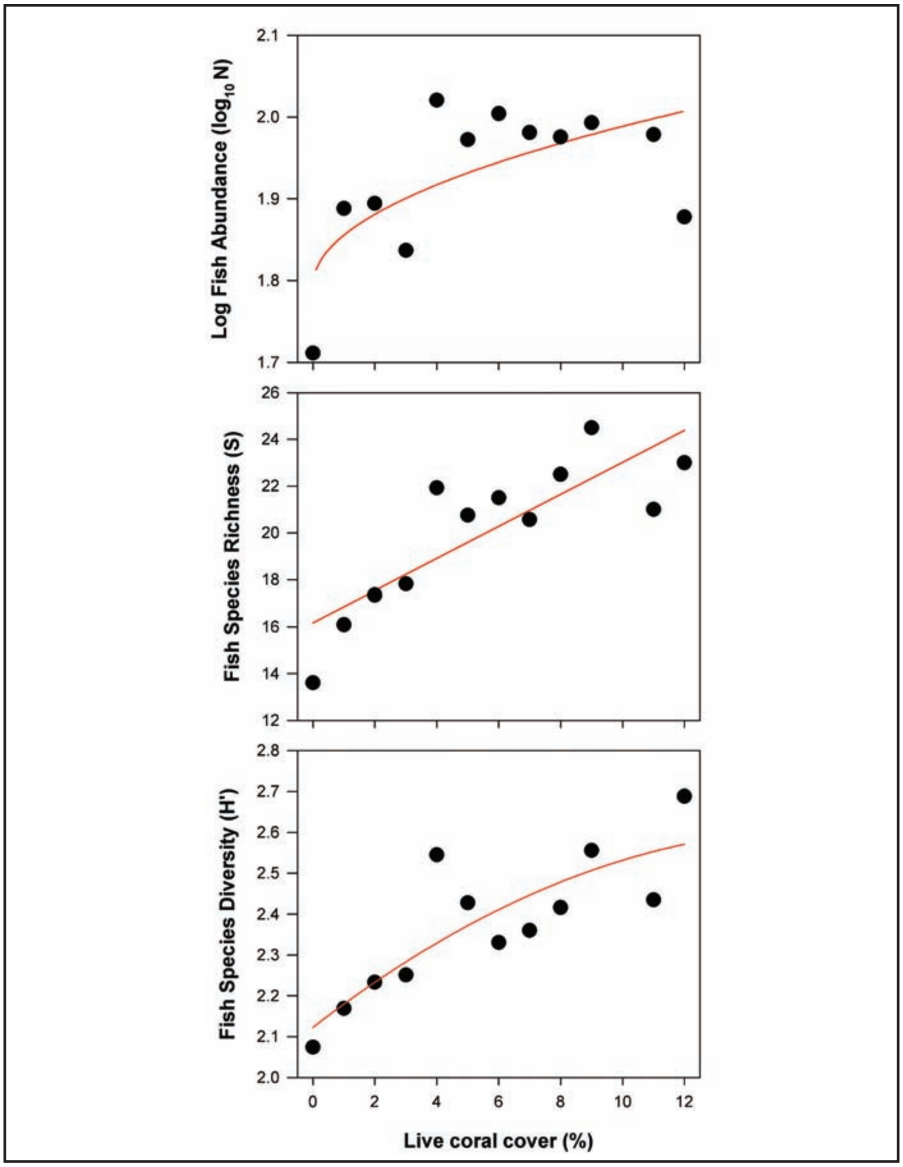

Figure 5.25. Comparison of log-transformed fish abundance, species richness, and diversity among reef sites classified by percent live coral cover, 2002-2004. Source: CCMA-BT, unpublished data.

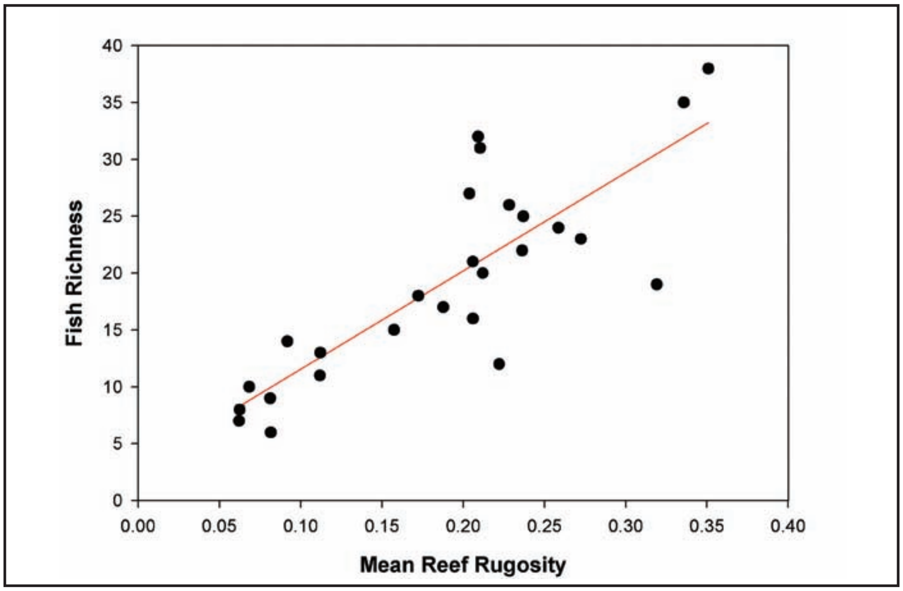

Figure 5.26. Results of regression between mean reef fish richness and mean reef rugosity, 2002-2004. Source: CCMA-BT, unpublished data.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

The purpose and priorities of the Coral Reef Monitoring Program for Puerto Rico were initially presented by the DNER to the U.S. Island Coral Reef Initiative of NOAA in 1997. The main objectives of the program were to map the geographical distribution of coral reefs, produce a baseline characterization of priority reef sites, and establish a monitoring program targeting a selection of high-priority reef sites. The monitoring program would provide information needed for effective resource management and public awareness, while constructing a scientific data base for long-term analysis of the coral reefs in natural reserves of Puerto Rico.

The benthic habitat maps of Puerto Rico and the USVI developed by NOAA in 2001 provided a valuable information source on the geographical distribution of Puertorrican reefs and other benthic habitats of the insular shelf. A more detailed physical assessment of benthic habitats using side-scan sonar technology has been produced for the reef system of La Parguera (Prada, 2002). These works corroborated and expanded upon an initial geographical inventory of Puertorrican reefs by Goenaga and Cintrón (1979). The initial work of Goenaga and Cintrón (1979) combined with studies on reef physiography and community structure (Cintrón et al., 1975; Canals and Ferrer, 1980; Canals et al., 1983) established criteria for designation of marine areas with coral reefs as natural reserves by the government of Puerto Rico. Still, there is a need for more specific physical and biological characterization of hard ground features of the insular shelf, preliminarily those classified as “linear reefs” and other hard ground habitat designations by NOAA (2000).

DNER has identified the natural reserves of Mayaguez Bay, Desecheo Island, Rincón, La Parguera, Bahía de Jobos, Ponce Bay, Cordillera de Fajardo and the islands of Culebra and Vieques as high-priority monitoring sites. Baseline characterizations for these reef systems were prepared by García-Sais et al. (2001a, b, c) and are available online at http://www.coralpr.net/index.php. The baseline characterization and monitoring for the LPCMFR was prepared by Hernández-Delgado (2003). The baseline characterization of the Tres Palmas Reef in Rincón is underway. This report includes monitoring data from a total of 12 reef sites under the U.S. Coral Reef Monitoring Program funded by NOAA and two additional reef sites monitored since 1999 as part of U.S. EPA 301(h) studies associated with operations of the submarine outfalls of the RWWTPs at Arecibo and Aguadilla, on the north and northeast coasts, respectively. La Parguera, on the southwest coast, is a CARICOMP monitoring site. The CARICOMP database is available online (CARICOMP, http://www.ccdc.org.jm/caricomp.html, Accessed: 12/29/04).

Public awareness and outreach programs focused on the ecological and socioeconomic value of Puerto Rico’s coral reef systems have started in the form of special television presentations transmitted by the government television channel, WIPR, through the series “Geoambiente”. An interagency committee directed to promote public awareness on the importance of coral reefs has prepared a local action strategy (LAS) to convey basic knowledge about coral reefs to secondary level students in the public education system. The plan integrates municipal governments and the tourism industry in an effort to promote awareness of human activities that negatively affect coral reef health. UPR’s Sea Grant Program has played an important role in disseminating information geared toward the general public and local fishers based on scientific research regarding the ecological health of coral reef systems and associated fisheries in Puerto Rico. Educational brochures on marine life at highly impacted recreational reef sites at La Parguera and the LPCMFR have been produced and distributed.

The Caribbean Fisheries Management Council (CFMC) and the NOAA Fisheries office in Puerto Rico have collaborated with DNER scientists and management to significantly revise Puerto Rico’s fisheries law. The new law is directed to protect the integrity of coral reef systems by regulating fishing activities through the implementation of catch quotas, establishment of no-take areas within three natural reserve sites (Culebra, Desecheo and Rincón) and seasonal fishing closures for overexploited species including red hind (*Epinephelus guttatus*), mutton snapper (*Lutjanus analis*) and queen conch (*Strombus gigas*).

Designations of coastal areas with extensive coral reef development as natural reserves by the DNER represents a first step towards conservation of Puertorrican coral reef resources. Natural reserves in Puerto Rico are regulated by restrictive zoning designations to protect the marine ecosystem from detrimental effects of activities occurring upstream in the watershed, such as the increased rates of terrestrial sediment runoff associated with soil movement during construction work. DNER has assigned personnel to enforce regulations applicable to the commercial and recreational utilization of marine resources within natural reserves.

The ever increasing pressure to develop the coastline into urban, industrial and tourist centers has dramatically influenced the modification of initial watershed zoning designations pertaining to many natural reserves in Puerto Rico. The trend is towards less restrictive zoning designations that allow for increased urban development within the watershed and open rural areas to tourism and commercial development. The effects have been a decrease in water quality due to increased sediment runoff and an exponential increase in the recreational utilization of marine resources. Water quality monitoring programs have been implemented to focus specifically on effects of submarine outfalls in the vicinity of Arecibo, Aguadilla, Carolina, San Juan and Ponce and thermoelectric power plant thermal discharges in the vicinity of San Juan, Guayanilla and Guayama.

Other activities underway include an evaluation of the status of organism collecting for the aquarium trade.

OVERALL CONCLUSIONS AND RECOMMENDATIONS

The benthic habitat mapping effort by Kendall et al. (2001), in conjunction with the initial inventory of coral reefs by Goenaga and Cintrón (1979) and the most recent work by Prada (2002) in La Parguera, have provided important data on the geographical location of coral reefs and other benthic habitats in Puerto Rico. Continued field validations of this preliminary work will lead to more specific and accurate classification of the benthic habitats. A comprehensive baseline characterization of the main Puertorrican coral reefs has been produced. The database includes quantitative assessments of substrate cover by benthic categories and abundance estimates of fishes and motile megabenthic invertebrates from 28 reefs in Puerto Rico. Permanent transects allow for prospective quantitative monitoring of these reefs.

Reefs with the highest substrate cover of live corals were generally found at the leeward side of oceanic islands (e.g., Desecheo, Mona); at offshore islands within the Puertorrican shelf (e.g., Vieques, Culebra, Cayo Diablo); and associated with the mainland shelf-edge in the south (e.g., Derrumbadero), southwest (e.g., La Boya Vieja) and west coasts (e.g., Tourmaline). Boulder star coral, *Montastrea annularis,* is the dominant coral species in terms of substrate cover in reefs with relatively high coral cover. Great star coral, *Montastrea cavernosa, Siderastrea* spp., and *Porites astreoides* constitute the main coral assemblage of degraded reefs.

Year-round high water transparency and protection from extreme wave action are the main factors associated with healthy coral reef systems in Puerto Rico. Rivers represent the main sources of material loading to coastal waters of Puerto Rico, including pollutants in the form of suspended sediments, biological oxygen demand, chemical oxygen demand, fecal coliforms, heavy metals, and pesticides. Coral reef monitoring programs associated with the 301(h) RWWTP submarine outfall study in Aguadilla show that no major changes of live coral cover have occurred during the last four years of observations. The first monitoring cycle of reefs through NOAA's U.S. Coral Reef Monitoring Program in 2001 did not detect any major shifts in community structure, nor live coral cover in 16 of the 18 reefs studied. The second monitoring cycle (2004) is currently in progress. The marked decline of live coral cover from the reefs at the LPCMFR, combined with the outbreak of cyanobacterial colonization of reef substrate, was unprecedented and deserves further monitoring and evaluation.

A positive correlation exists between species richness of reef fishes and the percent of live coral cover in reefs around Puerto Rico. Coral reefs with high live coral cover generally exhibit relatively high abundance and a diverse assemblage of zooplanktivorous fishes (*Chromis* spp., *Clepticus* spp., *Stegastes partitus*), whereas coral reefs with low live coral cover numerically dominated by dusky damselfish (*Stegastes dorsopunicans*). Large, commercially important reef fishes have virtually disappeared from shallow reefs around Puerto Rico. Preliminary findings from the LPCMFR suggest that commercially important reef fishes are increasing in size and abundance within reserve boundaries.

Public awareness and outreach programs that educate the Puertorrican community about coral reef systems, the role they play in our society, and how they can be most effectively managed and utilized are underway by several organizations, including an interagency (DNER, CFMC, NOAA Fisheries, Sea Grant) effort to develop LASs and a weekly television program from the government channel, WIPR, entitled 'Geoambiente.'

The initial objectives of the U.S. Coral Reef Initiative Program for Puerto Rico, such as the mapping of benthic habitats (including coral reefs), the baseline quantitative characterization of coral reef communities, training of DNER personnel for coral reef monitoring, monitoring of reef sites, and the launching of a coral reef public awareness and outreach program have been fully addressed and achieved to a significant level due to the combined effort from local government, Federal agencies, public and private universities, and NGOs. It is time for evaluation of new priorities and re-definition of program goal objectives.

Recommendations

Recommendations for future management activities include defining and implementing a long-term coral reef monitoring program focused on a selected group of eight reef sites where baseline characterizations and previous monitoring is already available. The recommended sites include reefs within no-take MPAs (e.g., Desecheo, Tres Palmas, LPCMFR), shelf-edge reefs (Tourmaline, Boya Vieja, Derrumbadero), representative mid-shelf/coastal reefs that can be monitored cost-effectively (Media Luna, Caribes, Barca), and representative island reefs with high recreational potential (La Cordillera de Fajardo, Vieques) that are currently unprotected. Proposed coral reef monitoring sites and the region in which they are located include:

- Puerto Canoas/Puerto Botes Reefs - Desecheo
- Tourmaline Reef – Mayaguez Bay
- Boya Vieja/Media Luna Reefs – La Parguera
- Derrumbadero Reef – Ponce
- Caribes/La Barca Reefs – Guayama
- LPCMFR Reefs – Culebra
- Comandante/Esperanza/Mosquito Reefs – Vieques
- Tres Palmas Reef – Rincón
- La Cordillera Reefs – Fajardo

Field validation and classification of selected reef habitats as they appear in the benthic habitat map of Puerto Rico (Kendall et al., 2001) are required. The priority is to refine the classification of reefs as coral reef, hard ground, or rock reef habitats in order to validate area estimates of benthic habitats and their distribution within the Puertorrican shelf.

In addition, exploratory surveying, mapping, and monitoring of deep coral reef systems within the 30-50 m depth range is needed. Preliminary surveys indicate that deeper water reefs exhibit exceptionally high live coral cover and rich biological communities, particularly within deep sections of the eastern and western shelf of Puerto Rico.

Management activities must also be supported with an increased effort to raise public awareness and develop outreach activities on coral reef ecology and resource conservation, focusing on fishers and communities adjacent to natural reserves. It is also recommended that the topic of coral reef ecology and resource conservation be incorporated into the science curriculum at all educational levels in Puerto Rico. Guidelines for recreational use of coral reefs and associated ecological systems within natural reserves are needed and should be widely disseminated.

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