The State of Coral Reef Ecosystems of Puerto Rico

Jorge García-Sais[1], Richard Appeldoorn[1], Tim Battista[2], Laurie Bauer[2], Andy Bruckner[3], Chris Caldow[2], Lisamarie Carrubba[4], Jorge Corredor[1], Ernesto Diaz[5], Craig Lilyestrom[6], Graciela García-Moliner[7], Edwin Hernández-Delgado[8], Charles Menza[2], Julio Morell[1], Anthony Pait[9], Jorge Sabater[10], Ernesto Weil[1], Ernest Williams[1] and Stephanie Williams[1]

INTRODUCTION AND SETTING

The Commonwealth of Puerto Rico is comprised of a number of islands in the northern Caribbean, including the island of Puerto Rico and offshore islands such as Culebra, Vieques, Monito, and Desecheo (Figure 3.1). The following information adds to the comprehensive overview of Puertorrican reefs provided in the previous edition of this report (García-Sais et al., 2005). The coral reef ecosystem in Puerto Rico is a complex mosaic of interrelated habitats, including mangrove forests, seagrass beds and coral reefs, as well as other coral communities. Mangrove forests can be found on coral cays and fringing the shoreline along the coast. In areas along the coast where development is occurring, mangrove forests and other wetlands continue to be impacted by cutting, filling and other disturbances. The desire for water access and increases in boating also impact both mangroves and seagrass beds directly through construction and indirectly through changes in water quality associated with accidental spills of petroleum products, accidental groundings and propeller damage, and increases in marine debris. Impacts to these important habitats also lead to effects in coral reefs due to the loss of juvenile habitat for reef species such as spiny lobster, snappers, and groupers. Frias-Torres (2006) demonstrated that, for mangrove-dependent juveniles of goliath grouper in the Florida Keys, spatially complex fringing red mangrove habitat was essential to the growth of this species and the later presence of adults in coral reefs and colonized hardbottom.

Figure 3.1. A map of Puerto Rico showing locations mentioned in this chapter. Map: K. Buja.

Seagrass beds provide habitat for various life stages of numerous highly mobile species that also utilize red mangrove roots and coral reefs during various parts of their life cycle. Aguilar-Perera (2004) evidenced the importance of seagrasses in La Parguera Natural Reserve as habitat for juvenile populations of species of commercial importance such as grunts and snappers. Similarly, the underestimation of the extent of seagrass habitats often results in lesser protection to these important communities. The proper definition of the extent of seagrass habitat is confounded by various factors, including temporal changes that may be a function of season, changes in light penetration, wave energy, and direct human disturbances such as dredging, propeller wash and scars, and anchoring (Fonseca et al., 1998). The Caribbean Fishery Management Council or CFMC (2004) states that the degradation and loss of patchy seagrass habitat, essential for the settlement and development of juvenile conch, may be one of the reasons the species is considered overfished, as a reduction in juvenile habitat results in a loss of productivity. Overall, the proper definition of the extent of seagrass habitats should recognize the variability of seagrass coverage, the reproductive needs of the grasses (vegetative and sexual), and the historical record related to seagrass presence in an area. Estimates of seagrass habitat coverage based on one-time observations will probably result in underestimates.

1. University of Puerto Rico, Mayaguez
2. NOAA Ocean Service, Center for Costal Monitoring and Assessment, Biogeography Branch
3. NOAA Fisheries, Office of Habitat Conservation
4. NOAA Fisheries, SERO Protected Resources Division
5. Puerto Rico Costal Zone Management Program
6. Puerto Rico Department of Natural and Environmental Resources
7. Caribbean Fisheries Management Council
8. University of Puerto Rico, Rio Piedras
9. NOAA Ocean Service, Center for Costal Monitoring and Assessment, Coastal Oceanographic Assessment Status and Trends Branch
10. Reef Research, Inc

In addition to human impacts to benthic habitats that form the coral reef ecosystem in Puerto Rico, declines in the health of important reef-building corals have become a concern of NOAA in the U.S. Caribbean and Florida. In 2004, NOAA Fisheries received a petition from the Center for Biological Diversity to protect elkhorn (*Acropora palmata*), staghorn (*A. cervicornis*) and fused staghorn (*A. prolifera*) corals under the Endangered Species Act (ESA) of 1973. NOAA Fisheries found the petition had merit and convened a Biological Review Team (BRT) to review the status of these species. The BRT found that elkhorn and staghorn corals used to be the most abundant and most important species on many Caribbean coral reefs in terms of reef formation and the provision of habitat for other reef organisms (Acropora Biological Review Team, 2005). The BRT determined that, due to the decreased abundance of elkhorn and staghorn corals, it is likely that the ecosystem functions related to growth of coral reefs and provision of habitat have been greatly compromised (Acropora Biological Review Team, 2005). The BRT determined that disease, temperature-induced coral bleaching, and physical damage from hurricanes were the greatest threats to these corals followed by anthropogenic physical damage such as groundings, anchoring, and divers/snorkelers. Based on the results of the status review, NOAA Fisheries decided to list elkhorn and staghorn corals as threatened throughout their known range. This designation became final in May 2006. In addition, because the species were listed as threatened, NOAA Fisheries proposed take prohibitions under Section 4(d) of the ESA. Once final, these prohibitions will protect these corals from damage related to collection, construction, groundings, and other anthropogenic activities while still allowing scientific investigation and education to promote their recovery. NOAA Fisheries is also proposing the designation of critical habitat for these species that would protect hardbottom habitat where these corals were present historically or are currently found.

In addition to the reef types described in García-Sais et al. (2005a), deep hermatypic coral formations off the south coast of Vieques, Isla Desecheo and Bajo de Sico in Mona Passage have recently been described by García-Sais et al. (2004, 2005b, 2005c, 2006) as part of the Puerto Rico National Coral Reef Monitoring Program of the Department of Natural and Environmental Resources (DNER), and the Essential Fish Habitat Program of the CFMC, both programs sponsored by NOAA. Quantitative assessments of reef substrate cover by sessile-benthic, motile megabenthic and fish communities were produced by García-Sais et al. (2004, 2005b, 2005c, 2006) for these deep hermatypic reef systems (mesophotic reefs). The benthic communities associated with the upper slope habitat off La Parguera were described by Singh et al. (2004) from photographic records provided by the SeaBED Autonomous Underwater Vehicle. information on additional mesophotic reef types is provided below.

Deep Hermatytpic Coral Formations (Mesophotic reefs)

Deep hermatypic coral formations recently described in Puerto Rico include the “Deep Terrace”, “Drop-off Wall” and “Rhodolith” reefs, which contain nodules of unattached, branching, coralline algae. “Deep Terrace” reefs have been found at depths between 30-90 meters growing over flat or gently sloping terraces in very clear water. The dominant coral species is a flattened plate morphotype of *Montastraea annularis* complex; lettuce corals (*Agaricia lamarki*, *A. grahame*) and *Porites astreoides* are also common. García-Sais et al. (2004) described one of these reefs, locally known as Black Jack, off the south coast of Isla de Vieques (Figure 3.2). The reef is similar to those reported by Nemeth et al. (2004), and Armstrong et al. (2006) within the Marine Conservation District off the south coast of St. Thomas, U.S. Virgin Islands (USVI), a known spawning aggregation site for red hind (*Epinephelus guttatus*; Nemeth et al., 2005). Similar reef formations may be present off the east and south coasts of Vieques, north-east coast of Culebra, and on deep terraces of the outer insular shelf of the USVI. Some of these reefs are important spawning aggregation sites for groupers. El Seco, an undescribed deep terrace reef formation located off the east coast of Vieques is a known spawning aggregation site for tiger grouper (*Mycteroperca tigris*; Sadovy et al., 1994).

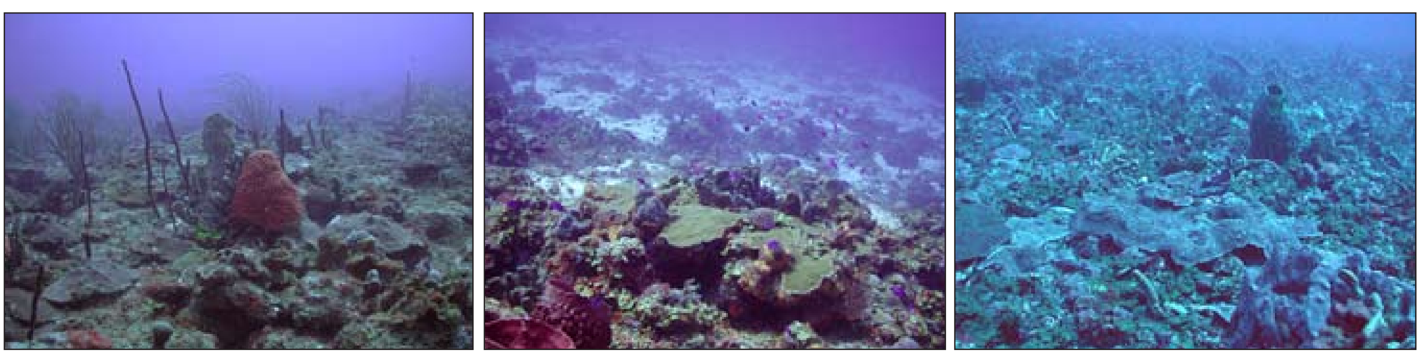

Figure 3.2. Types of deep hermatypic reef systems in Puerto Rico. From left to right: deep terrace reef type; Black Jack Reef, Isla de Vieques, Puerto Rico (34 m; left); Drop-off wall reef type, and southeast Wall Reef, Isla Desecheo, Puerto Rico (40 m; center); and Rhodolith reef type. Agelas Reef, Isla Desecheo, Puerto Rico (50 m; right). Source: García-Sais et al., 2005.

A total of 25 species of scleractinian corals, two antipatharians and one hydrocoral were identified during the snapshot survey of Black Jack Reef by García-Sais et al. (2004). Live coral cover averaged 28.8% (range 25.0-40.4%) within video-transect areas. The *Montastraea annularis* complex was the dominant coral species in terms of substrate cover (mean: 21.9%), representing 76% of the total live coral cover at depths between 36-40 m., and generally exhibited laminar or flattened growth with closely spaced colonies of moderate size and low relief. Corals grow mostly from a pedestal of unknown origin, creating protective habitat underneath the coral. The laminar growth pattern appears to be an adaptation for optimum light utilization. Other coral species that presented substrate cover above 1% and that were present in at least four out of five transects surveyed include *Porites astreoides*, *Agaricia grahamae* and *M. cavernosa*. One large colony of the bushy black coral (*Antipathes caribbeana*) was present at the deep terrace of Black Jack Reef. Turf algae was the dominant biological assemblage in terms of reef substrate cover with 57.4 %. Fleshy (*Lobophora variegata*) and calcareous algae (*Halimeda* sp.) were also present within transect areas. The combined mean reef substrate cover by benthic algae within transect areas surveyed was 64.2% (García-Sais et al., 2004).

A total of 54 reef fishes were identified from Black Jack Reef, 33 of which were present within three (3 x 10 m) belt-transects surveyed between 10:00–12:00 AM (García-Sais et al., 2004). The mean abundance of fishes was 549.3 individuals/30 m^2 and the mean number of species per transect was 16. An assemblage of three species represented 95% of the total fish abundance within belt-transects. The numerically dominant species was the masked goby (*Coryphopterus personatus*) with a mean abundance of 390 individuals/30 m^2. This is the highest density ever reported for a demersal fish within a belt-transect from a reef surveyed in Puerto Rico. Following in abundance were the Creole wrasse (*Clepticus parrae*) with 93.0 individuals/30 m^2 and the blue chromis (*Chromis cyanea*) with 36.7 individuals/30 m^2.

An extensive Deep Terrace reef formation associated with the submerged seamount at Bajo de Sico (Mona Passage) has been recently described (García-Sais et al., unpub. data). The reef extends across the entire northwest section of the seamount at depths between 45 and 90 meters over a relatively flat, gently sloping, hard bottom terrace. Biological characterization and benthic habitat mapping efforts of this reef system are ongoing at present as part of a project sponsored by the CFMC and NOAA, with the support of NOAA's Center for Coastal Monitoring and Assessment Biogeography Branch (CCMA-BB).

Drop-off Wall Reefs

Deep hermatypic reefs have developed on drop-off walls at the upper slope of oceanic islands, such as Isla Desecheo (García-Sais et al., 2005b), and on the reef top and upper slope of the seamount at Bajo de Sico in Mona Passage (García-Sais et al., in review). The Southwest Wall reef of Isla Desecheo is found at depths between 30-40 m and is dominated by benthic macroalgae (mostly *Lobophora variegata*), sand, sponges and massive scleractinian corals (García-Sais et al., 2005b). Sponges are highly prominent (mean surface cover: 17.3%), growing mostly as large erect and branching forms that provide substantial topographic relief and protective habitat for fishes and invertebrates. In many instances, sponges grow attached to stony corals forming sponge-coral bioherms of considerable size. One of the most common associations consists of brown tube (*Agelas conifera*, *A. sceptrum*) and row pore sponges (*Aplysina* spp.) with star corals (*Montastraea cavernosa*, *M. annularis*). A total of 25 scleractinian corals, three hydrocorals and two antipatharian (black coral) species were identified from the Southwest Wall Reef at Isla Desecheo. Great star corals (*M. cavernosa*, *M. annularis* complex) were the dominant species of scleractinian corals at the site (García-Sais et al., 2005b).

A total of 70 fish species were identified from depths below 30 m at southwest Wall reef (García-Sais et al., 2005b). The numerically dominant ichthyofauna within belt-transects surveyed was comprised by zooplanktivorous taxa, suggesting that planktonic food webs are most relevant on deep hermatypic reefs. Drop-off wall reefs studied at Isla Desecheo are the natural habitats of many exploited commercially important food fishes, such as large groupers (*Epinephelus striatus*, *E. guttatus*, *Mycteroperca venenosa*) and snappers (*Lutjanus spp.*), and target species of the aquarium trade (*Chromis cyanea*, *Gramma loreto*, *Centropyge argi*, *Chaetodon* spp., *Opistognathus* spp.). Densities of adult red hind (*E. guttatus*) from 40 m at the southwest Wall are the highest reported for Puerto Rico (García-Sais et al., 2005b).

Rhodolith Reefs

Rhodolith reefs have developed along gently sloping terraces below depths of 40 m at Isla Desecheo and Bajo de Sico. Agelas Reef is a crustose algal rhodolith formation colonized by encrusting brown algae (*Lobophora variegata*), large erect and branching sponges (*Agelas* spp., *Aplysina* spp.) and lettuce corals (*Agaricia* spp) found at depths of 40-70 m in Isla Desecheo (García-Sais et al., 2005b; Figure 3.2). The sessile-benthic biota, including corals, grows attached to a vast deposit of rhodolite nodules that are loosely anchored to the bottom. Reef substrate cover by live biota is over 95%. Agelas Reef has very low topographic relief and massive corals do not contribute significantly to its rugosity. A total of 18 species of scleractinian corals, two hydrozoans (*Millepora alcicornis* and *Stylaster roseus*) and the antipatharian black wire coral (*Stichopathes lutkeni*) have been reported from Agelas Reef (García-Sais et al., 2005b). The combined mean substrate cover by the nine species of scleractinian corals present within video-transects at Agelas Reef was 13.1% (range: 7.4-36.4%). Irregular sheets or laminar growth by lettuce corals prevailed at depths between 45 and 53 meters, with a combined reef substrate cover of 8.9%, representing 70% of the total cover by scleractinian corals. Lamark's sheet coral (*Agaricia lamarki*) and Graham's sheet coral (*A. grahamae*) were the main coral species present within transects surveyed (García-Sais et al., 2005b).

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

The 2005 coral bleaching event and post-bleaching coral mass mortality during 2006 had a dramatic impact on Puerto Rican coral habitats. Major coral bleaching resulted from record-breaking warm sea surface temperatures (SSTs; up to 31.8ºC at 30 m depths, and up to 33.1ºC at reef crests), and a maximum of 14.3 accumulated degree heating weeks or DHW (Hernández-Delgado, unpub. data). A total of 82 cnidarian species were impacted by bleaching in Puerto Rico during 2005, including 52 scleractinians, 13 octocorals, four hydrocorals, four zoanthideans, four actiniarians, three corallimorpharians and two scyphozoans (Hernández-Delgado et al.,unpub. data; García-Sais et al., 2006).

Stratified random belt transects (back reef and fore reef locations from 1-30 m depth) were conducted off La Parguera, Mayaguez, Boqueron, Rincon and the offshore islands of Desecheo and Mona Island in December, 2005 and August 2006 to quantify the extent of bleaching and patterns of recovery. Of over 4,000 corals examined in all sites during December (70 belt transects in 28 locations), 65% of the corals exhibited signs of bleaching ranging from fully bleached (white) to partially bleaching (pale yellow or mottled appearance), represented by 73% of the total living coral cover, while 35% of the colonies did not appear to have been affected by this event. Differences in bleaching severity and extent of mortality were observed between species, colony size, locations and depths (Figures 3.3, 3.4, and 3.5). Overall, colonies in Parguera exhibited higher rates of bleaching (all species pooled) and higher percent of recent tissue loss (5.4%) when compared to sites off the west coast (1.4-2.8%), while more normal, unbleached corals were observed on reefs off Mona Island (42%) and Desecheo Island (47%). The most severe bleaching (all sites pooled) was observed among *Montastraea annularis* complex (94%), *Helioseris cucullata* (94%), *Colpophyllia natans* (83%), *Siderastrea siderea* (65%), *Millepora* spp. (63%), *Mycetophyllia* spp.(62%), *Diploria* spp.(54%), *Agaricia* spp. (48%) and *M. cavernosa* (46%). In contrast, *Eusmilia fastigiata* (22%), *Meandrina meandrites* (26%), and *Porites* spp. (36%) appeared to be less susceptible to bleaching. Several less common species, such as *Dichocoenia stokesii, Dendrogyra cylindricus*, *Isophyllia sinuosa*, *Mussa angulosa*, *Scolymia lacera* and *Manacina areolata* were fully bleached on reefs around La Parguera, and less frequently bleached in other locations. *Millepora alcicornis* exhibited complete bleaching at all sites, and most colonies (>65%) had died by December 2005. Complete bleaching and extensive partial mortality of *Acropora palmata* colonies was documented off Parguera; this species was partially bleached off Mayaguez and no bleaching was observed within *A. palmata* thickets off Rincon, Boqueron and Mona Island. Differences in the extent of bleaching were largely size dependent, with the smallest corals exhibiting both the highest resistance to bleaching (mean diameter of unbleached corals=20 cm) and the most severe bleaching among larger corals (>29 cm diameter). By December, most of the larger colonies (mean diameter=40-49 cm) were pale white to light yellow although many also had patches of light brown tissue within the colony surface or along the margin. In particular, many of the *M. annularis* complex colonies had begun regaining color and were mottled in appearance. These colonies also exhibited extensive signs of recent mortality including the sudden emergence of a disease (a white syndrome resembling white plague). By August 2006, most corals had regained normal coloration. However, *M. annularis* colonies throughout the

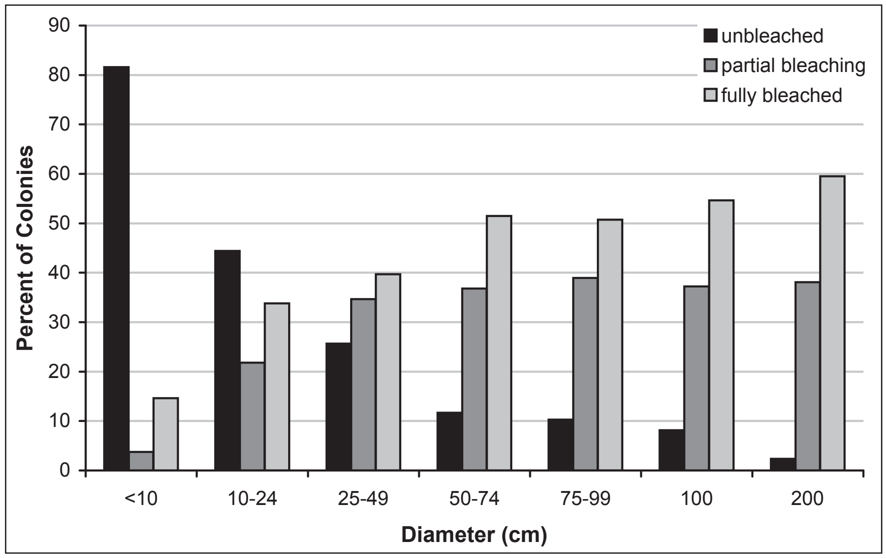

Figure 3.3. Relationship between colony size and bleaching severity, recorded as unbleached, partial bleaching and fully bleached (all locations and species are pooled). Source: Hernández-Delgado, unpub. data.

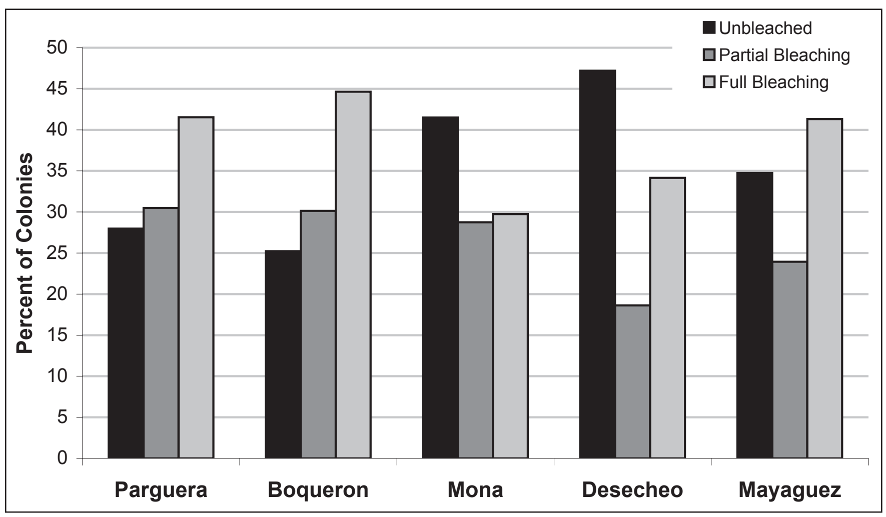

Figure 3.4. Site specific variation in bleaching observed on 70 belt transects (1 x 30 m) off southwest Puerto Rico, Mona Island and Desecheo Island (28 reefs <30 m depth). Colonies (all species pooled, n=4,030 corals) were identified as unbleached (normal pigmentation), partially bleached (pale or mottled coloration) or fully bleached (>80% of colony surface). Source: Hernández-Delgado, unpub. data.

region experienced extensive partial and full colony mortality, and coral cover declined throughout the region by 40-60%.

On the east coast of Puerto Rico, bleaching was significantly more severe and prolonged at protected (leeward) reefs than at reefs under moderate or strong water circulation (Hernández-Delgado et al., 2006). Bleaching affected 80-97% of the corals at leeward reefs, 60-80% at reefs with moderate circulation and only 20-60% at exposed reefs with stronger water circulation (Figure 3.6). A total of 37% of surveyed coral species suffered a 100% bleaching frequency, 24% of the species suffered 80-99% bleaching, 29% of the species suffered 50-80% bleaching, and 10% suffered 20-50% bleaching (Figure 3.7).

Coral bleaching along the south and west coasts of Puerto Rico during late 2005 was particularly detrimental to coral reefs in which boulder star coral *(Montastraea annularis)* complex was the principal reef building species and dominant in terms of reef substrate cover. This includes some of the best coral reef systems of Puerto Rico in terms of live coral cover, such as those from Isla Desecheo (Puerto Canoas Reef, Puerto Botes Reef), and shelf-edge reefs off Ponce (Derrumbadero Reef), La Parguera (Boya Vieja Reef; García-Sais et al., 2006) and those from Mona Island (Hernández-Delgado et al., unpub. data). Coral mortality from these reefs was on the order of 50% (García-Sais et al., 2006). Reefs from the Tres Palmas system in Rincon, which are dominated by elkhorn coral (*Acropora palmata*) and great star coral (*M. cavernosa*) were the least affected by bleaching among reefs surveyed (García-Sais et al., 2006).

Bleaching was followed by a white plague-like massive outbreak that caused mass mortality and resulted in a net 20-60% decline in living coral cover at surveyed reefs of the east coast within a period of approximately six months. Nearly 100% of the colonies of important reef-building coral species such as *Montastraea annularis*, *M. faveolata*, *M. franksi* and *Acropora cervicornis* suffered significant partial colony mortality in Culebra Island (Figure 3.8). There was also a massive collapse of lettuce corals (*Agaricia* spp.) and cactus corals (*Mycetophyllia* spp.) at most reefs along the east, south and west coasts. The severe coral tissue loss and prolonged bleaching stress are also believed to be responsible for reproductive collapse during the 2006 spawning cycle, since physiological starvation from bleaching probably precluded coral gamete production (Hernández-Delgado et al., unpub. data).

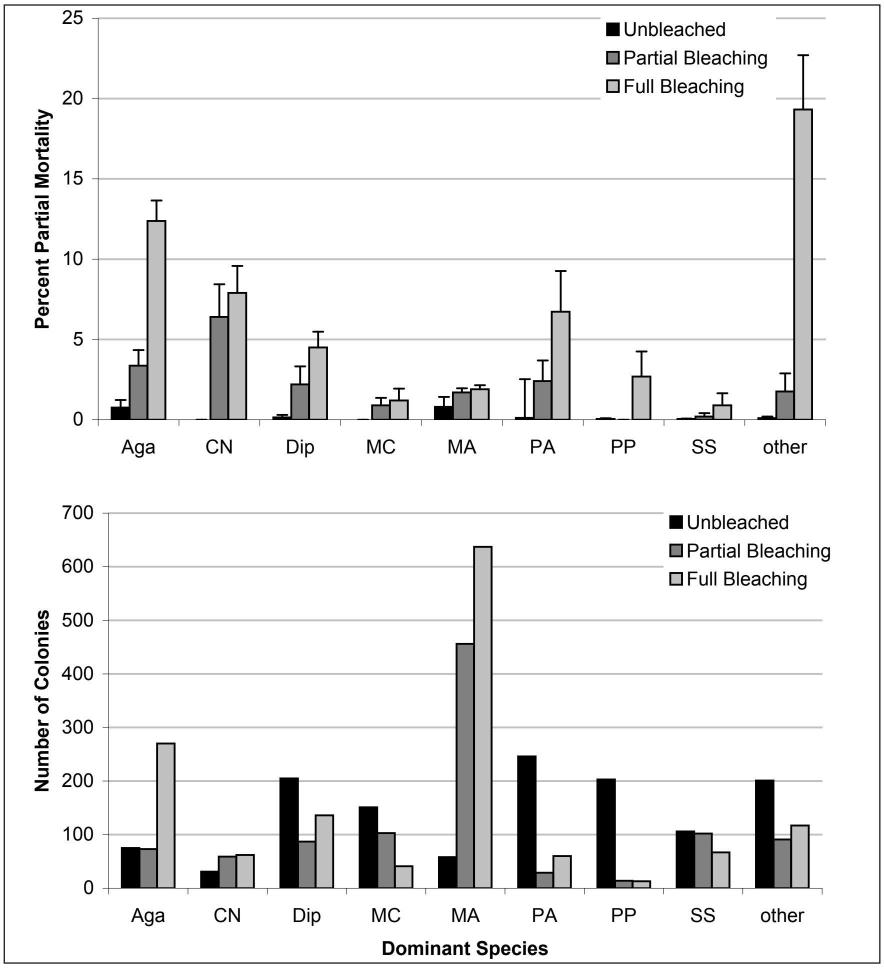

*Figure 3.5. Top panel shows relationship between bleaching severity and extent of recent partial mortality in December 2005 for dominant species observed in belt transects at all locations are pooled. Aga=*Agaricia *spp., CN=*Colpophyllia natans*, DIP=*Diploria *spp., MC=*Montastraea cavernosa*, MA=*M. annularis *(complex), PA=*Porites astreoides*, PP=*Porites porites*, SS=*Siderastrea siderea*, Other=16 other species of scleractinian and hydrozoan corals. Bottom panel shows number of unbleached, partially bleached and fully bleached colonies for dominant species observed in belt transects off southwest Puerto Rico (all sites and depths pooled). Source: Hernández-Delgado, unpub. data.*

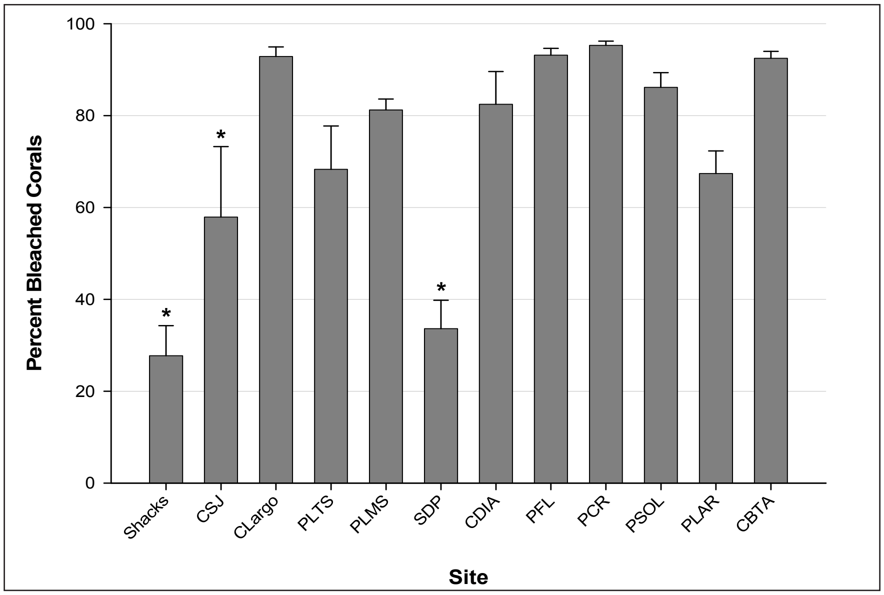

Figure 3.6. Percent frequency of coral bleaching across Puerto Rico during 2005. Bars represent one standard error. Asterisks (*) indicate locations exposed to strong water circulation. Source: Hernández-Delgado et al., 2006.

In La Parguera more than 40% of all coral colonies were bleached at eight of nine reefs surveyed; five of the reefs exhibited a bleaching prevalence higher than 50% and four had values higher than 70%. Higher prevalence of bleaching was found at intermediate distances to the coast and at intermediate depths. Among coral species from reefs in La Parguera, *Agaricia*, *Undaria*, *Montastraea*, *Colpophyllia*, *Acropora*, *Mycetophyllia*, *Millepora*, *Erythropodium* and *Briareum* were the most affected genera (Weil, unpub. data). Coral mortality was compounded by outbreaks of white plague type II (WP-II) and Caribbean yellow band disease (YBD) that primarily affected the *Montastraea* species complex right after the peak of the 2005 bleaching event. In Turrumote Reef, preliminary estimates indicate that colonies of *Montastraea* spp. lost an average of 50-60% of their live tissue at intermediate and deep habitats in the year after the bleaching-infectious disease (WPD) event began in 2005.

The sudden collapse of entire assemblages of several coral species at many reefs suggest the onset of a rapid Allee effect which could result in prolonged reproductive failure for reef-building species. Further, the continuous decline in percent cover of *Montastraea annularis* complex may have prolonged negative effects on their reproductive potential, sexual recruitment success and net reef accretion rates. Such unprecedented declines have already caused significant phase shifts in coral reef benthic community structure, presenting managers and decision makers with major challenges. These may include the need to develop aggressive and effective coral reef conservation-oriented management and research strategies aimed at dealing with unequivocal loss of resistance, resilience and ecological function.

The massive coral bleaching event throughout the Caribbean in 2005 has highlighted concerns regarding the sensitivity of coral reefs to climate change. Analysis of DHW, a parameter developed by NOAA's Coral Reef Watch for the estimation of the magnitude and duration of heat exposure for marine organisms, indicated sustained levels above or near the coral bleaching threshold during the period between August and November 2005. Satellite sensors documented the development of a coherent mesoscale structure with a SST water mass exceeding 30°C that traversed the northeastern Caribbean and impacted the southern coast of Puerto Rico. Sea surface height anomaly products by CCAR and Aviso both depict an anticyclone of approximately 14 cm that was spatially and temporally coincident with the zone of elevated SST.

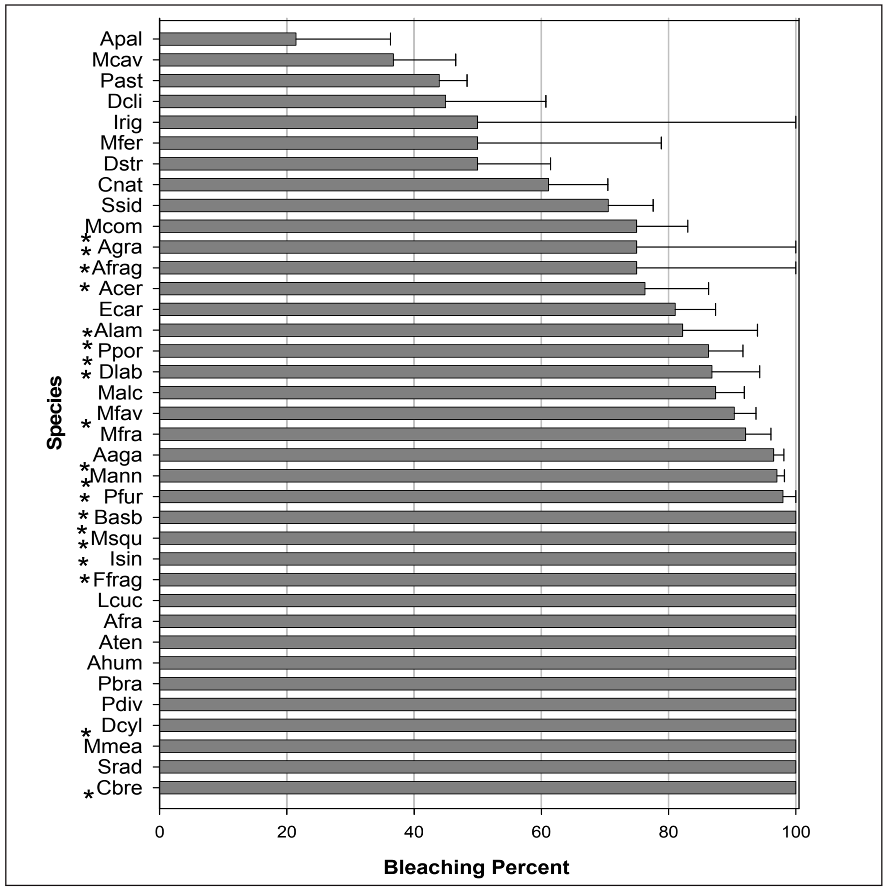

Figure 3.7. Percent frequency of bleaching in coral species at 12 locations in Puerto Rico during 2005. Asterisks indicate important reef-building species. Apal=Acropora palmata; *Mcav*=Montastraea cavernosa; *Past*=Porites astreoides; *Dcli*=Diploria clivosa; *Irig*=Isophyllastrea rigida; *Mfer*=Mycetophyllia ferox; *Dstr*=Diploria strigosa; *Cnat*=Colpophyllia natans; *Ssid*=Siderastrea siderea; *Mcom*=Millepora complanata; *Agra*=Agaricia grahamae; *Afrag*=Agaricia fragilis; *Acer*=Acropora cervicornis; *Ecar*=Erythropodium caribaeorum; *Alam*=Agaricia lamarcki; *Ppor*=Porites porites; *Dlab*=Diploria labyrinthiformis; *Malc*=Millepora alcicornis; *Mfav*=Montastraea faveolata; *Mfra*=Montastraea franksi; *Aaga*=Agaricia agaricites; *Mann*=Montastraea annularis; *Pfur*=Porites furcata; *Basb*=Briareum asbestinum; *Msqu*=Millepora squarrosa; *Isin*=Isophyllia sinuosa; *Ffrag*=Favia fragum; *Lcuc*=Leptoseris cucullata; *Afra*=Agaricia fragilis; *Aten*=Agaricia tenuifolia; *Ahum*=Agaricia humilis; *Pbra*=Porites branneri; *Pdiv*=Porites divaricata; *Dcyl*=Dendrogyra cylindrus; *Mmea*=Meandrina meandrites; *Srad*=Siderastrea radians; *Cbre*=Colpophyllia breviserialis. *Source: Hernández-Delgado et al., unpub data.*

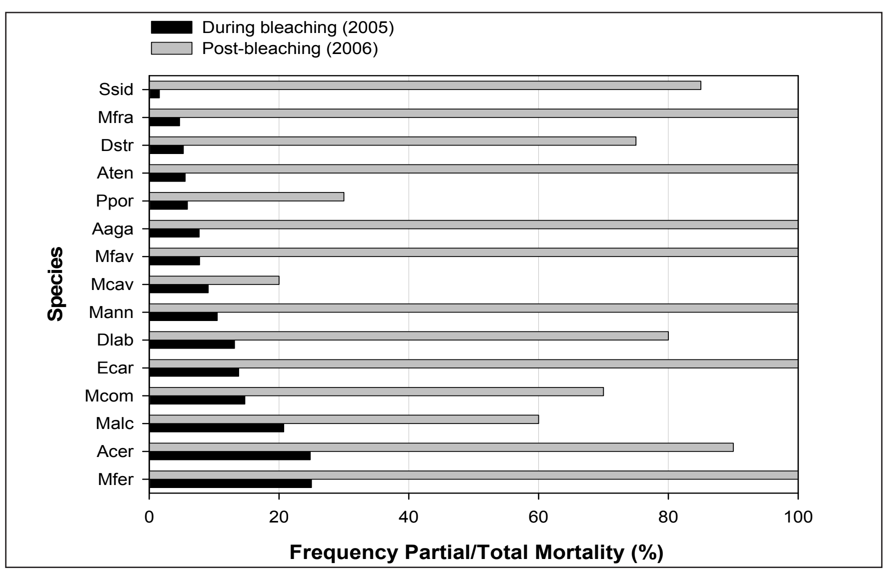

Figure 3.8. Percent frequency of partial and/or total tissue mortality in selected coral species from Culebra Island during and six months after bleaching. Species codes provided in Figure 3.7 caption. Source: Hernández-Delgado et al., unpub. data.

Anticyclonic eddies are recurrent features in the western tropical Atlantic and Caribbean basin. Four to five occur each year in the Caribbean with temporal scales of close to one month. Due to their clockwise circulation and Coriolis forcing, surface waters accumulate at the eddy center causing an increase in the mixed layer depth, which limits heat dissipation and exchange with surrounding water masses and results in a significant enhancement of the Ocean Heat Content. It is possible that the anticyclonic eddy is responsible for the observed DHW during the 2005 event. Anticyclonic eddies have recently been implicated in the acute intensity of Hurricane Katrina in the Gulf of Mexico and Hurricane Georges in the Caribbean.

Diseases

Over the past several decades, coral reef communities around the world have experienced increasingly stressful conditions from a combination of natural and anthropogenic factors. These factors can act alone or in synergy, and may vary at different spatial and temporal scales (Figure 3.9). Bleaching and coral reef infectious diseases are two "natural" factors that have become major players in the deterioration of coral reef health (Hughes, 1994; Smith et al., 1996; Hoegh-Guldberg, 1999; Glynn et al., 2001; Miller et al., 2001; Weil et al., 2002; Richardson and Aronson, 2002; McClanahan, 2004; Weil, 2004; Ward et al., 2006). Coral reef disease research in Puerto Rico started a decade ago and has produced important information about the number, distribution, prevalence and impact of diseases/syndromes in several reef localities (Bruckner and Bruckner, 1997, 2006; Weil et al., 2002, 2003; Weil, 2004; Ballantine et al., 2005). The best studied areas include La Parguera and Guánica on the southwest coast, where well developed and extensive reefs are found, the Fajardo and Culebra area on the east coast, and reefs in the islands of Mona and Desecheo off the west coast.

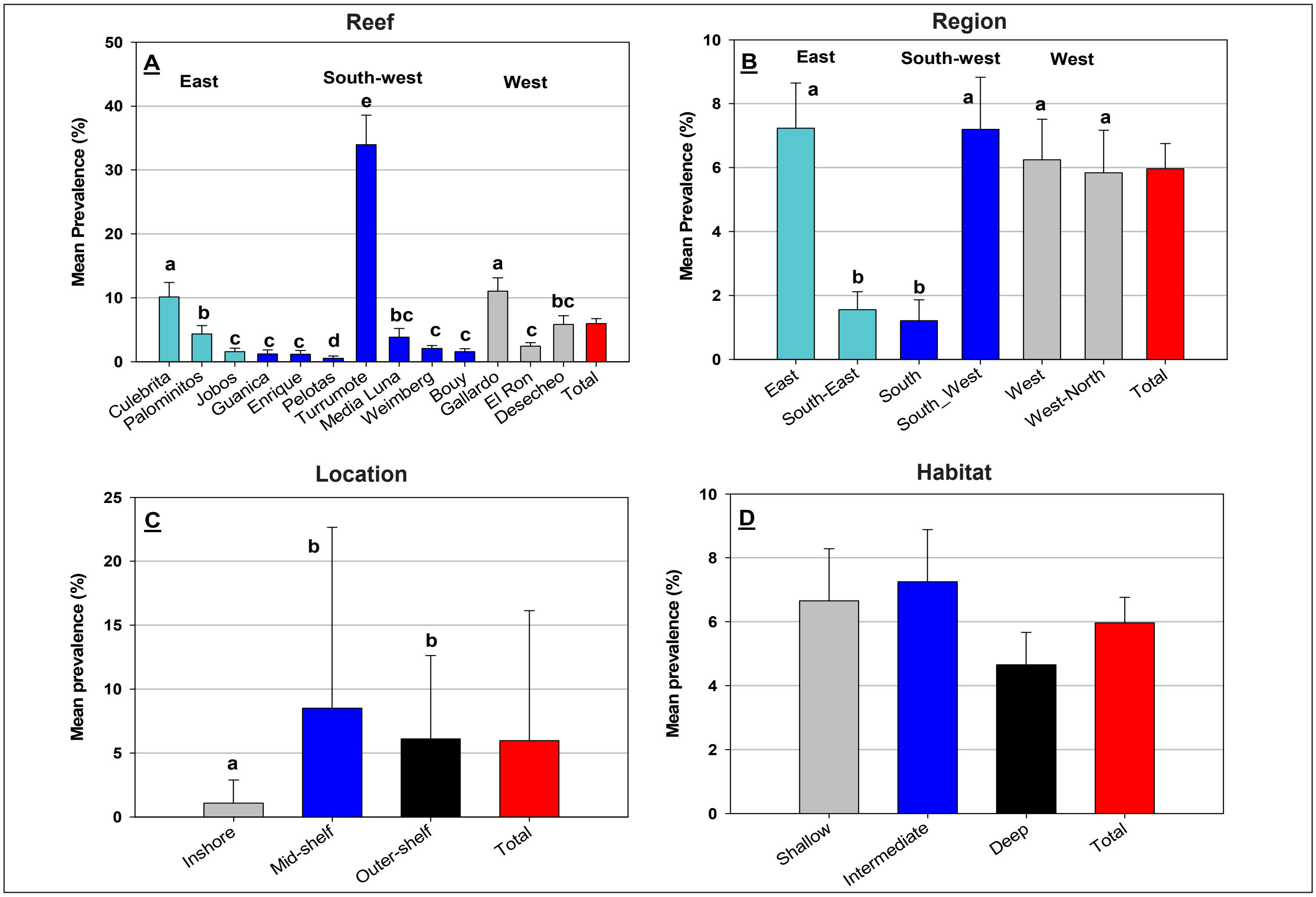

Figure 3.9. Variability at different spatial scales of coral infectious disease prevalence (% ±SE) at the community level in 2006. (A) across reefs, (B) across geographic regions, (C) across location from near-shore to off-shore reefs and (D) habitats. The different letters above bars indicate significant differences (Kruskall-Wallis, p<0.05). Note different scales in the among graphs. Source: Weil et al., unpub. data.

Most diseases or syndromes reported for the Caribbean are present in Puerto Rico, and frequent epizootics of WP-II, YBD, white band (WBD), white pox (patchy necrosis; WPX), bleaching and aspergillosis (ASP) continue to result in significant losses of coral cover (i.e., biomass and photosynthetically active surface area) in most reefs around the island (Figure 3.10). These epizootic events usually occur during the summer and fall and disappear during the winter when temperatures drop. Qualitative surveys of more than 100 coastal and offshore localities around the island during the last 25 years indicate a significant decline in populations of *Acropora* spp. in most localities, with minor ephemeral recovery at a few sites (Weil et al., 2003). A similar decline is now occurring within the *Montastraea* species complex, due largely to the effects of WP-II, YBD and bleaching in the last five years (Weil, unpub. data).

An island-wide survey was recently carried out to determine the status of diseases in coral reef communities. A total of 16 reefs were surveyed during summer of 2006. Using standard sampling protocols to assess the number, distribution and prevalence of diseases in corals, octocorals, sponges and crustose coralline algae (Weil et al., 2002). Overall, 16 different infectious diseases and syndromes were identified in Puerto Rican coral reef communities. Of these, 11 are affecting scleractinian corals, three are affecting octocorals, two are affecting zoanthids, at least two are affecting sponges and one is affecting crustose coralline algae. Bleaching, a non-infectious disease, has affected an increasing number of taxa in different biological groups in recent years (Figure 3.11). The most common diseases in Puerto Rico include some of the most infectious and damaging that have been described for the wider Caribbean (WP-II, YBD, WBD, Black Band Disease or BBD, ASP, Coralline white band or CCAWB and bleaching), but their distribution and prevalence is highly variable on spatial and temporal scales.

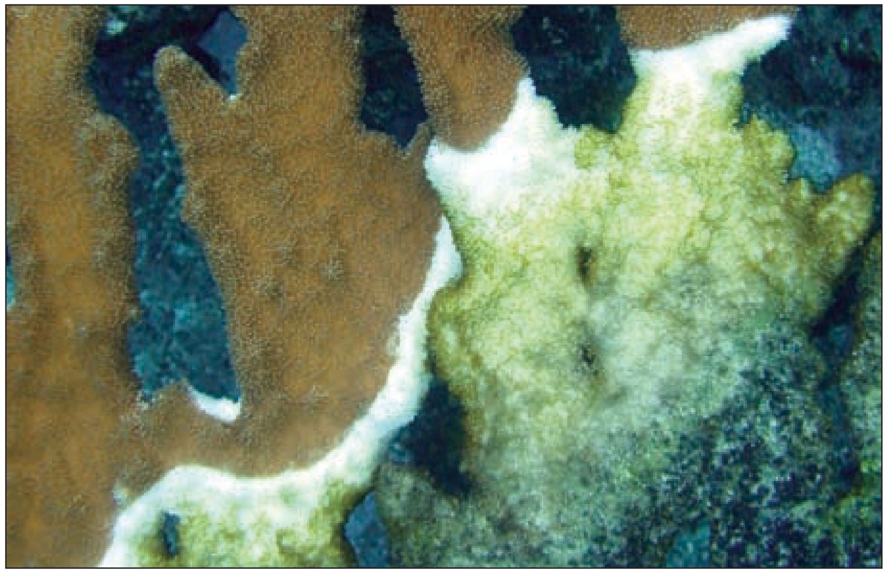

Figure 3.10. Acropora palmata *with the distinctive white band for which WBD is named. Photo: A. Bruckner.*

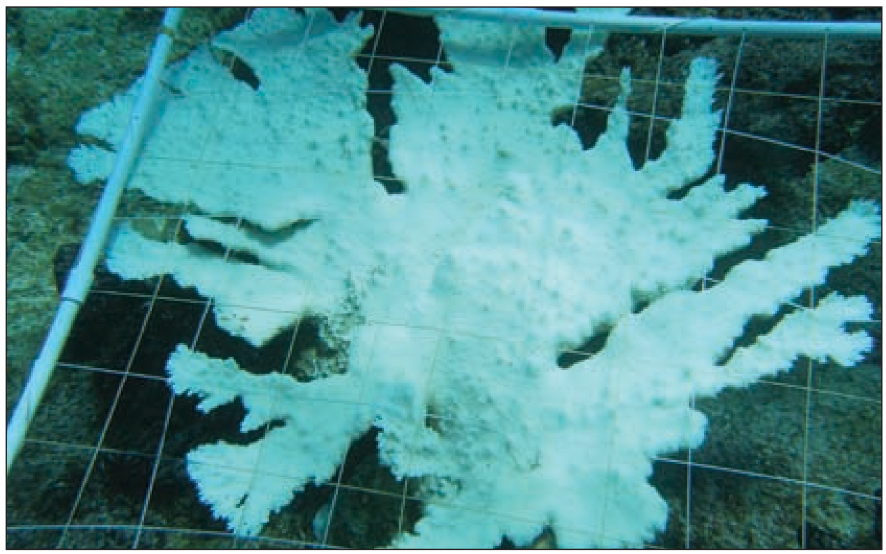

Figure 3.11. Bleaching, such as in this colony of Acropora palmata*, can increase the susceptibility of corals to disease. Photo: CCMA-BB.*

White Plague (WP) was first reported from La Parguera in 1995, and has since been observed throughout Puerto Rico and offshore islands, where it affects over 40 species of coral (Bruckner and Bruckner, 1997; Weil, 2004). This particular disease is considered one of the most damaging to coral populations because of its frequent outbreaks, wide range of hosts, and high virulence; WP can kill live coral tissue at rates that may exceed 1-2 cm per day (Weil, 2002; Weil et al., 2002; Weil, 2004). Since 1999, WP has been reported with increasing frequency from a growing number of shallow and deep reefs off La Parguera, Mona, Desecheo and Culebra. Most recently, in November and December 2005, extensive outbreaks of white plague affecting the genera *Montastraea*, *Diploria*, *Colpophyllia*, *Agaricia* and *Mycetophyllia* were observed.

WBD, the leading cause of mortality for Caribbean *Acropora* spp., was first reported in the early 1980s by Goenaga, who found that 20-33% of the *A. palmata* colonies at one reef near La Parguera were affected (Davis et al., 1986). Isolated cases of WBD were observed between 1995 and 2003, including an outbreak that affected 15% of the standing colonies on a reef off the east coast of Mona Island (Bruckner and Bruckner, 2006). 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). Recently, the more virulent form of WBD has been reported among inshore *A. cervicornis* nurseries and in reef environments around Culebra (E. Hernandez-Delgado, pers. comm.).

Another important source of mortality to *A. palmata* is WPX, also termed patchy necrosis and white patch disease. WPX is a widespread condition observed throughout southwest Puerto Rico since the mid 1990s (Bruckner, 2003; Weil, 2004). A large stand of *A. palmata* off Mona Island (Sardinera Reef) was first observed with WPX in 1996. Within two large permanent plots, 5-27% of the live colonies have been observed with this disease each summer through 2006. Affected colonies had multiple, irregular-shaped lesions 2-10 cm in diameter. Lesions were rapidly colonized by algae and cyanobacteria, expanding in size over a period of several years until the colony died completely. WPX was first observed at Carmelita, at the north end of the reef tract, in 2001. Initially, WPX showed a prevalence of 12%, which increased to 27% by May 2003 and to 40% by August 2005. Although WPX was rare (<0.1%) at both sites in February and December 2005, older lesions failed to heal at Sardinera and populations continued to decline, while affected colonies at Carmelita displayed rapid recovery, with new tissue and skeleton forming over old lesions. WPX has not been observed off the east coast of Mona.

Other diseases that have increased in abundance since 1999 on reefs near La Parguera, Desecheo and Mona Islands include YBD among *M. faveolata* and *M. annularis* and a “dark spots” disease on *S. siderea* and other species (Bruckner, unpub. 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 had been the greatest threat affecting the survival of *Montastraea* spp. populations until the massive coral bleaching event of 2005 that was associated with elevated SST.

Although incidences of black band disease (BBD) are rare, localized outbreaks have been recorded. BBD was first reported from Puerto Rico in 1972 (Antonius, 1973) and quantitative data was first collected in 1994 (Bruckner, 1999). Between 2002 and 2006, outbreaks were observed at shelf edge sites off La Parguera and off Mona Island among shallow habitats dominated by *Diploria* spp. BBD continues to affect massive and plating corals throughout the region, to depths of 30 m. Infections have been sporadic and uncommon (<0.5%), with a slight increase following the 2005 bleaching event and seasonal increases during summer and fall months.

Tropical Storms

Hurricanes are natural, catastrophic events that have caused massive mortalities to coral reef and other coastal marine communities in Puerto Rico. 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 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 for several days after the passage of hurricanes. Since the passage of Hurricane Georges in 1998, there have been no other major storms affecting coral reef ecosystems in Puerto Rico (Figure 3.12).

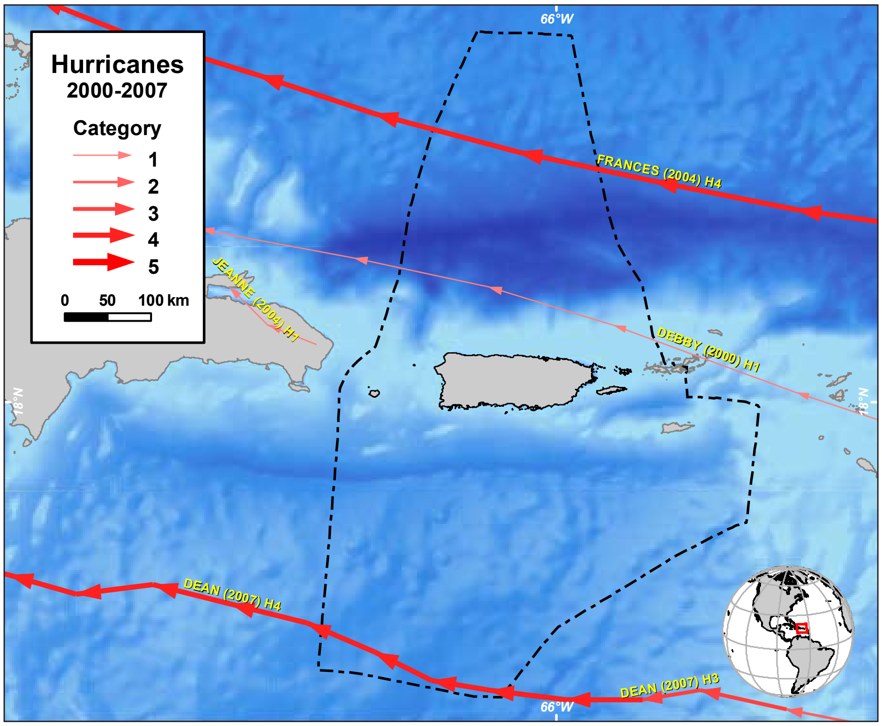

Figure 3.12. The path and intensity of hurricanes passing near Puerto Rico between 2000-2007. Year of storm, hurricane name and storm strength on the Simpson scale (H1-5) are indicated for each. Map: K. Buja. Source: http://maps.csc.noaa.gov/hurricanes/.

Coastal Development and Runoff

In addition to permits issued for point and nonpoint source discharge by industries and wastewater treatment plants (discussed in the following section), the U.S. Environmental Protection Agency (EPA) issues Nonpoint Source Discharge Elimination System (NPDES) permits for construction activities on sites with more than 0.2 ha (0.5 acre). To date, problems with these permits have been the lack of knowledge on the part of developers regarding permit requirements, the lack of EPA personnel to inspect construction sites and ensure compliance, and the lack of implementation of adequate stormwater and erosion controls. Like the permits previously discussed, these require monitoring to ensure compliance with water quality standards. However, even when sites comply with NPDES permit requirements, stormwater and erosion control measures are often inadequate to ensure protection of downstream fishery habitat, including coral reefs.

In terms of impacts of coastal construction on the coral reef ecosystem in Puerto Rico, from October 2004 to September 2007, 336 water resources development projects were reviewed by the NOAA Fisheries Caribbean Field Office. Of these, an average of approximately 69 percent of the projects involved potential adverse interactions with fishery habitat (Carrubba, unpub. data). The construction of docks and piers, housing developments, and navigation projects, including marinas and maintenance dredging, were the most common type of projects proposed. Direct impacts that could result from the permitting of these projects included the elimination of seagrass beds, corals or coastal wetland, in particular mangrove forest for the construction of docks, piers and navigation projects. These projects also lead to indirect impacts such as increases in accidental groundings, propeller wash and propeller scarring associated with increased boating. Housing development projects typically involved proposed alterations to wetlands and channels, including the conversion of natural streams to concrete culverts and the filling of wetlands. Mitigation for many of the permitted projects, in particular those related to wetland impacts, is rarely successful as evidenced by site inspections of mitigations around Puerto Rico (Carrubba, pers. obs.; Roman, pers. comm.). Seagrass mitigation is also unsuccessful if the transplant location is not carefully selected and proper site preparation is not completed. Thus, water resources development projects around Puerto Rico have resulted in losses of wetlands and alteration of seagrass habitat, as well as alterations in hydrology. Hydrologic alterations affecting patterns of flow and nutrient and sediment transport, as well as the loss of coastal wetlands and seagrass beds that form natural filters minimizing the transport of materials to coral reefs, likely play an important role in the declining health of Puerto Rico's coral reef ecosystem. Recent efforts are now underway to try and link these causes and effects in order to better understand the role of land based activities and develop more effective management strategies to conserve marine resources.

Coastal Pollution

Most industrial discharges around Puerto Rico include those associated with Regional Wastewater Treatment Plants (RWWTP) administered by the Puerto Rico Aqueducts and Sewers Authority (PRASA), thermoelectric power plants administered by the Puerto Rico Electric Power Authority, and private industry. These discharges are regulated by the EPA as part of their obligations under the Clean Water Act (CWA). The Puerto Rico Environmental Quality Board with oversight from EPA establishes the water quality standards with which these discharges need to comply. Monitoring requirements are a part of the permits issued for industrial discharges in order to ensure continued compliance with Puerto Rico's water quality standards.

For instance, EPA-mandated monitoring of zooplankton entrainment by the privately owned EcoEléctrica power plant is ongoing in Guayanilla Bay. Some of the major findings from this entrainment monitoring study are that (a) the mean daily flow rate of entrained seawater by EcoEléctrica during 2005 (28,921 m^3/day) represented approximately 0.0006 (or 0.06 %) of the Guayanilla Bay volume and 0.006 (or 0.6 %) of the "average" daily tidal flow exchange; (b) the mean daily entrainment of total zooplankton by the power plant represents about 0.3% of the "average" daily tidal exchange; and (c) the equivalent adult fish mortality (0.46 million individuals) represents 0.92% of the equivalent adult fish survival estimate for Guayanilla Bay. Based on these results, it is unlikely that entrainment will have a measurable ecological effect on zooplankton and the fish community in the bay at the present seawater entrainment flow rates (Vicente, unpub. data). Similar EPA mandated CWA 316 (a-b) studies are being performed for the thermoelectric power plants of Costa Sur, Guayanilla; Aguirre, Guayama; San Juan; and Palo Seco and Toa Baja, all of which are operated by PRASA. It should be noted that these monitoring programs are established based on permit requirements that address water quality standards, which are established to protect human health. Water quality standards are not necessarily appropriate for the continued maintenance of healthy coral reefs.

Due to continued concerns related to the discharge of thermal effluents that do not comply with water quality standards, in particular for PRASA plants in Aguirre and Guayanilla, EPA and PRASA are working toward an analysis of alternatives. EPA has declined to issue CWA waivers that would allow PRASA to continue violating water quality standards related to temperature. In Guayanilla, where the alternatives analysis process has been ongoing for a couple of years now, PRASA is considering the construction of a submarine outfall, as well as upgrades to the plant to reduce the temperature of the treatment water discharge. The discharge frequently exceeds the Puerto Rico water quality standard of 32.2°C (90°F), often reaching 43.3°C (110°F) in the summer months when energy demand is greatest. Ongoing modifications to the plant would lower the discharge temperature to 35.6°C (96°F). The Guayanilla discharge currently enters a thermal cove of altered mangrove wetlands, before passing into the waters of Guayanilla Bay. Even if the discharge is modified to meet current water quality standards, the standard is higher than the temperature for optimal coral growth and the maintenance of good coral condition.

RWWTPs operated by PRASA discharge primary treated effluents to the ocean via submarine outfalls. Four of these outfalls are located on the north coast (Carolina, Bayamon/Puerto Nuevo, Arecibo and Aguadilla), one is on the south coast (Ponce), and one is on the west coast (Mayagüez). The submarine outfalls of the north coast discharge within the insular shelf platform near the shelf-edge at depths that vary between 15 and 42 m. The Ponce outfall discharges at a depth of approximately 150 m on the insular slope and below the picnocline. Only the submarine outfall in the Ponce area is located in the vicinity of a shelf-edge reef; the other outfalls are in largely uncolonized benthic habitats. This discharge was relocated in an effort to improve nearshore water quality. Recently, problems with the discharge pipeline in Ponce led to renewed discharge of primary treated sewage in nearshore waters. In addition to the RWWTP, most of the smaller plants operated by PRASA in the coastal zone of Puerto Rico discharge primary or secondary treated effluent to streams, rivers or directly to the sea along the coast. Inland treatment plants also use streams and rivers as their discharge points. Over the past several years, there have been efforts to begin upgrading the smaller plants to advanced secondary treatment and connecting coastal communities to the sewer system rather than allowing the proliferation of septic systems in low-lying areas. Studies of intestinal bacteria in marine waters near small treatment plants indicate that bacterial contamination is common at low levels (Otero, unpub. data.)

NOAA Center for Coastal Monitoring and Assessment Contaminants Study in La Parguera

Pollution has been identified as one of the major threats to coral reef ecosystems (Burke and Maidens, 2004; FDEP, 2004; Waddell et al., 2005), but the concentration of pollutants in and around coral reefs is not well characterized, and even less is known regarding linkages between individual pollutants and overall coral condition. Two projects are being conducted in Puerto Rico as part of an assessment framework developed by NOAA's CCMA, to quantify the relationship between chemical contaminants and coral condition. The first is in southwest Puerto Rico near the town of La Parguera; the second project is on the island of Vieques. The study areas were chosen based on established partnerships, data availability, and the need to characterize chemical contaminants and/or coral resources. Partners in the projects include NOAA, the University of Puerto Rico (UPR), Puerto Rico DNER, U.S. Fish and Wildlife Service (FWS), and the University of Hawaii.

Methods

In both projects, a stratified random sampling design was used for site selection in order to better characterize the distribution and concentrations of chemical contaminants in the study areas. In southwest Puerto Rico, 43 sites were sampled in August 2005 (Figure 3.13). In Vieques, approximately 45 sites were sampled in May 2007 around the entire island. Sediments were collected using either a sediment grab or by hand using divers. Coral tissues (*Porites astreoides*) were also collected. CCMA's National Status and Trends (NS&T) Program protocols were employed for sample collection and analysis, and in both studies over 150 organic (e.g., PAHs and PCBs) and inorganic (major and trace elements) contaminants were analyzed, some of which are listed in Table 3.1. The NS&T Program monitors chemical contamination in coastal waters of the U.S. and is a well documented, quality assured "industry standard" that has been in place since 1984. Additional information on sampling protocols can be found in Lauenstein and Cantillo (1993). On the island of Vieques, portions of which were used in the past for the storage and firing of munitions by the military, sediment samples were also collected and are being analyzed for another 15 compounds, termed "energetics". Results of the analysis of samples from Vieques will be available in early 2009. Results from the study in southwest Puerto Rico are discussed below.

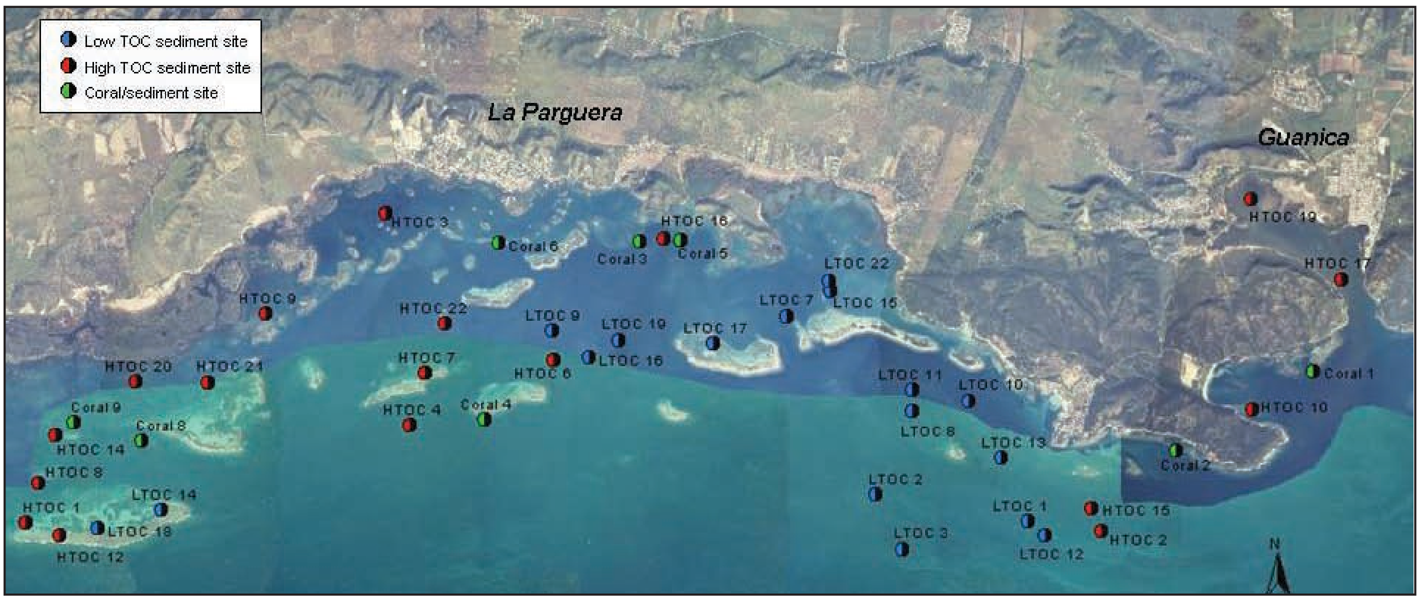

Figure 3.13. La Pargurea contaminants study area sampling sites in southwest Puerto Rico. Source: Pait et al., 2007.

Results and Discussion

Analysis of samples from southwest Puerto Rico indicated that, in general, the levels of both organic and inorganic chemical contaminants in the sediments and coral tissues were fairly low. At most sites around La Parguera, sediment contaminant concentrations were less than the national NS&T median values. A number of the contaminant classes indicated higher concentrations in embayments and behind emergent reefs, while concentrations at offshore sites tended to be lower. An example of the results from the analysis of sediments for polycyclic aromatic hydrocarbons (PAHs) is shown in Figure 3.14. PAHs are associated with the use and combustion of fossil fuels (e.g., oil and gasoline) and other organic materials (e.g., wood). Total PAHs as shown represents the sum of 24 of the PAHs analyzed by the NS&T Program. Elevated levels of PAHs were found adjacent to the town of La Parguera and at two sites sampled in Guanica Bay.

Results from the analysis of sediments for chromium are shown in Figure 3.15. A similar pattern was observed for this trace element, that is higher contaminant levels adjacent to the town of La Parguera and in Guanica Bay. At the two sites sampled in Guanica Bay (HTOC 17 and 19), chromium levels were over an order of magnitude higher than any of the other sites sampled, which may be related to some of the industrial activities that have occurred there over the years. The Effects Range-Median (ERM) is the concentration above which toxicity in test organisms is more frequently (50th percentile) observed. In Figure 3.15, the ERM value for chromium was exceeded at both sites in Guanica Bay indicating that toxicological effects on the aquatic biota in these areas are more likely. Additional details on the results of the sediment contaminant analyses can be found in Pait et al. (2007).

Table 3.1. Selected chemical contaminants analyzed in southwest Puerto Rico and Vieques. Source: NOAA CCMA.

PAHS	PESTICIDES	PCBS	MAJOR AND TRACE ELEMENTS
Naphthalene	Aldrin	PCB18	Aluminum (Al)
1-Methylnaphthalene	Dieldrin	PCB28	Antimony (Sb)
2-Methylnaphthalene	Endrin	PCB31	Arsenic (As)
2,6-Dimethylnaphthalene	Heptachlor	PCB44	Cadmium (Cd)
1,6,7-Trimethylnaphthalene	Heptachlor-Epoxide	PCB49	Chromium (Cr)
Biphenyl	Oxychlordane	PCB52	Copper (Cu)
Acenaphthylene	Alpha-Chlordane	PCB56/60	Iron (Fe)
Acenaphthene	Gamma-Chlordane	PCB66	Lead (Pb)
Fluorene	Trans-Nonachlor	PCB70	Manganese (Mn)
Anthracene	Cis-Nonachlor	PCB74/61	Mercury (Hg)
Phenanthrene	Alpha-HCH	PCB87/115	Nickel (Ni)
1-Methylphenanthrene	Beta-HCH	PCB95	Selenium (Se)
Fluoranthene	Delta-HCH	PCB99	Silicon (Si)
Pyrene	Gamma-HCH	PCB101/90	Silver (Ag)
Benz[a]anthracene	2,4'-DDD	PCB110/77	Tin (Sn)
Chrysene	4,4'-DDD	PCB118	Zinc (Zn)
Benzo[b]fluoranthene	2,4'-DDE	PCB138/160	--
Benzo[k]fluoranthene	4,4'-DDE	PCB146	--
Benzo[e]pyrene	2,4'-DDT	PCB149/123	--
Benzo[a]pyrene	4,4'-DDT	PCB151	--
Perylene	1,2,3,4-Tetrachlorobenzene	PCB153/132	--
Indeno[1,2,3-c,d]pyrene	1,2,4,5-Tetrachlorobenzene	PCB156/171/202	--
Dibenzo[a,h]anthracene	Hexachlorobenzene	PCB158	--
Benzo[g,h,i]perylene	Pentachloroanisole	PCB170/190	--
	Pentachlorobenzene	PCB174	--
BUTYLTINS	Endosulfan II	PCB180	--
Monobutyltin	Endosulfan I	PCB183	--
Dibutyltin	Endosulfan Sulfate	PCB187	--
Tributyltin	Mirex	PCB194	--
Tetrabutyltin	Chlorpyrifos	PCB195/208	--
		PCB209	--

Abbreviations: PAH, polycyclic aromatic hydrocarbon; PCB, polychlorinated biphenyl; HCH, hexachlorocyclohexane.

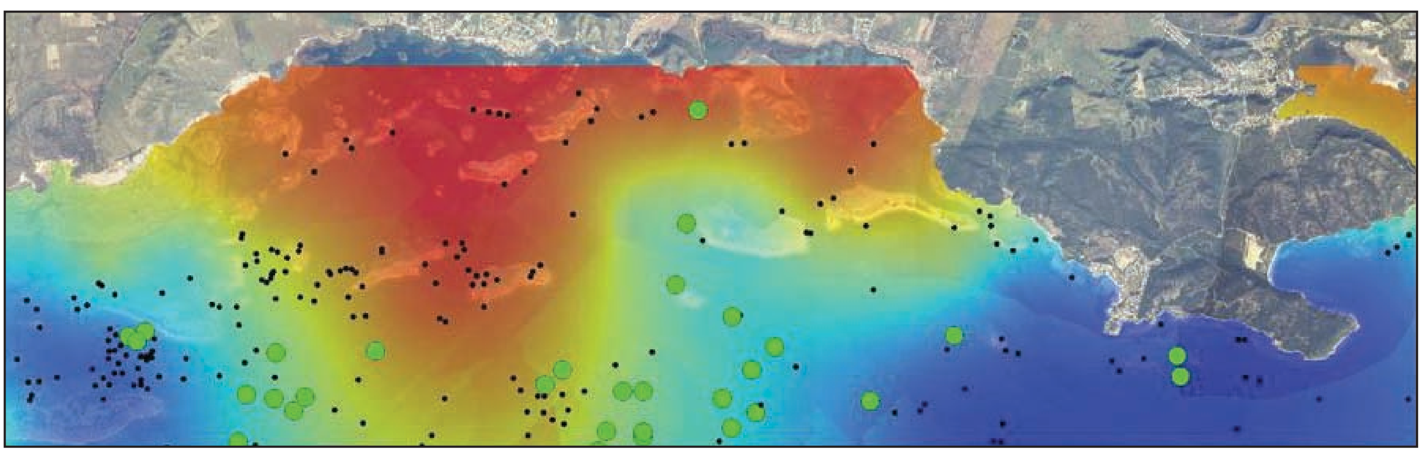

Figure 3.14. Kriging of total PAHs and coral species richness. Interpolated surface showing high (red) to low (blue) concentrations of PAHs in the nearshore environment (p=0.0425). Black dots indicate survey points for NOAA's CCMA-BB. Green dots indicate locations where coral species richness was in the top 25th percentile. Source: NOAA CCMA.

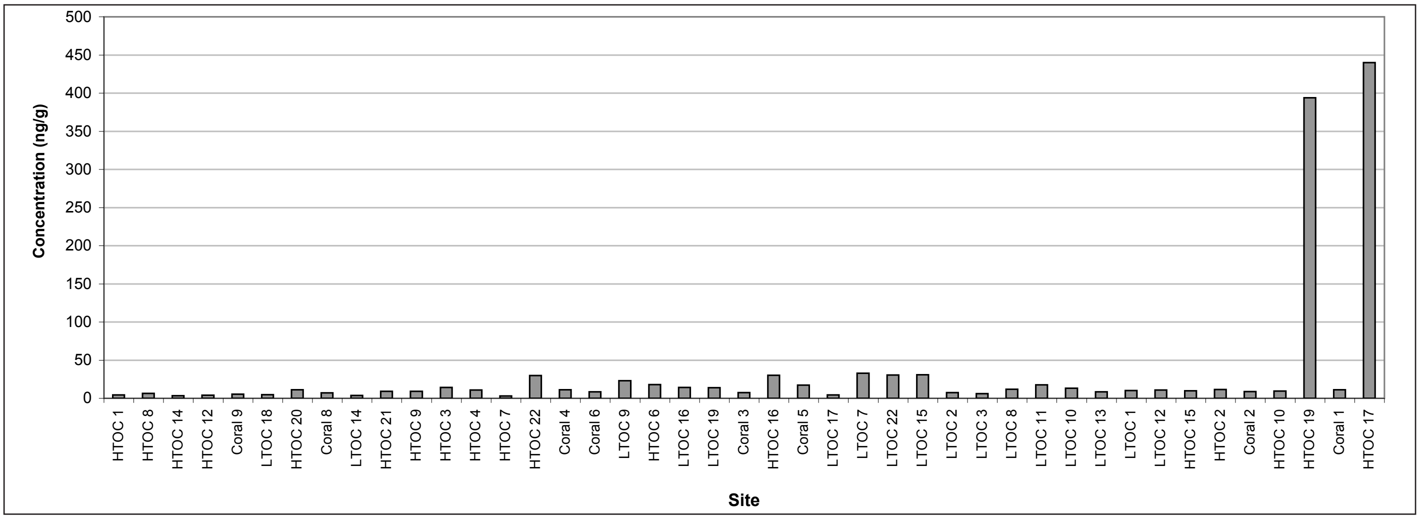

Figure 3.15. Chromium levels, like many contaminants, displayed a pattern of higher concentrations nearshore, particularly in Guanica Bay, and lower concentrations offshore. Source: Pait et al., 2007.

One of the major goals of the assessment framework is to establish linkages between chemical contaminants and coral ecosystem condition. To begin to address this goal, an exercise was conducted to look for correlations between PAH sediment concentrations and coral species richness in southwest Puerto Rico. A geospatial model was first constructed for the spatially autocorrelated PAH data. Existing mapped data on coral species richness from NCCOS' CCMA-BB was then overlaid on the modeled PAH concentrations. A nonparametric analysis of the modeled PAH data and coral species richness for the major reef building species indicated a strong negative correlation between modeled PAH concentrations and coral species richness, i.e., higher total PAH concentrations in the sediments were associated with lower coral species richness. The cause for the negative correlation between sediment PAHs and coral species richness is currently unknown. A variety of other physical, chemical and biological factors could be responsible for the observed pattern, in addition to the presence of contaminants. Efforts are currently underway to quantify contaminants and coral pathogens in the coral tissues from southwest Puerto Rico, which should provide more insight into the observed patterns of species richness. Future projects in southwest Puerto Rico, in Vieques, and in other parts of the Caribbean using the assessment framework will help scientists better understand how contaminants impact corals and coral reefs. By bringing the various data types and scientific expertise together in the assessment framework, an essential analytical capability is created that can be used to better assess the effects of chemical contaminants on corals and coral reefs, ultimately resulting in better management of these valuable and fragile ecosystems.

Tourism and Recreation

DNER is currently in the process of completing a socioeconomic valuation of the coral reef ecosystem for the east coast of Puerto Rico in order to determine the value people place on these systems and efforts of scientists and educators to study and educate regarding these systems. The results of the study will be used to guide management and education and outreach efforts geared toward this part of the island, including Culebra and Vieques.

The effect of tourism activities upon coral reef systems in Puerto Rico is not well known. Tourism-related development continues to increase, especially in areas outside the metropolitan area of San Juan, as indicated in Figure 3.16. Due to constantly increasing numbers of personal watercraft, as well as the influx of boaters from other islands and the U.S., many of this development includes the construction of marinas or docks. A recent study by NOAA Fisheries and the U.S. Army Corps of Engineers in Fulladosa Bay, Culebra, at the Ponce Yacht and Fishing Club, Ponce and various areas in Florida, found that 63 percent of the docks in Fulladosa Bay were not authorized and their construction and use had resulted in the loss of at least 5 percent of the seagrass beds in the bay (Shafer et al., unpub. data). The dock in Ponce, although built with a type of grated decking, had resulted in the loss of a section of dense turtle grass due to shading from the dock, in addition to the loss of seagrass habitat due to dredging to accommodate larger vessels (Shafer et al., unpub. data). The increase in recreational vessels also

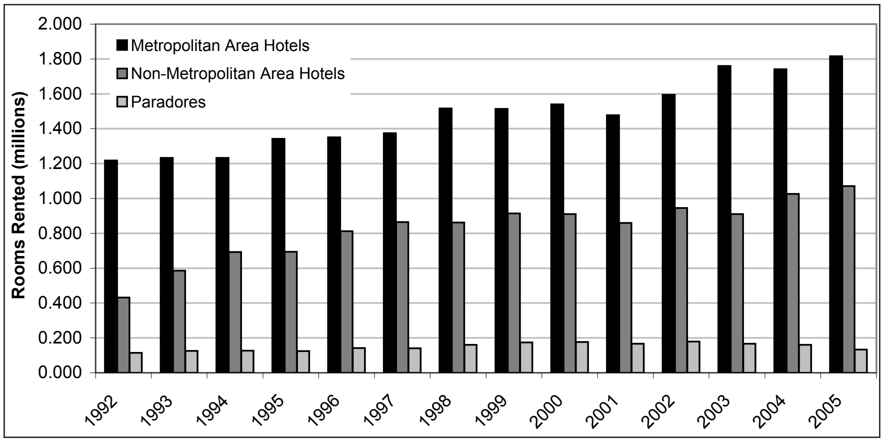

Figure 3.16. Room occupancy for hotels and paradores between fiscal years 1992-2005. Source: Puerto Rico Tourism Co., 2005.

leads to an increase in mechanical damage in seagrass beds. Carrubba et al. (2003) documented major propeller scar impacts in various locations in La Parguera Reserve, including shallows near Magueyes Island, and back reefs of Cayo Caracoles and Cayo Collado where 43-74% of the area potentially affected by boat traffic showed damage due to propeller scarring. In La Cordillera Reefs Natural Reserve, Otero and Carrubba (2007) found that impacts were concentrated in a few cays where boaters converge in order to access beaches. Based on estimates of probable and potential impact areas, at least 7, 14 and 21% of the seagrass habitats examined have been impacted in Palominito, Palomino and Icacos, respectively (Otero and Carrubba, 2007). In addition, the type of mechanical damage to seagrass beds from boats in Cordillera differed greatly than that observed in Parguera. Damages in Cordillera were almost exclusively due to anchoring in seagrass beds. Because boaters in Cordillera often have larger vessels than many of those in La Parguera and moor their vessels using a bow and a stern anchor, anchor damage is extensive in Cordillera in a few concentrated sites where recreational boaters congregate. Also, because boaters in Cordillera anchor with the stern of their vessel toward the shore in shallow waters, evidence indicated that some of the sandy bottom areas adjacent to popular beaches are barren of vegetation due in part to propeller wash.

In Puerto Rico, Law 430 of 2000, the Navigation and Aquatic Safety Law, and its associated Regulation 6979 of 2005, establish measures to protect the marine flora and fauna from recreational and other human activities. For instance, Article 24 of Regulation 6979 prohibits the mooring of any vessel in mangroves, coral reefs, or seagrass beds. The fine for violating this regulation is $250 and can be issued in the form of a ticket by any enforcement official (Article 35). The regulation also contains requirements related to the reporting of groundings. DNER is working to become more active in the documenting of recreational vessel groundings in order to characterize the cumulative impacts of these accidents on the coral reef ecosystem (Lilyestrom, pers obs.). However, a lack of enforcement and a serious lack of understanding on the part of the public, as well as regulatory and enforcement agencies regarding the importance of the coral reef ecosystem and reporting requirements has resulted in increases in accidental groundings of recreational vessels. NOAA ResponseLink data indicate that, from November 2007 to February 2008, 7 incidents caused by recreational vessels involving boat groundings with associated oil or gasoline spills were reported to the National Response Center. The incidents occurred in Joyuda, Mayagüez, Fajardo, Culebra, and San Juan. These incidents were apparently too small to result in activating a response under the Oil Pollution Control Act. The cumulative impacts to the reef environment of small spills and recreational vessel groundings is currently understudied and therefore unknown in Puerto Rico.

According to the Puerto Rico Tourism Company (PRT, 2005), between 2002 and 2005 the occupancy rate in hotels and “paradores” fluctuated between 2.72 and 3.02 million rooms. The total room occupancy has maintained a gradually increasing rate from 1992 to 2005 (Figure 3.16). Approximately 60.1% 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. 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.

Fishing

In the coastal waters of Puerto Rico, authority for fisheries management from the shoreline to nine 16.7 km is with the Commonwealth of Puerto Rico, while the CFMC is responsible for fisheries management in federal waters extending from 16.7 km to 370.4 km (the Federal Exclusive Economic Zone or EEZ). The fish, of course, do not recognize these boundaries, and most stocks are managed jointly. Efforts to achieve consistency in fisheries management have resulted in regulations such as a total prohibitions on the harvest of Nassau and goliath groupers, seasonal closures to protect spawning aggregation sites for groupers and snappers, bans on certain gears in particular locations (e.g., three area closures off the west coast of Puerto Rico), and size (spiny lobster, queen conch, yellowtail snapper) and bag limits (queen conch, dorado) for species caught from the shoreline to the EEZ.

Commercial and recreational fisheries land over 179 edible fish species, as well as numerous species for the ornamental and aquarium trade. Commercial fishing is conducted inshore and offshore from both large and small boats, with gear including traps and pots, bottom longlines, and gill and trammel nets. Hook-and-line recreational fishing is conducted from shore, or from charter, rental or privately-owned boats, while recreational divers may capture spiny lobster by hand or reef fish by spear. Most species caught are associated with coral reef habitats, and the harvest is shared by commercial (artisanal) and recreational fishers. Some species are caught primarily by the recreational fishery (including surgeonfishes, angelfishes, tilefish and jacks), others are shared approximately equally among the commercial and recreational sector (red hind, queen snapper), and some are caught primarily by the commercial fisheries, including silk snapper, yellowfin grouper, squirrelfish, parrotfishes, spiny lobster and queen conch. Of these species, the vast majority are harvested from the insular shelf, except in the case of deep water snappers (e.g., silk, and queen), which have become popular with the recreational fishers and are harvested at depths between 60 and 560 m.

In 2005, the CFMC amended several Fishery Management Plans with measures to improve the collection of fishery-dependent data and to group reef fish species into Fishery Management Units or FMUs (CFMC, 2005) based mostly on local expert knowledge. Total landings by FMU for the years in which there are data available are compared for both the commercial and recreational sectors in Table 3.2, excluding pelagic species (dorado, mackerels, tunas, sharks), near-shore species such as tarpon and snook, mojarras, sardines and other baitfish reported in the catches. Figure 3.17 shows that in four of the six years, reported recreational total landings were higher than commercial landings, despite the fact

Table 3.2. Reef fishery landing averages for Puerto Rico (in pounds). Commercial landings were averaged for the period between 1997 and 2001. Recreational landings were averaged for the period between 2000 and 2001 Source: CFMC, 2005.

STOCK	Commercial Landings	Recreational Landings	TOTAL	Commercial Allocation	Recreational Allocation
SNAPPER					
Unit 1: (black, blackfin, silk, vermilion, unc)	267,089	153,274	420,363	64%	36%
Unit 2: (queen, wenchman)	72,244	60,612	132,856	54%	46%
Unit 3: (gray, lane, mutton, dog, schoolmaster, mahogany)	360,080	117,548	477,628	75%	25%
Unit 4: (yellowtail)	298,845	24,135	322,980	93%	7%
GROUPER					
Unit 1: (Nassau)	16,241	3,772	20,013	81%	19%
Unit 2: (goliath)	61	6,169	6,230	1%	99%
Unit 3: (hind, red, coney, rock, graysby, crolefish)	75,050	55,266	130,316	58%	42%
Unit 4: (red, misty, tiger, yellowfin, yellowedge, unclassified)	61,535	21,309	82,844	74%	26%
REEF FISHES					
Grunts: (white, porkfish, margate, bluestriped, french, tomtate)	134,898	19,051	153,949	88%	12%
Goatfish: (spotted, yellow, unc)	20,587	1,510	22,097	93%	7%
Porgies: (jolthead, sea bream, sheepshead, pluma, unc)	31,102	2,887	33,989	92%	8%
Squirrelfish: (bigeye, longspined, unc, blackbar, soldierfish)	14,924	6,593	21,517	69%	31%
Tilefish: (blackline, sand, unc)	514	1,765	2,279	23%	77%
Jacks: (blue runner, horse-eye, black, almaco, bar, greater amberjack, yellow, unc)	83,411	167,140	250,551	33%	67%
Parrotfishes: (blue, midnight, princess, queen, rainbow, redfin, redtail, stoplight, redband, striped, unc)	92,207	29,214	121,421	76%	24%
Surgeonfish: (blue tang, ocean, doctorfish, unc)	8	630	638	1%	99%
Triggerfish: (filefish, scrawled, whitespotted; triggerfish: ocean, black, sargassum, queen, unc)	58,781	74,355	133,136	44%	56%
Boxfish: (cowfish: honeycomb, scrawled; trunkfish: spotted, smooth)	83,271	4,257	87,528	95%	5%
Wrasses: (unc, spanish hogfish, puddingwife)	58,485	7,417	65,902	89%	11%
Angelfish: (queen, gray, french)	71	1,278	1,349	5%	95%
FINFISH TOTAL	**1,729,404**	**758,182**	**2,487,586**	**70%**	**30%**
LOBSTER					
Lobster: (spiny, spotted)	290,555	135,633	426,188	68%	32%
CONCH					
Conch	248,437	132,121	380,558	65%	35%
GRAND TOTAL	**2,268,396**	**1,025,936**	**3,294,332**	**69%**	**31%**

that reported recreational landings do not include any information on queen conch, spiny lobster or other shellfish harvested by recreational fishers. Commercial fishers have been voluntarily sharing landings data since 1967 and by law since 2005 (Juhl and Cabro, 1972); recreational harvest data is primarily from the Marine Recreational Fisheries Statistics Survey (MRFSS), which has been conducted in Puerto Rico since 2000 (NMFS, 2007). Data from this program is available at http://www.st.nmfs.noaa.gov/st1/recreational/overview/overview.html.

Recognizing that there are problems with the commercial and recreational catch databases, with under-reporting being a primary concern, the Puerto Rico DNER has included a correction factor that varies from year to year for commercial fisheries. The landings were thus adjusted by 0.50 and 0.86 for the commercial fisheries between 2000 and 2005 (D. Matos-Caraballo, pers. comm.; Matos-Caraballo 2004b). Figure 3.18 shows a comparison between the uncorrected commercial data, corrected commercial data and the recreational catch data from 2000 to 2005. Users of catch data from these sources should be cautious in how it is applied, given the concerns about over reporting and misreporting in addition to the use of data correction factors.

The recreational fisheries data from MRFSS also has potential sources of error, since the catch weights that are used to estimate total recreational catch are obtained mostly from telephone interview surveys. In spite of the sources of error in the data, the trends represented in the data need to be taken seriously in light of the cumulative impact that an uncontrolled recreational fishery could have on reef-associated fishery resources. The removal of juvenile fish, queen conch, lobster and the herbivorous fish that help maintain healthy coral reefs is of particular concern.

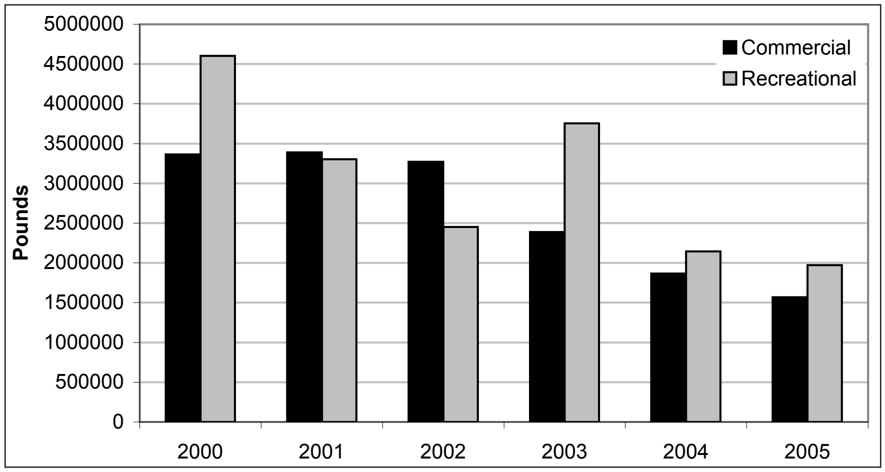

Figure 3.17. Reported landings for Puerto Rico between 2000 and 2005. Sources: NMFS Commercial Fishery Statistics Program and MRFSS database.

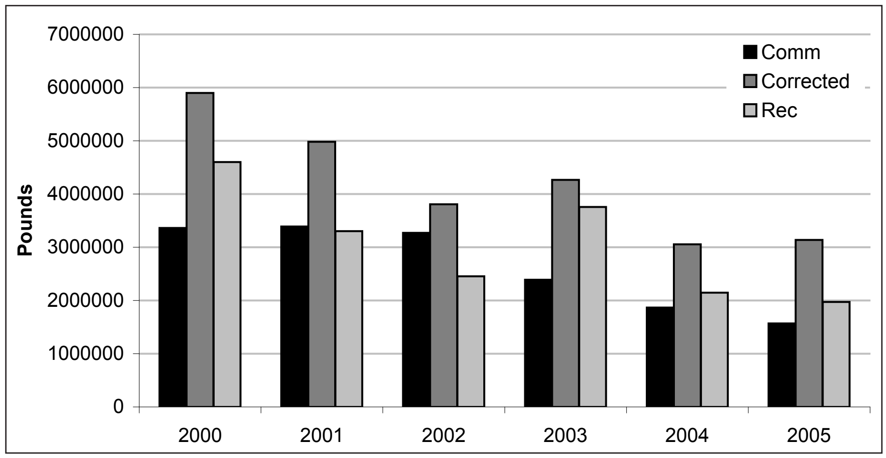

Figure 3.18. Commercial, corrected commercial and recreational landings in Puerto Rico between 2000 and 2005.Sources: NMFS Commercial Fishery Statistics Program and MRFSS database.

Table 3.3. MRFSS summary data for 2000-2006 for all fish species by mode reported for Puerto Rico (LBS=pounds of fish, Trips=number of trips reported). Source: MRFSS database.

		MODE			
		CHARTER	PRIVATE	SHORE	TOTAL
2000	LBS	48,173	4,195,832	357,736	**4,601,741**
	TRIPS	16,899	522,914	792,890	**1,332,703**
2001	LBS	23,281	2,752,165	526,476	**3,301,922**
	TRIPS	10,919	504,349	896,675	**1,411,943**
2002	LBS	22,438	2,236,507	193,103	**2,452,048**
	TRIPS	34,227	572,844	693,938	**1,301,059**
2003	LBS	28,254	3,320,974	405,735	**3,754,963**
	TRIPS	21,764	471,741	617,900	**1,111,405**
2004	LBS	40,435	1,940,892	164,148	**2,145,475**
	TRIPS	22,028	389,469	638,802	**1,050,299**
2005	LBS	41,689	1,835,863	93,711	**1,971,263**
	TRIPS	17,969	379,910	468,843	**866,722**
2006	LBS	N/A	N/A	N/A	**N/A**
	TRIPS	16,906	386,111	493,565	**896,582**

Recreational Fisheries

The MRFSS database also includes information on the various modes that make up the recreational fishing sector including charter boat operations, shoreline fishing and the private/rental boat sector. Table 3.3 and Figure 3.19 summarize the data available for each of the modes (charter, shore and private) for the years 2000 to 2005. The private recreational mode, which includes boat owners or rentals, but not charters or for-hire vessels, had 88 to 93% of the harvest from 37 to 44% of the trips taken. The shoreline fishers accounted for 4 to 10% of the catch from 53-60% of the trips taken, and the charter operations accounted for 1 -2% of the total catch from 2% of the trips taken per year. The MRFSS includes both local and out-of-state fishers; in Puerto Rico, the ratio is about 4:1 local to out-of-state. This could indicate that the amount of fish being harvested exceeds the regulatory limit for recreational catch. In 2004, DNER established limits for the recreational harvest of several species (i.e., bag limits; Puerto Rico Fishing Regulation #6768, February 11, 2004), and instituted requirements for licenses and permits. The regulations include a total prohibition on the harvest of goliath and Nassau groupers. Licenses and permits have not been implemented, thus the number and true impact of recreational fishers in Puerto Rico continues to be unknown.

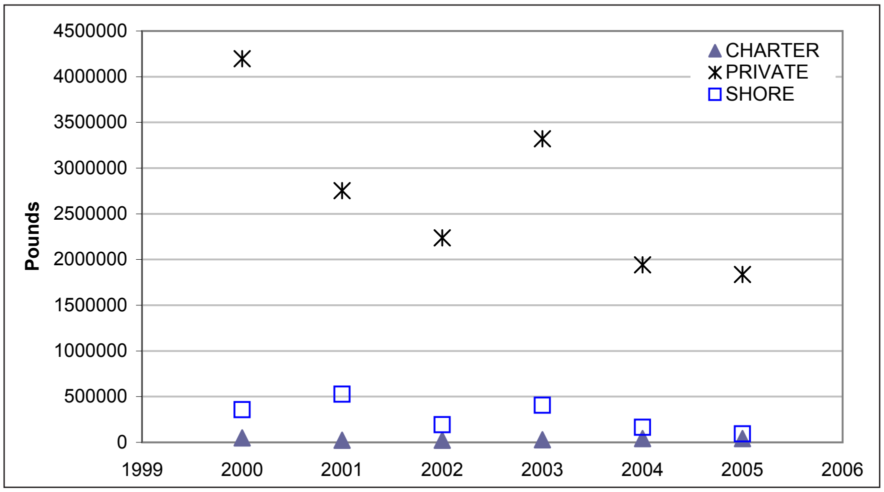

Figure 3.19. Recreational landings in Puerto Rico, 2000-2006. Source: MRFSS database.

Commercial Fisheries

There were 1,163 active commercial fishers in Puerto Rico in 2002, (Matos-Caraballo, 2004a) utilizing 956 fishing vessels with lengths of 5-9 m (about 15-30 ft). The number of active fishers varied by about 500 individuals between 1996 (1,758 active fishers) and 2002. Commercial fishers have been reporting catches since 1967 and provide their landings by gear type (Figure 3.20; D. Matos-Caraballo, unpub. data; Matos-Caraballo, 2004b). The commercial catch data indicate that all gear types have been used to harvest the 27 family groups (groupers, snappers, goatfish, etc.) recorded in the database; specific information on over 24 species (e.g., red hind, silk snapper, spotted goatfish, queen triggerfish; Matos-Caraballo 2004b) is also provided. Since the 1990s, the primarily trap-based fishery of Puerto Rico has been replaced by a bottom line fishery that uses multiple hooks on each weighted line. Increases in the harvest of deep water snapper species and pelagic fish such as dorado have been most noticeable. Although landings for the top families (snappers, groupers and grunts) have remained stable, changes in species-specific landings have been reported, such that silk and queen snappers have become the top landed species. Since the 1990s, pelagic species (e.g., tunas, dorado or mackerels) have ranked among the top three species-groups landed. Thus, shifts in fishing methods and species collected, taken together with the overall decline in landings, have refocused the commercial fisheries of Puerto Rico from a shallow-water, coral reef-associated trap fishery to a fishery associated with pelagic and deeper reef species. However, the diversity of the catch composition persists.

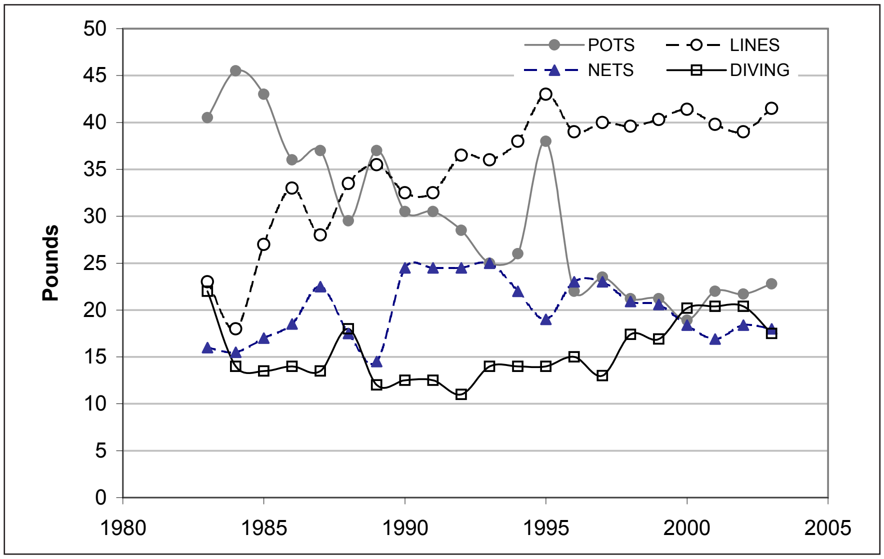

Figure 3.20. Percent commercial landings by gear in Puerto Rico from 1983 to 2004. Source: Matos-Caraballo, pers. comm.

Several important changes are evident in the fisheries of Puerto Rico over recent decades. The abundance of shallow water reef fish and associated species have generally declined, with possible causes including overfishing, changes in nearshore habitats (sedimentation, eutrophication and pollution), higher SSTs associated with bleaching and coral diseases, increased use of marine resources by boaters, recreational fishers, etc. Overfishing has been implicated in the decline in landings observed among coral reef-associated fish and shellfish species. The documented trends have recently resulted in determinations that Nassau and goliath groupers (*Epinephelus striatus* and *E. itajara*) and queen conch (*Strombus gigas*) are being overfished (CFMC, 2005). The trends also indicate that overfishing occurs in Snapper Unit 1, Grouper Unit 4 and the parrotfish complex (Table 3.2; CFMC, 2005). Bycatch occurs within Puerto Rico's commercial and recreational fisheries, but its impact on local fish populations is not fully known. Types of bycatch include regulatory discards such as yellowtail snapper less than 12 inches TL (total length – from tip of snout to tip of tail), or discards that occur because the fishes are potentially ciguatoxic (e.g., great barracuda) or simply not marketable (e.g., butterflyfishes; Matos-Caraballo, 2005). Although difficult to document, commercial fishers have claimed that the declines in fisheries are a result of habitat loss and degradation, which has reduced recruitment of larvae and juveniles to the population. Fishing communities are being impacted by changes to marine habitats, development of the coastline and overfishing. Management urgently needs to better monitor commercial and recreational fisheries, assess the impacts of environmental factors on fisheries, and enforce existing fishing and environmental regulations.

In response to concerns over declines in some reef fish species, in 1996, the CFMC, in cooperation with the Puerto Rico DNER and the commercial fishermen of the west coast, took action to protect deep reefs that are known spawning aggregation sites for red hind (*Epiniphelus guttatus)* in three areas off Puerto Rico's west coast (CFMC, 1996). At the request of the commercial fishers and with the recommendation of the CFMC's Reef Fish Committee, the CFMC established seasonal closures at Bajo de Sico, Tourmaline Bank and Abrir La Sierra to protect spawning sites for this grouper species, which is important for commercial and recreational fisheries (Figure 3.1). Each closure measures 16.7 km^2 and prohibits all fishing from December 1 to February 28. Additionally, in 2005, the use of all bottom-tending gear (traps, pots, bottom longlines or gill and trammel nets) was prohibited from these areas year-round (CFMC/NMFS, 2005).

The Southeast Area Monitoring and Assessment Program for the Caribbean (Rosario, 1996), a fishery-independent biological survey, together with anecdotal information provided by commercial fishers, were used to locate red hind spawning aggregations in Bajo de Sico and Abrir La Sierra (A. Rosario, pers. comm.). Initial characterization of the deep reefs in these areas was completed in 2004 (García-Sais et al., 2005b). Detailed high resolution bathymetric surveys of all three closed areas were conducted jointly by the CFMC and CCMA-BB with support from the NOAA Coral Reef Conservation Program (CRCP) in 2007. The surveys yielded the first video footage of an extensive deep hermatypic reef system at depths between 50-90 m (NOAA, 2007; http://ccma.nos.noaa.gov/products/biogeography/usvi_nps/2007/updates/april.html). Plans are in place to complete the seafloor characterization and bathymetric surveys of these areas during the next visit of the NOAA ship *Nancy Foster* in the spring of 2008.

Puerto Rico's commercial fishers from the west coast have also provided valuable information on the location of deep water populations of queen conch (*Strombus gigas*) in Abrir La Sierra. The queen conch fishery in federal waters off the west coast of Puerto Rico was closed in 2005 (CMFC/NMFS 2005). Although such regulations exist, little monitoring is conducted in closed areas, and additional research is needed to document changes to the population post-closure.

Trade in Coral and Live Reef Species

Puerto Rico laws and regulations allow only for the collection of small pieces of dead coral (small enough to fit in the palm of your hand) as souvenirs from beaches around the island. The collection of live or dead coral for scientific purposes requires a permit from DNER. Similarly, artisans with a valid DNER permit can collect dead coral from beaches for use in their works of art. At this time, only about five artisans around Puerto Rico possess this permit (DNER, unpub. data). Federal regulations also prohibit the collection of live or dead coral within federal waters except for scientific purposes and with authorization from the CFMC. Recently, NOAA Office of Law Enforcement and NOAA Fisheries Caribbean Field Office have been working with the Transportation Security Administration (TSA), Homeland Security (Customs and Border Patrol), and DNER Rangers to address the ever larger problem of coral souvenir collection. With the opening of the Aguadilla and Ponce airports to commercial flights from the U.S., the unauthorized transport of corals in luggage has increased dramatically, although it is also a problem in the San Juan airport. TSA reported one tourist as having a suitcase weighing more than 60-pounds of which most of the weight was composed of coral heads traveling through the Aguadilla airport. The tourist explained that she was taking the coral heads home to be used as door stops. DNER Rangers in Ponce report regular transport of pieces of coral, as well as undersized queen conch shells, which are also prohibited for possession. TSA in San Juan report that they regularly process suitcases with 15-35 pounds of coral packed as souvenirs of the trip to Puerto Rico. In January 2008, a tourist was stopped in the San Juan airport with a suitcase full of still wet finger coral, most of which had live tissue at the time of the intervention. Because of this increasing problem, NOAA Fisheries has begun a campaign through a local tourism program and signs in airports and the CFMC and NOAA Office of Law Enforcement are also planning educational campaigns. NOAA is also working closely with TSA to train officers in the identification of corals and interventions with persons in possession of these souvenirs.

Staghorn coral, which is now listed as threatened under the ESA, is one of the corals being collected as a souvenir. On December 14, 2007, NOAA Fisheries published a proposed rule to extend ESA Section 9 prohibitions to elkhorn and staghorn corals. Under this rule, these corals would be treated as endangered species and their collection, possession, harm, take, intent to take, sale, etc. would be prohibited. Only scientific and educational activities with appropriate authorization would be permitted for this species. Thus, if unauthorized souvenir collection continues at its current rate, enforcement may involve federal ESA penalties if the persons are convicted. This may assist in curbing the current souvenir collection as current regulations have not proven sufficient.

Ships, Boats and Groundings

Since the 326-foot freighter M/V *Fortuna Reefer* ran aground on the southeast coast of Mona Island on July 24, 1997, scientists have continued to monitor the condition of 1,857 fragments of elkhorn coral (*Acropora palmata)* that were reattached to the substrate as part of a restoration effort. Fragments experienced high rates of early mortality (57% surviving after two years), with losses attributed primarily to wire breakage and removal during winter storms, overgrowth by bioeroding sponges, disease and predation by corallivores (*Coralliophila abbreviata* gastropods). After nine years (August, 2006), 10% (n=185) of the original fragments are still alive and now resemble adult colonies, with extensive branching patterns and substantial increases in height (mean=39 cm tall). They range in maximum diameter from 15-300 cm (mean=76 cm), with larger fragments attached to the reef (mean=79 cm versus 68 cm). Roughly half of these have live tissue covering most of their skeletal surfaces, and they have produced numerous new branches (48%, mean=five branches/coral, 89 cm in length), although only 21% (n=39) have accreted tissue and skeletal material onto the substrate and are firmly attached. Most surviving fragments are attached to the reef (n=129; 70%), and are oriented upright (n=108), although fragments attached to *A. palmata* skeletons have more living tissue on their branch surfaces (mean=62% versus 51%). Fragments attached to coral skeletons also had lower levels of recent mortality (0.3%) and a lower prevalence of disease and corallivore predation, although both groups have a similar number and size of new branches. The most significant ongoing sources of mortality include predation by corralivores (8%), overgrowth by sponges in the genus *Cliona* (6%), and disease (6%). In addition to the substantial loss of restored fragments, this reef has been impacted by a severe outbreak of WBD that has persisted since 2001 and has eliminated over 95% of coral colonies that were not part of restoration efforts.

In the most recent major ship grounding in Puerto Rico, the M/T *Margara*, a 228 m tanker, ran aground on the reefs off of Guayanilla, Puerto Rico on April 27, 2006. The damage was extensive and estimated to have impacted up to 8,500 m^2 of reef. The grounding occurred at approximately 10.5 m depth on a bank type coral reef near the shelf edge that had significant live cover of corals and gorgonians. Emergency Restoration activities were conducted to facilitate the recovery of the natural resources by reattaching the remaining viable corals, stabilizing rubble berms and removing antifouling paint. Thousands of scleractinian corals and gorgonians were reattached to available substrate with hydraulic cement. The ER was a cooperative effort between the Responsible Party (represented by Continental Shelf Associates, Inc.) and the co-trustees, Puerto Rico DNER and NOAA. Damage assessment activities involved mapping impacted reef areas as well as a preliminary characterization of the surrounding reef community to establish a baseline of conditions in the area. Spur and groove coral reef habitats, like the area impacted by the M/V *Margara*, have complex topography and high species diversity compared with hard ground coral reef communities of low topographic complexity, where flat limestone pavements are colonized by crustose coralline algae, gorgonians and isolated coral colonies. This site will be monitored over time to determine the effectiveness of restoration activities and track any recovery that occurs.

In addition to groundings, shipping is often responsible for the release of petroleum products into the environment. NOAA ResponseLink data for November 2007 through January 2008 indicate that five spills of petroleum products from tug boats, tankers, and cargo vessels were reported to the National Response Center. The events occurred in San Juan, Ponce, and Yabucoa. While these areas are active harbors, reef resources are located in close proximity. In addition to these small reported spills, a large spill occurred in Guánica in August 2007. This spill went unreported and resulted in damage to mangrove forests, beaches, and coral cays from Guánica to Parguera along the southwest coast of Puerto Rico. Spill response also resulted in damage to shallow seagrass beds and mangrove forests during site access. The response took approximately one month and some areas, such as interior mangrove forests, could not be thoroughly cleaned. The U.S. Coast Guard (USCG) has identified the party responsible but the Oil Pollution Control Act allows compensation and restoration only for damages directly related to the spill. Therefore, there are no scientific investigations ongoing or planned in order to characterize the environmental impacts of this large magnitude spill.

The number of recreational vessels and personal watercrafts has been continuously increasing since 1993 (Figure 3.21). The DNER's Office of the Commissioner of Navigation keeps records of the USCG vessels larger than 16 feet. USCG boating statistics show that there were between 7 and 18 boating accidents reported in Puerto Rico between 2001 and 2005 to which the USCG responded (http://www.uscgboating.org/). However, no groundings or striking of submerged objects were reported.

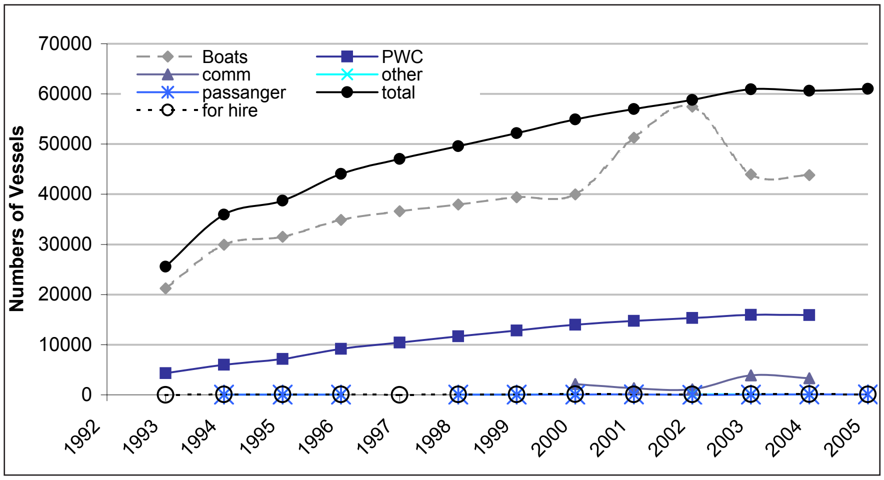

Figure 3.21. USGS registered vessels in Puerto Rico from 1993 to 2005. Source: Office of the Commissioner of Navigation, Puerto Rico DNER.

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

Aquatic Invasive Species
No updated information on this topic was provided.

Security Training Activities
The islands of Vieques, Culebra and Desecheo served as training ranges for the U.S. Navy since the 1940s. Military activities ceased in 2001 on the western end of Vieques, and in 2003 on the eastern half of the island. In 2005, the EPA placed the former Navy areas on the National Priorities List (or Superfund). On the western side of the island, the Navy is

identifying contaminated areas and performing cleanup of some of the sites. In the Live Impact Area, where cleanup efforts are more intensive due to the possible presence of unexploded live ordnance, the Navy has cleared several beaches and trails. The FWS, the agency now responsible for the management of the lands of eastern Vieques, has made some of the areas accessible to the public but most of eastern Vieques is still closed to the public as cleanup efforts continue. Because cleanup efforts include blow in place of unexploded ordnance, the Navy has agreed to restore some mangrove forests and coastal lagoons impacted by past military activities, as well as during the cleanup effort. Although no cleanup efforts have begun in the water, the Navy anticipates starting cleanup of unexploded ordnance in the water by 2010. A recent study (GMI, 2005) found that reefs in former military areas are in similar condition to the civilian areas, although the two sites with the poorest condition were located in the military target area. Although the extent of damage is not thoroughly established, recent efforts have highlighted the areas of greatest concern and estimated the amount of reef habitat that is potentially impacted by ordnance (GMI, 2003). NOAA's CCMA-BB recently conducted field surveys to characterize fish, benthic communities, marine debris, contaminants, and water column nutrients in coral reef ecosystems island-wide. The results and interpretation of this work will be provided in the next reporting effort. The Navy and NOAA have partnered to complete submarine mapping of potential areas of concern where unexploded ordnance may be present using different types of sonar. The results of these studies will help focus cleanup efforts. In addition, the results of these surveys have been used to determine where to install warning buoys notifying mariners of the danger of navigating and, in particular, weighing anchor in certain bays. NOAA is also conducting an artificial reef study to determine the form and composition of structures that are most successful in enabling coral recruitment and coral transplant survival. The results of this study will be used to guide mitigation planning as part of future underwater cleanup efforts.

In Culebra and its surrounding island and cays, the U.S. Army Corps of Engineers (COE) is responsible for cleanup efforts due to Culebra's classification as a Formerly Used Defense Site. This is also true for Desecheo Island due to the length of time since active military activities took place. COE has completed site inspections for Desecheo Island and is in the planning stages for determining the level of cleanup necessary in coordination with the FWS, as the agency responsible for management of Desecheo Island, which is a National Wildlife Refuge. The site inspection revealed that, in addition to possible ordnance on land, the area on the west of the island that was used as a target contains potential items of concern in areas of coral reefs. No decisions have been made to date regarding cleanup of these items. In terms of Culebra, efforts are already underway to clean some of the larger cays where sea bird and sea turtle nesting are not a concern. COE will also begin cleanup of beaches around Culebrita Island, as well as Flamenco beach. COE also completed a test of one of the sonar devices employed by the Navy to do underwater mapping of the coast of Culebra in the area of Canal Luis Peña Natural Reserve. If the results of the study reveal areas of potential unexploded ordnance, COE will proceed with the development of a plan for cleanup of these areas. To date, the potential impacts of ongoing cleanup efforts around Culebra on the coral reef ecosystem are related to the potential for accidental groundings during access of offshore islands and cays and blow in place of large bombs on cays of less than 0.5 acre, which could result in the elimination of the cay. COE has not been responsive to concerns related to potential impacts of cleanup on marine resources at this time. Therefore, FWS as the agency responsible for management of most of the offshore islands and cays as part of the Culebra Wildlife Refuge, may deny access to the Refuge.

The transfer of lands that were formerly part of Naval Station Roosevelt Roads also includes cleanup efforts. Piñeros and Cabeza de Perro Islands, formerly part of the base, were used to conduct training activities for Navy SEALs, as well as firing range practice, underwater demolitions, and other military training activities. The Navy, as part of cleanup efforts and a possible plan to transfer these two islands to DNER to become a Natural Reserve, investigated the lands and waters around these islands to determine potential hazards related to unexploded ordnance. A significant number of potential hazards were identified during underwater mapping of four sites around the islands. The Navy is now drafting a work plan for intrusive exploration of these sites and blow in place of items that prove to be unexploded ordnance. Because the areas are located in benthic habitats such as coral reefs and seagrass beds, cleanup activities are likely to result in impacts to marine resources. For this reason, the Navy is also working on potential measures to minimize impacts, as well as compensatory measures to address unavoidable impacts to seagrass beds and coral reefs.

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

The Department of Marine Sciences (DMS) from the University of Puerto Rico, Mayaguez Campus (UPRM) plays a leading role in scientific research related to coral reefs, associated reef communities and the physical characteristics and processes affecting reef systems. Data from these studies are often published in scientific journals and books or are available as theses or dissertations in UPRM's DMS Library (http://www.uprm.edu/library). The DMS also serves as the administrative office and operations center for the recently created Caribbean Coral Reef Institute (CCRI), which provides funding for coral reef related research in Puerto Rico and the Caribbean. CCRI has sponsored 12 projects since 2004, six of which have involved data collection, including annual monitoring of corals, diseases, macroinvertebrates, fishes at Culebra Island, Fajardo, Cabo Rojo, Mayaguez and Guánica.

The Coral Reef Ecosystem Studies (CRES) program at the DMS-UPRM has conducted routine sampling of coral reefs in La Parguera. Fixed transects are located on three inshore, three mid-shelf and two shelf edge locations, with three depths sampled at each location and three replicate transects at each depth. Quantitative sampling has been conducted since 2003 for corals (including recruits and coral diseases), algae, gorgonians, and fishes. Frequency of sampling varies depending on taxa, being lower for corals and gorgonians and higher for algae, fishes and coral recruits and diseases. Water quality has been monitored continuously at inshore, mid-shelf and shelf edge locations- temperature, salinity, turbidity, pH, photosynthetically active radiation (PAR)- with more detailed short-term measurements occurring at 14 locations from the shoreline to the shelf edge (temperature, salinity, turbidity, pH, PAR, Chlorophyll a, DCOM). At these latter sites sediment samples have been analyzed for stable isotopes. Additional sediment trap samples have been collected at all fixed transect sites at bimonthly intervals. All CRES field data collections ended in the spring of 2007. Table 3.4 summarizes data-gathering activities by ongoing coral reef monitoring programs in Puerto Rico and Figure 3.22 shows the distribution of monitoring sites.

Table 3.4. Data sets selected to describe the current condition and status of coral reef ecosystems in Puerto Rico for the period 2004-2007. Source: S. Williams and J. García-Sais, unpub. data.

ECOSYSTEM COMPONENT	DATA SET	SOURCE AGENCY/ ORGANIZATION	PROGRAM INFORMATION
Water Quality	Coral Reef Early Warning System	NOAA Coral Health and Monitoring Program	CREWS Station, La Parguera
	301-h Program	PRASA-CSA/CH2MHill	Submarine Outfalls
Benthic Habitats	Puerto Rico Coral Reef Monitoring Program (National Coral Reef Ecosystem Monitoring Program)	PRDNER, NOAA	Baseline characterization and monitoring of reef systems in Natural Reserves
	Media Luna Reef, La Parguera, PR	Caribbean Coastal Marine Productivity (CARICOMP)	CARICOMP Data Management Centre, Kingston Jamaica
	CRES	NOAA/CSCOR	http://ccma.nos.noaa.gov/ecosystems/coralreef/cres.html
	301-h Program	PRASA-CSA/CH2MHill	Submarine Outfalls
	Coral Reef Monitoring Program	NOAA CCMA-BB	http://ccma.nos.noaa.gov/ecosystems/coralreef/cres.html
Associated Biological Communities	Reef Fish Monitoring Program (National Coral Reef Ecosystem Monitoring Program)	PRDNER, NOAA	Baseline characterization and monitoring of reef systems in Natural Reserves
	Coral Reef Monitoring Program	NOAA CCMA-BB	http://ccma.nos.noaa.gov/ecosystems/coralreef/cres.html

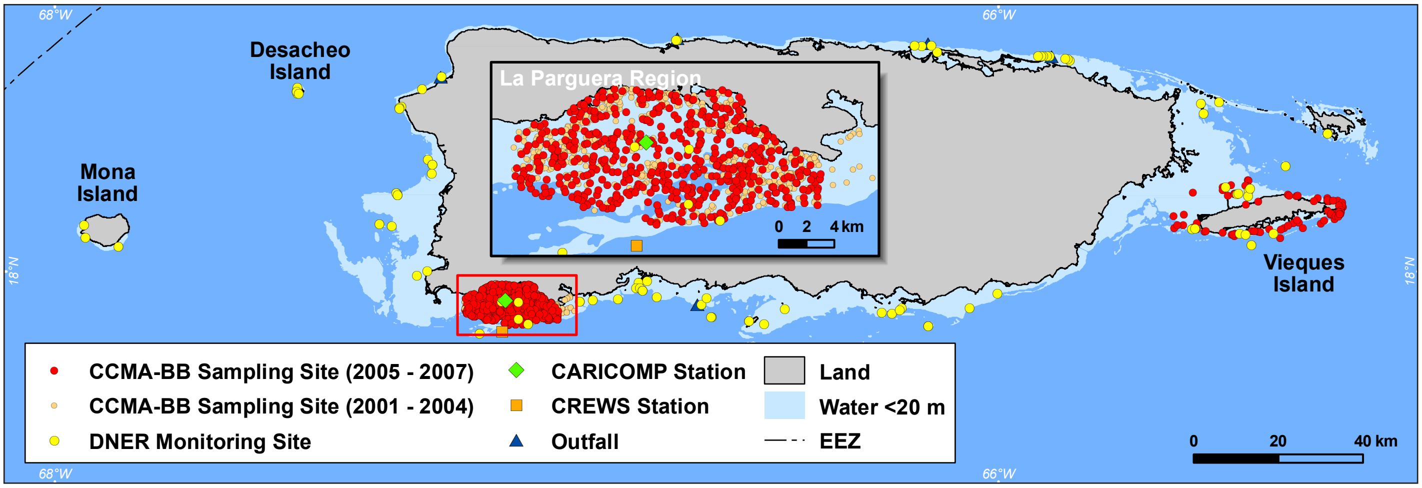

Figure 3.22. Monitoring locations throughout Puerto Rico. Map: K. Buja.

WATER QUALITY AND OCEANOGRAPHIC CONDITIONS

Coral Reef Early Warning System (CREWS) Station

NOAA's Coral Health and Monitoring Program has a Coral Reef Early Warning System (CREWS) Station that was installed at Media Luna Reef (17°52.326'N; 067°03.128'W) within the La Parguera Marine Reserve, Puerto Rico. The instruments and electrical infrastructure were installed in December, 2005, and the station began transmitting on January 15, 2006. Sensors provide measurements of wind speeds and gusts, barometric pressure, relative humidity, precipitation, photosynthetically available radiation (PAR, above and below water), ultraviolet radiation (UV 305, 330, 380 nm, above and below water), state of tide, sea temperature, salinity, and pulse amplitude modulating fluorometry on up to four species of coral. Validation runs and complete cleaning of the sensors and structure are performed on a continuous monthly basis. The station also serves as a navigational light between Cabo Rojo and Ponce, and an entrance channel marker to the reserve and general embayment area. Roy Armstrong and Francisco Pagan of UPR/DMS are the local contacts. To check archives and latest up-to-date information, visit the NOAA/CREWS Web site at http://ecoforecast.coral.noaa.gov/.

Puerto Rico Aqueduct and Sewer Authority 301-h Program

PRASA operates a series of RWWTP that discharge primary treated effluents to the ocean via submarine outfalls. Discharges from PRASA facilities are regulated by a National Pollutant Discharge Elimination System permit from the EPA, Region II. Section 301(h) of the Clean Water Act and its implementing regulations require that a waiver recipient develop and implement a comprehensive marine monitoring program to determine whether discharges from the subject primary plant adversely affect the marine environment. The 301(h) program was originally designed to be carried out on a quarterly basis, but is at present performed semiannually at most plants. The 301(h) monitoring program elements include: influent and effluent water quality (150 parameters); receiving water quality (152 parameters); sediment quality; benthic (infaunal) invertebrate communities; fish and epibenthic invertebrate communities; and coral community assessment. The typical sampling station design includes one reference (control) station, one up-current and one down-current far field stations, one station at each end of the outfall structures, and at the boil whenever evident. Reports are prepared for PRASA by CSA Architects and Engineers/CH2MHILL/CSA Group, and submitted to the EPA Region II, Division of Environmental Planning and Protection, with copies to the Environmental Quality Board of Puerto Rico.

Table 3.5 presents data from a selected group of water quality parameters measured during the November 2005 monitoring survey in the vicinity of the Aguadilla RWWTP submarine outfall. Note that all dissolved nutrient concentrations and bacteriological analyses were below the detection limits established to protect human health or between the reporting limit and the detection limit during this survey. This data shows that coastal waters in the vicinity of the Aguadilla RWWTP submarine outfall tend to retain their oligotrophic character despite the influence of the effluent discharge. Other plants, such as the Ponce RWWTP have had problems that have resulted in unauthorized discharges to marine waters.

Table 3.5. Water quality of surface waters near PRASA-RWWTP in Aguadilla, PR during November, 2005. Source: CH2MHILL, 2006.

PARAMETER	UNITS	STATIONS				
		BOIL	A-1	A-3	A-4	A-7
Temperature	°C	26.15	26.61	26.32	26.25	26.20
Salinity	ssu	36.41	36.65	35.54	36.51	35.56
Dissolved Oxygen	mg/l	5.95	6.12	6.21	6.14	6.07
O_2 Saturation	(%)	91.5	95.0	95.2	94.6	93.1
pH	su	8.02	8.05	7.98	8.04	7.97
Total Suspended Solids	mg/l	5U	5U	5U	5U	5U
Turbidity	NTU	0.22J	0.43J	0.2J	0.15J	0.24J
Total Phosphorus	mg/l	NA	0.01U	0.01U	0.01U	0.01U
Ammonia as N	mg/l	0.15U	0.03UJ	0.03UJ	0.03UJ	0.03UJ
Total Kjeldahl Nitrogen	mg/l	1.6J	0.13J	0.21	0.2J	0.20
$N0_3/N0_2$-N	mg/l	0.03J	0.03J	0.03J	0.03J	0.03J
Chlorophyll-a	mg/m^3	0.19	0.11	0.10U	0.32J	0.31J
Total Coliforms	col/100ml	99	10U	10U	10U	10U
Fecal Coliforms	col/100ml	2U	2U	2U	2U	2U

U: below detection limit
J: Estimated value; compounds detected at concentrations between the reporting limit and the detection limit.

BENTHIC HABITATS

National Coral Reef Ecosystem Monitoring Program (NCREMP): Puerto Rico Habitat Monitoring

The Puerto Rico Coral Reef Monitoring Program (PRCREMP), which is sponsored by NOAA and administered by the DNER, began in 1999; the program is now fully implemented and is achieving its goals in collaboration with federal and local governmental agencies and marine scientists from research institutions. The main objectives of the program are to map the spatial distribution of coral reefs, produce a baseline characterization of priority reef sites and establish a monitoring program for high-priority reefs. The monitoring program provides 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 purpose and priorities of the PRCREMP were initially presented by the DNER to NOAA's U.S. Island Coral Reef Initiative in 1997.

DNER identified the natural reserves of Mayaguez Bay, Desecheo Island, Mona Island, Rincón, Guánica, Caja de Muerto Island, Ponce Bay, La Parguera, 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, 2001b, 2001c, 2001d, 2004, 2005c, 2006). The baseline characterization and monitoring for the Culebra Marine Reserve was prepared by Hernández-Delgado (2003). This report includes annual monitoring trends from 12 stations at six reefs surveyed as part of PRCREMP. These included reefs at Isla Desecheo, Rincon, Mayaguéz, Guánica, Isla Caja de Muerto and Ponce. At each reef, quantitative measurements of the percent substrate cover by sessile-benthic categories and visual surveys of species richness and abundance of fishes and motile megabenthic invertebrates were performed along five permanent transects per station. Table 3.6 provides sites for which quantitative baseline characterizations are available, along with geographic references and depths. During fiscal year 2008, three additional reefs from Mona Island will be included in the monitoring program.

Table 3.6. Geographic coordinates and depths of coral reefs surveyed as part of the Puerto Rico Coral Reef Monitoring Program. Source: García-Sais et al., 2005c.

REEF SITE	DEPTH (m)	LATITUDE	LONGITUDE
Rincón			
Rincón elkhorn reef	3	18° 21.023' N	067° 15.959' W
Rincón mid shelf	10	18° 20.832' N	067° 16.206' W
Rincón shelf edge	20	18° 20.790' N	067° 16.248' W
Isla Desecheo			
Desecheo inner shelf - Puerto Botes	15	18° 22.920' N	067° 29.300' W
Desecheo mid shelf - Puerto Botes	20	18°22.900' N	067° 29.315' W
Desecheo shelf edge - Puerto Canoas	30	18°22.706' N	067° 29.199' W
Mayaguez			
Tourmaline 10 m	10	18° 09.788' N	067° 16.424' W
Tourmaline 20 m	20	18° 09.910' N	067° 16.512' W
Tourmaline 30 m	30	18° 09.985' N	067° 16.581' W
Ponce			
West Reef of Caja de Muerto	7.6	17° 53.701' N	066° 31.703' W
Derrumbadero	20	17° 54.2371' N	066°36.5161'W
Guánica			
Cayo Coral	7.6	17° 56.173' N	066° 53.303' W

Methods

At each site, reef substrate cover by sessile-benthic categories (including corals) was monitored using the Caribbean Coastal Marine Productivity (CARICOMP, 1996) chain link method. Five, 10 m-long permanent transects were surveyed per reef. Belt-transects (5-10 m long x 3 m wide) were surveyed for determinations of taxonomic composition and abundance of fishes and motile megabenthic invertebrates. Monitoring surveys were conducted annually at each reef during a period that extended from late spring through summer (May–August).

Results and Discussion

The sessile-benthic community at the reef systems of Puerto Botes and Puerto Canoas (Isla Desecheo), Tourmaline Reef (Mayaguez), Cayo Coral (Guánica), West Reef (Caja de Muerto–Ponce) and Derrumbadero Reef (Ponce) presented statistically significant reductions of live coral cover (Figure 3.23). The most pronounced declines of live coral cover were observed between the 2005 and the 2006 monitoring surveys. Reductions of live coral cover up to 59% were measured at Derrumbadero Reef between the 2005 and 2006 surveys. A decline of 56% was measured from a depth of 20 m at Puerto Canoas Reef at Desecheo Island. West Reef at Caja de Muerto Island declined 42% over the same period. In all cases, the decline of (total) live coral cover at the community level was driven by mortality of *Montastraea annularis* complex, a highly dominant species in terms of reef substrate cover and the principal reef-building species in Puerto Rico and the Caribbean (Figure 3.23). A proportional increase of cover by turf algae was typically observed (Figure 3.23).

The Tres Palmas Reef system in Rincon did not exhibit any major structural changes, nor statistically significant variations of percent substrate cover by live corals at any of the three depths surveyed between the initial 2004 baseline characterization and subsequent 2005 and 2006 monitoring surveys. The fringing shoreline reef at Tres Palmas is largely an elkhorn coral (*Acropora palmata*) biotope, and is dominated by encrusting great star coral (*Montastraea cavernosa*) at the patch reef formations of the mid-shelf (10 m depth). The shelf-edge reef at Tres Palmas was studied at a depth of 20

m. It is dominated by *Montastraea annularis* complex, but reductions of live coral cover at the 20 m depth were small and not statistically significant (ANOVA; p>0.05).

Tourmaline Reef in Mayaguez Bay exhibited significant declines of cover of *Montastraea annularis* complex at 10 and 20 meter depths, but differences of substrate cover by sessile-benthic components were not statistically significant at the 30 meter depth, which was the deepest station examined. The decline of live coral cover from the 30 m depth station at Puerto Canoas Reef, Isla Desecheo was less pronounced than at shallower stations examined (e.g., 20 and 10 m), but it was still substantial (ca. 23 %), statistically significant, and found consistently throughout all transects.

The sharp decline of live coral cover at many of the reefs included in this monitoring program was associated with a severe massive regional coral bleaching event that affected the USVI and Puerto Rico during August through October, 2005 (García-Sais et al., 2006). The massive bleaching of corals coincided with an extended period of elevated sea SSTs. As much as 14 DHW, an indicator of thermal stress acting upon shallow reef communities, were measured from daily temperature records produced by a NOAA/National Environmental Satellite, Data, and Information Services satellite infrared radiometer. The exposure of reef systems to such high SSTs was influenced by the presence of a warm anticyclonic eddy passing along the south (Caribbean) coasts of Puerto Rico and the USVI (see the Climate Change and Coral Bleaching Section of this chapter). During 2006 coral monitoring surveys, approximately six to nine months after the bleaching event, a relatively high proportion of live corals, particularly *Montastraea annularis* complex were observed to still retain partially bleached conditions. The potential recuperation of these (partially bleached) corals is uncertain at this point. Lingering effects of the October 2005 bleaching event were evaluated during the 2007 coral monitoring surveys and will be presented in the next report.

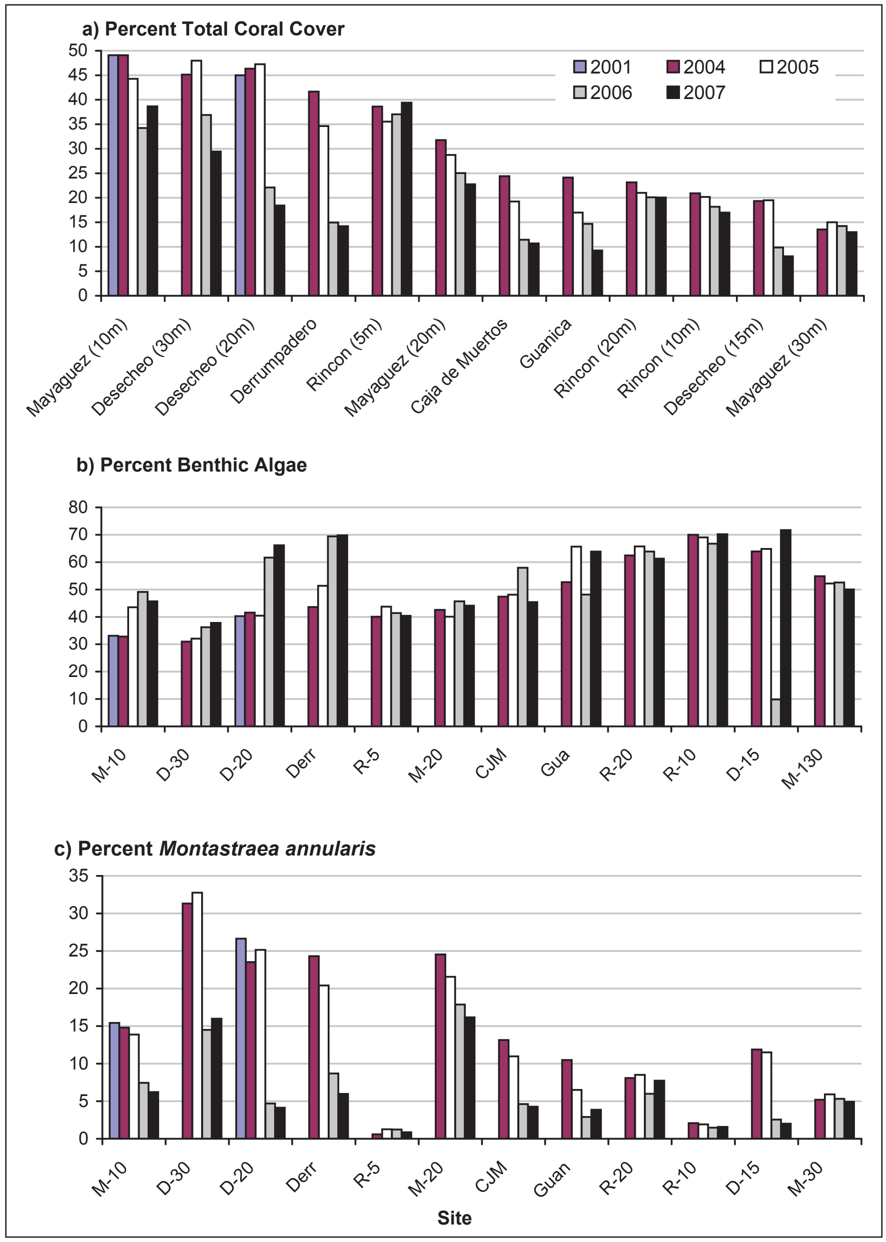

Figure 3.23. Annual trends of (a) percent total coral cover, (b) percent cover by benthic algae, and (c) percent cover by Montastraea annularis *from coral reefs monitored as part of the U. S. National Coral Reef Monitoring Program in Puerto Rico. García-Sais et al., 2007.*

Fish populations presented a general trend of declining abundance and species richness within belt-transects. Reductions of fish abundance were statistically significant in seven out of the 12 reef stations surveyed. These included Tourmarine Reef (Mayaguez) at 20 m; Puerto Botes Reef (Isla Desecheo) at 15 m; Tres Palmas Reef (Rincon) at 10 and 20 m; Derrumbadero Reef (Ponce) at 20 m and West Reef (Isla Caja de Muerto) at 8 m. Likewise, statistically significant reductions of fish species richness were observed at Tourmarine Reef (Mayaguez) at 20 m; Puerto Botes Reef (Isla Desecheo) at 15 m; Tres Palmas Reef (Rincon) at 10 m and West Reef (Isla Caja de Muerto) at 8 m. Variations between surveys were mostly associated with reductions of abundance by numerically dominant populations that exhibit highly aggregated distributions in the immediate vicinity of live coral heads, such as the masked goby (*Coryphopterus personatus*) and the blue chromis (*Chromis cyanea*). It is uncertain at this point if such reductions of abundance by reef fishes closely associated with coral habitats are related to the massive coral mortality exhibited by reef systems in the monitoring program. Although in low abundance, large demersal (top predator) fishes were detected during active search census surveys in several reefs. These include yellowfin, tiger, goliath and Nassau groupers (*Mycteroperca venenosa*, *M. tigris*, *Epinephelus itajara* and *E. striatus*), and the Cubera, dog and mutton snappers (*Lutjanus cyanopterus*, *L. jocu* and *L. analis*).

Caribbean Coral Reef Institute

CCRI is a cooperative program between the UPRM and NOAA, and sponsors management-driven research through a request-for-proposal and peer review process. CCRI-sponsored research funds work related to mapping and resource assessment, anthropological and biological aspects of Marine Protected Area (MPA) design and implementation, applied coral reef biology and ecology and technology development.

Spawning Aggregations

Many commercially important fishes form spawning aggregations that are highly predictable in space and time, a behavior that makes them highly vulnerable to fishing. Many of these aggregations have been overfished, some to the point of collapse. If management/conservation intervention occurs before complete collapse, they have the potential to recover. Edgardo Ojeda led an investigation to identify potential spawning aggregations using traditional ecological knowledge. Interview-based surveys were conducted to identify additional potential spawning aggregation sites throughout Puerto Rico. The survey targeted 50 key stakeholders consisting of commercial and sport fishers using skin-diving who were identified as knowledgeable, long-term users of local fisheries resources.

Using charts and Geographic Information System (GIS) analysis, information was obtained about 27 past and 93 present "potential" (non-overlapping) spawning aggregation sites, spawning times, changes in species composition in time and space, spawning-site fidelity, as well as 71 sites supporting multiple spawning species. The information included a total of 59 species, primarily snappers (12), groupers (11), jacks (seven) and mackerels and other fish of the family Scombridae (five). Table 3.7 shows the number of potential extant and former spawning aggregations for shallow water snappers, groupers and the hogfish. The percentage of potentially extant aggregations shows a general decline with increasing size, showing that larger, more commercially desirable species have been most severely impacted. It is assumed that the numbers of collapsed aggregations are underestimated. The status of rare species, e.g., Cubera snapper (*Lutjanus cyanopterus*) and black grouper (*Mycteroperca bonaci*) is poorly understood.

Table 3.7. Potential number of extant and collapsed spawning aggregations of shallow water snappers, groupers and the hogfish as identified by knowledgeable stakeholders in Puerto Rico, along with an index of maximum length (mm). Source: R. Appeldoorn, modified from Ojeda-Serrano et al., 2007; fish lengths from http:/www.fishbase.org.

	EXTANT	COLLAPSED	PERCENT EXTANT	LENGTH
GROUPERS				
Cephalopholis cruentata	4	0	100	415
Epinephelus guttatus	37	13	74	471
E. adscensionis	10	3	77	499
Mycteroperca interstitialis	3	0	100	690
Cephalopholis fulva	13	0	100	699
M. tigris	15	1	94	740
E. morio	8	1	89	854
M. venenosa	25	4	86	860
E. striatus	14	5	74	938
M. bonaci	7	0	100	1352
E. itajara	3	4	43	2394
Hogfish	--	--	--	--
Lachnolaimus maximus	6	3	67	913
SNAPPERS				
Lutjanus apodus	14	0	100	570
L. mahogani	12	2	86	618
L. griseus	7	0	100	722
L. jocu	7	0	100	854
L. analis	25	3	89	939
L. cyanopterus	6	0	100	1400

Assessment of Ornamental Fishery Stocks

Attempts at regulation of the ornamental fishery in Puerto Rico were hindered by an information gap that led to worst-case assumptions of impact and a closure of the fishery, setting the stage for threatening personal confrontations and lawsuits. One particular scenario led to *de facto* resource management by judicial order. Following the judicial action, an assessment of wild populations relative to harvest levels was undertaken by Steve LeGore. Visual censuses stratified by habitat were conducted in areas of western Puerto Rico where most of the fishing activity is located. Results were used to calculate a first-order estimate of the total populations of each of 16 species of fish and 21 species of invertebrates.

Results and Discussion

Comparisons of aggregated fish population estimates against annualized harvest data derived from export records from the 1998-2000 year period (Table 3.8) show that this finfish fishery represents a very small percentage of the estimated populations. Only two species had exports that represented more than 1% of the estimated populations, namely the rock beauty (*Holacanthus tricolor)* with 1.56%, and the French angelfish (*Pomacanthus paru)* with 1.16%.

Table 3.8. Fish and invertebrate population estimates and harvest for two areas of western Puerto Rico. Source: LeGore, 2006.

Common Name: Fishes	**AGGREGATE POP. EST.**	**HARVEST/ANNUM[1]**	**PERCENT HARVESTED**
Royal gramma	2,776,826	15,024	0.54% [2]
Blue chromis	12,329,818	1,419	0.01%
Bluehead wrasse	37,852,014	844	<0.01%
Red lip blenny	176,307	1,366	0.78% [2]
Blackbar soldier	2,187,854	344	0.02%
Blue tang	1,002,650	868	0.09%
Neon wrasse	2,074,370	500	0.02%
Rock beauty	81,014	1,263	1.56% [2]
Yellowhead jawfish	1,001,130	3,388	0.34%
French angel	44,274	513	1.16% [2]
Gray angel	68,330	87	0.13%
Spanish hogfish	122,607	716	0.58% [2]
Beaugregory	1,578,978	56	<0.01%
Sharpnose puffer	1,045,101	160	0.02%
Yellowtail hamlet	170,194	4	<0.01%
Yellowtail damsel	3,585,369	454	0.01%
Common Name: Invertebrates	**AGGREGATE POP. EST.**	**HARVEST/ANNUM[1]**	**PERCENT HARVESTED**
Blue legged hermit crab	629,507,025	18,936	<0.01%
Pink tip anemone	1,067,422	17,518	1.64% [2]
Feather duster	5,511,839	1,550	0.03%
Curly cue anemone	5,167,892	1,300	0.03% [2]
Flame scallop	12,414	1,341	0.80%
Sea mat	N/A	1,594	N/A
Sea cucumber	39,817,333	1,200	<0.01%
Emerald crab	3,276,842	3,155	0.01% [2]
Red thorn starfish	173,072	650	0.38%
Sunray anemone	14,149	600	4.24%
Pincushion urchin	11,213,888	600	0.01%
Carpet anemone	1,947,691	554	0.03% [2]
Bahamas starfish	346,195	300	0.09%
Shaving brush	515,610,763	240	<0.01%
Brittle starfish	62,254,955	4,162	0.01%
Harlequin serpent star	98,862,296	424	<0.01%
Long spine urchin	45,711	200	0.44%
Corky sea fingers	29,291,774	190	<0.01%
Fan halimeda	200,831,013	150	<0.01%
Red rock urchin	143,452,102	150	<0.01%

[1] = Annualized over 30-month period 1998-2000. [2] = Potentially overstated percent harvest.

Similar results were obtained for invertebrates. Export of only three species represented more than 1% of the population estimates, namely the pink tip anemone, the flame scallop and the sunray anemone. In the cases of the pink tip anemone and the flame scallop, results are somewhat misleading because in both of these cases primary habitat was not sampled and their extant populations are probably underestimated, resulting in overstated harvest rates.

These population estimates are considered "minimum" estimates, in that there are at least as many individuals in the wild populations. Existing ornamental fisheries are currently considered small in terms of impact and number of collectors (20-25) and provide an excellent opportunity to implement rational management policies that assure the continued vigor of the wild populations while providing for sustainability of ornamental fishery income.

Habitat Mapping of Western Puerto Rico

Puerto Rico's western insular shelf is a diverse mosaic of benthic habitats and supports known reef fish spawning aggregation sites, three of the six federal U.S. Caribbean MPA's and longstanding and intense fishing activities. However, much work needs to be done to better characterize this region. Unfortunately, due to prevalence of habitats in water depths <30 m and turbidity in the region, extensive areas of the western shelf were classified as unknown in the maps NOAA generated in 1998 based on aerial photographs of the region. Since publication of NOAA's map products, Jose Rivera has been using acoustic technology such as sidescan sonar to expand the extent and precision of benthic habitats in this area, and NOAA has targeted this area for deepwater multibeam sonar bathymetric surveys as described below.

Side scan sonar data was used to resolve benthic habitats, while a drop camera was used to ground-truth classification accuracy. From the imagery, GIS-based maps were developed with a minimum mapping unit of 8 m^2. Focus areas for this period covered nearshore locations off Añasco, Mayagüez, Guanajibo and Boquerón.

Results and Discussion

Four detailed habitat maps, including over 20 habitat types, were produced covering a total area of 6,975 ha. These benthic habitat maps have increased benthic knowledge of the western insular shelf. Of the total area mapped, 5,455 ha provide information for previously unidentified or unknown benthic habitats. The high resolution habitat maps generated through this work also provides information for ecosystem-based fishery management policies and for more precise inventories of the marine ecosystem present on the western shelf.

NOAA's Benthic Habitat Mapping of Puerto Rico

CCMA-BB initiated benthic mapping activities to inventory the reef ecosystem and associated bottom types for Puerto Rico in 1998. Twenty-one distinct benthic habitat types within eight geomorphological zones were mapped directly into a GIS using visual interpretation of orthorectified aerial photographs. Benthic features covering over 1600 km^2 were mapped according to methods described in Kendall et al. (2001). Data revealed 49 km^2 of unconsolidated sediment, 721 km^2 of submerged vegetation, 73 km^2 of mangroves, and 756 km^2 of coral reef and colonized hardbottom (Figure 3.24). Maps and associated products are available at http://ccma.nos.noaa.gov/products/biogeography/benthic/welcome.html.

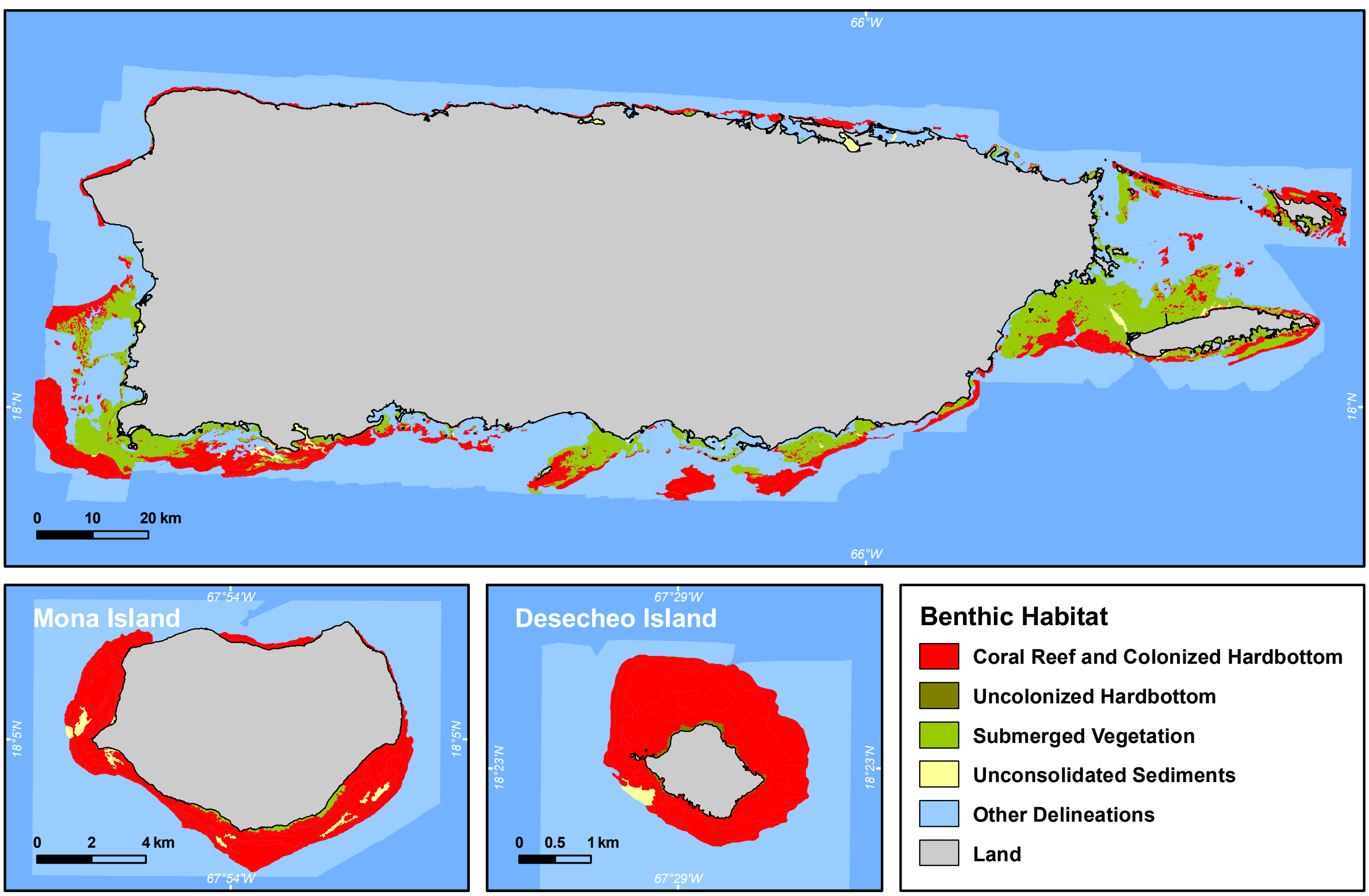

Figure 3.24. Benthic habitat maps showing the distribution and extent of primary habitat types in Puerto Rico. Map: K. Buja.

NOAA's Coral Reef Ecosystems Study

Based at the UPRM, NOAA's Center for Sponsored Coastal Ocean Research initiated a CRES in 2002 that consisted of a five-year collaborative research program involving five universities, one non-governmental organization (NGO) and two federal agencies. The study addressed 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 marine protected areas. Specific results relative to coral diseases and bleaching are reported elsewhere; selected results relative to resource condition are presented below.

Algal Population Dynamics

On healthy coral reefs, macroscopic algae are relatively inconspicuous but relatively abundant, with high species richness. Long-term sampling has shown the benthic algal community to be highly dynamic as well. Figure 3.25 illustrates the changes in average algal cover observed at the edge of the insular shelf off La Parguera over a three-year period. The most conspicuously dominant algal species is *Lobophora variegata.* An increase in the cover of this species (to approximately 25%) since October 2004 is largely driving an increase in total algal cover, from 42.9% to 69.7%. Two large blooms of cyanobacteria (*Schizothrix* sp.) also occurred during this period. Despite over two decades of observation, cyanobacterial blooms were not observed at shelf edge locations until a few years ago. There are disturbing trends as the site illustrated is a coral dominated reef site that is being increasingly covered by algae. This steady increase in algal cover at offshore sites (in addition to presence of cyanobacterial blooms) may well indicate the development of an alternative state in these reefs.

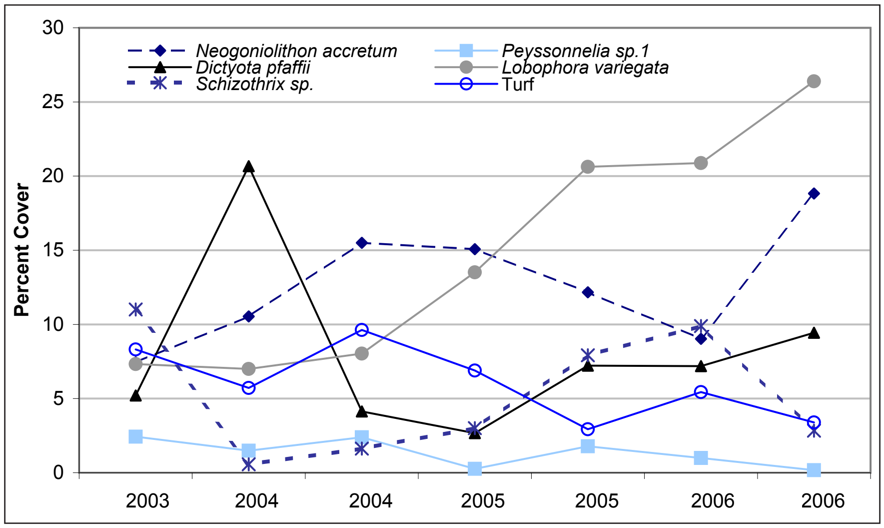

Figure 3.25. Percent cover of principal benthic algal components from 2003 to 2006 at Weinberg, a site at the shelf edge off La Parguera, Puerto Rico. Source: D.L. Ballantine and H. Ruíz, unpub. data.

Nutrient and Sediment Transport Pathways

One of the basic premises of the CRES program was that the integrity of coral reef ecosystems depends upon low rates of transport of watershed-based materials to the marine environment. A secondary premise was that offshore transport rates result from interactions between geomorphological features, wind, wave and tidal patterns. These premises are supported by CRES results. Data from sediment traps, sediment cores, runoff studies, water quality and current meters indicate that flow in the La Parguera area can be divided into two components: inshore and offshore.

Local runoff from La Parguera watersheds is entrained near the shoreline and moves westward. During larger runoff events the outer extension of the sediment plume may reach only the middle emergent reefs (e.g., Cayo Enrique) and San Cristobal to the west. Thus, during normal conditions the outer emergent reefs and the outer shelf are protected from local runoff. Runoff from upstream of La Parguera comes from the east (e.g., Guanica, Guayanilla and Ponce). Wind driven circulation wraps around the eastern margin of La Parguera to flow along the reef margin and enter the basin inside the outermost emergent reefs before being transported out through cuts between the outer reefs. Thus, the outer reefs and shelf extending to the shelf edge are primarily influenced by upstream sources of nutrients, turbidity and sediments. The combined flow patterns essentially isolate the reefs from local runoff effects, with water borne nutrients and particulates channeled behind the inner reefs and kept within seagrass and mangrove areas.

Sediment cores form inshore sites do not show increased rates of sedimentation, but the dates associated with the cores do not extend beyond the period of active coastal development within La Parguera. Outer sediment cores show some evidence of increased sedimentation rates over time. This suggests that impacts from upstream development have been increasing overtime, which is supported by the observations of increased algal growth at the shelf edge.

Assessment of Reef Fisheries

In developing models to provide management applications from the CRES program, researchers from the University of Miami tested a length-based stock assessment model using data from the commercial fisheries. The model compares actual mean lengths of populations to those calculated for a theoretical unfished population (Figure 3.26). While the parameters, and hence results, for individual species may vary, the results are robust across the suite of species to give a broad look at the reef fishery as a whole. The majority of species were found to be overfished, with some substantially overfished. The larger groupers that have not been overfished are rare or known to cause ciguatera poisoning in humans. Overall, this suggests that, despite evidence of a substantial decrease in fishing effort over the last 20 years, the reef fish fishery is still suffering from an excess of fishing pressure. These results support the more stringent regulations recently introduced by the Puerto Rico government and the CFMC.

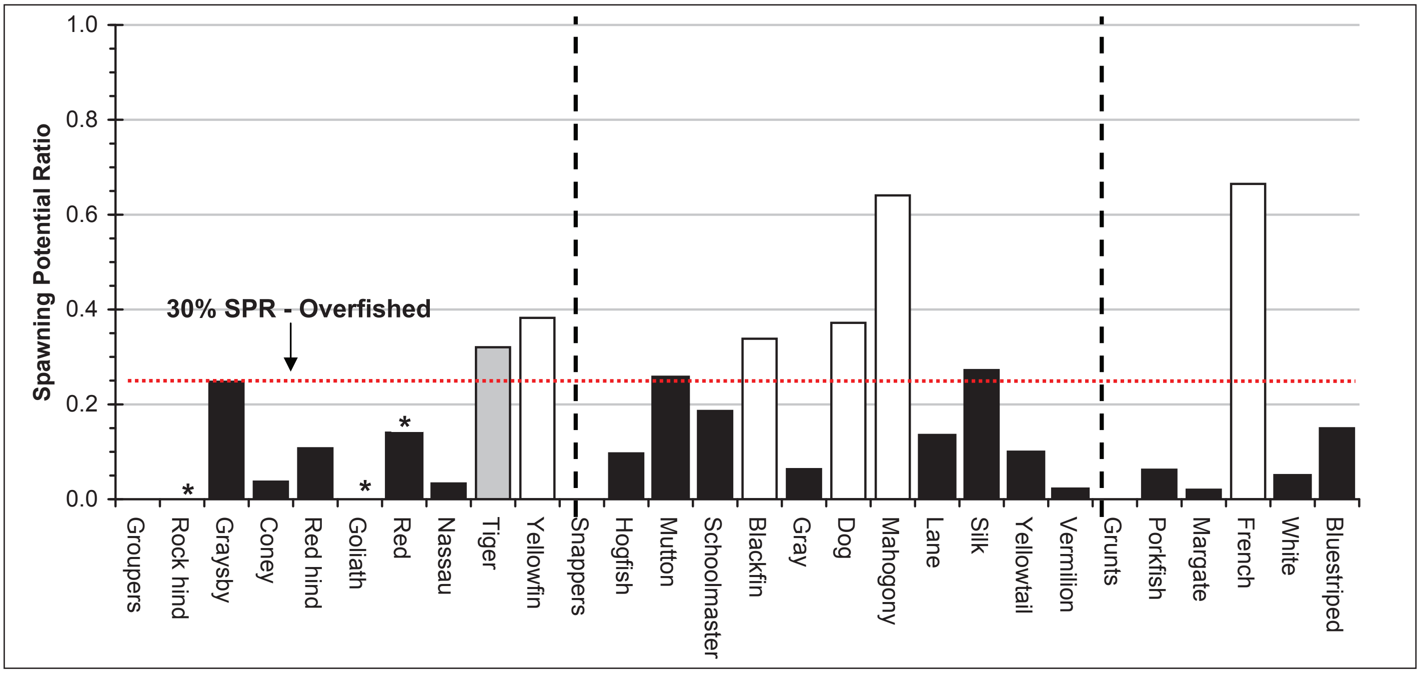

Figure 3.26. Comparative spawning potential ratio (SPR) analysis for 25 exploited reef fish species from Puerto Rico between 2000-2002. Dark bars indicate overfished stocks, open bars indicate stocks that are above the 30% SPR standard and gray bars indicate that stocks are within 3% of the SPR standard. Asterisks (*) denote species with unreliable estimated rates of fishing mortality. Source: Ault et al., in review.

Impacts of Water Quality on Reef Communities

Sediment and nutrient inputs increase water turbidity, which limits light availability, reduces photosynthetic capacity, causes stress and in extreme cases suffocation or death among coral colonies. With support from the Puerto Rico DNER, Researchers from the UPR Department of Marine Sciences studied the relationship between water turbidity, measured as vertical attenuation of PAR (Kd), and coral and fish communities. The 35 study sites were located in southwest Puerto Rico, had a constant depth of 10 m, and spanned a range of water turbidity levels. At each site, fish and coral communities were characterized using visual census and benthic surveys, respectively. Vertical attenuation of PAR was measured several times over the year to include wet and dry seasonal effects.

Results and Discussion

For sites along the southwest coast that displayed similar reef structure, coral cover (%) showed a strong correlation with light attenuation (Figure 3.27), which itself was strongly correlated to distance from shore. The fish community also varied with light attenuation, with fish density (r^2=0.322; Figure 3.27) and biomass (r^2=0.229) being positively related to water clarity. This effect was independent of the positive correlation of fish density (r^2=0.259) and species richness (r^2=0.382) to rugosity, or the positive correlation of species richness and percent live coral cover (r^2=0.267). Results indicate that deterioration in water quality due to increases in anthropogenic sources of nutrients and sediments will result in further degradation of reef communities. These results may also explain the strong correlation between reef health and distance from shore that was observed in several monitoring programs in Puerto Rico.

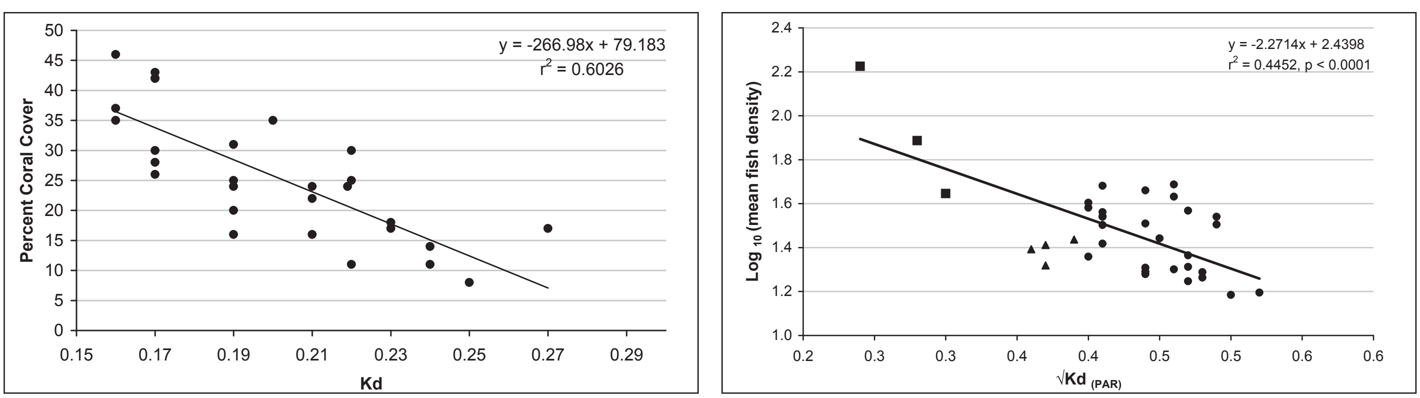

Figure 3.27. Regression of the vertical attenuation coefficient of light and percent live coral cover (left) and mean fish density (right). Squares indicate Mona Island sites, triangles are hardbottom sites and circles indicate all other sites. Source: Bejarano-Rodriguez, I, 2006.

NOAA's Coral Reef Ecosystem Monitoring Project in La Parguera

The goals and objectives of CCMA-BB's Caribbean Coral Reef Ecosystem Monitoring Project are five fold: 1) to spatially characterize and monitor the distribution, abundance, and size of both reef fishes and macro-invertebrates (conch, lobster, *Diadema*); 2) to relate this information to *in situ* data collected on associated benthic composition parameters; 3) to use this information to establish the knowledge base necessary for enacting management decisions in a spatial setting; 4) to establish the efficacy of those management decisions; and 5) to work with the National Coral Reef Ecosystem Monitoring Program to develop data collection standards and easily implemented methodologies for transference to other agencies. In Puerto Rico, CCMA-BB's work focuses on coral reef ecosystems in the La Parguera region of southwestern Puerto Rico and monitors sites based on random sampling within habitat strata. Field missions have been conducted two or three times per year since 2001 and involve collection of data on fish, macro-invertebrates and benthic composition at approximately 90 monitoring sites. Data has been collected in collaboration with and extensively used by the University of Miami, UPR, Puerto Rico DNER, the CFMC, NOAA's National Marine Fisheries Service and others. Data collected by CCMA-BB can be accessed at http://www8.nos.noaa.gov/biogeo_public/query_main.aspx.

Methods

Survey sites are selected using a stratified random sampling design that incorporates strata derived from CCMA-BB's nearshore benthic habitat maps (Kendall et al., 2001) to ensure comprehensive coverage of the study region. At each site, fish, macro-invertebrates, water quality and habitat information are quantified following standardized protocols that are available online at http://ccma.nos.noaa.gov/ecosystems/coralreef/reef_fish/protocols.html. CCMA-BB's field methodology consists of two complementary components. A 25 x 4 m belt transect is used to quantify fish species size and abundance at sites chosen through random stratified sampling. The second component involves taking detailed habitat measurements at five locations along the same belt transect. Fish data is then analyzed in conjunction with habitat information to identify spatial patterns in community structure.

Results and Discussion

A total of 442 surveys were conducted on randomly selected coral reef and hardbottom sites from 2001-2006. Over the six-year sample period, turf algae accounted for the highest mean percent cover, followed by macroalgae, gorgonians, hard coral and sponges (Figure 3.28). Cover of turf algae exhibited wide temporal variation; in most years it ranged from 20-40% but exceeded 50% during two survey periods in 2002. Mean macroalgal cover generally ranged between 10-20% with a low of 2.6 ± 1.6% in May 2001 and a high of 37.8 ± 17.7% in January 2001. Crustose coralline algae comprised a smaller component of the algal community; mean cover was ≤3.5% in all years. Mean sponge cover ranged from 1.7 ± 0.4% to 4.5 ±0.8%; mean gorgonian cover ranged from 4.0 ± 0.7% to 9.6 ± 2.0%.

Mean ± SE live coral cover has ranged from a low of 4.2 ± 0.8% in August 2006 to >10% in 2001/2002. Mean fire coral (*Millepora* spp.) cover was less than 1% in all years. Live scleractinian cover in La Parguera comprised 25 genera (Figure 3.29). The most abundant coral genera was *Montastraea*, followed by *Porites, Agaricia, Diploria* and *Siderastrea*. Following the Caribbean-wide bleaching event of 2005, bleaching in February 2006 was observed at 84% of all surveyed reef sites (n=37). Incidences of bleaching had declined by the August 2006 surveys, when bleached coral was observed at 10% of surveyed reefs (n=5).

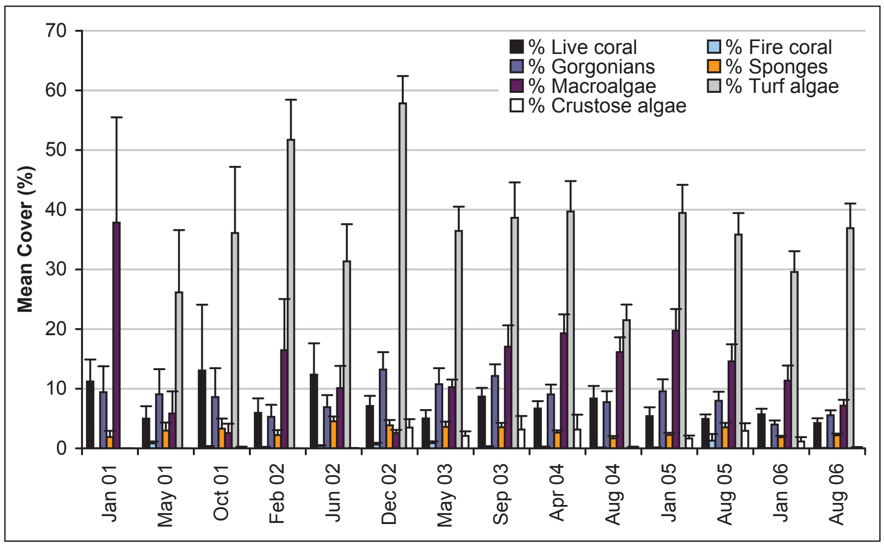

Figure 3.28. Comparison of mean (± SE) percent cover of benthic cover groups among years. Source: CCMA-BB.

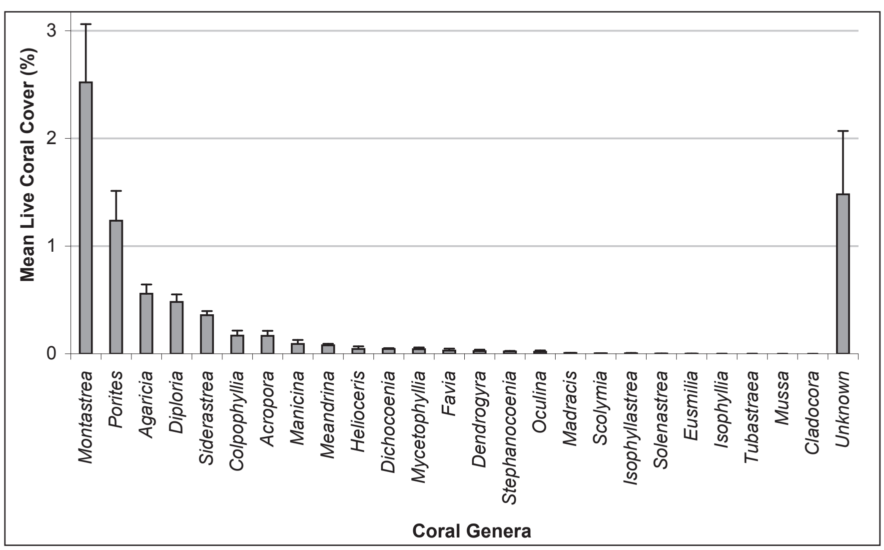

Figure 3.29. Mean (± SE) percent live coral cover of coral genera on randomly selected reef/hardbottom sites in study area. Source: CCMA-BB.

Characterization of Vieques, PR

CCMA-BB has also recently initiated a monitoring project focused on coral reef ecosystems near the island of Vieques, in cooperation with NOAA's Office of Response and Restoration. CCMA-BB completed a two-week mission in May 2007 to characterize the fish and benthic communities on reef and hardbottom habitats at 75 sites around Vieques, Puerto Rico using the same methods as employed at other coral ecosystem monitoring locations monitored by the group. Analytical results from the Vieques surveys are under development, and summary information will be provided in a future version of this report.

In conjunction with the field monitoring, the CCMA-BB is completing a nearshore benthic habitat map for Vieques using IKONOS satellite imagery. Results and interpretation from both components will be included in an integrated assessment of the marine resources of Vieques. The report, raw data, imagery, and delineated maps will be distributed on a CD and online. More information can be found at http://ccma.nos.noaa.gov/ecosystems/coralreef/vieques.html.

Mid- and Deepwater Seafloor Characterization in the U.S. Caribbean

Since 2004, NOAA's CCMA-BB has conducted annual scientific research missions on the NOAA ship *Nancy Foster* to explore, and as another component of NCREMP, characterize U.S. Caribbean habitats from 10 to 1,000 m using high-resolution bathymetry and backscatter data with complementary video and still imagery. Since 2006, the mapping missions have also included parts of the Puertorrican shelf in an effort to fill gaps in CCMA-BB's previous mapping effort (Kendall et al., 2001) and integrate abiotic and biotic data in order to extend the benthic habitat maps to mid- and deepwater areas (Table 3.9). Missions have focused on areas north of St. Croix, areas south of St. Thomas and parts of southwestern Puerto Rico, including La Parguera, Mona Island, Bajo de Sico and Abrir la Sierra bank, all of which contain MPAs (Figure 3.30). As part of this effort, scientists have collected 470 km^2 of multibeam data, conducted 125 km of ROV transects and captured thousands of images at 84 drop camera sites (http://ccma.nos.noaa.gov/products/biogeography/usvi_nps/data.html). The project aims to meet the identified need for detailed bathymetric models of the Puerto Rican seafloor, as well as for continued benthic habitat characterizations and ecological inventories beyond the depth limits of optical remote sensing technologies. Integration of acoustical mapping technologies with traditional optical sensing methods enables the creation of near-seamless habitat maps from the shoreline to 1,000 m water depth.

Table 3.9. Survey effort for NOAA Biogeography Branch's mid and deepwater seafloor mapping around Puerto Rico. Source: CCMA-BB.

METRICS	2007	2006	TOTAL
Area Ensonified (km^2)	115	63	178
Ship Track lines (km)	1,084	298	1,382
ROV Track lines (km)	0	14	14
# Drop Camera Sites	84	0	84

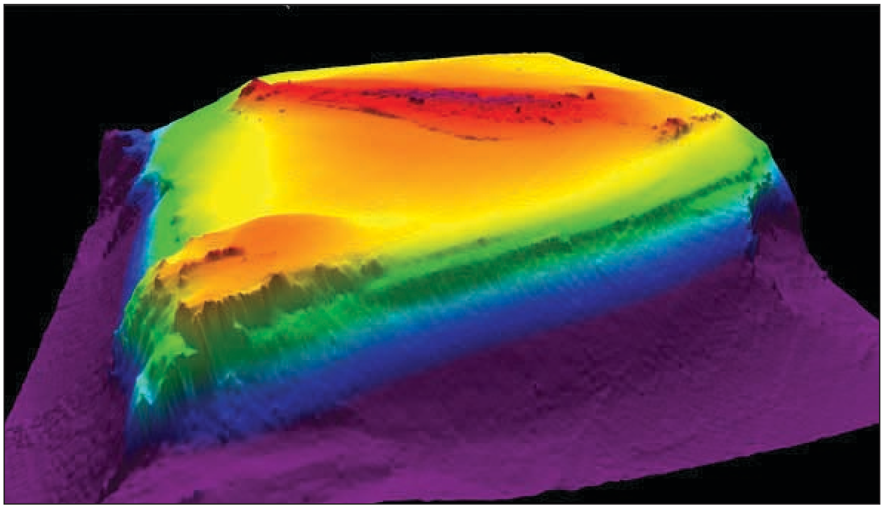

Figure 3.30. Multibeam bathymetry of Bajo de Sico, Mona Passage was collected by scientists on the NOAA ship Nancy Foster *in 2007. Source: CCMA-BB.*

Several Web-accessible products have been generated from the project. A Benthic Habitat Viewer database comprising over 9,000 underwater seafloor images, along with information on each image's location, biological inventory, benthic habitat characterization, geomorphological structure, and seafloor terrain characteristics (i.e., bathymetry, slope, and rugosity), is available online at http://www8.nos.noaa.gov/bhv/bhvMapBrowser.aspx. Multibeam bathymetric data are in the public domain in a variety of formats including ASCII XYZ text files, ESRI Grids and georeferenced TIFF images. Mosaics of multi-beam backscatter data that were geometrically and radiometrically corrected are also available online as geotiffs and are ready for use in a GIS. Other derived products include ESRI grids of bathymetric slope and rugosity. Slope was calculated as degrees inclination above the horizontal with the ESRI ArcGIS Spatial Analyst extension. Rugosity, a common index of bottom complexity, was generated with the Benthic Terrain Modeler, an ArcGIS toolset developed by the University of Oregon. For more information and free access to the acoustic and optical data, please visit http://ccma.nos.noaa.gov/products/biogeography/usvi_nps/overview.html.

ASSOCIATED BIOLOGICAL COMMUNITIES

National Coral Reef Ecosystem Monitoring Program (NCREMP): Puerto Rico Reef Fish Monitoring

Methods

Quantitative and qualitative surveys of diurnal, non-cryptic reef fishes have been conducted annually 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

A total of 171 species of diurnal, non-cryptic fish species have been identified under NCREMP. Mean fish abundance within 30 m^2 belt transects at reef sites ranged from a maximum of 444.6 individuals per transect at Puerto Canoas Reef, Isla Desecheo to a minimum of 56.2 individuals per transect at Tres Palmas Reef in Rincon (Table 3.10). Likewise, the mean number of fish species per 30 m^2 transect was highest (31.6 species) from Puerto Canoas Reef and lowest (10.6 species) from the Tres Palmas Reef. The highest number of diurnal, non-cryptic fish species observed within the five belt transect surveys was also from Puerto Canoas Reef with a total of 50 species.

Table 3.10. Mean abundance and species richness of fishes within belt-transects at reefs included in the coral reef monitoring program between 1999–2007. Source: Garcia-Sais et al., 2001a, 2001b, 2001c, 2001d, 2005c; 2006, 2007.

REEF	SITE	DEPTH (m)	MONITORING PERIOD	MEAN SPECIES (PER 30 m^2)	MEAN ABUNDANCE (PER 30 m^2)	MEAN LIVE CORAL COVER (%)	MEAN RUGOSITY (m)
Tres Palmas	Rincon	5	2004-2007	10.6	56.2	37.6	2.6
Tres Palmas	Rincon	10	2004-2007	17.6	118.8	19.2	1.7
Tres Palmas	Rincon	20	2004-2007	24.3	334.0	21.0	3.2
Puerto Botes	Isla Desecheo	15	2004-2007	23.8	216.3	14.2	3.0
Puerto Botes	Isla Desecheo	20	2000/2004-2007	27.4	170.8	36.4	3.8
Puerto Canoas	Isla Desecheo	30	2004-2007	31.6	444.6	39.8	4.2
Tourmaline	Mayaguez	10	1999/2004-2007	22.6	95.2	43.1	3.6
Tourmaline	Mayaguez	20	2004-2007	24.6	196.4	27.1	5.3
Tourmaline	Mayaguez	30	2004- 2007	20.7	196.0	13.9	5.7
Cayo Coral	Guanica	10	1999/2005-2007	21.0	59.0	16.6	4.4
Caja de Muerto	Ponce	7	1999/2005-2007	23.8	160.6	16.4	5.6
Derrumbadero	Ponce	20	2001/2005-2007	23.4	128.6	26.4	3.0

The Rincon and Isla Desecheo reef systems presented a pattern of increasing number of fish species per transect with increasing depth. This pattern was inconsistent at the Mayaguez site because richness of fish species declined at the 30 m depth, relative to shallower stations. Although the reef system at Mayaguez (30 m) presented the highest rugosity (mean: 5.7 m) among reefs surveyed, live coral cover was lower than at shallower reef stations. García et al. (2005) demonstrated that live coral cover was the best predictor of fish species richness during the baseline surveys at 57 reefs. A particular exception to this model is the case of the Tres Palmas Reef (5 m), which is an *Acropora palmata* biotope. This reef had the lowest mean number of fish species per transect (10.6 species) with a relatively high mean substrate cover by live corals (37.6%), but very low rugosity (Table 3.10). It appears that the high energy environment at this shallow reef may allow development of elkhorn coral but limit the number of fish species adapted to withstand such stress. Also, the low reef rugosity implies reduced habitat heterogeneity, with implications for a relatively lower complexity of the fish species assemblage.

During the monitoring program, fish populations have exhibited a temporal pattern of stable species richness and taxonomic composition, but a trend of declining abundance within belt transects was statistically significant in seven out of the 12 reef stations surveyed (García-Sais et al., 2007). Variations between surveys were mostly driven by fluctuations in the abundance of small but numerically dominant species which exhibit highly aggregated distributions, such as the masked goby (*Coryphopterus personatus*) and the blue chromis (*Chromis cyanea*). It is uncertain at this point if such reductions of reef fish abundance in coral habitats are related to the marked decline of live coral cover documented by the monitoring program. Although in low abundance, large demersal fishes that have been overfished during the last decades have been detected at several reefs during the surveys. These include yellowfin, tiger, goliath and Nassau groupers (*Mycteroperca venenosa*, *M. tigris*, *Epinephelus itajara* and *E. striatus*), as well as the cubera, dog and mutton snappers (*Lutjanus cyanopterus*, *L. jocu* and *L. analis*).

NOAA's NCREMP and Caribbean Coral Reef Monitoring Project: La Paguera

The goals and objectives of CCMA-BB's Caribbean Coral Reef Ecosystem Monitoring Project are introduced in the Benthic Habitats section of this chapter.

Methods

Survey sites are selected using a stratified random sampling design that incorporates strata derived from CCMA-BB's nearshore benthic habitat map (Kendall et al., 2001) to ensure comprehensive coverage of the study region. At each site, fish, macro-invertebrates, water quality and habitat information are quantified following standardized protocols that are available online at http://ccma.nos.noaa.gov/ecosystems/coralreef/reef_fish/protocols.html. CCMA-BB's field methodology consists of two complementary components. A 25 x 4 m belt transect is used to quantify fish species size and abundance at sites chosen through random stratified sampling. The second component involves taking detailed habitat measurements at five locations along the same belt transect. Fish data is then analyzed in conjunction with large-scale habitat information to identify spatial patterns in community structure.

Results and Discussion

Since 2001, a total of 1,035 locations have been sampled in southwestern Puerto Rico (includes coral reef/hardbottom, mangrove and seagrass). In the last reporting effort (2005), CCMA-BB demonstrated how measures of fish community structure (abundance, species richness, and species diversity) differed among the habitat types sampled. In contrast, the goal of this report is to characterize the temporal patterns in these metrics as well as for metrics of several key taxonomic groups and species.

Species richness and Shannon's species diversity index showed little annual change between 2001 and 2006 (Figure 3.31). Although richness was slightly higher than average in September 2003 and slightly lower than average in February 2002 and 2006, it was relatively constant over the survey period. Similarly, there was no noticeable trend in species diversity. Community biomass and abundance exhibited moderate variation between survey periods (Figure 3.32). Although there was no overall trend between 2001 and 2006, there was a large spike in community biomass in December 2002; this can be attributed to the sighting of a large tiger shark (*Galeocerdo cuvier*), which accounted for 21% of the biomass estimate for the entire mission. Community abundance was usually higher during summer surveys than those conducted during the winter and early spring, although this was not consistent across all years. The highest mean abundance occurred in August 2004, followed by September 2003 and June 2002.

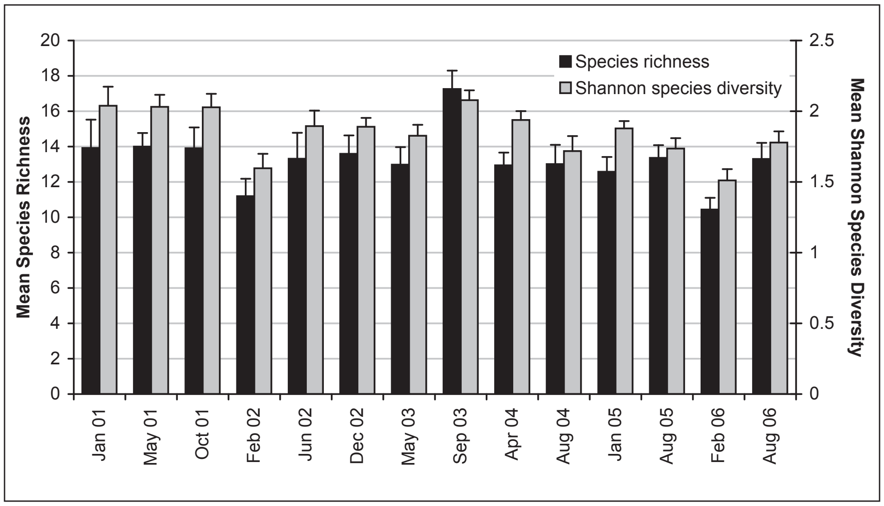

Figure 3.31. Fish species richness and diversity at La Parguera study area. Source: CCMA-BB.

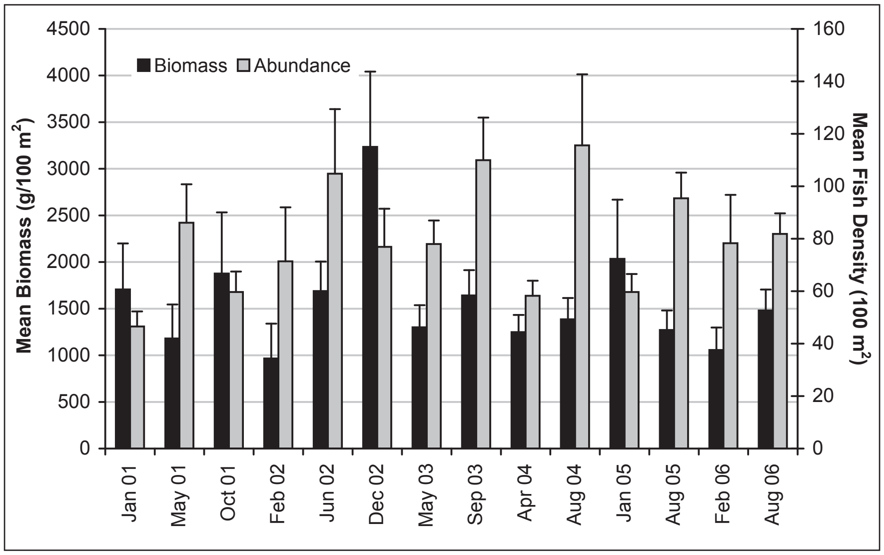

Figure 3.32. Mean (± SE) fish community biomass and abundance in La Parguera study area. Source: CCMA-BB.

Metrics for trophic and taxonomic components of the fish community were more variable than for changes in the whole community. None of the metrics showed identifiable seasonal patterns or long-term trends. Herbivore biomass (H) was approximately two times greater than piscivore biomass (P; mean 1.22 and 0.58 g/100 m^2 transect, respectively) and was significantly less variable (CV 29 and 83, respectively). Their ratio (H:P) fluctuated between one and eight, and in October 2003 piscivore biomass was slightly greater than herbivore biomass (Figure 3.33). Fluctuations in the H:P ratio were directly linked to whether or not large (>50) schools of jacks (family Carangidae) or snappers (family Lutjanidae) were observed during surveys.

The fish community surveyed in the study area consists of 57 taxonomic families (Figure 3.34). Biomass and abundance are unevenly distributed throughout these taxonomic groupings. Over 90% of individuals and biomass come from seven and 14 families, respectively. The majority of surveyed individuals come from one family (Clupidae), which make up less than 1% of the biomass. Large schools of juvenile clupeiids, often numbering in the 1,000s, were characteristic at many mangrove sites. Parrotfishes (family Scaridae) were typically the most numerically abundant group at reefs/hardbottom, followed by wrasses (family Labridae), damselfishes (family Pomacentridae), gobies (family Gobiidae) and surgeonfishes (family Acanthuridae). Grunts, gobies, parrotfishes and wrasses were the dominant taxa on softbottom substrates.

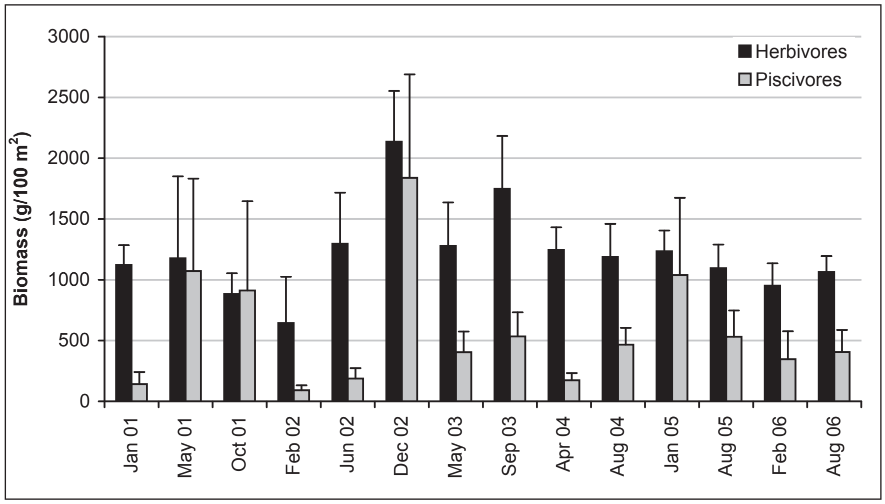

Figure 3.33. Herbivore and piscivore biomass estimates from all surveys in La Parguera study area. Source: CCMA-BB.

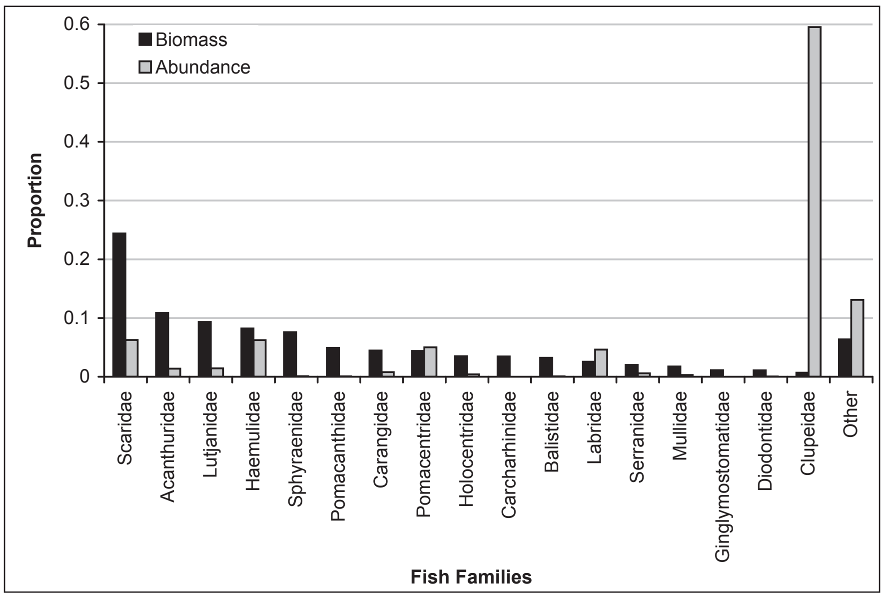

Figure 3.34. Proportional distribution of biomass and abundance of major families in La Parguera study area. Source: CCMA-BB.

The majority of fished large-bodied groupers (Genera: *Epinephelus*, *Cephalopholis* and *Mycteroperca*) were detected on reef/hardbottom habitats (98.3%, n=238). Community structure of fished groupers has shifted over time. Initially red hind (*E. guttatus*) were the most prevalent species, then for a time Coney (*C. fulvus*), and most recently Graysby (*C. cruentatus*; Figure 3.35). Since September 2003, Graysby have generally made up well over 50% of the fished groupers, and in August 2006 (the latest survey analyzed) Graysby were >90% of all fished groupers. Nassau grouper (*E. striatus*), black grouper (*M. bonaci*) and rock hind (*E. adcensionis*) have also been observed, but are very rare (six sightings in 1,035 sites). Almost no coney were detected during the first four synoptic surveys (January 2001 to June 2002), but a surge was detected in June 2002. Following the surge, there has been a downward trend in density. Similarly, the density of red hind has decreased continuously since 2001.

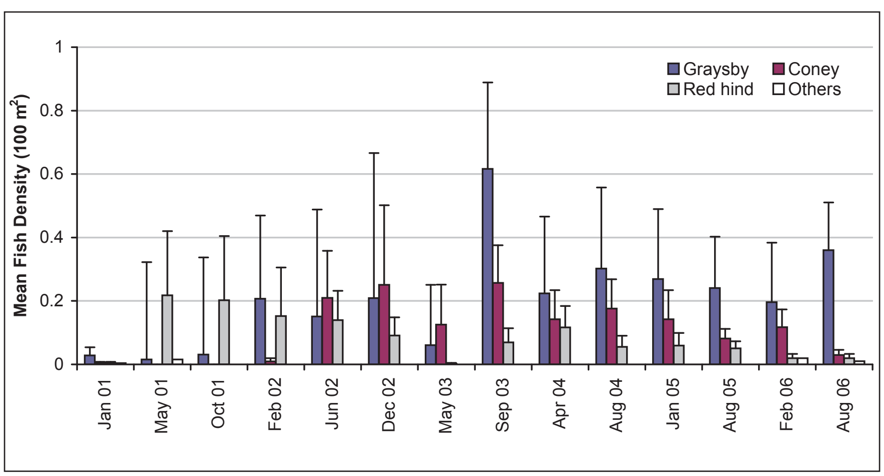

*Figure 3.35. Density of large grouper (*Epinephelus, Cephalopholis *and* Mycteroperca spp.*) from all surveys in La Parguera study area. Source: CCMA-BB.*

Snappers (family Lutjanidae) were detected frequently among all investigated habitats, including reef/hardbottom, sand/seagrass and mangroves. The majority of individuals were observed among mangroves (Figure 3.36), except for yellowtail snapper (*Ocyurus chrysurus*), which was frequently detected among reef/hardbottom habitats. Relatively few mature adult snappers were observed in any habitat. Snapper densities in mangroves were generally between 10-20 individuals per 100 m^2, but in August 2006 densities approached 60 individuals per transect (Figure 3.36). Long-term trends or seasonal patterns of density were not observed. When densities of juvenile and adult life-stages were examined separately, the ratio of juvenile to adult yellowtail snapper showed an increasing trend (i.e., more juveniles than adults in later surveys).

Grunts (family Haemulidae) were a conspicuous component of the reef fish community in mangroves. They were also seen in reef/hardbottom and softbottom habitats but usually much less frequently and in lower numbers (Figure 3.37). Most individuals were tomtates (*Haemulon aurolineatum*) french grunts (*H. flavolineatum*), or bluestriped grunts (*H. sciurus*). Mean densities in mangroves ranged between 15 and 75 individuals per transect. Densities were significantly lower in surveys conducted between April and August compared to other months (Kruskal-Wallis; $p<0.01$). Generally, density of grunts on softbottom habitats vary between five and 30 individuals per transect, but in August 2005 and February 2006 density estimates were exceptionally high. In February 2006, the average density in softbottom habitats surpassed the density in mangrove habitats. Densities on reef/hardbottom habitats were much lower, generally less than five individuals per transect. In August 2004, unusually large schools of juvenile grunts (length <5 cm) were observed at reef/hardbottom sites and the density of grunts surged to 20 individuals per transect.

Parrotfishes (Scaridae family) made up more of the reef fish community biomass than any other family in the study area. They are moderately abundant, but are generally larger bodied than most other families. Density is generally greater on hardbottom sites, but during June 2001 was greatest in mangroves and in January 2005 was greatest on softbottom habitats (Figure 3.38). In all habitats combined density typically ranges from 25 to 45 individuals per transect. An unusually high density was found during September 2003. The main reason for this surge was the detection of several large schools of princess parrotfish (*Scarus taeniopterus*), which were infrequently sighted in other surveys. Investigation of the princess parrotfish and other species did not reveal any seasonal patterns or long-term trends.

Hogfish (*Lachnolaimus maximus*) are an economically important component of the wrasse community (family Labridae). Wrasses are generally rare, but the data suggests an increasing trend in their density over time. A surge in juvenile density was detected in May and September 2003 surveys. Afterward, mature adult hogfish densities were higher than before the pulse, except for in April 2004 and January 2005. In August 2006, the latest analyzed survey, the hogfish density estimate was the greatest it has ever been.

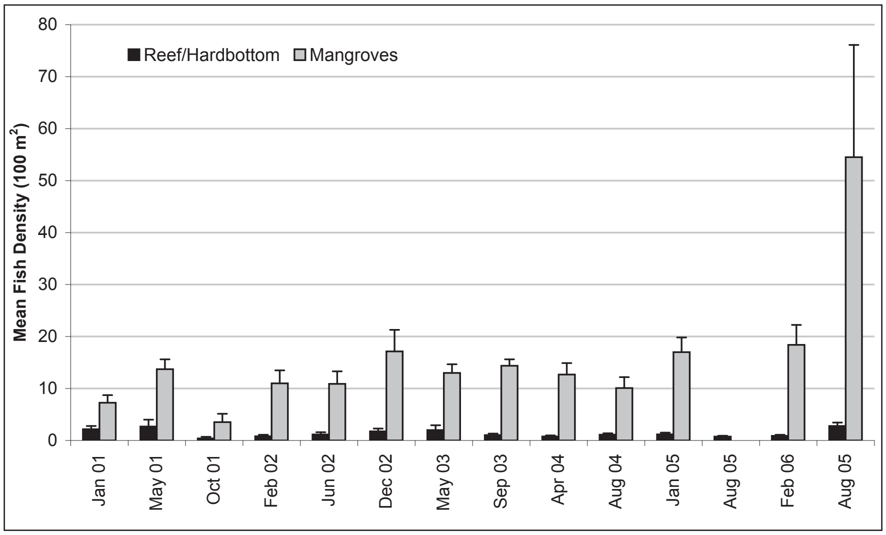

Figure 3.36. Density estimates of snapper (family Lutjanidae) in mangrove, softbottom and reef/ hardbottom habitats. Source: CCMA-BB.

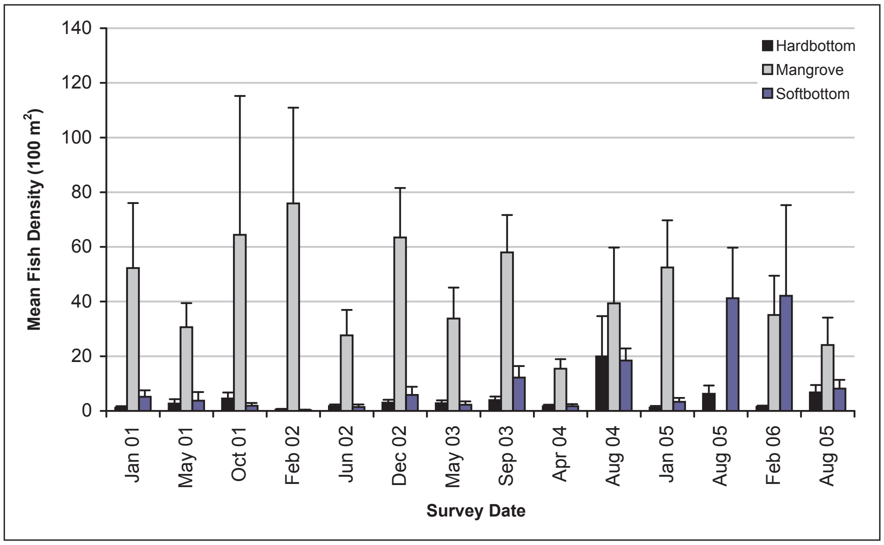

Figure 3.37. Density estimates of grunts (family Haemulidae) in mangrove, softbottom, and reef/hardbottom habitats. Source: CCMA-BB.

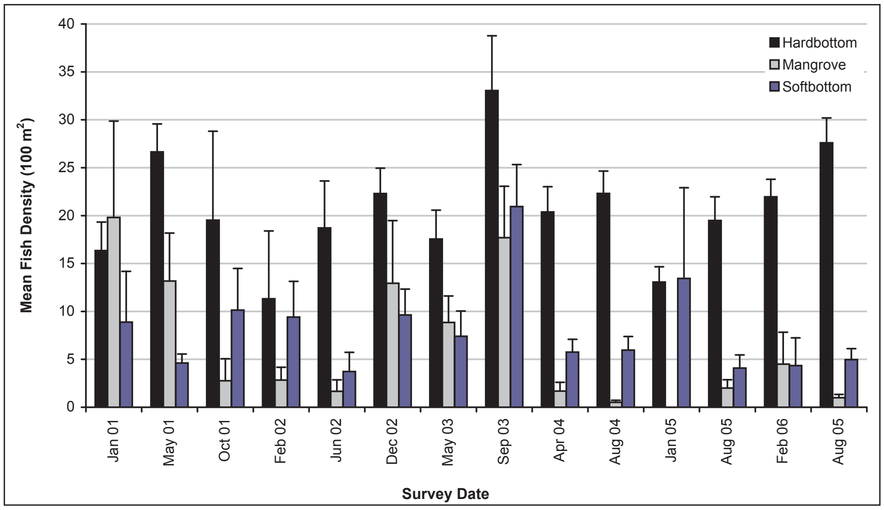

Figure 3.38. Density estimates of parrotfish (family Scaridae) in mangrove, softbottom and reef/hardbottom habitats. Source: CCMA-BB.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Several coastal areas with extensive coral reef development have been designated as MPAs by the DNER and represent a first step towards conservation of Puertorrican coral reef resources. In total, the government of Puerto Rico has established 37 MPAs that fall within four categories: natural reserves, marine reserves, no-take zones, and state forests. There are 31 natural reserves, 26 of which are administered by the DNER. The Conservation Trust of Puerto Rico administers four natural reserves and the Puerto Rico National Parks Company administers one. DNER also administers two marine reserves, a no-take zone in Condado Lagoon, and a coastal state forest that is the only one not also designated a natural reserve. In addition to the 26 sites under Puerto Rico's jurisdiction, there are four MPAs that the Puerto Rico government jointly manages with the federal government. These are the Jobos Bay National Estuarine Research Reserve which is jointly managed with NOAA; and three seasonal closure areas, Tourmaline Bank, Bajo de Cico and Abrir la Sierra which are jointly managed with the CFMC. Abrir la Sierra is in federal waters. These areas protect spawning aggregations of red hind (*Epinephelus guttatus*) off the west coast of Puerto Rico. All fishing is prohibited in these areas from December 1 through February 28.

There are two Natural Reserves that contain no-take areas. These are the Canal Luis Peña Natural Reserve and the Mona and Monito Islands Natural Reserve (Wusinich-Mendez et al., 2007). The no-take zone around Mona and Monito Islands was established in 2004 under Puerto Rico Fishing Regulation No. 6768, amended in March 2007 (Regulation 7326). The no-take zone includes all of the insular platform around Mona and Monito Islands except for the area between Punta Arenas and Cabo Barrionuevo where recreational hook-and-line fishing is permitted. In all other Natural Reserves, fishing is prohibited in zones designated as bathing areas by the Puerto Rico Planning Board.

The DNER has a Maritime Ranger Unit of approximately 200 rangers that enforce local coral reef, navigation and fishery regulations, as well as the regulations that are specific to certain MPAs. Within the unit there are, at present, a Coral Reef Ranger Task Force and a Fisheries Task Force. The Coral Reef Task Force is responsible for special projects such as ship groundings and coral reef restoration. The Fisheries Task Force consists of Rangers who have been deputized to enforce both local and federal fishing regulations. DNER is currently planning to unite these two units such that they can enforce local and federal regulations for the protection of all marine species. A joint enforcement agreement was signed between DNER and NOAA in 2007 enabling the Rangers to be deputized and providing additional federal funding for enforcement work.

The DNER is working to develop comprehensive management plans for its MPAs because, at present, none has an approved management plan. Draft management plans have been completed for the Canal Luis Peña Natural Reserve, La Cordillera Reefs Natural Reserve, and Tres Palmas Marine Reserve. These plans now require coordination with the PR Environmental Quality Board for the preparation of environmental documents and public hearings and public comment periods, final approval by the Puerto Rico Planning Board, and adoption of the plans as part of the Island-wide Land Use Plan. A total of 11 natural reserves have field officers and managers who are physically present within the facilities and oversee day-to-day management activities (Wusinich-Mendez et al., 2007) based on current regulations for the protection of marine resources.

The CFMC and NOAA have also collaborated with DNER scientists and managers to significantly revise Puerto Rico's fisheries regulations and federal regulations in response to the Sustainable Fisheries Act and revisions to the Magnuson-Stevens Fishery Conservation and Management Act. The revised regulations are directed at protecting the integrity of essential fish habitats, including coral reefs, seagrass beds and coastal wetlands, by regulating fishing activities through the establishment of quotas, no-take areas, and seasonal or permanent fishing closures for overexploited species including red hind (*E. guttatus*), mutton snapper (*Lutjanus analis*) and queen conch (*Strombus gigas*). The revisions to the Puerto Rico Fishing Regulations were published in March 2007.

Through collaborative efforts funded by the NOAA CRCP through NOAA Fisheries Caribbean Field Office, DNER was able to install navigational markers on shallow coral reefs and additional mooring buoys in La Parguera Natural Reserve in 2006 and 2007 to minimize impacts to shallow seagrass beds and coral reefs caused by accidental groundings and anchoring. DNER also installed mooring buoys in seagrass beds in the Canal Luis Peña Natural Reserve in 2007 and completed educational brochures for users of these two reserves regarding the importance of appropriate anchoring and navigation to protect marine resources. These efforts will continue in 2008 with the installation of mooring buoys and educational signage and an educational campaign aimed at recreational boaters to protect coral reefs and seagrass beds in La Cordillera Reefs Natural Reserve. Collaborative efforts funded by CRCP also included a partnership between NOAA Fisheries Caribbean Field Office and the Puerto Rico Tourism Company and Puerto Rico National Parks Company beginning in 2005. This campaign to educate public beachgoers regarding the importance of marine resources such as MPAs, coral reefs, and seagrass beds at the beaches is still ongoing and includes an educational segment on a local television program geared to local tourists, a public service announcement that aired in movie theaters and on local television, a full page newspaper announcement, educational brochures, and educational signage at public beaches.

OVERALL CONCLUSIONS AND RECOMMENDATIONS

The initial objectives of the U.S. Coral Reef Initiative Program for Puerto Rico, such as the mapping of benthic habitats (including coral reefs), conducting baseline quantitative characterizations of coral reef communities, routine monitoring of selected reef sites, and launching of a coral reef public awareness and outreach program have been fully addressed and achieved to a significant level due to the combined efforts of local government, federal agencies, public and private universities and NGOs.

Continued efforts directed towards the mapping and biological characterization of benthic habitats by the CFMC and CCRI with technical and funding support from NOAA have significantly expanded our knowledge of the geographic distribution and extent of coral reef ecosystems in Puerto Rico. Of particular relevance has been the reporting of mesophotic reefs associated with submerged platforms at depths between 45-70 m at Isla Desecheo (Agelas Reef) and at depths of 45–90 m at Bajo de Sico in Mona Passage. These reefs are important residential and/or foraging habitats for large, commercially exploited reef fish populations and serve as recruitment habitats for a variety of shallow reef fish populations.
The Puerto Rico Coral Reef Ecosystem Monitoring Program, sponsored by NOAA and administered by the DNER since 1999, is fully implemented and is achieving its goals in collaboration with federal and local governmental agencies and marine scientists from research institutions. A total of 12 reefs from six MPAs are presently included in the annual monitoring program. These include reef sites at Isla Desecheo, Rincón, Mayagüez, Guánica, Isla Caja de Muerto and Ponce. Data produced by the program has shown that the sessile-benthic community at some of the reef systems evidenced statistically significant differences of live coral cover between annual monitoring surveys. Expansion of the existing coral reef monitoring program sponsored by CCRI-NOAA and DNER is underway in order to determine whether this pattern exists in other MPAs.

A sharp decline in live coral cover was detected between surveys in 2005 and 2006 and has been attributed to the severe coral bleaching event in the U.S. Caribbean that began in the fall of 2005. The coral bleaching event coincided with an extended period of elevated sea SSTs. Live coral cover during the most recent 2007 monitoring survey presented a pattern of mild reductions relative to 2006 levels for almost all reef sites monitored. Declines of live coral cover between the 2006 and 2007 surveys were statistically significant (ANOVA; $p<0.05$) at Tourmaline Reef 20 m in Mayaguez, and at Puerto Canoas Reef 30 m in Isla Desecheo. Such reductions of live coral cover appear to be lingering effects of the 2005 coral bleaching event and warrant continued observation. In addition to the decline in (total) live coral cover at the reef community level, severe tissue loss and prolonged bleaching stress resulted in reproductive collapse during the 2006 mass spawning cycle for boulder star coral, *Montastraea annularis* (complex), lettuce corals (*Agaricia* spp.), staghorn coral (*A. cervicornis*) and cactus corals (*Mycetophyllia* spp.).

Fish populations from natural reserves presented a general trend of declining abundance. Reductions in fish abundance were statistically significant in seven out of the 12 reef stations surveyed. Variations between surveys were mostly associated with reductions in abundance of numerically dominant populations that exhibit highly aggregated distributions in the immediate vicinity of live coral heads, such as the masked goby (*Coryphopterus personatus*) and the blue chromis (*Chromis cyanea*). It is uncertain at this point if such reductions in abundance of reef fishes closely associated with coral habitats are related to the recent massive coral mortality exhibited by reef systems. Although in low abundance, large demersal (top predator) fishes were detected during active search surveys in several reefs. These included yellowfin, tiger, goliath and Nassau groupers (*Mycteroperca venenosa*, *M. tigris*, *Epinephelus itajara* and *E. striatus*, respectively), as well as the cubera, dog and mutton snappers (*Lutjanus cyanopterus*, *L. jocu* and *L. analis,* respectively).

Overfishing has been implicated in the decline in landings of coral reef associated fish and shellfish species. For this reason, 2005 amendments to the Fishery Management Plans of the CFMC included the year-round prohibition on fishing of queen conch (*Strombus gigas*) in federal waters around Puerto Rico. The CFMC also established stricter gear controls as part of these amendments in response to data related to the impacts of bottom-tending gears on important benthic habitats, particularly corals.

Shipping activity continues to pose a threat to the coral reef ecosystem as evidenced by events such as the grounding of the M/T *Margara*, a 228-m tanker that ran aground on the reefs of Guayanilla Bay, southwestern Puerto Rico on April 27, 2006. The damage was extensive and estimated to have impacted up to 8,500 m^2 of reef. This was the second grounding in the same area within one year, indicating that additional aids to navigation or other measures need to be implemented to reduce the risk of large vessel groundings to coral reefs.

Coastal development continues to pose a significant threat to the coral reef ecosystem in Puerto Rico as evidenced by data on the evaluation of proposed water resources development projects from the NOAA Fisheries Caribbean Field Office. Docks, housing developments, and marinas were consistently the most common projects proposed and 69% of these projects had the potential to impact seagrass beds, coastal wetlands, and corals. In addition, despite educational efforts by numerous entities, including DNER, NOAA, Sea Grant, and NGOs, there continues to be an increase in unauthorized construction and land clearing activities that result in impacts to the coral reef ecosystem. Thus, there is a need for continuing public education and outreach and a change in focus in existing programs in order to have a greater impact on increasing public awareness of the importance of the coral reef ecosystem.

Recent studies of the impacts of recreational boating indicate that heavily visited areas are likely to lose seagrass due to anchoring in La Cordillera Reefs Natural Reserve, while propeller scarring and propeller wash resulted in the loss of seagrass in La Parguera Natural Reserve. An ongoing study in Culebra also indicates that dock construction and associated boating activity results in the loss of shallow seagrass beds. The results of these studies indicate a need for stricter management of recreational boating activity related to the construction of docks and marinas and the designation of anchorage areas, as well as the enforcement of existing laws and regulations.

Recommendations

After the acute and unprecedented loss of live coral from Puertorrican reefs in 2005-2006 induced by elevated SSTs, government agencies, scientists, NGO's and the public need to promote policies to avoid further degradation of coral reefs. Anticipating that further coral bleaching, disease, and mortality will likely accompany future elevated SST events, strategies for restoring reefs with heat tolerant strains of corals must be considered and evaluated. Therefore, research directed towards the physiological, genetic, cellular-molecular and general ecological aspects of heat tolerant corals should be supported. Considering that the warm water mass that induced such mass coral mortality was associated with the pass of a mesoscale anticyclonic eddy, further attention should be given to oceanographic processes as they appear to be of critical importance to coral reef ecosystem health. Coral bleaching response action plans should be developed and incorporated into coral reef monitoring programs to allow for a rapid and efficient implementation for characterization of affected reef systems during future events. In addition, management measures to reduce other stresses to the coral reef ecosystem from human activities need to be developed and implemented in order to assist in lessening the impact of climate change stressors such as rising SSTs.

One of the main concerns regarding the health of the coral reef ecosystem in Puerto Rico is the unknown recreational carrying capacity of these systems due to impacts from activities such as recreational fishing, anchoring and boating, trampling of corals and seagrass during snorkeling and bathing activities, and the contamination of the water by garbage, petroleum products, and other substances. Guidelines for recreational use of coral reefs and associated ecological systems within MPAs are needed and should be widely disseminated. There has been an increasing trend of utilization of coastal resources by local and foreign tourists without consideration of the maximum level of resource utilization that the systems can withstand. There is a need to establish a maximum number of boats allowed at each reef or within each MPA and guidelines for compatible use of marine resources in order to ensure that recreational activities are sustainable.

There is a need to monitor coral reef associated fisheries under management and to increase the enforcement effort in Puerto Rico, particularly in the existing seasonal and permanent closed fishing areas. A comprehensive assessment of the impact of recreational fishing activities on reef fish, queen conch, and spiny lobster populations must be performed as data on the contribution of this fishery to species' stock status are relatively few. The queen conch population needs to be assessed to determine its reproductive viability and role of the deeper water populations in rebuilding the fishery in state waters since the closing of the fishery in federal waters in 2005. This assessment should be performed first in the closed areas off the west coast of Puerto Rico as part of a monitoring effort to document the rebuilding of managed stocks.

Exploration, mapping, and biological characterization of deep reef systems are needed around the Puerto Rico shelf but particularly within the 30-50 m depth range off the eastern and western coasts. Preliminary surveys indicate that mesophotic reefs occupy much larger areas than previously thought. Ongoing studies have identified these reefs as critically important resident, foraging, reproductive and recruitment habitats for commercially exploited fish and listed sea turtle populations.

Management activities, which are possibly the most critical components in maintaining a healthy coral reef ecosystem due to their relationship in supporting enforcement and compliance, encouraging community involvement, and increasing public awareness, must be more strongly supported. Management and research need to be better integrated in order to ensure that management actions are driven by science and research efforts focus on obtaining the information managers need to adequately conserve trust resources. It is also recommended that the topic of marine ecology and resource conservation be incorporated into the science curricula at all educational levels in Puerto Rico through a concerted effort by DNER and other local and federal partners to work with the Puerto Rico Department of Education to promote stewardship of Puerto Rico's marine resources.

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